Spectral SP: A New Approach to Mapping Reservoir Flow and Permeability

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Total Project Funding: $ $1,106,271

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Research and Development/Geophysics

Relevance/Impact of Research

Statement of the Problem

- Surface exploration technologies are able to identify heat sources but cannot provide information on reservoir permeability/fluid flow distributions
- Geothermal exploration/development wells frequently encounter suboptimal production rates substantially increasing costs of power production
- Access to detailed models of geophysical survey data typically require extremely sophisticated and expensive computer and numerical modeling

Project Objectives

- Develop geophysical survey technology to allow mapping of fluid flow distribution within and around geothermal prospects
- Develop software packages to facilitate visualization of resistivity and flow distributions within geothermal prospects
- Develop software packages to serve as an “expert system” that can guide less experienced staff in processing and analyzing geophysical analysis/interpretation processes

Relevance/Impact of Research

Project Impacts

- With better permeability information, fewer “dry holes” during the critical exploration stage will reduce both risks and start-up time and costs for new geothermal development
- Better permeability information will facilitate field expansion efforts by minimizing well interference and will optimize drilling costs
- Better permeability information will also provide guidance on fluid disposal/reinjection and avoid short-circuiting of injection fluids thereby reducing risks of premature degradation of a viable geothermal reservoir
- Overall effect will be to reduce levelized costs of geothermal energy

Relevance/Impact of Research

Use of Data and Results

- Magnetotelluric data sets are being generated that provide EM field data and electrical potential difference data in the time domain
- The analysis and inversion of the data will provide 2-D and 3-D imagery representing distribution of subsurface resistivity and fluid flow through the hydrothermal systems being surveyed
- Results of the analysis will be published in the open literature
- Data collected on public lands will be provided to the Geothermal Data Repository as the data is validated and analyzed
- Data collected on private lands will need to meet sequestration requirements imposed by landowners
- Reports of resource characteristics will be provided to partner State and Federal agencies and to regulatory bodies within the State
- Software developed under this program will be marketed by industry partner

Scientific/Technical Approach

- MT/SSP surveys are being conducted in areas of known permeability distribution ~ active hydrothermal system at Kilauea Summit and East Rift Zone (Lower Puna)
- An existing data set is being re-analyzed and expanded with newly acquired data
- Surveys will take advantage of existing exploration and research (cored) wells drilled in this highly active regime
- Development of software tools will be done in collaboration with recognized experts in the field using both current and legacy geophysical data
- Design hardware and methods enabling us to collect electrical field data at higher resolution and produce the required hardware

Technical Challenges
& Solutions

- **New generation of field equipment**

LBNL partners vetted new equipment and worked with supplier to develop software protocols and established requirements for MT survey

- **Unusually strong SP signals**

Berkeley partners developed methods enabling us to collect electrical field data at higher resolution and produced the required hardware for its application

- **High levels of natural & anthropogenic noise on Hawaii Island**

Conducted extensive testing of remote reference sites on Hawaii Island in order to identify locations that are able to provide the required data quality. Currently occupying two remotes with lowest noise levels based on parallel magnetic field testing

Worked with staff of Hawaiian Volcano Observatory to coordinate collection of volcanological, seismic, geodetic, meteorological, and emissions data to compare with MT/SSP data sets at Kilauea summit

Accomplishments, Results and Progress

- **Challenging field conditions**

Developed detailed field protocols required to obtain quality field data and conducted extensive training of field crew to ensure successful collection

- **Restrictive access conditions placed on entry to Kilauea Summit**

High quality data acquired at 18 MT stations at Kilauea Summit with data analysis underway

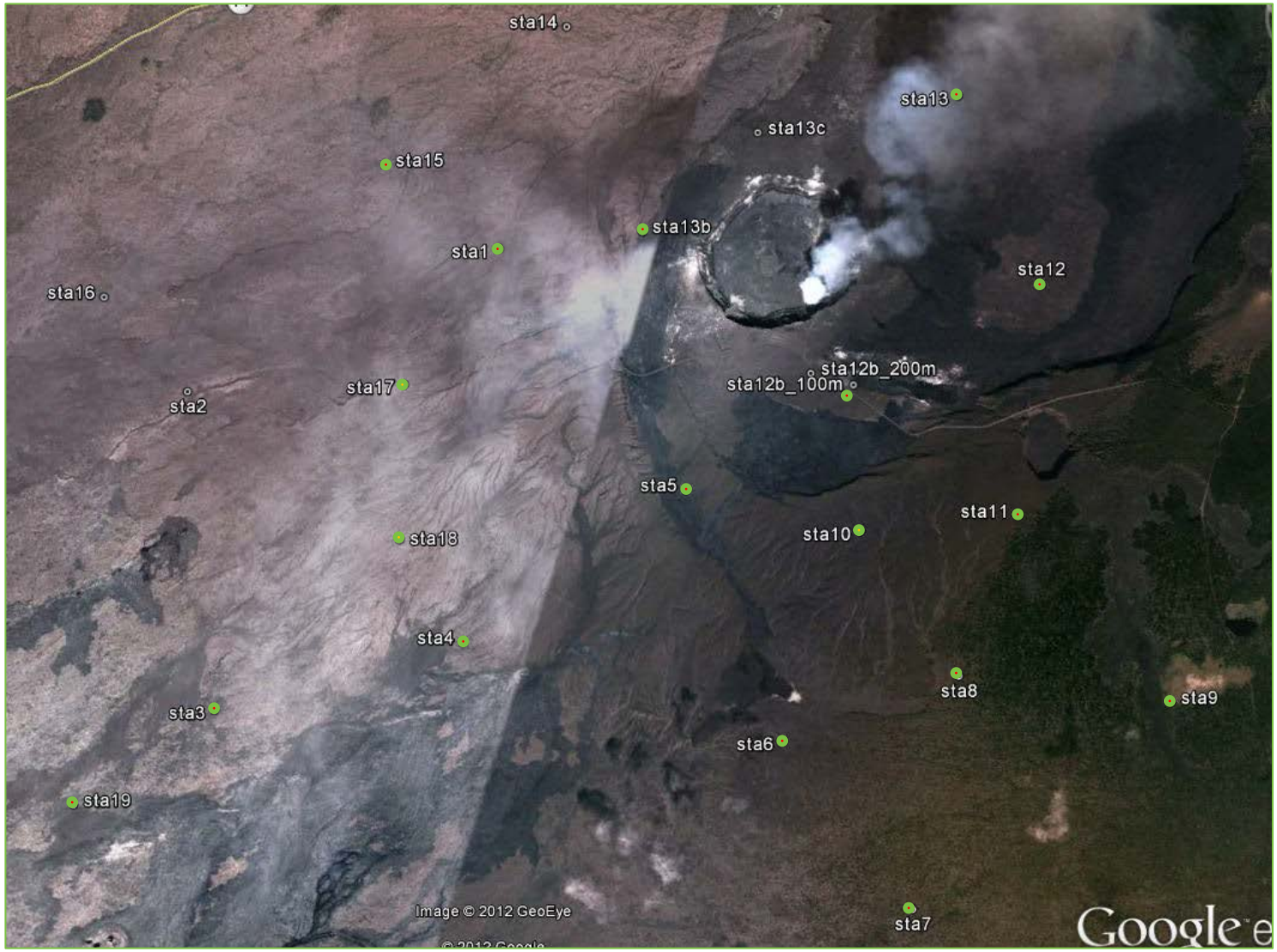
- **Restrictive entry onto public and private lands**

Worked extensively with State agencies and private interests to develop rights of entry for large areas of Hawaii Island

- **Delayed start-up of data acquisition and availability of field data**

Industry partner Avalor worked with surrogate MT data to develop data visualization software and have beta version available for finalization with new field data as soon as it is available.

Accomplishments, Results and Progress



Kilauea Summit

- 4 stations per acquisition
- Obvious hydrothermal activity
- Associated with DI events
- Magma conduit

Protocol for MT data acquisition

Groups of stations with synchronized data acquisition

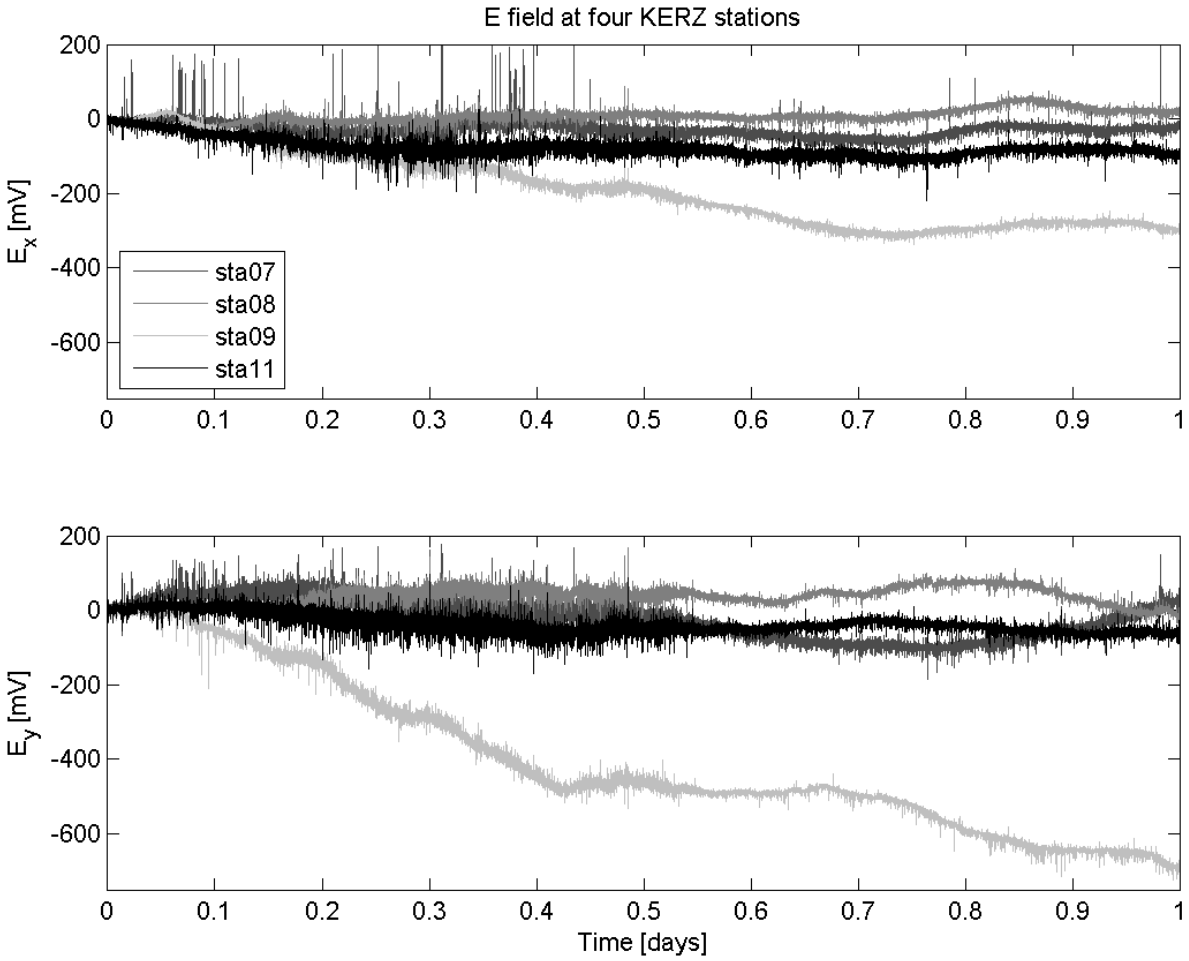
Long term acquisition (~ 5 days) at high and low sampling frequencies to improve signal to noise ratio and provide electric field data for time series analysis

Dual remote reference stations to help account for noisy magnetic fields and ground motion.

Acquiring repeat site with each group of stations to tie to previous data sets

Auto offset at 12 hour intervals to avoid saturation of highly variable E field

Accomplishments, Results and Progress



E field timeseries

- March 5th – March 6th
- Shallow hydrothermal activity at station 9
- Deflation event
- Magma conduit

Original Planned Milestone/ Technical Accomplishment Phase I (KERZ)	Actual Milestone/Technical Accomplishment	Date Completed
PLAN FIRST FIELD SURVEYS		
Procure/Rent MT Equipment – 12/11	Purchased MT array	6/2012
	Refine software and develop expanded gain protocol	10/2012
	Complete field testing inst.	10/2012
Begin Kilauea Surveys – 1/12	Initiate Kilauea Surveys	11/2012
	Identify acceptable remotes	1/2013
Complete Summit Surveys 2/12	Complete Summit Surveys	3/2013
Initiate Lower Puna Surveys 2/12	Initiate Puna Surveys	4/2013
Initiate Kilauea Data Processing 3/12	Initiate Kilauea Data Processing	3/2013
Develop Data Visualization Software 8/12	Draft Visualization Software complete	11/2012

Future Directions

- Complete data acquisition on southeast end of East Rift Zone while analysis of Kilauea data is underway
- Establish that the E field data will provide permeability information
- Begin Phase II Mauna Kea Rift Zone data acquisition
- Begin technology development efforts as soon as data is available for that purpose
- Develop electrical resistivity and permeability models
- Expand the areas of MT assessment as broadly as possible using complementary funds to provide the broadest possible range of conditions against which to test and validate the improved technology and software
- Work with industry and private partners to encourage exploration for geothermal energy resources

Future Directions

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

Milestone or Go/No-Go	Status & Expected Completion Date
HVNP data acquisition	Completed 03/2013
Puna data acquisition	Begin 04/2013, Expected completion 07/2013
Data Analysis HVNP	FY2013
Data Analysis Puna	FY2013
Phase II Mauna Kea Rift Zone	FY2013

Summary

- Data acquisition for testing methodology and analysis is underway, with the first phase nearing completion
- Unique, dynamic environment in which to test the concept: electric field data show large variability over time in areas of elevated hydrothermal activity
- Well positioned to undertake the detailed data analysis and modeling tasks required to reach the Go/No Go decision point
- Strong local support, logistical and financial, has been provided by all sectors of Hawaii including government, private industry, and community leaders
- Land access obtained for phase I of project will help further accessibility for phase II
- Strong interest in the results of the project as they relate to both local and industry-wide success of geothermal projects

Project Management

Timeline:

	Planned Start Date	Planned End Date	Actual Start Date	Current End Date
Phase I	10/1/2011	9/30/2012	5/1/2012	9/30/2013
Phase II	10/1/2012	9/30/2013	10/1/2013	9/30/2014

Budget:

Federal Share	Cost Share	Planned Expenses to Date	Actual Expenses to Date	Value of Work Completed to Date	Funding needed to Complete Work
$977,541	$128,730		$306,671		~$800,000
	$876,521		$322,765		

- **We have worked closely with State and Federal agencies to leverage funding from this project to expand our technology development efforts and to increase the overall knowledge of Hawaii's geothermal resources**
  - **The additional data generated by expanded surveys will feed back into the validation of the models developed under the technology development work**
- **Strong interest in results from this work by private sector that has facilitated access to private lands for the execution of expanded surveys**
- **Redesigned project for longer term development of the technology and longer term benefit to geothermal development in Hawaii**
  - **Cost has been higher and more time expended than originally anticipated**
- **Project is ~ 1 year behind original schedule due to initial funding delays and added burden of equipment procurement and refinement of its capabilities**