MAJOR OIL PLAYS IN UTAH AND VICINITY

QUARTERLY TECHNICAL PROGRESS REPORT

Reporting Period
Start Date: July 1, 2004
End Date: September 30, 2004

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

UTAH GEOLOGICAL SURVEY

January 2005

Contract No. DE-FC26-02NT15133

Submitting Organization: Utah Geological Survey
1594 West North Temple, Suite 3110
P.O. Box 146100
Salt Lake City, Utah 84114-6100
Ph.: (801) 537-3300/Fax: (801) 537-3400

Rhonda Jacobs, Contract Manager
U.S. Department of Energy
National Petroleum Technology Office
1 West 3rd Street
Tulsa, OK 74103-3532

DISCLAIMER

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ABSTRACT

Utah oil fields have produced over 1.2 billion barrels (191 million m^3) of oil from 241 million barrels (38.3 million m^3) of proved reserves. However, 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. The Utah Geological Survey believes this trend can be reversed 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 ninth quarter of the project (July 1 through September 30, 2004). This work included (1) describing the Jurassic Twin Creek Limestone thrust belt play, and (2) technology transfer activities.

One of the most prolific oil plays in the Utah/Wyoming thrust belt province is the Jurassic Twin Creek Limestone, having produced over 15 million barrels (2.4 million m^3) of oil and 93 billion cubic feet (2.6 million m^3) of gas. Traps form on discrete subsidiary closures along major ramp anticlines where the low-porosity Twin Creek is extensively fractured. Hydrocarbons in Twin Creek reservoirs were generated from subthrust Cretaceous source rocks. The seals for the producing horizons are overlying argillaceous and clastic beds, and non-fractured units within the Twin Creek.

The Twin Creek Limestone thrust belt play is divided into two subplays: (1) Absaroka thrust - Mesozoic-cored structures and (2) Absaroka thrust - Paleozoic-cored structures. The Mesozoic-cored structures subplay represents a linear, hanging wall, ramp anticline parallel to the leading edge of the Absaroka thrust. Fields in this subplay produce crude oil and associated gas. The Paleozoic-cored structures subplay is located immediately west of the Mesozoic-cored structures subplay. It represents a very continuous and linear, hanging wall, ramp anticline where the Twin Creek is truncated against a thrust splay. Fields in this subplay produce nonassociated gas and condensate. Traps in both subplays consist of long, narrow, doubly plunging anticlines. Prospective drilling targets are delineated using high-quality two-dimensional and three-dimensional seismic data, forward modeling/visualization tools, and other state-of-the-art techniques.

Future Twin Creek Limestone exploration could focus on more structurally complex and subtle, thrust-related traps. Potential also exists for locating Twin Creek oil reserves in the central Utah thrust belt where reservoir and structural characteristics should be similar to the productive play area to the north.

Technology transfer activities during this quarter consisted of exhibiting a booth display of project materials at the 2004 Rocky Mountain Section Meeting of the American Association of Petroleum Geologists, a technical presentation on oil plays in the Uinta Basin, and publications. Project team members met with the Technical Advisory and Stake Holders Boards to review the project activities and results. Project team members also joined other 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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Utah oil fields have produced over 1.2 billion barrels (191 million m^3) of oil from 241 million barrels (38.3 million m^3) of proved reserves. However, 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. The overall objectives of this study are to (1) increase recoverable oil from existing field reservoirs, (2) add new discoveries, (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 ninth quarter of the project (July 1 through September 30, 2004). This work included (1) describing the Jurassic Twin Creek Limestone thrust belt 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 and Wyoming. Oil plays are specific geographic areas having petroleum potential due to favorable source rock, migration paths, reservoir characteristics, and other factors. One of the most prolific oil reservoirs in the Utah/ Wyoming thrust belt province is the Jurassic Twin Creek Limestone, having produced over 15 million barrels (2.4 million m^3) of oil and 93 billion cubic feet (2.6 million m^3) of gas.

The Twin Creek Limestone was deposited in a shallow-water embayment south of the main body of a Middle Jurassic sea. Traps form on discrete subsidiary closures along major ramp anticlines where the low-porosity Twin Creek is extensively fractured. Hydrocarbons in Twin Creek reservoirs were generated from subthrust Cretaceous source rocks. The seals for the producing horizons are overlying argillaceous and clastic beds, and non-fractured units within the Twin Creek. Most oil and gas production is from perforated intervals in the Watton Canyon, upper Rich, and Sliderock Members of the Twin Creek Limestone. These members have little to no primary porosity in the producing horizons but exhibit secondary porosity in the form of fracturing.

The Twin Creek Limestone thrust belt play is divided into two subplays: (1) Absaroka thrust - Mesozoic-cored structures and (2) Absaroka thrust - Paleozoic-cored structures. The Mesozoic-cored structures subplay represents a linear, hanging wall, ramp anticline parallel to the leading edge of the Absaroka thrust. Fields in this subplay produce crude oil and associated gas. The Paleozoic-cored structures subplay is located immediately west of the Mesozoic-cored structures subplay. The subplay represents a very continuous and linear, hanging wall, ramp anticline also parallel to the leading edge of the Absaroka thrust. The eastern boundary of the subplay is defined by the truncation of the Twin Creek against a thrust splay. Fields in this subplay produce nonassociated gas and condensate. Traps in both subplays consist of long, narrow, doubly plunging anticlines.

Prospective drilling targets in the Twin Creek Limestone thrust belt play are delineated using the following: high-quality two-dimensional and three-dimensional seismic data, forward

modeling/visualization tools, well control, dipmeter information, surface geologic maps, and incremental restoration of balanced cross sections to access trap geometry. Determination of the timing of structural development, petroleum migration, entrapment, and fill and spill histories are critical to successful exploration.

Future Twin Creek Limestone exploration could focus on more structurally complex and subtle, thrust-related traps. Potential also exists for locating Twin Creek oil reserves in the central Utah thrust belt where reservoir characteristics should be similar to the productive reservoirs to the north. Anticlines associated with the Gunnison thrust, a blind thrust in the region, form multiple structural traps that could contain hydrocarbons generated from Mississippian or Permian source rocks.

Technology transfer activities during the quarter consisted of exhibiting a booth display of project materials at the 2004 Rocky Mountain Section Meeting of the American Association of Petroleum Geologists in Denver, Colorado. A poster technical presentation was made at the meeting on oil plays in the Uinta Basin. Project team members met with both the Technical Advisory and Stake Holders Boards in Denver to review the project activities and results. Project team members also joined other 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. Project team members published an abstract, semi-annual report, and two non-technical articles detailing project progress and results.

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, 2004). However, the 13.7 million bbls (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 (Utah Division of Oil, Gas and Mining, 2002). Proven reserves are relatively high, at 241 million bbls (38.3 million m^3) (Energy Information Administration, 2003). With higher oil prices now prevailing, secondary and tertiary recovery techniques should boost future production rates and ultimate recovery from known fields.

Utah's drilling history has fluctuated greatly due to discoveries, oil price trends, and changing exploration targets. During the boom period of the early 1980s, activity peaked at over 500 wells per year. Sustained high petroleum prices are likely to provide 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 1). 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.

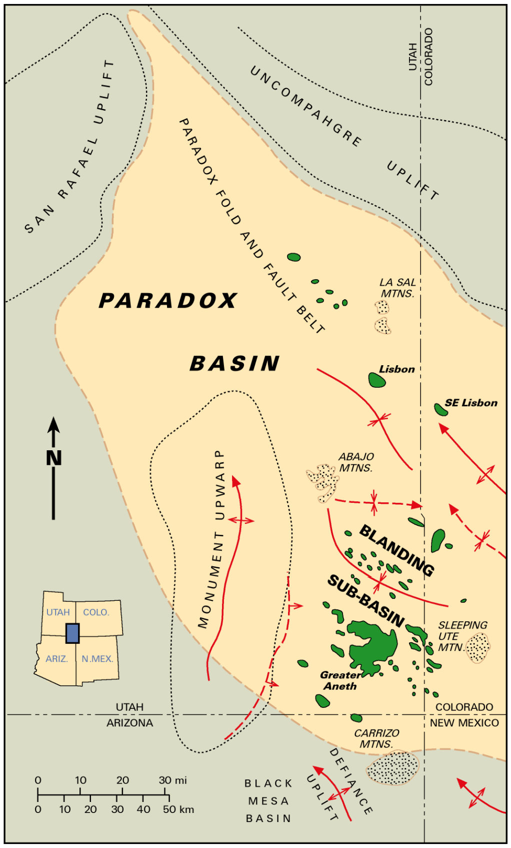
This report covers research activities for the ninth quarter of the project (July 1 through September 30, 2004). This work included (1) describing the Jurassic Twin Creek Limestone thrust belt play, and (2) technology transfer activities.

Project Benefits

The overall goal of this multi-year project is enhanced petroleum production in the Rocky Mountain region. Specifically, the project goal will benefit from the following projects:

(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 rapid facies changes) to increase recoverable reserves,



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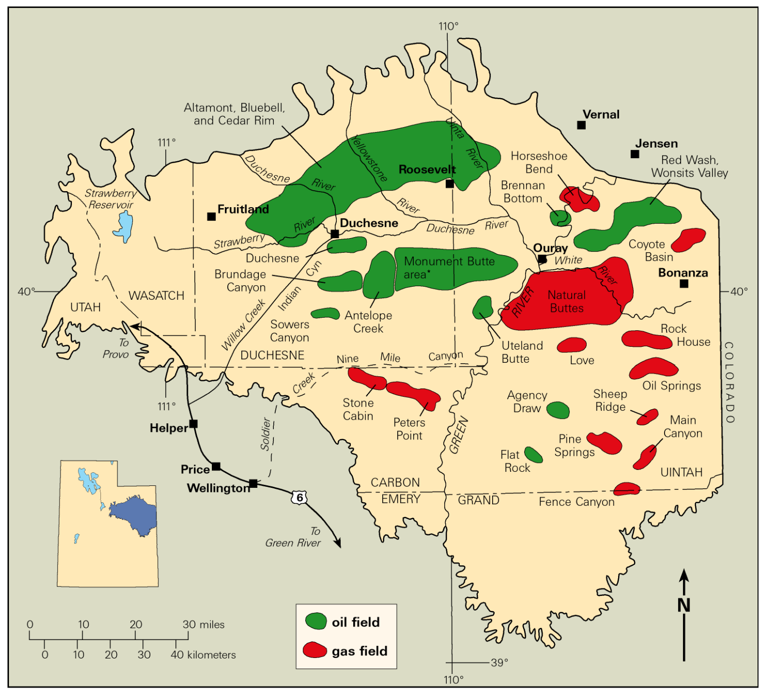

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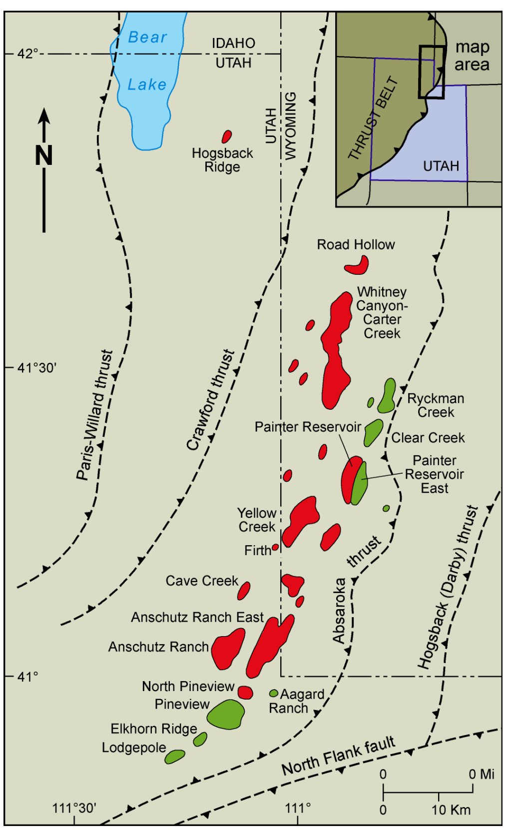

C

Figure 1. Major oil-producing provinces of Utah and vicinity. A - Oil and gas fields in the Paradox Basin of Utah and Colorado. B - Oil and gas fields in the Uinta Basin of Utah. C - Oil and gas fields, uplifts, and major thrust faults in the Utah-Wyoming thrust belt.

(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 identified basins or 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 to reduce development costs and risk, and allow limited energy investment dollars to be used more productively, and

(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 TWIN CREEK LIMESTONE THRUST BELT PLAY – DISCUSSION AND RESULTS

Thrust Belt Overview

The Utah-Wyoming-Idaho salient of the Cordilleran thrust belt is defined as the region north of the Uinta Mountains of northeastern Utah and south of the Snake River Plain of Idaho, with the Green River basin of Wyoming forming the eastern boundary. Thrusting extends westward into the Great Basin for more than 100 miles (160 km). There are four major thrust faults in the region (from west to east): the Paris-Willard, Crawford, Absaroka, and Hogsback (Darby). These thrust faults represent detached (not involving basement rock), compressional styles of deformation. The thrusts generally trend in a north-northeast direction. The leading edges of these faults are listric in form and structurally complex, with numerous folds and thrust splays.

The Absaroka thrust moved in Late Cretaceous time (pre-mid-Santonian to pre-Campanian-Maestrichtian according to Royse and others, 1975). Most thrust belt oil fields are on the Absaroka thrust plate (figure 1C). Traps form on discrete, seismically defined, subsidiary closures along major ramp anticlines.

Twin Creek Limestone Thrust Belt Play Description

A prolific oil and gas play confined to the hanging wall of the Abasroka thrust system is the Jurassic Twin Creek Limestone thrust belt play (figure 2). The Twin Creek has produced over 15 million barrels (2.4 million m^3) of oil and 93 billion cubic feet (2.6 million m^3) of gas. The play outline 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 Twin Creek thrust belt 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 Twin Creek play may meet the exploration guidelines of major oil companies while other aspects meet the development guidelines of small, independent companies.

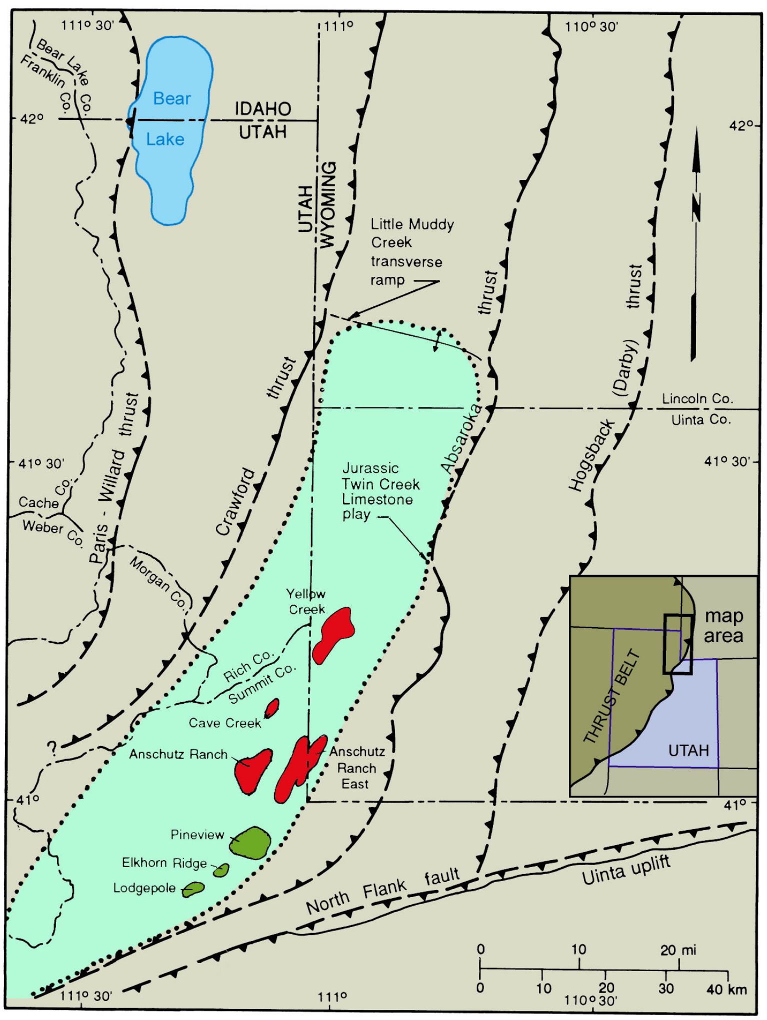

Figure 2. Location of reservoirs that produce oil (green) and gas and condensate (red) from the Jurassic Twin Creek Limestone, Utah and Wyoming; major thrust faults are dashed where approximate (teeth indicate hanging wall). The Twin Creek Limestone thrust belt play area is dotted (modified from Sprinkel and Chidsey, 1993).

Prospective drilling targets in the Twin Creek Limestone thrust belt play are delineated using high-quality seismic data (two-dimensional [2-D] and three-dimensional [3-D]), 2-D and 3-D forward modeling/visualization tools, well control, dipmeter information, high-quality surface geologic maps, and detailed analyses of structural geometry (Chidsey, 1999; Meneses-Rocha and Yurewicz, 1999). Incremental restoration of balanced cross sections is one of the best methods to access 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).

The Jurassic Twin Creek Limestone thrust belt play is in the southwest Wyoming and northern Utah thrust belt (figure 2). Pineview field was the first to produce oil and gas from the Twin Creek in 1975 (Conner and Covlin, 1977; Petroleum Information, 1981). There are currently seven Twin Creek fields, with only one in Wyoming (Yellow Creek). Geologic data for individual fields in the play are summarized in table 1. The Twin Creek Limestone play is divided into two subplays (1) Absaroka thrust - Mesozoic-cored structures and (2) Absaroka thrust - Paleozoic-cored structures.

Depositional Environment

The Twin Creek Limestone and equivalent rocks were deposited in a shallow-water embayment south of the main body of a Middle Jurassic sea that extended from Canada to southern Utah (figure 3) (Imlay, 1980; Kocurek and Dott, 1983; Hintze, 1993). Eustatic fluctuations caused numerous transgressions and regressions resulting in deposition of shallow-water carbonates, fine-grained clastic redbeds, and sabkha evaporites (Imlay, 1967, 1980; Kocurek and Dott, 1983). Carbonate mudstone (figure 4) was deposited in backbank, low-energy brackish water environments. Sporadic oolitic- and peloid-bearing beds represent higher energy environments; a few zones contain fossils and fossil hash.

Stratigraphy and Thickness

Seven formal members are recognized in both nearby outcrops and the subsurface within the Twin Creek Limestone thrust belt play area (Imlay, 1967) and each member has a characteristic geophysical log response (figure 5). Thickness of the Twin Creek ranges from approximately 1400 feet to nearly 1900 feet (470-630 m) (Imlay, 1967; Sprinkel and Chidsey, 1993) in the thrust belt, where it is overlain by the Preuss Formation and underlain by the Nugget Sandstone, both Jurassic in age. The average depth to the Twin Creek for these reservoirs is 6598 feet (2011 m).

Lithology and Fracturing

The Twin Creek Limestone is composed of a variety of lithologies including micritic to argillaceous limestone, evaporites, and siltstone and claystone. Tightly cemented oolitic grainstone, dolomitized zones, and thin shaly intervals are also present (Bruce, 1988; Parra and Collier, 2000). Post-burial diagenesis includes cementation, compaction, and fracturing. Oil and gas production comes from zones in the denser, naturally fractured carbonate beds in the

Table 1. Geologic, reservoir, and production data for fields in the Jurassic Twin Creek Limestone thrust belt play. Data from Petroleum Information (1981), Bruce (1988), Benson (1993a, 1993b), Cook and Dunleavy (1993), Sprinkel and Chidsey (1993), Utah Division of Oil, Gas and Mining (2004, and well records), and Wyoming Oil & Gas Conservation Commission (2004).

State	County	Field	Discovery Date	Active Producers	Abandoned Producers	Acres	Spacing (acres)	Pay (feet)	Porosity (%)	Perm. (mD)	Temp. (°F)	Initial Reservoir Pressure (psi)	Average Monthly Production		Cumulative Production	
													Oil (bbl)	Gas (MCF)	Oil (bbl)	Gas (BCF)
Utah	Summit	Anschutz Ranch	1978	5	7	2880	320	520	3	30	124	2660	425	34,230	701,323	46.569
Utah	Summit	Anschutz Ranch East	1991	1	0	80	80	322	4	NA	188	NA	143	3477	1002	0.024
Utah	Summit	Cave Creek	1983	0	3	1600	640	20	4	NA	125	2396	0	0	133,208	9.761
Utah	Summit	Elkhorn Ridge	1977	3	3	480	40	90	3	7	168	3854	22	0	1,837,067	0.849
Utah	Summit	Lodgepole	1976	4	4	640	160	75	3	7	168	4474	386	0	1,675,009	0.520
Utah	Summit	Pineview	1975	7	12	2080	80	200	2	3.8	210	4200	7451	17,044	8,731,711	10.544
Wyoming	Uinta	Yellow Creek	1976	1	27	7840	160	170	2	NA	117	2555	13	2237	2,029,877	24.777

NA = Not Available

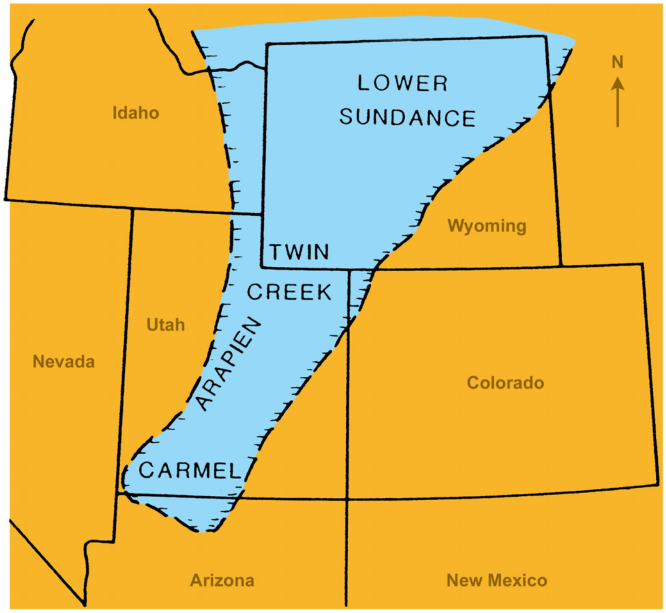

Figure 3. Generalized map of the Middle Jurassic marine invasion of the Sundance-Twin Creek-Arapien-Carmel seas from the north (modified from Kocurek and Dott, 1983; Hintze, 1993).

Figure 4. Typical Twin Creek Limestone, Watton Canyon Member, from the UPRR No. 3-3 well (section 3, T. 2 N., R. 7 E., SLBL, slabbed core from 8749 feet) showing finely laminated, carbonate mudstone deposited in backbank, low-energy brackish water environment. Note that essentially no porosity is present.

middle to lower part of the formation (figure 6). Fracturing is related to fault-propagation folding during the Sevier orogeny (Royce and others, 1975; Conner and Covlin, 1977; Dixon, 1982; Lamerson, 1982; Bruce, 1988). In Lodgepole field (figure 2) and elsewhere, the fracture intensity is controlled by lithology (Parra and Collier, 2000). Dolomitized mudstone has considerable fracturing; for example, significant fracturing occurs near the base of the Watton Canyon Member. Fracture intensity decreases as silt content increases and dolomitization decreases; for example, only rare fractures are found in the Giraffe Creek and upper Leeds Creek Members (Parra and Collier, 2000).

Hydrocarbon Source and Seals

Hydrocarbons in Twin Creek Limestone reservoirs were generated from subthrust Cretaceous source rocks (Warner, 1982; Bruce, 1988). These include organic-rich units in the Bear River, Aspen (Mowry equivalent [Nixon, 1973]), and Frontier Formations. The source rocks began to mature after being overridden by thrust plates. Hydrocarbons were then generated, expelled, and subsequently migrated, primarily along fault planes, into overlying traps.

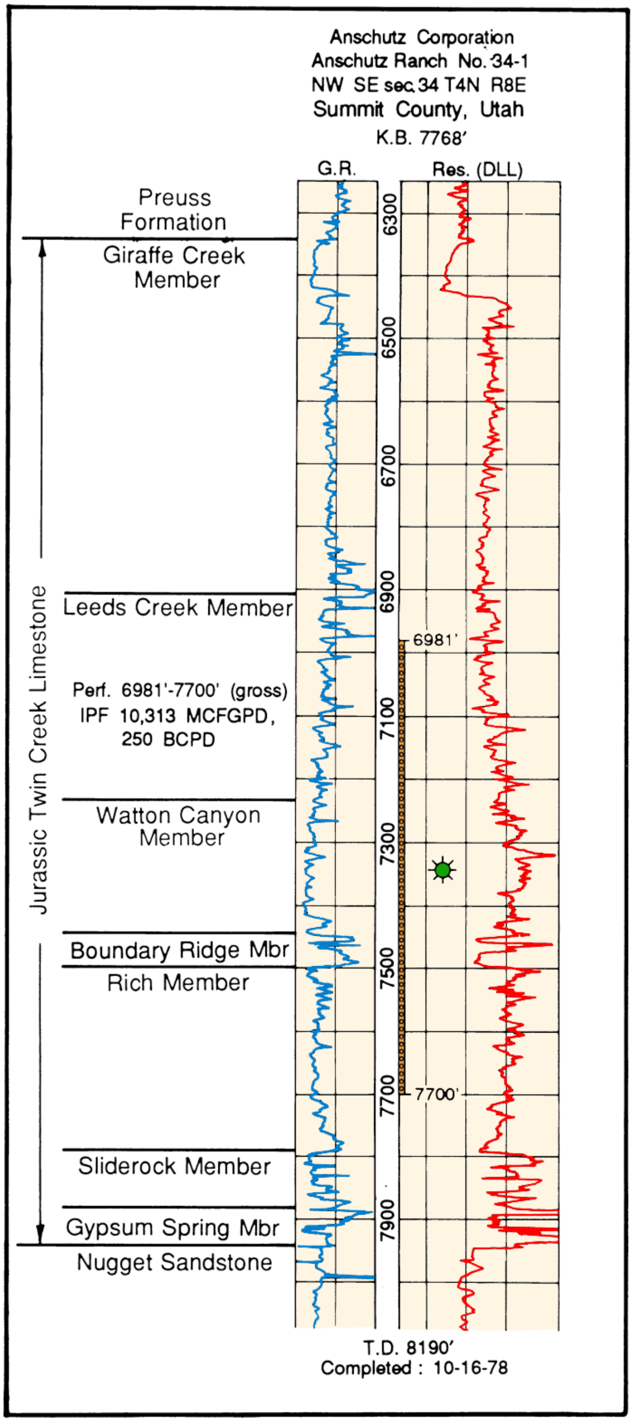

Figure 5. Typical gamma ray-resistivity log of the members of the Twin Creek Limestone, Anschutz Ranch field discovery well, Summit County, Utah.

Figure 6. Twin Creek Limestone reservoir rock, Watton Canyon Member, from the UPRR No. 3-3 well (section 3, T. 2 N., R. 7 E., SLBL, slabbed core from 8747 feet) showing highly fractured carbonate mudstone with open, bitumen-lined and calcite-filled fractures. Note zone of fossil hash at the base of the core.

Burtner and Warner (1984) evaluated the hydrocarbon generation from the Mowry Shale in the Green River Basin (overridden in the western part by the thrust belt) and other northern Rocky Mountain basins. Their study showed that the Mowry ranges from 0.7 to 4.1 weight percent total organic content (TOC) and contains a mixture of type II (marine) and type III (terrestrial) organic matter. In the Green River Basin, areas of Mowry with T_{max} values (the temperature during pyrolysis of peak hydrocarbon generation) greater than 435ºC coincide with areas anomalously low in TOC, indicating that hydrocarbons and CO_2 were generated and subsequently migrated out of the source beds (Burtner and Warner, 1984).

The seals for the producing horizons are overlying argillaceous and clastic beds, and non-fractured units within the Twin Creek Limestone. Hydrocarbons in the Twin Creek are further sealed by salt beds within the overlying Preuss Formation.

Structure and Trapping Mechanisms

Absaroka thrust – Mesozoic-cored structures subplay: The Twin Creek Limestone Absaroka thrust - Mesozoic-cored structures subplay is located in the western part of Summit County, Utah and Uinta County, Wyoming (figure 7). The subplay represents a linear, hanging wall, Mesozoic-cored, ramp anticline parallel to the leading edge of the Absaroka thrust (figure 8). This ramp anticline can be divided into a broad structural high (culmination) and a structural low (depression) within the subplay area. The culmination is present in the southern part of the subplay and related to the proximity of a transverse ramp associated with the Uinta uplift (Lamerson, 1982; Chidsey, 1993). The depression is located in the northernmost part of the subplay area in Summit County, Utah, and southwestern Uinta County, Wyoming, between the culmination to the south and another culmination related to the Muddy Creek transverse ramp to the north in Lincoln County, Wyoming (figure 2) (Lamerson, 1982; Chidsey, 1993). The eastern boundary of the subplay is defined by the truncation of the Twin Creek Limestone against the leading edge of the Absaroka thrust. The western boundary is defined by a branch line representing the intersection of the thrust planes of the Absaroka thrust and a large imbricate thrust (Boyer and Elliott, 1982). The southern part of the Absaroka thrust plate trends southwest toward the Wasatch Range where the Twin Creek Limestone play area terminates. The subplay extends north as a 5-mile- (8-km-) wide band into Uinta County, Wyoming (figure 7).

Potential petroleum-trapping mechanisms in the Twin Creek Limestone Absaroka thrust - Mesozoic-cored structures subplay consist of long, narrow, doubly plunging anticlines (figure 9) (Royce and others, 1975; Conner and Covlin, 1977; Dixon, 1982; Lamerson, 1982). These anticlines are asymmetric, overturned to the east, and often develop en echelon structures along the leading edge of the Absaroka thrust because of variations in the competence and thickness of the stratigraphic sequence (West and Lewis, 1982). Traps on the culmination typically produce oil and associated gas; traps on the depression produce nonassociated gas and retrograde condensate. All fields in the Twin Creek Limestone Absaroka thrust - Mesozoic-cored structures subplay are located on subsidiary closures associated with the southern culmination in Utah. Pineview field, Summit County, Utah, exemplifies the traps in the subplay (figures 7, 9, and 10). The reservoir covers approximately 1280 acres (572 ha) with more than 1000 feet (300 m) of structural closure. However, to date, no Twin Creek production has been discovered on traps in the structural depression.

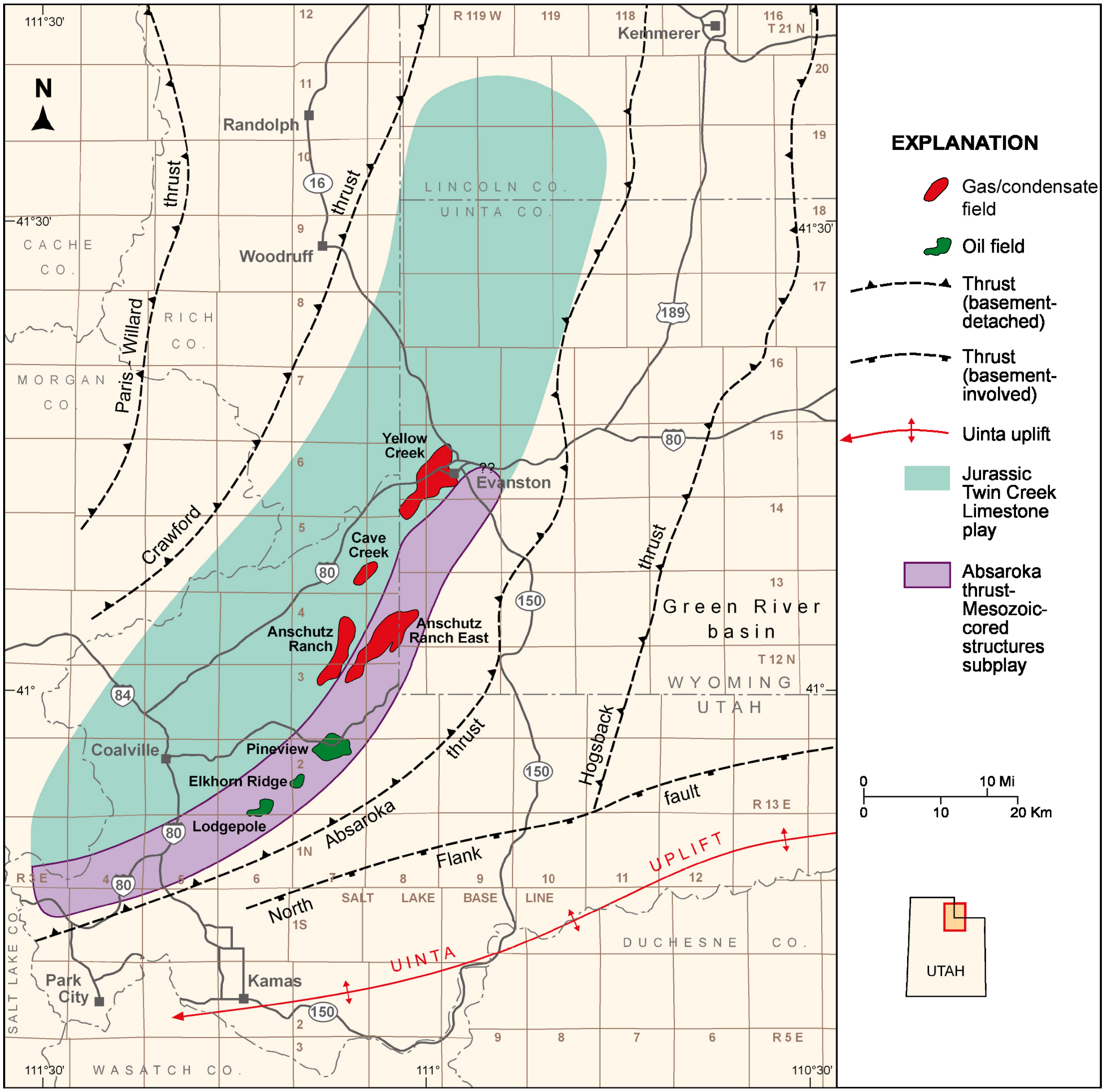

Figure 7. Location of the Twin Creek Limestone Absaroka thrust - Mesozoic-cored structures subplay, Summit County, Utah and Uinta County, Wyoming.

<u>Absaroka thrust – Paleozoic-cored structures subplay:</u> The Twin Creek Limestone Absaroka thrust - Paleozoic-cored structures subplay is located immediately west of the Mesozoic-cored structures subplay (figure 11). The subplay represents a very continuous and linear, hanging wall, Paleozoic-cored, ramp anticline parallel to the leading edge of the Absaroka thrust (figure 12). The eastern boundary of the subplay is defined by the truncation of the Twin Creek against a thrust splay. The western boundary is defined as the point at which the dips on the west flank of the ramp anticline begin to flatten out. The southern part of this ramp anticline trends southwest toward the Wasatch Range where the play area terminates. The play extends north as a 3-mile- (4.8-km-) wide band through Summit County, Utah and into Uinta County, Wyoming (figure 11).

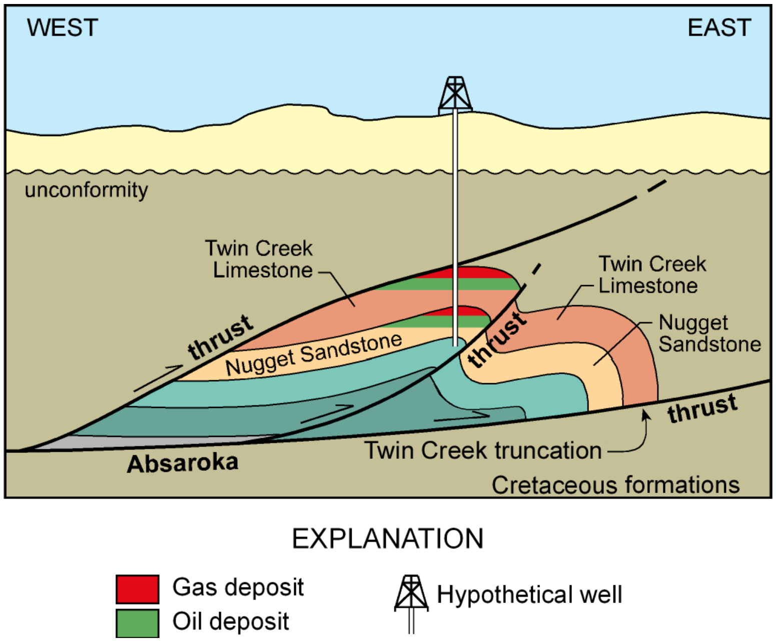

Figure 8. Schematic cross section of traps in the Twin Creek Limestone Absaroka thrust - Mesozoic-cored structures subplay.

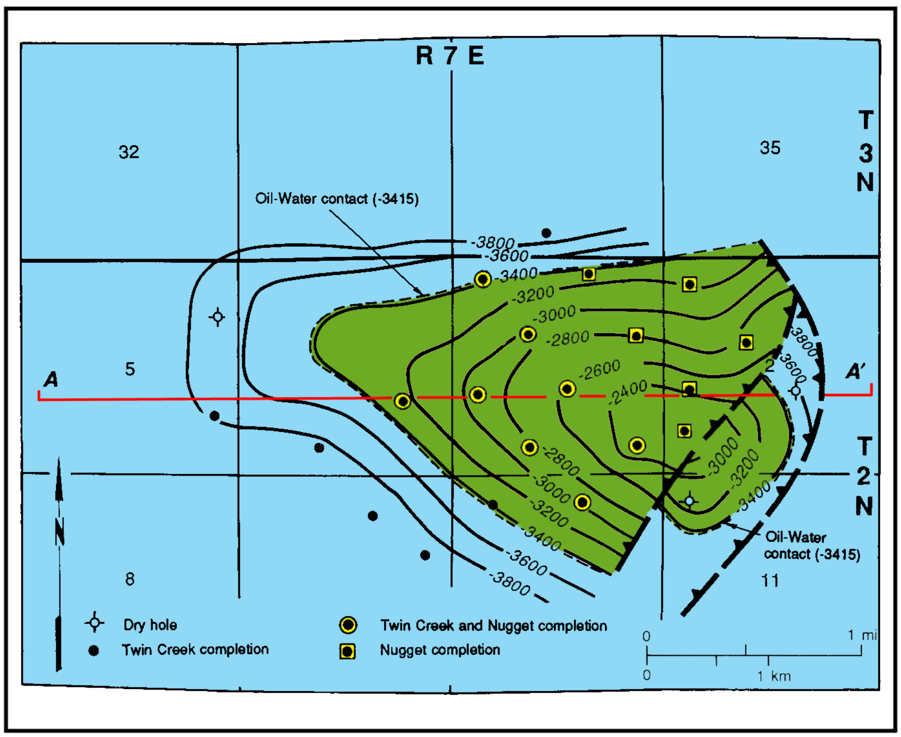

Figure 9. Structure contour map of the base of the Twin Creek Limestone/top of the Nugget Sandstone, Pineview field, Summit County, Utah, typical of the geometry of Mesozoic-cored structures on the southern culmination, Jurassic Twin Creek Limestone thrust belt play. Oil is trapped in an asymmetrical thrusted anticline in the hanging wall of the Absaroka thrust system. After Utah Division of Oil, Gas and Mining (1978). Cross section A-A' shown on figure 10.

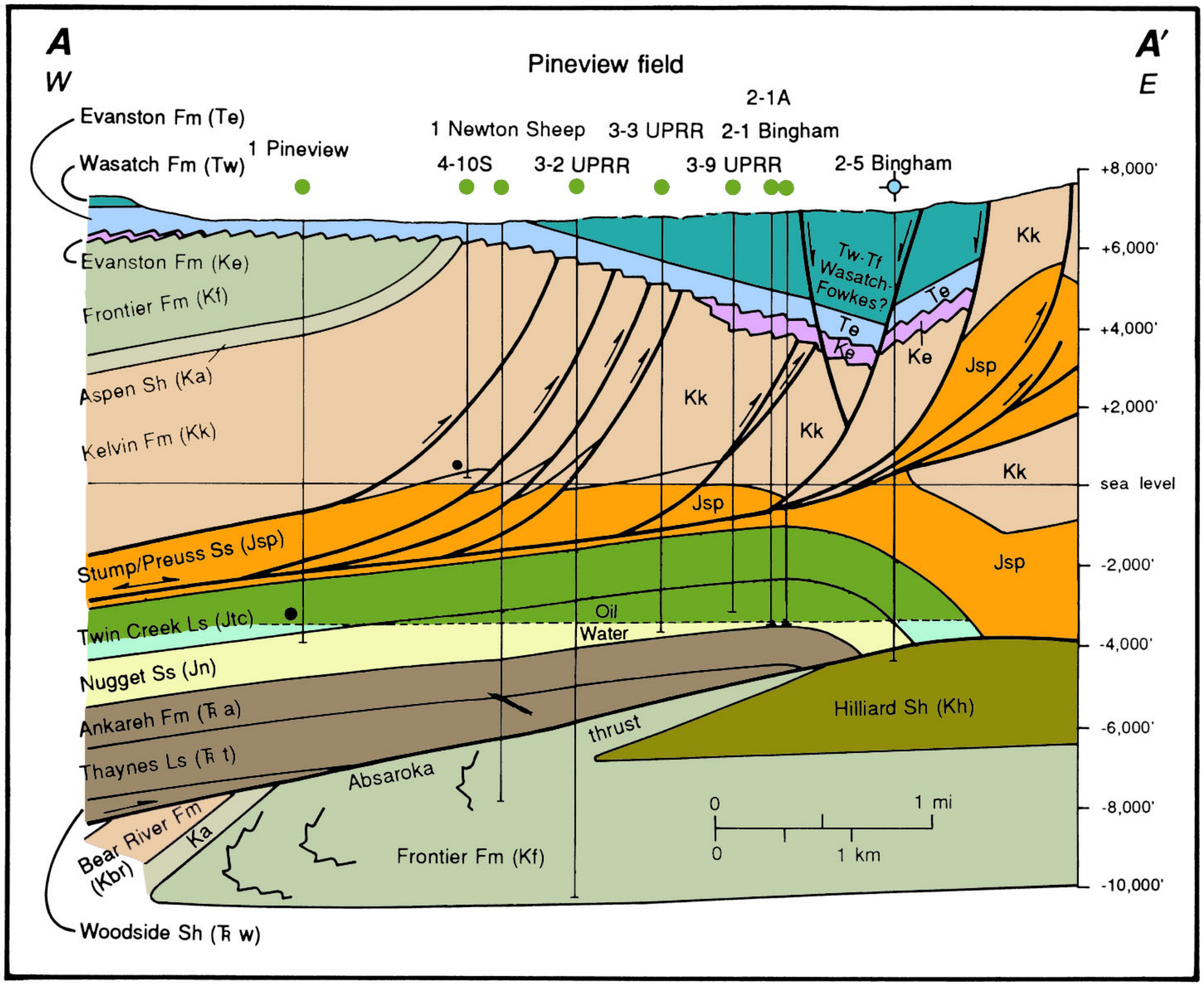

Figure 10. East-west cross section through the Pineview structure. Line of section shown on figure 9. Note that the reservoir also produces oil from the Jurassic Nugget Sandstone that has a common oil/water contact with the Twin Creek Limestone. Reservoirs are juxtaposed against Cretaceous source rocks in the subthrust along the east flank of the structure. After Lamerson (1982).

Potential petroleum-trapping mechanisms in the Twin Creek Limestone Absaroka thrust - Paleozoic-cored structures play also consist of long, narrow, doubly plunging anticlines that trend north to northeast (figures 13 and 14) (Royce and others, 1975; Conner and Covlin, 1977; Petroleum Information, 1981; Dixon, 1982; Lamerson, 1982; Bruce, 1988). These anticlines are also asymmetric and overturned to the east. Splay faults and salt near the anticlinal axes are common, complicating drilling operations and compartmentalizing productive zones. There are three fields in the Twin Creek Limestone Absaroka thrust - Paleozoic-cored structures subplay (figure 11). For example, the Anschutz Ranch field, Summit County, Utah, consists of a large, elongate anticline with more than 7100 feet (2164 m) of structural closure involving Jurassic through Ordovician rocks; the reservoir covers approximately 2880 acres (1170 ha).

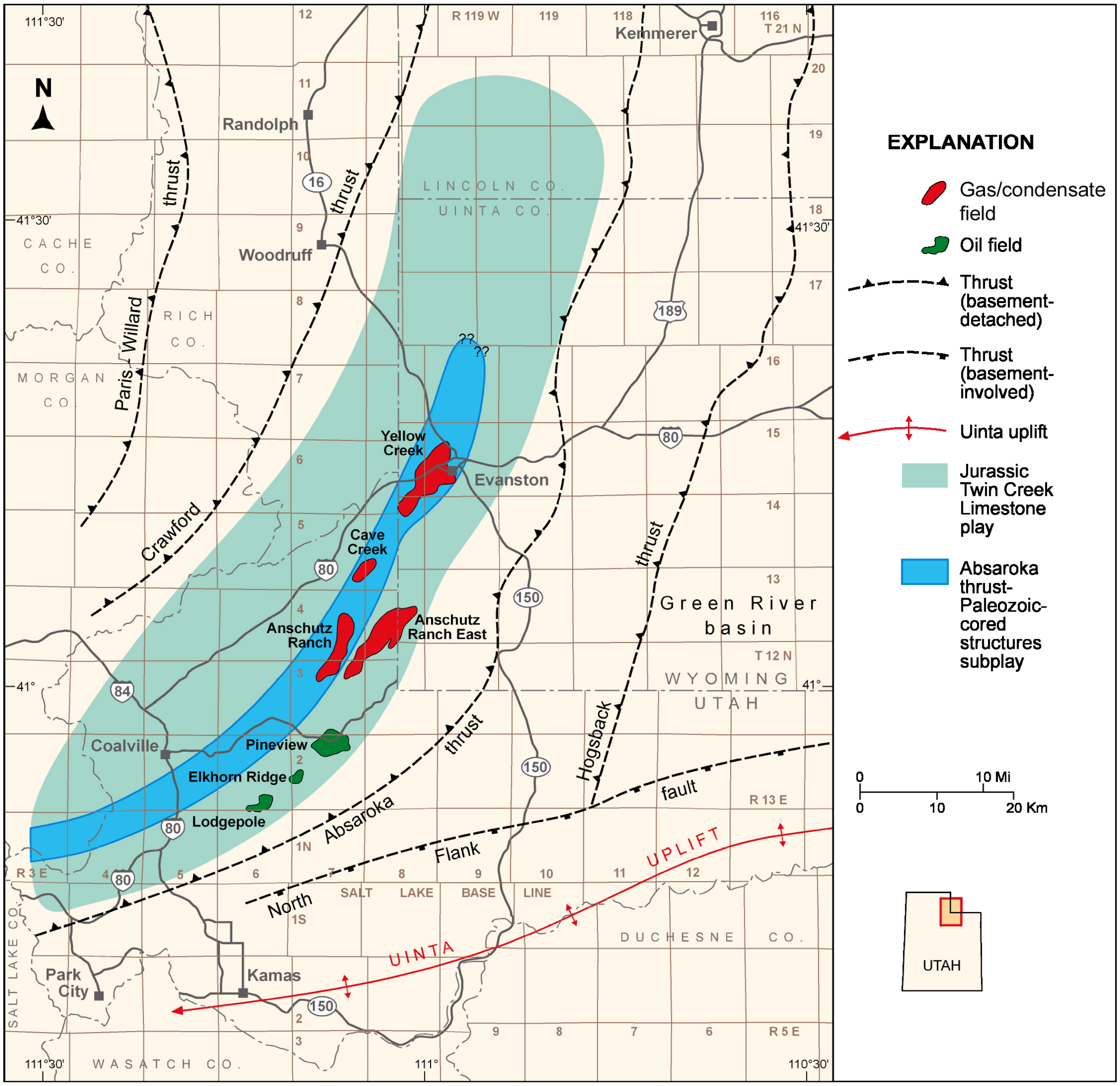

Figure 11. Location of the Twin Creek Limestone Absaroka thrust - Paleozoic-cored structures subplay, Summit County, Utah and Uinta County, Wyoming.

Reservoir Properties

Most oil and gas production is from perforated intervals in the Watton Canyon, upper Rich, and Sliderock Members (figure 5). These members have primary porosity ranging from 2 to 4 percent, when present, in the producing horizons (Bruce, 1988), but exhibit significant secondary porosity in the form of fracturing. Permeabilities in these members range from 4 to more than 30 millidarcies (md) (Benson, 1993a, 1993b; Cook and Dunleavy, 1993; Sprinkel and Chidsey, 1993). The permeability is also formed by natural fractures, and controls hydrocarbon production and injection fluid pathways (Parra and Collier, 2000). Other members produce hydrocarbons, but the volume is typically small and the production zones generally require acidizing or other stimulation. The net pay thickness is variable, depending on fracturing, and ranges from 30 to 150 feet (10-50 m).

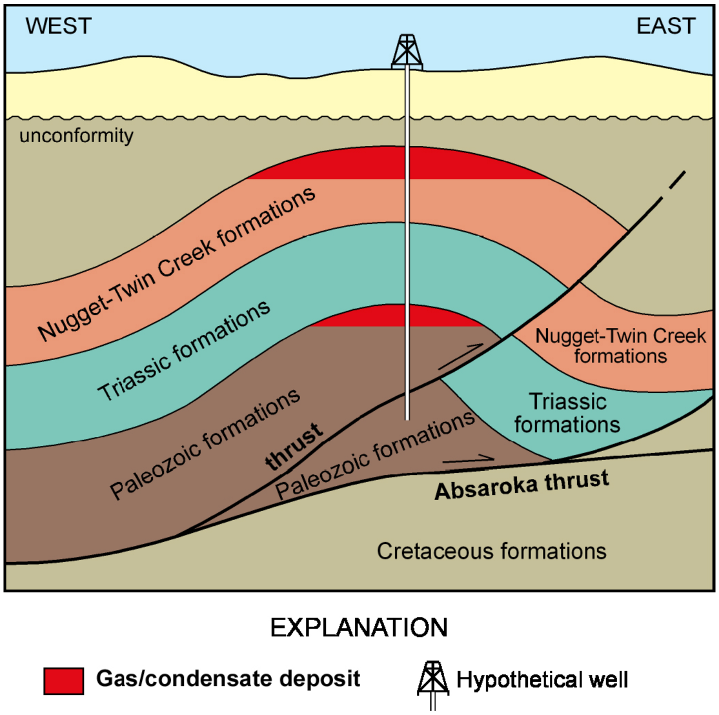

Figure 12. Schematic cross section of traps in the Twin Creek Limestone Absaroka thrust - Paleozoic-cored structures subplay.

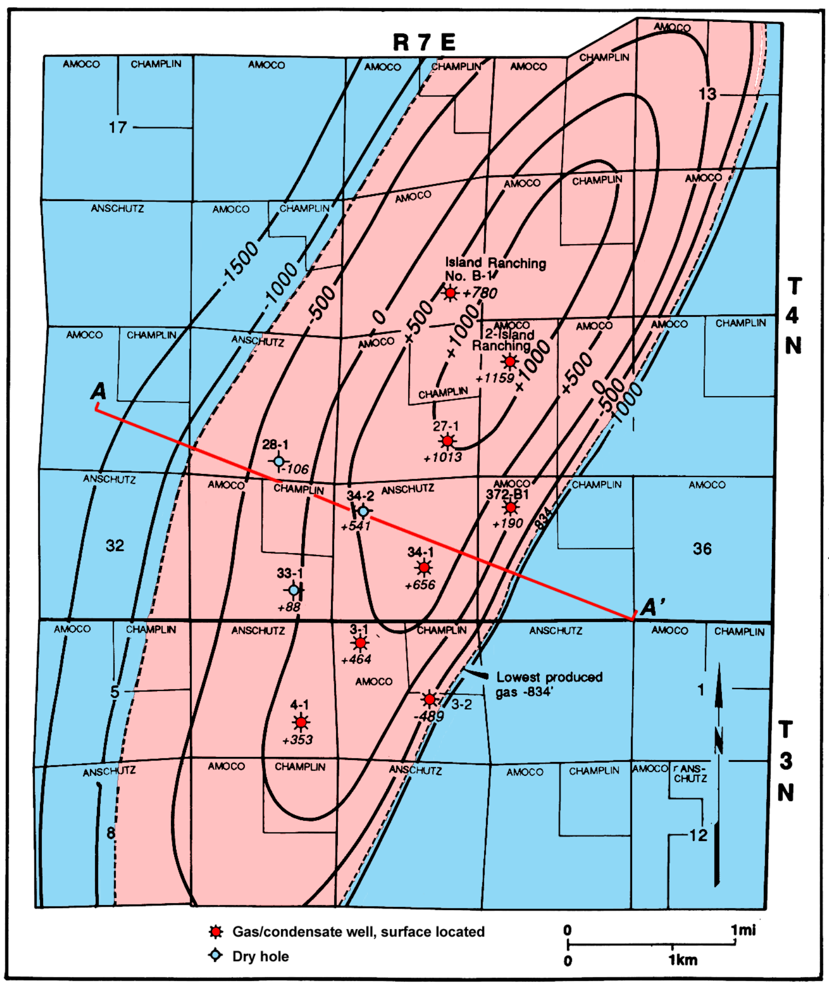

Figure 13. Structure contour map of the top of the Twin Creek Limestone, Anschutz Ranch field, Summit County, Utah, typical of the geometry of Paleozoic-core structures in the Jurassic Twin Creek Limestone thrust belt play. Gas and condensate are trapped by the doubly plunging, asymmetric anticline in the hanging wall of the Absaroka thrust system. Modified from Utah Division of Oil, Gas and Mining (1980a). Cross section A-A' shown on figure 14.

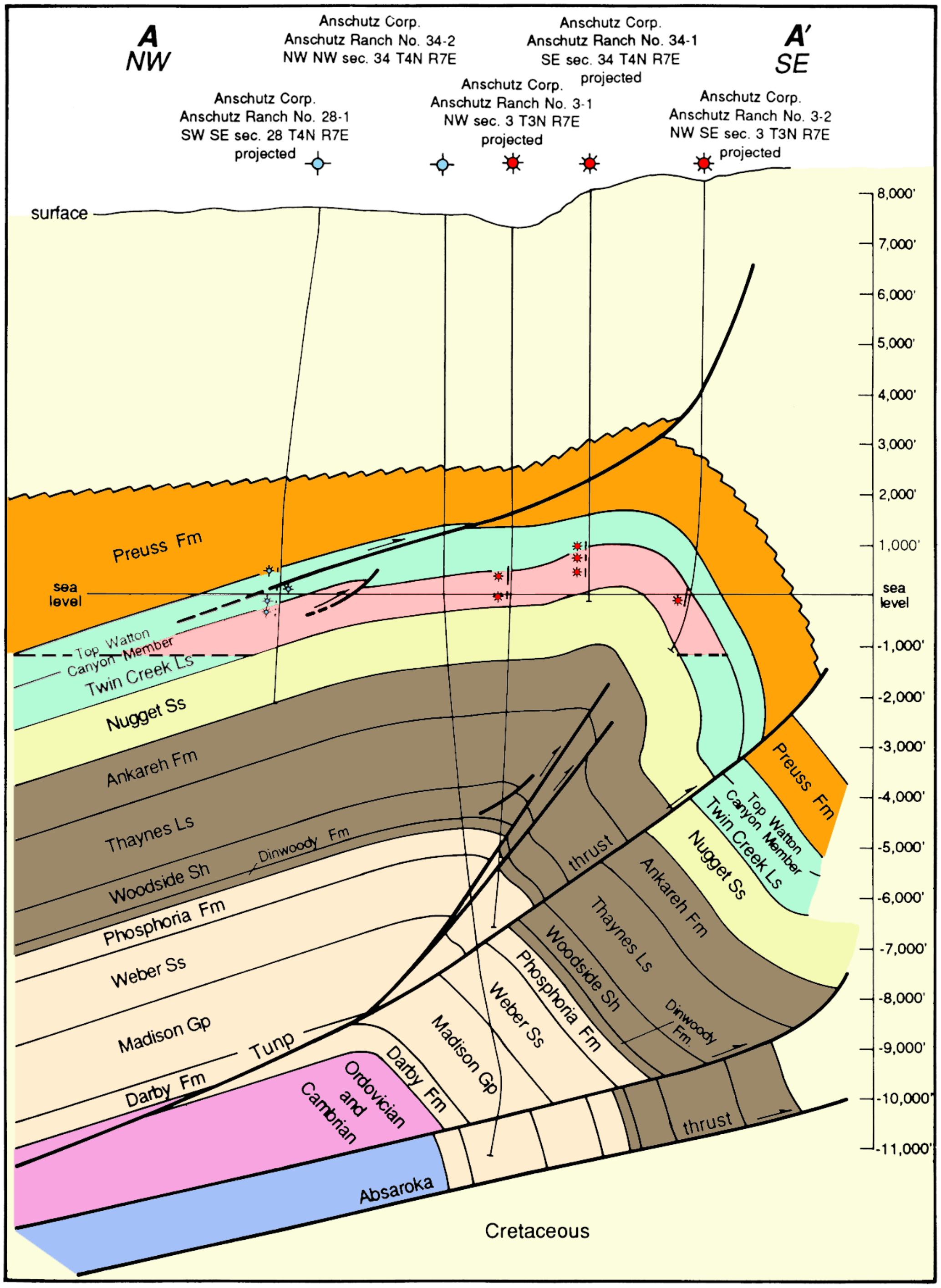

Figure 14. Northwest-southeast cross section through the Anschutz Ranch structure. Line of section shown on figure 13. Cretaceous formations in the footwall of the Absaroka thrust system charge the overlying, highly fractured limestone beds of the Twin Creek Limestone with gas, condensate, and oil. Modified from Utah Division of Oil, Gas and Mining (1980b).

Closely spaced fractures are developed on bedding planes and within dense, homogeneous, non-porous (in terms of primary porosity) limestone beds of the Rich and Watton Canyon Members. The contact with the basal siltstone units (where fractures are sealed) of the overlying members set up the Rich and Watton Canyon for hydrocarbon trapping and production. Thin-bedded siltstone within the Rich and Watton Canyon Members creates additional reservoir heterogeneity.

The average Twin Creek reservoir temperature is 150ºF (65ºC). Water saturations range from 15 to 37 percent, with a salinity of 25,000 ppm NaCl and a resistivity (R_w) of 0.160 ohm-m at 68ºF (20ºC) (Benson, 1993a, 1993b; Cook and Dunleavy, 1993). Initial reservoir pressures average about 4200 pounds per square inch (29,000 kPa). The reservoir drive mechanisms include pressure depletion, active drive, and solution gas.

Reservoir data for individual fields in the Jurassic Twin Creek Limestone thrust belt play are summarized in table 1.

Oil and Gas Characteristics

In major reservoirs, the produced Twin Creek oil is a volatile crude (gas-oil ratio between 1035 and 1198 cubic feet/bbl) (Sprinkel and Chidsey, 1993). The API gravity of the oil ranges from 24.1º to 45.7º; condensate API gravity ranges from 67.5º to 73.5º. Oil colors vary from amber to dark brown, and condensate is clear. The viscosity of the crude oil averages 2.0 centistokes (cst) at 104ºF (40ºC), but can be as high as 7.9 cst at 122ºF (50ºC); in Saybolt Univeral Seconds (sus) the viscosity averages 32.6 sus at 104ºF (40ºC), but can be as high as 51.7 sus at 122ºF (50ºC). The viscosity of the condensate is 0.51 cst and 27.4 sus at 104ºF (40ºC). The pore point of the crude oil ranges from 20 to 70ºF (-7 to 21ºC). The average weight percent sulfur and nitrogen of produced Twin Creek hydrocarbon liquids are 0.07 and 0.008, respectively.

Composition of associated gas from the Pineview Twin Creek Limestone reservoir contains 17 percent methane, 27 percent ethane, 35 percent propane, 16 percent butane, 4 percent pentane, and 1 percent other components (Moore and Sigler, 1987). The gas has a heating value of 2321 British thermal units/cubic foot (Btu/ft^3). Composition of nonassociated gas from Anschutz Ranch, Cave Creek, and Yellow Creek reservoirs is remarkably uniform and significantly different from the associated gas. Gas from these reservoirs contains 75 to 80 percent methane, 7 to 9 percent ethane, 4 percent propane, 3 percent butane, 1 percent pentane, 6 to 7 percent nitrogen, and 1 percent other components (Petroleum Information, 1981; Moore and Sigler, 1987). Heating values average 1170 Btu/ft^3. Gas produced from the reservoirs in the Twin Creek play contains no hydrogen sulfide.

Production

Fields in the Jurassic Twin Creek Limestone Mesozoic-cored structures subplay produce crude oil and associated gas. Pineview, Elkhorn Ridge, and Lodgepole fields (figure 2) are located on the culmination part of the subplay, and combined, have produced 12.2 million bbls of oil (MMBO [1.9 MMCMO]) and 11.9 billion cubic feet of gas (BCFG [0.34 BCMG]) from the Twin Creek as of August 1, 2004 (Utah Division of Oil, Gas and Mining, 2004) (table 1). In the depression part of the subplay, only one well, within Anscutz Ranch East field, is productive from the Twin Creek. There are currently 15 active producers and 19 abandoned wells in the Twin Creek Mesozoic-cored structures subplay (table 1).

Current Twin Creek production in the Jurassic Twin Creek Limestone Absaroka thrust - Paleozoic-cored structures subplay consists of nonassociated gas and condensate. Anschutz Ranch, Cave Creek, and Yellow Creek fields (figure 2) are located in this subplay and combined have produced 2.9 million bbls of condensate (MMBC [0.5 MMCMC]) and 81.1 BCFG (2.30 BCMG) from the Twin Creek as of August 1, 2004 (Utah Division of Oil, Gas and Mining, 2004; Wyoming Oil & Gas Conservation Commission, 2004) (table 1). There are currently 6 active and 37 abandoned Twin Creek producers in the Paleozoic-cored structures subplay (table 1).

In 2004, the monthly production from the Twin Creek Limestone averaged 1400 bbls of oil (and condensate) (223 MCMO) and 0.014 BCFG (0.0004 BCMG) (Utah Division of Oil, Gas and Mining, 2004; Wyoming Oil & Gas Conservation Commission, 2004). Monthly production peaked in 1979, and has generally declined since then. However, in the 1990s, the intensely fractured and depositionally heterogeneous Watton Canyon and Rich reservoirs of the Twin Creek in the Elkhorn Ridge, Lodgepole, and Pineview fields were successfully exploited using horizontal-drilling techniques. Elkhorn Ridge and Lodgepole fields were sub-commercial prior to the horizontal-drilling programs. A successful horizontal-drilling program also revitalized production from the Twin Creek in Cave Creek field.

Exploration Potential and Trends

Future exploration could focus on more structurally complex and subtle, thrust-related traps that overlie organic-rich Cretaceous strata. Possible structural targets include complex traps formed by true duplexes, overlapping ramp anticlines, and hybrid duplexes (Mitra, 1986). In these structures, the dense, naturally fractured limestone beds and the overlying seals of the Twin Creek Limestone are repeated many times. Other thrust-related structural traps include subtle fault-propagation folds formed by imbricate thrust faults or stacked imbricate faults. These traps may be developed along secondary fault-propagation folds, along backlimb thrust faults, or between imbricate splays on the forelimb of anticlines (Mitra, 1986, 1990).

Potential for locating Twin Creek oil reserves also exists in the central Utah thrust belt, often referred to as the "Utah Hingeline" (figure 15). Producing members (Watton Canyon, Rich, and Sliderock) of the Twin Creek are correlated with limestone beds that separate overlying mudstone and evaporite beds of the Jurassic Arapien Shale from the underlying Jurassic Navajo Sandstone (Sprinkel, 1982, 1991; Sprinkel and Waanders, 1984). Exploration for oil should be confined to a belt east of the inferred surface trace of the Charleston-Nebo thrust system (Hintze, 1980, 1993). Along this belt, the Twin Creek should have reservoir characteristics similar to the productive reservoirs to the north. Anticlines associated with a blind thrust (Gunnison [?] thrust of Villien and Kligfield, 1986) should form multiple structural traps (Sprinkel, 1990).

The Gunnison thrust in this 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 thrust create multiple potential drilling targets (figure 16) (Villien and Kligfield, 1986). These features are obscured by complex surface geology which includes (1) angular unconformities, (2) Oligocene volcanic rocks, (3) Basin and Range-age (Miocene-Holocene) listric (?) normal faulting, and (4) local diapirism. The Gunnison thrust represents, perhaps, the youngest and last of the Sevier-age thrusts in central Utah. It likely abuts or ceased eastward movement against the seismically

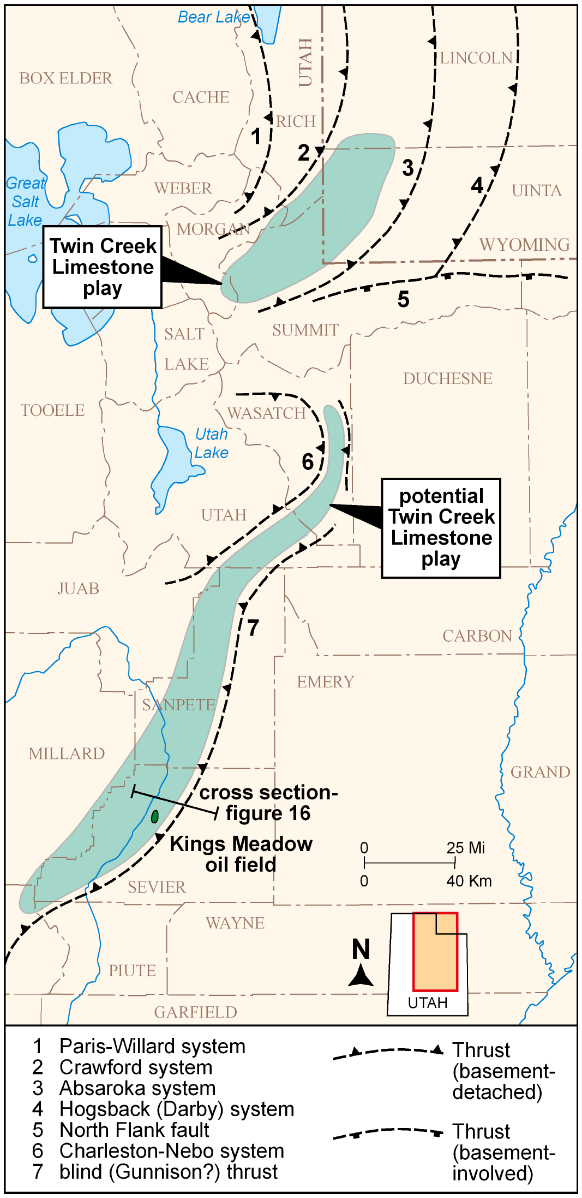

Figure 15. Selected thrust systems of southwestern Wyoming-northern Utah and central Utah. Numbers and teeth are on the hanging wall of the corresponding thrust system. Colored (light blue) areas show present and potential Jurassic Twin Creek Limestone thrust belt plays; Kings Meadow oil field, Sevier County, Utah, shown in green.

defined, probable Laramide-age, basement-involved, down-to-the-west, Ephriam fault (figure 16). We suggest that, unlike the Twin Creek Limestone thrust belt play to the north, the structures and faults are not in contact with Cretaceous source rocks. However, potential source rocks do include the Mississippian Delle Phosphatic Member of the Deseret Limestone (Sandberg and Gutschick, 1984), Mississippian Chainman Shale, Mississippian-Pennsylvanian Manning Canyon Shale, and Permian Park City/Phosphoria Formation (Sprinkel and others, 1997), all requiring migration of hydrocarbons from the north or west.

As a result of the complex geology, unsuccessful exploration for petroleum in the central Utah thrust belt has continued in cycles for over 50 years. Finally, in 2004, Wolverine Oil & Gas Company's No. 17-1 Kings Meadow Ranches well (SE1/4NW1/4 section 17, T. 23 S., R. 1 W., SLBL, Sevier County) reportedly tested nearly 1000 bbls of oil per day and has produced over 100,000 bbls from the Jurassic Navajo Sandstone in this trend (Petroleum Information/Dwights Drilling Wire, 2004a, 2004b). This major discovery, now Kings Meadow field (figure 15), is leading to increased exploration, and ultimately, additional discoveries may include reservoirs in the Twin Creek Limestone.

TECHNOLOGY TRANSFER

The Utah Geological Survey (UGS) is the Principal Investigator and prime contractor for the PUMPII project. 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*.

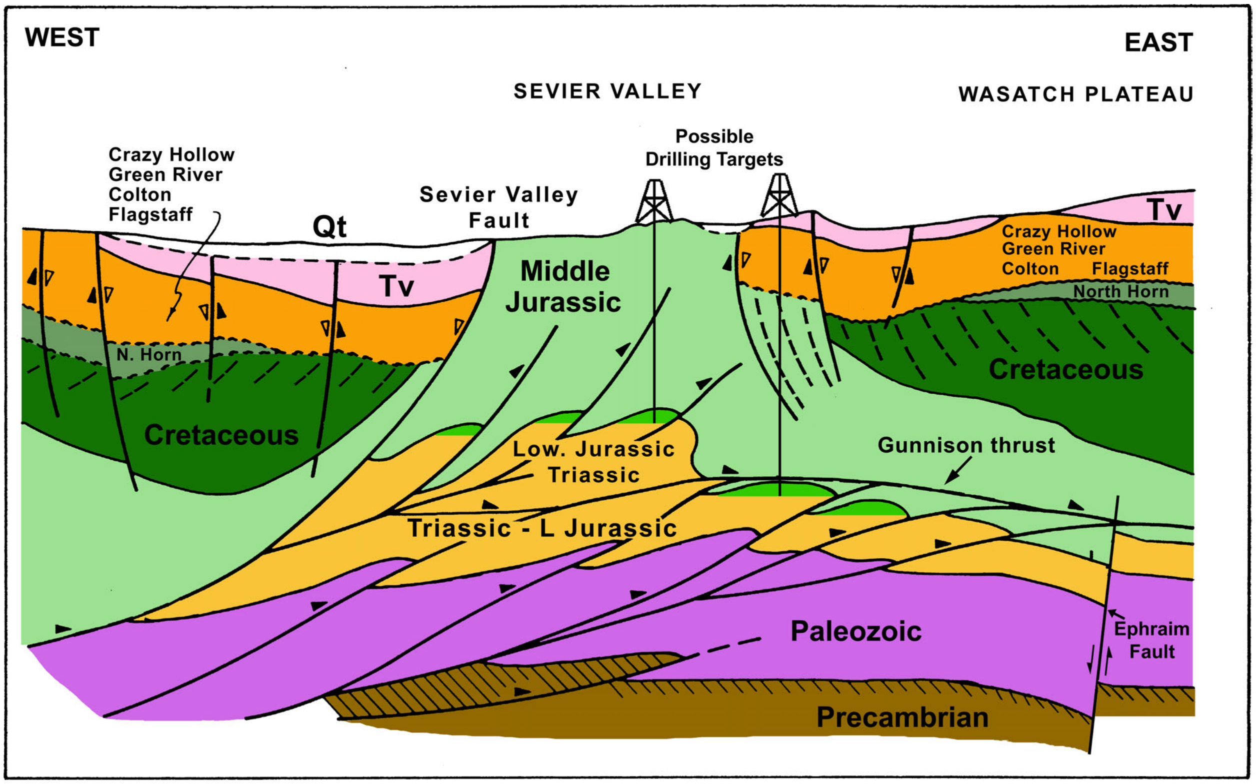

Figure 16. Schematic east-west structural cross section through Sevier Valley, Utah (line of section shown on figure 15), just north of the 2004 discovery of Kings Meadow oil field (Jurassic Navajo Sandstone), showing potential Lower Jurassic exploratory drilling targets in thrust imbricates and duplexes above and below the Gunnison thrust. Modified from Villien and Kligfield (1986).

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 will also provide field and reservoir data, especially data pertaining to best practices. During the quarter, the project technical team met with both the Technical Advisory and Stake Holders Boards in Denver, Colorado, on August 12, 2004. Project team members also joined Utah Stake Holders Board members in attending the Uinta Basin Oil and Gas Collaborative Group meeting in Vernal, Utah, on September 28, 2004. Project activities, results, and recommendations were presented at these meetings.

Project materials, plans, objectives, and results were displayed at the UGS booth at the AAPG Rocky Mountain Section Meeting/Rocky Mountain Natural Gas Strategy Conference and Investment Forum (hosted by the Colorado Oil & Gas Association), August 9-11, 2004, in Denver, Colorado. Four UGS scientists staffed the display booth at these events. Project displays will be included as part of the UGS booth at professional meetings throughout the duration of the project.

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.

Technical Presentation

The following technical presentation was made during the quarter as part of the technology transfer activities:

> "Basin-wide Correlation of Petroleum Plays and Subplays in the Green River Petroleum System, Uinta Basin, Utah" by Craig D. Morgan and Kevin McClure, AAPG Rocky Mountain Section Meeting/Rocky Mountain Natural Gas Strategy Conference and Investment Forum (hosted by the Colorado Oil & Gas Association), August 9-11, 2004, in Denver, Colorado. The poster presented plays and subplays bounded by key marker beds, identified on geophysical well logs, representing time lines between which reservoir rocks of the Tertiary Green River Formation were deposited.

Project Publications

Chidsey, T.C., Jr., Morgan, C.D., and Bon, R.L., 2004, Major oil plays in Utah and vicinity – quarterly annual technical progress report for the period April 1 to June 30, 2004: U.S. Department of Energy, DOE/FC26-02NT15133-8, 22 p.

Chidsey, T.C., Jr., and Wakefield, S., 2004, New oil and gas fields map of Utah – just the facts!: Utah Geological Survey, Survey Notes, v. 36, no. 3, p. 8-9.

Chidsey, T.C., Jr., and Wakefield, S., 2004, New oil and gas fields map of Utah: U.S. Department of Energy, The Class Act, v. 10, no. 1, p. 1-3.

Chidsey, T.C., Jr., Wakefield, S., Hill, B.G., and Herbertson, M., 2004, Oil and gas fields of Utah: Utah Geological Survey Map 203DM, scale 1:700,000.

Morgan, C.D., and McClure, K, 2004, Basin-wide correlation of petroleum plays and subplays in the Green River petroleum system, Uinta Basin, Utah [abs.]: American Association of Petroleum Geologists, Rocky Mountain Section Meeting Official Program Book, p. 110 and 112.

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 and Wyoming. Oil plays are specific geographic areas having petroleum potential due to favorable source rock, migration paths, reservoir characteristics, and other factors.

2. One of the most prolific oil plays in the Utah/Wyoming thrust belt province is the Jurassic Twin Creek Limestone thrust belt play, having produced over 15 million bbls (2.4 million m^3) of oil and 93 BCFG (2.6 million m^3). The Twin Creek was deposited in a shallow-water embayment south of the main body of a Middle Jurassic sea that extended from Canada to southern Utah. Traps form on discrete subsidiary closures along major ramp anticlines where the low-porosity Twin Creek is extensively fractured. The seals for the producing horizons are overlying argillaceous and clastic beds, and non-fractured units within the Twin Creek.

3. Hydrocarbons in Twin Creek Limestone reservoirs were generated from subthrust Cretaceous source rocks. The source rocks began to mature after being overridden by thrust plates. Hydrocarbons were then generated, expelled, and subsequently migrated into overlying traps, primarily along fault planes.

4. Most oil and gas production is from perforated intervals in the Watton Canyon, upper Rich, and Sliderock Members of the Twin Creek Limestone. These members have little to no primary porosity in the producing horizons, but exhibit secondary porosity in the form of fractures. Identification and correlation of barriers and baffles to fluid flow, and recognizing fracture set orientations in individual Twin Creek reservoirs in the thrust belt is critical to understanding their effects on production rates, petroleum movement pathways, and horizontal well plans.

5. The Twin Creek Limestone thrust belt play is divided into two subplays: (1) Absaroka thrust - Mesozoic-cored structures and (2) Absaroka thrust - Paleozoic-cored structures. The Mesozoic-cored structures subplay represents a linear, hanging wall, ramp anticline parallel to the leading edge of the Absaroka thrust. This ramp anticline is divided into a broad structural high (culmination) and a structural low (depression). Fields in this

subplay produce crude oil and associated gas. The Paleozoic-cored structures subplay is located immediately west of the Mesozoic-cored structures subplay. This subplay represents a very continuous and linear, hanging wall, ramp anticline, that is also parallel to the leading edge of the Absaroka thrust. The eastern boundary of the subplay is defined by the truncation of the Twin Creek against a thrust splay. Fields in this subplay produce nonassociated gas and condensate. Traps in both subplays consist of long, narrow, doubly plunging anticlines.

6. Prospective drilling targets in the Twin Creek Limestone thrust belt play are delineated using the following: high-quality 2-D and 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 access trap geometry. Determination of the timing of structural development, petroleum migration, entrapment, and fill and spill histories is critical to successful exploration.

7. Future Twin Creek Limestone exploration could focus on more structurally complex and subtle, thrust-related traps. Potential also exists for locating Twin Creek oil reserves in the central Utah thrust belt. Exploration for oil should be confined to a belt east of the inferred surface trace of the Charleston-Nebo thrust system where the Twin Creek should have reservoir characteristics similar to the productive reservoirs to the north. Anticlines associated with the Gunnison thrust, a blind thrust in the region, should form multiple structural traps containing hydrocarbons possibly generated from Mississippian or Permian source rocks.

ACKNOWLEDGMENTS

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Oil analyses were provided by Humble Geochemical Services and Amoco Oil Company, Salt Lake Business Unit (now operated by Tesoro Corporation). Kevin McClure (UGS) assisted with data compilation. Jim Parker and Cheryl Gustin of the UGS prepared the figures; Carolyn Olsen and Tom Dempster photographed core. This report was reviewed by Dave Tabet and Mike Hylland of the UGS. Cheryl Gustin, UGS, formatted the manuscript.

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