# Characterizing Structural Controls on Geothermal Systems in the Northwestern Great Basin through Integrated Geologic and Geophysical Analyses

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**Proposal submitted in response to a REQUEST FOR PROPOSALS from the Great Basin Center for Geothermal Energy**
**Proposal Deadline: Feb. 18, 2005**

## ABSTRACT

We propose an integrated structural, geophysical, and GIS study of a relatively large suite of geothermal fields in the northwestern Great Basin. The primary purpose of this study is to characterize the structural controls on these fields in order to determine favorable areas for future development. This project will involve 1) detailed geologic mapping and reconnaissance within and directly adjacent to the fields; 2) structural analysis of related fault zones; 3) gravity and magnetic studies; and 4) GIS compilation of available geologic, geophysical, and subsurface data. The geologic mapping, structural analysis, and reconnaissance will establish the structural and stratigraphic framework of the fields, thus elucidating the subsurface framework and structural controls on geothermal reservoirs. Structural analyses of exposed faults will also determine which faults have accommodated dilational strain and are therefore more likely to serve as channelways for geothermal fluids. Recent studies in the northern Great Basin have shown that geothermal fields are commonly focused in stepovers or terminations of northerly striking normal fault zones, where multiple fault splays increase fracture density and enhance permeability. The gravity and magnetic studies will help to define the location of faults and stepovers in the subsurface and facilitate detailed modeling of profiles critical to understanding the fields and sites of future development. The GIS compilation will greatly facilitate access to and integration of the multiple data bases, while also permitting preliminary three-dimensional modeling of the fields. We are working closely with industry in several of the proposed study areas. Thus, results of this project will be quickly assimilated into both exploration strategies and targeting favorable areas for drilling, which will in turn directly enhance utilization of geothermal resources in the western United States.

**Total Federal Funds Requested: $212,823**

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# DESCRIPTION OF PROJECT

## Background and Relevance

In the Great Basin of the western US, geothermal fields are most abundant in northern Nevada and neighboring parts of northeast California and southern Oregon (Coolbaugh et al., 2002; Coolbaugh and Shevenell, 2004; Fig. 1). The geothermal systems cluster in discrete NNE to NE-trending belts, including the Humboldt structural zone and Black Rock Desert region (Faulds et al., 2004). Volcanism in most of this region ceased ~3 to 10 Ma, which suggests that magmatism is not a source for most of the geothermal activity. Why this region has such widespread geothermal activity is therefore an intriguing question.

The tectonic setting of the northwestern Great Basin may account for much of the activity. In the western Great Basin, the Walker Lane is a system of right-lateral strike-slip faults (Stewart, 1988; Oldow, 1992; Faulds et al., 2005) accommodating ~15-25% of relative motion between the Pacific and North American plates (Bennett et al., 2003; Hammond and Thatcher, 2004). Relatively high rates of recent (<10 Ma) WNW-directed extension (Henry and Perkins, 2001; Surpless et al., 2002; Colgan et al., 2004) absorb northwestward declining dextral motion in the Walker Lane, diffusing that motion into the Basin-Range. Abundant geothermal fields cluster in NE-trending belts in the northern Great Basin orthogonal to the extension direction (Fig. 1). The Walker Lane begins losing displacement to the northwest in west-central Nevada near the southeast margin of the region with abundant geothermal activity. Individual fields are largely controlled by NNE-striking normal faults (Blackwell et al., 2002; Johnson and Hulen, 2002; Waibel et al., 2003; Faulds et al., 2003, 2004). The prolific geothermal activity may therefore result from a transfer of NW-trending dextral shear in the Walker Lane to WNW extension in the northern Great Basin. Enhanced extension favors dilation and deep circulation of aqueous solutions along NNE-striking faults. The individual belts of geothermal fields may reflect loci of strain transfer (Faulds et al., 2004).

Despite the abundance of geothermal fields and regional compilations indicating significant structural control on geothermal activity, few detailed investigations have been conducted on the controls of individual fields within the Great Basin. Moreover, it is not known whether certain characteristic structures are particularly conducive for geothermal activity. Knowledge of such structures would greatly facilitate exploratory drilling in known, but as yet undeveloped fields, expansion in producing fields, and identification of promising areas for blind (or hidden) geothermal resources.

We therefore propose to analyze a suite of geothermal fields in a large swath of the northwestern Great Basin within and directly northeast of the Walker Lane through integrated geologic, geophysical, and GIS studies (Fig. 1). This entire region is well situated to supply power to major electrical markets in the western United States (e.g. Lovekin, 2004). Because of its proximity to the Walker Lane and likelihood of both enhanced extension and multiple intersecting fault sets, this region also has some of the greatest geothermal potential within the Great Basin. We plan to study both developed (e.g. Stillwater, Soda Lake) and undeveloped fields (e.g. Salt Wells, Patua Hot Springs (Hazen), Needle Rocks at Pyramid Lake, Gerlach, and Fly Ranch). Most of the undeveloped fields are currently being scrutinized by industry, while some of the producing fields are under consideration for expansion.

Thus, a major goal of this project is to delineate favorable areas for future drilling thereby contributing directly toward major industry efforts in the region and enhancing utilization of geothermal resources in the western United States. As listed in the *Request for Proposals*, this project specifically addresses several areas under the topic of *Geothermal Resource Assessment and Exploration*, including A) inventory of existing geothermal resources in GIS context, B) identification and characterization of new potential geothermal resource targets, C) geologic mapping and fault characterization, D) geophysical imaging, and E) improving the success rate of siting of drilling targets. Our findings may also have implications for identifying geothermal *hotspots* in relatively amagmatic extensional or transtensional settings in other parts of the western US and world.

## Proposed Research

We propose to delineate the structural controls of geothermal systems within the northern Walker Lane and adjacent parts of the Basin and Range province through integrated geologic and geophysical

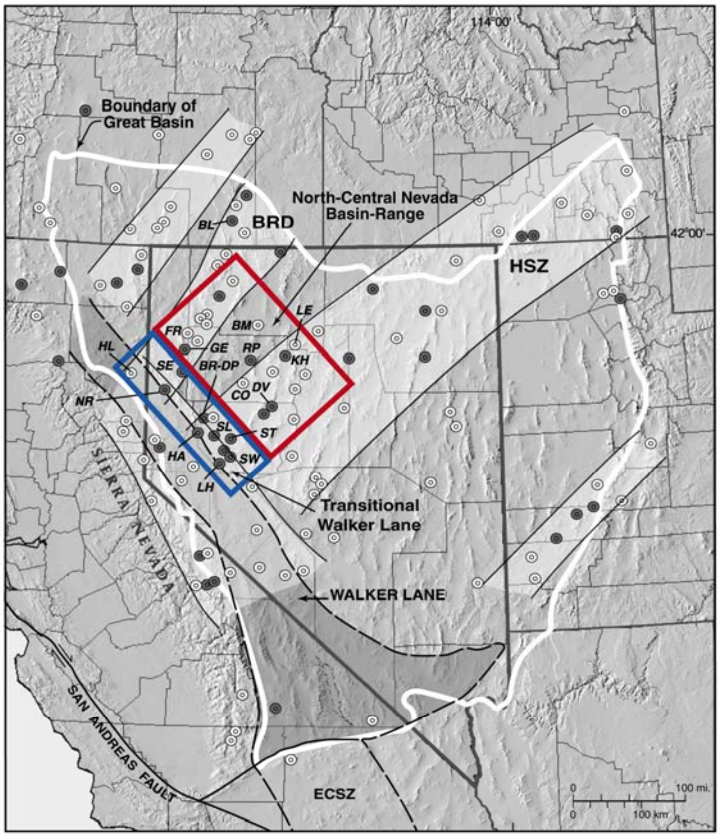


**Figure 1**. The northwestern Great Basin has the greatest concentration of geothermal fields in the western US. White circles are systems with maximum temperatures of 100-160°C; grey circles have maximum temperatures >160°C. BRD, Black Rock Desert geothermal belt; ECSZ, eastern California shear zone; HSZ, Humboldt structural zone. Abbreviations for individual fields: BL, Borax Lake; BM, Blue Mountain; BR-DP, Brady-Desert Peak; CO, Colado; DV, Dixie Valley; FR, Fly Ranch; GE, Gerlach; HL, HA, Hazen; Honey Lake; KH, Kyle Hot Springs; LE, Leach Hot Springs; LH, Lee Hot Springs; NR, Needle Rocks; RP, Rye Patch; SE, San Emidio; SL, Soda Lake; ST, Stillwater; SW, Salt Wells.

analyses. This project builds on recently completed regional compilations (Coolbaugh et al., 2002, 2005a; Coolbaugh and Shevenell, 2004; Faulds et al., 2004, 2005) and detailed analyses of the Desert Peak and Brady's fields (Faulds et al., 2003; Faulds and Garside, 2003). It also complements ongoing regional studies of GPS-derived strain rates, geochemistry, and favorable exploration terranes (Schochet et al., 2002; Nathwani and Creed, 2002; Blewitt et al., 2003; Arehart et al., 2003; Robertson-Tait and Morris, 2003; Shevenell et al., 2004; Coolbaugh et al., 2002, 2005b), as well as several proposed studies (e.g. analysis of timing of Holocene faulting along Nevada's geothermal systems by J. Bell). Furthermore, our study is coordinated with industry exploration in several areas (see attached letters at end of proposal).

In order to facilitate characterization of the structural controls, this study will focus on representative sets of fields in two regions of the northern Great Basin. The first region lies within or directly adjacent to the Walker Lane and is therefore termed "transitional Walker Lane". This transtensional setting contains both NW-striking right-lateral faults and northerly striking normal faults. Fields within the transitional Walker Lane include Lee Hot Springs, Salt Wells, Rawhide, Stillwater, Soda Lake, Hazen (Patua Hot Springs), Desert Peak, Brady's, Needle Rocks at Pyramid Lake, and Honey Lake (Fig. 1). Only a few fields within this region (e.g. Desert Peak, Brady's, and Soda Lake) have been analyzed in detail (Benoit et al., 1982; McNitt, 1990; Faulds et al., 2003). The second region is situated fully within the Basin and Range to the northeast of the Walker Lane in north-central Nevada and is referred to as the "north-central Nevada Basin-Range". Here, NNE-striking normal faults dominate most areas but locally link with ENE-striking oblique slip (left-lateral and normal components) in the Humboldt structural zone (Rowan and Wetlaufer, 1980; Faulds et al., 2003). Fields within this region include Gerlach, San Emidio, Fly Ranch, Blue Mountain, Kyle Hot Springs, Jersey Valley Hot Springs, Colado, Rye Patch, and Dixie Valley (Fig. 1). Similar to the transitional Walker Lane, few fields (e.g. Dixie Valley and Rye Patch) have been studied in detail in the north-central Nevada Basin-Range (e.g. Caskey and Wesnousky, 2000; Blackwell et al., 2002; Johnson and Hulen, 2002; Waibel et al., 2003).

It is important to note that many of these fields were initially studied in the 1970's and 1980's (e.g. Benoit et al., 1982; Keller and Grose, 1978). However, a tremendous amount has been learned in the past few decades about the three-dimensional geometry of normal fault systems and regional tectonics of the Great Basin (e.g. Wernicke, 1992; Atwater and Stock, 1998; Faulds and Stewart, 1998), while techniques have also been developed or greatly refined for determining slip sense along faults and deducing principal strain and stress axes from slip data (e.g. Angelier et al., 1985; Petit, 1987; Marrett and Allmendinger, 1990). In light of these recent advances, a closer look at many of the fields is warranted.

Our regional assessment of structural controls shows that N- to NE-striking faults (N0$^{o}$E-N60$^{o}$E) are the primary controlling structure for ~75% of the geothermal fields in Nevada, and this control is strongest for higher temperature systems (Coolbaugh et al., 2002; Faulds et al., 2004). In the northwestern Great Basin, where the extension direction trends west-northwest, NNE-striking controlling faults oriented approximately orthogonal to the extension direction dominate. Other important structural trends include NW-striking faults in the Walker Lane and Black Rock Desert regions and ENE-striking faults in the Humboldt structural zone.

A closer look at individual fields reveals that the controlling NNE-striking structures are typically moderately to steeply dipping normal fault zones, as exemplified at the Dixie Valley (Blackwell et al., 1999; Johnson and Hulen, 2002; Wannamaker, 2003), Rye Patch (Waibel et al., 2003), Brady's, and Desert Peak fields (Benoit et al., 1982; Faulds et al., 2003). However, most fields in the north-central Nevada Basin-Range occur along or near major range-front faults, whereas fields in the transitional Walker Lane are typically situated along less prominent and, in some cases, somewhat innocuous normal fault zones. For example, the Brady's, Desert Peak, and Salt Wells fields in the transitional Walker Lane occupy discrete left steps in overlapping en echelon, NNE-striking normal fault zones that have generally accommodated less than 1.5 km of displacement. In fact, the Salt Wells field appears to reside at the intersection of oppositely dipping normal fault systems, where the two systems overlap, terminate, and have minimal displacement. In the north-central Nevada Basin-Range, many of the fields (e.g. Dixie Valley, Kyle Hot Springs, Leach Hot Springs, and Rye Patch) are focused near apparent steps in major range-front normal faults. At Gerlach, the field occurs near the southern end of a major range-front fault presumably where it horsetails and breaks into multiple splays.

Despite differences in overall structural setting between the transitional Walker Lane and north-central Nevada Basin-Range, many geothermal fields in both regions appear to occupy discrete steps in fault zones or lie in belts of intersecting, overlapping, and/or terminating faults. Multiple fault splays in such areas probably increase fracture density and provide favorable channelways for geothermal plumes.

Our findings are compatible with the conclusions of Micklethwaite and Cox (2004), who found that zones of high permeability around fault systems can be predicted if fault segments and likely locations of paleo-rupture arrest can be located. The rupture-arrest regions correspond to areas of aftershocks and multiple interconnecting fault splays, where fluid flow is favored. In normal fault systems, these rupture arrest regions commonly correspond to discrete stepovers in fault zones or reversals in the dominant dip direction of entire systems of faults (e.g. Roberts and Jackson, 1991; Faulds and Varga, 1998). Such rupture arrest regions may also account, at least in part, for high-permeability flow paths occurring in spatially discrete but negligible overall fractions of individual faults, as documented in the Borax Lake geothermal field in southern Oregon (Fairley and Hinds, 2004).

It is important to emphasize, however, that detailed studies of structural controls have only been conducted on a few geothermal fields within the Great Basin. In addition, our regional assessments generally do not facilitate selection of specific drilling targets within a given field. It is therefore imperative to analyze a large group of fields in detail to better characterize the structural controls and determine the most favorable areas for geothermal activity both within individual fields and within individual regions. For example, structural controls and the most favorable sites for geothermal activity may differ somewhat between the dextral-shear-dominated Walker Lane and more purely extensional Basin and Range province. It is also noteworthy that large amounts of geothermal resources in the Great Basin have no surficial expression (e.g. Desert Peak). Thus, characterization of favorable structural settings may significantly enhance exploration for blind geothermal fields.

## Work Plan

We will conduct detailed geologic mapping and structural analyses on 2-3 fields in both the transitional Walker Lane and north-central Nevada Basin-Range, as well as detailed reconnaissance on an additional ~6 fields in each area. We have already completed a detailed study of the Desert Peak and Brady's fields and started work on several other fields, including Salt Wells and Gerlach. This work will be conducted by Drs. James Faulds, Gary Oppliger, and Mark Coolbaugh at the University of Nevada, Reno (UNR). Faulds is a structural geologist who has over 17 years of experience in analyzing structurally complex parts of the Basin and Range through detailed mapping, structural analysis, paleomagnetic studies, and $^{40}Ar/^{39}Ar$ dating. Coolbaugh is an economic geologist and GIS specialist who has over 20 years of experience in the region. Oppliger is a geophysicist who also has more than 20 years of experience in the Great Basin. Graduate students at UNR will also conduct much of the research. One student, Melissa Edwards, will begin work on the Salt Wells field in spring 2005. Incorporation of graduate students serves several purposes, including 1) expanding our capabilities in terms of areal coverage, 2) providing challenging, societally relevant thesis projects for students, and perhaps most importantly 3) engaging a new generation in geothermal studies, thereby encouraging them to enter the discipline upon graduation. Faulds will coordinate the overall project and supervise most of the students.

**Geologic Studies**: The structural investigations will involve 1) detailed geologic mapping (1:24,000 scale) or reconnaissance of bedrock exposures in the vicinity of the fields, as well as surficial sinter, silicified deposits, hot springs, fumaroles, and other surface geothermal features within the fields; 2) assessment of the Tertiary stratigraphy; 3) analysis of the geometry and kinematics of major fault systems; and 4) $^{40}Ar/^{39}Ar$ dating and teprhochronology. The goals of this work are to a) delineate the structural controls of each field, b) elucidate possible relations between stratigraphic features and geothermal reservoirs, c) better define the overall extent of the reservoirs, and d) better constrain the late Miocene to recent strain and stress fields in the region. Detailed structural studies will focus on geothermal fields that reside within or directly adjacent to good bedrock exposures (e.g. Salt Wells, Rawhide, Needle Rocks, San Emidio, and Fly Ranch). Some fields lie within large alluviated basins and therefore do not lend themselves to structural analysis (e.g. Stillwater and Soda Lake). Analysis of the subsurface structure in such areas will rely on the geophysical investigations described below.

The geologic mapping and reconnaissance, together with the geophysical studies, will constrain the geometry of the controlling faults. The kinematics will be determined from geometric patterns at both the macroscopic and mesoscopic scale and examination of any exposed fault surfaces. Slip sense will be determined on such surfaces through combined analysis of stratigraphic separation, fault striae (slickenlines), and several more reliable features, such as Riedel shears and rough facets (e.g. Angelier et al., 1985; Petit, 1987). The kinematics of fault sets will then be scrutinized using methods developed by Marrett and Allmendinger (1990). From this analysis, we will infer principal shortening and extension axes for each fault set and assess the degree of kinematic compatibility of the various fault sets.

Faulds and Coolbaugh will conduct the geologic investigations, with assistance from graduate and undergraduate students. Under their supervision, 1-2 graduate students and 1-2 undergraduates will assist in the acquisition, processing, and interpretation of the geologic data, including geologic mapping of some fields (e.g. Salt Wells by Edwards) and compiling data bases of available subsurface data.

**Geophysical Studies**: Local-scale gravity investigations of geothermal fields commonly elucidate the underlying geologic structure that might otherwise require extensive drilling (e.g. Blackwell et al., 1999). Larger scale regional compilations with lower resolution magnetic and gravity data also aid geothermal assessment by identifying bedrock structure beneath alluvium and volcanic covered areas. In this study we will bring both detailed and regional gravity analysis together and prepare some innovative interpretational products to support the structural analysis of our study areas.

The geophysical work is divided into six tasks. Task 1 produces optimally prepared compilations of publicly available gravity and magnetic data. Emphasis will be placed on creating a new quality-checked regional gravity compilation with new terrain and isostatic corrections. This product will integrate several geothermal gravity studies that we have recently completed (Oppliger et al., 2002, Faulds et al., 2003) or located from other sources. We will also seek additional industry data contributions. The available aeromagnetic data is generally of low spatial resolution, so it will be applied only to the regional scale analysis. Task 2 develops a suite of derived geophysical products which best separate depth to basement, regional deep structure, and shallow local structure. Task 3 synthesizes and assesses the preliminary GIS geophysics and geoscience data to set priorities for additional gravity work. Task 4 collects and integrates up to 450 new gravity stations (30 field days) focused to delineate regional structure as a geothermal control. Task 5 repeats tasks 1 and 2 but integrates the new gravity work. Task 6 produces final interpreted geophysical products. Final geophysical products are GIS layers and surface grids of reduced data, regional and shallow crustal anomaly separations, and total horizontal gradients.

In addition to these products, we will generate a specialized product based on our recently developed method for estimating total bedrock relief (Oppliger, unpublished). This total bedrock relief surface combines depth-to-basement interpretation from gravity with the surface topography to better trace regional faulting that vertically displaces bedrock. Total horizontal gradients of this bedrock relief surface were found in our recent geothermal potential mapping studies to have a higher statistical association with geothermal systems than any other single parameter outside of well temperatures (Coolbaugh et al., 2004, 2005c). This work will focus on the identification of fault-block edges and bedrock structural relief.

Gravity data will be collected using UNR's LaCoste and Romberg model G gravimeter and Trimble 4000 series geodetic grade GPS receivers. A digital elevation model will be used to implement full terrain corrections. The gravity data will be reduced using the Geosoft Xcelleration package and analyzed using Fourier transform-based potential field processing tools. Oppliger will train and supervise one of the project's graduate students, who will collect the new gravity and GPS control data and perform basic data reductions. Oppliger will be responsible for all other geophysical data processing and interpretive tasks.

**GIS Database Compilations**: For each of the fields to be studied in detail or by reconnaissance (~16 total), available geographic, geologic, geochemical, subsurface (e.g. temperature-gradient and lithologic well data), and geophysical data will be compiled in digital format and combined in GIS databases to permit an integrated analysis of the newly mapped structural and geothermal features. Where available, recent digital maps of crustal strain rates (derived from GPS station velocities), InSAR ground displacement images, earthquake epicenters, and regional-scale geothermal favorability maps will also be included. These databases will facilitate a cross-disciplinary analysis of the relationships between the structural settings and their associated geothermal systems and may also permit 3D visualization of some of the fields. This work will be carried out by Coolbaugh and Gary Johnson (GIS Specialist at the Nevada Bureau of Mines and Geology), with assistance from graduate and undergraduate students. The GIS labs at UNR are equipped with the latest computer hardware and GIS software which allows modeling, analysis, and visualization of earth resource systems in 2D and 3D space. The NBMG lab utilizes ArcView, IDRISI, ENVI, and Arc/Info GIS and image processing software. We will also use Log Plot (e.g. Rockworks) and other sophisticated software packages that will permit full 3D visualization of the fields (e.g. 3DMove by Midland Valley, Vulcan by MapTek, and GOCAD by MiraGeoscience). UNR has already obtained 3DMove and Vulcan but annual fees are required to maintain the licenses.

## DELIVERABLES AND SCHEDULE

The deliverables are listed below, with period of work and completion date (month/year) in parentheses. Year 1 will focus on the transitional Walker Lane, and Year 2 on the north-central Nevada Basin-Range.

1. Complete gravity collection, ~8 fields in transitional Walker Lane (Year 1, 7/06).
2. Reconnaissance maps, ~6 fields in transitional Walker Lane (Year 1, 9/06).
3. Detailed geologic map-cross sections, 2 fields in transitional Walker Lane (Year 1, 12/06).
4. GIS databases of ~8 geothermal fields in transitional Walker Lane (Year 1, 12/06).
5. Complete gravity collection, ~8 fields in north-central Basin-Range (Year 2, 7/07).
6. Reconnaissance maps, ~6 fields in the north-central Nevada Basin-Range (Year 2, 9/07).
7. Detailed geologic map-cross sections, 2 fields in N-central Nevada Basin-Range (Year 2, 10/07).
8. GIS databases of ~8 geothermal fields in north-central Basin-Range (Year 2, 10/07).
9. Complete structure and bedrock relief products deduced from geophysical data (Years 1-2, 9/07).
10. Suggested drilling targets in analyzed geothermal fields (Years 1-2, 10/07).
11. Published papers in GRC proceedings describing project results (Years 1-2, 9/05, 9/06, and 9/07).
12. All required quarterly-annual reports for GBCGE and/or Department of Energy (Years 1-2).
13. Major synthesis paper in peer-reviewed journal (e.g. GSA Bulletin) (12/07).

## MILESTONES

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| Submission of paper on preliminary results for annual GRC meeting 2005 | May 2005 |
| Presentation of preliminary results, GRC annual meeting | September 2005 |
| Completion of report discussing year 2005 research results | December 2005 |
| Preliminary regional magnetic and gravity grids | December 2005 |
| Submission of paper for annual GRC meeting 2006 | May 2006 |
| Preliminary structure and bedrock relief products from geophysical data | June 2006 |
| Complete gravity collection of transitional Walker Lane | July 2006 |
| Presentation of interim results, GRC annual meeting | September 2006 |
| Completed reconnaissance of ~6 fields in transitional Walker Lane | October 2006 |
| Completion of report discussing year 2006 research results | December 2006 |
| Detailed map-cross sections of two fields in transitional Walker Lane | December 2006 |
| Structural analysis of faults of several fields in transitional Walker Lane | December 2006 |
| Completion of GIS databases of fields in transitional Walker Lane | December 2006 |
| Submission of paper for annual GRC meeting 2007 | May 2007 |
| Complete gravity collection of north-central Basin-Range | July 2007 |
| Presentation of final research results, GRC annual meeting | September 2007 |
| Completed reconnaissance of ~6 fields in north-central Basin-Range | September 2007 |
| Final structural and bedrock relief products deduced from geophysical data | September 2007 |
| Detailed map-cross sections of two fields in north-central Nevada Basin-Range | October 2007 |
| Structural analysis of faults of several fields in north-central Basin-Range | October 2007 |
| Completion of GIS databases of several fields in transitional Walker Lane | October 2007 |
| Final synthesis of structural controls of systems in northwestern Great Basin | December 2007 |
| Completion of report discussing year 2007 research results | December 2007 |
| Completion of major peer-reviewed paper on structural controls of systems | December 2007 |

## RESULTS FROM PREVIOUS AWARDS

The Great Basin Center for Geothermal Energy previously awarded Faulds and Oppliger two grants to analyze the Desert Peak and Brady geothermal fields through integrated geologic, geophysical, and GIS studies and synthesize findings into a regional assessment of geothermal activity in the northern Great Basin. Work began in May 2002 and will be completed by summer 2005. The geologic investigations included detailed mapping of the northern Hot Springs Mountains (~100 $km^2$ at 1:24,000 scale), including a transect between the Desert Peak and Brady's fields (Faulds and Garside, 2003), delineation of Tertiary strata, analysis of faults and folds, detailed analysis of core from 8 wells, and $^{40}Ar/^{39}Ar$ dating and geochemical correlation of key units. The main objectives have been a) delineating the late Cenozoic 3D strain field, b) elucidating relations between faults, stratigraphic features, and thermal aquifers, and c) constraining strain and stress orientations. Also, a new Gravity survey was completed (>500 stations) that reveals significant subsurface structures and patterns in pre-Tertiary basement depth. This is important because pre-Tertiary rocks host the *blind* Desert Peak reservoir. The new geologic and gravity data, as well as existing well data (lithologies from 31 wells and temperature data from 86 wells), have been compiled into a GIS database.

Collectively, these data sets have permitted 1) characterization of the links between geothermal reservoirs and structural and stratigraphic features in the Hot Springs Mountains – both fields appear to be localized in discrete steopovers in NNE-striking normal fault zones; 2) better definition of the boundaries of the geothermal reservoirs, which are elongated along a NNE trend parallel to the fault zones; 3) preliminary 3D modeling of the Desert Peak-Brady geothermal fields, showing that the geothermal plume at Desert Peak is centered within the stepover in the fault system; and 4) assessment of the late Cenozoic strain and stress fields (on the basis of fault-slip data), which favors dilation along the NNE-striking faults (Faulds et al., 2002, 2003). Recently, this work was synthesized into a regional assessment of the tectonic and structural controls of geothermal activity in the northern Great Basin (Faulds et al., 2004, 2005, in review), which shows that geothermal activity is related to a transfer of NW-directed dextral shear from the Walker Lane to WNW extension in the northern Great Basin.

**Presentations:** The following presentations have been given at professional meetings describing this work (arranged in reverse chronological order).

Geologic and Geophysical Analysis of the Desert Peak-Brady's Geothermal Fields: Elucidating Structural Controls on Geothermal Resources in the Great Basin, Great Basin Geothermal Workshop, Reno (November 2004).

Why is Nevada in hot water? Structural controls and tectonic model of geothermal systems in the northwestern Great Basin: Geothermal Resources Council Meeting, Palm Springs, California (September 2004).

Why is Nevada in hot water? Relations between plate boundary motions, the Walker Lane, and geothermal activity in the northern Great Basin: Geological Society of America Cordilleran Meeting, Boise, Idaho (May 2004).

Structural and geophysical analysis of the Brady and Desert Peak geothermal fields, western Nevada: Implications for structural controls on geothermal fields in the northern Great Basin, Nevada Petroleum Society monthly meeting, Reno (January 2004).

Structural analysis of the Desert Peak-Brady geothermal fields, northwestern Nevada: Implications for understanding linkages between northeast-trending structures and geothermal reservoirs in the Humboldt structural zone: Geothermal Resources Council Meeting, Morelia, Mexico (October 2003).

Progress report on the structural and geophysical analysis of the Desert Peak-Brady geothermal fields, western Nevada: Ormat International office, Reno (August 2003).

Geologic setting and preliminary analysis of the Desert Peak – Brady geothermal field, western Nevada: Geothermal Resources Council Meeting, Reno, Nevada (September 2002).

**Publications**: The following publications have resulted directly from this project.

Faulds, J.E., Garside, L., Johnson, G., Muehlberg, J., and Oppliger, G.L., 2002, Geologic setting and preliminary analysis of the Desert Peak – Brady geothermal field, western Nevada: Transactions Geothermal Resource Council, v. 26, p. 491-494.

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Blewitt, G., Coolbaugh, M., Holt, W., Kreemer, C., Davis, J.L., and Bennett, R.A., 2002, Targeting of potential geothermal resources in the Great Basin from regional relationships between geodetic strain and geological structures: Transactions Geothermal Resource Council, v. 26, p. 523-526.

Caskey, S.J., and Wesnousky, S.G., 2000, Active faulting and stress redistributions in Dixie Valley, Beowawe, and Bradys geothermal fields: Implications for geothermal exploration in the Basin and Range: 25th workshop on Geothermal Reservoir Engineering, Stanford University.

Colgan, J.P., Dumitru, T.A., and Miller, E.L., 2004, Diachroneity of Basin and Range extension and Yellowstone hotspot volcanism in northwestern Nevada: Geology, v. 32, p. 121-124.

Coolbaugh, M.F., Taranik, J.V., Raines, G.L., Shevenell, L.A., Sawatzky, D.L., Minor, T.B., and Bedell, R., 2002, A geothermal GIS for Nevada: defining regional controls and favorable exploration terrains for extensional geothermal systems; Proceedings, Annual Meeting, Reno, NV., Sept. 22-25, 2002, Geothermal Resources Council Transactions, v. 26, p. 485-490.

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Coolbaugh, M.F., Arehart, G.B., Faulds, J.E., and Garside, L.J., 2005b, Geothermal systems in the Great Basin: modern analogues to the roles of magmatism, structure, and regional tectonics in the formation of mineral deposits; *in* Geological Society of Nevada Symposium Proceedings, in press.

Coolbaugh, M.F., Zehner, R., Kreemer, K., Blackwell, D., Oppliger, G., Sawatzky, D., Blewitt, G., Pancha, A., Richards, M., Helm-Clark, C., Shevenell, L., Raines, G., Johnson, G., and Minor, T., 2005c, Preliminary Geothermal Potential Map, Great Basin: Nevada Bureau of Mines and Geology, in press.

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Faulds, J.E., Henry, C.D., and Hinz, N.H., 2005, Kinematics of the northern Walker Lane: An incipient transform fault along the Pacific – North American plate boundary: Geology, in press.

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Henry, C.D., and Perkins, M.E., 2001, Sierra Nevada – Basin and Range transition near Reno, Nevada; Two stage development at ~12 and 3 Ma: Geology, v. 29, p. 719-722.

Johnson, S.D., and Hulen, J.B., 2002, Subsurface stratigraphy, structure, and alteration in the Senator thermal area, northern Dixie Valley geothermal field, Nevada: Transactions Geothermal Resource Council, v. 26, p. 533-542.

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Oppliger, G.L., Widmer, M., Faulds, J.E., and Henry, C.D., 2002, Extensional and strike-slip faulting interactions in the northern Sierran – Great Basin transition zone inferred from new integrated gravity data: Geological Society of America Abstracts with Programs, v. 34, no. 6, p. 20.

Petit, J.P., 1987, Criteria for the sense of movement on fault surfaces in brittle rocks: Journal of Structural Geology, v. 9, p. 597-608.

Roberts, S., and Jackson, J., 1991, Active normal faulting in central Greece: An overview: Geological Society of London Special Publication 56, p. 125-142.

Robertson-Tait, A., and Morris, C., 2003, Progress and future plans at the Desert Peak East EGS project: Geothermal Resources Council Transactions, v. 27, p. 871-878.

Rowan, L.C., and Wetlaufer, P.H., 1981, Relation between regional lineament systems and structural zones in Nevada: AAPG Bulletin, v. 65, p. 1414-1452.

Schochet, D., Robertson-Tait, A., and Schriener, A., 2002, Desert Peak, Nevada: A step toward EGS commercialization in the Basin-Range: Transactions Geothermal Resource Council, v. 26, p. 251-254.

Shevenell, L., Coolbaugh, M., Faulds, J., Oppliger, G., Calvin, W., Louie, J., Blewitt, G., Kratt, C., Arehart, G., Sladek, C., Lechler, P., and Garside, L., 2004, Accomplishments at the Great Basin Center for Geothermal Energy: Geothermal Resources Council Transactions, v. 28: 47-52.

Stewart, J.H., 1988, Tectonics of the Walker Lane belt, western Great Basin: Mesozoic and Cenozoic deformation in a zone of shear, *in* Ernst, W. G., ed., The Geotectonic development of California: Prentice Hall, Englewood Cliffs, New Jersey, , p. 683-713.

Surpless, B.E., Stockli, D.F., Dumitru, T.A., and Miller, E.L., 2002, Two-phase westward encroachment of Basin and Range extension into the northern Sierra Nevada: Tectonics, v. 21, no. 1, p. 2-1 to 2-13.

Waibel, A., Blackwell, D., and Ellis, R., 2003, The Humboldt House-Rye Patch geothermal district: An interim view: Geothermal Resources Council Transactions, v. 27, p. 33-36.

Wannamaker, P.E., 2003, Initial results of magnetotelluric array surveying at the Dixie Valley geothermal area, with implications for structural controls and hydrothermal alteration: Geothermal Resources Council Transactions, v. 27, p. 37-40.

Wernicke, B., 1992, Cenozoic extensional tectonics of the U.S. Cordillera, *in* Burchfiel, B.C., Lipman, P.W. and Zoback, M.L., eds., The Cordilleran orogen: conterminous U.S.: Boulder, Geological Society of America, The Geology of North America, v. G-3, p. 553-581.

## BUDGET JUSTIFICATION and EXPLANATION

**Salaries:** Faulds is a tenure-track Research Geologist with the Nevada Bureau of Mines and Geology (NBMG), which is a research department in the College of Sciences at the University of Nevada, Reno (UNR). He has a standard 9-month faculty contract. Faulds also serves on the Graduate Faculty and advises several graduate students. Oppliger is an Associate Research Professor in the Arthur Brant Laboratory for Exploration Geophysics at UNR. Coolbaugh is an Research Assistant Professor in the Great Basin Center for Geothermal Energy at UNR. Johnson is a GIS specialist with NBMG and has a full-time classified staff position (53% hard money). Johnson teaches two GIS courses at UNR. Graduate and undergraduate students will assist in all phases of the research, including collection, compilation, and digitization of data. This work will be part of several graduate and undergraduate theses. Faulds has committed ~42 days and Oppliger ~28 days as match from state-allocated funds.

**Fringe Benefits**: Fringe rates are 27% for soft-money faculty (Oppliger and Coolbaugh), 4% for faculty with 9-month *hard-money* contracts (Faulds), 10% for graduate students, 40% for classified staff (Johnson), and 2% for undergraduate students.

**Travel:** Travel expenses include mileage ($0.43/mile) for NBMG vehicles and/or daily rental fees for 4-WD field vehicles. Minimum per diem is requested principally for accommodations in areas distant from Reno. Accommodations near some of the more remote field areas will save large amounts of vehicle-mileage expenses and/or equipment set-up time. Lodging and airfare expenses are also requested for Faulds to attend the 2006 GRC meeting (note that such costs are not requested for 2005, because the meeting is in Reno).

**Operating Expenses:**

1. Air photos and maps are needed for the proposed mapping, reconnaissance, and structural and stratigraphic analyses. This includes color stereo air photos, where available, and high-resolution geo-referenced digital ortho-photoquads.
2. Standard thin sections at $11/section are needed for stratigraphic analyses.
3. Cartographic services @$38/hour, which includes drafting and digitizing of geologic maps and preparation of figures and posters for meetings. NBMG is well staffed in graphic and cartographic services, but most individuals have “soft money” positions. Thus, funds are requested for these services.
4. Software licenses: Several sophisticated software packages will be used in 3D modeling of the geothermal fields, including Rockworks, 3DMove, Vulcan, and possibly GOCAD. Funds are requested for annual license fees for 3DMove and Vulcan and purchasing the most recent version of both Rockworks and GOCAD.
5. Standard servicing and shipping costs for gravimeter.
6. $^{40}Ar/^{39}Ar$ dating at $500/sample for stratigraphic correlations and determining timing of deformation in several geothermal fields. Analyses will be done at the New Mexico Tech Geochronological Laboratory.
7. Geochemical correlations of tephras (tephrochronology) @$250/sample for stratigraphic correlations and constraining timing of deformation. Analyses will be done at the University of Utah.
8. Registration costs are requested for Faulds to attend the 2005 and 2006 annual GRC meetings.

**Tuition:** Required for graduate-student research assistantships—currently @$128/credit.

**Indirect Costs**: The University of Nevada, Reno, calculates indirect cost at 45% for all items except tuition and equipment.

## Dr. James E. Faulds

### Education

B.S. University of Montana, Geology, 1981 (highest honors)
M.S. University of Arizona, Geology, 1986
Ph.D. University of New Mexico, Geology, 1989

### Areas of Expertise

Disciplines: Structural geology, tectonics, paleomagnetism, and geochronology.
Topical: Segmentation of normal-fault systems, evolution of strike-slip faults, fault kinematics, Extensional-transtensional tectonics, volcanic stratigraphy, evolution of western North America.

### Professional Work Experience

1997-present - Research Geologist/Graduate Faculty (associate professor level; tenured 2000), University of Nevada, Reno; structural, tectonic, paleomagnetic research in western Cordillera

1992-1997 – Assist. Professor, Univ. of Iowa; structural geology, tectonics, field geology.
1991-1992 - Visiting Assistant Professor, University of Iowa
1990-1991 - Post-doctoral Research Associate, University of Southern California
1989-1990 - Post-doctoral Research Associate, University of Nevada, Las Vegas
1984-1989 - Silver-Kelley Fellow and Research/Teaching Assistant, University of New Mexico
1981-1984 - NSF Graduate Student Fellow, University of Arizona

### Recent Publications Related to Geothermal

**Faulds, J.E**., Coolbaugh, M., Blewitt, G., and Henry, C.D., 2004, Why is Nevada in hot water? Structural controls and tectonic model of geothermal systems in the northwestern Great Basin: Geothermal Resources Council Transactions, p. 649-654.

Shevenell, L., Coolbaugh, M., **Faulds, J**., Oppliger, G., Calvin, W., Louie, J., Blewitt, G., Kratt, C., Arehart, G., Sladek, C., Lechler, P., and Garside, L., 2004, Accomplishments at the Great Basin Center for Geothermal Energy: Geothermal Resources Council Transactions, v. 28: 47-52.

**Faulds, J.E.,** Garside, L.J., and Oppliger, G., 2003, Structural analysis of the Desert Peak-Brady geothermal fields, northwest Nevada: Implications for understanding links between northeast-trending structures and geothermal reservoirs in the Humboldt structural zone: Geothermal Resources Council Transactions, v. 27, p. 859-864.

**Faulds, J.E.,** and Garside, L.J., 2003, Preliminary geologic map of the Desert Peak – Brady geothermal fields, Churchill County, Nevada: Nevada Bureau of Mines and Geology Open-File Report 03-27.

**Faulds, J**.**E.**, Garside, L., Johnson, G., Muehlberg, J., and Oppliger, G.L., 2002, Geologic setting and preliminary analysis of the Desert Peak – Brady geothermal field, western Nevada: Transactions Geothermal Resource Council, v. 26, p. 491-494.

### Other Selected Recent Publications

**Faulds, J.E**., Henry, C.D., and Hinz, N.H., 2005, Kinematics of the northern Walker Lane: An incipient transform fault along the Pacific – North American plate boundary: In press.

Henry, C.D., **Faulds, J.E**., and dePolo, C.M., 2005, Geometry and timing of strike-slip and normal faults of the northern Walker Lane, northwestern Nevada and northeastern California: Strain partitioning, sequential extensional and strike-slip deformation, or both? Geological Society of America Special Paper, in press.

Varga, R.J., **Faulds, J.E**., Snee, L.W., Harlan, S.S., and Bettison-Varga, L., 2004, Miocene extension and extensional folding in an anticlinal segment of the Black Mountains accommodation zone, Colorado River extensional corridor, southwestern USA: Tectonics, v. 23, no. 11, TC109 [DOI 10.1029/2002TC001454], 19 p.

**Faulds, J.E**., Olson, E.L., Harlan, S.S., and McIntosh, W., 2002, Miocene extension and fault-related folding in the Highland Range, southern Nevada: A 3-D perspective: Journal of Structural Geology, v. 24, p. 861-886.

**Faulds, J.E.**, Bell, J.W., and Olson, E.L., 2002, Geologic map of the Nelson SW Quadrangle, Clark County, Nevada (with accompanying text): Nevada Bureau of Mines and Geology Map 134.

**Faulds, J.E**., Feuerbach, D.L., Miller, C.F., and Smith, E.I., 2001, Cenozoic evolution of the northern Colorado River extensional corridor, southern Nevada and northwest Arizona: Pacific Section of the American Association of Petroleum Geologists Publication GB 78, p. 239–272.

**Faulds, J.E**., Wallace, M.A., Gonzalez, L.A., and Heizler, M.T., 2001, Depositional environment and paleogeographic implications of the late Miocene Hualapai Limestone, northwest Arizona and southern Nevada, in Young, R.A. and Spamer, E.E., eds., Colorado River: Origin and evolution: Grand Canyon Association Special Volume, p. 81-87.

**Faulds, J.E**., Price, L.M., and Wallace, M.A., 2001, Pre-Colorado River paleogeography and extension along the Colorado Plateau - Basin and Range boundary, northwest Arizona, in Young, R.A. and Spamer, E., eds., Colorado River: Origin and evolution: Grand Canyon Assoc. Special Vol., p. 93-99.

Bachl, C.A., Miller, C.F., Miller, J.S., and **Faulds, J.E**., 2001, Construction of a pluton: Evidence from an exposed cross section of the Searchlight pluton, Eldorado Mountains, Nevada: Geological Society of America Bulletin, v. 113, no. 9, p. 1213–1228.

**Faulds, J.E**., and Varga, R., 1998, The role of accommodation zones and transfer zones in the regional segmentation of extended terranes: Geological Society of America Special Paper 323, p. 1-46.

**Faulds, J.E**., Schreiber, B.C., Reynolds, S.J., Gonzalez, L., and Okaya, D., 1997, Origin and paleogeography of an immense, nonmarine Miocene salt deposit in the Basin and Range: Journal of Geology, v. 105, p. 19–36.

**Faulds, J.E**., Feuerbach, D.L., Reagan, M.K., Metcalf, R.V., Gans, P., and Walker, J.D., 1995, The Mt. Perkins block, northwestern Arizona: An exposed cross section of an evolving, preextensional to synextensional magmatic system: Journal of Geophysical Research, v. 100, p. 15,249–15,266.

## Recent Books

**Faulds, J.E**., and Stewart, J.H., eds., 1998, Transfer zones and accommodation zones: The regional segmentation of the Basin and Range province: Geological Society of America Special Paper 323, 257 p.

Erskine, M.C., **Faulds, J.E**., Bartley, J.M., and Rowley, P.D., eds., 2001, The geologic transition, High Plateaus to Great Basin—A symposium and field guide: The Mackin volume: Pacific Section of the American Association of Petroleum Geologists Publication GB 78, 430 p.

## Professional Societies

American Geophysical Union
Geological Society of America
Sigma Xi
Geological Society of Nevada
Nevada Petroleum Society

## Current Support

National Science Foundation: Elucidating physical processes in crustal magma systems - Evidence from Miocene intrusive and extrusive sequences in southern Nevada, **$85,036**, 7/1/04 to 6/30/07, PI.

U.S. Geological Survey, STATEMAP, 2004: Geologic mapping of the Fernley East Quadrangle: 5/1/04 to 8/31/05, **$40,121**, PI.

Department of Energy (DOE) through Great Basin Center for Geothermal Energy: Geologic and geophysical analysis of the Desert Peak-Brady geothermal fields: Structural controls on geothermal reservoirs in the Humboldt structural zone: 10/1/03 to 9/30/05, **$135,392**, PI.

National Science Foundation, Neogene development of the northern Walker Lane: An evolving transform plate boundary: 1/1/02 to 12/31/05, **$272,596**, PI.

# Gary L. Oppliger

*Research Associate Professor*
*Arthur Brant Laboratory for Exploration Geophysics*
*Dept. of Geological Sciences and Engineering, University of Nevada, Reno*
*Tel (775) 784-7056, Email: oppliger@mines.unr,edu*


## Education

***Ph.D.*** Engineering Geoscience, (1982) University of California, Berkeley, CA,
Electromagnetic methods, instrumentation and digital signal processing.
Dissertation Advisor: H. Frank Morrison.

***M.S.*** Engineering Geoscience, (1977) University of California, Berkeley, CA

***B.S.*** Engineering Geoscience, (1975) University of California, Berkeley, CA

## Areas of Expertise

Satellite radar interferometry and GPS applications, Potential fields and electrical methods for water, mineral and geothermal exploration, Local gravimetric geoid computation for geodetic applications.

## Academic Experience

***Nov 1999 - present***, Associate Research Professor, Arthur Brant Laboratory for Exploration Geophysics, Department of Geological Sciences and Engineering, University of Nevada, Reno.

## Industry Experience

***1997-1999,*** District Geophysicist, Kennecott Exploration Co., Reno NV.
***1995-1996,*** Sr. Research Geophysicist, Electromagnetic Instruments Inc, Berkeley, CA.
***1990-1995***, Sr. Geophysicist, Western Mining Corp. North America, Reno, NV
***1980-1989,*** Research Geophysicist, Newmont Exploration Ltd, Tucson. AZ.

## Professional Activities

Session organizer and chair: Great Basin Center for Geothermal Energy, Workshop, University of Nevada, Reno, Nov 5, 2004.
Reviewer: Society of Exploration Geophysicist annual meeting 2004.
Member: American Geophysical Union; Member, Geological Society of America, Society of Exploration Geophysicist

## Representative Journal Publications

Murphy, B. J., **Oppliger, G. L**., Brimhall Jr., G., and Hynes, A. J., 1999. Mantle Plumes and Mountains: *American Scientist*, v. 87, p. 146-153.

Murphy, B. J., **Oppliger G. L**., Brimhall Jr., G., and Hynes, A. J., 1998. Plume Modified Orogeny: an example from the southwestern United States: *Geology* 26:731-734.

**Oppliger, G. L.,** Murphy, B. J., Brimhall Jr., G., 1997. Is the ancestral Yellowstone hotspot responsible for the Tertiary "Carlin mineralization in the Great Basin of Nevada?: *Geology* 25:627-30.

**Oppliger, G. L**., 1984, Three-Dimensional Terrain Corrections for Mise-a-la-masse and Magnetometric Resistivity Surveys: *Geophysics*, Vol. 49, No. 10; P. 1718-1729,

## Representative Conference Publications

**Oppliger, G.,** Coolbaugh, M., Foxall, W., 2004, Imaging structure with fluid fluxes at the Bradys geothermal field with satellite interferometric radar (InSAR): New insights into reservoir extent and structural controls. *Geothermal Resources Council Transactions*, Vol. 28,

pages:37-40.

**Oppliger, G.,** Coolbaugh, M., 2004, Imaging structure with fluid fluxes at the Brady, Nevada, U.S.A, geothermal field with satellite interferometric radar (InSAR), *Society of Exploration Geophysicists*, 74th Annual International Meeting, Oct. 10-15, Denver, Colorado., Extended Abstracts Volume, 4 pages, 3 figs.

Faulds, J., Garside, L., **Oppliger, G.**, 2003, Structural Analysis of the Desert Peak-Brady Geothermal Fields, Northwestern Nevada: Implications for Understanding Linkages between Northeast-Trending Structures and Geothermal Reservoirs in the Humboldt Structural Zone, *Geothermal Resources Council Transactions* Vol. 27, pages: 859-864.

Coolbaugh, M., Sawatzky, D., **Oppliger, G**., Minor, T., Raines, G., Shevenell, L., Blewitt, G., 2003, Geothermal GIS Coverage of the Great Basin, USA: Defining Regional Controls and Favorable Exploration Terrains, *Geothermal Resources Council Transactions* Vol. 27, pages: 9-13.

## Current Research Support

*Washoe County Department of Water Resources and Regional Water Planning Commission:* A cooperative study of the relation between satellite radar differential interferometry (D-InSAR) ground deformation observations and groundwater production and level data in the South Truckee Meadows, (PI $18k 10/2004-7/2005.) G. Oppliger.

*U.S. Department of Energy:* Investigating the relation between geothermal reservoir compaction, geometry and production rates from a ten-year InSAR ground displacement history at the Bradys and Desert Peak Fields, (PI $72k 7/2003-9/2005 ) G. Oppliger M. Coolbaugh.

*U.S. Department of Energy:* Regional assessment of exploration potential for geothermal systems in the Great Basin using a geographic information system (GIS) – Part II, (co-PI, $93K, 7/2003- 6/ 2005), M. Coolbaugh, G. Raines, Shevenell, T. Minor, D. Sawatzky, G. Oppliger.

## Recent Research Support

*NASA EPSCoR core*: InSAR-GPS Investigation of Seasonal Groundwater Response in Reno, (PI $8k for 3/2003-8/2004.) G. Oppliger.

*U.S. Department of Energy:* Geologic and Geophysical Analysis of the Desert Peak-Brady Geothermal Fields: Part II - Structural Controls on Geothermal Reservoirs in the Humboldt Structural Zone (co-PI $98K, 7/2003- 6/2004), J. Faulds, L. Garside, G. Oppliger, R. Anooshehpoor.

## Current Dissertation/Thesis committee member for:

Cheryl Goudy, Ph.D. student in Geology

Jim Scott, Ph.D. student in Geophysics Seismology

Jessica Muehlberg, M.S. student in Geology

Blake Morrow M.S. student in Geology

Richard Redd, M.S. student in Hydrology

Kurt Katzenstein, Ph. D. student in Geo Engineering

**Recent Collaborators:** (not listed above)

Jim Carr, Jim Trexler, Pat Cashman.

## Dr. Mark F. Coolbaugh

Research Assistant Professor
Great Basin Center for Geothermal Energy, University of Nevada, Reno
Geological Sciences Department, MS 172, Reno, Nevada 89557-0138
Tel: (775) 784-1415; E-mail: cool.78@alum.mines.edu


## Professional Preparation

**Ph. D., Geology, 2003**
University of Nevada, Reno, Mackay School of Mines, Reno, Nevada
**M. S., Geological Engineering, 1985**
University of Arizona, College of Mines, Tucson, Arizona
**B. S., Geological Engineering, 1978**
Colorado School of Mines, Golden, Colorado

## Professional Assignments

**Research Assistant Professor, March 2002 to Present**
Great Basin Center for Geothermal Energy, University of Nevada, Reno. Research on modern geothermal systems using a GIS, spatial statistics, remote sensing, aqueous and gas geochemistry, and GPS-based crustal strain measurements. (For more detail, see research projects listed below.)

**Research Assistant and Teaching Assistant, August 1998 – March 2002**
Arthur Brant Laboratory for Exploration Geophysics, Dept. of Geological Sciences, UNR. Dissertation research develops geothermal and mineral exploration models using a GIS, spatial statistics (weights-of-evidence and logistic regression), and remote sensing imagery (including ASTER, TIMS, and AVIRIS). Additional research included the use of a GIS to assess natural sources of mercury to the atmosphere.

**Exploration Manager – Mongolia, September 1996 - February 1998**
Cascadia Chemicals & Minerals Corp., Ulaanbaatar, Mongolia
Developed and managed all corporate exploration programs for copper and gold.

**Research Assistant and Teaching Assistant, July 1995 - August 1996**
University of British Columbia, Vancouver, B.C., Canada
Development of new lithogeochemical exploration tools in the search for mineral deposits, particularly Carlin-type, sediment-hosted gold deposits.

**Chief Geologist, April 1994 - June 1995**
Carson Gold Corp., Vancouver, B. C., Canada
Designed and managed all corporate overseas exploration programs, with projects in South and Central America, the Philippines, and Mongolia.

**Senior Exploration Geologist/Geological Engineer, November 1991 - January 1994**
Coeur Rochester, Inc., Lovelock, Nevada, USA
Development of district-wide gold exploration program. Assistance with open-pit mine geology, ore control, and engineering.

**Consultant, February 1991 - October 1991**
Mine and Exploration Services, Monte Vista, Colorado, USA
Mine permitting and compliance issues, exploration programs, production geology, and ore reserve development.

**Chief Geologist/Manager/Senior Geologist, June 1984 - January 1991**
Summitville Consolidated Mining Co., Inc., Del Norte, Colorado, USA
Supervision of mine geology and exploration departments responsible for development of ore reserves, open-pit ore control, regional exploration, and land acquisition.

**Geologist, June 1983 - June 1984**
Pegasus Gold Corporation, Reno, Nevada, USA
Management of district exploration program.

**Associate Geologist, June 1980 - Dec. 1982, summers of 1977 - 1979**
Climax Molybdenum Co., div. of AMAX, Golden, Colorado, USA
Geologic mapping and field work for molybdenum exploration and mining.

**Underground Motorman's Assistant, June 1976 - September 1976**

ASARCO, Inc., Leadville, Colorado, USA
Track haulage of ore, equipment, and supplies in an underground lead-zinc-silver mine.

## Selected Publications and Presentations

Coolbaugh, M.F. and Bedell, R., 2005, A Simplification of weights of evidence using a density function and fuzzy distributions: a comparison of probability modeling techniques in the designation of geothermal systems in Nevada; Geol. Assoc. Canada Special Paper "GIS applications in the Earth Sciences", *in press*.

Coolbaugh, M.F., Arehart, G.B., Faulds, J.E., and Garside, L.J., 2005, Geothermal systems in the Great Basin: modern analogues to the roles of magmatism, structure, and regional tectonics in the formation of mineral deposits; *in* Geological Society of Nevada Symposium Proceedings, May 11-21, 2005, *under review*.

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## Current and Past Geothermal Research

1) Regional Assessment of Exploration Potential for Geothermal Systems in the Great Basin using a Geographic Information System (GIS): Collaborators: Mark F. Coolbaugh, Gary L. Raines, Lisa A. Shevenell, Tim B. Minor, Don L. Sawatzky, and Gary Oppliger: funded by DOE.

A geographic information system (GIS) is being used to integrate diverse types of geologic, chemical, and physical information to predict where high-temperature geothermal systems are most likely to occur in the Great Basin of western North America. Spatial analysis using weights-of-evidence and logistic regression is being used to quantify relationships between geothermal systems and the map data and clarify the conditions necessary for the formation of high-temperature geothermal systems.

2) Remote Sensing for Exploration and Mapping of Geothermal Resources: Collaborators: Wendy Calvin and Mark F. Coolbaugh: funded by DOE.

Hyperspectral and multispectral remote sensing, in the visible, near-infrared, and thermal infrared ranges, is being used to identify anomalous surface features related to active geothermal systems. These features include areas of high heat flow (thermal anomalies), diagnostic rocks (sinter and evaporite assemblages), hydrothermal alteration (alunite and clay minerals), and vegetation anomalies.

3) Geochemical Characterization of Magmatic-related vs. Extension-related Geothermal Systems in the Great Basin: Implications for Exploration, Exploitation, and Environmental Issues: Collaborators: Greg B. Arehart, Mark F. Coolbaugh, and Simon R. Poulson: funded by DOE.

This research will identify the distinguishing chemical characteristics of magmatic and extensional geothermal systems, and relate those differences to differences in host rock lithologies, magma compositions, or other physical and chemical parameters. The significance those differences have for exploration, exploitation, and effects on the environment is being reviewed.

4) Targeting of potential geothermal resources in the Great Basin from regional relationships between geodetic strain and geological structures: Collaborators: Geoff Blewitt and Mark F. Coolbaugh: funded by DOE.

The ability of GPS-based measurements of geodetic strain to identify zones of crustal extension, and the role those zones of extension play in controlling geothermal activity, is being investigated. The Quaternary structural fabric of Nevada is being used to help constrain the mode and location of strain.

**Melissa Edwards**
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**4005 Moorpark Court Apt. 213**
**Sun Valley, NV 89433**
**(775) 673-1204**
**edward58@unr.nevada.edu**

**Educational Information:**

**Schools***:*

-University of Nevada, Reno (August 2004 to present); Currently enrolled, M.S. candidate
-Arizona State University; Graduated 5/2003; Bachelors of Science in Geology w/ honors, Cumulative GPA: 3.45
-Math-Science Honors Program at Arizona State University (summer 1998), Grade: 3.2 GPA
-Gilbert High School; Graduated 5/1999; top 5% of class, Grades: 4.0 GPA and above

***Honors & Awards****:*

-Arizona State University's President's and Regents Scholarships – 1999/2000, 2000/2001, 2001/2002, 2002/2003
-The Robert S. Dietz Geological Sciences Field Camp Scholarship – 2002
-Arizona State University Dean's Honor List – fall 1999, fall 2000, spring 2001
-President's Award for Educational Excellence – 1999
-Mesa Association of School Administrators Award – 1995/1996

**Work Experience:**

*Research Assistant*

For Dr. Jim Faulds with the Nevada Bureau of Mines and Geology from August 2004 to present
-Running samples in paleomagnetic laboratory
-Digitizing geologic maps
-Compiling data on various geologic topics

*Staff Geologist*

For Ninyo and Moore from July 2003 to July 2004
-Logging soil samples & drill cores as well as test pits
-Manually gathering soil samples outside/inside residences/businesses
-Marking out borings
-Performing & contouring manometer surveys
-Documenting distress features exhibited in homes
-Compiling data & documentation
-Assisting in writing of reports
-Reviewing boring and test pit logs
-Performing percolation tests
-Assessing stability of road cuts for Arizona Department of Transportation

*Teaching Assistant*

For Dr. Don Burt at Arizona State University from June 2003 to July 2003
For Dr. Susanne Neuer at Arizona State University from January 2003 through May 2003
-Documenting lectures (for Dr. Neuer only)
-Grading homework & tests
-Managing grades and posting them on Internet along with other material
-Preparing equipment for lectures
-Copying & organizing material for distribution
-Creating homework assignments & tests
-Assisting students

*Human Resources Clerk:*

For ConocoPhillips from December 2000 through January 2003

For Adecco from June 2000 through December 2000
-Providing & gathering information
-Assisting co-workers
-Filing, sorting, & copying
-Purging files & I-9s
-Processing new hire paperwork for filing

*Receptionist:*

For Adecco at Lanier Worldwide Incorporated from May 2000 through June 2000
-Assisting callers & receiving packages
-Sending mail & making copies

amp RESOURCES

February 17, 2005

Jim Faulds
Nevada Bureau of Mines and Geology
University of Nevada, Reno
MS 178
Reno, NV 89557-057

Re: Support Letter for Grant Proposal

Jim:

I am writing this letter in support of the Great Basin Center for Geothermal Energy and their involvement with the Salt Wells Geothermal Power Plant development program. To date Jim Faulds and Mark Coolbaugh have performed tasks including surface mapping and structural analysis of faults, which have been integrated into the geophysical database. This work is the instrument for choosing the production and injection well locations for the new binary cycle power plant at Salt Wells. Further study of the Salt Wells basin would be instrumental in understanding the controls and mechanisms of the shallow and deep systems at Salt Wells as well as improving the database of the Great Basin and the known geothermal resources within this area. Amp Resources welcomes the opportunity for a graduate student to continue the research started with this initial program.

Sincerely,

Amp Resources
Brad Platt, Vice President

# High Desert GeoCulture, LLC

February 17, 2005

Dr. James Faulds
Nevada Bureau of Mines and Geology
University of Nevada, Reno
Reno, NV 89557

Dear Jim:

Thanks very much for informing me of your plans to conduct studies of the Gerlach and Fly Ranch geothermal fields as part of your proposed assessment of structural controls of geothermal systems in the northwestern Great Basin. I think this is an excellent idea. These types of studies are desperately needed in order to facilitate targeting of the most favorable areas for drilling in existing fields, such as Gerlach, San Emidio and Fly Ranch.

We would be happy to collaborate with you on these efforts and will make our new magnetic and gravity data available to you for interpretation. Combining our data bases with your proposed work will be extremely helpful in developing the geothermal fields at both Gerlach and Fly Ranch (and possibly others in the region—e.g. San Emidio and Hazen).

We look forward to this collaboration and good luck with the proposal.

Sincerely,

F. Mack Shelor - President

High Desert GeoCulture LLC 890 Schellbourne Street Reno, Nevada 89511
75-843-2363, 775-848-5274 (phones) 775-852-1683 (Fax) hdg-nv@sbcglobal.net