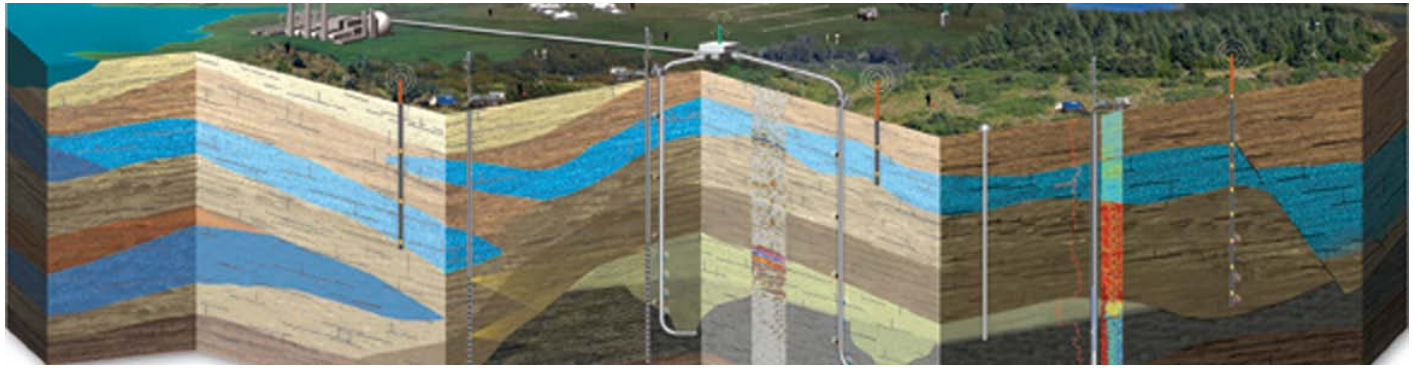

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Two Elk Energy Park Carbon Site Characterization Study

Preliminary Geologic Model—Update

DOE NETL Annual Meeting November, 15-17, 2011

November 17, 2011

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Two Elk Project Location

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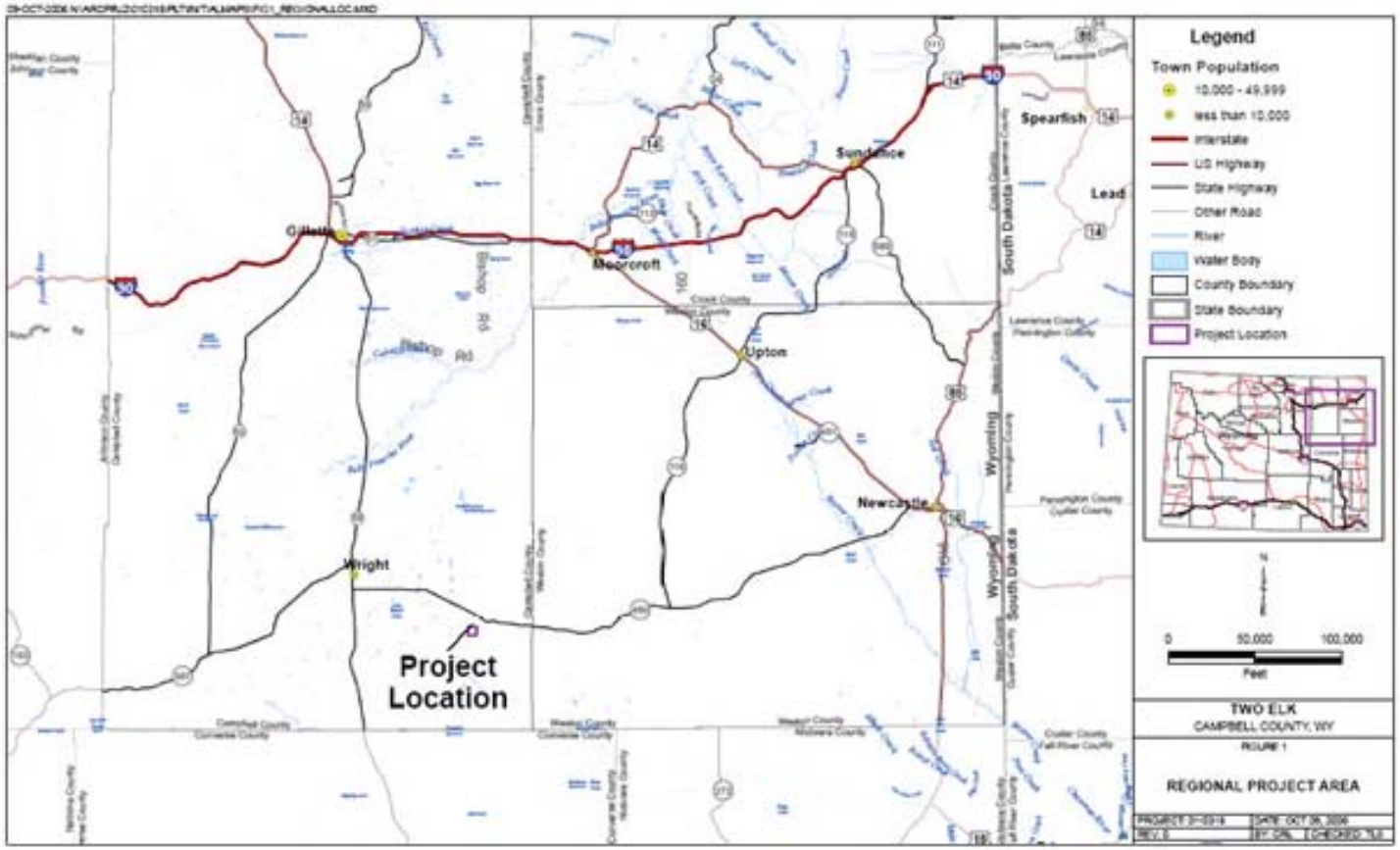

Work Flow and Project Integration

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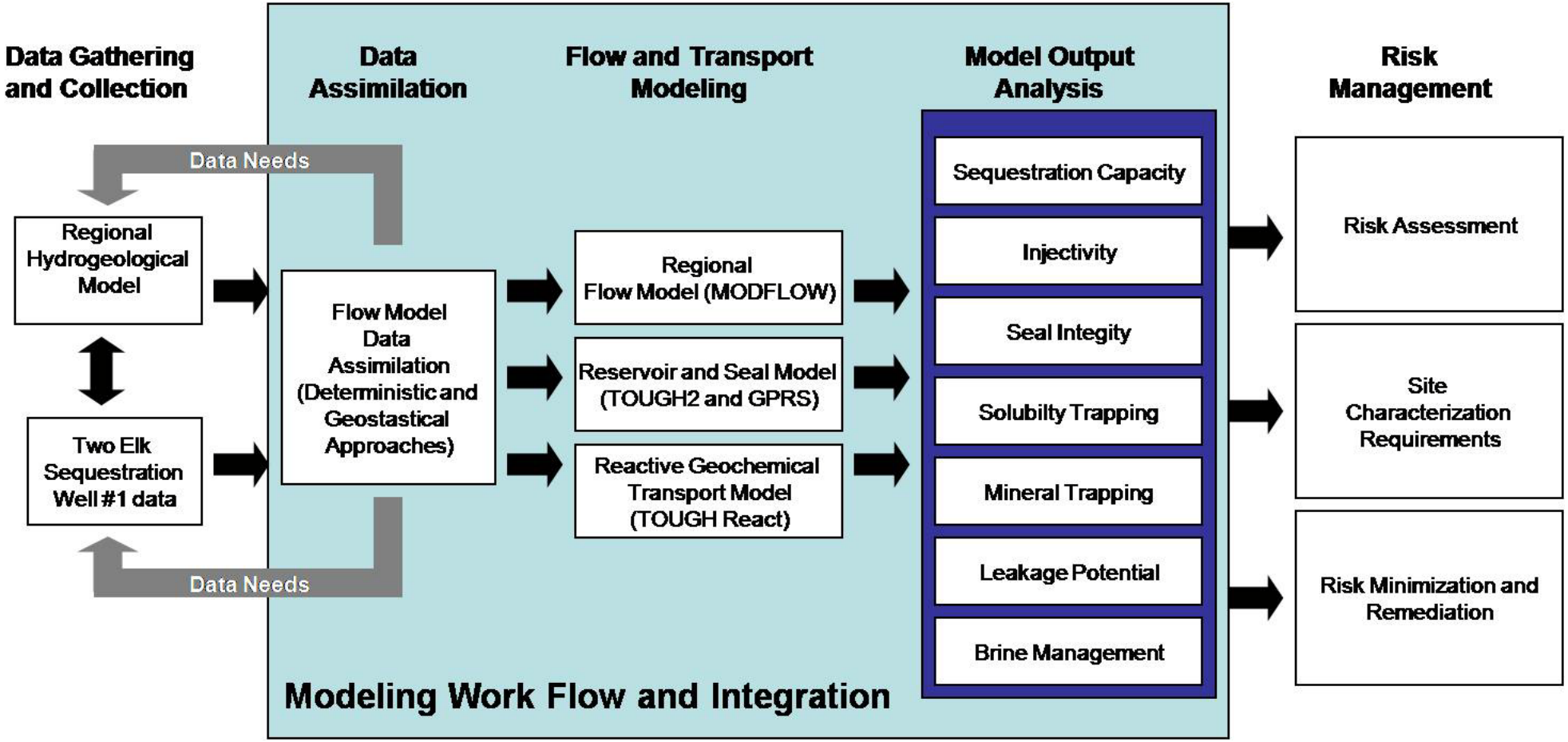

Modeling Approach

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- Model basin architecture is basically constructed from data within a 25 x 25 mile square area
- Geologists reviewed data and correlated tops and surfaces
- Porosity, permeability, petrophysics and other information correlated from that data to create a baseline model
- Additional data has yet to be added from seismic information and from on-site penetrations below 10,000 ft.

Preliminary Model

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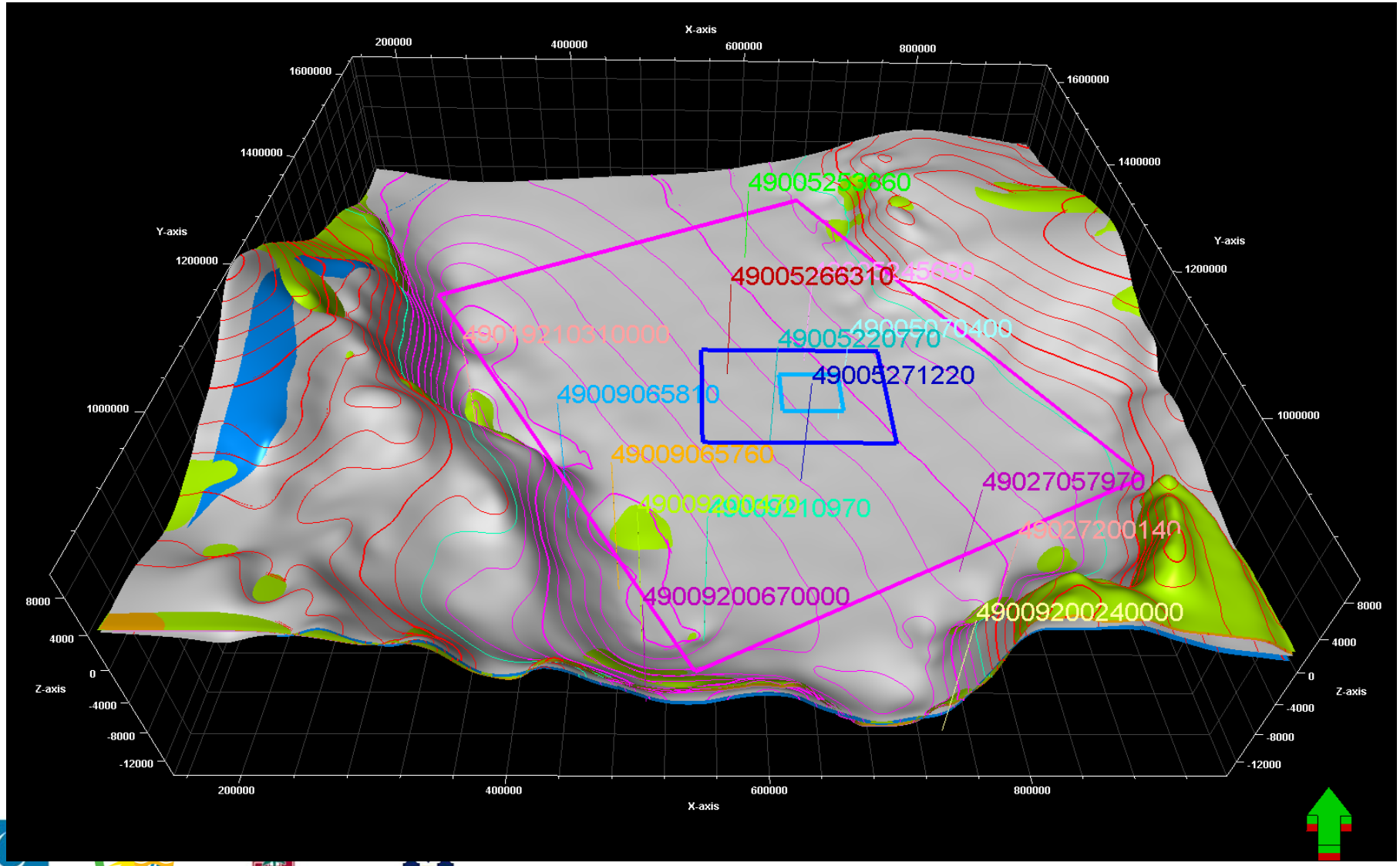

TWOELK GENERATION PARTNERS NAPG STANFORD UNIVERSITY MONTANA STATE UNIVERSITY

Preliminary Model

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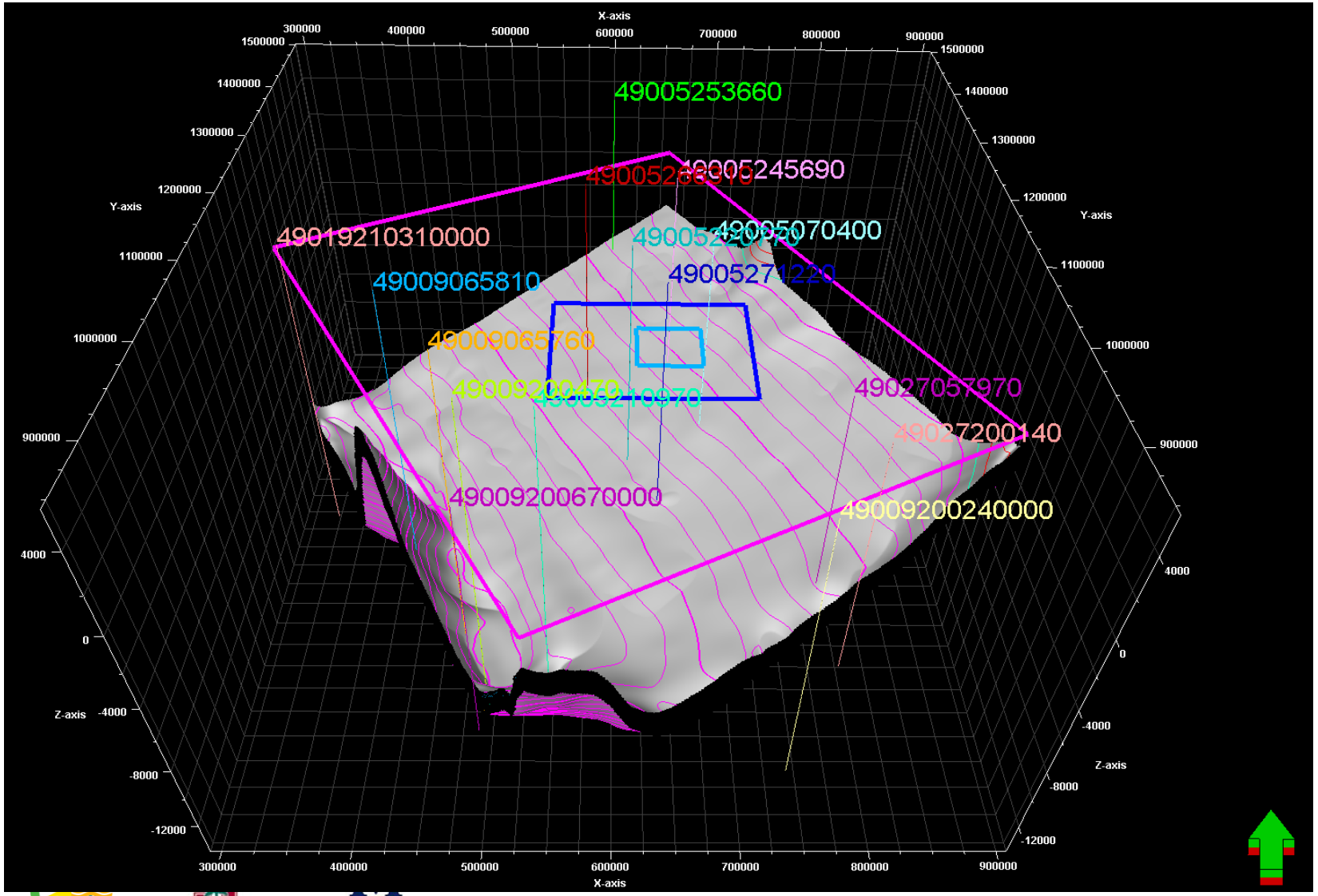

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Preliminary Model

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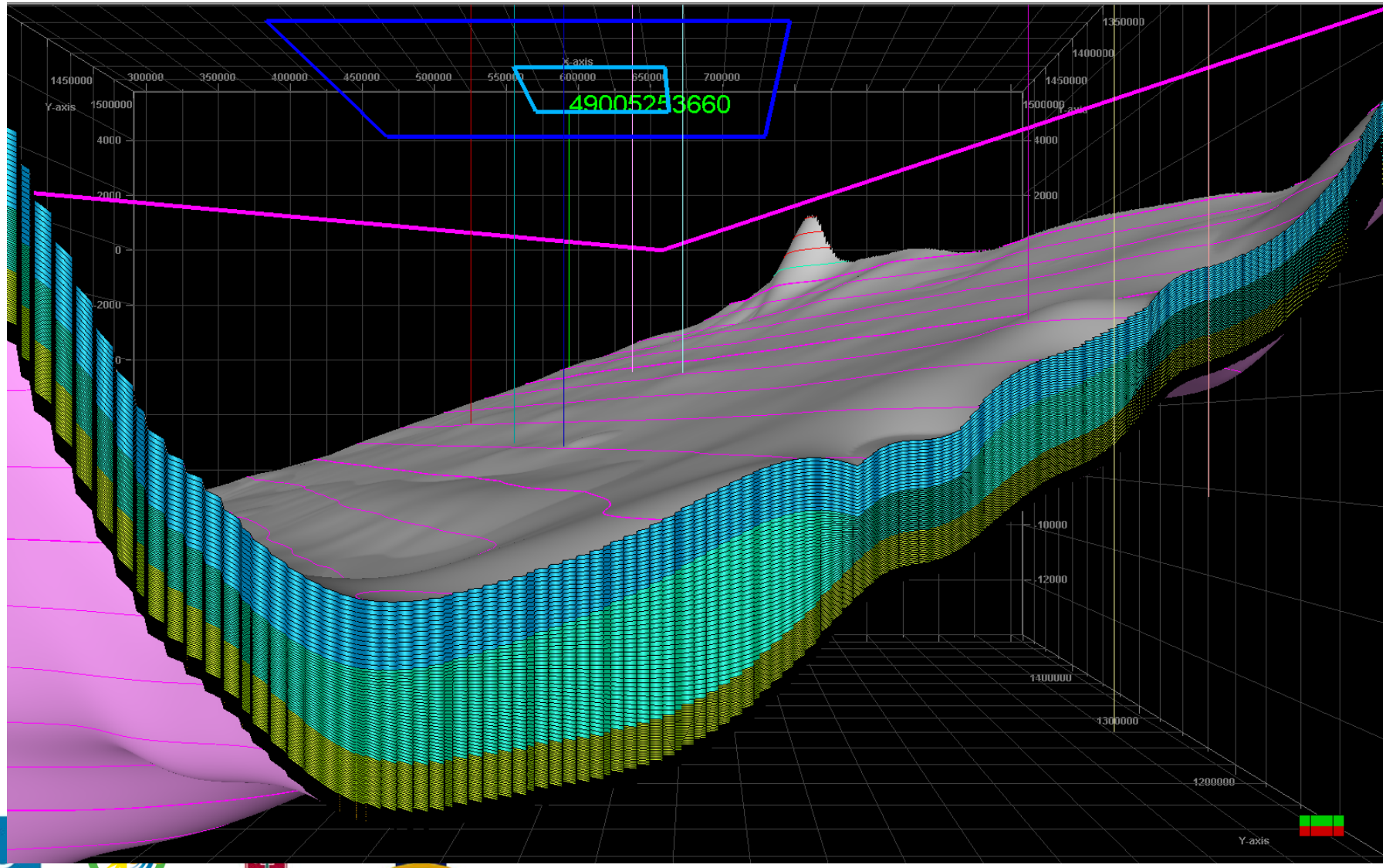

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Preliminary Modeling Petrophysics

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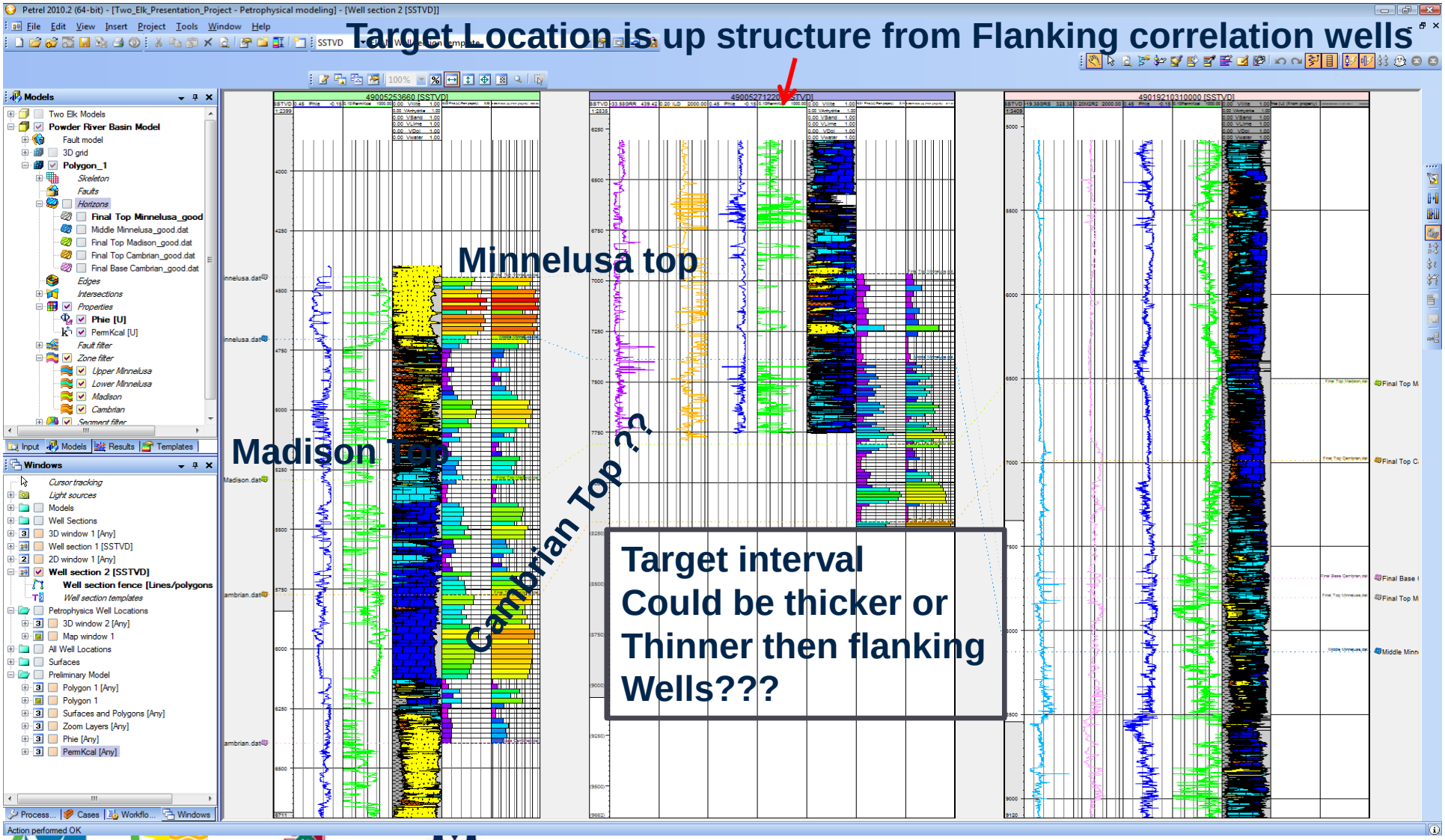

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West-to-East Cross Section Through Phi-Model

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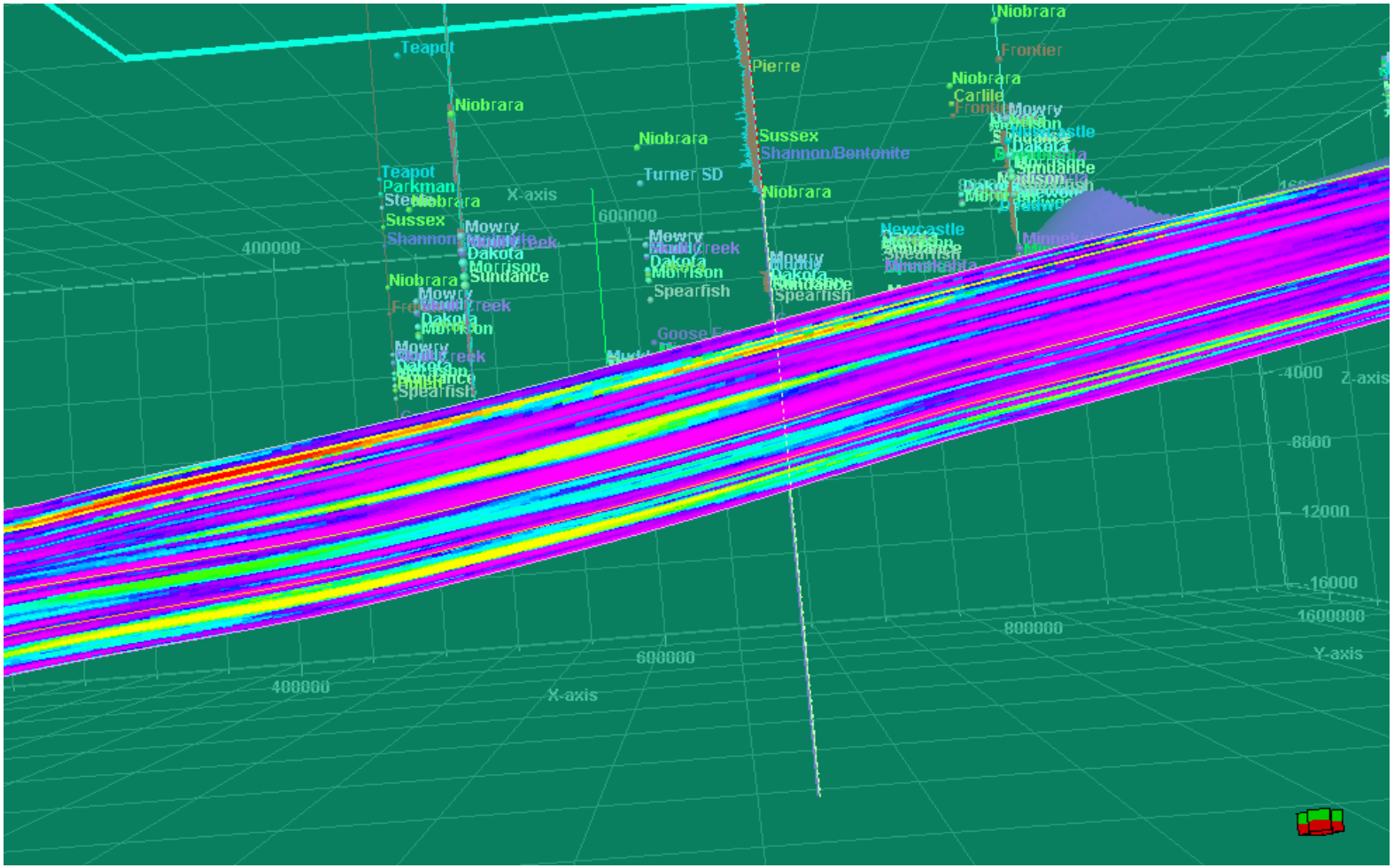

West-to-East Cross Section Through Perm-Model

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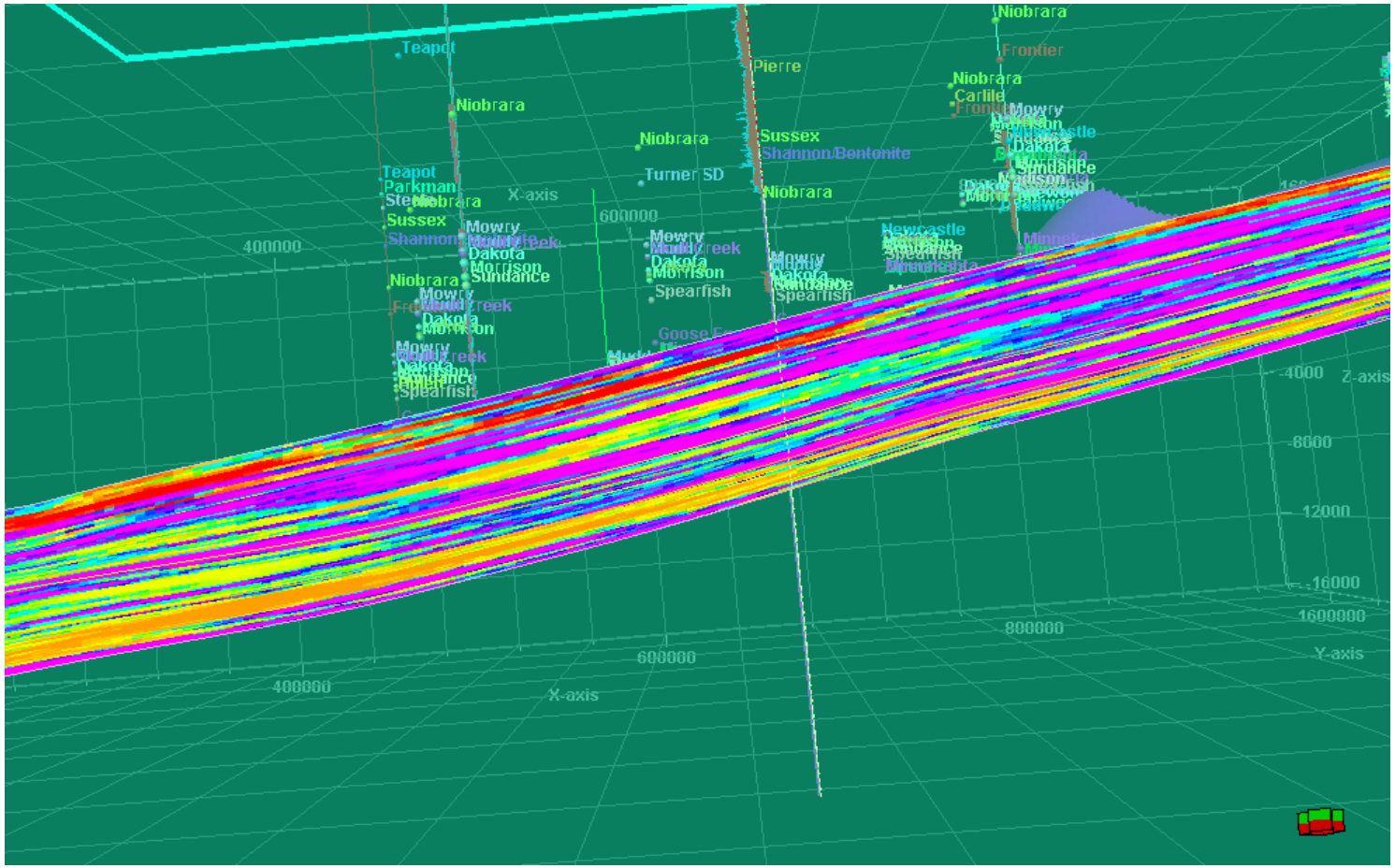

Injectivity and Plume Modeling

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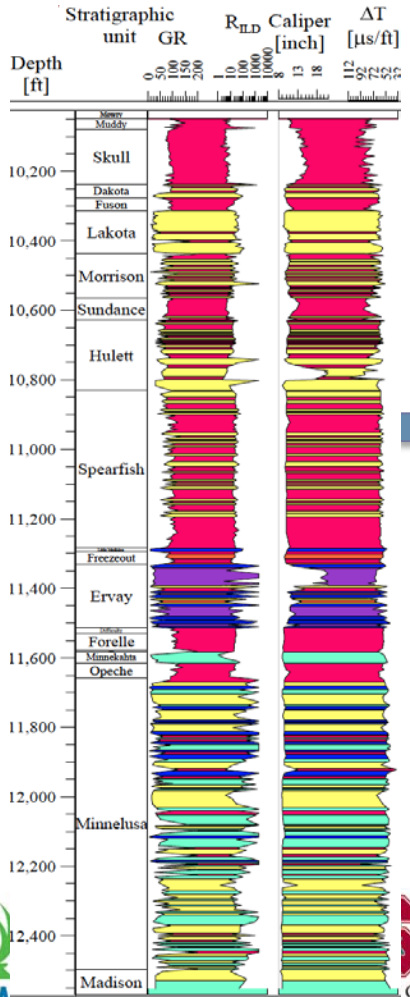
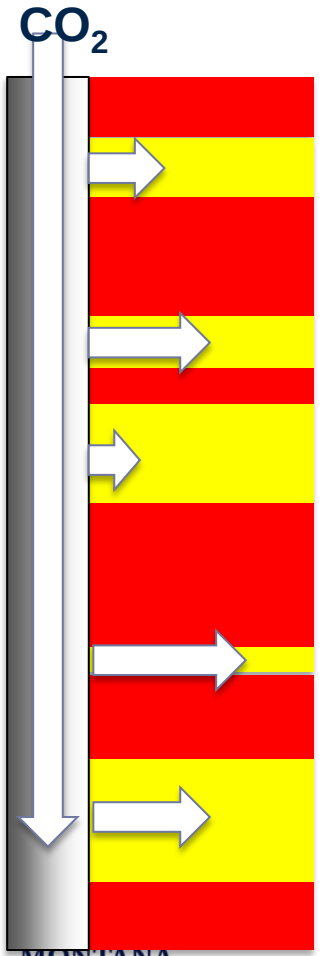
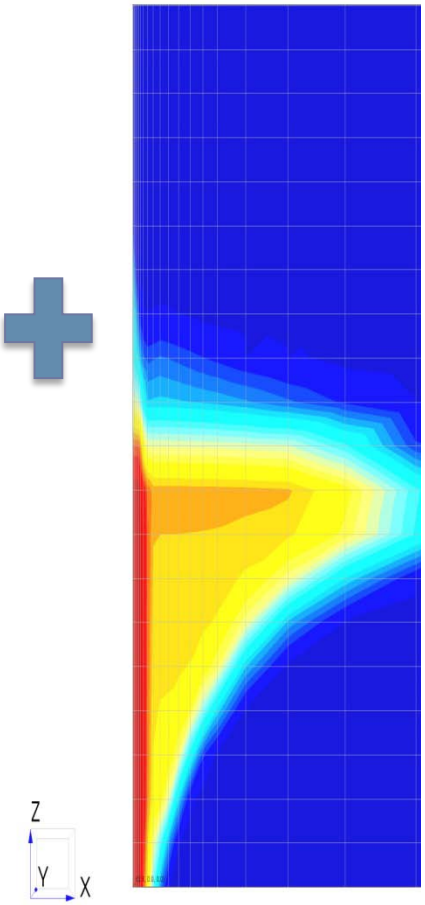
High Resolution Geological Model



Develop Screening Tools for Injectivity and Plume Modeling



Simulations for Assessing Seal Adequacy



Capacity Estimates

Injectivity Estimates

Containment Estimates

High Resolution Geological Model

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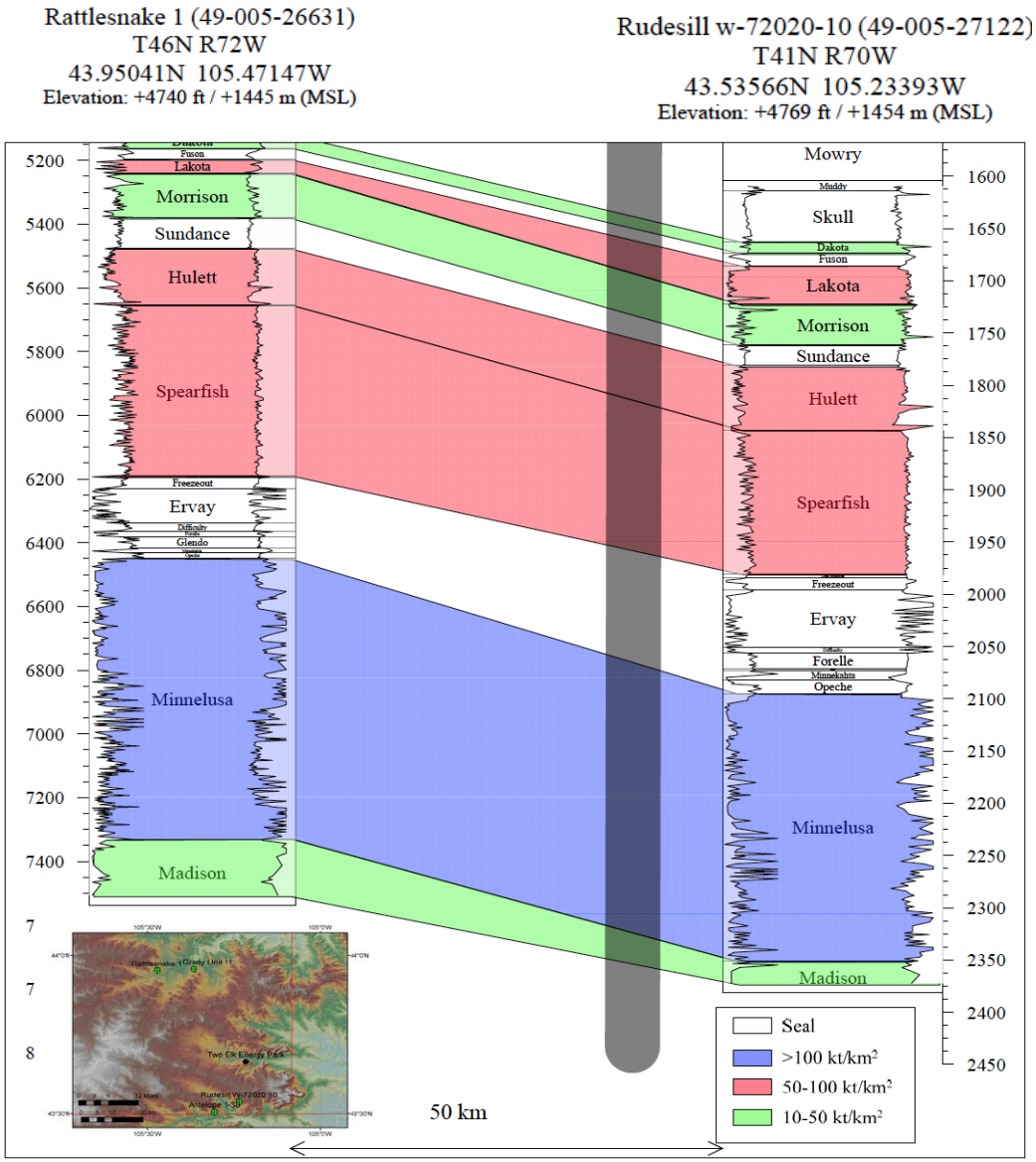

Complex Stratigraphy

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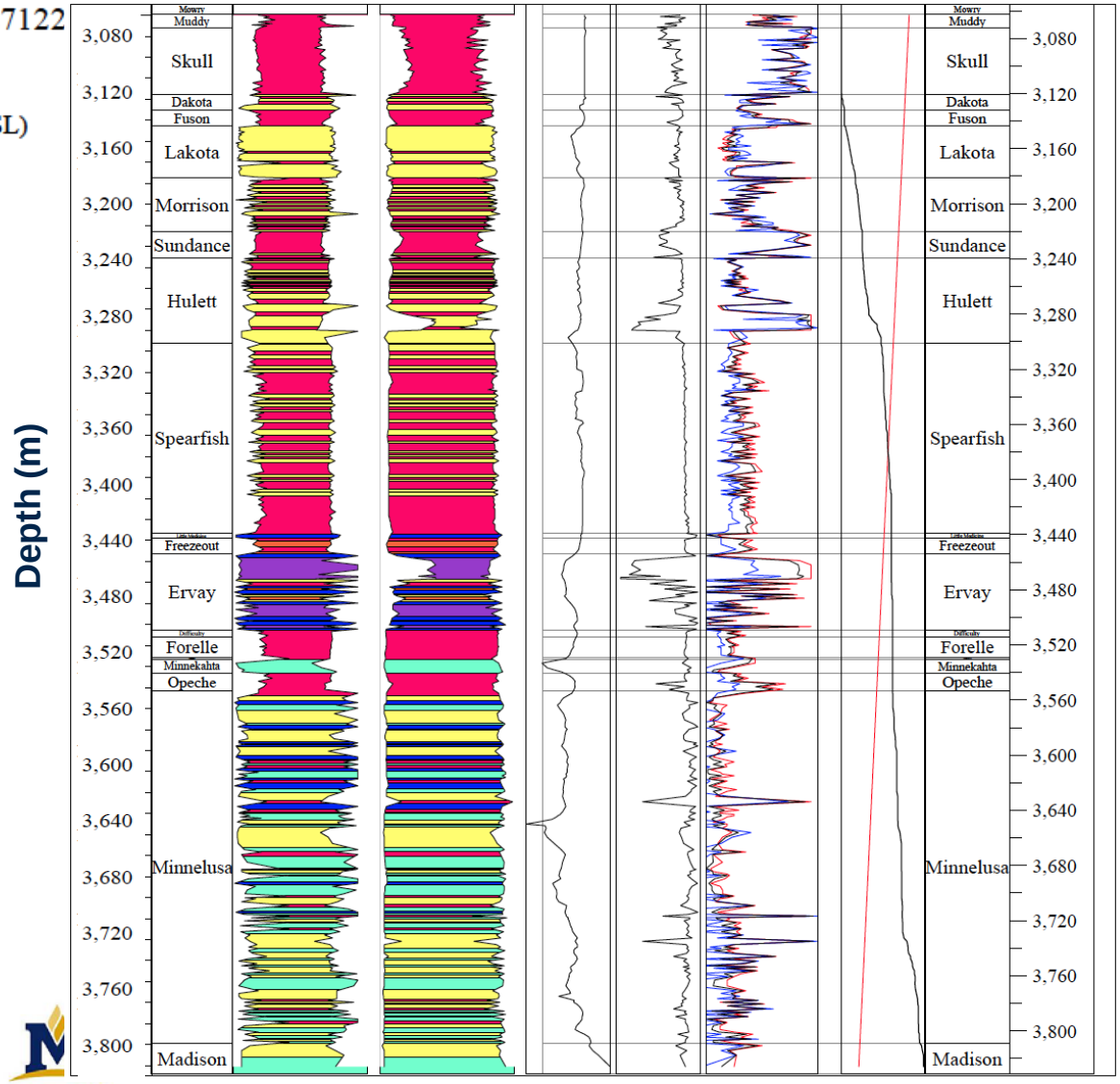
Rudesill w-72020-10 (49-005-27122
T41N R70W
43.53566N 105.23393W
Elevation: +4769 ft / +1454 m (MSL)



Preliminary Properties and Storage Capacity Based on the Closest Wells*

North American Power Group

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Formation	Depth to top [ft]	Depth to top [m]	Total thickness [m]	# of sandstone layers	Total sandstone thickness [m]	Total shale thickness [m] *	Sand ratio [%]	Porosity average [%]	CO2 capacity [kt per 1 sq-km]	% of total capacity **	Rank	CO2 capacity [kt per 1 sq-km]	% of total capacity **	Rank
Mowry	9876	3010	53	0	0	53	0	-	-	-	-	-	-	-
Muddy	10048	3063	9	0	0	9	0	-	-	-	-	-	-	-
Skull	10080	3072	49	0	0	49	0	-	-	-	-	-	-	-
Dakota	10238	3121	11	3	7	4	64	12.2	14	4	6	14	4	4
Fuson	10275	3132	12	0	0	12	0	-	-	-	-	-	-	-
Lakota	10314	3144	37	3	34	3	92	10.1	53	14	3	81	22	3
Morrison	10436	3181	39	10	19	20	49	10.4	28	7	5			
Sundance	10564	3220	19	2	2	17	10	18.8	7	2	7	7	2	8
Hulett	10628	3239	62	13	40	22	65	15.0	88	24	2	137	37	1
Spearfish	10830	3301	138	18	42	96	30	7.7	49	13	4			
Little Medicine	11282	3439	4	0	0	4	0	-	-	-	-	-	-	-
Freezeout	11295	3443	11	0	0	11	0	-	-	-	-	-	-	-
Ervay	11331	3454	55	3	5	50	9	8.0	6	2	8	6	2	9
Difficulty	11513	3509	5	0	0	5	0	-	-	-	-	-	-	-
Forelle	11530	3514	15	0	0	15	0	-	-	-	-	-	-	-
Glendo	11578	3529	2	0	0	2	0	-	-	-	-	-	-	-
Minnekahta	11584	3531	9	0	0	9	0	-	-	-	-	-	-	-
Opeche	11615	3540	13	0	0	13	0	-	-	-	-	-	-	-
Minnelusa	11657	3553	256	21	103	153	40	8.2	129	34	1	129	34	2
Madison	12497	3809	31	1	10	21	32	12.2	19	-	-	19	-	-

*** Adequate data for the Madison Formation in this area are not yet available**

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Complex Stratigraphy

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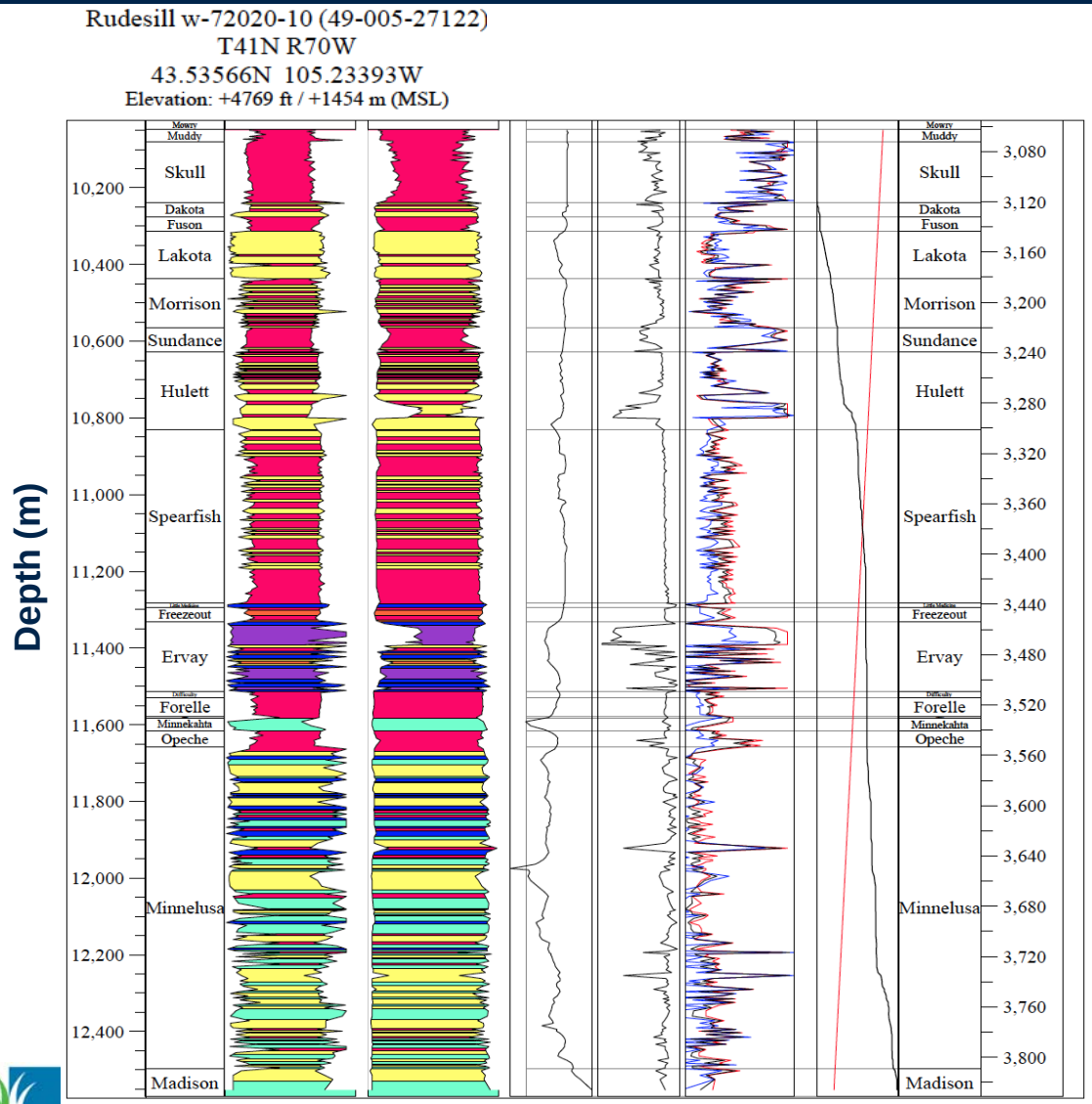

Conceptual Model

- Thick sequence of reservoirs
- Low porosity and permeability
- Many intra-reservoir seals
- No single stratigraphic target
  - ➢ Injection into many thin layers using a single well
  - ➢ Low permeability layers limit vertical movement and inter layer flows

Key Questions

- Is it possible to use a single borehole to inject into many layers?
- Will there be sufficient injectivity to support a commercial scale project?

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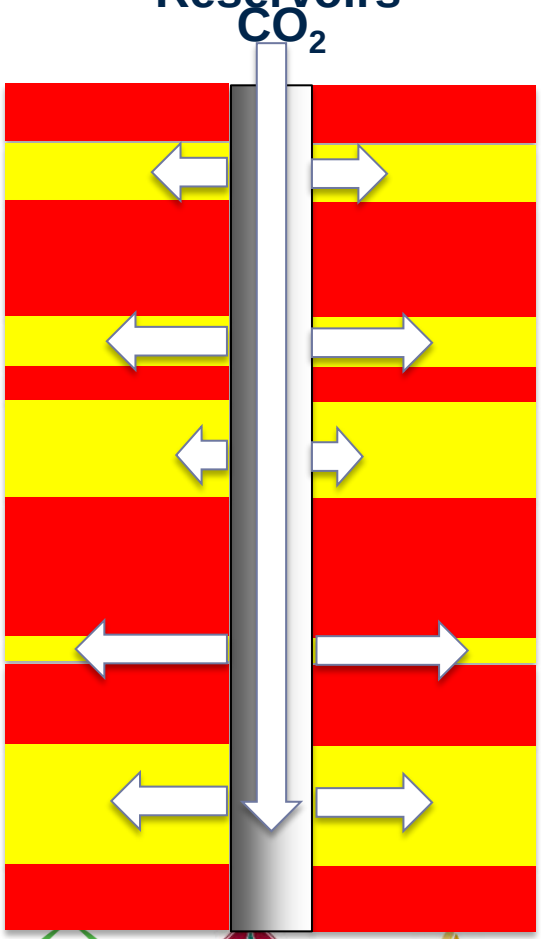
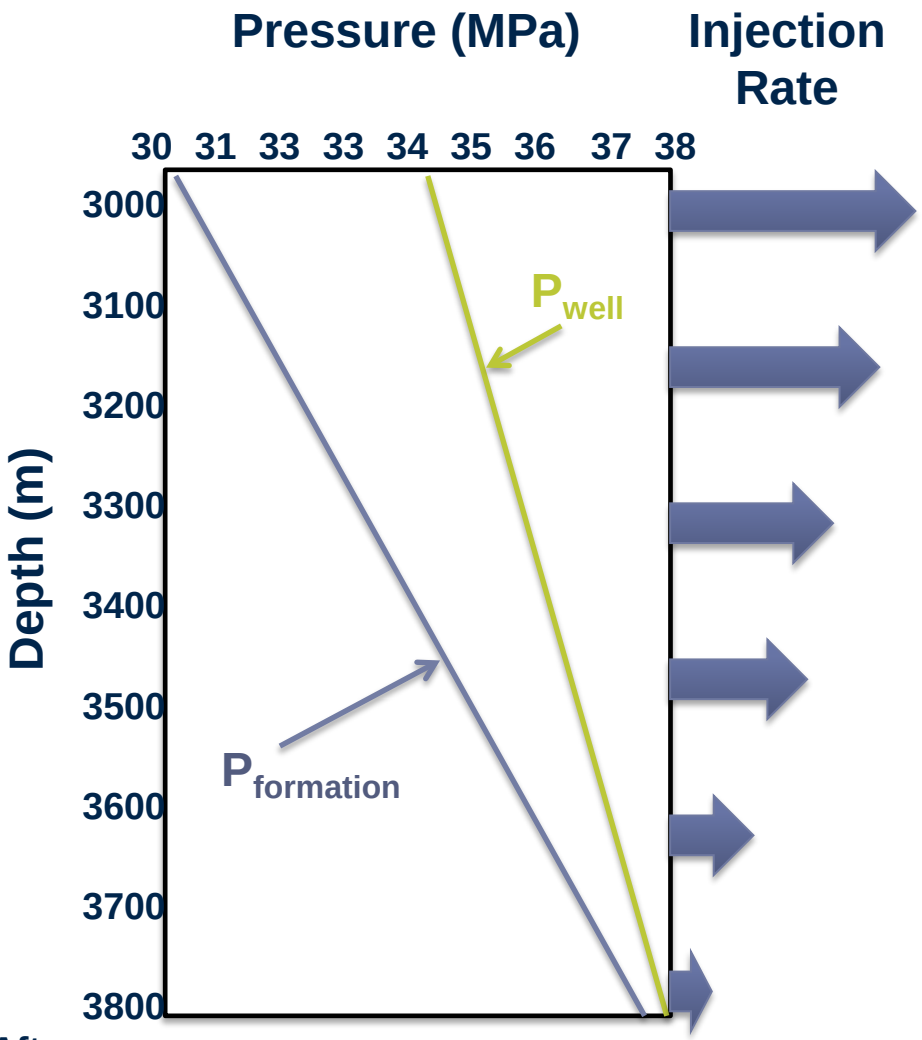
Injection Into Layered Radially Symmetric Reservoirs





After *Kumar, N., Bryant, S.L. 2009. "Semi-analytical model to determine perforation interval for secure CO_2 storage in saline aquifers." Energy Procedia 1.*

Model Description (I)

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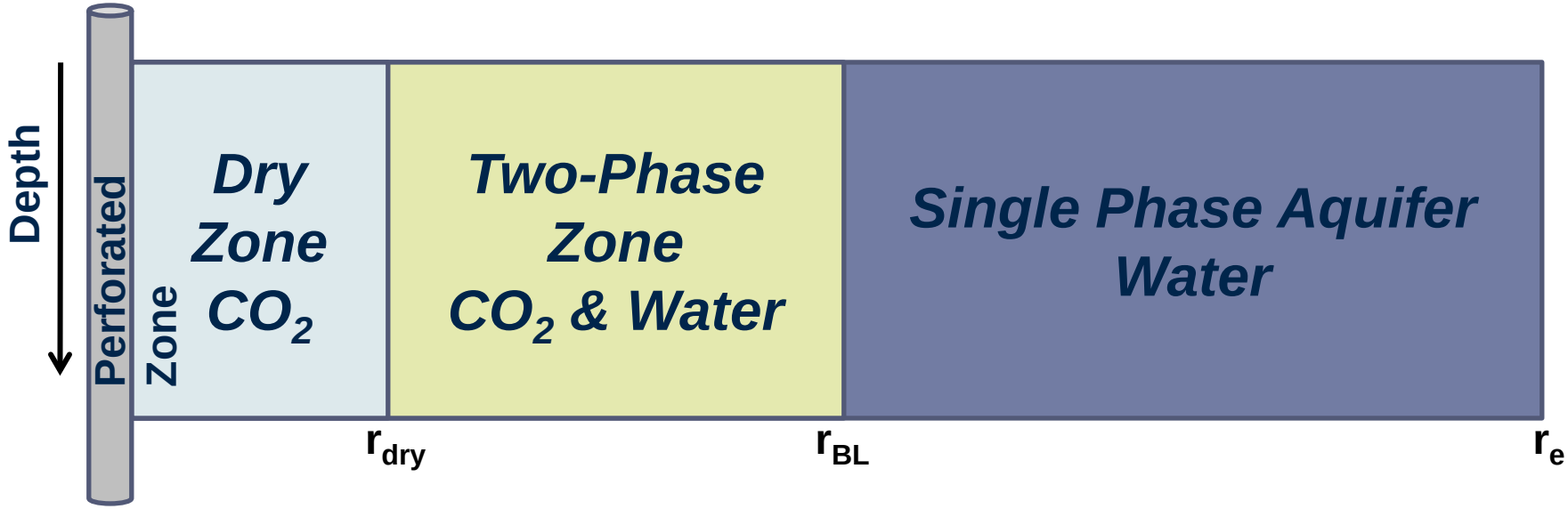

For each layer in the model:

$$r_{dry} = r_e \sqrt{t_D \cdot \left(\frac{\delta f_g}{\delta s_{CO_2}} \right)_{s_{CO_2,dry}}} \qquad r_{BL} = r_e \sqrt{t_D \cdot \left(\frac{\delta f_g}{\delta s_{CO_2}} \right)_{s_{CO_2,BL}}}$$

where

$$t_D(z) = \frac{Q_{CO_2}(z)}{\pi \phi r_e^2} \cdot \frac{\Delta t}{\Delta z} \quad \text{and} \quad r_e(z) = \sqrt{\frac{2k(z)t}{\phi(z)\mu_w c_t}}$$

Model Description (II)

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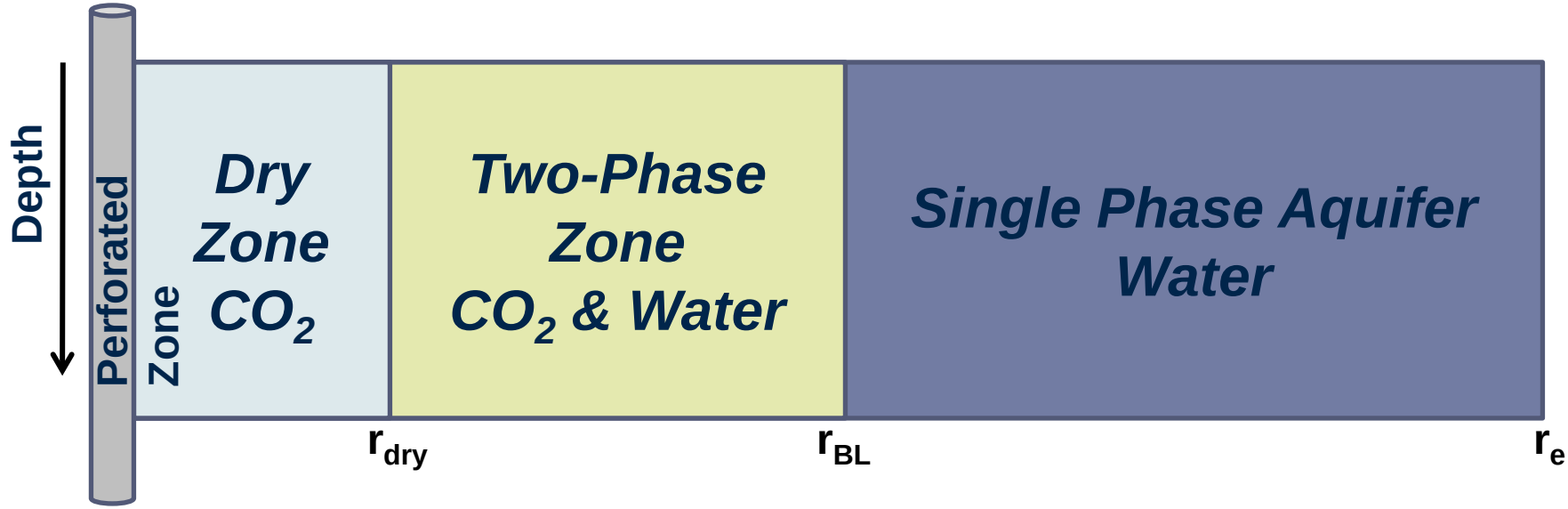

$$Q_{CO_2}(z) = \frac{kM_{ave}(z)}{\ln\left(r_e / r_w\right)}\left(2\pi\Delta P(z)\cdot \Delta z\right)$$

$$Q_{TOT} = \sum_{1}^{Number\ of\ layers} Q_i(z)$$

$$M_{ave} = \frac{\ln\left(r_e / r_w\right)}{\frac{\ln\left(r_e / r_{BL}\right)}{M_{water}} + \frac{\ln\left(r_{BL} / r_{dry}\right)}{M_{BL}} + \frac{\ln\left(r_{dry} / r_w\right)}{M_{Dry}}}$$

Iterate to find Δp_{well} and $Q_i(z)$

Model Inputs

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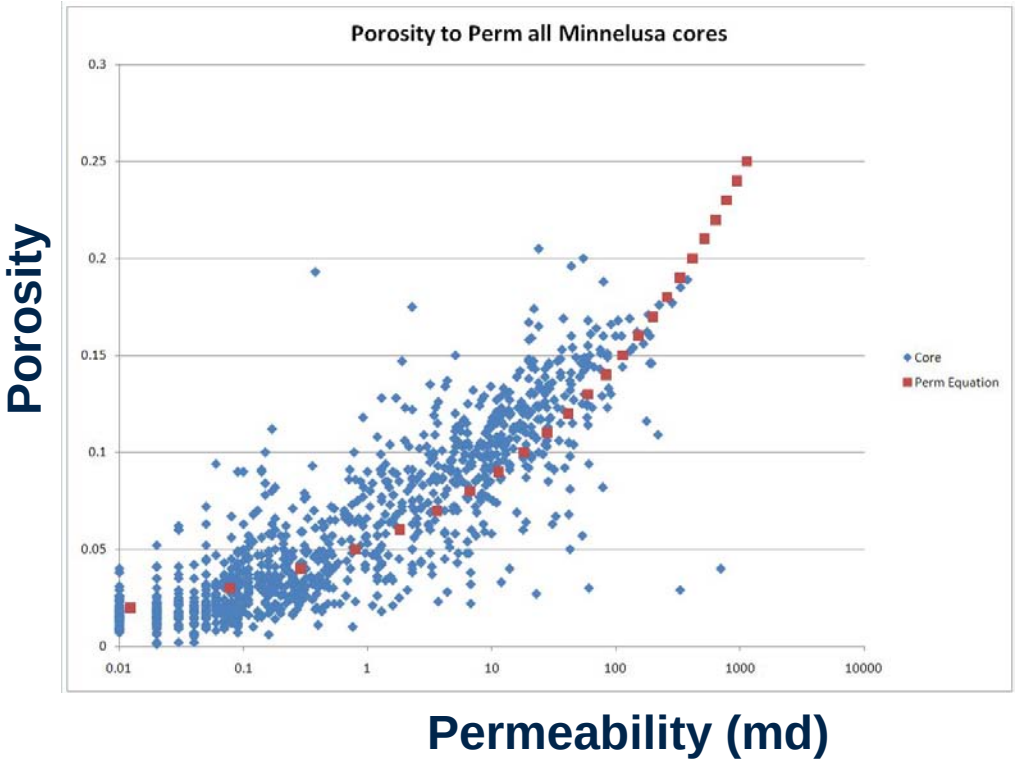

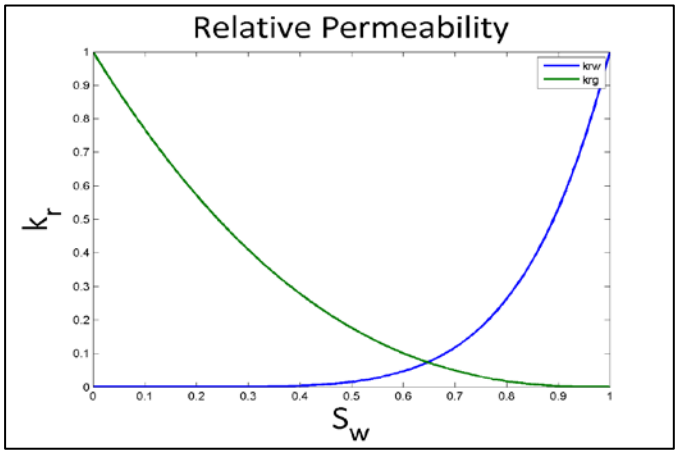

Relative permeability measured Berea Sandstone

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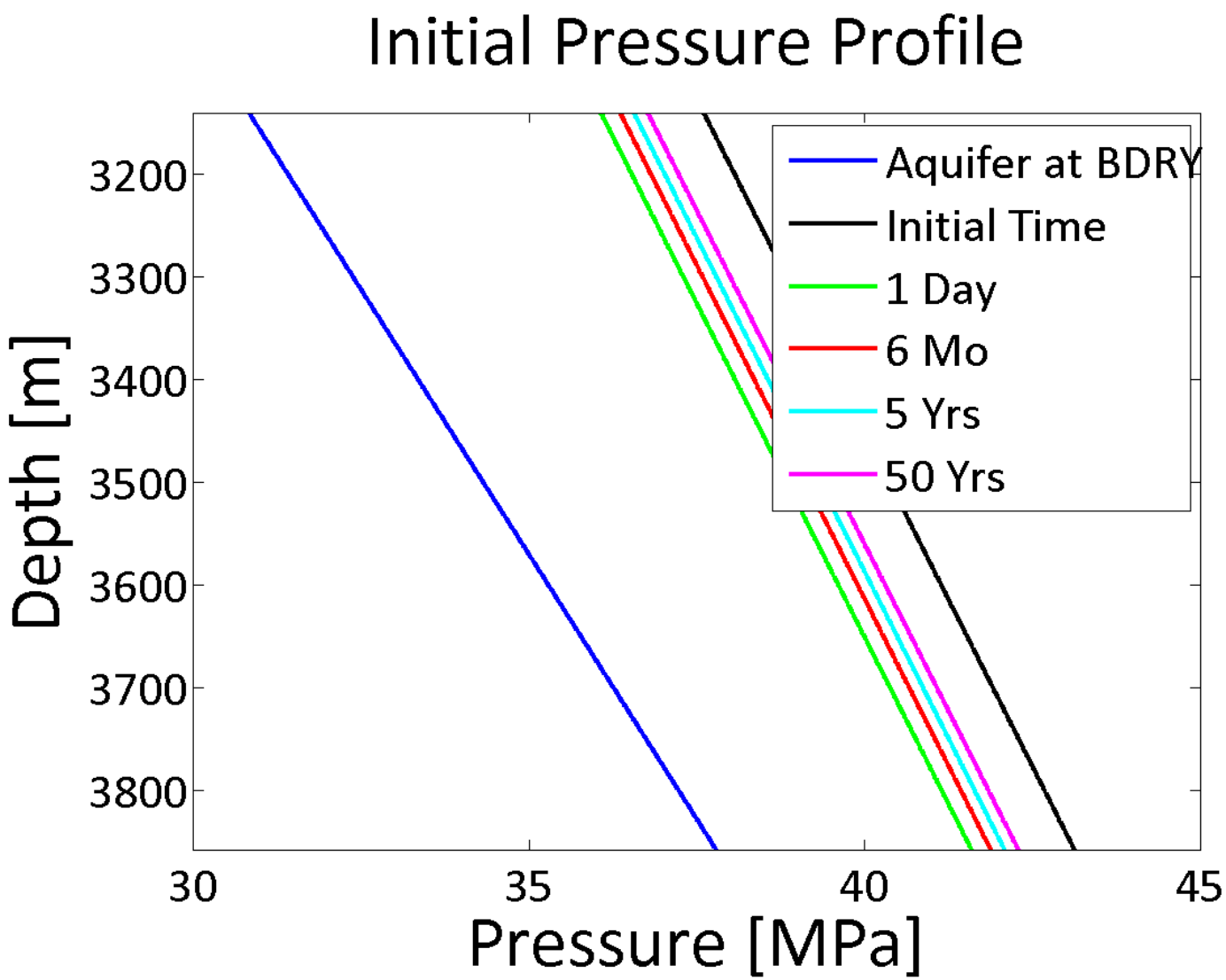

Results: Propagation of the Dry Zone, CO_2, and Pressure "Fronts"

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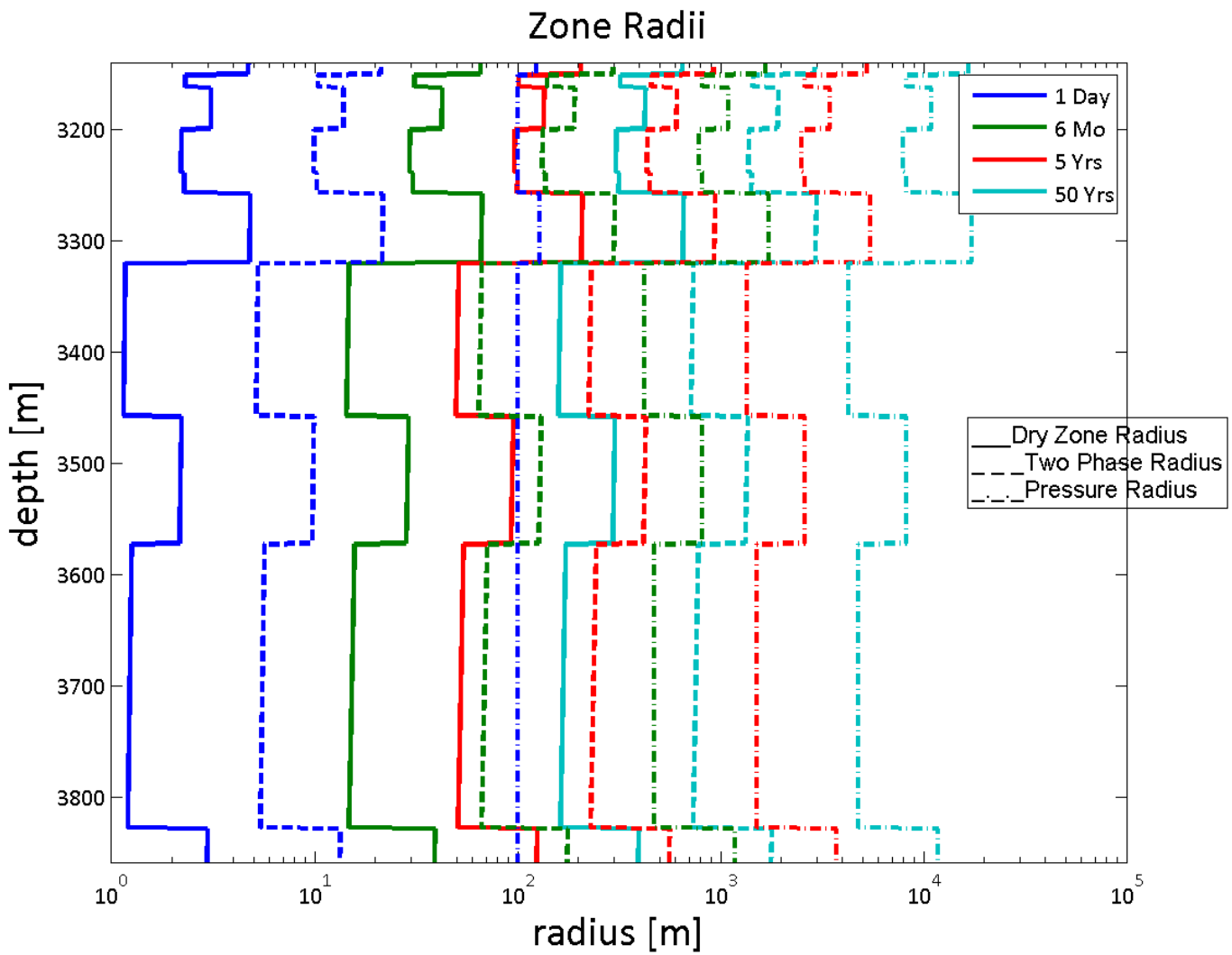

Results : Distribution of Injection CO_2

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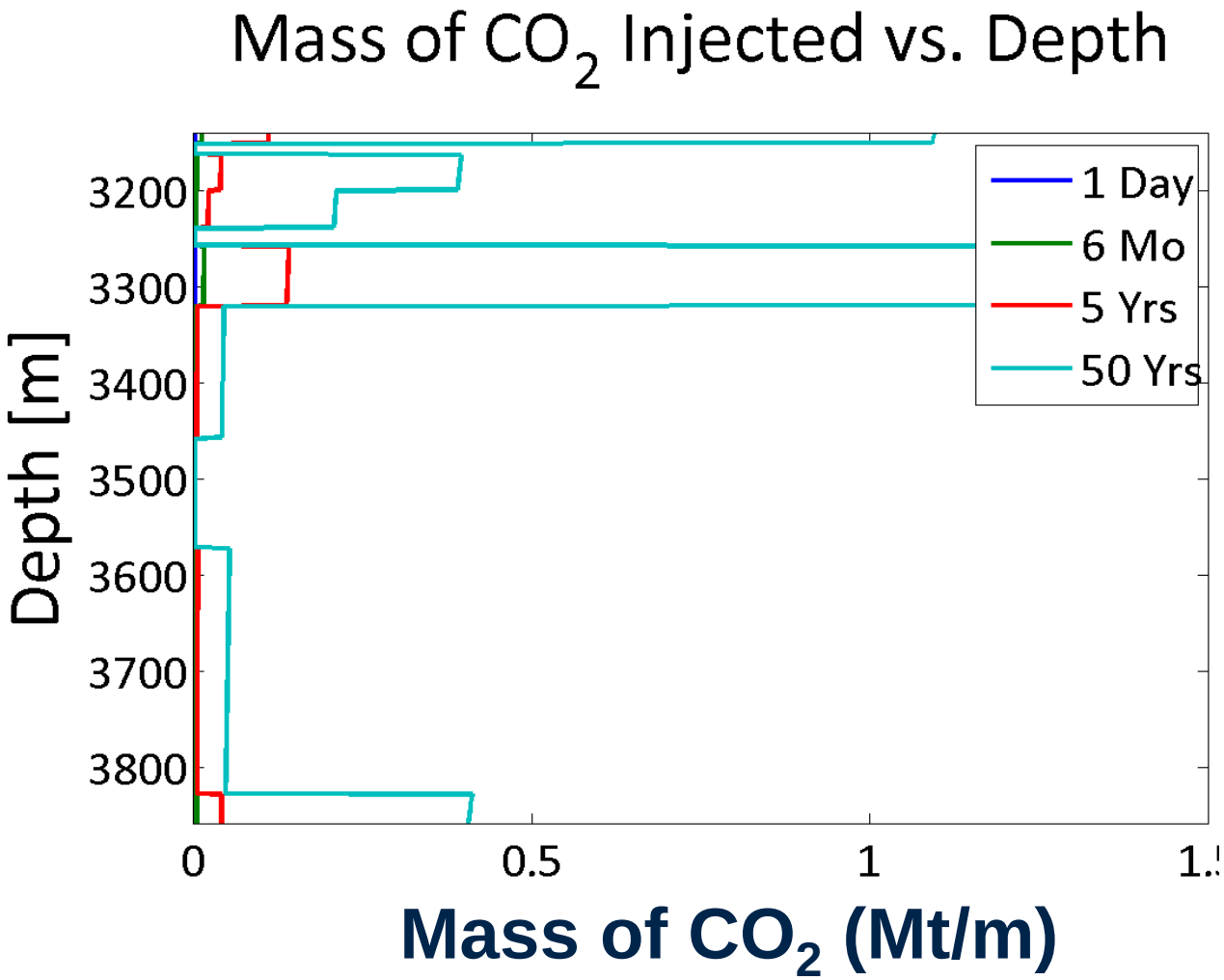

Summary and Conclusion

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- Developed detailed stratigraphic model of the region
  - Complex stratigraphy
  - Low porosity
  - Thin moderate permeability beds
- Developed a new model for calculating pressure buildup and injectivity for thick heterogeneous storage systems
- Preliminary data suggests that injection into thick but low quality reservoirs may be possible at commercial scale
- Site specific data is needed to provide reliable inputs to models