Characterization and Modeling of the Mississippian Lodgepole Carbonate Mound Complex in Stark County, North Dakota, Using Macrofacies and Microfacies Indicators

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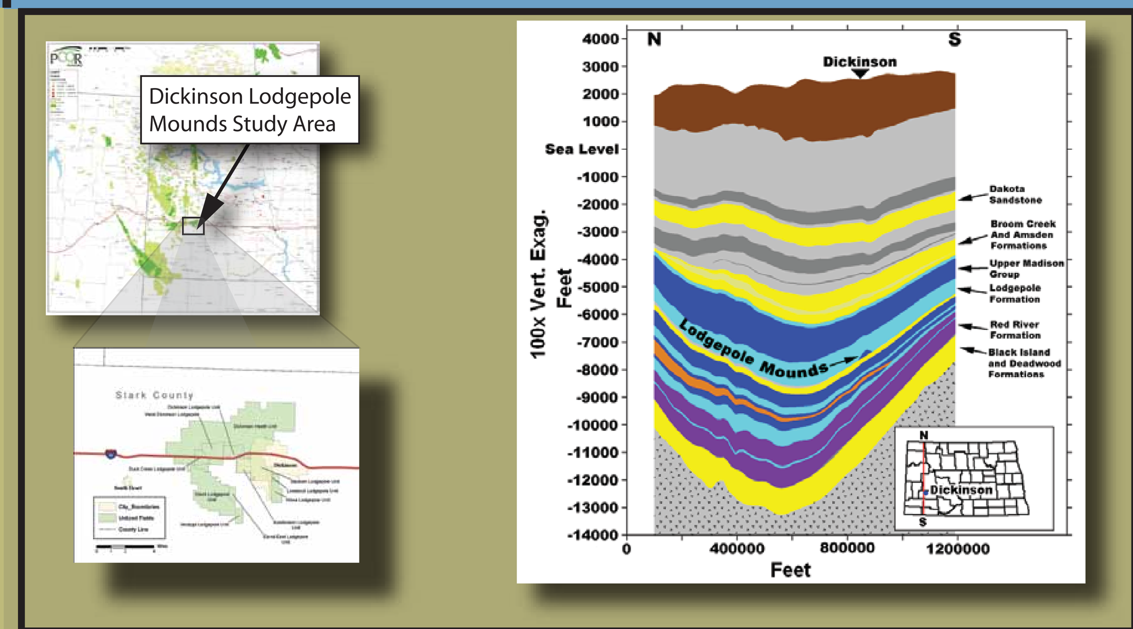
ABSTRACT

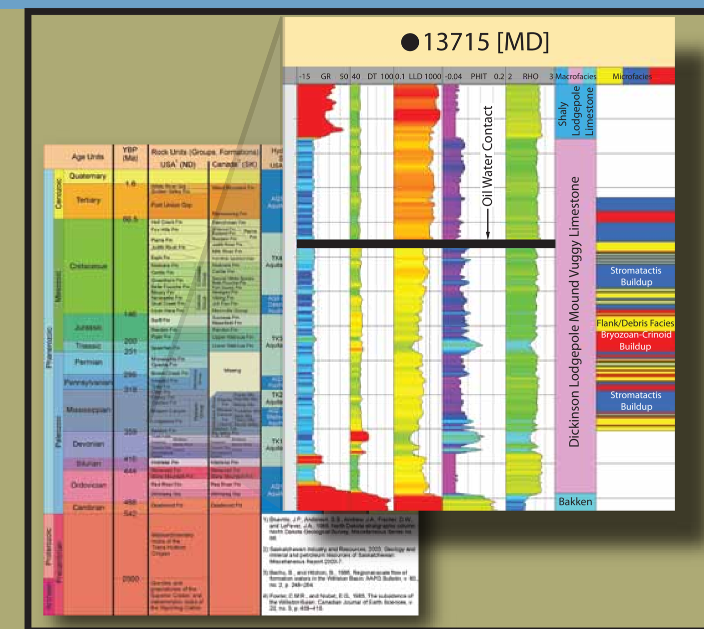
The Stark County Lodgepole mound complex in North Dakota is part of the Lower Mississippian Lodgepole Formation and is a fractured, vuggy carbonate sequence with a sharp macrofacies transition zone separating the shaly lower Lodgepole carbonate and the mound complex clean carbonate. The Lower Lodgepole mounds, sometimes referred to as Waulsortian or Waulsortian-like mounds, range from 250 to 320 ft thick and contain a heterogeneous internal structure, facies, and diagenetic alterations. These mounds have undergone multistage fracturing, assumed to be greatest along the flanks of the mounds because of their steep nature and differential compaction rates. Major fracturing along the base of the mounds may be due to differential stresses and other tectonic controls that would also be a source for fracturing throughout the rest of the mound complex. Traditional drill stem tests indicate the mounds have permeability ranging from 2 mD to a maximum of 2000 mD, and wells 2 to 3 miles apart within the same pool show a pressure response within just a few minutes, indicating a high degree of transmissivity within the complex. Three-dimensional sequential indicator simulation proved to be more effective than traditional surface modeling in delineating the mound surface and shape. Log indicator values were formed representing either mound macrofacies or shaly Lodgepole macrofacies, and sequential indicator simulations were performed to find the most probable volumetric structure of the mound. This provided the active domain for the mound reservoir porosity and permeability model. Upon the development of a porosity and permeability transform for the mounds, it appeared that either compartmentalization or major facies changes are occurring in the mounds. Viewing of the cores suggests that there are at least three microfacies rock fabrics within the mounds: debris flank deposits, bryozoan–crinoid buildup, and a dominant stromatactis algal buildup. High-, mid-, and low-case porosity and permeability transforms were produced for each microfacies. By using a combination of macrofacies mound delineation, mound microfacies rock fabric classification, and a dual porosity and permeability system, a more representative reservoir model was produced.

The Plains CO_2 Reduction (PCOR) Partnership is a collaborative program assessing regional CO_2 storage opportunities. Its primary sponsor is the U.S. Department of Energy National Energy Technology Laboratory, with additional support from its more than 80 partners.

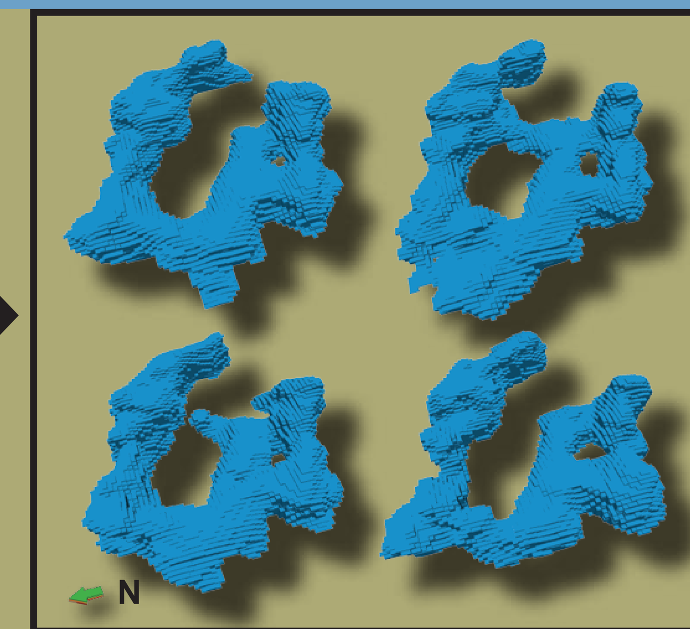
CARBONATE MOUND CHARACTERIZATION AND MODELING WORKFLOW



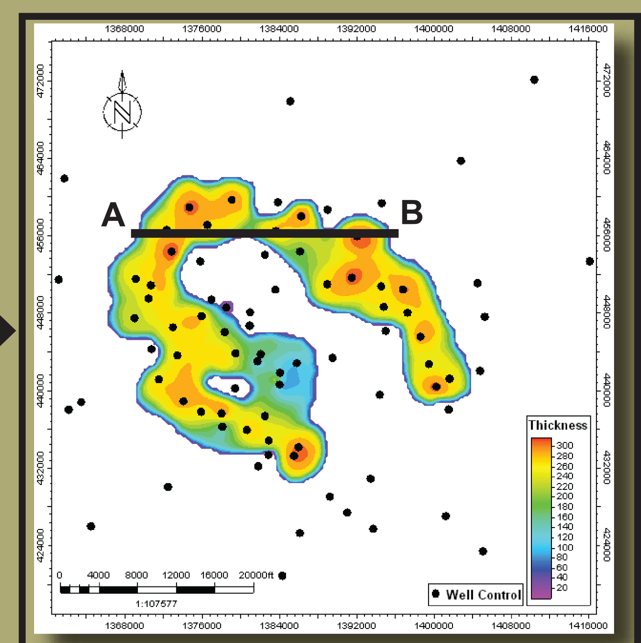
As part of the PCOR Partnership Phase II site selection process, CO_2 sources and geological sinks were evaluated and the Dickinson Lodgepole mounds (DLM) were selected as a potential CO_2 storage and enhanced oil recovery (EOR) site.



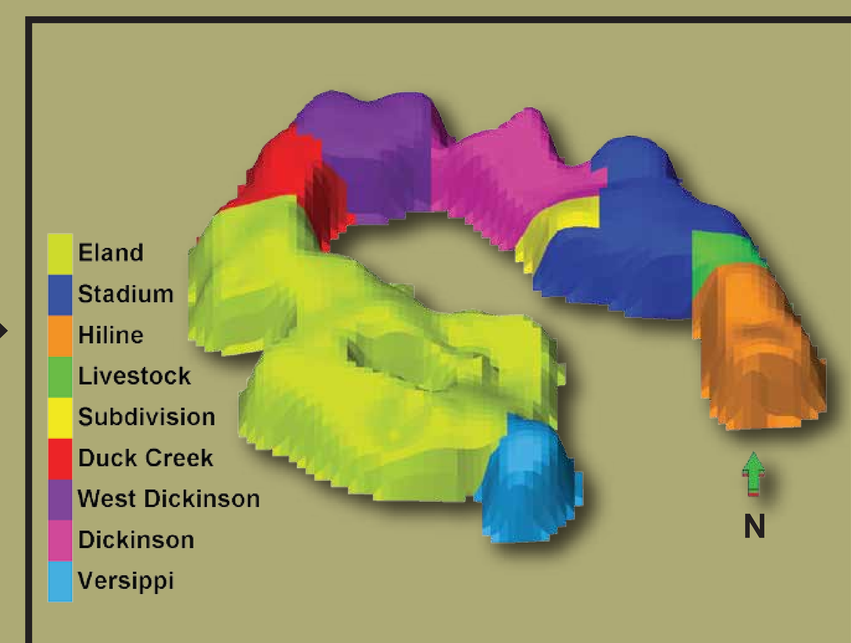
Core data, core images, and wireline logs were used to determine macrofacies and microfacies logs, formation tops, and the oil–water contact (OWC).



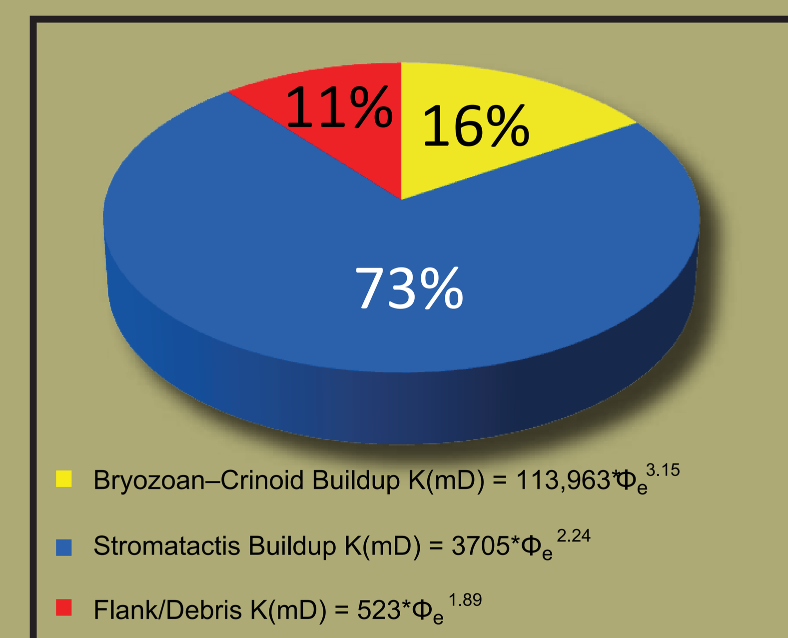
A total of 201 macrofacies realizations were produced to form the most probable volume and thickness.



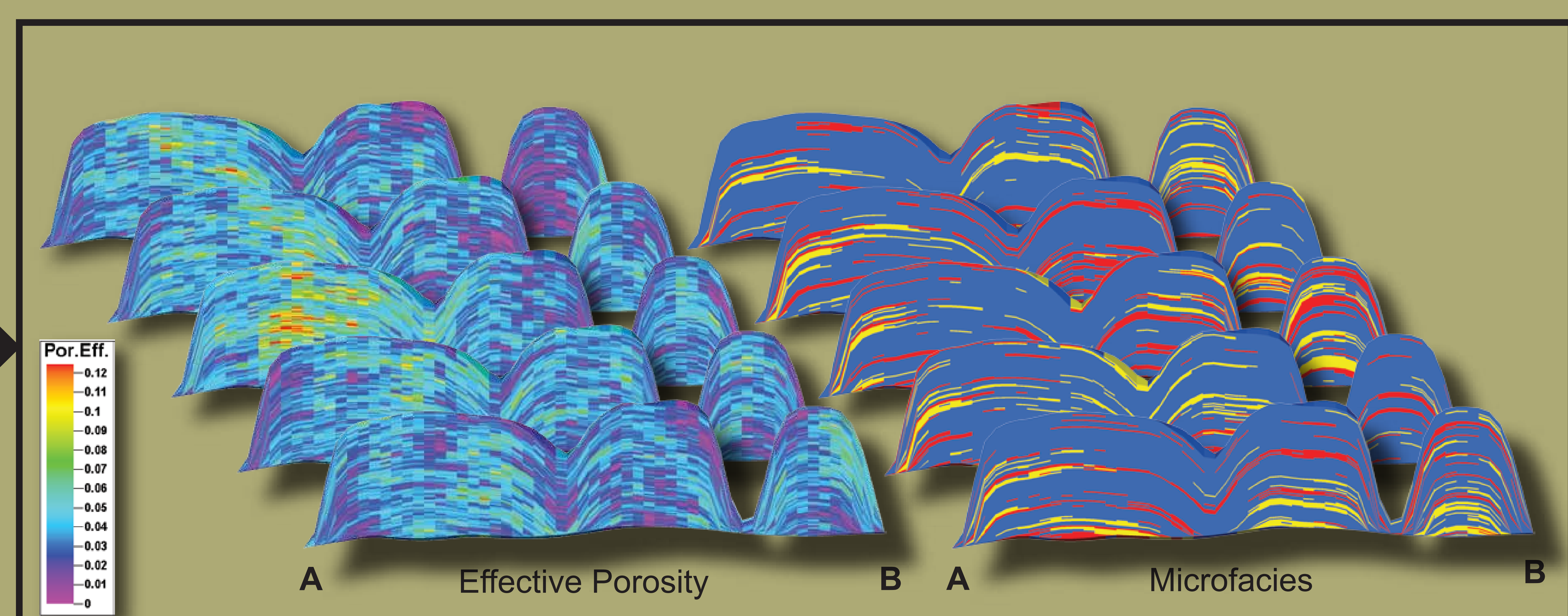
Gross thickness map of the DLM produced from the most probable indicator macrofacies model.



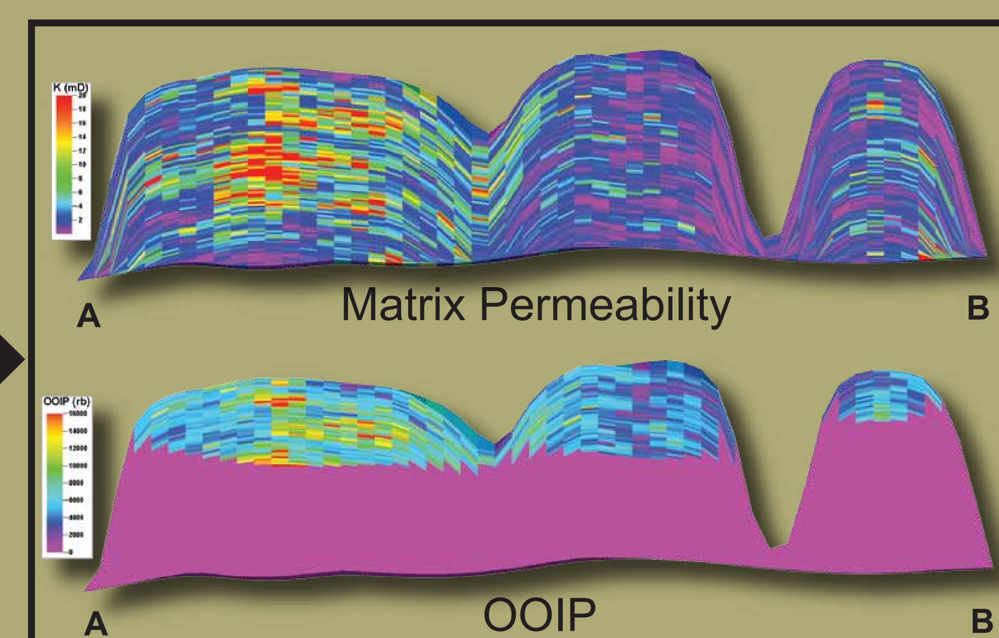
3-D representation of the DLM with color-coded unitized fields.



Microfacies proportions with midcase porosity to matrix permeability transforms.

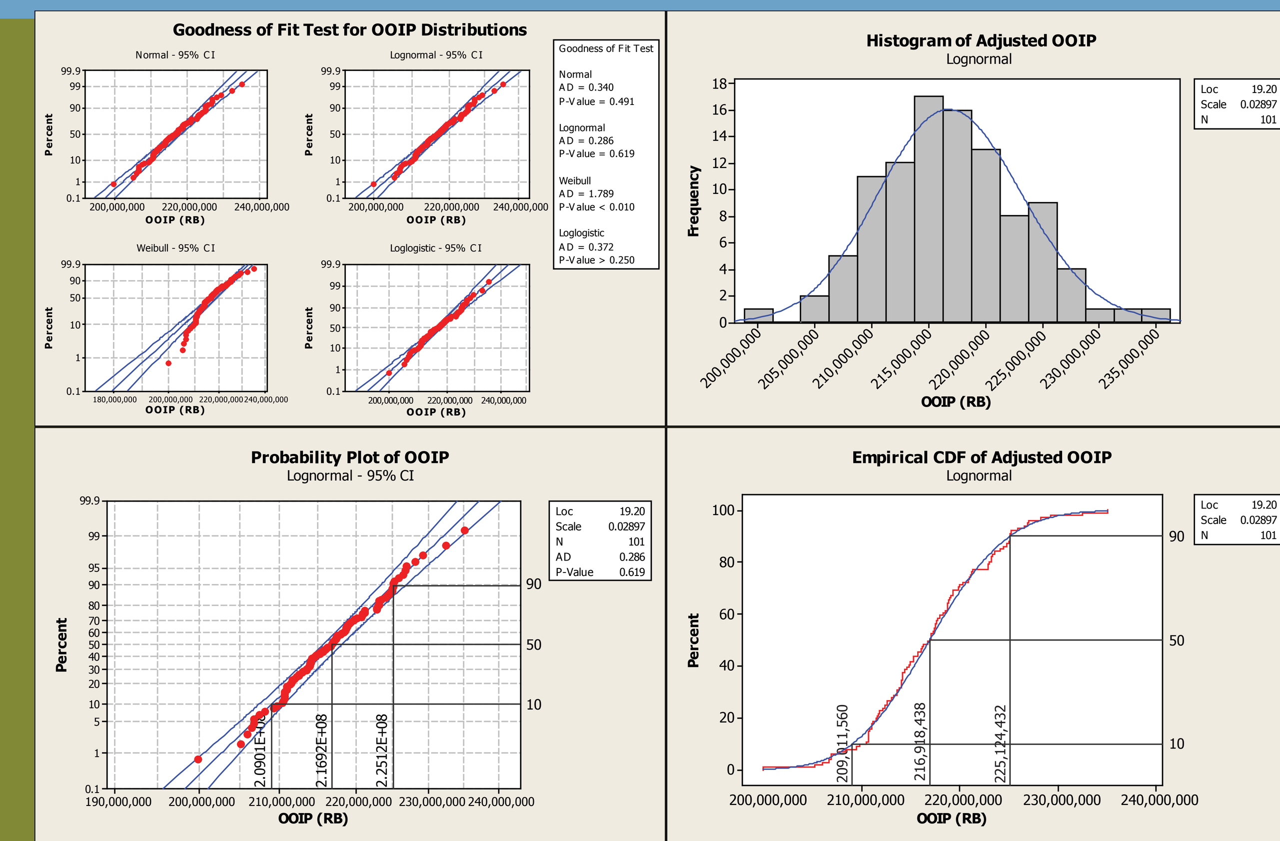


Five cross sections of equiprobable effective porosity and microfacies realizations. A total of 101 porosity and microfacies realizations were produced. Above the OWC, separate disconnected vugs contained all connate water, so effective pore volume above the OWC was used to compute original oil in place (OOIP).



Cross-sectional output for reservoir logistics and dynamic model. An indicator volume was produced representing volume of oil (ind=1) and volume of water (ind=0). This volume was then multiplied by effective pore volume to acquire OOIP.

ESTIMATION OF OOIP, CO_2 INCREMENTAL OIL RECOVERY (IOR), AND CO_2 STORAGE CAPACITY



101 OOIP volumes were plotted, and goodness-of-fit tests suggested that the distribution was lognormal, which is common for uncertainty ranges.

DLM Unitized Fields OOIP with Produced Oil per Field						Potential IOR			CO_2 Volume and Mass Required for EOR		
		MMRB				MMRB			Bcf (MMtons)		
		Produced Oil	Log Distribution			0.1 R_f	0.125 R_f	0.15 R_f			
Field	B_o		P90	P50	P10	P90	P50	P10	P90	P50	P10
Eland	1.29	35.74	84.68	89.99	95.63	8.47	11.25	14.34	42.34 (2.45)	73.11 (4.24)	114.76 (6.65)
Stadium	1.35	15.13	26.22	28.79	31.63	2.62	3.60	4.74	13.11 (0.76)	23.4 (1.36)	37.95 (2.2)
Dickinson	1.29	8.83	18.13	22.12	26.99	1.81	2.77	4.05	9.07 (0.53)	17.97 (1.04)	32.39 (1.88)
West Dickinson	1.29	6.59	27.59	30.39	33.47	2.76	3.80	5.02	13.8 (0.8)	24.69 (1.43)	40.17 (2.33)
Hiline	1.35	2.28	20.01	22.79	25.96	2.00	2.85	3.89	10.01 (0.58)	18.52 (1.07)	31.15 (1.81)
Duck Creek	1.29	1.97	7.15	7.98	8.91	0.71	1.00	1.34	3.57 (0.21)	6.48 (0.38)	10.69 (0.62)
Versippi	1.35	0.72	8.50	9.69	11.04	0.85	1.21	1.66	4.25 (0.25)	7.87 (0.46)	13.25 (0.77)
Livestock	1.32	0.28	4.46	5.36	6.43	0.45	0.67	0.97	2.23 (0.13)	4.35 (0.25)	7.72 (0.45)
Subdivision	1.36	0.23	4.11	5.05	6.20	0.41	0.63	0.93	2.06 (0.12)	4.1 (0.24)	7.44 (0.43)
Total	1.32	71.78	200.85	222.16	246.27	20.09	27.77	36.94	100.43 (5.83)	180.51 (10.47)	295.52 (17.14)

B_o = Formation Volume Factor and R_f= Recovery Factor

A distribution was produced for each field, and summing the totals shows a greater range of uncertainty than a distribution for the whole mound complex, suggesting better local accuracy. Volume of CO_2 required was calculated for a range of recovery factors from 10% to 15% using the equation:

$$V_{CO_2r} = \text{OOIP} \times R_f \times \frac{V_{CO_2}}{V_{Oil}}$$

Where V_{CO_2r} is the necessary volume of CO_2 to achieve EOR potential (in Mcf), Rf is the expected recovery factor of the IOR, and $\frac{V_{CO_2}}{V_{Oil}}$ is the ratio of CO_2 injected to oil produced (Mcf/STB, ranging from 5000 to 8000).

SUMMARY

A model was produced showing the DLM as a composite mud ridge, and the mounds were examined and compared to similar structures from around the world. The model was used to calculate revised estimates of OOIP through the integration of historic production data and macro- and microfacies modeling. The DLM have been identified as having a high potential for CO_2 EOR, with estimated incremental recovery in the 20- to 37-million-barrel range and associated storage of 6 to 17 million tons of CO_2.

References:

Knudsen, D.J., Bremer, J.M., Gorecki, C.D., Sorensen, J.A., Smith, S.A., Steadman E.N., and Harju, J.A., 2009, Site characterization of the Dickinson Lodgepole mounds for potential CO_2 enhanced oil recovery: DOE Cooperative Agreement No. DE-FC26-05NT42592.