

**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 2.2.1B
THREE-DIMENSIONAL GEOLOGIC
MODELS: LITTLE UTE AND SLEEPING
UTE FIELDS, MONTEZUMA COUNTY,
COLORADO**

Submitted by

Utah Geological Survey
Salt Lake City, Utah 84114
July 2004



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INTRODUCTION

Over 400 million barrels (64 million m³) 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 m³) 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 the previously 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 m³) 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 small portions 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).

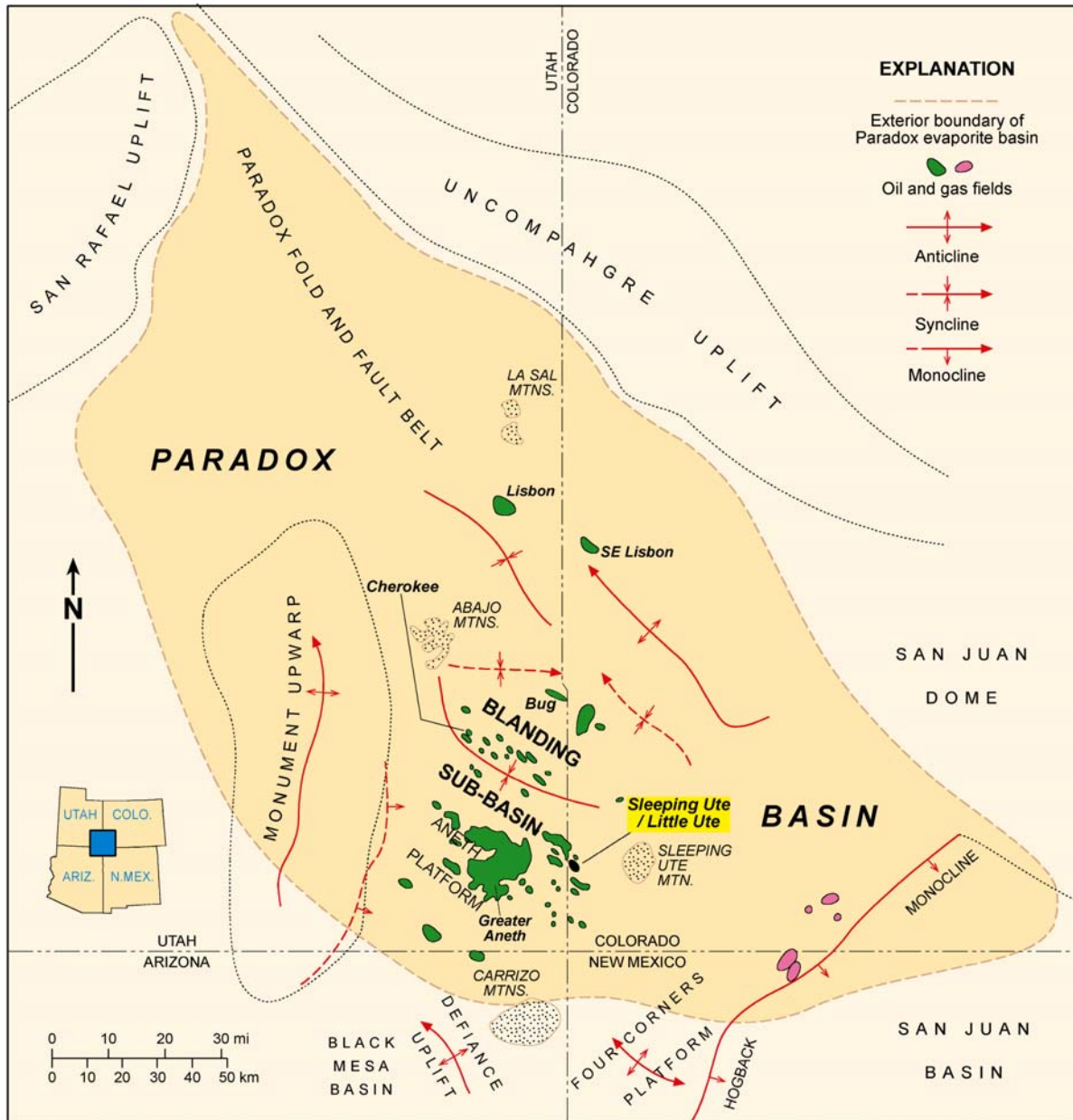


Figure 1. Location map of the Paradox Basin, Utah, Colorado, Arizona, and New Mexico showing producing oil and gas fields, the Paradox fold and fault belt, and Blanding sub-basin as well as surrounding Laramide basins and uplifts (modified from Harr, 1996).

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.

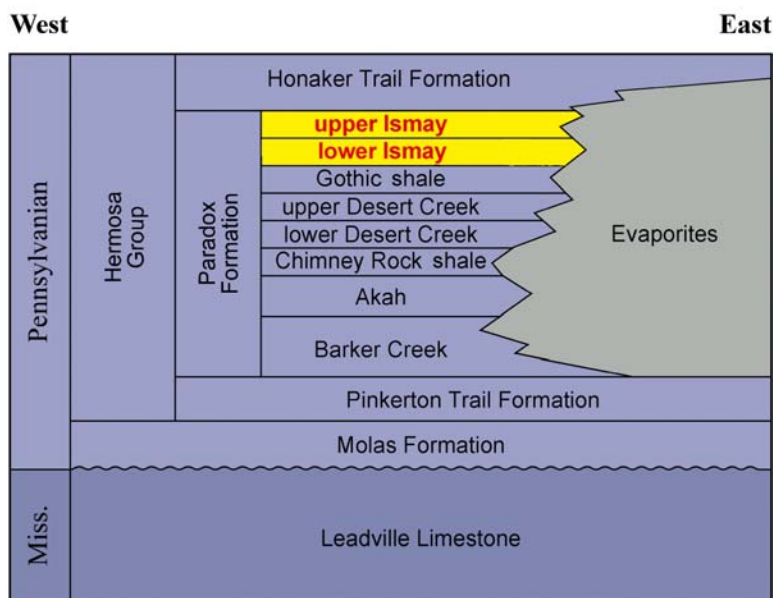


Figure 2. Pennsylvanian stratigraphy of the southern Paradox Basin including informal zones of the Paradox Formation.

CASE-STUDY FIELDS: LITTLE UTE AND SLEEPING UTE

Two Colorado fields were selected for local-scale evaluation and geological characterization also selected for evaluation: Little Ute and Sleeping Ute in the Ismay trend (figure 4). This evaluation included data collection and reservoir mapping used to create three-dimensional (3-D) models of these fields, summarized 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 were 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.

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.

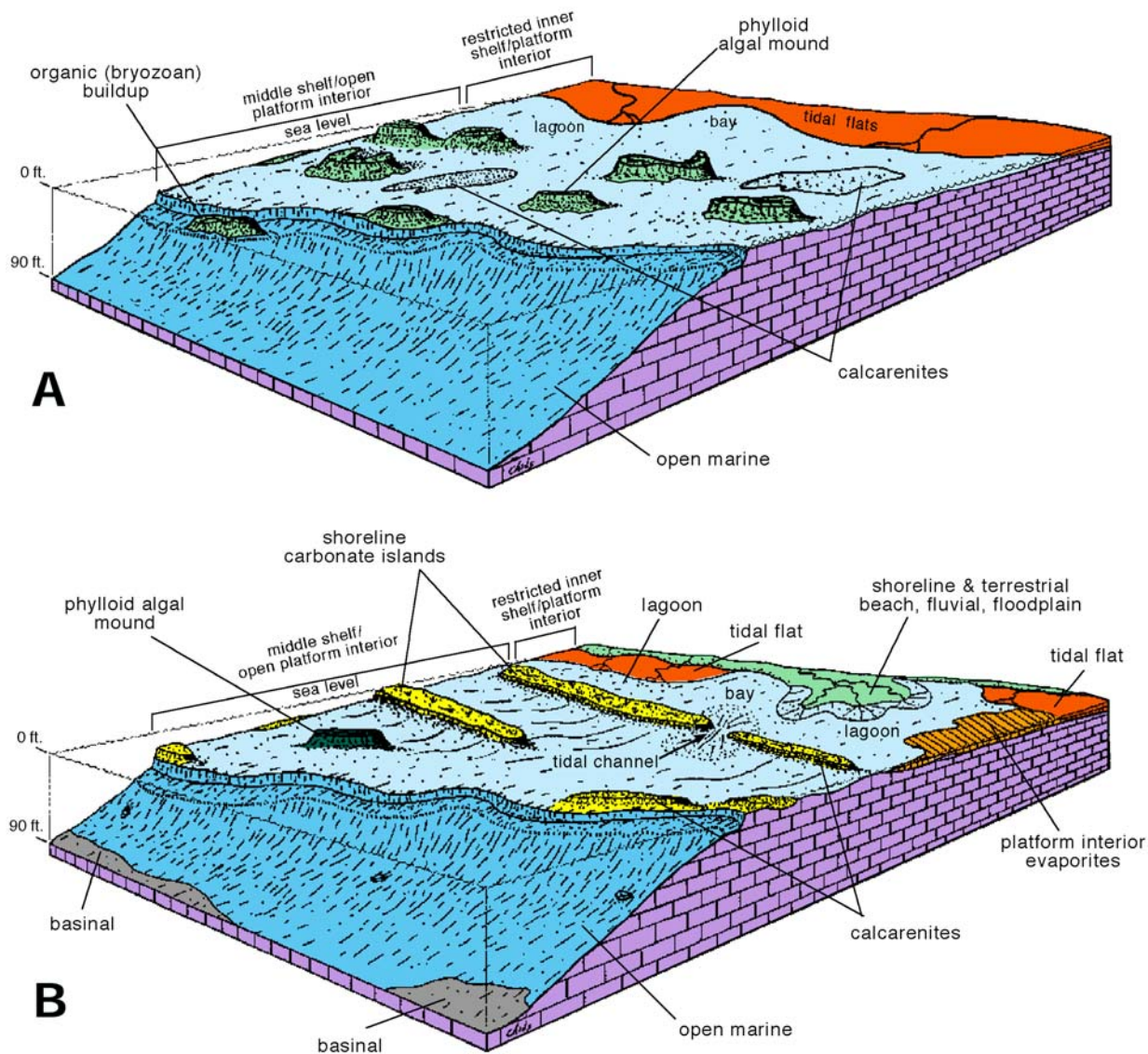


Figure 3. Block diagrams displaying major depositional facies, as determined from core, for the Ismay (A) and Desert Creek (B) zones, Pennsylvanian Paradox Formation, Utah and Colorado.

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.

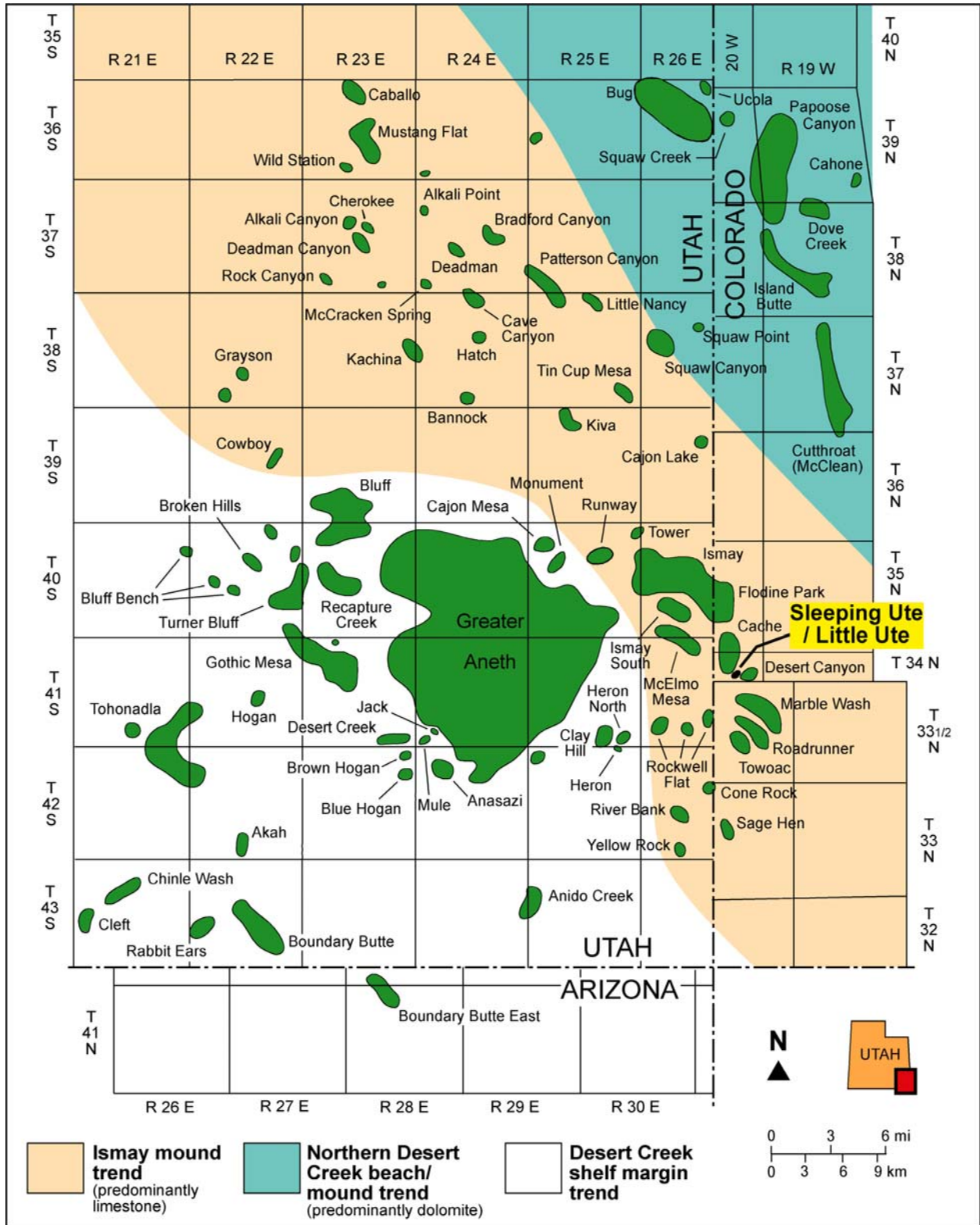


Figure 4. Map showing the project study area and fields (case-study fields in black) within the Ismay and Desert Creek producing trends in the Blanding sub-basin, Utah and Colorado.

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 m³) of oil and 750 million cubic feet (21 million m³) of gas.

THREE-DIMENSIONAL MODELING

Methods

The 3-D models were created in Environment Systems Research Institute, Inc. (ESRI) ArcView® 3D Analyst. Structure, isochore, and other reservoir property contour maps (see Deliverable 1.41 and 1.4.2 – Cross Sections and Field Maps: Little Ute and Sleeping Ute Fields, Montezuma County, Colorado) were digitized using AutoCad®, then brought into ArcView®. These AutoCad® files were first converted to shape files and then to grids. Next Triangulated Irregular Network (TIN) files were created. A TIN is an object used to represent a surface. It partitions a surface into a set of contiguous, non-overlapping, triangles. Attribute and geometry information was stored for the points, lines, and faces that comprise each triangle. This information was used for display, query, and analysis purposes. A height value was recorded for each triangle node. Heights between nodes were interpolated, thus allowing for the definition of a continuous surface. TINs can accommodate irregularly distributed, as well as selective data sets. This made it possible to represent a complex and irregular surface with a small data set (ESRI, 1998).

The TIN was imported into a 3D Analyst scene (called a viewer) and a projection was set selected from a specific projection or coordinate system from one of the following categories: Projections of the World, Projections of a Hemisphere, Projections of the United States, State Plane – 1927, State Plane – 1983, Universal Transverse Mercator (UTM), or National Grids. Once the map projections or coordinate system categories has been selected, ArcView® displays the parameters that it uses in the projection, such as the Ellipsoid, Central Meridian, Reference Latitude and Standard Parallels. If no projection is set, TIN themes are displayed using the coordinates found in their data set. Also brought into the scene was a feature theme for the wells created from UTM coordinates. Each well has a set of coordinates. Feature themes and TIN themes had to be in the same coordinate system to display them together without a projection. To set a projection, feature themes had to be in decimal degrees and TIN themes had to be in the projection set for them (ESRI, 1998).

The scene's 3-D properties were set to control certain aspects of scene display such as sun azimuth (the compass direction of the sun), sun altitude (the height of the sun), and a vertical exaggeration factor. The vertical exaggeration factor is a multiplier used to increase or decrease the vertical dimension of data displayed in the scene's 3-D viewer (ESRI, 1998).

After the viewer scene was projected, each theme property was set. Setting the theme properties allowed us to define height, extrusion, shading, navigation simplification, and transparency properties individually. Each TIN theme had its own legend display in the view's Table of Contents. A TIN theme's legend specified what triangle points, lines, or faces were drawn and what colors were used to draw them. This controlled how the TIN theme was displayed in the view (ESRI, 1998).

The scene was shifted, rotated, panned, or zoomed to any angle without disturbing the way each theme was lined up. After all the angles were set for best viewing position, they were exported as a joint photographic expert group (.jpg) or bitmap (.bmp) image file. This image file was used to create a layout. A layout is a map used to display views and is used to prepare graphics for output from ArcView® (ESRI, 1998). Layouts were printed and exported to a number of formats. The annotations (labels, descriptions, titles, and so forth) were added at this time.

Results

The structure and isochore maps used to generate 3-D models employed a correlation scheme developed early in the project. These maps incorporated unit tops and thickness from all geophysical well logs in the area. The correlation scheme tied the core-derived, typical, vertical sequence or cycle of depositional facies from the case-study fields to the corresponding gamma-ray and neutron-density curves from geophysical well logs. The correlation scheme identified major zone contacts, seals or barriers, baffles, producing or potential reservoirs, and depositional facies. All the 3-D diagrams (plates 1 through 7) discussed in this section show Ismay producers, dry holes, and wells with cores.

Three-dimensional diagrams with structure contours on the top of the upper Ismay zone (plate 1) and the lower Ismay zone (plate 2) of the Paradox Formation were constructed for Little Ute/Sleeping Ute/Desert Canyon area. These 3-D models show general regional dip to the southwest. A prominent southwest-trending structural nose is displayed in the Sleeping Ute field area upon which the carbonate buildup likely developed.

A 3-D block diagram of the thickness of the net thickness for the upper and lower Ismay zones was also generated (plate 3), showing the characteristic elongate, northwest-southeast depositional trend of the carbonate buildups in this part of the Blanding sub-basin. This trend indicates a nearshore shoreline linear facies tracts. In comparison, a 3-D block diagram of the net thickness of the underlying Gothic shale (plate 4) revealed the same depositional orientation. The relationship between the thickness shown on plates 3 and 4 suggests that carbonate buildups were initiated on Gothic shale topographic highs. Interestingly, the 3-D diagram with structure contours on top of the Desert Creek zone below the Gothic shale (plate 5) 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 (plate 4).

Two additional 3-D block diagrams, net porosity thickness of porosity greater than 6 percent (by log analysis) of the upper Ismay zone (plate 6) and of the lower Ismay zone (plate 7), reflect the same trends as mentioned above. They show an elongate reservoir buildup. Plate 7 indicates the buildup has two subsidiary thicks separated by a slightly thinner saddle that may represent an intermound trough.

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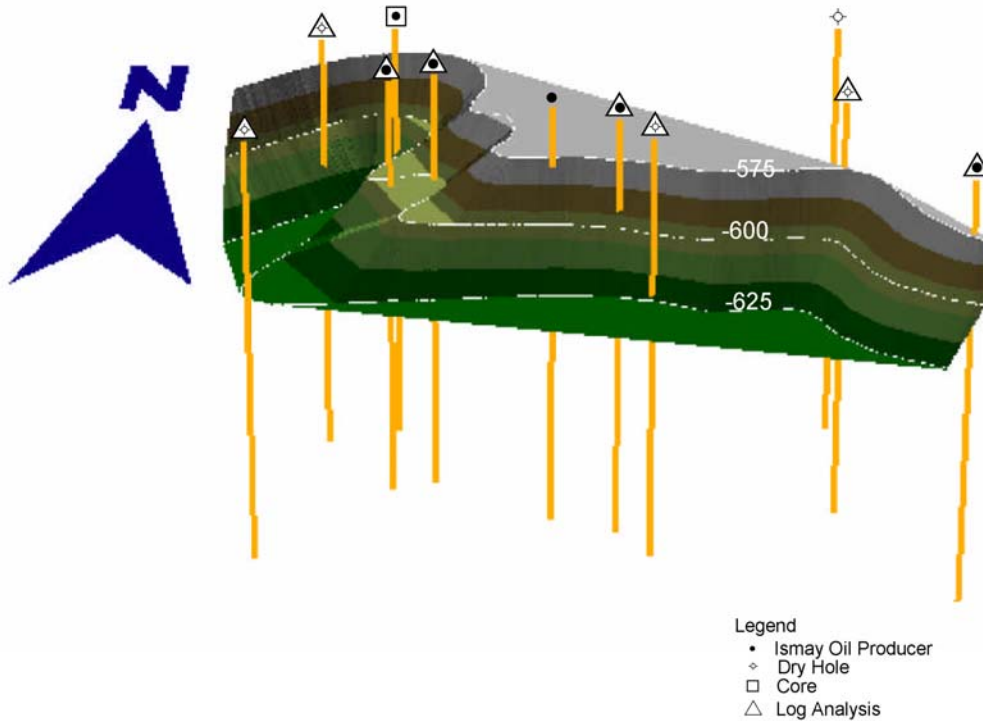


Plate 1. Three-dimensional block diagram with structure contours on top of the upper Ismay zone, Little Ute, Sleeping Ute, and Desert Canyon fields, Montezuma County, Colorado.

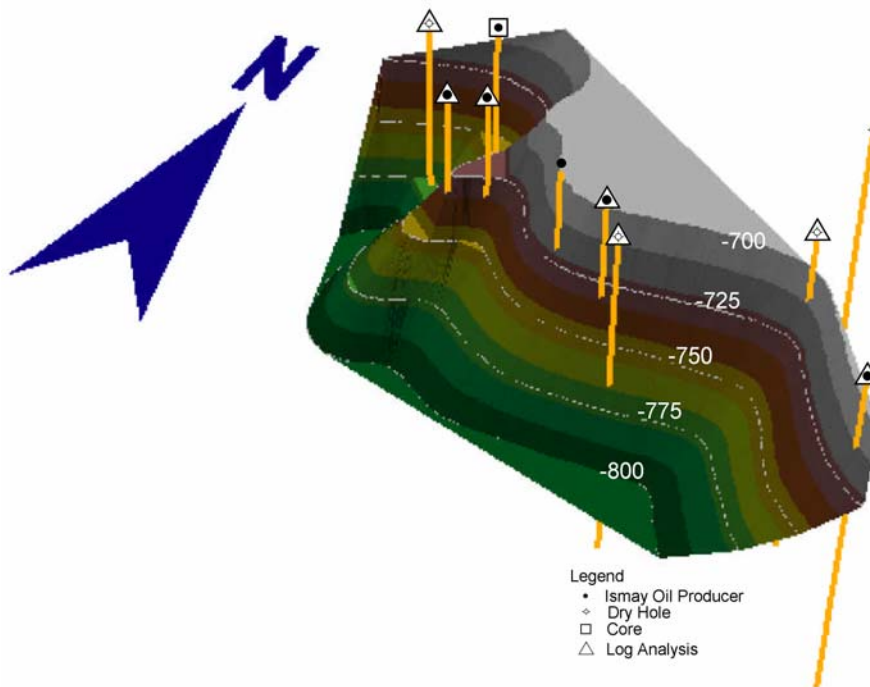


Plate 2. Three-dimensional block diagram with structure contours on top of the lower Ismay zone, Little Ute, Sleeping Ute, and Desert Canyon fields, Montezuma County, Colorado.

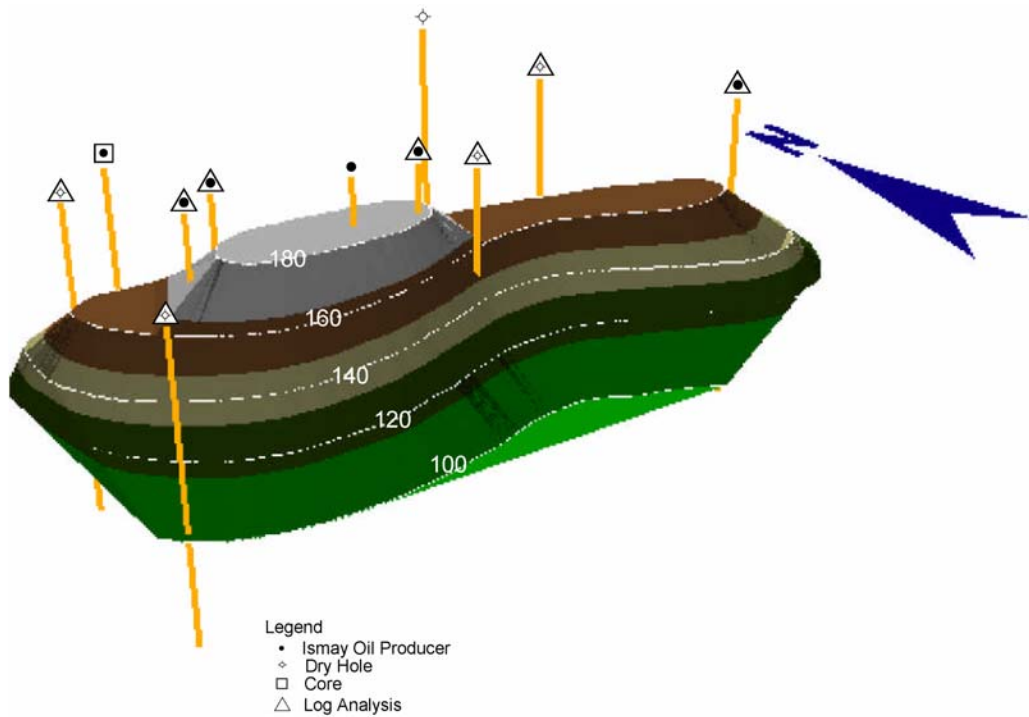


Plate 3. Three-dimensional block diagram of the net isochore of the upper and lower Ismay zone, Little Ute, Sleeping Ute, and Desert Canyon fields, Montezuma County, Colorado.

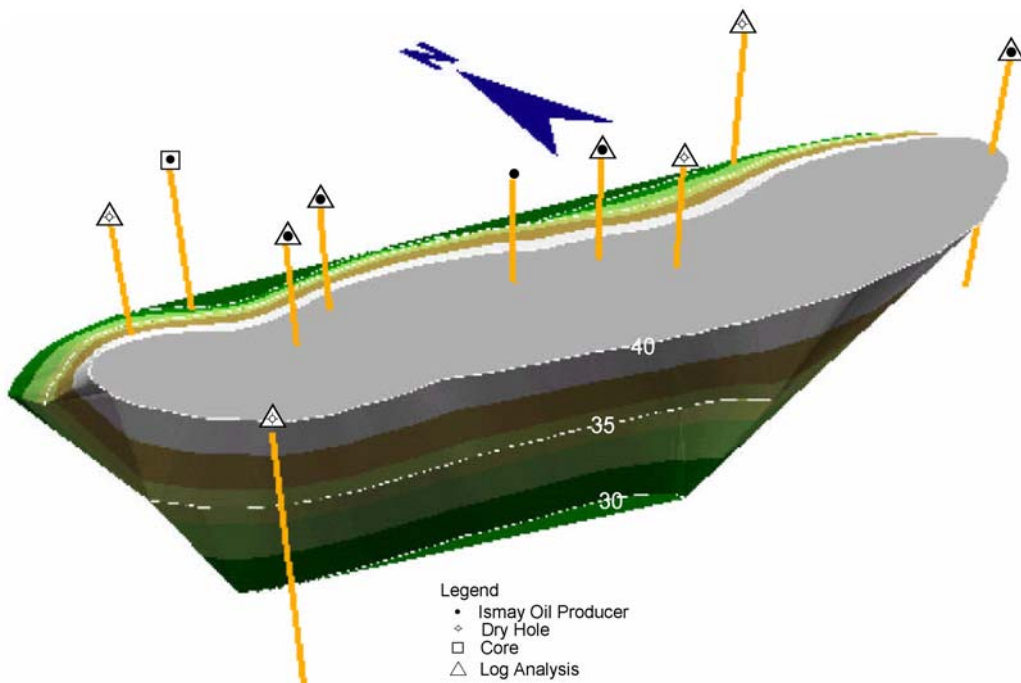


Plate 4. Three-dimensional block diagram of the isochore of the Gothic shale, Little Ute, Sleeping Ute, and Desert Canyon fields, Montezuma County, Colorado.

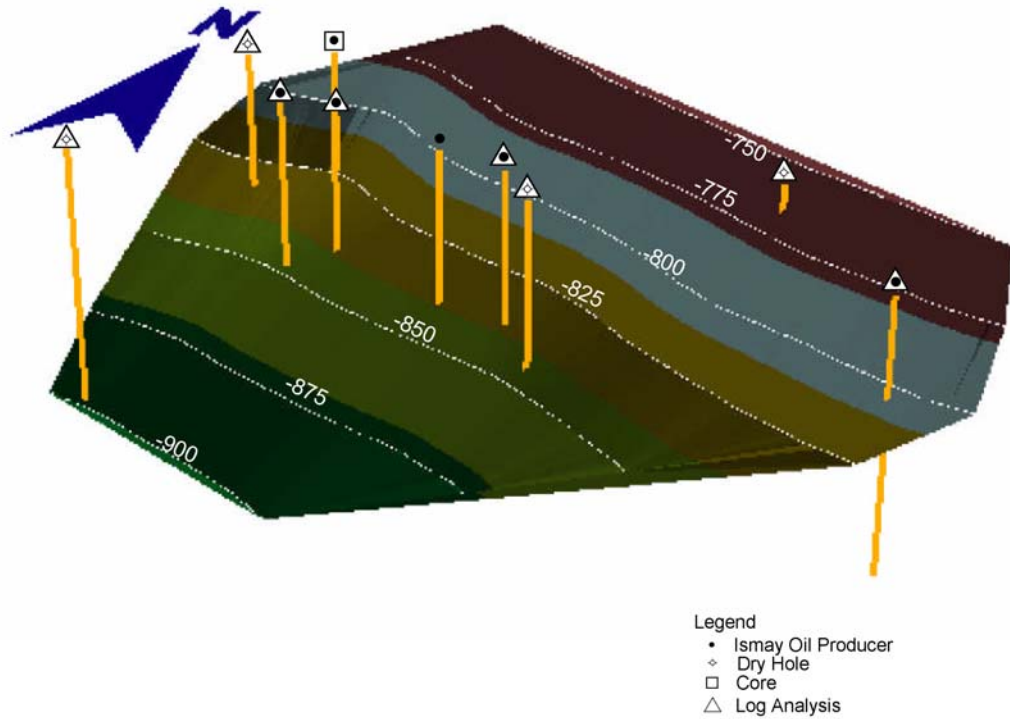


Plate 5. Three-dimensional block diagram with structure contours on top of the Desert Creek zone, Little Ute, Sleeping Ute, and Desert Canyon fields, Montezuma County, Colorado.

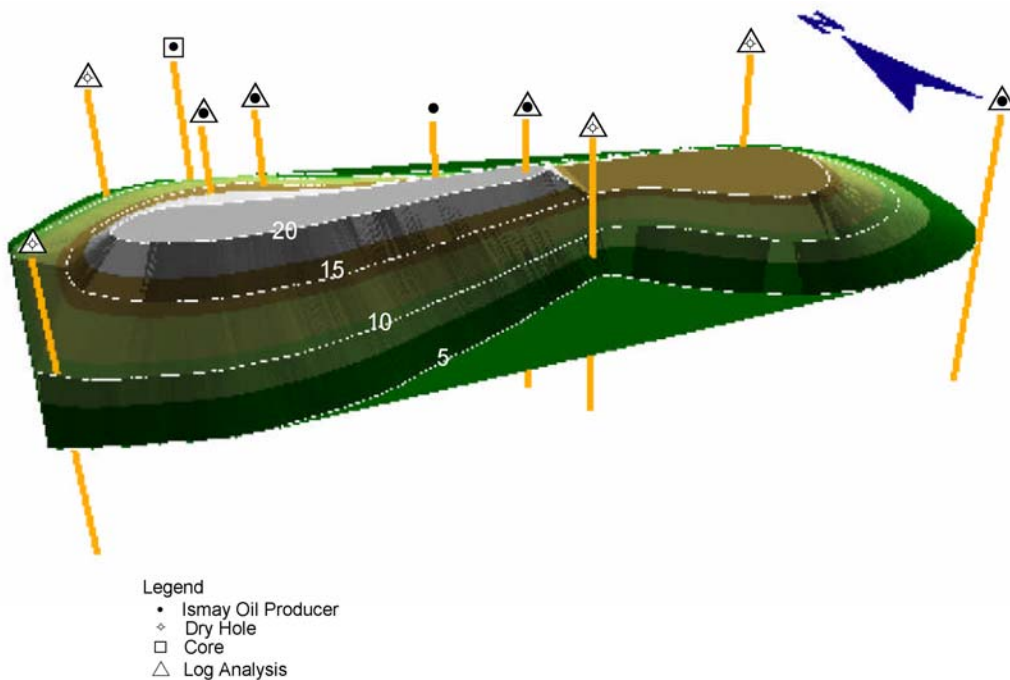


Plate 6. Three-dimensional block diagram, upper Ismay zone net feet of porosity, as determined by geophysical log analysis, for greater than 6 percent porosity, Little Ute, Sleeping Ute, and Desert Canyon fields, Montezuma County, Colorado.

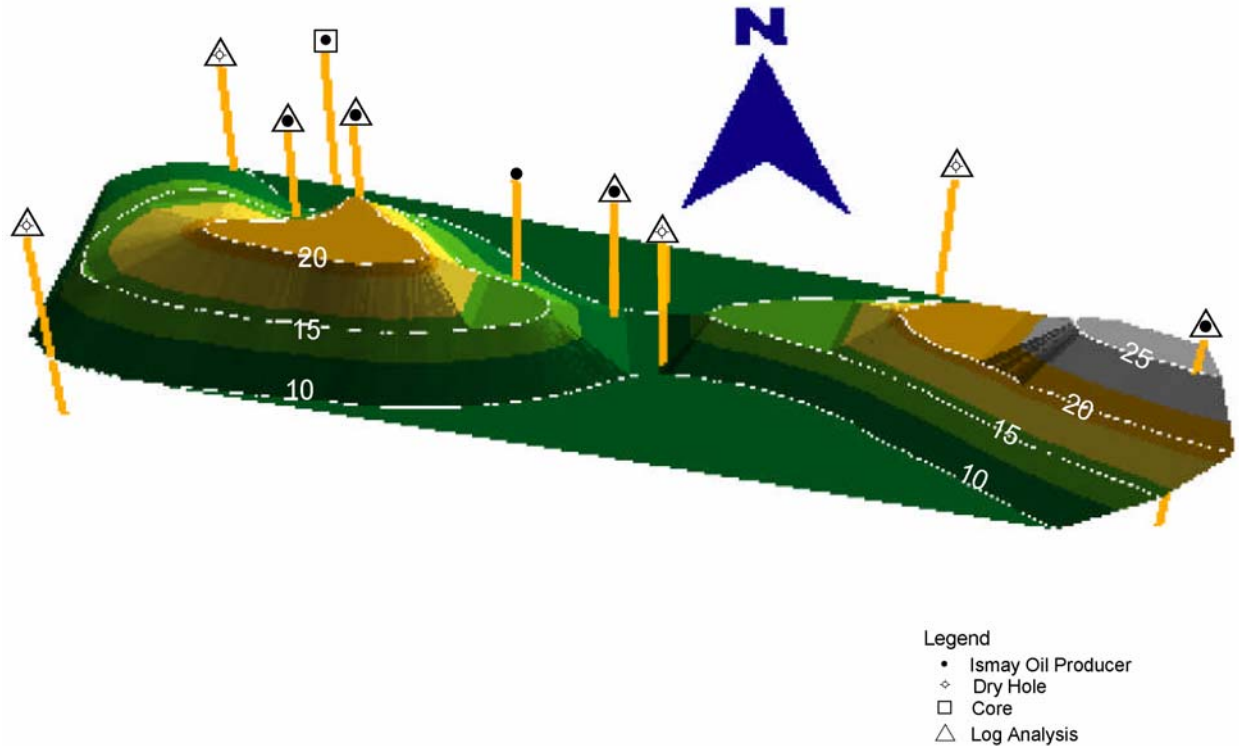


Plate 7. Three-dimensional block diagram, lower Ismay zone net feet of porosity, as determined by geophysical log analysis, for greater than 6 percent porosity, Little Ute, Sleeping Ute, and Desert Canyon fields, Montezuma County, Colorado.

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