

SEQUENCE STRATIGRAPHIC FRAMEWORK OF THE LATE DEVONIAN
(FRASNIAN) DUPEROW FORMATION IN WESTERN
AND CENTRAL MONTANA

by

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ABSTRACT

The Late Devonian Duperow Formation in western and central Montana and its equivalent lower Jefferson Formation, is comprised of shallow marine carbonate strata deposited on the western margin of North America. It has produced significant volumes of oil and natural gas in the Alberta and Williston basins where the sequence stratigraphic framework of the formation is well-documented. However, in western and central Montana, the Duperow remains largely understudied. Additionally, at Kevin Dome, in northwest Montana, the Duperow hosts a large naturally occurring carbon-dioxide (CO₂) accumulation which is a potential economic resource and an analog for CO₂ sequestration over geologic time scales. The goal of this study is to determine the facies relationships and sequence stratigraphic architecture of the Late Devonian Duperow Formation in western and central Montana. This interpretation could help in exploration for oil and natural gas and provide useful information to aid in future carbon sequestration efforts.

Multiple data sets are used in this study to best constrain depositional environments on the platform during Duperow deposition. Seven measured sections, three drill cores with associated well-logs, and forty-one thin sections are used to characterize facies, facies associations, parasequences, parasequence sets and sequences of the Duperow Formation and to construct the sequence stratigraphic framework within which these strata occur. Ten lithofacies comprising six lithofacies associations allow the interpretation of six depositional environments responsible for deposition of the Duperow Formation. The Duperow thins from the west and north onto the Central Montana Uplift, a paleohigh at the time, and thickens into the Central Montana Trough, a sub-basin on the platform.

Two 2nd order and seven 3rd order sequences are interpreted from measured sections. Sequences are comprised of a transgressive systems tract and a highstand systems tract with no evidence for lowstand strata on the shelf. Transgression across the Central Montana Uplift did not occur until after the basal sequence boundary of the upper 2nd order sequence. Prior to this transgression, sequences lapped out before reaching the Central Montana Uplift. Overall, the Duperow in central and western Montana exhibits retrogradational stacking and thus is part of the transgressive systems tract of a lower-order megasequence.

CHAPTER ONE

INTRODUCTION

Introduction and Objectives

The primary objectives of this study are to determine the facies relationships and sequence stratigraphic architecture of the Late Devonian Duperow Formation in western and central Montana (Figure 1). This is significant because these rocks are understudied compared to surrounding regions. A better knowledge of facies comprising the Duperow Formation and their stratigraphic relationships will aid in oil and gas exploration and development, mineral exploration and exploitation, and will provide insights to questions related to carbon sequestration.

This project utilizes seven measured outcrop sections to interpret and correlate stratigraphic sequences within the Duperow Formation. Outcrop and hand samples provide evidence for facies relationships and stratigraphic geometry while thin sections provide high resolution microfacies descriptions and reveal characteristics that cannot as easily be observed in outcrop due to heavy dolomitization. At Kevin Dome in northwest Montana where CO₂ is trapped within the middle Duperow Formation, drill cores provide data to interpret stratigraphic and reservoir characteristics, and well-logs provide information about both facies relationships, and facies stacking patterns. This project aims to provide a detailed

characterization of facies distribution and stratigraphic relationships of the Duperow Formation in western and central Montana.

The Duperow Formation is comprised of shallow marine carbonates of Late Devonian (Frasnian) age deposited on a westward dipping low-relief platform that occupied the margin of western North America (Baars, 1972; Johnson et al., 1985; Johnson & Sandberg, 1988; Dorobek & Smith, 1989; Haq & Schutter, 2008; Blakey, 2018). In the Alberta Basin to the north, these strata were deposited in a high-accommodation setting in depositional environments including subaerially exposed sabkhas, lagoon, shelf-edge reefs and shoals, and open marine shelves, slopes, and basins (Andrichuk, 1951; Dunn, 1975; Halabura, 1983; Moore, 1989; Wendte et al., 1992; and Wendte, 1992). In the Williston Basin to the east, these Upper Devonian strata were deposited in a lower-accommodation setting with thinner shoaling-upward cycles; the product of similar depositional environments (Baillie, 1955; Sandberg, 1961; Wilson, 1967; Wilson & Pilatzke, 1987; Alcorn, 2014). In western and central Montana, the Duperow Formation was deposited on a more slowly subsiding platform with much lower accommodation than both the Alberta and Williston basins resulting in fewer observed sequences comprising equivalent strata (Sloss, 1996; Witzke et al., 1996; Grader et al., 2014).

Significance

The Duperow Formation reservoirs prolific hydrocarbon resources in the Alberta and Williston basins and may have remaining potential in Montana where

it has been less densely explored (Dyman, 1995; Peterson, 1996; Pilatzke et al., 1987). In Alberta, the Duperow Formation has produced 800 million barrels of oil and 300 billion cubic feet of gas from the 1950's-1990 (Switzer et al., 1994; Oldale & Munday, 1994). In the Williston Basin of western North Dakota, the Duperow Formation along with the overlying Nisku (also called Birdbear) Formation, are together the 3rd most productive formations in the basin and have produced 174 million barrels of oil from 671 wells (Bader, 2018). In southeast Saskatchewan, the Duperow has produced 939,790 thousand barrels of oil from nine wells but has not produced oil in western or central Saskatchewan (Dunn, 1974; Yang, 2011). Throughout Montana, the Duperow Formation has cumulatively produced 5.8 million barrels of oil and 8.3 million cubic feet of gas from 1986 through 2018 (Montana Board of Oil and Gas Conservation). Most of the production in Montana comes from fields within the western Williston Basin.

Kevin Dome, located in Toole County north-central Montana, has been extensively studied as an analog for geological carbon sequestration and downdip regions as potential candidates for future carbon sequestration. It is a large structural dome that covers approximately 700 square miles at the Duperow stratigraphic level, with approximately 750 feet of structural relief. Naturally occurring CO₂ has been documented from numerous wells that have tested the Duperow Formation since oil and natural gas were first discovered there in 1922 (Collier, 1929; Nordquist & Leskela, 1968). CO₂ is trapped in two zones within the Duperow Formation, while oil and gas are trapped in

stratigraphically higher limestone, dolomite, and sandstone reservoirs in the Nisku Formation, Madison Group, Sawtooth Formation, Swift Formation, Cutbank Sandstone, Sunburst Sandstone, and Bow Island Sandstones. The Duperow hosts greater than 3 trillion cubic feet of CO₂ at Kevin Dome (Omosebi et al., 2018; Onishi et al., 2019) that has been trapped for tens of millions of years. This long-term storage indicates the potential of the formation to sequester CO₂ safely and securely elsewhere. The CO₂ at Kevin Dome also has the potential to be used for enhanced oil recovery (Daley et al., 2017).

Because of its proven oil and gas reservoir properties in the Alberta and Williston basins, the Duperow Formation has been extensively studied in these areas. The sequence stratigraphic framework is well documented (Day et al., 1996; Wendte & Uyeno, 2005; Cen, 2006; Cen & Hersi, 2009; Anna et al., 2010; Hopkins et al., 2010; Eggie et al., 2012; Alcorn, 2014; Gilhooly et al., 2014; Coleborne et al., 2015; Playton et al., 2016; Wong et al., 2016; Rogers, 2017; Bader, 2018). However, in western and central Montana, the Duperow Formation remains understudied. Only one prior study has placed the Duperow Formation in Montana into a sequence stratigraphic framework using outcrop data (Grader et al., 2016). One of the goals of this thesis is to build on the prior study to develop a robust sequence stratigraphic framework in western and central Montana that can be leveraged in hydrocarbon and mineral exploration, and carbon sequestration. As previously stated, the Duperow Formation has the potential to store CO₂. It also has several of the key essential elements of

petroleum systems including source, reservoir, and seal making it an attractive exploration target. The Duperow Formation is also known to host gold-tellurium and silver-lead-zinc mineral deposits in the Little Belt Mountains (Schutz et al., 1989), another reason to study this important formation and its associated economic resource potential.

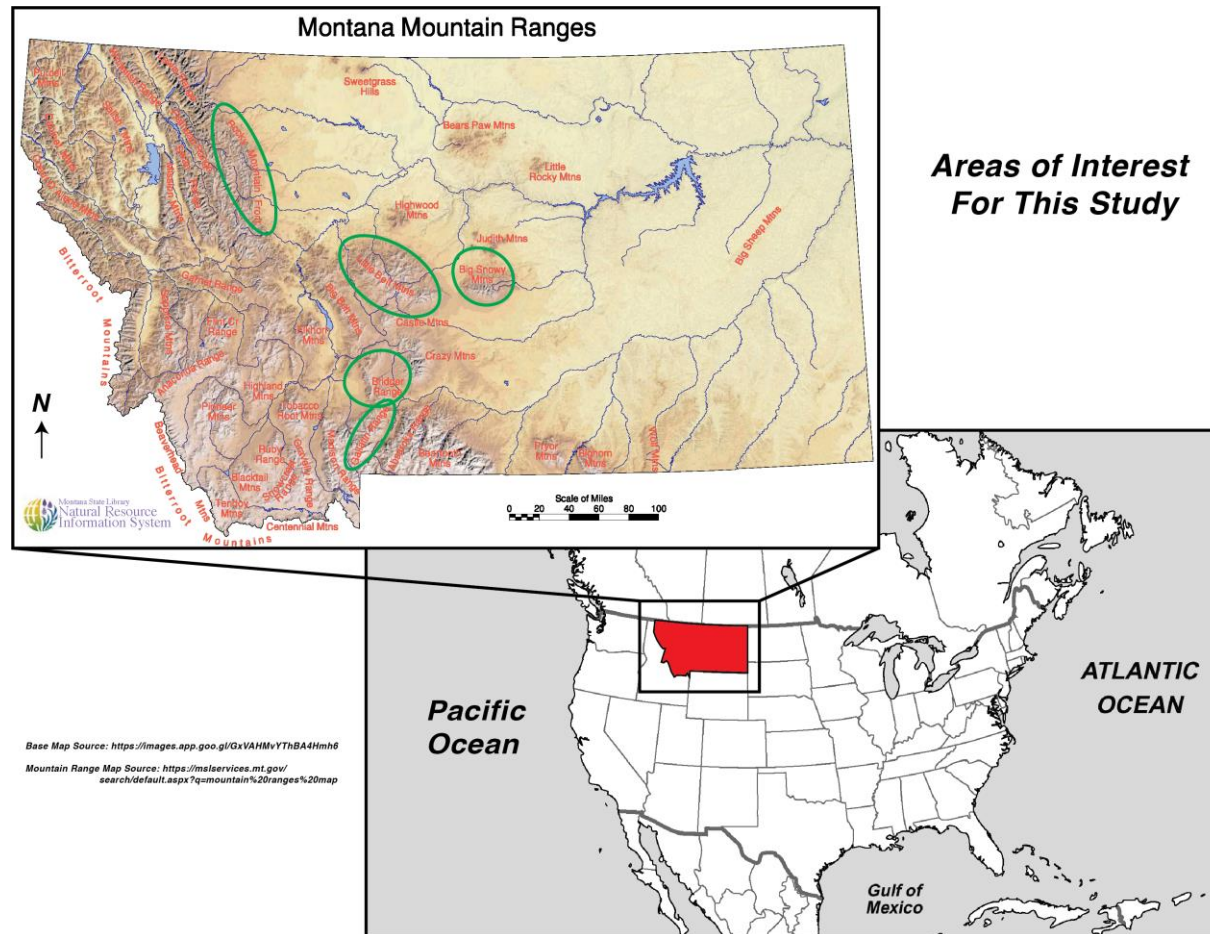


Figure 1. Map showing areas of interest for this study with mountain ranges containing measured sections highlighted in green.

CHAPTER TWO

GEOLOGIC SETTING

Overview

Devonian strata in western North America record the transition from a passive tectonic margin to an active tectonic margin during the Antler Orogeny (Johnson et al., 1985; Cocks & Torsvik, 2011; Yonkee, 2015), the transition from a greenhouse period of Earth's history to an icehouse period of Earth's history (Caputo & Crowell, 1985; Caputo et al., 2008), and one of the major extinction events experienced on the planet (Crowley & North, 1988; Racki, 1998; Sandberg et al., 2002; Flugel, 2010). *Stromatoporoids*, a calcareous sponge-like organism, dominated reef environments during the Devonian and were the main reef builders (Haynes, 1916; Eymann, 1951; Shah, 1966; Flugel & Flugel-Kahler, 1968; House, 1975; Stearn, 1975; Kaimierczak, 1976, 1981; Cockbain, 1984, 1989; Issacson & Dorobek, 1989; Stearn & Pickett, 1994; Stearn et al., 1999; Wood, 2000).

Beginning in Early Devonian time, the ancestors to modern land plants evolved (McGhee, 1996; Dahl et al., 2010), Earth was in a greenhouse period (Joachimski et al., 2009; Wong et al., 2016), and Western North America was a passive margin (Dickinson et al., 1983; Dickinson, 2004). By Late Devonian (end Famennian) time, Earth had fully transitioned into an icehouse period (Streel et al., 2000; Brett et al., 2011), Western North America had experienced multiple

glaciation events recorded in diamictites in South America (Caputo, 1984), carbonate belts had retreated to within 20° latitude of the equator compared to their prior 40° extent (Wendte et al., 1992), and the margin of Western North America had transitioned into an active tectonic regime with the Antler Orogeny beginning in Middle Devonian time (Burchfiel & Davis, 1972). Very late Frasnian to early Famennian glaciation is thought to have resulted in a major lowering of sea level and is considered a possible mechanism for the extinction of marine organisms recorded in death-beds of the Frasnian-Famennian mass extinction worldwide (Johnson, 1974; Caputo, 1984; Copper, 1977, 2002; Pekar, 2009; Elrick & Witzke, 2016; Mitchum, 2019).

During the Frasnian stage, western and central Montana were located on the western margin of the Laurentian continent 10°S of the equator (Wendte et al., 1992) in an arid tropical belt with trade winds blowing from the northeast (Figure, 2). Seas transgressed from the west and north out of the Idaho Foredeep and Alberta Basin onto a platform that occupied most of central Montana (Loucks, 1977). To the east of this platform, the Williston Basin formed an intracratonic basin with its main depositional center in central Saskatchewan. Duperow strata thin southwest and west out of the Williston Basin to a zero edge on the Central Montana Uplift (McCabe, 1954).

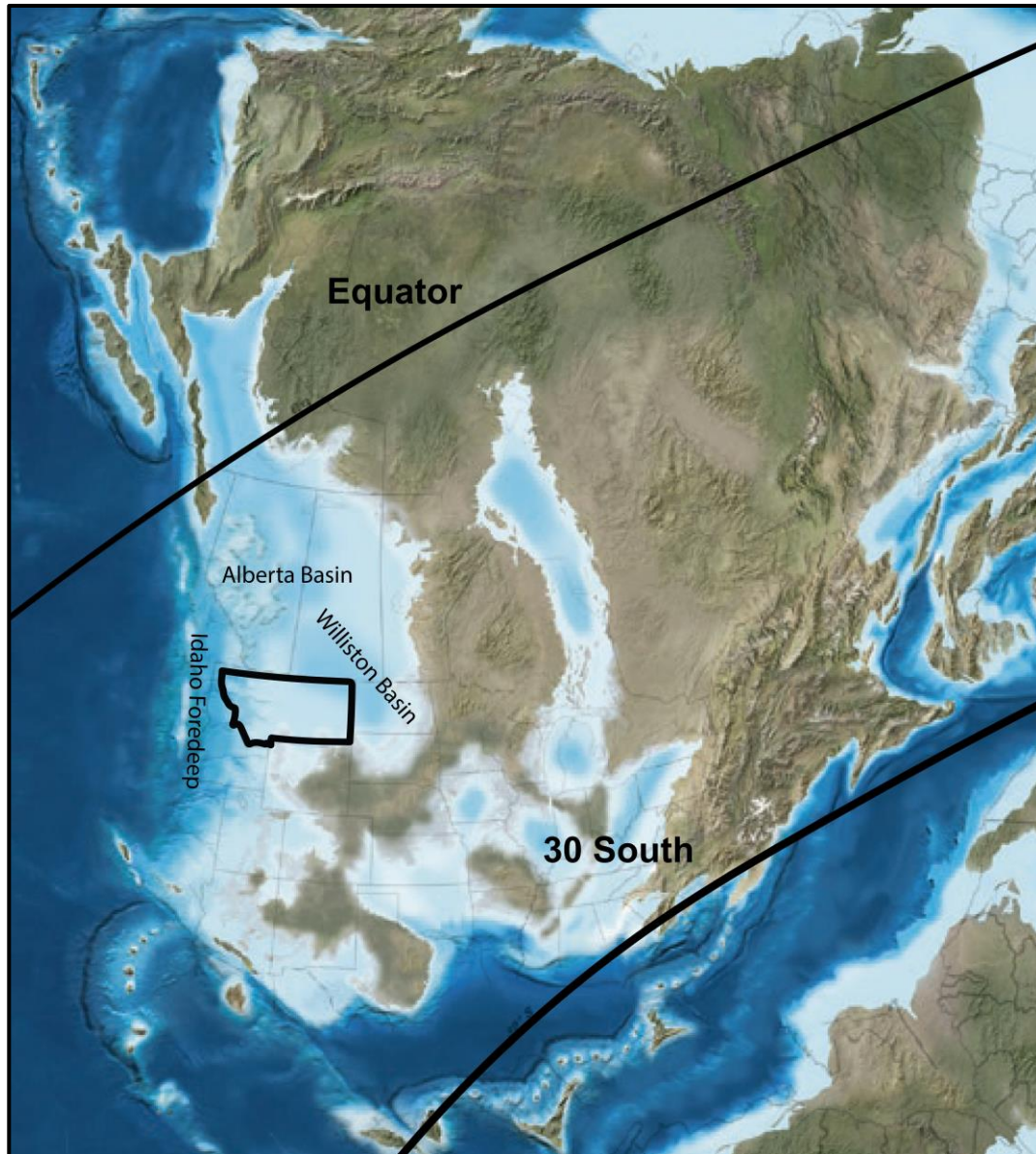


Figure 2. Paleogeographic map of North America during the Late Devonian (Frasnian) showing location of Montana relative to the equator and Williston and Alberta basins. Modified after Blakey, 2018 and Wendte et al., 1992.

From Late Proterozoic to Middle Devonian time, western North America was a passive margin until the Antler Arc collided with the continent's western margin (Figure 3) resulting in the Antler Orogeny (Kent, 1964; Blakey, 2018).

This orogeny is thought to have produced foreland flexures inboard of the continental margin on the platform in Montana and may be responsible for various structural features, such as the Central Montana Trough and Central Montana Uplift, through reactivation of basement faults and zones of weakness (O'Neill & Lopez, 1985; Dorobek et al., 1991; Giles & Dickinson, 1995).

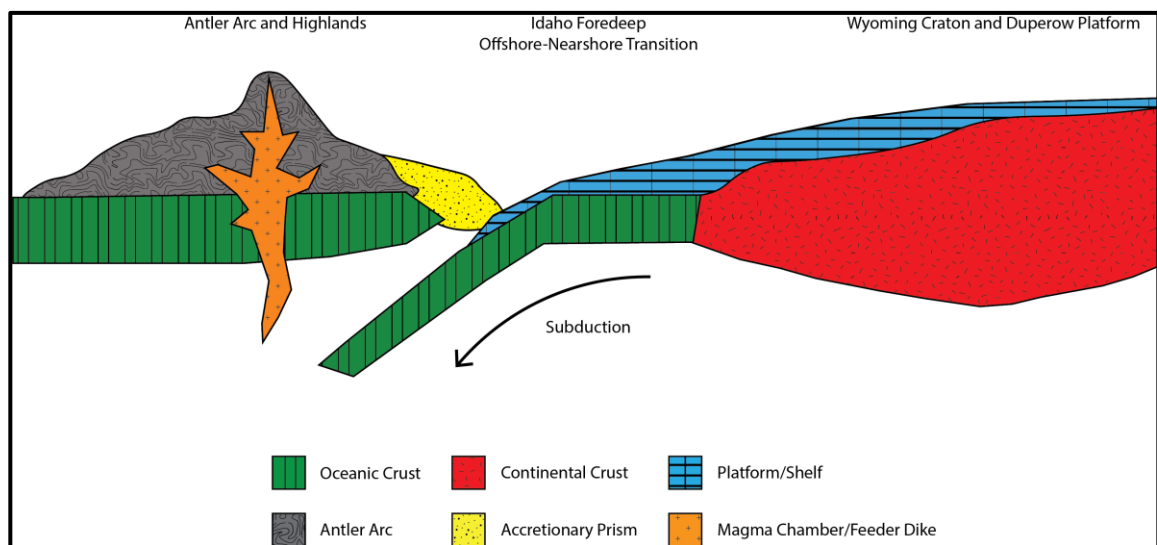


Figure 3. Schematic structural cross-section of the Antler Orogeny showing a west-east line of section through Western North America during the Late Devonian. Not to scale; modified after Burchfiel & Davis, 1972; Dickinson, 1977; Speed & Sleep, 1982; Dickinson et al., 1983; Dickinson, 2004; Isaacson et al., 2007; Ingersoll, 2008; and Blakey, 2013, 2018.

Field Sites

The Duperow is well exposed in the Fold and Thrust Belt of western Montana, across uplifts associated with igneous intrusive bodies, and on the margins of Laramide uplifts in the western Plains. Seven stratigraphic sections were measured for this project during July and August of 2018 (Figure 4).

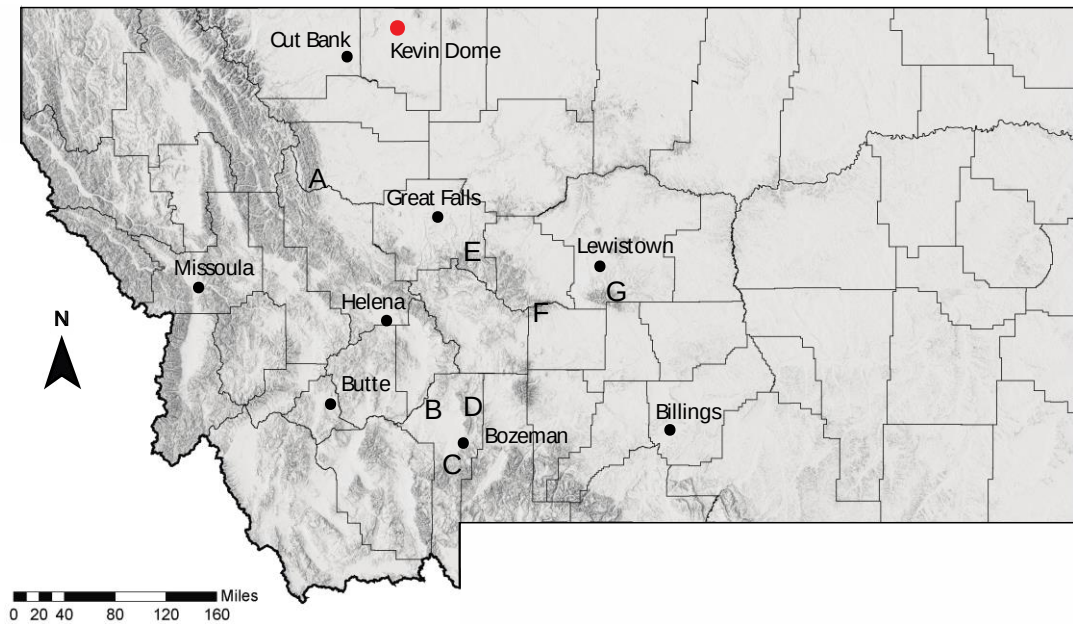


Figure 4. Location map of field sites marked with letters, drill core from Kevin Dome and major cities. A=Gibson Reservoir, B=Logan Gulch, C=Storm Castle Peak, D=Sacagawea Peak, E=Crown Butte, F=Haymaker Narrows Canyon, and G=Greathouse Peak.

Sections were picked based on accessibility, known outcrop-cover ratio from personal communication with advisors (Dr. David W. Bowen and Dr. David Lageson), previous studies, and Google Earth satellite imagery. Gibson Reservoir was selected based on its excellent exposure and paleo-geographic proximity to the shelf-margin break in eastern Idaho. Logan Gulch was selected for its excellent exposure, paleo-geographic location within the Central Montana Trough, and for being the type section of the Jefferson Formation (equivalent to the Duperow and Nisku Formations) in southwest Montana. Crown Butte was selected for its known exposure based on Campbell (1961) and its paleo-geographic location in a landward direction of Logan Gulch and Gibson Reservoir

sections approaching the Central Montana Uplift. Sacagawea Peak was selected for its excellent exposure, accessibility, and its paleo-geographic location on the margin of the Central Montana Trough approaching the Beartooth/Wyoming Shelf. Haymaker Narrows was selected for its accessibility (although not as accessible as initially interpreted from United States Forest Service maps and Google Earth images) and its location in the Little Belt Mountains continuing to paleo-geographically approach the Central Montana Uplift from a basinward direction. Greathouse Peak was selected for its complete exposure of Devonian strata based on a black and white photo of the outcrop from Deiss (1936) and its paleo-geographic location on the Central Montana Uplift.

Stratigraphic Setting

Late Devonian strata (Duperow Formation-Jefferson Formation and Nisku Formation-Birdbear Member) are the most widespread Devonian strata in Montana and the Alberta Basin (Kent & Christopher, 1994). In Alberta, the Duperow Formation is equivalent to the Woodbend or Fairholme Group and is comprised of the Leduc, Camrose, Cooking Lake, Cairn, Peechee, Southesk, Groto, and Grosmont Formations depending on locality (Table 1). The Nisku Formation is included in the groups above, not grouped, or grouped with the Winterburn Group. In Saskatchewan, the Duperow and Nisku Formations are part of the Saskatchewan Group and retain their formational nomenclature (Kent, 1968). In Montana, Duperow strata generally thin from west to east, southwest to northeast, and north to south onto the Central Montana Uplift prior to thickening

again in all directions approaching the Williston Basin (Sloss and Moritz, 1951). Devonian strata in western and central Montana lie unconformably on Cambrian-Ordovician age carbonates. Silurian rocks were either never deposited or completely eroded and are only present in easternmost Montana. Ordovician strata are present in south-central and eastern Montana (Baars, 1972). Devonian strata are comprised of the Beartooth Butte Formation (Early Devonian), Maywood-Souris River Formations (Givetian), Lower Jefferson-Duperow Formations, and Birdbear Member of the Jefferson Formation-Nisku Formation (Frasnian), and Three Forks Formation (Famennian). Any reference given here using the name Jefferson Formation is done so because previous authors did not differentiate between the Duperow Formation and the Nisku Formation/Birdbear Member of the Jefferson Formation. Where described as Lower and Upper Jefferson is in reference to the Duperow Formation and Nisku Formation respectively.

Table 1. Lithostratigraphic nomenclature of Early to Late Devonian and unconformably bounded strata in Montana, Idaho, Wyoming, North Dakota and Alberta. Compiled from Barrs, 1972 *In* Geologic Atlas of the Rocky Mountain Region.

	System	Series	Stage	SE Idaho	Central Idaho	SW Montana	NW Montana	N-Central MT	NE Montana and North Dakota	Southern Plains, Alberta	Central Plains, Alberta
				Lodgepole	Milligen	Lodgepole	Lodgepole	Lodgepole	Lodgepole Fm		
Devonian	Upper	Tournasian				Cottonwood Cyn Mb		Upper Black Shale	Upper Black Shale		
		Famennian		Leatham Fm		Three Forks Sappington	Upper SLTST	Upper SLTST	Medial Siltstone	Banff	Banff
						Basal Black Shale	Basal Black Shale	Lower Black Shale	Lower Black Shale	Exshaw	Exshaw
				Beirdneau Fm	Trident Member	Trident Mb	Trident	Three Forks	Three Forks	Wabamun	Wabamun
						Logan Gulch Mb	Logan Gulch	Logan Gulch		Big Valley	Big Valley
		Frasnian		Hyrum Fm	Birdbear	Birdbear	Birdbear	Birdbear	Birdbear	Crossfield/Stettler	Crossfield/Stettler
					Lower Member	Lower Member	Duperow	Duperow	Duperow	Crowfoot	Gramina
							Potlatch Anhydrite			Nisku	Blue Ridge
										Ireton	Calmar
	Middle	Givetian				Maywood	Souris River	Souris River	Souris River		Nisku/Zeta
		Eifelian			Unnamed Channel Fill Deposits						
Devonian	Lower	Coblenzian		Water Canyon	Beartooth Butte	Beartooth Butte		Beartooth Butte	Beartooth Butte		
	Gedinnian										
Underlying Units				Laketown Dolomite (Silurian)	Laketown Dolomite (Silurian)	Upper Cambrian	Upper Cambrian	Red River (Ordovician)	Interlake (Silurian)	Cambrian	Cambrian

Sloss' Megasequences and The Lower Kaskaskia Sequence. A cratonic sequence, megasequence or often referred to as "Sloss sequence," is a regional unconformity bounded stratigraphic sequence deposited during a second order marine transgressive and regressive cycle across a craton (Sloss, 1963). Each megasequence is bounded by a geological unconformity that separates it from overlying and underlying strata and represents a change in base level. Sloss (1963) distinguished six megasequences on the North American craton from late Precambrian to Eocene (Figure 5). This study discusses the Kaskaskia sequence on the North American craton spanning from mid-Early Devonian to Late Mississippian in Montana. Wheeler (1963) further separated the Kaskaskia Sequence into two divisions, the Piankasha sequence, late-Early to Late Devonian, and the Tamaroa sequence, Late Devonian-Mississippian. Wheeler argued that the presence of an unconformity (Acadian Unconformity) separated lower from upper Kaskaskia strata at the Devonian-Mississippian boundary and was significant to constitute further division. Sloss (1988) would later revise his Kaskaskia Sequence dividing it into a Kaskaskia I and II that aligned with Wheeler's interpretation.

Of significant implication is the unconformity between Cambrian and Devonian strata in Montana. This time period is represented by the Tippecanoe megasequence which spans from Middle Ordovician to Early Devonian (Sloss, 1963, 1964). Tippecanoe strata are for the most part missing in Montana but present in both the Alberta and Williston basins. Therefore, Montana was

topographically higher than other portions of Western North America at the time (Sloss, 1950; Sloss & Moritz, 1951). The Duperow-Nisku Formations are part of the Kaskaskia I or Lower Kaskaskia Sequence. During this time, sedimentation occurred on the cratons as shown by the Wheeler diagram and in accordance with sea-level rise (Figure 6).

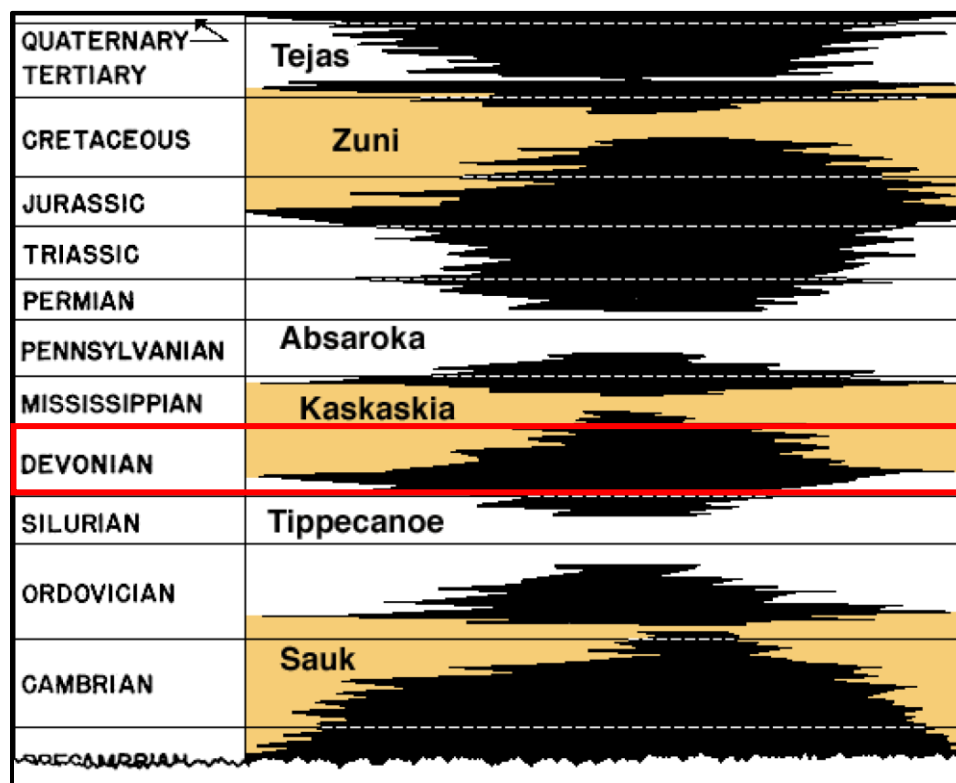


Figure 5. Time-stratigraphic relationships through geologic time with sedimentation represented by white and yellow and non-deposition by black areas. The Devonian section, part of the Lower Kaskaskia Sequence, is highlighted. The Duperow-Nisku Formations comprise the upper portion of the Kaskaskia I sequence. Modified after Sloss, 1963.

The Duperow was deposited during two second-order sea-level rises punctuated by shorter term sea-level changes that produced third-order

depositional sequences and fourth-order parasequences. Second-order sea-level cycles range from 3-10 million years in duration, third-order cycles range from 0.5-3 million years in duration, and fourth-order cycles are less than 0.5 million years in duration (Vail et al., 1977; Haq et al., 2008; Schlager, 2009). Second-order sea-level magnitude ranges from 10-60 meters, third-order from tens of meters to 100 meters or more, and fourth-order less than 25 meters (Haq et al., 2008). Second-order sea-level change is believed to be driven by slow tectonic processes that produce volumetric changes in ocean basins (Donovan & Jones, 1979; Johnson et al., 1985) while third and fourth-order cycles are thought to be produced by the stacking of climate regimes (greenhouse and icehouse) over periods of geologic time that then create punctuated higher frequency and higher amplitude sea-level changes (Fischer, 1982).

Sloss (1946, 1947) measured Devonian strata near the town of Three Forks, Montana and in the Little Belt Mountains that had originally been measured by Peale (1893), Weed (1900), and Berry (1943) along with new sections in the Lewis and Clark Range, Big Snowy Mountains, and Little Rocky Mountains, and used intervening drill cores to construct a regional lithostratigraphic correlation across the state of Montana. Measurements by Sloss (1946, 1947) reveal gradual thinning of all strata from westernmost Montana to Logan Gulch, abrupt thinning of lower Jefferson strata from Logan into the Big Belt Mountains with no significant change in other strata thickness, abrupt thickening of lower Jefferson strata from the Big Belt into the Little Belt

Mountains, absence of Maywood and lower Jefferson strata in the Big Snowy Mountains, and abrupt thickening and presence of all strata in the Little Rocky Mountains.

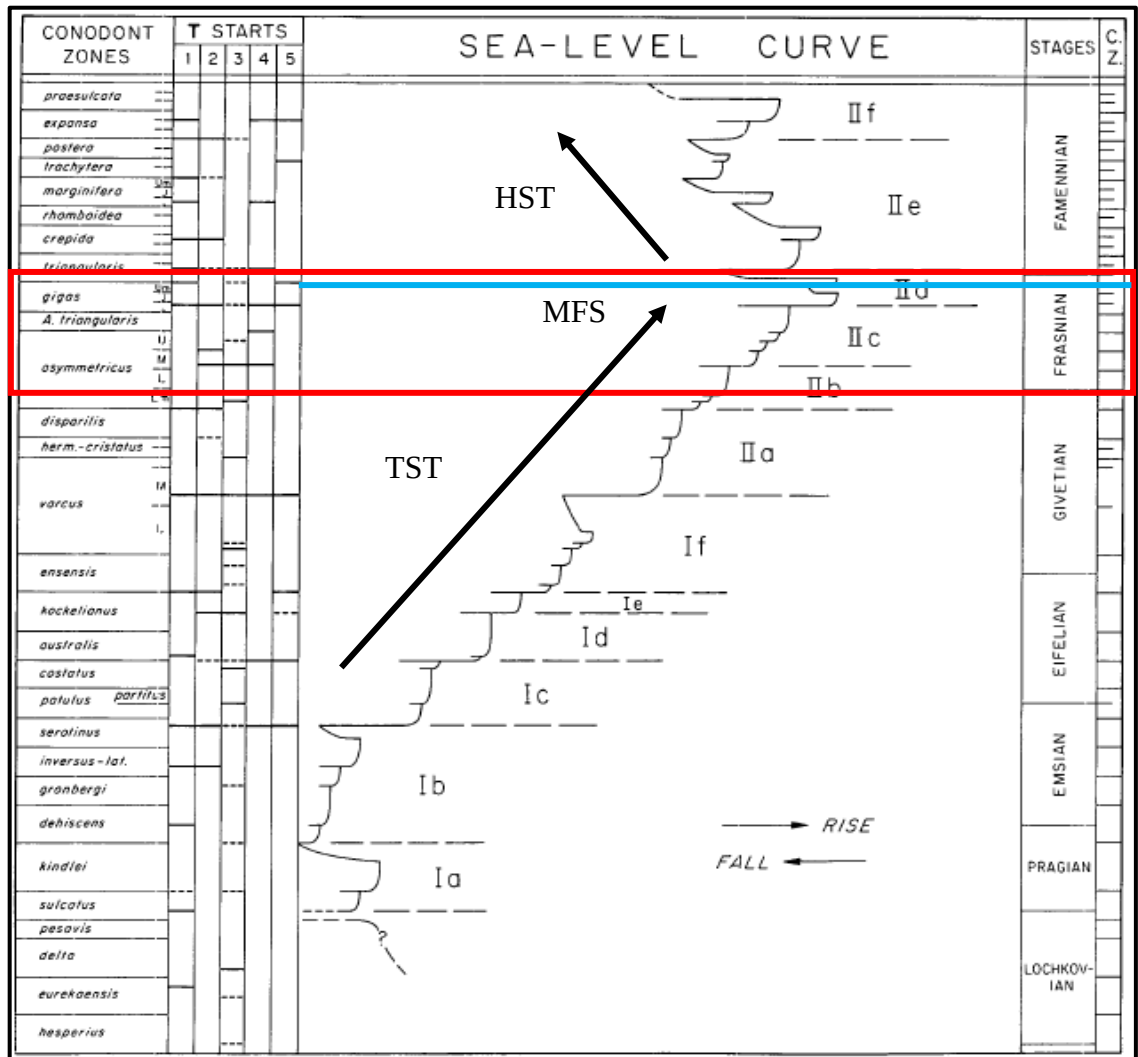


Figure 6. Qualitative eustatic sea-level curve for the Devonian constructed using biostratigraphic data on conodonts and highlighting cycles in the Frasnian. The Frasnian is highlighted along with the systems tracts of the Kaskaskia megasequence. After Sloss, 1963; Huddle, 1968; Macqueen & Sandberg, 1970; Kirchgasser, 1975; Rickard, 1975; Sandberg & Poole, 1977; Uyeno, 1974, 1979; Klapper, 1971; Brett & Baird, 1982; Geldsetzer, 1982; Lantos, 1983; Sandberg et al., 1983; Johnson & Murphy, 1984; Williams, 1984; and Johnson et al., 1985.

Beartooth Butte Formation. Preliminary fieldwork from this study reveals that Lower Devonian strata of the Beartooth Butte Formation may be present at Storm Castle Peak and at Logan Gulch between the Cambrian Pilgrim-Snowy Range Formations and Middle Devonian Maywood Formation. This observation has also been noted by McMannis (1962) who measured new and previously described Late Devonian sections in southwest Montana and reported finding Beartooth Butte equivalent strata at Squaw Creek Ranger Station near Storm Castle Peak in Gallatin Canyon and Nixon Gulch just north of Logan Gulch. Sandberg (1961) also found estuarine channel fill deposits of the Beartooth Butte Formation near Livingston, Montana southwest of Logan, in the Beartooth Mountains of south-central Montana, the Bridger Range, and the Little Belt Mountains. Early Devonian strata are only present in southwest, northeast, and north-central Montana (Figure 7). The Early Devonian Beartooth Butte Formation ranges in thickness from 0-150 feet and is not laterally extensive (Sandberg, 1961; Sandberg & Mapel, 1967). Much debate still exists about the age of strata between Cambrian and Late Devonian strata (Lochman, 1950). This stems from misuse of formational names and conflicting interpretations dating back to Peale (1893), Weed (1900), Deiss (1936), and Sloss & Laird (1947). Lochman (1950) reviewed these observations and interpretations regarding the Cambrian-Devonian contact at Logan, Montana and concluded that disputed siltstones-sandstones-shales and limestone-pebble-conglomerate beds of this interval are

part of the Cambrian Snowy Range Formation and not the Beartooth Butte Formation.

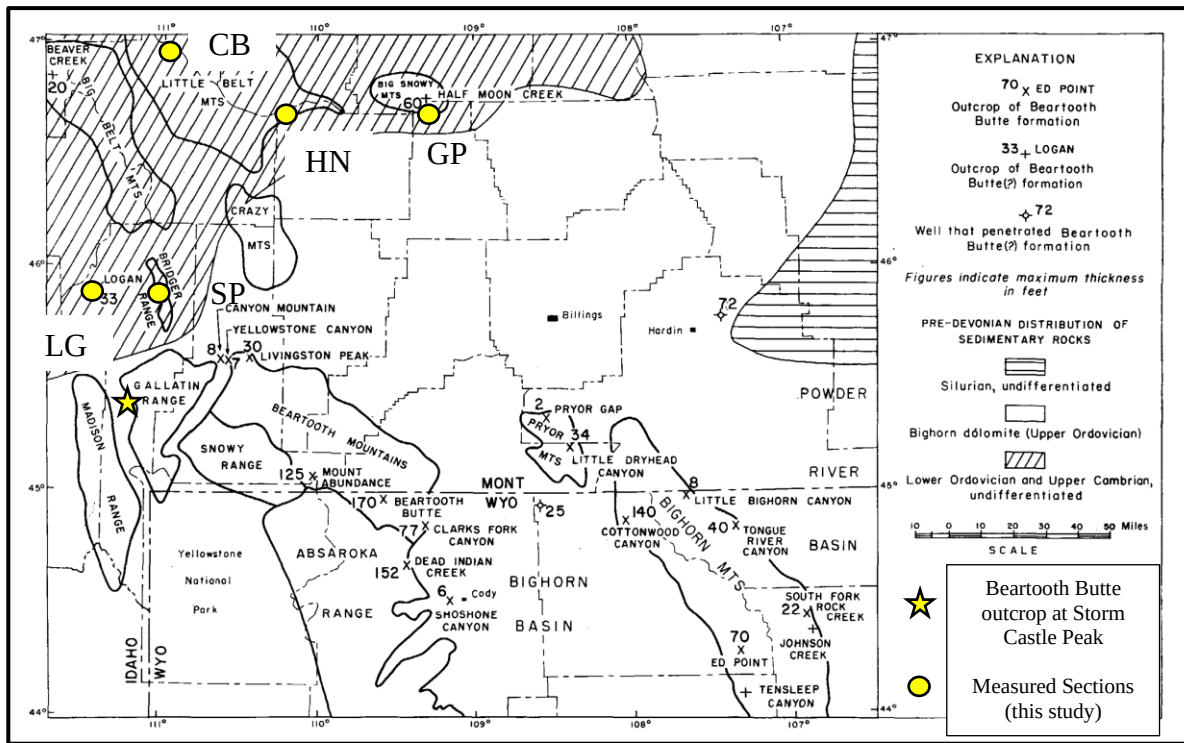


Figure 7. Map showing known locations of Beartooth Butte Formation outcrops in southern Montana with Storm Castle Peak in the Gallatin Range annotated (Modified after Sandberg, 1961). Measured section abbreviations are: CB=Crown Butte, GP=Greathouse Peak, HN=Haymaker Narrows, LG=Logan Gulch, and SP=Sacagawea Peak.

Maywood-Souris River Formation. Lower Middle Devonian (Eifelian and older) strata are present in northeast and north-central Montana. These strata include the Elk Point Group and the Dawson Bay Formation which are together 0-550 feet thick in Montana and up to 875 feet thick in the center of the Williston Basin (Sandberg, 1961; Lonnee, 1999, Rodgers, 2016).

Upper Middle Devonian (Givetian) strata include the Maywood and Souris River Formations (Figure 8). The Maywood Formation is comprised of red-green dolomitic shale, and red-brown argillaceous dolostone with brachiopods and is up to 300 feet thick in western Montana (Baillie, 1955; Benson, 1966; Sandberg & Hammond, 1958). The Souris River Formation (equivalent to the Maywood Formation) is a thinly interbedded, shaly dolomite, argillaceous limestone, shale, siltstone, and anhydrite with abundant *Spirorbis* worms (Sandberg, 1963). The Souris River Formation is up to 340 feet thick in the Williston Basin of Saskatchewan, thinning to 40 feet or less in northeast Montana, and is absent in southeast, south central, and central Montana (Sandberg, 1961; Stearn & Shah, 1990). These formations have been interpreted as being deposited in a shallow sea that transgressed westward from the Williston Basin following an Early to Middle Devonian sea-level lowstand. Benson (1966) recognized that Maywood-Souris River strata are confined to areas where the Lower Devonian Beartooth Butte Formation exists.

In the Little Rocky Mountains, the easternmost surface exposure of Devonian strata in Montana, the Maywood-Souris River Formation is 175 feet thick with 5 feet of silty pink dolomite and breccia at its base. Above this unit is light gray-green-yellow-brown dolomite followed by red platy calcareous shale and limestone (Knechtel, 1959). In the Sawtooth Range, the western- and northernmost field site, the Maywood Formation is 26 feet thick near Gibson Reservoir and thickens to 229 feet in the western part of the range across what

would have been the geosyncline/shelf break (Mudge, 1972). In the Sawtooth Range, Mudge (1972) divided the Maywood Formation into a lower gray-green-red mudstone and yellow-gray dolomite unit and an upper gray-brown-yellow mottled dolomite and limestone unit. In the Bridger Range, the Maywood Formation ranges in thickness from 39-92 feet, thickening from southeast to northwest (McMannis, 1955). The Maywood Formation is 80 feet thick in the Little Belt Mountains (Vuke et al., 2002). In the Big Snowy Mountains, the Maywood Formation is thought to be present as indicated by conodont ages however, uncertainty still exists (Lindsey, 1980; Porter et al., 1996).

Duperow Formation. Unconformably overlying the Maywood-Souris River Formations, the Duperow Formation is up to 700 feet thick in western and northern Montana (Figure 8). It is comprised of brown-yellow-gray limestone, dolomite, dolomitic limestone, sandy argillaceous dolomite, siltstone, and anhydrite (Sandberg, 1961). The lower Jefferson Formation is comprised dominantly of dolomite and dolomitic limestones and to a lesser extent limestone. Fossils are rare but when present include algal stromatolites, oncolites, amphipora, brachiopods, and stromatoporoids (Benson, 1966). In the Little Rocky Mountains to the east, the lower Jefferson Formation is 365 feet thick and comprised of thinly bedded dark gray-brown dolomite to limestone (Knechtel, 1959). In the Sawtooth Range, the lower Jefferson Formation is 300-650 feet thick, composed of dolomite with thin interbeds of limestone and intraformational breccia, and thickens to the west (Mudge, 1972). At Logan, the lower Jefferson

Formation is 470 feet thick (Kindle, 1908; Sandberg, 1965). McMannis (1955) notes that the lower and upper Jefferson Formation are 497-620 feet thick in the Bridger Range. In the Gallatin (Storm Castle Peak) and Madison Ranges of southwest Montana, the lower Jefferson Formation averages 400 feet thick (Montagne, no year). In the Little Belt Mountains, the lower Jefferson Formation ranges from 190-422 feet thick (Campbell, 1961; Vuke et al., 2002). The lower and upper Jefferson Formation are also lumped in the Big Snowy Mountains where they range in thickness from 100-160 feet (Lindsey, 1980).

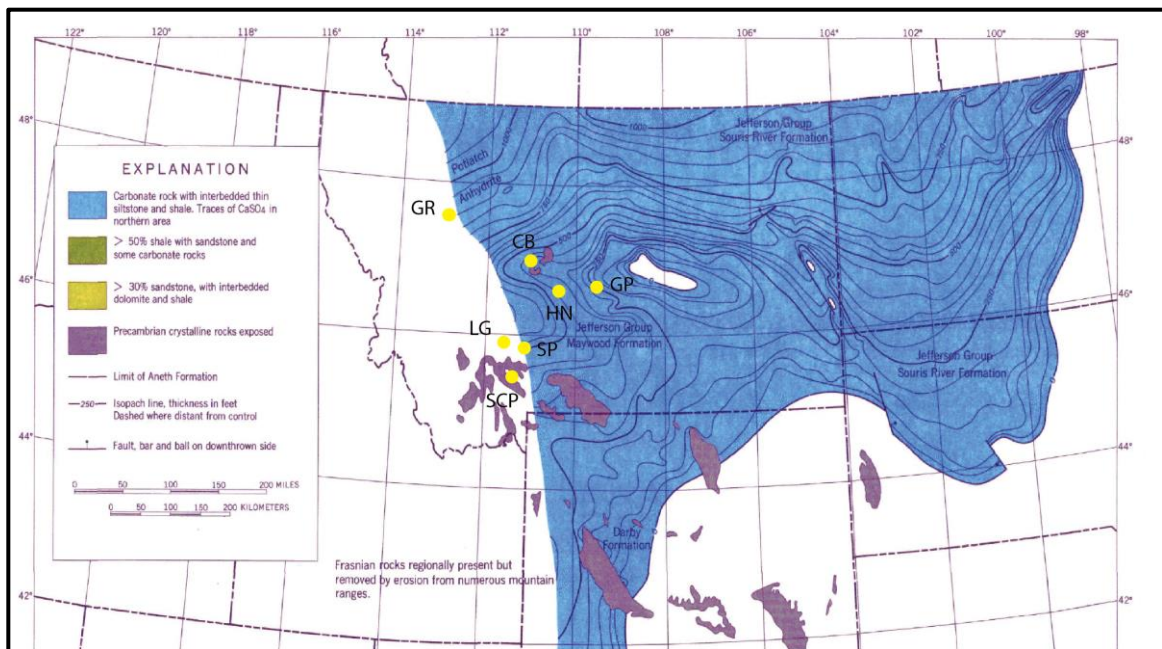


Figure 8. Total isopach map of Maywood-Souris River and Duperow-Nisku (Jefferson) Formations in Montana and North Dakota with measured sections from this study shown (Modified after Barrs, 1972). Measured section abbreviations are: CB=Crown Butte, GP=Greathouse Peak, GR=Gibson Reservoir, HN=Haymaker Narrows, LG=Logan Gulch, SCP=Storm Castle Peak, and SP=Sacagawea Peak.

Nisku-Birdbear Formation. Stratigraphically above the Duperow-Lower Jefferson Formation is the Nisku Formation (Birdbear Member-Upper Jefferson Formation), a fossiliferous brown to light-brown-gray finely crystalline dolomite forming thick bedded cliffs and averaging 60-115 feet thick (Figure 9). It contains corals, bryozoans, stromatoporoids, and algal material (Baillie, 1955). The Nisku Formation is equivalent to the upper 70 feet of the Jefferson Formation at Logan Gulch in western Montana (Sandberg, 1961). In central Alberta, the Nisku Formation is up to 328 feet thick (Stearn & Shah, 1990). In the Little Rocky Mountains, the upper Jefferson Formation is 65 feet thick and comprised of 15 feet of red-green-buff shale, siltstone, and silty dolomite to limestone grading upwards into massive light gray-buff fine-grained limestone and dolomite (Knechtel, 1959). In the Sawtooth Range, the upper Jefferson Formation is 150-235 feet thick and comprised of thin bedded dolomite and limestone with pinch and swell type bedding (Mudge, 1972). In the Little Belt Mountains, the upper Jefferson Formation is about 60 feet thick (Vuke et al., 2002).

Three Forks Formation. Late Devonian (Famennian) strata are present in northern and west-central Montana (Figure 9). These strata thin to near zero from the Williston Basin into eastern and north-central Montana and thicken to 200 feet in west-central Montana and up to 800 feet in northwest Montana (Sandberg & Hammond, 1958). Famennian strata in Montana are represented by the Three Forks Formation and include the Potlatch Anhydrite Member. The Frasnian-Famennian contact is easily recognized in the field by the unique green

shales of the Trident Member and a significant change in slope angle from the underlying Nisku Formation.

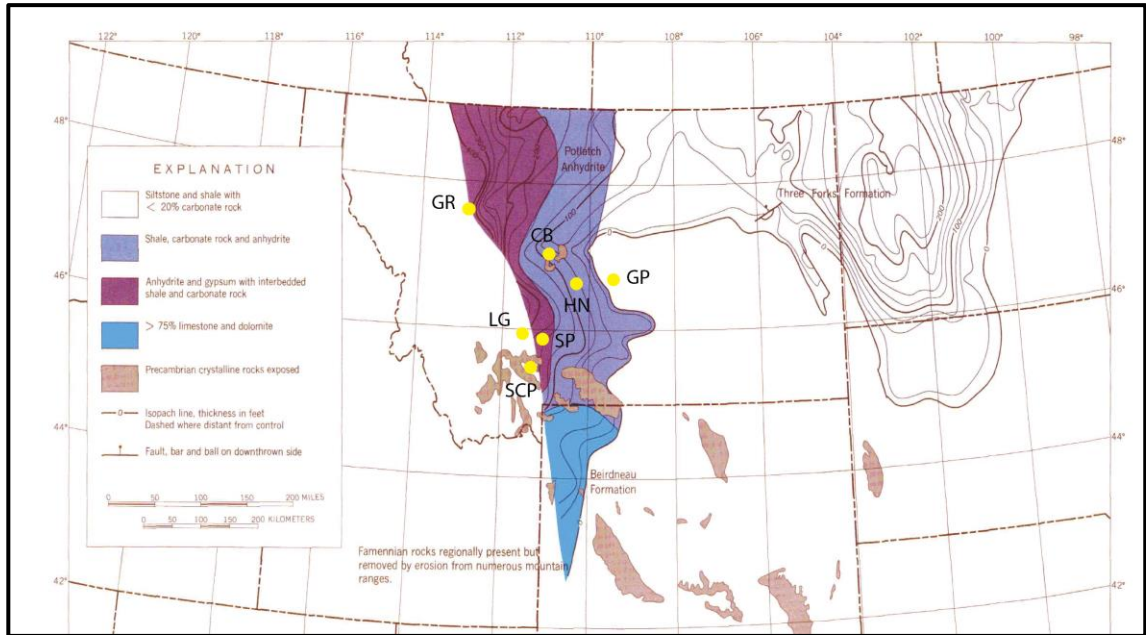


Figure 9. Total isopach map of the Three Forks Formation in Montana and North Dakota with measured sections from this study shown (Modified after Barrs, 1972). Measured section abbreviations are: CB=Crown Butte, GP=Greathouse Peak, GR=Gibson Reservoir, HN=Haymaker Narrows, LG=Logan Gulch, SCP=Storm Castle Peak, and SP=Sacagawea Peak.

Tectonic Setting

Structural features in western and central Montana have been attributed to basement involved and influenced tectonism (O'Neill & Lopez, 1985; Nelson, 1995). Basement features include the Great Falls Tectonic Zone, Pendroy Fault Zone, Lewis and Clark Line, Scapegoat-Bannatyne Lineament, Wyoming Craton, Medicine Hat Block, Belt Basin, and Montana Aulacogen (Figure 10). Kent (1964) suggests that zones of weakness between Precambrian basement blocks

produced flexures (anticlines) in overlying strata. These basement features are believed to form structural trends that may have controlled both salt-solution features and hydrocarbon migration pathways (Dunn, 1974 and 1975).

From Precambrian through Silurian time, western North America was a passive margin (Poole et al., 1977; Blakey, 2018). Beginning in the Middle Devonian, the Antler Arc collided with the edge of western North America where it eventually accreted to the continental margin producing compressional stress creating the Antler Highlands and a N-S trending foredeep from Utah through central Idaho (Figure 3). This orogeny created compressional stress inboard of the continental margin which several authors have interpreted to have reactivated basement structures resulting in positive features like the Central Montana Uplift and negative features like the Central Montana Trough (Winston, 1986; Maughan, 1989).

Included within this group of Devonian structural features are the Central Montana Trough, Central Montana Uplift, and Wyoming-Beartooth Shelf of southern Montana (Figure 11). These elements are briefly described below and their importance to the formation and distribution of sediments on the platform in Montana will be discussed later.

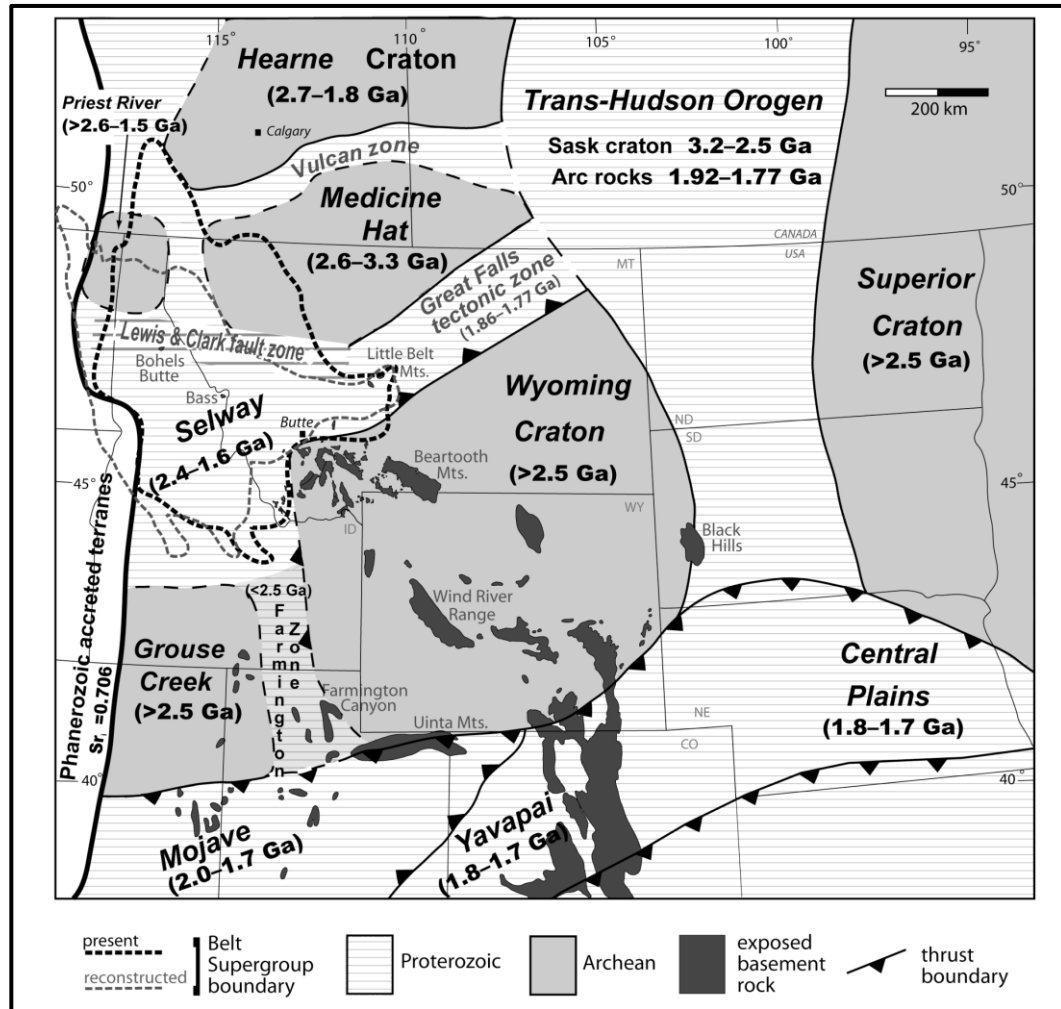


Figure 10. Tectonic map of Montana showing Precambrian basement structures in the study area (after Foster et al., 2006).

Great Falls Tectonic Zone and Basement Lineaments. The Great Falls Tectonic Zone (GFTZ) is a northeast trending basement feature that is believed to mark the boundary between the Wyoming Craton and the Medicine Hat Block, both of Archean age (O'Neill & Lopez, 1989; Sims, 1995). The GFTZ at 1.86-1.77 Ga is younger than both these Archean features and is thought to be the product of northward subduction of the denser Wyoming Craton beneath the Medicine

Hat Block (Gorman et al., 2002; Ross et al., 2002). The GFTZ is a predominant structural lineament along which many younger faults, folds, and igneous intrusives are located. Jorgensen (2004) uses regional gravity and magnetic data to suggest that the Scapegoat-Bannatyne Lineament is the actual boundary between the Wyoming Craton and Medicine Hat Block. These basement features were influential in the exhumation of Paleozoic strata in central and northern Montana.

Wyoming Craton. Previous work suggests that the Wyoming Craton (Archean) developed during extensive magmatism 2.5-2.9 Ga and extruded surrounding crust, melting it, and diverting it away from the craton and its mantle root (Mueller & Frost, 2006). This melt of felsic crust was determined to have migrated to weaker crustal zones, such as the Great Falls Tectonic Zone, where it produced mineral deposits and magmatism within Cretaceous rocks (O'Neill & Lopez, 1985; Foster et al., 2006).

Medicine Hat Block. The Medicine Hat Block is also of Archean age and is bounded to the southwest by the Lewis and Clark Fault Zone, the southeast by the Great Falls Tectonic Zone, the east by the Trans-Hudson Orogen, and the north by the Vulcan Low and Hearn Craton both in Alberta. It is uncertain whether the Medicine Hat Block is part of the Wyoming Craton or the Hearn Craton (Hoffman, 1989; Henstock et al., 1998; Ross & Eaton, 1999; Foster et al., 2006). The relationship of the Medicine Hat Block to other cratons in North America may be unresolved however, the consistent thickness of the Duperow-

Nisku system throughout Montana reveals that the Medicine Hat Block was an area of stable crust with very low rates of subsidence much like the Wyoming Craton.

Montana Aulacogen. The Montana Aulacogen is a middle Proterozoic aged rift that is thought to have formed from the breakup of the North American-Siberian-European megacontinent (Nelson, 1995). This 60-mile wide and 400-mile long graben structure connects the Williston Basin to the North American Cordillera and was reactivated throughout geologic time (Sears, 1988; Nelson et al., 1993). The Montana Aulacogen has been responsible for producing an estimated \$19 billion in silver, gold, lead, zinc, copper, and hydrocarbon resources (Shepard, 1987). The Central Montana Trough and Central Montana Uplift are re-activated structural features located within the older Montana Aulacogen.

Sweetgrass Arch and Pendroy Fault Zone. The Sweetgrass Arch, in its current configuration, is a 200-mile-long, north plunging anticline offset 30 miles midway down plunge by a right-lateral fault and whose southern limit encompasses the Little Belt Mountains (Stebinger, 1916; Shepard & Bartow, 1986). This offset is thought to coincide with the Pendroy Fault Zone, a northeast-trending Precambrian basement feature associated with the suturing of the Medicine Hat Block of southern Alberta and the Wyoming Craton (Smith, 1970; Lorenz, 1982). During the Paleozoic, the ancestor to the modern Sweetgrass Arch was frequently inverted to form both positive and negative

features. During the Paleozoic, this precursor to the present day Sweetgrass Arch was characterized by moderate subsidence and depositional rates punctuated by episodes of uplift and erosion while the Wyoming Shelf to the south was characterized by slow subsidence and deposition (Sloss, 1950). Kevin Dome is a structural culmination along the Sweetgrass Arch in northern Montana related to Paleocene and younger tectonics. Radiometrically dated Paleocene-Eocene (54-50 my) plutons emplaced on the east flank of the Sweetgrass Arch are thought to have influenced the arch's current configuration (Marvin et al., 1980; Shepard & Bartow, 1986).

Along this trend are the Little Belt Mountains which contain intrusives of Oligocene-Miocene age and the Little Rocky Mountains which contain a Paleocene (67-60 my) porphyry intrusion. These intrusives are thought to be associated with magma chambers that intruded and exploited weak crust along basement structural lineaments related to Proterozoic tectonics of the GFTZ and subsequent formation of the Belt Basin (Smith, 1970). Basement lineaments have also been proposed to influence structural features of the western Montana Disturbed Belt (O'Neill & Lopez, 1989). The western edge of the Belt Basin is thought to coincide with the present eastern extent of the Disturbed Belt in Montana and the Idaho Foredeep/Geosyncline during Devonian time (Harrison et al., 1974).

Central Montana Trough (CMT). The Central Montana Trough is a northwest-southeast trending negative feature bordering the Wyoming-Beartooth

Shelf to the south, Alberta Shelf to the north, and associated with the Montana Aulacogen (Figure 11). The Central Montana Trough is thought to have connected to the Williston Basin to the east through the Montana Aulacogen and the open ocean to the west through the Central Idaho Trough-geosyncline/foredeep (Nelson, 1995).

Central Montana Uplift (CMU). The Central Montana Uplift is a positive feature east of the Central Montana Trough comprised of east trending anticlines and synclines. Late Devonian strata here are less than 100 feet thick or absent from low accommodation for syntectonic sedimentation and Early Mississippian erosion (Sandberg, 1961). The Central Montana Uplift separated depositional areas in Montana during Mid to Late Devonian time with the Souris River Formation deposited to the north and east and the Maywood Formation to the south and west.

Wyoming-Beartooth Shelf. The Wyoming-Beartooth Shelf extended into southern Montana from Wyoming (Andrichuk, 1956). During Early and Middle Devonian time, the Beartooth Shelf was subaerially exposed causing erosional valleys to form which were filled by incised valley-fill deposits of the Beartooth Butte Formation. Subsequent transgression from the east, north, and west deposited the Maywood-Souris River Formation and by Late Devonian time the Beartooth Shelf was fully submerged allowing for Jefferson Formation and later Three Forks Formation strata to be deposited (Mikesh, 1965).

Sedimentation and accommodation on the platform are associated with eustatic sea-level fluctuations and tectonism. As previously noted, this tectonism produced various structural features such as the Central Montana Uplift and Central Montana Trough. These structural features formed prior to Frasnian seas transgressing onto the continental margin. Tectonism therefore determined the configuration of paleo-lows and paleo-highs on the platform prior to sedimentation. The influence of basement tectonics and local structures on subsidence, sedimentation, and accommodation during Duperow time will be explored further in future chapters.

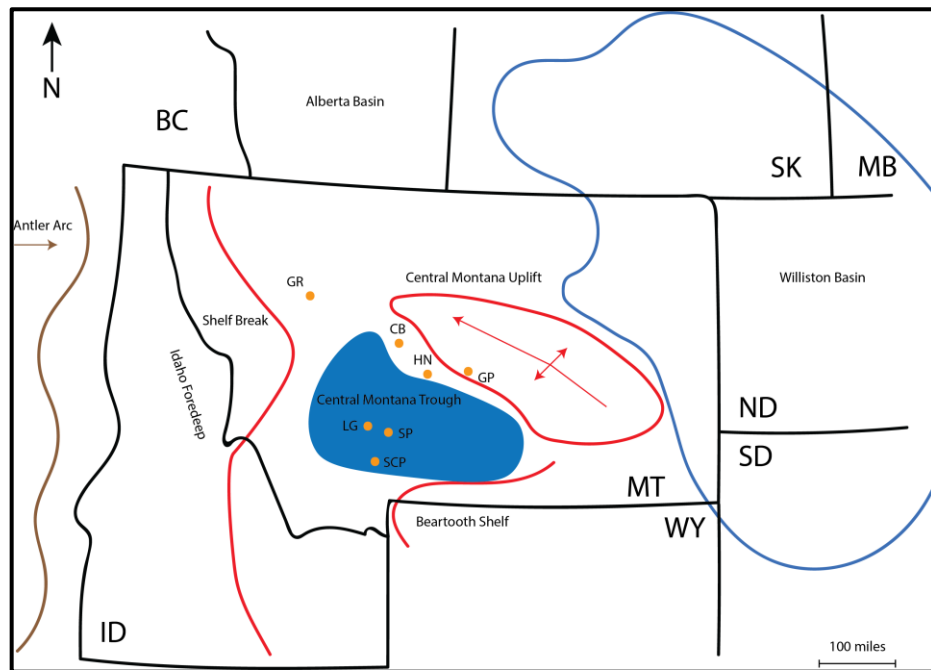


Figure 11. Map of Montana showing active structural features during the Late Devonian. Field site abbreviations are: CB=Crown Butte, GP=Greathouse Peak, GR=Gibson Reservoir, HN=Haymaker Narrows, LG=Logan Gulch, SCP=Storm Castle Peak, and SP=Sacagawea Peak (Modified after Shepard & Bartow, 1986; Peterson, 1986, 1988; Dorobek & Smith, 1989; Grader et al., 2016; North Dakota Geological Survey).

CHAPTER THREE

DATA AND METHODS

Data

This study utilizes data at various scales to interpret a stratigraphic framework of the Late Devonian Duperow Formation in Montana. Seven measured outcrop stratigraphic sections provide high resolution data on facies relationships and stratigraphic geometry. Cores and their corresponding geophysical wireline logs from Kevin Dome provide high resolution interval data on which to interpret middle and upper Duperow facies. Thin sections provide higher-resolution data for observationally estimating porosity, interpreting dolomitization and its relationships to other or predecessor lithologies, and aid in determining key facies-specific textures and fossil organisms collected from outcrop samples. Outcrop samples often have partial to complete re-organization of original fabrics and features caused by pervasive dolomitization which microfacies analysis can aid in distinguishing.

Outcrop and Measured Sections

Gibson Reservoir, Sawtooth Range, Montana. The Gibson Reservoir section is the most complete and detailed measured section of this study due to excellent and accessible exposure (Figure 12). Strata here strike 358° and dip 64°W . The Duperow Formation here is 400.5' thick. Bedding and facies contacts

are best distinguished by hiking to the second cliff above the trail and following this up-section. The Maywood Formation-Duperow Formation contact has interestingly been marked by some previous worker with a nail along the trail (Figure 13) and the Duperow Formation-Nisku Formation contact is covered. Outcrop location is: NE $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 4. T. 21 N., R. 9 W. of the Patricks Basin 7.5' Quadrangle.

Sun River Canyon in the Sawtooth Range is situated within the eastern region of the leading edge of the Disturbed Belt associated with Sevier style thin-skinned deformation in Montana (Mudge, 1966, 1970). Throughout Phanerozoic time, the area east of Sun River Canyon has periodically been a basement high coinciding with the Sweetgrass Arch and may have further influenced fold-fault relationships as older strata of the Belt Basin acted as a buttress to thrust strata (Shepard & Bartow, 1986). Deformation of the Disturbed Belt in Montana began in the Late Cretaceous and ended in late Eocene time. It should be noted that this section resides on several detachment thrust sheets that have been transported 100-km or more inboard from their original depositional environment and position on the platform (Mudge, 1972).



Figure 12. Annotated photopan of the Gibson Reservoir section. View looking north-northeast (Source: Google Earth, 2019).



Figure 13. Nail marking the contact between the Maywood Formation and Duperow Formation at Gibson Reservoir. UTM location is 12N 366510 E, 5273410 N, 4869 feet elevation.

Logan Gulch, Horseshoe Hills, Montana. Logan Gulch is the type section for the Jefferson Formation in western Montana and is part of the Horseshoe Hills which lie on the Perry Line and form the southern margin of the Mesoproterozoic Belt Basin that was later reactivated as the Helena Salient of the Sevier fold-and-thrust belt (Lageson et al., 2019). The entire Maywood, Duperow, Nisku, and Three Forks Formations are exposed here along the Gallatin River however, the majority of the area is private land. The outcrop location is SE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 25. T. 2 N., R. 2 E. of the Logan 7.5' Quadrangle. This area is part of the Cenozoic Three Forks Basin (Hallock, 1955). The Logan Gulch section is a complete section however, resolution is limited near the very base and top of the measured stratigraphic column as the outcrop is on private land and the author was not allowed to access the site for a second summer. Much of the detail in this section is collected from field notes and photographs (Figure 14). Strata here strike 130° and dip 42° NW. At this location, the contact between the Maywood Formation and the Duperow Formation is defined by thin carbonate mudstone beds interbedded with shale and forming a small ledge with a short recessive slope above up to the first Duperow Formation outcrop. The Duperow Formation here is 405.5-420' thick.

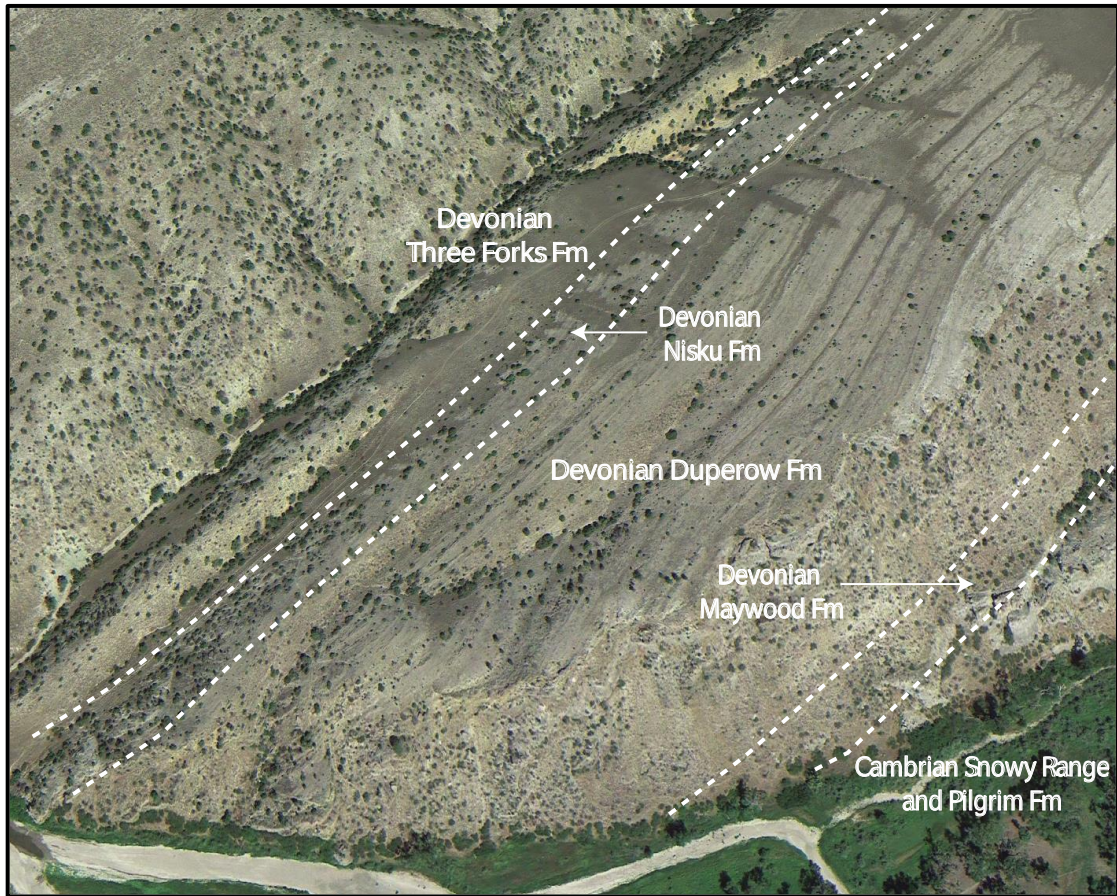


Figure 14. Annotated photopan of the Logan Gulch Section. North is to the top of the picture (Source: Google Earth, 2019).

Storm Castle Peak, Gallatin Canyon, Montana. The Duperow Formation here is poorly exposed on the nose of the ridge running south into Squaw Creek and immediately east of Storm Castle Peak (Figure 13). This site is accessible via the turn off from Highway 191/Gallatin Rd onto Squaw Creek Rd/Storm Castle Rd. The outcrop location is NE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 34. T. 4 S., R. 4 E. of the Garnet Mountain Quadrangle. The Cambrian-Devonian contact is covered here. The contact between the Duperow Formation and the Nisku Formation is well-defined.

McMannis (1962, 1964) describes Early Devonian Beartooth Butte Formation strata within the proximity of the Squaw Creek Ranger Station located at the base of the ridge adjacent to that of this study's measured section. Several parasequences of the Duperow are exposed in the gully to the east of the unnamed ridge mentioned above. The Nisku Formation is entirely exposed here. Strata strike 034° and dip 26°NE . Using the total thickness of Jefferson Formation strata that McMannis (1955) measured at 310 feet here and subtracting the known Nisku Formation thickness measured reveals the Duperow Formation is up to 265 feet thick. A tabular stromatoporoid reef is well-developed at the base of the first cliff, one of the better examples seen in all Duperow Formation outcrops measured (Figure 15).

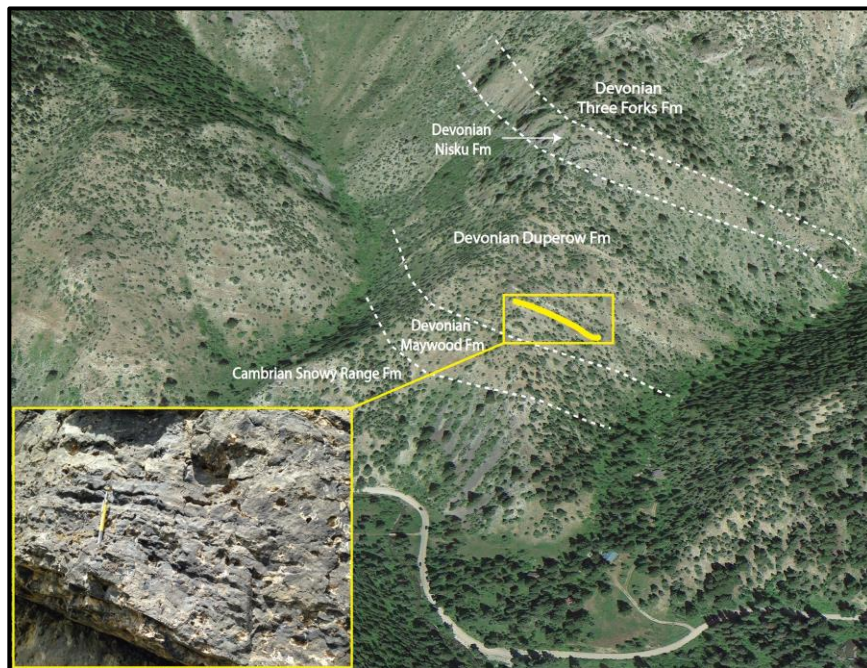


Figure 15. Annotated photopan of Storm Castle Peak section with the location of a tabular stromatoporoid reef highlighted. The ridge annotated trends N-S with north to the top right of the picture (Source: Google Earth, 2019).

Sacagawea Peak, Bridger Range, Montana. The Duperow is well-exposed on the north and west flank of Sacagawea Peak and the east and south flank of Pomp Peak (Figure 16). This site is accessible via a 1.8-mile hike from the Fairy Lake trailhead. The outcrop location is SE $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 27. T. 2 N., R. 6 E. of the Sacagawea Peak 7.5' Quadrangle. Here, the Cambrian-Devonian contact is defined as the surface above biostromal algal/microbial limestones weathering whitish-gray that are located in the Upper Snowy Range Formation of Cambrian age. These algal limestones form the grassy slope and re-entrant to the west of Sacagawea Peak and are unconformably overlain by the Maywood Formation, here comprised of reddish-brown dolomitic and brecciated mudstones. The Maywood Formation is often more red brown in color compared to the dark brown of the Duperow Formation.

The Bridger Range overlaps five major tectonic provinces which include the southern margin of the Middle Proterozoic Belt Basin-Helena Embayment, the Sevier fold and thrust belt, the Laramide foreland, easternmost Basin and Range, and is adjacent to the Yellowstone hot spot (Lageson, 1989; Skipp et al., 1999; Lageson et al., 2019). The northern portion of the Bridger Range is associated with thin-skinned Sevier folding and thrusting while the southern portion is associated with Laramide-style uplift (Skipp et al., 1999). During Late Devonian time, the Bridger Range was a positive feature trending east-west mimicking the Little Belt-Big Snowy uplifts and the southern half of the range was part of the Wyoming Shelf (McMannis 1955; Sloss 1950). The Pass Thrust and

Cross Range Thrust Zone are two prominent structural features of the range. The Pass Thrust is middle Proterozoic in age and is believed to have controlled deposition at the southern edge of the Belt Basin before dying out in the Perry Line; the southern edge of the failed Montana Aulacogen of Precambrian age located east-northeast of the range (McMannis, 1955).

The Sacagawea Peak section is almost completely exposed except for thick intervals of supratidal and tidal flat deposits visible on recessive slopes (Figure 16). Strata here strike 030°N and dip 55°E. The Duperow Formation here is 337.5 feet thick.

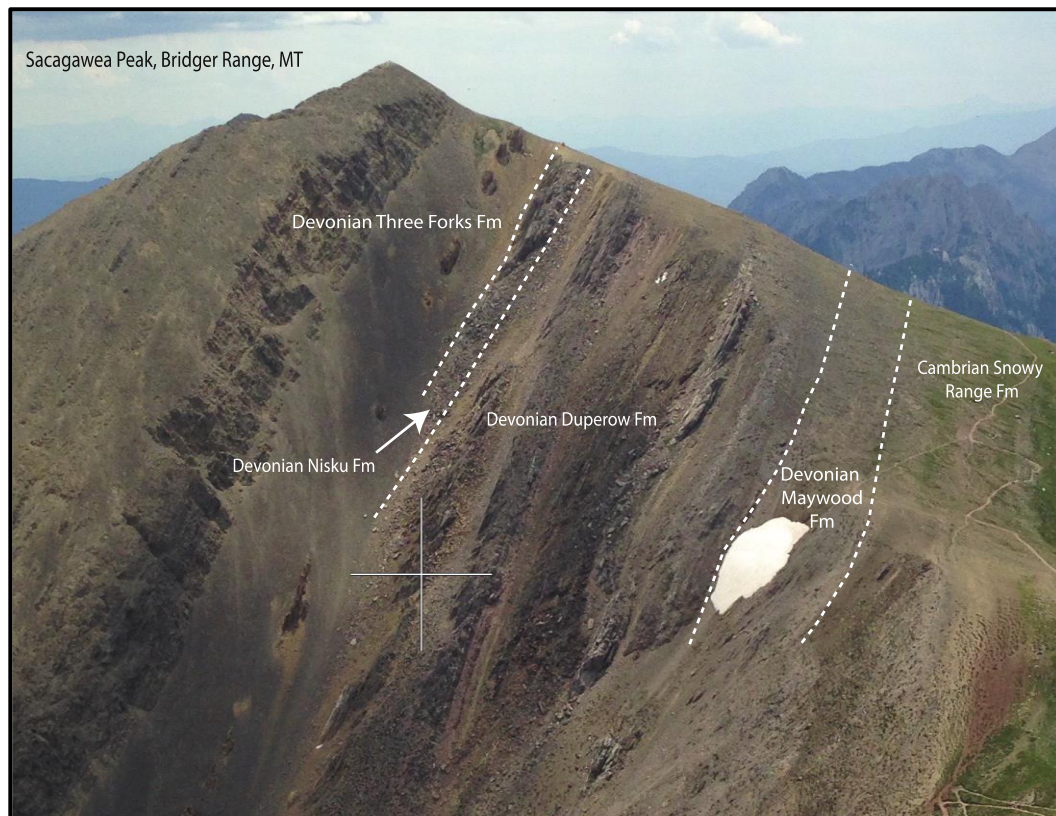


Figure 16. Annotated photopan of the Sacagawea Peak section. View is looking south.

Crown Butte, Little Belt Mountains, Montana. Crown Butte is located in the northern Little Belts northwest of Monarch, Montana. This site is accessed via Logging Creek Road and a short hike from the intersection of Logging Creek Road and Lick Creek Lane. The best outcrop is in the gully to the southwest of Crown Butte and on the south face of Crown Butte itself. The outcrop location is SW $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 20. T. 16 N., R. 6 E. of the Riceville 7.5' Quadrangle.

The Little Belt Mountains are a broad, low lying anticline that's current configuration is likely due to doming and faulting associated with igneous intrusions (Weed, 1900). The flanks of the anticline are steep, and folding of the region, as with the Big Snowy Mountains to the east, was due to northeast-southwest compression associated with Sevier and Laramide deformation (Bird, 2002).

Strata here strike 035°N and dip 05°NE (Figure 17). The Duperow Formation here is 378 feet thick. The Duperow Formation at Crown Butte is the second most weathered of all sections next to Haymaker Narrows and is a much darker brown in color here than anywhere else observed in this study.



Figure 17. Annotated photopan of the Crown Butte section. View is looking northeast.

Haymaker Narrows Canyon, Little Belt Mountains, Montana. Haymaker Narrows is located in the southern Little Belts west of the town of Harlowton, Montana and is accessed via Haymaker Road off Montana State Highway 12. The Duperow Formation crops out 7-miles up the canyon near the top of the first cliff from the canyon floor on the eastern walls (Figure 18). The outcrop location is SW $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 26. T. 11 N., R. 12 E. of the Haymaker Narrows 7.5' Quadrangle.

The Haymaker Narrows section is poorly exposed. Strata here strike 005° and dip 09°E . Using thickness measurements from Campbell (1961) at an outcrop across the gully, the Duperow here is up to 349 feet thick.

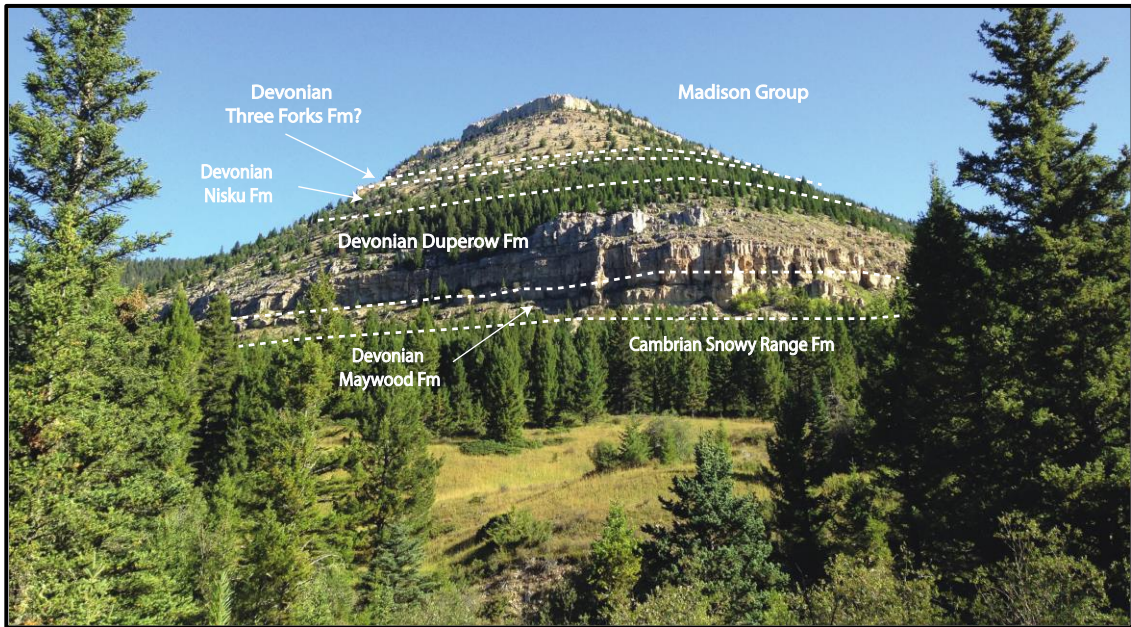


Figure 18. Annotated photopan of the Haymaker Narrows section. View is looking east-northeast.

Greathouse Peak, Big Snowy Mountains, Montana. Greathouse Peak is accessible via Swimming Woman Road and a 4-mile hike from the end of the road. The Duperow Formation is well-exposed throughout the walls of this glacial cirque, however much of the outcrop is inaccessible due to cliff exposure. Two points allow some access, a gully on the southeast face of Greathouse Peak and a trail on the southeast face of the adjoining ridge to the south that provides access to the upper portion of the section. The outcrop location is SW $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 29. T. 12 N., R. 19 E. of the Half Moon Canyon 7.5' Quadrangle.

The Big Snowy Mountains are a single multi-kilometer wavelength and amplitude asymmetric anticline trending approximately east-west and bounded by synclines on either side. Like the Little Belts, the area is outlined and

frequently intruded by laccoliths. Strata dip steeply on the southern flank of the range into the Wheatland Syncline and gently on the northern flank into the Blood Creek Syncline (Reeves, 1930; Lageson, 1985).

The Greathouse Peak section is fully exposed (Figure 19). Strata here strike 110° and dip 05°NW and the Duperow here is 119.5 feet thick. The contact between the Maywood Formation and the Duperow Formation is placed on top of the skeletal grainstone with a karsted surface and paleosol, however debate continues as to whether the Maywood Formation is actually present here (Deiss, 1936; Sandberg, 1961).

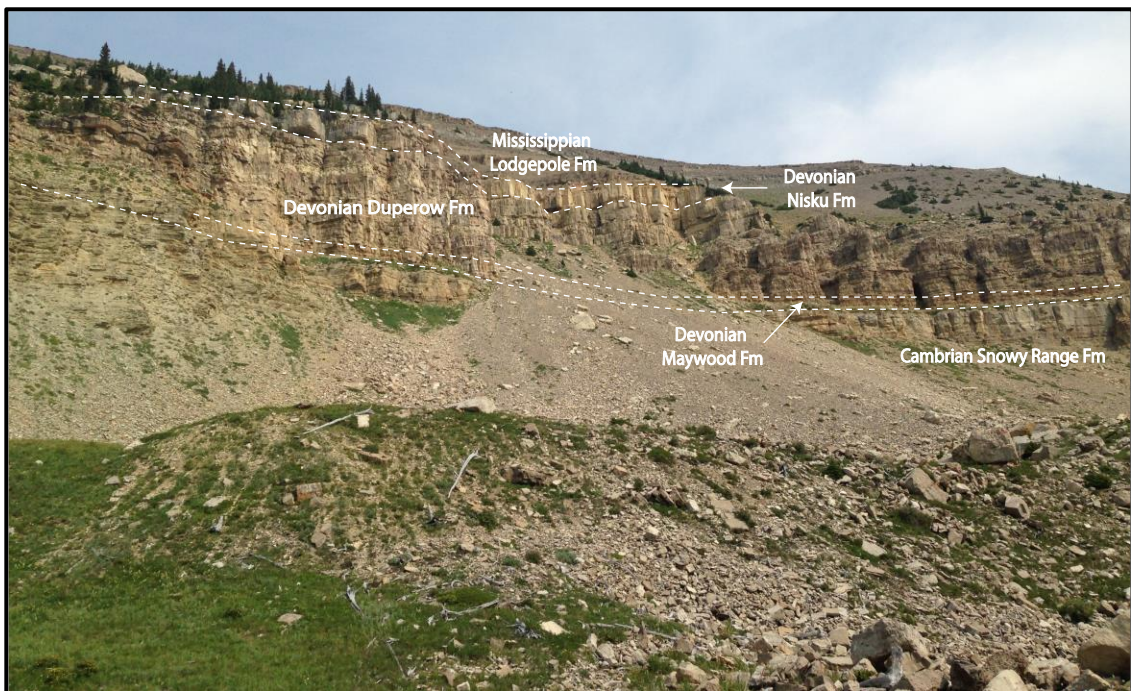


Figure 19. Annotated photopan of the Greathouse Peak Section. View is looking north. Note thin black shale beds on top of the Nisku Formation, this is the base of the Exshaw/Lodepole Formation. Three Forks Formation strata are neither mapped on geologic maps nor present here.

Drill Core

Three drill cores were logged from Kevin Dome (Figure 20) and they include the Wallewein 22-1 (240 feet) located in SE SW Section 22, T36N, R1W, the Danielson 33-17 (180 feet) located in NW SE Section 17, T35N, R1W, and the Plain Kevin 15-26 (91.5 feet) located in SE SE Section 26, T35N, R4W. The Danielson 33-17 (API #25-101-24243-0000) core stratigraphically overlaps approximately 100 feet of the lower portion of the Wallewein 22-1 (API #25-101-24242-0000) core and the Plain Kevin 15-26 (API #52131-11-0015) core sits within approximately the same stratigraphic interval that the Danielson 33-17 core represents (Appendix B).

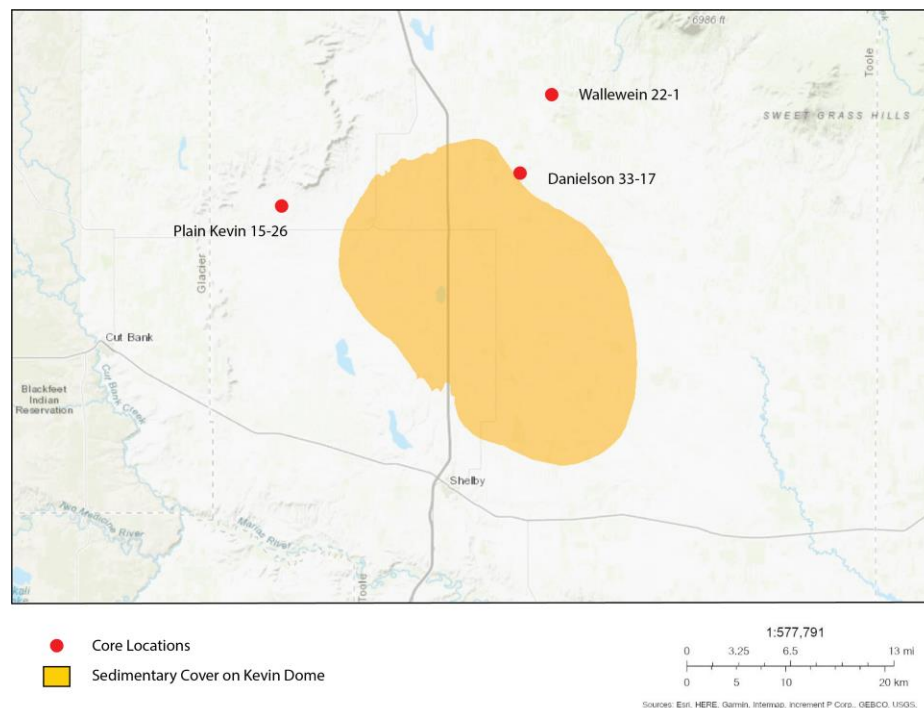


Figure 20. Map showing location of the three cores from this study in Toole County, Montana (BSCSP, 2019).

Thin Sections

Thin sections from outcrop samples are comprised of calcite, dolomite, and reveal skeletal grains, fabric, and textural elements not visible in hand sample. Table 2 summarizes grain types in associated facies. For further detail, see Appendix D and E. The most common grains are tabular *stromatoporoid* fragments associated with fore-reef and back reef facies; spherical to hemispherical *stromatoporoid* fragments associated with reef and shoal facies and to a lesser extent lagoonal facies; peloids associated with lagoonal and tidal flat facies; microbial mat/stromatolite fragments; intraclasts; brachiopod fragments in all facies except supratidal; trilobite fragments in shoal, lagoon, and tidal flat facies; algal and minor skeletal grains in lagoon, tidal, and supratidal facies; and calcispheres in lagoonal to tidal flat facies. Fewer numbers of bivalves, crinoids, echinoderms, bryozoans, tentaculitids, corals, and foraminifera are also present. Dolomite and calcite are micritic to microspar sized with the only calcite spar seen in skeletal grains of reef facies. Every sample was dolomitized with the exception of sample F3 from Storm Castle peak interpreted to be shoal facies made up entirely of calcite. The 41 thin sections from outcrop samples do not contain as many euhedral dolomite crystals as thin sections from the Wallewein 22-1 and Danielson 33-17 cores at Kevin Dome, possibly due to weathering.

Table 2. Grain types versus depositional environments in the Duperow Formation as derived from thin section analyses. Note general trend of decreasing grain size moving from more basinward to more landward depositional environments.

	Algae & Foraminifera	Calcispheres	Peloids	Microbial Mats & Stromatolites	Trilobite Fragments	Brachiopod Fragments	Spherical or Hemi-spherical Stromatoporoid Fragments	Tabular Stromatoporoid Fragments	Echinoderm Fragments (Crinoids & Echinoids)	Tentaculitids & Bryozoan Fragments	Bivalve Fragments	Rip-Up Clasts & Intraclasts
Supratidal	X	X	X	X								
Tidal Flat	X	X	X	X	X	X						X
Lagoon	X	X	X		X	X	X		X	X	X	
Back-Reef/Patch Reef	X		X		X	X	X	X		X		
Shoal					X	X	X		X		X	
Reef						X	X		X	X		
Fore-Reef	X	X				X		X	X	X	X	

METHODS

Outcrop and Measured Sections

Outcrops accessible and suitable for measuring section were found using previous literature, Google Earth, geologic maps from the Montana Bureau of Mines and Geology website, and 7.5' topographic maps from the United States Geological Survey. Geologic and topographic maps downloaded as KMZ files and imported into Google Earth aided in finding the best exposed and accessible strata. A 1.5-meter Jacob's Staff and Brunton Geo Pocket Transit compass were used for measuring section. Samples were taken every time new facies were observed and oriented with a stratigraphic up arrow. A mixture of hydrochloric acid (HCl) and Alizarin Red-S ($C_{14}H_7NaO_7S$) were used in the field for determining limestone from dolostone. Facies were assigned in the field and later verified or modified upon cutting of samples to better determine grain type and composition. Measured sections were then drafted in EasyCopy's [®]EasyCore logging software.

Drill Core

Drill cores were logged in the core lab at Montana State University (MSU) and drafted using [®]EasyCore software. Lithology, grain size and type, fossils present, physical structures, and color were noted. Photographs of the Wallewein 22-1 and Danielson 33-17 cores were provided by the Big Sky Carbon Sequestration Partnership. The Plain Kevin 15-26 core, extracted by Plain

Energy LTD, was photographed in the MSU core lab. These cores were acquired from Kevin Dome in Toole County, Montana as part of the Big Sky Carbon Sequestration Partnership in collaboration with the Energy Research Institute at Montana State University and the United States Department of Energy. The Plain Kevin 15-26 core was donated to the Big Sky Carbon Sequestration Partnership by Normont Energy.

Thin Sections

Forty-one standard 3x2" thin sections were made by TPS Enterprises LLC and prepared using a blue epoxy impregnation for porosity recognition. Half of each slide was stained with Alizarin Red-S. Thin sections were analyzed under a Leica DM2500P microscope and pictures of each slide taken using an Industrial Digital Camera (model CMOS05100KPA) mounted to the microscope objectives from above. Each thin section was scanned at 5000 dpi using a Meyers Instrument PathScan Enabler 5 which allows for the entire field of view of the thin section to be recorded in one image.

Appropriate lithologic names were given to samples based on Folk (1959, 1962) and Dunham's (1962) classification schemes to better compare textural calls in the field and hand sample to microscopic facies analysis. Dolomitization is classified after Randazzo & Zachos (1983) and Sibley & Gregg (1987). Stylolites are classified after Koehn et al., (2016). Porosity is classified after Choquette & Pray (1970) and Lucia (1999) and estimated visually.

CHAPTER FOUR

LITHOFACIES AND LITHOFACIES ASSOCIATIONS

Lithofacies

Lithofacies are the sum of all sedimentological and paleontological data derived from outcrop hand sample, thin section, peels, or polished slabs (after Flugel, 2010). For this study, descriptions of rock characteristics such as lithology, color, grain size, grain type, texture, nature of bedding (thickness and contact with other beds), sedimentary structures (a function of flow regime and sediment availability), fossils and diagenetic features present were made. These lithofacies characteristics can be used to assign and interpret lithofacies associations that are linked to form depositional environments which then form a depositional system (Brown & Fisher, 1977). Depositional systems respond cyclically to changes in relative sea-level to produce parasequences and parasequence sets that can be grouped into systems tracts and sequences (Catuneanu, 2019). Thus, first understanding lithofacies and lithofacies associations is key to understanding depositional environments, depositional systems and sequence stratigraphic architecture. Analysis of carbonate lithofacies is best performed both in outcrop and thin section, especially with heavily dolomitized strata like the Duperow Formation.

Ten lithofacies are recognized in the Duperow Formation for this study which are grouped into six lithofacies associations from which depositional environments are interpreted.

Lithofacies Associations

I recognize 6 lithofacies associations (LFA) in the Duperow Formation in western and central Montana based on grain type/size, fossil content, sedimentary structures and color, and from these interpret various depositional environments. Lithofacies associations are summarized in Table 3 and designated as LFA-2A, LFA-2B, LFA-3A, LFA-3B, LFA-4A, LFA-4B, LFA-4C/LFA-1A, LFA-5A, and LFA-6A.

LFA-2A

LFA-2A is comprised of light to medium gray, very coarse to gravel sized stromatoporoid boundstone to rudstone with massive to very thick beds and cross-bedded in places. Fossils include crinoids, brachiopods, corals, abundant tabular stromatoporoids, and nodular chert. This lithofacies forms small distinctive knobby cliffs to ledges in many outcrops (Figure 30).

Microscopically, LFA-2A is observed to be a dolomitic biolithite with calcite and equigranular anhedral dolomite within microcrystalline to granular and blocky micrite to microspar sized cement (Figure 21). Common fossils include brachiopods, bivalves, tabular and hemispherical to spherical stromatoporoids,

and coral fragments. Porosity types include fracture to intercrystalline and intraparticle with a visual estimate of up to 5% (Gib-G4, SC-F3, SC-F6, HC1-F2).

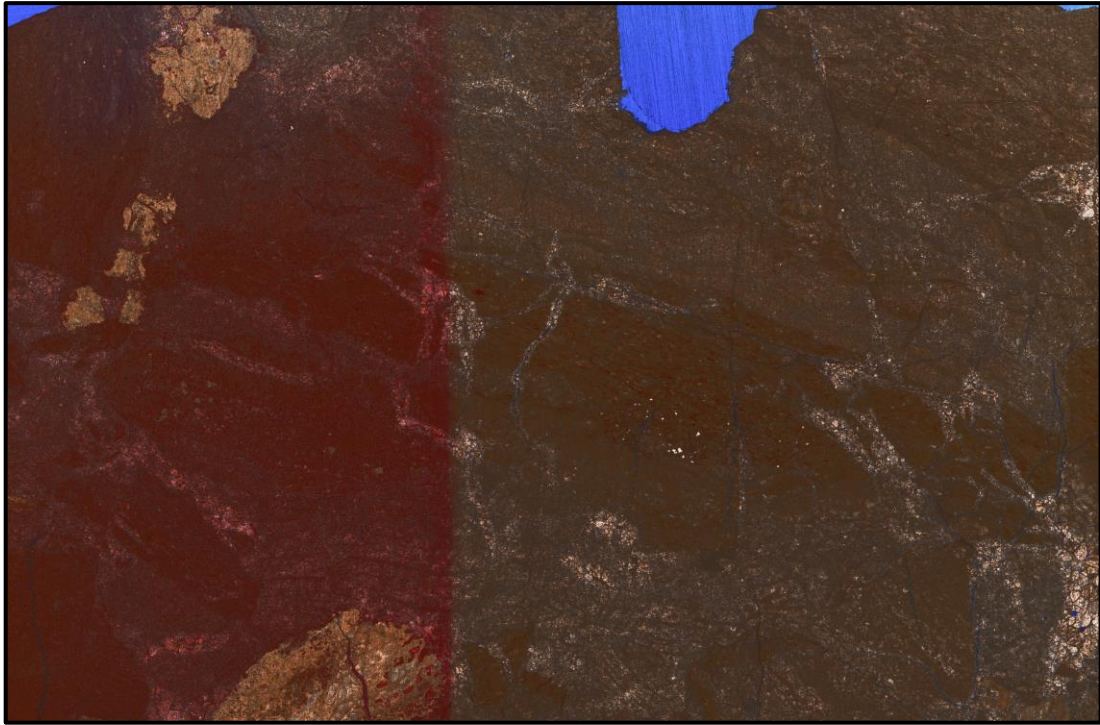


Figure 21. Whole thin section photograph showing a stromatoporoid and skeletal boundstone to rudstone interpreted to be facies LFA-2A. Sample F2 from Haymaker Narrows. Scale and view is approximately 3x2 inches, standard thin section size.

LFA-2A is interpreted to have been deposited in a low- to moderate-energy fore-reef depositional environment, within or just below fair-weather wave base, where tabular (also known as laminar or lamellar) reef-forming stromatoporoids reside, along with deposits of reef debris equal to or greater than 2 mm in diameter eroded from the reef above.

Table 3. Lithofacies, lithofacies associations, and depositional environments of the Duperow. Colors correspond to those on stratigraphic columns in Appendix A, B, and C. Environments interpreted after Flugel, 2010.

Abbreviated Facies Code	Dunham Name	Lithology and Grain Size	Notes	Interpreted Hydrodynamic Processes	Depositional Environment
LFA-2A	Stromatoporoid Boundstone/Rudstone	Limestone, very coarse to gravel sized skeletal fragments	Abundant brachiopods, tabular stromatoporoids, and skeletal debris	Below fair-weather wave base, low to moderate energy	Fore-Reef
LFA-2B	Stromatoporoid Framestone	Limestone to dolomitic limestone, coarse to very coarse grains	Spherical to hemispherical stromatoporoids most common, rare corals and crinoids	Within fair-weather wave base, moderate to high energy	Reef
LFA-3A	Stromatoporoid Grainstone	Limestone, medium to coarse grained	Spherical stromatoporoids and crinoids/skeletal debris most common	High energy	Shoal (basinward)
LFA-3B	Skeletal Packstone/Grainstone	Limestone to dolomitic limestone, medium grained	Hardgrounds, intraclasts and skeletal debris of brachiopods, crinoids, and stromatoporoids	Lower energy than 3A	Shoal/Beach rock (landward or on leeward side of reef and 3A shoal)
LFA-4A	Stromatoporoid Floatstone/Bindstone	Dolomitic limestone to dolostone, medium to coarse grained	Tabular stromatoporoids, brachiopods, and amphipora common	Moderate energy	Back Reef or Patch Reef
LFA-4B	Faintly Laminated Mudstone/Wackestone	Dolomitic limestone to dolostone, fine grained	Amphipora common, faintly and finely laminated	Low to moderate energy	Outer Lagoon
LFA-4C and LFA-1A	Peloidal Mudstone/Wackestone/ Packstone	Dolomitic limestone to dolostone, fine to medium grained	Peloids most common here, thick definitive planar algal laminations	Low to moderate energy	Inner Lagoon
LFA-5A	Stromatolitic Mudstone	Dolomitic limestone to dolostone, fine to very fine grained	Stromatolites and rip up clasts common, rare peloids and skeletal debris	Moderate to high energy, influenced by tidal currents	Tidal Flat
LFA-6A	Mudstone	Dolostone, evaporitic, very fine grained	Mud cracks and cryptalgal laminate beds common	Very low energy, only wetted during storms	Supratidal

LFA-2B

LFA-2B consists of light to medium gray-brown, medium to coarse-grained stromatoporoid framestone with spherical stromatoporoids, segmented or individual crinoid columnals, large brachiopods, and is very thick bedded with nodular chert. This lithofacies forms distinctive knobby cliffs in many outcrops (Figure 31).

Microscopically, LFA-2B is observed to be a dolomitic biolithite with micritic to microspar sized granular and microcrystalline cement (Figure 22). Fossils include brachiopods, bivalves, echinoids, tentaculitids, spherical to hemispherical stromatoporoids, trilobites and possibly algae. Dolomite crystals are subhedral to euhedral in an inequigranular fabric and a visual estimate of porosity is 5% to 10-15%. Pore types include intercrystalline and intracrystalline, intraparticle, fracture, and moldic (Gib-G5, SC-J2, Logan L-J).

LFA-2B is interpreted to have been deposited in a moderate to high-energy reef environment, within fair-weather wave base, where the principal organisms were robust spherical stromatoporoids with lesser amounts of brachiopods and corals.

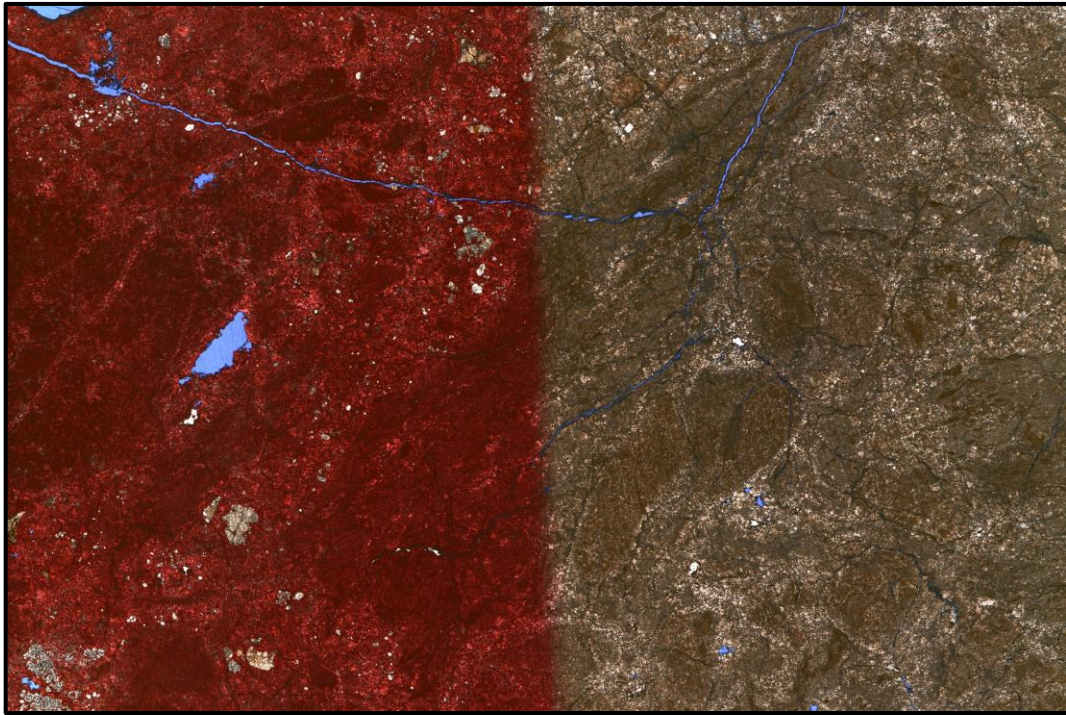


Figure 22. Whole thin section photograph showing a stromatoporoid biosparite/framestone interpreted to be facies LFA-2B. Sample G5 from Gibson Reservoir. Scale and view is approximately 3x2 inches, standard thin section size.

LFA-3A

LFA-3A is comprised of medium to dark gray and grayish pink, medium to coarse-grained spherical to hemispherical stromatoporoid grainstone with brachiopod and crinoid fragments, thick to very thick-beds, and rare stylolites (Figure 32).

Microscopically, LFA-3A is observed to be a dolomitic biomicrite to biosparite. This lithofacies is comprised purely of dolomite at times, and microspar to sparry blocky and granular cement (Figure 23). Dolomite is subhedral to euhedral and inequigranular to equigranular. Porosity is estimated

at 10-25% and includes intracrystalline, intercrystalline, fracture, and intraparticle pore types (Gib-G8, Sac-B8, Haymaker HC1-I, BS-A16, and BS-A29).

LFA-3A is interpreted to have been deposited in a high-energy shoal located basinward of the lagoon where waves break and distribute skeletal material derived from the reef. These shoals are believed to occupy roughly the same spatial position in the outer ramp as the reef (LFA-2B).

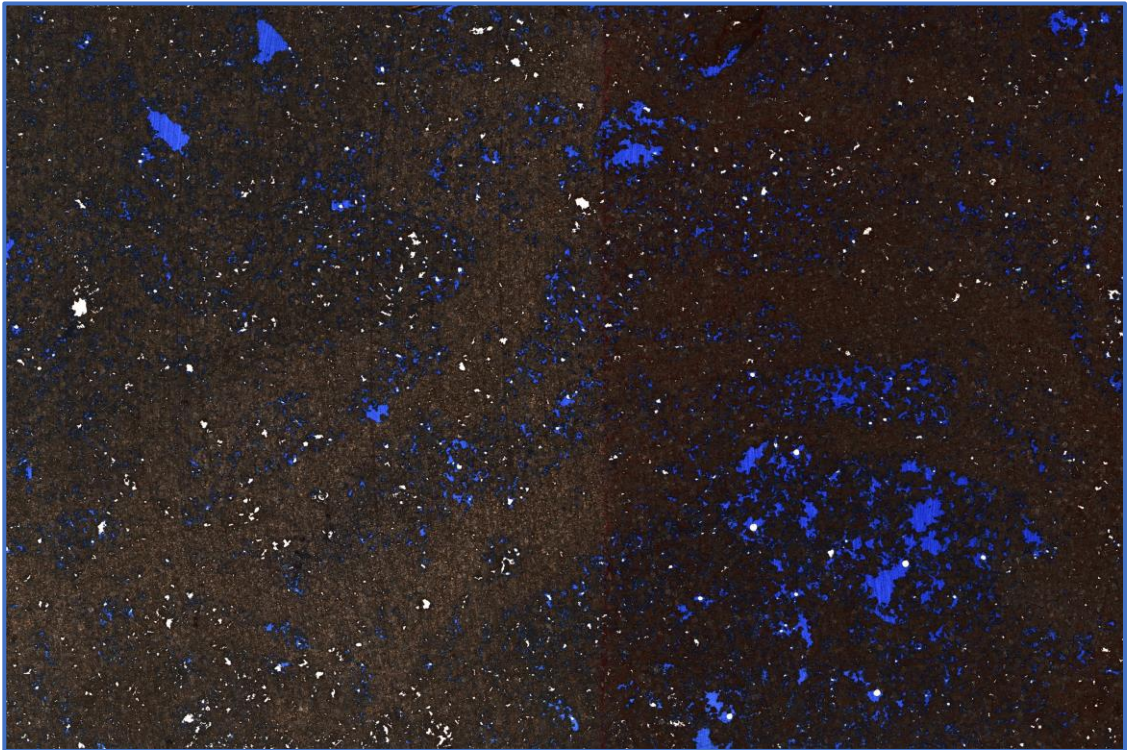


Figure 23. Whole thin section photograph showing a dolomitized stromatoporoid biosparite/grainstone interpreted to be facies LFA-3A. Sample A29 from Greathouse Peak. Scale and view is approximately 3x2 inches, standard thin section size.

LFA-3B

LFA-3B consists of light gray to grayish orange, medium-grained skeletal packstone to grainstone with thin to medium beds, brachiopods, crinoids, rip-up clasts and brecciated zones. LFA-3B has been observed as a single, thin ~1-3 cm hardground bed (Figure 33).

No petrographic thin sections were made or interpreted to be LFA-3B.

LFA-3B is interpreted to have been deposited in a backshore or beach depositional environment, either on or toward the leeward side of a shoal sheltered from the wind, or on the landward side of a lagoon.

LFA-4A

LFA-4A is comprised of dark brown to brown, coarse-grained tabular stromatoporoid and amphipora floatstone to boundstone with peloids and skeletal debris of brachiopods, trilobites, algae, bryozoans, and bivalves. This lithofacies is medium bedded and heavily dolomitized (Figure 34).

Microscopically, LFA-4A is observed to be a dolomitic biolithite with micrite to microspar sized granular to microcrystalline cement (Figure 24). Fossils include brachiopods, bryozoans, calcispheres, green algae, tabular stromatoporoids, trilobites and possibly crinoids. Dolomite is anhedral to euhedral in an equigranular to inequigranular fabric. A visual estimate of porosity is 1-7%. Pore types include fracture, intraparticle, and moldic (CB-F4, SC-F2, Sac-A3, Sac-B7, Logan L-O, and BS-A11).

LFA-4A is interpreted to have been deposited in a moderate- energy back-reef or patch reef depositional environment where tabular stromatoporoids, brachiopods, and amphipora were able to thrive.

LFA-4B

LFA-4B consists of yellowish gray to pale-yellow-gray, fine-grained peloidal mudstone-wackestone that is faint to well-laminated and thin bedded. Bioturbation and amphipora are common, and this lithofacies contains interbedded anhydrite laminations in core. Brachiopods, amphipora, and trilobites are common (Figure 35).

Microscopically, LFA-4B is observed to be a dolomitic pelmicrite to biomicrite with microcrystalline cement (Figure 25). Fossils include brachiopods, green algae, amphipora, trilobites, calcispheres, foraminifera, and possibly tentaculitids. Dolomite is variable from anhedral to euhedral and inequigranular to equigranular crystals. Stylolites and peloids are common. Porosity is estimated at 0-5% and includes fracture pore types (Gib-H6, Gib-H9, CB-W2, Sac-A4, Sac-A5, and BS-A12).

LFA-4B is interpreted to have been deposited in a low energy outer lagoon depositional environment where fine laminae are preserved and skeletal and stromatoporoid debris are rare. Anhydrite in core is interpreted to be of primary origin.

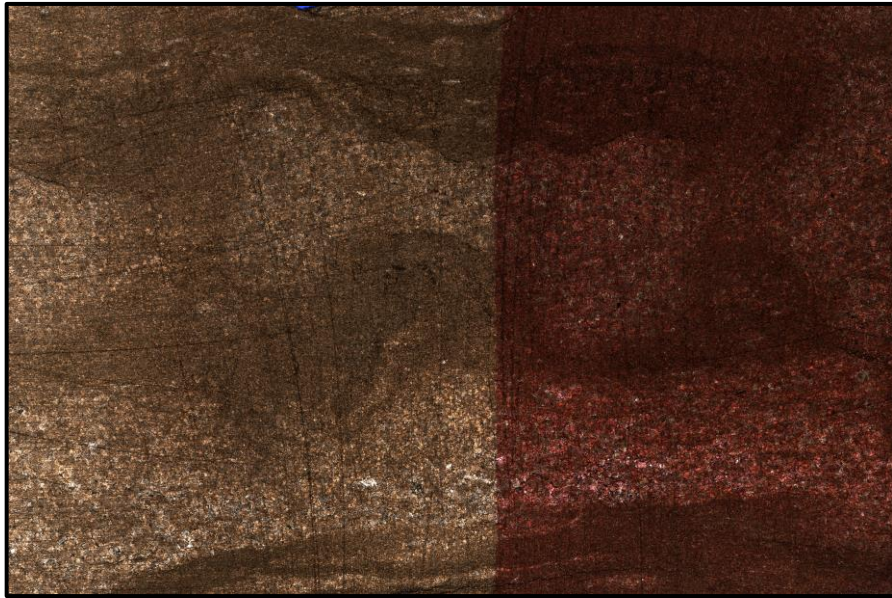


Figure 24. Whole thin section photograph showing stromatoporoid and dolomitized biolithite/boundstone with a peloidal fabric interpreted to be back reef or patch reef facies LFA-4A. Sample A3 from Sacagawea Peak. Scale and view is approximately 3x2 inches, standard thin section size.

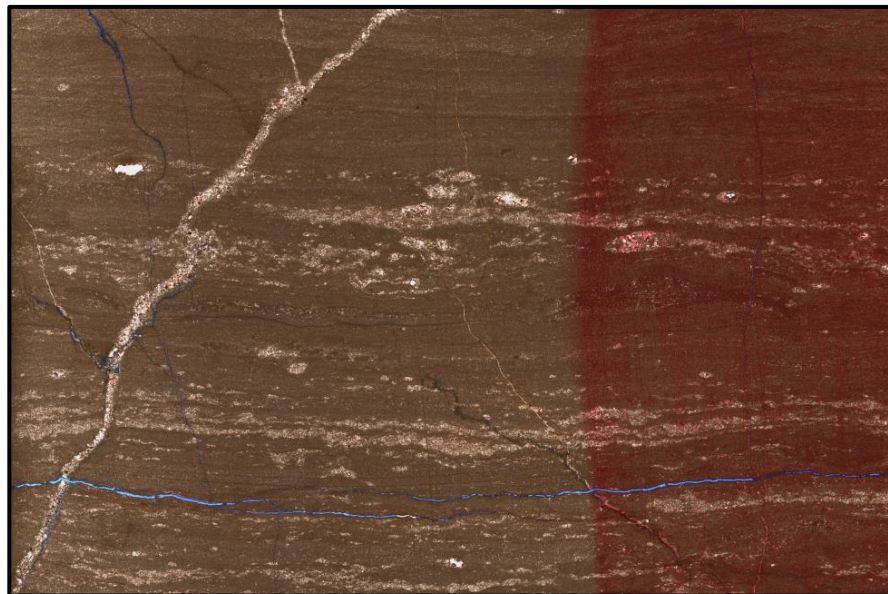


Figure 25. Whole thin section photograph showing finely laminated dolomitic pelmicrite/wackestone interpreted as facies LFA-4B. Sample W2 from Crown Butte. Scale and view is approximately 3x2 inches, standard thin section size.

LFA-4C and LFA-1A

LFA-4C is comprised of medium to dark brown and medium gray, medium-grained peloidal wackestone-packstone that is well-laminated and thin to medium bedded. Parallel horizontal laminae are thick, up to several millimeters in outcrop, and algae and amphipora are common with fewer spherical stromatoporoids. Dissolution breccia is common in this facies destroying fabric and texture. Anhydrite is common in core (Figure 36).

Microscopically LFA-4C is observed to be a dolomitic biomicrite to packed pelmicrite with foraminifera, algae, calcispheres, trilobites, and amphipora common (Figure 26). Tentaculitids, tabular and spherical stromatoporoids, and bivalves are all rare. Dolomite is anhedral to euhedral in an inequigranular to equigranular fabric. A visual estimate of porosity is less than 1% and up to 10%. Pore types include fracture, intraparticle, and intercrystalline to intracrystalline (Gib-G3, Gib-H7, CB-O, SC-J1, Logan L-I, Haymaker HC1-F8, and HC1-J).

LFA-1A consists of indistinctly laminated, organic rich, very fine-grained, medium gray to black lime mudstone to wackestone and rare dolomitic mudstone to wackestone. It is predominately non-fossiliferous with thin beds, rare burrow mottles, rare sub-vertical burrows, rare peloids, and rare stylolites. Laminae are either continuous, or taper out within a few centimeters, and are separated by thin organic or argillaceous laminae or lenses, giving the appearance of flaser-like bedding (Figure 37).

Microscopically, LFA-1A is observed to be a dolomitic micrite to sparse biomicrite and pelmicrite with elongate rip-up clasts of crystalline dolomite in a micritic and microcrystalline dolomitized matrix; and pelmicrite/wackestone with dolomite crystals, calcite grains, and microspar granular cement (Figure 27). Scattered within the micrite are rare unidentifiable fossil fragments, rare trilobite fragment, possible algal fragments, rare calcispheres, rare peloids, and local anhedral to subhedral dolomite in an equigranular peloidal fabric to mosaic-sutured fabric, with rare simple-wave stylolites, and a visually-estimated less than 1% fracture and stylolite porosity (CB-G, CB-H1, Sac-A11, Logan L-H1).

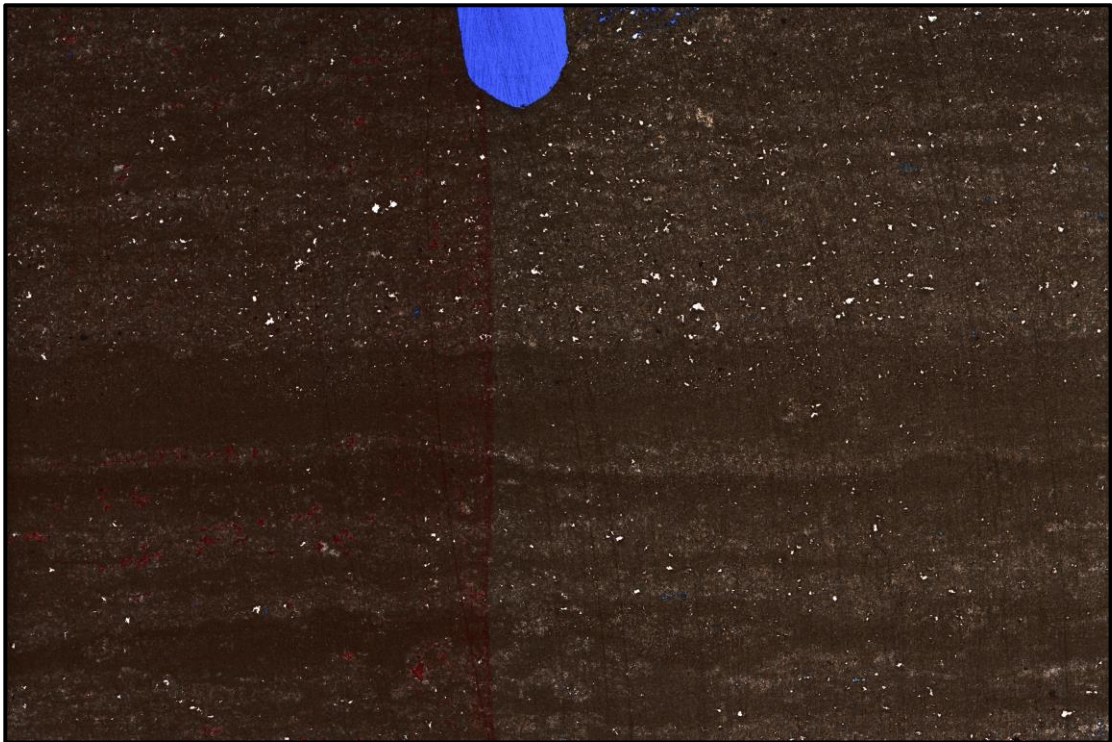


Figure 26. Whole thin section photograph showing well-laminated pelmicrite/packstone from Storm Castle Peak sample J1 interpreted to be lagoonal facies LFA-4C. Scale and view is approximately 3x2 inches, standard thin section size.

LFA-4C is interpreted to have been deposited in an inner lagoonal depositional environment where algal material and peloids are abundant and avoid winnowing due to low energy. Spherical stromatoporoids are interpreted to be washed into the lagoon from storm events as they are observed in masses within isolated beds. Anhydrite is interpreted to be the product of increasing restriction of the lagoon during higher frequency sea-level fluctuations or localized buildup of shoals thereby restricting flow in and out of the lagoon.

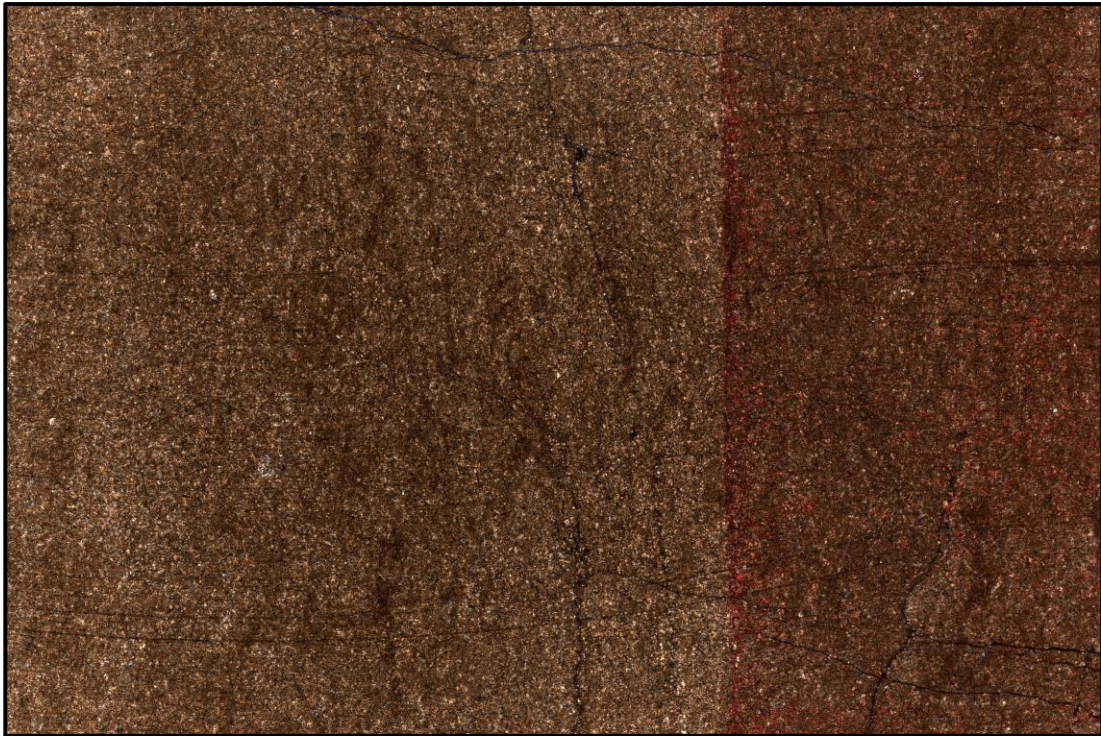


Figure 27. Whole thin section photograph showing a dolomitic micrite/mudstone interpreted to be facies LFA-1A. Sample H1 from Logan Gulch. Scale and view is approximately 3x2 inches, standard thin section size.

LFA-1A is interpreted to have been deposited in a very low energy, subtidal lagoonal depositional environment (deepest part of the lagoon) with

moderate to restricted circulation. Sedimentation is dominantly lime mud in an area generally protected from wave action, with minor, finely comminuted fossil debris generated and deposited during storm events.

LFA-5A

Macroscopically, LFA-5A consists of tan to pale red-green, fine to very fine-grained stromatolitic mudstone with faint laminations and very thin beds containing mud cracks, brecciated zones, rip-up clasts, and desiccation cracks. Bioturbation and oncoids are rare and microbial mats are common (Figure 38).

Microscopically, LFA-5A consists of micrite and dolomitic mudstone with microbial material (stromatolites) and micritic to microspar granular and microcrystalline cement (Figure 28). Peloids, foraminifera, calcispheres, and trilobite fragments are rare. Dolomite is anhedral to subhedral in an inequigranular fabric. A visual estimate of porosity is less than 5% and includes microporosity, fracture, intercrystalline, and intraparticle pore types (Gib-H8, Sac-A11, Haymaker HC1-F4, and BS-A8).

LFA-5A is interpreted to have been deposited in a low to moderate energy tidal flat depositional environment where sediment is submerged and exposed during tidal cycles, and skeletal material and peloids were derived from the lagoon or shoal.

LFA-6A

Macroscopically, LFA-6A is comprised of pale-yellowish-orange to moderate yellow and light gray, very fine-grained dolomitic mudstone to siltstone forming very thin to thin beds with anhydrite-gypsum weathering out to form vugs, fenestral porosity, crinkly algal laminations (cryptalgal laminite), brecciated zones, and desiccation cracks with anhydrite nodules and chicken wire structures common (Figure 39). This facies rarely outcrops due to its recessive nature; a function of its composition being mostly very fine carbonate mud.

Microscopically, LFA-6A is comprised of microcrystalline dolomite with algae and rare intraclasts and foraminifera (Figure 29). Dolomite is anhedral to subhedral in an equigranular fabric. No porosity was observed in the Sac-C4 thin section and a visual estimate of less than 10% porosity was observed in HC1-F4 which includes fracture and fenestral pore types.

LFA-6A is interpreted to have been deposited in a very low energy supratidal (sabkha) depositional environment where evaporites were common and the area was periodically wetted from storm events. Evaporites are interpreted to be deposited both during sea-level fall and rise which produced either brecciated surfaces due to exposure or complete preservation of strata by burial, respectively.

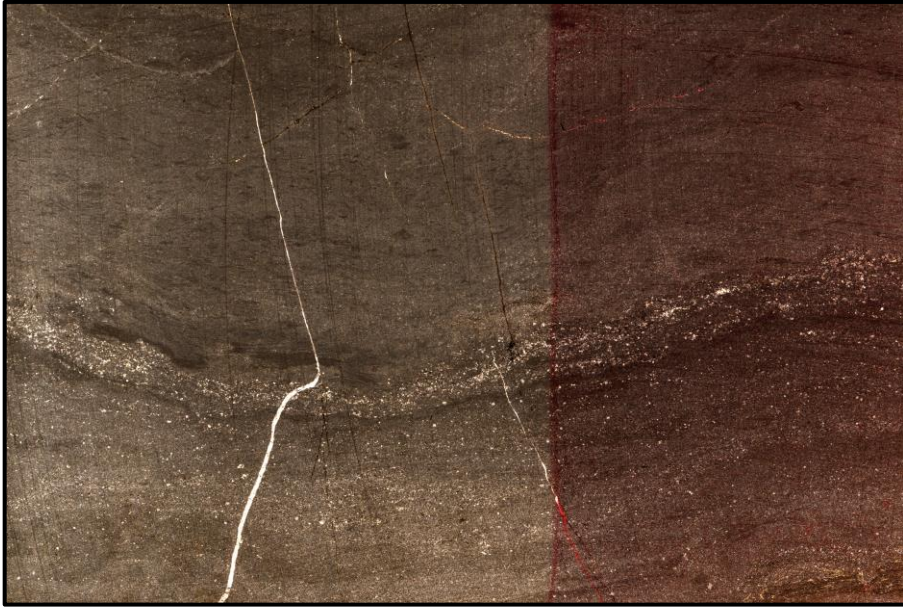


Figure 28. Whole thin section photograph of stromatolitic micrite/mudstone with floating to dispersed anhedral dolomite crystals. From Greathouse Peak sample A8 interpreted to be tidal flat facies LFA-5A. Scale and view is approximately 3x2 inches, standard thin section size.



Figure 29. Whole thin section photograph of cryptalgal dolomitic mudstone interpreted to be facies LFA-6A. Sample N from Logan Gulch. Scale and view is approximately 3x2 inches, standard thin section size.

Fore-Reef

Outcrop	Hand Sample	Description
		2A: Massive to very thick bedded to coarse to very coarse grained stromatoporoid boundstone to mudstone with corinoids, brachiopods, abundant tabular stromatoporoids, and nodular chert, weathers light to medium gray and medium to dark brown-gray fresh, forms knobby cliffs and is cross-bedded in places. Interpreted depositional environment: Fore-reef (low-moderate energy)

Figure 30. Lithofacies association 2A with outcrop and hand sample photos from Gibson Reservoir.

Reef

Outcrop	Hand Sample	Description
		2B: Very thick bedded medium to coarse grained framestone with crinoids, brachiopods, spherical stromatoporoids, weathers light to medium gray in color and light gray-brown fresh, forms knobby cliffs. Interpreted depositional environment: Reef (moderate to high energy)

Figure 31. Lithofacies association 2B with outcrop and hand sample photos from Sacagawea Peak and Gibson Reservoir.

Shoal-High Energy

Outcrop	Hand Sample	Description
		3A: Medium to coarse grained stromatoporoid and crinoidal grainstone, thick to very thick beds, contains brachiopod and coral fragments in places, medium to dark gray and grayish pink in color. Interpreted depositional environment: Shoal (high energy)

Figure 32. Lithofacies association 3A with outcrop and hand sample photos from Gibson Reservoir.

Moderate Energy Shoal or Shoreface

Outcrop	Hand Sample	Description
		3B: Medium to coarse grained skeletal packstone to grainstone with brachiopods, crinoids, rip up clasts, and brecciated zones, thin to medium bedded, light gray to grayish orange. Interpreted depositional environment: Shoal (leeward side of shoal or landward of lagoon, beach rock/shoreface)

Figure 33. Lithofacies association 3B with outcrop and hand sample photos from Sacagawea Peak and Gibson Reservoir.

Back-Reef or Patch Reef

Outcrop	Hand Sample	Description
		4A: Medium to coarse grained tabular stromatoporoid floatstone and boundstone with peloids and skeletal debris, brachiopods, bivalves, and trilobites common. Interpreted depositional environment: Back reef or patch reef (moderate energy)

Figure 34. Lithofacies association 4A with outcrop and hand sample photos from Sacagawea Peak.

Outer Lagoon

Outcrop	Hand Sample	Description
		4B: Faint to well-laminated, fine-grained, peloidal mudstone to wackestone, bioturbated in places, tan-brown color, thin bedded, few amphipora and spherical to hemi-spherical stromatoporoids in places. Interpreted depositional environment: Outer Lagoon (low energy)

Figure 35. Lithofacies association 4B with outcrop and hand sample photos from Gibson Reservoir.

Inner Lagoon

Outcrop	Outcrop and Hand Sample	Description
 	   	4C: Well-laminated, fine to medium grained, peloidal wackestone-packstone, medium to dark brown in color, thin bedded, laminae usually parallel and horizontal, amphipora and spherical to hemi-spherical stromatoporoids in places, interbedded anhydrite in core. Interpreted depositional environment: Inner Lagoon (low to moderate energy)

Figure 36. Lithofacies association 4C with outcrop and hand sample photos from Sacagawea Peak, Storm Castle Peak, and Gibson Reservoir.

Lagoon

Outcrop	Hand Sample	Description
		1A: Medium gray to black very fine to fine grained mudstone, organic rich, thin bedded, stylolitic, rare to few fossil fragments, peloids common, weathers chert-like or blocky, bioturbated in places. Interpreted depositional environment: Lagoon (deepest part, subtidal, very low energy)

Figure 37. Lithofacies association 1A with outcrop and hand sample photos from the Little Belt Mountains and Gibson Reservoir.

Tidal Flat

Outcrop	Hand Sample	Description
		5A: Fine grained, faintly laminated, stromatolitic mudstone, tan to pale red-green in color, very thin beds, contains mud cracks and brecciated zones in places, desiccation cracks and algal mats common, oncoids in places. Interpreted depositional environment: Tidal Flat

Figure 38. Lithofacies association 5A with outcrop and hand sample photos from Sacagawea Peak and Gibson Reservoir.

Supratidal

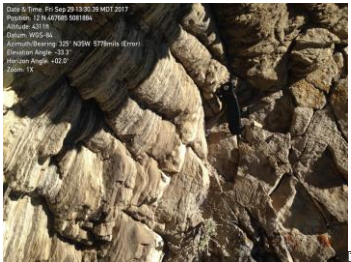
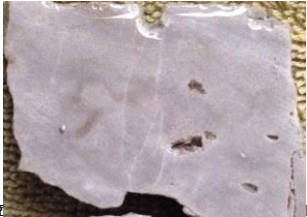
Outcrop	Hand Sample	Description
		6A: Very fine to fine grained mudstone with anhydrite-gypsum weathering out to form vugs and salt flats or fenestral porosity, crinkly algal laminations common, brecciated zones, desiccation cracks, chicken wire structures common, very thin to thin beds. Interpreted depositional environment: Supratidal (very low energy)

Figure 39. Lithofacies association 6A with outcrop and hand sample photos from Sacagawea Peak and Gibson Reservoir.

Depositional Environments

Using outcrop, hand sample, and thin section observations, I recognize six depositional environments based on lithofacies associations. These include fore-reef, reef, shoal, lagoon, tidal flat, and supratidal settings. More coarse-grained facies are interpreted to lie in a basinward direction while finer grained facies are interpreted to be more landward deposited from relatively decreasing wave energy.

A fore-reef is here defined as a low to moderate energy environment, below fair-weather wave base, where debris from the shoal and reef is distributed after being eroded by wave action or slumping and gravitational collapse. Fore-reef facies in the Duperow Formation are often much darker brown-gray than other facies and contain tabular stromatoporoids and reef debris. A reef is here defined as a moderate to high energy environment within fair-weather wave base where stromatoporoids flourish and sediment is produced and cemented penecontemporaneously. Reef facies in the Duperow Formation are often comprised entirely of spherical to hemispherical stromatoporoids and occasional corals and form thick to massive beds. A shoal is here defined as a high energy environment where stromatoporoids and skeletal debris are allochthonous and deposited by waves and carbonate mud is winnowed. Shoals within the Duperow Formation are comprised of stromatoporoids and skeletal debris and are thick bedded. A lagoon is here defined as a low to moderate energy body of water bound by shoals/reefs outboard and by tidal flats inboard. Lagoons within the

Duperow Formation are the most variable facies of the entire system. Lagoons are comprised of primarily carbonate mud with minor to moderate skeletal debris, occasional stromatoporoids, and evaporites. Tidal flats are here defined as moderate to high energy, periodically submerged and exposed carbonate mud flats, landward of the lagoon, where sediment is of both primary production from microbial mats and derived from the lagoon during tidal cycles or storm events. Tidal flat facies within the Duperow Formation are comprised of interbedded carbonate mudstones and shales with microbial mats and rare skeletal debris. Supratidal is here defined as a very low energy zone (sabkha), landward of a tidal flat, where microbial mats dominate and is submerged only during storm events or sea-level rise. Supratidal facies within the Duperow Formation are comprised of carbonate mudstones and shales with evaporites and microbial mats.

Facies Model

To interpret lateral and vertical facies relationships in outcrop and core, a generalized facies model was created based on lithofacies, lithofacies associations, and interpreted depositional environments (Figure 40). This provides a simplified method to interpret facies relationships and parasequences, parasequence sets, sequences, and composite sequence stacking patterns.

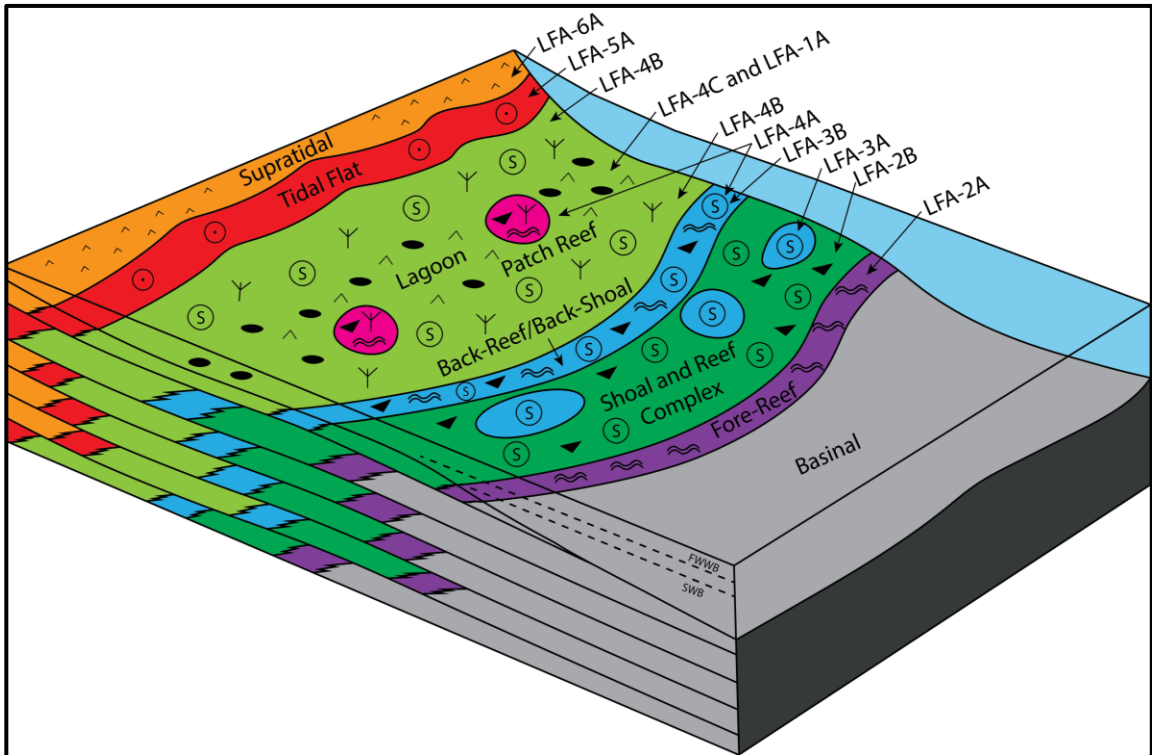


Figure 40. Generalized facies model for the Duperow Formation in western and central Montana. Basinal facies are not observed on the platform in Montana. Colors correspond to those in Table 3 and Appendix A-D. Modified after Flugel, 2010.

This model shows a gently dipping carbonate platform with a ramp-like geometry and little relief. From outboard to most proximal, facies within the Duperow Formation and in the study area include fore-reef, reef-shoal, back-reef/back-shoal, lagoon, patch reef, tidal flat, and supratidal.

CHAPTER FIVE

STRATIGRAPHIC FRAMEWORK

Sequence Stratigraphy

Sequence stratigraphy is a systematic method used to place significant elements of a depositional system into an interpreted framework that allows for predicting, correlating, and extrapolating facies, major depositional sequences, and their distribution to various parts of a basin (Vail et al., 1977; Van Wagoner et al., 1990; Blick & Driscoll, 1995; Catuneanu et al., 2011). Correlation using sequence stratigraphy is preferred over lithostratigraphy because traditional lithostratigraphy utilizes facies, facies boundaries, pebble lags, and transgressive surfaces as the basis for regional correlations and the subdivision of sedimentary rocks. Lithostratigraphy provides an excellent framework for mapping, defining, and naming stratigraphic units (Donovan, 1994). However, lithostratigraphy produces geometric stacking patterns that neither represent basin architecture in a reasonable way, nor agree with Walther's Law, which states that "Various deposits of the same facies-area and similarly the sum of the rocks of different facies-areas are formed beside each other in space, though in a cross-section we see them lying on top of each other..." (Walther, 1894, as referenced in Middleton, 1973). In contrast, sequence stratigraphy utilizes stratal surfaces as the basis for regional correlations. Stratal surfaces separate older rocks below from younger strata above, and therefore provide chronostratigraphic

significance (Catuneanu, 2006; Catuneanu et al., 2011). Since stratal surfaces typically cross lithostratigraphic boundaries and have chronostratigraphic significance, they can be used to subdivide the rock record into genetically-related packages of strata (beds, bedsets, parasequences, parasequence sets, sequences) that are inherently different from traditional lithostratigraphic units (beds, members, formations, groups). Thus, since sequence stratigraphy divides the rock record into time equivalent/genetically related packages, it provides a powerful tool to predict 3rd and 4th dimension facies distribution (Kreager & LaDue, 2017).

Third Order Sequences In the Duperow Formation

Third order sequences in the Duperow Formation average approximately 50 feet in thickness. I assume these are 3rd order cycles because of the thickness of parasequences and sequences in general on carbonate platforms however, no age constraint is possible from my data. Seven 3rd order sequences are recognized in the Duperow Formation except at Greathouse Peak where four are recognized (Appendix A and Figure 44). An additional eighth 3rd order sequence comprises the Nisku Formation. Each sequence is comprised of parasequences (Figure 41 and 42) which stack in a retrogradational pattern in the transgressive systems tract (TST) and in an aggradational to progradational pattern in the highstand systems tract (HST). Facies stack in a predictable pattern on the platform and their relationships are shown in detailed transect of a single 3rd order sequence in Figure 43. This transect is from distal to proximal

locations on the platform and attempts to account for the wrapping of facies around paleolows and paleohighs. Facies relationships and stacking patterns for all sequences within the Duperow Formation are then summarized in Figure 44 which is averaged and simplified in places to best represent how depositional environments are moving in response to sea-level changes across the platform.

The rate of sedimentation on carbonate platforms is a function of sediment producing organisms, sea-level, erosion, and subsidence (Bice, 1991; Masse & Montaggioni, 2001). Bosscher and Schlager (1993) use measured thickness of various carbonate platforms from geologic history and throughout the world to calculate that carbonate platforms grow at an average of 100 m/my. Using this time estimate and the Duperow Formation's average thickness of 350-400 feet in western and central Montana, the rate of deposition for the Duperow Formation was approximately 10.6-12.2 m/my. Powder et al. (1980) obtained a total thickness of the Nisku Formation in Alberta of 124 meters deposited over 3.5 my. This means the Nisku Formation in Alberta was deposited at an average rate of 35.4 m/my and because the platform in Montana is much shallower than that of the Alberta Basin, the rate of 10.6-12.2 m/my for Duperow Formation deposition in Montana is reasonable. This sedimentation rate does not account for missing time during lowstands and unconformities and therefore, is a generalized number that depicts uniform sedimentation over a constant interval without interruption from other factors such as sea-level change. The actual rate of sedimentation on

the platform is likely higher than this averaged value when unconformities and periods of exposure are considered.

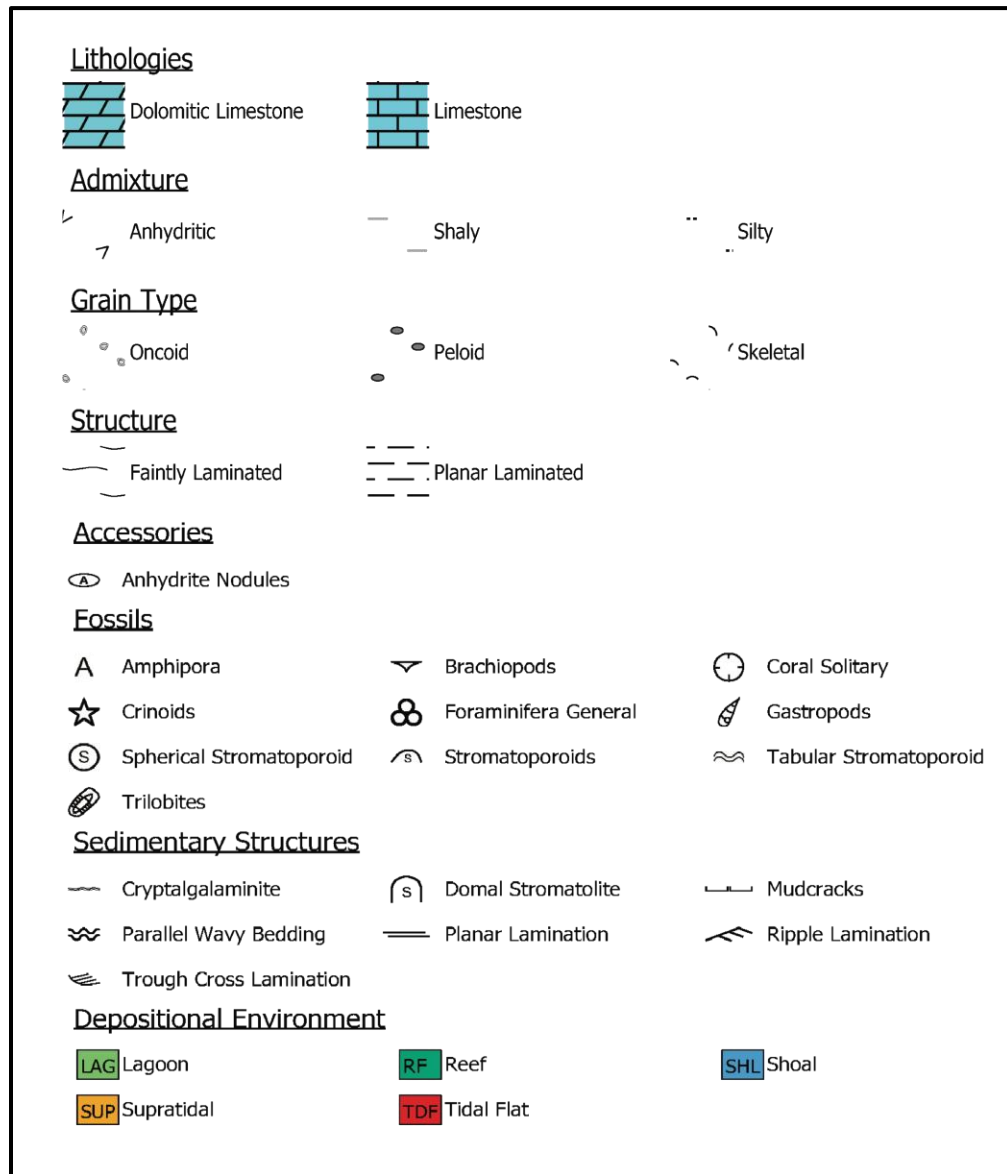


Figure 41. Legend for parasequences observed in the Duperow Formation in Montana (Created using ©EasyCore Software).

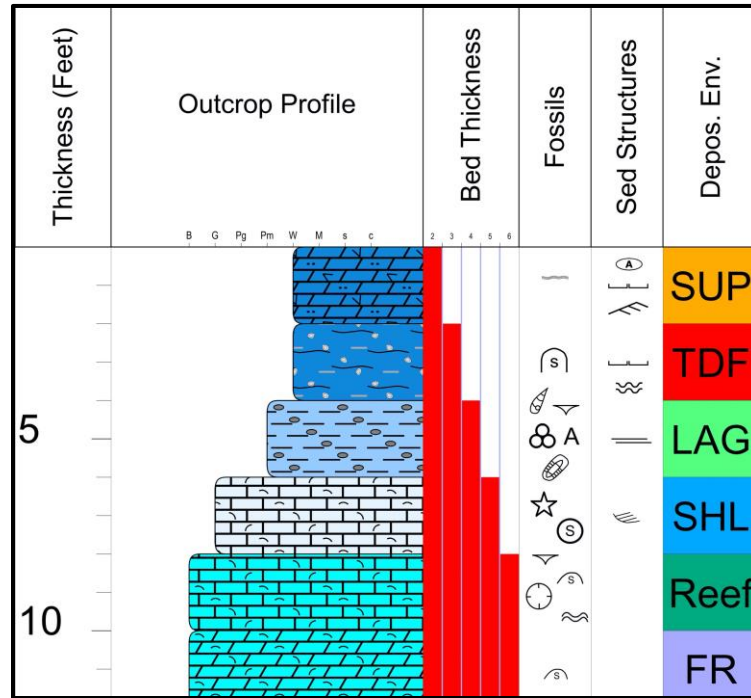


Figure 42. Ideal parasequence in the Duperow Formation. All facies are rarely present in a single parasequence (Created using ©EasyCore Software).

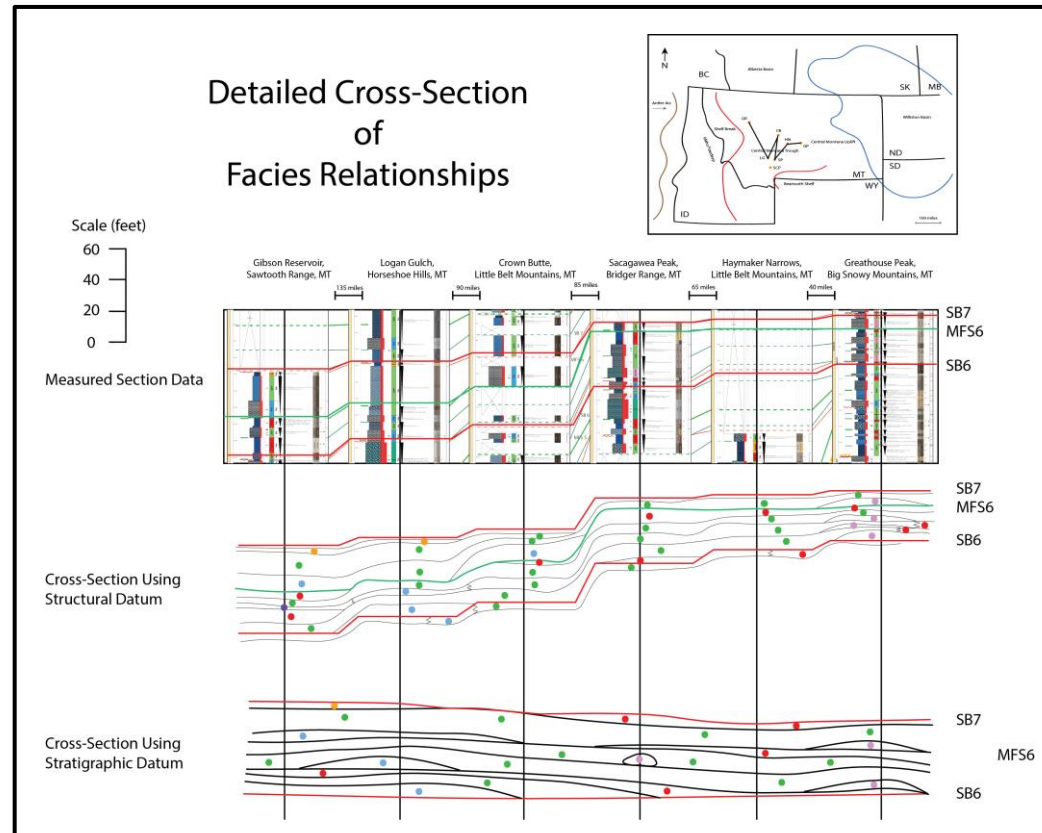


Figure 43. Cross-section of 3rd order sequence 6 showing geometry and transition of facies between measured sections. Colored dots match depositional environment colors from measured sections.

Gibson Reservoir. The first sequence from the base of this section is a series of parasequences comprised of lagoonal to shoal and tidal flat facies. The maximum flooding surface (MFS) in this sequence is placed within the reef between 410-420 feet and is followed by a progradational parasequence(s) that shoals to exposure as revealed by a heavily brecciated, coarse skeletal grainstone with supratidal mudstone unconformably above.

The second sequence recognized is comprised of supratidal mudstones and evaporite beds at the base unconformably overlying shoal facies of the sequence below and are interpreted to represent early TST intertidal deposits. The remainder of the TST is comprised of retrogradationally stacked parasequences with the MFS placed at the base of the highest shoal at 354 feet. From here, parasequences modestly prograde and lagoonal facies dominate the HST.

The third sequence is interpreted to begin where there is a significant landward shift in facies from lagoonal to fore-reef and reef facies at 329 feet. This surface is interpreted to represent both the sequence boundary and subsequent transgressive surface (TS). From here, the sequence stacks retrogradationally up to the MFS placed at 317 feet at the base of the highest shoal. From this point, the sequence stacks progradationally with thinning upward parasequences. A shoal near the top of the sequence is interpreted to be the product of higher frequency sea-level fluctuations and represents shallower water depths and decreasing accommodation compared to the thicker parasequences below.

The fourth sequence is interpreted to begin where fore-reef and reef facies overly lagoonal facies. This surface is again interpreted to represent superposition of the transgressive surface over the sequence boundary. Retrogradationally stacked parasequences transition at the MFS, at 240 feet, to progradational parasequences comprised of alternating lagoon and shoal facies. A slight thinning of parasequences is observed transitioning from the TST to HST however, this attribute is not as pronounced in this sequence compared to others.

The fifth sequence is interpreted based on parasequence thickness and recognized sequence boundaries at Sacagawea Peak, Haymaker Narrows, and Greathouse Peak that are then traced across sections. The most reasonable place for this sequence boundary is as shown at 210 feet where parasequences have stacked in a progradational manner and thinned from below then rapidly deepen and thicken above. No lowstand (LST) deposits are present and the transgressive surface (TS) is placed on top of the sequence boundary. The MFS is interpreted to be within the lower third of the massive reef-shoal complex present which could not be subdivided further in the field due to the homogeneity of this package of strata. Reef and shoal facies in the uppermost portion of this sequence are capped by supratidal deposits comprised of brecciated mudstones revealing both a basinward shift in facies and an exposure surface. The following sequence boundary is placed above these supratidal deposits that have been

brecciated and contain rip-up clasts interpreted to be the result of platform exposure.

The sixth sequence is comprised of thin bedded lagoonal and predominantly tidal flat deposits at the base that are eventually overlain by shoal facies as sea-level continues to rise. The MFS is placed at the base of the highest shoal facies at 136 feet. The sequence then shoals to exposure where supratidal deposits unconformably overly lagoonal facies.

The seventh sequence is covered however, the Nisku Formation is exposed and therefore a seventh sequence is interpreted to be represented by this covered portion. The MFS of 2nd order cycle number two is interpreted to be just above this sequence boundary.

The Nisku Formation here is comprised of a thin parasequence at the base and an MFS is placed at the base of the shoal deposit above this parasequence. This is also the first 2nd order cycle MFS. The majority of the Nisku Formation is interpreted to represent an early to late aggradational and progradational highstand here dominated by shoal and lagoonal facies. From the MFS, parasequences thin upward.

Logan Gulch. The first sequence at Logan Gulch is comprised of a thick stack of lagoonal facies that cannot be definitively divided into smaller parasequences than what is shown. The MFS is placed at the base of the back-reef facies at 426 feet and the HST is comprised of a thick package of lagoonal facies which reveals this location had greater accommodation and perhaps

deeper water than other parts of the platform at that time. Supratidal mudstones with cryptalgal laminate beds unconformably overly these lagoonal facies at 390 feet revealing the next sequence boundary.

The second sequence is a series of retrogradationally stacked parasequences with the MFS placed at the base of the thickest parasequence and highest shoal at 353 feet. This is also the 2nd order MFS. From here, the sequence shoals upward into lagoonal and tidal flat facies. The next sequence boundary is placed on top of heavily brecciated lagoonal rocks that are unconformably overlain by reef facies. The brecciation in the lagoonal rocks is interpreted to be the result of a late HST restricted environment where anhydrite was deposited and later dissolved out during shallow burial.

The third sequence is comprised of retrogradationally stacked parasequences with the MFS placed at the base of the highest reef at 299 feet. From here, parasequences prograde and thin upward and are capped by a brecciated lagoonal facies unconformably overlain by supratidal deposits of the following TST. This surface separating the third and fourth sequences is karsted.

The fourth sequence is comprised of thin intertidal to supratidal mudstones at the base and a single parasequence above comprised solely of lagoonal facies. The MFS is placed at the base of the first shoal at 236 feet coincident with MFS's traced across from Gibson Reservoir and Crown Butte. From here, parasequences thin slightly. A sequence boundary is interpreted to be at the base of a green fissile shale bed at 202 feet that lies on top of shoal

facies. This sequence boundary was chosen based on the thinning of parasequences from the MFS below to this point, the observed average thickness of sequences, and surfaces traced across from neighboring sections. This green shale bed can also be traced across sections based on surface geometry to the Greathouse Peak section on the Central Montana Uplift.

The fifth sequence is comprised of thickening upward and retrogradationally stacked parasequences. The MFS is placed at the base of a thick, heavily brecciated reef developed at 177 feet. Brecciation of this unit is likely the result of burial diagenesis. The next sequence boundary is placed on top of this reef as the geometry of this correlative surface can be traced from a more basinal direction at Gibson Reservoir where supratidal facies unconformably overlie reef and shoal facies suggesting that sea-level on the platform is falling. Resolution above this unit in outcrop and at this boundary is poor and therefore, the main basis for this sequence boundary is based on supratidal facies laying unconformably on more basinward facies at both Gibson Reservoir and Sacagawea Peak.

The sixth sequence is an aggradational stack of shoal and lagoonal facies with the MFS placed within the uppermost lagoonal facies at 134 feet. The lagoon is interpreted to be restricted below this surface, as evidenced by evaporite formation and subsequent dissolution. The sequence is interpreted to shoal to exposure as supratidal facies unconformably overly lagoonal facies.

The seventh sequence is another thick stack of shoal and lagoonal facies with the MFS placed within a thick package of lagoonal rocks at 85 feet. From here, the sequence shoals upward before sea-level falls depositing supratidal facies. The next sequence boundary is placed above these supratidal facies.

The overlying Nisku Formation is comprised of alternating lagoonal and shoal facies that represent the final 3rd order cycle of Frasnian seas on the platform. The next sequence boundary is placed at the base of the Three Forks Formation where evaporites have been dissolved out to form a brecciated siltstone.

Crown Butte. Surfaces are less defined here due to alternating outcrop and cover however, the geometry of sequences at Logan Gulch, basinward of Crown Butte, and those at Sacagawea Peak, landward, can be used to best interpret how this section fits into a sequence stratigraphic framework. Three sequence boundaries are definitively recognized with the remainder interpreted to be within covered portions.

Sequence one is comprised of retrogradationally stacked parasequences at the base with the MFS placed at 399 feet. This MFS could also be just below or within the reef facies developed at this location. The remainder of the sequence is covered except for a short interval of lagoonal facies. It is interpreted that this sequence shoals to exposure as revealed by supratidal facies unconformably overlying more basinward facies at Gibson Reservoir, Logan Gulch, and Sacagawea Peak.

Sequence two is comprised of subtidal parasequences with the MFS placed at the base of the highest shoal at 331 feet. From here, the sequence shoals, possibly to exposure as observed at Sacagawea Peak and Logan Gulch.

Sequence three is comprised of significant cover and therefore no parasequences are definitively recognized. This sequence is interpreted to shoal to exposure as revealed by supratidal facies above the overlying sequence boundary and brecciated lagoonal facies at Logan Gulch.

Sequence four is comprised of supratidal deposits and lagoonal facies at the base, interpreted to represent TST deposits. The MFS is placed at the base of the reef at 220 feet and progradational parasequences represent the HST. In a landward direction, this sequence shoals to exposure as revealed by brecciated units at Sacagawea Peak, Haymaker Narrows, and a karsted surface at Greathouse Peak however, no direct evidence for exposure exists at Crown Butte due to cover. There is also no evidence for exposure basinward and therefore it is possible Crown Butte remained submerged at this time.

Sequence five is comprised of lagoonal facies and is largely covered. The MFS is interpreted to occur between 150-160 feet correlating with the MFS at Logan Gulch and Sacagawea Peak.

Sequence six is comprised of lagoonal and shoal facies with significant cover. The MFS is interpreted to occur at the base of the shoal developed at 118 feet. This sequence is interpreted to shoal to exposure as revealed by exposure in basinward directions.

Sequence seven is comprised of all lagoonal facies that appear to deepen then shoal to exposure. The MFS is placed at 75 feet and interpreted based on relationships with Logan Gulch and Sacagawea Peak.

The Nisku Formation at Crown Butte is comprised of a single parasequence at the base with the MFS placed at the base of a developed reef revealing the most landward shift in facies during this 3rd order sequence. From here, the sequence stacks aggradationally to progradationally. The upper portion is covered however, a significant break in slope and green shale beds of the Trident Member of the Three Forks Formation outcrop well above.

Sacagawea Peak. The first sequence here is comprised of a single parasequence at the base and the MFS is placed above this at the bottom of the back reef at 393 feet. It is possible that a portion of or all of this back-reef facies is part of the underlying parasequence comprised of lagoonal facies. Therefore, the MFS may lie within the back-reef facies but is not interpreted to be at the base of the overlying shoal based on correlation from other sections. From here, the sequence shoals upward to the next sequence boundary at 369 feet where shoal facies overly tidal flat facies.

The second sequence is comprised of retrogradationally stacked parasequences at the base with the MFS placed within the reef facies at 357 feet. This MFS lies within a thick package of reef and shoal facies that could not be further divided into smaller parasequences. From here the sequences stack aggradationally and then shoal to exposure.

The third sequence is comprised of intertidal parasequences at the base that progressively thicken upwards. The MFS is placed at the base of a thin shoal developed at 289 feet. From here, the sequence shoals upward to exposure as revealed by supratidal deposits unconformably overlying lagoonal facies.

The fourth sequence is comprised of a thick package of lagoonal, tidal flat and supratidal mudstones that could not be differentiated into individual parasequences due to poor exposure. This portion of strata is interpreted to contain multiple 4th order parasequences. The upper portion of this sequence is covered, and the MFS is placed at the top of the tidal flat facies at 205 feet as best correlated across from other sections. The next sequence boundary is placed above one of the thinnest parasequences and based on the correlation of surfaces from neighboring sections.

The fifth sequence is comprised of retrogradationally stacked parasequences with the MFS placed at the base of the thick reef developed at 162 feet. The remainder of the sequence is comprised of progradational parasequences with the next sequence boundary placed where tidal flat facies unconformably overlie shoal facies.

The sixth sequence is comprised of lagoonal, back-reef, and tidal flat facies with the MFS interpreted to occur at the base of the highest lagoon at 107 feet based on correlations with other sections. From here, the sequence shoals to exposure as revealed by brecciated lagoonal facies and exposure in a basinward direction.

The seventh sequence is covered at the base with two parasequences exposed higher up at the contact with the overlying Nisku Formation. The sequence boundary is placed at the top of a brecciated shoal below Nisku strata.

The Nisku Formation is comprised of a thick package of shoal and reef facies that could not be further divided in the field. Based on the thickness of the Nisku Formation here, there are likely 3 parasequences that stack in a retrogradational manner up to the MFS and then stack aggradationally to progradationally. A brecciated shoal facies at the contact with the overlying Three Forks Formation reveals that the platform was exposed post-Nisku deposition and pre-Three Forks time.

Haymaker Narrows. The first sequence here is the most complete and is comprised of retrogradationally stacked parasequences with the MFS placed at the base of the first reef at 356 feet. Above overlying highstand parasequences, the sequence is covered and interpreted to shoal to exposure since basinward sections at Logan Gulch and Gibson Reservoir show possible evidence of such.

Most of the second sequence is covered and the MFS is interpreted to be within the upper portion of cover or at the base of the shoal that outcrops at 303 feet. The remainder of the sequence is interpreted to shoal to exposure based on basinward observations.

The third sequence is significantly covered however, the MFS is placed and interpreted to occur within the covered portion above the developed reef at 251 feet based on the MFS at Gibson Reservoir, Logan Gulch, and Sacagawea

Peak that can be traced to this location. The top of this sequence is covered and interpreted based on surface trajectories correlated from other sections.

The base of the fourth sequence is covered however, the MFS is interpreted to occur near 170 feet based on the geometry and trajectory of correlations made from Sacagawea Peak. The upper exposed portion reveals facies with a progradational stacking pattern interpreted to represent the HST with exposure at the overlying sequence boundary.

The remaining sequences are covered however, three are interpreted to exist based on those observed at Sacagawea Peak and Greathouse Peak. The contact with the Madison Group limestone above can be interpreted from the change in slope angle. None of the Three Forks Formation is recognized here as the slope is covered. The White Sulphur Springs 30' x 60' Geologic Map shows only a "trace" of Three Forks strata to be present at this location (Reynolds & Brandt, 2007). Field notes, Google Earth, and thickness measurements from Campbell (1961) were used to estimate the Duperow-Nisku Formation contact and Nisku-Three Forks Formation contact here.

Greathouse Peak. At Greathouse Peak, four 3rd order sequences are recognized and interpreted to correlate to the upper four sequences in the Duperow Formation at all other measured sections. The lower three sequences from other sections are interpreted to lap out prior to reaching this section.

The first sequence recognized here is comprised of retrogradationally stacked parasequences with the MFS placed at the base of the thickest

parasequence at 132 feet. From here, parasequences thin and stack progradationally to exposure as revealed by a brecciated shoal and karsted surface.

The second sequence is comprised of retrogradationally stacked parasequences at the base with the MFS placed at 107 feet. From here, the sequence stacks progradationally and shoals to exposure as revealed by exposure in a basinward direction.

The third sequence is comprised of retrogradationally stacked parasequences that shoal upwards with the MFS placed at the base of the thickest parasequence and back-reef at 68 feet. From here, the sequence continues to shoal upward and stacks progradationally, likely to exposure. Although exposure is not recognized here, exposure is documented in a more basinward direction.

The fourth sequence is comprised entirely of subtidal parasequences with the MFS placed at 38 feet based on correlative surfaces traced across from other sections. This sequence is exposed at the Duperow-Nisku contact.

A fifth sequence comprises the Nisku Formation. The Nisku Formation here is comprised of a thick package of shoal facies at the base interpreted to represent sea-level rise with thin bedded lagoonal facies above interpreted to represent the following HST. This sequence is then overlain by a thin black shale bed correlated to the black shale bed at the base of the Lodgepole Formation

and equivalent black shale bed in the Exshaw Formation in Alberta (Sandberg, 1967; Smith and Bustin, 2000).

Storm Castle Peak. The approximately 50 feet of Duperow Formation exposed here is comprised of at least 6 parasequences that crop out well in small cliffs. However, no evidence of third-order transgressive surfaces or sequence boundaries are recognized due to cover (Appendix C). It is possible the exposed portion represents a single 3rd order sequence based on parasequence stacking patterns and general thickness compared to that of 3rd order sequences in nearby sections however, no attempt was made to fit this section into the developed sequence stratigraphic framework due to the high degree of cover and minimal constraint of the section's correlation with other measured sections. The Nisku Formation is well-exposed here and comprised of retrogradationally stacked parasequences up to the MFS placed at the base of the thickest parasequence at 345 feet. From here, parasequences stack in a progradational manner and thin upward. An intrusive sill is present at the contact between the Nisku Formation and the Three Forks Formation. This location presents further challenges for studying the Nisku Formation because at no other location presented here was the Nisku Formation observed to be completely cross-bedded and interbedded with 4-6" chert nodules throughout. From a paleogeographical perspective, this location lies on the southern margin of the Central Montana Trough approaching the Wyoming-Beartooth Shelf which appears to have played a significant role in sedimentation.

Wallewein 22-1 Core. Two to four 3rd order sequences are represented by the core and correlate to sequences 6 and 7 in measured sections.

Four 3rd order sequences are recognized in the Wallewein 22-1 core based on parasequence stacking patterns, disconformable facies relationships, and general observed thicknesses as compared to measured sections.

The first sequence is comprised of one thick parasequence at the base with a transgressive surface interpreted to exist between the shoal and overlying reef facies at 4140 feet. The MFS of this sequence is placed at the top of the first parasequence where the highest shoal exists. A thinner parasequence is then overlain by a sequence boundary at 4090 feet interpreted based on correlations with the Danielson 33-17 and Plain Kevin 15-26 cores, general thickness of sequences, and parasequence stacking patterns. This single parasequence within the highstand likely contains more than one aggradationally stacked parasequences in the shoal facies above the MFS that could not be further separated out. Therefore, this HST is comprised of at least 2, if not 3 parasequences some of which are difficult to resolve within the thick shoal and lagoonal facies present.

The second sequence is comprised of retrogradationally stacked parasequences with significant anhydrite interbedded in lagoonal facies. These parasequences thicken upward to a MFS at 4056 feet which is also the base of the highest shoal in the sequence. The next sequence boundary is placed at

4042 feet where crinkly laminated mudstones, interpreted to be of supratidal origin, unconformably overly shoal facies.

The third sequence is comprised of interbedded anhydrite and dolomitic mudstones with minor back-reef to patch reefs developed which together reveal occasional restriction. The sequence is comprised of thickening upward retrogradationally stacked parasequences up to the MFS placed at 4004 feet and the base of the thickest parasequence. From here, parasequences thin upward and progradationally stack with an increasing abundance of anhydrite and a sequence boundary is placed at 3966 feet based on parasequence stacking patterns and a change from thinning upward to thickening upward parasequences.

The fourth sequence is comprised of thickening upward and retrogradationally stacked parasequences with the MFS placed at 3951 feet where the only shoal is developed. Above the MFS is a thick aggradational to progradational stack of parasequences comprised of black burrowed mudstone, interpreted to be the product of continued sea-level rise in the HST, and more common dolomitic mudstone-wackestone-packstone lagoonal facies that become increasingly restricted with evaporite deposition in the top 30 feet. The evaporites are believed to occur here due to increasing restriction in the HST. No sequence boundary is observed within the core however, based on the general thickness of 3rd order sequences in the Duperow Formation, the next sequence boundary is likely near the top or just above the strata that this core represents.

Danielson 33-17 Core. Three complete 3rd order cycles are recognized in the Danielson 33-17. A sequence boundary is placed at 3446.5 feet, the base of the core section, where lagoonal facies unconformably overly reef facies.

The first sequence is comprised of a single parasequence of lagoonal facies with interbedded anhydrite. The MFS is placed at 3433 feet at the base of the developed reef but may occur within the reef and shoal complex above as its exact location is indistinguishable. The next sequence boundary is placed at 3385 feet where fore-reef facies overlie shoal facies revealing rapid deepening that is here interpreted to also represent a transgressive surface superposed on a sequence boundary. This sequence boundary was chosen based on the average sequence thickness observed in measured sections and correlations with the other cores.

The second sequence is interpreted to be comprised of a single parasequence at the base, however there are likely at least two parasequences here with the MFS at the base of or hidden within the thick shoal facies. From this point, parasequence(s) shoal upward through lagoonal and tidal flat facies that are then overlain by a thin shoal deposit described as a stromatoporoid rudstone which may be the product of a storm event or a final surge before sea level falls relative to the platform. The top of this shoal is an unconformity with tidal flat facies above at 3343 feet. This is interpreted to be the next sequence boundary.

The third sequence is comprised of retrogradationally stacked parasequences from intertidal dominated at the base up into subtidal dominated. Within this TST, the parasequences also show a thickening upward trend. The MFS is placed at 3325 feet at the base of the fore-reef - reef complex. The thickest parasequence unconformably overlies shallower water lagoonal facies. The thickness of this fore-reef and reef complex reveals that organisms kept up with sea-level rise, stacking aggradationally before prograding in the late highstand. A localized exposure surface exists at the top of this section as revealed by back-reef to patch reef facies unconformably overlying stromatolitic mudstones of tidal flat facies. The next sequence boundary is placed at 3282 feet where fore-reef deposits lie on top of restricted lagoonal facies. Although this relationship is a normal flooding surface, it is interpreted that a sequence boundary is also located here because of the consistent thickness of sequences observed in outcrop and correlation with the other cores. This lagoonal facies with interbedded anhydrite is interpreted to be the product of increasing restriction during late HST.

Plain Kevin 15-26 Core. One complete 3rd order sequence is recognized in the Plain Kevin 15-26 with part of a second present. A sequence boundary and superposed transgressive surface are placed at the base of the core section where fore-reef facies overly lagoonal facies but may occur just below the strata that this core represents as correlated with the other cores and known average thickness of sequences from measured sections.

The first sequence is comprised of subtidal parasequences at the base that thicken upward and stack retrogradationally. The MFS is placed at 3930 feet at the base of the thickest parasequence. From here, the sequence becomes increasingly restricted with abundant anhydrite present in the uppermost parasequence interpreted to represent a late highstand restricted environment as the rate of sea-level rise decreases and then falls. The next sequence boundary is placed at 3898 feet where reef facies unconformably overly lagoonal facies. This sequence boundary is based on correlation from the Danielson 33-17 and Wallewein 22-1, the general thinning of parasequences, and a dominance of more landward facies (lagoon and back-reef) compared to lower in the sequence where reefs and shoals dominate.

The second sequence is comprised of thickening upward, subtidal parasequences with the MFS placed at the base of the second reef at 3966 feet. The next sequence boundary is likely just above the top of the core based on the known average thickness of sequences from measured sections.

Second Order Sequences In the Duperow Formation

Second order sequences are comprised of higher frequency 3rd order sequences and subordinate 4th order sequences. In any given location it is rare to see all Duperow facies present in a single parasequence (Figure 42). The Duperow Formation, in Montana, resides on a low angle ramp with no evidence for significantly deeper water until the shelf break along the northwest Montana-Idaho border trending down through central Idaho, and the northern margin of the

platform on the Canadian border. Increased accommodation is revealed by slight thickening of sections into the Central Montana Trough.

Two second order sequences are recognized in measured sections and summarized in Figure 44. Sequence one is comprised of a transgressive systems tract (TST) and highstand systems tract (HST) and ranges in thickness from 160-220 feet thick. The unconformity at the top of the Maywood Formation and base of the Duperow Formation is interpreted as a 2nd order sequence boundary with no evidence of lowstand (LST) deposits between this boundary and the overlying transgressive surface (TS). This 2nd order sequence is comprised of three 3rd order sequences. In the 2nd order transgressive systems tract, reef and shoal facies extend from the margin to Crown Butte and Sacagawea Peak shortly after initial transgression and move in a landward direction revealing the sequence is continuing to flood back onto the platform. Lagoonal facies are most abundant and thickest in the middle of the Central Montana Trough at Logan Gulch. Intertidal facies fringe the Central Montana Trough and alternate with shoal and lagoonal facies as higher frequency (4th order) sea level fluctuations occur. The maximum flooding surface (MFS) is interpreted to occur near the base of the second 3rd order sequence where basinward facies have shifted significantly landward. Above the MFS, 3rd order stacking changes to progradational in the highstand (HST). The next 2nd order sequence boundary is interpreted to merge with the unconformity interpreted as the first 2nd order sequence boundary at the top of the Maywood and base of the

Duperow Formations at Greathouse Peak located on the margin of the Central Montana Uplift (Figure 44). Third-order sequence boundaries and flooding surfaces within this first 2nd order sequence are interpreted to lap out prior to reaching the Central Montana Uplift and Greathouse Peak section. This is interpreted based on the thinned Duperow Formation and the presence of Nisku Formation strata revealing that significant flooding of this paleohigh had to occur by end Frasnian as global sea-level peaked at this time. The absence of these lower cycles are interpreted to be the result of non-deposition due to a broad gently uplifted paleohigh coincident with reactivated basement lineaments. Three Forks Formation (Famennian) strata are not present at this location which reveals continual uplift and or post-Famennian, pre-Mississippian erosion of the region.

Sequence two is comprised of five 3rd order sequences within a 2nd order transgressive and highstand systems tract with no evidence for lowstand systems tract strata in the study area. This sequence ranges in thickness from 200-265 feet thick depending on location on the platform and excluding Greathouse Peak on the Central Montana Uplift. The transgressive surface of this 2nd order sequence is interpreted to correlate (merge) with the first 2nd order sequence transgressive surface placed on the unconformity between the top of the Maywood and base of the Duperow Formations at Greathouse Peak.

Thin packages of shoal and reef facies are well-developed in the overlying Nisku Formation at Crown Butte, Sacagawea Peak, and Greathouse Peak

revealing that the MFS of this 2nd order sequence is stratigraphically at the base or just below the base of the Nisku Formation itself. Pale green dolomitic shale beds present at the contact between the Duperow Formation and the Nisku Formation in the study area are interpreted to be the most likely place for a MFS that resulted in deposition of the more basinal facies described above. The presence of shoal complexes in the uppermost Duperow and Nisku Formations at Greathouse Peak is particularly important as this section lies on the Central Montana Uplift meaning that this topographically high feature had to be submerged or partly submerged by late Frasnian time as a transgression occurred and onlap moved progressively landward. The same relationship occurs at Sacagawea Peak, also a slight paleohigh at the time (McMannis, 1955). The thick reef and shoal facies comprising the Nisku Formation at Sacagawea Peak supports the interpretation of a MFS near the base or at the base of the Nisku Formation itself. In the Williston Basin, the regional MFS is placed just below the Nisku Formation within the Ireton Formation black shale. There is no black shale in western and central Montana however, dolomitic pale green shales are observed throughout the Duperow revealing a shallow, well-oxygenated environment at flooding surfaces compared to deeper potentially anoxic waters in the Williston and Alberta basins. Within the upper Duperow Formation, widespread carbonate mudstones interbedded with anhydrite form recessive slopes and explain why the upper part of the formation is less exposed compared to lower in the formation.

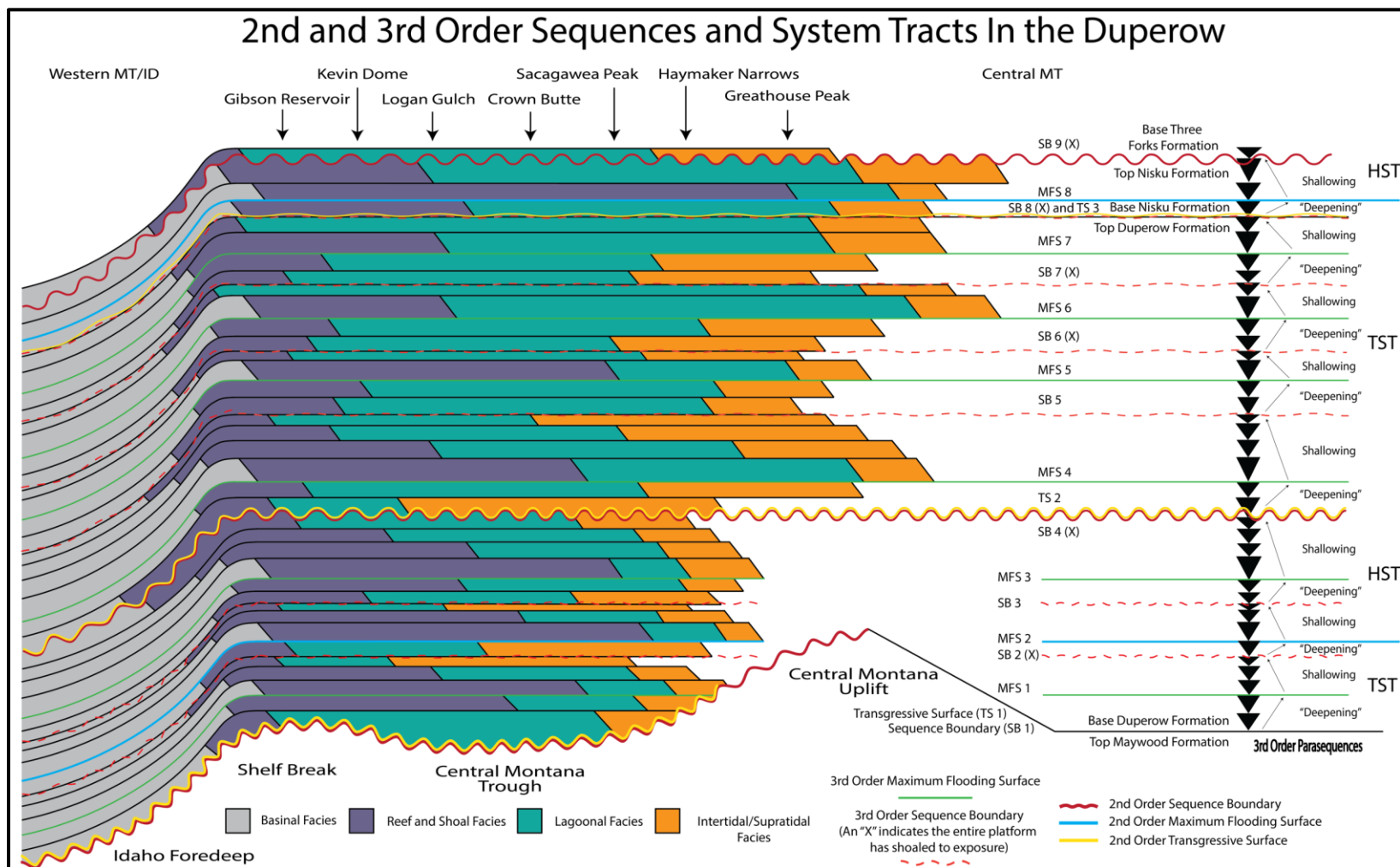


Figure 44. Summary of 2nd and 3rd order sequences in the Duperow Formation in western and central Montana.

Paleogeography

The Central Montana Uplift and Central Montana Trough are interpreted to be the result of reactivated zones of weakness within basement rock that produced areas of positive and negative relief on the Duperow platform (Nelson, 1995). Data collected within this study corroborates this interpretation. Measured section thicknesses of the Duperow Formation can be used to construct an isopach map that combines paleo-geographic features with field data and previous work by other authors to better constrain these basement tectonic influences on 2nd order sea-level fluctuation and sedimentation patterns (Figure 45).

The Duperow Formation thickens west and southwest towards the Idaho Foredeep, a trench-like and prominent negative feature outboard of the platform margin. This feature is associated with the Antler Orogeny and is interpreted to have trapped clastics as they were eroded and shed from the Antler Highlands (Speed & Sleep, 1982; Dickinson et al., 1983; Ketner, 2012). Siliciclastics are not observed in the Duperow Formation with the exception of dolomitic silty shale beds at flooding surfaces. Therefore, coarse siliciclastics did not reach the platform in western and central Montana. Minor siliciclastics are observed at flooding surfaces which the author interprets to originate either from the Central Montana Uplift or the Beartooth Shelf in Wyoming.

The Duperow Formation also thickens to the north and northeast, off the Central Montana Uplift, and into the Alberta and Williston basins, respectively. In

eastern Montana, the Duperow Formation thickens rapidly into the Sheep Creek Syncline and thins onto the adjacent Cedar Creek Anticline. To the south of the Central Montana Uplift, the Duperow Formation is a consistent thickness until reaching the zero edge on the Beartooth-Wyoming Shelf. Abrupt thickening occurs in southeast Idaho approaching the Snowcrest Trough and on the west side of the Lemhi Arch of central Idaho. The Lemhi Arch is a paleohigh associated with basement involved faulting much like the Cedar Creek Anticline and Central Montana Uplift (Sloss, 1954). This feature could have prevented clastics from reaching the platform in Montana and created a fairway-like margin in southwest Montana where the Duperow Formation thickness is fairly constant and merges with the Central Montana Trough (Figure 45).

The thinner Duperow Formation and general prevalence of tidal flat and supratidal facies preferentially preserved at Sacagawea Peak compared to other sections leads to the interpretation that this location was positioned on the margin of the Central Montana Trough and fringed the Beartooth-Wyoming Shelf. This is the only section with an abundance of interbedded shaly mudstone and siltstone in what are interpreted as supratidal and tidal flat facies. Tidal flat facies and intertidal parasequences are also prevalent in the lower half of the Greathouse Peak section. These observations support the interpretation that intertidal facies at times prograded from both the east and southeast off the Central Montana Uplift and Wyoming Shelf into the Central Montana Trough and basinward on the platform. Well-developed, thick packages of reef and shoal

facies present at Gibson Reservoir, Logan Gulch, and the lower half of the Crown Butte section support the interpretation that accommodation was high enough during early Duperow Formation deposition in these areas for more basinward facies to exist. To the east at Haymaker Narrows, lagoonal facies dominate the majority of the section with only thin reefs and shoals developed. Further east, the Greathouse Peak section is the thinnest section measured at approximately 1/3 the average thickness of other sections. The overall thickness of the Haymaker and Greathouse Peak sections is interpreted to mean that the Duperow Formation is thinning to the east onto the Central Montana Uplift and is only inundated for a short time during which more basinward facies were deposited before sea-level again fell. Logan Gulch is the thickest section and is interpreted to lie within or near the center of the Central Montana Trough where accommodation was greatest on the platform.

The Gibson Reservoir section is problematic for interpreting paleogeography. This section lies on thrust sheets that have been transported approximately 100-km inboard from their original position and therefore represent facies at or near the platform margin and shelf break. Therefore, during the time of Duperow Formation deposition, the platform extended further into northwest and western Montana but is not palinspastically restored on maps in this study. Reef and shoal facies are abundant throughout the Gibson Reservoir section, as well as the only fore-reef facies observed in this study other than those described in cores from Kevin Dome. These observations lead to the interpretation that this

section was located significantly further west on the platform where more basinward facies resided for greater durations of time.

The thickness, facies distribution, parasequences, parasequences sets, and sequences within the Duperow Formation correlate in an orderly and predictive pattern on the platform. The low relief nature of the platform, with the exception of the Central Montana Uplift and Central Montana Trough, extended for 100's of miles in either direction. An isopach map of the Duperow Formation demonstrates that the platform is a broad feature that covered the majority of Montana excluding the very western and northern margins of the state. The deepest water lay off the platform - shelf break in central and western Idaho, and in the Snowcrest Trough of southeast Idaho. The Duperow Formation thickens into the center of the Williston Basin in northwest North Dakota and southern Saskatchewan and continues to thicken into the Alberta Basin in a northwesterly direction in Alberta.

Schematic representations of paleogeography are shown for a single parasequence interval representing the distribution of depositional environments on the platform just prior to the following surfaces: sequence boundary 2 (SB2), maximum flooding surface 4 (MFS4), maximum flooding surface 6 (MFS6), and sequence boundary (SB9) (Figures 46-49). The distribution of depositional environments is not shown beyond the Montana state boundary since the data from this study does not allow for such an interpretation. Beginning with SB2, marine waters have partly inundated the platform with reef and shoal

environments present on the western shelf margin where water depth was sufficient (Figure 46). Lagoons are widespread covering most of the northern and western portions of the state and a thin band of intertidal facies fringes the Central Montana Uplift and occupies the Central Montana Trough. A relatively large portion of area surrounding the Central Montana Uplift and within southern Montana is subaerially exposed as Late Devonian seas have not flooded back far enough onto the platform.

At the time of MFS4, marine waters have fully inundated the platform forming reef and shoal environments that extend from the shelf margin through the western and northern part of the state (Figure 47). Reefs and shoals present at Logan Gulch, Crown Butte, and Gibson Reservoir reveal that marine waters have flooded back well into the center of the Central Montana Trough although only existed for a short duration of time. Lagoons fringe the Central Montana Trough and Central Montana Uplift and are widespread in the western and central portion of the state. Intertidal environments occupy most of southern Montana and the Central Montana Uplift.

At MFS6, reef and shoal environments are constrained to the margins of the platform and widespread lagoons occupy most of the state (Figure 48). Intertidal environments again occupy the majority of southern Montana and fringe the Central Montana Uplift.

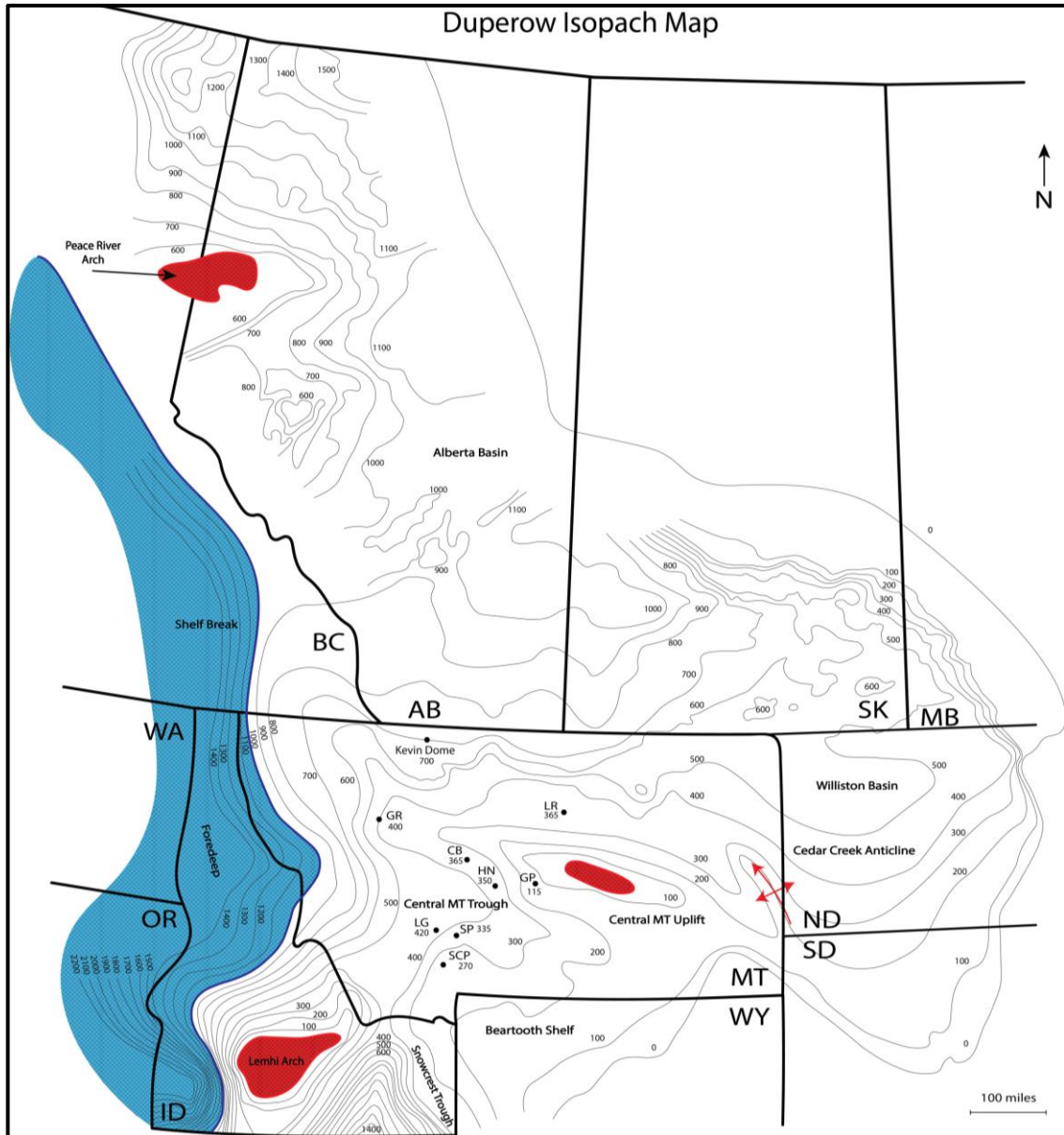


Figure 45. Isopach map of the Duperow constructed using measured section thickness from this study, known thickness from well-logs at Kevin Dome, and isopach maps from previous studies. AB=Alberta, BC=British Columbia, ID=Idaho, MB=Manitoba, MT=Montana, ND=North Dakota, OR=Oregon, SD=South Dakota, WA=Washington, and WY=Wyoming. Modified after Baars, 1972; eastern Montana, Wyoming, North and South Dakota after Sandberg, 1961; northern Montana after Kent, 1968; Alberta and western Saskatchewan after Switzer et al., 1994; very western Montana, Idaho, and Oregon after Grader et al., 2016; eastern Saskatchewan after TGI Williston Basin Working Group, 2018; and Blakey, 2018.

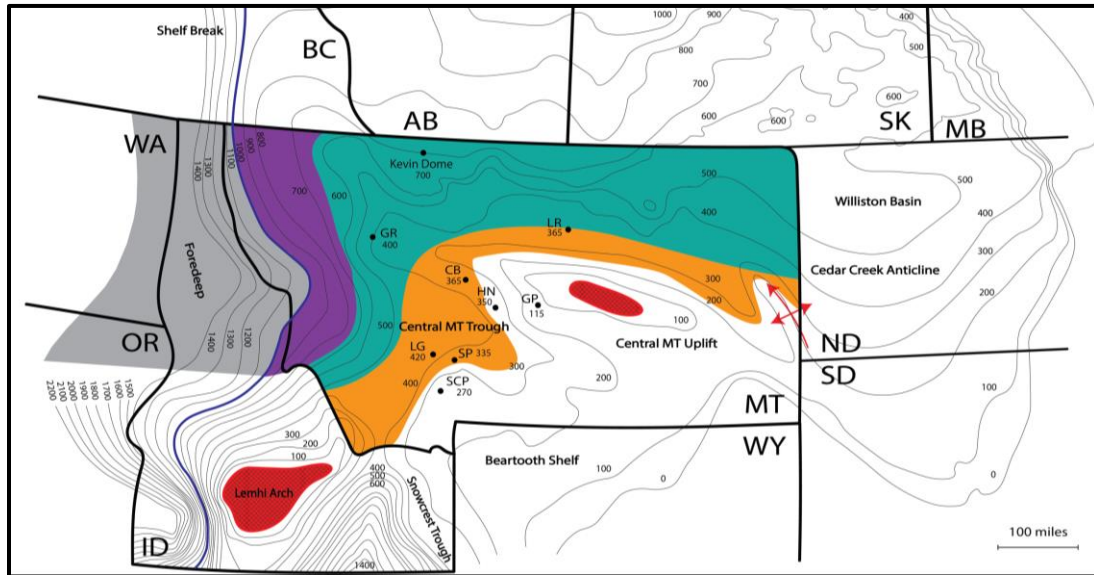


Figure 46. Paleogeographic map representing a single parasequence and showing the distribution of depositional environments on the platform in Montana just prior to Sequence Boundary 2. Location of depositional environments and color scheme matches that of Figure 44.

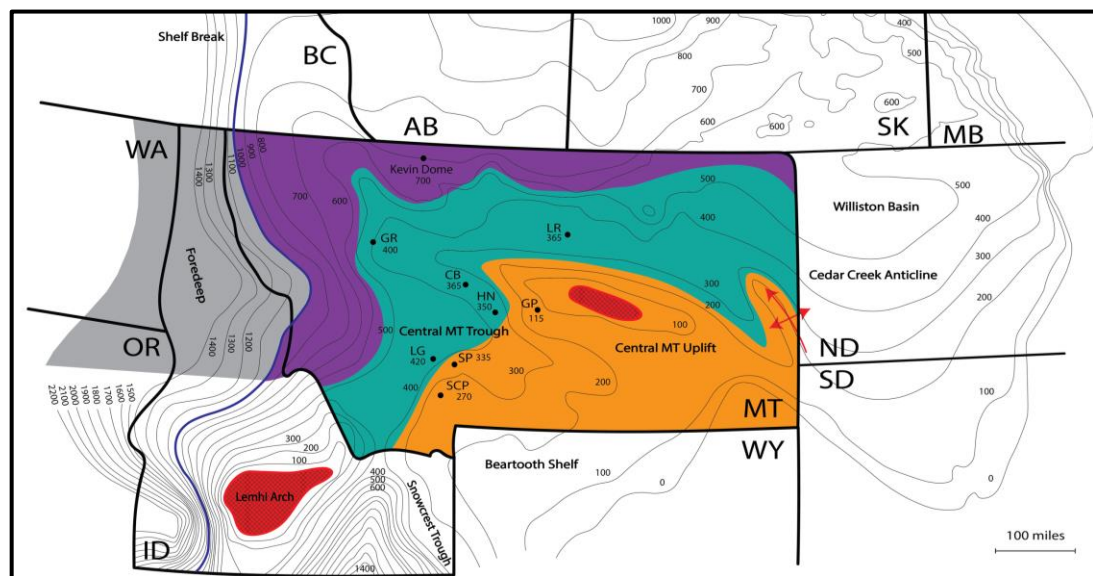


Figure 47. Paleogeographic map representing a single parasequence and showing the distribution of depositional environments on the platform in Montana just prior to Maximum Flooding Surface 4. Location of depositional environments and color scheme matches that of Figure 44.

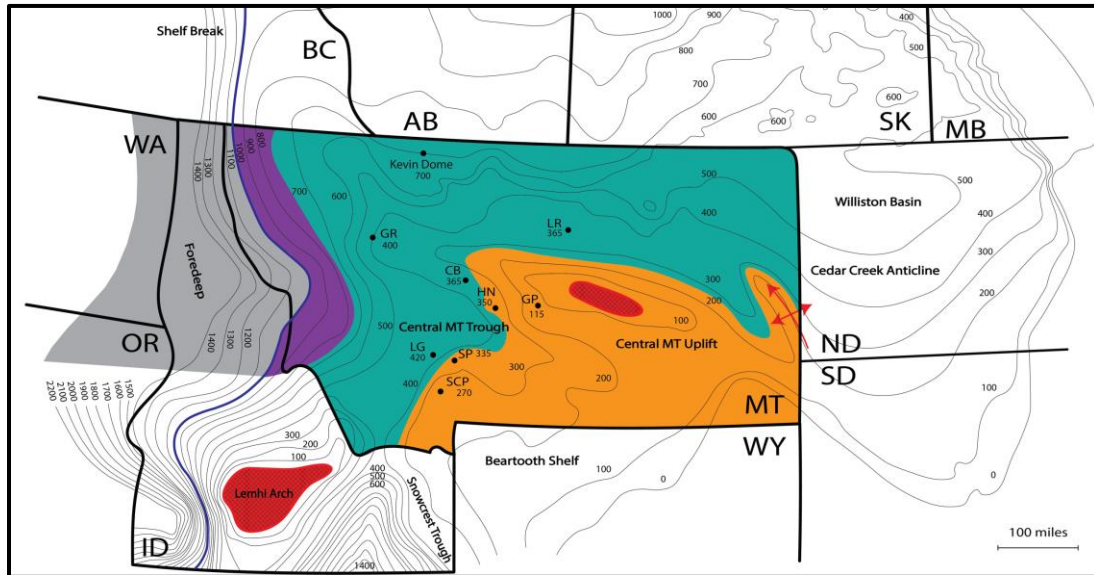


Figure 48. Paleogeographic map representing a single parasequence and showing the distribution of depositional environments on the platform in Montana just prior to Maximum Flooding Surface 6. Location of depositional environments and color scheme matches that of Figure 44.

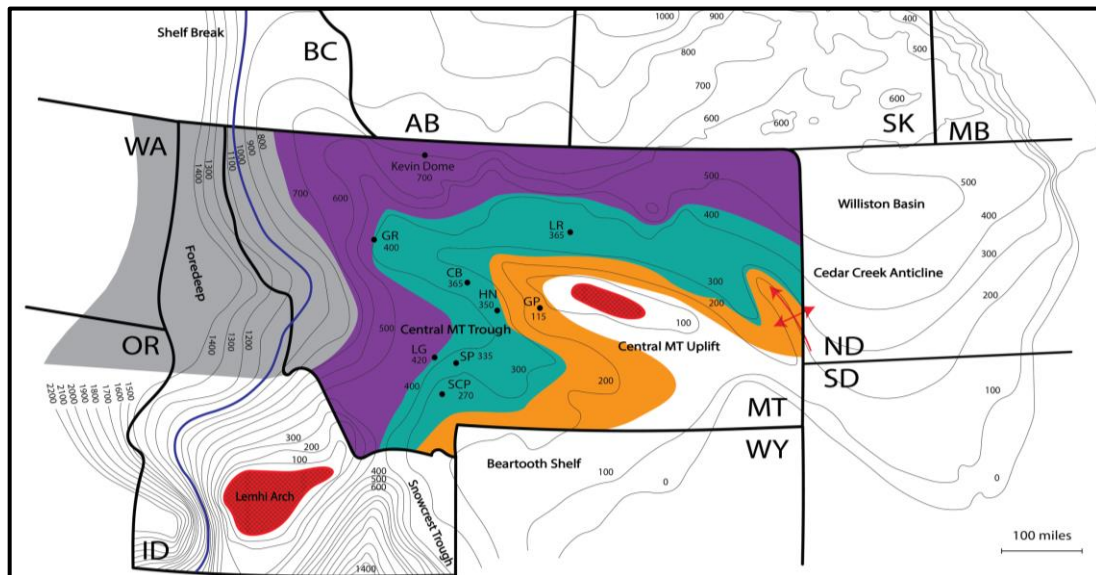


Figure 49. Paleogeographic map representing a single parasequence and showing the distribution of depositional environments on the platform in Montana just prior to Sequence Boundary 9. Location of depositional environments and color scheme matches that of Figure 44.

At SB9, marine waters have regressed significantly with reef and shoal environments occupying the deepest water on the platform to the west and north (Figure 49). Lagoons are constrained to central platform locations and intertidal environments fringe the Central Montana Uplift and occupy the Central Montana Trough. Part of the Central Montana Uplift is now subaerially exposed and will continue to be during proceeding Famennian and Three Forks time.

The Duperow platform is itself a container with sub-containers on it to fill. The largest container of which is the Central Montana Trough which extends from west-central Montana to near the southeast corner of the state. The Central Montana Trough occupied the majority of the southern portion of the state with a localized depocenter in southwest to west-central Montana. Cyclic changes in sea-level controlled deposition in the Central Montana Trough and on the Central Montana Uplift by depositing repetitive bands of facies. During sea-level rise, parasequences stack retrogradationally and their subordinate facies thus deepen upward overall. Facies fringed the Central Montana Trough and Central Montana Uplift forming bands of facies that wrapped in and around those features. From the MFS, facies stacked to form aggradational parasequences until sea-level waned and facies stacked to form progradational parasequences. As waters receded from the platform, these facies bands moved basinward. Eventually water receded so far that large portions of the platform in southwest and central Montana were exposed. This occurred multiple times during Duperow deposition. The relatively flat lying nature of the platform likely accentuated sea-level rise

and fall that produced dramatic shifts in facies belts. This geometry is also likely a factor in the inundation of the Central Montana Uplift because of evidence in Duperow-Nisku Formation strata that this paleohigh was fully submerged (at least at Greathouse Peak).

CHAPTER SIX

DISCUSSION

Geologic SignificanceOil and Gas Resources

Ultraviolet light photos of the Danielson 33-17 and Wallewein 22-1 cores reveals that residual oil was hosted within stromatoporoid reef-shoal and lagoonal facies and later migrated out of Duperow Formation strata (Appendix B). In the Williston Basin, permeability values for the Duperow Formation range from 1-123 mD with local vertical fractures and porosity ranging from 6 to greater than 30% (Pilatzke et al., 1987; Burke & Heck, 1988; Fischer et al., 2008). Therefore, there is potential for high porosity zones in the Duperow Formation and low-permeability seals. A source for the oil and gas within the Duperow Formation has not been determined for accumulations in western and central Montana but it is possible that organic-rich lagoonal facies within the Duperow Formation itself are a primary source. The fetid nature of the Duperow Formation in outcrop, i.e. the pungent smell, also reveals that oil and gas were hosted there at one time but no significant hydrocarbon reservoirs are known to exist within the western part of the state. The unconformable nature of the Duperow Formation on Cambrian strata also remains a challenge for interpreting this piece of the puzzle.

The Disturbed Belt in western Montana may host producible oil and gas. Perry et al., (1983) suggest there are structural traps beneath thrust sheets in

southwestern Montana but much of the land is designated as wilderness or National Park. There may also be isolated reservoirs within antiformal features that may provide an opportunity for CO₂ storage within thrust sheets if the overlying seals are competent.

Swenson (1967) drew the following conclusions regarding future exploration and hydrocarbon potential in the Nisku Formation:

- “1) Stratigraphic variations have an important regional effect on hydrocarbon accumulations in the Nisku but are less important with regard to individual traps,
- 2) Porosity variations between producing wells and off-structure dry holes result not from primary stratigraphic variations, but from secondary effects,
- 3) Structural closure is the principle trapping mechanism for the Nisku fields of northeast Montana,
- 4) The depositional edge of the salts of the Prairie Formation was 50-60 miles west and up-dip from the present-day solution edge, and
- 5) Structures which control the Nisku fields were formed by multiple-stage solution of the salts in the Middle Devonian Prairie Formation.”

These conclusions can be applied to the Duperow Formation in a similar way. Swenson (1967) refers to “stratigraphic variations” as lithologic variations i.e. evaporite, dolomite, and limestone beds. For the Duperow Formation, one of

the most prospective reservoirs would be within the reef and shoal facies. Organic-rich lagoonal facies could act as both source and reservoir while primarily evaporite-rich lagoonal and, to a lesser extent, supratidal to sabkha facies act as a seal. The lateral variation of facies and stacking pattern of parasequences would control migration of oil and gas into structural or stratigraphic traps. The most complete measured sections (Gibson Reservoir, Logan Gulch, Sacagawea Peak) show well-developed retrogradational to aggradational stacks of reef and shoal facies within the middle Duperow Formation interpreted to represent transgressive to early highstand deposits. These deposits are capped by late highstand progradational parasequences comprised of lagoonal to tidal flat and supratidal facies. These aggradational stacks with relatively impermeable strata on top would be an excellent exploration target especially when combined with a structural closure. Swenson (1967) notes that structural closures with producing Nisku Formation wells are less than one square mile in diameter in northeastern Montana. This reveals that large structural traps are not necessary for significant amounts of oil and gas to accumulate in the Duperow-Nisku system.

Therefore, the best play scenario would be where relatively thick parasequences comprised of reef and shoal or lagoonal facies exist with sufficient, low permeability mudstones and interbedded evaporites above to effectively seal the reservoir. Strata in western Montana may be too close to the shelf break to have sufficient overlying seals. Areas to the south of the Central

Montana Uplift may not contain sufficient porous Duperow Formation strata as the system thins onto the Beartooth Shelf. Plays may exist fringing the Central Montana Uplift particularly in the highstands of 3rd order sequences 4, 5, 6, and 7 (Figure 44) where porous reef and shoal facies deposited during the transgressive systems tract are overlain by low permeability lagoonal facies deposited during progradation in the highstand. Sequences 5, 6 and 7 are the most promising and specifically have organic-rich lagoonal facies in their highstands overlain by tight mudstones prior to the next sequence boundary. These are the only sequences in which reef-shoal or lagoonal facies are present on the Central Montana Uplift and capped by intertidal facies to create a source-reservoir-seal relationship.

The Central Montana Trough has potential for oil and gas in 3rd order sequences 1, 3, 4, 6, and 7 (Figure 44). Specifically, the late highstand of sequence 1, the highstand of sequence 3, the very late highstand of sequence 4, the highstand of sequence 6, and possibly the highstand of sequence 7. These corresponding portions of sequences have the necessary elements for a petroleum system. Sequences 1 and 6 at Logan Gulch contain the thickest lagoonal facies and may offer the best source rock potential on the platform. Sequence 3 is promising in the Central Montana Trough because of its abundant reef-shoal and lagoonal facies comprising parasequences with interbedded evaporites and supratidal mudstones as a sequence cap. Sequence 4 offers a similar potential and characteristics as sequence 3.

East of the Central Montana Uplift, the Duperow Formation again thins onto the Cedar Creek Anticline on the Montana-North Dakota border. Oil and gas potential within sequences here is likely similar to that of the Central Montana Uplift with targets in the highstands and upper portion of the formation although, specific targets cannot be assigned. Production occurs from the Duperow Formation only on the east side of the Cedar Creek Anticline at this time.

Carbon Sequestration

Prerequisites for carbon sequestration include: sufficient porosity within reservoir facies, low permeability sealing facies, reservoir waters with greater than 10,000 parts per million (ppm) total dissolved solids (TDS) to be classified as unsuitable for a drinking water aquifer, and appropriate burial depth for injected CO₂ to maintain a supercritical fluid state. The critical point for CO₂ at which the liquid, gas, and supercritical fluid phases join is at 31°C and 8.38 Mpa (U.S. Department of Energy). The thermal temperature gradient along the Montana-Alberta border is approximately 20-30°C per km and 25-40°C per km on the margins of the Williston Basin (Bachu & Burwash, 1994). Using this information, potential Duperow strata for carbon sequestration would need to be buried at least 1 km or greater.

The Big Sky Carbon Sequestration Partnership targeted high porosity zones within the middle Duperow Formation at Kevin Dome where large gas reserves are structurally and stratigraphically trapped. At Kevin Dome, the Duperow Formation is overlain by the Potlatch Anhydrite, up to 175 feet thick,

that along with interbedded mudstone and anhydrite in the upper Duperow Formation effectively seals off the CO₂ trapped there. The Kevin Dome project can be used as a natural analog for this study to predict where other high porosity zones may exist within the formation in Montana when coupled with the sequence stratigraphic framework developed from measured sections.

Permeability in the Duperow Formation at Kevin Dome ranges from 0.001-0.12 mD and porosity ranges from 0.8-7.5% (Omosebi et al., 2018; Onishi et al., 2019). It's possible that this high porosity zone is present elsewhere in Montana due to the gently dipping to flat lying geometry of the platform, the Duperow Formation's relatively consistent thickness in central platform locations, and the migration of facies in a predictable manner on the platform itself.

In the Duperow Formation cores, anhydrite increases in the upper third of the formation, above the CO₂ reservoir in the Wallewein 22-1 which, along with shales of the lower Three Forks Formation and equivalent Potlatch Anhydrite, provide an excellent seal to potential carbon sequestration reservoirs within the formation. The distribution of Three Forks/Potlatch strata is limited to east of the Rocky Mountain front into southwest, central, and northern Montana. No Three Forks/Potlatch Formation strata exist in the southeast ¼ of Montana. Therefore, potential reservoirs for sequestration of carbon dioxide would be immediately constrained to areas of deposition where sufficient low permeability mudstones and anhydrite in the upper Duperow Formation, the Potlatch Anhydrite and Three Forks Formations are present. The most prevalent evaporite-rich carbonate

mudstones occur fringing the Central Montana Uplift and Central Montana Trough as sea-level rose and fell during deposition of each sequence allowing for deposition of low permeability lagoonal, tidal flat and supratidal rocks off this paleohigh.

There are well-developed reef and shoal complexes capped by lagoonal to intertidal mudstones and evaporites in sequences 1, 3, 4 and 5 of the Duperow Formation at Gibson Reservoir, sequences 2, 3, 4, 5, and 6 at Logan Gulch, sequences 1, 2 and 4 at Crown Butte, sequences 2, 3, and 5 at Sacagawea Peak, and sequence 1 at Haymaker Narrows. I predict that these correlative sequences subsurface near these locations would be the most suitable for sequestering large amounts of CO₂. It's possible there are also reservoirs in the Thrust Belt, further east and to the north of the Central Montana Uplift, and slightly further east within the Central Montana Trough.

CHAPTER SEVEN

SUMMARY AND CONCLUSIONS

Introduction

The objective of this study was to characterize facies and develop a sequence stratigraphic framework for the Late Devonian Duperow Formation in western and central Montana. Measured outcrop sections, drill core, and thin sections provide a better understanding of depositional environments and facies relationships and geometries on the platform in Montana at time of deposition.

Summary and Conclusions

1. Ten lithofacies are identified in the Duperow Formation which are then grouped into six lithofacies associations and their respective interpreted depositional environments. These include: Fore-reef (LFA-2A), Reef (LFA-2B), Shoal (LFA-3A, LFA-3B), Back reef/patch reef (LFA-4A), Lagoon (LFA-1A, LFA-4B, LFA-4C), Tidal Flat (LFA-5A), and Supratidal (LFA-6A).
2. The Duperow Formation is comprised of two 2nd order cycles and seven 3rd order cycles with an eighth 3rd order cycle comprising the Nisku Formation. Each cycle (2nd and 3rd order sequence) contains a transgressive systems tract where parasequences and sequences stack in a retrogradational pattern and a highstand systems tract where

aggradational to progradational stacking is observed. No lowstand deposits were observed within the study area.

3. Sequences within the lower Duperow Formation lap out prior to reaching the Central Montana Uplift. Specifically 3rd order sequences 1, 2, and 3.
4. The platform is partially exposed at least five times during Duperow time. Evidence for subaerial exposure is prevalent at measured sections.
5. The interplay between subsidence, sea-level, and local basement tectonics controlled accommodation and thus paleogeography.
6. Oil and gas within the Duperow Formation may be self-sourced from organic-rich beds in lagoonal facies.
7. The most promising regions for oil and gas exploration are within the highstands of sequences 4, 5, 6, and 7 on the Central Montana Uplift and it's margins, as well as, possibly on the Cedar Creek Anticline in eastern Montana within those corresponding sequences. Within the Central Montana Trough, the highstand of sequences 1, 3, 4, 6, and 7 are most promising. These sequences have porous and organic-rich reef-shoal to lagoonal facies present with sufficient evaporite-rich lagoonal to intertidal and supratidal seals stratigraphically above.
8. The most promising sequences for carbon sequestration are: sequences 1, 3, 4 and 5 near Gibson Reservoir, sequences 2, 3, 4, 5,

and 6 near Logan Gulch, sequences 1, 2 and 4 near Crown Butte, sequences 2, 3, and 5 near Sacagawea Peak, and sequence 1 near Haymaker Narrows. Near the field sites mentioned and where these sequences and facies relationships exist greater than 1 km subsurface may be good targets for sequestration of CO₂.

Future Work

Future work should include measuring sections in the northern portion of the Little Rocky Mountains where Sandberg & Mapel (1967) noted good exposure in Brown's Gulch on the Fort Belknap Indian Reservation. Sections in the Big Belt Mountains and other ranges in western and southern Montana would be excellent opportunities to continue to build a more robust sequence stratigraphic framework and history for the Duperow Formation. Incorporating well-log data would also aid in creating a higher resolution sequence stratigraphic framework. A new type-section for the Duperow and Nisku Formations in southwest Montana is much needed as the current type section is on private land and difficult to gain access to.

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APPENDICES

APPENDIX A

SEQUENCE STRATIGRAPHIC FRAMEWORK: MEASURED SECTIONS
(SEE SEPARATE ATTACHMENT)

APPENDIX B

SEQUENCE STRATIGRAPHIC FRAMEWORK: CORES
(SEE SEPARATE ATTACHMENT)

APPENDIX C

STORM CASTLE MEASURED SECTION
(SEE SEPARATE ATTACHMENT)

APPENDIX D

SUMMARY TABLE OF THIN SECTION ATTRIBUTES

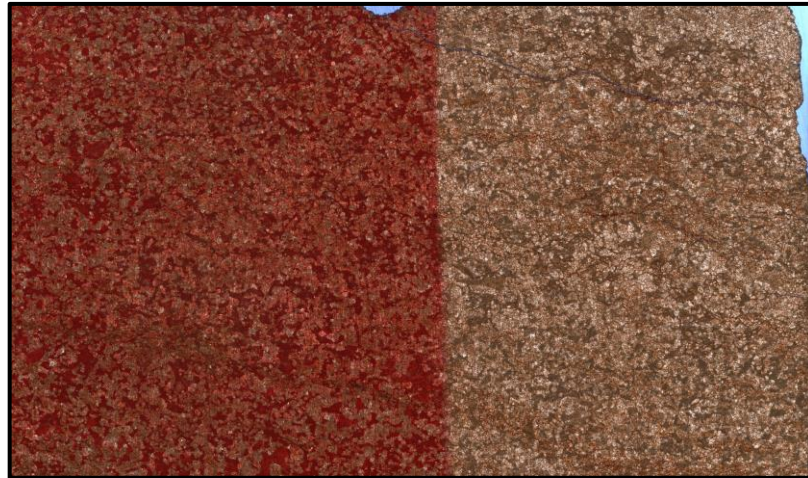
APPENDIX E

THIN SECTION NOTES AND PHOTOGRAPHS

Gibson Reservoir, Sawtooth Range, MT

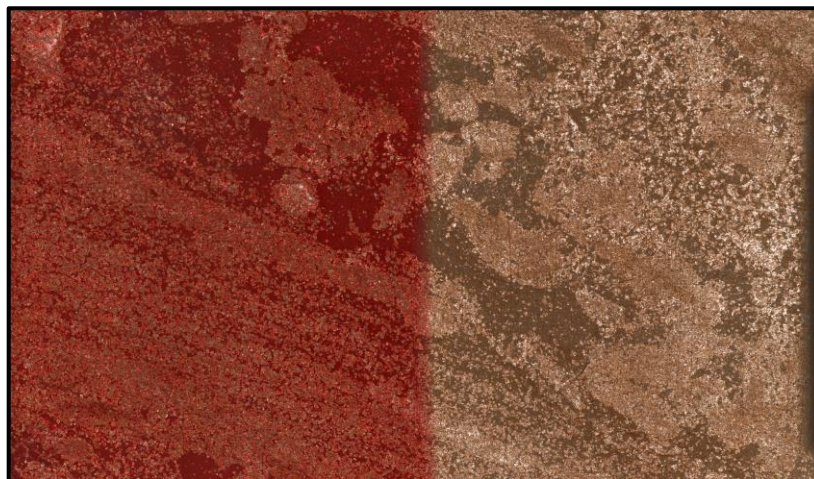
Gib-G3:

Stromatoporoid biosparite/grainstone with fracture, stylolite, and intercrystalline porosity along sutured grains. Euhedral to subhedral dolomite, appears to be at least 2 separate dolomitization events based on well-developed euhedral dolomite and other zones of subhedral dolomite in an overall porphyrotopic floating rhomb fabric. Dolomitization is fabric selective replacing stromatoporoids. Thin section blank shows faintly laminated fabric.



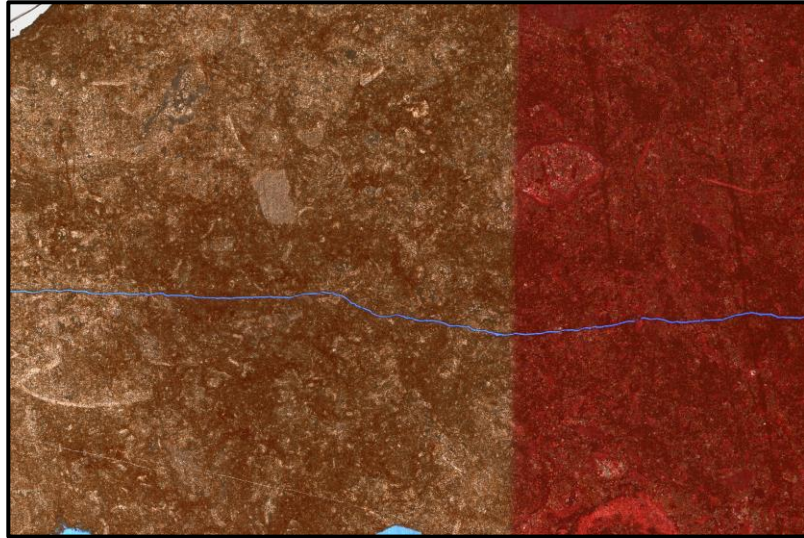
Gib-G4:

Stromatoporoid biomicrite/wackestone with micrite filled cavities and dolomitized laminations. Dolomite is euhedral with a porphyrotopic contact rhomb fabric within cellular structures of stromatoporoids to nonplanar sutured fabric in encrusting non-cellular layers. Less than 2% fracture porosity and rare to few dolomitized calcispheres. Rare tentaculitids and foraminifera.

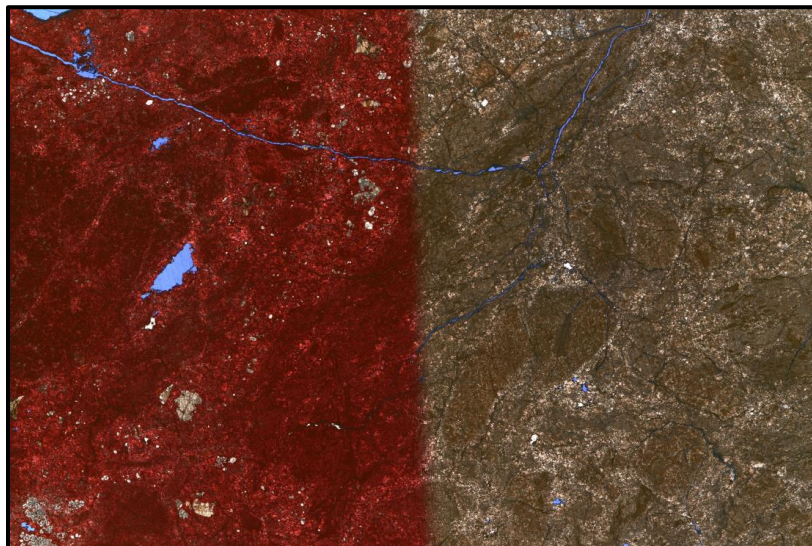


Gib-G5:

Skeletal biolithite/boundstone with calcispheres or tentaculitids, echinoids, phylloid algae that is calcareous and not dolomitized, also contains peloids, echinoderms, foraminifera, trilobites, brachiopods and bivalve fragments. Dolomite replaces calcispheres and overprints all other fabrics but does not replace other fossils. Dolomite is subhedral in a porphyrotopic floating rhomb fabric. Rare fracture porosity.

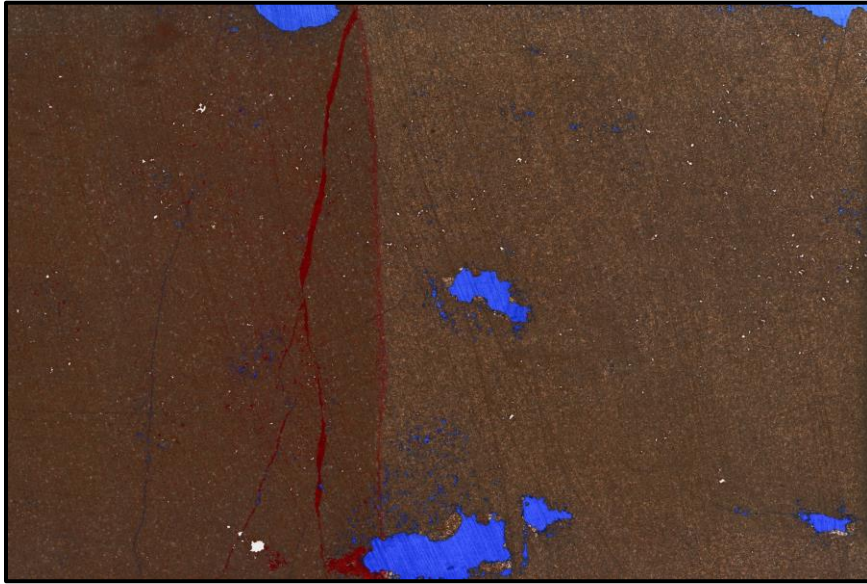
**Gib-G8:**

Stromatoporoid biolithite/framestone/rudstone with abundant fracture porosity and minor intercrystalline to intergranular porosity. Contains brachiopods and bivalves. Dolomite is nonplanar and in an equigranular peloidal fabric (i.e. sharp to diffuse clotting of crystals).

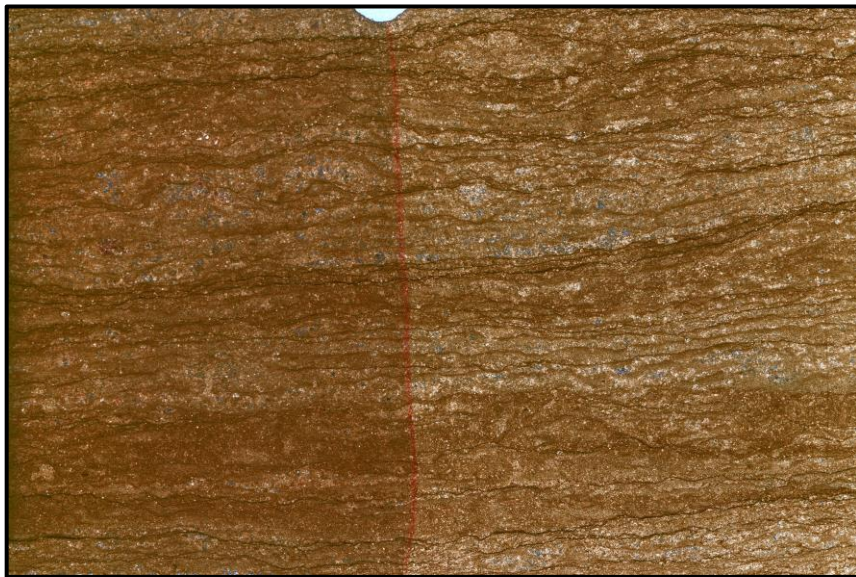


Gib-H6:

Stromatoporoid biosparite/grainstone with some intercrystalline, intracrystalline and vuggy porosity, minor fracture porosity, about 50% of overall porosity has been destroyed by infilling of calcite, completely dolomitized, blank shows peloid shaped grains but not distinguishable in thin section due to dolomitization.

**Gib-H7:**

Microbially laminated pelmicrite/wackestone with abundant simple wave stylolites, peloids, and calcispheres. Completely dolomitized, rare dedolomitization of euhedral dolomite, nonplanar equigranular sutured fabric.

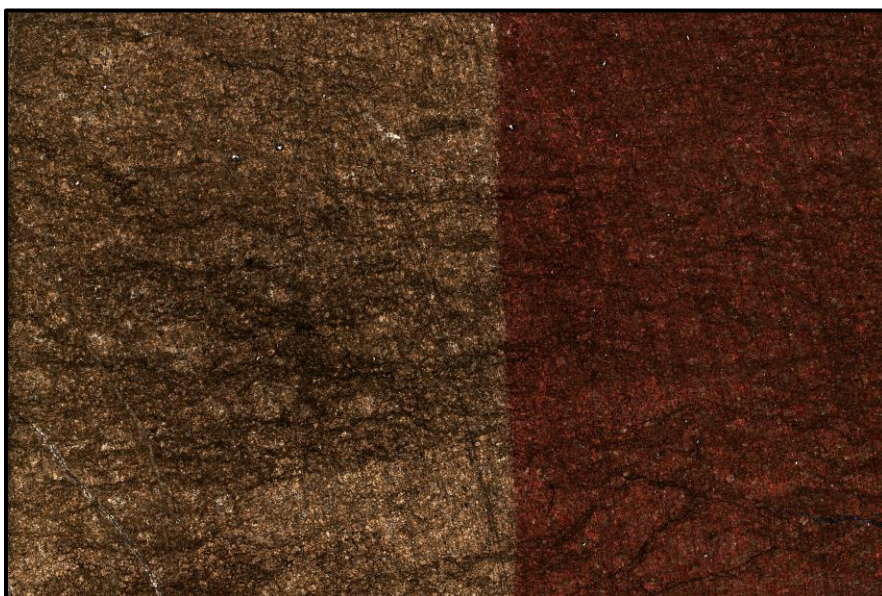


Gib-H8:

Algal biomicrite/mudstone, cellular cavities are calcite, outer layers are dolomite, few peloids and calcispheres, less than 5% intraparticle porosity within algal mats.

**Gib-H9:**

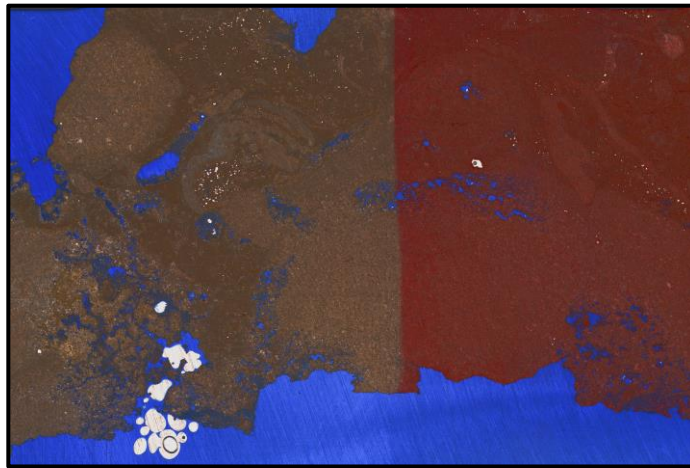
Microbially laminated pelmicrite/packstone with less than 3% fracture porosity, nonplanar anhedral to subhedral dolomite in an equigranular sutured fabric. Minor intracrystalline to fracture porosity and some foraminifera.



Crown Butte, Little Belt Mountains, MT

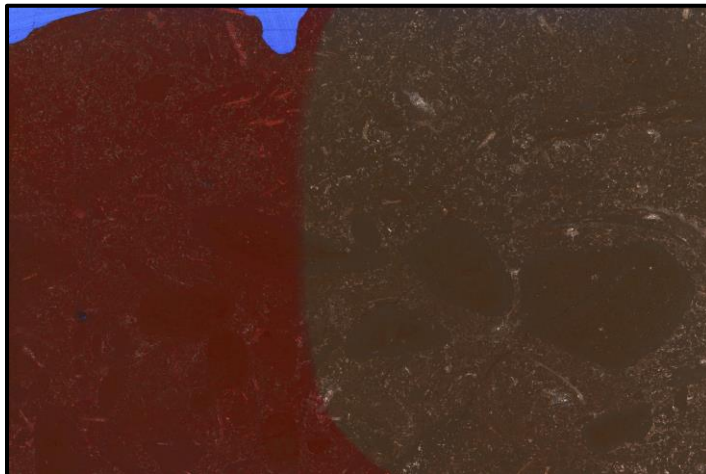
CB-F4:

Skeletal biolithite/boundstone with hemispherical to spherical stromatoporoids, phylloid algae and brachiopods bound between stromatoporoid laminations, 10-15% fabric selective intraparticle and fracture porosity, intraparticle porosity is within stromatoporoid cellular layers not micritic laminations that bind algae and other grains, very minor to rare dolomitization, subhedral to euhedral dolomite in an inequigranular porphyrotopic floating rhomb fabric, micritic to microspar microcrystalline and granular calcite cement.



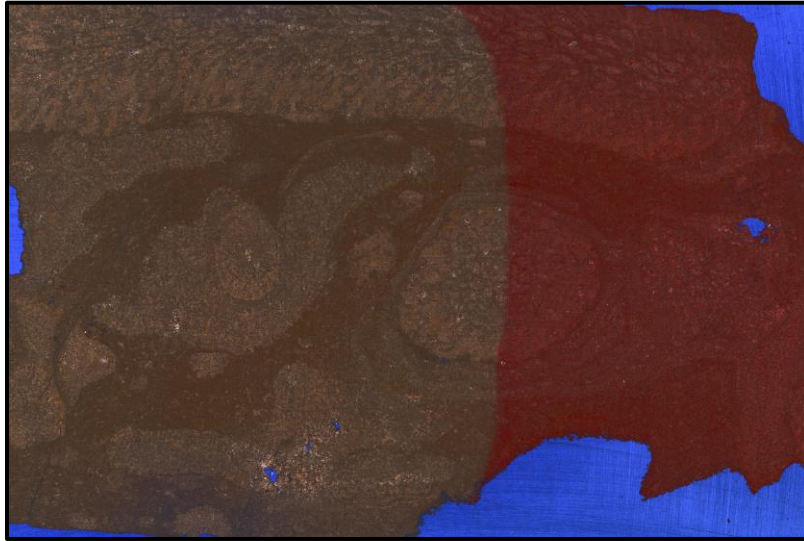
CB-G:

Biomicrite/packstone with brachiopods, calcispheres, Dasyclad green algae, phylloid algae, amphipora, bulbous/hemispherical stromatoporoids, trilobites, peloids, and possibly tentaculitids. Micritic and microcrystalline cement, subhedral to euhedral dolomite in an inequigranular porphyrotopic contact rhomb fabric. No porosity.

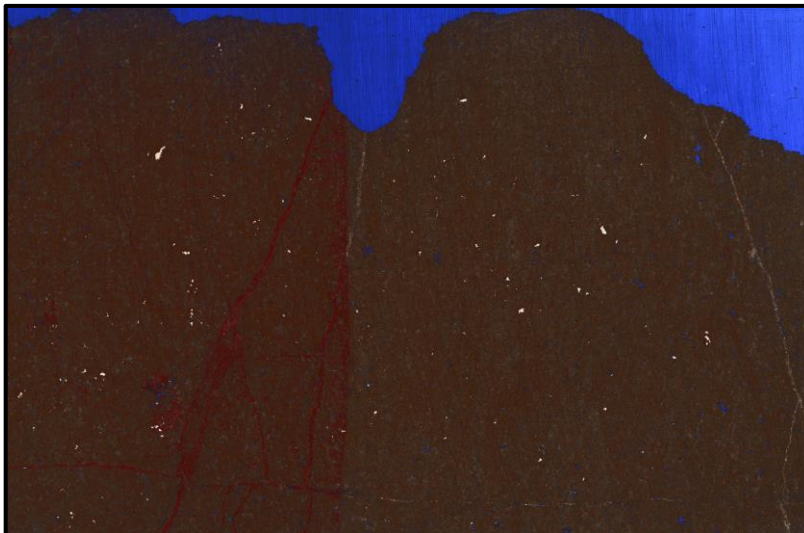


CB-H1:

Biosparmicrite/boundstone with abundant bryozoans, few crinoids and brachiopods, micritic and microcrystalline cement, anhedral to euhedral dolomite in an inequigranular porphyrotopic contact rhomb fabric, less than 5% fracture, intraparticle, and intercrystalline porosity.

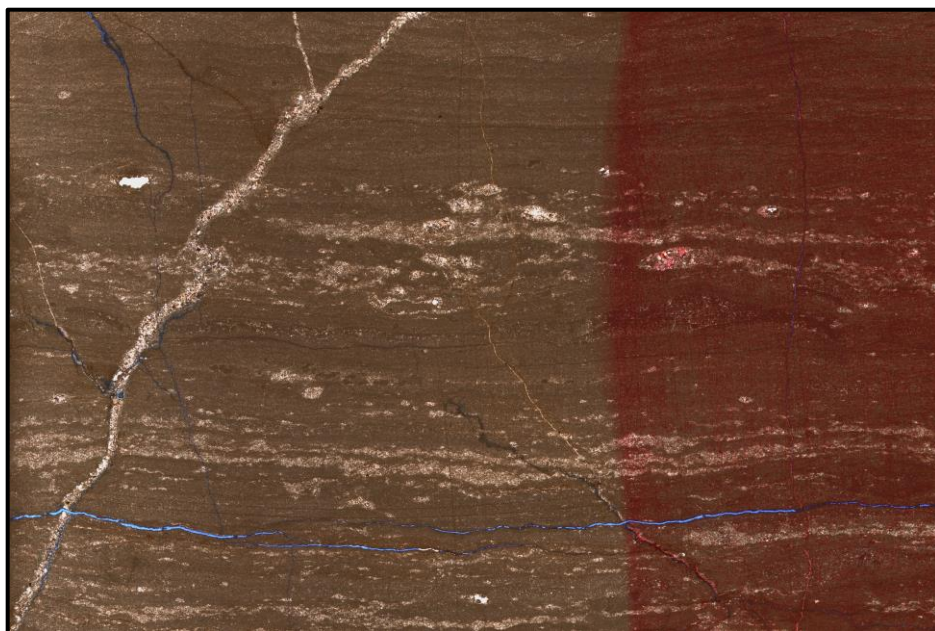
**CB-O:**

Biopelmicrite/packstone, almost completely dolomitized with subhedral to euhedral dolomite in an equigranular sutured fabric. 5-10% fracture, intercrystalline, and intracrystalline porosity, ghosts of calcispheres and brachiopods, some euhedral calcite stained red and filling fractures or voids. Unknown white mineral that is opaque/dark gray in XPL, non-pleochroic, no birefringence, low relief, anhedral to subhedral grains.



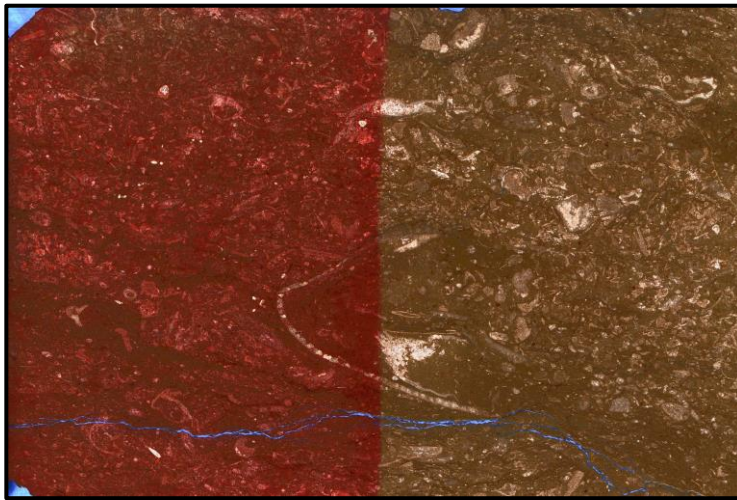
CB-W2:

Microbially laminated biomicrite/wackestone with peloids, foraminifera, and amphipora. One trilobite fragment, calcite filling fractures and being replaced in skeletal grains, 5% fracture porosity, dolomite is anhedral in an equigranular mosaic sutured fabric. Some simple wave stylolites.

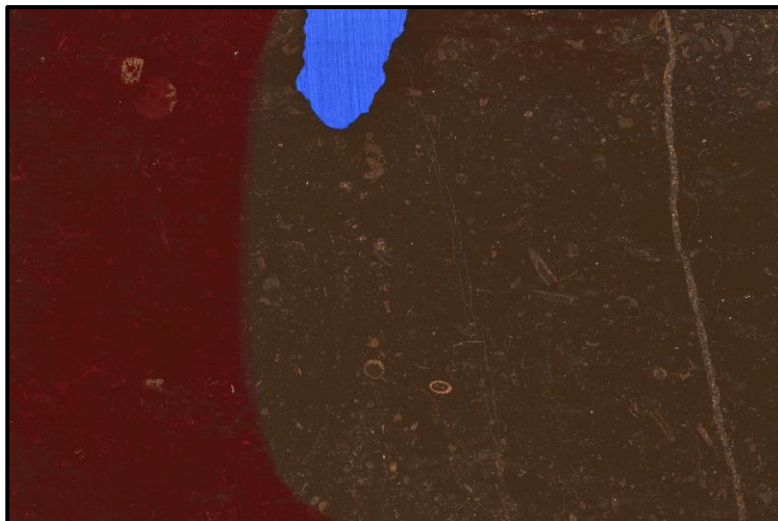


Storm Castle Peak, Gallatin Range, MT**SC-F2:**

Biosparmicrite/grainstone with trilobites, crinoids, echinoderms, bivalves, brachiopods, and Dasyclad green algae, cement is dolomitic but grains are calcite. Fracture and microporosity within dolomitic algal laminations total less than 5%, equigranular peloidal dolomite fabric, dolomitization and porosity is fabric selective.

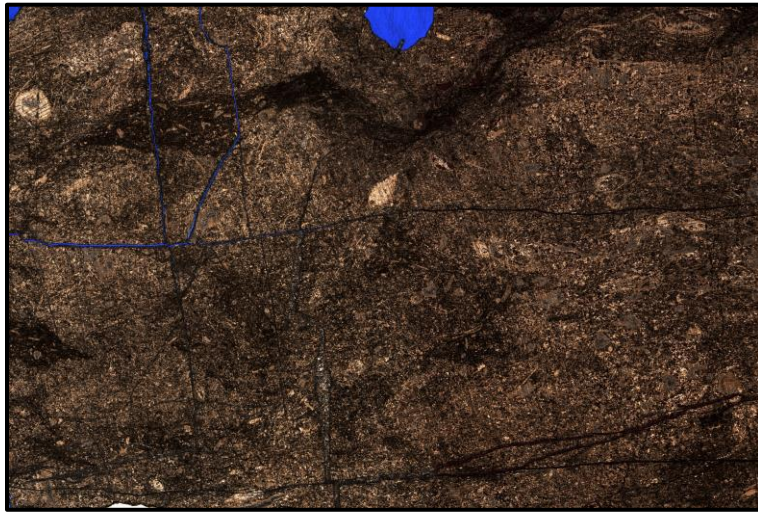
**SC-F3:**

Biosparmicrite/grainstone comprised of trilobites, bryozoans, brachiopods, bivalves, crinoids, echinoids, tentaculitids, rugose coral, and calcite. Minor dolomitization of micrite, no porosity. Non-planar dolomite replacing calcite grains.



SC-F6:

Biomicrite/packstone with brachiopods, phylloid algae, crinoids, foraminifera, calcispheres, peloids, tentaculitids (maybe), calcite filled fracture, minor fracture porosity less than 2%, anhedral to subhedral calcite, anhedral dolomite in an equigranular peloidal fabric.



SC-J1:

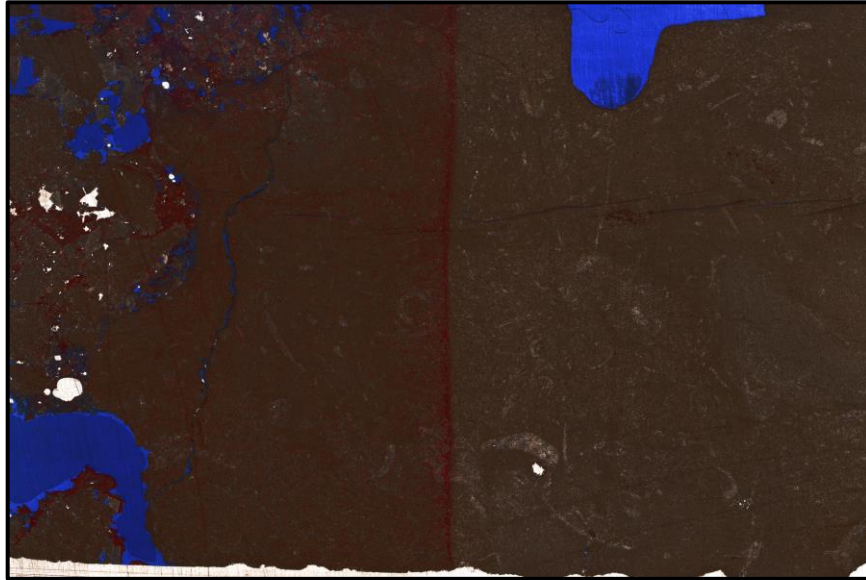
Laminated pelmicrite/wackestone with calcispheres, alternating layers of microcrystalline dolomite replacing algal material and more-coarse anhedral to subhedral dolomite replacing calcite layers. Less than 1% intercrystalline to interparticle porosity. Equigranular sutured fabric.

Unknown white mineral forming subhedral crystals, non-pleochroic, no birefringence, not stained red with Alizarin Red-s. Makes up 10-15% of the rock, probably quartz.



SC-J2:

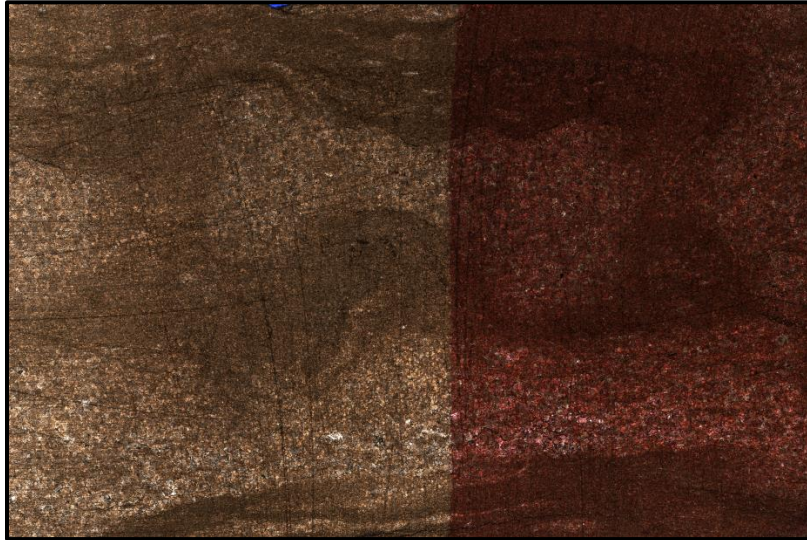
Biosparmicrite/packstone, partial stromatoporoid or coral (calcitic) being replaced by euhedral dolomite, possible tentaculitids, moderate amounts of crinoids, brachiopods, trilobites, micrite to microspar sized cement. Minor fracture and intraparticle porosity in brachiopods/trilobites (less than 1%), good intraparticle porosity approx. 20% within stromatoporoids/coral fragments, anhedral dolomite (euhedral dolomite replacing stromatoporoid/coral structure).



Sacagawea Peak, Bridger Range, MT

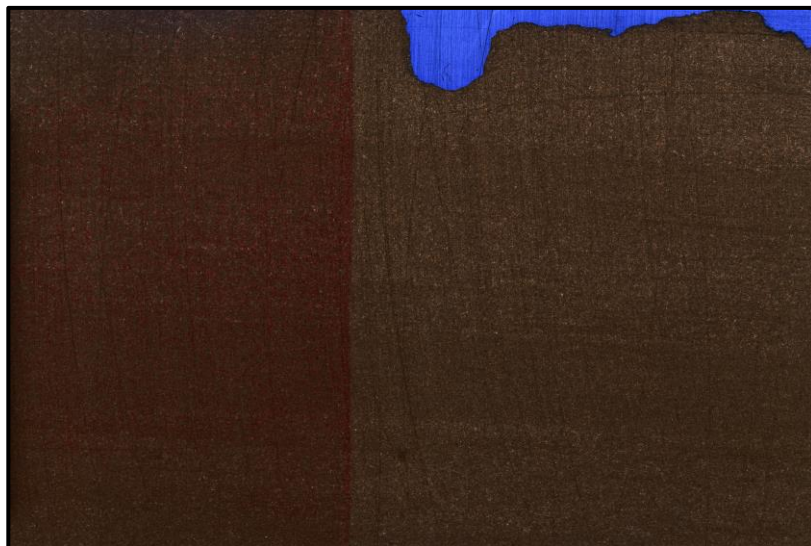
Sac-A3:

Biolithite/boundstone with encrusting tabular stromatoporoids, calcispheres, possibly green Dasyclad or phylloid algae, less than 1% fracture porosity, alternating organic laminations of anhedral sutured dolomite and subhedral to euhedral dolomite all in an inequigranular porphyrotopic contact rhomb fabric.



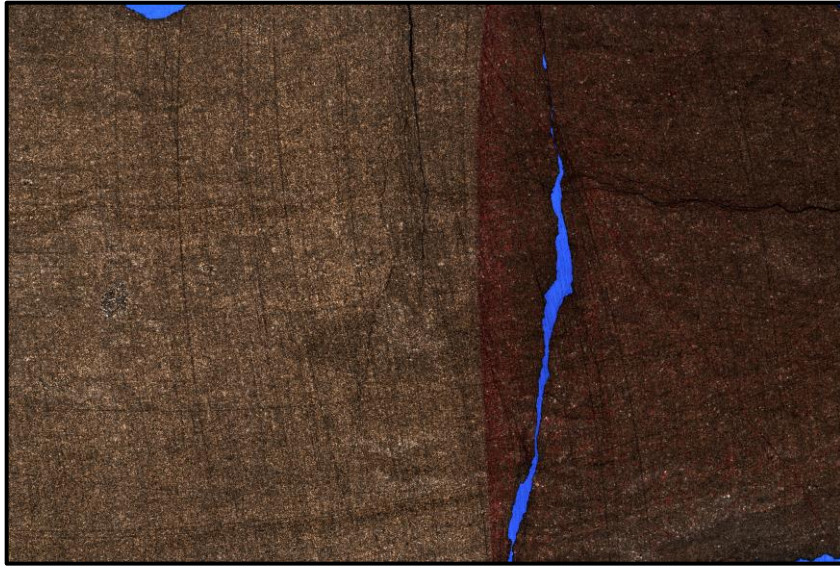
Sac-A4:

Pelmicrite/wackestone with calcispheres, trilobites, brachiopods, and possibly green Dasyclad or phylloid algae. Faint planar laminations, dolomitized with anhedral dolomite in an equigranular mosaic sutured fabric. No porosity, micritic to microcrystalline cement.

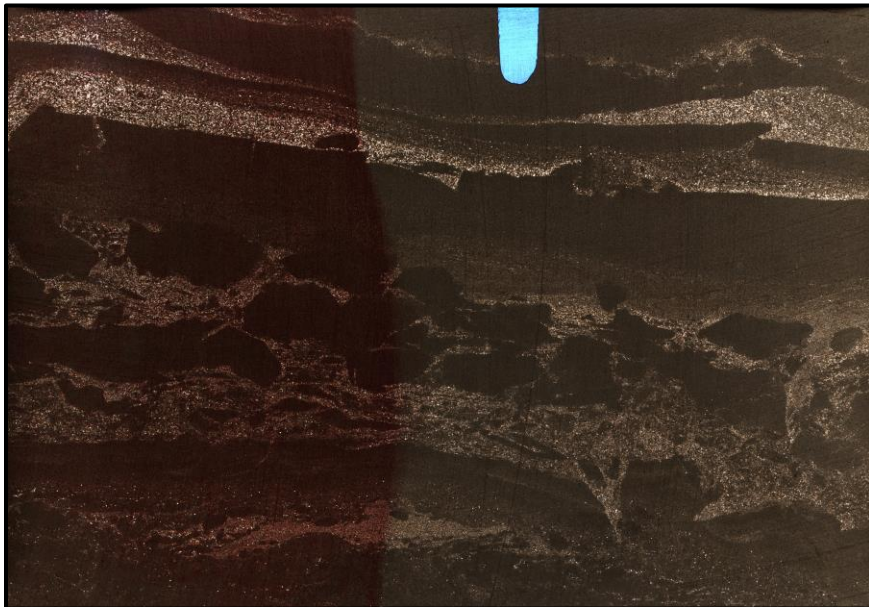


Sac-A5:

Biomicrite/mudstone with calcispheres, trilobites, brachiopods, possibly green Dasyclad or phylloid algae, faintly laminated, dolomite is anhedral in an equigranular mosaic sutured fabric, micritic and microcrystalline cement, minor fracture porosity less than 1%, simple wave stylolites.

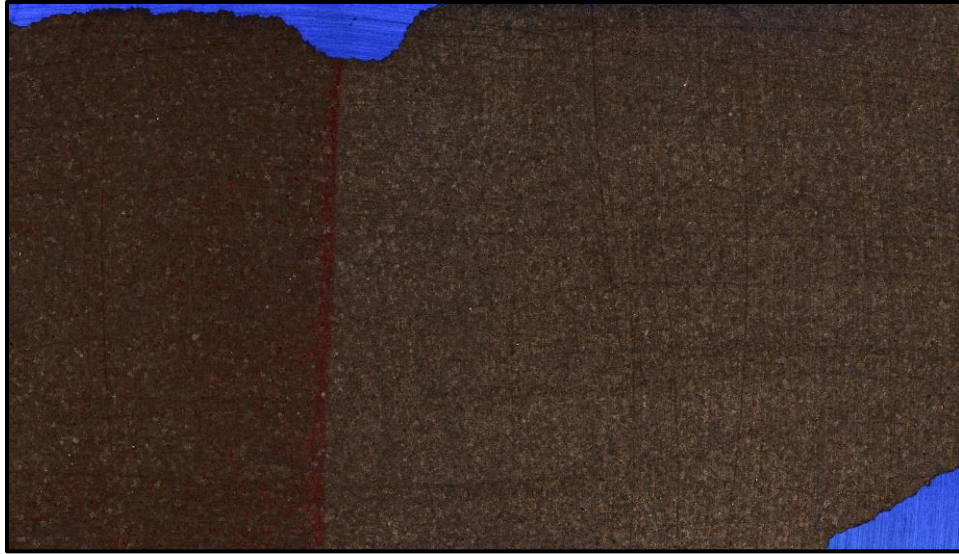
**Sac-A11:**

Micrite/mudstone with elongate rip up clasts of crystalline dolomite in a micritic and microcrystalline dolomitized micrite matrix, one trilobite fragment and few peloids, anhedral to subhedral dolomite in an equigranular peloidal fabric.

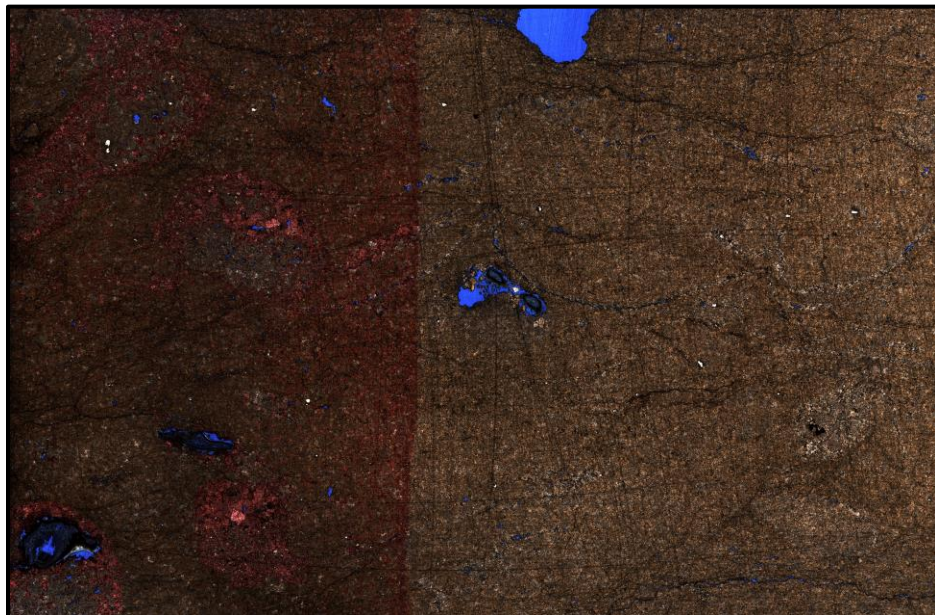


Sac-B5:

Faintly laminated micrite/mudstone with ghosts of calcispheres, some euhedral calcite grains, dolomite is anhedral to subhedral in a equigranular mosaic sutured fabric, less than 1% intercrystalline porosity.

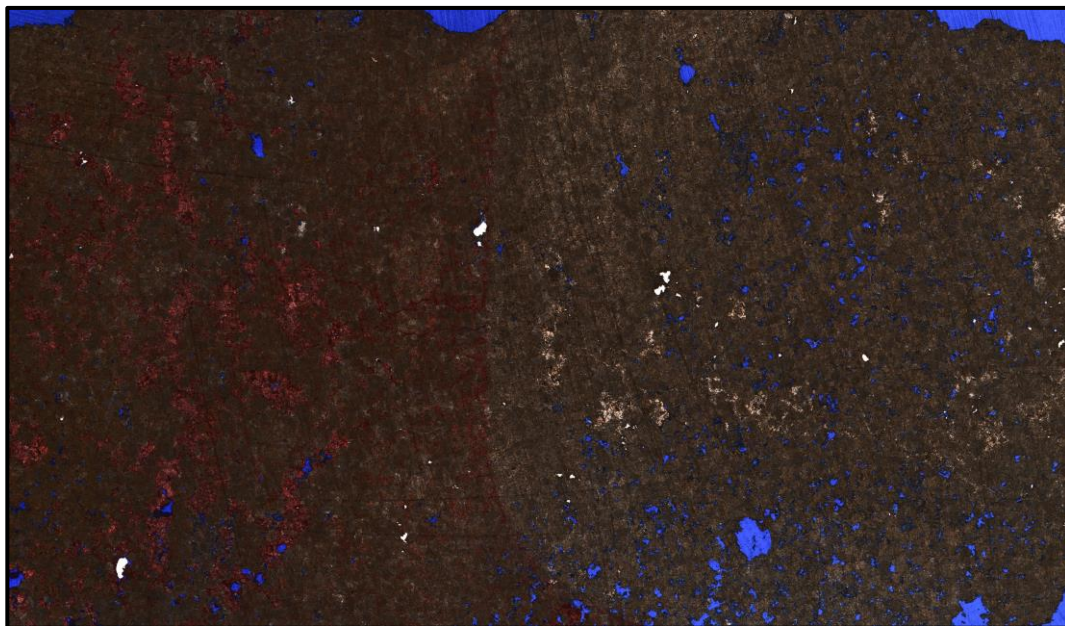
**Sac-B7:**

Biomicrite/boundstone with brachiopods, trilobites, crinoids, euhedral calcite grains comprising skeletal grains and being replaced by dolomite. Possibly algae and bryozoans (visible in blank). Anhedral to subhedral dolomite in an equigranular mosaic sieved fabric. Approx. 5-7% fracture, intraparticle, and moldic porosity.



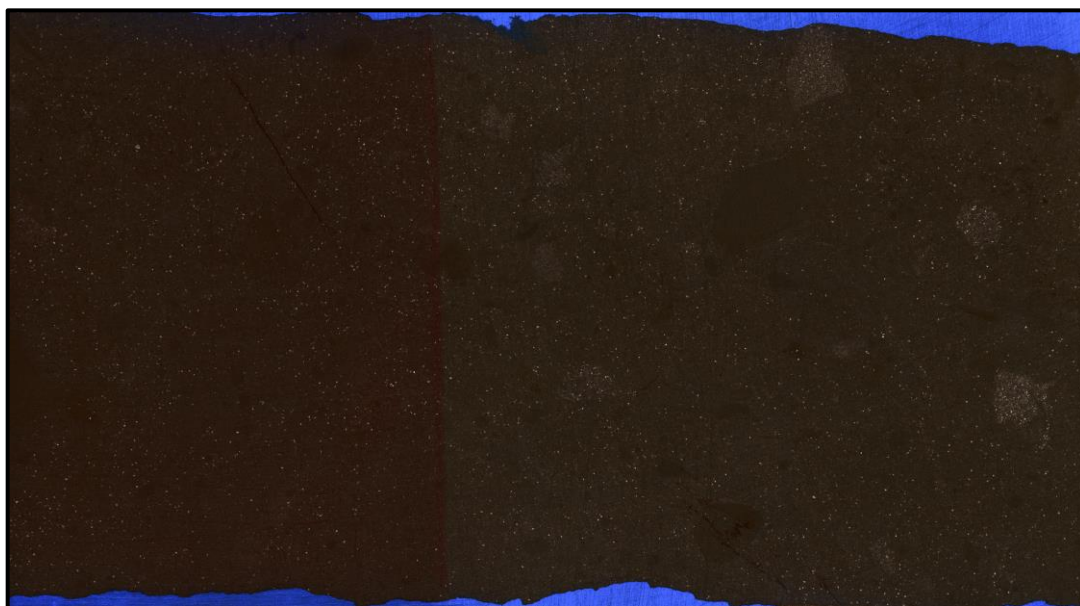
Sac-B8:

Stromatoporoid biosparite/grainstone with crinoids, brachiopods, calcite and dolomite. Dolomite is anhedral to subhedral in an equigranular peloidal fabric. Approx. 10% intraparticle and intercrystalline porosity.



Sac-C4:

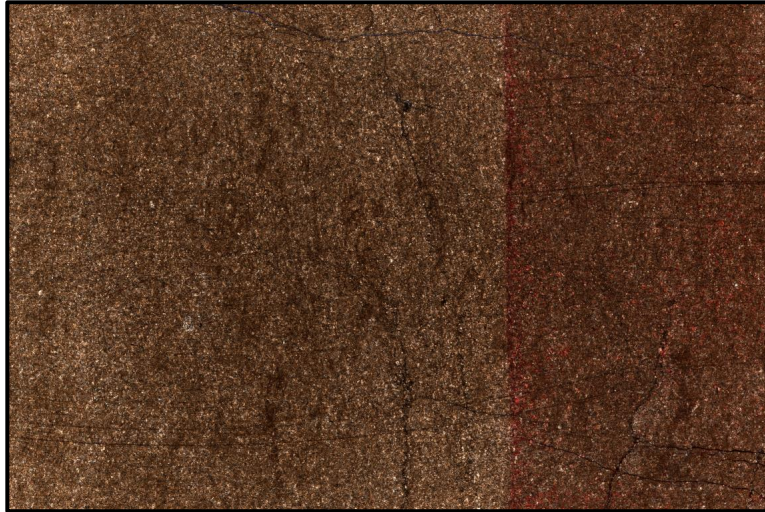
Biomicrite/mudstone with possible amphipora and foraminifera, intraclasts, peloids, micritic and microcrystalline cement. Dolomite is anhedral in an equigranular mosaic sutured fabric, no porosity.



Logan Gulch, Horseshoe Hills, MT

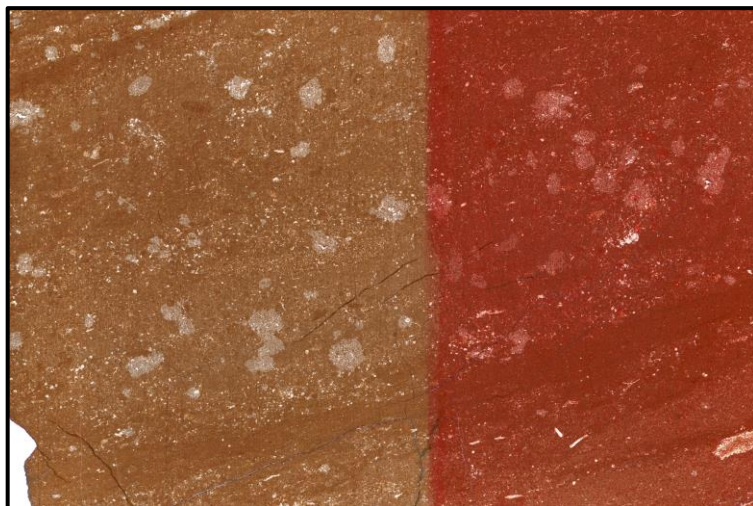
L-H1:

Pelmicrite/wackestone, possible algal material, rare calcispheres and peloids, dolomite, and calcite grains with microspar granular cement and heavily dolomitized. Dolomite is anhedral to subhedral in an equigranular mosaic sutured fabric, few simple wave stylolites and less than 1% fracture/stylolite porosity.



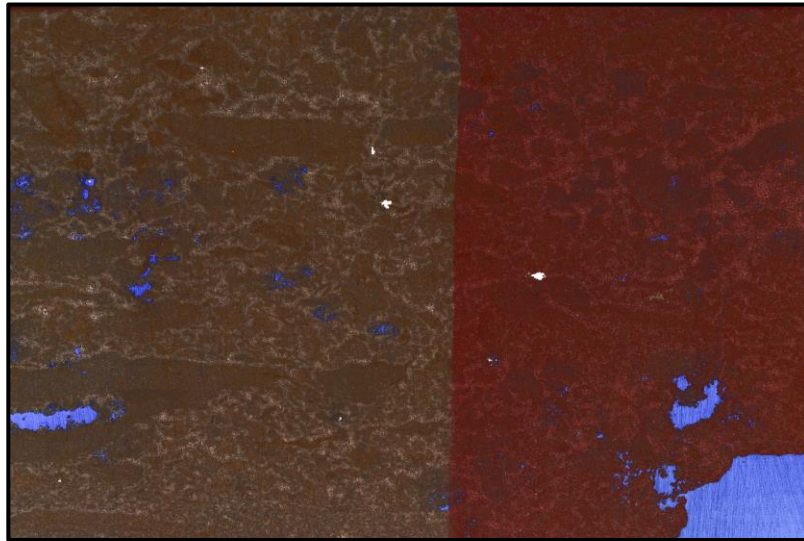
L-I:

Microbially laminated amphipora and peloidal biomicrite/packstone with green Dasyclad and phylloid algae, calcispheres, tabular stromatoporoids, and possibly brachiopod or bivalve fragments. Cement is micritic microcrystalline calcite and dolomite with dolomite forming anhedral to subhedral crystals in an inequigranular porphyrotopic floating rhomb fabric. Approx. 3% fracture and intraparticle porosity, simple wavy stylolites.



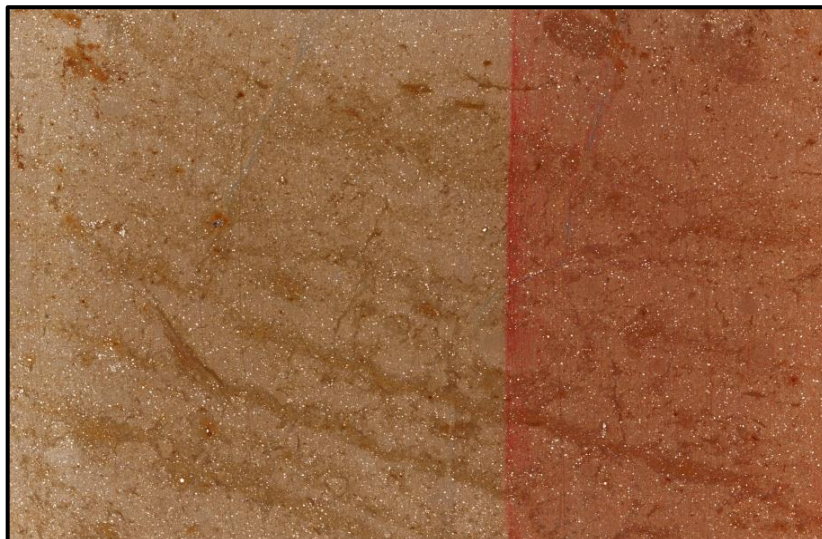
L-J:

Hemispherical to spherical stromatoporoid biolithite/boundstone with anhedral to subhedral dolomite in an equigranular mosaic sieved fabric. Dolomite replaces internal cavities of stromatoporoid structure while subhedral to euhedral calcite comprises the outer structural framework and is being replaced by dolomite. Approximately 15% intercrystalline, intracrystalline, intraparticle/moldic porosity.



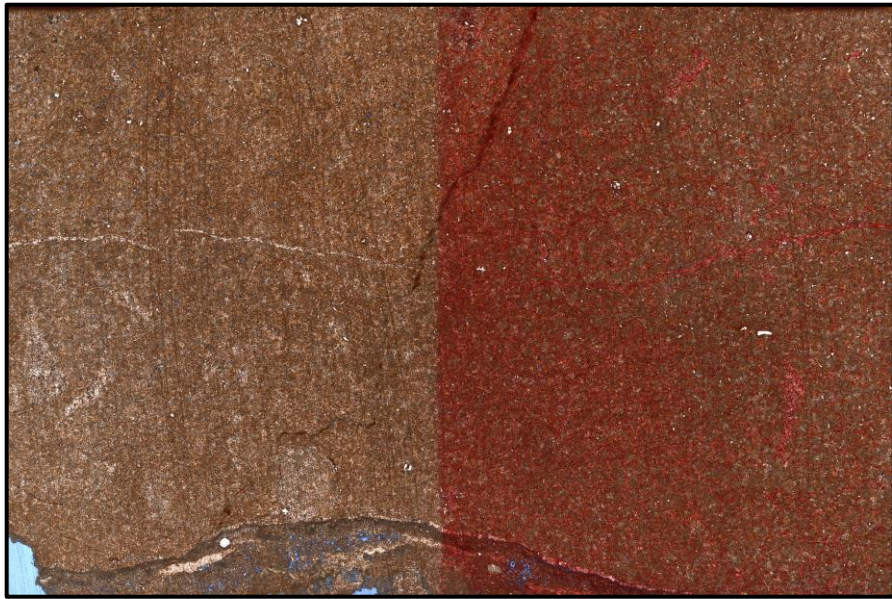
L-N:

Micrite/Mudstone with microbial laminations, less than 1% fracture porosity, micritic and microcrystalline cement, dolomitized, anhedral to subhedral dolomite in an inequigranular porphyrotopic floating rhomb matrix. Appears to be two dolomitization events, one that dolomitized the aphanotopic matrix followed by a later diagenetic event that produced subhedral floating rhomb crystals.



L-O:

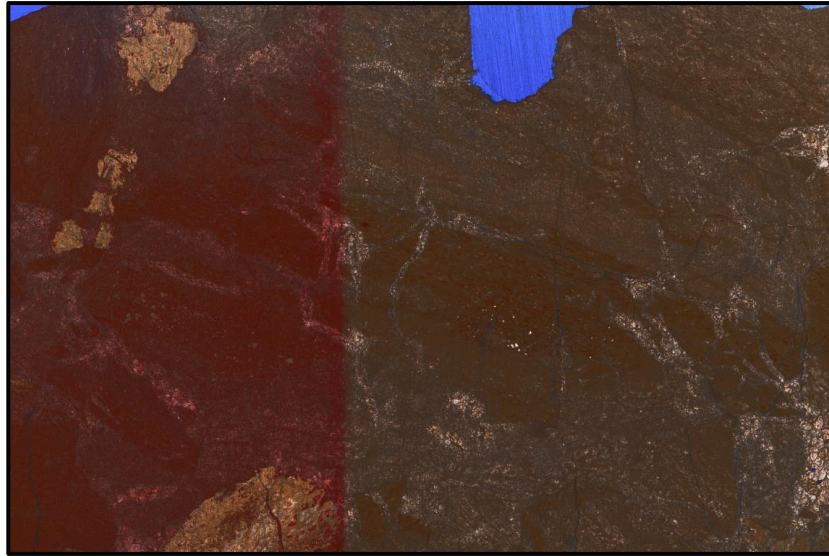
Biosparite/grainstone with spherical stromatoporoids and trilobite fragments, subhedral to euhedral calcite and dolomite and. Dolomite is in an equigranular mosaic sutured fabric, approximately 5% intercrystalline, fracture, and intraparticle porosity.



Haymaker Narrows Canyon, Little Belt Mountains, MT

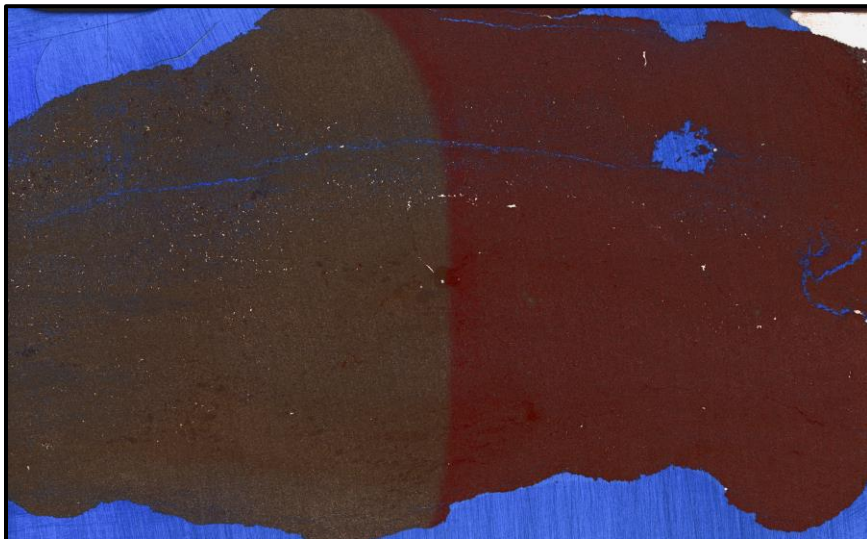
HC1-F2:

Biomic sparite/rudstone with hemispherical to spherical stromatoporoids with euhedral calcite comprising the main structure and micritic microcrystalline to microspar granular anhedral dolomite comprising cavities and matrix in an equigranular peloidal fabric. Approximately 5% fracture, intraparticle, and microporosity.



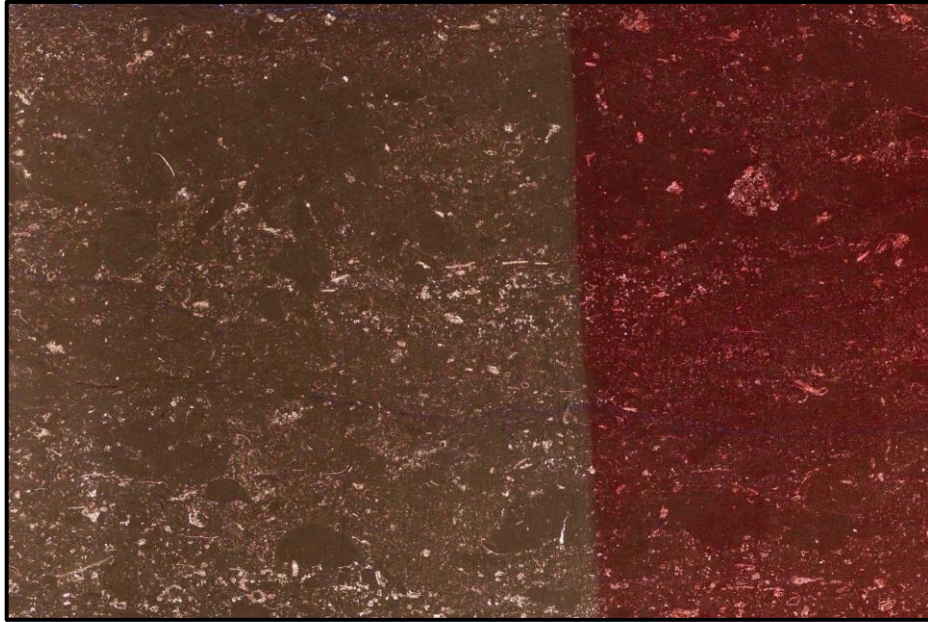
HC1-F4:

Microbially laminated pelmicrite/mudstone with 10-15% fracture, intraparticle, and fenestral porosity. Subhedral dolomite in an equigranular mosaic sieve fabric, micritic microcrystalline cement.



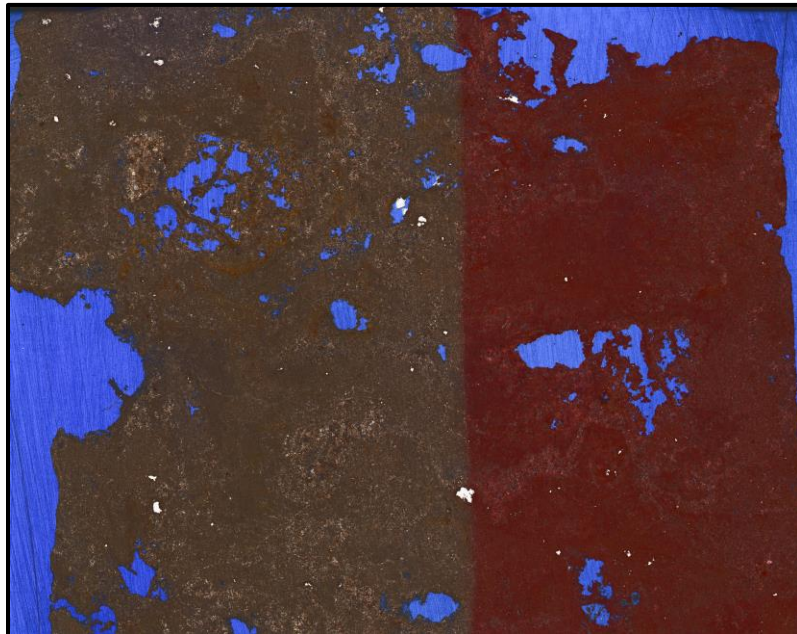
HC1-F8:

Laminated biomicrite/wackestone with brachiopods, trilobites, and euhedral dolomite in an inequigranular porphyrotopic floating rhomb fabric. Micritic and microcrystalline cement, less than 1% fracture porosity.



HC1-I:

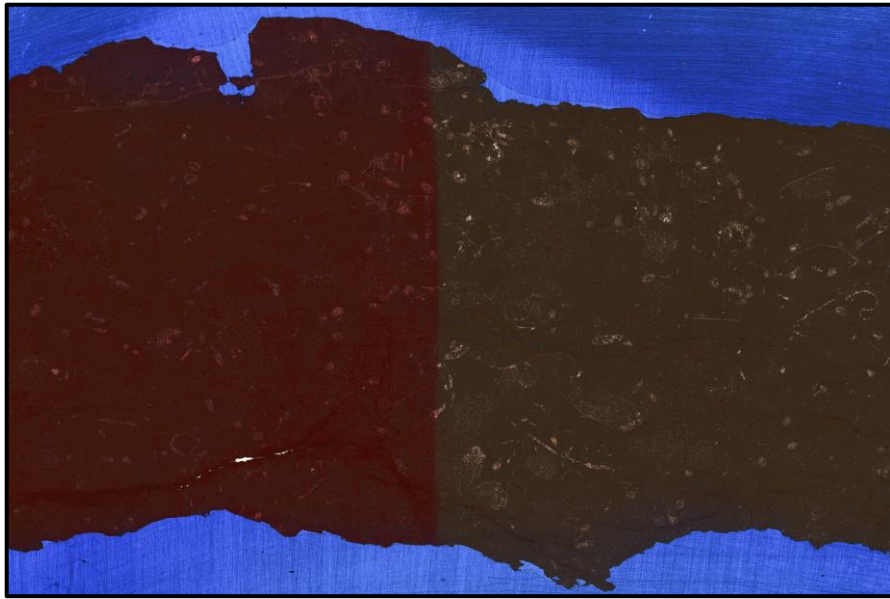
Stromatoporoid biosparite/grainstone with 10% intraparticle porosity and minor dolomitization replacing calcite.



HC1-J:

Pelmicrite/packstone with brachiopods, trilobites, amphipora, peloids, possibly green Dasyclad or phylloid algae with a micritic microcrystalline cement.

Euhedral dolomite in an inequigranular porphyrotopic floating rhomb fabric. Less than 2% fracture porosity, simple wave stylolites present.



Greathouse Peak, Big Snowy Mountains, MT

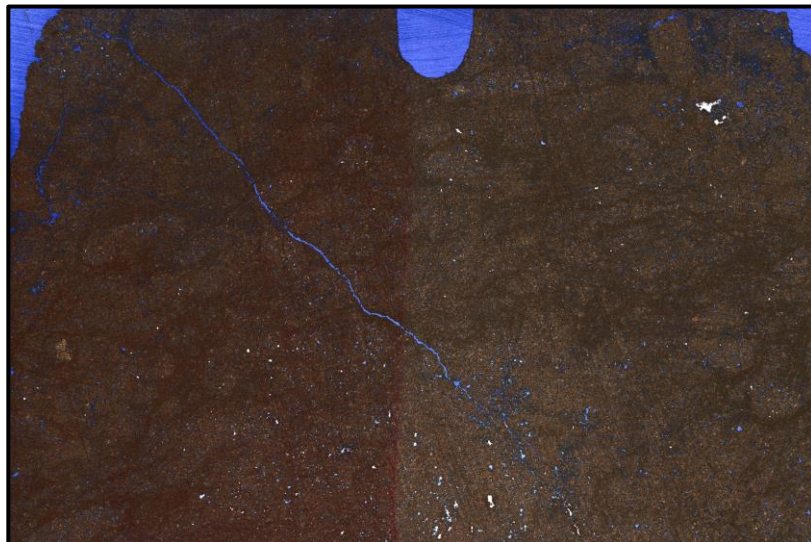
BS-A8:

Microbially laminated micrite/mudstone, some microbial laminations have coarse grained anhedral dolomite crystals however the majority of the rock is micrite (aphanotopic) sized dolomite, there are a few vertical fractures filled with calcite, no porosity, no visible fossils.



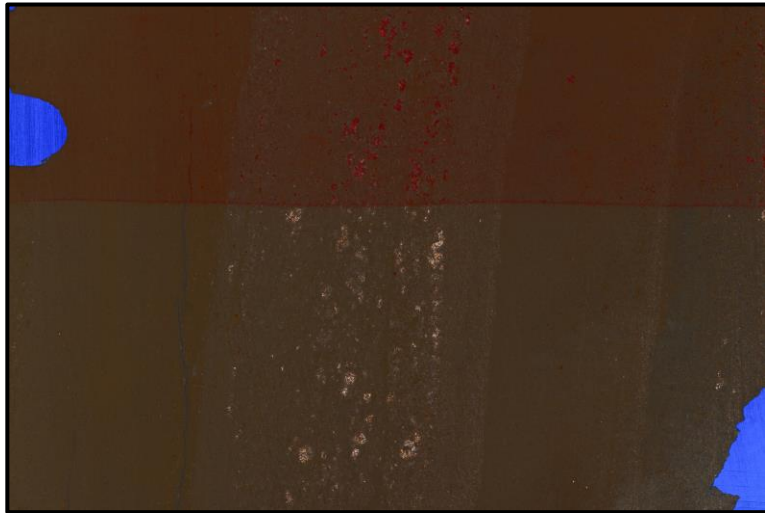
BS-A11:

Biopelsparite/packstone, completely dolomitized, 10-15% interparticle to intracrystalline and minor fracture porosity, fractures open, foraminifera and possibly calcisphere molds, subhedral to euhedral dolomite in an inequigranular porphyrotopic contact rhomb fabric



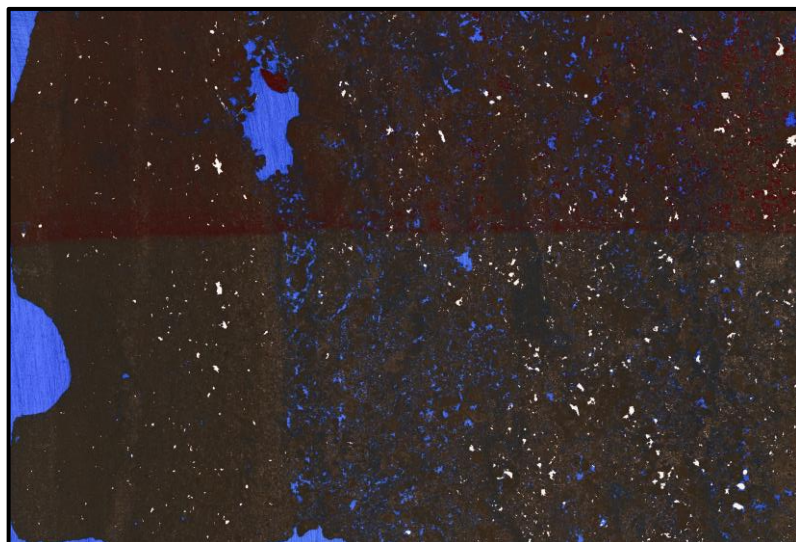
BS-A12 (strat up to left):

Microbially laminated micrite/mudstone with fenestral vuggy fabric filled with calcite spar and alternating with layers of peloidal aphanotopic dolomite, minor fracture porosity less than 2% however there is significant micro-porosity within aphanotopic dolomite layers making them appear entirely blue. Equigranular peloidal dolomite fabric, calcispheres common to abundant.



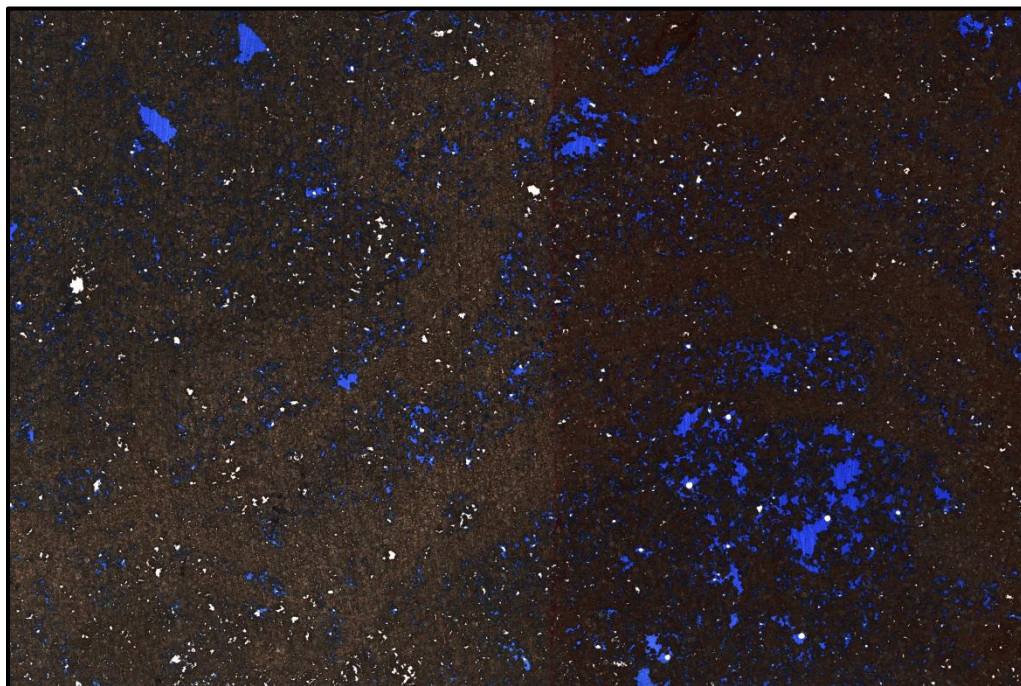
BS-A16 (strat up to left):

Biomic sparite/grainstone to framestone, dolomitized with an inequigranular mosaic fogged fabric, 20-25% intraparticle porosity, very high microporosity within finer aphanotopic dolomite layers that are located stratigraphically on top of stromatoporoid structure giving this layer a blue appearance from epoxy, euhedral calcite fills some to moderate amounts of voids within structure of stromatoporoid.



BS-A29:

Stromatoporoid biosparite/grainstone, dolomitized with an equigranular mosaic sieve fabric, 15% intraparticle and intracrystalline porosity, two algal structures possibly of Phylloid genus. Unknown mineral forming angular to subhedral crystals with low relief, non-pleochroic, opaque in XPL, makes up 5-10% of the rock, white in PPL with perfect cleavage.



APPENDIX F

MEASURED SECTION NOTES

*Note: Stratigraphic up numbering is in a descending order to correspond with drafted columns. Left column shows thickness in feet of individual units. Color code corresponds to the Hex Color Code and written color to the Munsell Color Chart.

Feet	Gibson Reservoir (NE $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 4. T. 21 N., R. 9 W.)
	Top of Section (12T 366370 E, 5273519 N, 4819 feet.
2	0 – 2 Covered green shale colored slope <i>Top Nisku/Base Three Forks Formation</i>
6	2 – 8 (Dry/wet color code: bcab9d/c3a982) Very coarse to gravel sized skeletal grainstone to rudstone with brachiopods, crinoids, stromatoporoids and cross-bedded in places, thick bedded, small ledge former. Dry/wet color name: Grayish orange pink/Grayish orange.
5.5	8 – 13.5 (Dry/wet color code: 534639/3f342a) Black organic shale laminated amphiopora wackestone with some skeletal fragments (brachiopods), fine grained, faintly laminated and thin bedded, recessive. Dry/wet color name: Grayish brown/Dusky brown.
2	13.5 – 15.5 (Dry/wet color code: bcab9d/84766b) Amphiopora and peloidal wackestone with few brachiopods, dolomitic, very fine to fine-grained and thin bedded, recessive. Dry/wet color name: Grayish orange pink/Pale brown.
2	15.5 – 17.5 (Dry/wet color code: b4af94/9a937a) Faintly laminated dolomitic mudstone forming platy to wave rippled very thin beds, very fine to fine-grained and anhydritic, forms re-entrant. Dry/wet color name: Yellowish gray/dusky yellow.
5.5	17.5 – 23 (Dry/wet color code: 84766b/534639) Very coarse stromatoporoid and skeletal grainstone with brachiopod fragments, dolomitic and thick bedded, small ledge former. Dry/wet color name: Pale brown/Grayish brown.
1.5	23 – 24.5 (Dry/wet color code: a1908e/6e5d5b) Amphiopora and peloidal wackestone with stylolites, dolomitic, fine-grained thin bedded and non-laminated, small ledge former to moderately recessive. Dry/wet color name: Pale red/Grayish red.

- 6 24.5 – 30.5 (Dry/wet color code: 84766b/534639)
Planar laminated peloidal and amphipora wackestone to packstone with minor bioturbation, fine-grained, thin bedded and heavily fractured unlike other units, possible mudcracks on uppermost beds, small ledge former. Dry/wet color name: Pale brown/Grayish brown.
- 2.5 30.5 – 33 (Dry/wet color code: 84766b/84766b)
Amphipora wackestone with few brachiopods and chicken wire anhydrite structures, fine to medium-grained, thin bedded and dolomitic with some nodular anhydrite, recessive. Dry/wet color name: Pale brown/Pale brown.
- 7 33 – 40 (Dry/wet color code: 84766b/534639)
Very coarse stromatoporoid grainstone with few amphipora, dolomitic and anhydritic forming thick beds, ledge to small cliff former. Dry/wet color name: Pale brown/Grayish brown.
- 3.5 40 – 43.5 (Dry/wet color code: bcab9d/84766b)
Non-laminated amphipora and peloidal packstone, fine to medium-grained, dolomitic and thin bedded, small ledge former. Dry/wet color name: Grayish orange pink/Pale brown.
- Approximate Top Duperow/Base Nisku*
- 65 43.5 – 108.5 Covered
- 2.5 108.5 – 111 (Dry/wet color code: d5c8b0/9d917d)
Brecciated dolostone/mudstone, very fine to fine-grained and very thin bedded, recessive. Dry/wet color name: Very pale orange/Pale yellowish brown.
- 5 111 – 126 (Dry/wet color code: 84766b/534639)
Faintly laminated amphipora and peloidal wackestone, fine to medium-grained, dolomitic and thin bedded, recessive. Dry/wet color name: Pale brown/Grayish brown.
- 10 126 – 136 (Dry/wet color code: 84766b/534639)
Spherical stromatoporoid grainstone forming medium beds, coarse grained, ledge former. Dry/wet color name: Pale brown/Grayish brown.

- 6 136 – 142 (Dry/wet color code: bcab9d/84766b)
Shaly mudstone to wackestone with 1-2" limestone rip-up clasts, wave rippled beds, chicken wire anhydrite structures, brachiopods and microbially laminated in places. Brecciated at base, very thin bedded, fine grained with very coarse to gravel sized skeletal fragments, recessive. Dry/wet color name: Grayish orange pink/Pale brown.
- 6 142 – 148 (Dry/wet color code: 84766b/534639)
Faintly laminated amphipora and peloidal packstone with foraminifera and algae, medium to coarse-grained and thin bedded, small ledge former. Dry/wet color name: Pale brown/Grayish brown.
- 9 148 – 157 (Dry/wet color code: d8c6bf/d5c8b0)
Microbially laminated mudstone with peloids forming very thin beds, fine to medium-grained, recessive. Dry/wet color name: Grayish orange pink/Very pale orange.
- 4 157 – 161 (Dry/wet color code: 84766b/534639)
Planar laminated amphipora and peloidal wackestone, medium to coarse-grained, dolomitic and thin bedded, recessive to small ledge forming. Dry/wet color name: Pale brown/Grayish brown.
- 1 161 – 162 (Dry/wet color code: d5c8b0/b4af94)
Brecciated dolomitic mudstone, fine-grained and very thin bedded, recessive. Dry/wet color name: Very pale orange/Yellowish gray.
- 3 162 – 165 (Dry/wet color code: c9c9c8/b3b4b4)
Spherical stromatoporoid grainstone forming medium beds, medium to coarse-grained, ledge former. Dry/wet color name: Very light gray/Light gray.
- 34 165 – 199 (Dry/wet color code: 84766b/84766b)
Massive stromatoporoid boundstone to rudstone and grainstones with brachiopods forming very thick beds, very coarse to gravel sized grains, cliff former. Dry/wet color name: Pale brown/Pale brown.
Dip/Dip-azimuth: 72/078.
Location: 12T 366405 E, 5273440 N, 4803 feet.

- 5 199 – 204 (Dry/wet color code: 84766b/84766b)
Planar laminated peloidal packstone with individual stromatoporoid heads weathering out, thin bedded, vuggy porosity, medium-grained, small ledge former. Dry/wet color name: Pale brown/Pale brown.
- 6 204 – 210 (Dry/wet color code: 84766b/84766b)
Stromatoporoid grainstone forming thick beds, medium to coarse-grained, ledge to small cliff former. Dry/wet color name: Pale brown/Pale brown.
- 2.5 210 – 212.5 (Dry/wet color code: 84766b/84766b)
Peloidal packstone with individual stromatoporoid heads weathering out, medium-grained, dolomitic and thin bedded, small ledge forming. Dry/wet color name: Pale brown/Pale brown.
- 3.5 212.5 – 216 (Dry/wet color code: 868888/6b6c6c)
Skeletal and cross-bedded grainstone with stromatoporoids, crinoids, and brachiopods, coarse to gravel sized grains, dolomitic and thick bedded, 4-6 inch beds forming ledges. Dry/wet color name: Medium gray/Medium dark gray.
- 4 216 – 220 (Dry/wet color code: 84766b/84766b)
Amphipora and peloidal packstone with stromatoporoid heads weathering out, medium-grained, dolomitic and thin bedded, small ledge forming. Dry/wet color name: Pale brown/Pale brown.
- 3 220 – 223 (Dry/wet color code: 84766b/534639)
Stromatoporoid grainstone, coarse-grained, dolomitic and thick bedded, 3-6 inch beds, ledge to small cliff forming. Dry/wet color name: Pale brown/Grayish brown.
- 6 223 – 229 (Dry/wet color code: d6c0be/bcab9d)
Faintly laminated amphipora and peloidal packstone with solution collapse breccia at top, medium to coarse-grained, dolomitic and thin bedded, recessive, small ledge former. Dry/wet color name: Grayish pink/Grayish orange pink.
- 3 229 – 232 (Dry/wet color code: 868888/6b6c6c)
Stromatoporoid grainstone, coarse to very coarse-grained, dolomitic and thick bedded, ledge to cliff forming. Dry/wet color name: Medium gray/Medium dark gray.

- 1 232 – 233 (Dry/wet color code: d5c8b0/9d917d)
Planar laminated peloidal wackestone forming thin beds and medium-grained., small ledger former. Dry/wet color name: Very pale orange/Pale yellowish brown.
- 2.5 233 – 235.5 (Dry/wet color code: 868888/6b6c6c)
Stromatoporoid grainstone forming thick beds, coarse to very coarse-grained, ledge forming. Dry/wet color name: Medium gray/Medium dark gray. Dip/Dip-azimuth 64/268.
- 4.5 235.5 – 240 (Dry/wet color code: c9c9c8/b3b4b4)
Cross-bedded tabular and spherical stromatoporoid rudstone to boundstone with chert nodules up to 6 inches in diameter, coarse to gravel sized grains, very thick bedded to massive, cliff forming. Dry/wet color name: Very light gray/Light gray.
- 4.5 240 – 244.5 (Dry/wet color code: 534639/3f342a and 84766b/84766b)
Amphipora and peloidal packstone with chicken wire structures and black organic shale laminae, dolomitic and anhydritic, medium-grained and thin bedded, small ledge former. Dry/wet color name: Grayish brown/Dusky brown and Pale brown/Pale brown.
- 3 244.5 – 247.5 (Dry/wet color code: 534639/3f342a)
Stromatoporoid grainstone forming thick beds, coarse-grained, ledge to small cliff forming. Dry/wet color name: Grayish brown/Dusky brown.
- 2.5 247.5 – 250 (Dry/wet color code: d5c8b0/d5c8b0)
Stromatoporoid framestone with brachiopods forming very thick beds, very coarse to gravel sized grains, cliff forming. Dry/wet color name: Very pale orange/Very pale orange.
- 2 250 – 252 (Dry/wet color code: 84766b/534639)
Faintly laminated amphipora packstone, fine to medium-grained and thin bedded, small ledge former. Dry/wet color name: Pale brown/Grayish brown.
- 4.5 252 – 256.5 (Dry/wet color code: 534639/3f342a)
Stromatoporoid grainstone with brachiopod fragments, coarse to very coarse-grained and thick bedded, ledge to small cliff former. Dry/wet color name: Grayish brown/Dusky brown.

- 6 256.5 – 262.5 (Dry/wet color code: 534639/3f342a)
Tabular and spherical stromatoporoid boundstone with crinoids, brachiopods, bivalve, echinoderms, and trilobites, very thick bedded to massive and very coarse to gravel sized grains, cliff forming. Dry/wet color name: Grayish brown/Dusky brown.
- 3.5 262.5 – 266 (Dry/wet color code: 868888/6b6c6c and 84766b/534639)
Microbially laminated and bioturbated peloidal wackestone with amphipora forming thin beds, fine to very coarse-grained, forms re-entrant. Dry/wet color name: Medium gray/Medium dark gray and Pale brown/Grayish brown.
- 10 266 – 276 (Dry/wet color code: 84766b/534639)
Stromatoporoid grainstone with crinoids forming thick beds, coarse-grained, cliff former. Dry/wet color name: Grayish orange pink/Pale brown.
- 2.5 276 – 278.5 (Dry/wet color code: 84766b/84766b)
Faintly laminated dolomitic mudstone with oncoids, fine to medium-grained and very thin bedded, recessive. Dry/wet color name: Pale brown/Pale brown.
- 1.5 278.5 – 280 (Dry/wet color code: a1908e/6e5d5b)
Peloidal wackestone with abundant individual stromatoporoid heads, medium to coarse-grained, dolomitic and thin bedded, small ledge former. Dry/wet color name: Pale red/Grayish red.
- 3 280 – 283 (Dry/wet color code: 3f4040/2a2b29)
Black organically laminated amphipora packstone with some skeletal debris, fine to very coarse-grained, dolomitic and medium bedded, small ledge former. Dry/wet color name: Grayish black/black.
- 10 283 – 293 (Dry/wet color code: a1908e/6e5d5b)
Peloidal wackestone with few individual stromatoporoid heads, fine to medium-grained, dolomitic and thin bedded, recessive to small ledge forming. Dry/wet color name: Pale red/Grayish red.
- 5 293 – 298 (Dry/wet color code: 84766b/534639)
Faintly laminated amphipora and peloidal wackestone with organic shale laminations, fine-grained and thin bedded, recessive. Dry/wet color name: Pale brown/Grayish brown.

- 6 298 – 304 (Dry/wet color code: bcab9d/84766b)
Microbially laminated dolomitic mudstone with oncoids, vuggy porosity, very fine to fine-grained and very thin bedded, recessive. Dry/wet color name: Grayish orange pink/Pale brown.
- 4.5 304 – 308.5 (Dry/wet color code: 534639/3f342a)
Black dolomitic mudstone with anhydrite chicken wire structures, very fine grained and very thin bedded, recessive. Dry/wet color name: Grayish brown/Dusky brown.
- 1.5 308.5 – 310 (Dry/wet color code: 8e735d/775b47)
Stromatoporoid packstone forming medium beds, medium-grained and dolomitic, ledge forming. Dry/wet color name: Light brown/Moderate brown.
- 1 310 – 311 (Dry/wet color code: 9d917d/6a6051)
Faintly laminated peloidal wackestone, fine to medium-grained, dolomitic and very thin bedded, recessive. Dry/wet color name: Pale yellowish brown/Dusky yellowish brown.
- 6 311 – 317 (Dry/wet color code: 8e735d/775b47)
Stromatoporoid grainstone with chert nodules up to 6 inches in diameter, very coarse to gravel sized grains, dolomitic and thick bedded, ledge to cliff forming. Dry/wet color name: Light brown/Moderate brown.
- 3 317 – 320 (Dry/wet color code: 84766b/84766b)
Amphipora wackestone with individual stromatoporoid heads, fine to medium-grained, dolomitic and thin bedded, moderately recessive. Dry/wet color name: Pale brown/Pale brown.
- 3 320 – 323 (Dry/wet color code: 84766b/84766b)
Stromatoporoid grainstone, medium to very coarse-grained, dolomitic and thick bedded, ledge forming. Dry/wet color name: Pale brown/Pale brown.
- 6 323 – 329 (Dry/wet color code: a2908b/a2908b)
Skeletal rudstone with intraclasts and abundant corals, brachiopods, crinoids, and stromatoporoid debris forming very thick to massive beds, medium to gravel sized grains, cliff forming. Dry/wet color name: Pale red/Pale red.

- 3.5 329 – 332.5 (Dry/wet color code: 6b6c6c/545554)
Faintly laminated amphipora and peloidal wackestone forming thin beds, medium-grained, abrupt upper contact, 1 inch beds, moderately recessive. Dry/wet color name: Medium dark gray/Dark gray.
- 1 332.5 – 333.5 (Dry/wet color code: 84766b/534639)
Planar laminated amphipora and peloidal wackestone, fine to medium-grained, dolomitic and very thin bedded, recessive. Dry/wet color name: Pale brown/Grayish brown.
- 1.5 333.5 – 335 (Dry/wet color code: 6b6c6c/545554)
Peloidal mudstone forming very thin 1-2 inch beds, fine to medium-grained, recessive. Dry/wet color name: Medium dark gray/Dark gray.
- 3 335 – 338 (Dry/wet color code: 84766b/534639)
Stromatoporoid packstone with amphipora, faintly laminated and forming medium beds, some skeletal debris, coarse-grained, small ledge former. Dry/wet color name: Pale brown/Grayish brown.
- 7 338 – 345 (Dry/wet color code: 67605b/3d3633)
Amphipora and peloidal wackestone forming thin beds, fine to medium-grained, 1 inch beds, moderately recessive. Dry/wet color name: Brownish gray/Brownish black.
- 1.5 345 – 346.5 (Dry/wet color code: 84766b/84766b)
Amphipora and peloidal wackestone forming thin beds, fine to medium-grained, recessive. Dry/wet color name: Pale brown/Pale brown.
- 8 346.5 – 354.5 (Dry/wet color code: 84766b/84766b)
Stromatoporoid grainstone with brachiopod and crinoid fragments, medium to coarse-grained and thick bedded to massive, small cliff former. Dry/wet color name: Pale brown/Pale brown.
- 7 354.5 – 361.5 (Dry/wet color code: 84766b/534639)
Planar laminated peloidal wackestone forming thin platy beds, fine to medium-grained, ½ to 1 cm beds, recessive. Dry/wet color name: Pale brown/Grayish brown.

- 3 361.5 – 364.5 (Dry/wet color code: 84766b/534639)
Black amphipora and peloidal wackestone, fine to medium-grained and thin bedded, ½ to 1 inch beds, moderately recessive. Dry/wet color name: Pale brown/Grayish brown.
- 4 364.5 – 368.5 (Dry/wet color code: 84766b/534639)
Amphipora and peloidal packstone with few individual spherical stromatoporoid heads, medium to coarse-grained and medium bedded, small ledge forming. Dry/wet color name: Pale brown/Grayish brown.
- 4.5 368.5 – 373 (Dry/wet color code: 775b47/5d4631)
Skeletal grainstone with stromatoporoids, brachiopods, and crinoids, coarse to very coarse-grained and thick bedded, 4-6 inch beds, forms knobby ledges. Dry/wet color name: Moderate brown/Moderate brown.
Dip/Dip-azimuth: 70/065.
- 6 373 – 379 covered
- 9 379 – 388 (Dry/wet color code: 775b47/5d4631)
Anhydrite and dolomitic mudstone with chicken wire structures, rare skeletal debris, fine to medium-grained and very thin bedded, recessive. Dry/wet color name: Moderate brown/Moderate brown.
- 1 388 – 389 (Dry/wet color code: d5c8b0/c3a982)
Coarse to very coarse skeletal grainstone with crinoids, brachiopods, and brecciated, coarse to gravel sized grains and medium bedded, forms re-entrant between ledges. Dry/wet color name: Very pale orange/Grayish orange. Location: 12T 366507 E, 5273446 N, 4907 feet.
- 5 389 – 394 (Dry/wet color code: 534639/413233)
Peloidal and amphipora packstone, anhydritic and dolomitic, medium to coarse-grained, thin bedded, few spherical individual stromatoporoid heads, small ledge forming. Dry/wet color name: Grayish brown/Blackish brown.
- 9 394 – 403 (Dry/wet color code: 84766b/3f342a)
Stromatoporoid grainstone with crossbeds, coarse to very coarse-grained and thick bedded, ledge forming. Dry/wet color name: Pale brown/Dusky brown.

- 17 403 – 420 (Dry/wet color code: 84766b/3f342a and 534639/413233)
Tabular stromatoporoid boundstone with some spherical stromatoporoids and crinoids, very coarse to gravel sized grains, and very thick bedded to massive, cliff forming. Dry/wet color name: Grayish brown/Blackish red and Pale brown/Dusky brown.
- 2.5 420 – 422.5 (Dry/wet color code: 84766b/3f342a)
Non-laminated peloidal and amphipora packstone, medium to coarse-grained and medium bedded, 2-4 inch beds, small ledge former. Dry/wet color name: Pale brown/Dusky brown.
- 2.5 422.5 – 425 (Dry/wet color code: 84766b/84766b)
Planar laminated dolomitic mudstone, fine-grained and thin bedded, ½ to 1 inch beds, recessive. Dry/wet color name: Pale brown/Pale brown.
- 2 425 – 427 (Dry/wet color code: d5c8b0/d5c8b0)
Microbially laminated anhydrite and dolomite with amphipora, very fine to medium-grained and very thinly bedded ½ to 1 inch beds, recessive. Dry/wet color name: Very pale orange/Very pale orange.
- 1 427 – 428 (Dry/wet color code: 84766b/84766b)
Very finely planar laminated mudstone with tabular stromatoporoids, dolomitic, fine to medium grained and very thin bedded, ½ to 1 cm beds, recessive. Dry/wet color name: Pale brown/Pale brown.
- 3 428 – 431 (Dry/wet color code: 84766b/534639)
Stromatoporoid grainstone with amphipora and crinoids, all dolomite (did not stain with Alizarin Red-s), very coarse-grained and thick bedded forming small ledge. Dry/wet color name: Pale brown/Grayish brown.
- 1.5 431 – 432.5 (Dry/wet color code: b4af94/9d917d)
Interbedded dolomitic mudstone and anhydrite, bioturbated in places, fine to medium-grained and thin bedded, 1 inch beds, recessive. Dry/wet color name: Yellowish gray/Pale yellowish brown.

- 2 432.5 – 434.5 (Dry/wet color code: 868888/6b6c6c and b4af94/9d917d)
Amphipora and peloidal mudstone, sucrosic texture, fine-grained and very thinly bedded, 1 inch beds, recessive. Dry/wet color name: Medium gray/Medium dark gray and Yellowish gray/Pale yellowish brown.
- 1.5 434.5 – 436 (Dry/wet color code: 84766b/84766b)
Planar laminated dolomitic mudstone with interbedded anhydrite, fine-grained and very thin bedded, cm-scale beds forming re-entrant. Dry/wet color name: Pale brown/Dusky yellowish brown.
- 2 436 – 438 (Dry/wet color code: 84766b/84766b)
Peloidal wackestone with brachiopod and crinoid fragments, abundant stylolites, fine to medium-grained and thin bedded, 4-6 inch beds forming small rounded ledge. Dry/wet color name: Pale brown/Pale brown.
- 3 438 – 441 (Dry/wet color code: b4af94/9d917d)
Faintly laminated peloidal mudstone with microbial laminations, fine-grained and very thin bedded 1-3 inch beds, recessive. Dry/wet color name: Yellowish gray/Pale yellowish brown.
- 2 441 – 443 (Dry/wet color code: b4af94/9d917d)
Amphipora mudstone, dolomitic and anhydritic, vuggy porosity, fine to medium-grained and thin bedded, 2-4 inch beds, recessive. Dry/wet color name: Yellowish gray/Pale yellowish brown.

Top Maywood/Base Duperow

(Exposure is best hiking up dip along base of cliff above trail and not on the trail itself until the massive stromatoporoid reef-shoal complex in upper Duperow)

- 7 443 – 450
Dolomitic mudstone, fine to medium-grained and thin bedded, wave rippled and bioturbated in places, nail in outcrop at Maywood-Duperow contact.

Base of section

0366569 E, 5273195 N, 4840 feet

Bedding: Dip/Dip-azimuth 60/090

Logan Gulch (SE ¼, SE ¼, Sec. 25. T. 2 N., R. 2 E.)

Top of section

- 5** 0 – 5 (Dry/wet color code: d5c8b0/e4c285)
Platy very thin beds of siltstone, recessive. Dry/wet color name: Very pale orange/Pale yellowish orange.

Top Nisku/Base Three Forks Formation

- 7** 5 – 12 (Dry/wet color code: b3b4b4/a09fa0)
Stromatoporoid grainstone, medium to coarse-grained and thick bedded, ledge former. Dry/wet color name: Light gray/Medium light gray.

- 7** 12 – 19 (Dry/wet color code: 6b6c6c/545554)
Peloidal wackestone, fine-grained and thin bedded, moderately recessive. Dry/wet color name: Medium dark gray/Dark gray.

- 9** 19 – 28 (Dry/wet color code: b3b4b4/a09fa0)
Stromatoporoid and skeletal grainstone, coarse-grained and medium bedded, ledge former. Dry/wet color name: Light gray/Medium light gray.

- 20** 28 – 48 (Dry/wet color code: 6b6c6c/545554)
Planar laminated peloidal wackestone, fine to medium grained and thin bedded, small ledge former. Dry/wet color name: Medium dark gray/Dark gray.

- 2** 48 – 50 (Dry/wet color code: d5c8b0/e4c285)
Dolomitic and anhydritic mudstone, fine grained, forms platy very thin beds, recessive. Dry/wet color name: Very pale orange/Pale yellowish orange.

Top Duperow/Base Nisku

- 20** 50 – 70 (Dry/wet color code: b3b4b4/a09fa0)
Stromatoporoid grainstone, coarse-grained, dolomitic and medium bedded, ledge former. Dry/wet color name: Light gray/Medium light gray.

- 23 70 – 93 (Dry/wet color code: 6b6c6c/ 545554)
Peloidal wackestone with zones of solution collapse breccia, anhydritic and dolomitic, fine to medium-grained and thin bedded, moderately recessive. Dry/wet color name: Medium dark gray/Dark gray. Location: 12T 0467573 E, 5081631 N, 4302 feet.
- 7 93 – 100 (Dry/wet color code: b3b4b4/a09fa0)
Stromatoporoid grainstone, medium to coarse-grained, dolomitic and medium bedded, ledge former. Dry/wet color name: Light gray/Medium light gray.
- 8 100 – 108 (Dry/wet color code: 6b6c6c/545554)
Planar laminated peloidal wackestone, fine-grained and thin bedded, moderately recessive. Dry/wet color name: Medium dark gray/Dark gray.
- 2 108 – 110 (Dry/wet color code: d5c8b0/e4c285)
Crinkly laminated dolomitic mudstone, fine-grained and very thin bedded, recessive. Dry/wet color name: Very pale orange/Pale yellowish orange.
- 24.5 110 – 134.5 (Dry/wet color code: 84766b/84766b)
Planar laminated peloidal packstone, dolomitic and anhydritic, medium-grained and thin bedded, small ledge former. Dry/wet color name: Pale brown/Pale brown.
- 2 134.5 – 136.5 (Dry/wet color code: 534639/534639)
Peloidal packstone with solution collapse breccia, medium to coarse grained, dolomitic and thin bedded, small ledge former. Dry/wet color name: Grayish brown/Grayish brown.
- 2.5 136.5 – 140 (Dry/wet color code: 84766b/84766b)
Planar laminated peloidal packstone, fine to medium-grained, dolomitic and thin bedded, small ledge former. Dry/wet color name: Pale brown/Pale brown.
- 4 140 – 144 (Dry/wet color code: b3b4b4/a09fa0)
Stromatoporoid grainstone, coarse-grained and medium bedded ledge former. Dry/wet color name: Light gray/Medium light gray.
- 5 144 – 149 (Dry/wet color code: 84766b/84766b)
Peloidal packstone, medium to coarse-grained, dolomitic and thin bedded, small ledge former. Dry/wet color name: Pale brown/Pale brown.

- 7.5 149 – 156.5 (Dry/wet color code: b3b4b4/a09fa0)
Stromatoporoid grainstone with brachiopod fragments, coarse-grained, dolomitic and medium bedded, ledge former. Dry/wet color name: Light gray/Medium light gray. Dip/Dip-azimuth: 42/300.
- 21 156.5 – 177.5 (Dry/wet color code: d0c7be/9c938c)
Stromatoporoid and skeletal rudstone to framestone with brachiopods, crinoids, and heavily brecciated throughout, karsted lower contact, very coarse to gravel sized grains, very thick to massive beds, cliff former. Dry/wet color name: Pinkish gray/Light brownish gray.
- 2 177.5 – 179.5 (Dry/wet color code: 6b6c6c/545554)
Faintly laminated to planar laminated dolomitic wackestone with amphipora and peloids, fine-grained and very thin bedded, recessive. Dry/wet color name: Medium dark gray/Dark gray.
- 14 179.5 – 193.5 (Dry/wet color code: b3b4b4/a09fa0)
Stromatoporoid grainstone, coarse-grained, dolomitic and medium bedded, ledge former. Dry/wet color name: Light gray/Medium light gray.
- 7.5 193.5 – 201 (Dry/wet color code: 6b6c6c/545554)
Faintly laminated peloidal wackestone with minor skeletal debris of brachiopods, dolomitic, fine to medium-grained and thin bedded, moderately recessive. Dry/wet color name: Medium dark gray/Dark gray.
- 1 201 – 202 (Dry/wet color code: a5b39d/88a079)
Green fissile shale bed, very fine-grained and very thin bedded, recessive. Dry/wet color name: Pale yellowish green/Moderate yellowish green.
- 4 202 – 206 (Dry/wet color code: b3b4b4/a09fa0)
Stromatoporoid grainstone, coarse-grained, dolomitic and thick bedded, ledge former. Dry/wet color name: Light gray/Medium light gray.
- 4 206 – 210 (Dry/wet color code: 6b6c6c/545554)
Planar laminated peloidal packstone, medium to coarse-grained, dolomitic and medium bedded, ledge former. Dry/wet color name: Medium dark gray/Dark gray.

- 4 210 – 214 (Dry/wet color code: b3b4b4/a09fa0)
Stromatoporoid grainstone, coarse-grained and thick bedded, ledge former. Dry/wet color name: Light gray/Medium light gray.
- 5 214 – 219 (Dry/wet color code: 6b6c6c/545554)
Planar laminated peloidal wackestone, fine to medium-grained, dolomitic and thin bedded, small ledge former. Dry/wet color name: Medium dark gray/Dark gray.
- 6 219 – 225 (Dry/wet color code: b3b4b4/a09fa0)
Stromatoporoid grainstone, medium to coarse-grained and thick bedded with stromatoporoid heads weathering out, ledge former. Dry/wet color name: Light gray/Medium light gray.
- 5 225 – 230 (Dry/wet color code: 6b6c6c/545554)
Planar laminated peloidal packstone, medium to coarse-grained, dolomitic and medium bedded, small ledge former. Dry/wet color name: Medium dark gray/Dark gray.
- 6 230 – 236 (Dry/wet color code: b3b4b4/a09fa0)
Stromatoporoid grainstone, coarse-grained and thick bedded, ledge to cliff former. Dry/wet color name: Light gray/Medium light gray.
- 7.5 236 – 243.5 (Dry/wet color code: 6b6c6c/545554)
Planar laminated wackestone with individual stromatoporoid heads and rare gastropods, fine-grained with very coarse to gravel sized skeletal debris and thin bedded, moderately recessive. Dry/wet color name: Medium dark gray/Dark gray.
- 2 243.5 – 245.5 (Dry/wet color code: a5b39d/88a079)
Green fissile shale bed, very fine-grained and very thin bedded, recessive. Dry/wet color name: Pale yellowish green/Moderate yellowish green.
- 4.5 245.5 – 250 (Dry/wet color code: e4c285/c3a982)
Interbedded dolomitic mudstone and siltstone, very fine to fine-grained and very thin to thin platy beds, recessive. Dry/wet color name: Pale yellowish orange/Grayish orange.

Dip/Dip-azimuth: 39/300.

Location: 12T 0467613 E, 5081622 N, 4228 feet.

- 4 250 – 254 (Dry/wet color code: 84766b/534639)
Peloidal packstone with solution collapse breccia, karsted upper contact, dolomitic, medium-grained and thin bedded, small ledge former. Dry/wet color name: Pale brown/Grayish brown.
- 3 254 – 257 (Dry/wet color code: b3b4b4/a09fa0)
Stromatoporoid grainstone, coarse-grained and medium bedded, ledge former. Dry/wet color name: Light gray/Medium light gray.
- 5 257 – 262 (Dry/wet color code: 6b6c6c/545554)
Planar laminated peloidal packstone, medium-grained, dolomitic and thin bedded, small ledge former. Dry/wet color name: Medium dark gray/Dark gray.
- 5.5 262 – 267.5 (Dry/wet color code: b3b4b4/a09fa0)
Stromatoporoid grainstone, coarse-grained and medium bedded, ledge former. Dry/wet color name: Light gray/Medium light gray.
- 5 267.5 – 272.5 (Dry/wet color code: 6b6c6c/545554)
Peloidal packstone, medium-grained, dolomitic and thin bedded, small ledge former. Dry/wet color name: Medium dark gray/Dark gray.
- 5.5 272.5 – 278 (Dry/wet color code: b3b4b4/a09fa0)
Stromatoporoid grainstone, coarse-grained and medium bedded, ledge to small cliff former. Dry/wet color name: Light gray/Medium light gray.
- 6 278 – 284 (Dry/wet color code: 6b6c6c/545554)
Planar laminated peloidal packstone, fine to medium-grained, dolomitic and thin bedded, moderately recessive. Dry/wet color name: Medium dark gray/Dark gray.
- 8 284 – 292 (Dry/wet color code: b3b4b4/a09fa0)
Stromatoporoid and skeletal grainstone with brachiopods and crinoids, coarse to very coarse-grained and medium bedded, ledge to small cliff former. Dry/wet color name: Light gray/Medium light gray.
- 7 292 – 299 (Dry/wet color code: d0c7be/b3b4b4)
Stromatoporoid framestone, very coarse to gravel sized grains and thick bedded, cliff former. Dry/wet color name: Pinkish gray/Light gray.

- 6 299 – 305 (Dry/wet color code: 6b6c6c/545554)
Peloidal packstone, medium-grained, dolomitic and thin bedded, small ledge former. Dry/wet color name: Medium dark gray/Dark gray.
- 6 305 – 311 (Dry/wet color code: b3b4b4/a09fa0)
Stromatoporoid grainstone, coarse-grained and medium bedded, ledge former. Dry/wet color name: Light gray/Medium light gray.
- 6 311 – 317 (Dry/wet color code: d0c7be/a09fa0)
Black tabular stromatoporoid boundstone to framestone with brachiopods and other skeletal debris, medium to gravel sized grains and thick bedded, cliff former. Dry/wet color name: Pinkish gray/Medium light gray. Dip/Dip-azimuth: 44/315 and 40/303. Location: 12T 0467619 E, 5081592 N, 4230 feet.
- 5 317 – 322 (Dry/wet color code: 6b6c6c/545554)
Peloidal packstone, medium-grained, dolomitic and thin bedded, small ledge former. Dry/wet color name: Medium dark gray/Dark gray.
- 6 322 – 328 (Dry/wet color code: a09fa0/868888)
Stromatoporoid grainstone, coarse-grained and medium bedded, ledge to small cliff former. Dry/wet color name: Light gray/Medium light gray.
- 6 328 – 334 (Dry/wet color code: d0c7be/b3b4b4)
Stromatoporoid framestone, coarse to gravel sized grains and thick bedded, cliff former. Dry/wet color name: Pinkish gray/Light gray.
- 2.5 334 – 336.5 (Dry/wet color code: 84766b/534639)
Peloidal packstone with solution collapse breccia, medium-grained, dolomitic, anhydritic and thin bedded, small ledge former. Dry/wet color name: Pale brown/Grayish brown.
- 0.5 336.5 – 337 (Dry/wet color code: a5b39d/88a079)
Green fissile shale bed, very fine to fine-grained and very thin bedded, recessive. Dry/wet color name: Pale yellowish green/Moderate yellowish green.
- 1 337 – 338 (Dry/wet color code: c3a982/9d917d)
Microbially laminated mudstone, anhydritic, fine-grained and very thin bedded, recessive. Dry/wet color name: Grayish orange/Pale yellowish brown.

- 8 338 – 346 (Dry/wet color code: 6b6c6c/545554)
Black peloidal packstone with amphipora and moderate amounts of skeletal debris, medium-grained, dolomitic and thin bedded, small ledge former. May be bioturbated in places. Dry/wet color name: Medium dark gray/Dark gray. Location: 12T 0467711 E, 5081654 N, 4289 feet.
- 7 346 – 353 (Dry/wet color code: b3b4b4/868888)
Stromatoporoid grainstone with brachiopods and bivalves, medium to coarse-grained and medium bedded, ledge former. Dry/wet color name: Light gray/Medium light gray.
- 8 353 – 361 (Dry/wet color code: 6b6c6c/545554)
Planar laminated peloidal wackestone, fine to medium-grained, dolomitic and thin bedded, small ledge former. Dry/wet color name: Medium dark gray/Dark gray.
- 7 361 – 368 (Dry/wet color code: b3b4b4/868888)
Stromatoporoid grainstone with crinoids and brachiopods, coarse to very coarse-grained and medium to thick bedded, ledge to small cliff former. Dry/wet color name: Light gray/Medium light gray.
- 6 368 – 374 (Dry/wet color code: 6b6c6c/545554)
Peloidal wackestone, fine to medium-grained, dolomitic and thin bedded, moderately recessive. Dry/wet color name: Medium dark gray/Dark gray.
- 5 374 – 379 (Dry/wet color code: b3b4b4/868888)
Stromatoporoid grainstone, coarse-grained and medium bedded, ledge to small cliff former. Dry/wet color name: Light gray/Medium light gray.
- 6 379 – 385 (Dry/wet color code: 6b6c6c/545554)
Faintly laminated black peloidal packstone with stylolites, medium-grained, dolomitic and thin to medium bedded, small ledge former. Dry/wet color name: Medium dark gray/Dark gray.
Dip/Dip-azimuth: 44/312.
- 5 385 – 390 (Dry/wet color code: d5c8b0/e4c285)
Cryptalgal laminite beds, very fine to fine-grained, anhydritic, dolomitic and very thin bedded, recessive. Dry/wet color name: Very pale orange/Pale yellowish orange.

- 8.5 390 – 398.5 (Dry/wet color code: 534639/3f342a)
Planar laminated peloidal wackestone with fenestral porosity, fine to medium-grained, dolomitic and thin bedded, moderately recessive. Dry/wet color name: Grayish brown/Dusky brown.
- 21.5 398.5 – 420 (Dry/wet color code: 868888/6b6c6c)
Amphipora and peloidal packstone with brachiopod fragments, solution collapse breccia zones and dolomite nodules up to ½ cm in diameter, anhydritic, medium-grained and medium bedded, small ledge former. Dry/wet color name: Medium gray/Medium dark gray. Dip/Dip-azimuth: 44/297.
- 6 420 – 426 (Dry/wet color code: 67605b/67605b)
Tabular to spherical stromatoporoid boundstone with amphipora and brachiopods, dolomitic, medium to very coarse-grained and medium to thick bedded, ledge former. Dry/wet color name: Brownish gray/Brownish gray.
- 29.5 426 – 455.5 (Dry/wet color code: 868888/6b6c6c)
Planar laminated peloidal packstone with brachiopods and trilobite fragments, individual stromatoporoid heads weathering out, medium-grained, dolomitic, anhydritic and thin bedded, moderately recessive to small ledge former. Dry/wet color name: Medium gray/Medium dark gray. Dip/Dip-azimuth: 42/307.
Location: 12T 0467753 E, 5081653 N, 4245 feet.
- 14.5 455.5 – 470 Covered

Approximate Top Maywood/Base Duperow

- 5 470 – 475 (Dry/wet color code: 868888/868888 and 805142/84766b)
Interbedded dolomitic mudstone and shale, recessive. Dry/wet color name: Medium gray/Medium gray and Moderate reddish brown/Pale brown. Dip/Dip-azimuth: 38/304.

Maywood Formation

Base of section

Crown Butte (SW ¼, NE ¼, Sec. 20. T. 16 N., R. 6 E.)

Top of section (500567 E, 5219644 N, 5955 feet).

- 3 0 – 3 (Dry/wet color code: c1cbc2/a5b29b)
 Pale green silty shale, fine grained and very thin bedded, recessive.
 Dry/wet color name: Light greenish gray/Pale green.

Approximate Top Nisku/Base Three Forks Formation

- 12.5 3 – 15.5 Covered
- 1 15.5 – 16.5 (Dry/wet color code: e4c285/e4c285)
 Planar laminated mudstone, very fine to fine-grained and very thin bedded, recessive. Dry/wet color name: Pale yellowish orange/Pale yellowish orange.
- 2.5 16.5 – 19 (Dry/wet color code: 868888/6b6c6c)
 Peloidal packstone with amphipora and solution collapse breccia, medium-grained and medium bedded, small ledge former. Dry/wet color name: Medium gray/Medium dark gray.
- 4 19 – 23 (Dry/wet color code: 9d917d/9d917d)
 Faintly laminated peloidal wackestone, dolomitic, anhydritic fine-grained and thin bedded, moderately recessive. Dry/wet color name: Pale yellowish brown/Pale yellowish brown.
- 3.5 23 – 26.5 (Dry/wet color code: 545554/2a2b29)
 Stromatoporoid grainstone with amphipora, coarse-grained and thick bedded, ledge former. Dry/wet color name: Dark gray/Black.
- 9 26.5 – 35.5 (Dry/wet color code: 545554/2a2b29)
 Skeletal and stromatoporoid framestone with spherical and tabular stromatoporoids, brachiopods, and crinoids, dolomitic, coarse to very coarse-grained and thick bedded, cliff former. Dry/wet color name: Dark gray/Black.
- 2.5 35.5 – 38 (Dry/wet color code: 9d917d/6a6051)
 Microbially laminated mudstone, dolomitic, very fine to fine-grained and very thin bedded, recessive. Dry/wet color name: Pale yellowish brown/Dusky yellowish brown.

- 6 38 – 44 (Dry/wet color code: a09fa0/6b6c6c)
Amphipora packstone with brachiopod fragments, dolomitic, medium-grained and medium bedded, small ledge former. Dry/wet color name: Medium light gray/Medium dark gray.
- 1 44 – 45 (Dry/wet color code: d5c8b0/d5c8b0)
Platy mudstone, dolomitic, very fine-grained and very thin bedded, recessive. Dry/wet color name: Very pale orange/Very pale orange.
- Top Duperow/Base Nisku*
- 5.5 45 – 50.5 (Dry/wet color code: a09fa0/6b6c6c)
Amphipora wackestone with few brachiopod fragments, dolomitic, fine to medium grained and thin bedded, moderately recessive. Dry/wet color name: Medium light gray/Medium dark gray.
- 5.5 50.5 – 56 (Dry/wet color code: 84766b/534639)
Peloidal and amphipora packstone with brachiopod fragments and solution collapse breccia, medium to coarse-grained and medium bedded, small ledge former. Dry/wet color name: Pale brown/Grayish brown.
- 11.5 56 – 67.5 Covered
- 2.5 67.5 – 69.5 (Dry/wet color code: 9d917d/a09fa0)
Tabular stromatoporoid boundstone at base grading upwards into a faintly laminated dolomitic wackestone with shale laminae, wave rippled beds, desiccation cracks, trilobites, and amphipora, . Fine to very coarse-grained and thin to thick bedded, recessive to ledge forming. Dry/wet color name: Pale yellowish brown/Medium light gray.
- 3.5 69.5 – 73 (Dry/wet color code: 868888/545554)
Planar laminated peloidal and amphipora packstone, dolomitic, medium grained and medium bedded, small ledge former. Dry/wet color name: Medium gray/Dark gray.
- 2 73 – 75 Covered
- 1 75 – 76 (Dry/wet color code: d5c8b0/d5c8b0)
Dolomitic and anhydritic mudstone forming platy very thin beds, very fine-grained, recessive. Dry/wet color name: Very pale orange/Very pale orange.

- 5 76 – 81 (Dry/wet color code: 534639/3f342a)
Faintly laminated peloidal and amphipora wackestone with anhydrite, fine-grained and thin bedded, moderately recessive. Dry/wet color name: Grayish brown/Dusky brown.
- 6 81 – 87 Covered
- 12.5 87 – 99.5 (Dry/wet color code: 534639/3f342a)
Black organic shale laminated mudstone forming shaly beds, very fine to fine-grained and thin bedded, recessive. Dry/wet color name: Grayish brown/Dusky brown. Location: 0500547 E, 5219437 N, 5798 feet.
- 6 99.5 – 105.5 Covered
- 12 105.5 – 117.5 (Dry/wet color code: 534639/3f342a)
Stromatoporoid and skeletal grainstone with brachiopods, dolomitic, coarse-grained and medium bedded, ledge former. Dry/wet color name: Grayish brown/Dusky brown.
Dip/Dip-azimuth: 04/310.
- 16.5 117.5 – 135 Covered
- 3.5 135 – 138.5 (Dry/wet color code: 534639/3f342a)
Peloidal wackestone with few brachiopod fragments, fine-grained and thin bedded, moderately recessive. Dry/wet color name: Grayish brown/Dusky brown.
- 7 138.5 – 145.5 Covered
- 3.5 145.5 – 149 (Dry/wet color code: 3f342a/3f342a)
Skeletal and stromatoporoid grainstone with brachiopods, coarse to very coarse-grained and thick bedded, ledge to small cliff former. Dry/wet color name: Dusky brown/Dusky brown.
Dip/Dip-azimuth: 04/295.
- 2 149 – 151 (Dry/wet color code: 3f342a/3f342a)
Planar laminated peloidal wackestone, fine-grained and thin bedded, moderately recessive. Dry/wet color name: Dusky brown/Dusky brown.
- 8 151 – 159 Covered

- 4 159 – 163 (Dry/wet color code: 3f342a/3f342a)
Planar laminated peloidal packstone with brachiopod and trilobite fragments, few gastropods and stromatoporoids, medium to coarse-grained and thick bedded, small ledge former. Dry/wet color name: Dusky brown/Dusky brown. Location: 0500550 E, 5219400 N, 5746 feet.
- 2.5 163 – 165.5 (Dry/wet color code: 3f342a/3f342a)
Planar laminated peloidal wackestone with few stromatoporoid heads, fine-grained and thin bedded, moderately recessive. Dry/wet color name: Dusky brown/Dusky brown.
- 165.5 – 176.5 Covered
- 5.5 176.5 – 182 (Dry/wet color code: 3f342a/3f342a)
Organic-rich wackestone with abundant brachiopod fragments and stromatoporoid heads weathering out, fine-grained and thin bedded, moderately recessive. Dry/wet color name: Dusky brown/Dusky brown.
- 8 182 – 190 Covered
- 18 190 – 208 (Dry/wet color code: 3f342a/3f342a)
Faintly laminated peloidal packstone with some stromatoporoid heads and brachiopods, solution collapse breccia, and black organic laminations, dolomitic, anhydritic, medium to coarse-grained and thin to medium bedded, small ledge former. Dry/wet color name: Dusky brown/Dusky brown.
- 4 208 – 212 (Dry/wet color code: 84766b/534639)
Stromatoporoid grainstone, coarse grained and thick bedded, ledge to small cliff former. Dry/wet color name: Pale brown/Grayish brown.
- 8 212 – 220 (Dry/wet color code: 84766b/534639)
Tabular stromatoporoid boundstone to rudstone with brachiopods and amphipora, dolomitic, very coarse to gravel sized grains and thick bedded, cliff former. Dry/wet color name: Pale brown/Grayish brown.
- Dip/Dip-azimuth: 04/305.
Location: 0500539 E, 5219369 N, 5701 feet.

- 1 220 – 221 (Dry/wet color code: 3f342a/3f342a)
Fissile shale bed, very fine-grained and very thin bedded, recessive. Dry/wet color name: Light green/Pale green.
- 14 221 – 235 (Dry/wet color code: 3f342a/3f342a)
Planar laminated peloidal packstone with abundant amphipora, some stromatoporoid heads, rare gastropods, chicken wire anhydrite structures, dolomitic, medium to coarse-grained and thin to medium bedded, small ledge former. Dry/wet color name: Dusky brown/Dusky brown.
Dip/Dip-azimuth: 02/315.
- 6 235 – 241 (Dry/wet color code: d5c8b0/e4c285)
Platy dolomitic and anhydritic mudstone, very fine-grained and very thin bedded, recessive. Dry/wet color name: Very pale orange/Pale yellowish orange.

241 – 248 Covered
- 6 248 – 254 (Dry/wet color code: 3f342a/3f342a)
Planar laminated amphipora and peloidal wackestone, dolomitic, medium-grained and thin bedded, moderately recessive. Dry/wet color name: Dusky brown/Dusky brown.
- 8 254 – 262 Covered
- 6 262 – 268 (Dry/wet color code: 84766b/84766b)
Stromatoporoid grainstone, medium to coarse-grained and medium to thick bedded, ledge former. Dry/wet color name: Pale brown/Pale brown.

Dip/Dip-azimuth: 05/300.
Location: 0500557 E, 5219344 N, 5625 feet.
- 22 268 – 290 Covered
- 4 290 – 294 (Dry/wet color code: 6e5d5b/413233)
Organic rich stromatoporoid boundstone with brachiopods, amphipora and some solution collapse breccia, dolomitic, coarse to gravel sized grains and medium bedded, ledge former. Dry/wet color name: Grayish red/Blackish red. Dip/Dip-azimuth: 02/290.
- 23 294 – 317 Covered

- 6 317 – 323 (Dry/wet color code: 84766b/84766b)
Faintly laminated peloidal packstone with stromatoporoid heads, medium-grained and medium bedded, small ledge former. Dry/wet color name: Pale brown/Pale brown.
- 8 323 – 331 (Dry/wet color code: 84766b/84766b)
Stromatoporoid grainstone, coarse-grained and thick bedded, ledge former. Dry/wet color name: Pale brown/Pale brown.
- 3 331 – 334 (Dry/wet color code: 84766b/534639)
Tabular stromatoporoid boundstone to rudstone with brachiopods and chert replacing stromatoporoids, dolomitic very coarse to gravel sized grains and very thick bedded, ledge former. Dry/wet color name: Pale brown/Grayish brown.
- 4 334 – 338 (Dry/wet color code: 534639/3f342a)
Amphipora packstone with stromatoporoid heads, dolomitic, medium to coarse-grained and thin to medium bedded, small ledge former. Dry/wet color name: Grayish brown/Dusky brown.
Location: 0500549 E, 5219317 N, 5580 feet.
- 8 338 – 346 (Dry/wet color code: 84766b/534639)
Stromatoporoid grainstone, coarse-grained and medium bedded, ledge former. Dry/wet color name: Pale brown/Grayish brown.
- 11 346 – 357 (Dry/wet color code: 84766b/534639)
Stromatoporoid framestone with brachiopods, crinoids, bryozoans, and corals, dolomitic, coarse to gravel sized grains and thick bedded, small cliff former. Dry/wet color name: Pale brown/Grayish brown. Dip/Dip-azimuth: 05/272.
- 26.5 357 – 383.5 Covered
- 4.5 383.5 – 388 (Dry/wet color code: 84766b/534639)
Hemi-spherical stromatoporoid packstone with peloids, amphipora, trilobites, calcispheres and brecciated zones, medium to very coarse-grained and medium bedded, small ledge former. Dry/wet color name: Pale brown/Grayish brown.
- 12 388 – 400 Covered

- 5.5 400 – 405.5 (Dry/wet color code: 84766b/84766b)
 Tabular and hemi-spherical stromatoporoid boundstone to framestone with brachiopods, dolomitic, very coarse to gravel sized grains and thick bedded, ledge former. Dry/wet color name: Pale brown/Pale brown.
- 21.5 405.5 – 417 (Dry/wet color code: 6e5d5b/413233)
 Stromatoporoid boundstone to rudstone with brachiopods and crinoids, dolomitic, very coarse to gravel sized grains and thick bedded, ledge to small cliff former. Dry/wet color name: Grayish red/Blackish red.
- 5 417 – 423 (Dry/wet color code: 6e5d5b/413233)
 Interbedded very fine-grained, organic-rich mudstone with amphipora and dolomitic peloidal wackestone forming very thin to thin beds, recessive. Dry/wet color name: Grayish red/Blackish red.
 Dip/Dip-azimuth: 02/245.
 Location: 0500564 E, 5219251 N, 5494 feet.
- Approximate Top Maywood/Base Duperow (Maywood and Snowy Range Formations exposed in gully below)*
- 2 423 – 425 Covered
- Maywood Formation*
- Base of section

Storm Castle Peak (NE ¼, SE ¼, Sec. 34. T. 4 S., R. 4 E.)

Top of section

- 4 0 – 4 (Dry/wet color code: c1cbc2/a5b39d)
 Green fissile shale, very fine to fine-grained and very thin bedded, recessive. Dry/wet color name: Light greenish gray/Pale yellowish green.
 Dip/Dip-azimuth: 26/049.
- 1 4 – 5 (Dry/wet color code: c1cbc2/a5b39d)
 Intrusive dike/sill at base of outcrop. Dry/wet color name: Light greenish gray/Pale yellowish green.

Approximate Top Nisku/Base Three Forks

- 15 5 – 20 Covered
- 5 20 – 25 (Dry/wet color code: 6b6c6c/545554)
 Skeletal and stromatoporoid grainstone with brachiopods and crinoids, cherty, medium to gravel sized grains and thick bedded, ledge former. Dry/wet color name: Medium dark gray/Dark gray.
 Dip/Dip-azimuth: 30/060.
 Location: 0483554 E, 5032341 N, 6295 feet.
- 2 25 – 27 (Dry/wet color code: 84766b/84766b)
 Planar laminated peloidal wackestone, medium-grained and thin bedded, moderately recessive. Dry/wet color name: Pale brown/Pale brown.
- 6 27 – 33 (Dry/wet color code: a09fa0/868888)
 Cross-bedded stromatoporoid grainstone with abundant chert nodules up to 6 inches in diameter, few brachiopod and crinoid fragments, medium to coarse-grained and thick bedded, cliff former. Dry/wet color name: Medium light gray/Medium gray.
 Dip/Dip-azimuth: 22/052.
 Location: 0483545 E, 5032323 N, 6275 feet.
- 2 33 – 35 (Dry/wet color code: 84766b/84766b)
 Planar laminated peloidal wackestone, medium-grained and thin bedded, small ledge former. Dry/wet color name: Pale brown/Pale brown.

- 10 35 – 45 (Dry/wet color code: a09fa0/868888)
Cross-bedded stromatoporoid grainstone with abundant chert nodules up to 6 inches in diameter, few brachiopod and crinoid fragments, medium to coarse-grained and thick bedded, cliff former. Dry/wet color name: Medium light gray/Medium gray.
- 3 45 – 48 (Dry/wet color code: 84766b/84766b)
Planar laminated amphipora and peloidal wackestone forming reentrant to cliff, medium-grained and thin bedded. Dry/wet color name: Pale brown/Pale brown.
- 8 48 – 56 (Dry/wet color code: b3b4b4/868888)
Cross-bedded stromatoporoid grainstone with abundant chert nodules up to 6 inches in diameter, few brachiopod and crinoid fragments, medium to coarse-grained and thick bedded, cliff former. Dry/wet color name: Light gray/Medium gray. Dip/Dip-azimuth: 24/068.

Top Duperow/Base Nisku

- 1 56 – 57 (Dry/wet color code: c3a982/ad9058)
Skeletal packstone to grainstone with trilobites, crinoids, brachiopods and stromatoporoid fragments, anhydritic, medium to very coarse-grained and thin to medium bedded, ledge former. Dry/wet color name: Grayish orange/Dark yellowish orange.
- 2 57 – 59 (Dry/wet color code: 84766b/84766b)
Faintly laminated mudstone with amphipora forming shaly beds, dolomitic, anhydritic, fine-grained and thin bedded, recessive. Dry/wet color name: Pale brown/Pale brown.
- 3 59 – 62 (Dry/wet color code: a09fa0/868888)
Stromatoporoid grainstone with brachiopods, medium to coarse-grained and medium to thick bedded, ledge former. Dry/wet color name: Medium light gray/Medium gray. Location: 0483547 E, 5032305 N, 6200 feet.
- 142 62 – 204 Covered (Followed nose of ridge)

- 1 204 – 205 (Dry/wet color code: 6b6c6c/545554)
Planar laminated peloidal and amphipora wackestone to packstone with solution collapse breccia, dolomitic, medium to coarse-grained and thin to medium bedded, small ledge former. Dry/wet color name: Medium dark gray/Dark gray. Dip/Dip-azimuth: 25/061 and 32/058.
- 5 205 – 210 (Dry/wet color code: b3b4b4/868888)
Stromatoporoid grainstone with crossbeds, medium to coarse-grained and medium to thick bedded, ledge former. Dry/wet color name: Light gray/Medium gray.
- 3 210 – 213 (Dry/wet color code: 6b6c6c/545554)
Faintly laminated peloidal wackestone with amphipora and some brachiopods, dolomitic, medium-grained and thin bedded, moderately recessive. Dry/wet color name: Medium dark gray/Dark gray.
- 7 213 – 220 (Dry/wet color code: b3b4b4/868888)
Skeletal grainstone with crinoids, brachiopods, and stromatoporoid heads weathering out, faint laminations, coarse to very coarse-grained and thick bedded, small cliff former. Dry/wet color name: Light gray/Medium gray.
- 4 220 – 224 (Dry/wet color code: 868888/6b6c6c)
Peloidal packstone with solution collapse breccia and stromatoporoid heads, dolomitic and anhydritic, medium to coarse-grained and medium bedded, ledge former. Dry/wet color name: Medium gray/Medium dark gray. Location: 0483559 E, 5032208 N, 6002 feet.
- 8.5 224 – 232.5 Covered
- 2.5 232.5 – 235 (Dry/wet color code: 6b6c6c/545554)
Peloidal packstone with minor skeletal debris of brachiopods, crinoids, trilobites and amphipora, dolomitic, medium-grained and medium bedded, small ledge former. Dry/wet color name: Medium dark gray/Dark gray.
- 2 235 – 237 (Dry/wet color code: 6b6c6c/545554)
Planar algal laminated peloidal packstone with stromatoporoid debris, minor solution collapse breccia, dolomitic and anhydritic, medium-grained and medium bedded, small ledge former. Dry/wet color name: Medium dark gray/Dark gray.

- 1 237 – 238 (Dry/wet color code: d5c8b0/e4c285)
Microbially laminated wave rippled mudstone, dolomitic, fine-grained and very thin bedded, recessive. Dry/wet color name: Very pale orange/Pale yellowish orange.
- 9 238 – 247 (Dry/wet color code: 6b6c6c/545554)
Amphipora and peloidal packstone with stromatoporoid heads and solution collapse breccia, dolomitic, anhydritic, medium to coarse-grained and medium bedded, small ledge former. Dry/wet color name: Medium dark gray/Dark gray.
Dip/Dip-azimuth: 23/064.
- 2 247 – 249 (Dry/wet color code: 6b6c6c/545554)
Peloidal wackestone, dolomitic, fine to medium grained and thin bedded, moderately recessive. Dry/wet color name: Medium dark gray/Dark gray.
- 3 249 – 252 (Dry/wet color code: 868888/6b6c6c)
Stromatoporoid and skeletal grainstone with crinoids and brachiopods, medium to very-coarse grained and thick bedded, ledge former. Dry/wet color name: Medium gray/Medium dark gray.
- 2 252 – 254 (Dry/wet color code: 3f4040/2a2b29)
Black tabular stromatoporoid boundstone, coarse to very coarse-grained and very thick to massive beds, ledge former. Dry/wet color name: Grayish black/Black.
- 3 254 – 257 (Dry/wet color code: 6b6c6c/545554)
Black wackestone with minor skeletal debris of brachiopods and crinoids, fine to medium-grained and thin bedded, moderately recessive. Dry/wet color name: Medium dark gray/Dark gray.
Dip/Dip-azimuth: 30/034.
- 75 257 – 332 Covered

*Approximate Top Maywood/Base Duperow
(Based on McMannis, 1955 total Duperow thickness and well-defined Nisku-Duperow contact higher up.)*
- 3 332 – 335 (Dry/wet color code: 84766b/84766b)
Skeletal grainstone with crinoid and brachiopod fragments, coarse-grained and medium to thick bedded, ledge former. Dry/wet color name: Pale brown/Pale brown.

- 5 335 – 340 (Dry/wet color code: 84766b/534639)
Peloidal wackestone, planar laminated in places, medium-grained
and thin bedded, Moderately recessive. Dry/wet color name: Pale
Brown/Grayish brown. Dip/Dip-azimuth: 30/055.

Maywood Formation

Base of section

Location: 483456 E, 5032315 N, 5897 feet.

West side of Purdy Creek, southeast of Storm Castle Peak.

Sacagawea Peak SE ¼, NW ¼, Sec. 27. T. 2 N., R. 6 E.

Top of section (502344 E, 5082475 N, 9502 feet)

- 5 0 – 5 (Dry/wet color code: 98b683/a5b29b)
Interbedded siltstones and shales, clay to silt sized grains and very thin bedded, recessive. Dry/wet color name: Light green/Pale green.

Top Nisku/Base Three Forks

- 8.5 5 – 13.5 (Dry/wet color code: f0ebd6/e4c2a4)
Stromatoporoid grainstone with amphipora and brachiopods, heavily brecciated, coarse-grained and thick bedded, ledge former. Dry/wet color name: Yellowish gray/moderate orange pink.

- 6 13.5 – 19.5 (Dry/wet color code: f0ebd6/d0c7be)
Cross-bedded stromatoporoid grainstone, coarse to very coarse-grained and medium to thick bedded, ledge former. Dry/wet color name: Yellowish gray/Pinkish gray.

- 47 19.5 – 66.5 (Dry/wet color code: c1cbc2/c9cbb7)
Stromatoporoid rudstone to boundstone and framestone with brachiopods and crinoids, coarse to gravel sized grains and very thick to massive beds, cliff former. Dry/wet color name: Light greenish gray/Light greenish gray.

Top Duperow/Base Nisku (502300 E, 5082506 N, 9489 feet)

- 4.5 66.5 – 71 (Dry/wet color code: b3b4b4/e4c285)
Heavily brecciated stromatoporoid grainstone, dolomitic, coarse to very coarse-grained and medium bedded, ledge former. Dry/wet color name: Light gray/Pale yellowish orange.

- 7.5 71 – 78.5 (Dry/wet color code: c9cbb7/e4c285)
Amphipora and peloidal packstone with mottled green-purple-tan interior, faintly laminated, dolomitic and anhydritic, medium to coarse-grained and medium bedded, small ledge former. Dry/wet color name: Light greenish gray/Pale yellowish orange.

- 24 78.5 – 102.5 Covered
Recessive slope with platy very thin bedded siltstones and shales.

- 4.5 102.5 – 107 (Dry/wet color code: 9d917d/9d917d)
Peloidal wackestone with solution collapse breccia, dolomitic, fine to medium-grained and thin bedded, moderately recessive. Dry/wet color name: Pale yellowish brown/pale yellowish brown.
Dip/Dip-azimuth: 60/299.
- 6 107 – 113 (Dry/wet color code: e4c285/e4c285)
Stromatolitic mudstone with wavy parallel beds, faintly laminated, dolomitic, fine-grained and very thin to thin bedded, recessive. Dry/wet color name: Pale yellowish orange/Pale yellowish orange.
- 2.5 113 – 115.5 (Dry/wet color code: c1cbc2/6b5c63)
Intensely bioturbated mudstone, mottled maroon-green with amphipora and Cruziana ichnofacies, possible mudcracks, very fine to fine-grained and very thin to thin bedded, recessive. Dry/wet color name: Light greenish gray/Grayish red purple.
- 7.5 115.5 – 123 (Dry/wet color code: a2908b/a2908b)
Amphipora and peloidal packstone with some individual stromatoporoid heads, dolomitic, medium-grained and thin to medium bedded, small ledge former. Dry/wet color name: Pale red/Pale red.
- 7 123 – 130 (Dry/wet color code: a2908b/a2908b)
Peloidal packstone, fine to medium-grained and thin bedded, small ledge former. Dry/wet color name: Pale red/Pale red.
- 6 130 – 136 (Dry/wet color code: 84766b/84766b)
Tabular stromatoporoid boundstone with amphipora and peloids, dolomitic, coarse to gravel sized grains and thick bedded, small ledge former. Dry/wet color name: Pale brown/Pale brown.
- 2.5 136 – 138.5 (Dry/wet color code: c1cbc2/655c6b and 814f4f/814f4f)
Intensely bioturbated and peloidal mudstone with wave rippled beds, mottled maroon-green, anhydritic, fine-grained and very thin bedded, recessive. Dry/wet color name: Light greenish gray/Grayish purple and Moderate red/Moderate red.
- 4.5 138.5 – 143 (Dry/wet color code: 9d917d/9d917d)
Stromatoporoid grainstone with few brachiopod fragments and amphipora, medium to coarse-grained and bed thickness increasing upward, ledge former. Dry/wet color name: Pale yellowish brown/Pale yellowish brown.

- 2.5 143 – 145.5 (Dry/wet color code: 84766b/84766b)
Peloidal wackestone, dolomitic, fine to medium-grained and very thin bedded, moderately recessive. Dry/wet color name: Pale brown/Pale brown.
- 3.5 145.5 – 149 (Dry/wet color code: 9d917d/9d917d)
Stromatoporoid grainstone with few brachiopod fragments, dolomitic, medium to coarse-grained and bed thickness increasing upward, ledge former. Dry/wet color name: Pale yellowish brown/Pale yellowish brown.
- 12 149 – 161 (Dry/wet color code: b3b4b4/a09fa0)
Stromatoporoid and skeletal framestone with brachiopods and crinoids, very coarse to gravel sized grains, very thick bedded to massive, cliff former. Dry/wet color name: Light gray/Medium light gray.
- 3 161 – 164 (Dry/wet color code: a1908e/a1908e)
Amphipora wackestone, dolomitic, fine to medium-grained and thin bedded, moderately recessive. Dry/wet color name: Pale red/Pale red.
- 3 164 – 167 (Dry/wet color code: 99977a/8e6e6c)
Intensely bioturbated mudstone with amphipora and wave rippled beds, mottled maroon-green, fine-grained and very thin bedded, recessive. Dry/wet color name: Pale olive/Moderate red.
- 4 167 – 171 (Dry/wet color code: 9d917d/c3a982)
Planar laminated stromatoporoid and peloidal packstone, faintly mottled maroon-green, medium to coarse-grained and medium bedded, small ledge former. Dry/wet color name: Pale yellowish brown/Grayish orange.
- 5 171 – 176 (Dry/wet color code: a1908e/917063)
Bioturbated mudstone forming platy very thin beds, possible mudcracks and very fine-grained, recessive. Dry/wet color name: Pale red/Pale reddish brown.
- 6 176 – 182 (Dry/wet color code: 84766b/534639)
Stromatoporoid and peloidal packstone with solution collapse breccia and few brachiopod fragments, medium-grained and thin to medium bedded, small ledge former. Dry/wet color name: Pale brown/Grayish brown.

- 24 182 – 206 Covered
- 3.5 206 – 209.5 (Dry/wet color code: 814f4f/814f4f)
Bioturbated mudstone with peloids and amphipora, very fine to fine-grained and very thin bedded, recessive. Dry/wet color name: Moderate red/Moderate red.
- 3.5 209.5 – 213 (Dry/wet color code: 9d917d/8e6e6c)
Intensely bioturbated mudstone with peloids and amphipora, mottled maroon-green, fine to coarse-grained and thin bedded, recessive. Dry/wet color name: Pale yellowish brown/Moderate red.
- 26.5 213 – 239.5 (Dry/wet color code: d5c8b0/e4c285)
Platy shales and siltstones forming covered slope, clay to silt sized grains and very thin beds, recessive. Dry/wet color name: Very pale orange/Pale yellowish orange.
- 9 239.5 – 248.5 (Dry/wet color code: a1908e/6e5d5b)
Peloidal wackestone, rare skeletal fragments of brachiopods or trilobites, dolomitic, medium-grained and thin bedded, moderately recessive. Dry/wet color name: Pale red/Grayish red. Dip/Dip-azimuth: 60/305.
- 7.5 248.5 – 256 (Dry/wet color code: 84766b/84766b)
Stromatoporoid grainstone with crinoids, coarse to very coarse-grained and medium bedded, ledge former. Dry/wet color name: Pale brown/Pale brown.
- 12 256 – 268.5 (Dry/wet color code: 84766b/84766b)
Stromatoporoid boundstone to rudstone with brachiopods, crinoids, tabular and spherical stromatoporoids, dolomitic, very coarse to gravel sized grains and very thick bedded, cliff former. Dry/wet color name: Pale brown/Pale brown. Location: 502202 E, 5082596 N, 9332 feet.
- 6 268.5 – 274.5 (Dry/wet color code: 534639/534639)
Black skeletal packstone with stromatoporoid, crinoid, and brachiopod debris, dolomitic and anhydritic, medium to coarse-grained and thin bedded, small ledge former. Dry/wet color name: Grayish brown/Grayish brown.
- 6 274.5 – 280.5 (Dry/wet color code: d5c8b0/d5c8b0)
Platy mudstone beds covering slope, recessive. Dry/wet color name: Very pale orange/Very pale orange.

- 6 280.5 – 286.5 (Dry/wet color code: 84766b/84766b)
Planar laminated peloidal wackestone to packstone with minor brachiopod fragments, dolomitic, fine to medium-grained and thin bedded, moderately recessive. Dry/wet color name: Pale brown/Pale brown.
- 1.5 286.5 – 288 (Dry/wet color code: d5c8b0/9d917d)
Stromatoporoid grainstone with brachiopods and crinoids, coarse to very coarse-grained and medium to thick bedded, ledge former. Dry/wet color name: Very pale orange/Pale yellowish brown.
- 12 288 – 300 (Dry/wet color code: 84766b/534639)
Faintly laminated amphipora and peloidal packstone, dolomitic, medium to coarse-grained and thin to medium bedded, small ledge former. Dry/wet color name: Pale brown/Grayish brown. Dip/Dip-azimuth: 50/295.
- 3 300 – 303 (Dry/wet color code: 84766b/534639)
Tabular and spherical stromatoporoid boundstone with brachiopods, trilobites and crinoids, dolomitic, coarse to gravel sized grains and thick bedded, small ledge former. Dry/wet color name: Pale brown/Grayish brown.
- 6 303 – 309 (Dry/wet color code: d5c8b0/d5c8b0)
Platy mudstone beds covered slope, recessive. Dry/wet color name: Very pale orange/Very pale orange.
- 4 309 – 313 (Dry/wet color code: 534639/534639)
Amphipora and stromatoporoid packstone with solution collapse breccia, dolomitic, medium to coarse-grained and medium bedded, small ledge former. Dry/wet color name: Grayish brown/Grayish brown.
- 2 313 – 315 (Dry/wet color code: 9d917d/9d917d)
Planar laminated mudstone with wave rippled beds, dolomitic and anhydritic, fine to medium-grained and very thin bedded, recessive. Dry/wet color name: Pale yellowish brown/Pale yellowish brown.
- 5 315 – 320 (Dry/wet color code: 84766b/534639)
Faintly laminated peloidal and amphipora packstone with zones of solution collapse breccia, dolomitic, medium-grained and thin bedded, moderately recessive. Dry/wet color name: Pale brown/Grayish brown.

- 7 320 – 327 (Dry/wet color code: 84766b/534639)
Tabular stromatoporoid boundstone with brachiopods and crinoids, dolomitic, coarse to gravel sized grains and medium to thick bedded, erosional scour at base, ledge former. Dry/wet color name: Pale brown/Grayish brown.
- 1 327 – 328 (Dry/wet color code: 9d917d/9d917d)
Bioturbated mudstone, dolomitic and anhydritic, fine-grained and very thin bedded, recessive. Dry/wet color name: Pale yellowish brown/Pale yellowish brown.
- 1 328 – 329 (Dry/wet color code: e4c285/e4c285)
Oxidized platy mudstone beds, dolomitic and anhydritic, very fine-grained and very thin bedded, recessive. Dry/wet color name: Pale yellowish orange/Pale yellowish orange.
- 12 329 – 341 (Dry/wet color code: d0c7be/d0c7be)
Cross-bedded stromatoporoid grainstone with amphipora, medium to coarse-grained and medium to thick bedded, cliff former. Dry/wet color name: Pinkish gray/Pinkish gray.
- 12 341 – 353 (Dry/wet color code: bcab9d/bcab9d)
Stromatoporoid and skeletal framestone with brachiopods, coarse to very coarse-grained and very thick bedded, abrupt basal contact, cliff former. Dry/wet color name: Grayish orange pink/Grayish orange pink.
- 1.5 353 – 354.5 (Dry/wet color code: cdcbac/cdcbac)
Bioturbated and microbially laminated mudstone, some rip-up clasts and trilobite fragments, very fine to fine-grained and thin bedded, recessive. Dry/wet color name: Pale greenish yellow/Pale greenish yellow.
- 3.5 354.5 – 358 (Dry/wet color code: 84766b/534639)
Peloidal packstone with solution collapse breccia, dolomitic, medium to coarse-grained and thin bedded moderately recessive. Dry/wet color name: Pale brown/Grayish brown.
- 2 358 – 360 (Dry/wet color code: b4af94/9a937a)
Faintly laminated shaly mudstone, dolomitic and anhydritic, fine-grained and very thin bedded, recessive. Dry/wet color name: Yellowish gray/Dusky yellow.

- 3 360 – 363 (Dry/wet color code: e4c285/c3a982)
Platy mudstone beds with current ripples, dolomitic and anhydritic, fine-grained and very thin bedded, recessive. Dry/wet color name: Pale yellowish orange/Grayish orange.

- 6 363 – 369 (Dry/wet color code: 84766b/534639)
Stromatoporoid grainstone with brachiopod fragments, dolomitic, coarse-grained and medium bedded, ledge former. Dry/wet color name: Pale brown/Grayish brown.

- 6 369 – 375 (Dry/wet color code: 9d917d/6a6051)
Faintly laminated amphipora and peloidal mudstone to wackestone with trilobite and brachiopod fragments, fine to coarse-grained and thin bedded, recessive. Dry/wet color name: Pale yellowish brown/Dusky yellowish brown.

- 3.5 375 – 378.5 (Dry/wet color code: 84766b/534639)
Planar laminated peloidal wackestone with trilobite and brachiopod fragments, dolomitic, medium-grained and thin bedded, moderately recessive. Dry/wet color name: Pale brown/Grayish brown.

- 6.5 378.5 – 385 (Dry/wet color code: 84766b/84766b)
Stromatoporoid grainstone, coarse to very coarse-grained and medium bedded, ledge former. Dry/wet color name: Pale brown/Pale brown.

- 8 385 – 393 (Dry/wet color code: 84766b/84766b)
Tabular stromatoporoid boundstone to rudstone with brachiopods and algal laminations, dolomitic, coarse to gravel sized grains and thick bedded, small ledge former. Dry/wet color name: Pale brown/Pale brown.

- 6 393 – 399 (Dry/wet color code: 3d3633/3d3633)
Black mudstone with bed parallel stylolites, fine-grained and very thin bedded, weathers white in outcrop unlike any other unit observed, recessive. Dry/wet color name: Brownish black/Brownish black.

Top Maywood/Base Duperow

- 6 399 – 405 (Dry/wet color code: a1908e/6e5d5b)
Peloidal and amphiopora wackestone to packstone, dolomitic,
medium to coarse-grained and thin bedded, small ledge former.
Dry/wet color name: Pale red/Grayish red. Dip/Dip-azimuth: 56/295.

Location: 502124 E, 5082625 N, 9260 feet.

Maywood Formation

Base of section

Haymaker Narrows Canyon (SW $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 26. T. 11 N., R. 12 E.)

Top of section

2 0 – 2 Covered

Approximate Top Nisku/Base Three Forks

28 2 – 30 Covered

Estimated Top Duperow/Base Nisku (based on Campbell, 1961)

105 30 – 135 Covered

5 135 – 140 (Dry/wet color code: 84766b/84766b)
Peloidal and amphipora packstone with solution collapse breccia, bioturbated in places, dolomitic and anhydritic, medium to coarse-grained and thin to medium bedded, small ledge former. Dry/wet color name: Pale brown/Pale brown. Location: 0562406 E, 5169554 N, 6585 feet.

7 140 – 147 (Dry/wet color code: d5c8b0/e4c285)
Platy mudstone beds forming covered slope, fine-grained and very thin bedded, recessive. Dry/wet color name: Very pale orange/Pale yellowish orange.

5 147 – 152 (Dry/wet color code: bcab9d/a2908b)
Bioturbated mudstone with oncoids, dolomitic and anhydritic, fine-grained and very thin bedded, recessive. Dry/wet color name: Grayish orange pink/Pale red.

5 152 – 157 (Dry/wet color code: 84766b/84766b)
Planar laminated amphipora and peloidal packstone, dolomitic and anhydritic, medium-grained and thin to medium bedded, small ledge former. Dry/wet color name: Pale brown/Pale brown.
Dip/Dip-azimuth: 08/270

15 157 – 172 Covered

5 172 – 177 (Dry/wet color code: 84766b/84766b)
Peloidal wackestone with stromatoporoid debris, dolomitic, fine to medium-grained and thin bedded, moderately recessive. Dry/wet color name: Pale brown/Pale brown.

- 38 177 – 215 Covered
- 5 215 – 220 (Dry/wet color code: 84766b/84766b)
Peloidal and amphipora wackestone to packstone with solution collapse breccia, minor skeletal debris of brachiopods, crinoids and trilobites, mottled dark brown-tan, dolomitic and anhydritic, fine to medium-grained and medium bedded, small ledge former. Dry/wet color name: Pale brown/Pale brown.
- 6 220 – 226 (Dry/wet color code: 84766b/84766b)
Bioturbated peloidal wackestone with rare skeletal debris of brachiopods, crinoids and trilobites, dolomitic and anhydritic, fine-grained and thin bedded, moderately recessive. Dry/wet color name: Pale brown/Pale brown. Location: 0562339 E, 5169594 N, 6468 feet.
- 20 226 – 246 Covered
- 2 246 – 248 (Dry/wet color code: 84766b/534639)
Amphipora and peloidal packstone with trilobite fragments, dolomitic medium-grained and thin bedded, small ledge former. Dry/wet color name: Pale brown/Grayish brown.
- 13 248 – 261 Covered
- 5 261 – 266 (Dry/wet color code: d5c8b0/c3a982)
Stromatoporoid grainstone to framestone, vuggy porosity, coarse to very coarse-grained and thick bedded, ledge to small cliff former. Dry/wet color name: Very pale orange/Grayish orange.
- 5 266 – 271 Covered
- 2 271 – 273 (Dry/wet color code: a2908b/6e5d56)
Amphipora and peloidal wackestone with solution collapse breccia, dolomitic and anhydritic, fine-grained and thin bedded, moderately recessive. Dry/wet color name: Pale brown/Grayish red.
- 15 273 – 288 Covered
- 6 288 – 294 (Dry/wet color code: 84766b/534639)
Faintly laminated peloidal and amphipora packstone with stromatoporoid heads near top, heavily fractured, dolomitic, medium-grained and medium bedded, small ledge former. Dry/wet color name: Pale brown/Grayish red.

- 8 294 – 302 (Dry/wet color code: bcab9d/a2908b)
Stromatoporoid grainstone, dolomitic, coarse-grained and thick bedded, ledge to small cliff former. Dry/wet color name: Grayish orange pink/Pale red. Dip/Dip-azimuth: 08/270.
Location: 0562304 E, 5169603 N, 6396 feet.
- 24 302 – 326 Covered
- 10 326 – 336 (Dry/wet color code: a2908b/6e5d56)
Faintly laminated peloidal and skeletal wackestone with stylolites interbedded with thin mudstone beds, abundant brachiopod and trilobite fragments, some amphipora, dolomitic, fine to medium-grained and thin bedded, moderately recessive. Dry/wet color name: Pale red/Grayish red.
Dip/Dip-azimuth: 10/280.
- 4 336 – 340 (Dry/wet color code: f0ebd6/d0c7be)
Stromatoporoid and skeletal grainstone with crinoids, medium to coarse-grained and medium bedded, ledge former. Dry/wet color name: Yellowish gray/Pinkish gray.
- 7.5 340 – 347.5 (Dry/wet color code: f0ebd6/d0c7be)
Stromatoporoid rudstone, minor boundstone with crinoids, tabular and hemi-spherical stromatoporoids, brecciated zones, very coarse to gravel sized grains and thick bedded to massive, cliff former. Dry/wet color name: Yellowish gray/Pinkish gray.
- 1 347.5 – 348.5 (Dry/wet color code: bcab9d/84766b)
Peloidal and amphipora wackestone, medium-grained and thin bedded, moderately recessive. Dry/wet color name: Grayish orange pink/Pale brown.
- 1 348.5 – 349.5 (Dry/wet color code: d5c8b0/e4c285)
Microbially laminated mudstone, dolomitic and anhydritic, fine-grained and very thin bedded, recessive. Dry/wet color name: Very pale orange/Pale yellowish orange.
- 3 349.5 – 352.5 (Dry/wet color code: 84766b/84766b)
Stromatoporoid grainstone with brachiopod fragments, dolomitic, medium to coarse-grained and medium bedded, ledge former. Dry/wet color name: Pale brown/Pale brown.

- 3.5 352.5 – 356 (Dry/wet color code: d0c7be/d0c7be)
Stromatoporoid framestone to rudstone, with brachiopods, crinoids, tabular and spherical stromatoporoids, dolomitic, very coarse to gravel sized grains and very thick bedded, cliff former. Dry/wet color name: Pinkish gray/Pinkish gray.
- 1 356 – 357 (Dry/wet color code: d5c8b0/e4c285)
Faintly laminated amphipora mudstone with brecciated zones, dolomitic and anhydritic, fine to medium grained and very thin bedded, moderately recessive. Dry/wet color name: Very pale orange/Pale yellowish orange.
Location: 0562272 E, 5169598 N, 6335 feet.
- 6.5 357 – 363.5 (Dry/wet color code: a1908e/84766b)
Faintly laminated amphipora and peloidal packstone, minor brachiopod and trilobite fragments, dolomitic, medium to coarse-grained and thin bedded, small ledge former. Dry/wet color name: Pale red/Pale brown.
- 2 363.5 – 365.5 (Dry/wet color code: a09fa0/868888)
Skeletal grainstone with rip-up clasts, stromatoporoids and brachiopods, medium to very coarse-grained and thick bedded, ledge former. Dry/wet color name: Medium light gray/Medium gray.
- 3 365.5 – 368.5 (Dry/wet color code: 84766b/84766b)
Intensely bioturbated peloidal wackestone, dolomitic and anhydritic, fine to medium-grained and thin bedded, moderately recessive. Dry/wet color name: Pale brown/Pale brown.
- 2 368.5 – 370.5 (Dry/wet color code: 84766b/84766b)
Amphipora and peloidal wackestone, rare crinoid debris, dolomitic and anhydritic, non-laminated, fine to medium-grained and thin bedded, moderately recessive. Dry/wet color name: Pale brown/Pale brown.
- 8.5 370.5 – 379 (Dry/wet color code: b4af94/b4af94)
Stromatoporoid grainstone with brachiopod fragments, medium to coarse-grained and thick bedded, ledge former. Dry/wet color name: Yellowish gray/Yellowish gray.

Top Maywood/Base Duperow

- 3.5 379 – 382.5 (Dry/wet color code: 84766b/84766b)
Shaly mudstone, dolomitic, fine-grained and very thin bedded,
recessive. Dry/wet color name: Pale brown/Pale brown.
Dip/Dip-azimuth: 09/258.

Maywood Formation

Base of section

Location: 0562272 E, 5169574 N, 6292 feet.

Greathouse Peak (SW ¼, SE ¼, Sec. 29. T. 12 N., R. 19 E.)

Top of section

- 2 0 – 2 (Dry/wet color code: 2a2b29/2a2b29)
 Black fissile shale beds, very fine to fine-grained and very thin bedded, recessive. Dry/wet color name: Black/Black.

Top Nisku/Base Lodgepole

- 12 2 – 14 (Dry/wet color code: bcab9d/84766b and 84766b/534639)
 Recessive mudstone beds forming reentrant at top of cliff, fine-grained and thin bedded. Dry/wet color name: Grayish orange pink/Pale brown.
- 13.5 14 – 27.5 (Dry/wet color code: bcab9d/bcab9d)
 Stromatoporoid grainstone, coarse to very coarse-grained and very thick bedded to massive, ledge to small cliff forming. Dry/wet color name: Pale brown/Grayish brown.
- 1.5 27.5 – 29 (Dry/wet color code: d5c8b0/e4c285)
 Dolomitic and anhydritic mudstone, fine-grained and very thin bedded, recessive. Dry/wet color name: Very pale orange/Pale yellowish orange.

Top Duperow/Base Nisku

- 5 29 – 34 (Dry/wet color code: 9d917d/84766b)
 Planar laminated mudstone, fine-grained and thin bedded, recessive. Dry/wet color name: Pale yellowish brown/Pale brown.
- 5 34 – 39 (Dry/wet color code: bcab9d/bcab9d)
 Stromatoporoid grainstone, coarse to very coarse-grained and very thick bedded to massive, ledge to small cliff forming. Dry/wet color name: Grayish orange pink/Grayish orange pink.
- 2.5 39 – 41.5 (Dry/wet color code: 9d917d/84766b)
 Planar laminated mudstone with some individual stromatoporoid heads, fine-grained and thin bedded, recessive. Dry/wet color name: Pale yellowish brown/Pale brown.

- 7 41.5 – 48.5 (Dry/wet color code: bcab9d/bcab9d)
Stromatoporoid grainstone, coarse to very coarse-grained and very thick bedded to massive, ledge to small cliff forming. Dry/wet color name: Grayish orange pink/Grayish orange pink.
- 4 48.5 – 52.5 (Dry/wet color code: 9d917d/6a6051)
Planar laminated mudstone, fine-grained and thin bedded, recessive. Dry/wet color name: Pale yellowish brown/Dusky yellowish brown.
- 5.5 52.5 – 58 (Dry/wet color code: bcab9d/ bcab9d)
Stromatoporoid grainstone, coarse to very coarse-grained and very thick bedded to massive, ledge to small cliff forming. Dry/wet color name: Grayish orange pink/Grayish orange pink.
- 0.5 58 – 58.5 (Dry/wet color code: d5c8b0/c3a982)
Dolomitic mudstone with microbial laminations and mudcracks, fine-grained and very thin bedded, recessive. Dry/wet color name: Very pale orange/Grayish orange.
- 3.5 58.5 – 62 (Dry/wet color code: 84766b/534639)
Non-laminated wackestone grading upwards into a planar laminated peloidal packstone, both dolomitic, fine to medium-grained and thin bedded, moderately recessive to small ledge forming. Dry/wet color name: Pale brown/Grayish brown.
- 6 62 – 68 (Dry/wet color code: bcab9d/bcab9d)
Stromatoporoid grainstone, coarse to very coarse-grained and very thick bedded to massive, ledge to small cliff forming. Dry/wet color name: Grayish orange pink/Grayish orange pink.
Location: 625546 E, 5180613 N, 8163 feet.
- 2.5 68 – 70.5 (Dry/wet color code: bcab9d/bcab9d)
Dolomitic mudstone with microbial laminations and mudcracks, fine-grained and very thin bedded, recessive. Dry/wet color name: Very pale orange/Grayish orange.
- 3 70.5 – 73.5 (Dry/wet color code: b4af94/9a937a)
Peloidal wackestone with individual stromatoporoid heads weathering out, dolomitic, fine to medium-grained and thin bedded, moderately recessive. Dry/wet color name: Pale brown/Grayish brown.

- 4 73.5 – 77.5 (Dry/wet color code: bcab9d/bcab9d)
Stromatoporoid grainstone, coarse to very coarse-grained and very thick bedded to massive, ledge to small cliff forming. Dry/wet color name: Grayish orange pink/Grayish orange pink.
- 2.5 77.5 – 80 (Dry/wet color code: 84766b/534639)
Planar laminated peloidal wackestone with some individual stromatoporoid heads, fine to medium-grained and thin bedded, moderately recessive. Dry/wet color name: Pale brown/Grayish brown.
- 0.5 80 – 80.5 (Dry/wet color code: 84766b/534639)
Dolomitic mudstone, fine-grained and very thin bedded, recessive. Dry/wet color name: Pale brown/Grayish brown.
- 1.5 80.5 – 82 (Dry/wet color code: bcab9d/bcab9d)
Stromatoporoid grainstone, coarse to very coarse-grained and very thick bedded to massive, ledge to small cliff forming. Dry/wet color name: Grayish orange pink/Grayish orange pink.
- 2 82 – 84 (Dry/wet color code: b4af94/9a937a)
Peloidal wackestone, dolomitic, fine to medium-grained and thin bedded, moderately recessive. Dry/wet color name: Yellowish gray/Dusky yellow.
- 5 84 – 89 (Dry/wet color code: bcab9d/bcab9d)
Stromatoporoid grainstone, coarse to very coarse-grained and thick bedded, ledge to small cliff forming. Dry/wet color name: Grayish orange pink/Grayish orange pink.
- 1 89 – 90 (Dry/wet color code: d5c8b0/9d917d)
Microbially laminated mudstone, dolomitic, fine-grained and very thin bedded, recessive. Dry/wet color name: Very pale orange/Pale yellowish brown.
- 6.5 90 – 96.5 (Dry/wet color code: 534639/3f342a)
Planar laminated peloidal wackestone, dolomitic, fine to medium-grained and thin bedded, moderately recessive. Dry/wet color name: Grayish brown/Dusky brown.
- 1.5 96.5 – 98 (Dry/wet color code: bcab9d/bcab9d)
Stromatoporoid grainstone, coarse-grained and medium bedded, ledge former. Dry/wet color name: Grayish orange pink/Grayish orange pink.

- 3 98 – 101 (Dry/wet color code: 9d917d/ 6a6051)
Very thin bedded dolomitic mudstone grading upwards into a faintly laminated peloidal dolomitic and anhydritic wackestone, fine to medium-grained and thin bedded, recessive. Dry/wet color name: Pale yellowish brown/Dusky yellowish brown.
- 6 101 – 107 (Dry/wet color code: 84766b/6a6051)
Amphipora and peloidal packstone with vuggy to fenestral porosity, dolomitic, medium to coarse-grained and medium bedded. Fissile green shale bed 1 cm thick at base, small ledge former. Dry/wet color name: Pale brown/Dusky yellowish brown.
- 3.5 107 – 110.5 (Dry/wet color code: c3a982/c3a982)
Bioturbated amphipora and peloidal wackestone, dolomitic and anhydritic, faintly laminated in places, fine to medium-grained and thin bedded, moderately recessive. Dry/wet color name: Grayish orange/Grayish orange.
- 2.5 110.5 – 113 (Dry/wet color code: e4c285/c3a982)
Planar laminated peloidal wackestone forming shaly beds, dolomitic and anhydritic, fine-grained and very thin bedded, recessive. Dry/wet color name: Pale yellowish orange/Grayish orange.
- 0.2 113 – 113.2 (Dry/wet color code: 98b683/88a079)
Green fissile shale bed, very fine to fine-grained and very thin bedded, recessive. Dry/wet color name: Light green/Moderate yellowish green.
- 4.3 113.2 – 117.5 (Dry/wet color code: c3a982/c3a982)
Stromatoporoid grainstone, dolomitic and anhydritic, coarse to very coarse-grained and thick bedded, karsted basal contact, ledge to small cliff forming. Dry/wet color name: Grayish orange/Grayish orange.
- 1.5 117.5 – 119 (Dry/wet color code: b4af94/9a937a)
Brecciated peloidal packstone, dolomitic, coarse-grained and thin bedded, small ledge former. Dry/wet color name: Yellowish gray/Dusky yellow.
- 1 119 – 120 (Dry/wet color code: 6a6051/6a6051)
Faintly laminated wackestone, dolomitic, fine-grained and thin bedded, moderately recessive. Dry/wet color name: Dusky yellowish brown/Dusky yellowish brown.

- 2 120 – 122 (Dry/wet color code: b4af94/9a937a)
Planar laminated peloidal wackestone with amphipora, dolomitic, fine to medium-grained and thin bedded, moderately recessive. Dry/wet color name: Yellowish gray/Dusky yellow.
- 0.5 122 – 122.5 (Dry/wet color code: b4af94/9a937a)
Dolomitic mudstone with 1 cm thick oxidized mudstone to siltstone bed on top, fine-grained and very thin bedded, recessive. Dry/wet color name: Yellowish gray/Dusky yellow.
- 3 122.5 – 125.5 (Dry/wet color code: 6a6051/6a6051)
Planar laminated peloidal packstone with solution collapse breccia, dolomitic and anhydritic, medium to coarse-grained and medium bedded, small ledge former. Dry/wet color name: Dusky yellowish brown/Dusky yellowish brown.
- 1.5 125.5 – 127 (Dry/wet color code: b4af94/9a937a)
Microbially laminated mudstone with rare brachiopod fragments, dolomitic, fine-grained and very thin bedded, recessive. Dry/wet color name: Yellowish gray/Dusky yellow.
- 5 127 – 132 (Dry/wet color code: 84766b/534639)
Peloidal packstone with solution collapse breccia and foraminifera, dolomitic and anhydritic, medium to coarse-grained and medium bedded, small ledge former. Dry/wet color name: Pale brown/Grayish brown.
- 2.5 132 – 134.5 (Dry/wet color code: b4af94/9a937a)
Microbially laminated mudstone, dolomitic, fine-grained and very thin bedded, recessive. Dry/wet color name: Yellowish gray/Dusky yellow.
- 1.5 134.5 – 136 (Dry/wet color code: 6a6051/6a6051)
Planar laminated peloidal packstone, dolomitic and anhydritic, medium to coarse-grained and medium bedded, small ledge former. Dry/wet color name: Dusky yellowish brown/Dusky yellowish brown.
- 2 136 – 138 (Dry/wet color code: b4af94/9a937a)
Microbially laminated mudstone, dolomitic, fine-grained and very thin bedded, recessive. Dry/wet color name: Yellowish gray/Dusky yellow.

3 138 – 141 (Dry/wet color code: 534639/534639)
Faintly laminated peloidal wackestone, dolomitic, fine-grained and thin bedded, moderately recessive. Dry/wet color name: Grayish brown/Grayish brown.

1 141 – 142 (Dry/wet color code: b4af94/6a6051 and 6a6051/6a6051)
Algal laminated mudstone to wackestone with stylolites, dolomitic, fine-grained and very thin bedded, recessive. Dry/wet color name: Dusky yellowish brown/Dusky yellowish brown and Yellowish gray/Dusky yellowish brown.

6.5 142 – 148.5 (Dry/wet color code: 84766b/534639)
Dolomitic mudstone with some individual stromatoporoid heads, fine-grained and thin bedded, moderately recessive. Green fissile shale bed 1 inch thick at base. Dry/wet color name: Pale brown/Grayish brown.

Top Maywood/Base Duperow

3 148.5 – 151.5 (Dry/wet color code: 98b683/a5b29b and c3a982/c3a982)
Stromatoporoid packstone to grainstone with karsted upper contact, dolomitic, medium to coarse-grained and thick bedded, ledger former. Dry/wet color name: Grayish orange/Grayish orange.

0.5 151.5 – 152 (Dry/wet color code: 937441/735e3f)
Oxidized amphipora packstone with carbonate mud stringers and anhydrite, medium-grained and thin bedded, moderately recessive. Dry/wet color name: Moderate yellowish brown/Dark yellowish brown.

5 152 – 157 (Dry/wet color code: 84766b/534639)
Skeletal packstone to grainstone with brachiopods, crinoids and stromatoporoid debris, dolomitic, medium to coarse-grained and thick bedded, ledge former. Dry/wet color name: Pale brown/Grayish brown.
Dip/Dip-azimuth: 05/020.

Top Cambrian Snowy Range/Base Maywood

2 157 – 159 Covered

- 5 159 – 164
Pale red/green shales and siltstones, silt to fine-grained and very thin bedded, recessive.

Cambrian Snowy Range Formation

Base of section
South wall in cirque below Greathouse Peak.
Location: 625559 E, 5180383 N, 7988 feet.

APPENDIX G

CORE NOTES

*Note: Measurements are in feet and decimal places are tenths of feet. Color code corresponds to the Hex Color Code and written color to Munsell Color Chart.

**Altamont Vecta Oil and Gas LTD Big Sky Wallewein 22-1 Core
Kevin Sunburst Field 22-1-36N-1W**

Core Interval: 3904.0 – 4150.0 feet (240 feet recovered)

Feet	Base
10.0	4150.0 – 4140.0 (Dry/wet color code: b3b4b4/9c938c) Stromatoporoid and skeletal grainstone, dolomitic and massive with brachiopods. Dry/wet color name: Light gray/Light brownish gray.
10.7	4140.0 – 4129.3 (Dry/wet color code: 9c938c/67605b) Hemispherical to tabular stromatoporoid boundstone with brachiopods and amphipora, anhydritic and dolomitic. Dry/wet color name: Light brownish gray/Brownish gray.
9.3	4129.3 – 4120.0 (Dry/wet color code: 9c938c/67605b) Stromatoporoid and skeletal grainstone with brachiopods, dolomitic and massive. Dry/wet color name: Light brownish gray/brownish gray.
2.2	4120.0 – 4117.8 (Dry/wet color code: c3a982/bcab9d) Peloidal grainstone with scattered skeletal debris of brachiopods and stromatoporoids. Dry/wet color name: Grayish orange/Grayish orange pink.
0.8	4117.8 – 4117.0 (Dry/wet color code: c3a982/bcab9d) Bioturbated dolomitic mudstone, Cruziana ichnofacies. Dry/wet color name: Very light gray/Very light gray.
7.8	4117.0 – 4109.2 (Dry/wet color code: c9c9c8/c9c9c8) Anhydrite, finely laminated in places. Dry/wet color name: Very light gray/Very light gray.
10.2	4109.2 – 4099.0 (Dry/wet color code: 9c938c/84766b) Peloidal and tabular stromatoporoid packstone to grainstone with amphipora, anhydrite nodules in a fenestral fabric, few finely laminated zones of anhydrite and mudstone. Dolomitic with minor skeletal debris of brachiopods. Dry/wet color name: Light brownish gray/Pale brown.

- 11.2 4099.0 – 4087.8 (Dry/wet color code: 9c938c/67605b)
Alternating peloidal wackestone and packstone with amphipora, tabular stromatoporoids and brachiopods. Dolomitic and anhydritic with fine laminations in places. Dry/wet color name: Light brownish gray/Brownish gray.
- 3.0 4087.8 – 4084.8 (Dry/wet color code: d0c7be/bcab9d)
Planar laminated peloidal and stromatoporoid grainstone, dolomitic and anhydritic. Dry/wet color name: Pinkish gray/Grayish orange pink.
- 1.7 4084.8 – 4083.1 (Dry/wet color code: c9c9c8/a7afb1)
Massive to nodular anhydrite. Dry/wet color name: Very light gray/Light bluish gray.
- 1.8 4083.1 – 4081.3 (Dry/wet color code: d5c8b0/c3a982)
Finely laminated dolomitic mudstone with nodular anhydrite. Dry/wet color name: Very pale orange/Grayish orange.
- 2.2 4081.3 – 4079.1 (Dry/wet color code: 84766b/67605b)
Stromatoporoid grainstone with brachiopods, dolomitic and anhydritic. Dry/wet color name: Pale brown/Brownish gray.
- 1.8 4079.1 – 4077.3 (Dry/wet color code: 84766b/67605b)
Peloidal wackestone, dolomitic and anhydritic. Dry/wet color name: Pale brown/Brownish gray.
- 4.6 4077.3 – 4072.7 (Dry/wet color code: c9c9c8/868888)
Finely laminated anhydrite. Dry/wet color name: Very light gray/Medium gray. Very light gray/Medium gray.
- 0.5 4072.7 – 4072.2 (Dry/wet color code: c9c9c8/868888)
Bioturbated wackestone, Cruziana ichnofacies. Dry/wet color name: Pale brown/Brownish gray.
- 7.1 4072.2 – 4065.1 (Dry/wet color code: c9c9c8/868888)
Finely laminated anhydrite. Dry/wet color name: Very light gray/Medium gray.
- 2.35 4065.1 – 4062.75 (Dry/wet color code: 84766b/67605b)
Amphipora and peloidal packstone. Dry/wet color name: Pale brown/Brownish gray.
- 0.6 4062.75 – 4062.15 (Dry/wet color code: d5c8b0/c3a982)
Dolomitic mudstone. Dry/wet color name: Very pale orange/Grayish orange.

- 4.9 4062.15 – 4057.25 (Dry/wet color code: c9c9c8/a09fa0)
Anhydritic mudstone to wackestone with rare brachiopod fragments. Dry/wet color name: Very light gray/Medium light gray.
- 7.55 4057.25 – 4049.7 (Dry/wet color code: 84766b/67605b)
Skeletal grainstone with brachiopod and coral fragments, dolomitic. Dry/wet color name: Pale brown/Brownish gray.
- 6.0 4049.7 – 4043.7 (Dry/wet color code: 84766b/67605b)
Anhydritic mudstone to wackestone with rare skeletal debris and nodular anhydrite. Dry/wet color name: Pale brown/Brownish gray.
- 2.7 4043.7 – 4041.0 (Dry/wet color code: d5c8b0/c3a982)
Peloidal and dolomitic mudstone. Dry/wet color name: Pale brown/Brownish gray.
- 1.8 4041.0 – 4039.2 (Dry/wet color code: d5c8b0/c3a982)
Crinkly laminated dolomitic mudstone. Dry/wet color name: Very pale orange/Grayish orange.
- 15.45 4039.2 – 4023.75 (Dry/wet color code: c9c9c8/a7afb1)
Interbedded anhydrite and dolomitic mudstone with rare tabular stromatoporoid. Dry/wet color name: Very light gray/Light bluish gray.
- 0.45 4023.75 – 4023.3 (Dry/wet color code: c3a982/84766b)
Stromatoporoid wackestone. Dry/wet color name: Grayish orange/Pale brown.
- 1.0 4023.3 – 4022.3 (Dry/wet color code: c3a982/84766b)
Peloidal and amphipora packstone, dolomitic, minor anhydrite. Dry/wet color name: Very light gray/Light bluish gray.
- 3.6 4022.3 – 4018.7 (Dry/wet color code: c3a982/84766b)
Finely laminated dolomitic and anhydritic mudstone interbedded with thin shale laminae. Dry/wet color name: Very light gray/Light bluish gray.
- 4.7 4018.7 – 4014.0 (Dry/wet color code: d0c7be/9c938c)
Amphipora wackestone and anhydrite, massive. Dry/wet color name: Pinkish gray/Light brownish gray.
- 11.2 4014.0 – 4002.8 (Dry/wet color code: 9c938c/67605b)
Nodular anhydrite and mudstone with sparse bioturbation (*Cruziana* ichnofacies). Dry/wet color name: Light brownish gray/Brownish gray and Light olive gray/Light brownish gray.

- 20.4 4002.8 – 3982.4 (Dry/wet color code: b3afa0/9c938c)
Planar laminated anhydrite and mudstone. Dry/wet color name: Light olive gray/Light brownish gray.
- 8.8 3982.4 – 3973.6 (Dry/wet color code: b3afa0/9c938c)
Nodular to planar laminated anhydrite and dolomitic mudstone with anhydrite increasing upwards. Dry/wet color name: Pinkish gray/Light brownish gray.
- 4.1 3973.6 – 3969.5 (Dry/wet color code: c9c9c8/c9c9c8)
Amphipora packstone, anhydritic and dolomitic. Dry/wet color name: Pinkish gray/Light brownish gray.
- 0.5 3969.5 – 3969 (Dry/wet color code: d0c7be/9c938c)
Planar and finely laminated anhydrite. Dry/wet color name: Very pale orange/Light Brownish gray.
- 3.6 3969 – 3965.4 (Dry/wet color code: d5c8b0/9c938c)
Nodular anhydrite. Dry/wet color name: Very light gray/Light bluish gray.
- 1.15 3965.4 – 3964.25 (Dry/wet color code: c9c9c8/a7afb1)
Massive anhydrite. Dry/wet color name: Very light gray/Light bluish gray.
- 2.95 3964.25 – 3961.3 (Dry/wet color code: 67605b/3d3633)
Finely laminated anhydrite. Dry/wet color name: Very light gray/Medium light gray.
- 0.8 3961.3 – 3960.5 (Dry/wet color code: 67605b/a7afb1)
Interbedded anhydrite and shale. Dry/wet color name: Very light gray/Medium light gray.
- 9.5 3960.5 – 3951.0 (Dry/wet color code: c9c9c8/a7afb1)
Planar laminated anhydrite and microbial interbeds. Dry/wet color name: Very light gray/Light bluish gray.
- 6.0 3951.0 – 3945.0 (Dry/wet color code: 9c938c/67605b)
Massive stromatoporoid grainstone to rudstone with amphipora and spherical to hemispherical stromatoporoids and infrequent chert. Dry/wet color name: Light brownish gray/Brownish gray.
- 7.5 3945.0 – 3937.5 (Dry/wet color code: 67605b/3d3633)
Bioturbated mudstone to wackestone with minor skeletal debris and anhydrite nodules in places. Dry/wet color name: Brownish gray/Brownish black.

- 15.5 3937.5 – 3922.0 (Dry/wet color code: c9c9c8/a7afb1)
Massive anhydrite with stromatoporoid debris from 3931-3929.5.
Dry/wet color name: Very light gray/Light bluish gray.
- 18.0 3922.0 – 3904.0 (Dry/wet color code: 9c938c/67605b)
Nodular anhydrite with rare stromatoporoid debris. Dry/wet color
name: Light brownish gray/Brownish gray.

Top

Danielson 33-17 Core

Kevin Sunburst Field 33-17-35N-1W

Core Interval: 3451.0 – 3271.0 feet (180.0 feet recovered)

Base

- 4.8 3451.0 – 3446.2 (Dry/wet color code: b3b4b4/a09fa0)
Hemispherical to tabular stromatoporoid boundstone to framestone
with anhydrite nodules. Dry/wet color name: Light gray/Medium
light gray.
- 14.6 3446.2 – 3432.6 (Dry/wet color code: a7afb1/777e82)
Interbedded anhydrite and dolomitic mudstone with stromatoporoid
debris. Dry/wet color name: Light bluish gray/Medium bluish gray.
- 13.3 3432.6 – 3420.3 (Dry/wet color code: b3b4b4/a09fa0 and
9c938c/67605b)
Stromatoporoid rudstone at base grading upwards into a
stromatoporoid grainstone to boundstone, anhydritic. Dry/wet color
name: Light gray/Medium light gray.
- 9.3 3420.3 – 3411.0 (Dry/wet color code: d0c7be/9c938c)
Massive stromatoporoid framestone, minor boundstone, anhydritic
at base. Dry/wet color name: Pinkish gray/Light brownish gray.
- 5.0 3411.0 – 3406.0 (Dry/wet color code: 9c938c/67605b)
Stromatoporoid boundstone with tabular crossbeds. Dry/wet color
name: Light brownish gray/Brownish gray.
- 7.0 3406.0 – 3399.0 (Dry/wet color code: 9c938c/67605b)
Stromatoporoid rudstone with chert and amphipora. Dry/wet color
name: Light brownish gray/Brownish gray.
- 10.0 3399.0 – 3389.0 (Dry/wet color code: a09fa0/868888)
Cherty mudstone. Dry/wet color name: Medium light gray/Medium
gray.

- 4.5 3389.0 – 3384.5 (Dry/wet color code: a09fa0/868888 and b3b4b4/a09fa0)
Tabular cross-bedded stromatoporoid grainstone. Dry/wet color name: Light gray/Medium light gray.
- 4.65 3384.5 – 3379.85 (Dry/wet color code: b3b4b4/a09fa0 and 9c938c/67605b)
Stromatoporoid grainstone. Dry/wet color name: Light gray/Medium light gray.
- 1.85 3379.85 – 3378.0 (Dry/wet color code: a09fa0/868888)
Stromatoporoid rudstone. Dry/wet color name: Medium light gray/Medium gray.
- 4.5 3378.0 – 3373.5 (Dry/wet color code: 9c938c/67605b)
Tabular cross-bedded peloidal packstone to stromatoporoid grainstone, dolomitic in places. Dry/wet color name: Light brownish gray/Brownish gray.
- 10.65 3373.5 – 3362.85 (Dry/wet color code: a09fa0/868888)
Cross-bedded stromatoporoid grainstone to rudstone. Dry/wet color name: Medium light gray/Medium gray.
- 4.15 3362.85 – 3358.7 (Dry/wet color code: c9c9c8/b3b4b4)
Dolomitic mudstone with laminated and nodular anhydrite. Dry/wet color name: Very light gray/Light gray.
- 2.2 3358.7 – 3356.5 (Dry/wet color code: d0c7be/9c938c)
Dolomitic peloidal packstone. Dry/wet color name: Pinkish gray/Light brownish gray.
- 4.5 3356.5 – 3352.0 (Dry/wet color code: b3b4b4/a09fa0)
Faintly laminated peloidal wackestone, anhydritic. Dry/wet color name: Light gray/Medium light gray.
- 7.2 3352.0 – 3344.8 (Dry/wet color code: b3b4b4/a09fa0 and e9eaea/c9c9c8)
Interbedded dolomitic and organic shale laminated peloidal mudstone and limestone, anhydritic. Flat pebble rip-up clasts in upper portion. Dry/wet color name: White/Very light gray.
- 1.95 3344.8 – 3342.85 (Dry/wet color code: a09fa0/868888)
Stromatoporoid rudstone. Dry/wet color name: Medium light gray/Medium gray.

- 2.85 3342.85 – 3340.0 (Dry/wet color code: 868888/6b6c6c)
Microbially laminated dolomitic mudstone with minor skeletal debris. Dry/wet color name: Medium gray/Medium dark gray.
- 3.5 3340.0 – 3336.5 (Dry/wet color code: b3b4b4/a09fa0)
Stromatoporoid wackestone, anhydritic and massive. Dry/wet color name: Light gray/Medium light gray.
- 1.0 3336.5 – 3335.5 (Dry/wet color code: 868888/6b6c6c)
Planar and organic shale laminated mudstone. Dry/wet color name: Medium gray/Medium dark gray.
- 1.8 3335.5 – 3333.7 (Dry/wet color code: c9c9c8/b3b4b4)
Stromatoporoid grainstone with anhydrite nodules. Dry/wet color name: Pinkish gray/Light brownish gray.
- 0.7 3333.7 – 3333.0 (Dry/wet color code: d5c8b0/c3a982)
Nodular anhydrite grading upwards into planar laminated anhydrite with amphiopora. Dry/wet color name: Very light gray/Light gray.
- 1.45 3333.0 – 3331.55 (Dry/wet color code: d5c8b0/c3a982)
Dolomitic and anhydritic mudstone with rare skeletal debris, massive. Dry/wet color name: Very pale orange/Grayish orange.
- 1.7 3331.55 – 3329.85 (Dry/wet color code: d0c7be/9c938c)
Stromatolitic mudstone with anhydrite nodules. Dry/wet color name: Pinkish gray/Light brownish gray.
- 1.85 3329.85 – 3328.0 (Dry/wet color code: c9c9c8/a7afb1)
Massive anhydrite. Dry/wet color name: Light bluish gray/Medium bluish gray.
- 2.0 3328.0 – 3326.0 (Dry/wet color code: 9c938c/67605b)
Peloidal and planar laminated wackestone, dolomitic. Dry/wet color name: Light brownish gray/Brownish gray.
- 9.3 3326.0 – 3316.7 (Dry/wet color code: 9c938c/67605b)
Stromatoporoid packstone to grainstone, minor boundstone at top, dolomitic. Dry/wet color name: Light brownish gray/Brownish gray.
- 4.6 3316.7 – 3312.1 (Dry/wet color code: 84766b/534639)
Stromatoporoid grainstone with solitary corals. Dry/wet color name: Pale brown/Grayish brown.

- 13.1 3312.1 – 3299.0 (Dry/wet color code: d5c8b0/9c938c)
Stromatoporoid framestone with corals, amphipora, and brachiopods. Dry/wet color name: Very pale orange/Light brownish gray.
- 4.9 3299.0 – 3294.1 (Dry/wet color code: 868888/6b6c6c)
Stromatoporoid grainstone. Dry/wet color name: Medium gray/Medium dark gray.
- 3.0 3294.1 – 3291.1 (Dry/wet color code: bcab9d/84766b)
Planar laminated peloidal packstone grading upwards into stromatolitic mudstone. Dry/wet color name: Grayish orange pink/Pale brown.
- 0.7 3291.1 – 3290.4 (Dry/wet color code: 868888/6b6c6c)
Stromatoporoid boundstone. Dry/wet color name: Grayish orange pink/Pale brown.
- 7.7 3290.4 – 3282.7 (Dry/wet color code: a7afb1/777e82)
Interbedded anhydrite and dolomitic mudstone. Dry/wet color name: Light bluish gray/Medium bluish gray.
- 7.2 3282.7 – 3275.5 (Dry/wet color code: 9c938c/67605b)
Skeletal and stromatoporoid wackestone with brachiopod fragments and bed parallel stylolites. Dry/wet color name: Light brownish gray/Brownish gray.
- 4.5 3275.5 – 3271.0 (Dry/wet color code: 9c938c/67605b)
Stromatoporoid wackestone with anhydrite cement, minor boundstone and minor replacement of stromatoporoids by anhydrite. Dry/wet color name: Light brownish gray/Brownish gray.

Top

Plain Energy LTD 15-26 Core
Kevin Sunburst Field 15-26-35N-4W
Core Interval: 3854.0 – 3947.0 feet (91.43 feet recovered)

Base

- 1.0 3945.5 – 3944.5 (Dry/wet color code: b3afa0/9c938c)
Massive dolomitic wackestone. Dry/wet color name: Light olive gray/Light brownish gray.

- 3.0 3944.5 – 3941.5 (Dry/wet color code: b3afa0/9c938c)
Bioturbated stromatoporoid and peloidal mudstone with black horizontal organic laminations, few bed parallel stylolites present (suture and sharp peak type), pyrite present throughout, amphiopora, 8" fracture from 3940-3941 feet filled with dolomite/calcite. Dry/wet color name: Light olive gray/Light brownish gray.
- 1.5 3941.5 – 3940 (Dry/wet color code: b3b4b4/a09fa0)
Stromatoporoid boundstone with brachiopods. Dry/wet color name: Light gray/Medium light gray.
- 0.6 3940 – 3939.4 (Dry/wet color code: c9c9c8/b3b4b4)
Faintly laminated skeletal boundstone with few brachiopods and crinoids. Dry/wet color name: Very light gray/Light gray.
- 5.23 3939.4 – 3934.17 (Dry/wet color code: c9c9c8/b3b4b4)
Tabular stromatoporoid boundstone with abundant bed parallel stylolites, 6" fracture filled with calcite/dolomite. Dry/wet color name: Very light gray/Light gray.
- 0.5 3934.17 – 3933.67 (Dry/wet color code: a09fa0/868888)
Spherical stromatoporoid floatstone with amphiopora and one stylolite (seismogram pinning type) capping the facies. Dry/wet color name: Very light gray/Light gray.
- 1.37 3933.67 – 3932.3 (Dry/wet color code: b3b4b4/a09fa0)
Spherical stromatoporoid floatstone with moderate brachiopods. Dry/wet color name: Medium light gray/Medium gray.
- 0.8 3932.3 – 3931.5 (Dry/wet color code: b3b4b4/a09fa0)
Tabular stromatoporoid boundstone. Dry/wet color name: Light gray/Medium light gray.
- 1.0 3931.5 – 3930.5 (Dry/wet color code: a09fa0/868888)
Stromatoporoid rudstone with crinoids and stylolites (simply wave-like type). Dry/wet color name: Medium light gray/Medium gray.
- 1.5 3930.5 – 3929 (Dry/wet color code: #9c938c/67605b)
Stromatoporoid grainstone. Dry/wet color name: Light brownish gray/Brownish gray.
- 4.5 3929 – 3924.5 (Dry/wet color code: d0c7be/9c938c)
Stromatoporoid rudstone to boundstone. Dry/wet color name: Pinkish gray/Light brownish gray.

- 8.5 3924.5 – 3916 (Dry/wet color code: 9d917d/9c938c)
Stromatoporoid grainstone. Dry/wet color name: Pale yellowish brown/Light brownish gray.
- 3.0 3916 – 3913 (Dry/wet color code: bcab9d/84766b)
Skeletal and peloidal packstone.
Planar laminated from 3913.8-3913.
Amphipora from 3913.8-3913.
Suture and sharp peak type stylolites throughout.
Gradual transition from lower facies with brachiopod fragments.
Dry/wet color name: Grayish orange pink/Pale brown.
- 1.0 3913 – 3912 (Dry/wet color code: bcab9d/bcab9d)
Hemispherical and tabular stromatoporoid rudstone to boundstone with anhydrite interbedded and grading into a spherical stromatoporoid rudstone at 3911.2. Dry/wet color name: Grayish orange pink/grayish orange pink.
- 0.8 3912 – 3911.2 (Dry/wet color code: 9c938c/9c938c)
Peloidal wackestone with rare skeletal debris (crinoids, brachiopods), simple wave like type stylolites (few), vertical fractures, seismogram pinning type stylolite at base of facies.
Dry/wet color name: Light brownish gray/Light brownish gray.
- 3.2 3911.2 – 3908 (Dry/wet color code: bcab9d/bcab9d)
Stromatoporoid boundstone with occasional brachiopod fragment/shell and interbedded anhydrite. Dry/wet color name: Grayish orange pink/grayish orange pink.
- 2.25 3908 – 3905.75 (Dry/wet color code: 9c938c/9c938c)
Peloidal and anhydritic wackestone with seismogram pinning type stylolites and planar laminations, amphipora in upper 8" and stromatactis at 3907 feet. Dry/wet color name:
- 7.25 3905.75 – 3898.5 (Dry/wet color code: a7afb1/a7afb1)
Nodular and bedded anhydrite. Dry/wet color name: Light bluish gray/Light bluish gray.
- 9.8 3898.5 – 3888.7 (Dry/wet color code: bcab9d/9d917d)
Spherical and tabular stromatoporoid framestone grading upward into a rudstone with stromatactis throughout. Dry/wet color name: Grayish orange pink/Pale yellowish brown.

- 3.1 3888.7 – 3885 (Dry/wet color code: 9d917d/84766b)
Skeletal grainstone with abundant brachiopods and crinoids, stromatactis at 3886 feet. Dry/wet color name: Pale yellowish brown/Pale brown.
- 1.0 3885 – 3884 (Dry/wet color code: 84766b/6a6051)
Planar laminated peloidal and amphipora packstone. Dry/wet color name: Pale brown/Dusky yellowish brown.
- 2.0 3884 – 3882 (Dry/wet color code: a7afb1/a09fa0)
Crinoidal grainstone with stromatoporoids and some planar to wavy laminations, anhydritic. Dry/wet color name: Light bluish gray/Medium light gray.
- 15.7 3882 – 3866.3 (Dry/wet color code: 9c938c/777e82)
Anhydritic and peloidal stromatoporoid wackestone with amphipora. Dry/wet color name: Light brownish gray/Medium bluish gray.
- 12.3 3866.3 – 3854 (Dry/wet color code: d0c7be/9d917d)
Spherical stromatoporoid rudstone to framestone, anhydritic. Dry/wet color name: Pinkish gray/Pale yellowish brown.

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