Dan River basin stratigraphic core hole 'Town of Walnut Cove' (SO-C-1-15), Stokes County, North Carolina: Preliminary results

By

Jeffrey C. Reid[1]
Kenneth B. Taylor[1]
Katherine J. Marciniak[2]
Walter T. Haven [2]
Ryan A. Channell[2]
Chandler I. Warner[2]

[1]North Carolina Geological Survey
[2]Energy Section
N.C. Division of Energy, Mineral, and Land Resources
N.C. Department of Environmental Quality

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Abstract

State-funded continuous wire line diamond drill coring in the Dan River basin was undertaken in June 2015 to further evaluate the State's Triassic rift / lacustrine basins for on-shore hydrocarbon potential. Drilling objectives were to provide scientific and technical data to improve the understanding of the Dan River basin including portions of Stokes County, North Carolina.

This preliminary report provides general information in response to a large number of inquiries about this core hole. The extensive organic-rich, thermally mature lacustrine rocks are a potential gas resource, are gas prone, and are a total petroleum system.

The core hole is located at 36°17'30.62"N., -80°07'36.87"W. with an approximate collar elevation of 604 feet above sea level. The main core hole was drilled to a depth of 1,477 feet. A side-track hole drilled from the same collar at 2° from vertical to a depth of 277 feet. The core hole was named 'The Town of Walnut Cove,' and the North Carolina Geological Survey number is SO-C-1-15. The core hole was drilled in June 2015 on land owned by the Town of Walnut Cove, and is the basin's first core hole since 1981. The core hole is down dip, basinward, and slightly northeast of the 1981 core hole (SO-C-2-81). There are neither known seismic lines nor oil and gas test holes in this basin.

The drill hole penetrated the basement (probable metavolcanic rocks) at a depth of 1,451.2 feet and reached a total depth of 1,477 feet. A thick pebble conglomerate beginning at a depth of 1,415.5 feet indicated the approaching basement contact. The entire Pine Hall Formation was penetrated; it will become the new type section for that formation (to be described in a forthcoming publication). The Pine Hall Formation contains previously unknown thin intervals of organic mudstone, more extensive coal, and coaly intervals than noted in previous geologic reports. It is unknown if these reflect limited local deposition, or more widespread lacustrine strata basinward – a hypothesis to be tested by subsequent drilling.

About 325 feet of organic lacustrine sediment (apparently the entire Walnut Cove Formation) was penetrated between 98 feet to 423.7 feet. The side track core hole (about ~2° from vertical) was advanced to fully recover a coal and coaly section that was penetrated in the main hole. Beginning at a depth of 253.1 feet in the side track hole, coring recovered at least three feet of coal followed by organic mudstone interspersed with siltstone, that when wetted with soapy water, showed apparent hydrocarbon outgassing and confirmed a total petroleum system. The remainder of the side track hole (total depth of 277 feet) is coaly black organic matter containing multiple gas shows including some from the siltstones.

The 2015-16 state budget has funds to analyze the cores for organic chemistry, thermal maturation, mineralogy, pore studies, rock mechanic studies and drilling return water for dissolved hydrocarbons. Core drilling is a cost effective tool to explore the Triassic rift / lacustrine basins.

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Introduction and objectives

This report was prepared to provide a preliminary overview of results of the 'Town of Walnut Cove' (SO-C-1-15) stratigraphic core hole drilled in June 2015 in Stokes County, North Carolina, in response to a number of general inquiries. The continuous wire line core hole was drilled with state appropriated funds. This was not an oil or gas test well, nor was it hydraulically fractured.

The U.S. Geological Survey previously numerically assessed the hydrocarbon potential of this basin in 2011 (basin #1250701061 of the USGS's national hydrocarbon basin inventory) (**Milici and others, 2012**).

The core hole objectives were to provide scientific and technical data to improve the geological understanding of the Dan River basin in North Carolina to further aid evaluation of the State's on-shore Triassic rift / lacustrine basins for hydrocarbon potential. The core hole was designed to penetrate the lower Dry Fork Formation, the Walnut Cove Formation, the Pine Hall Formation, and to terminate in basement rocks. It did not investigate the Cow Branch Formation.

Location of the stratigraphic core hole and related information

The hole was contract drilled and cored continuously to a depth of 1,477 feet using a Christiansen CT-14 truck mounted wire line core drilling rig (**Fig. 1**).The core hole collar is located at 36°17'30.62"N., -80°07'36.87"W. at an elevation of about 604 feet above sea level. The core hole is basinward, down dip, slightly northeast of a 1981 core hole (SO-C-2-81) (**Fig. 2**).

Drilling was confined to 'state owned' land by direction of the N.C. General Assembly in their FY2014-15 appropriation. The core hole location was on a small parcel owned by Town of Walnut Cove, Stokes County, North Carolina (PIN 6962-12-86-0638, Map ID 288E-4-26), near Town Creek (**Figs. 3, 4**). The location was the only one available on public land from which a small-scale coring operation could successfully retrieve the core required with available funds.

A nearby railroad cut containing weathered and slumped exposure of laminated shale and thin sandstones of the Dry Fork Formation was examined during drilling. The North Carolina Geological Survey's reference section for the Pine Hall Formation, located along the west side of the railroad cut beginning at the intersection of SR 1908 (Pine Hall Road) and the railroad tracks in Pine Hall, was visited during drilling operations.

Previously the North Carolina Geological Survey (NCGS) collected and analyzed surface rocks and samples from three existing, shallow, cores drilled in 1981 for clues to the hydrocarbon potential in the Dan River basin. This led to the Dan River basin being included in the U.S. Geological Survey's national assessment of potential oil and natural gas accumulations (**Milici and others, 2012**). The Dan River basin is one of a string of similar basins known as the Triassic rift / lacustrine basins in the eastern United States.

Reid and others (2015a) characterized the Walnut Cove and Cow Branch formations of the Dan River basin using organic geochemistry, thermal maturation data, and down hole whole rock mineralogy by x-

ray diffraction. They also obtained comprehensive rock mechanics data including triaxial compressive strength tests with acoustic velocities, pre- and post-CT scans, and Young's Modulus and Poisson's Ratio. In addition, mercury injection capillary pressure (MICP) data were obtained with a maximum pressure of 60,000 psia to provide pore aperture frequency down to nanometer-scale diameter. Pores were characterized using scanning electron microscopy (SEM) and an electron microprobe for examination of argon ion-beam milled samples. See also on-line natural gas publications at URL http://portal.ncdenr.org/web/lr/oilandgasresearch for related presentations and publications. Among those are **Reid and Milici (2008)** that has preliminary information about the Dan River basin's Triassic rift / lacustrine strata; see also **Reid and Taylor (2015b)**.

Geology overview and stratigraphy

The Dan River basin is a remnant of a number of formerly larger continental rift basins that formed during the Permian to Early Jurassic extension of Pangea as the supercontinent began to fragment (**Van Houten, 1977; Olsen, 1997**) (**Figs. 5, 6**). The half-graben's hanging wall is on the basin's west side; an idealized basin cross section shows the half-graben (**Fig. 7**). The Dan River basin was formally named by **Olsen and others (2015)**, whose main goal was to clarify previously confusing stratigraphic nomenclature resulting in a revised basin stratigraphy used herein – one that is slightly modified from that used by Milici and others in the 2011 assessment (**Fig. 8**). The Walnut Cove Formation and the Cow Branch Formation are the organic source rocks and unconventional reservoirs.

The Dan River basin section consists of five formations. In ascending stratigraphic order above the metamorphic rock basement they are the: Pine Hall Formation, Walnut Cove Formation, Dry Fork Formation, Cow Branch Formation, and Stoneville Formation (**Olsen and others, 2015**).

Preliminary drilling results

The core was logged following the rock formation descriptions of **Olsen and others (2015)** coupled with field visits to nearby key outcrops of the Dry Fork Formation and the Pine Hall Formation.

Diamond core drilling indicated that in contrast to previous mapping by **Thayer (1970)**, the strata's dip was nearly flat resulting in the intersection of the Walnut Cove Formation at a depth shallower than anticipated.

The drill hole was collared at an approximate elevation of 604 feet above sea level (**Fig. 9**). The drill hole penetrated the basement (metavolcanic rocks) at a depth of 1,451.2 feet and reached a total drilled depth of 1,477 feet. A pebble conglomerate beginning at a depth of 1,415.5 feet indicated the approaching basement contact.

Brief description of the strata in SO-C-1-15

The following are brief comments on the strata encountered in this core hole (**Fig. 9**). Descriptions and contacts are preliminary and subject to modification following additional studies. All depths are down hole (in feet).

Basement rocks

The basement was penetrated at an elevation of 1,451.2 feet, and the stratigraphic core hole terminated in basement rocks at a depth of 1,477 feet. The basement contact was abrupt with no paleosol or paleosaprolite. The basement rock is dark green to gray-green, well foliated, and has quartz segregations of various sizes. It is a metamorphic rock, likely a metavolcanic (**Fig. 10**). The basement rock is unconformably overlain by the basal pebble conglomerate of the Pine Hall Formation.

Pine Hall Formation

The basal pebble conglomerate of the Pine Hall Formation above the basement elevation was penetrated at 1,451.2 feet. The pebble conglomerate extends upward to 1,415.5 feet (about 35.7 feet of thickness). There is an abrupt transition at that point upward into red siltstone with laminations and very small scale cross-bedding. Rooting, mottling, and pedogenic features are common.

Most of the Pine Hall Formation consists of recurring fining upward "packages" of gray, medium- to coarse-grained sandstone (frequently calcareous) deposited as 4-6-inch high foreset cross bed packages that are capped by either red siltstone or gray to black, organic-rich siltstone or mudstone (**Fig. 11**). Individual foreset cross beds fine upward and into planar beds as water currents waned. The upper portion of the siltstone sequence frequently exhibits mottled, rooted, and burrowed pedogenic features that range from five to about 40 feet thick.

The succeeding depositional package begins with a similar sandstone "package", indicating the beginning of the next fining upward sequence scours into the top of the previous siltstone. The base of nearly all "packages" is marked by gravely and / or coarse-grained sandstone. Water depths were very shallow. The sandstones probably represent braided channels, and in some cases, very thin, or isolated, distal distributary channels in lacustrine strata.

The gray- to black organic-rich mudstone average about 1-3 feet in thickness. They are commonly laminated; individual laminae fine upward, and there are numerous small scale cross beds. The gray- to black organic-rich mudstones may occur with or without a red siltstone. Where they occur with a red siltstone, they most commonly cap a fining-upward sequence. Like the red siltstones, they are frequently mottled, rooted and exhibit pedogenic features. Where pedogenic features are extensive, the color of the rock becomes purple or red purple. It is unknown if the organic mudstone was deposited only locally on a fan delta surface, or if it portends thicker organic strata basinward. A step-out basinward core drill hole would be needed to test this.

Persistent thin coals or thin coaly beds or laminae recur throughout the Pine Hall Formation but mostly below a depth of 1,289 feet. Previous workers described some thin coals in the Dan River basin (**Stone, 1914; Chance, 1885**). However, the coals and coaly intervals encountered in this drill hole are somewhat thicker and more frequent than previously reported.

A few high angle fractures occur in these strata. They are fully healed, up to several inches in length, generally less than one-eight inch wide, and are filled initially with a carbonate mineral followed by vein-center quartz.

The transition stratigraphically upward into the Walnut Cove Formation occurs at a core hole depth of about 423 feet where coarse foreset gray cross bedded sandstone gives way to dark gray- to black organic-rich strata of the Walnut Cove Formation.

The entire Pine Hall Formation was penetrated; the drill hole will become the new type section to be described in a forthcoming publication. The lectostratotype for the Pine Hall Formation is from 573.0-806.2 feet core depth in drill hole SO-C-2-81, where it consists primarily of red clastic rocks with abundant carbonate nodules and mottled strata of probable pedogenic origin (**Olsen and others, 2015**).

Walnut Cove Formation

About 325 feet of organic lacustrine sediment (interpreted as the entire Walnut Cove Formation) were penetrated between a depths of 98 feet to 423.7 feet (**Fig. 12**). The side track core hole (about 2^{o} from vertical) was advanced to a total depth of 277 feet to fully recover a coal and coaly section that was penetrated in the main hole. Beginning at a depth of 253.1 feet, at least three feet of coal was recovered followed by organic mudstone interspersed with siltstone that when wetted with soapy water showed apparent hydrocarbon outgassing and confirmed a total petroleum system. The remainder of the side track hole is coaly black organic matter to its total depth and contains multiple gas shows including some from the siltstones.

The coal appears to be bituminous implying a temperature sufficient for hydrocarbon generation, but the coal rank needs verification. Other intervals are coaly as well. There is a wide range of bioturbation in the organic-rich units ranging from moderate- to complete. Most silty intervals fine upward. Cross stratification at laminae thickness provide complex cross bed relationships reflecting active water movement and not stagnant water.

The Walnut Cove Formation grades upward rapidly into the Dry Fork Formation at about 98 feet in the main core hole by the abrupt decrease of gray and black organic strata into gray sandstone and mudstone of the Dry Fork Formation. There is no red sandstone in the few feet of what is tentatively is interpreted as the Dry Fork Formation.

Dry Fork Formation

The Dry Fork Formation type section (**Olsen and others, 2015**) consists of "…tan to red sandstones with cyclically interbedded gray, purple and red mudstones." In this core hole, the upper 98 feet, tentatively assigned to the Dry Fork Formation, are gray- to dark gray siltstones, with gray calcareous very fine-grained sandstone composed of foreset cross beds capped by planar beds at the base of this interval (**Fig. 13**). There are a few very thin sandstone units (less than a foot in thickness) higher in this interval also with foreset cross beds.

Occasionally there are very thin intervals with concentrations of organic matter including one or two slightly coaly beds or laminae. Overall their frequency increases stratigraphically downward toward the preliminary contact picked with the Walnut Cove Formation.

The sandstone beds are characterized being slightly limey, and composed of occasional small scale trough cross beds, and more common foreset cross beds capped by planar lamina. The siltstone intervals commonly fine upward at the laminae scale, and exhibit cut and fill features from migrating silt waves reflecting active water movement and not stagnant water. Pedogenic features are essentially absent.

Summary and conclusions

Continuous diamond core drilling confirmed a total petroleum system in the 323-foot thick Walnut Cove Formation in Stokes County, North Carolina in the Triassic rift / lacustrine Dan River Basin.

The Walnut Cove Formation intercept in core hole 'Town of Walnut Cove' (SO-C-1-15) confirms that the Walnut Cove Formation extends into the basin, and for the first time provides a complete stratigraphic intercept of the formation, and its contacts with strata above and below it.

A three-foot-thick coal cored in the Walnut Cove Formation intercepted in this core hole has characteristics of a bituminous coal thus placing the Walnut Cove Formation in the window to generate hydrocarbons. Other coaly intervals may be at the same rank. The side track hole intercept encountered apparent hydrocarbons emanating from the coal and silty intervals immediately following core recovery.

A complete stratigraphic section of the Pine Hall Formation was cored. It will become the new type section for this formation when fully described. Thin beds of organic matter and coaly intervals occur in the Pine Hall Formation; it is unknown if these are local, or have thicker equivalents basinward.

Core samples will provide rock property data (velocities for potential future seismic studies) with newly appropriated funds to analyze the Walnut Cove Formation, the Pine Hall Formation, and the basement rocks.

The nature and composition of the basement rock has been determined, as well as its depth at one point in the basin. This will help calibrate potential future seismic surveys.

The 2015-16 state budget has funds to analyze the cores for organic chemistry, thermal maturation, mineralogy, pore studies, rock mechanic studies and drilling return water for dissolved hydrocarbons. Core drilling is a cost effective tool to explore the Triassic rift / lacustrine basins.

Additional information

Additional information about applied hydrocarbon research in the Triassic rift / lacustrine basins by the North Carolina Geological Survey is available at URL http://portal.ncdenr.org/web/lr/oilandgasresearch. The portal website for the North Carolina Geological Survey is http://portal.ncdenr.org/web/lr/geological_home.

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Funding for the drilling was provided by the North Carolina General Assembly (FY 2014-15) as part of appropriations to undertake additional geological studies of the Dan River basin.

We thank the Commissioners of the Town of Walnut Cove, North Carolina, for permission to drill this stratigraphic core hole on city property. Mr. Monty Stevens, Town Manager, was our primary point of contact with Town of Walnut Cove and his professionalism and assistance is much appreciated.

Mr. Orus F. Patterson III, Patterson Exploration Services, Inc., Sanford, N.C., was the drilling contractor. The core hole was drilled by Ruen Drilling Inc. in June 2015.

Fig. 1. Wire line core drill used for the Town of Walnut Cove (SO-C-1-15) stratigraphic core hole. The drill rig is a truck mounted Christianson CT-14 core drill. Visible in the photograph are support vehicles, some of the drill rods, cement (covered with black plastic), and logging table (under white tent).

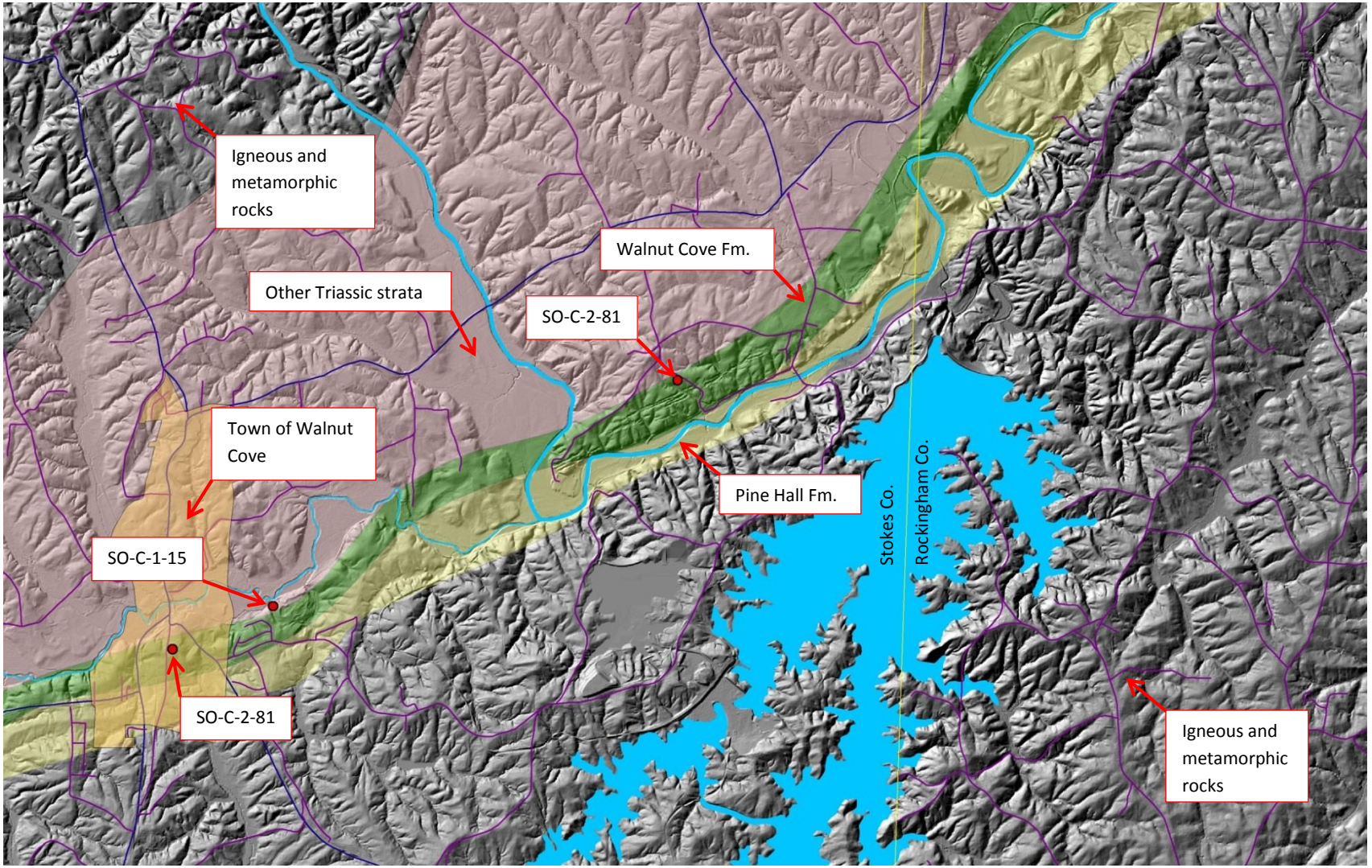

Fig. 2. Map showing details of the southern portions of Dan River basin in North Carolina. Two previous core holes (SO-C-1-81; SO-C-2-81) are shown in relation to 'The Town of Walnut Cove' stratigraphic core hole SO-C-1-15 drilled in June 2015. See Fig. 6 for a basin geologic map.

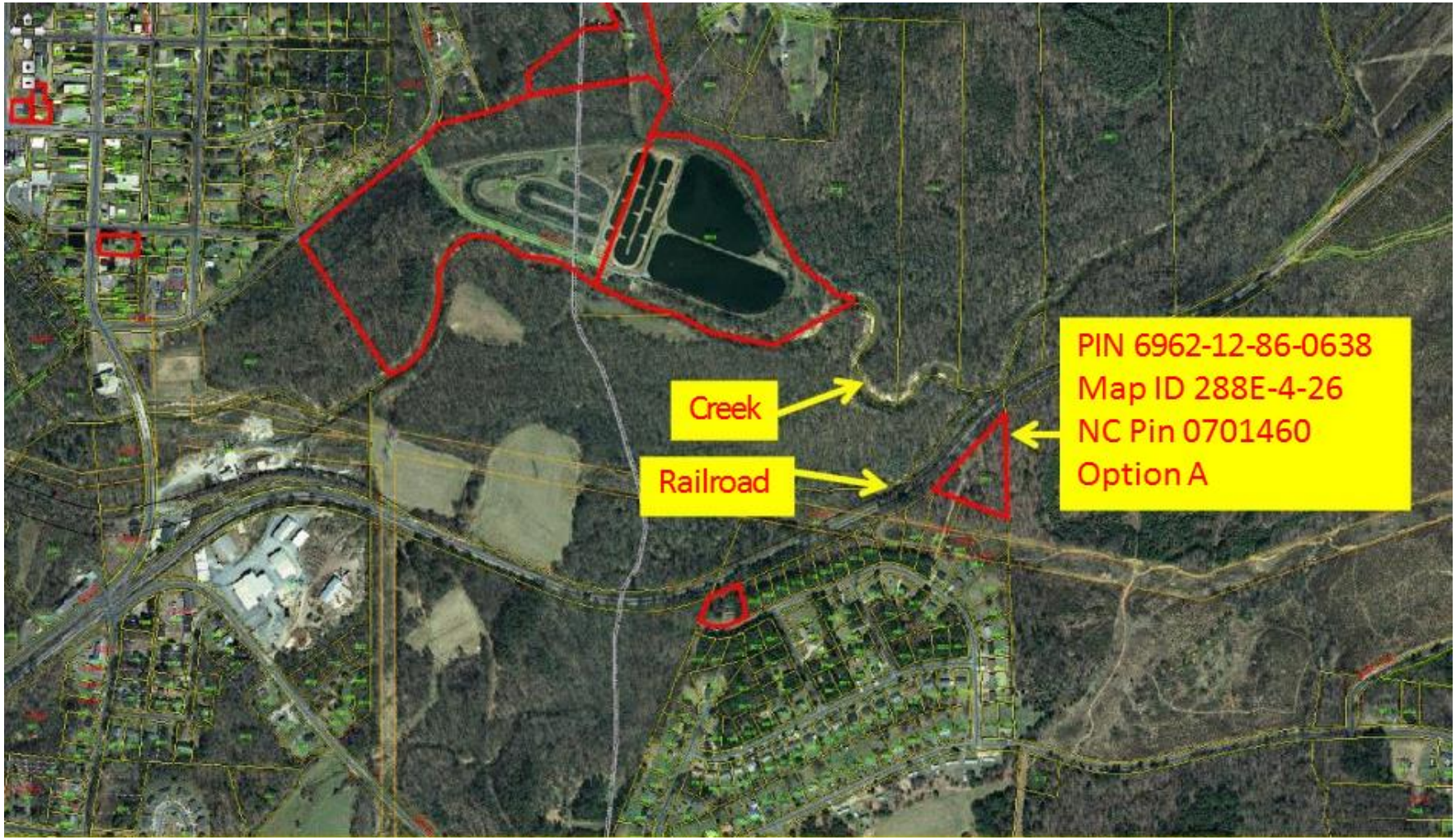

Fig. 3. Town of Walnut Cove parcels in area of interest (bordered in red). The 'Town of Walnut Cove' (SO-C-1-15) stratigraphic core hole was drilled on the triangular-shaped parcel (center right of field of view). A railroad track and the Town Fork Creek lie immediately to the northwest of the parcel.

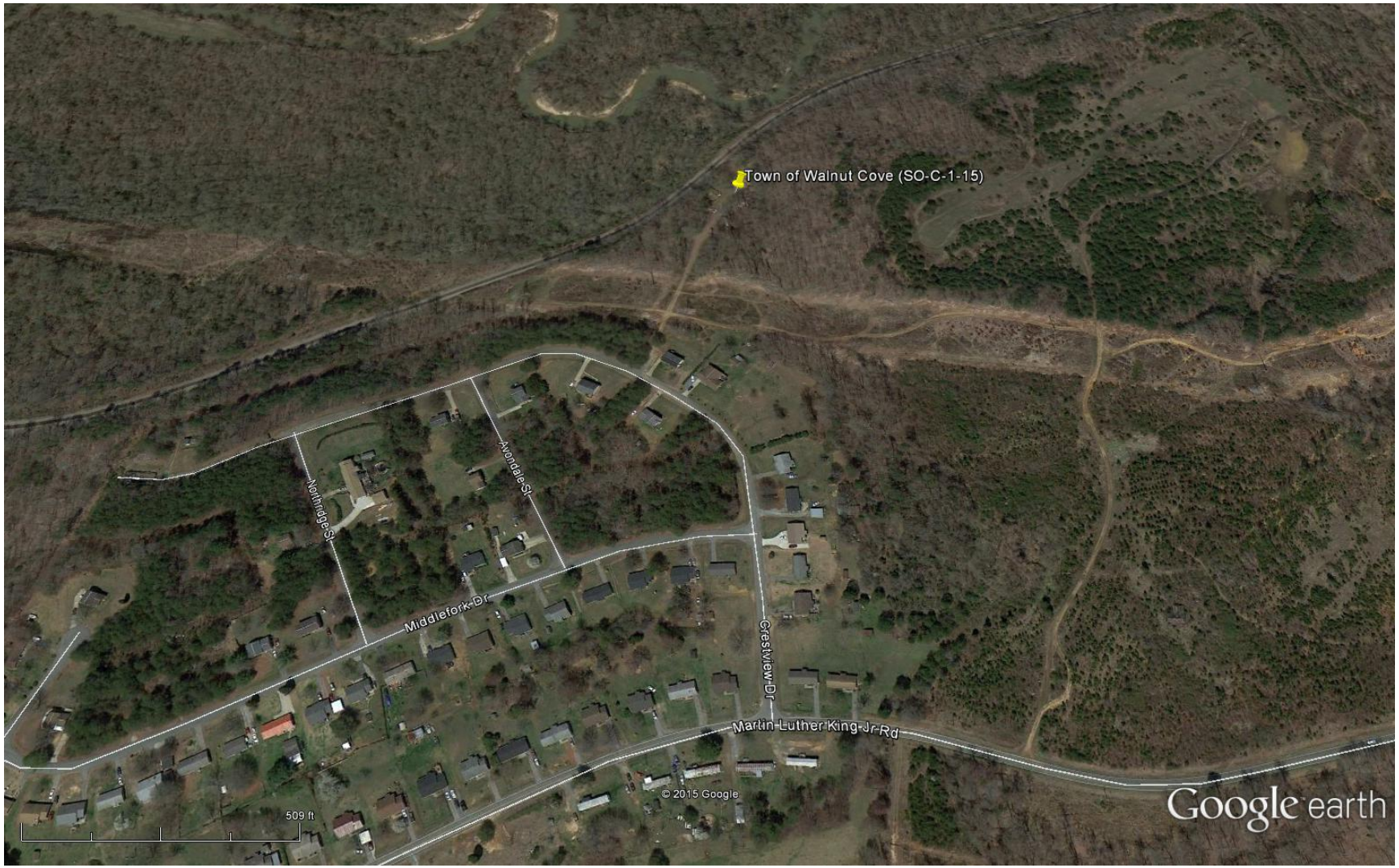

Fig. 4. Location map (detail) of stratigraphic core hole, 'Town of Walnut Cove' (SO-C-1-15).

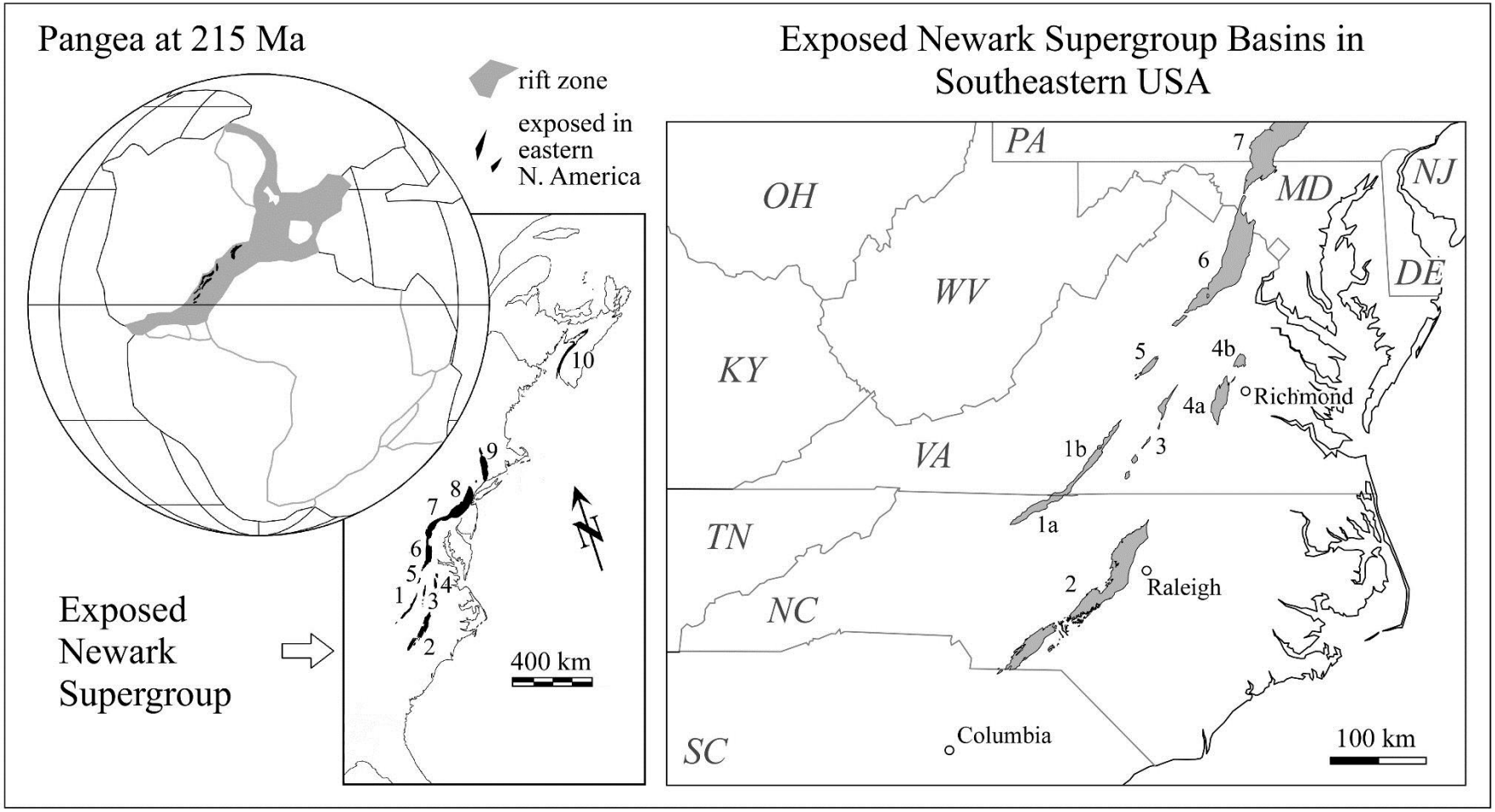

Fig. 5. Exposed Newark Supergroup basins in the Southeastern USA (from Olsen and others, 2015). The Dan River basin is labeled 1a and 1b. The Deep River basin is labeled 2.

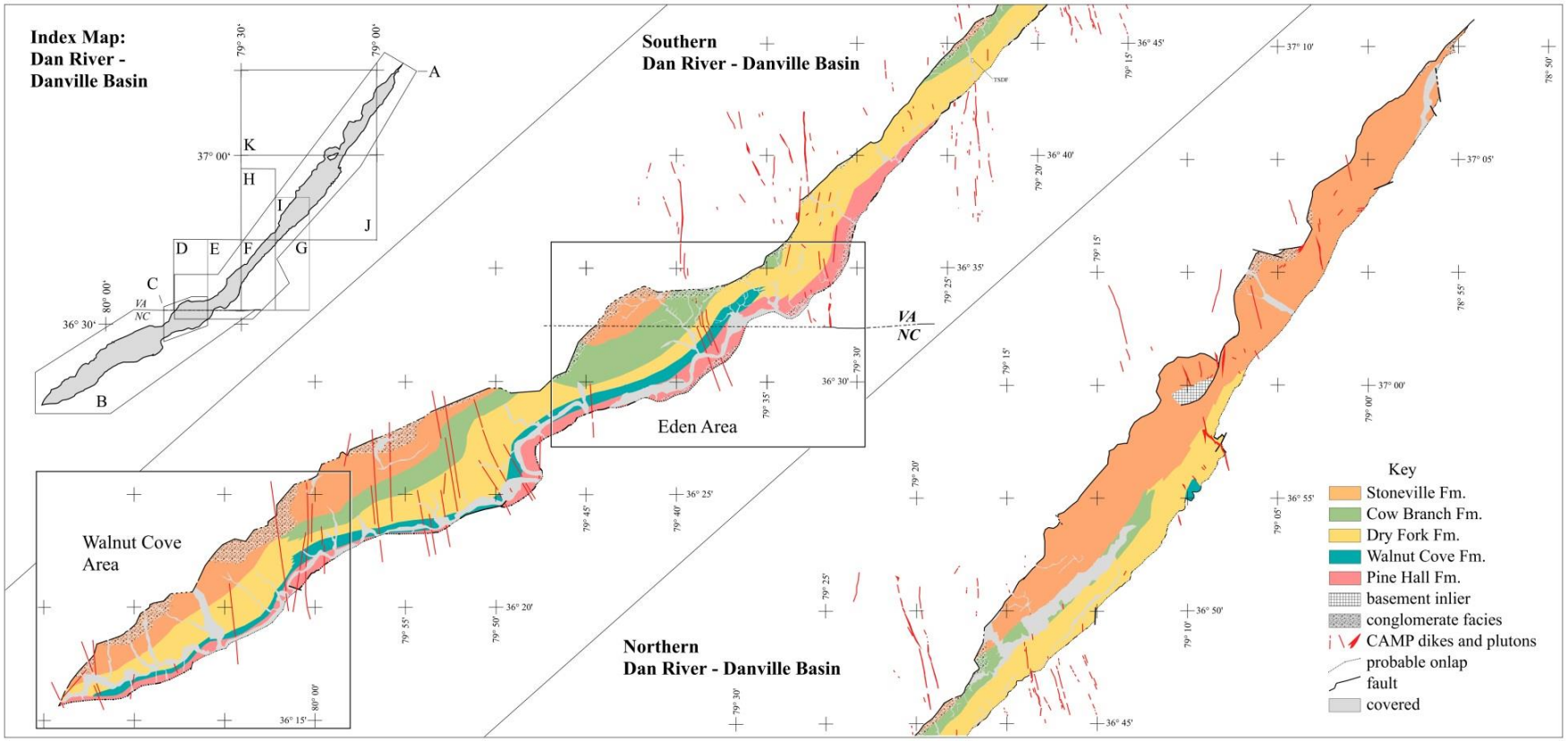

Fig. 6. Geologic map of the Dan River basin (from Olsen and others, 2015).

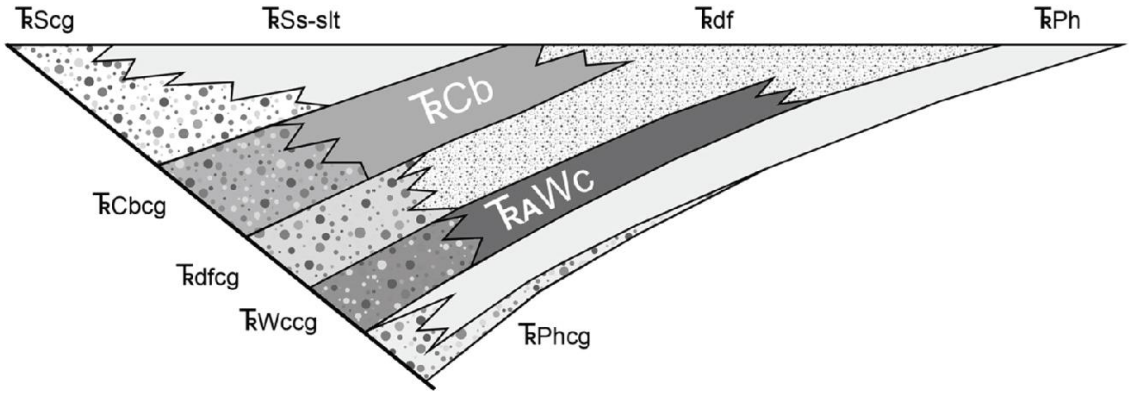

Fig. 7. Cross section across the Dan River basin (from Olsen and others, 2015). The cross section corresponds to a line approximately parallel to U.S. Highway 220 in Rockingham County, North Carolina from the eastern basin margin to the basin's western margin. A thin coal and carbonaceous interval is present in North Carolina but not in the Virginia portion of the basin.

The stratigraphic scheme used here is based on Olsen and others (2015) and slightly different from that used by Milici and others (2012). Abbreviations are: TRCb, Cow Branch Formation; TRCbcg, Cow Branch Formation, conglomerate facies; TRdf, Dry Fork Formation; TRdgcg, Dry Fork Formation conglomerate facies; THPh, Pine Hall Formation; TRPhcg, Pine Hall Formation conglomerate facies; TRScg, Stoneville Formation conglomerate facies; TRSs-slt, Stoneville Formation, sandstone-siltstone facies; TRWc, Walnut Cove Formation; and TRWccg, Walnut Cove Formation, conglomerate facies.

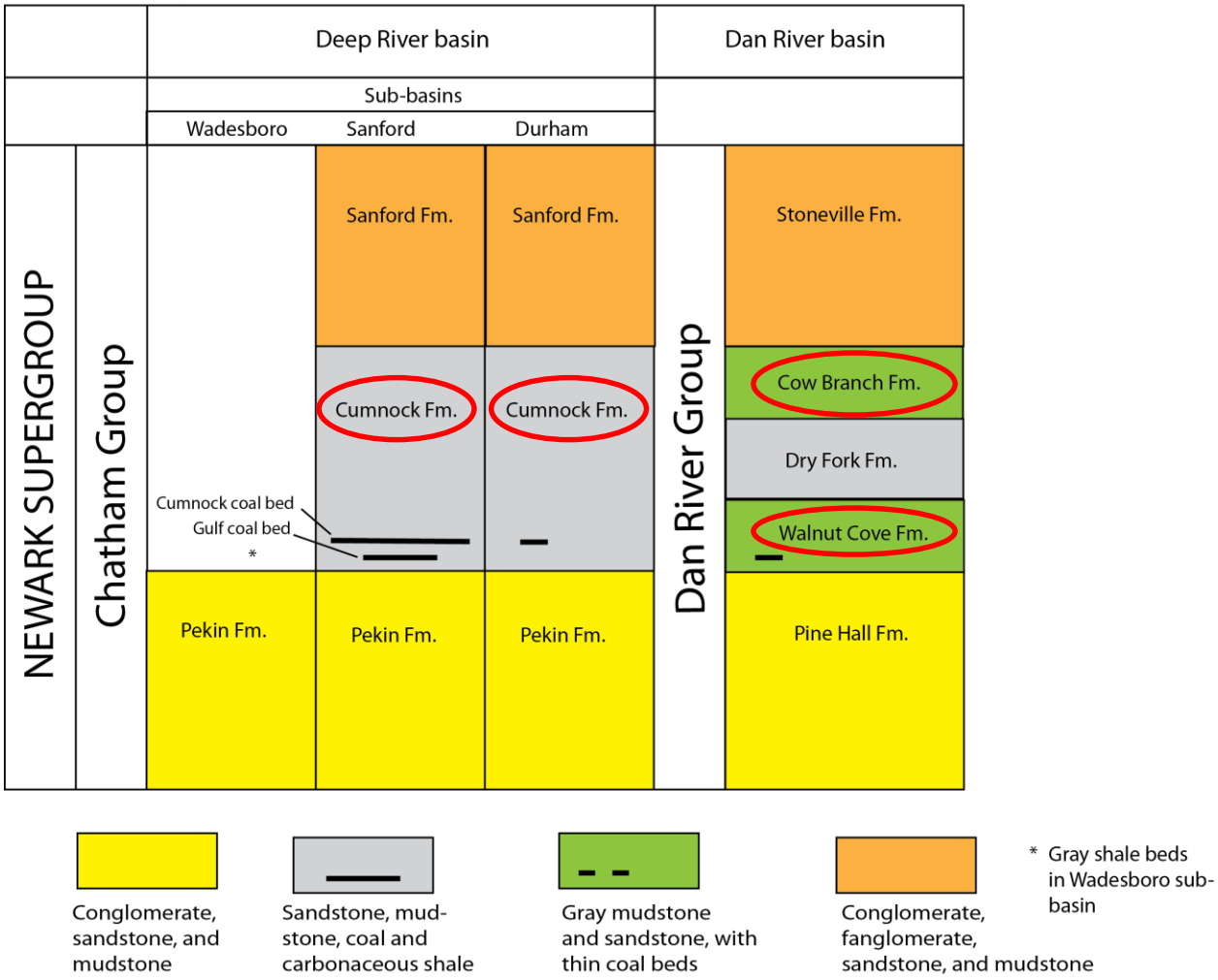

Fig. 8. Stratigraphy for the Deep River and Dan River basins. The lacustrine strata are gray in the Deep River basin and green in the Dan River basin. The Cumnock Formation (Deep River basin) and the Cow Branch and Walnut Cove formations (Dan River basin) are the organic source rocks and unconventional reservoirs. Formation names are in red ovals. The Deep River basin stratigraphy is from Reinemund (1955) and the stratigraphy for the Dan River basin is from Olsen and others (2015).

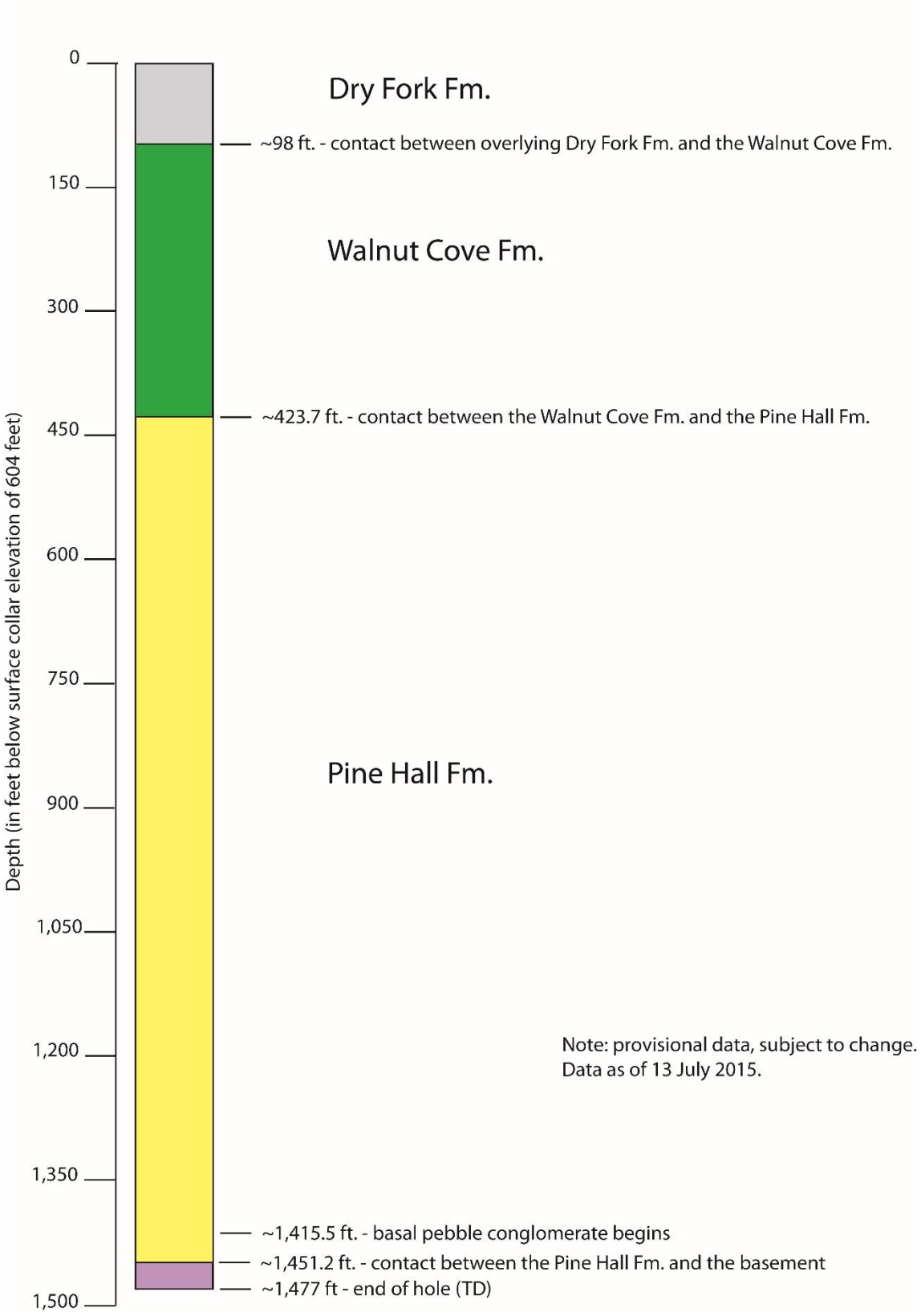

Fig. 9. Preliminary geology diagram of the stratigraphic core hole, 'Town of Walnut Cove,' (SO-C-1-15).

Fig. 10. Photograph of the basement rock in stratigraphic core hole, 'Town of Walnut Cove,' (SO-C-1-15).

Fig. 11. Photograph of the Pine Hall Formation in stratigraphic core hole, 'Town of Walnut Cove,' (SO-C-1-15).

Fig. 12. Photograph of the Walnut Cove Formation in stratigraphic core hole, 'Town of Walnut Cove,' (SO-C-1-15).

Fig. 13. Photograph of the Dry Fork Formation in stratigraphic side-track core hole, 'Town of Walnut Cove,' (SO-C-1A-15).