Research Performance Final Report

Federal agency and organization: DOE EERE – Geothermal Technologies Program

Recipient organization: University of Nevada, Reno
DUNS number: 14-651-5460
Recipient address: MS 168, Reno, NV 89557-0088

Award number: DE-FG36-02ID14311

Project title: Expanding geothermal resource utilization through directed research, education, and public outreach

Project period: March 20, 2002 to December 31, 2012

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Report submitted by: Wendy Calvin

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DOE Project Team: DOE Contracting Officer – Not assigned
DOE Project Officer – William Vandermeer
Project Monitor – Not assigned

Background: The Great Basin Center for Geothermal Energy (GBCGE or the Center) was established at the University of Nevada, Reno (UNR) in May 2000 to promote research and utilization of geothermal resources. The Center received funding through this grant to promote increased geothermal development in the Great Basin, with most of the funding used for peer-reviewed research. Funding to the Center and work under the contract were initiated in March 2002, with supplemental funding in subsequent years. The Center monitored the research projects that were competitively awarded in a series of proposal calls between 2002 and 2007. Peer-reviewed research promoted identification and utilization of geothermal resources in Nevada. Projects used geology, geochemistry, geophysics, remote sensing, and the synthesis of multi-disciplinary information to produce new models of geothermal systems in the Western U.S. and worldwide. Funds were also used to support graduate student research and training. Part of the grant was used to support public outreach activities, including webpages, online maps and data resources, and informational workshops for stakeholders.

Impact of research: Our integrated approach to regional assessment produced a wide array of publically available research results, databases, and maps. Our studies on fault controls, shallow temperature anomalies, remote sensing for geothermal indicators, and water chemistry from springs has resulted in the discovery of at least fourteen previously unknown geothermal systems in Nevada. In addition, many of the funded ARRA geothermal development projects in Nevada were motivated by data and maps generated through our efforts. Thus far in Nevada, new geothermal discoveries have generated $7.6 million in revenues from BLM lease sales. It is estimated that these new geothermal systems will likely generate at least $28 million per year in new electricity sales. Nevada has further benefited from construction of new power plants, estimated to cost $259 million. A more detailed summary including a complete list of publications, degrees conferred under all geothermal activities, and a summary of all research, regardless of funding source, is planned for an informal report, “A Decade of Geothermal Exploration in the Great Basin”. This report will be distributed at the annual GRC meeting.

Scientific approach: Tasks and funding were divided between peer-reviewed research (66%) and project management (34%). Past funded work has focused on geoscience research and developing technology to improve the assessment, exploration, and stimulation of geothermal resources, and creating online public data repositories. Projects were selected based on their benefit to the DOE Geothermal Technologies Program, technical merit and soundness, capability of investigators, likelihood that the projects will increase utilization of geothermal resources, and adequacy of commitment by the PI.

Summary of Accomplishments under this Award:

- 25 graduates involved, 11 degrees conferred (3 PhD, 8 MS)
- 80 undergraduates involved
- 215 publications
- 240 presentations
- 15 workshops with 1150 participants total
- development of Refraction Microtremor and ShakeZoning technologies

Total funding: $5,865,275

UNR cost share: $690,321

Follow on, competitively awarded funding: $7,853,088

DOE Funding History:

- 2002 $936,000
- 2003 $963,364
- 2004 $981,000
- 2005 $992,133
- 2006 $990,000
- 2007 $0
- 2008 *$320,000*
- 2009 $682,778

2008 funding was competitively awarded from DOE peer-review, other years were congressionally directed ("earmark") funding.

Project Overview – Summaries for each of the following projects are provided in this final report. Funding reflects amounts provided under this award.

- Project Management, Data Base Development, Public Outreach PI's Shevenell/Calvin, $1,892,125

- Twenty-two distinct research projects, related projects are grouped together in this list.
- Geology
    - Characterization of Active Faulting and Neotectonics at Nevada Geothermal Sites: Is there a Connection? PI - John Bell, $299,372
    - Structural and Geophysical analysis of geothermal systems in the Northern Great Basin. PI - Jim Faulds, $660,594
- Geochemistry
    - Geochemical Analysis of Magmatic Activity and Igneous Rocks. PI – Arehart, $141,873
    - Geothermal Applications of Mult-Gas Geochemistry. PI – Lechler, 126,210
    - Geochemical sampling of thermal and non-thermal waters. PI – Shevenell, $306,809
- Geophysics
    - Regional Database of Crustal Geophysical Controls on Geothermal Resource Assessment. PI – Louie, $383,879
    - Regional Resource Area Mapping Using the New USArray Seismic Network. PI – Biasi, $228,508
    - Satellite InSAR (Interferometric Synthetic Aperture Radar) Ground Displacement Analysis for Geothermal Reservoir Management and Development. PI – Oppliger, $280,896
- Remote Sensing/Geodesy
    - Targeting Potential Geothermal Resources from Regional Scale Relationships between Geodetic Strain and Geologic Structures. PI – Blewitt, $547,505
    - Remote Sensing for Geothermal Exploration. PI – Calvin, $236,241
- Exploration Techniques
    - Regional Assessment of Potential Geothermal Systems and Revival of Grass-Roots Geothermal Exploration. PI – Coolbaugh, $646,083
- Database Development
    - Geothermal Database Development. PI – Shevenell, $115,179

Project management, database development, public outreach – *Shevenell, Calvin*

Individual project titles:

- GeoPowering the West – *Taranik, Shevenell*
- Expanding geothermal resource utilization in Nevada – *Shevenell*
- Expanding geothermal resource utilization in Nevada through directed research and public outreach – *Shevenell, Calvin*

Summary: This grant supported public outreach activities, including a website which provides access to maps and data resources, and information workshops for stakeholders. We continually maintained and updated the website and online resources. The most recent update to the pages was made in November 2012, available at http://www.gbcge.org/.

Much work was done to produce a Nevada Geothermal Resources map which is now an interactive map online, Map 161 http://gisweb.unr.edu/geothermal/. The GBCGE interactive maps are a primary model for data dissemination and distribution intended through the National Geothermal Data System.

The GBCGE Director attends geothermal meetings within the U.S. and internationally to promote the Center and coordinates with the media, UNR and Truckee Meadows Community College faculty, students, geothermal organizations, federal and state government agencies, and industry stakeholders.

Funding: $1,892,125

Publications: 48

Presentations: 49

Graduate students involved: 3

Undergraduate students involved: 31

Degree Conferred: Coolbaugh, M. F. (2003), PhD, The prediction and detection of geothermal systems at regional and local scales in Nevada using a geographic information system spatial statistics, and thermal infrared imagery.

Workshops: 15 **Participants:** 1150

Status: Database work is continuing under NGDS funding. GBCGE administrative and communication tasks are continuing under DOE-0003997.

Active faulting at Nevada geothermal sites - *Bell*

Individual project titles:

- Pattern and timing of active faulting along Nevada geothermal systems: Is there a connection?
- Characterization of active faulting and neotectonics at Nevada geothermal sites

Summary: This work included studies of the spatial association, and likely genetic structural connection, between seismically active (Holocene) faults and high temperature (>100°C) geothermal sites. We utilized low sun angle aerial photography to detect active faults and found that out of a total of 37 high temperature sites, at least 32 lie directly on, or in close proximity to, active faults. These results have provided the basis for a conceptual exploration model currently in use on non-earmark studies.

Funding: $299,372

Publications: 2

Presentations: 4

Graduate students involved: 4

Undergraduate students involved: 0

Degrees Conferred: Affiliated with other advisors/projects.

Structural and geophysical analysis of geothermal systems in the northern Great Basin - *Faulds*

Individual project titles:

- Structural and geophysical analysis of the Brady-Desert Peak geothermal field: Links between northeast-trending structures and geothermal anomalies in the Great Basin – *Faulds*
- Geologic and geophysical analysis of the Desert Peak-Brady geothermal fields: Structural controls on geothermal reservoirs in the Humboldt structural zone – *Faulds, Garside, Oppliger*
- Characterizing structural controls on geothermal systems in the northwestern Great Basin through integrated geologic and geophysical analyses – *Faulds, Oppliger, Coolbaugh, Johnson*
- Characterizing controls on geothermal systems in the northern Great Basin through integrated structural analysis and modeling - *Faulds*

Summary: The primary purpose of this project was to characterize the structural controls on geothermal fields in the Great Basin by an integrated study of structural, geophysical, and GIS data. Goals included development of a catalogue of favorable environments and models, improving site-specific targeting of resources through detailed studies of representative sites, and comparison of controls and models in different tectonic settings. Synthesis of complementary data lead to new methodologies for enhancement of exploration strategies and reduced risk of drilling non-productive wells in conventional systems. Most fields are not on major faults but on less conspicuous normal fault with stepovers, horse-tailing, overlapping, or intersecting features. This project began with a focus on the Brady's-Desert Peak geothermal area, which was studied throughout the decade. The project was expanded to include geologic and structural studies at other geothermal fields in the region; including Desert Queen, Lee-Allen Hot Springs, Astor Pass, Salt Wells and San Emidio.

Funding: $660,594

Publications: 44

Presentations: 52

Graduate students involved: 8

Undergraduate students involved: 0

Degrees Conferred: 5

Hinz, N. H. (2004), M.S., Tertiary volcanic stratigraphy of the Diamond and Fort Sage Mountains, northeastern California and western Nevada -- implications for development of the northern Walker Lane.

Delwiche, B. M. (2007), M.S., Oligocene paleotopography and structural evolution of the Pah Rah Range, western Nevada: implications for constraining slip on the right-lateral Warm Springs Valley fault in the northern Walker Lane.

Drakos, P. S. (2007), M.S., Tertiary stratigraphy and structure of the southern Lake Range northwest Nevada [microform]: assessment of kinematic links between strike-slip and normal faults in the northern Walker Lane.

Vice, G. S. (2008), M.S. Structural controls of the Astor Pass-Terraced Hills geothermal system in a region of strain transfer in the western Great Basin, northwestern Nevada.

Rhodes, G. T. (2011), M.S., Structural controls of the San Emidio geothermal system, northwestern Nevada.

Geochemical analysis of magmatic geothermal systems – *Arehart*

Individual project titles:

- Geochemical characterization of magmatic-related vs. extension-related geothermal systems in the Great Basin: Implications for exploration, exploitation, and environmental issues
- Dating young igneous rocks

Summary: We collected 31 samples of igneous rocks associated with geothermal systems across the Great Basin. Ages ranged from 15 Ma to 0.4 Ma. Some of the younger rocks indicate magmatic activity may be a driver from some Great Basin geothermal systems. Sixty four geothermal fluid samples were analyzed for a complete suite of trace components. Trace element data (Li, Cs, B, As) suggest there are distinct differences in geothermal systems driven by magmatism compared to those resulting from deep crustal circulation.

Funding: $141,873

Publications: 3

Presentations: 8

Graduate students involved: 0

Undergraduate students involved: 2

Geochemical sampling of thermal and non-thermal waters – *Shevenell*

Individual project titles:

- Collecting geochemical data at Nevada geothermal resources – *Shevenell*
- Geochemical sampling of thermal and non-thermal waters in Nevada: Continued evaluation of geothermal resources – *Shevenell, Lechler, Garside, Coolbaugh*

Summary: This grant supported geothermal fluid geochemical sampling and analysis. A total of 1155 geothermal spring and well sites were visited between 2002 and 2008 with over 450 water samples collected and analyzed for geochemistry (see map under Database Development). These data have been added to a 50,000 record geochemical database and we have provided geochemical mixing plots.

Funding: $306,809

Publications: 16

Presentations: 13

Graduate students involved: 0

Undergraduate students involved: 18

Geothermal applications of multi-gas geochemistry – *Lechler, Shevenell, Garside, Coolbaugh*

Summary: Mobile compounds such as Hg, CO_2, He, and NH_3 that occur in geothermal systems can rise through pore spaces and up to the surface. This provides a potential method of detecting blind systems that have no obvious surface expression. Research was directed toward refining the mercury technique and determining the effectiveness of measuring other gases in geothermal exploration.

Funding: $126,210

Publications: 3

Presentations: 2

Graduate students involved: 0

Undergraduate students involved: 3

Regional database of crustal geophysical controls on geothermal resource assessment – *Louie*

Individual project titles:

- Crustal seismic velocity and density database
- Continued implementation of a regional database of crustal geophysical controls on geothermal resource assessment, and a new seismic survey of the northwesternmost Great Basin

Summary: This project developed new facilities and capabilities at the University of Nevada, Reno. We established the Long-Range Seismic Refraction Facility, which conducted crustal seismic surveys contributing to regional assessments of geothermal power-potential. This project ran new crustal-scale surveys across the Northern Walker Lane (NWL, 2003), the Idaho-Nevada-California (INC, 2004), and the Northern Nevada – Utah (NNUT, 2005) Transects. The surveys determined crustal-thickness variations across these provinces. In addition, the facility seeded development of the Refraction Microtremor and ShakeZoning technologies. The Refraction Microtremor technology has been licensed by UNR to Optim, Inc. and has generated hundreds of thousands of dollars in royalty payments. ShakeZoning 3d model-construction technology is available open-source at crack.seismo.unr.edu/NSZ .

Funding: $383,879

Publications: 4

Presentations: 29

Graduate students involved: 3

Undergraduate students involved: 16

Degrees Conferred:
Michelle Heimgartner, 2007, The geophysical structure of the Sierra Nevada crustal root, M.S. thesis, University of Nevada, Reno: Reno, NV, USA

James B. Scott, 2007, Seismic noise in the shallow subsurface: Methods for using it in earthquake hazard assessment, Ph.D. thesis, University of Nevada, Reno: Reno, NV, USA

Detailed regional resource area mapping using natural and mining seismic sources and the new USArray seismic network – *Biasi*

Summary: The temporary seismic network installed by the USArray Transportable Array (TA) in Nevada and the Great Basin provides new station coverage for regional seismic imaging. Work applies strengths of body- and surface-wave approaches to geothermal reconnaissance and favorability. Some trends in velocity have surface manifestations. Extreme crustal extension seems a likely cause for the low velocities of the Carson Sink. High Vp/Vs rations show where fluids or extension has decreased shear-wave velocity more than compressional velocity.

Funding: $228,508

Publications: 4

Presentations: 4

Graduate students involved: 0

Undergraduate students involved: 0

Satellite InSAR (Interferometric Synthetic Aperture Radar) ground displacement analysis for geothermal reservoir management and development – *Oppliger, Coolbaugh, Shevenell*

Summary: Surface deformation is an expected consequence of the production of geothermal fluids and steam even if the reservoir is kilometers deep and isolated from shallow groundwater. Knowledge of changes in the extent and compaction rates of producing geothermal reservoirs observed through subtle surface subsidence patterns promise to assist with geothermal field expansion and sustainability through improvements in production and reinjection well siting and management. This project investigated the relation between geothermal reservoir compaction, geometry, and production rates by recovering a ten-year InSAR ground displacement history at the Brady's and Desert Peak geothermal fields. Studies were also performed at Steamboat Hills.

Funding: $280,896

Publications: 18

Presentations: 14

Graduate students involved: 1

Undergraduate students involved: 1

Degrees Conferred: 1

Huebner, L. E. (2009), M.S., Investigations of the Steamboat Hills geothermal reservoir beneath the University of Nevada, Reno's Redfield campus using shallow geophysical techniques.

Targeting geothermal resources using geodetic strain - *Blewitt*

Individual project titles:

- Targeting of potential geothermal resources
- Targeting of potential geothermal resources in the Great Basin from regional to basin-scale relationships between geodetic strain and geologic structures

Summary: This project created a basin-wide mobile array of GPS stations to determine crustal strain rates, fault slip rates, and their association with geothermal resources. The rate, pattern, and style of ongoing strain deformation results in the stressing of pre-existing structures. It has been observed that areas of higher ambient strain rate may have greater geothermal potential. Geodetic techniques are now capable of measuring very low rates of motion (<1 mm/yr) which allows us to establish whether some parts of the target area are deforming differently or more quickly. The rate and style of strain derived from GPS measurements from these two projects provide a foundation model layer for geothermal potential maps generated by the Center. Such maps provide regional information for assessing the potential for high—temperature geothermal systems in the Great Basin, that is, those systems that are most likely to be capable of producing electrical energy.

Funding: $547,505

Publications: 9

Presentations: 19

Graduate students involved: 1

Undergraduate students involved: 0

Degrees conferred: 1

Hill, E.M. 2005, Ph.D. Dissertation title not available via on-line sources or UNR library system.

Remote sensing for geothermal exploration – *Calvin*

Individual project titles:

- Testing unique surface identifiers for geothermal site characterization
- Remote sensing for geothermal exploration

Summary: We used remote sensing data from a variety of satellite and airborne instruments to characterize mineral, vegetation, and thermal properties as surface indicators of geothermal resources in the Great Basin. Satellite data was analyzed as a reconnaissance tool to target higher resolution airborne data collections. Spectral data are collected from field surface locations and samples to validate remote identifications and refine mineral maps. We have explored 9 regional areas in Nevada and have identified geothermal indicator minerals at all sites using visible, near, shortwave, (0.4 – 2.5 μm) and/or thermal infrared (8 – 12 μm) remote sensing data. To best understand geothermal systems and constrain fluid pathways underground, surficial mineral maps are integrated with a strong understanding of local structural geology. Modern remote sensing tools provide a rapid regional assessment to help define high priority targets for additional studies including field geologic and structural mapping, shallow temperature surveys, geophysical surveys, geochemistry, and lastly drilling.

Funding: $236,241

Publications: 16

A summary of past work has been submitted to *Remote Sensing*.

Presentations: 22

Graduate students involved: 3

Undergraduate students involved: 2

Degrees Conferred:

Kratt, C. B. Geothermal exploration with remote sensing from 0.45 - 2.5 μm over Brady-Desert Peak, Churchill County, Nevada, M.S. thesis, University of Nevada, Reno: Reno, NV, USA, 2005, 110 pp.

Littlefield, E. F. Analysis of remote sensing data for geothermal exploration over Fish Lake Valley, Esmeralda County, Nevada, M.S. thesis, University of Nevada, Reno: Reno, NV, USA, 2010, 167 pp.

Regional assessment of geothermal potential – *Coolbaugh*

Individual project titles:

- Regional assessment exploration for potential geothermal systems – *Coolbaugh*
- Revival of grass-roots geothermal exploration in the Great Basin (where to look for new geothermal fields) – A new approach to assessing geothermal potential using a geographic information system parts IV and V – *Coolbaugh, Shevenell, Zehner, Kreemer, Oppliger, Taranik, Faulds*

Summary: The relationship of geothermal activity to active crustal strain, young fault orientations, and other geologic factors has been quantified, and new spatial analytical (GIS) techniques have been developed which have improved the ability to integrate exploration data and predict where these undiscovered resources are most likely to occur.

Funding: $646,083

Publications: 28

Presentations: 17

Graduate students involved: 2

Undergraduate students involved: 2

Geothermal database development – *Shevenell*

Summary: This work involves integration of geothermal field data, photographs, descriptions, chemistry, etc., from the Nevada Bureau of Mines and Geology website with the newly completed web-based interactive Map 161 (http://gisweb.unr.edu/geothermal/), among other interactive maps. Work is continuing under separate NGDS award.

Funding: $115,179

Publications: 20

Presentations: 7

Graduate students involved: 0

Undergraduate students involved: 5