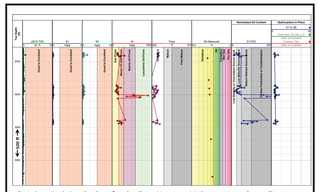
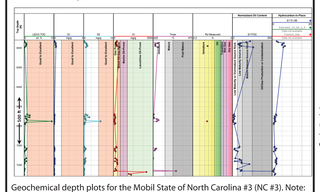
Stratigraphy, Geochemistry, and Organic petrology data from the Esso Hatteras Light #1 and the Mobil State of North Carolina #3 and their effect on hydrocarbon prospectivity in coastal North Carolina

North Carolina Geological Survey
Open-File Report 2018-06

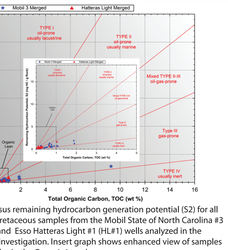
Basic organic chemistry (TOC, HI, and OI)



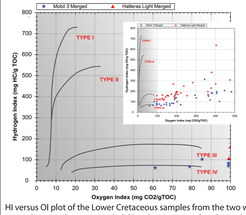
Geochemical depth plots for the Esso Hatteras Light #1. Note: Some Tmax and NOC values plot off-scale.



Geochemical depth plots for the Mobil State of North Carolina #3 (NC #3). Note: Some Tmax and NOC values plot off-scale.



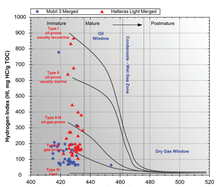
TOC versus remaining hydrocarbon generation potential (S2) for all Lower Cretaceous samples from the Mobil State of North Carolina #3 (NC#3) and Esso Hatteras Light #1 (HL#1) wells analyzed in the current investigation. Insert graph shows enhanced view of samples which plot in the Organic Lean box.



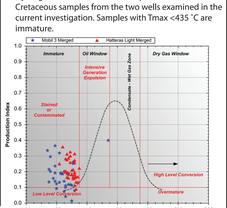
HI versus OI plot of the Lower Cretaceous samples from the two wells; insert diagram shows expanded OI scale. Most samples plot in the gas-prone Type III region, but others appear to represent a mixture with oil-prone algal Type II kerogen and degraded/oxidized Type IV kerogen.

Note: Basic organic chemistry, maturity, and geochemical plots from Weatherford Laboratories (WFT), 2017. The original Weatherford report is in Reid 2018b. Normalized oil content (NOC) = (S1/TOC) X 100.

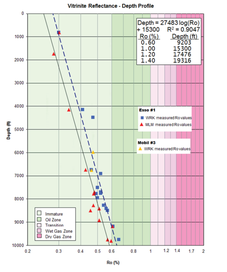
Kerogen facies and Maturity



Hydrogen Index (HI) versus Tmax plot of the Lower Cretaceous samples from the two wells examined in the current investigation. Samples with Tmax <435 °C are immature.

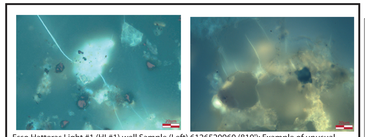


Production Index (PI) versus Tmax plot of the Lower Cretaceous samples from the two wells examined in the current investigation. Trend envelop shown by dashed line is based on WFT Labs analysis of over 5,000 shale samples.

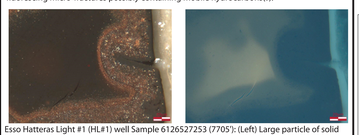


Thermal maturation based on measured vitrinite reflectance (%R_r) versus depth for the samples examined in this study (noted by Weatherford petrologist initials WRK) and pre-existing client vitrinite reflectance on samples from the Esso Hatteras Light #1(HL#1) well (petrologist initials MLM). The dashed trend line incorporates WRK data for the Esso Hatteras Light #1 (HL#1) well, while the solid trend line is for the MLM data set. The two samples from the Mobil State of North Carolina #3 (NC#3) well are shown against these trend lines and were not incorporated into the calculated results.

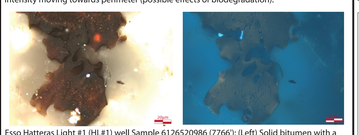
Organic petrology



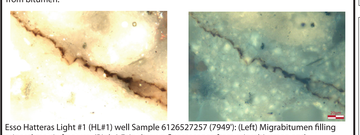
Esso Hatteras Light #1 (HL#1) well Sample (Left) 6126520960 (810'): Example of unusual, rare microfractures emanating from mineral matter filled with bluish-white fluorescence, suggesting a possible presence of light hydrocarbons. (Right) Sample 6126520988 (8280'): Example of rare orange/orange fluorescing mineral matter and surrounding yellow fluorescing micro-fractures possibly containing mobile hydrocarbons(?).



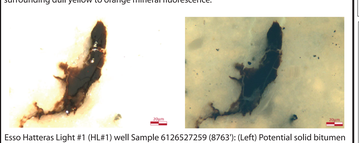
Esso Hatteras Light #1 (HL#1) well Sample 6126527253 (7705'): (Left) Large particle of solid bitumen with desiccation cracks. Reflectance from central measuring circle is 0.19% R_r. (Right) Dull orange fluorescence from center of bitumen particle with distinct reductions in intensity moving towards perimeter (possible effects of biodegradation).



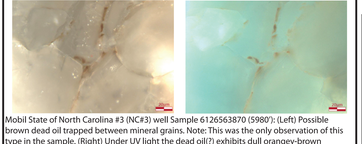
Esso Hatteras Light #1 (HL#1) well Sample 6126520986 (7766'): (Left) Solid bitumen with a reflectance reading 0.29%R_r from central measuring circle. (Right) Brown fluorescence from bitumen.



Esso Hatteras Light #1 (HL#1) well Sample 6126527257 (7949'): (Left) Migrabitumen filling mineral matrix fracture. (Right) Faint brown fluorescence from migrabitumen and surrounding dull yellow to orange mineral fluorescence.

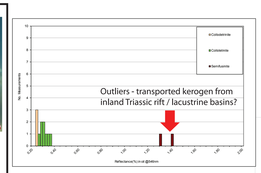


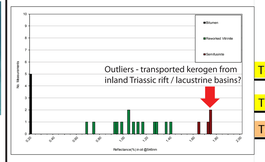
Esso Hatteras Light #1 (HL#1) well Sample 6126527259 (8763'): (Left) Potential solid bitumen particle. Reflectance reading not possible due to light intensity elevation from surrounding mineral matrix. (Right) Weak brown fluorescence from perimeter of solid bitumen.

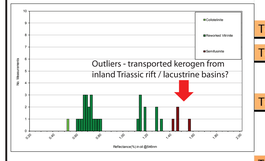


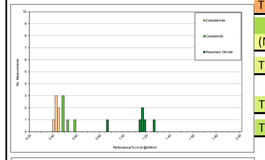
Mobil State of North Carolina #3 (NC#3) well Sample 6126563870 (5980'): (Left) Possible brown dead oil trapped between mineral grains. Note: This was the only observation of this type in the sample. (Right) Under UV light the dead oil(?) exhibits dull orangey-brown fluorescence.

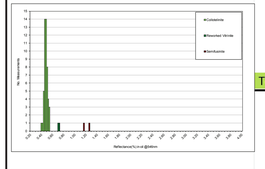
Vitrinite reflectance

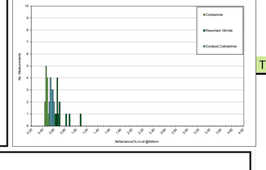




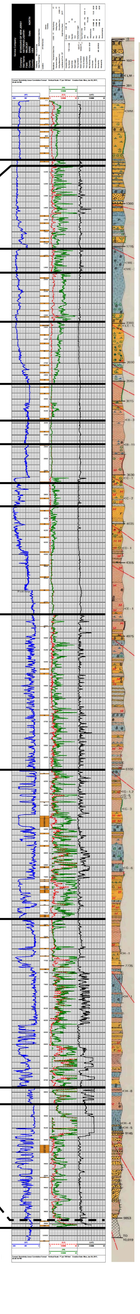


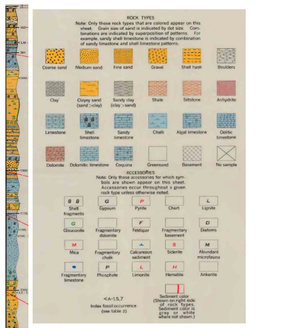






Esso Hatteras Light #1 (HL#1) - History of reported oil staining





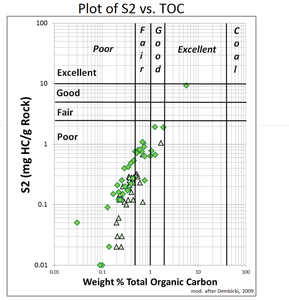
(Left) - Esso Hatters Light #1 well. Annotations below provide a historical perspective of the recognition of oil staining ranging from none in the original description (Spangler, 1950) to specific interals with oil staining noted by multiple contributors.

Plot shows available cored intervals, and formation tops.

Also shown are total organic carbon (TOC) analyses determined during this study. Over-all the TOC analyses are less than 1.0 wt. %. While a non-effective source, hydrocarbons can be generated but not effectively expelled.

The lithologic log for the Esso Hatteras Light #1well is from Brown *et al.*, 1972, Plate 30. Color and lithology key is above.

Dembicki Plot

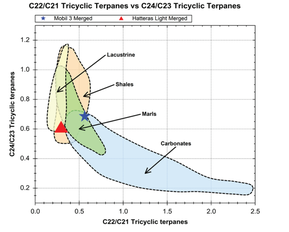


◆ Values from Mobil #3 St of NC

△ Values from Esso #1 Hatteras Light

Rock-Eval estimates the organic matter's hydrogen content with the S2 value, a quantification of the amount of hydrocarbons formed during the thermal decomposition of the kerogen measured in milligrams of hydrocarbons per gram of rock. By combining TOC and S2, you can get an idea of how much organic matter is present and how much hydrogen is associated with it, essentially how rich the source rock may be.

C22/C21 Tricyclic Terpanes vs C24/C23 Tricyclic Terpanes



A cross-plot of dibenzothiophene to phenanthrene and pristane/phytane allow the depositional environment of a source rock to be deduced (Hughes *et al.*, 1995). This suggests a Marine Shale source facies for both wells.

INITIAL ESSO HATTERAS LIGHT #1 ANALYSES

"No occurrences of oil or gas were found."

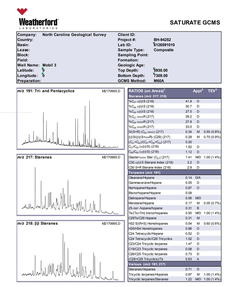
Spangler, AAPG v. 34, p. 100–132, 1950

THEN OTHERS LOOKED AT THE WELL CUTTINGS & CORES, AND REPORTED OIL STAINING

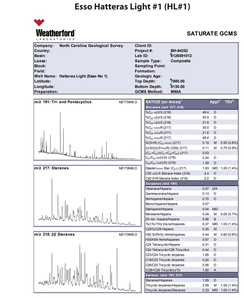
Undated post-drill sample log Sinclair Oil Co. staff (pre-dates 2008)	Malinconico (unpublished 2008) organic petrology	
@ ~7150' Questionable sl. oil stains in white fine xln. highly ool ls	6734' – 6744' oil stain 6909' – 6918' oil stain	
	7949' – 7951' oil stain	
		Oil staining rept'd by Coffey & Sunde, 2009
@~8500' White por consl ss tr lignite, spotty dead oil residue tr lignite "Greasy" app oil stained ss	8500' – 8510' oil stain	8400
	8917' – 8922' oil stain	9200

Biomarkers

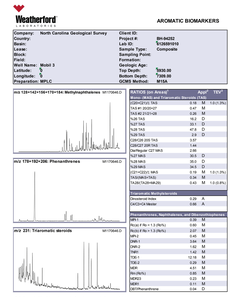
Mobil State of North Carolina #3 (NC#3)



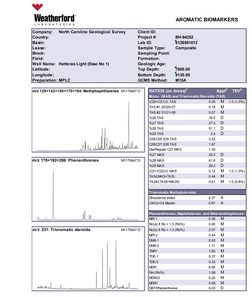
Esso Hatteras Light #1 (HL#1)



Mobil State of North Carolina #3 (NC#3)



Esso Hatteras Light #1 (HL#1)



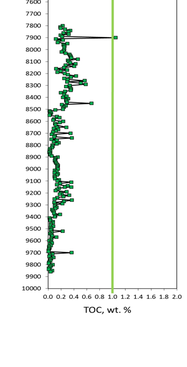
Well	TOC % Range / Av.	%Ro Depth (ft)	%Ro Range	Onset Oil Generation (%Ro 0.60*) Depth (ft)
Esso Hatteras Light #1	0.01 – 1.05 / 0.17	810 – 9,750	0.30 – 0.66	~9,200
Mobil St. of NC #3	0.01 – 9.30 / 0.73[1] 0.01 – 1.91 / 0.50[2]	5,985 6,755	0.47 0.46	*Not Reached*

* "A logarithmic regression line based on all samples containing representative vitrinite produce a trend that suggests onset of oil generation window (0.6%Ro) occurs at approximately 9,200'."

(1) including the value of 9.3 @ 6,750'
(2) excluding the value of 9.3 @ 6,750'

Mobil State of North Carolina #3 (NC#3) and Esso Hatteras Light #1 (HL#1) geochemical study results summary.

TOCs are low: Are the oils *in situ* or migrated?



Discussion and Conclusions

- Drilling for oil/gas in coastal NC began in 1921. Thermogenic oil and/or gas shows have been reported in at least 19 wells, and oil occurrences were described in local, early 20th century newspapers. No reports of thermogenic oil/gas shows have been found in wells in similar settings in VA, SC, and GA. No onshore, or offshore commercial oil/gas fields have been found to date.
- Geological and geochemical data from this study indicate potential source rock sampled intervals in the studied wells are too thin, organically lean, and immature to source commercial volumes of oil and/or natural gas conventional or unconventional hydrocarbons in the onshore or state waters of NC. Regional subsurface correlations do not indicate thickening or better in any of these intervals.
- In conjunction with present-day and paleo heat flow and the shallow depth of "basement", the sedimentary stratigraphic column is too thin to have buried any potential source rocks if they had sufficient TOC (which they do not) deeply enough to achieve hydrocarbon maturation levels greater than the earliest onset of oil generation (~VR_r >0.6).
- Direct evidence from organic petrology and fluid inclusion stratigraphy with petrography confirm that oil and natural gas are found in microscopic (and possibly larger?) quantities in several intervals of the two study wells. Reports of thermogenic oil/gas shows appear to be restricted to the area associated with the "Carolina Ridge Complex".
- Fluid inclusion stratigraphy (Coleman *et al.*, 2014) documented long chain heavy atomic unit molecules indicating oil in the lower portion of the State of North Carolina #3 (NC#3)well, and updip of the Esso Hatteras Light #1 (HL#1) well. Possible occurrences of mobile hydrocarbons were detected by organic petrology in Tertiary strata at a depth of ~810 ft in the Esso Hatteras Light #1(HL#1) well.
- Constraints on source rocks and thermal maturity are:
  - To the west, the sedimentary section is thinner, and crops out, resulting in lower and thermal maturity,
  - Finding other sedimentary rocks deeper is precluded by the Esso Hatteras Light #1 (HL#1) well that terminated in "medium-coarse crystalline granite with pegmatitic texture and some schistosity" at a measured depth of 10,054 ft,
  - Along strike, wells in the adjacent states of VA, SC, and GA do not have thermogenic hydrocarbon shows, and
  - Sedimentary strata seaward and downdip are interpreted to have higher thermal maturity based on a thicker sedimentary column, and possibly a higher organic matter content.
- Biomarkers in aggregated samples appear to originate from marine shale source rocks at immature/early maturity levels of thermal maturity. Oleanane suggests the hydrocarbons are Cretaceous or Jurassic age. This is in contrast to Coffey and Sunde (2009) who favored a carbonate-rich source rock.
- Variably mature, marginal to good quality source rocks are known to be present downdip in the Federal Outer Continental Shelf (OCS) area at DSDP 603B, and to the north in the Baltimore Canyon Trough.
- Hydrocarbon chimneys indicating vertical migration or leakage in the sedimentary column are visible on reflection seismic data in the U.S. Atlantic OCS area downdip from the NC study area.
- Anomalously high %R_r values within the overall population of those identified in the Esso Hatteras Light #1 (HL#1) may be due to allochthonous kerogen. These values suggest that their provenance may be from nearby (to the west) exposed Triassic rift basins of the Piedmont. Analyses of these basins indicate ~3,300 ft. – ~10,000 ft of syn-rift strata were removed during their inversion, exhumation, and erosion. A heavy mineral provenance study will test this hypothesis.
- The *in situ* or migrated nature of the hydrocarbons remains problematic. Biomarkers suggest an *in situ* origin. However, in the HL#1, interpreted mobile hydrocarbons were detected at ~815 ft in Tertiary strata, and solid bitumen and migrabitumen sporadically were identified in Cretaceous rocks. These, the lack of viable source rocks, and low level of thermal maturity suggest their relation to a migration focus, the "Carolina Ridge Complex". Both interpretations suggest better hydrocarbon source rock potential and generation–expulsion–migration may exist farther offshore in deep water OCS Assessment Units interpreted by the U.S. Bureau of Ocean Energy Management. Sea-surface hydrocarbon seepage slicks identified on satellite synthetic aperture radar images, and hydrocarbon-related diagenetic zones and "chimneys" interpreted on reflection seismic data suggest vertical hydrocarbon migration in this area (Post *et al.*, 2018). An analog for the Carolina Ridge Complex could be the plunging South Tano Nose offshore Ghana. This feature is a migration focus for Jubilee and its satellite fields that have discovered resources of >1 Billion barrels of oil equivalent, and the TEN field complex where 555 Million barrels of oil equivalent have been discovered.

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- Contact the State Geologist, North Carolina Geological Survey, Raleigh, NC, to arrange access to well records, logs, and core and cutting samples. The agency's repository is located in Raleigh, NC.

Panel 3 - Organic petrology, biomarkers, discussion and conclusions.