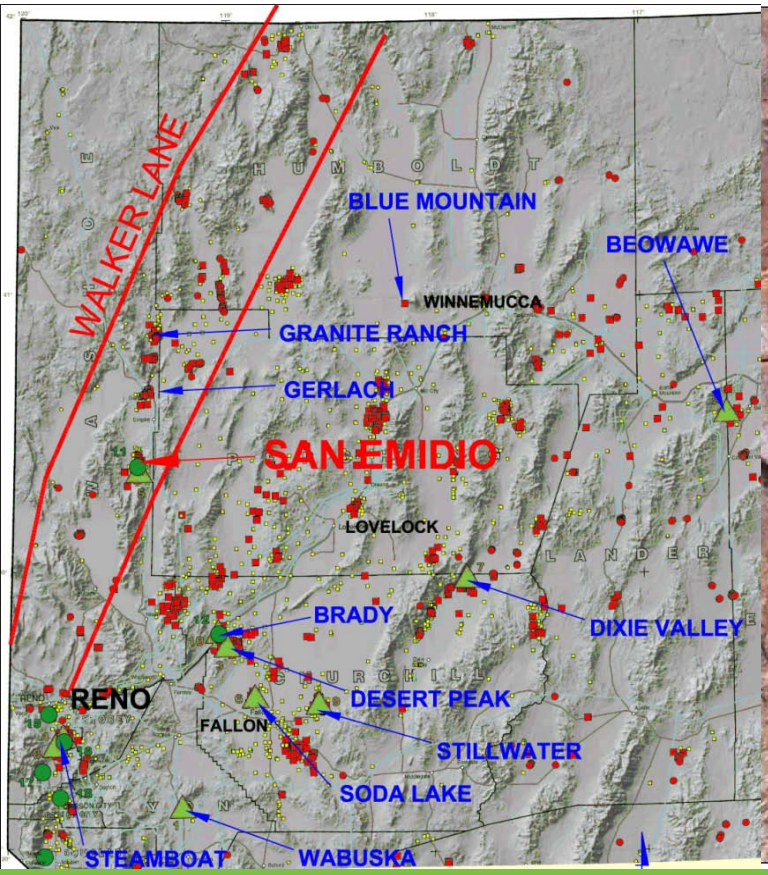


Finding Large Aperture Fractures in Geothermal Resource Areas Using a Three-Component Long-Offset Surface Seismic Survey

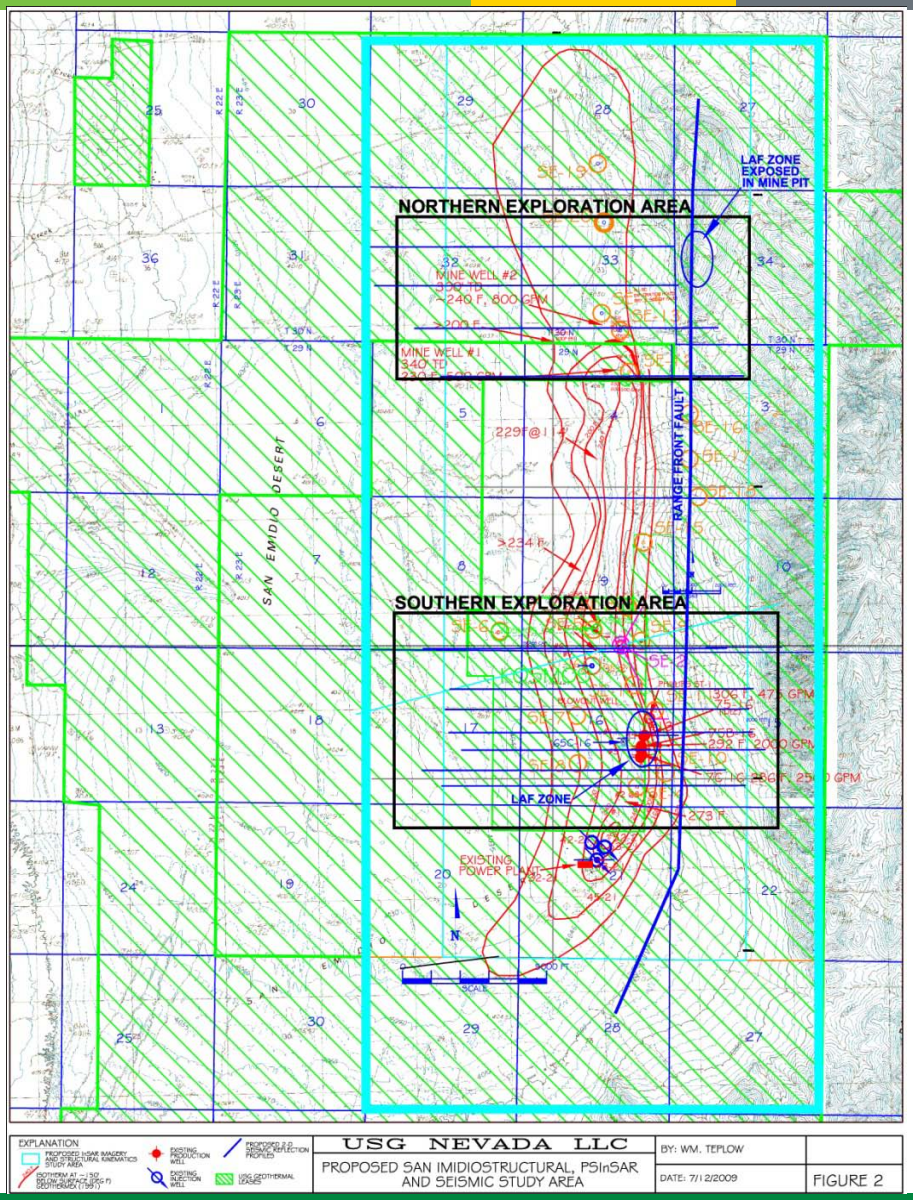
May 19, 2010

William Teplow

US Geothermal, Inc.

Track Name

San Emidio Geothermal Resource, Nevada



San Emidio Exploration Project Overview

- Project Elements and Schedule
  - Phase 1: Exploration – April 2010 to December 2010.
    - Task 1: Geologic mapping and kinematic analysis
    - Task 2: PSInSAR (Permanent Scatter InSAR)
    - Task 3: Long-offset seismic refraction survey and processing.
    - Milestone: 3-D mapping of Large Aperture Fractures (LAF's)
    - Budget: $679,000
  - Phase 2: Drilling – January-December, 2011.
    - Task 4: Stepout drilling from existing production wells.
    - Milestone: Intersect and test LAF at location specified in Task 1.
    - Task 5: Full diameter exploration well San Emidio North
    - Task 6: Reservoir Testing
    - Budget: $6,530,000

San Emidio Exploration Project Overview – cont.

- Barriers: Archeological clearance for seismic lines
- Partners:
  - Dr. James Faulds, University of Nevada Reno
  - Dr. Mariana Eneva, Imageair, Inc.
  - Dr. Satish Pullamannapallil, Optim Software

Relevance/Impact of Research

- San Emidio Program Objectives:
  - Develop geophysical techniques to identify and map Large Aperture Fractures (LAF's) in a tensional tectonic environment.
  - Drill production/exploration wells targeted to intersect LAF's identified in this program.
  - Perform well and reservoir tests to quantify the production characteristics of wells drilled for this program.
- Expected Impacts of Program:
  - Reduce dry hole risk
  - Increase per-well productivity
  - Reduce parasitic pumping loads
  - Reduce environmental impacts by minimizing the number of wells for a given geothermal field capacity.
- Highlight innovative aspects of your project.
  - Integration of finite element structural kinematic analysis with measurement of ongoing surface deformation.
  - Use of 3-component long-offset seismic refraction to image LAF's.
  - Use of 3-component Vibroseis source

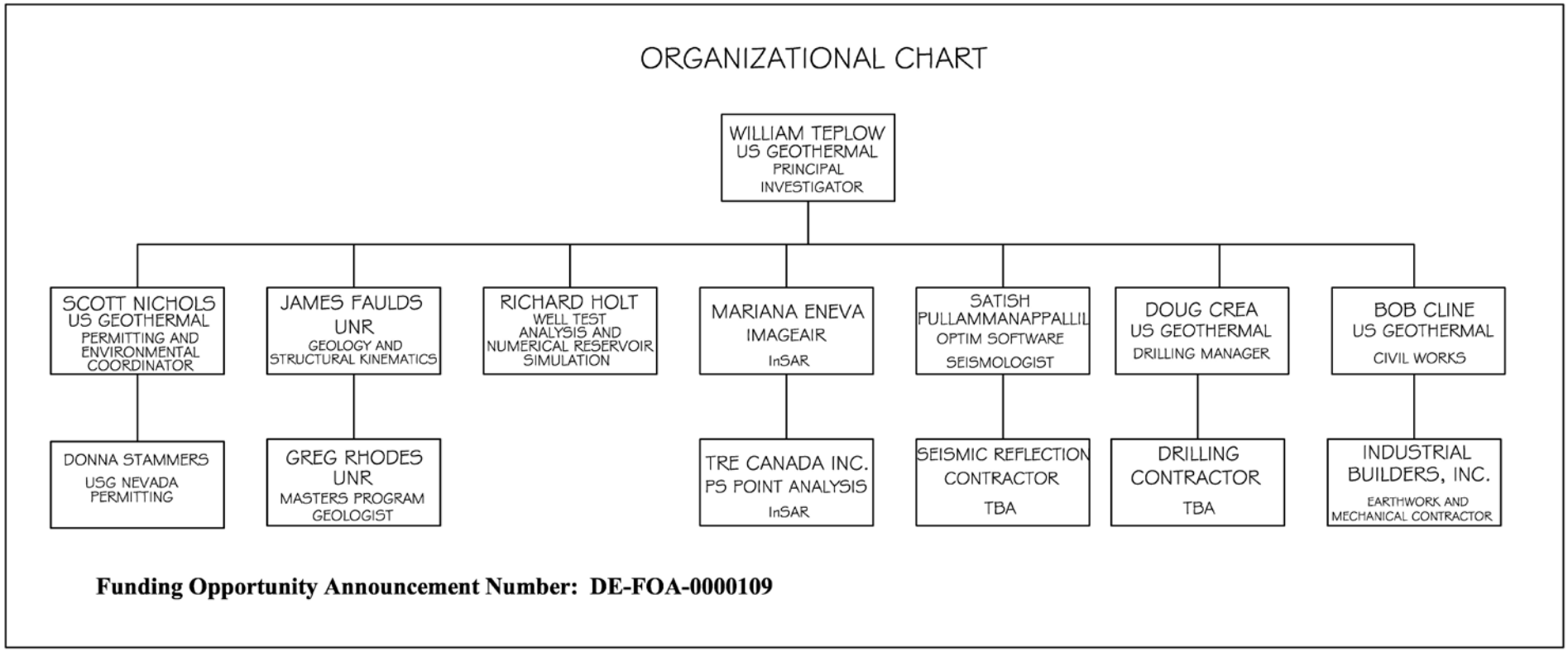
Scientific/Technical Approach

- Large aperture fractures occurring in normal faulting environments require ongoing tectonism to remain open.
- Ongoing tectonism can be quantified by a combination of rigorous structural kinematics, finite element analysis and measurement of ongoing surface deformation. Zones of maximum extension identified in this way become areas of focus for the seismic survey.
- Fluid filled LAF's are expected to have a well-defined seismic signature due to shear wave splitting and P-wave delay.
- Milestones for FY 2010:
  - Task 1: Complete Structural Kinematics Study-
    - Progress to date: Geologic mapping completed.
  - Task 2: Complete PSInSAR Study.
    - Progress to date: 58 radar images 1993 to 2008 acquired and currently being processed.
  - Task 3: Complete Seismic Survey and Analysis:
    - Progress to date: Seismic crew contracted for Sept. 13, 2010 start. Seismic lines permitted pending archeological clearance.

Accomplishments, Expected Outcomes and Progress

- Progress to Date:
  - LAF previously identified at San Emidio by drilling, mine excavation and surface mapping are incorporated in 3-D structural model.
  - Surface mapping of faults and slip orientation completed.
  - Resource characteristics of known LAF's at San Emidio are extensively tested and have been in production for over 20 years.
- Team Qualifications:
  - William Teplow, VP Exploration US Geothermal Inc., 30 years of successful geothermal exploration and development.
  - Dr. Mariana Eneva, Imageair Inc., expert in application of InSAR to surface deformation in geothermal field.
  - Dr. James Faulds, University of Nevada, Reno, expert in Basin and Range tectonics and kinematics.
  - Dr. Satish Pullamanapallil, Optim Software, developer of cutting egde seismic processing techniques.

Project Management/Coordination

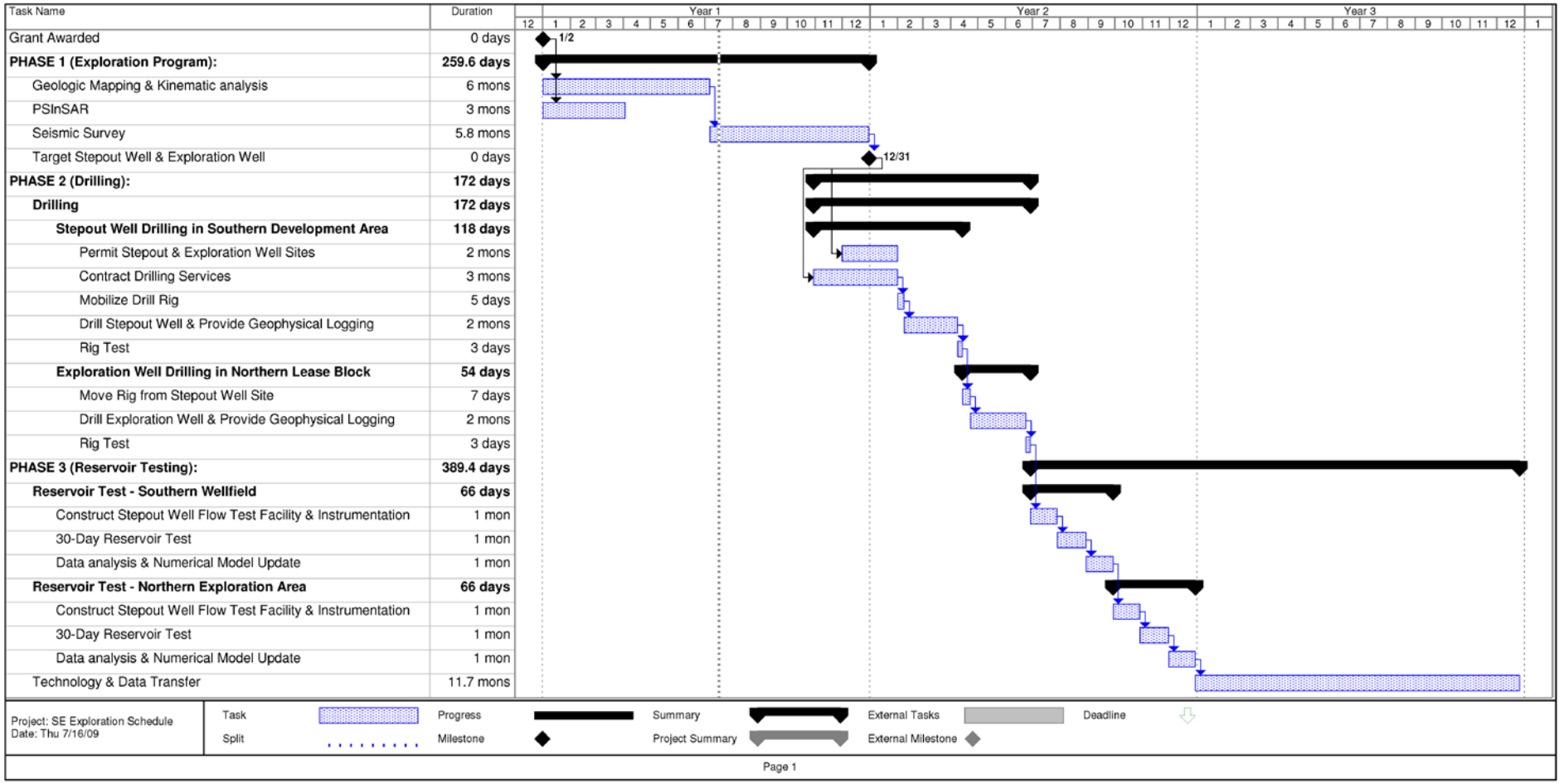


Future Directions

- Deployment strategy for techniques developed under the San Emidio exploration program:
  - Full development of San Emidio South lease block (16 MW).
  - Find, characterize and develop a commercial geothermal reservoir in San Emidio North lease block (+/-16 MW)
  - Apply program techniques to US Geothermal development properties:
    - Neal Hot Springs
    - Gerlach
    - Raft River
- Mitigation of risk of not achieving milestones.
  - Deep gradient holes (+/-2000') may be drilled at LAF targets prior to drilling full diamter exploration/production wells.

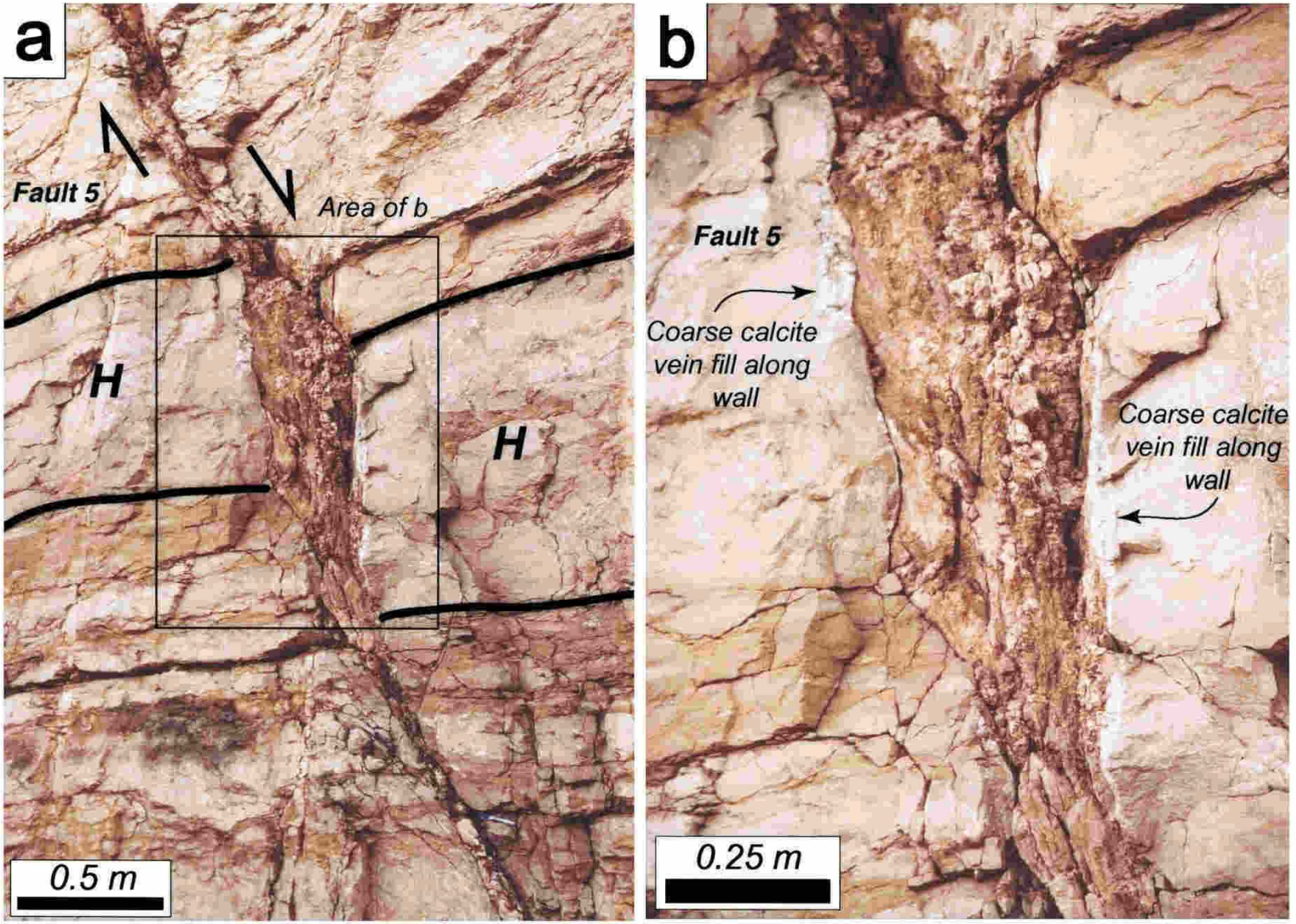
San Emidio Project Schedule

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



Task Name	Duration
Grant Awarded	0 days
PHASE 1 (Exploration Program):	**259.6 days**
Geologic Mapping & Kinematic analysis	6 mons
PSInSAR	3 mons
Seismic Survey	5.8 mons
Target Stepout Well & Exploration Well	0 days
PHASE 2 (Drilling):	**172 days**
Drilling	**172 days**
Stepout Well Drilling in Southern Development Area	**118 days**
Permit Stepout & Exploration Well Sites	2 mons
Contract Drilling Services	3 mons
Mobilize Drill Rig	5 days
Drill Stepout Well & Provide Geophysical Logging	2 mons
Rig Test	3 days
Exploration Well Drilling in Northern Lease Block	**54 days**
Move Rig from Stepout Well Site	7 days
Drill Exploration Well & Provide Geophysical Logging	2 mons
Rig Test	3 days
PHASE 3 (Reservoir Testing):	**389.4 days**
Reservoir Test - Southern Wellfield	**66 days**
Construct Stepout Well Flow Test Facility & Instrumentation	1 mon
30-Day Reservoir Test	1 mon
Data analysis & Numerical Model Update	1 mon
Reservoir Test - Northern Exploration Area	**66 days**
Construct Stepout Well Flow Test Facility & Instrumentation	1 mon
30-Day Reservoir Test	1 mon
Data analysis & Numerical Model Update	1 mon
Technology & Data Transfer	11.7 mons

Large Aperture Fracture Formation in Normal Fault, (Ferril, David A. and Alan P. Morris, 2002, *Dilational Normal Faults*, Jounal of Structural Geology 25 (2002) pp 183-196)



Calcite Filling in Range Front Fault, San Emidio North

Calcite Rhombs Filling Large Aperture Fracture, San Emidio North

Large Aperture Fracture, Neal Hot Springs, Oregon

Summary of San Emidio Exploration Project

- Drilling into large aperture open fractures (LAF's) typically yield production wells with high productivity and low pressure drawdown.
- Developing geophysical and geologic techniques for identifying and precisely mapping LAF's in 3-D will greatly reduce dry hole risk and the overall number of wells required for reaching a particular geothermal field power capacity.
- Advanced seismic reflection and refraction techniques combined with detailed structural analysis have the potential for precise 3-D mapping of LAF's.