Mesozoic rift basins – Onshore North Carolina and south-central Virginia, U.S.A.: Deep River and Dan River total petroleum systems (TPS) and assessment units (AU) for continuous gas accumulation, and the Cumberland-Marlboro 'basin', North Carolina

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Note: References are grouped by report section.

Mesozoic rift basins – Onshore North Carolina and south-central Virginia, U.S.A.: Deep River and Dan River total petroleum systems (TPS) and assessment units (AU) for continuous gas accumulation, and the Cumberland-Marlboro 'basin', North Carolina

By Jeffrey C. Reid, Robert C. Milici, and James L. Coleman, Jr.

Abstract

Two continuous gas assessment units (AUs) are present in the Late Triassic (Norian) onshore rift basins of North Carolina and south-central Virginia. Continuous AUs are the USGS classification/nomenclature for the oil and gas rich resource plays industry has been pursuing and exploiting throughout the continental United States. "Continuous gas assessment units" include tight gas sandstone as well as two resource plays – coalbed methane and shale gas/oil. The USGS assessed the East Coast Mesozoic rift basins as continuous gas AU's primarily as tight gas AU's because oil and gas have been found (although not produced) from tight (*i.e.*, low porosity and permeability) sandstones, coal beds, and shale beds/intervals. The source rocks are lacustrine shales that were deposited in freshwater lakes that were near the paleo-equator after the onset of Pangea rifting.

These two rift basins, the Deep River basin wholly within North Carolina, and the Dan River-Danville basin, located in north-central North Carolina and south-central Virginia were assessed numerically as part of the USGS's National Petroleum Resource Assessment (**Fig. 1**). The name 'Dan River-Danville basin' is used by the U.S. Geological Assessment team for assessment, and the name, 'Dan River basin' is used herein following stratigraphic revision and formal basin naming in 2015 (**Olsen *et al.*, 2015**). These two rift basins are part of a series of larger continental series rift basins that formed during the Permian to Early Jurassic extension in central Pangea as the supercontinent began to fragment.

These continuous gas-prone AUs each have a single total petroleum system (TPS). The Deep River basin continuous AU has an estimated mean gas content of 1,660 billion cubic feet of gas (BCFG) and an estimated mean of 83 million barrels of natural gas liquids (MMBNGL). Noble gases (He (~0.20% to 0.24% of crustal origin, not mantle), Ne (0.11 to 0.04 ppm), Ar, and traces of Xe and Kr) were documented from two shut-in wells in the Deep River basin by **Reid *et***

***al.*, 2015**. The Dan River-Danville basin continuous AU has an estimated mean gas content 49 BCFG and no natural gas liquids from data available in 2011 assessed by the U.S. Geological Survey (**Milici *et al.*, 2012**) (**Table 1**). Helium and light hydrocarbons were documented using fluid inclusion stratigraphy (FIS) from five core holes in that basin (**Reid, 2018b).** FIS is not sufficiently sensitive to detect the other noble gases.

The Dan River basin stratigraphy was clarified by **Olsen *et al.* (2015)**. A continuous 1,477-foot-deep stratigraphic core hole drilled in 2015 by the North Carolina Geological Survey penetrated a 323-ft-thick unconventional lacustrine shale reservoir containing a 3-ft-thick coal with gas shows in the coal and lower siltstone, and was advanced through an underlying siliciclastic formation containing previously unknown thin organic strata, to basement at a depth of 1,451.2 ft below the surface.

The Cumberland-Marlboro 'basin', a large, strike parallel and seaward negative aeromagnetic anomaly that is buried beneath thin unconsolidated coastal plain sediments also was drilled and cored (three Rotasonic holes) in 2015 by the North Carolina Geological Survey. Metasedimentary Paleozoic(?) basement rock was recovered with no Triassic strata present.

Basic information and data (organic geochemistry and thermal maturation analyses, organic petrology, whole rock XRD mineralogy, rock mechanics, well logs, core descriptions, high pressure air / mercury infusion capillary pressure (MICP), microprobe analysis or porosity and permeability, uninterpreted and paired interpreted seismic lines, stable carbon and oxygen isotope data, noble gas isotope data, etc.) that underlie this report are found in **Reid (2018a,b)** for the Deep River- and Dan River basins respectively. A summary of investigations for the Cumberland-Marlboro 'basin' is in **Reid *et al.* (2016a,b)**.

This report provides an overview of the Triassic rift / lacustrine basins and their hydrocarbon potential in North Carolina. The companion report by **Reid (2018a)** is a gateway to the published technical hydrocarbon potential literature for the Deep River basin. The companion report by **Reid (2018b)** is a gateway to the published technical hydrocarbon potential literature for the Dan River basin.

The Deep River basin continuous gas AU, North Carolina

The Deep River basin continuous gas AU occupies a 150-mi-long northeast-trending half-graben with a steeply-dipping eastern border fault in central North Carolina **(Fig. 1**). The basin is divided into three sub-basins, which are named from north to south, the Durham sub-basin, the Sanford sub-basin and the Wadesboro sub-basin (**Fig. 2**). The Sanford sub-basin contains a total TPS with a source rock (the Cumnock Formation), seal (the Sanford Formation), and has structural and stratigraphic traps. This relatively untested area has been drilled, and has two shut-in natural gas wells (both with documented noble gas concentrations); about 5,835 ac were under lease as of July 2015.

The three sub-basins are filled with ~7,000 ft of Triassic strata, divided into the following three formations in ascending stratigraphic order: (1) Pekin Formation (gray sandstone and shale) is mostly fluvial with basin-border conglomerates, (2) Cumnock Formation (black shale, with some beds of gray shale, sandstone and coal) is lacustrine, and the (3) Sanford Formation (red and gray siltstone and shale) is mostly fluvial, some lacustrine, and basin-border conglomerates. The Cumnock Formation includes a thick interval (up to ~800 ft) of Late Triassic (Norian) organic-rich black shale. This shale extends across ~59,000 ac, at depths of less than 3,000 ft in the Sanford sub-basin, within Lee and Chatham counties, North Carolina.

Organic geochemistry and thermal maturation analyses indicate that the black shale in the Cumnock Formation is gas-prone, and that values of total organic carbon (TOC) exceed 1.4% in places. The Cumnock Formation contains systematic fractures that are observable in outcrop, in drill cores and on 1:24,000-scale geologic maps superimposed on LiDAR data. The primary fractures trend northwest, whereas the conjugate fractures trend northeast. In some places along the west side of the basin, the northwesterly-trending fractures are filled with diabase dikes (that locally heated the adjacent Cumnock Formation).

Mapping in underground coal mines (now abandoned) has shown that a diabase sheet fringing the northwestern Sanford sub-basin margin does not extend far into the basin. The diabase dikes are very narrow in width (up to tens of feet), vertical, limited in number, and have heated the sedimentary strata to about one-half the width of a dike on each side – a volumetrically small amount, unlikely to have significantly increased hydrocarbon generation in the Cumnock source rock.

Four exploration wells preceded acquisition of ~75 line-miles of dip and strike seismic lines that provide considerable two-dimensional (2D) control in the Sanford sub-basin and the Durham sub-basin. The deeper parts of the Sanford sub-basin are under-explored and are constrained by two drill holes that penetrated basement. Preliminary seismic interpretation suggests multiple stratigraphic and/or structural targets.

The primary exploration focus has been on the Sanford sub-basin and its TPS because of the abundance of drill core, geophysical logs, two shut-in wells with measured pressures (Butler #3 [~900 psi], Simpson #1 [~250 psi]), gas chemistry (molecular, BTU content, and carbon, oxygen and nitrogen stable isotopes), rock exposures including thin coal beds, and a basinal network of 2D seismic lines. Key references for the Sanford sub-basin are: **Reinemund (1949**,

1955); **Arbogast (1976)**; **Olsen and Gore (1989)**; **Hu (1991)**; **Reid and Milici (2008)**; **Reid and Taylor (2008**, **2009a-c)**; **Reid (2009)**; **Reid *et al.* (2010a,b)**; **Reid *et al.* (2014 a,b)**; **Reid and Taylor (2011)**; **Whiteside *et al.* (2011)**, and **Reid (2018a)**. **Reid *et al.* (2015)** published noble gas concentrations and their isotopes along with their molecular organic geochemistry and corresponding stable isotopic distribution from the Butler #3 and Simpson #1 wells.

Reid *et al.* (2014a,b) provided comprehensive, integrated and robust characteristics of the Cumnock Formation. They used: 1) high pressure air / mercury infusion capillary pressure (MICP); 2) pore characterization using scanning electron microscopy (SEM) with argon-ion beam milled samples; 3) geomechanical analyses for triaxial shear, Poisson's ratio, Young's modulus accompanied by whole rock XRD mineralogy of core through the entire vertical extent of the "sweet spot" (thickest organic shale and coals, highest TOC, and $\%R_o$ at least in the oil window) and basin center of the Cumnock Formation; and 4) light microscopy using ultrathin thin sections. Multiple porosity types were identified from argon-ion beam milled samples using SEM and an electron microprobe. Porosity types include: 1) intergranular (particularly between clay particles), 2) intragranular (especially in phosphate grains), 3) diagenetic growth of pyrite, and 4) pore development from the consumption of kerogen during hydrocarbon generation. Combinations of these porosity types were observed. The Cumnock Formation's average porosity in the "sweet spot" (drill hole CH-C-1-45) is 2.28%; the minimum is 0.44%, the maximum is 6.43%, and the standard deviation is 1.46%. The average permeability in the "sweet spot" (drill hole CH-C-1-45) is 1.75×10^{-5} mD. The minimum is 0.090×10^{-5} mD, the maximum is 7.11×10^{-5} mD, and the standard deviation is 1.77×10^{-5}. Porosity near the basin center (V.R. Groce #1) averages 1.58%; the minimum is 0.24%; the maximum is 3.74%, and the standard deviation is1.03%. Average permeability near the basin center is 1.61×10^{-5} mD; the minimum is 0.05×10^{-5} mD, the maximum is 6.68×10^{-5} mD, and the standard deviation is 1.99×10^{-5} mD. Molecular chemistry and stable isotopes of the gas from two shut-in wells (Butler #3 and Simpson #1) have been obtained. The related pore study provided argon ion-milled images of the pores using a scanning electron microscope (SEM) and an electron microprobe.

The Durham sub-basin, located north of the Sanford sub-basin, has had fewer studies. However, it has three available vibroseis seismic lines, and intensive geotechnical exploration study of the shallow subsurface in the Sanford Formation for the construction of a nuclear power plant, and for the characterization of a multi-state low-level radioactive waste disposal (LLRW) facility (effort now abandoned). The USGS Sears No. 1 test well (API 32-183-00001; NCGS well code WA-T-01-76) was drilled to a depth of 3,725 ft. and correlated to the V.R. Gross well (API 32-105-0001; NCGS well code LE-OT-01-74) (**Brown, 1988**). The drill hole was abandoned before penetrating the source rock/target formation because of sabotage. The extensive geotechnical studies investigated a depth shallower than most of the Cumnock Formation. The vibroseis data show several horsts and grabens in a basin of similar depth to the Sanford sub-basin.

Carpenter and Reid (2015) provided a geologic model that explains these relationships involves uplift of the Rolesville batholith resulting in erosion and formation of a clastic wedge on a pediment surface that extended to the west. During the early history of the Durham sub-basin, the clastic wedge probably extended over the entire basin, and was captured by the basin during periods of subsidence along the Jonesboro fault. So long as the clastic wedge extended over the entire basin, rock units surrounding the basin were covered and did not contribute sediment. The northern portion of the Durham sub-basin is interpreted as a principal depo-center.

From here, sediment was re-transported to more southerly portions of the sub-basin along basin axial flow. These finding complement the depositional, erosional, and tectonic history of the area and recent studies on the natural gas resource potential of the Deep River basin (**Reid and Milici, 2008**; **Reid and Taylor (2011**).

The Wadesboro sub-basin, south of the Sanford sub-basin, is the least well known of the three sub-basins lacking both detailed geologic mapping, drilling or seismic data. However, the Cumnock Formation is exposed in clay pits and basin margin outcrops, and has been investigated by vertebrate paleontologists. During initial geologic mapping in the Wadesboro sub-basin, **Brazill *et al.* (2012)** found thin intervals of organic rich gray shale and other lacustrine marginal lacustrine lithofacies. However, the extent, thickness, TOC and maturity of the source rock are unknown because source rock outcrops are sparse in this sub-basin. **Swe (1963)** mapped the sub-basin's western margin characterizing it as 'splintered' by a series of nearly parallel faults that formed several parallel, long and narrow horsts and grabens. These were filled by coarse-grained conglomerates as alluvial cones at the bases of steep fault scarps.

Dineen (1982) studied the Ellerbe basin, a 20-square-mile Triassic basin geographically separated from the Wadesboro sub-basin. The Ellerbe basin's depth ranges from 10 ft to not more than 200 ft. It is filled with coarser siliciclastic sediments, and lacks organic-rich source rocks.

Area

Sanford sub-basin (146,530 ac); Durham sub-basin (405,236 ac), and Wadesboro sub-basin (205,809 ac), or ~757,575 total ac.

Age of synrift basin-fill strata

Late Triassic (Norian).

Type

Half-graben rift basin: principle normal fault zone on the southeast basin margin.

Thickness of basin-fill strata

Maximum estimated basin depth of 7,100 ft based on two-way travel time from seismic and control of two wells penetrating basement rocks.

Exploration wells (including coal core holes)

Eleven of the 28 wells (including old coal exploration drill holes) that penetrated the

Cumnock Formation have natural gas and oil shows. Two shut-in wells have measured pressures of 900 psi (Butler #3) and 300 psi (Simpson #1). Coal mines, now closed, had underground oil shows and multiple fatal methane gas mine explosions.

Oil and gas shows

Numerous (see 'Exploration wells [including coal]' above) hydrocarbon shows in the Cumnock Formation including oil, gas, asphalt, and pyrobitumen were encountered while drilling and were reported from underground coal workings (now abandoned). Degraded oil and pyrobitumen occur in the Sanford Formation that overlies the Cumnock Formation. Methane was detected while drilling through thick intervals of the Sanford Formation (potential tight gas sandstone reservoir?). Complete molecular composition, BTU, and stable isotopic data (Δ Nitrogen, Δ Carbon, and Δ Deuterium), and helium in the shut-in well gases and pressures were obtained from the Butler #3 and Simpson #1 wells. More complex hydrocarbon molecules, "wet ends" (ethane, ethylene, propane, iso-butane, n-butane, n-pentane, and hexanes+) are present in measurable quantities in gases collected from these two wells. The presence of these complex hydrocarbon molecules indicates that the gases are generated thermogenically rather than biogenically. However, a biogenic component cannot be completely ruled out based on stable isotope data from the Simpson #1 well. The gas composition from the Butler #3 well is thought to be most representative of the reservoir and thermogenic gas composition. Neither hydrogen sulfide nor carbon dioxide was detected in either of these two wells. Limited gas composition and BTU data for the Dummitt-Palmer #1 well is available.

Noble gases

Helium was measured in both wells at a concentration of about 0.218 mol. % (Butler #3) and 0.223 mol. % (Simpson #1) as sampled in 2009 and reported in **Reid and Taylor (2011)**. Recently noble gas concentration and their isotopes became available (**Reid *et al.*, 2015**), along with confirming molecular organic geochemistry and corresponding stable isotopes similar to those listed in **Reid and Taylor (2011)**. Noble gas isotopes, major element isotopes, and gas composition were obtained from gas sampled from the Late Triassic, Norian age, Cumnock Formation in the shut-in Butler #3 (API 32-105-00008) and Simpson #1 (API 32-105-00007) wells, drilled in 1998. This is the first gas public report of chemistry compilation from these wells. This gas, sampled in 2009 and in 2014, had a strong 'fruity' light petroliferous odor and a visible condensate plume when the wells were flowed. Maturation data indicate these wells are in the oil and wet gas window. Shut-in well pressures were ~900psi (Butler #3), and ~200psi (Simpson #1); both had a substantial initial gas flow. Limited data are also available are from the 1982 Dummitt-Palmer #1 coal-bed methane (CBM) well (API 32-105-00002), now plugged and abandoned (**Hoffman and Buetel, 1991**).

Helium concentrations were ~0.20% to 0.24% from the noble gas analysis with neon ranging from 0.11 to 0.04 ppm and argon at approximately 33 ppm. The measured noble gas composition contains very low atmospheric contamination with helium isotopes (0.07 R/R_A)

clearly defined by a crustal origin, while neon and krypton and are mainly attributed to atmospheric origin ($^{20}Ne/^{22}Ne$ ~9.8, $^{86}Kr/^{84}Kr$ ~0.3). Argon isotopes are mixed between crustal and atmospheric origins with $^{40}Ar/^{36}Ar$ values ~ 418 to 520. The $F^{20}Ne/^{36}Ar$ (~0.9 to 2.6), $F^{84}Kr/^{36}Ar$ (~0.8) and $F^{132}Xe/^{36}Ar$ (0.6-0.7) in the gas show enrichment in the light isotopes associated with multi-stage fractionation processes with gas and fluid interaction (**Reid *et al.*, 2015**).

Source rock and maturity

The Cumnock Formation lacustrine shale is up to 800 ft thick and contains a bituminous coal up to 42 in thick. This is the core element of the gas-prone continuous AU. The average TOC content of the Cumnock Formation in the Sanford sub-basin is 1.89% (n=401). The average vitrinite reflectance, a measure of thermal maturity ($\%R_o$), of the Cumnock Formation in the Sanford sub-basin is 1.28% (n=42) which is within the current gas-generating window.

Reservoirs

Potential petroleum reservoirs are a continuous accumulation that could reside in the basin-border conglomerates, and very coarse-grained sandstones to mudstones, gray and black shale, and the coaly interval, or the source rocks themselves. The potential seals are shale beds interbedded with the coarser-grained strata. Systematic fractures trend northwesterly, whereas the conjugate fractures trend northeastward. Longitudinal basin faults and basinal cross faults, and a cross-basin trending anticline may provide structural plays in conjunction with the continuous accumulation.

Estimated technically recoverable resources

The Deep River basin continuous AU has an estimated mean of 1,660 BCFG and 83 MMBNGL (**Milici *et al.*, 2012**).

References

Arbogast, J.S., 1976, Fluvial deposition of Triassic red beds, Durham Basin, North Carolina: unpublished master's degree, Department of Geology, Duke University, 117p.

Brazill, S.J.; Diemer, J.A.; Felts, M.S.; Rachide, S.P., and Bobyarchick, A., 2012, Sedimentology and Depositional Environments of the Triassic Wadesboro basin, North Carolina, Department of Geography & Earth Sciences, University of North Carolina at Charlotte. Viewed on line September 24, 2018 at URL http://gsa.confex.com/gsa/2012SE/finalprogram/abstract_202255.htm.

Brown, Charles E., 1988, Determination of rock properties by borehole-geophysical and physical-testing techniques and ground-water quality and movement in the Durham Triassic Basin, North Carolina: U.S. Geological Survey, Professional Paper 1432, 29. Available on-line at URL https://pubs.usgs.gov/pp/1432/report.pdf.

Carpenter, Robert H., and Reid, Jeffrey C., 2015, Permian, Triassic, and Jurassic history of the Raleigh-Durham area, North Carolina. Presented at the 2015 annual meeting of the Southeastern Section, Geological Society of America, Chattanooga, Tennessee. Abstract number 251558, Abstracts with programs, v. 47, No. 2, p. 13. Available on-line at URL https://gsa.confex.com/gsa/2015SE/webprogram/Paper251558.html (abstract and poster [PDF]).

Dineen, Michael J., 1982, Geology of the Triassic "Ellerbe basin", Richmond County, North Carolina: unpublished master's degree thesis, North Carolina State University, Department of Marine, Earth and Atmospheric Sciences, Raleigh, N.C., 68p. plus two plates.

Hoffman, Charles W., and Buetel, Richard A., 1991, The Dummitt-Palmer #1 coal-bed methane test well, Lee County, North Carolina: North Carolina Geological Survey Open-File Report 91-1, 11p. Available on-line at URL https://files.nc.gov/ncdeq/Energy%20Mineral%20and%20Land%20Resources/Geological%20Survey/OFRs_Geological_Survey/NCGS_OFR_91-01_Dummitt_Palmer.pdf.

Hu, L., 1991, Petrology and depositional cycles of subsurface Triassic Cumnock formation of the Sanford sub-basin, North Carolina: unpublished master's thesis, Department of Geology, University of North Carolina, Chapel Hill, 81p.

Milici, Robert C.; Coleman, James L., Jr.; Rowan, E.L.; Cook, T.A.; Charpentier, R.R.; Kirschbaum, M.A.; Klett, T.R.; Pollastro, R.M., and Schenk, C.J., 2012, Assessment of undiscovered oil and gas resources of the East Coast Mesozoic basins of the Piedmont, Blue Ridge Thrust Belt, Atlantic Coastal Plain, and New England Provinces, 2011: U.S. Geological Survey Fact Sheet 2012–3075, 2 p. Available on-line at URL http://pubs.usgs.gov/fs/2012/3075/.

Olsen, Paul E., and Gore, P.J.W., 1989, Tectonic, depositional, and paleoecological history of Early Mesozoic rift basins, Eastern North America, 28th International Geological Congress, Field trip guidebook T351, Gulf, North Carolina, USA to Parrsboro, Nova Scotia, Canada: American Geophysical Union, 174p.

Olsen, Paul E.; Reid, Jeffrey C.; Taylor, Kenneth B.; Kent, Dennis V.; and Whiteside, Jessica H., 2015, Revised stratigraphy of Triassic age strata of the Dan River basin (Virginia and North Carolina, USA) based on drill core and outcrop data: *Southeastern Geology*, v. 51, No. 1, March 2015, p. 1-31.

Reid, Jeffrey C., and Milici, Robert C., 2008, Hydrocarbon source rocks in the Deep River and Dan River Triassic Basins, North Carolina, U.S. Geological Survey, Open-File report 2008-1108, 35 p. plus tables. Available on-line at URL http://pubs.usgs.gov/of/2008/1108/.

Reid, Jeffrey C., and Taylor, Kenneth B., 2008, Tools to Evaluate the Hydrocarbon Potential of the Mesozoic Basins, North Carolina, USA. Available on-line at URL http://www.searchanddiscovery.net/abstracts/html/2008/eastern-pittsburgh/abstracts/reid.htm?q=%2Btext%3Areid.

Reid, Jeffrey C., 2009, "Natural gas and oil in North Carolina," North Carolina Geological Survey, Information Circular 36, 8p. Available on-line at URL http://www.geology.enr.state.nc.us/pubs/PDF/NCGS_IC_36_Oil_and_Gas.pdf) – includes drilling regulations and permitting details (now superceded).

Reid, Jeffrey C., and Taylor, Kenneth B., 2009a, Shale Gas Potential in Triassic Strata of the Deep River Basin, Lee and Chatham Counties, North Carolina, USA. Available on-line at URL http://www.searchanddiscovery.net/abstracts/html/2009/eastern/abstracts/reid02.htm?q=%2Btext%3Areid; see also extended presentation (PDF) on AAPG's Search and Discovery site at URL http://www.searchanddiscovery.net/documents/2009/80072reid/ndx_reid.pdf.

Reid, Jeffrey C. and Taylor, Kenneth B., 2009b, Geology and Infrastructure Data for the Development of Shale Gas Wells in Triassic Strata of the Deep River basin, Lee and Chatham counties, North Carolina, USA. Available on-line at URL http://www.searchanddiscovery.net/abstracts/html/2009/eastern/abstracts/reid.htm?q=%2Btext%3Areid.

Reid, Jeffrey C., and Taylor, Kenneth B., 2009c, "Shale gas potential in Triassic strata of the Deep River basin, Lee and Chatham counties, North Carolina with pipeline and infrastructure data," North Carolina Geological Survey, Open-File Report 2009-01. Available on-line at URL http://www.geology.enr.state.nc.us/news.htm.

Reid, Jeffrey C.; Taylor, Kenneth B., and Cumberbatch, N.S., 2010a, Digital compilation map Sanford sub-basin, Deep River basin, parts of Lee, Chatham and Moore counties, North Carolina [Seismic lines, drill hole locations, geologic units (from Reinemund, 1955), hydrocarbon shows (gas, oil asphaltic – or combination), and $\%R_o$ in wells – Area within dotted line inferred extent of $\%R_o \geq 0.8$]: North Carolina Geological Survey, Open-file report 2010-07. Available on-line at URL https://files.nc.gov/ncdeq/Energy%20Mineral%20and%20Land%20Resources/Geological%20Survey/OFRs_Geological_Survey/NCGS%20Open-file%20Report%202010-07%20final%2020100707.pdf.

Reid, Jeffrey C.; Taylor, Kenneth B., and Simons, J.D., 2010b, North Carolina Shale Gas – A Progress Report – Lee, Chatham and Moore counties: American Association of Petroleum Geologists' Eastern Section Meeting, Kalamazoo, Michigan, September 25-29, 2010, program with abstracts, p. 52. Available on-line at URL http://www.searchanddiscovery.com/documents/2011/40704reid/ndx_reid.pdf.

Reid, Jeffrey C. and Taylor, Kenneth B., 2011, with contributions by Olsen, Paul E., and Patterson, III, O.F., "Natural Gas Potential of the Sanford sub-basin, Deep River Basin, North Carolina," 57p., *in* Taylor, Kenneth B. and Jeffrey C. Reid, editors, "Field Trip Guidebook – 60th Annual Meeting," Southeastern Section, Geological Society of America, Wilmington, North Carolina, March 2011. Note: The updated and revised version of this field trip guidebook prepared for the 2011 annual meeting of the Eastern Section, AAPG is available on-line at URL http://www.searchanddiscovery.com/documents/2011/10366reid/ndx_reid.pdf.

Reid, Jeffrey C.; McGlue, Michael M., and Ellis, Geoffrey S., 2014a, Porosity, permeability, and pore characterization of the Triassic Cumnock Formation: A continuous gas assessment unit, Sanford sub-basin, Deep River basin, Lee County, North Carolina, USA, (poster) Annual meeting of the American Association of Petroleum Geologists, Houston, Unconventional Reservoirs on 7 April 2014, program with abstracts, contribution #1841705. Available on-line at URL http://www.searchanddiscovery.com/documents/2014/10612reid/ndx_reid.pdf. See also Part 2 of the article, at AAPG's 'Search and Discovery' as article #10612 (2014) available on-line at URL http://www.searchanddiscovery.com/documents/2014/10662reid/ndx_reid.pdf.

Reid, Jeffrey C.; Taylor, Kenneth B., and McGlue, Michael M., 2014b, Porosity, permeability, and pore- and geomechanical characterization of the Triassic Cumnock Formation: A lacustrine / rift continuous gas assessment unit, Sanford sub-basin, Deep River basin, Lee County, North Carolina, USA, Part 2: (abstract and poster) presented at the annual meeting of the American Association of Petroleum Geologists' Eastern Section annual meeting, London, Ontario, Canada. Available on-line at URL http://www.searchanddiscovery.com/documents/2014/10662reid/ndx_reid.pdf. See also Part 1 of the article, Search and Discovery Article #10612 (2014) available on-line at URL http://www.searchanddiscovery.com/documents/2014/10612reid/ndx_reid.pdf.

Reid, Jeffrey C., 2015, Triassic rift / lacustrine continuous gas assessment units (AU): North Carolina and Virginia, USA, *in* Post, P.; Coleman, Jr., J. L.; Brown, D.; *et al.*, editors, Petroleum systems in "rift" basins: 34th Annual GCSSEPM Foundation Perkins-Rosen Research Conference Proceedings, December 13-16, 2015, Houston, TX, p. 287-306 plus Appendix (3 large format posters). The abstract can be viewed on-line at URL http://www.gcssepm.org/conference/2015_abstracts4.pdf. This was both an oral and poster presentation.

Reid, Jeffrey C.; Hunt, Andrew; Ellis, Geoffrey; Taylor, Kenneth B., and Patterson, Orus F., III, 2015, Noble gas isotopes, major element isotopes, and gas composition data from the Cumnock Formation: Sanford sub-basin, Deep River basin, North Carolina, U.S.A. Available on-line at URL http://www.searchanddiscovery.com/documents/2015/80492reid/ndx_reid.pdf.

Reid, Jeffrey C.; Coleman, Jr., James L.; Taylor, Kenneth, B.; Marciniak, Katherine J.; Haven, Walter T.; Channell, Ryan A.; and Warner, Chandler I., 2016a, North Carolina Geological Survey Open-File Report 2016-01: Cumberland-Marlboro basement drilling results – 2015: Cumberland, Hoke and Scotland counties, North Carolina, 34 p. Available on-line at URL https://files.nc.gov/ncdeq/Energy%20Mineral%20and%20Land%20Resources/Geological%20Survey/Oil%20and%20Gas%20Research/NCGS_OFR_2016-01_V_20160223.pdf.

Reid, Jeffrey C.; Taylor, Kenneth B.; Marciniak, Katherine J.; Haven, Walter T.; Channell, Ryan A.; Shields, Ann T., and Warner, Chandler, I., 2016b, Applications of scientific core drilling in North Carolina: Cumberland-Marlboro 'basin' (Hoke, Scotland and Cumberland counties), and the Triassic rift / lacustrine Dan River basin (Stokes County): Presented at the 45th Annual meeting, Eastern Section, American Association of Petroleum Geologists, September 25-27, 2016, Lexington, Kentucky. The abstract is in the meeting program with abstracts, p. 51-52 or on-line at URL http://www.searchanddiscovery.com/documents/2016/10897reid/ndx_reid.pdf.

Reid, Jeffrey C., 2018a, The Deep River Basin Total Petroleum System, North Carolina – Basin number 1250700461: North Carolina Geological Survey, Special Publication 9, 152 pages plus tables and appendices.

Reid, Jeffrey C., 2018b, The Dan River Total Petroleum System, North Carolina – Basin number 1250701061: North Carolina Geological Survey, Special Publication 10, 89 pages, plus tables and appendices.

Reinemund, John A., 1949, Geology of the Deep River coal field. Chatham, Lee and Moore counties, North Carolina: U.S. Geological Survey, Preliminary Map (in two sheets).

Reinemund, John A., 1955, Geology of the Deep River coal field North Carolina: U.S. Geological Survey Professional Paper 246, 159p. Available on-line at URL https://pubs.er.usgs.gov/publication/pp246.

Schruben, P.G.; Arndt, R.E., and Bawiec, W.J., 2006, Geology of the conterminous United States at 1:2,500,000 Scale – A digital representation of the 1974 P.B. King and H.M. Beikman map: U.S. Geological Survey Digital Data Series 11, Release 2.

Swe, W., 1963, Structural and stratigraphic relationship along the northwestern margin of the Wadesboro basin of North Carolina: unpublished M.S. thesis, University of North Carolina at Chapel Hill, 64p.

Whiteside, J.H.; Grogan, D.S.; Olsen, P.E., and Kent, D.V., 2011, Climatically driven biogeographic provinces of Late Triassic tropical Pangea. Published online before print, May 13, 2011. Doi: 10.1073/pnas. 1102473108, and in print at Proceedings of the National Academy of Sciences of the United States of America (PNAS), May 31, 2011, vol. 108, no. 22, pp. 8972-8977 with supporting information.

The Dan River-Danville basin continuous gas AU, North Carolina and Virginia

The Dan River basin is both a topographic and a structural basin (**Fig. 1**). The present-day topographic basin drains older igneous and metamorphic rocks that surround the basin, and the Dan River discharges water into Kerr Lake northeast of Dan River, Virginia.

The basin is a continuous gas-prone AU located in north-central North Carolina and south-central Virginia. This Triassic rift basin is one of a series of continental rift basins that formed during the Permian to Early Jurassic breakup of central Pangea as the supercontinent began to fragment. The ~93-mi-long basin is a northeast-trending half graben with a steeply-dipping western border fault zone. The southeast contact is a major unconformity of Triassic strata on metamorphosed Paleozoic rocks of the Piedmont province.

The basin is filled at present with ~5,000 ft of Triassic strata that dip at about 30^{o} to the west toward the border fault zone. **Olsen *et al.* (2015)** revised the stratigraphy of the Dan River basin to clarify and unify conflicting stratigraphy by earlier workers. They also formally named it the 'Dan River basin'. The U.S. Geological Survey assessment documentation refers to the 'Dan River-Danville basin'; herein the basin is referred to as the Dan River basin. The revised stratigraphy consists of, in ascending order, the Pine Hall, Walnut Cove, Dry Fork, Cow Branch, and Stoneville formations. The basal Pine Hall Formation is largely fluvial and consists of red, gray, buff and relatively coarse, fluvial clastic rocks. The Walnut Cove Formation consists of black and gray, largely lacustrine mudstone and minor coal. The Dry Fork Formation is comprised of gray, buff, and red lacustrine to fluvial strata. The Cow Branch Formation is made up of mostly black and gray, predominately lacustrine mudstone and sandstone. The uppermost unit is the Stoneville Formation consisting mostly of red clastic rocks with abundant gray lacustrine, and gray and red fluvial components.

The Late Triassic (Norian) Dan River basin contains a continuous gas assessment unit (AU) and a total petroleum system (**Reid *et al.*, 2015a**). The source rocks (Walnut Cove and Cow Branch formations) are thick grey and black freshwater shales. The stratigraphically lower Walnut Cove Formation has a three-foot-thick coal (likely bituminous rank) and coaly strata. These lacustrine strata were deposited in a rift basin near the paleo-equator after the onset of Pangea's breakup. The Dan River basin continuous gas AU has an estimated mean gas content of 49 BCFG and an estimated mean natural gas liquids content of 0 MMBNGL (**Milici *et al.*, 2012**) based on the limited data available in 2011.

The Walnut Cove Formation is up to 600 ft thick in some places with an outcrop strike of ~22 mi and a width of several miles. The Cow Branch Formation, up to 1,500 ft thick, is exposed in broad patches in Stokes and Rockingham counties, North Carolina, and in isolated localities in southernmost Virginia.

The potential of these two formations as shale gas reservoirs was characterized from the diamond drill core hole SO-C-02-81 (the type locality for the Walnut Cove Formation), and from the Cow Branch Formation exposed continuously in the Ararat (previously known as the Solite or Cemex) quarry located at the N.C.-VA state line north of Eden, N.C. In addition, new data from core drilling by the NCGS in 2015 provided additional information for the Walnut Cove Formation (**Reid *et al.*, 2015a**).

Characterization results reported by **Reid *et al.* (2015a,b)** for these two Triassic rift / lacustrine formations include substantial new data not available for the 2011 USGS assessment. They are: organic geochemistry and thermal maturation data (doubling the 2011 data set); and downhole whole rock mineralogy by XRD for Walnut Cove Formation (n=34), and outcrop whole rock XRD for the Cow Branch Formation (n=13). Comprehensive rock mechanics including triaxial compressive strength tests with acoustic velocities and pre- and post-CT scans, and Young's Modulus and Poisson's Ratio analyses were obtained for the Walnut Cove Formation (n=7), Cow Branch Formation (n=13). Mercury injection capillary pressure data (MICP) was also obtained to characterize porosity and permeability in the Walnut Cove Formation (n=14) and the Cow Branch Formation (n=27) with maximum pressure of 60,000 psia to provide a pore aperture frequency distribution down to nanometer-scale diameter. Pores were characterized using scanning electron microscopy (SEM) and an electron microprobe using argon ion-beam milled samples.

Key references to the Dan River basin are: **Olsen and Gore (1989)**; **Thayer and Robbins (1992)**; **Reid and Milici (2008)**; **Reid and Taylor (2008)**; **Reid (2009); Reid *et al.* (2011)**; **Reid and Taylor (2012)**; **Olsen *et al.* (2015); Reid *et al.* (2015 a,b)**, **Reid *et al.*, (2018**), and **Reid (2018)**.

Area

~64,800 ac (North Carolina), ~61,500 ac (Virginia), or ~126,300 total ac.

Age of synrift basin-fill strata

Late Triassic (Norian).

Type

Half-graben rift basin; principle basin-margin normal fault zone on the northwest basin margin.

Thickness of basin-fill strata

Maximum estimated basin depth of ~5,000 ft (current estimated depth).

Exploration wells

The basin is largely untested. No seismic lines are known in this basin. Three shallow diamond drill core holes in the Walnut Cove Formation were drilled in 1981. However, in 2015 a 1,447-ft continuous wire line stratigraphic core hole was drilled by the North Carolina Geological Survey (**Reid *et al.*, 2015a**). The stratigraphic core hole ('Town of Walnut Cove' or SO-C-01-15) began in the lower part of the Dry Fork Formation, and cored the entire Walnut Cove and Pine Hall formations before penetrating metamorphic basement rocks at a depth of

1,415.2 feet.

Oil and gas shows

No gas or oil shows had been reported in this basin until the ‘Town of Walnut Cove’ stratigraphic core hole was drilled in 2015. **Reid *et al.* (2015a,b)** reported encountering bubbling gas emanating from freshly recovered drill core in the sidetrack (~2 degree from vertical) SO-C-01-15 between the depth of 253.1 ft and 277 ft (*i.e.*, total depth of the side track hole). Bubbles (presumably hydrocarbons) were observed using soapy water on freshly recovered core emanating from a previously unknown three-foot-thick coal (appears bituminous but testing is required to confirm its rank) and from silty intervals to total depth of the side track in coaly- and silty strata to 277 ft. Fluid inclusion stratigraphy confirmed the presence of light hydrocarbons and helium from pores in five core hole intercepts of the Walnut Cove Formation (**Reid *et al.*, 2015a,b**; **Reid *et al.*, 2018**) including that of core holes SO-C-01-15 and SO-C-01A-15.

Fluid inclusion stratigraphy (FIS) has shown that C species up to C_9 are present. The most common C species are C_1 through C_5, with some C_6, C_7, and C_9 along with dry gas signals. In the core holes SO-C-1-15 and SO-C-1A-15 drilled in 2015, and the three 1981 core holes (SO-C-01-81; SO-C-02-81, and RC-C-01-81) – all in the Walnut Cove Formation, FIS data (see **Reid, 2018; Reid *et al.*, 2018**) confirms that hydrocarbons are preserved and that a total petroleum system is present **(Coleman *et al.*, 2015**; **Reid, 2018)**.

Chance (1885) noted sporadic coal occurrences in the Dan River basin and excavated pits to conclude the coal to be “…too thin, irregular and uncertain to be of any commercial value….”. **Stone (1914)** investigated a carbonaceous shale interval in the Walnut Cove Formation that is up to 225 ft thick and contains a coal about a foot thick but that it occurred only in Stokes and Rockingham counties, North Carolina. However, the ‘Town of Walnut Cove’ (SO-C-01-15) stratigraphic core hole penetrated coaly strata with a coal that was at least three-ft-thick. The latter coal is of comparable thickness to the Cumnock coal of the Deep River basin. The distribution of the coal basinward in the Dan River basin is currently unknown; diamond core drilling would be an effective method to determine the basinward extent of the unconventional reservoir and might add to the basin’s carbon endowment.

Noble gases

Helium was detected in each of these five core holes also using FIS (**Reid *et al.*, 2018; Reid, 2018**). FIS is not sufficiently sensitive to detect the other noble gases.

The correlative Cumnock Formation in the Sanford sub-basin, Deep River basin contains measured noble gases including helium, argon, neon and krypton **(Reid *et al.*, 2015c).**

Source rock and maturity

The two lacustrine source rocks in the Dan River basin are the Walnut Cove Formation and the Cow Branch Formation. The stratigraphically lower the Walnut Cove Formation, is locally over 400-ft-thick and in places is reported to be 600-ft-thick and, has a strike length of about twenty-two mi, and a probable width of ~1.1 mi – all in North Carolina. Its current average TOC is 3.55% (n=122) from outcrop and three diamond core holes drilled in 1981. The current average $\%R_o$ is 1.85 (n=23) within the gas-generating window. Overall the Walnut Cove Formation has a higher TOC and a lower $\%R_o$ compared to the stratigraphically higher Cow Branch Formation. No TOC nor $\%R_o$ data are currently available for the 'Town of Walnut Cove' stratigraphic core hole.

The stratigraphically higher Cow Branch Formation, is over 1,500 ft thick, has a strike length of at least 6.5 mi in North Carolina and an additional 2-3 mi in Virginia, and a probable width of about 1.5 mi – straddling the border between North Carolina and Virginia. Additional exposures occur to the southwest along strike up to ten miles; and an isolated patch occurs nearby Gretna, Virginia. In North Carolina, the formation has an average present-day TOC of 1.38% (n=42) from a continuous aggregate quarry section sample. The average $\%R_o$ is 2.08 (n=25) in the upper part of the gas-generating window.

Reservoirs

Potential petroleum reservoirs are a continuous accumulation that could reside in the basin-border conglomerates, and very coarse-grained sandstones to mudstones, gray and black shale, the source rock itself, and the coal and the coaly interval. Potential seals are shale beds interbedded with the coarser-grained strata. Systematic fractures trend northwest, whereas the conjugate fractures trend northeastward. A cross-basin anticline (Spray anticline) could be a potential structural trap, or could localize intraformational fracturing.

Estimated technically recoverable resources

The Dan River-Danville basin continuous AU has an estimated mean gas content of 49 BCFG and no NGL mmbngl from data available in 2011 assessed by the U.S. Geological Survey (**Milici *et al.*, 2012**).

References

Chance, Henry Martyn, 1885, An exploration of the coal fields of North Carolina: State Board of Agriculture, 66p. plus three plates, available on-line at URL http://archive.org/details/reportonexplorat00chan.

Coleman, James L., Jr.; Milici, Robert C., and Post, Paul J., 2015, Assessment of the Oil and Natural Gas Potential of the East Coast Mesozoic Rift Basins, Onshore and State Waters of the United States, *in* Post, P.; Coleman, J. L., Jr.; Brown, D., and others, editors, Petroleum systems in "rift" basins: 34th Annual GCSSEPM Foundation Perkins-Rosen Research Conference Proceedings, December 13-16, 2015, Houston, TX.

Milici, Robert C.; Coleman, James .L. Jr.; Rowan, E.L.; Cook, T.A., Charpentier; R.R., Kirschbaum, M.A.; Klett, T.R.; Pollastro, R.M., and Schenk, C.J., 2012, Assessment of undiscovered oil and gas resources of the East Coast Mesozoic basins of the Piedmont, Blue Ridge Thrust Belt, Atlantic Coastal Plain, and New England Provinces, 2011: U.S. Geological Survey Fact Sheet 2012–3075, 2 p. Available on-line at URL http://pubs.usgs.gov/fs/2012/3075/).

Olsen, Paul E., and Gore, P.J.W., 1989, Tectonic, depositional, and paleoecological history of Early Mesozoic rift basins, Eastern North America, 28th International Geological Congress, Field trip guidebook T351, Gulf, North Carolina, USA to Parrsboro, Nova Scotia, Canada: American Geophysical Union, 174p.

Olsen, Paul E.; Reid, Jeffrey C.; Taylor, Kenneth B.; Kent, Dennis V., and Whiteside, Jessica H., 2015, Revised stratigraphy of Triassic age strata of the Dan River basin (Virginia and North Carolina, USA) based on drill core and outcrop data: *Southeastern Geology*, v. 51, No. 1, March 2015, p. 1-31.

Reid, Jeffrey C., and Milici, Robert C., 2008, Hydrocarbon source rocks in the Deep River and Dan River Triassic Basins, North Carolina," U.S. Geological Survey, Open-File report 2008-1108, 35 p. plus tables. Available on-line at URL L http://pubs.usgs.gov/of/2008/1108/.

Reid, Jeffrey C., and Taylor, Kenneth B., 2008, Tools to Evaluate the Hydrocarbon Potential of the Mesozoic Basins, North Carolina, USA. Available on-line at URL http://www.searchanddiscovery.net/abstracts/html/2008/eastern-pittsburgh/abstracts/reid.htm?q=%2Btext%3Areid (AAPG Search and Discovery contribution).

Reid, Jeffrey C., 2009, "Natural gas and oil in North Carolina," North Carolina Geological Survey, Information Circular 36, 8p. Available on-line at URL http://www.geology.enr.state.nc.us/pubs/PDF/NCGS_IC_36_Oil_and_Gas.pdf) – includes drilling regulations and permitting information as of that date.

Reid, Jeffrey C.; Taylor, Kenneth B., and Simons, James D., 2011, "North Carolina Shale Gas: Dan River basin – Stokes and Rockingham counties," Program with abstracts, 49th Eastern Section Meeting, September 24-29, 2011, Arlington, Virginia, p. 44. Available on-line at URL http://www.searchanddiscovery.com/documents/2011/80199reid/ndx_reid.pdf.

Reid, Jeffrey C., and Taylor, Kenneth B., 2012, "North Carolina (USA) Mesozoic rift basin shale gas: A fifth year perspective," presented at the 7th International Symposium on Oil & Gas Resources in Western Newfoundland, September 12-14, 2012, Corner Brook, Newfoundland-Labrador. Available on-line at URL http://www.wnloilandgas.com/media/uploads/Jeff_Reid.pdf.

Reid, Jeffrey C.; Taylor, Kenneth B.; Marciniak, Katherine J.; Haven, Walter T.; Channell, Ryan A., and Warner, Chandler I., 2015a, Dan River basin stratigraphic core hole, 'Town of Walnut Cove' (SO-C-01-15), Stokes County, North Carolina: Preliminary results: North Carolina Geological Survey, Open-File Report 2015-06. Available on-line at URL https://files.nc.gov/ncdeq/Energy%20Mineral%20and%20Land%20Resources/Geological%20Survey/Oil%20and%20Gas%20Research/Dan%20River%20basin%20stratigraphic%20core%20hole%20%E2%80%98Town%20of%20Walnut%20Cove%E2%80%99%20%28SO-C-1-15%29.pdf

Reid, Jeffrey C.; Kenneth B. Taylor, and McGlue, Michael M., 2015b, Porosity, permeability, pore characterization and rock mechanics of the Triassic Cow Branch and Walnut Cove Formations: A continuous gas assessment unit, Dan River basin, Stokes and Rockingham counties, North Carolina, USA, Part 3. Available on-line at URL http://www.searchanddiscovery.com/documents/2015/10752reid/ndx_reid.pdf.

Reid, Jeffrey C.; Hunt, Andrew; Ellis, Geoffrey; Taylor, Kenneth B., and Patterson, Orus F., III, 2015c, Noble gas isotopes, major element isotopes, and gas composition data from the Cumnock Formation: Sanford sub-basin, Deep River basin, North Carolina, U.S.A. Available on-line at URL http://www.searchanddiscovery.com/documents/2015/80492reid/ndx_reid.pdf.

Reid, Jeffrey C., 2018, The Dan River Total Petroleum System, North Carolina – Basin number 1250701061: North Carolina Geological Survey, Special Publication 10, 89 pages, plus tables and appendices.

Reid, Jeffrey C.; Marciniak, Katherine J.; Haven, Walter T., and Taylor, Kenneth B., 2018, Confirmation of hydrocarbon shows and helium in the Walnut Cove Formation: Triassic rift / lacustrine Dan River basin (Stokes and Rockingham counties), North Carolina – A potential new helium province in the Eastern United States?: North Carolina Geological Survey, Open-File Report 2018-01, 2 panels. Available on-line at URLs https://files.nc.gov/ncdeq/Energy%20Mineral%20and%20Land%20Resources/Geological%20Survey/OFRs_Geological_Survey/NCGS_OFR_2018-01_Panel_1_of_2.pdf (Panel 1) and https://files.nc.gov/ncdeq/Energy%20Mineral%20and%20Land%20Resources/Geological%20Survey/OFRs_Geological_Survey/NCGS_OFR_2018-01_Panel_2_of_2.pdf (Panel 2).

Stone, R.W., 1914, Coal on the Dan River, North Carolina, *in*, Economic Paper 34, The Mining Industry in North Carolina during 1911 and 1912, by Joseph Hyde Pratt, The North Carolina Geological and Economic Survey, p. 115-148.

Thayer, Paul A., and Robbins, E.I., 1992, Sedimentology of Triassic Dan River Group, North Carolina and Virginia: *in* Dennison, J.M. and Steward, K.G., editors, Geologic field guides to North Carolina and vicinity: Southeastern Section, Geological Society of America, Winston-Salem, North Carolina, p. 189-200.

The Cumberland-Marlboro 'basin': Scotland, Hoke, and Cumberland counties, North Carolina

State-funded continuous Rotasonic coring in the Cumberland-Marlboro basin (CMB) was undertaken to evaluate a potential buried Triassic rift / lacustrine basins for on-shore hydrocarbon resource potential in May-June 2015.

The Cumberland-Marlboro basin (CMB) is a large negative aeromagnetic anomaly buried beneath thin (200-400-ft-thick) Coastal Plain cover. The anomaly is strike parallel and seaward of the Triassic Deep River rift basin previously assessed by the USGS for hydrocarbon potential **(Milici *et al.*, 2012) (Fig. 1)**. Geologic literature inconclusively postulated a Triassic rift / lacustrine basin to be present. The state groundwater well database (GW-1) provided equivocal data as to the presence of Triassic strata and limited information on bedrock well completions. Two earlier basement studies presented equivocal data that could be interpreted either as paleo-weathering of metavolcanic or metasedimentary rocks or deeply weathered paleo-scapolite developed on Triassic strata.

Three Rotasonic drill holes were advanced continuously from the surface into basement and recovered fresh-, four-inch diameter cores of basement rock along the CMB anomaly's strike extent in Cumberland, Hoke and Scotland counties, North Carolina. All three cores encountered metasedimentary basement rocks. Thus, metasedimentary rocks are the likely cause of the negative aeromagnetic anomaly along strike where the holes were drilled, and not Triassic rift / lacustrine strata. However, the presence of a very small rift / lacustrine basin like that in Bertie County, and Camden County, North Carolina, cannot be precluded, and a Triassic rift basin may yet exist in South Carolina based on water well data (**Reid *et al.*, 2016a,b**).

References

Milici, Robert C.; Coleman, James L., Jr.; Rowan, E.L.; Cook, T.A.; Charpentier, R.R.; Kirschbaum, M.A.; Klett, T.R.; Pollastro, R.M., and Schenk, C.J., 2012, Assessment of undiscovered oil and gas resources of the East Coast Mesozoic basins of the Piedmont, Blue Ridge Thrust Belt, Atlantic Coastal Plain, and New England Provinces, 2011: U.S. Geological Survey Fact Sheet 2012–3075, 2 p. Available on-line at URL http://pubs.usgs.gov/fs/2012/3075/.

Reid, Jeffrey C.; Coleman, Jr., James L.; Taylor, Kenneth, B.; Marciniak, Katherine J.; Haven, Walter T.; Channell, Ryan A.; and Warner, Chandler I., 2016a, North Carolina Geological Survey Open-File Report 2016-01: Cumberland-Marlboro basement drilling results – 2015: Cumberland, Hoke and Scotland counties, North Carolina, 34 p. Available on-line at URL https://files.nc.gov/ncdeq/Energy%20Mineral%20and%20Land%20Resources/Geological%20Survey/Oil%20and%20Gas%20Research/NCGS_OFR_2016-01_V_20160223.pdf.

Reid, Jeffrey C.; Taylor, Kenneth B.; Marciniak, Katherine J.; Haven, Walter T.; Channell, Ryan A.; Shields, Ann T., and Warner, Chandler, I., 2016b, Applications of scientific core drilling in North Carolina: Cumberland-Marlboro 'basin' (Hoke, Scotland and Cumberland counties), and the Triassic rift / lacustrine Dan River basin (Stokes County): Presented at the 45th Annual meeting, Eastern Section, American Association of Petroleum Geologists, September 25-27, 2016, Lexington, Kentucky. Available on-line at URL http://www.searchanddiscovery.com/documents/2016/10897reid/ndx_reid.pdf.

Regulatory framework overview and data access

Horizontal drilling and hydraulic fracturing became legal in North Carolina by an Act of the N.C. General Assembly in 2012. The same Act requires rules and regulations to be established for permitting. Rules were adopted on March 17, 2015; they can be viewed on-line at URL http://reports.oah.state.nc.us/ncac/title%2015a%20-%20environmental%20quality/chapter%2005%20-%20mining%20-%20mineral%20resources/subchapter%20h/subchapter%20h%20rules.pdf. The Mining and Energy Commission was dissolved July 31, 2015, as directed by Session Law 2014-4 (Senate Bill 786). The newly reconstituted N.C. Oil and Gas Commission met for the first time March 14, 2018.

The North Carolina Geological Survey is the custodian of geophysical well logs, cores and cutting samples, including those from a regional low-level waste (LLRW) disposal project. These are available for examination at its Raleigh, N.C. repository; sample borrowing agreements are available upon request. Contact the State Geologist to examine samples or to initiate a potential sample borrowing agreement.

Figure 1. Map of the Eastern United States showing the locations of the five quantitatively (volumetrically) assessed East Coast Mesozoic basins, the nine basins that were not volumetrically assessed, and the U.S. Geological Survey province boundaries. Each basin includes one continuous gas assessment unit. Basin assessment results for the Deep River basin and the Dan River-Danville basin are **in Table 1**. From **Milici *et al*., 2012**.

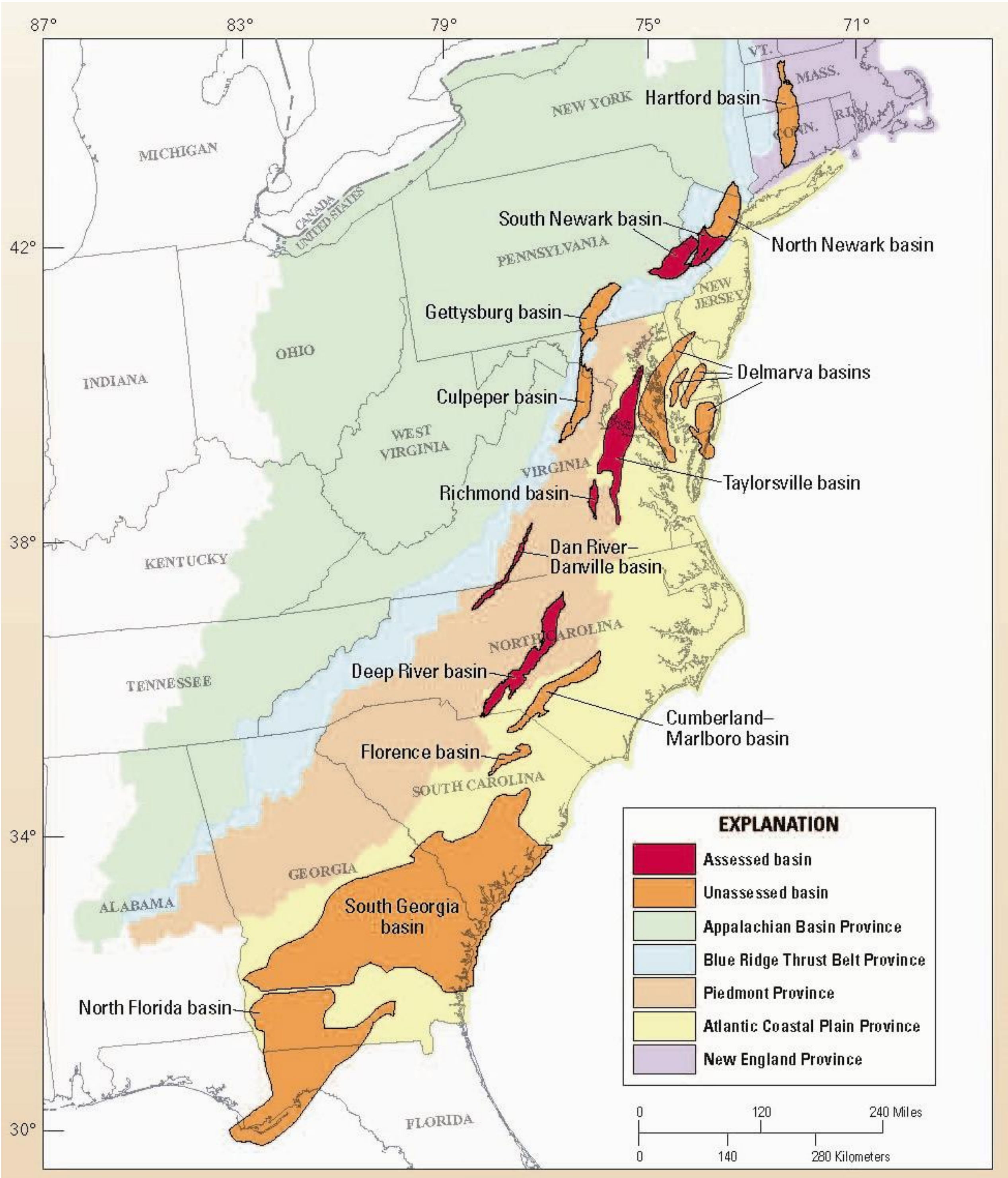

Figure 2. Generalized geologic map of North Carolina and adjacent states, showing major geologic regions and locations of drill holes in Triassic basins (Geological regions from **Schruben *et al.*, 2006**). Figure from **Reid and Milici (2008)**. Map numbers in the Deep River basin and Dan River basin correspond to drill holes tabulated in **Reid and Milici, 2008**; **Reid, 2018a,b**.

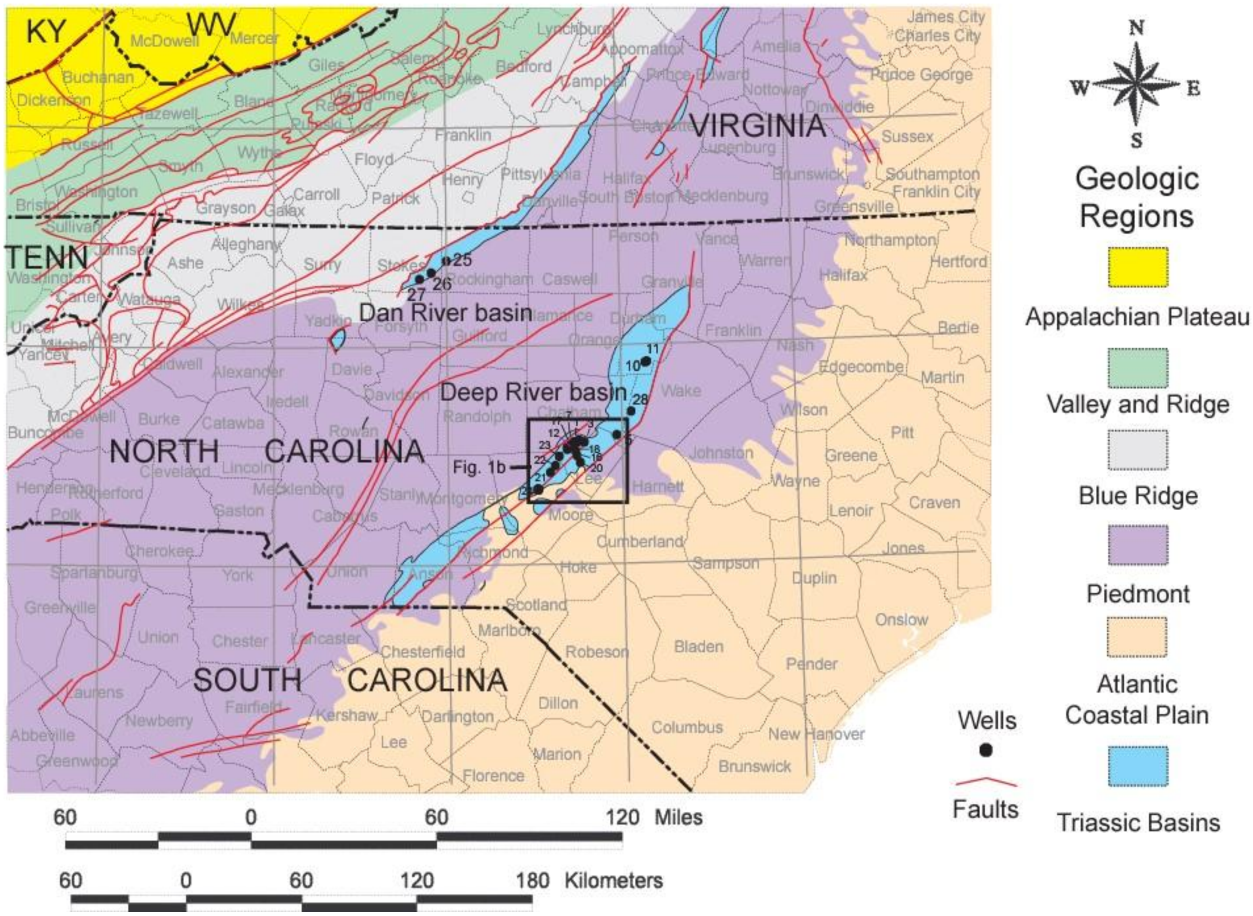

Table 1. East Coast Mesozoic basin assessment results; Deep River basin composite TPS and Dan River-Danville basin composite TPS. From **Milici *et al.*, 2012**.

Total Petroleum System (TPS) and Assessment Unit (AU)	Field Type	Total undiscovered resources											
		Oil (MMBO)				Gas (BCFG)				NGL (MMBNGL)			
		F95	F50	F5	Mean	F95	F50	F5	Mean	F95	F50	F5	Mean
Deep River Basin Composite TPS													
Deep River Basin Continuous Gas AU	Gas					779	1,527	2,990	1,660	35	75	158	83
Dan River-Danville Basin Composite TPS													
Dan River-Danville Basin Continuous Gas AU	Gas					17	42	106	49	0	0	1	0
Total North Carolina Assessed Resources						**796**	**1569**	**3096**	**1709**	**35**	**75**	**159**	**83**

[MMBO, million barrels of oil; BCFG, billion cubic feet of gas; MMBNGL, million barrels of natural gas liquids; TPS, total petroleum system; AU, assessment unit.

Results shown are fully risked estimates. For gas accumulations, all liquids are included as NGL (natural gas liquids). F95 represents a 95-percent chance of at least the amount tabulated; other fractiles are defined.