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

(Contract No. DE-2600BC15128)

DELIVERABLE 1.2.4
CARBON AND OXYGEN ISOTOPIC ANALYSIS: BUG, CHEROKEE, AND PATTERSON CANYON FIELDS, SAN JUAN COUNTY, UTAH

Submitted by

Utah Geological Survey
Salt Lake City, Utah 84114

December 2003

Contracting Officer's Representative

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DISCLAIMER

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INTRODUCTION

Over 400 million barrels (64 million m^3) of oil have been produced from the shallow-shelf carbonate reservoirs in the Pennsylvanian (Desmoinesian) Paradox Formation in the Paradox Basin, Utah and Colorado. With the exception of the giant Greater Aneth field, the other 100 plus oil fields in the basin typically contain 2 to 10 million barrels (0.3-1.6 million 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 from existing vertical development wells. In addition, horizontal drilling from existing wells minimizes surface disturbances and costs for field development, particularly in the environmentally sensitive areas of southeastern Utah and southwestern Colorado.

GEOLOGIC SETTING

The Paradox Basin is located mainly in southeastern Utah and southwestern Colorado with a small portion in northeastern Arizona and the northwestern most corner of New Mexico (figure 1). The Paradox Basin is an elongate, northwest-southeast trending evaporitic basin that predominately developed during the Pennsylvanian (Desmoinesian), about 330 to 310 million years ago (Ma). During the Pennsylvanian, a pattern of basins and fault-bounded uplifts developed from Utah to Oklahoma as a result of the collision of South America, Africa, and southeastern North America (Kluth and Coney, 1981; Kluth, 1986), or from a smaller scale collision of a microcontinent with south-central North America (Harry and Mickus, 1998). One result of this tectonic event was the uplift of the Ancestral Rockies in the western United States. The Uncompahgre Highlands in eastern Utah and western Colorado initially formed as the westernmost range of the Ancestral Rockies during this ancient mountain-building period. The Uncompahgre Highlands (uplift) is bounded along the southwestern flank by a large basement-involved, high-angle reverse fault identified from geophysical seismic surveys and exploration drilling. As the highlands rose, an accompanying depression, or foreland basin, formed to the southwest — the Paradox Basin. Rapid subsidence, particularly during the Pennsylvanian and then continuing into the Permian, accommodated large volumes of evaporitic and marine sediments that intertongue with non-marine arkosic material shed from the highland area to the northeast (Hintze, 1993). The Paradox Basin is surrounded by other uplifts and basins that formed during the Late Cretaceous-early Tertiary Laramide orogeny (figure 1).

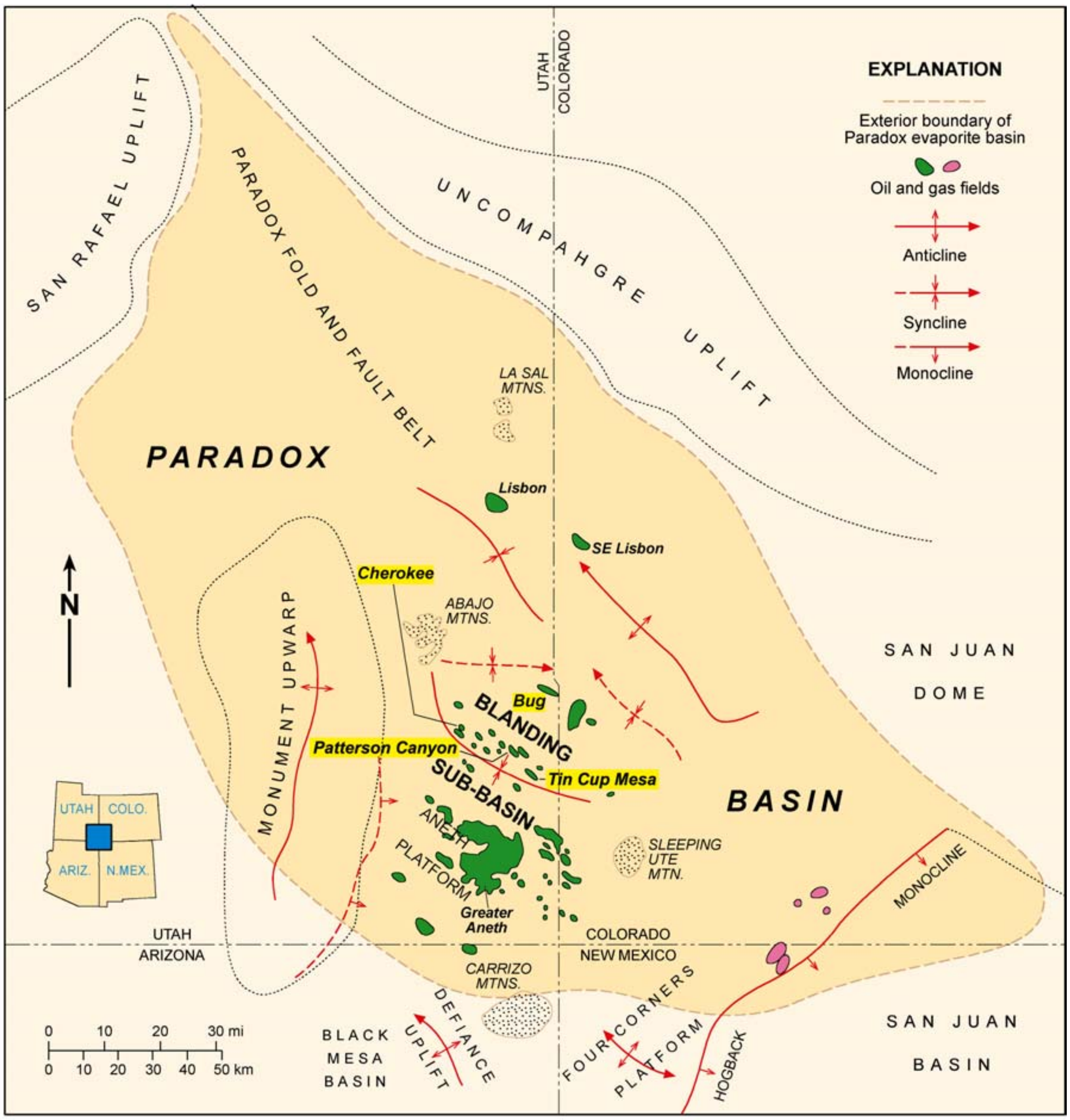


Figure 1. Location map of the Paradox Basin, Utah, Colorado, Arizona, and New Mexico showing producing oil and gas fields, the Paradox fold and fault belt, and Blanding sub-basin as well as surrounding Laramide basins and uplifts (modified from Harr, 1996).

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

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

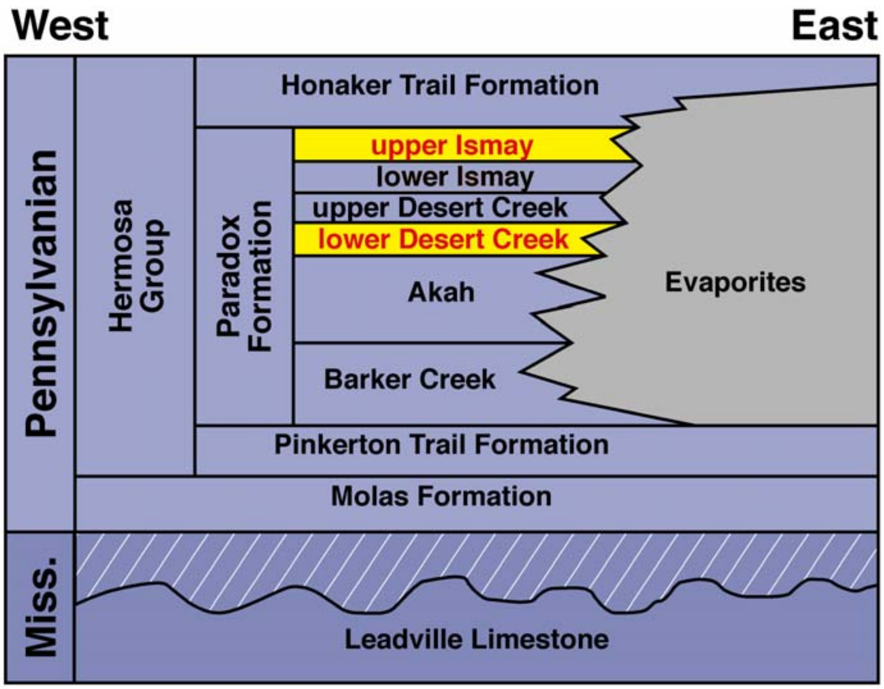
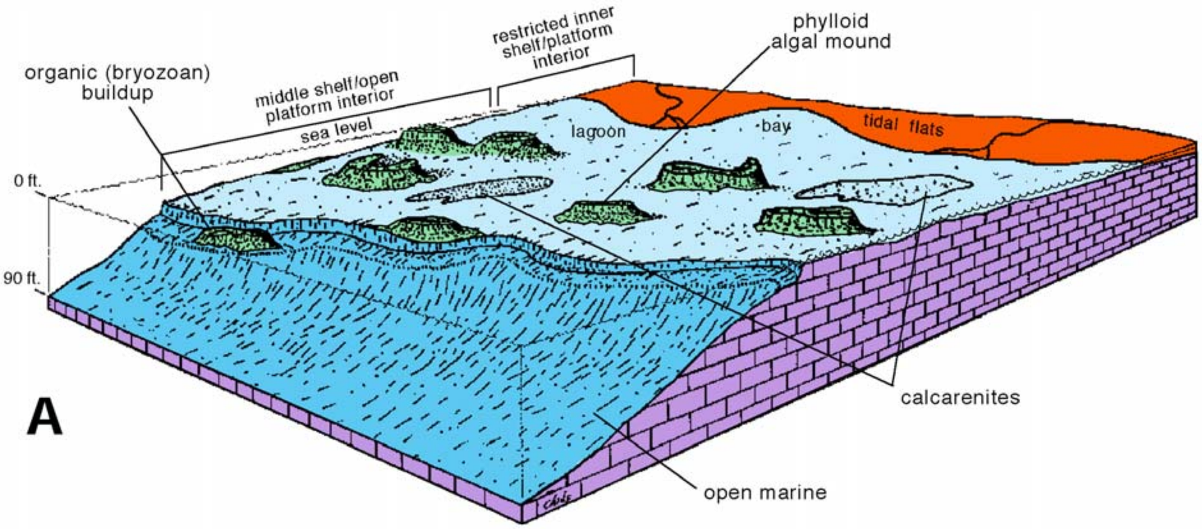


Figure 2. Pennsylvanian stratigraphy of the southern Paradox Basin including informal zones of the Paradox Formation; the upper Ismay and lower Desert Creek zones productive in case-study fields are highlighted.

CASE-STUDY FIELDS

Two Utah fields were selected for local-scale evaluation and geological characterization: Cherokee in the Ismay trend and Bug in the Desert Creek trend (figure 4). The diagenetic evaluation included basic isotopic analysis, stable carbon/oxygen, from selected samples from wells in these fields as well as Patterson Canyon and Tin Cup Mesa fields (figure 4), as summarized in this report.

This geological characterization focused on reservoir diagenesis, 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.



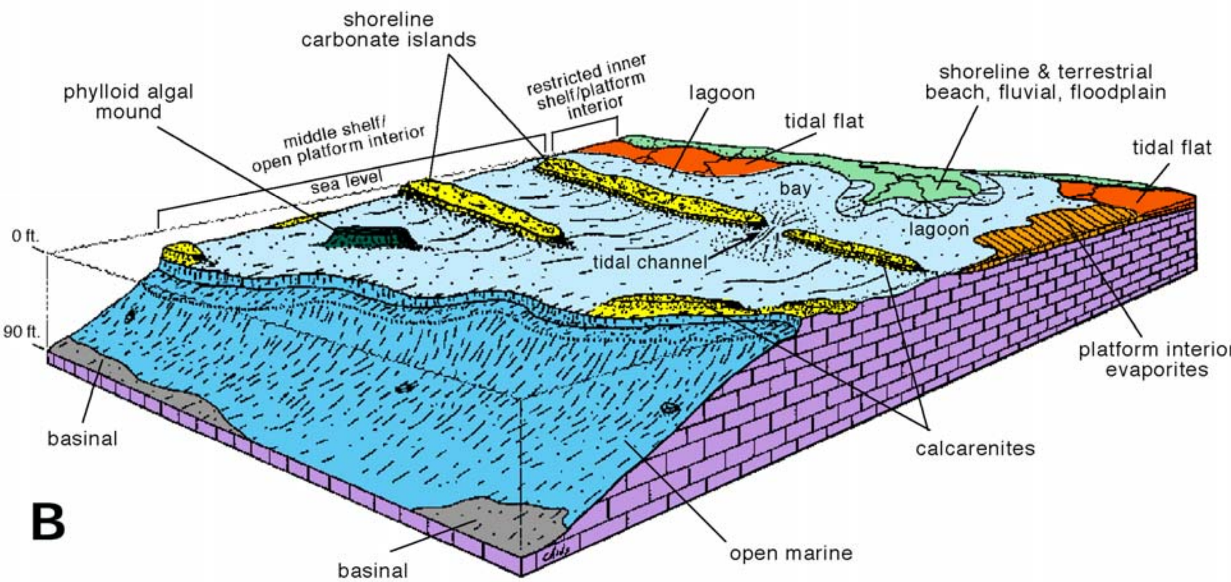


Figure 3. Block diagrams displaying major depositional facies, as determined from core, for the Ismay (A) and Desert Creek (B) zones, Pennsylvanian Paradox Formation, Utah and Colorado (tan and blue areas shown in figure 1).

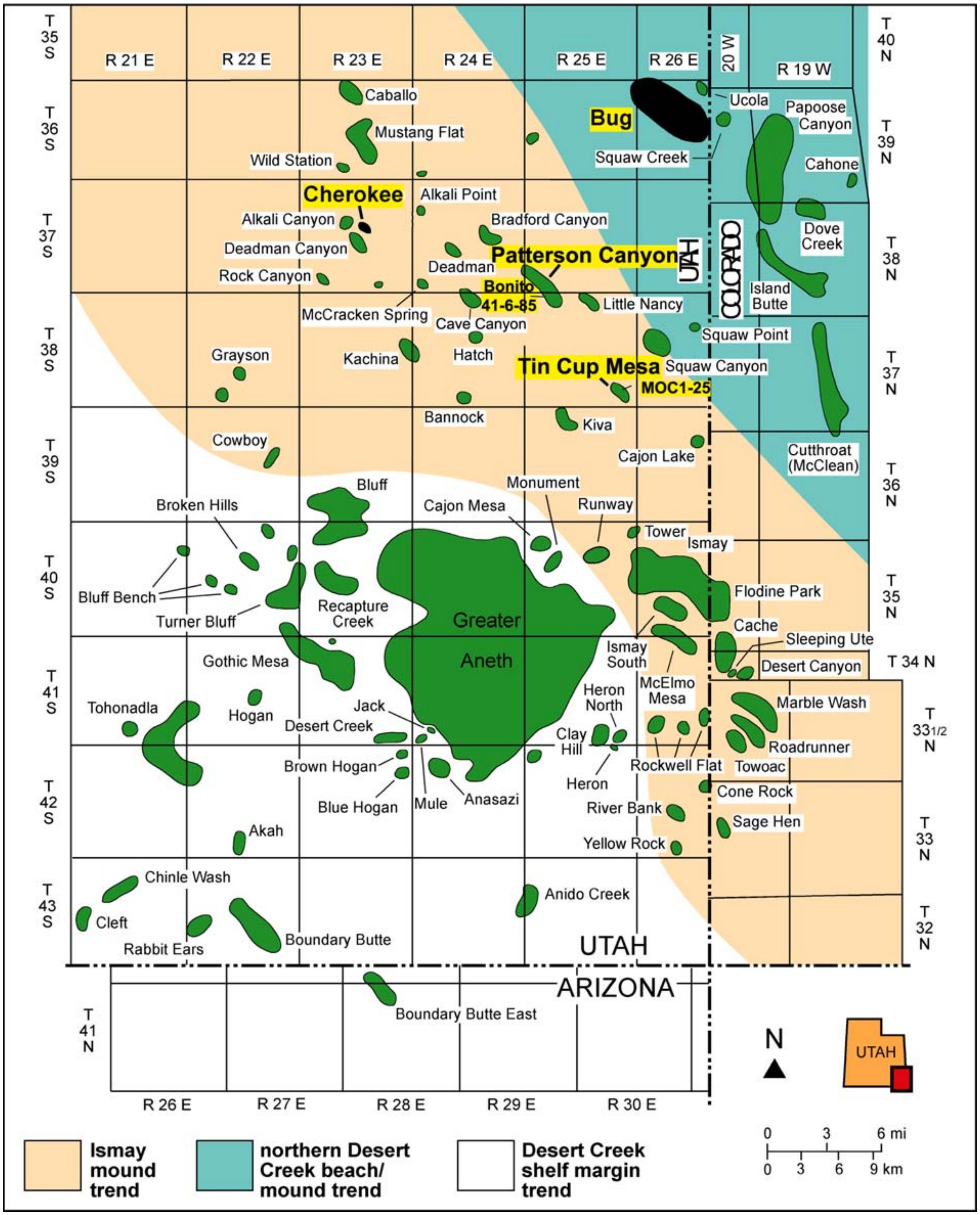


Figure 4. Map showing project study area and fields (case-study fields in black) within the Ismay and Desert Creek producing trends, Utah and Colorado. Fields sampled for isotope analyses are highlighted in yellow.

Cherokee Field

Cherokee field (figure 4) is a phylloid-algal buildup capped by anhydrite that produces from porous algal limestone and dolomite in the upper Ismay zone. The net reservoir thickness is 27 feet (8.2 m), which extends over a 320-acre (130 ha) area. Porosity averages 12 percent with 8 millidarcies (md) of permeability in vuggy and intercrystalline pore systems. Water saturation is 38.1 percent (Crawley-Stewart and Riley, 1993).

Cherokee field was discovered in 1987 with the completion of the Meridian Oil Company Cherokee Federal 11-14, NE1/4NW1/4 section 14, T. 37 S., R. 23 E., Salt Lake Base Line and Meridian (SLBL&M); initial potential flow (IPF) was 53 barrels of oil per day (BOPD) (8.4 m^3), 990 thousand cubic feet of gas per day (MCFGPD) (28 MCMPD), and 26 barrels of water (4.1 m^3). There are currently three producing (or shut-in) wells, one abandoned producer, and two dry holes in the field. The well spacing is 80 acres (32 ha). The present field reservoir pressure is estimated at 150 pounds per square inch (psi) (1,034 Kpa). Cumulative production as of June 1, 2003, was 182,071 barrels of oil (28,949 m^3), 3.65 billion cubic feet of gas (BCFG) (0.1 BCMG), and 3,358 barrels of water (534 m^3) (Utah Division of Oil, Gas and Mining, 2003). The original estimated primary recovery is 172,000 barrels of oil (27,348 m^3) and 3.28 BCFG (0.09 BCMG) (Crawley-Stewart and Riley, 1993). The fact that both these estimates have been surpassed suggests significant additional reserves could remain.

Bug Field

Bug field (figure 4) is an elongate, northwest-trending carbonate buildup in the lower Desert Creek zone. The producing units vary from porous dolomitized bafflestone to packstone and wackestone. The trapping mechanism is an updip porosity pinchout. The net reservoir thickness is 15 feet (4.6 m) over a 2,600-acre (1,052 ha) area. Porosity averages 11 percent in moldic, vuggy, and intercrystalline networks. Permeability averages 25 to 30 md, but ranges from less than 1 to 500 md. Water saturation is 32 percent (Martin, 1983; Oline, 1996).

Bug field was discovered in 1980 with the completion of the Wexpro Bug No. 1, NE1/SE1/4 section 12, T. 36 S., R. 25 E., SLBL&M, for an IPF of 608 BOPD (96.7 m^3), 1,128 MCFGPD (32 MCMPD), and 180 barrels of water (28.6 m^3). There are currently seven producing (or shut-in) wells, six abandoned producers, and two dry holes in the field. The well spacing is 160 acres (65 ha). The present reservoir field pressure is 3,550 psi (24,477 Kpa). Cumulative production as of June 1, 2003, was 1,622,2020 barrels of oil (257,901 m^3), 4.47 BCFG (0.13 BCMG), and 3,181,448 barrels of water (505,850 m^3) (Utah Division of Oil, Gas and Mining, 2003). Estimated primary recovery is 1,600,000 bbls (254,400 m^3) of oil and 4 BCFG (0.1 BCMG) (Oline, 1996). Again, since the original reserve estimates have been surpassed and the field is still producing, significant additional reserves likely remain.

ISOTOPIC GEOCHEMISTRY

Modification of rock fabrics and porosity within the lower Desert Creek and upper Ismay zones of the Blanding sub-basin study area is quite complex. Diagenesis played a major role in the development of reservoir heterogeneity in Bug, Cherokee, and Patterson Canyon fields as well as throughout the Paradox Formation fields. Diagenetic processes started during deposition and continued throughout burial history (figure 5). A complete discussion on the diagenetic history based upon visual core examination and thin section petrography is contained in separate deliverables (Deliverables 1.2.1 – Thin Section Descriptions, and 1.2.3 – Scanning Electron Microscopy and Pore Casting).

Stable isotope geochemistry has been used in recent years to provide insights into the chemical differences between preserved remnants of depositional components from various diagenetic events in carbonate rocks as recognized from core examination and thin section petrography. Figure 6 shows a graph of carbon versus oxygen isotope compositions for a range of carbonate rock types from various published sources as compiled by Roylance (1990). Broad fields of carbon and oxygen isotope compositions for various carbonate rock settings are indicated, including modern marine ("subsea") cements, various marine skeletons and sediments, deep-water ("pelagic") limestones, Pleistocene carbonates, and meteoric carbonates ("speleothems and veins").

Previous Work

The only previously published isotope composition data for lower Desert Creek rocks for the project area was completed at the Marathon Petroleum Technology Lab in Littleton, Colorado for the M.S. thesis work of Roylance (1984). That data and the location of the wells sampled can be seen in tables 1 and 2, and figures 7 and 8. Brinton (1986) collected and interpreted a robust data set of carbon and oxygen isotopes (84 samples) from four cores in Ismay field, Utah and Colorado, which is outside the project area. Comments about the general isotopic ranges of various diagenetic rock components within the Ismay zone in cores from Ismay and Greater Aneth fields (outside of the Blanding sub-basin project area) have been published by Dawson (1988).

Methodology

Isotopic composition analyses for carbon and oxygen were completed for a variety of whole rock and diagenetic phases for core samples from the lower Desert Creek zone from Bug field and the upper Ismay zone from Cherokee field (tables 1, 3, and 4, and appendix). In addition, a series of samples from whole rock, dolomite, and various cement generations were selected from an upper Ismay buildup in a recently drilled well at Patterson Canyon field (the Samedan Bonito No. 41-6-85, completed in July 2002) containing well-cemented oolitic beds and phylloid-algal mound fabrics (table 5). Figure 4 shows the location of the fields or well names sampled for isotope geochemistry. Individual samples were collected as powdered rock using a Dremel drill equipped with precision bits. All analyses were completed at the Brigham Young University (BYU) Geology Department Stable Isotope Laboratory, Provo, Utah. The internal standard used in the BYU lab is the UCLA Carrara marble. The accepted values for this internal standard were matched consistently during the analysis of the Paradox core samples selected for this study. All isotopic compositions are reported relative to PeeDee Belemnite (PDB) (see Land, 1980, figure 6 for definition relative to SMOW).

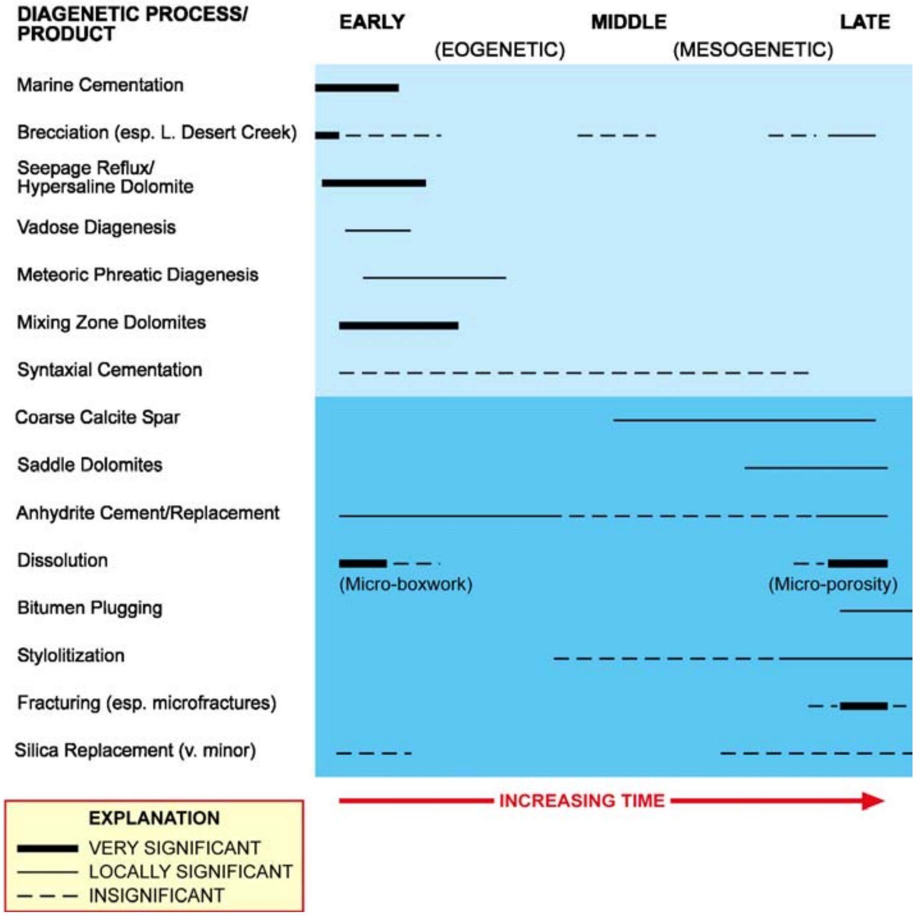


Figure 5. Diagenetic sequence diagram for Bug and Cherokee fields.

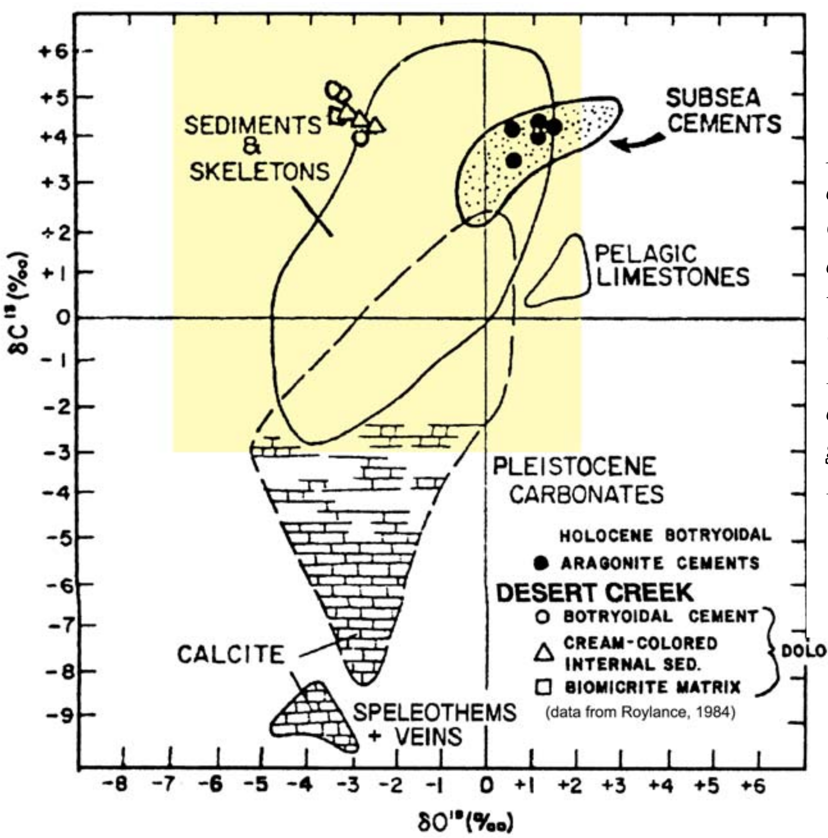


Figure 6. Graph of carbon versus oxygen isotope compositions. Other compositional facies compiled from various published work (modified from James and Ginsburg, 1979 by Roylance, 1990). The yellow area in this cross plot is the same part of the graph shown in figures 8, 10, 11, 14, and 16 of this study.

Table 1. Location of cores used in the isotope geochemistry study.

Zones	Well Name	Location
Lower Desert Creek	*Wexpro May-Bug 2 (this study)	NE1/4 SW1/4 Sec. 7, T36S, R26E UT
	*Wexpro Bug 4 (this study)	NE1/4 SW1/4 Sec. 16, T36S, R26E UT
	*Wexpro Bug 13 (Roylance, 1984)	NE1/4 NW1/4 Sec. 17, T36S, R26E UT
	*Wexpro Bug 16 (Roylance, 1984)	NE1/4 SW1/4 Sec. 17, T36S, R26E UT
	MOC Tin Cup Mesa 1-25	SW1/4 NW1/4 Sec. 25, T38S, R25E UT
Upper Ismay	†Cherokee 22-14 (this study)	SE1/4 NW1/4 Sec. 14, T38S, R23E UT
	†Cherokee 33-14 (this study)	NE1/4 NW1/4 Sec. 14, T38S, R23E UT
	Samedan Bonito 41-6-85 (this study)	NE 1/4 NE1/4 Sec. 6, T38S, R25E UT

*Well locations are shown in figure 7
†Well locations are shown in figure 13

Table 2. Previous stable carbon and oxygen isotope data from lower Desert Creek zone, Bug and Tin Cup Mesa fields (analyses from Roylance, 1984).

Sample Groups:	del 13C	del 18O
BUG FIELD - Lower Desert Creek Cores Dolomitized Whole Rock Matrix (biomicrite in algal bafflestone)		
Bug 13: 5940.7'C	+4.7	-3.3
Dolomitized Internal Sediment (within phylloid-algal bafflestone)		
Bug 13: 5939.3'A	+4.4	-2.9
Bug 13: 5940.7'A	+4.3	-2.5
Bug 16: 6313.4'A	+4.8	-3.3
Dolomitized Botryoidal Cements		
Bug 13: 5939.3'B	+5.0	-3.3
Bug 13: 5940.7'B	+4.0	-2.9
Bug 16: 6313.4'B	+5.2	-3.4
TIN CUP MESA FIELD - Lower Desert Creek Cores Limestone Whole Rock Matrix (calcite fraction [micrite and crinoid, bryozoan and brachiopod fragments] of dolomitized bioclastic wackestone)		
Tin Cup Mesa #1-25: 5667' calcite	+0.9	-3.3
Dolomite Fraction of Whole Rock Matrix (dolomitized micrite matrix of bioclastic wackestone)		
Tin Cup Mesa #1-25: 5667' dolomite	+0.9	-1.6

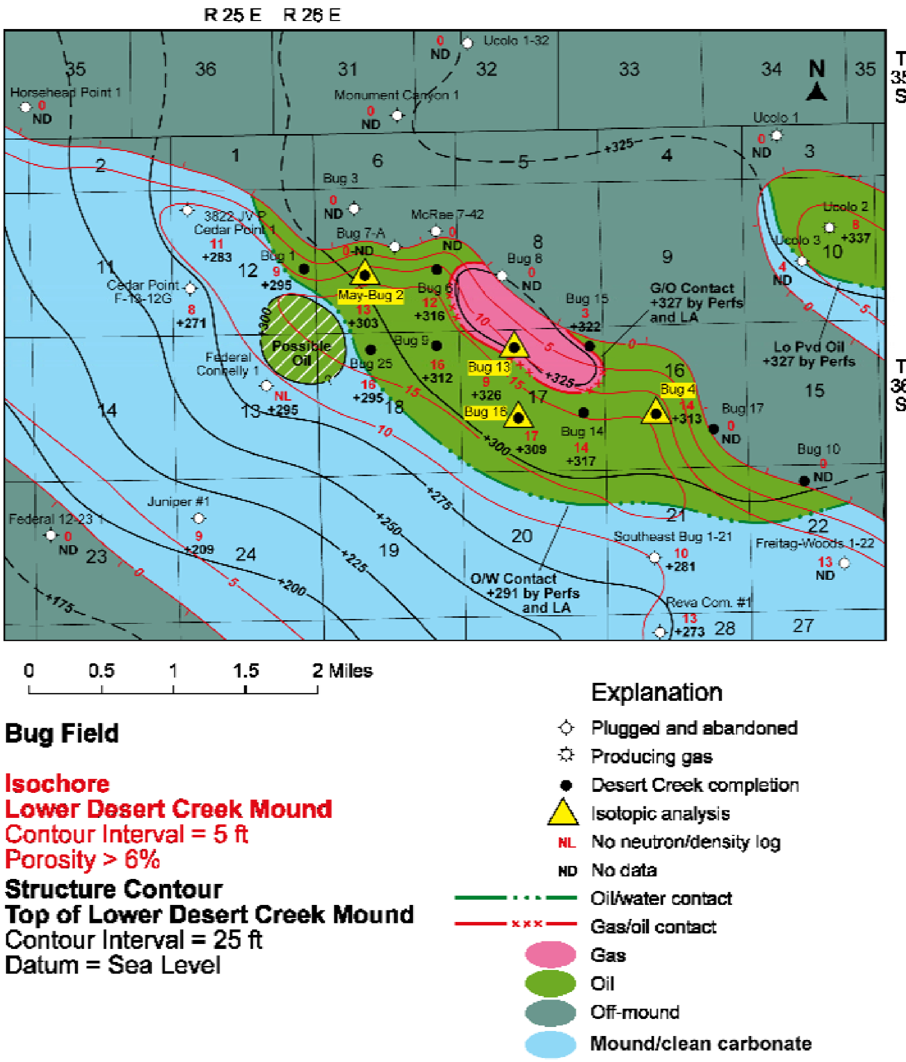


Figure 7. Map of combined top of structure and isochore of lower Desert Creek zone mound, Bug field, San Juan County, Utah. Well cores used for isotope sampling for this study are highlighted with a yellow triangle.

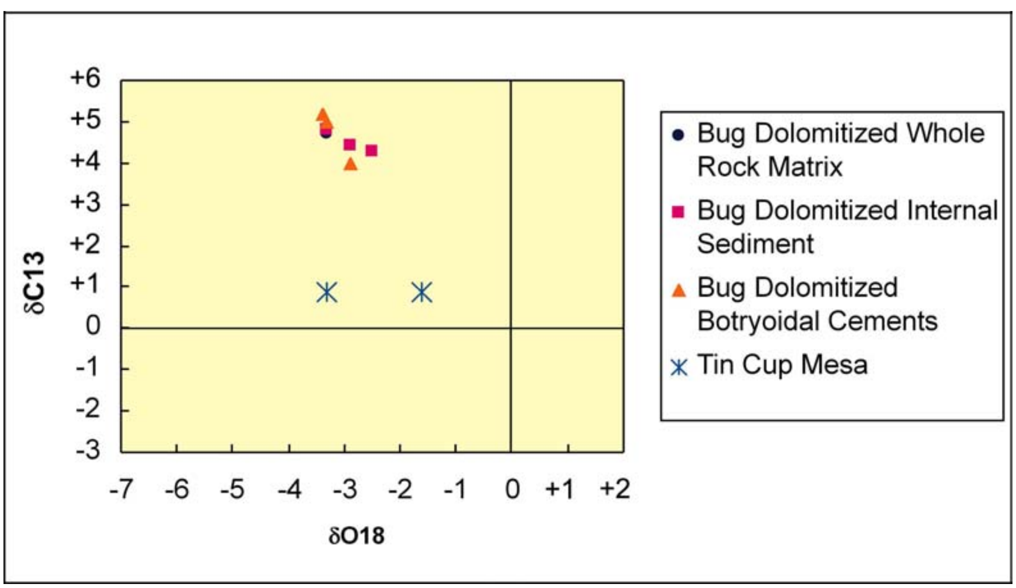


Figure 8. Graph of carbon versus oxygen compositions for Bug and Tin Cup Mesa fields determined by Roylance, 1984.

Table 3. New stable carbon and oxygen isotope data from the lower Desert Creek zone dolomites, Bug field.

Sample Groups:	del 13C	del 18O
BUG FIELD - Lower Desert Creek Cores		
Whole Rock Dolomite		
May Bug 2: 6304'A (phylloid-algal mound & marine sediment)	+4.49	-4.72
May Bug 2: 6315' B (phylloid-algal mound fabric)	+4.03	-4.42
Dolomitized Internal Sediment (cream-colored)		
May Bug 2: 6304'B	+4.30	-4.50
May Bug 2: 6315'A	+4.16	-4.15
May Bug 4: 6297.4'B	+4.52	-4.67
Dolomitized Micro-Boxwork Fabric (probably botryoidal cements)		
May Bug 2: 6304'C	+4.40	-4.56
May Bug 4: 6289.7'	+4.77	-4.58
May Bug 4: 6297.4'A	+4.76	-4.46

Table 4. New stable carbon and oxygen isotope data from the upper Ismay zone, Cherokee field.

Sample Groups:	del 13C	del 18O
CHEROKEE FIELD - Upper Ismay Cores		
Whole Rock		
Cherokee 22-14: 5827.7' (mostly dolomite, w/ moldic porosity)	+5.41	-2.90
Cherokee 22-14: 5836.8' (limestone; phylloid-algal mound fabric)	+5.02	-4.55
Cherokee 33-14: 5781.2'A (mostly dolomite)	+4.67	-6.08
Micro-Porous Dolomite Zones (often w/ pyrobitumen)		
Cherokee 22-14: 5768.7'	+3.57	-2.92
Cherokee 33-14: 5781.2'B	+4.85	-4.54

Table 5. New stable carbon and oxygen isotope data from the upper Ismay zone buildup, Samedan Bonito No. 41-6-85 core.

Sample Groups:	del 13C	del 18O
Whole Rock (dolomitized oolite)		
Bonito 41-6-85: 5544'A	+4.53	-5.10
Dolomitized Cements (in oolite)		
Bonito 41-6-85: 5544'B	+4.51	-5.15
Calcite Cements (within phylloid-algal buildup)		
Bonito 41-6-85: 5592'A (black cement)	+6.30	-5.10
Bonito 41-6-85: 5592'B (gray cement)	+5.67	-5.68
Bonito 41-6-85: 5592'C (brown cement ? w/sediment?)	+5.56	-5.87
Bonito 41-6-85: 5592'D (white cap cement; no sediment)	+5.73	-5.05
Bonito 41-6-85: 5592'E (coarse blocky cement)	+5.69	-6.41

Carbon and Oxygen Isotopes from Lower Desert Creek Dolomites

Isotopic composition analyses for carbon and oxygen were completed for a variety of whole rock and diagenetic phases for core samples from the lower Desert Creek dolomite interval from Bug field (table 1, figure 7). Values obtained in this project were compared to stable carbon and oxygen isotopic measurements reported by Roylance (1984, 1990), and included in this report in figure 8 and table 2. A total of eight powdered samples were drilled from core samples from two Bug field wells and analyzed (table 3). The samples were selected to analyze dolomitized phylloid-algal mound fabrics and breccias, cream-colored dolomitized internal sediments, and dolomitized void-filling cements (mostly botryoids and blunt-ended fibrous fans). Annotated close-up core photos (figure 9) show the approximate locations of the drilled and powdered samples from the May Bug No. 2 and Bug No. 4 wells. A plot of carbon versus oxygen compositions for all Bug field samples obtained in this study is shown on figure 10 (see also table 3). Comparison of the new data with previously reported Bug field isotope compositions (Roylance, 1984, 1990) is shown in figure 10.

Carbon isotopic compositions for the eight Bug field dolomite samples (figure 10) all cluster very close around a mean value of +4.43‰ PDB (range of +4.03 to +4.77‰). Interestingly, the range for del ^{13}C values is slightly higher for the Bug 4 well (+4.03 to +4.77‰) than for the May Bug No. 2 well (+4.52 to +4.77‰), although their means (+4.28 versus 4.68‰) may not be significantly different. The carbon isotope values for Bug field dolomites are remarkably similar for all the rock components analyzed, including "whole rock" samples from the phylloid-algal mound fabrics and associated marine sediments, internal sediments within shelter pores, and early cements lining original pores. The mean value of del ^{13}C for all Bug field samples in this study is also very close to the mean of +4.6‰ (range of +4.0 to +5.2‰) for seven samples from two other Bug field cores (Bug No. 13 and Bug No. 16) analyzed by Marathon's lab (see table 3, p. 125 in Roylance, 1984; see figure 8). Despite dolomitization, all of the lower Desert Creek samples from Bug field analyzed in this project and by Marathon show carbon isotope compositions that are very close in value to modern marine carbonates ("sediments and skeletons" on figure 6) and Holocene botryoidal marine aragonite cements (James and Ginsburg, 1979; "subsea cements" on figure 6). Furthermore, carbon isotopic compositions for former aragonite marine cements from the Late Permian Capitan Reef complex in southeastern New Mexico are calculated to be about +5.3‰ by Given and Lohmann (1985). Hence, it appears that the carbon isotope geochemistry of all of the lower Desert Creek dolomites at Bug field have retained a strong influence from Pennsylvanian marine water composition. Meteoric waters, which typically would tend to lower the carbon isotope values significantly (Hudson, 1975), do not appear to have had any effect on the composition of these lower Desert Creek dolomites.

Oxygen isotopic compositions for the eight Bug field dolomite samples (figure 10 and table 3) also cluster in a very narrow range around a mean value of -4.51‰ PDB (range of -4.15 to -4.72‰). There is no significant difference in oxygen values between the two Bug wells studied. However, the oxygen compositions in the dolomites sampled here for May Bug No. 2 and Bug No. 4 are significantly different from the values reported by Roylance (1984, 1990) for seven samples processed from the same stratigraphic interval in the Bug No. 13 and Bug No. 16 wells (figure 10, table 2). The mean oxygen isotopic composition for the latter wells is -3.1‰ PDB (range of -2.5 to -3.4‰). Thus, the oxygen values in the May Bug No. 2 and Bug No. 4 cores are more negative by nearly 1.5‰. The oxygen isotopic composition data from Bug No. 13 and Bug No. 16 cores, which are situated near the center of the Bug field buildup (figure 7), are rather close to the values for modern marine carbonates ("sediments and skeletons" on figure 6) and to values inferred for unaltered Pennsylvanian marine cements (Lohmann, 1983).

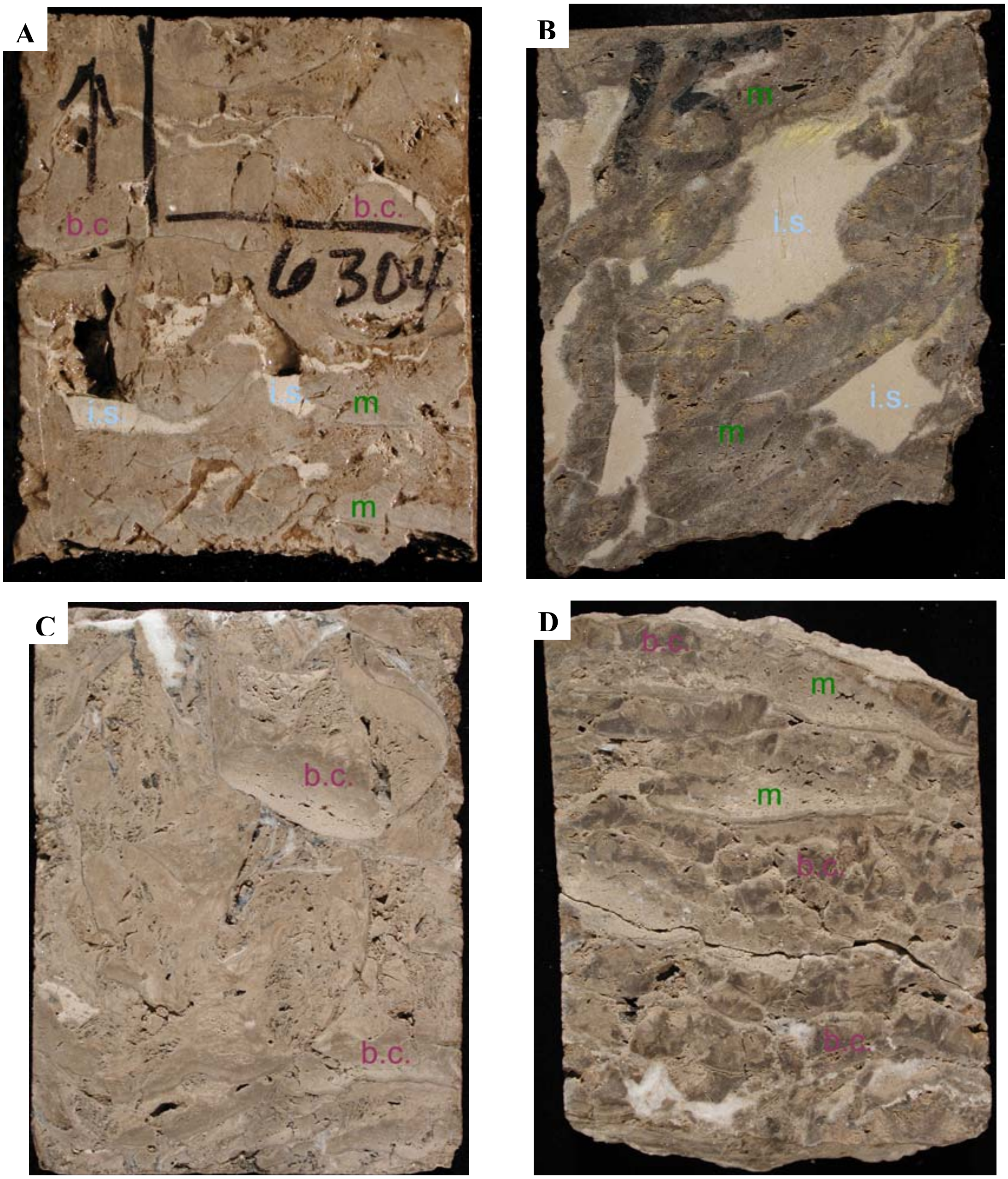


Figure 9. Core photos of typical Bug field components sampled for stable carbon and oxygen isotope analysis. (A) May Bug No. 2: 6,304 feet - the "whole rock" dolomitized phylloid-algal mound fabric (m; sample 6,304' A) in medium gray, the dolomitized cream-colored internal sediment (i.s.; sample 6,304' B), and dark gray dolomitized botryoidal cements (b.c.; sample 6,304' C) as well as associated micro-box-work fabric were sampled for isotopic analysis. (B) May Bug No. 2: 6,315 feet - both the "whole rock" dolomitized phylloid-algal mound fabric (m; sample 6,315' B) in dark gray and the dolomitized cream-colored internal sediment (i.s.; sample 6,315' A) were sampled for isotopic analysis. (C) Bug No. 4: 6,289.7 feet - dolomitized, dark gray botryoidal cements (b.c.; sample 6,289.7 feet) displaying micro-box-work fabric were sampled for isotopic analysis. (D) Bug No. 4: 6,297.5 feet - "whole rock" dolomitized phylloid-algal mound fabric (m; sample 6,297.5' B) and dark gray dolomitized botryoidal cements (b.c.; sample 6,297.5' A) as well as associated micro-box-work fabric were sampled for isotopic analysis.

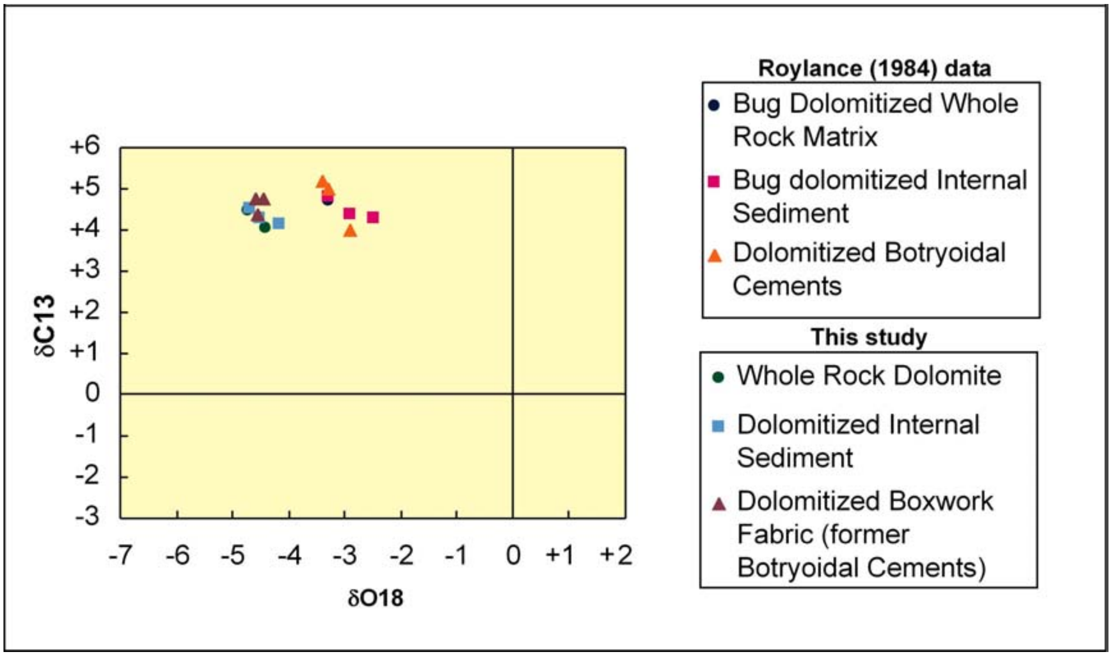


Figure 10. Graph comparing carbon versus oxygen compositions for Bug field dolomites by Roylance (1984) versus those completed for this study.

Oxygen isotopic compositions for former aragonite and magnesium calcite marine cements from the Late Permian Reef complex in southeastern New Mexico are calculated to be between –2.8 and -2.5‰ by Given and Lohmann (1985, 1986). The lighter oxygen values obtained from samples in the May Bug No. 2 and Bug No. 4 cores, which are located along the margins or flanks of Bug field (figure 7), may be indicative of exposure to higher temperatures, to fluids depleted in ^{18}O relative to sea water, or to hypersaline waters (Land, 1980, 1982) during burial diagenesis. It is also interesting to note that the two wells with the lightest oxygen isotope compositions in the lower Desert Creek dolomites (May Bug No. 2 and Bug No. 4) have produced significantly greater amounts of hydrocarbons. Production through May 2003 is 340,562 BO (54,149 m^3) and 0.76 BCFG (0.02 BCMG) for May Bug No. 2, and 236,248 BO (37,563 m^3) and 0.48 BCFG (0.01 BCMG) for Bug 4, while Bug No. 13 and Bug No. 16 have produced only 86,786 BO (13,799 m^3) and 0.4 BCFG (0.01 BCMG), and 24,385 BO (3,877 m^3) and 0.84 BCFG (0.02 BCMG), respectively (Utah Division of Oil, Gas and Mining, 2003). The gross productive lower Desert Creek reservoir zone within each of these wells is less than 20 feet (6 m) thick. Clearly, there are economically significant changes in the reservoir quality and the diagenetic history between these well pairs.

Two samples of regional, non-reservoir, open-marine lower Desert Creek zone from Tin Cup Mesa field were analyzed by Marathon's lab for carbon and oxygen isotope composition (MOC No. 1-25 well; figure 4, table 2). The isotopic values for these samples (a limestone and a dolomite) are significantly different from the Bug field reservoir dolomites (figure 8 and 11). The biggest difference is the much lighter (by greater than 3‰) carbon isotope compositions in the Tin Cup Mesa lower Desert Creek samples than at Bug field. For oxygen isotope composition, the limestone (calcite fraction) is significantly heavier (at -1.6‰ PDB) than either the dolomite sample in the Tin Cup Mesa sample (at –3.3‰ PDB) or the mean values in the two different Bug field dolomite data sets (-3.1‰ for the two poor wells and –4.51‰ for the two excellent wells).

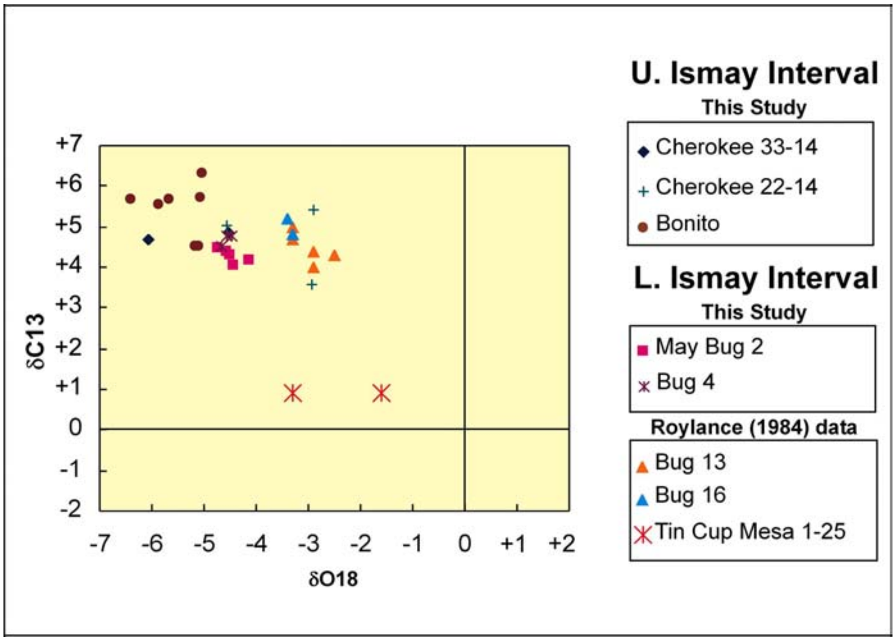


Figure 11. Summary graph of carbon versus oxygen compositions for all components sampled for this study and previously published data by Roylance (1984).

Carbon and Oxygen Isotopes from the Upper Ismay Zone of Cherokee Field

Isotopic composition analyses for carbon and oxygen were completed for a variety of whole rock and diagenetic phases for core samples from the upper Ismay zone in Cherokee field (figures 4 and 12; table 1). A total of five powdered samples were drilled from core samples of the two cored, upper Ismay wells at Cherokee field and were analyzed (table 3). The samples were selected to analyze typical dolomitized calcarenite (bioclastic grainstone), limestone phylloid-algal fabric, dolomitized cryptalgal (stromatolitic) laminites, and microcrystalline, microporous dolomite. Annotated close-up core photos (figure 13) show the approximate locations of the drilled and powered samples from the Cherokee No. 22-14 and Cherokee No. 33-14 wells. A plot of carbon versus oxygen compositions for all Cherokee field samples obtained in this study is shown on figure 14 (see also table 4).

Carbon isotopic compositions for the five upper Ismay dolomite samples from Cherokee field (figure 14) have a mean value of +4.70‰ PDB (range of +3.57 to +5.11‰). Although the mean carbon isotopic composition appears to be higher in the upper Ismay carbonate samples from Cherokee field than in the lower Desert Creek dolomites at Bug field, the values are not distinguishable at the 95 percent confidence level (t-test). In addition, the limestone (calcite) sample from representative phylloid-algal mound fabrics displays a del ^{13}C value within the same range as the dolomite samples (table 4). Brinton (l986, p. 217-218) reported a possible mean marine del ^{13}C value of +3.9‰ PDB during the time of Ismay deposition from analysis of unaltered brachiopods from Ismay field core. Carbon isotopic compositions for former aragonite marine cements from the Late Permian Capitan Reef complex in southeastern New Mexico are about +5.3‰ (Given and Lohmann, 1985). This may suggest that the fluids responsible for upper Ismay carbonates within Cherokee field, have slightly heavier carbon isotope compositions than marine brachiopods at Ismay field, or slightly lighter than late Paleozoic seawater. But as with the Bug field dolomite samples, the Cherokee field carbonates fall within the same range of carbon isotope compositions as modern marine sediments, skeletons, and marine cements (see figure 6).

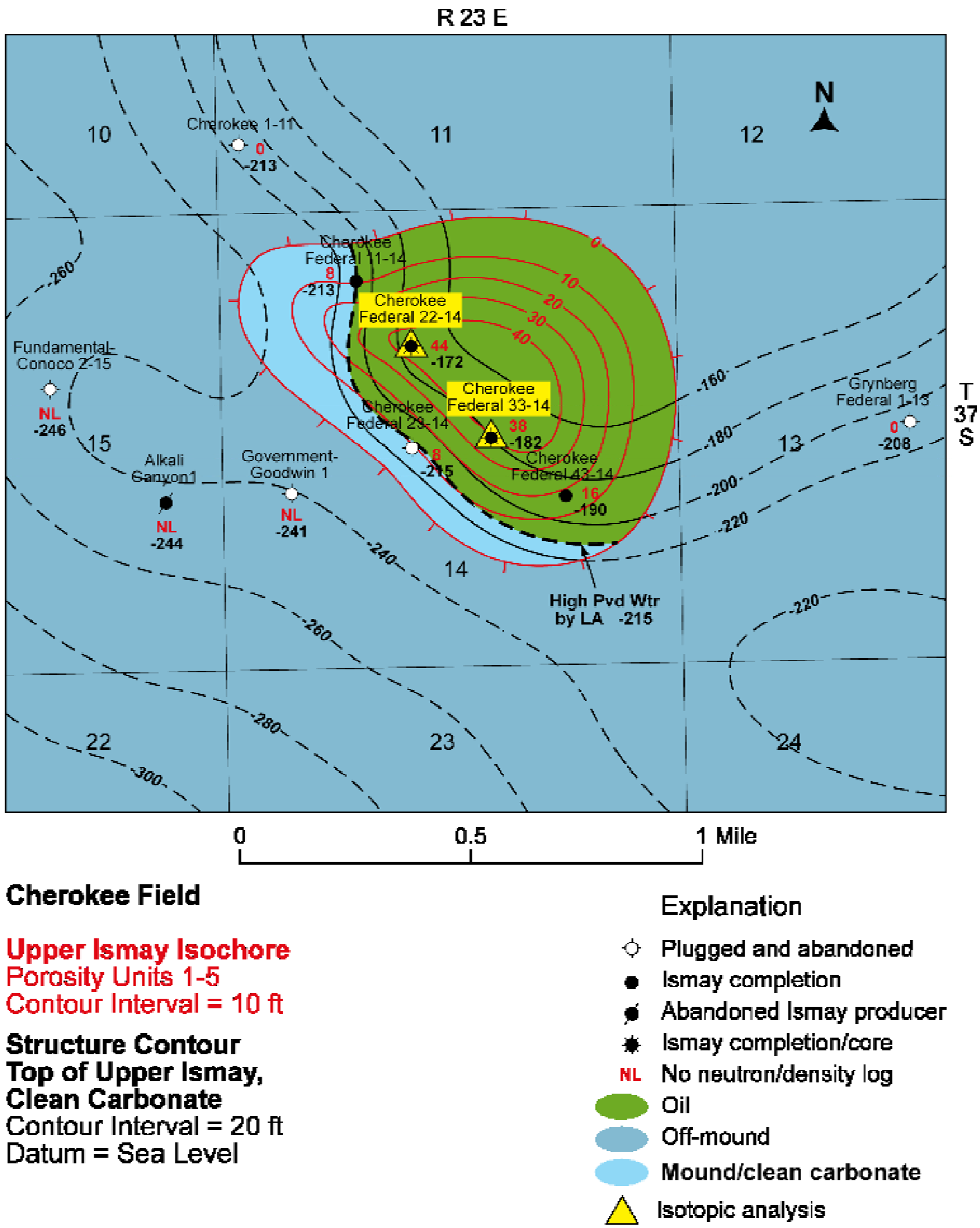
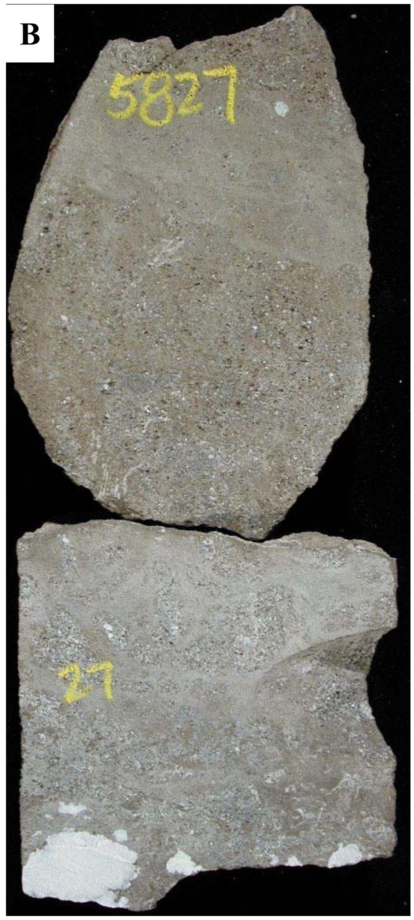


Figure 12. Map of combined top of "clean carbonate" structure and isochore of porosity units 1 through 5, upper Ismay zone, Cherokee field, San Juan County, Utah. Well cores used for isotope sampling for this study are highlighted with a yellow triangle.



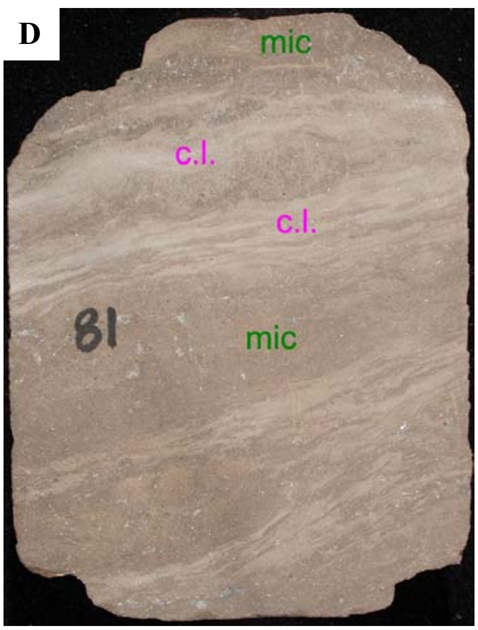


Figure 13. Core photos of typical Cherokee field components sampled for stable carbon and oxygen isotope analysis. (A) Cherokee No. 22-14: 5,768.7 through 5,769.2 feet - microporous dolomite surrounded by black pyrobitumen was sampled at 5,768.7 feet for isotopic analysis. (B) Cherokee No. 22-14: 5,827 feet - a "whole rock" sample of dolomitized calcarenite (bioclastic grainstone) was drilled at 5,827.7 feet for isotopic analysis. There is significant moldic porosity present in this interval. (C) Cherokee No. 22-14: 5,837 feet - a "whole rock" limestone sample of phylloid-algal mound fabric was drilled at 5,826.8 feet for isotopic analysis. (D) Cherokee No. 33-14: 5,781 feet - both the "whole rock" dolomitized cryptalgal laminite (c.l.; sample 5,781.2' A) and microporous dolomite (mic; sample 5,781.2' B) were sampled for isotopic analysis.

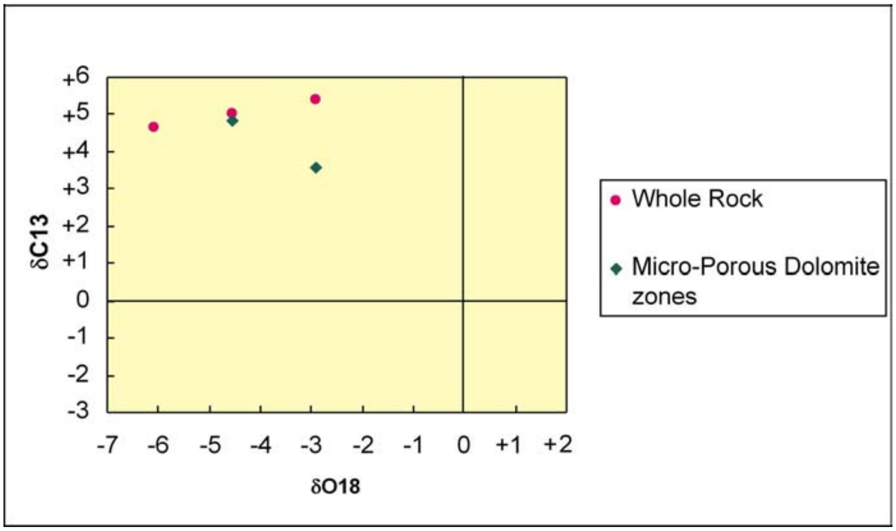


Figure 14. Graph of carbon versus oxygen compositions for Cherokee field components completed for this study.

The del ^{13}C values of the Cherokee field upper Ismay components overlap or are slightly heavier than any of the diagenetic components reported by Dawson (1988) in Ismay field for meteoric-phreatic cements (del ^{13}C = +2.5 to +4.8‰), and are uniformly heavier than either deep burial ferroan calcite cements (del ^{13}C = +1.8 to +3.2‰) or saddle dolomites (mean del ^{13}C = +3.4‰). The range of del ^{13}C values at Cherokee field has a better overlap with values reported from marine botyroidal-fibrous (marine) cements and "neomorphosed matrix sediments" in Ismay field cores (Brinton, 1986) that range between +4.2 to +5.0‰. In addition, Brinton (1986, figure 62) shows that various forms of microcrystalline dolomite in Ismay field have isotopic values that cluster between +3.0 and +6.0‰ for del ^{13}C. As with the lower Desert Creek dolomites in Bug field, it does not appear that meteoric waters, which typically would precipitate carbonates with more depleted carbon isotope values, have had major effects on the composition of the Ismay carbonate components in Cherokee field. Rather, it is likely that most of the carbonates present within Ismay carbonates (as well as throughout the lower Desert Creek) have retained a marine-influenced isotope geochemistry throughout marine cementation as well as through post-burial recycling of marine carbonate components during dolomitization, stylolitization, dissolution, and late cementation. Such an explanation is in agreement with the model for the positive carbon isotope values of many ancient carbonates proposed by Hudson (1975).

Oxygen isotopic compositions for the Cherokee field limestone and dolomite samples (figure 14 and table 4) form a wide range of values around a mean value of -4.20‰ PDB (range of –2.90 to –6.08‰). As with the carbon isotope data, there is no significant difference between the oxygen isotope compositions from lower Desert Creek dolomite samples in Bug field and the upper Ismay limestones and dolomites from Cherokee field. There is no apparent pattern in the Cherokee field del ^{18}O values other than the deeper samples contain the more depleted (more negative) values. However, the range of values is probably too wide to suggest a depth-related temperature increase for the lowered del ^{18}O values. A similar range of del ^{18}O values was reported by Dawson (1988) from a variety of cement generations from Ismay field cores. Only very late ferroan calcites and baroque dolomites in Dawson's (1988) data displayed more negative oxygen isotope compositions than the Cherokee field limestones and dolomites.

Brinton (l986, p. 217-218) reported a possible mean marine del ^{18}O value of –4.7‰, during the time of Ismay deposition, from analysis of unaltered brachiopods from Ismay field core. This proposed Ismay marine value is very close to two of the Cherokee field values (see table 4), and to the mean value of all the samples. However, two of the samples (at –2.90 and –

2.92‰) are significantly heavier than Brinton's marine del ^{18}O value calculated from unaltered marine fossils. They are closer to Given and Lohmann's (1985, 1986) marine diagenesis as determined from former aragonite and magnesium calcite marine cements in the Captian Reef. These heavier del ^{18}O samples (both dolomites) contain oxygen values similar to two cement-filled crinoids and many of the microcrystalline dolomites analyzed by Brinton (1986). One of the dolomitized samples in Cherokee field, from cryptalgal laminites, has a much lighter oxygen composition (-6.08‰). Only certain saddle dolomite cements, late equant calcite spars, and neomorphosed calcites commonly had such light compositions in Brinton's (1986) work on Ismay field cores. The depleted del ^{18}O value of this one dolomite sample (Cherokee No. 33-14: 5,781.2' A [1,762 m]) suggests neomorphism, cementation, and/or dolomitization from warm or isotopically light subsurface waters.

Carbon and Oxygen Isotopes from an Upper Ismay Buildup, Patterson Canyon Field

Carbon and oxygen isotopic analysis was completed on various whole rock and diagenetic cement generations from the upper Ismay oolite/phylloid-algal buildup along the southwest margin of Patterson Canyon field (figure 4, table 1). The Samedan Bonito No. 41-6-85 well cored approximately 25 feet (8 m) of very well-cemented, phylloid-algal mound limestone (a "reef wall" at the margin of the Patterson Canyon phylloid-algal reservoir) and 31 feet (10 m) of overlying tight oolitic and pelloidal calcarenites. Two samples were drilled from core near the top of the oolitic grainstone section, and five samples were drilled from the cements near the base of the well-cemented mound section. Annotated close-up core photos (figure 15) show the approximate locations of the drilled and powdered samples from the oolite and "reef cementstone" interval selected in the Bonito No. 41-6-85 well. This particular core was analyzed, despite its location outside of either of the two project fields (Bug and Cherokee) because of the spectacular development of cements that display visual characteristics suggesting different generations of development, most of which appear to have been early, or prior to significant burial. A plot of carbon versus oxygen compositions for all Samedan Bonito No. 41-6-85 limestone samples obtained in this study is shown on figure 16 (see also table 5).

Carbon isotopic compositions for the seven upper Ismay limestone samples in the core from the cemented buildup in Patterson Canyon field have a mean value of +5.43‰ PDB (range of +4.51 to +6.30‰). These values are distinguishable at the 95 percent confidence level (t-test) from the Cherokee field carbonate samples and at the 90 percent level from the Bug field dolomites, but like the Bug and Cherokee values of del ^{13}C, they are much heavier than the mean value of +0.56‰ (standard deviation of 1.55) for a large sampling ($n = 272$) of Phanerozoic marine limestones (Hudson, 1975). However, the samples can really be divided into two populations with regard to carbon isotopic composition. The five calcite samples from the deeper cemented phylloid-algal buildup have a mean value of +5.79‰ PDB (range of +5.56 to +6.30‰) while the oolite and cement samples from the capping grainstone have a mean value of +4.52‰ PDB (range of +4.51 to +4.53‰). Since both of these carbon isotope populations are significantly heavier than Brinton's (1986) value for unaltered brachiopods from Ismay field, it is likely that an isotopically heavier fluid, possibly from concentrated (higher salinity) or closed-system sea water, is recorded in both populations.

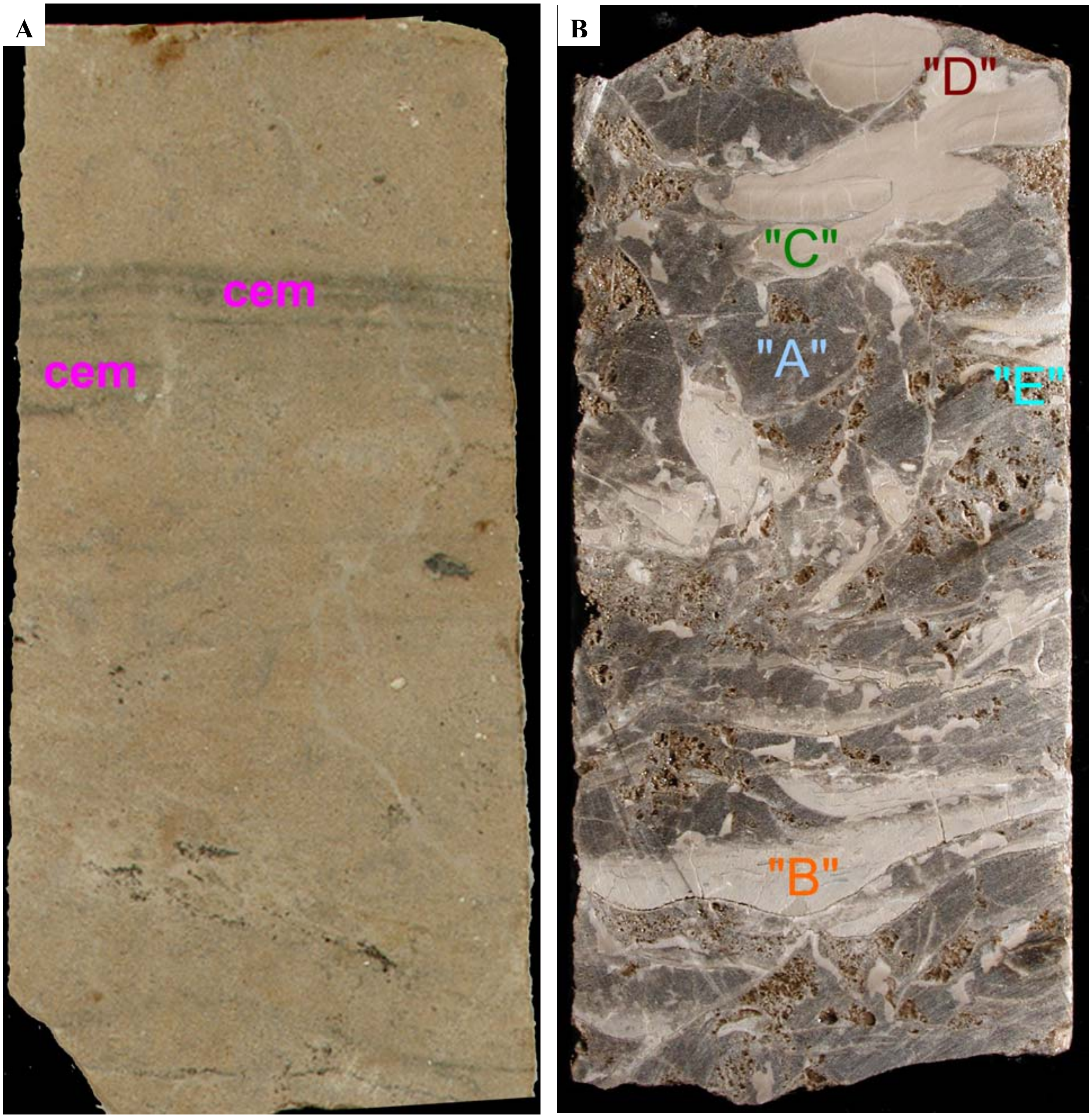


Figure 15. Core photos of whole rock and cement components sampled for stable carbon and oxygen isotope analysis in the upper Ismay buildup of the Samedan Bonito No. 41-6-85 well. (A) Bonito No. 41-6-85: 5,544 feet - both the "whole rock" limestone (an oolitic grainstone; sample 5,544 feet A) and calcite cement bands (cem; sample 5,544 feet B) along bedding were sampled for isotopic analysis. (B) Bonito No. 41-6-85: 5,592 feet – five calcite cement generations were sampled for isotopic analysis. Sample 5,492' A – black cements that appear to have originally been botryoidal cement fans. Sample 5,492' B – gray marine cements. Sample 5,492' C – brown cements containing sediments at the bottoms of pores, often display geopetal relationships. Sample 5,492' D – white cements that fill the tops of geopetal cores. Sample 5,492' E – coarse, blocky calcite spar cements.

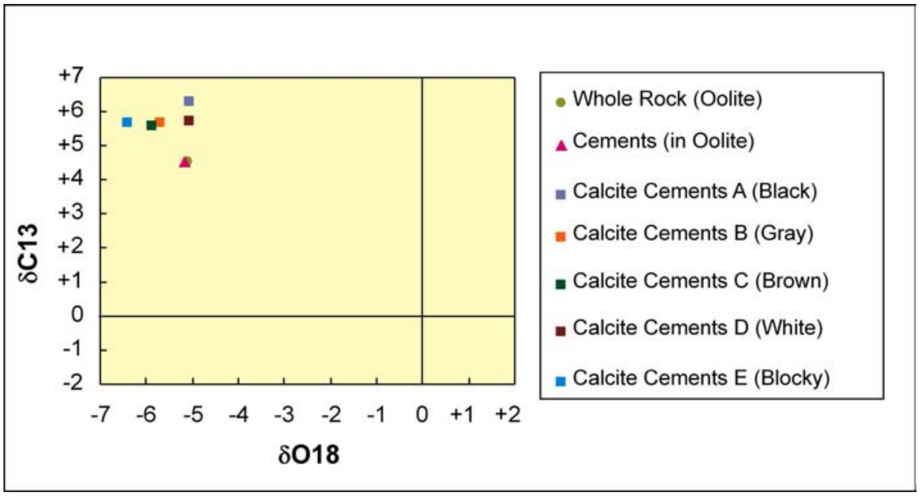


Figure 16. Graph of carbon versus oxygen compositions for whole rock and cement components in an upper Ismay buildup, Samedan Bonito No. 41-6-85 well, completed for this study.

Interestingly, Given and Lohmann's (l985) calculated value (+5.3‰ PDB) from Late Paleozoic marine cements from the Permian Basin reef front falls between the two Bonito No. 41-6-85 well populations. It does not appear that meteoric waters, which typically would precipitate calcites with more depleted carbon isotope values, were involved in the diagenesis of the tight Patterson Canyon well buildup. But why the significant difference in del ^{13}C values between the well-cemented oolite samples and the cements present in the underlying reef? Clearly the waters were somehow different in composition between the phylloid-algal mound cements and the lithified oolites. One possible scenario is that the waters responsible for the several generations ("A" through "E") of mound cement were confined to a "closed hydrologic system" that allowed a fluid with heavier carbon to evolve. The oolite and cement bands therein may have been in a more open system allowing water exchange such that waters with a composition slightly lighter than Brinton's proposed Ismay marine value (derived from unaltered brachiopods) were involved in the lithification and diagenesis of the capping oolite.

Oxygen isotopic compositions for the seven upper Ismay limestone samples of the cemented buildup in Patterson Canyon field form a moderate range of values around a mean value of –5.48‰ PDB (range of –5.05 to –6.41‰). As with the carbon isotope data, there is a significant difference (at the 95 percent confidence level) between the Bonito No. 41-6-85 oxygen isotope compositions and those from both the lower Desert Creek dolomites and the upper Ismay at Cherokee field. There is no significant difference in the del ^{18}O values between the deeper mound, early cement samples (mean value of -5.62‰ PDB) and the overlying lithified oolite (mean of -5.58‰ PDB). All seven of the Bonito No. 41-6-85 limestone samples, regardless of component or cement type, are lighter on average by about 1.0‰ PDB than the Bug and Cherokee field samples. These Patterson Canyon samples' del ^{18}O values from diagenetic components are also lighter than either Brinton's marine del ^{18}O value calculated from unaltered marine fossils or Given and Lohmann's (1985, 1986) values of –2.8 to -2.5‰ for former aragonite and magnesium calcite marine cements from the Late Permian Reef complex in southeastern New Mexico. The reasons for these significant differences are not immediately clear. It is possible that the oxygen isotope signatures indicate waters with depleted ^{18}O characteristics evolved in the mound cavities and ooid grainstone pores, without any influence by hypersaline waters. Alternatively, the limestones in this sample set may have all been modified via neomorphism by isotopically light subsurface waters.

CONCLUSIONS

Diagenesis is the main control on the quality of the Ismay and Desert Creek reservoirs. Much of the porosity development occurred in a mesogenetic (burial) setting, mostly post-dating stylolitization. Maximum porosity is developed as dissolution adjacent to stylolites, especially in phylloid-algal mounds.

It is likely that most of the carbonates present within the Ismay zone (as well as throughout the lower Desert Creek) have retained a marine-influenced isotope geochemistry through marine cementation as well as post-burial recycling of marine carbonate components during dolomitization, stylolitization, dissolution, and late cements. Such an explanation is in agreement with the model for the positive carbon isotope values of many ancient carbonates proposed by Hudson (1975).

Specific conclusions of the isotopic analyses conducted for the project are as follows:

1. Carbon isotopic compositions for Bug field dolomite samples have a mean value of +4.43‰ PDB. Despite dolomitization, all of the lower Desert Creek samples from Bug field show carbon isotope compositions that are very close in value to modern marine carbonates and Holocene botryoidal marine aragonite cements.
2. The carbon isotope geochemistry of all of the lower Desert Creek dolomites at Bug field has retained a strong influence from Pennsylvanian marine water composition. Meteoric waters do not appear to have had any effect on the composition of these lower Desert Creek dolomites.
3. Oxygen isotopic compositions for the Bug field dolomite samples have a mean value of -4.51‰ PDB. The lighter oxygen values obtained from wells located along the margins or flanks of Bug field may be indicative of exposure to higher temperatures, to fluids depleted in ^{18}O relative to sea water, or to hypersaline waters during burial diagenesis.
4. The wells in Bug field with the lightest oxygen isotope compositions in the lower Desert Creek dolomites have produced significantly greater amounts of hydrocarbons.
5. Carbon isotopic compositions for the upper Ismay dolomite samples at Cherokee field have a mean value of +4.70‰ PDB. As with the Bug field dolomite samples, the Cherokee field carbonates fall within the same range of carbon isotope compositions as modern marine sediments, skeletons, and marine cements. It does not appear that meteoric waters, which typically would precipitate carbonates with more depleted carbon isotope values, have had major effects on the composition of the Ismay carbonate components.
6. Most of the Ismay carbonates (as well as those throughout the lower Desert Creek) have retained a marine-influenced carbon isotope geochemistry throughout marine cementation as well as post-burial recycling of marine carbonate components during dolomitization, stylolitization, dissolution, and late cementation.
7. Oxygen isotopic compositions for the Cherokee field limestone and dolomite samples form a wide range of values around a mean value of -4.20‰ PDB. There is no significant difference between the oxygen isotope compositions from lower Desert Creek dolomite samples in Bug field and the upper Ismay limestones and dolomites from Cherokee field.

8. One of the dolomitized samples in Cherokee field, from cryptalgal laminites, has a much lighter oxygen composition. The depleted del ^{18}O value of this one dolomite sample suggests neomorphism, cementation, and/or dolomitization from warm or isotopically light subsurface waters.
9. Carbon isotopic compositions for upper Ismay limestone samples in the cemented buildup of Patterson Canyon field have a mean value of +5.43‰ PDB. However, the samples can be divided into two populations with regard to carbon isotopic composition: isotopically heavier mound cemented and isotopically lighter oolite and cement bands.
10. Mound cements were confined to a "closed hydrologic system" that allowed a fluid with heavier carbon to evolve. The oolite and cement bands therein may have been in a more open system allowing water exchange such that waters with a composition slightly lighter were involved in the lithification and diagenesis of the capping oolite.
11. Oxygen isotopic compositions for upper Ismay limestone samples of the cemented buildup in Patterson Canyon field have a mean value of –5.48‰ PDB, lighter than Bug and Cherokee samples.
12. The oxygen isotope signatures indicate waters with depleted ^{18}O characteristics evolved in the mound cavities and ooid grainstone pores, without any influence by hypersaline waters. Alternatively, the limestones in this sample set may have all been modified via neomorphism by isotopically light subsurface waters.

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REFERENCES

Brinton, Lisë, 1986, Deposition and diagenesis of Middle Pennsylvanian (Desmoinesian) phylloid algal banks, Paradox Formation, Ismay zone, Ismay field and San Juan Canyon, Paradox Basin, Utah and Colorado: Golden, Colorado School of Mines, M.S. thesis, 315 p.

Crawley-Stewart, C.L., and Riley, K.F., 1993, Cherokee, *in* Hill, B.G., and Bereskin, S.R., editors, Oil and gas fields of Utah: Utah Geological Association Publication 22, non-paginated.

Dawson, W.C., 1988, Ismay reservoirs, Paradox Basin - diagenesis and porosity development, *in* Goolsby, S.M., and Longman, M.W., editors, Occurrence and petrophysical properties of carbonate reservoirs in the Rocky Mountain region: Rocky Mountain Association of Geologists, p. 163-174; 442-443.

Given, R.K., and Lohmann, K.C., 1985, Derivation of the original isotopic composition of Permian marine cements: Journal of Sedimentary Petrology, v. 55, p. 430-439.

---1986, Isotopic evidence for the early meteoric diagenesis of the reef facies, Permian reef complex of West Texas and New Mexico: Journal of Sedimentary Petrology, v. 56, p. 183-193.

Harr, C.L., 1996, Paradox oil and gas potential of the Ute Mountain Ute Indian Reservation, *in* Huffman, A.C., Jr., Lund, W.R., and Godwin, L.H., editors, Geology of the Paradox Basin: Utah Geological Association Publication 25, p. 13-28.

Harry, D.L., and Mickus, K.L., 1998, Gravity constraints on lithopheric flexure and the structure of the late Paleozoic Ouachita orogen in Arkansas and Oklahoma south-central North America: Tectonics, v. 17, no. 2, p. 187-202.

Hintze, L.F., 1993, Geologic history of Utah: Brigham Young University Studies Special Publication 7, 202 p.

Hite, R.J., Anders, D.E., and Ging, T.G., 1984, Organic-rich source rocks of Pennsylvanian age in the Paradox Basin of Utah and Colorado, *in* Woodward, Jane, Meissner, F.F., and Clayton, J.L., editors, Hydrocarbon source rocks of the greater Rocky Mountain region: Rocky Mountain Association of Geologists

Hudson, J.D., 1975, Carbon isotopes and limestone cements: Geology, v. 3, p. 19-22.

James, N.P., and Ginsburg, R.N., 1979, The seaward margin of Belize barrier and atoll reefs: International Association of Sedimentologists Special Publication 3, 191 p.

Kluth, C.F., 1986, Plate tectonics of the Ancestral Rocky Mountains: American Association of Petroleum Geologists Memoir 41, p. 353-369.

Kluth, C.F., and Coney, P.J., 1981, Plate tectonics of the Ancestral Rocky Mountains: Geology, v. 9, p. 10-15.

Land, L.S., 1980, The isotopic and trace elements geochemistry of dolomite - the state of the art, *in* Zenger, D.H., Dunham, J.B., and Ethington, R.L., editors, Concepts and models of dolomitization: Society for Sedimentary Geology (SEPM) Special Publication 28, p. 87-110.

---1982, Dolomitization: American Association of Petroleum Geologists Short Course Note Series No. 24, 20 p.

Lohmann, K.C., 1983, Diagenetic history of carbonate reservoirs – integration of petrographic and geochemical techniques, *in* Wilson, J.L., Wilkinson, B.H., Lohmann, K.C., and Hurley, N.F., editors, New ideas and methods of exploration for carbonate reservoirs: Dallas Geological Society, unpaginated.

Nuccio, V.F., and Condon, S.M., 1996, Burial and thermal history of the Paradox Basin, Utah and Colorado, and petroleum potential of the Middle Pennsylvanian Paradox Formation, *in* Huffman, A.C., Jr., Lund, W.R., and Godwin, L.H., editors, Geology of the Paradox Basin: Utah Geological Association Publication 25, p. 57-76.

Martin, G.W., 1983, Bug, *in* Fassett, J.E., editor, Oil and gas fields of the Four Corners area, volume III: Four Corners Geological Society, p. 1073-1077.

Oline, W.F., 1996, Bug, *in* Hill, B.G., and Bereskin, S.R., editors, Oil and gas fields of Utah: Utah Geological Association Publication 22 Addendum, non-paginated.

Roylance, M.H., 1984, Depositional and diagenetic control of petroleum entrapment in the Desert Creek interval, Paradox Formation, southeastern Utah and southwestern Colorado: Lawrence, University of Kansas, M.S. thesis, 178 p.

---1990, Depositional and diagenetic history of a Pennsylvanian algal-mound complex - Bug and Papoose Canyon fields, Utah and Colorado: American Association of Petroleum Geologists Bulletin, v. 74, p. 1087-1099.

Utah Division of Oil, Gas and Mining, 2003, Oil and gas production report, May: non-paginated.

APPENDIX
LISTING OF CARBON AND OXYGEN ISOTOPE COMPOSITIONS COMPLETED FOR THIS PROJECT

Carbon and oxygen isotope compositions completed for Bug, Cherokee, and Patterson Canyon fields as part of UGS project.

	WELL	DEPTH (ft)	COMMENTS	d13C*	d18O*
Lower Desert Creek	May Bug 2	6304' A	Dol. – Phylloid algal md. + mar. sed.	+4.49	-4.72
	May Bug 2	6304' B	Dol. – Internal sed. (lt. brn.)	+4.30	-4.50
	May Bug 2	6304' C	Dol. – Micro-boxwork/mar. cement	+4.40	-4.56
	May Bug 2	6315' A	Dol. – Internal sed. (lt. brn.)	+4.16	-4.15
	May Bug 2	6315' B	Dol. – Phylloid algal md.	+4.03	-4.42
	Bug 4	6289.7'	Dol. - Micro-boxwork/mar. cement	+4.77	-4.58
	Bug 4	6297.4' A	Dol. – Micro-boxwork/mar. cement	+4.76	-4.46
	Bug 4	6297.4' B	Dol. – Phylloid algal md. + marine sed.	+4.52	-4.67
Upper Ismay	Cherokee 22-14	5768.7'	Dol. – micro-porosity w/ bit	+3.57	-2.92
	Cherokee 22-14	5827.7'	Dol. – micro-porosity	+5.41	-2.90
	Cherokee 22-14	5836.8'	Ls. – Phylloid algal md.	+5.02	-4.55
	Cherokee 33-14	5781.2' A	Dol. – Cryptalgal laminate	+4.67	-6.08
	Cherokee 33-14	5781.2' B	Dol. – Micro-porosity	+4.85	-4.54
	Samedan Bonito 41-6-85	5544' A	Ls. – Dolitic grain-stone	+4.53	-5.10
	Samedan Bonito 41-6-85	5544' B	Ls. – Gray cement band	+4.51	-5.15
	Samedan Bonito 41-6-85	5592' A	Ls. – Blk marine cement	+6.30	-5.05
	Samedan Bonito 41-6-85	5592' B	Ls. – Gray marine cement	+5.67	-5.68
	Samedan Bonito 41-6-85	5592' C	Ls. – Brn., sed.-rich cement	+5.56	-5.87
	Samedan Bonito 41-6-85	5592' D	Ls. – White, sed.-free cement	+5.73	-5.05
	Samedan Bonito 41-6-85	5592' E	Ls. - Blocky spar cement	+5.69	-6.41

*All values reported relative to PDB standard

BYU lab calibration to an internal standard.

Sample No.	d13C*	d18O*
UCLA-1/17/2003	+2.59	-2.01
UCLA-4/9/2003	+2.44	-2.23
UCLA-4/10/2003	+2.35	-2.33
UCLA-2/18/2003	+2.58	-1.92
UCLA-2/10/2003	+2.49	-1.83
UCLA-2/6/2003	+2.45	-2.06
UCLA-6/30/2003	+2.56	-1.89
mean	+2.49	-2.04
1 std dev.	0.09	0.18

*UCLA Carrara Marble, with accepted values of d13C = +2.495 and d18O = -2.027