ANNUAL PROGRESS REPORT

PROJECT TITLE: Expanding Geothermal Resource Utilization in Nevada through Directed Research and Public Outreach

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RECIPIENT: University of Nevada, Reno,
MS 178, Reno, NV 89557-0088

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BACKGROUND / APPROACH: The Great Basin Center for Geothermal Energy (GBCGE) was established at the University of Nevada, Reno in May 2000, to promote research on and utilization of geothermal resources in the Great Basin of the Western United States. On March 22, 2002, the Center received initial funding of $936,000 to promote increased geothermal development in the Great Basin; this included funding of seven research projects. In June, 2003, the Center successfully obtained an additional $963,364, augmenting the scope of its work with the addition of three more research projects, with six of the original projects being renewed. About 80% of Center funding is used to fund peer-reviewed research projects, progress of which is described in this annual report. Approximately 10% of the granted funds are used to accomplish the goals of stakeholder outreach and information dissemination; another 10% is used to provide partial administrative and management support.

Following is a brief descriptive list of the components currently (March 2002 through March 2003) funded with this grant:
(1) Management of the Center
(Lisa Shevenell and Jane Long)
(2) GeoPowering of the West (GPW) - Outreach Activities and Workshops
(Lisa Shevenell and Jane Long)

(3) Geochemical characterization of magmatic-related vs. extension-related geothermal systems in the Great Basin: Implications for exploration, exploitation, and environmental issues, $71,128 (Greg Arehart, Mark Coolbaugh, Simon Poulson)
(4) Targeting potential geothermal resources in the Great Basin from regional relationships between geodetic strain and geological structures $86,917 (Geoff Blewitt)
(5) Testing unique surface identifiers for geothermal site characterization from remote sensing imagery, $63,733 (Wendy Calvin, Mark Coolbaugh)
(6) Structural and geophysical analysis and characterization of the Desert Peak-Brady Geothermal Field: Implications for understanding linkages between northeast-trending structures and geothermal anomalies $95,811 (James Faulds, Larry Garside)
(7) Assembly of a crustal seismic velocity and density database for the western Great Basin, $144,584 (John Louie)
(8) Geochemical sampling of thermal and nonthermal waters in Nevada: Evaluation of geothermal resources for electrical power generation and direct-use applications - $117,359 (Lisa Shevenell, Larry Garside)
(9) Regional assessment of exploration potential for geothermal systems in Nevada using a Geographic Information System (GIS) - $146,026 (James Taranik, Mark Coolbaugh, Gary Raines, Lisa Shevenell, Tim Minor, Don Sawatzky, Richard Bedell)

Work is proceeding on each of these, and preliminary results were presented for each at the annual GRC meeting in September 2002.

The following details are provided about the background and approach for work undertaken from the various research initiatives/perspectives made possible by these grant funds in alignment with the goals of the Department of Energy in furthering use of geothermal resources.

(1) Management Activities

This part of the grant is used to support activities related to management of the Center and, preparation of required reports, and overseeing and coordinating its research programs.

(2) Geopowering of the West (GPW)

Lisa Shevenell and Jane Long

This part of the grant is used to support public outreach activities, including web page and database development and informational workshops for stakeholders. Web page development is on-going, and several workshops were organized and executed during the reporting period.

(3) Geochemical characterization of magmatic-related vs. extension-related geothermal systems in the Great Basin: Implications for exploration, exploitation, and environmental issues

Greg Arehart, Mark Coolbaugh and Simon Poulson

The objective of this research project to classify geothermal systems so that similarities and differences among groups of systems are elucidated and better predictive models assembled. The research being undertaken will increase utilization of geothermal resources by providing data that will be critical in developing exploration models and exploitation strategies for geothermal energy in the Great Basin. In addition, understanding the geochemical evolution of these various types of systems will provide important insights into the possible contributions of geothermal systems to groundwater chemistry and development of mitigation strategies for possible environmental issues.

(4) Targeting potential geothermal resources in the Great Basin from regional relationships between geodetic strain and geological structures

Geoff Blewitt

One key to targeting regions with potential geothermal resources is to understand the role of faults in controlling fluid flow in the crust. There is evidence that critically stressed fractures and faults can play an important role in geothermal fields. We hypothesize that the continuous regional accumulation of tectonic strain acts to maintain faults and fractures as conduits for fluid flow, hence acting to sustain geothermal systems. This model would predict an enhancement of this effect if the regional tendency of fault strikes is favorably oriented in the ambient strain field. In particular, maximum effect would be predicted for fault strikes oriented perpendicular to the direction of maximum extensional strain. The Great Basin appears to be an optimal natural laboratory for testing our working hypothesis, as its dominant structural features are major normal-fault systems set within an extensional strain field. High strain rates are accommodated episodically by earthquakes, and therefore high strain rates correlate with active faults. Many of these normal fault systems are active, are oriented sub-perpendicular to the current minimum horizontal stress, and are accommodating significant present-day extensional crustal strains. The density of Quaternary faults in the Great Basin is such that it is possible to define the general tendency of fault strike orientation at almost any point as a continuous variable. Moreover, Global Positioning System (GPS) data have been collected at many stations in the Great Basin for several years, thus allowing for precise (but not necessarily high resolution) determination of strain accumulation at the level of several parts per billion in some locations. Specifically, this type of model would predict that geothermal activity would be spatially correlated with areas of high inter-seismic strain accumulation, especially when faults are favorably oriented with respect to the strain-rate tensor field. In the first year of funding, we test these predictions in the Great Basin using tectonic velocity gradients derived from a network of Global Positioning System (GPS) sites, producing a regional strain-rate map with precision approaching a few parts per billion per year in some regions. Our hypotheses predict that regions of high inter-seismic strain accumulation should correlate significantly with high geothermal well temperatures and the locations of geothermal power-producing sites. In addition we tested the prediction that fault orientation is also important, and that this information can be used to enhance the predictive capability of regional geodetic strain to target potential geothermal resources.

(5) Testing unique surface identifiers for geothermal site characterization from remote sensing imagery

Wendy Calvin and Mark Coolbaugh

Thermal infrared imagery has been used previously to locate hot springs above geothermal resources, but its usefulness in exploration has been limited because the thermal anomalies were detected only in the immediate vicinity of known hot springs or fumaroles. Hyperspectral imagery in the visible and near-infrared has long been used to map surface mineralogy and alteration deposits. Recent significant advances in the availability and quality of both short-wave and thermal infrared imagery demand a reassessment of their role in geothermal exploration. The proposed work builds on our demonstrated success using both TIMS and ASTER data that show increases in the number of remotely detected thermal anomalies by an order of magnitude. This initial study was performed in the Steamboat Springs region. Preliminary work with ASTER data suggests the potential for obtaining similar results over the Brady Hot Springs region. At 90m/pixel, this space-borne data can easily identify an outcrop ~2 km in length. The work acquired higher resolution airborne imagery to map mineralogy and other features at known vents and fumaroles in the region and provide a regional scale assessment of other thermal anomalies at the site.

(6) Structural and geophysical analysis and characterization of the Desert Peak-Brady Geothermal Field: Implications for understanding linkages between northeast-trending structures and geothermal anomalies

Jim Faulds and Larry Garside

A broad region of high heat flow, the Battle Mountain heat flow high, covers much of northern Nevada and includes an east-northeast-trending zone extending from near Reno to Carlin. The Steamboat, Desert Peak-Brady, Soda Lake, Rye Patch, Dixie Valley, and Beowawe geothermal fields lie within this zone. Northeast-striking faults that roughly parallel the Battle Mountain heat flow high appear to host most of these geothermal fields. This belt of east-northeast- to northeast-striking faulting and high heat flow has been referred to as the Humboldt structural zone. The abundance of producing geothermal fields and regional extent of the heat flow anomaly indicate high potential for discovering additional geothermal reservoirs in this region.

Despite the economic significance of the Humboldt zone, its structural and geophysical framework has not been comprehensively studied. Although significant contributions have recently been made, the temporal and spatial relationships between various structural features within the zone and how individual faults, stratigraphic units, or sets of structures control fluid pathways and geothermal resources are generally poorly understood. We have therefore embarked upon an integrated structural, geophysical, geochronologic, and Geographic Information Systems (GIS) investigation of the Desert Peak-Brady geothermal field in the Hot Springs Mountains of western Nevada. This area was chosen for study because it is one of the better-exposed geothermal fields in the Humboldt structural zone. This study will help to characterize features that localize geothermal reservoirs in the Humboldt zone and may therefore facilitate future exploration and discovery of geothermal resources in northern Nevada.

(7) Assembly of a crustal seismic velocity database for the western Great Basin

John Louie

This sub-project is concerned with assembling a three-dimensional reference model of seismic velocity for the western Great Basin region of Nevada and eastern California. Exploration for hidden resources requires a realistic crustal and upper-mantle model to understand the deep sources of geothermal heat. In the western Great Basin, crustal properties and thickness are known only at wide spacing, but the structure of the urban basins and certain geothermal regions is known at some detail. We are compiling velocity information from sources in the literature, results of previous seismic experiments and earthquake-monitoring projects, and data donated from mining, geothermal, and petroleum companies. We also collected (May 2002) one new crustal refraction profile across western Nevada and the northern Sierra to Auburn, Calif. This section had not been characterized previously. The resulting seismic velocity model will consist of simplified rule-based representations of some of the region's geothermal areas and sedimentary basins. Very shallow velocities are constrained by geotechnical data; seismic receiver-function and refraction analyses constrain deep Moho depths. The model is specified in a form compatible with computer codes developed for SCEC and EarthScope. We are developing from the seismic velocity database a geographic index of the likelihood of geothermal resources. The likelihood index will contribute to regional databases of economic geothermal indicators.

(8) Geochemical sampling of thermal and nonthermal waters in Nevada: Evaluation of geothermal resources for electrical power generation and direct-use applications

Lisa Shevenell and Larry Garside

There are more than 350 known geothermal systems in Nevada. At least 30% of these systems do not have modern, complete water analyses, with analyses for many of these from only one spring in a group of springs. Often it is not known from which spring in a group the sample was taken or if the

sampled spring was from the highest temperature spring in that group. Additional data are available from a previously digitized database containing all springs and wells on 7.5' quadrangles. From these digitized site locations, there are ≈1000 springs for which a location is known, but for which there are no available temperature (or chemical) measurements. Although many of these sites are within known geothermal areas and are located near springs for which temperature and/or geochemical data are available, many of these sites are not so located and require evaluation before the geothermal potential of the area can be assessed. A sampling team was assembled and collaboration with researchers at Lawrence Berkeley National Laboratory (Thijs van Soest and B. Mack Kennedy) was initiated in the first year of this project. Fluid sampling for geochemical analysis was initiated and data analysis is proceeding.

(9) Regional assessment of exploration potential for geothermal systems in Nevada using a Geographic Information System (GIS)

James Taranik, Mark Coolbaugh, Gary Raines, Lisa Shevenell, Tim Minor, Don Sawatzky and Richard Bedell

There is a need for the numerous datasets relevant to geothermal exploration and assessment to be compiled and simultaneously modeled using a GIS system to identify likely targets for future geothermal resource exploration drilling and development. There are three primary objectives of this type of research: 1) analyze spatial correlations and inter-relationships between geothermal systems and map features such as geologic rock types, young faults, young volcanism, depth to water table, 2) combine geologic, geochemical, and geophysical maps together into an overall predictive model for geothermal systems in the Great Basin, and 3) make this GIS database accessible to the public to promote greater resource utilization.

PROJECT OBJECTIVE: The Great Basin Center for Geothermal Energy (GBCGE) is conducting work encompassing two main tasks. (1) We are (a) producing a web-based, stakeholder geothermal information system for Nevada geothermal data relevant to assessing and developing geothermal resources, and (b) we are holding informational stakeholder workshops (both as part of the GeoPowering the West Initiative). (2) We are conducting an applied research program of peer-reviewed geothermal research with the goal of increasing production and utilization of geothermal energy in the Great Basin.

Specific project-oriented objectives:

(1) Management Activities

Lisa Shevenell and Jane Long

The objective of this part of the grant is to coordinate research projects and database development; organize and oversee workshops; manage the research projects; track spending; and, prepare required reporting to DOE and other entities. This part of the grant funds salaries for the Principal Investigators (PIs) (Shevenell and Long), the administrative assistant, allowing for some student assistance, as well as other required travel and operating expenses needed to manage the grant.

(2) GeoPowering of the West (GPW)

Lisa Shevenell and Jane Long

The objective of this part of the grant is to conduct workshops and fund database and web development activities. This part of the grant funds salaries for web and database developers and part of the administrative asssitant who helps to coordinate and organize workshops, and maintain selected databases.

(3) Geochemical characterization of magmatic-related vs. extension-related geothermal systems in the Great Basin: Implications for exploration, exploitation, and environmental issues

Greg Arehart, Mark Coolbaugh and Simon Poulson

The objective of this project is to classify geothermal systems so that similarities and differences among groups are elucidated and better predictive models are assembled.

(4) Targeting potential geothermal resources in the Great Basin from regional relationships between geodetic strain and geological structures

Geoff Blewitt

The objective of this part of the grant is to assess a new method to target potential geothermal resources on the regional scale. The method is based on seeking relationships between geologic structures and geodetic observations of regional tectonic strain. The working hypothesis is that geothermal plumbing systems might in some regions be controlled by fault planes acting as conduits that are continuously being stressed apart by tectonic activity. This part of the grant funded salaries for the PI (Blewitt) and a Graduate Research Assistant at UNR (Sarah Mahoney), and subcontracts to the State University of New York at Stony Brook (Bill Holt) and to the Harvard Smithsonian Center for Astrophysics (Jim Davis).

(5) Testing unique surface identifiers for geothermal site characterization from remote sensing imagery

Wendy Calvin and Mark Coolbaugh

The objective of this research is to establish mineral or thermal anomaly markers that could lead to identification of new resources or expansion of existing sites. Minerals associated with fumarole deposits or mineral variation occurring due to closed hydrothermal systems are particularly targetted along with day/night temperature variations as indicators of hot spot potential. This work seeks to define surface identifiers of geothermal sources through analysis of remote sensing imagery to characterize mineral, vegetation, and thermal properties at a known source region (Steamboat Hills) and compare the results to similar properties at an area with geothermal exploration potential (near Bradys Hot springs).

(6) Structural and geophysical analysis and characterization of the Desert Peak-Brady Geothermal Field: Implications for understanding linkages between northeast-trending structures and geothermal anomalies

James Faulds and Larry Garside

James Faulds, Larry Garside, and Gary Oppliger are conducting an integrated geologic, geophysical, and Geographic Information System (GIS) investigation of the Desert Peak-Brady geothermal field in the Hot Springs Mountains of western Nevada. Two power plants and one vegetable dehydration plant currently operate in this field. The geologic investigations involve detailed mapping of critical areas, delineation of Tertiary stratigraphy, analysis of faults and folds, and $^{40}Ar/^{39}Ar$ dating and geochemical correlation of key units. The objective of this sub-task is to delineate the late Cenozoic three-dimensional strain field in the area; elucidate relations between faults, stratigraphic features, and thermal aquifers; and, help define the current stress field. Gravity data are being utilized to reveal significant structures and their intersections, as well as define patterns in pre-Tertiary basement depth. This is important because pre-Tertiary rocks host the *blind* Desert Peak reservoir. The geologic and gravity studies, as well as existing drill-hole, temperature, and electrical conductivity data, are being incorporated into a GIS database. Collectively, these data sets will permit comprehensive three-dimensional visualization and modeling of the geothermal field. The initial goals of this part of the

project are to (a) characterize the links between thermal aquifers and structural and stratigraphic features and (b) better define the boundaries of the geothermal reservoirs.

(7) Assembly of a crustal seismic velocity database for the western Great Basin

John Louie

The objective of this sub-project is to assemble a three-dimensional reference model of seismic velocity for the western Great Basin region of Nevada and eastern California. The resulting seismic velocity model will consist of simplified rule-based representations of some of the region's geothermal areas and sedimentary basins. From the seismic velocity database we are developing a geographic index of the likelihood of geothermal resources. The likelihood index will contribute to regional databases of economic geothermal indicators.

(8) Geochemical sampling of thermal and nonthermal waters in Nevada: Evaluation of geothermal resources for electrical power generation and direct-use applications

Lisa Shevenell and Larry Garside

The objective of this part of the project is to obtain geochemical data from springs (and some wells) for which data are not publicly available, or for which the analyses are incomplete or poor. With these data, geothermometers will be calculated and a preliminary assessment of the geothermal potential and ranking of the sampled areas will be conducted using the new geochemical data.

(9) Regional assessment of exploration potential for geothermal systems in Nevada using a Geographic Information System (GIS)

James Taranik, Mark Coolbaugh, Gary Raines, Lisa Shevenell, Tim Minor, Don Sawatzky and Richard Bedell

The objective of this sub-task is to develop a geographic information system (GIS) of geothermal systems of the Great Basin. Included in this GIS is a detailed database of known geothermal systems in the Great Basin, as well as co-registered geological, geochemical, hydrological and geophysical maps useful in defining geothermal potential. These databases will be assembled in collaboration with other PIs working on Center projects.

STATUS / ACCOMPLISHMENTS: Highlights of accomplishments over the past year of funding under these research projects are described below:

(1) Management Activities

Lisa Shevenell and Jane Long

Former Center Director, Dr. James Taranik, stepped aside to become the Mackay School of Mines acting Dean. He was replaced with Dr. Jane Long. On March 6, the PIs met with the new Director of the Center (Jane Long) and briefed her on the status of the projects. Later, on March 26, 2003, a one-half day meeting was held with participation from all currently funded investigators and two of the student contributors. Current progress and accomplishments were discussed, and collaboration among researchers was enhanced. Preparation of an integrated paper on current results among all researchers was discussed, and the forum suggested for such a paper was the American Geophysical Union's (AGU) EOS.

The administrative assistant (Linda Ward) left her position with the Center to pursue another opportunity that offered more stable funding. One temporary assistant was hired, but was not found to be suitable for the position; another has been retained.

The Center prepared a 3-year, $3,000,000 proposal and submitted it to DOE-ID for continuation of funding for the Center. We also issued a request for proposals under this funding to Mackay School of Mines and Desert Research Institute faculty.

All database construction and GIS activities of the individual projects are being coordinated through the Center to avoid any duplication of efforts and to assist researchers in obtaining complementary data sets being developed under other projects. The proposals for these projects are posted on our web site at: http://www.unr.edu/geothermal/projects.html

Center personnel have submitted three proposals to conduct geothermal work in addition to what is covered under this grant.

(1) National Renewable Energy Laboratory (DOE) ($499,494). Exploratory drilling program to evaluate the lifetime and current potential of the Humboldt House geothermal system, Pershing County, Nevada. (awarded to Tempel, Shevenell, Arehart, Poulson, Ellis, Waibel, Barta).

(2) Fallon Paiute Shoshone Indian Reservation (Bureau of Indian Affairs pass-through) ($39,686) Geothermal Assessment of Fallon Paiute Shoshone Indian Reservation Lands (awarded to Garside, Shevenell).

(3) DOE EPSCoR Development of a New Geophysical Research Capability for Evaluating Natural and Production-Related Dynamics of Geothermal Systems (Taranik, Oppliger, Coolbaugh) (not funded, but received good reviews).

Work has begun on the first and second projects.

Student working on various geothermal projects over the period have included Ben Delwiche, Sean Keefe, Chris Kratt, Deborah Goetz, Shane Smith, Wesley Thelen, Sarah Mahoney, Jessica Muehlburg, Scott Phillips, Zach Wood and Tamison Irwin Joyer, to assist with research on this and other geothermal projects, as well as with selected administrative work as needed.

Shevenell has responded to numerous email and phone inquiries regarding the Center and availability of data. Various data were supplied to individuals, consultants and geothermal companies

(2) GeoPowering of the West (GPW)

Lisa Shevenell and Jane Long

Outreach activities included database and web page development, which are continually in progress, and workshops.

Workshops that have been conducted as part of the GPW activities over the year include the following:

1. *Geothermal Opportunities in Nevada* involved representatives from Nevada's geothermal industry, academia, and state and federal government agencies, and was organized by the Center and held on January 11, 2002. Over 200 people attended the highly successful workshop that identified barriers to geothermal development. Presentations from the meeting can be found at http://www.unr.edu/geothermal/meetingsandpresentations/geooppsnv.htm.
2. Another workshop was held January 17, 2002 at UNR to discuss and initiate Center collaboration with researchers from Lawrence Berkeley National Laboratory and Lawrence Livermore National Laboratory
3. A third workshop was held on April 18 and 19 at the Desert Research Institute in Reno, titled *Introduction to Geothermal Energy* and it was cosponsored with the Geothermal Resources Council (GRC) and the U.S. Department of Energy (DOE) GPW Program.
4. A fourth workshop, cosponsored by DOE, was held in Reno June 12-14, 2002 to highlight *DOE Sponsored Research at the Dixie Valley Geothermal Area*. Following formal presentations, working groups were assembled and a document was produced summarizing the results of research at the site. Presentations and the summary document are at:

http://www.unr.edu/geothermal/meetingsandpresentations/meetings_dixie.html

During the first quarter of 2003, a meeting was held with funded PIs to discuss web page structure, development, and content. The web pages design meeting resulted in design and formatting for the data product web pages of the GBCGE web site. The data pages link is titled "Geothermal Exploration & Assessment Data" and contains several links to categories of information relevant to and useful in creating maps and illustrations related to geothermal energy exploration in the Great Basin. The "Base Map Layers" pages primarily will list links to existing reference sources for base maps, geologic maps and satellite images in the on-line map database at UNR's Keck Library. Pages for other types of information will include links to new exploration and assessment data generated by research projects supported by the GBCGE. Thus far, data links have been added under the "Geochemistry", "Thermal Data", and "Production Data" categories. New data for "Geophysics" and "Geothermal GIS" and "Geochemistry" have been acquired on our server; links to these data are being added.

The structure of the web site has been revised, and PIs are slowly populating it with data generated from their research projects. Shevenell continues to advise the web master in development of the Center web page, and database and web page development continues with the assistance of several student workers.

The Great Basin Geothermal data service has been further improved with installation of ESRI ARCIMS-ARCMAP Server. This software allows creation of ARCIMS websites with ESRI ARCGIS8. The advantage of ARCMAP Server is the inclusion of image data in the form of ESRI grids and other formats. These data can be in different map projections prior to their inclusion and are re-projected to the projection of the website. This is the last important software module needed for serving data from the Geothermal website

A web page was created to provide task details, sample plots, and links to the evaluation datasets. See: Improved Resolution GIS Compatible Gravity and Aeromagnetic Data Sets for Great Basin Geothermal Exploration at http://able1.mines.unr.edu/oppliger/Greatbasin_geophysics1/project.htm. The gravity maps were created from custom processing of a new merge of databases covering the Great Basin. The data include recent coverage over the Desert Peak geothermal study area and the NGS 1999 and USGS Nevada 1997 databases. The new derived gravity anomaly products include: *complete Bouguer anomaly, isostatic residual anomaly, shallow crustal residual, and deep crustal anomaly.* The aeromagnetic total intensity anomaly dataset was derived from the USGS Composite Magnetic Anomaly Grid of the Western U.S., Kucks (2001). Terrain maps, based on a scale-compatible (600 meter cell) digital elevation model, were also produced. Typical file size is 40-50 MB. When complete, the total data suite will occupy about 2 GB.

Dr. Gary Oppliger has produced an evaluation suite of six ArcView GIS compatible Great-Basin-region gravity and magnetic datasets that provide significantly improved spatial resolution compared to previously available GIS compatible products. The new products allow associations to be made between the geophysical and other suitably accurate GIS datasets at scales of 1:250,000 or better, whereas previous GIS compatible geophysical products generally allowed only 1:1,000,000-scale work. Designed to be complimentary to and compatible with other geothermal GIS geodatabases, the datasets provide continuous coverage over the Great Basin region [–123°W to –110°W; 34.5°N to 45°N]. These new datasets are offered in three ArcView compatible data types: a) grid values in binary raster format at 1-km resolution, b) color shaded-relief surfaces as geo-registered *tif* images with 300 meter pixels, and c) vector graphics shape files of contours and data point locations. The datasets are duplicated in two map projections: Lambert Conformal Conic (Great Basin) and UTM zone 11, both in NAD27 datum. The preliminary datasets are available only in the Lambert projection.

Dr. Oppliger continues to test and define specifications for the improved-resolution, GIS-compatible gravity and magnetic datasets of the Great Basin region. Working closely, Don Sawatzky and

Gary Oppliger defined an improved data archiving and delivery structure to provide most categories of Center-developed data to the geothermal community. These data will be made available via a descriptive data product web page, direct FTP internet file access, and an ArcIMS Internet Map Server. Prototype data structures were created for these media/services and populated with our preliminary data sets.

(3) Geochemical characterization of magmatic-related vs. extension-related geothermal systems in the Great Basin: Implications for exploration, exploitation, and environmental issues

Greg Arehart, Mark Coolbaugh and Simon Poulson

Additional data analysis was completed on the sample set. In the Great Basin, extensional systems are lower in As than magmatic systems, and also lower in Li, Cs, and B (when corrected for temperature of the reservoir). Ni, and possibly Ga, appear to be in higher concentrations in extensional systems; however additional data from high-temperature (producing) extensional systems are needed to better understand these possible trends. A draft of a paper outlining these correlations was prepared for the Geothermal Resources Council (GRC) meeting, and a peer-reviewed journal publication may be prepared in the future.

Preliminary analysis of over 70 hot springs and production fluids from known extensional and magmatic geothermal systems is compatible with our analysis of the smaller data set at the end of the field season, 2002. Elements As, B, Li, and Cs appear to be elevated in magmatic systems when compared to extensional systems. In addition, Tl, Sb, Ge, and Se appear to have a similar distribution, that is, they appear elevated in magmatic systems compared to extensional systems. Scandium appears to show a linear relationship with SiO2, the cause of which is unclear at present.

(4) Targeting potential geothermal resources in the Great Basin from regional relationships between geodetic strain and geological structures

Geoff Blewitt

The objectives of this project have already been completed earlier in the first year, and now we are in a phase of refining previously reported results. Our results strongly support our working hypothesis that geothermal plumbing systems in identified regions are likely to be controlled by fault planes acting as conduits that are continuously being stressed apart by tectonic activity. Regions of high inter-seismic strain accumulation correlate significantly with high geothermal well temperatures and the locations of geothermal power-producing sites. The most important style of strain is found to be shear. Using digitized fault geometries, our strain analysis indicates that faults oriented normal to the direction of maximum extensive shear should be targeted. We have presented the GIS-encoded maps that show regions that match this description.

Jim Davis's group subcontracted at Smithsonian Astrophysical Observatory produced an updated GPS velocity solution which was passed on to Bill Holt subcontracted at State University New York for subsequent strain analysis. Bill Holt, meanwhile, has extended our current compilation of velocity solutions from various other sources, including new data from the (U.S. Geological Survey) USGS, in preparation for a final geodetic strain calculation for this project. At UNR, the PI, together with Mark Coolbaugh, have identified Buffalo Valley, near Battle Mountain, as a candidate target area for exploration of (blind) geothermal resources, based on an anomalously high rate of extensive shear strain across faults bounding the valley. Subsequent correlation with results from other tasks enhance this conclusion: (1) John Louie's task (seismic velocity database) indicate that this region does in fact have an anomalously short depth to the Moho, which of course would explain the high heat flux in the Battle Mountain area; (2) Lisa Shevenell's task (geochemical sampling) does indicate the presence of a moderate temperature geothermal reservoir based geothermometer calculations on samples from springs

on the southern boundary of the area of high strain rates. We note that the southern end of Buffalo Valley is bounded by ~1 Ma cinder cones, which may be associated with crustal extension and thinning.

In preparation for investigating the role of fault orientation, a database of Quaternary faults from C.M. dePolo (private communication, Nevada Bureau of Mines and Geology) was incorporated into a GIS database along with preliminary strain tensor data, site positions, and various geothermal parameters with the assistance of Mark Coolbaugh. The PI with Coolbaugh and student Sarah Mahoney have completed an initial strain rate analysis, computing the magnitudes of various styles of strain in the Great Basin. A technical breakthrough was made by the PI in the mathematical description of fault-azimuth statistics and fault-normal strain statistics that allowed the fault-normal strain analysis to be completed 2 months ahead of schedule, and this was presented at the GRC conference in September 2002.

The extensional strain project has achieved the stated goal of producing and publishing (at the GRC 2002 conference) updated maps of various types of strain in the Great Basin, concluding that, on the regional scale, the extensional component of strain normal to favorably-oriented quaternary faults does well to predict the spatial trends of current geothermal power production and high well temperatures, particularly along the Humboldt lineament and in the Walker Lane; conversely, the maps, therefore, suggest a much lower geothermal potential toward the east-central to south-east regions of Nevada where strain rates are extremely small.

(5) Testing unique surface identifiers for geothermal site characterization from remote sensing imagery

Wendy Calvin and Mark Coolbaugh

Meetings: Calvin presented preliminary results at the annual GRC conference in Reno in September, 2002**.** Both Chris Kratt and Calvin attended the annual AVIRIS workshop held Feb 25-28, in Pasadena. This was to prepare for analysis and interpretation of visible, near-infrared and shortwave infrared hyperspectral data sets (0.4 to 2.5 µm). Work Progress: Hyperspectral data sets of Dixie Valley were delivered from Bill Pickles of LLNL in late January. This includes 18 flightlines (about 45 Gbytes total) of data in both radiance and reflectance values. Dr. Pickles was also instrumental in obtaining no-cost AVIRIS flights over Fish Lake Valley. These data were flown March 20. Quicklooks of Fish Lake have been provided, but no calibrated data have been delivered to date. We spent several days at Dixie Valley getting a preliminary field assessment of the site, and Calvin lead an initial exploration of the flight lines. SpecTIR data flown over Brady's hot springs in summer 2002 were delivered in radiance format in early March 2003. Preliminary calibration of the data was performed using field average data of selected playa targets. Reflectance data were delivered in early April but are unreasonably noisy so we will continue using our field calibration as we attempt to understand the SpecTIR calibration issues. We have used ASTER data for initial mineral mapping assessment (rather than thermal) and are proceeding with surface mapping at Brady's with our rough calibration. The Brady's analysis is the primary responsibility of student Chris Kratt. Mark Coolbaugh focused on the analysis of the ASTER thermal work in preparation for submission as noted below.

Industry Collaborations: Mark Coolbaugh has been the primary interface to industry collaborators, providing awareness of our analysis and results and obtaining authorization as required to field check and validate the remote sensing results. We have worked with:

1) Ormat at the Brady's Power Plant (provided thermal images and GPS maps of fumaroles and warm ground that they can use to help locate secondary structures at depth)
2) Gilroy Foods at the Brady's Hot Springs (provided the same thermal images and GPS maps of fumaroles and warm ground for use in locating possible secondary structures).
3) Nevada Department of Transportation, Carol Callaghan (provided thermal images of Steamboat Springs to be used in on-going engineering studies for the freeway extension in that area).

An analysis of ASTER data over Brady's Hot Springs was completed as part of a lab project for a graduate-level course in thermal remote sensing. After corrections for albedo, topographic slope, and thermal inertia, improved anomaly definition was obtained, and the thermal anomaly was detectable over a minimum distance of 4 kilometers. These anomalies were verified in the field by using GPS units to produce a detailed map of fumaroles and warm ground. The GPS-generated maps confirmed indications from the thermal imagery that multiple faults with multiple strikes were responsible for the surface thermal features. The thermal imagery and fumarole maps have been given to Ormat, who will use the information to help locate secondary structures at depth. A PowerPoint talk discussing these results was given at the annual meeting of the Geologic Remote Sensing Group (affiliated with the British Geological Society) in London on December 6th.

Thermal infrared imagery from the SEBASS airborne scanner and the ASTER satellite scanner were used to map alteration minerals associated with geothermal activity at Steamboat Springs, Nevada and map structures along a 4-km-long thermal anomaly at Brady's Hot Springs, Nevada; these results were published in *Remote Sensing of the Environment*.

At the Denver annual meeting of the Geological Society of America on Oct. 30th, a PowerPoint talk provided an update on the geothermal remote sensing research, including results from Brady's Hot Springs using ASTER and results from Steamboat Springs using SEBASS. The SEBASS imagery has proved capable of mapping several hot-spring-related minerals including opal (sinter) and clay minerals. Old and young sinters have been distinguished based on the strength of their absorption features.

(6) Structural and geophysical analysis and characterization of the Desert Peak-Brady Geothermal Field: Implications for understanding linkages between northeast-trending structures and geothermal anomalies

Jim Faulds and Larry Garside

Faulds and Garside have conducted detailed geologic mapping along a northwest-southeast transect through the Hot Springs Mountains. This transect includes both the Brady and Desert Peak power plants and associated geothermal fields, as well as the Enhanced Geothermal Systems (EGS) site currently under investigation by Ormat International. Approximately 85% of the mapping transect has now been completed, including nearly all of the EGS site.

In the Desert Peak sub-project, the major accomplishments to date include: 1) compilation of existing isothermal, well, and geologic data into a GIS data base; 2) completion of a new detailed gravity survey (323 stations covering 200 km^2); 3) construction of a new Bouguer gravity map of the northern Hot Springs Mountains; and 4) enhanced understanding of the subsurface geologic framework of the Hot Springs Mountains, including depth to basement and geometry of faults (Faulds, Garside).

Major geologic findings and accomplishments include:

1. Significant refinement of the Tertiary stratigraphy, which will facilitate interpretation of well logs and estimation of depth to basement.
2. Discovery of several basaltic intrusions; Desert Peak itself consists of a large basaltic plug.
3. Sampling of basaltic lavas and intrusions for geochronologic analysis.
4. Submittal of two tephras to Dr. Mike Perkins at the University of Utah for tephrochronology (i.e., geochemical fingerprinting).
5. Acquisition of slip data from several fault surfaces, which will help constrain the orientation of stress fields responsible for the faulting and folding and elucidate the structural controls of geothermal aquifers; and, which suggests that most of the NNE-striking faults accommodated mainly normal-slip with little, if any, strike-slip motion.
6. Recognition that the NNE-striking, NW-dipping "Rhyolite Ridge" fault, which lies directly east of the Desert Peak Power Plant and along the west margin of the EGS site, consists of several strands, all of

which appear to lose displacement northward and terminate just to the east of the summit of Desert Peak.

7. Recognition that displacement on the southeast-dipping Desert Queen fault, which cuts the eastern fringe of the EGS site decreases significantly southward. Thus, the EGS site largely consists of a narrow horst block between the tips of two overlapping, oppositely dipping normal fault zones.
8. The Miocene section within the vicinity of the EGS site appears to be significantly thinner than that in the hanging wall of the Rhyolite Ridge fault zone, suggesting that much of the Tertiary section is synextensional.
9. Well data for holes 35-13 and 22-22 (lithologic logs and some temperature data) were obtained from Ormat and digitized in the Nevada Bureau of Mines and Geology (NBMG) GIS lab.
10. Discovery and sampling of several datable tephras and lava flows, which should permit tight bracketing of the age of the Tertiary strata and will better constrain the timing of deformation.
11. Observation that at least some of the folds in the area result from a combination of normal drag and tilting on listric (concave upward geometry) normal faults.
12. X-ray diffraction analysis of the matrix of a basalt-breccia unit (which underlies a massive flow unit), which indicates the presence of a smectite clay (montmorillonite) and a zeolite (probably clinoptilolite). Clay and zeolite mineral formation could be syngenetic or diagenetic (possibly related to the present geothermal system). In conjunction with the already completed gravity work by Gary Oppliger (described below), we are now gaining significant insight into the geometry of faults and depth to basement in the Hot Springs Mountains. For example, both geologic and gravity data suggest that a major NNE-striking fault dies out toward the northeast near the Desert Peak power plant. The *damage zone* associated with this fault termination may play an important role in channelizing fluids in that area. In addition, digitization of the old geologic map by Benoit et al. (NBMG Bulletin 97, 1982) was completed by Gary Johnson.

In addition to the geologic work, the gravity program was expanded over the Desert Peak geothermal reservoir area with the acquisition and processing of 43 new gravity stations. This work was partially funded by Ormat's EGS project. This work concluded the gravity collection and processing phases of our project and brings the total of new gravity stations collected in this study to 368. Specific-gravity density determinations were made on a representative suite of 18 drill-core rock samples from the Desert Peak area provided by Ormat.

Oppliger finished integrating the Phillips 1979 Desert Peak gravity data with his current Desert Peak gravity work and produced a new preliminary gravity map. The central area of the Phillips survey contains about 10 stations having large (1 – 2 mgal) errors that made their deletion necessary. To remove other minor discrepancies scattered over the overlap area, an additional 14 points were deleted- for a total of 24 out of the 113 Phillips stations. The remaining Phillips stations are either in good agreement with the current survey results or are several hundred meters distant from any current survey stations so possible modest errors are not discernable. The resulting gravity map appears to be in reasonable harmony with known geology. Because most of the highly erroneous data from the Phillips survey was located over the eastern part of Desert Peak reservoir and the EGS area, Oppliger plans to collect an additional 20 new stations in these areas to improve the anomaly definition.

The new merged-surveys gravity contour map overlain on geology (in PDF format) along with several map images of the data integration process are available on a web page created to communicate the gravity investigation progress:
http://able1.mines.unr.edu/oppliger/Desert_PK_gravity/Desert_pk_grv.htm

We are also working closely with several other groups studying the Hot Springs Mountains and other geothermal fields in the region, including the EGS investigation by Ormat International and the remote sensing study by Wendy Calvin and Mark Coolbaugh. The latter group has mapped the location

of fumaroles in the vicinity of the Brady power plant. The distribution of these fumaroles suggests that the Brady geothermal anomaly is centered on a small left step in a northeast-striking fault system that has probably accommodated left-lateral motion.

(7) Assembly of a crustal seismic velocity database for the western Great Basin

John Louie

A regional geophysical database supporting the exploration for new, hidden geothermal fields has been initiated with a resolution of 8 km, and supplemented by a successful deep seismic sounding experiment in May 2002 that provided the first evidence of a deep crustal root to the Sierra Nevada This sub-project has investigated how to integrate the crustal thickness and velocity results gained during the May 2002 field project into the existing background of crustal geophysical data. A map of the profile is available through the sub-project's web site at www.seismo.unr.edu/geothermal. The profile suggests very thin (<25 km) crust in central Nevada. Similar experiments conducted in the 1980's in the easternmost Great Basin of Utah also suggested thin crust and low Pn velocities. We expect to complete integration with the sparse data available in northern Nevada (from 1960's experiments) during the next year.

We also continued to work in close concert with another project, sponsored by LLNL, that has developed a prototype velocity model assembler code. This code and an updated velocity data-base are available on a semi-private web server (URL: shake.seismo.unr.edu:8081/wgbcvm/).

Twenty Texan recorders and accessory equipment were delivered complete by 9/15/02, and the facility is now operational. Most of the data analysis tasks of year-1 of this sub-project have been completed, with its refraction and geothermal index results presented at the American Geophysical Union Fall Meeting in December 2002 in San Francisco. A graduate student (Shane Smith) and an undergraduate worker (Wesley Thelen) completed the data analysis and literature searches. `The May 2002 field project yielded data from a large quarry blast in Watsonville, Calif., as well as from the GoldStrike mine in eastern Nevada. As a result, even though we were at the time unable to gain cooperation from quarry operators in the Auburn, California area, a complete interpretation of the crustal profile could be obtained.

We also presented two posters at a national scientific meeting in December, and received comments from scientific colleagues as well as geothermal operators such as the US Navy Geothermal Programs Office. The presentations are available on the project's public web site.

(8) Geochemical sampling of thermal and nonthermal waters in Nevada: Evaluation of geothermal resources for electrical power generation and direct-use applications

Lisa Shevenell and Larry Garside

During the first year of spring sampling, over 70 analyses were obtained from springs with previously limited, poor, or no data to begin filling data gaps. Some of the areas sampled in this work were previously known to have good geothermal potential (e.g.., Hazen), yet relatively little was known of many of the remaining sites. Analyses are complete for most samples collected in year-1.

We began revising and updating the text of Bulletin 91 (Thermal Waters of Nevada, by Garside and Schilling, 1979) with data collected from field visits to the selected sites. Considerable time was also spent by Shevenell and student Deborah Goetz verifying geothermal site locations. This effort was undertaken to revise the current location map, and is benefiting this and another DOE sponsored project. As part of this sampling project, we also collaborated with Dick Benoit (independent consultant) on water sampling of relatively remote areas that we would not have had time to visit. Benoit visited two sites, photographed and documented the areas, and collected and submitted five samples for chemical analysis, which is currently underway. He also supplied us with all of the documentation and photos, which were

scanned. All activities have also been coordinated with USGS assessment efforts through project lead Colin Williams.

Geothermometers were calculated from the analyzed chemical data, and these estimated reservoir temperatures are being interpreted and evaluated. A preliminary evaluation of geothermometer temperatures indicates that most of the areas have relatively low geothermal potential, however, possible mixing and re-equilibration at lower, near surface temperatures needs to be evaluated at some of the sites. At most of the sites, the waters are not fully equilibrated (Giggenbach, 1988), and hence, the Na-K-Ca geothermometer may not be appropriate. Of the sites not previously identified as having high geothermal potential, the following have the highest potential for electrical power production (based on chalcedony geothermometer temperatures, which should provide a conservative estimate): Hot Creek Canyon Area (136ºC), Buffalo Valley (130ºC), Pumpernickel Valley (Tipton Ranch; 125ºC), Smith Creek Valley (119ºC). One sample from Smith Creek Valley was apparently a fully-equilibrated water and its Na-K-Ca geothermometer temperature indicates 141ºC. Considerable interest has been expressed by individuals in the industry, their consultants, land owners, lease holders and county officials for the data being collected in this study. Data have been requested by and supplied to numerous individuals from the following areas: Blue Mountain, Crescent Valley, Eureka, Hazen, Hot Creek Canyon, Grass Valley, Smith Creek Valley, and Wells.

(9) Regional assessment of exploration potential for geothermal systems in Nevada using a Geographic Information System (GIS)

James Taranik, Mark Coolbaugh, Gary Raines, Lisa Shevenell, Tim Minor, Don Sawatzky and Richard Bedell

An informal agreement has been reached with the Geo-Heat Center of Klamath Falls, Oregon to jointly develop an integrated Great Basin geochemical database that will include geothermometer temperatures. When completed and finalized this database will be posted on the GBCGE web site. Work has continued on a Great Basin-wide compilation of geothermal systems and hot springs. Multi-state geothermal databases from the GeoHeat Center in Klamath Falls, OR were added to the geothermal GIS and geothermometer temperatures were calculated. A statistical training site database of all known geothermal systems with maximum temperatures ≥100° C was updated using this new information. Systematic work also began on geothermal systems with temperatures <100° C. Special subsets of high-temperature magmatic and extensional geothermal systems in the Great Basin were created to allow a statistical comparison between the two.

Regional seismic data recently compiled by the John Louie research project were integrated into the geothermal GIS. This included a map of moment release (calculated from earthquake magnitudes) and a map of crustal thickness, both covering the states of Utah, California, and Nevada. These maps were statistically evaluated using the new subsets of high-temperature magmatic and extensional geothermal systems of the Great Basin (see above). It was found that extensional systems correlate well with thin crust and correlate poorly with natural seismic activity, whereas magmatic systems are associated with thicker crust on the margins of the Great Basin, in areas where natural seismic activity is anomalously high.

The constructed database was used to contour geothermal system temperatures throughout the Great Basin. An experimental contouring technique was used, wherein contouring was conducted at three different regional scales, which resulted in significantly different patterns. These patterns in turn have been related to scale-dependent structural and crustal phenomena, and the results were discussed at the January 17, 2003 meeting of the Geological Society of Nevada.

A new and more detailed map of groundwater table depth for the state of Nevada has been completed by Tim Minor of the Desert Research Institute as a subcontract to this project. The apparent

correlation of high-temperature geothermal systems (>160°C) with areas of shallow groundwater (≤ 20m) improved slightly when this new groundwater map was used instead of an earlier less-accurate version.

Statistical integration of GPS-derived crustal strain rate maps (from the Blewitt research project) continued during year-1. Hybrid strain rate-heat flow maps are proving to be excellent predictors of regional geothermal activity.

Documentation/Information Dissemination: Detailed explanatory text has been added to a PowerPoint talk originally presented at the Geothermal Resources Council annual meeting in Reno, Nevada on September 25, 2002. This PowerPoint file has been posted on the web site of the Great Basin Center for Geothermal Energy.

A paper that was submitted earlier for a special volume of the Geological Association of Canada (Coolbaugh and Bedell, 2003) was accepted for publication. In December 2002, a talk on the geothermal GIS work was given at the annual meeting of the Geological Remote Sensing Group (part of the Geological Society of Britain) in London.

Maps of the GPS-derived strain-rate, depth to groundwater, heat flux, and deep geothermal gradient have been added to an existing geothermal GIS (of Nevada and the Great Basin) and used to predict geothermal potential in areas where geothermal activity at the surface may be suppressed because of groundwater characteristics.

PLANNED FY 2004 MILESTONES:

(1) Management Activities

Lisa Shevenell and Jane Long

We plan to hire a new, permanent administrative assistant in the next quarter. The Center will receive, process, review, send for external review, rank and select proposals for funding in spring/summer 2003.

No problems have been encountered that would impact milestones. Required quarterly and annual reports have been, and will continue to be prepared and submitted.

(2) GeoPowering of the West (GPW)

Lisa Shevenill and Jane Long

We will continue working on web page and database development. As requested by Elko County Commissioner Warren Russell, Shevenell will continue to provide advice and assistance in organizing a workshop to discuss and encourage business development in Elko County that will utilize geothermal resources for direct use applications.

Development of geodatabases and management of the Geothermal database continues. Relevant geodata files available from several databases are being considered for addition to the Geothermal database. These will include base maps of cartographic and topographic information; geologic, geochemical, geophysical, economic, and geothermal scientific data in vector format; and an abundance of satellite and aircraft images and thematic maps; and tabular data. Additional consideration is being given for serving geothermal data for public viewing and public and private use as well as for disseminating propriety research materials to dispersed research teams.

Gary Oppliger will complete the creation of the suite of improved resolution GIS compatible gravity and aeromagnetic datasets, finalize the descriptive web page and place the data in the publicly accessible FTP and ArcIMS Internet Map Server sites.

Several research activities supported by GBCGE in the last year have produced new geologic, geochemistry, and aircraft images and analyses. These and other new data will be added to the GBCGE

database as they become available. One workshop is contemplated for Fall 2003 to showcase the Center's research findings.

(3) Geochemical characterization of magmatic-related vs. extension-related geothermal systems in the Great Basin: Implications for exploration, exploitation, and environmental issues

Greg Arehart, Mark Coolbaugh, Simon Poulson

We plan to complete evaluation of acquired data and prepare a final report comparing the geochemical signatures of the magmatic versus Nevada extensional geothermal systems.

(4) Targeting potential geothermal resources in the Great Basin from regional relationships between geodetic strain and geological structures

Geoff Blewitt

We will continue the regional-scale study, but add a significant new component of the study to investigate the relationship of the pattern of strain accumulation on the basin scale at two locations already targeted by the regional-scale studies. One basin-scale site will be investigated (Buffalo Valley), which is currently unexploited. As a control area, the second site will be the Desert Peak-Brady's Hot Springs area, which, last year, was investigated using geophysics and structural tectonics methods (Faulds). The basin-scale studies will test the hypothesis that the controlling tectonic features are abrupt changes in the strike of faults within the regional strain field.

We will install approximately 10 stations at each of the two basin-scale areas. These will be monitored by 10 GPS receivers that will be rotated to cover all sites, so that each station records data regularly throughout the year. After two years of data collection, strain rates of sufficient accuracy and spatial resolution are predicted to be at the level required to discriminate hypotheses from each test area regarding which structures are tectonically active, and to invert for tectonic parameters that are relevant to geothermal models. The outcome of this work will be the identification at the basin-scale of specific structures that might be targeted for geothermal exploitation, with a level of confidence that is commensurate with our demonstrated ability to positively identify active structures at the Desert Peak-Brady's control area.

(5) Testing unique surface identifiers for geothermal site characterization from remote sensing imagery

Wendy Calvin and Mark Coolbaugh

Mapped imagery will be geo-rectified to standard projections so that they can be readily included in regional and site specific databases. We will build upon our previous work which established the use of day/night imagery to identify surface thermal anomalies, mapping both known and hidden resources at Steamboat Springs and at Brady Hot Springs. Our work in the next year extends our analysis to new basins at Buffalo Valley near Battle Mountain, NV, Dixie Valley past Fallon, NV and Fish Lake Valley west of Goldfield, NV. Buffalo Valley was identified by other Center work as a high strain location and of exploration interest. Dixie Valley is a known production site. The program continues collaborative efforts with remote sensing projects at LLNL and the University of Santa Cruz, through shared imagery and group visits to field locations.

A technical paper will be prepared and presented at the annual Geothermal Resources Council meeting in Morelia, Mexico.

(6) Structural and geophysical analysis and characterization of the Desert Peak-Brady Geothermal Field: Implications for understanding linkages between northeast-trending structures and geothermal anomalies

Jim Faulds and Larry Garside

We will expand our ongoing investigation of the geologic and geophysical character of the Desert Peak-Brady geothermal fields in the Hot Springs Mountains of western Nevada. In the next year, we will seek to 1) expand the detailed mapping and structural analysis to include remaining parts of the northern Hot Springs Mountains, 2) acquire a greater density of gravity stations across several critical profiles, 3) conduct a micro-earthquake (MEQ) study, and 4) continue the GIS compilation. Radiometric dating, geochemical analyses, and paleomagnetic investigations will complement the geologic work. The mapping and structural analysis will better define the Tertiary stratigraphy and structure, thus elucidating the 3D strain field, subsurface framework, and structural and stratigraphic controls on geothermal reservoirs. The enhanced gravity survey will facilitate detailed modeling of several profiles critical to understanding producing fields and sites of future development (EGS site). The MEQ study will reveal the subsurface geometry of faults and fractures that channel fluids and define the present-day stress field. The ultimate goal of this study is to develop a comprehensive 3D model of a major geothermal field within the Humboldt structural zone of northern Nevada, a broad region of NE-striking faults and high heat flow that contains many of the geothermal fields in the Great Basin (Steamboat, Dixie Valley, Desert Peak-Brady). Such a model may facilitate exploration and/or enhancement of geothermal resources elsewhere within the Humboldt zone.

A technical paper will be prepared and presented at the annual Geothermal Resources Council meeting in Morelia, Mexico.

(7) Assembly of a crustal seismic velocity database for the western Great Basin

John Louie

In the next year, we will survey additional regions of the western Great Basin of Nevada and eastern California for evidence of the thin crust found by the previous project below the Battle Mountain heat-flow high. Exploration for hidden resources requires a realistic three-dimensional crustal model to understand the deep sources of geothermal heat in the crust. Current data suggest extensional tectonic geothermal fields are associated with thin crust (<30 km), while thicker crust hosts only magmatic fields. Crustal properties and thickness are known only at wide spacing, so new surveys are needed from the mines hosting blasts that we have been able to record at distances exceeding 450 km.

We will also compile additional velocity information from sources in the literature, results of previous seismic experiments and earthquake-monitoring projects, and data donated from mining, geothermal, and petroleum companies. The two new crustal seismic refraction profiles will cross the central Walker Lane, and central Nevada. The central Walker Lane shows nearly the level of geothermal resources of the northern Walker Lane, but central Nevada (Carlin to Las Vegas) has very few. Our three surveys resulting from this year-2 work will thus sample the full range of occurrence of geothermal resources in the Great Basin. The resulting seismic velocity model will be contributed to the associated projects to assemble geographic databases of geothermal indicators.

(8) Geochemical sampling of thermal and nonthermal waters in Nevada: Evaluation of geothermal resources for electrical power generation and direct-use applications

Lisa Shevenell and Larry Garside

We will evaluate the chemical data and geothermometers acquired and calculated in the first year to prioritize which sites appear to have the greatest potential for geothermal development. A paper will be prepared that evaluates the utility of various of the geothermometers in estimating subsurface temperatures at currently producing sites. We will evaluate data compiled under a separate project, along with the data collected here to prioritize additional sites for sample collection, and we will continue the sampling of geothermal waters in Nevada to fill in additional data gaps as they are identified.

A technical paper will be prepared and presented at the annual Geothermal Resources Council meeting in Morelia, Mexico.

(9) Regional assessment of exploration potential for geothermal systems in Nevada using a Geographic Information System (GIS)

James Taranik, Mark Coolbaugh, Gary Raines, Lisa Shevenell, Tim Minor, Don Sawatzky, Richard Bedell

This project will expand the GIS database developed in year-1 to cover the entire Great Basin. The objectives are fourfold: 1) integrate and evaluate new geothermal data developed by the GBCGE and other sources, 2) regionally assess the potential for geothermal energy throughout the Great Basin, 3) evaluate and quantify regional relationships between geothermal activity and geological, geochemical, and geophysical features, and 4) make digital geothermal data of the Great Basin accessible to industry, researchers, and the public.

By including the entire Great Basin, it will be possible to evaluate both magmatic and extensional-type geothermal systems and identify the most prospective areas for future exploration of each. The research will include a regional assessment of southern Idaho, where potential for both magmatic and extensional high-temperature systems exists but where laterally-flowing groundwaters may prevent the formation of hot springs that would otherwise reveal their locations.

Geothermal-related data will be integrated into a GIS using ArcView® and related software, and evaluated quantitatively using weights-of-evidence, logistic regression, and other statistical measures. The GIS data will be posted on the web site of the GBCGE for public access. The data will be presented in a format allowing for selective extraction, overlaying, and viewing of data using ArcExplorer® or similar "freeware" and data will be available for downloading in ArcView and other database formats.

A technical paper will be prepared and presented at the annual Geothermal Resources Council meeting in Morelia, Mexico.

PATENTS:

None.

PUBLICATIONS/PRESENTATIONS:

Publications

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Vaughan, R.G., Calvin, W.M., and Taranik, J.V., 2002, SEBASS hyperspectral thermal infrared data: surface emissivity measurement and mineral mapping: Remote Sensing of the Environment, *in press*.

Vaughan, R.G., S.J. Hook, W.M. Calvin, and J.V. Taranik, Surface mineral detection with multi-wavelength thermal infrared images. Submitted to J. Geophys. Research-Solid Earth, Feb. 2003. Discusses mineral mapping capability between multi and hyperspectral data over Steamboat Springs.

At the request of Joel Renner (INEEL), annual reports of the subprojects were requested from the PIs, and the following were submitted to the DOE (psdrept@id.doe.gov) and Joel Renner in 2003:

Coolbaugh, M., Taranik, J., Raines, G., Shevenell, L., Minor, T., Sawatzky, D., Bedell, R., 2003. Regional Assessment of Exploration Potential for Geothermal Systems in the Great Basin using a Geographic Information System (GIS). March 22-September 30, 2002, 4 pp.

Faulds, J., Garside, L., and Oppliger, G. 2003. Structural and geophysical analysis and characterization of the Desert Peak-Brady Geothermal Field: Implications for understanding linkages between northeast-trending structures and geothermal anomalies. March 22-September 30, 2002, 3 pp.

Shevenell, L., 2002. Annual Report to DOE on the Project: Expanding Geothermal Resource Utilization in Nevada through Directed Research and Public Outreach, March 22-September 30, 2002, 4 pp.

Shevenell, L., 2003. Annual Report to DOE describing the Management of the Great Basin Center for Geothermal Energy, March 22-September 30, 2002, 4 pp.

Shevenell, L., 2003. Annual Report to DOE on the Project: Great Basin Center for Geothermal Energy Outreach Activities: Workshops and Web Page Development, March 22-September 30, 2002, 4 pp.

Shevenell, L., 2003. Geothermal Annual Operating Plan for the Great Basin Center for Geothermal Energy. Submitted to DOE, 2 pp.

Shevenell, L., Garside, L., 2003. Annual Report to DOE on the Project: Geochemical sampling of thermal and nonthermal waters in Nevada: Evaluation of geothermal resources for electrical power generation and direct-use applications, March 22-September 30, 2002, 3 pp.

Presentations

Calvin, Wendy, 2002. Thermal infrared remote sensing for geothermal site characterization. Geological Society of America, 2002 Annual meeting, Denver, Colorado.

Coolbaugh, M., 2002. Regional Geologic Controls, Geochemical Characteristics, and Thermal Infrared Signatures of Geothermal Systems of the Great Basin. Geological Society of Nevada, January 17, 2002 meeting, Reno, Nevada.

Coolbaugh, M., 2002. Enhancement of geothermal anomalies using ASTER thermal infrared images at Brady's Hot Springs, Nevada, USA. 2002 annual meeting of the Geologic Remote Sensing Group, London, England.

Coolbaugh, 2003. A talk on the geothermal GIS and related research was given at the monthly meeting of the Geological Society of Nevada in Reno on January 17th, 2003; the text and PowerPoint slides from that talk have been posted on the web site of the Great Basin Center for Geothermal Energy.

Garside, L. - Geology of Geothermal Energy, presented at the *Nevada Indian Commission's Renewable Energy Summit* for Nevada Tribes, September 10, and *Introduction to Geothermal Energy,* April 18-19, 2002.

Garside, L. - History of Nevada Geothermal Resources Research, presented at a regional GPW meeting on September 26, 2002.

Louie, J., 2002. The Northern Walker Lane Seismic Refraction Experiment. American Geophysical Union 2002 Fall meeting, San Francisco, California, December 7, 2002.

Pancha, A., 2002. Reno Area Basin Seismic Response: Ground Motion Simulations in Reno, Nevada. American Geophysical Union 2002 Fall meeting, San Francisco, California.

Thelen, W.A., 2002. Developing a Geothermal Indicator Index From Crustal Geophysical Data for the Western Great Basin. American Geophysical Union 2002 Fall meeting, San Francisco, California, December 6, 2002.

Presentations at the *Geothermal Opportunities in Nevada*, January 11, 2002, meeting:

Arehart, G. - Geochemical Techniques for Exploration and Assessment
Coolbaugh, M. - Regional Controls on the Distribution of Geothermal Systems in Nevada
Shevenell, L. - Updated Database and Assessment of Nevada Geothermal Resources

Presentations at the *Annual Geothermal Resources Council Meeting,* Reno, NV, September 23-5, 2002:

Arehart, G. - Geochemical Characterization of Geothermal Systems in the Great Basin: Implications for Exploration, Exploitation and Environmental Issues.

Blewitt, G. - Targeting of Potential Geothermal Resources in the Great Basin from Regional Relationships between Geodetic Strain and Geological Structures, (poster only).

Calvin, W. - Geothermal Site Characterization Using Multi- and Hyperspectral Imagery.

Coolbaugh, M. - Geothermal GIS for Nevada: Defining Regional Controls and Favorable Exploration Terrains for Extensional Geothermal Systems.

Oppliger, G. - Geologic Setting and Preliminary Analysis of the Desert Peak-Brady Geothermal Field, Western Nevada

Garside, L. - Status of Nevada Geothermal Resource Development Spring 2002.

Louie, J.N. - Assembly of a crustal seismic velocity database for the western Great Basin (oral and poster).

Shevenell, L. - Overview of Activities of the Great Basin Center for Geothermal Energy.

Shevenell, L. - Geochemical Sampling of Thermal and Nonthermal Waters in Nevada to Evaluate the Potential for Resource Utilization.

Informal presentations were made by the PIs at the Great Basin Center for Geothermal Energy, Reno, NV, March 26, 2003, and with program Manager Joel Renner on April 3, 2003:

Arehart, G., Coolbaugh, M. F., Poulson, S. R and DeRocher, T. (Caithness Operating Co., LLC., Reno, Nevada) Geochemical characterization of geothermal systems in the Great Basin: Implications for exploration, exploitation, and environmental issues.

Blewitt, G. Results of GPS-strain measurements.

Calvin, W. M., Coolbaugh, M. F. and Vaughan, R. G. Thermal Infrared Remote Sensing for Geothermal Site Characterization

Coolbaugh, 2003. Status of GIS research.

Faulds, J. E. and Garside, L. J., Oppliger, G. L., Johnson, G. L. and Muehlberg, J. Geologic and Geophysical Analysis of the Desert Peak-Brady Geothermal Field, Western Nevada.

Louie, J. Evaluation of crustal thicknesses from a crustal seismic velocity model.

Shevenell, L., 2003. Estimated subsurface temperatures at recently sampled hot spring areas in Nevada.

MILESTONE STATUS TABLE

BUDGET DATA (as of March 31, 2003):

Phase/Budget Period			Approved Spending Plan			Actual Spent to Date		
From	To		DOE	Cost	Total	DOE	Cost	Total
03/20/2002	03/31/2003		Amount	Share		Amount	Share	
		UNR Acct #	$	$	$	$	$	$
(1) Project Management		1330-114-0065	113,770	0	113,770	81,372	0	81,372
(2) GeoPowering the West		1330-114-0072	96,672	0	96,672	89,129	0	89,129
Research Projects:								
(3) Arehart	- Magmatic vs Extension	1330-114-0066	71,128	0	71,128	61,587	0	61,587
(4) Blewitt	- GPS Strain	1330-114-0070	86,917	0	86,917	65,993	0	65,993
(5) Calvin	- Remote Sensing	1330-114-0067	63,733	0	63,733	50,919	0	50,919
(6) Faulds	- Desert Peak	1330-114-0068	95,811	0	95,811	54,630	0	54,630
(7) Louie	- Seismic Database	1330-114-0069	144,584	0	144,584	138,405	0	138,405
(8) Shevenell	- Sampling	1330-114-0064	117,359	0	117,359	40,478	0	40,478
(9) Taranik	- GIS	1330-114-0071	146,026	0	146,026	132,298	0	132,298
		Totals	936,000	0	936,000	714,811	0	714,811

SPENDING PLAN FOR FY 2004

Spending Plan for the Next Year
Grant Expires 9/30/04

Month	Estimated Spending
Apr-03	$15,000
May-03	$10,000
Jun-03	$30,000
Jul-03	$30,000
Aug-03	$30,000
Sep-03	$20,000
Oct-03	$25,000
Nov-03	$15,000
Dec-03	$5,000
Jan-04	$7,500
Feb-04	$10,000
Mar-04	$10,000
Total	**$207,500**