

# Seismic Fracture Characterization Methods for Enhanced Geothermal Systems

May 19, 2010

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Principal Investigator:  
**John H. Queen**  
**Hi-Q Geophysical Inc.**

Track Name: Seismicity and Reservoir Fracture Characterization

- **Timeline**
  - Project start date: March 2009
  - Project end date: June 2012
  - Percent complete: 33%
- **Budget**
  - Total project funding: \$1,359,757
  - DOE share: \$817,757
  - Awardee and Partner share: \$542,000
  - DOE funding received in FY09: \$200,184. Cost Share: \$90,000
  - DOE funding for FY10: \$222,920. Cost Share \$77,000
- **Barriers**
  - Site Selection Barriers - Barrier B: Inadequate measuring techniques
  - Reservoir Validation Barrier - Barrier I: Images of Fractures After Stimulation
  - Partners: Stephen G. Muir, Lawrence Berkeley National Laboratory, Ormat Technologies, Inc.

Objective: Make Seismic Work in Geothermal Areas;  
Characterize Fractures/Faults

- Seismic Is Highest Resolution Geophysical Method
- Little Positive Outcome in Geothermal Areas
  - Volcanic Cover
  - Highly Altered Rock
  - Severe Structure
- Modeling Has Shown Ways To Overcome These Problems
  - Model learnings must be field tested
- Impact of Seismic Fracture/Fault Characterization
  - Stress modeling and prediction
  - EGS stimulation response
  - Complement Micro Seismic

- Approach – Brady's Hot Springs KGRA
  - Detailed modeling to address geological problems
  - Extensive field tests to determine best parameters
    - Fine spacing, subsurface receivers (VSP), orientation, multicomponent
  - 3D acquisition and processing
- Phase I Milestones:
  - 3D geological description, **completed on time** end May 2009
  - 3D seismic models, **completed on time** end November 2009
  - Seismic simulation, design of acquisition plan for seismic orientation test and VSP, **completed on time** end February 2010.
- Phase II Milestones:
  - Surface orientation tests, micro gravity survey, end June, 2010
  - Near offset VSP, end September 2010
  - Design 3D surface seismic, VSP, end February 2011.

- Peter Drakos, Ormat Technologies Inc.
  - Geologist, geothermal field development
- Ezra Zemach, Ormat Technologies Inc.
  - Director of Advanced Energy Technologies
- Stephen G. Muir, Consulting Geologist and Geophysicist
  - Geologist, seismic contractor, 30+ years, Nevada, California
- Ernie Majer, LBNL
  - Geothermal research, field methods, VSP, micro seismic, fractures
- Marge Queen, Hi-Q Geophysical Inc.
  - 13+ years fluid flow research, business manager
- John Queen, Hi-Q Geophysical Inc.
  - PI, 30+ years geophysical research, seismic, fractures
- Other Collaborations
  - Jim Faulds, University Nevada Reno, NBMG, geological mapping of Brady's
  - Ann Robertson-Tait, Geothermex, PI Brady's EGS demonstration project
  - Lianjie Huang, LANL, 3D seismic imaging, Brady's

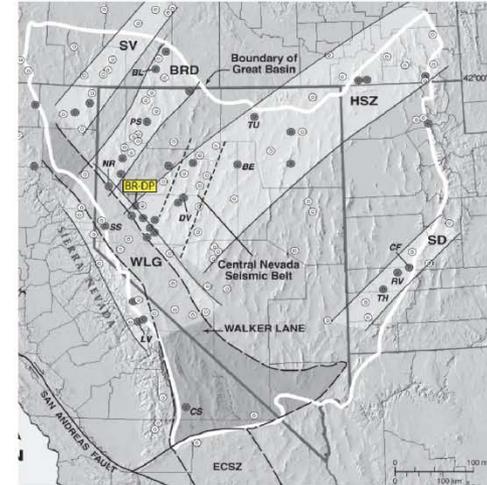
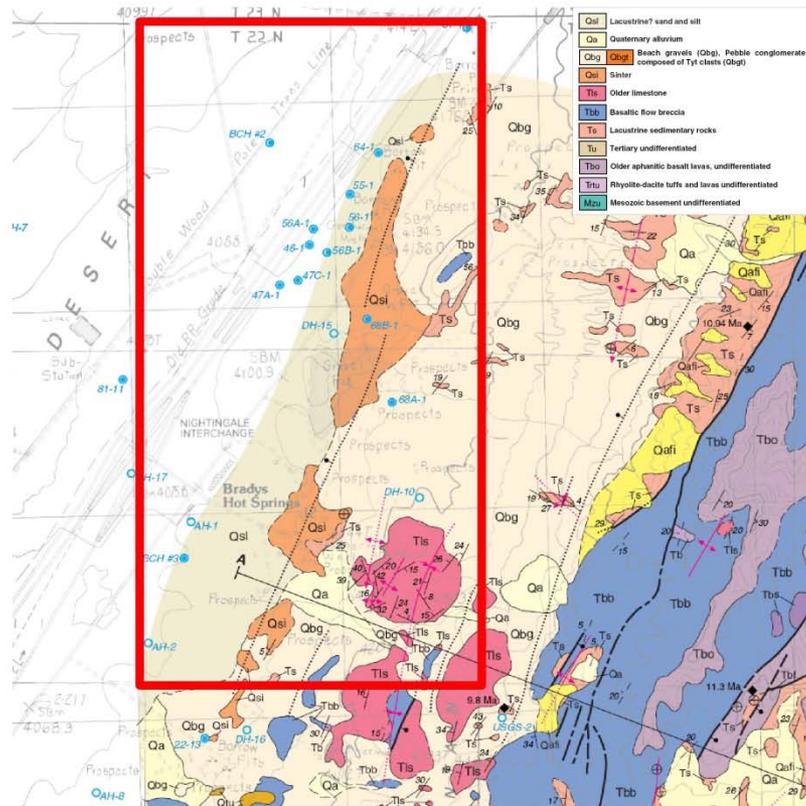
## Major Accomplishments:

- Geological Description of Brady's Hot Springs
  - Reviewed existing data
  - Interpreted well log, core, drilling reports
  - Generated cross sections
- 3D Geophysical Model And Seismic Simulation
  - Built 2D & 3D velocity, density model of Brady's Hot Springs
  - Simulated 275 shot 2D surface CDP line
  - Completed 3D elastic simulation with & without fractures
- Plan for Phase II Geophysical Field Program
  - 800 station micro gravity survey designed
  - Surface orientation test designed
  - Near offset VSP designed

## Brady's Hot Springs

Faulds, J.E., and Garside, L.J., 2003, Preliminary geologic map of the Desert Peak - Brady geothermal fields, Churchill County, Nevada: Nevada Bureau of Mines and Geology Open-File Report 03-27.

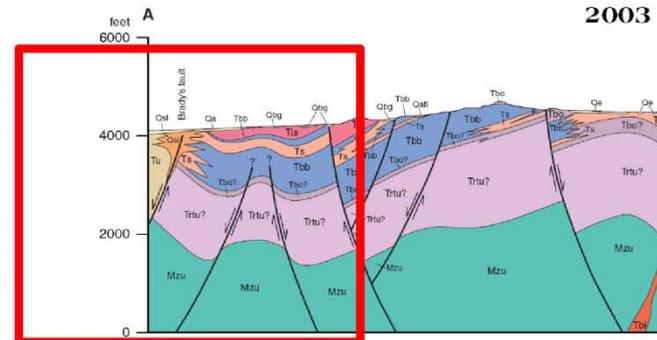
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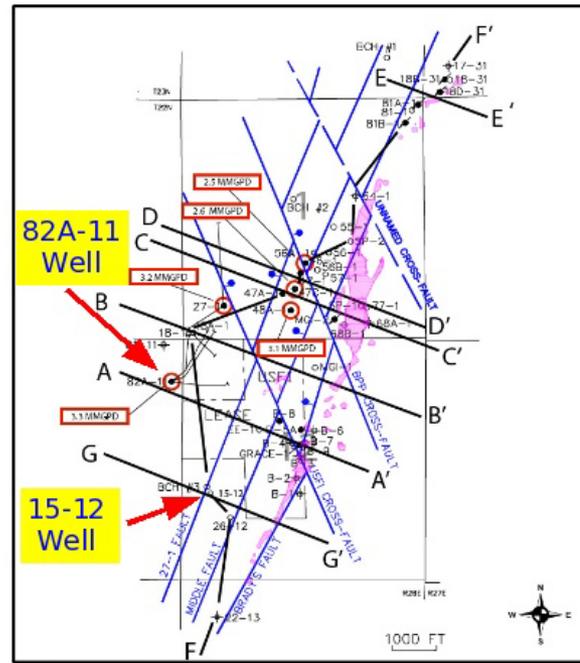
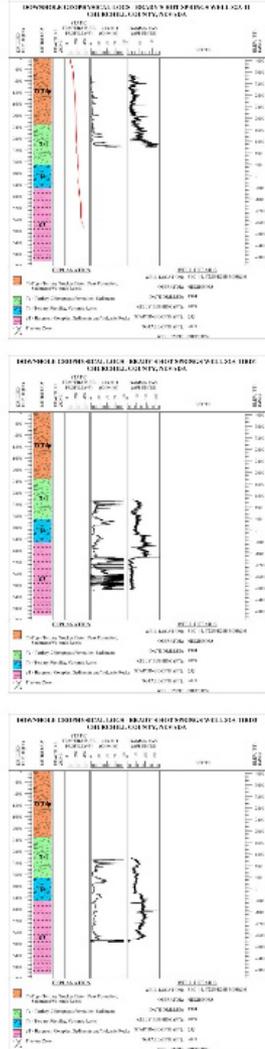
### THE DESERT PEAK - BRAD

James E. Faulds and

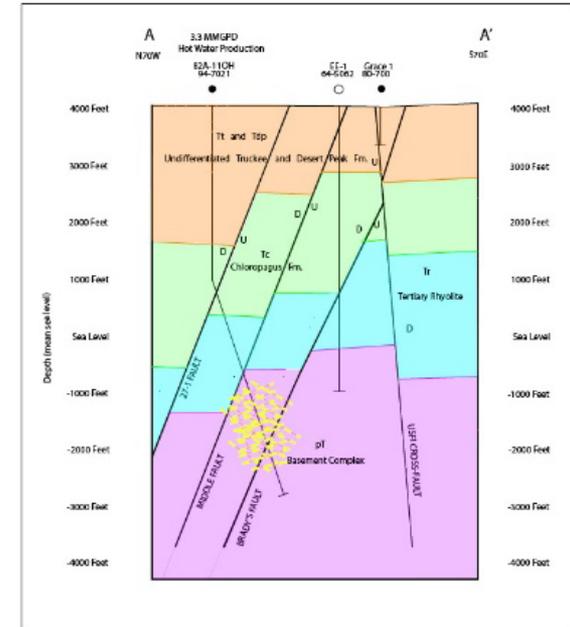
2003



## Geological Model



Geologic Structure and Surface: Thermal Anomalies adapted from Mosquito Group, LLC (1999)  
 Structure Map Provided by Ormat



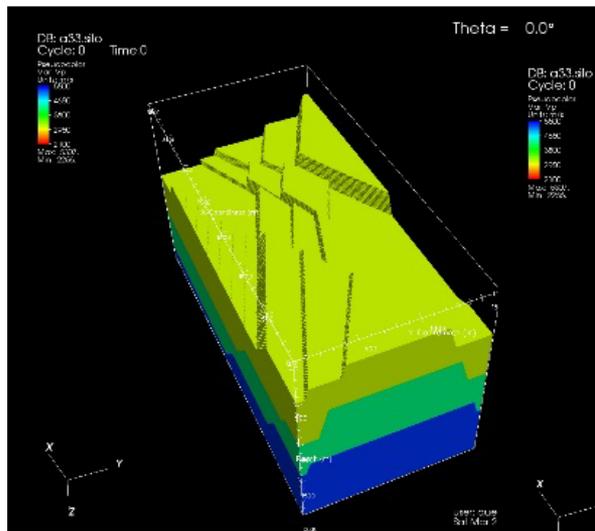
Geology adapted from Mosquito Group, LLC (1997), Ormat and others (1980), Frantz and others (2003)  
 Explanation  
 ○ Observation Well  
 ● Geothermal Producing Well  
 Scale in Feet

Cross-Section A-A'

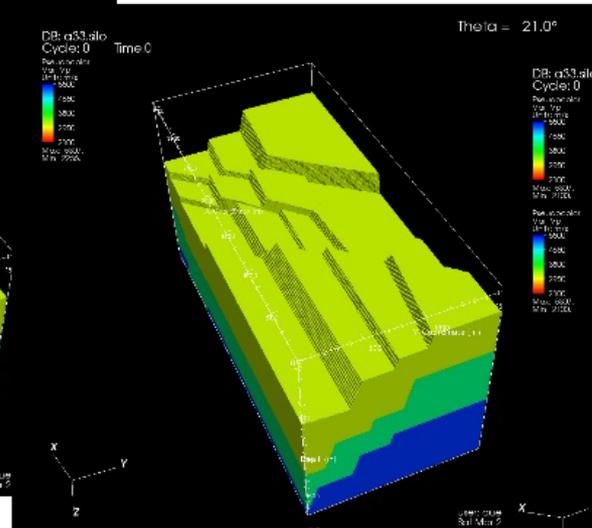
82A-11 well logs

## 3D Seismic Models

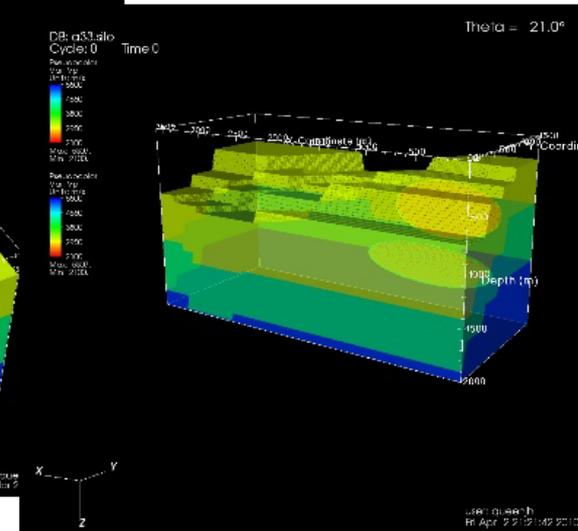
North in X-direction  
East in Y-direction



Rotated 21°  
Aligns X with Faults

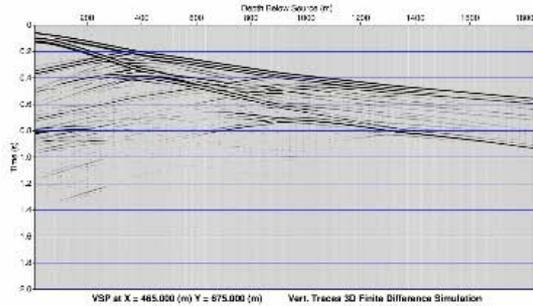


Model with Fracture  
Zones

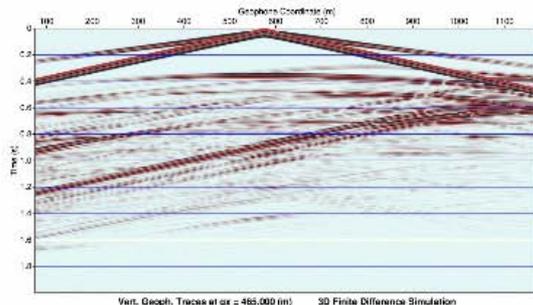


## 15-12 Simulation Results

### VSP Traces

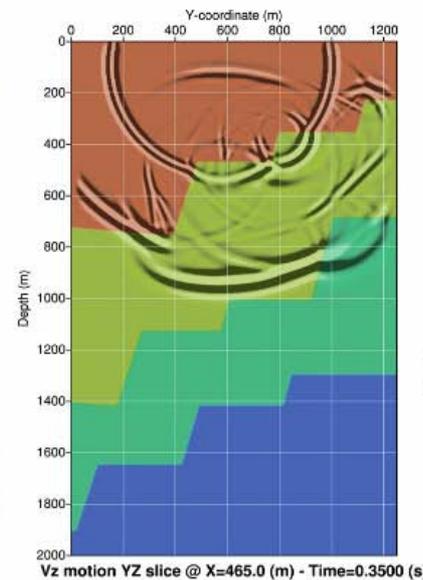


### Surface Traces

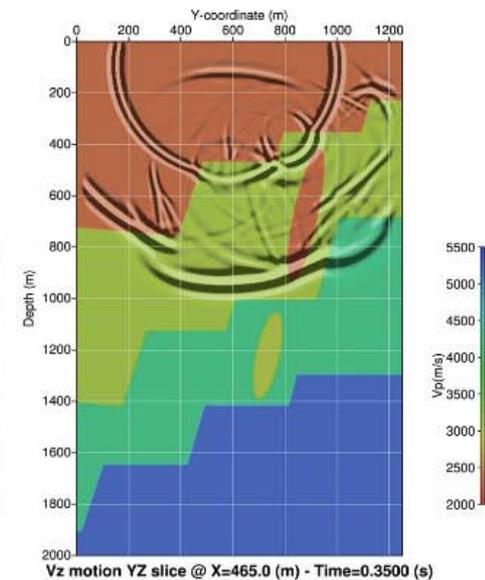


### Wavefield Snapshots

#### Model w/o fracs



#### Model with fracs

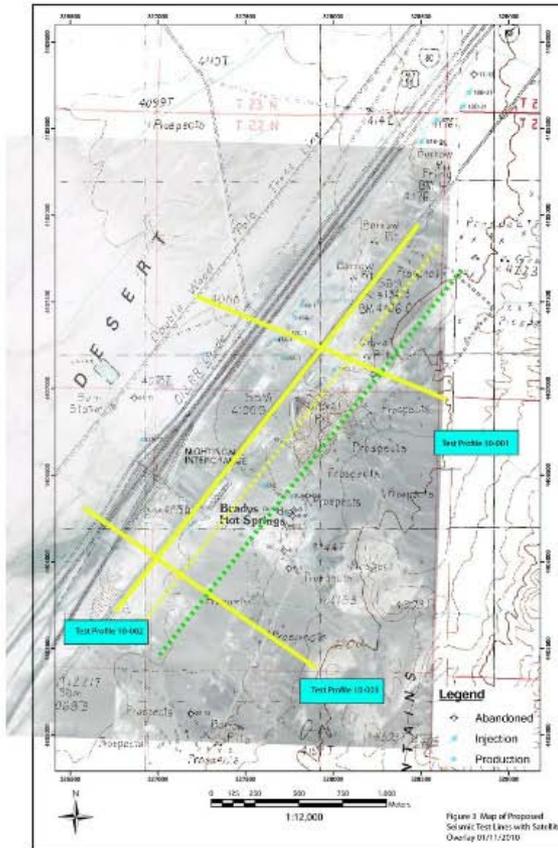


## Modeling and Simulation Key Learnings

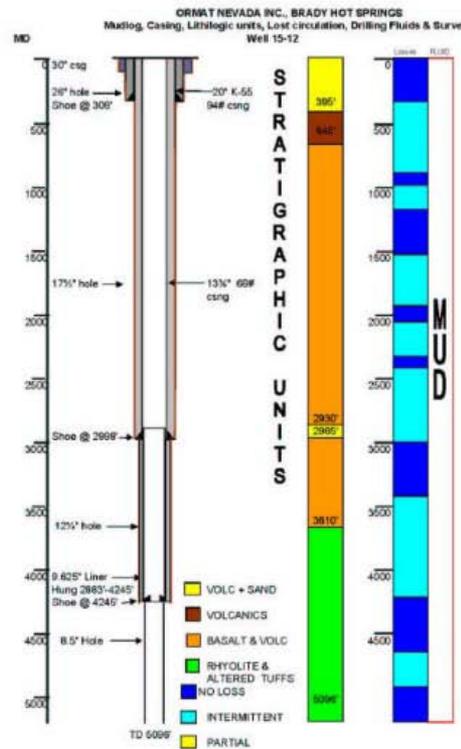
- Fracture/Fault Characterization
  - VSP
  - Multicomponent
- Structural Mapping
  - Surface seismic
- Complex Structure
  - Fine spacings
  - Orientation
  - 3D acquisition and imaging

## Acquisition Plan

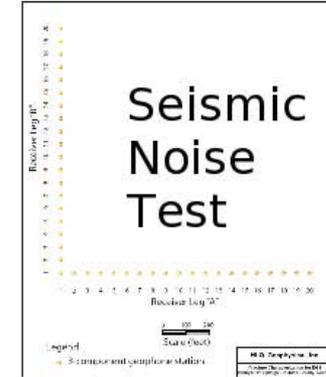
### Orientation Test



### VSP Well 15-12



### Micro-Gravity Survey



	Description	Start Date	Completion Date	% Actual Completion	Approved Budget	Cost Share
<b>Phase 1</b>						
Task 1	Data collection and Evaluation	03/04/2009	05/31/2009	100	\$52,329.00	\$65,000.00
Task 2	Model Building	06/01/2009	11/30/2009	100	\$67,800.00	\$10,000.00
Task 3	Seismic Simulation and Survey Design	09/01/2009	02/28/2010	100	\$80,055.00	\$15,000.00
<b>Phase 2</b>						
Task 4	Surface Orientation Tests	03/03/2010	06/30/2010	10	\$109,865.00	\$52,000.00
Task 5	Near Offset VSP	06/01/2010	09/30/2010		\$31,200.00	\$15,000.00
Task 6	Final Modeling and Acquisition Design	09/01/2010	02/28/2011		\$81,855.00	\$10,000.00
<b>Phase 3</b>						
Task 7	Multi Offset VSP	03/04/2011	06/30/2011		\$26,765.00	\$350,000.00
Task 8	High Areal Coverage Surface Seismic	07/01/2011	11/31/2011		\$287,165.00	\$15,000.00
Task 9	Final Interpretation	11/01/2011	02/28/2012		\$58,933.00	\$10,000.00
Task 10	Technology Transfer	03/01/2010	06/15/2012		\$21,790.00	
Task 11	Project Management and Reporting	06/25/2010	06/29/2012			
Totals					\$817,757.00	\$542,000.00

- Integrated With Brady's EGS Field Demonstration Project
  - Seismic simulation results transferred to Lianjie Huang, LANL, imaging
  - Collaboration with Jim Faulds, NMBG, stress modeling
- Partnered with ORMAT, LBNL, Seismic Contractor

- **FY10 Milestones**
  - Surface orientation tests, micro gravity survey, end June, 2010
  - Near offset VSP, end September 2010
- **FY11 Milestones**
  - Final modeling and 3D acquisition design, end February 2011
  - Multi offset VSP acquisition, end June 2011
- **FY12 Milestones**
  - High areal coverage (3D) surface seismic acquisition, end November 2011
  - Final interpretation, end March 2012
  - Technology transfer, ongoing through June 2012
- **Major Risks**
  - Permitting, weather are critical unknowns with field acquisition
  - May lead to no-cost shuffling, extension of milestone dates

- **Expected Outcomes**
  - Approach for acquiring valuable reflection, VSP in geothermal areas
  - Seismic fracture/fault characterization
- **Deployment**
  - Presentations to industry at major meetings
  - Journal publication
  - Through existing extensive seismic contracting industry
- **Future Research**
  - Instrumented micro wells
  - Time lapse acquisition and processing

- Seismic Will Have High Impact on EGS
- Approach Based on Field Testing and Development
  - Tough problem
  - Modeling used to guide parameter selection
  - Learnings from many field tests lead to ultimate methods
- Coordinated with Industry, Contractors, National Labs
- Accomplishments:

	<b>FY2009</b>	<b>FY2010</b>		
<b>Targets</b>	Geological Description	Seismic Model Building	Seismic Simulation and Survey Design	VSP, Surface Orientation Tests, Micro Gravity
<b>Results</b>	Completed 05/31/2009	Completed 11/30/2009	Completed 02/28/2010	Underway

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- We thank Ormat Technologies, Inc. for their contributions as a major participant in this project giving extensive access to their data and to the Brady's Hot Springs Known Geothermal Resource Area, and for permission to present this material