MAJOR OIL PLAYS IN UTAH AND VICINITY

QUARTERLY TECHNICAL PROGRESS REPORT

Reporting Period
Start Date: July 1, 2003
End Date: September 30, 2003

by

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and
Thomas C. Chidsey, Jr., Principal Investigator/Program Manager
Utah Geological Survey

November 2003

Contract No. DE-FC26-02NT15133

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ABSTRACT

Utah oil fields have produced over 1.2 billion barrels (191 million m^3). However, the 13.7 million barrels (2.2 million m^3) of production in 2002 was the lowest level in over 40 years and continued the steady decline that began in the mid-1980s. The Utah Geological Survey believes this trend can be reversed by providing play portfolios for the major oil-producing provinces (Paradox Basin, Uinta Basin, and thrust belt) in Utah and adjacent areas in Colorado and Wyoming. Oil plays are geographic areas with petroleum potential caused by favorable combinations of source rock, migration paths, reservoir rock characteristics, and other factors. The play portfolios will include: descriptions and maps of the major oil plays by reservoir; production and reservoir data; case-study field evaluations; summaries of the state-of-the-art drilling, completion, and secondary/tertiary techniques for each play; locations of major oil pipelines; descriptions of reservoir outcrop analogs; and identification and discussion of land-use constraints. All play maps, reports, databases, and so forth, produced for the project will be published in interactive, menu-driven digital (web-based and compact disc) and hard-copy formats.

This report covers research activities for the first quarter of the second project year (July 1 through September 30, 2003). This work included (1) describing the Conventional Southern Uinta Basin Play, subplays, and outcrop reservoir analogs of the Uinta Green River Conventional Oil and Gas Assessment Unit (Eocene Green River Formation), and (2) technology transfer activities.

The Conventional Oil and Gas Assessment Unit can be divided into plays having a dominantly southern sediment source (Conventional Southern Uinta Basin Play) and plays having a dominantly northern sediment source (Conventional Northern Uinta Basin Play). The Conventional Southern Uinta Basin Play is divided into six subplays: (1) conventional Uteland Butte interval, (2) conventional Castle Peak interval, (3) conventional Travis interval, (4) conventional Monument Butte interval, (5) conventional Beluga interval, and (6) conventional Duchesne interval fractured shale/marlstone. We are currently conducting basin-wide correlations to define the limits of the six subplays.

Production-scale outcrop analogs provide an excellent view, often in three dimensions, of reservoir-facies characteristics and boundaries contributing to the overall heterogeneity of reservoir rocks. They can be used as a “template” for evaluation of data from conventional core, geophysical and petrophysical logs, and seismic surveys. Outcrop analogs for each subplay except the Travis interval are found in Indian and Nine Mile Canyons.

During this quarter, the project team members submitted an abstract to the American Association of Petroleum Geologists for presentation at the 2004 annual national convention in Dallas, Texas. The project home page was updated on the Utah Geological Survey Internet web site.

EXECUTIVE SUMMARY

Utah oil fields have produced over 1.2 billion barrels (191 million m^3). However, the 13.7 million barrels (2.2 million m^3) of production in 2002 was the lowest level in over 40 years and continued the steady decline that began in the mid-1980s. The overall objectives of this study are to: (1) increase recoverable oil from existing field reservoirs, (2) add new discoveries, (3) prevent premature abandonment of numerous small fields, (4) increase deliverability through identifying the latest drilling, completion, and secondary/tertiary techniques, and (5) reduce development costs and risk.

To achieve these objectives, the Utah Geological Survey is producing play portfolios for the major oil-producing provinces (Paradox Basin, Uinta Basin, and thrust belt) in Utah and adjacent areas in Colorado and Wyoming. This research is funded by the Preferred Upstream Management Program (PUMPII) of the U.S. Department of Energy, National Petroleum Technology Office (NPTO) in Tulsa, Oklahoma. This report covers research activities for the first quarter of the second project year (July 1 through September 30, 2003). This work included: (1) describing the Conventional Southern Uinta Basin Play, subplays, and outcrop reservoir analogs of the Uinta Green River Conventional Oil and Gas Assessment Unit (Eocene Green River Formation), and (2) technology transfer activities.

The U.S. Geological Survey defines two assessment units within the Green River Total Petroleum System in the Uinta Basin: the Deep Uinta Overpressured Continuous Oil Assessment Unit and the Uinta Green River Conventional Oil and Gas Assessment Unit. We are currently evaluating plays and subplays in the Uinta Green River Conventional Oil and Gas Assessment Unit. The Conventional Oil and Gas Assessment Unit can be divided into plays having a dominantly southern sediment source (Conventional Southern Uinta Basin Play) and plays having a dominantly northern sediment source (Conventional Northern Uinta Basin Play). The Conventional Southern Uinta Basin Play is divided into six subplays: (1) conventional Uteland Butte interval, (2) conventional Castle Peak interval, (3) conventional Travis interval, (4) conventional Monument Butte interval, (5) conventional Beluga interval, and (6) conventional Duchesne interval fractured shale/marlstone. We are currently conducting basin-wide correlations to: (1) define the limits of the six subplays, (2) define subplays in the Conventional Northern Uinta Basin Play, and (3) define plays and subplays in the Deep Overpressured Continuous Oil Assessment Unit.

Utah is unique in that it has representative outcrop analogs for each major oil play. Production-scale outcrop analogs provide an excellent view, often in three dimensions, of reservoir-facies characteristics and boundaries contributing to the overall heterogeneity of reservoir rocks. Outcrop analogs can be used as a "template" for evaluation of data from conventional core, geophysical and petrophysical logs, and seismic surveys. When combined with subsurface geological and production data, outcrop analogs can improve development drilling and production strategies, reservoir-simulation models, reserve calculations, and design and implementation of secondary/tertiary oil recovery programs and other best practices used in the oil fields of Utah and vicinity. Outcrop analogs for each subplay except the Travis interval are found in Indian and Nine Mile Canyons.

During this quarter, the project team members submitted an abstract to the American Association of Petroleum Geologists for presentation at the 2004 annual national convention in Dallas, Texas. The project home page was updated on the Utah Geological Survey Internet web site.

INTRODUCTION

Project Overview

Utah oil fields have produced over 1.2 billion barrels (bbls) (191 million m^3) (Utah Division of Oil, Gas and Mining, 2003). However, the 13.7 million bbls (2.2 million m^3) of production in 2002 was the lowest level in over 40 years and continued the steady decline that began in the mid-1980s (Utah Division of Oil, Gas and Mining, 2002). Proven reserves are relatively high, at 283 million bbls (45 million m^3) (Energy Information Administration, 2001). With higher oil prices now prevailing, secondary and tertiary recovery techniques should boost future production rates and ultimate recovery from known fields.

Utah's drilling history has fluctuated greatly due to discoveries, oil price trends, and changing exploration targets. During the boom period of the early 1980s, activity peaked at over 500 wells per year. Sustained high prices are likely to entice less risk-averse exploration investment (more wildcats), resulting in new discoveries.

Utah still contains large areas that are virtually unexplored. There is significant potential for increased recovery from existing fields by employing improved reservoir characterization and the latest drilling, completion, and secondary/tertiary technologies. New exploratory targets may be identified from three-dimensional (3D) seismic surveys. Development of potential prospects is within the economic and technical capabilities of both major and independent operators.

The primary goal of this study is to increase recoverable oil reserves from existing field reservoirs and new discoveries by providing play portfolios for the major oil-producing provinces (Paradox Basin, Uinta Basin, and thrust belt) in Utah and adjacent areas in Colorado and Wyoming (figure 1). These play portfolios will include: descriptions (such as stratigraphy, diagenetic analysis, tectonic setting, reservoir characteristics, trap type, seal, and hydrocarbon source) and maps of the major oil plays by reservoir; production and reservoir data; case-study field evaluations; summaries of the state-of-the-art drilling, completion, and secondary/tertiary techniques for each play; locations of major oil pipelines; and descriptions of reservoir outcrop analogs for each play. Also included will be land-use constraints to development such as wilderness or roadless areas, and national parks within oil plays.

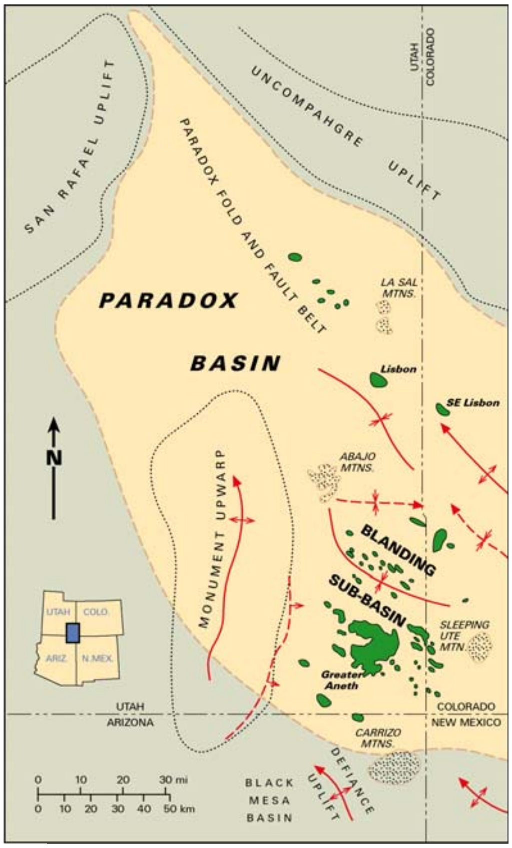
Project Benefits

The overall benefits of this multi-year project will be enhanced petroleum production in the Rocky Mountain region. Specifically, the benefits expected from the project are:

(1) increasing oil production and reserves by improved reservoir characterization,

(2) preventing premature abandonment of numerous small fields in the Paradox and Uinta Basins,

(3) increasing recoverable reserves by identifying the type of untapped compartments created by reservoir heterogeneity (for example, diagenesis and rapid facies changes),



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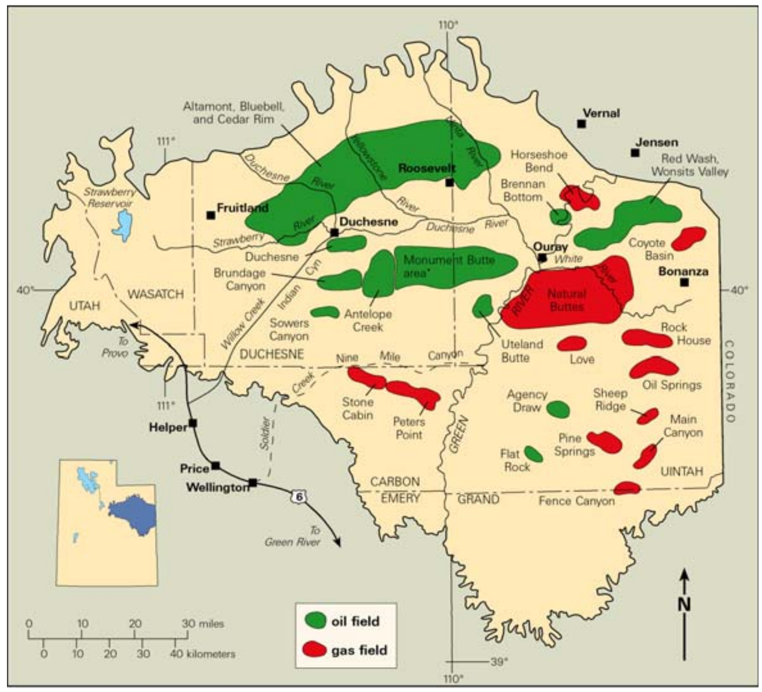

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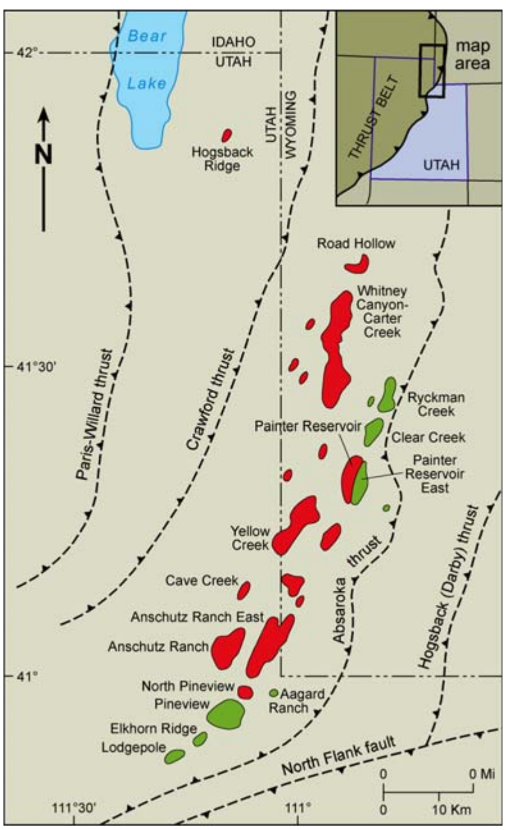

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Figure 1. Major oil-producing provinces of Utah and vicinity. (A) Oil and gas fields in the Paradox Basin of Utah and Colorado. (B) Oil and gas fields in the Uinta Basin of Utah. (C) Oil and gas fields, uplifts, and major thrust faults in the Utah-Wyoming thrust belt.

(4) increasing deliverability through identifying the latest drilling, completion, and secondary/tertiary techniques,

(5) identifying reservoir trends for field extension drilling and stimulating exploration in producing fairways,

(6) encouraging the use of technology employed in other identified basins or trends with similar types of reservoirs,

(7) reducing development costs and risk by reducing the number of wells needed to successfully drain the reservoir,

(8) allowing limited energy investment dollars to be used more productively, and

(9) increasing royalty income to the Federal Government; Utah, Wyoming, and Colorado state and local governments; the Navajo Nation and Ute Mountain Ute Indian Nation; and fee owners.

The Utah play portfolios produced by this project will provide an easy-to-use geologic, engineering, and geographic reference to help petroleum companies plan exploration and land-acquisition strategies. These portfolios may also help pipeline companies plan future facilities and pipelines. Other users of the portfolios will include petroleum engineers, petroleum land specialists, landowners, bankers and investors, economists, utility companies, manufacturers, county planners, and numerous government agencies.

The results of this project will be transferred to industry and other interested parties through establishment of Technical Advisory and Stake Holder Boards, an industry outreach program, and technical presentations at national and regional professional meetings. All of this information will be made public (1) through the Utah Geological Survey (UGS) Internet web site, (2) as an interactive, menu-driven digital product on compact disc, and (3) as hard copy publications in various technical or trade journals.

UINTA BASIN – DISCUSSION AND RESULTS

Overview

The Uinta – Piceance Province in northeastern Utah and northwestern Colorado, as defined by the U.S. Geological Survey (USGS), includes the contiguous outcrops of the Maastrichtian and Tertiary rocks and the southwest- to northeast-trending Wasatch Plateau and Castle Valley (Dubiel, 2003). Our discussion is restricted to the Uinta Basin portion of the province, which includes a small portion of the western flank of the Douglas Creek arch that separates the Uinta and Piceance Basins (figure 2). The Uinta Basin area covers nearly 16,000 square miles (41,000 km^2). The Uinta Basin (excluding the Wasatch Plateau and Castle Valley) is a topographic and structural trough that is sharply asymmetrical, with a steep north flank bounded by the east-west-trending Uinta Mountains, and a gently dipping south flank.

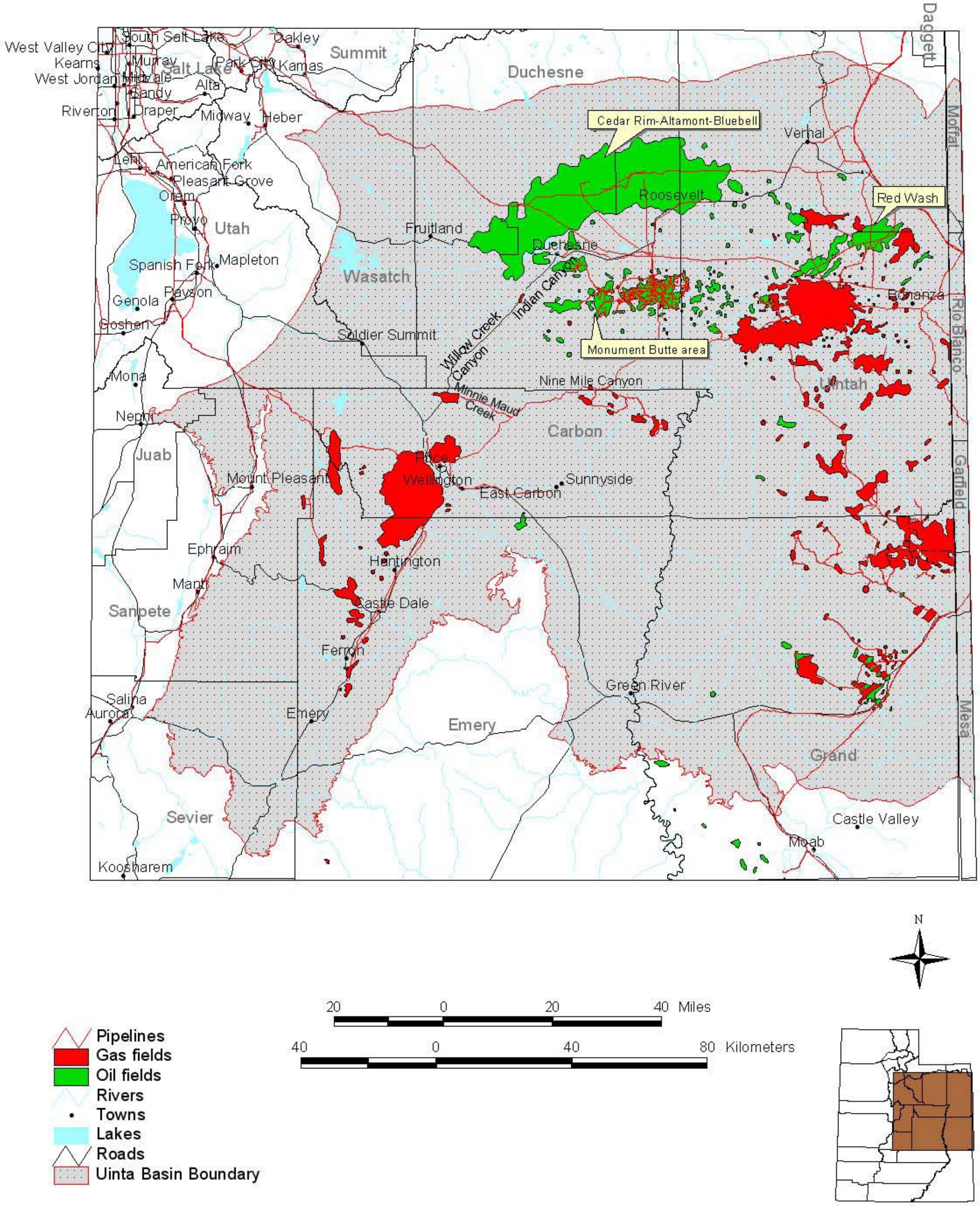


Figure 2. Map showing the location of the Uinta Basin as defined by Dubiel (2003), and the oil and gas fields in and around the basin.

The Uinta Basin formed in Late Cretaceous (Maastrichtian) time, when a large structural sag with internal drainage formed. The earliest deposits in the intermontane basin were predominantly alluvial (Ryder and others, 1976) with some shallow lacustrine and palludal deposits that comprise the North Horn Formation. In early late Paleocene time, a large lake developed in the basin (Francyk and others, 1992), known as ancestral Lake Uinta. Deposition in and around Lake Uinta consisted of open- to marginal-lacustrine sediments that make up the Green River Formation. Alluvial redbed and floodplain deposits that are laterally equivalent to, and intertongue with, the Green River make up the Colton (Wasatch) Formation (figure 3). The Eocene Uinta Formation and the Eocene to lower Oligocene Duchesne River Formation overlie the Green River.

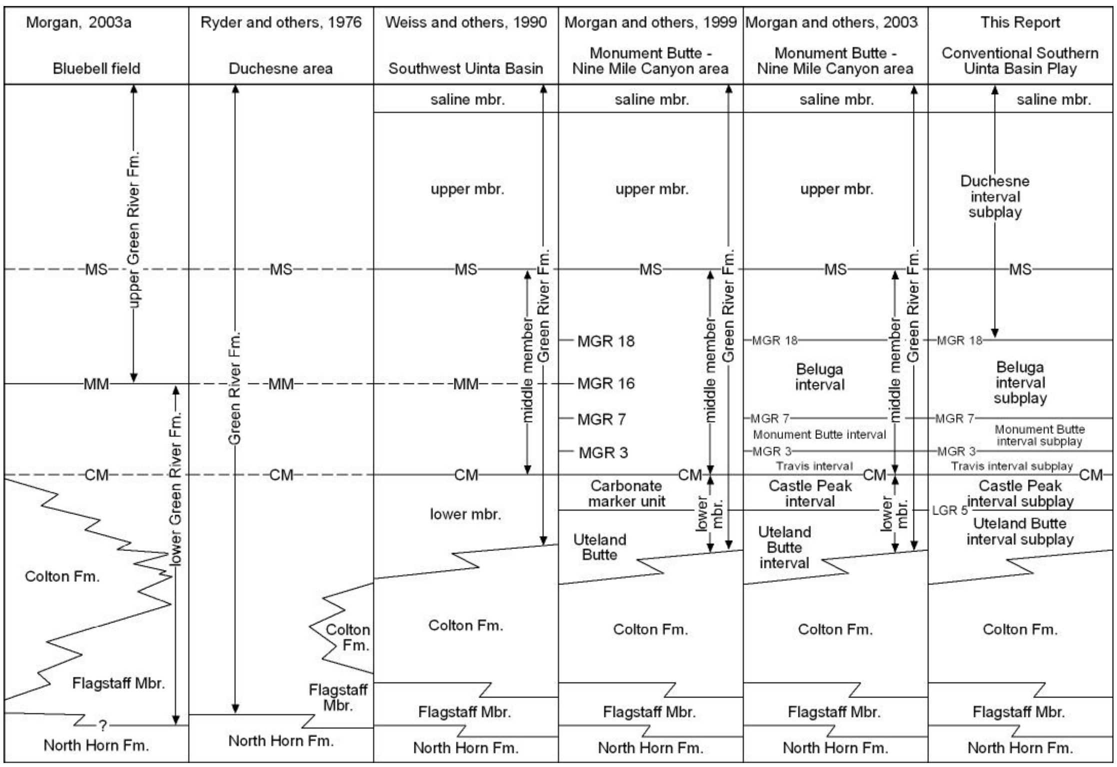


Figure 3. Comparative nomenclature used for the Green River Formation in the central Uinta Basin. MS = Mahogany oil shale, MM = middle marker, CM = carbonate marker, MGR 3 = middle Green River marker 3.

Uinta Basin Green River Total Petroleum System

The USGS defines the Green River Total Petroleum System (TPS) as a complex of entirely continental rocks (North Horn, Wasatch, Colton, Green River, Uinta, and Duchesne River Formations) that host gilsonite veins, oil shales, tar sands, and oil and gas, all sourced from lacustrine rocks within the Paleocene and Eocene Green River Formation (Dubiel, 2003). Source rocks are: (1) type I kerogen from the open-lacustrine facies, (2) types I, II, and III kerogen from the marginal lacustrine facies, and (3) type III kerogen from alluvial facies (Dubiel, 2003).

The maximum depth to the base of the Green River TPS is about 20,000 feet (6,100 m) along the axis of the Uinta Basin (Fouch and others, 1994). Operators typically assign all strata containing red beds to the Wasatch or Colton Formation; however, hydrocarbon production is mostly from tongues of the Green River Formation within the alluvial Wasatch and Colton (Fouch and others, 1992, 1994).

The USGS (Dubiel, 2003) defines two assessment units in the Green River TPS within the Uinta Basin: (1) the Deep Uinta Overpressured Continuous Oil Assessment Unit (AU 50200561) and (2) the Uinta Green River Conventional Oil and Gas Assessment Unit (AU 50200501) (figure 4). The Green River Conventional Oil and Gas Assessment Unit extends farther west than the Uinta Basin boundary. The western boundary of the Uinta Basin in Wasatch and Utah Counties is defined by the Charleston-Nebo thrust fault and Maastrichtian and Tertiary rocks beneath the thrust define the assessment unit boundary.

The USGS defines the Deep Uinta Overpressured Continuous Oil Assessment Unit by overpressured (gradient > 0.5 pounds per square inch per foot [psi/ft] [3.4 kpa]) source and reservoir rocks in the Green River Formation. The overpressuring is located near the basin center mostly in the Colton Formation and Flagstaff Member of the Green River in the Altamont, Bluebell, and Cedar Rim fields. The 0.5 psi/ft gradient is encountered as shallow as 8,500 feet (2,600 m). However, most of the high-volume, overpressured oil production is typically from 12,000 to 14,000 feet (3,600-4,300 m) in the Flagstaff Member.

The USGS defines the Uinta Green River Conventional Oil and Gas Assessment Unit by the distribution of normally pressured oil and gas accumulations in the Green River Formation at depths less than 8,500 feet (2,600 m) (Dubiel, 2003). The unit overlies the entire area of the Deep Uinta Overpressured Continuous Oil Assessment Unit (figure 4). The Uinta Green River Conventional Oil and Gas Assessment Unit consists entirely of the part of the Green River Formation that overlies the Colton and Wasatch Formations.

The dominant sediment source for the Green River and Colton Formations in the Cedar Rim, Altamont, Bluebell, and Red Wash fields was to the north, while the sediment source for the greater Monument Butte area, Duchesne, Brundage Canyon, Sowers, Antelope Creek, and Uteland Butte fields was to the south (figure 5). As a result, the deposition and the resulting reservoir properties are significantly different between south-sourced and north-sourced depositional systems. We divide the Uinta Green River Conventional Oil and Gas Assessment Unit into a Southern Uinta Basin Play and a Northern Uinta Basin Play and each are further divided into subplays. We divide the Deep Uinta Overpressured Continuous Oil Assessment Unit into an Overpressured Colton/Flagstaff Play and an Overpressured Lower Green River Play (table 1). The Conventional Southern Uinta Basin Play and subplays of the Uinta Green River Conventional Oil and Gas Assessment Unit are discussed in this report.

Conventional Southern Uinta Basin Play

The southern shore of Lake Uinta was often very broad and flat, which resulted in laterally extensive transgressions and regressions of the shoreline in response to climatic and tectonic-induced rise and fall of the lake. The cyclic nature of Green River deposition in the central Uinta Basin resulted in numerous stacked deltaic deposits. Distributary-mouth bars, distributary channels, and nearshore bars are the primary producing reservoirs in the area.

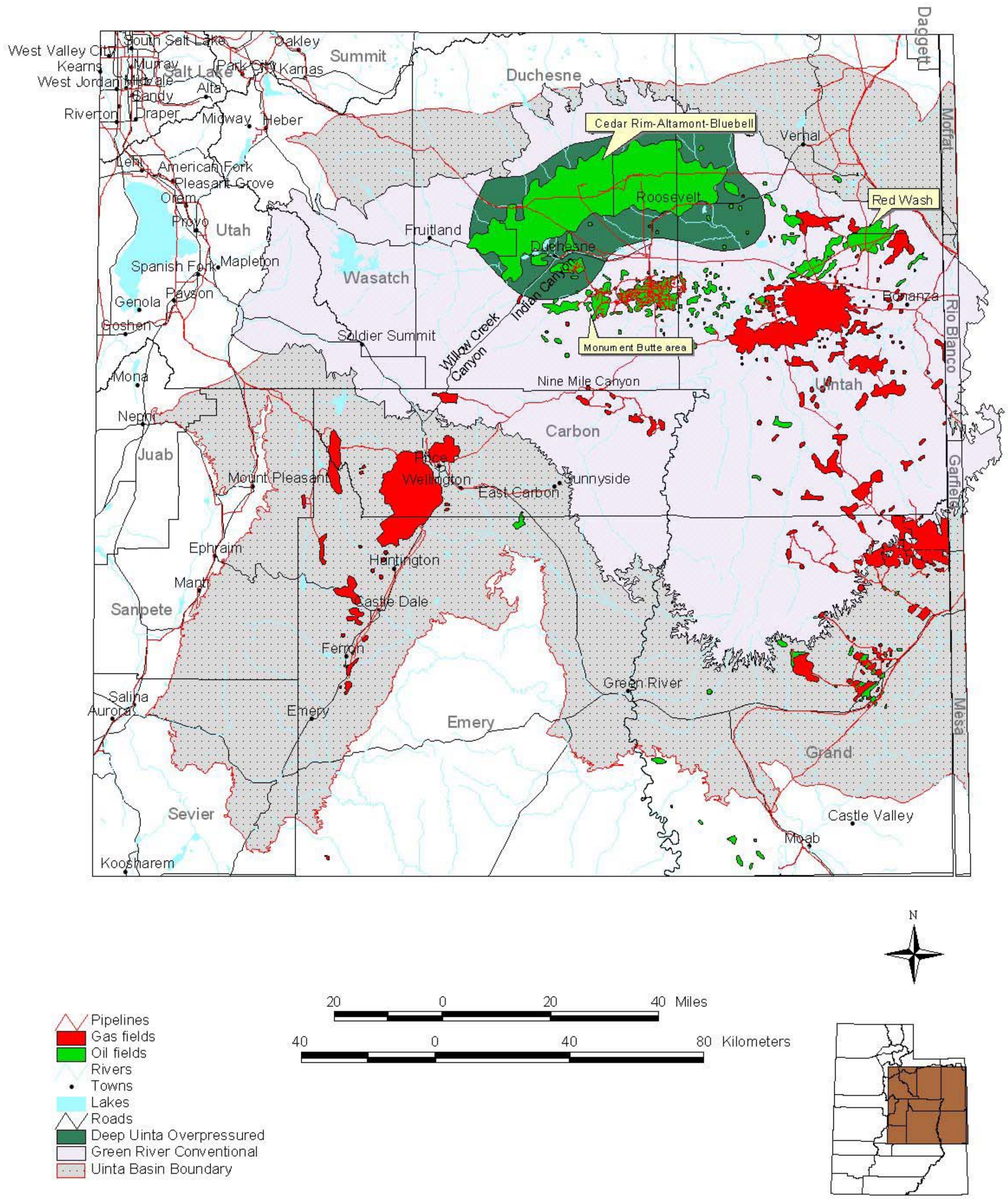
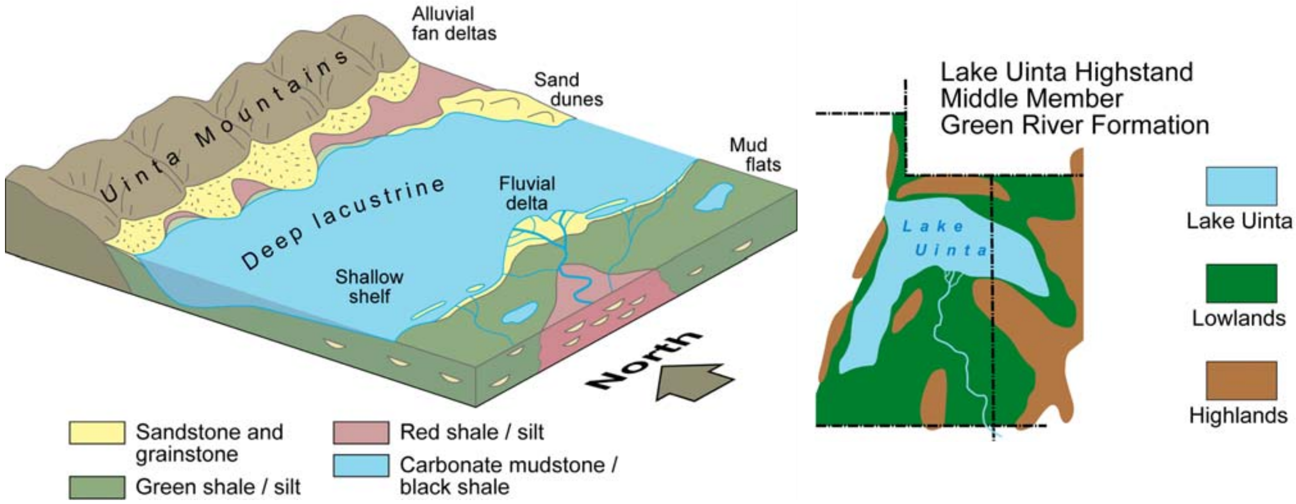


Figure 4. Map showing the Uinta Basin and the USGS Deep Uinta Overpressured Continuous Oil Assessment Unit (AU 50200561) and the Uinta Green River Conventional Oil and Gas Assessment Unit (AU 50200501). Source: Dubiel, 2003.



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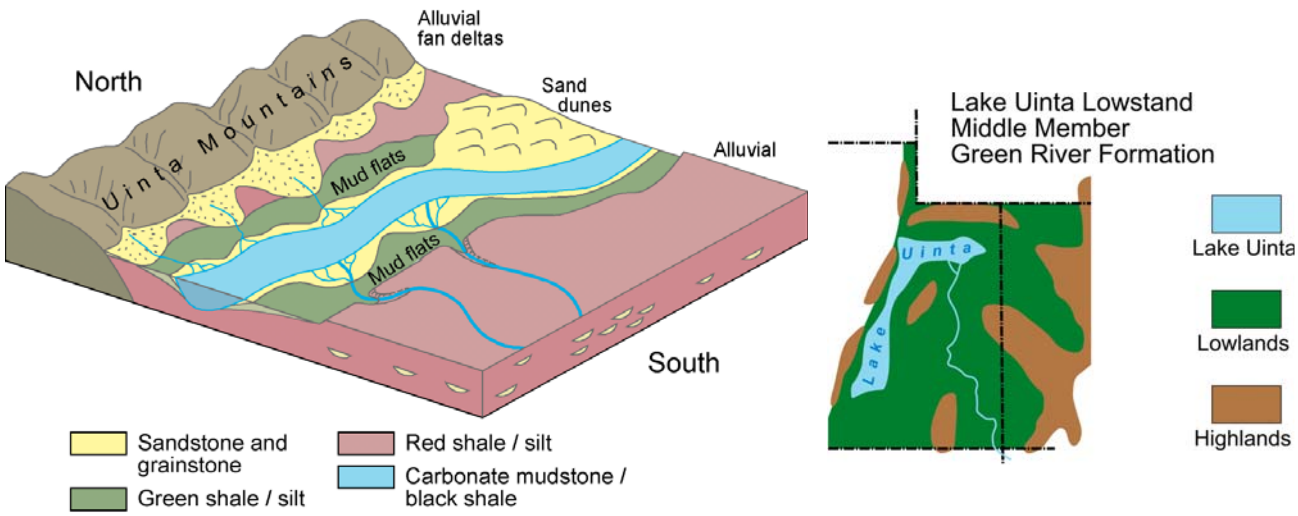

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Figure 5. Diagrams showing the generalized depositional setting for Lake Uinta during high lake levels (A) and low lake levels (B). The Uinta Mountains were the source for the sediments in the northern portion of the lake while the southern portion of the lake was sourced from the much larger Four Corners area.

Table 1. Plays and subplays in the Uinta Basin Green River Total Petroleum System.

GREEN RIVER FORMATION TOTAL PETROLEUM SYSTEM, UINTA BASIN		
Deep Uinta Overpressured Continuous Oil Assessment Unit (AU 50200561*)		
	Overpressured Colton/Flagstaff Play	
	Overpressured Lower Green River Play	
Uinta Green River Conventional Oil and Gas Assessment Unit (AU 50200501*)		
	Conventional Northern Uinta Basin Play	
		Conventional Altamont-Bluebell-Cedar Rim Subplay
		Conventional Red Wash-Wonsits Valley Subplay†
	Conventional Southern Uinta Basin Play	
		Conventional Uteland Butte Interval Subplay
		Conventional Castle Peak Interval Subplay
		Conventional Travis Interval Subplay
		Conventional Monument Butte Interval
		Conventional Beluga Interval Subplay
		Conventional Duchesne Interval Fractured Shale/Marlstone Subplay

*Dubiel, 2003.
†Conventional Red Wash-Wonsits Valley Subplay may be divided into multiple subplays.

The Conventional Southern Uinta Basin Play is divided into six distinct subplays. In stratigraphically ascending order, the subplays are: (1) conventional Uteland Butte interval, (2) conventional Castle Peak interval, (3) conventional Travis interval, (4) conventional Monument Butte interval, (5) conventional Beluga interval, and (6) conventional Duchesne interval fractured shale/marlstone. The reservoir in the Uteland Butte interval is mainly lacustrine limestone with rare bar sandstone beds, whereas the reservoirs in the overlying four intervals are mainly distributary channel and shallow lacustrine sandstone beds (Morgan and Bereskin, 2003; Morgan and others, 2003). The reservoir in the fractured shale/marlstone is formed by naturally occurring fractures in the upper member of the Green River Formation.

The changing depositional environments of Paleocene-Eocene Lake Uinta controlled the characteristics of each interval and the reservoir rock contained within. The Uteland Butte reservoir consists of carbonate and rare, thin, shallow-lacustrine sandbars deposited during the initial rise of the lake. The Castle Peak reservoir was deposited during a time of numerous and rapid lake-level fluctuations, which developed a simple drainage pattern across the exposed shallow and gentle shelf with each fall and rise cycle. The Travis reservoir records a time of tectonism that created a steeper slope and a pronounced shelf break where thick cut-and-fill valleys developed during lake-level falls and rises. The Monument Butte reservoir represents a return to a gentle, shallow shelf where channel deposits are stacked in a lowstand delta plain and amalgamated into the most extensive reservoir in the central Uinta Basin. The Beluga reservoir represents a time of major lake expansion with fewer, less pronounced lake-level falls, resulting in isolated single-storied channel and shallow-bar sand deposits. The fractured shale/marlstone rocks in the upper part of the middle member, the upper member, and the saline member of the Green River Formation were deposited during the maximum rise and waning stages of Lake Uinta.

Conventional Uteland Butte Interval Subplay

The Uteland Butte interval represents the first major transgression of the lake after deposition of the alluvial Colton Formation. The interval ranges in thickness from less than 60 feet (20 m) to more than 200 feet (60 m) in the central Uinta Basin. The Uteland Butte interval is defined as the stratigraphic interval from the top of the Colton Formation to the top of LGR 5 (figure 3), a log marker defined by Morgan and others (1999). The Uteland Butte is equivalent to the first lacustrine tongue of Bradley (1931), lower black shale facies of Abbott (1957), basal limestone facies of Little (1988) and Colburn and others (1985), Uteland Butte limestone of Osmond (1992), and basal limestone member of Crouch and others (2000). The black shale facies described by Wiggins and Harris (1994) includes the Uteland Butte and overlying Castle Peak intervals.

Little (1988), working in the Minnie Maud Creek to Willow Creek Canyon area (figure 2), described the Uteland Butte environment as shallow-water mud flats to offshore lacustrine. The lithologies are dolomitized ostracod and pellet grainstone and packstone, and pelecypod-gastropod sandy grainstone interbedded with silty claystone or carbonate mudstone. Little (1988) describes 3- to 6-foot (1-2 m) thick beach- or bar-sandstone beds in the Minnie Maud area, but these beds are absent in Willow Creek Canyon.

The Uteland Butte interval was deposited during a major rise in lake level. The Uteland Butte is distinctive in its abundance of carbonate rocks and lack of sandstone, which could have been caused by one or both of the following situations: (1) the rapid lake-level rise caused siliciclastic sediments to be deposited in proximal alluvial channels, or (2) the main sediment inflow into the lake was far from the central Uinta Basin area, perhaps flowing into the southern arm of the lake south and west of the San Rafael uplift (McDonald, 1972).

Conventional Castle Peak Interval Subplay

The Castle Peak interval (figure 3) is defined as the stratigraphic section from the top of the Uteland Butte to the top of the carbonate marker bed of Ryder and others (1976). It is equivalent to the Wasatch (Colton) tongue and second lacustrine tongue of Bradley (1931), the Colton tongue and carbonate marker unit of Ryder and others (1976), and is included in Picard's (1955) black shale facies. The alluvial Colton tongue is exposed in Willow Creek and Nine Mile Canyons but extends only a few miles north. Above the Colton tongue, the Castle Peak consists of interbedded black shale, limestone, and limy mudstone, with some sandstone and siltstone. The sandstone beds, which are productive in some areas, are generally fine to medium grained, and were deposited as isolated channels.

The Castle Peak sandstone is typically medium grained (0.36 to 0.44 mm), poorly to moderately sorted, angular to very well rounded, mostly lithic arkose or feldspathic litharenite. Lithics are mostly chert but include metamorphic, granitic, and volcanic rock fragments. Most of the other sandstone beds in the Green River Formation are very fine to fine grained. Framework elements of the Castle Peak sandstone include: (1) monocrystalline and polycrystalline quartz, (2) potassium feldspar (orthoclase and microcline), (3) plagioclase, (4) chert, (5) sheared metaquartz, recrystallized metaquartz, and hydrothermal quartz, (6) intrusive rock fragments, (7) dolomite, siltstone and mudstone clasts, (8) carbonate ooids, (9) isolated mica booklets (biotite, chlorite, and muscovite), (10) some red-brown hematite staining, and (11) assorted heavy minerals such as zircon, epidote, tourmaline, sphene, and rare amphibole.

The Castle Peak sandstone is typically highly compacted with extensive quartz and some feldspar cementation. Porosity is typically the result of dissolution of feldspars and some rock fragments. Fractures in the sandstone are necessary for good hydrocarbon production and are most commonly developed at the base of the bed where the carbonate content is highest, which results in increased brittleness.

The Castle Peak in the central Uinta Basin, as defined by Ryder and others (1976), consists of isolated marginal lacustrine channel sandstone beds encased in carbonate that were deposited during lake level fall and rise. These channel deposits are typically limited in lateral extent; channel stacking is rare. The lack of channel stacking is attributed to short-duration cycles of lake-level rise and fall. As a result, the drainage system for each cycle never advanced beyond the initial stage. Schumn and Ethridge (1994) show that the initial drainage pattern on an exposed shelf is typically a series of subparallel, unconnected channels.

Conventional Travis Interval Subplay

The Travis interval is defined as the stratigraphic section from the top of the lower member of the Green River Formation (carbonate marker bed) to the top of the MGR 3 marker (figure 3). The interval is part of the middle member and ranges in gross thickness from 270 to 700 feet (80 to 200 m) in the central Uinta Basin (Morgan and Bereskin, 2003; Morgan and others, 2003).

The Travis interval consists of sand-rich alluvial and deltaic deposits of the Renegade Tongue (Cashion, 1967) in Desolation Canyon, fluvial-deltaic deposits in Nine Mile Canyon, and the green shale facies (Picard, 1955, 1957) in Willow Creek Canyon. This represents a significant basinward shift of facies. In the Monument Butte area, however, the rocks consist of the black shale facies and do not show evidence of a major regression. A significant basinward shift of the shoreline without evidence of shallowing, and perhaps even deepening in the distal reaches, may be the result of tectonic movement in the basin. This tectonic activity may have shifted the regional drainage to the central Uinta Basin area, resulting in the sand–rich deltaic deposits in Desolation and Nine Mile Canyons. Prior to this, channel deposits in the lower member of the Green River Formation in the central Uinta Basin were generally small and isolated, indicating only a local drainage system. Also, a relatively prominent shelf break developed at this time in the Monument Butte area.

Many of the oil-productive sandstone beds in the Travis interval are channel and shallow bar deposits. The primary reservoirs in the Travis are turbidite and shallow lacustrine sandstone beds deposited in narrow cut-and-fill valleys along the shelf break during several lake level fall-and-rise cycles. The Travis is the only stratigraphic interval in the lower or middle members where there is evidence of a sharp shelf break in the central area. Lutz and others (1994) described the Travis reservoir as moderate- to low-density turbidite channel, debris flow, and gravity flow deposits.

Two rock types comprise the majority of the sandstone beds in the Travis reservoir. Rock-type T-1 is a very poorly sorted combination of silt and very fine grained sand that commonly contains detrital clay coatings around many of the grains as well as large clasts of highly compacted dolomitic and illitic mudstone. It typically has poor porosity and permeability due to tight grain packing, sporadic detrital clay coatings, and pseudomatrix formation of mudstone clasts. Rock-type T-2 is a laminated assemblage of very fine to fine-grained sandstone that has the appearance of a chaotic breccia of haphazardly distributed carbonate mudstone clasts in a poorly sorted silt to very fine grained matrix with abundant soft-sediment deformation features. It typically has low porosity and permeability due to tight grain packing, illite coating the grains, and a general lack of secondary intergranular pores. Fractures in the Travis reservoir sandstone are rare due to the clay content reducing the overall brittleness of the beds.

Conventional Monument Butte Interval Subplay

The Monument Butte interval is defined as the stratigraphic section from the top of the MGR 3 marker (Travis reservoir) to the top of the MGR 7 marker (figure 3). The interval ranges in thickness from 250 feet (75 m) to almost 500 feet (150 m) in the central Uinta Basin (Morgan and Bereskin, 2003; Morgan and others, 2003). The Monument Butte is the primary oil-producing interval in the central Uinta Basin. The reservoir consists of amalgamated channel and distributary-mouth bar sandstone deposited on the distal, lower delta plain of Lake Uinta when the lake was at a low level, with an area of sediment bypass forming the updip trap (Morgan and others, 2003).

Two rock types comprise most of the sandstone beds in the Monument Butte reservoir. Rock-type MB-1 is the most abundant and is typically very fine to fine grained (median 0.11 to 0.17 mm), moderately well sorted to well sorted, with subangular to subrounded grains. The framework assemblage is similar in composition and abundance to the medium-grained sandstone in the Castle Peak, except the rock-type MB-1 has more biotite, chlorite, and muscovite. Also, in rock-type MB-1 the mudstone fragments are dolomitic, ankeritic, and carbonate allochems including ankeritic/dolomitic ooids, ankeritic/dolomitic rip-ups, ostracods, or intraclasts.

Some of the MB-1 sandstone had early cementation with iron-poor calcite, which greatly reduced the effects of compaction. Later dissolution of the iron-poor calcite resulted in some beds with permeabilities in the tens of millidarcies (md) and porosity more than 20 percent. Other sandstone had a later stage of cementation with dolomite, ankerite, siderite, and iron-rich calcite, which greatly reduced the rock pore space. Partial dissolution of the late-stage cement restored some of the reservoir potential of the rock, resulting in greater than 10 percent porosity but less than 20 md permeability.

Rock-type MB-2 is sandstone consisting of very fine grained sand and coarse silt with increased clay content compared to MB-1. Rock-type MB-2 is a ripple-drift lamination facies found in the upper portion of fining-upward sandstone sequences. Compared to MB-1, it is more poorly sorted, angular to subangular, and has more grains coated with illite. It also contains more mica, especially muscovite, than the rock-type MB-1 sandstone. Examination of rock-type MB-2 sandstone shows that severe compaction occurred soon after deposition, which resulted in abundant microstylolite development. Rarely is early iron-poor calcite cement found in rock-type MB-2. Dissolution of feldspars is minor, resulting in low porosity (<10 percent) and low permeability (<0.1 md).

Conventional Beluga Interval Subplay

The Beluga interval is defined as the stratigraphic section from the top of the MGR 7 to the top of the MGR 18 (figure 3). The interval ranges in thickness from 550 feet (170 m) to more than 1,200 feet (370 m) in the central Uinta Basin (Morgan and Bereskin, 2003; Morgan and others, 2003).

The Beluga interval consists of interbedded sandstone, shale, and limestone. The interval was deposited during a time of overall lake-level rise, and is transitional from the underlying delta facies in the Douglas Creek Member to the overlying deep-lake oil shale deposits of the upper member. This trangressive facies deposition resulted in less total sandstone and more common individual, isolated channel and bar deposits. The sandstone in the Beluga reservoir is similar in composition to the Monument Butte reservoir sandstone. There are fewer fining-upward sequences and therefore less rock-type MB-2 ripple-drift laminated facies.

Conventional Duchesne Interval Fractured Shale/Marlstone Subplay

The Duchesne interval is defined as the stratigraphic section from the MGR 18 to the top of the Green River Formation, which includes part of the middle member and all of the upper and saline members of the Green River (figure 3). The Duchesne interval fractured shale/ marlstone subplay consists of shale (including oil shale), marlstone, and rare sandstone. Oil is stored in naturally occurring fractures in the shale and marlstone beds. Most of the fractured shale/marlstone interval is at shallow drill depths in the basin. As a result, the formation temperatures are often near or below the pour-point temperature of the oil, making it a difficult reservoir to exploit.

Outcrop Analogs for the Conventional Southern Uinta Basin Play

Utah is unique in that representative outcrop analogs (depositional or structural) for each major oil play are present in or near the thrust belt, Paradox Basin, and Uinta Basin. Production-scale analogs provide an excellent view, often in 3D, of reservoir-facies characteristics, geometry, distribution, and the nature of boundaries contributing to the overall heterogeneity of reservoir rocks. The specific objectives of this project are to: (1) increase understanding of vertical and lateral facies variations and relationships within major reservoirs; (2) describe the lithologic characteristics; (3) determine the morphology, internal geometries, and possible permeability and porosity distributions; and (4) identify potential impediments and barriers to fluid flow.

An outcrop-analog model, combined with the details of internal lithofacies characteristics, can be used as a "template" for evaluation of data from conventional core, geophysical and petrophysical logs, and seismic surveys. When combined with subsurface geological and production data, the analog model will improve development drilling and production strategies, reservoir-simulation models, reserve calculations, and design and implementation of secondary/tertiary oil recovery programs and other best practices used in the oil fields of Utah and vicinity. Outcrop analogs for the major oil reservoirs in the Green River Formation in the Conventional Southern Uinta Basin Play are presented in the following sections.

The Green River Formation is well exposed in Willow Creek, Indian, and Nine Mile Canyons in the south-central Uinta Basin (figure 2). Morgan (2003b) presented road logs describing the exposures in these canyons. The exposures in Willow Creek Canyon are generally limited to road cuts, which provide easy access but limited lateral extent. Indian Canyon provides an excellent view of the upper and saline members of the Green River. Nine

Mile Canyon has more than 30 miles (50 km) of continuous exposures of the Green River Formation.

Outcrop Analog for the Uteland Butte Interval Subplay

The Uteland Butte interval is exposed at the junction of Minnie Maud and Nine Mile Canyons (figure 6). At this location, the Uteland Butte interval overlies the Colton Formation and is overlain by a tongue of the Colton (figure 7). Little (1988) described the interval as dolomitized ostracod and pellet grainstone and packstone deposited in shallow-water mudflats; pelecypod-gastropod sandy grainstone, commonly interbedded with silty claystone or carbonate mudstone, was deposited in shallow open-lacustrine environments, and dark-gray kerogen-rich carbonates were deposited in deeper offshore environments (figures 8 and 9).

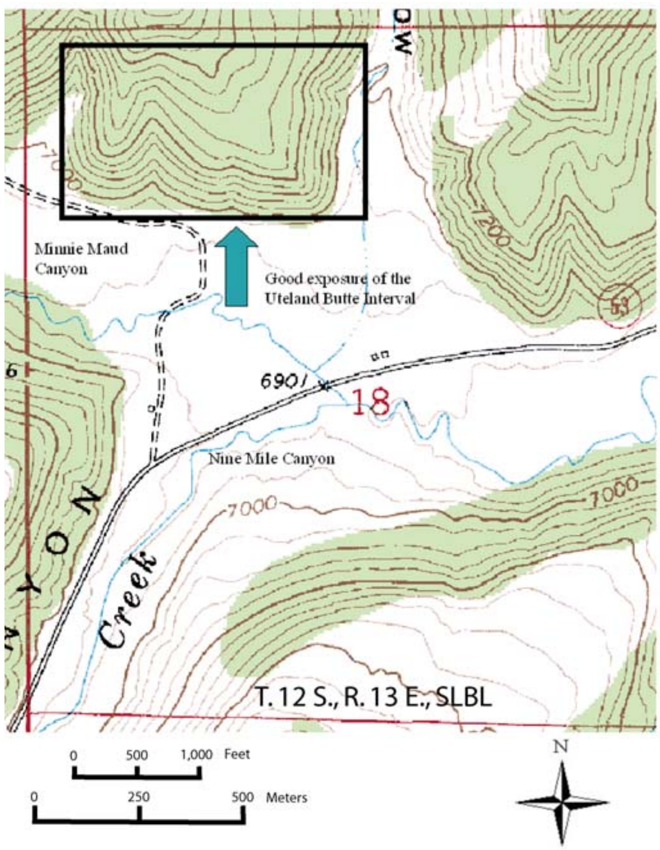

Figure 6. Map showing the location of exposures of the Uteland Butte interval in the Green River Formation, described by Little (1988) at the junction of Minnie Muad and Nine Mile Canyons. Base map modified from the USGS Minnie Maud Creek East 7.5 minute quadrangle.

Outcrop Analog for the Castle Peak Interval

The Castle Peak interval is exposed in the western portion of Nine Mile Canyon (figure 10). At this location, the interval overlies the Colton tongue and is overlain by the Travis interval. The top of the Castle Peak is picked at the top of the carbonate marker bed of Ryder and others (1976). At this location, Remy (1992) measured 443 feet (135 m) of interbedded carbonate, shale, and sandstone (figure 11). The primary reservoir rocks are the channel sandstone beds described as generally having a sharp base with some rip-up clasts and trough cross-beds, fining upwards from medium to fine grained, with low-angle to planar bedding (Appendix A). The sandstone beds are typically isolated channel deposits (figure 12).

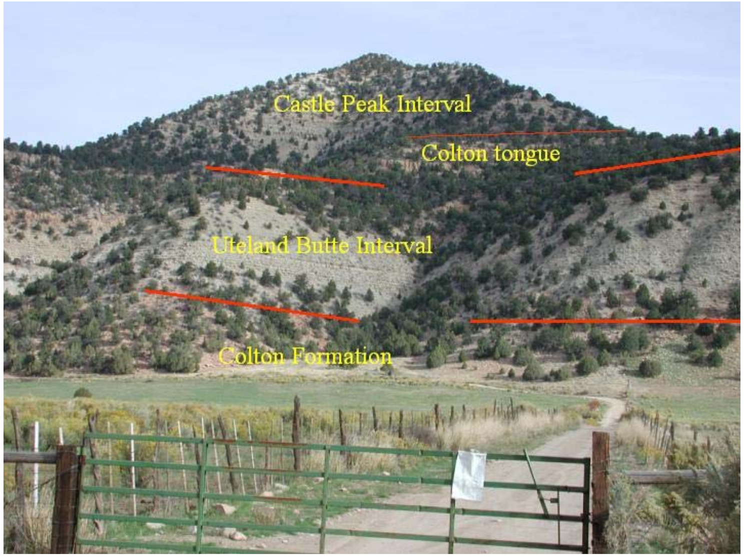

Figure 7. Exposure of the Uteland Butte interval of the Green River Formation at the junction of Minnie Maud and Nine Mile Canyons; see figure 6 for location.

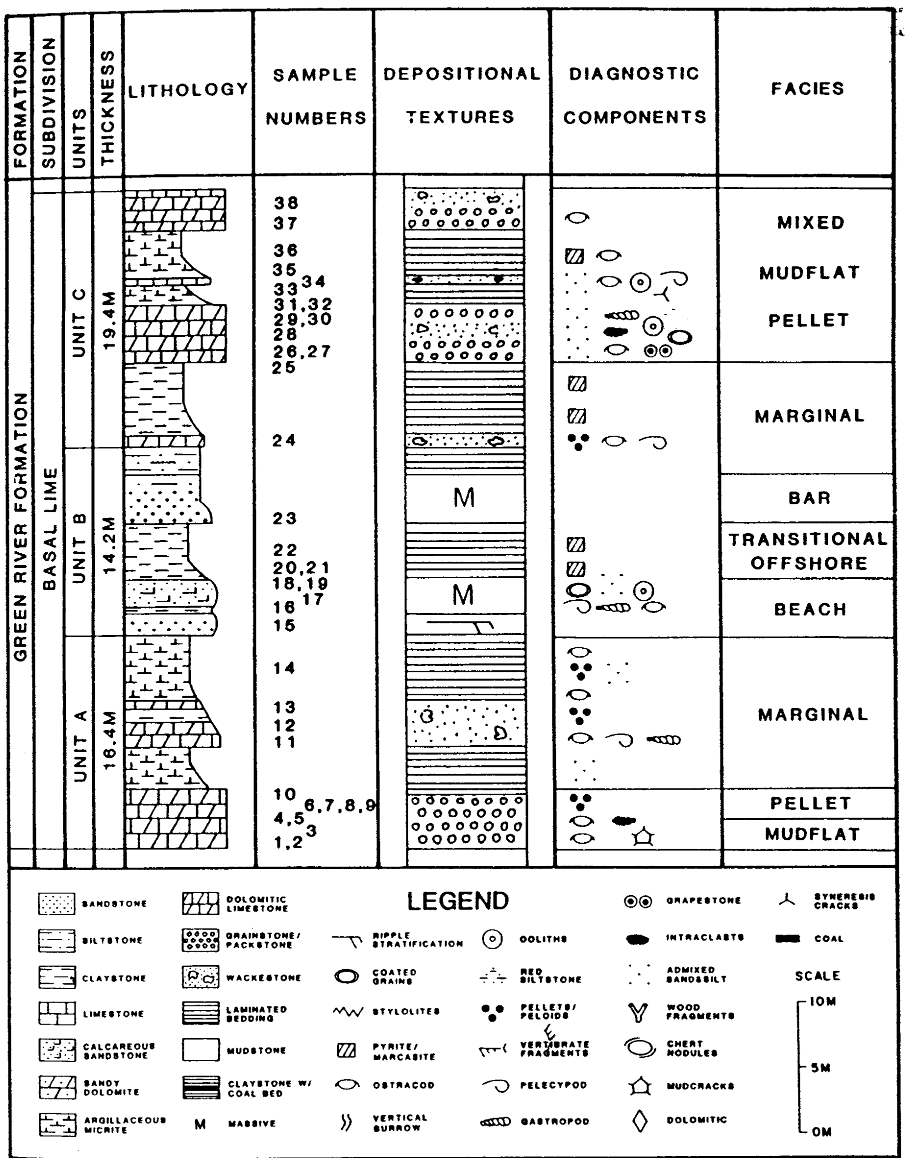

Figure 8. Stratigraphic measured section by Little (1988) of the Uteland Butte interval of the Green River Formation (Little's basal limestone facies) at the junction of Minnie Maud and Nine Mile Canyons.

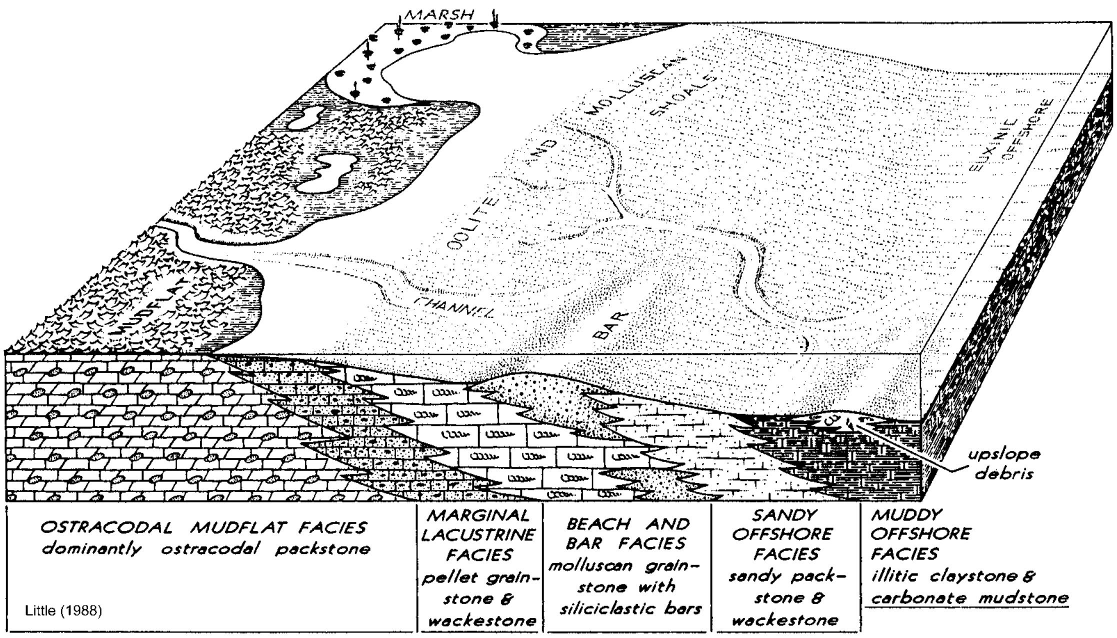

Figure 9. Conceptual three-dimensional diagram depicting major facies of the Uteland Butte interval of the Green River Formation. From Little (1988).

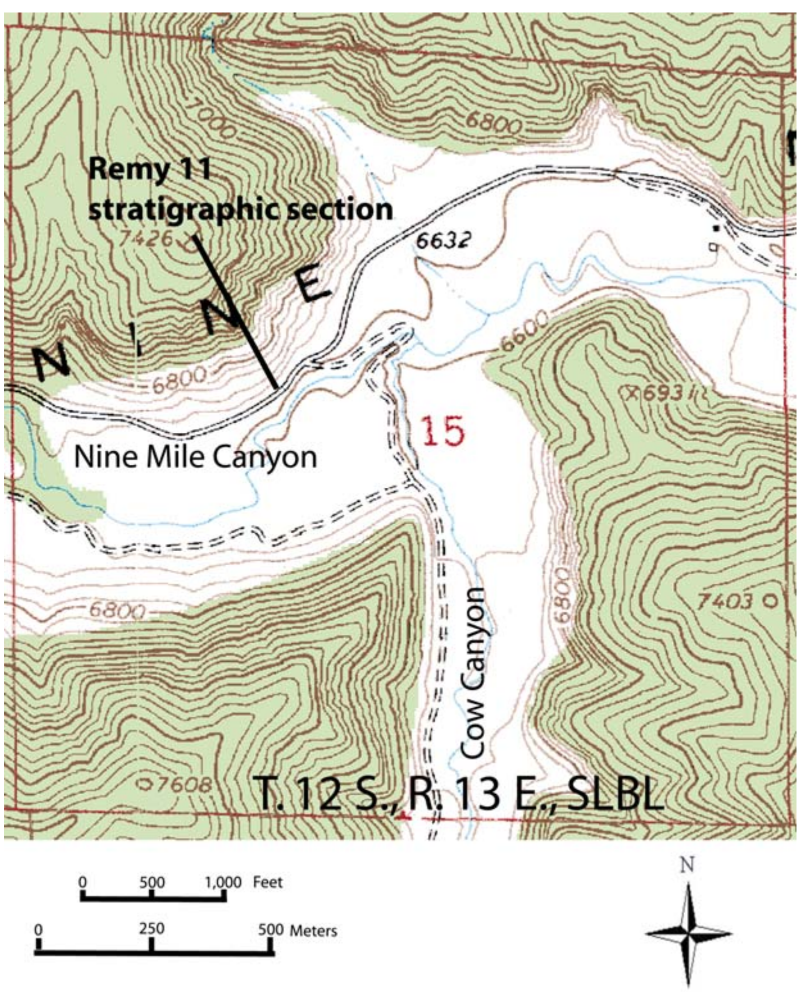

Figure 10. Map showing the location of the stratigraphic measured section (Appendix A) of the Castle Peak interval and lower part of the Travis interval of the Green River Formation, by Remy (1992). Base map modified from the USGS Wood Canyon 7.5-minute quadrangle.

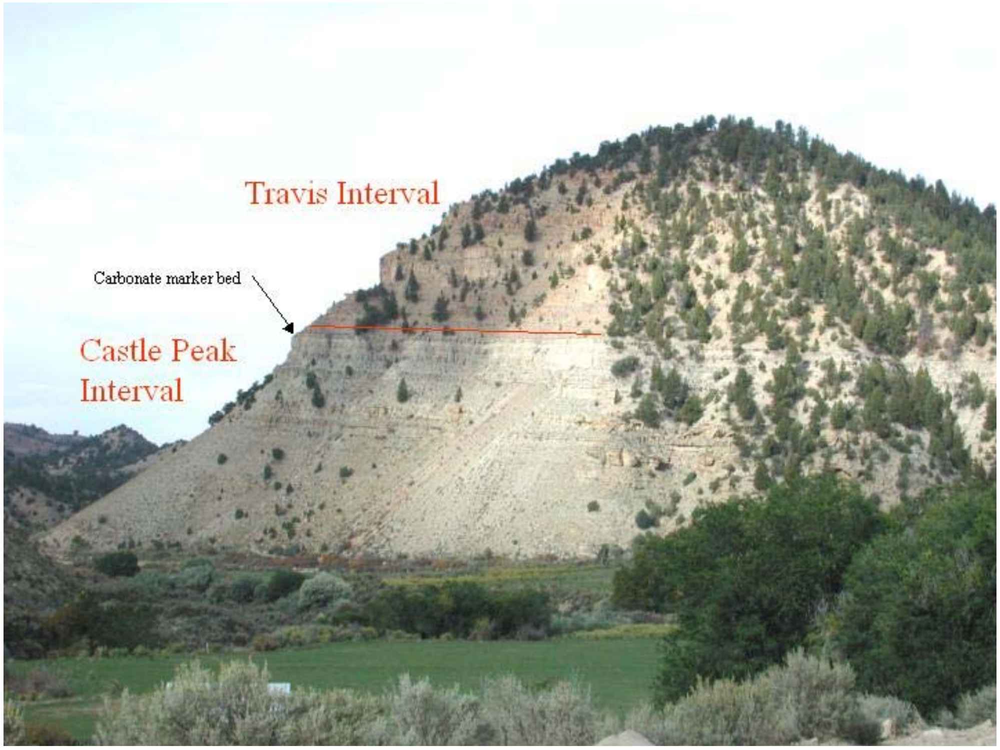

Figure 11. Photograph showing the location (figure 10) of Remy's (1992) stratigraphic measured section of the Castle Peak interval and lower part of the Travis interval of the Green River Formation (Appendix A).

Figure 12. Photograph of a carbonate bed and overlying channel sandstone deposit in the Castle Peak interval of the Green River Formation, Nine Mile Canyon.

Outcrop Analog for the Travis, Monument Butte, and Beluga Intervals

The primary reservoirs for the Travis interval are turbidite and gravity-flow deposits, which have not been identified in outcrop. The secondary reservoirs in the Travis interval and the primary reservoirs in the Monument Butte and Beluga intervals are distributary-channel deposits. The Monument Butte interval typically contains amalgamated stacked channel deposits, whereas in the Travis and Beluga intervals, the distributary channels are generally isolated individual channels. Although the volume of reservoir rock varies between the intervals, the depositional and petrophysical properties are similar. Therefore, one location is described as an outcrop analog for the Travis (secondary reservoir), Monument Butte, and Beluga intervals.

We studied the outcrops from Petes Canyon to Gate Canyon in Nine Mile Canyon (figure 13) as an analog to the oil reservoirs in the Monument Butte and adjacent oil fields (Morgan and others, 2003). These outcrops, termed the Nutter's Ranch study site because of its proximity to the historical Nutter Ranch house, lie within section 32, T. 11 S., R. 15 E. (Salt Lake Base Line [SLBL]), in Duchesne County, and contain a well-exposed, large-scale depositional cycle (table 2). The complete sequence exposed at the Nutter's Ranch study site was described by Remy (1992, Appendix B).

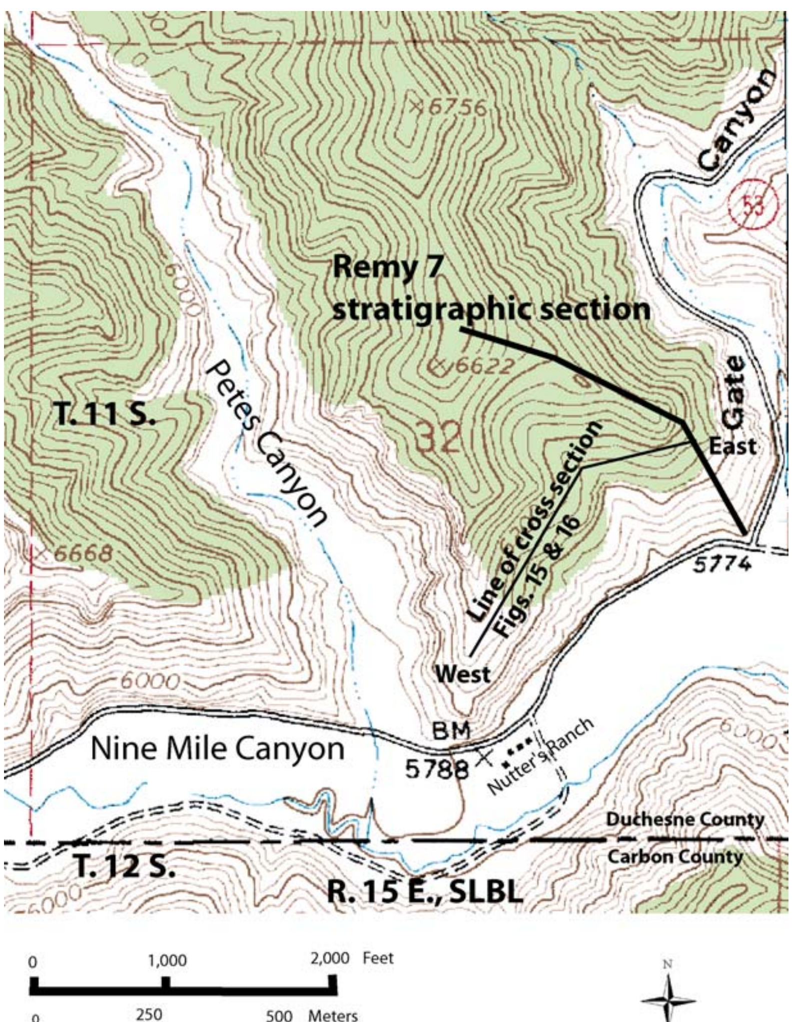

***Figure 13.** Map showing the location of the stratigraphic measured section (Appendix B) of the Monument Butte and Beluga intervals of the Green River Formation, by Remy (1992), and the Nutter's Ranch study site between Petes and Gate Canyons in Nine Mile Canyon. Base map modified from the USGS Current Canyon 7.5-minute quadrangle.*

Table 2. Lithology, description, and depositional interpretations from the Nutter's Ranch study site.

Lithology (bed designations)	Description	Depositional environment
Carbonate (C)	Oolitic/ostracodal grainstone and micrite, typically contains fossil hash. The beds weather orange.	Lagoonal, beach to shallow nearshore.
Sandstone (Ss-a)	Fine grain, rippled, tabular, thin (<3 feet), laterally continuous except where it is cut by channel sandstone body.	Flood-plain sheet flow.
Sandstone (Ss-b)	Fine grain, deeply incised channel-form bed, trough cross-beds, rip-up clasts and ooids common in lower portion, upper portion some ripples and soft-sediment deformation.	Nonsinuous streams on the upper delta plain.
Sandstone (Ss-c)	Fine grain, channel-form bed, laterally extensive amalgamated channels, planar base due to restrictive carbonate bed preventing downward cutting, promoting lateral migration. Fining upwards with upward decrease in scale of sedimentary structures from trough and low angle cross-beds to planar and rippled. Szantat (1990) Type I sandstone body.	High sinuosity, anastomosing channel deposit in the lower delta plain.
Sandstone (Sd-d)	Fine grain, channel-form bed, laterally limited, incised, individual channel deposit, concave upward lower bounding surface, fining upwards with upward decrease in scale of sedimentary features from lateral accretion beds, trough and low angle cross-bedding to planar and rippled.	Meandering distributary channel.
Sandstone (Ss-e)	Fine grain, channel-form bed, laterally extensive amalgamated channel deposits, concave upward lower bounding surface, fining upwards with upward decrease in scale of sedimentary features from lateral accretion beds, trough and low angle cross-bedding to planar and rippled. Szantat (1990) Type II sandstone body.	High sinuosity, anastomosing channel deposit in the lower delta plain.
Sandstone (Ss-f)	Fine grain, incised channel-form bed, laterally limited, typically inclined trough sets with shale drapes.	Proximal crevasse splay.
Sandstone (Ss-f)	Fine grain, coarsening upward with generally flat top, rippled, thin 1 to 3 feet thick, laterally extensive.	Distal crevasse splay.
Shale and siltstone	Green to gray-green shale and siltstone, typically thinly covered, highly weathered. Some thick covered slopes interpreted to be underlain by shale and siltstone.	Upper and lower delta plain, flood plain to mudflat, to swamp, possibly abandoned channel and overbank deposit.

Detailed examination of the outcrop identified the potential heterogeneity that can exist between wells in two dimensions (as well as over a square mile), as an analogy to a typical water-flood unit in the Monument Butte area to the north. Wells in the Monument Butte area are drilled on 40-acre (16.2-ha) spacing resulting in about 1,320 feet (400 m) between wells. The typical water-flood unit in the Monument Butte area is a square mile (one section) or larger, with wells in the center of every 40-acre (16.2-ha) lot, or 16 wells per section. The wells are initially completed as oil wells, but after they have all been drilled and the primary production drops below a minimum level, every other well is converted to a water injection well, resulting in eight producing and eight injection wells per section.

The Nutter's Ranch study site includes portions of Petes Canyon and Gate Canyon, and the portion of Nine Mile Canyon between these canyons. The exposure is about 2,000 feet (600 m) in the east-to-west direction in Nine Mile Canyon and in the north-to-south direction in Gate Canyon, and about 4,200 feet (1,300 m) in the north-to-south direction in Petes Canyon.

The stratigraphic interval studied is slightly more than 100 feet (30 m) thick, and is bounded by carbonate beds at the base (M8) and at the top (M9) (figure 14). Eight sections were measured and described, and gamma-ray data were gathered from five of the sections. To aid in the stratigraphic interpretation, the site was photographed from the canyon walls opposite the study site, and photomontages were compiled. The photomontages were used to map out individual beds and their relationships (Morgan and others, 1999, 2003).

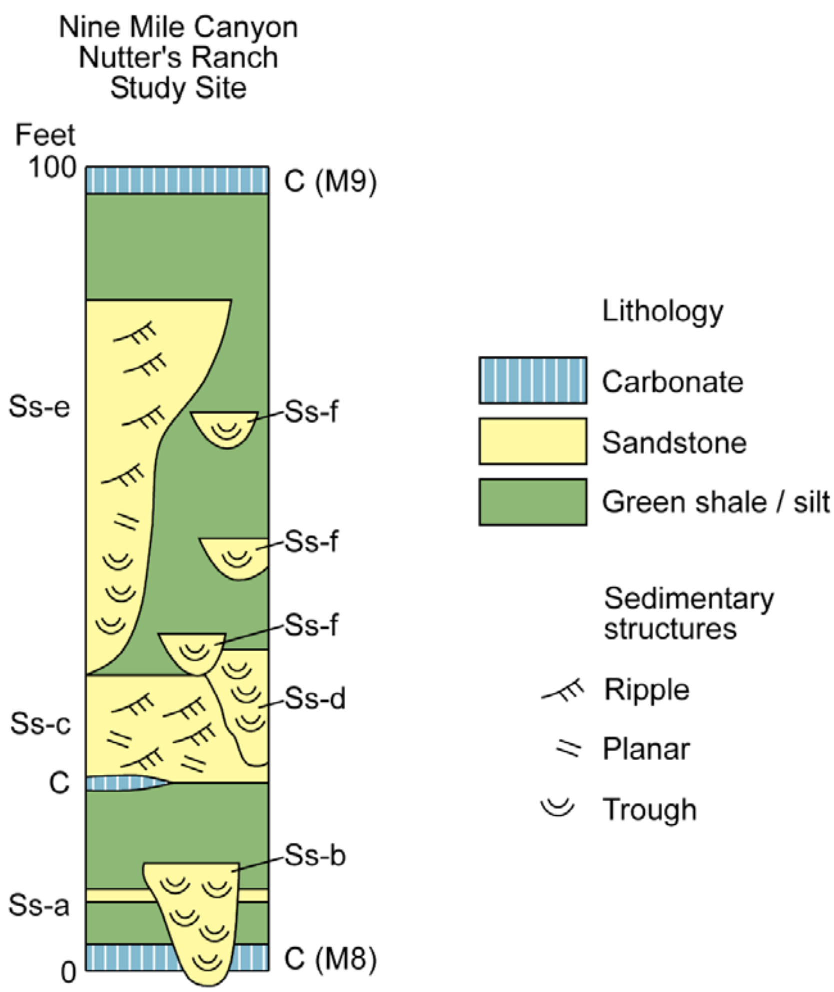

Figure 14. Composite vertical stratigraphic section of the Green River Formation, 100-foot depositional cycle in the Nutter's Ranch study site in Nine Mile Canyon. C = carbonate, Ss = sandstone.

Two-dimensional reservoir model of the Nutter's Ranch study site: Two imaginary wells along the Nine Mile Canyon portion of the Nutter's Ranch study site are shown 1,320 feet (400 m) apart to illustrate the type of reservoir heterogeneity that could exist between two wells drilled on 40-acre (16.2-ha) spacing units (figures 15 and 16). Both of the imaginary wells encounter a carbonate bed above (M9) and below (M8), and two reservoir-quality sandstone beds.

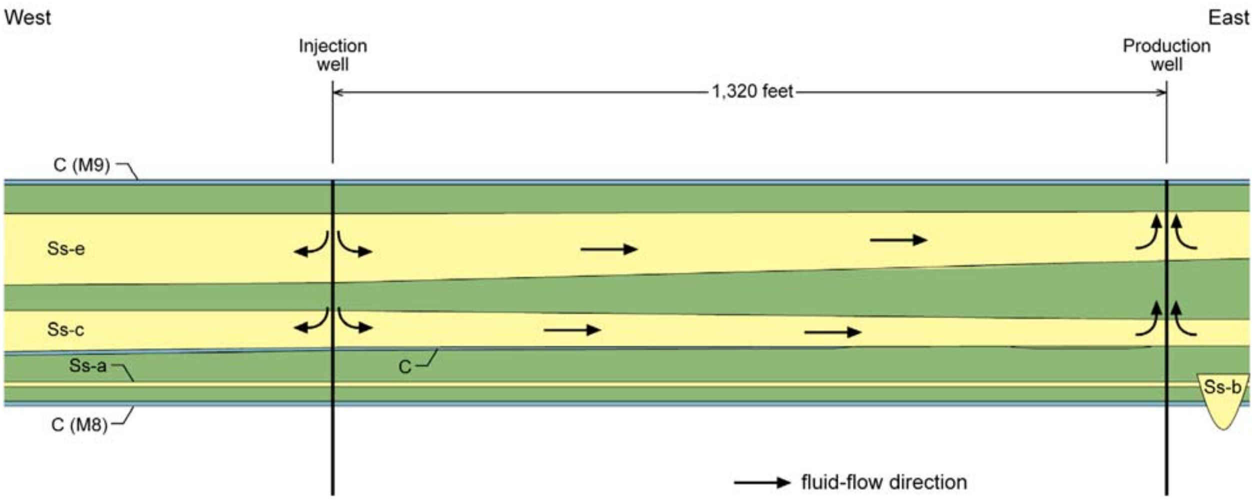

Figure 15. Hypothetical two-dimensional correlation and potential fluid-flow pattern between two imaginary wells "drilled" at the Nutter's Ranch study site. See figure 13 for location of cross section.

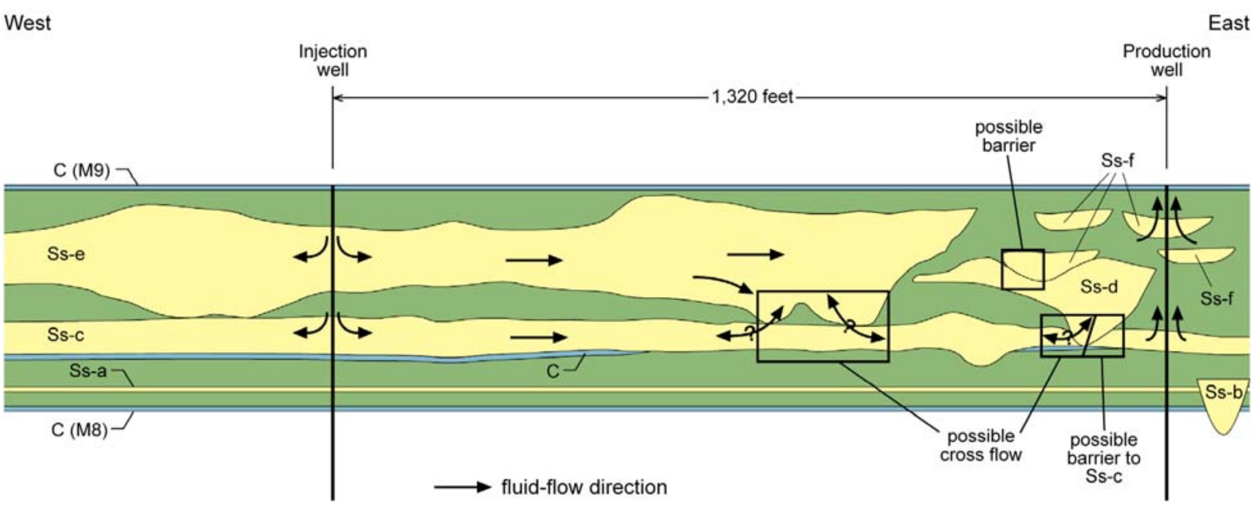

Figure 16**. **Actual two-dimensional correlation and potential fluid-flow pattern between the same two imaginary wells "drilled" at the Nutter's Ranch study site as in figure 15. The water-flood effectiveness and the "total oil produced" are much less than in the hypothetical model due to the reservoir heterogeneity. If a barrier exists between Ss-f and Ss-e, and a barrier exists between Ss-d and Ss-c, then oil in Ss-e and most of the oil in Ss-c will not be produced. Oil in Ss-d will also probably not be produced. The production "well" will only produce oil from Ss-f and a very limited amount of oil from Ss-c. See figure 13 for location of cross section.

Well logs could be interpreted to show excellent correlation of the carbonate and sandstone beds (figure 15). As a result, good lateral continuity of the sandstone beds would be expected. However, contrary to the interpretation in figure 15, the upper sandstone in the two wells is actually two separate deposits (Ss-e and Ss-f) that would probably have very poor to no fluid flow between them (figure 16). Ss-e is an amalgamated channel deposit that has good reservoir potential, but Ss-f is a crevasse splay deposit that has complex internal heterogeneity in the proximal channel facies and high clay content in the distal bar facies. As seen on outcrop, the lower sandstone (Ss-c) is the same bed in both of the wells, but has been locally cut out by the overlying channel sandstone (Ss-d). In some places Ss-e has incised down to Ss-c, creating a potential for fluid-flow communication between the two sandstone beds. Ss-d nearly cuts out Ss-c and is a potential reservoir that is not penetrated by either of the imaginary wells. Ss-a is laterally continuous but thin and has poor porosity and permeability due to abundant clay. Ss-b is a very narrow bed that would rarely be penetrated by a well with 40-acre (16.2-ha) spacing and would probably not have sufficient storage capacity to be an economical oil reservoir.

Three-dimensional reservoir model of the Nutter's Ranch study site: The thickness of the three potential reservoir sandstone beds (Ss-c, Ss-d, and Ss-e) was determined by direct measurement and by extrapolating between the measured sections using photomontages. The sandstone thickness values and associated Universal Transverse Mercator (UTM) coordinates were entered into an Arcview® database.

The section that contains the study site (section 32, T. 11 S., R. 15 E., SLBL) was divided into 40-acre (16.2-ha) lots, and the UTM coordinates for the center of each lot were determined and entered into the database as an oil well location with a well number (figure 17). Every other well was designated as a water injection well, the typical pattern for a water flood in the Monument Butte area. The imaginary wells in the two-dimensional model were located directly along the outcrop. The imaginary well locations for the three-dimensional model are the centers of 40-acre (16.2-ha) lots, and are not the same as the two-dimensional model imaginary well locations.

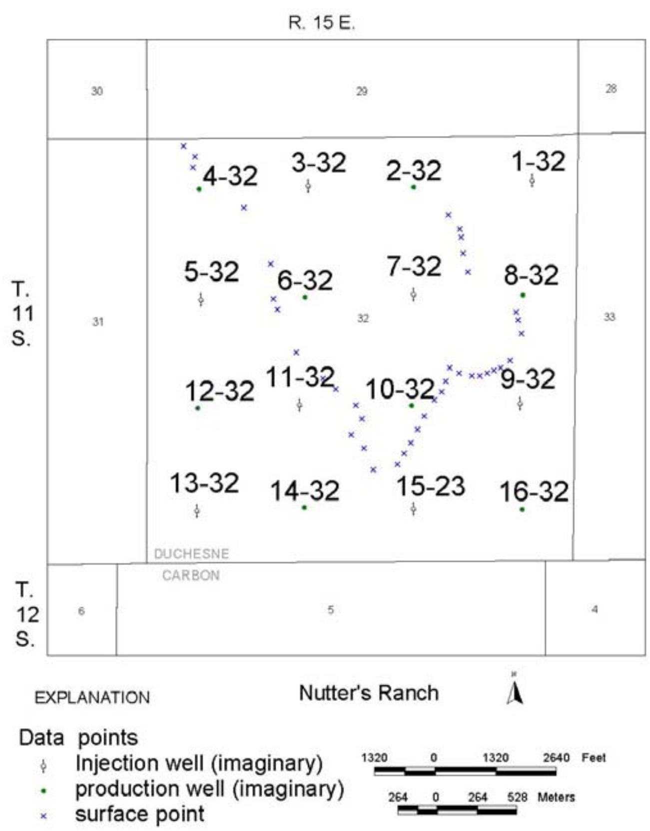

Figure 17. Map of the Nutter's Ranch study site with imaginary well locations in the center of 40-acre lots.

Sandstone thickness maps, based on the outcrop values, were constructed using Arcview Spatial Analyst® and by hand contouring. Sandstone thickness for each of the three beds was assigned to the imaginary wells based on the draft thickness maps and entered into the database. Final sandstone thickness maps for the three beds were generated using Arcview Spatial Analyst.

Ss-c (figure 18) is the most laterally extensive of the three potential reservoir beds. The bed is laterally extensive because it overlies a muddy limestone that it could not cut through, causing the channel to migrate back and forth resulting in laterally extensive deposits. The alternating pattern of producer well and injector well locations would have some success in this bed. However, the thickest portion of this bed, located in the northwest quarter of the section, is not penetrated and would be produced by wells on the flanks of the sandstone trend. Ss-d, which was shown in the two-dimensional model to nearly cut out Ss-c, isolates a portion of Ss-c in the center of the easternmost portion of the section.

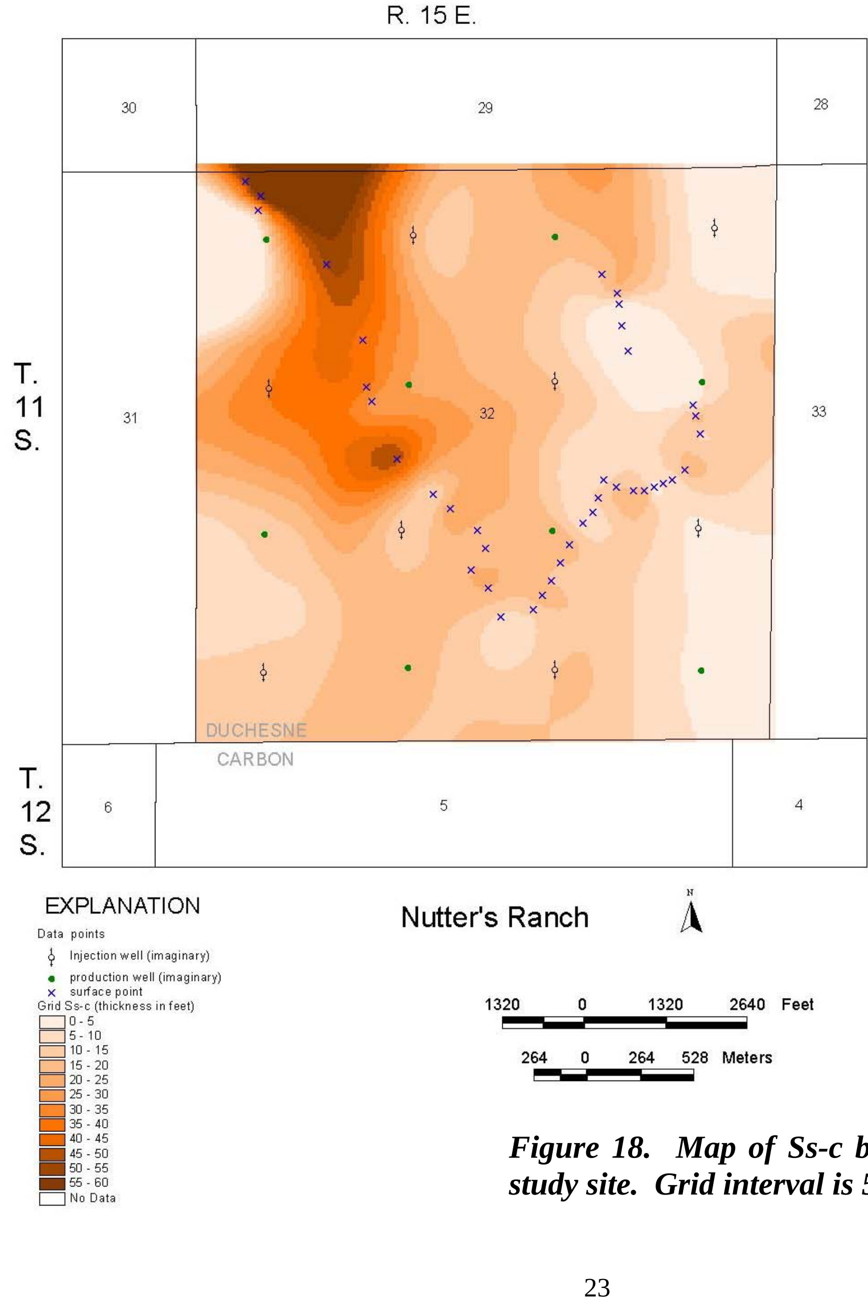

Figure 18. Map of Ss-c bed in the Nutter's Ranch study site. Grid interval is 5 feet.

Ss-d is narrow, has a very limited extent in the study area (figure 19), and would contain a very limited volume of oil. The 8-32 production well and the 9-32 injection well penetrate Ss-d, but not along the axis of the sandstone bed. As a result, only a small portion of the limited oil volume of Ss-d would be produced.

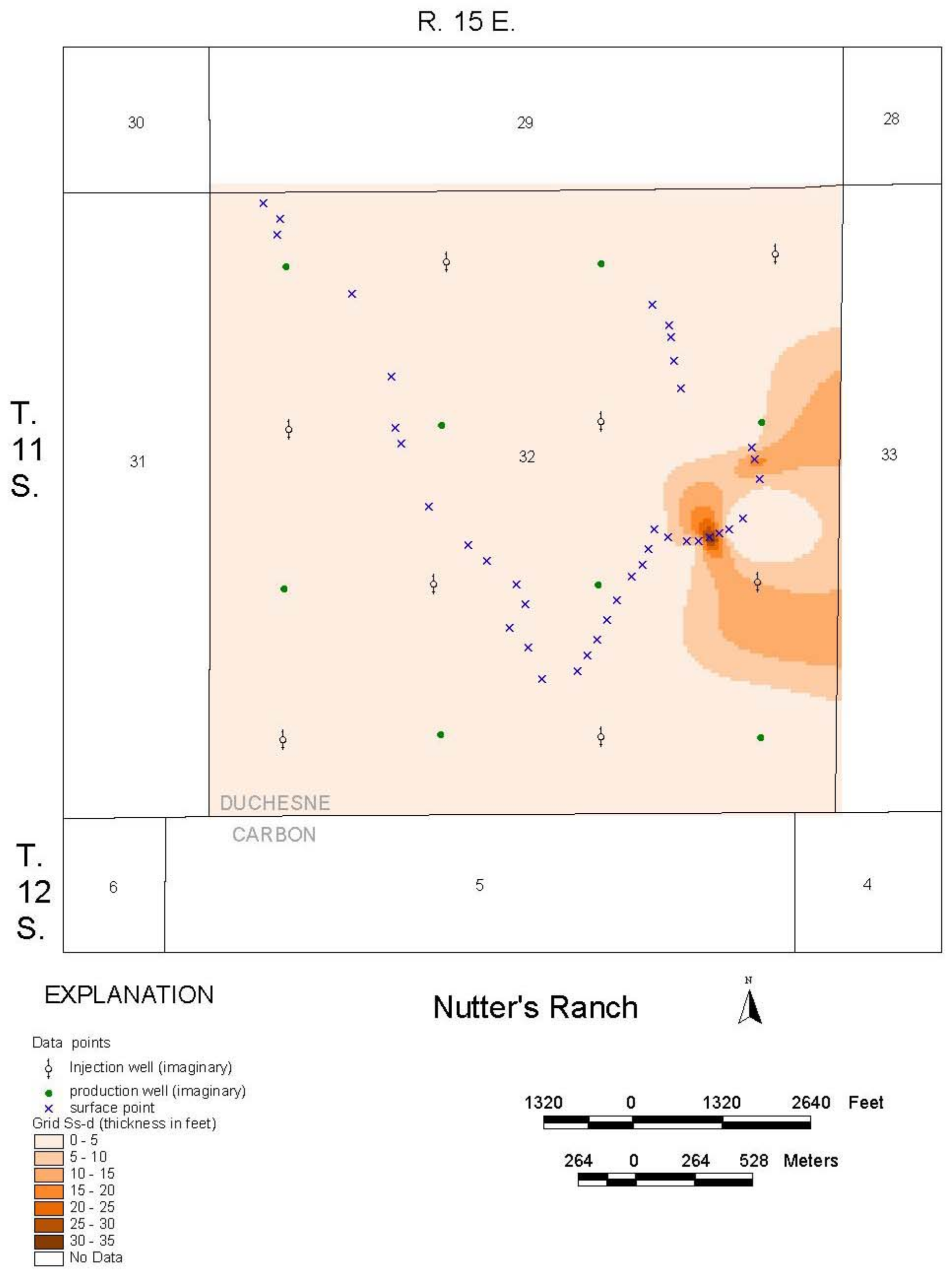

Figure 19. Map of Ss-d bed in the Nutter's Ranch study site. Grid interval is 5 feet.

Ss-e is moderately laterally extensive in the study site but is generally thicker, where present, than Ss-c (figure 20). The alternating pattern of production and injection wells appears to be moderately effective in Ss-e. Some of the thickest sandstone is between injection well 7-32 and production well 8-32. Production well 8-32 penetrates only 4 feet (1.2 m) of Ss-e; as a result, it would probably be a very poor producer because most of the oil contained in the thick sandstone between the two wells would remain in the ground.

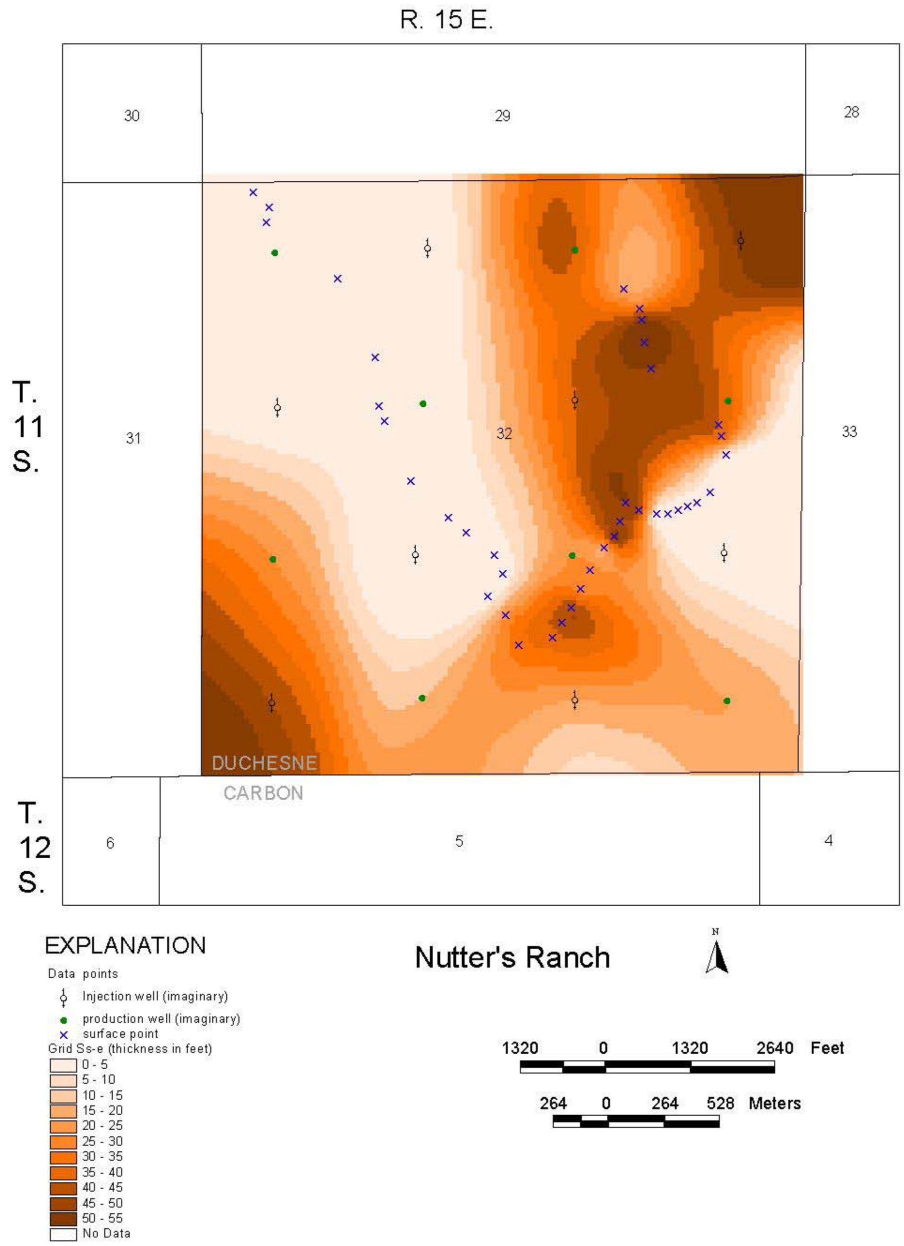

Figure 20. Map of Ss-e bed in the Nutter's Ranch study site. Grid interval is 5 feet.

Outcrop Analog for the Duchesne Interval Fractured Shale/Marlstone Subplay

The Duchesne interval is defined as from MGR 18 to the top of the Green River Formation, and includes the upper portion of the middle member and all of the upper and saline members. The interval represents the maximum rise and eventual waning stages of ancient Lake Uinta and is well exposed in Indian Canyon south of the town of Duchesne (figure 2). Fractures can be observed in the Green River Formation in Indian Canyon and throughout the surface exposures in the Duchesne field along the Duchesne fault zone. Any fractured outcrop in the upper and saline members can be considered a reservoir analog, but a person can take a hike to the abandoned wurtzillite mine in Indian Canyon to observe fractures containing hydrocarbons. Wurtzillite is a solid hydrocarbon that was mined from the saline member (?). The trail begins 16.1 miles (25.9 km) south on U.S. Highway 33 from the junction of U.S. Highway 33 and U.S. Highway 40 in the town of Duchesne, 0.4 miles (0.6 km) past the Forest Service sign.

TECHNOLOGY TRANSFER

The UGS is the Principal Investigator and prime contractor for the PUMPII project. All play maps, reports, databases, and other deliverables produced for the PUMPII project will be published as interactive, menu-driven digital (web-based and compact disc) and hard-copy formats by the Utah Geological Survey for presentation to the petroleum industry. Syntheses and highlights will be submitted to refereed journals, as appropriate, such as the *American Association of Petroleum Geologists (AAPG) Bulletin* and *Journal of Petroleum Technology*, and to trade publications such as the *Oil and Gas Journal*. An abstract was submitted to the AAPG on outcrop analogs for major oil reservoirs in Utah. If the paper is accepted, it will be presented during the 2004 AAPG annual national convention in Dallas, Texas. This information will also be released through the UGS periodical *Survey Notes* and on the UGS project Internet web page.

Survey Notes provides non-technical information on contemporary geologic topics, issues, events, and ongoing UGS projects to Utah's geologic community, educators, state and local officials and other decision makers, and the public. *Survey Notes* is published three times yearly. Single copies are distributed free of charge and reproduction (with recognition of source) is encouraged. The UGS maintains a web site on the Internet, http://geology.utah.gov. The UGS site includes a page under the heading *Utah Geology/Oil and Energy*, which describes the UGS/DOE cooperative studies (PUMPII, Paradox Basin [two projects], Ferron Sandstone, Bluebell field, Green River Formation), and has a link to the DOE web site. Each UGS/DOE cooperative study also has its own separate page on the UGS web site. The PUMPII project page, http://geology.utah.gov/emp/pump/index.htm, contains (1) a project location map, (2) a description of the project, (3) a reference list of all publications that are a direct result of the project, and (4) quarterly technical progress reports.

The technology-transfer plan included the formation of a Technical Advisory Board and a Stake Holders Board. The Technical Advisory Board advises the technical team on the direction of study, reviews technical progress, recommends changes and additions to the study, and provides data. The Technical Advisory Board is composed of field operators from the oil-producing provinces of Utah that may also extend into Wyoming or Colorado. This board ensures direct communication of the study methods and results to the operators. The Stake Holders Board is composed of groups that have a financial interest in the study area including representatives from the State of Utah (School and Institutional Trust Lands Administration and Utah Division of Oil, Gas and Mining) and the Federal Government (Bureau of Land Management and Bureau of Indian Affairs). The members of the Technical Advisory and Stake Holders Boards receive all quarterly technical reports and copies of all publications, and other material resulting from the study. They will also provide field and reservoir data, especially data pertaining to best practices.

CONCLUSIONS

- The USGS defines two assessment units within the Green River Total Petroleum System in the Uinta Basin: the Deep Uinta Overpressured Continuous Oil Assessment Unit and the Uinta Green River Conventional Oil and Gas Assessment Unit. We are currently evaluating plays and subplays in the Uinta Green River Conventional Oil and Gas Assessment Unit.

- The Conventional Oil and Gas Assessment Unit can be divided into plays having a dominantly southern sediment source (Conventional Southern Uinta Basin Play) and plays having a dominantly northern sediment source (Conventional Northern Uinta Basin Play).

- The Conventional Southern Uinta Basin Play is divided into six subplays: (1) conventional Uteland Butte interval, (2) conventional Castle Peak interval, (3) conventional Travis interval, (4) conventional Monument Butte interval, (5) conventional Beluga interval, and (6) conventional Duchesne interval fractured shale/ marlstone.

- Outcrop analogs for each subplay except the Travis interval are found in Indian and Nine Mile Canyons.

- We are currently conducting basin-wide correlations to: (1) define the boundaries of the six subplays, (2) define subplays in the Conventional Northern Uinta Basin Play, and (3) define plays and subplays in the Deep Overpressured Continuous Oil Assessment Unit.

ACKNOWLEDGMENTS

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Jim Parker and Vicky Clarke of the UGS prepared the figures. This report was reviewed by Dave Tabet and Mike Hylland of the UGS. Cheryl Gustin, UGS, formatted the manuscript.

REFERENCES

Abbott, W.O., 1957, Tertiary of the Uinta Basin, *in* Seal, O.G., editor, Guidebook to the geology of the Uinta Basin: Intermountain Association of Petroleum Geologists Eighth Annual Field Conference, p. 102-109.

Bradley, W.H., 1931, Origin and microfossils of the oil shale of the Green River Formation of Colorado and Utah: U.S. Geological Survey Professional Paper 168, 56 p.

Cashion, W.B., 1967, Geology and fuel resources of the Green River Formation, southeastern Uinta Basin, Utah and Colorado: U.S. Geological Survey Professional Paper 548, 48 p.

Colburn, J.A., Bereskin, S.R., McGinley, D.C., and Schiller, D.M., 1985, Lower Green River Formation in the Pleasant Valley producing area, Duchesne and Uintah Counties, Utah, *in* Picard, M.D., editor, Geology and energy resources, Uinta Basin, Utah: Utah Geological Association Publication 12, p. 177-186.

Crouch, B.W., Hackney, M.L., and Johnson, B.J., 2000, Sequence stratigraphy and reservoir character of lacustrine carbonates in the basal limestone member - lower Green River Formation (Eocene), Duchesne and Antelope Creek fields, Duchesne Co., Utah [abs.]: American Association of Petroleum Geologists Annual Convention, Official Program with Abstracts, v. 10, p. A34.

Dubiel, R.F., 2003, Geology, depositional models, and oil and gas assessment of the Green River total petroleum system, Uinta-Piceance province, eastern Utah and western Colorado, *in* U.S. Geological Survey Uinta-Piceance Assessment Team, compilers, Petroleum Systems and Geologic Assessment of Oil and Gas in the Uinta-Piceance province, Utah and Colorado: U.S. Geological Survey Digital Data Series DDS-69-B

Energy Information Administration, 2001, U.S. crude oil, natural gas, and natural gas liquids reserves – 2000 annual report: U.S. Department of Energy DOE/EIA-0216 (2000), p. 20.

Fouch, T.D., Nuccio, V.F., Anders, D.E., Rice D.D., Pitman, J.K., and Mast, R.F., 1994, Green River petroleum system, Uinta Basin, Utah, U.S.A., *in* Magoon, L.B., and Dow, W.G., editors, The petroleum system - from source to trap: American Association of Petroleum Geologists Memoir 60, p. 399-421.

Fouch, T.D., Nuccio, V.F., Osmond, J.C., MacMillan, Logan, Cashion, W.B., and Wandrey, C. J., 1992, Oil and gas in uppermost Cretaceous and Tertiary rock, Uinta Basin, Utah, *in* Fouch, T.D., Nuccio, V.F., and Chidsey, T.C., Jr., editors, Hydrocarbon and mineral resources of the Uinta Basin, Utah and Colorado: Utah Geological Association Publication 20, p. 9-47.

Franczyk, K.J., Fouch, T.D., Johnson, R.C., Molenaar, C.M., and Cobban, W.A., 1992, Cretaceous and Tertiary paleographic reconstructions for the Uinta-Piceance Basin study area, Colorado and Utah: U.S. Geological Survey Bulletin 1878-Q, 37 p.

Little, T.M., 1988, Depositional environments, petrology, and diagenesis of the basal limestone facies, Green River Formation (Eocene), Uinta Basin, Utah: Salt Lake City, University of Utah, M.S. thesis, 154 p.

Lutz, S.J., Nielson, D.L., and Lomax, J.D., 1994, Lacustrine turbidite deposits in the lower portion of the Green River Formation, Monument Butte field, Uinta Basin, Utah [abs.]: American Association of Petroleum Geologists Annual Convention, Official Program with Abstracts, v. 3, p. 203.

McDonald, R.E., 1972, Eocene and Paleocene rocks of the southern and central basins, *in* Mallory, W.W., editor, Geologic atlas of the Rocky Mountain region: Rocky Mountain Association of Geologists, p. 243-256.

Morgan, C.D., editor, 2003a, The Bluebell oil field, Uinta Basin, Duchesne and Uintah Counties, Utah - characterization and oil well demonstration: Utah Geological Survey Special Study 106, 95 p.

---2003b, Geologic guide and road logs of the Willow Creek, Indian, Soldier Creek, Nine Mile, Gate, and Desolation Canyons, Uinta Basin, Utah: Utah Geological Survey Open-File Report 407, 57 p., appendix.

Morgan, C.D., and Bereskin, S.R., 2003, Characterization of petroleum reservoirs in the Eocene Green River Formation, central Uinta Basin, Utah: Rocky Mountain Association of Geologists, Mountain Geologist, v. 40, no. 4, p. 111-127.

Morgan, C.D., Chidsey, T.C., Jr., Hanson, J.A., McClure, K.P., Weller, K., Bereskin, S.R., Deo, M.D., and Yeager, R., 1999, Reservoir characterization of the lower Green River Formation, southwest Uinta Basin, Utah: Utah Geological Survey, unpublished biannual technical progress report to the U.S. Department of Energy for the period 10/1/98 through 3/31/99, 11 p.

Morgan, C.D., Chidsey, T.C., Jr., McClure, K.P., Bereskin, S.R., and Deo, M.D., 2003, Reservoir characterization of the lower Green River Formation, southwest Uinta Basin, Utah: Utah Geological Survey Open-File Report 411, CD-ROM, 140 p.

Osmond, J.C., 1992, Greater Natural Buttes gas field, Uintah County, Utah, *in* Fouch, T.D., Nuccio, V.F., and Chidsey, T.C., Jr., editors, Hydrocarbon and mineral resources of the Uinta Basin, Utah and Colorado: Utah Geological Association Publication 20, p. 143-163.

Picard, M.D., 1955, Subsurface stratigraphy and lithology of the Green River Formation in Uinta Basin, Utah: American Association of Petroleum Geologists Bulletin, v. 39, no. 1, p. 75-102.

---1957, Green shale facies, lower Green River Formation, Utah: American Association of Petroleum Geologists Bulletin, v. 41, p. 2373-2376.

Remy, R.R., 1992, Stratigraphy of the Eocene part of the Green River Formation in the south-central part of the Uinta Basin, Utah: U.S. Geological Survey Bulletin 1787-BB, 79 p.

Ryder, R.T., Fouch, T.D., and Elison, J.H., 1976, Early Tertiary sedimentation in the western Uinta Basin, Utah: Geological Society of America Bulletin, v. 87, p. 496-512.

Schumn, S.A., and Ethridge, F.G., 1994, Origin, evolution and morphology of fluvial valleys, *in* Dalrymple, R.W., and Zaitlin, B.A., editors, Incised-valley systems - origin and sedimentary sequences: Society of Sedimentary Geology Special Publication no. 51, p. 11-27.

Szantat, A.W., 1990, Paleohydology and paleomorphology of early Eocene Green River channel sandstone, Uinta Basin, Utah: Fort Collins, Colorado State University, M.S. thesis, 109 p.

Utah Division of Oil, Gas and Mining, 2002, Oil and gas production report, December 2002: non-paginated.

---2003, Oil and gas production report, June 2003: non-paginated.

Weiss, M.P., Witkind, I.J., and Cashion, W.B., 1990, Geologic map of the Price 30’ X 60’ quadrangle, Carbon, Duchesne, Uintah, Utah, and Wasatch Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1981, 1:100,000.

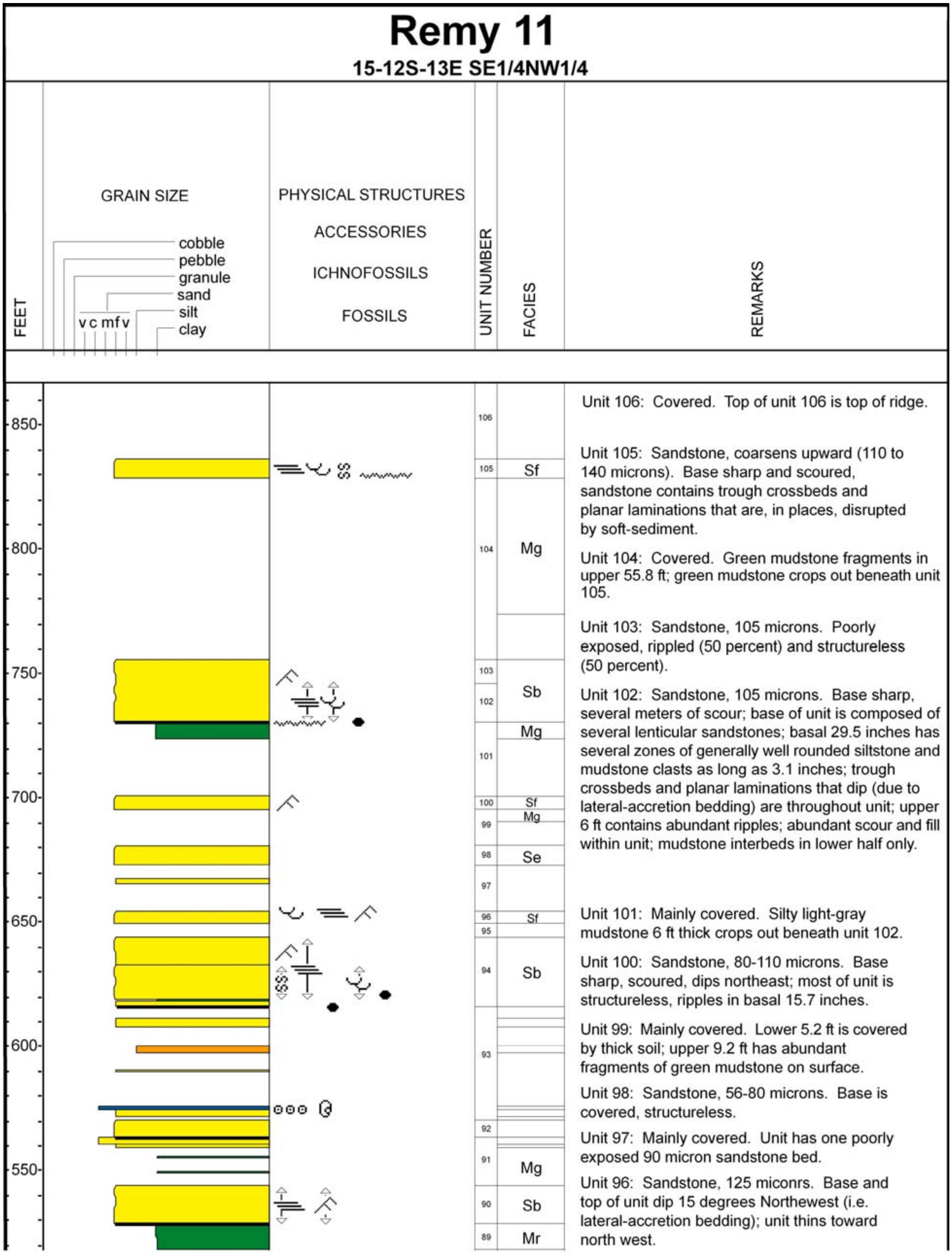
Wiggins, W.D., and Harris, P.M., 1994, Lithofacies depositional cycles, and stratigraphy of the lower Green River Formation, southwestern Uinta Basin, Utah, *in* Lomando, A.J., Schreiber, B.C., and Harris, P.M., editors, Lacustrine reservoirs and depositional systems: Society for Sedimentary Geology (SEPM) Core Workshop No. 19, p. 105-141.

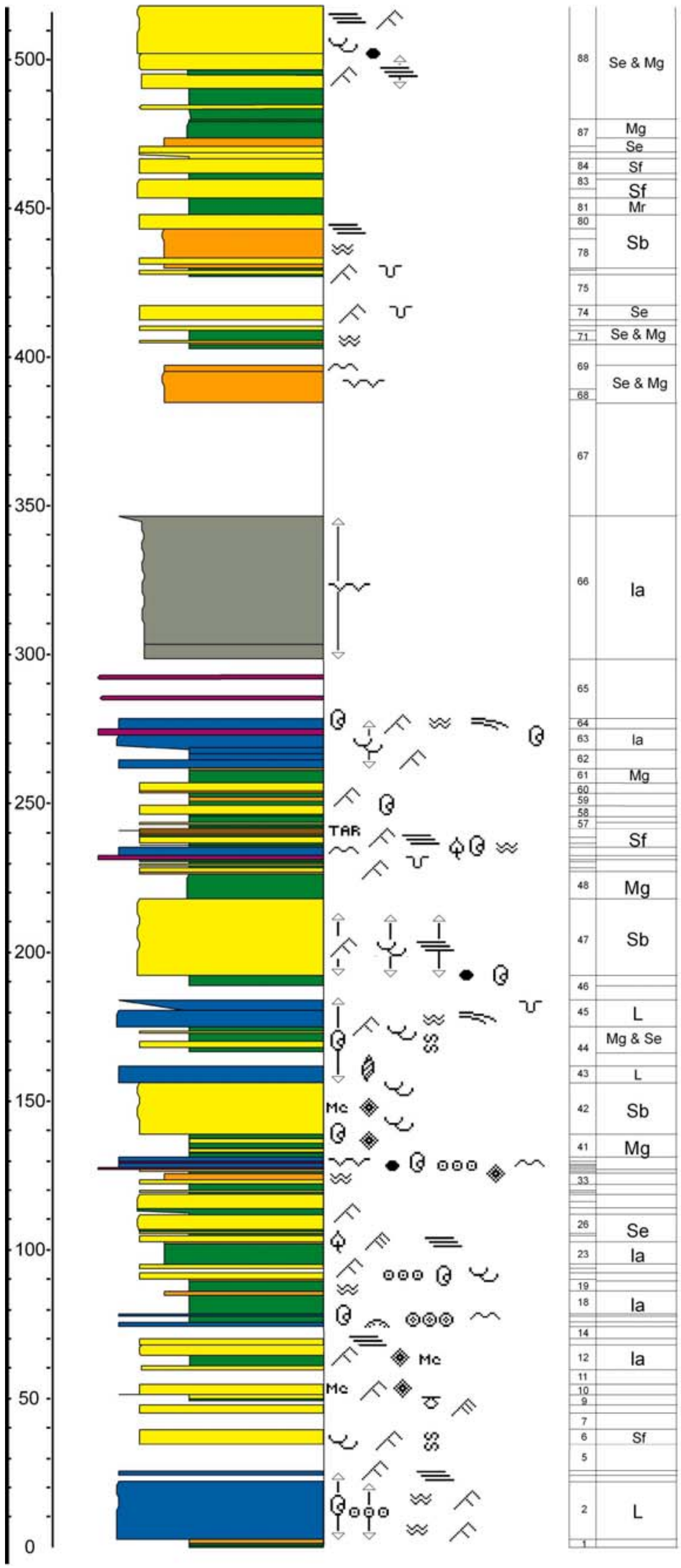
APPENDIX A

Stratigraphic Measured Section Remy 11

Section 15, T. 12 S., R. 13 E., SLBL

Modified from Remy, 1992


Remy 11
15-12S-13E SE1/4NW1/4
FEET
GRAIN SIZE
cobble
pebble
granule
sand
silt
clay
v c m f v
PHYSICAL STRUCTURES
ACCESSORIES
ICHNOFOSSILS
FOSSILS
UNIT NUMBER
FACIES
REMARKS
850
800
750
700
650
600
550
106
105
104
103
102
101
100
99
98
97
96
95
94
93
92
91
90
89
Sf
Mg
Sb
Mg
Sf
Mg
Se
Sf
Sb
Mg
Sb
Mr
Unit 106: Covered. Top of unit 106 is top of ridge.
Unit 105: Sandstone, coarsens upward (110 to 140 microns). Base sharp and scoured, sandstone contains trough crossbeds and planar laminations that are, in places, disrupted by soft-sediment.
Unit 104: Covered. Green mudstone fragments in upper 55.8 ft; green mudstone crops out beneath unit 105.
Unit 103: Sandstone, 105 microns. Poorly exposed, rippled (50 percent) and structureless (50 percent).
Unit 102: Sandstone, 105 microns. Base sharp, several meters of scour; base of unit is composed of several lenticular sandstones; basal 29.5 inches has several zones of generally well rounded siltstone and mudstone clasts as long as 3.1 inches; trough crossbeds and planar laminations that dip (due to lateral-accretion bedding) are throughout unit; upper 6 ft contains abundant ripples; abundant scour and fill within unit; mudstone interbeds in lower half only.
Unit 101: Mainly covered. Silty light-gray mudstone 6 ft thick crops out beneath unit 102.
Unit 100: Sandstone, 80-110 microns. Base sharp, scoured, dips northeast; most of unit is structureless, ripples in basal 15.7 inches.
Unit 99: Mainly covered. Lower 5.2 ft is covered by thick soil; upper 9.2 ft has abundant fragments of green mudstone on surface.
Unit 98: Sandstone, 56-80 microns. Base is covered, structureless.
Unit 97: Mainly covered. Unit has one poorly exposed 90 micron sandstone bed.
Unit 96: Sandstone, 125 miconrs. Base and top of unit dip 15 degrees Northewest (i.e. lateral-accretion bedding); unit thins toward north west.



Unit 95: Mainly covered. Friable, very fine grained sandstone crops out beneath unit 96.

Unit 94: Sandstone, 100-140 micron. 19.7-23.6 inches of scour (truncates siltstone and mudstone); Basal 19.7-23.6 inches is 140 micron sandstone containing mudstone clasts; 23.6-31.5 inches above base is mudstone; 2.6-16.7 ft is sandstone which has basal siltstone clasts as long as 3.9 inches; 16.7 ft to top. Beds of unit are hoizontal along measured section but 164-246 ft west same unit contains lateral-accretion beds that dip to northeast(sandstone beds are 6-9 ft thick and thin downdip, mudstone interbeds thicken downdip).

Unit 93: Covered (65 percent), minor sandstone, siltstone, and limestone.

Unit 92: Sandstone, coarsens upward (70 to 115 microns). Base sharp and flat, bed thickness 19.7-23.6 inches, small sand filled channel cuts top of unit, structureless.

Unit 91: Mainly covered. Several outcrops of green mudstone; 19.7-in-thick be of 70 micron sandstone; toward west unit is all sandstone.

Unit 90: Sandstone, 100-125 microns. Base is sharp and scoured; 80 percent structureless, 10 percent planar laminated, and 10 percent rippled; lenticular geometry, sandstone beds within unit dip 20 degrees North 5 degrees East (lateral accretion bedding).

Unit 89: Mudstone. Red, mainly covered.

Unit 88: Sandstone and mudstone. Complex sandstone body composed of three subunits: (1) Basal 9.8 ft is interbedded red and green mudstone (80 percent) and very fine grained sandstone (20 percent), bed thickness less than 9.8 inches, sandstones have sharp bases and tops, base of subunit flat; (2) 9.8 to 22 ft above base is interbedded sandstone (80 percent) and mudstone (20 percent), beds dip 35 degrees northeast (lateral accretion bedding), sandstone beds merge updip and truncate mudstones, sandstone are 80-110 microns, 50 percent structureless, 30 percent rippled, 20 percent planar laminations; (3) 22 ft to top is sandstone, fines upward (140 to 100 microns), mudstone clasts at base.

Unit 87: Siltstone and mudstone. Basal 2.3 ft is silstone; upper 6.6 ft is red mudstone overlain by 11.8-in-thick be of green mudstone.

Unit 86: Sandstone, 100 micron. Structureless.

Unit 85: Mudstone. Green, poorly exposed.

Unit 84: Sandstone, coarsens upward (65 to 90 microns).

Unit 83: Sandstone (67-70 microns). and green mudstone. Poorly exposed; lower half sandstone; upper half green mudstone.

Unit 82: Sandstone, coarsens upward (65 to 100 microns). Structureless.

Unit 45: Limestone. Ostracode grainstone; basal 3.3 ft contains wavy planar laminations that have low-angle truncations, trough crossbeds, and minor ripples; upper 6.9 ft is mainly structureless and contains few ripple foresets or wavy surfaces, burrows, and thin mudstone interbeds.

Unit 44: Mudstone and sandstone. Basal third covered; upper two-thirds green mudstone containing one 7.9-in-thick bed of rippled very fine grained sandstone and one 23.6-in-thick bed of 175 micron trough crossbedded sandstone containing ostracodes in places and some soft-sediment deformation.

Unit 43: Limestone. Ostracode grainstone, relatively abundant gastropods.

Unit 42: Sandstone, fines upward (175 to 135 microns) Base sharp and flat except one zone with 11.8-15.7 inches of scour; base contains 15-20 percent ostracodes; top 6.6 ft possible trough cross beds.

Unit 41: Interbedded mudstone (60 percent) and sandstone(40 percent). Basal 19.7 inches and upper 15.7 inches are mainly green mudstone; middle is interbedded green mudstone and very fine grained sandstone containing abundant fine-grained carbonaceous debris along some bedding planes, bed thickeness 3.9-5.9 inches.

Unit 40: Limestone. Ostracode grainstone.

Unit 39: Dolostone and limestone. Brown, kerogenous, laminated dolostone (oil shale) with very large mudcracks filled with ostracode grainstone.

Unit 38: Limestone. Clast-supported mix of ooids, ostracodes, and 0.004- to-0.6 inches long micrite intraclasts.

Unit 37: Limestone. Several beds of ostracode grainstone.

Unit 36: Dolostone. Medium brownish gray, structureless, very fine grained, weathers light green, abundant mudcracks filled with ostracodes.

Unit 35: Sandstone, 110 microns. Lower few centimeters contains carbonaceous debris in places; thinckens and thins.

Unit 34: Mudstone. Greenish gray, top conains carbonaceous debris.

Unit 33: Sandstone and siltstone. Lower half coarsens upward from 65 to 85 micron sandstone; upper half is fine to very coarse grained siltstone, lower 25.6 inches contains wavy planar laminations and wave ripples.

Unit 32: Mudstone. Greenish gray, similar to unit 30.

Unit 31: Sandstone, 125 microns.

Unit 30: Mudstone. greenish gray, moderately silty, moderately calcareous, typical mudstone weathering.

Unit 29: Sandstone, fines upward (150-125 microns). Unit thickens to west, contains scattered small hematite concretions.

Unit 28: Sandstone, less than 90 microns.

Unit 81: Mudstone. Poorly exposed; lihgt to medium grayish purple in lower 3.9 ft; green in upper 2 ft.

Unit 80: Sandstone, 65-70 microns. Structureless except for laminations at base, breaks into thin slabs.

Unit 79: Siltstone. Medium brownish gray, slightly calcareous, poorly exposed.

Unit 78: Siltstone and sandstone (80 microns). Basal 3.3 ft grades from siltstone to sandstone; upper 7.2 ft is siltstone, breaks into curving plates.

Unit 77: Mudstone. Green.

Unit 76: Sandstone. Base gradational from green mudstone through siltstone to 70-80 micron sandstone; 60 percent of unit is structureless, 40 percent ripples; vertical burrows, laterally persistent.

Unit 75: Covered. Green mudstone 7.9 inches thick at top.

Unit 74: Sandstone, fines upward (105 to 65 microns). Base gradational from very coarse grained siltstone to sandstone; 85-90 percent of unit structureless, 10-15 percent rippled; upper third of unit contains small concretions or burrows.

Unit 73: Covered. Green mudstone under soil.

Unit 72: Sandstone, 65-70 microns. Structureless, moderately calcareous.

Unit 71: Mudstone. Green, silty, poorly exposed.

Unit 70: Sandstone and siltstone. Base transitional from silty mudstone to siltstone to 95 micron sandstone; top of unit grades into siltstone that breaks to wavy plates.

Unit 69: Siltstone and mudstone, 50 percent covered. Base is medium-grained calcareous brownish-gray siltstone, large mudcracks; 6.6-8.5 ft is calcareous medium-gray siltstone, breaks into thin plates, some of which exhibit symmetrical undulations (wave ripples?); 8.5-14.8 ft is covered; 14.8 ft to top is silty greenish-gray mudstone.

Unit 68: Siltstone, very coarse grained. Calcareous, forms resistant ledge.

Unit 67: Mainly covered. Top of unit is 7.9-in-thick bed of coarse grained siltstone.

Note: At contact between units 66 and 67 there is a regional change in the weathered color of the rocks from light gray below to brown above.

Unit 66: Mudstone-siltstone. Moderately fissile, slightly to moderately calcareous silty mudstone-siltstone, variable colors; basal 10.2 ft is medium brown; 10.2-13.4 ft is light medium gray; 13.4-42.6 ft is medium brownish gray; 42.6 ft to top is light gray; mudcracks in places; 5.9-in-thick bed of 135 micron sandstone 4.9 ft above base.

Unit 27: Shale. Medium gray, slope forming, slightly silty, slightly calcareous.

Unit 26: Sandstone, variable grain size (70-140 microns).

Unit 25: Mudstone. Light olive gray, carbonized plant impressions and few very thin coal seams.

Unit 24: Sandstone, 100 microns. Basal 3.9 inches contains planar laminations and plant debris; upper 19.7 inches current ripples; few hematite concretions in upper 7.9 inches.

Unit 23: Shale and siltstone. Dark-gray, slightly calcareous shale, forms slope; upper 5.9 inches of unit is siltstone.

Unit 22: Sandstone, 70-80 microns. Truncates unit 21 and most of unit 20 northwest of measured section; unit 22 appears to dip to northwest(lateral accretion bedding).

Unit 21: Covered.

Unit 20: Sandstone, 70-150 microns. Basal 7.9 inches is one bed of 70 micron sandstone containing wavy planar laminations; upper 11.8 inches is 150-125 micron sandstone that fines upward, contains 15-20 percent ostracodes and ooids, scours 3.9 inches into underlying sandstone bed.

Unit 19: Shale and siltstone. Basal 3.3 ft is poorly exposed light-olive-gray, slightly calcareous shale; upper 15.7 inches is light-gray, medium-to-coarse-grained siltstone.

Unit 18: Shale and siltstone. Light-to medium-brownish-gray shale containing siltstone, coarsens upward; top 19.7 inches is thin bedded gray siltstone that contains wavy planar laminations.

Unit 17: Limestone. Yellow silty micrite, sparse to abundant ostracodes and ooids; upper 2 inches is wave rippled sandy ostracode and ooid grainstone.

Unit 16: Shale. Medium greenish gray, breaks into slabs a few millimeters thick.

Unit 15: Limestone. Basal 11.8 inches is medium-brownish-yellow limestone, contains some algal laminations; top 3.9 inches consists of small domal stromatolites.

Unit 14: Covered.

Unit 13: Sandstone, 80-135 microns. Indistinct planar laminations and ripples, organic matter in center of unit.

Unit 12: Interbedded shale and sandstone. Partly exposed unit consists of interbedded dark-gray, silty, fissile shale and rippled 90 micron sandstone; several sandstone beds contain hematite concretions.

Unit 11: Covered.

Unit 10: Sandstone, 75-110 microns. Basal 13.8 inches is 75 micron sandstone; 13.8-29.5 inches is 110 micron sandstone, abundant mica and organic matter along ripple -bedding planes; 29.5 inches to top is 110 micron sandstone, minor amounts of mica and organic matter.

Unit 9: Mainly covered. Dark-gray, silty mudstone and thin-bedded 65 micron sandstone that has sole marks, crop out beneath unit 10.

Unit 8: Sandstone, 115-125 microns. Partly exposed, base dips 26 degrees North and 60 degrees East.

Unit 7: Covered.

Unit 6: Sandstone, coarsens upwards (95 to 120 microns).

Unit 65: Dolostone. Poorly exposed, laminated, medium to dark brown, weathers into paper shale.

Unit 64: Limestone. Ostracode grainstone, most structureless, minor ripples and trough crossbeds in places, unit breaks into thin wavy slabs suggesting wavy planar laminations or HCS.

Unit 63: Dolostone and limestone. Basal 2 inches of unit is white limestone interbedded with ostracode grainstone; most of unit is laminated and kerogenous (oil shale), calcareous, medium brown, some ostracodes.

Unit 62: Limestone. Ostracode grainstone, bed thickness 3.9-15.7 inches, few thin greenish-gray mudstone and brown fissile shale interbeds; 70-80 percent structureless; 20-30 percent has trough crossbeds and ripples; one bed in center of unit contains coated ostracodes in top 2-3.9 inches.

Unit 61: Mudstone and siltstone. Greenish-gray to light-gray mudstone containing beds of light-gray medium-grained siltstone; upper 11.8 inches is all greenish gray mudstone.

Unit 60: Sandstone, 70-80 microns. Base sharp, rippled, few thin green mudstone interbeds near base.

Unit 59: Mudstone and siltstone. Mudstone-siltstone contacts are gradational.

Unit 58: Sandstone. Basal 25.6 inches grades upward from mudstone through siltstone to very fine grained sandstone; upper 17.7 inches fines upward (130 to100 micron), 0-10 percent ostracodes.

Unit 57: Mudstone, green.

Unit 56: Mudstone, siltstone, and sandstone. Grades upward from green mudstone through siltstone to 70-80 micron sandstone.

Unit 55: Sandstone, 80-100 microns, coarsens upward. Basal 25.6 inches contains planar laminations and ostracode limestone laminae (20 percent of interval); upper 3.1 ft contains a few ostracode limestone laminae and is rippled and tar saturated in places.

Unit 54: Interbedded siltstone, mudstone, and sandstone. Basal 1.2 inches is laminated siltstone; 1.2-4.3 inches is light-to-medium-gray calcareous mudstone; 4.3-5.9 inches is 65 microns sandstone; 5.9 inches to top is live gray to greenish gray mudstone.

Unit 53: Limestone. Basal 11.8 inches is ostracode grainstone that contains wavy planar laminations and few thin interbeds of grayish-brown, fissile dolostone, limestone bed thickness less than 3.9 inches, some beds have symmetrical undulatory bases; middle 11.8 inches is ostracode grainstone; top 7.9 inches consists of well-rounded carbonate grains, minor ostracodes.

Unit 52: Dolostone. Laminated and kerogenous (oil shale), grayish brown (5YR 3/2).

Unit 51: Sandstone, 65-70 microns.

Unit 50: Mudstone and sandstone. Poorly exposed green mudstone containing one 3.9-in-thick bed of very fine grained sandstone in center.

Unit 49: Sandstone, 65-70 microns. Basal 5.9 inches sturctureless; upper 9.8 inches rippled, few vertical burrows.

Unit 5: Mainly covered. Dark-gray siltstone crops out beneath unit 6; 23-26 feet west of measured section interval consists of lenticular sandstone.

Unit 4: Limestone. Mainly medium-grayish-brown micrite containing a few ostracodes; top 3.9 inches of unit is ostracode grainstone.

Unit 3: Covered.

Unit 2: Limestone. Composed of grain-supported ostracodes (80-90 percent) and ooids (10-20 percent); one bed contains minor chert nodules.

Unit 1: Mudstone, shale, ostracode grainstone, and sandstone.

Unit 48: Mudstone and siltstone. Mudstone dusky yellow green, poorly exposed; 7.9-in-thick bed of very coarse grained siltstone crops out beneath unit 49.

Unit 47: Sandstone, fines upward (160-90 microns). Basal 3.9 inches consists of matrix of 160 micron sand and angular mudsonte clasts as long as 3.9 inches, hematite-stained plant debris, muscovite, small yellow limestone fragments, and ostracodes; top 15.7 inches contains laminations that dip as much as 20 degrees toward 310 degrees (lateral accretion bedding?); unit is laterally persistent for at least 246 ft but appears to thicken and thin.

Unit 46: Interbedded green mudstone (65 percent) and sandstone-siltstone (35 percent). Lower half covered; sandstone is very fine grained; sandstone and siltstone beds have sharp bases and tops and are less than 3.9 inches thick; mudstone is moderatley to very silty and calcareous.

LEGEND

LITHOLOGY

Sandstone

Siltstone

Mudstone/Shale

Coal

Mudstone-Siltstone

Covered

Limestone

Dolostone

CONTACTS

Sharp

PHYSICAL STRUCTURES

- Trough Cross-Strat.
- Mud Cracks
- Ripples, Unknown
- Wavy Planar Laminations
- Planar Lamination
- Load Casts
- Wave Ripples
- Intraformational Conglomerate (IFC)
- Hummocky Cross-Strat.
- Soft Sediment Deformation
- Current Ripples
- Scour

LITHOLOGIC ACCESSORIES

Mc - Micaceous

TAR - Tar

- Oolitic
- Pisolites

ICHNOFOSSILS

- Vertical Burrows

FOSSILS

- Stromatolite, Domal
- Plant Remains
- Gastropods
- Carbonate Debris
- Ostracods

APPENDIX B

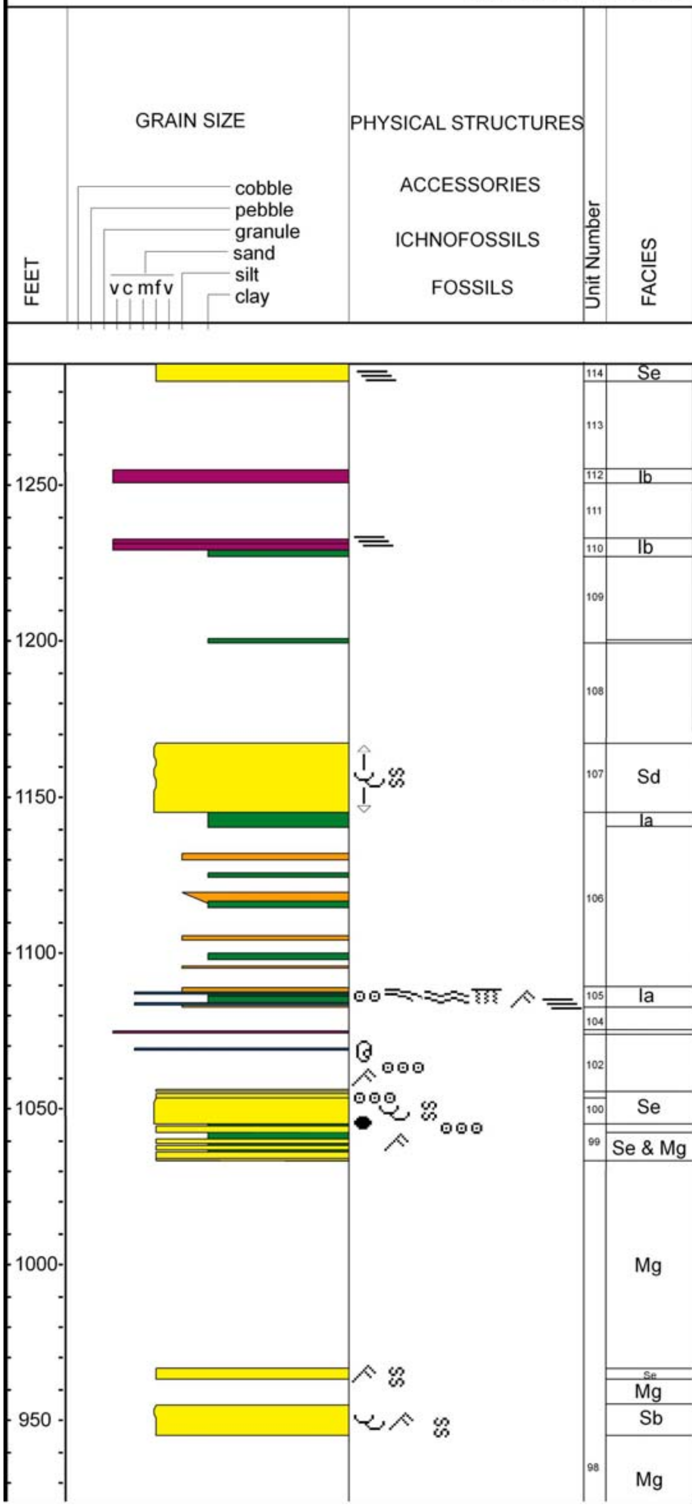
Stratigraphic Measured Section Remy 7

Section 32, T. 11 S., R. 15 E., SLBL

Modified from Remy, 1992

Remy 7

32-11S-15E NE1/4SE1/4



REMARKS

Unit 114: Sandstone, fines upward (280-170 microns). Planar laminations with parting lineations.

Unit 113: Covered.

Unit 112: Dolostone. Laminated and kerogenous (oil shale), upper half weathers to paper shale.

Unit 111: Covered.

Unit 110: Mudstone and dolostone. Basal 23.6 in is yellowish-brown mudstone; 23.6-51.2 in is laminated, kerogenous dolostone (oil shale); 51.2 in to top is laminated dolostone. All three subunits contain streaks of yellow silty rock (tuff?).

Unit 109: Mainly covered: 9.8 in thick bed of light brown calcareous mudstone grading into kerogenous dolostone (oil shale) at base.

Unit 108: Covered interval.

Unit 107: Sandstone, 175-300 microns. Base sharp and scours 7.9 in into underlying mudstone; well exposed large-scale trough crossbeds, some are oversteepened.

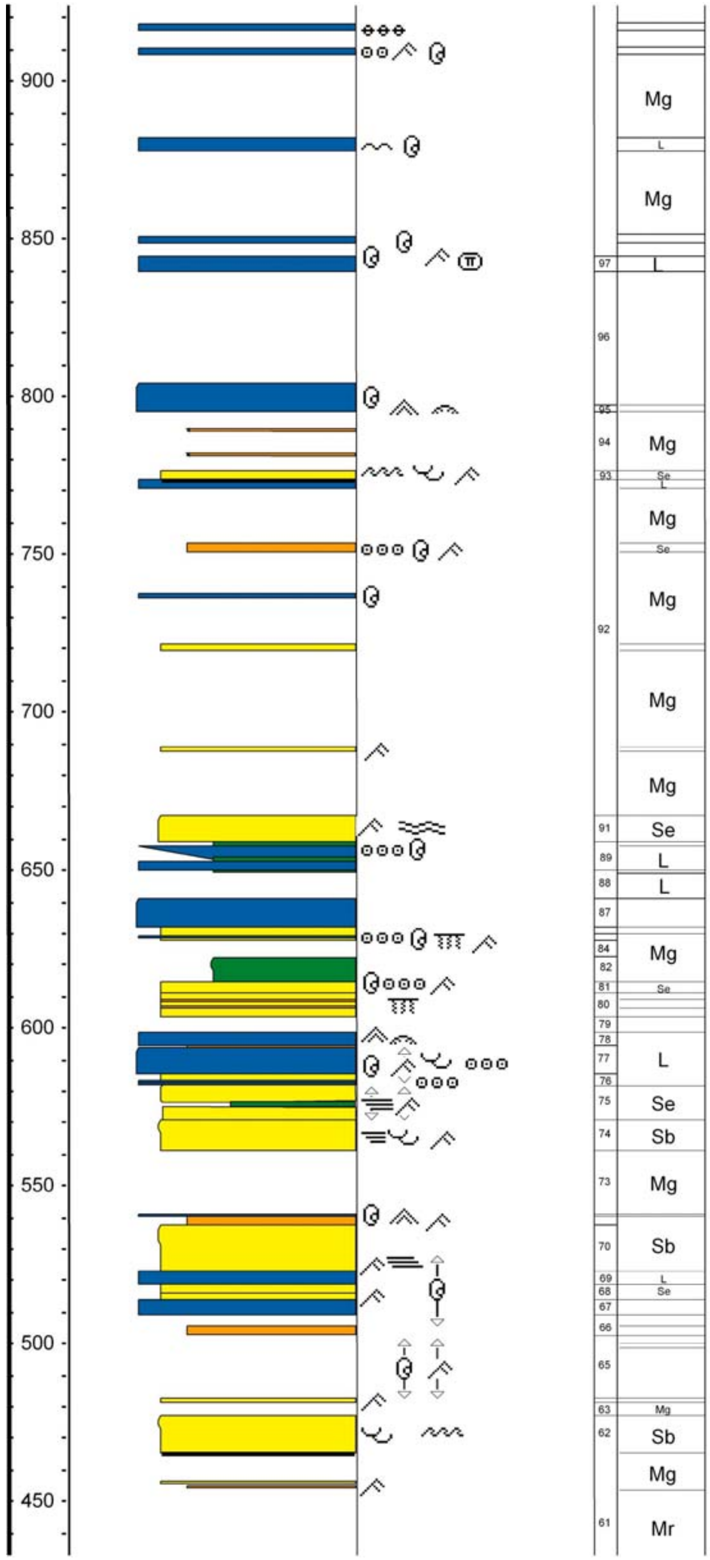
Unit 106: Mainly covered. Light-gray soil, few thin outcrops of calcareous, coarse grained siltstone and medium brown calcareous mudstone; brown laminated mudstone crops out beneath unit 107.

Unit 105: Interbedded siltstone, mudstone, limestone and sandstone. Basal 6.3 in is coarse grained siltstone; 6.3-10.6 in is covered; 10.6-40.6 in is light gray-olive is massive calcareous mudstone grading up to silty mudstone;40.6-51.2 in is calcareous coarse grained siltstone; 51.2 in to top is sandy limestone.

Unit 104: Covered slope.

Unit 103: Dolostone. Laminated and kerogenous (oil shale), light bluish gray weathered color, very dark gray fresh color, slight oily smell.

Unit 102: Mainly covered. 3 thin outcrops: Base consists of thin lenticular sandstone, rippled, 125 microns; middle 90 micron sandstone containing minor ooids and ostracodes; top is ostracodal grainstone with coated carbonate grains.



Unit 101: Sandstone, seperated into 3 beds by covered slope. Basal bed 5.9 in thick, ooids; middle bed 7.9 in thick; top bed 3.1in thick. All beds have poorly exposed ripples.

Unit 100: Sandstone, fines upward. Base is sharp and dips 5 degrees to N.30E. Truncates unit 99, usually lacks lag deposits, but locally can contain large (11.8 by 5.9 by 5.9in) limestone blocks. Mudstone interbeds near top.

Unit 99: Interbedded green mudstone, sandstone, siltstone and limestone. Bed thickness less than 31.5 in, siltstone coarse and rippled, in places top 13.8 in is a bed of ooid grainstone.

Unit 98: Poorly exposed interval. 3.6 feet above base is ostracodal grainstone. At 877.7 feet there is a 4.9 foot bed of silty micrite which contains green mudstone partings and thin interbeds. At 908.9 and 915.4 feet there are two thin beds of rippled ostracodal limestone and a bed of limestone containing coated carbonate grains, respectively. Two small sandstone beds between 944.9 feet and 967.9 feet.

Unit 97: Limestone. Base is very light gray micrite; middle is rippled ostracodal grainstone containing minor intraclasts and fish scales; top is ostracodal grainstone.

Unit 96: Mainly covered. Slope covered with soil and talus; few thin outcrops of ostracode limestone near base.

Unit 95: Limestone.

Unit 94: Mostly covered. Scattered fragments of green mudstone and a few very thin outcrops of siltstone.

Unit 93: Sandstone, fines upward (140 to 125 microns).

Unit 92: Mainly covered. Abundant fragments of green mudstone. Some beds of limestone, siltstone and sandstone.

Unit 91: Sandstone, 110-135 microns. Base sharp and flat, well-exposed ripples throughout.

Unit 89: Limestone, mudstone and sandstone.

Unit 88: Mainly covered. Green mudstone crops out beneath unit 89.

Unit 87: Limestone (?). Silty micrite (?), fine-grained to moderately silty, very calcareous.

Unit 86: Sandstone, 140 microns. Structureless.

Unit 85: Lower two-thirds is 140 micron sandstone, bed thickness less than 0.8 in. Upper one-third limestone.

Unit 84: Mainly covered. Abundant green mudstone fragments and green mudstone beneath unit 85.

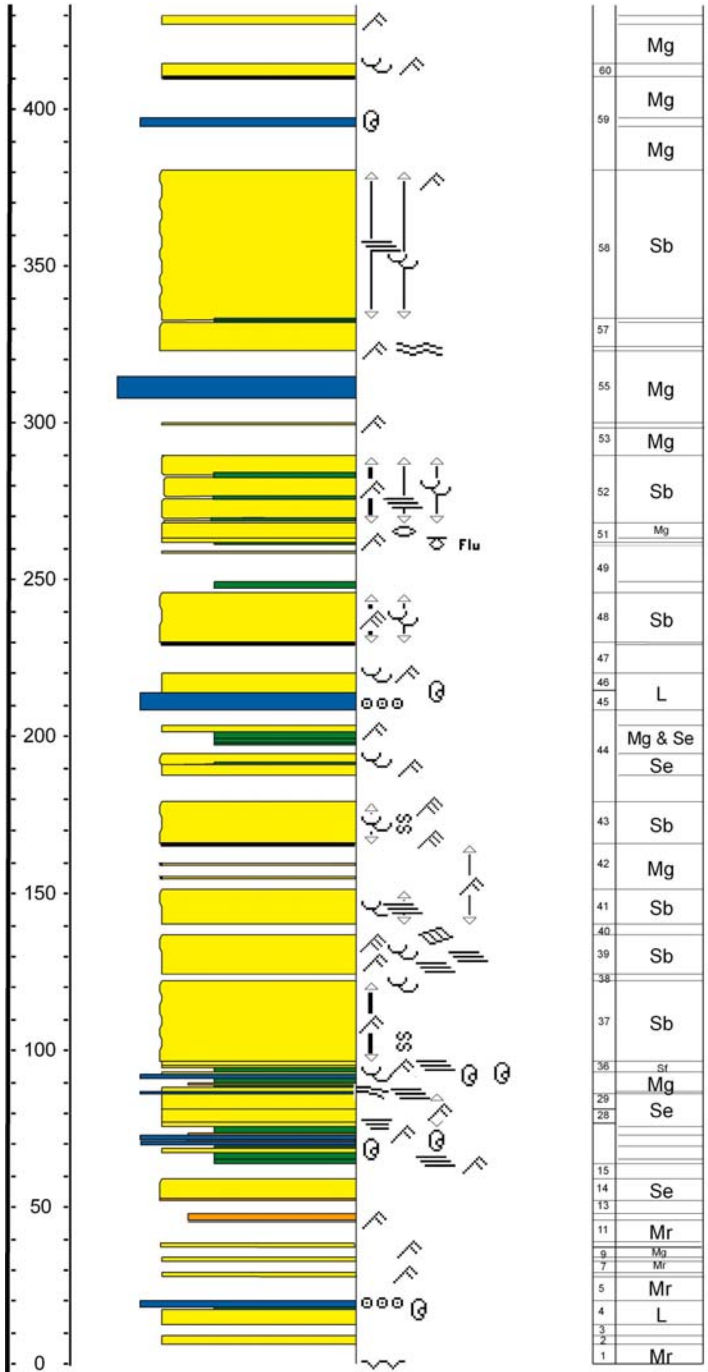
Unit 83: Sandstone, 100 microns.

Unit 82: Mudstone. Greenish gray, poorly exposed.

Unit 81: Sandstone, mainly 150 microns, top 7.9 in is 80 microns. Mostly structureless, except ripples(?) in top 7.9 in.

Unit 80: Interbedded sandstone (< 100 microns), siltstone and green mudstone

Unit 79: Covered.



Unit 34: Mudstone. Greenish gray, ostracodes in places, weathers into small angular fragments.

Unit 33: Siltstone, coarse-grained. Structureless.

Unit 32: Mudstone, Green.

Unit 78: Limestone. Lower half consists of large (up to 23.6 in) domal stromatolites; upper half consists of pillar-type stromatolites.

Unit 77: Limestone. Mainly ostracode grainstone. Top 11.8 in is siltstone containing ostracodes.

Unit 76: Limestone, siltstone and sandstone. Overall unit coarsens upward.

Unit75: Interbedded sandstone (<100 microns) and green mudstone.

Unit 74: Sandstone, 90-125 microns. Base dips 15 degrees WNW; ripples and planar laminations with low-angle truncations and minor trough cross beds.

Unit 73: Covered. Abundant green mudstone fragments and green mudstone beneath unit 74.

Unit 72: Limestone. Ostracode grainstone, small pillar-type stromatolites at base.

Unit 71: Siltstone, coarse-grained. Poorly exposed.

Unit 70: Sandstone, fines upward (160-110 microns). Scours all of unit 69 and part of unit 68 in places. Consists of two subunits: (1) basal lag deposit 0 to few feet thick, small to large angular framents of limestone from unit 69, IFC as multiple lenses, matrix of well-sorted 160 micron sand, planar laminations with low-angle truncations and ripples; (2) upper zone of 120-110- micron sandstone, 6.6 to 13.1 feet thick, lateral-accretion bedding cuts through subunit 1 and into unit 68 downdip, multiple internal scours and ripples (wave?), thin green mudstone interbed and thin IFC lens at top.

Unit 69: Limestone. Basal 3.3 feet is ostracode grainstone; top 15.9 in is silty micrite (?) containing ostracodes.

Unit 68: Sandstone and Siltstone. Basal 23.6 in is rippled sandstone (100-130 microns); Top 3.3 feet is interbedded sandstone and siltstone.

Unit 67: Mainly covered. Similar to unit 65.

Unit 66: Upper half mainly ostracode grainstone and lower half mainly thin bedded siltstone.

Unit 65: Mainly covered. Numerous thin outcrops of rippled siltstone and ostracode limestone.

Unit 64: Sandstone, 90 microns. Sparse to abundant clasts in upper half.

Unit 63: Covered. Abundant green mudstone fragments.

Unit 62: Sandstone, fines upward (190-125 microns). 19.7 in of basal scour; some troughs have oversteepened crossbeds. Sedimentary structures are not well exposed.

Unit 61: Mainly covered. Thick soil and abundant float. A few beds sandstone, siltstone and mudstone.

Unit 60: Sandstone, 125-155 microns.

Unit 59: Mainly covered. Thick soil and abundant talus; two beds of ostracode limestone and micrite; friable very fine grained sandstone at top.

Unit 31: Sandstone, 110 microns. Sharp base, poorly exposed.

Unit 30: Upper third consists of interbedded sandstone (<130 microns) and limestone.

Unit 30: Limestone. Mainly ostracode grainstone, base sharp, 3.9 in basal scour; contains ripples, planar laminations, and hummocky cross-stratification; limestone is sandy, amount of sand increases upward; upper third of unit consists of interbedded sandstone (<130 microns) and limestone.

Unit 29: Sandstone, 115 microns. Base sharp, 1.9-2.4 in of basal scour, top sharp, rippled (type unknown).

Unit 28: Sandstone. Four beds (base to top). (1) 3.9 in, structureless, 110 microns, (2) 1.9 in, structureless, 110 microns, (3) 21.7 in, 100 micron sandstone that grades through siltstone to 1.9 in of green mudstone, structureless, (4) 15.7 in, 150 micron sandstone at base, most is 70 micron, rippled at top.

Unit 27: Mudstone, fine-grained. Greenish gray, slightly calcareous.

Unit 26: Sandstone, fines upward (130 to 70 microns). Unknown ripples and unknown planar laminations, top sharp.

Unit 25: Interbedded mudstone and siltstone.

Unit 24: Siltstone. Relatively sharp base and top.

Unit 23: Limestone. Dark-gray micrite containing ostracodes.

Unit 22: Siltstone. Gradational with unit 21, sharp top, contains ostracodes.

Unit 21: Limestone. Ostracode grainstone.

Unit 20: Mudstone. Green, poorly exposed.

Unit 19: Sandstone, 100 microns. Sharp base, unknown wave ripples.

Unit 18: Mudstone, greenish-gray

Unit 17: Limestone. Mainly ostracode grainstone, base sharp and slightly scoured, top sharp; 3.9-13.8 in above base thin siltstone interbeds; 7.9-13.8 in above base horizontally laminated; top 5.9 in mainly structureless, faint ripples in places.

Unit 15: Mostly covered. Beneath unit 16 is green mudstone overlain by 5.9-in-thick bed of silty limestone or very calcarous siltstone.

Unit 14: Sandstone, 90 microns. Wave ripples, burrows on some bedding planes.

Unit 13: Mainly covered, top 13.8 in is friable 65 micron sandstone that grades into unit 14. Sandstone is massive and structureless.

Unit 12: Siltstone, coarse-grained. Base gradational over 3.9 in with underlying red mustone, rippled (?).

Unit 11: Covered. Red mudstone crops out beneath unit 12.

Unit 10: Base and top sharp and irregular (0-1.9 in of relief), faint ripples. 100 microns.

Unit 58: Sandstone, most of unit is 120-150 microns, upper 6.6 feet is 110 microns. Probably composite amalgamated sandbody containing scattered internal IFC zones and mulitple internal scoured sandstone-sandstone and sandstone-mudstone contacts. Most of unit contains planar laminations with low-angle truncations, few log impressions; basal 9.8 ft exhibit lateral-accreation bedding, beds dip northeast.

Unit 57: Mainly covered. Top 19.7 in is interbedded sandstone, siltstone and mudstone.

Unit 56: Sandstone, 70-150 microns.

Unit 55: Covered. Green soil and green mudstone chips suggests unit is green mudstone.

Unit 54: Sandstone, 100 microns.

Unit 53: Covered. Green soil and green mudstone fragments suggests unit consists of greenish-gray mudstone.

Unit 52: Sandstone, 100-110 microns. Few thin mudstone interbeds. Numerous stacked and mutually truncating lenticular 32.8-49.2 ft sandbodies.

Unit 51: Interbedded Sandstone (65 microns) and mudstone. Bed thickness 7.9 in or less.

Unit 50: Sandstone, 100 microns. Base contains sole marks, load structures, and tool marks or flutes.

Unit 49: Mainly covered. A couple mudstone beds and a thin bed of fine-grained sandstone.

Unit 48: Sandstone, coarsens upward (65 to 110 microns).

Unit 47: Mainly covered. One 7.9 in thick bed of 90 micron sandstone and mudstone.

Unit 46: Sandstone, 100-120 microns. Complex interlensing of sandstone and lesser ostracode limestone and limestone with limestone intraclasts. Individual beds are discontinuous. Unit thickens to the east.

Unit 45: Limestone. Basal 7.9 in is sandy ostrocode grainstone, most of unit is a dark-yellowish-orange micrite.

Unit 44: Partly exposed interval of sandstone, mudstone, and siltstone. Interval is 60 percent covered.

Unit 43: Sandstone, 120-130 microns. Unit contains large scale trough crossbeds and soft sediment deformation.

Unit 42: Mostly covered. Four to five thin outcrops of fine-grained rippled sandstone.

Unit 41: Sandstone, 120-130 microns.

Unit 40: Covered. Greenish-gray mudstone and fissile medium-grained siltstone beneath the soil.

Unit 39: Sandstone 110-150 microns. Basal 31.5 in contains planar laminations that have parting lineations; 31.5 in to 5.7 ft contains trough crossbeds, ripples, and some planar lamination; upper 6.39 ft contains trough crossbeds, 3-D current ripples and some climbing ripples.

Unit 9: Covered. Green mudstone crops out beneath unit 10.

Unit 8: Well exposed wave ripples (wave ripples have chevrons, bidirectional cross laminations, bundled upbuilding, and irregular and undulatory ripple-set boundaries). 90 microns.

Unit 7: Covered. Red soil suggests red mudstone.

Unit 6: Rippled , base fairly sharp, breaks into thin wavy plates. 65 microns.

Unit 5: Deep soil, red musstone cropping out beneath unit 6 and red color of soil suggest unit is red mudstone.

Unit 4: Interbedded limestone, sandstone and mudstone.

Unit 3: Covered. Some green mudstone fragments on surface.

Unit 2: Base grades upward to finer grained sandstone. 100 microns.

Unit 1: Covered. Fragments of mudcracked red mudstone at base.

Unit 38: Mainly covered. Unit forms bench between ledges formed by units 37 and 39.

Unit 37: Sandstone, 100-160 microns. Base sharp, tool marks and load structures; massive except one distinct 7.9 in bed about 6.6 feet above base that contains soft-sediment deforamation and one distinct 9.8 in bed at top that contains ripples and few cross beds.

Unit 36: Interbedded mudstone, sandstone and ostracode limestone. Beds are lenticular and contain local concentrations of carbonized wood or small clasts of sandstone and limestone.

Unit 35: Limestone and sandstone. Sandy limestone grades upward to 65 micron sandstone; trough crossbeds or scours througthout; linguoid ripples at top of unit. Unit grades laterally into interval consisting of complex mix of sand and ostracodes having no vertical trends.

LEGEND

LITHOLOGY

Sandstone | Mudstone/Shale | Covered Slope | Dolostone

Siltstone | Limestone

CONTACTS

Sharp

PHYSICAL STRUCTURES

- Trough Cross-strat.
- Wavy Laminations
- Convolute Bedding
- Load Casts
- Ripples
- Wave Ripples
- Climbing Ripples
- Lenticular Bedding
- Mud Cracks
- Flu - Flute Casts
- Current Ripples
- Planar Lamination
- Hummocky Cross-strat.
- Synaeresis Cracks
- Soft sediment deformation
- Intraformational Conglomerate (IFC)

LITHOLOGIC ACCESSORIES

- Oolitic
- Coated Grains

FOSSILS

- Algal Stromatolite
- Fish Scales
- Ostracods
- Pillar-Type Stromatolite