HETEROGENEOUS SHALLOW-SHELF CARBONATE BUILDUPS IN THE PARADOX BASIN, UTAH AND COLORADO: TARGETS FOR INCREASED OIL PRODUCTION AND RESERVES USING HORIZONTAL DRILLING TECHNIQUES

(Contract No. DE-2600BC15128)

DELIVERABLE 1.4.1 AND 1.4.2 CROSS SECTIONS AND FIELD MAPS: CHEROKEE AND BUG FIELDS, SAN JUAN COUNTY, UTAH, AND LITTLE UTE AND SLEEPING UTE FIELDS, MONTEZUMA COUNTY, COLORADO

Submitted by

Utah Geological Survey
Salt Lake City, Utah 84114
December 2003

UTAH GEOLOGICAL SURVEY

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DISCLAIMER

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INTRODUCTION

Over 400 million barrels (64 million m^3) of oil have been produced from the shallow-shelf carbonate reservoirs in the Pennsylvanian (Desmoinesian) Paradox Formation in the Paradox Basin, Utah and Colorado. With the exception of the giant Greater Aneth field, the other 100 plus oil fields in the basin typically contain 2 to 10 million barrels (0.3-1.6 million m^3) of original oil in place. Most of these fields are characterized by high initial production rates followed by a very short productive life (primary), and hence premature abandonment. Only 15 to 25 percent of the original oil in place is recoverable during primary production from conventional vertical wells.

An extensive and successful horizontal drilling program has been conducted in the giant Greater Aneth field. However, to date, only two horizontal wells have been drilled in small Ismay and Desert Creek fields. The results from these wells were disappointing due to poor understanding of the carbonate facies and diagenetic fabrics that create reservoir heterogeneity. These small fields, and similar fields in the basin, are at high risk of premature abandonment. At least 200 million barrels (31.8 million m^3) of oil will be left behind in these small fields because current development practices leave compartments of the heterogeneous reservoirs undrained. Through proper geological evaluation of the reservoirs, production may be increased by 20 to 50 percent through the drilling of low-cost single or multilateral horizontal legs from existing vertical development wells. In addition, horizontal drilling from existing wells minimizes surface disturbances and costs for field development, particularly in the environmentally sensitive areas of southeastern Utah and southwestern Colorado.

GEOLOGIC SETTING

The Paradox Basin is located mainly in southeastern Utah and southwestern Colorado with a small portion in northeastern Arizona and the northwestern most corner of New Mexico (figure 1). The Paradox Basin is an elongate, northwest-southeast trending evaporitic basin that predominately developed during the Pennsylvanian (Desmoinesian), about 330 to 310 million years ago (Ma). During the Pennsylvanian, a pattern of basins and fault-bounded uplifts developed from Utah to Oklahoma as a result of the collision of South America, Africa, and southeastern North America (Kluth and Coney, 1981; Kluth, 1986), or from a smaller scale collision of a microcontinent with south-central North America (Harry and Mickus, 1998). One result of this tectonic event was the uplift of the Ancestral Rockies in the western United States. The Uncompahgre Highlands in eastern Utah and western Colorado initially formed as the westernmost range of the Ancestral Rockies during this ancient mountain-building period. The Uncompahgre Highlands (uplift) is bounded along the southwestern flank by a large basement-involved, high-angle reverse fault identified from geophysical seismic surveys and exploration drilling. As the highlands rose, an accompanying depression, or foreland basin, formed to the southwest — the Paradox Basin. Rapid subsidence, particularly during the Pennsylvanian and then continuing into the Permian, accommodated large volumes of evaporitic and marine sediments that intertongue with non-marine arkosic material shed from the highland area to the northeast (Hintze, 1993). The Paradox Basin is surrounded by other uplifts and basins that formed during the Late Cretaceous-early Tertiary Laramide orogeny (figure 1).

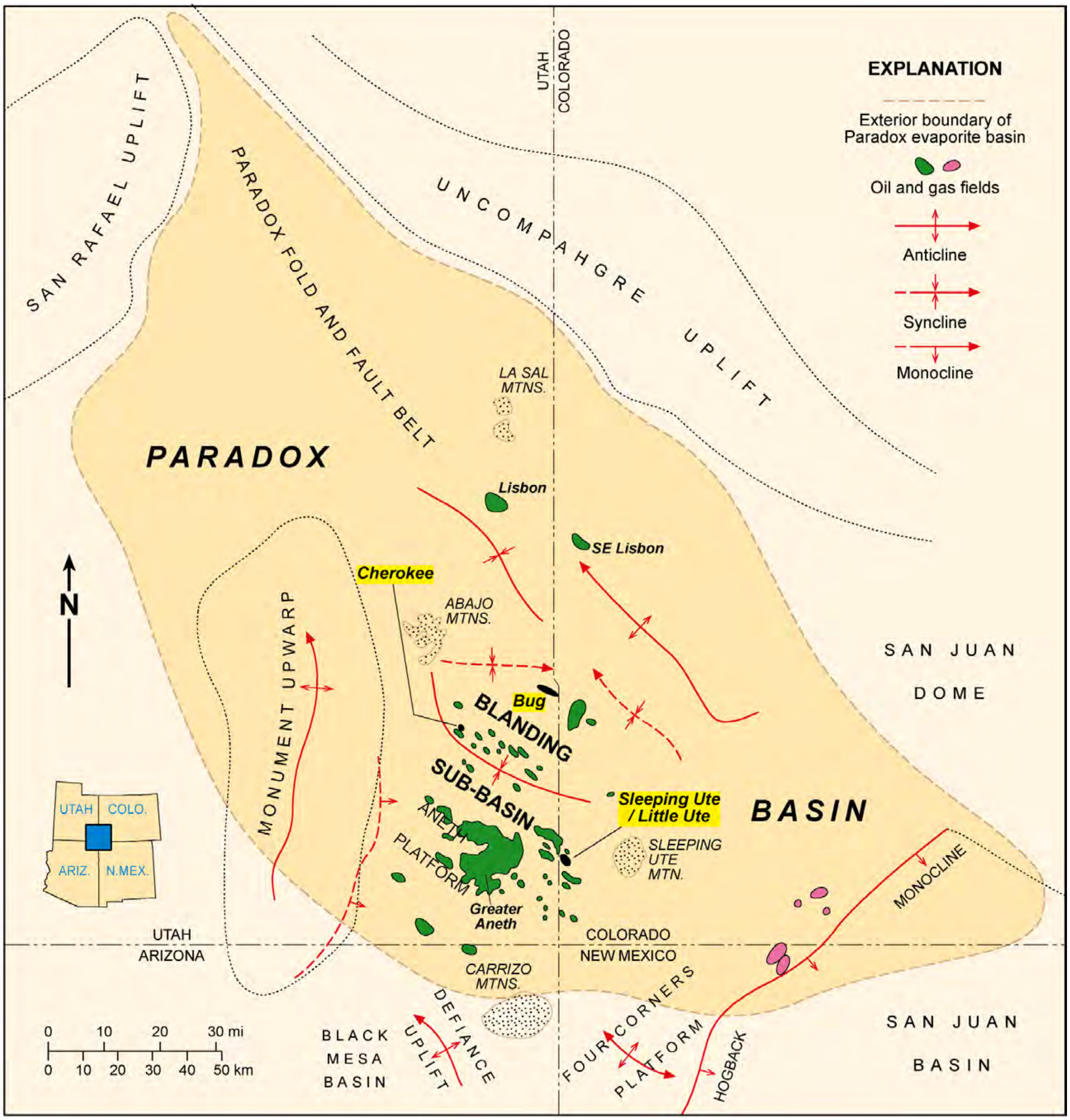

Figure 1. Location map of the Paradox Basin, Utah, Colorado, Arizona, and New Mexico showing producing oil and gas fields, the Paradox fold and fault belt, and Blanding sub-basin as well as surrounding Laramide basins and uplifts (modified from Harr, 1996).

The Paradox Basin can generally be divided into two areas: the Paradox fold and fault belt in the north, and the Blanding sub-basin in the south-southwest (figure 1). Most oil production comes from the Blanding sub-basin. The source of the oil is several black, organic-rich shales within the Paradox Formation (Hite and others, 1984; Nuccio and Condon, 1996). The relatively undeformed Blanding sub-basin developed on a shallow-marine shelf which locally contained algal-mound and other carbonate buildups in a subtropical climate.

The two main producing zones of the Paradox Formation are informally named the Ismay and the Desert Creek (figure 2). The Ismay zone is dominantly limestone comprising equant buildups of phylloid-algal material with locally variable small-scale subfacies (figure 3A) and capped by anhydrite. The Ismay produces oil from fields in the southern Blanding sub-basin (figure 4). The Desert Creek zone is dominantly dolomite comprising regional nearshore shoreline trends with highly aligned, linear facies tracts (figure 3B). The Desert Creek produces oil in fields in the central Blanding sub-basin (figure 4). Both the Ismay and Desert Creek buildups generally trend northwest-southeast. Various facies changes and extensive diagenesis have created complex reservoir heterogeneity within these two diverse zones.

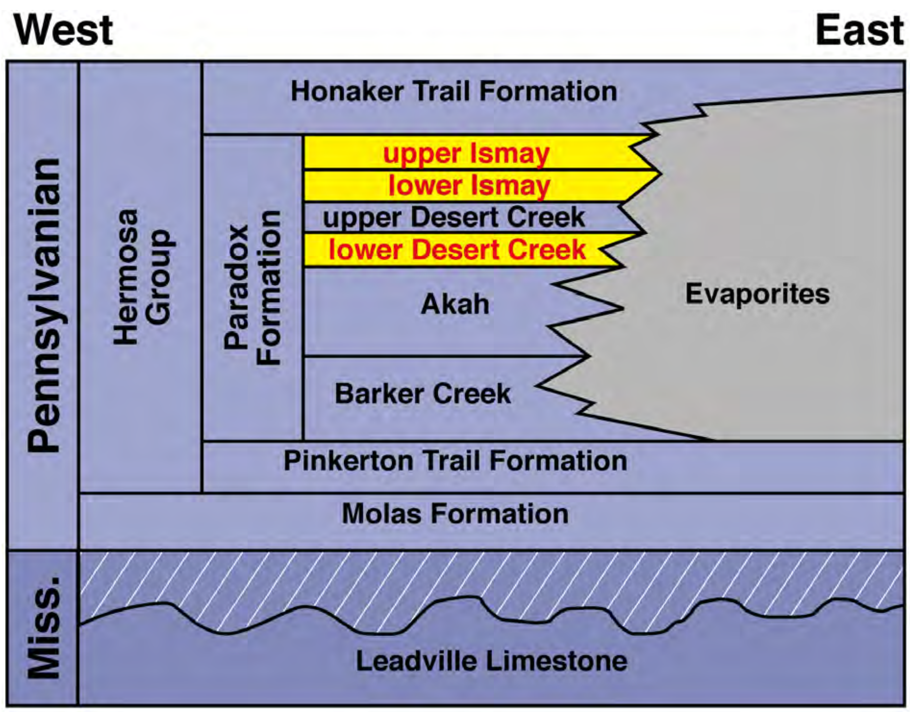

Figure 2. Pennsylvanian stratigraphy of the southern Paradox Basin including informal zones of the Paradox Formation; the Ismay and Desert Creek zones productive in the case-study fields described in this report are highlighted.

CASE-STUDY FIELDS

Two Utah fields were selected for local-scale evaluation and geological characterization: Cherokee in the Ismay trend and Bug in the Desert Creek trend (figure 4). Two Colorado fields are also selected for evaluation: Little Ute and Sleeping Ute in the Ismay trend (figure 4). This evaluation included data collection, cross sections, and various maps (top of structure, thickness, porosity, permeability, facies, and so forth) of these fields as presented in this report.

This geological characterization focused on reservoir heterogeneity, quality, and lateral continuity, as well as possible compartmentalization within the fields. From these evaluations, untested or under-produced compartments can be identified as targets for horizontal drilling. The models resulting from the geological and reservoir characterization of these fields can be applied to similar fields in the basin (and other basins as well) where data might be limited.

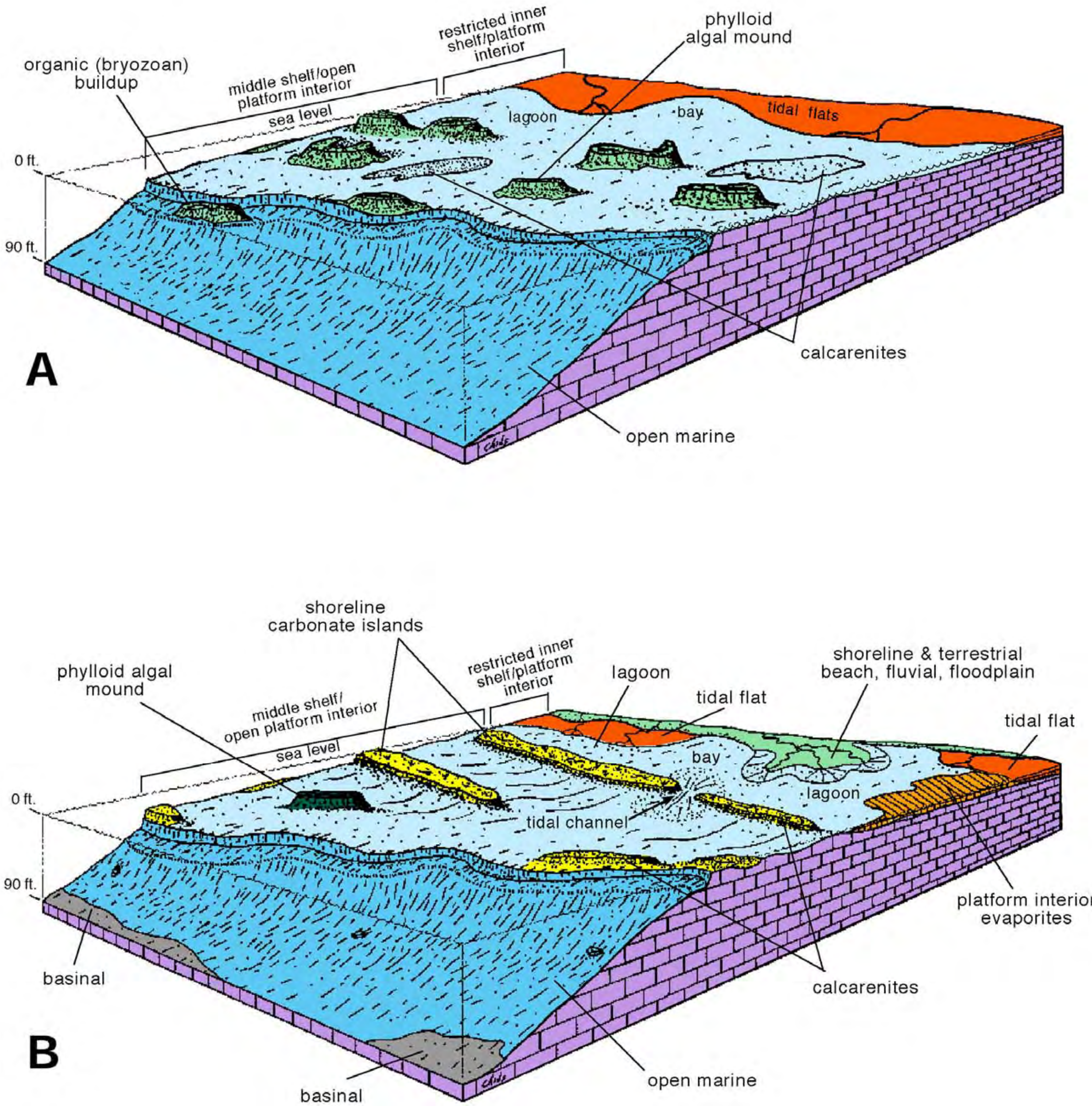

Figure 3. Block diagrams displaying major depositional facies, as determined from core, for the Ismay (A) and Desert Creek (B) zones, Pennsylvanian Paradox Formation, Utah and Colorado.

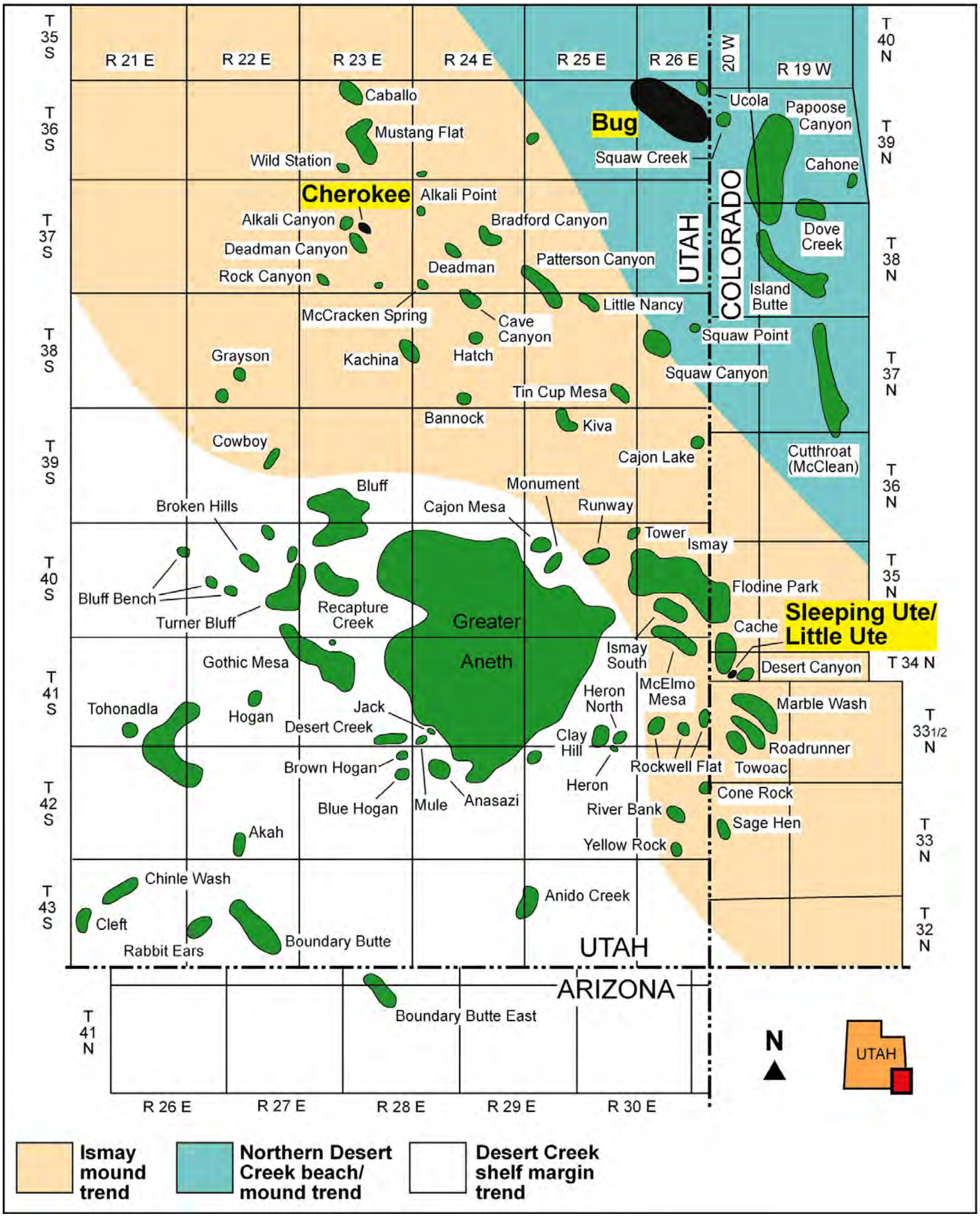

Figure 4. Map showing the project study area and fields (case-study fields in black) within the Ismay and Desert Creek producing trends in the Blanding sub-basin, Utah and Colorado.

Cherokee Field

Cherokee field (figure 4) is a phylloid-algal buildup capped by anhydrite that produces from porous algal limestone and dolomite in the upper Ismay zone. The net reservoir thickness is 27 feet (8.2 m), which extends over a 320-acre (130 ha) area. Porosity averages 12 percent with 8 millidarcies (md) of permeability in vuggy and intercrystalline pore systems. Water saturation is 38.1 percent (Crawley-Stewart and Riley, 1993).

Cherokee field was discovered in 1987 with the completion of the Meridian Oil Company Cherokee Federal 11-14, NE1/4NW1/4 section 14, T. 37 S., R. 23 E., Salt Lake Base Line and Meridian (SLBL&M); initial potential flow (IPF) was 53 barrels of oil per day (BOPD) (8.4 m^3), 990 thousand cubic feet of gas per day (MCFGPD) (28 MCMPD), and 26 barrels of water (4.1 m^3). There are currently four producing (or shut-in) wells and two dry holes in the field. The well spacing is 80 acres (32 ha). The present field reservoir pressure is estimated at 150 pounds per square inch (psi) (1,034 Kpa). Cumulative production as of June 1, 2003, was 182,071 barrels of oil (28,949 m^3), 3.65 billion cubic feet of gas (BCFG) (0.1 BCMG), and 3,358 barrels of water (534 m^3) (Utah Division of Oil, Gas and Mining, 2003). The original estimated primary recovery is 172,000 barrels of oil (27,348 m^3) and 3.28 BCFG (0.09 BCMG) (Crawley-Stewart and Riley, 1993). The fact that both these estimates have been surpassed suggests significant additional reserves could remain.

Bug Field

Bug field (figure 4) is an elongate, northwest-trending carbonate buildup in the lower Desert Creek zone. The producing units vary from porous dolomitized bafflestone to packstone and wackestone. The trapping mechanism is an updip porosity pinchout. The net reservoir thickness is 15 feet (4.6 m) over a 2,600-acre (1,052 ha) area. Porosity averages 11 percent in moldic, vuggy, and intercrystalline networks. Permeability averages 25 to 30 md, but ranges from less than 1 to 500 md. Water saturation is 32 percent (Martin, 1983; Oline, 1996).

Bug field was discovered in 1980 with the completion of the Wexpro Bug No. 1, NE1/SE1/4 section 12, T. 36 S., R. 25 E., SLBL&M, for an IPF of 608 BOPD (96.7 m^3), 1,128 MCFGPD (32 MCMPD), and 180 barrels of water (28.6 m^3). There are currently eight producing (or shut-in) wells, five abandoned producers, and two dry holes in the field. The well spacing is 160 acres (65 ha). The present reservoir field pressure is 3,550 psi (24,477 Kpa). Cumulative production as of June 1, 2003, was 1,622,2020 barrels of oil (257,901 m^3), 4.47 BCFG (0.13 BCMG), and 3,181,448 barrels of water (505,850 m^3) (Utah Division of Oil, Gas and Mining, 2003). Estimated primary recovery is 1,600,000 bbls (254,400 m^3) of oil and 4 BCFG (0.1 BCMG) (Oline, 1996). Again, since the original reserve estimates have been surpassed and the field is still producing, significant additional reserves likely remain.

Little Ute and Sleeping Ute Fields

Little Ute and Sleeping Ute fields are located in Montezuma County, Colorado (sections 3, 10, and 11, T. 34 N., R. 20 W. (figure 4). The producing reservoirs consist of phylloid-algal buildups in the Ismay zone flanked by bryozoan mounds and mound flank debris. These porous mounds, capped by impermeable anhydritic dolomite, produce primarily from porous phylloid-algal limestones, some of which have been dolomitized. The net reservoir thickness is 30 feet (9.1 m), which extends over approximately 640 acres (260 ha). Porosity ranges from 4 to 20 percent with 1 to 98 millidarcies (md) of permeability in vuggy and intercrystalline pore systems.

The first well drilled in the Little Ute/ Sleeping Ute study area was a dry hole, completed in 1959. The Calvert Drilling Company Desert Canyon No. 1 was drilled in the SW/4 of section 10, T. 34 N., R. 20 W., to a total depth of 5,938 feet (1,810 m) to the Gothic shale as a test of the Ismay and Desert Creek zones of the Paradox Formation. The well was plugged and abandoned on September 29, 1959, after a drill-stem test and four cores were taken in the Ismay and Desert Creek. The results of the drill-stem test, taken over the interval of 5,697 to 5,840 feet (1,736-1,780 m), were discouraging in that there was a very weak blow of air to the surface that died in 5 minutes and only 55 feet (17 m) of drilling mud was recovered. Somewhat more encouraging were the cores taken from 5,675 to 5,739 feet (1,730-1,749 m), 5,729 to 5,782 feet (1,746-1,762 m), 5,782 to 5,820 feet (1,762-1,774 m), and 5,880 to 5,938 feet (1,792-1,819 m). Over that entire interval, there were favorable reports of petroliferous odor, visible vuggy and intercrystalline porosity, and bleeding oil.

There are currently three producing wells and three dry holes in the Little Ute and Sleeping Ute study area proper. Well spacing is 80 acres (32 ha). The net reservoir thickness is 20 feet (6 m) over a 240-acre (97 ha) area. Porosity averages 15 percent and permeability is 0.01 to 2 md. Water saturation is 50 percent (Ghazal, 1978). Cumulative production from these three wells, plus the Desert Canyon No. 3 well that defined the Desert Canyon field, exceeds 325,000 barrels (51,675 m^3) of oil and 750 million cubic feet (21 million m^3) of gas.

FIELD DATA COLLECTION

Reservoir data, cores and cuttings, geophysical logs, various reservoir maps, and other information from the project fields and regional exploratory wells were collected by the Utah Geological Survey (UGS) and Colorado Geological Survey (CGS). Well locations, production data, completion tests, basic core analysis, formation tops, porosity and permeability data, and other data were compiled and entered in a database developed by the UGS. This database, INTEGRAL, is a geologic-information database that links a diverse set of geologic data to records using MS Access™. The database is designed so that geological information, such as lithology, petrophysical analyses, or depositional environment, can be exported to software programs to produce strip logs, cross sections, lithofacies maps, various graphs, statistical models, and other types of presentations.

Geological characterization on a local scale focused on reservoir heterogeneity, quality, and lateral continuity as well as possible compartmentalization within case-study fields. This utilized representative core and modern geophysical well logs to characterize and initially grade various intervals in the fields for horizontal drilling suitability.

LOG-BASED CORRELATION SCHEME

The typical vertical sequence or cycle of depositional facies from Cherokee and Bug fields, as determined from conventional core, was tied to the corresponding gamma-ray and neutron-density curves from geophysical well logs. The correlation scheme enabled us to identify the major zone contacts, seals or barriers, baffles, producing or potential reservoirs, and depositional facies (figures 5 through 7, and table 1). These contacts were used to produce field cross sections (plate 1 and figures 8 through 11) and a variety of structure and isochore maps (figures 12 through 68) which were incorporated into reservoir models.

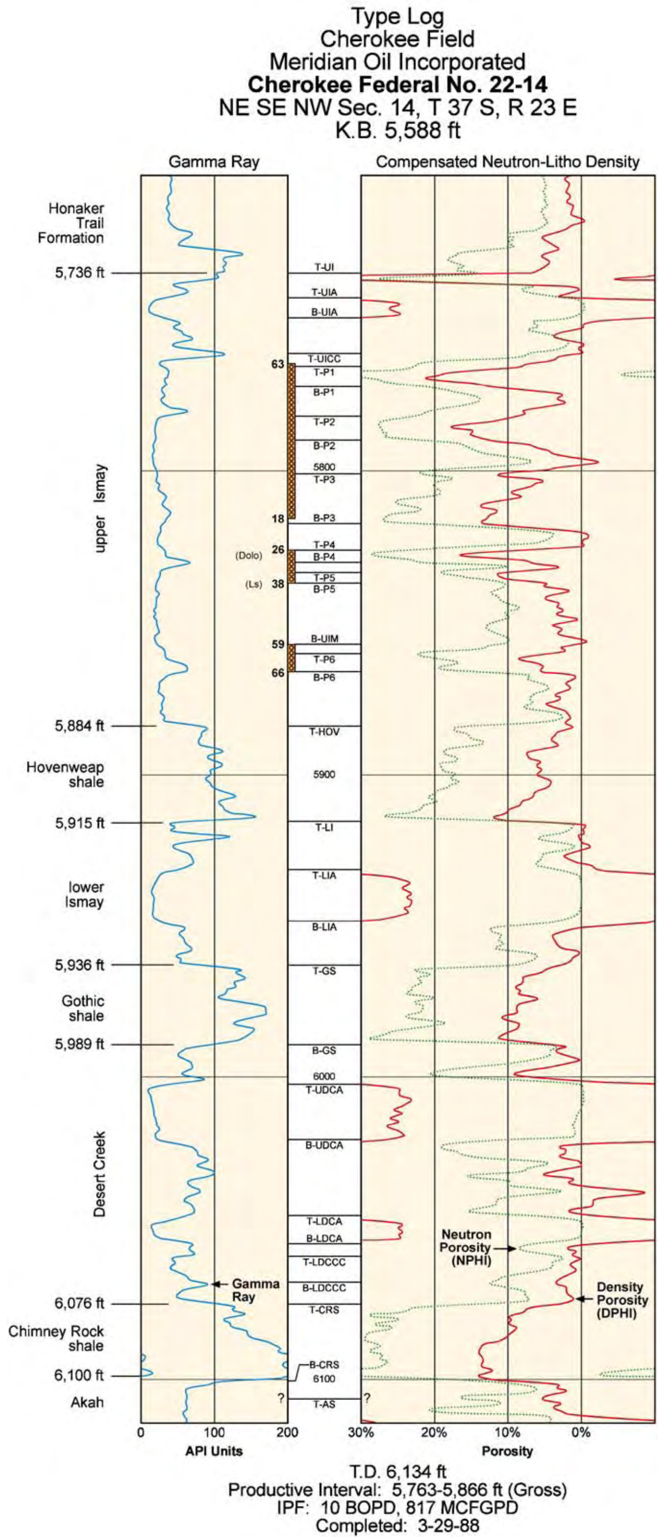

Figure 5. Type log for the Cherokee field (gamma-ray, compensated neutron-litho density) from the Cherokee Federal No. 22-14 well, showing the Ismay and Desert Creek correlation scheme, major units, and productive intervals (refer to table 1 for explanation of unit abbreviations).

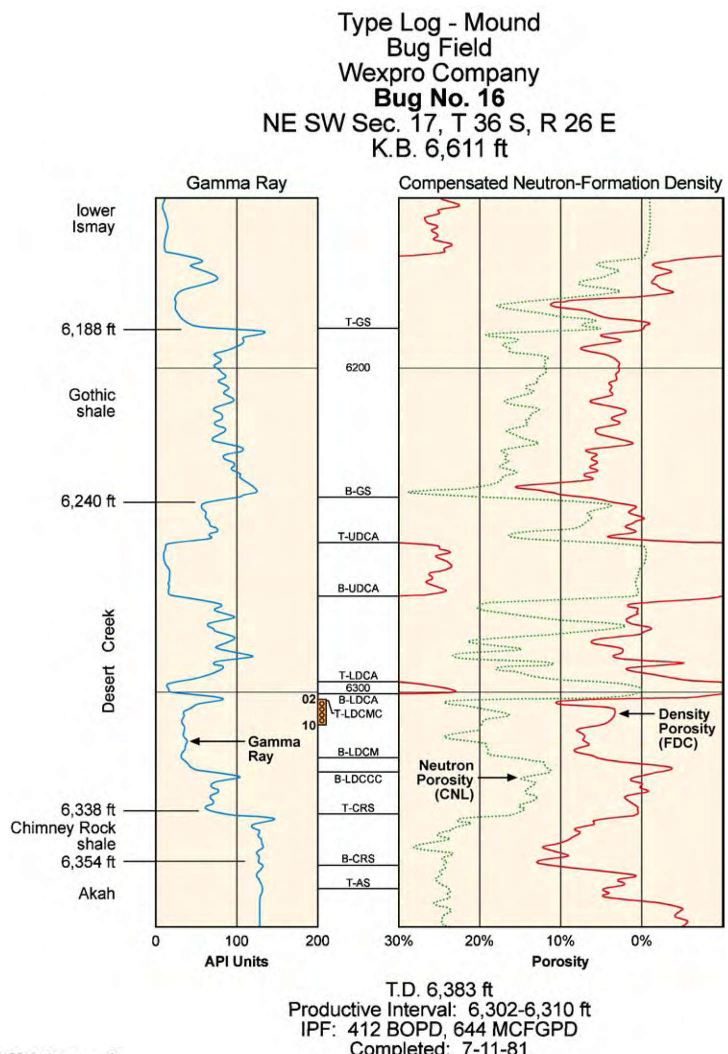

Figure 6. Type log for the Bug field mound (gamma-ray, compensated neutron-formation density) from the Bug No. 16 well, showing the Desert Creek correlation scheme, major units, and productive interval (refer to table 1 for explanation of unit abbreviations).

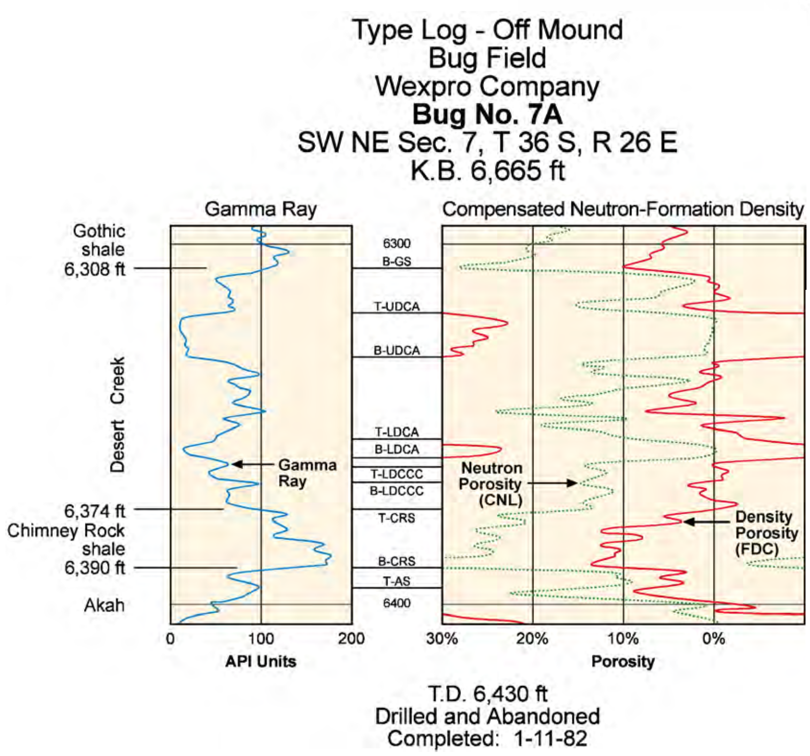

Figure 7. Type log for the Bug field off-mound area (gamma-ray, compensated neutron-formation density) from the Bug No. 7A well, showing the Desert Creek correlation scheme and major units (refer to table 1 for explanation of unit abbreviations).

Table 1. Correlation scheme used for Ismay and Desert Creek zones of the Paradox Formation in the Blanding sub-basin, Utah and Colorado.

Unit Code	Description
T-UI	Top - upper Ismay zone
T-UIA	Top - upper Ismay anhydrite
B-UIA	Base - upper Ismay anhydrite
T-UICC	Top - upper Ismay clean carbonate
T-P1 (Cherokee field)	Top - Porosity Unit #1
B-P1 (Cherokee field)	Base - Porosity Unit #1
T-P2 (Cherokee field)	Top - Porosity Unit #2
B-P2 (Cherokee field)	Base - Porosity Unit #2
T-P3 (Cherokee field)	Top - Porosity Unit #3
B-P3 (Cherokee field)	Base - Porosity Unit #3
T-P4 (Cherokee field)	Top - Porosity Unit #4
B-P4 (Cherokee field)	Base - Porosity Unit #4
T-P5 (Cherokee field)	Top - Porosity Unit #5
B-P5 (Cherokee field)	Base - Porosity Unit #5
B-UIM	Base - upper Ismay mound
B-UICC	Base upper Ismay clean carbonate
T-P6 (Cherokee field)	Top - Porosity Unit #6
B-P6 (Cherokee field)	Base - Porosity Unit #6
T-HOV	Top - Hovenweep shale
T-LI	Top - lower Ismay zone
T-LIA	Top - lower Ismay anhydrite
B-LIA	Base - lower Ismay anhydrite
T-GS	Top - Gothic shale
B-GS	Base - Gothic shale
T-UDCA	Top - upper Desert Creek anhydrite
B-UDCA	Base - upper Desert Creek anhydrite
T-LDCA	Top - lower Desert Creek anhydrite
B-LDCA	Base - lower Desert Creek anhydrite
T-LDCMC	Top - lower Desert Creek mound cap
B-LDCM	Base - lower Desert Creek mound
T-LDCCC	Top - lower Desert Creek clean carbonate
B-LDCCC	Base - lower Desert Creek clean carbonate
T-CRS	Top - Chimney Rock shale
B-CRS	Base - Chimney Rock shale
T-AS	Top - Akah Subaerial

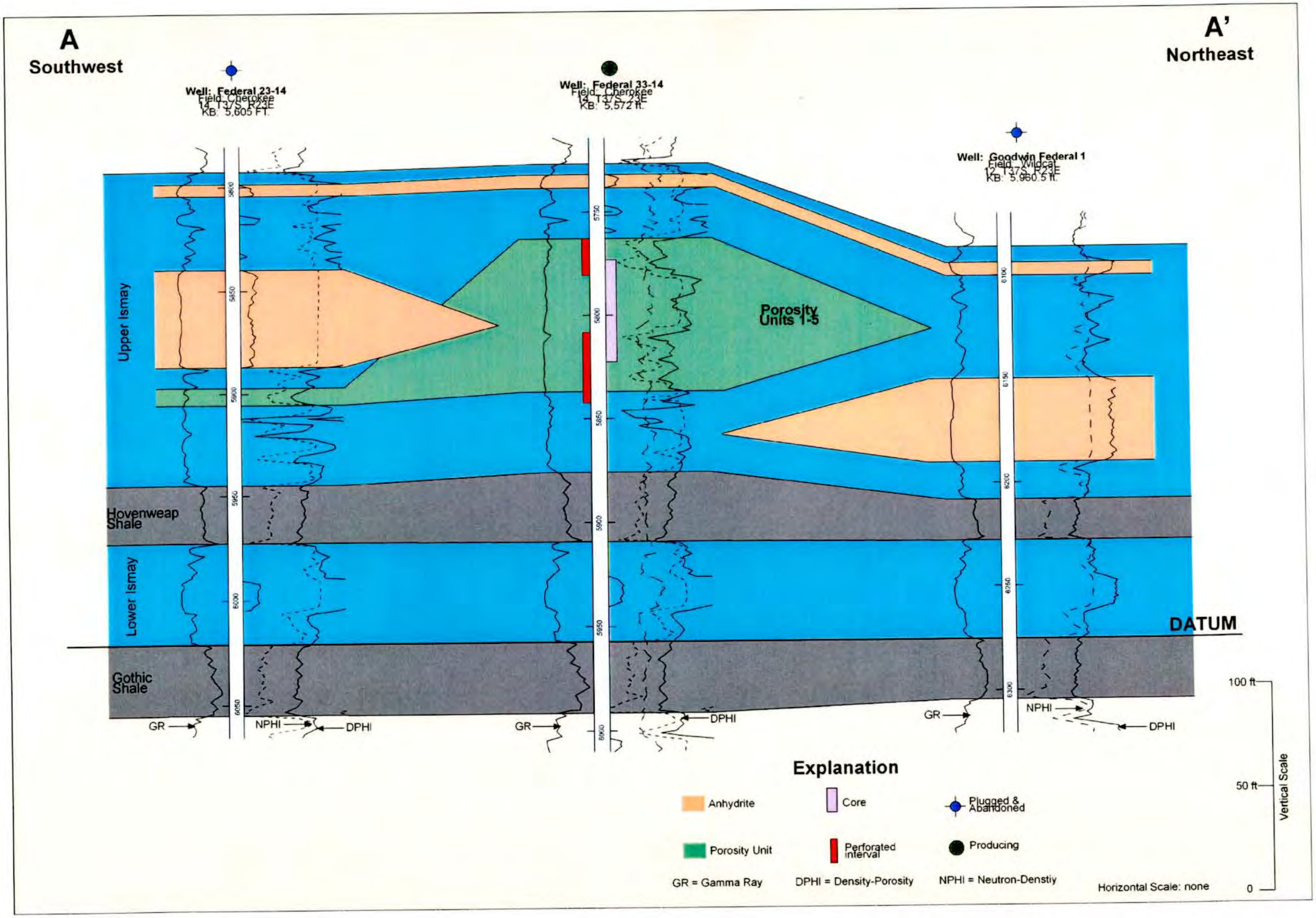

Figure 8. Southwest to northeast stratigraphic cross section, Cherokee field, Utah.

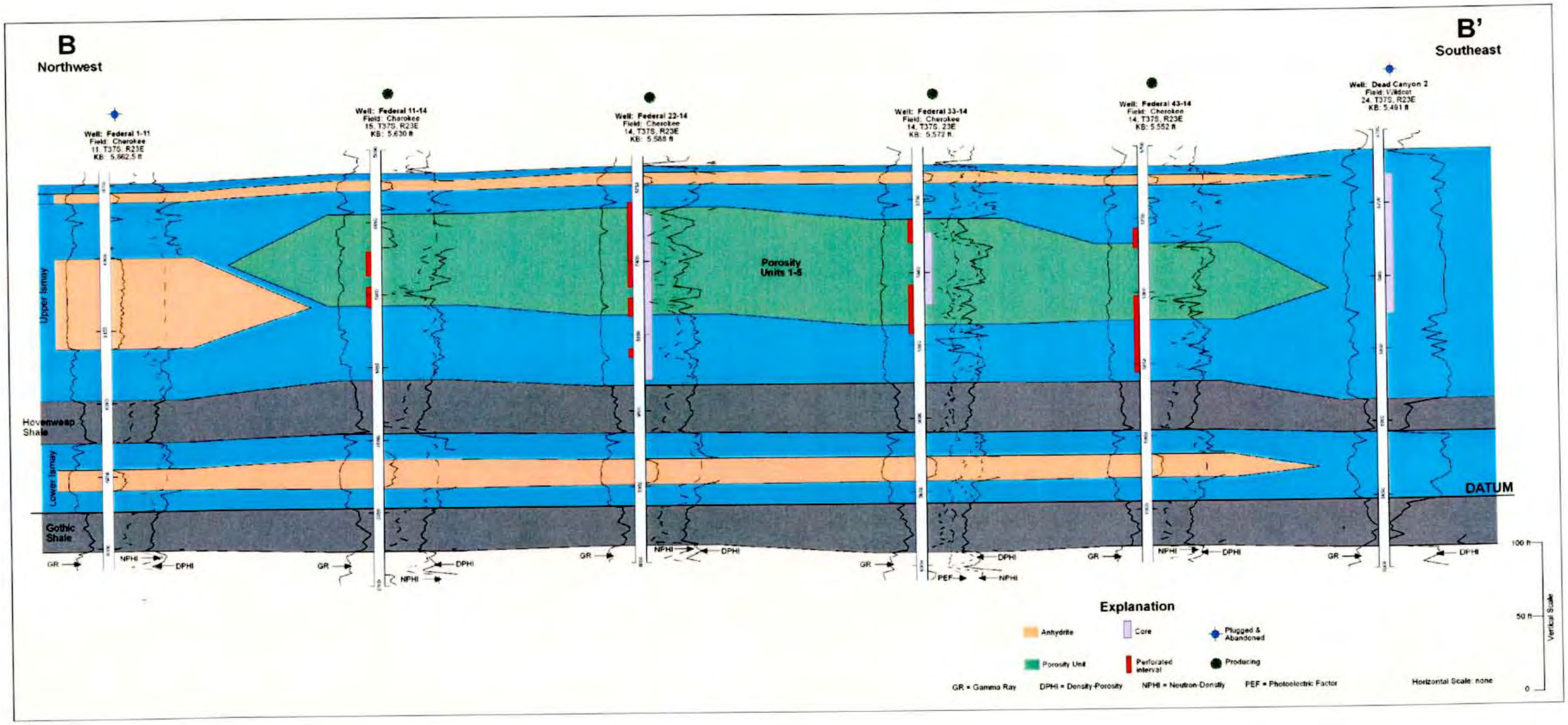

Figure 9. Northwest to southeast stratigraphic cross section, Cherokee field, Utah.

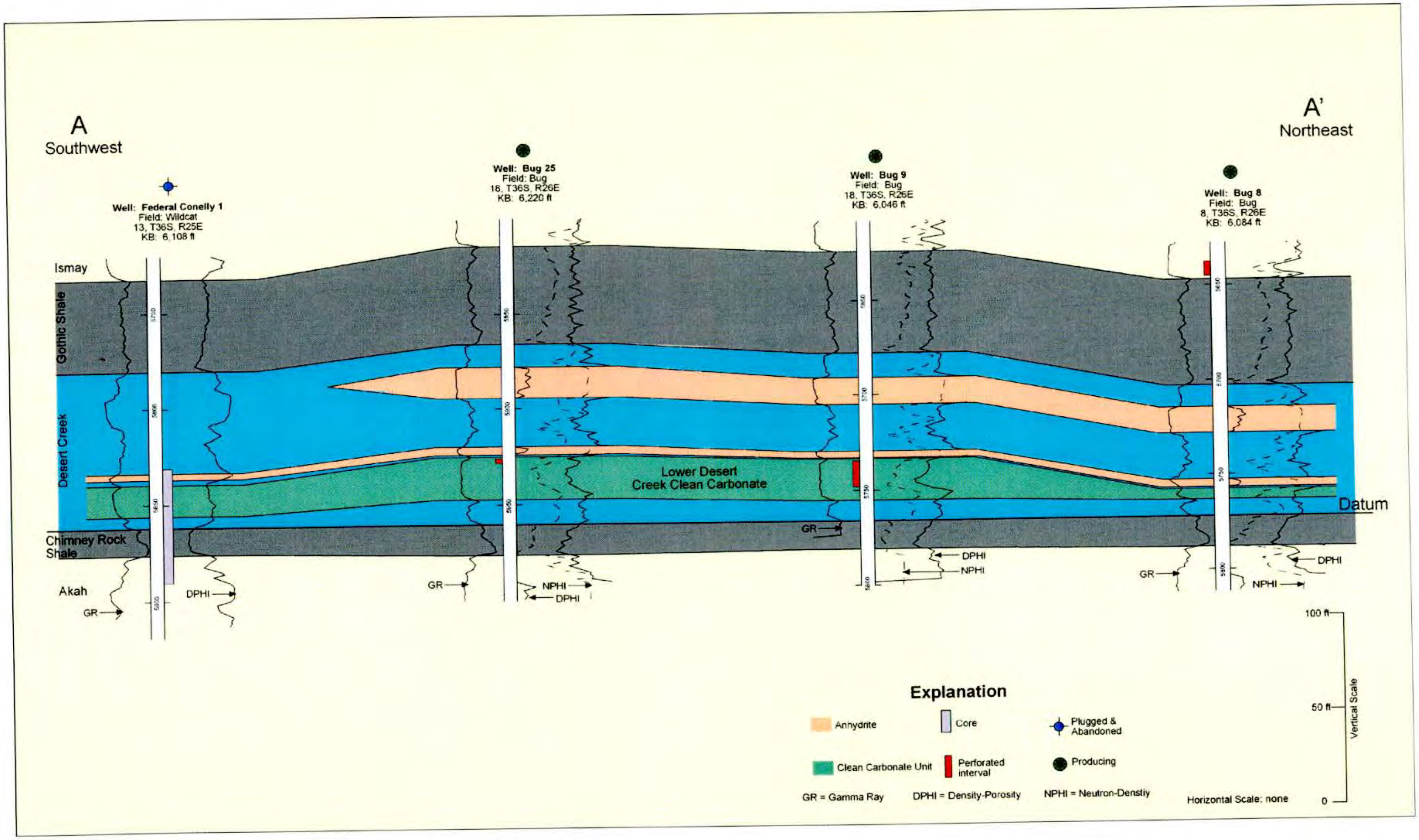

Figure 10. Southwest to northeast stratigraphic cross section, Bug field, Utah.

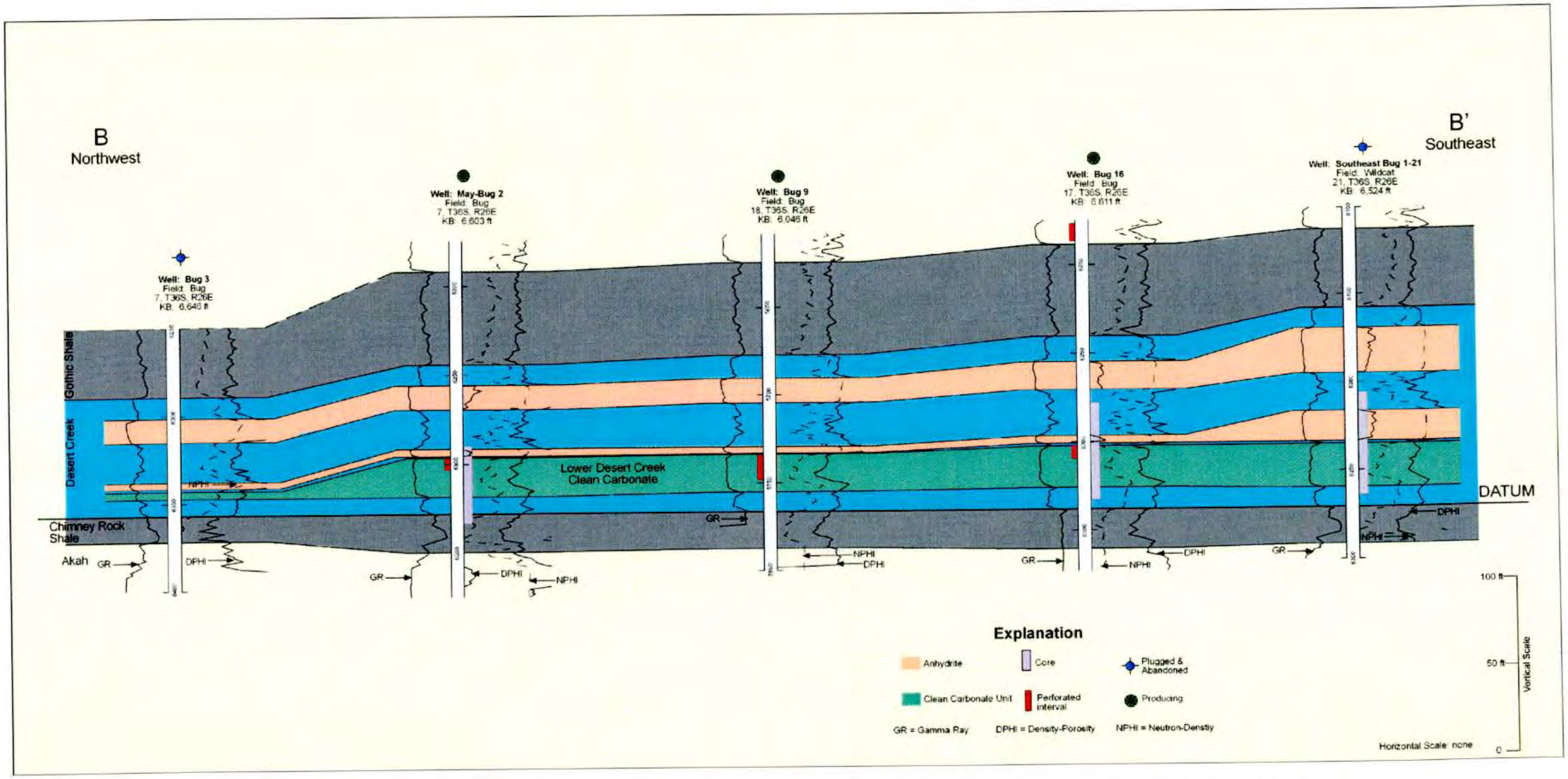

Figure 11. Northwest to southeast stratigraphic cross section, Bug field, Utah.

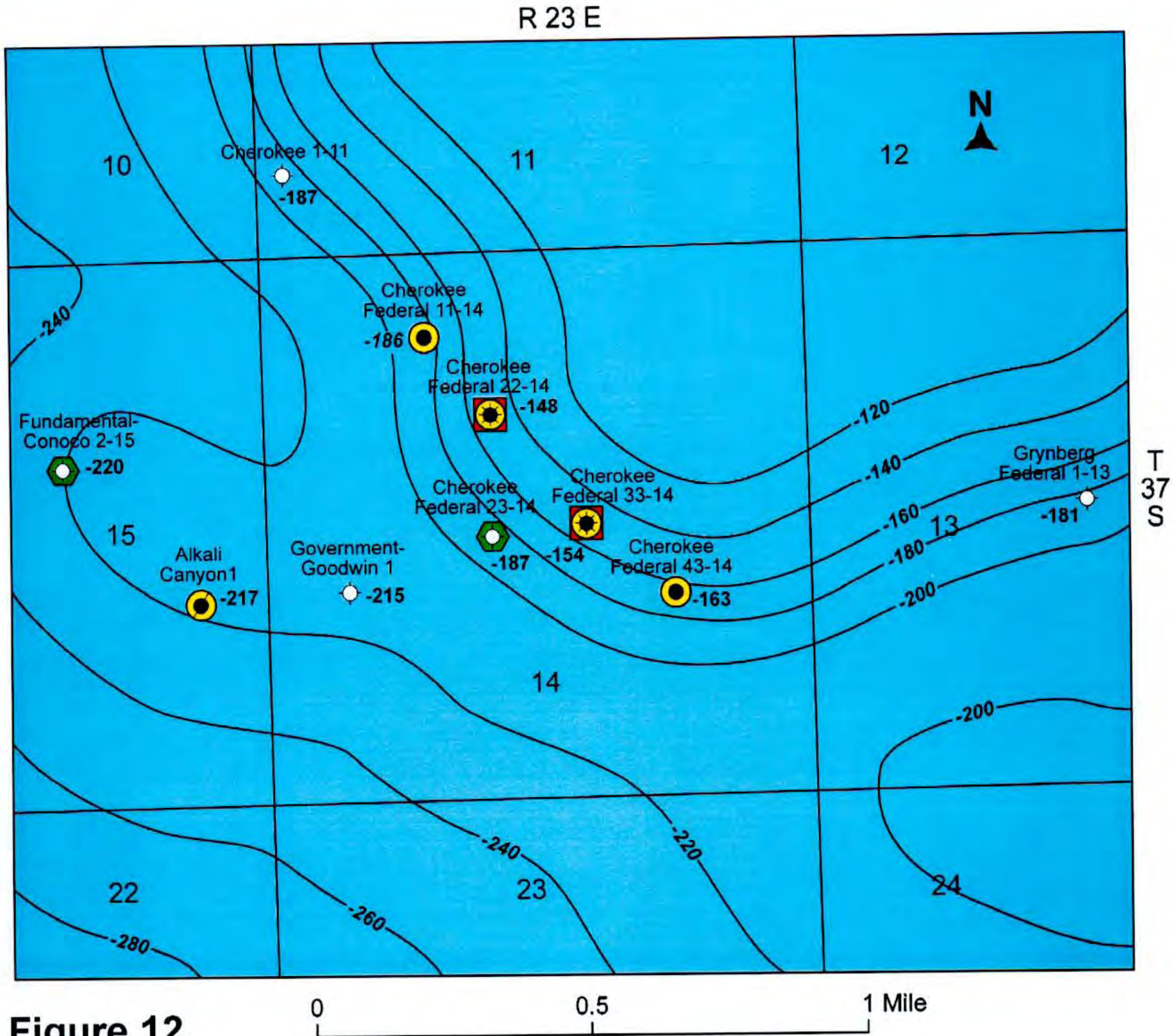

Figure 12

Structure Contour
Top of Ismay
Contour Interval = 20 ft
Datum = Sea Level

Cherokee Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Ismay drill-stem test
- Ismay completion
- Abandoned Ismay producer
- Ismay completion/core

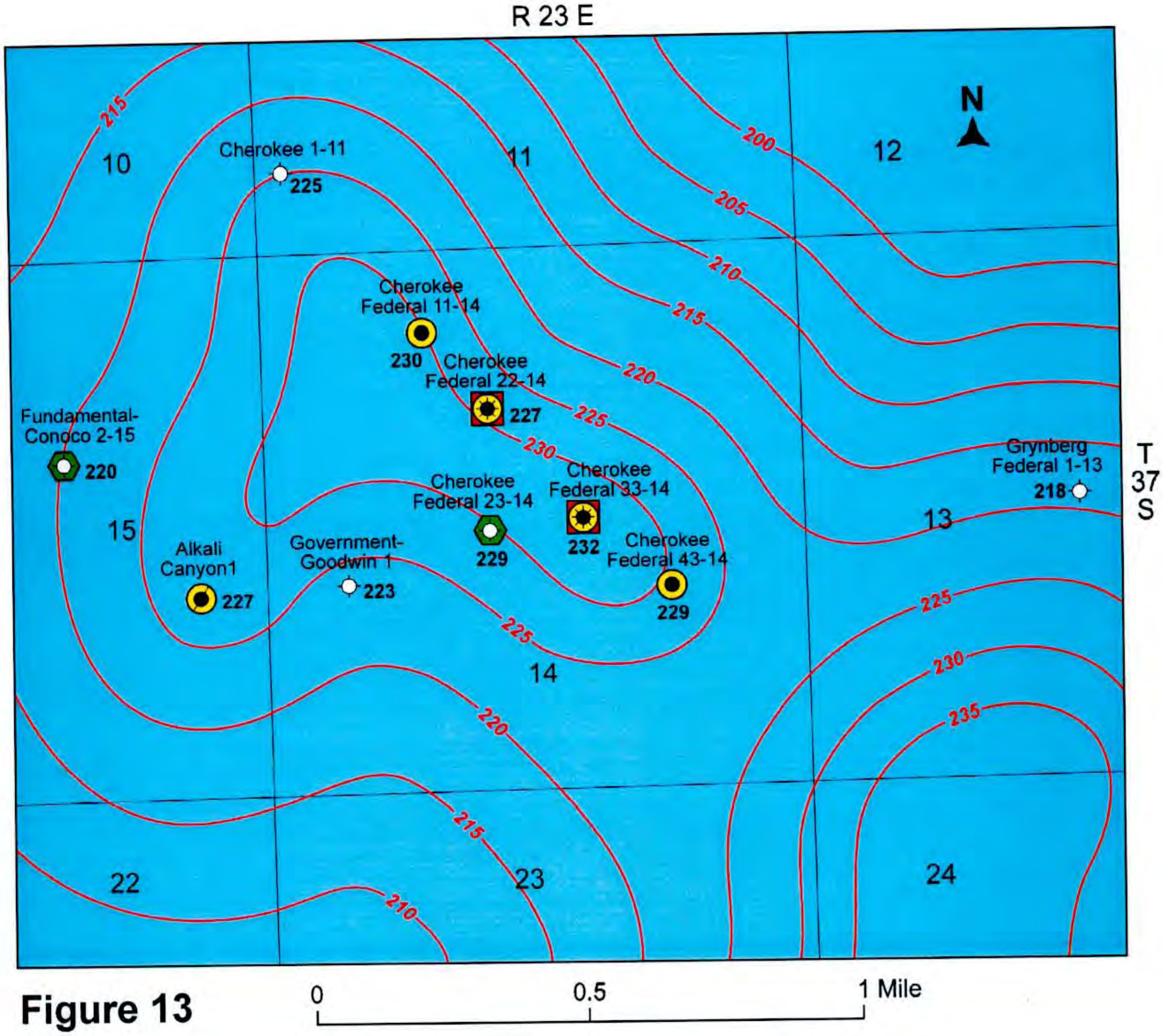

Figure 13

Ismay Isochore
Contour Interval = 5 ft

Cherokee Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Ismay drill-stem test
- Ismay completion
- Abandoned Ismay producer
- Ismay completion/core

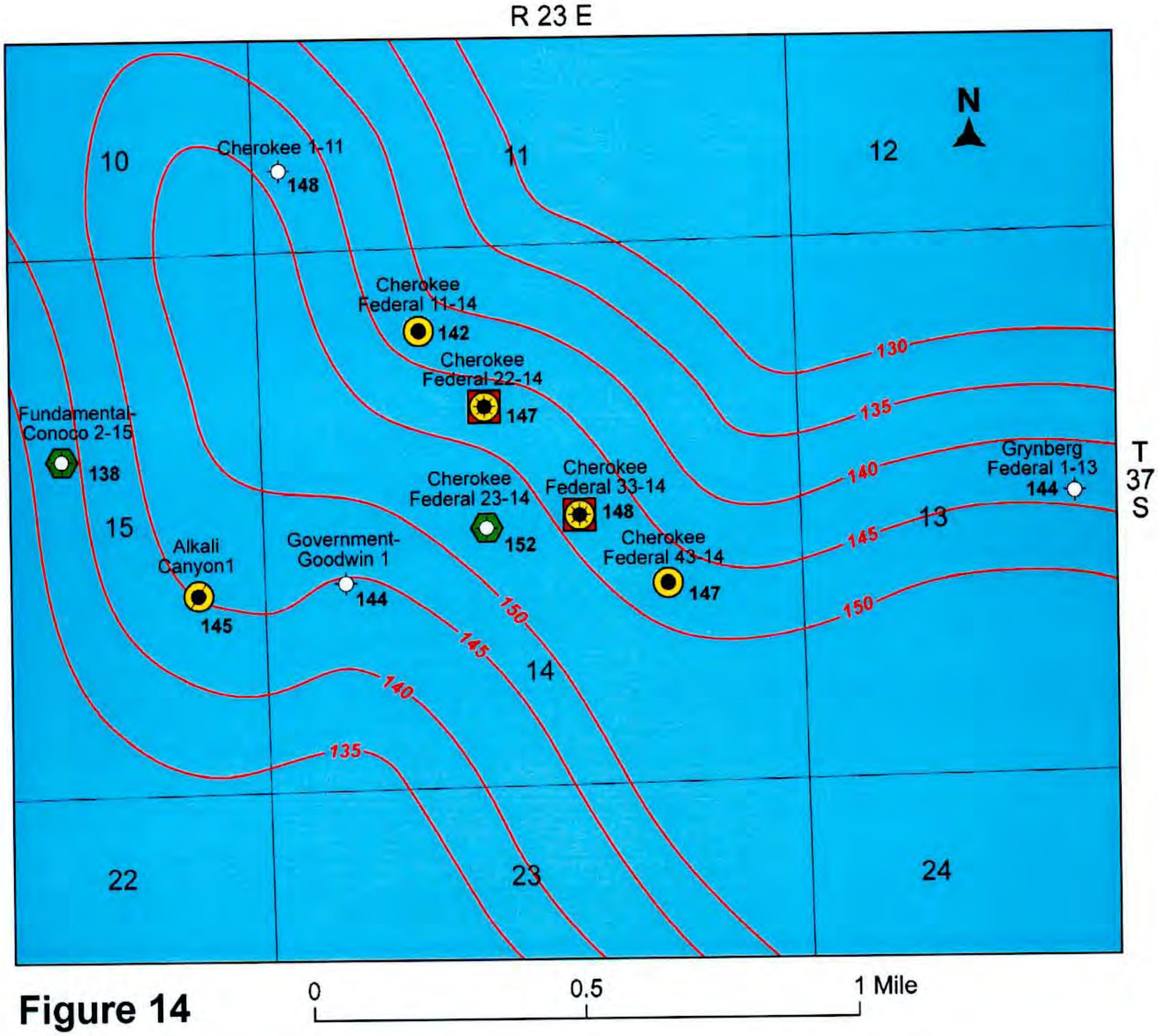

Figure 14

Isochore: Upper Ismay Zone
Contour Interval = 5 ft

Cherokee Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Ismay drill-stem test
- Ismay completion
- Abandoned Ismay producer
- Ismay completion/core

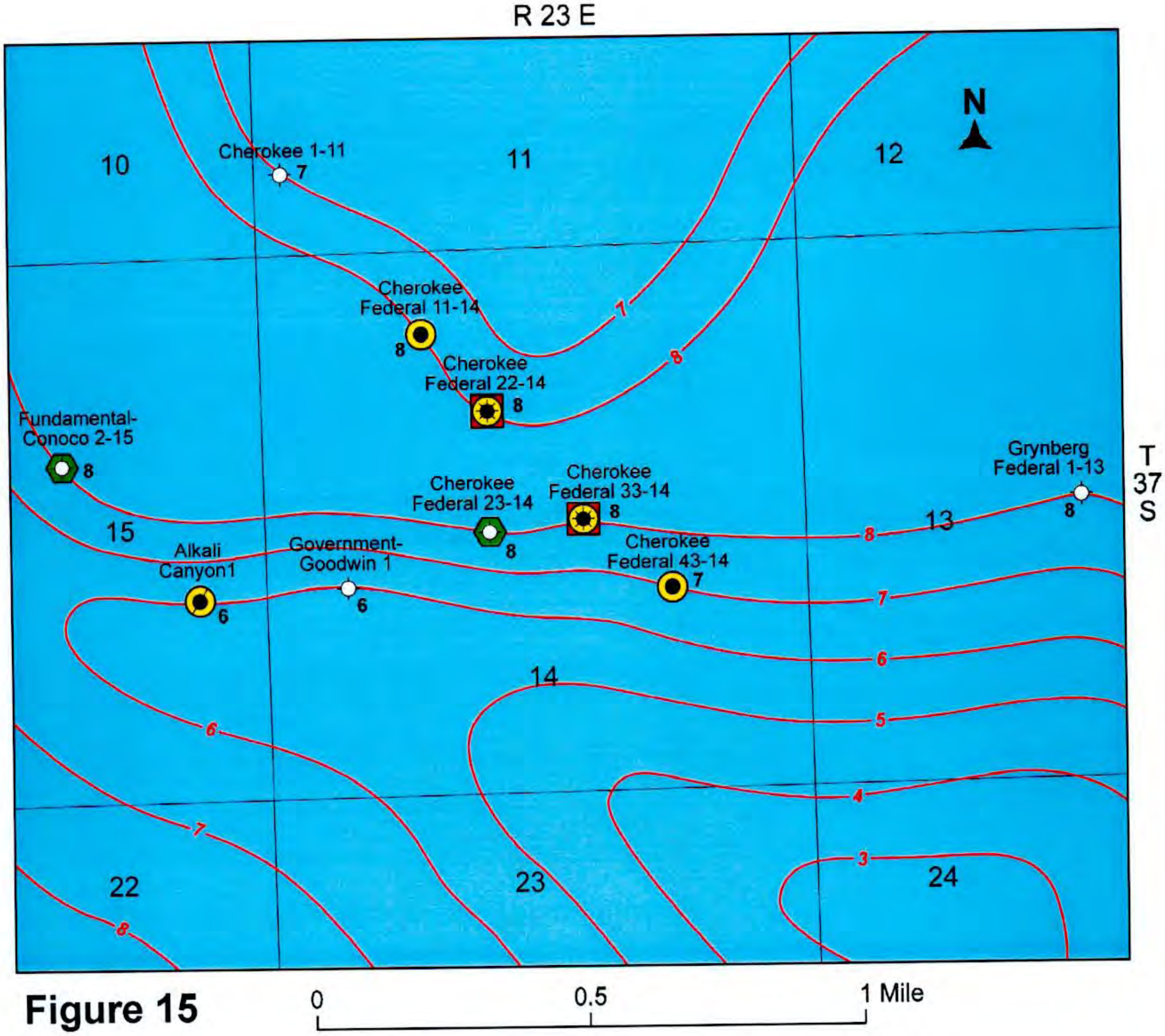

Figure 15

Isochore: Upper Ismay Anhydrite
Contour Interval = 1 ft

Cherokee Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Ismay drill-stem test
- Ismay completion
- Abandoned Ismay producer
- Ismay completion/core

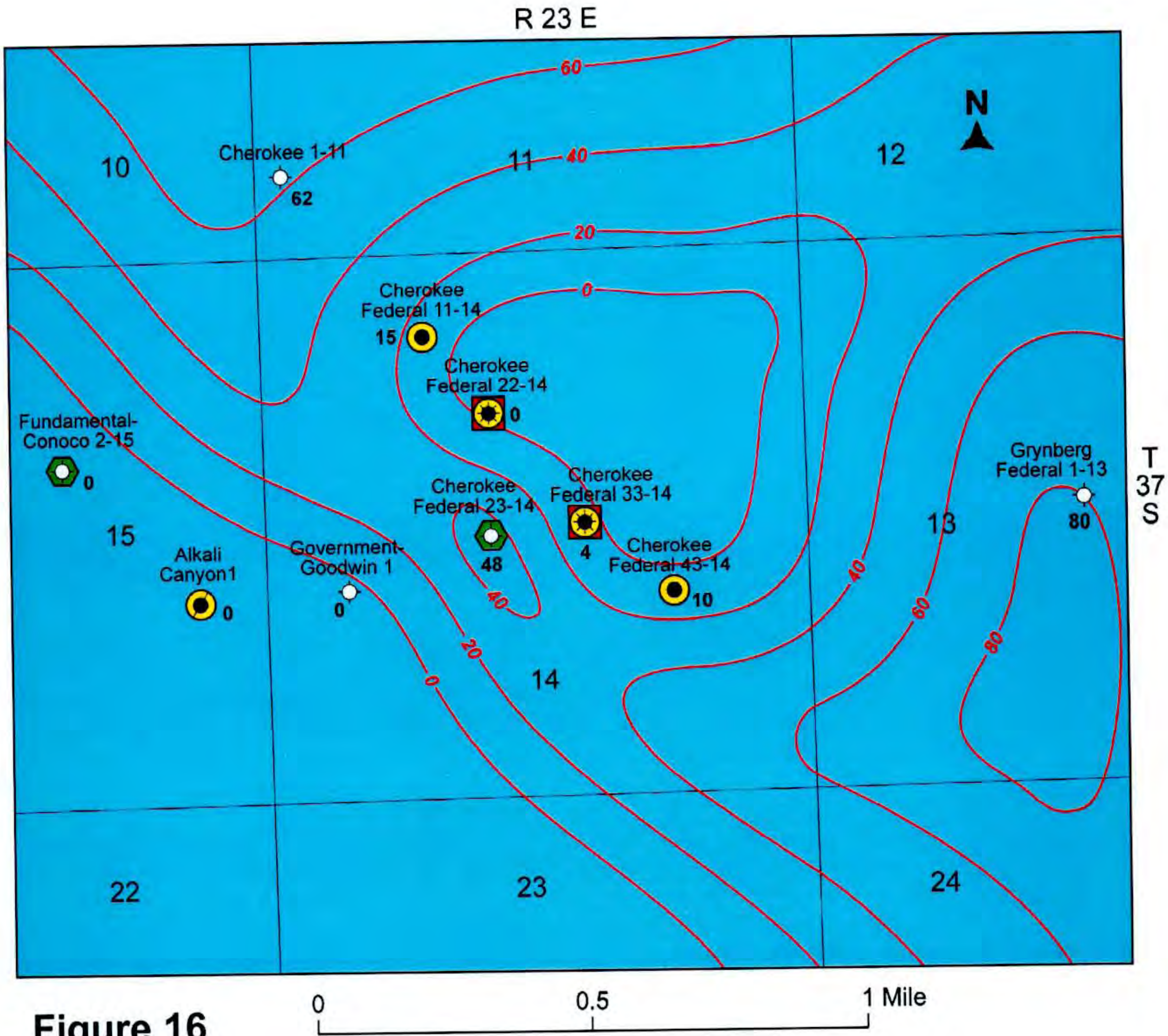

Figure 16

Isochore: Upper Ismay Anhydrite 2
Contour Interval = 20 ft

Cherokee Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Ismay drill-stem test
- Ismay completion
- Abandoned Ismay producer
- Ismay completion/core

R 23 E

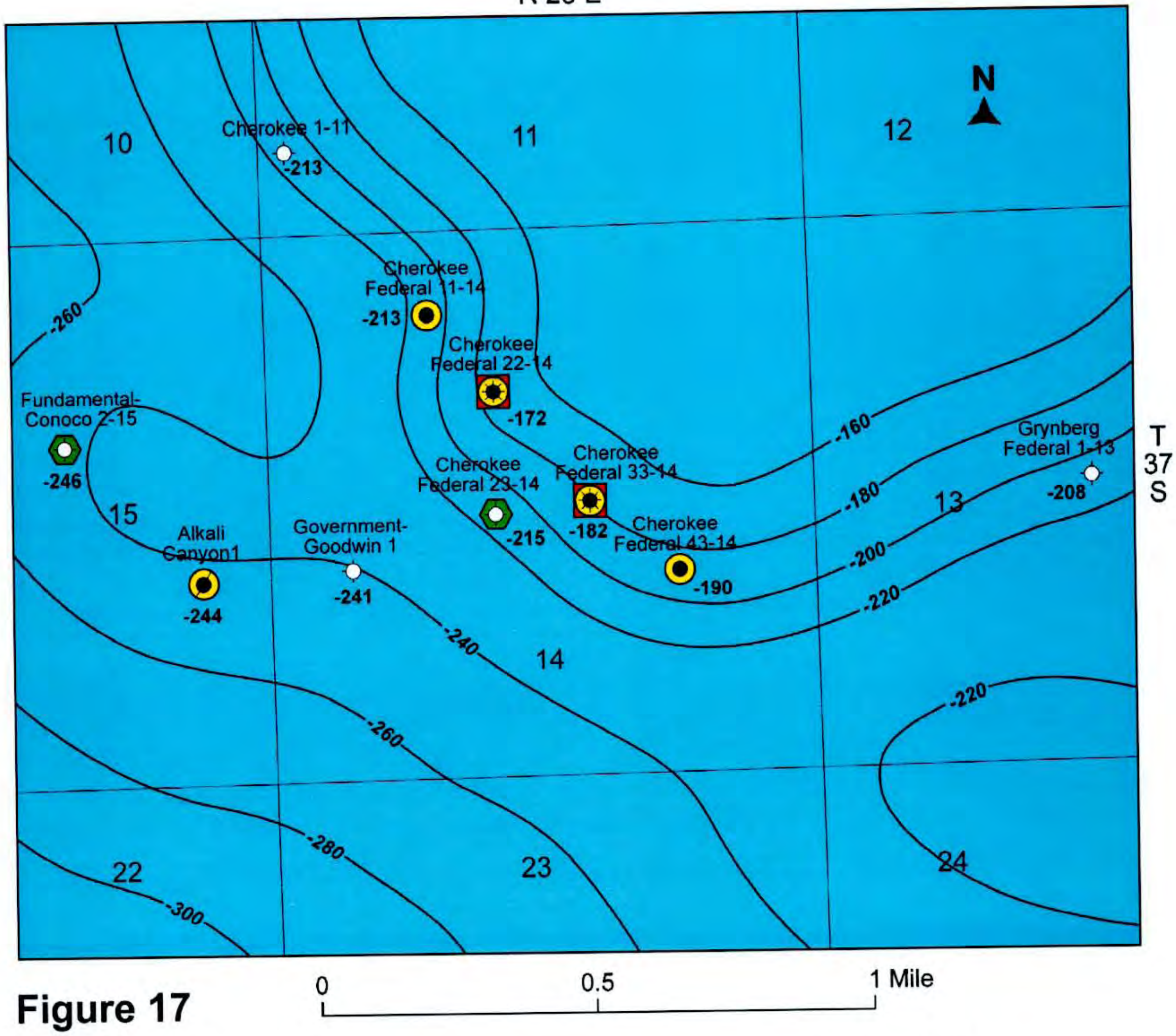

Figure 17

Structure Contour
Top of Upper Ismay
Clean Carbonate
Contour Interval = 20 ft
Datum = Sea Level

Cherokee Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Ismay drill-stem test
- Ismay completion
- Abandoned Ismay producer
- Ismay completion/core

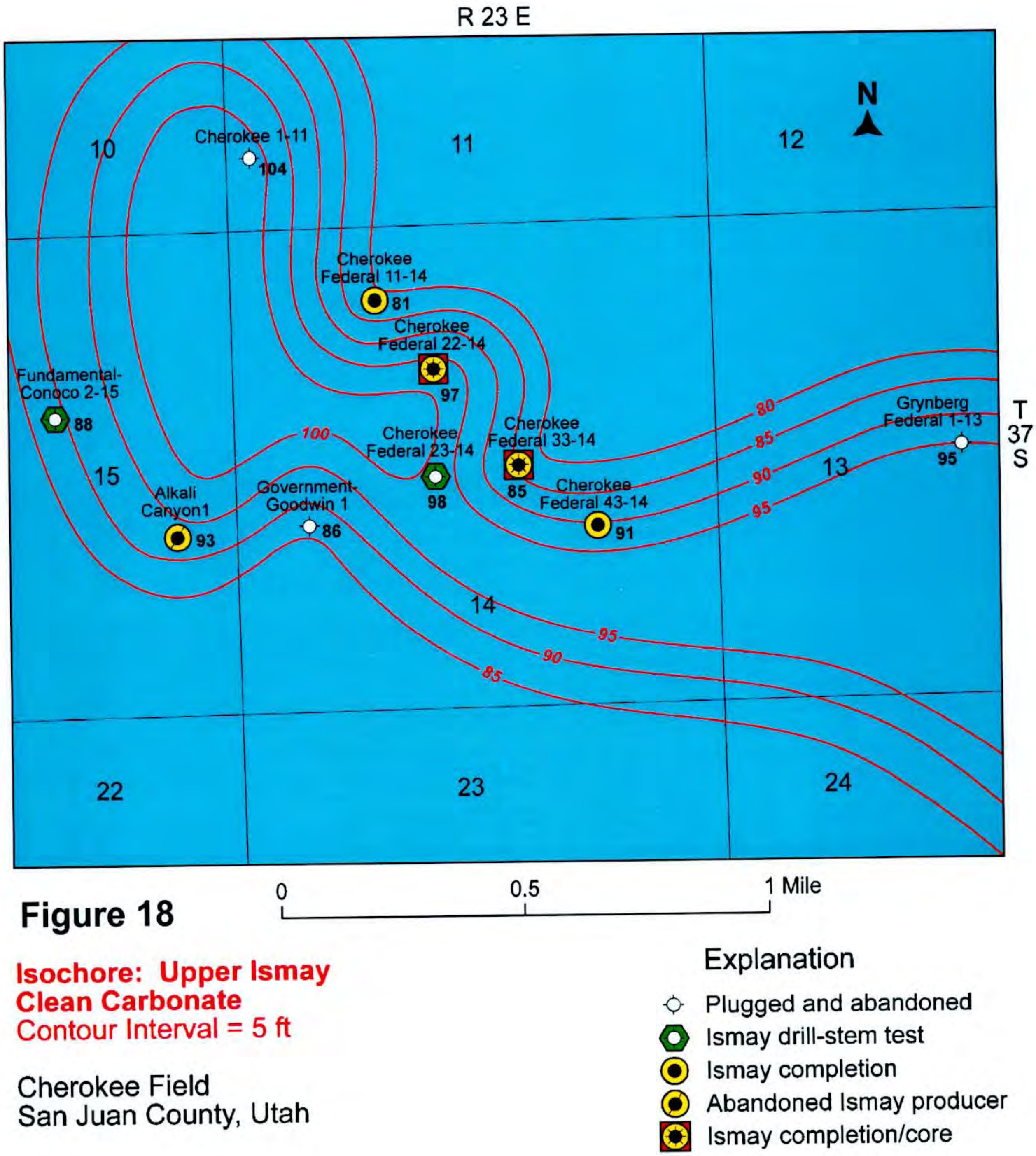

Figure 18

Isochore: Upper Ismay Clean Carbonate
Contour Interval = 5 ft

Cherokee Field
San Juan County, Utah

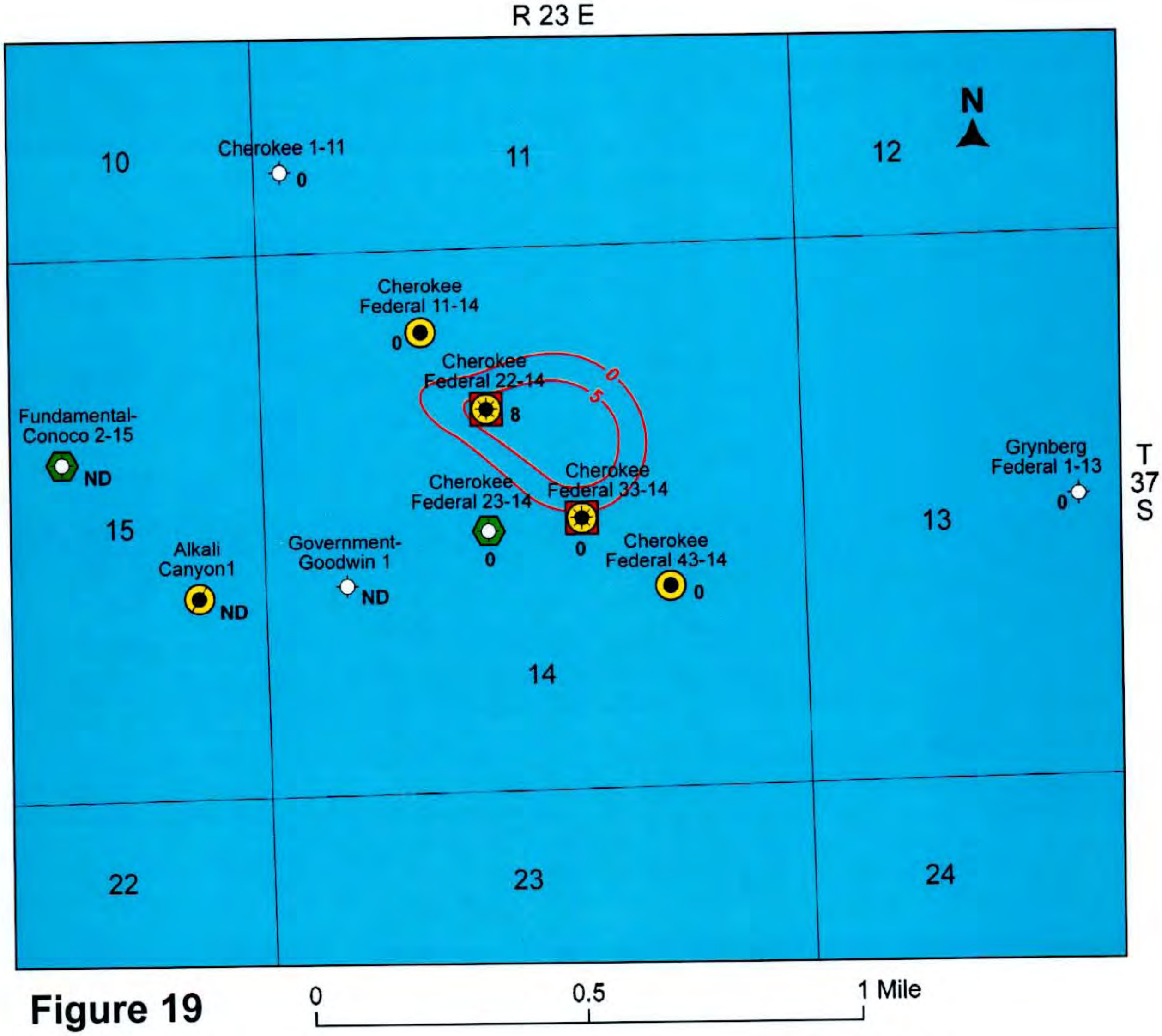

Figure 19

Isochore: Ismay Zone, Porosity Unit 1
Contour Interval = 5 ft

Cherokee Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Ismay drill-stem test
- Ismay completion
- Abandoned Ismay producer
- Ismay completion/core
- ND No neutron/density log

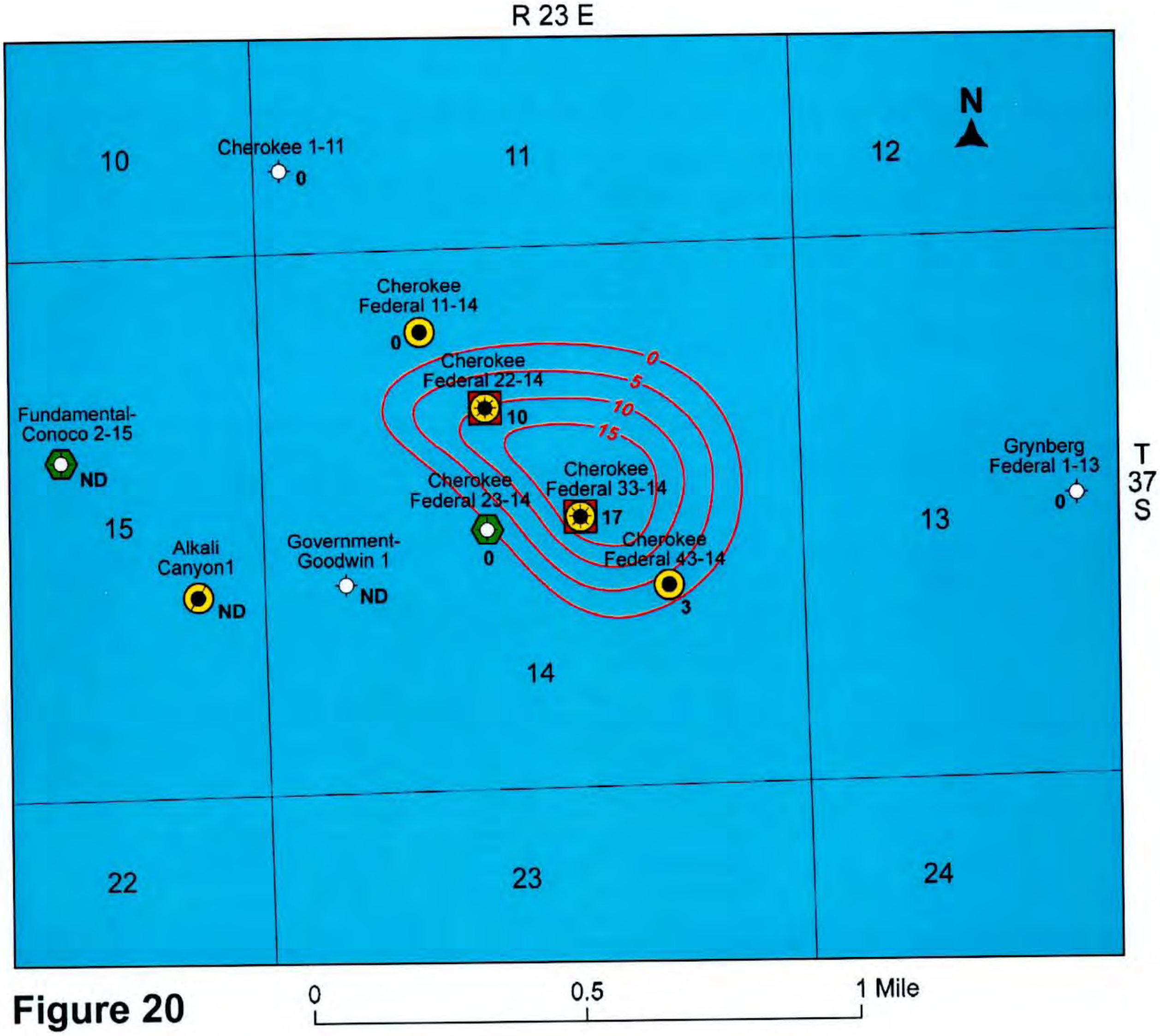

Figure 20

Isochore: Ismay Zone, Porosity Unit 2
Contour Interval = 5 ft

Cherokee Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Ismay drill-stem test
- Ismay completion
- Abandoned Ismay producer
- Ismay completion/core
- ND No neutron/density log

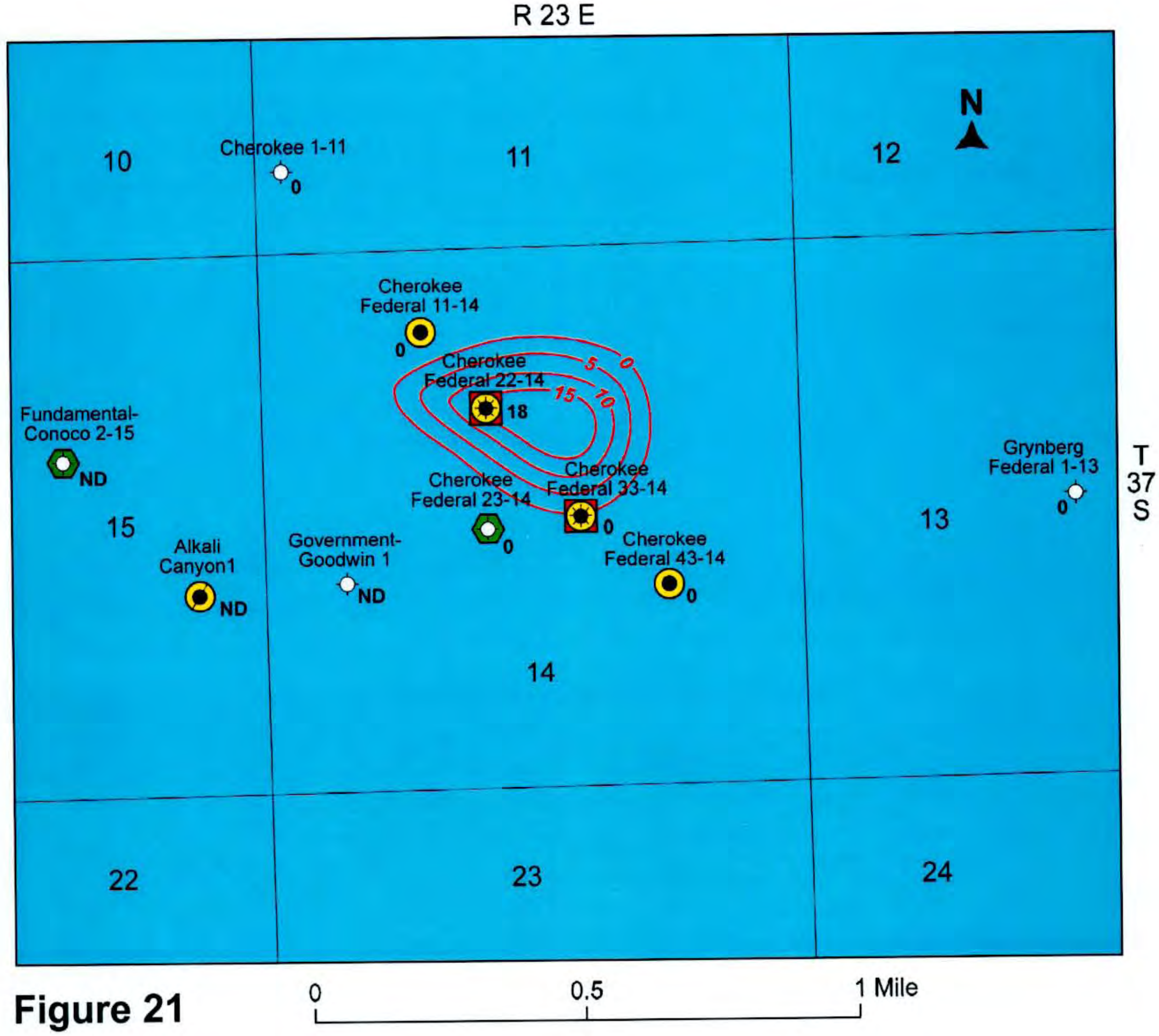

Figure 21

Isochore: Ismay Zone, Porosity Unit 3
Contour Interval = 5 ft

Cherokee Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Ismay drill-stem test
- Ismay completion
- Abandoned Ismay producer
- Ismay completion/core
- ND No neutron/density log

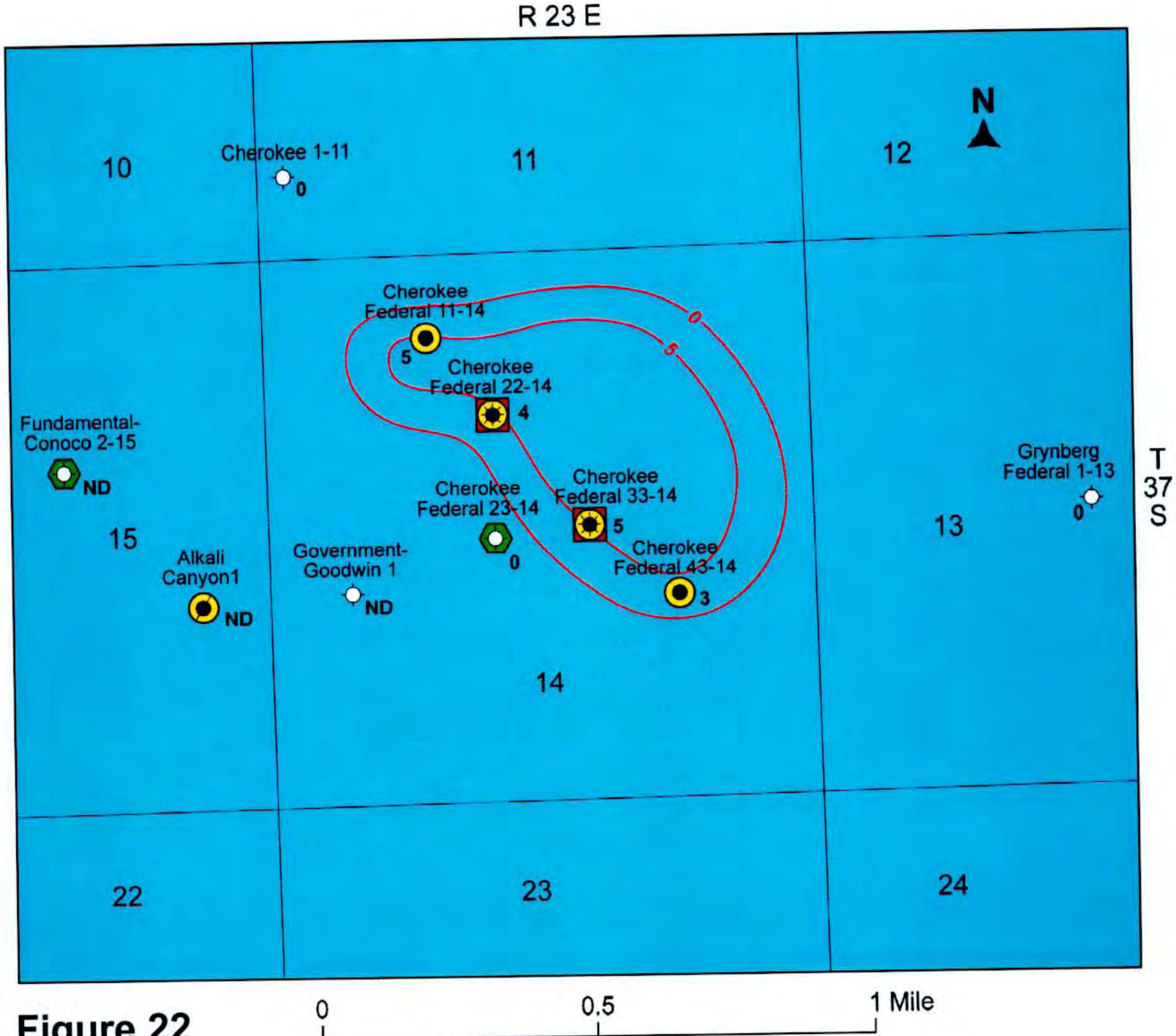

Figure 22

Isochore: Ismay Zone, Porosity Unit 4
Contour Interval = 5 ft

Cherokee Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Ismay drill-stem test
- Ismay completion
- Abandoned Ismay producer
- Ismay completion/core
- ND No neutron/density log

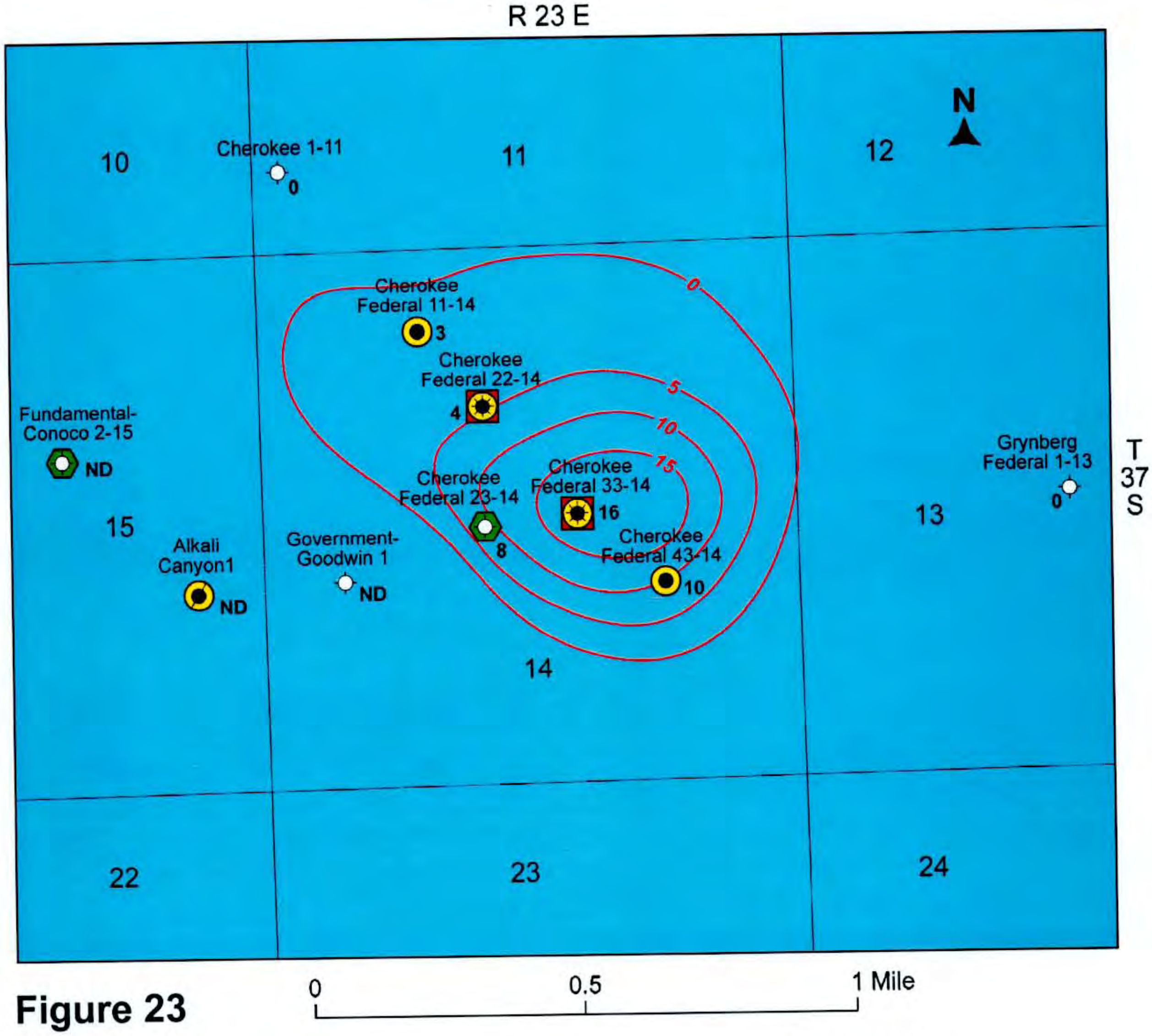

Figure 23

Isochore: Ismay Zone, Porosity Unit 5
Contour Interval = 5 ft

Cherokee Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Ismay drill-stem test
- Ismay completion
- Abandoned Ismay producer
- Ismay completion/core
- ND No neutron/density log

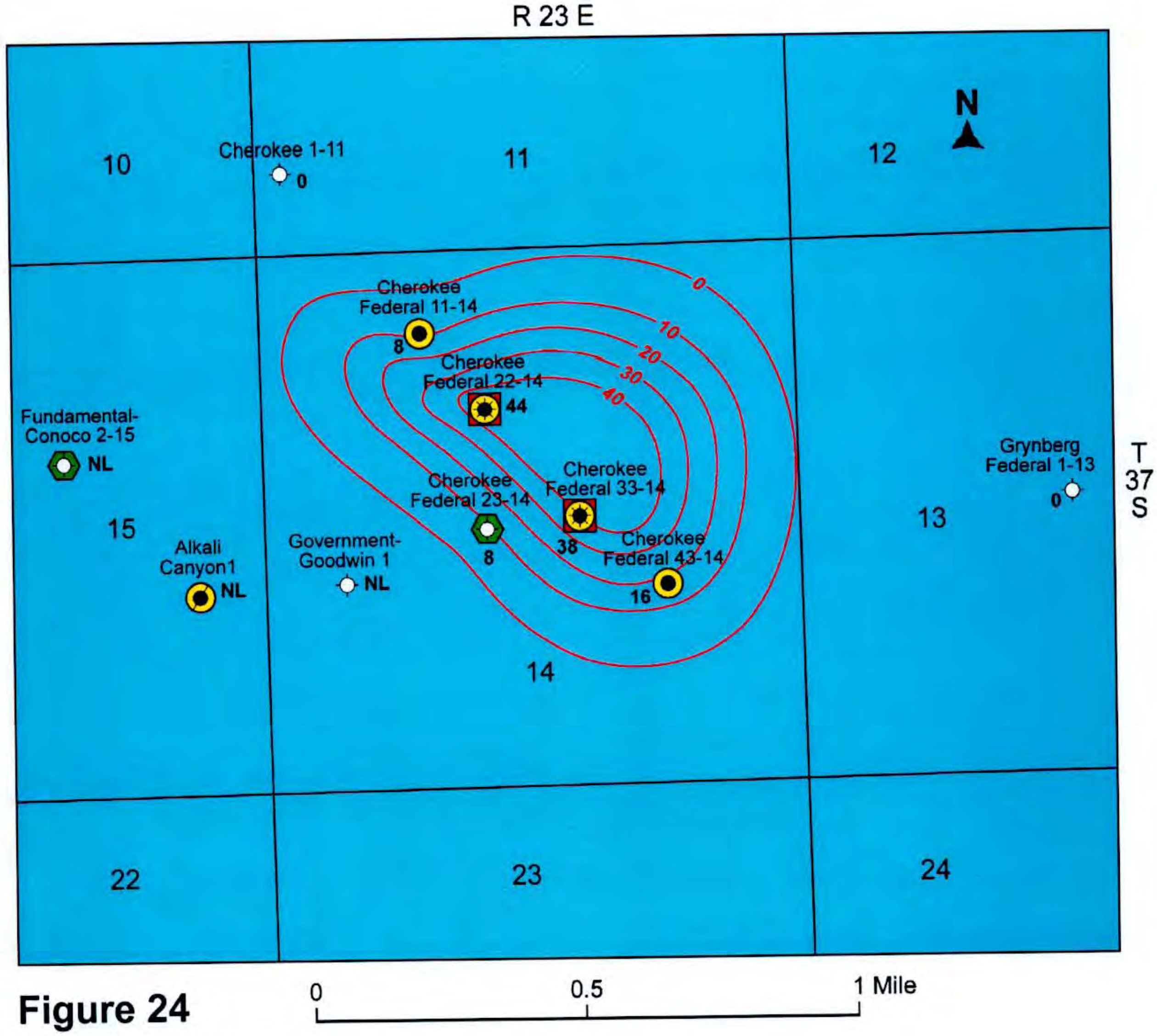

Figure 24

Upper Ismay Isochore
Porosity Units 1-5
Contour Interval = 10 ft

Cherokee Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Ismay drill-stem test
- Ismay completion
- Abandoned Ismay producer
- Ismay completion/core
- NL No neutron/density log

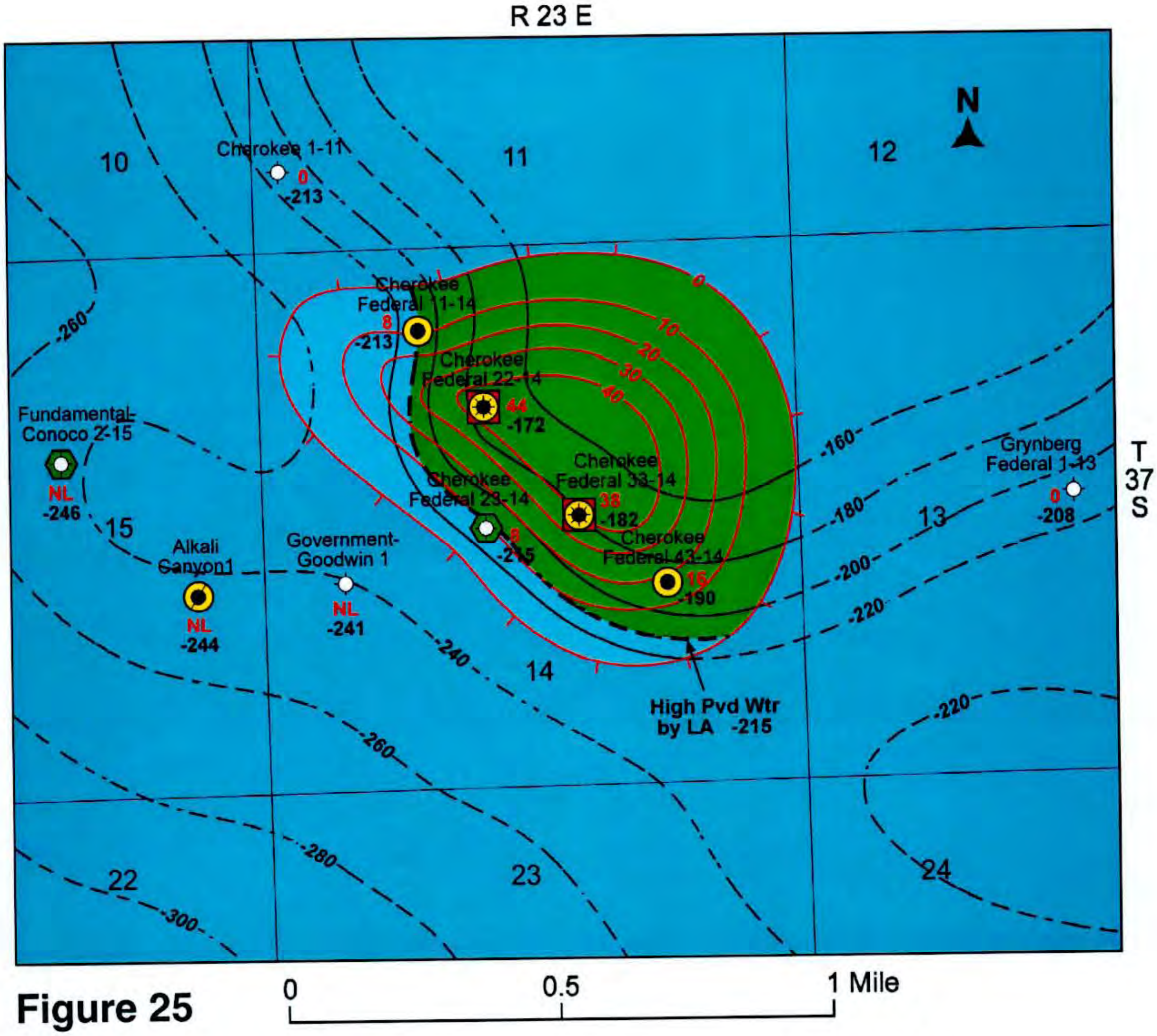

Figure 25

Upper Ismay Isochore
Porosity Units 1-5
Contour Interval = 10 ft

Structure Contour
Top of Upper Ismay,
Clean Carbonate
Contour Interval = 20 ft
Datum = Sea Level

Cherokee Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Ismay drill-stem test
- Ismay completion
- Abandoned Ismay producer
- Ismay completion/core
- NL No neutron/density log
- Oil
- Off-mound
- Mound/clean carbonate

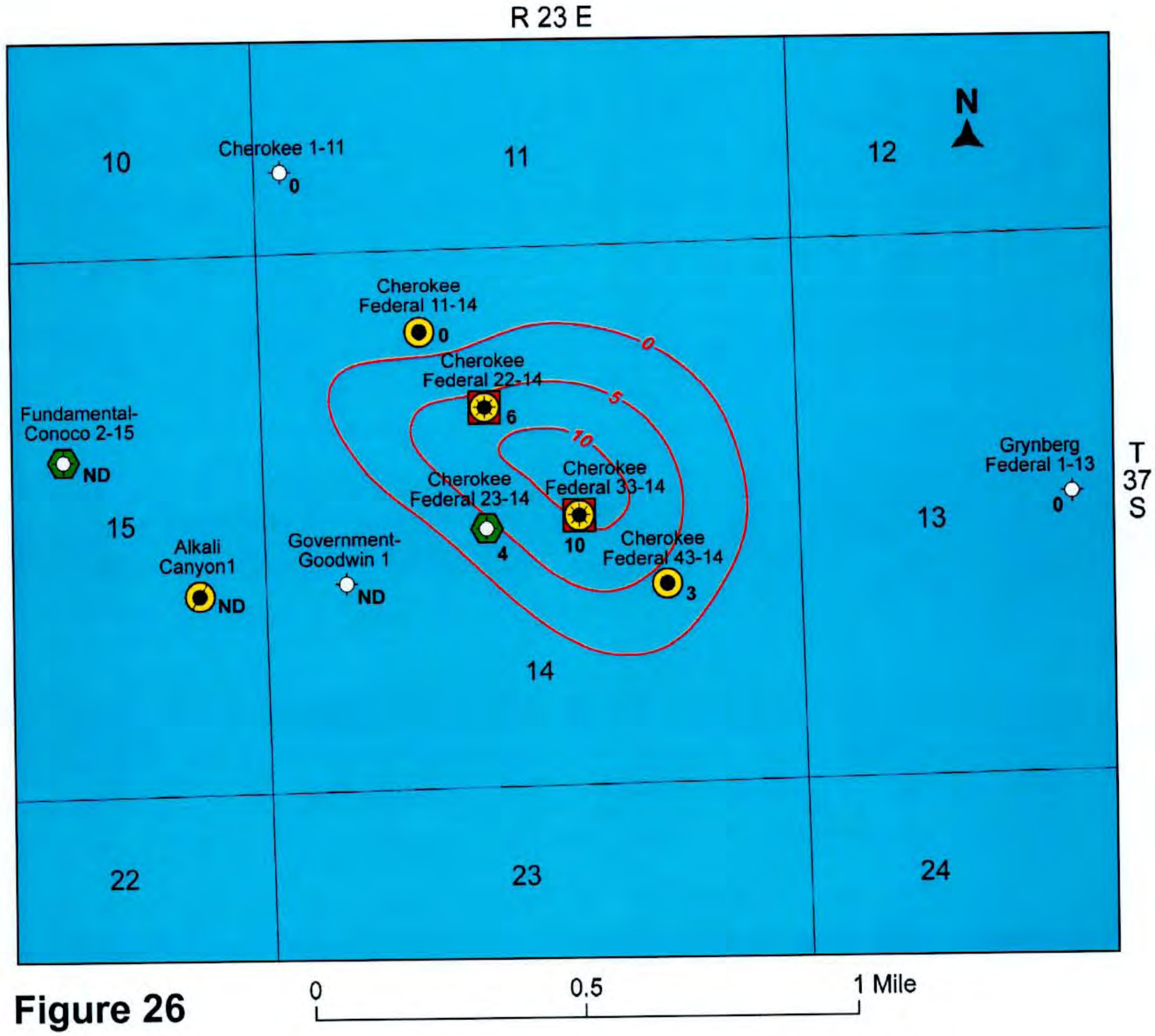

Figure 26

Isochore: Ismay Zone, Porosity Unit 6
Contour Interval = 5 ft

Cherokee Field
San Juan County, Utah

Explanation
- Plugged and abandoned
- Ismay drill-stem test
- Ismay completion
- Abandoned Ismay producer
- Ismay completion/core
- ND No neutron/density log

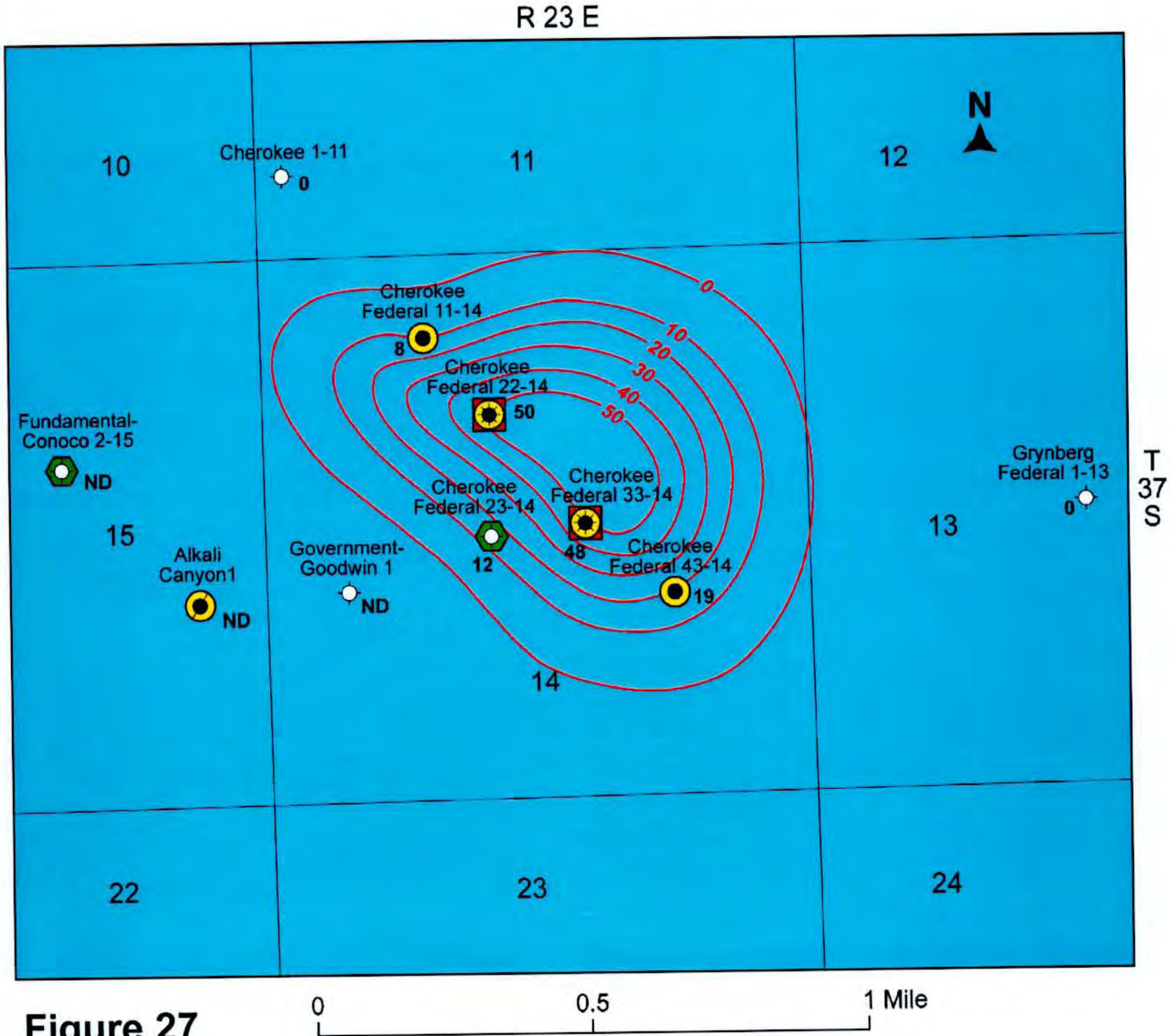

Figure 27

Isochore: Ismay Zone, Porosity Units 1-6
Contour Interval = 10 ft

Cherokee Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Ismay drill-stem test
- Ismay completion
- Abandoned Ismay producer
- Ismay completion/core
- ND No neutron/density log

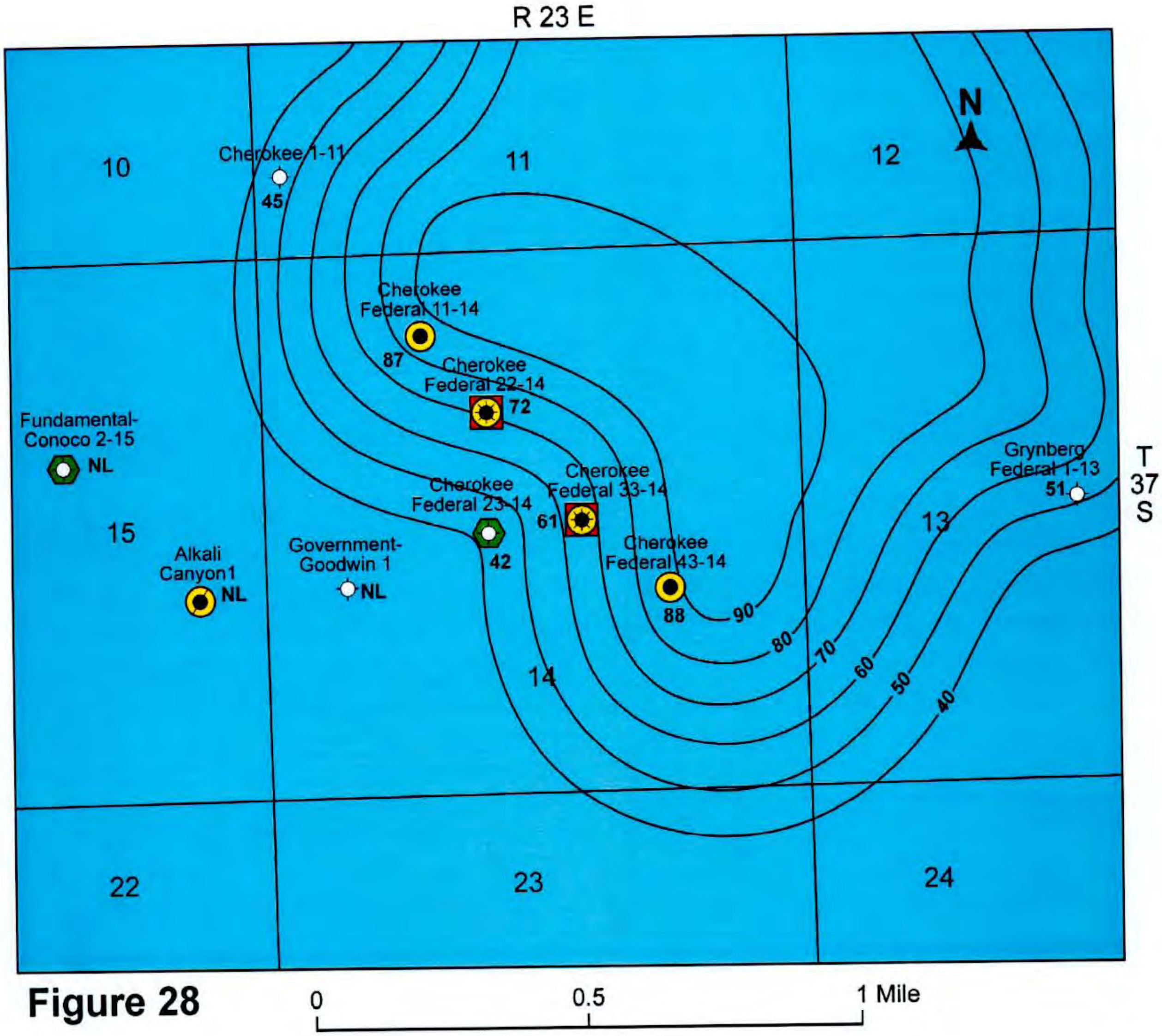

Figure 28

Upper Ismay:
Net Feet of Limestone (from LA)
Contour Interval = 10 ft

Cherokee Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Ismay drill-stem test
- Ismay completion
- Abandoned Ismay producer
- Ismay completion/core
- NL No neutron/density log

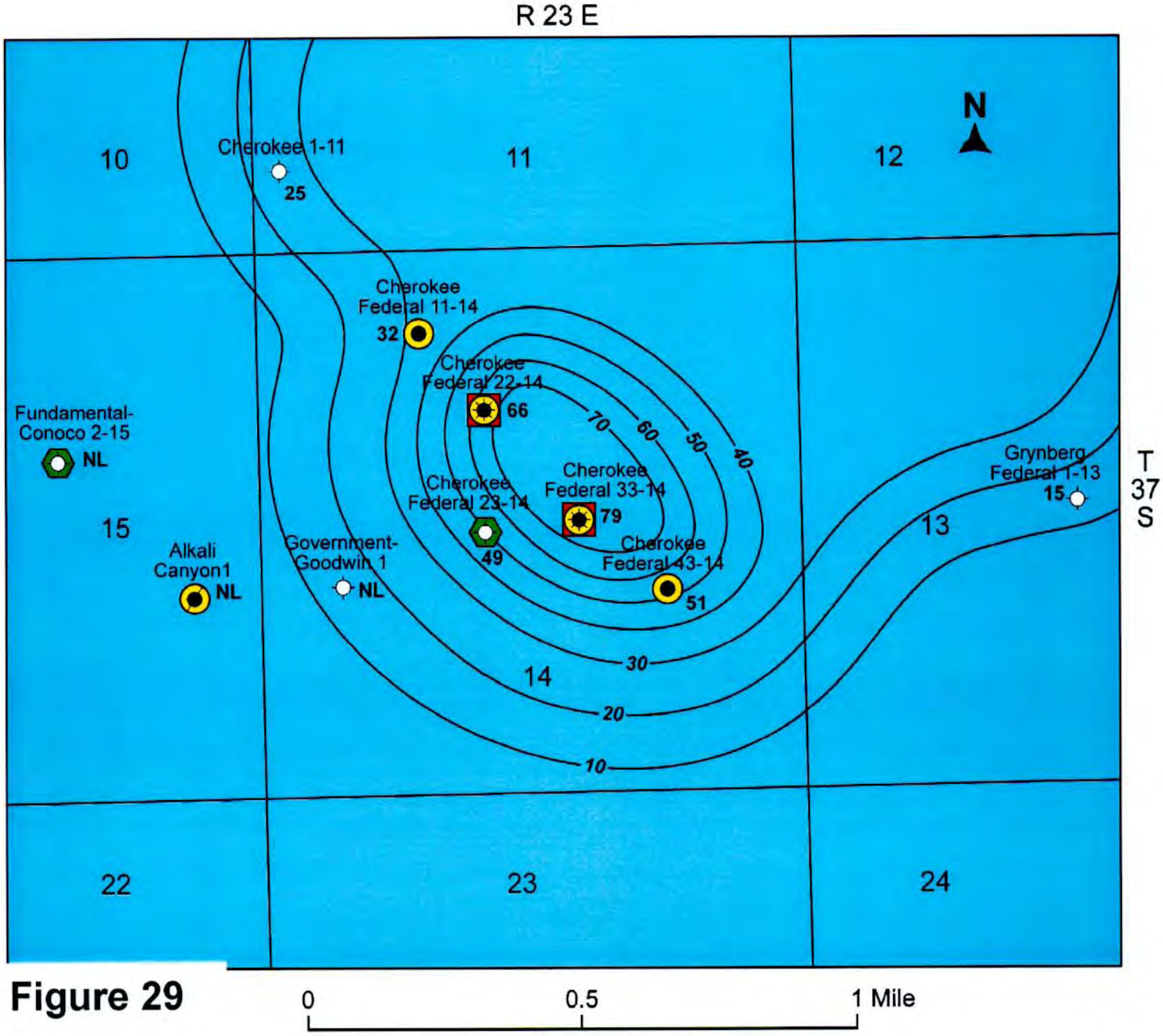

Figure 29

Upper Ismay:
Net Feet of Dolomite (from LA)
Contour Interval = 10 ft

Cherokee Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Ismay drill-stem test
- Ismay completion
- Abandoned Ismay producer
- Ismay completion/core
- NL No neutron/density log

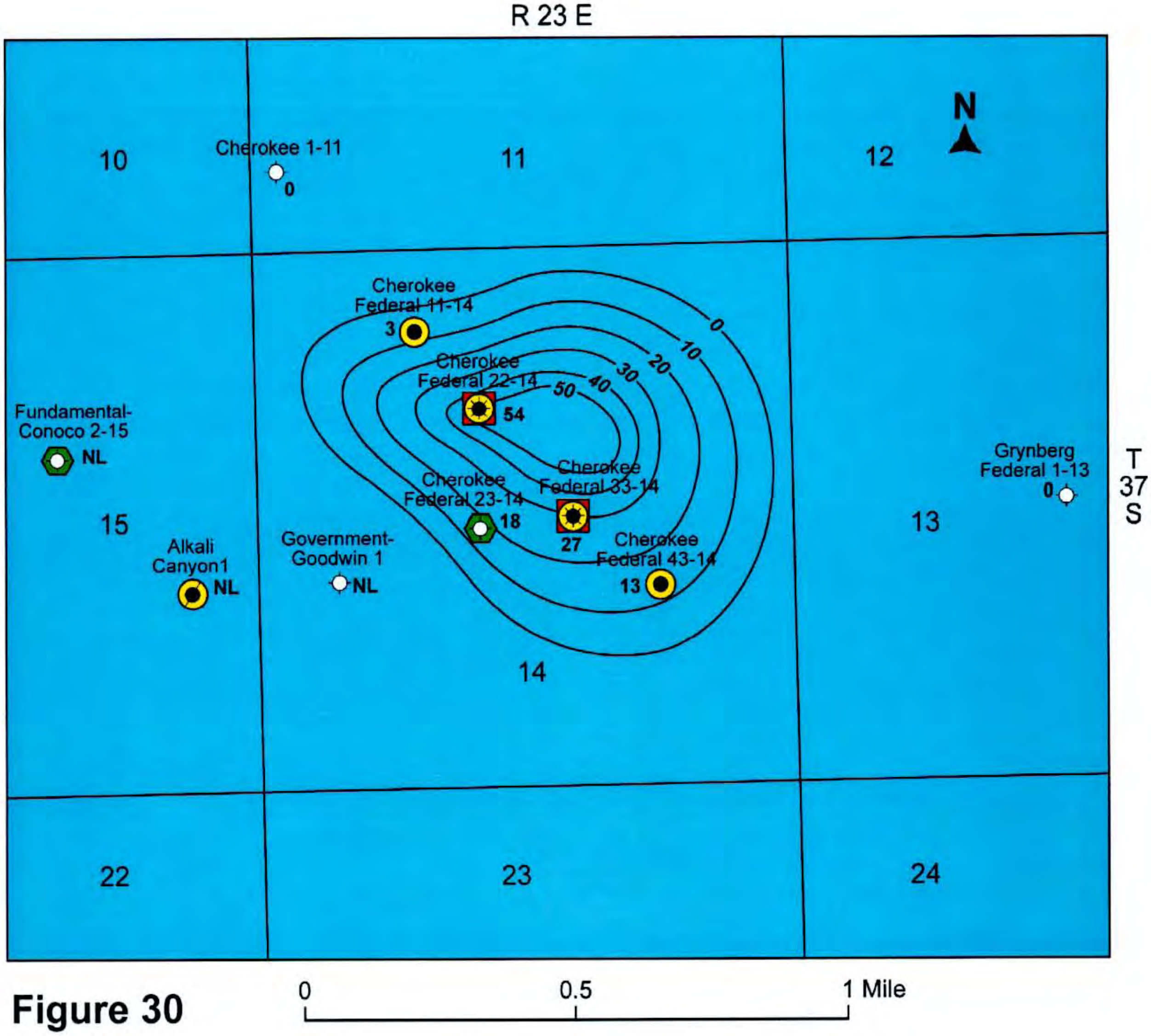

Figure 30

Upper Ismay:
Net Feet of Porosity (>10% by LA)
Contour Interval = 10 ft

Cherokee Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Ismay drill-stem test
- Ismay completion
- Abandoned Ismay producer
- Ismay completion/core
- NL No neutron/density log

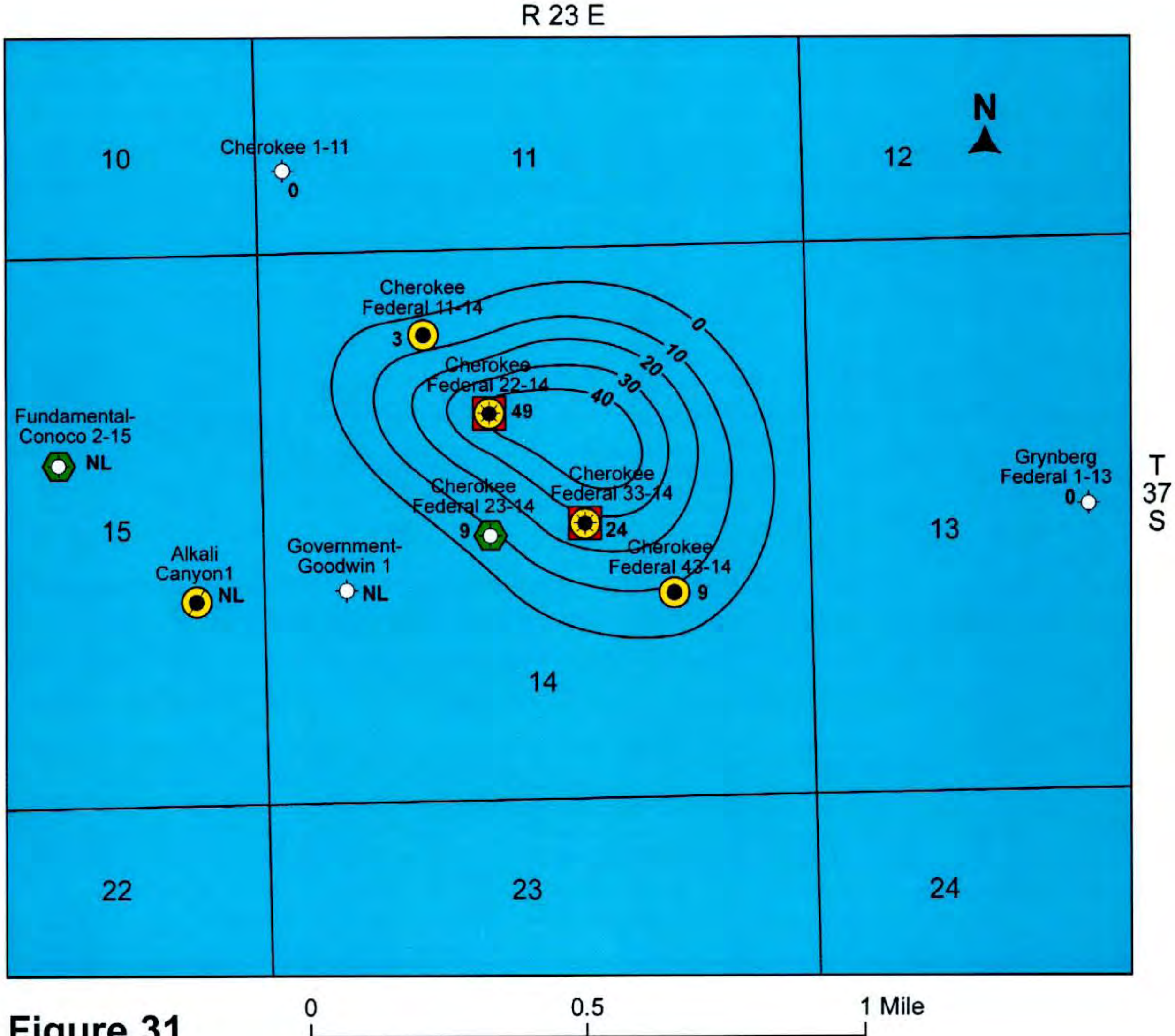

Figure 31

Upper Ismay:
Net Feet of Porosity (>12% by LA)
Contour Interval = 10 ft

Cherokee Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Ismay drill-stem test
- Ismay completion
- Abandoned Ismay producer
- Ismay completion/core
- NL No neutron/density log

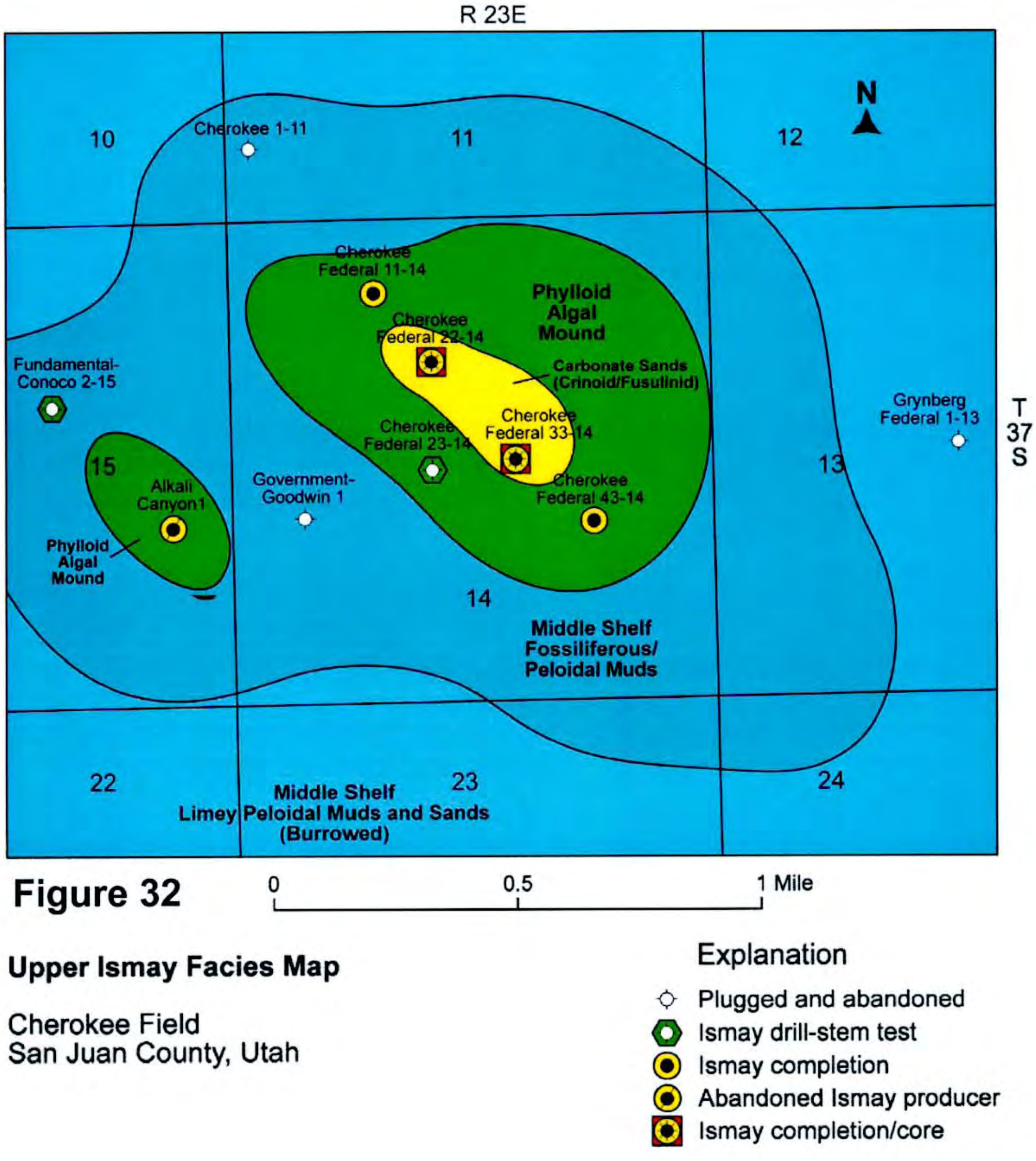

Figure 32

Upper Ismay Facies Map

Cherokee Field
San Juan County, Utah

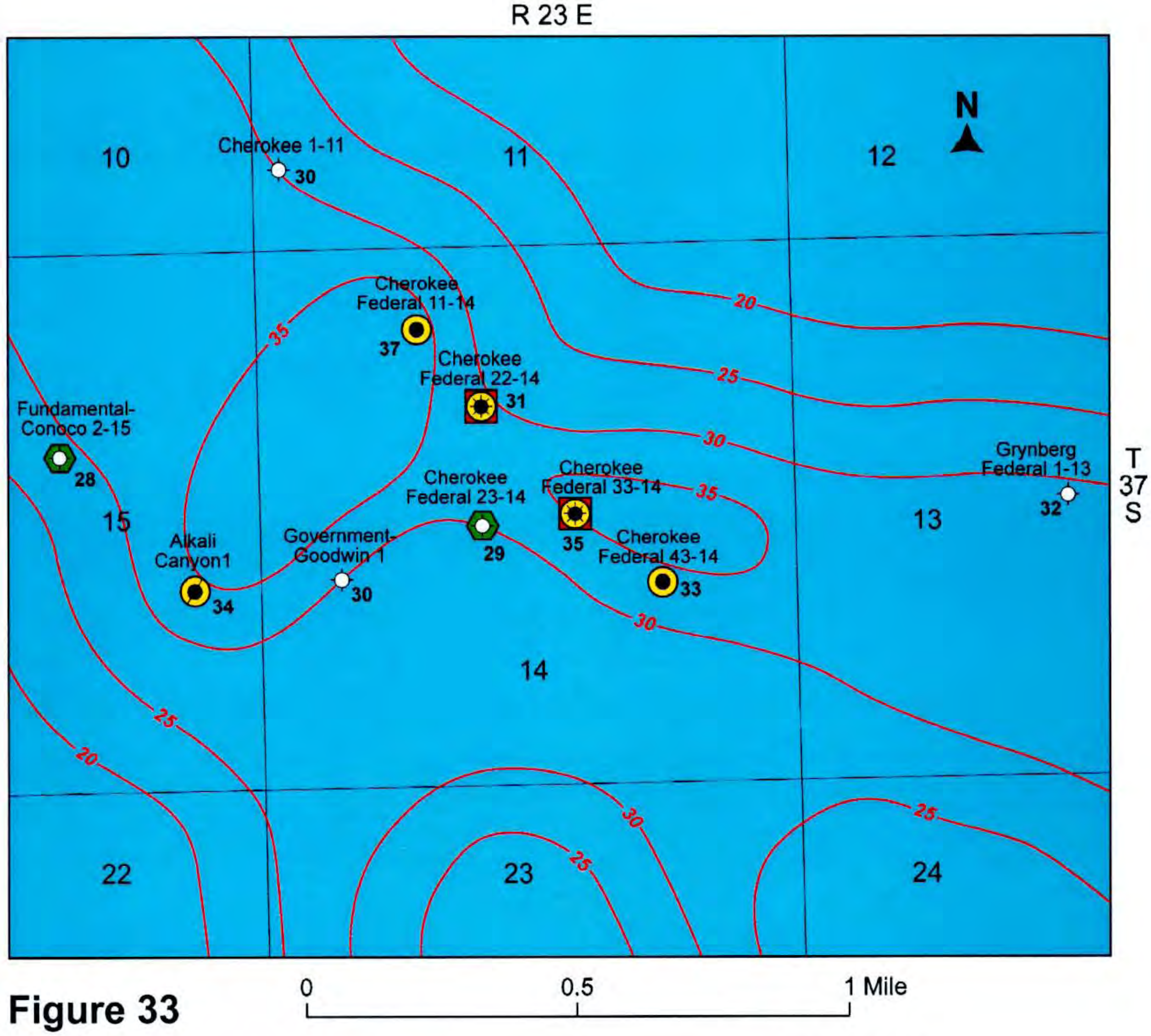

Figure 33

Isochore: Hovenweep Shale, Ismay Zone
Contour Interval = 5 ft

Cherokee Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Ismay drill-stem test
- Ismay completion
- Abandoned Ismay producer
- Ismay completion/core

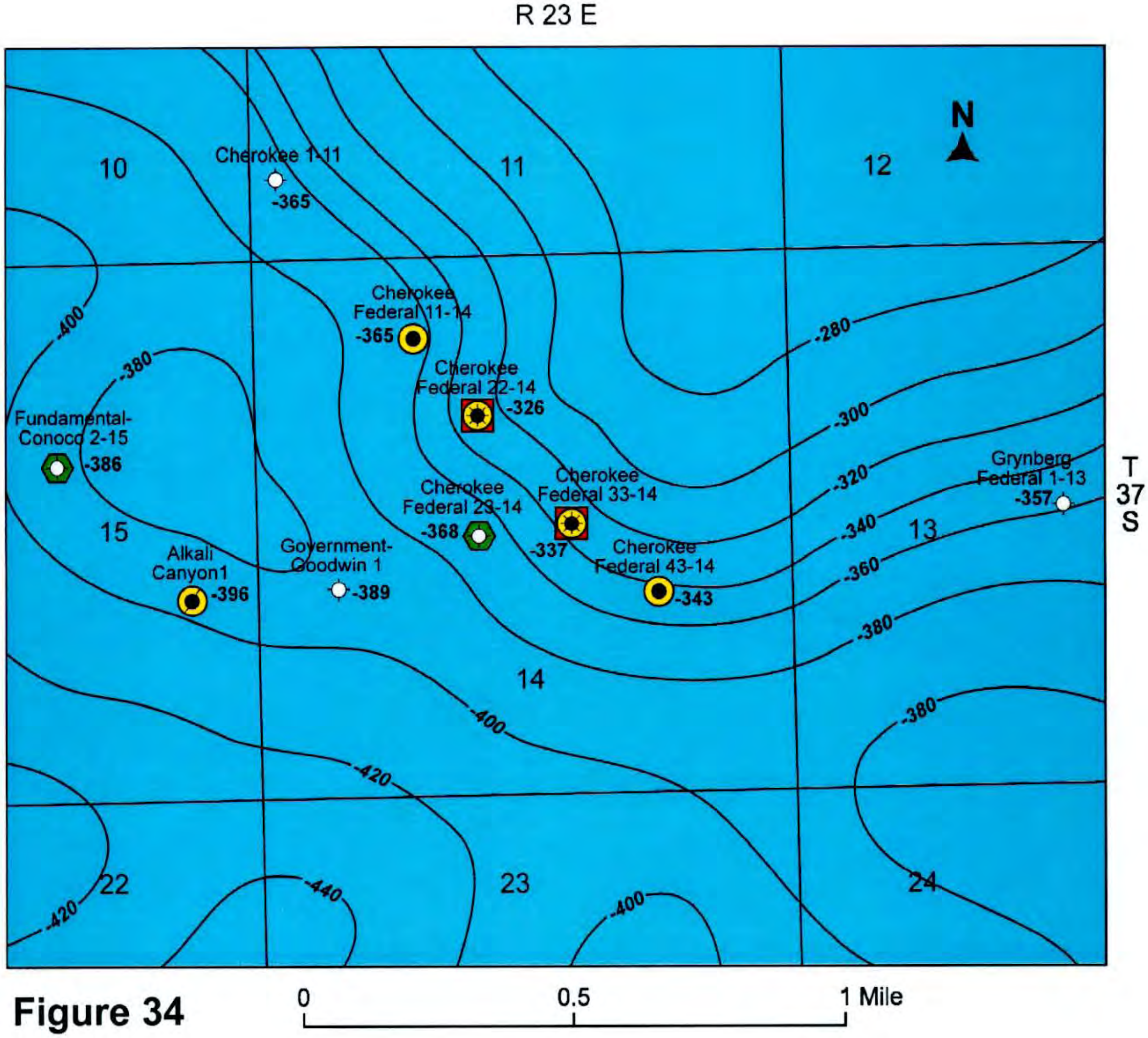

Figure 34

Structure Contour
Top of Lower Ismay
Contour Interval = 20 ft
Datum = Sea Level

Cherokee Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Ismay drill-stem test
- Ismay completion
- Abandoned Ismay producer
- Ismay completion/core

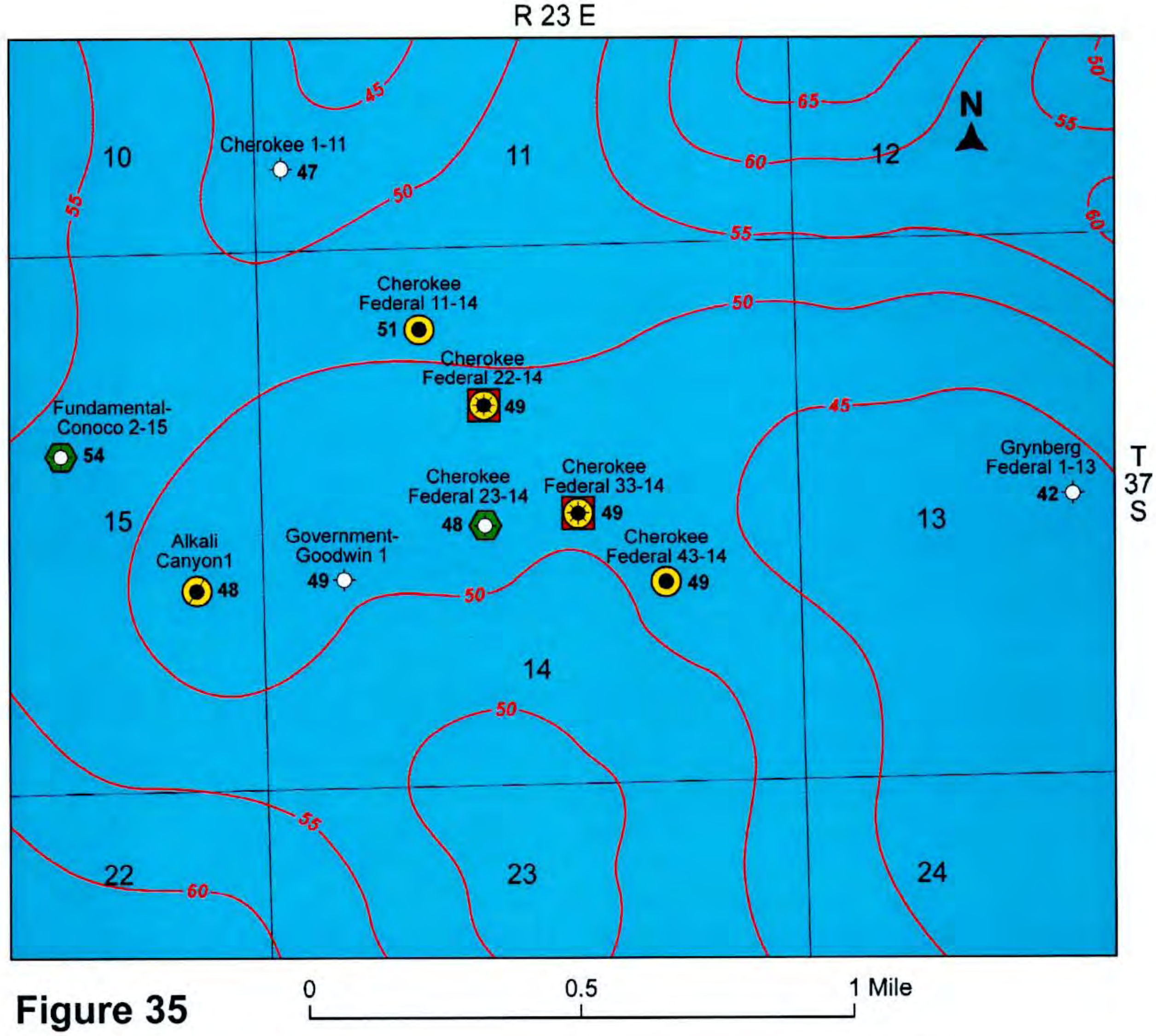

Figure 35

Isochore: Lower Ismay
Contour Interval = 5 ft

Cherokee Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Ismay drill-stem test
- Ismay completion
- Abandoned Ismay producer
- Ismay completion/core

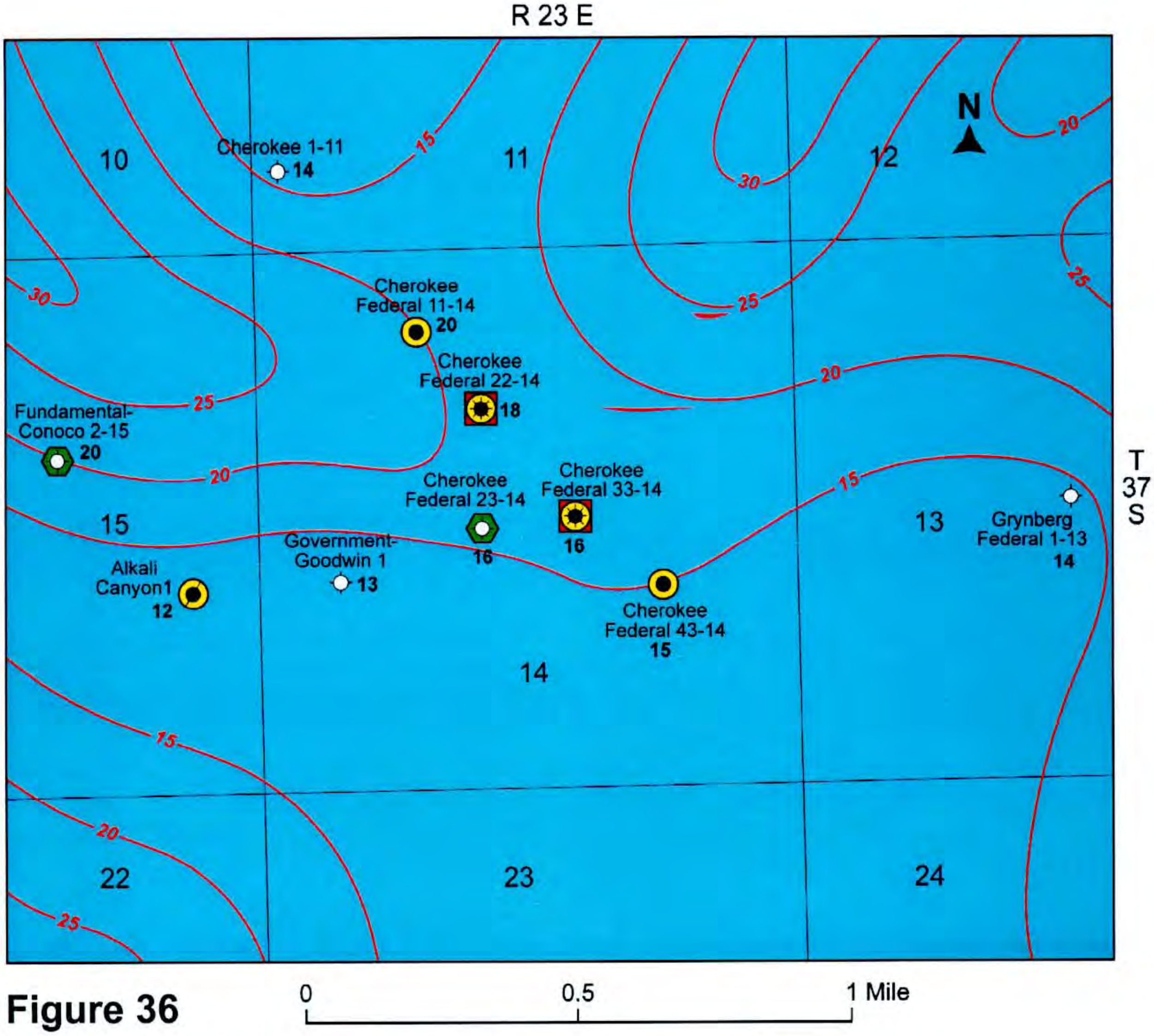

Figure 36

Isochore: Lower Ismay Anhydrite
Contour Interval = 5 ft

Cherokee Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Ismay drill-stem test
- Ismay completion
- Abandoned Ismay producer
- Ismay completion/core

R 23 E

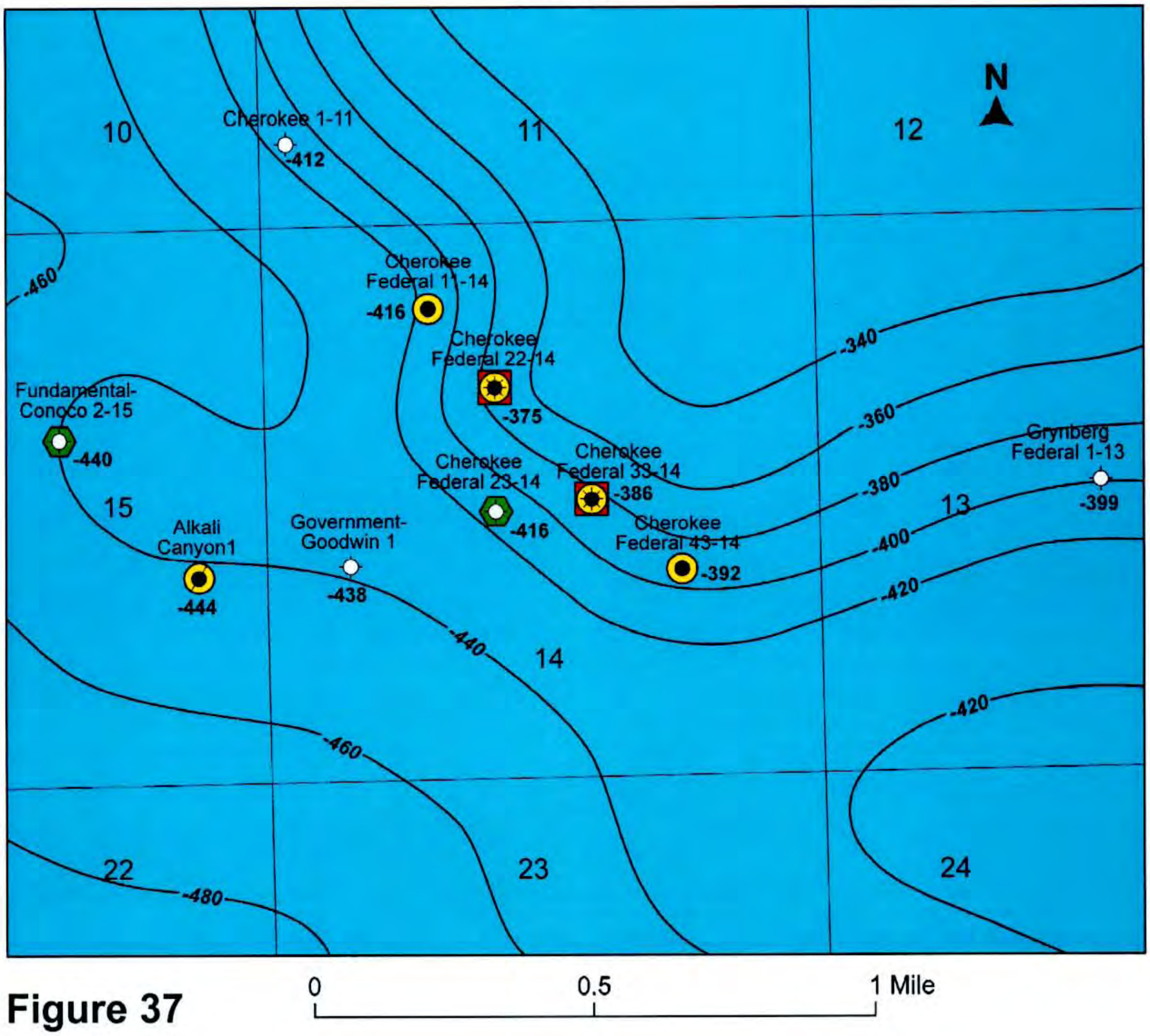

Figure 37

Structure Contour
Top of Gothic Shale
Contour Interval = 20 ft
Datum = Sea Level

Cherokee Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Ismay drill-stem test
- Ismay completion
- Abandoned Ismay producer
- Ismay completion/core

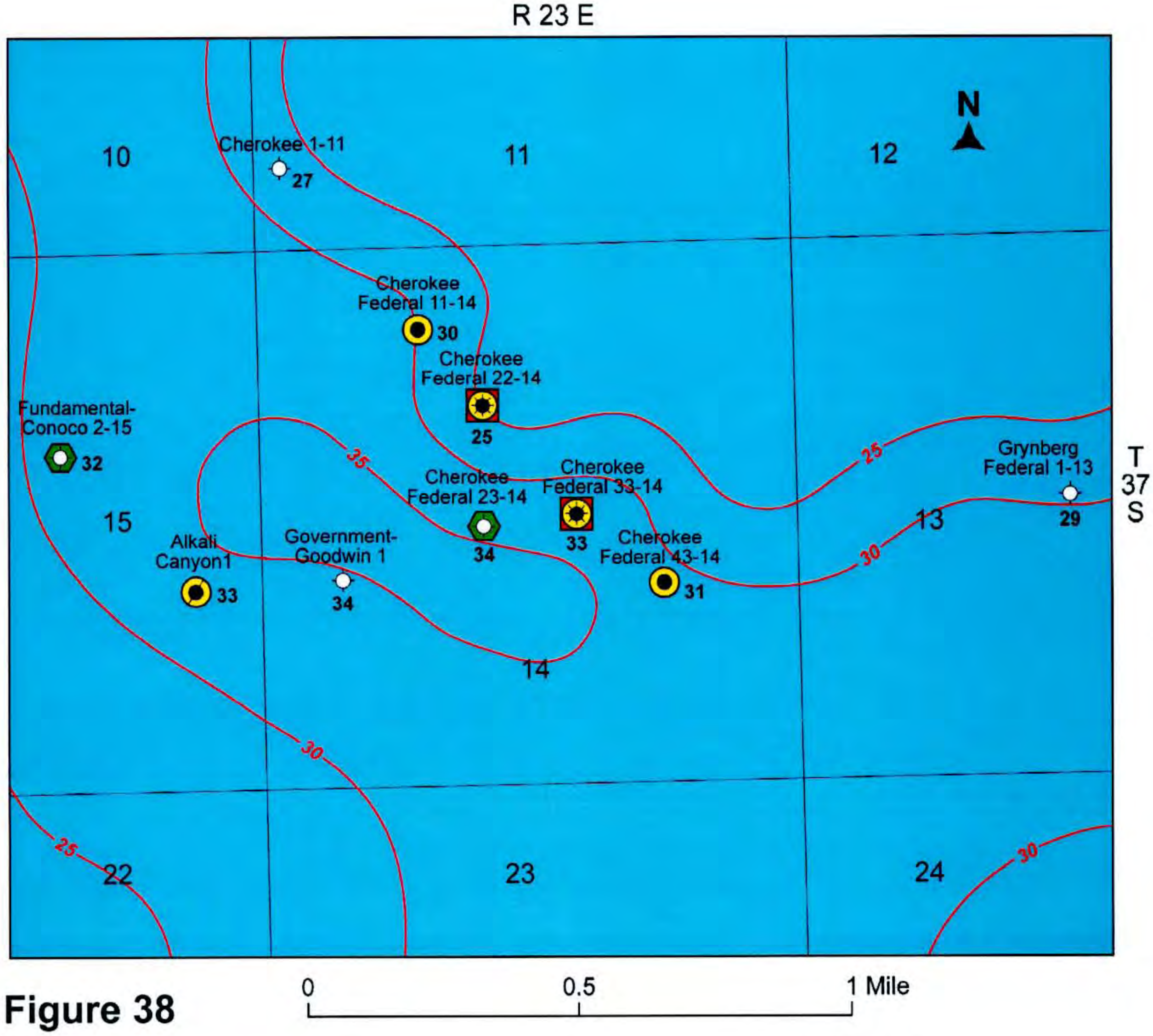

Figure 38

Isochore: Gothic Shale
Contour Interval = 5 ft

Cherokee Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Ismay drill-stem test
- Ismay completion
- Abandoned Ismay producer
- Ismay completion/core

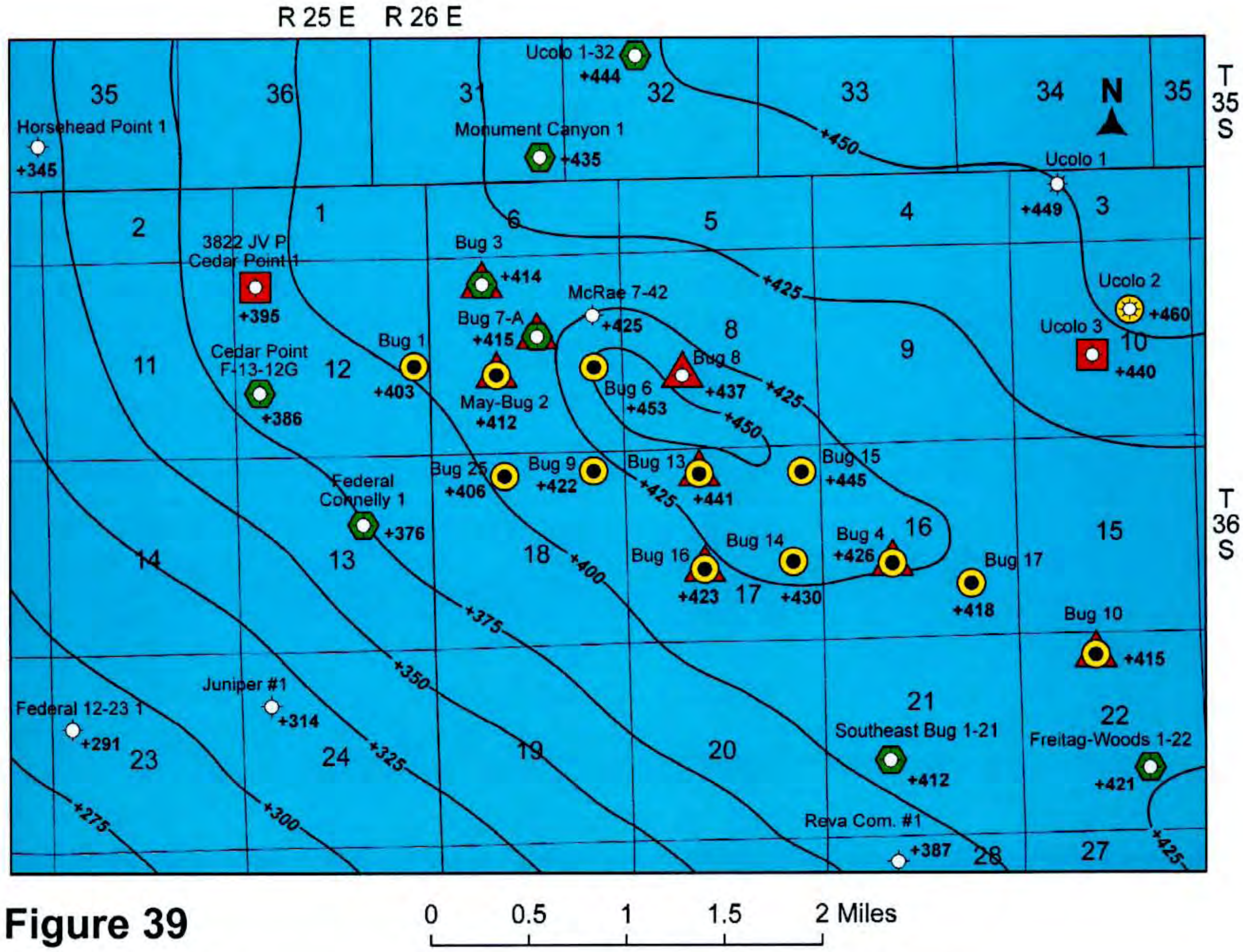

Figure 39

Structure Contour
Top of Gothic Shale
Contour Interval = 25 ft
Datum = Sea Level

Bug Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Producing gas
- Desert Creek drill-stem test
- Desert Creek completion
- Desert Creek completion attempt
- Desert Creek core

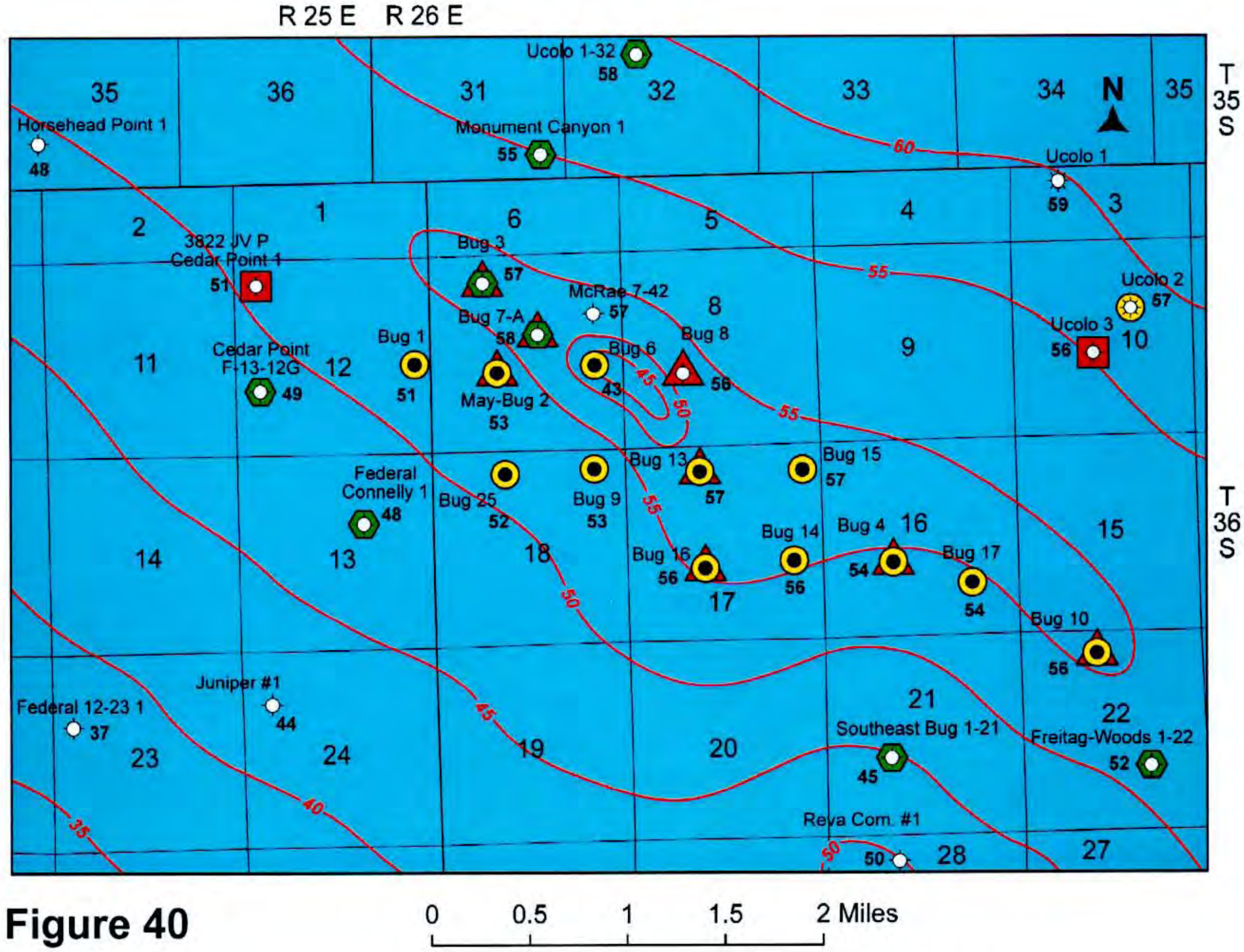

Figure 40

Isochore
Gothic Shale
Contour Interval = 5 ft

Bug Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Producing gas
- Desert Creek drill-stem test
- Desert Creek completion
- Desert Creek completion attempt
- Desert Creek core

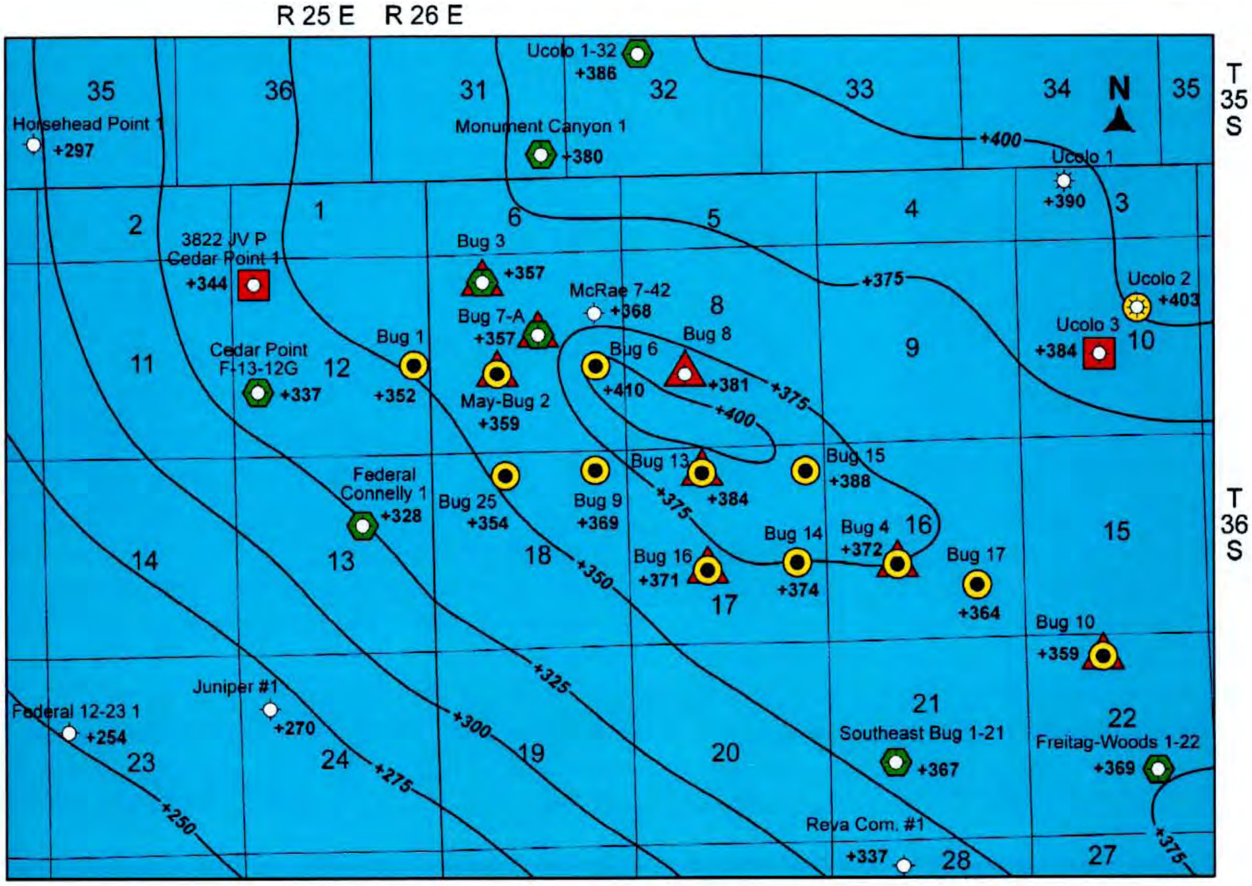

Figure 41

0 0.5 1 1.5 2 Miles

Structure Contour
Top of Desert Creek Zone
Contour Interval = 25 ft
Datum = Sea Level

Bug Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Producing gas
- Desert Creek drill-stem test
- Desert Creek completion
- Desert Creek completion attempt
- Desert Creek core

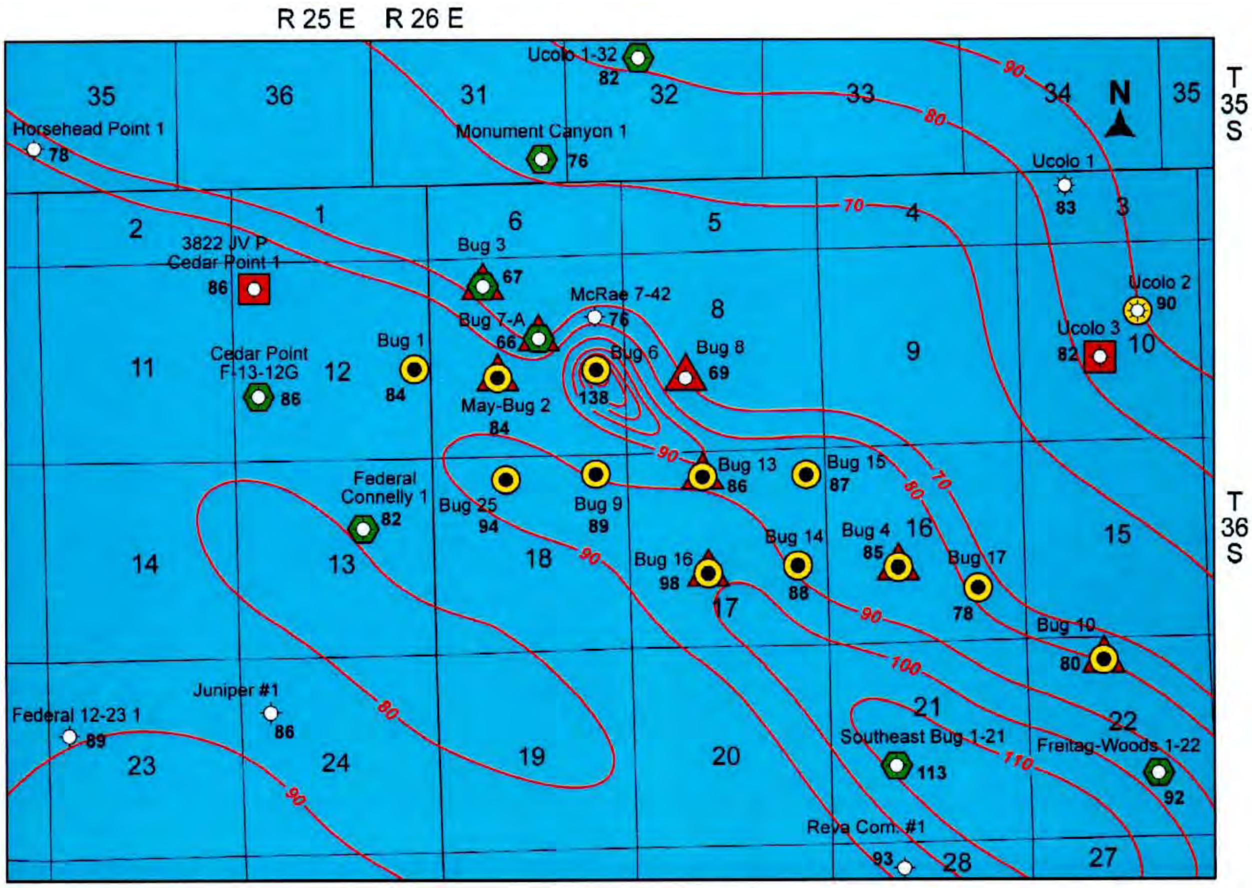

Figure 42

0 0.5 1 1.5 2 Miles

Isochore
Desert Creek
Contour Interval = 10 ft

Bug Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Producing gas
- Desert Creek drill-stem test
- Desert Creek completion
- Desert Creek completion attempt
- Desert Creek core

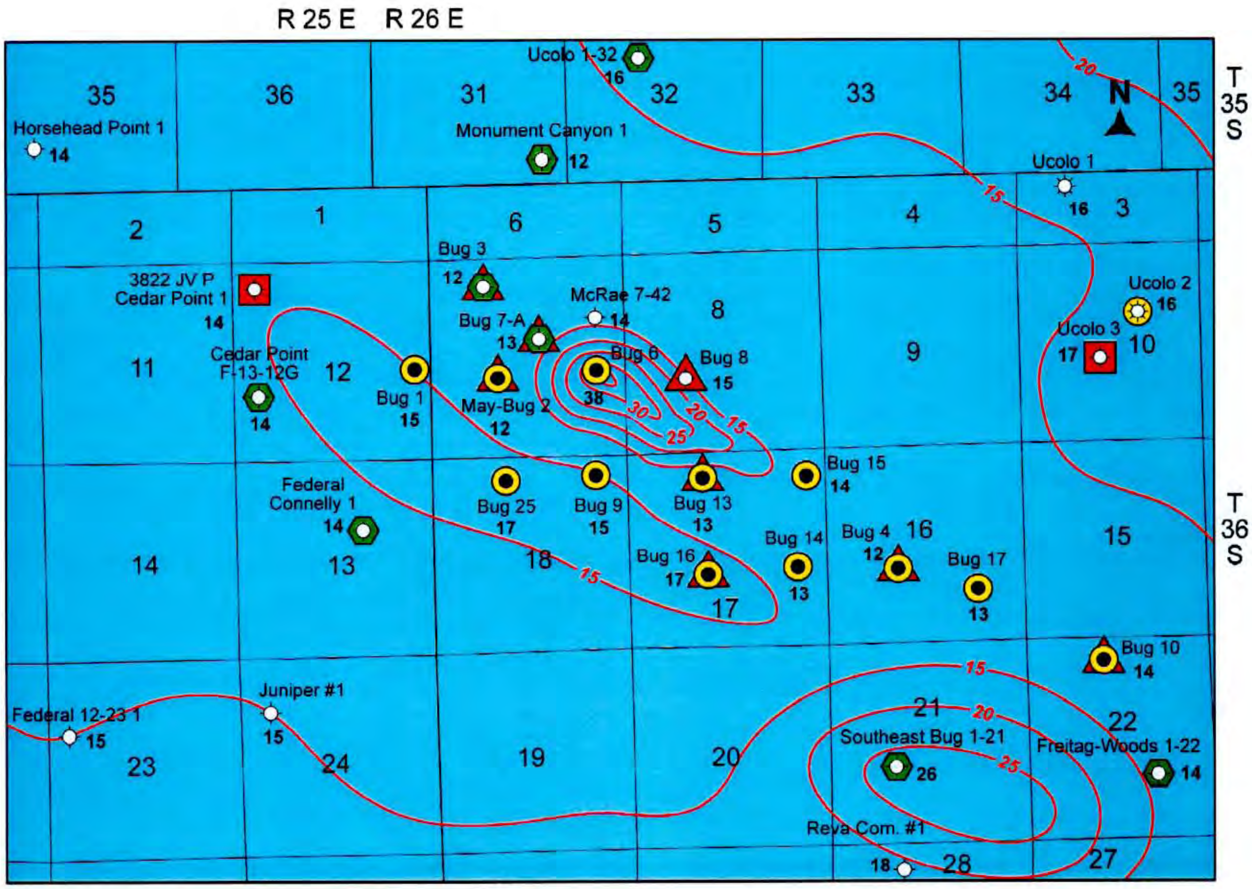

Figure 43

0 0.5 1 1.5 2 Miles

Isochore
Upper Desert Creek Anhydrite
Contour Interval = 5 ft

Bug Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Producing gas
- Desert Creek drill-stem test
- Desert Creek completion
- Desert Creek completion attempt
- Desert Creek core

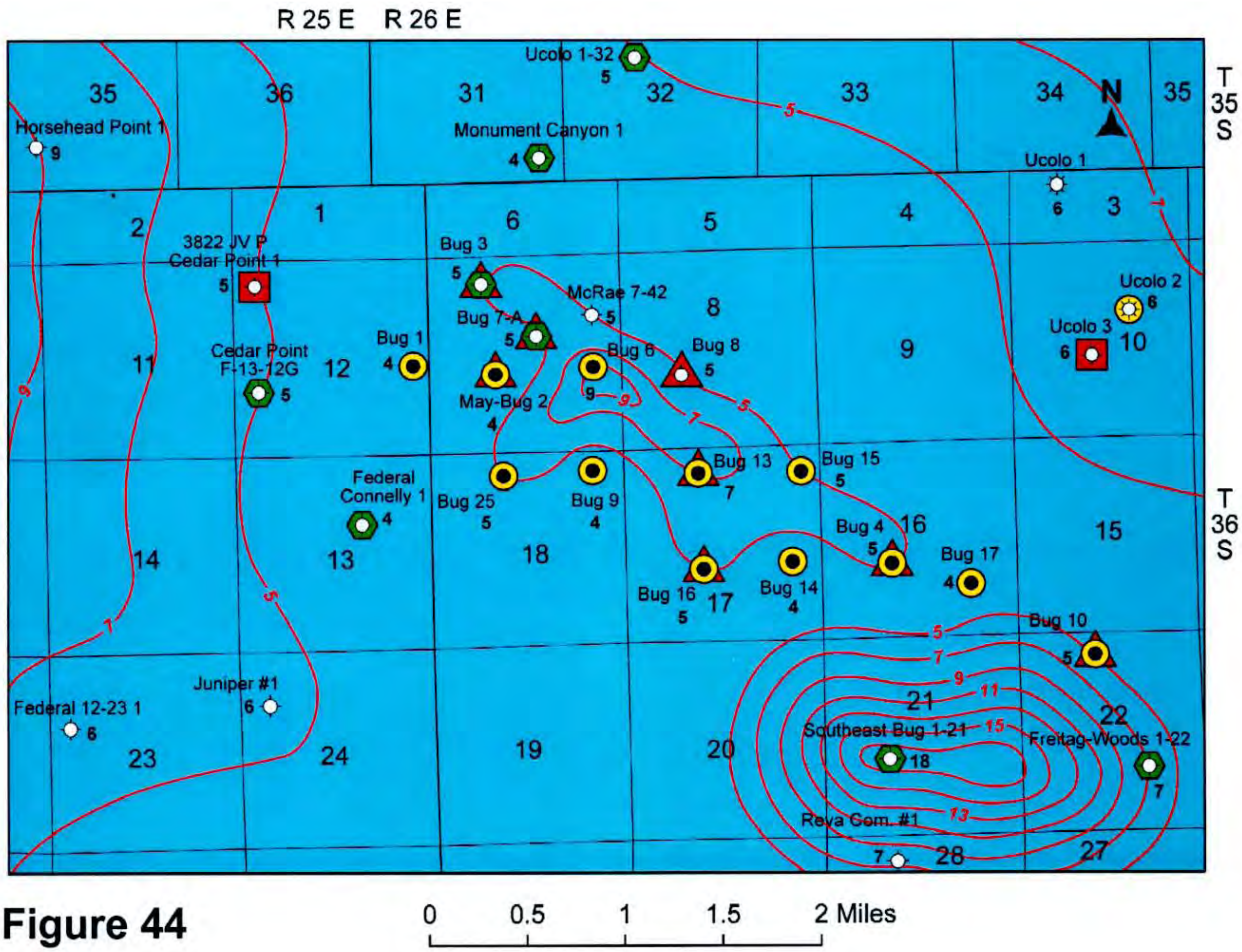

Figure 44

Isochore
Lower Desert Creek Anhydrite
Contour Interval = 2 ft

Bug Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Producing gas
- Desert Creek drill-stem test
- Desert Creek completion
- Desert Creek completion attempt
- Desert Creek core

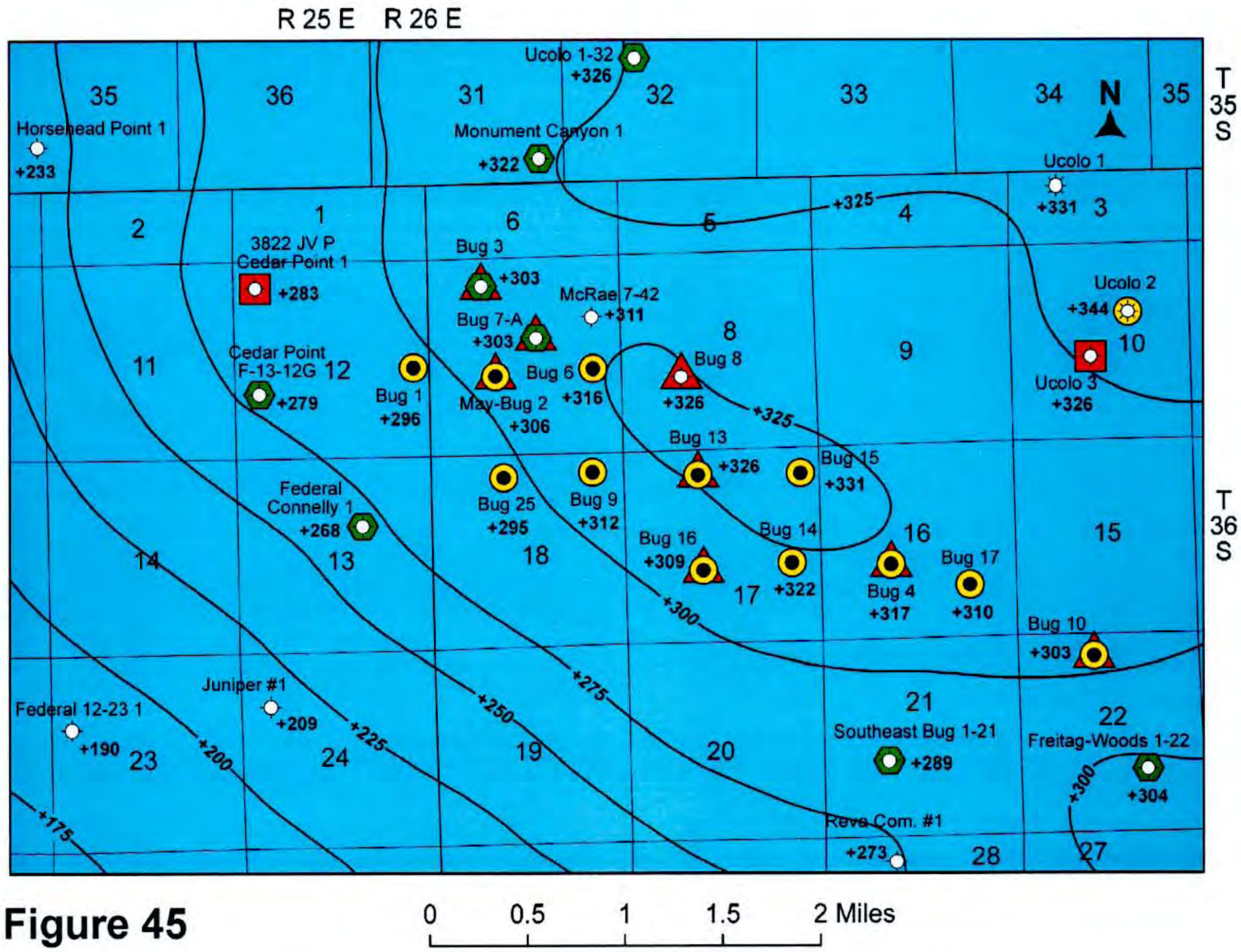

Figure 45

Structure Contour
Top of Lower Desert Creek
Clean Carbonate
Contour Interval = 25 ft
Datum = Sea Level

Bug Field
San Juan County, Utah

Explanation
- Plugged and abandoned
- Producing gas
- Desert Creek drill-stem test
- Desert Creek completion
- Desert Creek completion attempt
- Desert Creek core

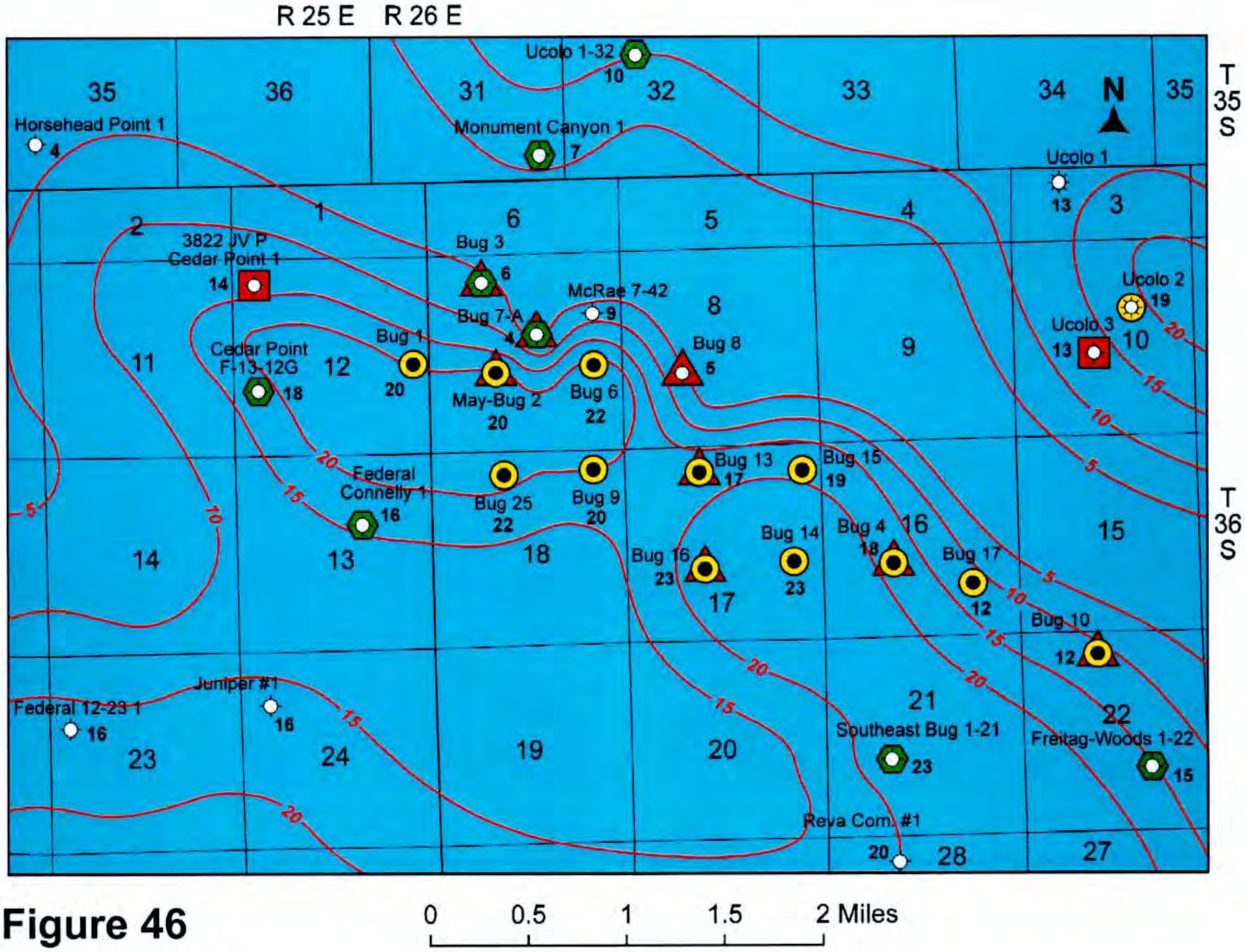

Figure 46

Isochore
Lower Desert Creek
Clean Carbonate
Contour Interval = 5 ft

Bug Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Producing gas
- Desert Creek drill-stem test
- Desert Creek completion
- Desert Creek completion attempt
- Desert Creek core

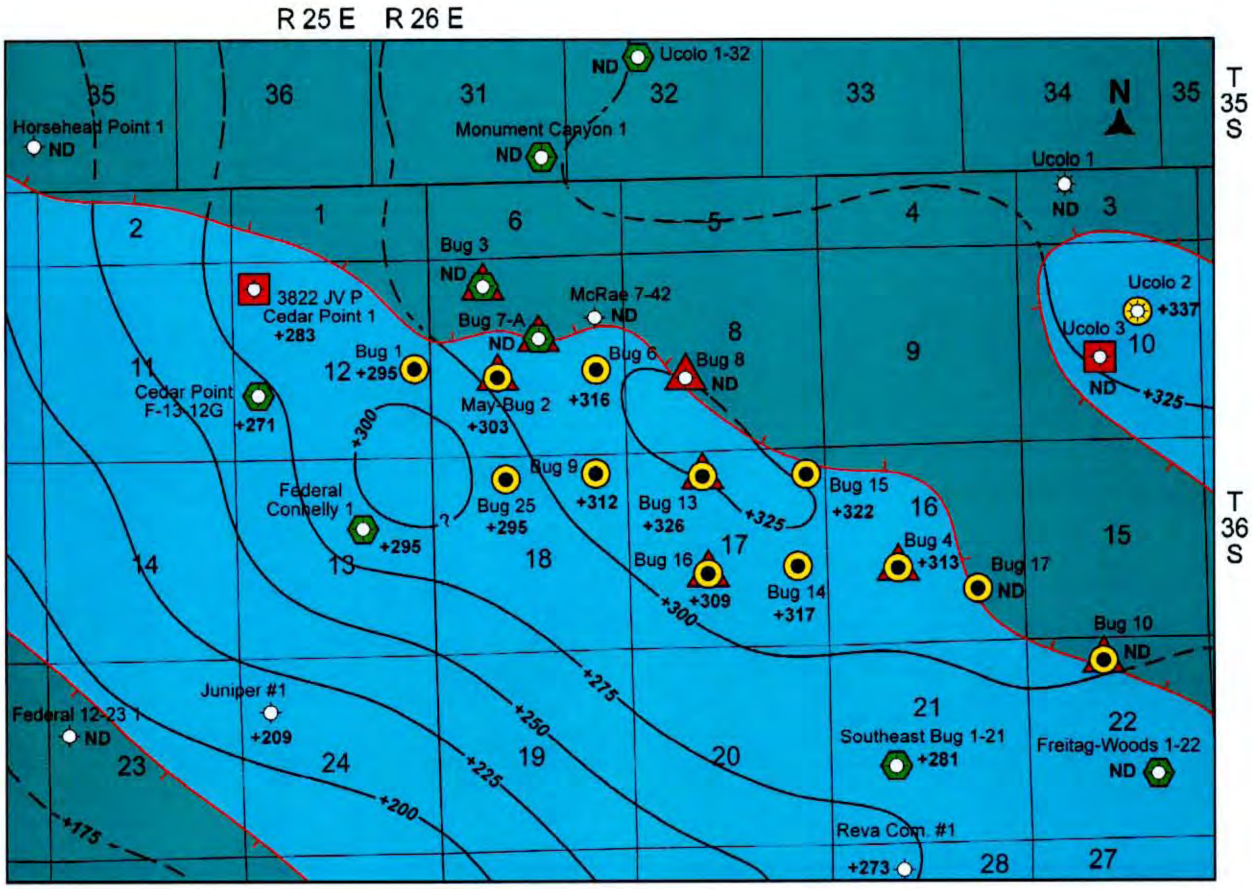

Figure 47

0 0.5 1 1.5 2 Miles

Structure Contour
Top of Lower Desert Creek Mound
Contour Interval = 25 ft
Datum = Sea Level

Bug Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Producing gas
- Desert Creek drill-stem test
- Desert Creek completion
- Desert Creek completion attempt
- Desert Creek core
- ND No data
- Off-mound

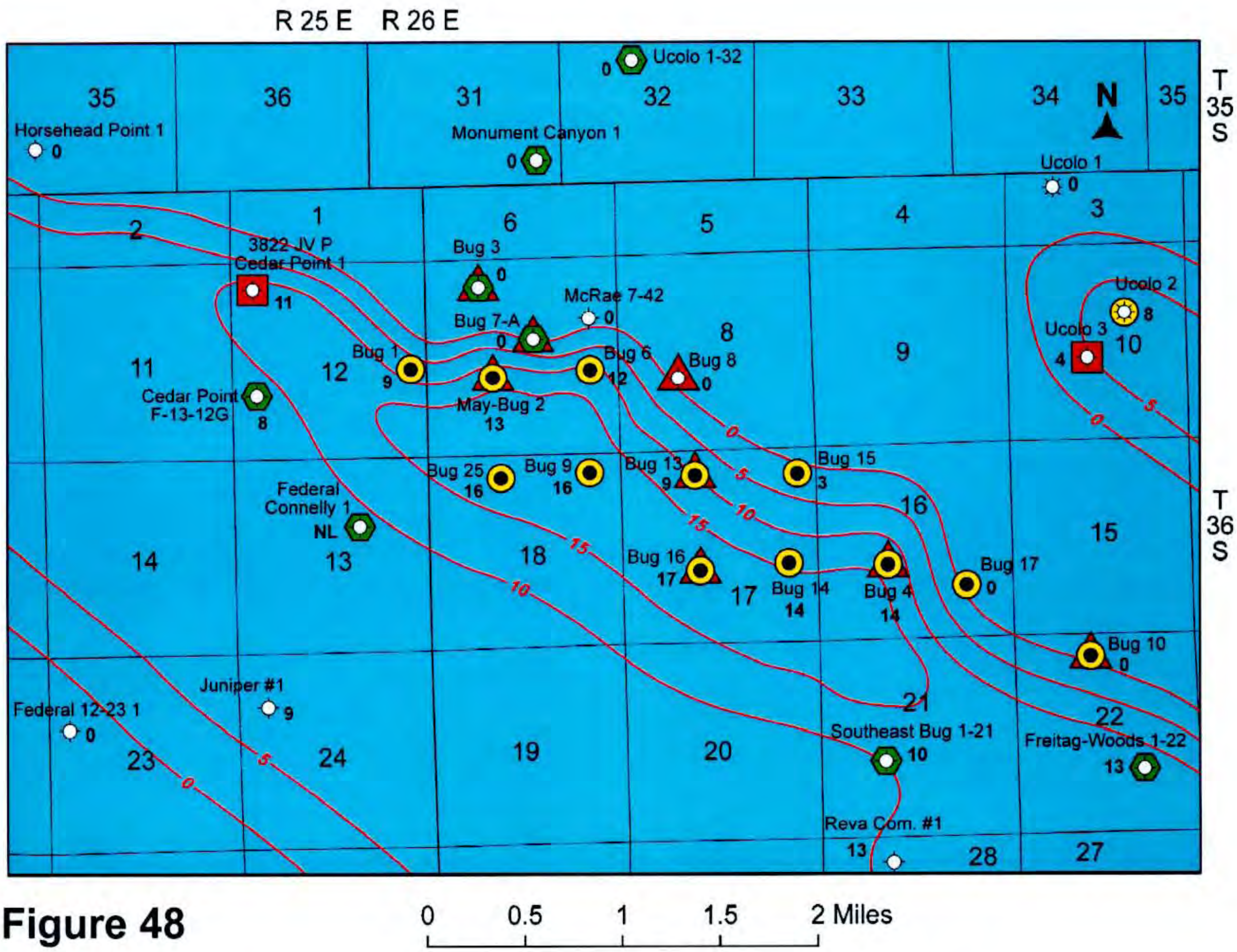

Figure 48

Isochore
Lower Desert Creek Mound
Contour Interval = 5 ft
Porosity > 6%

Bug Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Producing gas
- Desert Creek drill-stem test
- Desert Creek completion
- Desert Creek completion attempt
- Desert Creek core
- NL No neutron/density log

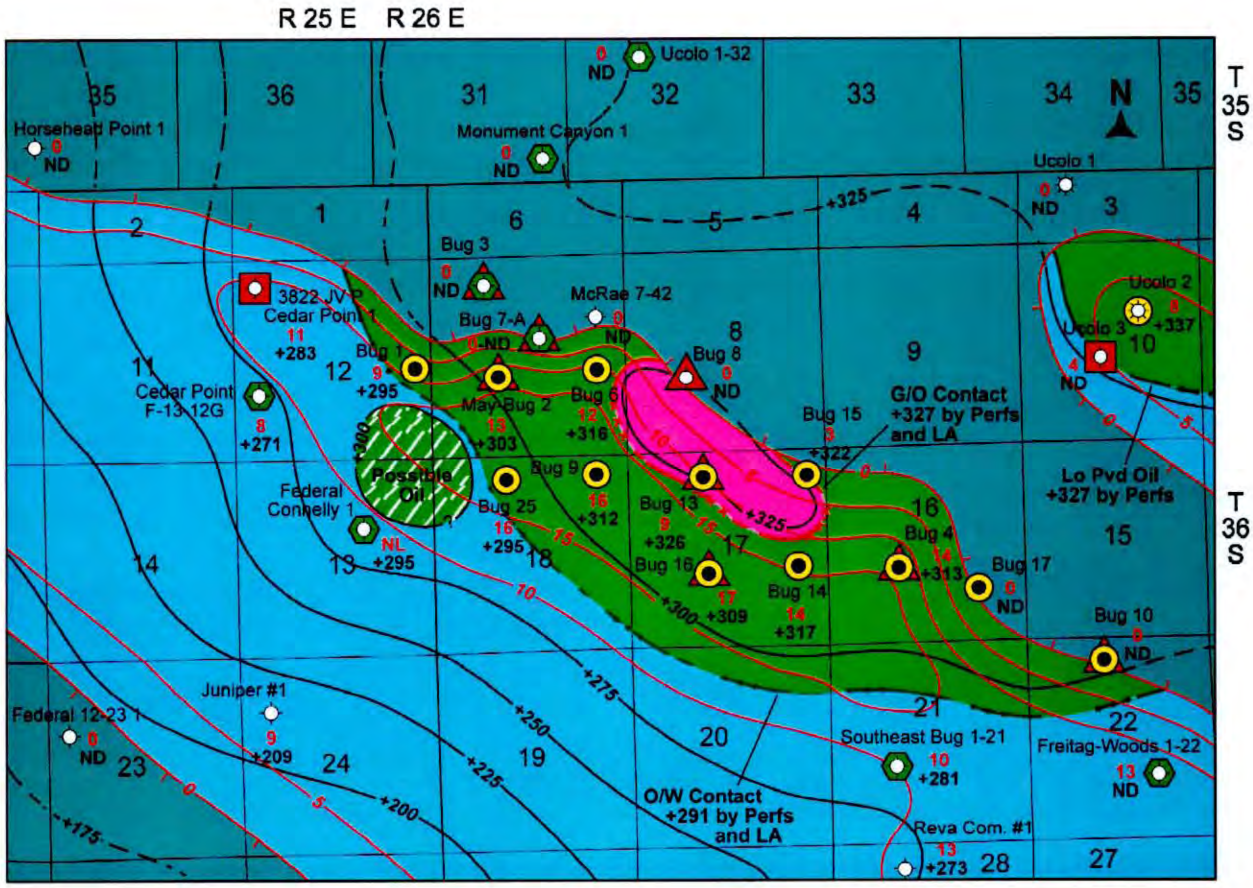

Plate 49

0 0.5 1 1.5 2 Miles

Isochore
Lower Desert Creek Mound
Contour Interval = 5 ft
Porosity > 6%

Structure Contour
Top of Lower Desert Creek Mound
Contour Interval = 25 ft
Datum = Sea Level

Bug Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Producing gas
- Desert Creek drill-stem test
- Desert Creek completion
- Desert Creek completion attempt
- Desert Creek core
- NL No neutron/density log
- ND No data
- Oil/water contact
- Gas/oil contact
- Gas
- Oil
- Off-mound
- Mound/clean carbonate

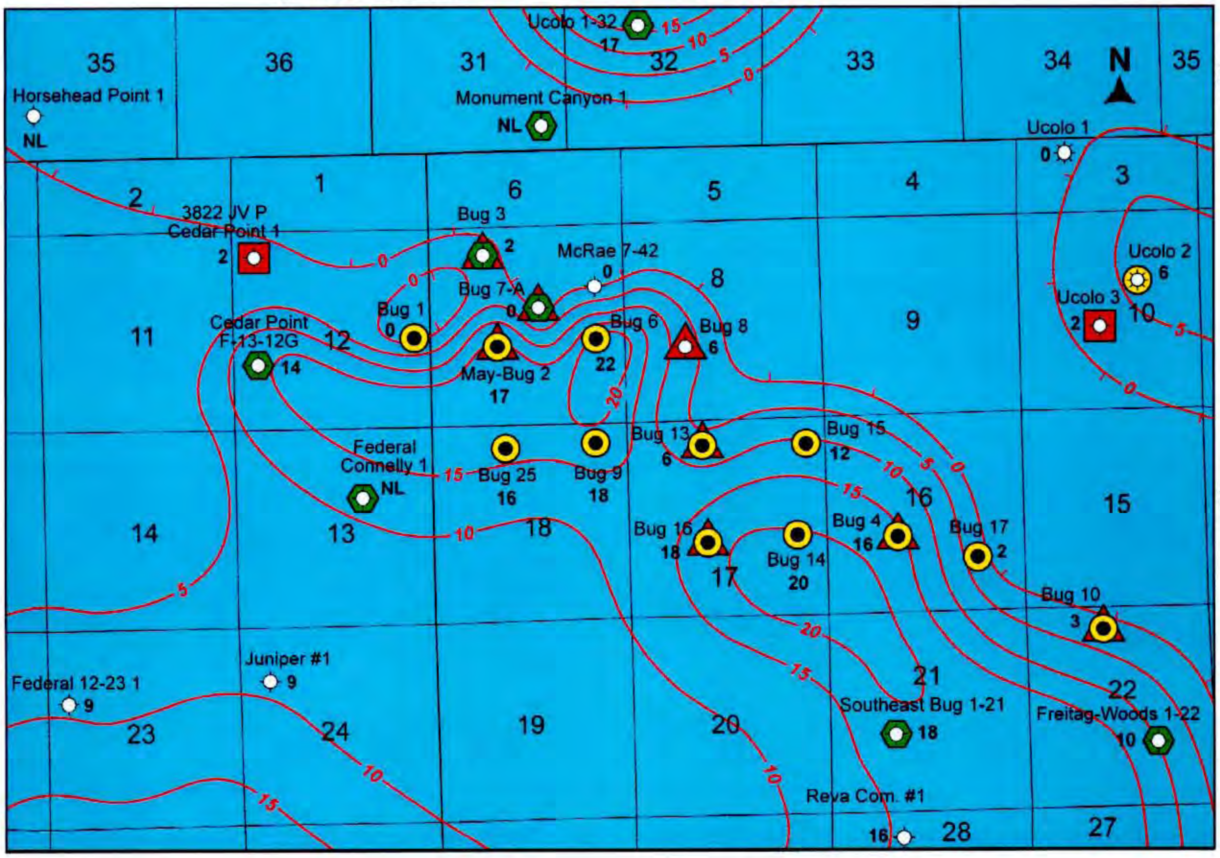

Figure 50

0 0.5 1 1.5 2 Miles

Lower Desert Creek Clean Carbonate - Net Feet of Porosity (> 10% LA)
Contour Interval = 5 ft

Bug Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Producing gas
- Desert Creek drill-stem test
- Desert Creek completion
- Desert Creek completion attempt
- Desert Creek core
- NL No neutron/density log

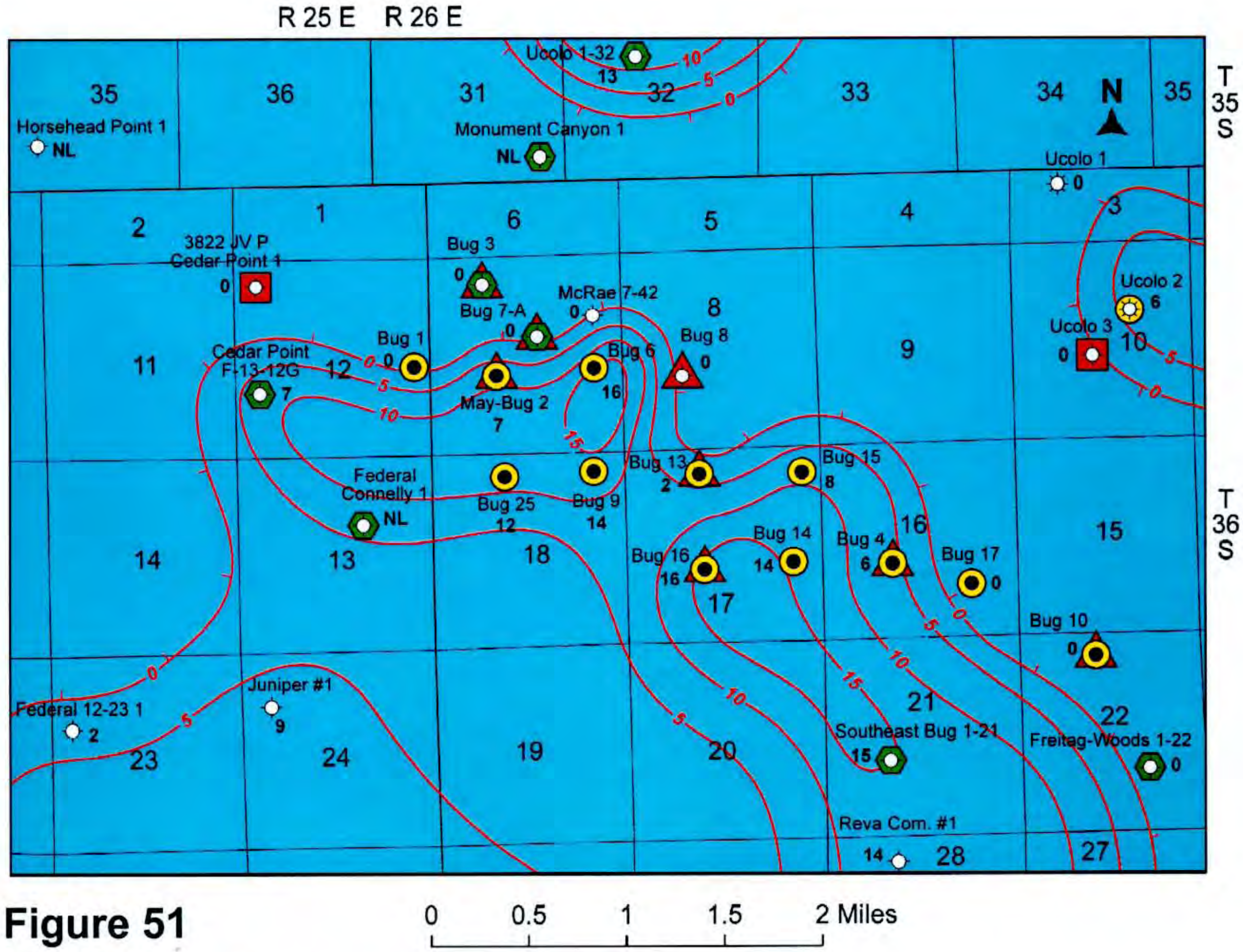

Figure 51

Lower Desert Creek Clean Carbonate - Net Feet of Porosity (> 12% LA)

Contour Interval = 5 ft

Bug Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Producing gas
- Desert Creek drill-stem test
- Desert Creek completion
- Desert Creek completion attempt
- Desert Creek core
- NL No neutron/density log

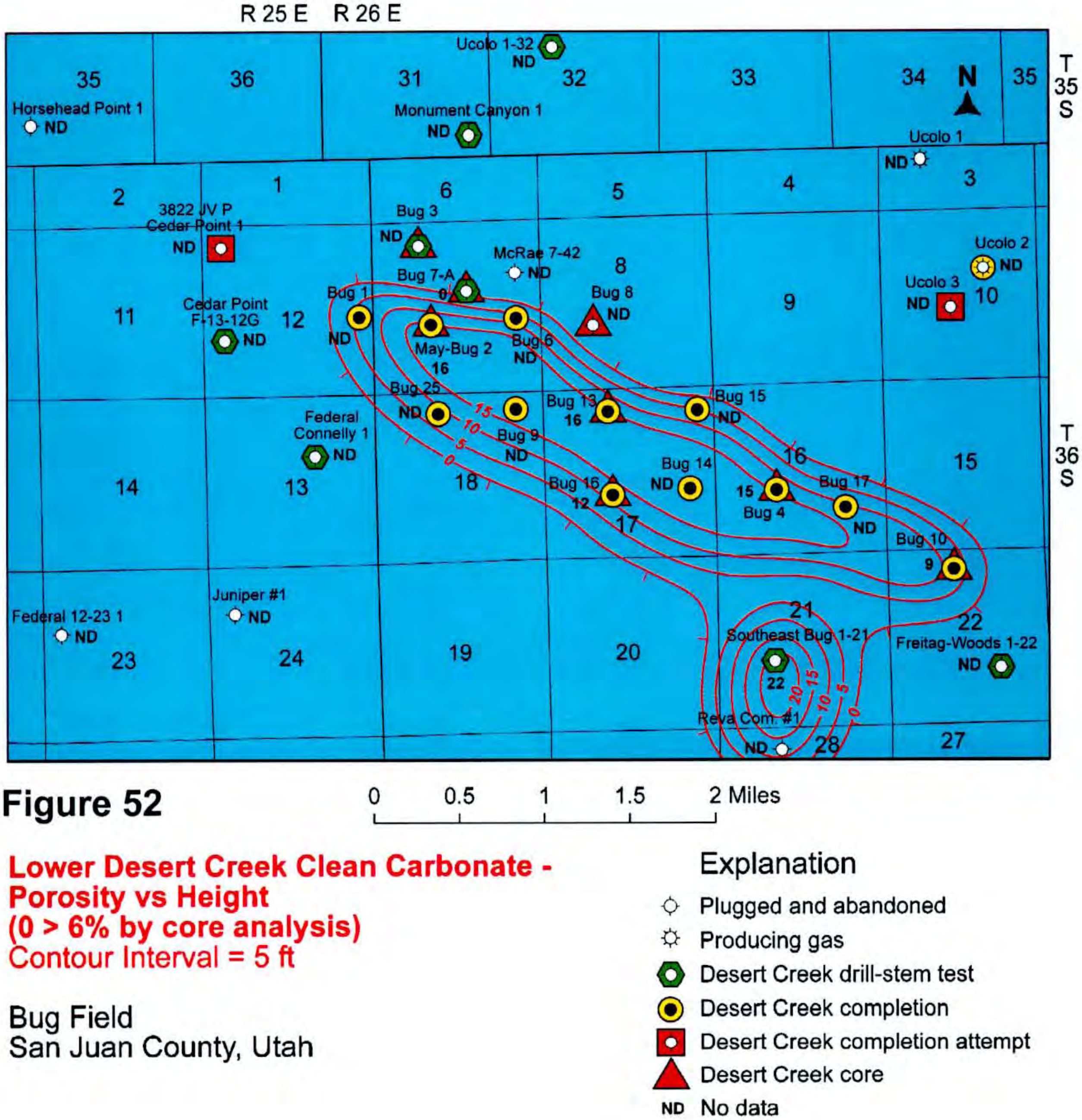

Figure 52

Lower Desert Creek Clean Carbonate - Porosity vs Height (0 > 6% by core analysis)
Contour Interval = 5 ft

Bug Field
San Juan County, Utah

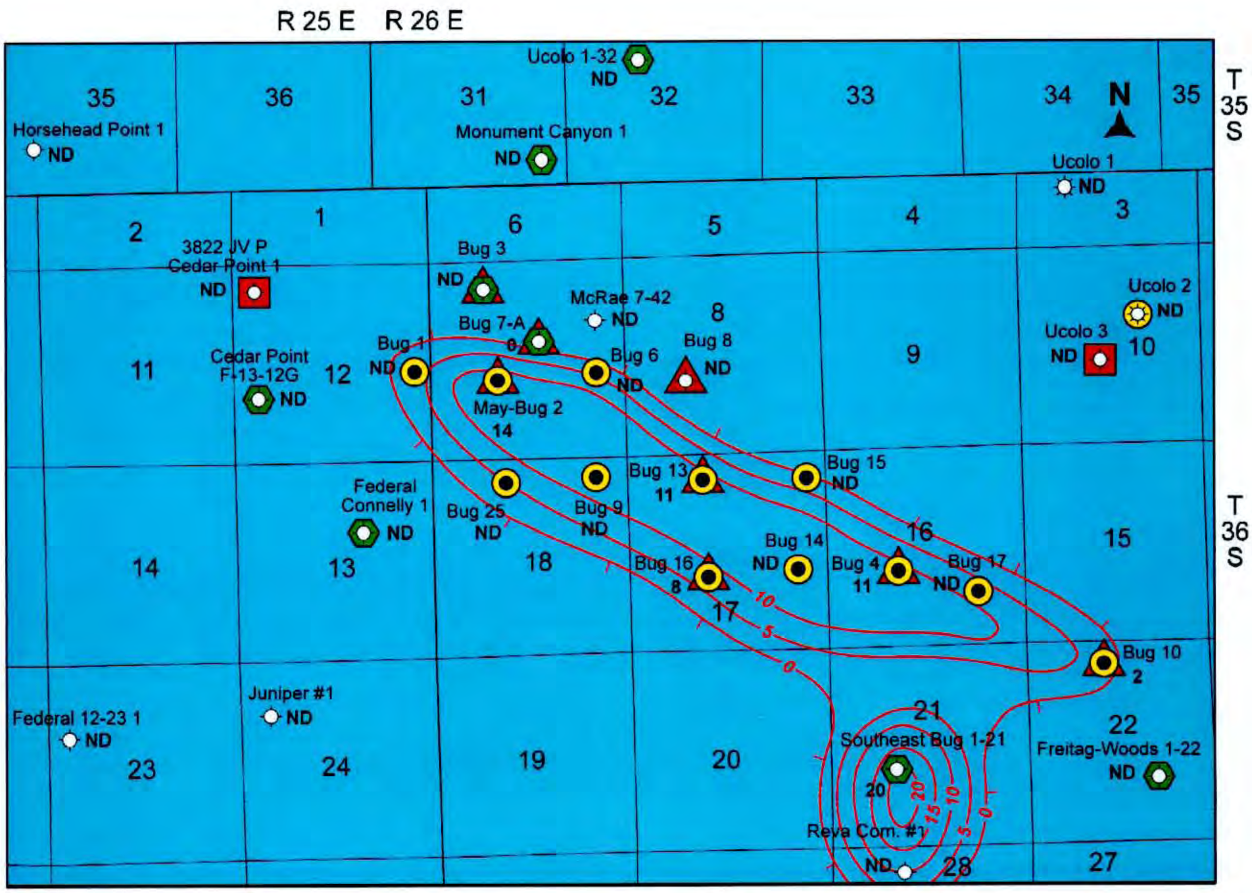

Figure 53

0 0.5 1 1.5 2 Miles

Lower Desert Creek Clean Carbonate - Porosity vs Height (0 > 10% by core analysis)
Contour Interval = 5 ft

Bug Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Producing gas
- Desert Creek drill-stem test
- Desert Creek completion
- Desert Creek completion attempt
- Desert Creek core
- ND No data

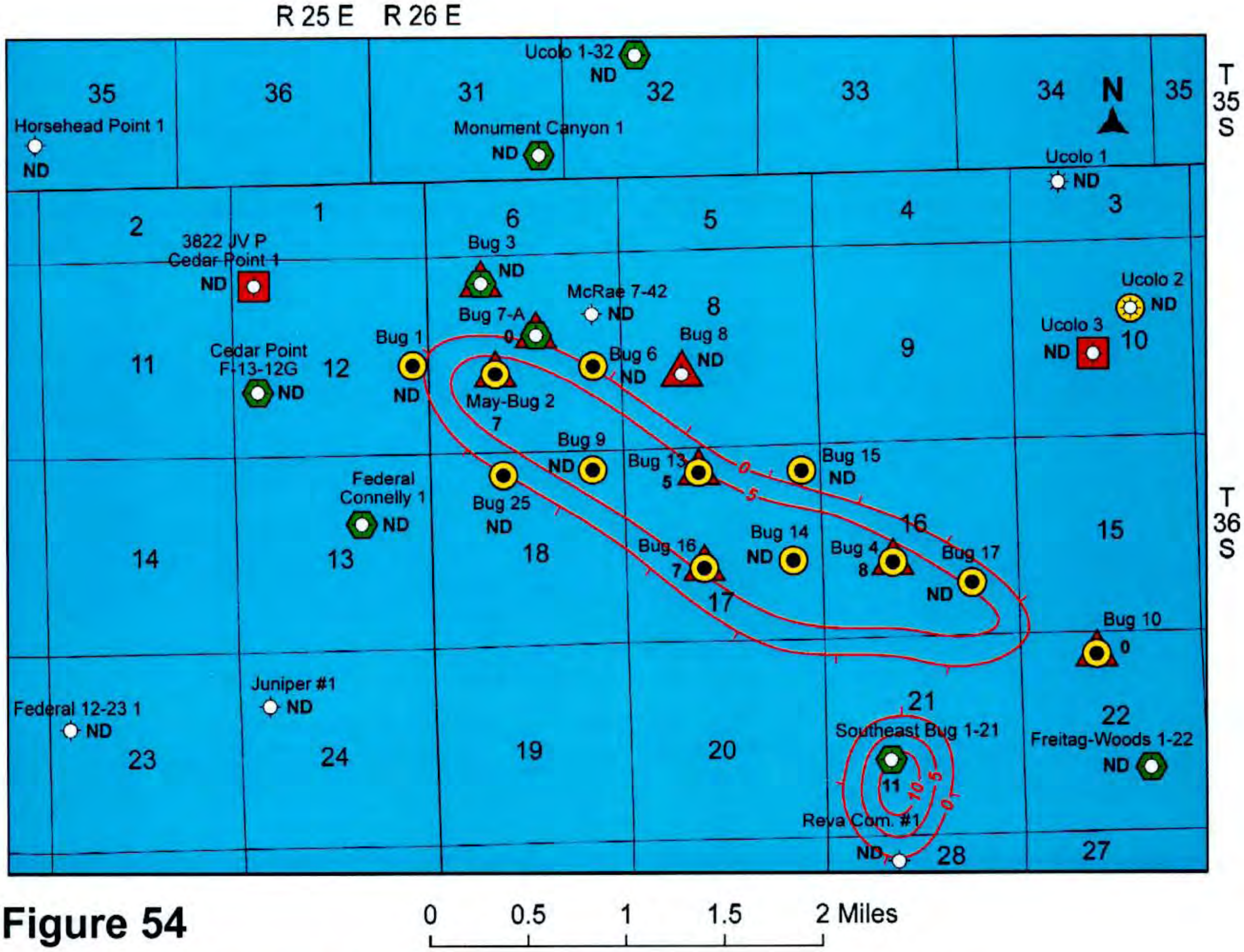

Figure 54

Lower Desert Creek Clean Carbonate - Porosity vs Height (0 > 12% by core analysis)

Contour Interval = 5 ft

Bug Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Producing gas
- Desert Creek drill-stem test
- Desert Creek completion
- Desert Creek completion attempt
- Desert Creek core
- ND No data

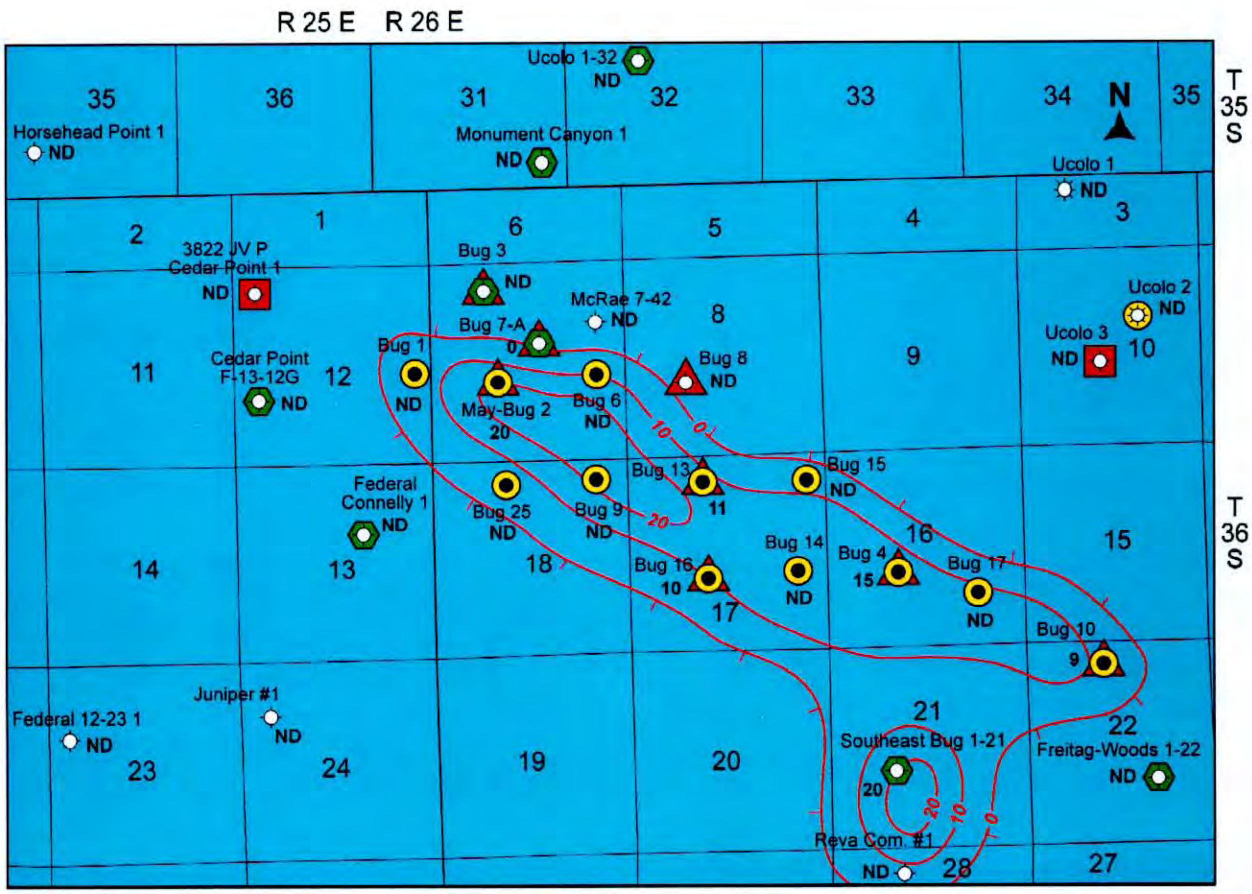

Figure 55

0 0.5 1 1.5 2 Miles

Lower Desert Creek Clean Carbonate - Permeability vs Height (kh > 2 md)
Contour Interval = 10 ft

Bug Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Producing gas
- Desert Creek drill-stem test
- Desert Creek completion
- Desert Creek completion attempt
- Desert Creek core
- ND No data

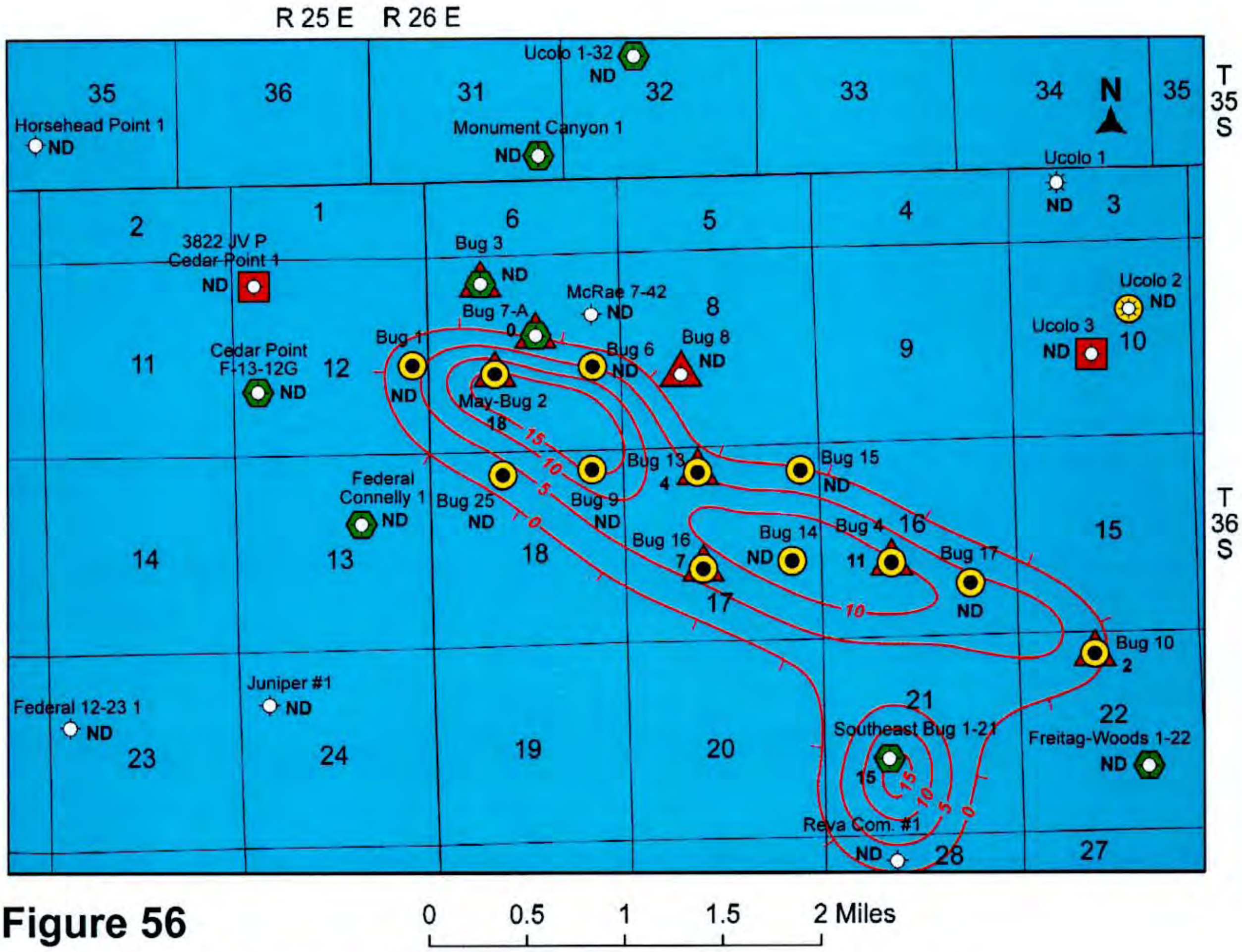

Figure 56

Lower Desert Creek Clean Carbonate - Permeability vs Height (kh > 10 md)
Contour Interval = 5 ft

Bug Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Producing gas
- Desert Creek drill-stem test
- Desert Creek completion
- Desert Creek completion attempt
- Desert Creek core
- ND No data

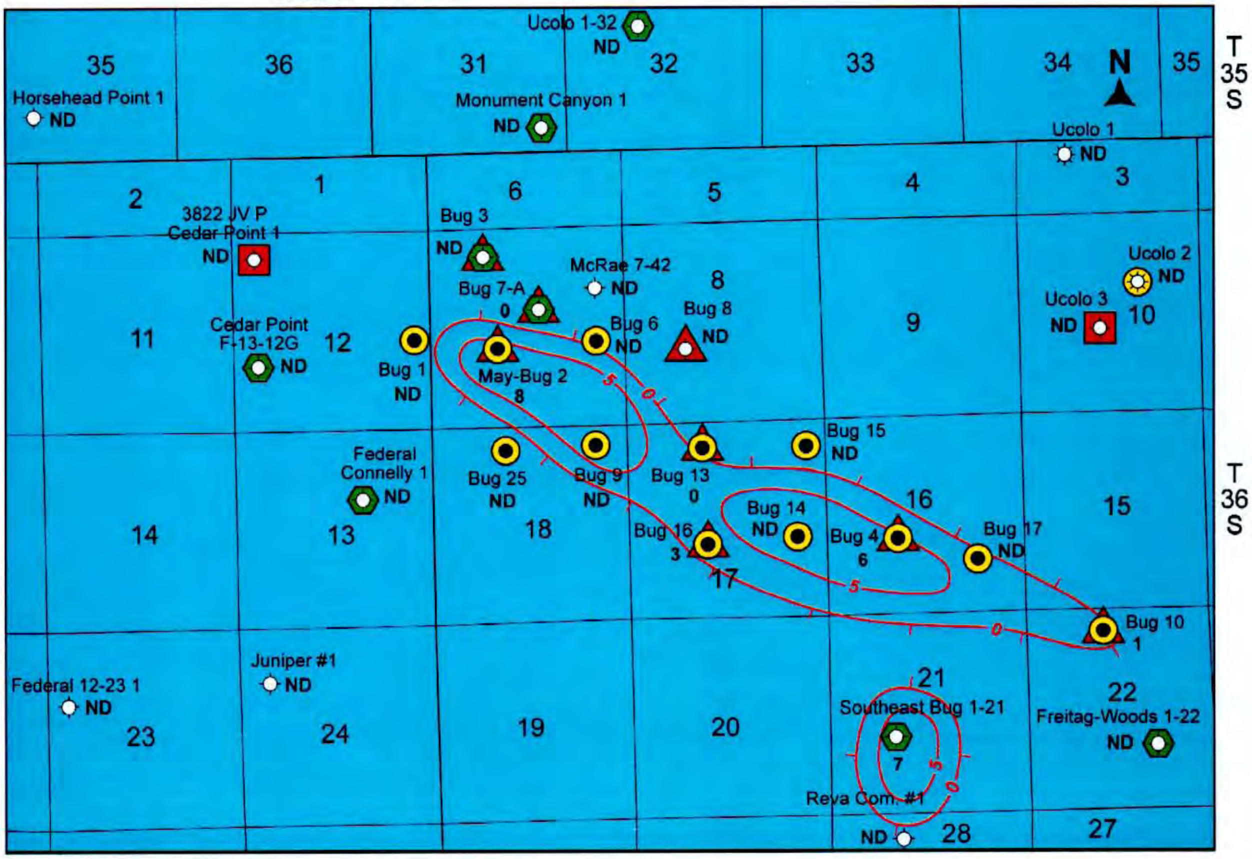

Figure 57

0 0.5 1 1.5 2 Miles

Lower Desert Creek Clean Carbonate - Permeability vs Height (kh > 50 md)
Contour Interval = 5 ft

Bug Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Producing gas
- Desert Creek drill-stem test
- Desert Creek completion
- Desert Creek completion attempt
- Desert Creek core
- ND No data

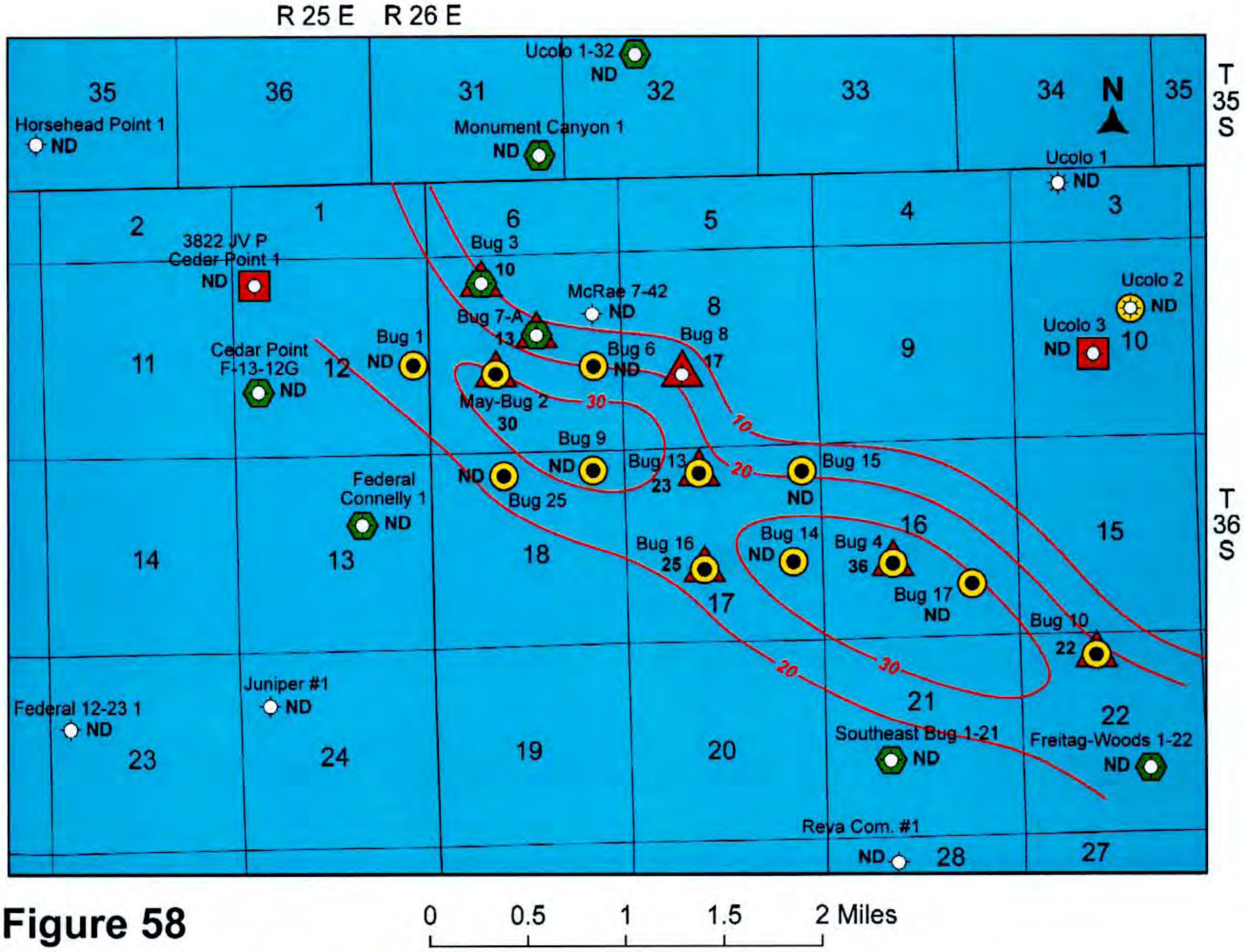

Figure 58

Lower Desert Creek Clean Carbonate - Net Feet of Dolomite (from core)

Contour Interval = 10 ft

Bug Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Producing gas
- Desert Creek drill-stem test
- Desert Creek completion
- Desert Creek completion attempt
- Desert Creek core
- ND No data

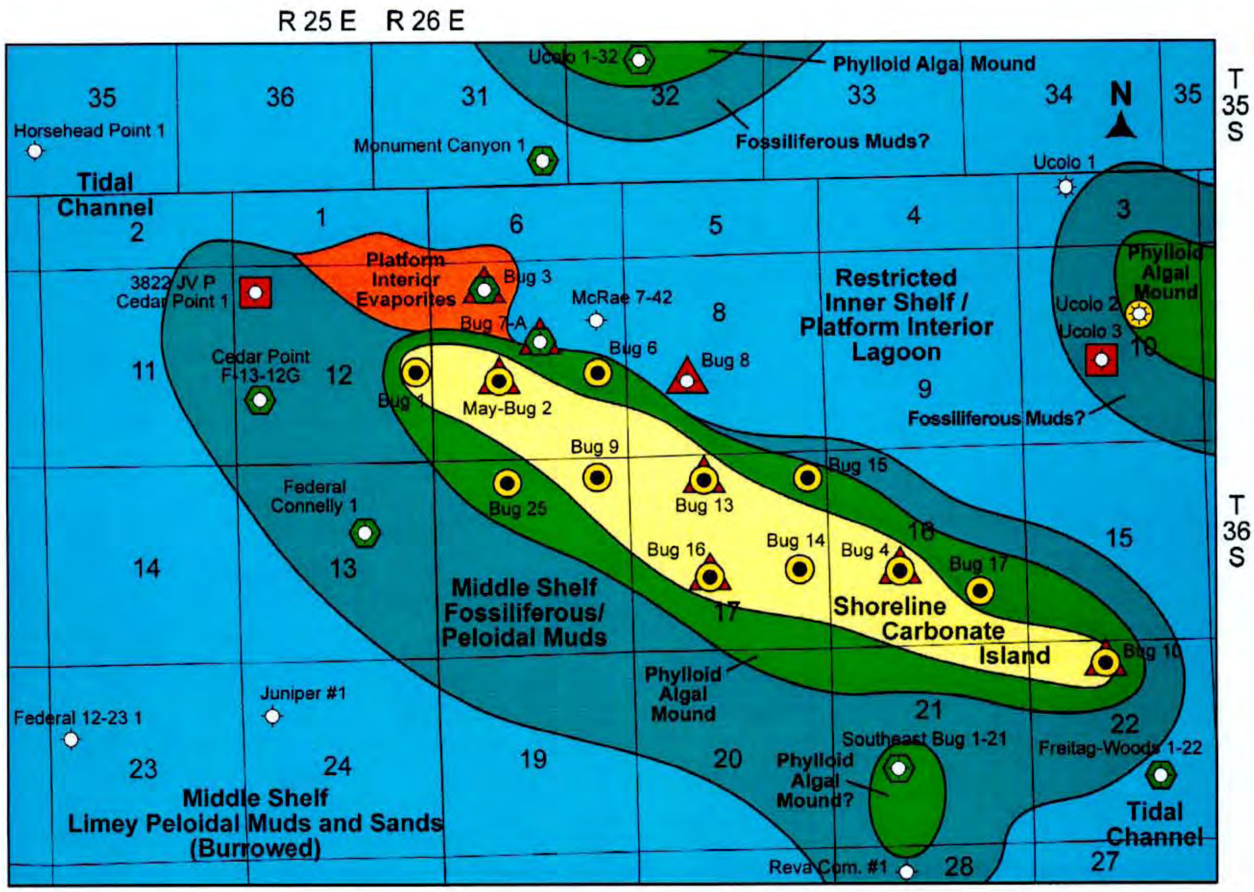

Figure 59

0 0.5 1 1.5 2 Miles

Lower Desert Creek Facies Map

Bug Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Producing gas
- Desert Creek drill-stem test
- Desert Creek completion
- Desert Creek completion attempt
- Desert Creek core

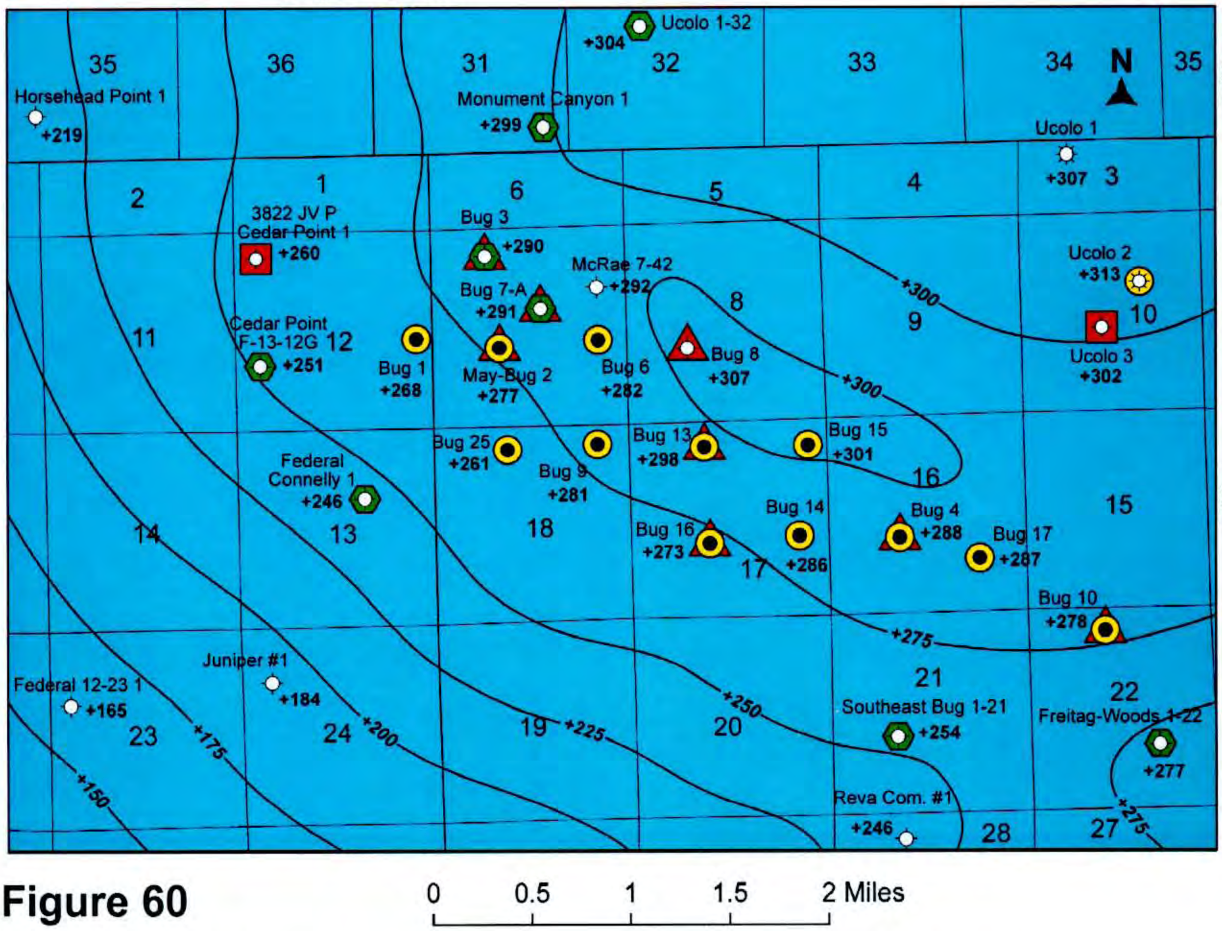

Figure 60

Structure Contour
Top of Chimney Rock Shale
Contour Interval = 25 ft
Datum = Sea Level

Bug Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Producing gas
- Desert Creek drill-stem test
- Desert Creek completion
- Desert Creek completion attempt
- Desert Creek core
- NL No neutron/density log

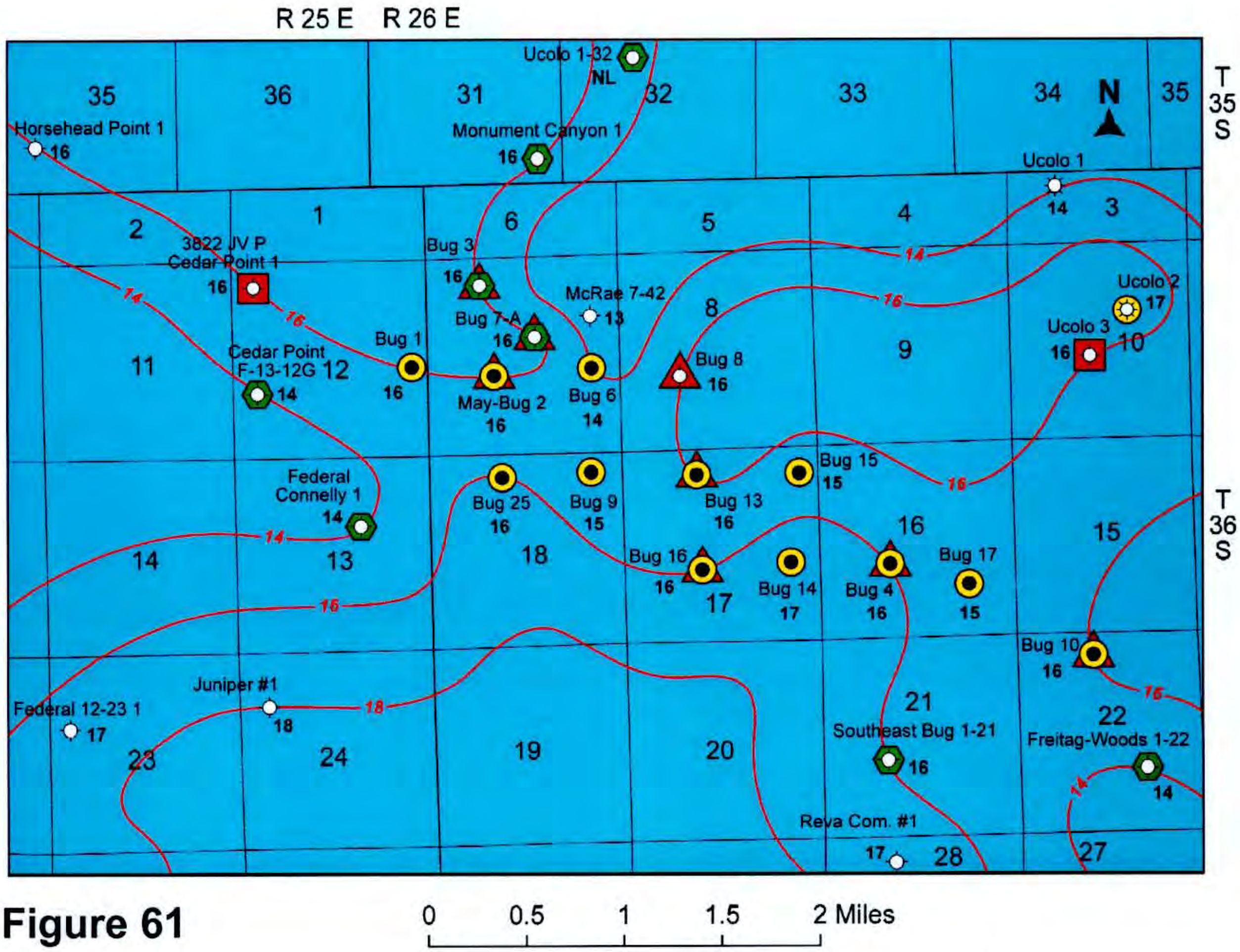

Figure 61

Isochore
Chimney Rock Shale
Contour Interval = 2 ft

Bug Field
San Juan County, Utah

Explanation

- Plugged and abandoned
- Producing gas
- Desert Creek drill-stem test
- Desert Creek completion
- Desert Creek completion attempt
- Desert Creek core
- NL No neutron/density log

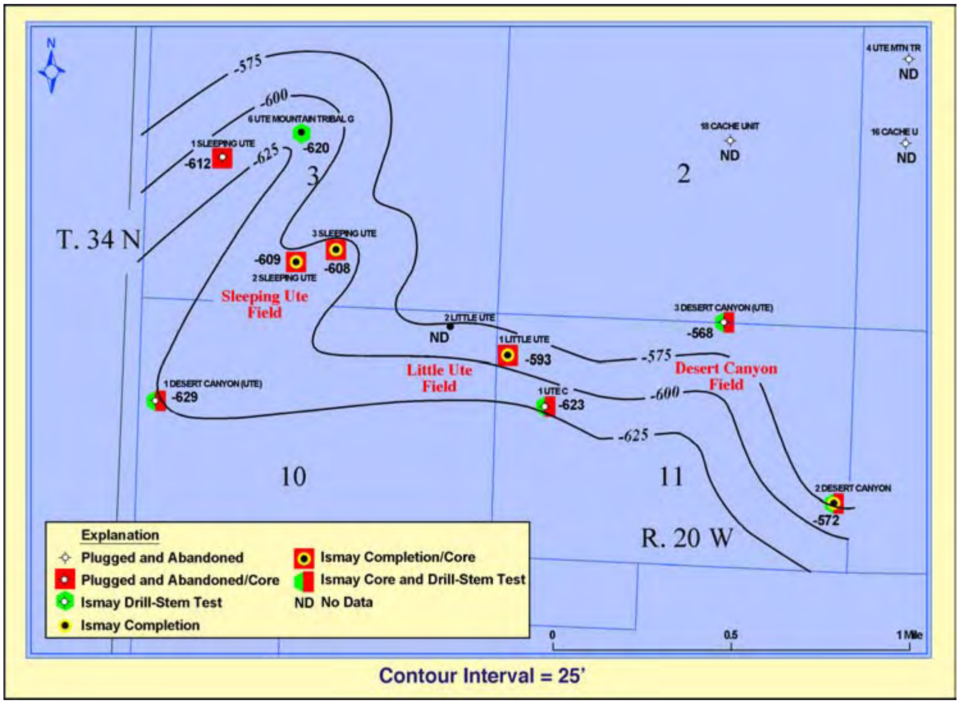

Figure 62. Upper Ismay zone structural contour map, Little Ute, Sleeping Ute, and Desert Canyon fields, Montezuma County, Colorado.

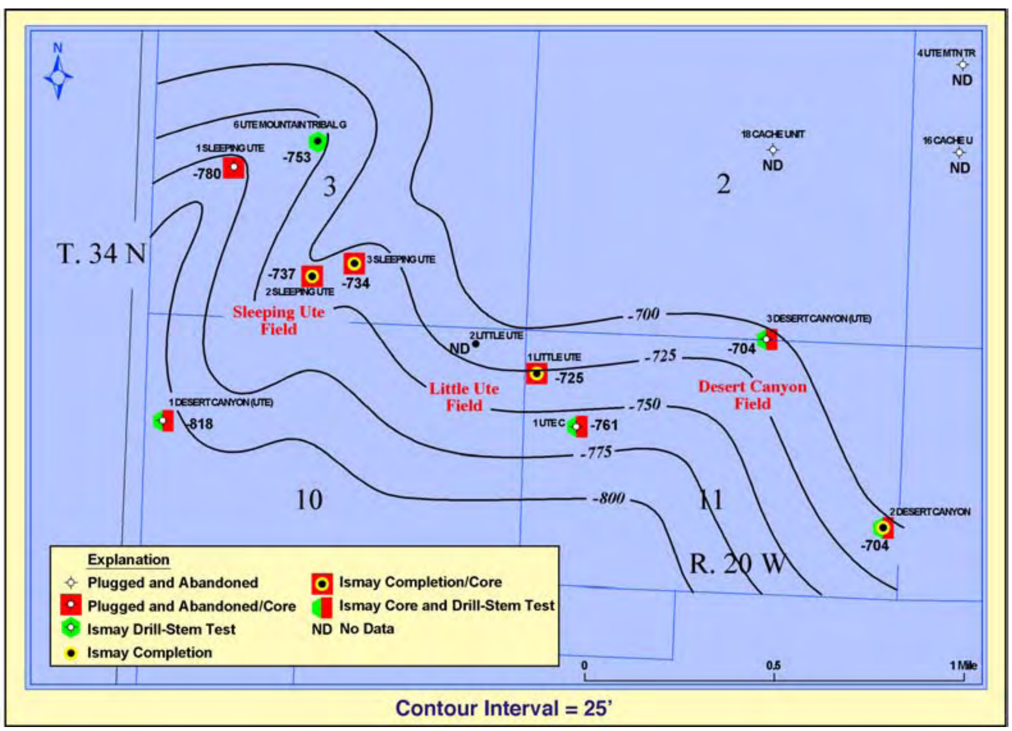

Figure 63. Lower Ismay zone structural contour map, Little Ute, Sleeping Ute, and Desert Canyon fields, Montezuma County, Colorado.

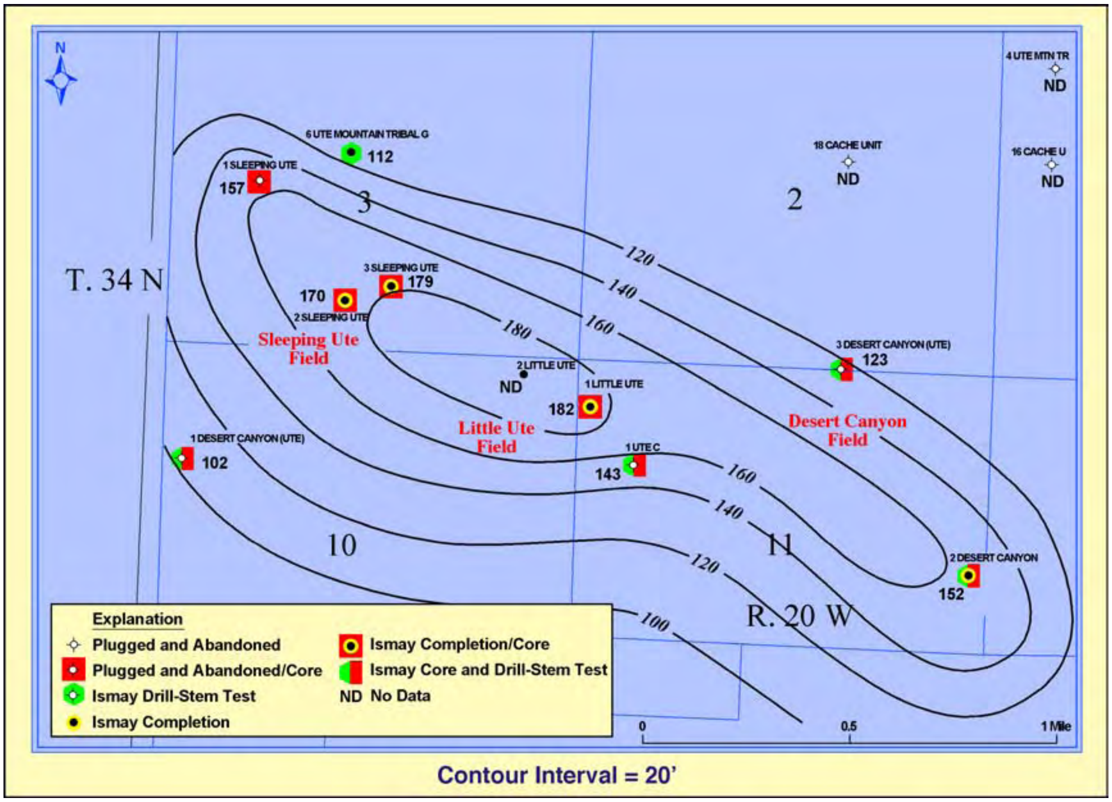

Figure 64. Upper and lower Ismay zone net isopach map, Little Ute, Sleeping Ute, and Desert Canyon fields, Montezuma County, Colorado.

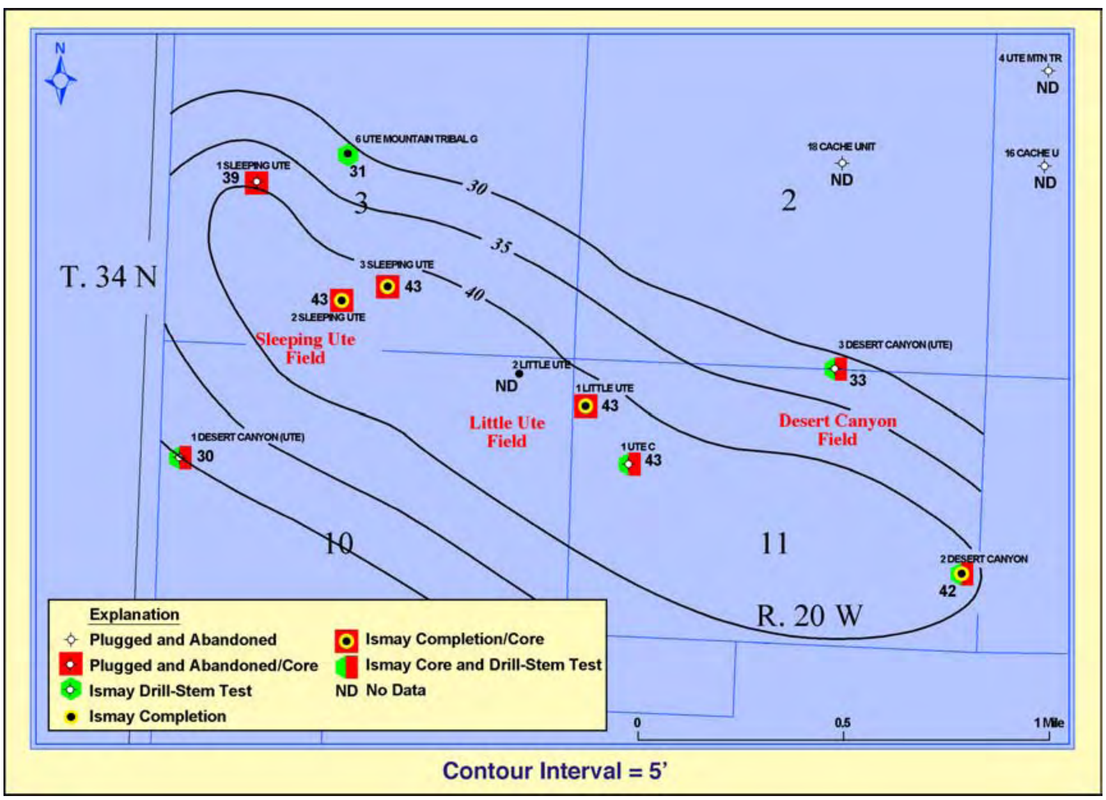

Figure 65. Gothic shale isopach map, Little Ute, Sleeping Ute, and Desert Canyon fields, Montezuma County, Colorado.

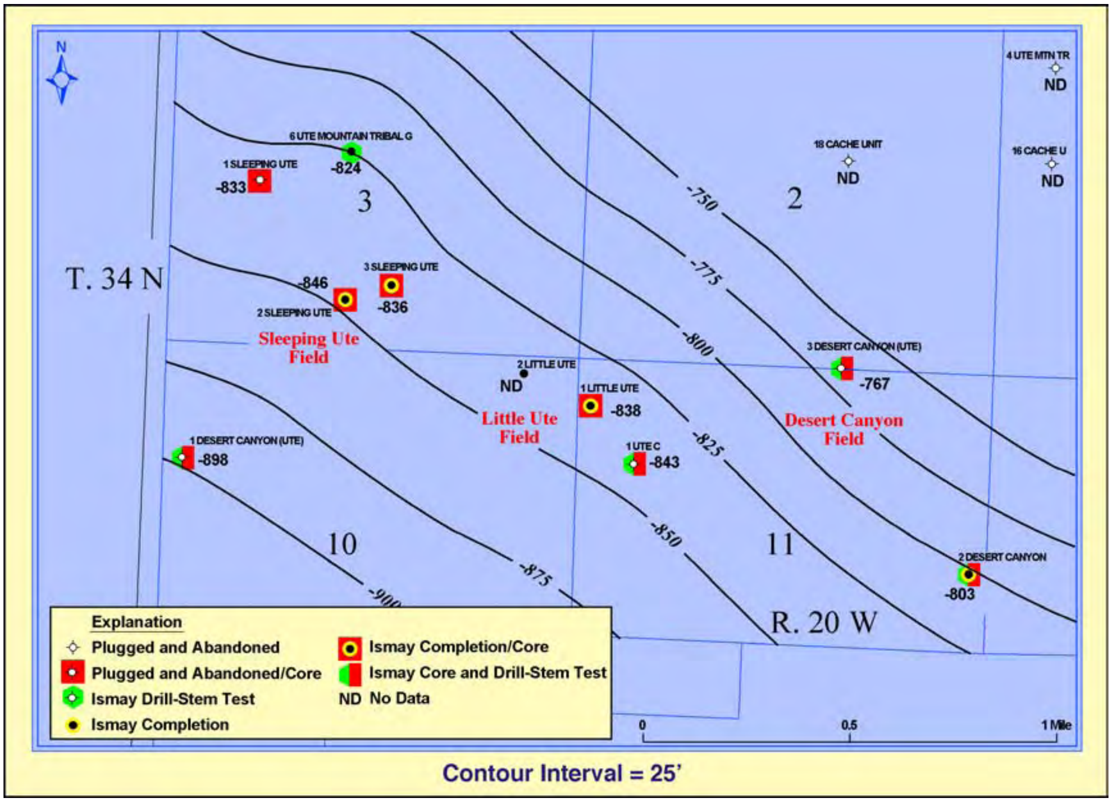

Figure 66. Desert Creek zone structural contour map, Little Ute, Sleeping Ute, and Desert Canyon fields, Montezuma County, Colorado.

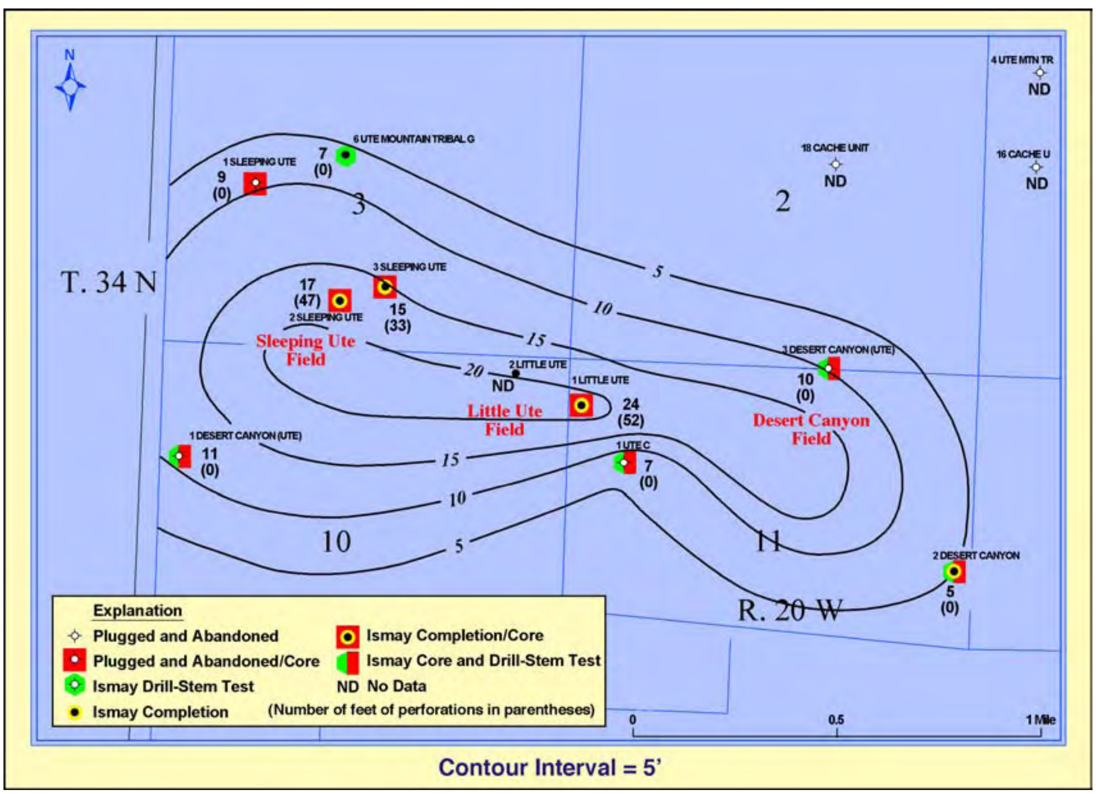

Figure 67. Upper Ismay zone net porosity (≥ 6 percent) isopach map, Little Ute, Sleeping Ute, and Desert Canyon fields, Montezuma County, Colorado.

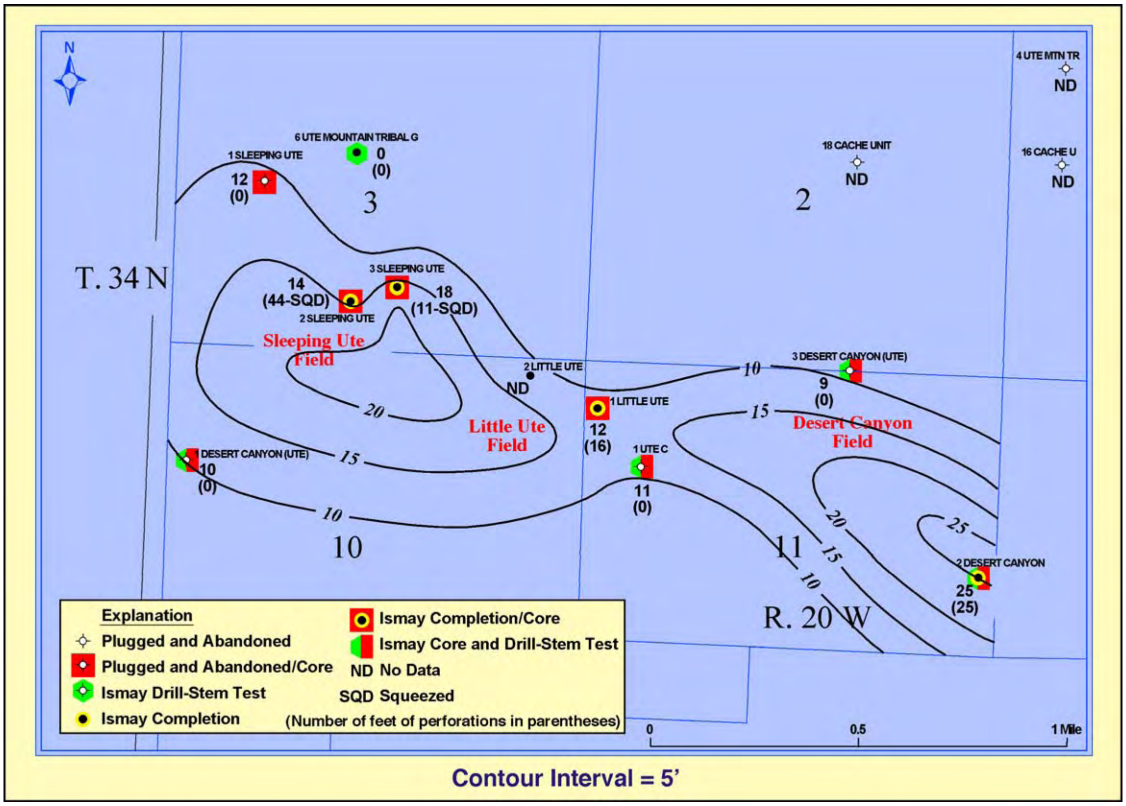

Figure 68. Lower Ismay zone net porosity (≥ 6 percent) isopach map, Little Ute, Sleeping Ute, and Desert Canyon fields, Montezuma County, Colorado.

Seals or barriers include anhydite layers and thick (black) shales such as the Hovenweep shale, which separates the upper Ismay from the lower Ismay. Baffles are those rock units that restrict fluid flow in some parts of the fields but may develop enough porosity and permeability in other parts, through diagenetic processes or facies changes, to provide a conduit for fluid flow or even oil storage. The reservoirs are those units containing 6 percent or more porosity based on the average of the neutron and density porosity values.

Depositionally, rock units are divided into seals or barriers (anhydrites and shales), mound (carbonate buildup [bafflestone, bindstone, grainstone, and packstone]), and off mound (mudstone and wackestone) (plate 1 and figures 8 through 11). Porosity units, and reservoir or potential reservoir layers, are identified within the mound and off-mound intervals. The mound, and some of the off-mound units, are part of the “clean carbonates” - intervals containing all productive reservoir facies and where carbonate mudstone and shale are generally absent. The clean carbonate packages abruptly change laterally into thick anhydrite packages, particularly in the upper Ismay zone.

The top and base of all these intervals (seals, mound, clean carbonate, as well as porosity units) were determined and coded as listed on table 1. The unlisted intervening units represent the baffles or non-reservoir rocks, such as non-porous packestone or wackestone. The mound/mound cap intervals usually have porosity greater than 6 percent, while the clean carbonate intervals are defined by lithology only (such as bafflestone or grainstone), although there may be occasional isolated porosity zones. The top and base of the mound/mound cap intervals are often equivalent to the top and base of the clean carbonate intervals. In addition, the top and base of the mound/mound cap intervals may be equivalent to the top and base of the thinner off-mound clean carbonate intervals.

The correlation scheme was be used for: (1) predicting changes in reservoir and non-reservoir rocks across the field, (2) comparing field to non-field areas, (3) estimating the reservoir properties and identifying facies in wells which were not cored, and (4) determining potential units suitable for horizontal drilling projects. It can be applied to other fields in the Blanding sub-basin, both those with cores and without.

RESERVOIR MAPPING

Structure and isochore maps of the Ismay and Desert Creek zones (including clean carbonates, mounds, and/or porosity units) of the Paradox Formation were constructed for the case-study fields (figures 12 through 68). These field maps incorporate unit tops and thickness from all geophysical well logs in the areas determined using the correlation scheme. The isochore maps of the upper Ismay and lower Desert Creek were generated for reservoir units containing 6 percent or more porosity based on the average of the neutron and density porosity values. The maps display well names, Ismay or Desert Creek completions, completion attempts, drill-stem tests, wells with core, and the subsea top and interval thickness for each well. Other maps include net limestone and dolomite, facies, and permeability. Structure or isochore maps were constructed for major shales (such as the Hovenweep, Gothic, and Chimney Rock) and anhydrites. These units represent effective seals.

The structure contour, isochore, and other maps, such as anhydrite and shale isochore maps, were used to produce three-dimensional reservoir models. They were combined to show carbonate buildup trends, define limits of field potential, and indicate possible horizontal drilling targets.

Cherokee and Bug Fields

In Cherokee field, six porosity units were identified from geophysical well logs, five of which occur in the upper Ismay mound and the other one in the lower part of clean carbonate (figures 8 and 9, 19 through 23, and 26). The lower porosity unit exhibits a “false porosity” on geophysical well logs that led the operator to perforate the interval and attempt a completion. However, examination of core, thin sections, and porosity and permeability data from core plug analysis shows the unit is incapable of fluid flow due to low permeability. Therefore, porosity units 1 through 5 were mapped together to produce a gross interval isochore that represents the actual producing reservoir (figures 24 and 25).

In the lower Desert Creek zone of Bug field, the top of the mound/mound cap interval is equivalent to the top of the clean carbonate interval (figures 10 and 11). In addition, the top mound/mound cap interval is equivalent to the top of the thin off-mound clean carbonate interval. The reservoir porosity unit is the entire mound/mound cap interval (figure 49).

Little Ute and Sleeping Ute Fields

A cross section (plate 1) and structure contour maps on the top of the upper Ismay zone (figure 62) and the lower Ismay zone (figure 63) of the Paradox Formation were constructed for Little Ute/Sleeping Ute study area. A net isopach map for the upper and lower Ismay zones was also generated (figure 64), showing the characteristic northwest-southeast depositional trend of the carbonate buildups in this part of the Blanding sub-basin. In comparison, a net isopach map was constructed for the underlying Gothic shale (figure 65) that revealed the same depositional orientation. The relationship between the thickness shown on figure 64 and 65 suggests that carbonate buildups were initiated on Gothic shale topographic highs. Interestingly, the structure map on top of the Desert Creek zone below the Gothic shale (figure 66) displays gentle ramp dips to the southwest, giving no indication of topography that would account for the northwest-southeast-trending thick in the Gothic shale (figure 65). The factors responsible for these isopach trends in both the Gothic shale and the upper and lower Ismay zones (figure 64 and 65) are unknown at this time. Two additional maps, net porosity iospach of the upper Ismay zone (figure 67) and of the lower Ismay zone (figure 68), reflect the same trends as mentioned above.

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Plate 1. East-west stratigraphic cross section, Sleeping Ute and Little Ute fields, Colorado.