Geothermal Technologies Office 2013 Peer Review

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Soda Lake field work
Left : UNR students James McChesney, Kelly Eloyan and Kate Schnoor at the NE end of the reflection line.
Right: UNR students James McChesney and Kegan Rahe transport a seismic station (BIHO) box, provided by IRIS/PASSCAL

Development of a low cost method to estimate the seismic signature of a geothermal field from ambient seismic noise analysis

Project Officer Mark Ziiegenbein
Total Project Funding: $401241
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Principal Investigator
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EE0005518

Collaborations

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- **Project collaborators**:

  - **Industry**:

    Mr. Monte Morrison, Magma Energy Inc., VP, Exploration and Chief Geologist

    Dr. Satish Pullammanapallil, Optim Inc., subawardee

  - **University of Nevada, Reno**

    Dr. James Faulds, Nevada Bureau of Mines and Geology

    Dr. David von Seggern, Nevada Seismological Laboratory

    <u>Graduate student</u>: Holly McLachlan

    <u>Undergraduate Students</u>: James McChesney, Jehren Boehm, Kegan Rahe, Darcy Fisher, Kelly Elloyan and Kate Schnoor

Challenges:

- To date, no widely accepted, technically feasible and cost-effective method for high-resolution compressional (*P*), shear (*S*) seismic velocity models and buried fault location estimation has been developed. This information is essential in geothermal exploration.

- Identifying new seismic parameters (attenuation, spectral and stochastic properties) to be used for geothermal reservoir characterization.

Innovative aspects of this research:

- Demonstration and validation of a relatively inexpensive seismic exploration technique, using ambient seismic noise, as opposed to active sources recorded at arrays and reflection lines.
- The method has the potential to provide knowledge of existing fault dips using ambient seismic noise processing.
- The method has the potential to estimate a preliminary shear velocity model which, unlike the *P*-velocity model, is not yet satisfactorily accomplished by conventional seismic reflection surveys and which has the potential to provide important independent information.
- Investigation of supplementary seismic indicators (attenuation, spectral content and stochastic properties) of geothermal reservoir favorability;
- Statistical evaluation, integration and synthesis of seismic and other geothermal favorability parameters.

Impact on costs

Unlike active surveys, passive surveys can be conducted under casual use provisions on federal lands.

A rough calculation shows a total cost of~$7000 per km of deployment for the active surveys deployed by Magma Energy Corp. An UNR survey near Reno was two times denser and had a cost of ~$1700/km.

Impact of the project on the Geothermal Technologies Program’s goals

- Develops "geophysical surveying tools, techniques and processing not previously utilized in geothermal exploration or only to a limited extent” and

- Develops and validates “cost-competitive technologies and tools to accelerate the growth of geothermal energy in the United States”

Scientific/Technical Approach

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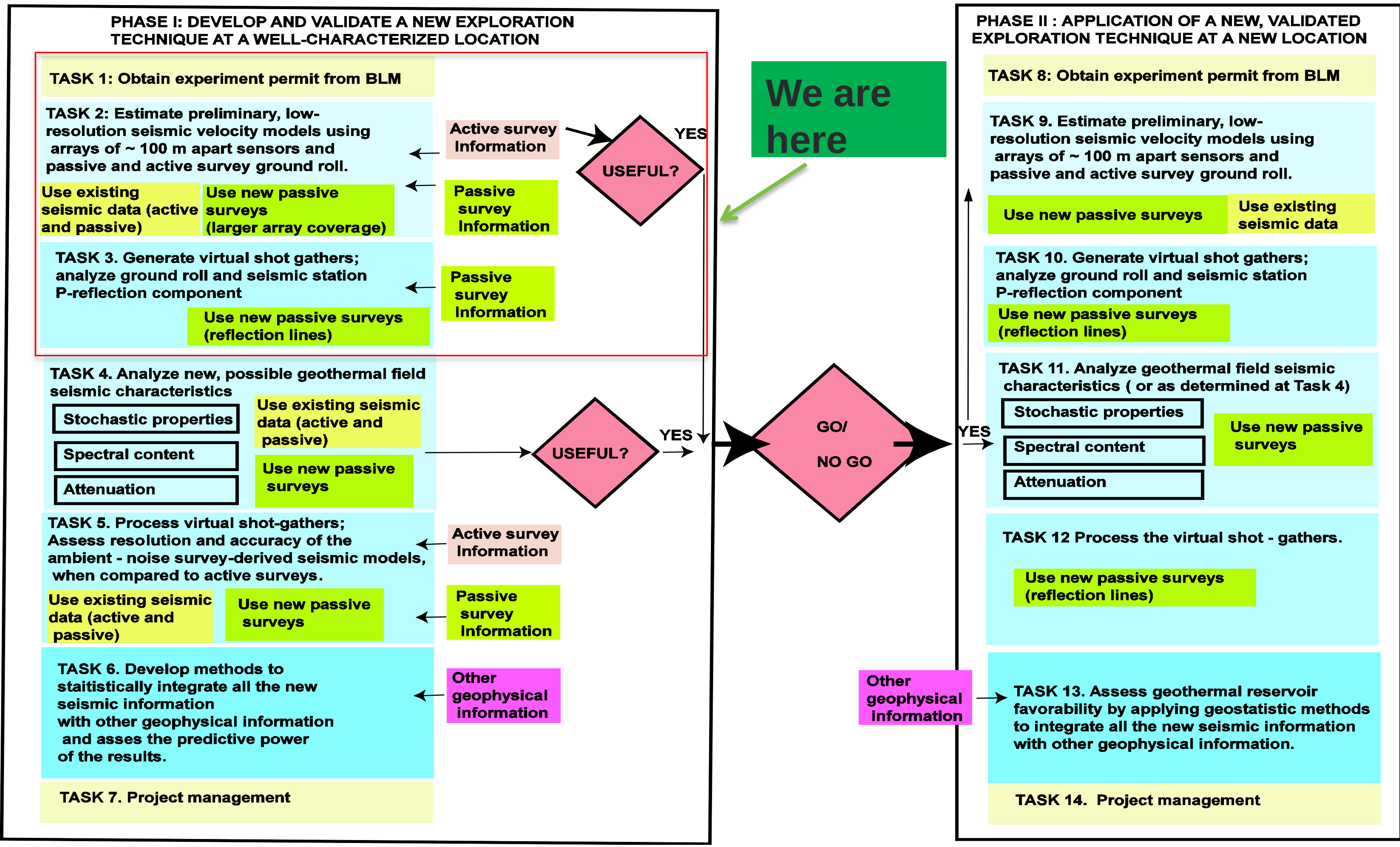

Phase 1. Proof of Concept:
Method development, feasibility assessment and validation

Tasks 1-3

Task 1. Administrative activities and experiment permitting
Experiment permitting, over a time period from March 2012 to October 10, 2012, included obtaining land usage approval from public and private land owners. The permitting activities continued until Nov 20, 2012.

Task 2. Estimation of a preliminary, ~ 100 m resolution P/S seismic velocity model using new passive seismic arrays; Assessment of the usefulness of ground roll from existing 3D active seismic surveys for low-resolution shear-wave model estimation.
A passive, 67 three component L28 geophone array was deployed and recorded ambient seismic noise for two weeks, from November to December 2012, at locations in the vicinity of a geophone reflection line (Task 3). Waveforms are currently assembled into an Antelope database.

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Scientific/Technical Approach

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Phase 1. Proof of Concept: Method development, feasibility assessment and validation

Tasks 1-3

Task 3. Estimation of a high resolution P/S seismic velocity model using a passive reflection line deployment and ambient-noise analysis; Assessment of the usefulness of ground roll from existing 3D active seismic surveys for high-resolution shear wave model estimation.

New seismic data acquisition along a reflection line was the objective a field work campaign of 21 days, from October to November 2012. The 3C L28 seismic sensors were deployed in a line at 100 ft inter-station distance. Sensor locations were the same as the locations of a 2010 Magma Energy active seismic line. Some of the sensors on the reflection line were left in place and recorded during the seismic array campaign (Task 2). An Antelope waveform database is in preparation.

Tasks 2 and 3 – Use of existing data sets in the study area

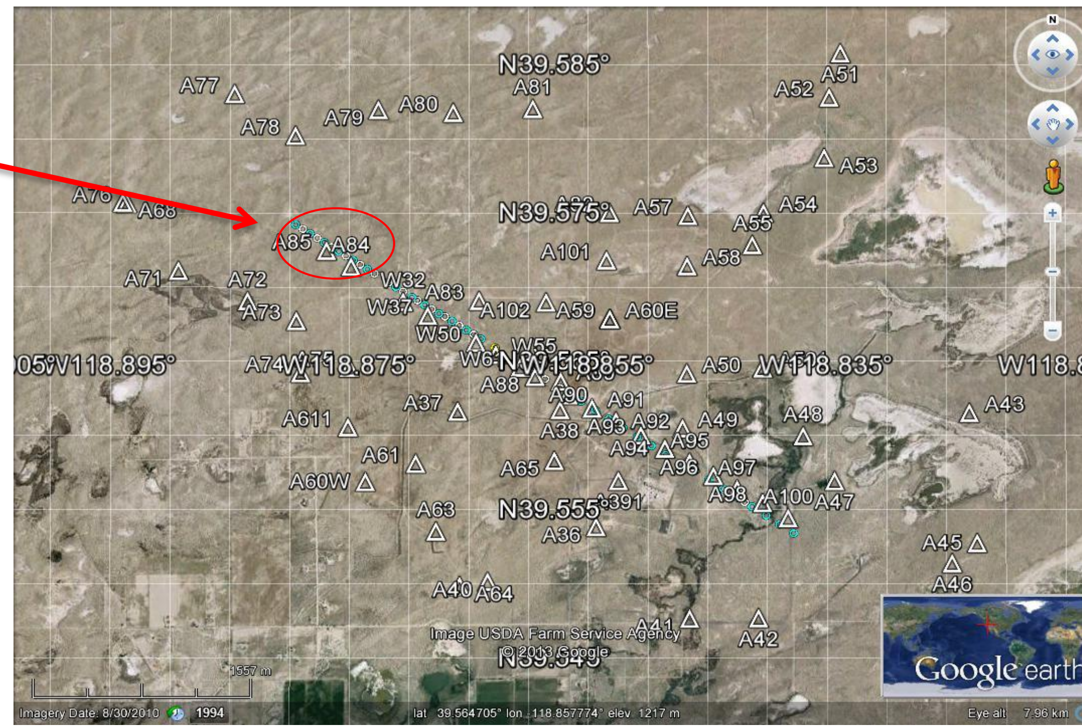
1) We are currently investigating an existing 3D active survey database and a seismic passive database collected by UNR and ImageAir in 2010. We aim to assess the potential of obtaining seismic S-velocity model constraints from ground roll dispersion;
2) We are analyzing a geophysical database in the study area, provided by Magma Energy Inc.

Tasks 2 and 3
New seismic data acquisition- continuous ambient seismic noise records

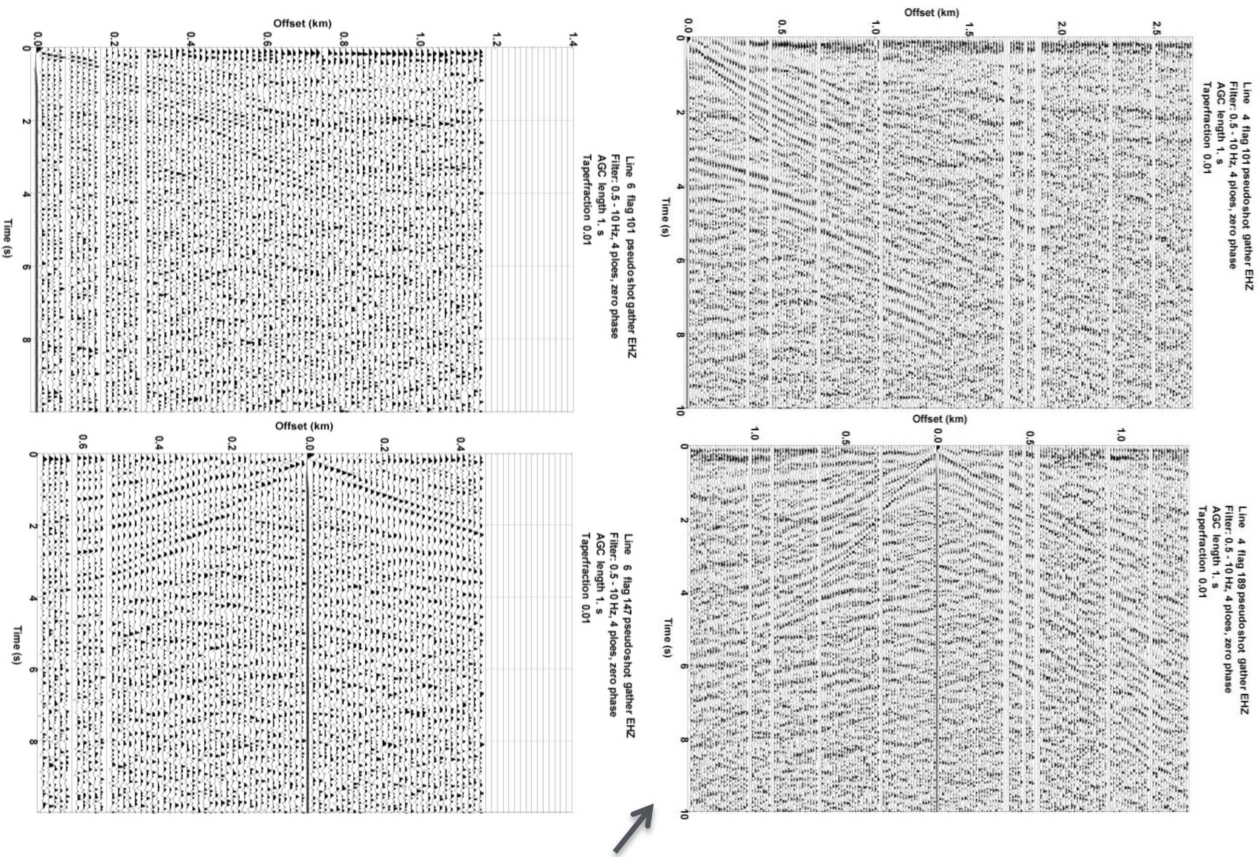
The deployment, with the line of sensors in the same location as a 2010 active survey of Magma Energy Inc included:

1) 30 Vertical 4.5Hz geophones with "Texan" digitizers at the northwest end of the line (circles in Figure 1), recording for 3 day-periods (the battery life-time) before the digitizers were switched;

2) 96 three-component L28 sensors (4.5Hz) with Reftek RT130 dataloggers, powered by solar panels and 12.8 V batteries.



The sensors were provided by the Incorporated Research Institutions for Seismology (*IRIS*) Program for Array Seismic Studies of the Continental Lithosphere (*PASSCAL*) Instrument Center.
Michael Johnson was the PASSCAL representative who advised and helped with field work.



Credibility/Technical feasibility:

We have encouraging preliminary results of testing the new method at another potential geothermal site near Reno for only three days of ambient noise recordings. The inter-sensor distance was 15 m.

Remaining key issues:

- best deployment time length, configuration;
- noise directionality effects;
- best processing methods (C- cube; optimal filtering; attenuation along the line)

Accomplishments, Results and Progress

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Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Task 1 Permitting	100%	11/20/2012
Task 2 Acquisition of new array data Processing of the new seismic data (database building, seismic interferometry, interpretation) Previous seismic survey assessment	100% 25% 25%	12/31/2012 In progress In progress
Task 3 Acquisition of new reflection survey data Processing of the new seismic data (database building, seismic interferometry, interpretation) Previous seismic survey assessment	100% 25% 25%	12/31/2012 In progress In progress

Future Directions

	FY2013	
Target/Milestone	**Estimated completion date**	**Notes**
Complete the new seismic data analysis; Determine whether previous 3D active seismic surveys are of value for the project; Build velocity model;	June June July	Tasks 2-3
Analyze stochastic heterogeneity, spectral properties and attenuation variations;	August	Task 4
Assess seismic model resolution and accuracy; Statistically assess geothermal reservoir favorability.	September October	Task 5 Task 6
Go/No-Go Decision		
Final report	December	Task 7

Summary

We are testing and evaluating a novel seismic exploration method based on analysis of body-waves and surface-waves extracted from ambient seismic noise;

We have completed the seismic data acquisition sub-tasks and we are currently processing the waveforms;

The technique we develop is cost-effective, consisting of statistical integration of inexpensive seismic analysis results with information from other geological and geophysical data;

We are investigating whether or not this new technique allows reliable geothermal reservoir characterization and estimation of a drilling favorability map at Soda Lake, Nevada.

Project Management

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Timeline:

Planned Start Date	Planned End Date	Actual Start Date	Current End Date
January 1, 2012	Dec 31, 2014	September 30, 2012	October 1, 2015

Budget:

Federal Share	Cost Share	Planned Expenses to Date	Actual Expenses to Date	Value of Work Completed to Date	Funding needed to Complete Work
$360841	$40,400	$20748	$19,820	$23298	$337543

Coordination with industry

We have received help and full cooperation during the seismic deployments from Mr. Monte Morisson, Mr. Greg Champneys and the personnel of the Alterra Power Corp.

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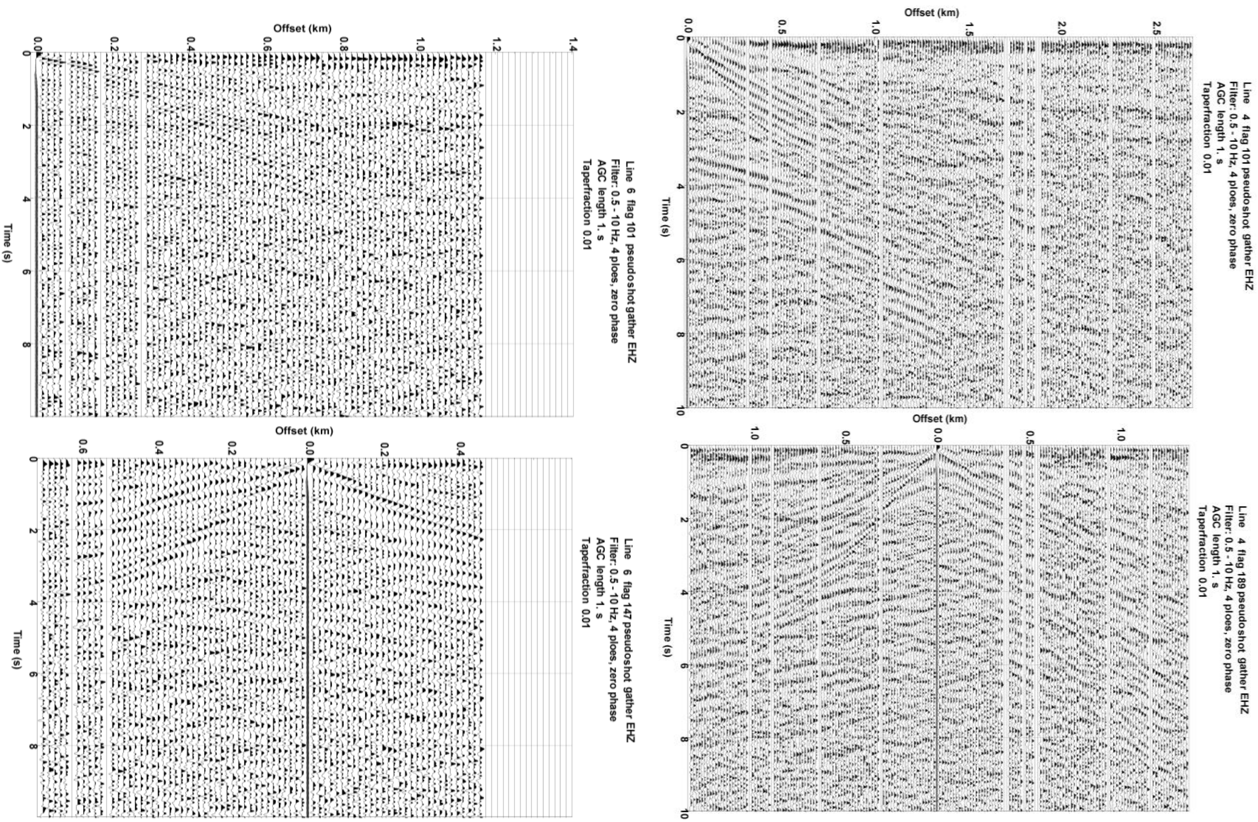
Credibility/Technical feasibility:

We have encouraging preliminary results of testing the new method at a potential geothermal site near Reno.

Three days of ambient noise were recorded by a deployment of ~350 high-frequency geophones with "Texan" digitizers co-located with an active source survey. The inter-sensor distance was 15 m. Line 4 is parallel to the road, line 6 is perpendicular to the road.



<u>Left plots:</u> Examples of ground roll and P-arrivals resulting from ambient - noise crosscorrelation stacks on line 6 for flag 101 (upper left plot) and flag 147 (lower left plot). The null lines are for sensors which did not record. <u>Right plots:</u> Examples of ground roll and P-arrivals resulting from ambient - noise crosscorrelation stacks on line 4 for flag 101 (upper right plot) and flag 189 (lower right plot).

No data pre-filtering has been applied before cross-correlations. Average gain control (AGC) was applied on each waveform in 1 sec windows.

Additional Information

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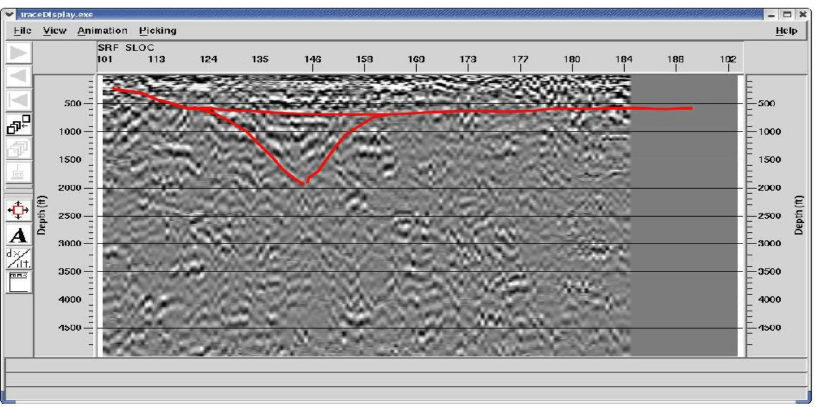
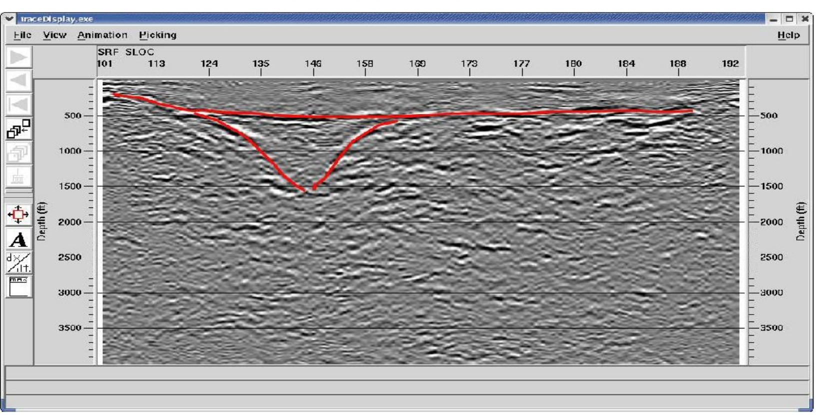
Credibility/ Technical feasibility: Three-day noise surveys produce similar results (although currently with less resolution) to active survey results for one reflection line which crosses a known fault (line 6). The results do not match well for line 4 (not shown here). Useful information for higher resolution preliminary velocity models can be extracted from ambient noise autocorrelations.

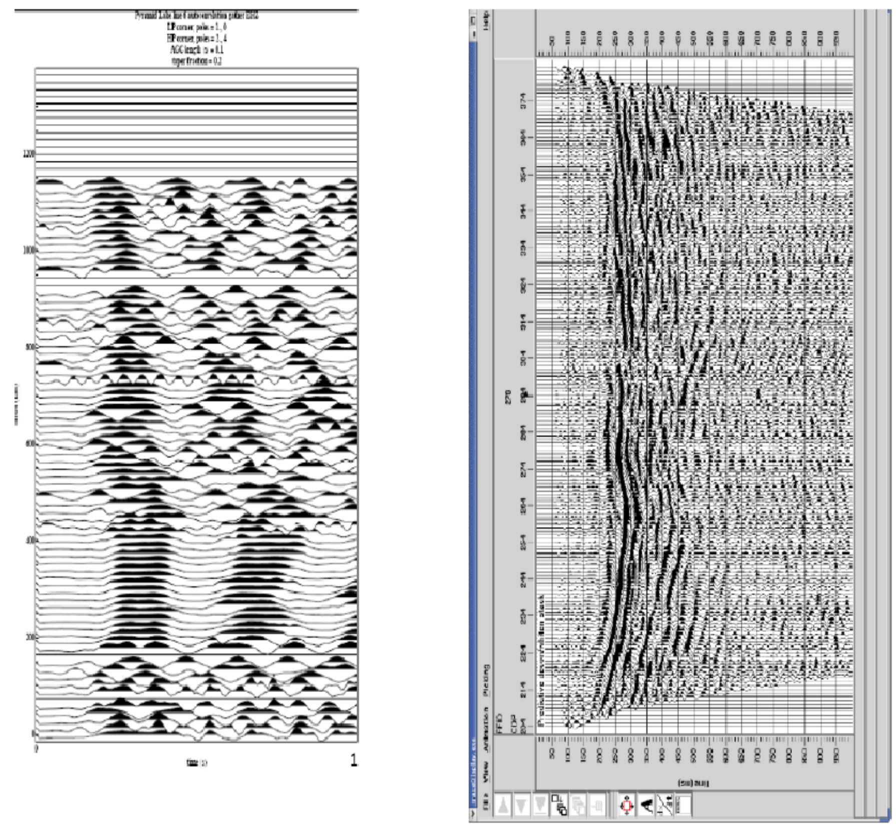
LINE 6 AMBIENT-NOISE SURVEY INTERPRETATION



LINE 6 ACTIVE SURVEY INTERPRETATION



Ambient noise autocorrelations (left) compared to active source results (right)



Plots by Satish Pullammannappallil in Tibuleac et al., 2010, AGU poster