MAJOR OIL PLAYS IN UTAH AND VICINITY

QUARTERLY TECHNICAL PROGRESS REPORT

Reporting Period
Start Date: July 1, 2006
End Date: September 30, 2006

by
Thomas C. Chidsey, Jr., Principal Investigator
and Douglas A. Sprinkel
Utah Geological Survey

March 2007

Contract No. DE-FC26-02NT15133

Submitting Organization: Utah Geological Survey
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DISCLAIMER

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ABSTRACT

Utah oil fields have produced over 1.2 billion barrels (191 million m^3) of oil and hold 256 million barrels (40.7 million m^3) of proved reserves. The 13.7 million barrels (2.2 million m^3) of production in 2002 was the lowest level in over 40 years and continued the steady decline that began in the mid-1980s. However, in late 2005 production increased due to the discovery of Covenant field in the Jurassic Navajo Sandstone "Hingeline" play (described in this report). The Utah Geological Survey believes this new upward production trend can continue by providing play portfolios for the major oil-producing provinces (Paradox Basin, Uinta Basin, and thrust belt) in Utah and adjacent areas in Colorado and Wyoming. Oil plays are geographic areas with petroleum potential caused by favorable combinations of source rock, migration paths, reservoir rock characteristics, and other factors. The play portfolios will include descriptions and maps of the major oil plays by reservoir; production and reservoir data; case-study field evaluations; locations of major oil pipelines; identification and discussion of land-use constraints; descriptions of reservoir outcrop analogs; and summaries of the state-of-the-art drilling, completion, and secondary/tertiary recovery techniques for each play.

This report covers research activities for the seventeenth quarter of the project (July 1 through September 30, 2006). This work included (1) describing the Jurassic Navajo Sandstone Hingeline play, and (2) technology transfer activities.

The Jurassic Navajo Sandstone Hingeline play is the only petroleum play in the central Utah thrust belt. The 2004 discovery of Covenant field in the Hingeline (central Utah thrust belt) changed the oil development potential in the play from hypothetical to proven. Cumulative production from Covenant field from late 2004 through September 30, 2006, was 2,611,688 barrels (415,258 m^3) of oil, averaging over 6000 barrels (950 m^3) of oil per day. The original oil in place is estimated at 100 million barrels (15.9 million m^3); the estimated recovery factor is 40 to 50 percent.

Traps in the central Utah thrust belt include anticlines associated with latest Jurassic through early Tertiary thrust imbricate and duplex structures, positioned near Middle Jurassic extension faults. The Navajo Sandstone reservoir was deposited in an extensive dune field that extended from present-day Wyoming to Arizona. The principal regional seal for the Lower Jurassic Navajo producing zones consists of salt, gypsum, mudstone, and shale of the overlying Jurassic Arapien Shale. Hydrocarbons were likely generated from Mississippian source rocks in Late Cretaceous to early Tertiary time.

Prospective drilling targets in the Navajo Sandstone thrust belt play have been delineated using high-quality, two-dimensional seismic data, along with well control, dipmeter information, surface geologic maps, and incremental restoration of balanced cross sections to assess trap geometry and location. Future exploration in the central Utah thrust belt should focus on Paleozoic-cored, blind, thrust structures east of the exposed Charleston-Nebo and Pavant thrusts. The lack of associated gas at Covenant field suggests the possibility that gas-charged traps may be present in the play area because the gas may have been driven off early during migration from sediment or thrust-plate loading.

As part of technology transfer activities during this quarter, an abstract describing Covenant field in the central Utah thrust belt play was submitted to the American Association of Petroleum Geologists, for a possible presentation at the 2007 annual convention in Long Beach, California. Technology transfer activities also included a presentation and publication. Project team members joined Utah Stake Holders Board members in attending the Uinta Basin Oil and Gas Collaborative Group meeting in Vernal, Utah. The project home page was updated on the Utah Geological Survey Web site.

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EXECUTIVE SUMMARY

Utah oil fields have produced over 1.2 billion barrels (191 million m^3) of oil and hold 256 million barrels (40.7 million m^3) of proved reserves. The 13.7 million barrels (2.2 million m^3) of production in 2002 was the lowest level in over 40 years and continued the steady decline that began in the mid-1980s. However, in late 2005 production increased due to the discovery of Covenant field in the Jurassic Navajo Sandstone "Hingeline" play (described in this report). The overall objectives of this study are to (1) continue adding new discoveries, (2) increase recoverable oil from existing field reservoirs, (3) prevent premature abandonment of numerous small fields, (4) increase deliverability through identifying the latest drilling, completion, and secondary/tertiary recovery techniques, and (5) reduce development costs and risk.

To achieve these objectives, the Utah Geological Survey is producing play portfolios for the major oil-producing provinces (Paradox Basin, Uinta Basin, and thrust belt) in Utah and adjacent areas in Colorado and Wyoming. This research is partially funded by the Preferred Upstream Management Program (PUMPII) of the U.S. Department of Energy, National Petroleum Technology Office (NPTO) in Tulsa, Oklahoma. This report covers research activities for the seventeenth quarter of the project (July 1 through September 30, 2006). This work included (1) describing the Jurassic Navajo Sandstone Hingeline play, and (2) technology transfer activities.

A combination of depositional and structural events created the right conditions for oil generation and trapping in the major oil-producing provinces (Paradox Basin, Uinta Basin, and thrust belt) in Utah and adjacent areas in Colorado, Wyoming, and Arizona. Oil plays are specific geographic areas having petroleum potential due to favorable source rock, migration paths, reservoir characteristics, and other factors. The Jurassic Navajo Sandstone Hingeline play is the only petroleum play in the central Utah thrust belt. The 2004 discovery of Covenant field in the central Utah thrust belt changed the oil development in the Utah Hingeline from hypothetical to proven.

Traps in the central Utah thrust belt include anticlines associated with latest Jurassic through early Tertiary thrust imbricate and duplex structures, positioned near Middle Jurassic extension faults. The principal regional seal for the Lower Jurassic Navajo producing zones consists of salt, gypsum, mudstone, and shale of the overlying Jurassic Arapien Shale. Hydrocarbons were likely generated from Mississippian source rocks. The source rocks began to mature after loading by overriding of thrust plates during Late Cretaceous and early Tertiary time. Hydrocarbons were generated, expelled, and subsequently migrated into overlying traps, primarily along fault planes.

The Navajo Sandstone reservoir was deposited in an extensive dune field that extended from Wyoming to Arizona. The Navajo has heterogeneous reservoir properties because of (1) cyclic dune/interdune lithofacies with better porosity and permeability that developed in certain dune morphologies, (2) diagenetic effects, and (3) fracturing. Identifying and correlating barriers and baffles to fluid flow, and recognizing fracture set orientations in potential Navajo reservoirs are critical to understanding their effects on production rates, petroleum movement pathways, secondary/tertiary enhanced recovery projects, and pressure maintenance programs.

The Navajo Sandstone at Covenant field has 424 feet (139 m) of net pay, an average of 12 percent porosity, up to 100 millidarcies of permeability, an average water saturation of 38 percent, and a strong water drive. Cumulative production from 10 wells, from late 2004

through September 30, 2006, was 2,611,688 barrels (415,258 m^3) of oil, averaging over 6000 barrels (950 m^3) of oil per day. The original oil in place is estimated at 100 million barrels (15.9 million m^3); the estimated recovery factor is 40 to 50 percent.

Prospective drilling targets in the Navajo Sandstone thrust belt play have been delineated using high-quality, two-dimensional seismic data along with well control, dipmeter information, surface geologic maps, and incremental restoration of balanced cross sections to assess trap geometry and location. Determination of the timing of structural development, petroleum migration, entrapment, and fill and spill histories are critical to successful exploration. Future exploration in the central Utah thrust belt should focus on Paleozoic-cored, blind, thrust structures east of the exposed Charleston-Nebo and Pavant thrusts. The lack of associated gas at Covenant field suggests the possibility that gas-charged traps may be present in the play area because the gas may have been driven off early during migration from sediment or thrust-plate loading.

Technology transfer activities during this quarter included a technical presentation describing best practices in the Uinta Basin given at an American Petroleum Institute meeting. An abstract describing Covenant field in the central Utah thrust belt play was submitted to the American Association of Petroleum Geologists, for a possible presentation at the 2007 annual convention in Long Beach, California. Project team members joined Utah Stake Holders Board members in attending the Uinta Basin Oil and Gas Collaborative Group meeting in Vernal, Utah, September 2006. The project home page was updated on the Utah Geological Survey Web site. Project team members published a Quarterly Technical Progress Report detailing project work, results, and recommendations.

INTRODUCTION

Project Overview

Utah oil fields have produced over 1.2 billion barrels (bbls) (191 million m^3) (Utah Division of Oil, Gas and Mining, 2006). The 13.7 million barrels (2.2 million m^3) of production in 2002 was the lowest level in over 40 years. However, in late 2005 production increased (figure 1), due to the discovery of Covenant field in the Jurassic Navajo Sandstone "Hingeline" play, and reversed the decline that began in the mid-1980s (Utah Division of Oil, Gas and Mining, 2006). Proven reserves are relatively high, at 256 million bbls (40.7 million m^3) (Energy Information Administration, 2006). With higher oil prices now prevailing, secondary and tertiary recovery techniques should boost future production rates and ultimate recovery from known fields.

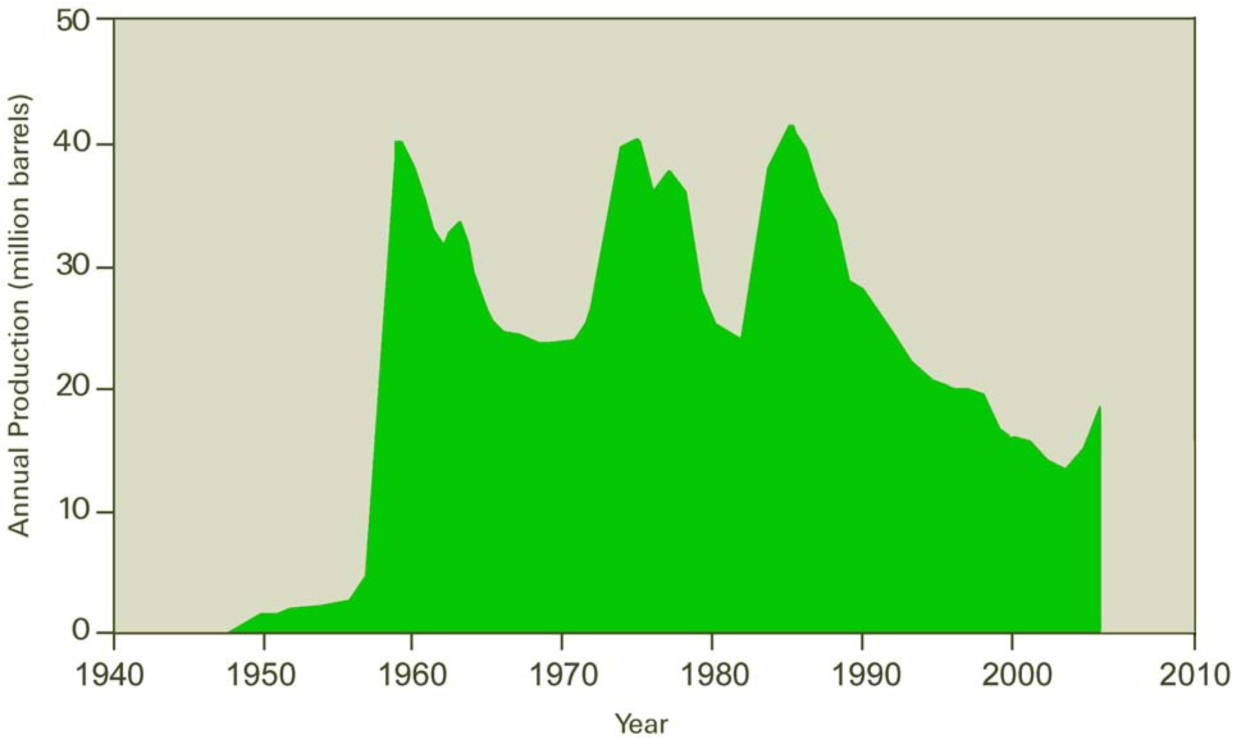

Figure 1. Oil production in Utah through 2005 showing an increase due, in part, to the discovery of Covenant field in the new Jurassic Navajo Sandstone Hingeline play of the central Utah thrust belt. Source: Utah Division of Oil, Gas and Mining production records.

Utah's drilling history has fluctuated greatly due to discoveries, oil and gas price trends, and changing exploration targets. Utah has entered another boom period rivaling the early 1980s. In 2005, the Utah Division of Oil, Gas and Mining issued a record 1629 drilling permits and 876 wells were spudded. Sustained high petroleum prices are providing the economic climate needed to entice more high-risk exploration investments (more wildcats), resulting in new discoveries.

Utah still contains large areas that are virtually unexplored. There is also significant potential for increased recovery from existing fields by employing improved reservoir characterization and the latest drilling, completion, and secondary/tertiary recovery technologies. New exploratory targets may be identified from three-dimensional (3D) seismic surveys. Development of potential prospects is within the economic and technical capabilities of both major and independent operators.

The primary goal of this study is to increase recoverable oil reserves from existing field reservoirs and new discoveries by providing play portfolios for the major oil-producing provinces (Paradox Basin, Uinta Basin, and thrust belt) in Utah and adjacent areas in Colorado and Wyoming (figure 2). These play portfolios will include descriptions (such as stratigraphy, diagenetic analysis, tectonic setting, reservoir characteristics, trap type, seal, and hydrocarbon source) and maps of the major oil plays by reservoir; production and reservoir data; case-study field evaluations; summaries of the state-of-the-art drilling, completion, and secondary/tertiary techniques for each play; locations of major oil pipelines; and descriptions of reservoir outcrop analogs for each play. Also included will be an analysis of land-use constraints on development, such as wilderness or roadless areas, and national parks within oil plays.

This report covers research activities for the seventeenth quarter of the project (July 1 through September 30, 2006). This work included (1) describing the Jurassic Navajo Sandstone Hingeline play (figure 3), and (2) technology transfer activities.

Project Benefits

The overall goal of this multi-year project is enhanced petroleum production in the Rocky Mountain region. Specific benefits expected to result from this project include the following:

(1) improved reservoir characterization to prevent premature abandonment of numerous small fields in the Paradox and Uinta Basins,

(2) identification of the type of untapped compartments created by reservoir heterogeneity (for example, diagenesis and abrupt facies changes) to increase recoverable reserves,

(3) identification of the latest drilling, completion, and secondary/tertiary techniques to increase deliverability,

(4) identification of reservoir trends for field extension drilling and stimulating exploration in undeveloped parts of producing fairways,

(5) identification of technology used in other basins or producing trends with similar types of reservoirs that might improve production in Utah,

(6) identification of optimal well spacing/location to reduce the number of wells needed to successfully drain a reservoir, thus reducing development costs and risk, and allowing more productive use of limited energy investment dollars, and

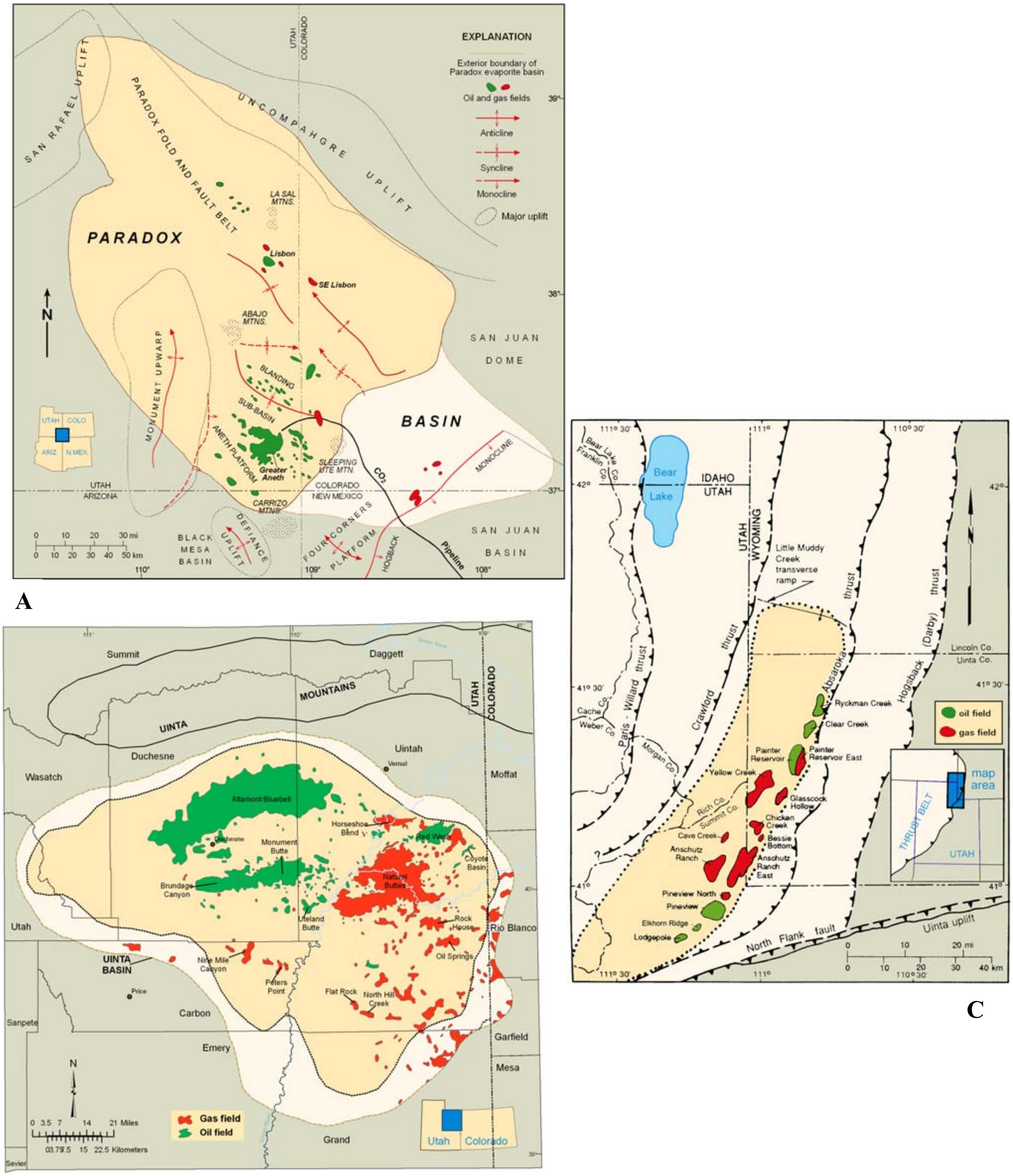

Figure 2. Major oil-producing provinces of Utah and vicinity. A - Oil and gas fields in the Paradox Basin of Utah, Colorado, and Arizona (modified from Harr, 1996). B - Oil and gas fields in the Uinta Basin of Utah (modified from Chidsey and others, 2004). C - Oil and gas fields, uplifts, and major thrust faults in the Utah-Wyoming thrust belt.

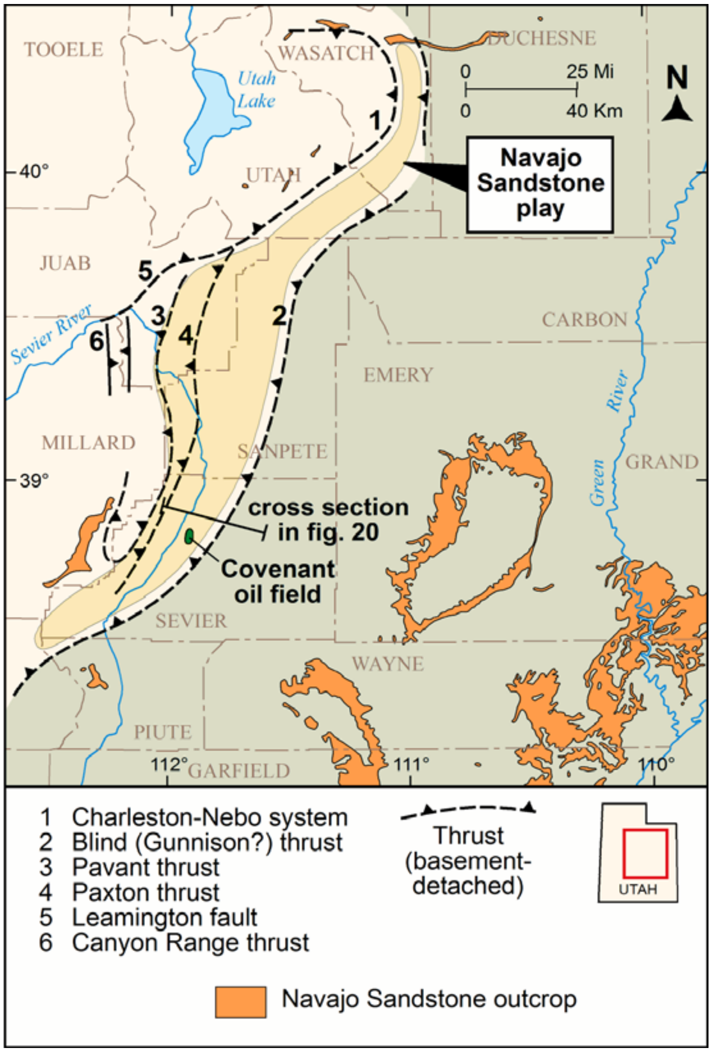

Figure 3. Location of Covenant oil field, uplifts, and selected thrust systems in the central Utah thrust belt province. Numbers and sawteeth are on the hanging wall of the corresponding thrust system. Colored (light orange) area shows present and potential extent of the Jurassic Navajo Sandstone Hingeline play. Modified from Hintze (1980), Sprinkel and Chidsey (1993), and Peterson (2001).

(7) technology transfer to encourage new development and exploration efforts, and increase royalty income to the federal, state, local, Native American, and fee owners.

The Utah play portfolios produced by this project will provide an easy-to-use geologic, engineering, and geographic reference to help petroleum companies plan exploration, land-acquisition strategies, and field development. These portfolios may also help pipeline companies plan future facilities and pipelines. Other users of the portfolios will include petroleum engineers, petroleum land specialists, landowners, bankers and investors, economists, utility companies, manufacturers, county planners, and numerous government agencies.

The results of this project will be transferred to industry and other interested parties through establishment of Technical Advisory and Stake Holders Boards, an industry outreach program, and technical presentations at national and regional professional society meetings. All of this information will be made public through (1) the Utah Geological Survey (UGS) Web site, (2) an interactive, menu-driven digital product on compact disc, and (3) hard-copy publications in various technical or trade journals and UGS publications.

JURASSIC NAVAJO SANDSTONE HINGELINE PLAY—DISCUSSION AND RESULTS

Introduction

Central Utah has seen petroleum exploration for the past 50 years because explorationists viewed the geology as a natural extension of successful plays in the Utah-Wyoming-Idaho salient of the Cordilleran thrust belt to the north (figure 4). Early efforts tested anticlines identified from surface mapping and seismic reflection data. During the late 1970s to early 1980s companies drilled thrust belt-style structures in the wake of the 1975 Pineview discovery in northern Utah (figure 2C). Although these efforts failed, companies confirmed the area was similar in structural style, reservoir types, and timing to the productive thrust belt to the north. The lack of Cretaceous hydrocarbon source beds below the thrust structures seemingly was to blame for the earlier exploration failures; however, oil and gas shows were commonly noted in Mississippian, Permian, Triassic, and Jurassic rocks. The recent discovery of Covenant field (figure 3) by Wolverine Gas and Oil Company in the Jurassic Navajo Sandstone along the Sanpete-Sevier Valley antiform changed the oil development potential in the central Utah thrust belt from hypothetical to proven.

Central Utah Thrust Belt–Hingeline Overview

The central Utah thrust belt, also referred to by many geologists as "the Hingeline," is part of the Cordilleran thrust belt (figure 4) and is loosely defined as the region south of the Uinta Mountains of northeastern Utah trending through central Utah to the southwest corner of the state. Classic papers describing and interpreting the geology of the Hingeline region include Eardley (1939), Kay (1951), Armstrong (1968), and Stokes (1976). Throughout this area's geologic history, the Hingeline has marked a pronounced boundary between different terrains. During Late Proterozoic to Devonian time, it marked the boundary between a very thick sequence of sediments deposited in western Utah and a thin sequence deposited in eastern Utah. During Cretaceous to early Tertiary time, the Hingeline coincided with the eastern edge of the Sevier orogenic belt. Today it marks the general boundary between the Basin and Range and Colorado Plateau physiographic provinces.

In reality, the Hingeline is an area rather than a line, and includes geologic features common in both the Basin and Range and Colorado Plateau physiographic provinces: Sevier orogenic thrust faults, basement-cored Late Cretaceous-Oligocene Laramide uplifts (plateaus and the Wasatch monocline), and Miocene to Holocene normal faults. Paleozoic rocks are generally thin cratonic deposits whereas the Upper Cretaceous section includes thick synorogenic deposits reflecting proximity of the Sevier orogenic belt to the west. Several depositional environments during the Mississippian and Permian produced organic-rich deposits capable of generating hydrocarbons.

An extensional fault system, including the high-angle, basement-involved "ancient Ephraim fault," was located in central Utah during the Middle Jurassic (Moulton, 1976; Schelling and others, 2005). In the Late Jurassic, Utah was mostly a forebulge high (Willis, 1999). In central Utah, large-scale thrust sheets were emplaced during latest Jurassic through early Tertiary time by compression of the actively evolving foreland basin (Schelling and

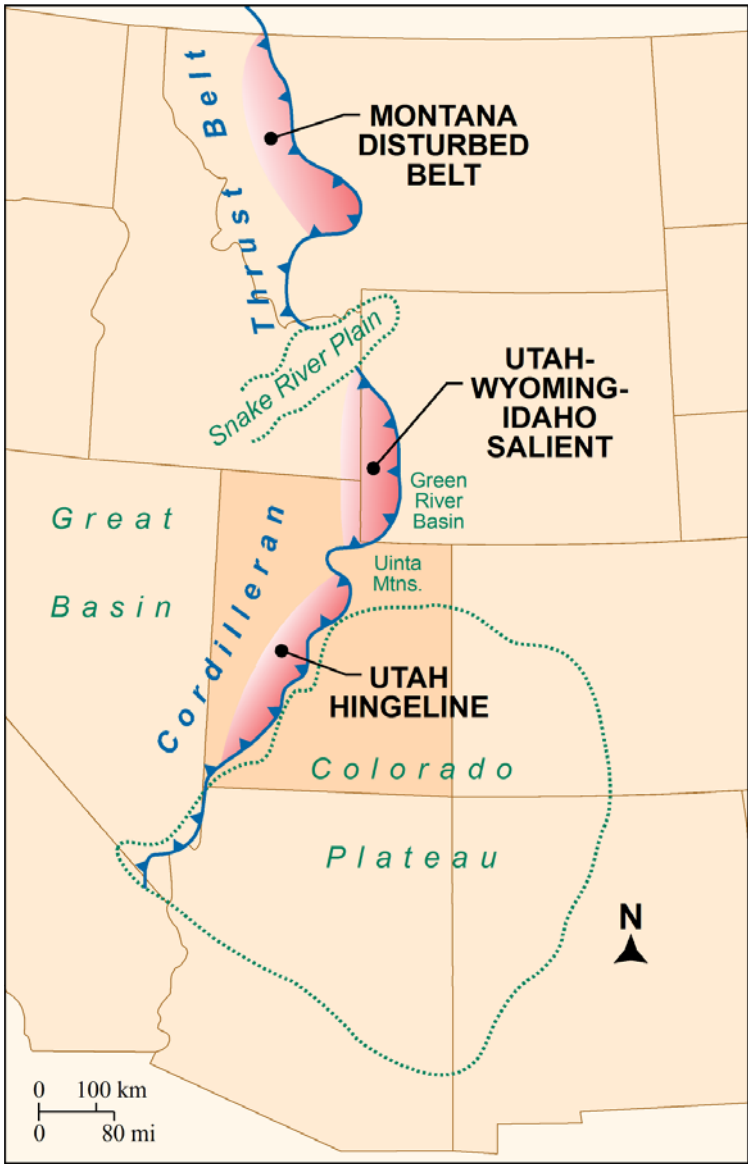

Figure 4. Location of the Cordilleran thrust belt including the Montana "Disturbed" belt, Utah-Wyoming-Idaho salient, and Utah "Hingeline." Modified from Gibson (1987).

others, 2005; (DeCelles and Coogan, 2006). The youngest evidence of thrust faulting is 40 million years in central Utah (Willis, 1999). Thrusting extended westward for more than 100 miles (160 km).

Major thrust faults in central Utah (from west to east) include the Canyon Range thrust, Leamington fault, Pavant thrust (Royse, 1993), Paxton thrust, Charleston-Nebo thrust system, and the Gunnison thrust (Villien and Kligfield, 1986) (figure 3). These thrust faults represent detached, thin-skinned, compressional styles of deformation, with eastward movement greater than 90 miles (>140 km) for the Canyon Range and Pavant thrusts (DeCelles and Coogan, 2006). Easternmost thrust systems moved less than western thrust systems and are generally younger; the Canyon Range thrust was emplaced during latest Jurassic-Early Cretaceous time, the Pavant thrust was emplaced in Albian time, the Paxton thrust was emplaced in Santonian time, and the Gunnison thrust was active from late Campanian through early Paleocene time (DeCelles and Coogan, 2006). The Ephraim fault and other Middle Jurassic faults may have also experienced additional Laramide-age (Maastrichtian through Eocene) movement.

Surface traces of the thrust faults generally trend in a north-northeast direction. Some of the thrust faults do not extend to the surface, and the term "blind" thrust is applied to buried faults like the Gunnison thrust. The Pavant, Paxton, and Gunnison thrust systems contain Lower Cambrian through Cretaceous strata. Jurassic shale, mudstone, and evaporite beds serve as the glide planes along the hanging-wall flats of these thrust systems.

The leading edges of the thrust faults are listric in form and structurally complex. They include numerous thrust splays, back thrusts, duplex systems (particularly in eastern thrusts), fault-propagation folds (fault-bend folds), and ramp anticlines such as the huge fold that created Mount Nebo (near the town of Nephi) along the Charleston-Nebo thrust system where overturned upper Paleozoic and attenuated Triassic and Jurassic rocks are spectacularly displayed. The duplex systems are similar to those found in the Alberta Foothills in the eastern Canadian Rocky Mountains (Dahlstrom, 1970); these types of features are not present in the Utah-Wyoming-Idaho salient of the thrust belt to the north.

Central Utah thrust plates, like the Canyon Range thrust plate, are up to 36,000 feet (12,000 m) thick (DeCelles and Coogan, 2006), although eastern plates tend to be thinner. The eastern plates also deformed into smaller amplitude fault-propagation folds and ramp anticlines than western plates (Willis, 1999). Middle Jurassic extensional faults, such as the ancient Ephraim fault and similar faults in the region, determined the position of these ramp anticlines and associated duplexes along thrust systems by acting as a buttress to plate movement (Schelling and others, 2005; D.A. Wavrek, Petroleum Systems International, Inc., verbal communication, 2005). However, a blind, low-angle thrust fault continues east of the Ephraim fault within in the Jurassic Arapien Shale-Carmel Formation under the Wasatch Plateau (Neuhauser, 1988). Smaller imbricate faults from the décollement form fault-propagation/fault-bend folds, which are some of the producing anticlines on the Wasatch Plateau.

Neogene reactivated movement along many thrust ramps, splays, and associated back thrusts formed listric normal faults and other normal faults related to Basin and Range extension, dissecting thrust plates into additional, compartmentalized blocks (Schelling and others, 2005). The Wasatch monocline and other monoclinal structures formed at this time. Some local ductile deformation of Jurassic evaporites further complicated the structural picture of the region (Witkind, 1982). Potential hydrocarbon traps form on discrete, seismically defined, subsidiary closures along strike on major ramp anticlines and fault-propagation/fault-bend folds.

Jurassic Navajo Sandstone Hingeline Play Description

The Jurassic Navajo Sandstone Hingeline play is the only petroleum play in the central Utah thrust belt. The play extends 200 miles (320 km) south-southwest from 20 miles (30 km) north of Provo, Utah, to southwestern Sevier County, and thins from 25 miles (40 km) wide in the north to zero in the south (figure 3). It lies due south of the Utah-Wyoming-Idaho salient and straddles the boundary between the eastern Basin and Range (eastern Millard, Juab, and Utah Counties) and High Plateaus (central Sevier and Sanpete Counties) physiographic provinces.

The Jurassic Navajo Sandstone Hingeline play is the only proven oil play in the region and contains one, but significant, field—Covenant. Covenant field, Sevier County, Utah (figures 3 and 5), was discovered in 2004 by Michigan-based Wolverine Gas & Oil Company with the completion in the Navajo Sandstone of the No. 17-1 Kings Meadow Ranches well

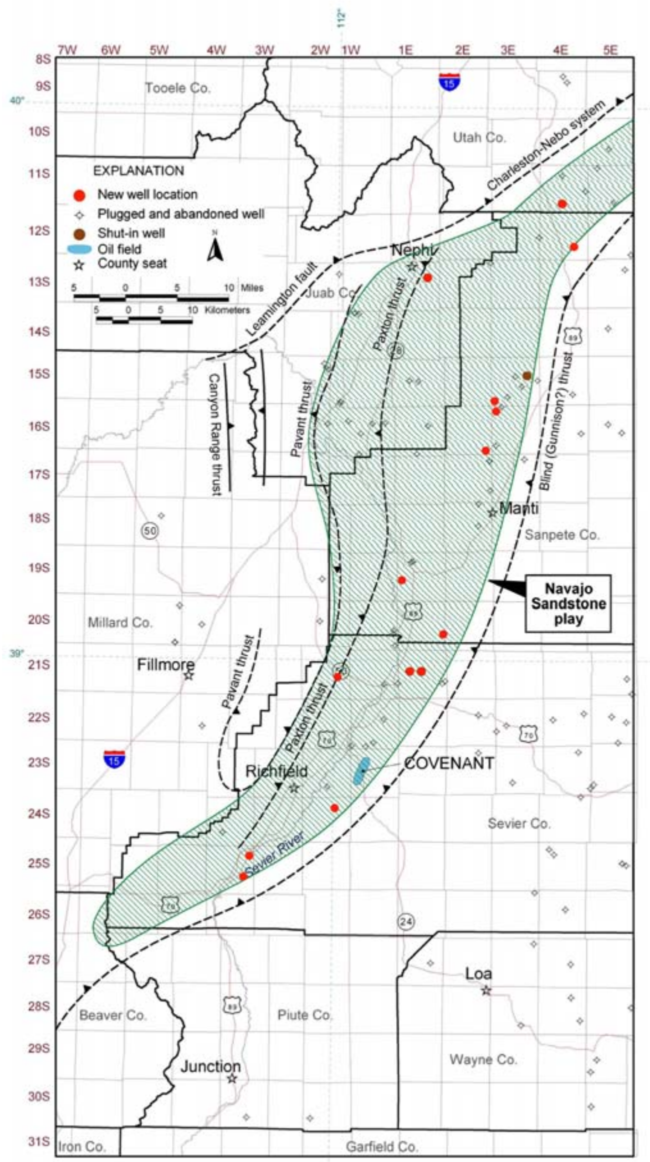

Figure 5. Jurassic Navajo Sandstone Hingeline play area showing regional exploratory well locations.

(SE1/4NW1/4 section 17, T. 23 S., R. 1 W., Salt Lake Base Line and Meridian [SLBL&M]). The map on figure 5 represents about 276 square townships. Since 1918, the area has had fewer than 120 wells drilled, which means only one well has been drilled per every two townships, or one well per about 72 square miles (186 km^2). The first well in region was drilled in 1918. No wells were drilled during the Great Depression years of the 1930s followed increases each decade through the 1980s (figure 6). The increase in drilling during the 1970s and 1980s was due to a significant increase in oil prices from the Arab oil embargo, the discovery of Pineview field in northern Utah, and the Iranian revolution. Drilling peaked in 1985 but decreased thereafter due to low oil prices and the high risk associated with exploration in the Hingeline area. Wolverine dominates drilling activity in the current decade, but Ansbro Petroleum, Clearly Petroleum, Delta Petroleum, and PetroHunt are also active in the area.

The Jurassic Navajo Sandstone Hingeline play area represents the maximum extent of petroleum potential in the geographical area as defined by producing reservoirs, hydrocarbon shows, and untested hypotheses. The attractiveness of the Jurassic Navajo Sandstone Hingeline

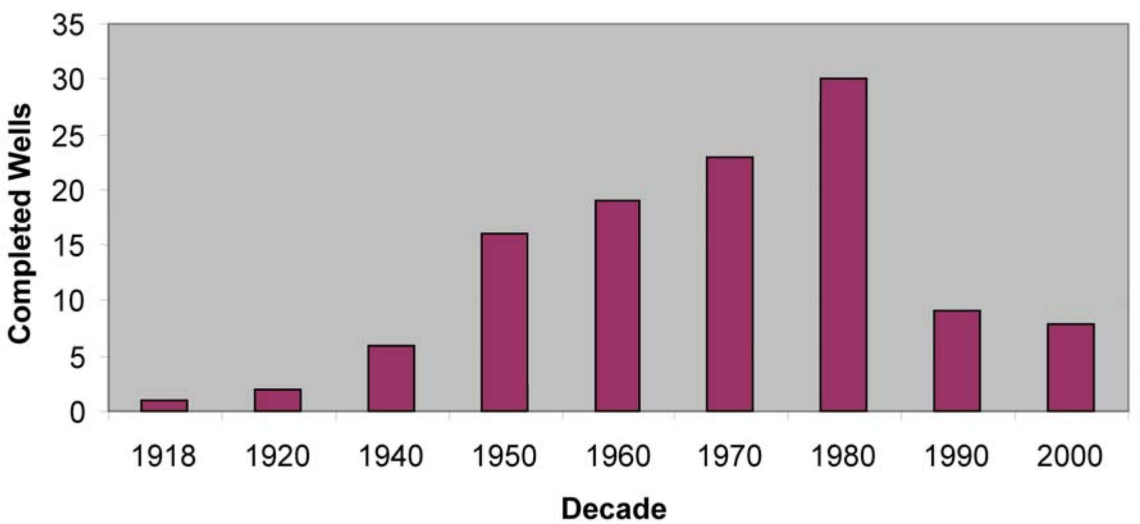

Figure 6. Exploration history of central Utah (Utah Division of Oil, Gas and Mining well files).

play (and other thrust belt plays) to the petroleum industry depends on the likelihood of successful development, reserve potential, pipeline access, drilling costs, oil and gas prices, and environmental concerns. When evaluating these criteria, certain aspects of the Navajo play may meet the exploration guidelines of major oil companies while other aspects meet the development guidelines of small, independent companies.

Prospective drilling targets in the Jurassic Navajo Sandstone Hingeline play are delineated using high-quality two-dimensional (2-D) and, in the near-future, three-dimensional (3-D) seismic data, 2-D forward modeling/visualization tools, well control, dipmeter information, high-quality surface geologic maps, and detailed analyses of structural geometry (Meneses-Rocha and Yurewicz, 1999). Incremental restoration of balanced cross sections is one of the best methods to assess trap geometry (Meneses-Rocha and Yurewicz, 1999). Several techniques can be used to determine the timing of structural development, petroleum migration, and entrapment, and to decipher fill and spill histories. These techniques include illite age analysis, apatite fission track analysis, and use of fluid inclusions (Meneses-Rocha and Yurewicz, 1999).

Depositional Environment

In Early Jurassic time, Utah had an arid climate and lay 15° north of the equator (Smith and others, 1981). The Navajo Sandstone and age-equivalent rocks were deposited in an extensive dune (erg) field (eolian environment) which extended from present-day Wyoming to Arizona (figure 7), and was comparable to the Sahara desert in North Africa or the Alashan area of the Gobi desert in northern China. The source of the sand was perhaps the Pennsylvanian Quadrant Quartzite in Montana, or possibly even as far away as the Appalachian area in the eastern U.S., based on zircon similarities (Rahl and others, 2003). The eolian deposits included dunes, interdunes, and sand sheets. Navajo dunes were large to small, straight-crested to sinuous, coalescing, transverse barchanoid ridges as suggested by large-scale cross-bedding (Picard, 1975; Fryberger, 1990). Regional analyses of the mean dip of dune foreset beds indicate paleocurrent and paleowind directions were dominantly from the north and northwest (figure 7) (Kocurek and Dott, 1983).

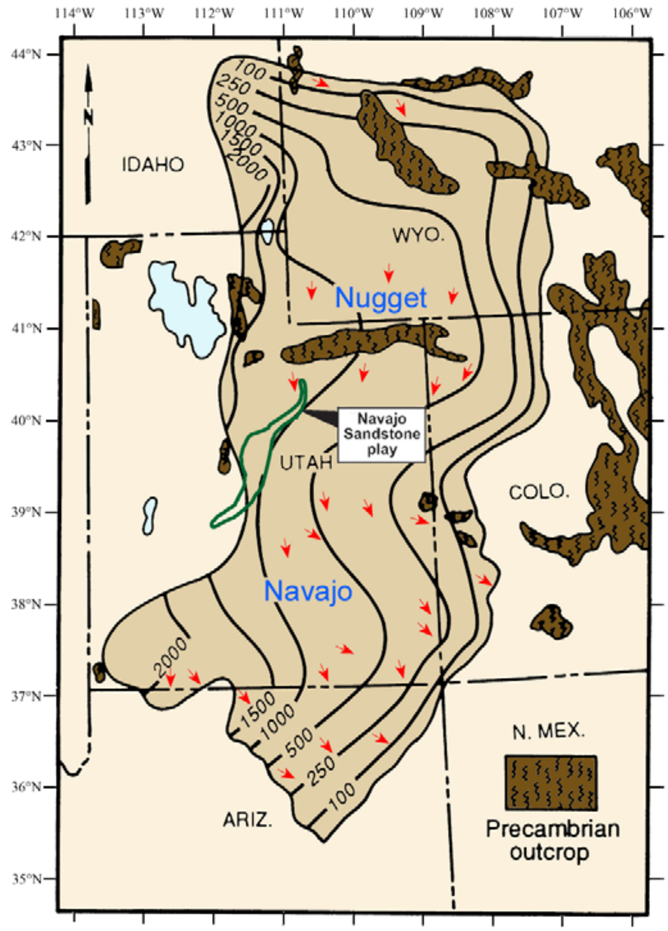

Figure 7. Regional isopach map of the Navajo/Nugget Sandstone based on measured sections and well data. Paleowind generally from the north and northwest is shown by arrows. Contours are in feet. Modified from Picard (1975); Kocurek and Dott (1983).

In addition to a "sea" of wind-blown sand dunes, the Navajo erg system included interdune playas and oases. A high water table produced oases; deposition occurred when spring and lakes existed for relatively long periods of time. The high water table also resulted in early soft-sediment deformation in overlying dune sands (Sanderson, 1974; Doe and Dott, 1980). Some Navajo interdunes were erosional (deflation) areas associated with running water, such as a wadi or desert wash (a wadi is a usually dry streambed or channel in a desert region). Sand sheets represented by low-relief, poorly drained, vegetated or gravel pavement deposits were also common (Lindquist, 1988). These areas acted as sand transport surfaces.

Stratigraphy and Thickness

The Navajo Sandstone is 740 to 1700 feet (250-570 m) thick in the play area (Hintze, 1993) and has a characteristic geophysical log response (figure 8). At Covenant field, the Navajo is divided into lower, middle, and upper units based on core and geophysical log analysis (figure 8). The lower and upper units have subtle but distinct characteristic geophysical log responses; the middle unit has a high gamma-ray profile recognized on other logs regionally and can be tied to the Navajo outcrop.

The central Utah thrust belt is divided into eastern, central, and western areas based on stratigraphy (figures 9 and 10). In Covenant field (central area) the Navajo Sandstone is overlain by the Jurassic Twin Creek Limestone and underlain by the Jurassic Kayenta Formation. The depth to the Navajo in Covenant field is 5840 feet (1780 m).

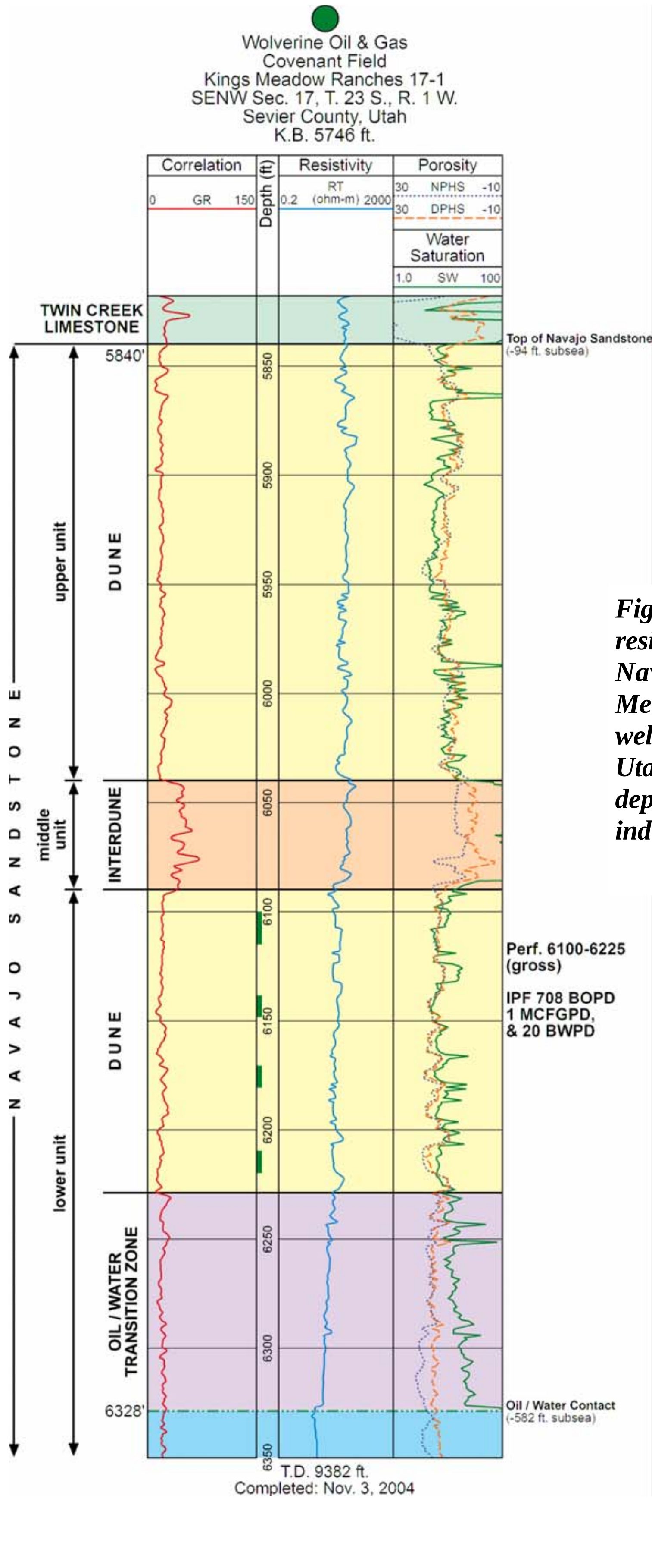

Figure 8. Typical combined gamma ray, resistivity, and neutron-density log of the Navajo Sandstone from the Kings Meadow Ranches No. 17-1 discovery well of Covenant field, Sevier County, Utah. The vertical green bars between depths of 6100 and 6225 feet on the log indicate producing (perforated) intervals.

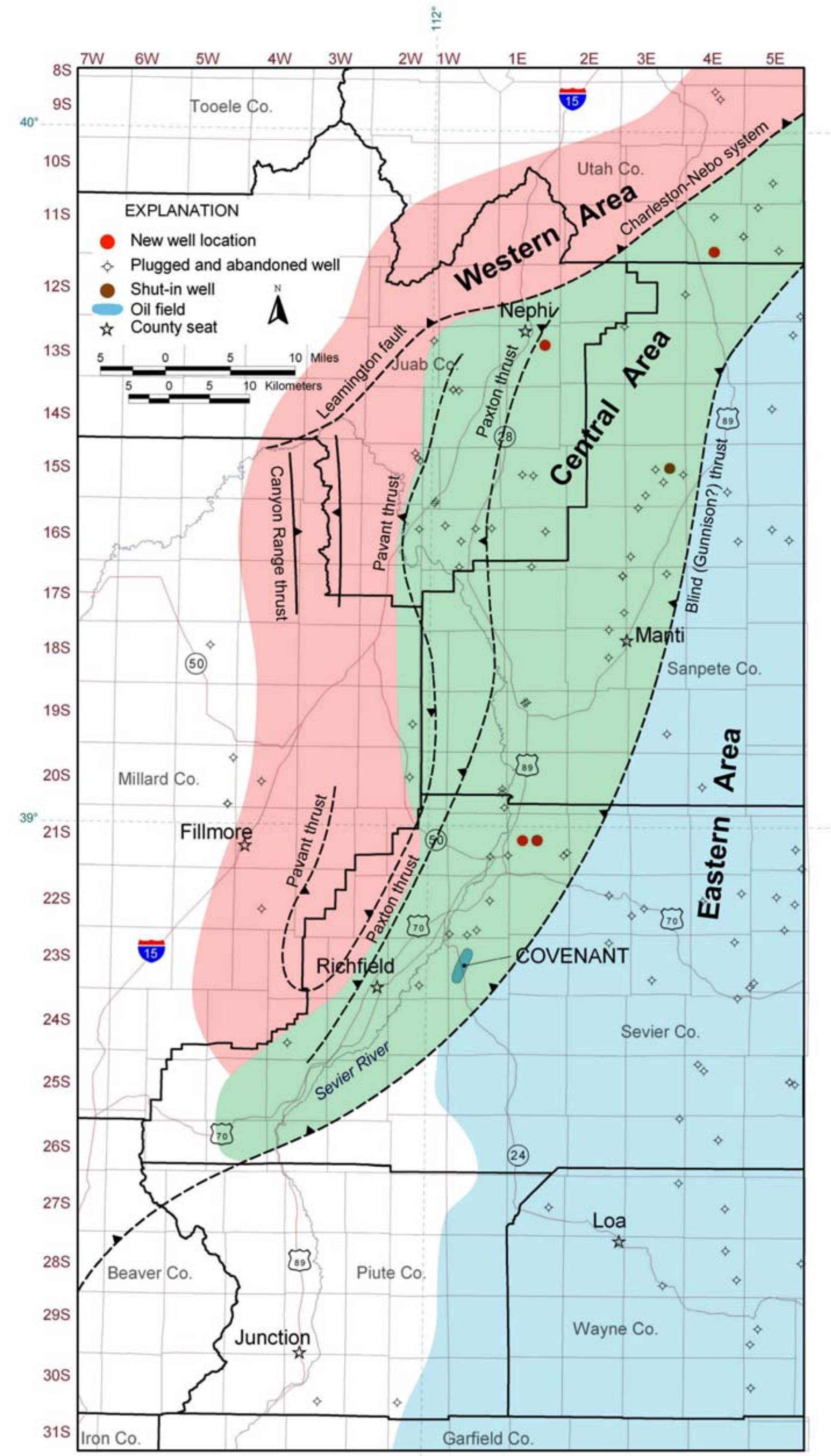

Figure 9. Eastern, central, and western areas of the central Utah thrust belt based on stratigraphy.

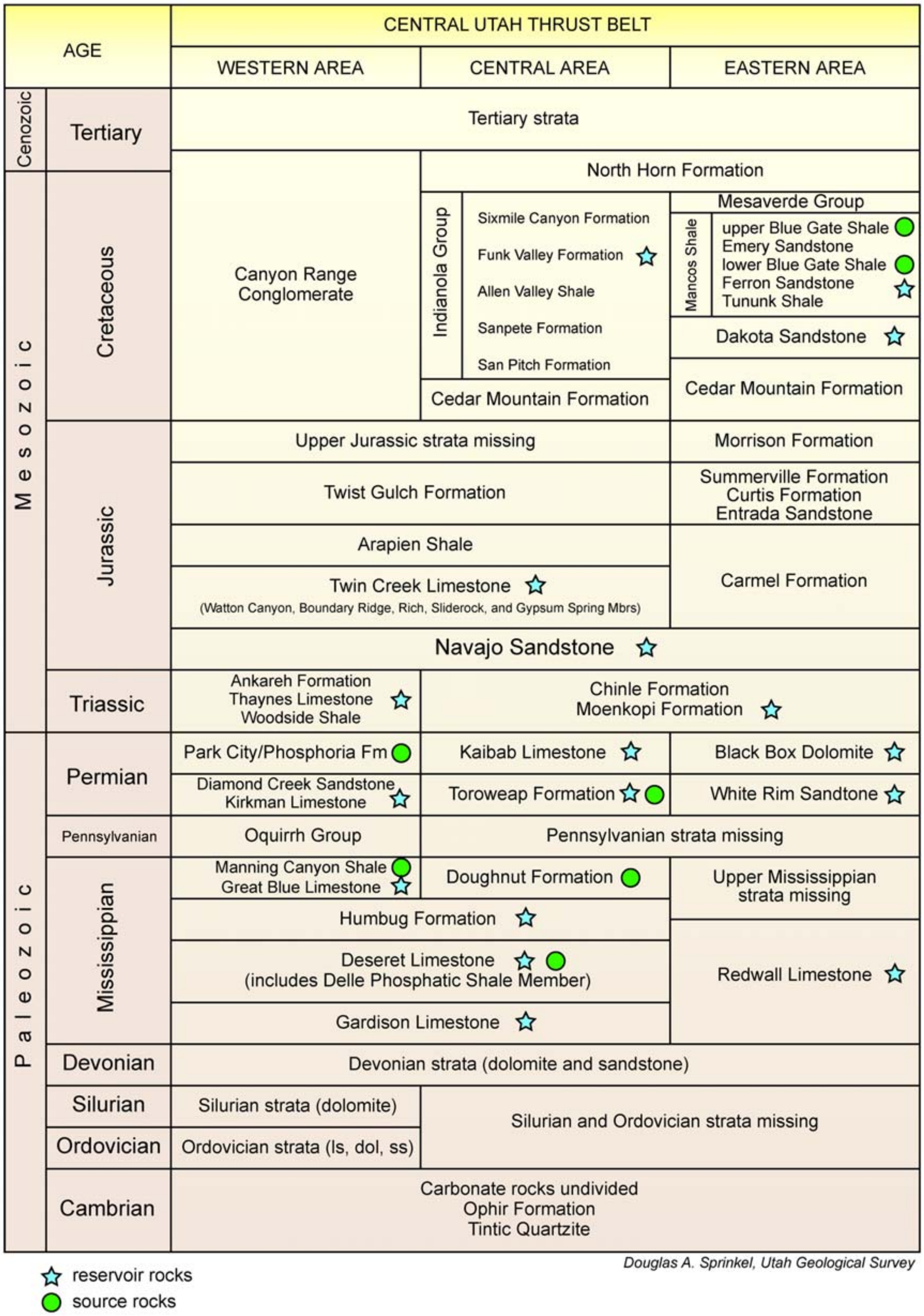

Figure 10. Detailed stratigraphic correlation chart showing Navajo Sandstone and other potential reservoir rocks as well as source rocks in central Utah (see figure 9 for location of eastern, central, and western areas).

Lithology and Fracturing

The productive part of the lower unit of the Navajo Sandstone is about 240 feet (80 m) thick; the upper unit is about 200 feet (70 m) thick. These units are characterized by the large-scale, trough, planar, or wedge-planar cross-beds (35 to 40°) commonly recognized as classical eolian dune features (figure 11); contorted bedding, wind ripples, and small-scale cross-beds are also common (Sanderson, 1974). Dune lithofacies from the brink to the toe of the dune slipface consist of (1) thin, graded, tabular grainfall laminae (rarely preserved), (2) thick, subgraded avalanche laminae, and (3) thin, tightly packed, reworked ripple strata at the dune toe (Lindquist, 1983). Massive, homogenous beds with no distinct sedimentary structures or laminations are also recognized in the Navajo and were probably formed by water-saturated sand (Sanderson, 1974).

In general, the lower and upper units of the Navajo consist of very well to well-sorted, very fine to medium-grained (1/16 mm to ½ mm), subangular to subrounded sand or silt grains cemented by carbonate cement. However, some intervals show a bimodal grain-size distribution representing silty laminae between sand beds (figure 12). The typical sandstone is 97 percent white or clear quartz grains (usually frosted) with varying amounts of K-feldspar. Very little clay is present in the Navajo (Strickland and others, 2005).

Figure 11. Typical upper unit of the Navajo Sandstone, from the Kings Meadow Ranches No. 17-3 well (slabbed core from 6669 feet), Covenant field, showing cross-bedding in fine-grained sandstone deposited in a dune environment.

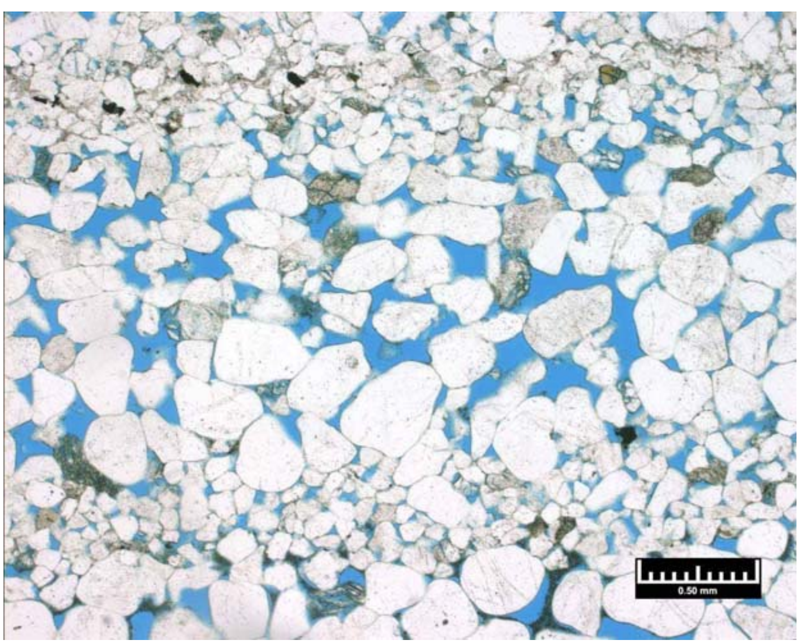

Figure 12. Representative photomicrograph (plane light) from the lower unit of the Navajo Sandstone showing bimodal distribution of subangular to subrounded quartz sand and silt. Note a few fractured and corroded K-feldspar grains are present. Blue space is intergranular porosity. Kings Meadow Ranches No. 17-3 well, 6773 feet, porosity = 14.8 percent, permeability = 149 mD based on core-plug analysis.

The middle unit of the Navajo is a more heterogeneous, 50-foot-thick (17 m) interdunal section. This unit is characterized by low-angle to horizontal laminae or distorted bedding consisting of very fine to fine-grained, thin, poorly sorted sandstone, siltstone, and shale (figure 13). Horizontal stratification often contains silty laminae between beds. These beds may also display wind ripples or fluvial characteristics (scour). Interdunal fluvial characteristics indicate sheet flow or flooding events in a wadi while other deposits suggest wet playa or lacustrine conditions.

Fractures in the Navajo Sandstone consist of two types: (1) early, bitumen and gouge-filled, silica-cemented, impermeable fractures (figure 14), and (2) later, typically open (little gouge or cement), permeable fractures. The later fractures are related to fault-propagation folding during the Sevier orogeny after deep burial (Royce and others, 1975).

Figure 13. Typical middle unit of the Navajo Sandstone, from the Kings Meadow Ranches No. 17-3 well (slabbed core from 6752 feet), Covenant field, showing siltstone laminae and shale deposited in an interdune environment.

Figure 14. Early, bitumen and gouge-filled, silica-cemented, impermeable fractures, with slight offsets, in the Navajo Sandstone, from the Kings Meadow Ranches No. 17-3 well (slabbed core from 6776 feet), Covenant field.

Hydrocarbon Source and Seals

The lack of good Cretaceous source rocks was blamed for earlier exploration failures in the central Utah thrust belt; however, oil and gas shows were common in Mississippian, Permian, Triassic, and Jurassic rocks. Although some coaly beds are present in the Upper Cretaceous rocks in the eastern area, the Cretaceous strata become more fluvial and nonmarine to the west and probably are only gas-prone. Unlike the producing thrusted structures of the northern thrust belt play, the structures and faults of the central Utah play are not in contact with good Cretaceous source rocks.

Potential central Utah source rocks include marine shales and mudstones of Mississippian and Permian age. The most likely source rocks include the Mississippian Delle Phosphatic Member of the Deseret Limestone (figure 15) (Sandberg and Gutschick, 1984), the Mississippian Chainman Shale (Wavrek and others, 2005) (figures 15 and 16), the Mississippian-Pennsylvanian Manning Canyon Shale (figure 16), and the Permian Park City/ Phosphoria Formation (Sprinkel and others, 1997; Peterson, 2000, 2001). Total organic carbon for some units within these rocks is 15 percent (D.A. Wavrek, Petroleum Systems International, Inc., verbal communication, 2005). Figure 17 is a graph plotting stable carbon-13 saturated versus aromatic hydrocarbons from the Covenant field oil with other well-documented Cretaceous and Permian oils. The Covenant oil is clearly Paleozoic in origin, but significantly different from the Permian oils. We believe that it is derived from a Mississippian source.

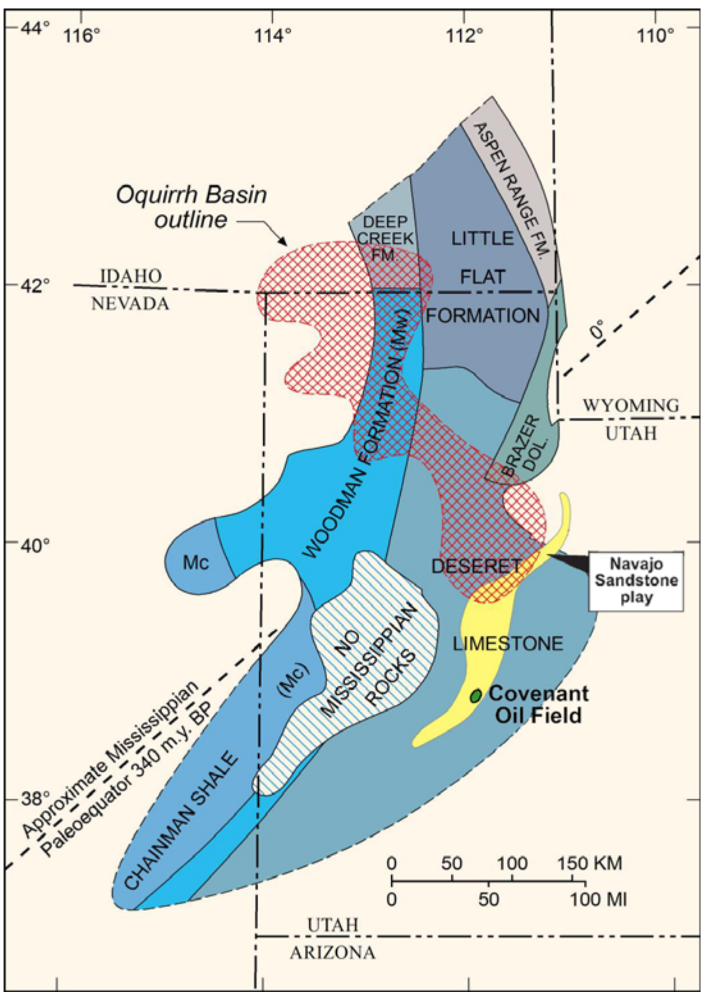

Figure 15. Location of the Mississippian Delle Phosphatic Member present in the Deseret Limestone and other Mississippian formations (modified from Sandberg and Gutschick, 1984).

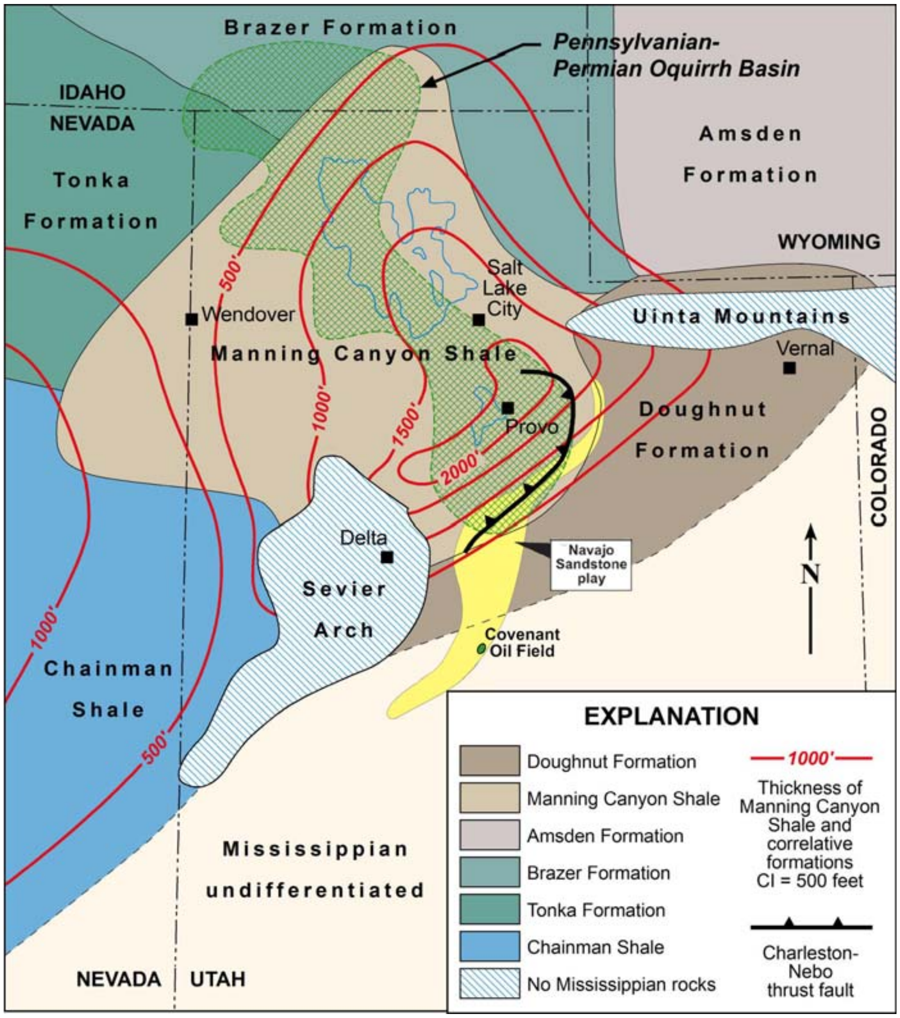

Figure 16. Location and thickness of the Manning Canyon Shale and correlative formations (modified from Moyle, 1958).

As stated earlier, thrusting in this area is Cretaceous to early Tertiary in age. Most of the hydrocarbon generation and migration probably occurred during this period. However, some hydrocarbon generation and migration probably began as early as Permian or Triassic time in the older Paleozoic rocks and as late as Tertiary time in Mesozoic rocks. Late Tertiary extension in this area may have disrupted the traps more than in the productive thrust belt of northern Utah and southwestern Wyoming. Oil migrating from the Mississippian Chainman Shale in western Utah seems fraught with problems. It requires a post-Sevier-orogeny, long-distance migration, and must circumvent the Sevier arch where no Mississippian rocks are present (figures 15 and 16).

We believe the more likely hydrocarbon sources are the Mississippian Delle Phosphatic Member and Mississippian-Pennsylvanian Manning Canyon Shale (containing 2 to 15 percent total organic content), but not from the Pennsylvanian/Permian Oquirrh basin to the north where they would have been deeply buried and too highly “cooked,” resulting in the migration of hydrocarbons prior to the formation of the thrust belt traps (figures 15 and 16). In central Utah, the question remains whether these rocks have been buried deep enough on the western parts of the hanging walls of the thrust faults to generate hydrocarbons. However, at least as far east as the Paxton thrust (figure 3), the Mississippian section lies just below the basal décollement in the footwall where thrust loading could have generated hydrocarbons. Finally, just south of the play area, heat from Tertiary (Oligocene) volcanism may have provided an extra mechanism to stimulate hydrocarbon generation.

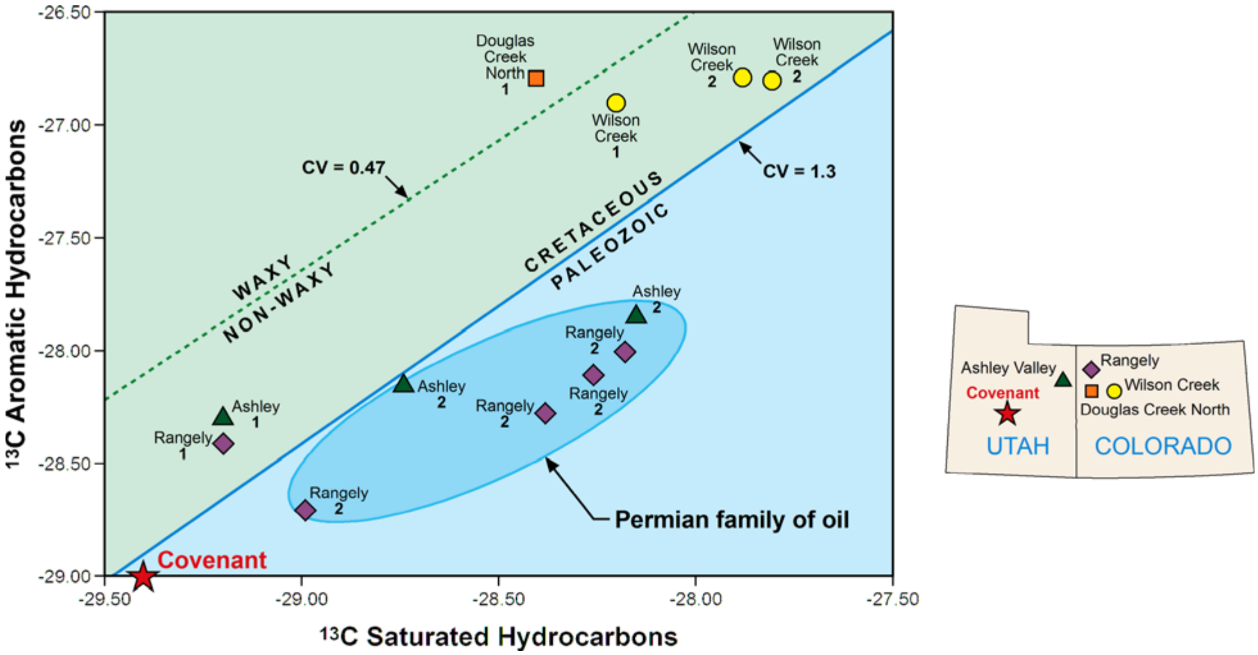

Figure 17. Stable carbon-13 isotope ratios for saturated versus aromatic hydrocarbons from the Covenant field oil and Cretaceous and Permian oils. Units on both axes of the graph depict the carbon isotopes measured in the oil versus the Pee Dee Belemnite (PDB) standard in parts per thousand; a negative value implies the oil sample is depleted in the heavy isotope relative to the standard. Data sources: 1 = Sprinkel and others, 1997; 2 = Lillis and others, 2003; 3 = Baseline DGSI, 2005. CV = canonical variable (Sofer, 1984).

The principal regional seal for the Navajo producing zones consists of salt, gypsum, mudstone, and shale in the Jurassic Arapien Shale (figures 10 and 18). Shale intervals above the dense limestone members in the overlying Jurassic Twin Creek Limestone may serve as additional seals. Interdunal shale and mudstone within the Navajo Sandstone (figure 13), and splay and back thrust faults may act as local seals, barriers, or baffles to fluid flow.

Structure and Trapping Mechanisms

Internal deformation within large-scale thrust plates includes frontal and lateral duplex zones. The deformation front along the leading edge of these major thrusts, particularly the Paxton and Gunnison thrusts, includes complex back thrusting, tectonic-wedge formation, triangle zones, and passive-roof duplexing (Schelling and others, 2005). Fault-propagation/ fault-bend folds and low-amplitude anticlines in both the hanging walls and footwalls of thrusts associated with these features may form multiple structural traps. These features are obscured by complex surface geology which includes (1) major folds (figure 19), (2) angular unconformities, (3) Oligocene volcanic rocks, (4) Basin and Range-age (Miocene-Holocene) listric(?) normal faulting, and (5) local diapirism. There is also potential for updip pinchout and isolated stratigraphic traps in the Mesozoic section.

The Gunnison thrust in the eastern play area is primarily a bedding-plane fault developed in weak mudstone and evaporite beds of the Arapien Shale. Thrust imbricates or imbricate fans above and antiformal stacks of horses forming a duplex below the Gunnison


Figure 18. Arapien Shale exposed in Salina Canyon north of Covenant field; inset photo of salt core from Redmond quarry in the Arapien north of the town of Salina.

thrust create multiple, potential drilling targets (figure 20) (Villien and Kligfield, 1986). Jurassic extensional faults may be the key to hydrocarbon migration pathways and locating antiformal stacks that may contain traps along thrusts (Schelling and others, 2005; Strickland and others, 2005).

Covenant field (figure 3), Sevier County, is located along the east flank of the Sanpete-Sevier Valley fold (figure 19). The Kings Meadow Ranches No. 17-1 discovery well (SE1/4NW1/4 section 17, T. 23 S., R. 1 W., SLBL&M) was drilled updip from two abandoned wells about 2 miles (3 km) to the north: the Standard Oil of California Sigurd Unit No. 1 (NE1/4SE1/4 section 32, T. 22 S., R. 1 W., SLBL&M) drilled in 1957, and the Chevron USA Salina Unit No. 1 (NE1/4NE1/4 section 33, T. 22 S., R. 1 W., SLBL&M) drilled in 1980. The Navajo Sandstone was encountered at subsea depths of –3390 feet (-1033 m) and -2973 feet (-906 m), respectively, in these wells. The dipmeter in the Salina Unit No. 1 well showed 16° structural dip to the northwest in the Navajo. This dip combined with seismic data indicate a structural high to the south. The Kings Meadow Ranches No. 17-1 well penetrated the Navajo at a subsea depth of -94 feet (-29 m).

The Covenant field trap is an elongate, symmetric, northeast-trending fault-propagation/fault-bend anticline, with nearly 800 feet (270 m) of structural closure with a 450-foot (150 m) oil column (Strickland and others, 2005). The Navajo reservoir covers about 960 acres (390 ha). The structure formed above a series of splay thrusts in a passive roof duplex along the Gunnison thrust and west of a frontal triangle zone within the Arapien Shale. The Twin Creek Limestone and Navajo Sandstone are repeated due to an east-dipping back-thrust detachment within the structure. This back thrust forms a hanging-wall cutoff along the west flank and north-plunging nose of the fold. Only the Navajo in the hanging wall of the back thrust (and possibly the Twin Creek) is productive.

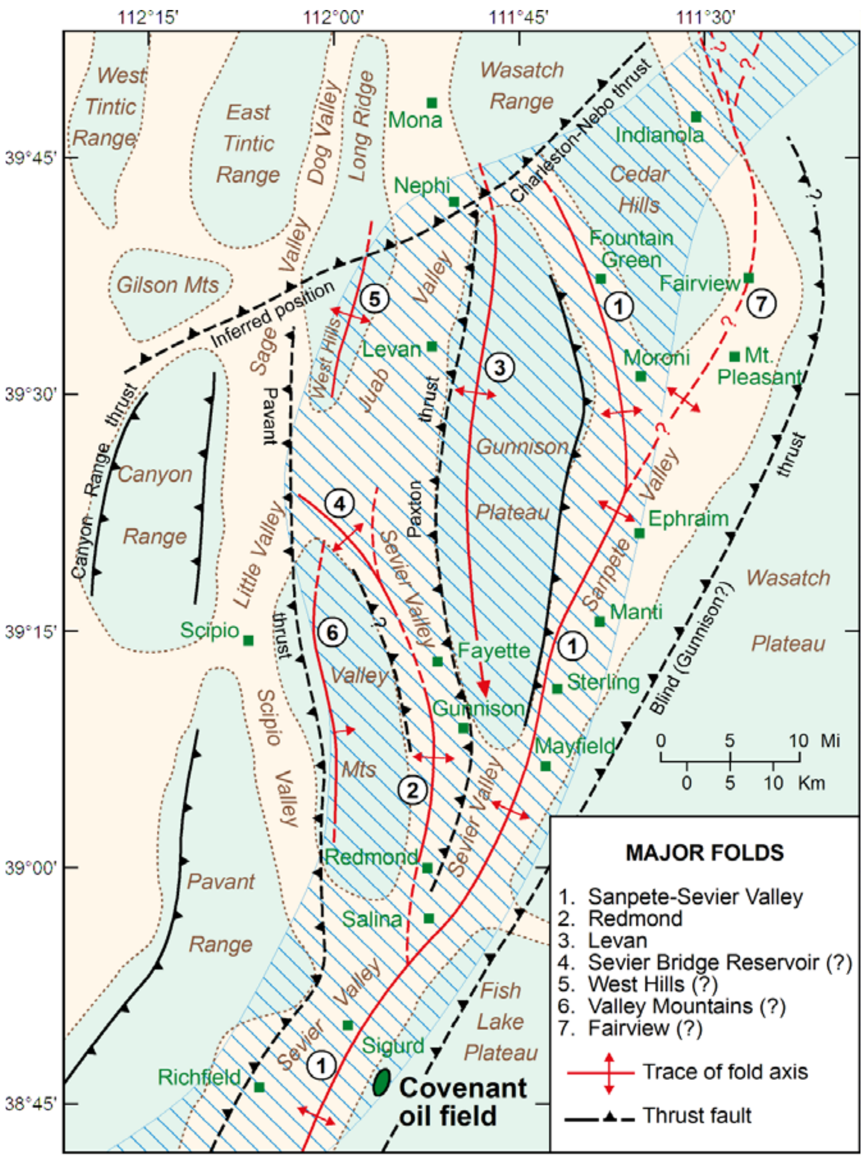

Figure 19. Major folds in central Utah (modified from Witkind, 1982). Play area represented by hachured pattern.

Reservoir Properties

The Navajo has heterogeneous reservoir properties because of (1) cyclic dune/interdune lithofacies with better porosity and permeability in certain dune morphologies, (2) diagenetic effects, and (3) extensive fracturing. These characteristics can be observed in outcrops around the play area (figure 3). Genetic units of eolian sandstone deposits are separated by 1st-order bounding surfaces formed by interdune deposits or major diastems. Internal bounding surfaces are also found within dune cross-beds (Ahlbrandt and Fryberger, 1981; Fryberger, 1990; Grammer and others, 2004). Stacking surfaces or 2nd-order bounding surfaces (superposition surfaces) within a single genetic unit can divide the cross-strata of two dunes and are formed by migrating dunes superimposed on the slipfaces of the underlying dunes (Fryberger, 1990; Grammer and others, 2004; Morris and others, 2005). Growth surfaces or 3rd-order bounding surfaces are high-angle reactivation surfaces dividing sets of ripple strata related to the advance

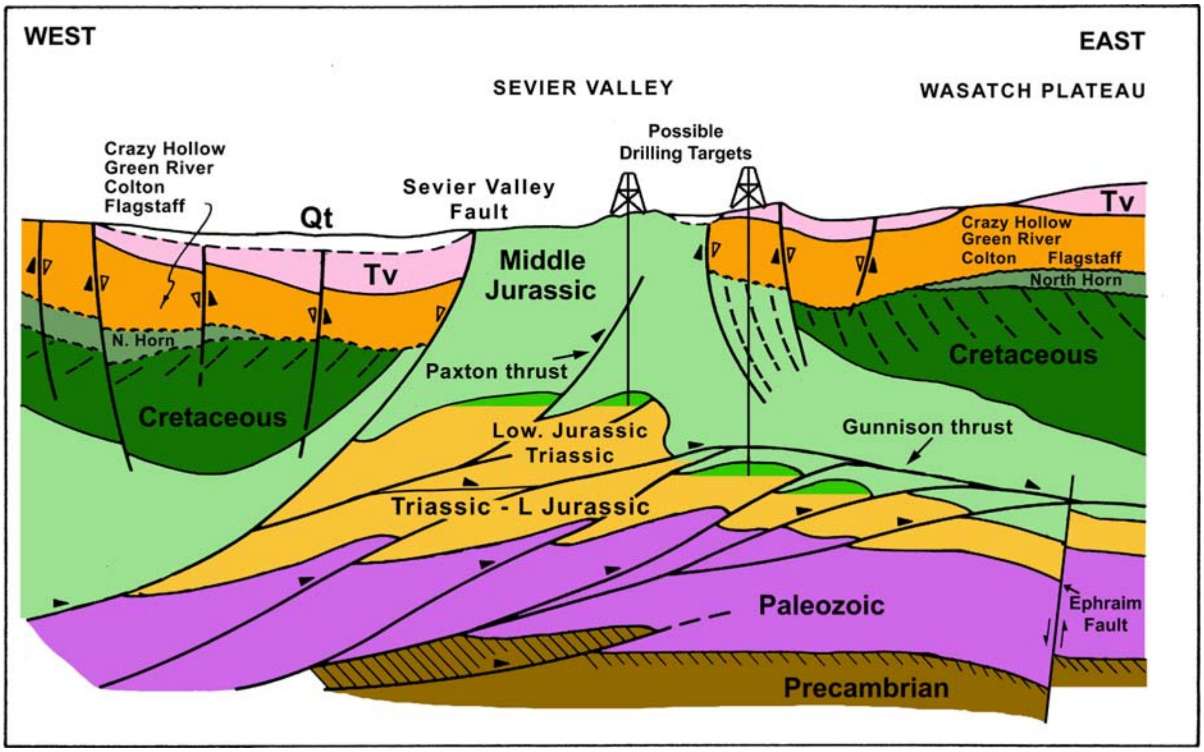

Figure 20. Schematic east-west structural cross section through Sevier Valley, Utah (line of section shown on figure 3), just north of the 2004 Covenant field discovery (Jurassic Navajo Sandstone), showing potential Lower Jurassic exploratory drilling targets in thrust imbricates, fault-propagation folds, and duplexes above and below the Gunnison thrust. Note the presence of the basement-involved Ephraim fault in relationship to the duplex system. Modified from Villien and Kligfield (1986).

of a single dune (Fryberger, 1990; Grammer and others, 2004). These bounding surfaces represent possible barriers or baffles to fluid flow, both vertically and horizontally, within the Navajo reservoir. Identification and correlation of the numerous bounding surfaces as well as recognition of fracture set orientations and types in individual Navajo reservoirs are critical to understanding their effects on production rates, petroleum movement pathways, directionally drilled well plans, and future pressure maintenance programs.

The average porosity for the Navajo Sandstone at Covenant field is 12 percent (Strickland and others, 2005); the average grain density is 2.651 g/cm^3 based on core-plug analysis. Sandstone exhibits significant secondary porosity in the form of fracturing. Permeabilities in the Navajo from the core data are upwards of 100 millidarcies (mD). The best permeability within Navajo dune deposits is along bounding surfaces (bedding planes), with preferred directions along the dip and strike of the individual slipfaces or lee faces (cross-beds) (figure 21; Lindquist, 1983). Porosity and permeability should be greatest in thickly laminated avalanche deposits (Hunter, 1977; Schenk, 1981). Navajo interdunes, as expected, have significantly poorer reservoir characteristics than the dune lithofacies and represent significant barriers to fluid flow. Plotting porosity versus permeability shows gradational changes in reservoir quality within the various dune lithofacies and transitional changes to interdune lithofacies (figure 22). Mapping dune lithofacies prior to a well completion results in identifying zones of maximum drainage effects (Strickland and others, 2005).

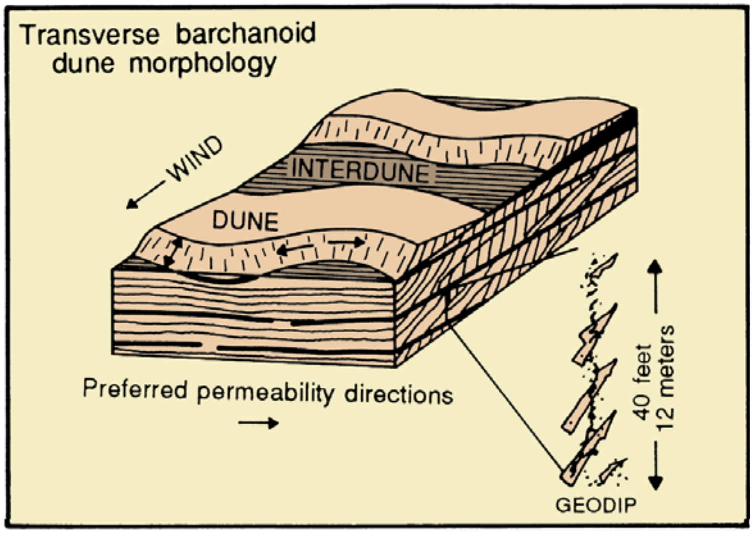

Figure 21. Schematic of the dune/interdune sequence in the Navajo Sandstone correlating transverse barchanoid dune morphology to structurally corrected stratigraphic dipmeter data (Geodip). The slipface of a dune (surface between the dune brink and toe), on which deposits form cross-beds, dips in the downwind, dune-migrating direction. Arrows indicate preferred permeability directions along the dip and strike of dune slipfaces (cross-beds) (after Lindquist, 1983).

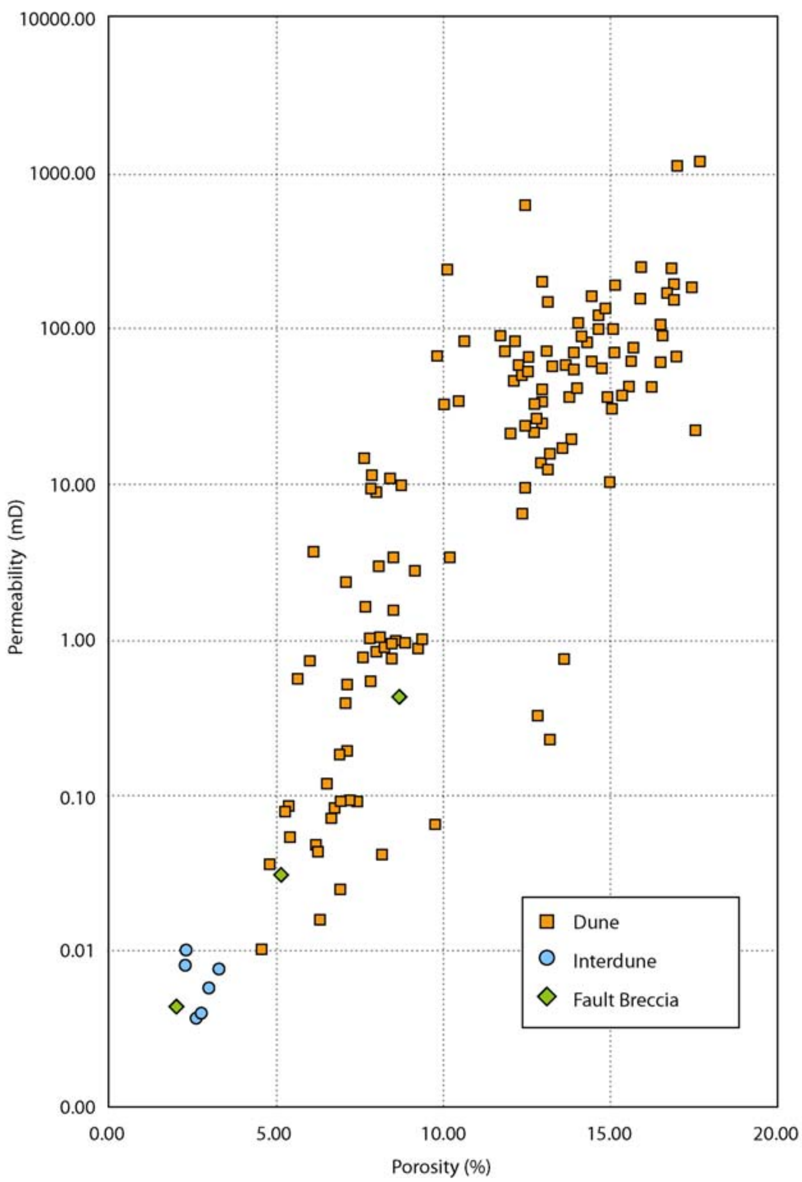

Figure 22. Porosity versus permeability cross plot from the Navajo Sandstone in Covenant field, based on core-plug analysis, showing gradational changes in reservoir quality within the various dune lithofacies and transitional changes to interdune lithofacies; zones of brecciation from faulting are also plotted.

Diagenetic effects and fracturing can both reduce and enhance the reservoir permeability of the Navajo Sandstone. At Covenant field, there are only minor overgrowths of quartz. Some authigenic clay mineralization has occurred in the form of grain-coating, pore-bridging, and fibrous illite. Some ferroan(?) dolomite and fractured, corroded K-feldspar are also present (Strickland and others, 2005). Development of bitumen and gouge-filled, silica-cemented fractures locally reduce reservoir permeability. Dissolution of silicate minerals and the development of open fractures increase reservoir permeability.

Navajo Sandstone gross-pay thickness at Covenant field is 487 feet (148 m) and net-pay thickness is 424 feet (129 m), a net-to-gross ratio of 0.87 (Strickland and others, 2005). The Navajo reservoir temperature is 188ºF (87ºC). The average water saturation is 38 percent, and average produced water resistivity (R_w) is 0.279 ohm-m at 77ºF (25ºC) containing 26,035 total dissolved solids. Initial reservoir pressures average about 2630 pounds per square inch (18,134 kPa). The reservoir drive mechanism is a strong active water drive. Geophysical well logs show a transition zone in terms of water saturation above a very sharp oil/water contact (figure 8).

Oil Characteristics

Covenant field's Navajo oil is a dark brown, low-volatile crude. The API gravity of the oil is 40.5º; the specific gravity is 0.8280 at 60ºF (16ºC). The viscosity of the crude oil is 4.0 centistokes (cst) at 77ºF (25ºC) and the pour point is 2.2ºF (-16.5ºC). The average weight percent sulfur of produced Navajo oil is 0.48; nitrogen content is 474 parts per million. Stable carbon-13 isotopes are -29.4‰ and -29.0‰ for saturated and aromatic hydrocarbons, respectively. The pristane/phytane ratio is 0.96 (Baseline DGSI, 2005).

Production

Covenant field produces oil and water (about 5 percent), and essentially no gas. Cumulative production as of October 1, 2006, was 2,611,688 bbls (415,258 m^3) of oil and 434,629 bbls (69,106 m^3) of water (Utah Division of Oil, Gas and Mining, 2006). Daily oil production averages over 6000 bbls (950 m^3) of oil and just over 1500 bbls (240 m^3) of water. Production steadily increased through July 2006 as new development wells and infrastructure were completed; a slight decline is shown beginning in August 2006 (figure 23). The field currently has 10 producing wells and one dry hole, drilled from two pads. The well spacing is about 40 acres (16 ha) within the Covenant unit.

Wells are completed with small acid (hydrochloric) treatments primarily to clean perforations of clays from drilling muds. Five wells are completed in the lower Navajo unit and five in the upper Navajo unit; none are commingled (Ellis Peterson, Wolverine Gas & Oil Corp., verbal communication, February 2007). Production facilities at the site include two 20,000-barrel (3200 m^3) storage tanks. Oil is trucked to Salt Lake City or to a pipeline at Montezuma Creek in southeastern Utah. The fully developed cost for this first field will be around $56.3 million.

Original oil in place (OOIP) reserves are estimated at 100 million bbls (15.9 million m^3) (John Vrona, Wolverine Gas & Oil Corp., written communication, February 2007). A 40 to 50 percent recovery of the OOIP may be achieved with efficient operations and completion techniques (Strickland and others, 2005). Secondary and tertiary recovery programs may include nitrogen injection and/or a carbon dioxide flood.

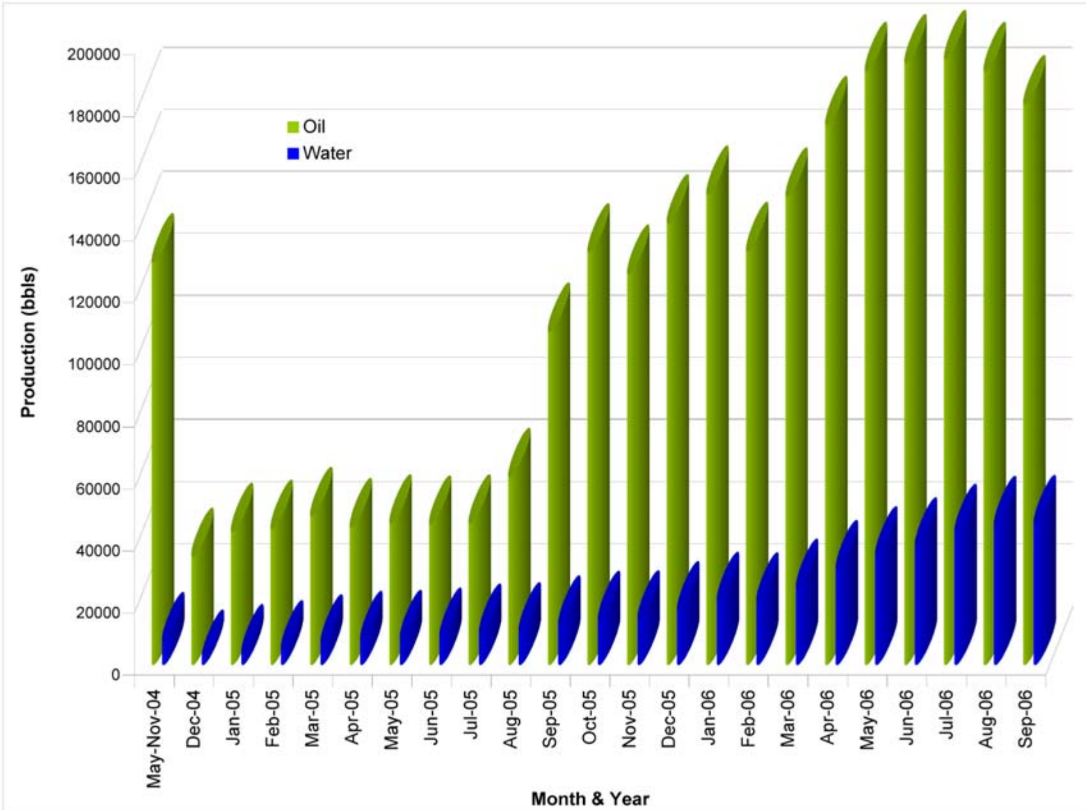

Figure 23. Monthly oil and water production from wells in Covenant field (Utah Division of Oil, Gas and Mining, 2006).

Exploration Potential and Trends

The result of the Covenant discovery has been high prices and competition for available leases in the play, hundreds of miles of new seismic surveys over much of the play area, and new well permits to test various parts of the play. From 2004 through 2006, extensive two-dimensional (2-D) seismic acquisition was permitted and conducted within the play area. Companies may soon turn to three-dimensional seismic to define the crests of structures identified by 2-D seismic. The current high price of oil and the potential to discover other major, or even smaller, oil fields in this play makes the development potential of this play high during the next 15 years.

Exploration in the central Utah thrust belt will focus on Paleozoic-cored, blind, thrust structures east of the exposed Charleston-Nebo and Pavant thrusts. Targets include anticlines associated with thrust imbricate and duplex structures, positioned near Jurassic extensional faults, in the Navajo Sandstone and other reservoirs such as the Permian Park City-Kaibab Formations, Triassic Moenkopi Formation, and Jurassic Twin Creek Limestone (figure 20).

Significant questions remain to be answered concerning the hydrocarbon source and migration history. The lack of any associated gas at Covenant field suggests the possibility that sediment or thrust-plate loading may have driven the gas off during hydrocarbon migration (D. A. Wavrek, Petroleum Systems International, Inc., verbal communication, 2005; Wavrek and others, 2005) or faults acting as baffles caused gas to migrate along different paths than oil. Thus, potential gas-charged traps may be present in the play area.

The potential for finding hydrocarbons may be considerably higher in the southern play area due to the proximity of the Oligocene-age Marysvale volcanic field and likely associated intrusions. High heat flow and igneous activity may have generated carbon dioxide from Paleozoic carbonate or hydrocarbon source rocks in the area.

TECHNOLOGY TRANSFER

The UGS is the Principal Investigator and prime contractor for this project under the U. S. Department of Energy (DOE) Preferred Upstream Management Program (PUMPII). All play maps, reports, databases, and other deliverables produced for the PUMPII project will be published in interactive, menu-driven digital (Web-based and compact disc) and hard-copy formats by the UGS for presentation to the petroleum industry. Syntheses and highlights will be submitted to refereed journals, as appropriate, such as the *American Association of Petroleum Geologists (AAPG) Bulletin* and *Journal of Petroleum Technology*, and to trade publications such as the *Oil and Gas Journal*.

The technology-transfer plan included the formation of a Technical Advisory Board and a Stake Holders Board. These boards meet annually with the project technical team members. The Technical Advisory Board advises the technical team on the direction of study, reviews technical progress, recommends changes and additions to the study, and provides data. The Technical Advisory Board is composed of field operators from the oil-producing provinces of Utah that also extend into Wyoming or Colorado. This board ensures direct communication of the study methods and results to the operators. The Stake Holders Board is composed of groups that have a financial interest in the study area including representatives from the State of Utah (School and Institutional Trust Lands Administration and Utah Division of Oil, Gas and Mining) and the federal government (Bureau of Land Management and Bureau of Indian Affairs). The members of the Technical Advisory and Stake Holders Boards receive all quarterly technical reports and copies of all publications, and other material resulting from the study. Board members also provide field and reservoir data, especially data pertaining to best practices. During the quarter, project team members joined Utah Stake Holders Board members in attending the Uinta Basin Oil and Gas Collaborative Group meeting in Vernal, Utah, on September 21, 2006. Project activities, results, and recommendations were presented at this meeting.

An abstract was submitted to the AAPG on describing Covenant field and the potential for additional discoveries in the central Utah thrust belt play. If the paper is accepted, it will be presented at a poster session during the 2007 AAPG annual convention in Long Beach, California.

Utah Geological Survey *Survey Notes* and Web Site

The UGS publication *Survey Notes* provides non-technical information on contemporary geologic topics, issues, events, and ongoing UGS projects to Utah's geologic community, educators, state and local officials and other decision-makers, and the public. *Survey Notes* is published three times yearly. Single copies are distributed free of charge and reproduction (with recognition of source) is encouraged.

The UGS maintains a Web site on the Internet, http://geology.utah.gov. The UGS site includes a page under the heading *Utah Geology/Oil, Coal, and Energy*, which describes the

UGS/DOE cooperative studies (PUMPII, Paradox Basin [two projects], Ferron Sandstone, Bluebell field, Green River Formation), and has a link to the DOE Web site. Each UGS/DOE cooperative study also has its own separate page on the UGS Web site. The PUMPII project page, http://geology.utah.gov/emp/pump/index.htm, contains (1) a project location map, (2) a description of the project, (3) a reference list of all publications that are a direct result of the project, (4) poster presentations, and (5) quarterly technical progress reports.

Presentation

The following presentation was made during the reporting period as part of the technology transfer activities:

> "Discovering Oil in Old Wells: Recent Success in the Roosevelt Unit and Bluebell Field, Uinta Basin, Utah" by C.D. Morgan, September 13, 2006, at the American Petroleum Institute Rocky Mountain Section Meeting, Roosevelt, Utah. An overview of Uinta Basin oil plays, the geology of Bluebell field, and best practices were included in the presentation.

Project Publication

Bon, R.L., and Chidsey, T.C., Jr., 2006, Major oil plays in Utah and vicinity – quarterly technical progress report for the period April 1 to June 30, 2006: U.S. Department of Energy, DOE/FC26-02NT15133-16, 68 p.

CONCLUSIONS AND RECOMMENDATIONS

1. A combination of depositional and structural events created the right conditions for oil generation and trapping in the major oil-producing provinces (Paradox Basin, Uinta Basin, and thrust belt) in Utah and adjacent areas in Colorado, Wyoming, and Arizona. Oil plays are specific geographic areas having petroleum potential due to favorable source rock, migration paths, reservoir characteristics, and other factors.

2. The only play in the central Utah thrust belt is what we call the Jurassic Navajo Sandstone Hingeline play. The Navajo was deposited in an extensive dune field that extended from Wyoming to Arizona. Playas, mudflats, and oases developed in interdune areas. Traps include anticlines associated with thrust imbricate and duplex structures, positioned near Jurassic extension faults. The principal regional seal for the Navajo producing zones consists of salt, gypsum, mudstone, and shale in the Jurassic Arapien Shale.

3. Hydrocarbons in Navajo Sandstone reservoirs were likely generated from Mississippian source rocks. The source rocks began to mature after loading or overridding by thrust plates. Hydrocarbons were then generated, expelled, and subsequently migrated into overlying traps, primarily along fault planes. Additional study is needed to determine hydrocarbon paths and migration history.

4. The Navajo Sandstone has heterogeneous reservoir properties because of (1) cyclic dune/interdune lithofacies with better porosity and permeability that developed in certain dune morphologies, (2) diagenetic effects, and (3) fracturing. Identifying and correlating barriers and baffles to fluid flow, and recognizing fracture set orientations in potential Navajo reservoirs are critical to understanding their effects on production rates, petroleum movement pathways, secondary/tertiary enhanced recovery projects, and pressure maintenance programs.

5. The Navajo Sandstone at Covenant field has 424 feet (139 m) of net pay, an average of 12 percent porosity, up to 100 mD of permeability, an average water saturation of 38 percent, and a strong water drive. Cumulative production from 10 wells, as of October 1, 2006, was 2,611,688 bbls (415,258 m^3) of oil, averaging over 6000 bbls (950 m^3) of oil per day. The OOIP is estimated at 100 million bbls (15.9 million m^3); the estimated recovery factor is 40 to 50 percent.

6. Prospective drilling targets in the Jurassic Navajo Sandstone Hingeline play are delineated using high-quality 2-D (and in the near-future 3-D) seismic data, 2-D and 3-D forward modeling/visualization tools, well control, dipmeter information, surface geologic maps, and incremental restoration of balanced cross sections to determine trap geometry. Determination of the timing of structural development, petroleum migration, entrapment, and fill and spill histories are critical to successful exploration.

7. Future exploration in the central Utah thrust belt should focus on Paleozoic-cored, blind, thrust structures east of the exposed Charleston-Nebo and Pavant thrusts. The lack of associated gas at Covenant field suggests the possibility that gas-charged traps may be present in the play area.

ACKNOWLEDGMENTS

Funding for this ongoing research was provided as part of the Preferred Upstream Management Program of the U.S. Department of Energy, National Petroleum Technology Office, Tulsa, Oklahoma, contract number DE-FC26-02NT15133. The Contracting Officer's Representative is Virginia Weyland. Support was also provided by the UGS.

We thank Wolverine Gas & Oil Corporation for providing core descriptions, photomicrographs, petrophysical data, and other reservoir analyses from Covenant field; field cores were described by L.F. Krystinik, geologic consultant. James Parker, Liz Paton, Sharon Wakefield, and Cheryl Gustin of the UGS prepared the figures; Michael Laine and Brad Wolverton of the UGS Core Research Center photographed core. Cheryl Gustin formatted the manuscript. This report was reviewed by David Tabet and Michael Hylland of the UGS.

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