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**ANALYSIS OF LITHOFACIES, PETROLOGY/PETROGRAPHY, AND
POROSITY/PERMEABILITY OF THE LOWER GREEN RIVER FORMATION:
WILLOW CREEK**

An Initial Report

by

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PREFACE

The data from this report have not been fully interpreted. There are several items relative to deposition facies interpretations and reservoir quality studies that are not as yet accomplished.

Stratigraphic Section:

The 849.16 meter stratigraphic section was measured during consecutive spring field seasons and involved 14 senior level undergraduate students, 4 graduate students, and three members of the project. This section represents the "lower" Green River Formation which on the southwest flank of the basin rests stratigraphically above the dominant red beds of the Colton Member of the Green River Formation. The transition from Colton rocks to Green River rocks is gradual in the study area.

Although every effort was made to be consistent in naming lithology in the field, there is probably some inherent variation, due to the number of people involved in collecting the data. For example, a common lithology in the field was one that contains an appreciable amount of silt and would "fizz" when sprinkled with dilute HCl. Depending upon the amount of silt in the sample and the experience of the evaluator, one might call the rock a "limy siltstone" whereas the next person might call it a "silty limestone". For this reason we have made thin sections of these rock types. Obviously the thin sections, where taken, should be used as the most accurate lithologic name.

The section was recorded on an Apple IIsi computer using a software program called AppleCore. This user friendly and efficient program was written by a geologist named Mike Ranger from Calgary, Alberta. The enclosed disk is PC formatted and includes an ASCII file called GreenRiv.ASC.

Petrology/Petrography:

Petrographic classification and textural analysis has been completed on 33 thin sections. These thin sections represent the volumetric majority of rock types in the measured section as well as a few less common but very interesting lithofacies. All sand-dominated clastic rocks were point counted (17 samples). A minimum of 300 point counts were done on each sample. These data will be incorporated into the final depositional facies analysis. Classification of clastic rocks was from Carozzi (1993), which was modified from Dott, Jr. (1964). Carbonate rocks were classified according to Dunham (1962).

Porosity/Permeability:

Core plugs were taken from every lithology that was petrologically analyzed. Permeabilities were analyzed using a pressure transducer in a Hassler sleeve. Porosities from the lab were compared to point count porosities. In general there was good agreement and where there is some disagreement an explanation is given in the petrologic description. It appears that the sandstone lithofacies have much greater interparticle porosity. This is important to the study because these sandstones likely have greater hydrocarbon storage capacity than do the carbonate rocks. Porosity development in the deep subsurface of the Uinta Basin may be different from outcropping lithology. This will be investigated further during the course of the project.

Lower Green River - Willow Creek

Date logged: March 25, 1994

Logged by: Tom Morris, Ann Garner, and undergrads, Spring - '92, '93

Datum elevation: 0.00 m

Remarks: Section was measured along road outcrops of Hwy 33 (191) on the south flank of the Roan Cliffs. Section begins in NW1/4 of SE1/4 of Sec. 23, T11S, R8W, Matts Summit 7 1/2 Quad and ends in W1/2 of SE1/4 of Sec. 11, T7S, R8W, Jones Hole 7 1/2 Quad. Total = 849.16 m

LEGEND

LITHOLOGY

	SAND/SANDSTONE		silty shale		Ash		Chert
	silty sand		sandy shale		LIMESTONE		Silty Limestone
	SILT/SILTSTONE		clay/claystone		DOLOSTONE		Silty Limestone
	sandy silt		organic shale		Dolomitic Lst		Sandy Limestone
	clayey silt		coal		Calcareous shale		Graded Pebble Conglom
	SHALE/MUDSTONE		matrix supported		Dolomitic shale		

CONTACTS

Sharp	Scoured	Uncertain	GRADATIONAL
			Undulating

PHYSICAL STRUCTURES

Ripple Laminated	Trough Cross-strat.	Planar Lamination
High Angle Tabular Bedding	Low Angle Tabular Bedding	Flaser Bedding
Wavy Parallel Bedding	Lenticular Bedding	Convolute Bedding
Scour	Reverse Graded Bedding	Mud Cracks
Synaeresis Cracks	Load Casts	Stylolites
Low angle trough cross sets	Rip-up lag	

LITHOLOGIC ACCESSORIES

Sand Lamina	Silt Lamina	Shale Lamina
Pebbles/Granules	Coal Lamina	Organic Shale Lamina
Calcareous	Dolomitic	Cherty
Fe Ferruginous	Rip Up Clasts	Micaceous
Fecal Pellets		Silty
Concretion/Nodule		

ICHTNOFOSSILS

Rootlets

Skolithos

Undifferentiated Bioturbation

Inclined Burrows

FOSSILS

Algal Stromatolite

Fish Remains

Molluscs (undifferentiated)

Gastropods

Ostracods

Plant Remains

Vertebrates

GRAIN SIZE

cobble
pebble
granule
sand
silt
clay

METERS

SOILING

POSSIBILITY

vcmfv

wmfv

Cycles

11
8
9
8
7
6
5
4

850
848
846
844
842
840
838
836
834

Three lenticular limestone interbeds (2 cm. thick)

Banded - 8 to 12 cm. thick in "cycles"

Color banded

Unit contains bands of fine-grained sand that are 2 mm. thick; pyrite blebs

Sandy, pyritic dolomite; fills syneresis cracks of lower bed

Sandy, pyritic dolomite that pinches out and swells

Syneresis cracks at top of unit are filled by overlying unit but do not penetrate the claystone interbeds

Color bands 8-12 cm. thick and are somewhat "cyclic"; pyrite nodules in a 5 cm. band midway up the unit; tar in vertical fractures

- Tar siltstone
- Alternating colored laminations are 2-4 mm. thick; iron nodules 10- 15 mm. long and 7-8 mm. thick; odoriferous
- Crystalline limestone (3 cm.) that forms a prominent ledge
- Laminations at base (2-3 mm. thick) and fade in upper portion of unit
- Alternating olive gray (upto 10 mm. thick) and light olive (1-2 mm. thick) laminations; syneresis cracks in this unit and underlying unit
- Well defined alternating bands of yellow and olive-gray; laminations are 1-3mm thick
- Thin laminations
- Thin laminations
- 4 cm. iron-rich band 20 cm. from the top of unit
- Thin laminations
- Chert nodules(?); thin laminations
- Laminations less than 1 mm. thick are present

Fecal pellets(?)

Covered gulch offset of approximately 10 meters

Cycles

780
778
776
774
772
770
768
766
764
762
760
758
756

- Black-brown shale
- Black-brown shale
- Thin Sections 638-RC32 A and 638-RC32B; Syneresis dikes and stylolites within this varved-like unit
- Black-brown shale
- Black-brown shale
- Syneresis dikes and stylolites are found within this varved-like unit
- Black-brown shale
- Paper shale with woody fragments
- Hematite-filled fractures
- Some hematite filled fractures
- Thin Section 623-RC17; Oil shale; varve-like laminations; faintly odoriferous; Mahogany Marker(?)
- Carbon staining from organic matter
- Basal 2 cm. is a poorly sorted matrix supported pebble conglomerate
- Upper portion contains "organic hash"
- Unit has 1-3 cm. iron concretions; syneresis dikes (possibly mud

cracks) are found within this unit and are filled with the same lithology

Limestone clasts (upto 3 cm. in diameter) and shell hash packstone occasionally tar saturated; note that tar within unit pinches and swells and is not ubiquitous

There is a large channel-form sandstone (with mudstone drape) complex laterally offset from the sections measured; the complex shows lateral and vertical accretion of thin bedded sandstone and mudstone; sandstones are very fine-grained; moderate porosity

Thin Section 608-RC2; Tar sand with some zones being odoriferous; contains iron and mica-rich concretions

Interbeds of silty mudstone and fossiliferous (fish scales) carbonate rip-up limestone packstone; upper portion of unit has interbeds of sandy limestone

5 cm. thick bed with rip-up clasts upto 7 mm. in diameter

Laterally equivalent unit was sampled - Thin Section GB2 (this unit has pebble conglomerate rip-ups)

— Rod-shaped stromatolites upto 10 cm. in diameter are randomly oriented at the base of this unit: interpreted to represent very shallow water at the lake or local pond edge

— Rip-up clasts are upto 7 mm. in length
 — Unit pinches out laterally: contains white clasts 2-3 mm. in size

6 Rhythmites

thins and swells but does not pinch out in outcrop

Abundant rip-up clasts from 1 mm. to 15 cm. long

Some foundering (load casting) with overlying unit

Base of unit has mudcracks(?) or syneresis cracks(?) with polygons 8 cm. to 25 cm. long

Gar fish scales at bottom of unit

Alternating light and dark planer laminations (varves?)

Rip-up clast and fossil-rich packstone that fines upward

Finger-like intrusions of unit above (foundering)

Thin Section 479-CC4; Graded limestone pebble conglomerate; unit is very flat bottomed and knife-blade sharp; upper contact is gradational; clast size from 5 mm. to 2 cm.

Plumose structures on weathered surfaces

Plumose structures on weathered surfaces

Interbeds of ostrocod cross-bedded limestone (packstone(?))

Interbeds of ostocod and fish scale cross-bedded limestone

A couple of interbeds of cross-bedded ostrocod limestones

Slight kerogen smell with acid

— Sigmoidal and lensoidal sandstone channel-forms scour the underlying mudstone but not the sandstone

— White limestone bed has a laminae of gar fish scales (fish kill(?)); light gray limestone has cross beds of bone and organics, uppermost layer is orange colored similar to the ash bed below

— Multilateral accretion sets; bone fragment and gar scales in channel; skolithos on top of channel sandstone

— Thin Section 451-AA52

— Finely crystalline limestone

— Clay rip-ups dip 20 degrees to the south

— Weathered surface has "leopard" spots and good plumose fracture surfaces

— Channel-form sandstone and mudstone

Original section 424-AA25 and 424-AA25, original
tooth at the base

Thin Section 438-AA39: Calcite replaced fish vertebrae

Greenish gray and gray-red alternating beds

Red bed

Gray-red fresh color

Thickens toward a channel to the south; interpreted to be a splay
sandstone

Thin Section 424-AA25: L insoidal and sigmoidal channel-form
sandstones with mudstone/siltstone drapes

Weathered surface has excellent plumose structures

— Alternating green with 2 red to brown units; some units have more silt and are more resistant

— "Pencil-lead"-like plant hash(?)

— Moderate reddish brown color with "leopard"-like spots on surface

— Trace fossil assemblage of glossifungites

— Between these two units and laterally offset is a series of 6 sandstone and mudstone channels and associated mudstone drapes, channels appear to have both lateral and vertical accretion, maximum thickness of series is 2.1 m., sandstones have upto high porosity, plant hash on drape of bottom channel sandstone

40 cm. mudstone filled channel within unit

— Alternating colors from greens to reds and browns

Broad swaley beds of siltstone and discontinuous broad lenses of mudstone

Individual units of sandstone well and thin at low angles - one such bed can be traced laterally into a channel-form sandstone body; overbank or splay sandstones (?)

Aggrading channel-form sandstones with mudstone drapes; porosity in drapes is poor while some sandstones have excellent porosity

Ash (?)

Three interbeds 1-3 cm. in thickness that are muddy; one 5 cm. bed 20 cm. from base has approximately 5% fish hash and is slightly odoriferous

2 cm. unit pinches out then reappears

A single channel-form sandstone

Units downcuts in lower unit; channel

Sandstones downcut approximately 2.25 m. into lower units; interpreted to be fluvial channel sandstone bodies

Wackestone has gastropods, reeds and twigs

Interbeds ranging from 1.86 m. to 3 cm.

Ledge and slope former, odoriferous

Thin Section 282-RP35

Upper portion odoriferous

At least six laterally accreting lensoidal sandstone bodies with interbedded thin mudstone drapes; interpreted to be a sinuous channel system with significant aggradation

Alternating ledge and slope former in thin to medium beds

Thin Section 265-RP18 - probably taken from "coarser silt" ledge forming unit as thin section shows wispy ripple lamination

Lower contact slightly bioturbated

Interbeds of alternating slope and ledges; medium beds

Occasional fish fossils

1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14. 15. 16. 17. 18. 19. 20. 21. 22. 23. 24. 25. 26. 27. 28. 29. 30. 31. 32. 33. 34. 35. 36. 37. 38. 39. 40. 41. 42. 43. 44. 45. 46. 47. 48. 49. 50. 51. 52. 53. 54. 55. 56. 57. 58. 59. 60. 61. 62. 63. 64. 65. 66. 67. 68. 69. 70. 71. 72. 73. 74. 75. 76. 77. 78. 79. 80. 81. 82. 83. 84. 85. 86. 87. 88. 89. 90. 91. 92. 93. 94. 95. 96. 97. 98. 99. 100.

Two blocky sandstones 50 cm. thick; mudstone drapes

Five laterally continuous thin to medium sandstone beds

Plant fragments are several cm. long

Mudstone drape at top

Mudstone is red

— Blackish red crumbly limestone mudstone (?); there is a fine line in these units with limy silty shales/claystones

— Upper mudstone interbeds are blackish red

— Sandstones grade vertically into siltstones; siltstone is splotchy green/gray to brown to olive

— Probably several cycles as per units beneath but outcrop exposures hard to get to (vertical cliff nearly inaccessible)

— Red-brown shale; only slightly limy; slightly coarsening upward

— Limy mudstones drape channel sandstones; lower contact has scoured into lower unit

— Unit grades in color from yellow at base to brownish red in the middle to green at top; basal yellow portion is not carbonate cemented

— "Crystalline" limestone

— Aggrading channel complex; contains siltstone lenses

— Thin beds of sandstone have undulatory bottom contacts, small tcs, are well sorted and have high porosity

— Thin sandstone interbeds are well sorted, show small tcs, and have good to excellent

— Upper half of unit shows varves (?)

— Laterally accreting lenses with mudstone drapes; laterally this unit downcuts into unit below approximately 0.5 m. Interpreted to be a meandering fluvial system

— Possible odor (kerogen (?))

— Possible odor (kerogen (?))

— Possible odor (kerogen (?))

— Thin bedded rhythmites of resistive and non-resistive mudstones - units tend to fine upward from silt to shale

— Interbedded limy claystone with lensoidal ostracod packstones - lenses contain flame structures and lcs

— Upper portion shows mud drapes over troughs

— Brown colored

— Interbeds of aggrading sandstone lenses that have mudstone drapes - lenses are upto 18m long and 1.3m thick

— Normal scale

- Brown color
- Sandstone lens pinches out on both sides - 70cm. max thickness - high porosity
- Fossilized bone (mammal(?))
- Interbeds of sandstone up to 12 cm.
- Fish scales
- 8 cm sandstone with flaser lamination, tcs, and gar fish scales
- Two brown colored mudstones (red beds (?)) in bottom half of unit
- Sandstone lenses (near base) within crumbly limy mudstone
- Iron concretions; possible HCS (?)
- Siltstone lenses pinchout to the north; max. thickness of lenses = 26 cm.
- Shale break; mudcracks extend through shale and are filled with sandstone from above
- Sandstone thins to the south; iron concretions
- Also pinches out to the north
- Sandstone lens that pinches out to the north; maximum thickness in outcrop is 73 cm.
- Iron stained concretions

Outcrop Marker

134
132
130
128
126
124
122
120
118
116
114
112
110

- 2 mm "white" seam at top; mud covered
- Mud covered
- Mud covered
- Odoriferous; This unit marks the top of a prominent cliff-forming outcrop section which is approximately 3.5 m. thick
- Mud covered
- Mud covered
- Mud covered
- Mud covered; very odoriferous
- Thin Sections 113-EH58 bag and block; Mud covered
- Slightly odoriferous; outcrop covered with mud
- Poorly exposed outcrop - vertical face covered with mud
- Slightly odoriferous
- Weathers into crumbly chips

— Thin ss lenses with mudstone drapes; interbedded flat bottomed laterally continuous ss bodies (overbank splays (?))

— Lenticular ss bodies that pinch out laterally; mudstone drapes over ss; interbeds of flat bottomed laterally continuous ss (overbank splay-type deposits(?))

— Small channel-like lenses down to 3cm in thickness

— Lenticular ss bodies pinch out laterally and are draped by mudstone; flaser bedding in mudstones; very fine sand

— Recessive, slope covered

— Thin Section 47-DN47; Kerogen-rich (occasionally)

— Kerogen-rich

— Thin Section 43; Kerogen-rich

— Lower portion "Banded"; kerogen-rich

— Chert bands 5mm - 4cm thick; kerogen-rich (odiferous)

— Thin Section 37-DN37

— Thin Section 36-DN36

— Shaley interbeds 10 cm thick

Gypsum filled fractures

Bivalves, gastropods

Banded dolomite; interbeds of ostracods and gastropods

Gypsum filled fractures

Fossiliferous packstone; bivalves, gastropods

Gypsum filled fractures

Bivalves, gastropods

Thin Section 21-DN21; *Terratella* (?), gypsum present

Ostracods, fish scales

Gastropods, leaf hash

Bivalve-rich packstone

Very thin bedded coal

Gypsum filled fractures

Gypsum filled fractures

Carbonate cemented

Channel sandstone with clay drapes

Thin Section 7-DN7

Thin Section 5-DN5

**Petrographic Description of Lower Green River Formation
Samples Taken in Willow Creek Canyon**

5-DN5--300 point count.

Constituent	Number=Percent	Constituent	Number=Percent
Quartz	85=28.3	Polyxlline Quartz	0=0.0
Feldspar	56=18.6	Fe-oxide	0=0.0
Lithics	12=4.0	Chert	15=5.0
Cement	32=10.6	Porosity	14=4.6
Matrix	53=17.6	Mica	4=1.3
Organics	29=9.6	Fossils	0=0.0

Moderately sorted, angular, lower fine-grained to lower very fine-grained quartz wacke with very little interparticle porosity. The cement in this thin section looks like a fairly equal mixture of calcite and quartz. The feldspars are highly altered. The lithic count may be low due to the difficulty of exactly identifying some of the smaller fragments. The organic count may all be Fe-oxides but there was not enough biotite to account for all the iron.

7-DN7--Fossiliferous packstone with fragments of ostracodes, gastropods, and bivalves with original aragonite. There are also some phosphatic fossils in this section which may be fish debris. Most of the fossil fragments have two sizes of calcite cement. There has been solution enlargement and spar filling in the areas around the fragments. Some of the intraparticle porosity has been filled with organic material. There is some minimal open fracture porosity.

37-DN37--Ostracodal packstone with micrite and calcite reduced to filled intra- and interparticle porosity. Some of the calcite cement has been followed by silica cement and a lot of the matrix has undergone aggrading neomorphism from micrite to microspar. The ostracodes have all been lined up perpendicular to the up direction of the thin section and many of them have been crushed, indicating compaction. Bits of organic material have also been lined up roughly perpendicular to the up direction of the thin section.

43--Mudstone with about 5% fossil hash and solution enlarged spar filled mesomoldic porosity. Organic material has been collected along concentrations of moldic porosity. (Percentage is visual estimate only).

47-DN47--Mudstone with ostracod fragments(?) and organic-rich matrix. There is no

open porosity. There are some small variations in the blue tinge of the thin section due to some layers that seem to be made up of small peloids glued together with fossil fragments by micrite.

102-EH47--Mudstone with lighter and darker colored micritic laminae (varves?). The darker color may be due to a concentration of very fine-grained organic material. There are a few bits of quartz and mica. Some of the mud clasts (peloids) look like they may have some intraparticle porosity but the amounts are not significant. Vertical fractures and microfaults have been sealed with micrite.

113-EH58 block--Mudstone with about 1% solution enlarged, cement reduced micromoldic and microvuggy intraparticle porosity. (Percentage is visual estimate only).

140-EH85--300 point count.

Constituent	Number=Percent	Constituent	Number=Percent
Quartz	94=31.3	Polyxline Quartz	2=0.6
Feldspar	60=20.0	Fe-oxide	29=9.6
Lithics	1=0.3	Chert	14=4.6
Cement	20=6.6	Porosity	72=24.0
Matrix	6=2.0	Mica	2=0.6
Organics	0=0.0	Fossils	0=0.0

Well sorted, subrounded, upper to lower fine-grained quartz arenite with interparticle porosity. A lot of the quartz grains have overgrowths. The cement in this section looks like fragments or grains which are approximately the same size as the mineral grains. There is not very much mica in this sample so that which is listed as Fe-oxide could be organic material.

140-EH85A--300 point count.

Constituent	Number=Percent	Constituent	Number=Percent
Quartz	110=36.6	Polyxline Quartz	21=7.0
Feldspar	78=26.0	Fe-oxide	3=1.0
Lithics	0=0.0	Chert	5=1.6
Cement	1=0.3	Porosity	52=17.3
Matrix	20=6.6	Mica	1=0.3

Organics	9=3.0	Fossils	0=0.0

Very well sorted, subangular to subrounded, lower fine-grained quartz arenite with interparticle porosity. Some of the quartz grains have overgrowths. Both organic material and Fe-oxides can be found in this thin section. The organics are a reddish brown and the Fe-oxides are black and are associated with disintegrating biotite fragments.

265-RP18--300 point count.

Constituent	Number=Percent	Constituent	Number=Percent
Quartz	35=11.6	Polyxline Quartz	1=0.3
Feldspar	54=18.0	Fe-oxide	1=0.3
Lithics	0=0.0	Chert	8=2.6
Cement	86=28.6	Porosity	16=5.3
Matrix	78=26.0	Mica	2=0.6
Organics	5=1.6	Fossils	14=4.6

Well sorted, angular, lower very fine-grained feldspathic wacke with a lot of biotites, some of which are calcite replaced. The biotites are oriented parallel to fractures. Most of the porosity is fracture porosity but there is also some interparticle porosity. The feldspars are so highly altered that it is difficult to determine whether they should be considered a feldspar grain or calcite cement. Because of this, the point count may be skewed toward cement.

282-RP35--300 point count.

Constituent	Number=Percent	Constituent	Number=Percent
Quartz	79=26.3	Polyxline Quartz	1=0.3
Feldspar	59=19.6	Fe-oxide	4=1.3
Lithics	1=0.3	Chert	7=2.3
Cement	99=33.0	Porosity	17=5.6
Matrix	25=7.6	Mica	9=3.0
Organics	0=0.0	Fossils	1=0.3

Well sorted, subangular, upper fine-grained to upper very fine-grained quartz arenite

with interparticle and mesovuggy porosity. The matrix of this section looks like it has undergone aggrading neomorphism from micrite to microspar. Most of the feldspar grains in this sample are only slightly altered. The porosity count may be low because it occurs as tiny spots randomly scattered throughout the cement. The porosity stain can also be seen on top of mineral fragments which were counted as grain.

424-AA25--300 point count.

Constituent	Number=Percent	Constituent	Number=Percent
Quartz	94=31.3	Polyxline Quartz	4=1.3
Feldspar	108=36.0	Fe-oxide	10=3.3
Lithics	3=1.0	Chert	6=2.0
Cement	14=4.6	Porosity	46=15.3
Matrix	4=1.3	Mica	10=3.6
Organics	0=0.0	Fossils	0=0.0

Well sorted, angular, upper to lower fine-grained feldspathic arenite with interparticle porosity. Some of the quartz grains have abraided overgrowths and the feldspars are highly altered. The micas are oriented perpendicular to the up direction and, where there is a concentration of biotite fragments, it seems that a lot of them have been altered to Fe-oxides.

451-AA52--Peloidal quartz mudstone with very few fossil fragments and no obvious open porosity. There are a few random fragments of Fe-oxide or organic material and there seems to be some solution enlarged cement filled microvuggy porosity. Some of the micritic matrix has been neomorphosed to microspar.

479-CC4--Peloidal mudstone that has been interlaminated with silty peloidal mudstone. There is no open porosity and some of the matrix has undergone aggrading neomorphism from micrite to microspar.

608-RC2--300 point count.

Constituent	Number=Percent	Constituent	Number=Percent
Quartz	70=23.3	Polyxline Quartz	2=0.6
Feldspar	86=28.6	Fe-oxide	9=2.9
Lithics	7=2.6	Chert	5=1.6
Cement	98=32.6	Porosity	9=3.0
Matrix	11=3.6	Mica	3=1.0

Organics	0=0.0	Fossils	0=0.0

Well sorted, subangular, lower medium-grained to lower fine-grained feldspathic arenite with interparticle and vuggy porosity and poikilotopic calcite cement. The feldspars in this section vary from being clean to highly altered. Most of the lithics looked like quartz grains with altered feldspar lathes in them.

632-RC17--Mudstone with about 15% organic filled wispy fracture porosity. Much of the matrix of this thin section has undergone aggrading neomorphism from micrite to microspar. (Percentage is a visual estimate only).

638-RC32--Mudstone that looks like a small scale turbidity sequence that coarsens upward within each layer but fines upward through the whole sequence. Part of this sequence has been fractured and brecciated and has been injected with a silty mudstone. There is about 1% open fracture porosity. There is also a stylolite through this section that looks like it has organic material and/or Fe-oxides concentrated along it. (Percentage is a visual estimate only).

GB2--Interlaminations of well sorted, subangular, very fine-grained quartz wacke with some fossil fragments, micrite clasts (very few), about 50% calcite cement (after micrite) and silty mudstone. Mica fragments are evenly distributed throughout the whole section. There is not any obvious open porosity but the entire thin section has a blue tinge from the porosity staining, especially in the sandy areas.

J3--300 point count.

Constituent	Number=Percent	Constituent	Number=Percent
Quartz	68=22.6	Polyxline Quartz	1=0.3
Feldspar	59=19.6	Fe-oxide	2=0.6
Lithics	12=4.0	Chert	3=1.0
Cement	48=16.0	Porosity	42=14.0
Matrix	54=18.0	Mica	10=3.3
Organics	0=0.0	Fossils	1=0.3

Well sorted, subrounded, lower fine-grained to lower very fine-grained quartz wacke with interparticle porosity. This rock is very dirty and the edges of many of the altered grains are blurred into the cement or matrix. Consequently, the cement and matrix counts may be a little high.

2nd J7--300 point count.

Constituent	Number = Percent	Constituent	Number = Percent
Quartz	101 = 33.6	Polyxline Quartz	8 = 2.6
Feldspar	62 = 20.6	Fe-oxide	0 = 0.0
Lithics	12 = 4.0	Chert	9 = 3.0
Cement	58 = 19.3	Porosity	45 = 15.0
Matrix	2 = 0.6	Mica	3 = 1.0
Organics	0 = 0.0	Fossils	0 = 0.0

Well sorted, subrounded, lower medium-grained to lower fine-grained quartz arenite with interparticle and mesovuggy porosity and poikilotopic calcite cement. There are some quartz overgrowths and the feldspar grains are clean to moderately altered. The porosity count may be low because numerous large vugs were not crossed during counting.

4th J7--Well sorted, subangular, lower medium-grained to upper fine-grained quartz arenite with some fragments of mica as well as grains of feldspar and chert. About 50% poikilotopic calcite cement-filled interparticle porosity. Only about 1% of the viewing area is open interparticle porosity. (Percentages are visual estimates only).

4th J7 with clasts--300 point count.

Constituent	Number = Percent	Constituent	Number = Percent
Quartz	58 = 19.3	Polyxline Quartz	8 = 2.6
Feldspar	60 = 20.0	Fe-oxide	2 = 0.6
Lithics	43 = 14.3	Chert	16 = 5.3
Cement	110 = 36.6	Porosity	0 = 0.0
Matrix	2 = 0.6	Mica	1 = 0.3
Organics	0 = 0.0	Fossils	0 = 0.0

Well sorted, angular to subangular, upper medium-grained to upper fine-grained quartz arenite with interparticle and moldic porosity. There are also some micritic/fossiliferous clasts and some random bivalve(?) fragments.

RC?--Peloidal and micritized ostracodal packstone with 5% quartz grains and some solution enlarged cement reduced inter- and intraparticle porosity. This grades upward into a peloidal wackestone with 15% quartz grains and the same porosity. A few of the quartz grains in this section are polycrystalline. Many of the peloids look like intraclasts or superficially coated grains. (Percentages are visual estimates only).

11-10-12-1a--300 point count.

Constituent	Number = Percent	Constituent	Number = Percent
Quartz	103 = 34.3	Polyxlline Quartz	0 = 0.0
Feldspar	58 = 19.3	Fe-oxide	1 = 0.3
Lithics	12 = 4.0	Chert	8 = 2.6
Cement	95 = 31.6	Porosity	15 = 5.0
Matrix	6 = 2.0	Mica	1 = 0.3
Organics	1 = 0.3	Fossils	0 = 0.0

Very well sorted, subangular, lower medium-grained to upper fine-grained quartz arenite with interparticle and moldic porosity and poikilotopic calcite cement. Some of the quartz grains have overgrowths and the feldspars vary from clean to highly altered.

11-10-12-2--300 point count.

Constituent	Number = Percent	Constituent	Number = Percent
Quartz	89 = 29.6	Polyxlline Quartz	0 = 0.0
Feldspar	52 = 17.3	Fe-oxide	1 = 0.3
Lithics	23 = 7.6	Chert	2 = 0.6
Cement	115 = 38.3	Porosity	16 = 5.3
Matrix	0 = 0.0	Mica	2 = 0.6
Organics	0 = 0.0	Fossils	0 = 0.0

Very well sorted, subangular, lower medium-grained to upper fine-grained quartz arenite with interparticle and moldic porosity and poikilotopic calcite cement. Most of the lithics look like quartz with altered feldspar laths embedded in them. The porosity count may be slightly low because the porosity stain often coated grains that didn't have obvious holes between them. These were counted as grains.

11-10-12-3a--300 point count.

Constituent	Number = Percent	Constituent	Number = Percent
Quartz	67 = 22.3	Polyxlline Quartz	3 = 1.0
Feldspar	79 = 26.3	Fe-oxide	2 = 0.6

Lithics	10=3.3	Chert	4=1.3
Cement	103=34.3	Porosity	30=10.0
Matrix	1=0.3	Mica	1=0.3
Organics	0=0.0	Fossils	0=0.0

Well sorted, angular, upper medium-grained to upper fine-grained feldspathic arenite with interparticle, mesovuggy and fracture porosity and poikilotopic calcite cement. There are some quartz overgrowths and the feldspar grains vary from being clean to highly altered. The lithics seem to be both metamorphic (schist) and igneous (quartz with feldspar laths).

11-10-13-1b—300 point count.

Constituent	Number=Percent	Constituent	Number=Percent
Quartz	80=26.6	Polyxline Quartz	2=0.6
Feldspar	80=26.6	Fe-oxide	5=1.6
Lithics	1=0.3	Chert	2=0.6
Cement	2=0.6	Porosity	75=25.0
Matrix	23=7.6	Mica	30=10.0
Organics	0=0.0	Fossils	0=0.0

Very well sorted, subangular, lower fine-grained to lower very fine-grained quartz arenite with interparticle and moldic porosity. The mica fragments are oriented roughly parallel to the low angle laminations that are evident in hand sample.

11-10-13-1c—300 point count.

Constituent	Number=Percent	Constituent	Number=Percent
Quartz	90=30.0	Polyxline Quartz	0=0.0
Feldspar	46=15.3	Fe-oxide	3=1.0
Lithics	38=12.6	Chert	5=1.6
Cement	6=2.0	Porosity	68=21.9
Matrix	32=10.6	Mica	14=4.6
Organics	0=0.0	Fossils	0=0.0

Moderately sorted, angular to subrounded, lower medium-grained to lower very fine-grained quartz arenite with interparticle, moldic and vuggy porosity. The lithics are peloids with very small fragments of quartz, feldspar, mica, Fe-oxide and some fossil hash. The larger fragments of mica in this section are oriented roughly perpendicular to the up direction of the section.

11-10-13-1f--300 point count.

Constituent	Number=Percent	Constituent	Number=Percent
Quartz	72=24.0	Polyxlline Quartz	0=0.0
Feldspar	73=24.3	Fe-oxide	8=2.6
Lithics	0=0.0	Chert	3=1.0
Cement	6=2.0	Porosity	98=32.6
Matrix	22=7.3	Mica	18=6.0
Organics	0=0.0	Fossils	0=0.0

Very well sorted, subrounded, upper fine-grained to upper very fine-grained quartz arenite with interparticle porosity. There is very little obvious cement and the feldspars are slightly to highly altered. The mica fragments in this thin section are oriented roughly parallel to the low angle laminations that are evident in hand sample. The porosity count may be high because of overcompensation for the occurrence of porosity stain on top of mineral grains.

21-DN21--Fossiliferous wackestone to packstone with ostracod and gastropod fragments. There is compaction breakage of the ostracodes and the matrix is organic rich. There are solution enlarged spar filled intraparticle porosity and there is about 3% solution enlarged fracture porosity. (Percentage is a visual estimate only.)

36-DN36--Wackestone with organic rich matrix, 20% potato chip looking fossils and 10% wispy fracture porosity. (Percentages are visual estimates only).

438-AA39--Mudstone with about 5% fossil fragments and some solution enlarged cement filled mesomoldic and microvuggy porosity. There is one small open fracture and some random bits of organic material or Fe-oxide.

MB1-A--Algal and micritic concretions around something, possibly twigs(?), which has since been dissolved. Some of the micrite has also been dissolved. The resulting porosity has been filled in by a pore reducing microspar then by a pore filling poikilotopic calcite cement. There was a secondary dissolution of some of the micrite and cement leaving mesovuggy pore spaces, some of which have been filled in with organic material.

ROUTINE CORE ANALYSIS

**BRIGHAM YOUNG UNIVERSITY
DEPARTMENT OF GEOLOGY**

**GREEN RIVER FORMATION OUTCROP SAMPLES
UINTAH & DUCHESNE COUNTIES, UTAH**

Prepared for:

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**August 1993
TerraTek Project No. 5500**

INTRODUCTION

TerraTek, Inc. received thirty-one (31) outcrop samples from the Geology Department at Brigham Young University for porosity and permeability determination. In general, two plug samples were drilled from each sample for testing: one parallel to bedding for porosity and permeability testing and one perpendicular to bedding for permeability testing only. There were two exceptions, the sample marked 638-RC32 and the sample marked 11-10-12-3a. Sample 638-RC32 contained prominent stylolites and two sets of samples were requested. The samples for the first set were to include stylolites and the samples for the other set were to exclude stylolites. As for sample 11-10-12-3a, a portion of the sample contained what appeared to be rip up clasts. A second horizontal plug from the zone containing the clasts was requested. The sample locations and the desired direction of the sample orientation were clearly marked on each of the outcrop samples provided.

PROCEDURES

Plug samples, one-inch in diameter, were drilled at each location marked on the outcrop samples. Horizontal plugs, parallel to bedding, and vertical plugs, perpendicular to bedding, were drilled from each of the outcrop samples. A diamond impregnated coring bit and fresh water as bit coolant were used in the process. The plugs were then dried in a convection oven at 110°C for 48 hours prior to porosity and permeability testing.

Porosities were determined on each of the horizontal plug samples by measuring grain volumes and bulk volumes. Grain volumes were measured in a helium expansion porosimeter using Boyle's law. Bulk volumes were measured by buoyant weight in mercury using Archimedes' principle of buoyancy. Grain volumes and sample dry weights were also utilized to determine a grain density value for each sample.

Permeabilities to nitrogen gas were measured on all of the prepared samples in a pressurized Hassler core holder. A sleeve pressure of 400 psi was applied to prevent gas from flowing around the outside of the sample being measured. Downstream steady-state flowrate was determined using a calibrated orifice-equipped pressure transducer. Darcy's law was employed to calculate absolute gas permeability.

RESULTS

Results of the tests described above are tabulated on the enclosed table. Three crossplots are also provided. One depicts horizontal permeability versus porosity, one depicts vertical permeability versus porosity, and the final one depicts horizontal permeability versus vertical permeability. Various statistical values are also included on the crossplot pages.

POROSITY & PERMEABILITY MEASUREMENTS
GREEN RIVER FORMATION OUTCROP SAMPLES
UTAH & DUCHESNE COUNTIES, UTAH

Sample Number	Sample Designation	Permeability Horizontal (md)	Permeability Vertical (md)	Porosity %	Grain Density (gm/cc)
1	5-DN5	0.07	0.05	10.9	2.67
2	7-DN7	0.66	0.02	2.7	2.76
3	37-DN37	4.4	0.53	27.2	2.78
4	43	<0.01	<0.01	7.7	2.76
5	47-DN47	<0.01	0.01	3.8	2.47
6	102-EH47	93. +	<0.01	4.7	2.48
7	113-EH58 (bag)	0.01	0.01	3.1	2.63
8	113-EH58 (block)	0.01	0.01	5.8	2.71
9	140-EH85	235.	208.	23.7	2.66
10	140-EH85A	46.	19.	23.0	2.63
11	265-RP18	0.20	<0.01	6.6	2.65
12	282-RP35	0.13	0.05	14.5	2.60
13	424-AA25	18.	4.4	21.9	2.64
14	451-AA52	0.01	<0.01	8.3	2.71
15	479-OC4	<0.01	<0.01	12.8	2.75
16	608-RC2	0.69	0.02	7.7	2.60
17	623-RC17	0.01	<0.01	0.2	2.23
18	638-RC32 A	0.09	0.01	12.7	2.72
19	638-RC32 B	0.01	<0.01	14.1	2.72
20	GB2	0.03	0.02	14.2	2.62
21	H10	0.63	0.88	17.2	2.79
22	J3	0.04	0.03	13.2	2.66
23	2nd J7	1241.	1342.	25.8	2.64
24	4th J7	3.4 +	0.01	4.0	2.67
25	RC	0.01	<0.01	15.0	2.72
26	RC?	<0.01	<0.01	3.0	2.76
27	11-10-12-1a	0.03	0.02	5.5	2.66
28	11-10-12-2	0.02	0.02	3.4	2.65
29	11-10-12-3a A	0.01	0.01	3.3	2.66
30	11-10-12-3a B	0.05	NA	3.9	2.67
31	11-10-13-1b	6.5	2.0	24.0	2.61
32	11-10-13-1c	2.2	0.53	23.9	2.60
33	11-10-13-1f	15.	1.3	25.1	2.63

+ - Fracture affecting permeability

NA - Not analyzed for vertical permeability

Terra Tek Geoscience Services®

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HORIZONTAL PERMEABILITY VS POROSITY

BYU GEOLOGY DEPARTMENT
Outcrop Samples
Green River Formation
Uintah & Duchesne Counties
August 9, 1993

TerraTek File# 5500		
Porosity (phi), %		
Min	Max	Average
0.240	27.157	11.901
Horizontal Perm (Kh), md		
Min	Max	Geo. Ave
0.004	1241.213	0.240
Equation of the Line		
$\log Kh = a \phi + b$		
$\log Kh = 0.1189 \phi - 2.0343$		
Correlation Coefficient: 0.646		

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VERTICAL PERMEABILITY VS POROSITY

BYU GEOLOGY DEPARTMENT

Outcrop Samples
Green River Formation
Uintah & Duchesne Counties
August 9, 1993

TerraTek File# 5500

Porosity (phi), %

Min	Max	Average
0.240	27.157	12.151

Vertical Perm (Kv), md

Min	Max	Geo. Ave
0.002	1341.523	0.069

Equation of the Line

$$\log K_v = \alpha \phi + \beta$$

$$\log K_v = 0.1354 \phi - 2.8074$$

Correlation Coefficient : 0.799

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VERTICAL PERMEABILITY VS HORIZONTAL PERMEABILITY

BYU GEOLOGY DEPARTMENT

Outcrop Samples
Green River Formation
Uintah & Duchesne Counties
August 9, 1993

TerraTek File# 5500		
Horizontal Perm (Kh), md		
Min	Max	Geo. Ave
0.004	1241.213	0.253
Vertical Perm (Kv), md		
Min	Max	Geo. Ave
0.002	1341.523	0.069
Equation of the Line		
$\log K_v = \alpha \log K_h + \beta$		
$\log K_v = 0.7214 \log K_h - 0.7322$		
Correlation Coefficient : 0.793		

DATE

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END