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

Biannual Technical Progress Report

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C. D. Morgan, Program Manager
T. C. Chidsey, Jr., and K. P. McClure
Utah Geological Survey
S. Robert Bereskin, Tesseract Inc.
Milind D. Deo, University of Utah,
Kevin Weller, Inland Production Resources, Inc.,
Randy Yeager, Halliburton Energy Services

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Virginia Weyland, Contract Manager
U.S. Department of Energy
National Petroleum Technology Office
Tulsa, Oklahoma

Submitting Organization: Utah Geological Survey
1594 West North Temple, Suite 3110
P.O. Box 146100
Salt Lake City, Utah 84114-6100
(801) 537-3300

ABSTRACT

Cycles in the Middle and Lower Members of the Green River Formation, including boundaries, total sandstone, and total feet of porosity, are being correlated using geophysical well logs. Regional outcrop investigations were conducted in Willow Creek and Nine Mile Canyons. Numerous carbonate marker beds are found in the Middle Member and can be traced laterally for several miles in Nine Mile Canyon. Most of the carbonate beds represent flooding events that can be used to define depositional cycles. The carbonate markers are typically ostracodal or oolitic grainstone and micritic limestone representing shoreline, and restricted lacustrine (possibly lagoonal), deposits. The dominant rock types between the carbonate markers are green, some red, shale to siltstone, and interbedded sandstone. The sandstone beds are generally very fine- to fine-grained, channel form, with current ripples as the dominant bedding feature.

Total gamma-ray (GR) curves generated from the data gathered from the exposures in Willow Creek and Nine Mile Canyons are used to correlate the stratigraphic section from the surface to subsurface. Regional interpretation of the depositional environments within the Green River Formation will be based on integration of the correlation and mapping of the log cycles, core descriptions from wells, and study of the outcrop.

A detailed study site was selected in Nine Mile Canyon near the Nutter's Ranch house. The Nutter's Ranch study site has exposures on three sides; the longest side is about 2000 ft (600 m) representing a slightly larger distance than typically exists between two wells when they are drilled on 40-acre (16.2-ha) spacing (1320 ft [402.3 m]). The thickness of the stratigraphic interval being studied is about 100 ft (30 m) bounded by carbonate beds. The interval contains two sandstone beds that are the typical thickness of reservoir beds in the Monument Butte and surrounding fields to the north. Within the Nutter's Ranch study site the upper sandstone cuts down to the lower sandstone in several locations, creating what would be a fluid-flow path. Within the same exposure much of the upper sandstone pinches out in one location, creating what would be a significant impedance to fluid flow in a reservoir. Work is continuing on the site and the data will be incorporated into the geostatistical model.

A combination of 1237 ft (377.0 m) of conventional core from 20 wells along with 66 rotary sidewall cores from other wells in the project area, have been studied and described in detail. Thin sections made from many of the samples are currently being analyzed. The reservoir rock is dominantly very fine to fine-grained lithic arkose and feldspathic sandstone. Current ripples and soft sediment deformation are the most common bed forms. Most sandstone beds are channels deposited in the lower delta plain.

Sandstone reservoir quality, as determined by porosity and permeability, is primarily a function of diagenesis. Good reservoir quality exists where there has been dissolution of iron-poor calcite cement, potassium feldspar, and various mudstone and siltstone lithotypes, but reservoir quality can be reduced or completely ruined where there has been secondary cementation with iron-rich calcite and/or ankerite.

Technology transfer activities included a booth display of project material at both the national and regional meetings of the American Association of Petroleum Geologists (AAPG). A poster was presented at the Rocky Mountain regional meeting in Bozeman, Montana, highlighting the correlation scheme with the preliminary surface-to-subsurface correlations of the Green River Formation. A home

page for the project was developed on the Utah Geological Survey's (UGS) web site.

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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.

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 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. As of September 30, 1999, logs from more than 600 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.

Regional investigation of the surface exposures of the Green River Formation in Willow Creek and Nine Mile Canyons was begun. Numerous stratigraphic sections in the Middle Member of the Green River were measured and described. Spectral gamma-ray (GR) data were collected over three regional stratigraphic sections totaling about 3700 ft (1130 m) in the Green River Formation; one in Willow Creek Canyon, and two in Nine Mile Canyon. Curves generated from the GR data are being correlated with GR curves from wells in the area. Several carbonate marker beds deposited during highstands of Lake Uinta are found in the Middle Member. The carbonate markers define large-scale (about 100-ft [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.

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 2000 ft (600 m) in the east-to-west direction and about 500 ft (150 m) in the north-to-south direction. The stratigraphic interval being studied is slightly more than 100 ft (30 m) thick, bounded by carbonate beds. As of September 30, 1999, six sections have been 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 photomosaics were compiled. Data from the study site will provide significant information about the reservoir heterogeneity in the interwell environment.

Core from 30 wells in the project area have been described. Thin sections of reservoir beds were prepared for detailed petrophysical analysis. Outcrop samples were also collected for thin section preparation and analysis. Results will be compared to the core samples.
Many of the cores had never been slabbed and described in detail. Porosity and permeability data are available for all of the conventional core. Maceral and vitrinite reflectance analyses were performed on two coal samples found in the core.

Hydraulic fracture analysis was compiled and incorporated into the reservoir simulation model. The geologic data currently being gathered and interpreted will also be incorporated into the reservoir

simulation model.

Project material was displayed at the UGS booth at both the National and regional AAPG meetings. A poster was presented at the Rocky Mountain regional meeting of the AAPG in Bozeman, Montana, highlighting the correlation scheme and preliminary surface-to-subsurface correlations of the Green River Formation. A home page was developed containing information about the project.

INTRODUCTION

Geologic Setting

The Uinta Basin is a topographic and structural trough encompassing an area of more than 9300 square miles (14,900 km^2) in northeast Utah (Fig. 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 from the northern shoreline deposits of Lake Uinta, while the fields in the Monument Butte area produce from deltaic southern shoreline deposits as preserved in the Middle and Lower Members of the Green River. The southern shore of Lake Uinta was 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 aid understanding of 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.

Core from 30 wells (Table 1) in the project study area has been described and depositional environments interpreted. Thin sections have been made from many of the reservoir rocks for further petrophysical analysis. Coal samples are being analyzed petrographically to determine the type of macerals, and vitrinite reflectance was measured to assess thermal maturity. Bed forms, depositional interpretations, and petrophysical analyses will be compared to interpretations and samples from the outcrop.

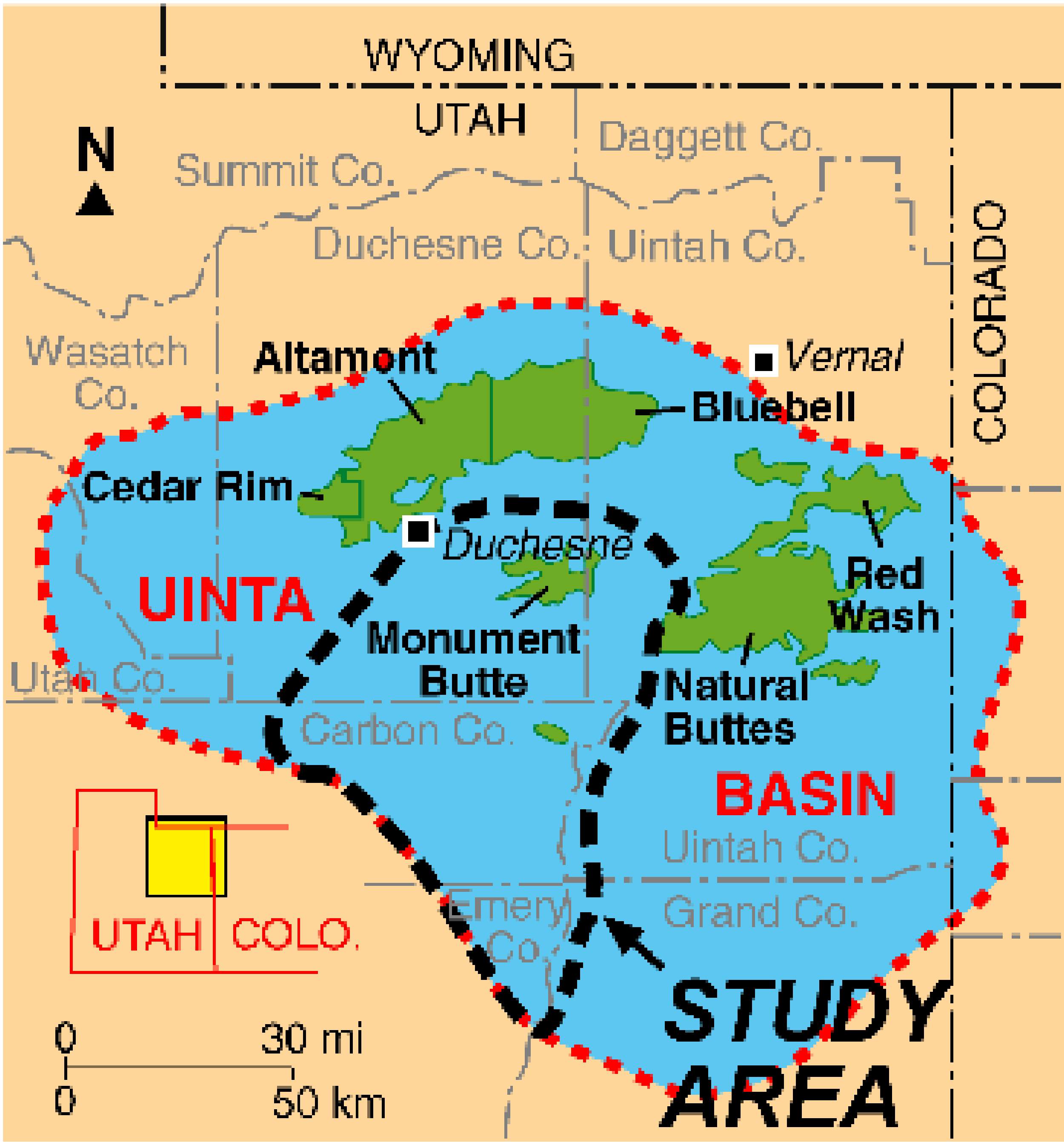


Fig. 1. Index map of the Uinta Basin, Utah showing study area and major oil and gas fields in the basin.

Table 1. List of well core that has been examined as of September 30, 1999.

WELL	API NUMBER	LOCATION	CORED INTERVAL[1]	WF UNIT[2] /FIELD[3]	STRATIGRAPHIC INTERVAL UGS (operator[4])	THIN SECTIONS	PHOTOS	P&P[5]	REPOSITORY[6]
St 4-27	43-013-31131	27, T5S, R4W	6 rotaries	/BC					SRB
St 2-25	43-013-31833	25, T5S, R5W	5527-5596	/BC	carbonate marker unit (CP)	Yes		Yes	UGS
14A-28	43-013-30792	28, T8S, R16E	5550-5646	Travis/MB	MGR2-MGR6 (GG-DC D & C sands)	Yes	Yes	Yes	EGI
St 13-32	43-013-31112	32, T8S, R16E	7 rotaries	Wells Draw/MB					SRB
Fed 5-33	43-013-31435	33, T8S, R16E	24 rotaries	Travis/MB					SRB
Fed 2-33	43-013-30749	33, T8S, R16E	5647-5676	Travis/MB	MGR2 (LDC)			Yes	EGI
Fed 6-33	43-013-30747	33, T8S, R16E	5596-5615	Travis/MB	MGR1 (LDC)			Yes	EGI
Fed 9-34	43-013-31407	34, T8S, R16E	15 rotaries	Monument Butte/MB		Yes			SRB
Fed 10-34	43-013-31371	34, T8S, R16E	rotaries	Monument Butte/MB		Yes			SRB
Fed 6-35	43-013-30751	35, T8S, R16E	5026-5033 5042-5048	Monument Butte/MB	MGR7 (DC D sand)			Yes	EGI
Fed 12-35	43-013-30744	35, T8S, R16E	5021-5033	Monument Butte/MB	MGR7 (DC D sand)			Yes	EGI

WELL	API NUMBER	LOCATION	CORED INTERVAL[1]	WF UNIT[2] /FIELD[3]	STRATIGRAPHIC INTERVAL UGS (operator[4])	THIN SECTIONS	PHOTOS	P&P[5]	REPOSITORY[6]
3A-35	43-013-30608	35, T8S, R16E	4993-5022	Monument Butte/MB	MGR7 (DC D sand)	Yes		Yes	UGS
12-21	43-013-31440	21, T8S, R17E	12 rotaries	Boundary /TB					SRB
Fed 23-25	43-047-325229	25, T8S, R17E	5145-5185	Humpback /EMFN	MGR5 (DC C sand)	Yes		Yes	UGS
St 6-32	43-013-30748	32, T8S, R17E	5042-5053	Gilsonite /MB	MGR5 (DC C sand)			Yes	EGI
Fed 12-4	43-013-30699	4, T9S, R16E	4878-4933	Wells Draw /MB	MGR7-MGR6 (DC D&C sand)			Yes	Baylor
Fed 33-11J	43-013-31451	11, T9S, R16E	4840-4870 5158-5207 5370-5424	Johan/MB	MGR5 (DC C sand) MGR3 (LDC) MGR1(LDC)	Yes		Yes	UGS
Fed 1-26	43-013-30609	26, T9S, R16E	5266-5321	/MB	carbonate marker unit (CP)			Yes	
Allen 34-5	43-013-30721	5, T9S, R17E	4995-5045	Pleasant Valley/MB	MGR3 (LDC)	Yes		Yes	UGS
Fed 33-8	43-013-31427	8, T9S, R17E	4632-4660 5440-5470	Beluga/MB	carbonate marker unit (CP)	Yes		Yes	UGS
Paiute 34-8	43-013-30778	8, T9S, R17E	4050-4129	Beluga/MB	MGR13 (GG)	Yes		Yes	UGS
Fed 41-8	43-013-30741	8, T9S, R17E	4105-4156 4993-5052	Pleasant Valley/MB	MGR13 (GG) MGR3 (LDC)	Yes	Yes	Yes	

WELL	API NUMBER	LOCATION	CORED INTERVAL[1]	WF UNIT[2] /FIELD[3]	STRATIGRAPHIC INTERVAL UGS (operator[4])	THIN SECTIONS	PHOTOS	P&P[5]	REPOSITORY[6]
11-16H	43-013-30616	16, T9S, R17E	4336-4358 4578-4638	Beluga/MB	MGR9-MGR8 (GG) MGR6 (DC C sand)	Yes		Yes	
Pariette 5	43-047-10298	9, T9S, R18E	5407-5457	/EMFN	carbonate marker unit (CP)	Yes		Yes	UGS
Pariette 6	43-047-10873	5, T9S, R19E	4454-4488 4867-4894 5047-5080	/PB	MGR8 (GG) MGR3 (LDC) MGR3 (LDC)	Yes		Yes	UGS
St 13-16J	43-047-31128	16, T9S, R19E	4238-4328 5350-5385	/PB	MGR7 (DC D sand) LGR3 (UB)	Yes		Yes	UGS
Fed 15-17	43-047-31002	17, T9S, R19E	4255-4306	/PB	MGR6 (DC C sand)	Yes		Yes	UGS
Fed 15-24B	43-047-32420	24, T9S, R19E	4738-4817	/NB		Yes		Yes	UGS
Island 16	43-047-31505	11, T10S, R18E	4690-4739 4746-4812	/UB		Yes		Yes	UGS
West Desert Spring 11-20	43-013-32088	20, T10S, R17E	4971-5030 5100-5150	/wildcat	LGR1, LGR2, LGR3 (UB)	Yes		Yes	UGS

Cored Interval[1]: Conventional, slabbed core except rotaries which are rotary sidewall core plugs. Rotaries are point data not intervals.

WF Unit[2]: Water-flood unit name, left blank if the well is not in a unit.

/Field[3]: Left blank if the well is not in a field.

- BC = Brundage Canyon
- EMFN = Eight Mile Flat North
- MB = Monument Butte
- NB = Natural Buttes
- PB = Pariette Bench
- TB = Treaty Boundary
- UB = Uteland Butte

(operator[4]):
- CP = Castle Peak
- DC = Douglas Creek
- LDC = lower Douglas Creek
- UB = Uteland Butte

P&P[5]: Porosity and permeability data from core-plug analysis.

Repository[6]:
- UGS = Utah Geological Survey
- EGI = Earth and Geological Institute (University of Utah)
- Baylor = Baylor University
- SRB = S. Robert Bereskin

A 1900-ft (580-m) stratigraphic section of the Green River Formation was measured and described, and spectral gamma-ray data were gathered in Willow Creek Canyon (Fig. 2). The Green River was measured and described (1200 ft [370 m]), and spectral gamma-ray data were gathered in the east portion of Nine Mile Canyon and in the central portion of the canyon (600 ft [183 m]) (Figs. 3 and 4). Curves were generated from the GR data and used to correlate the sections to the geophysical logs of nearby wells (Figs. 5 and 6). Large-scale (about 100-ft thick [30-m]) depositional cycles are defined in the Nine Mile Canyon area by a series of laterally continuous carbonate marker beds deposited during lake level rise. A series of measured sections by the UGS, and published sections by Remy (1992), are used to correlate the carbonate beds and the depositional cycles they define for about 20 miles (32 km) in Nine Mile Canyon (Figs. 3 and 7).

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 (Fig. 8). The exposure provides a three-dimensional perspective that, in the longest dimension, is a slightly greater distance than that which would exist between two wells if they were drilled on 40-acre (16.2-ha) spacing.

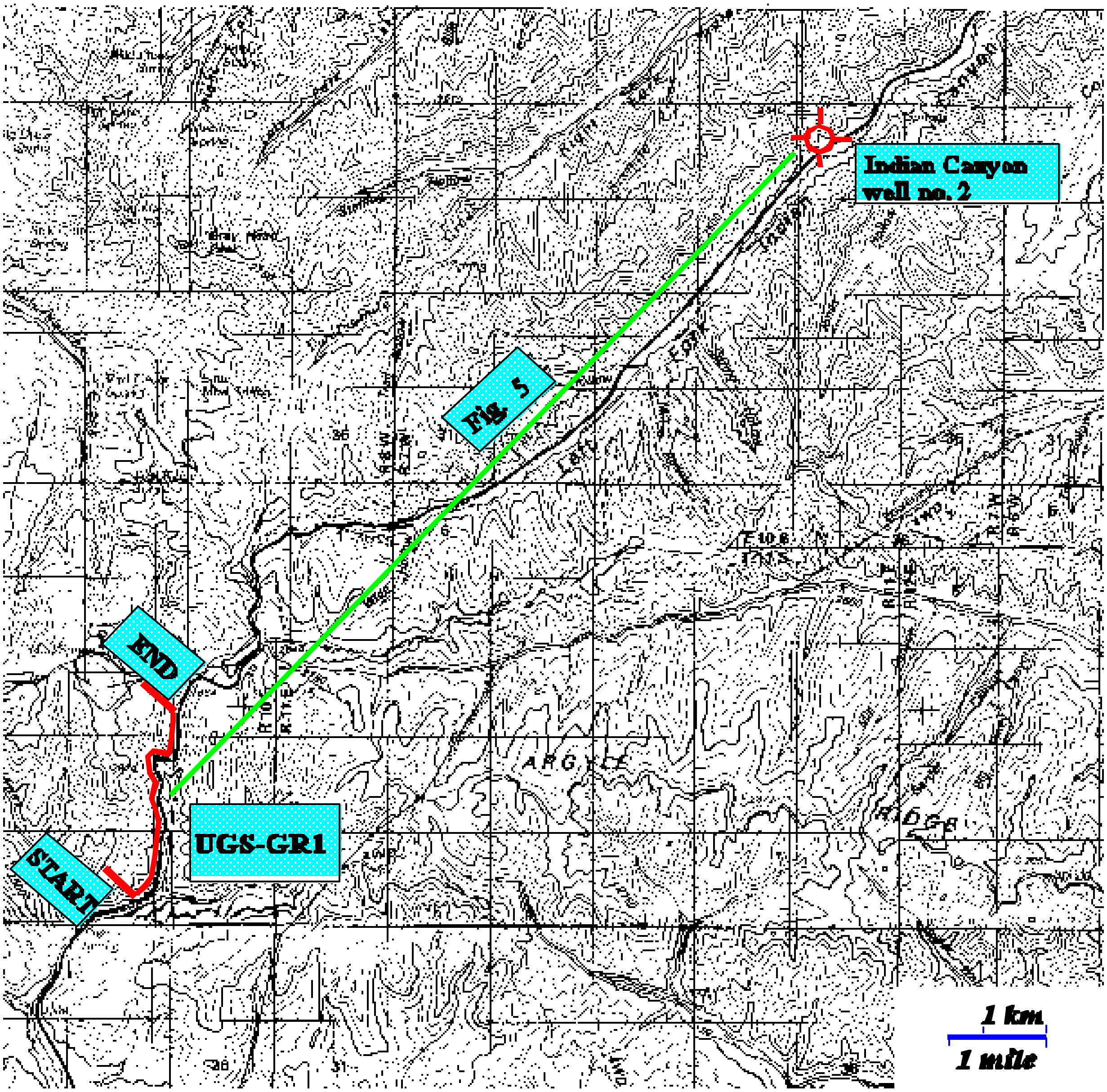


Fig. 2. Map showing the location of the Willow Creek Canyon stratigraphic section UGS-GR1, and the Indian Canyon well no. 2. Correlation of UGS-GR1 to the Indian Canyon well is shown in Fig. 5. The base map is the Price 1:100,000-scale metric topographic map. Contour interval is 50 meters.

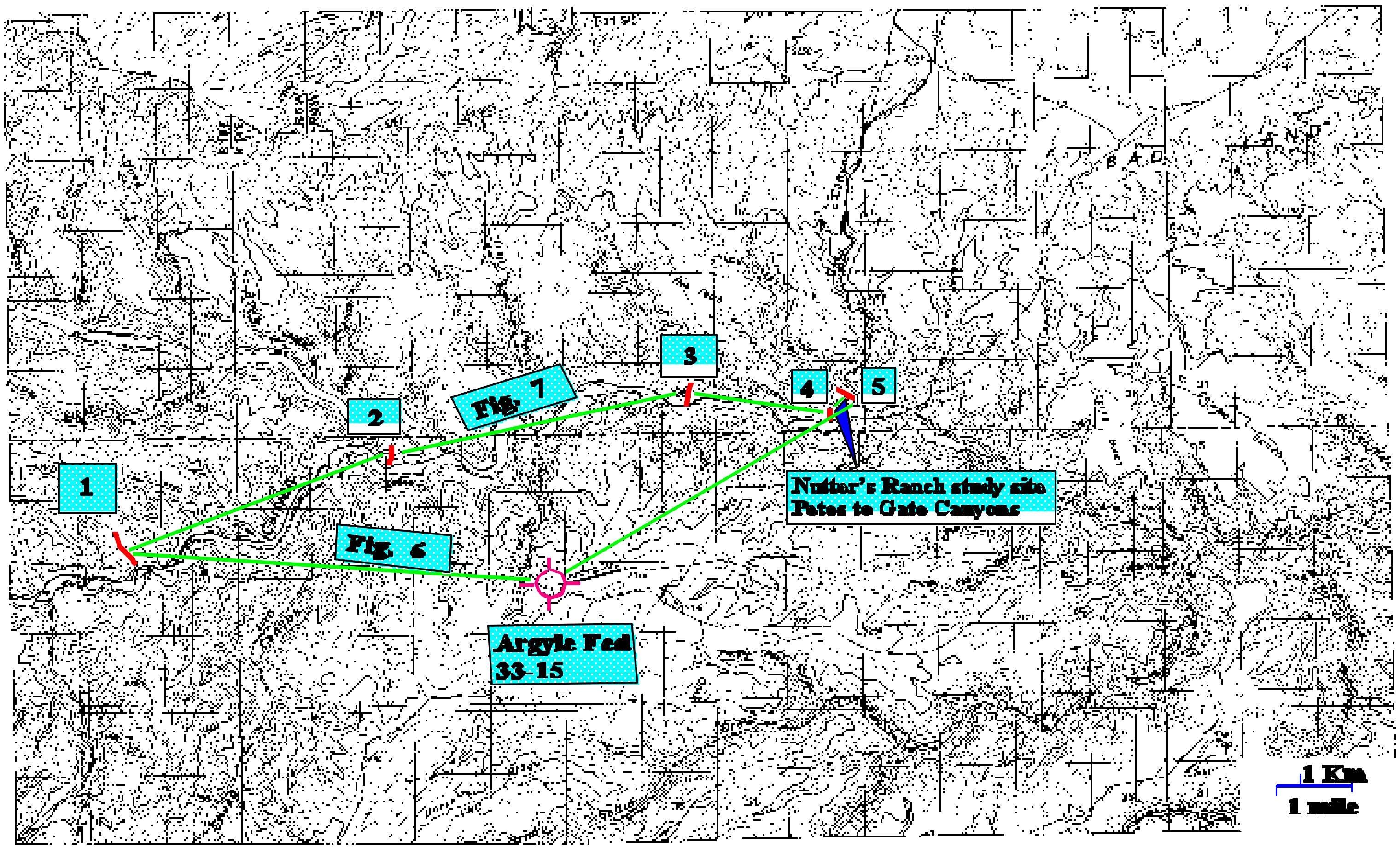


Fig. 3. Map showing the location of the stratigraphic sections in Nine Mile Canyon. (1) UGS-GR2 and UGS-GR3, which closely follow Remy's (1992) section 16, (2) Remy's section 8, (3) UGS Current Canyon section, (4) UGS Petes Canyon section, (5) UGS-GR4 and Remy's section 7. Correlation of UGS-GR2, UGS-GR3, and UGS-GR4, with the Argyle well is shown in Fig. 6. The correlation of the carbonate marker beds at locations 1 through 5 is shown in Fig. 7. The base is the Price 1:100,000-scale metric topographic map. Contour interval is 50 meters.

Fig. 4. Gathering gamma-ray data every meter over Remy's (1992) measured section 7, UGS-GR4. See Fig. 3 for location.

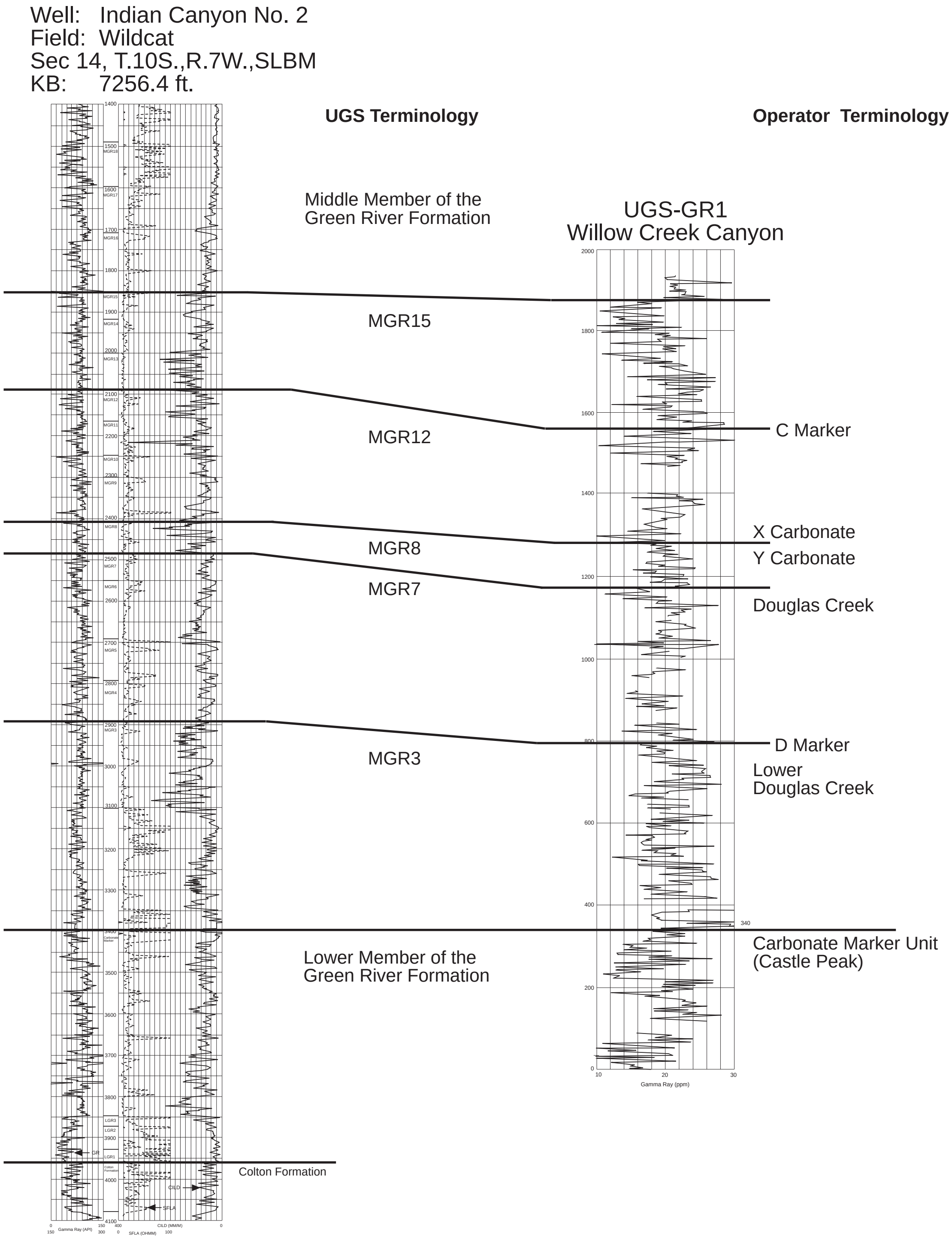


Fig. 5. Correlation of Indian Canyon No. 2 Well to the gamma-ray curve UGS-GR1. See Fig. 2 for location of the gamma-ray section and well.

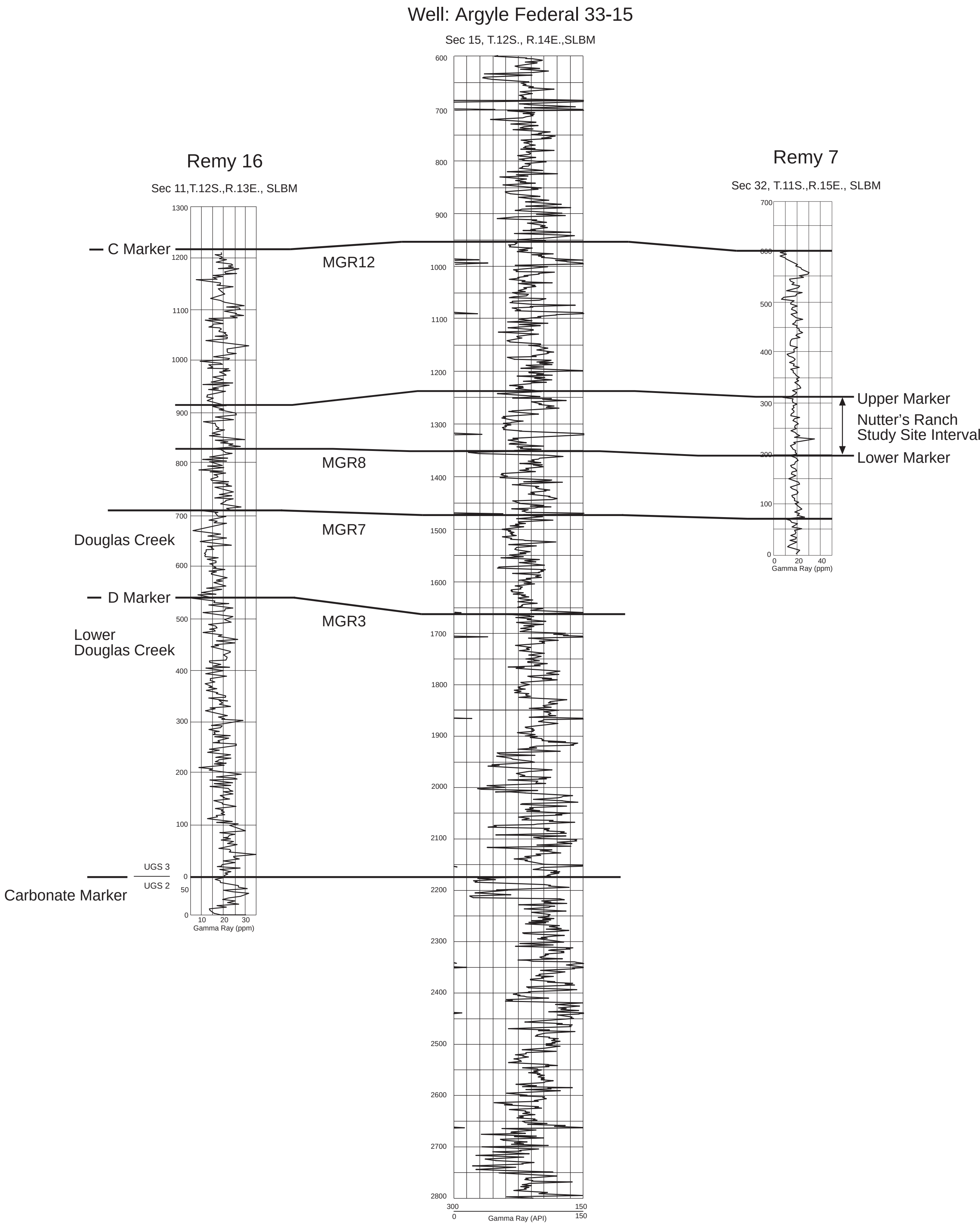


Fig. 6. Correlation of gamma-ray curves UGS-GR2, UGS-GR3, and UGS-GR4 with Argyle Federal 33-15 well (section 15, T. 12S., R. 14E., Salt Lake Base Line and Meridian (SLBM). See Fig. 3 for location of gamma-ray sections (labeled 1 and 5) and well.

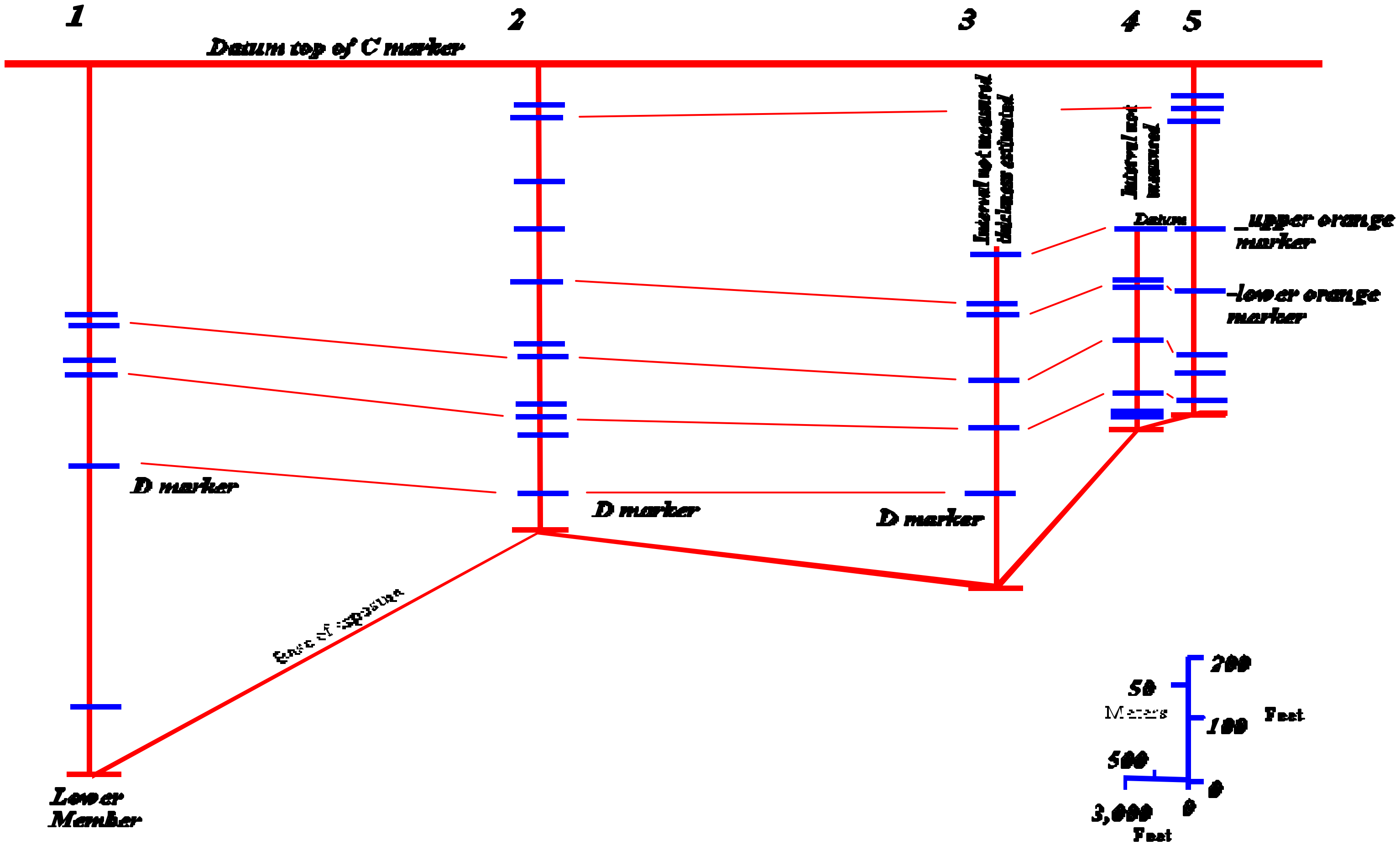


Fig. 7. Correlation of carbonate marker beds in Nine Mile Canyon, see Fig. 3 for location of the measured sections. C and D markers refer to Remy (1992). Upper and lower orange markers refer to the carbonate markers that define the stratigraphic interval being studied at the Nutter's Ranch study site (see Figs. 8 and 9). (1) Remy measured section 16, (2) Remy measured section 8, (3) UGS Current Canyon measured section, (4) UGS Petes Canyon measured section, (5) Remy measured section 7.

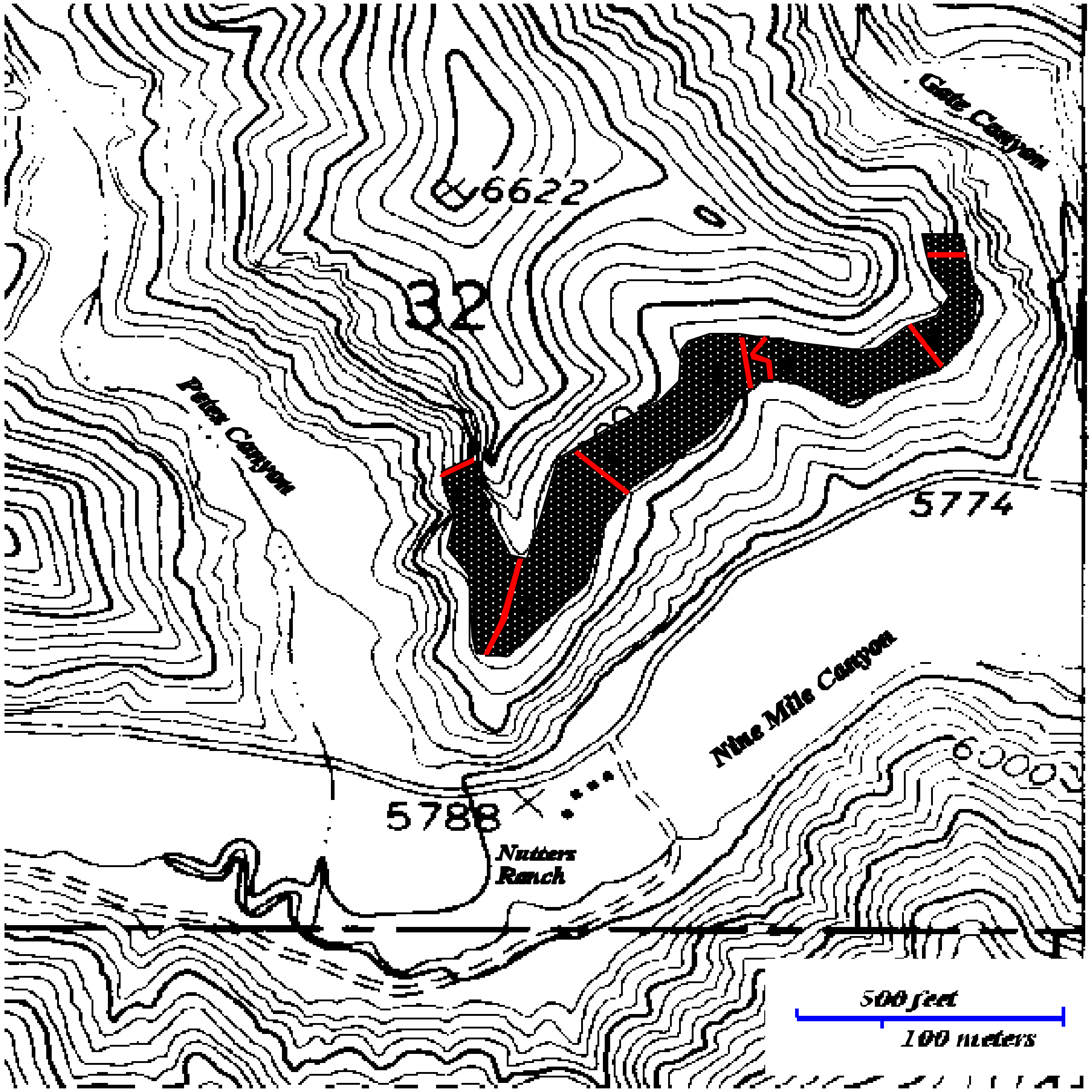


Fig. 8. Map showing the location of the Nutter's Ranch study site in Nine Mile Canyon (section 32, T. 11 S., R. 15 E., SLBM). The approximate location of the stratigraphic interval being studied is shown by the shading. The numbers in the shaded area refer to measured sections which include gamma-ray data (except at 1) gathered every 3 ft (1 m). The sections are named: (1) Petes Canyon, (2) Nutter's Point, (3) Lunch Stop, (4) Alcove, (5) East Alcove, (6) Remy 7, (7) Gate Canyon. Correlation of the sections 2 through 7, is shown in Fig. 9. Base is the Current Canyon Quadrangle 7.5-minute topographic map. Contour interval is 40 ft.

GEOLOGIC INVESTIGATION OF THE GREEN RIVER FORMATION IN THE SUBSURFACE

Geophysical Well Logs

Twenty-two log cycles defined on geophysical well logs for the Middle and Lower Members of the Green River Formation are being correlated using an alpha-numeric scheme described in the first biannual technical report (Morgan and others, 1999b). The top of each log cycle, total feet of sandstone, and total feet of sandstone with ten percent or more porosity, are entered into the Geographical Information System (GIS) database. The GIS database will be used to map and interpret regional trends and depositional environments of each of the log cycles after completion of the correlations. Logs from more than 600 wells have been correlated as of September 30, 1999.

The log cycles are patterns that are bounded by distinctive beds or surfaces that can be identified on well logs for hundreds of square miles. It is believed that the log cycles approximate depositional packages because of the lateral extent of the bounding surfaces. Ideally, each depositional package in the Green River Formation should consist of a lake level rise and fall.

Total sandstone in each cycle (except in cycles LGR1 through LGR3) is defined by 80 API GR units or less. This cutoff does not uniquely represent sandstone, because the carbonate beds found in many of the cycles have very low GR values and therefore they too are included in the total sandstone. Maps generated from the total sandstone data should show changes in the sandstone deposition because most of the carbonate beds are laterally extensive and vary only slightly in thickness. Total sandstone in cycles LGR1 through LGR3, commonly referred to as the Uteland Butte Limestone, is defined by 60 API GR units or less. These cycles are almost entirely carbonate and the 60 API GR cut off represents clean (little to no clay content) carbonate rock which is an oil reservoir in some parts of the project area.

Total porosity in each cycle is the total feet of rock with 80 API GR units or less (60 API units or less in LGR1-LGR3) that has 10 % or more porosity based on a density log, assuming a 2.68 g/cc grain density. The total porosity will primarily represent porosity trends in the sandstone because the carbonate beds typically have low porosity. Also, the grain density of the carbonate beds is typically 2.71 g/cc or higher, therefore the log porosity is underestimated at 2.68 g/cc.

Sandstone thickness and porosity trend maps for each cycle, along with the depositional and petrophysical interpretation of core and outcrop, will be used to develop a geologic model for each log cycle. The geologic model will help identify additional potential in established fields and new areas for exploration.

Well Core

Core from 30 wells in the project area has been described, and depositional environments have been subsequently interpreted. Thin sections have been made from many reservoir and nonreservoir lithotypes for further petrophysical analysis. The following are preliminary conclusions based on the combined petrologic analysis.

The most common sandstone types are very fine- to fine-grained lithic arkoses and feldspathic litharenites, containing orthoclase and microcline potassium feldspars, and sodium-rich plagioclase. Other framework grains are mostly monocrystalline quartz and some polycrystalline quartz, especially evident in the medium-grained sandstones of the black shale facies of Picard and others (1973), perhaps laterally equivalent to a tongue of the Colton Formation. Rutile inclusions in the quartz, and the heavy mineral sphene are fairly common and may directly indicate a granitic or basement provenance. The provenance for the sandstone is mainly igneous; granodiorite, and quartz monzonite. Heavy minerals include tourmaline, zircon, epidote, and sphene. Also, there are indications of some metamorphic and sedimentary sources such as sheared metaquartz, rounded overgrowths in monocrystalline quartz, chert, siltstone, and mudstone fragments. The Uncompaghre uplift of western Colorado appears to be the dominant source area based on compositional similarities with the basement rocks present in that region. During the erosion of Uncompaghre basement highs in the Eocene, major stream flow leading to the deposits of the Green River Formation in the southern portion of the Uinta Basin was from south-southeast to north-northwest.

The silicate minerals commonly possess extensive overgrowths, which serve to cement the sandstones to varying degrees. This phenomenon is especially common for quartz, and for certain plagioclase grains. Compaction and cementation processes are, however, quite variable, both horizontally and vertically, even within a single thin-section sample. Dolomite, ankerite, calcite, and iron-rich calcite are the most common carbonate cements. Iron-rich carbonate rims usually envelope iron-poor carbonate varieties. Ankerite is apparently the latest phase of carbonate cementation, often rimming precursor iron-rich calcite and dolomite cements. Compaction is modestly limited in sandstone samples where early carbonate cementation occurred, but when early calcite cementation did not take place, the compaction is severe with interpenetrative contacts and mildly sutured grains.

The best quality reservoir rocks (permeability from 10 to 100 mD) in the Monument Butte area are sandstone that possess indisputable evidence of dissolution of the: (1) early iron-poor, calcite cement, (2) potassium feldspars, and (3) various mudstone or siltstone lithoclasts. Reservoir quality is reduced or completely ruined, when iron-rich calcite and/or ankerite have occluded the secondary intergranular voids created through the dissolution of the iron-poor calcite cement. Obviously, reservoir quality can also be totally diminished when severe compaction and cementation of silicate minerals is evident.

The depositional environments of the sandstone also play a significant, but subordinate, diagenetic role in development of reservoir quality rock. Large amounts of silt and detrital clay in the sandstone are especially detrimental to reservoir quality. Silt and clay are commonly found (1) in the basal portion of distributary channels (pseudo matrix of rip-ups), (2) in laminated overbank deposits, (3) in the ripple-drift laminated (muscovite-rich) upper portion of distributary channels, and (4) in the turbidite(?) facies in which the sandstone beds contain framework grains coated by detrital illite.

Finally, cores of the carbonate beds that are used for correlation purposes, both correlation markers on the surface and in the subsurface, reveal lateral variation in facies from light brown-gray algal boundstone and ostracodal packstone/grainstone, in the southern environments, to very dark gray argillaceous carbonate in the deeper, more northerly, open lacustrine environments.

GEOLOGIC INVESTIGATION OF THE OUTCROP OF THE GREEN RIVER FORMATION

Regional Outcrop Study

Published measured sections by Remy (1992) were reviewed in the field and additional sections were measured and described by the UGS. Gamma-ray data were collected over three stratigraphic sections (Figs. 2 and 3), and spectral gamma-ray data were collected over two of the sections. Ratios of potassium (K), uranium (U), and thorium (T) will be compared to the lithologic descriptions to determine if the data can be used to help interpret depositional environments. The GR data from all three sections were used to generate curves that were correlated to geophysical well logs (Figs. 5 and 6).

A 1900-ft (580-m) stratigraphic section of the Green River Formation was measured and described, and spectral gamma-ray data were gathered in Willow Creek Canyon. The section (UGS-GR1) began in the carbonate marker unit of the Lower Member of the Green River Formation (SW1/4 section 23, T. 11 S., R. 10 E., SLBM) and ended in MGR17 (Morgan and others, 1999b) (NW1/4 section 12, T. 11 S., R 10 E., SLBM) (Fig. 2). The Green River is exposed in a series of road cuts along State Route 33; between the road cuts the formation is covered with a thick vegetative soil. Spectral gamma-ray data were gathered every 3 ft (1 m) with a one minute sample time. The GR (parts per million [ppm]), K (%), U (ppm), and T (ppm) and the counts for each value were recorded. Spectral gamma-ray data were not gathered between the road cuts because of the thick soil cover.

A 1200-ft (360-m) stratigraphic section of the Green River Formation was measured and described, and spectral gamma-ray data were gathered in the west portion of Nine Mile Canyon in two parts. The first part of the section (UGS-GR2) began near the top of the carbonate marker unit of the Lower Member of the Green River Formation and ended a few feet into the Middle Member (SW1/4, section 11, T. 12 S., R. 13 E., SLBM). About 100 ft (30 m) to the east, the second part of the section (UGS-GR3) began near the base of the Middle Member and ended in MGR12 (Remy C marker [1992]) (NW1/4, section 11, T. 12 S., R. 13 E., SLBM) (Fig. 3). Rock exposures are fair to good through the section. Some parts of the section have moderate tree and bush cover, but many of the slopes have only minor plant cover and the weathered slopes give a good indication of the dominant underlying rock type. Spectral gamma-ray data were gathered every 3 ft (1 m) with a two minute sample time. The GR (ppm), K (%), U (ppm), T (ppm), and the counts for each value were recorded. The UGS-GR3 section is in the same area as Remy (1992) measured section 16.

Spectral gamma-ray data were gathered in the central portion of Nine Mile Canyon along 586 ft (183 m) of Remy's (1992) measured section 7. The section (UGS-GR4) began in the Middle Member of the Green River Formation at about MGR6 (SE1/4, section 32, T. 11 S., R. 15 E., SLBM) and ended at MGR12 (Remy's C marker) (NE1/4, section 32, T. 11 S., R. 15 E., SLBM) (Fig. 3). Rock exposures are good to excellent through the section. Most of the slopes have only minor plant cover, and the weathered slopes give a good indication of the dominant underlying rock type. GR data were gathered every meter, closely correlating with Remy's measured section. Only the GR (ppm) values were recorded using a 30-second sample time in order to reduce the field time needed to complete the section.

Curves generated from the GR data were used to correlate the stratigraphic sections to the geophysical logs of nearby wells (Figs. 5 and 6). Large-scale (about 100-ft [30-m]) depositional cycles are defined in the Nine Mile Canyon area by a series of laterally continuous carbonate marker beds deposited during high lake levels. A series of measured sections by the UGS and published sections by Remy (1992) are used to correlate the carbonate beds and the depositional cycles they define for about 20 miles (32 km) in Nine Mile Canyon (Figs. 3 and 7). Nine Mile Canyon has a length of about 40 miles (32 km), not 9 miles (14 km) as the name implies.

Detailed Study Site

A study site was selected to better understand the interwell-scale reservoir heterogeneity in one depositional cycle. The location, 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 (Fig 8). The exposure is about 2000 ft (600 m) in length in the west-to-east direction, a slightly greater distance than the 1320 ft (402.3 m) between two wells if they are drilled on 40 acre (16.2 ha) spacing. The study site extends about 500 ft (150 m) in the south-to-north direction in the two tributary canyons providing a three-dimensional perspective.

The Nutter's Ranch study site was photographed on all three sides from the opposite side of the canyons. The photographs were digitally joined into mosaics that will be used to correlate the beds along the entire length of the exposure (Figs. 9 and 10). Seven stratigraphic sections were measured and described, and GR data were gathered over six of the sections (Fig. 11). Correlation of the primary sandstone beds shows down-cutting of the upper sandstone bed to form a single unit with the lower sandstone bed in places and rapid thinning of the upper sandstone bed in other places (Figs 9, 10, and 11).

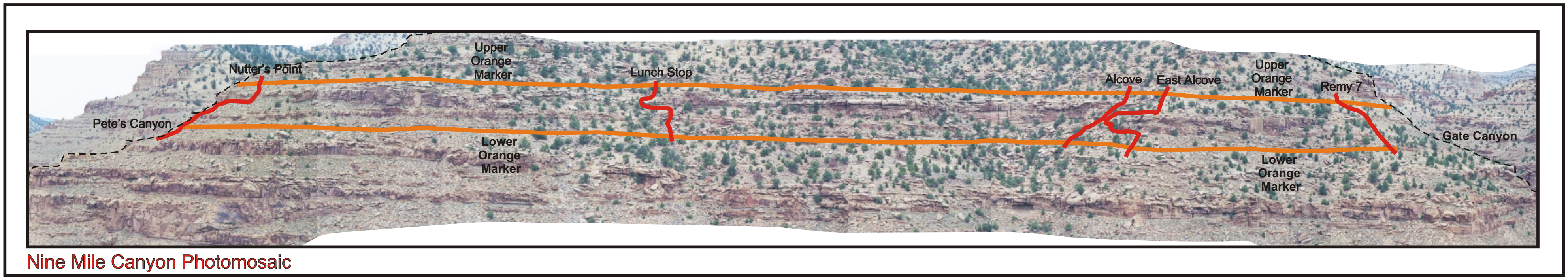
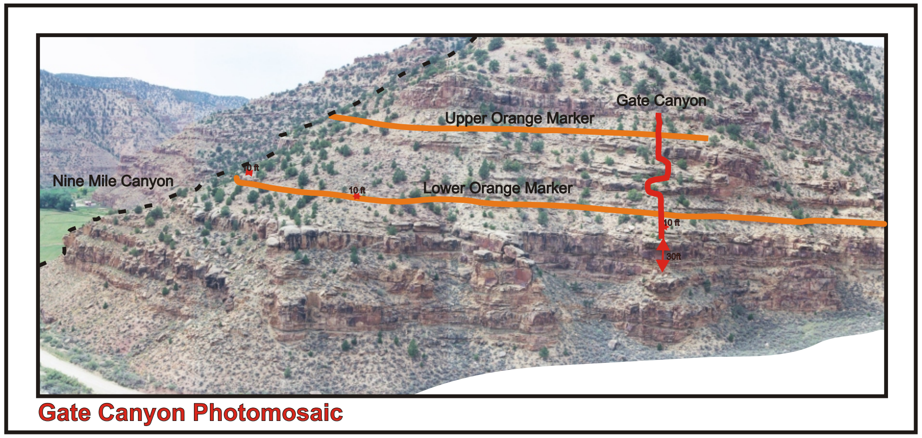


Fig. 9. Photomosaic of the Nine Mile Canyon portion of the Nutter's Ranch study site. The upper and lower orange markers are carbonate beds that define the upper and lower boundaries of the stratigraphic interval being studied. Nutter's Point, Lunch Stop, Alcove, East Alcove, and Remy 7, are measured sections (see Fig. 11).



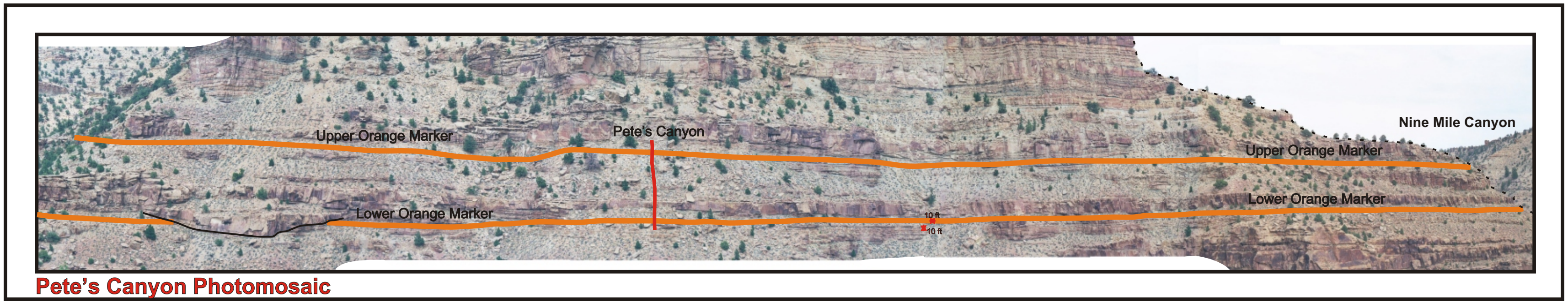


Fig. 10. Photomosaics of the Gate Canyon and Petes Canyon portions of the Nutter's Ranch study site. The upper and lower orange markers are carbonate beds that define the upper and lower boundaries of the stratigraphic interval being studied. Vertical lines labeled Gate Canyon and Pete's Canyon are the location of measured sections.

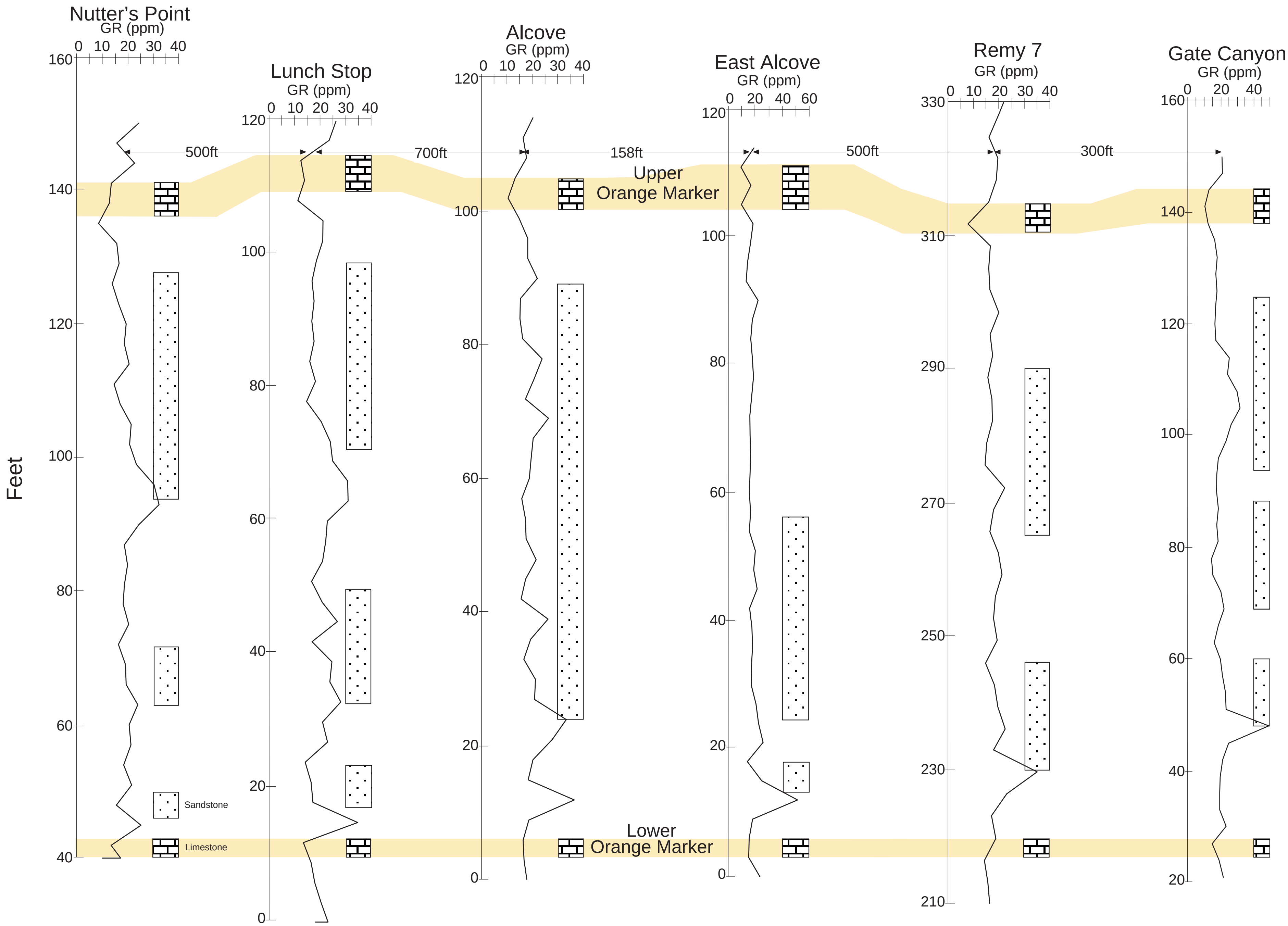


Fig.11. Stratigraphic cross section of the Nutter's Ranch study site. The cross section is an example of the heterogeniety that can exist between two wells spaced about 1320 ft (402.3 m) apart. Only primary limestone and sandstone beds are shown. See Fig. 8 for location of sections.

RESERVOIR SIMULATION ACTIVITY

The Monument Butte area has been modeled extensively (Deo and others, 1994; Deo and others, 1996; and Pawar and others, 1996). In these studies, the petrophysical properties for the region of interest were generated using purely geostatistical methods. At unit scales, the models did provide good history matches and insight into the water-flood mechanics. However, since local geology was not incorporated into the models directly, the effect of geology on production from different parts of the field was not evident. In this project, an attempt is being made to include as much geologic information as is possible and compare the petrophysical and subsequently the reservoir simulation model with that obtained using only geostatistical methods. In order to incorporate local geology, a software tool titled HERESIM® will be used.

HERESIM®, which stands for **HE**terogeneities of **RE**servoir **SIM**ulations, provides a geologic infrastructure to integrate log information, core data, and other geologic input, and serves as a bridge between geoscientists and engineers. It can be used to better understand the internal architecture of a reservoir. Since development of the petrophysical model for reservoir simulation input is a joint effort between geologists, reservoir and petroleum engineers, mutual understanding of the reservoir performance and reservoir management is facilitated.

In HERESIM®, individual lithofacies in each of the wells in a given study area are identified and provided as input. Several different geologic concepts can be inputted and tested. The spatial variability is modeled using vertical proportion curves and variograms. Three-dimensional images of reservoirs can be generated and tested against any hypotheses. The process guarantees generation of the most realistic and geologically consistent reservoir information. HERESIM®, which is marketed and maintained by BEICIP-FRANLAB® Petroleum Consultants, was installed and a sample data set is being used to understand data relevance and dependence.

The original approach of generating geostatistically determined equally probable reservoir images will be implemented using a program entitled Uncertainty Analysis® (UNCERT®), a public domain software. The software is being installed and tested on our computers.

All the reservoir simulation tools for the parallel reservoir simulation of fractured or nonfractured media are in place.

TECHNOLOGY TRANSFER

The UGS displayed an overview of the project at the National AAPG convention in April and at the AAPG Rocky Mountain Section meeting in August. Also, a poster was presented at the Rocky Mountain Section meeting (Morgan and others, 1999a).

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, 1999 through March 31, 2000:
(1) Correlation of well logs will continue. We anticipate that logs from about 800 wells should be correlated and the results entered into the database by January 2, 2000, at which time we will begin generating regional structure, sandstone-thickness, and feet-of-porosity isochore maps. The maps, core, and outcrop data will be used to help interpret the distribution of the regional depositional environments within the Middle and Lower Members of the Green River Formation, and ultimately identify areas with exploration potential.

(2) Additional well core will be described and sampled. Analysis of thin sections made from core and outcrop samples will continue, and some samples will be selected for scanning electron microscopy. These analyses will help further refine our interpretation of the diagenesis of the reservoir rock. Much of the core and the thin sections will be photographed. The reservoir rocks will be divided into subfacies and correlated to the well logs, and porosity and permeability values will be applied to each subfacies. Geophysical well logs will be used to correlate the subfacies with the other wells in the areas selected for reservoir simulation modeling that do not have core. These data will be used to further refine the numerical reservoir simulation modeling.

(3) The field work data will be interpreted. The photomosaics, GR curves, and measured sections of the Nutter's Ranch study site will be used to develop detailed three-dimensional cross sections of the selected stratigraphic interval. This data will be used to develop variograms of the interwell environment.

(4) Data from the core, well log correlations, and outcrop study will be incorporated into the reservoir simulation model of the Northeast Monument Butte water-flood unit which produces from the MGR7, MGR6, and MGR5 sandstone beds. Data will be gathered and modeling will begin of the Brundage Canyon field, which produces from the carbonate marker unit, and of the Uteland Butte field, which produces from the LGR1, LGR2, and LGR3 carbonate beds.

(5) Technology transfer activities will continue. The project team will meet with the technical advisory board to review the data and current status of work on each of the project tasks. The board will be asked to advise the project team on what type of additional work needs to be done in the field. The biannual technical report will be sent to all interested parties and posted on the project web site.

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