RESERVOIR CHARACTERIZATION OF THE LOWER GREEN RIVER FORMATION, SOUTHWEST UINTA BASIN, UTAH

Biannual Technical Progress Report

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ABSTRACT

Preliminary maps were constructed, and are currently being edited, of depositional cycles in the Middle and Lower Members of the Green River Formation, including boundaries, total sandstone, and total feet of porosity. Some key beds in the stratigraphic sections from Willow Creek, Nine Mile, and Desolation Canyons have been correlated between the sections and to geophysical logs from wells in the area. Work on the stratigraphic sections is continuing in hope of defining more detail in the depositional interpretation and in the surface-to-subsurface correlations.

A detailed study site was selected in Nine Mile Canyon near the Nutter's Ranch house. The photomosaics of the study site were annotated to show bed relationships, major bed forms, and fracture patterns. The annotations were field checked and additional detail was added to the interpretation.

Interpretation of the preliminary regional isochore maps and the stratigraphic sequence in the Nutter's Ranch study site indicates there may have been three areas where most of the shorelines of Lake Uinta developed during Lower and Middle Green River deposition. The southernmost shoreline identified in the Nutter's Ranch study site is south of Nine Mile Canyon, referred to in this report as the Roan Cliffs shoreline (RCS). Grainstone exposed in the study site was deposited along the RCS. A shoreline existed north of Nine Mile Canyon but south of the Monument Butte area, and is referred to in this report as the Badlands Cliff shoreline (BCS). Many of the anastomosing channels exposed in the study site are believed to be related to the BCS. A third shoreline, which existed just north of the Monument Butte area, is called the Myton Bench shoreline (MBS). Many of the oil-productive channel sandstones in the Monument Butte area are believed to be related to this shoreline. Isolated, relatively deeply incised channels exposed in the study site are believed to be related to the MBS.

Geological characterization of a portion of the Monument Butte Northeast water-flood unit, Uteland Butte, and Brundage Canyon oil fields has helped improve our understanding of the differing types of reservoirs within the Lower and Middle Member of the Green River Formation. Oil production from the Monument Butte Northeast water-flood unit is controlled by the distribution and diagenesis of the sandstone in the Middle Member. Oil production from the Uteland Butte field is from carbonates in the Lower Member and is controlled by permeability distribution related to subtle facies changes. Oil production from the Brundage Canyon field is from sandstone in the Lower Member, but reservoir quality is controlled by fracture density.

TABLE OF CONTENTS

ILLUSTRATIONS

TABLES

EXECUTIVE SUMMARY

The objectives of the study are to increase both primary and secondary hydrocarbon recovery through improved characterization (at the regional, unit, interwell, well, and microscopic scale) and numerical simulation modeling 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.

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. 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. More than 1,000 wells have been correlated, and data on cycle boundaries, total sandstone, and total feet of porosity for each cycle have been entered into the well database and preliminary maps have been constructed.

Geological characterization of three oil fields, representing three reservoir types, was carried out. The three fields are: (1) Monument Butte Northeast, productive from the Middle Member of the Green River Formation; (2) Uteland Butte, productive from carbonates in the Lower Member; and (3) Brundage Canyon, productive from fractured sandstone in the Lower Member. Lithotypes were defined in the Monument Butte Northeast water-flood unit based on log-derived porosity values. Lithotypes were simulated over the unit using the appropriate variograms and the generated reservoir description is being used to simulate production from the unit. Numerical simulation models will be constructed for Uteland Butte and Brundage Canyon fields as well.

Numerous stratigraphic sections of the Middle Member of the Green River were measured and described in Willow Creek, Nine Mile, and Desolation Canyons. Spectral gamma-ray (GR) data were collected over four regional stratigraphic sections totaling 5,123 feet (1,561.5 m) in the Green River Formation: one in Willow Creek Canyon, and three in Nine Mile Canyon. Curves generated from the GR data have been correlated with GR curves from wells in the area.

A detailed study site was selected in Nine Mile Canyon, extending from Petes Canyon to Gate Canyon, which are tributaries to Nine Mile Canyon. The exposure is about 2,000 feet (600 m) in an east-west direction and about 500 feet (150 m) in a north-south direction. The stratigraphic interval studied is slightly more than 100 feet (30 m) thick, bounded above and below by carbonate beds. Six sections have been measured and described, and GR data gathered from five of the sections. To aid interpretation, the canyon walls of the site were photographed from the opposite side of the canyon, and photomosaics were compiled. The photomosaics have been annotated showing bed relationships, major bed forms, and fractures. The annotations were field checked and more detailed information added. Data from the study site provides significant information about the potential reservoir heterogeneity in the interwell environment.

Technology transfer activities included presentations at the June 2000, U.S. Department of Energy (DOE), contractor review meeting in Denver, Colorado, and at the American Association of Petroleum Geologists (AAPG) Rocky Mountain Section meeting in Albuquerque, New Mexico. Project materials were displayed at the Utah Geological Survey (UGS) exhibitor's booth at the AAPG Annual Convention in New Orleans, Louisiana and at the AAPG Rocky Mountain Section meeting in New Mexico. Presentations were made to the Technical Advisory

Board and planned activities were discussed. A home page for the project is maintained on the UGS web site.

INTRODUCTION

Geologic Setting

The Uinta Basin is a topographic and structural trough encompassing an area of more than 9,300 square miles (14,900 km^2) 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 Paleocene to Eocene time, creating a large area of internal drainage which was filled by ancestral Lake Uinta. 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 Formation (Wasatch).

More than 450 million barrels of oil (63 MT) 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 Monument Butte area 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 Monument Butte area resulted in numerous stacked deltaic deposits. Distributary-mouth bars, distributary channels, and nearshore bars are the primary producing sandstone reservoirs in the area.

Project Status

We are studying the Green River Formation on outcrop and in the subsurface to increase our knowledge of its reservoir characteristics, and to improve our ability to identify new play areas. 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. The regional correlation nomenclature will help identify which intervals are productive in the southwest Uinta Basin. 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. More than 1,000 wells have been correlated and entered into the geographic information system (GIS) database and preliminary maps have been constructed. The maps are currently being checked for errors, such as incorrect well locations and data entry errors. Based on some of the preliminary maps and the outcrop study, we believe there were at least three areas where shorelines of Lake Uinta commonly developed: (1) south of Nine Mile Canyon, (2) between Nine Mile Canyon and the Monument Butte area, and (3) north of the Monument Butte area.

Core from 32 wells in the project study area has been described and depositional environments interpreted. Editing of the core descriptions is complete and a final report will be prepared.

Geological characterization of three oil fields, (1) Monument Butte Northeast, (2) Uteland Butte, and (3) Brundage Canyon, is nearly completed. Sandstone thickness, total feet of porous sandstone, and structural elevation of every productive bed in each of the three fields were determined and entered into the GIS database. Porosity and fluid saturation were also determined from the geophysical logs at a 1-foot (0.3 m) scale for each bed. This data is being used to construct a numerical simulation model of the Monument Butte Northeast water-flood unit and will be used to construct models for the Uteland Butte and Brundage Canyon oil fields.

Several stratigraphic sections had previously been measured and described, and spectral gamma-ray (GR) data were gathered in Willow Creek and Nine Mile Canyons. Curves were generated from the outcrop GR data and correlated to the geophysical logs of nearby wells. Additional sections were measured and described in Desolation Canyon and Trail Canyon, a tributary to Nine Mile Canyon. The Desolation Canyon section is the easternmost exposure studied. Gamma-ray data were gathered over the Trail Canyon section to help correlate it to well logs that lay directly north and south of the section. A few marker beds have been correlated between the stratigraphic sections, and using the GR curves these beds have been correlated to well logs. Detailed correlation between the various surface stratigraphic sections, and between the surface stratigraphic sections and the subsurface well logs, is continuing. Hopefully, some of the cycles identified on the well logs, and regionally mapped, can be correlated to depositional cycles identified on the surface stratigraphic sections. This effort will be supplemented with additional field work.

A study site was selected to better understand the interwell-scale reservoir heterogeneity of one depositional cycle. The site, referred to as the Nutter's Ranch study site, lies along Nine Mile Canyon from Petes Canyon to Gate Canyon, both tributaries to Nine Mile Canyon. The exposures provide a three-dimensional perspective that, in the longest dimension, covers about the distance between two wells if drilled on 40-acre (16.2-ha) spacing. Seven stratigraphic sections have been measured and described, and GR data were gathered over six of the sections. Photomosaics were constructed and annotated. The annotations were field checked, and paleoflow and fracture data were gathered. A depositional interpretation of the strata studied was developed and will be presented to the Technical Advisory Board during a fall field review.

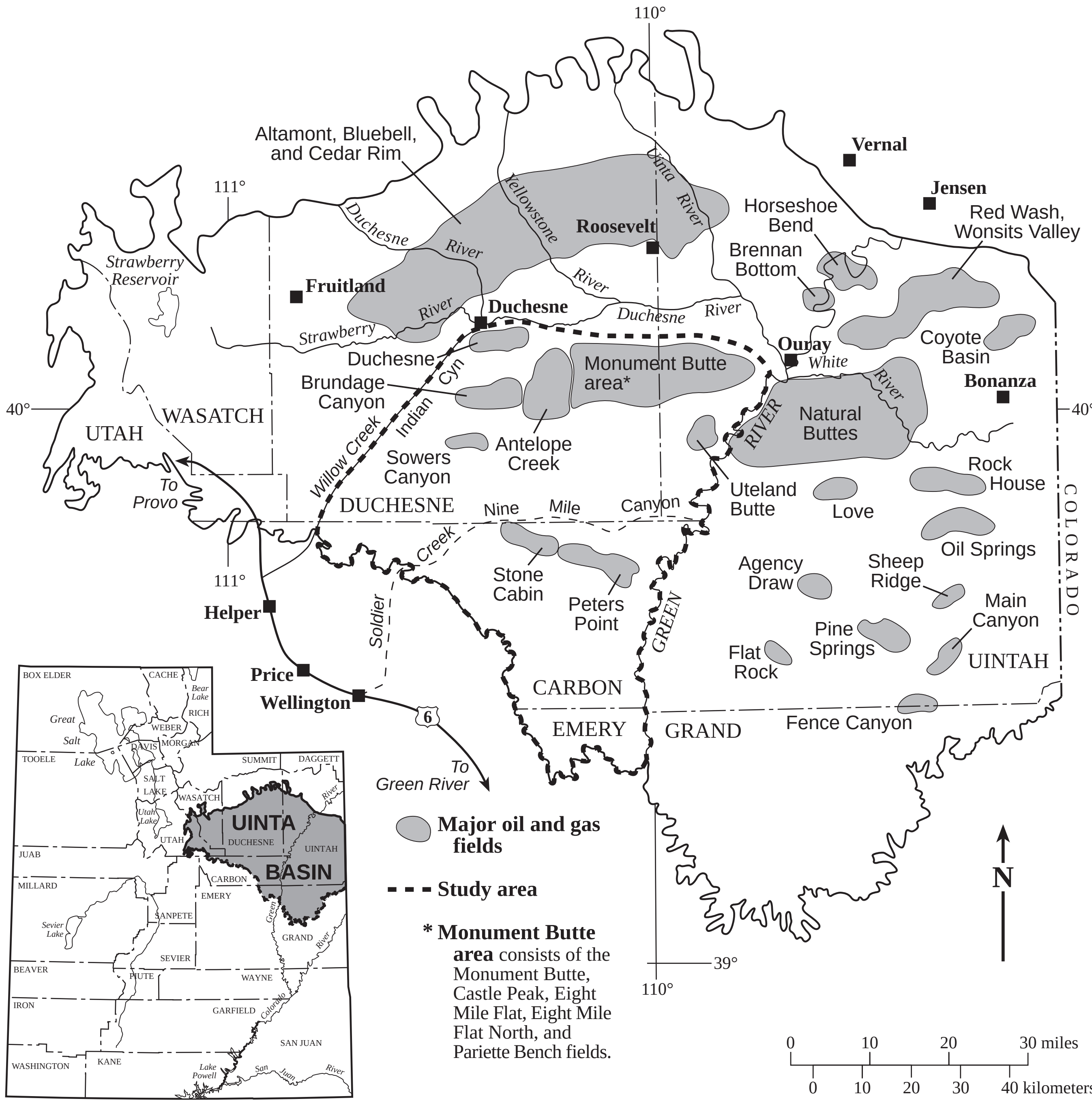


Figure 1. Index map of the Uinta Basin, Utah, showing study area and major oil and gas fields.

GEOLOGIC INVESTIGATION OF THE GREEN RIVER FORMATION IN THE SUBSURFACE

Regional Characterization

Geophysical well logs were used to define 22 log cycles for the Middle and Lower Members of the Green River Formation (figure 2). The logs were correlated using an alpha-numeric bed numbering scheme described in the first biannual technical report (Morgan and others, 1999a). The drill-depth top of each log cycle, total feet of sandstone, and total feet of sandstone with 10 percent or more porosity were entered into the GIS database. The GIS database is being used to map and interpret regional trends and depositional environments of each of the 22 log cycles. Logs from more than 1,000 wells have been correlated and entered into the database. The final product will be an interactive GIS project in which the user can view maps within the GIS project or use the data files to construct their own maps.

Field-Scale Characterization

Geological characterization, consisting of correlating and mapping all perforated beds, was carried out on portions of three oil fields: (1) Monument Butte Northeast, (2) Uteland Butte, and (3) Brundage Canyon (figure 3). The fields are examples of three different reservoir types found in the southwest Uinta Basin. The geological characterizations will be used for reservoir numerical simulation modeling.

The Monument Butte Northeast water-flood unit has beds perforated throughout the Lower and Middle Members of the Green River Formation. However, most of the oil production is from units MGR 4 through MGR 7 (B, C, and D sands in operator terminology). The Uteland Butte field produces oil from units LGR 1 through LGR 5 (Basal Limestone or Uteland Butte Limestone in operator terminology) of the Lower Member. The Brundage Canyon field produces oil from sandstone beds in the carbonate marker unit (Castle Peak Sandstones in operator terminology) in the Lower Member.

Monument Butte Northeast Water-flood Unit

The Monument Butte Northeast water-flood (secondary recovery) unit covers all of section 25, and parts of sections 24 and 26, T. 8 S., R. 16 E., of the Salt Lake Base Line (SLBL), Duchesne County, Utah. The study focused on the 16 wells drilled in section 25, but wells bordering the section were correlated for mapping. There are 27 beds which have been perforated in one or more wells in section 25 (figure 4). Most of the wells are perforated in units MGR 4 through MGR 7 (Douglas Creek B, C, and D, sands in operator terminology) which are the primary objective beds. Most of the other beds are secondary objective beds and are only perforated in one to three wells.

Wells in Monument Butte Northeast were completed by perforating all the beds that had a favorable show of hydrocarbon while drilling and/or from interpretation of the well logs. When section 25 was fully drilled (16 wells, one well per 40 acres [1.6 ha]) secondary recovery was begun. Every other well was converted to a water-injection well. Many of the secondary objective beds are not being fully exploited during the secondary recovery phase of production

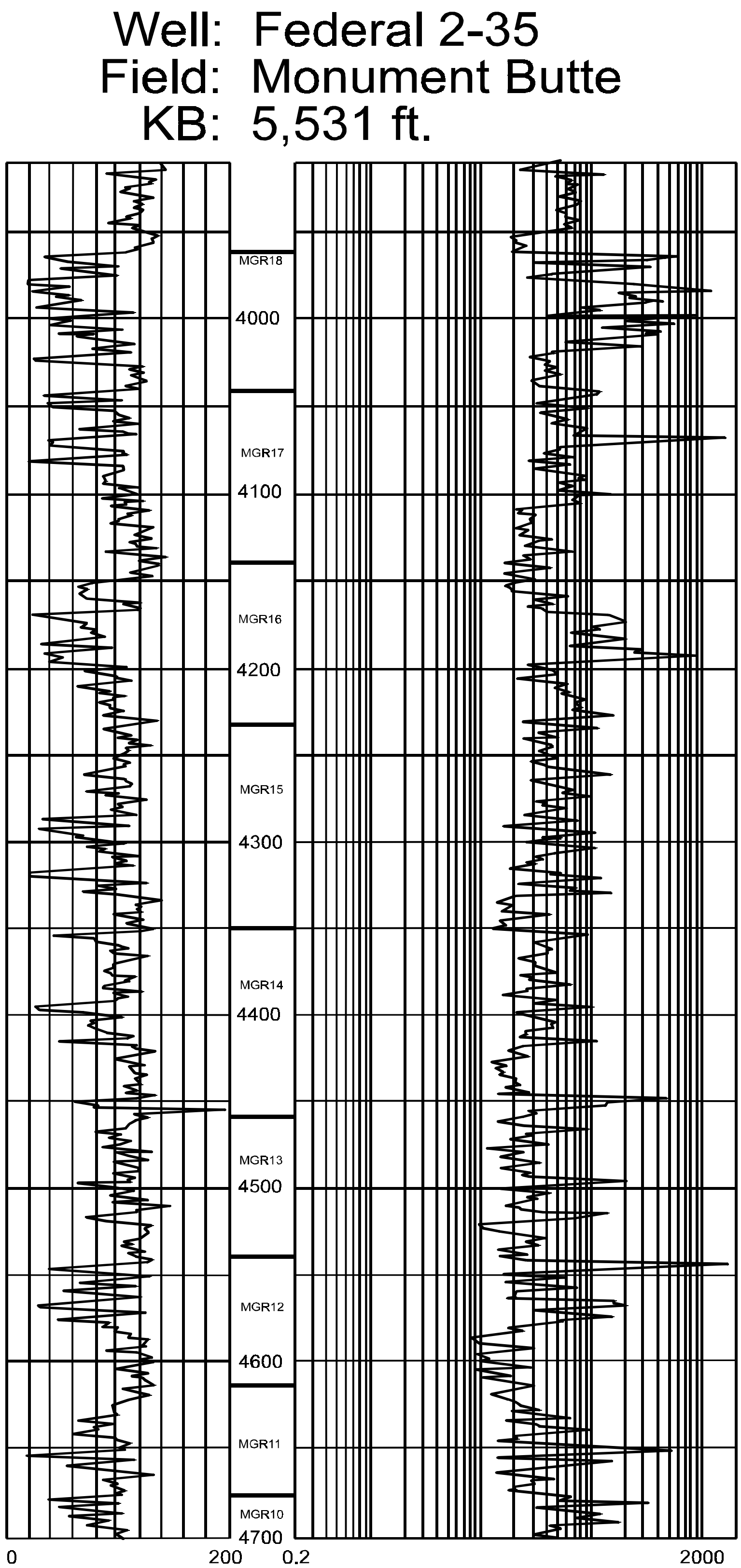


Figure 2. Type log showing the log cycles in the Lower and Middle Members of the Green River Formation.

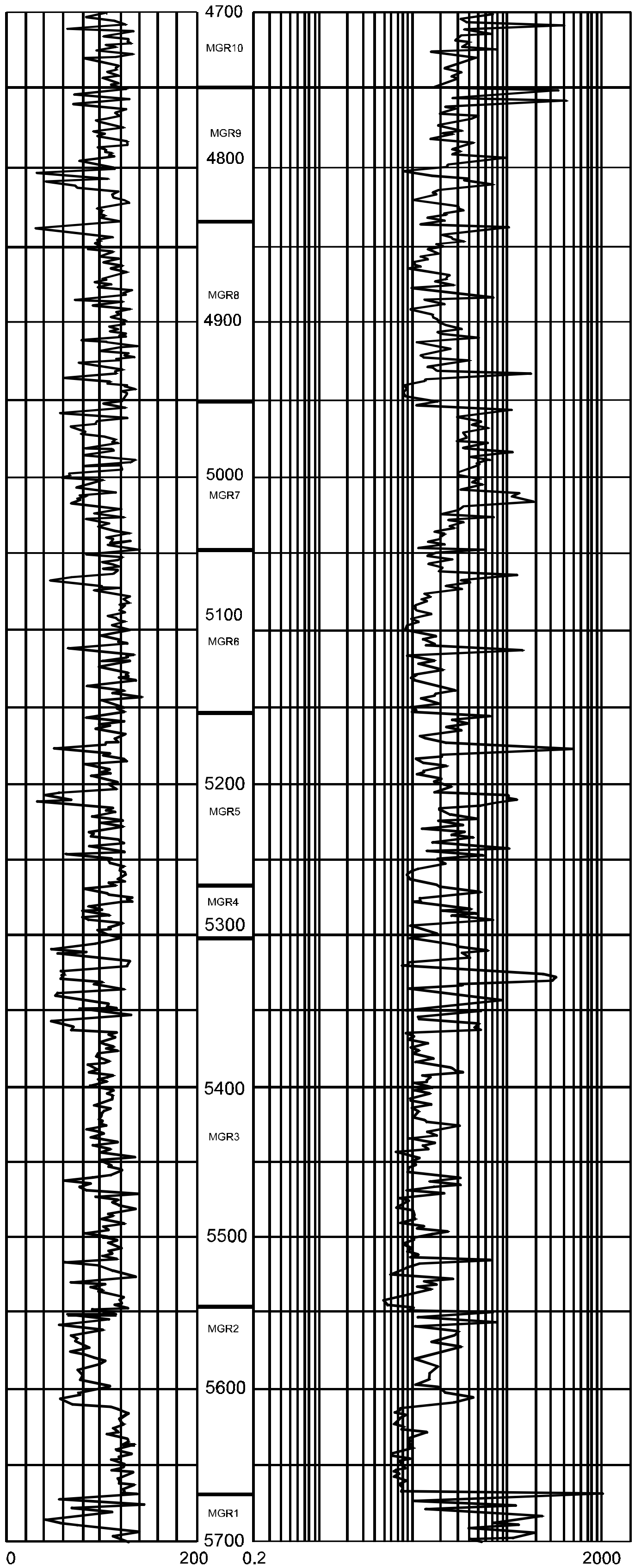
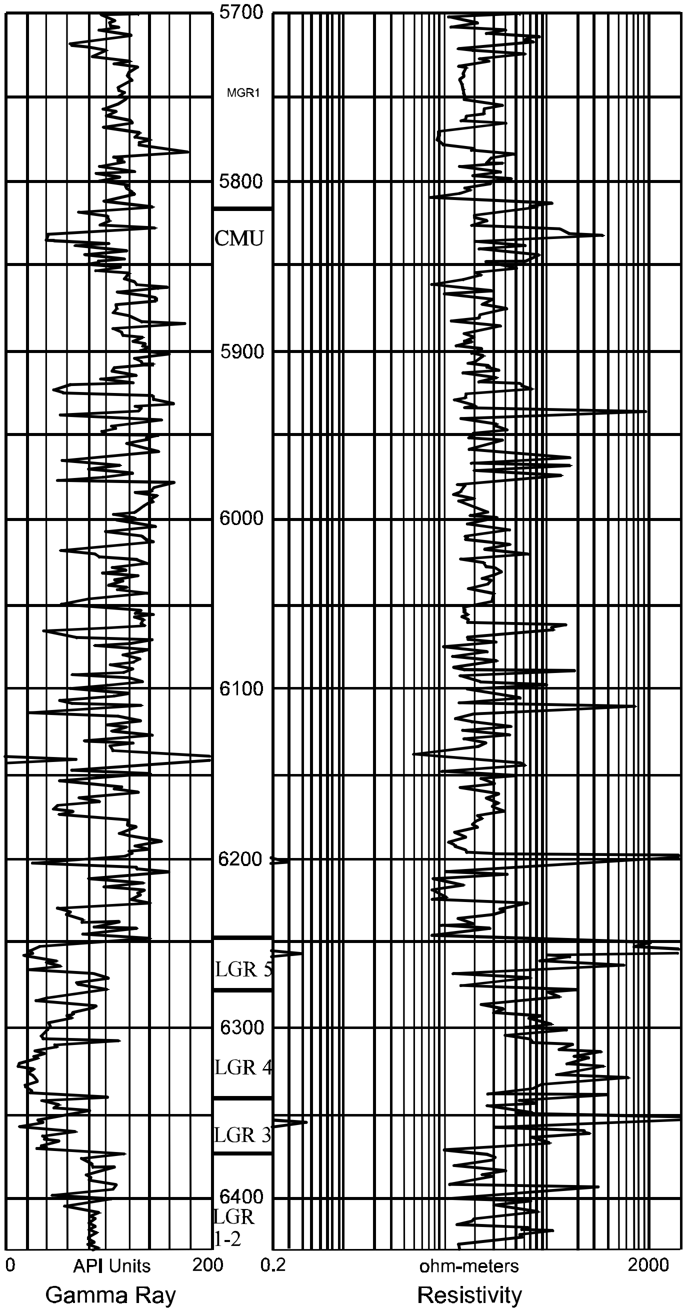

4700
MGR10
MGR9
4800
MGR8
4900
5000
MGR7
5100
MGR6
5200
MGR5
MGR4
5300
5400
MGR3
5500
MGR2
5600
MGR1
5700
0
200
0.2
2000

Figure 2b.



Total Depth 6,440 ft.

Figure 2c.

Figure 3. Index map showing the location of the three oil fields, Brundage Canyon (section 25 only), Monument Butte Northeast and Uteland Butte, that were geologically characterized and will be used for numerical simulation modeling.

Figure 4. Type log for the Monument Butte Northeast water-flood unit in section 25, T. 8. S., R. 16 E., SLBL. Log cycles and some common operator terminology are shown for the Lower and Middle Members of the Green River Formation. The log is from the 10-25 well in the NW1/4SE1/4 section 25, T. 8 S., R. 16 E., SLBL.

because some are only perforated in injection wells while others are only perforated in producing wells (figure 5).

The producer-injector pattern also does not always fully exploit the primary objectives. Many of the beds could be more effectively exploited with a pattern based on the sandstone trend. This could be accomplished by infill drilling along the sandstone trends or drilling short horizontal laterals from existing wells (figures 5 and 6).

Uteland Butte Oil Field

The Uteland Butte oil field covers parts of sections 2, 3, 10, and 11, T. 10 S., R. 18 E., SLBL, Uintah County, Utah. The wells are perforated in units LGR 5 through LGR 1, (Basal Limestone or Uteland Butte Limestone in operator terminology) in the Lower Member of the Green River Formation (figure 7). The reservoir is dominantly carbonate, varying from limestone to limy dolomite to dolomite, with rare thin sandstone beds in an area of regional north dip and no structural closure (figure 8). The field is in primary production. The wells are low volume, typically producing less than 100,000 barrels (14,000 MT) of oil per well (figure 8). Bed thickness defined with the gamma-ray curve, and porosity determined by the density and neutron logs, show only minor variation over the field area and do not define the reservoir and trap. Subtle permeability changes related to the gradual lithology variations probably provide the stratigraphic trap in the Uteland Butte field. The LGR 5 through LGR 1 reservoir is a secondary objective in most other fields in the southwest Uinta Basin because of the low volume of oil production.

Brundage Canyon Oil Field

The Brundage Canyon oil field covers most of T. 5 S., R. 4 W., and the eastern portion of T. 5 S., R. 5 W., Uinta Base Line (UBL), Duchesne County, Utah. Our study focused on all of section 25 and part of section 24, T. 5 S., R. 5 W., UBL, and parts of sections 19 and 30, T. 5 S., R. 4 W., UBL (figure 9) There are 10 beds perforated in one or more wells in the portion of the Brundage Canyon field studied (figure 10).

The objective in Brundage Canyon field is sandstone beds in the carbonate marker unit (Castle Peak Sandstones in operator terminology) of the Lower Member of the Green River Formation. The field is in primary production. Sandstone distribution and porosity (figures 11 and 12) are important reservoir parameters but reservoir quality is very dependent on natural fractures in the sandstone beds. As a result, individual well performance can vary widely (figure 9). Non-fracture density-log porosity is typically 2 to 4 percent and 8 to 12 percent when density and neutron porosities are averaged. The CMUc bed (figures 11 and 12) has the best porosity of all the perforated beds in the Brundage Canyon study area.

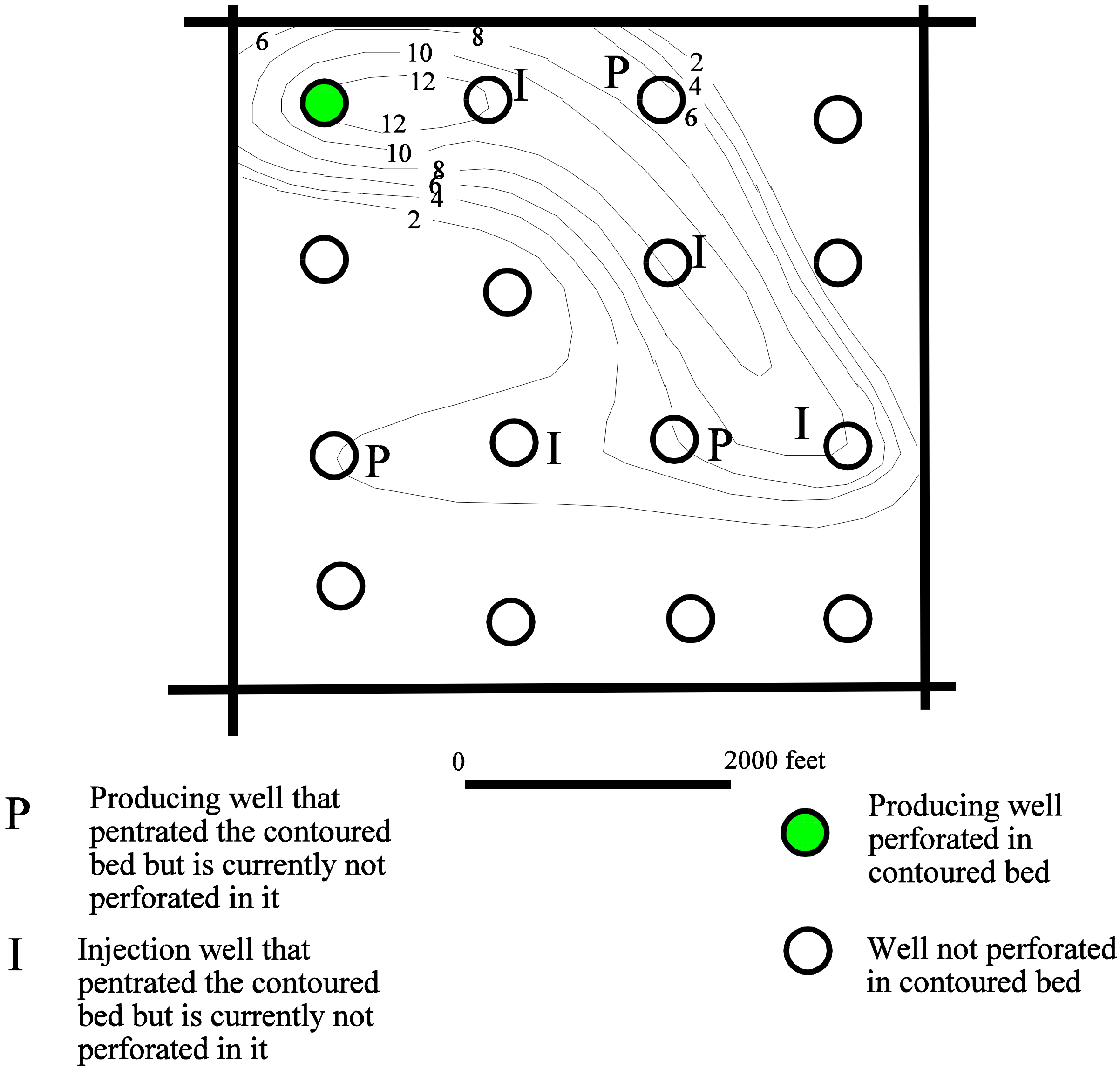


Figure 5. Isochore of net sandstone in bed MGR 10a in the Monument Butte Northeast water-flood-unit section 25, T. 8 S., R. 16 E., SLBL. This is an example where only one well (NW1/4NW1/4) is perforated in the bed and is not being flooded. Oil production from this bed might be improved if the neighboring injection well (NE1/4NW1/4) were perforated in this same bed. Also, other production and injection wells that penetrated the sandstone may have potential for additional oil production. Contour interval is 2 feet.

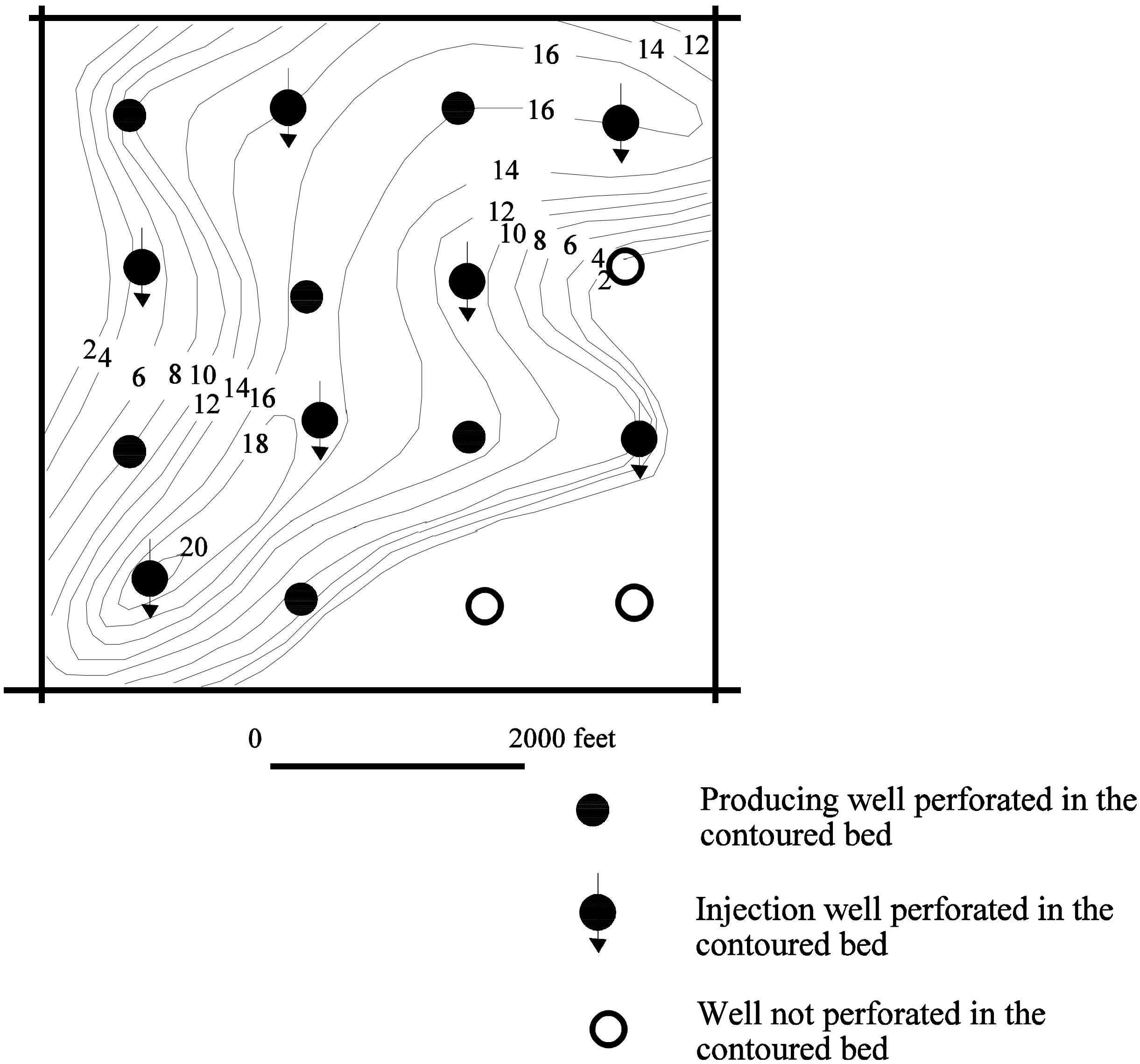


Figure 6. Isochore of the net sandstone in bed MGR 7b in the Monument Butte Northeast water-flood-unit section 25, T. 8 S., R. 16 E., SLBL. This is an example where the production-injection well pattern does not fully exploit the trend of the sandstone bed. One way to increase production from this bed would be to drill a production well between the two injection wells in the SW1/4. Another way to improve production from this bed would be to drill short horizontal laterals parallel to the trend of the bed in the wells in the NW1/4NE1/4 and SE1/4SW1/4, and pependicular to the trend of the thickest portion of the sandstone body in the other producing wells. Contour interval is 2 feet.

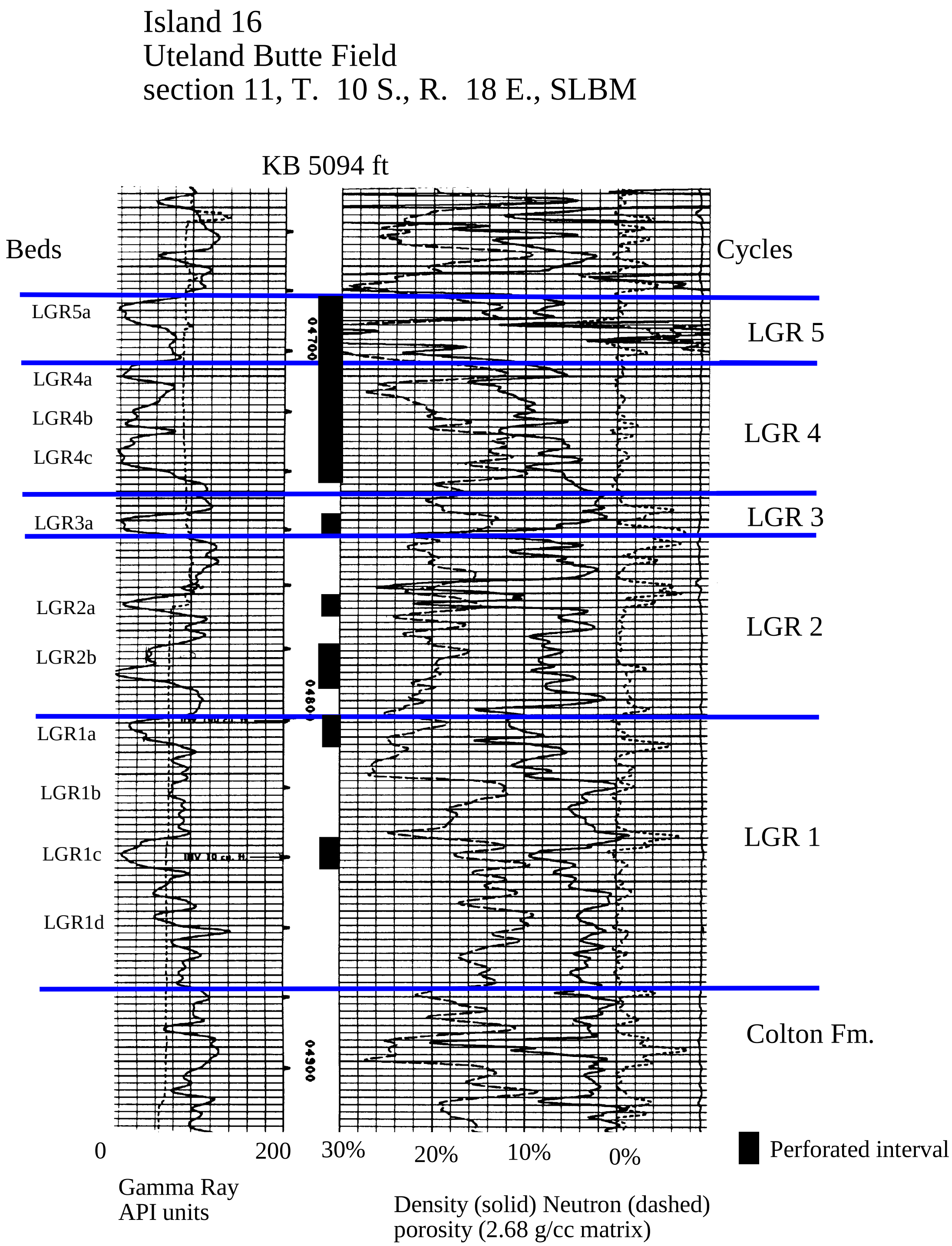


Figure 7. Type log for the Uteland Butte oil field showing desigination of log cycles and beds.

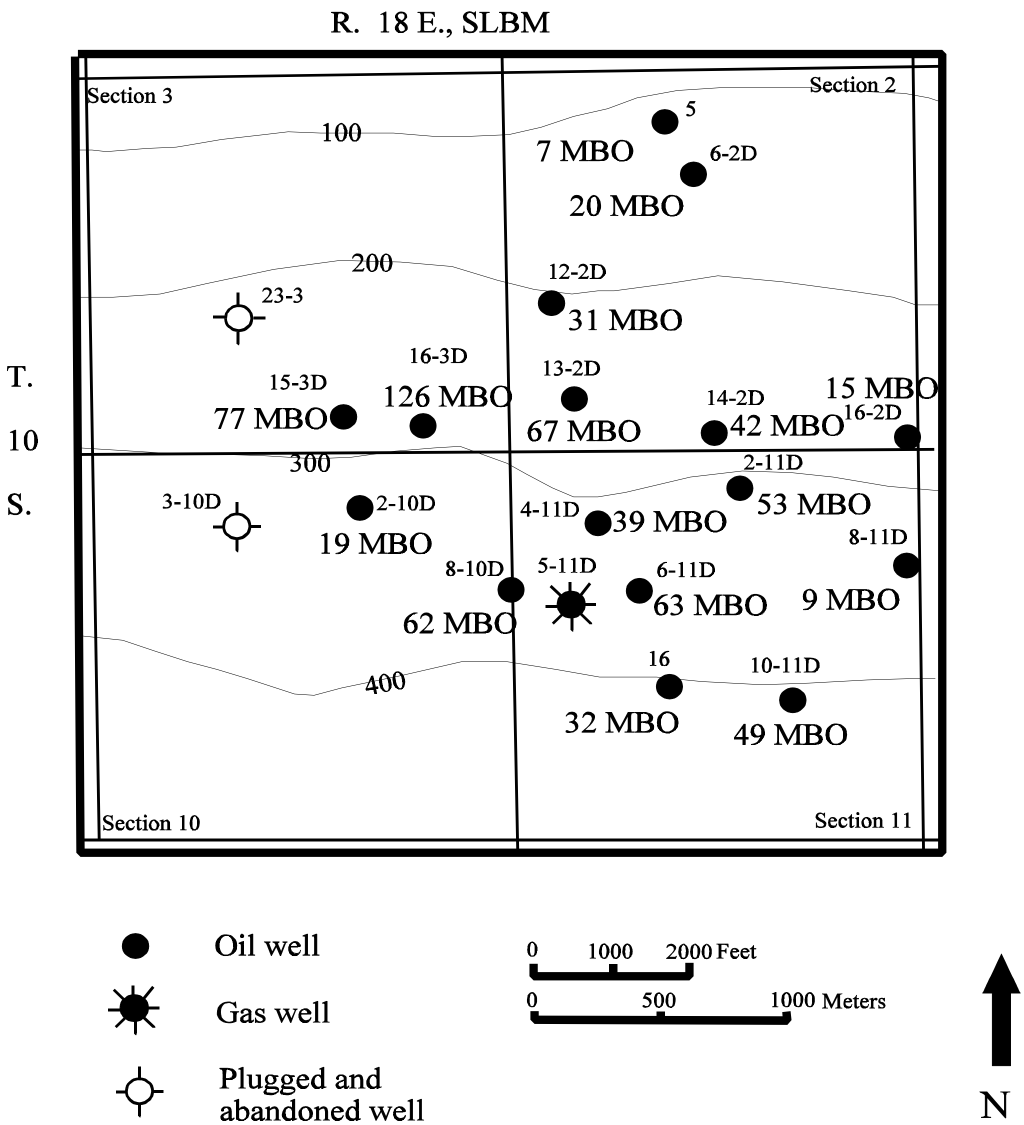


Figure 8. Index map of the Uteland Butte oil field showing structure of the top of the LGR 5 bed (contour interval 100 feet sea level datum) and the cumulative oil production as of June 30, 2000. Production data from the Utah Division of Oil, Gas and Mining.

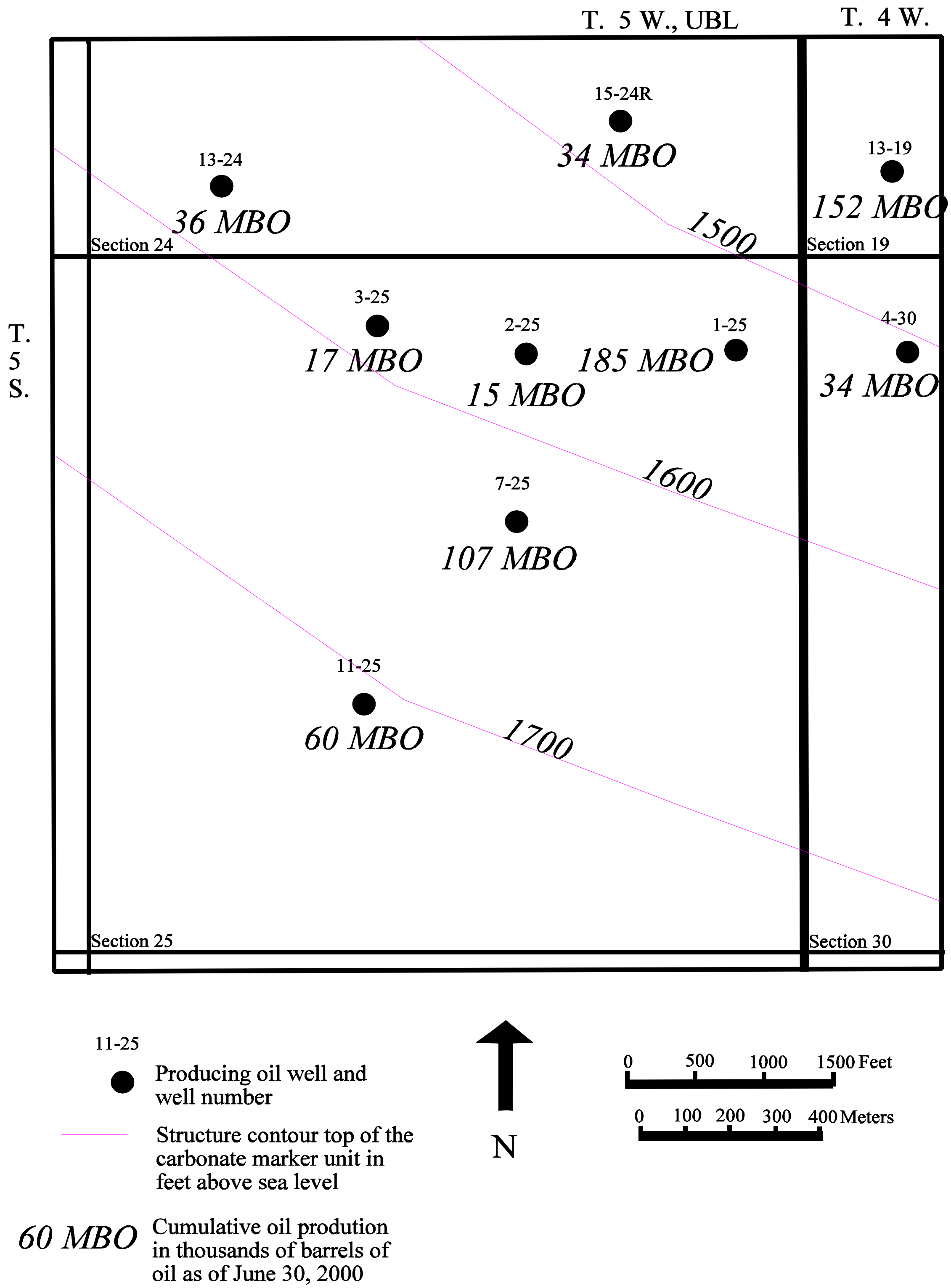


Figure 9. Index map of the study area within the Brundage Canyon oil field showing structure of the top of the carbonate marker unit and cumulative oil production as of June 30, 2000 Production data from the Utah Division of Oil, Gas and Mining.

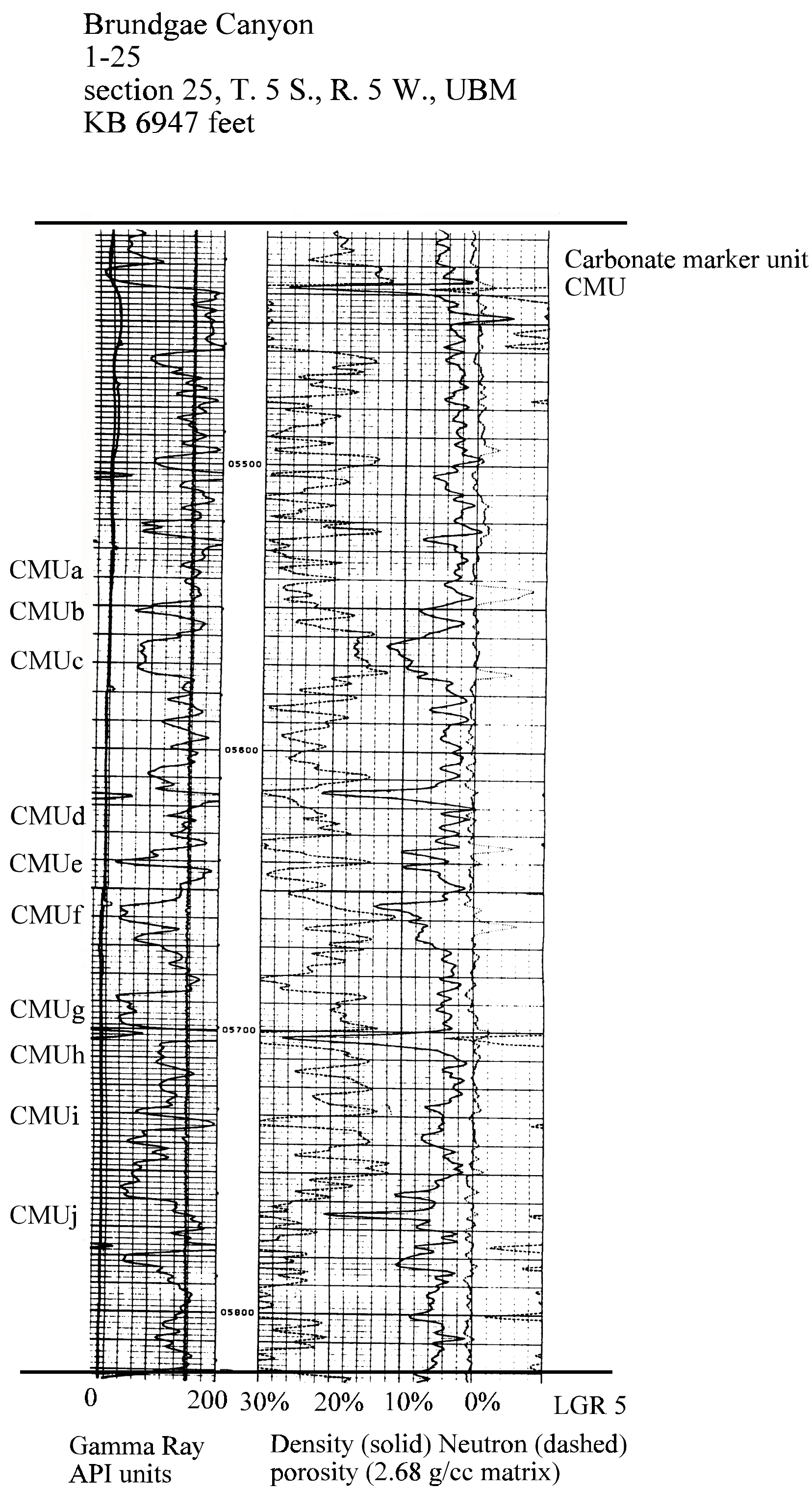


Figure 10. Type log for the Brundage Canyon oil field showing bed designations used for oil productive beds in the carbonate marker unit (CMU).

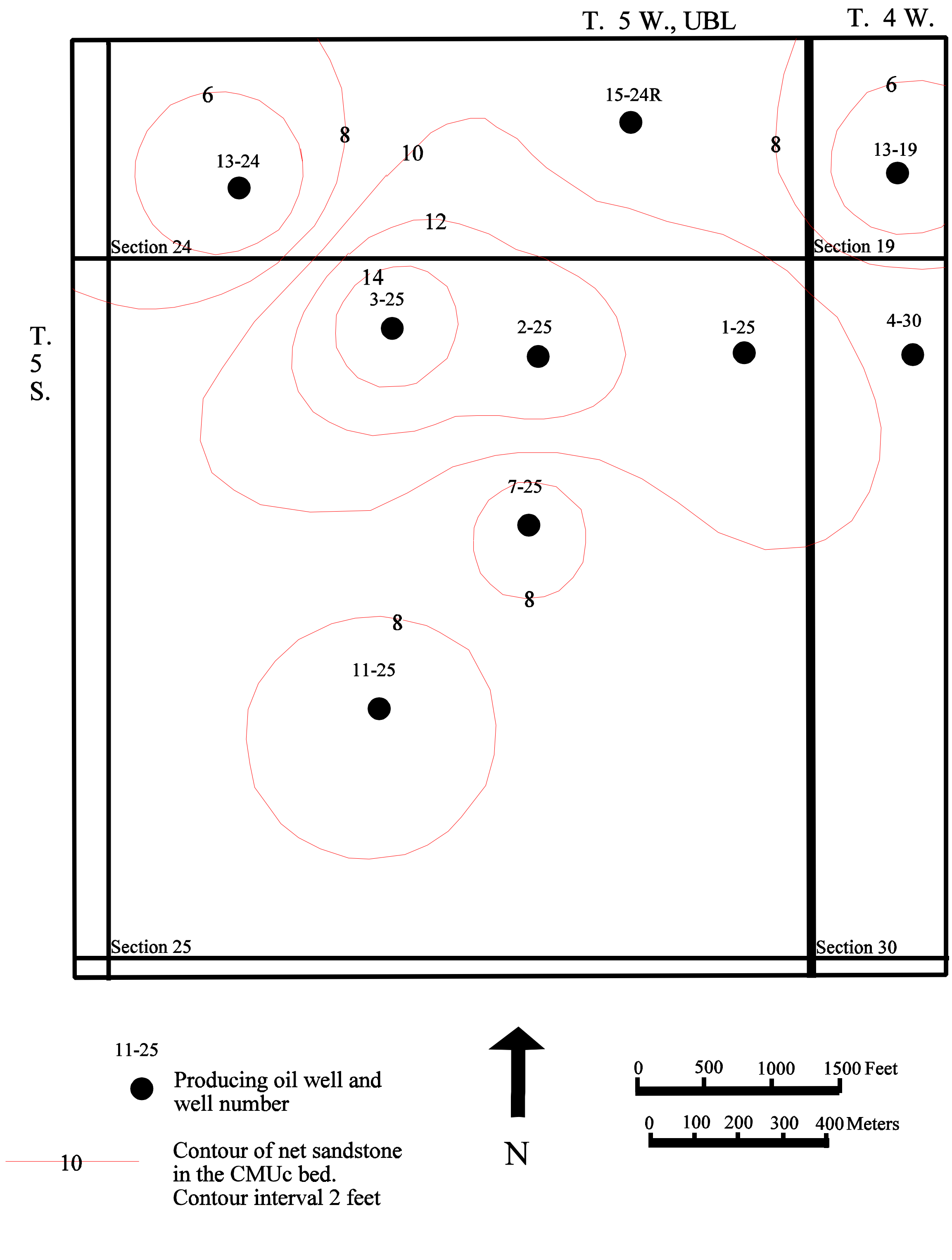


Figure 11. Isochore map of the CMUc sandstone in the Brundage Canyon oil field study area. Contour interval is 2 feet.

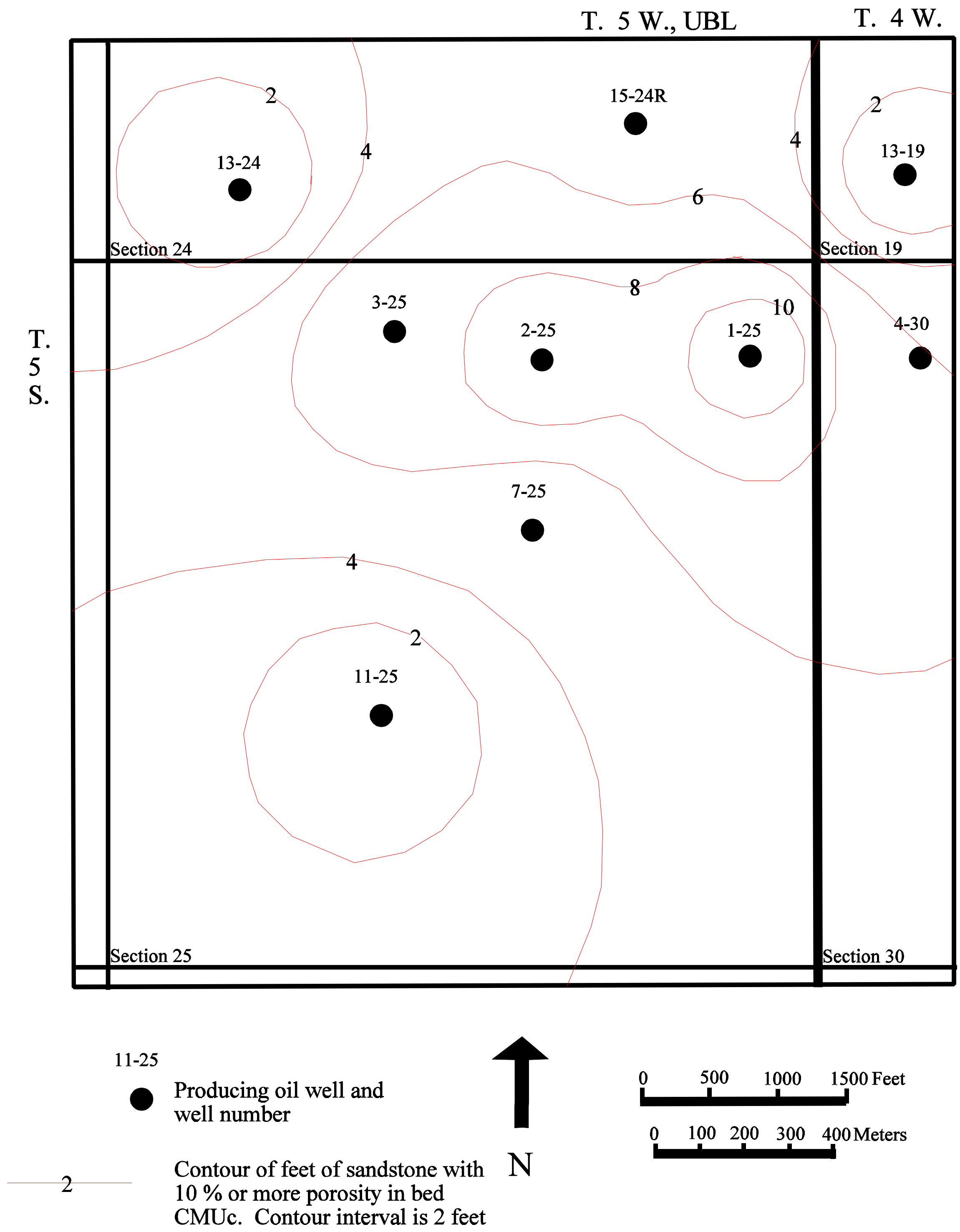


Figure 12. Feet of sandstone with 10 percent or more porosity in the CMUc sandstone. Contour interval is 2 feet.

GENERATION OF RESERVOIR MODELS

Petrophysical properties have been derived for the strata of the Monument Butte Northeast water-flood unit in section 25, T. 8 S., R. 16 E., SLBL. Figure 13 shows the 15 wells in section 25 and the reference grid that was used, which was 20 blocks in the x-direction and 20 blocks in the y-direction. The block dimensions in both the x and y directions were 264 feet (80.5 m) each. The log-derived information included porosities and water saturations at 0.5-foot (0.15-m) intervals. The first step was to define lithofacies based on porosities which are shown in table 1.

Table 1. Lithofacies and lithotype assignments.

Porosities (percent)	Lithofacies	Lithotypes
10 to 12.5	10	1
12.6 to 15	20	2
15.1 to 17.5	30	3
17.6 to 20 or more	40	4

Lithotypes, in four of the wells (10-25, 11-25, 12-25, and 13-25) are shown in figure 14. Multiple lithotypes can be defined in a lithofacies but in this model a one-to-one assignment was made (lithotype 1 is the same as lithofacies 10, for example). The upper (10) and lower (20) surfaces are the upper and lower boundaries of the sandstone bed, while the middle surface (15) was chosen at the middle of each bed simply as a reference surface (figure 14). A northwest-southeast cross section through section 25 is shown in figure 15. The surfaces for the cross section are shown in figure 16.

The entire MGR 7b and MGR 7c (D-sandstone in operator terminology) reservoir was modeled as one lithounit. A parallel grid was used in describing the stratigraphy. Permeability was modeled using the cross-plot shown in figure 17. A semi-logarithmic correlation between permeability and porosity was found to fit most measured porosity and permeability values across the field. The equation for the permeability-porosity cross-plot is:

$$\mathbf{Log}\ (K) = 0.218\ \varphi - 2.225$$

where, K is in millidarcies and φ is in percentage. The general statistics for the entire data set for permeability and porosity are shown in Table 2.

Table 2. General permeability (millidarcies [mD]) and porosity (percent [%]) statistics for the entire section.

	Lithofacies 40		Lithofacies 30		Lithofacies 20		Lithofacies 10	
Attribute	φ (%)	K(mD)	φ (%)	K(mD)	φ (%)	K(mD)	φ (%)	K(mD)
#samples	86	86	114	114	121	117	91	80
Min	15.93	17.7	15.03	11.2	12.28	2.8	10.01	0.9
Max.	20.3	158.7	17.49	38.7	16.34	21.8	12.51	3.2
Mean	18.6	74.02	16.2	21.1	13.9	6.992	11.5	2.085
Stdev	0.854	33.24	0.71	7.7	0.79	2.78	0.71	0.63

A map of the elevation of the top surface is shown in figure 18 and the corresponding map for the bottom surface is in figure 19. The reservoir is basically constrained between these two surfaces. The thickness distribution is shown in figure 20. The reservoir is thickest in the central portion and tapers off at the edges.

Using the appropriate variogram parameters, lithotypes were simulated over the entire field. Lithounit distribution in the same cross section (as in figure 15) is shown in figure 21. Corresponding porosities and permeabilities are shown in figures 22 and 23.

At the current model resolution, there are a total of about 250 half-foot (0.15-m) layers, which would yield a total of 100,000 grid blocks. It is possible to build a reservoir model with that many blocks; however, the awkward aspect ratios of grid blocks would cause numerical instabilities. Therefore, the first series of reservoir models was built by upscaling the blocks vertically. A total of 13 vertical blocks was created. The proportion of porosity as a function of elevation is shown in figure 24. This diagram is used to select locations of upscaled layers which were selected at regular intervals. A reservoir model that is suitable for simulation was built using the upscaled information. The reservoir grid (plan view) is shown in figure 25.

The upscaled cross sections for the section shown in figure 15 are presented in figures 26 (porosity), figure 27 (permeability), and figure 28 (water saturation). The basic quality of petrophysical property distribution is preserved in the upscaling process.

The generated reservoir description is being used to simulate production in section 25 and to see if production results match the field data. Simulators were provided to the University of Utah by the Computer Modeling Group, Inc., Calgary, Canada. A copy of the current simulation file is provided in Appendix A. Simulation results are currently being compiled.

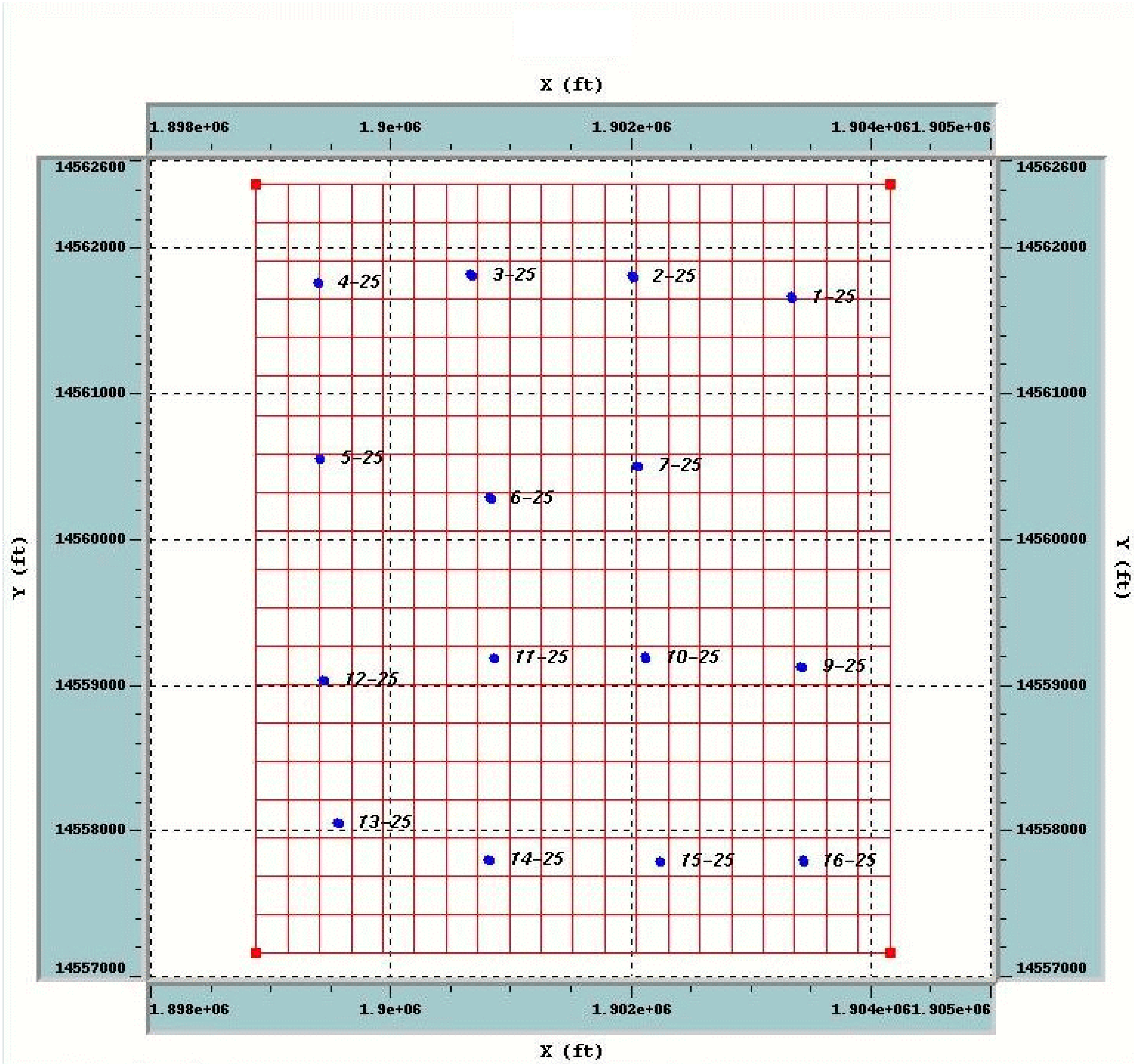


Figure. 13. Map of section 25, T. 8 S., R. 16 E., SLBL, showing the grid and wells in the Monument Butte Northeast water-flood unit.

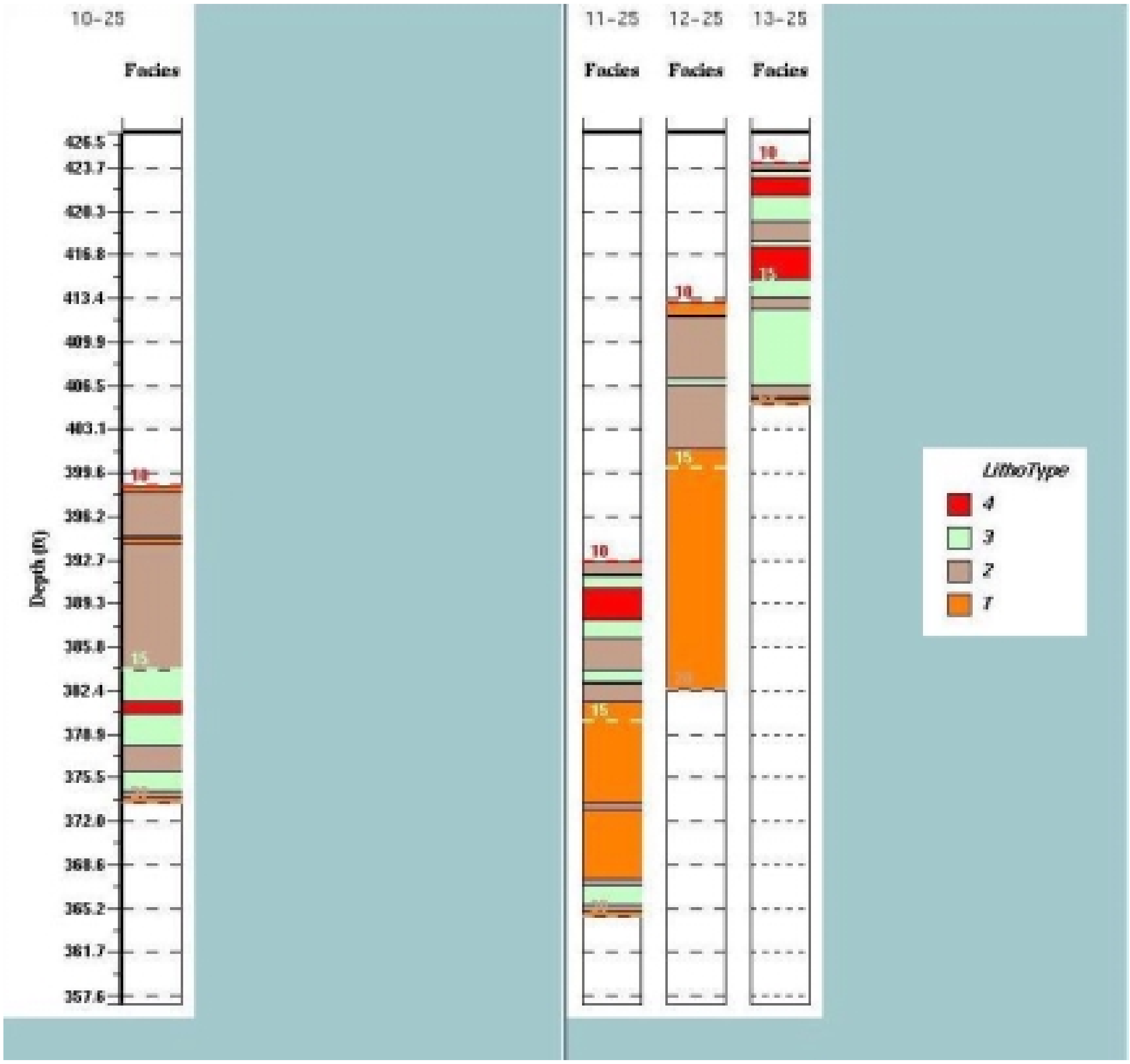


Figure 14. Lithotypes in some of the wells in the Monument Butte Northeast water-flood unit. See table 1 for lithotype definitions. The numbers 10, 15, and 20, refer to the upper, middle, and lower surface of the sandstone bed.

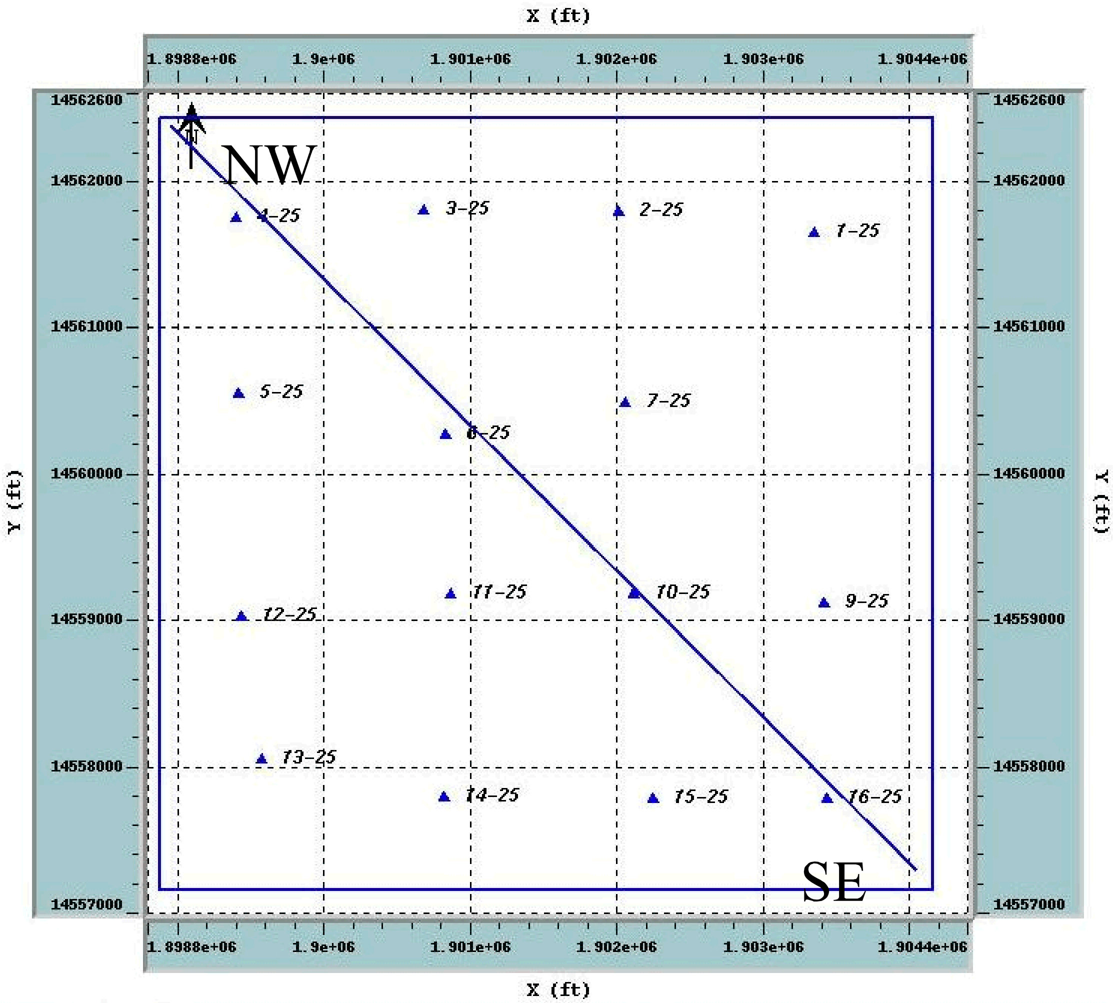


Figure 15. Location of the northwest-to-southeast cross section shown in figures 16, 21, 22, 23, 26, 27 and 28.

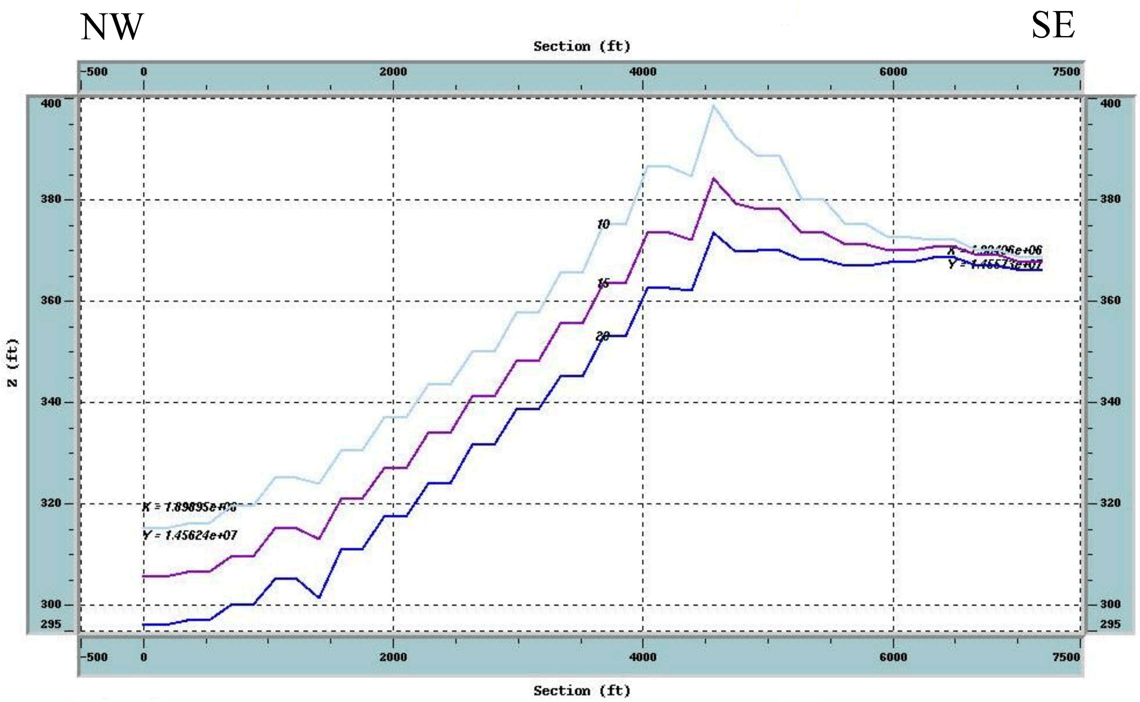


Figure 16. Three surfaces along a northwest-to-southeast cross section. Location of the cross section is shown in figure 15.

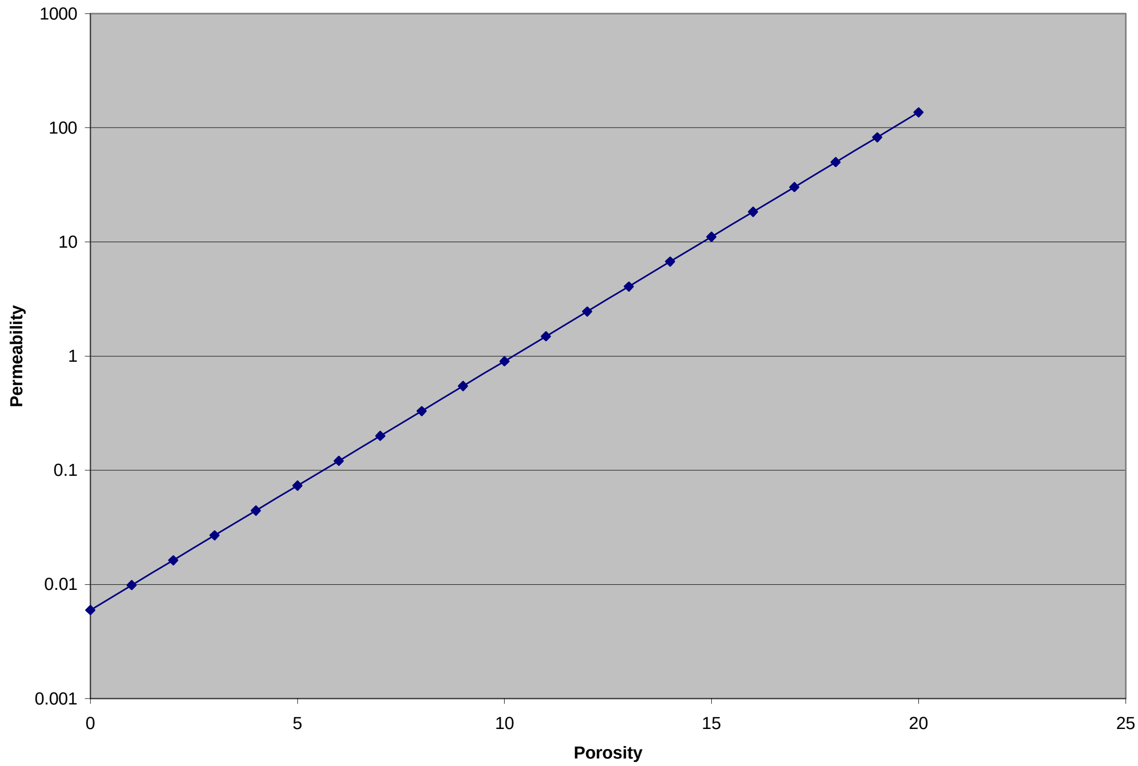


Figure 17. Porosity (in percent) versus permeability (in millidaries) cross-plot used in deriving the petrophysical properties.

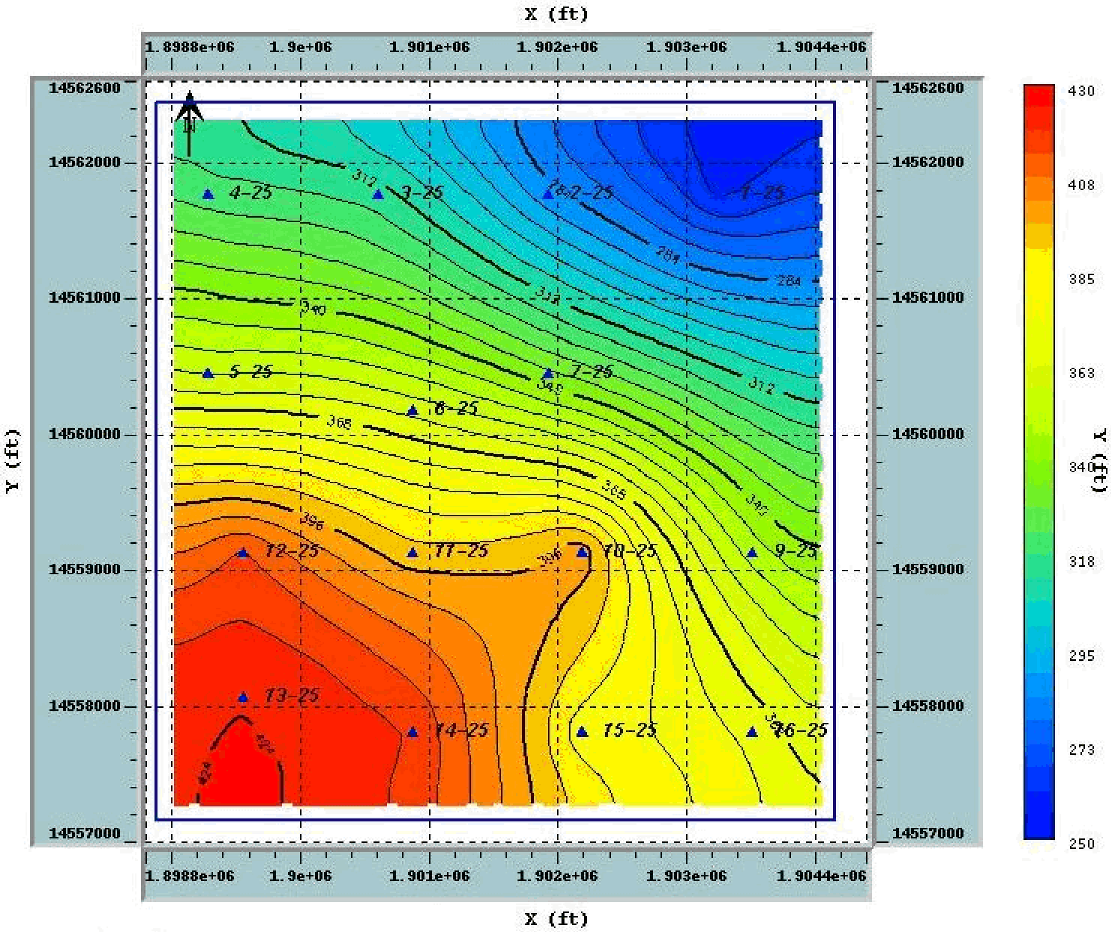


Figure 18. Structure contour map of the top of the MGR 7b bed (D sandstone), sea level datum. Contour interval is 5.6 feet.

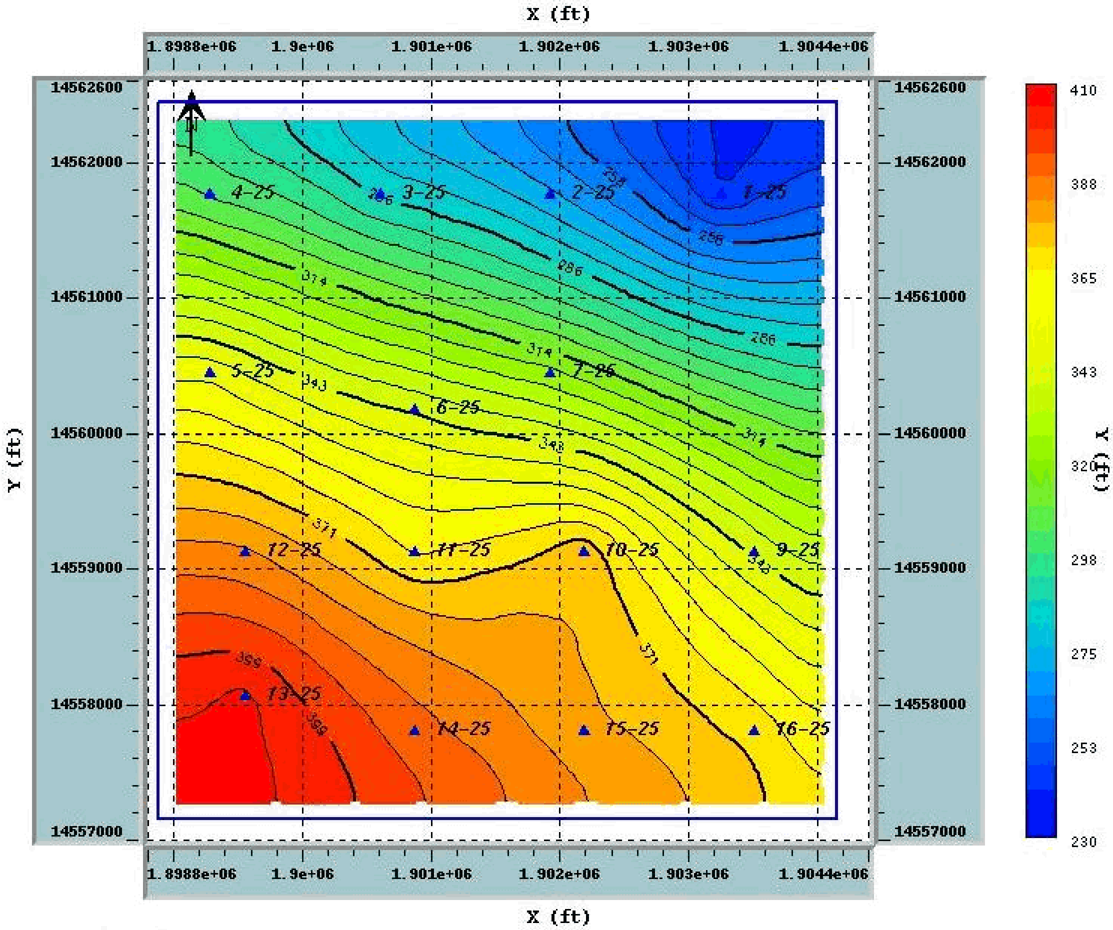


Figure 19. Structure contour map of the base of the MGR 7c bed (D sandstone), sea level datum. Contour interval is 5.6 feet.

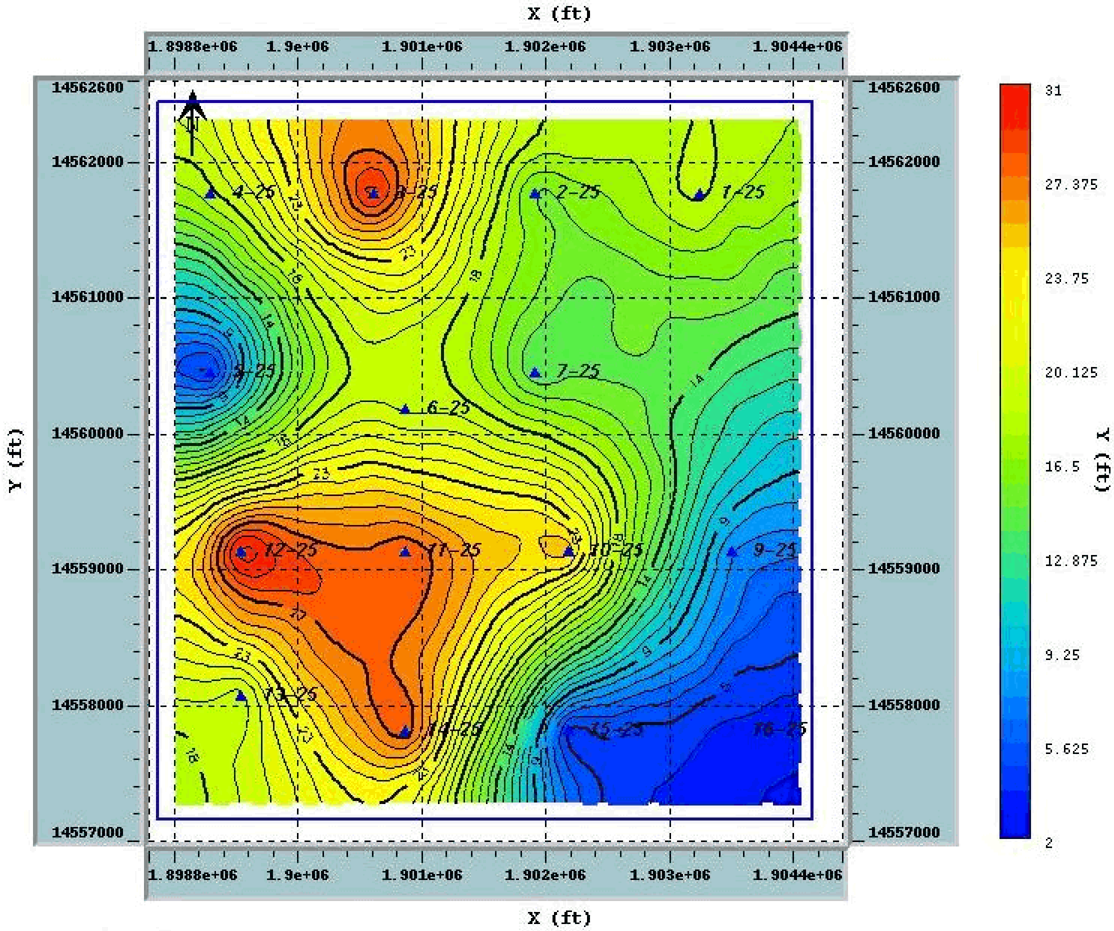


Figure 20. Isochore map of the MGR 7b and MGR 7c beds (D sandstone). Contour interval is 0.8 feet.

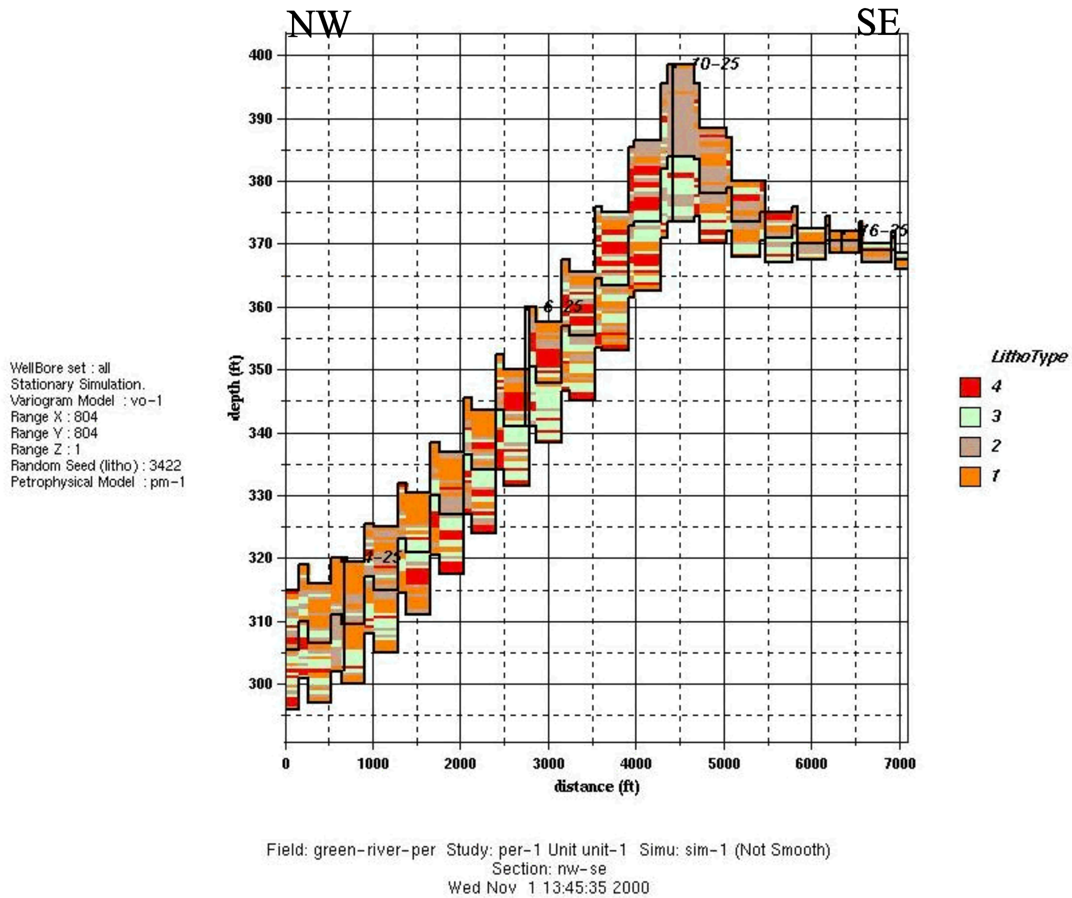


Figure 21. Cross section of lithotype distribution in the northwest-to-southeast direction. See table 1 for lithotype definitions. Cross section location shown in figure 15.

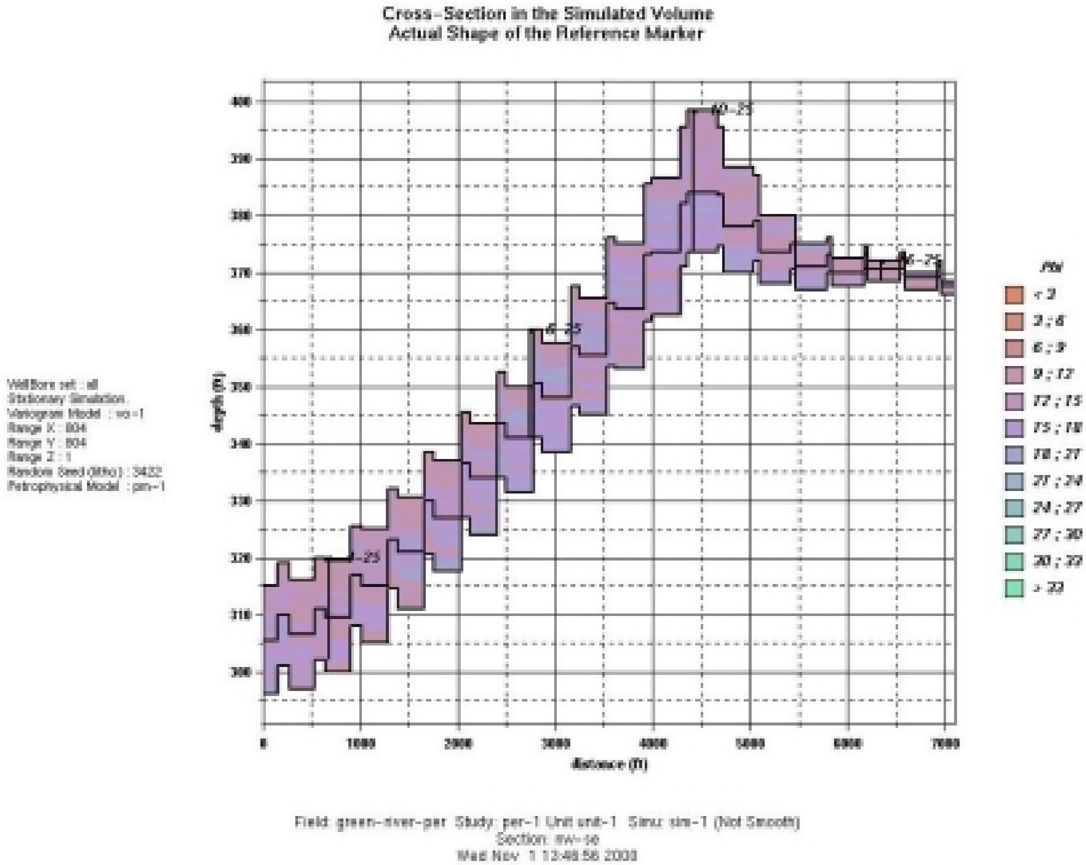


Figure 22. Cross section of porosity distribution in the northwest-tosoutheast direction. Cross section location shown in figure 15.

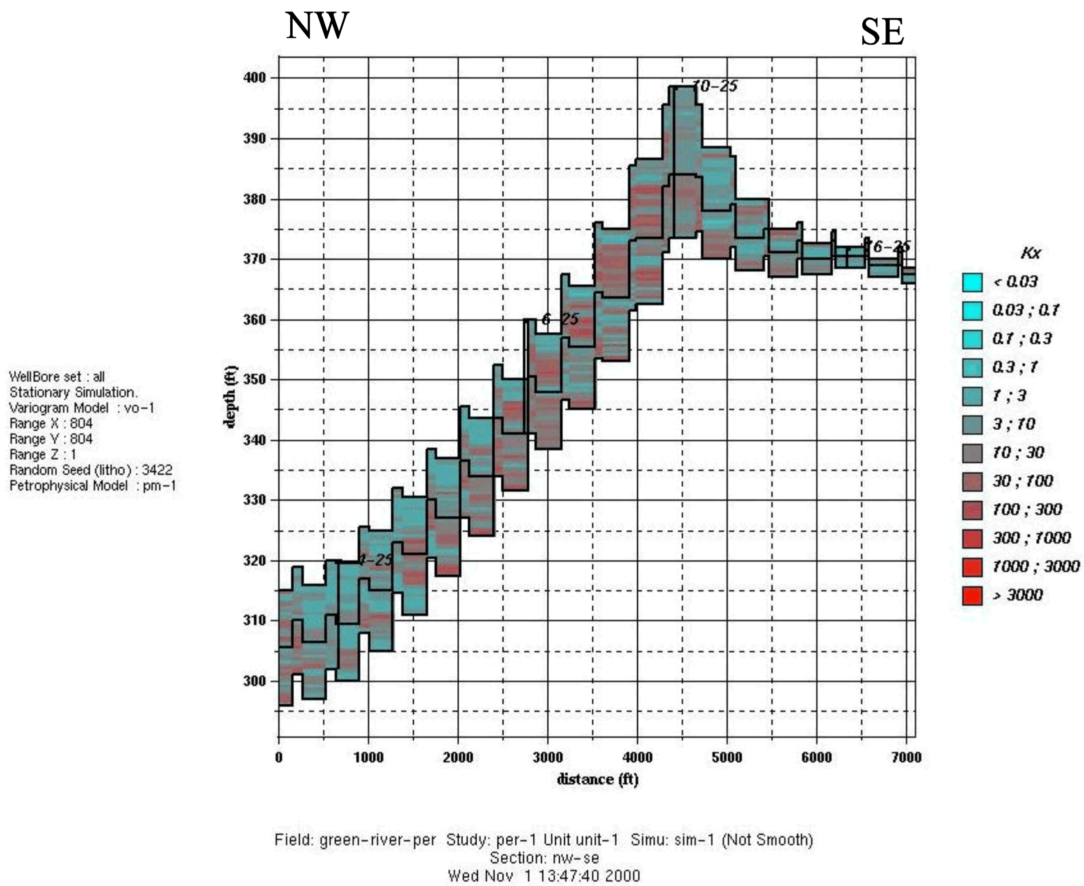


Figure 23. Cross section of permeability distribution in the northwest-to-southeast direction. Cross section location is shown in figure 15.

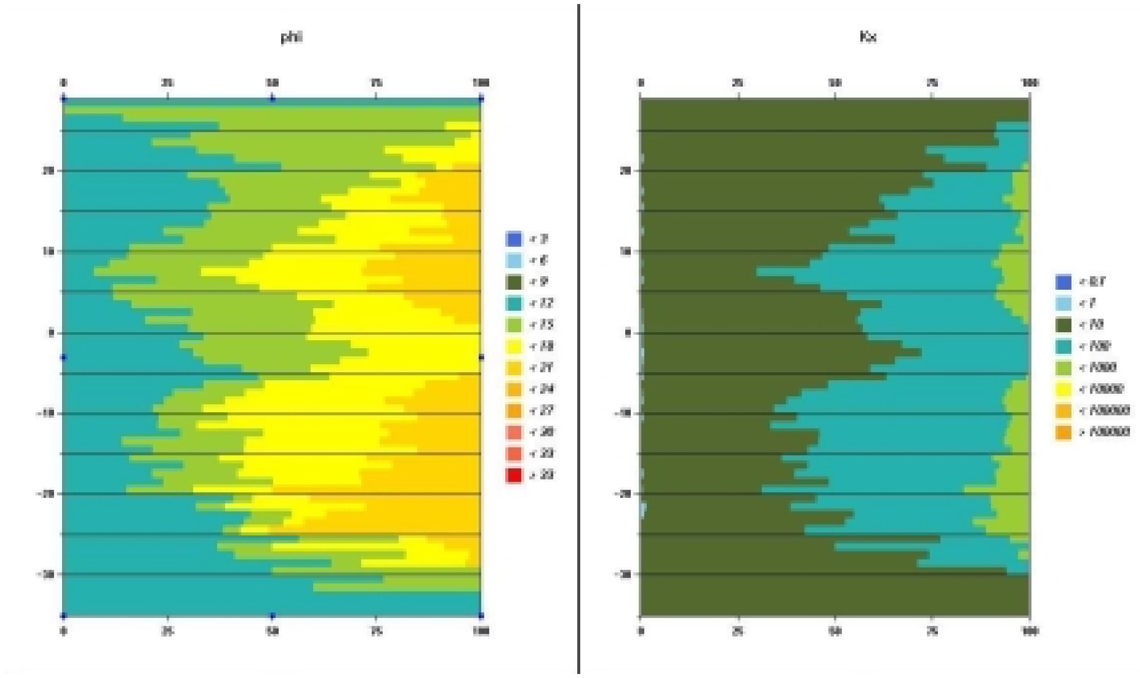


Figure 24. Porosity and permeability proportion of curves and locations of upscaled layer boundaries.

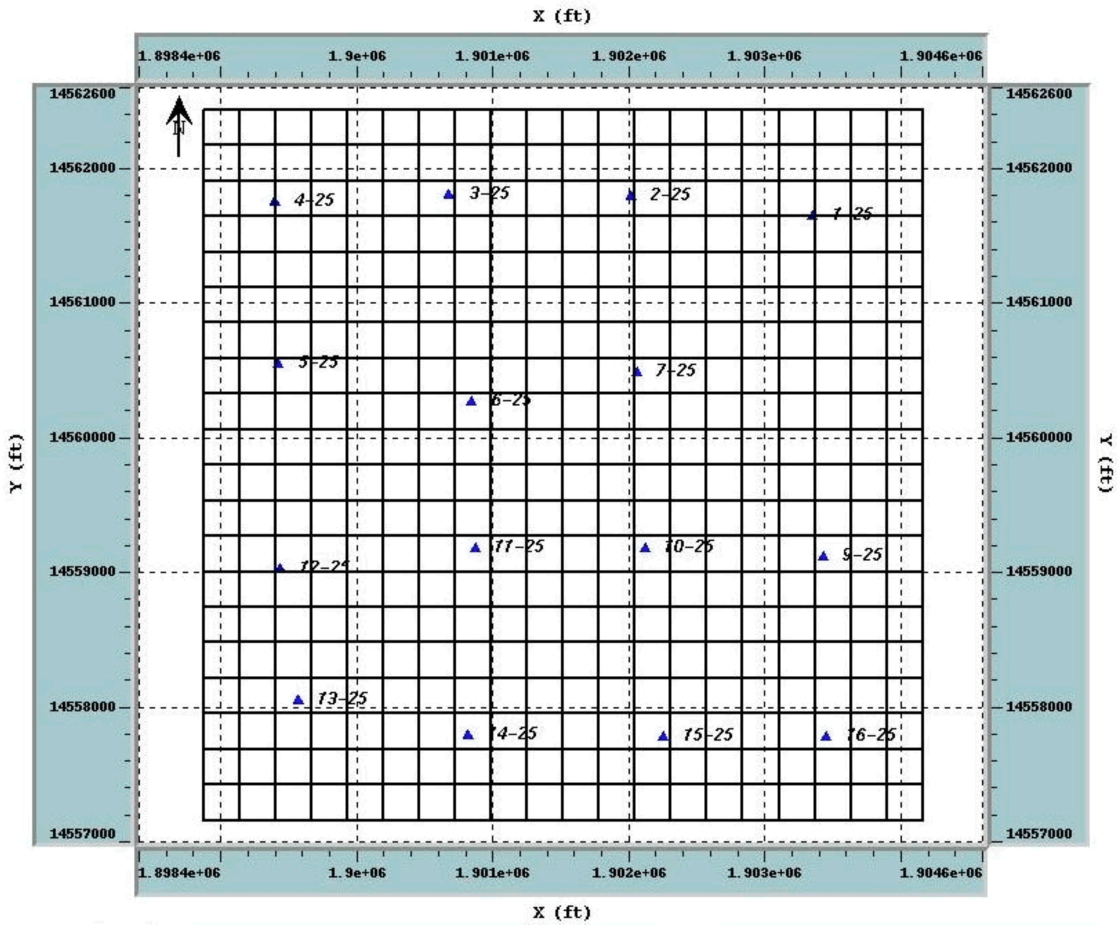


Figure 25. Plan view of the upscaled reservoir grid.

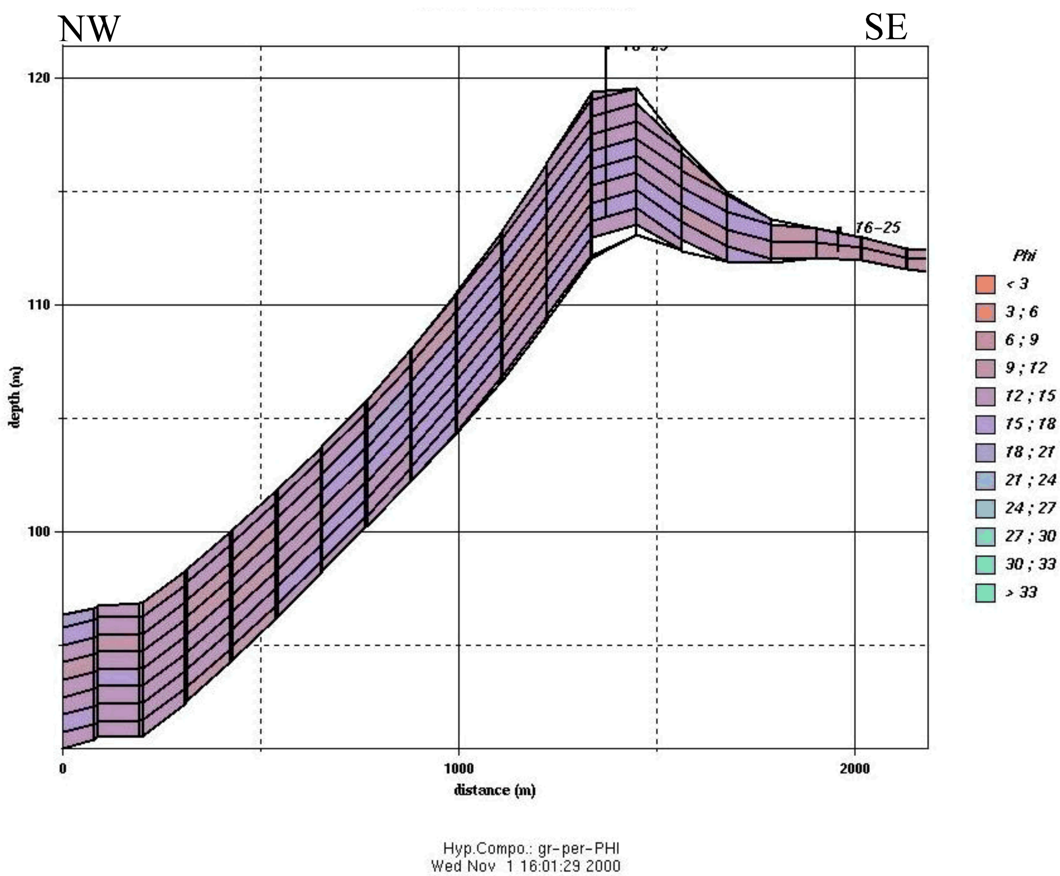


Figure 26. Cross section of porosity distribution for the upscaled reservoir model in the northwest-to-southeast direction. Cross section location is shown in figure 15.

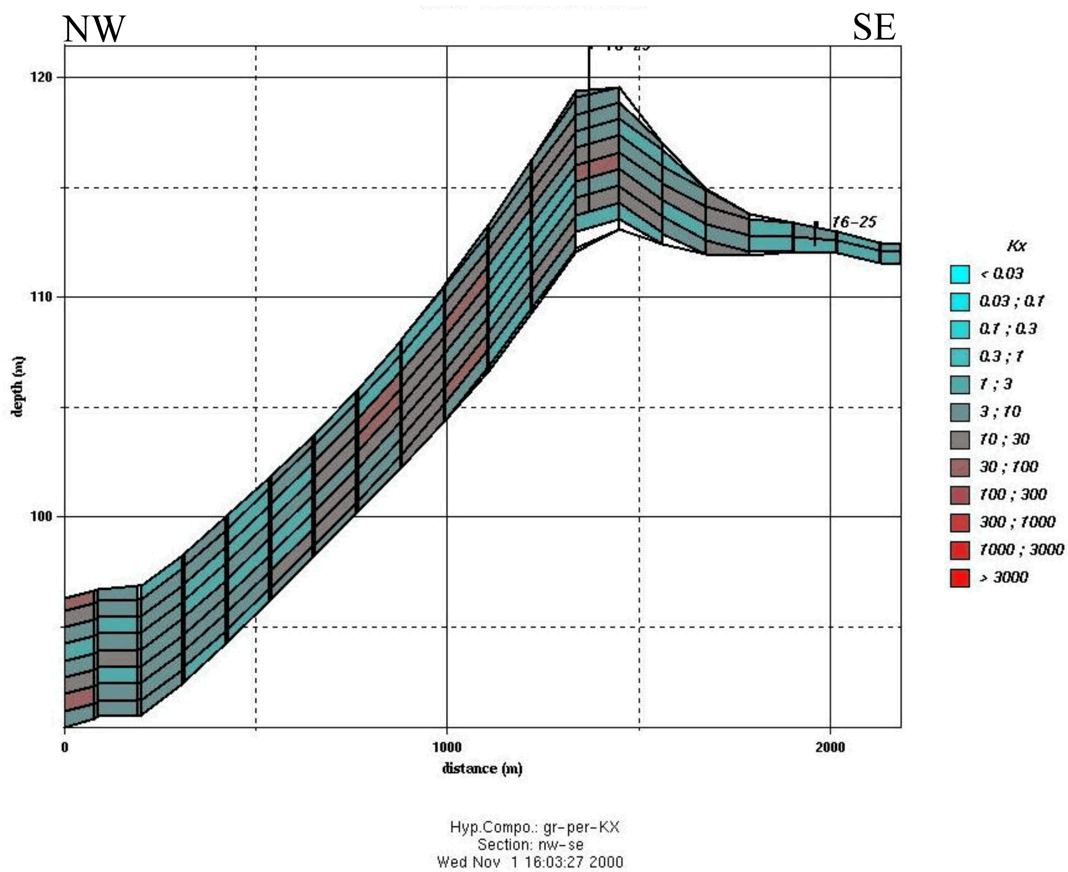


Figure 27. Cross section of permeability distribution for the upscaled reservoir model in the northwest-to-southeast direction. Cross section location is shown in figure 15.

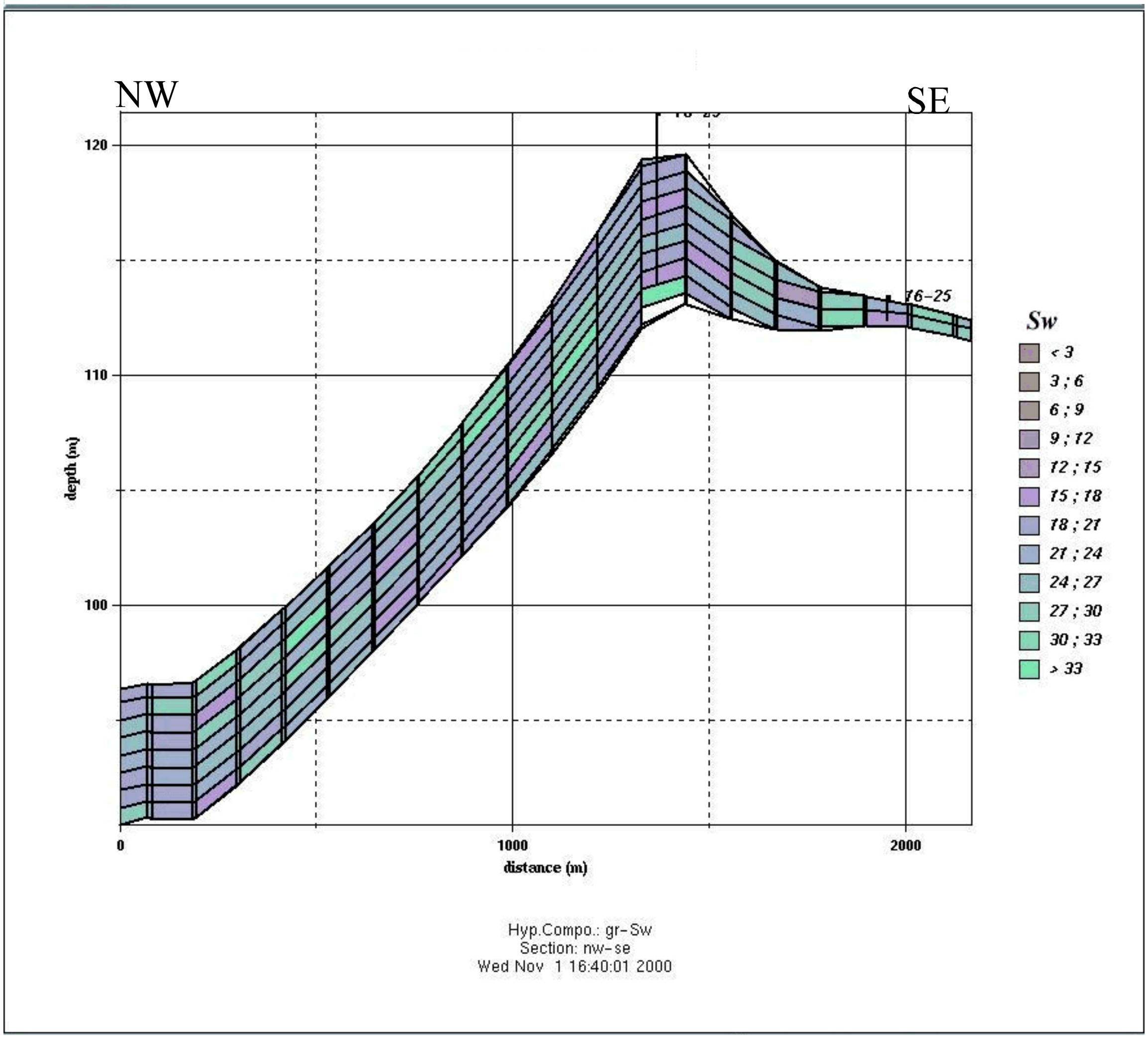


Figure 28. Cross section of water saturation distribution for the upscaled reservoir model in the northwest-to-southeast direction. Cross section location is shown in figure 15.

GEOLOGIC INVESTIGATION OF THE OUTCROP OF THE GREEN RIVER FORMATION

Regional Outcrop Study

The UGS measured and described four stratigraphic sections ranging in total thickness from 1,064 to 1,935 feet (324.3 to 589.8 m) in Willow Creek, Nine Mile, and Desolation Canyons. Gamma-ray data were gathered over three of the UGS sections and over one section by Remy (1992). The primary marker beds, Remy D and C (Remy, 1992) have been correlated between the stratigraphic sections and to geophysical logs from neighboring drill holes. Work is continuing to better define individual depositional cycles in the surface stratigraphic sections and correlate them to the log cycles (Morgan and others, 1999a) that have been mapped throughout the region. During the 2001 field season we will study lateral facies changes in the depositional dip (south-north) direction in Nine Mile and Desolation Canyons .

Nutter's Ranch Study Site

A study site was selected to better understand the interwell-scale reservoir heterogeneity that exists in one depositional cycle that is bounded above and below by carbonate beds. The study site, referred to as the Nutter's Ranch study site, was described in Morgan and others (1999b). The Nutter's Ranch study site was photographed and digitally joined into mosaics that were used to correlate the beds along the entire length of the exposure. The correlations were checked in the field and modified as needed, by walking out each of the bed boundaries.

Reservoir Characteristics of the Interwell Environment

Figure 29 is a west-to-east diagram showing the correlation of the beds in the study site. Two imaginary wells are shown 1,320 feet (402 m) apart to illustrate the type of reservoir heterogeneity that could exist between two wells drilled on 40 acre (16.2 ha) spacing units. Both of the imaginary wells encounter a carbonate bed above and below two reservoir-type sandstone beds. Well logs would show excellent correlation of the carbonate and sandstone beds. As a result, good lateral continuity of the sandstone beds would be expected. However, in this example, the upper sandstone in the two wells comprises two separate channel deposits (Ss-a and Ss-b) that would probably have very poor fluid flow between each other. While the lower sandstone (Ss-d) is the same bed in both of the wells, it has been locally cut out by the overlying channel sandstone (Ss-c). In some places Ss-a has incised down to Ss-d, creating a potential for fluid-flow communication between the two sandstone beds. Ss-c nearly cuts out Ss-d and is a potential reservoir that is not penetrated by either of the imaginary wells. The lowermost sandstone (Ss-e) could be an oil reservoir in the subsurface but is very narrow and would probably deplete very rapidly.

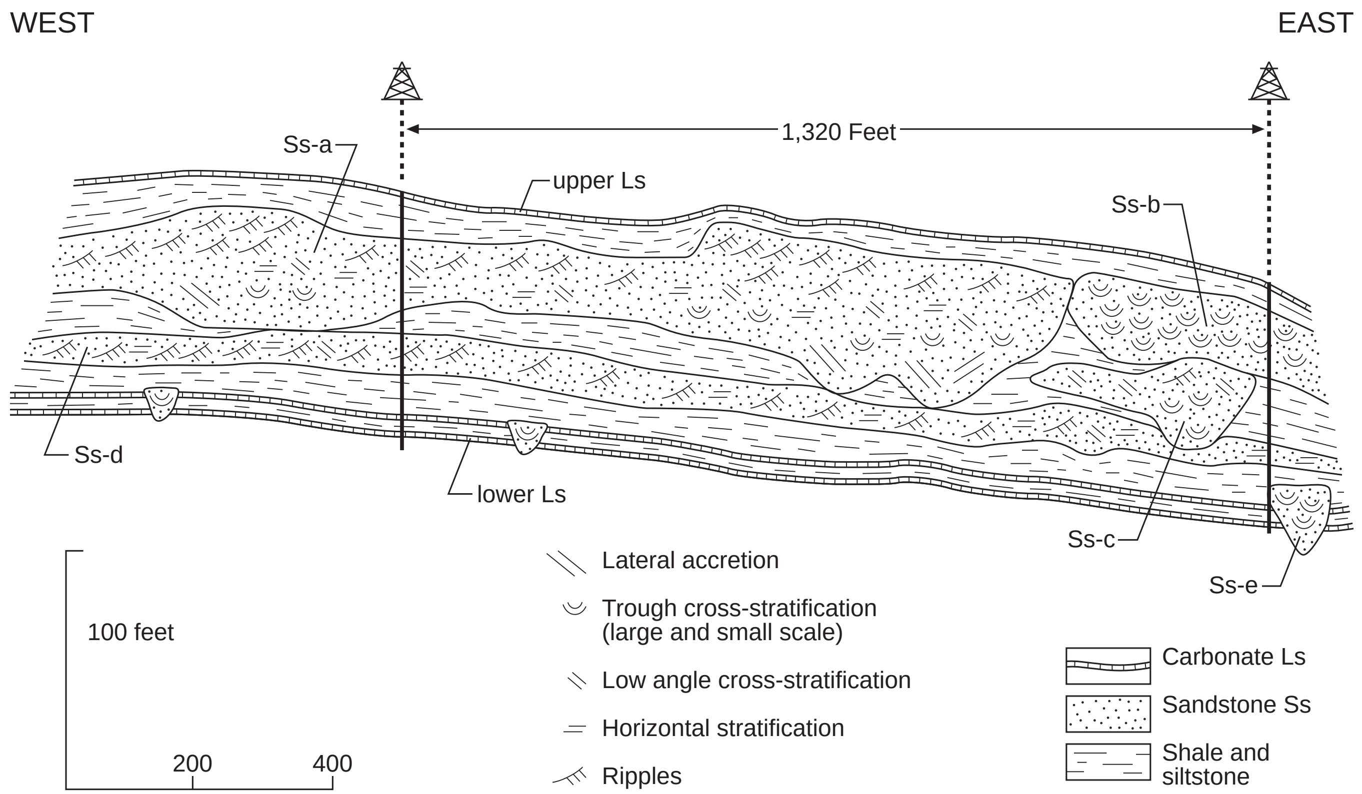


Figure 29. Generalized interpretation of the primary lithofacies within the Nutter's Ranch study site showing the heterogeneity that could exist between two wells drilled 1,320 feet apart at typical 40 acre spacing.

Paleodepositional Interpretation of the Nutter's Ranch Study Site

The following interpretation is preliminary, and the reader is cautioned not to strongly rely on it, but realize that the study at present is incomplete. Additional data and peer review may result in a slightly revised or totally different interpretation. The lithologies described in the Nutter's Ranch study site are shown in table 3.

Table 3. Lithology, description, and depositional interpretations from the Nutter's Ranch study site.

Lithology	Description	Depositional environment
Carbonate	Oolitic/ostracodal grainstone and micrite, typically contains fossil hash. The beds weather orange.	Lagoonal, beach to shallow nearshore.
Sandstone	Fine grain, rippled, tabular, thin (<3 ft), laterally continuous except where it is cut by channel sandstone body.	Flood-plain sheet flow.
Sandstone	Fine grain, incised channel-form, laterally limited, typically inclined trough sets with shale drapes.	Meandering channel in upper delta plain.
Sandstone	Fine grain, channel-form, 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	Fine grain, channel-form, 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.
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.

The Nutter's Ranch study site contains the deposits of several lake-level fluctuations. The depositional environments interpreted in the Nutter's Ranch study site are shown in figure 30. The deposits in the study site are from three generalized lake levels defined as the: (1) Roan Cliffs shoreline (RCS), (2) Badlands Cliffs shoreline (BCS), and (3) Myton Bench shoreline (MBS) (figure 31). The three shoreline locations are speculative and have not been accurately determined by surface and subsurface correlations. The vertical stacking pattern from oldest (bottom) to youngest (top) observed at the Nutter's Ranch study site (figure 32) is a result of the shoreline fluctuation from RCS to MBS to BCS to MBS to BCS to MBS to BCS to RCS (figure 33). The RCS? shown on figure 32 is not represented in figure 33 because it is unclear if the carbonate bed labeled RCS? was deposited as a result of lake-level rise to RCS or if it was deposited in a lower delta plain pond associated with BCS.

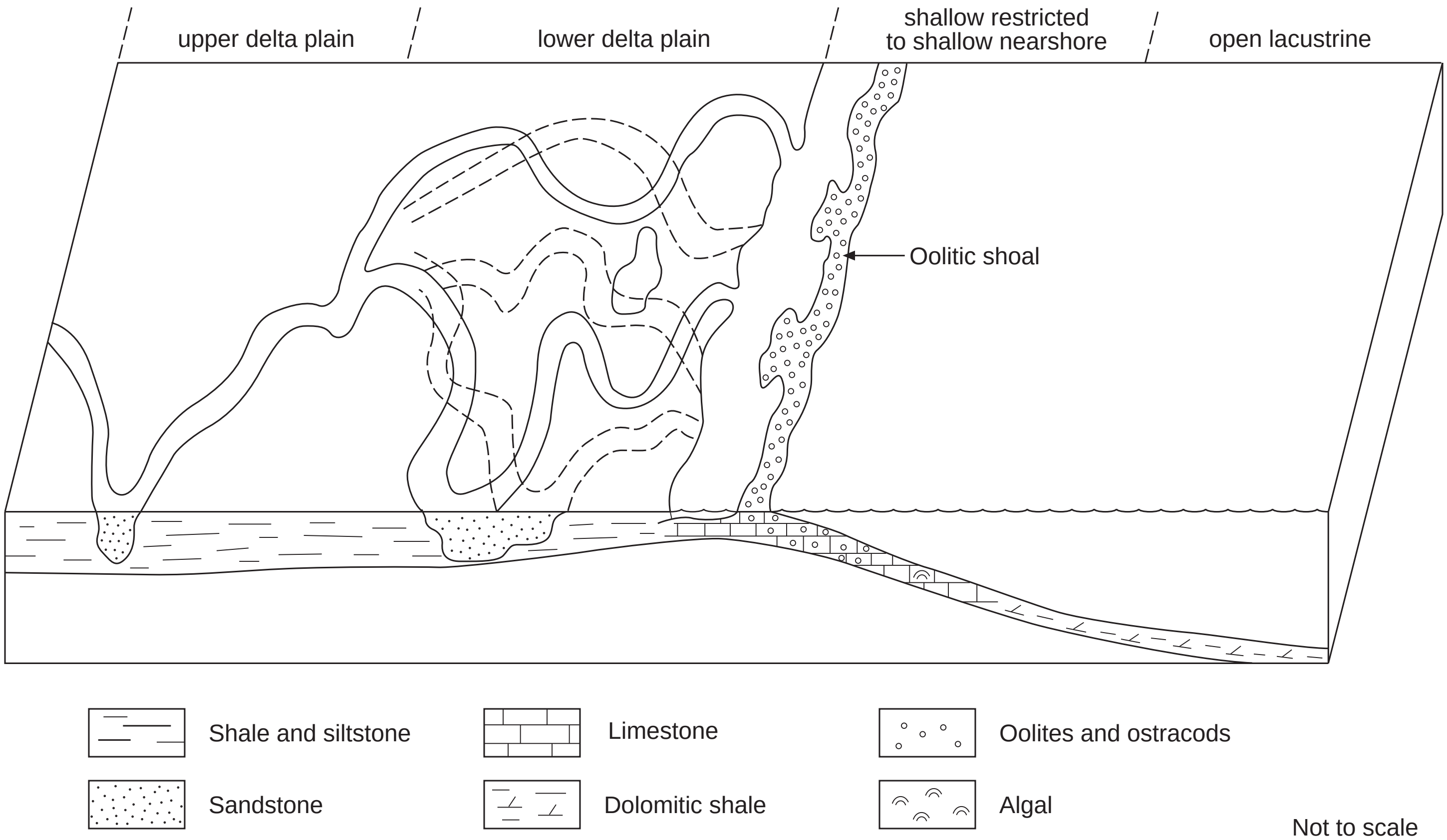


Figure 30. Primary lithofacies and simplified interpretation of the depositional environments identified in the stratigraphic sequence in the Nutter's Ranch study site.

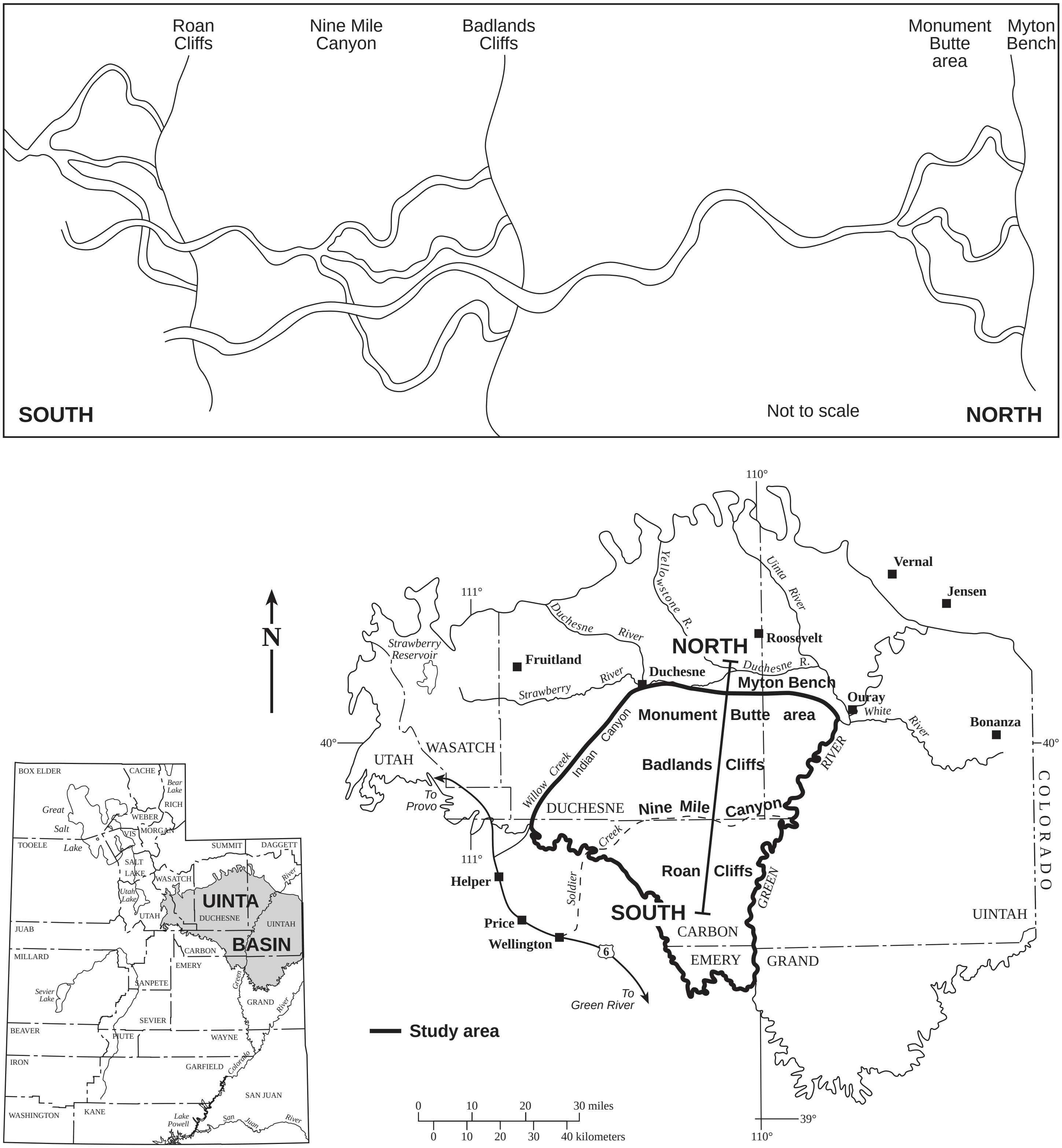
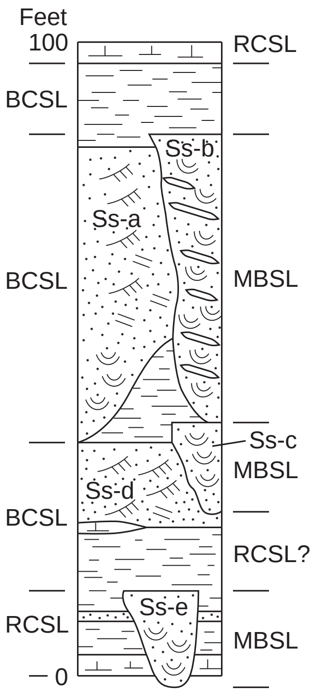


Figure 31. The three generalized shorelines associated with lake-level fluctuation as interpreted in the Nutter's Ranch study site in Nine Mile Canyon. The shoreline locations as shown on the index map are speculative and have not been determined by surface and subsurface correlations.



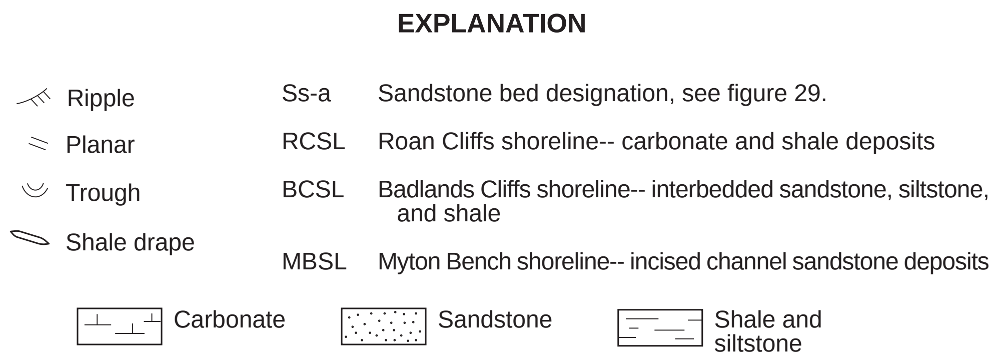


Figure 32. Composite vertical stratigraphic section of a 100-foot depositional cycle in the Nutter's Ranch study site in Nine Mile Canyon. Lithofacies are associated with three generalized shorelines.

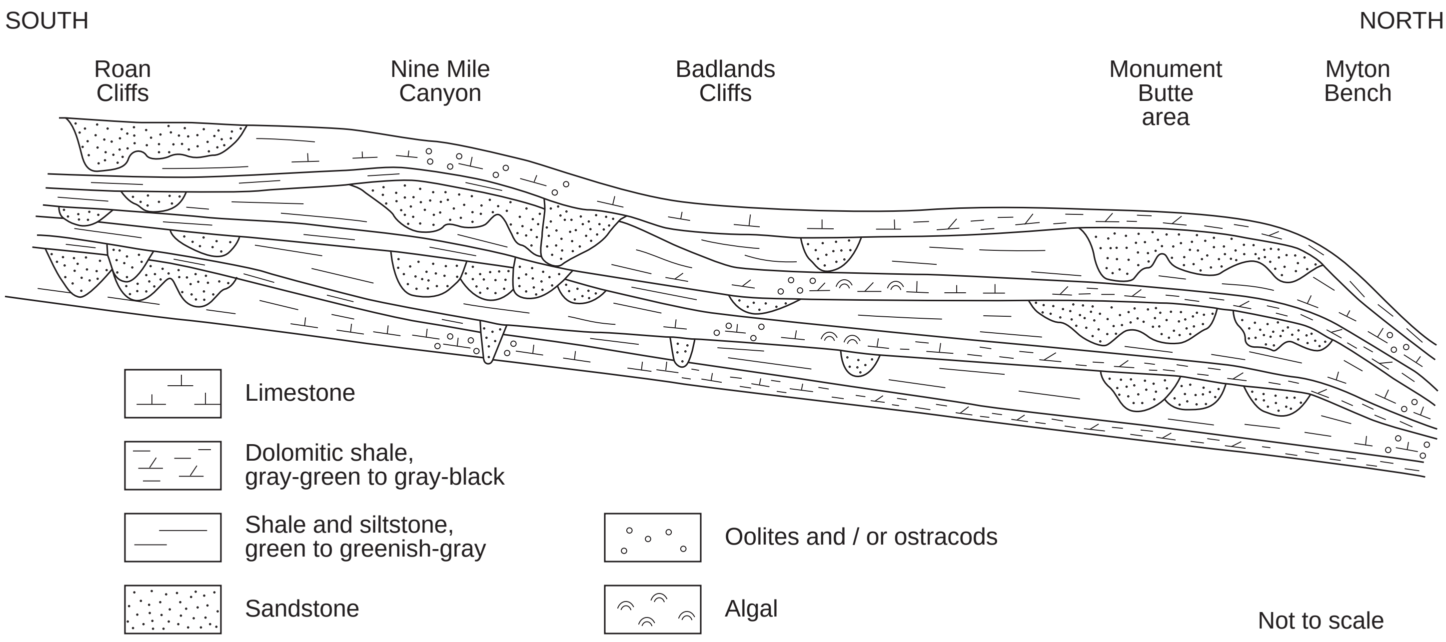


Figure 33. Vertical stacking pattern in a 100-foot-thick depositional cycle over a south-to-north distance of about 30 miles based on the interpretation of the Nutter's Ranch study site in Nine Mile Canyon. Lateral relationships are speculative and have not been determined by surface and subsurface correlations.

TECHNOLOGY TRANSFER

Results from the study were presented at the DOE June 2000 contractors review meeting in Denver, Colorado. A paper was presented at the American Association of Petroleum Geologists (AAPG) Rocky Mountain Section meeting in Albuquerque, New Mexico entitled *Nine Mile Canyon - outcrop analogue for oil reservoirs in the Monument Butte area, Uinta Basin, Utah.* (Morgan and others, 2000) Project materials were displayed at the UGS exhibitor's booth during the AAPG Annual Convention in New Orleans, Louisiana, and the AAPG Rocky Mountain Section meeting in Albuquerque, New Mexico.

Copies of the Biannual Technical Report for the period from October 1, 1999 to March 31, 2000, were sent to everyone on the project mailing list and then posted on the Green River Study home page where it can be downloaded.

The UGS maintains a Green River Study home page on its web site containing the following information: (1) an index map of the study area, (2) a copy of the proposal and statement of work, (3) each of the Biannual Technical Progress Reports, and (4) an extensive selected reference list for the Uinta Basin and lacustrine deposits worldwide. The home page address is ***http://www.ugs.state.ut.us/greenriv.htm***

FUTURE ACTIVITIES

The following work is planned for the period of October 1, 2000 through March 30, 2001:

(1) A field review will be held October 2000 to show the Technical Advisory Board and other invited basin operators the work completed in Willow Creek and Nine Mile Canyons. The board will be asked to advise the project team on the interpretation and what type of additional work is needed.

(2) The biannual technical report will be sent to all interested parties and posted on the project web site.

(3) Preliminary maps of the structure, sandstone thickness, and feet-of-sandstone with 10 percent or more porosity, based on well-log data, will be edited and interpreted.

(4) The Trail Canyon measured section and gamma-ray curve, which was completed in September 2000, will be correlated with other stratigraphic sections in Nine Mile Canyon and with logs from wells north and south of the Trail Canyon section.

(5) Correlation between the stratigraphic sections and correlation of the surface-to-subsurface will continue.

(6) Final editing of the well-core descriptions is completed and the petrophysical report will be written.

(7) Paleoflow and fracture data were gathered from the Nutter's Ranch study site. The data will be mapped and interpreted.

(8) The geological characterization of the Monument Butte Northeast, Uteland Butte, and Brundage Canyon fields will be incorporated into the numerical reservoir simulation models for each of the fields.

(9) Field work in Nine Mile Canyon and tributaries of Desolation Canyon will begin as soon as the snow clears and will concentrate on studying lateral facies change in the depositional dip (south-to-north) direction.

REFERENCES

Morgan, C.D., Bereskin, S.R., Chidsey, Jr., T.C., and McClure, K.P., 2000, Nine Mile Canyon - outcrop analogue for oil and gas reservoirs in the Monument Butte area, Uinta Basin, Utah: AAPG Bulletin, v. 84, no. 8, p. 1242-1243.

Morgan, C.D., Chidsey, T.C., Jr., Hanson, J.A., McClure, K.P., Weller, Kevin, Bereskin, S.R., Deo, M.D., and Yeager, Randy, 1999a, Reservoir characterization of the lower Green River Formation, southwest Uinta Basin, Utah, Biannual technical progress report for the period 4/1/9 to 9/30/99: U.S. Department of Energy unpublished report, 26 p.

Morgan, C.D., Chidsey, T.C., Jr., Hanson, J.A., McClure, K.P., Weller, Kevin, Bereskin, S.R., Deo, M.D., and Yeager, Randy, 1999b, Reservoir characterization of the lower Green River Formation, southwest Uinta Basin, Utah, Biannual technical progress report for the period 10/1/98 to 3/31/99: U.S. Department of Energy unpublished report, 26 p.

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.

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

APPENDIX

The appendix is available at:

http://www.ugs.state.ut.us/greenriv