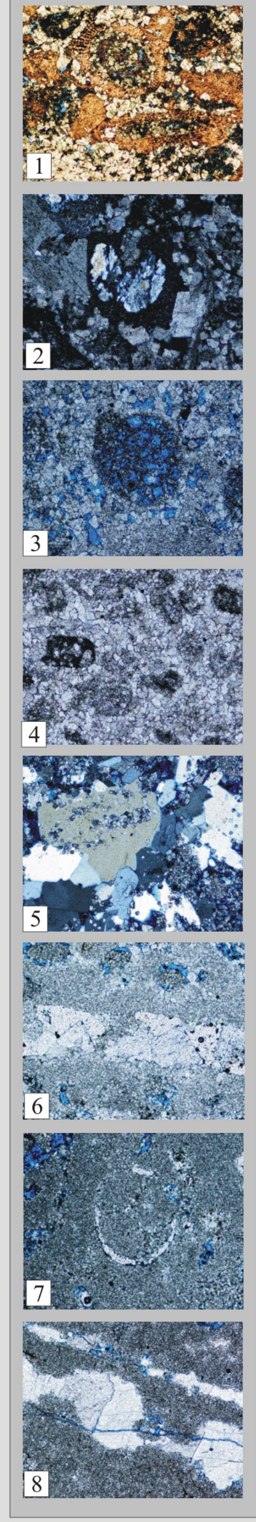
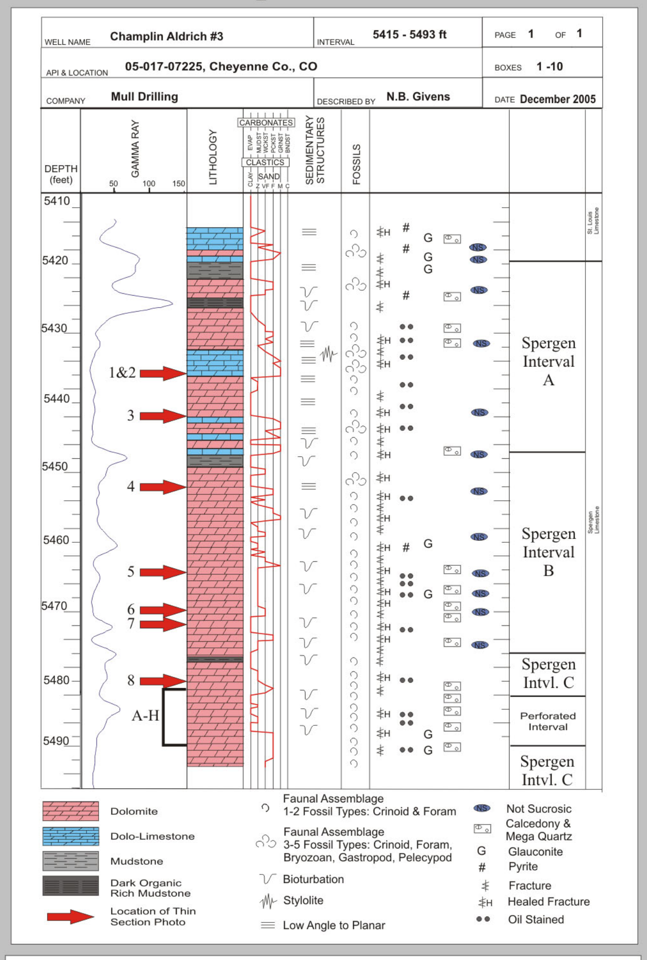
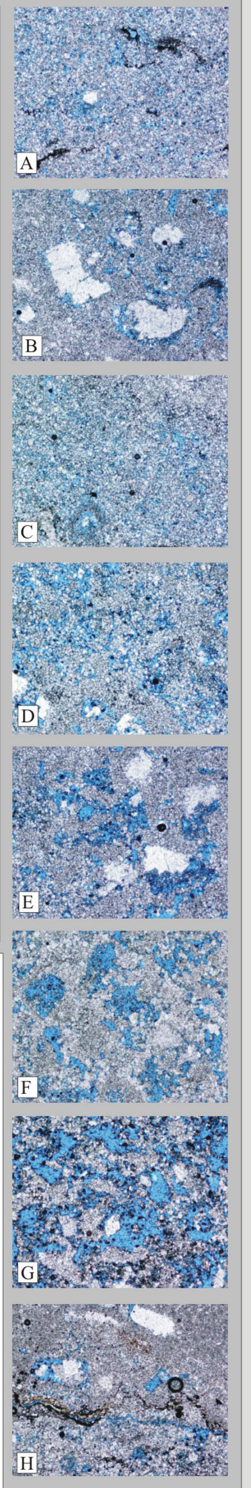
Core Description and Thin Section Analysis

Champlin Aldrich #3





Perf Interval



1. (5435.2) Stained slide showing calcite (pink) fossil fragments, cement, dolomite (colorless) and solution-enhanced porosity (blue) (4x).

2. (5435.2) Silica replacement of crinoid fragment (crossed polars) (4x).

3. (5441.3) Very fine to medium crystalline dolomite with foram moldic and solution-enhanced porosity (4x).

4. (5451.2) Foram rich wacke-packstone with no visible solution-enhanced porosity (4x).

5. (5463.7) Megaquartz solution-enhanced void fill and fine crystalline dolomite (crossed Nicols) (4x).

6. (5469.5) Baroque dolomite replacement (4x).

7. (5470.8) Baroque dolomite replacement of fossil fragment (4x).

8. (5479.9) Baroque dolomite fill of solution-enhanced fracture (4x).

A. (5482.4) Area of higher percentage of solution-enhanced porosity within a mudstone (4x).

B. (5484.5) Baroque dolomite filling solution-enhanced porosity (4x).

C. (5485.5) Very fine crystalline dolomite with small solution-enhanced porosity (4x).

D. (5486.2) Baroque dolomite filling solution-enhanced porosity (4x).

E. (5486.4) Large solution-enhanced and possibly moldic porosity filled by baroque dolomite (4x).

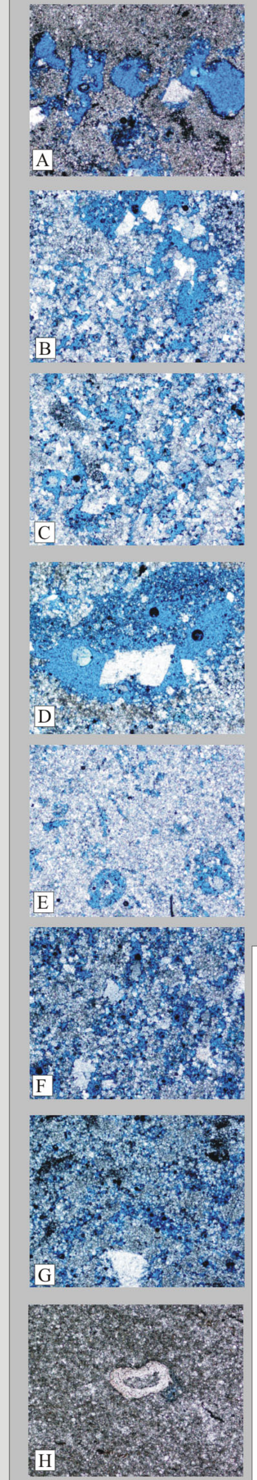
F. (5487.2) Large solution-enhanced and moldic porosity, less baroque dolomite (4x).

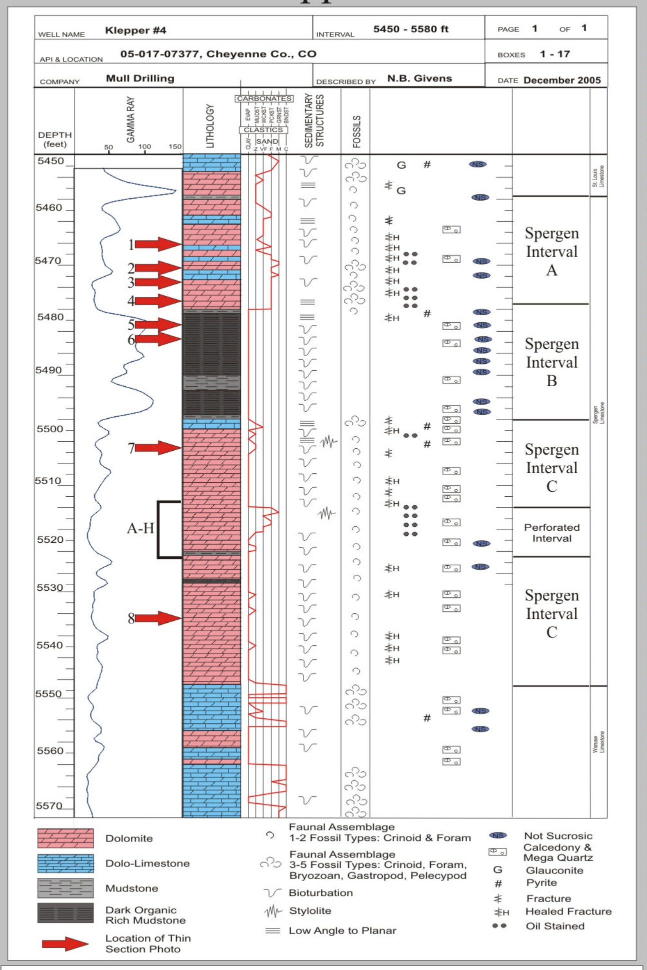
G. (5487.8) Large solution-enhanced and moldic porosity and some baroque dolomite (4x).

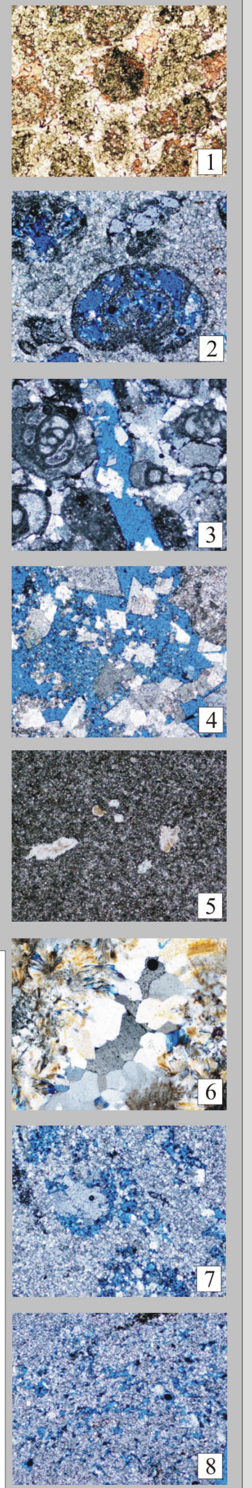
H. (5488.3) Less solution-enhanced porosity with baroque dolomite fill (4x).

Klepper #4

Perf Interval







A. (5514.2) Very fine crystalline dolomite and solution-enhanced porosity (4x).

B. (5415.4) Fine to medium crystalline dolomite and baroque dolomite filling solution-enhanced porosity (crossed Nicols) (4x).

C. (5416.5) Meduim crystalline dolomite and baroque dolomite filling solution-enhanced porosity (crossed Nicols) (4x).

D. (5418.8) Large solution-enhanced porosity with baroque dolomite fill (crossed Nicols) (4x).

E. (5419.6) Moldic and solution-enhanced porosity in a finely crystalline dolomite (crossed Nicols) (4x).

F. (5420.7) Solution-enhanced porostiy and baroque dolomite fill (crossed Nicol) (4x).

G. (5422.7) Solution-enhanced porosity (crossed Nicols) (4x).

H. (5479.9) Fossil fragment in very finely crystalline dolomite mudstone (4x).

1. (5466.5) Stained slide showing calcite (pink) fossil fragments and cement, dolomite (colorless), no visible solution-enhanced porosity (4x).

2. (5470.5) Foram moldic porosity (4x).

3. (5472.7) Baroque dolomite in fracture in a foram grainstone (crossed Nicols) (4x).

4. (5477.5) Large solution-enhanced porosity with baroque dolomite (4x).

5. (5480.4) Calcedony crystals in an organic rich mudstone (4x).

6. (5481.2) Calcedony (brown), mega-quartz (colorless) and baroque dolomite (colorless - center) solution-enhanced void fill (crossed Nicols) (4x).

7. (5502.7) Fine to medium crystalline dolomite with baroque dolomite filling solution-enhanced porosity (4x).

8. (5534.5) Smaller solution-enhanced porosity in a fine crystalline dolomite (4x).

Core Description

Core description reveals a complex history for the reservoir. Based on the faunal and lithofacies assemblages, the depositional environment is interpreted to be on a normal marine shelf with a migrating shoal. Lithofacies range from mudstone to grainstone; however, the entire section has been heavily dolomitized, obscuring primary depositional structures. Porosity is intercrystalline, moldic, and solution enhanced. Moldic porosity is mostly of foraminifera, crinoids, and bryozoans. Fractures identified in the cores are typically filled with baroque dolomite.

Klepper #4 (K 4) producing zone has larger, more well-connected pores, whereas the Champlin Aldrich #3 (CA 3) has more moldic porosity and fractures.

Core of the CA 3 contains very little of the organic rich mudstone, whereas the K 4 contains a large section of organic rich mudstone. This differing amount of organic rich mudstone can be seen in other wells across the field; however, amount of organic rich mudstone apparently has no effect on production.

Thin Section Analysis

Two hundred representative samples from the Spergen from the two cores were taken and made into1"x 2" thin sections. Ninety-four thin sections were stained using the Dickson Formula (1965). This formula uses Potassium ferricyanide and Alizarin Red S to help differentiate between calcite and dolomite. It also will differentiate between high and low iron content in the calcite and dolomite. Calcite will turn pink to purple, with respect to low or high iron content, and dolomite will either stay colorless (no iron) or turn a turquoise blue (high iron content). The staining revealed a few 1' to 2' intervals within each core containing calcite. These intervals (referred to as dolo-limestones) occur at a range of depths. The pattern of selective dolomitization is not fully understood at this time.

Thin sections were used in the development of the following hypothesized paragenesis of the Spergen: 1.Deposition of mudstone to fossiliferous grainstone in a migrating shoal. 2. Begin first stage of dolomitization, replacement of lithofacies and dissolution to create solution-enhanced and moldic porosity. 3. Hydrothermal fluids, possibly from the Las Animas Arch feature, migrating through the Spergen and precipitating calcedony, megaquartz, and baroque dolomite, all three of which indicate hydrothermally active areas.

Core Petrophysical Properties

Lithofacies, Permeability, Porosity

Lithofacies and early diagenesis are major controls on permeability (k) and porosity (ϕ) despite complex diagenetic overprinting k and ϕ decrease with decreasing grain/mold size from packstone to mudstone (a trend exhibited by other Mississippian carbonates). **Figure 1**

The permeability-porosity trends for all lithofacies for the Kansas Mississippian and Cheyenne Wells are approximately bounded within 2.5 orders of magnitude by trendlines defined by:

$$\log \boldsymbol{k}_{in\ situ} = 0.25\ \phi_{in\ situ} - 2.2$$

$$\log \boldsymbol{k}_{in\ situ} = 0.25\ \phi_{in\ situ} - 4.9$$

Between these bounding trends each lithofacies exhibits a generally unique range of k and ϕ which together define a continuous trend, with k decreasing with decreasing grain/mold size for any given porosity. At Cheyenne Wells each lithofacies generally exhibits a unique sub-parallel trend to the general trend:

$$k_{in\ situ} = A\phi^{B}$$

where $A=3x10^{-6}x3^{Lith}$ and B =~3.45, and where Lith represents an integer classification of the lithfacies (0-mudstone, 1-mud-wacketone, 2-wackestone, 3-wacke-packstone, 4-packstone, 5-pack-grainstone). **Figure 2**

Comparison of full-diameter and plug permeability-porosity trends indicates that fracturing plays little role in permeability at this scale. Differences between plug and full-diameter permeabilities reflect effects of confining stress difference. **Figures 3 and 4**

Permeability values for the CA 3 and K 4 wells are similar at any given porosity except for some mudstone-wackestone and wackestone samples. The significantly better permeabilities of the CA 3 samples may result from improved moldic porosity connectivity. This is still under investigation.

Figure 5 (K 4 has lighter colored symbols and CA 3 has darker symbols on graph).

Figure 1

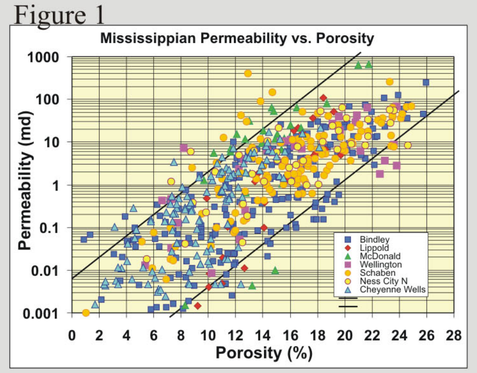


Figure 2

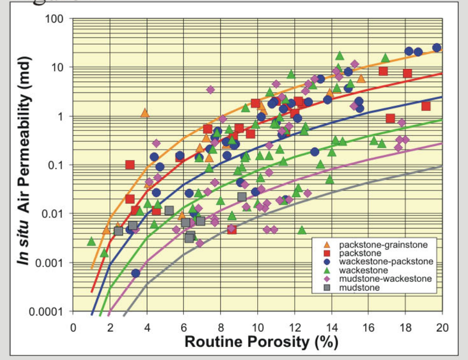


Figure 3

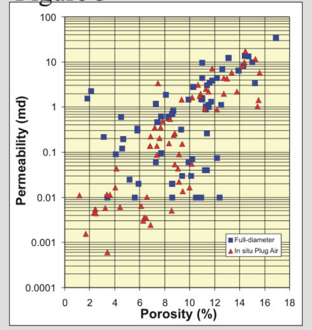
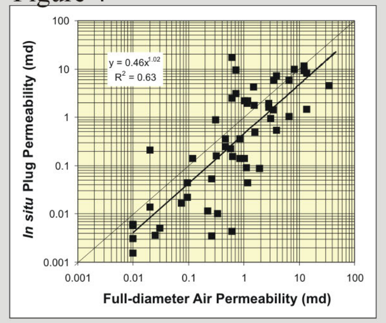
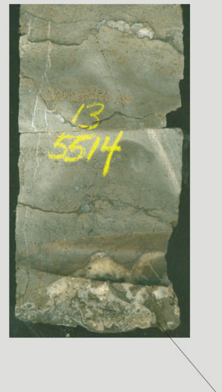


Figure 4



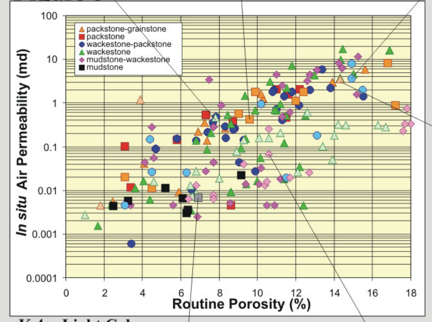
Wackestone



Packstone

Wackestone-Packstone

Figure 5



K 4 = Light Colors
CA 3 = Dark Colors

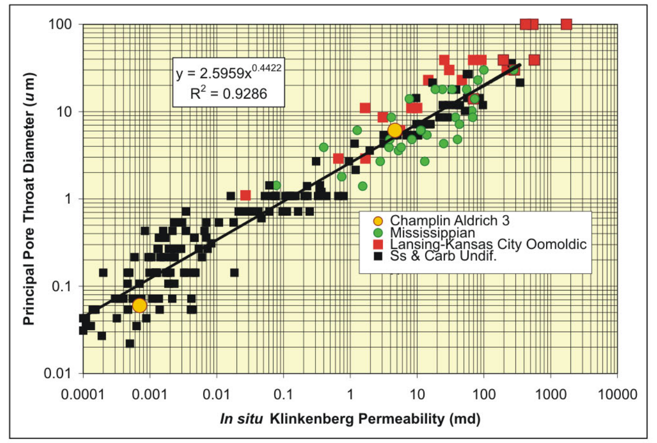
Packstone-Grainstone

Mudstone

Mudstone-Wackestone

Permeability and Pore Throats

Though permeability is shown correlated with porosity, variables that control permeability in Mississippian rocks include pore throat size and distribution, grain size distribution, moldic pore size and packing, and moldic pore connectivity. Porosity is only one of the variables controlling permeability and bivariate correlation therefore relies on the correlation between porosity and the other controlling variables. A crossplot of permeability and principal pore throat diameter (PPTD) illustrates the control PPTD exerts on permeability. Two Cheyenne Wells samples from the CA 3, a mudstone-wackestone (k=0.0025 md *in situ* air, k = 0.0007 md *in situ* Klinkenberg) and packstone ((k=5.67 md *in situ* air, k = 4.66 md *in situ* Klinkenberg), exhibit PPTD consistent with other other rocks including Mississippian rocks.



Capillary Pressure

Capillary pressures and corresponding water saturations (S_w) vary among lithofacies, and with porosity/permeability and gas column height. Threshold entry pressures and corresponding heights above free water level are well correlated with permeability and consistent with the relationship between pore throat size and permeability.

Capillary pressure curves for a mudstone-wackestone and packstone illustrate approximate upper and lower limits for rocks from the Cheyenne Wells field. Permeable packstones exhibit sufficiently low entry pressure (and equivalent oil column height). These pressures are insufficient for low permeability mudstones, which are water saturated (S_w=100%).

Pore throat size distributions are consistent with unimodal distribution indicating that moldic porosity is only accessed through matrix porosity.