FACIES AND DIAGENESIS ANALYSES OF THE FORT TERRETT FORMATION OF THE LOWER CRETACEOUS EDWARDS GROUP, NEAR JUNCTION, TEXAS

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FACIES AND DIAGENESIS ANALYSES OF THE FORT TERRETT FORMATION OF THE LOWER CRETACEOUS EDWARDS GROUP, NEAR JUNCTION, TEXAS

By

Richard A Urwin Jr, Bachelor of Science

Presented to the Faculty of the Graduate School of

Stephen F. State University

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FACIES AND DIAGENESIS ANALYSES OF THE FORT TERRETT FORMATION OF THE LOWER CRETACEOUS EDWARDS GROUP, NEAR JUNCTION, TEXAS

By

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ABSTRACT

The Fort Terrett Formation was deposited on the western edge of the Comanche Shelf in central Texas. The predominating lithology of the Fort Terrett Formation is limestone which caps the hills that surround Junction, Texas. Deposition of the Fort Terrett Formation occurred within shallow, quiet waters during the Lower Cretaceous. Rose (1974) developed a general stratigraphic correlation and lithostratigraphic framework for the Cretaceous Shelf and established a regional correlation. Four stratigraphic divisions have been recognized in the Fort Terrett Formation. These are: a basal nodular unit, a burrowed unit, a dolomitic unit, and the Kirschberg evaporites. Wilkerson (2018) provided the addition of the Walnut Formation as part of the local stratigraphy. However, both the Walnut Formation and Kirschberg evaporites have been omitted from the local stratigraphy. In the Junction area, measured sections by Rose (1972) of the Fort Terrett Formation contain the lower two units which are the burrowed unit, distinguishable by bioturbation, and the basal nodular unit. Nine sections of the Fort Terrett Formation were measured along road cuts on I-10 near Junction, Texas and hand samples collected. This data was used to divide the Fort Terrett Formation into three lithostratigraphic units. The lower unit
contained thick-bedded limestone representing an open marine carbonate platform. The middle unit contains extensive chert nodules and fossils that indicate intertidal to subtidal facies. The upper unit contains thick bedded limestone with dolomite indicating shallow intertidal facies. This study has divided the Fort Terrett Formation into 6 facies in the Junction area to determine depositional environment. Diagenesis of the Fort Terrett Formation is complex ranging from shallow marine diagenesis, burial, hydrothermal, and telogenesis. Dolomitization of the Fort Terrett is also the focal point of several previous study. This study is to provide a new perspective on late stage dolomitization by burial and hydrothermal activity.
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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>i</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>iii</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>v</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>vi</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>vii</td>
</tr>
<tr>
<td>CREATACEOUS GEOLOGIC ELEMENTS</td>
<td>v</td>
</tr>
<tr>
<td>STRATIGRAPHY OF JUNCTION AREA</td>
<td>1</td>
</tr>
<tr>
<td>HENSEL FORMATION</td>
<td>12</td>
</tr>
<tr>
<td>GELN ROSE FORMATION</td>
<td>17</td>
</tr>
<tr>
<td>FORT TERRETT FORMATION</td>
<td>20</td>
</tr>
<tr>
<td>SEGOVIA FORMATION</td>
<td>21</td>
</tr>
<tr>
<td>STUDY AREA</td>
<td>25</td>
</tr>
<tr>
<td>METHODOLOGY</td>
<td>26</td>
</tr>
<tr>
<td>STRATIGRAPHIC ANALYSIS</td>
<td>31</td>
</tr>
<tr>
<td>BASAL UNIT</td>
<td>33</td>
</tr>
<tr>
<td>THIN BED UNIT</td>
<td>36</td>
</tr>
<tr>
<td>DOLOMITIZED UNIT</td>
<td>38</td>
</tr>
<tr>
<td>PETROGRAPHIC ANALYSES</td>
<td>41</td>
</tr>
<tr>
<td>FACIES ANALYSES</td>
<td>44</td>
</tr>
<tr>
<td>SPARSE BIOMICRITE (F1)</td>
<td>48</td>
</tr>
<tr>
<td>DOLOMITIZED SPARSE BIOMICRITE (F2)</td>
<td>50</td>
</tr>
<tr>
<td>BIVALVE PACKED BIOMICRITE (F3)</td>
<td>53</td>
</tr>
<tr>
<td>PELOIDAL MICROSPAR (F4)</td>
<td>56</td>
</tr>
<tr>
<td>POROSITY RICH SPARSE BIOMICRITE (F5)</td>
<td>58</td>
</tr>
<tr>
<td>DOLOMITIZED MICRITIE (F6)</td>
<td>60</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

Figure 1. Interior seaway of the Zuni sequence during Albian time (modified from Blakey, 2013).................................................................................................................................................. 5

Figure 2. The interior seaway is regressing during very late Albian time (modified from Blakey, 2013)........................................................................................................................................... 6

Figure 3. Regional deposition of Lower Edwards carbonates (modified from Rose, 1972).................................................................................................................................................................. 7

Figure 4. A simplified stratigraphic column of the Comanche Shelf. (modified from Phelps 2013)................................................................................................................................................ 8

Figure 5. Surface and subsurface correlations of the Edwards Group (modified from Rose, 1972)...................................................................................................................................................... 14

Figure 6. The generalized stratigraphic column of the Lower Cretaceous Group near Junction, Texas (from Wilkerson, 2018)......................................................................................................... 15

Figure 7. The general lithostratigraphy for the study area near Junction, ........................................ 16

Figure 8. A paleogeographic representation of depositional systems in Texas of the Trinity Group (from Payne 1982)................................................................................................................... 19

Figure 9. Diagram of diagenetic features of the depositional environments within the Fort Terrett Formation (Trabelsi 1984). .................................................................................................................. 24

Figure 10. Regional extent of the Cretaceous age Fort Terrett Formation (Kft) where it outcrops in Texas (Wilkerson 2018)......................................................................................................... 28
Figure 11. Geologic map of Kimble County, Texas. This map outlines the geologic formations that outcrop in Kimble County (modified from Wilkerson 2018).......................... 29

Figure 12. Map showing the locations of the 9 measured sections used for the purpose of this thesis.................................................................................................................. 30

Figure 13. The three mapped units in the study area per the USGS geologic formations map.......................................................................................................................... 34

Figure 14. General lithostratigraphic section of the Fort Terrett Formation near Junction, Texas. ..................................................................................................................... 35

Figure 15. This outcrop shows the conformable surface between the basal unit and the thin bed unit in the study area.......................................................................................... 37

Figure 16. This outcrop shows a visual representation of the thin bed unit in the study area.............................................................................................................................. 39

Figure 17. This outcrop shows the conformable surface between the Basal unit and the thin bed unit in the study area.......................................................................................... 40

Figure 18. This outcrop shows the surface between the thin bed unit and the dolomitized unit in the study area............................................................................................... 42

Figure 19. Sedimentary features observed in hand samples collected at various road cuts................................................................................................................................. 43

Figure 20. This figure shows a detailed stratigraphic column of the Fort Terrett Formation. The Fort Terrett Formation is split into 3 lithostratigraphic units (Basal unit, thin bed unit, and the dolomitized unit). Those three units are then split into 6 facies (F1, F2, F3...Etc.). Fossils and key features for each facies are also displayed............................................. 46

Figure 21. The legend used for the detailed stratigraphic column in Figure 20 ............. 47
Figure 22. This thin section represents F1 and is a sparse biomicrite. Allochems are common but are not the primary makeup of the matrix. .......................................................... 49

Figure 23. Represents F2 and is inferred as a dolomitized sparse biomicrite. .................. 52

Figure 24. This thin section represents F3 and the second facies of the thin bed unit. Petrography analysis of F3 shows a packed biomicrite within an intertidal to shallow subtidal environment. .................................................................................. 54

Figure 25. This thin section represents the chert nodules found in F3. Chert nodules observed in F3 also display dissolution with splays of megaquartz filling the voids. ....... 55

Figure 26. This thin section shows F4 which is the first facies of lithostratigraphic the dolomitized unit and is interpreted as an intertidal to subtidal facies. Petrographic analysis shows a poorly washed biosparite with a significant lack of biodiversity. There are also no indications of dolomite with very little micrite. ....................................................... 57

Figure 27. This thin section shows a sparse biomicrite from F5 and is the next facies in the dolomitized unit. This facies is interpreted as a subtidal facies. F5 is similar to F4, however, there is a complete lack of calcite spar within the matrix.............................. 59

Figure 28. This thin section shows a dolomitized sparse biomicrite of F6. F6 is the last facies of the upper part of the dolomitized unit. This facies is described was interpreted to be an intertidal to supratidal depositional environment where dolomite is very dominate within the matrix. .................................................................................. 61

Figure 29. This is a model for diagenesis for the fort Terrett Formation. This model illustrates when significant events occurred................................................................. 63

Figure 30. This thin section shows a thin micritic envelope around an allochem which suggest shallow marine diagenesis................................................................. 66

Figure 31. This thin section shows a gastropod surrounded by bivalves and peloids. Allochems in this thin section have micritic envelopes indicating shallow marine diagenesis. .................................................................................. 67
Figure 32. This thin section shows a bioturbated bivalve shell with micrite filling the pore space. These burrows are not as complete around the rim of other allochems but still illustrate how algal microboring are infilled with micrite. ................................................................. 68

Figure 33. This thin section shows a dissolved bivalve shell filled in with drussy mosaic calcite. This is representative of selective dissolution and is also responsible dissolution of select allochems ................................................................................................................. 69

Figure 34. This thin section shows F4 which is a microspar facies. Allochems are completely removed from this facies and only the “ghost” remnants of those allochems remain. These allochems were selectively dissolved later after the precipitation of the microspar........................................................................................................................................... 70

Figure 35. This thin section shows a broken bivalve which suggests light to moderate compaction occurred. Burial diagenesis is evident by fractures, broken allochems that aren’t imbricated, and styolites. ........................................................................................................................................... 73

Figure 36. This thin section shows a fracture though a sparse biomicrite infilled with calcite and silica. ..................................................................................................................................................... 74

Figure 37. This thin section shows a chert thin section where no sponge spicules or radiolarians were found, which suggests that the chert nodules in the Fort Terrett Formation are of an inorganic origin. ........................................................................................................................................... 75

Figure 38. This thin section shows dolomite as a primary cement in F6 of the Fort Terrett Formation. This type of dolomization is evident of saddle dolomite that occurs during late stage diagenesis........................................................................................................................................................................ 77

Figure 39. This thin section shows a chalcedony filled pore space. .................................................. 78

Figure 40. This thin section shows an allochem surrounded by oxide cementation. This suggests fresh water flushing dissolved the rim of the bivalve shell which allowed for oxide rich waters to fill the void space................................................................. 81
Figure 41. This thin section shows selective dissolution of a millioid with high Mg calcite precipitating around the rim. High mg calcite is distinguished by the powdery white color. Some crystals exhibit a slight reddish hue, indicating the Alizeran Red staining is not as effective on high Mg calcite ................................................................. 82

Figure 42. This thin section shows iron staining which indicates telogenesis occurring on the Fort Terrett Formation. Iron rich waters infiltrated facies during exposure and left behind iron staining that was either dark brown or orange.............................................. 83

Figure 43. These thin sections shows vuggy dissolution that occurred during telogenesis. Both thin sections shown have enhanced porosity that occurred after the exposure of the Fort Terrett Formation........................................................................ 84

Figure 44. These thin sections shows dolomite observed during the petrographic analysis. Two types of dolomite are seen and are described as euhedral, having rhombic crystal habits in F2 or xenotopic, infilling much of the void space as a cement in F6...... 97

Figure 45. This thin section shows moldic porosity within a bivalve shell. This is significant for the reflux model due to the enhanced porosity by dissolution................. 98

Figure 46. This thin section shows euhedral, planar dolomite in micrite matrix with overgrowth centers which indicates Type 3 dolomite................................................................. 99

Figure 47. This thin section shows dolomite in a micrite matrix but also shows selective dolomization within a foraminifera. Dolomite as a cementation indicates Type 4 dolomite and is very common in F6 of the Fort Terrett Formation. ................................................. 100

Figure 48. The seepage reflux model that is been proposed multiple times for the Fort Terrett Formation. ................................................................................................................ 101

Figure 49. This is a diagram showing the classification system for dolomite textures used by Gregg and Sbibley (1984). This classification was constructed to differentiate dolomites based on crystal morphology, crystal edge geometries, and matrix. .......... 102
Figure 50. This thin section shows dolomites (A.) in (F6) which have a textural maturity of Idiotopic – S, and Xenotopic – C texture ................................................................. 103

Figure 51. This thin section shows a close up of saddle dolomite ................................................................. 104

Figure 52. This thin section shows dolomite in F2 and is described as porphyrotopic with euhedral rhombs being matrix supported .................................................................................................................. 105

Figure 53. These thin sections shows the undulatory extinction observed in both idiotopic and xenotopic textures of dolomite .................................................................................................................. 106

Figure 54. This shows a depositional environment model for the 6 facies as well as an interpreted sea level curve for the purpose of this study ............................................................................................................. 112

Figure 55. This thin section shows thin section 001 at 4X magnification. This thin section shows a sparse biomicrite with preserved bivalve shell fragments (Gryphaea) (A.) and calcareous sponge (B.) allochems in a micrite matrix .................................................................................................................. 120

Figure 56. This thin section shows thin section 002 at 10X magnification. This thin section is a sparse biomicrite with preserved bivalve shell fragments (A.) and a milloid (B.) in a micrite matrix .................................................................................................................. 121

Figure 57. This thin section shows thin section 003 at 4X magnification. This thin section shows an almost complete lack of allochems in a poorly washed calcite spar matrix. Lack of allochems could be due to dissolution indicated by the vuggy porosity. ............................ 122

Figure 58. This thin section shows thin section 004 at 10X magnification. This thin section shows a poorly washed biosparite with a preserved bryozoan (B.) There is also an indication of dolomite (A.) within the matrix. Quartz (C.) is also observed within the matrix indicating a terrigenous influence. (Stained Alizeran Red) .................................................................................................................. 123

Figure 59. This thin section shows thin section 005 at 10X magnification. This thin section shows a packed biomicrite with bivalve fragments (A.) in a micrite matrix. Some wall structure of the bivalves is preserved. (Stained Alizeran Red) .................................................................................................................. 124
Figure 60. This thin section shows thin section 006 at 10X magnification. This thin section shows a packed biomicrite with bivalve fragments (A.) in a micrite matrix. Some wall structure of the bivalves is preserved. (Stained Alizaran Red) ........................................... 125

Figure 61. This thin section shows thin section 007 at 4X magnification. This thin section shows a sparse biomicrite with bivalve fragments (A.) and foraminifera (B.) in a micrite matrix. Other notable allochems include lithic fragments which are not very common for this facies or formation. ................................................................................................................................. 126

Figure 62. This thin section shows thin section 008 at 10X magnification. This thin section shows microcrystalline chert. Within this chert are channels of mega filled quarts (A.) with chalcedony (B.) along the rims of the porosity channels................................................................. 127

Figure 63. This thin section shows thin section 009 at 10X magnification. This thin section shows microcrystalline chert. Within this chert are channels of mega filled quarts channels and a mollusk shell (A.) with subhedral quartz (B.) filling the void space and outer edges of the shell. ................................................................................................................................. 128

Figure 64. This thin section shows thin section 010 at 10X magnification. This thin section shows an almost complete lack of allochems in a poorly washed calcite spar matrix. Lack of allochems could be due to dissolution indicated by the vuggy porosity.129

Figure 65. This thin section shows thin section 011 at 10X magnification. This thin section shows a sparse biosparite with a preserved bivalve shell fragments (Gryphaea) (A,) in a calcite spar matrix. Interior of shell has been replaced by chalcedony. (B,) There is also intraparticle porosity that appears fenestral. (C,) (Stained Alizeran Red)................................. 130

Figure 66. This thin section shows thin section 012 at 10X magnification. This thin section shows a poorly washed biosparite with a bivalve shell. (A,) Again, dolomite is part of the matrix suggesting the supratidal facies. Also, a well-developed dolomite rhombohedrum is observed. (B,) (Stained Alizeran Red) ....................................................... 131

Figure 67. This thin section shows thin section 013. This thin section shows a sparse biomicrite with a preserved bivalve shell (Gryphaea) (A,) in a poorly washed calcite spar/dolomite matrix. Irregular foliated structure consist of calcite lamellae within the preserved shell. Also present within the matrix are small clasts of subrounded quartz grains (B.). (Stained Alizeran Red) .................................................................................................................. 132
**Figure 68.** This thin section shows thin section 014 at 10X magnification. This thin section shows a poorly washed sparite. There is also an indication of dolomite (white grains) within the calcite spar matrix. Several of the dolomite grains have a dark shadow centered in the crystal which is an indication of overgrowths. (Stained Alizeran Red) 133

**Figure 69.** This thin section shows thin section 015 at 10X magnification. This thin section shows a poorly washed sparite. There is also an indication of dolomite (white grains) within the calcite spar matrix. Several of the dolomite grains have a dark shadow centered in the crystal which is an indication of overgrowths. Brownish iron oxide is also observed within the rims of the miliod (A.) centered in the thin section. .......................... 134

**Figure 70.** This thin section shows thin section 016 at 4 X magnification. This thin section shows an almost complete lack of allochems in a drusy mosaic calcite matrix. The calcite in this thin section is exceptionally larger and anhedral compared to other thin sections with calcite spar. Lack of allochems could be due to dissolution indicated by the vuggy porosity. (B.) ........................................................................................................................................ 135
INTRODUCTION

Carbonate rocks of middle Cretaceous age dominate much of the surface and subsurface in west central Texas. These carbonate units were deposited on the Comanche Shelf and represent the lower Edwards Group in the rock record. A major transgression created an interior seaway that dominated most of the central United States and stretched north into the Arctic Sea. The development of this interior seaway created the Zuni Sequence during Aptian time. Waters on the Comanche Shelf were warm and quiet which allowed a carbonate factory to develop. Many of the facies of the Lower Cretaceous carbonates represent progradation of subtidal, intertidal, and sabkha facies. Eustatic sea level change, climate variations, and tectonics are the primary factors controlling the depositional environment of the Edwards Group. These cycles mainly represent large 3rd and 4th order sequences.

One of the major units in the Edwards Group is the Fort Terrett Formation. The regional extent of this unit has been delineated and its lithology has been defined, but it varies significantly from place to place. The purpose of this study was to examine the Fort Terrett Formation of the Edwards Group and divide it into recognizable formations and sequences by
conducting a stratigraphic, petrographic, and facies analyses to either support previous studies or add new information. A dolomization model will also be constructed detailing how the Fort Terrett Formation became dolomitized.
CREASEOUS GEOLOGIC ELEMENTS

During the Cretaceous, the Western Interior Seaway extended from the present day Gulf of Mexico to the present day Arctic Ocean. This Cretaceous sea divided North America and created the shallow marine shelf environment described by Parrish (1984). Circulation patterns of the seaway produced a carbonate factory that generated the limestones seen in the Lower Cretaceous. The shallow sea allowed for thick successions of these limestone and dolomite units. The area situated between the 30°N and 30°S latitude that produced tropical climates that allowed carbonate producing organisms to thrive. The Stuart City Reef, an arch forming rudist reef, reduced storm energy and sediment influx into the basins of Texas (Parrish 1984). Figures 1 through 4 show the geometry, evolution, and orientation of the Western Interior Seaway from Albian time to late Aptian time (Blakey 2013).

Lower Cretaceous rocks are observed at the surface and within the subsurface of south-central Texas. The Lower Cretaceous Edwards Group is comprised of massively bedded limestones and porous dolomites that measure 40 to 60 feet in thickness. Deposition of these limestones and
dolomites occurred along the Comanche Shelf in shallow waters during Albian and Aptian time (Figures 1 & 2).
Figure 1. Interior seaway of the Zuni sequence during Albian time is displayed above. Known as the Skull Creek High stand, this is the focal point for the beginning of deposition for the upper Trinity and Lower Edwards groups. A shallow to moderately deep marine environment dominates the study area which is represented by the red rectangle. (modified from Blakey, 2013)
Figure 2. The interior seaway is regressing during very late Albian time. Deposition of the upper Trinity and lower Edwards Groups continues. A shallow marine environment dominates the location of the study area (red rectangle). (modified from Blakey, 2013)
Figure 3. Regional deposition of Lower Edwards carbonates (lines) along with the geologic elements in Texas of the Lower Cretaceous. These geologic elements control deposition of the lower Edwards Group carbonates. The Comanche Shelf (blue), Maverick Basin (yellow), Devils River Trend (orange), and Stuart City Reef (Green). (modified from Rose, 1972).
Figure 4. This is a simplified stratigraphic column of the Comanche Shelf. The Edwards Group is the primary focus of the study area in the red box (modified from Phelps 2013).
This marine environment consisted of medium- to high-energy sedimentation (Trabelsi 1984). The shallow marine platform stretched across most of western Texas, wrapping around central Texas, and extended into north Texas near Fort Worth. To the southeast of the Comanche Shelf is the Stuart City Reef that trends along the boundary of ancestral Gulf of Mexico. The Stuart City Reef contains a rudist reef complex and forms an arch style-architecture across the southeastern portion of Texas. The reef allowed for calm waters throughout its development and shielded the study area from wave-dominated processes. Formation of the Stuart City Reef may have begun during Glen Rose time (Winter 1961). Lower Cretaceous limestones and rocks were directly influenced by the geometry of the Comanche Shelf and associated basins. Figure 3 shows the Cretaceous geologic elements for Texas. Two basins lay juxtaposed against the Comanche Shelf, the Maverick Basin to the southeast and the North Texas-Tyler Basin to the northeast. Separating the two basins are two large tectonic elements, the Central Texas Platform and the San Marcos Arch in the southeastern portion of the shelf (Adkins 1933).

Starting in the Mesozoic era, two major tectonic cycles impacted Texas. The Absaroka sequence occurred during the Pennsylvanian to Jurassic and the Zuni sequence occurred during the Cretaceous. The Zuni sequence, also known as the Skull Creek Highstand, was primarily responsible for the interior
seaway in which many of the carbonates were deposited during the Cretaceous period. The Zuni sequence also marks the widening of the Atlantic Ocean along with the trailing plate margin of the Gulf of Mexico. The Zuni sequence is further divided by (Sloss 1988) into three divisions, Zuni I, Zuni II, and Zuni III. Vail (1977) and other sequence stratigraphers continued to pursue additional divisions within the Zuni sequence. Since the work of Sloss (1988) and Vail (1977), additional models have been further developed. Parasequences of the Zuni sequence have been determined to be third and fourth order cycles (Bally 1984). These parasequences are the primary focus of this study (Figure 4).

Transgression and then later retreat of the interior seaway demonstrated sea level rise and fall that caused deposition, subaerial erosion, and a hiatus (Miall 2008). Siliciclastic sediments that were shed off the mountains to the west during the orogenic events of the Jurassic dominate the Zuni I sequence. Sandstones, shales, and carbonates were deposited throughout the eastern platforms of the Comanche Shelf during the Zuni II sequence. Nearing the end of the Cretaceous, tectonic events created uplift throughout Western Laurentia and gradually caused relative sea level to fall. This caused subaerial exposure of the marine sediments and sequences which led to erosion and truncation of the Cretaceous units (Miall 2008).
The stratigraphic framework for the Lower Cretaceous units varies as they trend from the Balcones Fault Zone, to the Llano Uplift region, and moving west towards Junction, Texas. Exposures of the Lower Cretaceous are readily observed in outcrops along the boundaries of the Llano Uplift and upthrown blocks of the Balcones Fault Zone (Moore 1967). The carbonates of the Edwards Group around Junction, Texas are divided into the Fort Terrett Formation and the Segovia Formation (Rose 1974). These formations of the Edwards Group as well as the Glen Rose Formation and Hensel Formation of the upper Trinity Group are further defined in the stratigraphy section.
STRATIGRAPHY OF JUNCTION AREA

The Lower Cretaceous Edwards Group is split into several formations and members around the Comanche Shelf. Figure 5 shows the interpretation by Rose (1972) but includes a general lithostratigraphic description for the entire Comanche shelf. The stratigraphy of the Junction, Texas area begins at the base of the Hensel Formation with the Glen Rose Formation on top, followed by a disconformable surface with the Fort Terrett Formation (Jones and Kullman 1997). Disconformably overlying the Fort Terrett Formation is the Segovia Formation. The Glen Rose Formation is disconformably below the Fort Terrett Formation. The Burt Ranch Member is noted in Figure 5 but was not observed or measured in the study area. Figure 6 (Wilkerson 2018) shows a very similar stratigraphic column for the Lower Cretaceous near Junction. However, the difference is the inclusion of the Walnut Formation based on the observations of oysters, primarily *Texigryphea*, and interbedded marl beds. Figure 7 represents the stratigraphic section for observable formations around Junction for this study. This interpretation does not include the Walnut Formation nor the Kirschberg Evaporative unit described by Rose in 1972. The Walnut Formation was not included due to the conclusion that the marl beds are part of the Glen Rose Formation. *Texigryphea* is also a key fossil that has...
been recorded in Glen Rose outcrops (Moore 1961). The Kirschberg Evaporative unit is not included due to the complete lack of evaporite minerals observed during petrographic analyses. The Segovia Formation was observed further east of the study area on I-10 but was not measured or described for this study.
Figure 5. Surface and subsurface correlations of the Edwards Group by Rose. This correlation has an absence of the Hensel Formation which may be significant. The Burt Ranch Member is also noted in this section but was not observed or measured in the study area. Study area represented by the red box (modified from Rose, 1972).
Figure 6. The generalized stratigraphic column of the Lower Cretaceous Group near Junction, Texas. The notable difference here is the inclusion of the Walnut Formation (from Wilkerson, 2018).
Figure 7. This is the general lithostratigraphy for the study area near Junction, Texas. Though the Segovia Formation is included and was observed in the outcrops, it was not measured for the purpose of this thesis. Red lines are to show were disconformities are.
HENSEL FORMATION

The Hensel Formation consists of claystones and sandstones of the upper Trinity Group. Previous studies describe the Hensel Formation stretching from the Llano Uplift to west of Junction, Texas. Exposures are observed near the Llano River drainage basin and along I-10 near Junction, Texas. The Hensel Formation is described by Jones and Kullman (1997) to have distinct lithofacies. The first is a basal terrestrial facies with intraclast supported conglomerates, created by high energy fluvial processes (Figure 8). The second is another terrestrial facies consisting of alluvial sandstones and mudstones. Paleosols, calcrete, and rhizoconcretions are well developed in this middle facies. The cycles of paleosols with interbedded limestones and claystones exhibits a shallow marine depositional environment. The paleosols are an indication that subaerial exposure occurred during a regressive cycle. The limestones and claystones show transgression cycles occurred on the shallow shelf, intertidal lagoons, or tidal flats (Wilkerson 2018). The third is the upper facies and is comprised of fossiliferous siltstones that are interbedded with fossiliferous limestones near the top. Fossils observed in the Hensel Formation include foraminifera, bivalves, and ostracods. The Hensel Formation is also the
lateral equivalent of the Glen Rose Formation west of the Llano Uplift (Jones and Kullman 1997).
Figure 8. This is a paleogeographic representation of depositional systems in Texas of the Trinity Group. This figure also shows how the Llano Uplift contributed to sedimentation to the Maverick Basin. This could indicate the origin for silica rich sediment found in the study area (from Payne 1982).
The Glen Rose Formation is also Aptian age along with the Lower Edwards Group, however, the Glen Rose is part of the upper Trinity Group. The Glen Rose is primarily a limestone with interbedded shales and is usually fossiliferous and primarily composed of bivalves (Bergan 2009). Extensive marls divide the fossiliferous beds. The upper Glen Rose is distinguishable by iron staining observed in a marker bed. The lower Glen Rose is recognized by medium to thick beds of limestones containing Carprinid pelecypods. Dolomites observed in the Glen Rose are described to have occurred due to telogenetic processes during diagenesis (Burkholder, 1973).
FORT TERRETT FORMATION

The Fort Terrett is found in the west central section of Texas. The most predominate lithology of the Fort Terrett Formation is a thickly bedded limestone. It is exposed on the upper hills of Junction as limestone caps. Deposition of the Fort Terrett Formation occurred within shallow, warm waters during Albian time of the Cretaceous (Rose 1972).

Rose (1972) divides the Fort Terrett Formation into four informal members. In ascending order: a basal nodular member, a burrowed member, a dolomitic member, and on top the Kirschberg Evaporite member. The basal nodular member of the Fort Terrett has a low percentage of sand which is terrigenous in source. It also contains a siltstone marl that grades upwards to a nodular biomicrite with scattered bivalves and gastropods. These members also indicate facies changes ranging from subtidal to supratidal (Figure 9) (Trabelsi 1984).

The burrowed member ranges between 69 to 88 ft. (21-27 m) thickness. However, the thickness decreases to roughly 55 ft. (17 m) in exposure near the Llano Uplift (Trabelsi 1984). The burrowed member is a massive micrite limestone with scattered dolomitized zones that are more uncommon trending east toward the Llano Uplift. The burrowed member also contains thin laminar beds of miliolids, fragments of mollusks, and
distinguishable ripple marks and cross bedding. High porosity and permeability allows the borrowed member to be a significant water-bearing aquifer zone within the Edwards Group (Trabelsi 1984).

The dolomitic member of the Fort Terrett Formation is comprised of thin to thick beds that contain fine to medium dolomites. This dolomite bed alternates with fine mudstone beds. Thickness of the dolomitic member ranges from 12-27 ft. (4-8m), with thinner sections near the Llano Uplift. Sedimentary structures observed within the dolomitic member include stromatolite hard crusts, root casts, mud cracks, ripple marks, current ripples, and planar cross-bedding (Trabelsi 1984).

The Kirschberg Evaporite Member of the Fort Terrett Formation exhibits thin-bedded micrite, milioid grainstones and disseminated gray crystalline dolostones. Distinctive collapse breccias occur in this member of the Fort Terrett Formation and caused moderate folding structures while other outcrops display a more horizontal orientation. (Trabelsi 1984). Dissolution of the underlying sulfates within the Kirschberg evaporites could have caused the collapse breccias. Trabelsi (1984) stated that the driving mechanisms for collapse breccia zones could be major sea level regressions, extensive subaerial exposure, and shifting from a semi-arid climate to subtropical
environments. This climate change pattern could be indicative of global cooling cycles during Aptian (Trabelsi 1984).
Figure 9. Diagram of diagenetic features of the depositional environments within the Fort Terrett Formation. This diagram is distinguishing between different depositional environments and was used while conducting a petrographic analysis (Trabelsi 1984).

<table>
<thead>
<tr>
<th>SUPRATIDAL</th>
<th>INTERTIDAL</th>
<th>SHALLOW MARINE</th>
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<tbody>
<tr>
<td></td>
<td>(TIDAL FLAT)</td>
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<tr>
<td>Thinly layered grayish tight, finely crystalline dolostone intervals.</td>
<td>Distinctly laminated intervals and possible stromatolite.</td>
<td>Randomly oriented thallinodes burrows.</td>
</tr>
<tr>
<td>Mud-crack casts.</td>
<td>Flat- to round-crested eroded wave ripples.</td>
<td>Most bedding planes destroyed by bioturbation.</td>
</tr>
<tr>
<td>Flat pebble conglomerates</td>
<td>Some examples of fenestral cavities &quot;bird's-eye vugs.&quot;</td>
<td>Abundant and diverse fossils eg. forams, mollusks and ostracods.</td>
</tr>
<tr>
<td>Fenestral cavities &quot;bird's-eye vugs.&quot;</td>
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Tidal range
SEGOVIA FORMATION

The disconformity above the Fort Terrett Formation represents the Segovia Formation which is Aptian in age (Lock 1999). The Segovia Formation is seen on I-10 traveling West towards the town of Segovia. This unit is predominately limestone with interbedded marls, dolomite beds, and possibly breccia collapse zones similar to the ones observed in the Fort Terrett Formation near Junction (Lock 1999). The Segovia Formation has not been carefully studied in the Junction area. Described by Lock (1999), the Segovia Formation is separated into three members. First is known as the Marl Member, then the Minor Member, and lastly the Black Bed Member. The Segovia Formation has excellent bed ammonite used as marker beds. These ammonites can be found through much of the Segovia Formation as it extends across west Texas. Similar to the Fort Terrett Formation and Glen Rose Formation, the Segovia Formation is also interpreted to be a third order cycle, showing a large transgression which produces a disconformity at the top of the Fort Terrett Formation (Lock 1999).
STUDY AREA

Kimble County, Texas is the location of this study and is shown in the black box in Figure 10 with regional Fort Terrett Foramtion outcrops mapped. The study area is about 35 square miles in the vicinity of Junction, Texas. Figure 11 shows a more detailed geologic map of Kimble County with the study area centralized around Junction. This is significant because most of Kimble, County has several exposures of the Fort Terrett Formation in road cuts. The primary issue with measuring section in the area is the vast amount of private property. This makes finding a complete section for stratigraphic analysis difficult, as many residents in and around Junction do not allow people on their private property. A stratigraphic analysis of the Fort Terrett Formation (Edwards Group) was conducted on the outcrops indicated by the star markers in Figure 12. The Fort Terrett Formation is observable in the hills surrounding Junction. Due to how the topography has been eroded and private ownership of land, it is difficult to measure a complete section. The Fort Terrett Formation truncates the Glen Rose Formation of the upper Trinity Group within the study area. Outcrops and road cuts of the Glen Rose Formation are located along I-10 of the study area as well. Observing the outcrops of the Glen Rose Formation helped further assist in correlating the Fort Terrett Formation by using that contact as a
datum. These thinly bedded limestone units and chert layers have been lumped together as one unit in previous studies and thesis but are dissected in this study.
Figure 10. Regional extent of the Cretaceous age Fort Terrett Formation (Kft) where it outcrops in Texas. The county where the study area is located is outlined in black (Wilkerson 2018).
Figure 11. Geologic map of Kimble County, Texas. This map outlines the geologic formations that outcrop in Kimble County. The study area is illustrated by the black box. The Fort Terrett Formation makes up most of the higher topography of the area and caps the hill across the county (modified from Wilkerson 2018).
Figure 12. This map shows the locations of the 9 measured sections used for the purpose of this thesis. Most measured sections are done along Interstate Highway 10, however, a couple are measured along Highway 377 and 484. This was done to create a greater spatial distribution.
METHODOLOGY

Nine sections were measured in the Junction area along I-10 using a Jacob-Staff method and a measuring tape. Hand samples of limestone and chert were collected along every section. Samples were labeled and bagged and GPS locations were given for all sections. Photos of outcrops were taken. Hand samples were described in the laboratory using a binocular microscope.

Forty samples were then selected based on the lithologies. Two chert samples were selected from the study area. Thin sections were cut into 2X1” billets. The billets were then studied using a petrographic microscope. A petrographic analysis included a 300 point count manually, to determine rock lithology based on the Folk (1959) classification for carbonate rock. Six different facies were recognized based on lithology changes and biodiversity. Sixteen billets were selected based on their facies distribution, allochems, and unique diagenetic features. Billets were then sent to Spectrum Petrographics in Vancouver, Washington. Thin sections were cut and stained with Alizerin Red S to differentiate dolomite from calcite. Diagenesis history of the Fort Terrett Formation was also developed based on the petrographic analysis. Lastly, dolomization was further analyzed from diagenesis and a dolomization model
was constructed based on literature review, petrographic analysis, and an examination of dolomization patterns.
STRATIGRAPHIC ANALYSIS

A stratigraphic analysis was done using 9 measured sections of the Fort Terrett Formation near Junction, Texas. As previously noted, the Fort Terrett Formation makes up the upper most topography of the Junction area (Figure 13). The Fort Terrett Formation was split into 3 informal lithostratigraphic units through the study area and described by lithology, allochems, sedimentary features, and sedimentary structures. These 3 lithostratigraphic units will be referred to as the basal unit, the thin bed unit, and the dolomitized unit for the purpose of a general lithostratigraphic column (Figure 14) for Junction and a stratigraphic correlation.
Figure 13. The three mapped units in the study area per the USGS geologic formations map. The first formation (moving up section) is the Hensel Formation. Next, is the Glen Rose Formation followed by the Fort Terrett Formation outlined in a faint green. As previously noted, the Fort Terrett Formation dominates the higher elevation in the study area as seen in this outcrop. A disconformity is also observed at the top of this outcrop.
Figure 14. General lithostratigraphic section of the Fort Terrett Formation near Junction, Texas. Average thicknesses are also noted for each unit. Due to constraints of access to outcrops of the Fort Terrett Formation around Junction, a complete section was not able to be measured and described.
BASAL UNIT

The basal unit is described as a thickly bedded limestone. The basal unit was described using the Dunham classification for carbonates as a mudstone to wackestone. Fresh surface colors of the basal unit observed in outcrop were bright yellowish white that weathered to a dull grey or dark tan. Weathered surfaces were eroded to sheer cliffs in all outcrops where the basal unit was observed and measured. Allochems are present but decrease further up section towards the thin bed unit. Bivalves (Figure 19-D), gastropods (Figure 19-C), and other fossils along with bioturbation were seen in outcrop and hand samples. Presence of fossils, intraclasts, and pellets suggests the basal unit represents a moderate to shallow water environment where organisms could thrive. Sedimentary features were uncommon but laminations are faint and mostly localized near the contact between the basal unit and the thin bed unit. Bright orange banding was observed that was produced by minor iron oxide rich staining. Dissolution is also present in outcrop as well as hand samples. This dissolution is noted by vugular porosity. The lower contact of the basal unit is conformable with the Glen Rose Formation and the upper contact is conformable with the thin bed unit. The upper contact with the thin bed unit is often marked by a “chalk” like marker bed (Figure 15).
Figure 15. This outcrop shows the conformable surface between the basal unit and the thin bed unit in the study area. This contact is also easily distinguished by the "chalk" like surface of the basal unit. Also noted in this figure (red arrow) is another chalk like surface that possibly indicates a facies changes in the Fort Terrett Formation (Rock hammer for scale).
THIN BED UNIT

The thin bed unit is a thinly bedded limestone. This unit is defined using the Dunham (1962). Fresh surface colors of the thin bed unit observed in outcrop were a bright yellowish white that weathers to a dull light grey or tarnished black. Weathered surfaces eroded to form a sheer cliffs. Sedimentary features included thin laminations (Figure 19-B) within many of the thinner bed. Allochems included bivalves, mostly broken up into bivalve hash. Bivalve hash and bioturbation is present but is confined to localized areas. Dissolution is very prevalent in the thin bed unit with observations of vugular and fenestral porosity. This enhanced porosity along with pressure from overlying formations created localized collapse zones (Figure 16). Dark brown to black chert nodules are present in layers along bedding planes. Chert nodules do not show bedding and appear to have developed when silica rich waters invaded the vugular pore space in the thin bed unit (Figure 17). The upper section of this unit also exhibits isolated areas of collapse zones due to dissolution.
Figure 16. This outcrop shows a visual representation of the thin bed unit in the study area. Note the thin beds with linear chart nodules in them (red arrow). Dissolution is prevalent and creates small localities of collapse zones in this unit (Rock hammer for scale).
Figure 17. This outcrop shows the conformable surface between the Basal unit and the thin bed unit in the study area. This contact is also easily distinguished in this figure (red arrows) by the chert beds that are prevalent in the thin bed unit.
DOLOMITIZED UNIT

The dolomitized unit is described as a thick to massive bedded limestone. This unit is interpreted, using the Dunham (1962) classification of limestones, as a mudstone to wackestone. Fresh surface colors of the dolomitized unit are a bright yellowish white to white that weathers to a dull grey or tan. Outcrops of the dolomitized unit weather to form a sheer cliff (Figure 18). Allochems are present but not as prevalent as the thin bed unit. Allochems for the dolomitized unit include bivalves, bryozoans, and peloids. Sedimentary features are not common but bioturbated surfaces and minor patches of bivalve hash were noted in hand samples. Bioturbation is represented by burrowed surfaces. The upper contact for the dolomitized unit and the Fort Terrett Formation is heavily impacted by dissolution. Dissolution includes vugular and fenestral porosity which is seen in several hand samples (Figure 19-A). Laminations are also seen near the contact between the thin bed unit and the dolomitized unit. These laminations look similar to thin bedding in thickly bedded limestones.
Figure 18. This outcrop shows the surface between the thin bed unit and the dolomitized unit in the study area. This surface is somewhat difficult to distinguish in many outcrops due to the increase dissolution seen in the dolomitized unit. The thicker, tarnished grey bed is used as the contact for these surfaces as well as the point where chert nodules are no longer observed.
Figure 19 shows sedimentary features observed in hand samples collected at various road cuts. A. shows vugular porosity which is also observable in thin section. B. shows thin laminations that can be seen within the thin bed unit of the measured sections. C shows a gastropod, which is an uncommon allochems observed in the Fort Terrett Formation near Junction. D. shows bioturbation as well as dissolution from the basal unit of the measured sections.
PETROGRAPHIC ANALYSES

Forty samples were studied from each of the three units from different measured sections. Billets from those forty samples underwent a preliminary facies analysis and the billets were divided based on facies trends, allochems, and their localities. Sixteen billets were selected and sent to Spectrum Petrographics Inc. in Vancouver, Washington, to be cut into thin sections. Of the sixteen samples chosen to be cut, fourteen were limestones of the three lithostratigraphic units and the other two were from chert nodules. The petrographic analyses was conducted using the Folk (1959) classification to determine depositional environment and diagenesis. A 300 point count was done to determine allochems, matrix, and lithic percentages for each thin section.

FACIES ANALYSES

Facies analyses of the Fort Terrett Formation was done using the 40 billets and 16 petrographic thin sections. Facies for the purpose of this thesis are labeled as F1 through F6 to distinguish changes in depositional environment. Based on the data collected by facies analyses, the Fort Terrett Formation was divided into 6 significant facies changes. These facies changes were determined by 3 factors: allochems, diagenetic features, and matrix percentages. Either one
or a combination of these factors allowed for 6 divisions to be made within the 3 lithostratigraphic units mapped in the Junction area. Figure 20 shows a detailed stratigraphic column with these divisions as well as allochems and key features identified in each facies. Figure 21 is the legend for allochems and key features that are detailed in Figure 20.
Figure 20. This figure shows a detailed stratigraphic column of the Fort Terrett Formation. The Fort Terrett Formation is split into 3 lithostratigraphic units (Basal unit, thin bed unit, and the dolomitized unit). Those three units are then split into 6 facies (F1, F2, F3...Etc.). Fossils and key features for each facies are also displayed.
Figure 21. The legend used for the detailed stratigraphic column in Figure 20

Allochem/Key Features Symbols

- Algae
- Bivalves
- Bryozoans
- Burrows
- Chert Nodules
- Dolomite
- Echinoids
- Gastropods
- Foraminifera
- Peloids
- Sponges
- Quartz Grains
SPARSE BIOMICRITE (F1)

Facies 1 (F1) consists of all of the Basal unit. Allochems include bivalves, foraminifera, miliods, and calcareous sponges. Porosity in this facies was not well established or observed in petrographic analysis. Only a couple fractures were observed, in which calcite filled in the pore space. F1 was interpreted as a shallow carbonate shelf lacking in biodiversity. Water depths could range from 10 meters to 50 meters which explains the sparse biodiversity in F1 as well as the Basal unit. This facies is interpreted as a sparse biomictite (Figure 22). Lack of allochems and a dominate micrite matrix allows for a moderate to shallow water level. This facies is considerably thick ranging from 8 to 16 ft in measured section. There are also no indication of porosity meaning F1 did not undergo significant telogenesis events such as dissolution or dolomization.
Figure 22. This thin section represents F1 and is a sparse biomicrite. Allochems are common but are not the primary makeup of the matrix. Noted in this thin section is bladed calcite infilling pore space in a bivalve fragment (A). Calcareous sponges as well as milioids are common for this facies. This facies represents a subtidal environment with a moderate sea level. F1 has a very diverse set of allochems unlike the other facies which is also representative of a quiet, warm water setting.
DOLOMITIZED SPARSE BIOMICRITIC (F2)

F2 is the next facies division and also the beginning on the thin bed unit. Petrography analysis of F2 shows a sparse biosparite (Figure 23) but with a small increase in biodiversity from F1. There is also the presence of quartz grains which suggest some terrigenous influence on this facies. This could be possible due to lowering sea level and fluvial processes prograding toward the carbonate platform or shelf. The Llano Uplift was an island during this time and was proximal to the Junction area. Another difference from F1 is the presence of dolomite within the micrite matrix. There is a small increase in porosity for F2 due to dolomization occurring. The presence of dolomite suggests there is also a significant diagenesis event happening in F2, post deposition. Dolomization diagenesis and models for dolomite will be further discussed to explain this event. Allochems are more prevalent in F2 than in F1 and include bivalves, peloids, and various unidentifiable fossils within the matrix. F2 was interpreted as an intertidal depositional environment as the first facies of the thin bed unit. Dolomite and quartz are also present in a calcite spar matrix which indicates minimal sediment influx from terrigenous sources. Oxidation is also seen as dark brown patches of iron oxide that occupy interparticle porosity zones between the
calcite and dolomite. Thickness for this facies ranges from 2 to 5 ft. (0.6-1.5 m) in measured section.
Figure 23. This thin section represents F2 and is inferred as a dolomitized sparse biomicrite. Allochems (A) in F2 are more abundant and more abundant. There is also the addition of quartz grains (B), most likely imported from the Llano Islands to the north east of the study area. Dolomite is also very prevalent within the matrix which is not observed in F1. Dolomite is described as subhedral to euhedral dolomite within the micrite matrix. Brown staining (C.) indicates fresh water flushing with iron rich waters.
BIVALVE PACKED BIOMICRITe (F3)

F3 is the next facies of lithostratigraphic the Thin bed unit. Petrography analysis of F3 (Figure 24) shows a packed biomicrite within an intertidal to shallow subtidal environment. The abundance of biodiversity such as bivalves, micropeloids and calcareous sponges is significantly greater than the two previous facies. This facies has indication that the bivalve fragments were imbricated, possibly deposited on a tidal flat. The bivalve fragments are also responsible for the primary porosity within this facies. There is a lack of sponge spicules within the chert nodules which is indicative of inorganic origin. Chert nodules observed in F3 (Figure 25) also display dissolution with splays of megaquartz filling the voids. Along the rims of the filled voids is vibrant chalcedony which also indicates silica replacement. Most silica replacement that does occur usually does within organic rich materials such as bivalve shells, ooids, burrows, and stromatolites (Jacka 1974) and there are indications of the onset of localized biostromes. These small mounds could have been dissolved out and replaced by silica rich waters. This replacement produced nodules that are generally linear to each other in outcrop view.
Figure 24. This thin section represents F3 and the second facies of the thin bed unit. Petrography analysis of F3 shows a packed biomicrite within an intertidal to shallow subtidal environment. The abundance of biodiversity such as bivalves (A), micropeloids and calcareous sponges is significantly greater than the two previous facies. This facies has indication that the bivalve fragments were imbricated, possibly transported up against a tidal flat. The bivalve fragments are also responsible for the primary porosity within this facies.
Figure 25. This thin section represents the chert nodules found in F3. Chert nodules observed in F3 also display dissolution with splays of megaquartz filling the voids. This also seen in preserved allochems such as this mollusk shell (A.) with subhedral quartz infilling pore space. Along the rims of the filled voids is vibrant chalcedony (B.) which also indicates silica replacement. Most silica replacement that does occur usually does within organic rich materials such as bivalve shells.
PELOIDAL MICROSPAR (F4)

F4 is the first facies of lithostratigraphic the dolomitized unit and is interpreted as an intertidal to subtidal facies. Petrographic analysis shows a poorly washed biosparite (Figure 26) where biodiversity diminishes greatly. There is a complete lack of dolomite with almost complete recrystallization or microspar. There is an abundance of intraparticle porosity seen in thin section as well. This porosity could explain the almost complete lack of allochems for this facies. Microspar indicates replacement of aragonitic shells or pelletal material in the matrix but crystal sizes are not large enough to indicate meteoric influence is the cause of recrystallization. This recrystallization results from stagnant sea water settling in underlying facies allowing for recrystallization to occur of the micrite mud matrix. This is a late stage marine diagenesis as lower strata gets buried. Allochems were most likely dissolved out later during a mesogenesis or telogenesis event.
Figure 26. This thin section shows F4 which is the first facies of lithostratigraphic the dolomitized unit and is interpreted as an intertidal to subtidal facies. Petrographic analysis shows a poorly washed biosparite with a significant lack of biodiversity. There are also no indications of dolomite with very little micrite. Intraparticle porosity (A.) dominates the calcite spar matrix for this facies. This porosity could explain the almost complete lack of allochems for this facies. Calcite spar indicates replacement of aragonitic shells and micrite in the matrix.
POROSITY RICH SPARSE BIOMICRITE (F5)

F5 is the next facies in the dolomitized unit and is interpreted as a subtidal facies and. F5 is similar to F4, however, there is a complete lack of calcite spar within the matrix. Petrographic analysis showed a sparse biomicrite (Figure 27). Allochems are also present in this facies and include bivalves with large porosity vugs or interparticle porosity. Dissolution was prevalent in this facies and also has indications of silica replacement like F3. Within the thin lamellae of some bivalves is chalcedony replaced along the rims of the silica filled porosity. This facies could also indicate a standstill in sea level which allowed for organisms to grow to such a larger size when compared to other facies.
Figure 27. This thin section shows a sparse biomicrite from F5 and is the next facies in the dolomitized unit. This facies is interpreted as a subtidal facies. F5 is similar to F4, however, there is a complete lack of calcite spar within the matrix. Allochems are also present in this facies and include bivalves (A) with large porosity vugs (B) or interparticle porosity. Dissolution was prevalent in this facies and also has indications of silica replacement (C) like F3. Within the thin lamellae of some bivalves is chalcedony replaced along the rims of the silica filled porosity. This facies could also indicate a standstill in sea level which allowed for organisms to grow to such a larger size when compared to other facies.
DOLOMITIZED MICRITE (F6)

F6 is the last facies of the upper part of the dolomitized unit and the Fort Terrett Formation in the Junction area. Petrographic analysis of F6 is described as a dolomitized micrite (Figure 28) and was interpreted to be a subtidal depositional environment where dolomite is very dominate within the matrix. Allochems are rare and mostly make up small bivalve fragments. Well developed, euhedral dolomite rhombs are observed within thin section and filled much of the void space in the micrite cement. The presence of dolomite indicates this facies is an intertidal to supratidal facies, similar to F2, but dolomitization is not related to depositional environment in the Fort Terrett Formation. Dolomization in F2 and F6 will be further explained in the diagenesis section.
Figure 28. This thin section shows a dolomitized sparse biomicrite of F6. F6 is the last facies of the upper part of the dolomitized unit. This facies is described to be an intertidal to supratidal depositional environment where dolomite is very dominate within the matrix. Well developed, subhedral dolomite rhombs (A.) are observed within thin section and fill much of the void space in the calcite spar cement. There is also scattered grains of quartz (B.) which indicates fluvial influence on this facies, most likely originating from the Llano Islands to the north east of the study area. Allochems in this facies are not very common but do include preserved bryozoans (C.), which are exclusive to this facies. Again, fresh water diagenesis is primarily responsible for the dissolution and dolomite replacement. This event of dolomization is most likely a separate event from the dolomization that occurs in F2.
DIAGENESIS

Several diagenetic events have occurred within the Fort Terrett Formation which includes syndepositional and post depositional events. Changes in sea level are the primary factors contributing and controlling to earlier diagenetic changes such as micritization, cementation, and dolomization. Post depositional events that induced diagenetic changes includes burial and compaction, hydrothermal diagenesis, and dissolution. Telogenesis resulted in several significant changes such as enhancing porosity and oxidation. Three main diagenetic events that occurred include shallow marine diagenesis, burial/compaction, hydrothermal, and telogenesis. A model for diagenesis (Figure 29) has been constructed outlining the main events that impacted the Fort Terrett Formation. Specific sub diagenetic events are also shown in this model to better explain diagenetic features observed in thin section. Each diagenetic events is further explained in the following sections along with the sub events that accompany them. The model proposed is also supported by the petrographic analyses of the Fort Terrett Formation.
Figure 29. This is a model for diagenesis for the Fort Terrett Formation. This model illustrates when significant events occurred. Four primary events occurred for the Fort Terrett Formation near present day Junction. These include shallow marine diagenesis, burial diagenesis, hydrothermal diagenesis, and telogenesis. Specific sub diagenetic events are also shown in this model to better explain diagenetic features observed in thin section.
SHALLOW MARINE DIAGENESIS

Shallow marine diagenesis is the first syndepositional event to occur in the late Cretaceous. Micritization of lower facies as well as the presence of bladed calcite in several allochems. The occurrence of bladed calcite within bioclastic material suggests early marine diagenesis (Bathurst 1966). This also indicates that earlier facies were developed in calm waters in a moderately subtidal environment. Micritization is very prevalent throughout several thin sections of F1 which is observed in the matrix as well as a few allochems with micritic envelopes. The process of micritization was explained by Bathusrt (1966) to be the alteration of original skeletal or grain fabric to a microcrystalline texture. This is done by boring blue-green burrowing into carbonate grains or fabric with an eventual filling of the burrows with micrite. Figure 30 shows a thin micritic envelope around a small bivalve and gastropods which indicates shallow marine diagenesis. This process is also seen in a packed biomicrite (Figure 31) where the outer shells of bivalves and a gastropod have been burrowed away and subsequently filled with micrite. Figure 32 shows the micritization process where burrowing occurred into the allochems versus just around the rim. Those microborings in the allochems were then infilled with micrite. Small areas of bladed calcite are also observed within the burrowed bivalve shell. Calcite spar is
observed in F4 and scattered allochems which may suggest meteoric diagenesis and possible exposure of the Fort Terrett Formation. There is evidence of burrowing and bioturbation but this is not exclusive to sabka or supratidal facies. There were no instance of desiccations cracks or ryzoliths observed in the study area or petrographic analyses. There is also a lack of calcite spar being a primary cement or calcite rims around allochems that could suggest meteoric flushing. In instances where calcite spar is present, sea levels became stagnant and calcite spar is a result of recrystallization as water settled in lower lying facies. Figure 33 shows an allochem selectively dissolved and replaced by calcite spar. However the rest of the matrix is predominately micrite mud. In F4 (Figure 34) micro spar makes up the complete matrix of the facies and allochems are completely removed from F4. Marine diagenesis is best comprised of continual deposition of the Fort Terrett Formation in the Junction area with periodic times of prolonged water stagnation in underlying facies. This process of recrystallization is responsible for the calcite spar observed in F4 during the petrographic analysis.
Figure 30. This thin section shows a thin micritic envelope (A) around an allochem which suggest shallow marine diagenesis. Micritization occurs due to algal boring that is subsequently infilled with micrite. Also known as endolithic boring which is an early diagenetic process.
Figure 31. This thin section shows a gastropod (A) surrounded by bivalves and peoids. Allochems in this thin section have micritic envelopes indicating shallow marine diagenesis. Micritization occurs due to algal boring that is subsequently infilled with micrite. Also known as endolithic boring which is an early diagentic process. Also observed in this section are small patches of algae (B.).
Figure 32. This thin section shows a bioturbated bivalve shell (A) with micrite filling the pore space. These burrows are not as complete around the rim of other allochems but still illustrate how algal microboring are infilled with micrite. There is also small patches of bladed calcite that has replaced some of the bivalve shell. Bladed calcite is an indication of shallow marine diagenesis as well as micritization.
Figure 33. This thin section shows a dissolved bivalve shell filled in with drusy mosaic calcite (A). This is representative of selective dissolution and is also responsible dissolution of select allochems.
Figure 34. This thin section shows F4 which is a microspar facies. Allochems are completely removed from this facies and only the “ghost” remnants of those allochems remain. These allochems were selectively dissolved later after the precipitation of the microspar.
EARLY BURIAL DIAGENESIS

Styolites, fractures, fractured allochems (Figure 35), and silicification with chert nodules are also all indicative of burial diagenesis. Fractures are not very common but are seen in mudstone facies, mostly F1. They are very linear and infilled with calcite microspar and silica. Isopachous cements and micritic envelopes are also indicative of early burial diagenesis as upper Fort Terrett deposited on lower strata. This early stage diagenesis was most likely syndepositional with marine digenesis as micritization and recrystallization of microspar occurred. Fractures formed under a more moderate compaction when the Segovia Formation deposited on top of the Fort Terrett Formation. During burial diagenesis, silica rich water also infiltrated the enhanced porosity, precipitating subhedral quartz (Figure 36) in dissolved allochems or fractures. This addition of silica rich waters also allows for chert nodules to form in places where dissolution was more prevalent. Chert nodules are partially linear with some abnormality to their orientation. The addition of chert within packstone facies of the Fort Terrett Formation indicates fresh waters that are silica rich infiltrated the enhanced void spaces. Chert can either be inorganic or organic depending on the addition biogeneic sources for silica such as sponge spicules or radiolarians. Petrographic analysis of chert thin sections found no sponge
spicules or radiolarians which suggests that the chert nodules in the Fort Terrett multiple events of silicification that occurred during burial diagenesis and telogenesis in the chert nodules. Vugular porosity, infilled with subhedral quartz (Figure 37), also has chalcedony along the rim which indicates two events of silicification.
Figure 35. This thin section shows a broken bivalve which suggests light to moderate compaction occurred. Burial diagenesis is evident by fractures, broken allochems that aren't imbricated, and styolites. Compaction occurs during the late Cretaceous when the Segovia Formation deposited on top of the Fort Terrett Formation.
Figure 36. This thin section shows a fracture (A) though a sparse biomicrite infilled with calcite and silica. This is evident of burial diagenesis and/or telogenesis. Fractures are uncommon but are primarily seen in mudstone facies, mostly F1. They are predominantly linear and infilled with calcite spar and silica. During burial, fractures formed under moderate compaction when the Segovia Formation deposited on top of the Fort Terrett Formation during the Late Cretaceous.
Figure 37. This thin section shows a chert thin section where no sponge spicules or radiolarians were found, which suggests that the chert nodules in the Fort Terrett Formation are of an inorganic origin. This also shows vugular porosity infilled by quartz (A). The filled porosity is also rimmed by chalcedony (B.) showing two events of dissolution and silicification.
LATE BURIAL DIAGENESIS

Multiple silicification events would have occurred during both burial diagenesis and telogenesis. As other stratigraphic units such as the Georgetown, Eagle Ford, and Austin Chalk deposited on top of the Fort Terrett Formation, burial diagenesis occurred producing saddle dolomites (Figure 38). This suggests late stage burial dolomization occurred and will be further explained in the dolomization section. The addition of chalcedony (Figure 39) suggests a hydrothermal influence on the Fort Terrett Formation and the chert nodules could be the source of silica for chalcedony. Hydrothermal diagenesis occurs during the late Cretaceous when carbonates of the Edwards Group were still being deposited in tandem with Late Cretaceous volcanism. Hydrothermal diagenesis will also be used to explain the second instance of dolomization in F2.
Figure 38. This thin section shows dolomite as a primary cement in F6 of the Fort Terrett Formation. This type of dolomization is evident of saddle dolomite that occurs during late stage diagenesis. Features to observe are warped crystal lattices and curved crystal faces of the white dolomite crystals. Curvature on the crystal faces is where saddle dolomite derives its name.
Figure 39. This thin section shows a chalcedony fill pore space (A). During burial diagenesis, hydrothermal water infiltrated the enhanced porosity, precipitating mega quartz and chalcedony in dissolved allochems. Silicification is very common in F3 as well as F5. This event most likely happened proximal in time to hydrothermal dolomization.
TELOGENESIS

Telogenesis begins with exposure due to the uplift of the Comanche Platform when the Balcones Fault system begins to move during the late Paleogene into Tertiary time. The lower Edwards Group strata including the Fort Terrett Formation becomes exposed and subjected to erosion. This uplifting and exposure has continued into the present day and contributes to post deposition diagenesis (Anaya 2004). This late stage diagenesis is also responsible for the lack of anhydrite, gypsum, and other evaporite minerals that should be present due to dissolution. Dissolution of these minerals is the product of fresh water flushing during exposure of the Fort Terrett Formation (Fisher and Rodda 1969). The presence of oxides also suggests there is a significant influence of telogenesis. Oxidation is evident based on the observation of dark cementation (Figure 40) in thin section and bright orange staining on thin hand samples. Dolomite is also very evident in supratidal facies that were exposed drops in sea levels. These facies have evidence of enhanced porosity which allows for iron rich waters to infiltrate these facies during burial and/or exposure. Several allochems exhibit selective dissolution as well in F6. Dissolution appears to be selective in facies further up section and is rimmed by high Mg calcite (Figure 41). Dolomitized allochems (Figure
42) that have been dissolved also display evidence of dedolomization where dolomite has been reverted back to calcite but still retains the dolomite texture. Dissolution is observed in every facies except F1 with void spaces having high Mg calcite along the rims, similar to what’s seen in Figure 41. Dissolution (Figure 43) is evident of telogenesis due to the lack of mineralization in the void space such as dolomite and silica from burial diagenesis. The lack of these minerals only suggests this dissolution is post uplift and exposure. This will be used to further explain why seepage reflux or evaporative pumping for dolomization by enhanced porosity does not fit as a model for dolomization in the Fort Terrett Formation near Junction.
Figure 40. This thin section shows an allochem surrounded by oxide cementation (A). This suggests fresh water flushing dissolved the rim of the bivalve shell which allowed for oxide rich waters to fill the void space. This indicates burial diagenesis and/or telogenesis as well as a dysoxic environment when the Fort Terrett Formation became exposed. Dolomite is also very evident in facies that were exposed. These facies have evidence of enhanced porosity which allows for iron rich waters to infiltrate these facies during burial and/or exposure.
Figure 41. This thin section shows selective dissolution of a millioid with high Mg calcite (A.) precipitating around the rim. High Mg calcite is distinguished by the powdery white color. Some crystals exhibit a slight reddish hue, indicating the Alizéran Red staining is not as effective on high Mg calcite.
Figure 42. This thin section shows iron staining (A.) which indicates telogenesis occurring on the Fort Terrett Formation. Iron rich waters infiltrated facies during exposure and left behind iron staining that was either dark brown or orange. Different colors could indicate multiple flushing events with waters having different ferrous ions. There is also evidence of dedolomization which is the reverting of dolomite back into calcite. Dolomite rhomb crystal habits with overgrowths are observed being stained red (B) as calcite.
Figure 43. These thin sections shows vuggy dissolution that occurred during telogenesis. Both thin sections shown have enhanced porosity that occurred after the exposure of the Fort Terrett Formation. Dissolution is common in every facies except F1 and most void spaces have high Mg calcite along the rims, similar to what’s seen in Figure 48. This dissolution is evident of telogenesis due to the lack of mineralization in the void space such as dolomite and silica from burial diagenesis. If hydrothermal fluids or Mg-rich brines infiltrated the Fort Terrett Formation and these void spaces existed, they would mostly likely be infilled. The lack of these minerals only suggests this dissolution is post uplift and exposure.
DOLOMIZATION MODEL

The Fort Terrett Formation contains various zones of dolomization and dedolimination, specifically F2 and F6 of the facies model. Dolomite observed during the petrographic analysis (Figure 44) are described as euhedral, having rhombic crystal habits in F2 or xenotopic, infilling much of the void space as a cement in F6. Several rhombs also exhibited “shadows” or dim cloudy centers which is also indicative of overgrowths or zoning. Dolomization for the Fort Terrett Formation has been heavily debated and each model proposed will be dissected below.

Several models for dolomization have been proposed for the Fort Terrett Formation in both Kimble and Mason Counties in central Texas. Butler and Kinsman (1969) proposed supratidal dolostone formations were penecontemporaneously dolomitized. This model is known as the Persian Gulf model and illustrates that large anhydrite nodules in sabkha deposits would be dissolved, then eventually replaced by silica. This phenomenon seems to be comparable to dolomization within the Fort Terrett Formation, however, the Persian Gulf model also distinguished crystal sizes of dolomite rhombs. In sabkha facies, crystal face diameters could range from 1 to 20 microns. The
issue with this model is dolomization that occurs in subtidal to intertidal deposits could exhibit crystal faces up to 80 microns. There are also several instances where allochems or burrows are selectively dolomitized. In the Fort Terrett Formation, the largest crystal faces reach only about 3 microns and there is very little evidence of anhydrite nodules or selective dolomization (Butler 1969).

The next model proposed involves a method of dolomization using the base of a fresh water lens. Postulated by Hansahw in 1971, the fresh water lens would penetrate high porosity formations where Mg rich water settling near the bottom would precipitate dolomite in subtidal to intertidal facies. However, in 1974 Steinen conducted a case study of fresh water lens dolomization on the island of Barbados. His study concluded that fresh water lenses could in fact penetrate metastable carbonates but that no dolomization took place at the base of the lens or below it. The following model was established by Jacka (1975) from Texas Tech University. His study of subsurface carbonates in the Permian Basin explained dolomization of aragonitic mud or shells could produce neomorphic dolomite with euhedral rhombic fabrics. He also indicated that the dolomite could be replaced by calcite but maintaining that dolomite fabric or texture. This showed dedolomiaztion was common when aragonitic material was dolomitized. The point of conjecture for this “model” is that Jacka infers that neomorphic
dolomization of aragonite results in an abundance of intercrystalline porosity. While there is preserved intercrystalline porosity in the Fort Terrett Formation that is dolomitized, there are also other types of dolomization present. Jacka also doesn’t explain the origin of dolomization within that pore space. The mechanism that drives dolomization in the Fort Terrett Formation would have most likely replace the void space left behind by evaporites as Jacka suggests but is not fully described in his study.

This leaves two dolomization models left that were both considered by Fisher and Rodda (1969) and Rose (1972). Fisher and Rodda looked at the seepage reflux model of Edwards Group carbonates in Mason County while Rose looked at evaporative pumping in the same formations in Mason County. The seepage reflux model proposes that hypersaline waters would penetrate lower lying strata due to density variations. They could also be continually recharged by tidal influences or even storms. This could then allow for intertidal to supratidal deposits to become dolomitized. The evaporative pumping model by Rose (1972) suggested that Mg-rich brines could induce an upward flow into younger strata by a decrease in hydrodynamic potential. Both of these models are very similar in how dolomite replaces void space in the Fort Terrett Formation and are further discussed by Widodo and Laya (2017). In their paper discussing controls on diagenesis and dolomization, Widodo and Laya (2017) state that carbonate muds would have to contain a permeability of
240mD to allow fluid flow. However, Holocene to modern day carbonates from Florida and the Bahamas contain permeability ranges of 100mD to 203mD in older Holocene carbonate sediments (Sawatsky 1981). This then translates to another diagenetic influence on carbonates which would allow for greater permeability and penetration of Mg rich brines. In Mason County, the lower Edwards Group is dominated by mudstone facies in succession with skeletal-fenestral wackestone facies (Widodo and Laya 2017). That addition of fenestral porosity within those facies in Mason County contribute to extra porosity within the Fort Terrett formation and increase permeability. In Kimble County near Junction, within the study area of this thesis, the Fort Terrett Formation is mostly a dominated mudstone facies (F1, F4, F5, and F6) with a bivalve wackestone to packstone (F2 and F3) in succession. F2 and F3 along with a few other facies are also dominated by fenestral porosity as well interparticle and moldic porosity (Figure 45). This addition of fenestral porosity to these facies impacts porosity in mudstone dominated facies. Additionally, Widodo and Laya continue to describe how dolomite crystals in fenestral void space are continually fed by Mg rich brines. Coarsening occurs along with overgrowths developing on crystal faces. “Multiple zones of dolomite cortex overgrowths are distinguishable… for the Fort Terrett and Hensel Formations” (Widodo and Laya 2017). This is indicative of Type 3 dolomite (Figure 46) within the Fort Terrett Formation and is observed in all dolomitized facies in
the Fort Terrett Formation near Junction. Type 3 dolomite displays extensive coarsening and growth to a medium size. Development of euhedral dolomite rhombs and overgrowths are associated with increasing fabric maturity (Katz 1971). Observed in F2 of the Fort Terrett Formation near Junction, this facies demonstrates both euhedral, planar dolomite rhombs, instances of coarsening with the overgrowth inclusions seen on some of the crystal faces. This criteria suggests that F2 was dolomitized and continually influenced by Mg rich brines. Type 3 dolomite exists in F2 is also heavily influenced by vuggy and fenestral porosity. Type 4 dolomite is also observed as a cement or selectively replacing allochems in the matrix (Figure 47). The seepage reflux model (Figure 48) proposed by Fisher and Rodda (1969) is the most well accepted and better choice of the two models when compared to the evaporative pumping model. Carbonate muds could contain permeability up to values of 230 mD based on Holocene carbonates as previously stated. The addition of allochems creating packstone facies (F2) in succession with mudstone facies could enhance porosity as well as permeability through those facies. A primary problem with this model is the lack of enhanced porosity that was proposed by Widodo and Laya (2017). The enhanced porosity by interconnected pore spaces through fenestral void space, that allows Mg rich brines to continually feed dolomization, occurs during burial and telogenesis for this study. Seepage reflux would have to occur during a significant drop of sea level and exposure
for F2 and F6, but that extra fenestral void space would have not been produced yet. Meteoric processes would also be involved but there are little to no indications of meteoric influence on the Fort Terrett Formation near Junction. The seepage reflux model heavily relies on changes in sea levels as evaporation of sea water occurs. Another primary issue with this model is that lack of evaporites observed in hand samples and thin section and a primary exposed surface. Sulfate rich minerals should occupy the space within the void space of the Fort Terrett Formation. Reflux of Mg, Cl, and SO$_4$ rich brines occurs due to changes in hydrodynamic pressures. Those brines then infiltrate underlying facies with enhanced porosity over time and begin to precipitate dolomite along with other evaporites such as gypsum. The lack of these minerals could be explained by events of fresh water flushing during telogenetic events. Fresh water flushing during exposure of the Fort Terrett Formation during the late Paleogene (Anaya 2004) could indicate why minerals such as gypsum of anhydrite nodules are not found today. The addition of oxidation which is observed by the rich dark brown spots seen in thin section or the faint orange bands in hand sample also indicate telogenic events influencing the Fort Terrett Formation. However, there is no evidence of evaporites or their remnants in the petrographic analysis. The crystal habit of evaporites (needle-like) like gypsum should still be preserved in thin section after being replaced or dissolved, but there is no evidence of this occurring.
There is also no direct evidence of an exposed surface near the study area to suggest sea levels lowered far enough. The lack of extensive bioturbation in these facies, ryzoliths, and desiccation cracks contributes to an issue with this model.

The models proposed for the purpose of this thesis are low grade hydrothermal dolomization by burial and hydrothermal fluid activity. Burial dolomization will be used to explain hydrothermal dolomization by shallow burial while hydrothermal dolomization will be used to explain fluid migration and subsequent dolomization for the purpose of this thesis. Hydrothermal diagenesis for the purpose of this study will be an increase in transient temperatures of 5°C or more. Hydrothermal activity is generally discussed in association with magmatic systems and heated waters near 100 °C. Hydrothermal is commonly used for dolomization precipitated into a host rock at a temperature higher than the ambient temperature of that rock (Davies, Smith Jr. 2006). Late stage burial dolomization would have most likely occurred after the deposition of the Austin Chalk during very late Cretaceous (Campanian age) and produced saddle dolomite. This could have had deposition of several formation on top of the Fort Terrett Formation before they were exposed and eroded away. This would include the Segovia (avg thickness of 69 m), Georgetown (avg thickness of 8 m), Del Rio (avg thickness of 10 m), Buda (avg thickness of 12 m), Eagle Ford (avg thickness of 80 m),
and Austin Chalk formations (avg thickness of 130 m) burying the Fort Terrett Formation roughly 300 meters. This doesn’t account for possible tertiary clastic material or other possible carbonate strata that could have been deposited in the area. This burial could account for an increase in rock temperature of ~10°C when using a 30°C/Km increase standard. Saddle dolomite is defined as being xenotopic, fine grained, having curved surfaces, and a sweeping extinction, which indicates a distorted crystal lattice. Using the dolomite texture classification (Figure 49) proposed by Gregg and Sibley (1984) for burial dolomites, dolomite textures have been established to better understand origin. Dolomites in the upper facies (F6) (Figure 50) exhibit a textural maturity for Idiotopic – S, and Xenotopic –C texture, which presents almost mosaic, with irregular boundaries and poor to moderate sweeping undulatory extinction. Crystals are anhedral to subhedral, averaging 0.2mm-0.5mm across, and infilling as the predominate matrix. Xenotopic-C (cement) dolomites are infilling, irregular dolomite crystals that have been referred to as baroque or saddle-shaped crystals (Figure 51). Saddle dolomites are easily observed in thin section by a sweeping extinction and round edges that turn towards terminations (Gregg, Sibley 1984). Idiotopic-S (subhedral) dolomites are classified as low-porosity dolomites. This texture is defined by straight boundaries and preserved crystal faces. This texture can also include xenotopic dolomites (Gregg, Sibley 1984). Saddle dolomite is also useful as a
geothermal indicator, due to being produced in a temperature range of 60°-150°C (Radke and Mathis, 1980). This occurrence of saddle dolomite is evident of late stage diagenesis and hydrothermal activity. The appearance of saddle dolomite normally occurs as pore-filling cement or in veins and fractures (Hird et al., 1987) which is observed in F6. Burial was deep enough to induce a type hydrothermal dolomization that was the product of an increase in local geothermal temperature and pressure.

The second event of dolomization is explained by hydrothermal activity. Dolomite in F2 is described as porphyrotopic with euhedral rhombs being matrix supported (Figure 52). Free-floating rhombs in a limestone matrix have been categorized as a texture called idiotopic-P (porphyrotopic). These dolomites have been described to have sweeping extinction (Figure 53) under crossed polarized light or a “dirty” appearance (Katz, Mathews 1977). Friedman (1965) described this kind of dolomite texture as porphyrotopic in his texture classification system for burial (late stage) dolomization. This type of late stage dolomization will be explained by the addition of hydrothermal fluids into an already geothermally active system. Late Cretaceous volcanic activity reached a maximum during Austin Chalk and lower Taylor Group deposition around 80mya (Ewing and Caran 1982). Though this volcanism occurred roughly 100 miles east of present day Junction, it could have increased the geothermal gradient for the area. Hydrothermal mineralization was
conventionally accepted with White's (1957) definition of hydrothermal. His
definition states hydrothermal being “aqueous solutions that are warm or hot
relative to the surrounding environment.” This is without any indication of
needing a proximal magmatic source, fault systems, or fluid source. The
addition of silica precipitates, within some of the facies, especially facies with
significant porosity, also suggests hydrothermal diagenesis. Chalcedony is a
common hydrothermal alteration of silica or quartz. Natural chalcedony
typically forms at near surface conditions (<1 km) at low temperatures. These
conditions are restricted to sedimentary rocks and low-temperature
hydrothermal environments such as shallow burial (White, Corwin 1961). As
stated above for burial dolomization, ambient temperatures increased roughly
10°C. With the addition of hydrothermal fluids from proximal volcanism, the
regional geothermal gradient would have increased. This would have allowed
for hydrothermal fluids to penetrate and precipitate chalcedony and
hydrothermal dolomite.

Dolomite emplacement in the Fort Terrett Formation near Junction has
been heavily debated and the seepage reflux model has been argued by
many in previous works. This is analogous to the Fort Terrett Formation in
Mason County where Widodo and Laya (2017) use the seepage reflux model
to describe dolomization patterns seen there. However, enhanced porosity in
the Fort Terrett Formation as the primary mechanism for fluid flow of Mg rich
brines would not have been able to occur near Junction. Vuggy and fenestral porosity did not occur until after exposure of the Fort Terrett Formation near present day Junction. Therefore, the seepage reflux or evaporative pumping models would not work due to permeability values being too low. There is also the issue of evaporites missing from the Fort Terrett as well and evidence for an exposed surface. Based on textural maturity, crystal morphology, and how the dolomite is emplaced in the Fort Terrett Formation, hydrothermal dolomization is a better model for the Junction area. Water depths were too deep to allow for meteoric processes or brine infiltration. Therefore, dolomization is classified as an burial event during late stage burial. Two separate instance of dolomization occurs. The first is observed in F6 as a predominately xenotopic cement dolomite. This is has been established as burial dolomization producing poor saddle dolomites due to an increase of local geothermal temperature by continual burial throughout the late Cretaceous. The second event occurs penecontemporaneously with geothermal increase and the addition of hydrothermal waters. During the very late Cretaceous (~80mya), south and central Texas experienced regional volcanism. This volcanism would have generated another increase in regional geothermal temperature as well as mobilized hydrothermal waters into the surrounding regions. Hydrothermal dolomization is evident due to sweeping
extinctions observed in idiotopic dolomites from F2 as well as the addition of chalcedony in several facies.
Figure 44. These thin sections show dolomite observed during the petrographic analysis. Two types of dolomite are seen and are described as euhedral, having rhombic crystal habits in F2 or xenotopic, infilling much of the void space as a cement in F6. Type 4 dolomite (A.) presents itself as a cement either infilling or replacing the existing matrix. Type 3 dolomite (B.) is euhedral, displaying well developed crystal faces. Several rhombs also exhibited “shadows” or dim cloudy centers which is also indicative of overgrowths or zoning.
Figure 45. This thin section shows moldic porosity within a bivalve shell. This is significant for the reflux model due to the enhanced porosity by dissolution. Also note there is vuggy and fenestral porosity (A.) in this thin section as well. However, this dissolution occur post dolomitization, most likely during telogenesis when fresh water flushing occurred.
Figure 46. This thin section shows euhedral, planar dolomite (A) in micrite matrix with overgrowth centers which indicates Type 3 dolomite. There is also indications of dedolomization (B) where a faint dolomite rhomb has been replaced by calcite but has maintained the crystal habit of the dolomite as well as the overgrowth.
Figure 47. This thin section shows dolomite in a micrite matrix but also shows selective dolomization within a foraminifera (A). Dolomite as a cementation indicates Type 4 dolomite and is very common in F6 of the Fort Terrett Formation. Also to note is dolomite in this facies is anhedral to subhedral with curved crystal faces.
Figure 48. The seepage reflux model that is been proposed multiple times for the Fort Terrett Formation. F2 is exposed after the evaporation of sea water occurs dropping sea level (yellow arrows) followed by the reflux of Mg, Cl and SO₄ rich brines (orange layer) into underlying strata of F1 though permeable flow paths (red arrows). Dolomite then precipitates in the void space (gray rhombohedrons). The issue with this model is lack of sedimentary features that would indicate an exposed surface as well as evaporites missing.
Figure 49. This is a diagram showing the classification system for dolomite textures used by Gregg and Sibbley (1984). This classification was constructed to differentiate dolomites based on crystal morphology, crystal edge geometries, and matrix. The left side is for idiotopic textures that are generally euhedral to subhedral. Crystal boundaries are more common and easily observed. The right side is xenotopic textures where crystal boundaries are curved, or even distorted. Most dolomites are anhedral and lack the common rhombohedral shape for xenotopic textures.
Figure 50. This thin section shows dolomites (A.) in (F6) which have a textural maturity of Idiotopic – S, and Xenotopic – C texture. These two textures appear almost mosaic, with irregular boundaries and poor to moderate sweeping undulatory extinction. Distorted crystal faces are also very common for these textures and Type 4 dolomite. Crystals are anhedral to subhedral, averaging 0.2mm-0.5mm across, and infilling as the predominate matrix.
Figure 51. This thin section shows a close up of saddle dolomite. Most crystals observed in F6 are anhedral to subhedral. Xenotopic-C (cement) dolomites are irregular dolomite crystals that have been referred to as baroque or saddle-shaped crystals (Black arrows). Idiotopic-S (subhedral) dolomites are defined by straight boundaries and preserved crystal faces (Red Arrows). Both these textures commonly occur together.
Figure 52. This thin section shows dolomite in F2 and is described as porphyrotopic with euhedral rhombs being matrix supported. Free-floating rhombs in a limestone matrix have been categorized as a texture called idiotopic-P (porphyrotopic). This is also evident of type 3 dolomite due to the addition of overgrowths. This could account for hydrothermal waters continually feeding these dolomite rhombs.
Figure 53. These thin sections shows the undulatory extinction observed in both idiotopic and xenotopic textures of dolomite. Thin section (A.) shows a euhedral dolomite rhomb before extinction. Notice there are very faint shadows already inside the crystal face which gives it the “dirty” appearance. In (B.), the thin section has been slightly turned showing a weak sweeping of extinction from left to right (The entire crystal doesn’t turn black). This type of extinction is very common for burial or late stage hydrothermal dolomization.
DISCUSSION

The Fort Terrett Formation has undergone several facies changes as well as diagenetic alterations since deposition in the late Albian. Facies and petrographic analysis has shown that the Fort Terrett lithology ranges from bioclastic wackestones to packstones with a diverse set of allochems mostly comprised of bivalves, peloids, milioids, and gastropods. Chert nodules are common in the thin bed unit where dissolution is the very prevalent. Dolomite is also common in facies with a high percentage of void space as euhedral, Type 4 dolomite as seen in F2 or as weak, subhedral saddle dolomite in F6. Dolomite in F2 is well developed dolomite and matrix supported where F6 dolomite is predominately a cement by either infilling or replacing. Based on the transition of facies, a depositional environment model (Figure 54) was constructed to illustrate where these changes take place in the Fort Terrett Formation as well as interpreted sea level changes. Sea level changes are just for the purpose of this study and do not reflect overall changes for the entire Western Interior Seaway or the Comanche Shelf. The following will dissect Figure 54 to clarify the transition in facies trends as well as discuss the criteria used to distinguish changes in the fort Terrett Formation.
The model begins with an overall transgression sequence and the deposition of The Basal unit in moderately deep water. Depths could range anywhere from 5 to 10 meters based on quiet, mostly undisturbed waters inferred from the petrographic analyses of F1. This is a subtidal environment with very little biodiversity until moving up section near F2 and the start of the Thin bed unit.

The Thin bed unit and F2 begin with a sudden drop in sea level. This can be best interpreted as a transition from subtidal to intertidal environments. In F2 biodiversity is slightly greater than F1, however, many allochems may have been dissolved, iron stained or replaced. The addition of dolomite in F2 suggests hydrothermal processes were involved. Water depths are interpreted to be very shallow to possible exposure of the Fort Terrett Formation for brief periods of time but there are no indication found in the study area to suggest long term exposure. Though there is no indication of hardground, the addition of quartz sediment in the matrix does suggest a terrigenous influence on this facies. Pore filling microspar cement is also noted in F2.

F3 is marked by another rise in sea level, the addition of chert nodules, and a significant increase in biodiversity. Water depths are still within the phreatic zone, but quiet enough for marine life to flourish. F3 is interpreted as a packed biomicrite with a large abundance of bivalves with some micropeloids
and calcareous sponges. Several of the bivalves in thin section are relatively linear in orientation which suggest imbrication or even a type of channel deposit. F3 being a packed biomicrite allows for additional pore space in between grains to form. That extra void space could have been exploited during burial diagenesis by silica rich waters. Those waters would enhance porosity, dissolved allochems, and precipitated chert. Petrographic analysis of chert in F3 shows at least 2 stages of silicification. Within allochems and fenestral porosity channels is subhedral to euhedral quartz grains. Along the rims of these void spaces is chalcedony or micro crystalline quartz, most likely due to a second event of silicification during burial and compaction by hydrothermal waters.

F4 begins with the onset of another drop in sea level and the start of the dolomitized unit. However, this is not as drastic as the drop from F1 to F2. Calcite spar and micrite dominate the matrix, suggesting some minor meteoric influence. There is also a sever lack in biodiversity compared to other facies in the Fort Terrett Formation. Dissolution may have removed any indication of marine life in F4 while calcite spar replaced those allochems. Dolomite is also absent from this facies despite a drop in seal level. Brine reflux was probably not induced in this facies simply because pore space was not adequate. This means permeability was not high enough to allow fluid flow of dense Mg-rich brines. As stated in the dolomitization section, permeability values would have to reach at least 240mD. With calcite spar filling in any additional void space, the
lack of packed grains, and very little indication of fenestral porosity, F4 would have not undergone seepage reflux if the Mg-rich brines were present. The reflux also calls for the evaporation of seawater to allow for recharge of brines. Water depths in F4 might not have gotten shallow enough from the transition from F3 to F4.

F5 begins with an increase of water depth and is interpreted as a subtidal environment. Biodiversity is abundant with preserved *Texigryphea* bivalves reaching very large sizes when compared to other facies. Porosity in this facies is not very common, however, there are indication of selective dissolution of the larger allochems. Silica rich hydrothermal waters reached F5, selectively dissolved allochems, and infilled the space with chalcedony. Petrographic analyses for F5 also show foraminifera, milioids, and echinoids in a mostly micrite matrix. F5 is representative as a standstill in sea level that maintained depths within the photic zone. This allowed marine life to thrive in a quiet water environment with moderate water depths. Porosity and the removal of allochems is evident of burial diagenesis due to the selective dissolution followed by chalcedony precipitation.

The final facies of the dolomitized unit and the Fort Terrett Formation for this study is F6. F6 begins with another sudden drop in sea level. Poorly washed micrite with dolomite dominates this facies. Allochem percentages
decrease moving up section from F5 to F6 and well developed dolomite is observable in the matrix. Euhedral dolomite rhombs are uncommon but those that do exist are accompanied by overgrowths. Saddle dolomite is also seen as a cement mixed with small amounts of a micrite matrix, which suggests Type 4 dolomite (Widodo and Laya 2017). Dolomite primarily observed as anhedral to subhedral with xenotopic-C to idiotopic-S textures. These textures and crystal habits are indicative of burial dolomization. Allochems that remain preserved have some dolomization but are still primarily calcite. Quartz grains are observed in thin sections for F6 indicating a terrigenous influence from the Llano islands could have has a small impact on this facies. Dolomite makes up almost 50% of the matrix percentage based on point count averages for this facies. This means there was significant dissolution and replacement or overprinting by dolomite as well as a lack of allochem grains for F6. Being the last facies up section for the Fort Terrett Formation, burial diagenesis would have to account for the enhanced porosity. The Segovia Formation along with several others buried the Fort Terrett Formation during the late Albian. Burial depths are indicated to being significant due to the presence of iron staining, selective dissolution, and silica replacement which shows a dysoxic environment (Ellis 1986). Burial depths may not have been deep enough to induce fractures or preferential pathways for fluid flow though.
Figure 54. This shows a depositional environment model for the 6 facies as well as an interpreted sea level curve for the purpose of this study. A sea level curve is inferred based on changes in depositional environment but does not represent sea levels for the entire Comanche shelf.
CONCLUSIONS

The Fort Terrett Formation is found in outcrops near Junction, Texas in road cuts and dominates the upper topography surrounding Junction. Based on stratigraphic analysis and comparison of lithostratigraphy from Wilkerson (2018) and Rose (1972), the Fort Terrett Formation is disconformably bounded by the Glen Rose Formation below and the Segovia Formation above. The Walnut Formation was omitted from the stratigraphic column by concluding the marl beds were part of the Glen Rose Formation and the Texigryphea is also a key fossil for the Glen Rose Formation. The second notable formation not observed was the Kirschberg Evaporative unit. Though the Kirshberg Evaporites are prevalent further North West toward the Llano Uplift, the evaporites were not deposited near junction. There is a complete lack of evaporite minerals or traces that they were diagenetically altered. Deposition of the Fort Terrett occurred within the shallow, quiet waters during the late the Albian of the Lower Cretaceous on the Comanche Platform shelf margin. The Fort Terrett Formation is primarily a bivalve rich wackestone to packestone limestones in hand samples. Petrographic analyses of the 16 thin sections cut showed a range of sparse biomicrites, poorly washed sparites, and packed
biomicrites. From those 16 thin sections a facies and diagenesis analysis was conducted and determined there were 6 significant facies changes in the Fort Terrett Formation near Junction. These changes were dependent on lithology changes, bioclastic percentage and diversity, diagenetic features, and matrix. Porosity was also valuable in assessing facies trends as well as determining diagenetic events. Facies changes in the Fort Terrett Formation included transitions between subtidal and intertidal depositional environments. Supratidal environments have been proposed by previous studies, however, there is a lack of evidence to suggest exposure during the deposition of the Fort Terrett Formation near Junction. Subtidal to intertidal environment changes were noted by an increase in biodiversity such as bivalves. Dolomization in the Fort Terrett Formation is very well noted in previous studies in Kimble County as well as most of west central Texas. Dolomization for the Fort Terrett Formation near Junction includes several models that have been proposed, however, the Burial Dolomization and Hydrothermal Fluid Dolomization models are used for the purpose of this thesis. Burial of the Fort Terrett Formation by several stratigraphic units up to the Austin Chalk, as well as the addition of hydrothermal waters from Late Cretaceous volcanism are responsible for the dolomization events that occurred. Dolomization is just one of several diagenetic events to occur to the Fort Terrett Formation. Four primary diagenetic events are modeled for the study area and this thesis.
Shallow marine diagenesis, early burial, late burial associated with hydrothermal activity, and telogenesis are the controlling events on diagenetic changes observed in the petrographic analysis. The Fort Terrett Formation undergoes several mineralogy changes due to diagenesis and changes in depositional environment. The addition of chert, micro spar, dolomite, and oxide staining is evident that there are dynamic changes to this carbonate. Many of these changes are also analogous with facies and diagenetic analyses done on the Fort Terrett Formation in surrounding counties and also modernizes the depositional model for deposition near Junction, Texas. This thesis also provides a new, modern model for dolomization in the Fort Terrett Formation near Junction, Texas.
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APPENDIX A. THIN SECTIONS

Appendix A. is the petrography done on all 16 thin sections used for the petrographic and facies analyses of the Fort Terrett Formation. Included is a brief description of each thin section as well as the matrix percentages. Thin sections are numbered 001-016 for reference for this thesis.
Figure 55. This thin section shows thin section 001 at 4X magnification. This thin section shows a sparse biomicrite with preserved bivalve shell fragments (Gryphaea) (A.) and calcareous sponge (B.) allochems in a micrite matrix.

Matrix Percentage
Micrite 82%
Bivalve Fragments 8%
Milid 7%
Calcareous Sponges 2%
Other < 1%
Figure 56. This thin section shows thin section 002 at 10X magnification. This thin section is a sparse biomicrite with preserved bivalve shell fragments (A.) and a milloid (B.) in a micrite matrix.

Matrix Percentage
Micrite 80%
Bivalve Fragments 12%
Milloid 6%
Calcereous Sponges 1%
Other < 1%
Figure 57. This thin section shows thin section 003 at 4X magnification. This thin section shows an almost complete lack of allochems in a poorly washed calcite spar matrix. Lack of allochems could be due to dissolution indicated by the vuggy porosity.

Matrix Percentage
Calcite Spar 96%
Echinoids 3%
Other 1%
Figure 58. This thin section shows thin section 004 at 10X magnification. This thin section shows a poorly washed biosparite with a preserved bryozoan (B.) There is also an indication of dolomite (A.) within the matrix. Quartz (C.) is also observed within the matrix indicating a terrigenous influence. (Stained Alizeran Red)

Matrix Percentage
Calcite Spar 48%
Dolomite 38%
Quartz 6%
Bivalves 5%
Other 3%
Figure 59. This thin section shows thin section 005 at 10X magnification. This thin section shows a packed biomicrite with bivalve fragments (A.) in a micrite matrix. Some wall structure of the bivalves is preserved. (Stained Alizeran Red)

Matrix Percentage

Micrite 46%
Bivalve Fragments 52%
Calcareous Sponges 1%
Other < 1%
Figure 60. This thin section shows thin section 006 at 10X magnification. This thin section shows a packed biomicrite with bivalve fragments (A.) in a micrite matrix. Some wall structure of the bivalves is preserved. (Stained Alizeran Red)

Matrix Percentage
- Micrite 47%
- Bivalve Fragments 49%
- Micro Peloids 1%
- Calcareous Sponges 1%
- Green Algae 1%
- Other < 1%
Figure 61. This thin section shows thin section 007 at 4X magnification. This thin section shows a sparse biomicrite with bivalve fragments (A.) and foraminifera (B.) in a micrite matrix. Other notable allochems include lithic fragments which are not very common for this facies or formation.

Matrix Percentage

Micrite 67%
Bivalve Fragments 28%
Lithic Fragments 3%
Calcareous Sponges 1%
Other < 1%
Figure 62. This thin section shows thin section 008 at 10X magnification. This thin section shows microcrystalline chert. Within this chert are channels of mega filled quartz (A.) with chalcedony (B.) along the rims of the porosity channels.

Matrix Percentage

Chert 84%
Quartz 11%
Chalcedony 3%
Bivalves 2%
Figure 63. This thin section shows thin section 009 at 10X magnification. This thin section shows microcrystalline chert. Within this chert are channels of mega filled quarts channels and a mollusk shell (A.) with subhedral quartz (B.) filling the void space and outer edges of the shell.

Matrix Percentage

Chert 86%
Quartz 9%
Chalcedony 3%
Bivalves 2%
Mollusk 1%
Figure 64. This thin section shows thin section 010 at 10 X magnification. This thin section shows an almost complete lack of allochems in a poorly washed calcite spar matrix. Lack of allochems could be due to dissolution indicated by the vuggy porosity.

Matrix Percentage
Calcite Spar 94%
Bivalves 3%
Echinoids 2%
Other <1%
Figure 65. This thin section shows thin section 011 at 10X magnification. This thin section shows a sparse biosparite with a preserved bivalve shell fragments (Gryphaea) (A.) in a calcite spar matrix. Interior of shell has been replaced by chalcedony. (B.) There is also intraparticle porosity that appears fenestral. (C.) (Stained Alizeran Red)

Matrix Percentage
Calcite Spar 86%
Bivalves 10%
Peloids 2%
Echinoids 1%
Other <1%
Figure 66. This thin section shows thin section 012 at 10X magnification. This thin section shows a poorly washed biosparite with a bivalve shell. (A.) Again, dolomite is part of the matrix suggesting the supratidal facies. Also, a well-developed dolomite rhombohedrum is observed. (B.) (Stained Alizeran Red)

Matrix Percentage
Calcite Spar 45%  
Dolomite 42%  
Quartz 5%  
Bivalves 5%  
Other 3%
Figure 67. This thin section shows thin section 013. This thin section shows a sparse biomicrite with a preserved bivalve shell (Gryphaea) (A.) in a poorly washed calcite spar/dolomite matrix. Irregular foliated structure consist of calcite lamellae within the preserved shell. Also present within the matrix are small clasts of subrounded quartz grains (B.). (Stained Alizeran Red)

Matrix Percentage
Calcite Spar forty%
Dolomite 37%
Micrite 10%
Peloids 6%
Bivalves 6%
Other < 1%
Figure 68. This thin section shows thin section 014 at 10X magnification. This thin section shows a poorly washed sparite. There is also an indication of dolomite (white grains) within the calcite spar matrix. Several of the dolomite grains have a dark shadow centered in the crystal which is an indication of overgrowths. (Stained Alizeran Red)

Matrix Percentage
- Calcite Spar 49%
- Dolomite 33%
- Micrite 12%
- Bivalves 6%
- Other < 1%
Figure 69. This thin section shows thin section 015 at 10X magnification. This thin section shows a poorly washed sparite. There is also an indication of dolomite (white grains) within the calcite spar matrix. Several of the dolomite grains have a dark shadow centered in the crystal which is an indication of overgrowths. Brownish iron oxide is also observed within the rims of the miliol (A.) centered in the thin section.

Matrix Percentage
Calcite Spar 51%
Dolomite 31%
Micrite 9%
Bivalves 5%
Other 4%
Figure 70. This thin section shows thin section 016 at 4 X magnification. This thin section shows an almost complete lack of allochems in a drusy mosaic calcite matrix. The calcite in this thin section is exceptionally larger and anhedral compared to other thin sections with calcite spar. Lack of allochems could be due to dissolution indicated by the vuggy porosity. (B.)

Matrix Percentage

Calcite Spar 96%
Bivalves 2%
Other 2%
APPENDIX B. MEASURED SECTIONS

Appendix B will contain measured section descriptions as well as correlation charts for the study area. These were used to generate a facies model for the study area as well as correlate lithological changes. The map below shows the locations of the measured sections as well as transects for both correlations. The red line is for (A-A’) and the blue line is for (B-B’). Figures in this section are not listed in the LIST OF FIGURES.
The Basal unit

Middle Thin bed unit

Upper Dolomite Unit
**Upper Dolomite Unit:** Limestone. Micrite to wackestone. Fresh surface is a bright yellowish white. Weathers to a dull grey or tan. Tarnishes to a dark grey. Weathers to a sheer cliff. Thickly bedded. Allochems are present but decrease further up section. Lower contact conformable with The Thin bed unit. Upper contact is not observed.

**Middle The Thin bed unit:** Limestone. Wackestone. Fresh surface is a bright yellowish white. Weathers to a dull light grey or tarnishes black. Weathers to a sheer cliff. Thinly bedded. Thinly laminated with bivalve hash. Bioturbation is present as well as significant dissolution. Dark brown to black chert nodules are present. Lower contact is conformable with The Basal unit.

**The Basal unit:** Limestone. Micrite to wackestone. Fresh surface is a bright yellowish white. Tarnishes to a dark grey on weathered surfaces. Weathers to a sheer cliff. Thick to massively bedded. Bioturbated. Gastropods and bivalves are observable in some localities which suggest shallow water environment. Dissolution is present. Lower contact is not observed. Upper contact is marked by a white chalk/marl bed with streaks of orange iron oxide staining.
The Basal unit

Middle Thin bed unit

Upper Dolomite Unit

Fort Terrett Formation

Albian
**Upper Dolomite Unit:** Limestone. Micrite to wackestone. Fresh surface is a bright yellowish white. Weathers to a dull grey or tan. Tarnishes to a dark grey. Weathers to a sheer cliff. Thickly bedded. Allochems are difficult to distinguish. Lower contact conformable with The Thin bed unit. Upper contact is not observed.

**Middle The Thin bed unit:** Limestone. Wackestone. Fresh surface is a bright yellowish white. Weathers to a dull light grey or tarnishes black. Weathers to a sheer cliff. Thinly bedded. Thinly laminated with bivalve hash. Bioturbation is present as well as significant dissolution. Dark brown to black chert nodules are present. Lower contact is conformable with The Basal unit.

**The Basal unit:** Limestone. Micrite to wackestone. Fresh surface is a bright yellowish white. Tarnishes to a dark grey on weathered surfaces. Weathers to a sheer cliff. Thick to massively bedded. Bioturbated. Gastropods and bivalves are observable in some hand samples which suggest shallow water environment. Dissolution is present. Lower contact is not observed. Upper contact is marked by a white chalk/marl bed with streaks of orange iron oxide staining. Chalk bed looks to thin out moving west.
142

The Basal unit

Middle Thin bed unit

Upper Dolomite Unit

Albian

Edwards

Fort Terrett

15 ft

10 ft

5 ft

0 ft
### Upper Dolomite Unit:
Limestone. Micrite to wackestone. Fresh surface is a bright yellowish white. Weathers to a dull grey or tan. Tarnishes to a dark grey. Weathers to a sheer cliff. Thickly bedded. Allochems are difficult to distinguish and almost completely lacking. Lower contact conformable with The Thin bed unit. Upper contact is not observed.

### Middle The Thin bed unit:
Limestone. Wackestone. Fresh surface is a bright yellowish white. Weathers to a dull light grey or tarnishes black. Weathers to a sheer cliff. Thinline bedded. Thinly laminated with bivalve hash. Possible onset of biostrome based on increase in fossil content. Bioturbation is present as well as significant dissolution. Dark brown to black chert nodules are present but not as prevalent. Lower contact is conformable with The Basal unit.

### The Basal unit:
Limestone. Micrite to wackestone. Fresh surface is a bright yellowish white. Tarnishes to a dark grey on weathered surfaces. Weathers to a sheer cliff. Thick to massively bedded. Bioturbated. Gastropods and bivalves are observable in some hand samples which suggest shallow water environment. Dissolution is present. Lower contact is not observed. Upper contact is marked by a white chalk/marl bed with streaks of orange iron oxide staining.
**Glen Rose Formation:** Marl to Limestone. Wackestone. Fresh surface is a bright yellowish white. Weathers to a dull tan. Weathers to a steep slope. Thinly bedded and interbedded limestones. Bivalves are abundant near the upper surface. Burrowed. Lower contact is disconformable with the Hensel Formation.

**Hensel Formation:** Marl to siltstone. Interbedded red paleosol beds are observed and are intermittent. Fresh surface that isn’t a red bed is yellowish white. Weathers to a slight grey or light tan. Upward fining is observed moving from a claystone to a siltstone. *Exogyra* fossils were observed and collected. Lower contact not observed.
The Basal unit

Glen Rose Formation

Hensel Formation

Hensel Formation

Glen Rose Formation

Fort Terrett Formation

Edwards

Trinity

Aptian

Albian
<table>
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<tr>
<th><strong>The Basal unit:</strong> Limestone. Micrite to wackestone. Fresh surface is a bright yellowish white. Tarnishes to a dark grey on weathered surfaces. Weathers to a sheer cliff. Thickly bedded. Bioturbated. Fossils are observable in some hand samples but are not discernable. Dissolution is present. Lower contact is not observed. Upper contact is not marked by white chalk bed nor observed.</th>
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<td><strong>Glen Rose Formation:</strong> Marl to Limestone. Wackestone to Packstone. Fresh surface is a bright yellowish white. Weathers to a dull tan. Weathers to a steep slope. Thinly bedded and interbedded limestones. Interbedded limestones are thicker and more predominant in this outcrop. Bivalves are abundant near the upper surface and represent a bioherm. Burrowed. Lower contact is disconformable with the Hensel Formation.</td>
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<tr>
<td><strong>Hensel Formation:</strong> Marl to siltstone. Interbedded red paleosol beds are observed and are intermittent. Red beds aren't as noticeable and look more faint. Fresh surface that isn't a red bed is yellowish white. Weathers to a slight grey or light tan. Upward fining is observed moving from a claystone to a siltstone. <em>Exogyra</em> fossils were observed and collected. Lower contact not observed</td>
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Hensel Formation

Glen Rose Formation

The Basal unit

Middle Thin bed unit
Middle The Thin bed unit: Limestone. Wackestone. Fresh surface is a bright yellowish white. Weathers to a dull light grey or tarnishes black. Weathers to a sheer cliff. Thinly bedded. Thinly laminated with bivalve hash. Bioturbation is present as well as significant dissolution. Dark brown to black chert nodules are present. Lower contact is conformable with The Basal unit

The Basal unit: Limestone. Micrite to wackestone. Fresh surface is a bright yellowish white. Tarnishes to a dark grey on weathered surfaces. Weathers to a sheer cliff. Thick to massively bedded. Bioturbated. Gastropods and bivalves are observable in some localities which suggest shallow water environment. Dissolution is present. Lower contact is disconformable with the Glen Rose Formation. Upper contact is marked by a white chalk/marl bed with streaks of orange iron oxide staining.

Glen Rose Formation: Marl to Limestone. Wackestone to Packstone. Fresh surface is a bright yellowish white. Weathers to a dull tan. Weathers to a steep slope. Thinly bedded and interbedded limestones. Interbedded limestones are thicker and more predominant in this outcrop. Marl/Claystone beds are also much thick to massively bedded. Bivalves are abundant near the upper surface. Burrowed. Lower contact is disconformable with the Hensel Formation.

Hensel Formation: Marl to siltstone. Interbedded red paleosol beds are not observed here. Fresh surface that isn’t a red bed is yellowish white. Weathers to a slight grey or light tan. Upward fining is observed moving from a silty sandstone to a silty claystone. *Exogyra* fossils were observed and collected. Lower contact not observed
The Basal unit

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<th>Glen Rose Formation</th>
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<td>Aptian</td>
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<tr>
<td>Albian</td>
<td>Edwards</td>
<td>Fort Terrett Formation</td>
</tr>
</tbody>
</table>

Glen Rose Formation

0 ft

5 ft
**Glen Rose Formation:** Marl to Limestone. Wackestone. Fresh surface is a bright yellowish white. Weathers to a dull tan. Weathers to a steep slope. Thinly bedded and interbedded limestones. Bivalves are abundant near the upper surface. Burrowed. Lower contact is disconformable with the Hensel Formation.

| Hensel Formation: Marl to siltstone. Interbedded red paleosol beds are observed and are intermittent. Fresh surface that isn’t a red bed is yellowish white. Weathers to a slight grey or light tan. Upward fining is observed moving from a claystone to a siltstone. *Exogyra* fossils were observed and collected. Lower contact not observed |
Albian  Edwards  Fort Terrett Formation  5 ft

0 ft  Upper Dolomite Unit
**Upper Dolomite Unit**: Limestone. Micrite to wackestone. Fresh surface is a bright yellowish white. Weathers to a dull grey or tan. Tarnishes to a dark grey. Weathers to a sheer cliff. Thickly bedded. Thick laminations or bedding in between massive beds. Dissolution may have enhanced bedding plane appearance in this outcrop. Dissolution is heavily present. Allochems are not observed. Lower contact not observed. Upper contact is not observed.
**Upper Dolomite Unit:** Limestone. Micrite to wackestone. Fresh surface is a bright yellowish white. Weathers to a dull grey or tan. Tarnishes to a dark grey. Weathers to a sheer cliff. Thickly bedded. Allochems are difficult to distinguish and almost completely lacking. Lower contact conformable with middle the Thin bed unit. Upper contact is not observed but shows some brecciation.

**Middle The Thin bed unit:** Limestone. Wackestone. Fresh surface is a bright yellowish white. Weathers to a dull light grey or tarnishes black. Weathers to a sheer cliff. Thinly bedded. Thinly laminated with bivalve hash. Possible onset of biostrome based on increase in fossil content. Bioturbation is present as well as significant dissolution. Dark brown to black chert nodules are present but not as prevalent. Lower contact is conformable with the the Basal unit.

**The Basal unit:** Limestone. Micrite to wackestone. Fresh surface is a bright yellowish white. Tarnishes to a dark grey on weathered surfaces. Weathers to a sheer cliff. Thick to massively bedded. Bioturbated. Gastropods and bivalves are observable in some hand samples which suggest shallow water environment. Dissolution is present. Lower contact is not observed. Upper contact is marked by a white chalk/marl bed with streaks of orange iron oxide staining.
Middle Thin bed unit

Upper Dolomite Unit

The Basal unit

Glen Rose Formation

Hensel Formation

*Upper Contact with Fort Terrett Formation not observed
The Basal unit

Middle Thin bed unit

Glen Rose Formation

Hensel Formation

*Lower Contact with Hensel Formation not observed
VITA

After completing his work at Montgomery High School in Montgomery, Texas in 2009, Richard Urwin briefly attended Lone Star Community College while determining a career path. During the 2011 academic year, he transferred to Stephen F. Austin State University and received his Bachelor of Science in Geology in 2015 while working as a fitness assistant at Planet Fitness as well as a Community Assistant for Residence Life at SFA. In August 2016, he entered graduate school at Stephen F. Austin State University and worked as a graduate Teaching Assistant for Introduction to Geology. During the summer of 2018, Richard worked as an intern Geologist for Inspiration Energy in Tyler, Texas. In the spring semester of 2019, he received his degree of Master of Science in Geology.

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