APPENDIX A

Characterizing Controls on Geothermal Systems in the Northern Great Basin through Integrated Structural Analysis and Modeling

James Faulds, Nicholas Davatzes, Mark Coolbaugh, and Gary Oppliger
Great Basin Center for Geothermal Energy

ABSTRACT

We propose an integrated structural, geophysical, and GIS study of geothermal fields in the Great Basin. Our goals are to better characterize the structural controls on geothermal activity and determine favorable areas for future conventional and enhanced geothermal (EGS) development. This project will involve 1) detailed geologic mapping and reconnaissance within the fields; 2) structural analysis of related fault zones; 3) boundary element modeling of fault interactions; 4) limited geophysical studies; and 5) GIS compilation of geologic and geophysical data. The field-based studies will establish the geologic setting of the systems, thus elucidating the subsurface framework and controls on geothermal reservoirs. Structural analyses will determine which faults have accommodated dilation and are more likely to channel fluids. The numerical modeling will define local variations in stress and strain within fault systems thereby delineating favorable areas for dilation and fluid flow. The geophysical studies will help define the subsurface fault geometries. The GIS compilation will permit integration of multiple databases, while also facilitating preliminary 3D modeling. Our recent studies in the Great Basin have defined structural settings common to many geothermal fields, including stepovers or terminations of normal fault zones. The proposed research is 1) a necessary expansion of this work needed to more fully characterize geothermal settings, 2) a logical progression into quantitative modeling of the more favorable fault interactions, and 3) a necessity in terms of understanding the best locations for application of EGS technology. We are working closely with industry in proposed study areas. Thus, this research will be assimilated into exploration strategies and targeting drilling sites, thereby enhancing utilization of geothermal resources in the western United States.

DESCRIPTION OF PROJECT
Background and Relevance

In the Great Basin of the western USA, geothermal fields are abundant in northern Nevada and adjacent northeast California and southern Oregon (Coolbaugh et al., 2002, 2005c; Coolbaugh and Shevenell, 2004; Fig. 1). The geothermal systems cluster in NNE to NE-trending belts (Faulds et al., 2004). Volcanism in most of this region ceased ~3 to 10 Ma and is therefore an unlikely source for most of the geothermal activity. Faults are known to control most systems in the Great Basin, but many questions remain concerning which types of faults or segments of faults favor geothermal activity.

The tectonic setting of the northwestern Great Basin accounts for much of the geothermal activity. In the western Great Basin, a system of dextral faults known as the Walker Lane (Stewart, 1988; Oldow, 1992; Faulds et al., 2005b) accommodates ~20% of the Pacific–North American plate motion (Bennett et al., 2003; Hammond and Thatcher, 2004). Relatively high rates of NW-directed extension (e.g. Colgan et al., 2004) absorb NW-declining dextral motion in the Walker Lane. The Walker Lane begins losing displacement 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, 2006), and the NE-trending belts of geothermal activity are orthogonal to the extension direction (Fig. 1). The prolific geothermal activity may therefore result from a transfer of NW-trending dextral shear in the Walker Lane to NW-directed extension in the northern Great Basin. Enhanced extension favors high slip rates, dilation, deep circulation of fluids, and preservation of permeable pathways along NNE-striking faults.

The detailed interactions between faults and fluids are poorly understood, however. Our recent work shows that certain types of fault interactions, such as stepovers in NNE-striking normal faults and belts of overlapping and terminating faults, are common to many geothermal fields (Fig. 2; Faulds et al., 2006). Features indicative of these settings that may be helpful in guiding exploration include: a) major steps in range-fronts, b) interbasinal highs, c) mountain ranges consisting of relatively low, discontinuous ridges, and d) lateral terminations of mountain ranges. Most of this work has been based on field observations, including detailed mapping and analysis of fault geometries and kinematics, with subsurface control provided by gravity surveys and available well data. However, the controls on geothermal fields in the Great Basin have yet to be fully characterized, as relatively few fields have been studied in detail. Moreover, few studies have undertaken modeling of fault interactions, and many favorable structural settings have not been modeled quantitatively. A quantitative approach has proven useful in evaluating fluid flow in fault systems that host ore deposits and hydrocarbons (Maerten et al., 2000; Davatzes et al., 2005; Eichhubl et al., 2004; Mickelthwaite and Cox, 2004) and in a few geothermal fields (Barton et al., 1995, 1998). An integrated study combining field-based observations and quantitative boundary-element modeling of characteristic fault interactions would greatly facilitate exploratory drilling in known fields and identification of promising areas for both blind (or hidden) geothermal resources and EGS development.

We therefore propose to analyze several additional fields in the northern Great Basin (Fig. 1) through integrated structural, geophysical, and GIS studies. For representative fields, particularly those with well-defined fault geometries and kinematics, boundary-element modeling will be conducted to define the relation between geothermal activity and variations in stress and strain along controlling faults. The proposed work is directly related to our currently funded study aimed at characterizing structural controls of geothermal systems in the Great Basin, but it clearly represents 1) a necessary expansion of this work through study of additional areas, needed to more fully characterize favorable settings for geothermal activity, and 2) a logical progression of this work into quantitative modeling of some of the more favorable fault interactions, and 3) a necessity in terms of understanding the best locations for application of EGS technology.

A major goal of this project is to delineate favorable areas for future drilling thereby contributing toward industry efforts in the region and enhancing utilization of geothermal resources in the western US. As listed in the *RFP*, this project specifically addresses several topics under *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 drilling.

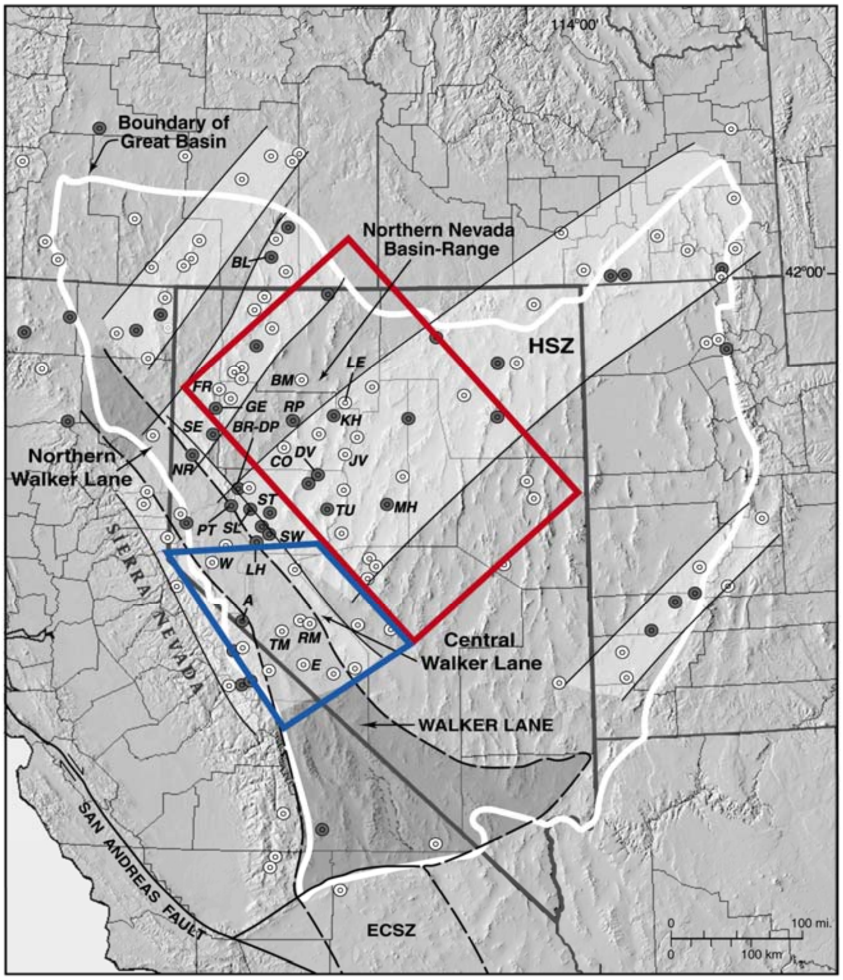

Figure 1. The northwest Great Basin has the greatest concentration of geothermal fields in the US. White circles have maximum temperatures of 100-160°C; grey circles >160°C. ECSZ, eastern California shear zone; HSZ, Humboldt structural zone. Abbreviations for individual fields: A, Aurora; BL, Borax Lake; BM, Blue Mountain; BR-DP, Brady-Desert Peak; CO, Colado; DV, Dixie Valley; FR, Fly Ranch; GE, Gerlach; JV, Jersey Valley hot springs; KH, Kyle Hot Springs; LE, Leach Hot Springs; LH, Lee-Allen Hot Springs; MH, McGinness Hills; NR, Astor Pass-Needle Rocks; PT, Patua Hot Springs; RM, Rhodes Marsh; RP, Rye Patch; SE, San Emidio; SL, Soda Lake; ST, Stillwater; SW, Salt Wells; TU, Tungsten Mountain; W, Wabuska.

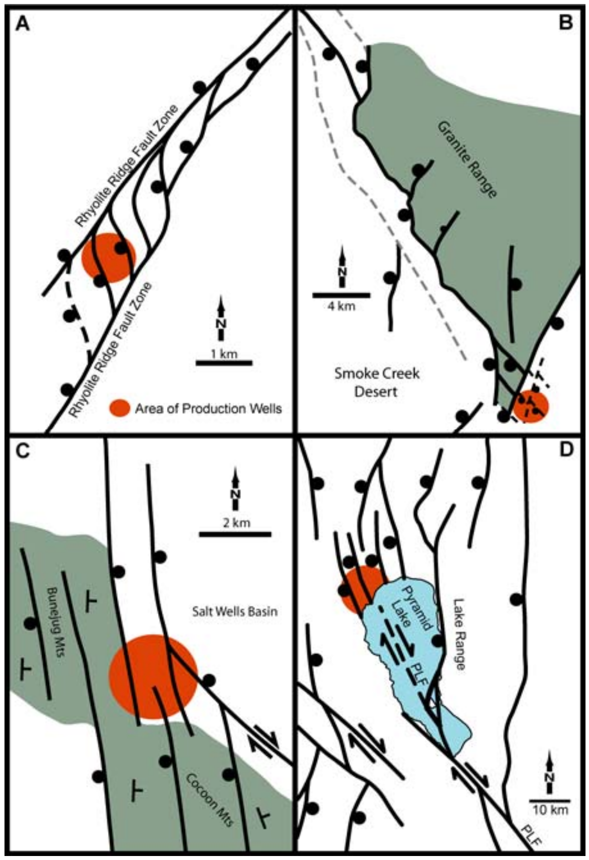

Figure 2. Favorable structural settings for geothermal fields. Red areas denote rough boundaries of geothermal field. Dark gray shows major bedrock ranges. A. Stepover in normal fault zone at Desert Peak. B. Terminating, horse-tailing, and intersecting range-front faults at Gerlach. C. Overlapping and terminating, oppositely dipping normal fault systems at Salt Wells. D. North end of right-lateral Pyramid Lake fault (PLF), where dextral shear strain is transferred to a system of en echelon normal faults at Astor Pass-Needle Rocks.

Proposed Research

We propose to better characterize the structural controls on geothermal systems in the Great Basin, including parts of the Walker Lane and Basin and Range province. This project builds on completed regional compilations (Coolbaugh et al., 2002, 2005a, c, 2006c; Coolbaugh and Shevenell, 2004; Faulds et al., 2004, 2005), our detailed analyses of several fields (Faulds et al., 2003, 2006; Faulds and Garside, 2003; Coolbaugh et al., 2006a,b; Vice et al., 2006), and complements ongoing and recent studies of GPS-derived strain rates, favorable exploration terranes, and relations between Quaternary faults and geothermal activity (Blewitt et al., 2003; Robertson-Tait and Morris, 2003; Coolbaugh et al., 2002, 2005b; Bell and Ramelli, unpub. work). It is also coordinated with industry exploration in the region.

To facilitate characterization of structural controls, this study will focus primarily on representative fields in the Basin and Range of northern Nevada and the *central* Walker Lane, as most areas in and near the *northern* Walker Lane have generally been addressed in our previous and ongoing work (e.g. Desert Peak, Brady's, Astor Pass-Needle Rocks at Pyramid Lake, Salt Wells, Lee Hot Springs, Gerlach). In the "northern Nevada Basin-Range", NNE-striking normal faults dominate but locally link with ENE-striking oblique slip faults (left-lateral and normal) in the Humboldt structural zone (Rowan and Wetlaufer, 1980; Faulds et al., 2003). Only a few fields (e.g. Dixie Valley and Rye Patch) in this region have been studied in detail (e.g. Blackwell et al., 2002; Johnson and Hulen, 2002; Waibel et al., 2003; Wanamaker et al., 2006). Relatively unstudied fields include San Emidio, Fly Ranch, Blue Mountain, Kyle Hot Springs, Jersey Valley Hot Springs, Colado, Tungsten Mountain (Edwards Creek Valley), and McGinness Hills

(Fig. 1). Similar to the Basin-Range, few fields have been analyzed in detail in the central Walker Lane (e.g. Hulen et al., 2005); little studied fields include Wabuska, Teels Marsh, Rhodes Marsh, and Aurora. We anticipate studying 1-2 representative fields each in the central Walker Lane and northern Nevada Basin-Range.

Although many fields were initially studied in the 1970-1980's (e.g. Benoit et al., 1982; Keller and Grose, 1978), much has since been learned about the 3D geometry of normal fault systems and regional tectonics of the Great Basin and Walker Lane (e.g. Wernicke, 1992; Faulds and Stewart, 1998; Oldow et al., 2001; Bennett et al., 2003; Faulds et al., 2005a, b). Techniques have also been developed or greatly refined for determining slip sense on faults (Angelier et al., 1985; Petit, 1987), deducing principal strain and stress axes from slip data (Marrett and Allmendinger, 1990), and quantitative modeling of fault interactions (Willemse et al., 1996; Crider and Pollard, 1998; Maerten et al., 2000; Davatzes et al., 2005). In light of these advances, a closer look at many 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 control in ~75% of geothermal fields in Nevada. This control is strongest for high temperature systems (Coolbaugh et al., 2002; Faulds et al., 2004). In the northwestern Great Basin, where the extension direction trends WNW, controlling faults generally strike NNE orthogonal to the extension direction. A closer look at individual fields reveals that the controlling NNE-striking faults typically dip moderately to steeply, as at Dixie Valley (Blackwell et al., 1999; Johnson and Hulen, 2002; Wannamaker, 2003), Rye Patch (Waibel et al., 2003), Brady's, Desert Peak (Benoit et al., 1982; Faulds et al., 2003), Salt Wells, and Gerlach (Faulds et al., 2006). A critical question is what portions of faults (e.g. tip vs. displacement maxima) are most favorable for geothermal activity. Many fields occupy discrete steps in fault zones or lie in belts of intersecting, overlapping, and/or terminating faults (Fig. 2; Curewitz and Karson, 1997; Faulds et al., 2006). Multiple fault splays in such areas increase fracture density and provide favorable channelways for geothermal plumes.

Interactions in complex fault systems produce local variations in stress that control the distribution and type of structures that accommodate strain near faults (Bourne and Willemse, 2001; Maerten et al., 2000; 2006; Davatzes et al., 2005) and host fluid flow along faults (Eichhubl et al., 2002, 2004; Micklethwaite and Cox, 2004). Mechanical interaction is also manifested in subtle variations of the slip distribution on faults revealed by detailed mapping and numerical analysis (Willemse et al., 1996; Willemse, 1997; Maerten et al., 1999, 2002; Maerten, 2000). Such analyses can also use these features to distinguish the most plausible fault model (Davatzes et al., 2005; Muller and Aydin, 2005) and identify regions of high strain. For example, high permeability zones that favor fluid flow in fault systems can be predicted by identifying locations of paleo-rupture arrest, which correspond to areas of aftershocks and multiple interconnecting fault splays. Such areas commonly occupy discrete stepovers or reversals in the dominant dip direction of normal fault systems (Roberts and Jackson, 1991; Faulds and Varga, 1998).

Thus, our investigation employs both numerical analyses and the geometry-kinematics established by field-based studies to model how faults control the distribution of geothermal systems. We stress that relatively few fields in the Great Basin have been studied in detail. To better characterize the favorable areas for geothermal activity and thus refine exploration and EGS strategies, it is therefore imperative both to analyze more fields in detail and to model characteristic fault interactions. This is especially important because the bulk of the geothermal resources may have no surface expression (Coolbaugh et al., 2006c).

Work Plan

We will conduct structural analyses and modeling on ~4 fields in the Walker Lane and Great Basin, as well as detailed reconnaissance on several additional fields. We have already or are currently conducting studies of the Desert Peak, Brady's, Desert Queen, Needle Rocks-Astor Pass, Salt Wells, Lee-Allen Hot Springs, Gerlach, and Blue Mountain geothermal fields. This work will be conducted by Drs. James Faulds (UNR), Nicholas Davatzes (USGS), Mark Coolbaugh (UNR), and Gary Oppliger (UNR). Faulds is a field-based structural geologist who has ~20 years experience in analyzing complex parts of the Great Basin through detailed mapping, structural analysis, and paleomagnetic studies. Davatzes is a quantitative structural geologist with a background in geomechanics, *in situ* stress measurement, and numerical modeling of fault interactions with ~8 years experience. Coolbaugh is an economic geologist and GIS specialist with over 20 years experience in the region. Oppliger is a geophysicist who also has over 20 years experience in the Great Basin. Graduate students at UNR will conduct some of the research. Faulds will coordinate the overall project and supervise the students.

Field-Based Studies: The field-based structural investigations will involve 1) detailed geologic mapping (1:24,000 scale) or reconnaissance of bedrock, sinter, silicified deposits, argillic alteration, hot springs, fumaroles, and other surface thermal features in and near the fields; 2) delineation of stratigraphy; 3) analysis of fault geometries and kinematics; and 4) $^{40}Ar/^{39}Ar$ dating and tephra-chronology. The goals of this work are to a) delineate the structural controls of each geothermal field, b) elucidate possible relations between stratigraphy and geothermal reservoirs, and c) define the extent of the reservoirs. The structural studies will focus on several new fields that reside within or near good bedrock exposures (Fig. 1; e.g. San Emidio, Fly Ranch, McGinness Hills, Tungsten Mountain, Blue Mountain, and potential field at Rhodes Marsh). However, some additional work on well cuttings and fault zones will also be conducted in the Desert Peak area in order to facilitate the new EGS study.

The mapping, structural analysis, and geophysical studies will constrain the geometry of controlling faults. The kinematics will be determined from geometric patterns at the macroscopic and mesoscopic scale and examination of exposed fault surfaces. Slip sense will be gleaned from such surfaces through analysis of various features, including fault striae (slickenlines), 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), which yield principal strain axes for each fault set.

Faulds and Coolbaugh will conduct the field-based studies, 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 and compiling data bases of available subsurface data.

Structural Modeling: The mechanical investigation will involve (Fig. 3): 1) integration of the field-based and geophysical studies into a 3D model of fault geometry; 2) establishing boundary conditions for remote loads driving deformation, the physical behavior of the meshed fault surfaces (e.g. friction), and mechanical properties of rock masses; 3) testing and refinement of numerical simulations against independent indicators of displacement and macroscopic structures accommodating strain; 4) deducing relations between simulated displacement, stress, and strain with independent evidence for fluid-flow history along key well-understood geothermal systems; 5) exploring critical parameters identified from comparison of simulated variations in displacement, stress, and strain with the geologic data in a sensitivity analysis. Steps 1 through 4 ensure use of a geologically valid model of fault behavior for understanding how stress/strain due to fault slip impacts the distribution, generation, and maintenance of permeable pathways necessary for a geothermal system. Step 5 identifies key controlling parameters and establishes criteria for exploration and targeting of well sites.

Boundary element methods provide an excellent, numerically efficient means for studies in which fault geometry, displacements, and stress or strain are key parameters. Fully 3-D numerical solutions will be obtained using Poly3D (Thomas, 1993), a boundary element code based on the displacement-discontinuity method. In this program a fault is defined by boundary surfaces discretized into triangular dislocations in a quasi-static, linear elastic, homogeneous, and isotropic half-space. The code has been extensively validated against analytical solutions and physical simulations. The triangular mesh permits production of complex fault geometries.

Davatzes will conduct the numerical simulations, with assistance from graduate students. To expeditiously contribute to exploration strategies, the mechanical investigation will initially focus on previously studied geothermal fields (e.g. Desert Peak, Brady’s, Salt Wells), where fault geometries and kinematics have already been well defined. Special emphasis will be placed on modeling faulter interactions in the Desert Peak area, which will greatly elucidate stress-strain relations at the Desert Peak EGS site. Anticipated contributions from this work include 1) elucidating relations between NNE-striking normal faults and regional stresses/strains; 2) establishing whether regions of enhanced dilatancy along faults coincide with geothermal activity; 3) predicting distributions and magnitudes of dilation, which might be critical to establishing/maintaining fluid flow; 4) defining geometries required to establish tall, vertically connected zones of fluid flow, and 5) determining which areas are most favorable for EGS development.

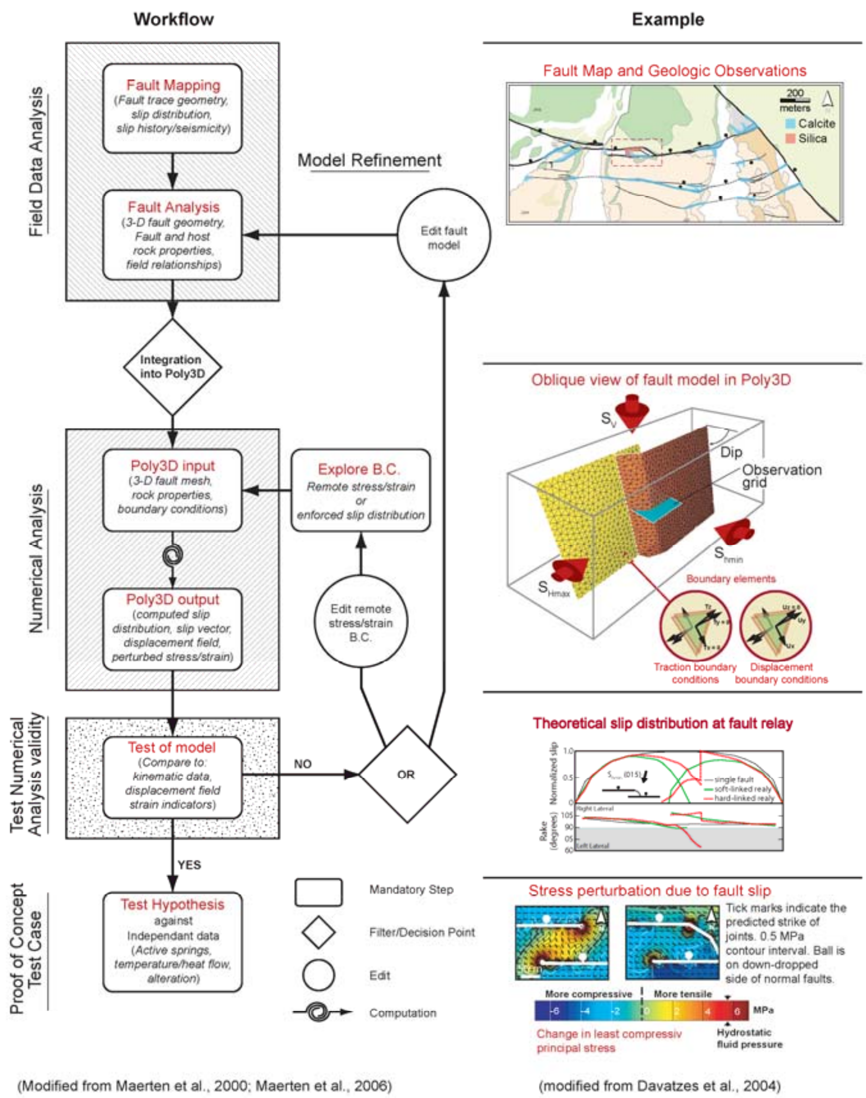

Figure 3. Workflow of numerical analyses from Moab fault, Utah (Davatzes *et al.*, 2005). Analysis involves 1) field constraints on fault geometry, 2) definition of boundary conditions, 3) computation of displacements, 4) calculation of stresses/strains, testing simulated results against field data, 5) model refinement, and 6) identification and analysis of critical controlling parameters.

Geophysical Studies: Local-scale gravity investigations of geothermal fields can elucidate the underlying structure that might otherwise require extensive drilling (Blackwell et al., 1999). Regional compilations of 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 combine detailed and regional gravity analysis and produce interpretations to support the structural analysis and modeling.

In Year 1, 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. The student will collect at least 15 field days of gravity data in each year. 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, and the data will be reduced using the Geosoft Xcelleration package and analyzed using Fourier transform-based potential field processing tools.

Oppliger is responsible for the final gravity map and interpretive products in the second year. This will include a suite of derived geophysical products, including depth to basement, deep regional structure, and shallow local structure. These products will integrate recent gravity studies and compilations (Oppliger et al., 2002; Faulds et al., 2003). We will also seek additional industry data contributions. The available aeromagnetic data is generally of low resolution, so it will apply only to the regional analyses.

GIS Database Compilations: For each studied field (~6-8 total), available geographic, geologic, geochemical, subsurface (temperature-gradient and lithologic well data), and geophysical data will be compiled in digital format and combined in GIS databases to permit integrated analysis of structural and geothermal features. Where available, maps of strain rates (derived from GPS station velocities), InSAR ground displacement images, earthquake epicenters, and regional-scale geothermal favorability maps may also be included. These databases will facilitate a cross-disciplinary analysis of the relations between structural settings and geothermal systems and may also permit 3D visualization of some fields. This work will be carried out by Coolbaugh and Gary Johnson (GIS Specialist at Nevada Bureau of Mines and Geology), with assistance from graduate-undergraduate students. The GIS labs at UNR are equipped with the latest GIS software that allows modeling, analysis, and 3D visualization. The labs utilize ArcView, IDRISI, ENVI, and Arc/Info GIS and image processing software, as well as other sophisticated software that permits 3D visualization (3DMove, GOCAD, and GeoModeller).

DELIVERABLES AND SCHEDULE

The deliverables are listed below, with period of work and completion date (month/year) in parentheses.

1. Gravity collection, one geothermal field by graduate student (Year 1).
2. Reconnaissance maps, ~1-2 fields in northern Nevada Basin-Range (Year 1).
3. 3-D models of fault geometry for numerical analysis (Year1).
4. Detailed geologic map-cross sections, 2 fields in northern Nevada Basin-Range (Year 1).
5. GIS databases of ~1-2 geothermal fields in northern Nevada Basin-Range (Year 1).
6. Numerical modeling of fault slip, stresses, and strains for 1-2 critical settings ()
7. Gravity collection, ~1-2 additional fields by graduate students (Year 2).
8. Reconnaissance maps, ~1-2 fields in central Walker Lane (Year 2, 9/09).
9. Detailed geologic map-cross sections of selected fields in central Walker Lane (Year 2).
10. GIS databases of ~1-2 mainly in central Walker Lane (Year 2).
11. Complete structure and bedrock relief products from geophysical data (Year 2).
12. Suggested drilling targets in analyzed geothermal fields (Years 1-2).
13. Publication in GRC, Stanford workshop, and peer-reviewed journals (9/08, and 9/09).
14. All required quarterly-annual reports for GBCGE and/or Department of Energy (Years 1-2).

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. An additional grant was awarded in 2005 to Faulds, Coolbaugh, and Oppliger to characterize structural controls on geothermal fields in the northern Walker Lane and northern Great Basin through integrated structural and geophysical analyses.

Work at Desert Peak and Brady's began in May 2002 and was completed in December 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, $^{40}Ar/^{39}Ar$ dating, geochemical correlation of key units, and a paleomagnetic investigation (16 sites, ~130 samples). The main objectives were to a) delineate the late Cenozoic 3D strain field, b) elucidate relations between faults, stratigraphic features, and thermal aquifers, and c) constrain strain and stress orientations. Also, a new Gravity survey was completed (>500 stations) that revealed 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 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 in 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 normal faults (Faulds et al., 2002, 2003). This work was then synthesized into a regional assessment of the tectonic and structural controls of geothermal activity in the northern Great Basin (Faulds et al., 2004, 2005), 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.

The 2005 grant involved similar geologic and geophysical investigations of additional geothermal systems in both the northern Walker Lane and Basin and Range province, including fields at Salt Wells, Gerlach, Astor Pass-Needle Rocks in the Pyramid Lake area, Patua Hot Springs, and Lee-Allen Hot Springs. Work was also conducted ~10 km east of Desert Peak in the Desert Queen area of the Hot Springs Mountains, which has a structural setting very similar to several other geothermal fields in the region and may therefore contain a blind geothermal system. Analyses of these fields has shown that geothermal systems are commonly focused within stepovers in normal-fault systems at fault intersections, and in belts of overlapping and terminating normal faults (Faulds et al., 2006). Also, a shallow temperature survey at Desert Queen has documented two major thermal anomalies that bode well for a significant geothermal system at depth (Coolbaugh et al., 2007). As part of this grant, we also conducted a comparison of the trends of controlling structures between young (<~7 Ma) epithermal mineral deposits and geothermal systems in the Great Basin, and we found a strong correspondence in trends between the two (Faulds et al., 2005a, b; Coolbaugh et al., 2005a, b).

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

Characterizing Structural Controls of Geothermal Fields in the Great Basin and Walker Lane: To be presented at the monthly meeting of the Nevada Petroleum Society (scheduled for April 5, 2007).

Cenozoic Extension and Structural Controls of Geothermal Systems in the Hot Springs Mountains, Western Nevada, USA: B.R.G.M., Orleans, France (Nov 2006).

Geologic and Geophysical Analyses of Geothermal Fields in the Northwestern Great Basin, Western USA: Characterizing Structural and Tectonic Controls: ENGINE Workshop (Enhanced Geothermal Innovative Network for Europe), Potsdam, Germany (Nov. 2006).

*Characterizing Structural Controls of Geothermal Fields in the Northwestern Great Basin: A Progress Report: Geothermal Resources Council Annual Meeting, San Diego (Sept 2006). *Won **Best Paper Award** for this session.

Cenozoic extension and structural controls of geothermal systems in the Hot Springs Mountains, western Nevada: Geological Society of America Cordilleran Section Meeting, Fairbanks, AK (May 2006).

*Influence of the late Cenozoic strain field and tectonic setting on geothermal activity and mineralization in the northwestern Great Basin: Geothermal Resources Council Annual Meeting, Reno (Sept 2005). *Won **Best Paper Award** for this session.

Late Cenozoic Strain Field and Tectonic Setting of the Northwestern Great Basin, Western USA: Implications for Geothermal Activity and Mineralization: Geological Society of Nevada Symposium, Reno, Nevada, Invited talk (May 2005).

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 previous support from the Great Basin Center for Geothermal Energy.

Coolbaugh, M.F., Arehart, G.B., Faulds, J.E., and Garside, L.J., 2005a, Geothermal systems in the Great Basin, western United States: Modern analogues to the roles of magmatism, structure, and regional tectonics in the formation of gold deposits: Geological Society of Nevada Symposium, p. 1063-1082.

Coolbaugh, M.F., Arehart, G.B., Faulds, J.E., Garside, L.J., and Shevenell, L.A., 2005b, Active geothermal systems and associated gold deposits in the Great Basin: Geothermal Resources Council Transactions, v. 29, p. 215-222.

Coolbaugh, M.F., Faulds, J.E., Kratt, C., Oppliger, G.L., Shevenell, L., Calvin, W., Ehni, W.J., and Zehner, R.E., 2006, Geothermal potential of the Pyramid Lake Paiute Indian Reservation, Nevada, USA: Evidence of previously unrecognized moderate temperature (150-170^{o}C) geothermal systems: Geothermal Resources Council Transactions, v. 30, p. 59-68.

Coolbaugh, M.F., Sladek, C., Kratt, C., Shevenell, L., and Faulds, J., 2006, Surface indicators of geothermal activity at Salt Wells, Nevada, USA, including warm ground, borate deposits, and siliceous alteration: Geothermal Resources Council Transactions, v. 30, p. 399-406.

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.

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., 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, v. 28, p. 649-654.

Faulds, J.E., Coolbaugh, M., Henry C.D., and Blewitt, G., 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 Abstracts with Programs, v. 36, p. 27.

Faulds, J.E., Henry, C.D., Coolbaugh, M.F., Garside, L.J., and Castor, S.B., 2005, Late Cenozoic Strain Field and Tectonic Setting of the Northwestern Great Basin, Western USA: Implications for Geothermal Activity and Mineralization: Geological Society of Nevada Symposium, p. 1091-1104.

Faulds, J.E., Henry, C.D., Coolbaugh, M.F., and Garside, L.J., 2005, Influence of the late Cenozoic strain field and tectonic setting on geothermal activity and mineralization in the northwestern Great Basin: Geothermal Resources Council Transactions, v. 29, p. 353-358.

Faulds, J.E., Garside, L., Oppliger, G., and Perkins, M., 2006, Cenozoic extension and structural controls of geothermal systems in the Hot Springs Mountains, western Nevada: Geological Society of America Abstracts with Programs, v. 38, no. 5, p. 79.

Faulds, J.E., Coolbaugh, M.F., Vice, G.S., and Edwards, M.L., 2006, Characterizing Structural Controls of Geothermal Fields in the Northwestern Great Basin: A Progress Report: Geothermal Resources Council Transactions, v. 30, p. 69-76.

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.

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.

Shevenell, L., Coolbaugh, M., Faulds, J., Oppliger, G., Calvin, W., Blewitt, G., Kratt, C., Arehart, G., Sladek, C., Lechler, P., Garside, L., and Zehner, R., 2005, Accomplishments of the Great Basin Center for Geothermal Energy: Geological Society of Nevada Symposium, p. 1131-1146.

Vice, G.S., Faulds, J.E., Ehni, W.J., and Coolbaugh, M.F., 2006, Characterizing the structural controls of the Terraced Hills-Astor Pass geothermal system, northwestern Nevada: Geological Society of America Abstracts with Programs, Rocky Mountain Section meeting for May 2007, in press.

REFERENCES CITED

Angelier, J., Colletta, B., Anderson, R.E., 1985, Neogene paleostress changes in the Basin and Range; a case study at Hoover Dam, Nevada-Arizona: Geological Society of America Bulletin, v. 96, p. 347-361.

Barton, C.A., Zoback, M.D., and Moos, D., 1995, Fluid flow along potentially active faults in crystalline rock: *Geology*, v. 23, no. 8, p. 683-686.

Barton C.A., Hickman, S., Morin, R., Zoback, M.D., and Benoit, D., 1998, Reservoir-scale fracture permeability in the Dixie Valley, Nevada, Geothermal Field: PROCEEDINGS, Twenty-Third Workshop on Geothermal Reservoir Engineering, SGP-TR-158, Stanford University, Stanford, California, January 26-28, 8 p.

Bennett, R.A., Wernicke, B.P., Niemi, N.A., Friedrich, A.M., and Davis, J.L., 2003, Contemporary strain rates in the northern Basin and Range province from GPS data: Tectonics, v. 22, no. 2, p. 3-1 – 3-31.

Benoit, W.R., Hiner, J.E., and Forest, R.T., 1982, Discovery and geology of the Desert Peak geothermal field: A case history: Nevada Bureau of Mines and Geology Bulletin 97, 82 p.

Blackwell D, Wisian K, Benoit D, Gollan B., 1999, Structure of the Dixie Valley Geothermal System, a “Typical” Basin and Range Geothermal system, From Thermal and Gravity Data: Geothermal Resource Council Transactions, v. 23, p. 525-531.

Blackwell, D.D., Leidig, M., and Smith, R.P., and Johnson, S.D., 2002, Exploration and development techniques for Basin and Range geothermal systems: Examples from Dixie Valley, Nevada: Transactions Geothermal Resource Council, v. 26, p. 513-518

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.

Bourne, S.J., and Willemse, E.J.M., 2001, Elastic stress control on the pattern of tensile fracturing around a small fault network at Nash Point, UK: Journal of Structural Geology, v. 23, p. 1753–1770.

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.

Coolbaugh, M.F. and Shevenell, L.A., 2004, A method for estimating undiscovered geothermal resources in Nevada and the Great Basin: Geothermal Resources Council Transactions, v. 28, p. 13-18.

Coolbaugh, M.F. and Bedell, R., 2005a, 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., 2005b, Geothermal systems in the Great Basin, western United States: Modern analogues to the roles of magmatism, structure, and regional tectonics in the formation of gold deposits, *in* Rhoden, H.N., Steininger, R.C., and Vikre, P.G., eds., Geological Society of Nevada Symposium 2005: Window to the World, Reno, Nevada, May 2005, p. 1063-1082.

Coolbaugh, M., Zehner, R., Kreemer, C., Blackwell, D., Oppliger, G., Sawatzky, D., Blewitt, G., Pancha, A., Richards, M., Helm-Clark, C., Shevenell, L., Raines, G., Johnson, G., Minor, T., and Boyd, T., 2005c, Geothermal potential map of the Great Basin, western United States: Nevada Bureau of Mines and Geology Map 151.

Coolbaugh, M.F., Faulds, J.E., Kratt, C., Oppliger, G.L., Shevenell, L., Calvin, W., Ehni, W.J., and Zehner, R.E., 2006a, Geothermal potential of the Pyramid Lake Paiute Indian Reservation, Nevada, USA: Evidence of previously unrecognized moderate temperature (150-170^{o}C) geothermal systems: Geothermal Resources Council Transactions, v. 30, p. 59-68.

Coolbaugh, M.F., Sladek, C., Kratt, C., Shevenell, L., and Faulds, J., 2006b, Surface indicators of geothermal activity at Salt Wells, Nevada, USA, including warm ground, borate deposits, and siliceous alteration: Geothermal Resources Council Transactions, v. 30, p. 399-406.

Coolbaugh, M.F., Raines, G.L., Zehner, R.E., Shevenell, L., and Williams, C.F., 2006c, Prediction and discovery of new geothermal resources in the Great Basin: Multiple evidence of a large undiscovered resource base: Geothermal Resources Council Transactions, v. 30, p. 867-873.

Crider, J., and Pollard, D., 1998, Fault linkage: Three dimensional mechanical interaction between echelon normal faults: Journal of Geophysical Research, v. 103, p. 24,373–24,391.

Curewitz, D. and Karson, J.A., 1997, Structural settings of hydrothermal outflow: Fracture permeability maintained by fault propagation and interaction: Journal of Volcanology and Geothermal Research, v. 79, p. 149-168.

Davatzes, N.C., Eichhubl, P., and Aydin, A., 2005, Structural evolution of fault zones in sandstone by multiple deformation mechanisms: Moab fault, SE Utah: Geological Society of America Bulletin, v. 117, no. 1/2, p. 135-148.

Eichhubl, P., Davatzes, N. C., and Aydin, A., 2002, Diagenetic sealing of fault-controlled hydrocarbon migration pathways: The Moab fault, SE Utah, USA.: 18th General Meeting of the International Mineralogical Association Program with Abstracts, p. 301.

Eichhuble, P., Davatzes, N.C., and Aydin, A., 2004, Fault architecture fluid flow and cementation: The Moab Fault, Utah, USA., in Geofluids IV, Extended Abstracts, 13 p.

Fairley, J.P., and Hinds, J.J., 2004, Rapid transport pathways for geothermal fluids in an active Great Basin fault zone: Geology, v. 32, no. 9, p. 825-828.

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.

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., 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.

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.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., 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.

Faulds, J.E., Henry, C.D., Coolbaugh, M.F., Garside, L.J., and Castor, S.B., 2005a, Late Cenozoic Strain Field and Tectonic Setting of the Northwestern Great Basin, Western USA: Implications for Geothermal Activity and Mineralization, *in* Rhoden, H.N., Steininger, R.C., and Vikre, P.G., eds., Geological Society of Nevada Symposium 2005: Window to the World, Reno, Nevada, May 2005, p. 1091-1104.

Faulds, J.E., Henry, C.D., and Hinz, N.H., 2005b, Kinematics of the northern Walker Lane: An incipient transform fault along the Pacific – North American plate boundary: Geology, v. 33, no. 6, p. 505-508.

Faulds, J.E., Coolbaugh, M.F., Vice' G.S., and Edwards, M.L., 2006, Characterizing Structural Controls of Geothermal Fields in the Northwestern Great Basin: A Progress Report: Geothermal Resources Council Transactions, v. 30, p. 69-76.

Hammond, W.C., and Thatcher, W., 2004, Contemporary tectonic deformation of the Basin and Range province, western United States: 10 years of observation with the Global Positioning System: Journal of Geophysical Research, v. 109, B08403, doi: 10.1029/2003JB002746.

Hulen, J.B., Nash, G.D., and Deymonaz, J., 2005, Geology of the Emigrant geothermal prospect, Esmeralda County, Nevada: Geothermal Resources Council Transactions, v. 29, p. 369-380.
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.
Keller, G.V., and L.T. Grose, eds., 1978, Studies of a Geothermal System in Northwestern Nevada - Part 1: Colorado School of Mines Quarterly, v.73, no.3, 84 p.
Maerten, L. Pollard, D.D., and Karpuz, R., 2000, How to constrain 3-D fault continuity and linkage using reflection seismic data: A geomechaical approach: American Association of Petroleum Geologists Bulletin, v. 84, no. 9, p. 1311-1324.
Maerten, L. Gillespie, P, and Daniel, J.-M., 2006, Three-dimensional geomechanical modeling for constraint of subseismic fault simulation: American Association of Petroleum Geologists Bulletin, 90, no. 9, p. 1337-1358.
Maerten, L., 2000, Variation in slip on intersecting normal faults: Implications for paleostress inversion: Journal of Geophysical Research, v. 105, p. 25,553– 25,565.
Maerten, L., E. J. M. Willemse, D. D. Pollard, and K. Rawnsley, 1999, Slip distributions on intersecting normal faults: Journal of Structural Geology, v. 21, p. 259– 271.
Maerten, L., P. Gillespie, and D. D. Pollard, 2002, Effect of local stress perturbation on secondary fault development: Journal of Structural Geology, v. 24, p. 145– 153.
Marrett, R., and Allmendinger, R.W., 1990, Kinematic analysis of fault-slip data: Journal of Structural Geology, v. 12, p. 973-986.
Micklethwaite, S., and Cox, S.F., 2004, Fault-segment rupture, aftershock-zone fluid flow, and mineralization: Geology, v. 32, no. 9, p. 813-816.
Muller, J., and Aydin, A., 2005. Using geomechanical modeling to constrain the fault geometry within the Marmara Sea, Turkey: Journal of Geophysical Research, v.110, B03407, p. 1-13.
Oldow, J. S., 1992, Late Cenozoic displacement partitioning in the northwestern Great Basin, *in* Structure, Tectonics and Mineralization of the Walker Lane, Stewart, J., ed., Walker Lane Symposium Proceedings Volume, Geological Society of Nevada, Reno, NV, p. 17-52.
Oldow, J.S., Aiken, C.L.V., Hare, J.L., Ferguson, J.F., and Hardyman, R.F., 2001, Active displacement transfer and differential block motion within the central Walker Lane, western Great Basin: Geology, v. 29, no. 1, p. 19-22.
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.
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.
Thomas, A.L., 1993, A three-dimensional, polygonal element, displacement discontinuity boundary element computer program with applications to fractures, faults, and cavities in the Earth's crust [M.S. thesis]: Stanford, California, Stanford University, 221 p.
Vice, G.S., Faulds, J.E., Ehni, W.J., and Coolbaugh, M.F., 2006, Characterizing the structural controls of the Terraced Hills-Astor Pass geothermal system, northwestern Nevada: Geological Society of America Abstracts with Programs, Rocky Mountain Section meeting for May 2007, in press.

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.

Wannamaker, P.E., Hasterok, D.P., and Doerner, W.M., 2006, Possible magmatic input to the Dixie Valley geothermal field, and implications for district-scale resource exploration, inferred from magnetotelluric (MT) resistivity surveying: Geothermal Resources Council Transactions, v. 30, p. 471-475.

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.

Willemse, E., Pollard, D.D., and Aydin, A., 1996, Three dimensional analyses of slip distributions on normal fault arrays with consequences for fault scaling: Journal of Structural Geology, v. 18, p. 295–309.

Willemse, E. J. M., 1997, Segmented normal faults: Correspondence between three-dimensional mechanical models and field data: Journal of Geophysical Research, v. 102, p. 675– 692.

Dr. James E. Faulds

Research Geologist/Graduate Faculty
Nevada Bureau of Mines and Geology
University of Nevada, Reno, NV 89557

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

Selected Recent Publications Related to Geothermal

Faulds, J.E., Coolbaugh, M.F., Vice, G.S., and Edwards, M.L., 2006, Characterizing Structural Controls of Geothermal Fields in the Northwestern Great Basin: A Progress Report: Geothermal Resources Council Transactions, v. 30, p. 69-76.

Coolbaugh, M.F., **Faulds, J.E**., Kratt, C., Oppliger, G.L., Shevenell, L., Calvin, W., Ehni, W.J., and Zehner, R.E., 2006, Geothermal potential of the Pyramid Lake Paiute Indian Reservation, Nevada, USA: Evidence of previously unrecognized moderate temperature (150-170^{o}C) geothermal systems: Geothermal Resources Council Transactions, v. 30, p. 59-68.

Faulds, J.E., Henry, C.D., Coolbaugh, M.F., and Garside, L.J., 2005, Influence of the late Cenozoic strain field and tectonic setting on geothermal activity and mineralization in the northwestern Great Basin: Geothermal Resources Council Transactions, v. 29, p. 353-358.

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.

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.

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: Geology, v. 33, no. 6, p. 505-508.

Faulds, J.E., Henry, C.D., Hinz, N.H., Drakos, P.S., and Delwiche, B., 2005, Transect Across the Northern Walker Lane, Northwest Nevada and Northeast California: An Incipient Transform Fault Along the Pacific – North American Plate Boundary, *in* Pederson, J., and Dehler, C.M., eds., Interior western United States: Geological Society of America Field Guide 6, p. 129-150, doi:10.1130/2005.fld006(06).

Faulds, J.E., Henry, C.D., Coolbaugh, M.F., Garside, L.J., and Castor, S.B., 2005, Late Cenozoic Strain Field and Tectonic Setting of the Northwestern Great Basin, Western USA: Implications for Geothermal Activity and Mineralization: Geological Society of Nevada Symposium, p. 1091-1104.

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. **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.

Professional Societies

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

Current Support

Bureau of Land Management: Clark County Geologic Mapping Program, $984,883, 9/01/06 to 8/31/09, Principal Investigator with J.Price and K.House as co-PI’s.

Department of Energy (DOE) through Great Basin Center for Geothermal Energy Office: Characterizing Structural Controls on Geothermal Systems in the Northwestern Great Basin through Integrated Geologic and Geophysical Analyses: $212, 823, 7/1/05 to 12/31/07, Principal Investigator (with G. Oppliger and M. Coolbaugh as co-PI’s).

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.

Dr. Nicholas C. Davatzes
Earthquake Hazards Team
U.S. Geological Survey
345 Middlefield Road, MS977
Menlo Park, CA 94025

Education

Ph.D. Stanford University, Structural Geology and Geomechanics, 2003
B.A. Bucknell University, Geology & Philosophy, 1998, Magna Cum Laude with Honors in Geology

Areas of Expertise

Disciplines: Structural geology, Fracture and fault mechanics, Geophysical well logging, Numerical modeling
Topical: Mechanical interaction of faults, geometry of fault systems, deformation mechanisms, fault mechanics, fault rock development, hydrology and slip behavior of fault zones, borehole stress analysis

Professional Experience

2005-Present - U.S. Geological Survey National Geothermal Resources Assessment
2004-Present - Mendenhall Postdoctoral Research Fellow, U.S. Geological Survey
2004 - Consultant Personnel Protection Technologies LLC: Algorithm development
2004 - Consultant Greystone Pictures: Countdown to Armageddon
2003-2004 - Stanford Rock Fracture Project Postdoctoral Fellow
2002 - Conoco Phillips Petroleum Company, Internship
2002 - British Petroleum Company (BP) well core study
1998, 1999 - Southwest Research Institute, Center for Nuclear Waste Regulatory Assessment, Internships

Miscellaneous Professional Activities

2007 - Chevron Corporation: Stress, faulting, and fluid flow in the Coso Geothermal Field; Insights into active processes from borehole logs.
2006 - DOE Sponsored Working Group: Exploration Research Planning Meeting:
2006 - Exploration Techniques Short Course: Geothermal Resources Council (GRC) Annual Meeting 2006: Structural Controls of Geothermal Systems.
2006 - Convener Stanford Geothermal Workshop special session on Coso Enhanced Geothermal Systems project
2006 - Energy Team, U.S. Geological Survey, Denver, CO: Invited Seminars: 1. The distribution and generation of fault rocks and fault properties along the Moab fault, Utah: Fluid flow and fault sealing. (Davatzes, N.C.); 2. Stress, Fault Rocks, and Fluid Flow: A complete system in the East Flank of the Coso Geothermal Field.
2006 - Shell Petroleum Company, Houston, TX: The distribution and generation of fault rocks and fault properties along the Moab fault, Utah.
2005 - Co-Convener AGU special session on Geothermal Energy
2004 - Fieldtrip leader, Sedimentology Research Group fieldtrip to Southern Nevada
2001 - Fieldtrip designer and Leader, Rock Fracture Project Field Workshop, Moab fault system, Utah
1999 - Fieldtrip designer and Leader, Rock Fracture Project Field Workshop, Waterpocket Monocline, Utah

Recent Publications Related to Geothermal and Fault Zone Hydrology

Rose, P., Hickman, S., McCulluch, J., **Davatzes, N.C.**, (along with 15 others), 2006, Creation of an Enhanced Geothermal System through Hydraulic and Thermal Stimulation. 237 pp.

Davatzes, N.C. and Hickman, S., 2006, Stress and Faulting in the Coso Geothermal Field: Update and Recent Results from the East Flank and Coso Wash, 31st Stanford University Workshop on Geothermal Engineering, January 30-February 1, SGP-TR-179, pp. 12

Davatzes, N.C. and Hickman, S., 2005, Controls on fault-hosted fluid flow: Preliminary results from the Coso Geothermal Field, California, *Geothermal Resources Council Transactions*, v. 19, p. 343-348.

Davatzes, N.C. and Hickman, S.H., 2005, Comparison of Acoustic and Electrical image logs from the Coso Geothermal Field, CA (30th Stanford University Workshop on Geothermal Reservoir Engineering, January 31 – February 2, 2005, SGP-TR-176, pp. 11.

Davatzes, N.C., Eichhubl, P., and Aydin, A., 2005, Structural evolution of fault zones in sandstone by multiple deformation mechanisms: Moab fault, SE Utah in *Geological Society of America Bulletin,* v. 117, no. 1/2, p. 135-148)

Davatzes, N.C. and Aydin, A., 2003, The formation of conjugate normal fault systems in folded sandstone by sequential jointing and shearing, Waterpocket Monocline, Utah, *Journal of Geophysical Research,* v 108(B10), p. 2478-2492

Davatzes, N.C., and Hickman, S., 2006, Stress and Faulting in the Coso Geothermal Field: Update and Recent Results from the East Flank and Coso Wash31st Stanford University Workshop on Geothermal Engineering, January 30-February 1, SGP-TR-179, pp. 12)

Selected Other Publications

Maerten, F., Maerten, L., **Davatzes, N. C.**, 2007, Poly3D boundary element code with inequality constraints: More potential to model natural structures, European Geophysical Union.

Davatzes, N.C. and Hickman, S., 2007, Stress and fault rock controls on fault zone hydrology, Coso Geothermal Field, CA. American Association of Petroleum Geologists (AAPG) 2007 National Meeting. ***Invited***.

Solum, J.G., **Davatzes, N.C.**, Lockner, D.A., 2007, Factors controlling the development and maintenance of fault seals in heterogeneous sedimentary rocks: A case study from the Moab Fault, Utah. American Association of Petroleum Geologists (AAPG) 2007 National Meeting.

Davatzes, N.C. and Hickman, S., 2006, Stress, faulting and fluid flow in the Coso Geothermal Field, CA. American Geophysical Union (AGU) 2006 National Meeting. # NG54A-01.

Lockner, D., Solum, J., and **Davatzes, N.C.**, 2006, The Effect of Brine Composition and Concentration on Strength of Expandable Clays. American Geophysical Union (AGU) 2006 National Meeting. # T31F-03.

Davatzes, A.E.K., Gulick, V.C., **Davatzes, N.C.**, 2006, Relationship of fault geometry to catastrophic outflow on Mars. American Geophysical Union (AGU) 2006 National Meeting. # P23B-0062.

Solum, J. G., **Davatzes**, **N. C.,** D. Lockner, 2006, Characterizing the formation of clay-bearing fault rocks: techniques and applications for understanding fault seal behavior**.** American Association of Petroleum Geologists (AAPG) 2006 National Meeting.

Davatzes, N.C. and Hickman, S.H., 2005, Fault rock mineralogy and fluid flow in the Coso Geothermal Field, CA. American Geophysical Union (AGU) 2005 National Meeting. # T23B-0546.

Davatzes, N.C., Solum, J.G., Lockner, D., Stanchits, S., 2005, Fault rock generation, frictional properties, and permeability in the Moab fault rocks, Utah. Geological Society of America Annual Meeting 2005 Abstracts with Programs. #226-6. ***Invited***.

Professional Affiliations

American Geophysical Union, Geological Society of America, American Association of Petroleum Engineers

Phi Beta Kappa, Sigma Xi

Current Support

- U.S. Geological Survey, National Geothermal Resources Assessment
- Department of Energy (DOE) Enhanced Geothermal Systems Project: “Creation of an Enhanced Geothermal System through Hydraulic and Thermal Stimulation: DE-FC07-01ID14186”

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 developed 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., Raines, G.L., and Zehner, R.E., accepted, Assessment of exploration bias in data-driven predictive models and the estimation of undiscovered resources: Natural Resources Research.

Coolbaugh, M.F. and Bedell, R., in press, 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: Geological Association of Canada Special Paper "GIS applications in the Earth Sciences".

Coolbaugh, M.F., Kratt, C., Fallacaro, A., Calvin, W.M., and Taranik, J.V., 2007, Detection of geothermal anomalies using Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) thermal infrared images at Brady's Hot Springs, Nevada, USA: Remote Sensing of Environment, v. 106, p. 350-359.

Coolbaugh, M.F., Faulds, J.E., Kratt, C., Oppliger, G.L., Shevenell, L., Calvin, W.M., Ehni, W.J., and Zehner, R.E., 2006, Geothermal potential of the Pyramid Lake Paiute Reservation, Nevada, USA: Evidence of previously unrecognized moderate-temperature (150-170°C) geothermal systems: Geothermal Resources Council Transactions, v. 30, p. 59-67.

Coolbaugh, M.F., Arehart, G.B., Faulds, J.E., and Garside, L.J., 2005, Geothermal systems in the Great Basin, western United States: Modern analogues to the roles of magmatism, structure, and regional tectonics in the formation of gold deposits, *in* Rhoden, H.N., Steininger, R.C., and Vikre, P.G., eds., Geological Society of Nevada Symposium 2005: Window to the World, Reno, Nevada, May 2005, p. 1063-1082.

Coolbaugh, M., Zehner, R., Kreemer, C., Blackwell, D., Oppliger, G., Sawatzky, D., Blewitt, G., Pancha, A., Richards, M., Helm-Clark, C., Shevenell, L., Raines, G., Johnson, G., Minor, T., and Boyd, T., 2005, Geothermal potential map of the Great Basin, western United States: NBMG Map 151.

Coolbaugh, M. F., Gustin, M. S., and Rytuba, J. J., 2002, Annual emissions of mercury to the atmosphere from natural sources in Nevada and California: Environmental Geology, v. 42, n. 4., p. 338-349.

Gray, J. E., and Coolbaugh, M. F., 1994, Geology and geochemistry of Summitville, Colorado: An epithermal acid sulfate deposit in a volcanic dome: Economic Geology, Special Issue on Volcanic Centers as Targets for Mineral Exploration, v. 89, no. 8, p. 1906-1923.

Gray, J. E., Coolbaugh, M.F., Plumlee, G. S., and Atkinson, W. W., 1994, Environmental geology of the Summitville Mine, Colorado: Economic Geology, Special Issue on Volcanic Centers as Targets for Mineral Exploration, v. 89, no. 8, p. 2006-2014.

Selected Current Geothermal Research

1) Revival of Grass-Roots Geothermal Exploration in the Great Basin (where to look for new geothermal fields) – A New Approach to Assessing Geothermal Potential using a Geographic Information System: Collaborators: Mark Coolbaugh, Rick Zehner, Corné Kreemer, Don Sawatzky, Gary Oppliger, David Blackwell, Lisa Shevenell, Jim Taranik, Gary L. Raines, and Jim Faulds: funded by DOE.

A geographic information system (GIS) is used to integrate diverse types of geologic, chemical, and physical information to predict not only where high-temperature geothermal systems are most likely to occur in the Great Basin, but also where such systems are most likely to remain hidden and undiscovered. Spatial analysis using weights-of-evidence and logistic regression is being used.

2) Geothermal Assessment of Pyramid Lake Paiute Reservation (PLPR) Lands: Collaborators: Lisa Shevenell, Mark Coolbaugh, Gary Oppliger, Jim Faulds, Wendy Calvin and John Louie: funded by the Pyramid Lake Paiute Tribe.

Reconnaissance geothermal exploration of the Pyramid Lake Paiute Reservation using state-of-the-art research tools including a geothermal GIS, hyperspectral remote sensing, detail magnetic and gravity geophysics, and new structural-tectonic interpretations.

3) Characterizing Structural Controls on Geothermal Systems in the Northwestern Great Basin through Integrated Geologic and Geophysical Analyses: Collaborators: James Faulds, Gary Oppliger, Mark Coolbaugh, Gary Johnson, and Melissa Edwards: funded by DOE.

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.

4) Satellite InSAR (Interferometric Synthetic Aperture Radar) Ground Displacement Analysis for Geothermal Reservoir Management and Development: Collaborators: Gary Oppliger, Mark Coolbaugh, Lisa Shevenell, Mike Widmer: funded by DOE.

Ground deformations mapped with InSAR are used to monitor production-induced changes in geothermal reservoirs and map structures controlling the flow of geothermal fluids.

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 elastic deformation analysis, 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. Academic funding: 0.5 FTE Arthur Brant Geophysics Chair.

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.
Member: American Geophysical Union; Member, Geological Society of America, Society of Exploration Geophysicist

Recent Conference Publications

Oppliger, G., M. Coolbaugh, and L. Shevenell. 2006, Improved visualization of satellite radar InSAR observed structural controls at producing geothermal fields using modeled horizontal surface displacements: *Geothermal Resources Council Transactions*, v. 30, p. 927-930.

Oppliger, G., M. Coolbaugh, L. Shevenell, J. Taranik, 2005, Elucidating deep reservoir geometry and lateral outflow through 3-D elastostatic modeling of satellite radar (InSAR) observed surface deformations: An example from the Brady's geothermal field: *Geothermal Resources Council Transactions*, v. 29, p. 419-424.

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*, v. 28, p. 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*, v. 27, p. 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,* v. 27, p. 9-13.

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*, v. 26 p. 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* v. 25 p. 627-630.

Oppliger, G. L., 1984, Three-Dimensional Terrain Corrections for Mise-a-la-masse and Magnetometric Resistivity Surveys: *Geophysics*, v. 49, n. 10; p. 1718-1729.

Current Research Support

So. Washoe Co. D-InSAR Archive, **PI: Oppliger,** OSPA #0612010, Sponsor: Washoe County, NV. Submitted May 2006, awarded Nov 2006.
New award for 2006-2009: $42,000

InSAR at Bradys-Desert Peak, **PI: Oppliger,** Coolbaugh, Shevenell, Taranik, OSPA # 2020443W, Sponsor: DOE, Sponsored Project #: DE-FG36-02ID14311, 03/20/02-09/30/07, Cumulative $275,500.
Renewed award for 2006-2007: $105,000

InSAR across the Sierra Nevada, PI: Bell J., **Oppliger,** G. , OSPA# 0511017, Sponsor: DOI-GS, (NHERP) funded, January 2006.
My part of new award for 2006-2007: $7,400

Characterizing Structural Controls on Geothermal Systems, PI: Faulds, J. , **Oppliger,** G., Coolbaugh, M., Johnson, G., and Edwards, M.. OSPA# 2020443AD, Sponsor: DOE, Project #: DE-FG36-02ID14311.
My part of new award for 2006-2007: $12,075

Grass-Roots Geothermal Exploration, Coolbaugh ,Zehner, Kreemer, Sawatzky, **Oppliger,** Blackwell, Shevenell, Taranik, Raines, Faulds. OSPA # 2020443T, Sponsor: DOE Project #: DE-FG36-02ID14311.
My part of new award for 2006-2007: $9540

Thesis committee chair/research advisor

Laura Huebner, M.S. Geophysics. Laura has a ARI geothermal fellowship involving a geophysical study at the UNR Redfield campus.

Niti Mankhemthong M.S. Geophysics. - Thesis project: a gravity study of the Fairview Peak – Dixie Valley, NV earthquake fault step-over.

Recent Collaborators: (not listed above) Michael Widmer

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 Science 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 a 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 ~45 days and Oppliger ~5 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), 15% for graduate students, 40% for classified staff (Johnson), and 2% for undergraduate students.

Travel: Travel expenses include mileage ($0.52/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.

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, GOCAD, and GeoModeller. Funds are requested for annual license fees for 3DMove and GeoModeller and purchasing the most recent version of Rockworks.
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 done at the University of Utah.
8. Registration costs are requested for Faulds and one graduate student to attend the 2007 and 2008 annual GRC meetings.

Tuition: Required for graduate-student research assistantships—currently @$113/credit.

Indirect Costs: The University of Nevada, Reno, calculates indirect cost at 40% for all items except tuition and equipment.

Subagreement with USGS, Menlo Park: Davatzes will conduct numerical simulations of fault behavior to investigate the potential relationships of fault mechanics and localized fluid flow. Davatzes anticipates including 1-2 graduate students in the numerical simulations including model building, testing of results against field observations (such as fault kinematics and 3-D structure from well logs and geophysics), and model refinement. Results from simulations will then be tested against independent constraints on fault zone hydrology such as hot ground, hydrothermal activity, alteration/mineralization, and the macroscopic structures in the vicinity of the fault zone. Requested funds cover salary for time on this project and travel to the field.