A Strategy for Modeling a CO2 Injection Site Using RockWorks and PetraSim

The purpose of this study was to evaluate the potential for CO2 injection into a deep Saline Aquifer (Figure 1).

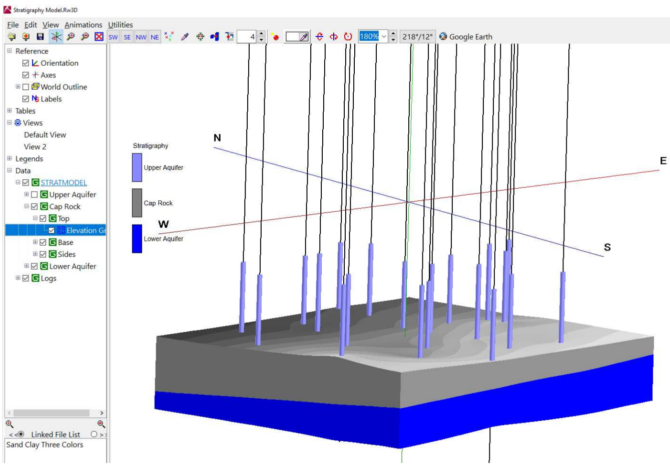

Figure 1: 3D Model showing well locations and modeled Stratigraphic grids

Raster logs were depth registered within the RockWorks Borehole Manager database and used to pick the top and base of the Injection Aquifer (blue) and Cap Rock (gray) using the RockWorks Stratigraphy Picker tool (Figure 2). The Stratigraphy | Layered Model tool was then used to interpolate a model based on stacked gridded surfaces (Figure 1). This model shows that the units have varying thicknesses and are dipping gently to the Northwest.

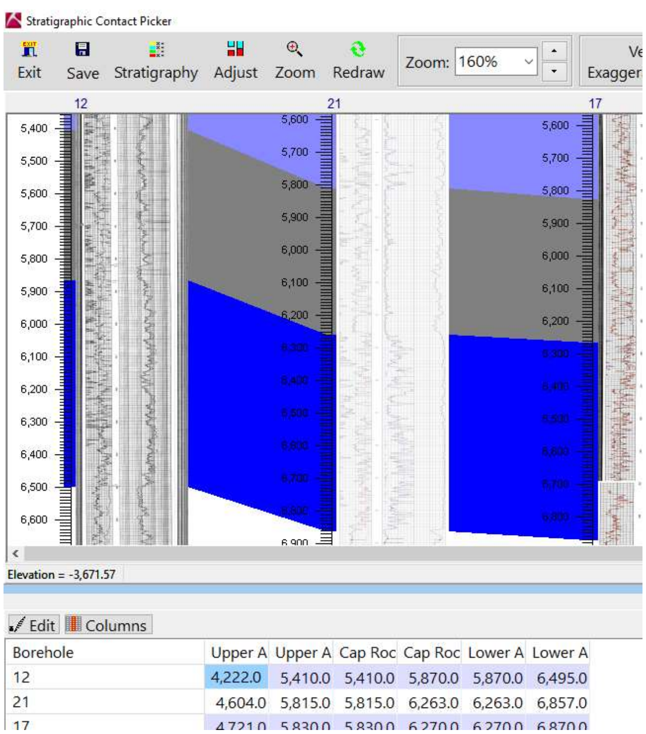

Figure 2: Raster logs displayed in cross-section using the RockWorks Strat Picker tool

Structure and Isopach Maps were created to define the top, base and thickness of the two formations (Figure 3). The structural surfaces were exported as ASCII files for use in the development of a TOUGH simulation mesh using the PetraSim GUI.

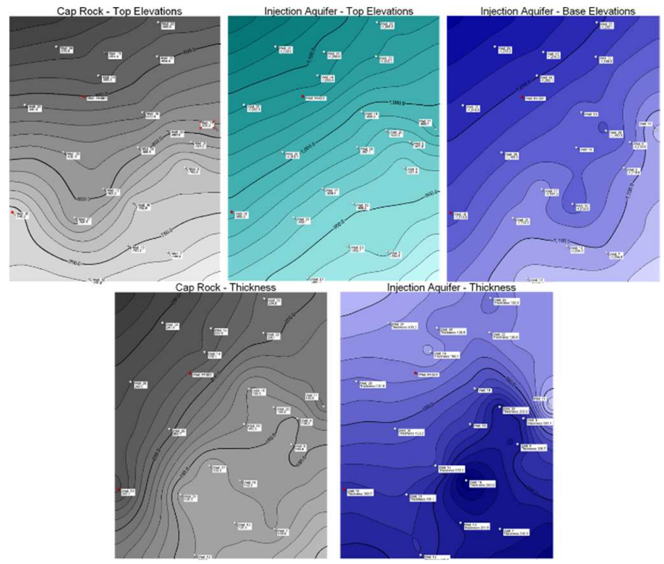

Figure 3: Structure and Isopach Maps

The raster logs were then digitized using the RockWorks Log Digitizing tool to extract SP data for each well. The SP data was normalized for use in cross-sections and solid modeling (Figure 4). Figures 4 and 5 show how block models can aid in the understanding of sand and shale distribution in the subsurface, with high SP values (shale) displayed with darker shades of brown and lower SP values (sand) displayed as yellow.

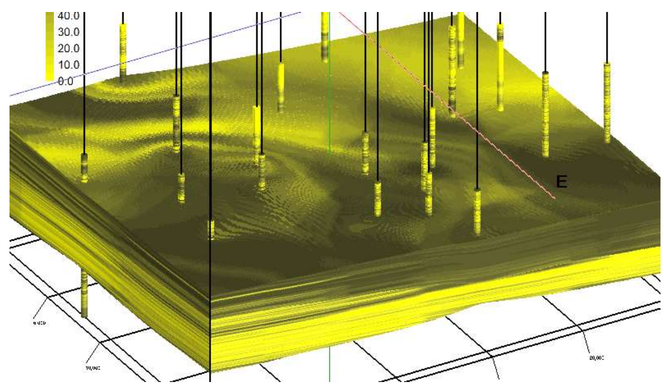

Figure 4: Geologic Model Cutaway View (Vertical Exaggeration = 5X

A cross-section projected through the solid model aided in the selection of a preliminary perforation interval at a proposed injection well. (Figure 5).

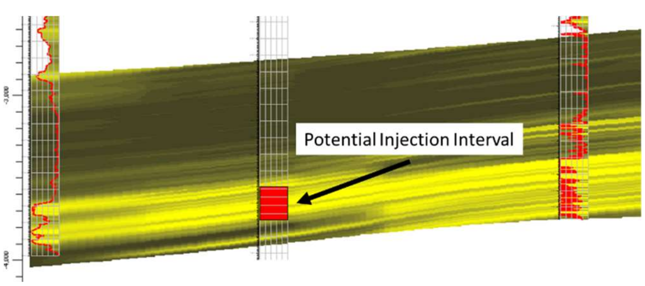

Figure 5: Section slicing through SP model at proposed injection well location

The PetraSim program was then used to create a simple reservoir simulation to determine the possible extent of a CO2 plume injected into the site. Structural surfaces exported from RockWorks as ASCII files were used to create a conceptual layered model that represents the elevations and thicknesses of the Cap Rock and Injection Aquifer (Figure 6). Next, a polygonal mesh was generated with refinement around the injection well.

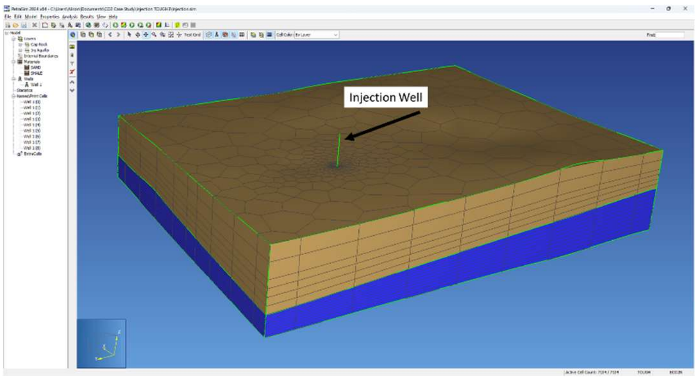

Figure 6: Layered TOUGH polygonal mesh with refinement around the injection well

Two materials (SAND and SHALE) were created to represent the Cap Rock (upper layer) and Injection Aquifer (lower layer) material (Table 1)

Material	Sand	Shale
SP Range	>60	<=60
Permeability	1e-13 m2	1e-18 m2
Porosity	0.2	0.05
RP	Van-Genuchten Mualem	Corey's Curve
CP	Van-Genuchten Mualem	Leverett's Function

Table 1: Material used in preliminary TOUGH injection model

The model was run to steady state with no injection to establish hydrostatic pressure conditions and a realistic temperature gradient (Figure 7) using the TOUGH3 Simulator developed and distributed by Lawrence Berkeley National Labs (ECO2N EOS Module) (Jung et al., 2018).

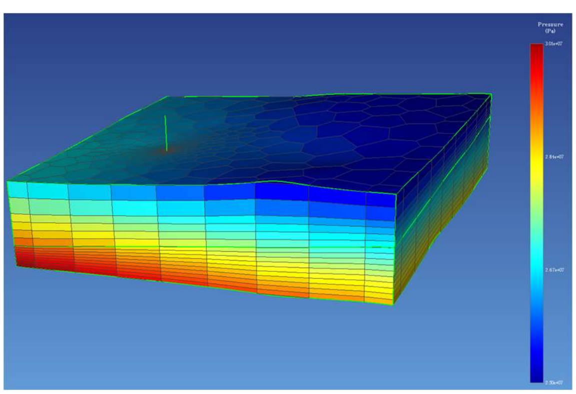

Figure 7: Initial pressure conditions based on hydrostatic pressure

CO2 injection was initiated at a rate of 30 kg/s and run for 30 years. Injection was then turned off while the simulation continued to run until 10,000 years after injection began.

The results of the model show the development of a CO2 gas plume growing as injection continues (Figure 8). After injection ceases, the gas plume migrates up dip and slowly shrinks as the CO2 gas dissolves into the saline water in the aquifer.

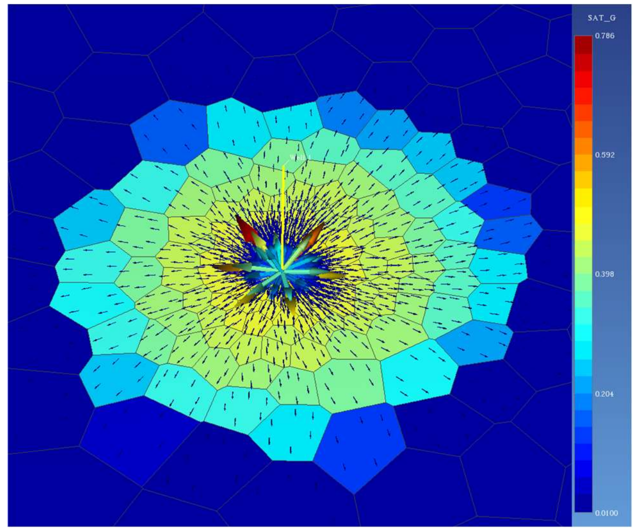

Figure 8: Gas saturation and gas flow vectors displayed around the injection well

To explore the effect of varying permeability on the results of the simulation, the TOUGH model was further refined by adding variable materials and permeability to the model, based on the SP model created in RockWorks. The SP model was filtered within RockWorks to divide the area into two lithology groups:

- Sand (SP < 60)
- Shale (SP >= 60)

Solid Math tools in Rockworks were used to create normalized "Variability" models. Larger Variability values were assigned to low SP values while smaller Variability values were assigned to high SP values (Figure 9).

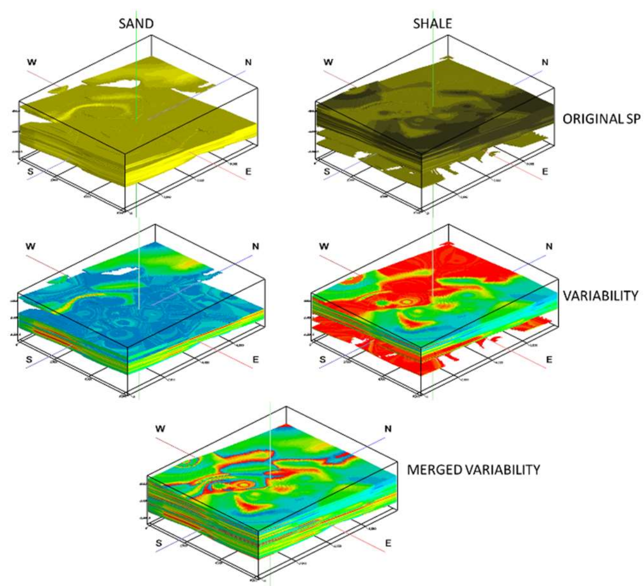

Figure 9: Permeability variability models based on normalized SP model

SP and Variability values were then transferred into the PetraSim model by taking the following steps:

- A list of element locations (XYZ centers) in the PetraSim mesh were exported through the **File | Write Mesh Data** menu. These were exported as an ASCII file that was subsequently imported into the RockWorks Datasheet.

- The RockWorks **Solid | Statistics | Extract from Solid** program was then used to extract SP and Variability values from the RockWorks RwMod files. The values extracted for each XYZ location match the model voxel that falls closest to the TOUGH element center.

- Values for each XYZ location were then imported into the PetraSim simulation through the **Model | Set Cell Data** menu (Figure 10). Element material type and Permeability Modifiers were added to the simulation, resulting in a model where "Sand" elements were assigned permeability values between 1e-12m2 and 1e-15m2 (Permeability Modifiers between 0.01 and 10) and "Shale" elements were assigned permeability values between 1e-17m2 and 1e-19m2 (Permeability Modifiers between 0.1 and 10).

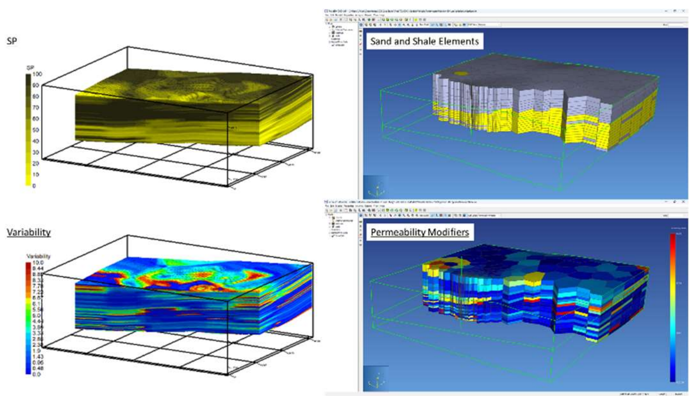

Figure 10: SP and Variability models displayed in RockWorks (left) and the results of the data import displayed in PetraSim (right)

Figures 11 and 12 depict a comparison of the results of the original model with homogeneous material properties to the model in which variable material properties were used. This comparison led to the following conclusions:

- Use of variable material properties within the simulation results in a more realistic plan view distribution of CO2 gas (Figure 11). The shape of the CO2 plume varies as gas preferentially travels into material with higher permeability.

- Variations in the permeability of the Cap Rock allow for vertical migration of CO2 gas above the Injection Aquifer (Figure 12). The cross-sectional views show how an increase in the permeability of the caprock might lead to unexpected upward movement of injected CO2 gas.

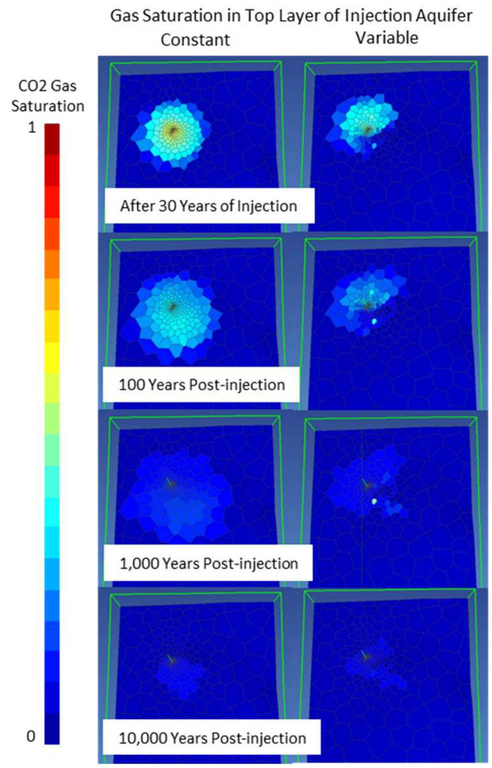

Figure 11: Plan view map showing Gas Saturation in the uppermost layer of the Injection Aquifer.

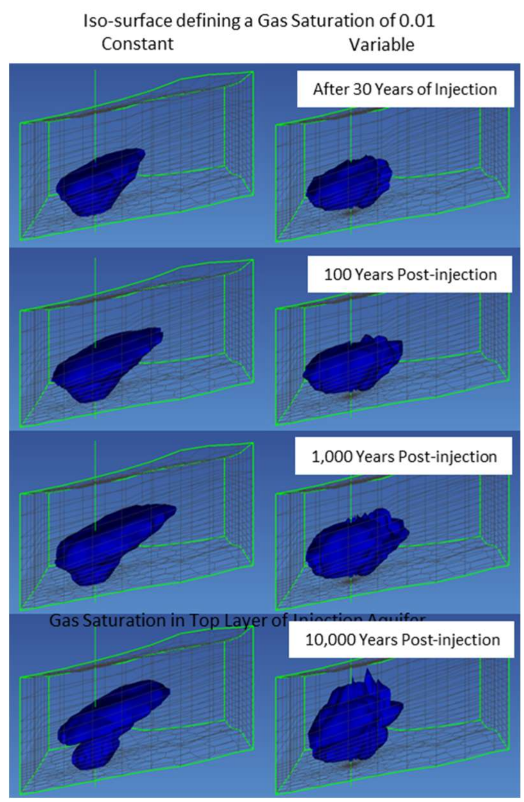

Figure 12: Cross-sectional views of Gas Saturation iso-surface (0.01)

References

Yoojin Jung, George Shu Heng Pau, Stefan Finsterle, Christine Doughty. TOUGH3 User's Guide. Berkeley, CA, USA : Earth Sciences Division, Lawrence Berkeley National Laboratory, February 2018. LBNL-2001093.