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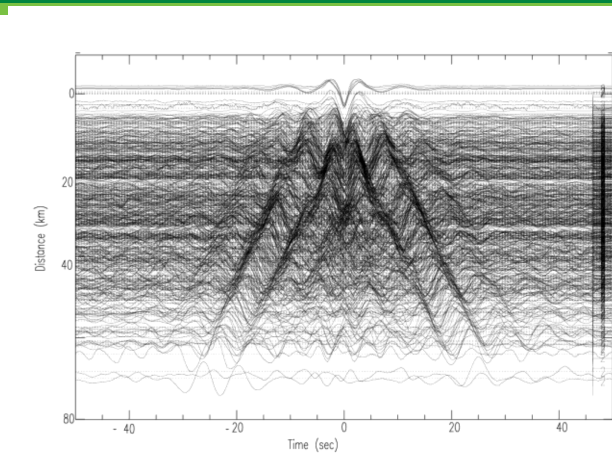

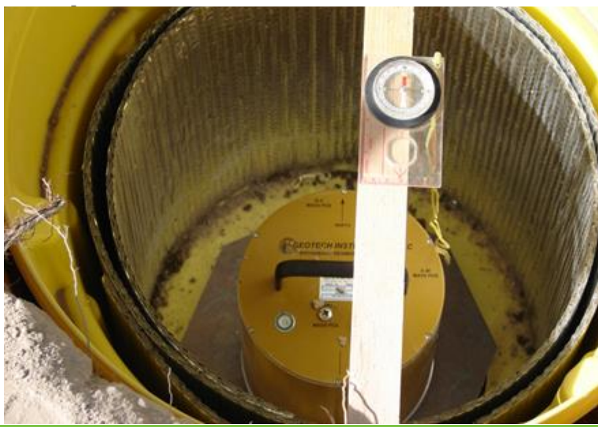

QUANTIFYING EGS RESERVOIR COMPLEXITY WITH AN INTEGRATED GEOPHYSICAL APPROACH- IMPROVED RESOLUTION AMBIENT SEISMIC NOISE INTERFEROMETRY

Project Officer:
William Vandermeer
Total Project Funding:
$427,847

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Track 3, EGS

Relevance/Impact of Research

Project objective:

Assess high resolution seismic interferometry analysis (from km to meter, to a depth of at least three km), in combination with other geophysical techniques, for EGS target identification.

Innovative aspects:

(1) Applying a relatively inexpensive seismic exploration technique, using ambient noise interferometry and methods previously used in nuclear monitoring, to EGS favorability estimation at a scale (and depth) not yet seen in active seismic surveys in geothermal fields;

(2) Potential to provide information on fault dips using ambient seismic noise processing, performance which has not been yet demonstrated by other groups;

(3) Investigation of supplementary seismic indicators of geothermal reservoir favorability;

(4) Statistical evaluation, integration and synthesis of seismic and other geothermal favorability parameters

Relevance/Impact of Research

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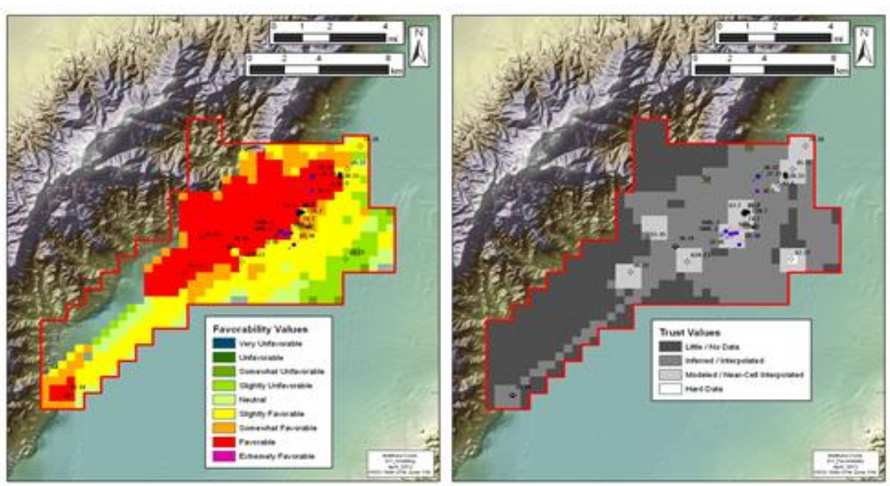
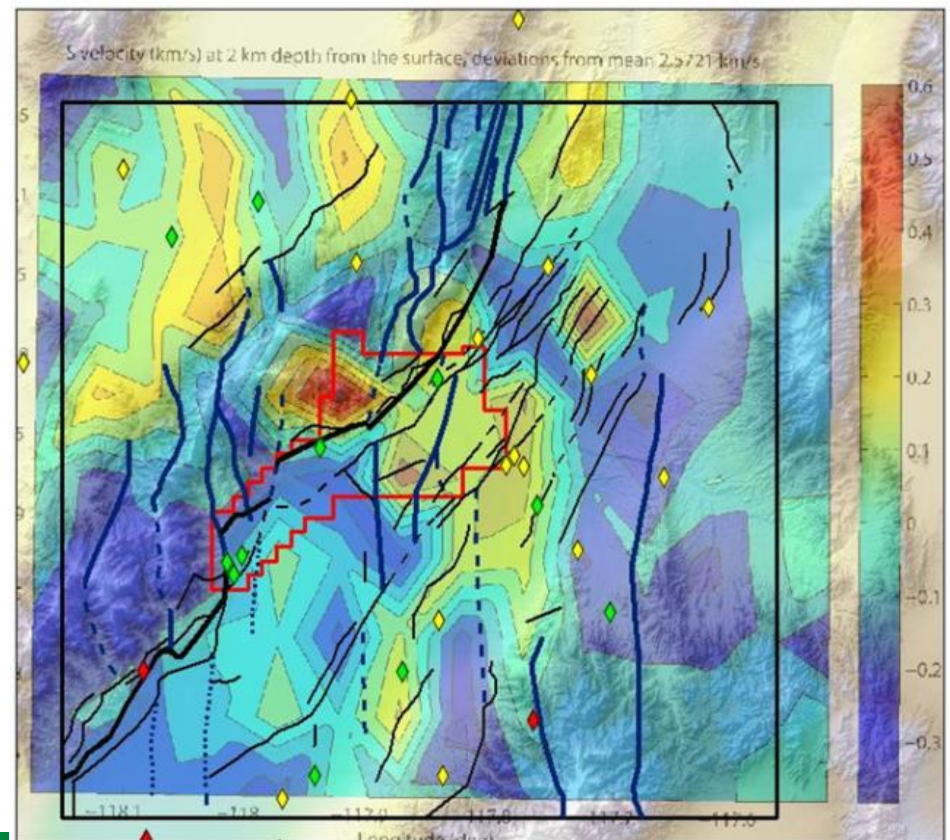
The seismic lines will be along the same profiles used in EE0002778 named EGS1 (AltaRock, 2014), where geological, well, magneto-telluric and gravity/magnetic data was collected. The red outline is the calibration area.

Note the low resolution of the S-velocity seismic model (2 km below the surface) as estimated at EGS1 when compared to the other geophysical technique results.



EGS Favorability-Trust Maps: Averaged Data and Weighting
Depth: 2.5km Below Sea Level



Knowledge gaps being addressed by this project:

We build and improve upon the work reported in EGS1, the AltaRock Energy Inc. in Dixie Valley on EGS target identification.

1) *An evaluation of this technique in comparison with other geophysical methods at the same location has never been performed at any EGS field at a high resolution (meter sq. vs km sq.)*

2) More subsurface geothermal system parameters (attenuation, spectral properties, stochastic properties) will be derived than were able to be derived in the original investigation (EGS1).

3) Seismic interferometry has significant potential for fault definition and P and S- velocity model estimation as well as being low cost and non-invasive. When combined with array processing (for ground roll dispersion measurements), with coda wave analysis techniques and filtering techniques such as wavelet analysis previously developed for nuclear monitoring, the result is a potentially disruptive technology in the field of seismic exploration

Physical subsurface parameters measured directly :

(1) P/S wave seismic velocity,
(2) seismic attenuation,
(3) stochastic heterogeneity, and
(4) earthquake focal mechanisms.

Subsurface parameters, measured indirectly will be

(1) temperature/pressure at depth,
(2) location and geometry of fractures/faults,
(1) stress and stress drop,
(2) lithology/heterogeneity at depth, and
(1) potential EGS reservoir volume.

Relevance/Impact of Research

Scientific/Technical approach:
Apply ambient noise seismic interferometry techniques, and seismic array signal processing techniques developed for nuclear monitoring to geothermal ambient seismic noise reflection surveys to evaluate, at the same scale, the usefulness for EGS exploration of seismic parameter information in comparison with information from other geophysical exploration methods.

For this purpose: 1) collect and analyze new data; 2) use seismic event waveforms from the existing EGS1 seismic surveys to investigate the possibility of extracting supplementary seismic parameter information and 3) generate new EGS favorability / trust maps by factoring the proposed higher seismic resolution data to compliment and improve the previous investigations.

Technical feasibility: Pilot studies at Soda Lake (Tibuleac and Eneva, 2011; Tibuleac et al., 2010) and results on EE0002778, EE0005518, and OE-EERE10EE0003997 showed that the method has encouraging results for velocity model inversion, fault definition, and that other seismic parameters (attenuation and spectral properties) show property variations in the exploration areas. Thus, this technique has a high probability to be successful.

Known Challenges/Barriers:

1) Ability to adapt the method designed for conventional geothermal analysis to larger scale and different EGS requirements, while preserving the low cost of the technique. EGS exploration seeks to identify relatively large targets of hot, competent rock, at depths of ≤3km, a scale larger than required for hydrothermal exploration. We plan to address this challenge through innovative deployment design and through modifications of the data processing technique, to shorten the duration of the experiment while obtaining the same resolution;
2) The potential of multiple seismic parameters (velocity, attenuation, waveform complexity, heterogeneity, stress drop, stress orientation) and of real and synthetic waveform analysis to improve characterization of lithology, temperature and fault orientation;
3) Whether we will find the best method to circumvent effects of the seismic noise directionality when assessing P/S velocity and attenuation. We plan to use the C3 function, the Correlation of Coda of Correlation described by Stehli et al., 2008 and by Zhang and Yang, 2013;
4) Effective management of time and resources, to finish the project in time and within scope.

Performance metrics, cost

Impact the on the Geothermal Technologies Office's goals:

GOAL: Systems Analysis – Lower risks and costs of exploration and development

The project provides a low-cost seismic approach to obtaining many of the native phase parameters. First high resolution ambient noise seismic survey that will demonstrate the utility of this low-cost and technically-effective method for EGS favorability assessment.

Technology	Unit[a]	Current State-of-the-art PME[b]	Min[c] RI[d] to PME	Target RI to PME	Over Target Improvement to PME
High resolution ambient seismic survey	dollar	$7000/km active survey		$2000/km ambient noise survey	$1700/km
	Inter-station distance	None in EGS	500m station spacing	<100m station spacing	Resolution increased 5-fold
	meter	Faults identified by active surveys	Faults identified by ambient noise surveys		Faults resolved within 100 m
DVGW[e]	km	16 km²	0.125 km³ grid resolution	0.05km³ resolution for the seismic data	Improved delineation of fault structure; Increased resolution P-wave and possibly S-wave velocity model; Improved seismic attenuation field-wide distribution may identify potential areas of increased fracturing; Potential higher resolution to the inferred lithology between wells; Potential higher resolution to the temperature field between wells
Geostatistical Analysis of DVGW[e]	Correlations between parameters	Seismic resolution too low for correlations with other geoscience parameters			10-fold higher resolution in seismic data may provide improved correlation with and prediction of geoscience parameters
	Improved parameter prediction				
Favorability /Trust Mapping	Improved predictability	Seismic resolution too low			10-fold resolution in seismic data may provide incorporation of seismic data in the mapping

[a] Unit of Measurement; [b] Performance Metric; [c] Minimum; [d] Requirement Improvement; [e] Dixie Valley Geothermal Wellfield updated per the new seismic data

Scientific/Technical Approach: Tasks

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Task	Task/Subtask	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
		BUDGET PERIOD 1																	BUDGET PERIOD 2							
		Time (months from the Notice to Proceed)																								
		Q1			Q2			Q3			Q4			Q5			Q6			Q7			Q8			Q9
1. Project Initation																										
1	1.1: Project Kick-off Meeting	x																								
	1.2: Equipment Acquisition	x	x																							
	1.3: Project Permitting	x	x																							
	Project Melstone No. 1		★																							
2. Seismic data Acquisition, Processing and Reporting																										
2	2.1: Seismic Equipment Installation		x	x	x	x	x	x																		
	2.1.1 Personnel training																									
	2.1.2 Seismic equipment request, and storage																									
	2.1.3 Installation																									
	2.1.4 Maintenance																									
	2.2: Seismic Data Acquisition and Processing			x	x	x	x	x	x	x	x	x	x	x	x	x										
	2.2.1 Database building																									
	2.2.2. Database analysis																									
	2.2.3. Process results																									
	2.3: Seismic Data Interpretation	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x									
	2.3.1 Sesimic Parameter Results																									
	2.4 Seismic Results Meeting																⬢									
	2.5 Seismic Results Report				x	x	x	x	x	x	x	x	x	x	x	x	x	x								
	2.5.1 Prepare DRAFT Report																									
	2.5.2 Review DRAFT Report																									
	2.5.3 Finalize Report																									
	Project Melstone No. 2																	★								
	Go/No-go																									
3	***3. Dixie Valley EGS Conceptual Model***																									
	3.1 Update Conceptual Model Development																	x								
	3.2 Updated Conceptual Model Meeting																	⬢								
	3.3 Updated Conceptual Model Report																	x	x	x						
	3.3.1 Prepare DRAFT Report																									
	3.3.2 Review DRAFT Report																									
	3.3.3 Finalize Report																									
	Project Melstone No. 3																			★						
4. Geostatistics																										
4	4.1 Exploratory Data Analysis (EDA)																				x	x				
	4.2 EDA Results Meeting																					⬢				
	4.3 EDA Report																					x	x			
	4.3.1 Prepare DRAFT Report																									
	4.3.2 Review DRAFT Report																									
	4.3.3 Finalize Report																									
	Project Melstone No. 4																						★			
5. EGS Favorability/Trust Maps																										
5	5.1 GEnerate New EGS Favorability Maps																							x		
	5.2 EGS Favorability/Trust Map Meeting																							⬢		
	5.3 EGS Favorability/trust Map Report																							x		
	5.3.1 Prepare DRAFT Report																									
	5.3.2 Review DRAFT Report																									
	5.3.3 Finalize Report																									
	Project Melstone No. 5																							★		
6. Project Management and Reporting																										
6	6.1: Project Management	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	6.2: Quarterly Reports			x			x			x			x			x			x			x			x	
	6.3: Final Scientific Report																								x	
	6.4: Conference/Workshop Presentations																									x
	6.5: Market Transformation/Commercialization																									x
	6.6: GDR Data Transfer																									x
	6.7 Project Audits																									x
	Project Melstone No. 6																									★

Accomplishments, Results and Progress

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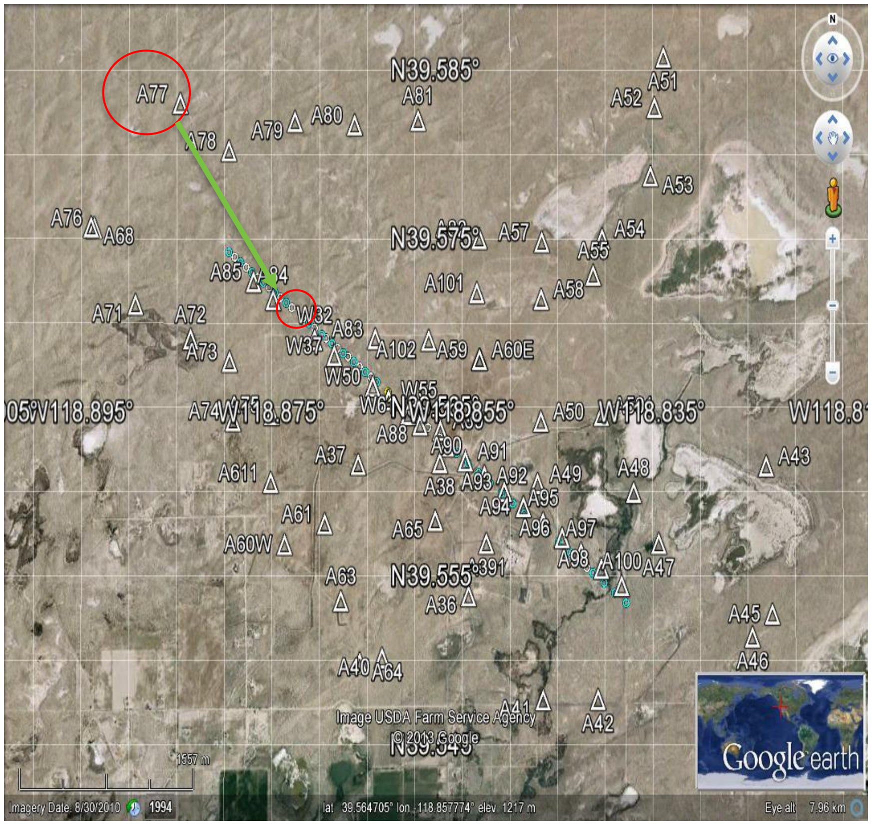
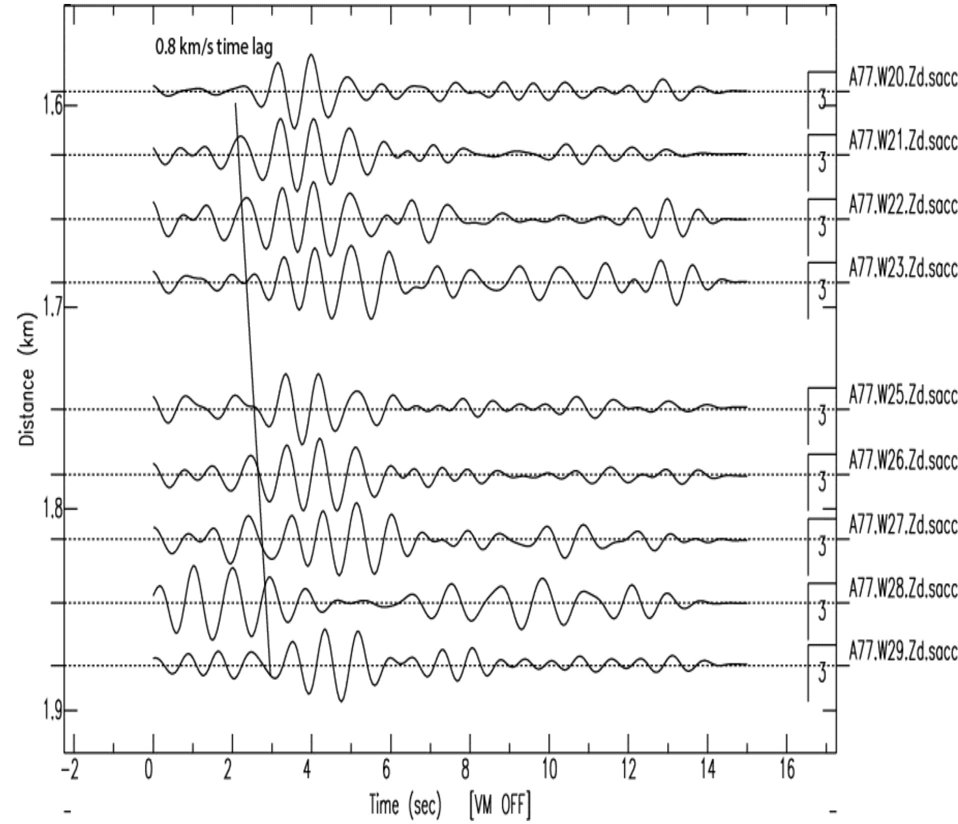
- Preliminary results on EE0005518 at Soda Lake show that Green's Functions can be extracted from ambient seismic noise at **a 6 km aperture array**. This array has dimensions similar to the proposed Dixie Valley seismic lines, and the sensors have similar density.





Technical accomplishments and progress

- The technique is currently being tested by the PI and collaborators in a hydrothermal setting at Soda Lake, NV. While virtual shot-gather interpretation is pending, we have encouraging results for S-velocity model inversion.

Future investigations based on lessons learned from our current projects:

1. Extraction and identification of P-arrivals at larger (km) inter-station distance will be investigated.

2. An innovative array design will alternate short period, broadband and high-frequency sensors. Based on how well P/Rg-arrivals will be extracted at Soda Lake, the sensor density in Dixie Valley will be changed, as well as the duration of each deployment.

3. Based on a current DOE project aiming to estimate attenuation in Dixie Valley, we expect significant spectral differences would be observed in the 5-15 Hz frequency band for seismic noise recorded at stations within, and outside of the production area.

Management Challenges to Date

Two major issues and one minor existed, of which one major was solved.

- The first major issue was, and still is, the delay in the project caused by the stipulation by DOE that initiation of Task 2 is subject to successful validation of the passive seismic methodology via the submission of the Phase I Report for the recipient's concurrent award DE-EE0005518. This schedule impact also affects Task 1.2 which cannot be completed until the current project has been approved to move forward on Task 2. We are working towards completion of said submission.
- The second major issue (now resolved) was that work on the project was hampered by the cessation of funding to award DE-EE0005518 from Dec 31 2014 to March 1 2015. Dr. Tibuleac and the UNR administrators worked with DOE and successfully resolved this issue in early March 2015.
- The minor issue is an apparent schedule error in the DOE contract award to UNR. The current contract states that the projected is to start on 1 October 2014 and be completed on 30 October 2015. According to this contract award the project duration is ~12 months. However, the project was proposed for 25-26 months. This contractual mix-up has caused management issues with UNR contracting and the project team.

Future directions

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FUTURE ACTIONS:

- The PI and collaborators are preparing a final report on concurrent Soda Lake award DE-EE0005518 which will be submitted on May 29, 2015. The information in this report should be sufficient to indicate whether the method is valid for hydrothermal systems, however, more research is necessary to establish the use of the method for EGS reservoir characterization which is the basis of the new project.
- Submission of the Soda Lake report and acceptance of its results by DOE will allow Task 2 for this new Dixie Valley Project to move forward.

SUMMARY

1. The method to be used in our study for EGS target identification integrates ambient seismic noise interferometry processing techniques developed and tested at three previous geothermal studies;

2. With this higher resolution study, we expect to

a) Match the scale of the previous geoscience work described in EGS1 allowing direct correlations with the previously generated geology, seismic reflection, gravity-magnetics and magnetotelluric models. The previous models in EGS1 were calibrated/validated by the available well data;

b) Generate favorability/trust maps for EGS targeting, incorporating seismic parameters.