Deposition and Diagenesis of the Blossom Sand, Panola County, Texas

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Deposition and Diagenesis of the Blossom Sand, Panola County, Texas

By

Hannah C. Chambers, Bachelor of Science

Presented to the Faculty of the Graduate School of
Stephen F. Austin State University
In Partial fulfillment
Of the Requirements

For the Degree of
Master of Science

Stephen F. Austin State University
May 2021
Deposition and Diagenesis of the Blossom Sand, Panola County, Texas

By

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ABSTRACT

The Late Cretaceous Blossom Sand within the Austin Group is a historic gas reservoir in the East Texas basin, located at depths of approximately 2,000 ft below the surface. Since the discovery of the Carthage Field in 1918 in the East Texas Basin, the Blossom Sand has produced approximately 26 BCF of gas with minor amounts of oil. Despite its notoriety in the Carthage Field, there is very little research that has been conducted on this unit, although it crops out in northeast Texas and is found in the subsurface of southwest Arkansas, western Louisiana, and the East Texas Basin. The origin of its sediments, clay minerals, and depositional style have gone largely unknown. This study provides insights into the depositional environment and diagenetic history of the Blossom Sand using thin section analysis, x-ray diffraction (XRD), x-ray fluorescence (XRF), scanning electron microscopy (SEM), and porosity and permeability measurements. Each of these methods were used to identify clay minerals and their associations and variability, and correlated with porosity/permeability throughout the core to determine controls.

The major minerals found in this formation include quartz, calcite, and illite; accessory minerals include, plagioclase, muscovite, biotite, hematite, and siderite. Despite the literature stating that glauconite is common, it was not detected in any of the analyses. The Blossom Sand is composed of two major sand facies that contain planar lamination, wavy bedding, bioturbation, pellets, casts and molds of *Inoceramus sp.*
bivalves and one specimen of *Exogyra sp*. These sand facies are interbedded with shales and siltstones throughout. The porosity varies from 2.6-33.7% with an average of 23.8%, while the permeability varies from 0.0002-146 mD, with an average of 25.4 mD. The porosity and permeability are inversely correlated with calcite content based upon Ca from the XRF data, indicating that calcite cement is the main controlling factor on porosity and permeability within the Blossom. The fine sands and sedimentary structures indicative of multidirectional currents and shallow marine fossils suggest that the sands were deposited in nearshore environments. The presence of trace fossils such as casts and molds indicate that dissolution and redistribution of local biogenic carbonate resulted in the calcite cement that controls the porosity and permeability of the Blossom Sand. Gaining a better understanding of the nature of porosity and permeability in sandstone reservoirs like the Blossom Sand can improve success in oil and gas exploration, secondary recovery, or carbon capture and storage.
PREFACE

This thesis has previously been accepted for publication at the South Texas Geological Society Bulletin in March 2021. This manuscript will be published in the GCAGS Journal in 2022. The original manuscript submitted to the South Texas Geological Society Bulletin was a short research summary and diagenetic history, while the new manuscript includes more data and a more detailed depositional and diagenetic history. Further details on stratigraphy and methods are also found in the appendices for further reference.
ACKNOWLEDGEMENTS

I would like to thank my thesis advisor Dr. Julie Bloxson and the rest of my thesis committee for their guidance and support throughout this project. I would also like to thank the Stephen F. Austin State University Department of Geology and the South Texas Geological Society for providing funding that made this project possible.
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1. Introduction

The Late Cretaceous Blossom Sand of the Austin Group consists primarily of fine to medium grained quartz sandstones deposited in a nearshore, tidally influenced, shallow marine environment, with secondary clay minerals precipitated throughout. It is found in the subsurface of east Texas, southwest Arkansas, and western Louisiana with outcrops located in northeast Texas (Stephenson, 1918). In Panola County, Texas, the Blossom Sand is a well-known gas reservoir within the Carthage Gas Field. As of August 2019, it had produced 26 BCF of gas since 1961 (Enverus, 2020).

Despite its notoriety in the Carthage Gas Field, there has been very little research conducted on this unit. Numerous AAPG Bulletins from as early as the 1920’s note oil and gas production from the Blossom Sand in various fields within northern Louisiana parishes, yet descriptions of the Blossom only give vague descriptions, stating that it is a fine to medium grained quartz sandstone with glauconite throughout. However, research on the Blossom specifically is scarce. The lack of in-depth research is partially because most literature that mentions this formation was published prior to widespread use of advanced analytical methods such as x-ray diffraction (XRD), x-ray fluorescence (XRF), and scanning electron microscopy (SEM). The Blossom is also primarily found in the subsurface, is relatively thin (50-90 feet), and produces exclusively within the East Texas Basin.
In order to gain a better understanding of the Blossom Sand, here we study the mineralogy, geochemistry, grain size, and sedimentary structures from core sourced from Panola County, TX, in order to determine the depositional and diagenetic history, and controls on porosity and permeability on this gas sand reservoir in East Texas.
2. Geologic Setting

This research focuses on the Blossom Sand in the Carthage Gas Field of Panola County, Texas (Figure 1). The Carthage Gas Field is located on the east flank of the East Texas Basin on top of the Sabine Uplift. The Sabine Uplift is a structural high that bestrides the border of Texas and Louisiana. It is bound to the west by the East Texas Basin and to the east by the Minden and Winnfield Basins of Louisiana.

![Figure 1. Study area and core locations.](image)

Since the Paleozoic, the Sabine Uplift has been a positive anomaly. This mid-rift horst is the result of tensional forces that are also responsible for the formation of the East
Texas Basin (Adams, 2009). During this time the study area was located at 10-15°N and rifting of the region resulted in steeply dipping normal faults throughout the East Texas Basin. This was a period of thermal uplift that resulted in sea level retreat that prompted deposition of the Werner Anhydrite, Louann Salt and the clastic sediments of the Norphlet. Thinning of inner shelf deposits of the Louann Group across the Sabine Uplift followed by shoaling facies in the Cotton Valley Lime on the western flank indicate a period of uplift during the Late Jurassic. The Sabine Uplift experienced no vertical movement from the Late Jurassic through the Early Cretaceous. During this time, a southeast sloping basin existed on top of the Sabine Uplift. In East Texas and North Louisiana, the presence of an angular unconformity indicates upwarping that occurred across the Sabine Uplift during the Late Albian. At the beginning of the Late Cretaceous, the Sabine Uplift began to slowly subside while maintaining elevation higher than the East Texas Basin (Jackson and Laubach, 1988). As the Late Cretaceous Austin Group was being deposited, regional subsidence of the Sabine Uplift combined with minor warping resulted in sea level fluctuations in the area. Sedimentation during this time was largely uninterrupted with the exception of minor hiatuses. As upwarping led to a minor fall in sea level, sands were deposited in the resulting shallow areas (Figure 2). These were likely the conditions in which the Santonian Blossom Sand was deposited (Rogers, 1968; Young, 1963).

As Gulfian deposition drew to a close, regional uplift resumed, causing sea level to retreat from the north. During the Early Cenozoic, the Sabine Uplift continued to rise
very slowly. The depositional environments at this time consisted of continental, lagoonal and likely deltaic settings. By the end of the Miocene, severe erosion over the Sabine Uplift removed overlying sediments down to the Wilcox Group (Rogers, 1968).

Figure 2. The study area during the Santonian (Modified from Blakey Maps, 2020). Shallow seas covered the area, resulting in fine to medium grain siliciclastic deposits across the area.
3. Stratigraphy

In Panola County, the Austin Group can be divided into four separate formations (Rogers, 1968). These formations include the Ector, Bonham Clay, Blossom Sand and the Brownstown Marl (Figure 3.). This study focuses on the Blossom Sand.

The Santonian Blossom Sand conformably overlies the Bonham Clay (Young, 1963; Rogers, 1968). These shallow marine sandstones range in thickness from 50 to 90 feet. This unit consists of greyish-green, medium to fine-grained, illitic, calcareous sandstones interbedded with dark green shales (Rogers, 1968). Though the Blossom Sand is sparsely fossiliferous, it is known to contain two genera of sharks and more than thirty species of mollusks. *Inoceramus deformis* and *Exogyra ponderosa* fossils are common mollusks, and fossilized teeth from sharks, *Corax* and *Otodus* are found in the Blossom Sand (Stephenson, 1918).
Figure 3. Stratigraphic Column of the Austin Group in Panola County, Texas.
4. Methodology

A combination of XRD, XRF, SEM, petrophysical analysis, and core analysis were used in this study to determine depositional and diagenetic history, along with controls on porosity and permeability. The primary source of data are five cores collected from Panola County, TX and archived in the East Texas Core Repository, Stephen F. Austin State University, Nacogdoches, TX (Table 1). The cores have a combined length of 216 feet. All five of the cores include butt ends, with one of the five containing an interval of seven slab packs.

Table 1. Details of the core used in this study.

<table>
<thead>
<tr>
<th>Core No.</th>
<th>API</th>
<th>Well Name</th>
<th>Top Depth (ft)</th>
<th>Bottom Depth (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>146</td>
<td>4236530251</td>
<td>No.3-A Gena Williamson</td>
<td>2026</td>
<td>2062</td>
</tr>
<tr>
<td>150</td>
<td>4236534070</td>
<td>Carthage Gas Unit No. 9-4A</td>
<td>1985</td>
<td>2044</td>
</tr>
<tr>
<td>151</td>
<td>4236534131</td>
<td>Carthage Gas Unit No. 9-5A</td>
<td>1986</td>
<td>2014</td>
</tr>
<tr>
<td>153</td>
<td>4236534412</td>
<td>No.1 Werner Smith</td>
<td>2058</td>
<td>2098</td>
</tr>
<tr>
<td>156</td>
<td>4236534711</td>
<td>Borders Smith No. 1-A</td>
<td>2010</td>
<td>2064</td>
</tr>
</tbody>
</table>
A detailed description of each core noted sedimentary structures, grain sizes, fossils and lithologies, which were used to determine the Blossom Sand’s depositional environment. Lithofacies were correlated across the five cores. Ten thin sections were made by National Petrographic to analyze grain size distribution, identify porosity types and sedimentary petrography. The thin sections were impregnated with blue epoxy to highlight porosity. The thin sections were analyzed using a Labomed Lx POL Polarizing microscope. Each thin section was analyzed under 400x magnification under cross polarized light and plane polarized light to observe primary and secondary porosity, verify mineralogy obtained by xrd, and observe relationships between minerals and pore spaces. To obtain grain size distributions, a photo of each thin section was taken under 400x magnification in cross polarized light. ImageJ was used to perform particle analysis with a 100 point count on each of the photos.

XRD was used to identify the bulk mineralogy on four samples. Sample prep followed Eberl (2008). The samples were run on a Bruker D8 Advance diffractometer with an angle range from 5° to 65° 2Θ, a step size of 0.02° 2Θ, 2 seconds per step, and a voltage/amp of 40 kV/40 mA. The resulting data was analyzed for mineral content and quantity using RockJock from the USGS (Eberl, 2008).

Trace elemental analysis was conducted using the Thermo Fisher Scientific Niton XL3t GOLDD+ XRF Analyzer. The device was set to the Test All Geo setting and used to sample each of the five cores at a resolution of four inches for a total of 180 seconds (30 seconds main, low and high each, and 90 seconds on light). Cores were rinsed with
deionized water, and measured down core, avoiding anomalies such as lone body fossils, and small concretions (<10 cm in diameter). The resulting geochemical data was processed in Excel. Areas containing abundances of Fe, Al and Mg were identified as areas of high clay content. Areas containing high concentrations of Ca were identified as areas of high calcite content.

Eleven plugs were extracted from the core to obtain porosity and permeability measurements by Stratum Reservoir, Houston, TX. Locations for the plugs were chosen based on the varying amount of clay minerals throughout the core that were identified from the geochemical data. The eleven plugs were taken from areas exhibiting high, moderate and low clay content. Samples were convection dried at 140°C. The porosity and permeability were then taken at a net confining stress of 800 psi, following protocols at Stratum Reservoir. The permeability measurements were corrected using the Klinkenberg method.

Sampling locations for SEM were chosen based on the concentration of Fe, Ca, Al, Si and Mg from the XRF data. To obtain higher quality images, chips of samples were coated with gold and vanadium to increase their conductivity. Using a JEOL Scanning Electron Microscope, SEM was conducted on four samples to help provide insight as to the origin of the glauconite and the order of events that occurred as diagenesis progressed within the Blossom Sand. These images displayed the orientation of the sand grains, clay minerals, pore spaces, and any other clays that were present.
5. Results

5.1 XRD

XRD results indicate the presence of primarily quartz, calcite, siderite, biotite, and illite in the Blossom Sand. The mineral composition is similar across the four samples. However, calcite is present only in the clean, well-cemented sections of sandstone (Figure 4-A), compared to the samples containing abundant clay minerals (Figure 4-B).

Table 2. Cores and depths from which XRD samples were taken.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Core Number</th>
<th>Depth (Ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>150</td>
<td>2012.07</td>
</tr>
<tr>
<td>2</td>
<td>153</td>
<td>2014.06</td>
</tr>
<tr>
<td>3</td>
<td>153</td>
<td>2029.04</td>
</tr>
<tr>
<td>4</td>
<td>150</td>
<td>2026.02</td>
</tr>
</tbody>
</table>
Figure 4. Diffractograms displaying the actual mineralogy of a (A) calcite cemented sandstone and (B) a sandstone containing no calcite with an abundance of authigenic illite. In the top right of each, are the actual samples from the core.
5.2 XRF
Ca, Fe, Al, and Mg were plotted with depth to observe variation in calcite (Ca) and illite (Fe, Al, Mg) content (Figure 5). In the plots for each core, it was noted that there were several depths at which Ca concentration increased, and concentrations of clay mineral components (Fe, A, Mg) decreased at these locations. Because few macrofossils were observed in the cores and only one Foraminfera was observed in thin section, high concentrations of Ca could not be attributed to calcite in body fossils. Therefore, depths with high concentrations of Ca were interpreted to be cemented with calcite.

5.3 Porosity and Permeability
To understand if porosity and permeability inhibition are linked to calcite cement or authigenic clays, samples for porosity and permeability testing were chosen based on the concentrations of Ca, Fe, Al and Mg. The resulting porosity and permeability data were plotted against Ca concentrations from the depths at which each individual sample for porosity and permeability was taken. The graphs for each display inversely proportional relationships between Ca and porosity as well as Ca and permeability (Figures 6 & 7). Regression statistics revealed an R² value of 0.84 for Ca-Porosity while Ca-Permeability resulted in an R² value of 0.11. The poor correlation with Ca and permeability is due to the wide range of permeability values, and the few points with extremely low permeabilities. The R² values indicate that calcite ultimately controls the porosity and permeability of the Blossom Sand.
Figure 5. Variation of calcite (Ca) and illite (Fe, Al, Mg) with depth for an example core.
Figure 6. Relationship between calcium content and permeability in the Blossom Sand.

Figure 7. Relationship between calcium content and porosity in the Blossom Sand.
5.4 SEM

The SEM images display minerals and pore spaces that coincide with the findings from the porosity and permeability data. Figure 8 displays a calcite cemented interval (Figure 8(A)) compared to an illite cemented interval (Figure 9 (B)) at similar magnifications. In Figure 8 (A), the pore spaces between the calcite and chlorite are approximately 1-10 µm wide. Conversely, Figure 8 (B) displays a pore space typical of the illite cemented sandstones of the Blossom Sand. Even with considerable illite precipitated around each sand grain, the pore spaces are approximately 100 µm wide. In addition to supporting the porosity and permeability data, clay minerals that formed prior to the beginning of diagenesis are displayed as pellets that have undergone ductile deformation as the sands started to compact. Authigenic clays are displayed as groups of thin platelets and fibrous clusters that formed between the compacted sand grains. Fecal pellets often display ductile or brittle deformation that occurred as a result of physical compaction of the sands (Figure 10). The SEM also showed chlorite (Figure 8-A) and kaolinite (Figure 9), whose concentrations were too low to be detected by the XRD.
Figure 8. SEM images of the Carthage Gas Unit No.9-4A. (A) Calcite cemented sandstone at 2011.92 feet. (B) Pore space between three sand grains coated with fibrous crystals typical of authigenic clays from a sandstone with no calcite from 2016.62 feet.

Figure 9. A pore space obstructed by kaolinite from a calcite cemented sandstone at 2011.92 ft in the Carthage Gas Unit No.9-4A.
According to the particle analyses conducted on the thin sections, the grain size of the Blossom Sand varies from 1-7 \( \phi \) (Figure 12). Due to the excess of fine silt found in the Blossom Sand, the histogram displays the sediments of this formation as slightly negatively skewed (Figure 11).

Figure 10. A fecal pellet deformed during compaction.
Figure 11. Grain size distribution of the Blossom Sand.
5.5 Thin Sections

Figure 12. Thin Section A at 400x magnification under cross polarized light. Thin section A is from a calcite cemented sandstone at 2012 feet in the Carthage Gas Unit No.9-4A

Figure 12 is a quartz arenite and has an average grain size of 3.9 φ. The clasts found in this sample are subrounded to well-rounded and are moderately sorted (Figure 12, 13). Point counts indicate that this thin section is composed of 42% quartz grains, 1% chalcedonic quartz, 9% pellets and 35% calcite cement. SEM images display biotite and kaolinite clays in this sample as well. This sample has undergone mechanical compaction likely from the gradual addition of overlying sediments. Most sand grains are very close
together and touching at least one other. Additionally, the pellets display ductile deformation from being compressed between the harder quartz and chalcedonic quartz sand grains.

Figure 13. Composition of sample A places it within quartz arenite of the modified Dott classification noted by a red star, after Pettijohn et al., (1987).
The quartz wacke found at 2016 in the Carthage Gas Unite No. 9-4A well has an average grain size of 3.9 $\phi$. The clasts found in this sample are angular to subrounded and are well sorted. The sandstone displayed in this thin section is composed of 61% quartz, 1% chalcedonic quartz, 4% pellets, 2% hematite and 25% matrix. This sample has undergone a considerable amount of mechanical compaction as most of the pellets display ductile deformation and the quartz and chalcedonic quartz grains are closely compacted (Figure 14, 15).
Figure 15. Composition of sample B places it within quartz wacke of the modified Dott classification noted by a red star, after Pettijohn et al., (1987).
The quartz wacke from 2022 feet from the Carthage Gas Unit No. 9-4A well has an average grain size of 1.2 φ (Figure 16, 17). The clasts found in this sample are angular to subrounded and well sorted. The sandstone displayed in this thin section is composed of 50% quartz, 10% chalcedonic quartz, 8% pellets 13 hematite and 16% matrix. This sample is very well compacted as there is very little to no space between grains and pellets display ductile deformation from being compressed amongst quartz grains. There is secondary porosity exhibited by the fractures in the reddish-brown detrital clays.
Figure 17. Composition of sample C places it within quartz wacke of the modified Dott classification noted by a red star, after Pettijohn et al., (1987).
Figure 18. Thin Section D at 400x magnification under cross polarized light. Thin section D is from a sandstone at 2037 feet from the Carthage Gas Unit No. 9-4A.

The quartz wacke from 2037 feet has an average grain size of 4 φ (Figure 18, 19). The clasts found in this sample are subangular to subrounded and are moderately sorted. The sandstone displayed in this thin section is composed of 44% quartz, 11% chalcedonic quartz, 2% pellets and 43% matrix. This sample is very well compacted as there is little to no space between grains, and pellets display ductile deformation from being compressed between quartz grains.
Figure 19. Composition of sample D places it within quartz wacke of the modified Dott classification noted by a red star, after Pettijohn et al., (1987).
Figure 20. Thin Section E at 400x magnification under cross polarized light. Thin section E is from a calcite cemented sandstone at 2043 feet from the Carthage Gas Unit No. 9-4A.

The quartz arenite from 2043 feet from the Carthage Gas Unit No. 9-4A well has an average grain size of 5.5 φ. The clasts found in this sample are angular to subrounded and are poorly sorted. The sandstone displayed in this thin section is composed of 53% quartz, 3% chalcedonic quartz, 13% pellets and 32% calcite and siderite cement. This sample is very well compacted both chemically and mechanically. The pellets display signs of ductile deformation from being compressed between quartz grains and the lack of porosity is due to calcite and siderite filling former pore spaces (Figure 20, 21).
Figure 21. Composition of sample E places it within quartz arenite of the modified Dott classification noted by a red star, after Pettijohn et al., (1987).
Figure 22. Thin Section F at 400x magnification under cross polarized light. Thin section F is from a section of a siltier wavy bedded sandstone at 2011 feet from the No.1 Werner Smith.

The quartz wacke from 2011 feet from the No. 1 Werner Smith well has an average grain size of 4.1 $\phi$ (Figure 22, 23). The clasts found in this sample are subangular and are moderately sorted. The sandstone displayed in this thin section is composed of 62% quartz, 3% pellets, and 35% matrix. This sample is very well compacted as there is little to no space between grains, and pellets display ductile deformation from being compressed between quartz grains. There is some secondary porosity exhibited by the fractures in the reddish-brown detrital clays.
Figure 23. Composition of sample B places it within quartz wacke of the modified Dott classification noted by a red star, after Pettijohn et al., (1987).
Figure 24. Thin Section G at 400x magnification under cross polarized light. Thin section G is from a sandstone at 2026 feet from the No.1 Werner Smith.

The quartz arenite from 2026 feet from the No. 1 Werner Smith has an average grain size of 5.5 φ (Figure 24, 25). The clasts found in this sample are subrounded to well rounded and are well sorted. The sandstone displayed in this thin section is composed of 30% quartz, 2% chalcedonic quartz, 20% pellets, 3% plagioclase, 45% calcite cement. This sample has undergone less mechanical compaction compared to our other sands as few of the pellets display ductile deformation and the quartz and chalcedonic quartz grains are close together without being tightly compacted. A considerable amount of the porosity is secondary via dissolution of what appears to have been feldspar (Figure 18).
Figure 25. Composition of sample G places it within quartz arenite of the modified Dott classification noted by a red star, after Pettijohn et al., (1987).
The quartz wacke from 2028 feet from the No. 1 Werner Smith has an average grain size of 5.7 $\phi$ (Figure 26, 27). The clasts found in this sample are angular to subangular and are poorly sorted. The sandstone displayed in this thin section is composed of 51% quartz, 3% chalcedonic quartz, 4% pellets, 4% plagioclase, and 38% matrix. This sample is very well compacted. The pellets display signs of ductile deformation from being compressed between quartz grains. There is secondary porosity exhibited by the fractures in the red-ish brown detrital clays (Figure 19).
Figure 27. Composition of sample B places it within quartz wacke of the modified Dott classification noted by a red star, after Pettijohn et al., (1987).
The quartz wacke from 2037 feet from the No.3-A Gena Williamson well has an average grain size of 18 $\phi$ (Figure 28, 29). The clasts found in this sample are angular to subangular and are poorly sorted. The sandstone displayed in this thin section is composed of 54% quartz, 2% chalcedonic quartz, 2% pellets, 42% matrix. This sample is very well compacted. The pellets display signs of ductile deformation from being compressed between quartz grains.
Figure 29. Composition of sample I places it within quartz wacke of the modified Dott classification noted by a red star, after Pettijohn et al., (1987).
Figure 30. Thin Section J at 400x magnification under cross polarized light. Thin section J is from a wavy bedded sandstone at 2059 feet from the Borders Smith No.1-A.

The quartz arenite from 2059 feet from the Borders Smith No.1-A well has an average grain size of 5.6 ɸ. The clasts found in this sample are subangular to subrounded and are poorly sorted. The sandstone displayed in this thin section is composed of 55% quartz, 13% chalcedonic quartz, 4% pellets, 2% plagioclase, and 24% calcite cement. This sample is very well compacted. The pellets display signs of ductile deformation from being compressed between quartz grains. Due to precipitation of calcite, this samples exhibits little to no porosity (Figure 30, 31).
Figure 31. Composition of sample J places it within quartz arenite of the modified Dott classification noted by a red star, after Pettijohn et al., (1987).
5.6 Core Descriptions

The Blossom Sand contains two major sandstone facies (Figure 34). The first is wavy bedded sandstone that is composed of alternating layers of fine sand and thinner layers of clay (Figure 34-B). The second sandstone facies is composed of fine sandstones that display faint planar lamination (Figure 34-A). The thin sections from the areas that display wavy bedding showed the most detrital clays (Figure 35-C). The wavy bedding seen in these sandstones is often severely deformed by intense bioturbation. The thin sections from the cleanest sands displayed the most authigenic illite and calcite cement (Figure 35-A&B). The wavy bedding indicates a bidirectional current influenced by tidal fluctuations while the planar lamination is indicative of multidirectional combined flows. Valves belonging to shallow marine bivalves, Inoceramus sp. and Exogyra sp. were found in the cores over the course of this study. The presence of these bivalves indicates that the Blossom Sand would have been deposited in a shallow marine environment in normal marine salinity. Ichnofossils observed in the cores include extensive burrows and casts and molds of bivalves.
Figure 32. The descriptions of the four cores used in this study. The Blossom Sand is flattened on its contact with the overlying Brownstown Marl. Lithofacies correlations of the Blossom Sand showing the depths at which calcite cement occurs according to the Ca curves derived from the XRF data.

The flooding surfaces found in the cores do not correlate well with one another (Figure 32). Though it should be noted that core 150 and 153 are missing several feet of
core that could contain another flooding surface. The thicknesses of the sands between the flooding surfaces also vary significantly for which the missing sections could also be responsible. Regardless of missing sections, there is one consistent flooding surface in red that appears in four of the cores that could indicate the last large-scale flooding event before the one that ended Blossom Deposition and began deposition of the Brownstown Marl.
Figure 33. The descriptions of the four cores used in this study. The Blossom Sand is flattened on its contact with the overlying Brownstown Marl. Correlations of wavy bedded sandstones and planar bedded sandstones. Flooding surfaces are denoted with the purple arrows. Purple arrows outlined in read denote the only consistent flooding surface found in the cores.
The inconsistencies in subsequent flooding surfaces could indicate that core 150 and 153 would have received a more consistent sediment supply than the other cores. The consistent sediment supply could have come from the output of a nearby river delta indicating that the sediments of the Blossom could be deltaic sands.

Figure 34. Core of the Blossom Sand from the Carthage Gas Unit No.9-4A displaying planar bedding (A) and wavy bedding altered by bioturbation (B).
Figure 35. Core from the Carthage Gas Unit No.9-4A with photos of thin sections under 40x magnification in cross polarized light. Pel indicates pellets, Q indicates quartz, CC indicates calcite cement, AC indicates authigenic clay, DC indicates detrital clay. (A) calcite cemented sandstone, (B) planar bedded sandstone with authigenic illite and (C) wavy bedded sandstone with reddish brown detrital clays.
6. Discussion

6.1 Clay Mineralogy

Contrary to previous research, there is no detectable glauconite in the Blossom Sand amongst any of the XRD results. No peaks in any of the diffractograms were comparable to glauconite spectra at low 2θ. The long, fibrous crystals of illite seen coating the sand grains in the SEM indicate that the green hue that inspired previous researchers’ interpretation of glauconite can instead be attributed to illite (Figure 8-B), combined with no detectable amounts of glauconite in the XRD (Figure 4). The illite in this formation appears to be authigenic and not detrital because it is displayed as fibrous crystals that coat sand grains and deformed fecal pellets (Figures 8-B, 10 & 14-B). The illite also would have been precipitated after deposition and compaction as it does not display any deformation due to compaction (Figures 8-B). Some models indicate that glauconitization favors environments with low sedimentation rates while illite prefers low sedimentation rates and hypersaline environments (Meunier and El Albani, 2007), while others suggest that the occurrence of glauconite depends on diffusion of K ions (Meunier and El Albani, 2007). This study found that the Blossom Sand has porosity and permeability that would allow for adequate diffusion rates. The lack of glauconite in this formation could be attributed to low concentrations of K in the pore waters. However,
conditions that are believed to favor glauconitization or illite precipitation continue to be highly disputed.

![Diagenetic model of the Blossom Sand](image)

Figure 36. Diagenetic model of the Blossom Sand displaying deposition of sands and calcareous organisms followed by precipitation of illite and finally precipitation of calcite.

6.2 Depositional Environment and Diagenesis

The grain sizes, sedimentary structures, fossils and bioturbation found in the core indicate that these sandstones were deposited in two separate shallow marine settings in normal marine salinity. The wavy bedding and such intense bioturbation in the muddy sands of this formation point to a depositional setting depositional setting that would have experienced bidirectional flow, fluctuating currents and sediment supply such as a lower shoreface (Figure 34-B). The lower shoreface would have been far enough below fair-weather wave-base for deposition of detrital clays. The faint planar bedding exhibited by the coarser, cleaner sands would have been deposited in much shallower waters such as those of the foreshore (Figure 34-A). A depositional setting on the upper shoreface would
have supplied the higher flow velocity and multidirectional flow necessary to form planar bedding and work out any detrital clays to be deposited in the offshore transition. Here, bivalve organisms like *Inoceramus* sp. and *Exogyra* sp. would have flourished. Following their burial, they would have begun dissolution in the pore fluids. Once the pore fluids became saturated, calcite would have begun exsolving from the pore fluids and precipitating in the voids between the sands and pellets (Figure 36). Since the calcite cement is not laterally continuous and instead occurs in lenses, the pore fluids likely became saturated before they could transport the dissolved calcite any considerable distance.

6.3 Controls on Porosity  
Calcite cement appears to be the controlling factor on porosity and permeability throughout the formation, rather than precipitation of clay minerals (Figures 7 & 8). The presence of casts and molds and abundance of trace fossils in the Blossom Sand suggests that the calcite cement is the result of dissolution and redistribution of local biogenic carbonates. The depths at which the calcite cement occurs are not continuous through all of the cores (Figure 32), which suggests that the calcite cemented intervals are not laterally continuous. The lack of support for lateral continuity indicates that the Blossom Sand is divided into compartments of high porosity and permeability that are separated from one another by the calcite cement.
7. Conclusions

The Blossom Sand was found to exhibit very high porosities and permeabilities constrained primarily by calcite cement. The calcite cement was found to lack lateral continuity and was found to occur in lenses instead. Combined with the sparse fossils of the Blossom Sand, the lenticular behavior indicates that the calcite cement is the result of dissolution of local calcareous organisms and precipitation of calcite. Though it is uncommon, in thin sections where calcite is seen in conjunction with illite, calcite is seen precipitated around the fibrous illite crystals which indicates that the illite would have begun nucleation on the sands and pellets prior to calcite dissolution, redistribution and precipitation (Figure 37).
Figure 37. Illite precipitated around sand grains in a calcite cemented sandstone at 400x magnification under cross polarized light.
As indicated by the XRD results, this study found that the long believed glauconitic sandstones of the Blossom Sand were found instead to be illitic sandstones. Though the Blossom Sand contains bright green fecal pellets, the pore fluids evidently either did not contain enough K to alter them to the glauconite typically seen in green fecal pellets or the flow rate through the formation was not adequate for the diffusion of K. As a result, the pellets instead were altered to illite.

The Blossom Sand was found to be the deposits of nearshore to foreshore environments. The wavy bedding indicated that the muddy sands of Blossom Sand were deposited in a nearshore setting while the planar bedding of the cleaner sands indicated that they were deposited under the higher velocities of the foreshore. In each of these environments, they hosted a variety of marine fauna including bivalves and extensive burrowers.
8. References


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Stephenson, L. W., 1918, A Contribution to the Geology of Northeastern Texas and Southern Oklahoma: Shorter Contributions to General Geology: USGS, v. 120, p. 129-163.


Appendices

Appendix A – XRF Graphs

Figure 37. XRF data from core 156.
Figure 38. XRF data from core 151.
Figure 39. XRF data from core 146.
Figure 40. XRF data from core 150.
Appendix B – XRD Spectra

Figure 41. Diffractogram from core 153 (No.1 Werner Smith) displaying mineralogy found at the 2014.06 ft.
Figure 42. Diffractogram from core 150 (Carthage Gas Unit No.9-4A) displaying mineralogy found at the 2026.02 ft.
Appendix C – Porosity and Permeability Data

Table 3. Porosity and permeability data from 12 plugs from the cores. Porosity was measured at a net confining stress (NCS) of 800 psi. Permeability was adjusted with the Klingenberg method.

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Appendix D – Raw XRF Data

Table 4. Raw XRF data derived from the Carthage Gas Unit No.9-4A at a sampling interval of 4 inches. Elemental concentrations in parts per million.

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Appendix E - Particle Analysis Data

Table 9. Grain size derived from particle analyses on each thin section.

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Appendix F-Point Count Data

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Thin Section D: Carthage Gas Unit No.9-4A, 2037 ft

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Thin Section G: Werner Smith No.1-A, 2026 ft
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Appendix G – Core Descriptions
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<td>Wavy bedding</td>
<td>Burrows</td>
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<td>siderite nodules and steaks</td>
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<td>random calcite cement</td>
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<td>Burrows</td>
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<td>calcite cement, siderite, lots of pellets</td>
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Table 21. Core description of the No.3-A Gena Williamson.

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<td>I 'spot with calcite cement</td>
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<td>still pretty homogenous aside from a burrow or two</td>
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No.3-A Gena Williamson
Table 22. Core description of the Werner Smith No.1-A.

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Table 23. Core description of the No.1 Borders Smith.

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Table 24. Core description of the Carthage Gas Unit No.9-5A.

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<td>Fossils</td>
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<td>Notes</td>
<td>Formation</td>
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Appendix H– Stratigraphy of the Austin Group

The lowermost of these formations is the Early Coniacian Ector. This formation consists of chalk deposited on a shallow marine inner shelf (Pearson, 2012; Rogers, 1968; Young, 1963). While clean chalk is the primary component of the Ector, it is interbedded with brown to grey, fissile shales as well as shaly, glauconitic chalks containing *Gryphaea aucella* and *Radiolites austinensis* fossils (Rogers, 1968).

The Late Coniacian to Early Santonian offshore shales of the Bonham Clay conformably overly the Ector (Rogers, 1968; Young, 1963). This 150 to 200 feet thick formation is primarily composed of fissile shales, and grey, calcareous shales. Interbedded with the primary lithologies of the Bonham Clay are beds of medium to fine-grained glauconitic sandstones (Rogers, 1968). The Bonham Clay contains *Inoceramus*, *Ostrea congesta*, *Baculites asper*, and *Gryphaea aucella* fossils (Stephenson, 1918).

The uppermost formation of the Austin Group is the Late Santonian to Early Campanian Brownstown Marl that conformably overlies the Blossom Sand (Rogers, 1968; Young, 1963). This unit can be as thick as 155 feet. The uppermost section of the Brownstown Marl is composed of offshore marls followed by grey, fissile, calcareous shales, which can be locally fossiliferous (Rogers, 1968). Fossils found in the Brownstown Marl include primarily bivalve mollusks such as *Exogyra ponderosa*, *Turritella quadrilla*, and *Paranomia scabra* (Stephenson, 1918). The primary sediments of this formation are interbedded with lenses of fine grained, glauconitic, calcareous sandstones, as well as brown sandy shales (Rogers, 1968).
Appendix I – Detailed Methods

A combination of XRD, XRF, SEM, petrophysical analysis, and core analysis were used in this study to determine depositional and diagenetic history, along with controls on porosity and permeability. The primary source of data are five cores collected from Panola County, TX and archived in the East Texas Core Repository, Stephen F. Austin State University, Nacogdoches, TX (Table 1). The cores have a combined length of 216 feet. All five of the cores include butt ends, with one of the five containing an interval of seven slab packs.

A detailed description of each core noted sedimentary structures, grain sizes, fossils and lithologies, which were used to determine the Blossom Sand’s depositional environment. Lithofacies were correlated across the five cores. Ten thin sections were made by National Petrographic to analyze grain size distribution, identify porosity types and sedimentary petrography. Locations for thin sections were chosen based on XRD and XRF data. The thin sections were impregnated with blue epoxy to highlight porosity. The thin sections were analyzed using a Labomed Lx POL Polarizing microscope.

To obtain grain size distributions, a photo of each thin section was taken under 400x magnification in cross polarized light. ImageJ was used to perform particle analysis and point counting on each of the photos. The scale was set in each photo and using the gridding tool, 500 points were placed on the images. At each point the mineralogy was noted which helped to identify accessory minerals whose percentages would have been
too inadequate to have been recognized by the XRD. The grids were removed from the images that were then converted to a 16-bit image. The converted images were then processed to highlight individual grains to make polygons that could be measured for area in square millimeters. Each image yielded areas for approximately 500 polygons. The areas were uploaded into Excel where the square root was taken for each measurement to obtain grain sizes in mm which were then converted to $\phi$ scale. Each thin section was analyzed under 400x magnification under cross polarized light and plane polarized light to observe primary and secondary porosity and any secondary minerals precipitated in pore spaces that were seen constricting porosity.

XRD was used to identify the bulk mineralogy on four samples. Samples for XRD were chosen based on lithologic changes, and sample prep followed Eberl (2008). The samples were ground using a porcelain mortar and pestle and then sieved using a 250 $\mu$m mesh sieve. Two grams of the sieved sample were added to 0.5 grams of ground corundum. The combined sample and corundum were milled in a McCrone Micronizing mill along with 5 ml of isopropyl alcohol for five minutes. The sample was placed into an oven at 80°C for 24 hours or until all of the isopropyl alcohol evaporated. The dried sample was gently ground back into a powder using an agate mortar and pestle, and placed into a test tube with 0.5 ml of hexane and shaken for ten minutes. Afterward, the sample was sieved once more using a 250 $\mu$m sieve. The sample was placed into a custom side-loading holder, with a piece of plexiglass with 600 grit sandpaper affixed to the opening. The samples were run on a Bruker D8 Advance diffractometer with an angle
range from 5 to 65 2Θ, a step size of 0.02 2Θ, 2 seconds per step, and a voltage/amp of 40 kV/40 mA. The resulting data was analyzed for mineral content and quantity using RockJock from the USGS (Eberl, 2008).

Trace elemental analysis was conducted using the Thermo Fisher Scientific Niton XL3t GOLDD+ XRF Analyzer. The device was set to the Test All Geo setting and used to sample each of the five cores at a resolution of four inches for a total of 180 seconds (30 seconds main, low and high each, and 90 seconds on light). Prior to sampling, any debris on the core was brushed off and each core was rinsed with deionized water and dried overnight. To ensure that measurements properly represented the lithologies and minerals present in any given location, anomalies such as lone body fossils, and small concretions (<10 cm in diameter) were avoided. A specific location was recorded for each reading to reference at any later time. The resulting geochemical data was processed in Excel. Areas containing abundances of Fe, Al and Mg were identified as areas of high clay content. Areas containing high concentrations of Ca were identified as areas of high calcite content. Having determined the clay and calcite content throughout the core, locations were chosen for porosity and permeability measurements to be taken.

Eleven plugs were extracted from the core to obtain porosity and permeability measurements by Stratum Reservoir, Houston, TX. Locations for the plugs were chosen based on the varying amount of clay minerals throughout the core that were identified from the geochemical data. The eleven plugs were taken from areas exhibiting high, moderate and low clay content. Samples were convection dried at 140°C. The porosity
and permeability were then taken at a net confining stress of 800 psi, following protocols at Stratum Reservoir. The permeability measurements were corrected using the Klinkenberg method.

Sampling locations for SEM were chosen based on the concentration of Fe, Ca, Al, Si and Mg from the XRF data. To obtain higher quality images, chips of samples were coated with gold and vanadium to increase their conductivity. Using a JEOL Scanning Electron Microscope, SEM was conducted on four samples to help provide insight as to the origin of the glauconite and the order of events that occurred as diagenesis progressed within the Blossom Sand. These images displayed the orientation of the sand grains, clay minerals, pore spaces, and any other clays that were present.
Vita

Hannah Chambers is a graduate of Mississippi State University where she received her B.S. in geology in 2019. Hannah is currently a graduate student at Stephen F. Austin State University where she will graduate with an M.S. in geology in May 2021. Her thesis research focuses on defining the depositional environment and diagenetic features of the Blossom Sand in Panola County, Texas. Hannah is a member of AAPG and SGE and is recognized as a Geologist-In-Training by the Mississippi Board of Registered Professional Geologists.

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This thesis was typed by Hannah C. Chambers in accordance with GSA guidelines