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

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Heterogeneous Shallow-Shelf Carbonate Buildups in the Paradox Basin, Utah and Colorado: Targets for Increased Oil Production and Reserves Using Horizontal Drilling Techniques

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ABSTRACT

The Paradox Basin of Utah, Colorado, Arizona, and New Mexico contains nearly 100 small oil fields producing from carbonate buildups within the Pennsylvanian (Desmoinesian) Paradox Formation. These fields typically have one to 10 wells with primary production ranging from 700,000 to 2,000,000 barrels (111,300-318,000 m^3) of oil per field and a 15 to 20 percent recovery rate. At least 200 million barrels (31.8 million m^3) of oil will not be recovered from these small fields because of inefficient recovery practices and undrained heterogeneous reservoirs. Several fields in southwestern Colorado and southeastern Utah are being evaluated for horizontal drilling from existing vertical field wells based upon geological characterization and reservoir modeling case studies. The results of these studies can be applied to similar fields in the Paradox Basin and the Rocky Mountain region, the Michigan and Illinois Basins, and the Midcontinent region.

This report covers research activities for the second half of the second project year (October 6, 2001, through April 5, 2002). This work includes description and analysis of cores, correlation of geophysical well logs, reservoir mapping, petrographic description of thin sections, cross plotting of permeability and porosity data, and development of horizontal drilling strategies for the Little Ute and Sleeping Ute fields in Montezuma County, Colorado. Geological characterization on a local scale focused on reservoir heterogeneity, quality, and lateral continuity, as well as possible compartmentalization, within these fields. This study utilizes representative core, geophysical logs, and thin sections to characterize and grade each field's potential for drilling horizontal laterals from existing development wells.

The typical vertical, core-derived sequence or cycles of depositional lithofacies from the Little Ute and Sleeping Ute fields, as determined from conventional core, was tied to its corresponding log response to identify reservoir and non-reservoir rock and determine potential units suitable for horizontal drilling projects. Structure contour maps on the top of the upper and lower Ismay and Desert Creek zones, and isopach maps of the Ismay and Gothic shale were constructed to show carbonate buildup trends, define limits of field potential, and also indicate possible horizontal drilling targets.

In order to determine the diagenetic histories of the various Ismay reservoirs, petrographic descriptions of 25 thin sections were completed from representative core samples. The diagenetic fabrics and porosity types found at Little Ute and Sleeping Ute fields are indicators of reservoir flow capacity, storage capacity, and potential for horizontal drilling. The reservoir quality of these fields has been affected by multiple generations of dissolution, anhydrite plugging, and various types of cementation which act as barriers or baffles to fluid flow. Based on cross plots of permeability and porosity data, the reservoir quality of the rocks in Little Ute and Sleeping Ute fields is most dependant on pore types, facies types, and diagenesis.

Two strategies for horizontal drilling are being developed for Little Ute and Sleeping Ute fields. First, depositional facies are targeted in the Ismay zone where multiple buildups can be penetrated with two opposed sets of stacked, parallel horizontal laterals. Second, multiple zones of diagenetically enhanced reservoir intervals in these mound buildups can be penetrated with multiple horizontal laterals.

Technology transfer activities consisted of exhibiting a booth display of project materials at the annual national convention of the American Association of Petroleum Geologists, technical presentations, publications, and newsletters. Project team members met with the Stake Holders and Technical Advisory Boards, the Southeastern Utah Industry/BLM/State/County

Work Group, and Utah Division of Oil, Gas and Mining Board to review the project activities and results. The project home page was updated for the Utah Geological Survey and Colorado Geological Survey internet web sites.

EXECUTIVE SUMMARY

The project's primary objective is to enhance domestic petroleum production by demonstration and transfer of horizontal drilling technology in the Paradox Basin, Utah, Colorado, Arizona, and New Mexico. If this project can demonstrate technical and economic feasibility, then the technique can be applied to approximately 100 additional small fields in the Paradox Basin alone, and result in increased recovery of 25 to 50 million barrels (4-8 million m^3) of oil. This project is designed to characterize several shallow-shelf carbonate reservoirs in the Pennsylvanian (Desmoinesian) Paradox Formation, choose the best candidate(s) for a pilot demonstration project to drill horizontally from existing vertical wells, monitor well performance(s), and report associated validation activities.

The Utah Geological Survey heads a multidisciplinary team to determine the geological and reservoir characteristics of typical small shallow-shelf carbonate reservoirs in the Paradox Basin. The Paradox Basin technical team consists of the Utah Geological Survey (prime contractor), Colorado Geological Survey, Eby Petrography & Consulting Inc., and Seeley Oil Company. This research is funded by the Class II Oil Revisit Program of the U.S. Department of Energy, National Petroleum Technology Office (NPTO) in Tulsa, Oklahoma. This report covers research activities for the second half of the first project year (October 6, 2001, through April 5, 2002). This work includes description and analysis of cores, correlation of geophysical well logs, reservoir mapping, petrographic description of thin sections, cross plotting of permeability and porosity data, and development of horizontal drilling strategies for the Sleeping Ute and Little Ute fields in Montezuma County, Colorado. From these evaluations, untested or under-produced reservoir compartments can be identified as targets for horizontal drilling. The results of this study can be applied to similar reservoirs in many U.S. basins.

Reservoir data (porosity and permeability), cores and cuttings, geophysical logs, various reservoir maps, and other information are being collected from the case-study fields and adjacent regional exploratory wells. Well locations, production reports, completion tests, core analysis, formation tops, and other data are being compiled and entered in a Utah Geological Survey database. Core photographs and descriptions were compiled for case-study field wells with special emphasis on identifying bounding surfaces and depositional environments of possible flow units. Typical vertical sequences or cycles of lithofacies from each field, as determined from conventional core, were tied to corresponding geophysical log responses. Structure contour maps on the top of the upper and lower Ismay and Desert Creek zones, and isopach maps of the Ismay and Gothic shale showed carbonate buildup trends, defined limits of field potential, and also indicated possible horizontal drilling targets.

The diagenetic fabrics and porosity types found in the various hydrocarbon-bearing rocks of Sleeping Ute and Little Ute fields are indicators of reservoir flow capacity, storage capacity, and potential for horizontal drilling. Based on petrographic descriptions of 25 thin sections from representative core samples, the quality of the reservoirs in these fields appears to have been affected by multiple generations of dissolution, anhydrite plugging, and various types of cementation which act as barriers or baffles to fluid flow. Based on cross plots of permeability and porosity data, the reservoir quality of the rocks in Little Ute and Sleeping Ute fields is most dependant on pore types, facies types, and diagenesis, rather than carbonate fabric or mineralogy.

Based on these findings, two strategies for horizontal drilling are being developed for Sleeping Ute, Little Ute, and similar fields in the Paradox Basin. All strategies involve drilling stacked, parallel horizontal laterals. Depositional facies are targeted in the Ismay zone where

multiple buildups can be penetrated with two opposed sets of stacked, parallel horizontal laterals. Similarly, a second strategy involves penetrating multiple zones of diagenetically enhanced reservoir intervals in these mound buildups. However, these strategies are preliminary and will be further refined as additional data are collected and analyzed, and three-dimensional reservoir models developed for the other case-study fields in the Paradox Basin.

Technology transfer activities consisted of exhibiting a booth display of project materials at the 2002 annual national convention of the American Association of Petroleum Geologists in Houston, Texas. A poster technical presentation was also made at the convention. Technical team members met with the Stake Holders and Technical Advisory Boards, the Southeastern Utah Industry/BLM/State/County Work Group, and Utah Division of Oil, Gas and Mining Board to review project activities and results. The project home page was updated for the Utah Geological Survey and Colorado Geological Survey internet web sites. The project team members submitted an abstract to the American Association of Petroleum Geologists for a presentation during the 2002 Rocky Mountain Section Meeting in Laramie, Wyoming, and a short course during the 2003 annual national meeting in Salt Lake City, Utah. Newsletters were published with an overview of the project results to date. Project team members published an abstract, semi-annual reports, and newsletters detailing project progress and results.

INTRODUCTION

Geologic Setting

The Paradox Basin is located mainly in southeastern Utah and southwestern Colorado, with a small portion in northeastern Arizona and northwestern New Mexico (figure 1). The Paradox Basin is an elongate, northwest-southeast-trending evaporitic basin that predominately developed during the Pennsylvanian (Desmoinesian), about 330 to 310 million years ago (Ma). During the Pennsylvanian, a series of basins and fault-bounded uplifts developed from Utah to Oklahoma as a result of the collision of South America, Africa, and southeastern North America (Kluth and Coney, 1981; Kluth, 1986), or from a smaller scale collision of a microcontinent with south-central North America (Harry and Mickus, 1998). One result of this tectonic event was the

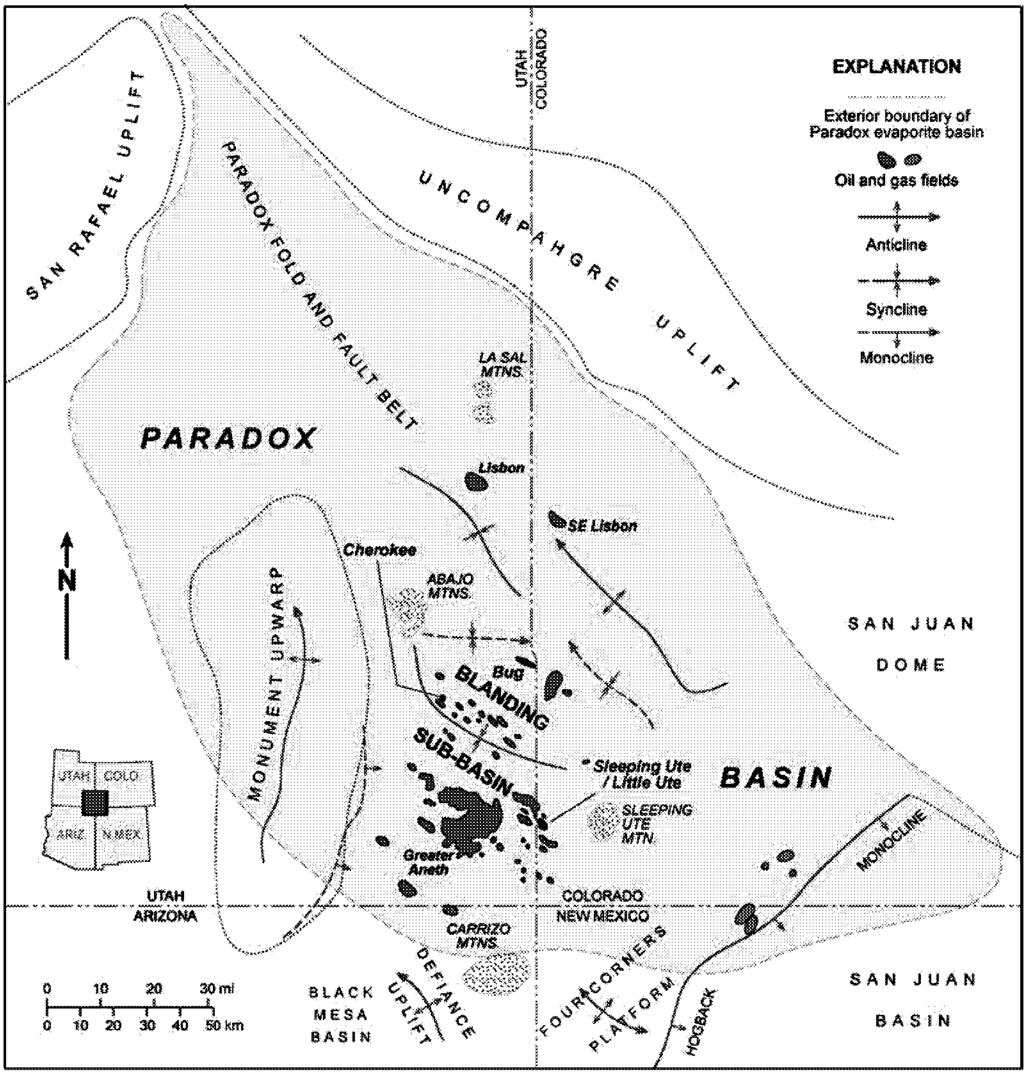


***Figure 1.** Location map of the Paradox Basin, Utah, Colorado, Arizona, and New Mexico showing producing oil and gas fields, the Paradox fold and fault belt, and Blanding sub-basin as well as surrounding Laramide basins and uplifts (modified from Harr, 1996).*

uplift of the Ancestral Rockies in the western United States. The Uncompahgre Highlands in eastern Utah and western Colorado initially formed as the westernmost range of the Ancestral Rockies during this ancient mountain-building period. The southwestern flank of the Uncompahgre Highlands (uplift) is bounded by a large basement-involved, high-angle reverse fault identified from seismic surveys and exploration drilling. As the highlands rose, an accompanying depression, or foreland basin, formed to the southwest – the Paradox Basin. Rapid subsidence, particularly during the Pennsylvanian and continuing into the Permian, accommodated large volumes of evaporitic and marine sediments that intertongue with non-marine arkosic material shed from the highland area to the northeast (Hintze, 1993). The Paradox Basin is surrounded by other uplifts and basins that formed during the Late Cretaceous-early Tertiary Laramide orogeny (figure 1).

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

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

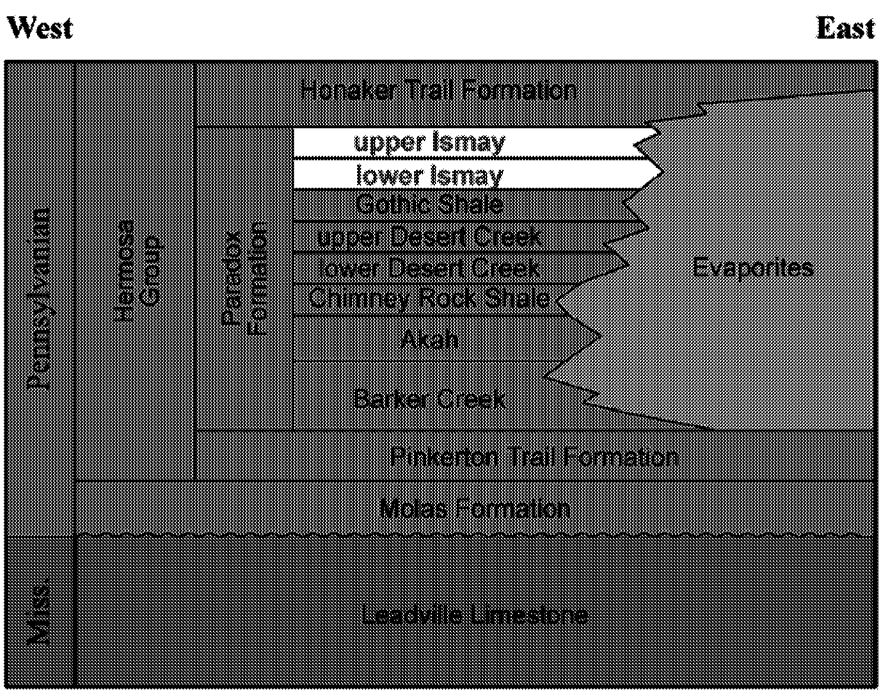


Figure 2. Pennsylvanian stratigraphy of the southern Paradox Basin including informal zones of the Paradox Formation; the Ismay zone productive in the case-study fields described in this report is highlighted.

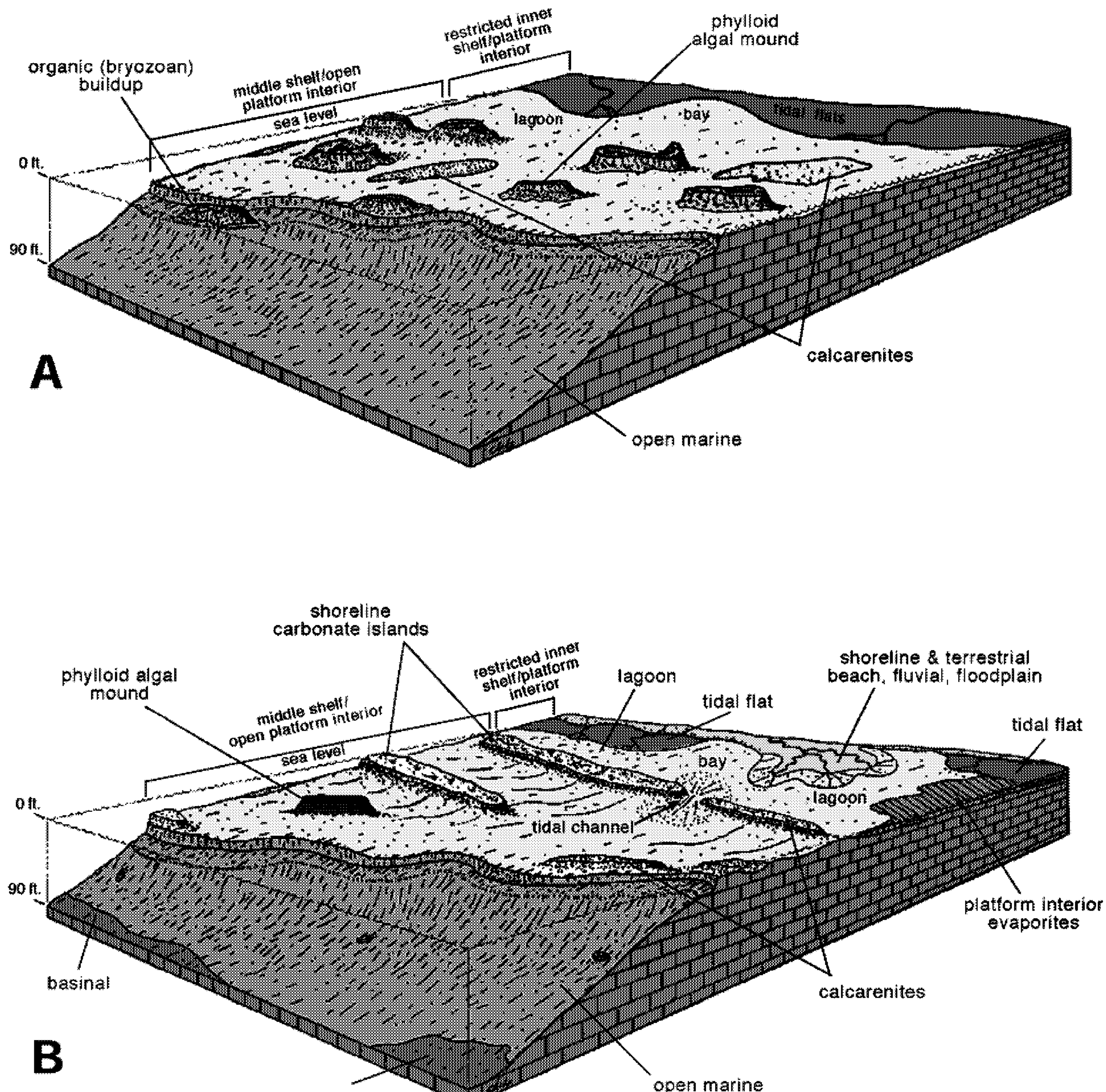


Figure 3. Block diagrams displaying major depositional facies, as determined from core, for the Ismay (A) and Desert Creek (B) zones, Pennsylvanian Paradox Formation, Utah and Colorado.

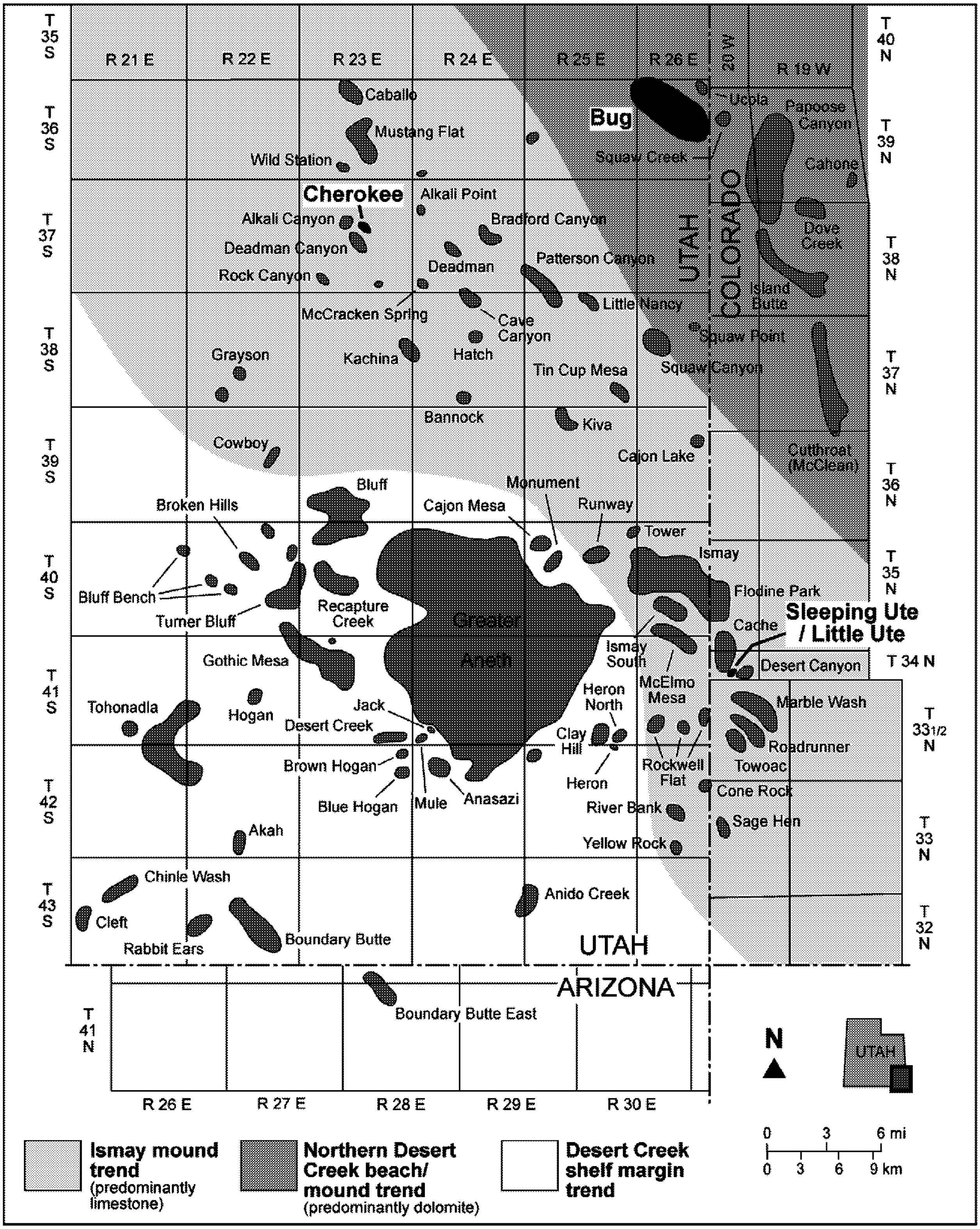


Figure 4. Map showing the project study area and fields (case-study fields in black) within the Ismay and Desert Creek producing trends in the Blanding sub-basin, Utah and Colorado. Bug and Cherokee fields are being evaluated by the Utah Geological Survey, and Sleeping Ute and Little Ute fields are being evaluated by the Colorado Geological Survey.

Project Overview

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

An extensive and successful horizontal drilling program has been conducted in the giant Greater Aneth field. However, to date, only two horizontal wells have been drilled in small Ismay and Desert Creek fields. The results from these wells were disappointing due to poor understanding of the carbonate facies and diagenetic fabrics that create reservoir heterogeneity. These small fields, and similar fields in the basin, are at high risk of premature abandonment. At least 200 million barrels (31.8 million m^3) of oil will be left behind in these small fields because current development practices leave compartments of the heterogeneous reservoirs undrained. Through proper geological evaluation of the reservoirs, production may be increased by 20 to 50 percent through the drilling of low-cost single or multilateral horizontal legs (figure 5) from existing vertical development wells. In addition, horizontal drilling from existing wells minimizes surface disturbances and costs for field development, particularly in the environmentally sensitive areas of southeastern Utah and southwestern Colorado.

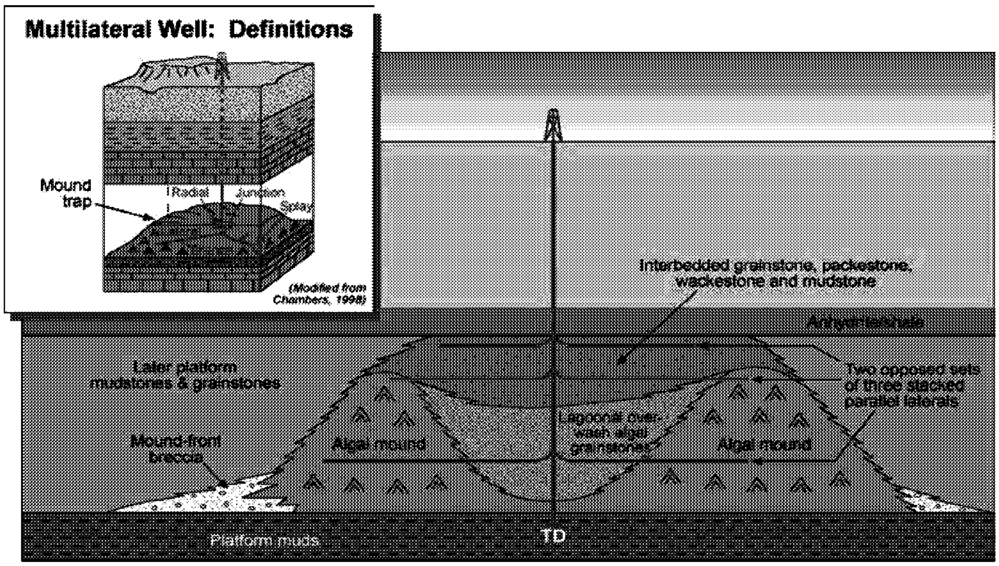


Figure 5. Schematic diagram of Ismay zone drilling targets by multilateral (horizontal) legs from an existing field well.

The Utah Geological Survey (UGS), Colorado Geological Survey (CGS), Eby Petrography & Consulting, Inc., and Seeley Oil Company have entered into a cooperative agreement with the U.S. Department of Energy as part of its Class II Oil Revisit Program. A three-phase, multidisciplinary approach will be used to increase production and reserves from the shallow-shelf carbonate reservoirs in the Ismay and Desert Creek zones of the Paradox Basin. Phase 1 is the geological and reservoir characterization of selected, diversified small fields, including Little Ute and Sleeping Ute fields in Montezuma County, Colorado (figure 4), to identify those field(s) having the greatest potential as targets for increased well productivity and ultimate recovery in a pilot demonstration project. This phase will include: (a) determination of regional geological setting; (b) analysis of the reservoir heterogeneity, quality, lateral continuity, and compartmentalization within the fields; (c) construction of lithologic, microfacies, porosity, permeability, and net pay maps of the fields; (d) determination of field reserves and recovery; and (e) integration of geological data in the design of single or multiple horizontal laterals from existing vertical wells.

Phase 2 is a field demonstration project of the horizontal drilling techniques identified as having the greatest potential for increased field productivity and ultimate recovery. The demonstration project will involve drilling one or more horizontal laterals from the existing vertical field well(s) to maximize production from the zones of greatest potential.

Phase 3 includes: (a) reservoir management and production monitoring, (b) economic evaluation of the results, and (c) determination of the ability to transfer project technologies to other similar fields in the Paradox Basin and throughout the U.S.

Phases 1, 2, and 3 will have continuous, but separate, technical transfer activities including: (a) an industry outreach program and project newsletters; (b) a core workshop/seminars in Salt Lake City; (c) publications and technical presentations; (d) a project home page on the Utah Geological Survey and Colorado Geological Survey Internet web sites; (e) digital databases, maps, and reports; (f) a summary of regulatory, economic, and financial needs; and (g) annual meetings with a Technical Advisory Board and Stake Holders Board.

Project Benefits and Potential Application

The overall benefit of this multi-year project would be enhanced domestic petroleum production by demonstrating and transferring an advanced-oil-recovery technology throughout the small oil fields of the Paradox Basin. Specifically, the benefits expected from the project are: (1) increasing recovery and reserve base by identifying untapped compartments created by reservoir heterogeneity; (2) preventing premature abandonment of numerous small fields; (3) increasing deliverability by horizontally drilling along the reservoir's optimal fluid-flow paths; (4) identifying reservoir trends for field extension drilling and stimulating exploration in Paradox Basin fairways; (5) reducing development costs by more closely delineating minimum field size and other parameters necessary for horizontal drilling; (6) allowing for minimal surface disturbance by drilling from existing vertical field wells; (7) allowing limited energy investment dollars to be used more productively; and (8) increasing royalty income to the Federal, state, and local governments, the Ute Mountain Ute Indian Tribe, and fee owners. These benefits may also apply to other areas including: algal-mound and carbonate buildup reservoirs on the eastern and northwest shelves of the Permian Basin in Texas, Silurian pinnacle and patch reefs of the Michigan and Illinois Basins, and shoaling carbonate island trends of the Williston Basin.

The results of this project are transferred to industry and other researchers through establishment of Technical Advisory and Stake Holders Boards, an industry outreach program, digital project databases, and web page. Project results will be disseminated via technical workshops and seminars, field trips, technical presentations at national and regional professional meetings, and papers in newsletters and various technical or trade journals.

GEOLOGICAL CHARACTERIZATION OF CASE-STUDY FIELDS, MONTEZUMA COUNTY, COLORADO – RESULTS AND DISCUSSION

Two Colorado fields were selected for local-scale evaluation during Budget Period I of the project (two Utah case-study fields have been described in previous reports [Chidsey and others, 2001a, 2001b]): Little Ute and Sleeping Ute in the Ismay zone trend (figure 4). This evaluation included data collection, core photography and description, determination of a typical vertical sequence from conventional core tied to its corresponding log response, reservoir mapping, determination of diagenetic fabrics from thin sections, and plots of core plug porosity versus permeability of these fields. This geological characterization focused on reservoir heterogeneity, quality, and lateral continuity, as well as possible compartmentalization within the fields. From these evaluations, untested or under-produced compartments can be identified as targets for horizontal drilling. The models resulting from the geological and reservoir characterization of these fields can be applied to similar fields in the basin (and other basins as well) where data might be limited.

Little Ute and Sleeping Ute Fields

Little Ute and Sleeping Ute fields are located in Montezuma County, Colorado (sections 3, 10, and 11, T. 34 N., R. 20 W. (figures 4 and 6). The producing reservoirs consist of phylloid-algal buildups in the Ismay zone flanked by bryozoan mounds and mound flank debris. These porous mounds, capped by impermeable anhydritic dolomite, produce primarily from porous phylloid-algal limestones, some of which have been dolomitized. The net reservoir thickness is 30 feet (9.1 m), which extends over approximately 640 acres (260 ha). Porosity ranges from 4 to 20 percent with 1 to 98 millidarcies (md) of permeability in vuggy and intercrystalline pore systems. Though no cores were examined east of these fields, three additional wells, the 1 Ute C, Desert Canyon No. 2, and Desert Canyon No. 3 (see figure 6 for their locations), have been incorporated into all the structure contour and isopach maps described in this report.

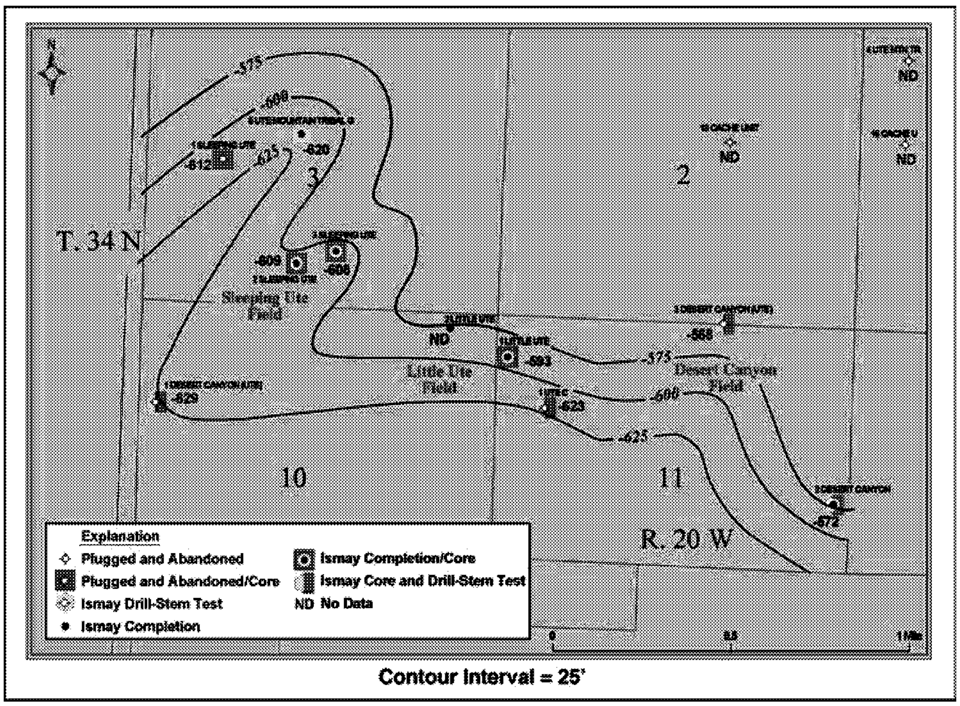


Figure 6. Upper Ismay zone structural contour map, Little Ute, Sleeping Ute, and Desert Canyon fields, Montezuma County, Colorado.

The first well drilled in the Little Ute/ Sleeping Ute study area was a dry hole, completed in 1959. The Calvert Drilling Company Desert Canyon No. 1 was drilled in the SW/4 of section 10, T. 34 N., R. 20 W., to a total depth of 5,938 feet (1,810 m) to the Gothic shale as a test of the Ismay and Desert Creek zones of the Paradox Formation. The well was plugged and abandoned on September 29, 1959, after a drill-stem test and four cores were taken in the Ismay and Desert Creek. The results of the drill-stem test, taken over the interval of 5,697 to 5,840 feet (1,736-1,780 m), were discouraging in that there was a very weak blow of air to the surface that died in 5 minutes and only 55 feet (17 m) of drilling mud was recovered. Somewhat more encouraging were the cores taken from 5,675 to 5,739 feet (1,730-1,749 m), 5,729 to 5,782 feet (1,746-1,762 m), 5,782 to 5,820 feet (1,762-1,774 m), and 5,880 to 5,938 feet (1,792-1,819 m). Over that entire interval, there were favorable reports of petroliferous odor, visible vuggy and intercrystalline porosity, and bleeding oil. The structure contour map of the upper Ismay (figure 6) shows this well, with encouraging hydrocarbon shows, to be down-dip of the later-developed Little Ute and Sleeping Ute fields.

There are currently three producing wells and three dry holes in the Little Ute and Sleeping Ute study area proper (figure 6). Cumulative production from these three wells, plus the Desert Canyon No. 3 well that defined the Desert Canyon field, exceeds 325,000 barrels (51,675 m^3) of oil and 750 million cubic feet (21 million m^3) of gas.

Field Data Collection and Compilation

Reservoir data, cores and cuttings, geophysical logs, various reservoir maps, and other information from the project fields and regional exploratory wells are being collected and analyzed by the UGS and CGS. Well locations, production data, completion tests, basic core analyses, formation tops, porosity and permeability data, and other data are being compiled and entered in a database developed by the UGS. This database, INTEGRAL, is a geologic-information database that links a diverse set of geologic data to records using MS Access™. The database is designed so that geological information, such as lithology, petrophysical analyses, or depositional environment, can be exported to software programs to produce strip logs, lithofacies maps, various graphs, statistical models, and other types of presentations. The database containing information on the geological and reservoir characterization study will be available at the UGS's and CGS's Paradox Basin project internet web sites at the conclusion of the project.

All available conventional cores from the Little Ute and Sleeping Ute fields were photographed and described. The core descriptions follow the guidelines of Bebout and Loucks (1984) which include: (1) basic porosity types; (2) mineral composition in percentage; (3) nature of contacts; (4) carbonate structures; (5) carbonate textures in percentage; (6) carbonate fabrics; (7) grain size (dolomite); (8) fractures; (9) color; (10) fossils; (11) cement; and (12) depositional environment. Carbonate fabrics were determined according to Dunham's (1962) and Embry and Klovan's (1971) classification schemes (figures 7 and 8).

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

The typical vertical sequence or cycle of lithofacies from the Little Ute and Sleeping Ute fields, as determined from conventional core, was tied to its corresponding log response. These sequences shown graphically in figure 7 and 8 include: (1) carbonate fabric, pore type, physical

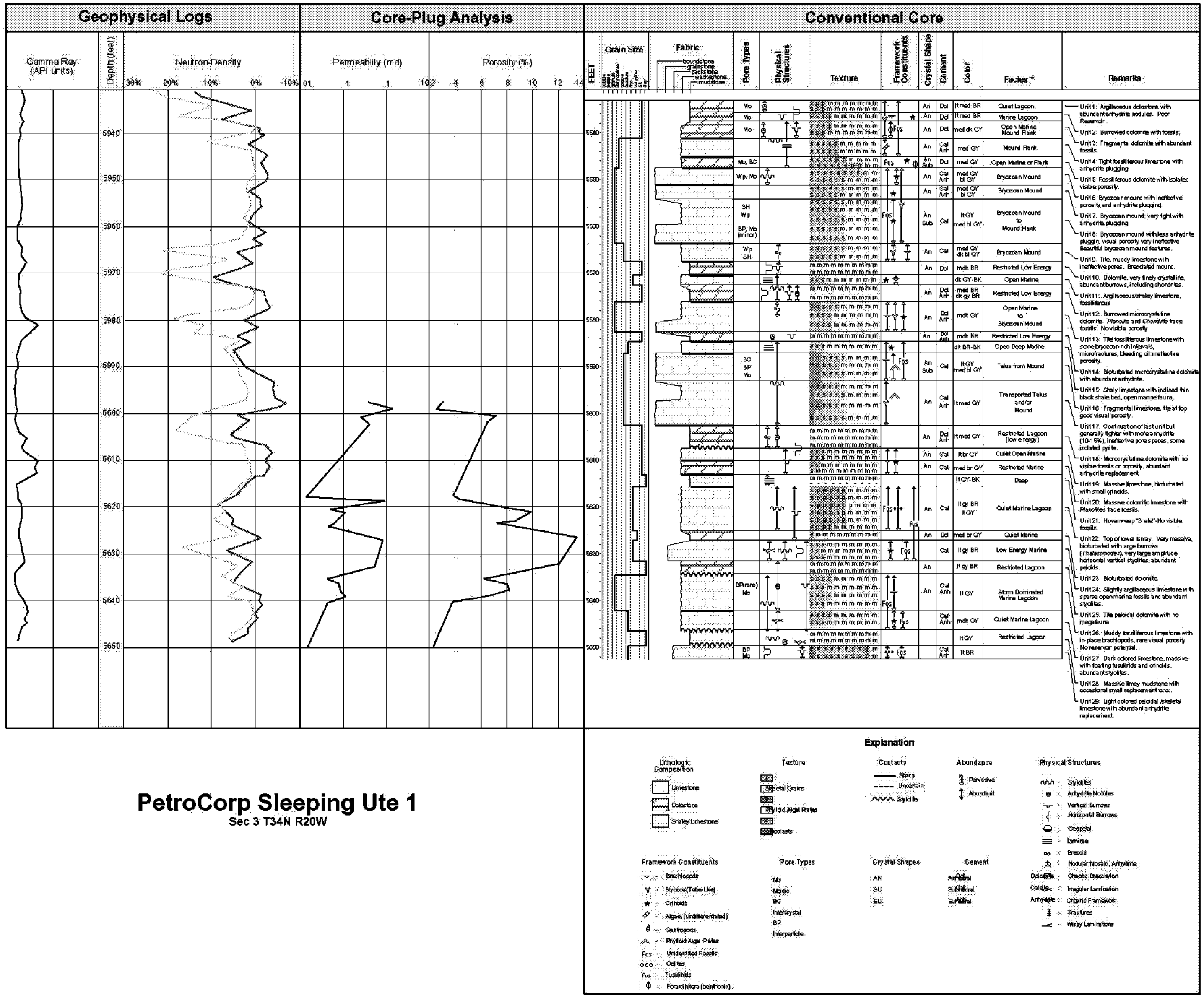


Figure 7. Typical vertical sequence from Little Ute field, including geophysical well logs, porosity/permeability, and core description of the Ismay zone, Little Ute No. 1 well, Montezuma County, Colorado.

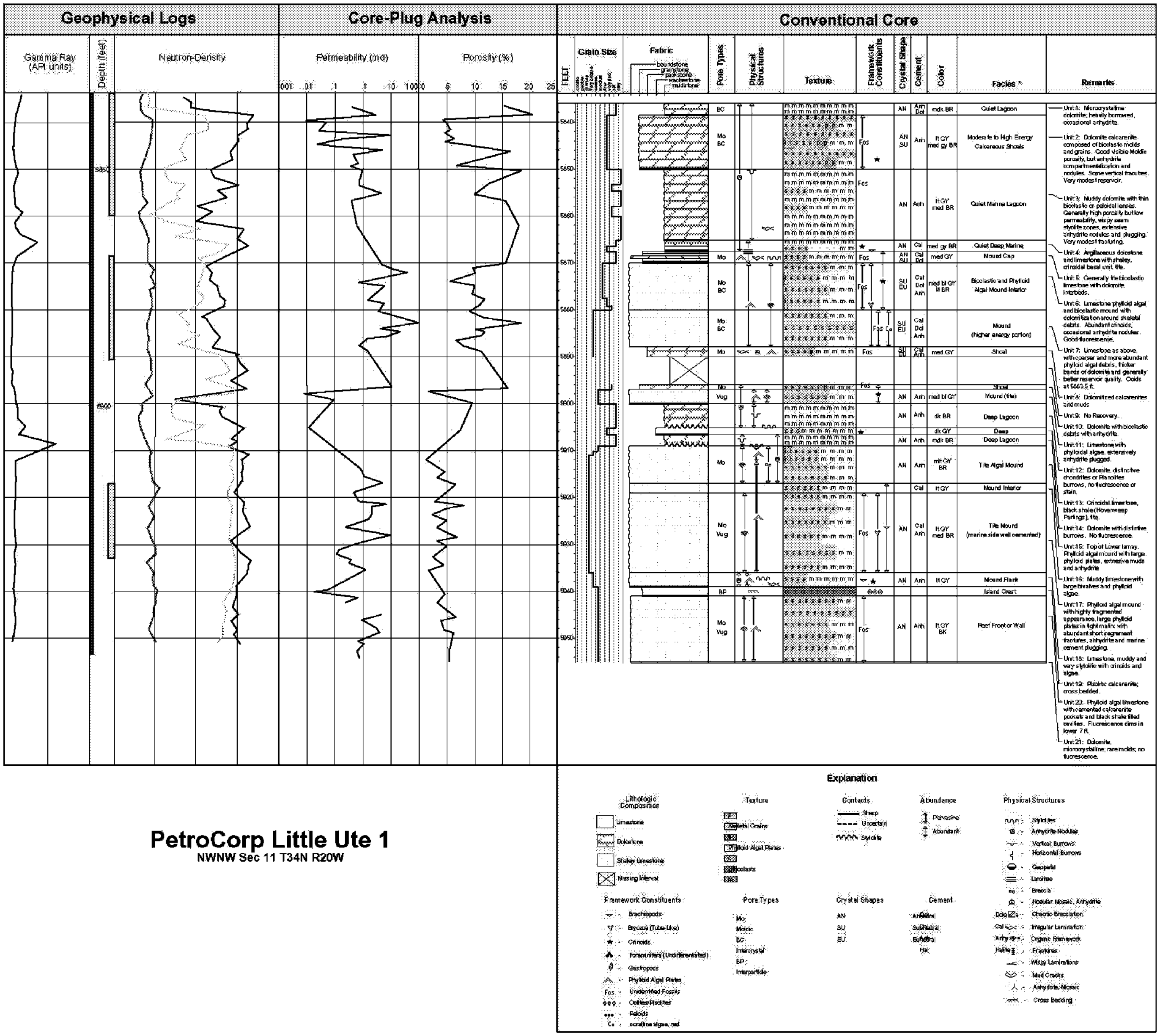


Figure 8. Typical vertical sequence from Sleeping Ute field, including geophysical well logs, porosity/permeability, and core description of the Ismay zone, Sleeping Ute No. 1 well, Montezuma County, Colorado.

structures, texture, framework grains, and facies described from core; (2) plotted porosity and permeability analysis from core plugs; and (3) gamma-ray and neutron-density curves from geophysical well logs. The graphs can be used for identifying reservoir and non-reservoir rock, determining potential units suitable for horizontal drilling projects, and comparing field to non-field areas.

Reservoir Mapping

All the maps discussed in this section show well names, Ismay completions, Ismay dry holes, drill-stem tests, and wells with cores. The symbols for each of these components are consistent on all maps (figures 6, 9, 10,11, 12, 13, and 14).

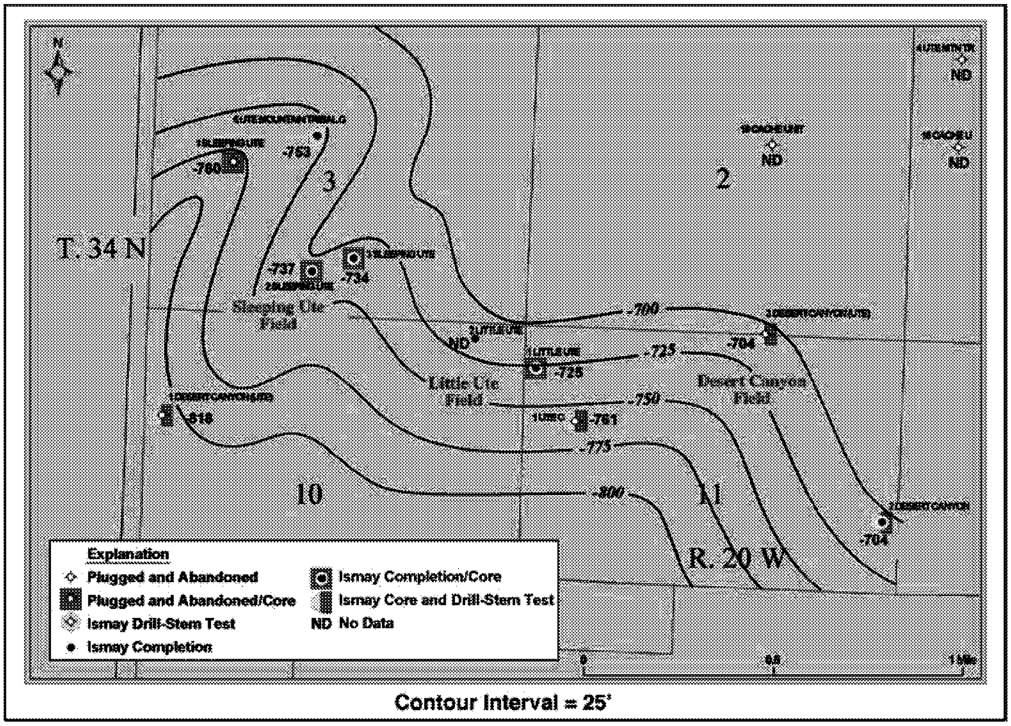


Figure 9. Lower Ismay zone structural contour map, Little Ute, Sleeping Ute, and Desert Canyon fields, Montezuma County, Colorado.

Structure contour maps on the top of the upper Ismay zone (figure 6) and the lower Ismay zone (figure 9) of the Paradox Formation were constructed for Little Ute/Sleeping Ute study area. A net isopach map for the upper and lower Ismay zones was also generated (figure 10), showing the characteristic northwest-southeast depositional trend of the carbonate buildups in this part of the Blanding sub-basin. In comparison, a net isopach map was constructed for the underlying Gothic shale (figure 11) that revealed the same depositional orientation. The relationship between the thickness shown on figures 10 and 11 suggests that carbonate buildups were initiated on Gothic shale topographic highs. Interestingly, the structure map on top of the Desert Creek zone below the Gothic shale (figure 12) displays gentle ramp dips to the southwest, giving no indication of topography that would account for the northwest-southeast-trending thick in the Gothic shale (figure 11). The factors responsible for these isopach trends in both the Gothic shale and the upper and lower Ismay zones (figures 10 and 11) are unknown at this time.

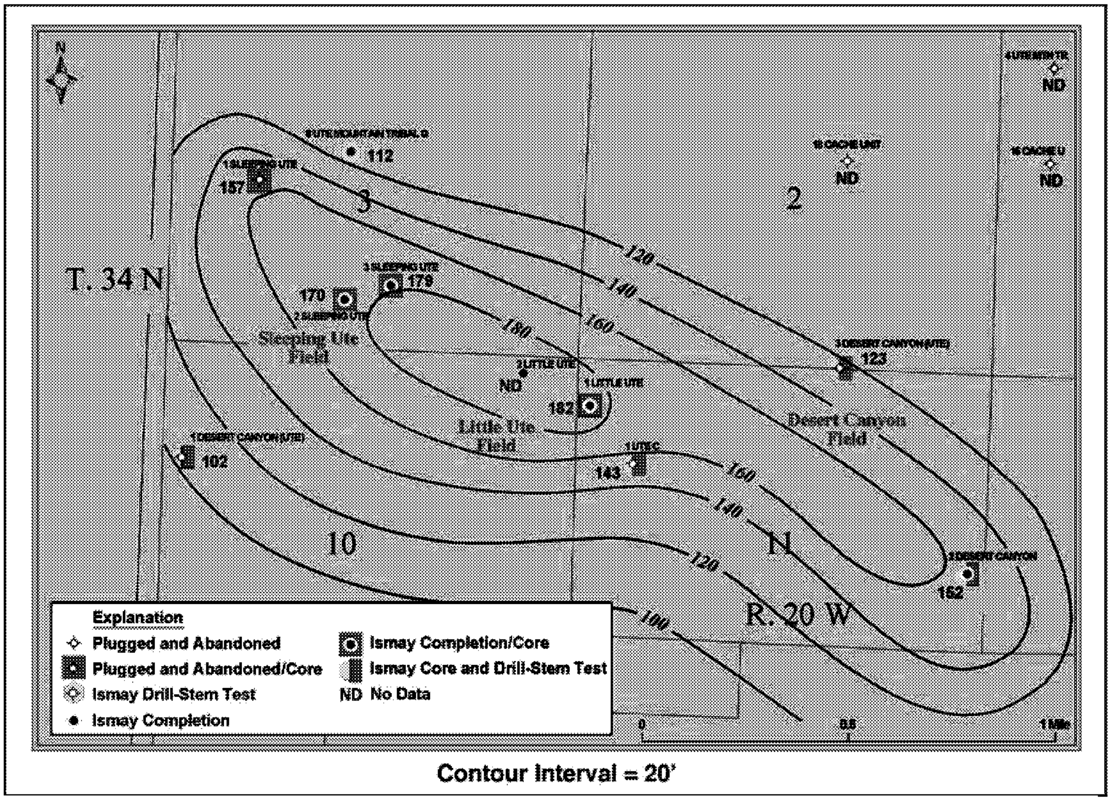


Figure 10. Upper and lower Ismay zone net isopach map, Little Ute, Sleeping Ute, and Desert Canyon fields, Montezuma County, Colorado.

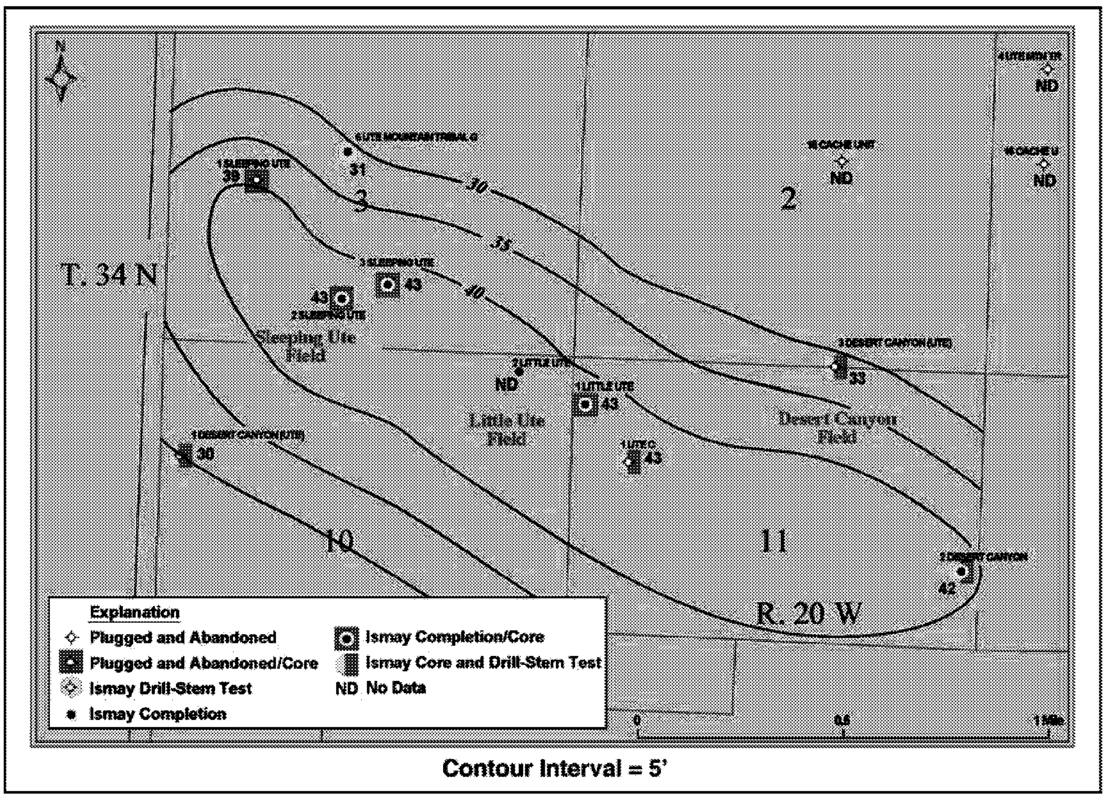


Figure 11. Gothic shale isopach map, Little Ute, Sleeping Ute, and Desert Canyon fields, Montezuma County, Colorado.

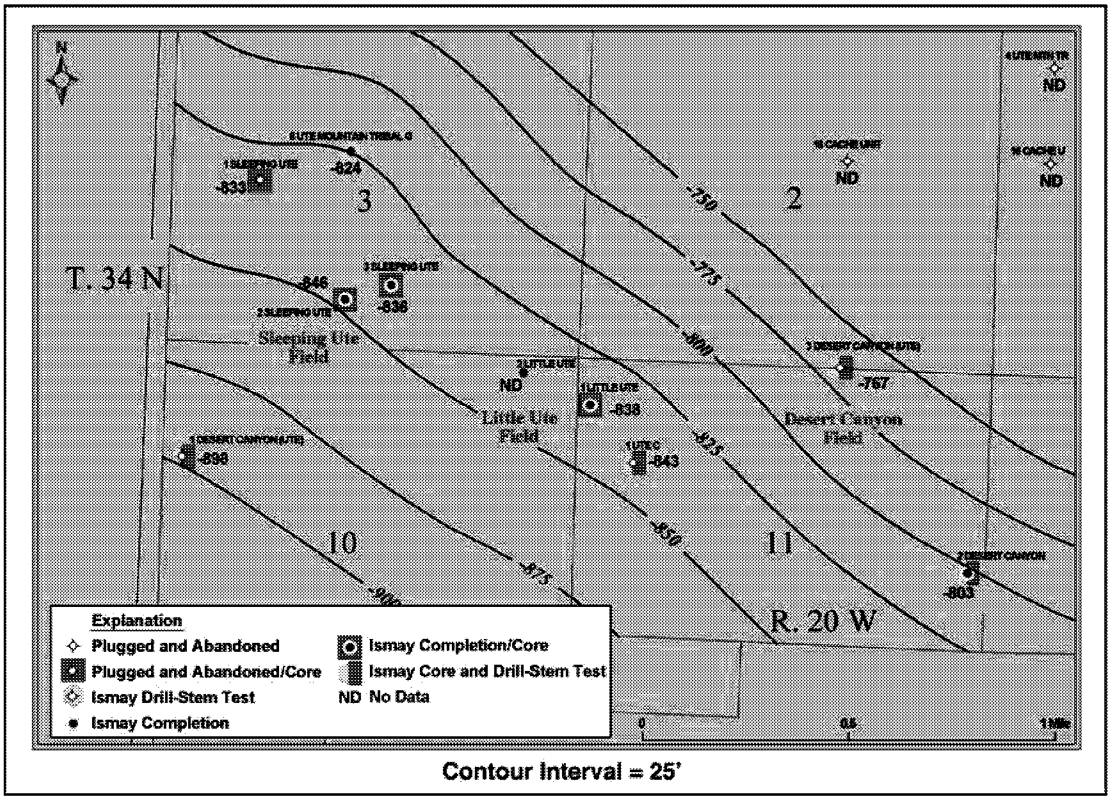


Figure 12. Desert Creek zone structural contour map, Little Ute, Sleeping Ute, and Desert Canyon fields, Montezuma County, Colorado.

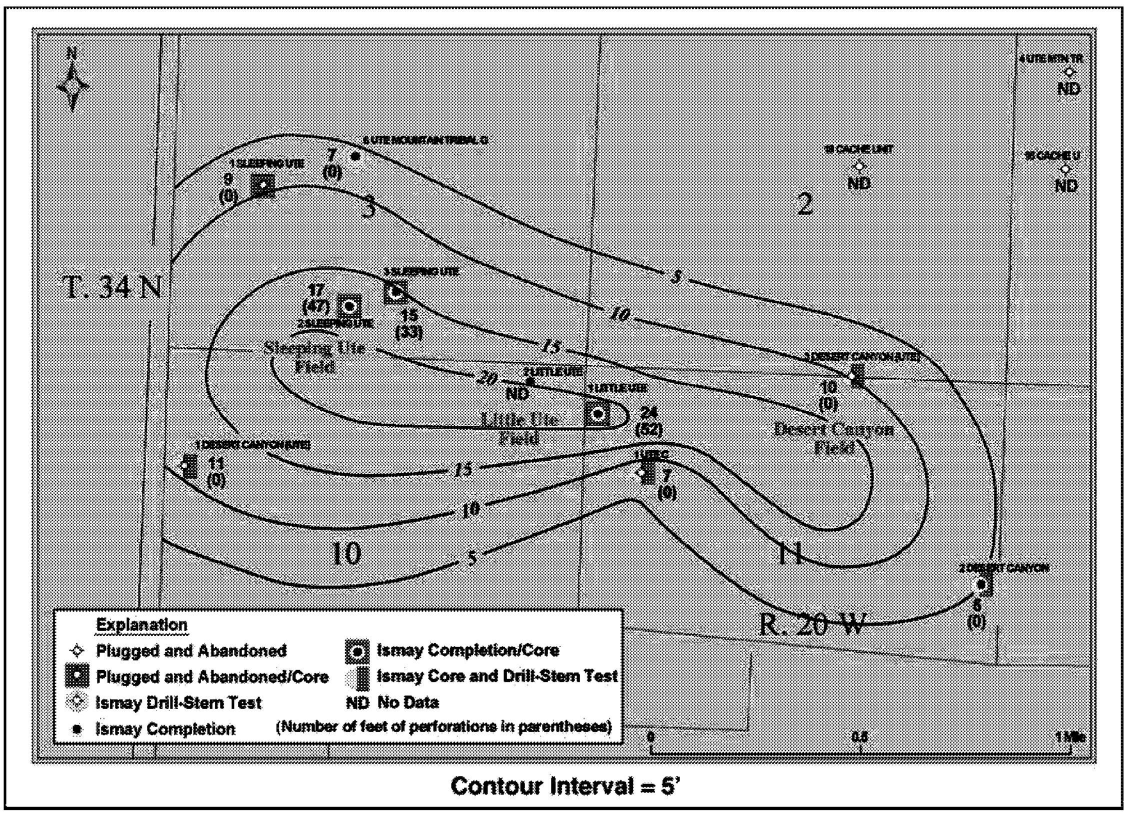
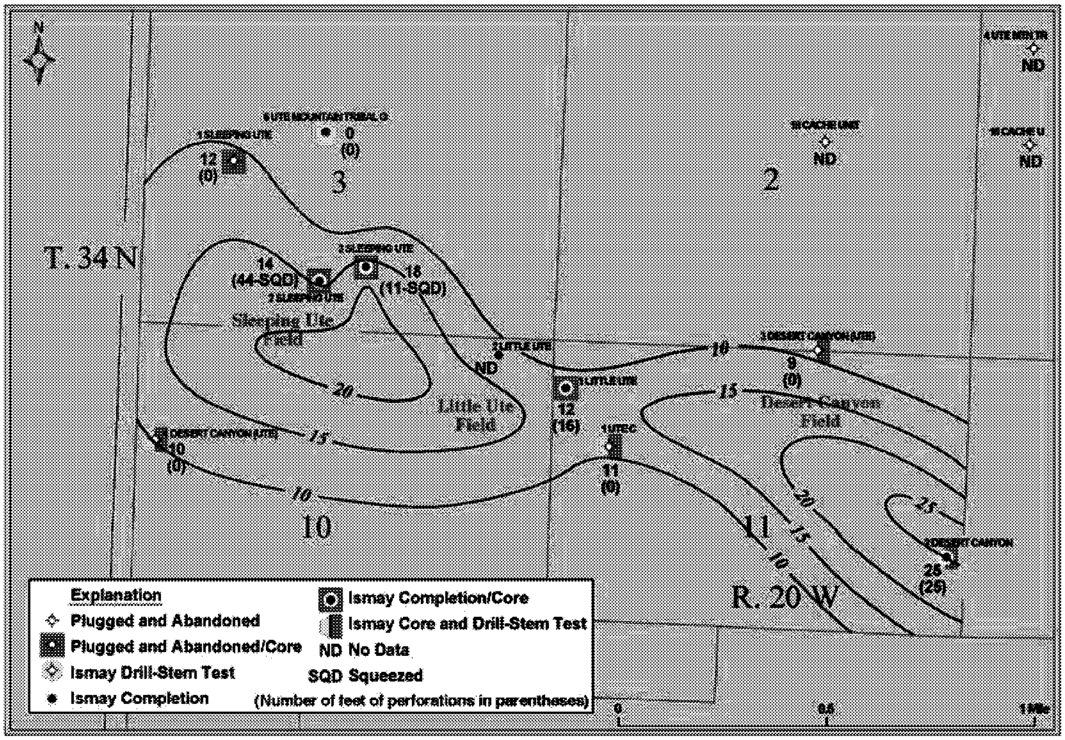


Figure 13. Upper Ismay zone net porosity (≥ 6 percent) isopach map, Little Ute, Sleeping Ute, and Desert Canyon fields, Montezuma County, Colorado.



Contour Interval = 5'

Figure 14. Lower Ismay zone net porosity (≥ 6 percent) isopach map, Little Ute, Sleeping Ute, and Desert Canyon fields, Montezuma County, Colorado.

Two additional maps, net porosity iospach of the upper Ismay zone (figure 13) and of the lower Ismay zone (figure 14), reflect the same trends as mentioned above.

These maps incorporated unit tops and thickness from all geophysical well logs in the area determined using the correlation scheme of Chidsey and others (2001a). This correlation scheme identifies major zone contacts, seals or barriers, baffles, producing or potential reservoirs, and depositional facies.

Depositionally, rock units are divided into seals or barriers (anhydrites and shales), mounds (both phylloid-algal mounds and bryozoan mounds), calcarenite shoals, open-marine facies, restricted lagoonal facies, and off-mound debris. Porosity units and reservoir or potential reservoir layers were identified within these facies and are visually displayed in the accompanying photomicrographs which will be discussed in the next section.

Facies Summary

Six representative facies were identified from core and geophysical well correlation from the Little Ute and Sleeping Ute fields: (1) phylloid-algal mounds; (2) bryozoan mounds; (3) mound talus; (4) calcarenite shoals; (5) open-marine carbonates; and (6) lagoonal/restricted shelf carbonates. In terms of cumulative production from the wells in Little Ute and Sleeping Ute fields, the phylloid-algal mound facies, developed in three separated intervals in the Little Ute No. 1 well, is the best reservoir in the area. A larger single interval of that facies is inferred to be present in the Sleeping Ute No. 2 well. Though this well was cored, the core was not available for detailed analyses in this study.

By comparison, the Sleeping Ute No. 1 well, the dry hole whose core was studied for this project, did not encounter the productive phylloid-algal mound facies. The minor porosity zones in the bryozoan mound and mound talus facies were insufficient for economic production. The Sleeping Ute No. 3 well encountered the phylloid-algal mound facies, but it was not as well developed as in the adjacent wells. Low cumulative production in the Sleeping Ute No. 3 well may be caused by the lack of significant phylloid-algal mound thickness or drainage from the Sleeping Ute No. 2 well (see proximity of spacing between these two wells on figures 6, and 9 through 14). However, the actual cause is unclear at this time based on the data available to this study. Pressure and production information from the operator would give some insight into this situation.

Representative photomicrographs of these various facies display the nature and extent of the reservoir porosity and permeability. The phylloid-algal mound facies photomicrograph (figure 15) shows the stunning reservoir development as seen by the blue impregnated pores. Leaching of the carbonate constituents, with porosity enhancement from dolomitization, creates an excellent reservoir. By comparison, the reservoir capability of the bryozoan mound facies (figure 16) is limited due to the isolated pores that are restricted to minor corrosion and intraparticle spaces.

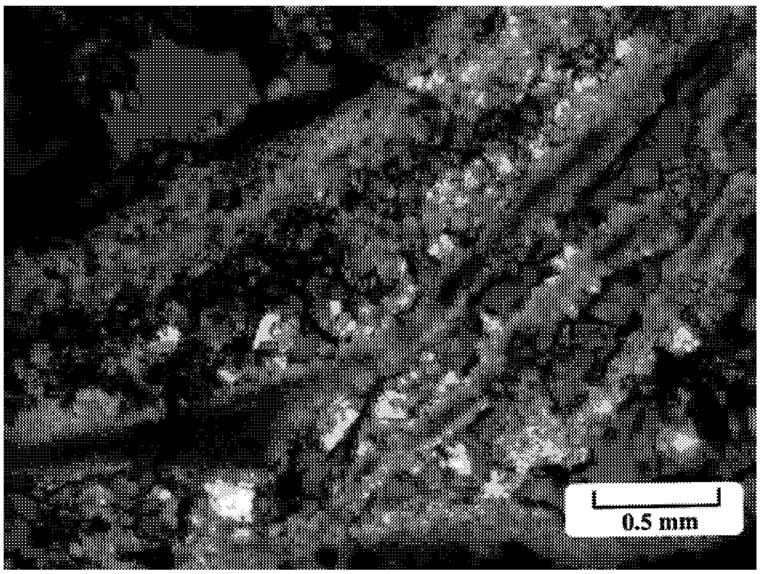


***Figure 15.** Photomicrograph (plane light with white card technique) showing a phylloid-algal mound bafflestone with a partially dolomitized and leached limestone stained with Alizarin Red-S solution. This sample exhibits much higher porosity and permeability than the undolomitized examples. Micritized remnants of phylloid algal plate rims (in red) are surrounded by partially dolomitized lime muds (white rhombs) and open pores (in blue). Little Ute No. 1 well, 5,882.5 feet, porosity = 18.4 percent, permeability = 95.6 md.*

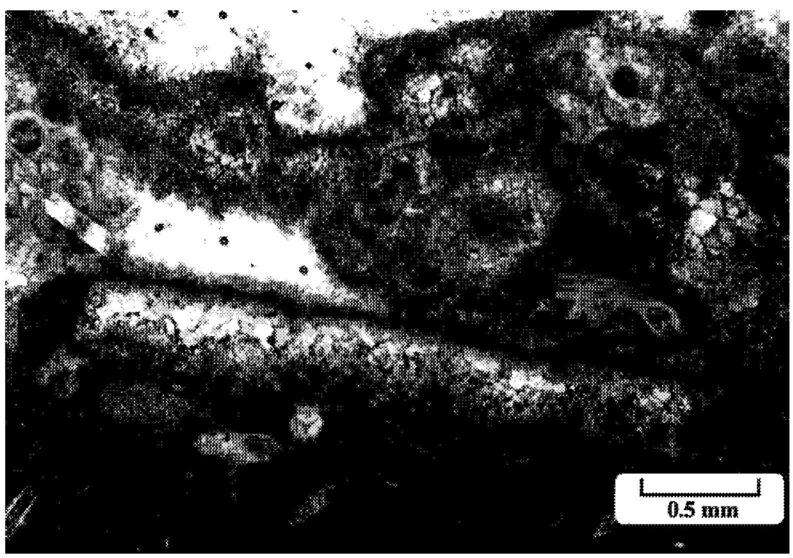


***Figure 16.** Photomicrograph (plane light) showing a bryozoan mound. This low-magnification micrograph shows poorly preserved remnants of bryozoan tubular clusters surrounded by vaguely peloidal lime muds. The large white masses in this view are composed of replacement anhydrite. Most of the porosity (in blue) is very isolated and restricted to minor corrosion and intraparticle spaces. Sleeping Ute No. 1 well, 5,599.3 feet, porosity = 2.5 percent, permeability = 1.30 md.*

The mound talus facies, in general, is not a good reservoir as shown in figure 17. The porosity that is present is remnant interparticle and some solution porosity as shown in blue in figure 17. The lagoonal/restricted marine facies (figure 18) has excellent porosity developed in a dolomitic mudstone with limited and variable permeability.

The calcarenite shoal facies is one that, on geophysical well logs, appears to be a fair to good reservoir due to its porosity development. The problem, however, is that the intergranular and moldic porosity seen in figure 19 is isolated, and thus the permeability is extremely low.

Finally, the open-marine facies is replete with fossil fragments, some of which contain isolated moldic pores. Porosity such as is shown in figure 20 is actually quite good, but the lack of permeability that can connect these isolated pores results in a poor reservoir rock.

Pore Types

The Ismay facies contain a wide variety of pore types and associated reservoir characteristics. Interparticle porosity, shown in figure 21, contains pores that are remnants of the original interparticle pore system between the skeletal components in this grainstone. The paragenetic sequence of diagenesis suggests that most of the original pore space has been occluded by early marine cements, meteoric calcite spar, and minor anhydrite precipitation. The diagenetic overprint on what was originally an excellent reservoir rock renders the resultant sample poor due to lack of permeability between the isolated pores.

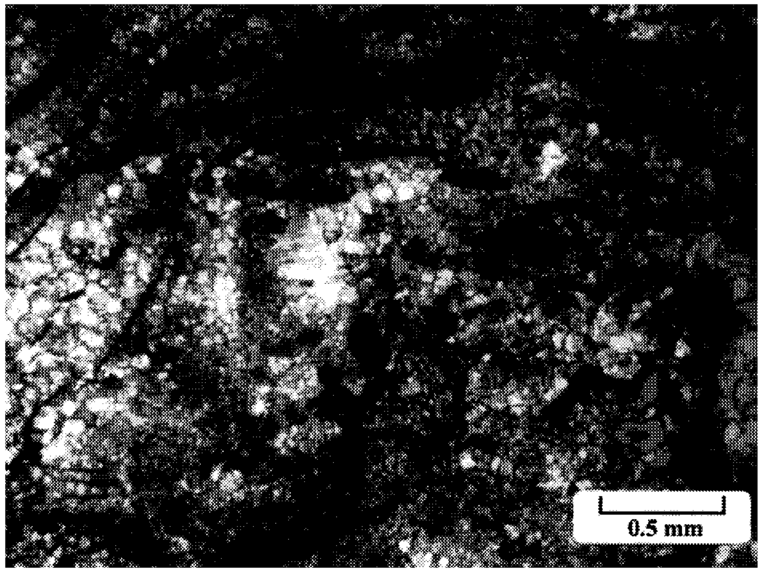


Figure 17. Photomicrograph (plane light) of mound talus showing elongate clasts of mud and fossil fragments that were probably derived from nearby bryozoan and phylloid-algal mounds. Remnant interparticle and modest solution porosity can be seen in blue. Sleeping Ute No. 1 well, 5,561.4 feet, porosity = 3.9 percent, permeability = 0.491 md.

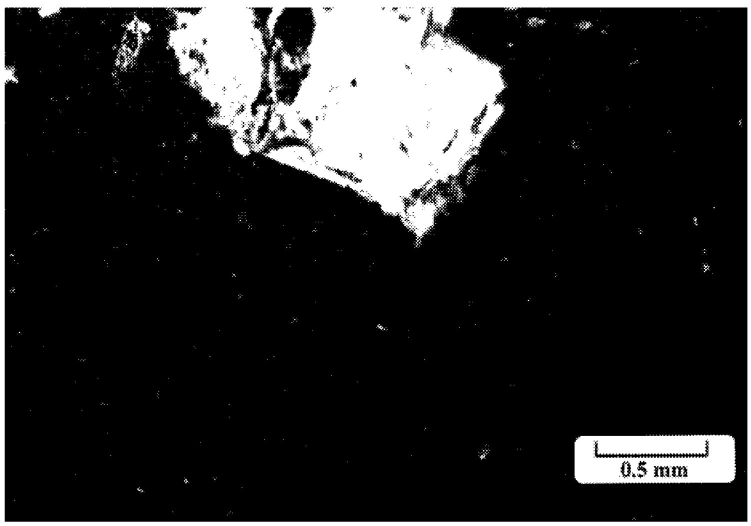


Figure 18. Low-magnification photomicrograph (plane light) of lagoonal/restricted marine facies showing crystal casts (in white) of early evaporite minerals (now anhydrite) surrounded by a dark-colored, dolomitic mudstone with sponge spicules (the very small white specks). Note the vague peloid outlines and microporosity (in blue) within this sample. Little Ute No. 1 well, 5,837.8 feet, porosity = 20.5 percent, permeability = 2.87 md.

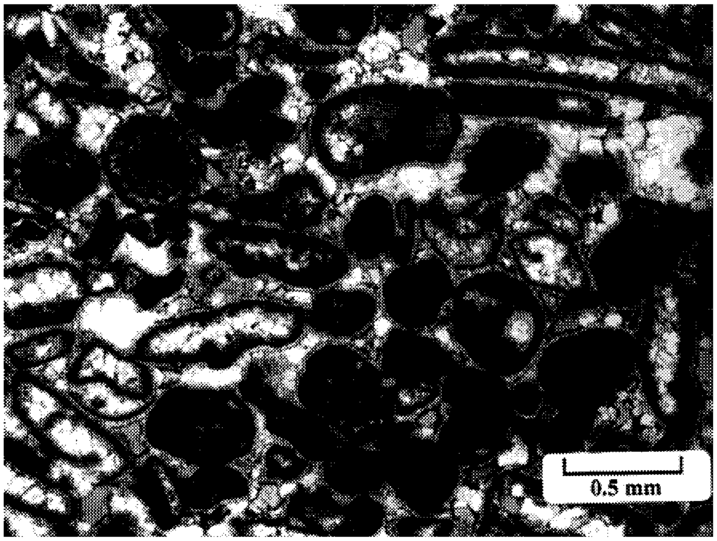
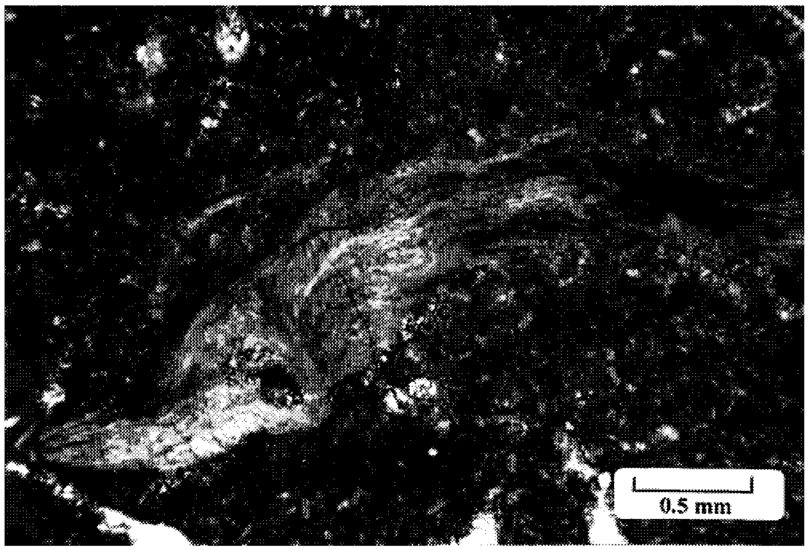


Figure 19. Photomicrograph (plane light) of high-energy shelf facies (calcarenite shoals) showing skeletal and aggregate grains within a high-energy grainstone. Among the typical grains of this facies are benthic forams (including fusulinids), phylloid-algal plates, "hard" peloids or micritized skeletal grains, and grain aggregates. Isopachous marine cements and "dogtooth" meteoric spar cements are present. Little Ute No. 1 well, 5,940.5 feet, porosity = 4.6 percent, permeability = 0.018 md.

Figure 20. Photomicrograph (plane light) of open marine facies showing fossiliferous wackestone with part of a well-preserved brachiopod shell as well as much smaller sponge spicules, echinoderm parts, and other bivalves. Note the vague peloidal fabric within the muds. Sleeping Ute No. 1 well, 5,636.6 feet, porosity = 8.0 percent, permeability = 0.080 md.



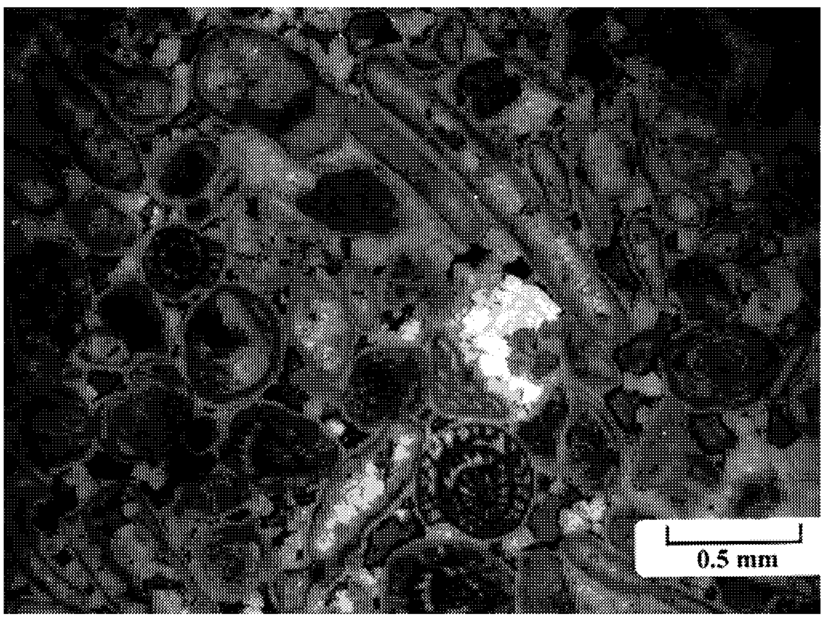


Figure 21. Photomicrograph (plane light with white card technique) of interparticle porosity. The scattered pores (in blue) visible in this micrograph are principally the remnants of primary interparticle space between the skeletal components of this grainstone. Early marine cements, followed by probable meteoric calcite spar and minor anhydrite (in white) have occluded most of the original interparticle porosity. Little Ute No. 1 well, 5,940.5 feet, porosity = 4.6 percent, permeability = 0.018 md.

Intraparticle porosity can create either good or poor reservoir rock, depending once again on the permeability network. Figure 22 shows good reservoir porosity, but a range in permeability that appears to be dependent upon the type of organisms in which the intraparticle porosity develops. This figure illustrates nicely that the phylloid-algal mound facies comprises superior reservoir characteristics compared to the bryozoan mound facies.

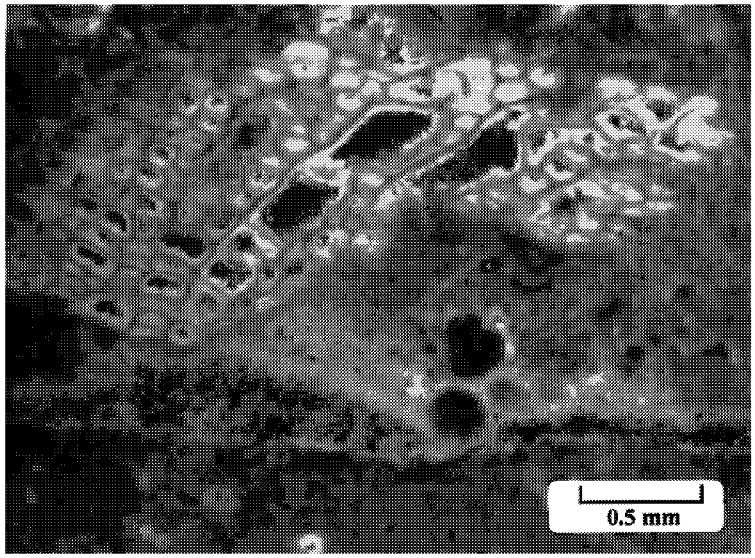


Figure 22. Photomicrograph (plane light with white card technique) of interparticle porosity. Open pores (in blue) are shown here within the uncemented chambers of encrusting organisms surrounded by lime muds. This sample is from within a phylloid-algal mound core. Little Ute No. 1 well, 5,870.9 feet, porosity = 9.8 percent, permeability = 12.2 md.

The phylloid-algal mound facies also contains examples of shelter porosity as seen in figure 23. Large pores develop under or between platy phylloid algal plates and/or curvilinear bivalve shells. Reservoir quality is degraded, however, when early cementation occludes these pores either partially or completely.

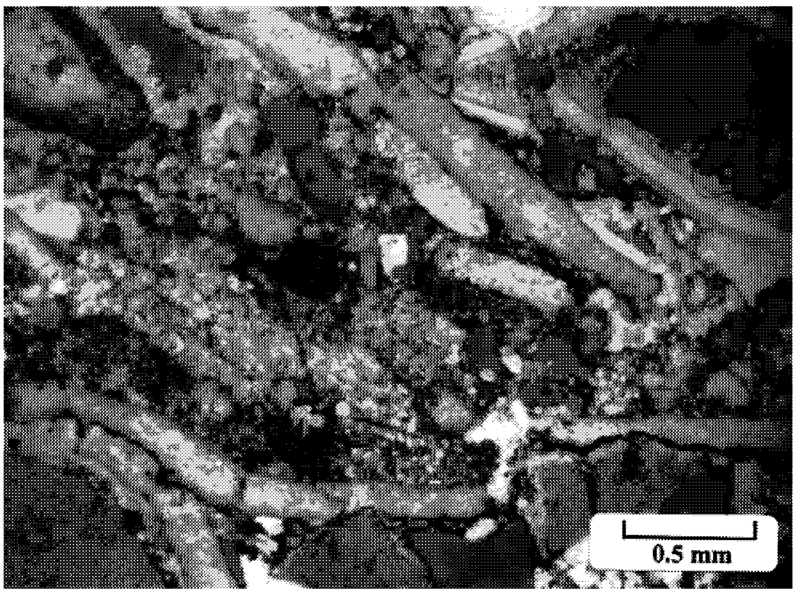


Figure 23. Photomicrograph (plane light with white card technique) of shelter porosity. Most of the large pores (in blue) occurring between platy phylloid-algal plates and the curvilinear bivalve shells are sheltered from internal sediment fillings. These preserved primary pores are often lined with early cements, thus limiting permeability. Some of the original grains and muds in this sample are associated with a phylloid-algal mound core. Little Ute No. 1 well, 5,946.3 feet, porosity = 3.9 percent, permeability = 0.881 md.

Early dissolution of skeletal grains and evaporite mineral crystals can also create moldic porosity, as seen in figure 24. These molds are large, but so isolated as to create very little permeability. Even extensive diagenetic dissolution that creates excellent porosity does not insure that a reservoir can be economically produced. Figure 25 shows large, open pores created by widespread dissolution of skeletal grains, carbonate clasts, and early carbonate cements. However, the permeability is ineffective in connecting this well-developed vuggy porosity.

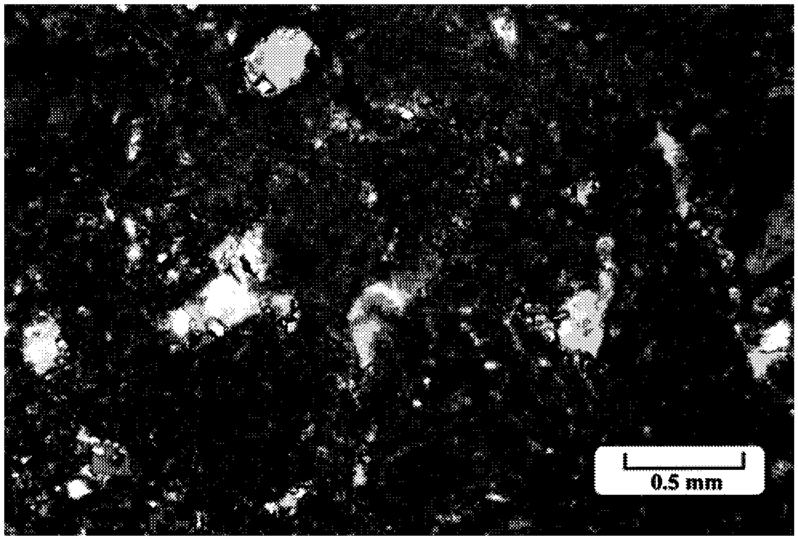


Figure 24. Photomicrograph (plane light) of moldic porosity. The isolated pores (in blue) are mostly from dissolved skeletal grains and early evaporite mineral crystals. These fossil and crystal molds are surrounded by dense lime muds. Sleeping Ute No. 1 well, 5,636.6 feet, = 8.0 percent, permeability = 0.080 md.

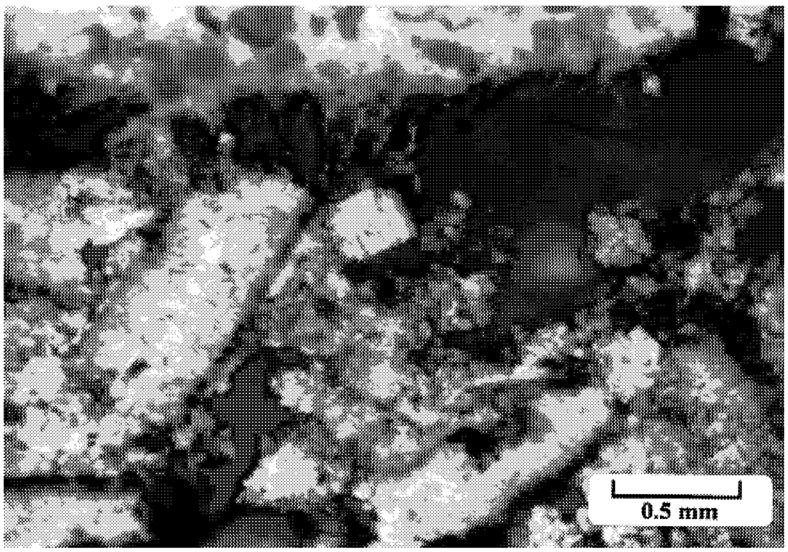


Figure 25. Photomicrograph (plane light with white card technique) of vuggy porosity. The oversized pores (in blue) shown here are solution-enlarged vugs. Early dissolution of skeletal grains, clasts and cements created these large, isolated pores. Little Ute No. 1 well, 5,946.3 feet, porosity = 3.9 percent, permeability = 0.881 md.

Though not abundant in the Little Ute and Sleeping Ute fields, intercrystalline porosity, developed between dolomite microcrystals, can create excellent reservoir rock as seen in figure 26. The introduction of evaporites that replace grains and occlude porosity prevent this sample from having much higher permeabilities. An excellent example of effective intercrystalline porosity is seen in figure 27. Not surprisingly, this example is from the phylloid-algal mound facies and has excellent porosity and permeability developed between rhombic dolomite crystals, allowing large, well-connected pores.

The final pore type seen in Little Ute and Sleeping Ute fields is microfractures, as displayed in figure 28. Reservoir quality is enhanced with extensive and abundant microfractures.

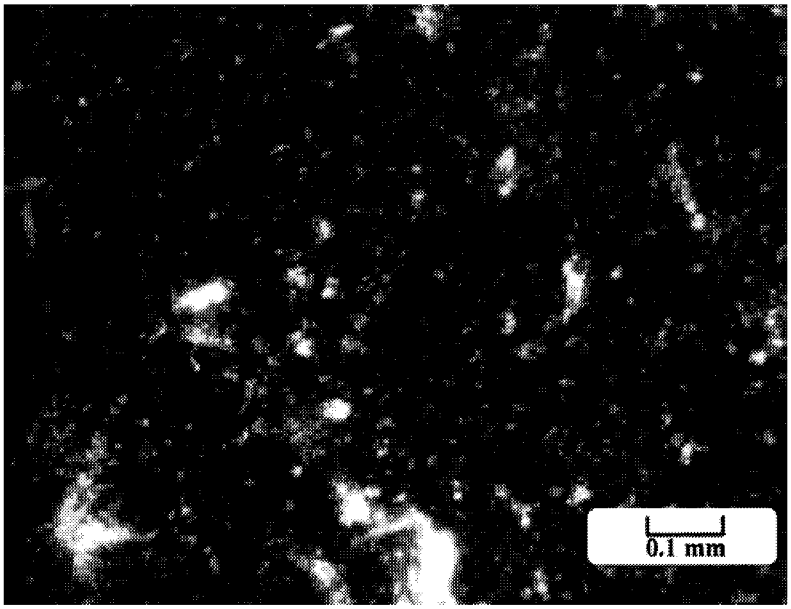


Figure 26. Photomicrograph (plane light) of intercrystalline porosity. The extremely small pores (in blue) of this view mostly occur between dolomite microcrystals. Crystal casts of evaporite minerals (in white) have grown displacively or replaced the dolomitic mud sediment. Little Ute No. 1 well, 5,837.8 feet, porosity = 20.5 percent, permeability = 2.86 md.

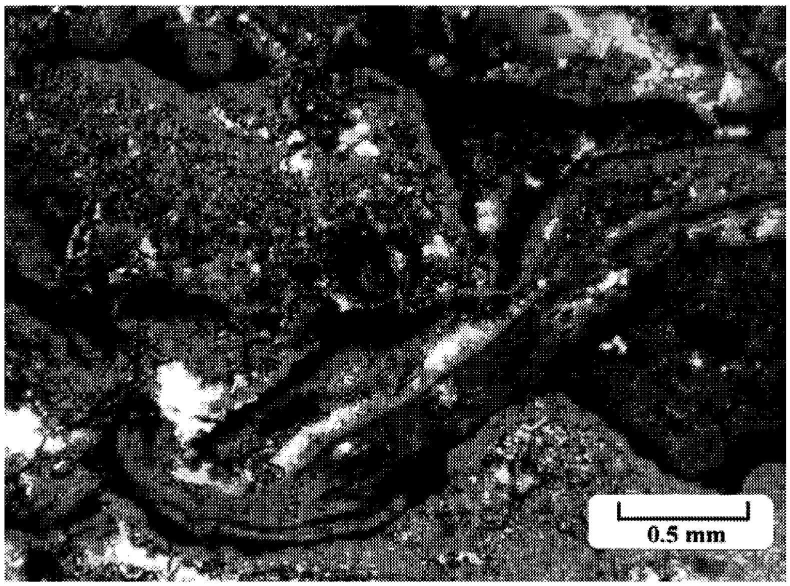


Figure 27. Photomicrograph (plane light) of intercrystalline porosity. The large, well-connected pores (in blue) in this view mostly occur between rhombic dolomite crystals. Some of the original grains and muds in this sample are associated with a phylloid-algal mound core. Little Ute No. 1 well, 5,882.5 feet, porosity = 18.4 percent, permeability = 95.6 md.

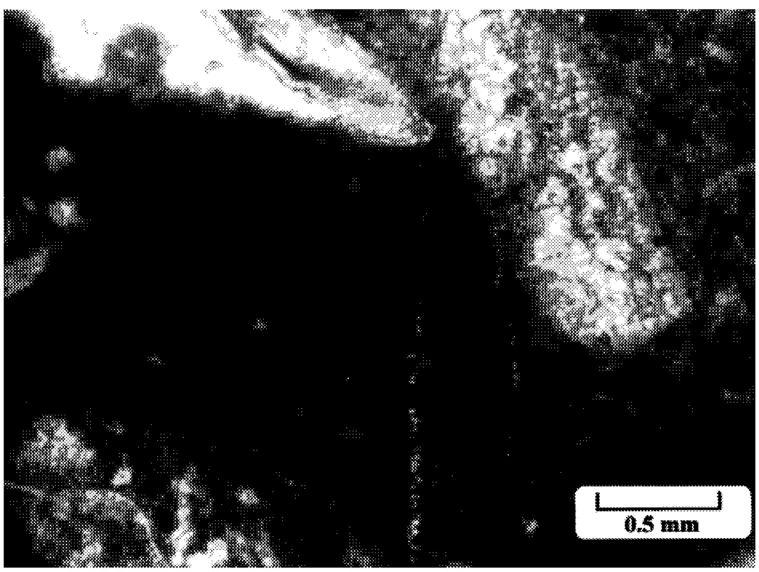


Figure 28. Photomicrograph (plane light) of microfractures. A pair of open microfractures (in blue) are illustrated here that cross lime muds within the sediments of a phylloid-algal mound interior. Recrystallized skeletal fragments (including phylloid-algal plates) are the white areas in this view. Little Ute No. 1 well, 5,919.2 feet, porosity = 8.0 percent, permeability = 0.398 md.

Mineralogy

Five distinct mineralogies are seen in Little Ute and Sleeping Ute fields. Simple limestone deposited as the calcite remains of phylloid-algal plates, marine fossils, and lime muds (figure 29), can have excellent porosity and permeability as a result of early dissolution by fresh waters. Dolomite, created during the diagenetic process in which organic mudstone is dolomitized (figure 30), can preserve high porosities and good effective permeabilities.

Several mixed mineralogies are created and preserved as well. Anhydritic limestone, in which the original calcite fossils have been partially replaced by anhydrite, does not create a good reservoir (figure 31). In contrast, anhydritic dolomite, as seen in figure 32, has abundant microporosity but very little permeability.

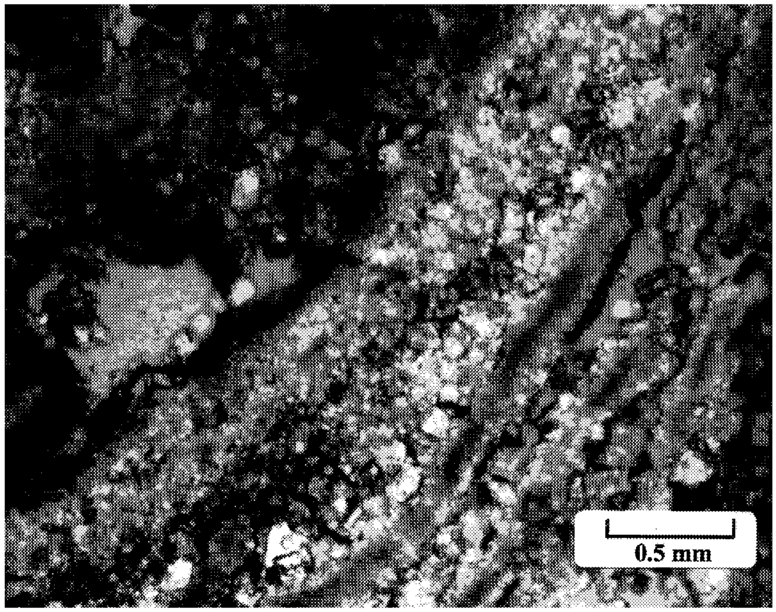


Figure 29. Photomicrograph (plane light with white card technique) of limestone where Alizarin Red-S staining shows the calcite composition of corroded remnants from phylloid-algal plates, marine fossils, and lime muds. Early dissolution by fresh waters has created some of the porosity (in blue). Little Ute No. 1 well,

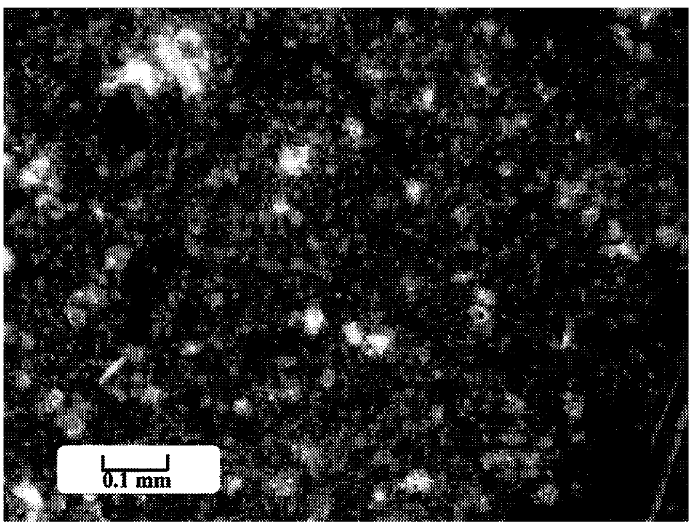


Figure 30. Photomicrograph (plane light with white card technique) of dolomite where sponge spicule-bearing, organic mudstone has been replaced by very finely crystalline dolomite. Note the very small intercrystalline and micro-moldic pores (in blue). Little Ute No. 1 well, 5,837.8 feet, porosity = 20.5 percent, permeability = 2.87 md.

Porosity and Permeability Cross Plots

Cross plots of porosity versus permeability for the various pore types for the two cored wells, seen in figures 33 and 34, show that intercrystalline and moldic pore types have the highest porosity and permeability of any of the other pore types. They also have a wide range of values with some samples being among the lowest for porosity and permeability. Note that the pore type symbols differ for this set of plots. From previous project work on Ismay reservoirs (Chidsey and others, 2001b), a rough economic cut-off for permeability was found to be 2 md. Accordingly, the productive Little Ute No. 1 well has a number of cored intervals that exceed 2 md, whereas the Sleeping Ute No. 1, a dry hole, has many fewer intervals greater than 2 md.

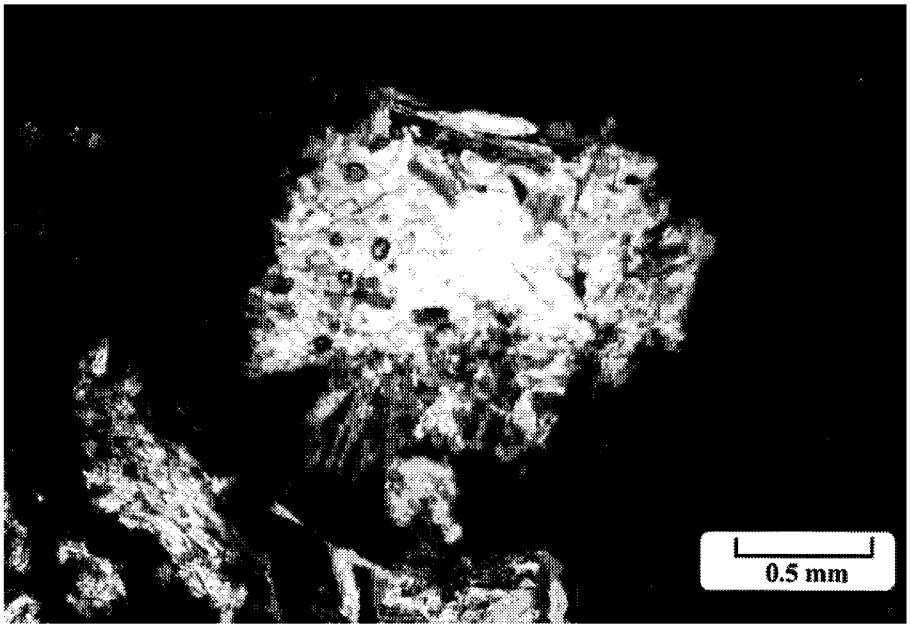


***Figure 31.** Low-magnification photomicrograph (crossed nicols) of anhydritic dolomite showing clusters of early evaporite minerals (now anhydrite) surrounded by a dark-colored, dense dolomitic mudstone. Sleeping Ute No. 1 well, 5,575.4 feet, porosity = 13.2 percent, permeability = 0.283 md.*

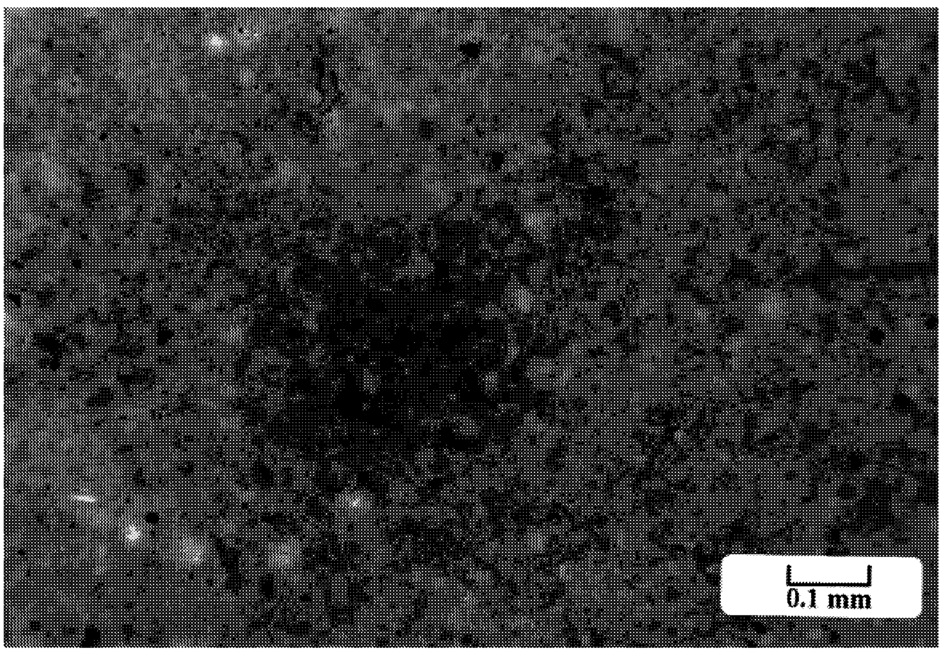


***Figure 32.** High-magnification photomicrograph (plane light with white card technique) of the same sample in figure 31 showing the very small crystal size of the dolomite matrix in this mixed mineralogy sample. Note the microporosity (in blue) within this sample.*

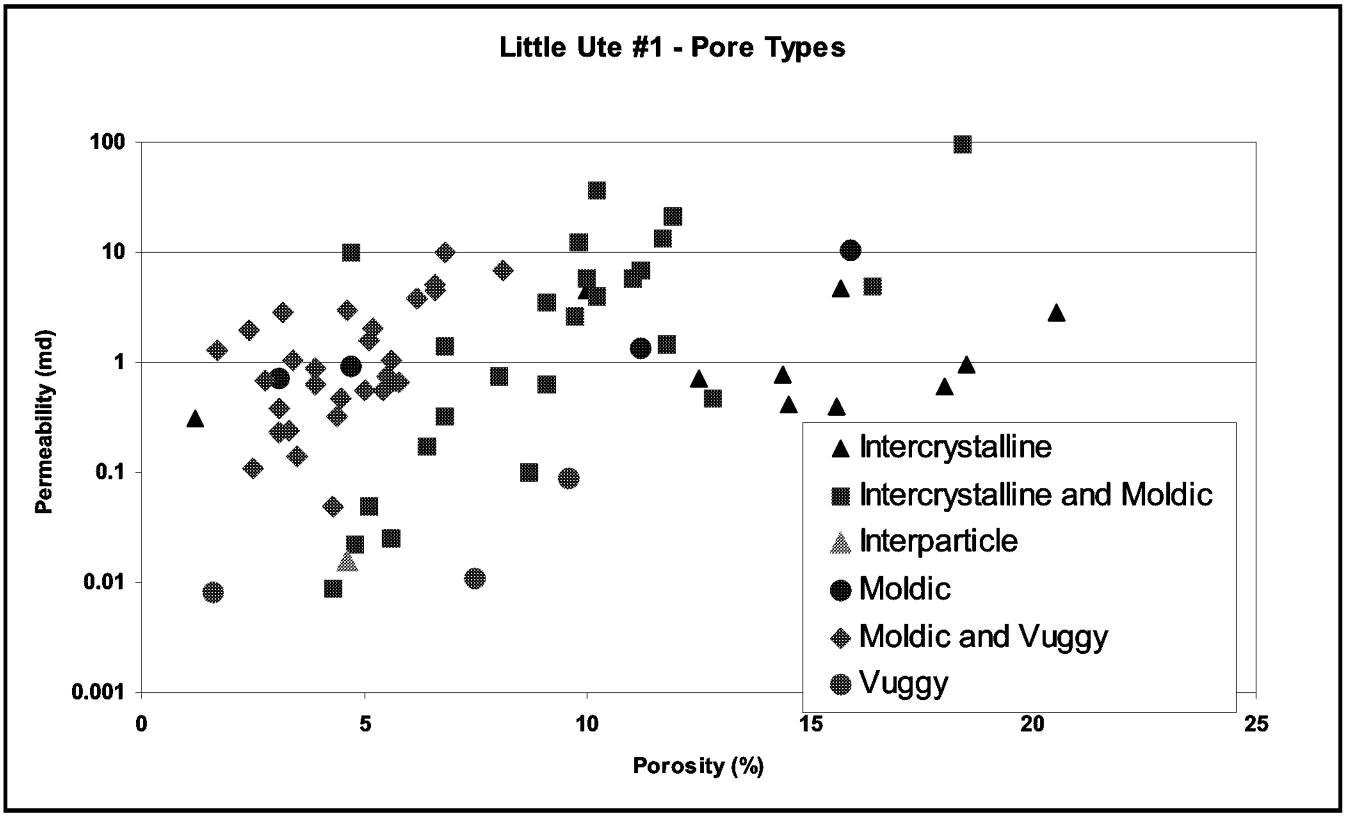


Figure 33. Little Ute No. 1 well permeability versus porosity cross plot by pore types.

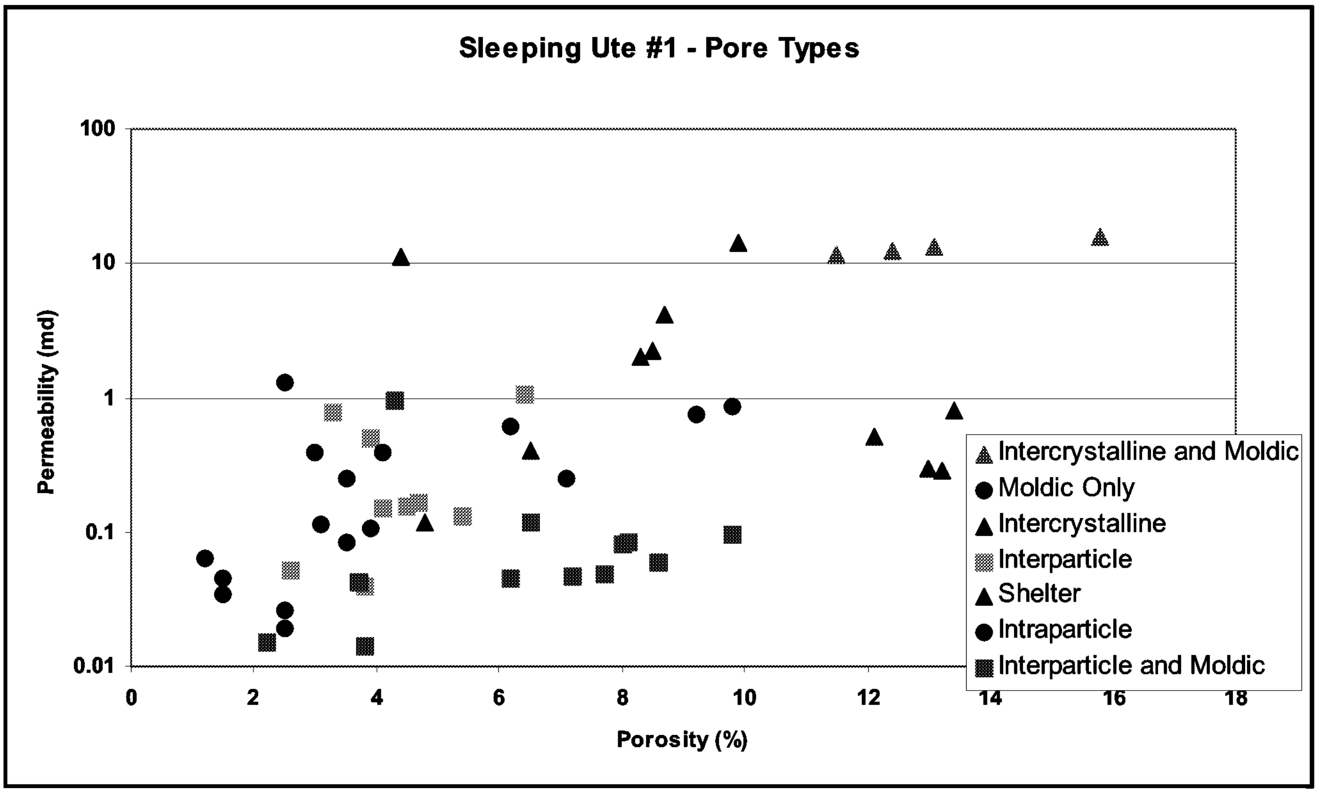


Figure 34. Sleeping Ute No. 1 well permeability versus porosity cross plot by pore types.

Cross plots of porosity versus permeability for the various facies are seen in figures 35 and 36. Using the 2 md economic cut-off, the productive Little Ute No. 1 (figure 35) contains numerous phylloid-algal mound reservoir intervals. By comparison, the non-productive Sleeping Ute No. 1 well contains no phylloid-algal mound facies. Only a few intervals in the Sleeping Ute No. 1 core (figure 36) exceed the 2 md cut-off.

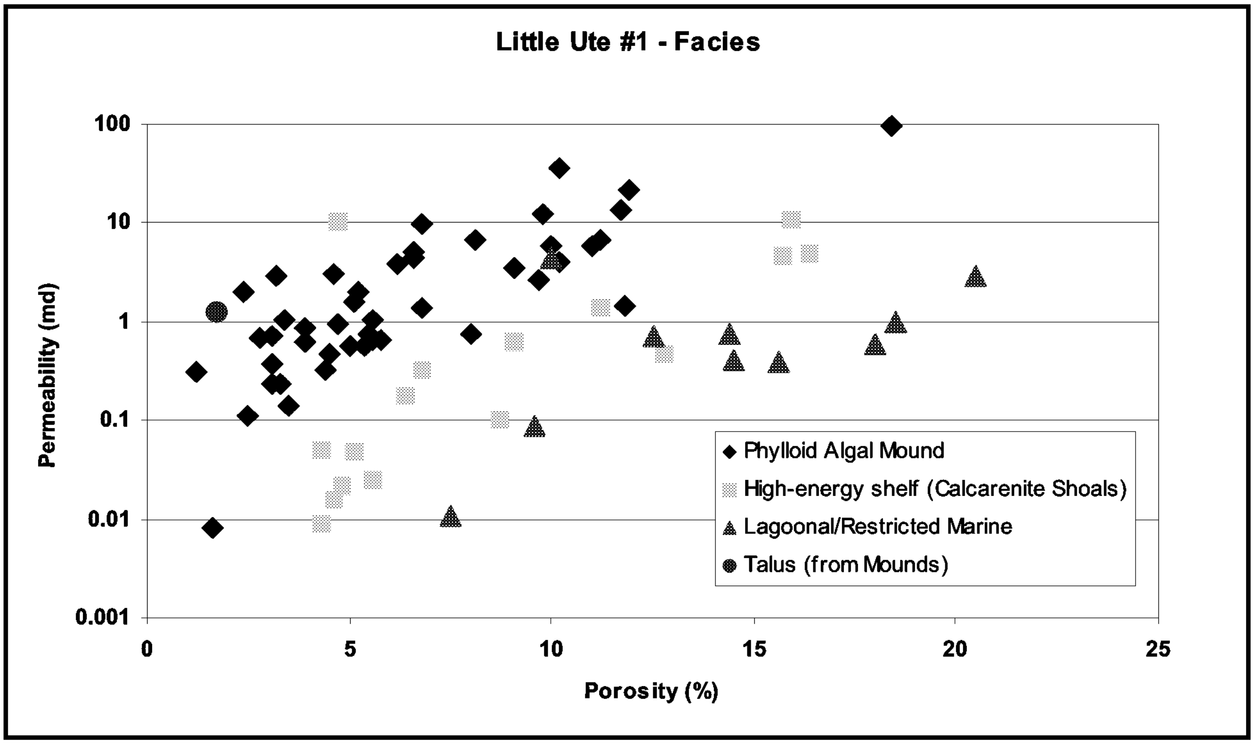


Figure 35. Little Ute No. 1 well permeability versus porosity cross plot by facies.

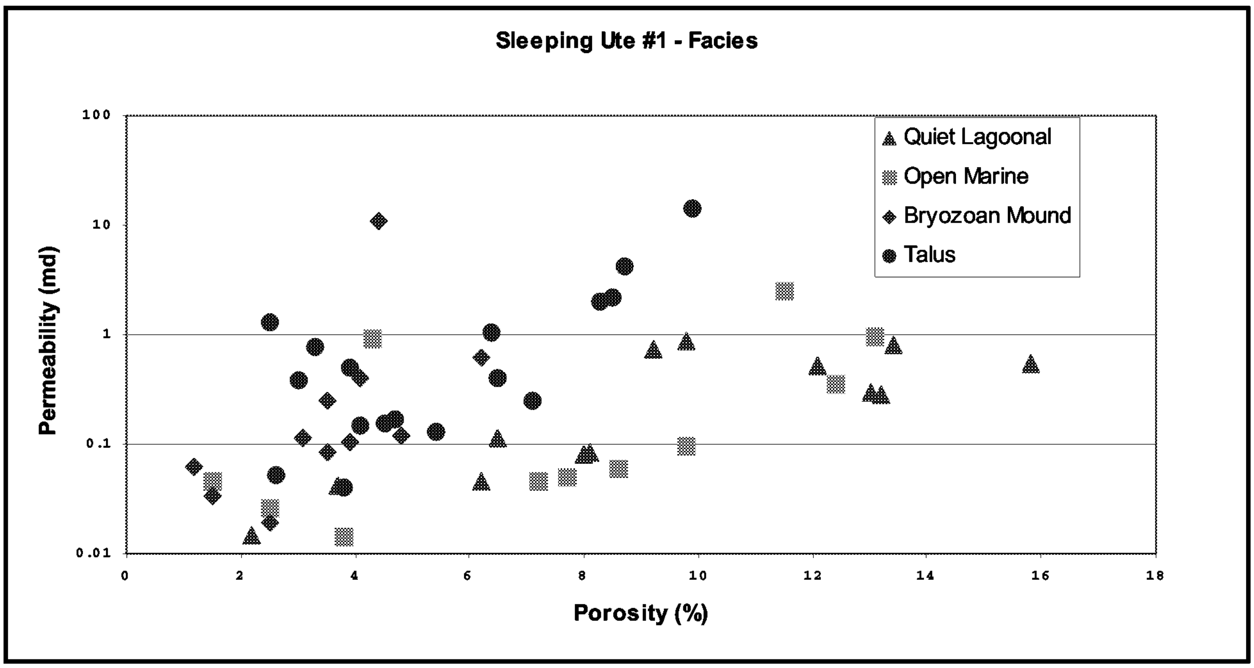


Figure 36. Sleeping Ute No. 1 well permeability versus porosity cross plot by facies.

Cross plots of the mineralogy are shown for the two cored wells in figures 37 and 38. Once again, the intervals that exceed 2 md are greater in number in the productive Little Ute No. 1 well (figure 37) than in the non-productive Sleeping Ute No. 1 well (figure 38). No single mineralogy seems to dominate the reservoir intervals in the Little Ute No. 1 core. In contrast, the non-productive Sleeping Ute No. 1 core has very few intervals with permeabilities greater than 2 md. The few samples that do fall into the higher permeability range are almost exclusively anhydritic dolomites.

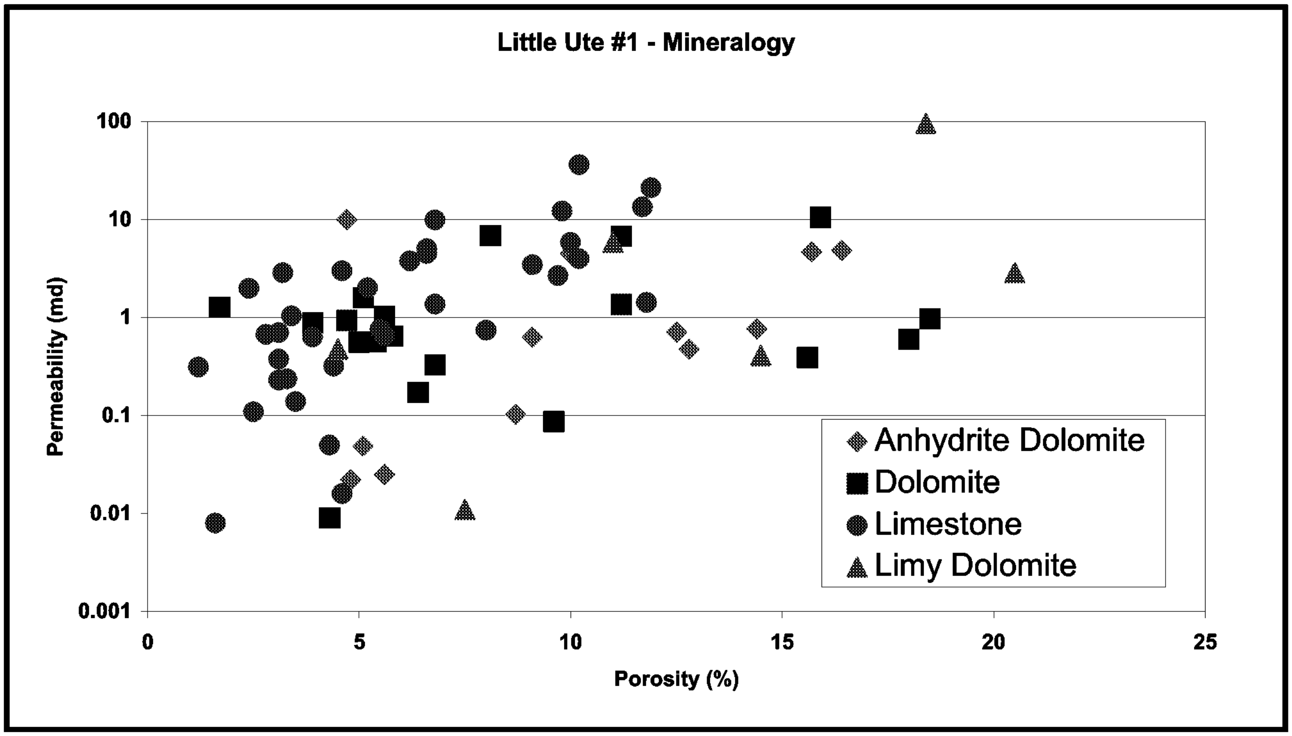


Figure 37. Little Ute No. 1 well permeability versus porosity cross plot by mineralogy.

TECHNOLOGY TRANSFER

The UGS is the Principal Investigator and prime contractor for five government-industry cooperative petroleum-research projects, including two in the Paradox Basin. These projects are designed to improve recovery, development, and exploration of the nation's oil and gas resources through use of better, more efficient technologies. The projects involve detailed geologic and engineering characterization of several complex heterogeneous reservoirs. The two Class II Paradox Basin (this report covers the Class II Revisit project) and the Class I Bluebell field (Uinta Basin) projects include practical oil-field demonstrations of selected technologies. The fourth project involves geological characterization and reservoir simulation of the Ferron Sandstone on the west flank of the San Rafael uplift as a surface analogue of a fluvial-dominated, deltaic reservoir. The fifth project involves establishing a log-based correlation scheme for the Tertiary Green River Formation in the southwestern Uinta Basin to help identify new plays and improve the understanding of producing intervals. The DOE and multidisciplinary teams from petroleum companies, petroleum service companies, universities, private consultants, and state agencies are co-funding the five projects.

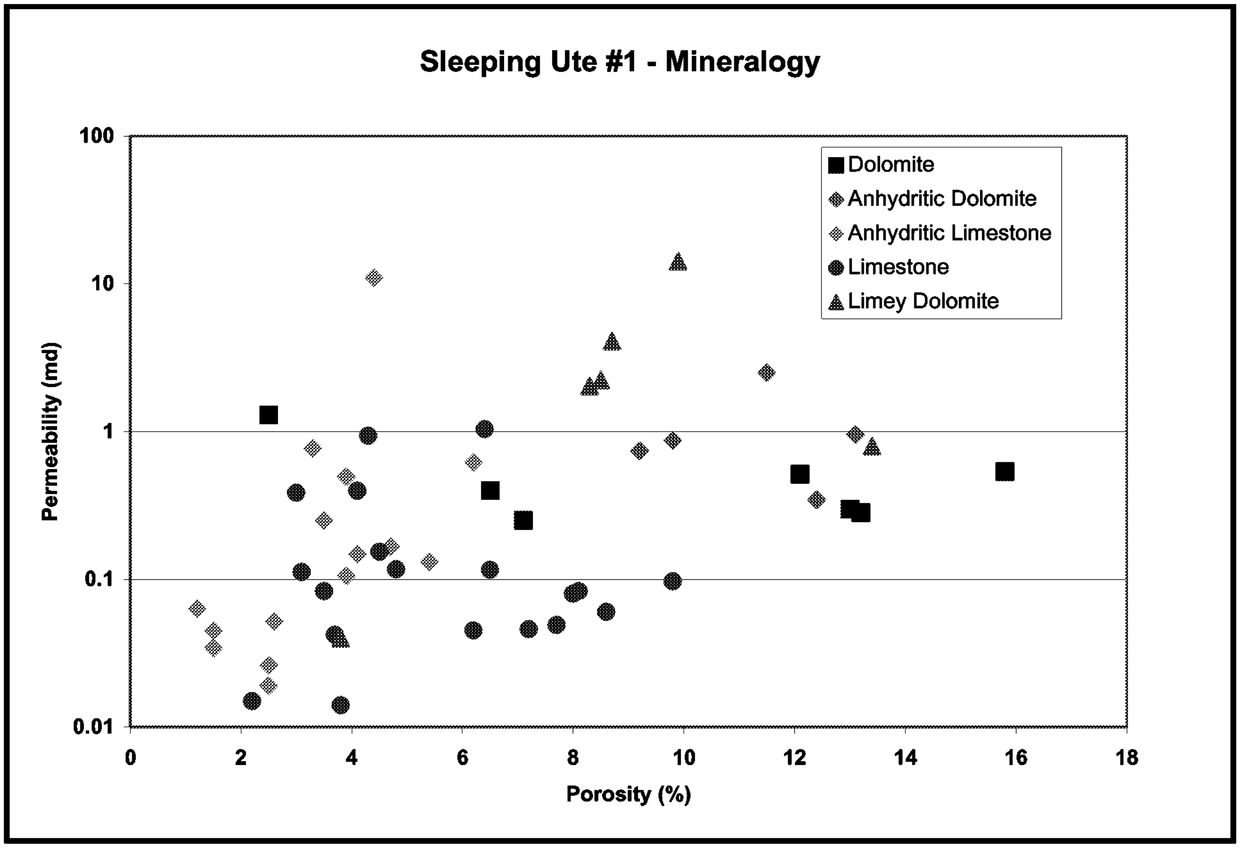


Figure 38. Sleeping Ute No. 1 well permeability versus porosity cross plot by mineralogy.

The UGS will release all products of the Paradox Basin project in a series of formal publications. These will include all the data as well as the results and interpretations. 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*. This information will also be released through the UGS periodical *Survey Notes* and on the project internet web pages.

The technical team reviewed project activities and results in a combined meeting, sponsored by the Utah Petroleum Association, of the Technical and Stake Holders Boards and the Southeastern Utah Industry/BLM/State/County Work Group in Moab, Utah, on January 24, 2002. The purpose of the Work Group is to establish dialog between the oil and gas industry and federal, state, and local governments for future development of hydrocarbon resources for the next decade. Project activities and results were also reviewed before the Board of the Utah Division of Oil, Gas and Mining Board on February 28, 2002. The technical team received feedback and advice concerning the project and horizontal drilling in the Paradox Basin. 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 Paradox Basin. This board ensures direct communication of the study methods and results to the Paradox Basin operators. The Stake Holders Board is composed of groups that have a financial interest in the study area including representatives from the Utah and Colorado state governments (Utah School and

Institutional Trust Lands Administration, Utah Division of Oil, Gas and Mining, and Colorado Oil and Gas Conservation Commission), Federal Government (U.S. Bureau of Land Management and U.S. Bureau of Indian Affairs), and the Ute Mountain Ute Indian Tribe. The members of the Technical Advisory and Stake Holders Boards receive all semi-annual technical reports and copies of all publications, and other material resulting from the study.

Project materials, plans, and objectives were displayed at the UGS booth during the AAPG annual national convention, March 10-13, 2002, in Houston, Texas. Four UGS scientists staffed the display booth at this event. Project displays will be included as part of the UGS booth at professional meetings throughout the duration of the project.

An abstract was submitted to the AAPG on diagenesis and porosity development in Cherokee field, San Juan County, Utah, another of the project case-study fields. The paper has been accepted and will be presented during the 2002 AAPG Rocky Mountain Section Meeting in Laramie, Wyoming.

The UGS has submitted a proposed short course, "Pennsylvanian Heterogeneous Shallow-Shelf Buildups of the Paradox Basin: A Core Workshop," to the 2003 AAPG Convention Committee. This event will take place on May 10, 2003, in Salt Lake City, Utah, during the annual national convention of the AAPG. The short course will be co-sponsored by the CGS and DOE. Core from representative Utah and Colorado Ismay and Desert Creek fields will be examined. All core displayed will be placed into regional paleogeographic settings. The core workshop will be organized into topical modules with participants performing a series of exercises using core, geophysical well logs, and photomicrographs from thin sections. These modules include: describing reservoir vs. non-reservoir facies, determining diagenesis and porosity from core, recognizing barriers and baffles to fluid flow, correlating core to geophysical well logs, and identifying potential completion zones and candidates for horizontal drilling.

Utah Geological Survey *Survey Notes* and Internet Web Sites

The purpose of *Survey Notes* is to provide nontechnical 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 database that includes those companies or individuals (more than 300 as of April 2002) specifically interested in the Paradox Basin project or other DOE-sponsored projects.

The UGS and the CGS maintain web sites on the internet, http://geology.utah.gov and http://www.dnr.state.co.us/geosurvey. The UGS site includes a page under the heading *Economic Geology Program*, which describes the UGS/DOE cooperative studies (Paradox Basin, Ferron Sandstone, Bluebell field, Green River Formation), contains the last issue of *Petroleum News*, 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 Paradox Basin project page http://geology.utah.gov/emp/Paradox2/index.htm contains: (1) a project location map, (2) a description of the project, (3) a list of project participants and their postal addresses and phone numbers, (4) a reference list of all publications that are a direct result of the project, and (5) semi-annual technical progress reports. The CGS web site contains the same project information.

Technical Presentation

The following technical presentation was made during the second six months of the second project year as part of the technology transfer activities.

"Heterogeneous Carbonate Buildups in the Colorado Portion of the Blanding Sub-Basin of the Paradox Basin, Colorado and Utah: Possible Targets for Increased Oil Production Using Horizontal Drilling Techniques" by Laura L. Wray, Neal DeShazo, and David E. Eby, American Association of Petroleum Geologists Annual Convention, Houston, Texas, March 12, 2002. Core photographs, graphs, maps, diagenetic analysis, and horizontal drilling recommendations were part of the presentation.

Project Publications

Chidsey, T.C., Jr., 2001, Carbonate buildups in the Paradox Basin, targeted for horizontal drilling: U.S. Department of Energy, The Class Act, v. 8, no. 1, p. 3-6.

Chidsey, T.C., Jr., Eby, D.E., and Wray, L.L., 2001, Heterogeneous shallow-shelf carbonate buildups in the Paradox Basin, Utah and Colorado: targets for increased oil production and reserves using horizontal drilling techniques – semi-annual technical progress report for the period April 6 to October 5, 2001: U.S. Department of Energy, DOE/BC15128-3, 32 p.

Wray, L.L., DeShazo, Neal, and Eby, D.E., 2002, Heterogeneous carbonate buildups in the Colorado portion of the Blanding sub-basin of the Paradox Basin, Colorado and Utah – possible targets for increased oil production using horizontal drilling techniques [abs.]: American Association of Petroleum Geologists Annual Convention, Official Program with Abstracts, v. 11, p. A192-193.

CONCLUSIONS

The Blanding sub-basin within the Pennsylvanian Paradox Basin developed on a shallow-marine shelf that locally contained algal-mound and other carbonate buildups. The two main producing zones of the Paradox Formation are the Ismay and the Desert Creek. The Ismay zone is dominantly limestone comprising equant buildups of phylloid-algal material. The Ismay is productive in fields of the southern Blanding sub-basin. The Desert Creek zone is dominantly dolomite comprising regional nearshore shoreline trends with highly aligned, linear facies tracts. Two Colorado fields were selected for evaluation on a local scale: Little Ute and Sleeping Ute fields in the Ismay zone trend (figure 4).

The typical vertical, core-derived sequence or cycles of depositional lithofacies from the Little Ute and Sleeping Ute fields, as determined from conventional core and tied to its corresponding log response, helped identify reservoir and non-reservoir rock. Structure contour maps on the top of the upper Ismay zone and the Desert Creek zone, as well as isopach maps of the upper and lower Ismay zones for Little Ute and Sleeping Ute fields, respectively, showed carbonate buildup trends, facies distribution, defined limits of field potential, and also indicated possible horizontal drilling targets.

The diagenetic fabrics and porosity types found in the various hydrocarbon-bearing rocks of Little Ute and Sleeping Ute fields are indicators of reservoir flow capacity, storage capacity, and potential for horizontal drilling. The reservoir quality of Little Ute and Sleeping Ute fields has been affected by multiple generations of dissolution, anhydrite plugging, and various types of cementation which act as barriers or baffles to fluid flow. The Ismay zone in Little Ute and Sleeping Ute fields differed most dramatically from the Ismay zone in Cherokee field in Utah (figure 4), in that the most significant and unique diagenetic characteristic observed in thin sections from Cherokee field was intense, late-stage microporosity development along hydrothermal solution fronts (Chidsey and others, 2001b). This late-stage diagenetic overprint is not present in the Little Ute and Sleeping Ute fields of Colorado. Cross plots of permeability versus porosity data indicate the reservoir quality of the rocks in Little Ute and Sleeping Ute fields is most dependant on pore types, facies types, and diagenesis.

Based on these findings, two strategies for horizontal drilling are being developed for Little Ute and Sleeping Ute fields involving drilling stacked, parallel horizontal laterals (figure 39). Depositional facies are targeted in the Ismay zone of Little Ute and Sleeping Ute fields where, for example, multiple buildups can be penetrated with two opposed sets of stacked, parallel horizontal laterals (figure 39A). Similarly, a second strategy involves penetrating multiple zones of diagenetically enhanced reservoir intervals in these mound buildups (figure 39B).

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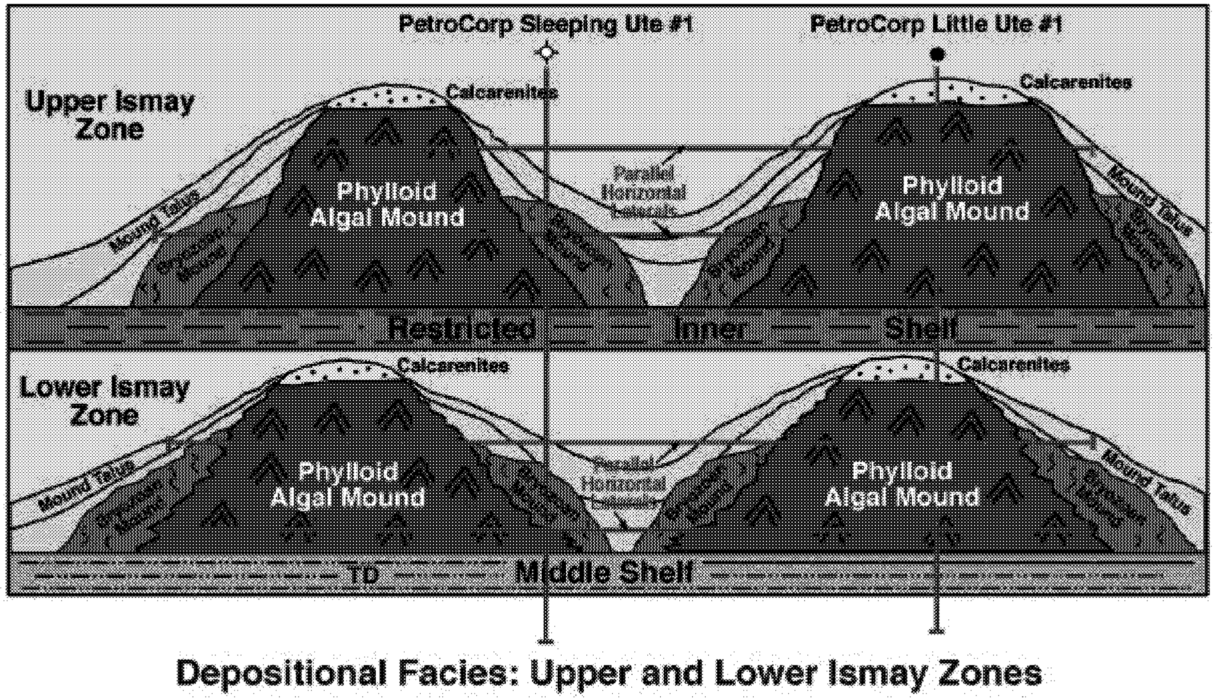
Core and petrophysical data were provided by PetroCorp, Inc. Jim Parker, Vicky Clarke, and Kevin McClure of the Utah Geological Survey drafted figures. Nicole Koenig assisted with maps. Technical oversight and support was provided by the Ute Mountain Ute Indian Tribe. The report was reviewed by David Tabet and Mike Hylland of the Utah Geological Survey. Cheryl Gustin, Utah Geological Survey, formatted the manuscript for publication.

A



B

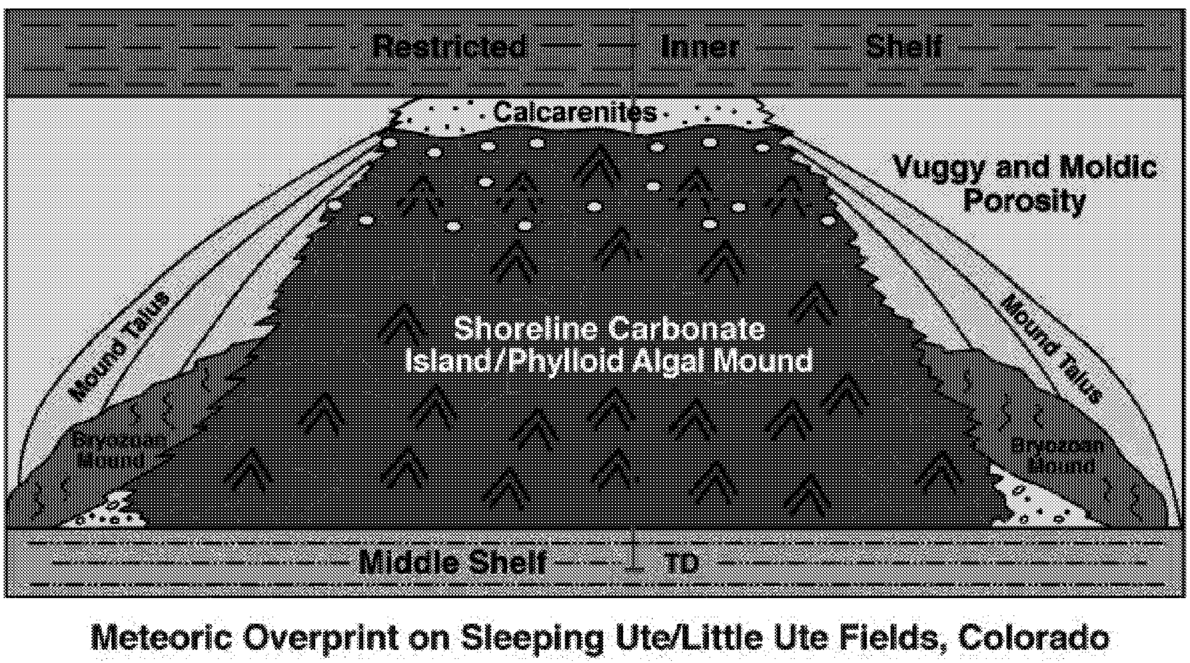


Figure 39. Strategies for horizontal drilling in the upper and lower Ismay zones of Sleeping Ute and Little Ute fields: (A) depositional facies, and (B) meteoric overprint within the shoreline carbonate island and upper phylloid-algal mound facies.

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