CONODONT BIOSTRATIGRAPHY OF THE UPPER OSAGEAN (LOWER VISEAN) OZARK UPLIFT, SOUTHERN MIDCONTINENT U.S.A.

By

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Abstract: Oil and gas exploration in Mississippian strata of the southern Midcontinent has increased interest in the lateral and vertical trends of reservoir facies and generated a need for more refined facies models. This study establishes a biostratigraphic framework for the Boone Group (upper Osagean), Mississippian Subsystem based on a bed by bed analysis of the Reeds Spring Formation and Bentonville Formation (formerly known as the Burlington-Keokuk Formation). Three outcrops along US Highway 65 in northwestern Arkansas (Boone County, Arkansas), and one outcrop along US Highway 71 (Benton County, Arkansas) were sampled for conodonts and acetate peel petrography. Conodont biozones were found to be unconstrained by facies and support the hypothesis that upper Osagean carbonate wedges are time transgressive. The middle "*texanus"* zone is found within the Reeds Spring Formation in Cherokee County, Oklahoma (middle to outer ramp facies) and Bentonville Formation in Benton County, Arkansas (inner ramp facies). This relationship clearly demonstrates multiple facies occur within one biozone, with higher energy facies in more proximal settings and lower energy facies in more distal settings. These higher and lower energy facies were previously called Burlington-Keokuk Formation and Reeds Spring Formation, respectively. Conodont biostratigraphy was used to pick the approximate position of the "contact" between the Reeds Spring and Bentonville formations, but higher-frequency sampling is necessary to clarify the boundary at some outcrops. The integration of the results of this study with previous biostratigraphic investigations (Thompson and Goebel, 1969; Thompson and Fellows, 1970) is helping improve our understanding of depositional processes and facies relationships in the upper Osagean of the southern Midcontinent.

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CHAPTER I

INTRODUCTION

Oil exploration in the southern Midcontinent, U.S. has established potential for unconventional oil and gas production in carbonate rock strata of the Carboniferous (Mississippian subsystem) and stimulated interest in the outcropping Mississippian section. Detailed carbonate petrography integrated with chronostratigraphy provides the framework required to fully understand the history of Mississippian deposition. This study examines upper Osagean formations within the Ozark Mountains, southern Midcontinent in order to chronostratigraphically constrain lithofacies. Biostratigraphic evidence in this study suggests that conodonts are vital in establishing time equivalent surface facies relationships in Mississippian rocks, and are an essential tool for constructing a stratigraphic framework for the subsurface Mississippian section.

This study is focused on defining upper Osagean rock units within the Mississippian outcrop belt of southwestern Missouri, southeastern Kansas, northwestern Arkansas, and northeastern Oklahoma (Figure 1). The outcrop formations of interest are, in ascending order, the Reeds Spring Formation, Bentonville Formation, and the Ritchey Formation, which make up the Boone Group. The stratigraphic nomenclature for the Boone Group was recently proposed based on lithologic variations within the field area (Mazzullo et al., 2013) (Figure 2). This study uses the newly proposed formational designations, with reference to the older nomenclature (Figure 2).

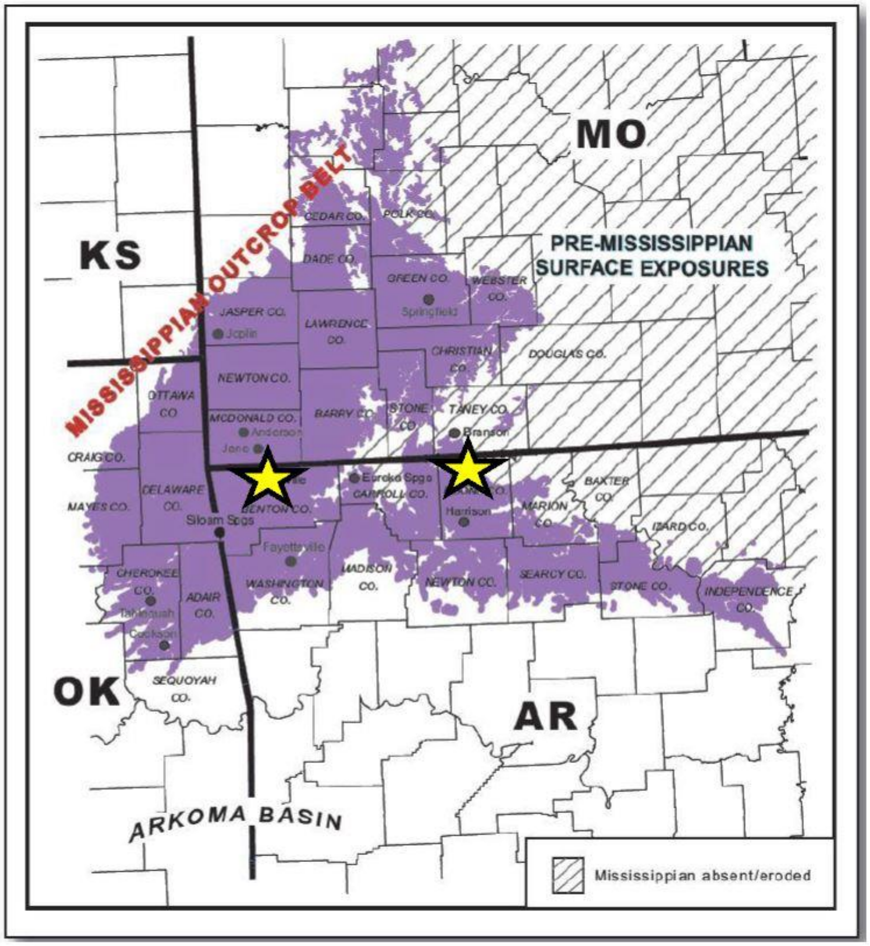


Figure 1. The Mississippian outcrop belt is displayed in purple. This map marks the extent of Mississippian exposures within the southern Midcontinent. The outcrop sites of interest are marked with yellow stars. Modified from Mazzullo et al., (2011).

The outcrop localities sampled in this study occur as road cuts along US Highway 65 twelve miles north of Harrison Arkansas and along US Highway 71 in Benton County Arkansas. The lithostratigraphy is examined along with conodont biostratigraphy to refine the stratigraphic framework for the upper Osagean to basal Meramecian section within the southern Midcontinent. The Mississippian limestone in this region was deposited in a carbonate ramp setting formerly known as the Burlington Shelf (Lane and Dekeyser, 1980).

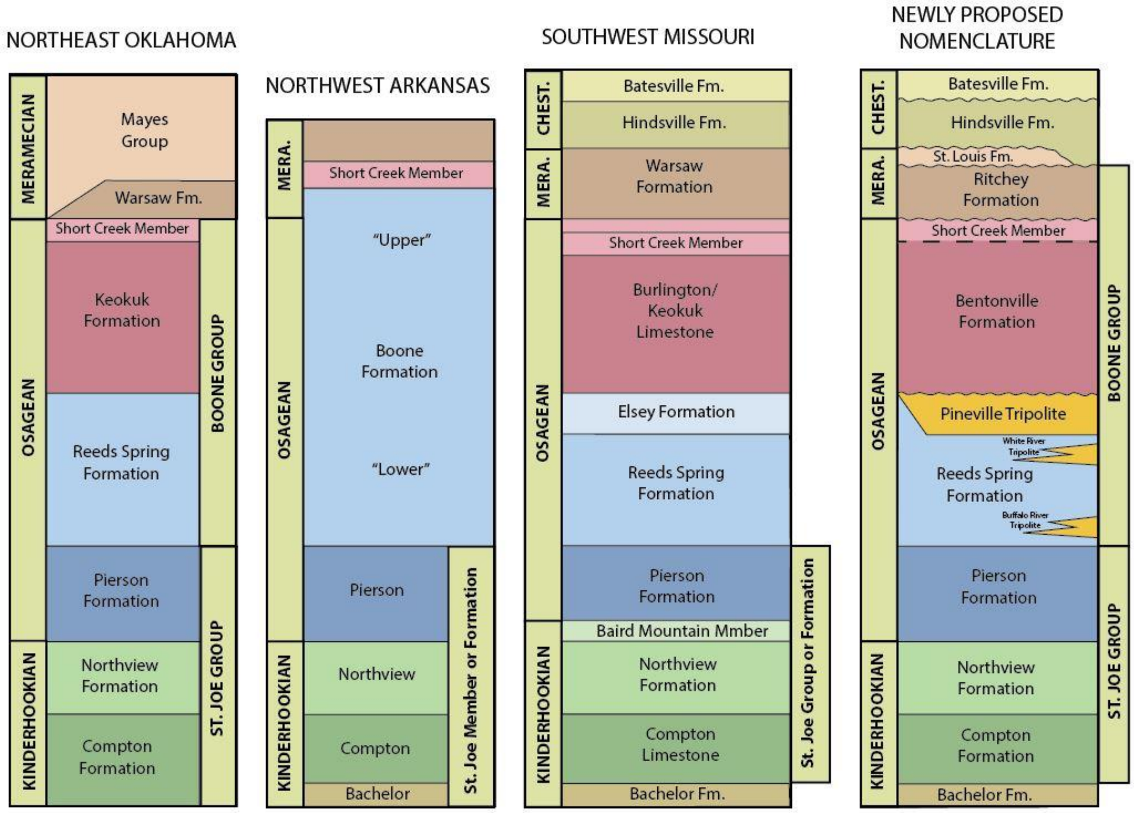


Figure 2. Stratigraphic nomenclature used within the field area. The newly proposed nomenclature (far right column) will be used within this study (Mazzullo et al., 2013).

The former "Burlington Shelf" is now interpreted as a carbonate ramp that developed east of the Transcontinental Arch and north of the Oklahoma Basin in the Midcontinent during Mississippian time. The Transcontinental Arch is a major SW-NE striking regional high which extends from the southwestern U.S. northward as far as northern Minnesota (Lane and DeKeyser, 1980). During Mississippian time the feature was subaerially exposed along which developed a series of interior passive margins separating continental epeiric seas, creating multiple carbonate platform environments (Gutschick and Sandberg, 1983; Lane and Dekeyser, 1980) (Figure 3).

The area of investigation is located along the western flanks of a paleohigh known as the Ozark Dome. The Ozark Dome is a broad asymmetrical paleohigh spanning an area of 103,599 square kilometers (40,000 square miles) in southern Missouri, northern Arkansas and eastern Oklahoma (Huffman, 1959; Huffman, 1964). The Ozark Dome directly influenced shallower water carbonate deposition within the area of investigation. A ramp environment was established with varying energy levels associated with the paleobathymetric gradient imposed by the geometry of the preexisting structure. Higher energy inner ramp deposits graded laterally into middle to outer ramp deeper water environments with distance from the topographic high (Figure 3).

The topography associated with the Ozark uplift locally created shallower water environments that modified ramp paleobathymetry and directly influenced sedimentation rates. In more proximal locations to the Ozark Dome carbonate production was high within the shallow water factory and sediments generated in up gradient locations on the dome likely were brought down dip on the ramp to deeper water settings during high energy storm events.

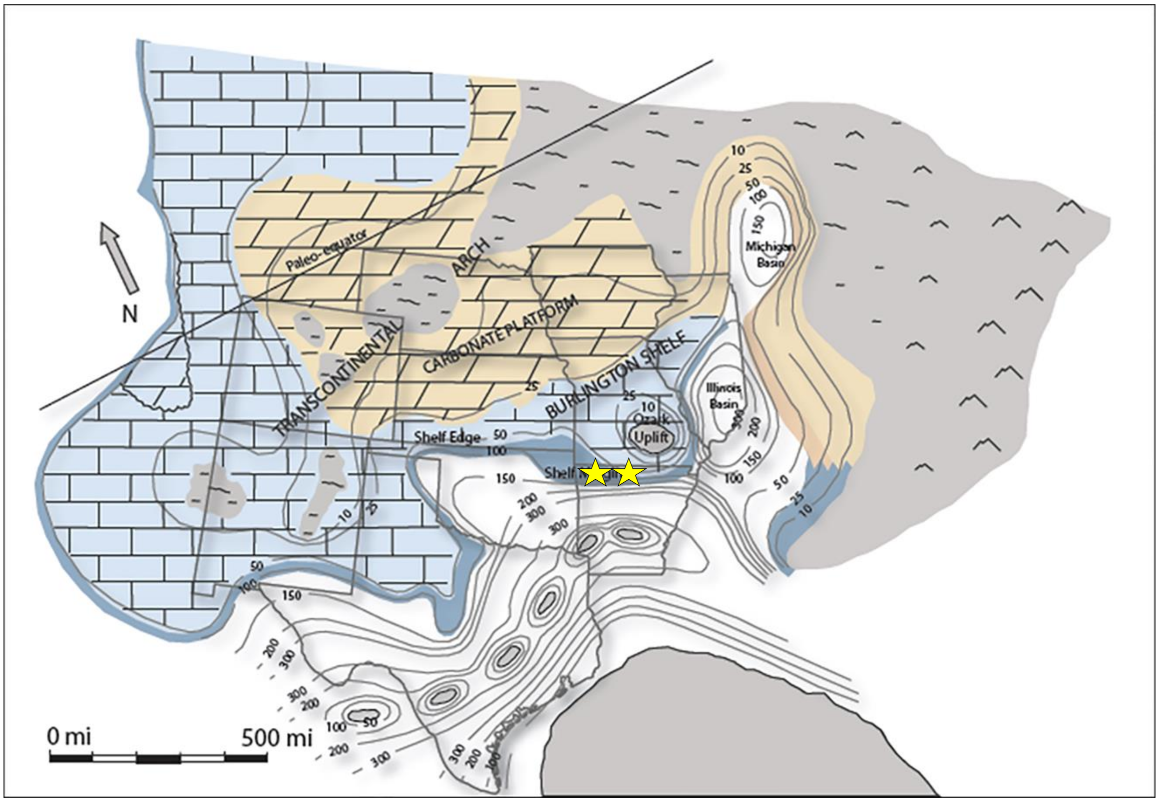


Figure 3. Paleogeographic map of the Mississippian subsystem with the "Burlington Shelf" displayed. Pre-Mississippian structures are shown in gray. The study location is marked by the yellow stars. Modified from Gutschick and Sandberg (1983). This shallow water setting is now interpreted as a distally steepened carbonate ramp in the western Ozark region (Price, 2014; Childress, 2014). The timing of this map coincides with the *Anchoralis-latus* conodont biozone. This biozone represents an interval of middle Mississippian time prior to upper Osagean deposition investigated in this study. It is important to note the yellow stars, and their position to the Ozark regional paleohigh. Paleobathymetric contours indicate the emphasis of the dome on paleobathymetry displaying a steep gradient off of the flanks of the dome to the south/southwest.

Defining the depositional environment as a carbonate shelf, versus a ramp is intimately tied to factors including sediment accumulation, transport, and paleobathymetry (Williams et al., 2001). It has been noted that carbonate environments through time may change geometries due to differences in these factors. For example, a ramp may develop into a rimmed platform with variations in tectonics, or by proliferation of reef developing organisms when environmental conditions become favorable for reef development (Schlager, 2005). This is commonly seen on seismic reflection patterns within modern carbonate depositional systems (Shlager, 2005). Reef building organisms were not prevalent during the upper Osagean, so it is unlikely that a transition from a rimmed margin to a ramp geometry would occur within the upper Osagean interval analyzed in this study. Mounds have been recorded within the underlying stratigraphy of the Compton and Pierson Formations (Unrast, 2013), but their occurrence is scattered within distal ramp environments, and likely does not govern a major change in geometry of the system for a transition from a ramp environment to that of a rimmed shelf (Price, 2014).

Carbonate ramps are shallowly dipping km scale features that develop in shallow sea environments within foreland and cratonic interior basins, and along passive margins (Ahr, 1973; Burchette and Wright, 1992). The typical carbonate ramp has higher energy grainstone deposition within the proximal location of the ramp nearest the paleoshoreline, and lower energy wackestone to mudstone deposition in deeper water, more distal, middle to outer ramp environments (Ahr, 1973; Burchette and Wright, 1992; Read, 1995).

Carbonate ramps differ from rimmed shelves with the noted absence of a barrier present at the shelf break (Ahr, 1973; Schlager, 2005; Burchette and Wright, 1992). Barriers can exist in the form of cemented skeletal and oolitic sand shoals, as well as reefs that build upward towards sea level (Read, 1995; Shlager, 2005). These features are commonly observed in tropical settings where carbonate production is high within shallow depths of less than 100 meters (Schalger, 2005). Barriers protect the inner shelf environment from incoming waves, resulting in quieter, lower energy, deposition proximal to the paleoshoreline. Slope deposits, adjacent to the barrier, occur in the form of turbidites, gravity flows, and slumps deposited basinward along the shelf break (Schlager, 2005). Ramps lack a barrier, but may have locally distributed patch reefs and mounds in middle to outer ramp settings (Burchette and Wright, 1992, Schlager, 2005).

Facies distribution on carbonate ramps resemble “facies belts” which are in strike with the paleoshoreline (Schlager, 2005). Facies changes occur down dip on the ramp with respect to changes in depositional regime from an inner to middle to outer ramp settings (Burchette and Wright, 1992). Facies mosaics are recognized from a lateral gradation from inner ramp higher energy deposits to progressively lower energy middle to outer ramp deposits (Burchette and Wright 1992; Read, 1995; Schlager, 2005). The inner ramp is a zone of deposition between the upper shoreface and fair-weather wave base. The seafloor in the inner ramp setting is constantly agitated by wave energy (Burchette and Wright, 1992). The middle ramp is a zone of deposition between fair-weather wave base and storm-wave base, in which the bottom sediment is often reworked by storm waves (Burchette and Wright, 1992). The outer ramp is a zone of deposition below normal storm-wave base, characterized by mudstone deposition and infrequent storm beds (Burchette and Wright, 1992). Slope deposits may exist in outer ramp settings depending on the steepness of the ramp gradient (Burchette and Wright, 1992; Read, 1995; Schlager, 2005).

Ramp environments can be subdivided into homoclinal and distally steepened ramps based on gradient geometry (Read, 1995). Homoclinal ramps have a relatively uniform gradient of a fraction of a degree per kilometer, and lack a sharp break in slope (Read, 1995). Distally steepened ramps are not as uniform, the depositional profile exhibits an increase in ramp gradient, and slope deposits consisting of allochthonous carbonate debris are often brought down ramp from the inner to middle ramp, to outer ramp settings where the ramp exhibits a distally steepened geometry (Read, 1995).

The km scale geometry of ramps coupled with their low gradient (<1 degree per kilometer), makes them susceptible to eustatic changes (Burchette and Wright, 1992; Price, 2015). When sea level fluctuations occur with geologic time, the ramp facies defined above migrate with the changing position of the paleoshoreline. This results in heterogeneity within the lateral and vertical distribution of facies on local to regional scales. Changes in water depth function as a primary driver for lateral and vertical facies variations related to the energy differences within the ramp setting throughout the time of deposition (Burchette and Wright, 1992). Water depth profiles vary as a function of ramp geometry and are unique to specific types of carbonate ramp systems. A subdivision of ramp systems from homoclinal to distally steepened is often needed for proper facies analysis with respect to energy variations with water depth in a given ramp system (Burchette and Wright, 1992). Other factors that affect water depth profiles are sediment supply and tectonics. These factors are dependent on the type of carbonate factory within the depositional system, and tectonic setting (Schalger, 2005). Mississippian subsurface cores, and outcrops have been recently described with an emphasis on a ramp depositional system (Mazzullo et al., 2011; Leblanc 2014; Price 2014; Childress, 2015). Based on the observations in this and previously cited studies, the former "Burlington Shelf" described by Lane and Dekeyser (1980) and Gutschick and Sandberg (1983), is now interpreted as a carbonate ramp. The terminology used within the study herein will be with direct reference to a carbonate ramp depositional system.

Lateral and vertical facies distributions on carbonate ramps respond to changes in water depth, therefore a critical analysis of the eustatic variation during Osagean time is needed for an accurate paleogeographic reconstruction. Global sea level changes with time as a result to changes in ocean basin volume caused by seafloor spreading and heat flow from mid oceanic ridges, and from changes in global ice volumes resulting from global climactic variations (Read, 1995). Eustatic variations can occur on varying orders of geologic time from orders of hundreds of millions of years to tens of thousands of years. Eustatic variations representing a single rise and fall in sea-level are known as cycles. These cycles have different driving mechanisms, which control their duration within the rock record, and each cycle has been categorized numerically based on a lower to higher order of occurrence with time. Lower order cycles have higher ordered cyclicity superimposed within the overall eustatic framework (Read, 1995).

First order cycles are estimated to be 200-300 million years in length and are associated with global changes in tectonics resulting from the formation and breakup of supercontinents associated with plate movement, and opening and closing of ocean basins over long periods of geologic time (Read, 1995). Second order cycles are estimated to be 10-50 million years in length, controlled by tectonics, changes in ocean basin volume, and to a lesser extent by global ice-volume (Read, 1995). Second order cycles form major widespread depositional sequences hundreds to a few thousand meters in thickness (Read, 1995). Third order cycles are 1-10 million years in length, and are superimposed within second order cycles (Read, 1995). Their origin is enigmatic, but is likely linked to changes in global ice volumes (Read, 1995).

Fourth order sequences and fifth order cycles are driven by global climate and its relationship to Milankovitch Cyclicity (Read, 1995; Price, 2014). Milankovitch Cyclicity is the result of variations in eccentricity, obliquity, and precession, which directly affect the intensity of solar radiation reaching the earth. Changes in solar variations have an effect on the earth's climate and resulting glaciations within relatively short (<1ma) periods of geologic time (Read, 1995). Fourth order sequences occur over intervals of 100-400 thousand years controlled by variations in eccentricity. Eccentricity is the variation of the earth's orbital patterns, and climatic variations related to the earth's distance from the sun. Fifth order cycles occur on orders of 40 to 20 thousand years, and are controlled by variations in the earth's tilt and wobble of its rotational axis (Read, 1995). Obliquity is the tilt of the earth's axis of rotation, and is responsible for cycles of approximately 40 thousand years. Precession is the wobble of the earth's axis, and is responsible for fifth order cycles of approximately 20 thousand years (Read, 1995).

The higher frequency fourth and fifth order cycles are superimposed within the third order cyclicity. The result of high frequency fluctuations in sea level is the primary driver for facies heterogeneity within carbonate platforms (Kerans, 2003; Price, 2014). In outcrop studies the recognition of facies stacking patterns on fourth and fifth order scales can aid in interpretation of the depositional system on a third order scale (Goldhammer, 1993; Schalger, 2005). Since the sequential patterns are superimposed within the hierarchy of sea level variations on orders of geologic time, the sequences identified at varying scales can give insight into the overall depositional system (Schlager, 2005).

When addressing the vertical and lateral facies migrations on a carbonate ramp with time, the use of sequence stratigraphy is imperative. Sequence stratigraphy is a branch of stratigraphy that utilizes genetically related packages of facies or sequences to interpret depositional processes (Read, 1995; Schlager, 2005). Sequence stratigraphy was originally applied to seismic data, where second order sequences observed on seismic reflectors, gave insight into carbonate platform profiles, and their changing geometries through time (Schlager, 2005).

On carbonate ramps sequences can be delineated with respect to rising or falling sea-level based on their vertical facies stacking patterns (Schlager, 2005). In general, the sequences identified within a carbonate ramp system consist of a transgressive systems tract (TST), highstand systems tract (HST), and lowstand systems tract (LST) (Handford and Loucks, 1993). If subsidence rates remain constant, the transgressive system tract consists of onlapping sedimentation of finer grained deposits during periods of sea level rise. This is represented by a series of high frequency deepening upward packages (Goldhammer, 1993). If sediment supply, and subsidence remain constant, the highstand systems tract occurs once sea level has reached its highest point. The highstand systems tract is an offlapping progradational phase where higher energy deposits migrate basinward with the paleoshoreline as available accommodation is filled (Hanford and Loucks, 1993). The lowstand systems tract forms when sea level is at its lowest point. The ramp setting is exposed, and sediments from the exposed up dip location on the ramp chemically and mechanically weather, and may migrate basinward. During lowstand, sediment generation is low within a carbonate setting (Handford and Loucks, 1993). Within a particular outcrop the subdivision of systems tracts has to be interpreted by the associated vertical facies stacking patterns (Goldhammer, 1993; Schlager, 2005). This can lead to an interpretation of the depositional system on sub seismic scales, which can aid in the interpretation of accommodation changes within third order sequences (Goldhammer, 1993; Schlager, 2005).

Specifically within the Carboniferous, sequence boundaries have been difficult to predict due to the onset of glaciation in a transition from greenhouse to icehouse conditions, and biostratigraphic data provide an accurate tool for identifying lower frequency, higher order sequence boundaries (Ross and Ross, 1988; Haq and Schutter, 2008). This study supports the recognition and dating of sequence boundaries by supplementing the existing biostratigraphic data. Proposed fourth order sequences and higher frequency fifth order cycles have been observed in cores, and in outcrops within the Midcontinent (Leblanc, 2014; Price, 2014, Childress, 2015). These higher order sequences and cycles have also been recognized as electrofacies on wireline logs (Bertalott, 2014). When identified depositional sequences can be integrated with biostratigraphic observations, more meaningful paleogeographic reconstructions result in sound interpretations of depositional history (Childress, 2015).

Conodonts have been used in previous studies for Mississippian stratigraphy in the United States (Branson, 1941; Mehl and Thomas 1947; Younquist and Miller, 1949; Younquist et al., 1950; Elias, 1959; Branson, 1959; Pinney, 1962; Thompson and Goebel, 1963; Rexroad and Collinson, 1965; Goebel, 1966; Goebel et al., 1967; Lane, 1967; Canis, 1968; Thompson and Goebel, 1969; Thompson and Fellows 1970; Collinson et al., 1970; Lane and Dekeyser, 1980; Boardman et al., 2013). Conodonts are calcium phosphate (apatite) fossils believed to be teeth belonging to marine annelids or fish (Knell, 2013). Determining the type of animal responsible for conodonts has been difficult to establish because it is believed to be soft bodied, and the only hard parts preserved are its teeth (Knell, 2013). These teeth display high morphological variation on the genus and species level during the Paleozoic, which makes them ideal for biostratigraphy (Goebel et al., 1967). Specific biostratigraphic boundaries have been recognized within the

Mississippian since the early to mid-1900's. On the genus level, significant boundaries can be identified within the Mississippian subsystem on a global scale. Basal Kinderhookian strata are dominated by conodonts belonging to the genus *Siphonodella*. In Osagean strata the siphonodellids are absent, and an increase in the occurrence of specimens belonging to the genus *Gnathodus* is evident (Pinney, 1962). The gnathodids diversify into separate species which can aid in identifying particular biozones. The biozones investigated in this study are upper Osagean in age. This particular interval of geologic time is difficult to resolve through conodonts, because the Osagean stratigraphy yields extremely sparse faunal recoveries per kilogram of rock processed (Youngquist et al., 1950). The addition of new specimens to existing faunal databases facilitates refinement of biozonational limits.

A biozone is a distinct interval of recorded geologic time where a single specimen of a particular genus, or numerous species can occur. The definition of a biozone is made based on the species type and abundance relative to other specimens occurring in stratigraphically higher or lower (older or younger) zones, all representing changes through time with the occurrence or extinction of particular specimens. The upper Osagean biozone investigated in this study is the *texanus* Zone (Lane et al., 1980), which was previously identified as the *Gnathodus texanus-Taphrognathus varians* Zone (Collinson et al., 1962, Rexroad and Collinson, 1965, Thompson, 1967, Thompson and Goebel, 1969, Thompson and Fellows, 1970). It was recently proposed that a subdivision can be observed within the broader extent of this zone based on specific variations in species of gnathodids within ascending strata (Boardman, 2013). In this study, the subdivision of the *texanus* Zone is investigated, and it is proposed through the fauna recovered that the formerly identified *texanus* Zone, can be subdivided into the lower, middle, and upper, "*texanus*" zones, based on the occurrence and extinction of specific gnathodids in the upper Osagean stratigraphy.

Within the field area, unconformable surfaces may be identified within the refined biozones where a chronostratigraphic correlation is problematic. Many chert reservoirs within the subsurface of Kansas and north central Oklahoma have been associated with possible unconformities (Goebel, 1966; Mikkelson, 1966; Montgomery et al., 1998; Rogers, 2001; Mazzullo, 2011; Mazzullo et al., 2013). This study investigates the possibility of missing zones within the field area, which may be indicative of time gaps associated with exposure and erosion of stratigraphic units. Goebel (1966) proposed that an unconformity separating the Osagean and Meramecian above the Short Creek Oolite Member of the Burlington-Keokuk Formation (Bentonville Formation in this study) is responsible for the formation of tripolitic chert reservoirs in the subsurface of Kansas. However, the low yields of conodonts across this interval raise concerns if such an unconformity exists. In the Mississippi River Valley, the unconformity is not formally recognized, and the subdivision between the Meramecian, and Osagean stage is not applied (Rexroad and Collinson, 1965). In the southern Midcontinent outcrops there is no golden spike to define the boundary between the Osagean and Meramecian Stages, but slight biostratigraphic variation occurs (Thompson and Goebel, 1963; Thompson and Goebel, 1969). The outcrops analyzed in this study provide a much needed addition of 260 whole specimens to refine upper Osagean stratigraphy, and increase our understanding of the faunal transition from the Osagean to Meramecian time. Furthermore, the added fauna help refine stratigraphic sequences within the upper Osagean section.

CHAPTER II

METHODS

OUTCROP METHODOLOGY

Field sampling for conodont recovery and petrographic description was the foundation for this study; three outcrops were selected based on their stratigraphic coverage and accessibility. These outcrops are road cuts along U.S. HWY 65 north of Harrison, Arkansas and south of Branson, Missouri in northern Boone County, Arkansas. Another outcrop, denoted as the Bentonville Type Locality, is located along US HWY 71 in Benton County, Arkansas and was sampled at a lower frequency for conodont recovery (Figure 12). The three outcrops sampled for high frequency analysis are the (1) Bentonville Co-Type Locality located 19.3 km (12 miles) north of Harrison, Arkansas, (2) Reeds Spring Formation\Bentonville Formation Contact I approximately 21.7 km (13.5 miles) north of Harrison, Arkansas, and (3) Reeds Spring Formation\Bentonville Formation Contact II approximately 22.4 km (13.9 miles) north of Harrison, Arkansas. These outcrops were sampled at a high frequency to establish facies type and distribution, and a biostratigraphic framework to allow temporal constraint of facies and interpret the overall stratigraphic architecture for the upper Osagean section of the Mississippian Subsystem. Every bed was sampled, and beds that exceeded 0.3 meters (1 ft) in thickness were sampled at 1 ft intervals to establish more detailed stratigraphic description and conodont biostratigraphy.

The complete Bentonville (formerly Burlington-Keokuk) succession is estimated to be around 61 meters (200ft) in thickness based on shallow subsurface logs within the field area (Thompson and Fellows, 1970). Finding a complete and accessible exposure of the Boone Group in a given outcrop is difficult. Due to this limitation, it was necessary to select three separate outcrops within close proximity (<3.2 km, 2 miles) to construct a composite section that included the complete Boone Group (Figure 4). The uppermost section of the Bentonville Formation, as well as the basal contact between the Reeds Spring Formation and overlying Bentonville Formation were sampled specifically to biostratigraphically constrain the age of the Bentonville Formation.

Figure 4. Outcrop localities examined in this study. The red stars indicate outcrops sampled at a high frequency (bed by bed, ft by ft) along US HWY 65. The yellow star marks the location of the Bentonville Type Locality on US HWY 71. Location #1 is the Bentonville Co-Type Locality, #2 Reeds Spring Formation/Bentonville Formation Contact I, and #3 is the Reeds Spring/Bentonville Formation Contact II. Aerial photographs of the outcrops were accessed via Google Earth (2015).

The Bentonville Co-Type Locality is located 19.3 km (12miles) north of Harrison, Arkansas on US HWY 65, and contains 23.5 meters (77 ft) of exposed section. The outcrop contains in ascending order 17.7 meters (58 ft) of the Bentonville Formation that is overlain by 1.5 meters (5ft) of the Short Creek Oolite Member. Overlying the Short Creek Oolite Member is 4.3 meters (14 ft) of the basal Ritchey Formation (Figure 5). The top of the Short Creek Oolite Member marks the top of the Osagean Stage (Mazzullo et al., 2013). The overlying Ritchey Formation is believed to be Meramecian in age and unconformably overlies the Short Creek Oolite Member (Boardman et al., 2013, Mazzullo et al., 2013). This locality was selected to evaluate lithologic and biostratigraphic changes across the recognized boundary between the Osagean and Meramecian stages. The outcrop was difficult to access along a continuous vertical transect, therefore it was sampled along the northern side and beds were traced laterally, and walked out southward to remain in a vertical stratigraphic succession. Ledges resulting from highway construction facilitated access to sample locations (Figures 6-9). Nine ledges were utilized as stratigraphic references denoted as L1-L9 (Figure 6).

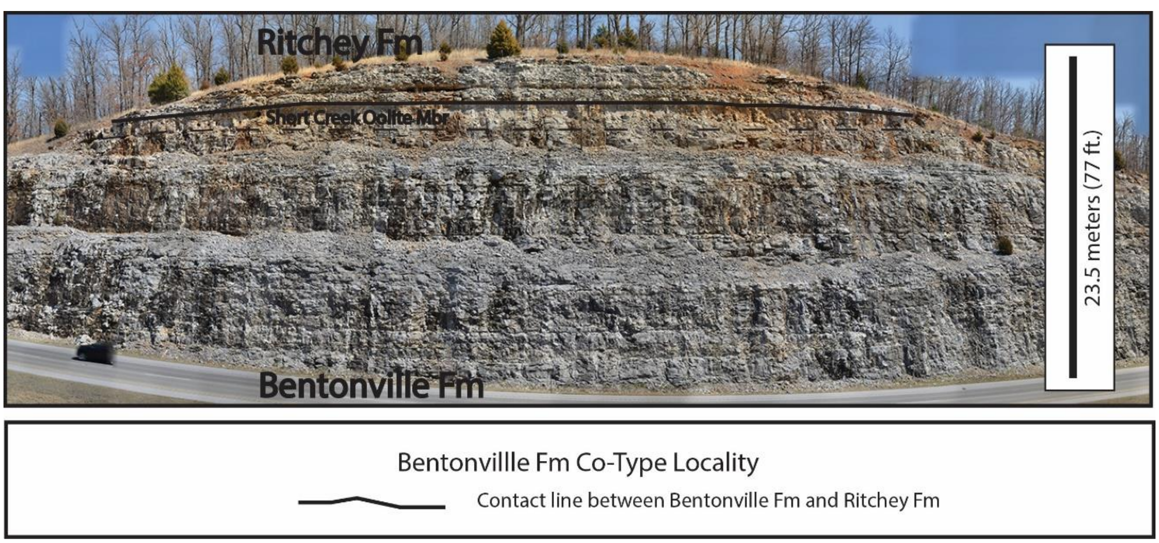


Figure 5. Panoramic photograph of the Bentonville Co-Type Locality. The contact between the Short Creek Oolite Member and the overlying Ritchey Formation is marked by the black contact line toward the top of the image.

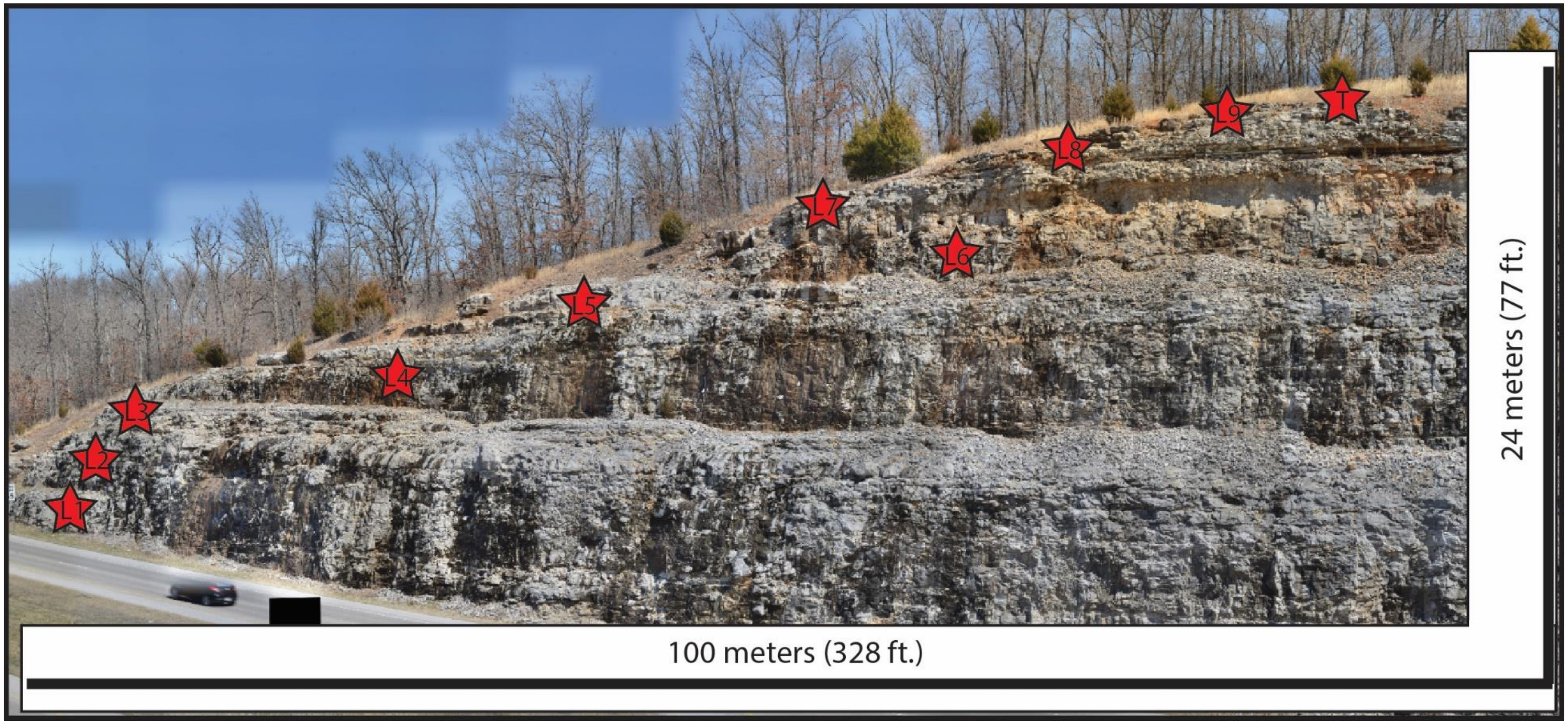


Figure 6. Panoramic photograph of the Bentonville Formation Co-Type locality (northern half). Ledges were utilized in the sampling process as references for labeling and marking stratigraphic position. Each interval sampled corresponds to a specific ledge marked by a red star. Ledges L1-L6 correspond to the Bentonville Formation. Above Ledge 6 is an erosive five feet interval containing the Short Creek Oolite Member. Overlying the Short Creek Oolite Member is the lower Ritchey Formation. Ledges L7-L9 as well as a single bed at the top of the outcrop correspond to the Ritchey Formation.

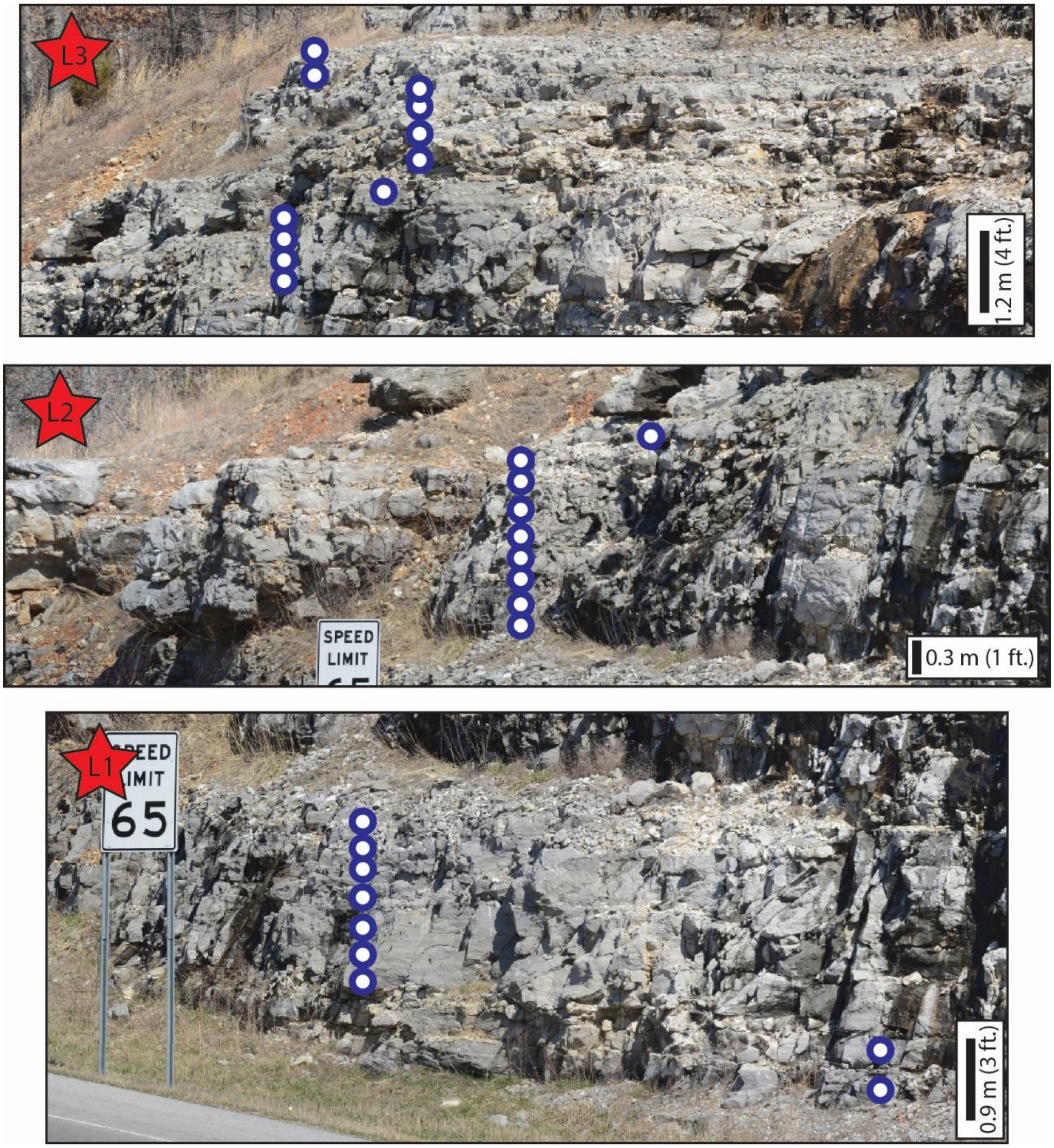


Figure 7. Photographs of Ledge 1-Ledge 3 (Bentonville Formation) at the Bentonville Formation Co-Type Locality. Locations sampled for conodonts and acetate peels are marked by the blue circles.

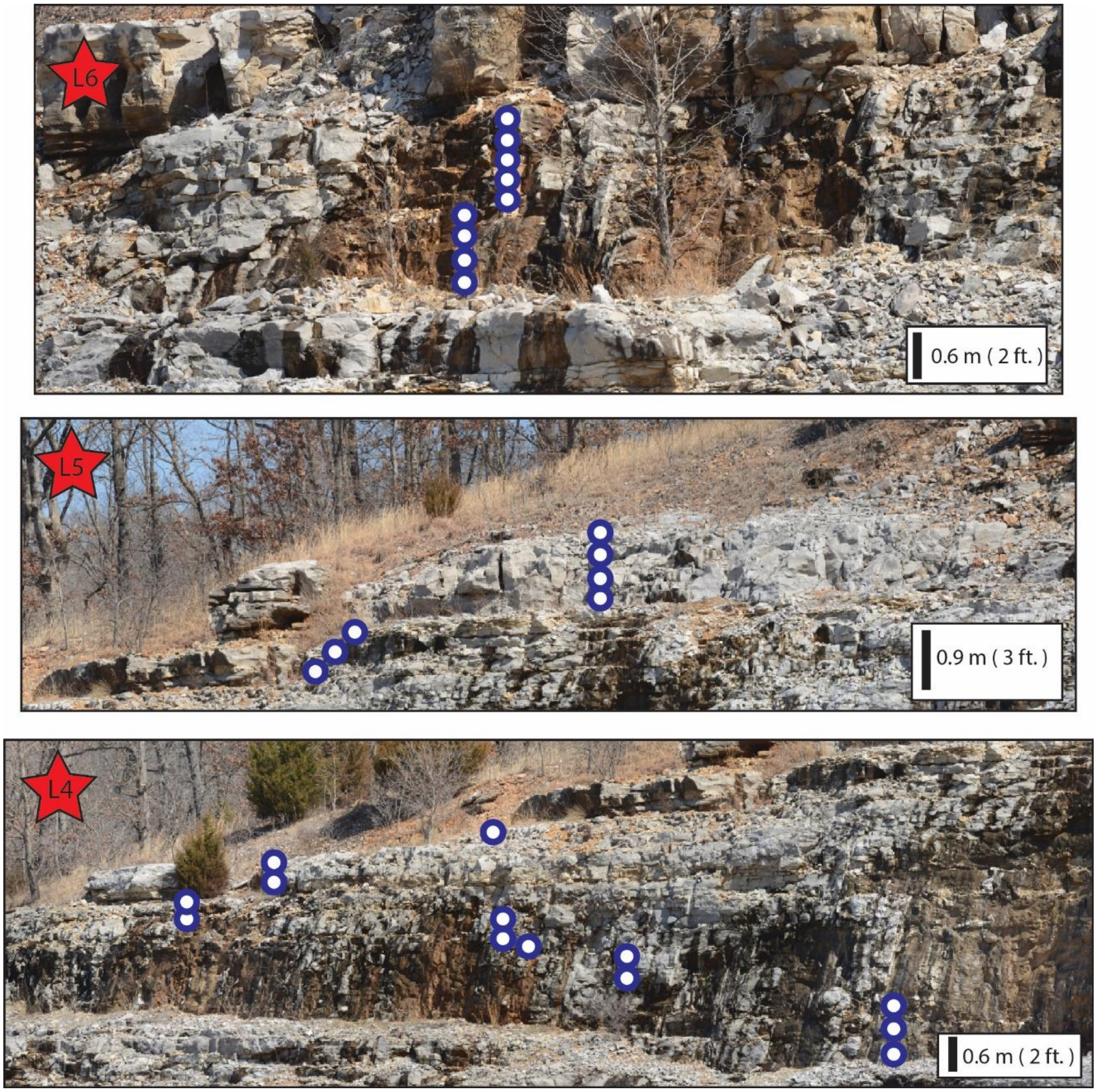


Figure 8. Photographs of Ledge 4-Ledge 6 (Bentonville Fm.) at the Bentonville Fm. Co-Type Locality. Sampled locations are marked by the blue circles

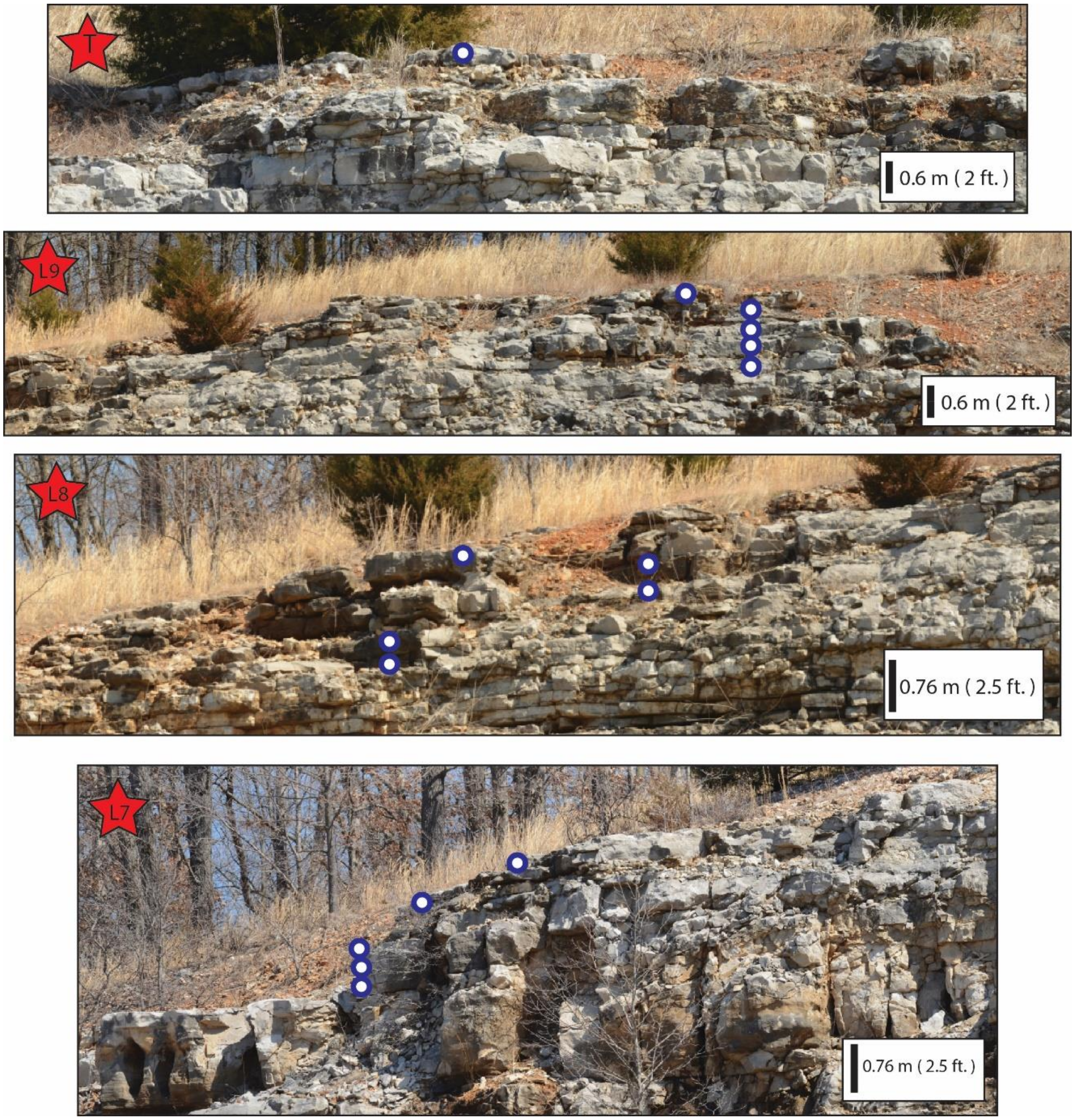


Figure 9. Photographs of L7-Top of exposure (Ritchey Fm.) at the Bentonville Fm. Co-Type Locality. Sampled locations are marked by the blue circles.

The second outcrop studied is the Reeds Spring Formation\Bentonville Formation Contact I, located 21.7 km (13.5 miles) north of Harrison, Arkansas on US HWY 65, and 2.4 km (1.5 miles) north of the Bentonville Co-Type Locality (Figure 10). The exposure contains 10.1

meters (33 ft) of exposed section. The exposure contains in ascending order, 7.4 meters (24.4 ft) of the Reeds Spring Formation, overlain by 2.9 meters (9.6 ft) of the basal Bentonville Formation. This section was chosen as a sampling site because the contact between the Bentonville Formation and Reeds Spring Formation can be identified.

A third outcrop was chosen for sampling denoted as the Reeds Spring Formation\Bentonville Formation Contact II, located 22.4 km (13.9 miles) north of Harrison, Arkansas and about 0.6 km (0.4 miles) north of the Reeds Spring Formation\Bentonville Formation Contact I outcrop (Figure 4). The outcrop is interpreted to contain the contact between the Reeds Spring Formation and the Bentonville Formation. The exposure contains 18.7 meters (61.4 ft) of measured section consisting of 7.8 meters (25.6 ft) of the Reeds Spring Formation overlain by 10.9 meters (35.8 ft) of the Bentonville Formation (Figure 11). The uppermost section of the Reeds Spring Formation was sampled, as well as the entire 10.9 meters (35.8ft) thick interval of the overlying Bentonville Formation. This section was difficult to sample along a vertical transect so bedding planes were traced laterally by walking out bedding contacts along the outcrop until they were accessible for sampling.

For each outcrop described above, individual beds were identified, delineated, photographed, described, and then sampled using a bull point chisel and masonry cracking hammer. Five kilograms of rock was collected for each sample, and placed in three gallon capacity plastic freezer bags. Of the five kilograms collected, 3 kg were allocated for acid digestion for conodont recovery. Larger 2 kg (~12.7cm x 7.6 cm, 5in x 3in) rock samples were collected and marked for stratigraphic up position to be used for a high resolution petrographic analysis using acetate peels.

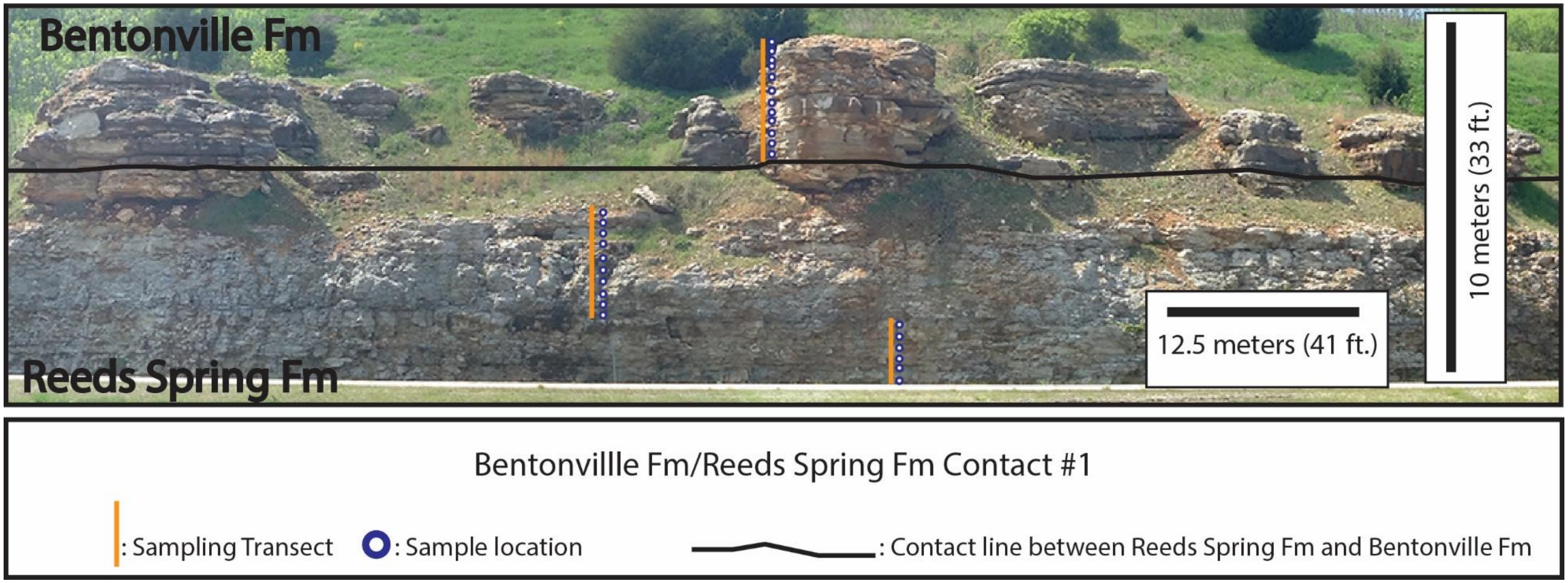


Figure 10. Panoramic photograph of the Reeds Spring Fm/Bentonville Fm Contact I outcrop. The entire exposure was sampled bed by bed. Sampling transects were chosen based on accessibility and are marked by the vertical orange lines. Sampled locations are marked by the blue circles. The contact established between the Bentonville Fm and the Reeds Spring Fm is based on the thickness of bedding and decrease in chert (Boardman, personal communication, 2015).

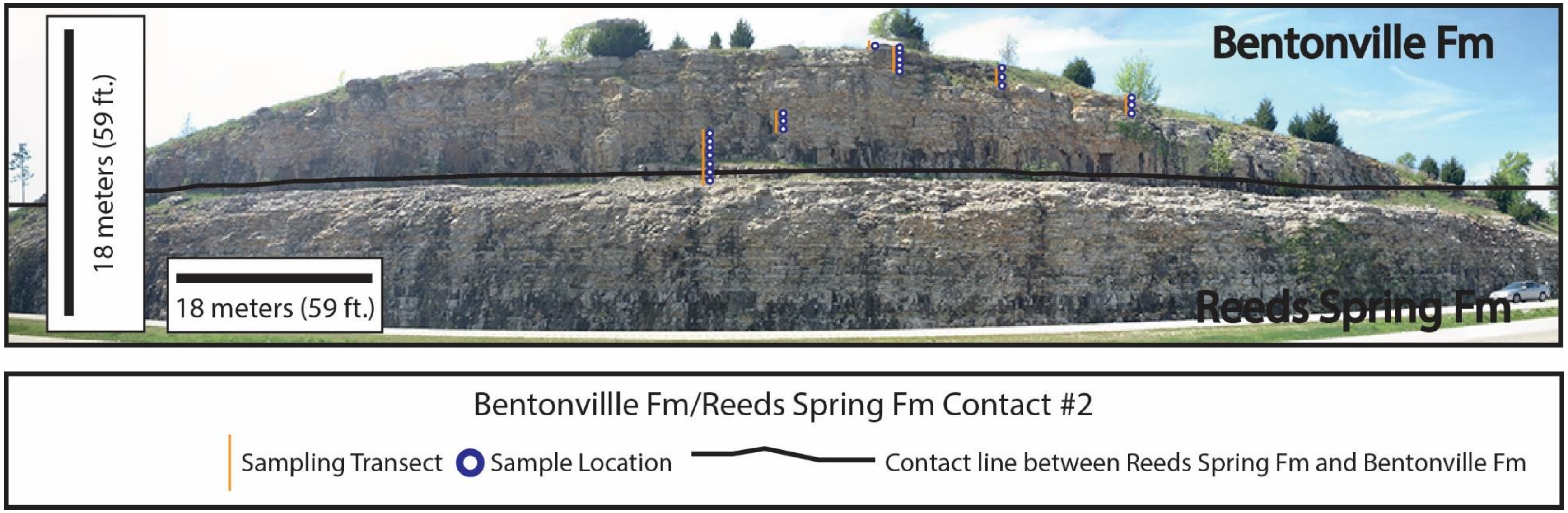


Figure 11. Panoramic photograph of the Reeds Spring Fm/Bentonville Fm Contact II outcrop. The upper Reeds Spring Fm and entire Bentonville Fm were sampled bed by bed. Sampling transects were chosen based on accessibility to bedding and safety. Transects are marked by the vertical orange lines. Blue circles correspond to sample locations. The contact between the Reeds Spring Formation and the overlying Bentonville Formation is based on a decrease in chert, and the first occurrence of a thick (6.5-7 ft.) bed of grainstone observed above the chert-rich Reeds Spring Formation (this study).

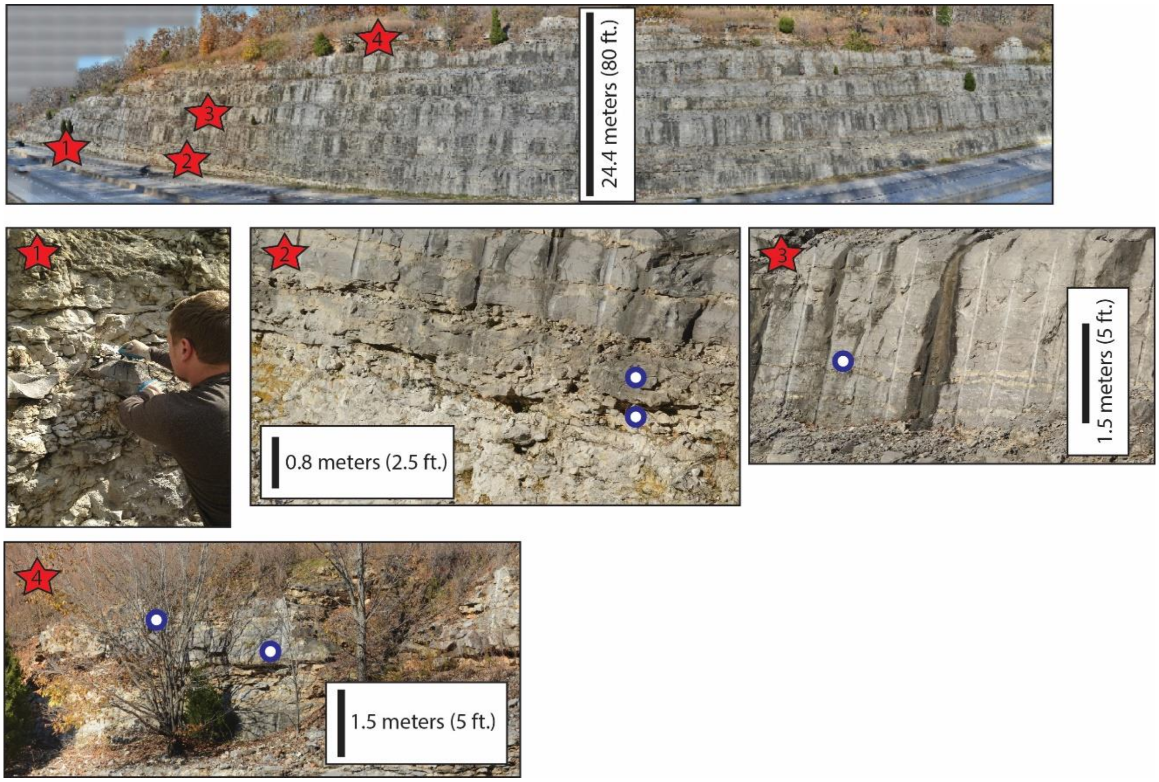


Figure 12. The Bentonville Fm Type Locality, in Benton County, Arkansas, was sampled at a lower frequency for conodont recovery. Generalized sampling locations are shown by the red stars. These selected intervals correspond to:

(1) Limestone lenses within the Pineville Tripolite facies of the Reeds Spring Formation

(2) The contact overlying the tripolite, and the base of the Bentonville Formation

(3) The middle of the Bentonville Formation, and

(4) The uppermost accessible beds of the Bentonville Formation

Sample sites are shown by the open blue circles.

LAB METHODOLOGY

Once field sampling was completed, a rigorous, time-intensive, lab routine was developed for conodont element recovery and acetate peel construction for petrographic analysis. A conodont element is any recoverable form of the specimen from whole intact specimens to fragmentary forms. Depending on the stage of development, conodonts which are larger (generally 0.75-1mm) are known as mature specimens, smaller forms also exist, and are referred to as juvenile specimens (Austin, 1987). Determining a juvenile form from a mature form is a limitation that is interpreted by the paleontologist based on the sizes of the recovered forms. In this study the conodonts recovered were <0.5mm, and smaller specimens (0.25mm-0.1mm) were recovered and given a juvenile designation. Larger specimens (>.25mm) were utilized in the SEM identification process for specimen identification.

To recover conodont elements, a series of rock digestion methods can be used depending on the mineralogy of the sample. A solution of dilute formic acid (10% strength) was utilized as the primary solvent to digest limestone samples. The process for conodont recovery, analysis, and application is outlined in Table 1, and lab techniques for conodont recovery can be seen in Figure 14.

The first step in processing samples for conodont element recovery involves breaking the rock into three centimeter-wide pieces to increase surface area exposure during acidification, ensuring dissolution of the rock within a 24-36 hour time frame. After the rock was initially broken down into three centimeter pieces, it was placed in a 19 liter (five gallon) bucket with a ten percent solution of dilute formic acid. Eleven liters of water were initially added to the sample bucket, followed by the addition of 1100 milliliters of formic acid. Once the rock is digested (usually within 24-36 hours) the liquid is decanted through a sieve stack to recover the insoluble residue containing phosphatic conodont elements.

Insoluble material was wet sieved using a stack containing in descending order 4 mesh, 35 mesh, and 120 mesh screens. The 4 mesh screen removed the coarser (4.7mm-3cm diameter) pieces of limestone that did not dissolve in the normal 24-36 hour digestion stage. The 35 mesh screen filters out fragments of medium sand (.5mm) to granule (3.3mm) sized rock fragments from the finer insoluble residue. The 35 mesh screenings were scanned for larger, more mature conodont elements, but none were recovered from the 35 mesh screened residues. The 120 mesh sieve was used for the primary residue collection. The 120 mesh screenings include medium sand (.5mm) to very fine silt (.0049mm) sized particles of insoluble residue, including most conodont elements. Fully preserved conodont micro fossils are larger than clay sized (.004mm) particles, and therefore the use of the 120 mesh is needed for an unbiased representation of the conodont elements recovered within a given sample. Each 1 kilogram sample of limestone in this study yielded approximately 2-20 grams of fine insoluble residue to be scanned for conodont elements.

After wet sieving, each insoluble residue was placed in a paper towel, and left in a sample drying oven set at 93.3 degrees Celsius (200 degrees Fahrenheit) for 24 hours. Once dried, each residue was placed in a sample envelope and stored prior to wet brush picking for conodont recovery.

Wet brush picking was accomplished using a fine detail, 10/0 sized, paintbrush under a binocular microscope set at 20X magnification. Each residue was examined by placing approximately one gram on the picking grid and scanning row by row to ensure all conodont elements were recovered. Once recovered, conodonts were placed on a microfossil storage grid, and covered using a glass 2.54 cm by 7.62 cm (1’’ by 3’’) microscope slide. The glass slide and storage grid were placed in a metal slide jacket.

Table 1: Conodont Recovery Summary

Step 1:	Preliminary breakdown of the rock into 3 cm x 3 cm fragments
Step 2:	Rock fragments placed in a solution of 10% dilute formic acid for 24-36 hours.
Step 3:	Sieving using 4, 35, and 120 mesh sieves to wet collect insoluble residues and conodont elements. Insolubles dried in a sample oven for 24 hours at 93.3 degrees Celsius (200 degrees Fahrenheit) prior to picking
Step 4:	Conodonts picked using a wet brush under a binocular microscope at 20X magnification
Step 5:	Specimens mounted to carbon tape in the proper orientation for SEM analysis.
Step 6:	SEM analysis of specimens for high resolution photography, leading to identification on the species level (if applicable)

Table 1. Representative procedure for recovering conodonts from the limestone samples.

After picking, conodonts were mounted to a fibered carbon-based tape. The larger more mature specimens were then mounted for high resolution photography, a necessary step in specimen identification. The more mature specimens display species level variation, which may not be seen in immature specimens. The type of specimen dictated mounting orientation. *Gnathodus* specimens were mounted in the oral view to identify on a finer scale, the nodal ornamentation and structure of the posterior platform. Other genera were also mounted in the oral or lateral view. Specifically, specimens of the *Spathognathodus* genera were mounted laterally because they have a thin platform, and species identification is based on the number, shape, and geometry of their denticles seen at the anterior end of the specimens. Other bar, non-platform type specimens were mounted laterally or inner/outer laterally for the best orientation for SEM analysis.

After mounting, selected specimens were sputter coated in gold and palladium to facilitate the emission of secondary electrons with varying energy levels and generate a high resolution image to photograph. Specimens were scanned using a FEI Quanta 600 field-emission-gun scanning electron microscope (Figure 14) at resolution of 1.2 nm at 30 kV, which was optimal for conodont identification on the species level.

Acetate peels were prepared for a representative sample of each conodont sampling location to determine grain size, allochem type and abundance, mud content, diagenetic products, and sedimentary structures (Figure 13). Rock samples for acetate peels were halved with a rock saw with one half selected for polishing prior to applying the acetate peel. Polishing of the rock face was initially done for 15 minutes with 320 grit powder on a motorized polishing wheel. This aided in removal of coarser saw marks. A finer 640 grit powder was used on the rock face on a glass plate to remove the finer saw marks that remained after coarse polishing. Once polished, the rock face was immersed in a 3 % HCl solution for ten seconds, sprayed with acetone, and then covered by acetate film. After fifteen minutes the film was peeled and mounted between two 5.1 cm by 7.6 cm (2’’ x 3’’) oversized glass microscope slides. Each acetate peel was analyzed using a petrographic microscope; a total of 117 were viewed from the three outcrops listed above. Photomicrographs of acetate peels were obtained using an Olympus Bx 51 polarizing microscope with color view soft image system. Images were captured in plane-polarized light (PPL) and cross-polarized light (XPL) to facilitate bioclast and matrix identification.

Once all acetate peels were imaged, grains were analyzed for type and abundance of skeletal and non-skeletal components, amount and composition of matrix, and type of diagenetic products. Peels were also examined for secondary and biogenic features that could be used to interpret depositional energy and setting.

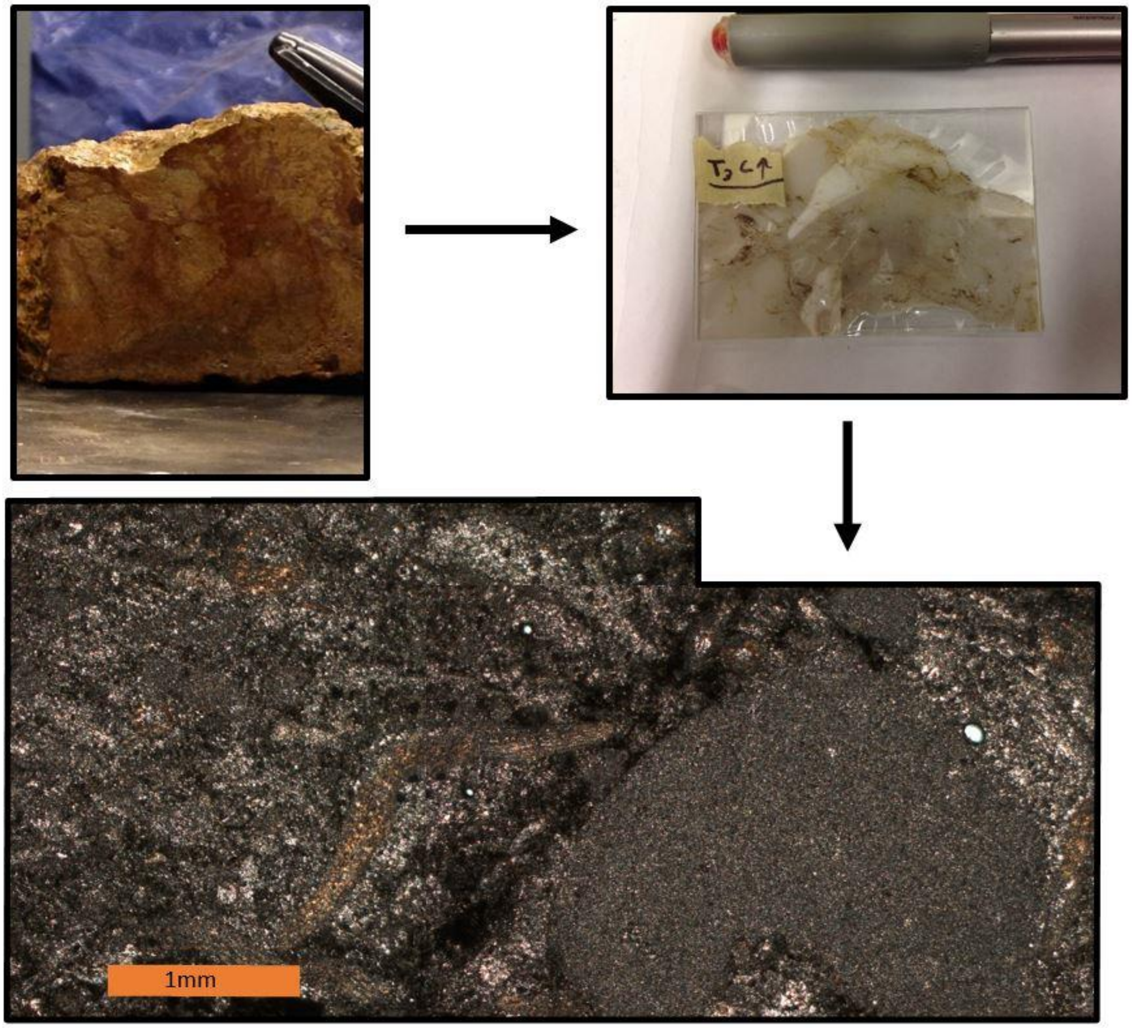


Figure 13. Images showing acetate peel construction and resolution. First the rock sample is cut, and polished (upper left). Once the rock is polished it is placed in dilute HCL for ten seconds, then rinsed and sprayed with acetone. The evaporative nature of the acetone creates a vacuum that pulls the acetate film onto the rock face. After fifteen minutes the film is peeled, and placed between two 2''x3'' glass microscope slides (upper right). The result is a thin-section like peel of the rock with resolution of up to ten microns for carbonate allochem identification and facies analysis (lower photomicrograph).

Figure 14. Series of images illustrating the processes required to recover and identify conodont specimens. 1: sampling of the outcrop, 2: initial rock crushing, 3-5: dissolving rock in dilute formic acid solution for 24-36 hours, 6: wet sieving of insoluble residue, 7: placement of fine residue into paper towel for drying, 8-9: scanning and picking insoluble residue at 20X magnification for conodont elements, 10: mounting of a conodont specimen to fibered tape, 11-12: high resolution photography of conodonts under the SEM, and species identification.

CHAPTER III

BIOSTRATIGRAPHY

Conodont biostratigraphy was used to establish chronostratigraphic correlations across the field area in NW Arkansas. Once the fauna were recovered and identified, biozones were established, and correlated across the region with previously recorded biostratigraphic sections. Macroinvertebrates were used in past studies (Cline, 1934; Laudon, 1948; Kammer, et al., 1990), but in this study the lack of a well preserved macrofauna precluded their use. Conodonts are sparse in the stratigraphic intervals sampled. The majority of the elements recovered were fragmentary, and in numerous cases the whole (non fragmentary) specimens recovered were poorly preserved and not useful for identification on the species level. The specimens in good to excellent states of preservation were mounted for SEM photography and are displayed in the plates herein (see appendix p. 113). A detailed explanation of each identifiable specimen in this study is in the systematic paleontology chapter (p.102). For an overview of the ranges of index conodonts used, see the paleontology sub section of the Findings and Discussion chapter (p. 87).

Four biostratigraphic zones were identified from the results of the high frequency sampling of outcrops on U.S. Highway 65. These are from oldest to youngest: the *bulbosus* zone, the lower “*texanus*” zone, middle “*texanus*” zone, and upper “*texanus*” zone. The *bulbosus* zone is indicative of the upper Reeds Spring Formation (Boardman et al., 2013), and the transition of the Reeds Spring Fm. into the thicker-bedded Bentonville Formation (formerly Burlington-Keokuk Formation). The lower and middle "*texanus*" zone correspond to the Bentonville Formation, and the upper "*texanus*" zone corresponds to the lower Ritchey Formation (Figure 15). The biozonation scheme in this study follows one proposed by Boardman et al. (2013). The zones are not formally named, but proposed.

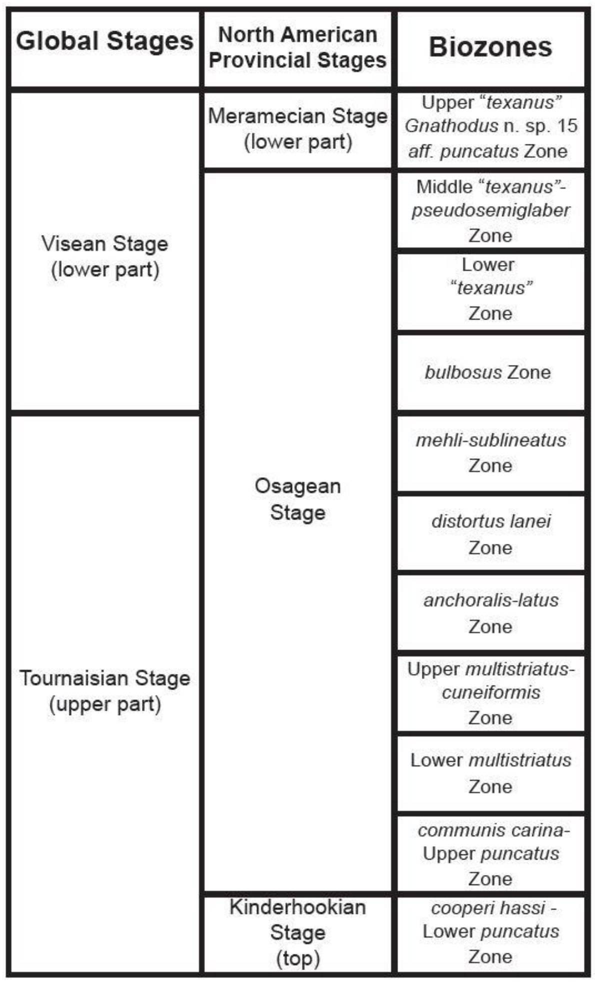


Figure 15. Newly proposed biozones for the Osagean Stage after Boardman et al. (2013)

The Mississippian interval examined in this study has not been the focus of biostratigraphic analysis. The interval was investigated in the Mississippi River Valley (Branson and Mehl, 1941; Rexroad and Collinson, 1965) and in southeastern Kansas, and southwestern Missouri (Thompson and Goebel, 1969, Thompson and Fellows, 1970). The localities in this study extend the biostratigraphic coverage to the south within the outcrop belt in northwestern Arkansas.

Boone Group sedimentation in the study area was within a middle to inner ramp setting marked by an increase in grainstones with shallower water depth (Mazzullo et al., 2013, Price, 2014). The shallow high-energy setting of these deposits fits well with the conodont yields obtained in this study. Conodonts within carbonate facies are known to occur in higher abundances within debris-flow limestones, fossiliferous mudstones, crinoidal bioherms, and calcareous concretions within shale zones, and are often scarce in carbonate platform rocks (Gutschick and Sandberg, 1983). Low conodont yields per kilogram were expected, so a bed by bed sampling protocol was necessary for adequate stratigraphic coverage, conodont recovery, and biozone determination.

The Reeds Spring Fm./Bentonville Fm. Contact I outcrop contains the *bulbosus* Zone, which is the oldest of the four zones identified (Figure 16). The fauna were recovered within the Bentonville Formation. The platform conodonts found in this zone all belong to the *Gnathodus bulbosus* species (Thompson and Fellows, 1970, Boardman et al, 2013). The *bulbosus* Zone occurs in the Reeds Spring Formation west of the study area in southwestern Missouri (Thompson and Fellows 1970, Boardman 2013), and is associated with the middle to upper Osagean strata. At the Reeds Spring Formation/Bentonville Formation Contact II outcrop, the *bulbosus* Zone does not occur at the same lithostratigraphic position. Instead *Gnathodus aff. pseudosemiglaber* was found within the Reeds Spring Formation, and *G. texanus* specimens were

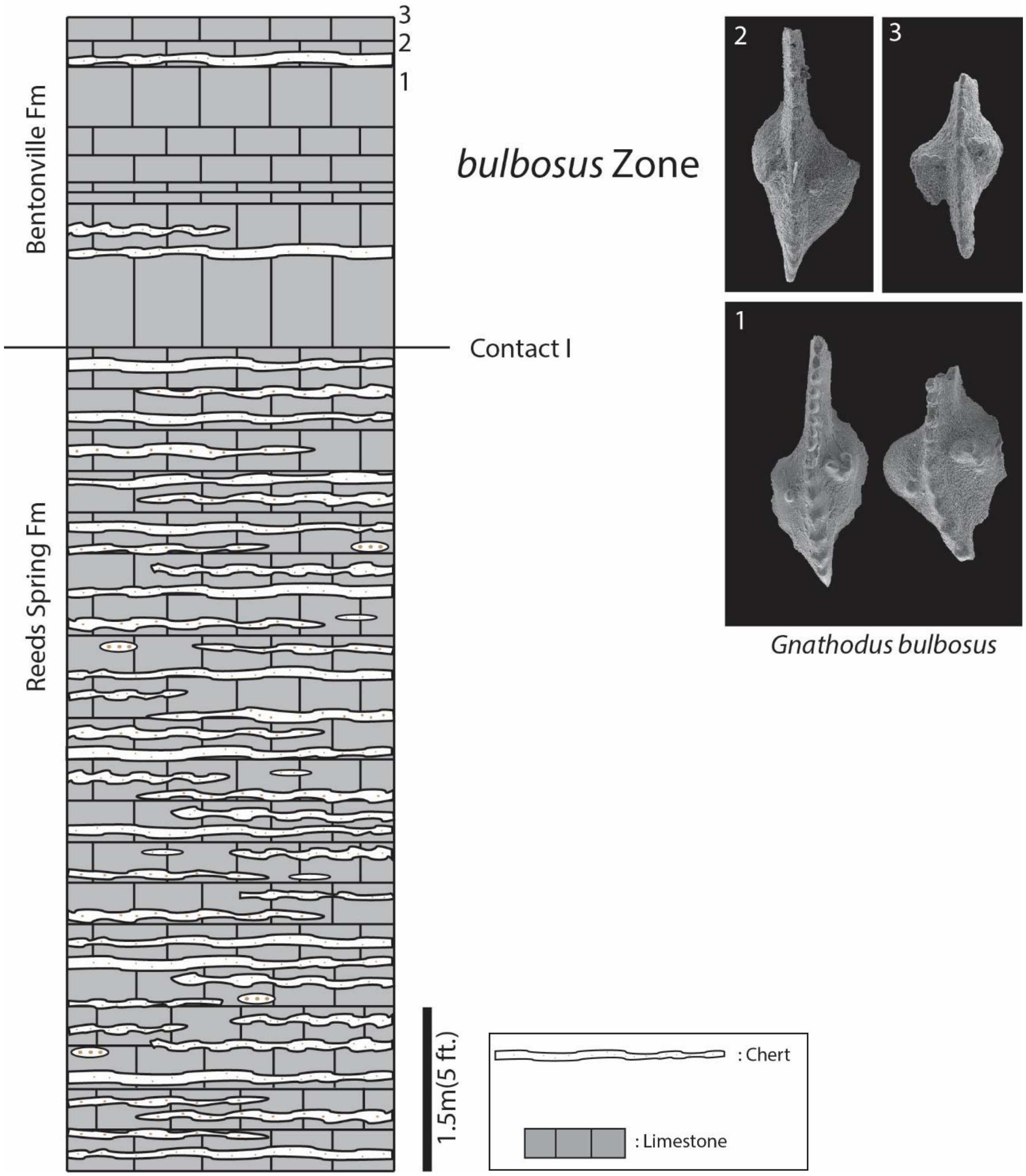


Figure 16. Stratigraphic section of the Contact I outcrop (left). The contact between the Reeds Spring Fm/Bentonville Fm is marked by a decrease in chert and increase in bedding thickness (Robertson, 1967, Mazzullo et al., 2011, Mazullo et al., 2013). Corresponding conodonts recovered from the Bentonville Formation displayed (right) belong to the *bulbosus* Zone.

found within the overlying Bentonville Formation (Figure 17). Though the two outcrops are located within one-half mile of each other, the faunal differences are evident.

The Reeds Spring Fm/Bentonville Fm Contact II outcrop contains specimens in affinity to *Gnathodus texanus* and can be assigned to the lower "*texanus*" zone (Figure 17). The decrease of *bulbosus* specimens present within this sampled section and higher occurrence of *G. texanus* type specimens support this assignment (Boardman et al., 2013). The section yielded only four well preserved specimens for SEM analysis and zonal designation was difficult, but was based primarily on increased abundance of *G. texanus* type specimens relative to *G. aff. pseudosemiglaber* recovered within this section.

The Bentonville Co-Type Locality contains the lower "*texanus*" zone, middle "*texanus*" zone, and upper "*texanus*" zone (Figures 18 and 19). The lower and middle "*texanus*" zones occur within the Bentonville Formation. The upper "*texanus*" zone is restricted to the Ritchey Formation. The Bentonville Formation at this locality measures 19.2 meters (63 ft), and is capped by 1.5 meters (5ft) of the Short Creek Oolite Member. The lower "*texanus*" zone occurs only in the basal 4.6 meters (15 ft) of the exposure. The fauna in this zone include *G. texanus, G* .n. sp. B *aff. texanu*s, and *G.bulbosus*. The interval where *G. bulbosus* is no longer present and *G. pseudosemiglaber* commonly occurs, is the transition from the lower "*texanus*" zone to the middle "*texanus*" zone.

The middle "*texanus*" zone is within the upper 14.6 meters (48 ft) of the Bentonville Formation at the Co-Type Locality. The zone is dominated by specimens identified as *Gnathodus pseudosemiglaber* and *Gnathodus aff. pseudosemiglaber*. Specimens of *Gnathodus texanus*, *Gnathodus aff. texanus*, *Gnathodus linguiformis* and *Gnathodus* n.sp. B *aff. pseudosemiglaber* were also found within the upper portion of the Bentonville Formation, and are now assigned to

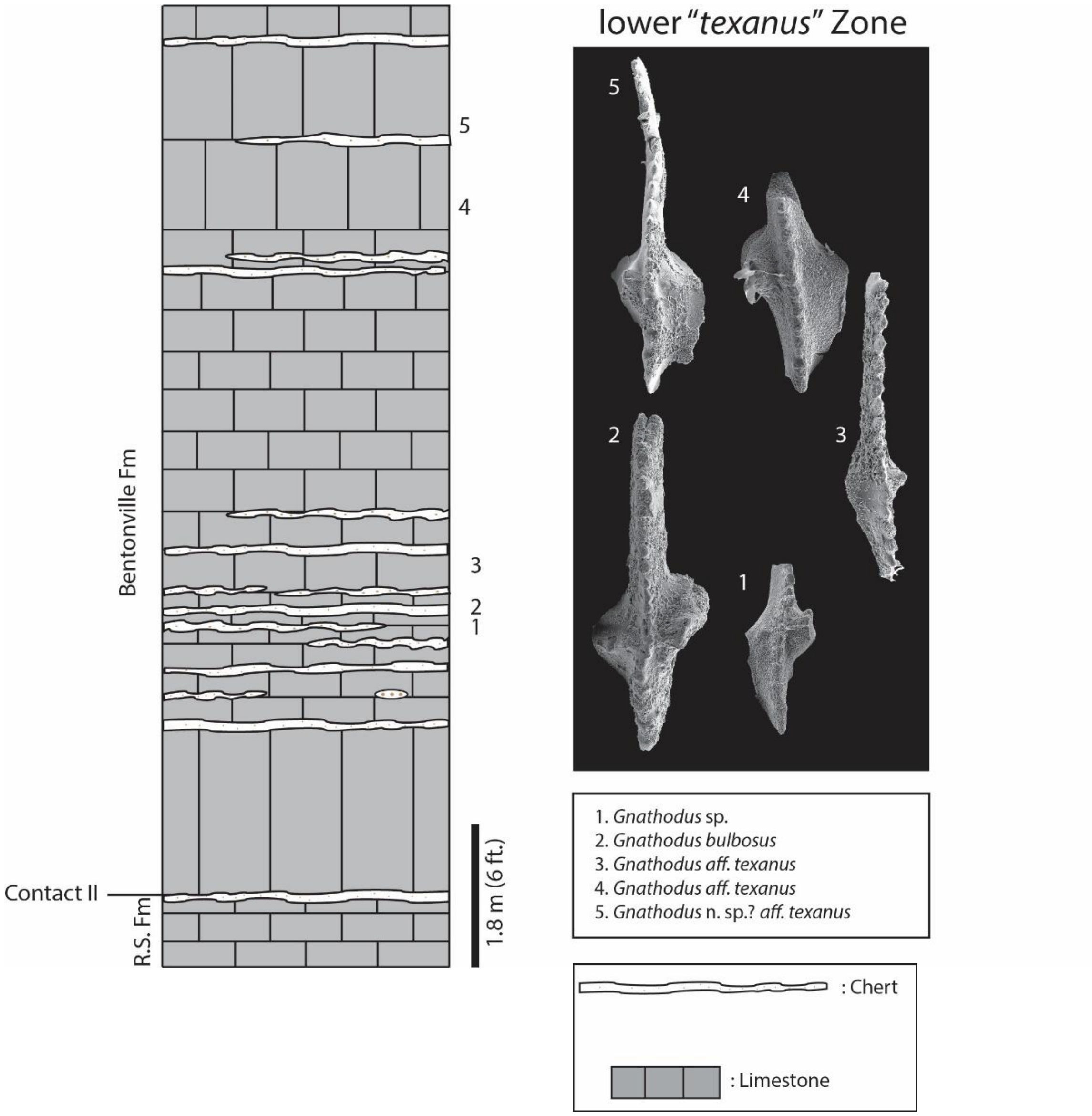


Figure 17. Stratigraphic section for the Contact II outcrop. The sampled contact between the upper Reeds Spring Fm and the Bentonville Fm is displayed at the base of the column (left). The contact between the two formations is marked by the first occurrence of a thicker, more massive bed and decrease in frequency of chert (this study). Conodonts recovered are displayed with numbers corresponding to bedding location (right). The conodonts recovered indicate a higher abundance of *G. texanus* type specimens relative to a marked decrease in abundance of *G. bulbosus*. The conodonts recovered place this section in the lower "*texanus*" zone (Boardman et al., 2013).

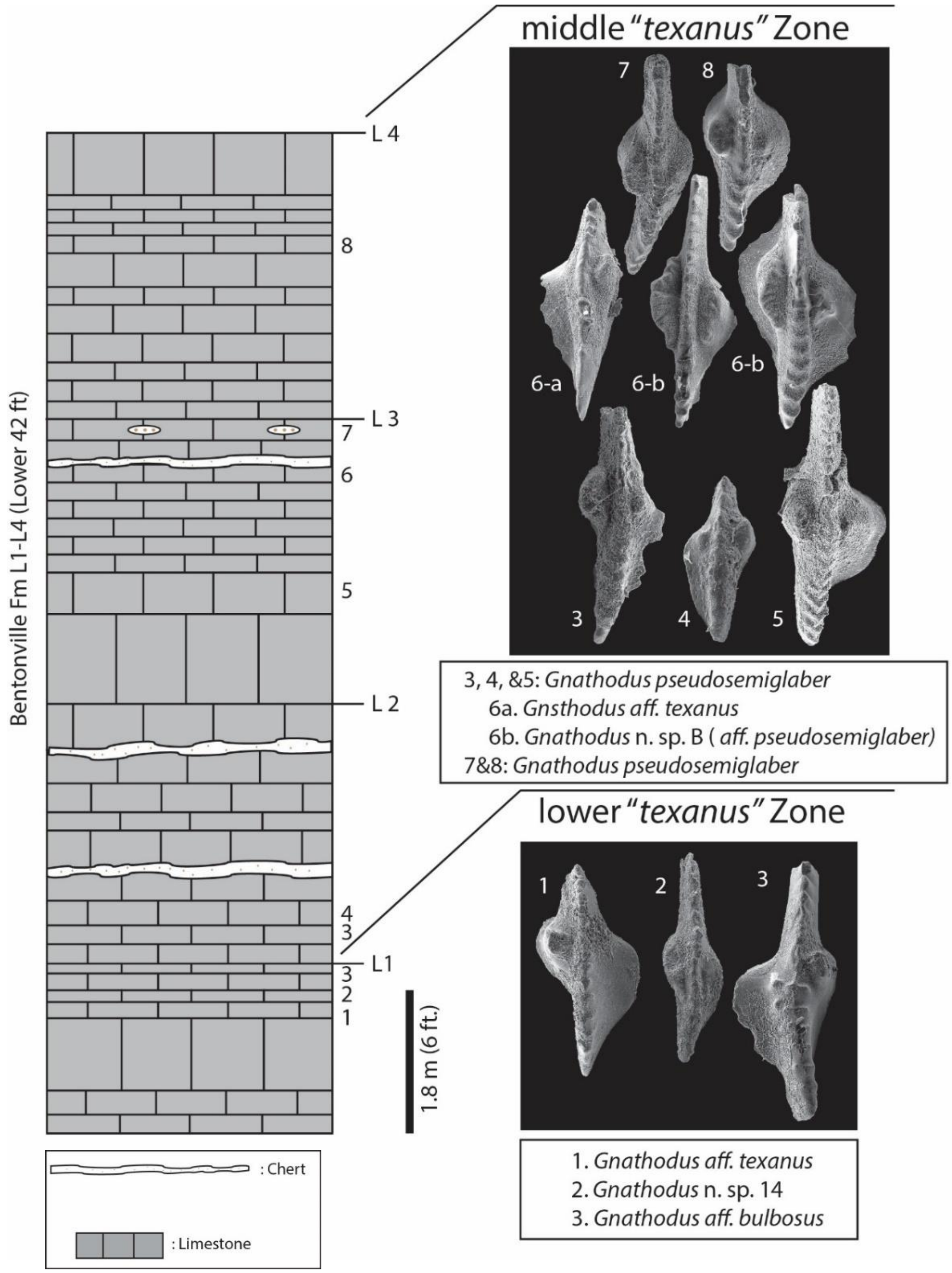


Figure 18. Stratigraphic section for the Bentonville Fm (lower section), Bentonville Co-Type Locality (left). Corresponding ledges used in sample labeling are displayed to the right of the column. Conodonts recovered are displayed with corresponding numbers referencing the sampled location. The lower "*texanus*" zone is only present within the basal nine feet of the outcrop. In overlying strata (L1-L4) *Gnathodus bulbosus* does not occur, and an increase in abundance of *Gnathodus pseudosemiglaber* and *G. aff. pseudosemiglaber* specimens is observed. The overlying strata are designated to the middle "*texanus*" zone (Boardman et al., 2013).

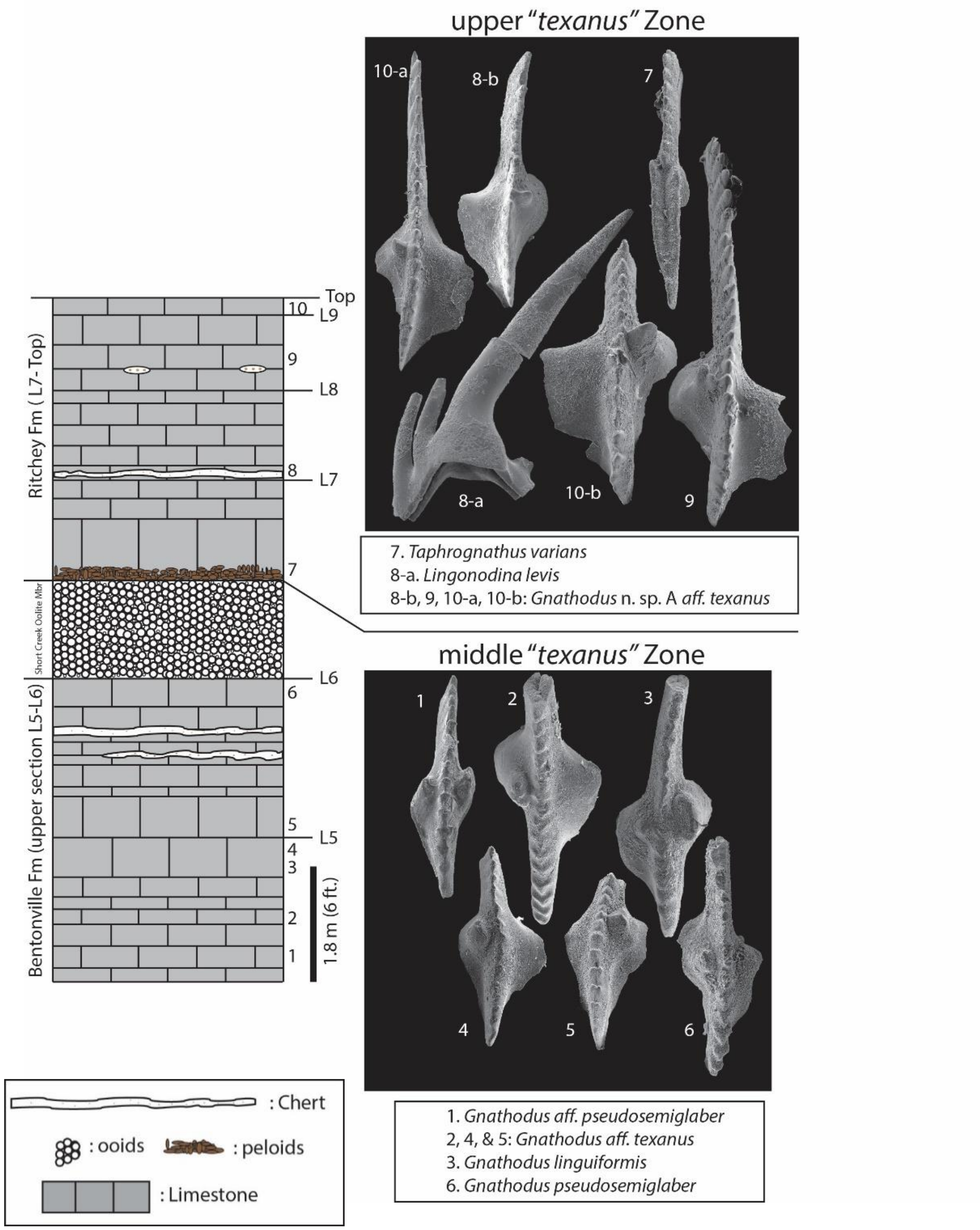


Figure 19. Stratigraphic section for the upper Bentonville Fm (L5-L6), and its Short Creek Oolite Mbr. Overlying the Short Creek Oolite Mbr is the lower portion of the Ritchey Fm (L7-Top)(left). The upper extent of the middle "*texanus*" zone occurs within the Bentonville Formation. Conodonts recovered are marked numerically to the beds sampled (right). The upper extent of the middle "*texanus*" zone is marked by the occurrence of *G. pseudosemiglaber*, *G. aff. pseudosemiglaber*, *G. linguiformis*, and *G. aff. texanus.* Overlying the oolite, the Ritchey Fm contains specimens of *Taphrognathus varians*, *Lingonodina levis*, and *G.* n. sp. A *aff. texanus*. The change in the fauna marks the transition from the middle "*texanus*" zone to the upper "*texanus*" zone.

the middle “*texanus*” zone, as originally proposed in Boardman et al. (2013). A specimen of *Cavusgnathus* sp.? Found within this interval poses difficulty in determining the zone as upper Osagean in age. However, the lack of occurrences of *Taphrognathus varians* within the sampled interval, and increased abundance in *Gnathodus texanus* type specimens support assignment to upper Osagean (Thompson and Geobel, 1969, Rexroad and Collinson, 1965). The middle “*texanus*” zone is capped by 1.5 meters (5 ft) the Short Creek Oolite Member, which yielded no conodonts.

The basal Ritchey Formation at the Bentonville Co-Type Locality measures 4.3 meters (14 feet) and the associated fauna belong to the upper “*texanus*” zone (Figure 19). This zone was previously interpreted to contain specimens of *Taphrognathus varians* and *Gnathodus* n. sp. 15 (*aff punctatus*) (Boardman, 2013). *Gnathodus* n. sp. 15 (*aff. puncatus*) was not found within the Ritchey Formation at this locality. It is known to occur in other Ritchey localities on US HWY 65, but is often rare in occurrence (personal communication with Cory Godwin, 2015). Recovered conodonts include: *Taphrognathus varians*, *Lingonodina levis*, *Lingonodina* sp., *Gnathodus* n. sp. A *aff. texanus*, and *Gnathodus aff. texanus*. The non-occurrence of *Gnathodus pseudosemiglaber*, and *Gnathodus aff. pseudosemiglaber*, and *Gnathodus linguiformis*, with the occurrence of species, *Taphrognathus varians* and *Lingonodina levis*, suggest an uppermost Osagean to lower Meramecian age assignment (Thompson and Goebel, 1969). The occurrence of abundant specimens of *Gnathodus* n. sp. A *aff. texanus* may be a key finding in defining the upper “*texanus*” zone, and possible biozonational change. It appears to differ from the underlying *G. texanus* specimens based on orientation of the node within the inner platform. The upper “*texanus*” zone, and the transition from Osagean to Meramecian time is difficult to define due to sparse yields of conodonts (Rexroad and Collinson, 1965, Goebel, 1966, Thompson and Goebel, 1969). More processing and specimen recoveries are necessary before definition of the fauna specific to this zone can be validated.

The Bentonville Type Locality in McDonald County, Missouri north of Bentonville, Arkansas was sampled for a chronostratigraphic correlation of the Bentonville Formation within the northwestern Arkansas-southwestern Missouri field area. The Bentonville Type Locality was sampled at a lower frequency than the Bentonville Co-Type Locality. The high frequency (bed by bed, ft by ft) sampling done at the Bentonville Co-Type Locality aided in recognizing the biozones within the formation. Lower frequency sampling was conducted at the Bentonville Type Locality since an understanding of the biozones was established from the high frequency analysis done at the Bentonville Co-Type Locality. The limestone lenses within the Pineville Tripolite facies, the contact between the Tripolite and the Bentonville Formation, the middle of the Bentonville formation, and uppermost section of the Bentonville Formation were designated as sample locations within the outcropping section. Specific intervals were sampled for conodonts to relate back to the higher frequency analysis on US HWY 65 for a chronostratigraphic correlation. Two kilograms of each sample collected from the Bentonville Type Locality were processed for conodont elements. The Bentonville Type Locality contains 24.4 meters (80 ft) of exposed limestone at its highest point (Price, 2014). The exposure has the Reeds Spring Formation at the base that measured to be at least 9.1 meters (30 ft) in thickness at the northern end of the exposure, and the overlying Bentonville Formation, which ranges from 15.2-21.3 meters (50-70ft) in thickness depending on location within the 400 meter (1300ft) long exposure (Price, 2014). The Short Creek Oolite Member which marks the top of the Bentonville Formation was not observed in the Bentonville Type Locality (Price, 2014).

Within the basal section of the outcrop, the Reeds Spring Formation is diagenetically altered to the Pineville Tripolite facies. The contact between the Reeds Spring Formation and the overlying Bentonville Formation is sharp. A 2.5 ft. thick massive bed of crinoidal grainstone that overlies a partially silicified bed of fossiliferous packstone marks the contact between the two formations (Price, 2014) (Figure 12). Limestone lenses 4-6 inches by 1 ft that occur within the tripolitic chert of the Pineville Tripolite Facies are mudstones. These lenses of limestone within the Pineville Tripolite facies were sampled for conodont element recovery, as were a silicified limestone bed and thicker grainstone bed at the contact, and the middle and upper sections of the Bentonville Formation.

The conodonts within the limestone lenses in the Pineville Tripolite facies of the Reeds Spring Fm. resemble specimens of *Gnathodus bulbosus;* they are listed in this study as *Gnathosus aff. bulbosus* (Figure 20) (Appendix p. 132, Plate 9, Figure 8). Another specimen (Appendix p. 137, Plate 12, Figure 5) recovered from the limestone lenses, was assigned *Gnathodus* sp because the specimen is etched to the point that species recognition cannot be completed with confidence. Conodont specimens are sparse within the limestone, and silicification of the Reeds Spring Formation at this locality limits the amount of rock available for sampling and acid digestion. Based on these recovered specimens, the Reeds Spring Formation at this location is currently assigned to the *bulbosus* Zone.

Overlying the Pineville Tripolite is a thin bed of silicified limestone that is likely the lowermost bed of the Bentonville Formation. This bed is a silicified fine-grained grainstone to mud-lean packstone. The conodonts recovered from this bed are *Gnathodus aff. texanus* and *Gnathodus aff. bulbosus*? As a result this bed is assigned to the lower "*texanus*" zone.

The 2.5 ft. thick bed of grainstone above the recognized Bentonville/Reeds Spring contact between the formations yielded specimens of *Gnathodus aff. pseudosemiglaber*. This conodont is younger in age and places the Bentonville Formation at this locality within the middle "*texanus*" zone. The middle section of the Bentonville Formation was sampled and contained a higher abundance of conodont elements. Conodonts recovered from beds assigned to the middle of the formation were *Gnathodus* sp. indeterminate, *Gnathodus aff. pseudosemiglaber*, *Taphrognathus varians*, and *Spathognathodus* sp. The occurrence of *Gnathodus aff.*

pseudosemiglaber and nonoccurrence of *Gnathodus bulbosus* places this interval in the middle "*texanus*" zone (Boardman et al., 2013). The upper section of the Bentonville Formation yielded one specimen of *Gnathodus aff. pseudosemiglaber* (*aff. linguiformis*?) **(** Appendix p. 121, Plate 4, Figure 3). This was the most mature and well preserved specimen recovered in this study, and its occurrence at the uppermost section of the Bentonville Formation confirms that the Bentonville Formation at this locality can be assigned to the middle "*texanus*" zone.

Sampling the Reeds Spring Formation and the Bentonville Formation at the Contact I, Contact II, Co-Type and Type Locality yielded upper Osagean fauna. The one notable difference was the vertical extent of the lower "*texanus"* zone. The zone was informally proposed based on the decrease in abundance of *Gnathodus bulbosus*, increase in abundance of *G. texanus* type specimens (many recently given new species designation, but not systematically defined and named), and non-occurrence of *G. pseudosemiglaber* (Boardman, 2013). The zone is difficult to define until more specimens related to the previously identified *G. texanus* specimens within the upper Osagean are formally given species designation. A discussion of the biozonational patterns within Osagean strata analyzed is found in the Paleontology sub section of the Findings and Discussion (p. 87).

The conodonts recovered within the Bentonville Formation at the Type Locality all can be assigned to the middle "*texanus*" zone. The vertical extent of the lower "*texanus*" zone at the Type Locality on HWY 71 is limited to the basal section of the outcrop, which is altered to tripolitic chert. The occurrence of *G. aff. texanus* and *G. aff. bulbosus* within this interval limits the amount biostratigraphic resolution for specific zone designation at this time. Further processing of limestone lenses within the Pineville Tripolite will aid in resolving the zone designation for this facies. The Bentonville Formation at this locality can be assigned to the middle "*texanus*" zone.

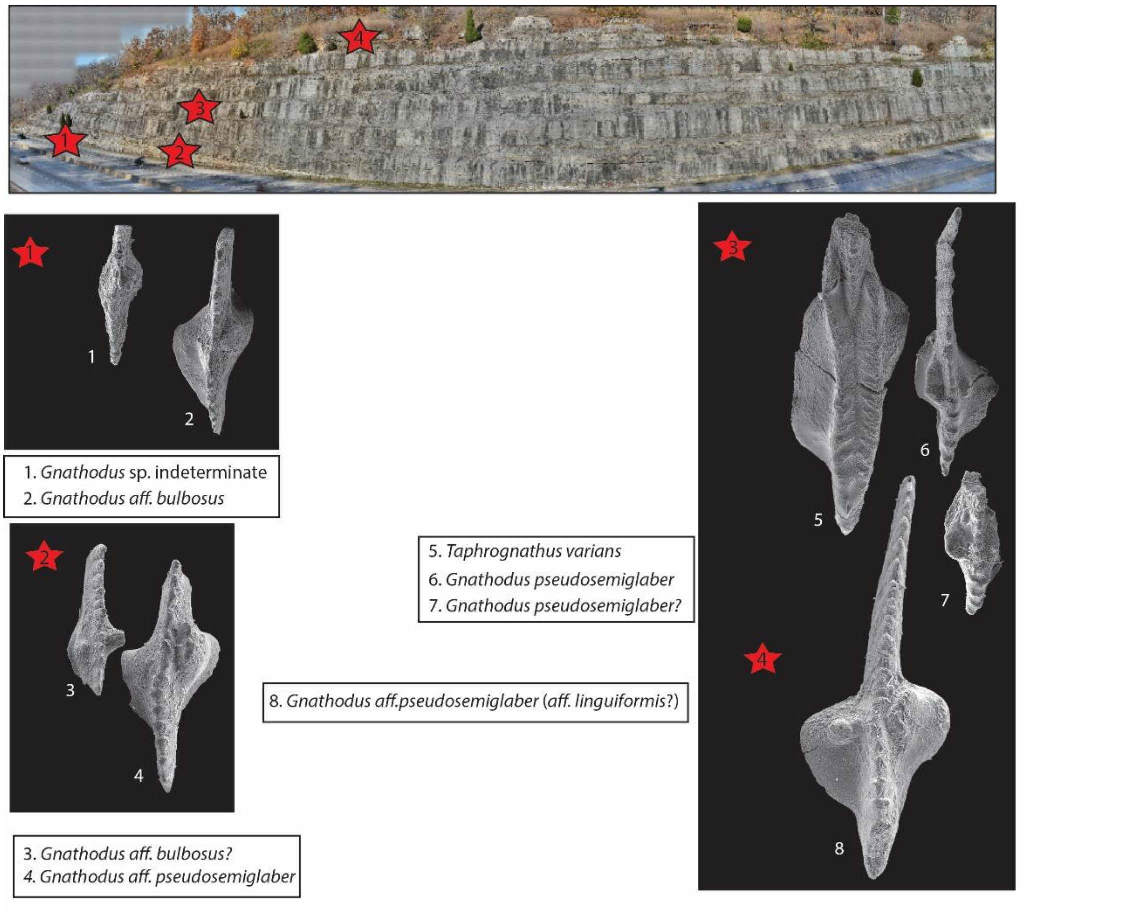


Figure 20: Conodonts recovered from the Bentonville Type Locality. The outcrop pictured above has sampled locations indicated by the red stars. (1) Limestone lenses within the Pineville Tripolite yielded a specimen resembling *G. bulbosus*, and an unidentifiable gnathodid (2) The contact between the Pineville Tripolite and the Bentonville Formation recovered *G. bulbosus*? below the contact, and *G. aff. pseudosemiglaber* above the contact within the first massive grainstone bed of the Bentonville Fm. (3) In the middle of the Bentonville Fm, *G. pseudosemiglaber* and *T. varians* were recovered. (4) At the top of the outcrop a specimen in affinity to *G. pseudosemiglaber* and possibly G. *linguiformis* was recovered. Conodonts are numbered corresponding to specimen ID. The tripolite either belongs to the lower "*texanus*" zone or *bulbosus* Zone. The Bentonville Formation is assigned to the middle "*texanus*" zone.

CHAPTER IV

LITHOSTRATIGRAPHY

An acetate peel petrographic analysis was performed on the intervals sampled for conodont element recovery. The acetate peels aided in general facies recognition within the Bentonville Co-Type Locality, Reeds Spring Fm/Bentonville Fm Contact I Locality, and Reeds Spring Fm/Bentonville Fm Contact II Locality. From the 117 acetate peels made ten (10) generalized facies were identified. The facies classification is based on the Dunham carbonate classification (Dunham, 1962) (Table 2).

The facies identified in outcrop indicate slight variations in depositional regime. The Dunham (1962) classification was used primarily to describe changes in grain and matrix content that reflect differences in depositional energy. In addition to reflecting depositional energy, grain typing was used as an indicator of paleoecologic variability across the sampled strata. Photomicrographs of each generalized facies observed are displayed on pages 46-50 (Figures 21-30).

The Reeds Spring Formation/Bentonville Formation Contact I Locality contained facies characteristic of a middle ramp to proximal inner ramp setting. The facies include: silicified limestone (SLS), skeletal wackestone to packstone (SWP), mud lean packstone (MLP), fine grained grainstone (FGGS), medium grained grainstone (MGGS), coarse grained grainstone (CGGS), and very coarse grained grainstone (VCGGS). The beds near the base of the exposure

(Reeds Spring Fm) contain more frequent occurrences of chert than the overlying Bentonville Formation (formerly Burlington-Keokuk Formation).

Table 2: Facies Observed in Outcrop

Facies Abbreviation:	Facies Name:	Description:
SLS	Silicified limestone	Limestone containing evidence of siliceous replacement. Primary rock fabrics observed to undergo silicification include mudstones, wackestones, mud lean packstones, and fine grained grainstones.
SWP	Skeletal wackestone to packstone	Limestone containing a 100% micrite matrix with bioclasts supported in places. Bioclasts are also observed to be mud supported within the rock. Primary skeletal grains include crinoids, brachiopods, and bryozoans.
MLP	Mud lean packstone	Limestone, grain supported, matrix contains both spar and micrite. The ratio of mud to spar is undeterminable without grain counting. Primary allochems include crinoids, brachiopods, and bryozoans.
FGGS	Fine grained grainstone	Limestone, grain supported, with fine crystalline sparry matrix. Grains are biogenic in origin consisting of broken unidentifiable skeletal fragments <.125 mm in diameter.
MGGS	Medium grained grainstone	Limestone, grain supported, with spar matrix. Grains are biogenic in origin consisting of skeletal fragments .25-.75mm in diameter. Grains are 80-90% disarticulated crinoidal skeletal debris. Arm fragments and crinoid ossicles are commonly seen in peel analysis. 10-20% of the grains consist of other skeletal fragments of brachiopods and bryozoans.
CGGS	Coarse grained grainstone	Limestone, grain supported, with spar matrix. Grains are biogenic in origin consisting of skeletal fragments .75-1mm in diameter. Grains are 80-90% disarticulated crinoidal skeletal debris. Crinoid ossicles are commonly seen in peel analysis. 10-20% of the grains consist of brachiopods and bryozoans.
VCGGS	Very coarse grained grainstone	Limestone, grain supported, with spar matrix. Grains are biogenic in origin consisting of skeletal fragments 1-2mm in diameter. Grains are 80-90% disarticulated crinoidal skeletal debris. Crinoid ossicles are commonly seen in peel analysis. 10-20% of the grains consist of brachiopods and bryozoans.
OGS	Oolitic grainstone	Limestone, grain supported, with spar matrix. Grains are inorganic, consisting of ooids .1-.4 mm in diameter.
MOGS	Micritized ooid grainstone	Limestone, grain supported, with spar matrix. Grains are inorganic, consisting of micritized ooids .1-.4 mm in diameter.
PSGS	Peloidal skeletal grainstone	Limestone, grain supported, with spar matrix. Grains are inorganic and biogenic. Peloids (pellets?) 0.05 mm in diameter constitute 15-25% of the grains. Crinoid ossicles .4-1mm in diameter, ostracodes, brachiopods and bryozoans are also present varying in overall size from .1-2mm in size.

Table 2. Facies identified in outcrop. Abbreviated facies shorthand classification (left), and facies descriptions (right) are used to designate rock types occurring in studied outcrop sections of the Boone Group.

Figure 21. Silicified limestone facies (SLS), in plane-polarized light (PPL) (left), and cross-polarized light (XPL) (right). Displayed is a wackestone with a fragmented crinoid columnal (center of photograph) and crinoid ossicles (upper left of photograph). The mud matrix, and bioclasts are silicified, shown by the first order gray interference color when viewed in XPL (right). The orange scale bar in the lower right of each image is 1mm in length.

Figure 22. Skeletal wackestone to packstone facies (SWP), in plane-polarized light (PPL) (left), and crossed-polarized light (XPL)(right). The matrix is 100% micrite. Grains are mostly skeletal (echinoderm fragments), ranging in size from 0.02-1.5mm in diameter. Bioclasts are grain-supported (upper left of photomicrograph), but appear to be mud supported in other areas (lower left of photomicrograph). The orange scale bar in the lower right of each image is 1mm in length.

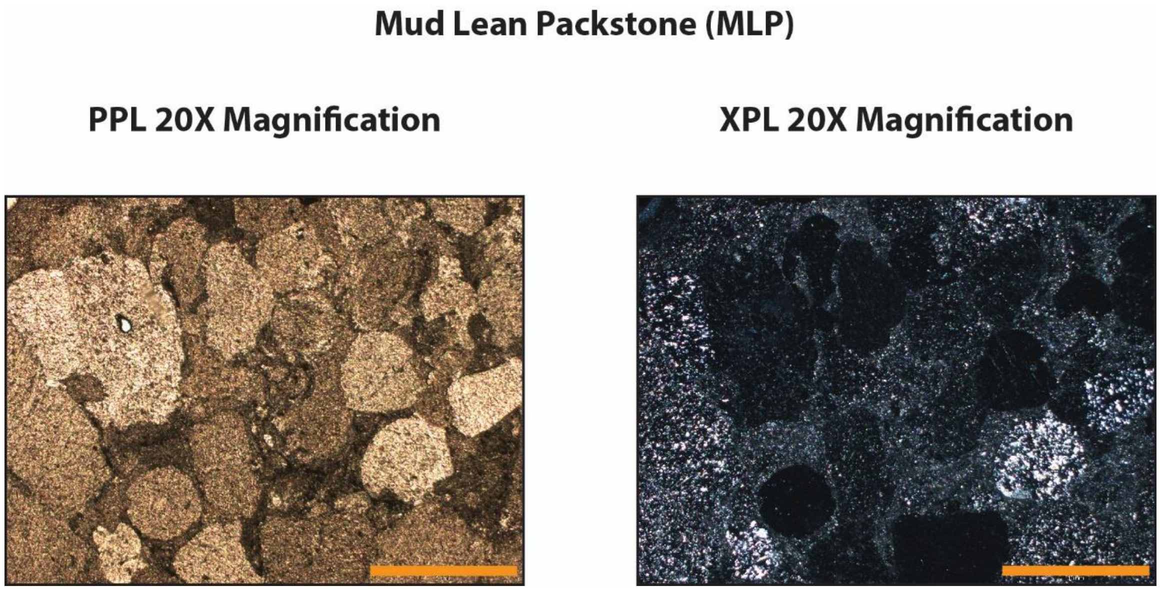


Figure 23. Mud lean packstone facies (MLP), in plane-polarized light (PPL) (left), and cross-polarized light (XPL)(right). The matrix consists of micrite and spar. Grains are mostly skeletal (echinoderm) fragments and range in size from 0.3-1mm in diameter. The lower half to the photomicrograph has a mud matrix, and the upper half is observed to have an increase in spar within the matrix. The orange scale bar in the lower right of each image is 1mm in length.

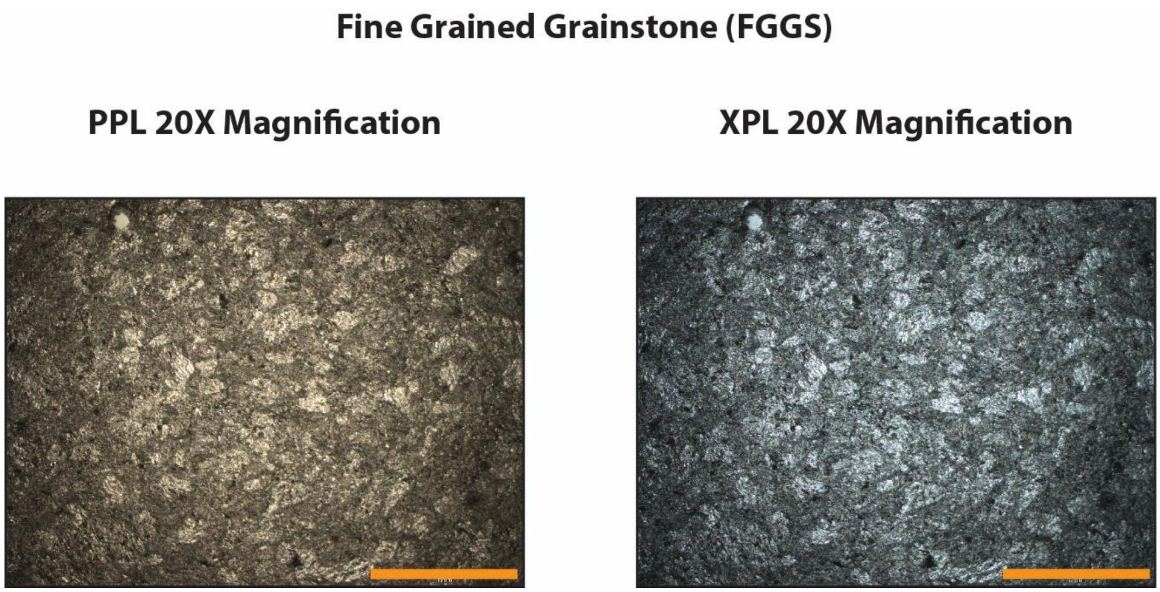


Figure 24. Fine grained grainstone facies (FGGS), in plane-polarized light (PPL) (left), and cross-polarized light (XPL) (right). Grains consist of unidentifiable skeletal fragments <1.25 mm in diameter. The orange scale bar in the lower right of each image is 1mm in length.

Figure 25. Medium grained grainstone facies (MGGS), in plane-polarized light (PPL) (left), and cross-polarized light (XPL) (right). The majority of grains are disarticulated crinoid debris; bioclasts are .25-.75 mm in diameter. The orange scale bar in the lower right of each image is 1mm in length.

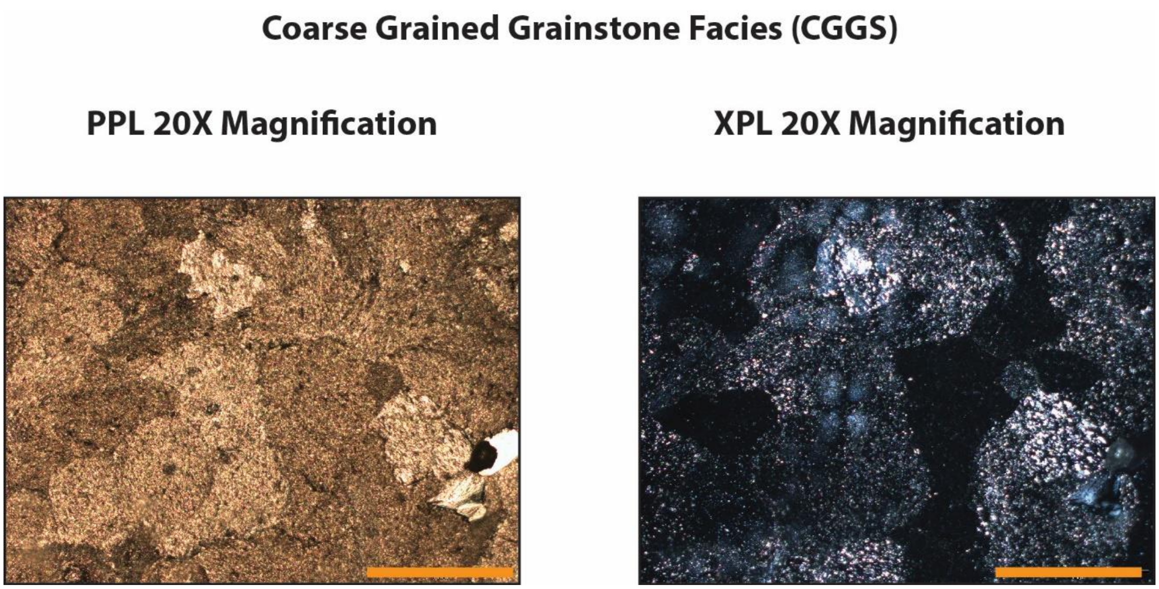


Figure 26. Coarse grained grainstone facies (CGGS), in plane-polarized light (PPL) (left), and cross-polarized light (XPL) (right). The majority of the bioclasts are disarticulated crinoid debris that are .75-1mm in diameter. The orange scale bar in the lower right of each image is 1mm in length.

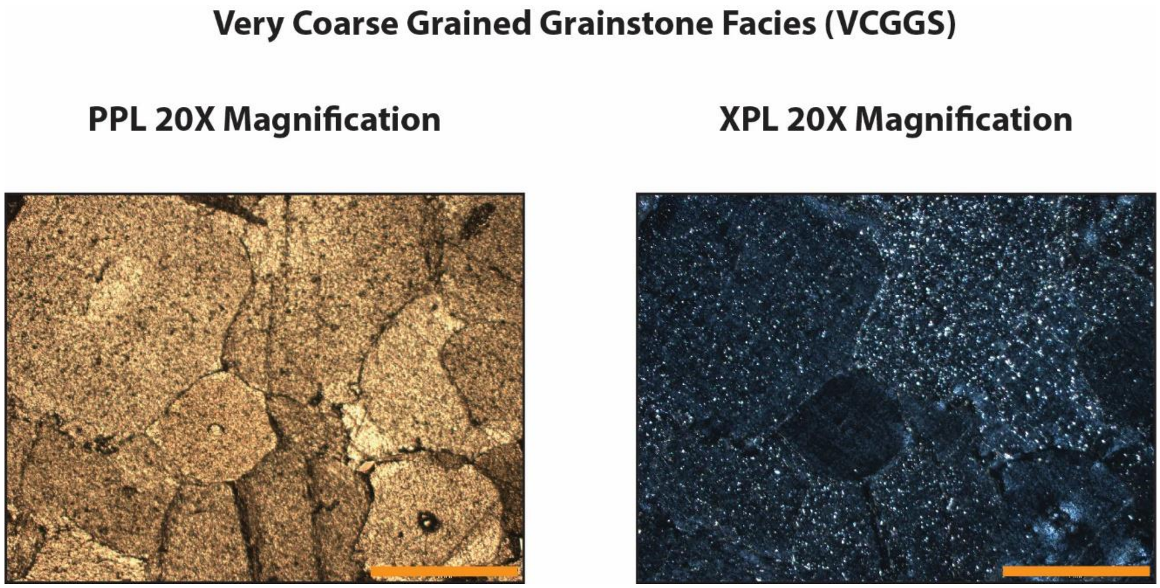


Figure 27. Very coarse grained grainstone facies (VCGGS), in plane-polarized light (PPL) (left), and cross-polarized light (XPL) (right). Bioclasts are mostly disarticulated crinoid debris that ranges 1-2 mm in diameter. The orange scale bar in the lower right of each image is 1mm in length.

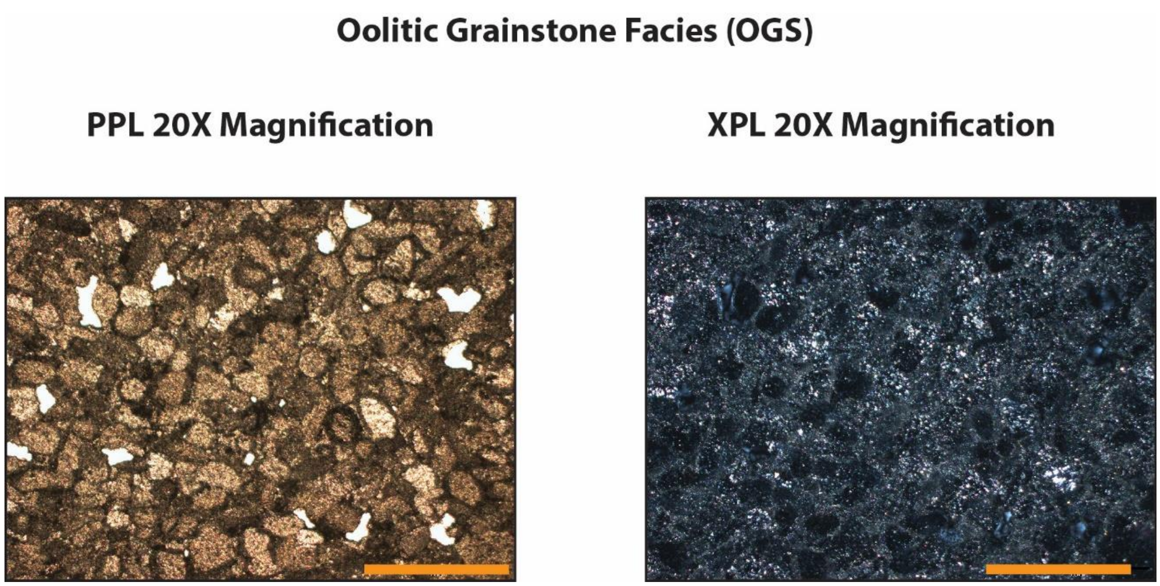


Figure 28. Oolitic grainstone facies (OGS), in plane-polarized light (PPL) (left), and cross-polarized light (XPL) (right). The rock appears to be 100% ooids that are sub spherical and 0.1-0.4 mm in diameter. The orange scale bar in the lower right of each image is 1mm in length.

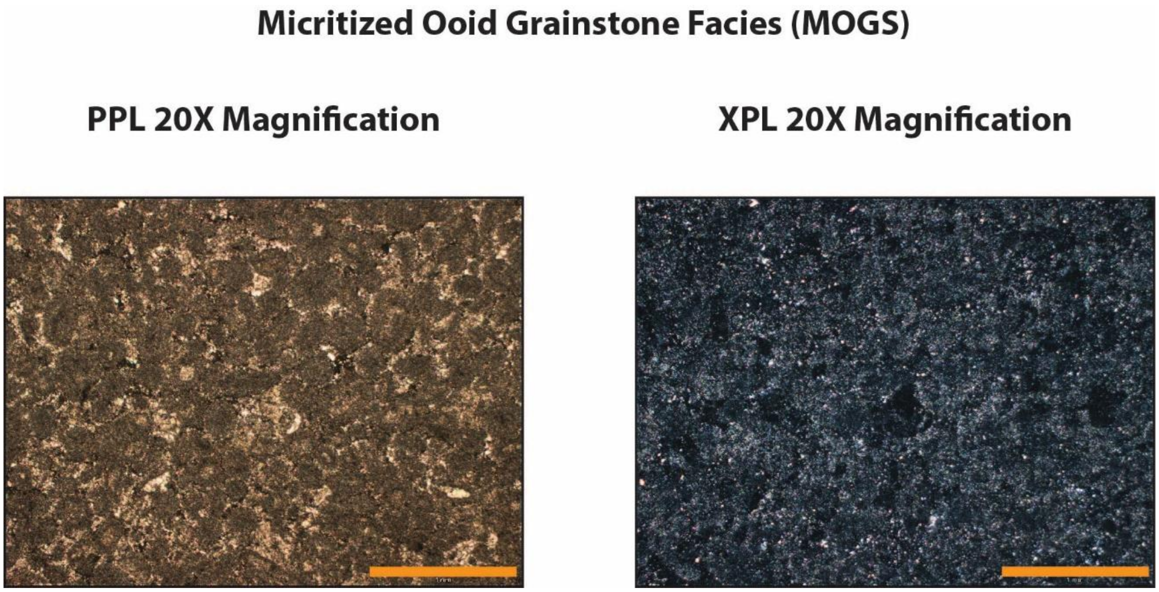


Figure 29. Micritized ooid grainstone facies (MOGS), in plane-polarized light (PPL) (left), and cross-polarized light (XPL) (right). The rock is 100% peloids, consisting of micritized ooids 0.1-0.4 mm in diameter. The orange scale bar in the lower right of each image is 1mm in length.

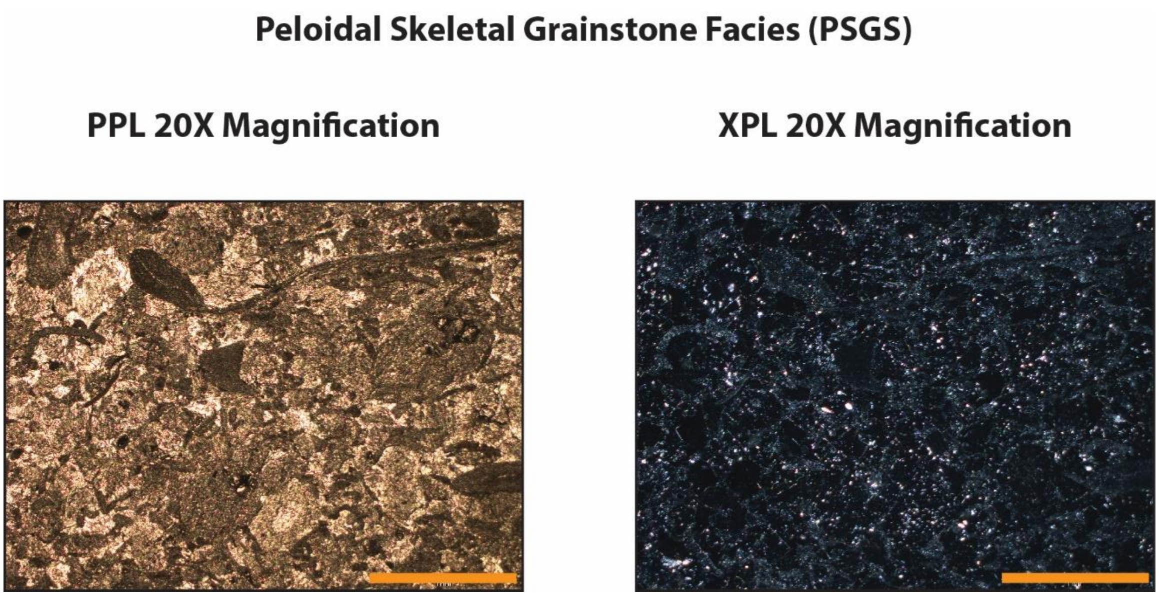


Figure 30. Peloidal skeletal grainstone facies (PSGS), in plane-polarized light (PPL) (left), and cross-polarized light (XPL) (right). PSGS is grain supported, with a spar matrix. Grains are inorganic and biogenic. Peloids 0.1-0.4 mm in diameter and pellets 0.05 mm in diameter constitute 25% of the grains. Crinoid ossicles 0.4-1mm in diameter, as well as ostracodes, brachiopods and bryozoans are present varying in overall size from 0.1-2mm in size. The orange scale bar in the lower right of each image is 1mm in length.

The Reeds Spring Formation also contains relatively lower energy deposits of more mud-rich facies within the base of the formation at the Contact I outcrop. The occurenece of mud within the facies implies that the basal section of the Reeds Spring Formation was likely deposited within a middle ramp setting below fair weather wave base and above storm wavebase (Burchette and Wright, 1992). The contact between the two formations was chosen based on the thickness of bedding and the increase in higher-energy facies of crinoidal grainstones. A generalized facies succession from a middle ramp setting, to a more proximal inner ramp setting, was recognized within the stratigraphy of the 10 meter (33ft) exposure (Figure 31).

The basal three feet of exposed section are partially silicified mudstones, wackestones, and packstones. The primary fabric of the rock was still preserved, but the peels revealed a chert overprint when viewed in cross-polarized light. The presence of silica assigns this interval to the SLS facies (Figure 31). Above this interval, facies become progressively more mud lean. Grainstone facies are dominant, and coarsen upward from fine grained grainstones, (FGGS) to medium grained grainstones (MGGS), to coarse grained grainstones (CGGS), and very coarse grained grainstones (VCGGS) (Figure 31). In the Reeds Spring Formation, limestone beds that measure from 10.2 cm to 30.5 cm (4 inches-1ft) in thickness are separated by networks of chert.

The chert within the Reeds Spring Formation, which occurrs between limestone beds, and within beds as anastomosing networks, measured to be 5.1cm-15.2 cm (2-6 inches) in thickness. It also occurrs locally as lenses 20.3 cm (8inches) thick and 30.5 cm (1ft) in width. The chert is dense and readily displays conchodial fracture. When struck with a hammer it often broke prismatically. Chert is often mottled with brown spots 8 mm (0.31 inches) diameter, which appear circular when viewed along a transverse plane and circular to elipsoidal when viewed along an axial plane. The chert is dominantly light gray to opaque white in color; some lighter blue semi translucent chert was observed.

The contact between the Reeds Spring and Bentonville formations is covered with vegetation across the majority of the exposure. The sampling transect was chosen because it was sparsely vegetated across the contact. The position of the contact was based on lithology and bedding thickness. The base of the Bentonville Formation is marked by a thick 0.8 meter (2.5 ft) bed of coarser grainstone (CCGS) that grades upward into very coarse grainstone (VCGGS). The chert content within the Bentonville Formation decreases up section. Above the Bentonville/Reeds Spring contact are grainstones with bioclasts that range from fine to coarse (FGGS-CGGS) indicating shallowing above the contact.

The Contact II outcrop is located 644 meters (0.4 miles) north of Contact I. The contact between the Reeds Spring Formation and the Bentonville Formation was placed at the top of a 1 meter (3.4 ft) thick interval of mud-lean packstones (MLP) (Reeds Spring Formation) that is overlain by a thin 0.09-0.23 meter (0.3 to 0.75 ft) interval of discontinuous chert and a thick 2-2.1 meter (6.5-7ft) bed of coarse-very coarse grainstone (Bentonville Formation) (Figure 32).

The Bentonville Formation above the thick basal grainstone bed consists of a 2.7 meter (9 ft) thick interval of medium grained grainstones (MGGS), fine grained grainstone (FGGS), mud lean packstones (MLP), and skeletal wackestone to packstone (SWP). The facies described in this interval more closely resemble those associated with the Reeds Spring Formation and lower energy deeper-water deposition, and may be a response to a higher frequency flooding event.

The uppermost section of the Bentonville Formation at the Contact II outcrop contains grainstone facies of varying bioclast diameter. Primary facies observed were coarse-grained grainstones (CGGS), although lesser amounts of medium-grained grainstones (MGGS) and fine-grained grainstones (FGGS) are present. Carbonate mud was not apparent in the coarser-grained limestone samples from the upper section.

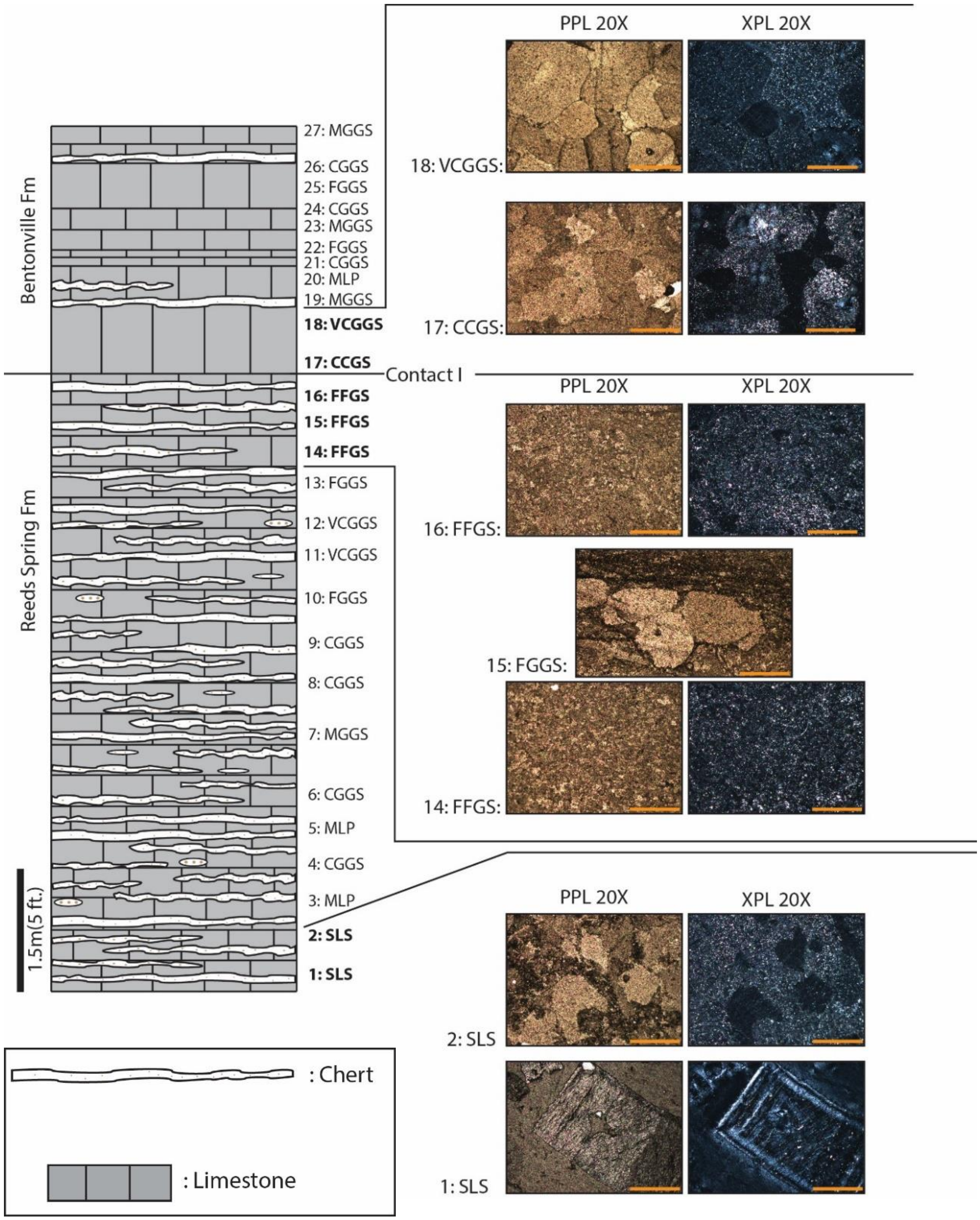


Figure 31. Bentonville Fm. /Reeds Spring Fm., Contact I outcrop. Facies shorthand designation is displayed to the right of the beds sampled. The bold text corresponds to the photomicrographs displayed (right). The SLS facies can be seen at the base of the Reeds Spring Fm., the contact between the Bentonville Fm and the Reeds Spring Fm. is based on the decrease in frequency of chert, and the first occurrence of a thicker massive grainstone. Facies of CGGS and VCGGS occur in a coarsening-upward interval of the Bentonville Fm, which overlies the basal limestone above FGGS facies of the Reeds Spring Fm. Each scale bar is 1 mm in length

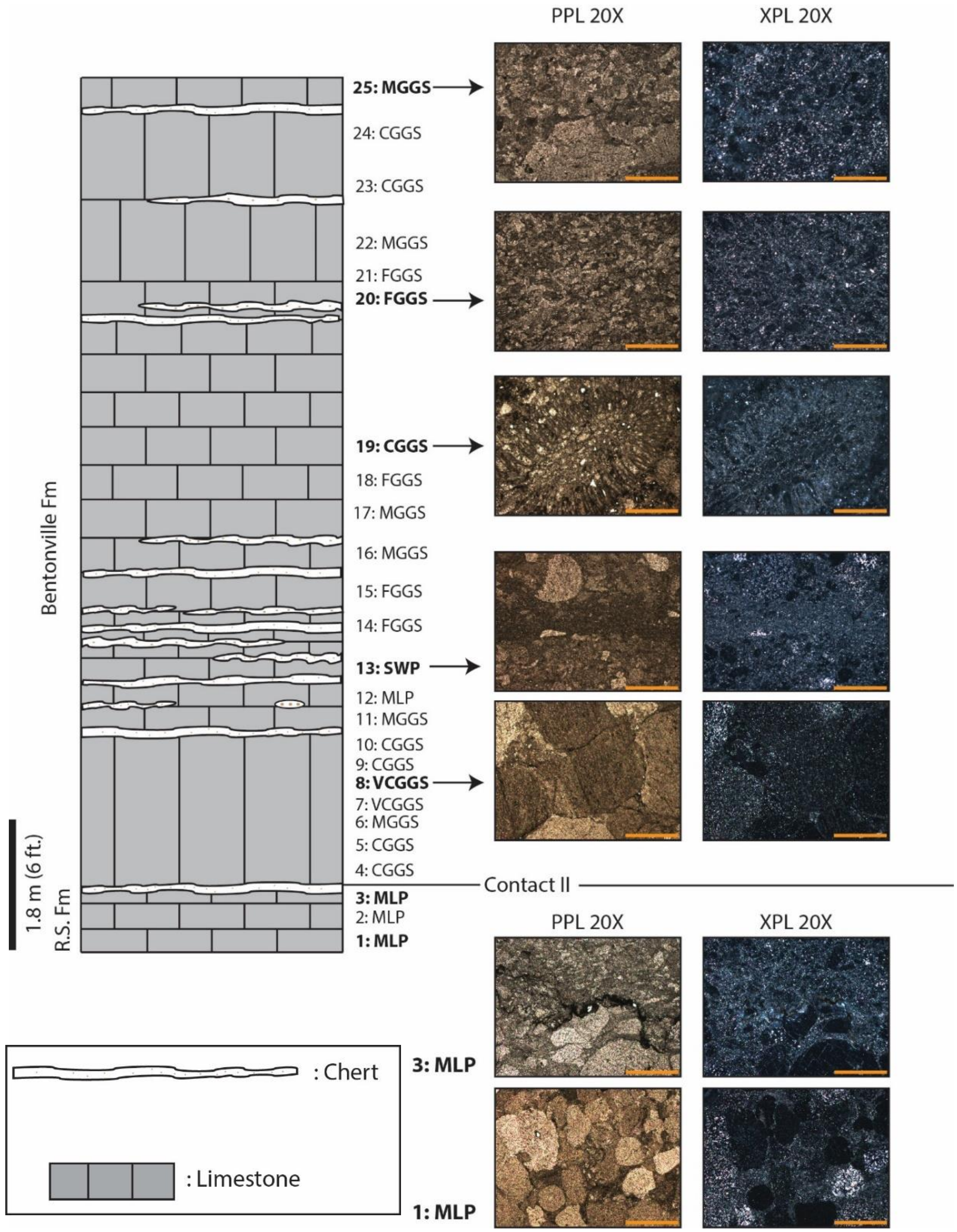
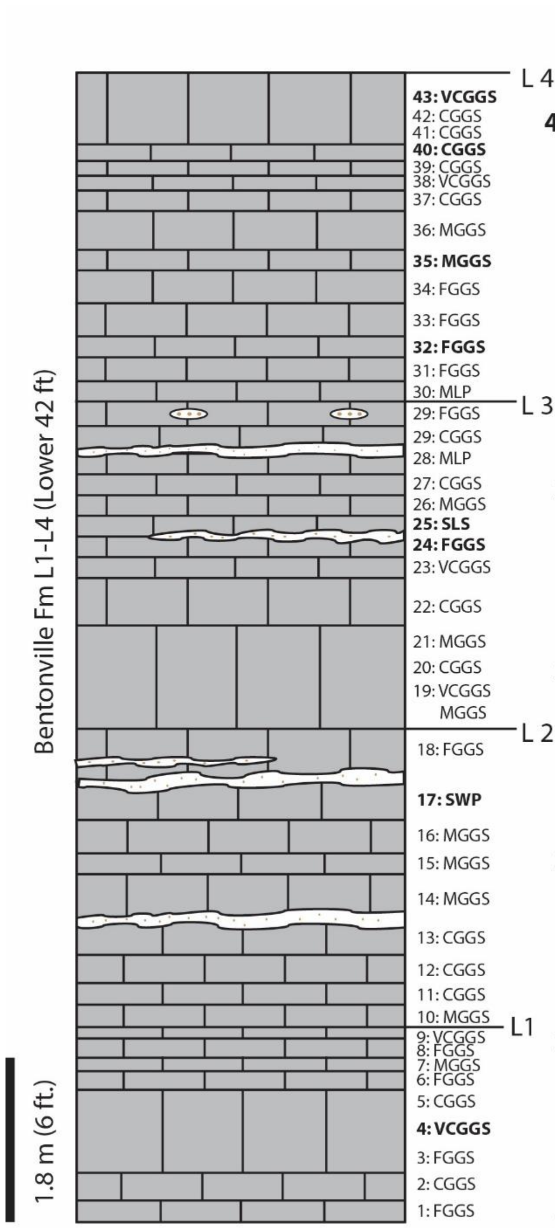


Figure 32. Bentonville Fm/Reeds Spring Fm Contact II outcrop. The contact was placed based on the occurrence of a 6.5-8 ft. bed of grainstone, overlying a 4-8 inch discontinuous chert interval. This section overlies the Reeds Spring Formation. The upper three (3) ft. of the Reeds Spring Formation was sampled and is represented by the MLP facies. Facies are represented to the right of the lithologic column at the position where samples for conodonts and acetate peels were collected. Bold text facies identify corresponding acetate peel photomicrograph. See figure 33 for lithologic symbols. Each orange scale bar is 1 mm in length.

The Contact I and Contact II outcrops represent the transition from the Reeds Spring Formation to the Bentonville Formation. The higher abundance micrite observed within the facies of the Reeds Spring Formation is indicative of a relatively lower energy environment of deposition when compared to the Bentonville Formation.

The Bentonville Co-Type Locality was also sampled for facies analysis. The Reeds Spring Formation was not observed at this locality and the Bentonville Formation includes the Short Creek Oolite Member, a 1.5 meter (5 ft) thick interval of oolitic grainstone (OGS). Overlying the Short Creek Oolite Member is 4.3 meters (14 ft) of the Ritchey Formation.

The Bentonville Formation is predominantly crinoidal grainstones. Bedding thickness within the 17.7 meter (58 ft) thick formation ranges from 15.2cm (6 inches) to as much as 1.2 meters (4 ft) in thickness. The section was sampled according to marked ledges seen within the vertical sampling transect. Ledges 1-4 represent the lower 12.8 meters (42 ft) of the exposure and represent the Bentonville Formation (Figure 33).Within this interval, facies include: fine to very coarse grained grainstones (FGGS, MGGS, CGGS, and VCGS), as well as mud lean packstones (MLP), skeletal wackestones-packstones (SWP), and silicified limestones (SLS) (Figure 33). The facies which contain micrite occur in lower frequencies relative to the grainstone facies. The micrite may be the result of storm events that brought mud from more distal deeper water settings below fair weather wavebase into the dominantly shallow water system, or a response to higher frquency cyclicity associated with Milankovitch driven transgressive events. Chert occurs infrequently within the Bentonville Formation; when present it is often associated with fine grained grainstones and carbonate mud (micrite). Ledges 5-9 represent the upper 10.7 meters (35 ft) of section sampled and contain the upper section of the Bentonville Formation and the Short Creek Oolite Member, and a basal section of Ritchey Formation (Figure 34).



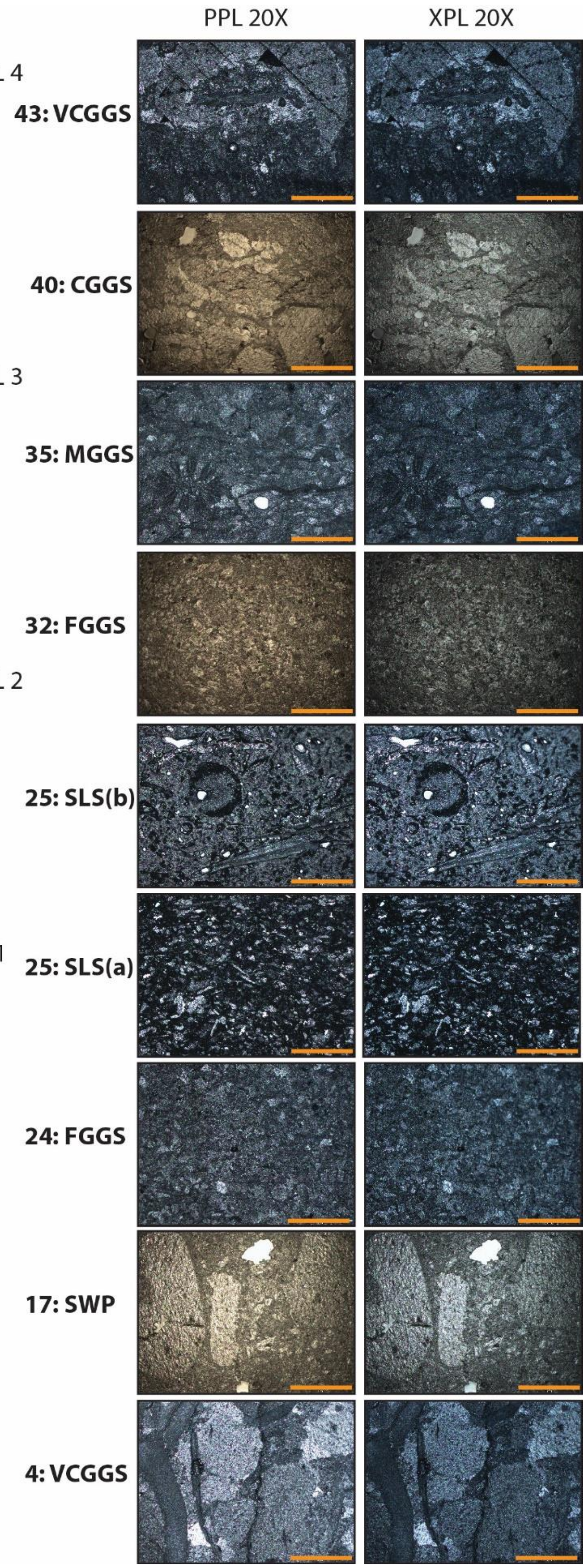


Figure 33. The lower 42 ft. of the Bentonville Co-Type Locality (L1-L4) with representative facies. Facies photomicrographs (right). The Bentonville Formation is represented by grainstones, and less frequent occurrences of chert. Where chert content increases, it is associated with lower energy facies of FGGS, MLP, and SWP. Orange scale bars are 1 mm in length. See Figure 32 for an explanation of lithologic symbols.

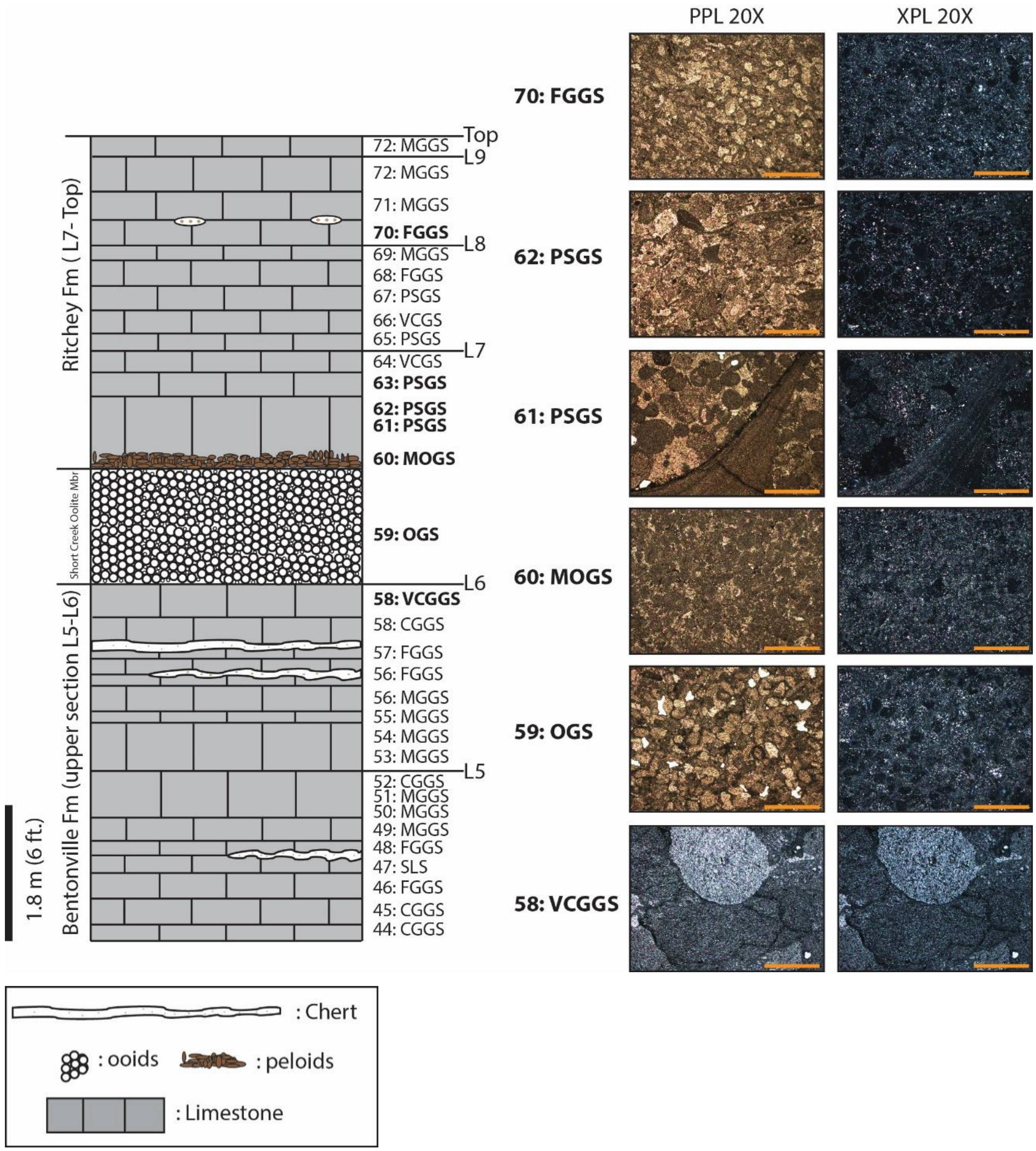


Figure 34. Upper section of the Bentonville Co-Type Locality (L5-L9-Top of outcrop). Photomicrographs of the representative facies observed are displayed (right). Orange scale bars are 1mm in length. Grainstone facies coarsen upward into the Short Creek Oolite Member of the Bentonville Formation. The oolite is directly overlain by the MOGS facies which grades vertically upward in the PSGS facies.

The uppermost unit in the Bentonville Formation is the Short Cheek Oolite Member. This section consists of oolitic grainstone (OGS) (Figure 34), which is the highest energy facies observed within the outcrop. Directly overlying the oolite is a 0.73 meter (29 inch) bed containing abundant peloids. At the base of this bed is the micritized ooid grainstone facies (MOGS) that is cemented with medium to fine crystalline sparry calcite. Within the same bed, skeletal grains of brachiopods, bryozoans, crinoids, and ostracodes are seen increasing in abundance relative to the micritized ooids. This increase in skeletal grains and decrease in micritized ooids results in a facies designation of peloidal skeletal grainstone (PSGS).

The PSGS facies occurs within the Ritchey Formation where PSGS is separated by beds of VCGGS and FGGS facies (Figure 34). Peloids in the PSGS are smaller in size, measuring .06-.01 mm in diameter. The smaller size is characteristic of pellets (Scholle and Scholle, 2003). Pellets and pelods require rapid cementation to be preseved within carbonate environments (Scholle and Scholle, 2003). The occurrence of the MOGS, and PSGS above the oolite suggest a lower energy facies that may be representative of an isolated back shoal lagoonal environment that was adjacent to a higher energy shoal bar represented by Short Creek Oolite and OGS facies.

CHAPTER V

FINDINGS AND DISCUSSION

DEPOSITIONAL ENVIRONMENT

Ten (10) generalized facies were observed within the three high frequency sampled outcrops. The grainstone facies that typifies the Bentonville Formation are interpreted to have been deposited within a proximal, relatively high energy setting of a carbonate ramp (Price, 2014). Previous studies within the southern Midcontinent have documented the Bentonville Formation, formerly referred to as the Burlington-Keokuk Formation and upper Boone Formation, as a high energy wave dominated skeletal shoal with diagnostic oscillation ripple marks (Thompson, 1986; Manger, 2014). Similar structures of oscillation ripples were observed within the Bentonville Formation (Figure 35). The grainstones of the Bentonville Formation occur in thicker more massive beds. The thickness in bedding and decrease in micrite are interpreted to indicate deposition within a high energy, wave dominated inner ramp setting (Burchette and Wright 1992). Within the Bentonville Co-Type Locality, the facies observed become more proximal up section, from coarse grained grainstones (CGGS), to oolitic grainstones (OGS), and peloidal skeletal grainstones (PSGS), representing the most proximal facies as a back shoal lagoonal environment at the base of the Ritchey Formation.

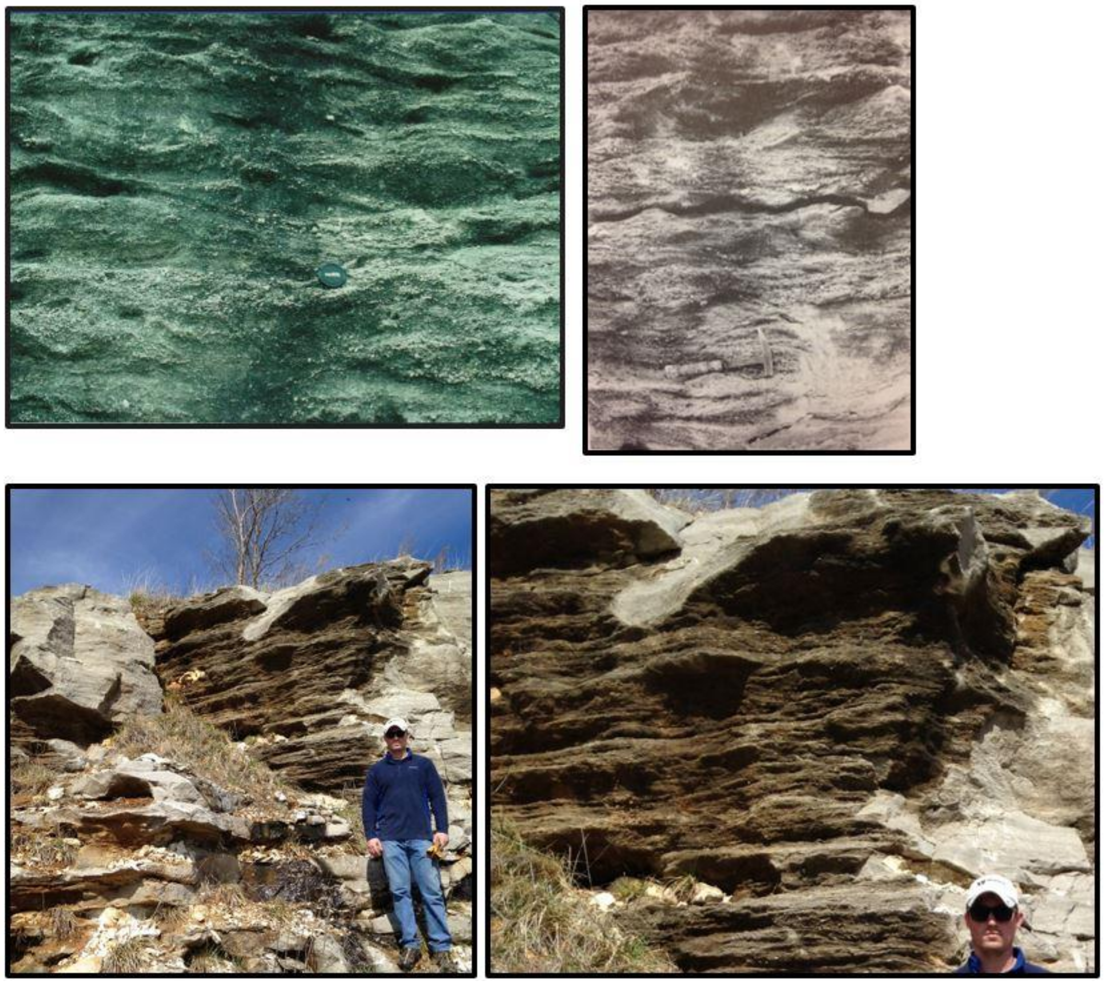


Figure 35. Wave ripple cross bedding observed within thick beds of the Bentonville Formation. Photographs of oscillation ripples observed within outcrops observed by Manger et al (2014) (upper right) and Thompson (1986). Similar sedimentary structures were observed within the Bentonville Formation in this study (bottom two photographs). Field photographs taken within the basal section of the Bentonville Formation at the Contact II outcrop, Cole Dyer, 6’0’’ for scale.

The Reeds Spring Formation exposed at the localities analyzed consists of a series of lower energy facies and higher energy facies with interbedded chert, suggesting a transition from an outer to middle ramp setting (Mazzullo et al., 2011). A similar facies of packstones with interbedded and nodular chert was observed by Elrick and Read (1991) within Mississippian deposits on the western flanks of the Transcontinental Arch. This facies was interpreted to have been deposited in a middle to outer ramp setting within 25-40 meters (82-131 ft) water depth, with the assumption of a 40 meter (131 ft) storm-wave base (Elrick and Read, 1991). The nodular bedding was attributed to initial patchy submarine cementation and burrowing, followed by differential compaction along argillite seams and early diagenetic chert layers (Elrick and Read, 1991). The lack of cross bedding, and similar abundance of chert in the Reeds Spring Formation leads to the inference that it was deposited within a similar setting below fair-weather wave base and above storm-wave base.

The chert within the Reeds Spring Formation displays a mottled texture, and occurs as lenticular and nodular masses, and as anastomosing networks between limestone lenses (Figure 36). The mottled texture is likely the result of sediment homogenization from burrowing organisms (Robertson, 1967). While the origin and diagenetic history of the Mississippian chert is enigmatic, it is hypothesized to be sourced primarily from sponge spicules (Robertson, 1967; Elrick and Read, 1991; Franseen, 2006; Mazzullo et al., 2009). Periodic upwelling of silica rich waters are believed to have resulted in an increasing number of silica secreting sponges within the depositional environment (Franseen, 2006; Mazzullo et al., 2009). The occurrence of chert is noted to become more frequent within the outer extent of the carbonate platform (Mazzullo et al., 2009) (referred to as a ramp within this study). Evidence of storm reworking was documented in acetate peels observed as laminae of coarser grains within the overall fine grained grainstones within the Reeds Spring Formation (Figure 37). Mazzullo et al., (2011) interpreted that mud and sediment within the Reeds Spring Formation was generated in an up dip proximal setting on the carbonate ramp, and was brought downslope during high energy storm events. The author agrees with this interpretation, and supports the depositional model proposed by Mazzullo et al., (2011) in which the Reeds Spring Formation represents deposition within a middle to outer ramp environment.

Figure 36: Chert in the Reeds Spring Formation. The photograph was taken within the upper section of the Reeds Spring Formation at the Contact I outcrop, rock hammer for scale. A closer view of the chert displays the mottled texture interpreted to be traces of burrowing organisms 0.16 centimeters (0.06 inches) in diameter (right).

Figure 37: A series of four stitched photomicrographs displaying coarse grains of crinoidal skeletal debris (center) surrounded by mud and very fine skeletal debris. The structure observed is interpreted to have formed during a high energy storm event. Photomicrographs were taken in PPL at 20X magnification. The orange scale bar is 1mm in length.

The Reeds Spring Formation within the localities analyzed on US HWY 65 more closely resembles the formerly designated Elsey Formation declared by Robertson (1967). It was given formational designation based on the occurrence of discontinuous chert interbeds and nodules 10-15 centimeters (4-6 inches) between calcarenites (grainstones) of equal thickness (Robertson, 1967). The contact between the formerly known Burlington-Keokuk Formation and the Elsey Formation was also noted to be hard to distinguish within the outcrops analyzed within the tristate district by Robertson (1967). The distinction between the underlying Reeds Spring Formation and overlying Elsey Formation was made based on observations that the Reeds Spring Formation was more argillaceous and fine crystalline in nature, with diagnostic blue semi translucent opal like chert (Robertson, 1967). The abandonment of the Elsey formational designation was recently proposed based on the lack of diagnostic features, and interpretations by Robertson (1967) that the chert was the primary diagnostic criterion used for formational designation. This criterion is not reliable because the chert is a diagenetic alteration, and multiple types are seen within the Mississippian stratigraphy in numerous outcrops and subsurface cores (Mazzullo et al., 2013). It was proposed that the formerly known Elsey Formation, resembled a gradational facies into the overlying Bentonville Formation, and that it should be referred to as the Reeds Spring Formation (Mazzullo, et al 2013).

The results of this study question the utility of declaring the Reeds Spring Formation and Elsey Formation. From the integrated biostratigraphic and lithostratigraphic data, it is clear that the stratigraphic succession comprising the Reeds Spring, Elsey, and Bentonville formations are all found within the field area as time equivalent facies deposited on a broad distally steepened ramp (Figure 38). The facies observed support a distally steepened ramp model in which skeletal sand shoals grade into slope deposits toward the distally steepened outer ramp setting. The proximal ramp consists of ooid shoal bars and protected lagoons. The inner ramp is dominated by massive crinoidal grainstones deposited above fair weather wave base. Crinoidal debris and mud is brought down slope from the inner ramp settings into middle to outer ramp settings represented by the Elsey to Reeds Spring facies. The Elsey facies contains crinoidal grainstones, chert, and mudlean packstones, interpreted to be brought down slope from the adjacent crinodal grainstones deposited within an inner ramp setting. Skeletal content decreases distally from the inner ramp setting, with the Reeds Spring facies representing a middle to outer ramp settings on the distally steepened ramp.

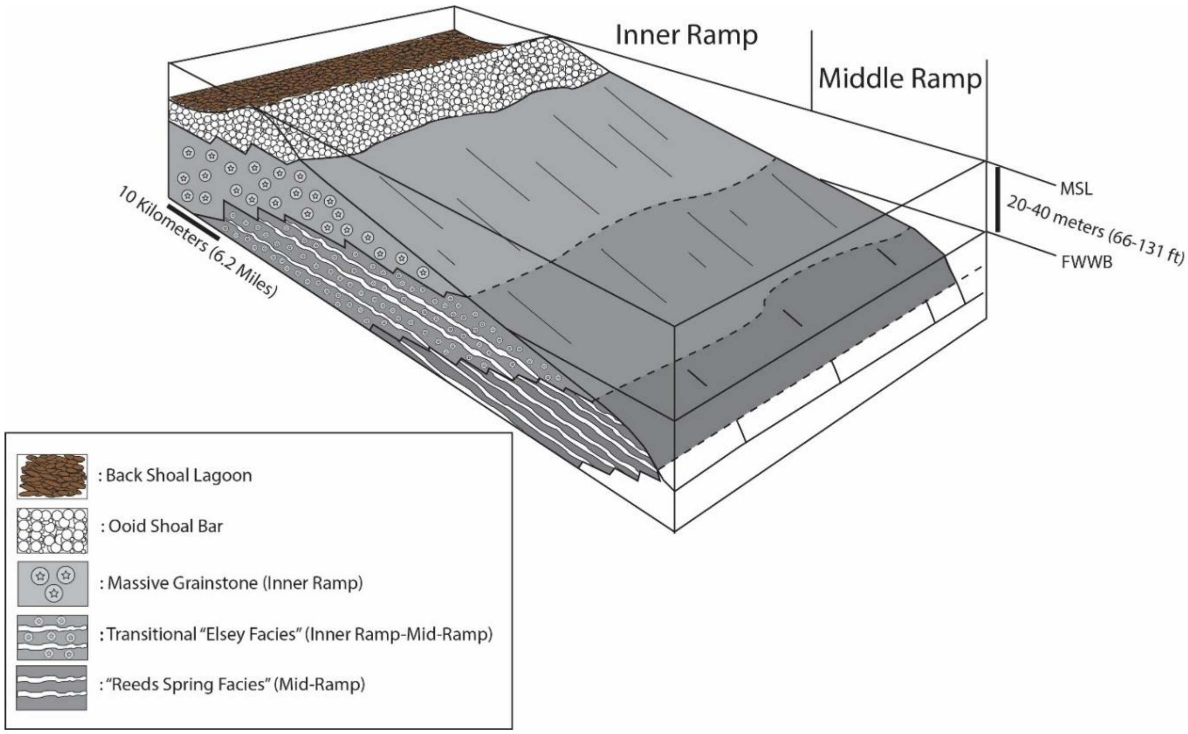


Figure 38: Three dimensional block diagram representing the depositional environment interpreted from this study. The facies observed represent carbonate deposition on a distally steepened ramp. Approximate depth of fair-weather wave base is estimated to be 20-40 meters. The facies succession consists of a peloid dominated bask shoal lagoon environment, which formed adjacent to an ooid shoal bar. A thick massive grainstone facies represents deposition within an inner ramp setting above fair-weather wave base. A transitional inner to middle ramp environment of grainstones and mud lean packstones with interbedded chert is represented by the Elsey facies. With decreasing skeletal content distally the Reeds Spring facies represents deposition within a middle to outer ramp environment.

When conodont biostratigraphy was integrated with outcrop lithostratigraphy mappable changes in facies were documented to contain the same biozone. These facies changes are interpreted to be caused by the ramp geometry and its relationship to progradational facies within the upper Osagean stratigraphy. The Bentonville Formation (formerly Bulington-Keokuk) will now be referred to as “massive grainstone facies” deposited within a proximal inner ramp setting. The former Elsey formation is a time equivalent facies designated as the “Elsey facies,” deposited within a middle ramp setting. Lastly the Reeds Spring Formation will be designated as the “Reeds Spring facies,” deposited within a middle to outer ramp setting. The facies designation is concluded based on biostratigraphic evidence across the field area, which represent individual chronostratigraphic time intervals in the upper Osagean. Furthermore, a facies designation, rather than a formational assignment, accounts for the time transgressive nature of facies on a distally steepened ramp. Individual biozones correspond to individual prograding wedges of sediment, which display a gradation regionally from the “massive grainstone facies” within a proximal setting, to the “Reeds Spring facies” in a distal setting.

DEPOSITIONAL HISTORY

Previous biostratigraphic studies provide evidence that supports the facies belt interpretation. Numerous outcrop localities were sampled in past studies that provide the foundation for interpreting the depositional history of the upper Osagean (Figure 39). The primary work was completed in the late 1960’s and early 1970’s by Thompson (1967), Thompson and Goebel (1969), and Thompson and Fellows (1970). This study contributes four outcrop localities to the cited volume of work and extends regional biostratigraphic coverage in the southern Midcontinent (Table 3).

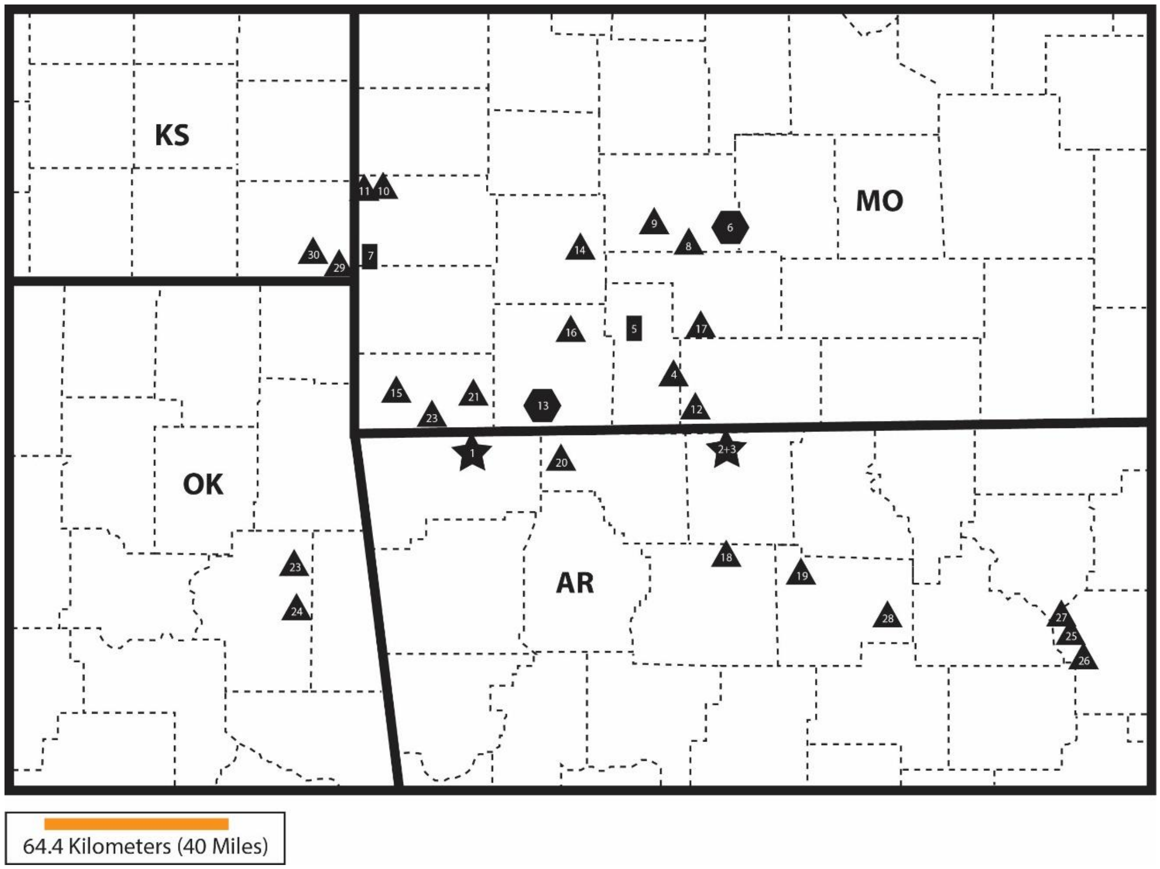


Figure 39: Outcrop localities referencing formations, and biostratigraphic information pertinent to upper Osagean stratigraphy examined in this study. Outcrop data utilized include: Robertson (1967), Thompson (1967), Thompson and Goebel (1969), Thompson and Fellows (1970), Boardman et al., (2013). Localities referenced in this study are marked by stars, triangles represent localities sampled in Thompson (1967), Thompson and Goebel (1969) Thompson and Fellows (1970), and hexagons represent outcrops referenced in both Thompson and Fellows, (1970) and in Boardman et al., (2013). Black rectangles are outcrops referenced in Robertson (1967).

Table 3: Outcrop Localities Information

Locality Number	Locality Name	Location	Report Referenced
1	Bentonville Type Locality	Benton County, AR	This Report
2	Bentonville Co-Type Locality	Boone County, AR	This Report
3	Reeds Spring Formation/Bentonville Formation Contact I and II	Boone County, AR	This Report
4	Reeds Spring Type Locality	Stone County, MO	Thompson and Fellows (1970)
5	Elsey Type Locality	Stone County, MO	Robertson (1967)
6	Turner Station	Greene County, MO	Thompson and Fellows (1970) Boardman et al., (2013)
7	Grand Falls Chert Type Locality	Jasper County, MO	Robertson (1967)
8	Lake Springfield	Greene County, MO	Thompson and Fellows (1970)
9	Brown Quarry	Greene County, MO	Thompson and Fellows (1970)
10	Shoal Creek	Newton County, MO	Thompson and Fellows (1970)
11	Kirshmann Jeffries Quarry	Jasper County, MO	Thompson and Fellows (1970)
12	Baird Mountain Quarry	Taney County, MO	Thompson and Fellows (1970)
13	Roaring River State Park	Barry County, MO	Thompson and Fellows (1970), Boardman et al., (2013)
14	Chesapeake	Lawrence County, MO	Thompson and Fellows (1970)
15	Lanagan Quarry	McDonald County, MO	Thompson and Fellows (1970)
16	Madry Quarry	Barry County, MO	Thompson and Fellows (1970)
17	Chestnut Ridge	Christian County, MO	Thompson and Fellows (1970)
18	Marble Falls	Newton County, AR	Thompson and Fellows (1970)
19	St. Joe	Searcy County, AR	Thompson and Fellows (1970)
20	Leatherwood	Carroll County, AR	Thompson and Fellows (1970)
21	Powell	McDonald County, MO	Thompson and Fellows (1970)
22	Tanner Branch	McDonald County, MO	Thompson and Fellows (1970)
23	Scraper	Cherokee County, OK	Thompson and Fellows (1970)
24	Tahlequah North	Cherokee County, OK	Thompson and Fellows (1970)
25	Type Walls Ferry	Independence County, AR	Thompson and Fellows (1970)
26	Glen Creek South	Independence County, AR	Thompson and Fellows (1970)
27	Walls Ferry Dam North	Independence County, AR	Thompson and Fellows (1970)
28	Sellers Creek	Searcy County, AR	Thompson and Fellows (1970)
29	P. Locality	Cherokee County, KS	Thompson and Goebel (1969)
30	Q. Locality	Cherokee County, KS	Thompson and Goebel (1969)

Table 3. Outcrops utilized in the biostratigraphic reconstruction of the upper Osagean. Localities are numbered, and numbers correspond to the outcrops identified in Figure 37. County locations are provided, as well as the referenced study in which biostratigraphic data was obtained.

Four time slices were constructed that incorporate biostratigraphic and lithologic data from the outcrop belt. The underlying stratigraphy containing the Reeds Spring Formation and the St. Joe Group (Figure 2) was sampled in decades past (Thompson and Goebel, 1969; Thompson and Fellows, 1970). Twenty two (22) previously sampled Reeds Spring localities, and three previously sampled Burlington-Keokuk (Bentonville) localities were incorporated into these facies maps (Figures 40-43). Each map represents the refined biozones proposed in Boardman et al. (2013) for the upper Osagean conodont fauna of the Boone Group. These facies maps represent time slices identified respectively as the *Anchoralis-latus, bulbosus,* lower "*texanus*" and middle "*texanus*" zones. The upper "*texanus*" zone was not incorporated into the facies model due to inadequate biostratigraphic coverage. For clarity in mapping these carbonate facies, lithostratigraphic formational nomenclature was not applied, but a generalized formation-linked facies approach was utilized. The "massive grainstone facies" corresponds to and typifies the Bentonville (Burlington-Keokuk) Formation of a proximal inner ramp depositional environment. The "Elsey facies" represents deposition within a lower inner-ramp to upper middle ramp transitional environment previously referenced as the Elsey Formation. The "Reeds Spring facies" represents more distal middle to outer ramp environment previously referred to as the Reeds Spring Formation.

The *Anchoralis-latus* Zone was not identified with the outcrops sampled in this study, it represents middle Osagean time prior to the overlying *bulbosus* Zone. It is important to recognize the position of this zone within the the Boone Group because the *Anchoralis-latus* Zone is identified in different facies deposited prior to *bulbosus* time. The "massive grainstone facies" (Bentonville/Burlington Keokuk Formation) outcropping in southeastern Greene County Missouri within Thompson's Turner Station locality recorded fauna corresponding to the *Anchoralis-latus* Zone (Thompson and Fellows, 1970). Approximately 7.6 kilometers (4.6 miles) south of the Turner Station locality is the Lake Springfield locality, where "Elsey facies" is present that contains fauna of the *Anchoralis-latus* Zone. The contact between the “massive grainstone facies” to the down dip “Elsey facies” was placed between these two localities based on the equivalent biostratigraphic data. In southern Christian County, Missouri at Thompson’s Chestnut Ridge locality a contact between the “Elsey facies”, and the “Reeds Spring” facies is observed. Fauna above and below the contact correspond to the *Anchoralis-latus* Zone. The “Reeds Spring facies” is observed farther south and west of the Chestnut Ridge locality and extends southward into northern Arkansas. The last recorded appearance of middle Osagean *Anchoralis-latus* Zone is in southeastern Searcy County, Arkansas at Thompson’s Sellers Creek locality. Here the underlying St. Joe Group is condensed to a 0.8 meter (2.5 ft) section, and overlying this section is an irregularly bedded argillaceous limestone with >50% chert interbeds corresponding to the “Reeds Spring facies” (Thompson and Fellows, 1970). The “Reeds Spring facies” at Sellers Creek is interpreted to represent deposition in a distal middle to outer ramp setting (Figure 40).

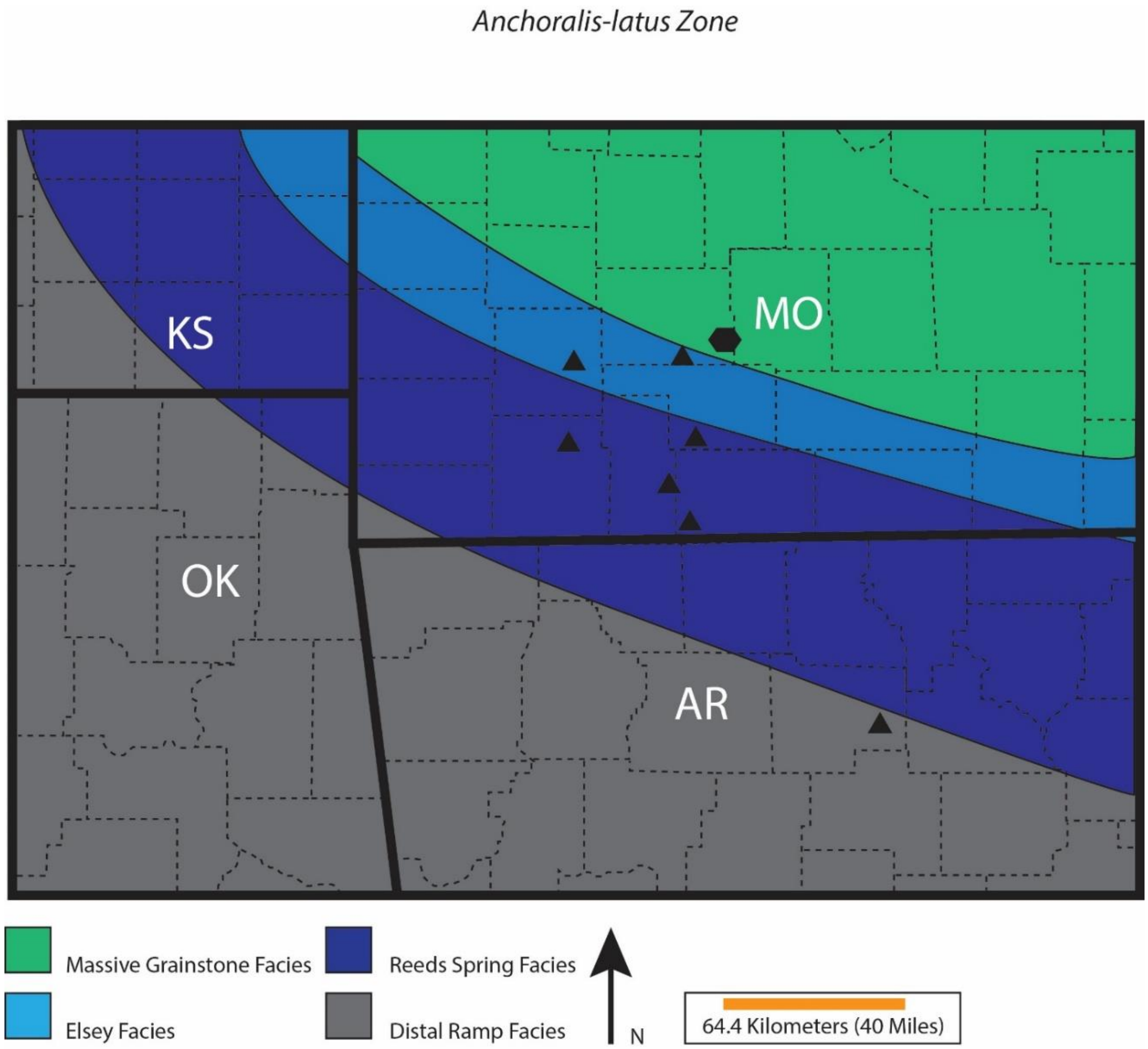


Figure 40. *Anchoralis-latus* Zone facies map. Generated from conodont data from (Thompson and Fellows, 1970).

The *Anchoralis-latus* Zone is well established by the previously cited studies of Thompson and Goebel (1969) and Thompson and Fellows (1970) who also recognized younger fauna that correspond to the fauna recovered in this study and overlying biozones. Thompson and Fellows (1970) proposed the *bulbosus* zone as a defined interval of time between the underling *Anchoralis-latus* Zone and overlying *G. texanus-T. varians* zone (lower and middle "*texanus*" zones in this study). However, at the time of this definition the lack of complete exposures available for sampling made it difficult to determine the distribution and validity of the *bulbosus* zone and interpret corresponding depositional facies. With the extension of HWY 65, years after the previous studies, more localities became available to sample, which was critical for modeling the ramp system. These outcrops also added a much needed opportunity to extend the biostratigraphic coverage of the "Elsey facies" and "massive grainstone" facies southward of the Thompson and Goebel (1969) and Thompson and Fellows (1970) study area in southwestern Missouri and southeastern Kansas. The distribution of fauna recovered from these added outcrops were tied to facies and plotted on maps, thereby proving insight into deposition toward the close of Osagean time.

The *bulbosus* Zone (upper-middle Osagean) records facies migration on the ramp to the south/southwest after *Ancoralis-latus* time. In the upper section of the Burlington Formation ("massive grainstone facies") at Thompson's Lake Springfield locality, *Gnathodus bulbosus* was found in beds above those containing specimens of *Gnathodus antetexanus* (*Anchoralis-latus* Zone) within a section of stacked grainstones, interpreted to represent a younger regressive phase of progradation on the ramp. South of the Lake Springfield locality in northern Boone County, Arkansas, at the Reeds Spring/Bentonville Contact I locality, the "Elsey facies" is observed transitioning into the "massive grainstone facies" that contains abundant representatives of *G. bulbosus*. Based on this discovery, the contact between the inner ramp "massive grainstone facies", and the inner to middle ramp to "Elsey facies" is placed near the Arkansas/Missouri state line.

The "Reeds Spring facies" sampled in southern Barry County, Missouri at the Roaring River State Park locality, is dark, fine crystalline mudstone with grainstone lenses (Thompson and Fellows, 1970). This lithology, when integrated with the faunal evidence, represents a transition to the south/southwest in which the "massive grainstone facies" and "Elsey facies" observed east of Barry County at the Contact I outcrop grades laterally into a middle to outer ramp environment represented by the time equivalent “Reed Spring facies” present at Roaring River State Park. South of Barry County in northeast Carroll County, Arkansas, the “Reeds Spring facies” is nodular limestone that is interbedded with anastomosing beds of bluish chert that yields *G. bulbosus* fauna (Thompson and Fellows, 1970). West of Carroll County, Arkansas and Barry County, Missouri, in McDonald County, Missouri, the *bulbosus* Zone is observed in the Reeds Spring facies as well as the underlying Pierson Formation. South of McDonald County in northern Benton County, Arkansas at the Bentonville Type Locality, *G. bulbosus* was found within the Pineville Tripolite facies of the Reeds Spring Formation. The correlation to the Pierson Formation and Reeds Spring Formation in the southwestern area during *G. bulbosus* time could be the result of bioherm development within the outer ramp setting (Figure 41).

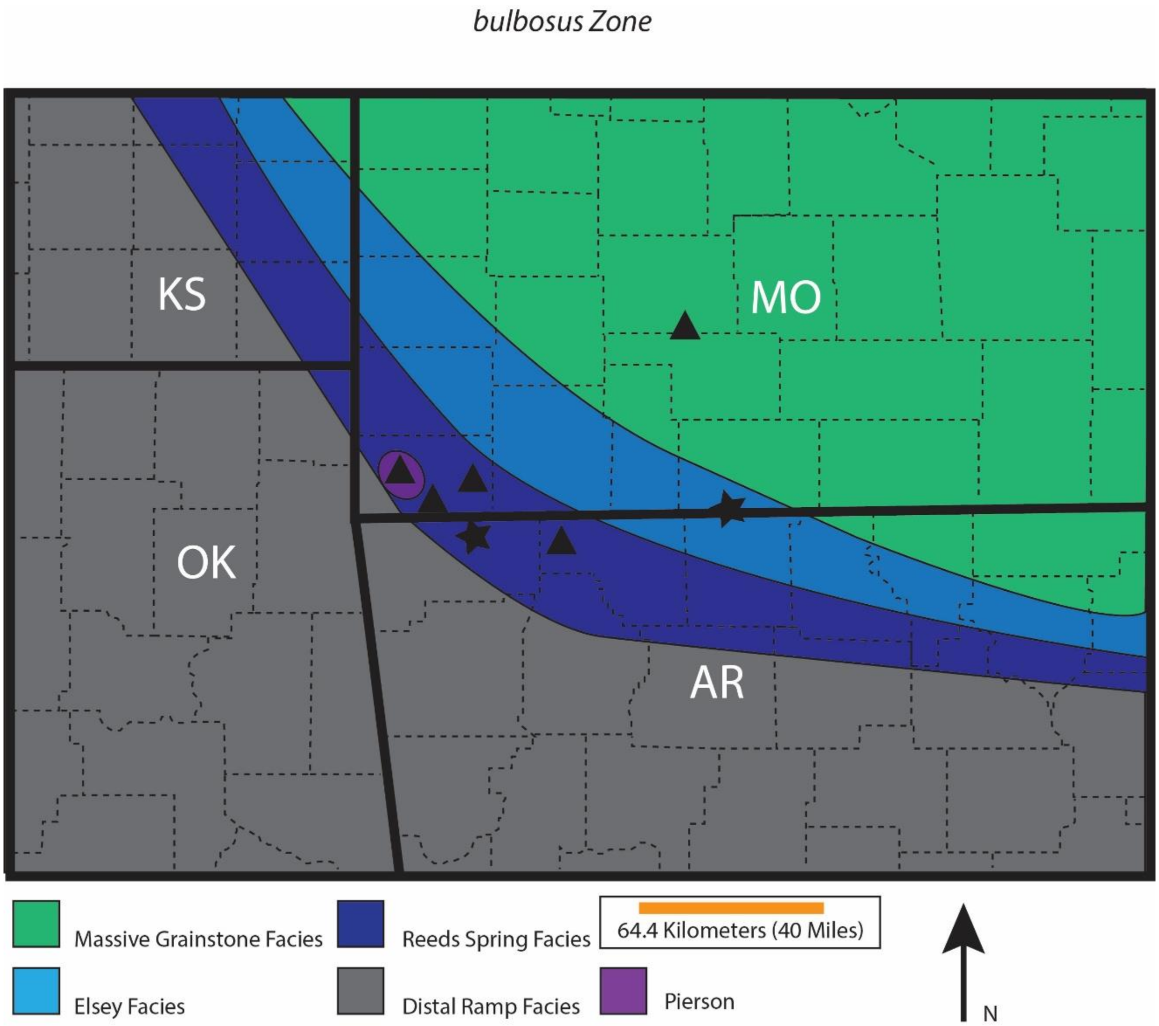


Figure 41. Facies map for the *bulbosus* Zone generated from conodont data from Thompson and Fellows, (1970) and this study. This pattern is interpreted as representing ramp deposition during *bulbosus* (middle to upper Osagean) time. The purple ellipsoid represents Pierson time equivalent strata reported by Thompson and Fellows, (1970).

Past subsurface studies have included the Pierson Formation as a lower member of the Fern Glen Formation, representing biohermal mounds that occur stratigraphically below the Reeds Spring Formation (Goebel, 1966). Mounds were also observed in the Pierson in northeastern Oklahoma, west of the biostratigraphic coverage of the *bulbosus* Zone (Laudon, 1939). At the Roaring River State Park locality, bryozoans were recorded "floating" in sparry cement within the upper Pierson, but no declaration of a possible biohermal mound complex was made (Moore, 1957). Bioherms were interpreted in field studies in McDonald County within the Pierson and Compton Formations of the St. Joe Group (Unrast, 2013). Their presence is known locally along the southwestern margin of the ramp during *bulbosus* time, and it is likely that the correlation of Pierson within the *G. bulbosus* Zone is strictly facies related to an outer ramp setting. Bioherms and mounds are not uncommon in ramp systems, and do occur scattered within middle ramp to outer ramp environments (Schlager, 2005). The scattered anomalous nature of the Pierson Formations time equivalency to the Reeds Spring facies, and field studies in eastern Oklahoma and McDonald County, Missouri done by Unrast (2013) support the presence of bioherms within the outer extent of the distally steepened ramp during *bulbosus* time.

After *G. bulbosus* time, the species is recorded in lower abundances, and *G. texanus* type specimens are prevalent. This marks the transition into the lower "*texanus*" zone (Boardman et al., 2013). The faunal recognition corresponding to the lower "*texanus*" zone was recorded in Thompson's Brown Quarry locality in Greene County, Missouri, 15 meters (50 ft) below the oolitic grainstone facies, within the "massive grainstone facies" (formerly referenced as the Keokuk Formation). South of Greene County, in the Bentonville/Reeds Spring Contact II locality, and in the Bentonville Co-Type Locality, Boone County, Arkansas, the lower "*texanus*" zone is found in the "massive grainstone facies". The facies relationship with time suggests that the most proximal extent of the "massive grainstone facies" occurred northward within Greene County, Missouri, while the distal extent of the facies is found southward within Boone County, Arkansas in outcrops sampled in this study.

In the southwestern part of the field area in eastern McDonald County, the "Elsey facies" was recognized at the Powell locality (Thompson and Fellows, 1970). The facies change marks the proposed contact between the "massive grainstone facies" and "Elsey facies" (Figure 42). In west-central McDonald County, Missouri at Thompson's Lanagan Quarry locality, the "Reeds Spring facies" is present overlying the Pierson Formation and contains only *G.texanus* specimens.

In southern McDonald County, Missouri at Thompson's Tanner Branch locality, the Reeds Spring facies also corresponds to the lower "*texanus*" zone (Thompson and Fellows, 1970). Based on the prior data, this suggests there is a transition of the "Elsey facies" to the "Reeds Spring facies" within McDonald County Missouri. In northwest Independence County, Arkansas the "Reeds Spring facies" becomes slightly enriched in chert above the thinning St. Joe Group. These outcrops represent the most southerly mapppable extent of the "Reeds Spring facies" during lower "*texanus*" time (Figure 42).

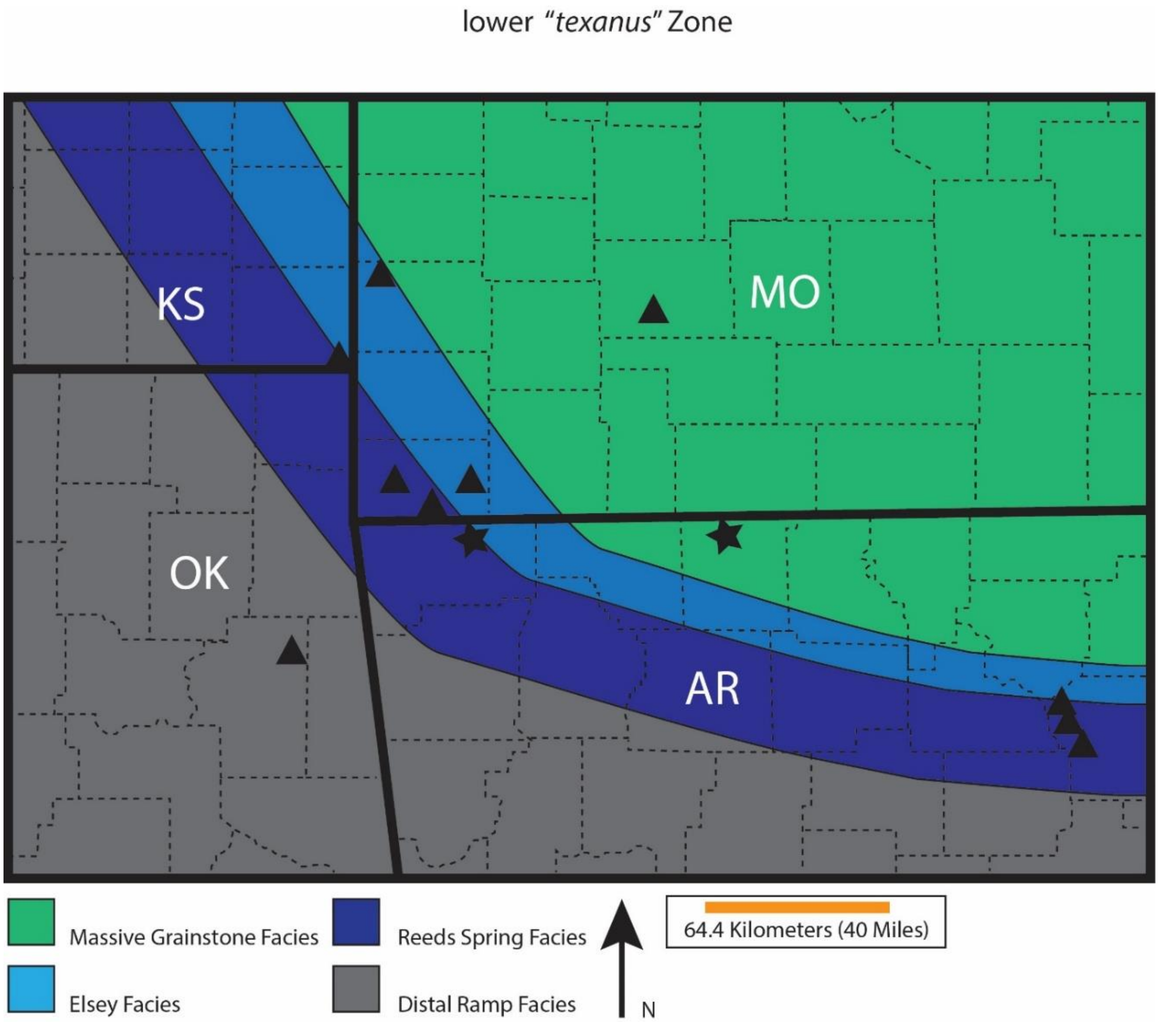


Figure 42. Lower "*texanus*" zone facies map generated from conodont data from Thompson and Fellows, (1970), Thompson and Goebel (1969), and this study.

The lower "*texanus*" zone is difficult to identify within the Bentonville Type Locality based on a single gnathodid recovered beneath the overlying Bentonville Formation, and it may be missing completely within this locality. The tripolite beds beneath the Reeds Spring Formation may be associated with a localized subaerial exposure surface in the vicinity. This may be exposure event may explain the lack of a defined lower "*texanus*" zone within the Bentonville Type locality. Southwest of the Bentonville Type Locality in northeastern Cherokee County, Oklahoma the lower "*texanus"* zone is present within an interval of the "Reeds Spring facies" containing 90% chert at the Scraper locality (Thompson and Fellows, 1970). The limestone preserved contains abundant crinoid fragments surrounded by pyrite (Thompson and Fellows, 1970). North of the Scraper locality in Thompson and Goebel's P locality within southeastern Cherokee County, Kansas, the base of their Osagean outcrop may correspond to the lower "*texanus*" zone. The lower section yielded multiple *G. texanus* specimens, and consists of 20 feet of thick beds of white chert with thin gray limestone interbeds (Thompson and Goebel, 1969). This is the westernmost extent of the outcrop belt before the Osagean formations dip into the subsurface. The increase in chert is noted to occur within the outer ramp environment due to the extent of upwelling of silica rich waters (Franseen, 2006, Mazzullo et al., 2009). It could also be a result of hydrothermal activity near faults (Robertson, 1967), and increases in pyrite within the western outcrops may support this hypothesis (Thompson and Fellows, 1970). The thicker beds of white chert also closely relate to the Grand Falls chert identified in western Jasper County, Missouri (Robertson, 1967). The P locality is adjacent to Jasper County and the Grand Falls Chert Type locality west of Joplin, Missouri. During lower "*texanus*" time, the "massive grainstone facies" and "Reeds Spring facies" belts extend farther to the southwest suggesting another phase of progradation. The higher occurrence of silica could be associated with an unconformity associated with a eustatic fall, tectonic uplift, or hydrothermal activity associated with Tri State District mineralization. These hypotheses warrant further investigation. Biostratigraphic evidence integrated with facies migration of the upper Osagean depositional system suggest that prior to any later occurring diagenetic alteration of the limestone, facies belts on the ramp were migrating to the south and southwest within the field area. (Figure 42).

The middle "*texanus*" zone records the final mappable extent of the upper Osagean conodont fauna (Figure 43). The fauna within the field area are found primarily within the "massive grainstone facies". In the upper section of Thompson's Lake Springfield locality, beneath the oolitic grainstone facies, there is an abundance of *G. texanus* relative to *T. varians*, and *T. varians* makes its first appearance. These fauna correlate to the upper "massive grainstone facies" below the oolitic grainstone facies at the Co-Type locality in northern Boone County, Arkansas, and to Thompson and Goebel's P and Q localities within southwestern Cherokee County, Kansas. The entire series of stacked massive grainstones present within the Bentonville Type locality above the Pineville Tripolite corresponds to this zone. The position of the Bentonville Type Locality within the field area marks the most southwestern outcrop of the "massive grainstone facies" in the middle "*texanus*" zone. Southwest of the Bentonville Type Locality in eastern Cherokee County, Oklahoma, at Thompson's Tahlequah North locality, the "Reeds Spring facies" is present with chronostratigraphic correlation to the up dip massive grainstone facies present at the Bentonville Type locality. The "massive grainstone facies" likely extends farther southwestward into northeastern Oklahoma, but it lacks outcrop coverage before dipping into the subsurface. Overall the during middle "*texanus*" time in the upper Osagean, the "massive grainstone facies" migrated farther southward and could represent the final regressive phase of upper Osagean progradation.

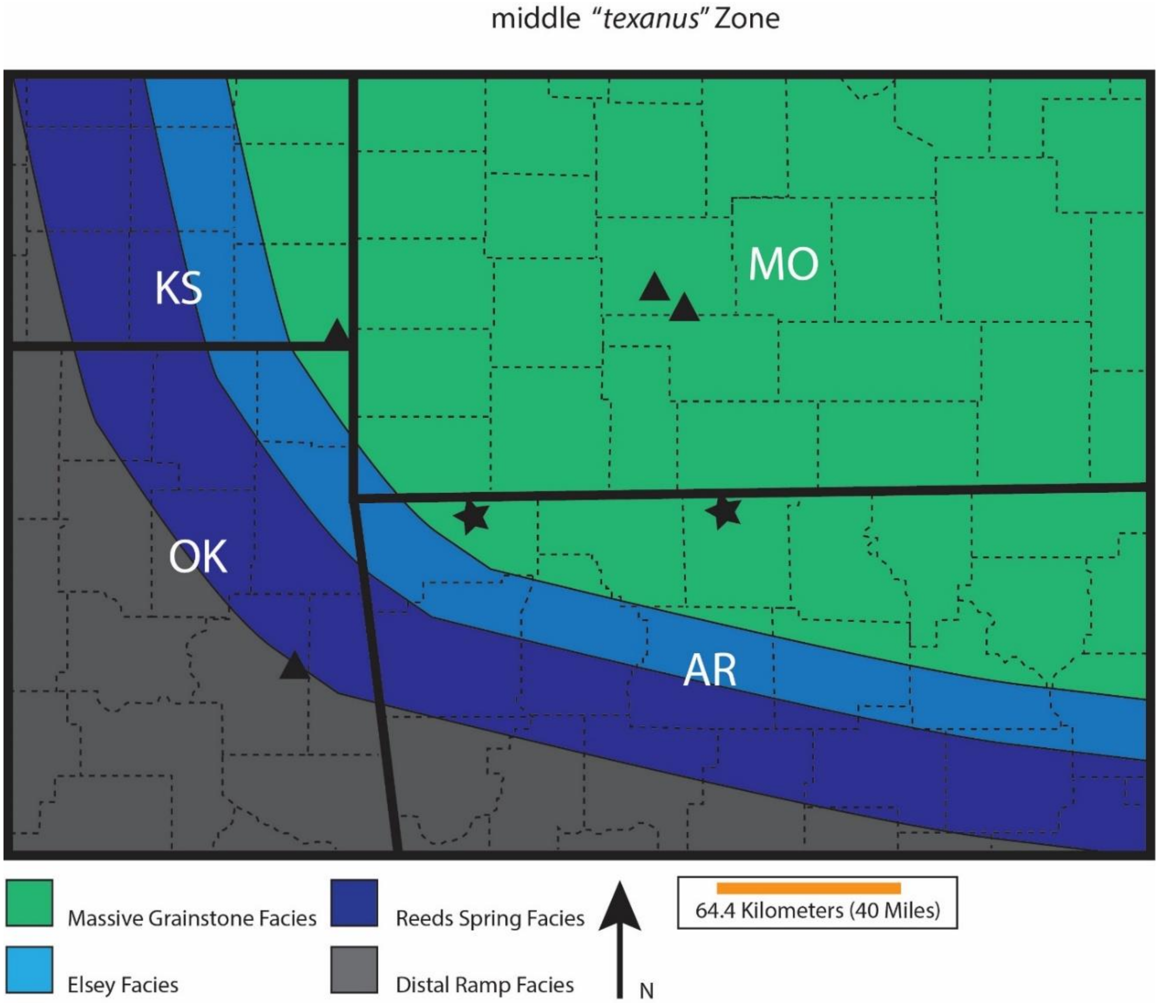


Figure 43. Middle "*texanus*" zone facies map generated from conodont data from Thompson and Fellows, (1970), Thompson and Goebel (1969), and this report. Representing ramp deposition during the uppermost mappable extent of Osagean time.

The biostratigraphic zones in this study record a depositional history for the upper Osagean within the outcrops of the southern Midcontinent. Four distinct progradational phases can be observed within the faunal zones identified. The migration of the ramp facies belts through time represent a series of stacked progradational wedges that extend across the field area with a migrating paleoshoreline to the south/southwest (Figure 44). Thompson's composite section in Greene County, Missouri is a 207 ft thick section of the "massive grainstones facies" lithostratigraphically recognized as the Burlington-Keokuk Formation (Thompson and Fellows, 1970). The base corresponds to the *Anchoralis-latus* Zone, and the upper extent capped by the oolitic grainstone facies corresponds to the middle "*texanus*" zone. This outcrop locality represents the middle to upper Osagean, and records the most proximal location of the ramp environment within the outcrop belt.

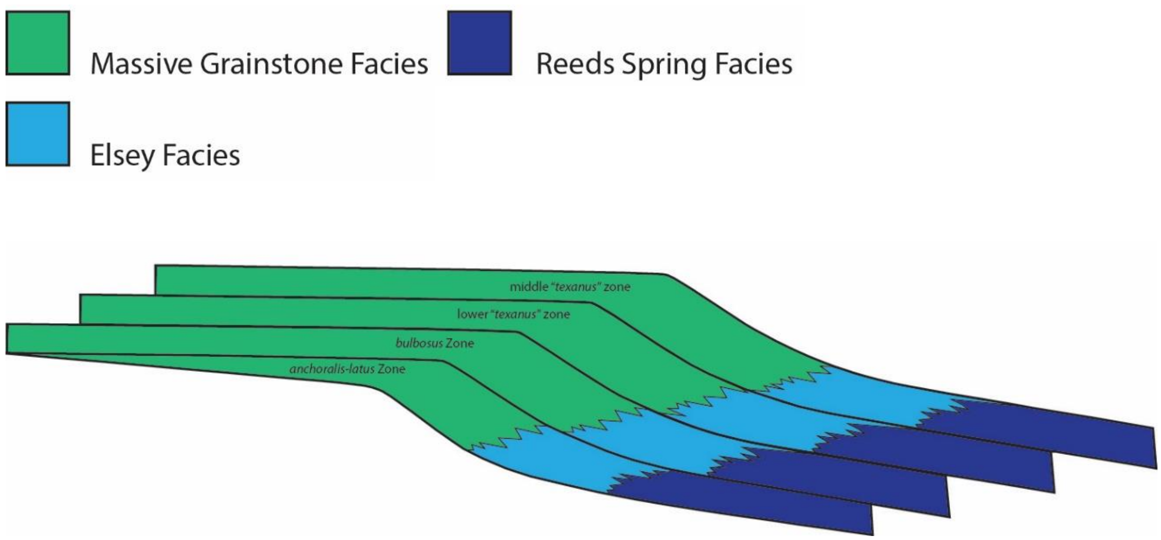


Figure 44. A generalized interpretation of the facies relationship within the biozones referenced in this study. Each individual biozone records an individual phase of progradation of the facies belts on the ramp. Within a proximal setting the "massive grainstone facies" (green) is present, which laterally grades into the "Elsey facies" (light blue), and "Reeds Spring facies" (dark blue). The position of the outcrops, with corresponding facies tied to biostratigraphic evidence supports a model for wedge on wedge deposition within a distally steepened ramp environment.

The biostratigraphic equivalents to each biozone recorded in the proximal area of Greene County, have down dip "Elsey facies" and "Reeds Spring facies" equivalents. The series of middle to upper Osagean section thus represent four biostratigraphically identifiable prograding wedges with diachronous facies changes within each wedge attributed to the facies architecture on a distally steepened ramp. The "massive grainstone facies", "Elsey facies", and "Reeds Spring facies" can occur in different stacking patterns depending on the relative location (proximal or distal) on the carbonate ramp. This facies relationship should be considered when core and other non biostratigraphically constrained subsurface data are used to predict the distribution of reservoir and seal facies. Overall the facies migrate basinward with time suggesting a long regression occurred during the upper Osagean.

APPLICATION TO SEQUENCE STARTIGRAPHY

It is interpreted that the outcrops analyzed in this study represent deposition within a highstand systems tract on a distally steepened ramp. Highstand system tract deposition occurs during the late part of a eustatic rise, a stillstand, and the early part of a eustatic fall (Handford and Loucks, 1993). During a highstand, shallow marine sedimentation rates commonly exceed accommodation creation. Factors of increasing sea level, and tectonic subsidence, which increase accommodation, cannot outpace the filling of accommodation from high rates of sedimentation. This results in a progradational depositional model as facies belts migrate basinward with time (Handford and Loucks, 1993, Schlager, 2005). Highstand systems are bounded by a basal maximum flooding surface, and an upper sequence bounding unconformity. They generally exhibit an offlapping clinoformal geometry, with sets of high frequency cycles displaying an upward shallowing and thinning trend. They are typically grainstone prone with less diverse skeletal assemblages (Kerans, 2003). In this study, the massive grainstone facies (inner ramp) is interpreted to have migrated to the south/southwest over previously deposited middle ramp facies. The facies identified within the outcrops referenced support the interpretation that the upper Osagean sediments were in a phase of progradation throughout *Anchoralis-latus* to middle "*texanus*" time. Regional biostratigraphic data within the field area, presented in the previous section, further aids in illustrating a highstand model for upper Osagean deposition through the migration of the facies belts to the south and southwest off of the flanks of the Ozark Dome.

The use of high frequency sequence stratigraphy coupled with biostratigraphic evidence validates this interpretation. Usually identified within seismic reflection patters, progradational offlap can be observed above the transgressive systems tract and overlying a maximum flooding surface (Schlager, 2005). Within ramp systems, and within interior platform carbonate deposits, a specific flooding event may not be readily identifiable on seismic (Goldhammer et al., 1993). The scale of the ramp system analyzed is hundreds of kilometers along depositional strike and dip. Stratigraphic surfaces generated from a regional flooding event, or associated with unconformities are likely not readily identifiable within a seismic survey due to the large (>100km) scale of the ramp system. To identify sequential changes in carbonate deposition within this system, it is necessary to evaluate the spatial distribution of facies and higher frequency cycles driven by Milankovitch eustatic variations. Third order depositional trends in accommodation can be identified by the nature of the facies stacks within identified high frequency cycles (Goldhammer et al, 1993). This is due to the fact that depositional sequences exhibit a hierarchy on different orders of magnitude within the context of geologic time. Superposition of composite fifth and fourth order cycles on orders of 10^4 and 10^5 years from high frequency sea level oscillations driven by Milankovitch cyclicity can be placed within third order cyclicity occurring on orders of 10^6 years (Goldhammer et al., 1993). The identification of higher frequency cycles identified in outcrop aided in the conclusion that the upper Osagean was within a period of highstand deposition on third order scale.

Facies stacks identified by Price (2014) as fourth and fifth order cycles within the Bentonville Type locality contain shoaling upward packstone to grainstone packages 5-7 meters (16.4-23 ft) in thickness. Price (2014) identified three fourth order sequences within the Bentonville Type locality. Silicified packstones represented the transgressive base of each fourth order sequence, which graded upward vertically into dominantly regressive packages of grainstones (Price, 2014). A similar facies succession was recognized within the Bentonville Co-

Type Locality in this study (Figure 45). Shallowing upward packages of grainstones were identified as fourth order sequences 3.6-7.3 meters (12-24 ft) in thickness. An ideal transgressive to regressive fourth order sequence consisted of the following facies: fine grained grainstone (grains <.125mm), medium grained grainstone (grains 25-.75mm), coarse grained grainstone (grains .75-1mm), and very coarse grained grainstone (1-2mm). The silicified intervals within the outcrops analyzed were not readily recognized as a cyclic facies, and were not included within the high frequency facies analysis. Three fourth order sequences were seen within the Bentonville Co-type locality section. The sequences represent a series of shallowing upward packages, and each sequence appears to thin vertically up section (Figure 46). Thinning of the higher frequency regressive sequences up section can be attributed to the filling of available accommodation as the sediments were prograding basinward with time (Goldhammer, 1993). This pattern is recognized in the section at the Bentonville Co-Type locality, and could be attributed to decreasing accommodation resulting from an increase in sedimentation rates and/or a eustatic fall in sea level.

It is estimated that each fourth order sequence resembles a time priod of 100-400 thousand years, driven by changes in the earth's orbital eccentricity (Read, 1995). The comparison of fourth order sequences with high resolution (bed by bed) biostratigraphic coverage, concluded that the biozones presented within this study do not have the accuracy to date fourth order sequences. The lower "*texanus*" zone, and middle "*texanus*" zone, and upper "*texanus*" zone were identified within the Bentonville Co-Type locality, but their resolution was beyond the scale of individual fourth order sequences (Figure 46). From this observation, it is proposed that conodont variation needed to define individual biozones, can be used for chronostratigraphic dating to approximately 1 million years. The overall biozonational trends observed from 27 outcrops referenced across the southern Midcontinent support that the "massive grainstone facies", "Elsey facies", and "Reeds Spring facies" were migrating to the south/southwest marked by the relationship between the older and younger biozones referenced in the previous section. The facies migration pattern, represents a series of regional progrades marked by the biozonational trends. When this is coupled with the high frequency cyclicity, as represented by uppward thinning, shallowing-upward fourth order sequences within a single outcrop, evidence for a highstand system can be supported within the hierarchy of the sequence stratigraphy. Whether or not each biozone records individual third order sequences could not be determined within this study because stratigraphic surfaces associated with third order flooding events and unconformities were not readily identified at the stratigraphic position where biozonational change occurred. The results of this study show that refined biozones are useful in delineating third order depositional patterns, but lack the resolution for constraining fourth order sequences.

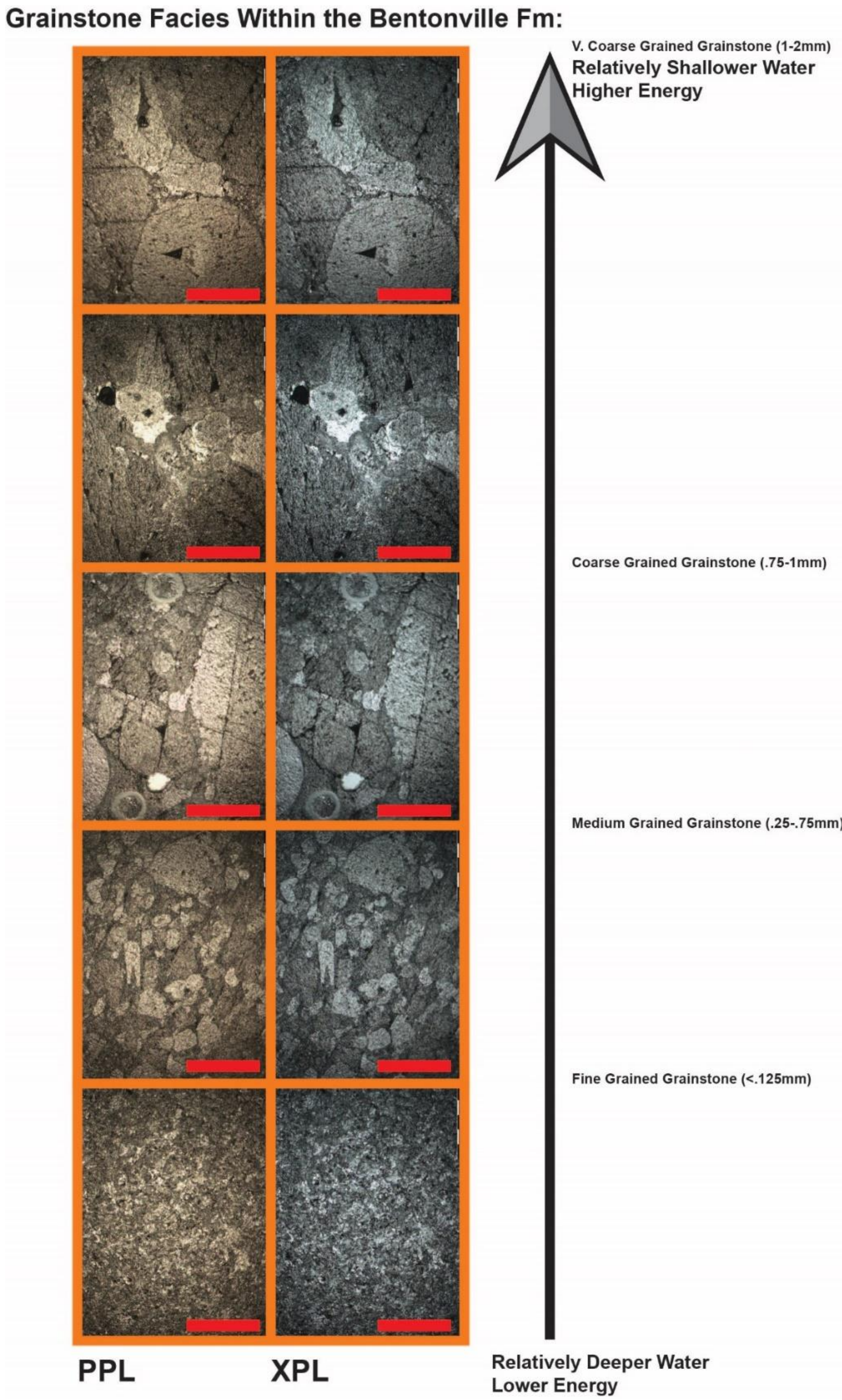


Figure 45. Idealized shallowing upward high frequency cycle within the massive grainstone facies. Acetate peel photomicrographs are displayed in plane-polarized light (left column) and cross-polarized light (right column). Each red scale bar is 1mm in length. Fine grained grainstones are deposited within deeper water settings, and represent the transgressive base of the high frequency cycles identified. The grainstones coarsen upward from medium, to coarse, to very coarse within the regressive phase of each high frequency transgressive to regressive cycle.

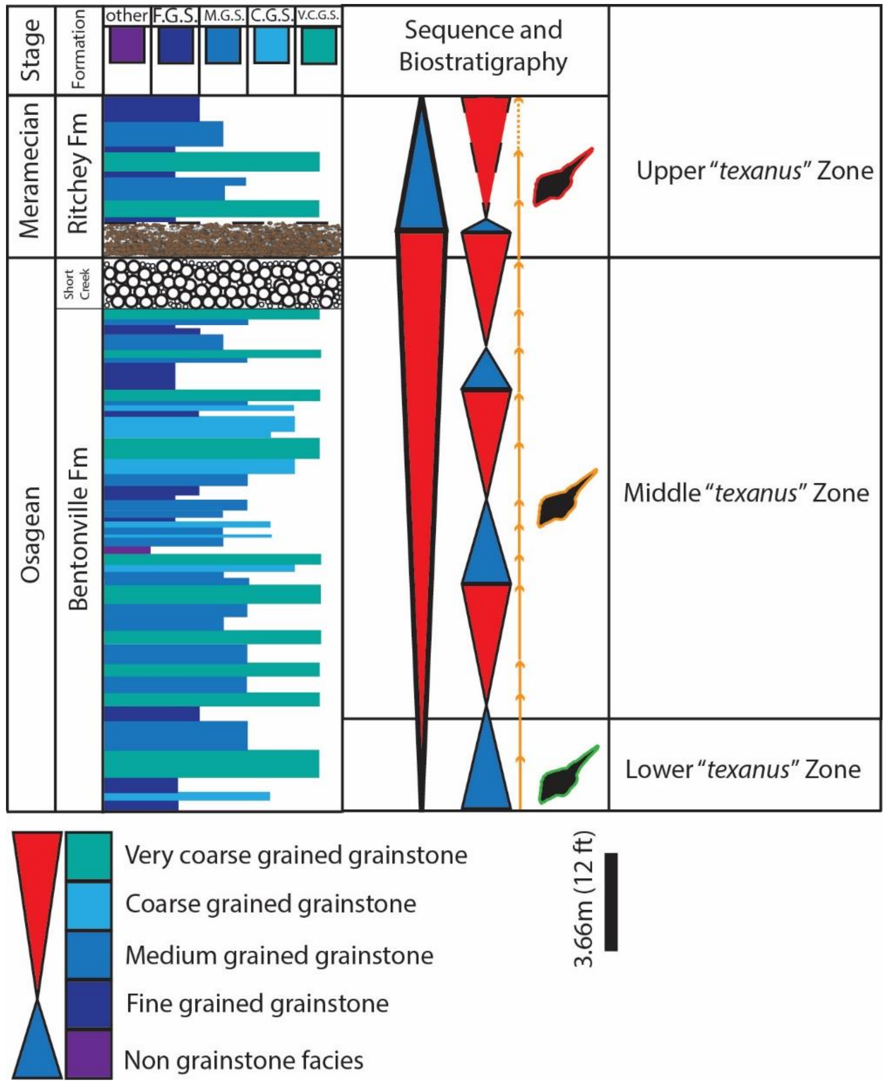


Figure 46. Facies data displayed by the corresponding colors, in relation to grain size variations observed within the Bentonville Co-Type Locality. Identified high frequency fourth and fifth order cyclicity is superimposed within the overall regressive third order sequence. Higher frequency fifth order cycles (orange arrows), are superimposed within fourth order sequences. Three fourth order sequences were identified within the Bentonville Co-Type Locality. The sequences are superimposed within the regressive third order sequence, and each fourth order sequence thins up section, which may be in response to overall filling of accommodation on a third order scale. The corresponding biostratigraphy (right) overlaps the timing of the fourth order cyclicity. Biozones may be used as chronstratigraphic markers for regional correlations, when coupled with high frequency facies analysis.

PALEONTOLOGY

Conodont studies dedicated to middle to upper Osagean stratigraphy have been conducted in the Mississippi Valley region in southeastern Iowa, southwestern Illinois and eastern Missouri, as well as in the southern Midcontinent in the subsurface of western Kansas, in outcrop in southeast Cherokee County Kansas, and in southwest Missouri within Greene County (Branson 1941 b, Mehl and Thomas, 1947, Younquist and Miller 1949, Younquist et. al, 1950, Pinney, 1962 Rexroad and Collinson, 1965, Goebel 1966, Goebel and Thompson, 1969, Thompson 1967, Thompson and Fellows, 1970, Boardman et al., 2013). All studies report similar recovery results that yielded fragmentary to few whole specimens per kg processed. This study is important in its analysis of the southern Midcontinent stratigraphy in that it is is the first biostratigraphic study of the Boone Group within northwestern Arkansas. Results from the Bentonville Type Locality in Benton County, Arkansas, and Bentonville Co-Type Locality in Boone County, Arkansas extend the biostratigraphic coverage farther south on the Mississippian carbonate ramp.

A total of 345 elements were recovered in this study from 148 kilograms of processed rock. The majority of residues yielded few whole intact specimens, and the ones that were intact often were poorly preserved. Two hundred and sixty (260) whole specimens were recovered, 9 confirmed lingonodinids, 65 spathognathodids, 50 gnathodids, and 136 other specimens that were not confirmed on the genus level during the picking process. Eighty five fragmentary specimens were also collected during the picking process. These low yields are expected from sampling of a proximal carbonate facies. The conodonts recovered compile the best representation to date for the upper Reeds Spring Formation, Bentonville (Burlington-Keokuk) Formation, and lower Ritchey Formation in the northern Arkansas field area. Of the 260 whole specimens recovered, 128 were mounted for high resolution SEM analysis, and 105 SEM photomicrographs at 60 X magnification are included within the 12 plates in this report (Appendix, page 113). The conodonts recovered are catalogued, and stored within the University of Iowa fossil repository, 121 Trowbridge Hall, Iowa City, Iowa 52242.

The Osagean conodont fauna differ considerably from the fauna of the underlying Kinderhookian Stage. Kinderhookian samples have higher conodont yields per kg, contain siphonodellids, and abundant specimens *Gnathodus delicatus,* and contain species of polygnathids (Pinney, 1962). The Osagean fauna differ from the older Kinderhookian by an absence of siphonodellids, considerable diversification of gnathodids, reduced speciation of polygnathids, and the first appearance of *Polygnathus communis carina*. Some gnathodids also are observed to have a widening of the posterior carina (Pinney, 1962).

The Osagean conodonts utilized in age correlation in this study include 9 genera and 20 species in order of oldest to youngest occurrence: *Bactrognathus hammatus, Bactrognathus excavata, Staurognathus cruciformis, Scaliognathus anchoralis, Doliognathus latus, Bactrognathus distortus, Pseudopolygnathus pinnatus, Gnathodus bulbosus, Gnathodus aff. texanus, Gnathodus pseudosemiglaber*, *Gnathodus aff. pseudosemiglaber, Gnathodus* n. sp. B *aff. pseudosemiglaber Gnathodus linguiformis, Gnathodus* n. sp. A *aff. texanus, Lingonodina levis*, *Taphrognathus varians.*

Specifically from the conodonts listed, *Gnathodus aff. bulbosus, Gnathodus* n. sp. B *aff.pseudosemiglaber*, *Gnathodus pseudosemiglaber, Gnathodus texanus, Taphrognathus varians*, *Gnathodus* n. sp. A *aff. texanus*, *Gnathodus linguiformis*, and *Lingonodina levis* were critical in establishing biozones within the outcrops sampled and furthering our knowledge of the represented fauna associated with the upper Osagean and basal Meramecian.

The gnathodids, in particular, were key specimens in defining chrostratigraphic changes within the Boone Group. The ornamentation of the nodes on the platform define specimens; their occurrence and disappearance within formations was a critical aspect of this study. In particular, the taxonomic evolution of the ancestral *Gnathodus bulbosus* to *Gnathodus pseudosemiglaber* confirms a change in time seen within the Upper Osagean from the *bulbosus* Zone to the proposed lower and middle "*texanus*" zones (Figure 47). The evolutionary transition is noted based upon the orientation of the primary node on the platform. The node changes from an orientation perpendicular to the central carina, to parallel. All other diagnostic aspects of the specimens are similar, suggesting a direct ancestry (Thompson and Fellows, 1970).

Problematic issues need to be discussed and further investigated within the evolution of the "*G. texanus"* specimens. The specimens formerly defined as *G. texanus* in previous reports have slight variations in nodal orientation that were seen in the specimens recovered. Boardman et al. (2013) proposed that the *G. texanus* species represent a clade of specimens rather than one particular species of gnathodid. This hypothesis was investigated within this study, but the low yields of adequately preserved specimens made it difficult to resolve the taxonomy in the scope of this project. The upper Osagean formations provide the first known occurrence of "*G. texanus"* type specimens, and the fact that their range has been noted to the Chesterian Barnett Shale suggests significant homeomorphy is involved within their ancestry (Boardman et al., 2013). In this study all specimens identified in relation to previous forms of *G. texanus* will be given new specimen or affinity designation, until more forms are found within this stratigraphic interval and are formally named. Based on previously documented studies, it also appears that formerly identified *G. texanus* specimens need to be further analyzed with similar technology before declaring identification on the species level.

Within the continuous vertical section sampled in the Bentonville Co-Type Locality a possible transition from *G. aff. texanus* to *G.* n. sp. A *aff. texanus* is noted based on the widening of the platform, and orientation of the node on the inner platform. *G. aff. texanus* likely evolves into the later occurring *G.* n.sp. A *aff. texanus* marking the proposed upper "*texanus*" zone. The platform widens, and the orientation of the prominent node changes from cylindrical, to more prominent extending past the denticles on the carina and is oriented forty five degrees from the carina at the anterior end of the inner platform (Figure 47).

The transition of *Taphrognathus varians* to *Cavusgnathus* sp. is not likely to have occurred as previously hypothesized (Rhodes et al., 1969). The defining blade attachment of *Taphrognathus varians* can be seen within specimens in the overlying stratigraphy, above the Short Creek Oolite Member at the Bentonville Co-Type Locality, and within the middle of the Bentonville Type Locality. This suggests *Taphrognathus varians* may appear after *Cavusgnathus* sp. based on the occurrence of *Cavusgnathus*? sp. within the upper 9.1 meters (30 ft) of the Bentonville Formation at the Co- Type Locality. The low yields provide minimal support for this conclusion, but if it is indeed true, then this would be the oldest documentation of *Cavusgnathus* sp. in the Mississippian stratigraphic record. It was previously reported by Thompson and Goebel, 1963 p. 12 to occur within the Salem and St. Louis formations during earliest Meramecian time. Based on this finding, and the fact that *T. varians* occurs in the Bentonville Formation, as well as the lower Ritchey Formation, the lower Ritchey formation, may be a younger prograde of Osagean or Meramecian carbonate that conforms down dip in the general progradation direction to the Bentonville Type locality where no oolite is present. *Taphrognathus varians* has been recovered within the upper 12.2 meters (40 feet) of the Bentonville Type Locality, but is not present within the basal section, suggesting that the Bentonville Formation is a series of stacked progradational grainstones that become younger up section in response to the migration with decreased accommodation.

It is likely that the Short Creek Oolite Member does not completely define the Osagean/Meramecian boundary. The oolite is interpreted to represent the shallowest facies within the regressive portion of a possible third order sequence. It has been discussed, but not formally documented, that two oolite intervals occur in this section (Thompson, 1986). If two oolite intervals do occur, then it would fit the interpretation that the oolite is likely a facies representing a regressive sequence "cap," rather than a regional marker bed separating the upper Osagean from the Meramecian. The boundary has been supported based on its macrofaunal distinction (Laudon, 1948; Kammer et al., 1990), but the conodont microfauna suggest the boundary is problematic. The boundary was previously recognized by the occurrence and abundance ratio of G. *texanus* type specimens to *T. varians* (Rexroad and Collinson, 1965, Thompson and Goebel, 1969), the findings of this study supports the accepted definition, but it is recommended that further investigation is needed to refine the location.

The three newly proposed biozones establish a higher frequency biozonation scheme for the upper Osagean and basal Meramecian that make up the lower Visean global stage. The *bulbosus* Zone should still be used as it can be readily recognized within the field area, the previous *G. texanus*-*T. varians* Zone, can now be subdivided into corresponding lower, middle, and upper "*texanus*" zones based on the appearance and disappearance of the index fossils utilized in this study (Figure 47). The lower "*texanus*" zone is defined by a decrease in abundance of *Gnathodus bulbosus,* and increase in abundance of *Gnathodus aff. texanus*.

The middle "*texanus*" zone is defined by the absence of *G. bulbosus,* and abundance of *Gnathodus psedudosemiglaber* and *Gnathodus aff. pseudosemiglaber*. *Taphrognathus varians* is also associated with the middle "*texanus*" zone appearing later than *G. pseudosemiglaber* and *G. aff. pseudosemiglaber*. *Gnathodus aff. linguiformis, Gnathodus linguiformis* and *G.* n. sp. B *aff. pseudosemiglaber* are also found within the middle "*texanus*" zone.

The upper "*texanus*" zone is defined by the disappearance of *G. pseudosemiglaber*, *G. aff. pseudosemiglaber*, *G. linguiformis, G. aff. linguiformis* and *G.* n. sp. A *aff. texanus*. The first appearance of *Gnathodus* n. sp A *aff. texanus*, *Lingonodina levis*, and *Gnathodus* n. sp. *aff. puncatus* can be used to distinguish this zone from the underlying middle "*texanus*" zone. Given the low yields, and lack of exposure of the upper "*texanus*" zone, additional work is needed to refine it with diagnostic specimens. *Gnathodus* n. sp. 15 *aff. puncatus* was reported to be found in this zone (Boardman, 2013, personal communication with Cory Godwin), but *G. puncatus* was not identified in this study. *Taphrognathus varians* is found within both the middle and upper "*texanus*" zones and it may appear in higher abundances within the upper "*texanus*" zone, and overlying stratigraphy (Rexroad and Collinson, 1965, Thompson and Goebel, 1969), but this is only hypothesized from previous work. The timing of the disappearances of *G. bulbosus*, *G. pseudosemiglaber*, and *G. aff. pseudosemiglaber*, provide a framework for defining the faunal changes in association with the refined biozones for the upper Osagean

Faunal variations reported in Thompson and Fellows, (1970) are corroborated by this study and distinguish individual sequences that contain middle to inner ramp facies of the Reeds Spring Formation and the proximal grainstone facies of the Bentonville (Burlington-Keokuk) Formation. The fauna range from those defined in the *Anchoralis-latus* Zone, to specimens recovered in the upper "*texanus*" zone.

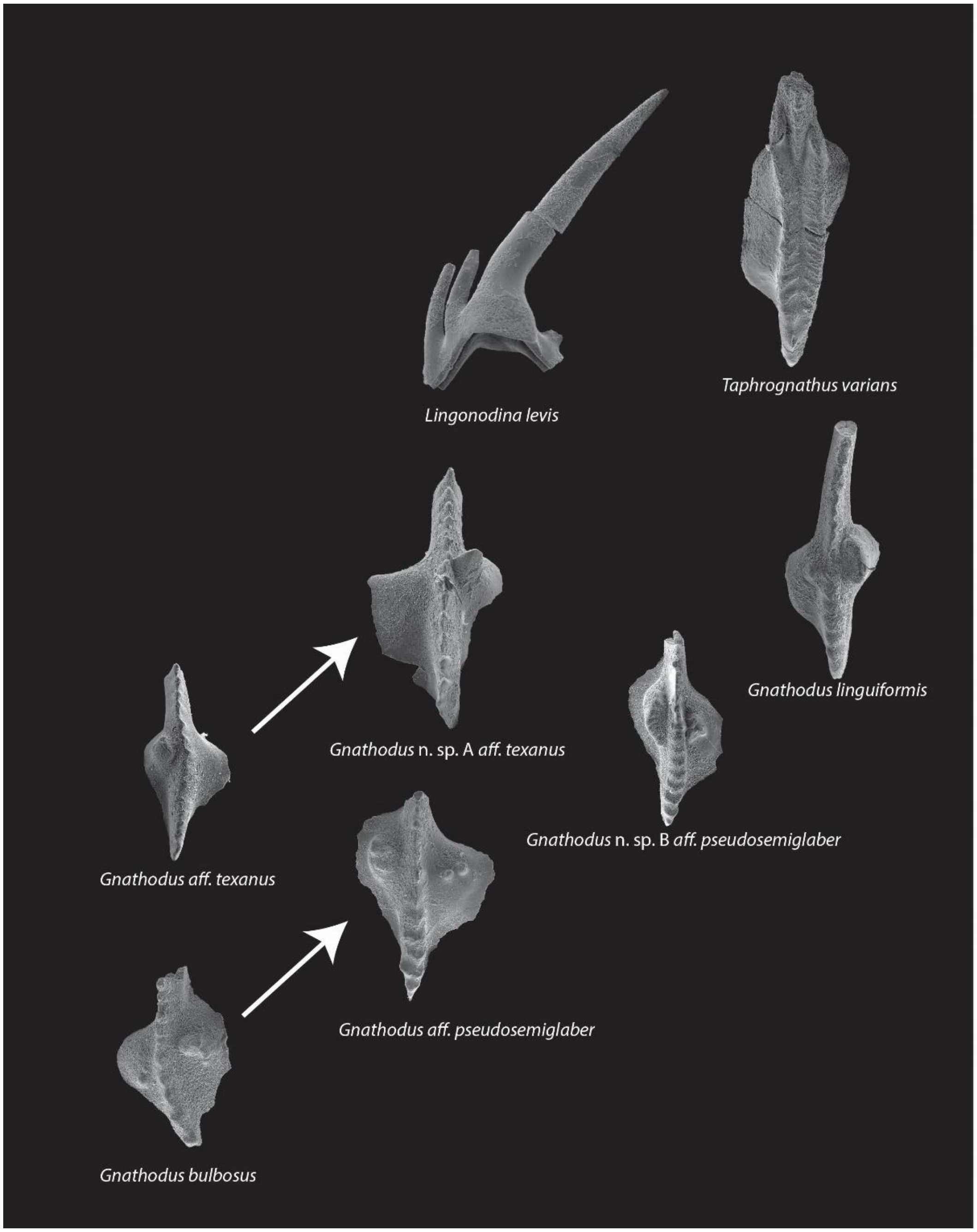


Figure 47. SEM photographs of conodonts displaying possible evolution and diversification of species through time. The species are arranged vertically with respect to occurrence within the upper Osagean stratigraphy. Nodal ornamentation changes from *G. bulbosus* to the later occurring *G. aff. pseudosemiglaber*, but all other diagnostic properties remain constant, suggesting a direct ancestry. *G. aff. texanus* transitions to *G.* n. sp. A *aff. texanus* based on a change in nodal orientation. Other upper Osagean gnathodids of *G. linguiformis* and *G.* n. sp. B *aff.* pseudosemiglaber are displayed to show variation on the species level with time. Younger specimens of the genus *Lingonodina* and *Taphrognathus* are more abundant in younger strata.

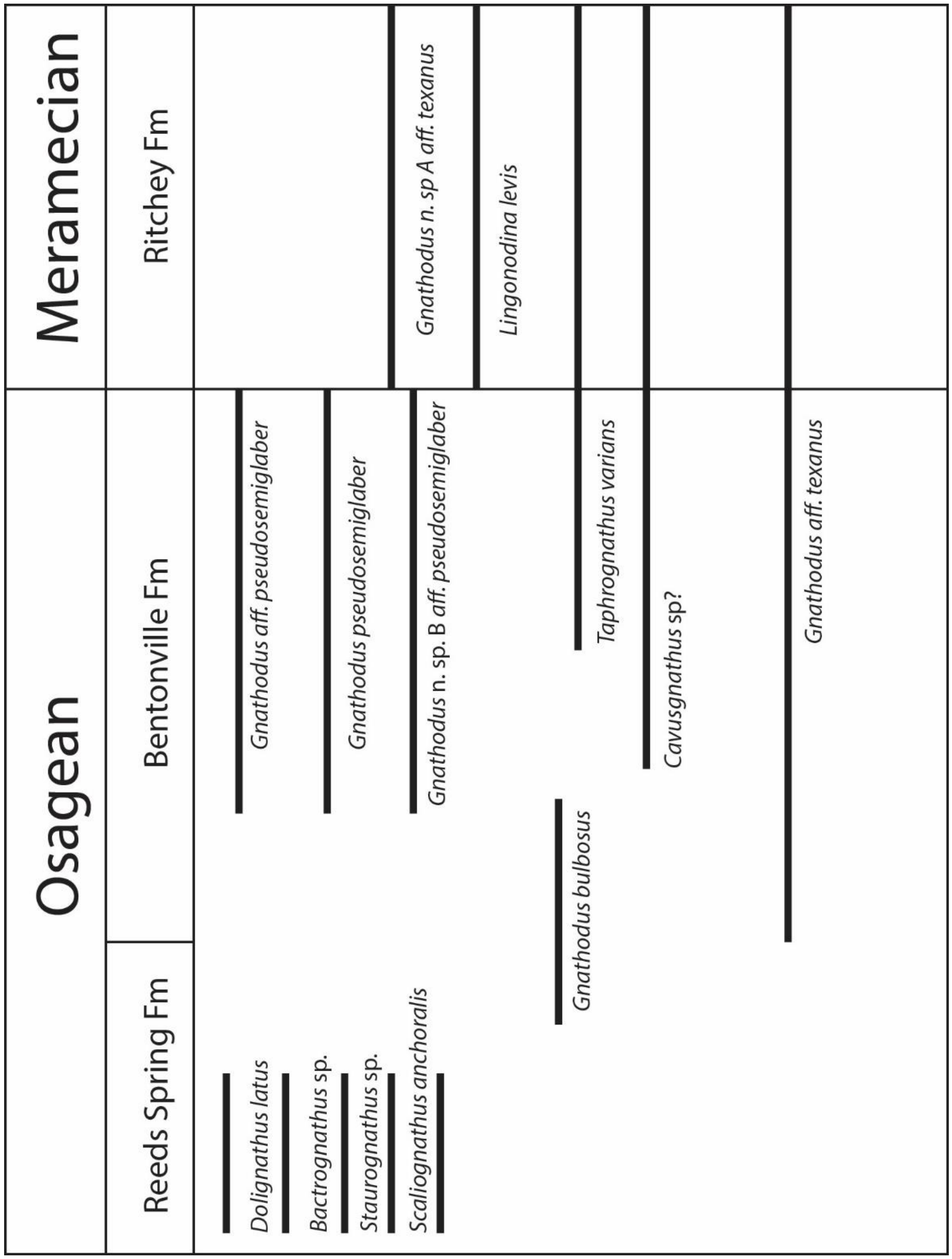


Figure 48. Conodont range chart for appearances and ranges of index fossils used within this study

CHAPTER VI

CONCLUSION

Lithostratigraphically, the Boone Group contains the Reeds Spring Formation, Bentonville (Burlington-Keokuk) Formation, and the Ritchey Formation (Mazzullo et al., 2013). The detailed integration of conodont biostratigraphy with facies analysis provided evidence that the lithostratigraphic names represent diachronous facies that formed on a broad distally steepened ramp. It may be appropriate to describe the Boone Group in a facies driven context in which the Boone Group consists of the “Reeds Spring facies” at the base, which transitions vertically into the “Elsey facies”, and finally into the “massive grainstone facies” of the Bentonville (Burlington-Keokuk) Formation. Together these facies represent a transition from a more distal mud-dominated middle ramp environment, to a proximal grainstone-dominated inner ramp environment. The integration of biostratigraphic data with lithologic observations make it apparent that specific species of biozone defining middle to upper Osagean conodonts occur in all three of the documented facies. Formerly designated as formations, rather than facies, the lithologic correlations became problematic resulting in numerous revisions to the stratigraphic nomenclature (Figure 2). From the results of this study, it is recommended that a facies approach coupled with conodont chronostratigraphic data, is needed to reconstruct facies belts and interpret depositional processes on the ramp within a given interval of Osagean time. The facies belts were observed to migrate to the south-southwest with time and became progressively younger. Depending on positioning (proximal or distal) relative to location on the ramp, higher abundances of chert may be seen in a distal position, versus thicker units of crinoidal grainstone in a more proximal position.

The formerly assigned *G. texanus-T. varians* Zone (Thompson, 1967; Thompson and Fellows, 1970) can be refined when sampling is conducted at a high frequency in a bed by bed analysis. Specifically, the occurrence and disappearance of *G. bulbosus* and *G. pseudosemiglaber* within the upper Osagean stratigraphy can aid in recognizing the *bulbosus* Zone, lower "*texanus* zone, and middle "*texanus*" zone. The upper "*texanus*" zone assigned to the basal Meramecian (Boardman et al., 2013), requires additional biostratigraphic support before a zonal definition can be designated with confidence.

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CHAPTER VII

SYSTEMATIC PALEONTOLOGY

The specimens identified in this study are listed in alphabetical order on the genus level, then on species level identification. The unmounted specimens recovered will be held within The Boone Pickens School of Geology – Oklahoma State University, Stillwater Oklahoma. Specimens mounted to SEM stubs will be stored at the University of Iowa fossil repository, 121 Trowbridge Hall, Iowa City, Iowa 52242.

Index specimens that were able to be identified on the species level, have a corresponding systematic paleontological description. The Specimens described in this chapter include: 5 genera, and 10 species. The specimens are listed in alphabetical order by the genus and corresponding species.

Genus GNATHODUS Pander, 1856

Type Species: *Gnathodus mosquensis* Pander 1856

Diagnosis: Compound unit with anterior free blade, and posterior platform over broad, deep, sub circular basal cavity. Oral ornamentation of the platform is extremely variable. Remarks: Speciation of specimens belonging to the genus *Gnathodus* sp. is based primarily on the shape of the posterior platform, posterior carina, and ornamentation of nodes on the posterior platform. It is common to observe numerous transitional gnathodids within the Mississippian strata. Many of the gnathodids exhibit homeomorphy as a result of transitional form**.**

Gnathodus bulbosus Thompson, 1967

Pl. 6 fig 6, Pl. 7 fig 1, Pl. 11 fig 3, 5, and 6

***Gnathodus bulbosus*:** THOMPSON, 1967, p. 66, pl. 3, figs 7 11, 14, 15, 18-21, p. 72, pl. 6, figs 2, 7; THOMPSON, 1970, p. 128, pl. 1, figs 3, 6, 8, 9, 12, 13; BOARDMAN, 2013, p. 148, pl. 14, figs 1-3, 5-11

Diagnosis: The specimen is defined by having a long anterior blade, not readily preserved in specimens. A broad Posterior platform. Inner and outer platform offset. Ornamentation of single node or fused nodes on the inner platform angled at a 45-90 degree angle to the central carina. Outer platform ornamented by single node, or row of nodes. Posterior carina wider than anterior, protrudes bulbously from the posterior end of the platform.

Remarks: Mature specimens recovered in this report resemble those described by Thompson, 1967, 1970, and Boardman, 2013. Mature specimens exhibit nodes on the inner and outer platform. Whereas immature specimens may not exhibit nodes on the outer platform (see pl. 9 fig 8, pl. 10 fig 5, pl. 11 figs 5 and 6). All specimens identified as *G. bulbosus* in this study exhibit all other diagnostic features of *G. bulbosus.* Other specimens that observed similar traits to *G. bulbosus,* but were not able to be confidently assigned to the species level were given affinity designation. Evidence for ancestry to later occurring specimens of *G. pseudosemiglaber* can be seen within pl. 8 fig 5. Here there are two nodes, circular, angled perpendicular to the central carina. The fusing of nodes with growth of specimen may be an adapted evolutionary observation. of *G. bulbosus* with later occurring *G. pseudosemiglaber*. *G. bulbosus* is distinguished from *G. texanus* in this study based on the widening of the carina at the posterior end, and presence of transversely oriented ridges on the posterior carina, versus a lack of thickening of the posterior carina and presence of a single row of denticles seen in *G. texanus*.

***Gnathodus linguiformis* Branson and Mehl 1941**

Pl. 9 fig 5.

Gnathodus linguiformis: BOARDMAN, 2013, p. 151 pl. 15 fig 4

Diagnosis: The specimen has anterior blade that widens toward the anterior end of the platform. The platform is assymetric, and offset. The inner platform is ornamented by a prominent ellipsoidal node oriented semi parallel to the carina. The outer platform displays a spherical node within the center of the carina. The posterior end of the carina is cut by slightly curved ridges, and is slightly curved.

Remarks: This specimen closely resembles *G. pseudosemiglaber*, and a distinction between the two is often difficult to make. This specimen differs from *G. pseudosemiglaber* based on the degree of asymmetry in relation to the inner and outer platform, and size of prominent node, and orientation relative to the overall size of the specimen. The slight curvature of the posterior end of the carina may also aid in defining this specimen.

***Gnathodus pseudosemiglaber* Thompson and Fellows, 1970**

Pl. 8-8

***Gnathodus texanus pseudosemiglaber*:** THOMPSON AND FELLOWS, 1970, p. 130, pl. 2 figs 6, 8, 9, and 11-13.

***Gnathodus pseudosemiglaber*:** BOARDMAN, 2013, p. 150, pl. 15 figs 1-3, and 6.

Diagnosis: Long free anterior blade one and a half times the length of the platform ornamented by a single row of denticles. Broad platform at the anterior end that thins toward to posterior. The specimen displays a prominent single node, series of fused smaller nodes, or parapet located on the inner platform, oriented semi parallel (within 10 degrees),or parallel to the axis of the central carina. Single circular node on the outer platform commonly seen. The carina is thin in the central platform adjacent to inner and outer nodes, and widens to two times the central width at the posterior end; the carina extends beyond the posterior platform, and is cut by a series of transverse ridges at the posterior end.

Remarks: specimens belonging to the species *G. pseudosemiglaber* closely resemble species of *G. bulbosus*, and *G. texanus*. They resemble specimens of G. *bulbosus* in all diagnostic characteristics, besides the orientation of the prominent node on the inner platform. The orientation is near parallel (within 10 degrees) or parallel to the axis of the central carina. Mature specimens display a smaller circular node in the central area of the outer platform (see pl. 4 fig 3). Immature specimens have a circular node on the outer platform placed in close proximity adjacent to the central carina. Extremely immature specimens may not have a circular node on the outer platform.

The best way to distinguish *G. pseudosemiglaber* from *G. texanus* is to use the thickness of the posterior carina. In *G. texanus* the posterior carina is the same thickness throughout the anterior and posterior end of the platform, where in *G. pseudosemiglaber* the posterior carina is one and a half times thicker than the carina at the anterior and central region of the platform.

To distinguish *G. pseudosemiglaber* from *G. bulbosus* the orientation of the prominent node on the inner platform is vital in the analysis. In *G. bulbosus* specimens the prominent node, or series of fused nodes, on the inner platform is oriented perpendicular or within a 45 degree angle to the central carina, where in *G. pseudosemiglaber* the prominent node is oriented semi parallel (less than ten degrees) or, in most cases, parallel to the central carina.

Abundance indicators within the vertical succession of rocks in this study provide evidence for the ancestry of *G. bulbosus* to the later occurring *G. pseudosemiglaber*. The conodonts recovered from the outcrops on US HWY 65 in this study display a systematic shift within the biozonation of the Upper Osagean Bentonville Formation. At the base of the Bentonville formation in the Reeds Spring Formation Bentonville Formation Contact I outcrop the gnathodids recovered belong to the *G. bulbosus* biozone. This biozones is dominated by the *G. bulbosus* specimens (Boardman et. al, 2013). In the Bentonville Co-Type Locality the base of the section is represented by *G. bulbosus*, but vertically up section in the formation representatives of *G. pseudosemiglaber* become more abundant, and *G. bulbosus* is no longer present. This may be due to the evolution of *G. bulbosus* to *G. pseudosemiglaber* with time in the Upper Osagean. Numerous transitional forms were observed in this report, and are refered to as *G. aff. pseudosemiglaber,* or *G. pseudosemiglaber*?

Gnathodus aff. texanus Roundy 1926

> ***Gnathodus texanus***: REXROAD AND SCOTT, 1964, p. 30, pl. 2, figs 11-14.
>
> ***Gnathodus texanus***: THOMPSON AND GOEBEL, 1969, p. 24, pl. 1, figs 1-3, and 5.
>
> ***Gnathodus texanus texanus***: THOMPSON AND FELLOWS, 1970, p. 89, pl. 2 figs 15 and 16.

Diagnosis: Gnathodid with a thin, smooth platform, having one prominent node or series of fused nodes on the inner platform forming a cylinder when completely fused. Inner platform does not extend to the posterior end of the specimen. The outer platform is smooth and is unornamented. Carina is thin throughout the entire length of the specimen, and consists of a single row of denticles.

Remarks: Specimens displayed in all plates represent all diagnostic features of *G. texanus*. Depending on fusion of the nodes on the inner platform there may be only one node seen on the specimen. Smaller immature specimens display the presence of two smaller nodes with a slight trough in the center of the node.

In Boardman et. al, 2013 it was recommended that *G. texanus* no longer should be used as a species designation due to the subtle variations observed within this clade of specimens, which is defined by diagnostic properties, that can be applied to numerous specimens. However, in this report a consistent *G. texanus* species can be recognized, that resembles specimens referenced in (Thompson and Goebel, 1969) and (Thompson and fellows, 1970). Abandonment of the species name is not recommended until more fauna are recovered. and *G. texanus* should be a recognized species seen in both the Lower *Gnathodus "texanus"* Zone, and Middle *Gnathodus "texanus"* Zone after (Boardman et. al, 2013). Its range extends in both of these zones, therefore it is not an index specimen, for the uppermost Osagean biostratigraphic zones, but it can be used to resolve the *G. bulbosus* zone from the newly proposed Lower *'texanus"* Zone. The first appearance of *G. texanus,* with a decrease in abundance of *G. bulbosus,* and occurrence of *G.* n. sp. 14 is a newly recommended proposal for defining the Lower "*texanus"* Zone from the underlying *G. bulbosus* Zone. The extent of the Lower "*texanus"* Zone is poorly observed in the Bentonville Formation within the localities studied. It is only seen at the basal 3.65 meters (12 feet) of the Bentonville Co-Type locality, and likely is present in the middle to lower section of the formation unexposed at the Co-Type Locality.

Gnathodus* n. sp. A *aff. texanus

Pl. 4 figs 1 and 2, Pl. 5 fig 5, Pl. 6 fig 7

Diagnosis: The specimen has a long anterior blade approximately 1.5 times the length of the posterior platform consisting of a high frequency of closely spaced sharp denticles. The anterior platform attaches to the blade at the anterior end of the platform then abruptly broadens one fifth of the length of the central carina at the anterior end. The Inner platform is one third of the width of the broader outer platform, and displays termination before the posterior tip of the platform. The inner platform is ornamented by a single prominent wedge like node at the anterior end and protrudes past the denticles on the central carina. The node on the inner platform also displays an angular orientation of 60 degrees with respect to the axis of the central carina. The outer platform is broad and smooth, displays no ornamentation, is curved toward the posterior end of the platform, and terminates at the posterior tip.

Remarks: The gnathodids described here closely resembles *G. texanus* in all diagnostic characteristics, but its single node on the inner platform is considerably different. The node is wedge shaped in *G.* n. sp. A versus cylindrical in *G. texanus*. It is also oriented 60 degrees from the axis of the central carina, versus more parallel in *G. texanus*.

Four well represented specimens were recovered at the Bentonville Co-Type Locality within the Basal Ritchey formation, above the Short Creek Oolite. They were not present beneath the Short Creek Oolite member. *G.* n. sp. A *aff. texanus* may be a key index fossil for depicting the base of the Meramecian Series from the top of the Osagean Series. Previous works suggested the occurrence of *G. texanus* and *T. varians* were useful in depicting a transition from Osagean to Meramecian time, but they are both seen above and below the proposed unconformable contact between the Bentonville Formation, and the Ritchey Formation within this report. They have also been known for having very long ranges (Thompson and Goebel, 1969). Therefore it is proposed that *G.* n. sp. A *aff, texanus* may be a better representative for picking the base of the Meramecian Stage or the top of the Osagean Stage.

Gnathodus n. sp. B _aff. pseudosemiglaber_

Pl. 9 figs 2 and 3

Diagnosis: Gnathodid with a long anterior blade, and thin platform. Inner and outer platform offset. Inner platform terminates one third of the distance from the posterior tip, and outer platform attaches to the posterior tip. Inner platform is ornamented by a series of fused denticles forming a crescent shaped parapet cut by grooves transverse to the denticles which terminate at the central carina. The outer platform is broader than the inner platform, and displays ornamentation of numerous nodes that are fused forming a prolate node parallel to the carina, and covering the majority of the outer platform in more mature specimens. The carina extends past the posterior end of the platform, and thickens toward the posterior tip, denticles form transverse ridges present on the posterior carina.

Remarks: Resembles *G. pseudosemiglaber*, but differs by thickness of the platform, shape of the prominent parapet on the inner platform, and prolate node on the outer platform, rather than circular as seen in mature specimens of *G. pseudosemiglaber*.

Genus LINGONODINA Ulrich and Bassler 1926

Type Species: *Lingonodina pectinata* Ulrich and Bassler 1926

Diagnosis: Unit consisting of a major terminal denticle at point of juncture of long, thin, straight denticulate posterior bar and downward and posteriorly curved denticulate inner lateral process. Individual species of Lingonodinids are defined based on the size, direction, and degree of curvature of the inner-lateral process.

***Lingonodina levis* Branson and Mehl**

Pl. 4 figs 5 and 7

Lingonodina levis: REXROAD AND COLLINSON, 1965, p. 10, pl. 1 figs 23-24

Lingonodina levis: THOMPSON AND GOEBEL, 1969 p. 30 pl. 2 fig 19, 20

Diagnosis: Lingonodinids characterized by curved delicate inner-lateral process forming approximately a 120 degree angle of intersection with the terminal denticle when viewed posteriorly. The terminal denticle, is delicate, and arches slightly back toward the posterior of the specimen.

Remarks: The *Lingonodina levis* specimens were extremely delicate. The specimen ID is primarily made based on the curvature of the main terminal denticle, and angle of intersecrion of the single posterior process like teeth.

Genus SPATHOGNATHODUS Branson and Mehl 1941

Type species: *Ctenognathus murchisoni* Pander 1856

***Spathognathodus* sp.**

Pl. 1 fig 3, Pl. 8 fig 4, Pl. 10 fig 2, and Pl. 11 fig 4

Diagnosis: *Spathognathodus* specimens are defined by having a thin platform, and cavity centralized within the center of the specimen that forms a pit extending to the anterior end of the specimens. They have fused denticles which extend across the central plane of the specimen. Often viewed laterally, they have prominent denticles located on the anterior end of the specimens, that aid in identification on the species level. None of the Spathognathodus specimens in this report were in good states of preservation for identification on the species level. They have been referred to as *Spathognathodus* sp.

Genus TAPHROGNATHUS Branson and Mehl, 1941

Type Species: *Taphrognathus varians* Branson and Mehl 1941

Diagnosis: Unit consisting of short posterior platform containing two lateral parapets separated by deep median trough. Anterior blade extends a short distance extends a short distance onto the platform as a short carina, which terminates at the anterior end of the platform between the two distinct parapets. Basal cavity is long, narrow, and shallow.

Remarks: *Taphrognathus* makes its first appearance in Late Osagean time, and continues throughout Meramecian time. Species designation within the genus *Taphrognathus* is based on the size and shape of the basal cavity, and the position of the posterior end of the blade with respect to the position of the two parapets on the platform.

Taphrognathus varians **Branson and Mehl 1941**

Pl. 5 figs 3 and 6

Taphrognathus varians: REXROAD AND COLLINSON, 1965

Taphrognathus varians: THOMPSON AND GOEBEL, 1968, p. 44, pl. 5 figs 2, 7, 9 and 12 only.

Taphrognathus varians: RHODES, AUSTIN, AND DRUCE, 1969, p. 241, pl. 13 fig 4 a only.

Taphrognathus varians: THOMPSON AND FELLOWS, 1970, p. 114, pl. 4 fig 10 only

Taphrognathus varians: BOARDMAN, 2013, p. 150, pl. 15 fig 8.

Diagnosis: *Taphrpgnathus varians* specimens are defined by having a relatively narrow platform. Anterior blade terminates at the anterior third of the platform forming a short anterior carina located between its two distinct parapets. Inner platform terminates within the anterior half of the platform, and displays a semicircular edge. Outer platform terminates within the posterior third of the platform. The inner platform is broader than the outer platform. Two parapets extend from the posterior end of the blade, and continue down the central axis of the platform extending past the posterior end of the platform, fusing together to form a posterior tip. Between the parapets is a deep median trough.

Remarks: *Taphrognathus varians* as a specimen has been described as a visibly distinct specimen in previous works, but slight variations can exist depending on maturity of the specimen, and location of the anterior blade with respect to the central axis of the platform. Maturity of the specimen can reveal variations in the shape of the inner and outer platform. In plate 5 fig 3 an immature specimen of *T. varians* is displayed. The outer platform isn't visible in this specimen, where in plate 5 fig 6 a more mature specimen is present, displaying a broader visible outer platform. It is likely that the outer platform becomes broader with growth of *T. varians*.

T. varians also closely resembles specimens of *Cavusgnathus* sp. thought to occur later within the stratigraphy. The genus *Cavusgnathus* is similar to *Taphrognathus*, but the primary difference in based on the location of the anterior blade in with respect to the posterior platform. In specimens belonging to the genus *Cavusgnathus* the anterior blade is connected to the primary (longer) parapet on the inner medial platform, but in *T. varians* the anterior blade terminates at the anterior end of the platform, forming a short anterior carina. Variations in this aspect of the anterior blade location with respect to the parapets can be seen in plate 5 figure 2. It's likely that the specimen figured in plate 5 figure 2 is a transitional form of *T. varians* to the later occurring *Cavusgnathus* sp. This specimen is denoted as *Cavusgnathus?* sp. was found within the Bentonville Formation at the type locality. The specimen is fragmentary, but the blade at the anterior end of this specimen is definitely not centralized. It occurred stratigraphically lower than the first occurrence of *Taphrognathus varians*. The proposed transition of *Taphrognathus* to *Cavusgnathus* should be further investigated, when determining if such a direct ancestry exists.

APPENDICES

CONODONT PLATES AND DESCRIPTIONS

All conodonts are displayed at 60X magnification

Description of Plate 1

Figures 1 and 7: *Gnathodus aff. pseudosemiglaber*

Figure 1: Sample 48, Bentonville Formation, Bentonville Co-Type Locality

Figure 7: Sample 12, Bentonville Formation, Bentonville Co-Type Locality

Figure 2: *Gnathodus sp.*

Sample 37, Bentonville Formation, Bentonville Co-Type Locality

Figure 4: *Gnathodus aff. bulbosus*

Sample 11, Bentonville Formation, Bentonville Co-Type Locality

Figure 5: New genus? New species? Fragmentary specimen

Sample 41, Bentonville Formation, Bentonville Co-Type Locality

Figure 6: *Gnathodus aff. texanus*

Sample 52, Bentonville Formation, Bentonville Co-Type Locality

Figure 8: *Gnathodus.* Sp. Indeterminate

Sample 35, Bentonville Formation, Bentonville Co-Type Locality

Figure 9: *Gnathodus pseudosemiglaber?*

Sample 31, Bentonville Formation, Bentonville Co-Type Locality

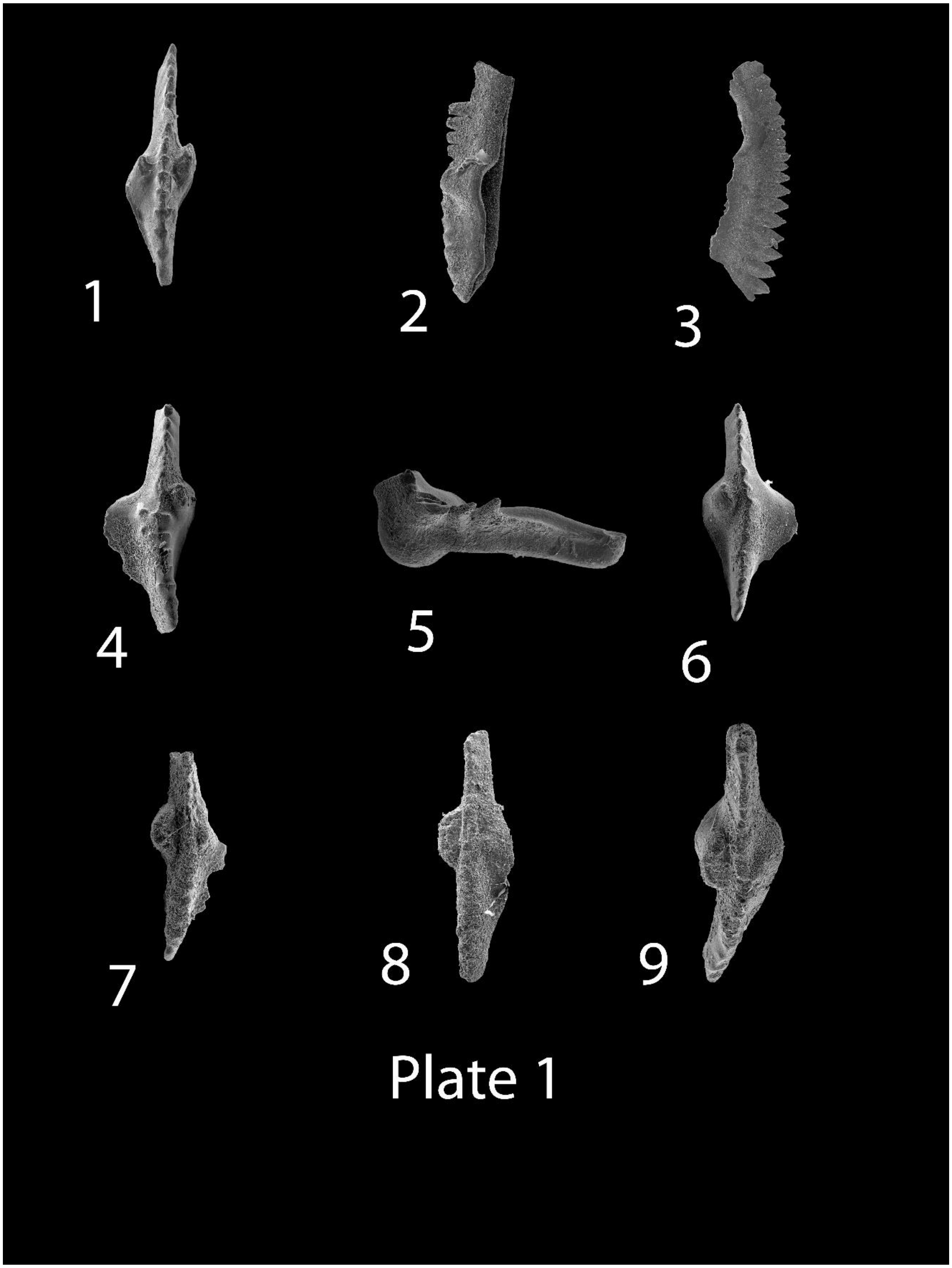
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Plate 1

Description of Plate 2

Figure 1, 3, 4, 8: *Gnathodus pseudosemiglaber?*

Figure 1: Sample 12, Bentonville Formation, Bentonville Co-Type Locality

Figure 3: Sample 31, Bentonville Formation, Bentonville Co-Type Locality

Figure 4: Sample35, Bentonville Formation, Bentonville Co-Type Locality

Figure 8: Sample 35, Bentonville Formation, Bentonville Co-Type Locality

Figure 2: *Gnathodus aff. bulbosus*

Sample 14, Bentonville Formation, Bentonville Co-Type Locality

Figure 5: *Gnathodus* n. sp. 14

Sample 7, Bentonville Formation, Bentonville Co-Type Locality

Figure 6: *Gnathodus texanus*

Sample 6, Bentonville Formation, Bentonville Co-Type Locality

Figure 7: *Gnathodus* sp. indeterminate

Sample 37, Bentonville Formation, Bentonville Co-Type Locality

Figure 9: *Gnathodus pseudosemiglaber*

Sample 38, Bentonville Formation, Bentonville Co-Type Locality

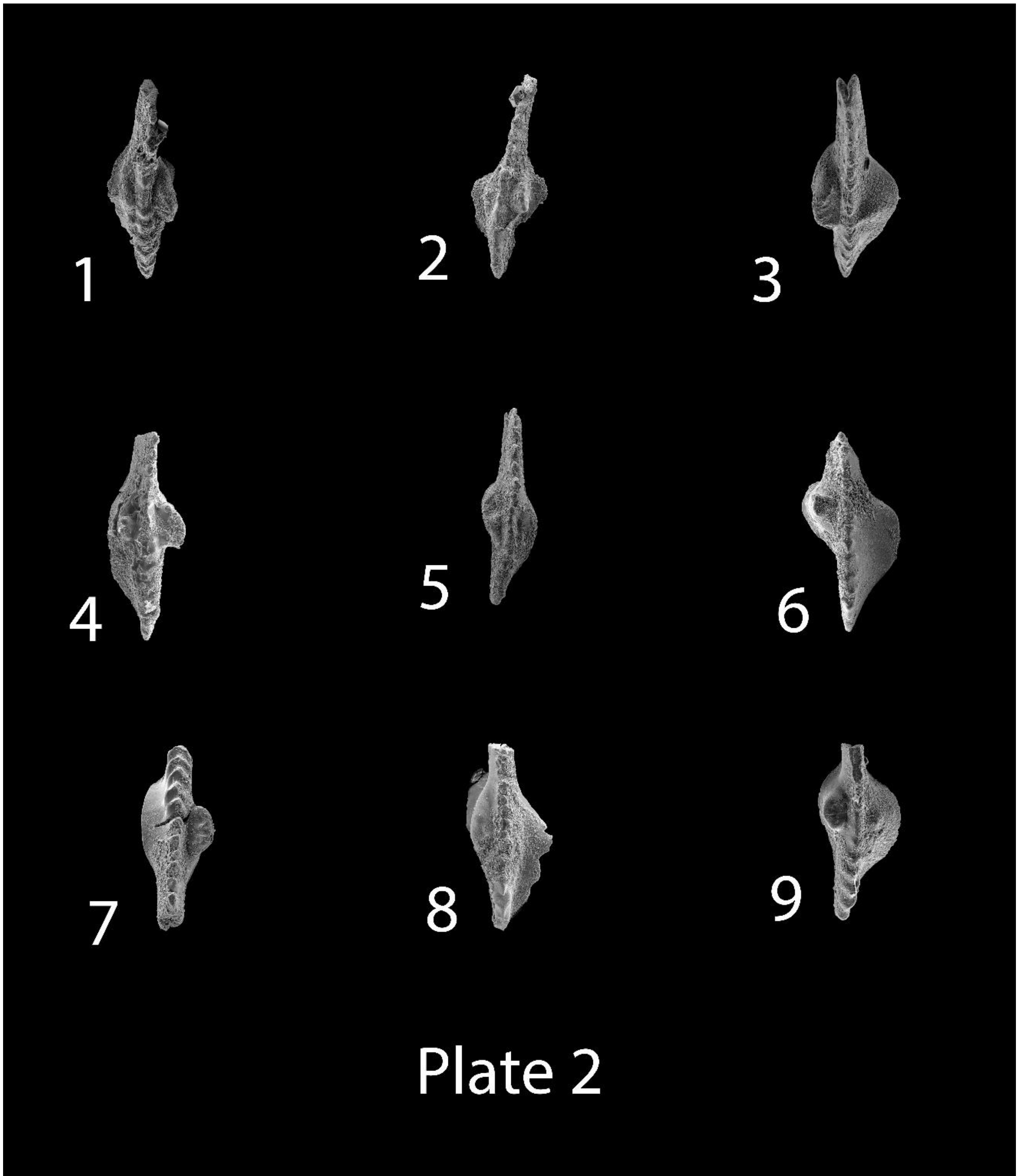
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Plate 2

Description of Plate 3

Figures 1-3: *Gnathodus pseudosemiglaber?*

Figure 1: Sample 37, Bentonville Formation, Bentonville Co-Type Locality

Figure 2: Sample 35, Bentonville Formation, Bentonville Co-Type Locality

Figure 3: Sample 13, Bentonville Formation, Bentonville Co-Type Locality

Figure 4: *Gnathodus* sp. indeterminate, fragmentary specimen

Sample 43, Bentonville Formation, Bentonville Co-Type Locality

Figure 5: Fragmentary specimen

Sample 6, Bentonville Formation, Bentonville Co-Type Locality

Figure 6: *Gnathodus* sp. indeterminate

Sample 57, Bentonville Formation, Bentonville Co-Type Locality

Figure 7: Immature specimen

Sample 45, Bentonville Formation, Bentonville Co-Type Locality

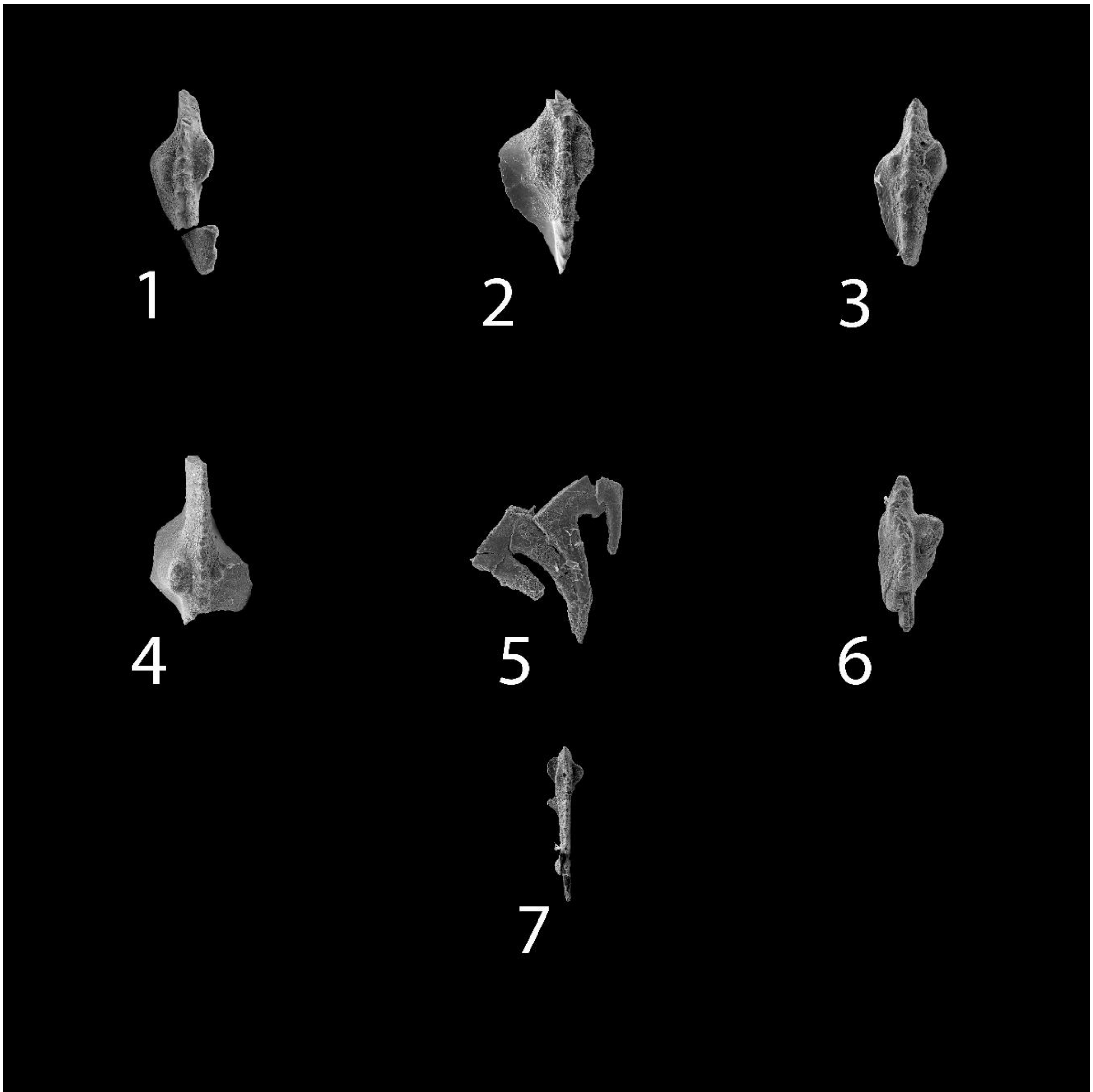

Plate 3

Description of Plate 4

Figures 1 and 2: *Gnathodus* n. sp. A *aff. texanus*

Figure 1: Sample 76, Ritchey Formation, Bentonville Co-Type Locality

Figure 2: Sample 78, Ritchey Formation, Bentonville Co-Type Locality

Figure 3: *Gnathodus aff. pseudosemiglaber* (*aff. linguiformis*?)

Top of section, Bentonville Formation, Bentonville Type Locality

Figure 4: *Gnathodus* sp. indeterminate

Sample 9, Bentonville Formation, Bentonville Co-Type Locality

Figures 5 and 7: *Ligonodina levis*

Figure 5: Sample 70, Ritchey Formation, Bentonville Co-Type Locality

Figure 7: Sample 72, Ritchey Formation, Bentonville Co-Type Locality

Figure 6: *Lingonodina* sp.

Sample 70, Ritchey Formation, Bentonville Co-Type Locality

Figure 8: *Gnathodus* sp.

Sample 30, Bentonville Formation, Bentonville Co-Type Locality

Figure 9: *Gnathodus aff. bulbosus?*

Sample 25, Bentonville Formation Reeds Spring Formation/Bentonville Formation Contact I

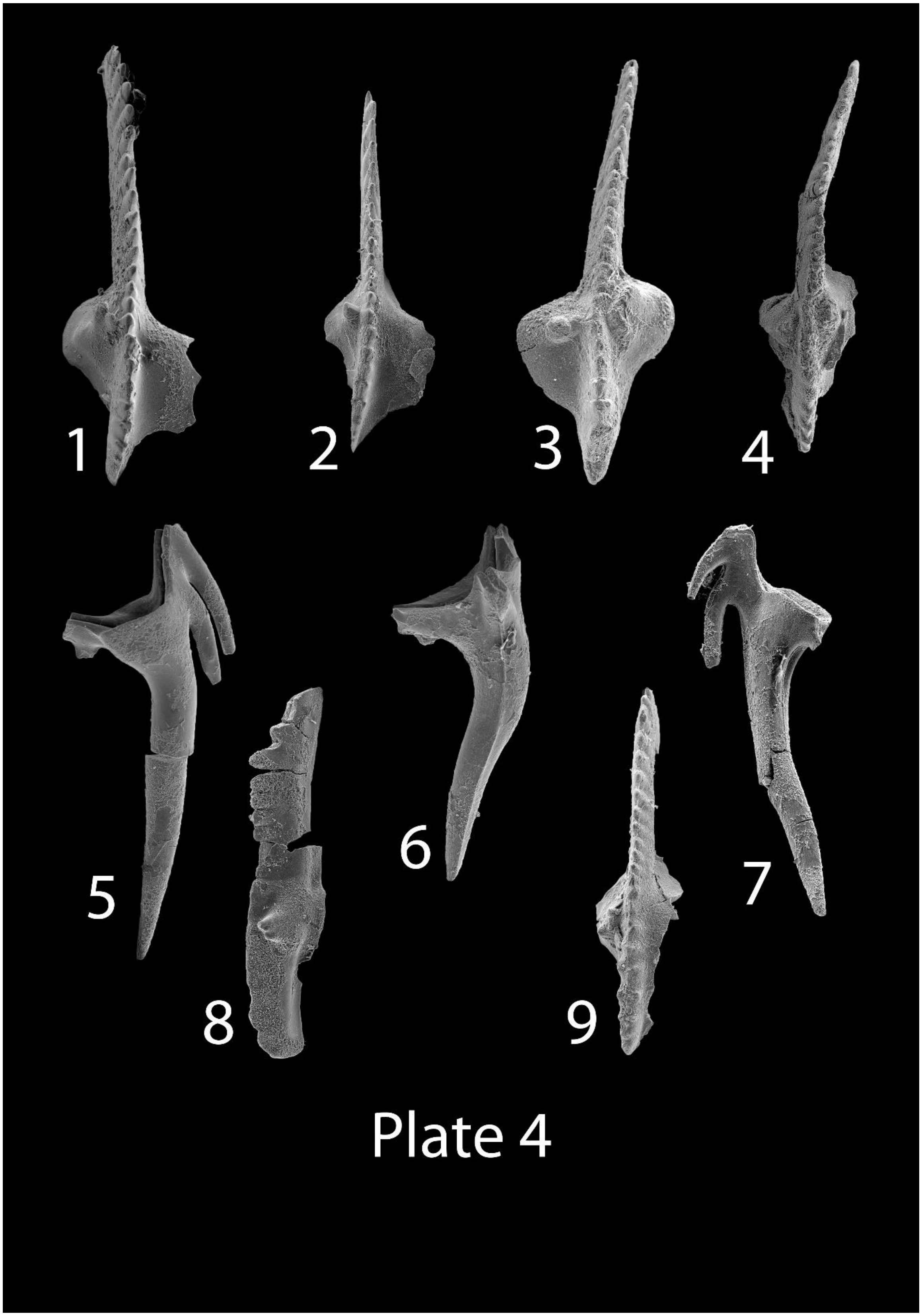
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Plate 4

Description of Plate 5

Figure1: *Gnathodus aff.* n. sp 14?

Sample 29, Bentonville Formation, Reeds Spring Formation/Bentonville Formation Contact II

Figure 2: *Cavusgnathus* sp.?

Sample 28, Bentonville Formation, Bentonville Co-Type Locality

Figures 3 and 6: *Taphrognathus varians*

Figure 3: Sample 65, Ritchey Formation, Bentonville Co-Type Locality

Figure 6: Middle of Bentonville Formation, Bentonville Type Locality

Figure 4: *Gnathodus aff. bulbosus*

Sample 26, Bentonville Formation Reeds Spring Formation/Bentonville Formation Contact I

Figure 5: *Gnathodus* n. sp. A *aff. texanus*

Sample 70, Ritchey Formation, Bentonville Co-Type Locality

Figure 7: *Gnathodus aff. texanus*

Sample 17, Bentonville Formation, Reeds Spring Formation/Bentonville Formation Contact II

Figure 8: Unknown bar type specimen

Sample 22, Bentonville Formation Reeds Spring Fromation/Bentonville Formation Contact I

Figure 9: *Gnathodus linguiformis*

Sample 53, Bentonville Formation, Bentonville Co-Type Locality

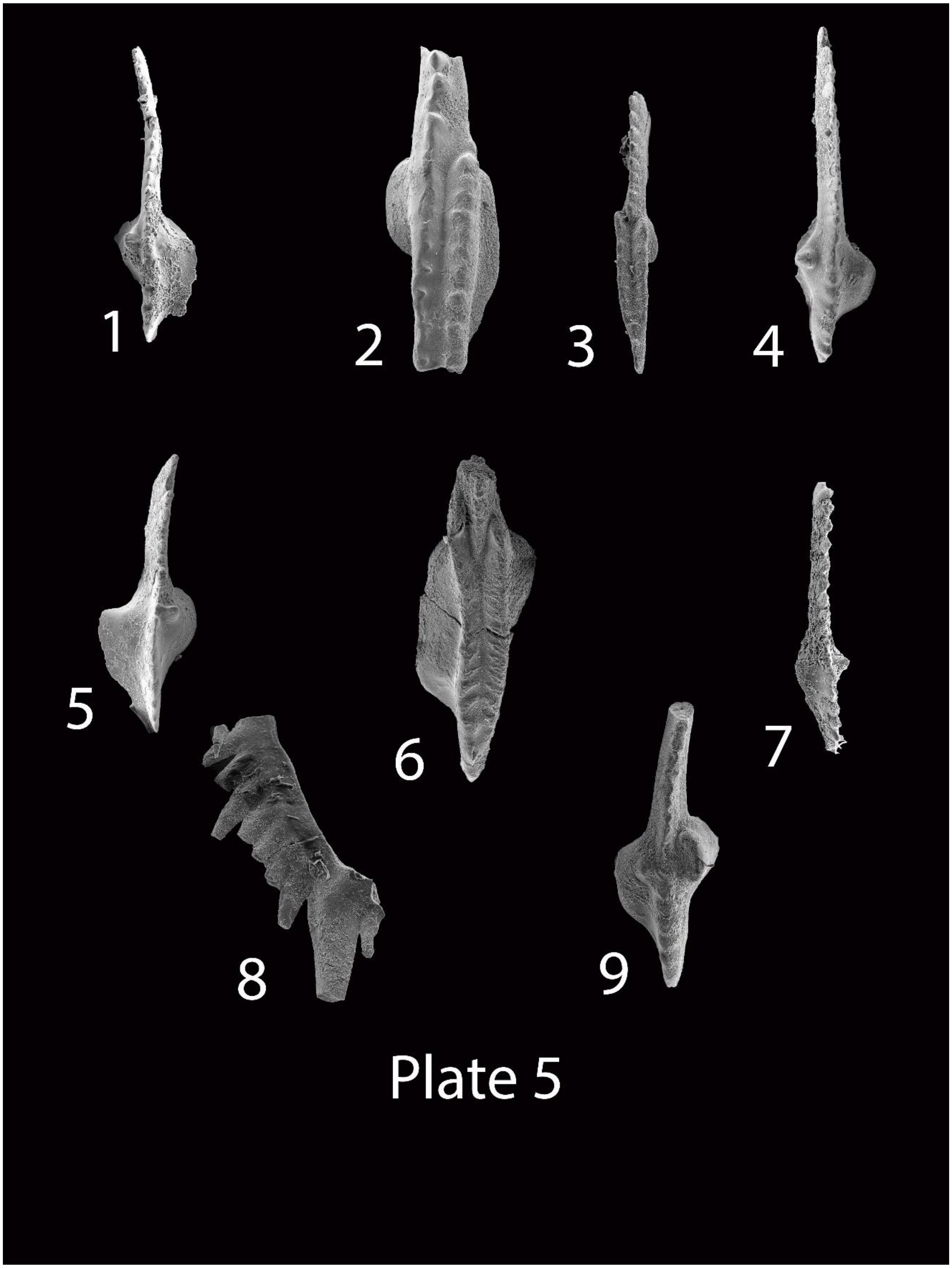
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Plate 5

Description of Plate 6

Figure 1: unknown specimen

Sample 21, Bentonville Formation Reeds Spring/Bentonville Formation Contact I

Figure 2 and 3: Fragmentary bar type specimens

Figure 2: Sample 17, Reeds Spring Formation, Reeds Spring Fm Bentonville Fm Contact II

Figure 3: Sample 17, Reeds Spring Formation, Reeds Spring Fm Bentonville Fm Contact II

Figure 4: *Gnathodus aff. pseudosemiglaber*

Middle of Bentonville Formation, Bentonville Type Locality

Figure 5: *Gnathodus aff. texanus*

Sample 53, Bentonville Formation, Bentonville Co-Type Locality

Figure 6: *Gnathodus bulbosus*

Sample 15, Bentonville Formation, Reeds Spring Formation/Bentonville Formation Contact II

Figure 7: *Gnathodus* n. sp. _ *aff. texanus*

Sample 78, Ritchey Formation, Bentonville Co-Type Locality

Figure 8: *Gnathodus* sp. indeterminate

Sample 30, Bentonville Formation, Bentonville Co-Type Locality

Figure 9: Fragmentary specimen

Confidential Location, Cored interval, subsurface of Oklahoma

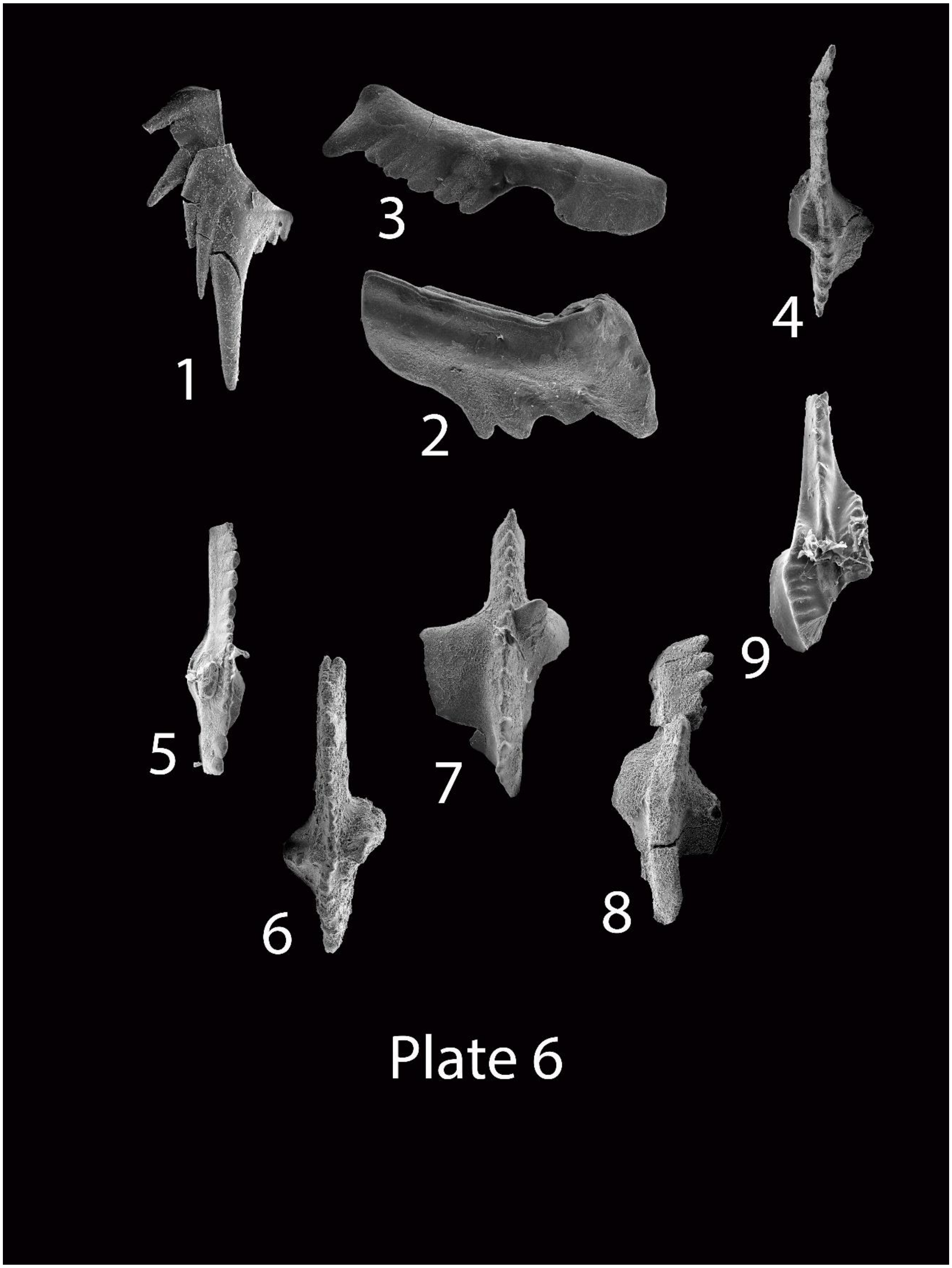
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Plate 6

Description of Plate 7

Figures 1 and 2: *Gnathodus bulbosus*

Figure 1: Sample 26, Bentonville Formation, Reeds Spring Fm/Bentonville Fm Contact I

Figure 2: Sample 26, Bentonville Formation, Reeds Spring Fm/Bentonville Fm Contact I

Figure 3 and 6: *Gnathodus aff. pseudosemiglaber*

Figure 3: Sample 50, Bentonville Formation, Bentonville Co-Type Locality

Figure 6: Sample 63, Bentonville Formation, Bentonville Co-Type Locality

Figures 4 and 5: *Gnathodus aff. bulbosus*

Figure 4: Sample 27, Bentonville Formation, Reeds Spring/Bentonville Formation Contact I

Figure 5: Sample 28, Bentonville Formation, Reeds Spring/Bentonville Formation Contact I

Figure 7: Fragmentary bar type specimen

Sample, 17, Bentonville Formation Reeds Spring/Bentonville Formation Contact I

Figure 8: *Neoprioniodus* sp.?

Sample 28, Bentonville Formation, Reeds Spring/Bentonville Formation Contact I

Figure 9: *Spathognathodus* sp.? *Gnathodus* sp.?

Sample 22, Bentonville Formation, Reeds Spring/Bentonville Formation Contact I

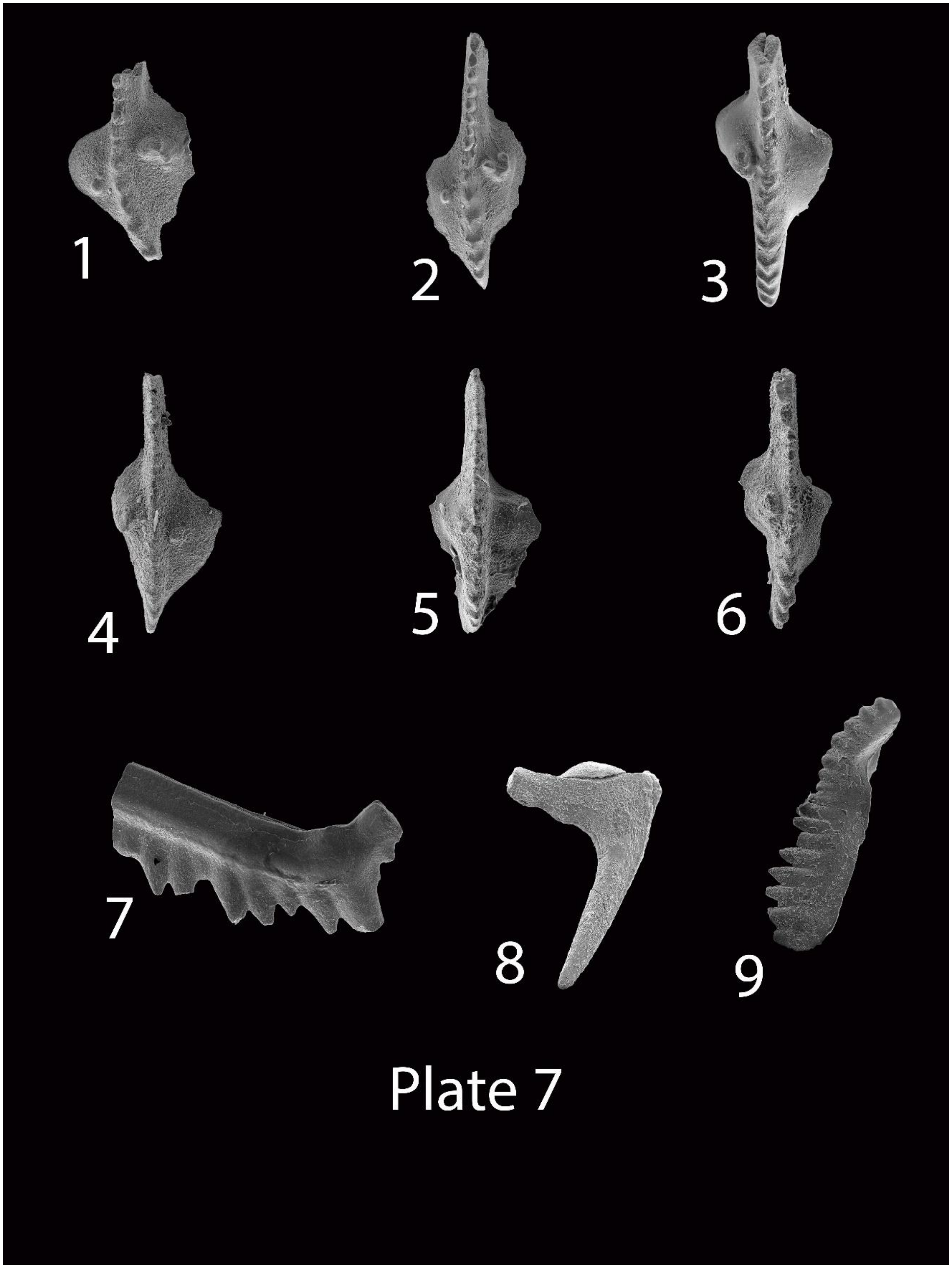
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Plate 7

Description of Plate 8

Figure 1: *Neoprioniodus* sp.?

Reeds Spring Formation, Reeds Spring Fm/Bentonville Fm Contact II

Figure 2: *Gnathodus aff. texanus*

First massive bed above Pineville Tripolite, Bentonville Formation, Bentonville Type Locality

Figure 3: *Neoprioniodus* sp.?

Sample 68, Ritchey Formation, Bentonville Co-Type Locality

Figure 4: *Spathognathodus* sp.

Sample 25, Bentonville Formation, Reeds Spring Fm/Bentonville Fm Contact I

Figure 5: *Gnathodus aff. pseudosemiglaber*

Figure 5: Sample 26, Bentonville Formation, Reeds Spring Fm/Bentonville Fm Contact I

Figure 6: *Gnathodus aff. bulbosus*?

Figure 6: Sample 26, Bentonville Formation, Reeds Spring Fm/Bentonville Fm Contact I

Figure 7: Fragmentary Bar Type Specimen

Sample 21, Bentonville Formation? Reeds Spring Fm/Bentonville Fm Contact I

Figure 8: *Gnathodus pseudosemiglaber*

Sample 23, Bentonville Formation, Bentonville Co-Type Locality

Figure 9: *Spathognathodus* sp.

Middle of Bentonville Formation, Bentonville Type Locality

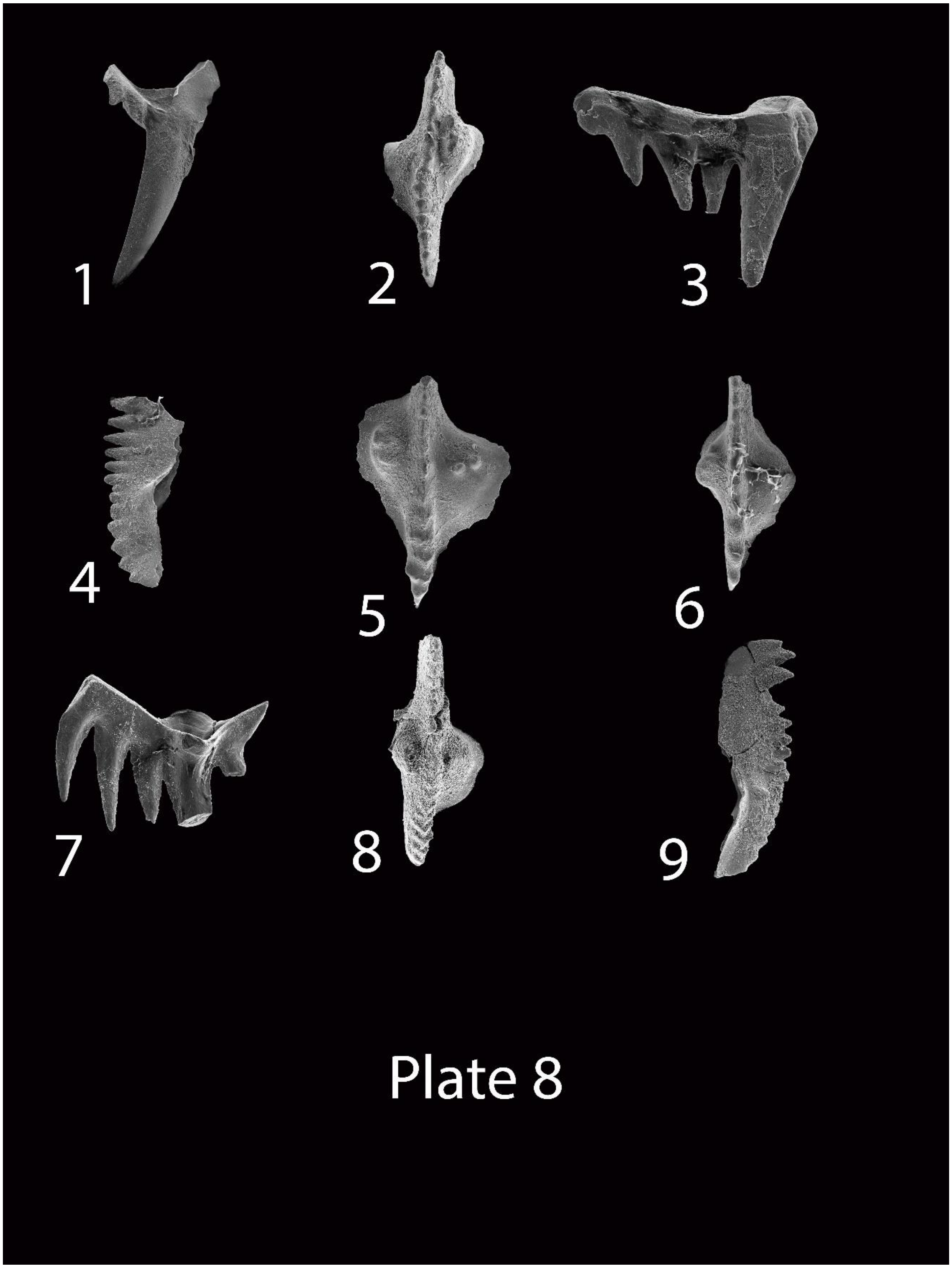

Plate 8

Description of Plate 9

Figure 1: *Gnathodus aff. linguiformis*

Sample 28, Bentonville Formation, Reeds Spring Fm/Bentonville Fm Contact I

Figures 2 and 3: *Gnathodus* n. sp. B *aff. pseudosemiglaber*

Figure 2: Sample 29, Bentonville Formation, Bentonville Co-Type Locality

Figure 3: Sample 29, Bentonville Formation, Bentonville Co-Type Locality

Figure 4: *Gnathodus aff. pseudosemiglaber?*

Sample 3, Reeds Spring Formation Reeds Spring Fm/Bentonville Fm Contact II

Figure 5: *Gnathodus aff. bulbosus* (juvenile specimen)

Sample 21, Bentonville Formation Reeds Spring Fm/Bentonville Fm Contact I

Figure 6: *Gnathodus* sp. indeterminate

Sample 72, Ritchey Formation, Bentonville Co-Type Locality

Figure 7: *Gnathodus aff. bulbosus*

Sample 28, Bentonville Formation, Reeds Spring Fm/Bentonville Fm Contact I

Figure 8: *Gnathodus aff. bulbosus*

Reeds Spring Formation Limestone in Tripolite, Bentonville Type Locality

Figure 9: *Lingonodina* sp?

Sample 24, Bentonville Formation, Reeds Spring Fm/Bentonville Fm Contact I

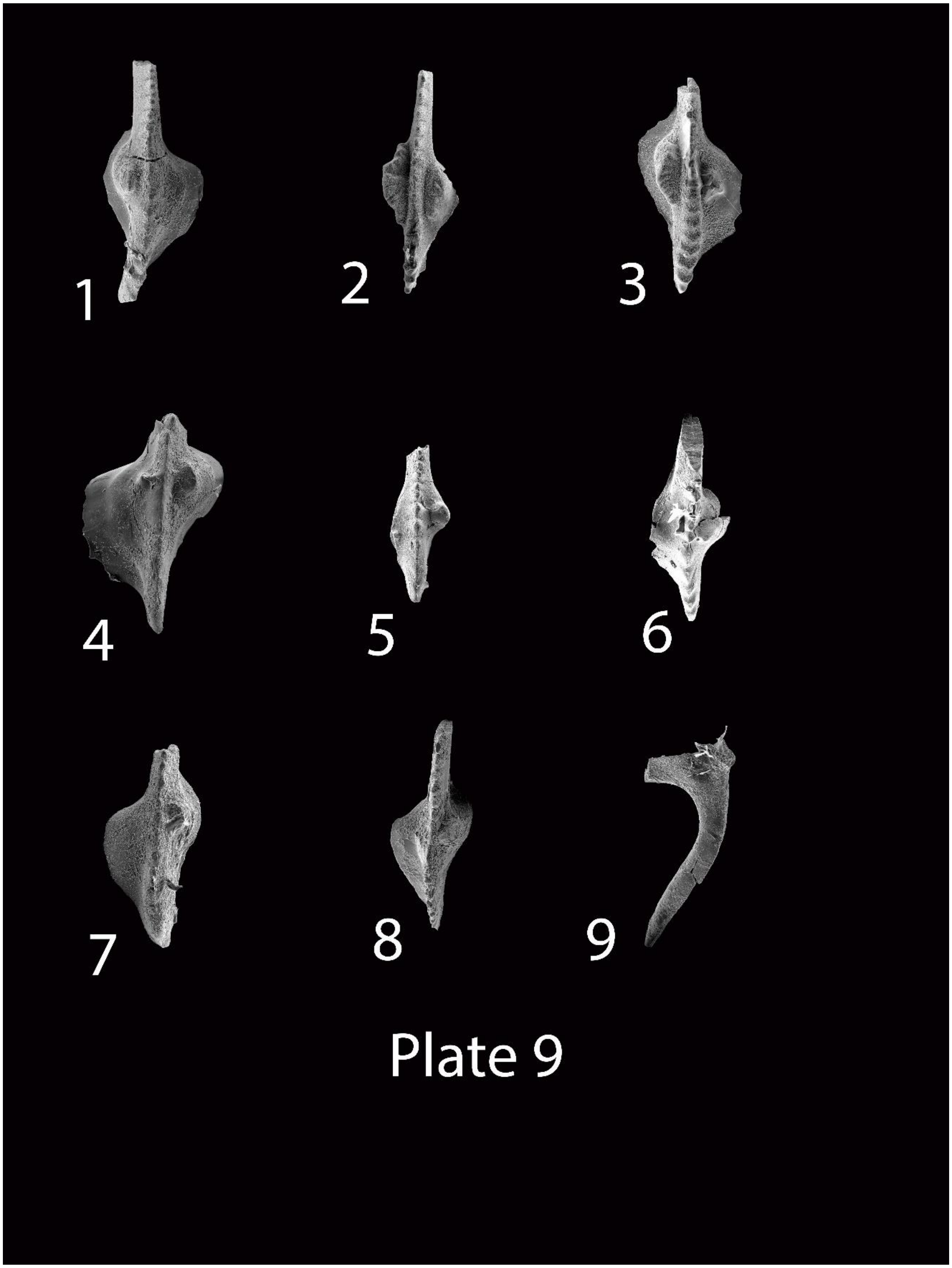
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Plate 9

Description of Plate 10

Figure 1: *Gnathodus sp.* (fragmentary)

Sample 72, Ritchey Formation, Bentonville Co-Type Locality

Figure 2: *Spathognathodus* sp.

Middle of Bentonville Formation, Bentonville Type Locality

Figure 3: *Gnathodus aff.* n. sp. 12 (*aff. pseudosemiglaber)*?

Base of Bentonville Formation? (In silicified bed Above Pineville Tripolite) Bentonville Type Locality

Figure 4: *Ozarkodina* sp.?

Sample 76, Ritchey Formation, Bentonville Type Locality

Figure 5: *Gnathodus aff. bulbosus*

Sample 21, Bentonville Formation, Reeds Spring Fm/Bentonville Fm Contact I

Figure 6: *Ozarkodina* sp.? (Fragmentary)

Sample 76, Ritchey Formation, Bentonville Co-Type Locality

Figure 7-9: *Gnathodus aff. texanus*

Figure 7: Sample 54, Bentonville Formation, Bentonville Co-Type Locality

Figure 8: Sample 29, Bentonville Formation, Bentonville Co-Type Locality

Figure 9: Sample 26, Bentonville Formation, Reeds Spring Fm/Bentonville Fm Contact II

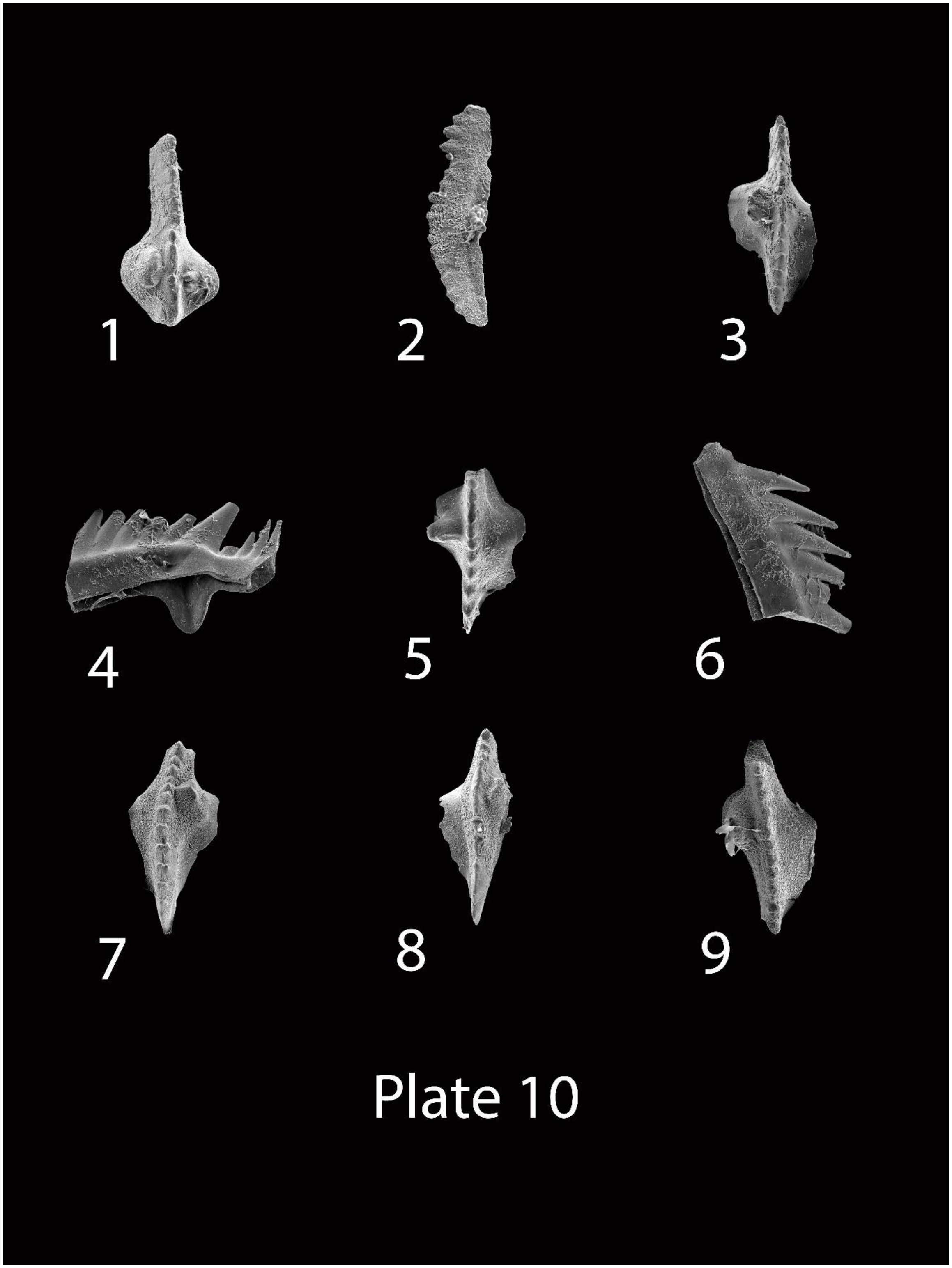
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Plate 10

Description of Plate 11

Figure 1: *Spathognathodus* sp.

Sample 22, Bentonville Formation, Reeds Spring Fm/Bentonville Fm Contact I

Figure 2: *Gnathodus aff. texanus*

Sample 53, Bentonville Formation, Bentonville Co-Type Locality

Figures 3, 5, 6: *Gnathodus bulbosus*

Figure 3: Sample 28, Bentonville Formation, Reeds Spring Fm/Bentonville Fm Contact I

Figure 5: Sample 24, Bentonville Formation, Reeds Spring Fm/Bentonville Fm Contact I

Figure 6: Sample 22, Bentonville Formation, Reeds Spring Fm/Bentonville Fm Contact I

Figure 4: *Spathognathodus* sp.?

Middle of Reeds Spring Formation, Reeds Spring Fm/Bentonville Fm Contact I

Figure 7: *Gnathodus aff. texanus?*

Sample 54, Bentonville Formation, Bentonville Co-Type Locality

Figure 8: Fragmentary bar type specimen

Sample 75, Ritchey Formation, Bentonville Co-Type Locality

Figure 9: *Gnathodus aff. texanus*? (immature)

Sample 28, Bentonville Formation, Reeds Spring Fm/Bentonville Fm Contact I

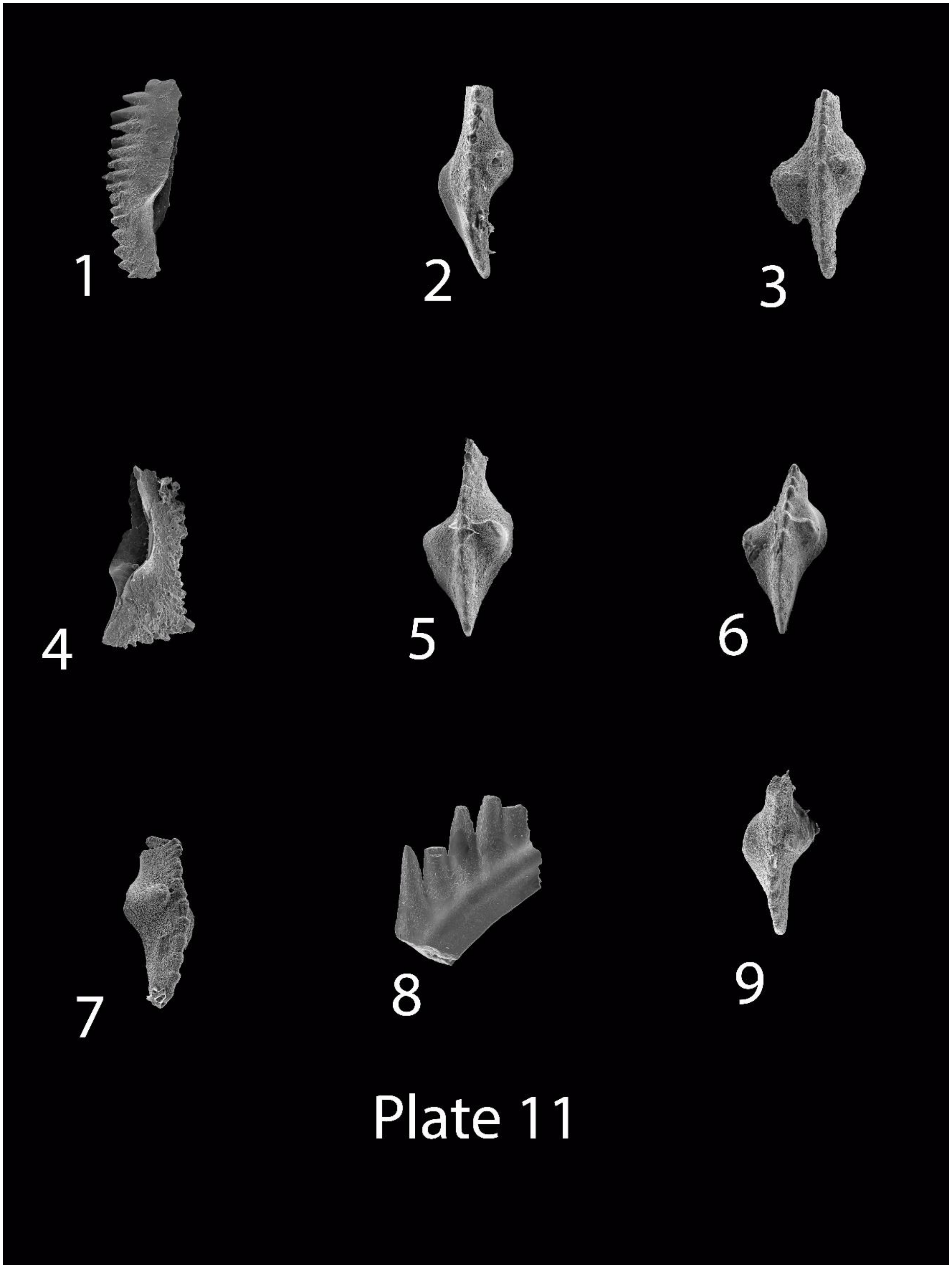
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Plate 11

Description of Plate 12

Figure 1: *Gnathodus* sp. indeterminate

Middle of Bentonville Formation, Bentonville Type Locality

Figure 2: Fragmentary bar form conodont

Sample 75, Ritchey Formation, Bentonville Co-Type Locality

Figure 3: *Gnathodus aff. pseudosemiglaber?*

Sample 14, Bentonville Formation, Reeds Spring Formation/Bentonville Formation Contact II

Figure 4: *Gnathodus aff. pseudosemiglaber?*

Sample 29, Bentonville Formation, Bentonville Co-Type Locality

Figure 5: *Gnathodus* sp. indeterminate

Limestone lenses within the Pineville Tripolite facies, Bentonville Type Locality

Figure 6: *Gnathodus aff. pseudosemiglaber?*

Above tripolite contact, within silicified mudstone to packstone Bentonville Formation?

Bentonville Type Locality

Figure 7: *Gnathodus aff. pseudosemiglaber*

Middle of Bentonville Formation, Bentonville Type Locality

Figure 8: Fragmentary Specimen *Lingonodina?*

Sample 75, Ritchey Formation, Bentonville Type Locality

Figure 9: Unknown specimen

Middle of Reeds Spring Formation, Reeds Spring Fm/Bentonville Fm Contact I outcrop

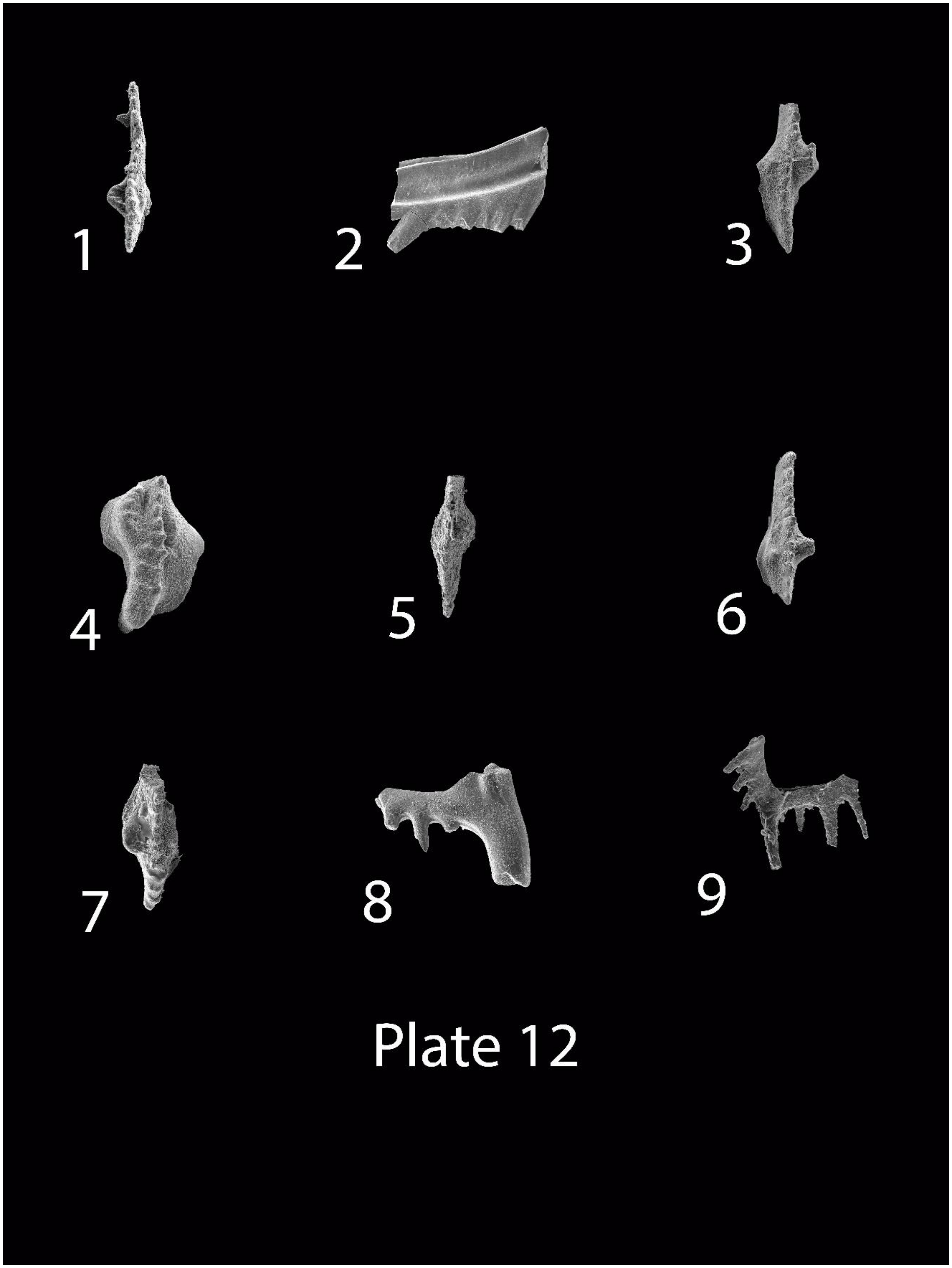
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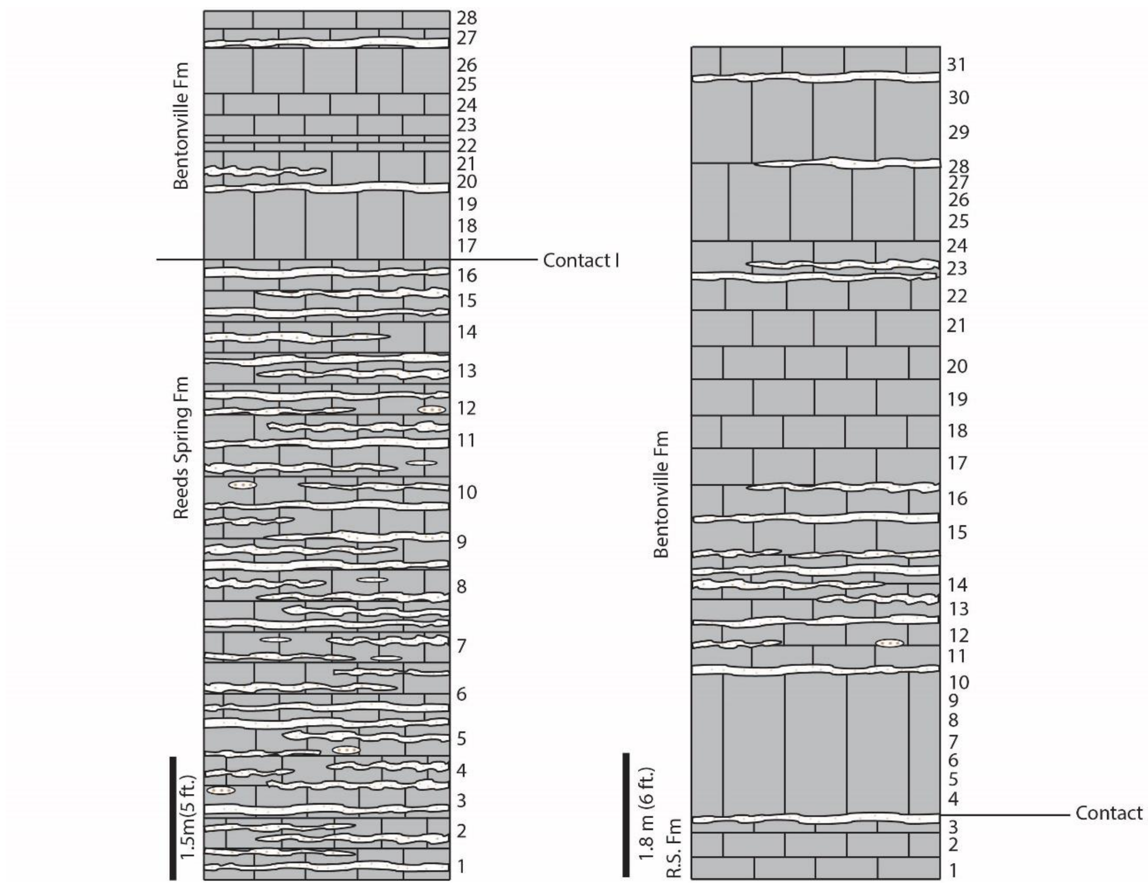
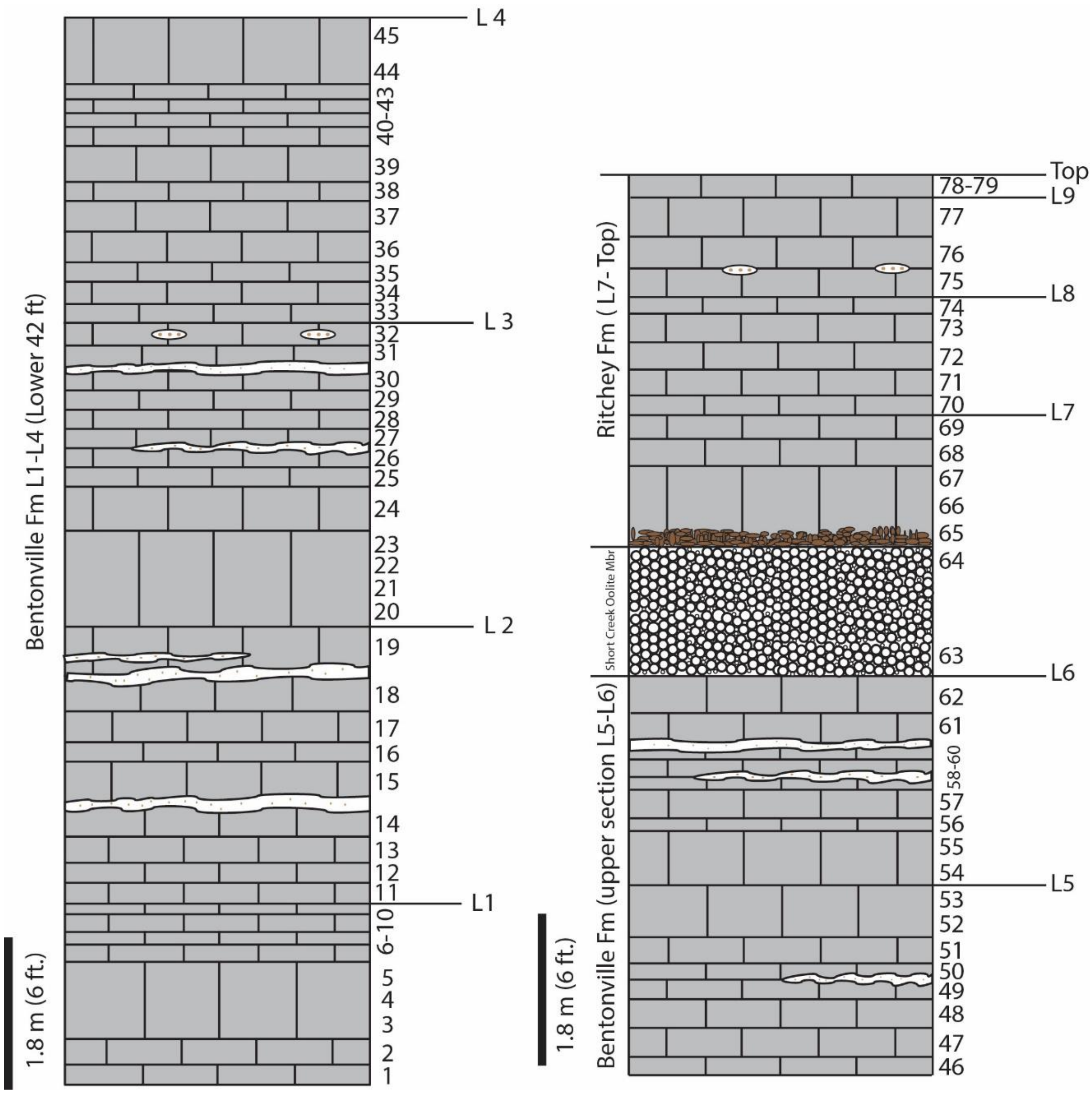
Plate 12

Contact I and Contact II Sample Locations



Pictured above is the sample locations corresponding to the conodonts found within the attached plates. After each conodont referenced within the plates is the sample number, formation, and outcrop designation. The sample number is shown to the right of the lithic column.

Bentonville Co-Type Locality Sample Locations



Pictured above is the sample locations corresponding to the conodonts found within the attached plates. After each conodont referenced within the plates is the sample number, formation, and outcrop designation. The sample number is shown to the right of the lithic column.

VITA

Jeffrey D. Miller

Candidate for the Degree of

Master of Science

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Geology intern, Conoco Phillips, Houston, Texas-2013

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Michael and Susan Gaskins Graduate Fellowship-2013
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