MAJOR OIL PLAYS IN UTAH AND VICINITY

QUARTERLY TECHNICAL PROGRESS REPORT

Reporting Period
Start Date: April 1, 2005
End Date: June 30, 2005

by
Thomas C. Chidsey, Jr., Principal Investigator
and
Craig D. Morgan
Utah Geological Survey

UTAH GEOLOGICAL SURVEY

September 2005

Contract No. DE-FC26-02NT15133

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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 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 twelfth quarter of the project (April 1 through June 30, 2005). This work included (1) gathering field data and analyzing best practices in the Jurassic Nugget Sandstone and Twin Creek Limestone thrust belt plays of Utah, and (2) technology transfer activities.

The most prolific oil plays in the Utah/Wyoming thrust belt province are the Jurassic Nugget Sandstone and Twin Creek Limestone thrust belt plays, having produced over 303 million barrels (49 million m^3) of oil. Traps form on discrete subsidiary closures along major ramp anticlines where the Nugget and Twin Creek are extensively fractured. Horizontal drilling in Utah thrust belt fields targets the heterogeneous Twin Creek Limestone and Nugget Sandstone reservoirs. Drilling techniques include new wells and horizontal, often multiple, laterals from existing vertical wells. Fractures and lithologic variations create potential undrained compartments ideally suited for horizontal drilling, particularly in the Watton Canyon Member of the Twin Creek. Horizontal wells should generally be drilled perpendicular to the dominant orientation of open fractures, and above and parallel to the low-proved oil or oil/water contacts. Horizontal drilling programs at Pineview, Lodgepole, and Elkhorn Ridge fields in the Utah thrust belt successfully extended the productive life of the fields. All three fields were at an advanced stage of depletion when the horizontal drilling began.

Condensate production is common in Absaroka thrust - Mesozoic-cored deep structures. In retrograde condensate reservoirs, the fluid changes from a single-phase rich gas to a two-phase gas and liquid mixture when the pressure drops below the dew-point pressure. Without pressure maintenance, the retrograde condensate remains in the reservoir and wells are less productive. The Nugget Sandstone in Anschutz Ranch East field on the Utah/Wyoming border is a major retrograde reservoir where pressure maintenance operations (using an injection of nitrogen and wet gas) have successfully maximized recovery. Cumulative production from the field is over 129 million barrels (20.5 million m^3) of condensate.

Technology transfer activities during this quarter consisted of exhibiting a booth display of project materials at the 2005 Annual Convention of the American Association of Petroleum Geologists (AAPG) and the central Utah Natural Resources Festival, presentations on the central Utah thrust belt Navajo Sandstone oil play, and publications. An abstract was submitted and accepted for a presentation on the play at the AAPG Rocky Mountain Section Meeting. 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 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 twelfth quarter of the project (April 1 through June 30, 2005). This work included (1) gathering field data and analyzing best practices in the Jurassic Nugget Sandstone and Twin Creek Limestone thrust belt plays of Utah, 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. The most prolific oil reservoirs in the Utah/ Wyoming thrust belt province are the Jurassic Nugget Sandstone and Twin Creek Limestone, having produced over 303 million bbls (49 million m^3) of oil and 5.2 TCFG (148 billion m^3). Traps form on discrete subsidiary closures along major ramp anticlines where the Nugget and Twin Creek are extensively fractured. Hydrocarbons were generated from subthrust Cretaceous source rocks.

The Nugget Sandstone thrust belt play is divided into three subplays: (1) Absaroka thrust - Mesozoic-cored shallow structures, (2) Absaroka thrust - Mesozoic-cored deep structures, and (3) Absaroka thrust - Paleozoic-cored shallow structures. Both Mesozoic-cored structures subplays represent a linear, hanging-wall, ramp anticline parallel to the leading edge of the Absaroka thrust. Fields in the shallow Mesozoic subplay produce crude oil and associated gas; fields in the deep subplay produce retrograde condensate. The Paleozoic-cored structures subplay is located immediately west of the Mesozoic-cored structures subplays. It represents a very continuous and linear, hanging-wall, ramp anticline where the Nugget is truncated against a thrust splay. Fields in this subplay produce nonassociated gas and condensate. Traps in these subplays consist of long, narrow, doubly plunging anticlines.

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 the same long, narrow, doubly plunging anticlines that produce from the Nugget Sandstone.

Horizontal drilling in Utah thrust belt fields targets the heterogeneous Twin Creek Limestone and Nugget Sandstone reservoirs. Drilling techniques include new wells and horizontal, often multiple, laterals from existing vertical wells. Multiple laterals are required where two separate, geologically distinct zones are present. Fractures and lithologic variations create potential undrained compartments ideally suited for horizontal drilling, particularly in the Watton Canyon Member of the Twin Creek. Horizontal wells should generally be drilled perpendicular to the dominant orientation of open fractures, and above and parallel to the low-proved oil or oil/water contacts.

Horizontal drilling programs at Pineview, Lodgepole, and Elkhorn Ridge fields in the Utah thrust belt successfully extended the productive life of the fields. Horizontal drilling was probably uneconomical at Pineview, marginally economic at Lodgepole, and economically successful at Elkhorn Ridge. All three fields were at an advanced stage of depletion when the horizontal drilling began and in structurally complex settings making it difficult to avoid formation water. An enhanced-oil-recovery waterflood project in the Elkhorn Ridge field also utilizes horizontal wells.

Condensate production is common in Absaroka thrust - Mesozoic-cored deep structures. In retrograde condensate reservoirs, the fluid changes from a single-phase rich gas to a two-phase gas and liquid mixture when the pressure drops below the dew-point pressure. Without pressure maintenance, the retrograde condensate remains in the reservoir and wells are less productive. Maximizing liquid recovery requires a thorough understanding of reservoir geometry, fluid distribution, and phase behavior. The Nugget Sandstone in Anschutz Ranch East field on the Utah/Wyoming border is a major retrograde reservoir where pressure maintenance operations have successfully maximized recovery. The full reservoir pressure maintenance program required initial injection of a buffer gas (a mixture of 35 percent nitrogen and 65 percent wet gas) equal in volume to 10 percent of the hydrocarbon pore volume, followed by the injection of pure nitrogen. Cumulative production from Anschutz Ranch East field is over 129 million bbls (20.5 million m^3) of condensate.

Technology transfer activities during this quarter consisted of exhibiting a booth display of project materials at the 2005 Annual Convention of the American Association of Petroleum Geologists (AAPG) in Calgary, Canada, and the central Utah Natural Resources Festival in Richfield, Utah. Project team members joined Utah Stake Holders Board Members in attending the Uinta Basin Oil and Gas Collaborative Group meeting in Vernal, Utah. Four public presentations and numerous interviews with the news media were given on the central Utah thrust belt Navajo Sandstone oil play. An abstract was submitted and accepted for a presentation on the play at the 2005 AAPG Rocky Mountain Section Meeting. The project home page was updated on the Utah Geological Survey Web site. Project team members published a non-technical article on the central Utah thrust belt oil play and Quarterly Technical Progress Report 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, 2005). 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.

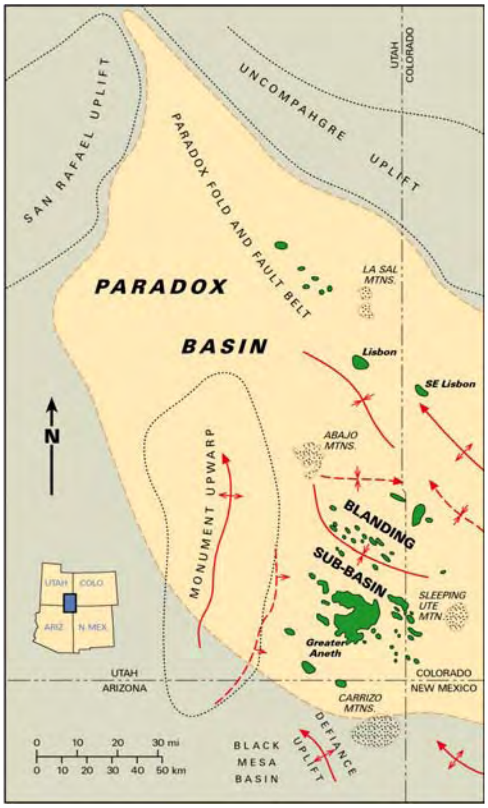
The primary goal of this study is to increase recoverable oil reserves from existing field reservoirs and new discoveries by providing play portfolios for the major oil-producing provinces (Paradox Basin, Uinta Basin, and thrust belt) in Utah and adjacent areas in Colorado and Wyoming (figure 1). These 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 twelfth quarter of the project (April 1 through June 30, 2005). This work included (1) gathering field data and analyzing best practices in the Jurassic Nugget Sandstone and Twin Creek Limestone thrust belt plays of Utah, and (2) technology transfer activities.

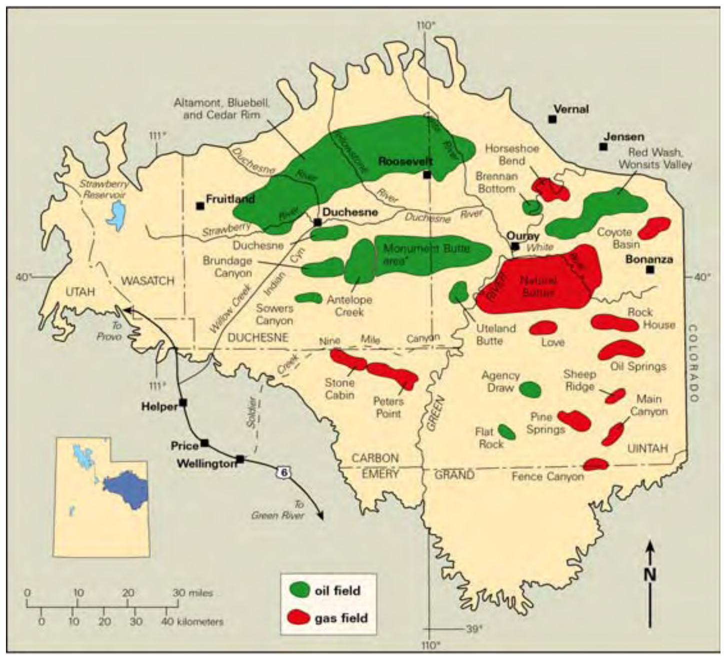
Project Benefits

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:

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



A



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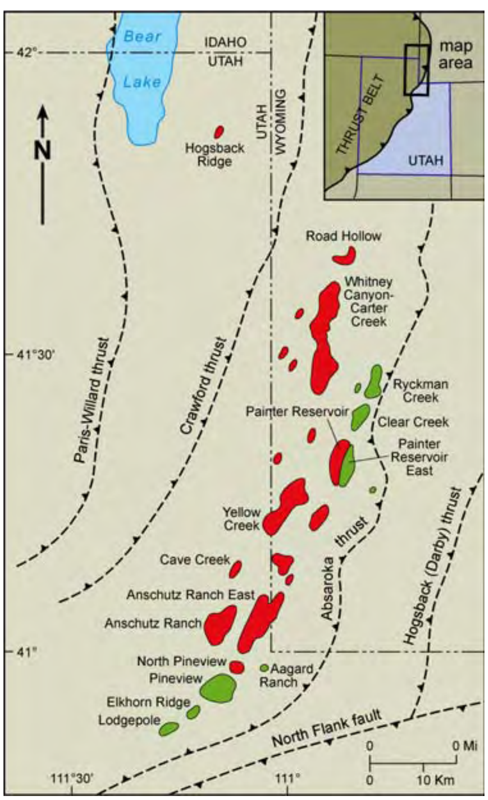


C

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.

(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

(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.

BEST PRACTICES FOR THE JURASSIC NUGGET SANDSTONE AND TWIN CREEK LIMESTONE THRUST BELT PLAYS, UTAH - DISCUSSION AND RESULTS

Introduction

Data were collected from the files of the Utah Division of Oil, Gas and Mining, where there is a wealth of publicly available information, and various publications for selected fields in the Utah portion of the thrust belt. This information includes structure maps and cross sections, production and pressure data, completion reports, drilling and development plans, and testimony given at spacing hearings and other hearings before the Utah Division of Oil, Gas and Mining. The purpose of this data collection is to help determine the best drilling, completion, and secondary/tertiary recovery techniques for these and similar fields in the thrust belt.

The principal oil-producing reservoirs for Utah thrust belt fields are the Jurassic Nugget Sandstone and Twin Creek Limestone. Two significant practices were employed in the later development of these fields to enhance the ultimate recovery of oil: (1) horizontal drilling and (2) pressure maintenance for retrograde condensate production.

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 strike on major ramp anticlines (Lamerson, 1982).

Nugget Sandstone Thrust Belt Play Description

The most prolific oil and gas play within the hanging wall of the Absaroka thrust system is the Jurassic Nugget Sandstone thrust belt play (figure 2). The Nugget has produced over 288 million barrels (46 million m^3) of oil and 5.1 trillion cubic feet of gas (TCFG [145 billion m^3]); however, much of the gas included in the production figures is cycled gas, including nitrogen, for pressure maintenance (Utah Division of Oil, Gas and Mining, 2005; Wyoming Oil & Gas Conservation Commission, 2005). Pineview field, Summit County, Utah, was the first to produce oil and gas from the Nugget in 1975 and led the way for additional discoveries in the thrust belt (figure 2).

The Nugget Sandstone was deposited in an extensive dune field (an eolian environment) which extended from Wyoming to Arizona, and was comparable to the present Sahara in North Africa or the Alashan area of the Gobi in northern China. Playas, mudflats, or oases developed in interdune areas. Traps form on discrete subsidiary closures along major ramp anticlines where the Nugget is extensively fractured. Hydrocarbons in Nugget reservoirs were generated from subthrust Cretaceous source rocks. The seals for the producing horizons are overlying argillaceous and gypsiferous beds of the Jurassic Twin Creek Limestone or a low-permeability zone at the top of the Nugget Sandstone.

The Nugget Sandstone has heterogeneous reservoir properties because of (1) cyclic dune/interdune lithofacies with better porosity and permeability in certain dune types, (2) diagenetic effects, and (3) fracturing. Identification and correlation of barriers and baffles to fluid flow, and recognition of fracture set orientations in individual Nugget reservoirs in the

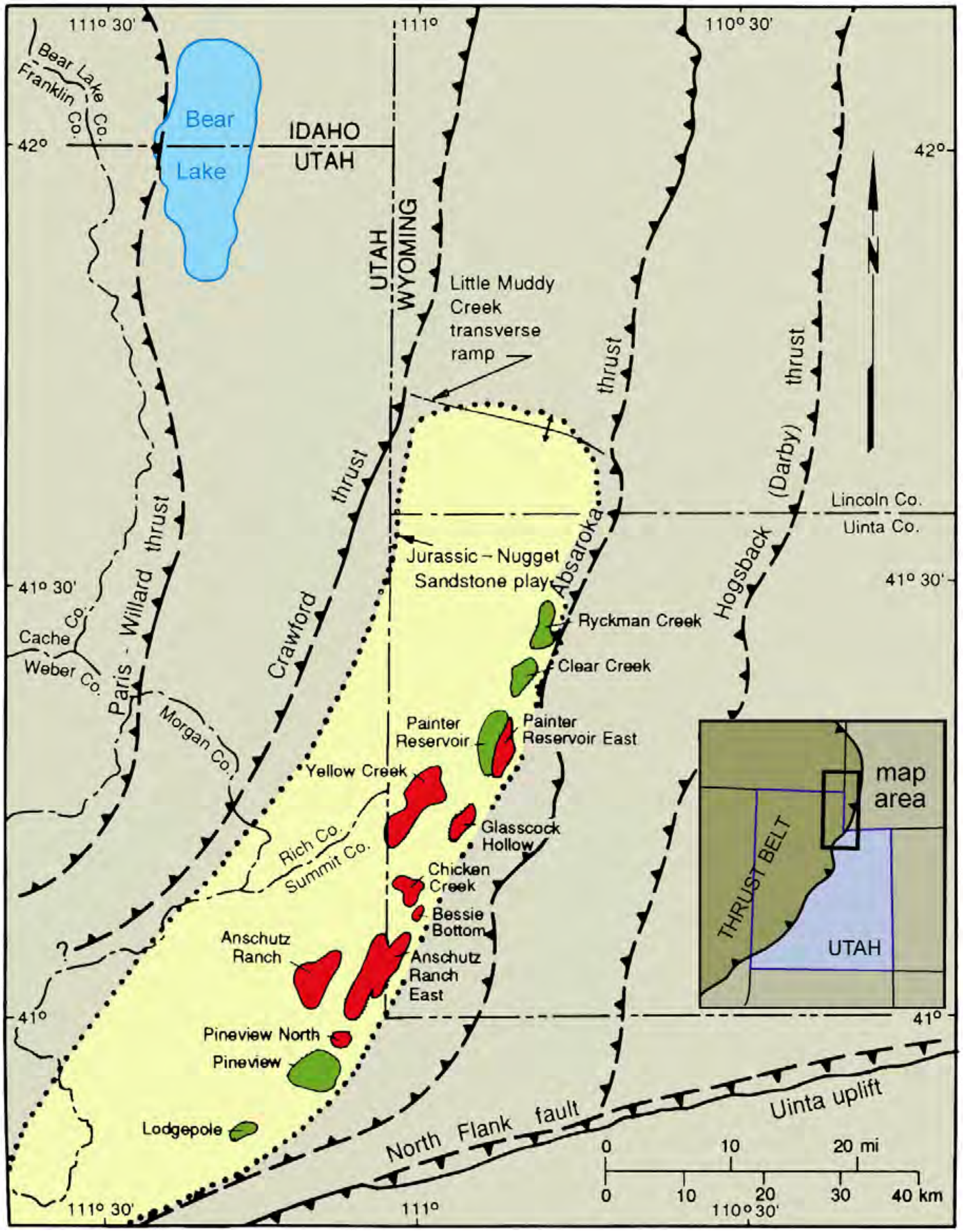


Figure 2. Location of reservoirs that produce oil (green) and gas and condensate (red) from the Jurassic Nugget Sandstone, Utah and Wyoming; major thrust faults are dashed where approximate (teeth indicate hanging wall). The Nugget Sandstone thrust belt play area is dotted. Modified from Chidsey (1993).

thrust belt are critical to understanding their effects on production rates, petroleum movement pathways, horizontal well plans, and pressure maintenance programs.

The Nugget Sandstone thrust belt play is divided into three subplays: (1) Absaroka thrust - Mesozoic-cored shallow structures (figure 3), (2) Absaroka thrust - Mesozoic-cored deep structures (figure 4), and (3) Absaroka thrust - Paleozoic-cored shallow structures (figure 5). Both Mesozoic-cored structures subplays represent a linear, hanging-wall, ramp anticline parallel to the leading edge of the Absaroka thrust. Fields in the shallow Mesozoic subplay produce crude oil and associated gas; fields in the deep subplay produce retrograde condensate.

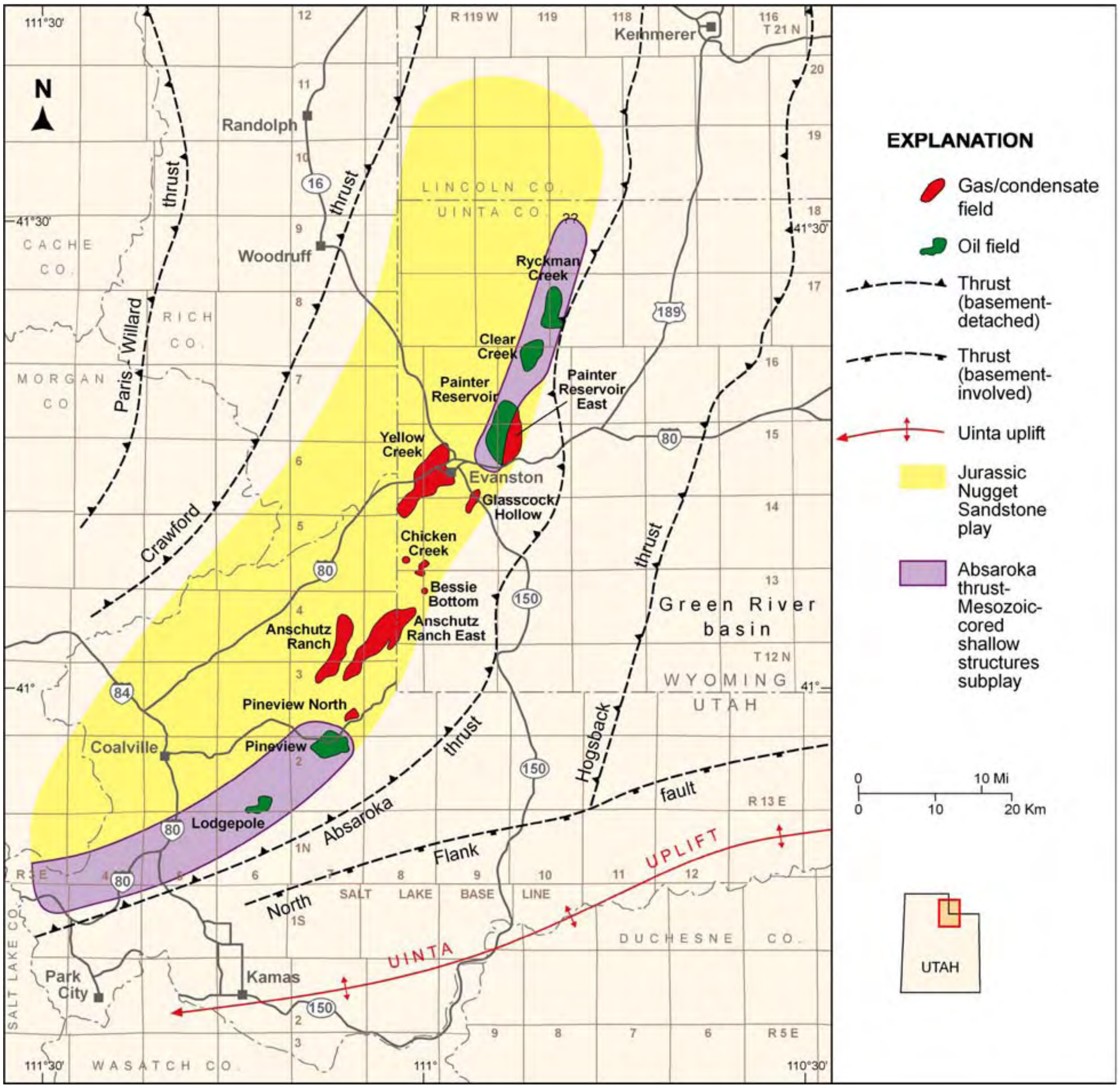


Figure 3. Location of the Nugget Sandstone Absaroka thrust - Mesozoic-cored shallow structures subplay, Summit County, Utah and Uinta County, Wyoming. Northern extent of the subplay is unknown.

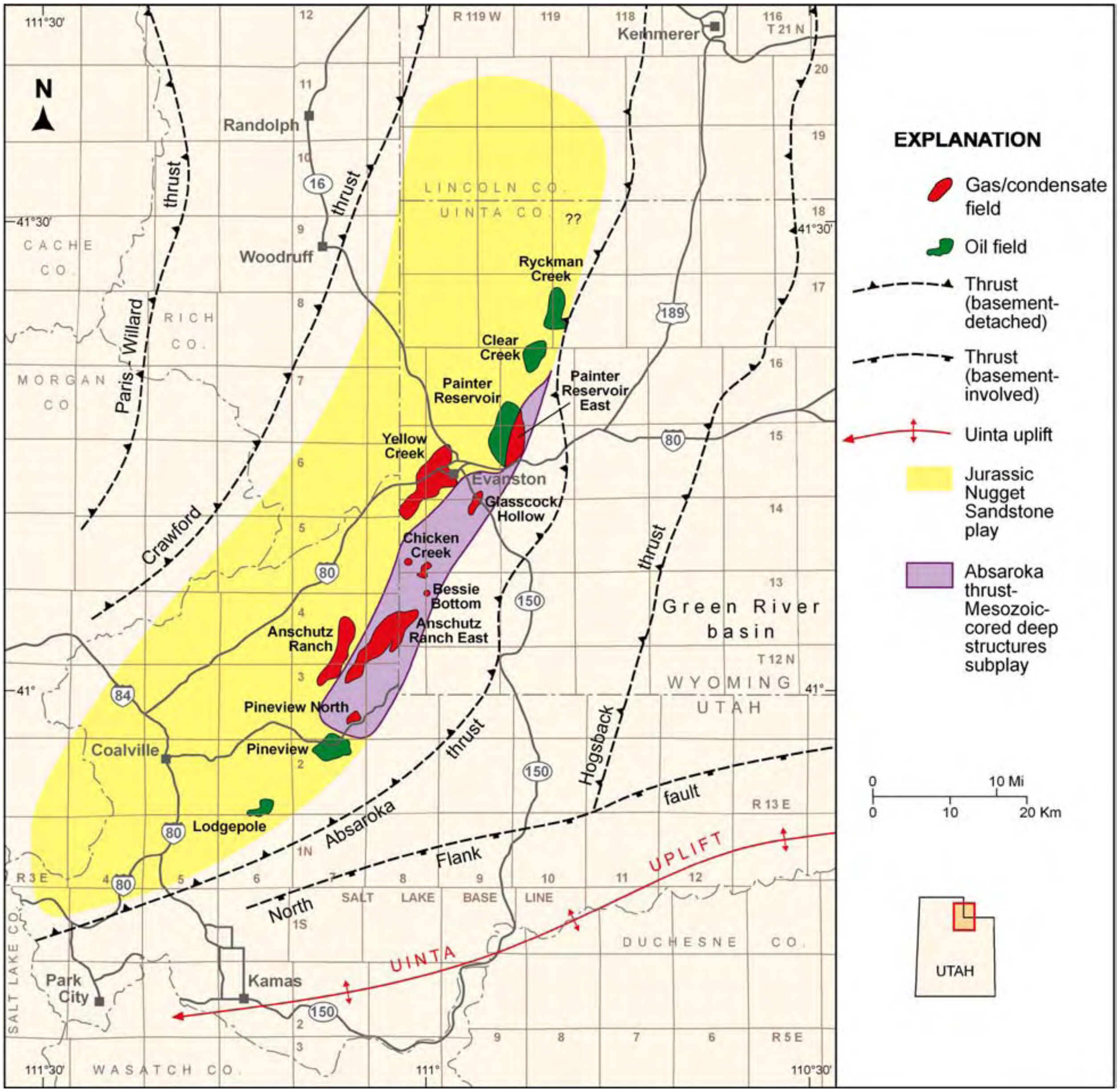


Figure 4. Location of the Nugget Sandstone Absaroka thrust - Mesozoic-cored deep structures subplay, Summit County, Utah and Uinta County, Wyoming. Northern extent of the subplay is unknown.

The Paleozoic-cored shallow structures subplay is located immediately west of the Mesozoic-cored structures subplays. 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 Nugget against a thrust splay. Fields in this subplay produce nonassociated gas and condensate. Traps in these subplays consist of long, narrow, doubly plunging anticlines (figures 6 through 11).

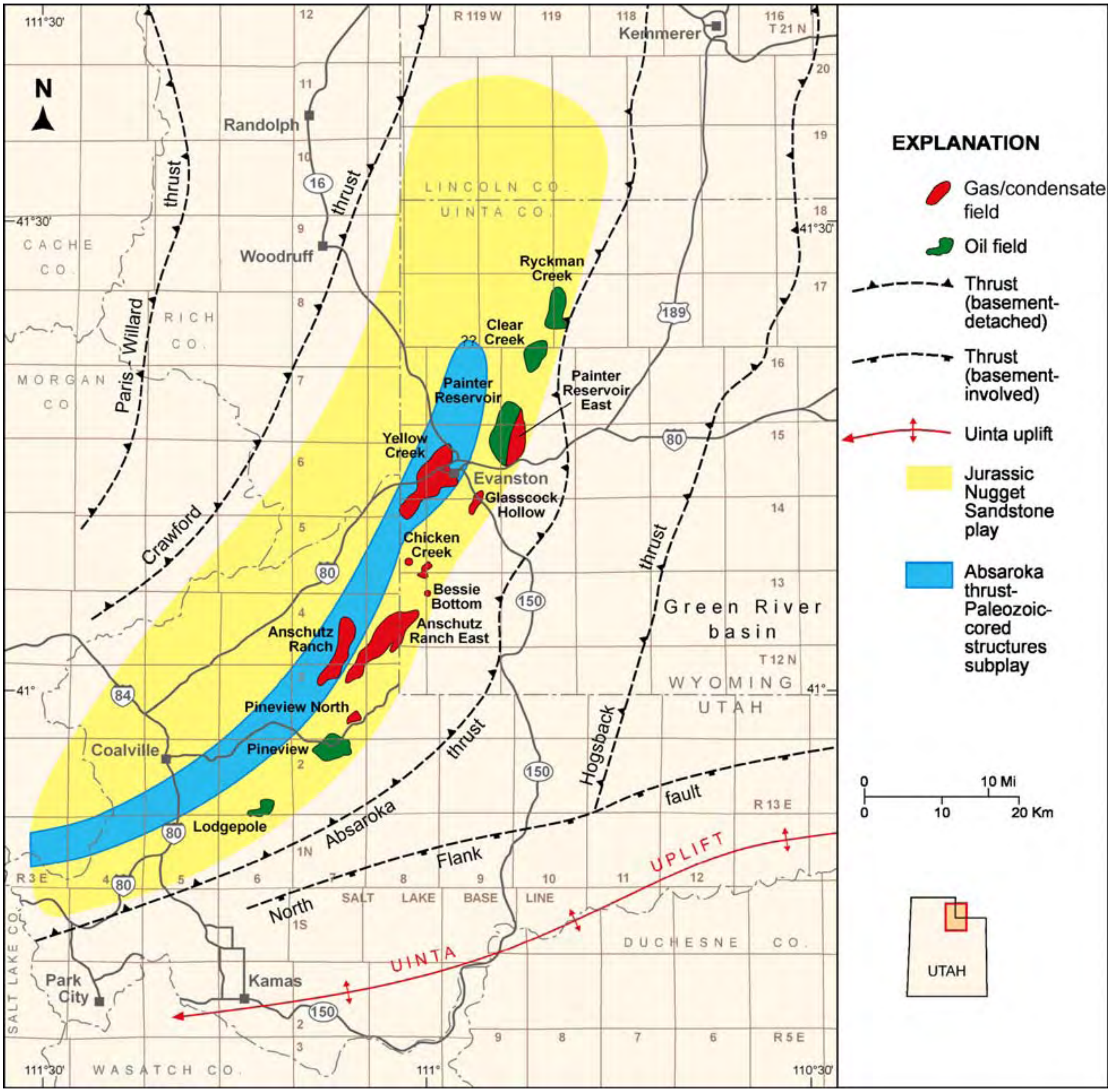


Figure 5. Location of the Nugget Sandstone Absaroka thrust - Paleozoic-cored shallow structures subplay, Summit County, Utah and Uinta County, Wyoming. Northern extent of the subplay is unknown.

Twin Creek Limestone Thrust Belt Play Description

The Jurassic Twin Creek Limestone is major oil play in the Utah/Wyoming thrust belt province (figure 12), 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 (Utah Division of Oil, Gas and Mining, 2005; Wyoming Oil & Gas Conservation Commission, 2005). Pineview field (figure 12) was also the first to produce oil and gas from the Twin Creek in 1975.

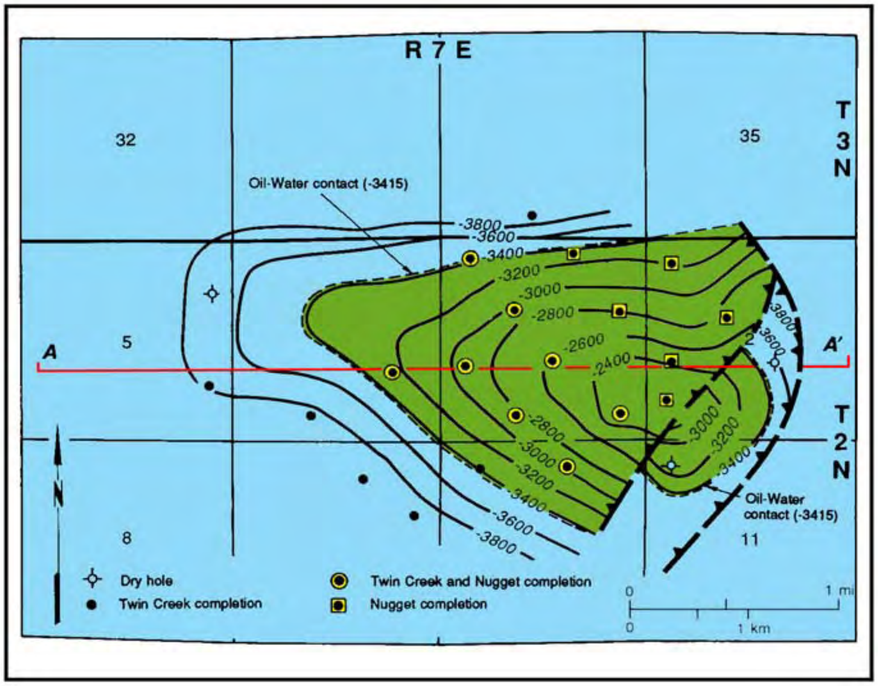
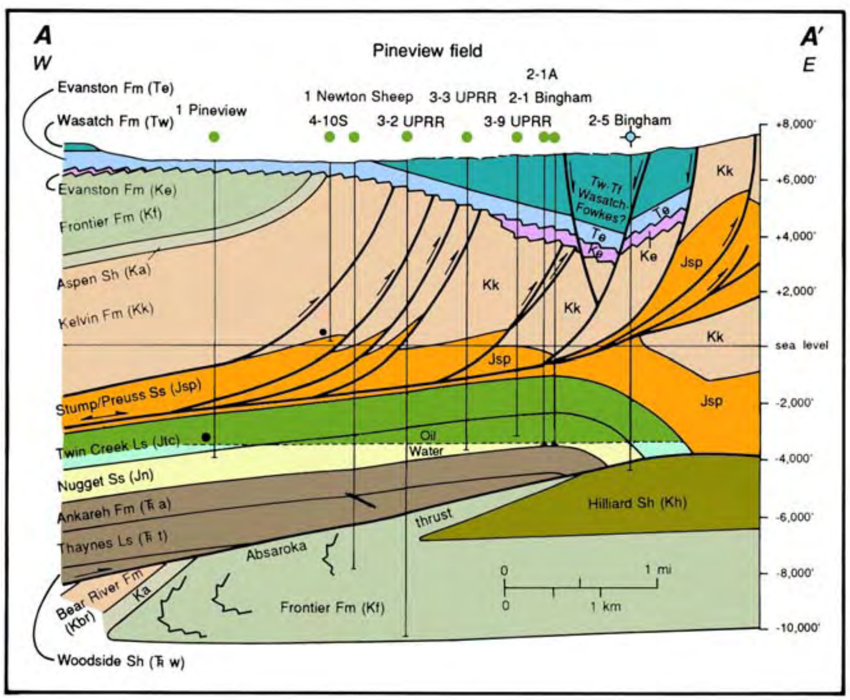


Figure 6. Structure contour map of the top of the Nugget Sandstone, Pineview field, Summit County, Utah, typical of the geometry of Mesozoic-cored shallow structures on the southern culmination, Jurassic Nugget Sandstone thrust belt play. Oil is trapped in an asymmetrical thrusted anticline in the hanging wall of the Absaroka thrust system. Contour interval = 200 feet, datum = mean sea level. After Utah Division of Oil, Gas and Mining (1978). Cross section A-A' shown on figure 7.

Figure 7. East-west cross section through the Pineview structure. Line of section shown on figure 6. Note that the field also produces oil from the Jurassic Twin Creek Limestone that has a common oil/water contact with the Nugget. Reservoir zones are juxtaposed against Cretaceous source rocks in the subthrust along the east flank of the structure. After Lamerson (1982).



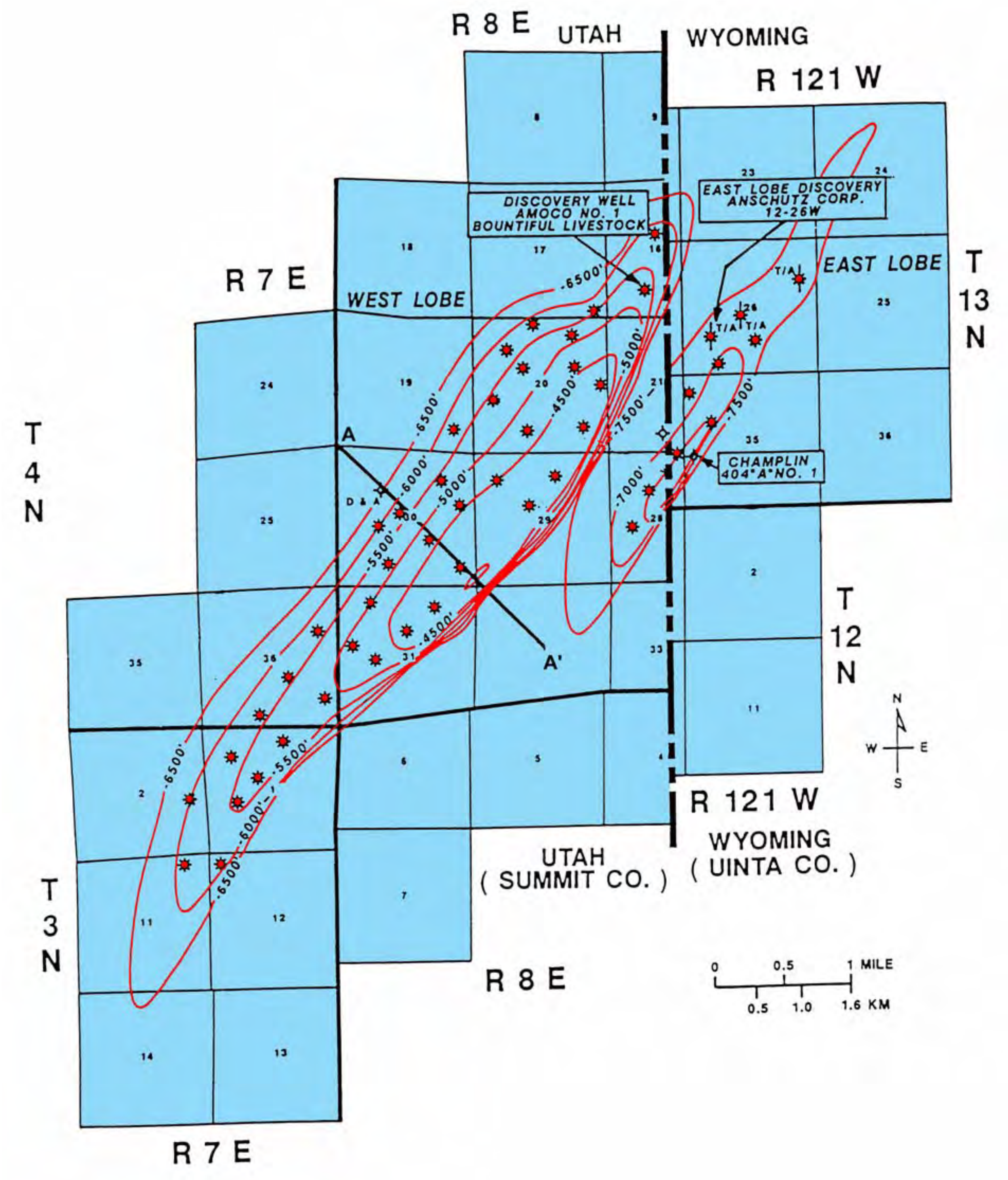


Figure 8. Structure contour map of the top of the Nugget Sandstone, Anschutz Ranch East field, Summit County, Utah and Uinta County, Wyoming, typical of the geometry of Mesozoic-cored deep structures, Jurassic Nugget Sandstone thrust belt play. Retrograde condensate and gas are trapped in east and west lobes of a large northeast-southwest-trending, thrusted anticline in the hanging wall of the Absaroka thrust system. Contour interval = 500 feet, datum = mean sea level. After Lelek (1982). Cross section A-A' shown on figure 9.

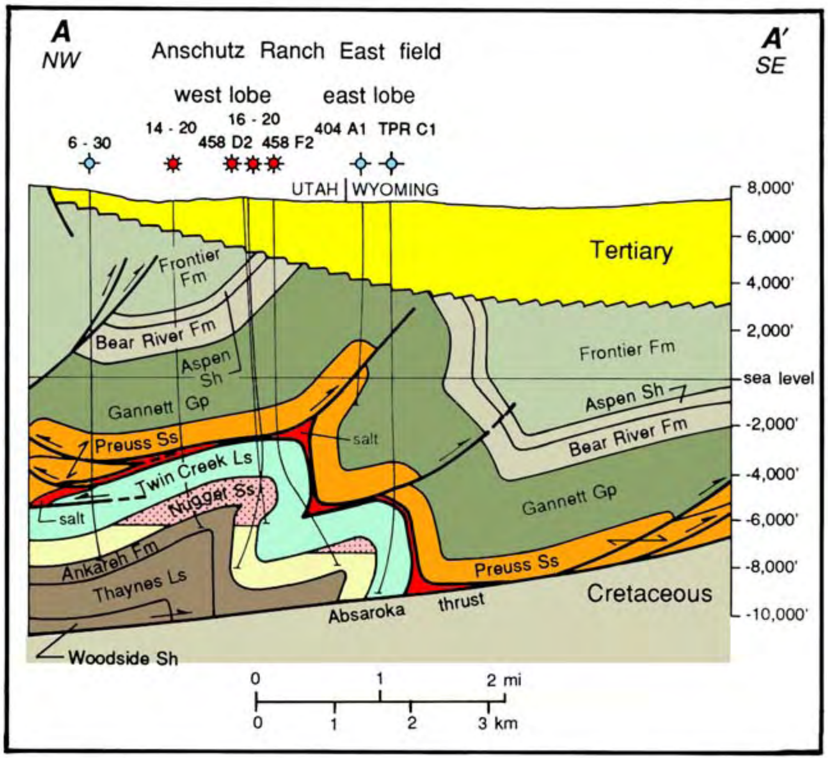


Figure 9. Northwest-southeast cross section through the Anschutz Ranch East structure showing the large west lobe and the deeper, smaller east lobe (base of pink stippled area represents the gas/condensate-water contact). Line of section shown on figure 8. After West and Lewis (1982).

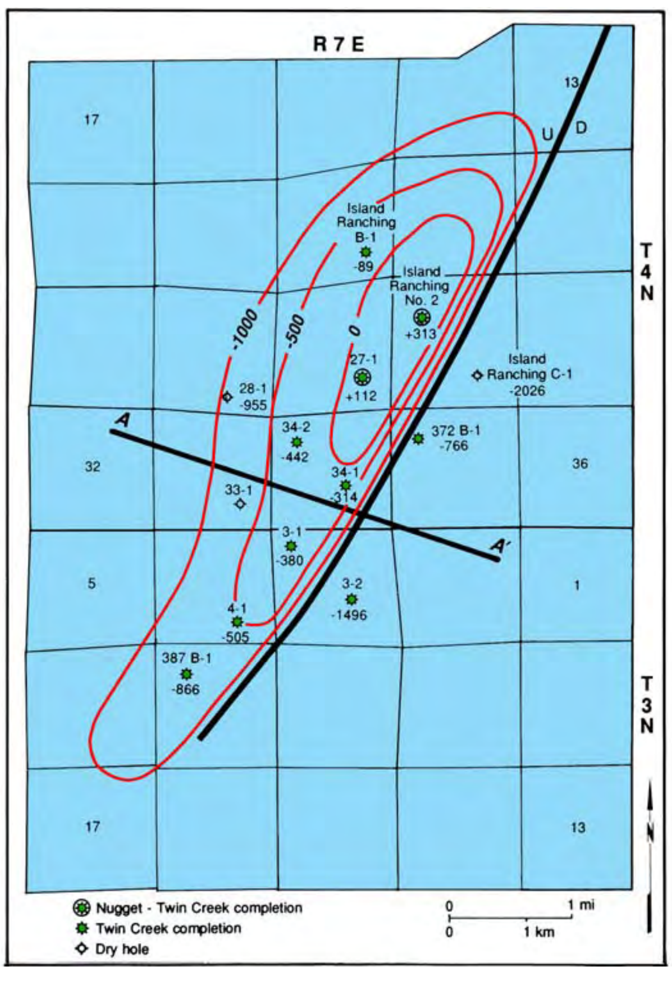


Figure 10. Structure contour map of the top of the Nugget Sandstone, Anschutz Ranch field, Summit County, Utah, typical of the geometry of Paleozoic-cored shallow structures in the Jurassic Nugget Sandstone thrust belt play. Gas and condensate are trapped only on the very crest of a large northeast-southwest-trending, doubly plunging, asymmetric, thrusted anticline in the hanging wall of the Absaroka thrust system. Contour interval = 500 feet, datum = mean sea level. Modified from Utah Division of Oil, Gas and Mining (1980a). Cross section A-A' shown on figure 11.

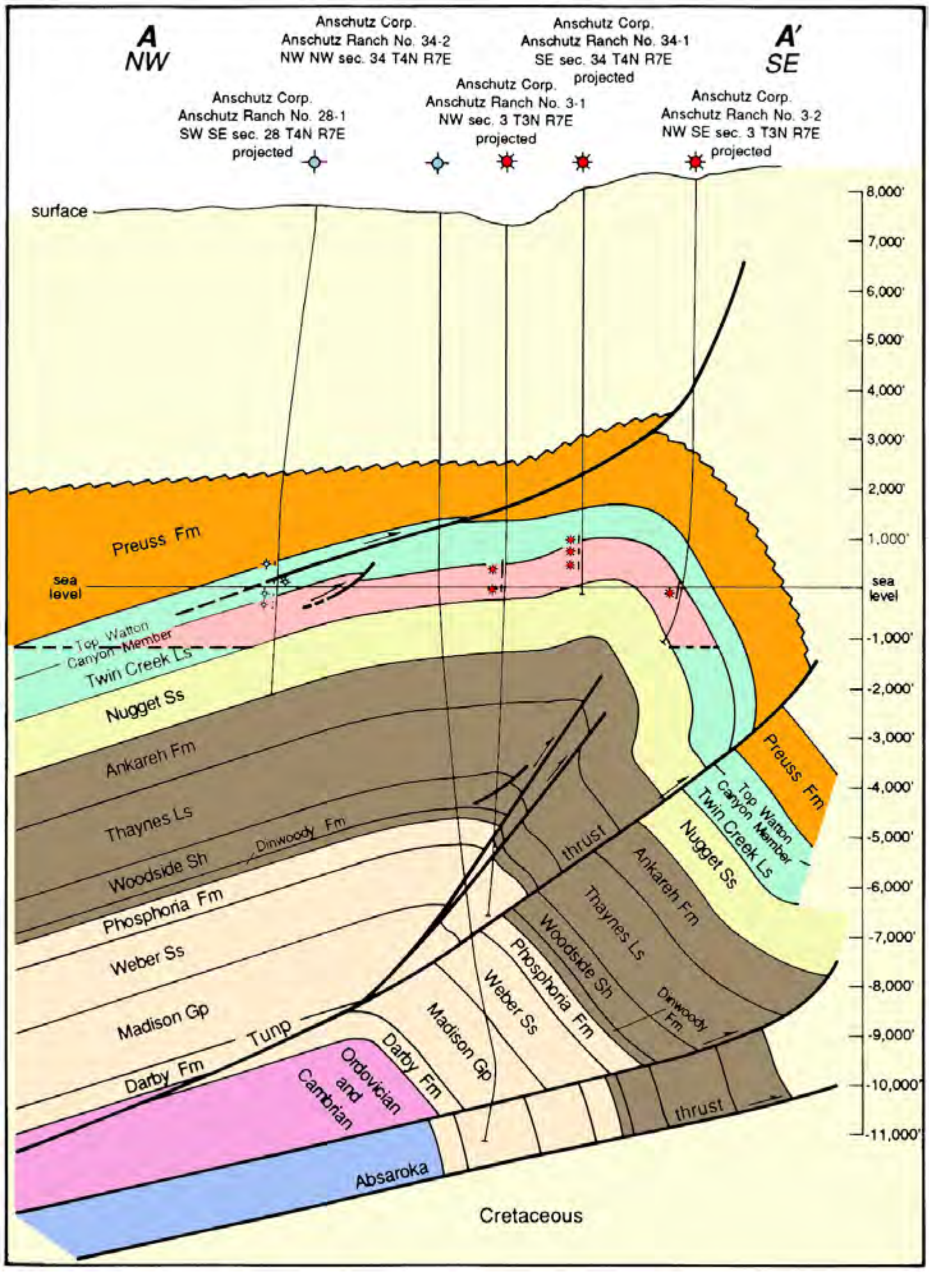


Figure 11. Northwest-southeast cross section through the Anschutz Ranch structure. Line of section shown on figure 10. Cretaceous formations in the footwall of the Absaroka thrust system charge the overlying, fractured sandstone units of the Nugget Sandstone with gas and condensate. Modified from Utah Division of Oil, Gas and Mining (1980b).

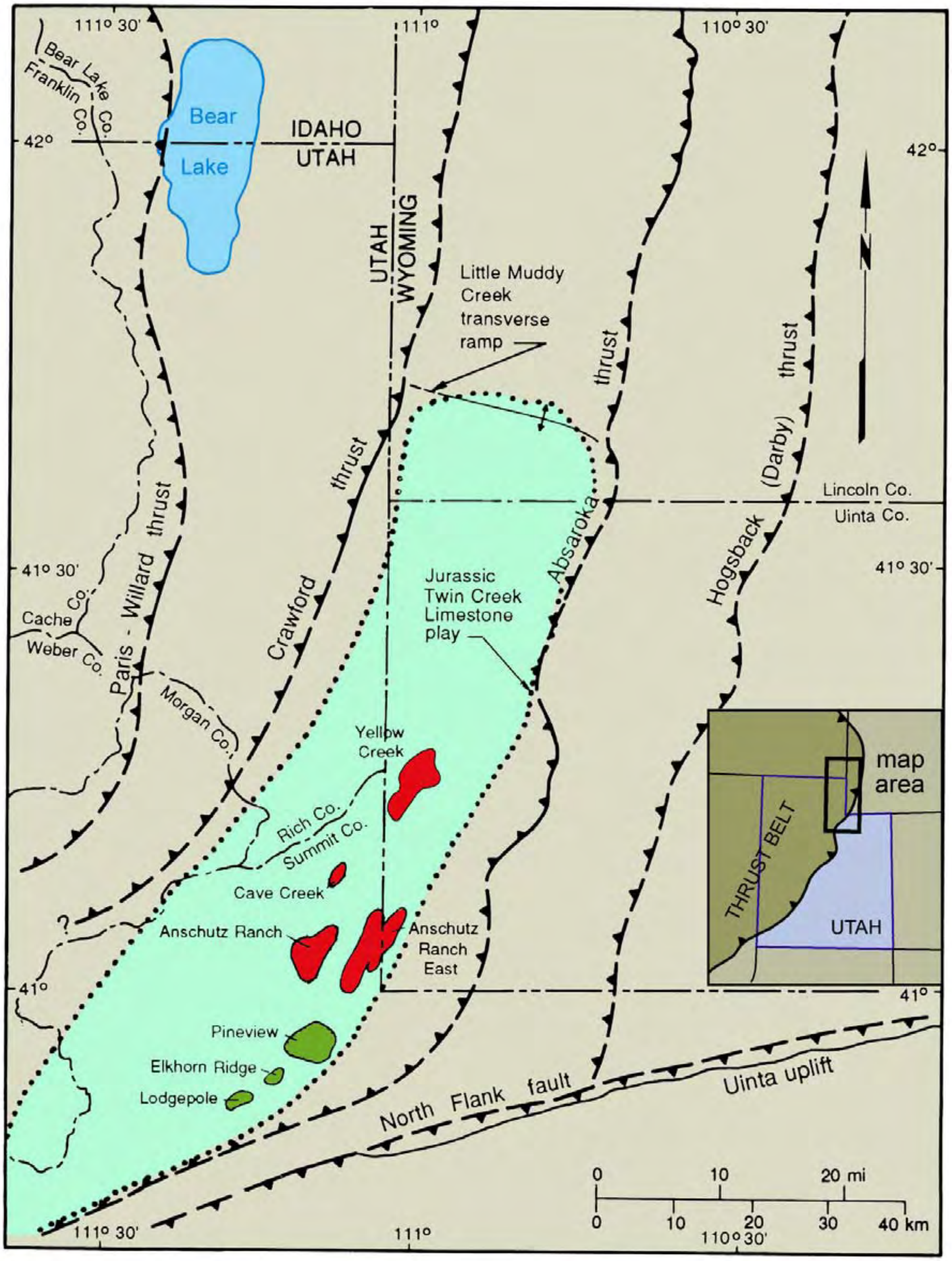


Figure 12. Location of reservoirs that produce oil (green) and gas and condensate (red) from the Jurassic Twin Creek Limestone, Utah and Wyoming; major thrust faults are dashed where approximate (teeth indicate hanging wall). The Twin Creek Limestone thrust belt play area is dotted (modified from Sprinkel and Chidsey, 1993).

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 likewise 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 (figure 13) and (2) Absaroka thrust - Paleozoic-cored structures (figure 14). 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

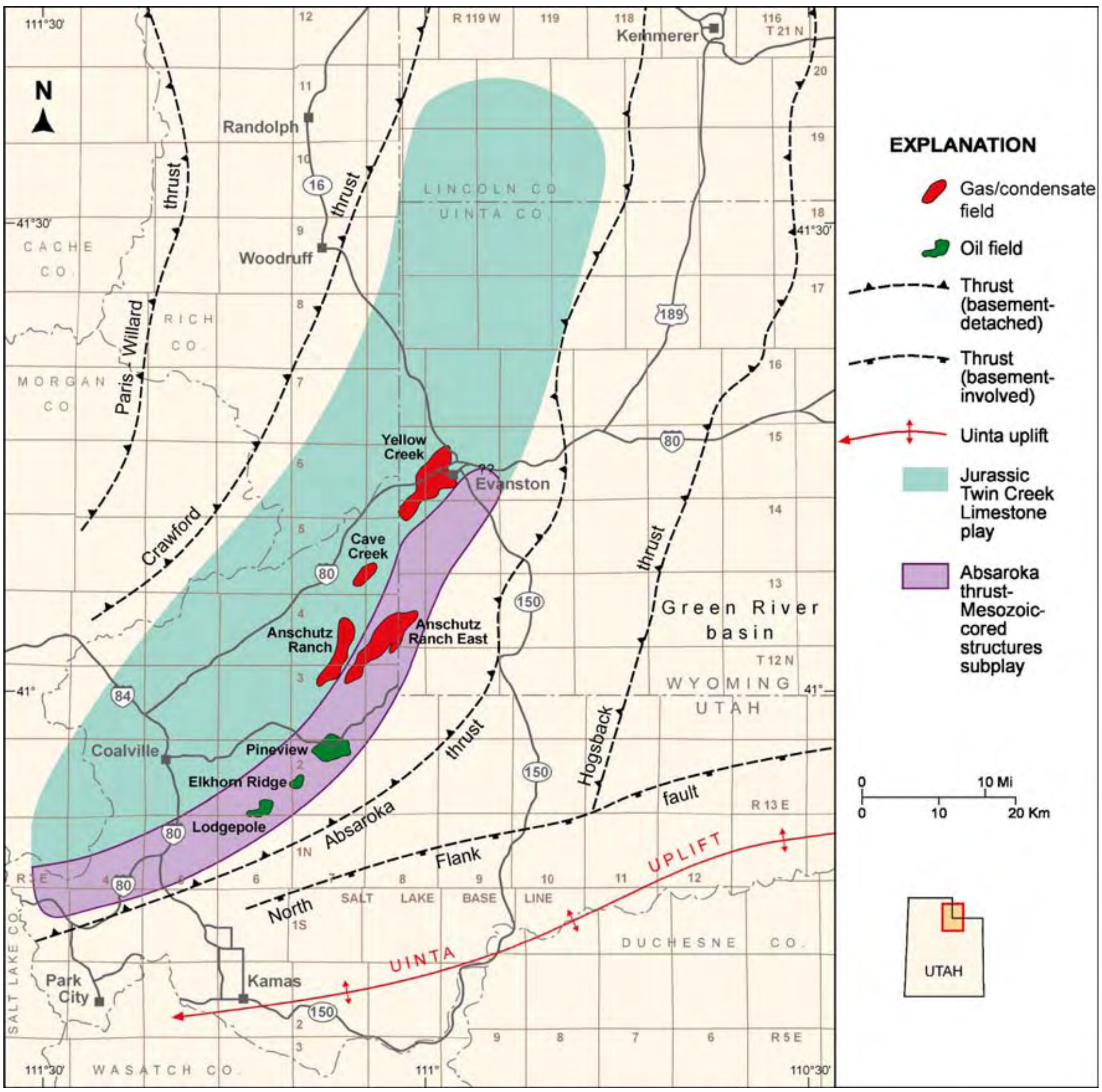


Figure 13. Location of the Twin Creek Limestone Absaroka thrust - Mesozoic-cored structures subplay, Summit County, Utah and Uinta County, Wyoming. Northern extent of the subplay is unknown.

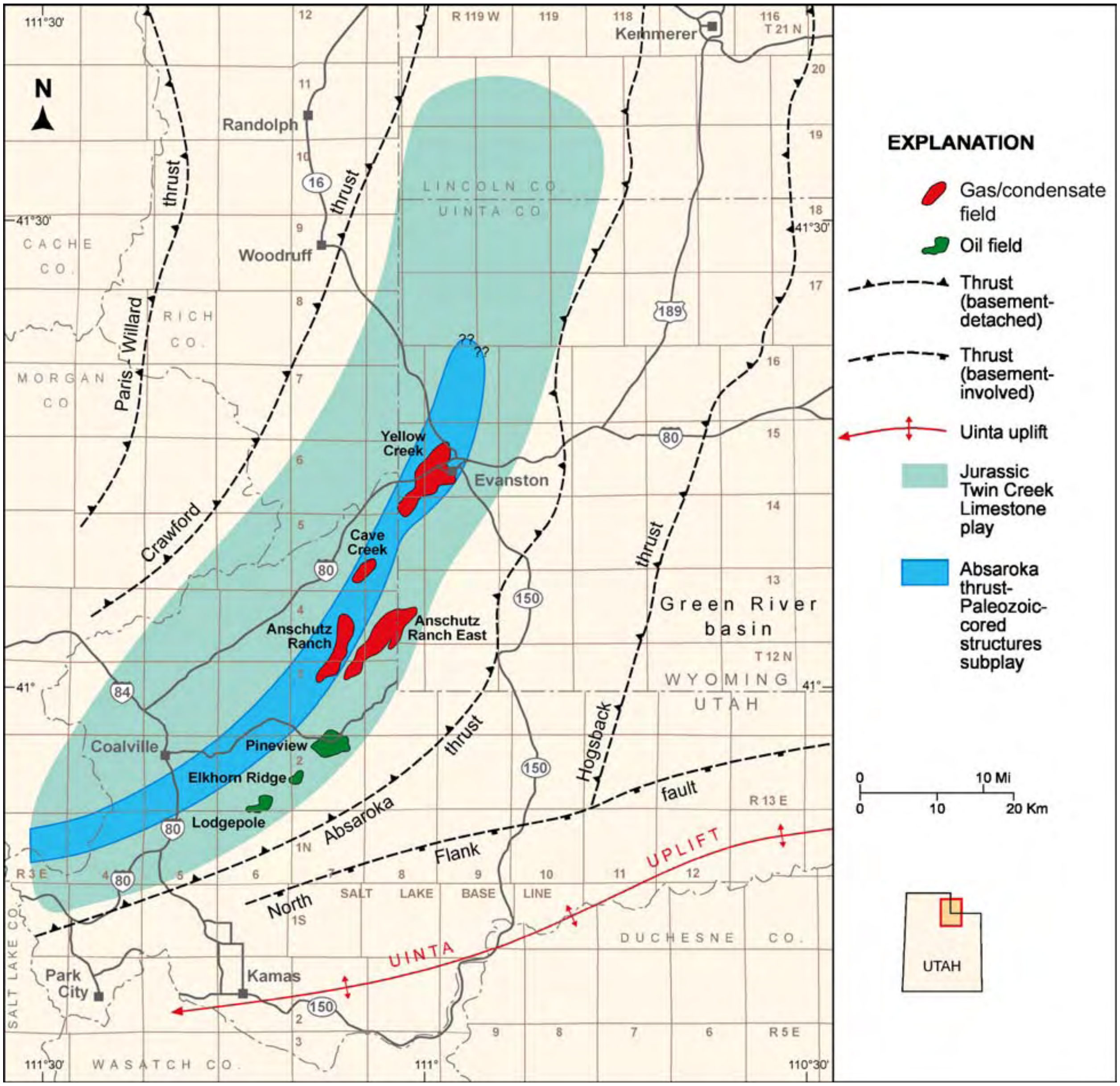


Figure 14. Location of the Twin Creek Limestone Absaroka thrust - Paleozoic-cored structures subplay, Summit County, Utah and Uinta County, Wyoming. Northern extent of the subplay is unknown.

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 the same long, narrow, doubly plunging anticlines that produce from the Nugget Sandstone (figures 6, 7, 10, 11, and 15).

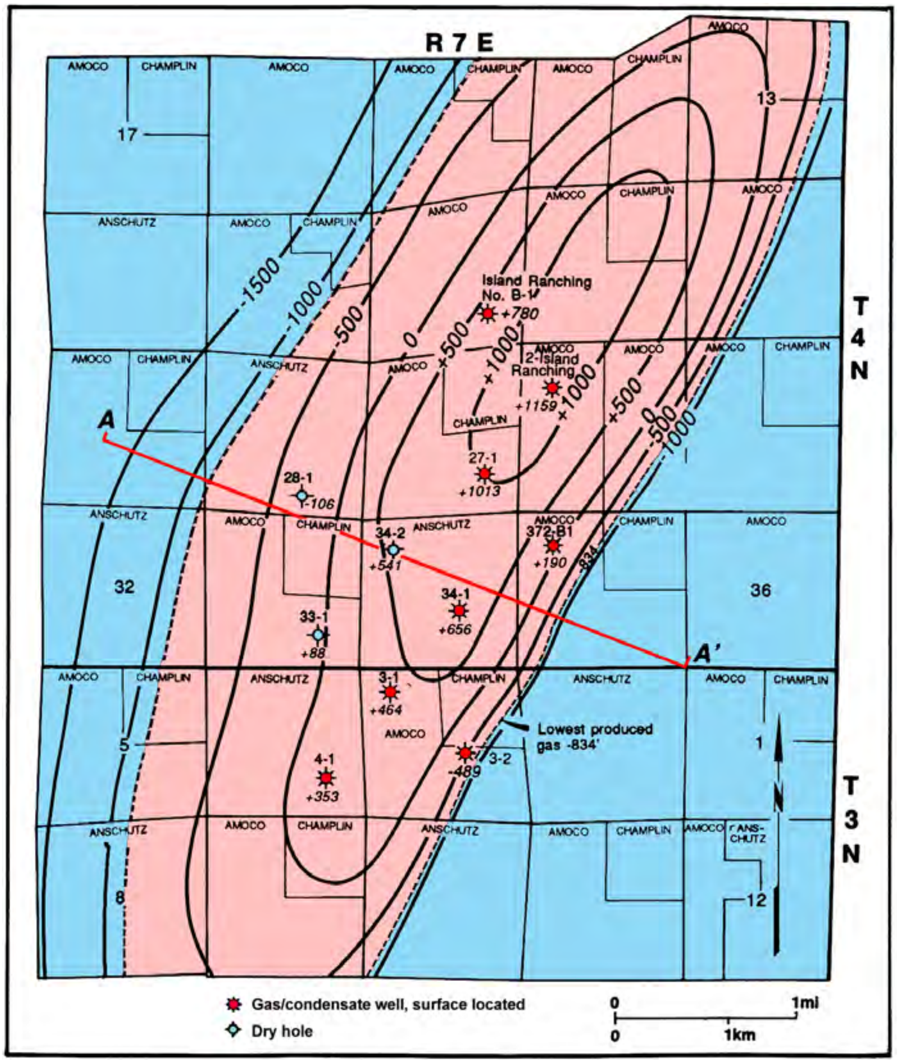


Figure 15. Structure contour map of the top of the Twin Creek Limestone, Anschutz Ranch field, Summit County, Utah, typical of the geometry of Paleozoic-core structures in the Jurassic Twin Creek Limestone thrust belt play. Gas and condensate are trapped by the doubly plunging, asymmetric anticline in the hanging wall of the Absaroka thrust system. Modified from Utah Division of Oil, Gas and Mining (1980c). Cross section A-A' shown on figure 11.

Horizontal Drilling

Introduction

Horizontal drilling, developed primarily in the 1990s, is now a common, economical technique to increase oil production and reserves. Advances in downhole motors, flexible drill pipe, and measurement while drilling technology (MWD) have resulted in improved success and reduced drilling costs. Drilling horizontally (1) improves well/reservoir productivity, (2) increases well drainage area and reservoir exposure particularly critical if the reservoir is fractured or thin (figure 16A, B, and C), (3) delays interface breakthrough (coning) (figure 16D), (4) improves sweep efficiency/ultimate recovery, (5) accelerates well payoff and rate of return, (6) reduces inertial (turbulence) pressure losses, (7) accesses remote and isolated zones, (8) improves reservoir characterization, and (9) exploits gravity drainage mechanism effectively (Kikani, 1993; Stark, 2003).

Horizontal wells are categorized by their radius of curvature: ultra-short radius, short radius, medium radius, and long radius (figure 17). The decision for drilling a particular category in thrust belt fields, and elsewhere, is based on the reservoir depth, regulatory

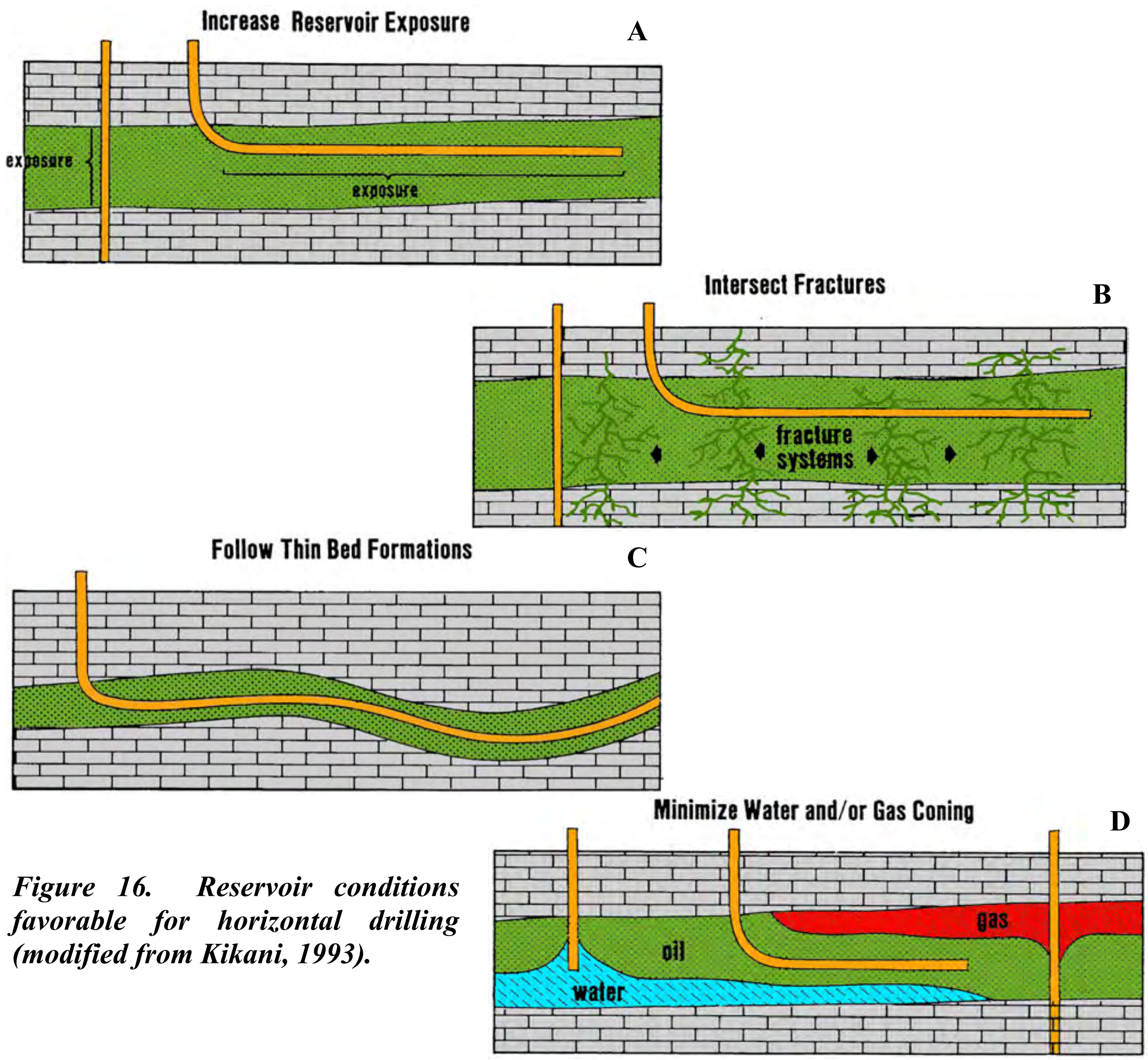


Figure 16. Reservoir conditions favorable for horizontal drilling (modified from Kikani, 1993).

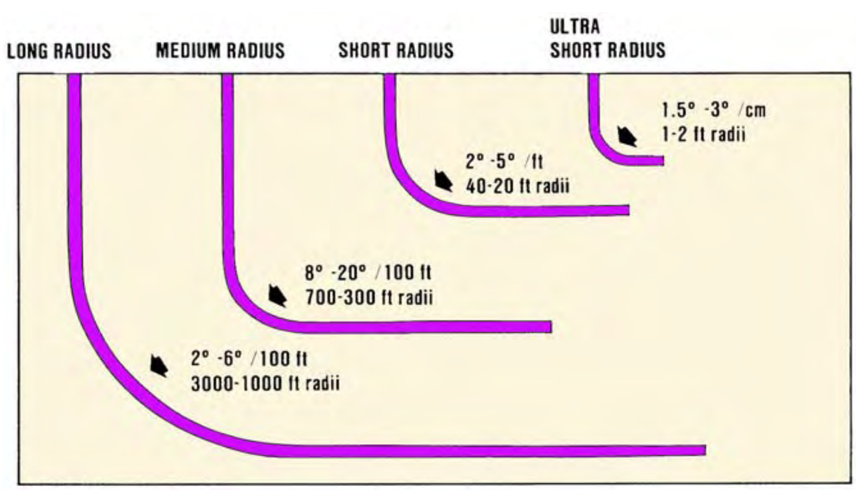


Figure 17. Radius of curvature and the angle building ranges for various horizontal well profiles (modified from Kikani, 1993).

requirements for spacing, type of application, and surface location to avoid topographic features (Kikani, 1993). Logging and production tests in horizontal wells typically use coiled tubing units (CTU) or pipe conveyed logging (PCL). Most horizontal wells are completed open hole, with slotted/pre-perforated liners, or cemented (Kikani, 1993).

Horizontal Drilling in the Utah Thrust Belt

Horizontal drilling in Utah thrust belt fields targeted the heterogeneous Twin Creek Limestone and Nugget Sandstone reservoirs. This heterogeneity, created by fracturing (or the lack thereof) and lithologic variations, provides both the reservoir storage capacity and/or seals (barriers) within the traps. The result is potential undrained compartments ideally suited for horizontal drilling. Oil recovery over a 10-year production span may be twice that of vertical wells (Lance Cook, Union Pacific Resources Company, verbal communication, 1997).

Fractures: Fractures in the Nugget Sandstone and Twin Creek Limestone, as is the case with other sedimentary rocks, generally have a consistent geometry with respect to the three principal stresses (σ_1 = greatest, σ_2 = intermediate, σ_3 = least principal compressive effective stress) at the time of the fracture (Stearns, 1984). Fractures near faults depict the stress field responsible for the fault. Fractures in folds are genetically related to the folding process itself, not a consequence of the regional stress field that produced the folding. Parallel fracture sets are commonly present, and their geometry results from compression and extension (when σ_2 is either parallel or normal to bedding) associated with the fold development as well as the type of sedimentary rock involved (Stearns, 1984). Four different orientations of the three principal stresses are recognized in folds (figure 18): (1) σ_1 and σ_3 in the bedding plane, σ_1 parallel to the dip direction, (2) σ_1 and σ_3 in the bedding plane, σ_1 parallel to the strike direction, (3) σ_2 parallel to bedding strike, σ_1 normal to bedding, and (4) σ_2 parallel to bedding strike, σ_3 normal to bedding. These four orientations produce 12 possible fracture planes – two shear and one extension for each orientation (Stearns, 1984). Both faulting and folding account for the oil accumulations in thrust belt fields. Thus, open and closed fractures have likely been generated by these structural events.

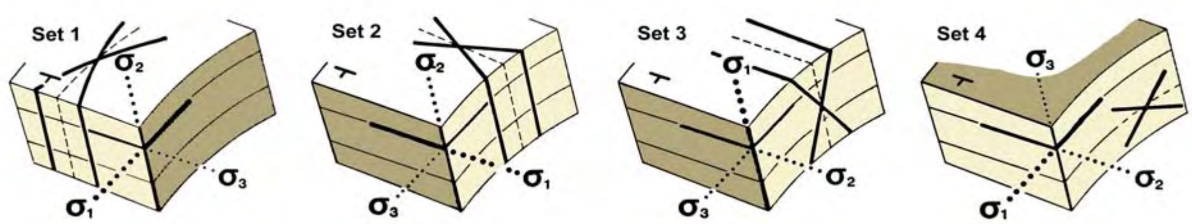


Figure 18. Fracture planes generated by four orientations of the three principal stresses during folding of sedimentary rocks (after Stearns, 1984).

The fracture patterns observed in outcrop and structural orientation are applied to planning directions and lengths of horizontal wells in Twin Creek and Nugget reservoirs (figure 19). In addition, borehole studies and Formation MicroImager (FMI) or other fracture-identification geophysical well logs are used to plan horizontal drilling programs.

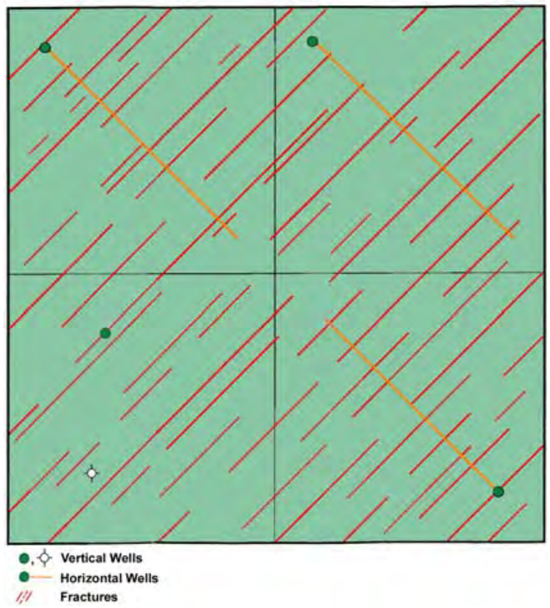


Figure 19. Idealized fracture pattern and horizontal well direction. Modified from Utah Division of Oil, Gas and Mining (1994).

Lithologic variations: The lower third of the Nugget Sandstone typically has lower porosity and permeability when compared to the highly productive upper portion. Thus, this lower interval was avoided as a target for conventional vertical wells drilled during the early development of Nugget fields. However, the interval has become a target of horizontal drilling techniques where it is oil saturated. This includes both new horizontal wells and horizontal laterals, economically drilled from existing vertical wells. Because the Nugget was deposited in an eolian environment, the reservoir also displays a great deal of heterogeneity. Interdune, foresets, and avalanche-slope deposits have different directional permeabilities. Dual horizontal laterals were drilled for Nugget from an existing well in Anschutz Ranch East field (figure 2) but were uneconomical. However, successful horizontal wells drilled in Nugget fields of the Wyoming thrust belt have proven the technique can be viable for Nugget reservoirs (Chidsey, 2003), and thus, additional potential remains in Utah fields.

The Twin Creek Limestone is composed of a variety of lithologies including micritic to argillaceous limestone, sabkha evaporites, and redbed siltstone and claystone. Tightly cemented oolitic grainstone, dolomitized zones, and thin shaly intervals are also present (Bruce, 1988; Parra and Collier, 2000). Most oil and gas production is from perforated intervals in the Watton Canyon, upper Rich, and Sliderock Members (figure 20). Seals for the producing horizons are overlying argillaceous and clastic beds, and non-fractured units within the Twin Creek Limestone. Reservoir heterogeneity within the Watton Canyon itself is created where thin-bedded siltstones create additional barriers or baffles to fluid flow. Successful horizontal programs have been conducted in Twin Creek reservoirs of three Utah thrust belt fields – Pineview, Lodgepole, and Elkhorn Ridge (figure 12).

Drilling techniques, drainage, well orientation: The Twin Creek Limestone is overlain by the Jurassic Preuss Sandstone that contains a basal layer of salt varying from a few feet to hundreds of feet thick, particularly near the leading edge of thrust faults where the hydrocarbon traps developed. To avoid making a 500-foot-radius (150-m) turn in the salt, which could cause the drill-pipe sticking and later casing collapse, requires drilling 500 feet (150 m) into the usually non-productive upper Twin Creek before turning horizontal (Hart's Oil and Gas World, 1995).

Horizontal wells are generally drilled perpendicular to the dominant orientation of open fractures. The depth is controlled to be above and parallel to the low-proved oil or oil/ water contacts. These contacts may have moved upward during the production history of the field so determining their exact elevation is a key component in drilling plans. Accurate determination of dip and strike of the complex producing structures is also critical to planning horizontal drilling operations. Sophisticated MWD techniques are applied to steer up and down the structure within the target member or zone. “Sweet spots” as thin as 30 feet (10 m) (in the Watton Canyon Member for example), based on extremely low gamma-ray counts and high resistivity, can also be targeted using MWD techniques.

The smallest area that can be effectively drained by a 2000-foot (600-m) horizontal well in fractured Twin Creek reservoirs is 640 acres (260 ha). Communication with other wells through fractures and water loss can result if horizontal wells extend beyond 2000 feet (600 m) (Ross Mathews, Union Pacific Resources Company, verbal communication, 1994).

Drilling techniques include new wells and horizontal, often multiple, laterals from existing vertical wells. Multiple laterals are required where two separate, geologically distinct zones are present. For example in the Twin Creek Limestone, the productive Rich (containing water with 15,000 to 25,000 parts per million [ppm] total dissolved solids [TDS]) and Watton Canyon (containing water with 50,000 to 60,000 ppm TDS) Members are separated by the shaley Boundary Ridge Member (figure 20). Multiple laterals are also used where mountainous terrain is a problem (Lance Cook, Union Pacific Resources Company, verbal communication, 1997).

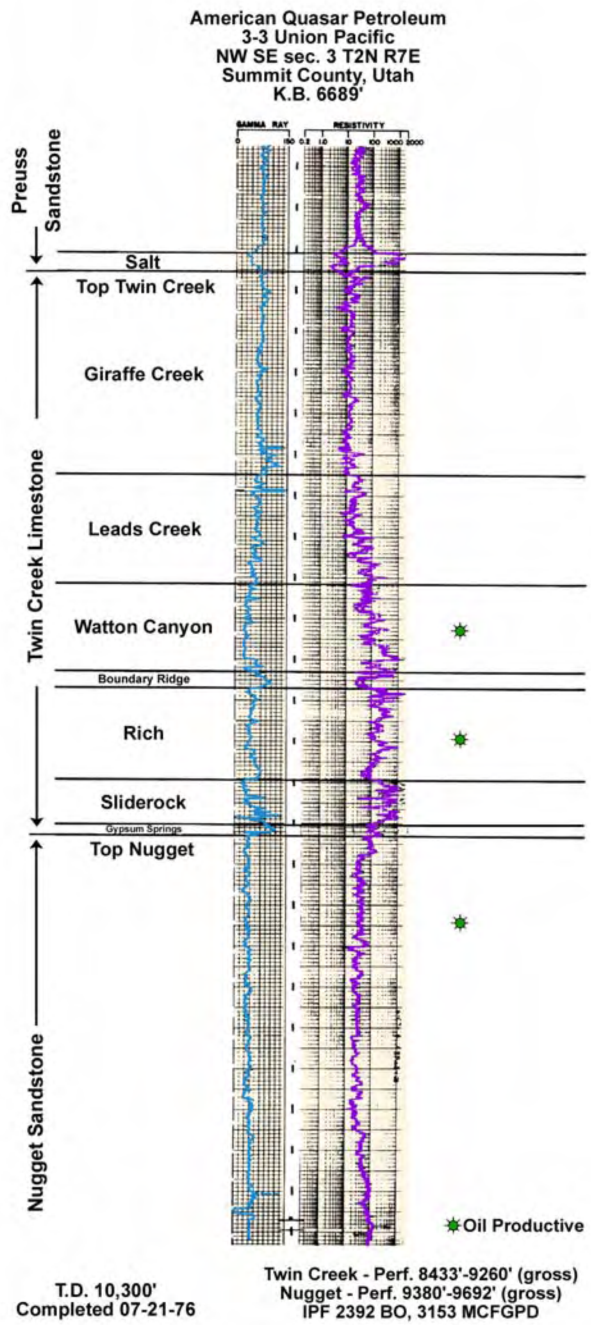


Figure 20. Typical gamma-ray-resistivity log of the Twin Creek and Nugget Formations in Pineview field.

Horizontal wells in the Utah thrust belt are completed open hole or through pre-perforated liners using submersible electric pumps. Problems include casing collapse in horizontal laterals and scale caused by certain water chemistries; the latter requires a scale-inhibitor program.

Drilling programs and production: By 1990, Pineview, Lodgepole, and Elkhorn Ridge fields were nearing depletion. Union Pacific Resources Company (UPRC), operator of the three fields, had gained high-quality experience drilling horizontal wells in the Gulf Coast Austin Chalk play, another fractured reservoir. Union Pacific Resources Company felt that horizontal drilling could recover additional oil from the fractured Twin Creek Limestone in the three Utah fields. The horizontal drilling programs required exceptions to spacing orders by the Utah Division of Oil, Gas and Mining. New spacing for horizontal drilling units was also approved that allowed two horizontal wells in the same formation but in two different members, the Rich and Watton Canyon.

Two horizontal wells were drilled in the Pineview field, four in the Lodgepole field, and five in the Elkhorn Ridge field. A horizontal lateral was drilled in the Rich Member of the Twin Creek at Lodgepole and Elkhorn Ridge fields; both proved uneconomical. All the other horizontal laterals were drilled in the Watton Canyon Member of the Twin Creek (figure 20).

As of January 1, 2005, horizontal wells have produced 58,400 bbls of oil (BO) (9300 m^3) of oil at Pineview field, 395,400 BO (62,900 m^3) at Lodgepole field, and 1,101,800 BO (175,200 m^3) at Elkhorn field, for a total contribution of 1,555,600 BO (247,300 m^3) (table 1). Most of these horizontal wells produced a large volume of water because they were drilled in nearly depleted fields and in structurally complex settings. Commonly a horizontal well may produce 100 percent water for the first several months as drilling fluids are flushed back into the wellbore. Oil production then gradually begins and increases (Hart's Oil and Gas World, 1995).

Table 1. Horizontal well production from the Utah thrust belt as of January 1, 2005. Data from Utah Division of Oil, Gas and Mining production records.

Well	Year Completed	MBO	MMCFG	MBW	Status
Pineview Field					
Bingham 2-6H	1997	57.3	85.6	46.9	POW
UPRC 3-11H	1997	1.1	3.4	58.3	Shut in
Pineview Field Totals		*58.4*	*89.0*	*105.2*	
Lodgepole Field					
Judd 34-1H	1994	235.7	50.4	87.5	POW
UPRR 35-2H	1994	159.7	25.2	115.1	Shut in
UPRC 27-1H	1996	0	0	0	P&A
Blonquist 26-1H	1996	0	0.2	95.0	Shut in
Lodgepole Field Totals		*395.4*	*75.8*	*297.6*	
Elkhorn Ridge Field					
UPRR 19-2 1H	1984	0	0	0	J&A
UPRR 19-2X 1H	1993	574.8	288.0	522.6	Shut in
UPRR 17-2H	1994	267.9	108.0	234.6	POW
Newton Sheep 24-1H	1995	122.2	39.7	396.2	Shut in
Newton Sheep 20-1H	1995	136.9	86.9	131.2	Water Injection Well
Elkhorn Ridge Field Totals		*1101.8*	*522.6*	*1284.6*	
Total Horizontal Production		**1555.6**	**687.4**	**1687.4**	

MBO = 1000 bbls of oil, MMCFG = million cubic feet of gas, MBW = 1000 bbls of water, POW = producing oil well, P&A = plugged and abandoned.

Case-Study Fields

Pineview field: Pineview field (figure 2) was discovered in 1975 and has produced over 31,000,000 bbls (4,900,000 m^3) of oil and 39.3 billion cubic feet (BCF [1.1 BCM]) of gas from the Jurassic Nugget, Twin Creek, and Stump Formations, and the Cretaceous Kelvin Formation. The trap is a rollover anticline with four-way closure (figures 6, 7, 21, and 22). The productive area is about 2180 acres (880 ha) (Cook and Dunlevay, 1996). Open fractures trend in a west-northwest direction.

Most of the production is from the Nugget and Twin Creek Formations. Two horizontal wells, the Bingham No. 2-6 H (SW1/4SW1/4 section 2, T. 2 N., R. 7 E., Salt Lake Base Line and Meridian [SLBLM]) and the UPRC No. 3-11 H (SW1/4SW1/4 section 3, T. 2 N., R. 7 E., SLBLM) were drilled in the Watton Canyon Member of the Twin Creek in 1997. Both horizontal lengths were nearly 3000 feet (1000 m) in a north-northeast direction (figure 21).

The two horizontal wells produced 58,000 BO (9200 m^3), 89 million cubic feet of gas (MMCFG [2.5 MMCMG), and 105,000 bbls of water (BW [16,700 m^3]), with more than 96 percent of the hydrocarbon production coming from the Bingham No. 2-6 H well (figure 23).

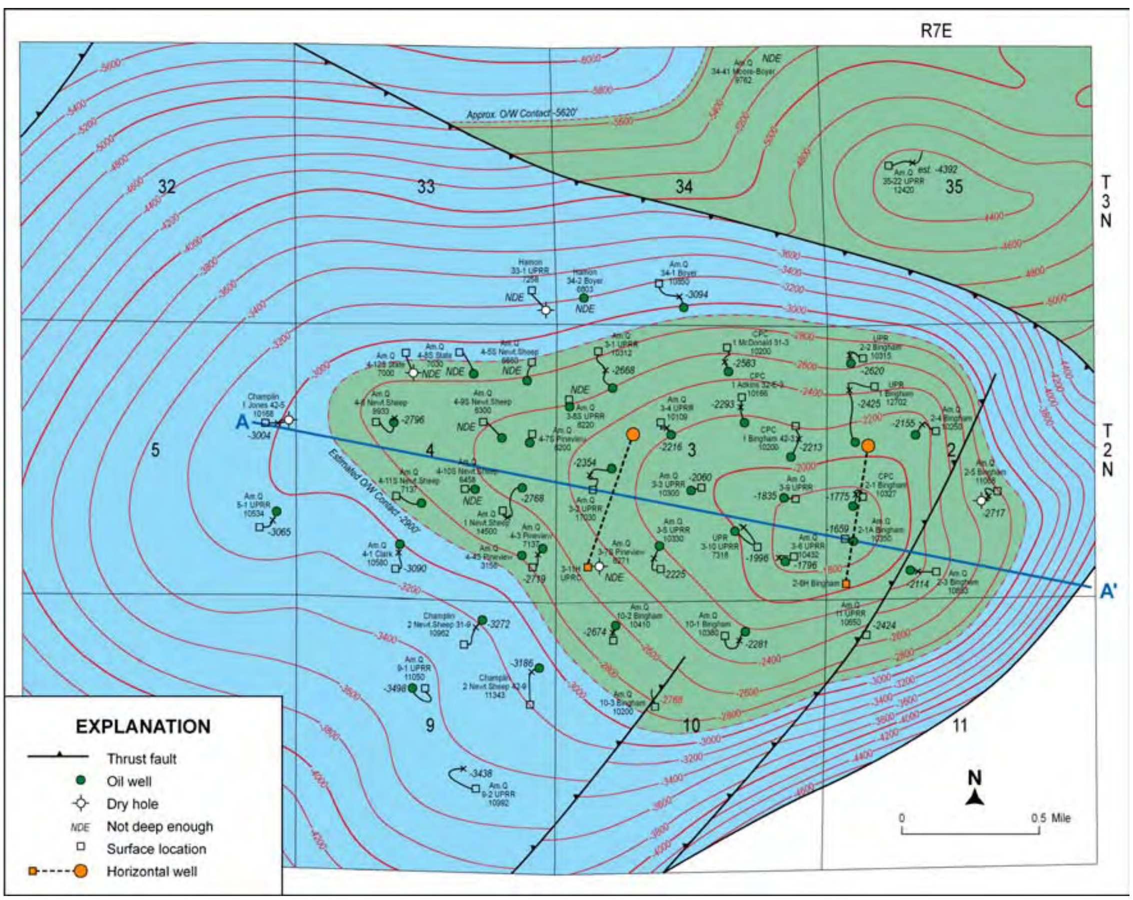


Figure 21. Structure contour map of the top of Watton Canyon Member and horizontal wells, Pineview field. Contour interval = 200 feet, datum = mean sea level. Cross section A–A' shown on figure 22. Modified from the Utah Board of Oil, Gas and Mining (1997a).

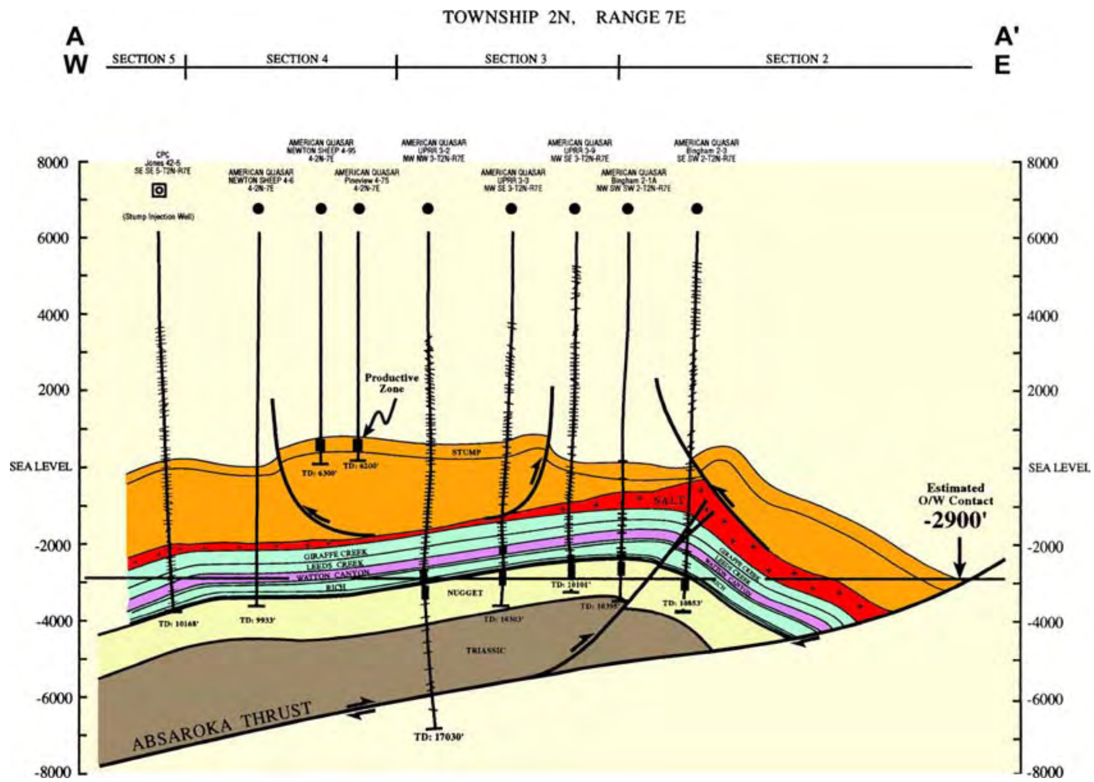


Figure 22. Detailed east-west structural cross section through Pineview field. Line of section shown on figure 21. The Watton Canyon Member of the Twin Creek Limestone, and primary target for horizontal drilling shown in purple. Dipmeter projections shown on some wellbores. After Utah Board of Oil, Gas and Mining (1997b).

Figure 23. Monthly oil production, in barrels, for Pineview field horizontal wells, Bingham Nos. 2-6H and UPRC 3-11H. The UPRC No. 3-11H well only produced for 10 months. Data from Utah Division of Oil, Gas and Mining production records through January 31, 2005.

Lodgepole field: Lodgepole field (figure 2) was discovered in 1976 and has produced over 2,100,000 million bbls (330,000 m^3) of oil and 0.74 BCF (0.021 BCM) of gas from the Nugget and Twin Creek Formations. The trap is a rollover anticline with four-way closure that is divided into two blocks by northeast-southwest-trending splay faults (figures 24 and 25). The structure is further divided into several subsidiary folds and an east-west-trending structural nose. The productive area is about 640 acres (260 ha) (Benson, 1993a). The dominant open fracture trend is northwest to southeast.

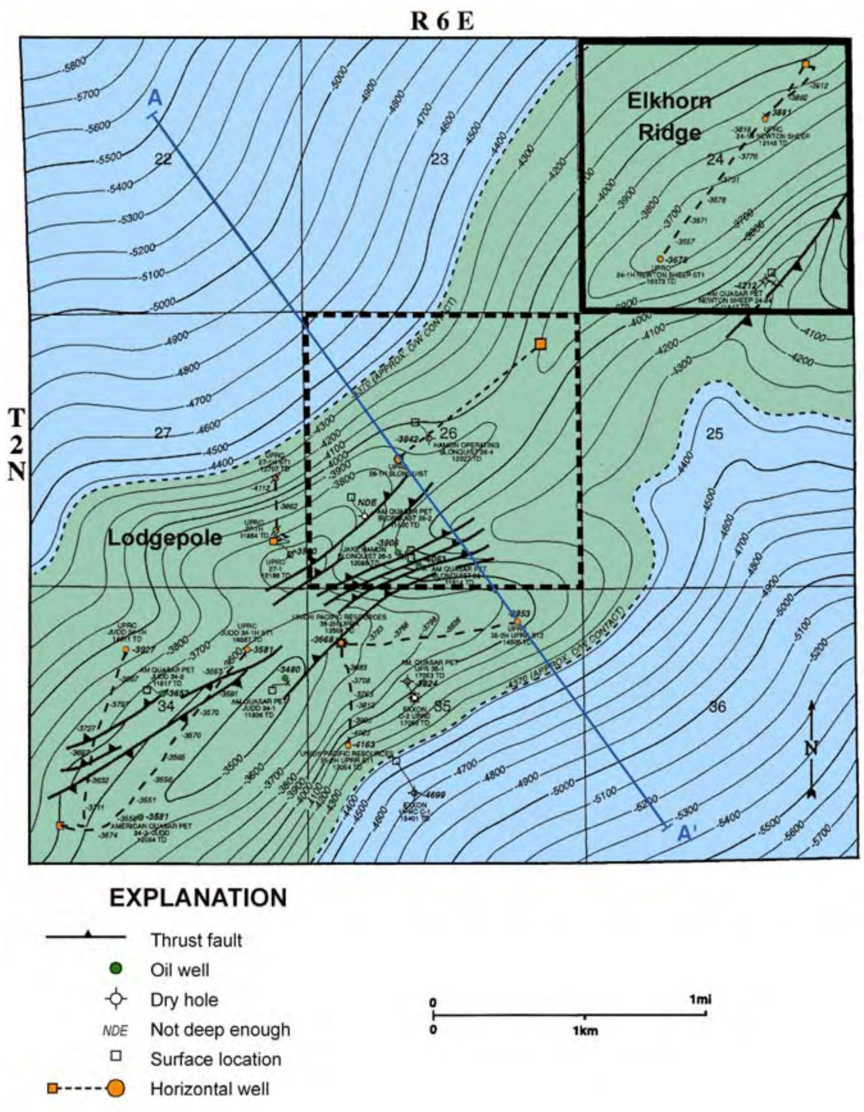


***Figure 24.** Structure map of top of the Watton Canyon Member and horizontal wells, Lodgepole field. Contour interval = 100 feet, datum = mean sea level. Cross section A–A' shown on figure 25. Heavy borders represent units. Modified from the Utah Board of Oil, Gas and Mining (1996a).*

Three horizontal wells, the Blonquist No. 26- 1H (NE1/4NE1/4 section 26, T. 2 N., R. 6 E., SLBLM), Judd No. 34-1 H (SW1/4SW1/4 section 34, T. 2 N., R. 6 E., SLBLM) with two laterals, and the UPRR No. 35-2 H (NW1/4NW1/4 section 35, T. 2 N., R. 6 E., SLBLM) with two laterals, were drilled in the Watton Canyon Member of the Twin Creek Limestone from 1993 through 1996. Horizontal lengths were nearly 3500 feet (1200 m) in north-northeast, east, south, and south-southwest directions depending on their locations on the complex Lodgepole structure (figure 24).

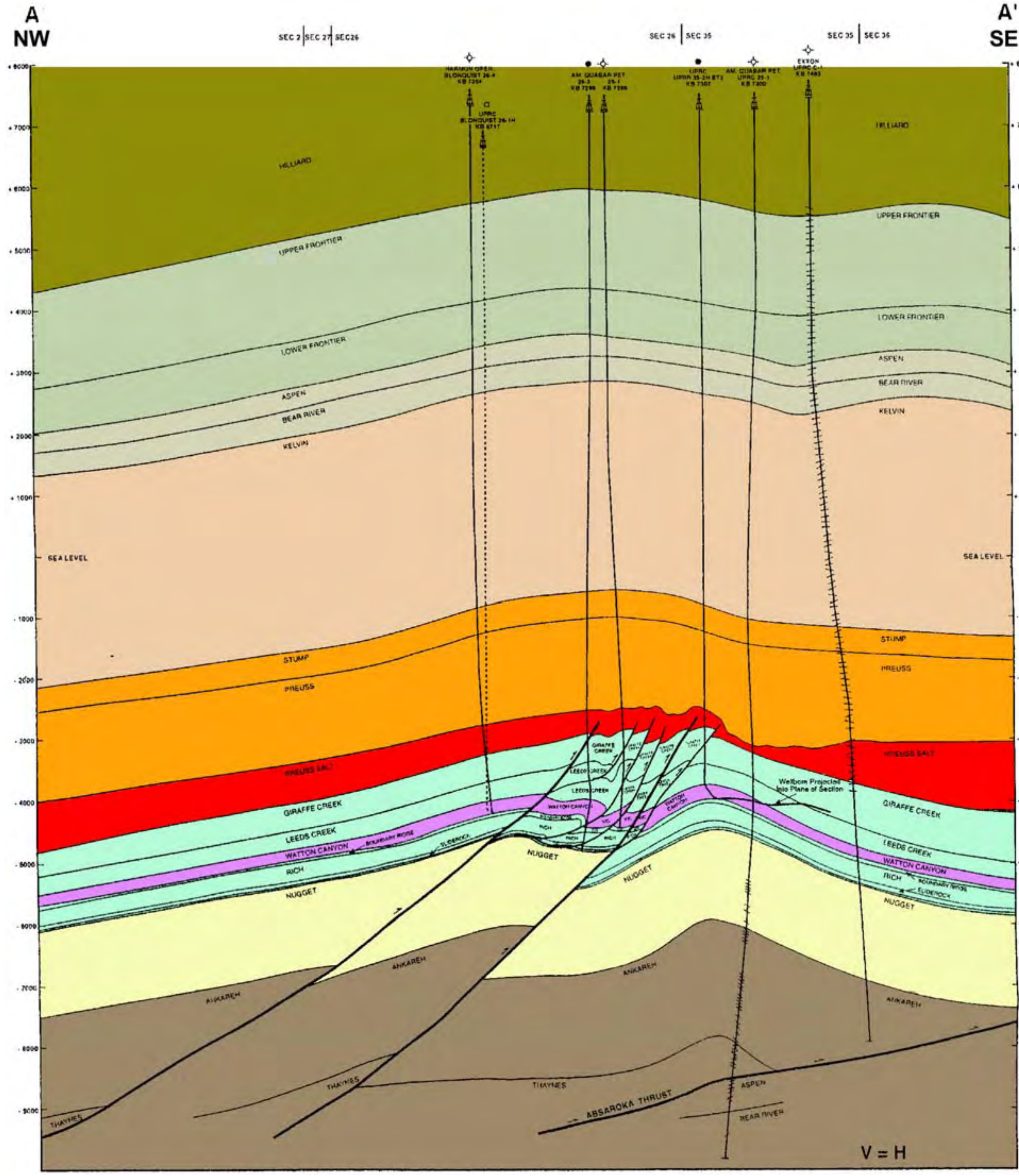


Figure 25. Detailed northwest-southeast structural cross section through Lodgepole field. Line of section shown on figure 24. The Watton Canyon Member of the Twin Creek Limestone, and primary target for horizontal drilling shown in purple. Dipmeter projections shown on some wellbores. After Utah Board of Oil, Gas and Mining (1996b).

Only the Nos. 34-1H and 35-2H wells are productive totaling 394,000 BO (62,600 m^3), 75 MMCFG (2.1 MMCMG), and 202,000 BW (32,100 m^3) (figure 26).

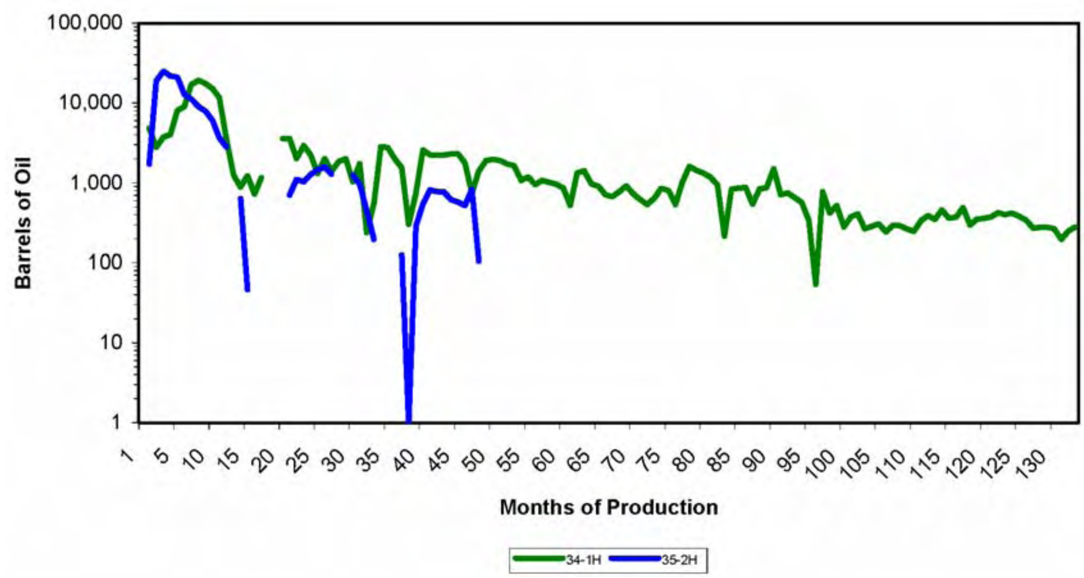


Figure 26. Monthly oil production, in barrels, from the Nos. 34-1H and 35-2H horizontal wells in Lodgepole field. Data from the Utah Division of Oil, Gas and Mining production records through January 31, 2005.

Elkhorn Ridge field: Elkhorn Ridge field (figure 2) was discovered in 1977 and has produced over 1,800,000 million bbls (290,000 m^3) of oil and 0.85 BCF (2,400,000 m^3) of gas from the Twin Creek Limestone (figure 27). Like the other fields on the trend, the trap is a rollover anticline with four-way closure (figures 28 and 29). The productive area about 2560 acres (1040 ha) (Benson, 1993b). Elkhorn Ridge field will be discussed in greater detail because it produces solely from the Twin Creek and the horizontal drilling program was the most successful of the three case-study fields.

The discovery well, the UPRC No. 19-1 (SW1/4NE1/4 section 19, T. 2 N., R. 7 E., SLBLM), was completed in the Rich Member of the Twin Creek Limestone. The UPRC No. 19-2 well (SW1/4NW1/4 section 19, T. 2 N., R. 7 E., SLBLM), drilled in 1979, was completed in the Watton Canyon Member. The Newton Sheep No. 18-1 well (SW1/4SE1/4 section 18, T. 2 N., R. 7 E., SLBLM) was completed in the Watton Canyon in 1987 (figure 30). The UPRC No. 17-1 well (SE1/4NW1/4 section 17, T. 2 N., R. 7 E., SLBLM) was drilled and temporarily abandoned in 1988; it was converted to a Nugget Sandstone salt water disposal well in 1993. From 1993 through 1995, four horizontal wells, the UPRC No. 17-2 H (SW1/4SW1/4 section 17, T. 2 N., R. 7 E., SLBLM), UPRC No. 19-2X H (SW1/4NW1/4 section 19, T. 2 N., R. 7 E., SLBLM), Newton Sheep No. 20-1 H (NW1/4NW1/4 section 20, T. 2 N. R. 7 E., SLBLM) with two laterals, and the Newton Sheep No. 24-1 H (NE1/4NE1/4 section 24, T. 2 N., R. 6 E., SLBLM), were drilled in the Watton Canyon Member of the Twin Creek. An early attempt, the UPRC No. 19-2 1 H well (SW1/4NW1/4 section 19, T. 2 N., R. 7 E., SLBLM), resulted in lost tools in the hole and was junked and abandoned in 1984. The four horizontal wells have produced 1,102,000 BO (175,200 m^3), 523 MMCFG (14.8 MMCMG), and 1,285,000 BW (204,300 m^3) (figure 31).

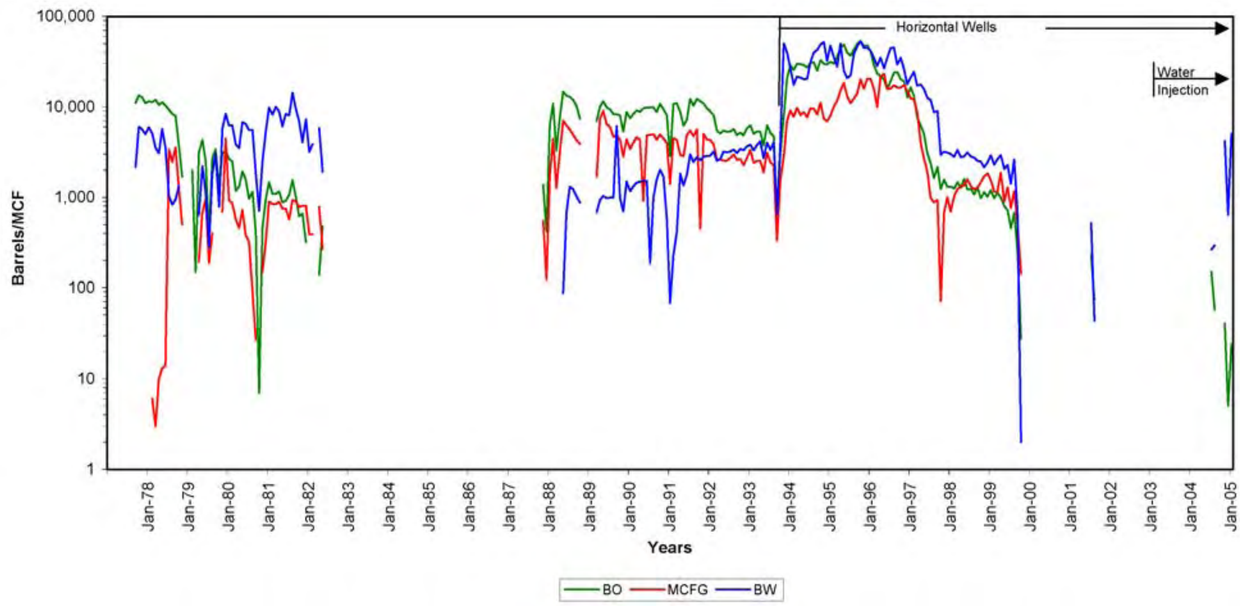


Figure 27. Historical production (oil, gas, and water) for Elkhorn Ridge field. Data from Utah Division of Oil, Gas and Mining production records through January 31, 2005.

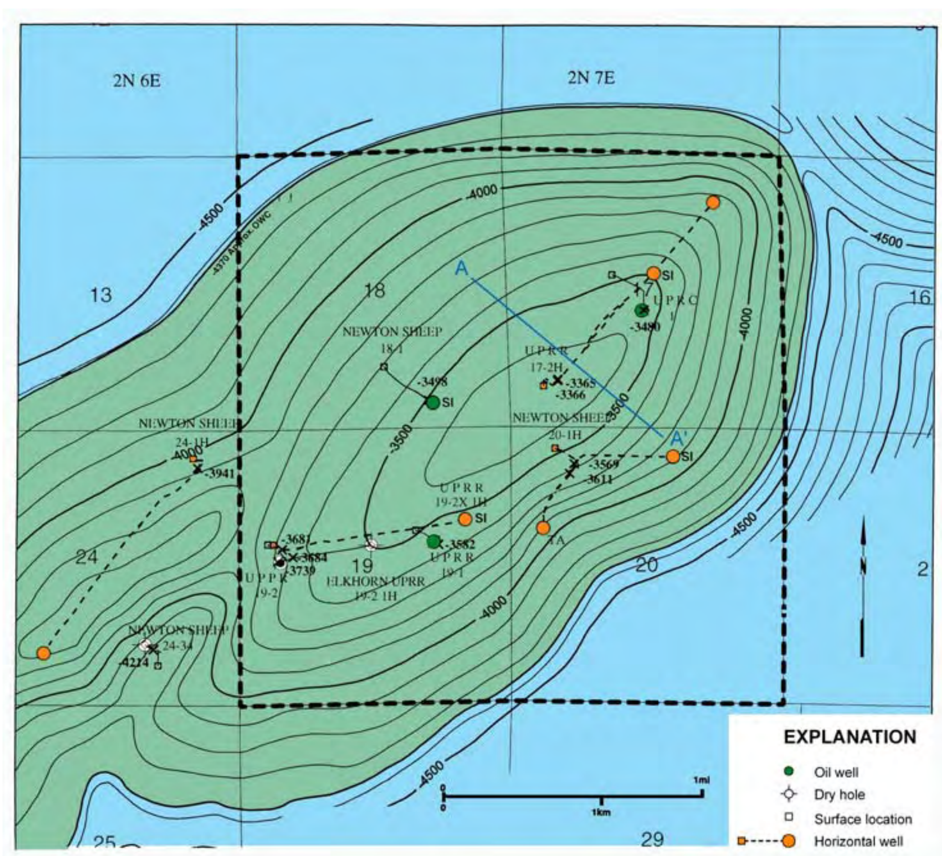


Figure 28. Structure map of top of the Watton Canyon Member and horizontal wells, Elkhorn Ridge field. Contour interval = 100 feet, datum = mean sea level. Cross section A–A' shown on figure 29. Heavy border represents a unit. Modified from the Utah Board of Oil, Gas and Mining (2003a).

The Watton Canyon Member of the Twin Creek Limestone is a low matrix, thinly bedded argillaceous limestone. The majority of the production is from the existing fracture system. Based on outcrop studies, formation imaging logs, and production data, UPRC determined the open fractures predominately trend northwest-southeast and dip to the southwest and northeast at about 60 degrees, parallel to the northwest flank of the structure. Fractures that trend north- northwest to south-southeast are generally closed and healed with mineral deposits (Utah Division of Oil, Gas and Mining, 2003e).

The upper 100 feet (30 m) of the Watton Canyon Member contains uneconomical volumes of hydrocarbons. The lower 190 to 200 feet (58-61 m) of the Watton Canyon can be economically productive if fractures are present. However, the bottom 100 feet (30 m) is less argillaceous and more likely to be fractured (Utah Board of Oil, Gas and Mining, 2003e). The target for the horizontal drilling was a 25- to 30-foot-thick (8-9 m), intensely fractured zone or "sweet spot" near the bottom of the Watton Canyon (figure 30). The four producing horizontal laterals average 2994 feet (912 m) (Appendix) within the 200-foot-thick (60-m) gross pay section, and 2216 feet (675 m) within the 25- to 30-foot-thick (8-9 m) "sweet spot" (Utah Board of Oil, Gas and Mining, 2003e).

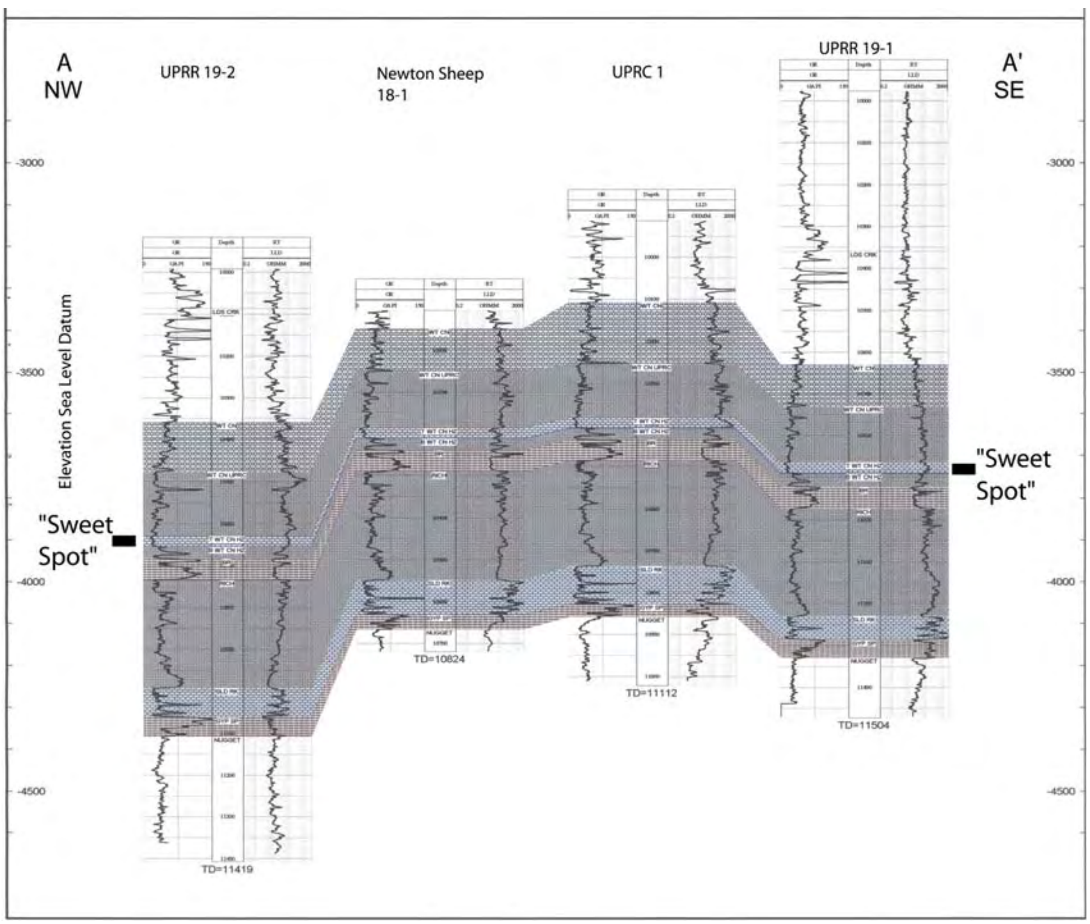


Figure 29. Northwest-southeast projected structural cross section of Elkhorn Ridge field using true vertical depth format. The "sweet spot" in the Watton Canyon Member was the primary target of the horizontal drilling. Approximate line of section shown on figure 28. After Utah Board of Oil, Gas and Mining Hearing (2003b).

The Elkhorn (Watton Canyon) Unit is an enhanced oil recovery unit that was approved for waterflood operations on July 30, 2003. The unit includes all of sections 17, 18, 19 and 20, T. 2 N., R. 7 E, SLBLM. The waterflood project uses the horizontal Newton Sheep No. 20-1H well for water injection and two horizontal wells, the UPRC Nos. 17-2H and UPRR 19-2X H, and one vertical well, the Newton Sheep No. 18-1, for production. The waterflood project calls for an average injection rate of 2250 BW/D (360 m^3/D) with a maximum injection pressure of 2000 pounds per square inch (psi [14,000 kPa]). The operator expects the waterflood to recover an additional 165,000 BO (26,200 m^3). Water injection into the Newton Sheep No. 20–1H well began in November 2003. Through 2004, the average injection rate was about 1300 BW/D (200 m^3/D) without any increase in oil production.

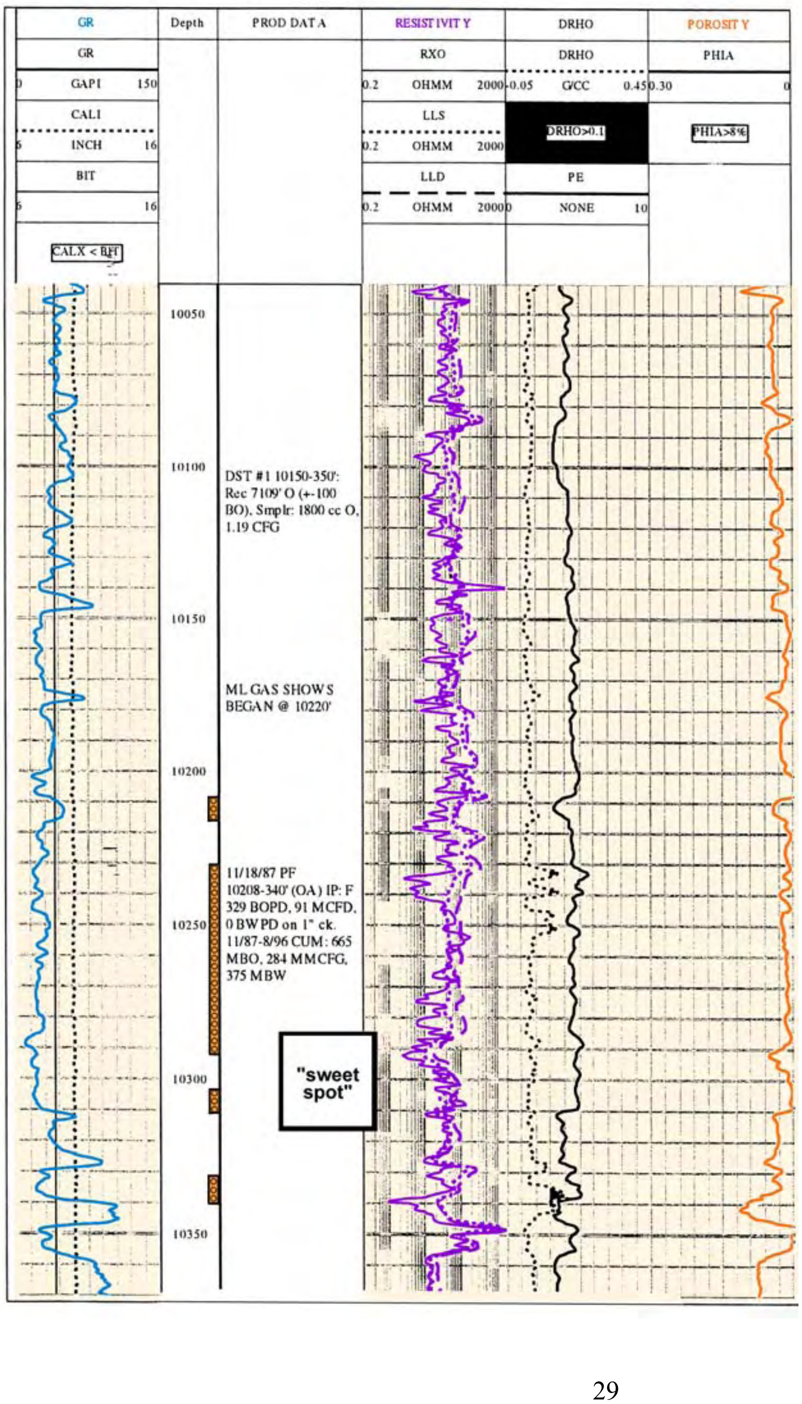


Figure 30. Newton Sheep No. 18-1 well type log of the Watton Canyon Member of the Twin Creek Limestone in Elkhorn Ridge field. The "sweet spot" was the primary target of the horizontal drilling. After Utah Board of Oil, Gas and Mining (2003c).

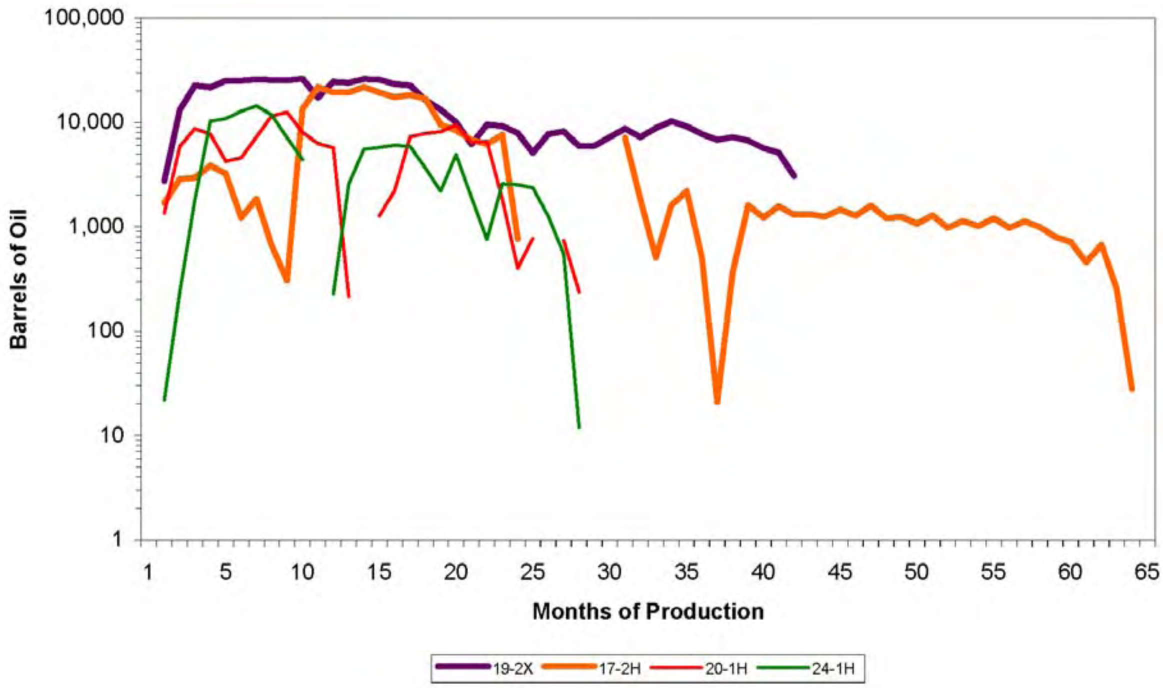


Figure 31. Monthly oil production, in barrels, from the four horizontal wells that produce in Elkhorn Ridge field. Data from Utah Division of Oil, Gas and Mining production records through January 31, 2005.

Retrograde Condensate Production

Condensate production is common in Absaroka thrust - Mesozoic-cored deep structures (figure 4). In retrograde condensate reservoirs, the fluid changes from a single-phase rich gas to a two-phase gas and liquid mixture when the pressure drops below the dew-point pressure (Kloepper, 1993). Without pressure maintenance, the retrograde condensate remains in the reservoir and wells are less productive. The Nugget Sandstone in Anschutz Ranch East field (figure 2) is a major retrograde reservoir where pressure maintenance operations have successfully maximized recovery. Condensate production under the pressure maintenance program covers the expense of the operation and positively affects the economics (Kloepper, 1993).

The following description of the best practices for condensate production was taken, with some modifications and updates, from "Maximizing Condensate Recovery in a Rich Gas Reservoir" by Welch (1993) in the "Atlas of Major Rocky Mountain Gas Reservoirs."

Introduction

Retrograde gas condensation occurs when a reservoir containing a single-phase gas forms a liquid phase while undergoing isothermal expansion during pressure depletion (Katz and others, 1959). Liquid condensate is first formed in the reservoir when the pressure of the expanding reservoir gas drops below the dew-point pressure. When liquid condenses in the reservoir, it can cause several adverse effects. The more common of these are a reduction in ultimate condensate recovery, a reduction in gas deliverability, and a reduction in ultimate gas recovery from that expected in the absence of liquid condensation. Depending on reservoir characteristics and/or reservoir fluid-phase behavior, the adverse effects associated with retrograde condensation can often be economically prevented or minimized. Anschutz Ranch East field (figure 2) is an example of an attempt to minimize retrograde condensate losses through implementation of a full pressure maintenance project. Pressure maintenance has been achieved in this field by injecting a mixture of dry hydrocarbon gas and nitrogen.

Although full pressure maintenance is the most effective way to alleviate the problems associated with retrograde condensation, it is not always economical to implement. Therefore, the virtues of depleting a reservoir under partial pressure maintenance and/or gravity drainage mechanisms should not be overlooked. Detailed reservoir analysis must be coupled with the analysis of surface facility design to identify the optimum development plan.

Methods

For a given reservoir temperature, retrograde condensate gas reservoirs lie between volatile oil and dry gas reservoirs in terms of molecular composition. As is true for all reservoirs, tests should be performed in a retrograde condensate reservoir to determine the reservoir fluid composition and its phase behavior. Caution must be exercised in sampling retrograde condensate fluids to ensure that the samples gathered are representative of the in-situ fluids because phase changes can take place during sampling. Surface separation studies should be conducted to determine the optimum separator stages to maximize condensate recovery from the produced gas.

An example of retrograde condensation is demonstrated in the constant composition expansion phase diagram of a hydrocarbon mixture (figure 32). The fluid initially exists at reservoir and temperature conditions indicated by point L. Until the pressure declines below the dew point (point D), only free gas exists. At the dew point, the first drops of liquid form. Between the dew point and point G, retrograde condensation is occurring and the liquid saturation is increasing. Between points G and E, retrograde vaporization is occurring and the liquid saturation is decreasing. Reducing the pressure to below point E will cause the mixture to pass back through the dew point and all the condensate will revaporize.

Although figure 32 is an accurate laboratory description of the phase behavior for a system undergoing a constant composition expansion, liquid that is condensed in the reservoir usually is not recoverable under primary pressure depletion (in the absence of water influx, reservoir depletion is more closely related to a constant volume depletion process). The reduction in condensate recovery is associated with a shift in the reservoir composition toward a heavier composition as the lighter

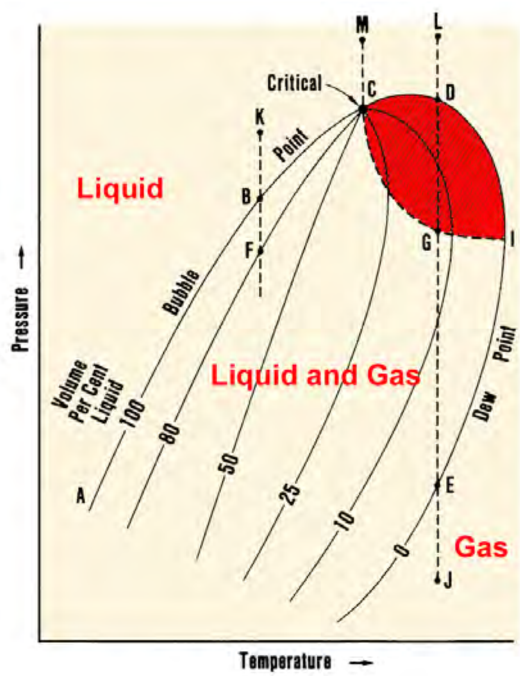


Figure 32. Phase diagram for a hydrocarbon mixture. After Katz and others (1959).

components are withdrawn from the reservoir in the form of gas production. This shifting composition depresses the lower portion of the dew-point curve (figure 32) making revaporization of the retrograde liquid more difficult. Condensate saturations will be highest in the vicinity of producing wells because of pressure drawdown and some migration of condensate to the wellbore area. Larger condensate dropout zones exist in the vicinity of the wellbores in lower-permeability reservoirs because of the need for larger pressure gradients to maintain a given level of well production.

Normally, any operating procedure that prevents reservoir pressure decline will have a positive effect on field recovery. However, pressure support through an aquifer and/or water injection may have more detrimental effects on ultimate recovery than the advantages of restricted pressure decline because of the trapping or bypassing of gas by the water front.

Generally, the best way to prevent or reduce retrograde losses in the reservoir is to implement a pressure maintenance project by gas injection. Partial pressure maintenance can be accomplished by re-injection of the produced gas after processing to remove liquids or heavy components. Full pressure maintenance can be achieved through the injection of a nonreservoir gas, such as nitrogen, or injecting the produced gas and adding a hydrocarbon make-up gas purchased from another source. Repressuring a depleted or partially depleted retrograde condensate can cause the condensate to partially revaporize and ultimately be produced in the gas-well stream.

Unfortunately, most of the pressure support projects that might be necessary for maximum fluid recovery require early installation of field equipment with major front-end cash investments. In the final analysis, any project to be implemented should be studied well to determine the economic merit of the application of improved recovery. In very general terms, the expected gas and condensate recovery can be estimated for primary depletion by first calculating the amount of sales gas and condensible liquids contained in the reservoir. Recoverable volumes can then be calculated using a recovery factor for each phase from correlations provided by Eaton and Jacoby (1970). Experimental laboratory depletion studies provide a more accurate estimate of expected reservoir performance.

The recovery for the pressure maintenance injection case may also be estimated from the in-place sales gas and condensate volumes. These volumes are converted to recoverable volumes by application of a recovery factor that reflects primarily the volumetric sweep that will be achieved by the injected gas. Volumetric sweep efficiency must be estimated considering placement of the injection wells, vertical heterogeneity of the formation, and gravity segregation tendencies of the reservoir and injected fluids.

Another mechanism that can increase condensate recovery is gravity drainage. In retrograde reservoirs where pressure maintenance is unattractive because of economics and/or poor reservoir or fluid characteristics, additional condensate may be recovered from the base of reservoir. Basement recovery of retrograde condensate is possible anywhere gravity forces can occur in real time (field operating life). This has been observed in the fractured Waterton reservoir in Alberta, Canada (Castelijns and Hagoort, 1984). Basement recovery can occur in both dipping and flat reservoirs. Figures 33 and 34 illustrate how condensate drainage occurs in a fracture matrix system.

These methods give reasonable approximations of recovery for screening purposes only. More detailed reservoir calculations including reservoir simulation studies should be used for detailed screening and project design.

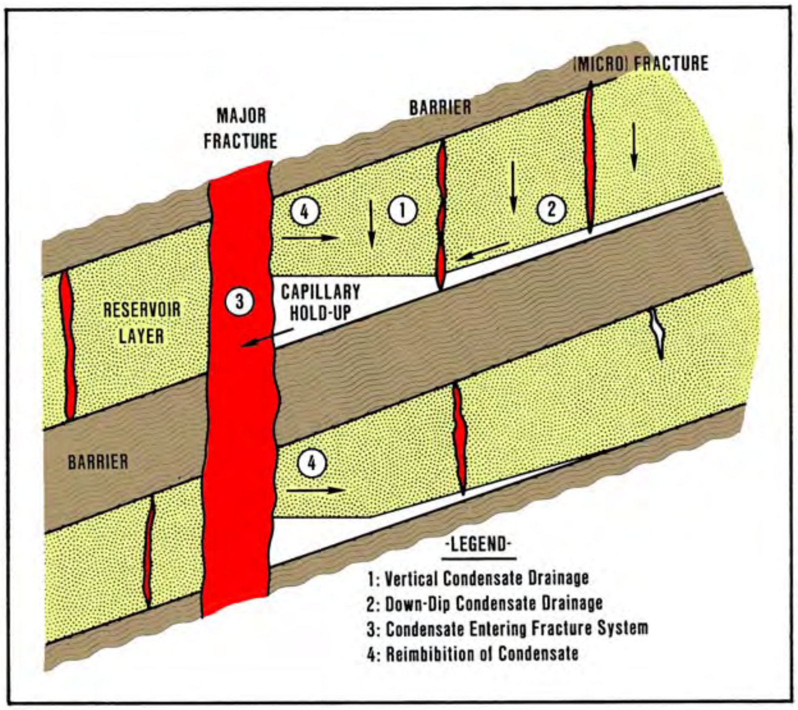


Figure 33. Schematic diagram of condensate drainage through fractures. After Castelijns and Hagoort (1984).

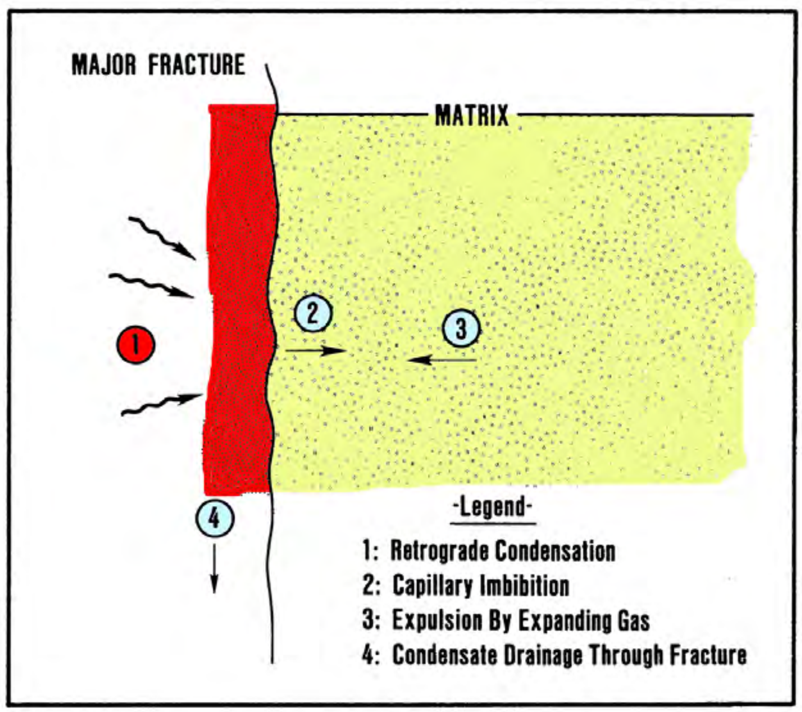


Figure 34. Schematic diagram of condensate drainage through matrix. After Castelijns and Hagoort (1984).

Anschutz Ranch East Case-Study Field

Anschutz Ranch East, straddling the Utah/Wyoming border, (figure 2) is the largest field in the Mesozoic-cored deep structures subplay in terms of hydrocarbon column thickness, cumulative production and reserves, and areal extent (figures 8 and 9). The reservoir covers approximately 4620 acres (1870 ha) and is divided into two structural lobes. The larger west lobe is a narrow, elongate anticline overturned to the east (Lelek, 1982). Average depth to the Nugget Sandstone in the west lobe is 12,900 feet (4300 m) with more than 2100 feet (700) of closure. When the west lobe reservoir was discovered in 1979, the hydrocarbon column was near the spill point. The smaller east lobe has the same general configuration as the west lobe, and is separated from it by an overturned syncline (Lelek, 1982). Average depth to the Nugget Sandstone in the east lobe is 14,325 feet (4775 m), and it has more than 1000 feet (330 m) of closure. When the east lobe reservoir was discovered in 1981, the hydrocarbon column was also near the spill point (Petroleum Information, 1984).

The Nugget is 1020 feet (310 m) thick with an average porosity of 10 percent. The permeability ranges from 0.1 to 400 millidarcies (Lindquist and Ross, 1993). The Nugget formation contains both open fractures and gouge or carbonate-filled fractures (Lelek, 1982). Reservoir performance is affected by fracturing and height above the free-water level (Sercombe, 1989). Cumulative production (figure 35) is over 129 million bbls (20.5 million m^3) of condensate, the largest Nugget producer of hydrocarbon liquids in the thrust belt, and nearly 3 trillion cubic feet (85 BCM) of gas (including cycled hydrocarbon gases and nitrogen) (Utah Division of Oil, Gas and Mining, 2005).

According to Metcalfe and others (1985), the field produces a rich (>200 bbls/MMCF [32 m^3/28MCM]) gas-condensate fluid. At the time of discovery, the field was just slightly above (150 to 300 psi [1030-2070 kPa]) the dew-point pressure of 5080 psi (35,000 kPa).

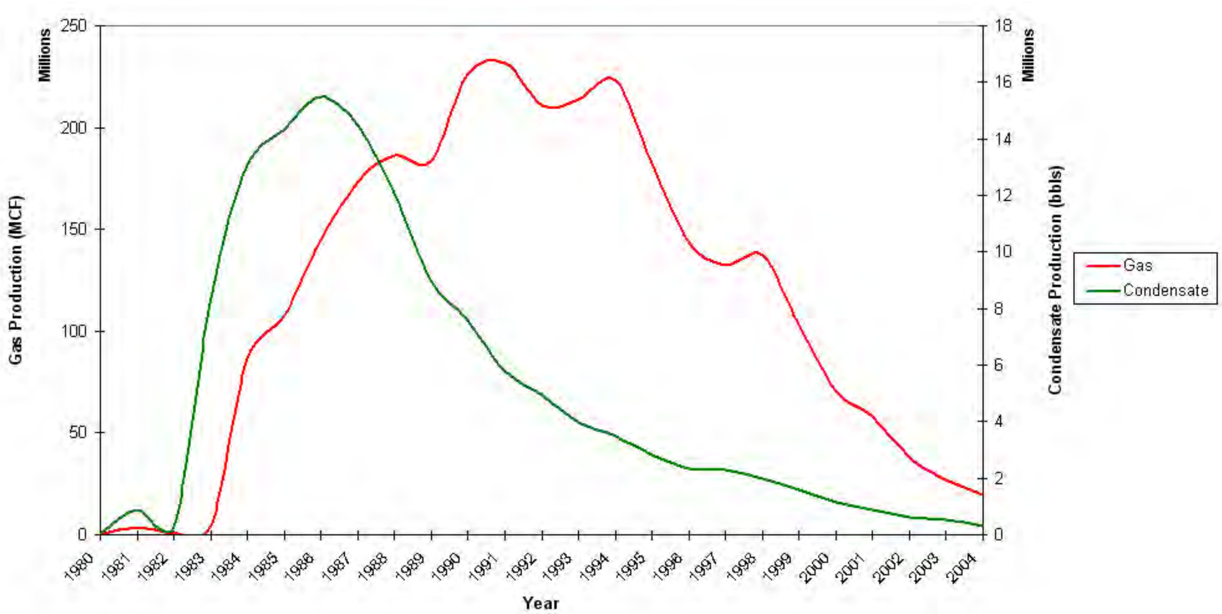


Figure 35. Historical production (condensate and gas) for Anschutz Ranch East field. Data from Utah Division of Oil, Gas and Mining production records through January 1, 2005.

Because of the reservoir size and potentially low liquid recovery through retrograde condensation in the reservoir, a plan of depletion had to be determined prior to opening the field to production (Kleinsteiber and others, 1983). The following is a brief summary of how this field was evaluated.

The depletion alternatives considered were pressure maintenance (full and partial) with wet or dry hydrocarbon gases, carbon dioxide, flue gas, and/or nitrogen. Table 2 lists advantages and disadvantages, applied to Anschutz Ranch East field, for the different injection gases. Well spacing, injection patterns, and completion strategies also were evaluated. The alternatives were studied initially with a cross-sectional model and two-dimensional Equation-of-State compositional simulator. From this study, the development plan (spacing and pattern), nitrogen injection plan, and the optimum well completion prognosis were developed.

After the initial scoping study, the reservoir was simulated (Wendschlag and others, 1983) with a full-field, three-dimensional model (an 84 x 20 areal grid and four layers) using both a nine-Component and a 17-Component compositional simulator. This second study was performed to verify past results and improve upon the performance forecasts obtained from the earlier model.

In addition to the simulation studies, an eight-well interference test was performed prior to placing the field in production (Pollock and Bennett, 1986). This test was intended to verify areal continuity and to determine if there was an extensive fracture system and/or any directional orientation to the reservoir flow capacity. The test consisted of placing the Anschutz Ranch East No.16-20 well in production for 50 days. As shown in figure 36, pressure response was monitored in seven wells. It was concluded that the reservoir was continuous and an extensive fracture system did not exist.

Table 2. Evaluation of potential fluids for pressure maintenance. After Kleinsteiber and others (1983).

Fluid	**Advantage**	**Disadvantage**
Carbon dioxide	Early gas sales Better recovery than nitrogen	Lack of availability Volume/compressibility Disadvantage Corrosion
Nitrogen	Early gas sales Availability Volume/ compressibility advantage Cost	Large power requirements Causes liquid to dropout in reservoir
Combustion flue gas	Early gas sales Availability Volume/compressibility advantage Smaller power requirements than nitrogen	More expensive than nitrogen Corrosion
Produced hydrocarbon gas	Best availability	Defers gas sales Permits only partial pressure Maintenance
Produced hydrocarbon gas with purchased hydrocarbon make-up	Best recovery	Defers gas sales Possibility of make-up source Interruptions Most expensive

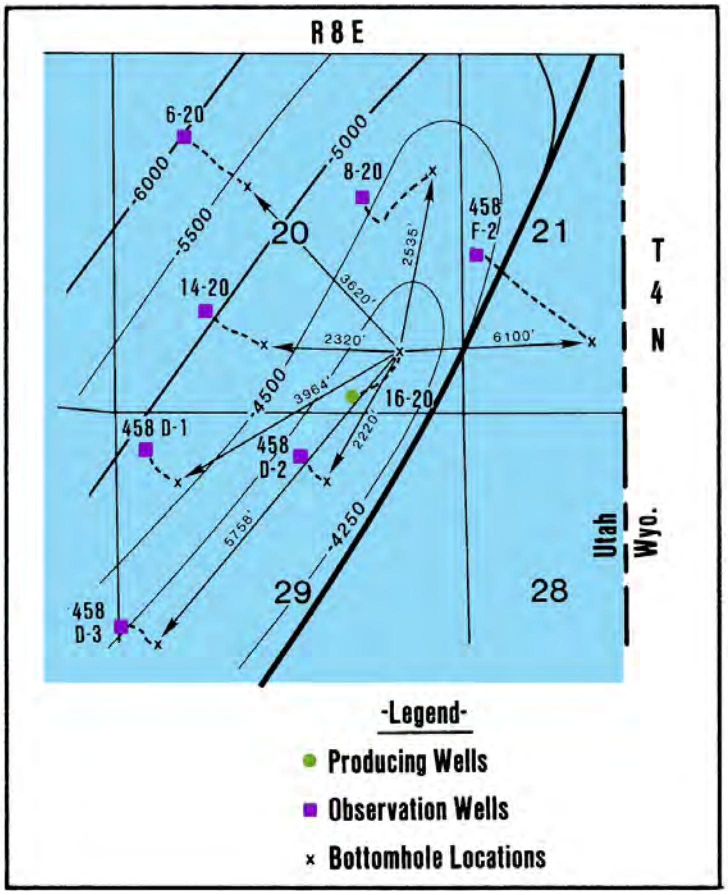


Figure 36. Producing and observation wells used in the interference test. After Pollock and Bennett (1986).

Through 1992, Anschutz Ranch East field had been operated under a full pressure maintenance program intended to minimize retrograde condensation. However, the proposed plan of depletion was delayed due to prevailing market conditions, periodic curtailment in gas sales, and other operating/economic conditions. The reservoir pressure has been maintained by injecting the processed (dry) gas stream, which is not sold, and using nitrogen gas to replace the remaining reservoir voidage (figure 37).

Partial pressure maintenance was evaluated for Anschutz Ranch East, but the final results indicated that full pressure maintenance would be the most profitable depletion plan. However, partial pressure maintenance by injecting the produced or residue gas after processing can be very attractive in other fields, particularly if a market does not exist for gas sales.

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*.

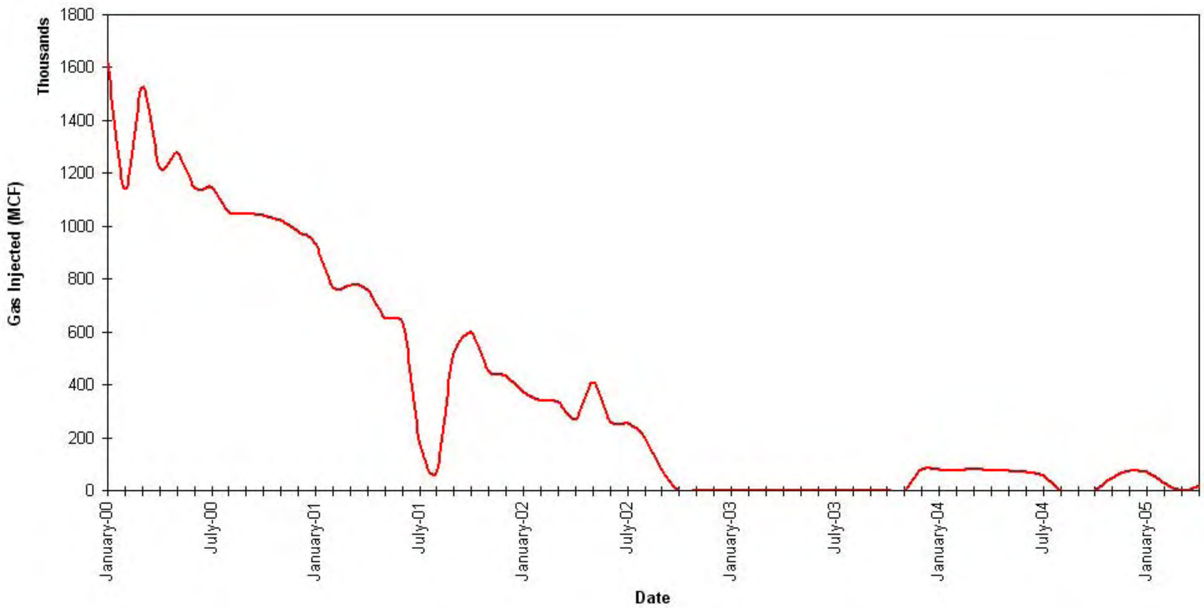


Figure 37. Gas injection at Anschutz Ranch East field since 2000. Data from Utah Division of Oil, Gas and Mining production records through January 1, 2005.

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, project team members joined Utah Stake Holders Board members in attending the Uinta Basin Oil and Gas Collaborative Group meeting in Vernal, Utah, on June 2, 2005. Project activities, results, and recommendations were presented at this meeting.

Project materials, plans, and objectives were displayed at the UGS booth during central Utah Natural Resources Festival, April 22-23, 2005, in Richfield, Utah, and the AAPG Annual Convention, June 19-22, 2005, in Calgary, Canada. Three UGS scientists staffed the display booth at these events. Project displays will be included as part of the UGS booth at professional and other public meetings throughout the duration of the project.

An abstract was submitted to the AAPG on the central Utah thrust belt Navajo Sandstone oil play and was accepted for oral presentation during the AAPG Rocky Mountain Section Meeting on September 26, 2005, in Jackson, Wyoming.

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.

Project Publications

Chidsey, T.C., Jr., and Sprinkel, D.A., 2005, “Elephant” discovered in central Utah: Utah Geological Survey, Survey Notes, v. 37, no. 2, p. 8-9.

Chidsey, T.C., Jr., and Sprinkel, D.A., 2004, Major oil plays in Utah and vicinity – quarterly technical progress report for the period January 1 to March 31, 2005: U.S. Department of Energy, DOE/FC26-02NT15133-11, 32 p.

Presentations

The following presentations were made during the reporting period as part of the technology transfer activities:

"The Jurassic Navajo Sandstone Central Utah Thrust Belt Exploration Play, Sanpete and Sevier Counties, Utah" by Thomas C. Chidsey, Jr., Manti, Utah, May 3, 2005, to the Sanpete County Commissioners and general public. The petroleum geology of the central Utah thrust belt play, the recent oil discovery of Covenant field, play potential, and the economic impact on the county were part of the presentation.

"Oil and Gas in Sevier County" panel discussion chaired by the Sevier County Community & Economic Development Director at the Central Utah Economic Summit, Richfield, Utah, May 6, 2005. Thomas C. Chidsey, Jr. served on the panel at this public event where the petroleum geology of the central Utah thrust belt play, the recent oil discovery of Covenant field, play potential, and the economic impact on the county were the focus of the discussion.

"Current Oil and Gas Program of the Utah Geological Survey" by Thomas C. Chidsey, Jr., at the Society of Petroleum Engineers, Salt Lake Petroleum Section, “Gas and Oil Developments in Utah: 2005 Update” symposium in Salt Lake City, Utah, May 20,

2005. The presentation reviewed DOE-funded UGS projects including the PUMPII (the subject of this report), Class II Oil Revisit Paradox Basin horizontal drilling, and the Advanced and Key Oilfield Technologies for Independents (Area 2 – Exploration) Leadville Limestone studies.

"Overview of Potential Energy Resource Development in Utah" panel presentation to the Natural Resources, Agriculture, and Environment Interim Committee, Utah State Legislature, in Salt Lake City, Utah, June 15, 2005. Thomas C. Chidsey, Jr. served on the panel at this open meeting where the petroleum geology of the central Utah thrust belt play, the recent oil discovery of Covenant field, play potential, and the economic impact on the State were part of the presentation and discussion.

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. The most prolific oil plays in the Utah/Wyoming thrust belt province are the Jurassic Nugget Sandstone and Twin Creek Limestone thrust belt plays, having produced over 303 million bbls (49 million m^3) of oil and 5.2 TCFG (148 billion m^3). Traps form on discrete subsidiary closures along major ramp anticlines where the Nugget and Twin Creek are extensively fractured. Hydrocarbons were generated from subthrust Cretaceous source rocks.

3. The Nugget Sandstone thrust belt play is divided into three subplays: (1) Absaroka thrust - Mesozoic-cored shallow structures, (2) Absaroka thrust - Mesozoic-cored deep structures, and (3) Absaroka thrust - Paleozoic-cored shallow structures. Mesozoic-cored structures subplays both represent a linear, hanging-wall, ramp anticline parallel to the leading edge of the Absaroka thrust. This ramp anticline is divided into a broad, shallow structural high (culmination) and a deep, structural low (depression). Fields in the shallow subplay produce crude oil and associated gas. Fields in the deep subplay produce retrograde condensate. The Paleozoic-cored shallow structures subplay is located immediately west of the Mesozoic-cored structures subplays. 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 Nugget against a thrust splay. Fields in this subplay produce nonassociated gas and condensate. Traps in these subplays consist of long, narrow, doubly plunging anticlines.

4. 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 of consist of the same long, narrow, doubly plunging anticlines that produce from the Nugget Sandstone.

5. Horizontal drilling in Utah thrust belt fields targets the heterogeneous Twin Creek Limestone and Nugget Sandstone reservoirs. Drilling techniques include new wells and horizontal, often multiple, laterals from existing vertical wells. Multiple laterals are recommended where two separate, geologically distinct zones are present. To avoid problems in the Preuss salt it is recommended that drilling penetrate 500 feet (150 m) into non-productive upper Twin Creek before turning horizontal. Fractures and lithologic variations create potential undrained compartments ideally suited for horizontal drilling. Horizontal wells should generally be drilled perpendicular to the dominant orientation of open fractures, and above and parallel to the low-proved oil or oil/water contacts. The smallest area that can be effectively drained with a 2000-foot (600-m) horizontal well in fractured Twin Creek reservoirs is 640 acres (260 ha).

6. The horizontal drilling programs at Pineview, Lodgepole, and Elkhorn Ridge fields in the Utah thrust belt, successfully extended the productive life of the fields. Horizontal drilling was probably uneconomical at Pineview, marginally economic at Lodgepole, and economically successful at Elkhorn Ridge. All three fields were at an advanced stage of depletion when the horizontal drilling began, and in structurally complex settings making it difficult to avoid production of formation water.

7. Horizontal drilling technology was not readily available when the Pineview, Lodgepole, and Elkhorn Ridge fields were discovered and developed. Horizontal drilling, particularly the success at Elkhorn Ridge field, does demonstrate that the fractured Watton Canyon Member of the Twin Creek Limestone is an excellent reservoir for horizontal drilling in other discoveries. If horizontal technology had been available these fields could have been developed with fewer wells (smaller footprint), and would have resulted in a greater ultimate oil recovery.

8. The enhanced oil recovery waterflood project in the Elkhorn Ridge field utilizes horizontal wells. The project is just beginning and it is too early to determine its effectiveness. The fractured nature of the Watton Canyon Member of the Twin Creek Limestone could result in early breakthrough of injected water. But, the alternative would have been abandonment of the field. The waterflood project will provide valuable information about the enhanced recovery potential of the Watton Canyon reservoir and similar fractured reservoirs.

9. Retrograde gas condenses from a single phase when the dew-point pressure is reached, and upon further pressure reduction, forms a liquid phase in the reservoir. As the reservoir pressure is depleted further, additional condensation will take place until a pressure is reached at which the liquid begins to vaporize. Thus, there is a maximum in the volume of liquid that condenses. Further pressure reduction will not revaporize all of the liquid, and some will be left as an immobile liquid phase in the reservoir at the time of abandonment. Reservoir management of retrograde condensate reservoirs is both critical, to maximize recovery and value from this type of reservoir, and challenging, because of the need to evaluate the phase behavior of retrograde condensate reservoir fluids under alternative depletion plans. To maximize liquid recovery, a thorough understanding of reservoir geometry, fluid distribution, and phase behavior must be included as part of the overall technical evaluation (from Welsh, 1993).

10. Anschutz Ranch East field on the Utah/Wyoming border is a prime example of a rich condensate gas reservoir. Soon after the field was discovered in 1979, the operators realized that it would require unitization to assure maximum liquid recovery through efficient reservoir management. Even prior to initiating full field production, the reservoir was evaluated to determine a plan of depletion. The evaluation of Anschutz Ranch East led to a full reservoir pressure maintenance project that required initial injection of a buffer gas equal in volume to 10 percent of the hydrocarbon pore volume. The buffer gas was a mixture of 35 percent nitrogen and 65 percent wet gas followed by the injection of pure nitrogen (from Welch, 1993). Cumulative production from Anschutz Ranch East field is over 129 million bbls (20.5 million m^3) of condensate.

ACKNOWLEDGMENTS

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James Parker, Sharon Wakefield, and Cheryl Gustin of the UGS prepared the figures. Cheryl Gustin, UGS, formatted the manuscript. Kevin McClure (UGS) assisted with data compilation. This report was reviewed by David Tabet and Robert Ressetar of the UGS.

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---1980c, Anschutz Ranch field, Twin Creek structure map: Cause No. 183-4, Exhibit No. 2, 1 inch = 2000 feet.

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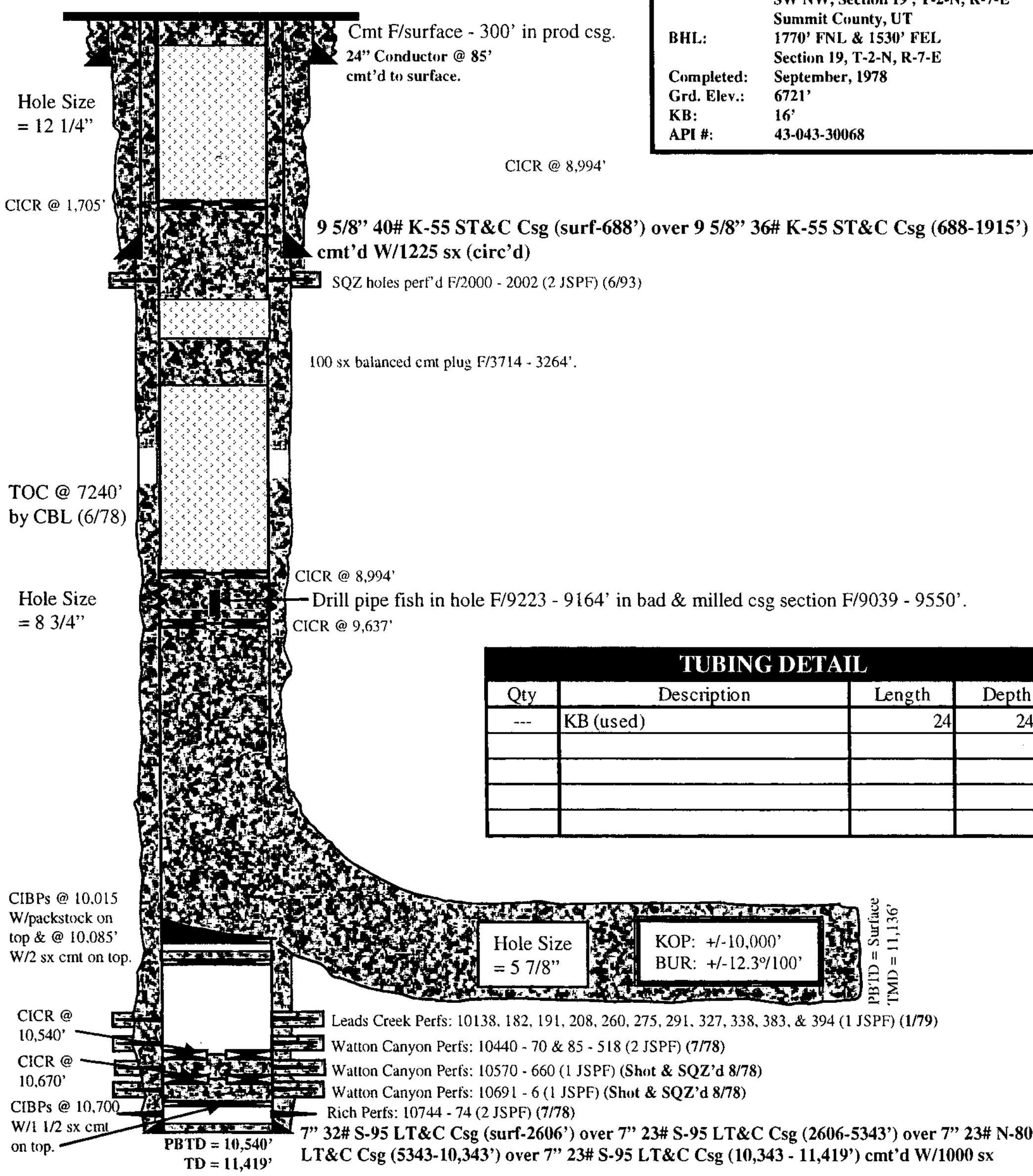
APPENDIX

WELLBORE DIAGRAMS AND INFORMATION, ELKHORN RIDGE FIELD, SUMMIT COUNTY, UTAH

CITATION OIL AND GAS CORPORATION
WELLBORE DIAGRAM AND INFORMATION

Well Name: UPRR #19-2 **Field:** Elkhorn
Date: December 30, 2002 **Location:** SW NW, Section 19, T-2-N, R-7-E
County: Summit **State:** Utah

Surface:	**1980' FNL & 660' FWL SW NW, Section 19 , T-2-N, R-7-E Summit County, UT**
BHL:	**1770' FNL & 1530' FEL Section 19, T-2-N, R-7-E**
Completed:	**September, 1978**
Grd. Elev.:	**6721'**
KB:	**16'**
API #:	**43-043-30068**



TUBING DETAIL

Qty	Description	Length	Depth
---	KB (used)	24	24.00

CITATION OIL AND GAS CORPORATION
WELLBORE DIAGRAM AND INFORMATION

Well Name:	UPRR #17-2H	**Field:**	UPRC Elkhorn
Date:	December 17, 2002	**Location:**	SW/SW Sec. 17, T2N, R7E
County:	Summit	**State:**	Utah

Surface:	**825' FSL & 663' FWL Sec. 17, T2N, R7E Summit County, UT**
BHL:	**2866' FSL & 2854' FWL Sec. 17, T2N, R7E**
Completed:	**March 1995**
Elevation:	**6,924'**
KB:	**24'**
API #:	**43-043-30304**

ROD DETAIL

Qty	Size	Type	Length
160	1 1/4"	F.G.	6,000
160	1"	"D"	4,000

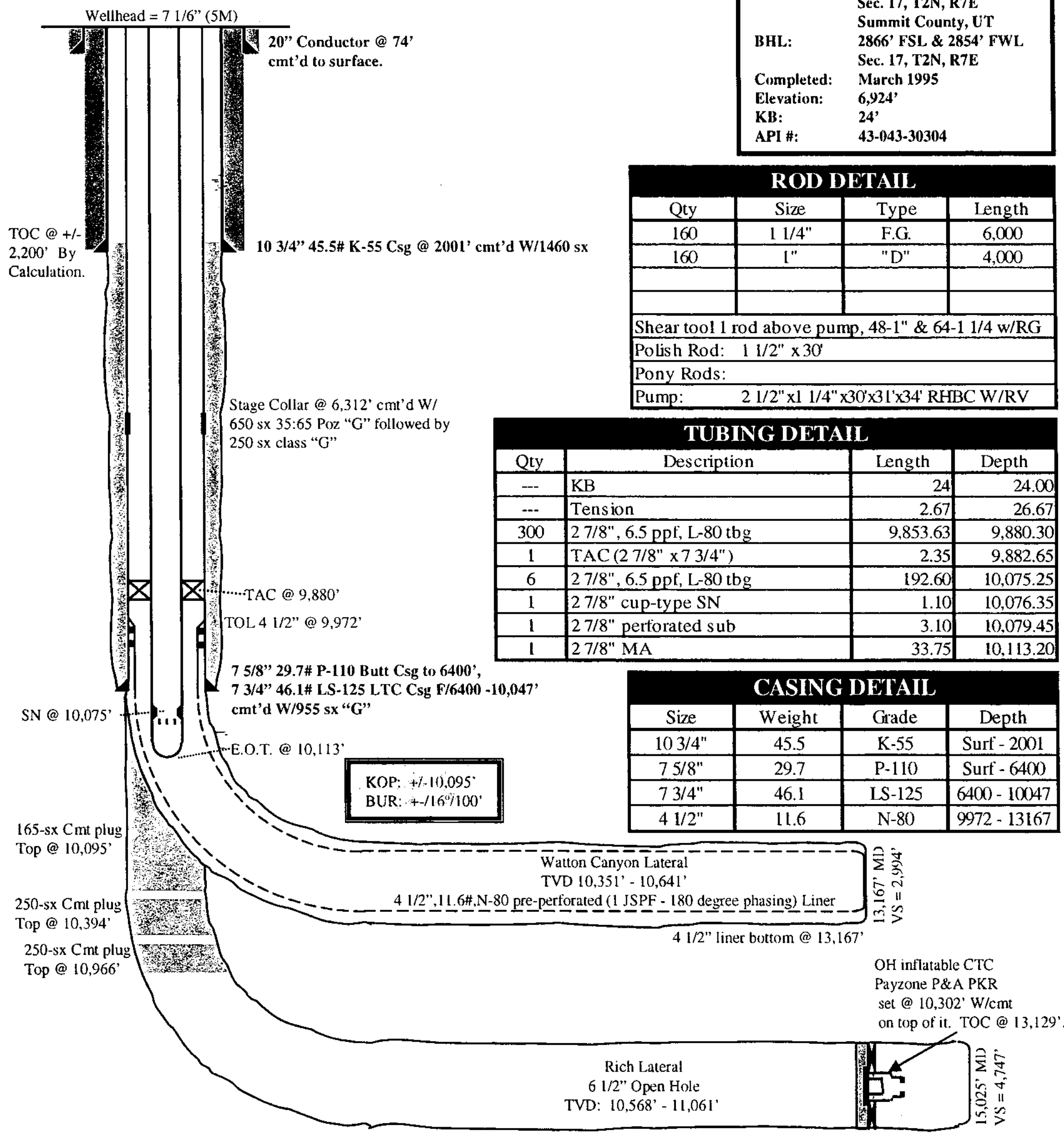
Shear tool 1 rod above pump, 48-1" & 64-1 1/4 w/RG
Polish Rod: 1 1/2" x30'
Pony Rods:
Pump: 2 1/2"x1 1/4"x30'x31'x34' RHBC W/RV

TUBING DETAIL

Qty	Description	Length	Depth
---	KB	24	24.00
---	Tension	2.67	26.67
300	2 7/8", 6.5 ppf, L-80 tbg	9,853.63	9,880.30
1	TAC (2 7/8" x 7 3/4")	2.35	9,882.65
6	2 7/8", 6.5 ppf, L-80 tbg	192.60	10,075.25
1	2 7/8" cup-type SN	1.10	10,076.35
1	2 7/8" perforated sub	3.10	10,079.45
1	2 7/8" MA	33.75	10,113.20

CASING DETAIL

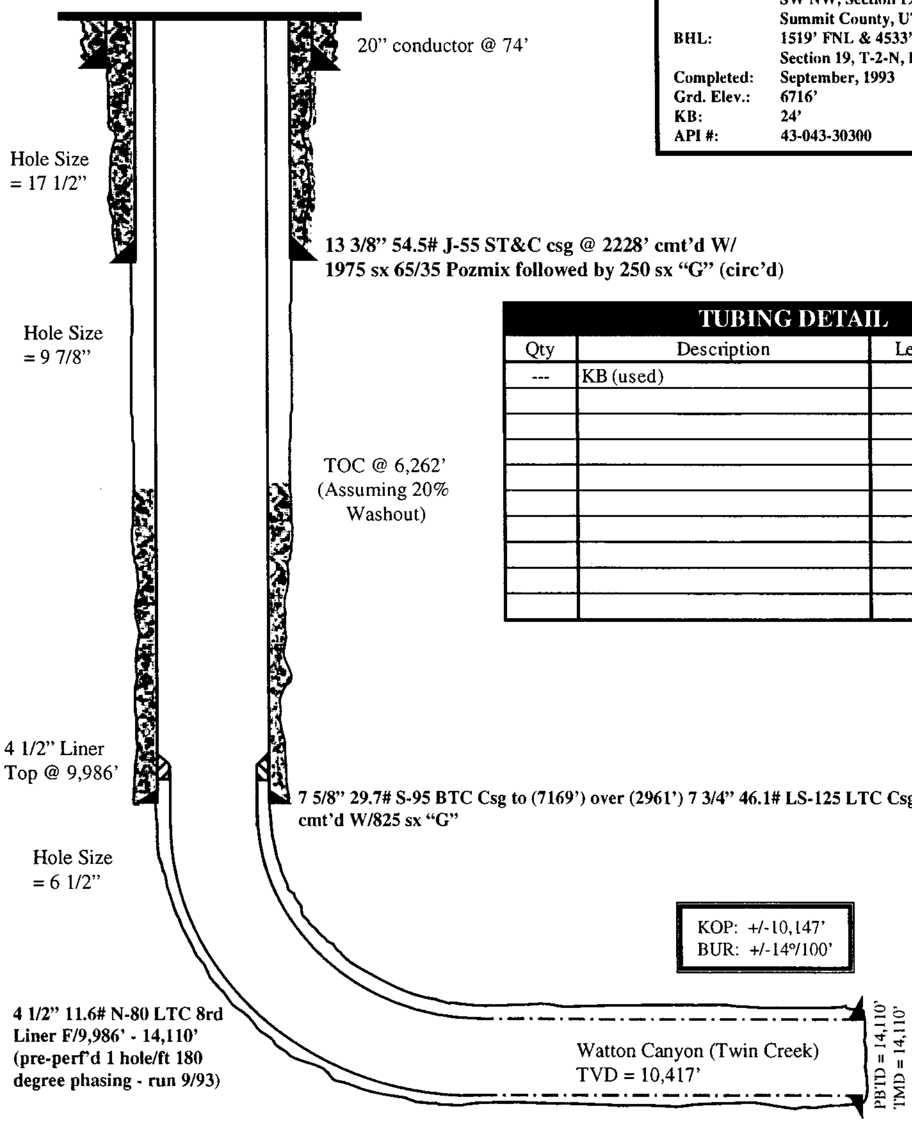
Size	Weight	Grade	Depth
10 3/4"	45.5	K-55	Surf - 2001
7 5/8"	29.7	P-110	Surf - 6400
7 3/4"	46.1	LS-125	6400 - 10047
4 1/2"	11.6	N-80	9972 - 13167



CITATION OIL AND GAS CORPORATION
WELLBORE DIAGRAM AND INFORMATION

Well Name: UPRC #19-2X 1H **Field:** Elkhorn
Date: December 30, 2002 **Location:** SW NW, Section 19, T-2-N, R-7-E
County: Summit **State:** Utah

Surface:	**2176' FNL & 554' FWL** **SW NW, Section 19 , T-2-N, R-7-E** **Summit County, UT**
BHL:	**1519' FNL & 4533' FWL** **Section 19, T-2-N, R-7-E**
Completed:	**September, 1993**
Grd. Elev.:	**6716'**
KB:	**24'**
API #:	**43-043-30300**



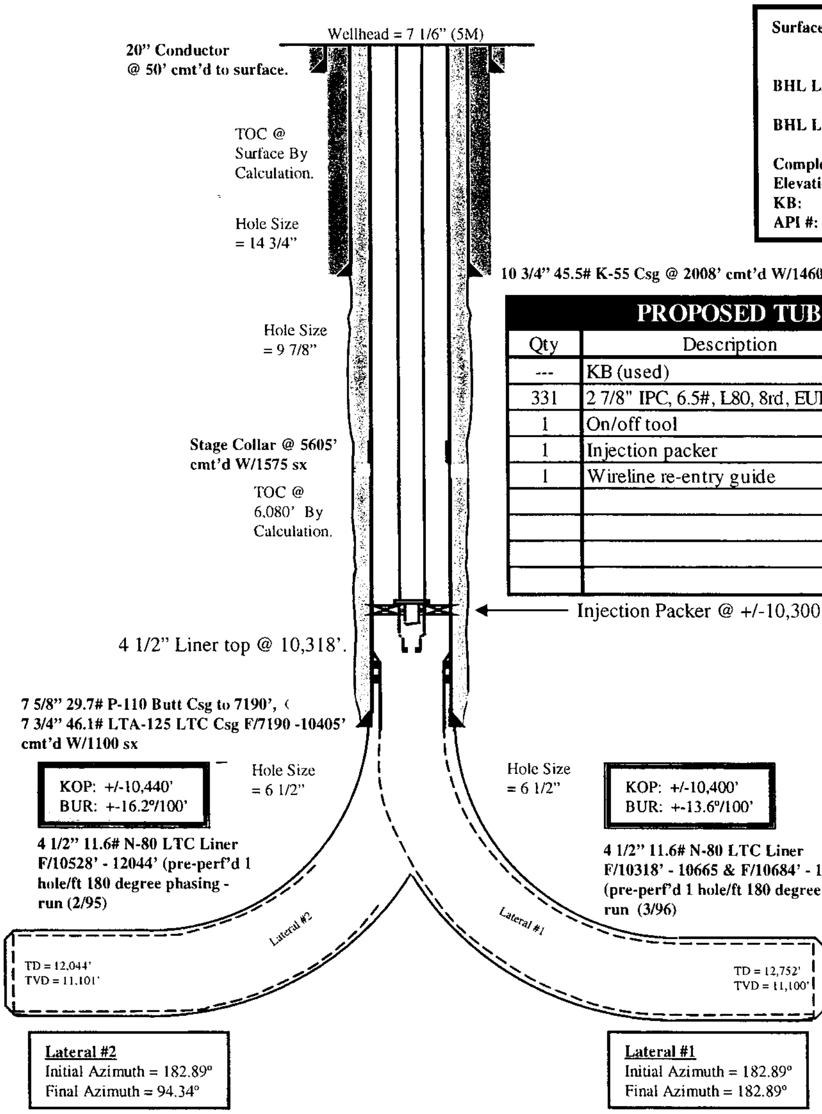
TUBING DETAIL

Qty	Description	Length	Depth
---	KB (used)	24	24.00

CITATION OIL AND GAS CORPORATION
PROPOSED INJECTION WELLBORE DIAGRAM AND INFORMATION

Well Name:	Newton Sheep #20-1H	**Field:**	Elkhorn
Date:	May 1, 2003	**Location:**	NW NW, Sec. 20, T-2-N, R-7-E
County:	Summit	**State:**	Utah

Surface:	**370' FNL & 856' FWL Sec. 20, T-2-N, R-7-E Summit County, UT**
BHL Lateral #1:	**570' FNL & 3158' FWL Sec. 20, T-2-N, R-7-E**
BHL Lateral #2:	**1945' FNL & 680' FWL Sec. 20, T-2-N, R-7-E**
Completed:	**March, 1995**
Elevation:	**7,035'**
KB:	**24'**
API #:	**43-043-30310**



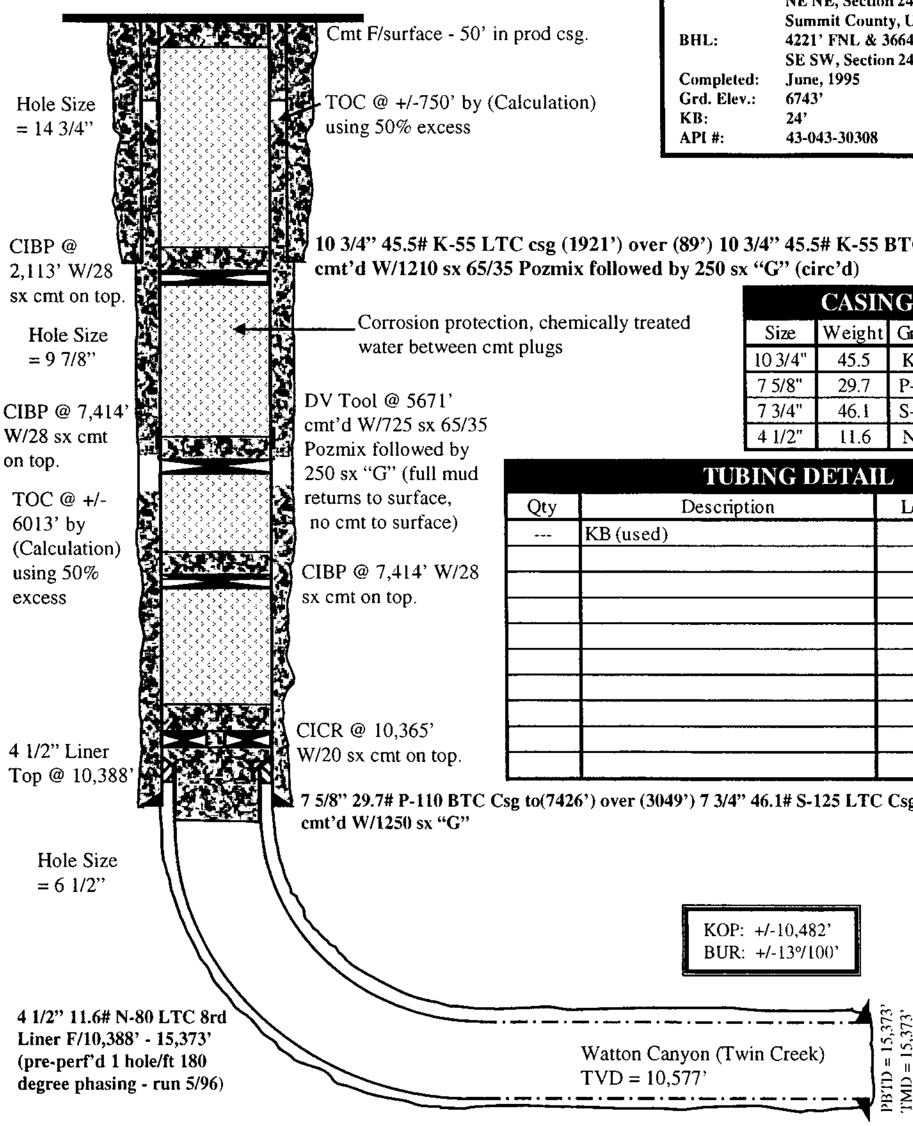
PROPOSED TUBING DETAIL

Qty	Description	Length	Depth
---	KB (used)	23.5	23.50
331	2 7/8" IPC, 6.5#, L80, 8rd, EUE tbg	10,266.50	10,290.00
1	On/off tool	3.00	10,293.00
1	Injection packer	7.00	10,300.00
1	Wireline re-entry guide	1.00	10,301.00

CITATION OIL AND GAS CORPORATION
WELLBORE DIAGRAM AND INFORMATION

Well Name: Newton Sheep Federal #24-1H **Field:** Elkhorn
Date: December 16, 2002 **Location:** NE NE, Section 24, T-2-N, R-6-E
County: Summit **State:** Utah

Surface:	**499' FNL & 860' FEL** **NE NE, Section 24 , T-2-N, R-6-E** **Summit County, UT**
BHL:	**4221' FNL & 3664' FEL** **SE SW, Section 24, T-2-N, R-6-E**
Completed:	**June, 1995**
Grd. Elev.:	**6743'**
KB:	**24'**
API #:	**43-043-30308**



CASING DETAIL

Size	Weight	Grade	Depth
10 3/4"	45.5	K-55	Surf - 2010
7 5/8"	29.7	P-110	Surf - 7426
7 3/4"	46.1	S-125	7426 - 10,475
4 1/2"	11.6	N-80	10,388 - 15373

TUBING DETAIL

Qty	Description	Length	Depth
---	KB (used)	24	24.00

Citation Oil & Gas Corporation
Elkhorn Field, UPRC #17-1 SWD

Wellbore Diagram

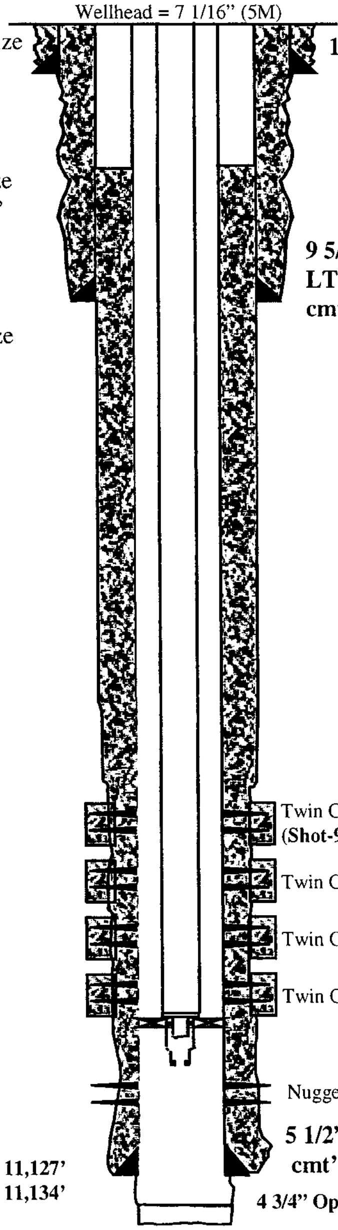
Present Status

Ground Elevation = 6756'
RKB = 6776'
KB = 20'

Surface Location

2335' FNL & 2052' FWL,
SE NW, Sec. 17, T-2-N,
R-7-E, Summit County, UT

Wellhead = 7 1/16" (5M)



Hole Size = 22"

16" @ 120' cmt'd W/? sx

TOC @ 800' calc.

Hole Size =12 1/4"

9 5/8" 40# N-80
LTC Csg @ 1545'
cmt'd W/835 sx

Hole Size = 6 1/2"

TUBING DETAIL			
Qty	Description	Length	Depth
---	KB (used)	20	20.00
1	2 7/8" 6.5# N-80 Duoline	31.39	51.39
1	2 7/8" pup jt	8.15	59.54
346	2 7/8" 6.5# N-80 Duoline	10,853.00	10,912.54
1	Model R-3 DG PKR	7.25	10,919.79
1	WLEG	1.23	10,921.02

Twin Creek Perfs: 10,398 - 428, 38 - 96, 514 - 26, & 36 - 41 (4 JSPF) **(Shot-9 & 10/88) (SQZ'd-12/93)**

Twin Creek Perfs: 10,574 - 602 (2 JSPF) **(Shot-8/88) (SQZ'd-9/88)**

Twin Creek Perfs: 10,692 - 720 (2 JSPF) **(Shot-8/88) (SQZ'd-12/93)**

Twin Creek Perfs: 10,826 - 64 & 72 - 903 (2 JSPF) **(Shot-7/88) (SQZ'd-12/93)**

Nugget Perfs: 10,950 - 11,100 (4 JSPF) **(12/93)**

5 1/2" 17,20 &23# Csg to 9936' & 5 1/2" 20# csg F/9936 - 11,112'
cmt'd W/2,900 sx Class H

PBTD = 11,127'
TD = 11,134'

4 3/4" Open Hole section F/11,112 - 11,134 W/7' of sand in bottom of section.

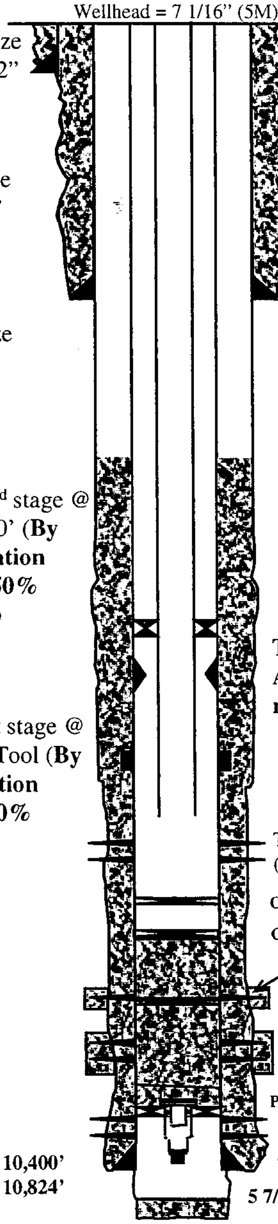
Citation Oil & Gas Corporation
Elkhorn Field, Newton Sheep #18-1
Wellbore Diagram

Present Status

Ground Elevation = 6530'
RKB = 6552'
KB = 22'

Surface Location

1239' FSL & 2390' FEL,
SW SE, Sec. 18, T-2-N,
R-7-E, Summit County, UT



TUBING DETAIL

Qty	Description	Length	Depth
—	KB (used)	22	22.00
283	2 7/8" 6.5# N-80 8rd EUE	8,915.00	8,937.00
1	2 7/8" X 7" TAC	3.00	8,940.00
44	2 7/8" 6.5# N-80 8rd EUE	1,386.00	10,326.00
1	2 7/8" SN	1.00	10,327.00
1	2 7/8" 6.5# N-80 8rd EUE	31.00	10,358.00

ROD & PUMP DETAIL

Qty	Description	Length	Depth
			0.00

PRODUCTION CASING DETAIL

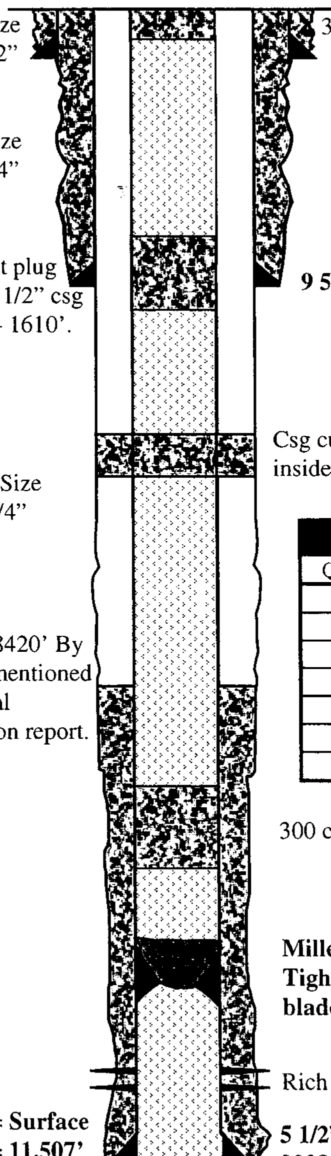
Size	Weight	Grade	Depth
7"	29#	N-80	Surf - 1000'
7"	26#	L-80	1000 - 4400'
7"	26#	K-55	4400 - 5744'
7"	26#	L-80	5744 - 7944'
7"	35#	N-80	7944 - 10774'

Citation Oil & Gas Corporation
Elkhorn Field, UPRR #19-1
Wellbore Diagram

Present Status

Ground Elevation = 7100'
RKB = 7120'
KB = 20'

Surface Location
1949' FNL & 1828' FEL,
SW NE, Sec. 19, T-2-N,
R-7-E, Summit County, UT



TUBING DETAIL

Qty	Description	Length	Depth
			0.00

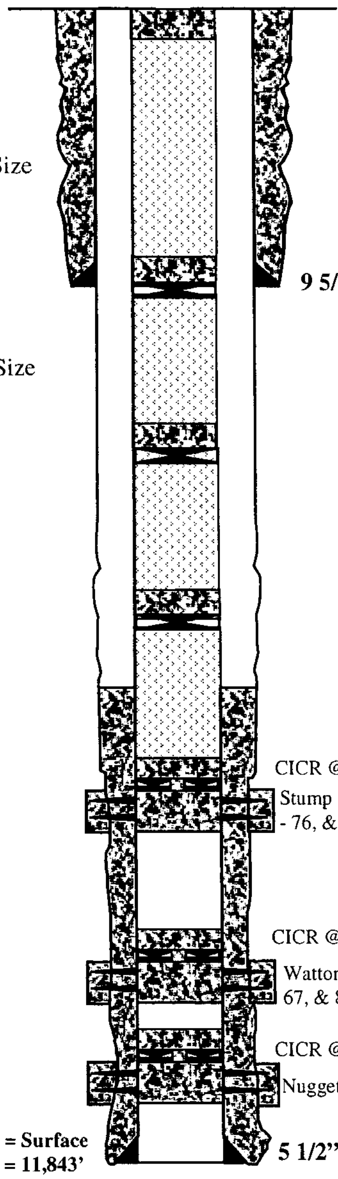
Citation Oil & Gas Corporation
Elkhorn Field, Newton Sheep #24-34

Wellbore Diagram

Present Status

Ground Elevation = 6705'
RKB = ?'
KB = ?'

Surface Location
794' FSL & 1555' FEL,
SW SE, Sec. 24, T-2-N,
R-6-E, Summit County, UT



TUBING DETAIL

Qty	Description	Length	Depth
			0.00