Lithostratigraphy and Diagenesis of the Upper Pennsylvanian (Missourian) Lansing-Kansas City Groups in Rooks County, Kansas

By

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Abstract

The Upper Pennsylvanian (uppermost Missourian) Lansing-Kansas City Groups (LKC) are prime oil reservoirs targeted by many petroleum companies exploring in Kansas and Nebraska. The LKC groups are a series of cyclothems with carbonate and terrigenous clastic components. A 240 foot, full-diameter core from within Dopita Field in Rooks County, Kansas that recovered the entire LKC section, along with thin sections and plugs (porosity and permeability tested), were studied to determine the depositional facies and diagenetic controls on reservoir development in these rocks, and to understand which producing zones in the study area, if any, would be candidates for a waterflood. The LKC section in the core (zones labeled A-L from top to bottom) was divided into lowstand-transgressive-highstand complete cycles and incomplete sub-cycles. A complete cycle consists of, from base to top: (i) a section with evidence of subaerial exposure,(ii) a transgressive-systems tract and ensuing maximum flooding surface, (iii) a regressive highstand-systems tract, and (iv) another section suggestive of subaerial exposure. An incomplete sub-cycle is represented by the upward change from transgression to highstand without evidence of subaerial exposure. Throughout the core there were 6 complete cycles and 10 incomplete sub-cycles identified. The study showed that any porosity and permeability (along with oil shows) present in the rocks had developed during times of subaerial exposure within shallow-water carbonate sands deposited in the highstand systems tracts of cycles. Currently plans are being made to begin waterflooding the south end of the Dopita Field. The results from this study are being implemented in deciding which zones to flood.

INTRODUCTION

The Lansing-Kansas City Groups comprise stacked cyclothems with locally prolific hydrocarbon-bearing carbonate reservoirs. They are sought-after throughout the midcontinent and are especially prolific on the Central Kansas Uplift and the Cambridge Arch (Figure 1, Figure 2). The Lansing-Kansas City groups are known not only to produce on structural highs but also areas off-structure where individual zones within the section thicken locally (Watney, 1980). Many regional studies of these rocks in the midcontinent have been done, primarily in Kansas and Nebraska (e.g., Parkhurst, 1959, 1962; Rascoe and Adler, 1971; Heckel and Baeseman, 1975; Heckel, 1980, 1984, 1986, 1995; Brown, 1984; Watney et al., 1989; Heckel et al., 2007;).

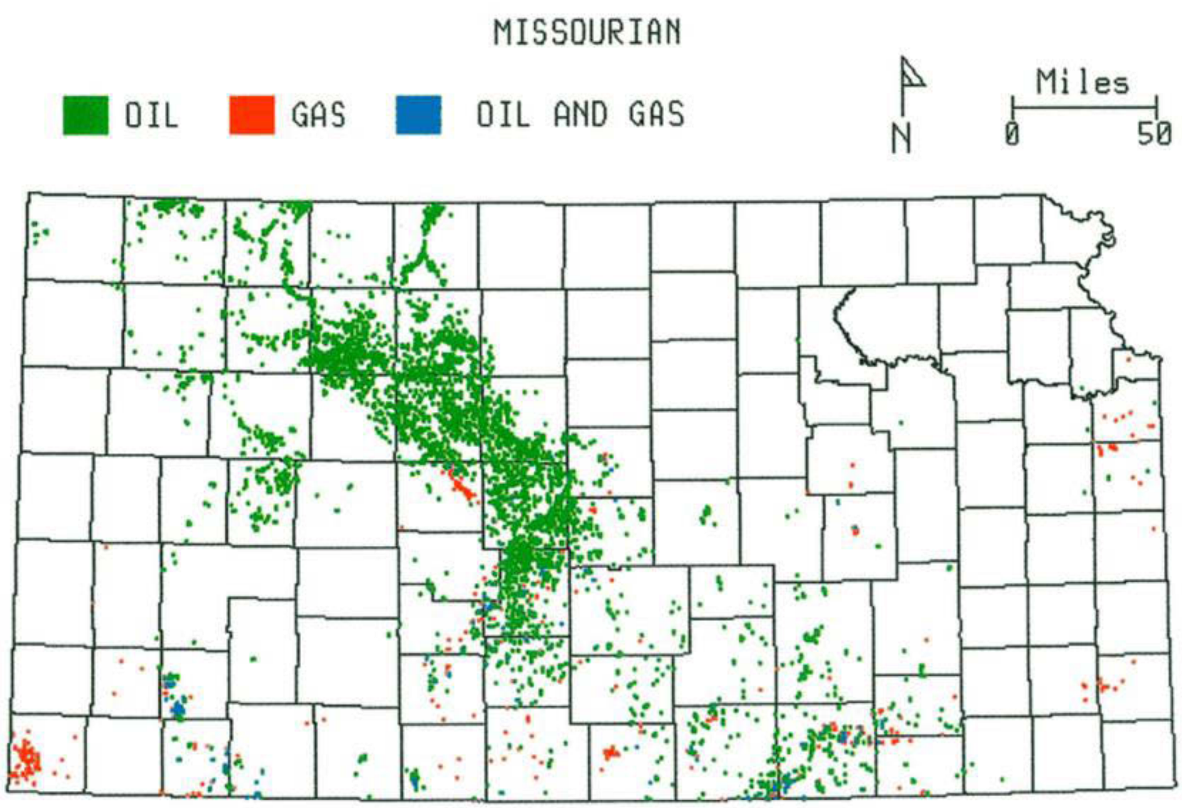

Figure 1 – Distribution of petroleum production in the Lansing-Kansas City/Pleasanton groups in Kansas (KGS, 1987).

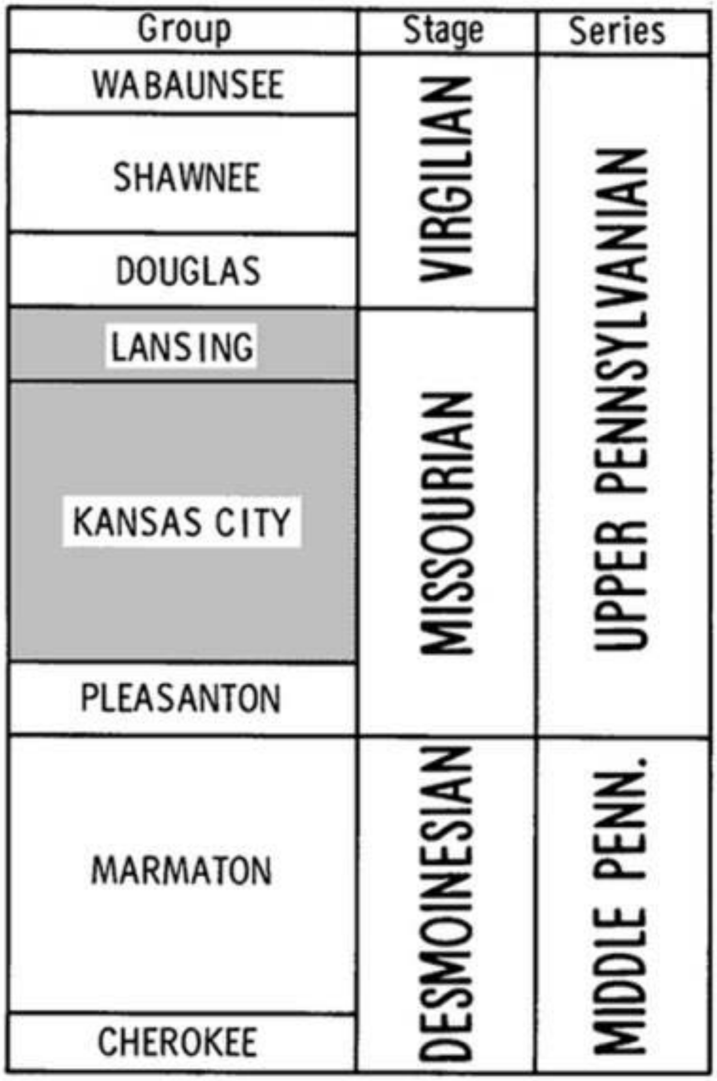

Figure 2 - Stratigraphy of the Lansing-Kansas City groups (from Zeller, 1968).

The purpose of this study is to get a better understanding of the lithological and diagenetic controls on reservoir development and continuity in the Lansing-Kansas City section in Dopita Field, with the end result aiding in a secondary recovery by waterflood.

Study Area

The study area, and the location of the core examined, is in the southern half of the Dopita Field on the northeastern edge of the Central Kansas Uplift, in approximately the center of Rooks County, Kansas. The field is about 10 sq. miles in size with approximately 180 wells drilled. Cumulative production of 13.8 million barrels is primarily out of the Arbuckle Group, and many wells in the field were later recompleted in, and new wells drilled into, the Lansing-Kansas City groups (Oil, 2013).

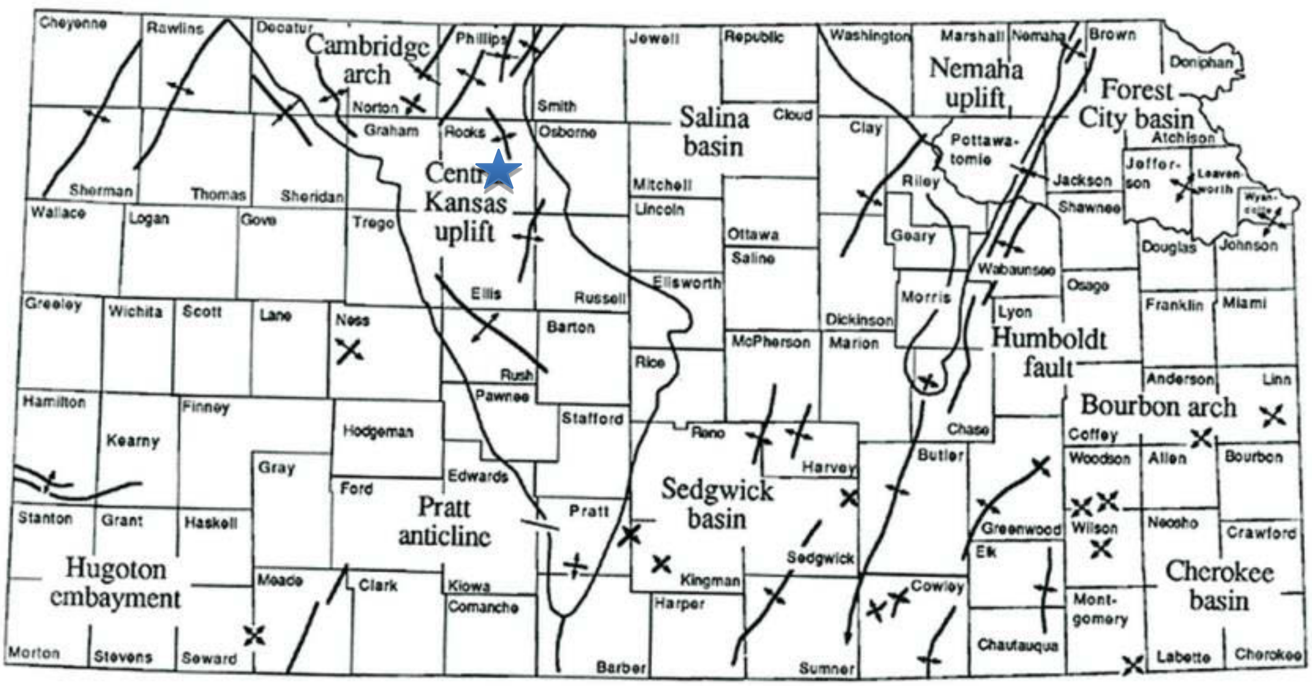

Figure 3 – Post-Mississippian structure map of Kansas (from Merriam, 1963). Blue star represents the location of the core used for this study.

General Geology of the Area

The study area is on the northern to northeastern flank of the Central Kansas Uplift, just southeast of the Cambridge arch and east of the Salina Basin (Figure 2). Both of these features came into existence during the pre-Morrowan Epeirogeny (pre-Pennsylvanian) (Rascoe and Adler, 1983). With structural folding and probable sea-level drop, Mississippian rocks were eroded off the Cambridge Arch and most of the Central Kansas uplift (Rascoe and Adler, 1983). In early Desmoinesian (uppermost Middle Pennsylvanian) time, the Arch and Uplift were clastic hills and were transgressed by seas through late Desmoinesian time (Rascoe and Adler, 1983). During Missourian time the Central Kansas Uplift and Cambridge Arch were transgressed by epeiric seas several times, likely caused by glacial eustasy (Boardman and Heckel, 1989). The Lansing-Kansas City groups on the Central Kansas Uplift were deposited during the Late Pennsylvanian (Missourian), a time of numerous eustatic sea level fluctuations (Boardman and Heckel, 1989). These eustatic fluctuations and resulting transgression and regression were likely the result of glacial buildups and alternating meltings (e.g., Wanless and Shepard, 1936; Crowell, 1978; Boardman and Heckel, 1989). Heckel (1980, 1984, 1994) ruled out the alternative explanations of local tectonism or migrating deltas that had been used previously to explain these cycles. Veevers and Powell (1987) found evidence that the glacial deposits on Gondwanaland (the megacontinent to the south of the study area) reached a peak during the Middle to Late Pennsylvanian time, and such glaciations and deglaciations presumably affected eustasy in the study area (Veevers and Powell, 1987). The periodicity and frequency of the cyclothems in the middle to late Pennsylvanian generally are ascribed to Milankovitch cycles such as those suggested for during the Pleistocene -- that is, one cycle per 20,000 to 40,000 years up to 100,000 to 400,000 years (e.g., Veevers and Powell, 1987).

Reservoir and Log Characteristics

The LKC zones in each well in the southern end of Dopita Field were correlated and mapped using gamma ray-density/neutron logs. A structure map was prepared for the top of the LKC and the base of the KC, an isopach map was made for the entire LKC, and Porosity*Feet "pay zone" maps also were prepared for every zone in the LKC. These mapped were prepared prior to coring so that an optimum core location could be decided on prior to drilling and obtaining the core. Percent porosity and zone thickness were used to estimate the Porosity*Feet values for the well logs. Only clean limestones (according to the gamma ray logs) with porosity of at least 5% were given values. The thickness in feet of the clean limestone in every LKC zone was multiplied by the average porosity through each individual zone to get an effective value of Porosity*Feet in the units mapped. Despite these maps, the cored well ran significantly lower and porosity values also were lower with respect to surrounding wells.

Methods of Study

Besides basic log analysis, a full-diameter core containing the entire LKC groups (240 feet), 7 representative thin sections, and 16 permeability plugs (tested for porosity and permeability) were analyzed from Trek AEC LLC's Dopita A #16 well in Rooks County, Kansas. As noted above, the well ran low to surrounding wells, and after a failure to produce the LKC 'G' and 'I' zones, the current plan is to make the well an injection well as part of the secondary recovery program that is in the process of being implemented.

The core was extracted by Devilbiss Coring Service, Inc. on W-W Drilling Rig #6. The core was taken in one-stand increments, with two 30 ft. core barrels recovering 60 ft. at a time. There were 4 total stands taken, with full recoveries on all 4 stands, resulting in 240 ft. of continuous core; the entire LKC groups and partial overlying and underlying units were recovered. The core was kept in aluminum sleeves cut in 3 ft. sections, capped, and transported back to Wichita State University Geology Department's rock preparation room in Wichita, Kansas. The core was personally slabbed by this author to minimize the potential for saw blade marks often left behind by major labs, then it was boxed and placed in the Carbonate Laboratory at WSU. Here, the slab faces were polished and then acidized (with 10% HCl) for a clean face with high relief. The prepared slabs were then analyzed using a binocular microscope. Alizarin Red S stain was used to distinguish between limestones and dolomites, and more dilute acid was used as needed. Dunham's (1962) classification of carbonate rocks was used to describe the lithologies of the core.

Seven representative thin sections were taken from two zones with production potential -- the LKC 'G' and 'I' zones. The thin sections were made using a blue-dyed epoxy to make any porosity readily visible, and they were examined using a standard petrographic microscope.

Sixteen 1" permeability plugs, each approximately 3" long, were drilled with a hole saw from the butt ends of the core. The depths selected for permeability plugs were based on the presence of porosity, oil staining, and degree of oil saturation. These plugs where sent to Weatherford Laboratories in Houston, Texas for a routine porosity and permeability analyses following standard analytical procedures. After extracting all the fluids, the plugs were vacuum dried at 180°F and tested with a net confining stress of 800 psi.

Lithostratigraphy

Cycles within the LKC section elsewhere in Kansas have been described by Watney et al. (1980) and others (Prather, 1984) as having 4 basic components: (i) a thin but distinctive basal transgressive unit deposited as sea level rose, (ii) overlain by a marine shale, (iii) overlain by a regressive carbonate and, in turn, (iv) a regressive shale deposited during sea level fall. The same cycle components were identified in the Dopita Field core, although differences in lithology and complexity of the cycles in the core were further evaluated to determine if any finer sedimentological details that may be present had relevance to petroleum reservoir development in the section. For example, some cycles in the core would indicate shallowing to the point of subaerial exposure, while other cycles included only a shallow-marine shale or tidal-flat deposit at the tops of (incomplete) cycles. For this study, the widely industry-accepted 'A' through 'L' zonal identification scheme of the LKC section was initially ignored and a sea-level curve was developed based on identification of cycles in the core. Afterwards, the zones within the LKC section were added to these interpretations (Boardman and Heckel, 1989).

When developing a columnar lithologic section for the core an attempt was made to distinguish more complete cycles from relatively more minor, incomplete cycles to determine what role cycle completeness might exert on petroleum reservoir (porosity) development. It was determined in the present study that a complete cycle in the core typically includes transgressive marine deposits overlying rocks affected by subaerial exposure (such as paleosols), and such transgression generally culminated in deposition of inferred maximum flooding surface deposits (generally black, phosphatic shale or dark gray shale)(Boardman et al., 1984). These deposits comprise the transgressive-systems tracts of LKC cycles. They are in turn overlain by regressive, upward-shallowing carbonate rocks that are micritic at the base and which pass upward into inferred high-energy biograinstone to packstone or oolite packstone to grainstone (carbonate sands) that comprise the highstand-systems tracts of LKC cycles. These highstand-systems tract deposits generally are overlain by paleosols in red mudrocks indicative of subaerial exposure (Figure 4-A). Incomplete, relatively minor sub-cycles include similar transgressive-systems tracts limestones overlain by upward-shallowing limestones, locally with some tidal-flat deposits (Figure 4-B-C), and without capping paleosols or only very poorly developed (incipient) paleosols in green mudrocks (Figure 4-D). Similar tidal-flat deposits and incipient paleosols have been described by many workers, including for example Shinn (1983) and Retallack (1988), respectively. Soilstone crusts were interpreted as inferred slight unconformities (Figure 5), and sediment accumulation beneath grains was interpreted as being caused by an abrupt sea level drop (Figure 6)(Shinn, 1983). The high-energy packstones and grainstones make up the reservoir rock for all the zones (Figures 7-12).

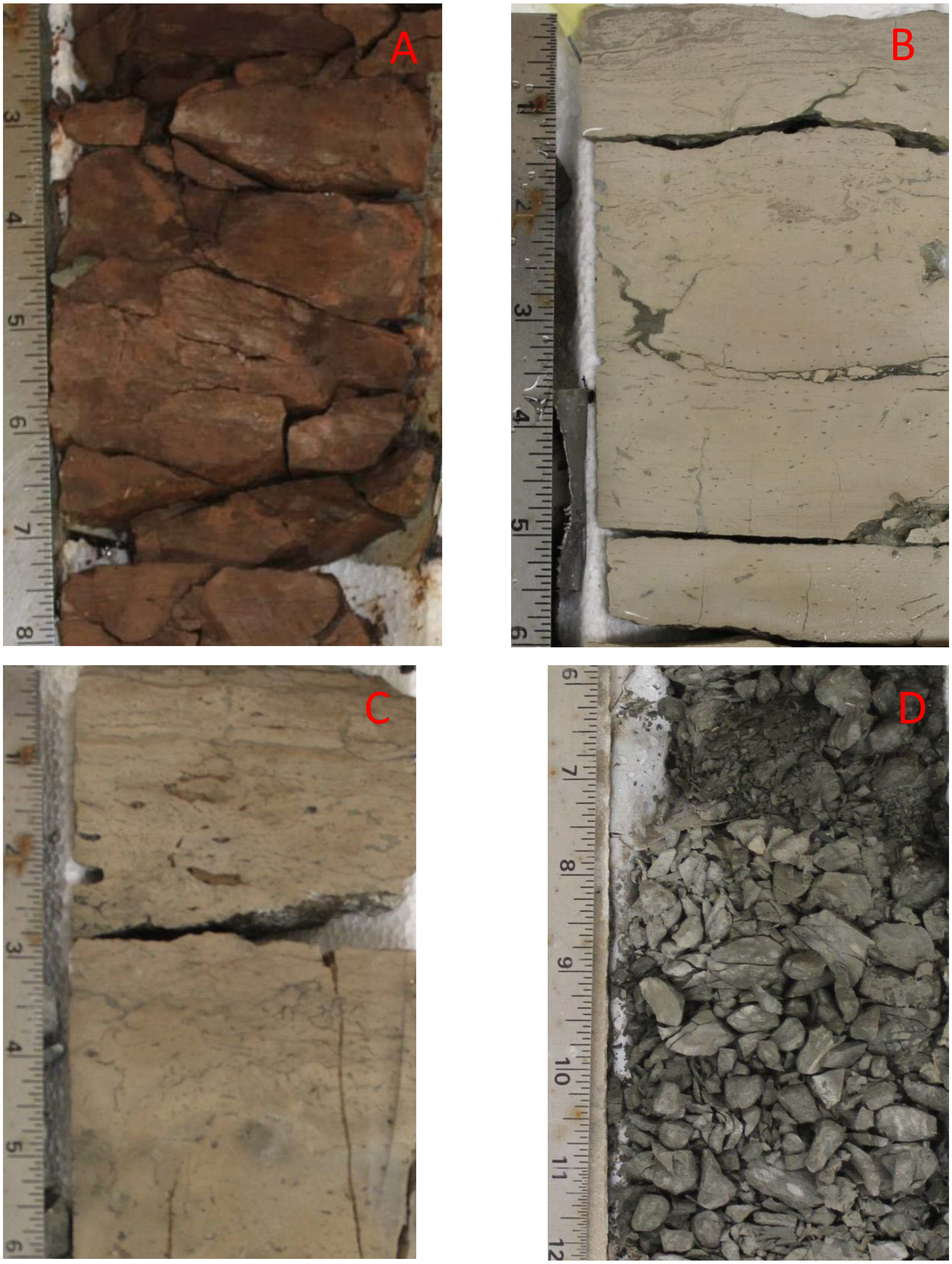

Figure 4 – Core photographs of the Dopita A #16; representative of the farthest points of regression in the LKC section: A) Red incipient paleosol indicative of a “full-cycle” regression to the point of subaerial exposure; Depth 3281’. B and C) Tan lime mudstone with birdseyes, *in situ* brecciation, and pore spaces filled with green calcitic shale indicative of a tidal-flat flat environment; Depths B-3258’6”, C-3324’. D) Green incipient paleosol with inferred poorly developed peds indicative of a very shallow environment, with inferred marine plant life, though not subaerially exposed; 3294’.

Figure 5 - ‘L’ Zone - well sorted oolitic lime grainstone with a soilstone crust (red arrow); indicative of an unconformity. Approximate Depth – 3347’.

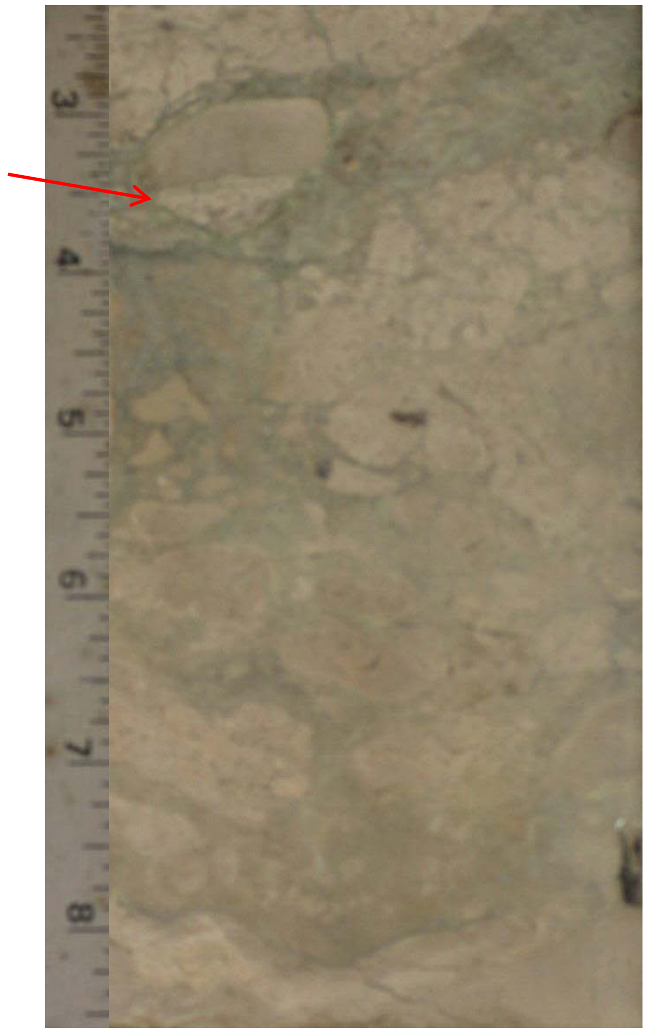

Figure 6 – 'I' Zone - carbonate clasts in a matrix of pale-green shale. Red arrow points to an accumulation of carbonate sediment below a larger carbonate clast; this indicates an abrupt sea-level fall resulting in water percolating through the rock, leaving sediment debris behind as it passes by larger clasts. Approximate depth – 3282'.

Figure 7 – 'K' Zone – lime grainstone with interparticle and vuggy porosity. Most the vugs (2-4mm in diameter) are filled with a moderately sorted, loosely consolidated and oil stained, carbonate sand. Unit contains lenses cemented by clear calcite and lack of readily visible porosity. Plug analysis results showed 5.5-6% porosity and permeability of .58-.64 mD; Approximate depth – 3326'.

Figure 8 – **'**I' Zone - lime packstone to grainstone with low to high relief stylolites; interparticle, intraparticle, and moldic porosity (from partial dissolution of fusulinid and bryozoan fragments - from thin section analysis), sparse lenses with reduced porosity. Plug analysis showed 13.9% porosity and permeability of 3.93 mD; approximate depth – 3288'6".

Figure 9 – 'G' Zone -well sorted oolitic sand shoal - grainstone, cross-stratified, with low-relief stylolites, indicative of a high-energy environment during a regression. This facies grades upward into a tidal flat environment in this cycle. Zone is completely oil saturated with 25% porosity and permeability of 2.68 md. Approximate depth – 3226'.

Figure 10 – ’I’ Zone – lime biopackstone to grainstone with low to moderate relief stylolites with interparticle and moldic porosity (partially dissolved fusulinid and sparse bryozoan fragments – from thin section analysis). Most porosity is localized around stylolites. Plug analysis results showed 7.4% porosity and permeability of .71 mD. Approximate Depth – 3284’6”.

Figure 11 – 'D' zone – lime biograinstone with low to moderate relief stylolites; contains interparticle, intraparticle, and vuggy porosity. Unit also contains fractures that were filled with calcite cement and partially dissolved. Plug analysis showed 9.1% porosity and permeability of 3.18 mD; Approximate depth – 3183'.

Figure 12 - 'A' Zone – lime biograinstone with an abundance of oncolites. Unit contains interparticle porosity and partial vuggy porosity. Two plugs were taken from the depths shown with the red arrows. Plug A results were 4.1% porosity with permeability of .0014 mD. Plug B results were 7.2% porosity and permeability of 4.23 m; Approximate depth – 3128'6".

Depositional Model

With the results compiled from all methods of study, a columnar section was constructed (Figure 13, or for large print see Plate 1) that shows the entire LKC in the core together with a brief lithologic description, presence of oil staining, porosity, fractures and inferred depositional environment. Also on the diagram are an inferred relative sea-level curve with complete cycles and minor cycles indicated.

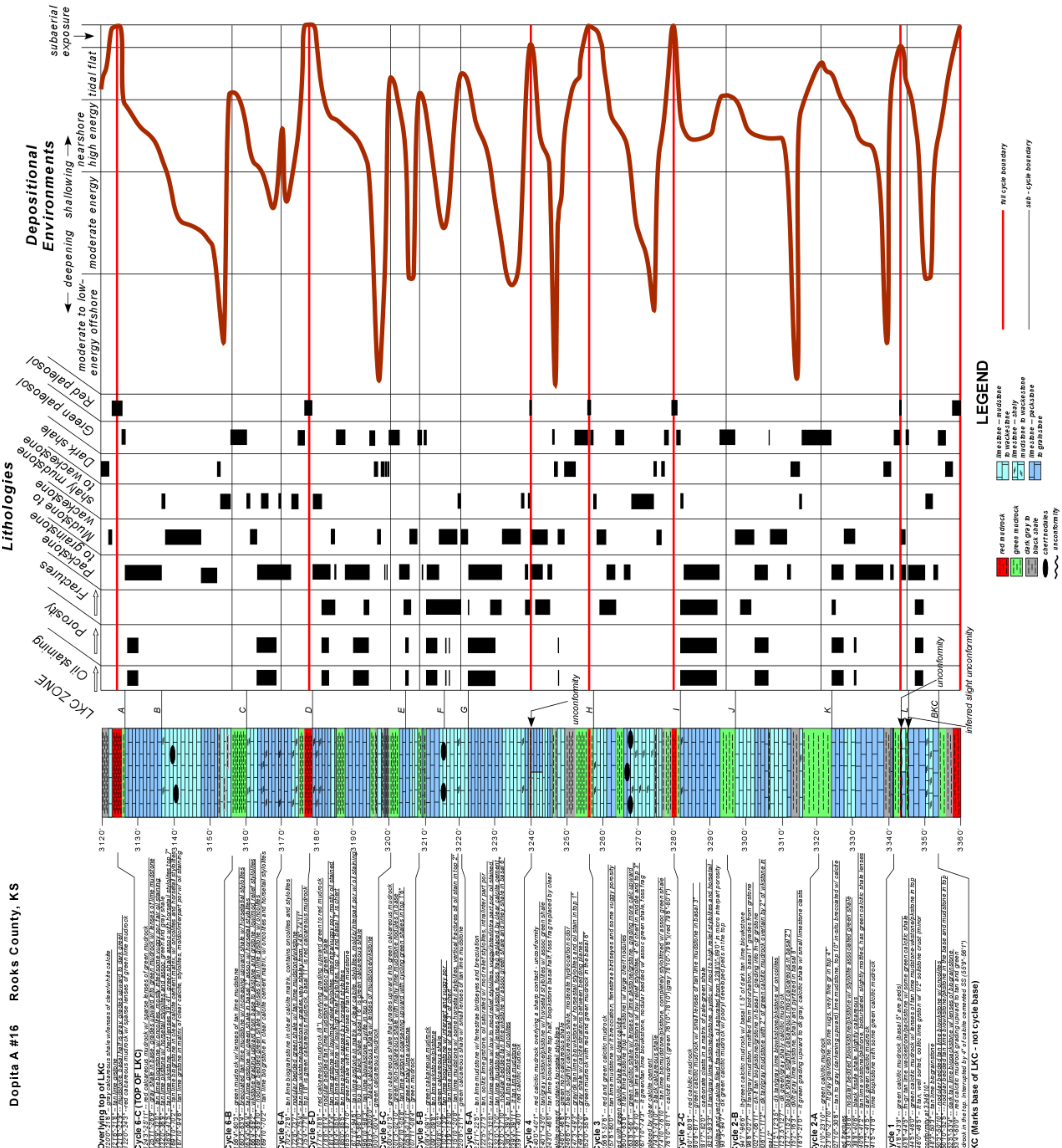

Figure 13 - Columnar section of the LKC groups based on the core analysis of the Dopita A #16 well in Rooks County, KS. - Larger Print is available, see Plate 2

Diagenetic History

Porosity development in carbonate rocks has been widely accepted as being secondary porosity primarily created or modified during the eogenetic stage attending meteoric subaerial exposure (Choquette and Pray, 1970). Partial enhancement or creation of secondary porosity can also occur through the mesogenetic (deep-burial) stage (e.g., Mazzullo and Harris, 1991). When carbonate sediments are deposited they commonly have primary porosities of 40-70% (Choquette and Pray, 1970). Post-depositional cementation reduces primary porosity, and burial-induced mechanical and chemical compaction also reduce porosity (Choquette and Pray, 1970). Analysis of the #16 core indicates that every zone in the LKC section was stylolitized during deep burial, and stylolitization generally increases rock density and likely reduces porosity even further (Mazzullo and Harris, 1991). The core analysis indicates that the only significant porosity present in the section is in rocks deposited in high-energy environments (packstones to grainstones) during regressions -- that is, in upward-shallowing highstand-systems tract deposits immediately beneath unconformities (see Figure 13). This observation suggests that the reservoirs were probably developed during the eogenetic stage attending periods of subaerial meteoric exposure. Porosity seemingly was the result of secondary dissolution of previously-precipitated, meteoric calcite cements. A similar mechanism of porosity development was suggested by (Watney et al., 1980) for LKC rocks elsewhere in Kansas.

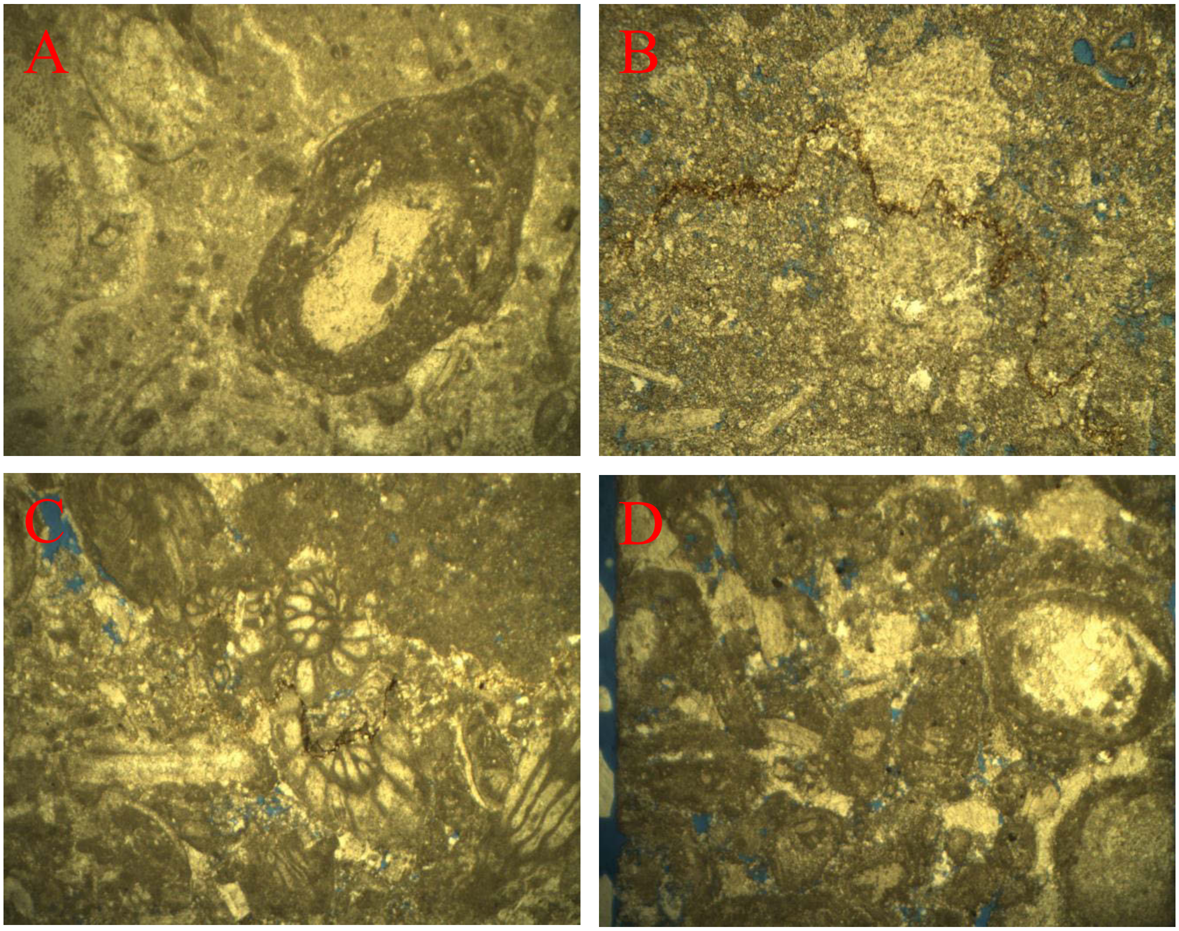

Figure 14 - Thin-section photomicrographs. **A)** 'I' Zone (plane light, 20X) - lime packstone to grainstone with no visible porosity. Rock contains many oncolites, fusulinids and some brachiopods and bryozoans. The primary porosity that was likely present has been filled with clear calcite cement that was not dissolved. Depth – 3292'0". **B)** 'I' Zone (plane light, 80X) - lime packstone to grainstone with mostly micro-interparticle porosity and some intraparticle and moldic (partly dissolved bryozoan fragments) porosity. Rock contains fusulinids and bryozoans and has dark oil staining along a moderate-relief stylolite. Depth – 3288'3". **C)** 'I ' Zone (plane light, 20X) - lime packstone to grainstone with very sparse interparticle, intraparticle, and moldic (partial dissolution of fusulinid and bryozoan fragments) porosity. Rock contains sparse oil spotting and some dark oil staining concentrated along a low-relief stylolites. Primary porosity was filled with clear calcite cement that later was partly dissolved, producing the secondary porosity in the rock. Thin section contains forams, bryozoans, peloids, brachiopods, crinoids, and fusulinids. Depth – 3285'8". **D)** 'I' Zone (plane light, 20X) - lime packstone to grainstone with mostly interparticle and moldic porosity (partially dissolved fusulinid and sparse bryozoan fragments). Primary porosity was filled by clear calcite cement that was later partly dissolved, creating the secondary porosity in the rock. Depth – 3284'0".

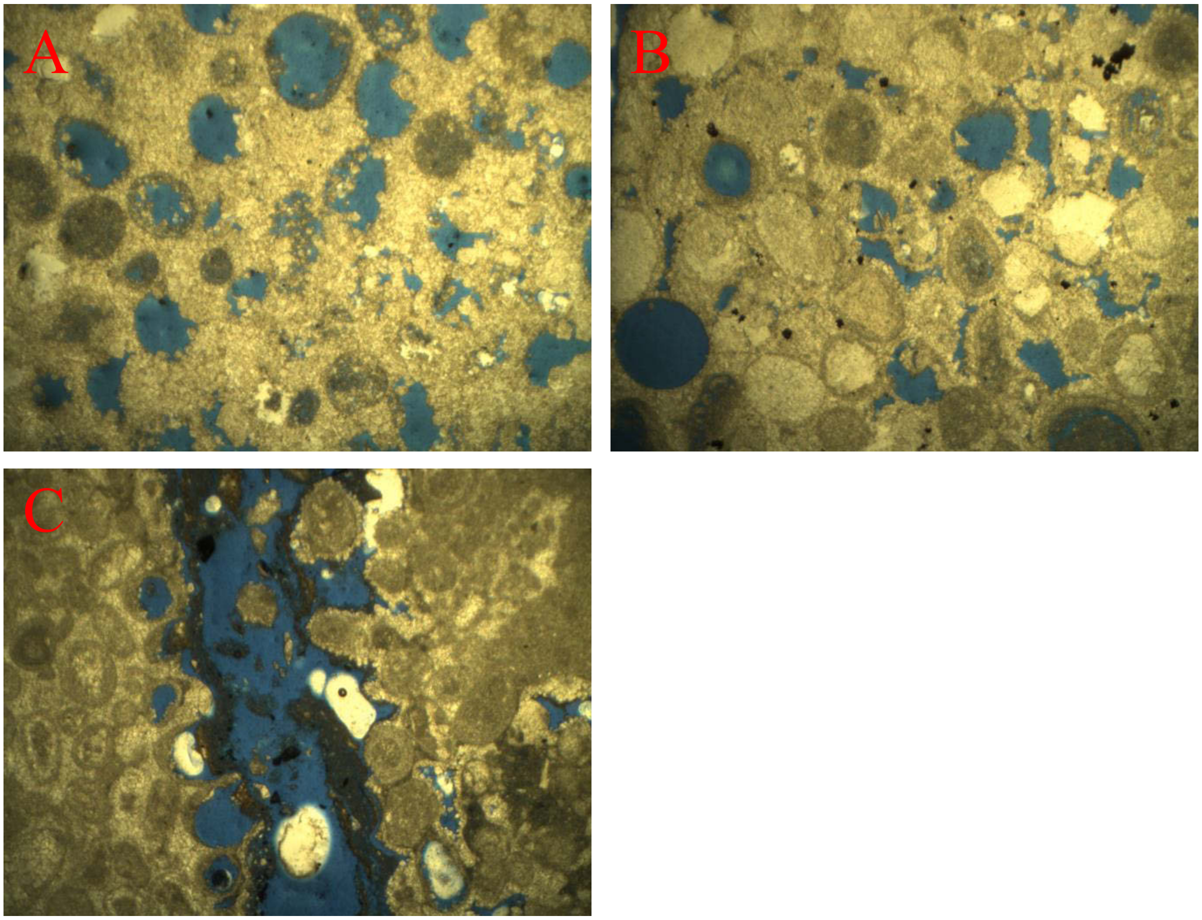

Figure 15 – Thin-section photomicrographs. **A)** 'G' Zone (plane light, 20X) - oolitic lime grainstone with oomoldic porosity and sparse interparticle porosity. Primary porosity was filled by clear calcite which was later dissolved, creating secondary porosity. Plug analysis showed 25. 2% porosity and permeability of 2.68 mD. Depth – 3226'4". **B)** 'G' Zone (plane light,20X) - oolitic lime grainstone with both interparticle and oomoldic porosity. An abundance of oil spots are also present in the pores. Porosity appears to be approximately 50% interparticle and 50% oomoldic. Primary porosity was filled with clear calcite cement and later partially dissolved, creating secondary interparticle and oomoldic porosity. Depth – 3224'3". **C)** 'G' Zone (plane light, 20X) - oolitic lime grainstone partially cemented by clear calcite. There is interparticle, oomoldic, and vuggy porosity. Most of the porosity present is moldic (oomolds) or vuggy. The primary porosity was filled with clear calcite cement and later dissolved, creating secondary porosity. Fractures are visible throughout the thin section and oil is present in some pores. Plug analysis showed 10.6% porosity and permeability of 111 mD (likely a pore space connected the length of the plug and misrepresentative of the overall formation). Depth – 3222'9".

Porosity and Permeability Analysis of Plugs from Prominent Dopita Field Reservoirs

Weatherford
LABORATORIES

SUMMARY OF ROUTINE CORE ANALYSES RESULTS

Vacuum Dried at 180°F Net Confining Stress: 800 psi

TREK AEC Kansas
Dopita A#16 Well

LKC Zone	Sample Depth, feet	Permeability, millidarcys		Porosity, percent		Grain Density, gm/cc
		to Air	Klinkenberg	Ambient	NCS	
A	3128'2"	0.0014	0.0003	4.1	4.0	2.71
A	3128'9"	4.23	3.20	7.2	7.1	2.71
D	3181'6"	3.63	2.92	8.3	8.2	2.71
D (v)	3182'7"	3.18	2.56	9.1	9.1	2.70
D (v)	3193'9"	0.013	0.0049	0.5	0.5	2.71
E (v)	3211'2"	10.4	8.40	13.6	13.5	2.74
Lower E (v)	3212'10"	0.0011	0.0002	3.3	3.2	2.71
G (v)	3223'3"	111.	99.2	10.6	10.5	2.71
G (v)	3226'0"	2.68	2.16	25.2	25.1	2.71
I	3284'2"	0.713	0.531	7.4	7.3	2.72
I	3288'4"	3.93	3.17	13.9	13.8	2.71
J	3303'10"	0.024	0.011	9.5	9.5	2.73
J (v)	3304'6"	0.113	0.067	11.8	11.7	2.73
K	3325'5"	0.581	0.429	5.5	5.4	2.71
K (v)	3326'4"	0.643	0.480	6.0	5.9	2.70
L	3348'10"	0.210	0.136	2.6	2.6	2.70
	Average values:	8.83	7.70	8.7	8.6	2.71

Figure 16 – Routine core analysis of porosity and permeability from permeability plugs (Weatherford Laboratories, 2013).

The plugs used for the porosity and permeability analysis (Figure 16) all came from high-energy packstones and grainstones within the labeled zones and were chosen by the presence of porosity and/or oil staining when analyzing the core. Within each zone, both porosity and permeability decrease upward, with the majority of the porosity and permeability concentrated in the middle of the zone. This is noticeable in Figure 16. It would appear that the 'E' zone is in an exception in the chart, though the two plugs were extracted from two separate, incomplete, sub-cycles (Figure 13 or Plate 1).

Discussion and Conclusions

The study showed that reservoir development in the Dopita A #16 well is present only in high-energy carbonate rocks in the cycles (highstand-systems tract packstones to grainstones) deposited during regression. Secondary porosity formation in these rocks resulted from meteoric dissolution beneath unconformities in the section. The high frequency glacial eustasy inferred during this time would give each zone in the LKC section the potential for developing porosity. Examination of the columnar section (Figure 13 and Plate 1) indicates that porosity development is dependent on regression. The extent of the regression appears to not have a direct correlation to the amount of porosity. As long as sea-level regressed to a tidal flat environment or shallower, porosity was able to develop by meteoric dissolution beneath unconformities.

It has been estimated that an oil-producing Lansing-Kansas City reservoir in Kansas with three or more wells would have a 75% chance of having some economic potential if waterflooded (Koudele and Wilhite, 1990). In the north end of the Dopita Field a waterflood has already been implemented and is proving to be very successful. Current estimates point to a secondary recovery of .82:1 ratio to their primary recovery (DeGood, 2013). It is highly likely that a flood will work in the south end of the field. Accidental casing leaks in the south end of the field have doubled the monthly production of some leases and immediately dropped production rates when the leaks were fixed.

Plans have already been made to make the Dopita A #16 an injection well as part of a waterflood proposal. Other wells in the field will be converted to injection wells and more wells will possibly be drilled.

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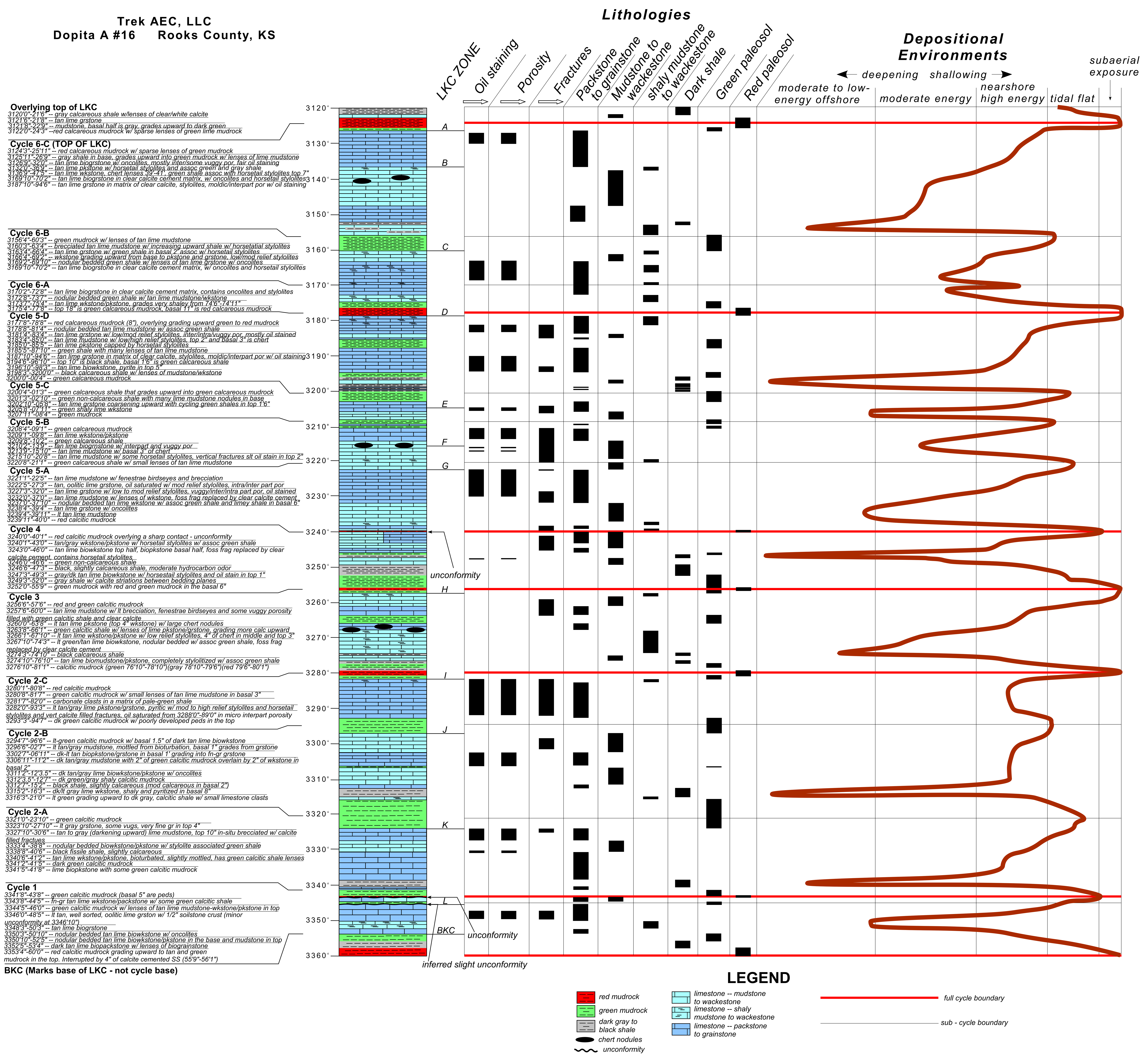
Trek AEC, LLC
Dopita A #16 Rooks County, KS
Lithologies
LKC ZONE
Oil staining
Porosity
Fractures
Packstone to grainstone
Mudstone to wackestone
shaly mudstone to wackestone
Dark shale
Green paleosol
Red paleosol
Depositional Environments
deepening
shallowing
subaerial exposure
moderate to low-energy offshore
moderate energy
nearshore high energy
tidal flat
Overlying top of LKC
3120'0"-21'6" -- gray calcareous shale w/lenses of clear/white calcite
3121'6"-21'8" -- tan lime grstone
3121'8"-22'9" -- mudstone, basal half is gray, grades upward to dark green
3122'0"-24'3" --red calcareous mudrock w/ sparse lenses of green lime mudrock
Cycle 6-C (TOP OF LKC)
3124'3"-25'11" -- red calcareous mudrock w/ sparse lenses of green mudrock
3125'11"-26'9" -- gray shale in base, grades upward into green mudrock w/ lenses of lime mudstone
3126'9"-32'0" -- tan lime biogrstone w/ oncolites, mostly inter/some vuggy por, fair oil staining
3132'0"-36'9" -- tan lime pkstone w/ horsetail stylolites and assoc green and gray shale
3136'9"-47'5" -- tan lime wkstone, chert lenses 39'-41', green shale assoc with horsetail stylolites top 7"
3169'10"-70'2" -- tan lime biogrstone in clear calcite cement matrix, w/ oncolites and horsetail stylolites
3187'10"-94'6" -- tan lime grstone in matrix of clear calcite, stylolites, moldic/interpart por w/ oil staining
Cycle 6-B
3156'4"-60'3" -- green mudrock w/ lenses of tan lime mudstone
3160'3"-63'4" -- brecciated tan lime mudstone w/ increasing upward shale w/ horsetatial stylolites
3163'4"-66'4" -- tan lime grstone w/ green shale in basal 2' assoc w/ horsetail stylolites
3166'4"-69'2" -- wkstone grading upward from base to pkstone and grstone, low/mod relief stylolites
3169'2"-69'10" -- nodular bedded green shale w/ lenses of tan lime grstone w/ oncolites
3169'10"-70'2" -- tan lime biogrstone in clear calcite cement matrix, w/ oncolites and horsetail stylolites
Cycle 6-A
3170'2"-72'8" -- tan lime biogrstone in clear calcite cement matrix, contains oncolites and stylolites
3172'8"-73'7" -- nodular bedded green shale w/ tan lime mudstone/wkstone
3173'7"-75'4" -- tan lime wkstone/pkstone, grades very shaley from 74'6"-74'11"
3175'4"-77'8" -- top 18" is green calcareous mudrock, basal 11" is red calcareous mudrock
Cycle 5-D
3177'8"-78'8" -- red calcareous mudrock (8"), overlying grading upward green to red mudrock
3178'8"-81'4" -- nodular bedded tan lime mudstone w/ assoc green shale
3181'4"-83'4" -- tan lime grstone w/ low/mod relief stylolites, inter/intra/vuggy por, mostly oil stained
3183'4"-85'0" -- tan lime mudstone w/ low/high relief stylolites, top 2" and basal 3" is chert
3185'0"-85'5" -- tan lime pkstone capped by horsetail stylolites
3185'5"-87'10" -- green shale with many lenses of tan lime mudstone
3187'10"-94'6" -- tan lime grstone in matrix of clear calcite, stylolites, moldic/interpart por w/ oil staining
3194'6"-96'10" -- top 10" is black shale, basal 1'6" is green calcareous shale
3196'10"-98'3" -- tan lime biowkstone, pyrite in top 5"
3198'3"-3200'0" -- black calcareous shale w/ lenses of mudstone/wkstone
3200'0"-00'4" -- green calcareous mudrock
Cycle 5-C
3200'4"-01'3" -- green calcareous shale that grades upward into green calcareous mudrock
3201'3"-02'10" -- green non-calcareous shale with many lime mudstone nodules in base
3202'10"-05'8" -- tan lime grstone coarsening upward with cycling green shales in top 1'6"
3205'8"-07'11" -- green shaly lime wkstone
3207'11"-08'4" -- green mudrock
Cycle 5-B
3208'4"-09'1" -- green calcareous mudrock
3209'1"-09'8" -- tan lime wkstone/pkstone
3209'8"-10'2" -- green calcareous shale
3210'2"-13'9" -- tan lime biogrnstone w/ interpart and vuggy por
3213'9"-15'10" -- tan lime mudstone w/ basal 3" of chert
3215'10"-20'8" -- tan lime mudstone w/ some horsetail stylolites, vertical fractures slt oil stain in top 2"
3220'8"-21'1" -- green calcareous shale w/ small lenses of tan lime mudstone
Cycle 5-A
3221'1"-22'5" -- tan lime mudstone w/ fenestrae birdseyes and brecciation
3222'5"-27'3" -- tan, oolitic lime grstone, oil saturated w/ mod relief stylolites, intra/inter part por
3227'3"-32'0" -- tan lime grstone w/ low to mod relief stylolites, vuggy/inter/intra part por, oil stained
3232'0"-37'0" -- tan lime mudstone w/ lenses of wkstone, foss frag replaced by clear calcite cement
3237'0"-37'10" -- nodular bedded tan lime wkstone w/ assoc green shale and limey shale in basal 6"
3238'4"-39'4" -- tan lime grstone w/ oncolites
3239'4"-39'11" -- lt tan lime mudstone
3239'11"-40'0" -- red calcitic mudrock
Cycle 4
3240'0"-40'1" -- red calcitic mudrock overlying a sharp contact - unconformity
3240'1"-43'0" -- tan/gray wkstone/pkstone w/ horsetail stylolites w/ assoc green shale
3243'0"-46'0" -- tan lime biowkstone top half, biopkstone basal half, foss frag replaced by clear calcite cement, contains horsetail stylolites
3246'0"-46'6" -- green non-calcareous shale
3246'6"-47'3" -- black, slightly calcareous shale, moderate hydrocarbon odor
3247'3"-49'3" -- gray/dk tan lime biowkstone w/ horsestail stylolites and oil stain in top 1"
3249'3"-52'0" -- gray shale w/ calcite striations between bedding planes
3252'0"-55'9" -- green mudrock with red and green mudrock in the basal 6"
Cycle 3
3256'6"-57'6" -- red and green calcitic mudrock
3257'6"-60'0" -- tan lime mudstone w/ lt brecciation, fenestrae birdseyes and some vuggy porosity filled with green calcitic shale and clear calcite
3260'0"-63'8" -- lt tan lime pkstone (top 4" wkstone) w/ large chert nodules
3263'8"-66'1" -- green calcitic shale w/ lenses of lime pkstone/grstone, grading more calc upward
3266'1"-67'10" -- lt tan lime wkstone/pkstone w/ low relief stylolites, 4" of chert in middle and top 3"
3267'10"-74'3" -- lt green/tan lime biowkstone, nodular bedded w/ assoc green shale, foss frag replaced by clear calcite cement
3274'3"-74'10" -- black calcareous shale
3274'10"-76'10" -- tan lime biomudstone/pkstone, completely stylolitized w/ assoc green shale
3276'10"-81'1" -- calcitic mudrock (green 76'10"-78'10")(gray 78'10"-79'6")(red 79'6"-80'1")
Cycle 2-C
3280'1"-80'8" -- red calcitic mudrock
3280'8"-81'7" -- green calcitic mudrock w/ small lenses of tan lime mudstone in basal 3"
3281'7"-82'0" -- carbonate clasts in a matrix of pale-green shale
3282'0"-93'3" -- lt tan/gray lime pkstone/grstone, pyritic w/ mod to high relief stylolites and horsetail stylolites and vert calcite filled fractures, oil saturated from 3288'0"-89'0" in micro interpart porosity
3293"3"-94'7" -- dk green calcitic mudrock w/ poorly developed peds in the top
Cycle 2-B
3294'7"-96'6" -- lt-green calcitic mudrock w/ basal 1.5" of dark tan lime biowkstone
3296'6"-02'7" -- lt tan/gray mudstone, mottled from bioturbation, basal 1" grades from grstone
3302'7"-06'11" -- dk-lt tan biopkstone/grstone in basal 1' grading into fn-gr grstone
3306'11"-11'2" -- dk tan/gray mudstone with 2" of green calcitic mudrock overlain by 2" of wkstone in basal 2"
3311'2"-12'3.5" -- dk tan/gray lime biowkstone/pkstone w/ oncolites
3312'3.5"-12'7" -- dk green/gray shaly calcitic mudrock
3312'7"-15'2" -- black shale, slightly calcareous (mod calcareous in basal 2")
3315'2"-16'3" -- dk/lt gray lime wkstone, shaly and pyritized in basal 8"
3316'3"-21'0" -- lt green grading upward to dk gray, calcitic shale w/ small limestone clasts
Cycle 2-A
3321'0"-23'10" -- green calcitic mudrock
3323'10"-27'10" -- lt gray grstone, some vugs, very fine gr in top 4"
3327'10"-30'6" -- tan to gray (darkening upward) lime mudstone, top 10" in-situ brecciated w/ calcite filled fractues
3333'4"-38'8" -- nodular bedded biowkstone/pkstone w/ stylolite associated green shale
3338'8"-40'6" -- black fissile shale, slightly calcareous
3340'6"-41'2" -- tan lime wkstone/pkstone, bioturbated, slightly mottled, has green calcitic shale lenses
3341'2"-41'5" -- dark green calcitic mudrock
3341'5"-41'8" -- lime biopkstone with some green calcitic mudrock
Cycle 1
3341'8"-43'8" -- green calcitic mudrock (basal 5" are peds)
3343'8"-44'5" -- fn-gr tan lime wkstone/packstone w/ some green calcitic shale
3344'5"-46'0" -- green calcitic mudrock w/ lenses of tan lime mudstone-wkstone/pkstone in top
3346'0"-48'5" -- lt tan, well sorted, oolitic lime grston w/ 1/2" soilstone crust (minor unconformity at 3346'10")
3348'3"-50'3" -- tan lime biogrstone
3350'3"-50'10" -- nodular bedded tan lime biowkstone w/ oncolites
3350'10"-52'5" -- nodular bedded tan lime biowkstone/pkstone in the base and mudstone in top
3352'5"-53'4" -- dark tan lime biopackstone w/ lenses of biograinstone
3353'4"-60'0" -- red calcitic mudrock grading upward to tan and green mudrock in the top. Interrupted by 4" of calcite cemented SS (55'9"-56'1")
BKC (Marks base of LKC - not cycle base)
3120'
3130'
3140'
3150'
3160'
3170'
3180'
3190'
3200'
3210'
3220'
3230'
3240'
3250'
3260'
3270'
3280'
3290'
3300'
3310'
3320'
3330'
3340'
3350'
3360'
A
B
C
D
E
F
G
H
I
J
K
L
BKC
unconformity
unconformity
inferred slight unconformity
LEGEND
red mudrock
green mudrock
dark gray to black shale
chert nodules
unconformity
limestone -- mudstone to wackestone
limestone -- shaly mudstone to wackestone
limestone -- packstone to grainstone
full cycle boundary
sub - cycle boundary