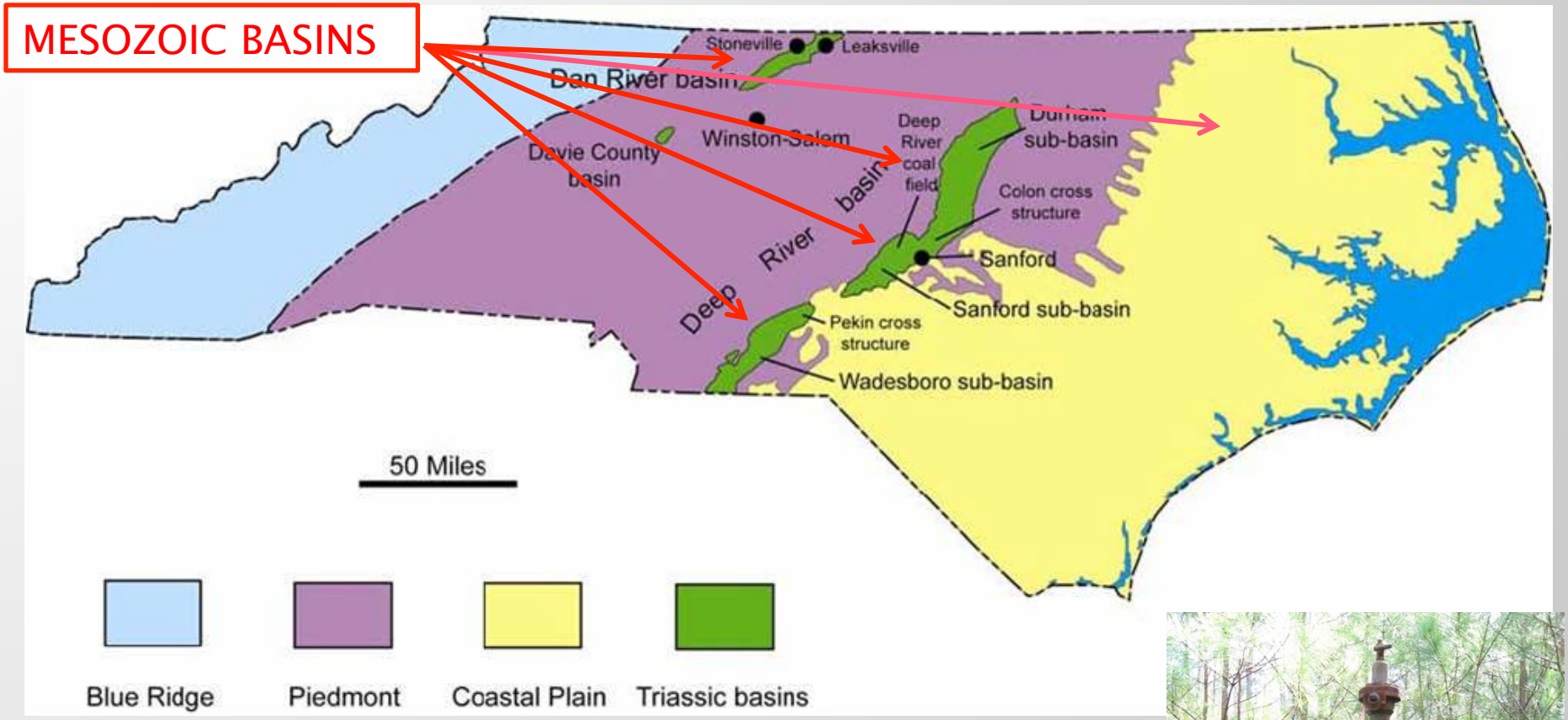


NORTH CAROLINA'S SHALE GAS POTENTIAL: WHO KNEW?

Jeffrey C. Reid, PhD, PG, CPG
Senior Geologist
North Carolina Geological Survey
v. 919.733.2423, email: jeff.reid@ncdenr.gov

Role of N.C. Geological Survey

- The North Carolina Geological Survey (NCGS) examines, describes and maps the geology, geologic hazards, and mineral resources of North Carolina and publishes these findings in NCGS reports and maps.
- Provide unbiased, impartial and relevant technical information to all parties.
- The NCGS is the custodian of rock cores, cuttings, geophysical logs, etc.
- We do not provide endorsements.
- We do not provide information or guidance about any type of mineral leases or natural gas / oil leases.

NC DENR 2019-2013 Strategic Plan

- NCGS natural gas studies are also done under DENR's strategic plan's heading:
  - "Growing a green economy"
    - "Continue and support the evaluation and exploration of natural gas resources in the state." (Lead: Division of Land Resources)

Who knew?

- Oil and gas industry largely unaware of rift basins in North Carolina.
- Thick organic-rich shale section with coals.
- Extensive organic geochemistry database.
- Interpreted seismic lines (~75 line miles) – shot after drilling.
- New gas chemistry and gas quality data.
- LiDAR delineation of geologic structures
- Total petroleum system recognized.
- Centrally located in state.
- Rural area, relatively undeveloped, low topographic relief.

Time line – Deep River Basin

- 1775 – Revolutionary War era, coal exploration for iron and munitions.
- 1776 – N.C. Colonial Records mentioned “Pit Coal” …in good quantities….
- 1820’s – 1850’s – Coal reports ‘rediscovered’.
- 1861 – 1873 – Civil war and post war coal production.
- 1920’s – 1940’s – Underground coal mining, exploration; 1925 coal mine explosion (killed 53 workers).
- ~ 1 million short tons coal produced – 1700’s–1930’s; (1980’s effort).
- 1980’s – 1990’s – Petroleum drilling (preceded seismic – vertical holes).
- 2008 – Organic geochemical data published (Reid and Milici – USGS OFR 2008–1108) .
- NCGS recognizes thick section of organic shale as a potential gas resource.
- 2008 (Reid and Taylor) – Initial industry presentation (AAPG–Eastern – Pittsburgh, PA).
- 2009 (Reid) – ‘Natural Gas and Oil in North Carolina’ Information Circular 36.
- 2009 (Reid and Taylor) – NCGS Open–File Report 2009–01 (Shale Gas Potential…).
- 2009 (Reid and Taylor) – Industry presentation (AAPG–Eastern – Evansville, IN).
- 2010 (Reid) – Industry presentations (Hart Energy conference – Ft. Worth, TX), Virginia Oil and Gas Association (late June 2010).
- 2010 (Reid and Taylor; Reid, Taylor and Simons) – two additional industry presentations in the fall.
- 2010 North Carolina Geological Survey / U.S. Geological Survey Resource assessment begins (currently in progress).

Current technology

- Current technology allows “shale gas = natural gas” to be recovered from shale formations with a high degree of organic content.
- Modern exploration and gas production technology, such as horizontal drilling and hydraulic-fracturing, has enabled the extraction of shale gas in similar formations in other states.
- Unconventional energy resource.

Why now? – 1

Compilation of data

- Years of scholarship locating and compiling data.
- Paper data converted to digital formats
- Organic geochemistry data collected and interpreted for first time.
- Focus was shallow coal bed methane, not shale gas.
- Wells drilled BEFORE seismic lines were run.
- Well depths were relatively shallow and did not target seismic features of potential interest as they were unknown then.

Why now? – 2

New emphasis

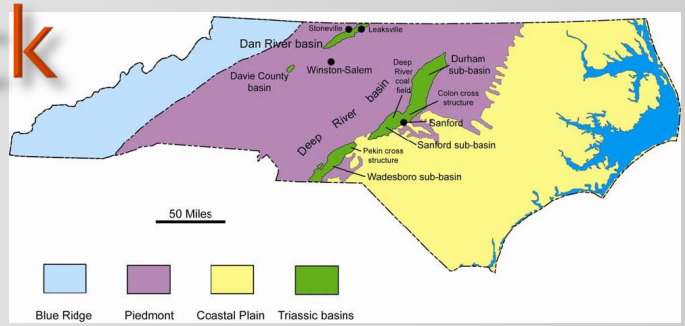
- Industry largely unaware of basins in North Carolina.
- USGS emphasis on Mesozoic basin energy systems.
- Thick organic-rich shale section previously not considered to be of interest.
- Similarity to other unconventional organic shale resources.

Why now? – 3

New techniques / interpretation

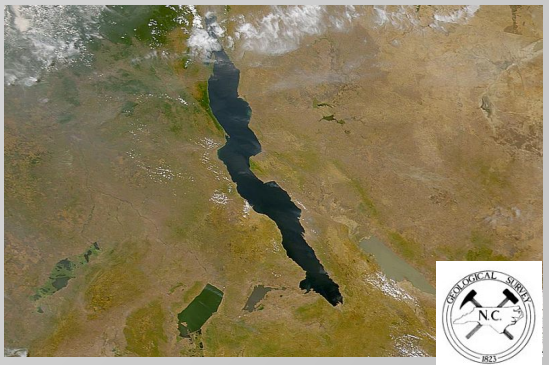
- New gas chemistry and gas quality data
- Seismic lines interpreted.
- Use of LiDAR to delineate geologic structures.
- Directional drilling.
- Recognition of a total petroleum system.
- New gas pipelines and nearby users.
- Rural area compared to other East Coast rift basins.

Basin and Source Rock Overview

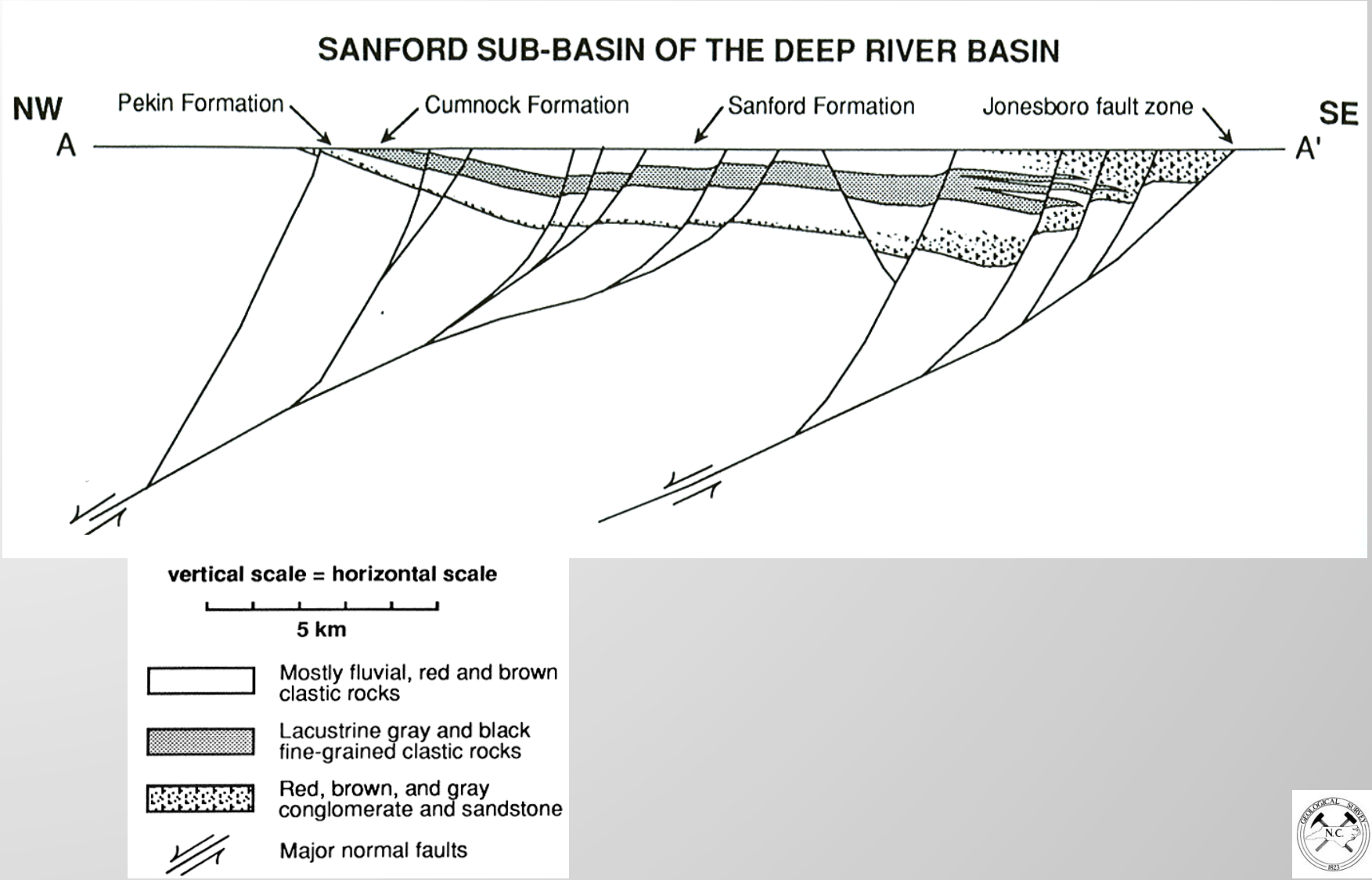


Map showing the distribution of Mesozoic basins in North Carolina (from Reid and Milici, 2008).

- Deep River Basin – 150-mile-long northeast trending half-graben (rift basin) with a steeply dipping eastern border fault.
- ~7,000 feet of Triassic strata.
- Lake deposits similar to African rift valley lakes.
- ~154,000-acre prospective area.
- Total petroleum system containing:
  - Source rock
  - Seal
  - Traps / reservoir
- Relatively untested exploration area.

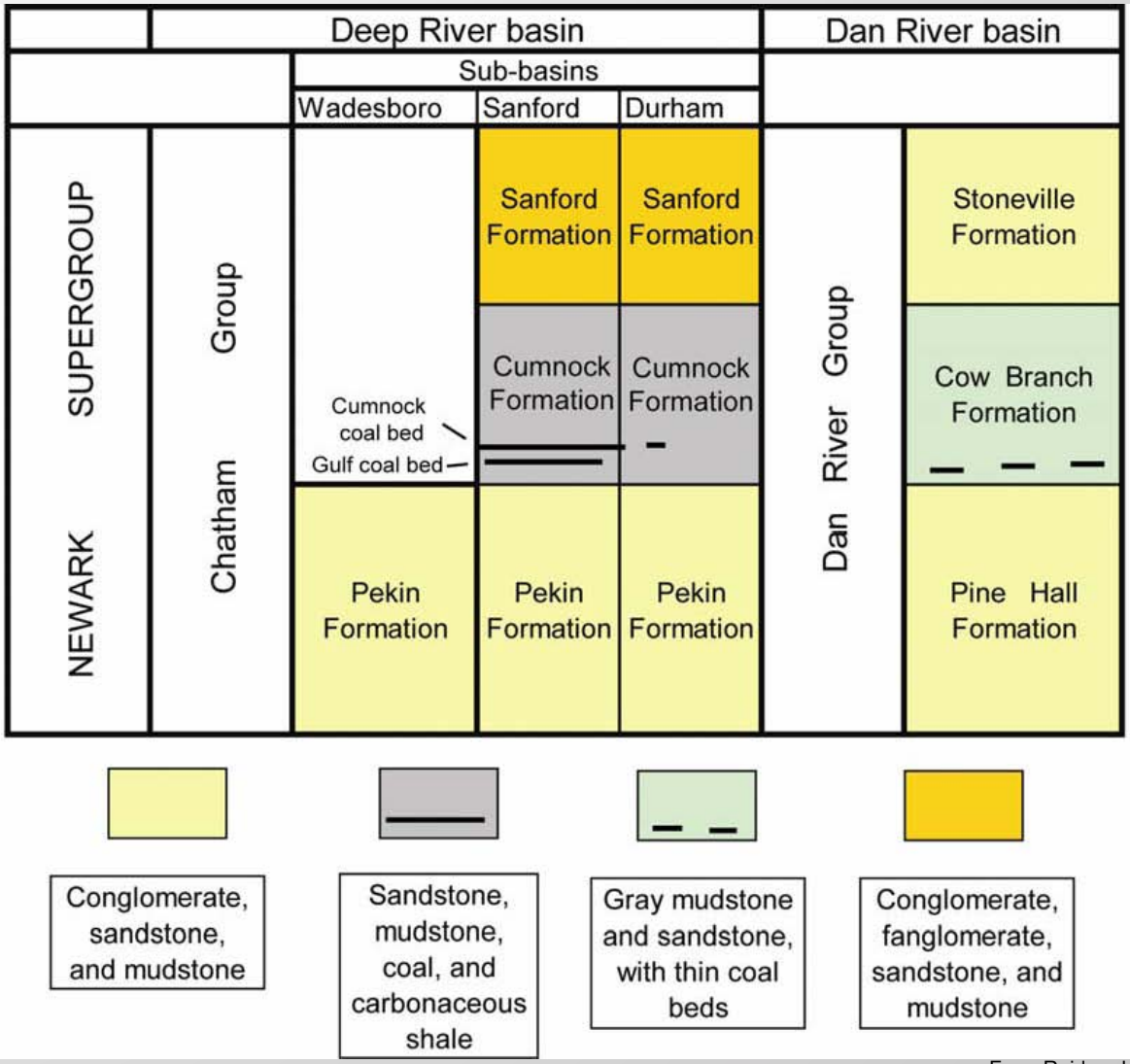


Generalized cross section



From Olsen and others, 1991

Stratigraphy



From Reid and Milici, 2008

Cumnock Fm. – note orthogonal fracture sets. Intergranular porosity and permeability of the Triassic strata are low, which makes fractured reservoirs more attractive as drilling targets.

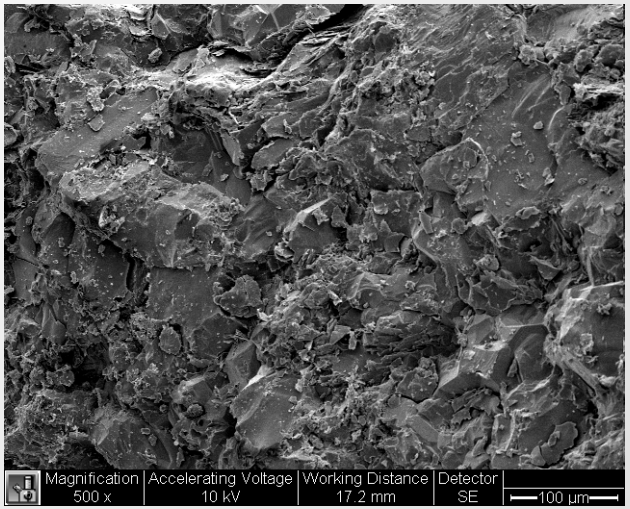
Deeper basin targets (undrilled) may include stratigraphic / structural traps based on current seismic interpretation.

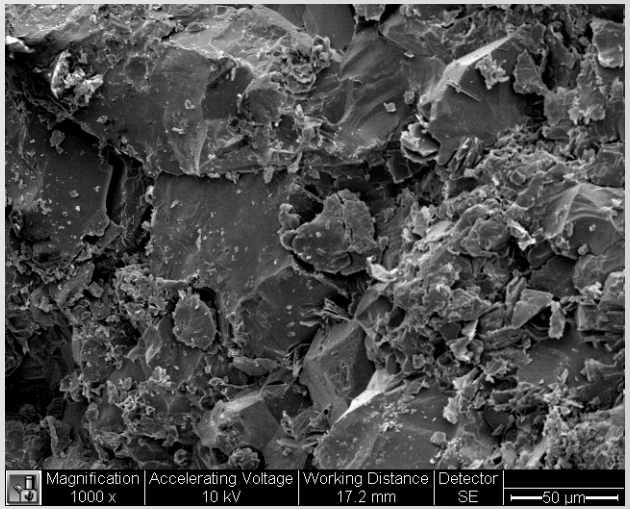
Location: Alton Creek, Lee County, NC

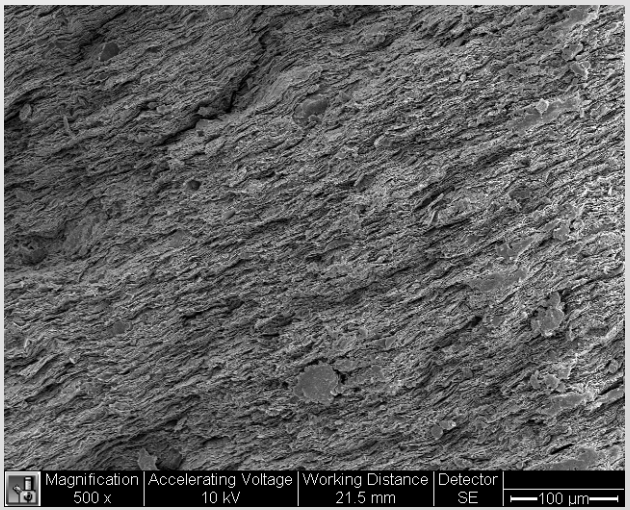
Gas and oil shows

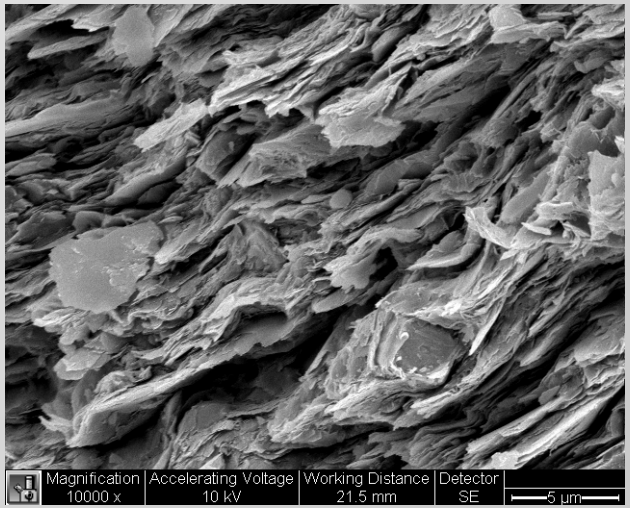
• Eleven of 28 drill holes (including old coal holes) have shows of gas, oil or both and some ‘asphalt’.
• Coal mines with underground oil shows; fatal methane gas mine explosion (mines long closed).
• Two shut-in wells with significant pressure (March 2009) – failed frac jobs
    •Butler #3 (upper left) – with pressure of 900 psi; initial flow rate: unknown
    •Simpson #1 (lower half) – with pressure of 250 psi; initial flow rate: 3,000 mcfd; settled at 231 mcfd; well flared.
    •Butler #1 (upper right) – well flared; small amount high paraffin, low flow temp. (hand warming) recovered.
•‘Black band’ rock retorted (1927) produced 3.6 – 12.4 gallons of oil per ton.

Porosity – SEM





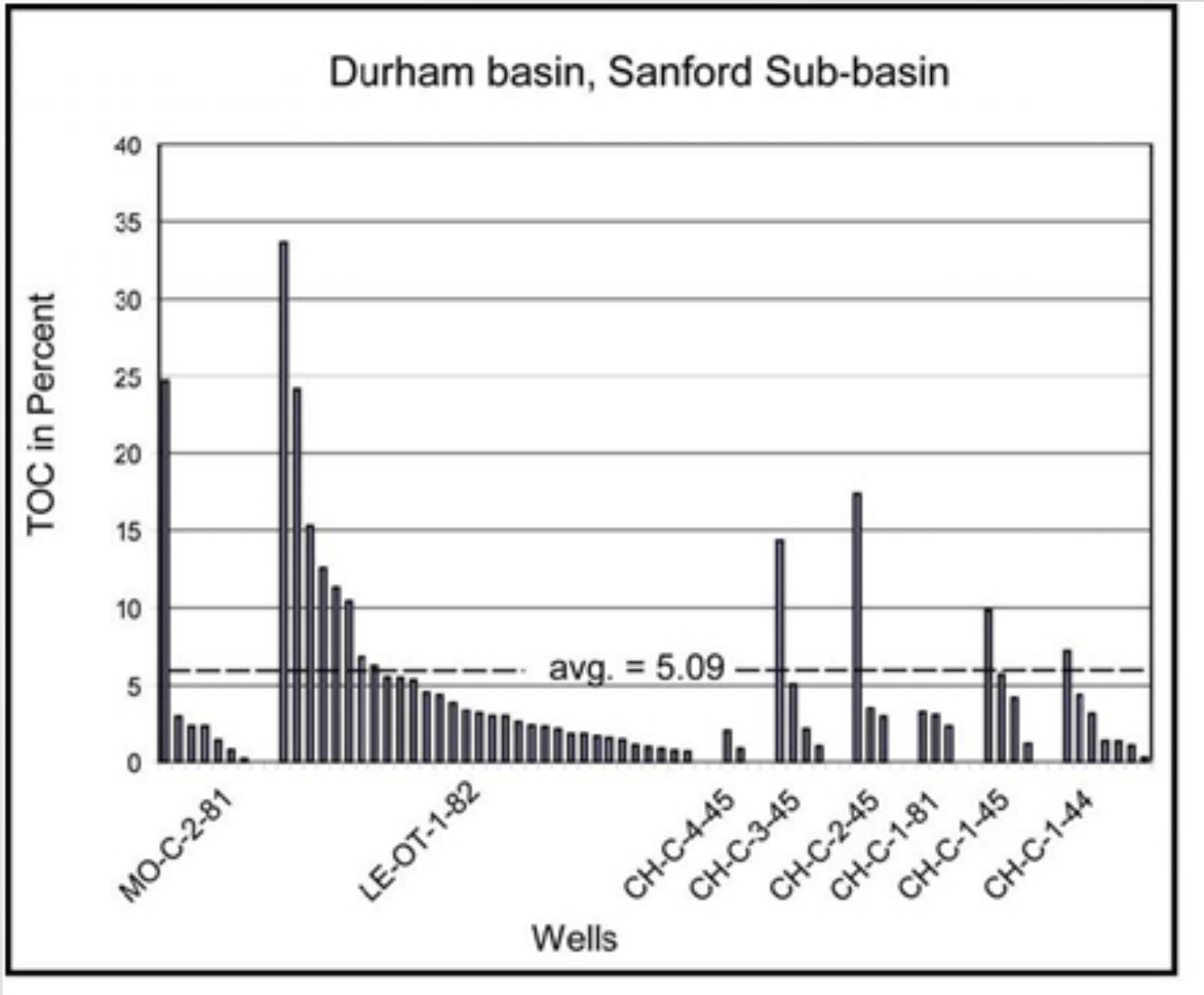




Organic geochemistry

- Sediments are predominantly gas prone with some oil shows.
- TOC data exceeds the conservative 1.4% threshold necessary for hydrocarbon expulsion.
- Organic matter derived from terrestrial Type III woody (coaly) material and from lacustrine Type I (algal material).
- Thermal alteration data (TAI) and vitrinite reflectance data (%Ro) indicate levels of thermal maturity suitable to generate hydrocarbons.

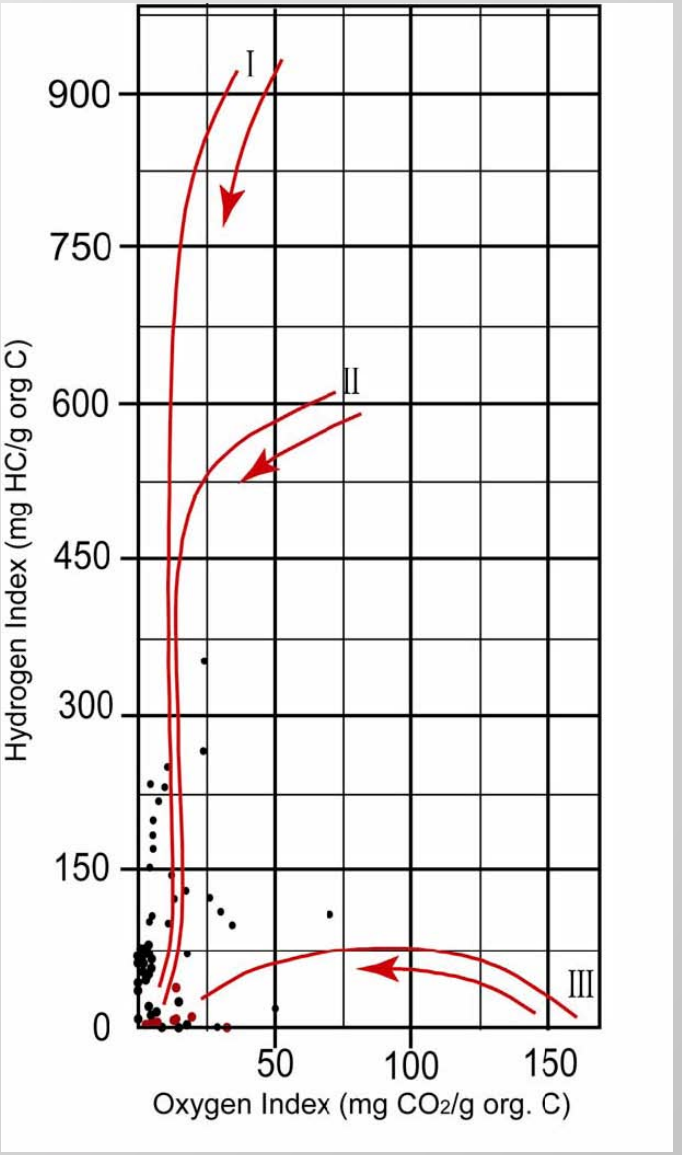
Reid and Milici (USGS OFR 2008-1108)



- Distribution of TOC data in wells in the Durham basin
- A threshold of 1.4% TOC is considered necessary for hydrocarbon expulsion
- From Reid and Milici, 2008

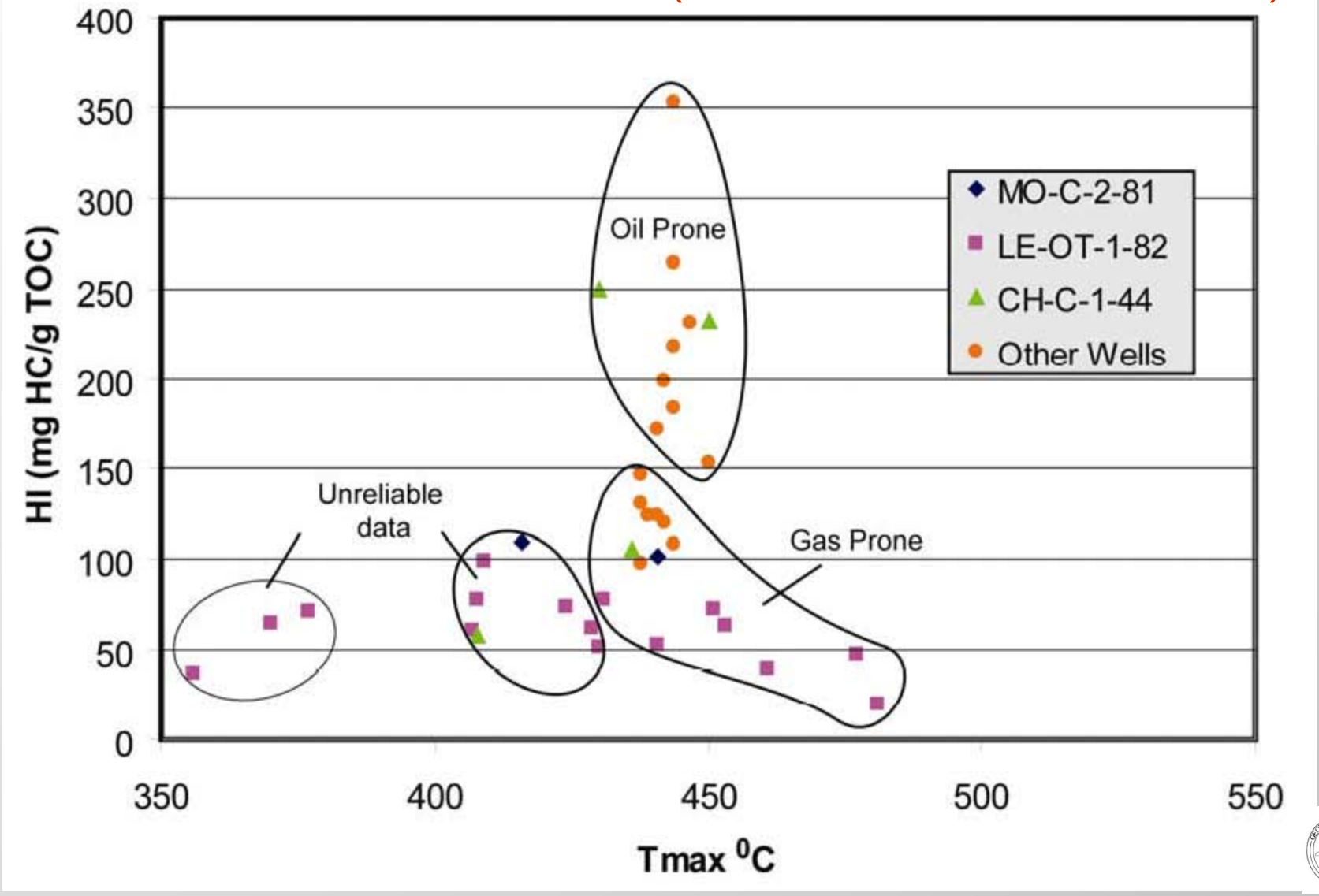
Hydrogen and oxygen indices

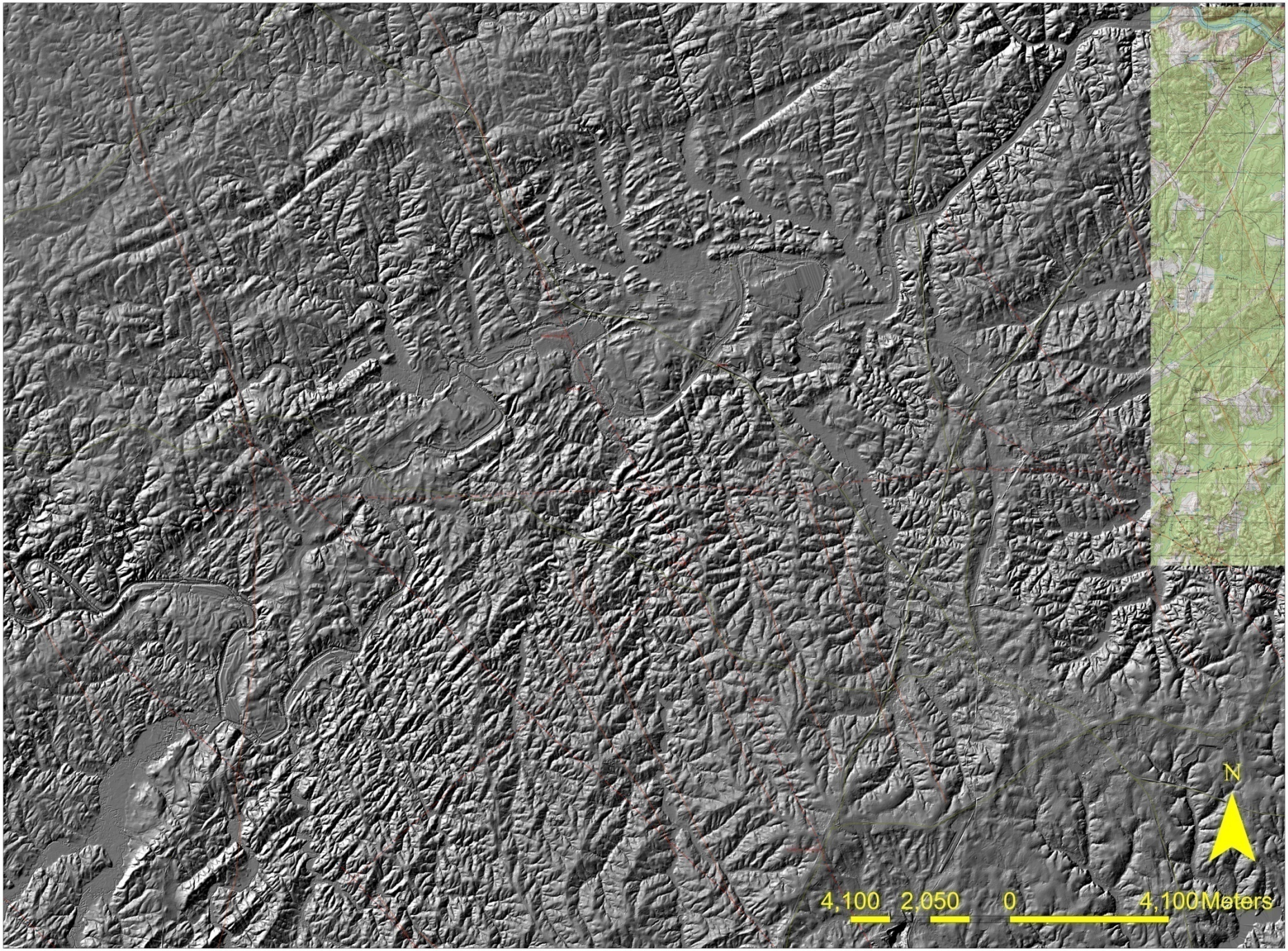
- Hydrogen and oxygen indices from Rock-Eval pyrolysis in relation to primary kerogen type
- The organic material in these formations was derived primarily from terrestrial Type III woody (coal) and secondarily from Type I (algal) matter.

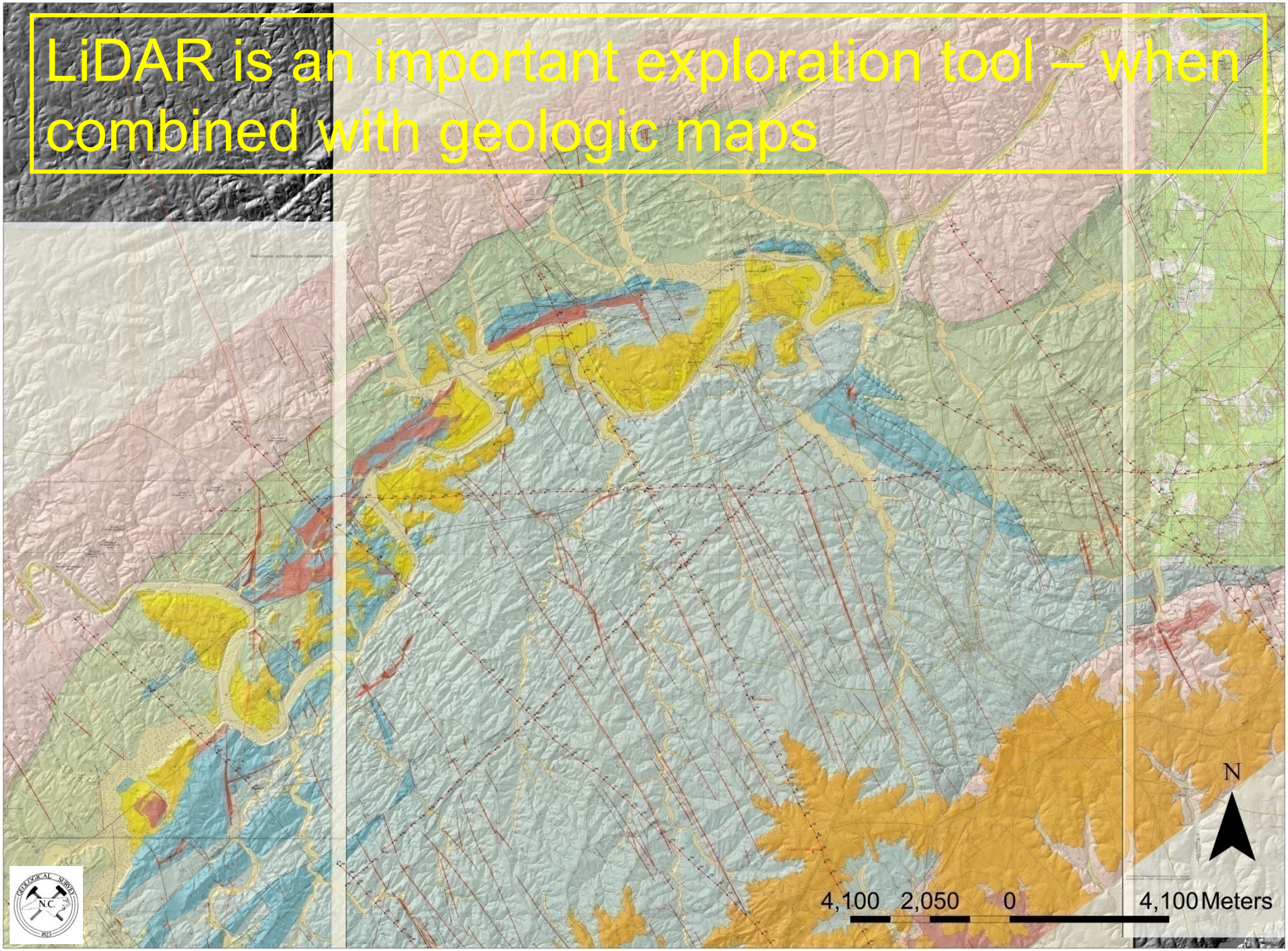


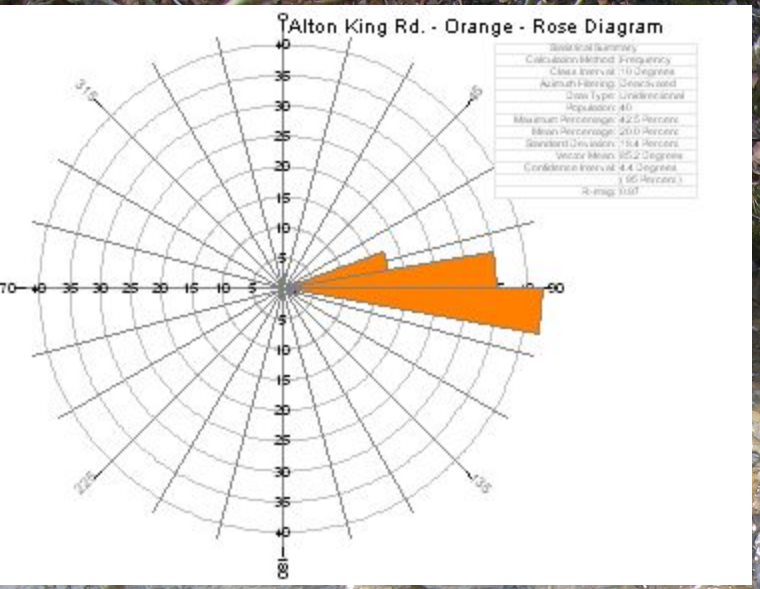
From Reid and Milici, 2008.

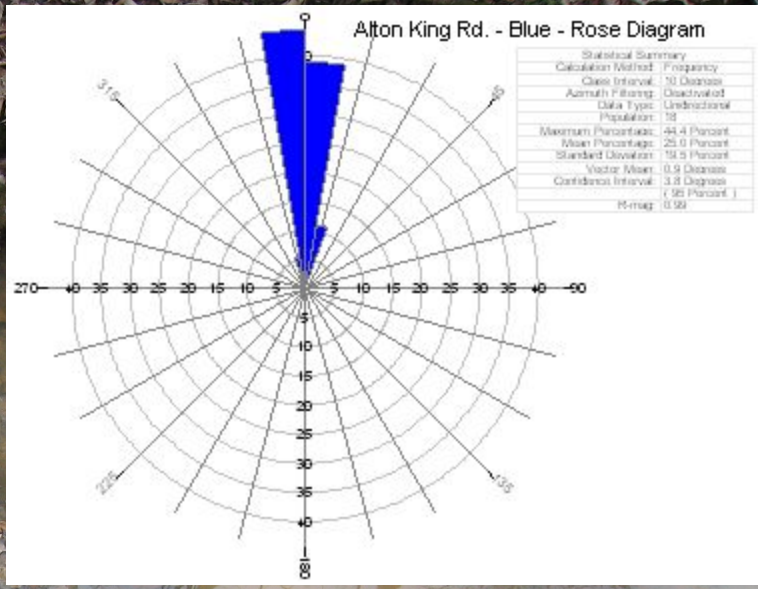
Comparison of Tmax and Hydrogen Index of samples from wells in the Sanford sub-basin (from Reid and Milici, 2008).




N
4,100 2,050 0 4,100 Meters


LiDAR is an important exploration tool – when combined with geologic maps
N
4,100 2,050 0
4,100 Meters





LiDAR fracture patterns can be traced to outcrops, and possibly to drill core

North


.5
.5
.5
CENTIMETRES
INCHES
.5

Drill Hole : USBM DH-2

NCGS No.: CH-C-1-45

Box No. : 116

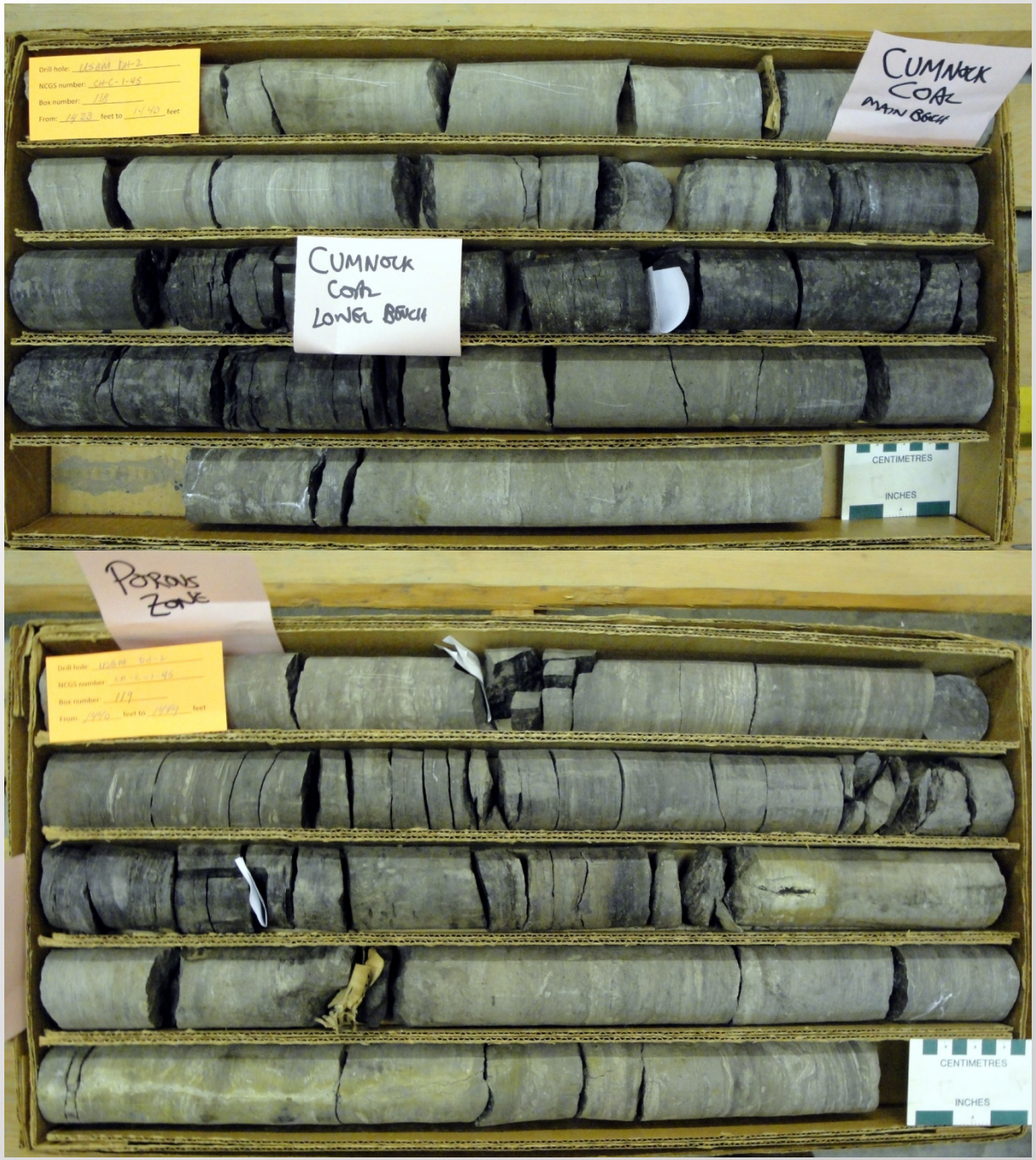
From : 1404 feet
to 1414 feet

Drill Hole :USBM DH-2

NCGS No.: CH-C-1-45

Box No. : 117

From : 1414 feet
to 1423 feet



Drill Hole : USBM DH-2

NCGS No.: CH-C-1-45

Box No. : 118

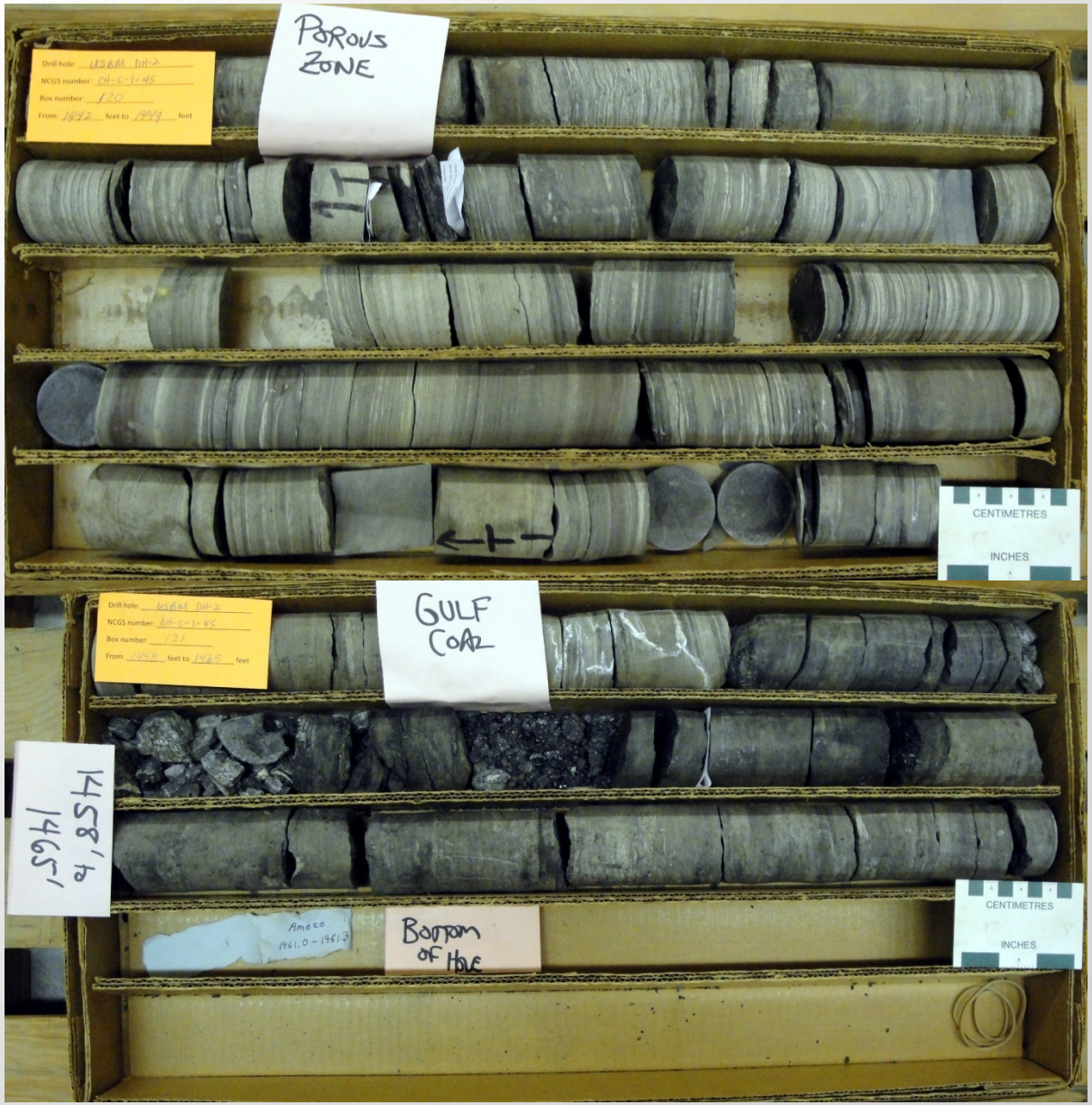
From : 1423 feet
to 1440 feet

Drill Hole :USBM DH-2

NCGS No.: CH-C-1-45

Box No. : 119

From : 1440 feet
to 1449 feet



Drill Hole : USBM DH-2

NCGS No.: CH-C-1-45

Box No. : 120

From : 1442 feet to 1449 feet

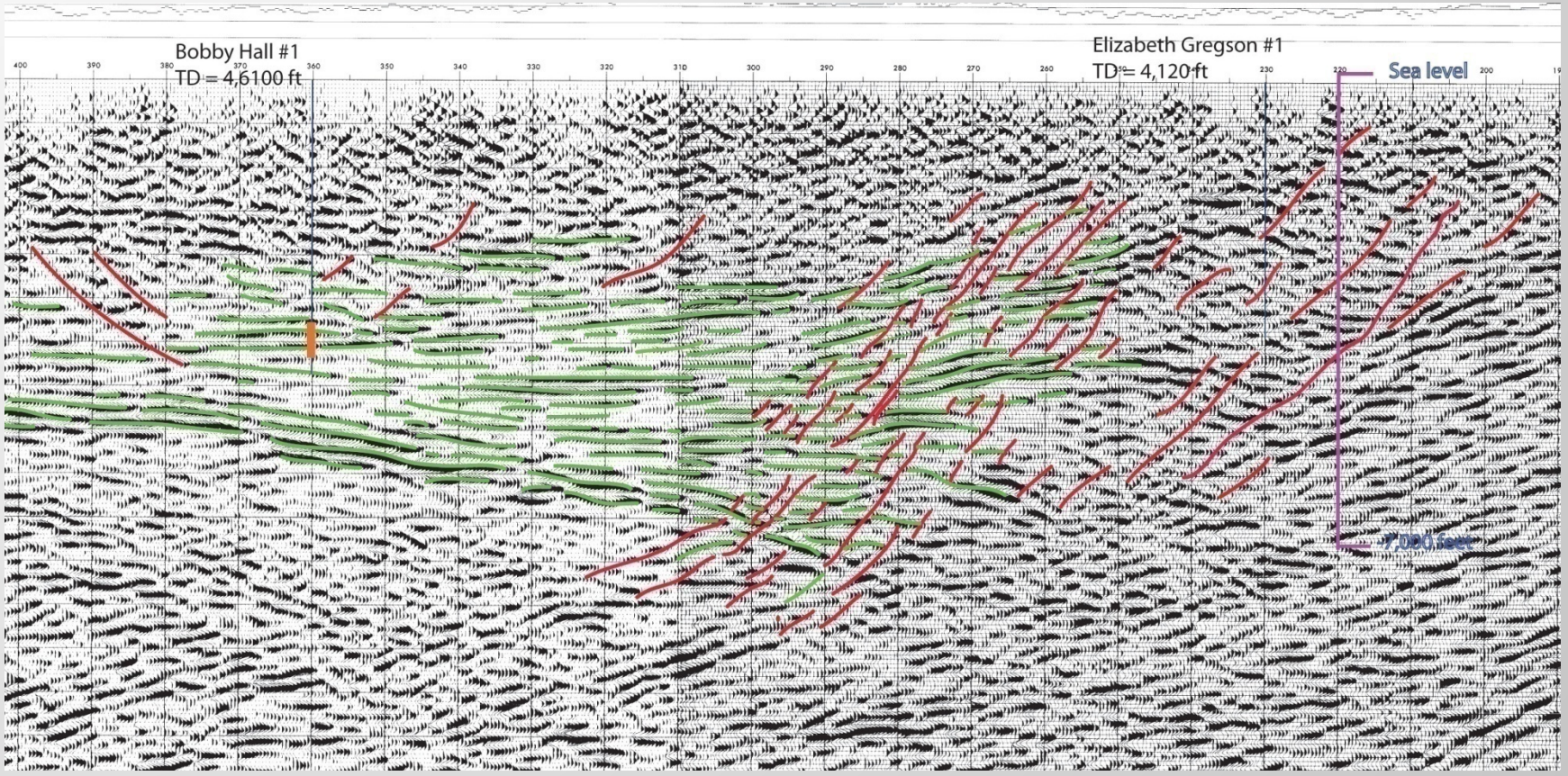
Drill Hole :USBM DH-2

NCGS No.: CH-C-1-45

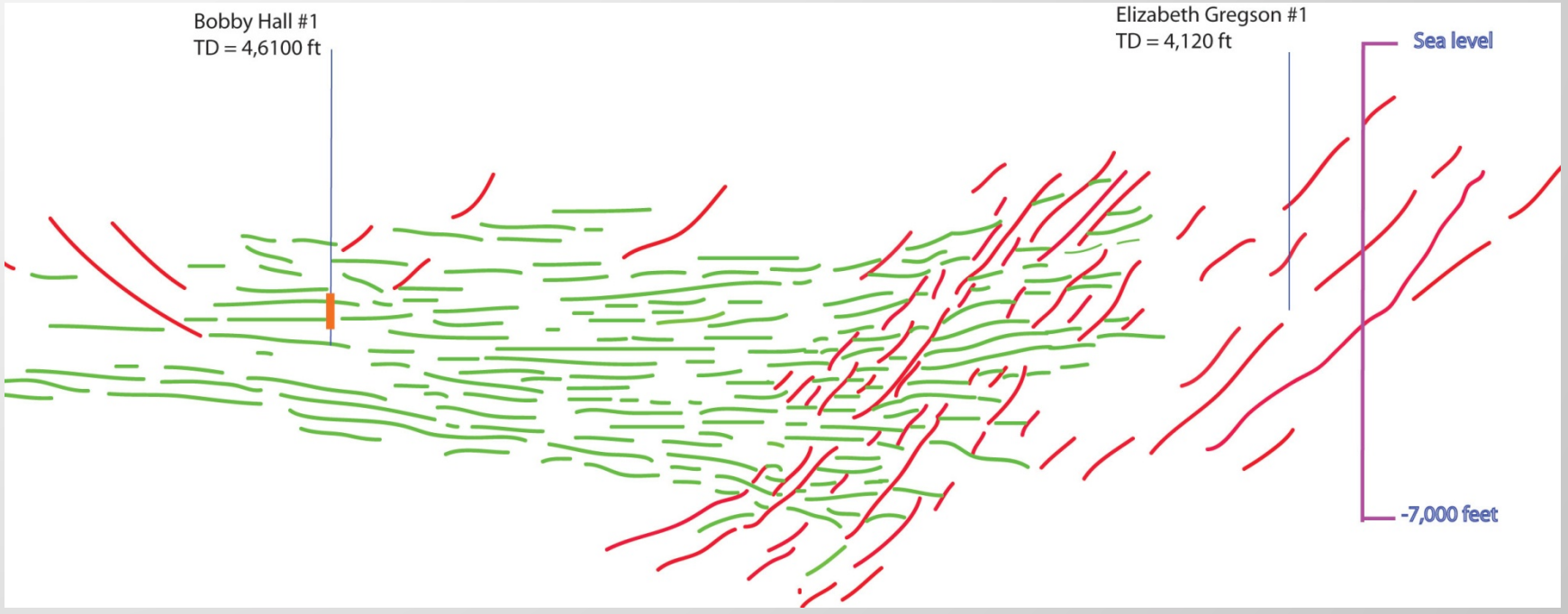
Box No. : 121

From : 1458 feet to 1465feet

Seismic Line 113



Seismic Line 113



Gas composition and BTU (C1 = methane)

Well	PSI	C1 %	N2 %	CO2	C2H6	BTU (Dry)	Comment	ΔN Per mill	ΔC Per mill (C1)	ΔD Per mill (C1)
Butler #3 - 2009	900	48.78	45.60		3.86	605	Small amounts other gases	-3.32	-45.11	-178.5
Simpson #1 - 1998	640-680	70.07	29.603		0.117	712.920				
Simpson #1 - 2009	~250	51.65	45.49		1.89	577	Small amounts other gases	-3.23	-51.41	-174.8
Dummitt-Palmer #1 – 1991 - Cumnock		96.95	2.4	0.24	0.024	986.25				
Dummitt-Palmer #1 – 1991 – Gulf coal		96.40	3.05	0.16	0.27	976.45				
Dummitt-Palmer #1 – 1991 – Black shale		88.40	10.85	0.17	0.30	908.95				

Note – ΔC and ΔD for light gases (ethane, propane, iso-pentane and N-butane along with specific gravity for 2009 analyses – not shown because of space)

USGS/NCGS Resource Assessment

- *Current focus:* Rigorous, science-based assessment of technically recoverable natural gas.
- *Methodology*: Numeric, conservative approach to be computed by the U.S. Geological Survey.
- *Completion date*: September 30, 2010.
- *Publication date*: sometime in 2011.

Open Issues

- 1945 Oil and Gas Conservation Act
  - Article 27, G.S. 113-378 through 113-415
- Horizontal drilling: Not currently allowed
  - Based on the Oil and Gas Conservation Act
- Hydraulic-fracturing: Not currently allowed
  - 15A NCAC 02C. 0213

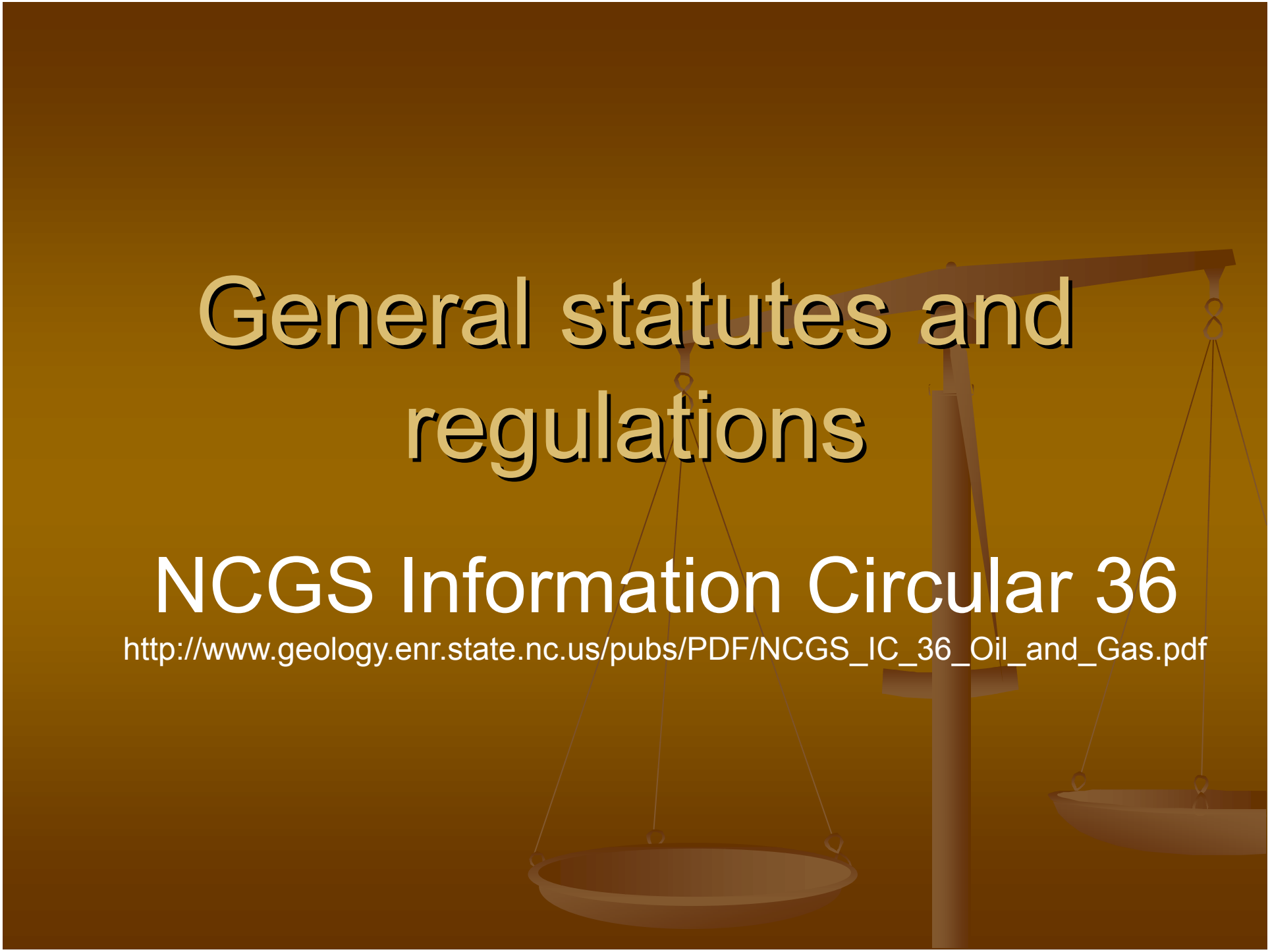
Permitting / Bond / Royalties

- Permit fees: Currently $50/well.
- Bonding: Currently $5,000/well.
- State royalties: $0.005/mcf (1,000 ft^3).

From: Oil and Gas Conservation Act of 1945

Environmental Issues

- Water resources for drilling and hydraulic-fracturing.
- Impacts on groundwater (quantity and quality).
- Solid and hazardous waste from drilling.
- Waste water from drilling and hydraulic-fracturing.
- Erosion and sedimentation control from construction of well pads, access roads and pipelines.



General statutes and regulations

NCGS Information Circular 36

http://www.geology.enr.state.nc.us/pubs/PDF/NCGS_IC_36_Oil_and_Gas.pdf

Summary

- 154,000+ prospective acres for exploration.
- Rift basin with depth of 7,000+ feet.
- 800-foot thick organic shale section with two coal beds.
- Gas prone section based on chemistry and maturation and two shut-in wells with pressure.
- Centrally located in state.
- Environmental and permitting issues.

Acknowledgements

- Portions of this work were defrayed by a grant from the U.S. Geological Survey (NCRDS Cooperative agreement G09AC00381), and
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Contact information

Dr. Jeffrey C. Reid, PG, CPG
Senior Geologist
North Carolina Geological Survey
Telephone 919.733.2423 x403
email: jeff.reid@ncdenr.gov

Dr. Kenneth B. Taylor, PG
Chief
North Carolina Geological Survey
Telephone 919.733.2423 x401
email: kenneth.b.taylor@ncdenr.gov

Mr. James D. Simons, PG, PE
Director and State Geologist
Division of Land Resources
Telephone: 919.733.3833
Email: jim.simons@ncdenr.gov