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RESERVOIR CHARACTERIZATION of the LOWER GREEN RIVER FORMATION, UINTA BASIN, UTAH

by

Craig D. Morgan, Thomas C. Chidsey Jr., Kevin P. McClure,
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RESERVOIR CHARACTERIZATION OF THE LOWER GREEN RIVER
FORMATION, SOUTHWEST UINTA BASIN, UTAH

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Southwest Uinta Basin, Utah

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ABSTRACT

The oil-productive lower and middle members of the Green River Formation in the southwest Uinta Basin are divided into five distinct reservoirs. The reservoirs in stratigraphically ascending order are: (1) Uteland Butte, (2) Castle Peak, (3) lower Douglas Creek, (4) upper Douglas Creek, and (5) Garden Gulch. The changing depositional environments of Lake Uinta controlled the characteristics of each of the reservoirs. The Uteland Butte consists of carbonate and rare, thin shallow-lacustrine sandstone bars deposited during the initial rise of the lake. The Castle Peak reservoir was deposited during a time of numerous and rapid lake-level falls and rises, which developed a simple drainage pattern across the exposed shallow and gentle shelf with each cycle. The lower Douglas Creek reservoir records a time of active tectonism which created a steeper slope and a pronounced shelf break where thick cut-and-fill valleys developed during lake-level falls and rises. The upper Douglas Creek reservoir represents a return to a very gentle shallow shelf where channel deposits became stacked in a lowstand delta plain and amalgamated into some of the best reservoir rock in the southwest Uinta Basin. The Garden Gulch reservoir represents a time of major lake expansion with fewer, less pronounced, lake-level falls, resulting in isolated single-storied channel- and shallow-bar sandstone deposits.

The rocks exposed in Nine Mile Canyon are a good analog to the oil reservoirs in the southwest Uinta Basin. Examination of the exposures of the middle member of the Green River Formation in Nine Mile Canyon revealed a high degree of heterogeneity in reservoir-quality sandstone beds. The heterogeneity identified on outcrop indicates that a significant amount of the oil is being left behind in the Green River Formation reservoirs in the southwest Uinta Basin, at the current well spacing.

Numerical simulation models were constructed for three fields, which produce from the Uteland Butte, Castle Peak, and upper Douglas Creek reservoirs. Modeling indicates that primary recovery from each of the reservoirs is less than 5 percent of the oil in place.

INTRODUCTION

The Utah Geological Survey led a four-year study of the lower and middle members of the Eocene Green River Formation in the southwest Uinta Basin, Utah (figure 1). The Green River is a highly oil-productive formation consisting of lacustrine- and marginal-lacustrine rocks deposited in and around Eocene-aged Lake Uinta. The objectives of the study were to increase both primary and secondary hydrocarbon recovery through improved characterization (at the regional, unit, interwell, well, and microscopic scale) of fluvial-deltaic lacustrine reservoirs, thereby preventing premature abandonment of producing wells. The study will encourage exploration and establishment of additional water-flood units throughout the southwest region of the Uinta Basin, and other areas with production from fluvial-deltaic reservoirs.

A log-based correlation scheme and nomenclature that reflect, as near as possible, time-correlative depositional cycles of the lower and middle members of the Green River Formation were established. The cycles are at a scale that is easily recognizable on geophysical well logs and can be correlated throughout most of the southwest Uinta Basin. Logs from more than 1,300 wells were correlated, and data on cycle boundaries, total sandstone, and total feet of porosity, for each cycle, were entered into the well database and used for mapping.

Regional investigation of the surface exposures of the Green River Formation was conducted in Willow Creek, Nine Mile, and Desolation Canyons. Numerous stratigraphic sections in the Green River were measured and described. Photomontages of nearly 4 miles (6 km) of outcrop in Nine Mile Canyon were compiled and used for correlation of key marker beds. Spectral gamma-ray (GR) data were collected using an Exploranium® GR - 256 spectrometer with a GPX - 21 scintillation detector, over four stratigraphic sections; one in Willow Creek Canyon, and three in Nine Mile Canyon. Curves generated from the GR data were correlated with GR curves from wells in the area. Several carbonate marker beds are found in the middle member, which define large-scale (about 100-foot [30-m] thick) depositional cycles and are used to correlate the cycles for tens of miles along the outcrop and in the subsurface. Smaller scale depositional cycles have been identified on outcrop but are difficult to correlate regionally.

Five reservoirs were identified in the middle and lower members of the Green River Formation based on the regional chronostratigraphic correlations, investigation of well core, and examination of the surface exposures. The five reservoirs in stratigraphically ascending order are: (1) Uteland Butte, (2) Castle Peak, (3) lower Douglas Creek, (4) upper Douglas Creek, and (5) Garden Gulch. Each reservoir consists of one or more beds with similar paleodepositional history, petrology, and diagenesis that are unique to the reservoir.

A detailed study site was selected in Nine Mile Canyon, from Petes Canyon to Gate Canyon, both tributaries to Nine Mile. The exposure is about 2,000 feet (600 m) in the east-to-west direction and about 4,200 feet (1,280 m) in the north-to-south direction. The stratigraphic interval studied is slightly more than 100 feet (30 m) thick, bounded by carbonate beds. Eight sections were measured and described, and GR data gathered from five of the sections. To aid in the interpretation, the site was photographed from the canyon walls opposite the study site, and photomontages were compiled. Data from the study site serves as an important analog for the reservoir heterogeneity that can be expected in the interwell environment and at the scale of a typical Monument Butte area water-flood unit.

Geostatistical analyses were conducted and numerical simulation models were constructed for the Uteland Butte field (Uteland Butte reservoir), Brundage Canyon field (Castle Peak reservoir), and Monument Butte Northeast unit (upper Douglas Creek reservoir). The Uteland Butte and Brundage Canyon fields are in primary production while the Monument Butte Northeast is a secondary-recovery water-flood unit.

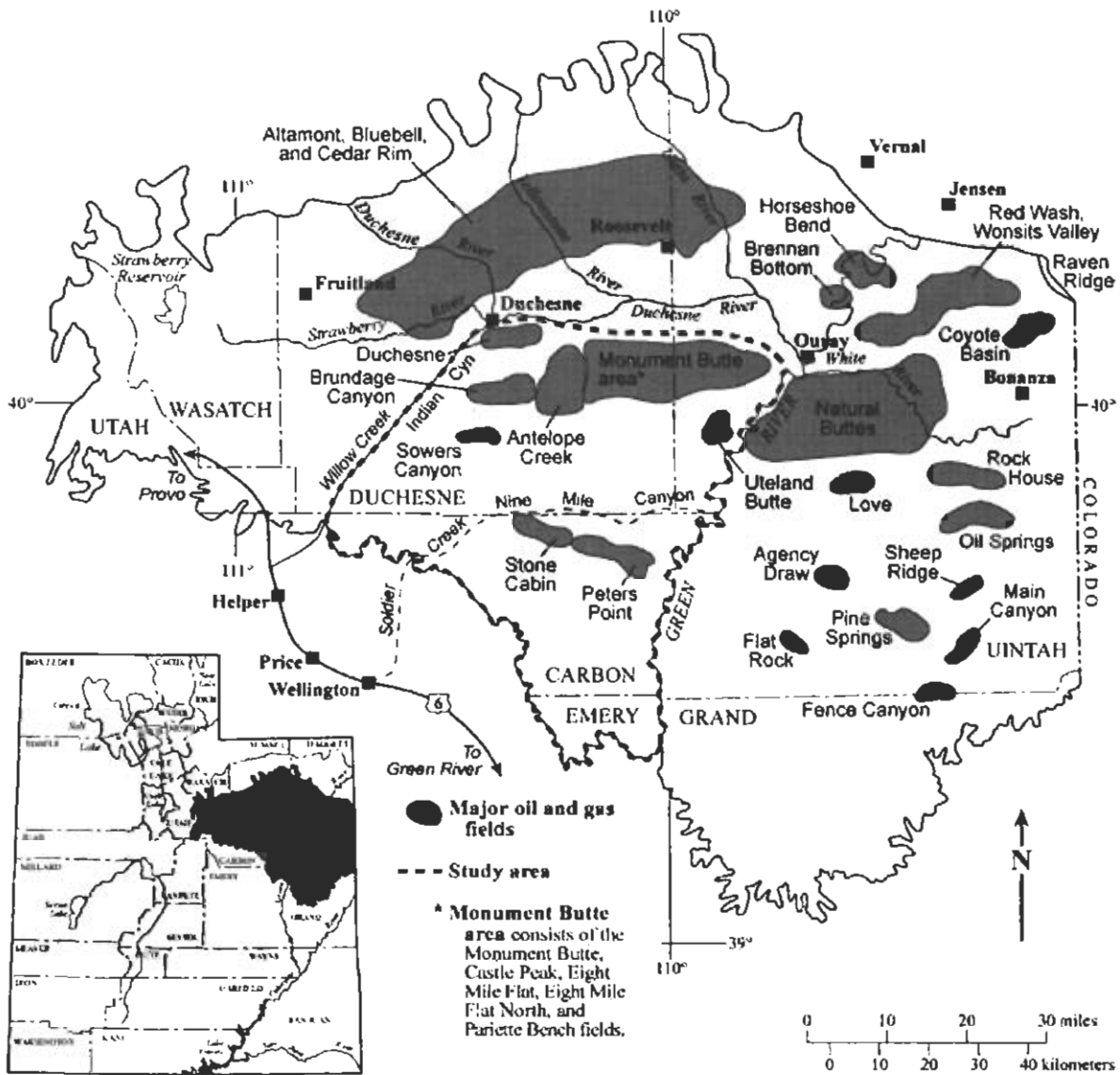


Figure 1. Location map of the Uinta Basin showing the southwest Uinta Basin study area.

Geophysical well log data were used to construct detailed the geostatistical models for the Monument Butte Northeast unit, that were upscaled to obtain reasonable number of grid blocks for reservoir simulation. Porosities, permeabilities, and water saturations required for reservoir simulation were generated from well log and core data. Comparison of the production results with the field data revealed that there was a phenomenological deficiency in the model. This was addressed by incorporating hydraulic fractures into the models resulting in much better agreement between simulated production and actual field production data.

The Brundage Canyon and Uteland Butte fields were simulated in primary production. Only preliminary simulations were undertaken since a number of critical data elements could not be obtained from the operators. These studies revealed that the production performance of the Brundage Canyon field is much better than what can be predicted from simulations of a typical non-fractured, undersaturated reservoir, indicating that naturally occurring fractures are an important part of the Castle Peak reservoir. Uteland Butte field performance was that of a typical undersaturated reservoir.

GEOLOGIC SETTING

The Uinta Basin is a topographic and structural trough encompassing an area of more than 9,300 square miles (14,900 km²) in northeast Utah (figure 1). The basin is sharply asymmetrical, with a steep north flank bounded by the east-west-trending Uinta Mountains, and a gently dipping south flank.

The Uinta Basin formed in Late Cretaceous Maastrichtian time, creating a large area of internal drainage, which was filled by ancestral Lake Uinta during the Paleocene and Eocene. Deposition in and around Lake Uinta consisted of open- to marginal-lacustrine sediments that make up the Green River Formation. Alluvial red-bed deposits that are laterally equivalent to, and intertongue with, the Green River make up the Colton (Wasatch) Formation.

More than 450 million barrels of oil (MMBO) (72 million m³) have been produced from the Green River and Colton Formations in the Uinta Basin. The Cedar Rim, Altamont, Bluebell, and Red Wash fields produce oil from the northern shoreline deposits of Lake Uinta, while the fields in the greater Monument Butte area (Duchesne, Brundage, Sowers, Antelope Creek, and Uteland Butte fields, and the Monument Butte area [figure 1]) produce from southern deltaic shoreline deposits as preserved in the middle and lower members of the Green River. The southern shore of Lake Uinta was often very broad and flat, which allowed large transgressive and regressive shifts in the shoreline in response to climatic and tectonic-induced rise and fall of the lake. The cyclic nature of Green River deposition in the southwest Uinta Basin resulted in numerous stacked deltaic deposits. Distributary-mouth bars, distributary channels, and nearshore bars are the primary producing sandstone reservoirs in the area.

PREVIOUS STUDIES AND STRATIGRAPHIC NOMENCLATURE

The stratigraphic nomenclature used to describe the Green River Formation in the Uinta Basin, Utah, is as diverse as the rocks themselves. The nomenclature is based on facies, which are often bounded by subtle and interfingering relationships that are difficult to carry with confidence any great distance within the basin. Regional facies studies such as Fouch (1975) and Ryder and others (1976), have greatly increased our knowledge of Lake Uinta as represented by the deposits of the Green River Formation, but rapid facies change with poorly defined boundaries has often led to confusing stratigraphic relationships, and questionable and confusing use of terminology.

In the eastern Uinta Basin, Bradley (1931) named and described the Douglas Creek, Garden Gulch, Parachute Creek, and Evacuation Creek Members of the Green River Formation. In the western Uinta Basin, Bradley (1931) defined the basal lacustrine phase, tongue of the Wasatch, second lacustrine phase, delta facies, oil shale facies, barren and saline facies (figure 2). Picard (1955) introduced the term black shale facies for the western Uinta Basin area for the rocks equivalent to the first lacustrine phase and Wasatch tongue of Bradley (1931). Abbott (1957) expanded the use of black shale facies to include the second lacustrine phase of Bradley (1931) and showed the delta facies to be equivalent to the Douglas Creek Member. Picard (1957a, 1957b) introduced the term green shale facies, which is equivalent to most of the delta facies. In the subsurface the black shale facies thickens from south to north at the expense of the green shale facies (Picard 1957a). Ryder and others (1976) defined the carbonate marker unit equivalent to the black shale facies below the carbonate marker bed.

Several workers have described the fluvial-deltaic and interfingering alluvial deposits associated with the southern shoreline of Lake Uinta in the southwest Uinta Basin (Cashion, 1967; Picard and High, 1970; Fouch, 1975; Ryder and others, 1976; Pitman and others, 1982). Remy (1992) described the exposures and depositional environments of the delta facies of the Green River in Nine Mile Canyon and some of its tributaries. Remy (1992) defines the Sunnyside delta interval in Nine Mile Canyon from the top of the carbonate marker bed to the C marker (Jacob, 1969), and from the C marker to the top of the S1 sandstone, just below the base of the Mahogany oil shale, as the transitional facies.

There are a few laterally extensive marker beds, which have been identified on the surface and in the subsurface (Jacob, 1969; Weiss and others 1990). These marker beds have been used for time-stratigraphic correlations that can cross facies boundaries. Several marker beds have been identified on the surface and correlated to well-log signatures in the subsurface. The top of the carbonate marker unit of Ryder and others (1976) is placed at the top of the carbonate marker bed, which has an easily recognizable well-log response throughout most of the southwestern Uinta Basin. Jacob (1969) defines several carbonate marker beds in Nine Mile Canyon such as the D marker which is about 500 feet (150 m) above the carbonate marker bed and contains a pisolite bed which makes it easy to identify throughout most of the western portion of Nine Mile Canyon, before it dips below the canyon floor. Jacob's (1969) C marker consists of three ostracod grainstones that he designated from base to top as C3, C2, and C1. The C1 marker is equivalent to the stromatolite marker of Remy (1989) and the C marker of Remy (1992). The C marker is about 700 feet (200 m) above the D marker.

Bradley 1931	Picard 1957	Weiss & others 1990	Remy 1992	Lomax unpublished	Morgan & others 1999		
		base of the Mahogany oil shale zone					
?	green shale facies	middle member	transitional facies	Garden Gulch	MGR 12		
delta facies			<i>C</i> marker			pay sands D C B A	MGR 7
			delta facies			<i>D</i> marker	<i>B</i> limestone
	carbonate marker bed (top)	(base)		lower Douglas Creek			
second lacustrine tongue	black shale facies	lower member	<i>CMU</i> (carbonate marker unit)	Castle Peak	<i>CMU</i> (carbonate marker unit)		
Colton Tongue							
first lacustrine tongue				Uteland Butte	LGR 1-5	lower member	

Figure 2. Generalized nomenclature for the Green River Formation (below the Mahogany oil shale zone) for the south-central to southwest Uinta Basin.

Weiss and others (1990) mapped a lower member, middle member, upper member, and saline member in the Nine Mile Canyon area. Weiss and others (1990) unlike previous workers, use the base of the carbonate marker bed instead of the top as a mapping horizon. To divide the lower member from the upper member we modified the lower member using the top of the carbonate marker bed as the top of the lower member - base of middle member. The modified lower member is equivalent to the black shale facies of Abbott (1957), the middle member from the top of the carbonate marker bed to the base of the Mahogany oil shale, is equivalent to all of the delta facies of Bradley (1931), Picard (1957), and the delta and transitional facies of Remy (1992). The upper member and saline member were not part of this study.

Recent workers have begun to use a sequence stratigraphic (chronostratigraphic instead of lithostratigraphic) approach to the Green River Formation. Crouch and others (2000) reported on their subsurface study of the Uteland Butte reservoir in Antelope Creek Field. Keighley and others (1999, 2001) studied the outcrops in Nine Mile Canyon while Borer and McPherson (1996), and Borer (1998), studied the outcrops at Raven Ridge and subsurface deposits at the neighboring Red Wash field. Our study uses chronostratigraphic correlations of surface outcrops and subsurface well logs to characterize the petroleum reservoirs in the lower and middle members of the Green River Formation in the southwest Uinta Basin.

STRATIGRAPHIC NOMENCLATURE AND CORRELATION MARKERS USED IN THIS REPORT

Members

Weiss and others (1990) divided the Green River Formation in the southwest Uinta Basin into informal members, in stratigraphically ascending order: (1) lower member, (2) middle member, (3) upper member, and (4) saline member. We studied only the lower and middle members. Weiss and others (1990) used the base of the carbonate marker bed to define the top of the lower member-base of middle member of the Green River Formation but previous workers used the top of the carbonate marker bed to define the top of the carbonate marker unit (Ryder and others, 1976; and Remy, 1992). The lower member includes the Uteland Butte reservoir also known as Bradley's (1931) first lacustrine phase, or the basal carbonate (Little, 1988) and the Castle Peak reservoir or carbonate marker unit (Ryder and others, 1976). We have adopted the lower and middle member terminology, but use the top of the carbonate marker bed as the top of the lower member - base of middle member (figure 3). The carbonate marker bed is easily identifiable on well logs throughout the region. The middle member is defined as from the top of the carbonate marker bed to the base of the Mahogany oil shale. The middle member contains the lower and upper Douglas Creek reservoirs and Garden Gulch reservoir. The middle member also consists of the Douglas Creek Member and part of the Garden Gulch Member (Bradley, 1931) and Remy's (1992) delta and transitional facies.

Log Cycles

The +2,000-foot-thick (600-m), Tertiary-aged lacustrine deposits of the middle and lower members of the Green River Formation contain the primary oil-producing reservoirs in the southwest Uinta Basin, Utah. We established a log-based correlation scheme and nomenclature that reflect, as near as possible, time-correlative depositional cycles of the middle and lower members of the Green River Formation (Morgan and others, 1999). The log-cycles are at a scale that is easily recognizable on geophysical well logs, typically range from 50 to 100 feet (15-30 m) thick, and can be correlated throughout most of the southwest Uinta Basin (figure 4).

The log cycles are numbered from the base of the member upward and were defined by gamma-ray and resistivity log patterns. Log patterns that may represent coarsening-upward sequences overlain by a flooding event or a rise-to-fall sequence were identified in key wells. The correlations were then made on regional east-to-west and north-to-south well-log cross sections (figure 5 and plates 1 through 4). Correlations that were difficult to make or appeared to have a limited extent were dropped. The correlations resulted in five cycles in the lower member of the Green River Formation (LGR) plus the carbonate marker unit, which was not divided because the log-cycle pattern was too small for reliable regional correlation. In the middle member (MGR), 18 cycles were identified although MGR 1 and MGR 2 proved to be unreliable correlations and were not picked in most well-log correlations.

The top of the uppermost cycle, MGR 18, correlates to the middle marker of Ryder and others (1976). This is the top of the stratigraphic sequence that we studied. There is about 500 to 600 feet (150-180 m) of middle Green River section from the top of the middle marker to the base of the Mahogany oil shale.

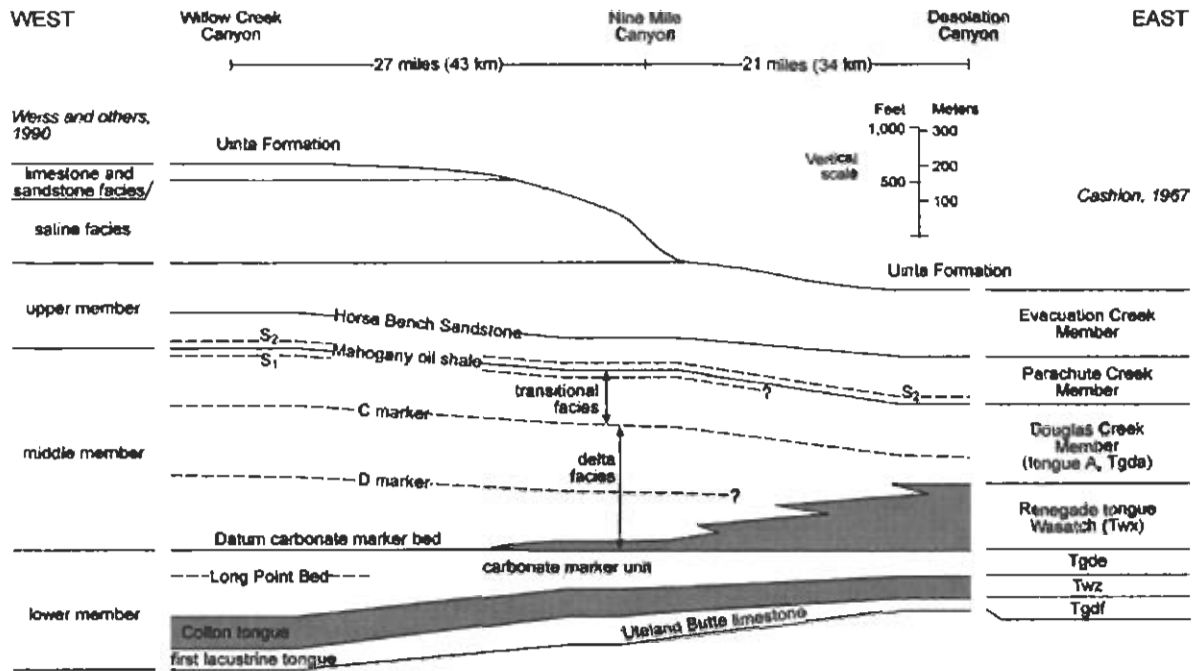


Figure 3. West to east stratigraphic cross section showing the stratigraphic nomenclature used in this report and some of the common stratigraphic names used by other workers.

Well: Federal 2-35
 Field: Monument Butte
 KB: 5,531 ft.

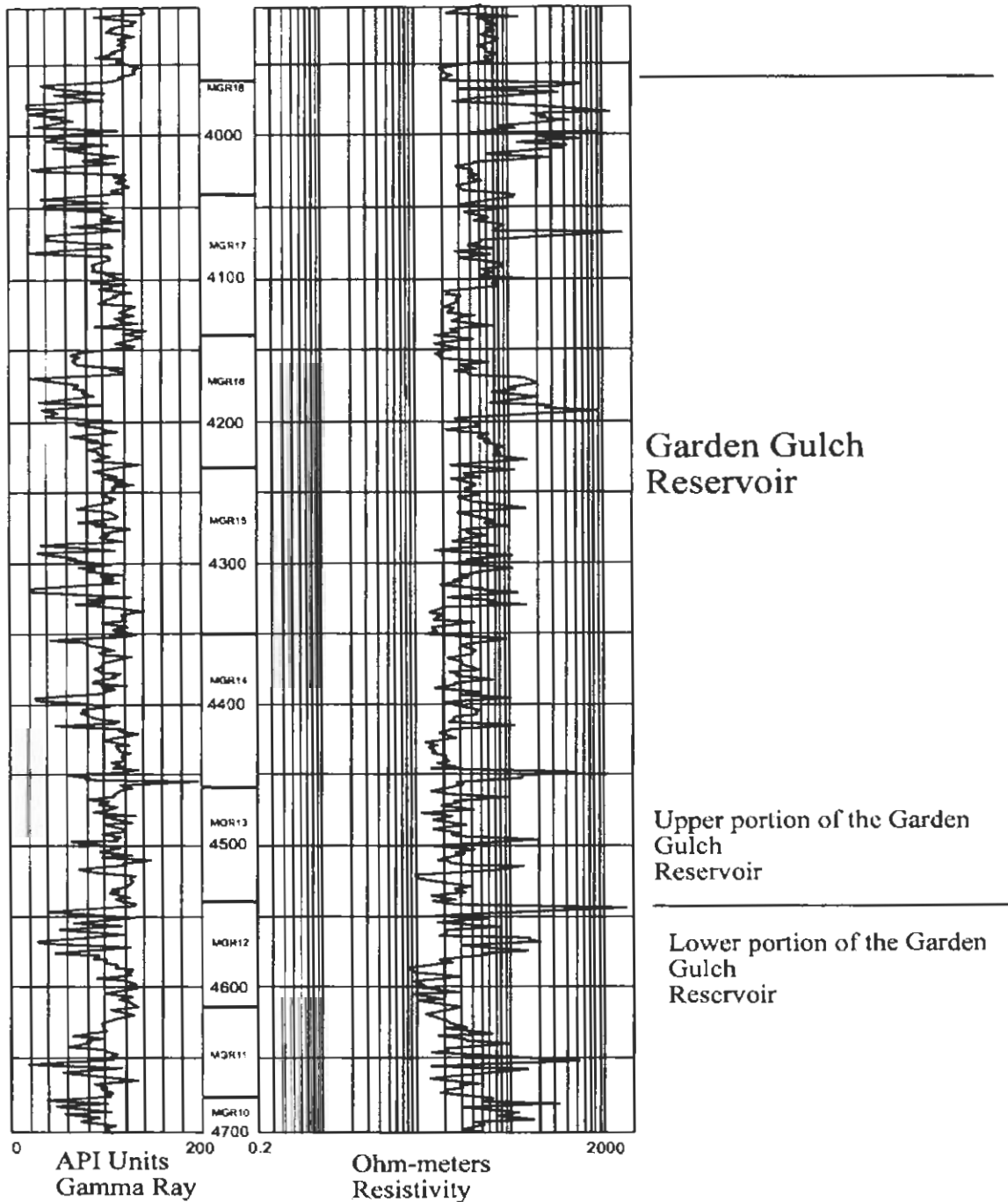


Figure 4. Type log showing the log cycles and oil reservoirs in the middle member (MGR) and lower member (LGR) of the Green River Formation. CMU is the carbonate marker unit of the lower member. Well location is NE1/4SE1/4 section 35, T. 8 S., R. 16 E., of the Salt Lake Base Line Salt Lake Base and Meridian.