An Image Log-based Geometrical and Textural Analysis of a Low-angle Normal Fault System Beneath the FORGE Site near the Mineral Mountains, Utah

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This document is intended for anyone interested in background information on the Utah FORGE site and data as well as the methodology for my data collection, results, and sources used for the poster.

Poster Abstract

Field-based studies of exhumed faults have provided valuable insight into the structural geometry and rock textures of fault systems, yet few studies have examined a vertical, subsurface profile through a low-angle normal fault (LANF) system. Seismic reflection data from near the Department of Energy's Frontier Observatory for Research in Geothermal Energy (FORGE) site to the west of the Mineral Mountains, UT, reveal a low-angle, W-dipping reflector underlying the basin fill. This surface is thought to represent a LANF, but its exact structural significance is still unclear. A Formation Microimager was logged in a vertical, 8.75 inch borehole over 2240-7550 ft in the Roosevelt Hot Springs Well 58-32 within the FORGE site, providing an "outcrop view" of the basin alluvium, igneous basement rock fabrics, and the textures and structures of this LANF system.

Sub-horizontal basin strata at the top of the logged interval (2240 ft) increase in dip with depth to a mean orientation (dip/azimuth) of 15/297 (n = 47) over 2700-3150 ft. Rare faults and fractures in the basin dip 45-55° toward the E and W. At the basin-basement contact at 3176 ft is a strongly conductive feature of 0.5 ft in thickness, oriented 26/250. The only substantive low-angle, W-dipping planes are associated with cataclastic textures over 3176-3186 ft and 3212-3222 ft with mean orientations of 13/300 (n = 16) and 26/268 (n = 8), respectively. Basement fabrics define an elongated, W-E dome with no significant preferred orientation that would indicate top to the W shearing. In the basement (3176-7550 ft), faults have mean orientations of 51/270 (n = 35), 47/074 (n = 8), and 76/176 (n = 4). Cataclastic textures are prevalent over 3176-3410 ft, and are only locally developed deeper in the basement within 2-12 ft of fault planes. Conductive fractures have a range of orientations, but they dominantly dip W with a mean orientation of 39/276 (n = 1260), or are sub-parallel to faults with mean orientations of 74/183 (n = 220), 67/133 (n = 110), and 38/084 (n = 180).

Results indicate that the shallowly W-dipping seismic reflector encountered by the borehole is a LANF that primarily accommodated deformation via brittle deformation mechanisms. No obvious shear or mylonitic textures are obvious from the image log, or are too fine-grained to observe.

Introduction/background

The Department of Energy's (DOE) Utah Frontier Observatory for Research in Geothermal Energy (FORGE) field site was established to test the feasibility of enhanced geothermal systems (EGS) as a clean source of heat energy to generate electricity for the United States electrical grid. Much of the geological and contextual information about the site and its set up is summarized in the Frontier Observatory for Research in Geothermal Energy Phase 2b Final Topical Report (Moore et al., 2018).

As part of their investigation, researchers collected a plethora of subsurface data, updated the regional geologic maps, and synthesized several datasets. A formation microscanner image (FMI) (see Brown et al., 2015) was run in well 58-32 over 2230-7540 ftMD (feet measured depth), and records an "outcrop-scale" electronic resistivity image of the basin sediments (2230-3176 ftMD) and crystalline basement rock (3176-7540 ftMD). The image was processed by Schlumberger and a preliminary interpretation of the log was interpreted by them. However, as a former consultant that primarily used electronic borehole image logs, I recognized that I could make a substantial contribution to the data collection, analysis, and interpretation of the subsurface geology of this log.

Methods

There were 5030 geologic planes that were manually identified through from interactive dip picking. The methodologies outlined in Ruehlicke et al., 2019 were followed to collect dip data and analyze them with stereonets using the statistical eigenvector analysis technique (SEAT).

The dip types that I chose to use for different geologic features are defined as follows:

- Bedding – resistivity contrast and/or textural change of basin sediments
- Breccia-Fol – (for breccia foliation) image texture shows conductive planes in between layers of resistive, crushed/brecciated rock fragments (cataclasite?)
- Deformed – planes adjacent to a fault plane that show a change in orientation approaching the fault plane **OR** planes that are ambiguous on the image (it is difficult to determine whether they are a fracture or fabric)
- Fabric – crystalline fabric defined by the alignment of minerals or alternating "layers" on the image with varying conductance
- Fault – planar feature that clearly juxtaposes two different image textures that may or may not have brecciated/cataclastic textures adjacent to it
- Frac-cond – conductive plane that is fully circumferential around the borehole – typically shows up in the static-normalized image
- Frac-res – resistive plane that is fully circumferential around the borehole
- Induced fracture – drilling-induced fracture, typically has a vertical orientation
- Lith-contact – planar feature that juxtaposes two different image textures (may or may not be a fault plane)
- Part_frac-cond - conductive plane that is partially circumferential around the borehole – may show up in the static-normalized image, but normally does not

Dip data were plotted as poles to planes onto lower hemisphere, equal-area stereonets according to dip type and were analyzed interactively with depth (Ruehlicke et al., 2019). All dips, means, and axes are reported as dip/plunge magnitude and dip/plunge azimuth (e.g. a plane of 20/270 is dipping 20° toward an azimuth of 270°). Means were calculated for fracture and fault planes, and axes were determined for breccia-fol (breccia-foliation) dip types.

Results

All results are preliminary. Nonetheless, several interesting observations have been made. The shallowly (20°) W-dipping seismic reflector underneath the FORGE site near the Mineral Mountains, UT is a fault zone characterized by a heavily fractured interval and several 2-12 ft thick cataclastic zones, mostly over 3150-3850 ftMD. Interestingly, the breccia-foliation planes define several shallowly W to NNW plunging axes. This may reflect a curved geometry of the fault plane(s) that accommodated low-angle fault deformation that affected the basement rocks. The dominant fracture and fault geometries, including the low-angle faults in the basement, likely formed under the modern-day N-S to NE-SW maximum horizontal stress field.

There is no obvious evidence of a strongly foliated, W-dipping shear zone down to 7545 ft MD. However, there is evidence for elongated minerals and foliations from core and the image log. While W to NW dipping fabrics exist, the overall data do not show a major W to NW dipping trend (i.e. W to NW dipping planes do not persist for > 30-40 ftMD). As a whole, the fabric dip data define a broad dome likely related to the intrusion of the igneous pluton(s) rather than shear deformation.

Future work

The data set needs to be cleaned up to eliminate errant picks, and to determine the nature of certain geologic features. For example, I need to determine what some of the "deformed" planes are, whether they are planes of fabric, fracture, or something else. I also intend to define rock lithofacies using the available core, image logs, and petrophysical response of the rock. This iterative process will help to better define the dip types and improve consistency among the data set.

I envision this project will contribute to improving our understanding about fracturing and faulting in the subsurface as well as the intrusion history of the pluton in the subsurface (perhaps correlating to observations in outcrop). This work may also help to improve knowledge of EGS systems

References

Data from the Utah FORGE project may be found at: https://gdr.openei.org/

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