Exploration for the Arkansas Novaculite Reservoir, in the Southern Ouachita Mountains, Arkansas*

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Abstract

The Arkansas Novaculite, famous for its whetstone characteristic, is also an oil and gas reservoir in the Ouachita overthrust belt of Oklahoma and Texas (Caballos Novaculite). Oil and gas fields such as Isom Springs in Oklahoma and McKay Creek, Pinion and Thistle fields in West Texas found reservoirs in this chert section some 30 years ago. The chert reservoir has shown to be productive when it is highly fractured in complex thrust faults. In Arkansas, outcrops of this chert present along the southern side of the Benton uplift often contain a considerable amount of carbonate. The carbonate can be identified at times as highly abraded fossil fragments but otherwise are found as individual calcium carbonate concretion-like masses and also single dolomite rhombs. When leached, it is referred to tripolitic chert and can have porosity measurements ranging to over 50% percent. Assuming the carbonate is leached in the subsurface, the Arkansas Novaculite would have matrix porosity with fractures, which was the concept for the Shell exploration well that drilled Prospect Rattler.

Prospect Rattler was drilled by Shell with the well named the 1-26 Arivett and is located in Pike County, Arkansas. The Arivett 1-26 well spudded in the Mississippian Stanley Shale and reached a total depth of 10,570 in the Silurian Blaylock Sandstone. The well penetrated a complete section of all three members of the Arkansas Novaculite, as described in the type section at Caddo Gap, Arkansas. This formation has very low dips in an otherwise non-internally faulted section. The well was air/mist drilled and flared several gas shows in sands and novaculite. The upper member of the Arkansas Novaculite contains an unleached carbonate-rich chert section based on cuttings, core analysis, and wireline logging. The results reveal little matrix porosity in the Arkansas Novaculite. However, small amounts of thermally “dead” oil residues or anthraxolite is present in some fractures and some micropores of leached carbonate material. This indicates that a hydrocarbon charge migrated through the Arkansas Novaculite but never accumulated. The vitrinite equivalent reflectance of the Arkansas Novaculite is 3.5%. Even at this high thermal maturity, the middle member shale has up to 4% total organic carbon content and is considered a major source rock. The failure mechanism was most likely a poor reservoir and a poor charge/timing as peak charge occurred before the trap was formed.

References

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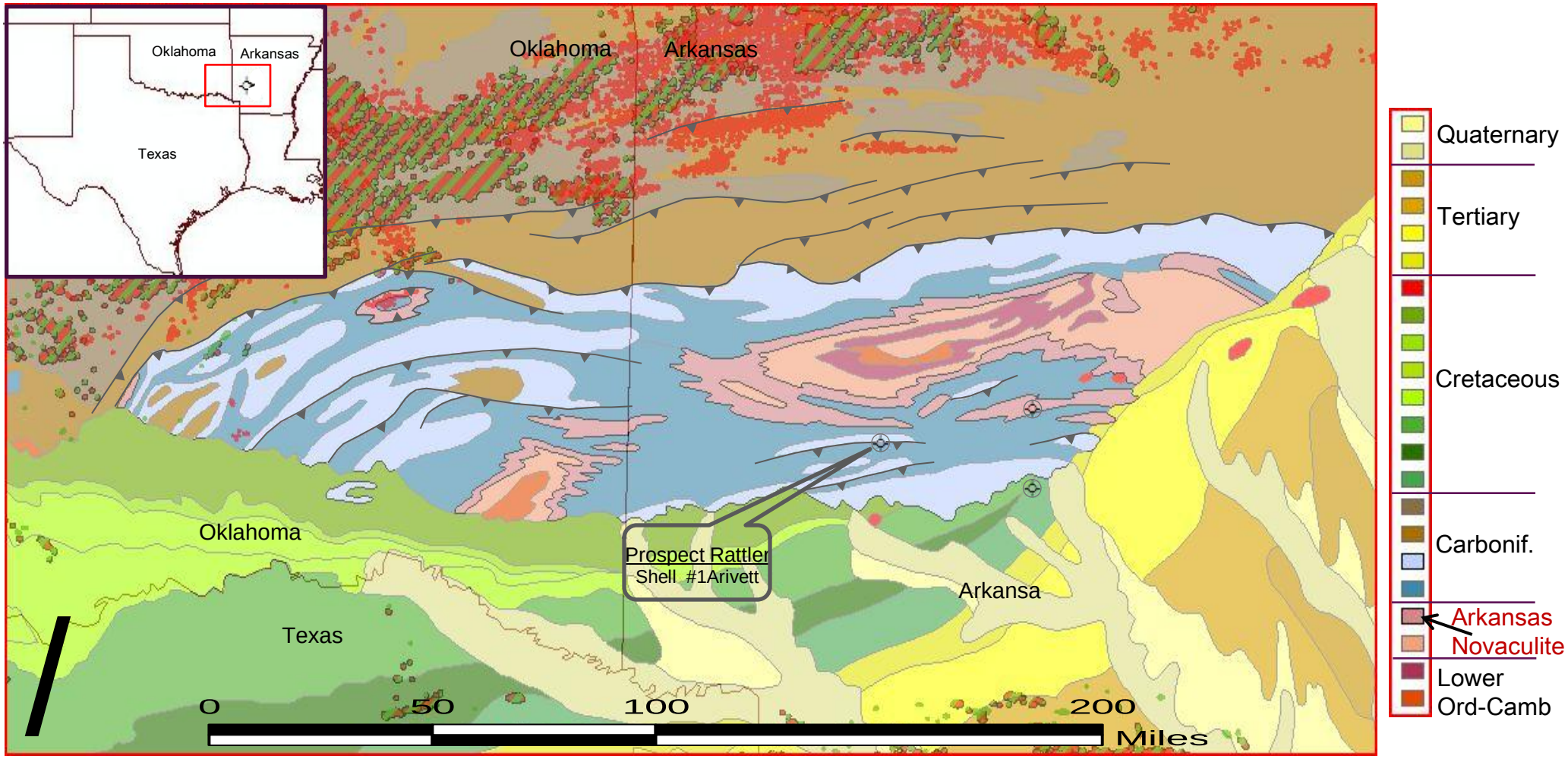
AAPG Annual Convention

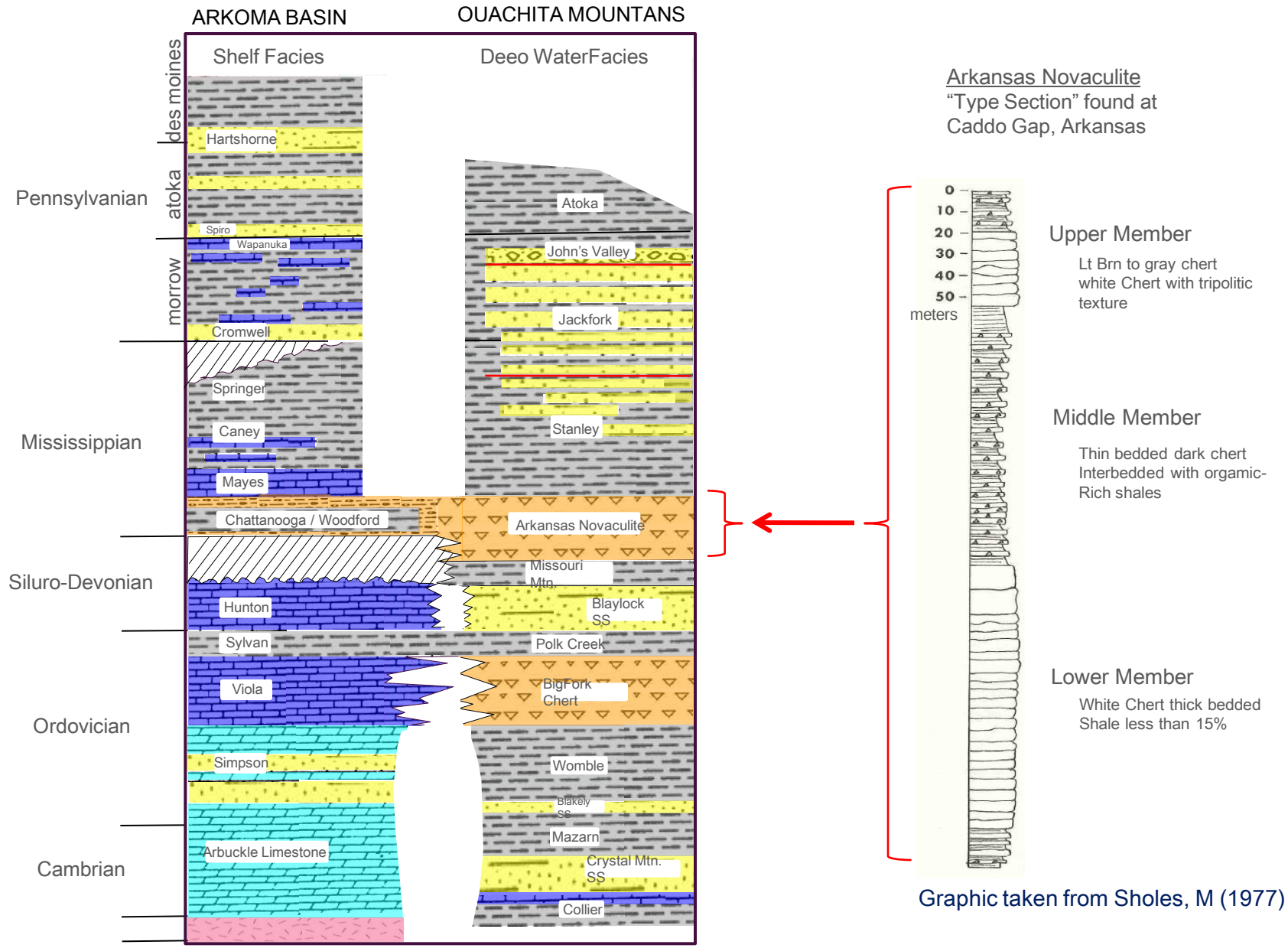
April 13, 2011

Ouachita Mountains – Surface Geologic Map



The Ouachita Mountains are a surface exposure of Paleozoic rocks that were deformed by compressionl directed from the south during the closing of the proto-Atlantic with the suturing of North and South America and Africa. The youngest thrusts are the most landward from the suture and are located in the present-day Arkoma foreland basin seen in brown-colored Pennsylvanian Atokan and Desmoinesian sediments. The blue-colored rocks of the Ouachita Mountains are lowermost Pennsylvanian Jackfork and Mississippian Stanley formations while the pinks and purples are rocks of Cambro-Ordovician thru Devonian age. The Arkansas Novaculite is colored light purple and is Devonian and Mississipian in age. The novaculite represents that last of the starved-basin sediments or sediments with relatively low sedimentation rates that existed just prior to the thick foreland basin section of turbidites deposited just in front of and then cannibalized by the advancing thrust belt. Shell's prospect Rattler drilled a major thrust slab that exposed Mississipian Stanley at the surface but drilled below the Arkansas Novaculite.

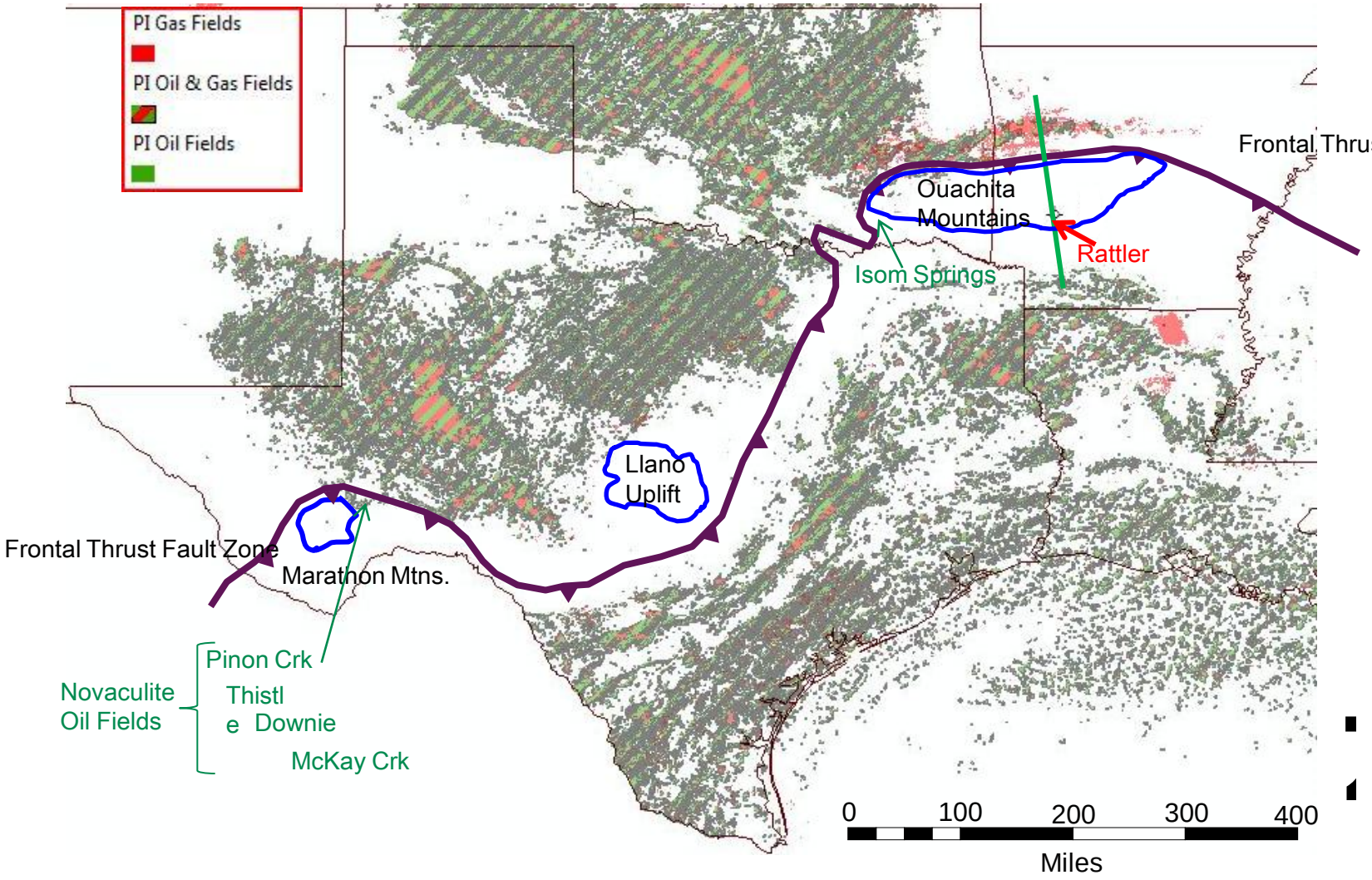
Stratigraphic Column – Shelf Facies and Deep Water



Graphic taken from Sholes, M (1977)

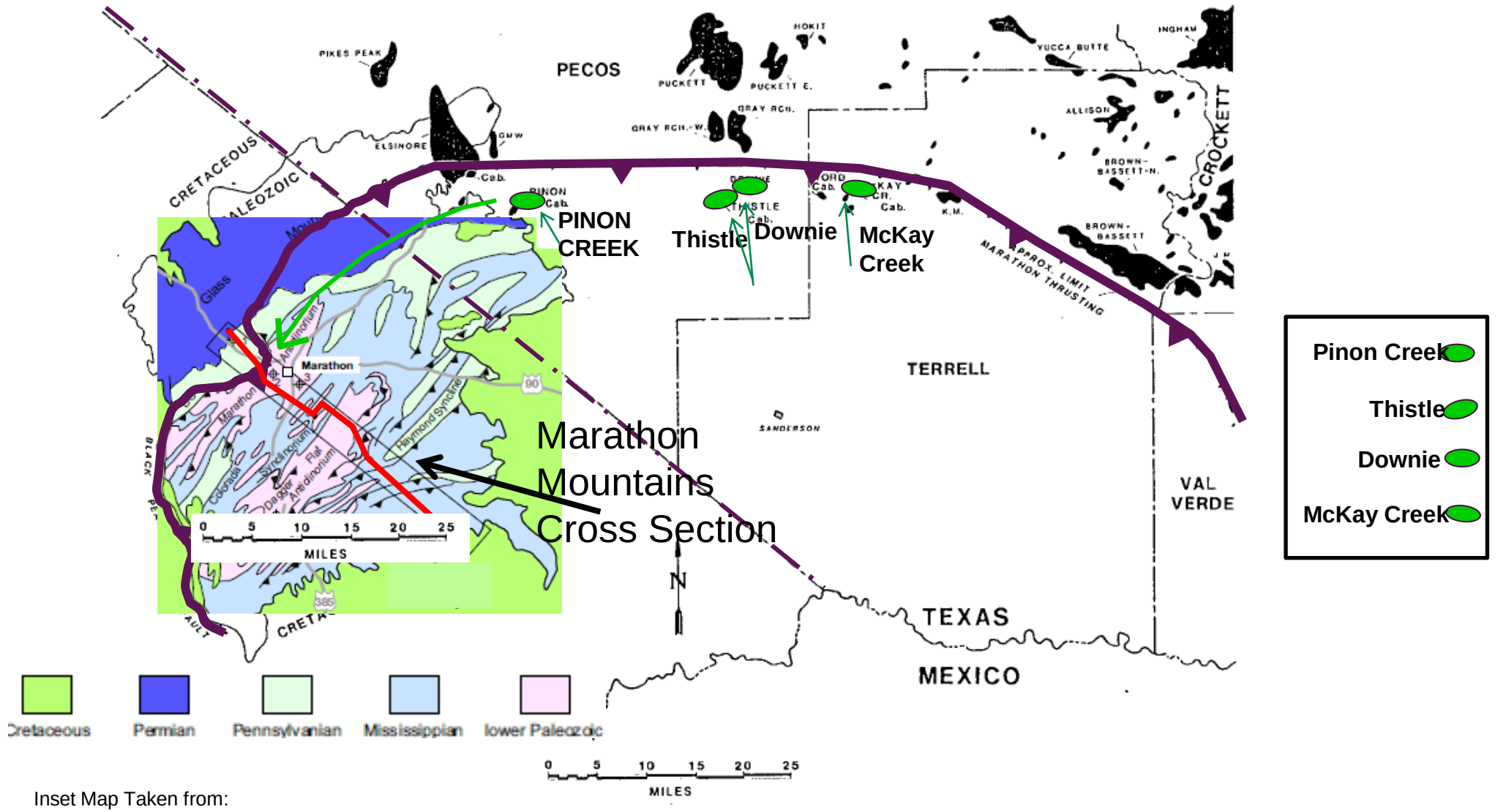
The stratigraphic column contrasts the lithologies of rocks deposited on the continental shelf located in the current Arkoma Basin area, with the lithologies deposited to the south and exposed now in the outcropping Ouachita Mountains. The Arkansas Novaculite (orange-colored chert section) can be further described, as shown in the enlargement as composed of three members illustrated in the unofficial type section described by Sholes at Caddo Gap.

Ouachita Overthrust Belt



The structural trend of the Ouachita Overthrust belt is shown by the purple thrust fault. This fault defines the frontal thrust fault in the Ouachita Mountains of Arkansas and Oklahoma. The thrust fault extends beneath the cover of Cretaceous sediments thru most of Texas to where the thrust belt is again exposed in the Marathon Mountains of far West Texas. There are very few fields that produce hydrocarbons from the Ouachita thrust belt. Only a handful of oil fields produce from the novaculite. All of the oil and gas fields southeast of the thrust fault produce from younger Mesozoic- and Tertiary- reservoired fields. Novaculite oil fields are all located near the frontal thrust fault.

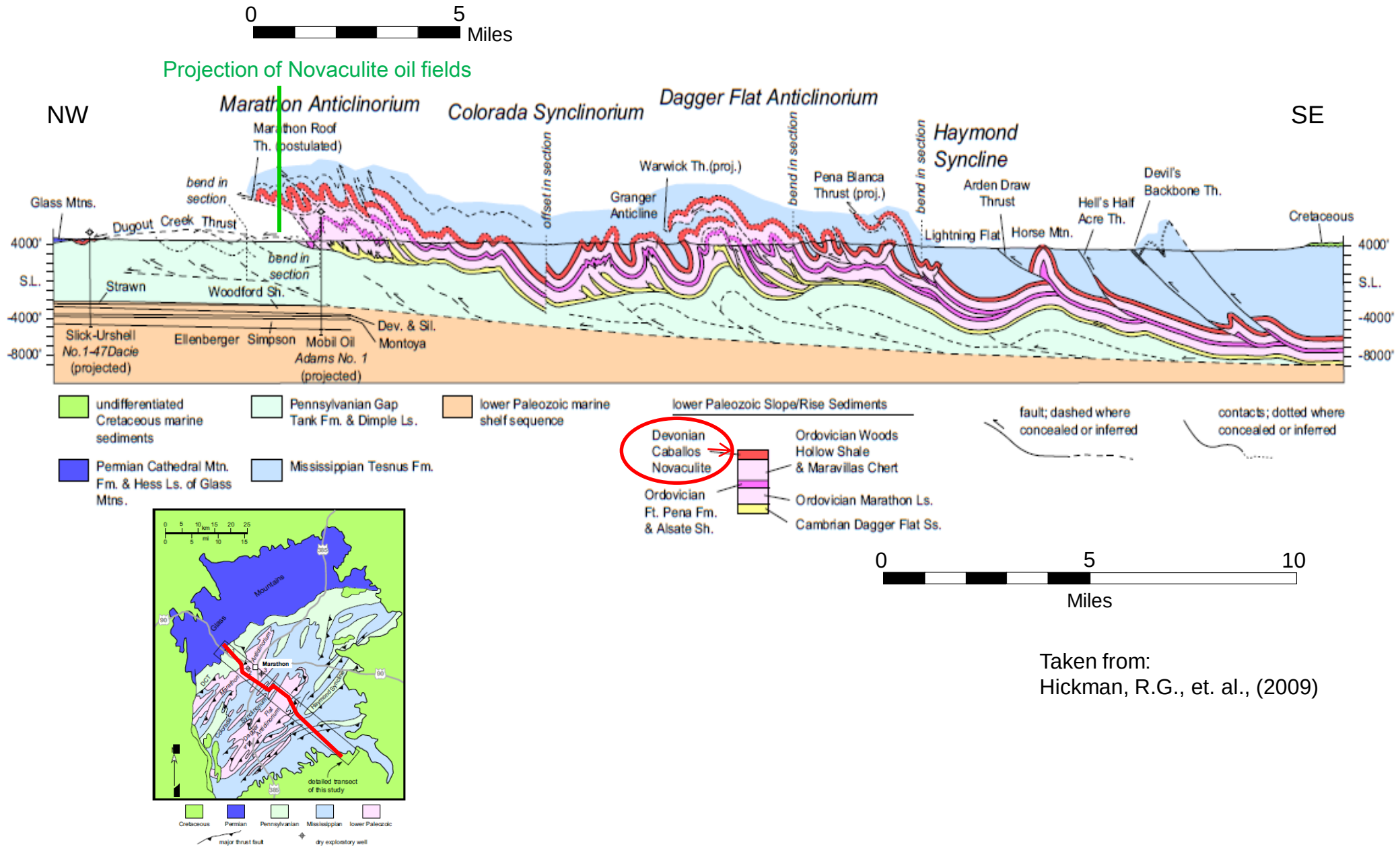
West Texas – Novaculite Fields



Inset Map Taken from:
Hickman, R.G, et. al. (2009)

In the Marathon Mountains are outcrops of Lower Paleozoic rocks shown in light pink. The Mississippian/Devonian Caballos Novaculite outcrop is included in this color. Four Caballos oil fields are found east of the Marathon mountains, located along the zone of the frontal thrust faults. The next slide is a cross section across the Marathon Mountain (shown in red) by Hickman modified from the 2009 publication in the Journal of Geology.

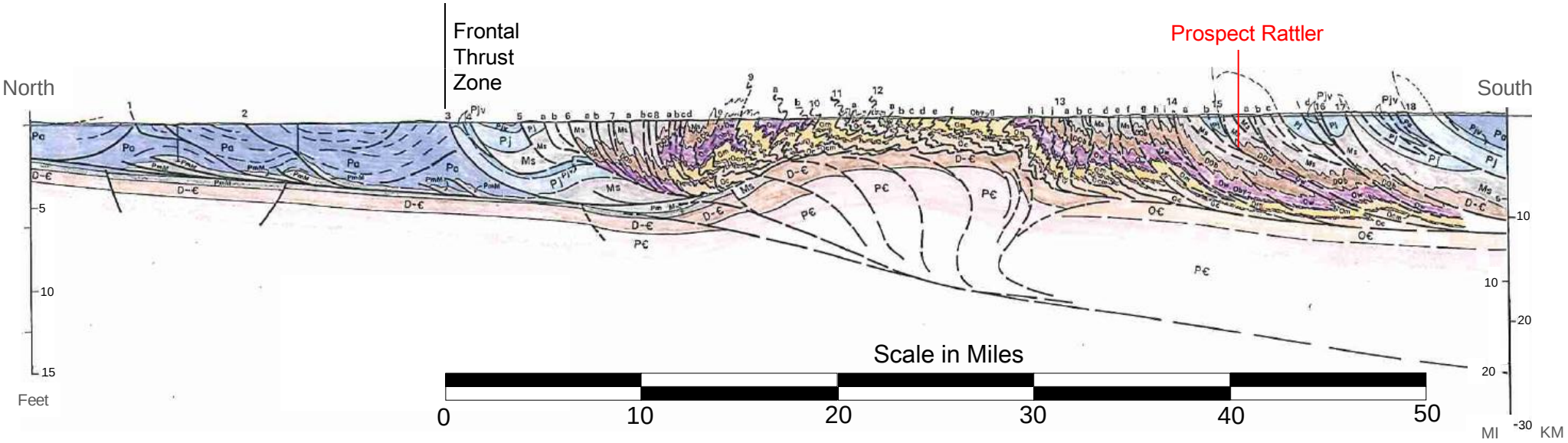
West Texas – Marathon Mountain Cross Section

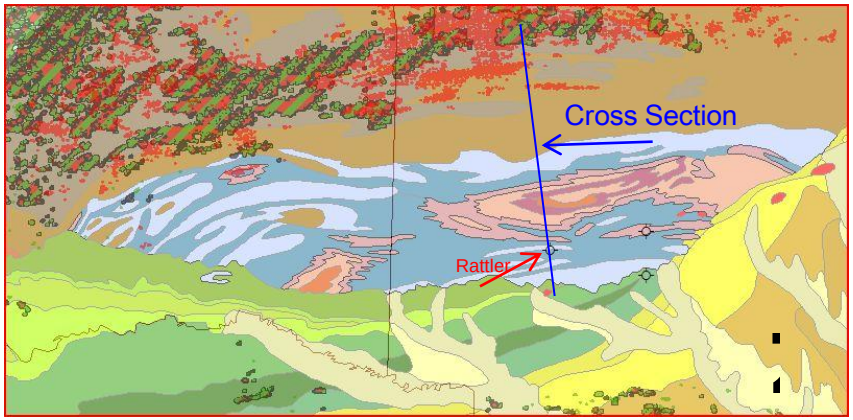


Taken from:
Hickman, R.G., et. al., (2009)

In Hickman's cross section, the Lower Paleozoic are presently exposed at the leading edge of the thrust belt. Erosion has exposed rocks older than the Caballos Novaculite shown in red. Hickman projected the younger novaculite section in the air above the currently mapped frontal thrust. By laterally projecting the four novaculite oil fields onto this line, we can see that these fields are located near the leading edge of the thrust faults.

Cross Section: Arkansas Ouachita Mountains



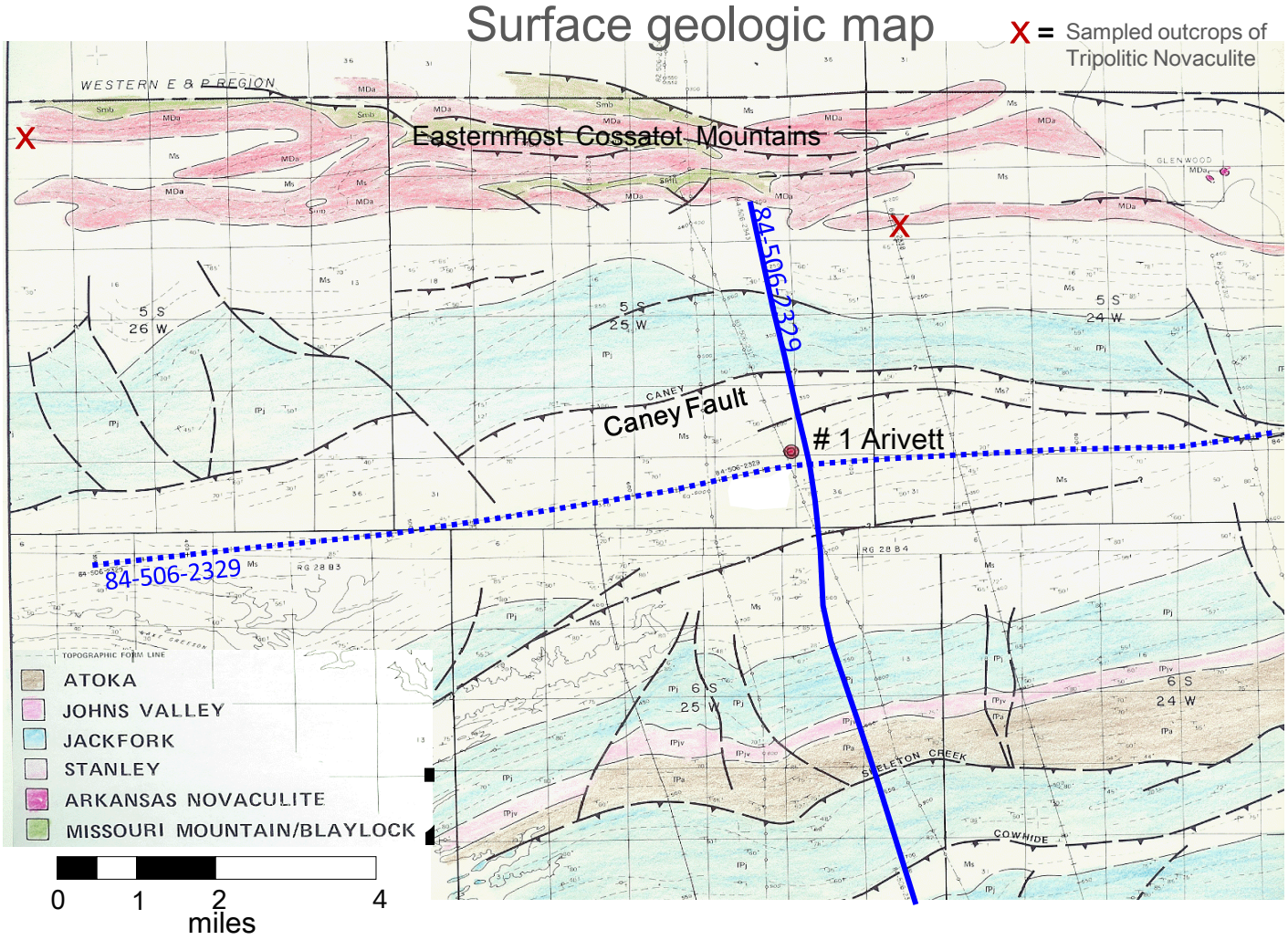


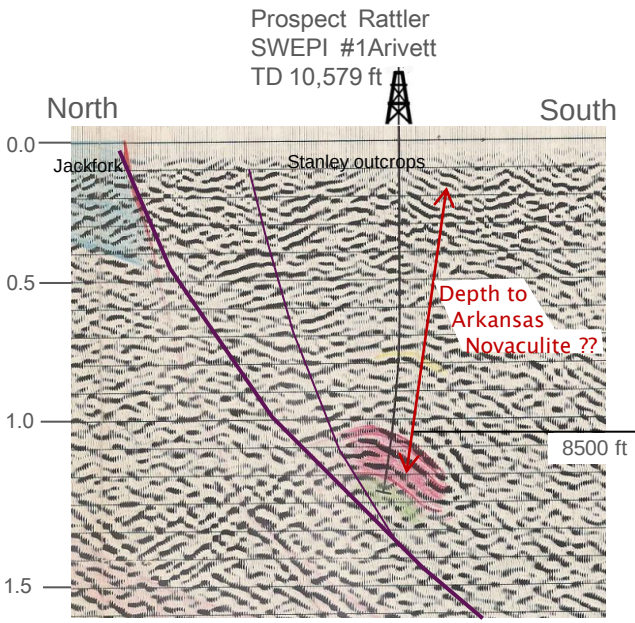
Rattler prospect is located some 40 miles interior of the leading thrust fault zone

Modified from Arbenz,1984

By comparison, the Rattler wildcat well was drilled well back in the interior portion of the thrust belt as demonstrated on this cross section drawn by Kaspar Arbenz in 1984 (shown in blue on the inset map). The large basement uplift shown on the cross section is referred to as the Benton uplift. The Benton uplift is thought to be a feature that involved the basement via a late compressional event that, when emplaced, overturned all of the previous north- vergent faulting and folding. Structural support for this is demonstrated by deep record seismic (COCORP). The basement uplift was also a focus for a late thermal heating event concentrated along its axis. This heating had a decreasing effect on thrusted sediments as distance increased away from the basement fold axis in both directions . This is based based on VR equivalent reflectance data from outcropping rocks.

Seismic Dip Line Location on Outcropping Thrust Sheet





When Shell began its exploration play efforts in the Arkansas Ouachitas, there was no seismic available. The Rattler area was intriguing as a large thrust sheet was mapped and deep erosion and removal of the Jackfork and younger section resulted in exposing a wide area of outcropping Stanley rocks. This deep erosion was thought to enable the Arkansas Novaculite to lie within reasonable drilling depths. The predicted floor to encounter rocks with an LOM of 18 or greenschist metapmorphism facies (VR>3%) was about 8000 feet. There were analogues for production in rocks with higher thermal maturity, and we hoped early porosity filled with hydrocarbons might result. The reservoir concept at Rattler was that a significant carbonate fraction in the novaculite might be leached in the subsurface. If the timing of leaching occurred prior to hydrocarbon charge, additional and possibly significant matrix porosity might combine with fracturing to create tripolitic novaculite reservoir rock.

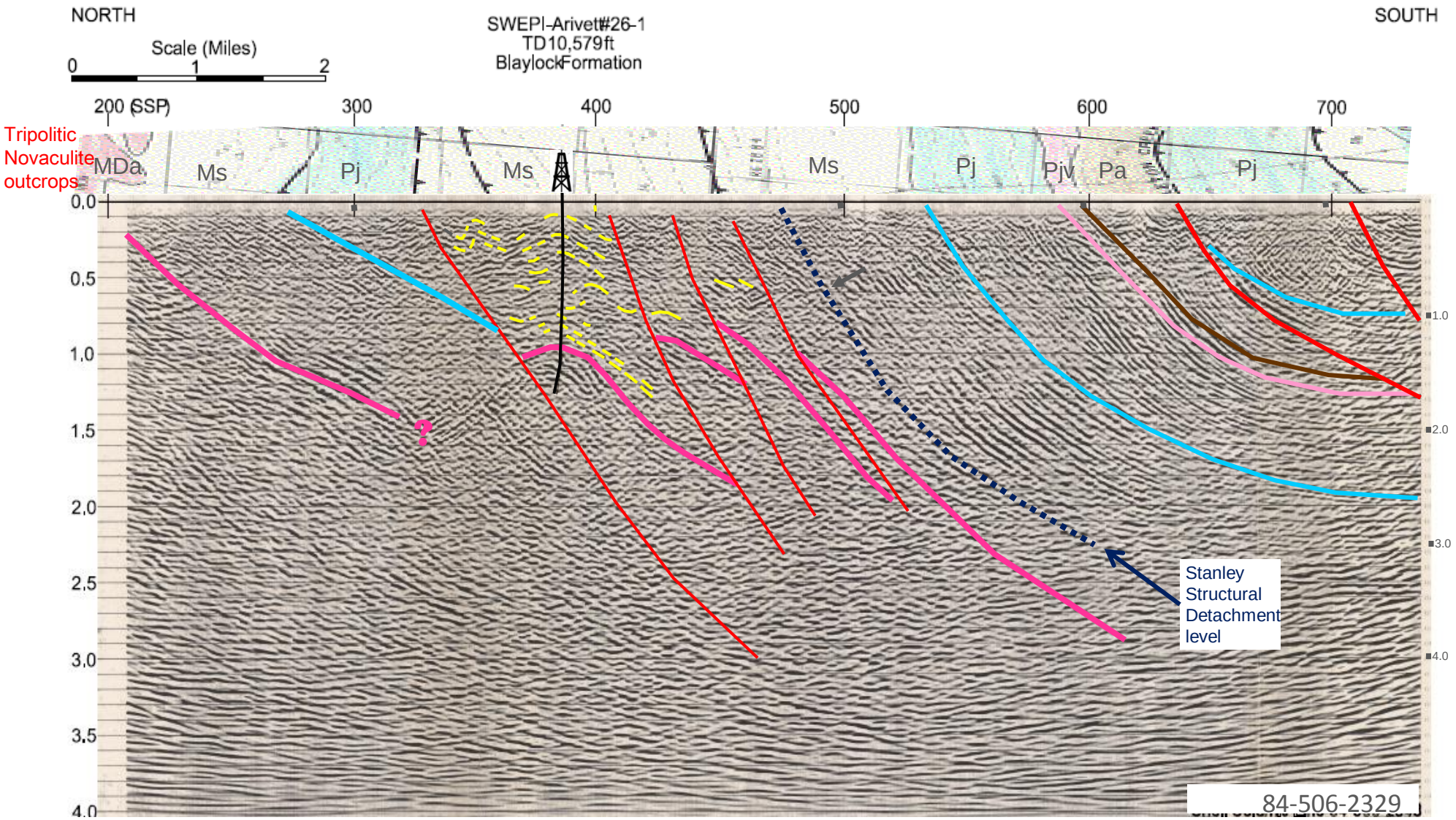
Outcrop Samples of (leached) Tripolitic Novaculite

"Powdery" Tripolitic Novaculite

"Vuggy" Tripolitic Novaculite

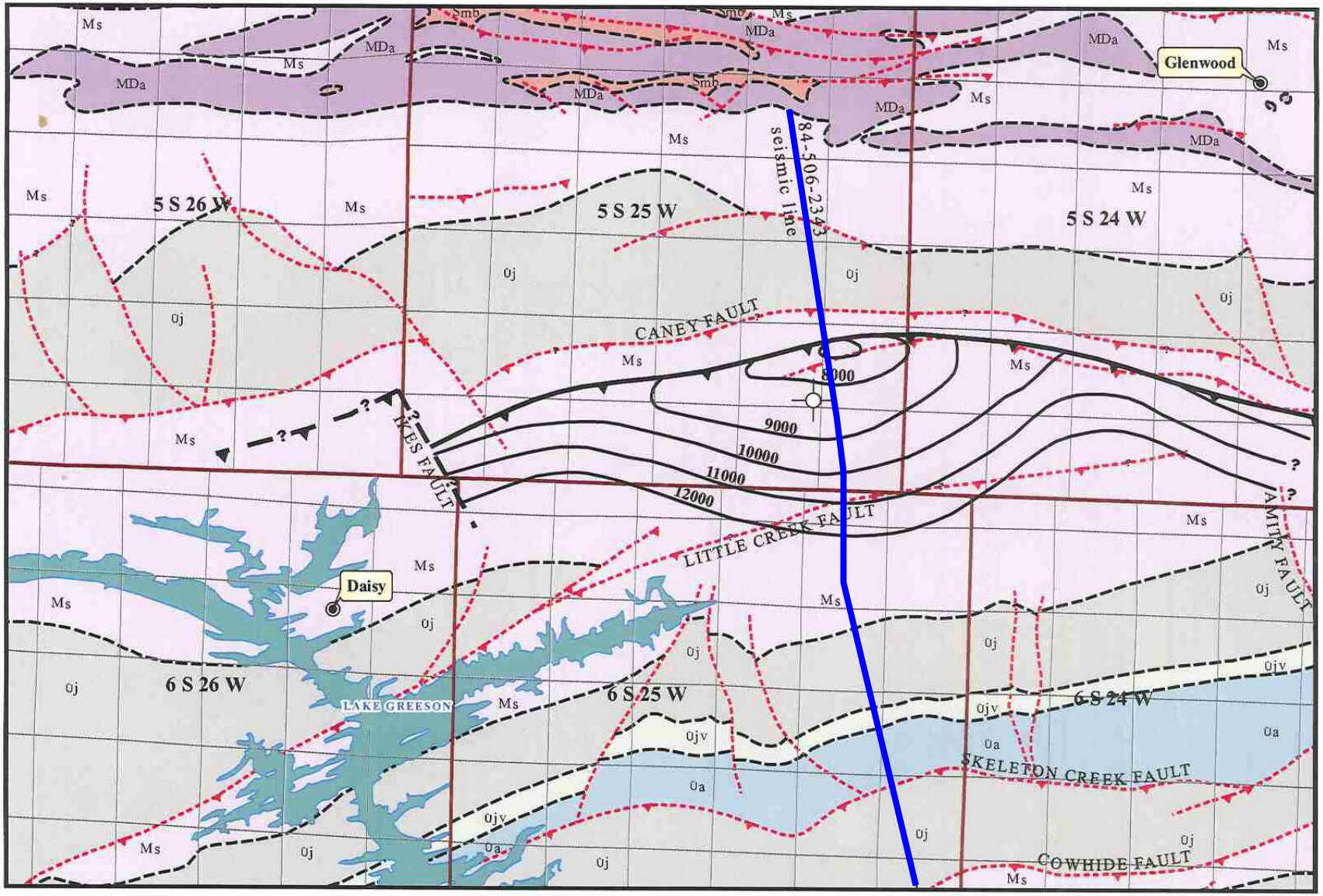
These photos were taken of typical outcrop samples of tripolitic novaculite found in the upper member of the Arkansas Novaculite along the southeastern Cossatot Mountains.

Seismic Dip Line



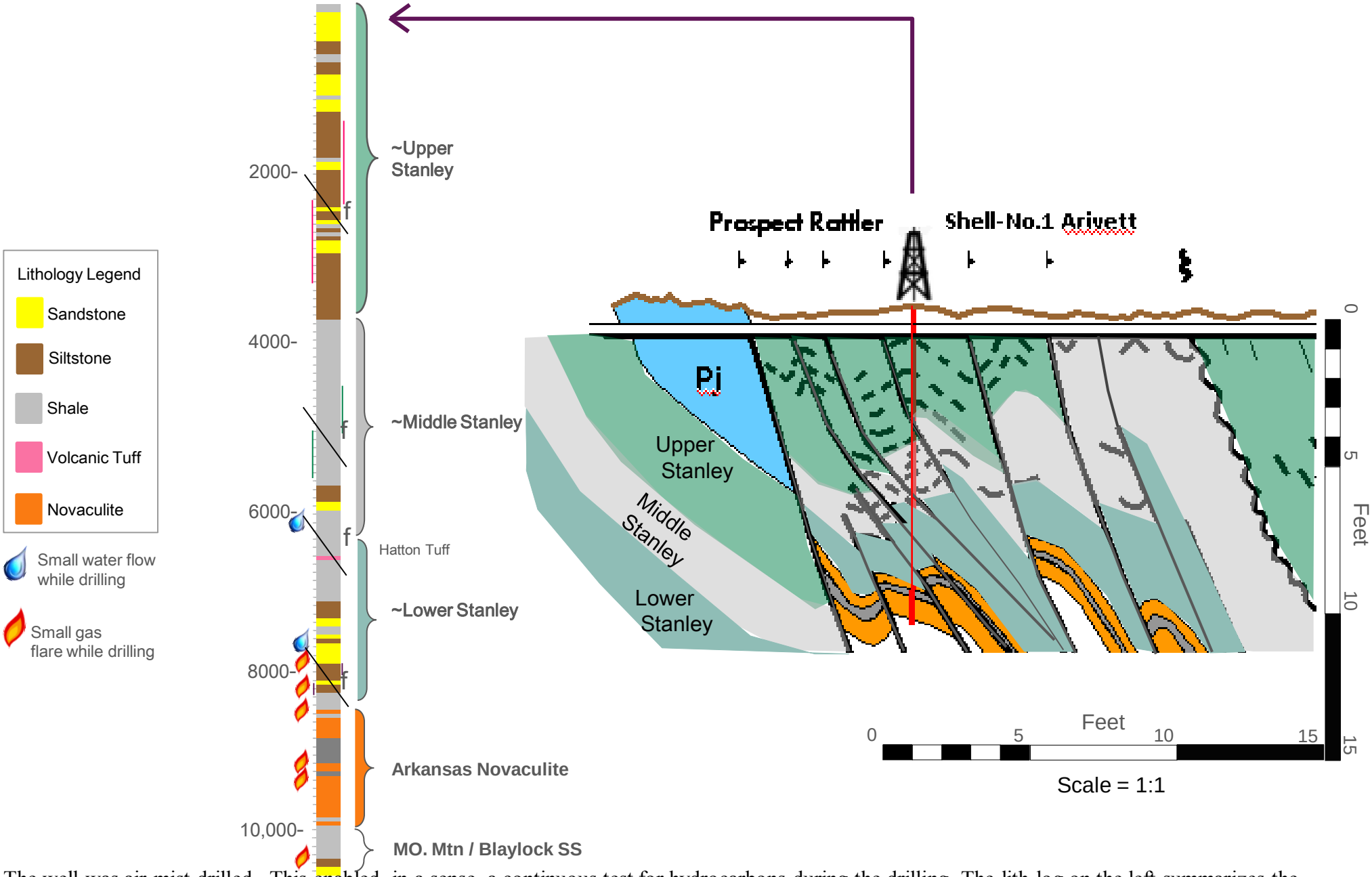
This seismic line shows the strong south-dipping reflections which dominate the regional structure. Interpretation is greatly aided by plotting the outcrop formation tops at the top of the seismic and projecting into the seismic. Formations younger than mid-Stanley Formation show the best reflectivity. About midway in the Stanley there is a marked detachment layer mappable in outcrop and seen on the seismic line as a change to more chaotically defined seismic dips. The Rattler prospect targeted a coherent patch of seismically strong events that terminate at the leading edge of the major Caney fault. The tripolitic novaculite crops out as a belt directly north of Rattler and at the left edge of this seismic line.

Structure Contours of Arkansas Novaculite overlain on Outcrop Map



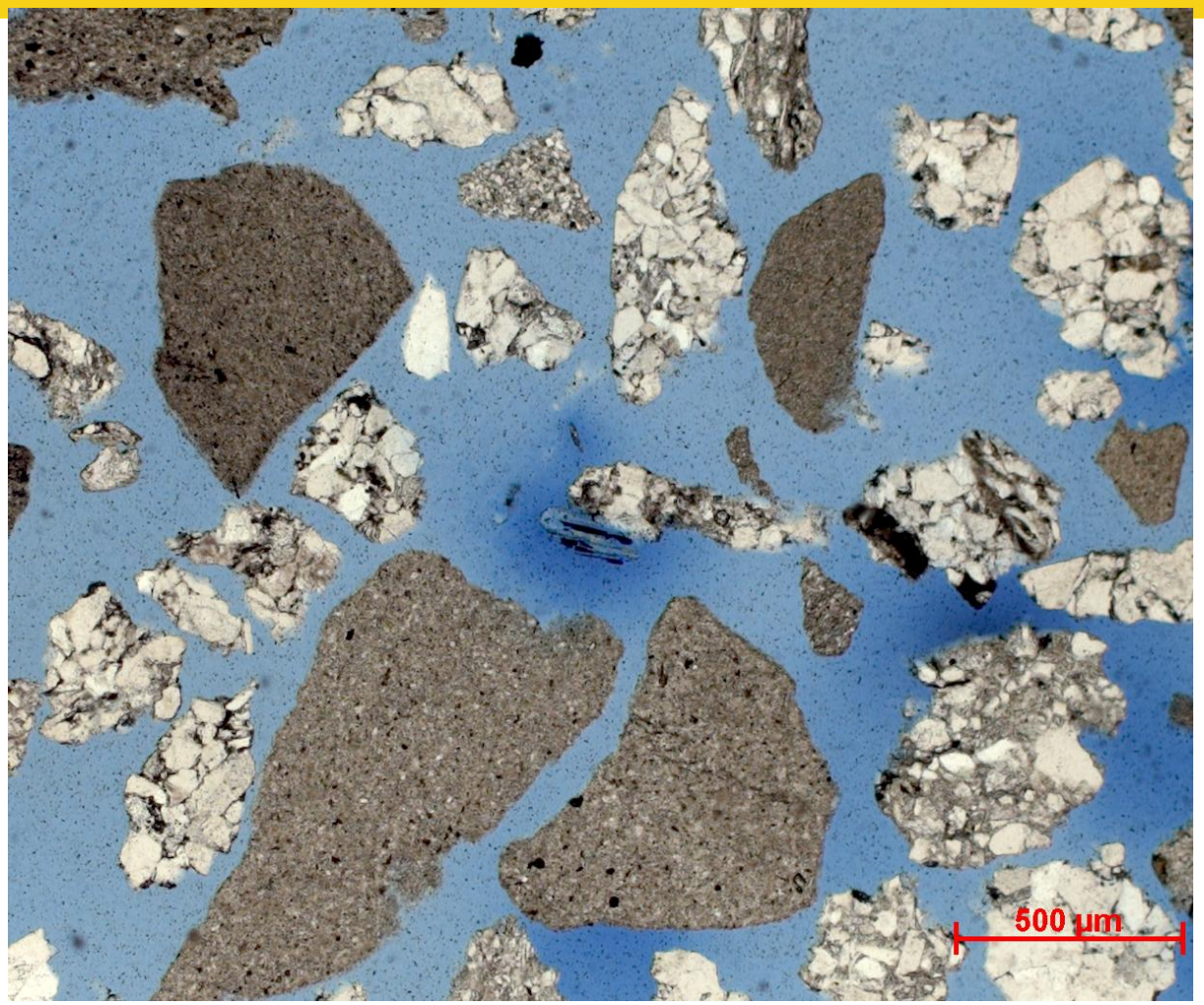
This is the same surface geologic map shown before, but here there are superimposed subsurface contours on the top of the Arkansas Novaculite, assuming the deepest occurrence that is associated with the strong amplitude "patch" of events. The map was considered a formline map at best, made on an envelope that likely contains complexly folded and faulted Arkansas Novaculite.

Well Results: Stratigraphy penetrated by the well

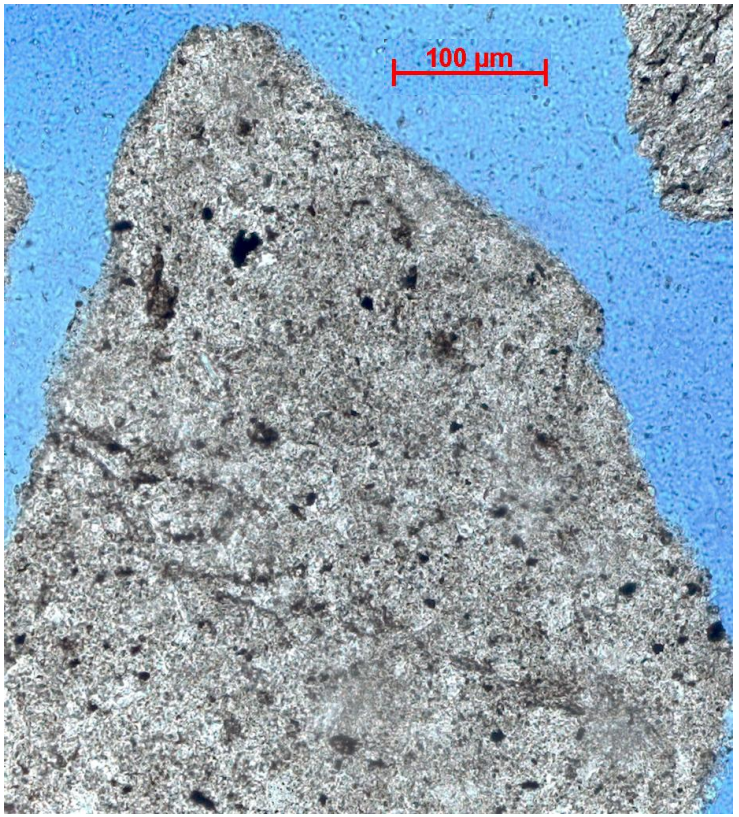


The well was air-mist drilled. This enabled, in a sense, a continuous test for hydrocarbons during the drilling. The lith log on the left summarizes the stratigraphy and general lithology that was penetrated. It appears that a rather complete section was drilled by the well beginning in the upper sandy Stanley through the middle shaly Stanley and then into the lower sandy Stanley (Hot Spring sand and Hatton Tuff equivalent section) before drilling the objective Arkansas Novaculite and reaching TD in the Silurian Missouri Mountain and perhaps a Blaylock sand. As indicated in the legend, some gas flares were produced below about 8000 feet. All flares produced were less than 6 feet long and lasting up to 25 minutes.

Well Results: Hatton Tuff Member in the lower Stanley Formation



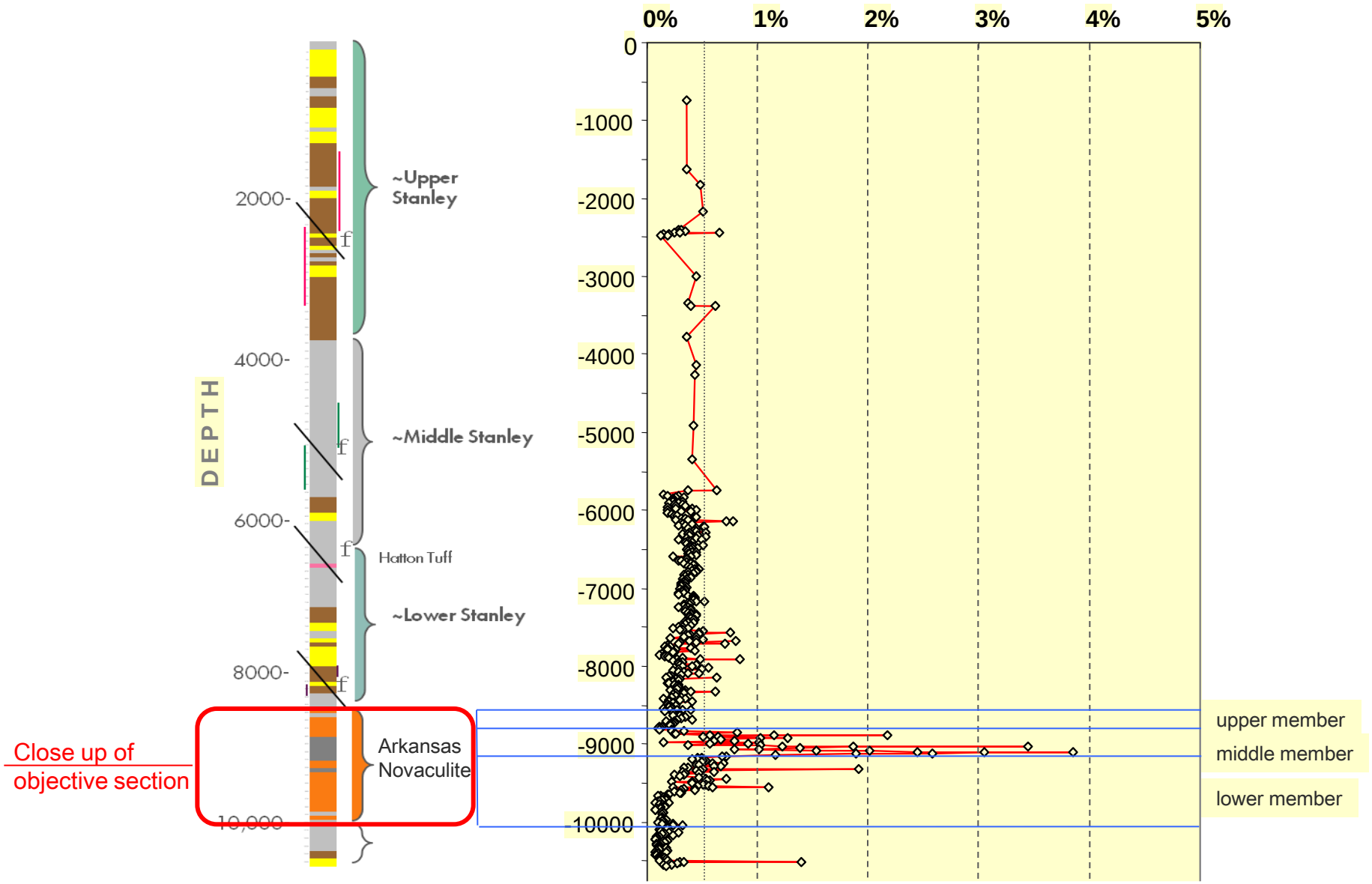
Ditch cuttings from 6650-60 ft



Close up of a welded tuff cutting

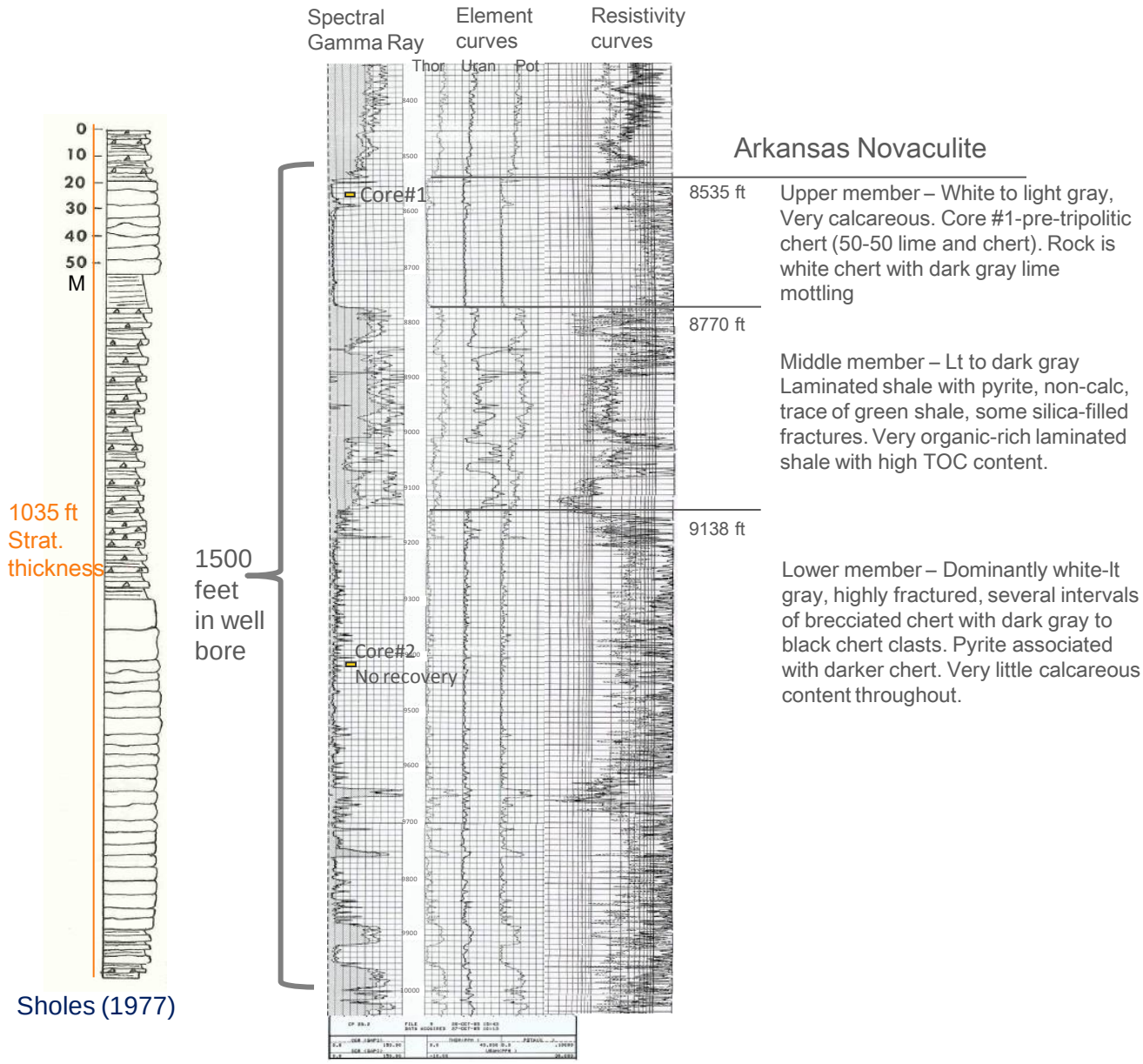
The photomicrographs were made from ditch cutting samples. In the left photomicrograph are darker colored cuttings that are examples of welded tuff within the Mississippian Stanley Formation that may be equivalent to the Hatton Tuff in outcrop found in the lower Stanley. From a sample log made on cutting analysis, a significant amount of this tuff occurs between 6650 and 6700 feet. Douglas Mose published in a 1969 article in GSA that the Hatton Tuff yielded an isochron age of 310 ± 15 m.y. ($_{Rb}^{87} = 1.39 \times 10^{-11} yr^{-1}$). "The age of the Hatton Tuff, when compared to the currently accepted geologic time scales, indicates that the lower Stanley Shale is Pennsylvanian in age." Other cuttings in the photo represent fine- to medium-grained Stanley sandstones.

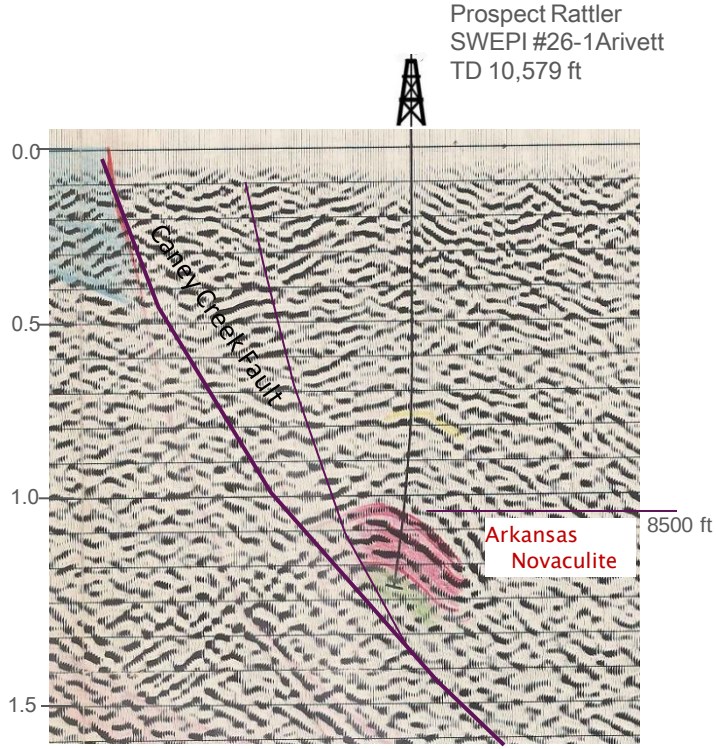
Well Results: Organic Richness(TOC%) -vs- Depth



The histogram illustrates the total organic richness as measured from cuttings for the entire well. The richest source rock found is in the middle member of the Arkansas Novaculite, as prognosed, with measured richness values up to nearly 4%. These values are not corrected back to original richness values based on the high maturities levels found in the well. It is likely that the original TOC values in the Arkansas Novaculite shales were over 15 percent. To support this, outcrop richness in this member can be measured in the mid teens from outcrops that have barely entered the oil window, such as at Black Knob Ridge in Oklahoma.

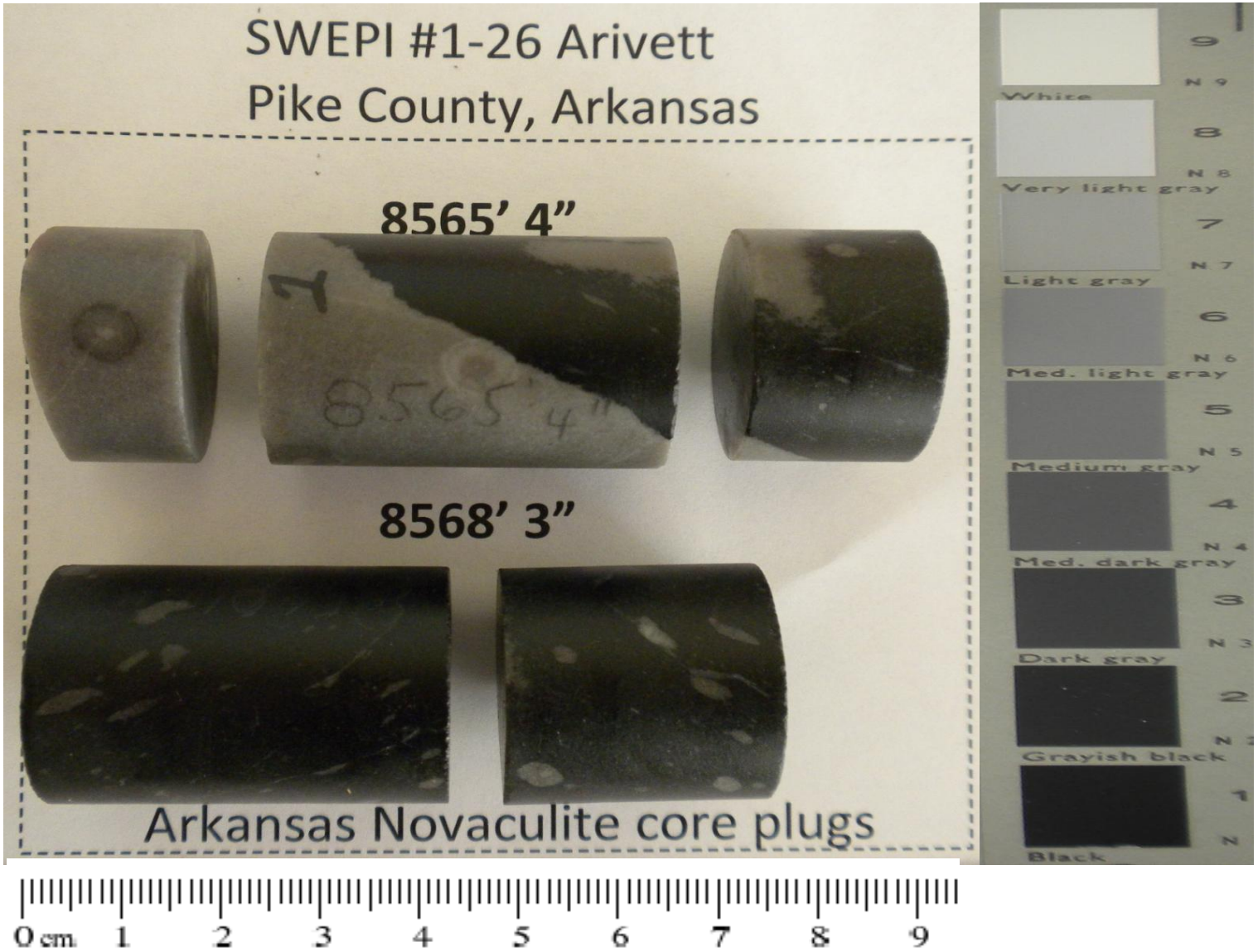
Well Results: Arkansas Novaculite – 3 members

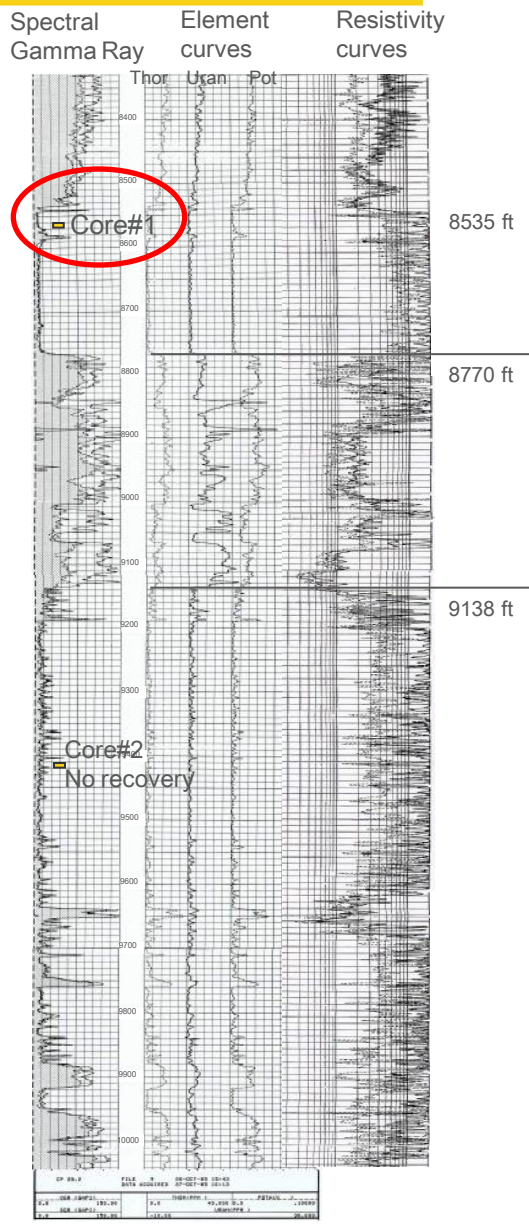




The Arkansas Novaculite in the well is nearly 1500 feet thick. The dipmeter indicates low dips, around 8 degrees, in the upper member with increasing dips to about 25 degrees in the lower member. The log curves shown are the total Gamma Ray curve on the far left with the 3 elemental curves of gamma ray in the center of the log, and on the far right are the resistivity curves. The richest TOC values measured correspond nicely to the highest concentrations of the Uranium curve from the spectral gamma ray log.

Well Results: Core Plugs from Whole Core

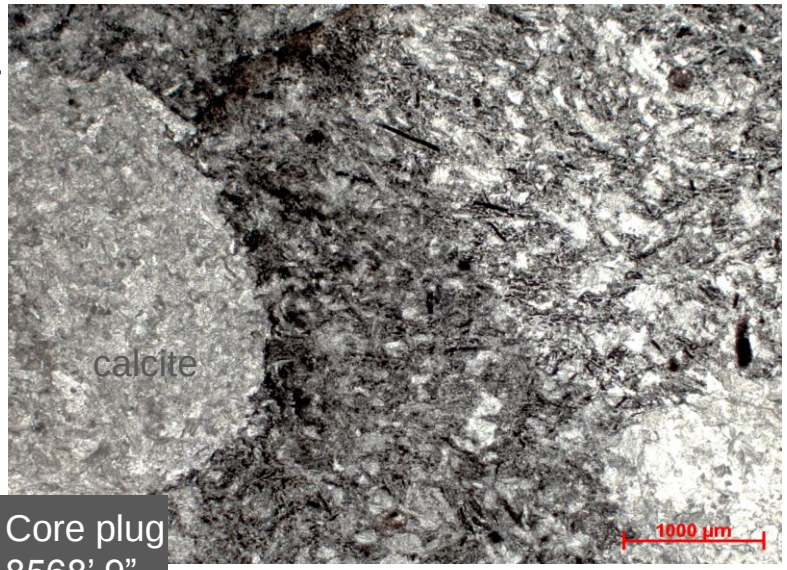




outcrop sample

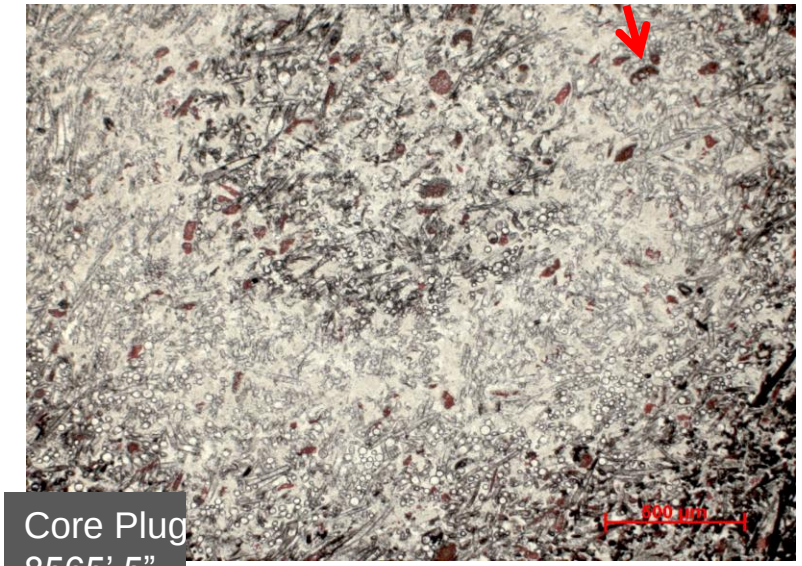
These two core plugs were taken from the whole core recovered between 8565 and 8569.5 feet. The disk-like shaped carbonate blebs resemble the leached or vugular novaculite outcrop sample in the lower left and shown earlier. Most of the whole core is light gray in color. These two example core plugs show the variety.

1



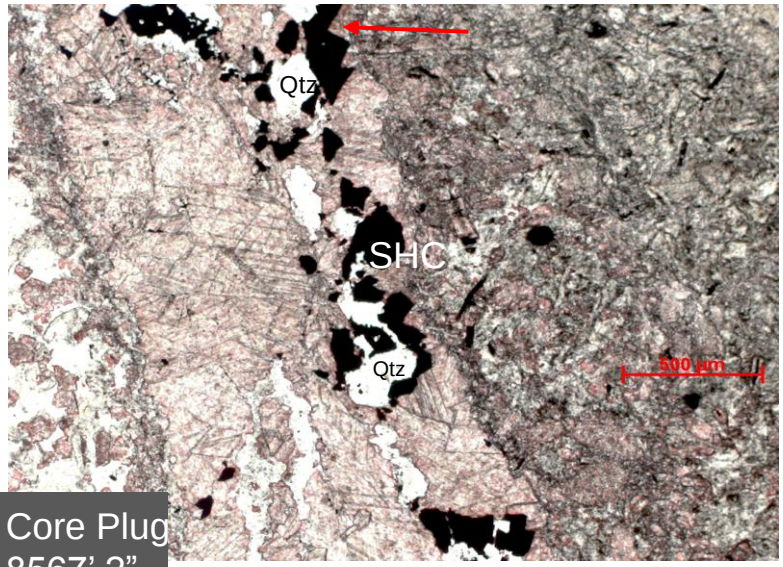
Core plug
8568’ 9”

2



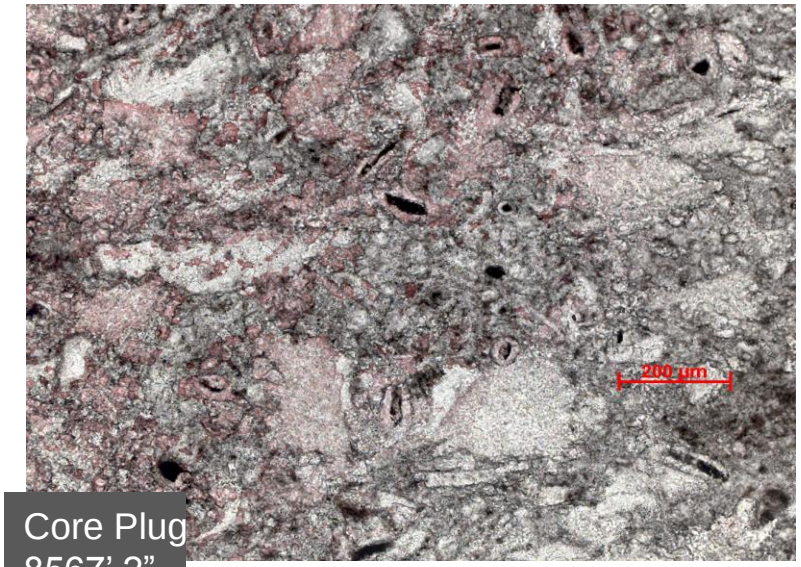
Core Plug
8565’ 5”

3



Core Plug
8567’ 2”

4



Core Plug
8567’ 2”

1)Many of the circular objects are filled with calcite and may represent a concretion. The groundmass is dominantly made up of sponge spicules and radiolarians. The dark color is likely anthraxolite or thermally dead hydrocarbon.

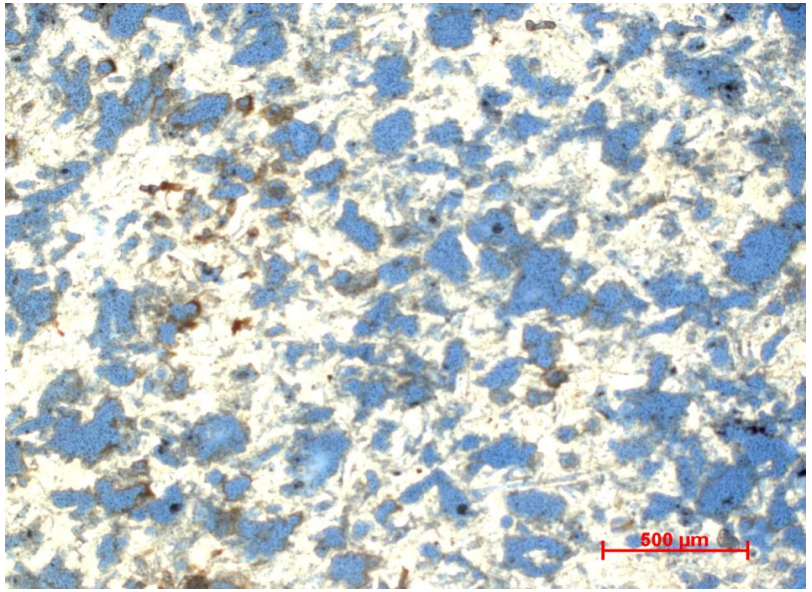
2)In this sample, the circular part does not appear to be made up of calcite but rather a zonation in color with the darker inner core stained by anthraxolite. The section is stained red for calcite composition. Sponge spicules and radiolarians are quite well defined and numerous. Is this also some sort of concretion? In the upper right corner calcite appears to have replaced a fossil shell.

3) This fracture fill in the novaculite contains euhedral calcite with a later-stage hydrocarbon fill that entered a partially open fracture. Note the euhedral calcite grains present in the open fracture with hydrocarbon fill (arrow). Quartz cement was introduced just after a hydrocarbon-fill phase.

4) In this slide, there are some curious fossil-like forms. If some are sponge spicules, they look different from previous, more readily identifiable forms. The disk-like objects crinoids? There also may be echinoid fragments in the rock.

Comparison of Leached and Unleached Tripolitic Novaculite

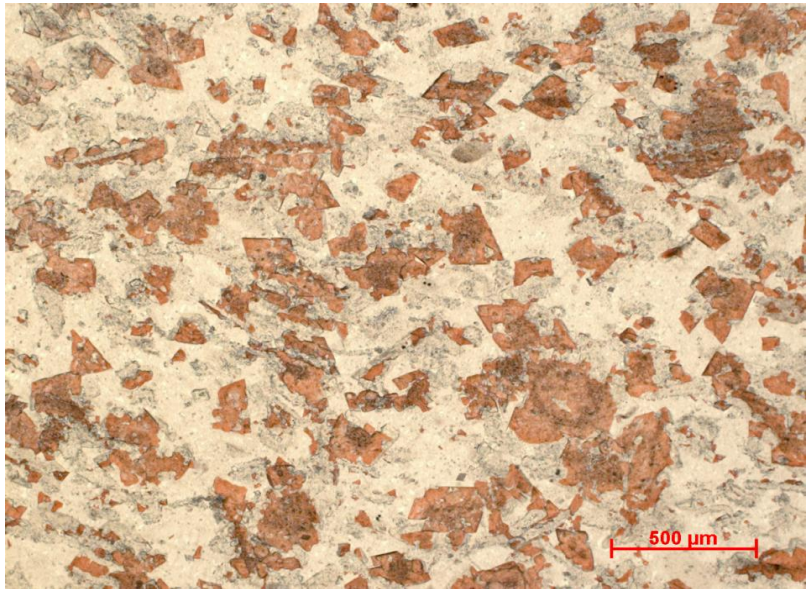
Thin Section from outcrop sample



Outcrop sample

Weathered Outcrop

- leached calcite from a novaculite matrix -



Subsurface Sample – unleached calcite

8565'2" from the Shell #1Arivett

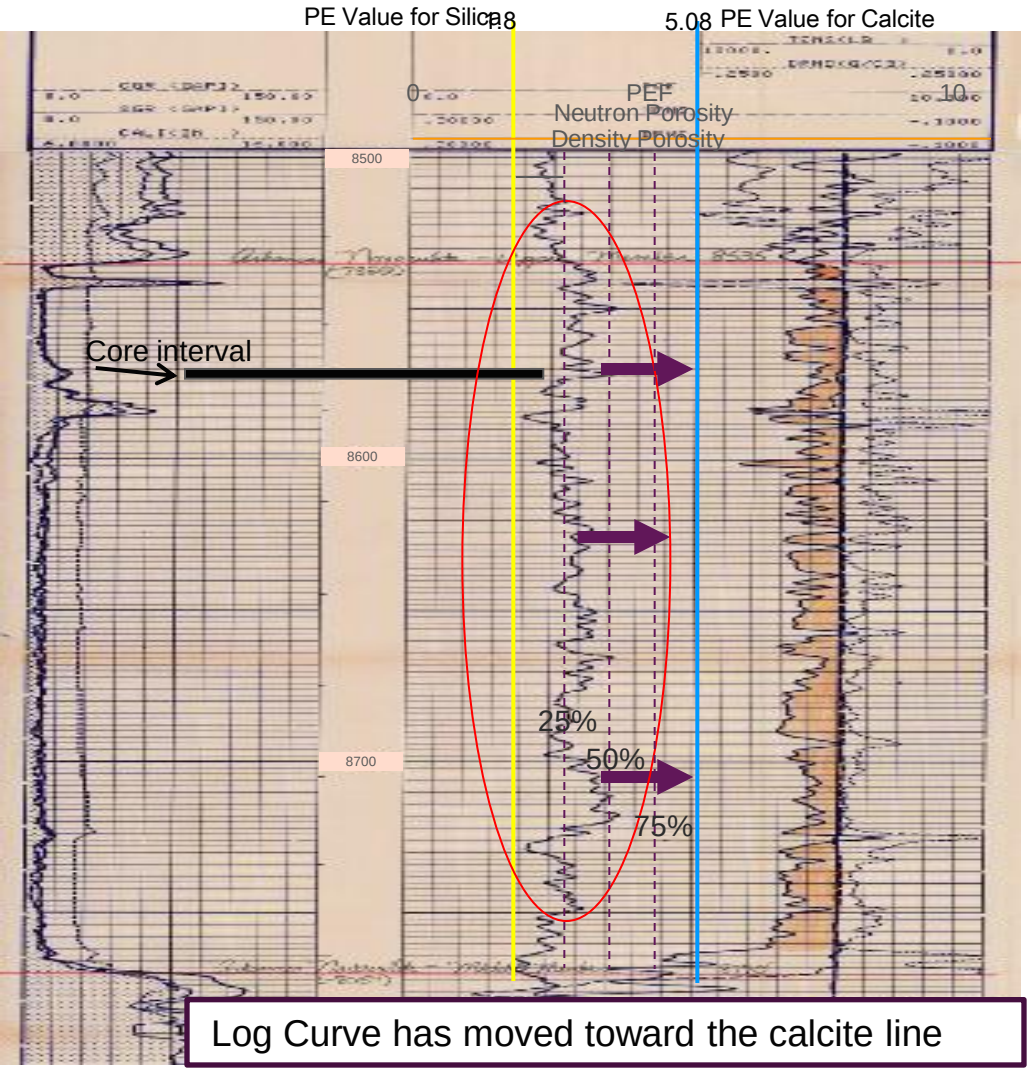
Here is a comparison of tripolitic novaculite in a leach outcrop sample with an unleached sample found in the Rattler well. Our hope in the pre-drill scenario at Rattler would be that the novaculite would look like the upper photo but filled with oil that had been thermally cracked to gas.

Well Result: PE log to estimate carbonate in novaculite

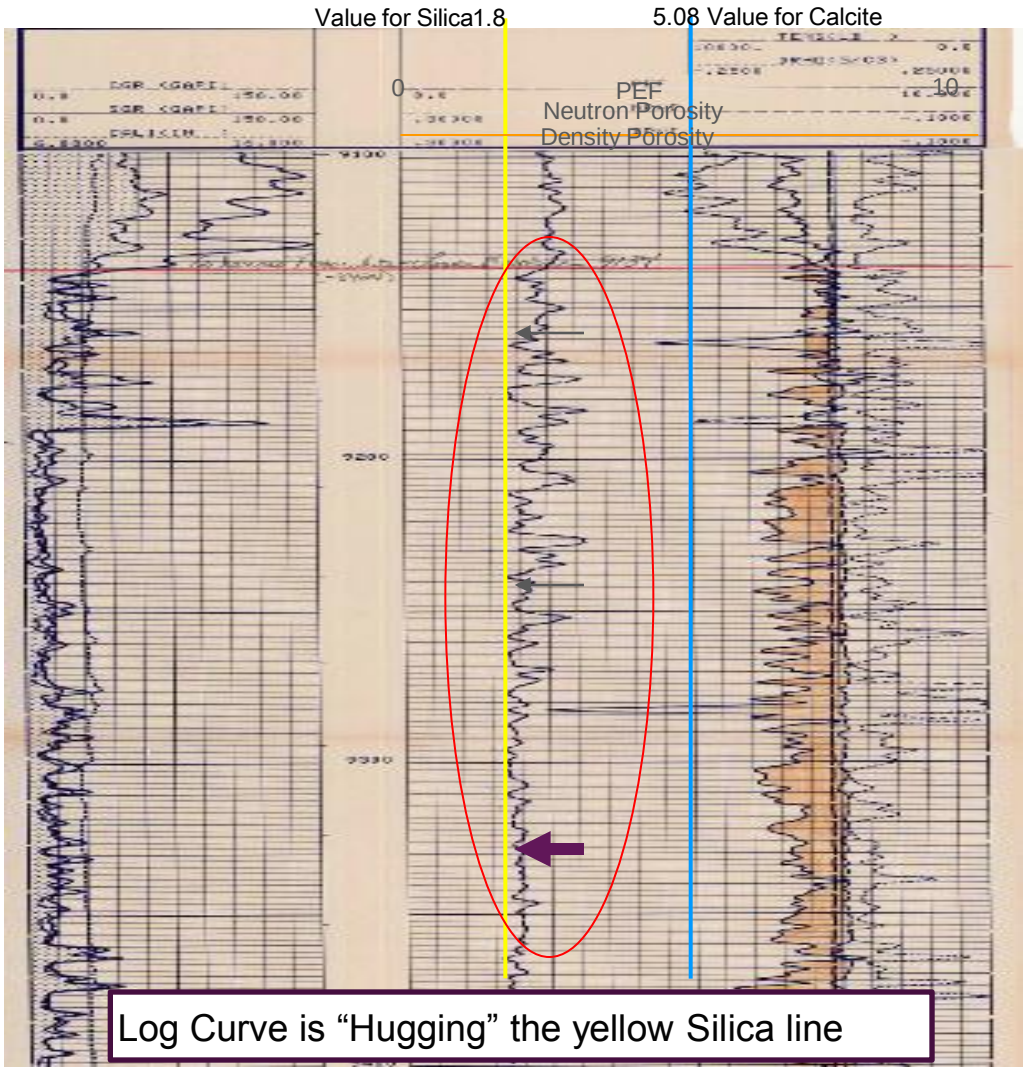
(PE log = Photo Electric Log)

Upper Member - More Calcite

Lower Member - Less Calcite



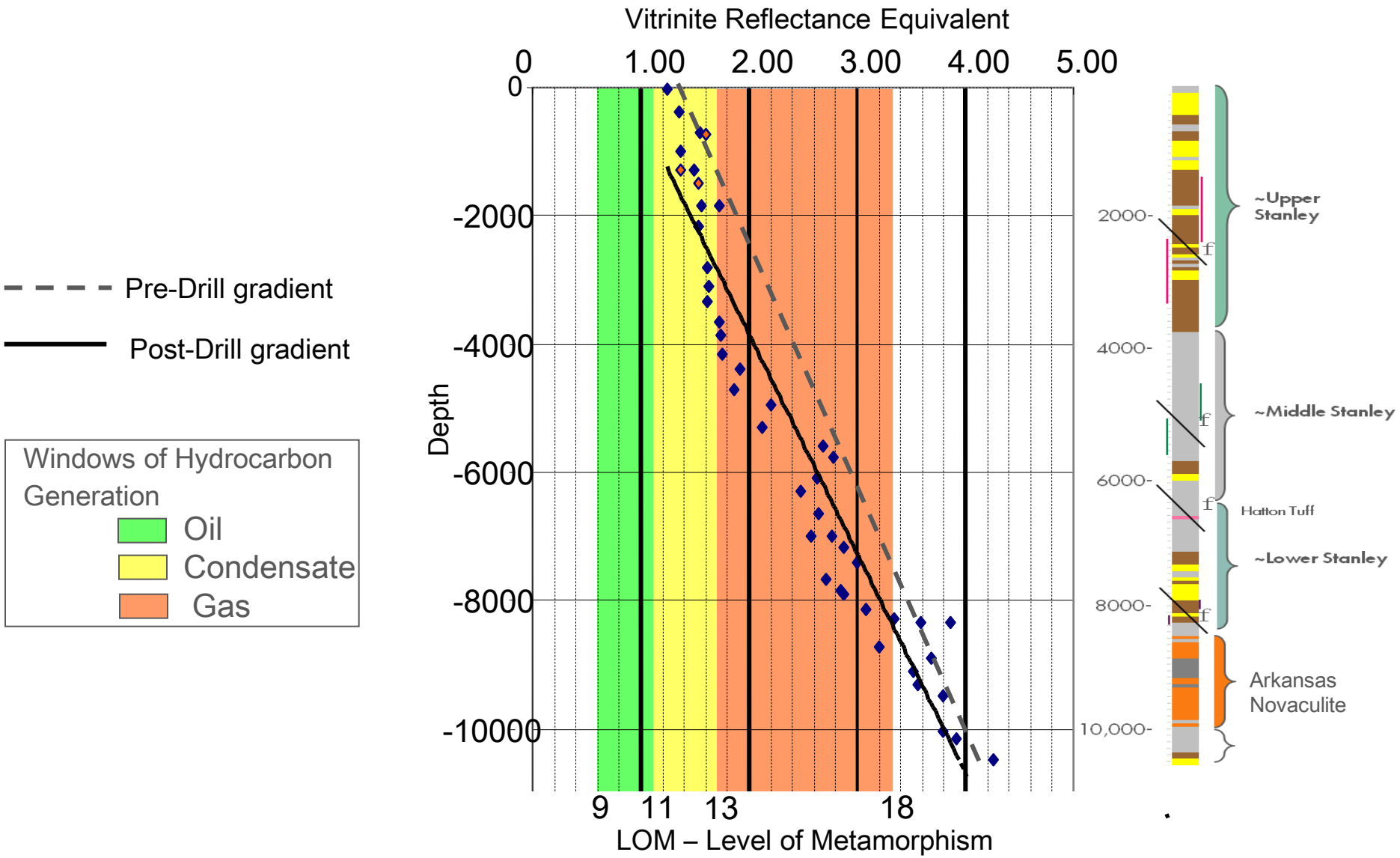
Log Curve has moved toward the calcite line



Log Curve is “Hugging” the yellow Silica line

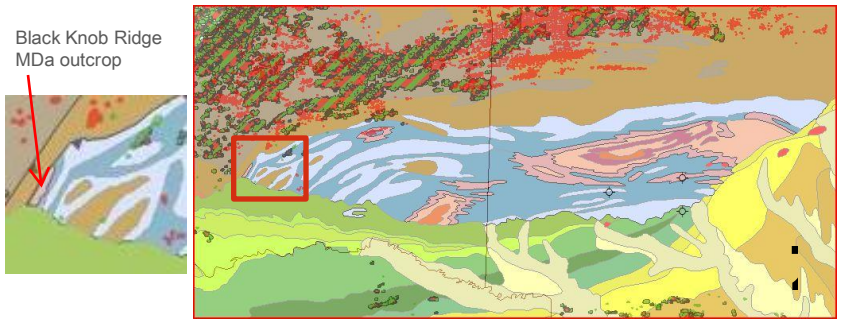
The PhotoElectric log was used to estimate the distribution and amount of silica in both upper and lower members of the novaculite. Novaculite is a good candidate for using this log evaluation approach since the rock is dominantly a 2-component combination of silica (chert) and calcite. A pure silica PE value is 1.8 whereas the pure calcite value is 5.08. The lower member on the right appears to have a value closer to silica and hence less carbonate. Compared to the upper member on the left, the PE curve has values greater than the pure silica value. The dashed lines show different quartile amounts spaced between silica and calcite. Allowing for some estimation error, the carbonate content may average 10 to 20 percent in the upper member.

Well Result: Thermal Maturity Profile

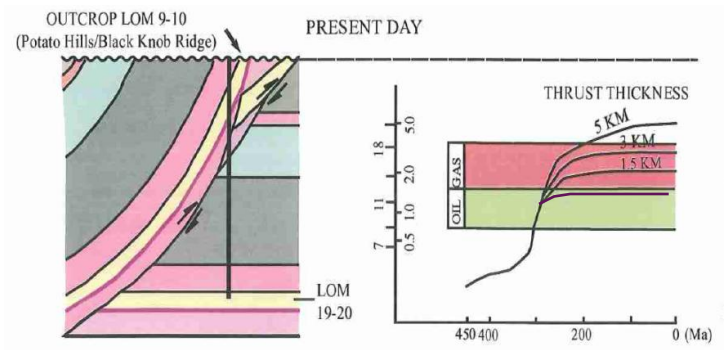


This chart shows the increasing thermal maturity of rocks with increasing depth as measured by vitrinite reflectance equivalent values on cuttings taken over the entire wellbore. Prior to the well spud, the thermal maturity of the outcrop at the well location was known and the predicted maturity gradient below that point was assessed using the average gradient from19 other Ouachita wells drilled in Oklahoma and Arkansas. This pre-drill gradient is drawn as the dashed gray line. After plotting the actual values from the Rattler well the best fit line for the data is drawn in a solid black line. The maturity floor (thought to be generally equivalent to a LOM value of 18) was found in Rattler at about 8100 feet.

Charge / Structural Timing Model (pre and post drill)



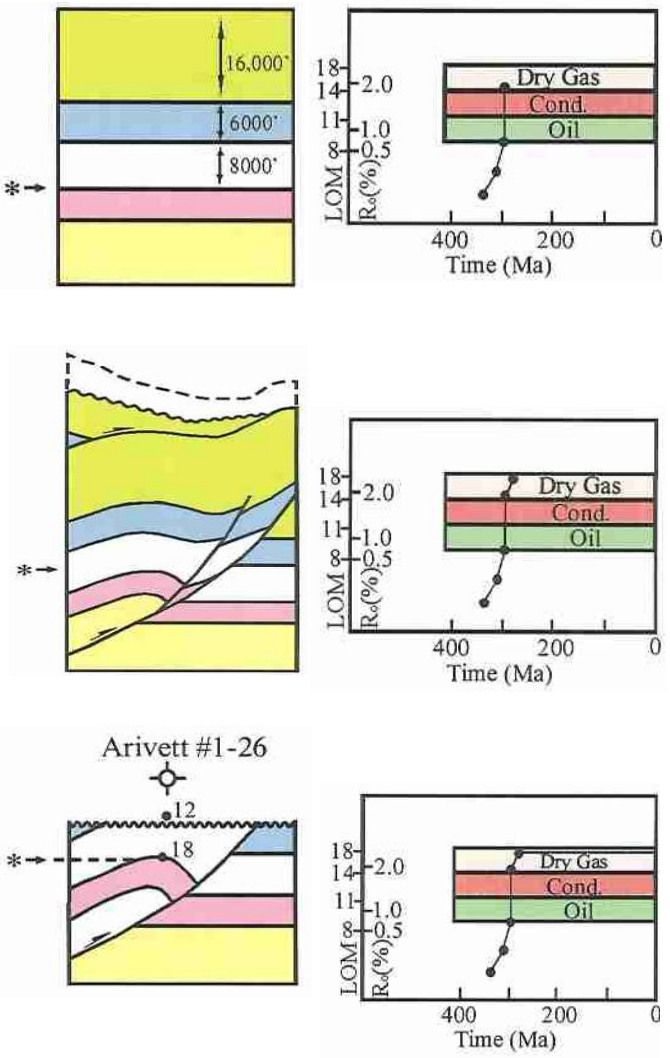
Pre-Drill Model



1) Novaculite outcrop in frontal Ouachitas measured <1%VR (oil window)
2) Thrusting began as SR entered oil window and with erosion, maturation slowed and stopped as overburden lessened.
3) In interior Ouachitas, higher outcrop maturities due to a) deeper basin b) with more overburden - so the question remained, would prospects have seen a gas charge and retained it?

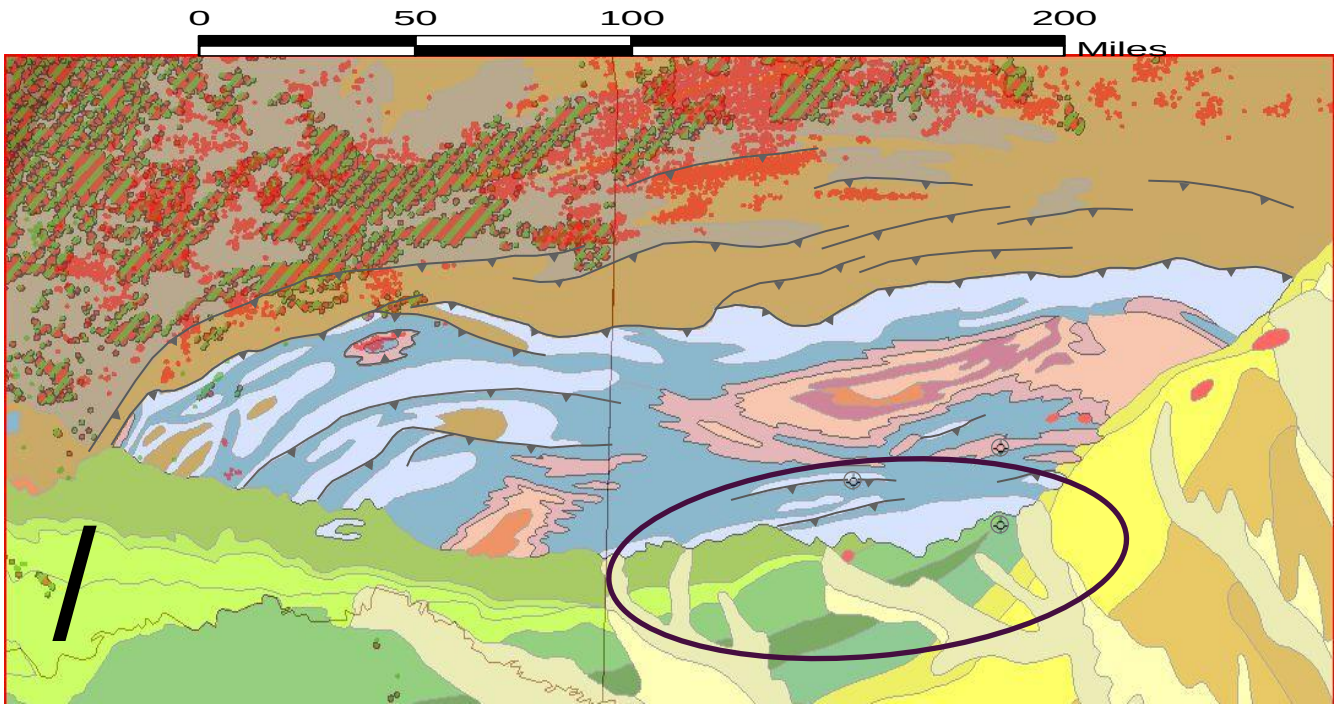
Post-Drill Model

Prior to thrusting >95% hydrocarbons generated from Arkansas Novaculite SR



This slide illustrates what the pre-drill model for charge/timing was and how it is now viewed. The overall learnings from the well can be generally characterized that in the interior position of the thrust belt the basement was at its deepest and the overburden was the thickest compared to the frontal thrust zone mapped today. As a result, the frontal thrust zone of the overthrust belt is still in the oil and gas window, while the interior portion mostly matured prior to charge, and then after structural emplacement, there remained a thick overburden.

Summary Points



The Rattler wildcat drilled in the interior portion of the Arkansas Ouachitas encountered the Arkansas Novaculite at the farthest southern position of any outcrop or well control. The Arkansas Novaculite appears very similar in general description and thickness to the unofficial "type section" located at Caddo Gap, Arkansas, including the description of the three members. The middle member was made up entirely of very rich intervals of lipid source rock that today is thermally very immature, with a vitrinite reflectance equivalent of 3.5 percent and higher. The Arkansas Novaculite contained significant amounts of carbonate material in the silica groundmass. Largely this carbonate material was not significantly leached. Small amounts of pyrobitumen (anthraxolite) are found in the microporosity and in some fracture linings of the novaculite. Small gas shows were encountered while drilling, but no hydrocarbon accumulation was found. Based on the results at Rattler, it appears that significant Carboniferous and a deep basement allowed for the burial depth of the Arkansas Novaculite source rock at Rattler to mature and expel hydrocarbons prior to final structural emplacement. This left only overmmature source rocks at Rattler--that were not able to charge the Rattler trap. The implications of the deep basement and deep burial by thick Carboniferous sediments in the interior of the Ouachita thrust belt indicate this area is thermally overmature for hydrocarbons. The potential for finding the source rock within the oil and gas window, and hence for viable hydrocarbon fields, remains to be found nearer the present-day frontal thrust zones of the Ouachitas.

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More information on this well and the Ouachita Mountain Overthrust can be found in an information circular to be published by the Arkansas Geologic Commission in 2011.