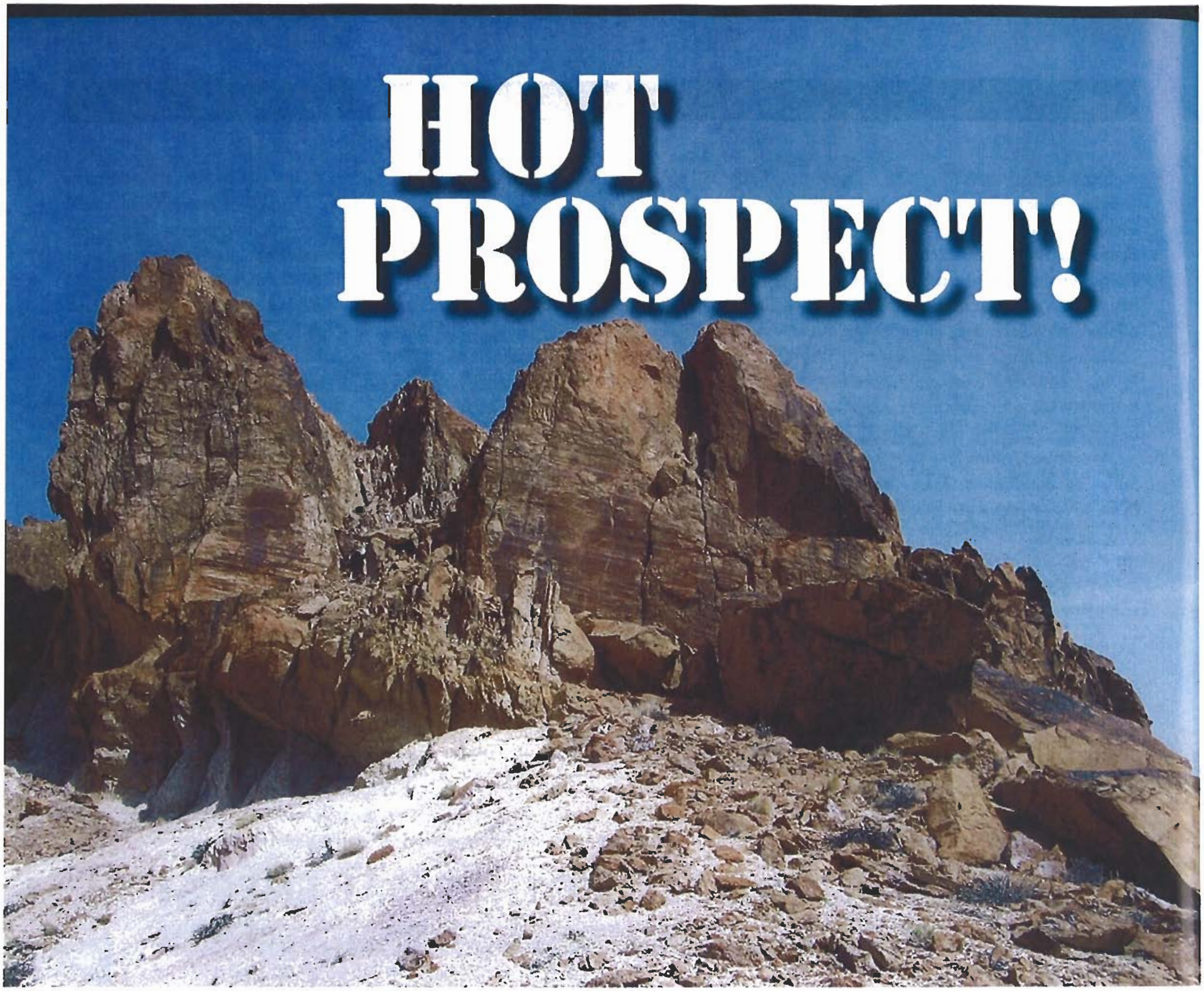


DOE Enables the Emigrant Geothermal Exploration and Slimhole Drilling Project in Fish Lake Valley, Nevada

By Jeffrey B. Hulen and Gregory D. Nash - EGI, University of Utah;
John Deymonaz – Fish Lake Green Power Co.; and Alex Schriener – Earth Systems Southwest

A key component of the Strategic Plan for the U.S. Department of Energy's (DOE) Geothermal Technologies Program is "...collaborative effort with industry to support exploration for and definition of new hydrothermal resources." To help implement this part of the Strategic Plan, the agency's Geothermal Resources Evaluation & Demonstration (GRED) Program assists industry in ameliorating the risks and costs of "greenfield" prospect evaluation.

Certainly among the most encouraging greenfield prospects yet to be meaningfully drill-tested in the western United States is the Emigrant property, at the northeastern edge of Nevada's famous Fish Lake Valley (Fig. 1). Detailed geologic mapping and data synthesis made possible by a GRED III grant to Esmeralda Energy Co. (EEC) have

Slickensided erosional remnant (klippe) of fractured, welded, Miocene ash-flow tuff (brownish-orange) in low-angle normal-fault contact with underlying, non-welded tuff (pale greenish- to purplish-gray) near the Emigrant geothermal prospect, Esmeralda County, Nevada. The fractured upper plates of these newly-recognized, regionally prevalent low-angle structures would be high-quality aquifers and geothermal-reservoir rocks in a deeply concealed, Emigrant geothermal system. View at the horizon is 60 m wide. Photo: Greg Nash confirmed the prospect's potential, and set the stage for slimhole core drilling into the upper reaches of a moderate- to high-temperature geothermal upflow plume. EEC and Fish Lake Green Power Co. (FL-GPC) are wholly owned subsidiaries of Geo-Energy Partners 1983 Ltd. (GEO-83).

Introduction

The Emigrant region's stellar geothermal potential was first recognized in the early 1980s by AMAX Exploration, Inc. (Deymonaz, 1984), when that company became aware of unusually high temperatures in shallow mineral-exploration boreholes being drilled at the time by U.S. Borax and Chemical Corp. AMAX entered into a cooperative agreement with Magma Power Co. (the leaseholder) and proceeded to drill additional, dedicated temperature holes. Shallow static thermal gradients in the U.S. Borax and AMAX holes locally exceeded 700° C/km to depths in excess of 100 m. Understandably encouraged by these numbers—and by the area's clearly favorable geologic setting—AMAX was poised to implement accelerated exploration and deep drilling of the Emigrant prospect when the company withdrew from all geothermal activities in 1984.

Magma shelved further exploration at Emigrant in favor of deep drilling at the nearby and now proven, commercially-producible Fish Lake geothermal system (Fig. 1). Magma was subsequently acquired by CalEnergy Co., which soon thereafter dropped the primary Emigrant leases. GEO-83 acquired these properties by filing for non-competitive lease applications in December 2000. Based on an evaluation of GEO-83's Emigrant database, Geothermex, Inc. (Richmond, CA - 2004) estimated that the property could be capable of producing 1,380 megawatt-years of electrical energy.

The Emigrant GRED III project has three phases: prospect evaluation and site characterization (Phase 1); slimhole drilling (Phase 2); and well testing (Phase 3). Phase 1, involving existing- data collation, classification, and synthesis as well as detailed geologic mapping, is well underway at this writing (August 2005). Drilling and well testing are to follow in 2006.

Phase 1 geologic mapping has revealed previously undocumented geologic features and relationships critical not only for drill-site selection, but for elaborating the unusual structural history of one of the most tectonically active regions in the United States. This article summarizes Phase 1 findings and

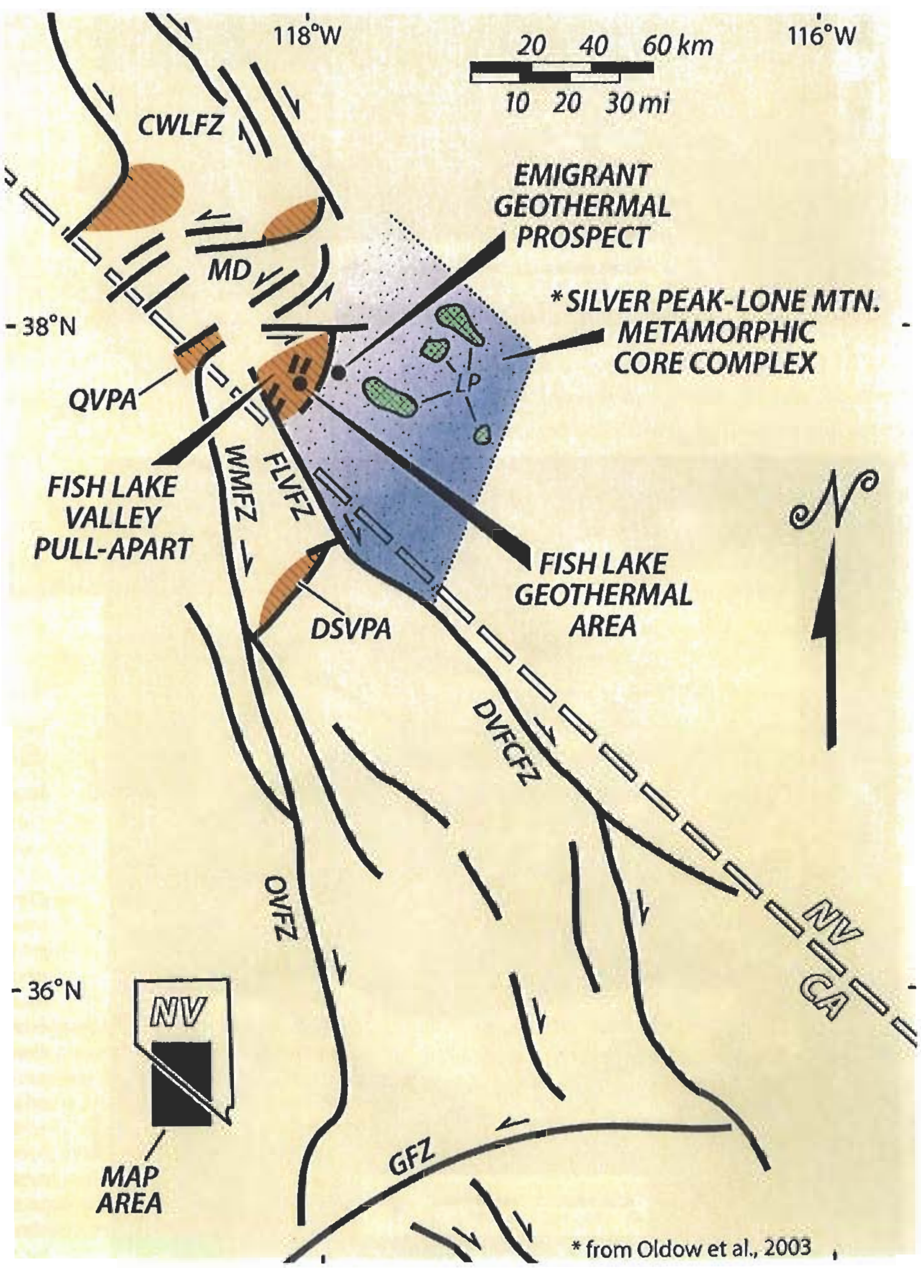


Figure 1 – Location map (generalized from Stockli et al., 2003) showing position of the Emigrant geothermal prospect relative to major structural elements of west-central Nevada and adjacent southeastern California. Bold black lines signify major high-angle fault zones, with arrows showing relative displacements. Lightly hatched, orange-colored areas highlight the Fish Lake Valley and other pull-aparts in the region. Crosshatched and green-colored areas show exposures of lower-plate (LP) tectonites in the middle to late Miocene Silver Peak-Lone Mountain metamorphic core complex (purple and light stipple; from Oldow et al., 2003). Additional abbreviations as follows: CWLFZ – Central Walker Lane fault zone; DSVPA – Deep Springs Valley pull-apart; DVFCFZ – Death Valley-Furnace Creek fault zone; FLVFZ – Fish Lake Valley fault zone; GFZ – Garlock fault zone; MD – Mina Deflection; OVFZ – Owens Valley fault zone; QVPA – Queen Valley pull-apart; WMFZ – White Mountains fault zone.

conclusions to date, and outlines the current drilling plan for penetrating the upper reaches of an Emigrant geothermal system at depth.

Geologic Setting

Fish Lake Valley occupies a classic "pull-apart" between two major dextral transcurrent fault zones: the Fish Lake Valley fault zone (FLVFZ) to the west; and the central Walker Lane to the east (Fig. 1; Reheis and Sawyer, 1997; Petronis et al., 2002; Stockli et al., 2003; Oldow et al., 2003). The pull-apart apparently began to form at about 6 Ma, following ostensible extinction of the southeast- adjoining, middle to late Miocene, Silver Peak-Lone Mountain (SPLM) metamorphic core complex (Oldow et al., 2003).

The FLVFZ, from which displacement is currently transferred eastward through the Fish Lake Valley pull-apart, has an integrated late Cenozoic slip rate of 5 mm/yr (Reheis and Sawyer, 1997). This slip speed makes the FLVFZ the single most active fault in the Great Basin. The kinematically coupled Fish Lake Valley pull-apart is only slightly less active (Reheis and Sawyer, 1997; see also references to the Emigrant Peak fault zone below), offering an ideal scenario for creation and frequent rejuvenation of fracture permeability in an Emigrant geothermal system.

Geology of the Emigrant Prospect

Because of its rapid erosional rate, sparse vegetation, excellent rock exposures, and key plate-tectonic significance, the Emigrant region had been geologically mapped many times in the past (see references in the foregoing section, as well as Albers and Stewart, 1972; and Robinson et al., 1976). However, none of the maps for these classic papers were sufficiently large-scale to permit effective drill-targeting for Phase 2 of this project. Accordingly, we geologically mapped the heart of the prospect at a scale of 1:4,000 (later consolidated to 1:10,000), with the aid of state-of-the-art

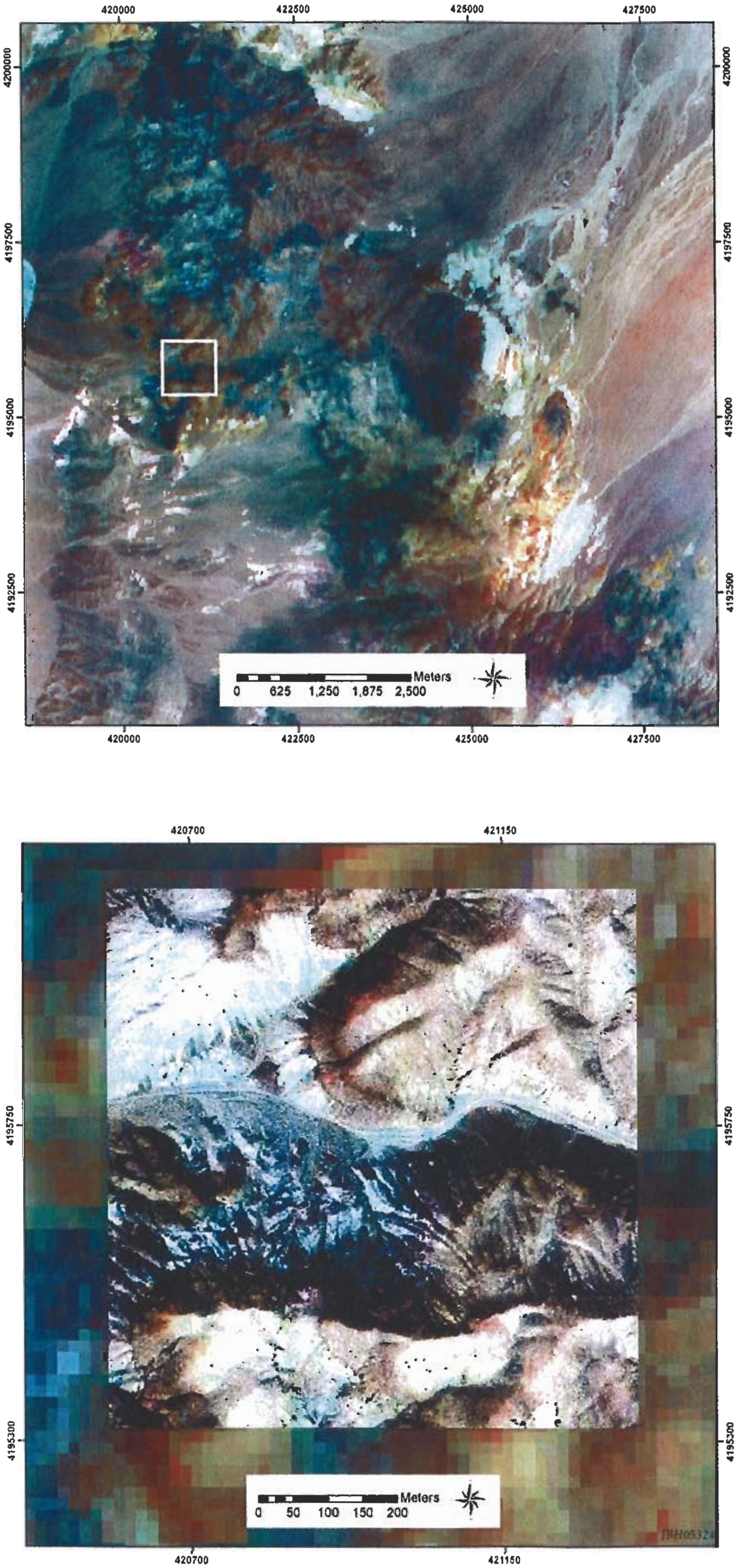


Figure 2 – A comparison of low-resolution ASTER imagery and the corresponding, high-resolution, fused panchromatic + ASTER imagery used to facilitate detailed geologic mapping for the Emigrant project. Top – 20-m-resolution ASTER imagery for the northern Silver Peak Range and a part of adjacent Fish Lake Valley to the west. Small, white-outlined square shows the area portrayed at larger scale below. Bottom – Enlargement of the white-bordered area showing fused panchromatic + ASTER imagery. The high-resolution (1-m) fused data retain virtually all of the advantages of the ASTER extravisual imagery. The fused image is surrounded, at the same scale, by adjoining pure-ASTER imagery to show the dramatic reduction in pixel size accomplished by the fusion.

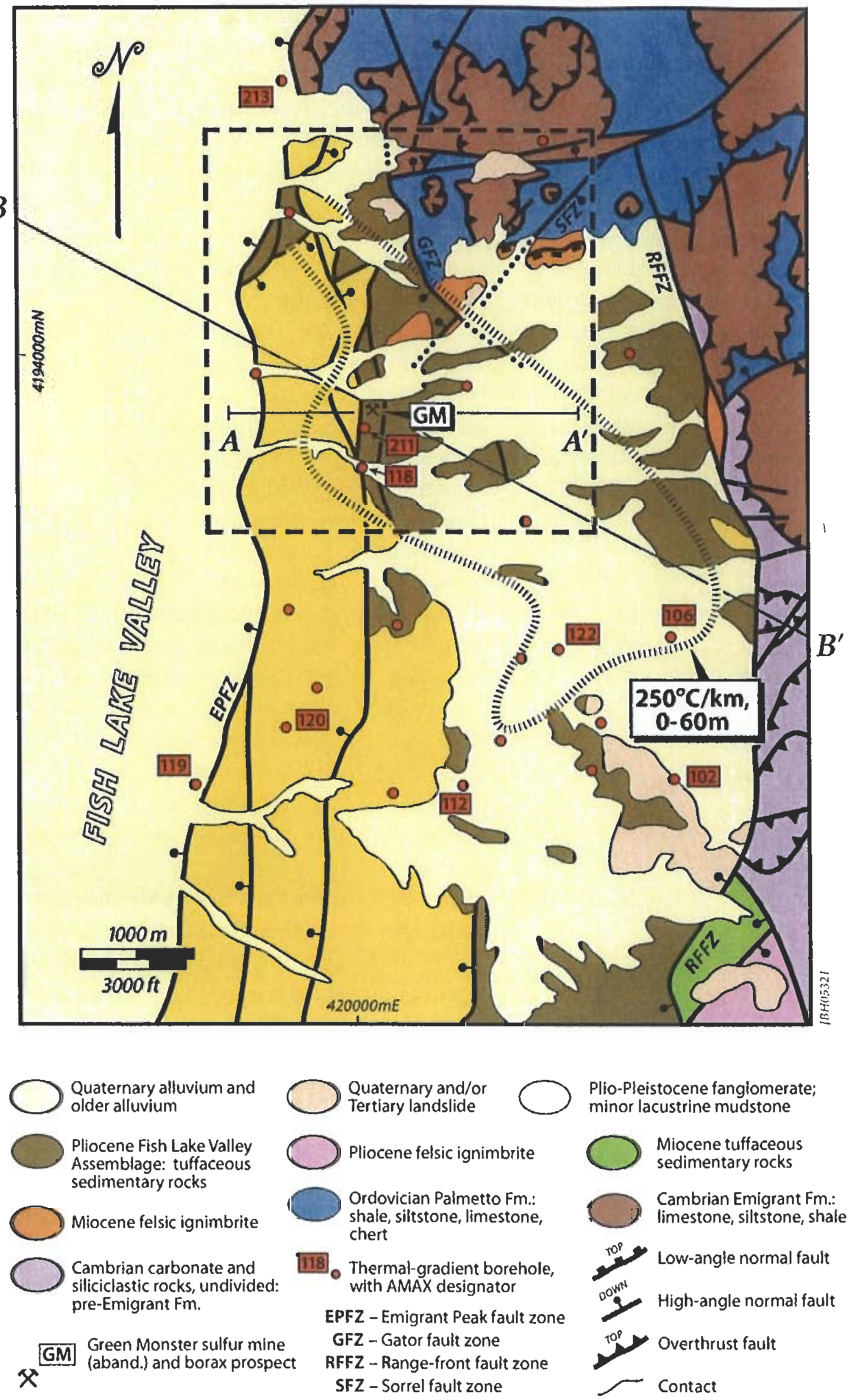


Figure 3 – Generalized geologic map of the Emigrant geothermal prospect and vicinity, illustrating, relative to major mapped faults, the northwest-trending, high-temperature nucleus of a broad, shallow, static thermal-gradient anomaly based on measurements made in 24 borax-exploration and dedicated-temperature boreholes. Dashed outline encloses that portion of the property: (1) geologically mapped by J. Hulen and G. Nash at 1:4000 for this investigation (see Hulen et al., 2005, for the detailed map); and (2) considered most favorable for drilling into a commercially viable, moderate- to high-temperature geothermal plume in the depth range 900-1300 meters. Geology beyond the borders of this area synthesized from Robinson et al. (1976; 1:62,500) and Reheis (1991; 1:24,000).

remote sensing technology, and with a focus on features most relevant to conceptual modeling of a geothermal system at depth. These include faults, fractures, fracture-amenable lithologies, active thermal phenomena, and hydrothermal alteration.

In preparation for the mapping, Greg Nash mathematically fused U.S. Geological Survey (USGS) Digital-Orthophoto-Quadrangle (DOQ) panchromatic imagery (1-m resolution) with selected spectral bands from the 15-30 m-resolution Advanced Spaceborne Thermal-Emission and Reflection Radiometer (ASTER). For details of the data-fusion process, refer to Hulen et al., 2005. Such fusion generates three-band imagery that can be printed as false-color composites with the fine-scale resolution of the panchromatic imagery and the extravisual imaging advantages of ASTER (Fig. 2). At minimal expense, the composites highlight rock types, structural trends, thermal features, and alteration that might otherwise readily escape detection.

The starkly exposed rocks of the Emigrant prospect occur within or rest upon the extensionally-attenuated upper plate of the SPLM core complex (Oldow et al., 2003). Within the upper plate, fractured and carbonate-leached calcareous siltstones and limestones of the Cambrian Emigrant Formation rest in overthrust contact upon the Ordovician Palmetto Formation—mostly a mélange of limestone and cherty limestone blocks, up to several hundred meters in diameter, in a sheared, dominantly calcareous shale matrix (Figs. 3 and 4). The Palmetto Formation is intruded locally by small bodies of equally sheared, Mesozoic or Tertiary granodiorite. Both the Emigrant and Palmetto Formations lie structurally above a thick sequence of thrust-faulted and folded Cambrian carbonate and siliciclastic formations that in turn are separated from lower-plate, Cambrian to Proterozoic tectonites by the regionally prevalent Mineral Ridge detachment (Fig. 4; Oldow et al., 2003).

The youngest rocks of the SPLM core complex are weakly to densely welded Miocene felsic ignimbrites that are locally intruded by Miocene or younger basalt, and are intricately dissected by low-angle faults and associated breccias and stockwork fractures almost certainly related to core-complex evolution (Figs. 3, 4, 5, lead photo). The ignimbrite is unconformably overlain, in succession (in the immediate prospect area) by Pliocene tuffaceous fluvial and lacustrine sedimentary rocks, Plio-Pleistocene fanglomerate, and at least two generations of alluvial fans. Quaternary and/or Tertiary landslides occur locally, and Holocene lacustrine muds occupy much of Fish Lake Valley west of the prospect. Miocene tuffaceous sediments and Pliocene ignimbrite occur just outside the prospect in the southeastern corner of the map area (Fig. 3).

The Emigrant rocks have been folded, fractured, sheared, and brecciated repeatedly during an intensive tectonic history stretching back at least to early Devonian time. Late Mississippian or early Devonian overthrust faults caught up in the upper plate of the SPLM core complex have almost certainly been reactivated as Cenozoic low-angle extensional features (Fig. 4). Low-angle normal faults in the prospect's early Miocene ignimbrites are also likely core-complex features. These remarkable faults (Fig. 5 and lead photo), individually at most just a few km^2 in areal extent, coalesce to form composite nappes throughout the northern Silver Peak Range over an area exceeding 100 km^2, and probably much more. The faults formed opportunistically at ignimbrite cooling-unit welding breaks, and these structures as well as overlying tuffs of the densely welded zones are commonly silicified, stockwork-fractured, and penetratively brecciated.

Moderate- to high-angle normal faults are the youngest structures exposed at Emigrant. In general, they trend east-west, northeast-southwest (e.g., the Sorrel fault; Figure 3) and northerly (the Gator, "Range-Front", and Emigrant Peak fault zones). The Emigrant Peak zone is marked by scarps in alluvium locally several meters high, consistent with a calculated Holocene slip rate for that structure ranging from 2.5 mm to 4 mm/year (Reheis and Sawyer, 1997). The also north-trending Green Monster fault zone, a little over a kilometer to the east, hosts the Emigrant prospect's only obvious surficial geothermal manifestations. These include a feeble fumarole and elemental sulfur deposit at the Green Monster mine, and associated, incipient, advanced argillic alteration.

Paleozoic and most Cenozoic rocks at Emigrant are hydrothermally altered to a greater or lesser extent, and this alteration must be taken into account in various ways for conceptual modeling of an underlying, convective geothermal system. For example, Paleozoic limestones and calcareous siliciclastic rocks are extensively carbonate-leached, forming or enhancing voids ranging from hairline openings to interconnected caverns a meter or more in diameter and tens of meters or more in individual length. The Paleozoic rocks are also locally silicified (thus embrittled) and laced with stockwork fractures and partially open veinlets of quartz, calcite, and other secondary minerals. Silicified low-angle fault zones and upper-plate densely welded zones in Miocene ignimbrite are penetratively fractured and brecciated, with secondary porosities locally exceeding an estimated 20 percent. Pliocene tuffaceous sedimentary rocks are massively argillized, and if sufficiently thick would provide an effective caprock on an underlying geothermal system. Fractured, silicified and pyritized zones disrupting the Pliocene strata in U.S. Borax and

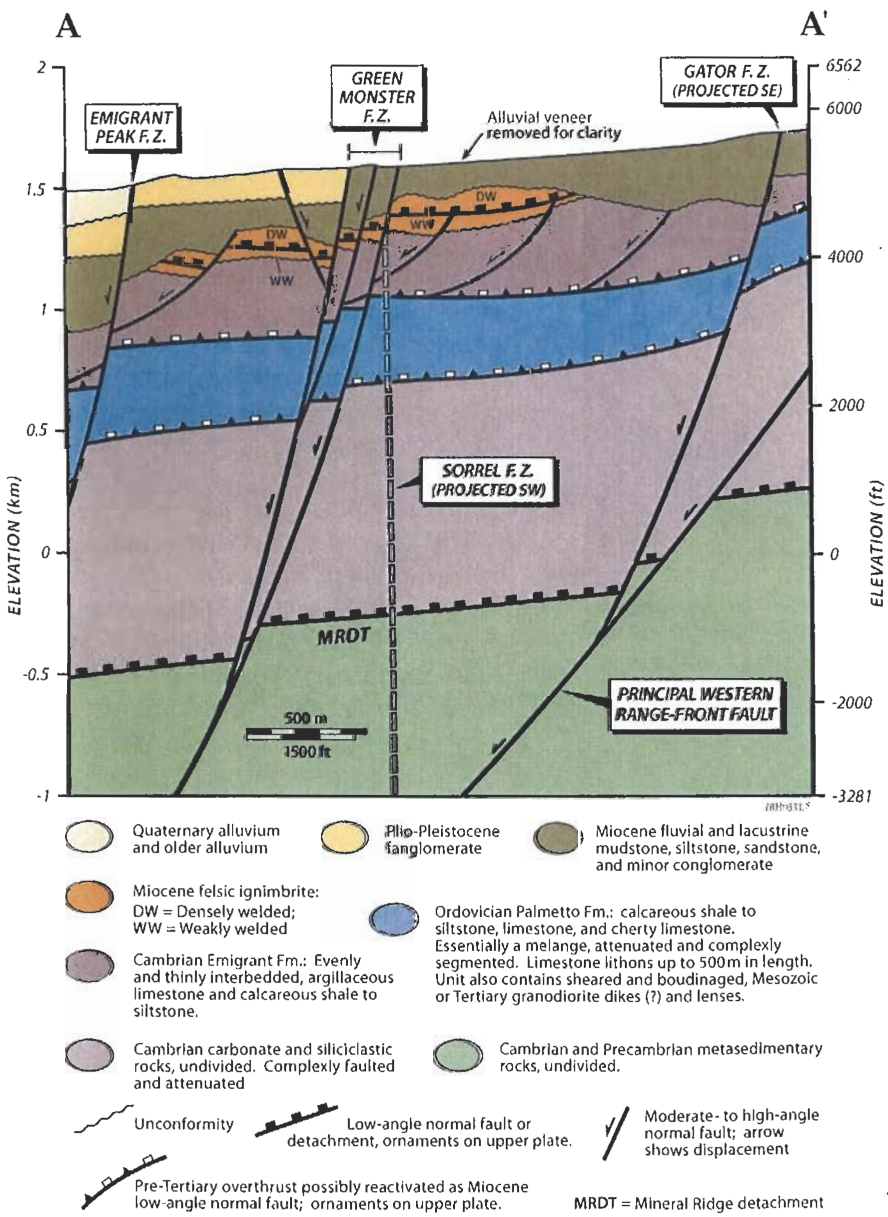


Figure 4 – Detailed, east-west geologic section through the interior of the Emigrant geothermal prospect. Please refer to Figure 3 for section location. Map features the Green Monster fault zone, along which the prospect's modern surficial geothermal manifestations are located.

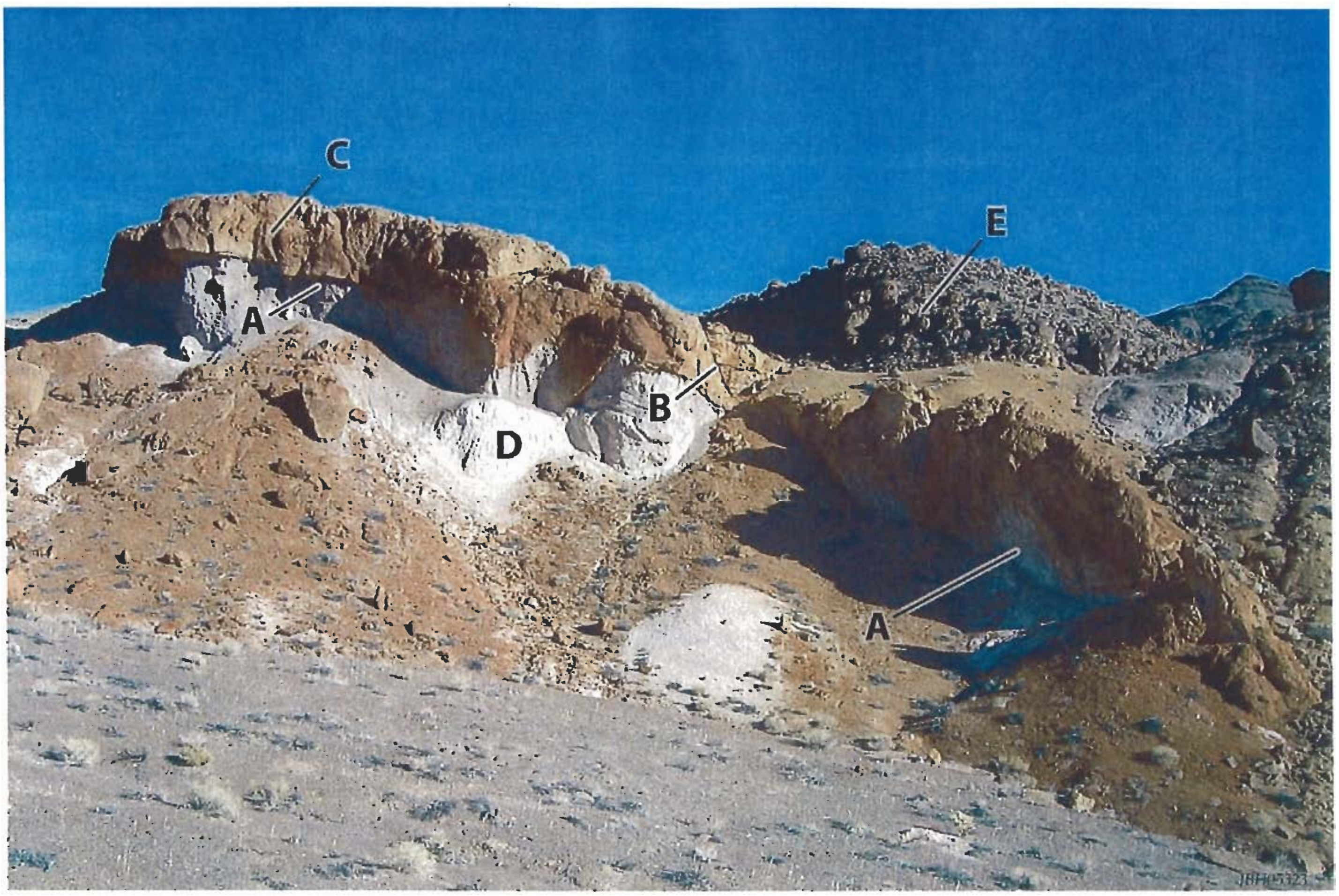
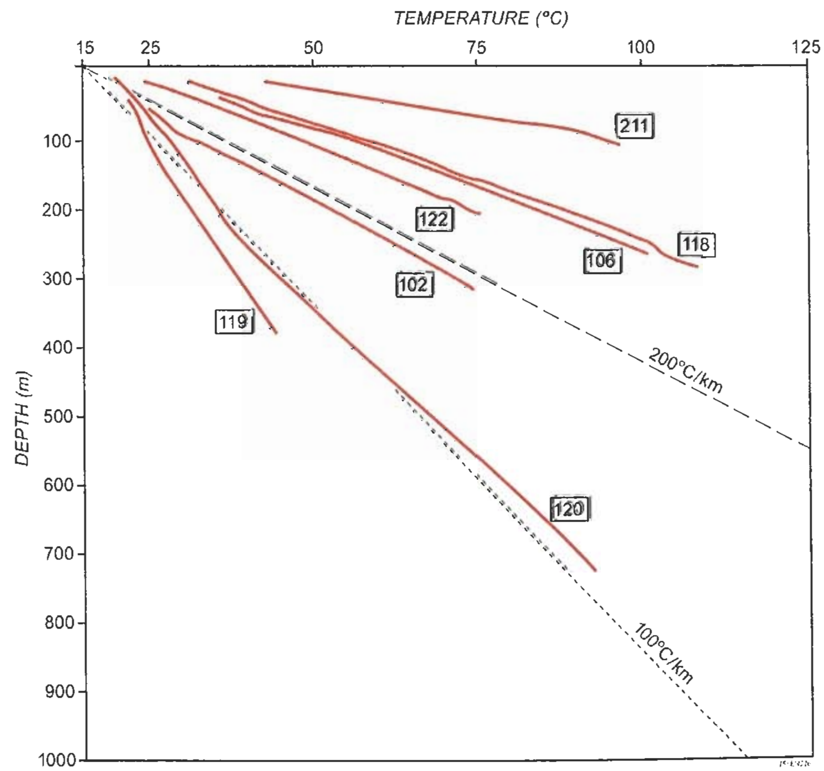
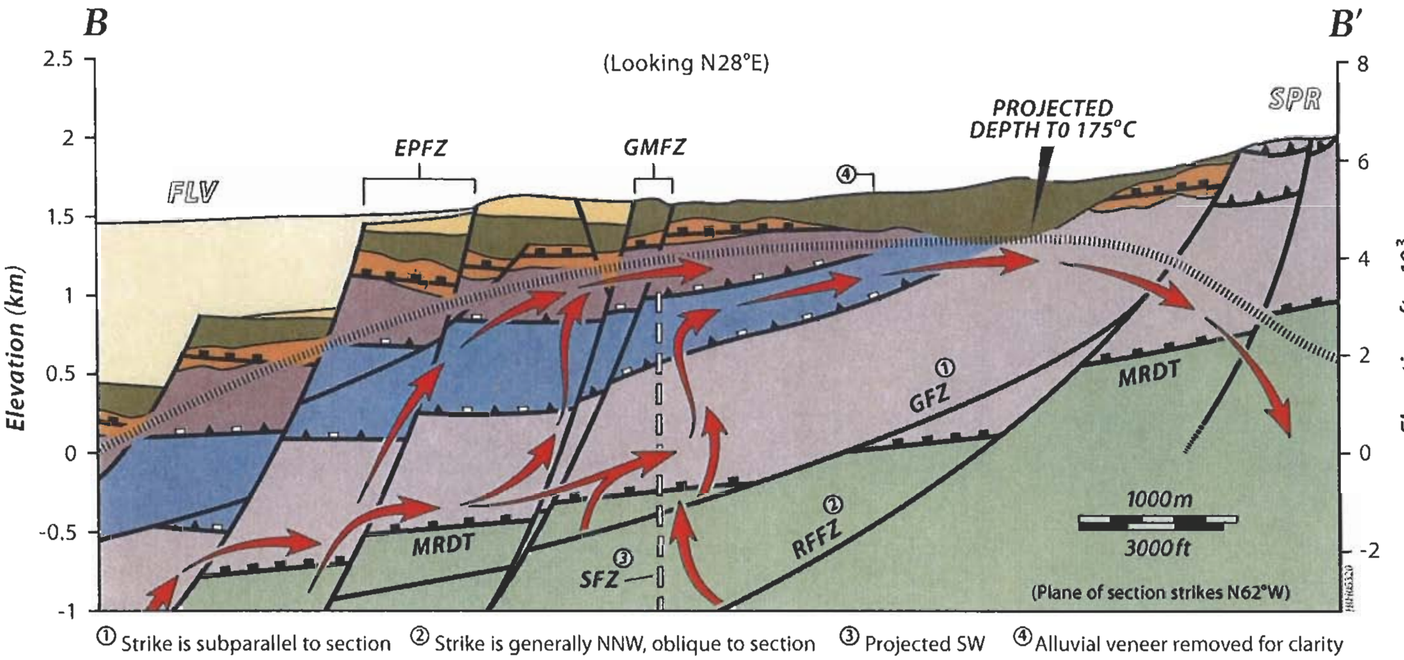


Figure 5 – Photograph (looking south-southeast) of part of a generally low-angle normal fault zone disrupting early Miocene felsic ignimbrite in the northeastern part of the Emigrant prospect (photo taken just south of the location marked by "SFZ" on Figure 3). Vertical ledge at left of photo is about 5 meters high. A – Undulatory, principal displacement surface (PDS), typically grooved, mullioned, and slickensided. At left, the PDS is subhorizontal; at right, it dips about 50° southward, oblique to and away from the picture plane. B – Subsidiary dip-slip and oblique-slip faults cutting the PDS, but extending no more than a few meters into that feature's upper and lower plates. These areally restricted faults appear to have formed contemporaneously with the PDS itself. C – Intensely fractured, moderately silicified, and hematitic "limonite"-stained damage zone above the PDS. D – Argillized, weakly welded tuff in the lower plate of the PDS. E (in immediate background) – Fractured, locally rubblized, and small normal-fault-segmented, moderately to densely welded tuff in the PDS upper plate. Compaction foliation in these upper-plate tuffs dips steeply into and abruptly terminates at the PDS. Where buried to sufficient depth, both the PDS damage zone and the ruptured upper-plate ignimbrites would constitute high-quality reservoir rocks in an Emigrant geothermal system.

Figure 6 (right) – Static thermal-gradient profiles for selected shallow boreholes in the Emigrant geothermal prospect. Refer to Figure 3 for borehole locations.





AMAX exploration drillholes (e.g., Hambrick, 1985) locally coincide with shallow hot-water entries.

The Emigrant Shallow Thermal Regime

Measurements in two dozen shallow borax- and geothermal-exploration boreholes have outlined a >250° C/km thermal anomaly (ground surface to 60 m depth) covering at least 12 km^2 (Fig. 3). The corresponding >100° C/km anomaly is at least three times that large. In the heart of this feature, near the Green Monster mine, thermal gradients commonly exceed 400° C/km, and locally reach 700° C/km (Fig. 6). Extrapolated even to moderate depths, these higher gradients would correspond to unrealistically high subsurface rock temperatures. An underlying, convective geothermal system is clearly implied.

The shallow thermal anomaly, and by extension the underlying geothermal system, surprisingly show no apparent spatial relationship to the active Emigrant Peak fault zone. Instead, the anomaly (and system) are oriented northwest-southeast, coincident with a system of left-stepping normal faults with Paleozoic basement on the east and Cenozoic cover on the west (Fig. 3). This type of structural control, with fracture complexity and permeability enhanced at the oversteps, has also been documented for several northern Nevada geothermal systems by Faulds et al. (2003).

Unambiguously indigenous hot-water samples were collected by AMAX from two shallow boreholes within the >250° C shallow thermal-gradient anomaly—one hole close to the Green Monster Mine, and the other about 5 km to the south. Geochemical analysis revealed the hot waters to be dilute (~0.3 wt.% total-dissolved-solids) sodium-chloride-bicarbonate-sulfate fluids (Deymonaz, 1984). Multiple chemical geothermometers applied to the two samples yielded estimated deeper equilibration temperatures ranging from 129° to 213° C, with SiO_2 (quartz) geothermometry indicating a range of 158° to 169° C (see Hulen et al., 2005, for greater detail). On the basis of just two samples, we cannot rule out derivation of these thermal fluids along various chemical mixing paths. If so, even higher subsurface temperatures at Emigrant are a distinct possibility. More rigorous assessment of the prospect's subsurface temperature regime must await drilling and well testing planned for project Phases 2 and 3.

Figure 7 – Conceptual geologic model of a moderate- to high-temperature convective geothermal system circulating beneath the heart of the Emigrant shallow-thermal-gradient anomaly (Fig. 3). At the center of this section is the drilling target currently considered optimum for penetrating, in the depth range 900-1300 m, the upper reaches of an upwelling geothermal plume. The target is centered on major fault intersections involving the Green Monster, Gator, and Sorrel fault zones. Red arrows trace conceptual thermal-fluid pathlines. EPFZ – Emigrant Peak fault zone; FLV – Fish Lake Valley; GFZ – Gator fault zone; GMFZ – Green Monster fault zone; MRDT – Mineral Ridge detachment; SFZ – Sorrel fault zone; SPR – northern Silver Peak Range. Rock units and symbols same as for Figure 4.

Conceptual Modeling and Drill Targeting

Key stratigraphic, lithologic, and structural features of the Emigrant prospect newly recognized during project Phase 1 have been combined with results of previous investigations to: 1) construct a conceptual model of the sought-after, moderate- to high-temperature geothermal system circulating at depth; and 2) select drilling targets optimum for penetrating the upper reaches of that system within the project's practical and fiscal constraints. Geologic and thermal-gradient data point strongly to one of these targets—immediately north of the Green Monster mine (Fig. 3)—as preeminently favorable. By the time this paper is published, the results of Phase 1 "fuzzy-logic" mathematical modeling (e.g., Zahdeh, 1971) of all the Emigrant geological, geochemical, geophysical, and thermal data will have either supported the provisional No. 1 target as most advantageous, or pointed more convincingly toward one or more alternative sites.

The current conceptual model of the envisioned Emigrant geothermal system is graphically portrayed in Figure 7. According to the model, thermal waters heated by deep circulation (there is no evidence for a magmatic heat source) buoyantly ascend along left-stepping segments of the basement to the east range front fault zone and perhaps to the structurally-dissected Mineral Ridge detachment. The rising fluids focus and accelerate upward at major fault intersections, for example, junctures between the Gator, Sorrel, and Green Monster fault zones. Beneath an impermeable argillized caprock, the fluids advect subhorizontally along subsidiary conduits ranging from carbonate-dissolution channels to flat stockwork-fracture and breccia zones associated with low-angle faults in Miocene ignimbrite. As with other Great Basin geothermal systems, modern recharge is likely to be minimal, and the bulk of the reservoir fluid will probably be fossil water of pre-Holocene age (Flynn and Buchanan, 1992).

Drilling and Well-Testing

Once the initial Emigrant drilling target has been confirmed, a vertical slimhole nominally 900-1300 m deep will be drilled during 2006 to penetrate the upper reaches of the postulated geothermal system. This work will be completed by a drilling company experienced in dealing with hot, hostile, subsurface geothermal environments. The drilling will proceed under close consultation with geologists thoroughly familiar with the site-specific intricacies of the prospect area.

To the extent possible, the slimhole will be completed by diamond coring, because core is far superior to cuttings in providing: 1) a record of the tectonic and hydrothermal history leading to circulation of the contemporary geothermal system; and (2) intact samples of geothermal reservoir rock for the characterization and quantification of porosity and permeability requisite for subsequent drilling and reservoir engineering. Following resistivity, density, and pressure-temperature-spinner (PTS) logging (borehole diameter and condition permitting), slotted tubing will be installed in the well, and an injection test will be performed to determine various reservoir characteristics.

Summary and Conclusions

This GRED III, DOE/industry cooperative project is providing the impetus and the means to test drill an important greenfield geothermal prospect in west-central Nevada. Should the project lead to discovery of an electric power-producing geothermal system at Emigrant, development at the nearby Fish Lake geothermal project (Fig. 1) will also inevitably be bolstered. One of the key deterrents to full commercialization at Fish Lake has been the cost of connecting a geothermal power plant to the electric grid with an approximately 50-km, 60-kilovolt power line. If as now seems quite possible, Emigrant becomes a second viable Fish Lake Valley geothermal field, then the two can share transmission expenditures and significantly reduce each project's total development cost.

Acknowledgments

Funding for G. Nash and J. Hulen's participation in this project has been furnished by EEC via subcontract to EGI. Supplemental funding for Hulen has come from his DOE/GTP Grant No. DE-FG36-04GO14296 for the study of low-angle fracture systematics in western U.S. geothermal systems. We thank Jack McNamara of GEO-83 for thoroughly reviewing an earlier draft of the manuscript, for pointing out factual errors in Hulen's initial account of the Emigrant property's ownership history, and for permission to publish this article. Hulen and Douglas Jensen respectively composed and finalized the graphic illustrations. Nash completed Figure 2 and performed all digital photography. ■

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