NRAP-ARRA Quarterly Report
FY2011, Q4
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D. Coblentz

Quarterly Progress/Activities Description

1. Development of the Geologic Framework Model.

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.

A. Geologic Stratigraphy

The Springerville area is comprised of relatively f1atlying 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).

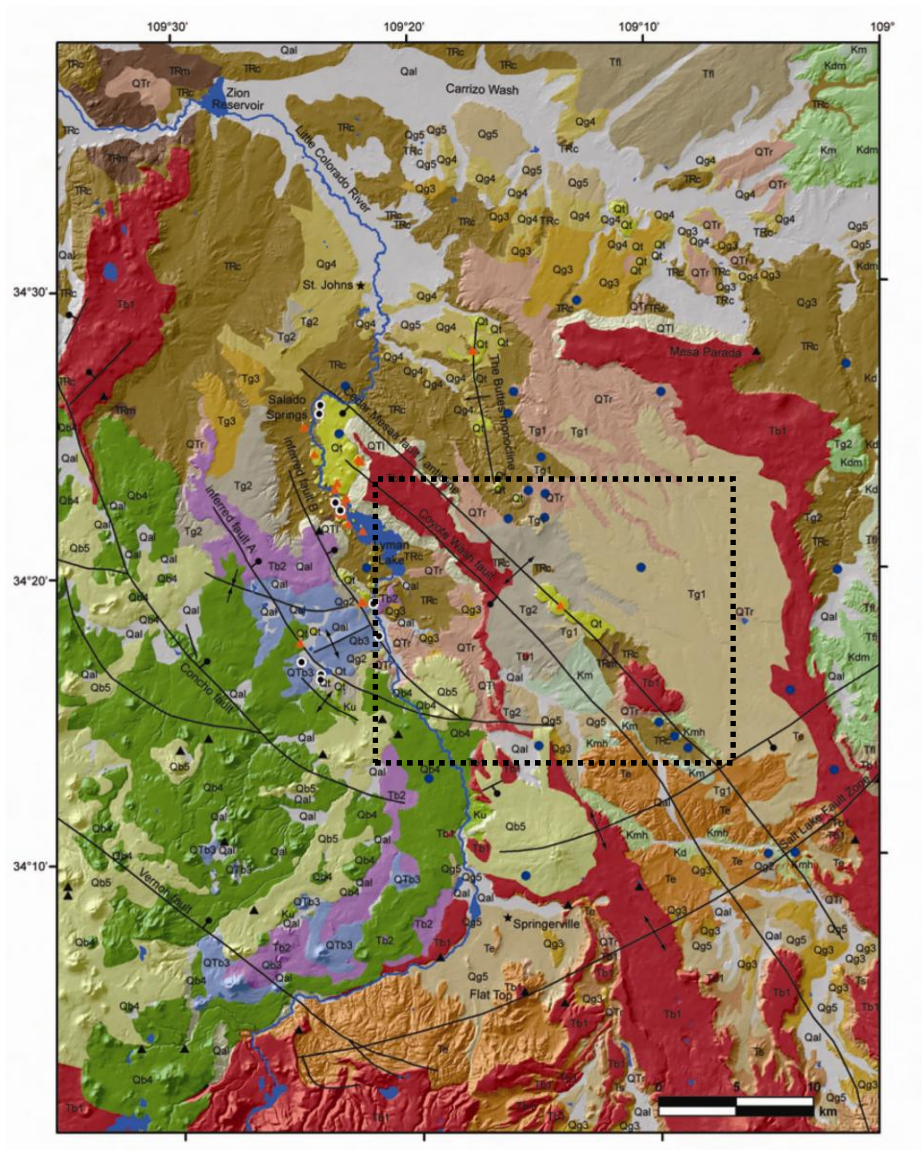

Figure 1: Surface geologic map of the Springerville area. Dashed outline defines the bounds of the numerical mesh.

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.

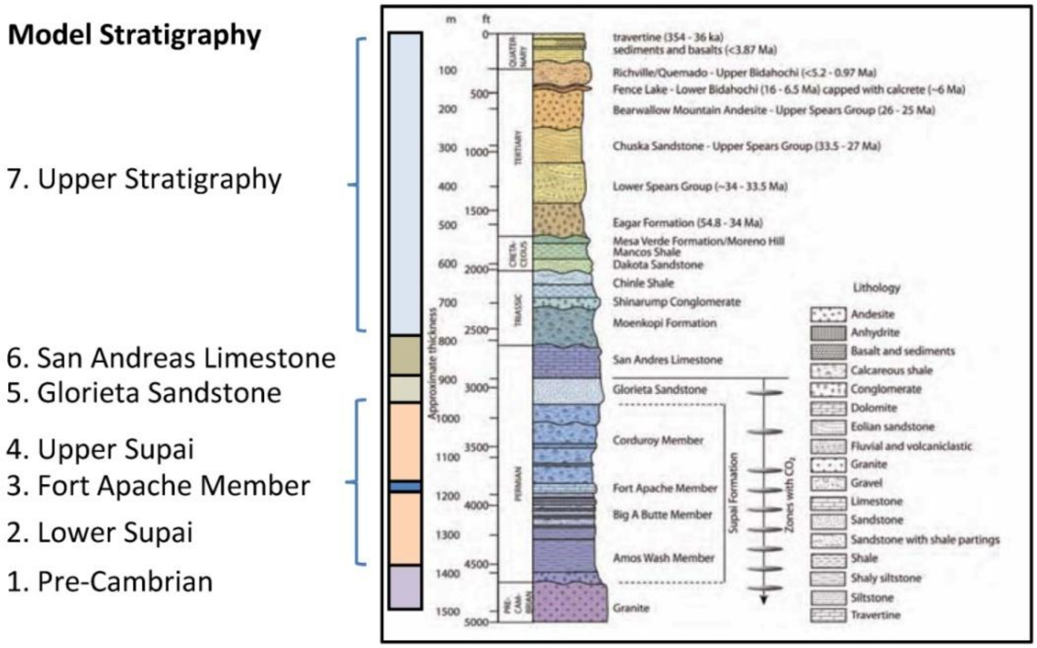

Figure 2: Generalized stratigraphic column for the Springerville area.

Within the context of the GFM, there are seven stratigraphic units of interest (Figure 2). The predominant CO_2-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

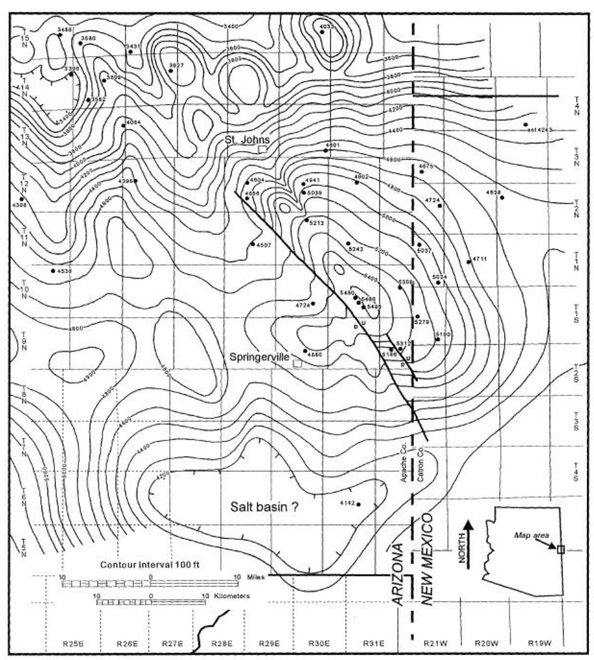

Figure 3: Structural contours for the base of the Fort Apache formation

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.

B. 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.

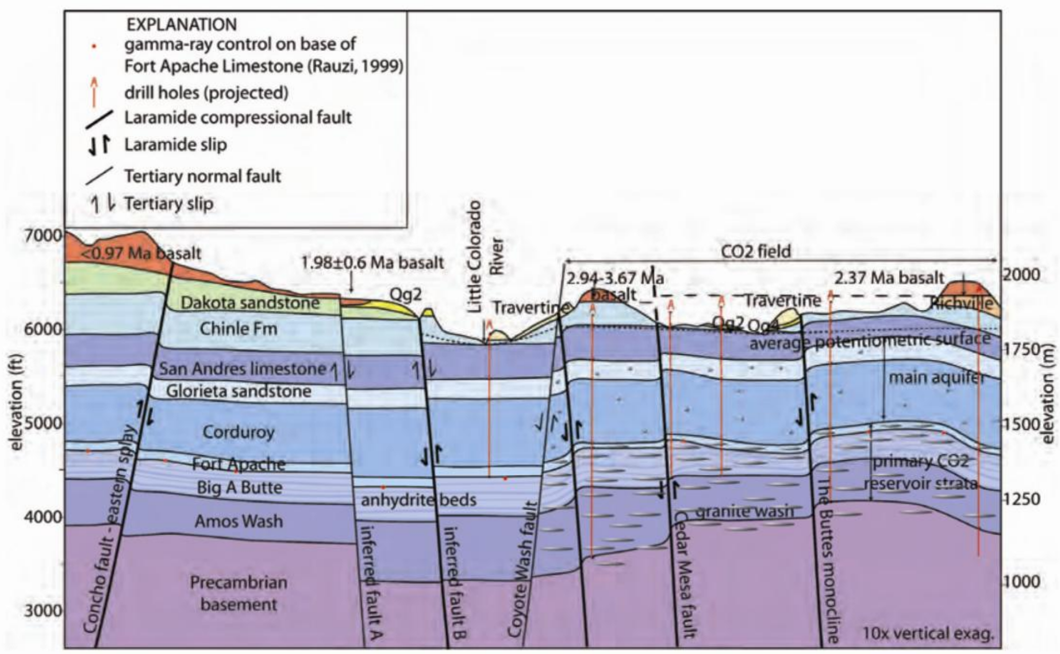

Figure 4: Generalized geologic cross-section through the Springerville area showing the inferred dip on the faults.

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.

C. 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.

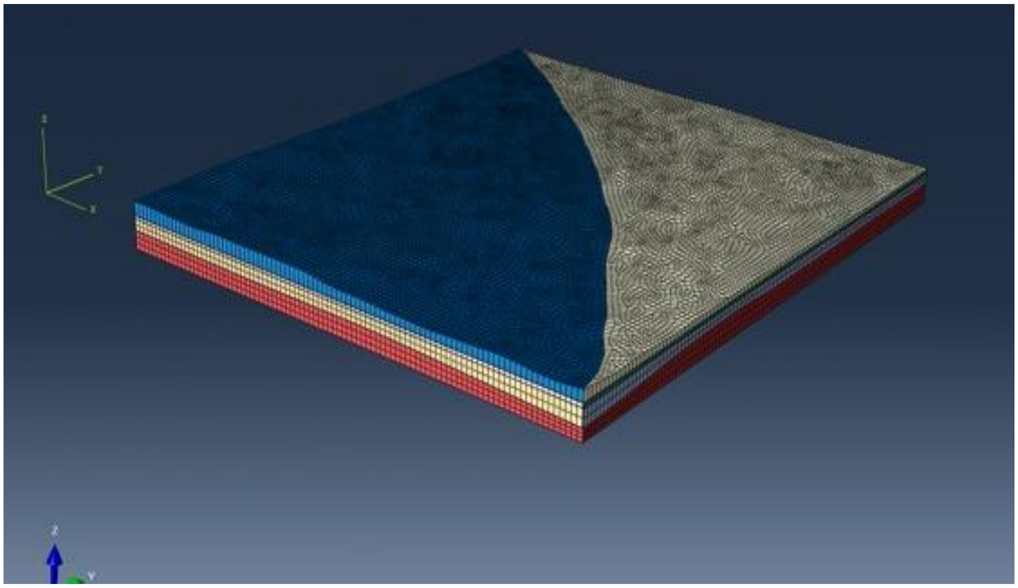

Figure 5: Meshed first-order GFM for the Springerville Area showing the geometry of the Coyote Wash fault and the geologic stratigraphy.

2. 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 CO2 along the major faults in the regional and therefore quantification of the regional stress field is an important component of the numerical modeling.

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.

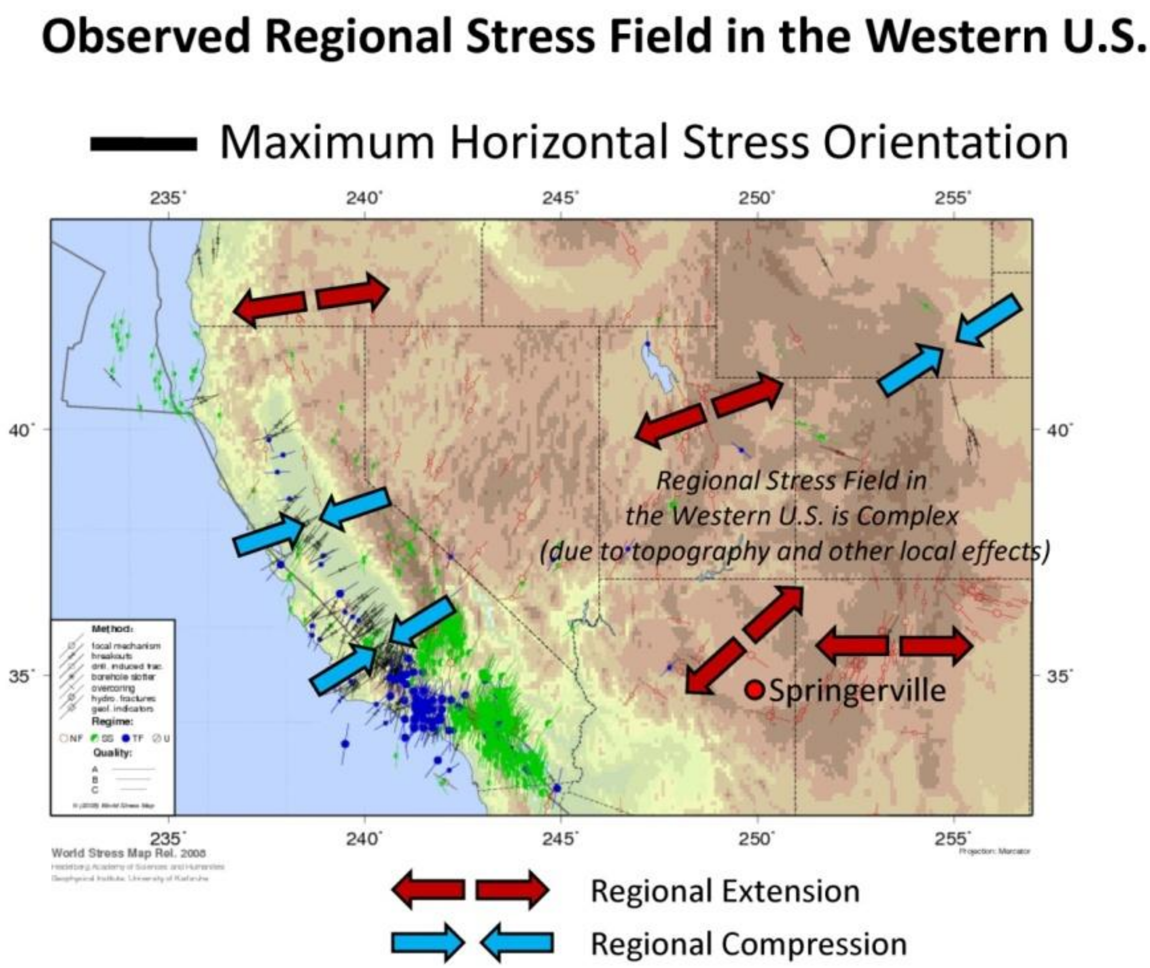

Figure 6: Variations in the orientation of the maximum horizontal compressive tectonic stress and tectonic stress regime in the Springerville area. The close proximity to the edge of the Colorado Plateau results in abrupt changes in the stress field in this region.

References

Condit, C. D. and Connor, C. B., 1996, Recurrence rates of volcanism in basaltic volcanic fields: An example from the Springerville volcanic field, Arizona: Geological Society of America Bulletin, v. 108, 1225-1241.

Connor, C., C.. Condit, L. Crumpler, and J. Aubele, Evidence of Regional Structural Controls on Vent Distribution: Springerville Volcanic Field, Arizona, J. Geophy. Res., 97, 12,349-12,359, 1992.

Embid, E. H. U-Series Dating, Geochemistry, and Geomorphic Studies of Travertines and Springs of the Springerville Area, East-Central Arizona, and Tectonic Implications, M.S. Thesis, UNM, 116 pp., 2009.

Frassetto, A., Gilbert, H., Zandt, G., Beck, S. and Fouch, M. J., 2006, Support of high elevation in the southern Basin and Range based on the composition and architecture of the crust in the Basin and Range and Colorado Plateau: Earth and Planetary Science Letters, v. 249, 62-73.

Peirce, H. W., and Scurlock, J. R., 1972, Arizona well information: Arizona Bureau of Mines Bull. 185.

Rauzi, S. L., Carbon Dioxide in the St. Johns-Springerville Area, Apache County, Arizona, Arizona Geological Survey Open-File Report 99-2, 22 p., 1999.

Zoback, M.L., and M. Zoback, State of Stress in the Conterminous United States, J. Geophy. Res., 85, 6113-6156, 1980.

Zoback, M. L., et al. (1989), Global patterns of tectonic stress, Nature, 341, 291– 298.