Lithofacies and Sequence Architecture of the Lower Desert Creek Sequence, Middle Pennsylvanian, Aneth, Utah

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Lithofacies and Sequence Architecture of the Lower Desert Creek Sequence, Middle Pennsylvanian, Aneth, Utah

Chanse James Rinderknecht

A thesis submitted to the faculty of Brigham Young University in partial fulfillment of the requirements for the degree of Master of Science

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ABSTRACT

Lithofacies and Sequence Architecture of the Lower Desert Creek Sequence, Middle Pennsylvanian, Aneth, Utah

Chanse James Rinderknecht
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Masters of Science

Middle Pennsylvanian (Desmoinesian) strata of the Lower Desert Creek (LDC) sequence within the sub-surface Greater Aneth Field (GAF) reflect a hierarchy of 4th and 5th order carbonate-dominated cycles. The Lower Desert Creek sequence, along the studied transect are composed of eight carbonate facies deposited on an east-facing shelf. There is a lateral transition from open marine algal buildup from the southeast (cores R-19, Q-16, O-16, and J-15) to a more restricted lagoonal environment to the northwest (core K-430 and E-313).

The Lower Desert Creek sequence within the GAF contains three main parasequence sets: a basal, relatively deep-water unit (LDC 1), a middle skeletal to algal unit (LDC 2-4), and a shallow, open-marine/restricted lagoonal unit (LDC 5-7). The southeast cores (R-19, Q-16, O-16, and J-15) contain the dolomitized basal unit in parasequence LDC 1. The northwest cores (K-430 and E-313) also contain the dolomitized basal unit in LDC 1, but show a deeper facies succession through LDC 2-4. Parasequences LDC 2-4 are the heart of the algal buildup in the GAF particularly in the southern part of the transect. The upper few parasequences (LDC 5-7) are dominated by an open marine environment represented by robust fauna. The upper parasequences (LDC 5-7) show the same shallowing upward trends with algal facies in K-430 and restricted lagoonal facies in E-313. Shoaling upward trends that characterize the Lower Desert Creek sequence terminate with an exposure surface at the 4th order (Lower Desert Creek-Upper Desert Creek) sequence boundary.

Porosity and permeability is weakly correlated to facies. Diagenesis within the algal reservoir is the most important factor in porosity and permeability. Marine diagenesis is observed in the form of micritization of Ivanovia, a phylloid alga. Thin fibrous isopachous rims of cloudy cement also indicate early marine diagenesis. Ghost botryoidal cements are leached during meteoric diagenesis. Meteoric drusy dog tooth cements as well as sparry calcite fill most depositional porosity. Neomorphism of micrite and the isopachous rim cements reflect meteoric diagenesis. Burial diagenesis is represented by baroque dolomite cement, compaction, and mold-filling anhydrite cement.

Keywords: Lower Desert Creek, Paradox Formation, Paradox Basin, Reservoir Characterization, Petroleum Geology,
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INTRODUCTION

The Paradox Basin of southeastern Utah and parts of adjacent Colorado, New Mexico and Arizona (Fig. 1) has been the site of hydrocarbon exploration and production since 1908 (Peterson, 1992). Exploration programs from 1908 until 1954 targeted surface structures and met with limited success. Two wells drilled by Shell Oil Company in the Desert Creek field identified upper Paradox carbonates as the main producer in the basin (Stevenson and Wray, 2009). In 1956, Texaco drilled a 1,700 BOPD wildcat well in the Desert Creek interval of the Paradox Formation north of Montezuma Creek, Utah. Further drilling delineated the giant Aneth carbonate buildup, a 12 x 12 mile-diameter, horseshoe-shaped carbonate complex located in the Blanding sub-basin (Peterson, 1992). Subsequent exploration, now targeting stratigraphic traps, resulted in discovery of several satellite fields corresponding to subsurface phylloid-algal mounds in the Desert Creek and Ismay zones of the Paradox Formation. Over 600 MMBO has been produced from Pennsylvanian carbonate reservoirs to date, two-thirds being derived from the lower and upper Desert Creek zones in the Aneth buildup (Peterson, 1992; Stevenson and Wray, 2009).

Studies of the Aneth carbonate buildup have been published by Peterson (1992) and by Weber et al. (1995). The latter study discussed reservoir performance of the Aneth field in the context of sea-level-controlled facies architecture resulting in the most comprehensive study of the Aneth buildup to-date. In 2016, Resolute Energy Corporation donated over 100 cores from producing Middle Pennsylvanian strata of the Aneth Field to the Utah Geological Survey along with logs and data from reservoir tests. These resources will make it possible to develop even more detailed depositional and diagenetic models for the Aneth carbonate complex than those developed by Weber et al. (1995). This thesis, focused on the Lower Desert Creek sequence in
the eastern part of the complex (Fig. 1), represents the first of many planned studies of the Resolute data to build a comprehensive depositional and diagenetic picture of the Aneth complex. A companion study by Evan Gunnell focuses on the Upper Desert Creek interval along the same traverse.
GEOLOGICAL BACKGROUND

Tectonics

The Paradox Basin is an asymmetrical, northwest-southeast-oriented intracratonic basin that extends from central Utah into northwestern New Mexico and southwestern Colorado (Fig. 2) and covers just over 10,000 square miles (Stevenson & Baars, 1988). The basin was surrounded by the Defiance-Zuni Uplift to the south, the Monument Upwarp/Emery-Piute Arch to the west, and Uncompahgre and San Luis uplifts to
the east and southeast (Guthrie and Bohacs, 2009; Blakey, 2009). The Paradox Basin was connected to the ocean through the Oquirrh Sag on the northwest terminus and Cabezon Accessway on the southeast end of the basin (Blakey, 2009). Three main facies belts developed: black shale, anhydrite, and halite in the basin center bounded by thick alluvial deposits along the Uncompahgre and San Luis uplifts located northeast of the basin center, and cyclic carbonates on the southwest shelf. The structure of the basin is attributed to reactivation of Precambrian basement faults as part of the Ancestral Rocky Mountains orogeny (Baars and Stevenson, 1982; Kluth and DuChene, 2009).

Basin subsidence followed a prolonged period of tectonic stability represented by shallow-water deposits of Devonian through early Mississippian age. These carbonates are no more than 1,800 to 2,400 feet thick and contain regional unconformities of late Devonian and late Mississippian age (Ohlen & McIntyre, 1965; Stevenson and Wray, 2009). The Morrowan Molas Formation, which represents reworked karst (developed locally on top of the Leadville Limestone) is the lowest Pennsylvanian unit in the Paradox Basin. Extension-related subsidence commenced during Atokan time resulting in development of the asymmetrical Paradox Basin by Middle Pennsylvanian time (Stevenson & Baars, 1986). The cyclic deposits of the Pinkerton Trail, Paradox, Honaker Trail, and Halgaito formations (up to 11,000 feet thick) represent filling of accommodation resulting from this tectonic activity.

**Stratigraphy**

Complimentary lithostratigraphic and sequence stratigraphic subdivisions have been previously proposed for Pennsylvanian strata in the Paradox Basin.

**Lithostratigraphy.** The lithostratigraphic terminology for Middle Pennsylvanian strata in the Paradox Basin is a combination of formal and informal designations. Woodruff (1910) originally
assigned the entire succession of Pennsylvanian strata exposed along the cliffs of the San Juan River to the Goodridge Formation, which nomenclature was followed by Miser (1924). Wengerd (1958) abandoned this fifty-year old convention, preferring a two-fold subdivision (Paradox and Honaker Trail formations) for these strata, the former established for basin-center salt cycles and the latter for their correlative shelf strata. The Paradox Formation was subsequently subdivided into informal subsurface zones bounded by readily identifiable and easily correlated black shale horizons. These zones were named, in ascending order, the Alkali Gulch, Barker Creek, Akah, Desert Creek, and Ismay zones (Fig. 3). Black shales at the base of the Desert Creek, Lower Ismay, and Upper Ismay zones were assigned to the Chimney Rock, Gothic, and Hovenweep shales respectively.

**Sequence Stratigraphy.** - The Paradox Formation has been divided into a hierarchy of depositional sequences by Goldhammer et al. (1991), Weber et al. (1995), and Gianniny and Simo (1996). The Paradox Formation is divided into four third-order sequences that roughly correspond with the Barker Creek, Akah, Desert Creek, and Ismay zones. These are divided into higher order (fourth-order) sequences based upon: 1) regionally traceable sequence boundaries that contain evidence of subaerial exposure, 2) onlapping of evaporites or draping of quartz sandstone, 3) occurrence of deep-water black shales near the bases of sequences, and 4) cyclic stacking patterns reflecting the development of lowstand, transgressive, and highstand systems tracts (Goldhammer et al., 1991). The fundamental building blocks of these lower-order sequences (third and fourth-order) are 2 to 7 meter-thick, shallowing-upward, fifth-order parasequences that reflect high-frequency, high-amplitude “ice-house” sea-level oscillation (Goldhammer et al., 1991).
METHODS

Slabbed cores and logs from six Greater Aneth wells were chosen for analysis of the Lower Desert Creek sequence. Of the analyzed cores, two are from the Aneth production unit.
and four are from the McElmo Creek production unit (Fig. 1). Well distribution follows a northwestern/southeastern trend over the major algal buildup in the McElmo Creek Unit. The total distance from one edge of the transect to the other is approximately 21 kilometers (13 miles). Distances between wells range from 2 to 5 kilometers. The vertical heterogeneity of lithofacies was analyzed at centimeter/millimeter-scale resolution. To better understand the lateral heterogeneity of facies and parasequences through the field, these six cores were correlated tracing parasequence-bounding flooding surfaces using Petra and illustrated using Adobe Illustrator. This transect goes through the main algal buildup in the McElmo Creek Unit, and then off the northeast edge of the buildup (Fig. 1). Analysis of the core allowed for description of lithofacies, sequence architecture, diagenetic patterns, and reservoir character. A total of 831 feet (250 m) of core was analyzed between the six cores.

Selected core intervals were destroyed by field operators during oil saturation tests. For these intervals, gamma ray and porosity logs were used for correlation of surfaces and interpretation of facies. A total of 180 blue-dyed, epoxy-impregnated Alizarin-stained thin sections were made by Wagner Petrographic. The thin sections allowed for accurate analysis of facies, faunal distribution, diagenesis, and pore-type analysis. Porosity and permeability data derived from one-inch core plugs (Core Laboratories Inc.) were provided by Resolute Resources. These data were assigned to the corresponding facies, then plotted as x-y scatter plots to determine the presence/absence of facies-linked porosity-permeability trends.

LITHOFACIES

Pray & Wray (1963) developed a five-fold facies classification for the Ismay interval that captured the shallowing-upward character of Paradox carbonate cycles. This terminology was followed and expanded by subsequent stratigraphers (Goldhammer et al., 1991; Weber et al.,
1995; Grammer and Eberli (2000) working in the Paradox Basin. With noted modifications we largely follow the same nomenclature used by the subsequent stratigraphers in delineating the following eight facies (Table 1).

**Black Laminated Mud Facies (BLM)**

*Description.* The black laminated mudstone facies (BLM) is dark-gray to black silty dolomitic shale and shaly mudstone that grades basinward into black sapropelic shale (Fig. 4) (Goldhammer et al. 1991; Guthrie and Bohacs, 2009). This facies designation was introduced by Goldhammer et al. (1991) for the Chimney Rock and other black shales exposed along Honaker Trail. Total organic carbon (TOC) values in the Chimney Rock Shale range from 2-5% (Grammer, 2000; Guthrie and Bohacs, 2009). Within the McElmo and Aneth Units of the Greater Aneth Field, thin-section analysis indicates that the BLM is composed of 40-60% carbonate mud, 20-35% angular to sub-rounded quartz silt (10-100um diameter), 5-10% organic-rich mud, and 2-5% clay minerals. In this study, the BLM facies is restricted to the Chimney Rock Shale which was recovered in only three cores, R-19, E-313, and J-15. The thickness of the Chimney Rock in gamma-ray logs across the Greater Aneth Field ranges from 20-30 ft (6-9 m).

*Interpretation.* -This facies is interpreted as the relatively deepest-water environment in the lower Desert Creek sequence because of the high mud and clay content, preservation of laminae, relatively high TOC, and paucity of benthonic fossils. These characteristics suggests a deep-water, dysoxic, low-energy setting that was inimical to benthonic organisms. The bedding-plane occurrences of fish teeth and deep-water, conodont elements (*Idiognathodus* spp.; Ritter et al., 2002) indicate open-marine conditions, in contrast to the “shallow-water” mesohaline model put forward by Weber et al. (1995). This facies represents the maximum-flooding facies of the third-order Desert Creek sequence (and fourth-order lower Desert Creek sequence). This
Figure 4. A) E-313 5899’ Black sapropelic dolomicitic mudstone with disarticulated inarticulate brachiopods and abundant microfossils, the latter introduced into the basin by storm events that have been washed downslope by storm events. Scale bar = 0.5 mm. B) Conodont elements of the offshore genus *Idiognathodus* from the Chimney Rock Shale and adjacent limestone facies in the Lower Desert Creek sequence (Desmoinesian). C) R-19 5866.7’ typical black laminated mudstone in the Lower Desert Creek Sequence in the Aneth buildup. D) E-313 5931’ massive black laminated mudstone E) Massive black laminated mudstone notice amount of quartz F) K-430 5729.3’ scale bar = 0.5 mm
lithology is significant because “black shales” are used to establish basin-wide correlation and because they constituted source rocks for Paradox Basin oil and gas fields during the oil-generating phase of basin development (Rasmussen and Rasmussen, 2009).

**Intermediate Facies (IF)**

Pray and Wray (1963) coined the term intermediate facies to describe strata in the shallowing-upward Lower Ismay cycle that were situated superpositionally and genetically between relatively deep-water dysoxic, subphotic, spicule-bearing mudstone (their sponge facies) and superjacent shallow-water, phylloid algae-dominated packstone (their sparry algal facies). Goldhammer et al. (1991) broadened this facies concept stratigraphically to characterize muddy, normal-marine, skeletal facies in the depositionally intermediate portions of shallowing-upward cycles throughout the Paradox and Honaker Trail formations. They listed common constituents of this facies as crinoids, brachiopods, bryozoans, corals, foraminifers, and sparse phylloid algae. Grammer (2000) subsequently subdivided the intermediate facies of the Paradox and Honaker Trail formations into intermediate-restricted and intermediate-diverse subfacies on the basis of faunal diversity. As denoted by the name, rocks of the former subfacies contain a relatively low diversity skeletal component that is “restricted” to crinoids, brachiopods, bryozoans, and ostracodes. Rocks of the intermediate-diverse fauna contain elements of the restricted fauna in addition to small foraminifera, molluscs, fusulinids, rugose corals, *Chaetetes*, and phylloid algae. Within the lower Desert Creek sequence, we likewise distinguish between skeletal limestones that contain lower diversity and higher diversity skeletal components. However, since the term restricted is ambiguous with respect to the physical or biological factor (or factors) that “restrict” the faunal diversity, and because the term restricted may connote a setting (ie. restricted lagoon) we prefer to subdivide the transitional intermediate facies into the
lower diversity intermediate-heterozoan (for rocks with light-independent crinoids, brachiopods, and bryozoa) and higher diversity intermediate-photozoan (for rocks with light-independent plus light-dependent taxa) following the definitions of James (1997).

**Description of the intermediate-heterozoan facies (IF-H).**-The intermediate heterozoan facies is characterized by wackestone to mud-dominated packstone textures with a heterozoan fossil assemblage comprised of articulate brachiopods, echinoderms, bryozoans, ostracods, and rare trilobites and phosphatic inarticulate brachiopods (Fig.5). Rocks of this facies may be dominated by skeletal elements of a predominant taxon (ie. articulate brachiopods or crinoids) or may contain remains of several heterozoan taxa. The matrix is generally comprised of dark gray to black carbonate mud. This facies exhibits laminations in the deeper part of the section and contains disarticulated and whole fossils that range from coarse sand to gravel size.

Microbioclasts may be common constituents of the matrix. The intermediate heterozoan facies is prevalent in the lower two parasequences through the Aneth transect and ranges from one-half to three meters in thickness.

**Interpretation.**- This facies is interpreted to represent deposition below fair-weather wave base in a normal-marine setting where light is restricted at least intermittently by turbidity or by depth. Microbioclasts were transported into this environment from higher on the shelf by storms. The heterozoan faunal assemblage has been interpreted as evidence of cool-water deposition by several authors (James, 1997; Beauchamp and Desrochers 1997; Brandley and Krause, 1997). However, given the proximity to the low paleo-latitudinal setting of the Paradox Basin during the Pennsylvanian Period, cool-water conditions are unlikely (Roylance, 1990).
Figure 5. Intermediate Facies: Heterozoan A) O-16 5577-5' Sparse wackestone with bioclasts of brachiopods, undenominable microbioclasts, and sponge spicules. B) J-15 5639.3' Heterozoan wackestone with crinoid columns and abundant microbioclasts of bryozoans, echinoderms, and articulate brachiopods. C) J-15 5651' Sparse wackestone with dark matrix D) 5891' Crinoids in mud matrix. E) R-19 5863.2 Heterozoan fossil assemblage, partially dolomitized. F) R-190 5618.4' articulate brachiopod in mud matrix. Scale bar=0.5 mm
Description of the intermediate-photozoan facies (IF-P).- The intermediate photozoan facies is most commonly mud-dominated packstone and occasionally wackestone with a photozoan grain assemblage (Fig. 6). The photozoan fossils that are most prevalent are fusulinids, small foraminifera and phylloid algae. The fusulinids are mostly species of the genus *Beedeina* with rare occurrences of *Wedekindellina*. The common small foraminifera in this facies are *Endothyra, Tubertina, Paleotextularia, Tetrataxis, Biseriella, Earlandia, Staffella, Bradyina*, and irregular encrusting forms. These fossils are commonly whole to disarticulated with very little abrasion. The IF-P is highly variable and can include the full photozoan fossil assemblage, or be dominated by a single taxon. Strata of this facies are heavily bioturbated with sparry calcite-reduced shelter porosity. The muds are commonly peloidal and somewhat mottled.

Interpretation.- Grammer’s (2000) Intermediate Facies-Diverse is essentially synomous with this facies, which is represented by bioturbated, skeletal wackestone to packstone with thin-to medium-scale undulatory bedding and a diverse array of skeletal grains. The IF-P was deposited in a well-lit, open-marine environment as indicated by the diverse fossil assemblage that includes light-dependent calcareous algae and fusulinids. This facies is restricted to the upper few parasequences and constitutes 10-15% of the Lower Desert Creek sequence.
Figure 6. Intermediate Facies - Photozoan

A) O-16 5758' Sparse wackestone with bioclasts of recrystallized phylloid algae and irregular encrusting foraminifera.
B) O-16 5763 9' Wackestone to mud-dominated packstone with a diverse small foraminifera fauna. Large foraminifera is *Bradyina* sp.
C) Q. 16 5480.7' Packstone with *poloetoxularia* and *stafella*. D) J-13 5541' Packstone with *Biseriola* and *Bradyina*. E) Q-16 5484.2' Packstone, large foraminifera is *Bradyina*, note the complex wall structure.
F) R-19 5791' Mud-dominated packstone with irregular encrusting foraminifera, *Beedeina*, and *Ivanovia*. Scale bar = 0.5 mm.
Algal Facies (AF)

**Description.** - The phylloid algal facies is texturally diverse, represented by wackestone, bafflestone, and packstone (Fig. 7). Grainier subfacies often contain the highest percentages of macroporosity and form reservoir intervals in the Lower Desert Creek sequence. As the name implies, the main fossil constituent is phylloid algae, although other skeletal grains are present in limited numbers. The phylloid thalli are seldom preserved intact. Taphonomically, partial remains range from relatively larger and intact undulatory segments, to largely fragmented, or fragmented and “unzipped” (ie. split through the medulla) thalli. In situ cup-shaped thalli were not observed. The fronds are usually micritized and encrusted by irregular foraminifera and other microbionts. Although rare, the preservation of utricles in some thin sections suggests that *Ivanovia* is the dominant alga in this facies and in algal-dominated mounds. The AF is divided into three categories based upon mud content and algal taphonomy (preservation).

A) **Phylloid wackestone.** - This facies is characterized by relatively larger phylloid fronds floating in a mud matrix; the carbonate mud acting as a structural support for the phylloid fronds (Fig. 7, E and F). The mud is typically dense and recrystallized to microspar. Peloidal muds are minor constituents of this subfacies. The phylloid wackestone facies generally exhibits low porosity and permeability owing to the mud infill. B) **Phylloid bafflestone.** - As the name implies, this facies designation is somewhat interpretive as it implies that the texture is the result of a specific process (ie. baffling of mud). We apply it to poorly washed, grain-rich packstone that appears to have resulted from baffling of fines by relatively well preserved algal fronds (Fig. 7, C and D). This facies is distinguished from the previous algal subfacies by the lower percentage of interstitial mud and the slightly more fragmented nature of the algal thalli. Interstitial mud ranges from dense to peloidal and may reflect microbial activity in cavities between the algal grains.
The phylloid wackestone and phylloid bafflestone are what Gournay (1999) referred to as having biomicritic fabric. Cement-reduced and cement-filled shelter pores are common.

C) Phylloid-rich grain-dominated packstone.- This subfacies is characterized by broken thalli and grain-supported textures (Fig 7, A and B). Shelter pores in this facies are filled with calcite.
cement and only vuggy and moldic porosity remains. Gournay (1999) referred to this texture as a biosparite fabric.

**Interpretation.** Phylloid-rich facies reflect a spectrum of conditions that represent the evolution of algal-rich mounds from low-energy wackestone to bafflestone to high-energy algal-fragment packstone. The phylloid wackestone, which often grades into bafflestone is interpreted to represent incipient algal-mound development. The phylloid bafflestone is interpreted as an *in situ* deposit in an open-marine environment of moderate energy. The growth of the algal mounds kept pace with sea-level rise, allowing for vertical growth of the mound. The phylloid packstone is interpreted to have been deposited in a shallower, higher-energy marine setting where the phylloid thalli were broken and where much of the mud was removed. The algal facies dominates the lower four parasequences on the eastern side of the Aneth buildup (wells R-19, Q-16, O-16, and J-15). This facies ranges from 3 to 30 ft (1-10 m) in thickness, becoming increasingly sparse in wells K-430 and E-313. This lithology forms the reservoir facies for conventional Lower Desert Creek reservoirs in the Aneth field (Peterson, 1992).

**Ivanovia.** The main constituent of the “phylloid algae” facies is broken and often recrystallized thalli of the genus *Ivanovia* Khvorova, 1946. The thallus of well-preserved specimens (as diagnosed by Torres, 1995) is cup-shaped or cyathiform and the membrane structure consists of bilateral cortices with utricles. *Ivanovia’s* medulla is constructed of tubular coenocytes. Broken thalli are identified based upon the pattern of the bilateral utricles (Fig. 8).

The steps leading to fossilization of *Ivanovia* are 1) precipitation of opaque micrite cement in open utricles, 2) breakage of some thalli followed by micritization of resulting algal blades (including the broken ends of blade fragments), 3) encrusting of algal blades by irregular foraminifera and other organisms (particularly on the upper side), 4) selective leaching of
medullary aragonite permitting splitting of algal blades through center of the mold, 5) precipitation of a thin isopachous rim of fibrous, cloudy marine cement, and 6) partial to
complete occlusion of algal molds with equant, sparry calcite cement. Growth of cement within the mold of the thallus is often displacive, causing the phylloid fragment to unzip and split into two fragments through the medullary region.

**Skeletal Capping Facies (SCF)**

*Description.*- The SCF is comprised of grain-dominated packstone to grainstone with disarticulated to whole skeletal grains as the dominant grain constituent (Fig. 9). Microbioclasts are common. The lack of mud matrix allowed for primary interparticle porosity that has been cement reduced to filled. This facies contain rare small-scale trough cross stratification, ripple lamination, and burrows. The SCF is subdivided into three main categories. A) crinoidal skeletal cap; capping facies dominated by disarticulated crinoid columnals. Common characteristics are; grain-to-grain dissolution and cement-filled interparticle porosity. B) foraminiferal skeletal cap; capping facies dominantly comprised of foraminifera and rare peloids. This facies is only found in one core (Q-16). The majority of the foraminifera are irregular encrusters. C) diverse skeletal cap facies: capping facies comprised of a range of skeletal grains. The most common constituents are: *Beedeina*, small foraminifera, crinoids, and rare peloids. In each of the categories the fossil grains are slightly micritized, and abraded.

*Interpretation.*- The grain-supported textures, abraded and micritized skeletal debris, and the presence of encrusting foraminifers, indicate, shallow subtidal or shoaling conditions (Goldhammer, 1991). This facies could also be interpreted as high-energy channels between algal mounds. The water depth was approximately one to five meters deep. In the Lower Desert Creek this facies is not common, observed only in R-19, O-16, and J-15 (Fig. 1). In these cores the thickness of the facies is uniform at one meter. This facies is distinguished from intermediate photozoan facies by a lower content of carbonate mud.
Figure 9. Skeletal Cap Facies: A) R-19 5712' Photozoan grainstone comprised of broken skeletal grains with thin micrite matrix. Note abundant interparticle and moldic porosity. B) Q-16 5447.2' Grainstone comprised chiefly of irregular foraminifera. Inter- and intraparticle pores are filled with equant sparry calcite cement. C) Q-16 5812' Photozoan grainstone comprised of echinoderms, bryozoans, and small foraminifera. Meteoric diagenesis and compaction has filled porosity with sparry calcite. D) Q-16 5447.2' Grainstone comprised chiefly of irregular foraminifera. Inter- and intraparticle pores filled with equant sparry calcite cement. E) J-15 5549' fusulinid-rich skeletal cap facies. F) R-19 5731' Irregular foraminifera skeletal cap facies: with only vuggy porosity. Scale bar = 0.5 mm
Non-Skeletal Capping Facies (NSCF)

**Description.** The NSCF is similar to the skeletal capping facies in the sense that they are made up of grain-dominated packstones to grainstones, however the main constituents are non-skeletal grains (Fig. 10). In the area of interest, the NSCF is subdivided into two main categories: First the oolitic non-skeletal capping facies is comprised of oolitic grainstones and more rarely oolitic grain-dominated packstones. Due to the relatively high primary interparticle porosity there have been a wide range of diagenetic features in the oolitic NSCF. Most commonly are cement-reduced to filled interparticle porosity, and oomoldic porosity. The matrix is most commonly calcite cement and rarely the entire facies has been dolomitized. The second subdivision is peloidal non-skeletal capping facies. This facies is also most commonly a grainstone to grain-dominated packstone made of peloid grains. The interparticle porosity is either cement or mud filled. There are occasionally floating skeletal grains (most commonly brachiopods and foraminifera).

**Interpretation.** The NSCF is developed toward the top of the Lower Desert Creek sequence below the 4th order sequence boundary, and is only seen in R-19, O-16, Q-16, and J-15. This facies represents a shallow, high- to low-energy depositional environment. The ooids indicate a shallow to shoaling-water, high-energy environment. Aragonite seas prevailed during the Middle Pennsylvanian epoch (Sandberg, 1983) suggesting that ooids in the NSCF were originally composed of aragonite. Patterns of selective and complete leaching of ooids, which mimics that of aragonite molluscs and phylloid algae, confirms this suggestion. We interpret the peloidal skeletal cap to represent deposition in high-energy, shallow-water settings formed by shoaling or a drop in sea level. This facies is relatively thin only being one to two meters in
Figure 10. Non-Skeletal Cap Facies A) R-19 5695° Oolitic grainstone showing surgical dissolution of selected cortical layers. B) O-16 5780.8 Non skeletal grainstone consisting of peloids and aggregate grains. Sparry calcite reduced interparticle porosity. C) Q-16 5468.1° Peloid and aggregate grainstone, with marine isopachus rims. D) Q-16 5417 E) E-313 5844.6 Ooid grainstone with partial dissolution of cortices F) K-430 5574.2° Oolitic grainstone comprised of radial and sparse superficial ooids. Interparticle pores filled with sparry calcite cement. Scale bar = 0.5 mm
thickness. The NSCF is developed toward the top of the Lower Desert Creek sequence toward the 4\textsuperscript{th} order sequence boundary, and is only seen in R-19, O-16, Q-16, and J-15.

**Restricted Lagoon Facies (RLF)**

*Description.*- The Restricted Lagoon Facies is a largely non-skeletal wackestone to mud-dominated packstone (Fig. 11). Rare disarticulated skeletal grains are present, usually brachiopods and ostracods. The non-skeletal grains are generally peloids, with irregular encrusting foraminifera. The restricted lagoonal facies is often characterized by a clotted texture that is a result of microbiially-induced precipitation of mud. Small, 2-4 mm diameter, silt-filled burrows are common.

*Interpretation.*- This facies is interpreted to have been deposited in a restricted lagoon during the onset of the transgressive systems tract or the end of the highstand. In the Lower Desert Creek, this facies is rare in the algal-dominated, windward, portion of the transect (R-19, O-16, Q-16, and J-15) in parasequences six and seven. Off the algal mound in wells K-430 and E-313, the restricted lagoonal facies is up to 10 meters thick in parasequences 5-7.

**Quartz Sand Facies (QSF)**

*Description.*- The Quartz Sand Facies (QSF) was originally named by Pray and Wray (1963) and has been subsequently used (Goldhammer et al, 1991; Eberli and Grammer, 1995) to describe strata that are composed of well sorted, angular to subrounded, coarse silt to fine quartz sand which is 50-150 um diameter (Fig. 11). Additionally, there is essentially no clay and up to 30\% calcareous material in the form of peloids, ooids or worn skeletal grains. (Goldhammer et al., 1991). Within the six described cores there are four 1-2 ft. thick QSF packages (Q-16, O-16, Navajo J-15, R-19).
Figure 11. Quartz Sandstone Facies & Restricted Lagoonal Facies. A) O-16 5466.1° Sandstone comprised of well sorted, very fine, angular quartz sand grains with an admixture of peloids. Note stained calcite cement in lower left. B) Q-16 5447.2° Grainstone comprised chiefly of irregular foraminifera. Inter- and intraparticle pores filled with equant sparry calcite cement. C) Q-16 5531.2° Peloidal wackestone with limited faunal diversity representing deposition a bank top lagoon. DJ-J 5531.2° Peloidal wackestone with limited faunal diversity. D) E-313 5879.6° Peloidal wackestone to mud-dominated packstone. F) E-313 5898.7° Mottled restricted lagoon peloidal mudstone. Scale bar = 0.5 mm.
**Interpretation.**- The quartz grains suggest an eolian source, which are deposited at all times. However, the high percentage of quartz grains in this facies implies that there is very little to no carbonate pollution of the sand. Therefore, this facies is interpreted as a lowstand accumulation of air-fall grains that accumulated atop the exposure surface and that reworked during early transgression of the subsequent sea-level cycle. Since this facies is associated with the lowstand system tract, we use the base of this bed as the 4th order sequence boundary between the Lower and Upper Desert Creek sequences. As specific evidence to support this boundary, in the Q-16 core, the QSF was deposited directly on top of a rhizolith-bearing exposure surface.
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<th>Grain Type</th>
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**Table 1: Summary of Lower Desert Creek Facies**
SEQUENCE STRATIGRAPHY

Background

The sequence stratigraphic framework for Atokan through Virgilian (upper Bashkirian through Kasimovian) strata in the Paradox Basin was developed by Goldhammer et al. (1991), Weber et al. (1995), and Gianniny and Simo (1996). These stratigraphers effectively illustrate how 5th order parasequences stack to form 4th order sequences, and that 4th order sequences stack to form 3rd order composite sequences. These reflect a complex combination of eustatic sea-level fluctuations, subsidence, sediment accumulation rates, and climate that determine carbonate depositional geometries and facies stacking patterns. However, eustatic sea-level fluctuation, sediment accumulation rates, and subsidence are the most important variables.

Crevello et al. (1989) suggest that in shallow-shelf settings, long-term subsidence rates are constant at a range of 1-25 cm per 1,000 years (Schlager, 1981). Carbonate sediment accumulation rates are also relatively constant at 0.1-1m per 1,000 years (Schlager, 1981). This leaves eustatic sea-level fluctuations as the main player in controlling the facies stacking patterns. Fluctuations in sea level occur at different frequencies. Utilizing Vail et al. (1977) there are different orders of eustasy and each have characteristic amplitudes. Superimposing these complex eustatic orders can give a succession of sea-level oscillations. The hierarchy of stratigraphic forcing is as follows; (3rd Order) 1-10 m.y year duration, (4th Order) 100,000- 1m.y. duration, (5th Order) 10,000-100,000 year duration. These different packages are of integral importance in determining stratigraphic packaging at sequence and cycle scale.

Through the Greater Aneth Field, the Lower Desert Creek interval consists of six to seven shallowing-upward 5th order parasequences (Fig. 12). Parasequences are defined by marine flooding surfaces, and sequences are defined (bounded) by unconformities. Such surfaces
represent chronostratigraphic horizons and are characterized by significant facies offsets. The architecture of the resulting packages of strata allow for analysis and further understanding of the vertical stacking pattern, but also the lateral heterogeneity of the facies. Within the Lower Desert Creek, parasequence boundaries are represented by marine flooding surfaces, where a relatively deeper facies abruptly overlies a shallower facies typically IF-H or IF-P, overlying AF or NSCF (Fig.12). Within the 5th order shallowing-upward cycles in the Lower Desert Creek, signs of subaerial exposure were noted at the top of parasequences LDC 6 and LDC 7 of wells R-19, Q-16, O-16, and J-15. The development of caliche and hardgrounds also can be a boundary for a parasequence foretelling a marine flooding surface.

The systems tracts for the Lower Desert Creek interval are as follows:

**Lowstand Systems Tract**

Although absent in the cores, the base of the Lower Desert Creek sequence of the Paradox Formation is characterized by a thin (approximately 1m) lowstand sandstone Goldhammer et al. (1991). On top of the 4th order sequence boundary between the Lower and Upper Desert Creek intervals, there is evidence of subaerial exposure. Calcretes and rhizoliths mark the exposure surface that underlies the basal upper Desert Creek lowstand sand in wells Q-16, J-15, and K-430. This lowstand sand was transported onto the shelf by eolian processes as indicated by the well-sorted and sub-angular nature of the quartz grains, and was subsequently reworked during initial transgression.

**Transgressive Systems Tract**

The transgressive systems tract of the lower Desert Creek sequence is a thin, deepening-upward package of strata that includes two meters of oolitic to skeletal limestone and the basal few meters of the Chimney Rock Shale. This interval was not cored in the Aneth wells used in
this study but has been documented on outcrop and in the subsurface by Goldhammer et al. (1991) and Weber et al. (1995).

**Highstand Systems Tract**

This systems tract comprises most of the Lower Desert Creek 4th order sequence studied in core and is divided into seven 5th order parasequences that are described below.

**Highstand Parasequences**

*Introduction.* The base of the Chimney Rock Shale was selected as a regional datum on which to correlate wells (Fig. 12). The nature and lateral variation of constituent parasequences are described below.

**LDC 1.** This parasequence includes the Chimney Rock Shale (above the maximum-flooding surface) and 15-20 feet (5-6 meters) of overlying carbonate strata. It exhibits many specific characteristics that are pervasive and consistent within the transect. The carbonate component of the parasequence ranges from 15-25 feet (Fig. 12) and is comprised of intermediate heterozoan and algal wackestone facies. In Core R-19, the post-Chimney Rock portion of LDC-1 (15 ft) is comprised of intermediate heterozoan facies overlain by phylloid wackestone and phylloid bafflestone facies. This stacking pattern is typical in the Greater Aneth buildup, although the phylloid wackestone facies is not always present. The core with the most significant difference in vertical stacking pattern is core O-16 where there is no intermediate heterozoan facies separating the Chimney Rock Shale from the overlying incipient mound facies. Rocks within this parasequence have been partially dolomitized, and in some instances the micrite is significantly neomorphosed. The top of this parasequence is noticeable on logs, especially the neutron log where it shows up as a major porosity increase. This porosity increase is interpreted to be due to the dolomitization of the superjacent facies, resulting in enhanced intercrystal porosity.
**LDC 2-4.** The middle parasequences within the Lower Desert Creek are comprised of intermediate heterozoan facies, each of the three algal subfacies, intermediate photozoan facies, and restricted lagoonal facies. These parasequences display a southeast-to-northwest transition from phylloid-dominated facies in wells R-19, Q-16, O-16, and J-15 to intermediate-heterozoan facies in K-430 and E-313. These parasequences comprise 54 feet (18 m) with the average parasequence thickness of 19 feet (6.3 m).

In core R-19, LDC 2 is composed of a thick, intermediate heterozoan bed, followed by a one foot-thick phylloid wackestone interval that grades into a phylloid bafflestone. The flooding surface between LDC 2 and 3 is denoted by the juxtaposition of phylloid wackestone (deeper facies) on top of a phylloid bafflestone. LDC 3 is made up of 10 feet (3 m) of phylloid packstone facies. The flooding surface between LDC 3 and 4 placed at the stratigraphic level where phylloid wackestone abruptly replaces phylloid bafflestone.

This interval within the Q-16 core is completely missing, and is thus interpreted from gamma ray logs, neutron logs, and porosity and permeability data. Flooding surfaces were picked using low porosity points within the permeability data that corresponded with gamma ray shale kicks.

LDC 2 in O-16 has a one foot-thick (30 cm) intermediate heterozoan interval followed by a 10 foot-thick (3 m) phylloid bafflestone. The flooding surface between LDC 2 and 3 is marked by intermediate heterozoan facies on top of a phylloid bafflestone. LDC 3 continues by grading from an phylloid wackestone facies to a phylloid bafflestone and has a total thickness of 15 feet
Figure 12. Cross section of Greater Aneth Field, created using core transect. Vertical stacking patterns and lateral heterogeneity shown through the transect. Systems tracts are illustrated, and parasequence boundaries are traced laterally through the transect. Datum is Chimney Rock Shale.
(5 m). The parasequence boundary between 3 and 4 is marked by a flooding surface which superimposes a phylloid wackestone facies on top of a phylloid bafflestone. LDC 4 is made up of 20 feet (6.4 m) of phylloid bafflestone.

Off the mound in K-430, LDC 2 is 17 feet (5.6 m) thick and consists of a carbonate mudstone grading upward into phylloid bafflestone. The flooding surface at the top, is marked by an increase in micritic mud placing an intermediate photozoan facies on top of a phylloid bafflestone. LDC 3 grades from the intermediate photozoan facies into a 20 foot-thick (6.6 m) phylloid bafflestone facies. The flooding surface between LDC 3 and 4 is picked using gamma ray and permeability data. All through this zone there is significant intervals of core missing.

The last core in the transect E-313 has a noticeable lack of algal facies. LDC 2 consists of 10 feet (3.3 m) of IF-H at the base that grades into an IF-P. The flooding surface that marks the boundary between LDC 2 and 3 is placed at the abrupt transition from IF-P to IF-H limestone. The parasequence is relatively thin and places a 2 foot-thick (0.66 m) algal bafflestone on top of the intermediate heterozoan facies. The flooding surface that marks the beginning of the LDC 4 is placed where intermediate heterozoan facies abruptly overlie algal bafflestone. LDC 4 grades from an intermediate heterozoan facies to an intermediate photozoan facies, but also contains a significant amount of restricted lagoonal facies. The top of LDC 4 is marked by a caliche-bearing exposure surface.

The overall trends in LDC 2-4 in the Lower Desert Creek show that there is significant algal reservoir in the main buildup, but stepping off the buildup in either a northerly or southerly direction, there is a significant drop in the amount of algal reservoir facies. Off-mound strata
consist mostly of intermediate heterozoan, intermediate photozoan, and restricted lagoonal facies.

**LDC 5-7.** The parasequences that make up the upper succession of the Lower Desert Creek are comprised of mostly shallow-water facies such as intermediate photozoan facies, non-skeletal capping facies, skeletal capping facies, phylloid bafflestone facies, and restricted lagoonal facies. However, there are a few occurrences of intermediate heterozoan facies.

In well R-19, LDC 5 starts with a thin intermediate heterozoan bed that grades upward into a phylloid bafflestone. This parasequence is 16 feet (5.1 m) thick. The flooding surface shows an increase in mud, placing an intermediate photozoan facies on top of a phylloid bafflestone. This facies grades from an intermediate photozoan facies to a shallow phylloid facies to a restricted lagoonal facies. At the top of this facies there are signs of prolonged subaerial exposure. Namely, there are rhizoliths and circumgranular cements marking the sequence boundary.

Well Q-16 displays a parasequence stacking pattern similar to that occurring in core R-19. The base of LDC 6 is a phylloid wackestone facies that grades into a thick (18 ft, 6 m) succession of intermediate photozoan facies. An increase in peloids and microbial muds illustrates that the facies is grading into a lagoonal facies. The top of the Lower Desert Creek sequence in core Q-16 is marked by a lagoonal facies with rhizoliths.

In well O-16, LDC 5 contains a phylloid wackestone facies that grades to a phylloid packstone. The flooding surface that marks the boundary between LDC 5 and 6 is represented by an increase in micritic mud. LDC 6 grades from intermediate photozoan to a skeletal capping facies that is comprised of echinoderms. LDC 7 in well O-16 grades from intermediate
photozoan to a non-skeletal capping facies. These parasequences are 66 feet (22 m) thick and the average thickness per parasequence is 22 feet (3.1 m).

Compared to the other wells, the parasequence stacking patterns in well E-313 is considerably muddier with a limited representation of skeletal/algal carbonate facies. LDC 5 in E-313 is comprised of entirely restricted lagoonal facies. The facies consist of peloids, *Staffella*, burrows, and a minor occurrences of crinoid columnals. The capping facies of LDC 5 is a non-skeletal capping facies that consists of peloids and ooids. The flooding surface that marks the boundary between LDC 5 and 6 is a five foot-thick interval of intermediate photozoan facies. The restricted lagoonal facies then reappears and marks the top of the Lower Desert Creek sequence.

Individual core analysis through transect R-19, Q-16, O-16, J-15, K-430, E-313 (Fig. 13 - 18). The major trends that are found in the LDC 5-7 are similar to those of the lower parasequences where stepping off the buildup increases the amount of mud in the facies. It is easy to point to glacial eustatic sea-level change as the reason for the large-scale heterogeneity. However, the lateral and vertical heterogeneity on a 5th order scale may be influenced heavily by other factors. Grammer et al. (2000) point out that the lateral heterogeneity in 5th and 6th order cycles could be facies-controlled. Differential sediment accumulation and production rates between algal mound facies, shoals, and subtidal platform carbonates may result in significant lateral variability in thickness within a single cycle. Another possible reason for the lateral heterogeneity on such a fine scale could be prevailing wind direction where headwinds could be coming from the south which would help explain the low energy facies to the north. However, this seems unlikely as the Paradox Basin would have been approximately 15 degrees north during this time (Elias, 1963; Peterson and Hite, 1969; Heckel, 1977, 1980; Scotese et al., 1979;
Parrish, 1982) which would suggest the trade winds would be from the northeast. Another possible explanation comes from the southeast opening to open ocean. Wave energy from the southeast was expended on the southeastern portion of the Aneth buildup, and bring in sufficient nutrients for the phylloid facies. The wave energy could be expelled on these facies, explaining why the northwestern portion of the Aneth buildup contains more restricted lagoonal facies.
Figure 1.3. Detailed core description of Core R-19 including petrophysical gamma ray and neutron porosity logs, porosity and permeability data, rock fabrics, rock textures, depositional environment, constituents, facies type, and sequence stratigraphy.
Figure 14. Detailed core description of Core Q-16 including petrophysical gamma ray and neutron porosity logs, porosity and permeability data, rock fabrics, rock textures, depositional environment, constituents, facies type, and sequence stratigraphy.
Figure 15. Detailed core description of Core O-16 including petrophysical gamma-ray and neutron porosity logs, porosity and permeability data, rock fabrics, rock textures, depositional environment, constituents, facies type, and sequence stratigraphy.
Figure 16: Detailed core description of Core J-15 including petrophysical gamma ray and neutron porosity logs, porosity and permeability data, rock fabrics, rock textures, depositional environment, constituents, facies type, and sequence stratigraphy.
Figure 17. Detailed core description of Core K-430 including petrophysical gamma ray and neutron porosity logs, porosity and permeability data, rock fabrics, rock textures, depositional environment, constituents, facies type, and sequence stratigraphy.
Figure 18. Detailed core description of Core E-313 including geophysical gamma and neutron porosity logs, porosity and permeability data, rock fabrics, rock textures, depositional environment, constituents, facies type, and sequence stratigraphy.
Charts derived from thin section analysis show fossil abundance patterns within facies (Fig. 19-24). The fossil abundance charts were used to differentiate intermediate heterozoan and intermediate photozoan facies. The fossil assemblage is a good indication for paleoenvironment. In core O-16, J-15, Q-16, K-430, R-19 there is a significant trend that illustrates a shallowing upward trend through the sequence. At deeper depths the fossil assemblage has a low diversity of heterozoan fossils such as articulate brachiopods, echinoderms, bryzoans, ostracods, and bivalves. This trend continues through the first parasequence, but the intermediate photozoan and algal facies introduce a robust fossil assemblage. The overall shallowing of the sequence allows for the robust fossil assemblage to persist through most of the Lower Desert Creek interval. However, in core E-313 there is a significant drop in fossil abundance. This is most likely due to the environment being restricted lagoonal. Toward the top of the sequence and on the sequence boundary the fossil assemblage disappears and gives way to the quartz sandstone facies. This is especially evident in J-15 where a robust fossil assemblage disappears in just 4 feet. The fossil assemblage, and lack thereof give great evidence for placing the sequence boundary and exposure surface here. The paleontology and paleoecology helps define facies, but was also broadly used to help identify the shallowing upward trend on both the 5th and 4th order scale.
### Fossil Abundance Core R-19

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**Legend:**
- Absent (0)
- Rare (1-10)
- Common (10-50)
- Abundant (50+)

**Figure 19:** Fossil abundance chart core R-19 including non-skeletal grains, heterozoan fossil assemblage, and photozoan fossil assemblage through Desert Creek Sequence.
Figure 20: Fossil abundance chart core Q-16 including non-skeletal grains, heterozoan fossil assemblage, and photozoan fossil assemblage through Desert Creek Sequence.
### Fossil Abundance Core O-16

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Figure 21. Fossil abundance chart core O-16 including non-skeletal grains, heterozoan fossil assemblage, and photozoan fossil assemblage through Desert Creek Sequence.
Figure 22. Fossil abundance chart core J-15 including non-skeletal grains, heterozoan fossil assemblage, and photozoan fossil assemblage through Desert Creek Sequence.
Figure 23. Fossil abundance chart core K-430 including non-skeletal grains, heterozone fossil assemblages, and photozoan fossil assemblage through Desert Creek Sequence.
Figure 24. Fossil abundance chart core E-313 including non-skeletal grains, heterozoan fossil assemblage, and photozoan fossil assemblage through Desert Creek Sequence.
DIAGENESIS

Heckel (1983) developed a paragenetic model for high-frequency Pennsylvanian icehouse cycles in the American midcontinent that characterized the effects of marine and meteoric fluids (both vadose and phreatic) through a typical sea-level cycle that can be meaningfully applied to the Lower Desert Creek sequence of the Aneth buildup (Fig. 25). Roylance (1990), Gournay (1999), and Longman (1980) also addressed the diagenesis of Pennsylvanian carbonate facies. The five main diagenetic environments that have altered the mineralogy and pore distribution of Lower Desert Creek strata are (roughly in order of influence) the marine phreatic, marine vadose, meteoric phreatic, meteoric vadose, and burial environments. These environments and their effects on rocks of the Lower Desert Creek sequence are discussed in the following paragraphs (Table 2).
Marine-Phreatic Environment

The marine-phreatic environment is defined as the zone where pore space is saturated with normal-marine water. This zone, located at or below the sediment-water interface is where most carbonate sediment is produced and deposited. Seafloor sediment is subjected to a range of biostratinomic (boring, micritization, breakage, disarticulation) and chemical (cementation) processes. This environment can be subdivided into two categories; the “active” and “stagnant” zones.

Active Zone.- In the “active” zone, waves, tides, and currents force sea water through the sediment. The environment is favorable for CO2 loss from degassing, and photosynthesis. These conditions oversaturate the water with respect to CaCO3 facilitating precipitation of carbonate cement. This most commonly occurs in course-grained sediment and on topographic highs (Heckel, 1983). The cements that precipitate in this environment are aragonite or high Mg calcite depending upon the age of the precipitate (ie. aragonite versus calcite seas, Sandberg, 1983). The forms of cement range from micrite to isopachous rims that possess steep-sided rhombic crystals. Botryoidal cements may be common in this environment. These cements form rapidly and with only shallow burial, little to no compaction of grains takes place. This is also the zone where skeletal remains are disarticulated, abraded, and broken. Shells most susceptible to breakage are reduced to microbioclasts in this setting. In the Lower Desert Creek Sequence the marine phreatic “active” zone is made manifest by isopachus fibrous cements (Fig. 26, A, D, E, F).

Although described as a common diagenetic component of other phylloid mounds (Roylance, 1990 and Gournay, 1999 ), few if any distinct botryoidal cements are present in algal facies of the Lower Desert Creek sequence in the rocks studied for this thesis. However, there appear to be ghost botryoids (Fig. 27, D) with a subcircular outline but lacking the fibrous
Figure 26. Marine Diagenesis

A) J-15 5541’ preserved fibrous marine cement lining a fusulinid. Original cement was probably fibrous aragonite, now neomorphosed to bladed calcite. 

B) J-15 5628’ Early marine micritization allowed these phylloids to be preserved, the micritic envelop is also encrusted by irregular foraminifera.

C) O-16 5786’ Early marine micritization and encrusting foraminifera

D) O-16 5789.8’ Fibrous marine cement lining a fusulinid.

E&F) Q-16 5458’ Isopachus early marine cement. Cement has since been neomorphosed. Scale bar = 0.5 mm
cement fans. If these patches are in fact botryoids, subsequent leaching, dissolution, and precipitation of calcite cements has obscured many of characteristic fabric elements.

**Stagnant Zone**.-The stagnant zone occurs where water is impounded or moves only slowly through the sediment such that cements are not precipitated between grains. The stagnant zone is common in fine-grained sediment where compaction expels water and reduces porosity and permeability. In low-energy settings where grains may be stabilized by algal filaments and incipient compaction, the surfaces of skeletal and coated grains may become infested with endolithic algae (micritization) or encrusted by a variety of benthonic organisms. Precipitation of minor amounts of marine cement, selective micritization of coated and skeletal grains, and encrustation of algal grains represent marine diagenetic alterations of depositional fabrics. Skeletal grains including the thalli of *Ivanovia* have undergone micritization. Stagnant marine phreatic diagenesis is integral in the fabric of the Lower Desert Creek Sequence. Micritization defines the outlines of many of the fossil constituents such as *Ivanovia*, and acts as structural support during burial. (Fig. 26, B, C).

**Marine Vadose Environment**

The marine vadose environment is a narrow zone along the shoreline where pores are only partially filled by tide and wave-driven sea water. In this zone interparticle cement precipitates rapidly due to CO\(_2\) degassing. The cements found in the marine vadose environment are micritic to fibrous aragonite and high-Mg calcite. Within the partially filled pores, meniscus and pendant cements predominate. However, isopachous rims may also form. There is no specific evidence of a marine vadose environment in the Lower Desert Creek sequence. Pendant and meniscus cements are absent in thin section. However, the most likely position in which to
find this environment and vadose marine cements would be in the shallowest parasequences toward the top of LDC 5-7 where shoaling conditions may have hosted short-lived marine vadose conditions.

**Meteoric Vadose Environment**

Exposure of metastable carbonate sediment to meteoric waters results in transformation of aragonite and high-magnesium calcite to low-magnesium calcite through calcitization or dissolution of metastable grains to create new porosity and permeability (Allan and Matthews, 1982; James and Choquette, 1984; Moore and Wade, 2013). Dissolution of aragonite drives mineral-controlled precipitation of calcite cement in nearby pore spaces (James and Choquette, 1984).

The meteoric vadose environment is developed when carbonate sediment is exposed terrestrially due to shoaling or relative sea level fall (Fig. 27). In this environment pore space is filled with air and pockets of fresh water. There is a zone of solution at or just below the land surface. In this environment, under-saturated rainwater moves downward through sediment. The diagenetic process that is most common in this zone is the dissolution of aragonite and high-Mg calcite. In an arid environment, such as that represented during Lower Desert Creek time, rates of percolating meteoric water would have been intermittent and slow, resulting in selective surgical removal of skeletal or oocortical layers (Fig. 10, A). Hazrd et al. (2017) coined the term laminamoldic porosity to describe the result of this process. Laminamolds have also been reported from coeval strata across the Caribbean and South Florida (Friedman, 1964; Robinson, 1967; Budd, 1988; and Boardman and Carney, 1997) and from Jurassic ooids in Saudi Arabia (Cantrell, 2006).
The “zone of precipitation” can occur anywhere in the meteoric vadose zone. The meteoric water eventually becomes saturated with respect to CaCO$_3$ and starts to precipitate cement. In this environment, the cements are low-Mg calcite and are focused on grain contacts.
where meniscus and pendant fabrics can develop. The cements usually lack crystal terminations because growth occurs only at the water-air interface. The cements range in texture from micrite to caliches.

**Meteoric Phreatic Environment**

The meteoric phreatic environment is below the water table, where all pore space is filled with fresh water (Fig. 25). The fresh water in the meteoric phreatic environment contains different amounts of CaCO₃. The meteoric phreatic environment is subdivided into an “undersaturated” and an “active-saturated” zone (Heckel, 1983). The undersaturated zone is where water is largely under-saturated with respect to CaCO₃ resulting in dissolution of aragonite and high Mg calcite that forms vugular and moldic porosity. The active-saturated zone beneath the water table, is where the pore water becomes saturated with respect to CaCO₃. In this zone, large amounts of low Mg calcite cement are precipitated as cement. The cement often precipitates in primary pores, but also fills secondary porosity given a change in the water table. The low-Mg calcite cement ranges from drusy dogtooth rims to blocky mosaics. There is also a “stagnant-saturated” zone where there is little water movement resulting in little cementation. Neomorphism is common in this environment.

**Meteoric Diagenesis of Lower Desert Creek strata.** In the Lower Desert Creek sequence, the most common diagenetic feature is the pore-reducing or pore-filling equant sparry calcite. Such cement is found in a wide range of pores including interparticle, intraparticle, moldic, and vuggy pores (Fig. 27). This precipitation results in significant drusy dog tooth and blocky sparry calcite cements. The isopachus rim formed during early marine diagenesis is generally neomorphosed and can be hard to identify, but usually appears as a darker blanket or halo surrounding the frond (Fig 27, A). Reservoir quality porosity and permeability occurs where
interparticle and moldic pores have not been completely filled with meteoric cement.

Neomorphism is present in the majority of the micritic mud.

**Burial Diagenesis**

Mechanical compaction is evident in some of the facies (Fig. 16). The evidence of compaction in thin section comes mostly from the brecciation of phylloid fronds in the algal facies, and styolites, dissolution seam, and grain-to-grain suturing in packstone to grainstone facies. Stylolites are present in the core, and have an insoluble lining that creates a dark band. There is very little evidence of significant compaction in the majority of the algal facies, this could be a product of early marine and meteoric cementation filling in porosity and acting as a structural support. Mold filling anhydrite crystal growth may represent early burial diagenesis. Boroque or saddle dolomite are the most recognized form of burial cement in the Lower Desert Creek Sequence. These are easily recognized by curved crystal lattices and a cloudy crystal appearance. Boroque dolomites reflect burial diagenesis due to their formation in elevated temperatures.
Figure 28. Burial Diagenesis
A) J-13 3333.3′ Chemical dissolution is marked by concentration of insoluble material along the irregular surface.
B) O-16 5812′ Grain-to-grain suturing between echinoderms.
C) O-16 5866′ Baroque or saddle dolomite with curved crystal faces and cloudy appearance, baroque dolomite indicate elevated temperatures.
D) O-16 5866′ Baroque dolomite in crossed polarized light, sweeping extinction.
E) O-16 5901′ Baroque dolomite (unstained crystal with curved faces) most likely resulting from thermochemical sulfate reduction.
F) O-16 5812′ Echinoderms in cross-polarized light, syntactical overgrowth evident.

scale bar = 0.5 mm
Porosity and permeability data were obtained from Resolute Energy Corporation. The data were derived from core plug analysis. The facies of the sampled intervals were extrapolated from detailed stratigraphic columns by correlating the depth of the sample with the facies that characterized that particular depth. Porosity and permeability cross plots were produced for each well (Fig. 29-33).
Figure 29. Porosity and permeability data from core R-19.
Figure 30. Porosity and permeability data from core Q-16.
Figure 31. Porosity and permeability data from core O-16.
Figure 32. Porosity and permeability data from core K-430.
Figure 33. Porosity and permeability data from core E-313.
The most abundant porosity types are interparticle, intraparticle, moldic, vuggy, and shelter pores (Fig. 34). The highest porosity values (20-25%) generally occur in the non-skeletal capping facies. Highest values of permeability (> 100 md) occur in algal wackestones.

**Well R-19.**- NSCF within this well cluster around 20% porosity with 1 md permeability. This non-skeletal capping facies is a soil horizon similar to that which is found in (Fig 27, E). There is also clustering of the algal wackestone and algal packstones around (1-3%) porosity and (0.015-.018 md). The algal facies that form this cluster are from a range of well depths, and are comprised mostly of algal wackestones that have significant cement-reduced or cement-filled shelter, interparticle, and intraparticle porosity.

**Well O-16.**- The SCF in this well has significant clustering along and 1% porosity and (.0001 md). The SCF is known to be a reservoir facies, but in this instance has very poor reservoir characteristics. This particular facies (Fig. 28, A, B) is a skeletal cap facies that has been significantly altered by meteoric and burial diagenesis. Non-skeletal cap facies clusters around 9% porosity and 10 md permeability. This facies is similar to those found in the well R-19 non-skeletal cap facies and is illustrated in (Fig. 27, E) which shows a soil horizon.

**Well E-313.**- The porosity of all facies varies from (.01-18%), but the permeability rarely is over (.01 md). The most significant differences in porosity and permeability through the transect are shown in the well E-313. Through core and thin section there is a significant increase in carbonate mud due to stepping off the algal buildup. The increase in mud has significant impact on the porosity permeability of the overall well.

The overall trend in porosity/permeability is observed to change along the transect. From SE to NW the facies become muddier, and this is evident in the significant decrease in permeability.
Many of the facies have similar porosity and permeability values, a wide range of values which overlap one another. It is reasonable to conclude that while facies type factors into porosity and permeability, especially in the muddy facies, it is not the main factor that determines porosity and permeability values. It is reasonable to conclude that the meteoric and burial diagenesis overprint is the main factor in porosity and permeability.

Reservoir Considerations

The diagenesis that occurs in the grain-dominated reservoir facies dictates whether the facies will be a quality reservoir. The changes in porosity and permeability both laterally and vertically through a facies control reservoir quality on a micro-and macro-scale. Understanding the processes and timing of the diagenesis within these algal reservoir facies as a consequence of sea-level-change and development of systems tracts could play a role in better primary, secondary, and tertiary oil recovery methods. Within the GAF zones 1 and 2 (LDC 1-4) of the algal buildup (R-19, O-16, Q-16, J-15, and K-430) would yield more oil production based on facies and diagenetic trends. Zone 1 makes a reservoir due to the dolomitization of the parasequence. Zone 2 (LDC 2-4) should be a target for completions due to the abundant algal bafflestone facies, and relative lack (compared to zone 3) of cement-reduced to cement-filled interparticle, moldic, and shelter porosity.

CONCLUSIONS

Study and correlation of cores R-19, O-16, Q-16, J-15, K-430, and E-313 has allowed for analysis of sedimentology, stratigraphy, sequence architecture, biofacies, and reservoir character of the Lower Desert Creek interval of the Paradox Formation within the Greater Aneth buildup. There are eight different facies types within the Lower Desert Creek. Each facies represents a different depositional environment. The Lower Desert Creek can be divided into seven 5th order
cycles “parasequences” that stack into a 4th order cycle that is marked by exposure surfaces at the base and top. The parasequences can be subdivided into 3 main zones. LDC 1 is a highly dolomitized, relatively deep-water intermediate heterozoan facies capped by an algal facies. LDC 2-4 are the main reservoir facies and range from intermediate heterozoan to intermediate photozoan facies, with the majority of these parasequences being comprised of algal facies. LDC 5-7 are shallower cycles with the majority being algal, restricted lagoon, skeletal capping facies, and non-skeletal capping facies. The parasequences show a shallowing up vertical stacking pattern. Lateral heterogeneity of the 4th order Lower Desert Creek Sequence can be explained by lateral shift of facies belts driven by glacial eustatic sea-level change. Lateral heterogeneity on a 5th order scale is a function of within-platform depositional heterogeneity. The transect from southeast to northwest shows an algal buildup to the southeast, and shallower, more restricted lagoon environment to the northwest.

Faunal distribution is used to differentiate facies, and is used broadly to help recognize shallowing upward trends within the parasequences and overall sequence. Porosity and permeability show that facies play a factor in overall porosity and permeability, but that it is not the most significant factor. Diagenesis is the main factor in porosity and permeability within the algal reservoir. Early marine diagenesis is the cause of the micritic envelopes of the thalli of Ivanovia. Isopachus fibrous cement also indicate early marine diagenesis. The rare early aragonite botryoidal cements are leached, and replaced during meteoric diagenesis. Meteoric diagenesis has the most significant overprint. Drusy dog tooth and sparry calcite are pervasive through the algal reservoir. Burial diagenesis is seen in compaction, development of baroque dolomite, anhydrite crystal growth, and stylolitization.
REFERENCES


Kelley, V.C., 1958, Tectonics of the region of the paradox basin, In. Sanborn, A.F (ed.), Guidebook to the geology of the paradox basin: Intermountain Association of Petroleum Geologists, p. 31-38


