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Quarterly Report for LANL Activities: FY11-Q4

National Risk Assessment Partnership (NRAP): Industrial Carbon Capture Program

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FWP FE-102-002-FY10

SUBMITTED BY

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Executive Summary:

This report summarizes progress of LANL activities related to the tasks performed under the LANL FWP FE102-002-FY10, National Risk Assessment Partnership (NRAP): Industrial Carbon Capture Program. This FWP is funded through the American Recovery and Reinvestment Act (ARRA). Overall, the NRAP activities are focused on understanding and evaluating risks associated with large-scale injection and long-term storage of CO_2 in deep geological formations. One of the primary risks during large-scale injection is due to changes in geomechanical stresses to the storage reservoir, to the caprock/seals and to the wellbores. These changes may have the potential to cause CO_2 and brine leakage and geochemical impacts to the groundwater systems. While the importance of these stresses is well recognized, there have been relatively few quantitative studies (laboratory, field or theoretical) of geomechanical processes in sequestration systems. In addition, there are no integrated studies that allow evaluation of risks to groundwater quality in the context of CO_2 injection-induced stresses. The work performed under this project is focused on better understanding these effects. LANL approach will develop laboratory and computational tools to understand the impact of CO_2-induced mechanical stress by creating a geomechanical test bed using inputs from laboratory experiments, field data, and conceptual approaches. The Geomechanical Test Bed will be used for conducting sensitivity and scenario analyses of the impacts of CO_2 injection. The specific types of questions will relate to fault stimulation and fracture inducing stress on caprock, changes in wellbore leakage due to evolution of stress in the reservoir and caprock, and the potential for induced seismicity. In addition, the Geomechanical Test Bed will be used to investigate the coupling of stress-induced leakage pathways with impacts on groundwater quality.

LANL activities are performed under two tasks: 1) develop laboratory and computational tools to understand CO_2-induced mechanical impacts and 2) use natural analog sites to determine potential groundwater impacts. We are using the Springerville-St. John Dome as a field site for collecting field data on CO_2 migration through faults and groundwater impacts as well as developing and validating computational models.

During the FY11 fourth quarter we have been dealing with a setback in procurement of experimental apparatus for the tri-axial core-flood system which will delay completion of building the equipment. We have developed a geologic framework model that will be the basis of geomechanical and groundwater impact numerical simulation models. Our planned groundwater sampling activities at Springerville were delayed due to wildfires and evacuations in that area.

Progress:

Task 1 Develop laboratory and computational tools to understand CO_2-induced mechanical impacts:

We have acquired 60% of the instrumentation needed for our triaxial tomographic experimental system. This includes all of the fluid delivery system (pumps, accumulators, valves, tubing), the geomechanical data analysis instrumentation, and the pressure control and measurement devices. Unfortunately, we are still stalled with our purchase of the core-holder. We are in ongoing negotiations between Los Alamos contracting and our vendor, New England research.

A 3-D Geologic Framework Model (GFM) for the Springerville site is being developed to provide a modeling framework for the hydrologic and stress-permeability modeling components of the NRAP-ARRA project. The GFM will incorporate geologic stratigraphy and fault information that is relevant for the modeling.

Geologic Stratigraphy

The Springerville area is comprised of relatively flat sedimentary rocks of Tertiary to Paleozoic age overlying granitic basement rocks. The sedimentary rocks range in age from late Pennsylvanian to Quaternary. During pre-Late Cretaceous time, erosion removed the entire Jurassic System and beveled the surface so that progressively older rocks crop out to the south. Drilling logs indicate the depth to Precambrian granitic basement ranges from about 2300 to 4600 ft. A single deep borehole east of Springerville (Peirce and Scurlock, 1972) confirms the continuation of the principal Paleozoic units beneath the White Mountain volcanic field. These stratigraphic units are the Kaibab Limestone, the Coconino Sandstone and the Supai Formation, all of Permian age.

The sedimentary rocks are only locally exposed, being covered by extrusive igneous rocks of the White Mountain volcanic field (Figure 1).

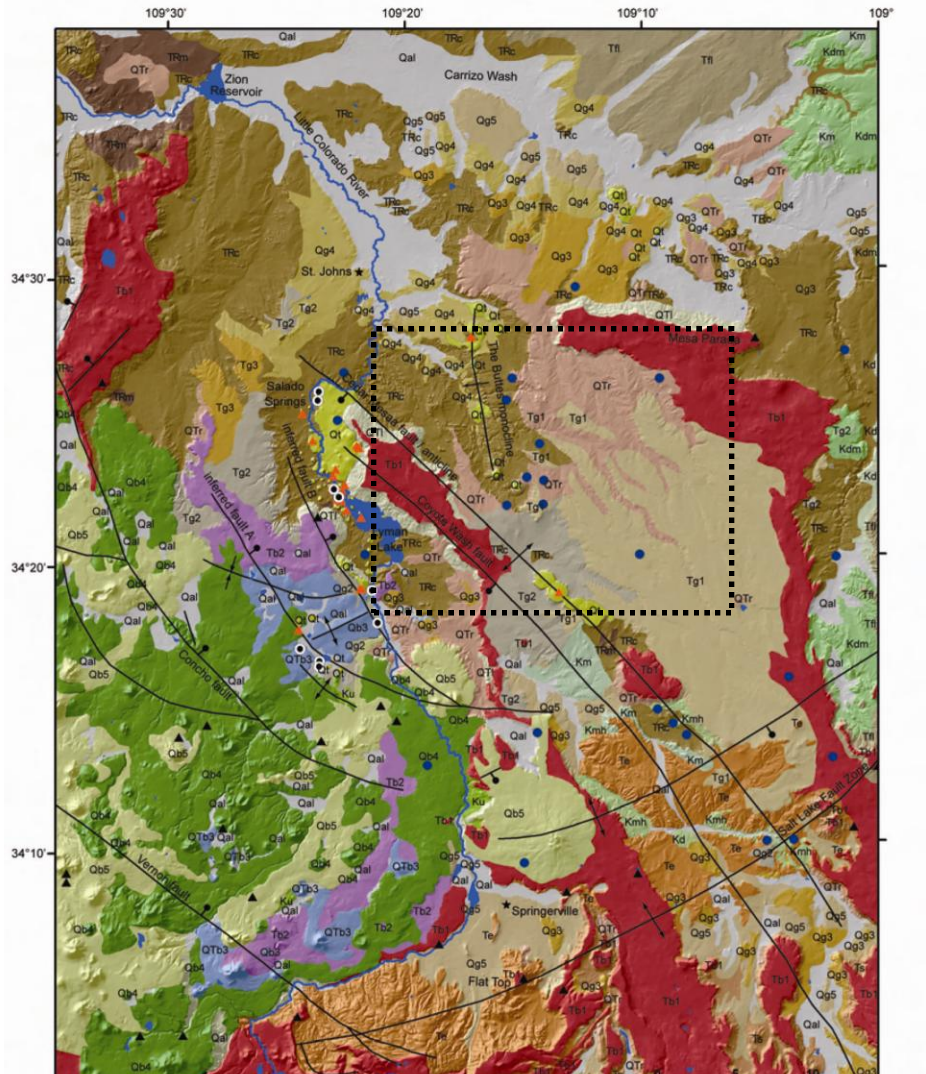

Figure 1. Surface geologic map of the Springerville area. Dashed outline defines the bounds of the numerical mesh.

The area exposes Eocene to Quaternary strata that place constraints on the interaction of uplift, volcanism, and the hydrologic system. The modern surface is formed by broad pediments of non-resistant Triassic Chinle Formation, remnants of a succession of Eocene and younger gravel terraces deposited during dry climatic cycles, windows of Cretaceous sandstone, and basalt flows and volcaniclastics from successive episodes of volcanism that have occurred from 32 ma to at least 10 ka.

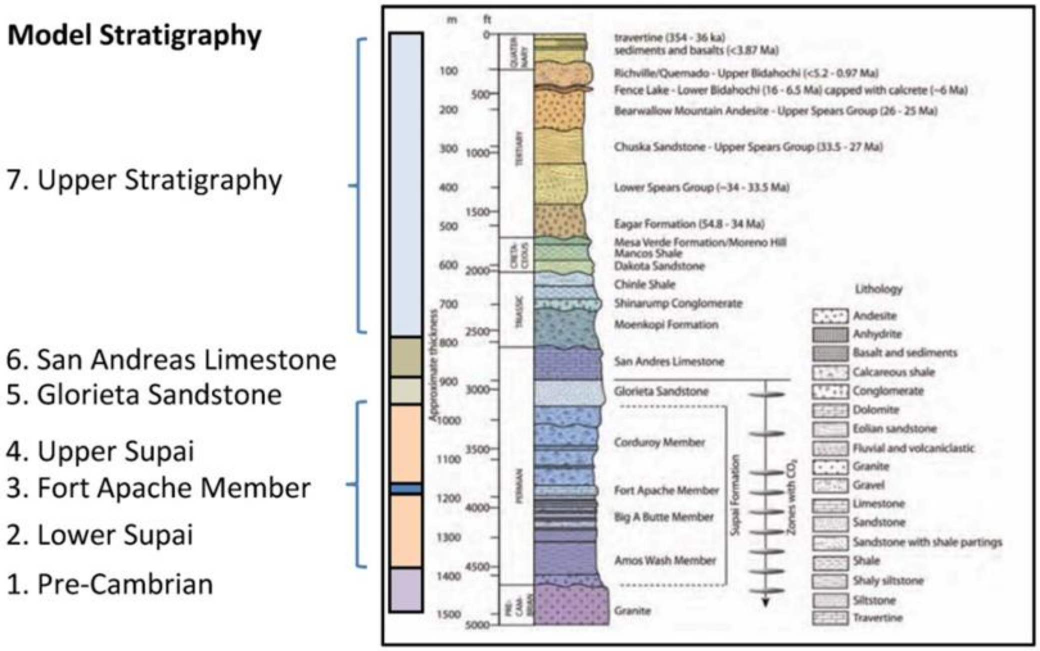

Figure 2. Generalized stratigraphic column for the Springerville area.

Within the context of the GFM, there are seven stratigraphic units of interest (Figure 2). The predominant CO2-containing strata in the area are the folded and faulted Fort Apache, Big A Butte, and Amos Wash members of the Permian Supai Formation with impermeable anhydrite and mudstone capping layers and the fractured and highly weathered Precambrian granite at the base of the Supai. The GFM includes the high CO_2 producing Fort Apache Member contained in the larger Supai Formation, and the overlying aquifers in the Glorieta Sandstone and the karstified San Andres Limestone (Rauzi, 1999). The geology above the San Andreas Limestone is represented by a single unit. Information about the spatial variation in the stratigraphic thickness of the geologic layers is provided by a detailed structural contour map of the base of the Fort Apache Member of the Supai Formation (Figure 3, from Rauzi, 1999) and generalized stratigraphic thicknesses from Embid, 2009.

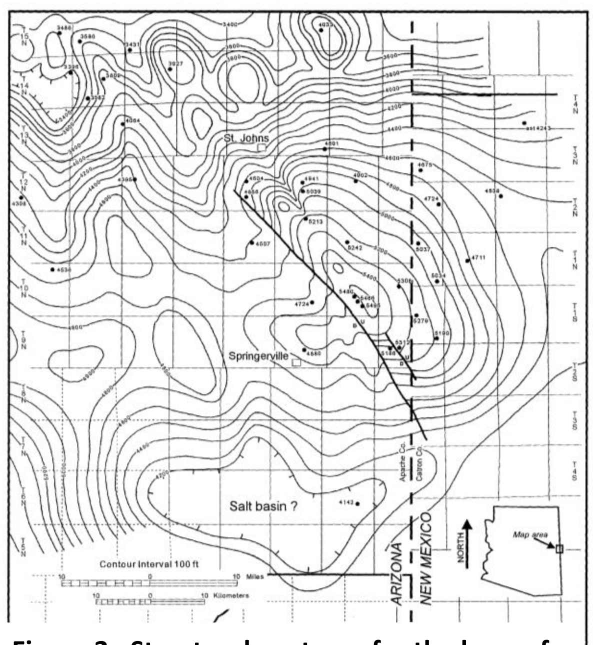

Figure 3. Structural contours for the base of the Fort Apache formation.

Faults

The Springerville-St. Johns Anticlinal Dome (see Figure 3) is formed at the intersection of two major regional structural fabrics that reflect different stress regimes that have affected the area. The dominate fault in the area (Coyote Wash) bounds the anticline on the west (Figure 3) and is part of a discontinuous system of northwest-trending faults and small undulations superimposed on the broad fold. The axis of the Cedar Wash anticline parallels the Coyote Wash fault and is faulted at depth at least in segments. The first-order GFM includes only the Coyote Wash Fault.

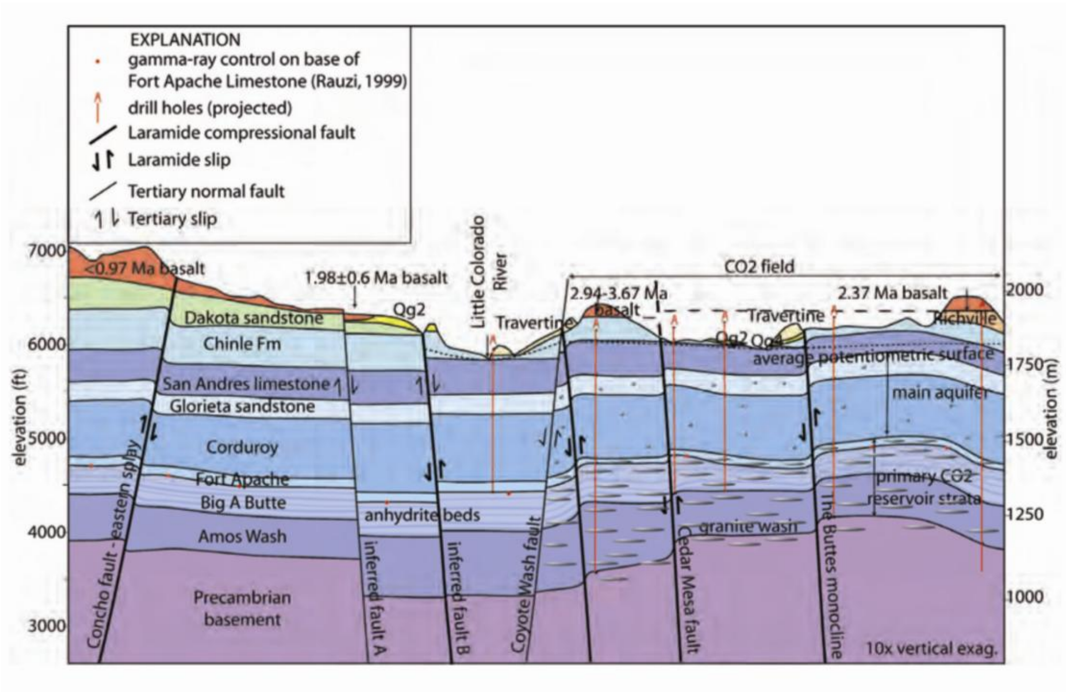

Figure 4. Generalized geologic cross-section through the Springerville area showing the inferred dip on the faults.

The dip on the faults is not constrained but is inferred from Figure 4 to be high angle (>70 degrees). The highest concentration of CO_2 gas in the Springerville-St. Johns Dome has recently been discovered near this intersection 60 m beneath the Permian strata in granite wash, suggesting the possibility of enhanced influx and trapping of deeply-sources fluids at the juncture of the two fault zones.

Numerical Modeling

Numerical meshes of the GFM described above have been developed for numerical modeling of the hydraulic flow-and-transport as well as a finite-element analysis of the stress-permeability relationship along the Coyote Wash fault that is thought to be controlling the flow of CO_2 to the surface in the Springerville area. An important component of this modeling is the quantification of the regional stress field and its perturbation in response to local geologic structures (see section below). Work on this aspect will continue in the first quarter of FY12. An example mesh of the GFM is shown in Figure 5.

Estimate of the principal stress orientations

The tectonic evolution (and related state of tectonic stress) of the Colorado Plateau, the southern Basin and Range, the Arizona Transition Zone, and the Rio Grande Rift tectonic provinces in eastern Arizona and western New Mexico (Figure 6) is still debated. Persistent questions include: What is the tectonic relationship between the Colorado Plateau to the Basin and Range? How is strain in the lithosphere accommodated in this region? and What are the geologic controls on the rapid spatial change in the orientation and magnitude of the regional stress field in the Springerville area? The regional stress exerts a fundamental control on the flow of CO_2 along the major faults in the regional and therefore quantification of the regional stress field is an important component of the numerical modeling.

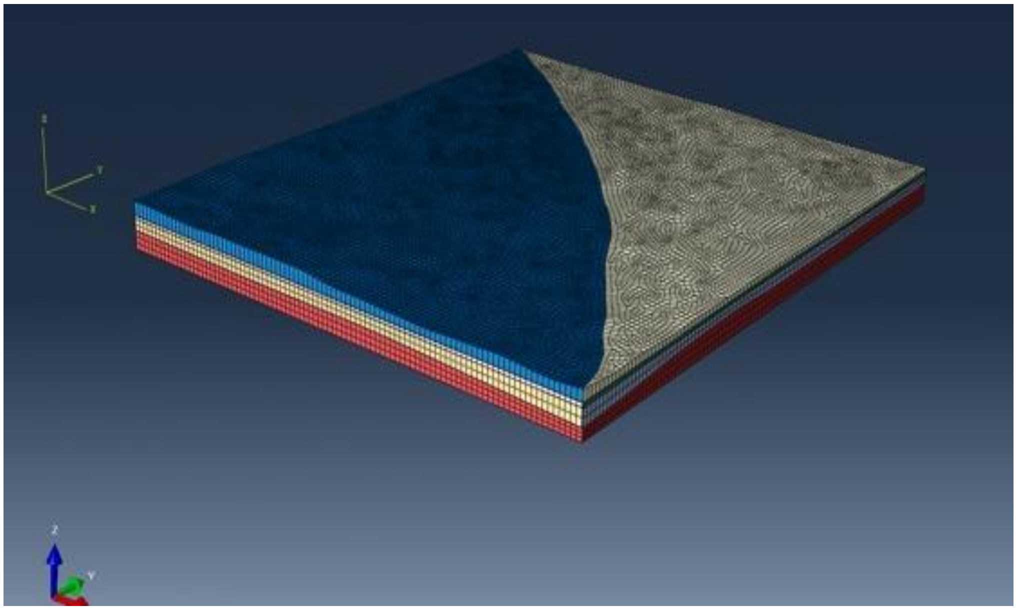

Figure 5. Meshed first-order GFM for the Springerville area showing the geometry of the Coyote Wash fault and the geologic stratigraphy.

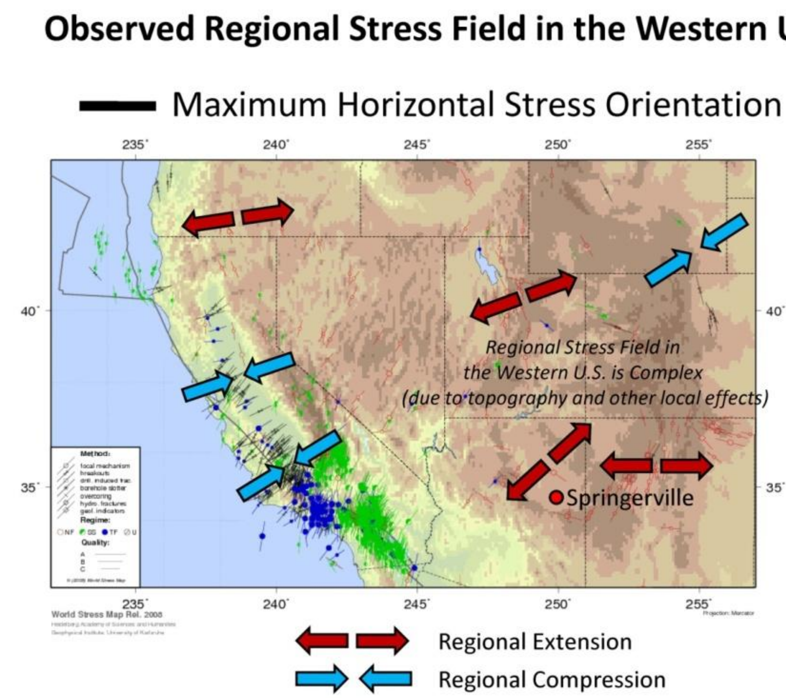

Figure 6. Variations in the orientation of the maximum horizontal compressive tectonic stress and tectonic stress regime in the Springerville area. The close proximity to the edge of the Colorado Plateau results in abrupt changes in the stress field in this region.

Volcanic vent alignments in the Springerville area indicate the presence of fractures or faults, along which magma ascended more readily than elsewhere and provide first-order evidence of the crustal stress orientation (Conner et al., 1992). The fact that most are subparallel to regional physiographic features, such as the Mogollon Rim, suggests that the overall arcuate pattern observed in cinder cone alignments is a reflection of the structural margin of the Colorado Plateau. This supports the conclusion of Zoback and Zoback, 1980 and Zoback et al., 1989 that stress fields near tectonic boundaries reflect structural transitions. The fractures or faults implied by vent alignments within the Springerville Volcanic Field may be related to extension associated with deformation of the Colorado Plateau margin, and to a lesser degree to a minor Basin and Range imprint. Furthermore, Late Cenozoic volcanism in the Springerville volcanic field suggests that tectonic activity on the southern periphery of the Colorado Plateau has also been recent (Condit and Connor, 1996). Evidence for regions of partial melt in the crust related to Quaternary volcanism has been suggested from teleseismic converted phases that characterize the bulk composition of the crust (Frassetto, et al., 2006). Information about the magnitude of the regional stress field in the study area is poorly constrained. We plan to use a finite-element analysis of the intraplate tectonic stress in this region to evaluate both the magnitude and orientation of the regional stress field.

Development of the Springerville reservoir model.

We have built an initial reservoir model based on the GFM described earlier. A preliminary coarse grid has been generated and tested. The model contains 4 basic hydrogeologic units as well as a major fault. Figure 7 shows the Hydrologic Framework Model (HFM). Table 1 gives a description of the units. Figure 8 shows the grid numerical grid containing about 40,000 nodes. Figure 9 shows the nodes associated with the fault. This model will be used to perform initial scoping calculations and increase resolution will be added.

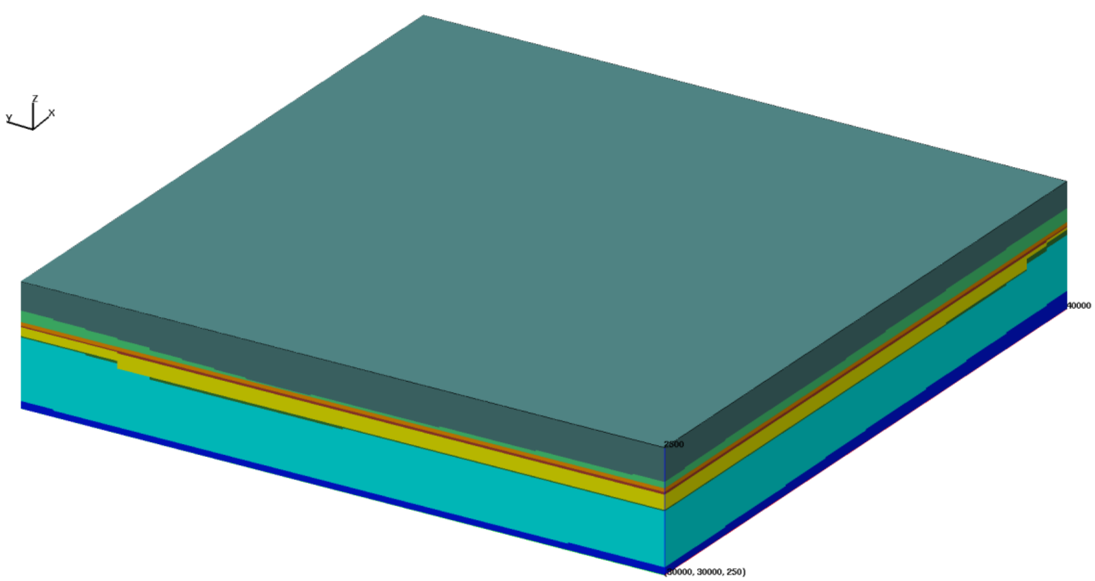

Figure 7. Simplified hydrogeology of the Springerville reservoir.

Table 1. Identification of hydrogeologic units in Springerville model.

Material #	Stratigraphic unit	Color
material 8	above topography	gray
material 7	upper units	green
material 6	san andreas	orange
material 5	glorieta	red
material 4	upper supai	yellow
material 3	ft. apache	brown
material 2	lower supai	blue-green
material 1	precambrian	blue

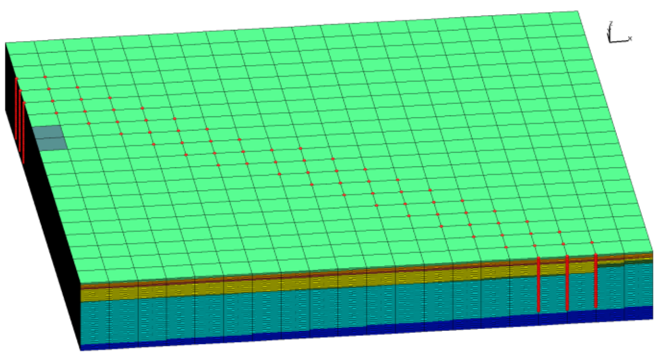

Figure 8. Numerical grid (without nodes above the ground surface) showing nodes (red dots) assigned to the fault region.

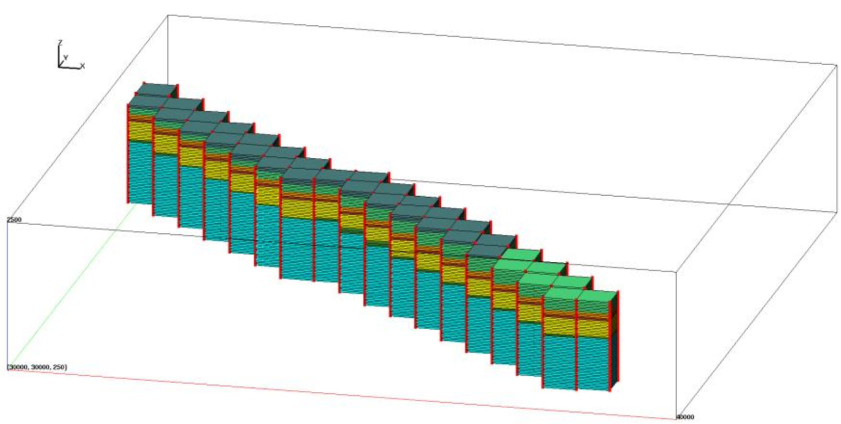

Figure 9. Nodes assigned to the fault.

Development of permeability-stress modeling capability in FEHM

In potential CO_2 reservoirs such as Springerville, CO_2 or brine leakage from CO_2 reservoirs to fresh water aquifers can occur in faults, caprock, and wellbores. Thermal-hydrologic-mechanical (THM) models often need equations that relate the rock permeabilities to stress changes. Existing models relied on tensile failure models or hydraulic fracturing formulas. These methods are useful in understanding near wellbore rock failure under pumping conditions or temperature changes. Faults and to a lesser extent fractures, especially those that are sub vertical, are often thought to fail due the shear slip along the fault or fracture faces. This failure or movement is also responsible for seismic events. We have added a new shear-based permeability enhancement model to FEHM and tested it. The theory is summarized below.

A general framework was developed for a shear failure – permeability module in FEHM. The intent is to model permeability changes resulting from shear failure along either pre-existing fault planes specified by the user or the plane that maximizes the value of the excess shear stress (τ_{excess}) given by:

$$\tau_{excess} = |\tau| - S_o + \mu * \sigma$$

where $|\tau|$ is the absolute value of the shear stress on a plane, σ is the effective stress normal to that plane, S_o is shear strength, and μ is the coefficient of friction on the plane. The maximum value of the excess shear stress τ_{excess} is given by:

$$\tau_{excess}(\max) = \frac{1}{2}(\sigma_1 - \sigma_3)(\mu^2 + 1)^{1/2} - \frac{1}{2}\mu(\sigma_1 + \sigma_3)$$

and occurs at an orientation β with respect to the maximum principal stress (σ_1) given by:

$$\tan(2\beta) = -\frac{1}{\mu}$$

Here σ_3 is the minimum principal stress at the point.

It is assumed that the principal axis of the permeability tensor coincide with those of the stress tensor. When the failure criteria is satisfied, the principal permeabilities are multiplied by a user specified factor as a function of the excess shear stress and then the permeability components along the grid axis are calculated. The multiplication factor is ramped over a user specified range of the excess shear stress to avoid step changes. The Young's modulus can be decreased by a user specified factor in an analogous manner.

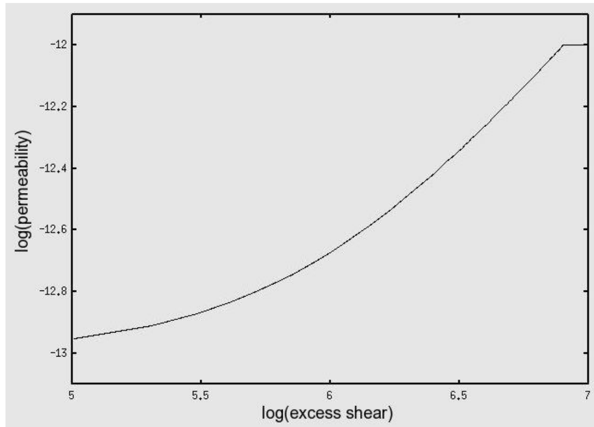

Figure 10. Permeability Vs. excess shear stress. (original units are m^2 and Mpa respectively).

Besides the permeability model, a plastic failure model was also added. That model should be useful for studying the mechanical behavior softer caprocks.

Task 2 Use natural analog sites to determine potential geochemical impacts:

A groundwater sampling trip to Springerville including wells on Tucson Electric Power property and the Salado Springs area is tentatively scheduled for the week of November 7. In support of the core samples collected from the Arizona Geologic Survey that were submitted for thin section preparation in Q3, a draft summary of the observed core was prepared. This summary includes a stratigraphic context for all samples collected and photographs of the core.

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Milestones and Status:

1.1: Acquire triaxial core flood system (Completion Date: 12/31/2011)

Status: Delayed due to setback in vendor contract negotiations

1.2: Complete geomechanical flow-through experiments: caprock (Completion Date: 9/30/2012)

Status: not started.

1.3: Complete geomechanical flow-through experiments: wellbore materials (Completion Date: 9/30/2013)

Status: not started.

2.1: Complete geomechanical simulations (Completion Date: 9/30/2013)

Status: Initiated.

2.2: Create geomechanical test bed (Completion Date: 6/30/2012)

Status: Initiated

2.3: Sensitivity and scenario analysis (Completion Date: 9/30/2013)

Status: not started.

3.1: Baseline predictive reactive-transport model for natural analog site (Completion Date: 9/30/2012)

Status: Initiated.

3.2: Groundwater chemistry observations at a natural analog site, compared to reactive-transport (Completion Date: 9/30/2012)

Status: not started.

3.3: Assessment of predictive capability of reactive-transport models and value of information assessment (Completion Date: 9/30/2013)

Status: not started.