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The Snake River Geothermal Drilling Project – Innovative Approaches to Geothermal Exploration

Phase 1 Report

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INTRODUCTION

The Yellowstone-Snake River Plain (YSRP) volcanic province, which began ≈17 Ma under eastern Oregon and northern Nevada and is currently under the Yellowstone Plateau, is the world's best modern example of a time-transgressive hotspot track beneath continental crust (Figure 1). Recently, a 100 km wide thermal anomaly has been imaged by seismic tomography to depths of over 1000 km beneath the Yellowstone Plateau *(Waite et al 2006; Yuan and Dueker 2005; Xue and Allen, 2010; James et al 2009).* The Yellowstone Plateau volcanic field consists largely of rhyolite lavas and ignimbrites, with few mantle-derived basalts (*Christiansen 2001*). In contrast, the Snake River Plain (SRP), which represents the track of the Yellowstone hotspot, consists of rhyolite caldera complexes that herald the onset of plume-related volcanism and basalts that are compositionally similar to ocean island basalts like Hawaii (*Pierce et al 2002*). The SRP preserves a record of volcanic activity that spans over 16 Ma and is still active today, with basalts as young as 200 ka in the west and 2 ka in the east. Thus, the Snake River volcanic province represents *the* world-class example of active time-transgressive intra-continental plume volcanism. The SRP is unique because it is young and relatively undisturbed tectonically, and because it contains a complete record of volcanic activity associated with passage of the hotspot (Shervais et al, 2006a). The heat propagated by this hotspot drives high surface heat flows and numerous hot springs.

The Snake River volcanic province overlies a thermal anomaly that extends deep into the mantle and represents one of the highest heat flow provinces in North America, and an area with the highest calculated geothermal gradients (Figure 2; *Blackwell 1980; Blackwell et al 1989, 1991, 1992; Blackwell and Richards 2004*). This makes the SRP one of the most under-developed and potentially highest producing geothermal districts in the United States. Elevated heat flow is typically highest along the margins of the topographic Snake River Plain and lowest along the axis of the plain, where thermal gradients are suppressed by the Snake River aquifer. Beneath this aquifer, however, thermal gradients rise again and may tap even higher heat flows associated with the intrusion of mafic magmas into a geophysically-imaged mid-crustal sill complex (*e.g., Blackwell 1989; Peng and Humphreys 1998*).

The Snake River Geothermal Drilling Project received its conditional award on March 5, 2010; the award was finalized on July 9, 2010, with a Kick-off Conference Call on July 12, 2010. The Lead PI is John Shervais at Utah State University with co-PI James Evans at *Utah State University*, and funded co-investigators Lee Liberty (*Boise State University*), Doug Schmitt (*University of Alberta*), and David Blackwell (*Southern Methodist University*). Our partner on the drilling activities is Drilling, Observation, and Sampling of the Earth's Continental Crust, Inc. (*DOSECC*), a nonprofit consortium of universities which administers the US Continental Scientific Drilling program. Cost share is provided by Utah State University, Southern Methodist University, the University of Alberta, and the International Continental Drilling Program (*ICDP*), located at the GeoForschungsZentrum *(GFZ)*, Potsdam, Germany.

An ICDP-funded Technical Workshop was held in September 2009. This workshop addressed technical and logistical issues associated with a major drilling project in this region, visited two potential drill sites, and met with representatives from all three drill sites. Topics included drill hole and casing design, technical issues in basalt-rhyolite bore holes, the wireline logging campaign, hydraulic testing and water sampling, and the surface geophysical surveys. The attendees included several of the project principal investigators or co-investigators, representatives from the *US Geological Survey* and the *Idaho National Laboratory*, and the President, Operations Manager, and Chairman of the Board of *DOSECC, Inc.* All of the attendees have extensive experience with scientific drilling projects and/or working with drill core. This workshop laid the groundwork for our subsequent planning efforts and focused those responsible for managing the project on the central technical issues.

GEOTHERMAL POTENTIAL OF SNAKE RIVER VOLCANIC PROVINCE

Geothermal power has long been used in southern Idaho, but it has been confined almost exclusively to direct use applications such as space heating and aquaculture *(e.g., Sherman 1982; Mitchell et al 2003; Neely 1996; Fleischmann, 2006).* There is only one site where geothermal resources are used for power generation – the Raft River Valley site *(Nathenson et al 1980; Peterson et al 2004; Neely and Galinato 2007).* Nonetheless, the potential for power generation is significant, especially using binary generation systems that can exploit lower temperature resources (*Sanyal and Butler 2005; Neely and Galinato 2007*).

The Snake River Plain in southern Idaho represents the track of deep-seated mantle hotspot that has thinned the lithosphere and fueled the intrusion of up to 10 km of hot basaltic magma into the lower and middle crust. The heat from these intrusions, and from rhyolites formed by the basalt, drives the high heatflow and geothermal gradients observed in deep drill holes from throughout the Snake River Plain (*Blackwell 1978, 1980, 1989; Brott et al 1976, 1978, 1981; Lewis and Young 1989*). Heat flow in the SRP tends to be high along the margins of the plain (80-100 mW/m^2-s) and low when measured in shallow drill holes along the axis of the plain (20-30 mW/m^2-s). However, deep drill holes (> 1 km) in the axial portion of the plain are characterized by high heat flows and high geothermal gradients below about 500 m depth (*Blackwell 1989*). This discrepancy is caused by the Snake River aquifer – a massive aquifer system fed by the Lost River system north of Idaho Falls that extends under the plain and emerges at Thousand Springs, Idaho. This aquifer varies in thickness from <100 m to >450 m in the eastern-most SRP. Thermal gradients through the aquifer are static until the base of the aquifer is reached, then rise quickly at deeper levels in the crust (*e.g., Blackwell 1989; Blackwell et al 1992; Smith 2004*). Below the aquifer along the axis of the plain, heat flow values are comparable to heat flow values along the margins of the plain or higher (75-110 mW/m^2-s; Blackwell 1989). Bottom hole temperatures for wells along the margins of the plain near Twin Falls are typically around 30-60°C at 400-600 m depth (*Baker and Castelin 1990*) and as high as 120°C at 2800 m depth in the axial region of the plain (*Blackwell 1989*).

Our primary goal is to evaluate geothermal potential in two distinct settings: (1) the high sub-aquifer geothermal gradient associated with the intrusion of mafic magmas and the release of crustal fluids from the associated wall rocks, and (2) the valley-margin settings where surface heat flow may be driven by the up-flow of hot fluids along buried caldera ring-fault complexes. Both settings are found within the central Snake River Plain and represent previously untested targets for geothermal exploration. We also plan to explore the use of surface geophysical studies, including gravity, magnetic, and seismic techniques, in identifying these resources, and to verify their application by drilling slimhole test wells that will be cored and logged by conventional wireline and walk-away vertical seismic profiles. An additional goal is to test these same applications in a more conventional setting – a sedimentary basin adjacent to range-front faults in a large complex graben. An overview map of the Snake River Plain with locations discussed in the text is presented as Figure 3.

DRILLING PROSPECTUS [Task 1]

We plan to drill three deep test wells for this project that will provide detailed thermal gradient data and ground truth for our geophysical surveys. Drilling plans were formulated at an ICDP-sponsored Technical Workshop convened on 21 September 2009 in Twin Falls, Idaho. There were 18 participants from four countries (US, Germany, Canada, UK), including site representatives from the US Air Force (Mountain Home AFB), the Bureau of Land Management (BLM), and University of Idaho-Extension Farm. Also present were Dennis Nielson (DOSECC President), Anthony Walton (Chairman, DOSECC Board of Directors), and Chris Delahunty (DOSECC Operations Manager). The main focus of the workshop was on the technical and logistical aspects of drilling and sampling -- what size core, to which depth, casing or not; geophysical logging campaign - which tools, open hole or in rods, how to stage; protocols for water and gas sampling; permitting, environmental and safety issues, design issues for each site, and conditional use issues with each of the site owners. All of the workshop participants had extensive experience with drilling-related projects, and were able to anticipate potential problems and discuss their solutions.

DOSECC's mission is to provide leadership and technical support in subsurface sampling and monitoring technology for addressing topics of scientific and societal importance. They maintain the infrastructure for continental scientific drilling in the United States, including a range of special purpose drill rigs and assemblies.

All of the deep wells will be drilled with DOSECC's Atlas-Copco CS4002 truck mounted drill rig (Figure 4). This compact, truck-mounted rig was purchased by DOSECC with Project Hotspot in mind as a potential user. The CS4002 can be deployed on a pad as small as 80 feet by 40 feet, although larger areas are preferred. It has a lift capability of 18,000 kg and can hang up to 1050 m of PQ drill string, 1600 m of HQ drill string, and 2450 m of NQ drill string. This gives us the flexibility to extend drilling to depths below our planned targets if drilling is proceeding well and costs are lower than expected.

Design of the drill holes and coring strategy was driven by State of Idaho regulations, the science goals, and the capabilities of the CS4002 drill rig. The Idaho Department of Water Resources (IDWR) and the Idaho Department of Environmental Quality (IDEQ) are the lead agencies in charge of administering and enforcing the various rules and regulations governing water use and water quality in the State of Idaho. IDWR is responsible for issuing water rights, well construction permits, and underground fluid injection wells. The IDEQ is responsible for administering surface disposal of wastewater, including geothermal fluids.

The IDWR is the lead agency responsible for regulating all water wells, monitoring wells, low temperature geothermal wells, injection wells and other artificial openings and excavations in the ground greater than 5.48 vertical meters (18 feet) below land surface. A surface conductor and its annular seal must extend to not less than 12.1 m (40 feet) below land surface for the proposed wells. The minimum annular space required between the borehole and the surface casing must provide for a uniform seal thickness not less than two inches larger than the outside diameter of the casing to be sealed. These administrative regulations governing well construction described in IDAPA 37, Title 3, Chapter 9 will be followed in our well design and permit applications.

Workshop participants who are currently involved in drilling activities elsewhere on the SRP strongly recommend drilling the upper portion of each hole as deep as possible with PQ drill rod to allow two size reductions at depth (to HQ and NQ) in case the drill string becomes stuck during drilling. This is especially important in the basalt sections, where rubble intervals may be encountered. They further recommend that after switching from PQ to HQ drill rod, we continue with HQ to the maximum depth achievable before switching to NQ, for the same reasons.

Subsequent to the workshop, PI *Shervais* and *Delahunty from DOSSEC*, met with the cognizant official at IDWR to discuss permitting and licensing issues; the results of those talks have been integrated into our revised drilling plans and budget, as discussed below. The most significant impact is that IDWR will require the upper part of each deep hole be cased so that an annular blow-out prevention device can be attached if bottom hole temperatures exceed 100ºC. This casing must extend to at least 15% of total anticipated well depth. We will also be required to have an annular blow-out prevention device on-site so that it can be installed when conditions warrant. IDWR also requires that we post a surety bond of $20,000 per hole until each hole is completed by the plug and abandon process. This is in addition to the drillers bond that is posted by DOSECC.

This Drilling Prospectus covers the first two drill holes in this series – one hole to be drilled at Kimama in Lincoln County and one hole to be drilled at University of Idaho Research Farm in Kimberly, Twin Falls County. Target depths for the two holes are 1400 m (4600 feet) for Kimama and 1800 m (6000 feet) for Kimberly. We have obtained our drilling permits from IDWR (attachments), based on this drilling prospectus, and can begin drilling as soon as Phase 2 funds are released by DOE. The Mountain Home site will be permitted separately, after completion of a Federal Energy Management evaluation, being carried out by personnel from the Idaho National Laboratory. Site locations and the rationale for all three sites are discussed in later sections of this report.

Permitting and Environmental Review

A cultural and biological assessment of both drill sites (Kimama and Kimberly) was carried out by USU Archeological Services, Inc., in July 2010; a copy of their report has been submitted to the Golden Field Office for review. The survey found no endangered species at either site, and no significant cultural artifacts. Both sites have been disturbed by previous activities and drilling operations will have no significant impact on the either location. We have budgeted funds for remediation of each site at the owner's discretion.

Drilling permits for both the Kimama and Kimberly sites were issued to USU/DOSECC by the Idaho Department of Water Resources September 2010, after we submitted our revised drilling prospectus and posted surety bonds to IDWR in the amount of $20,000 for each well. Copies of the drilling permits are attached to this report in the appendix, along with the lease agreement for the Kimama site and the MOU with the University of Idaho for use of the Kimberly site.

Drilling and Logging Plan

DOSECC will drill the initial 12.2 m (40 feet) and install surface conductors, as specified by IDWR drilling regulations, which call for a 1" cement-filled annulus around a quarter-inch steel surface conductor. After installation of the surface conductors, each well will be drilled in three stages and logged between stages, as shown in Figure 5. We had originally planned to drill the upper portion using PQ drill string, but IDWR regulations for low-temperature geothermal wells require that we cement in casing to 15% of anticipated total well depth, with a 1" cement-filled annulus around the casing. As a result, we will drill the upper 250-400 m (800-1300 feet) with HQ drill string, producing HQ size core (63.4 mm/2.5" diameter) in a 96 mm (3.78") hole, and then ream out the drill hole with a rotary bit before setting HWT casing in the upper part of the hole. This strategy will allow us to penetrate the upper portion of the drill holes quickly, and will ensure that we maintain fluid circulation during drilling at depth (since lost circulation is most likely in the uppermost part of the basalt section). Wireline geophysical logs will be run through the drill string, then the drill string will be pulled and wireline logs will be run in the open hole. After logging is complete, the HWT casing will be installed and drilling will continue with HQ size drill string. This strategy produces the same effect as starting with PQ drill string, because reaming the hole to install the HWT casing allows us to continue with HQ drill string, as in the original drill plan.

Drilling with HQ drill string will continue to target depth of 1500 m (4920 feet). The HQ drill string will be left in place as a temporary casing and drilling will continue to target depths with the NQ drill string, producing 47.6 mm (1.87") core in a 76 mm (3.0") hole (Figure 5). If problems are encountered above 1500 m, we will switch to NQ at shallower depth. For the deeper Kimberly well, we have a target depth of 1500 m with HQ rod, after which we will continue drilling with NQ drill string to total depth. Total depth for the Kimberly drill hole is funded at 1.8 km (6000 feet) but we will go deeper if funds are available to continue drilling, up to a maximum of 2.2 km (7200 feet).

A geologist will be on site at each hole 24 hours per day, and the Chief Scientist will be either onsite or available a short drive from the site. A maximum reading bottom hole thermometer will be deployed once each day (approximately every 100 feet depth) to monitor bottom hole temperatures (BHT). IDWR will be notified if low-temperature geothermal fluids are encountered (T > 29°C or 85°F). If BHT approaches 100°C (212°F), drilling operations will stop and IDWR will be notified immediately. An annular blow-out prevention (BOP) device will be installed before drilling resumes.

After each hole reaches it final depth and wireline geophysical logs have been completed, a walk-away vertical seismic profile (VSP) will be run at each hole, in which geophones are installed in the drill hole as a seismic source (mini-vibroseis truck) "walks away" from each site in several directions. This walk-away VSP will produce a detailed stratigraphy of each hole that extends in 3-dimensions, with an effective horizontal radius slightly less than the depth of the well.

Plug and Abandon (P&A) Process

We plan to keep each hole open for 2-3 months after completion in order for temperatures to re-equilibrate to the normal thermal gradient. During this time, science crews from the Geothermal Lab at Southern Methodist University (David Blackwell, Director and co-investigator) will log thermal profiles of each hole. After thermal gradient logging has been completed, we will plug and abandon each well in accord with IDWR regulations. The P&A will follow IDWR regulations in regard to installation of the fill material and the nature of the fill material. We plan to use a neat cement slurry plug to the surface if we encounter any low temperature thermal zones. The non-low temperature thermal zones will be plugged with 3/8" bentonite chip material to the near surface where a neat cement plug will be installed to 3 feet off of the surface and then back filled with native soil.

Geophysical Logging

Doug Schmitt and *Jochem Kück (ICDP Operational Support Group -- OSG)* have prepared a comprehensive logging plan for each hole, including vertical seismic profiles using equipment from the University of Alberta and Boise State University. Wireline logging will include dual lateral log resistivity (DLL), spectrum of natural gamma ray (U/Th/K) (SGR) and total natural GR, magnetic susceptibility (MS), acoustic televiewer (FAC40), oriented 4-arm dipmeter (DIP), and borehole sonic (BS). Some tools must be run within the drill rod before pulling for open hole logging. These tools include total gamma (used to cross-correlate logs and cores), gamma-gamma and neutron logs (because these tools contain a radioactive source), and a deviation log (gyroscope) to correct magnetics for non-vertical hole orientation. After these logs are run within the drill string, the string will be pulled for open hole logging, and then re-hung before continued drilling. A preferred strategy is to continue drilling though the drill string with a smaller rod size, log that within rod, then log the open hole in stages as the rod is pulled. The USGS may also provide support from their logging group, which has a depth capability of 760 mbs. *OSG* has slimline tools for most of these logs, but not for those containing a radioactive source (e.g., neutron log). To run these tools a commercial US-based logging operation must be contracted; this group could also be contracted to run the other logs as well, depending on cost. We have received bids from CoLog and Century for these services.

In addition to constraining borehole stratigraphy, wireline and thermal logs of the wells can be used to find hydrologically active fractures within the borehole, to delineate fracture-controlled hydrologic flow patterns, and to estimate flow velocities within these fractures *(Ge 1998; Paillet 1999, 2000)*. These tools will be especially important for evaluating hydraulic conductivity and comparison with post-drilling core studies.

In the course of geophysical logging, fluid samples will be taken using gas-tight downhole samplers. Promising fluid bearing horizons may be defined according to significant changes in salinity; OSG also has appropriate gas-tight fluid samplers.

Thermal logging will be carried out by the SMU Geothermal Lab (*David Blackwell*) using their equipment. The thermal logs will be run immediately after drilling is complete, and again after the well approaches equilibrium. In addition, a bottom hole thermometer will be used to monitor well-bottom temperatures daily during drilling (e.g., approximately every 30 m).

FIELD STUDIES AND DATA COMPILATIONS [Task 2]

Geologic Map and Data Compilation

[Note: Maps discussed below are presented in the relevant site discussion sections]

Geologic mapping in the central SRP northeast of Twin Falls has been carried out over the last decade by the PI and his students, and by personnel of the Idaho Geological Survey, resulting in the publication of several geologic maps at 1/24000 or 1/100,000 scales *(Kauffman et al, 2005a, 2005b; Shervais et al, 2006c, 2006d; Cooke et al, 2006a, 2006b; Matthews et al., 2006a, 2006b)* and unpublished thesis maps (*Cooke, 1999; Matthews, 2000; Hobson, 2009; DeRaps, 2009)*. This mapping ties into published mapping by the US Geological Survey in the Craters of the Moon 1/100,000 sheet *(Kuntz et al 2007)* and into unpublished mapping by the PI and his graduate students east of longitude 114°W in the Sid Butte, Senter Butte, Kimama Butte, and Black Ridge Crater 1/24000 quadrangles. The PI prepared a field guide to this area for the 2005 national meeting of the Geological Society of America and led a field trip based on this guide (*Shervais et al., 2005*). Extension of this mapping into the Lake Walcott 1/100,000 sheet is in progress on a reconnaissance basis, using existing geologic maps and new mapping by the PI and his students. Finally, this mapping is being compiled into a single map sheet that covers the entire central SRP (Figure 6). We are using Google Earth for our initial development platform but will switch to Arc GIS in September when we hire a GIS technician.

We have also prepared geologic maps of eight 1/24,000 quadrangles in the Mountain Home area for publication by the Idaho Geological Survey. These quadrangles, which were mapped prior to this project, have been combined into a single map sheet in Arc GIS for publication. This map covers Mountain Home AFB and a large part of the surrounding region and is referenced during our discussion of that site.

The principal result from the geologic mapping is to show that Quaternary volcanism is widespread throughout the central SRP, with young vents occurring both along the margins of the plain and near its center. Nonetheless, young volcanic vents are dominant within the axial volcanic zone. While some vents with similar ages may align parallel to the NS-trending volcanic rift zones defined by *Kuntz (1992; Kuntz et al 2002)*, other young vents are as likely to define other alignments, e.g., Wilson Butte and Rocky Butte, which are aligned ~WNW and have nearly identical ages and compositions (Figure 6). These trends are often highlighted on regional magnetic maps, since basalts with similar ages will commonly have the same magnetic polarity, resulting in striped magnetic alignments.

Young basaltic volcanism tends be concentrated along the axial volcanic high, with older vents dominantly exposed along the margins of the plain (Figures 3, 6). Unlike the eastern plain, however, this trend does not continue to the SW. Northwest of Twin Falls, vents become less common and the basalt flows thin out and become intercalated with fluvial and lacustrine sediments. This is well-documented in the Wendell-RASA well (342 m), which has 122 m of young Quaternary basalt (<400 ka) separated from older basalts deeper in the well by 60 m of sediment *(Whitehead and Lindholm, 1985)*. The older basalts (1.0-4.5 Ma) are themselves underlain by more sediment. Basalt flows also thin towards the margins of the plain, where they may sit directly on rhyolite or on sediment horizons that rest on rhyolite. This is in contrast to the 1500 m deep WO-2 well at the INL site, which contains ~1200 m of basalt with minor intercalated sediments on top of 300 m of rhyolite, with no intervening sediments and no major sediment horizons within the basalt *(Morgan, 1990; Hackett et al 2002; William Hackett, unpublished well log)*.

The concentration of young Quaternary volcanism near the Axial Volcanic Zone, and the nexus of volcanic rift zones, which trend NNW and EW makes this region a high priority for geothermal exploration *(Shervais et al 2005, 2006a, 2006b)*. Vent concentrations are highest between the Great Rift and the Twin Falls-Shoshone area (Figure 6), so our model suggests that this region, centered around our Kimama drill site, is more likely to encounter high temperature resources at depth than areas lying farther west; the Great Rift itself lies within Craters of the Moon National Monument, and is off-limits to exploration. A more detailed assessment of this region is presented below.

Regional reconnaissance mapping of structural trends in the Twin Falls-Kimberly area has been carried out by the PI using NASA 10 m DEM data in the software GeoMapApp (*Goodwillie and Ryan, 2009*). These data are used to produce shaded relief maps and topographic maps with 10 m contour intervals that are more detailed than published 1/24,000 topographic maps, and which reveal structural lineaments more clearly than topographic maps or air photographs. Many of the lineaments mapped using this technique appear on previous geologic maps; others are more clearly revealed using the new DEM data. These lineaments reflect in part western SRP fault trends (WNW) and in part more northerly trends that may represent a transition between the western SRP trends and the NS-oriented Basin and Range trends. This mapping will be discussed in more detail under the Site Selection discussion for Kimberly.

Gravity data for the State of Idaho *(Kucks 1999)* were used by Liberty to produce regional Bouguer anomaly maps for both the central SRP north of Twin Falls and for the western SRP near Mountain Home. The gravity database was compiled within Arc GIS and maps were produced using a gradational color scale to indicate relative anomalies. The maps are plotted here with the station locations indicated so that the density of data stations relative to the anomalies can be assessed. In addition to the Bouguer anomaly maps, Liberty produced "upward continued" gravity models for the western SRP that emphasize mid- to lower crustal structures and minimize the affects of density variations in the shallow crust (e.g. the presence and thickness of basalt flows). The results of the gravity mapping are discussed in detail for the specific sites under study.

Water well and shallow geothermal well data were compiled from drillers logs (off of the State of Idaho Department of Water Resources website) and from previous compilations published by the Idaho Department of Water Resources and US Geological Survey (*Street and deTar, 1987; Lewis and Young, 1989; Baker and Castelin, 1990*). Well logs are especially useful in the Twin Falls region because of the large number of shallow geothermal wells, which are generally deeper than water wells and are more likely to have temperature data. In the area around Kimama, groundwater data were compiled and analyzed by *Smith (2004), Smith et al (2002, submitted), McLing et al (2002), Johnson et al (2000)*, and *Rohe et al (2002).* Though we do not have access to the database that supports these publications, the figures in *Smith (2004)* and *Smith et al (submitted)* are sufficiently detailed to allow us to use their results here. We also used USGS data for water wells in the western SRP to assess temperature distributions around the Mountain Home Air Force Base. These data were gridded using next-nearest neighbor algorithms to illuminate regional trends in the data.

Geophysical Site Surveys

Geophysical site characterization will comprise two separate campaigns – shallow seismic surveys carried out by *Lee Liberty* (Boise State University) and *Doug Schmitt* (University of Alberta), and gravity and magnetic surveys carried out by *Jonathan Glen* (USGS). The purpose of these studies is to establish a regional geophysical and geologic framework that can be calibrated using the borehole stratigraphy at each site. This will allow us to extend our results over a wider area and gain a deeper understanding of rock distribution. We are not using these surveys to locate optimal drill site locations, because the thick basalt cover renders these surveys difficult to interpret without bore hole data. Further, these studies will be used to assess underlying basement structures that may be tied to enhanced geothermal potential. In particular, we will be looking for buried fault zones and volcanic eruptive centers that have ring-fractures on the margins, which may be linked to enhanced geothermal fluid upflow zones *(Melosh et al, 2010; Ronne et al, 2010).*

Seismic Reflection Surveys: High-resolution seismic studies are critical to our estimates of eruptive flux. Our approach will be to use long sweep times using both *p*-wave and *s*-wave methods (sources and receivers), look for both pure *p*- and *s*- returns, and also mode-conversions and anisotropy *(e.g., Liberty 1998; Liberty et al 1999, 2001; Janik et al, 2004; Bradford et al 2006).* Since we will be operating in a very complex velocity/density medium, we will rely on borehole geophysics to ground-truth our surface results and forward model using observed velocity and density measurements. This approach will be enhanced by the vertical seismic profiles, which will provide a detailed assessment of seismic response with depth.

The Boise State geophysics group has a 120-channel Geometrics RX system, with possibly an additional 120 channels from IRIS, with 200 kg drop weight source. The Alberta group has a similar 240 channel acquisition system with a IVI 6000 lb force Vibroseis source that has been used on previous ICDP projects. These groups will work together to acquire seismic lines that run both parallel and perpendicular to the SRP axis. In addition, Boise State has access to a library of relatively high quality seismic lines acquired in the western plain south and west of Boise by Chevron. These lines document stratigraphy at the western end of our transect, as documented by Spence Wood in a series of publications (*e.g., Wood and Clemens 2002*).

Geophysical investigations of the area near the Mountain Home AFB are currently in an advanced state of planning. *Shervais, Liberty and Schmitt* met in Boise in July to plan the seismic surveys and to scout locations for a ~10 km long high-resolution seismic line that will begin in the area immediately to the west of MH-AFB, which has a thin cover of basalt, and progress south, crossing the canyon onto an area with no basalt cover. This was chosen purposefully to allow for examination of the effects of the basalt on the quality of seismic imaging. It is intended that this long profile will be connected to the yet undecided location of the Mountain Home borehole by a smaller survey later.

At this writing, preparations are underway to ship the University of Alberta equipment to Boise at the beginning of September 2010. The joint groups of the U of Alberta and Boise State intend to carry out these surveys beginning 27 September 2010 for a period of 7 to 10 days. In addition, a small test vertical seismic profile will be carried out in a recently drilled ~150 m deep water well on the NE corner of the base. The analysis of these data will progress through the fall of 2010.

Gravity and Magnetic Surveys: The USGS will carry out gravity and magnetic surveys of the Snake River Plain to provide the geophysical framework for studies within and surrounding the plain. This work will entail the compilation, re-reduction, and editing of existing gravity and magnetic data, the collection of new gravity data, the collection of rock property data, 2D potential field modeling along selected transects, regional geophysical mapping of structures, and an attempt to model basalt thickness throughout the plain. Potential field studies offer the unique advantage of providing a relatively inexpensive means of obtaining information on subsurface structure across a wide area *(e.g., Glen and Ponce 2002; Glen et al 2006).*

We plan to acquire gravity and ground-magnetic data along a select number of transects (stations spaced about 1/4- to 1-mile apart along profiles), while regional gravity data will be collected over the entire area, focusing on areas of sparse coverage. Representative rock samples will be collected concurrently with the gravity and magnetic data collection, and their physical properties (density and magnetic susceptibility, and magnetic remanence) will be determined in the laboratory to aid in quantitative modeling of measured geophysical anomalies. Finally, we will develop two-dimensional geophysical models of the subsurface to estimate basalt thickness, to define the shape and structure of buried calderas, to locate faults, and to delineate changes in the basement geology. The goals of this work, which include (1) mapping structures that may be important targets for drilling and (2) estimating basalt thickness, may significantly influence drilling strategies and priorities. By providing a region-wide geologic and geophysical framework this work will allow for more informed decisions regarding drill-site planning.

Glen began field studies in August 2010, in the area around Mountain Home AFB, and will continue field studies in early September 2010 in the central SRP near Twin Falls.

SITE CHARACTERIZATION AND SELECTION

Two new intermediate depth (1.4-1.8 km) slim-hole exploration wells will be drilled in the central Snake River Plain near Twin Falls, Idaho, during Phase 2 of this study. These wells will be used to validate the surface and geophysical studies of Phase 1, which will further constrain the extent and quality of the geothermal resources in this region. These holes will be located west of the Great Rift and NE of Twin Falls, Idaho, and close together longitudinally so that they overlie similar age and composition basement. The 1.4 km deep Kimama well will be sited to test the extent of geothermal resources along the axis of the plain, beneath the Snake River aquifer, in an area where the enhanced volcanism of the axial volcanic high and elevated groundwater temperatures imply a significant flux of conductive or advective heat flow from below (*e.g., Smith 2004; Smith et al, 2002*). Fracture systems here may be related to the volcanic rift zones or Basin and Range extension.

The 1.8 km deep Kimberly well will be sited to evaluate geothermal resources along the margins of the plain, focusing on a buried caldera complex and the ring-fractures that define its margins. High measured heat flow along the margins of the plain suggest that thermal resources are closer to the surface but the shallow resources may be more prone to disturbance by excessive pumping (*Brott et al 1981; Lewis and Young 1989*). In addition, we touch briefly on the Mountain Home AFB test hole, which is sited on the margin of a buried horst block, and may provide a geothermal energy resource to the US Air Force.

Kimama – Elevated Heat Flux Under the Volcanic Axis

The primary goal of the Kimama drill site is to test the extent of geothermal resources along the axis of the plain, beneath the Snake River aquifer, in an area where elevated groundwater temperatures imply a significant flux of conductive or advective heat flow from below (*e.g., Smith, 2004; Smith et al, 2002, submitted*). The use of shallow temperature gradient drill holes to define a thermal anomaly is not a meaningful test in this situation because of the refrigeration effect of the massive shallow groundwater flow.

This site was chosen because it sits on an axial volcanic zone that is defined by high topography to the east (Figure 3) and by electrical resistivity (ER) logs that define a buried keel of basalt underlying the topographic high (Figure 7). The ER logs define the depth to saturated basalt – generally interpreted to represent the base of the younger Quaternary basalts, and excluding older Pliocene basalts which have limited porosity (*e.g., Lindholm 1996*). Based on these ER logs and nearby wells, the depth to base of Pleistocene basalt at the Kimama site is about 850 m (2800 feet). For comparison, the WO-2 borehole on the Idaho National Laboratory (INL) site is located on the same ER depth contour, and sampled 1200 m (3900 feet) of basalt (Figure 8). The basalt thickness estimated from ER measurements most likely corresponds very approximately to the base of the Snake River aquifer, which is sealed by authigenic mineralization of the older basalts that seals off permeability (*e.g., Morse and McCurry 2002*). The Wendell-RASA borehole, situated near the 500 m ER depth contour, encountered 335 m (1100 feet) of basalt plus sediment, but did not encounter rhyolite basement (Figure 8).

Detailed assessments of groundwater temperatures and flow paths beneath the Idaho National Lab and adjacent areas have been made by *Smith (2004)*, *Smith et al (2002)*, and *McLing et al (2002)*. They show that the base of the Snake River aquifer varies from 200 m to 500 m depth, based on the inflection depth of groundwater temperatures in deep wells, which change from isothermal within the aquifer to conductive below the aquifer (Figure 9). Thick portions of the aquifer correspond to massive inputs of cold water from (1) the combined Snake River-Henrys Fork River drainages and (2) the Centennial Mountains, including the Big Lost River, Little Lost River, and Birch Creek drainages (Figures 3 and 10).

This flux of cold water is concentrated in groundwater plumes that follow the southern and northern margins of the Snake River Plain, paralleling flow of the Snake River (in the south) and the Little Wood River (in the north), and skirting the thick axis of basalt volcanism that underlies the central volcanic axis of the plain (Figure 10). Goundwater temperatures form a linear high along the central axis of the Snake River Plain that corresponds with both the axial topographic high and the axial volcanic keel (*Smith 2004; Smith et al, 2002,* *McLing et al 2002*; Figure 10). The elevated groundwater temperatures are especially remarkable in light of the massive flow of cold water documented by deep wells and by cold springs that emerge from the aquifer west of Twin Falls.

The conceptual model for this process is shown in Figure 11, taken from *Smith (2004)*, which depicts a longitudinal profile along the axis of the central and eastern SRP. Cold water enters the system from the surrounding mountains, fed by major river systems from the north, east and southeast. This plume of cold water is gradually heated from below by the high plume-derived heat flux, which is focused under the axis of the plain (Figure 11). The axial heat flux is enhanced by the intrusion of the mid-crustal sill complex, which advects heat into the middle crust as magma, and continuously releases latent heat of fusion as the sills cool and crystallize (*Shervais et al 2006b*).

We selected the Kimama site for several reasons, based on the analysis above. First, it sits within the an area that has a high concentration of Quaternary volcanic vents. Second, it sits on the Axial Volcanic Zone where heat from the underlying mantle plume and sill complex should be highest. Third, it sits above the elongated plume of warm ground water defined by *Smith (2004)*, which shows that this heat is being advected to the surface. Finally, as shown in the following section, it appears to sit above the eastern margin of a buried caldera complex, which may provide enhanced pathways for heat transport along its ring fracture system.

Proposed depth for the Kimama drill hole is 1400 m, with an estimated basalt thickness of about 1200 m, similar to hole WO-2 at the Idaho National Laboratory site, or less (Figure 8). This depth will allow us to get below the base of the Snake River aquifer (which we estimate to lie at ≤350-450 mbs) and to penetrate deeply into the underlying volcanic basement to assess its geothermal potential (temperature and fracture porosity). We plan to drill to some depth into the rhyolite, which underlies the basalt, so that we can assess which of these potential reservoirs (basalt or rhyolite) presents the most favorable hydrologic properties for geothermal development.

Our selected location is on private land located just north of the former Kimama township site – which lies along the Union Pacific railroad line, and is now the site of a railroad siding and several grain storage elevators. This site was chosen because it sites squarely on the keel of the axial volcanic high; it is not too far east of the proposed rhyolite site at Kimberly (so that it penetrates the same age basement), and it is about 40 km west of the Great Rift – a volcanically active rift zone with anomalous crust that has likely been affected by hydrothermal circulation *(Kuntz et al 1982).* Note that the Great Rift lies within Craters of the Moon National Monument, and is off-limits to development.

The Kimama site was also chosen for its logistical advantages: it is located off of a wide, well-graded gravel road less then half a mile from paved highways, about 25 miles north of a major town (Burley). This allows us to house the drillers and science crews in local motels, so we do not have to provide lodging and meals onsite. The site has an existing power line and the landowner has contracted to provide a power drop to our office and lab trailers, so that we will not need to use diesel generators for electric power. The owner has also contracted to drill a water well on the property so that we do not have to lease a water truck, purchase water in town, and truck it to the site. Should a viable geothermal resource be discovered, the site is favorably located for its development.

The site has been disturbed by previous development, including the construction of two airstrips for crop dusters (one is currently active but the other has been abandoned), and several dirt or gravel roads that cross the property. No endangered species are present, and there are no culturally significant artifacts, as determined by consultants at USU Archeological Services, Inc., who conducted cultural and biological surveys in July 2010. A copy of their report has been transmitted to DOE.

Kimberly – Up-flow along a Buried Caldera Margin

The primary goal of the Kimberly drill hole is to assess the geothermal potential of up-flow zones along a buried caldera margin. The large number of shallow geothermal wells in the Twin Falls area makes this area one of the best characterized stratigraphically, and a prime location to explore for higher temperature resources at depth (*Street and deTar, 1987; Lewis and Young, 1989; Baker and Castelin, 1990*). The proposed drill site lies south of the Snake River where groundwater flow is dominated by water that originates in the mountains to the south, and penetrates deeply into the crust where it is heated before upwelling in the Twin Falls low-temperature geothermal district (*Street and deTar, 1987; Baker and Castelin, 1990).* Geothermal wells in the Twin Falls Groundwater Management Area range in temperature from around 30°C to 72°C, with the highest temperature occurring along the Buhl-Berger lineament. High temperatures are also found in the Kimberly area (up to 55°C) near the site of our proposed deep well (*Baker and Castelin, 1990).*

Stratigraphy in the Twin Falls area is well-defined by exposed sections and by well data that extend to depths of 700 m below surface (mbs). The oldest volcanic rocks in region are ash flow tuffs and pyroclastic deposits of the Idavada Group (*circa* 10-12 Ma); these have been subdivided into more detailed local units, but may be conveniently grouped together here for discussion *(e.g., Street and DeTar 1987; McCurry et al, 1996; Bonnichsen et al 2008).* These are commonly overlain by fine-grained lacustrine sediments (mudstone, shale, siltstone) that are generally correlated with the Glenns Ferry Formation (*Street and DeTar 1987).*

Overlying this in places is the Twin Falls rhyolite, also known as the Shoshone Falls rhyolite, a circa 4.5 Ma lava flow that is exposed in the Snake River Canyon from Shoshone Falls in the east to west of the Perrine Bridge in Twin Falls (*Bonnichsen et al 2008).* The Twin Falls rhyolite lava flow varies from zero to 150 m thick. Where it is exposed in the Snake River Canyon north of Twin Falls, the upper surface is an exhumed paleo-flow top marked by ogives and ramp structures (Figure 12). We interpret this unit to represent a post-caldera rhyolite flow erupted from ring fractures along a caldera margin that is now buried by younger basalt flows. Similar caldera-margin lavas are well-known in other eruptive centers, most notably the Yellowstone caldera *(e.g., Christiansen, 2001).* These ring fractures are our proposed target for fluid up flow.

This sequence is overlain by 100-300 m of basalt, commonly with a thin horizon of fine- to medium grained fluvial sediments separating the rhyolite from the basalt (Figure 13). Where the Twin Falls rhyolite lava flow is not present, lake sediments continue upwards to the base of the basalt (Figure 14). This succession is well-documented in water wells and geothermal wells through the region, with the contact of "rhyolite" underlying sediment (all that can be discerned from most drillers records) varying in elevation from as low as 2300 feet above sea level (650 m asl) to a high of 3400 feet asl (1100 m asl) (see appendix).

We have compiled and mapped surface structural elements in a region surrounding Twin Falls between about longitudes 114°W and 115.6°W and latitudes 42°-43°N (Figure 15). Our base map, as described previously, is derived from a NASA 10 m resolution DEM for the United States (http://seamless.usgs.gov / index.php), contoured with 10 m contour intervals in GeoMapApp (Goodwillie and Ryan, 2009). The resulting contour map was combined with a greyscale shaded relief image from the same 10 m data, with the maps in separate layers to enable toggling between them. Lineaments were identified from existing geologic maps, from lineations in the shaded relief map, or from offsets in contours that define lineaments (figure 15). Using the live GeoMapApp projection, sun illumination angles were altered to enhance the visibility of lineaments with different orientations.

The lineaments form three groups, based on orientation and location (Figure 15). West of Buhl and north of the Bruneau-Jarbidge eruptive center, the lineaments trend approximately 275°-285°, or roughly parallel to range front faults in the western SRP *(e.g., Shervais et al 2002; Wood and Clemens, 2002).* Lineaments with these trends also form the northern border of the Bruneau-Jarbidge eruptive center *(Bonnichsen et al 2008).* South and west of this region, the lineaments trend more northerly (~325°), including those within the Bruneau-Jarbidge eruptive center (Figure 15). This includes the Buhl-Berger lineament identified by *Street and DeTar (1987),* which cuts Berger Butte and may control its elongate shape. Finally, lineaments in the Cassia Mountains and in the Rogerson graben trend ~NS to 005°, more or less parallel to regional basin and range trends. There are some exceptions to these groups: Hansen Butte near Kimberly appears to be cut by an EW-trending fault, and there are many small cross-faults within the Cassia Mountains.

Overall, the pattern suggests a transition from western SRP orientations in the NW to Basin-and-Range orientations in the south. For the most part these lineaments can be shown to represent normal faults that offset topography, and many form small grabens that can be in both the topographic map and in the shaded relief map. The lineaments are more common where the underlying basement rock is older (rhyolite, lake sediments, or Paleozoic sediments), less common where underlain by Tertiary basalt, and essentially absent in areas covered by Quaternary basalts. This relationship implies that the faulting itself is older than Quaternary, and most likely formed coevally with the western SRP graben and Basin-and-Range extension. We note, however, that the absence of surface manifestations of these faults in the Quaternary basalts does not mean that they are absent in the subsurface. Indeed, it seems likely that since some faults are present in the late Pliocene age basalts, faulting continued up to the Pliocene-Pleistocene boundary, and that faults with these same orientations are likely to underlie the younger Quaternary basalts. The orientation of Rock Creek Canyon south of Twin Falls is subparallel to the Berger Butte trend, suggesting that the course of this creek is itself control by pre-existing fractures.

Also shown on the 10 m DEM topographic map are measured flow directions for ash-flow tuffs in the Cassia Mountains, as mapped by *McCurry et al (1996)*, along with the southern extent of these ash-flow sheets (Figure 15). These flow directions are based on hundreds of field measurements and document clearly a source vent located north of the central Cassia Mountains, in the vicinity of Kimberly, Idaho. As we noted earlier, post-caldera rhyolite flows are exposed in the Snake River Canyon NW of Kimberly, suggesting that the now buried southern margin of the caldera vent which erupted these ash flows is somewhere near Kimberly, and that the central vent lay somewhere north of Kimberly. The inferred boundary of the Twin Falls caldera complex is shown on Figure 15 as a dashed white line.

In order to clarify the possible location of the source vent for the Cassia Mountains ash-flow tuffs, we produced a Bouguer gravity map of the central SRP covering an area slightly larger than the 10 m DEM topographic map. The Bouguer gravity map is characterized by low gravity along the margins corresponding to sediment-filled basins, rhyolite ash flows, or Paleozoic carbonate basement (Figure 16). The pronounced gravity high to the west continues beneath the western SRP, and may represent a buried horst block within the WSRP graben (see section on Mountain Home drill site for detailed discussion of the western SRP gravity structure). North of Twin Falls is a prominent gravity low surrounded by a rim of slightly higher gravity material (dashed white line). We interpret this structure to represent a buried caldera complex associated with eruption of the Idavada rhyolite tuffs. The Kimberly drill site lies along the southern margin of this structure, which lies more-or-less where we predicted it based on geologic mapping. We also note that the Kimama drill site lies along the NE margin of this same structure, and we may find analogous fracture porosity at that site (Figure 16).

The area underlain by the ring-like structure is covered with a more-or-less uniform carapace of Quaternary basalts, so it cannot be interpreted to result from the distribution of surface basalt flows. The relative density contrast, the shape, and the size of this structure are all consistent with its interpretation as a buried eruptive complex *(e.g. Morgan et al 1984)*. It also lies in the appropriate location for the source vent of the Cassia Mountain ash-flows. Richard Smith of INL developed the concept of using gravity to locate buried caldera complexes in the mid-1990's, which he applied to the eastern SRP with some success *(Smith et al 1994)*. We believe that his approach will also work in the central SRP and provides an innovative way to see below the thick carapace of basalt, and to test the geothermal potential of these ring fracture systems.

The proposed depth of the Kimberly drill hole is 1.8 km. This depth is based on estimates of rhyolite thickness outside the plain. If our costs are lower than estimated, we have the option to extend drilling on the Kimberly hole up to 2.2 km depth.

The proposed drill site is on the University of Idaho Extension Farm, located 3 km NE of Kimberly town and 10 km east of Twin Falls. This location was chosen because it lies on the southern margin of the topographic Snake River Plain, and on or near the margin of the Twin Falls caldera complex, as defined by outflow sheets in the nearby Cassia Mountains *(McCurry et al 1996)* and by the regional Bouguer gravity anomaly discussed above. This site offers the logistical advantage of being located just off a state highway, on property owned by the University of Idaho, which is a partner in the Project Hotspot initiative. The infrastructure present includes power, water, diesel fuel station, and a variety of buildings. We have located a potential well-head site north of the main office buildings and greenhouse that will absorb noise from the drill rig, and which has easy access from existing farm roads. Site preparation will include laying down a layer of gravel which will be retained by the Research Farm for their equipment parking site.

Permitting for this site has been completed. A cultural and biological survey of the site was carried out in July 2010 by *USU Archeological Services, Inc.*, and their report has been transmitted to DOE. The site is located in a dirt parking lot for farm equipment that contains no cultural artifacts or endangered species. A memorandum of understanding (MOU) with the University of Idaho – College of Agriculture, which owns the site, was negotiated in May-June 2010 and signed by administrative vice presidents from both universities in July 2010. Based on our revised drilling prospectus, the IDWR issued our drilling permit for this site in August 2010.

Mountain Home – Geothermal Potential Under the MH Air Force Base and Western SRP

The primary science goal of the Mountain Home drill core is to assess the geothermal potential under the AFB, building on results from a geothermal test well drilled in 1985-86 *(Lewis and Stone, 1988)*. The previous geothermal test well had a BHT of 93°C, but it was not possible to perform a pump test due to the hole size. Our goals for this hole are to first sample basalts and lacustrine sediments in the upper 300 m of the section, which were not sampled by the existing Mountain Home Air Force Base (MH-AFB) MH-1 test hole, and second to deepen this hole with sufficient bore to carry out a robust flow test of the hydrothermal waters. A geologic map of this area is being prepared for publication (Figure 17).

Mountain Home AFB is currently undergoing a Federal Energy Management evaluation, directed by Robert Breckenridge of the Idaho National Lab. We have contributed our existing data to this report, and will also provide breaking data as we acquire it, until the report is finalized in October 2010.

The western SRP has a long history of passive geothermal space heating applications, especially within the city of Boise. Previous wells (MH-1, Bostic 1-A: Figure 18) have documented elevated temperatures at depth that are close to those needed to sustain geothermal development, and elevated groundwater temperatures are found in some areas *(Lewis and Stone 1988; Arney 1982; Arney et al 1982, 1984)*. A prominent gravity anomaly in the regional Bouguer gravity map *(Liberty, personal communication, 2010)* has been shown near Boise to represent an uplifted horst block in the subsurface *(Wood, 1994)*. This same gravity high extends to the east beneath Mountain Home, and can be seen in both the Bouguer gravity anomaly map (Figure 19a) and an upward continued gravity map that removes shallow density variations and emphasizes deep crustal structures (Figure 19b).

Mountain Home AFB sits on the southern edge of this prominent gravity anomaly, as can be seen in the more detailed Bouguer gravity map in Figure 20, which shows the gravity contour map without and with the gravity stations used to produce it. This gravity high that has been interpreted by *Shervais et al (2002)* to represent a buried horst block with the larger western SRP graben. This interpretation is consistent with reflection seismic data from Boise-Caldwell area that documents a buried horst block below the Glenns Ferry formation *(Wood 1994)*. Confirming this interpretation requires that we run new seismic reflection surveys in the area adjacent to MH-AFB; these surveys are planned for September 2010. Figure 21 shows a detail of the positive gravity anomaly that lies just north of the base, along with planned seismic reflection profiles. These reflection profiles should delineate basement structure in some detail and lead to a clearer understanding of the nature of the prominent positive gravity anomaly.

A report by *Innovative Technical Solutions, Inc. (2003)* suggests that geothermal potential under MH-AFB is limited, based on low groundwater temperatures in many of the monitoring wells. They do note however that *"A sharp groundwater gradient trending northwesterly exists just outside the northeastern corner of the base; it was assumed that this gradient may be controlled by basement topography which may in turn be due to a northwest-trending structure (typical of regional structural trends and thus a potential deep fluid upflow zone)" (Innovative Technical Solutions, Inc., 2003).* We used data from the US Geological Survey groundwater database for western Idaho *(Parliman, personal communication, 2010)* to produce a gridded map of groundwater temperatures in the Mountain Home area (Figure 22). This map, based on next-nearest neighbor gridding algorithms, shows this prominent NW-trending thermal anomaly, as well as the relatively cold groundwater temperatures found west and northwest of the base. These zones of low groundwater temperatures correspond to the drainage of Canyon Creek, a prominent drainage that channels cold water from the Danskin Mountains (north of Mountain Home) diagonally across the map area from NE to SW. We infer that the low observed temperatures in this region result from refrigeration by cold surface waters, and not from a lack of warm water upflow. The NW-trending thermal anomaly coincides more-or-less with the southern margin of the positive gravity feature identified in Figures 20 and 21; we infer from this that the groundwater thermal anomaly does in fact represent a regional warm-water upflow zone controlled by bounding faults on the buried horst structure.

The difference in stratigraphy between the MH-1 well *(Lewis and Stone 1988)* and Bostic 1A well *(Arney et al 1984)* is best explained by their positions relative to the inferred basement high, with MH-1 bottoming on top of the inferred horst block (but near its southern margin) and Bostic 1A traversing a thick section of sediments and volcanic flows filling the small graben that lies north of the horst block, and south of the Danskin Mountains (Figure 18). There may in fact be vertical upflow zones along both the northern and southern margins of this inferred horst block, explaining the elevated bottom hole temperatures found in both wells *(Lewis and Stone 1988; Arney et al 1982, 1984).*

The proposed depth for the new MH-AFB drill hole is 700 mbs. This depth would penetrate the lake sediments and overlying basalts, and tag lower basalts at around 600 mbs *(Lewis and Stone 1988).* The USAF may fund an extension of this well to ~1200 m to test the economic potential of the known geothermal resource that exists under the Base.

One potential drill site is located in the undeveloped NW corner of MHAFB. This site is less than 2 km from the original MH-1 (1342 m) geothermal exploration well, which was drilled along the eastern margin of the Base. The overall stratigraphy at this site is expected to be more or less identical to that found in the MH-1 well. The proposed site is within a few hundred meters of an existing 150-meter deep monitoring well (MW-3-2), and near two other monitoring wells, so the upper stratigraphy is well-known. However, no core is available from the monitoring wells. An alternative site would be along the eastern edge of MHAFB, closer to the original geothermal test well and within the area of elevated groundwater temperatures identified in the gridded map (Figure 22). This site is also close to a monitoring well that can be used to guide drilling in the upper portion of the new drill hole.

Because drilling at this site will be carried out in conjunction with the Air Combat Command of the USAF as part of their geothermal exploration project, the USAF will acquire all the necessary permits and complete any needed surface restoration for this site. They will assume ownership of the drill hole on completion and may keep this well open to use as a monitoring well. The Air Force is interested in obtaining geophysical logs for the proposed well, especially detailed thermal logs. A further goal is to carry out aquifer tests at deeper intervals, which will require a relatively large diameter drill hole.

Logistically, MHAFB location is 24 km from the town of Mountain Home (population 13,000), which has most needed services, and 100 km from Boise, Idaho, which hosts a major regional airport.

Core Handling

Core from Kimama and Kimberly will be processed initially at the USU Core Facility, established for this project. It contains core-splitting saw, drill press for paleomag cross-cores, a DMT image scanner, and Geotek MultiSpectral Scanner, a computer with the ICDP Drilling Information System software installed and configured for our project, and a dual-screen workstation for the Corewall system.

Core will be archived at the USGS Core Research Center in Denver, Colorado. This facility is centrally located in the geographic center of the United States, and is close to a major international airport with direct flights from almost anywhere in the United States. It is easily accessible to scientists from any country and contains a wide range of tools as described in the letter from the CRC Director, including large work spaces, core saws, binocular and petrographic microscopes, and meeting space for workshops and sample parties. Core from the lacustrine sediment section at Mountain Home will be archived at the LaCore facility, as described in our previous proposal.

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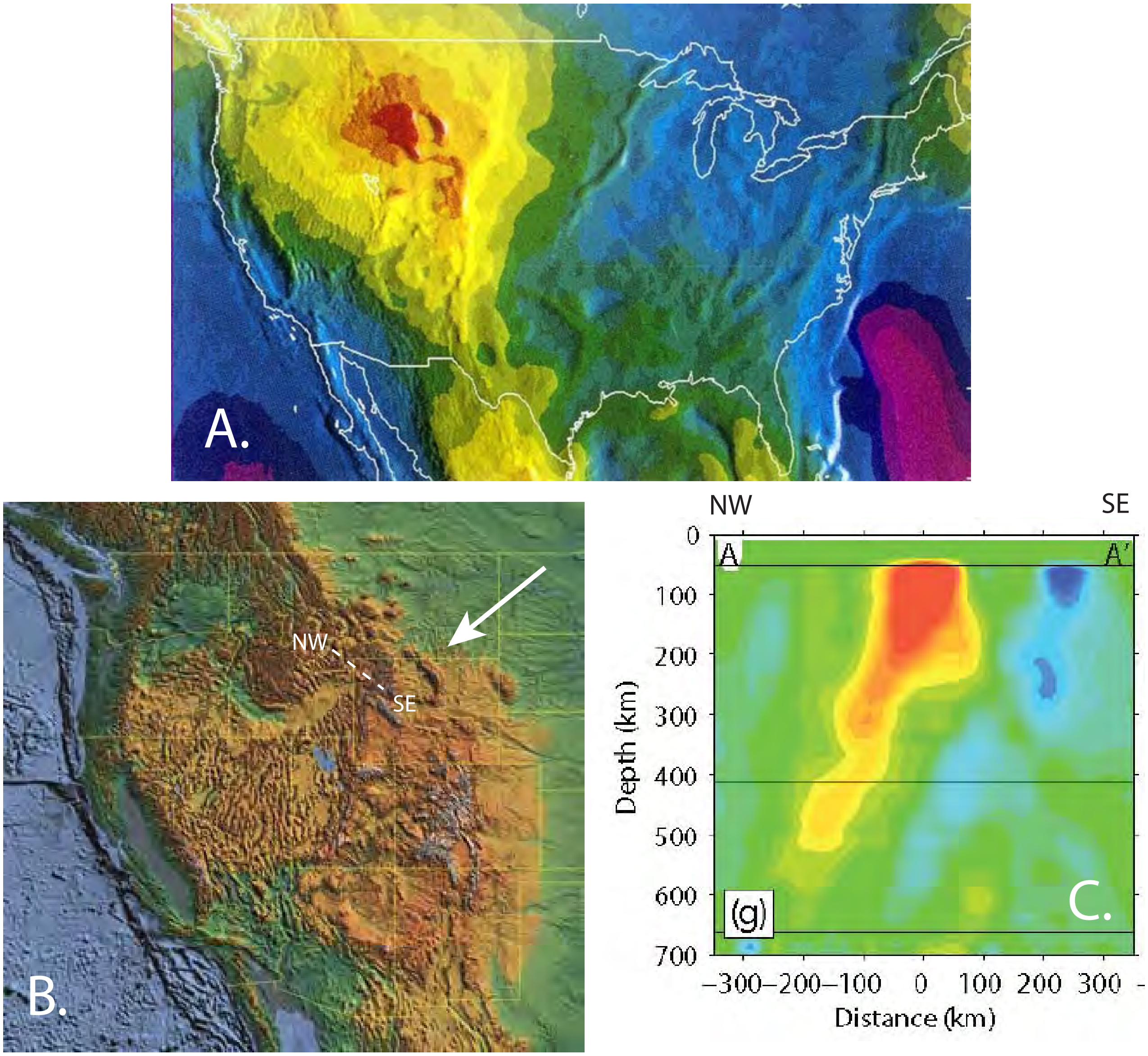


Figure 1. Impact of the Snake River - Yellowstone plume on North America. (A) Geoid map of North America, showing prominent positive geoid anomalie of +15 m centered on current location of Snake River-Yellowstone hotspot. (B) digital topographic map which shows effect of the plume tail on topography, cutting across the regional Basin & Range trend to form a broad depression approximately 100 km across and several hundred km long. White arrow shows direction of North American plate motion, dashed white line shows approximate location of seismic tomograph section in figure 1C. (C) Seismic tomograph of Yellowstone thermal anomaly; anomaly plunges approximately 65° WNW (plane of section). Note the high velocity (cold) lithospheric root of Wyoming craton, which extends to at least 300 km depth SE of the thermal anomaly. Tomograph from Yuan and Dueker, 2005.

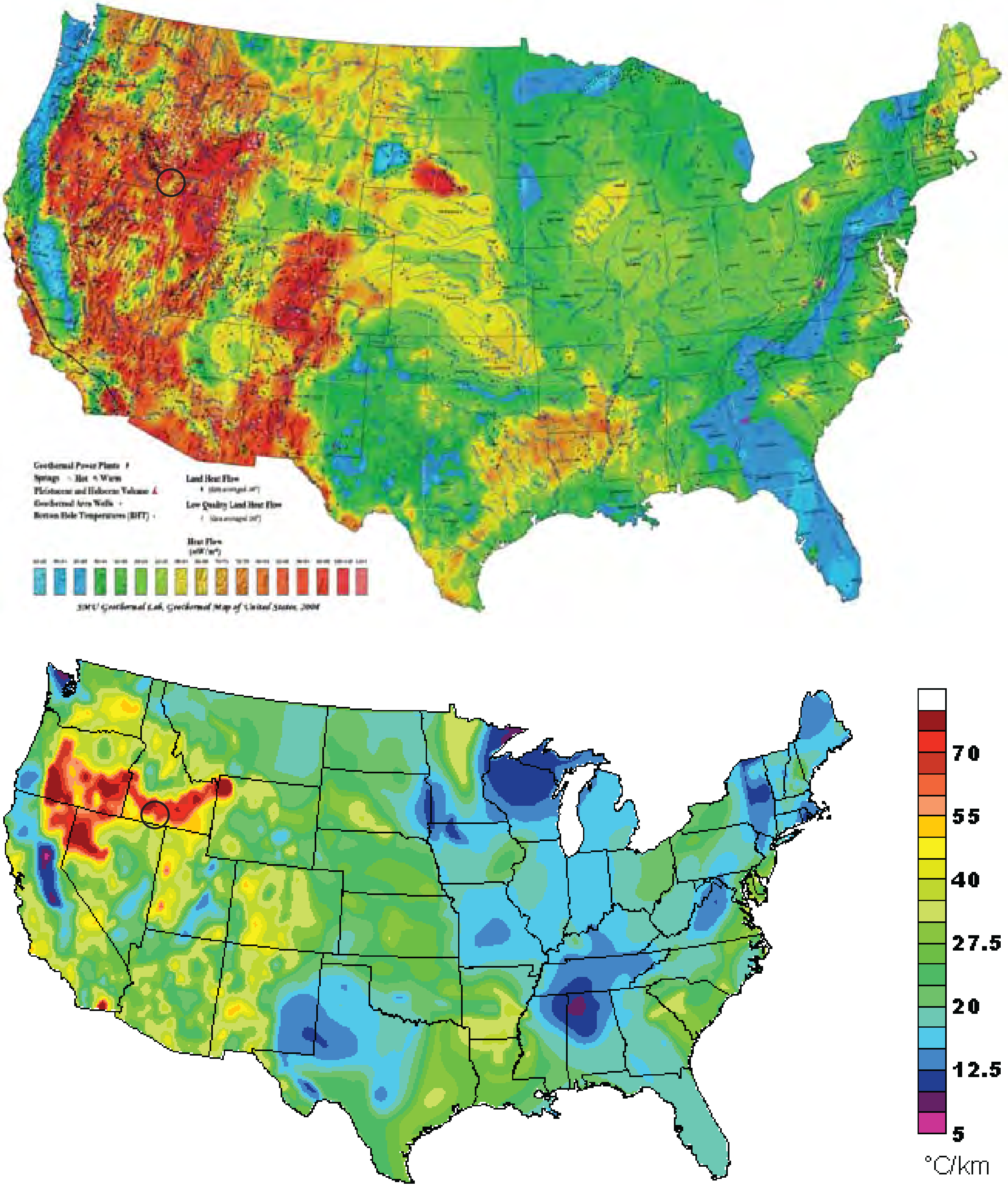


Figure 2. (A) Top. Heat flow map of United States showing generally elevated heat flow across much of western US, primarily in the Great Basin and southern Idaho. (B) Heat flow gradient map of United States, showing extremely high surface gradients concentrated in northern Great Basin and along Snake River Plain-Yellowstone trend. Both maps from Southern Methodist University Geothermal Laboratory and Professor David Blackwell.

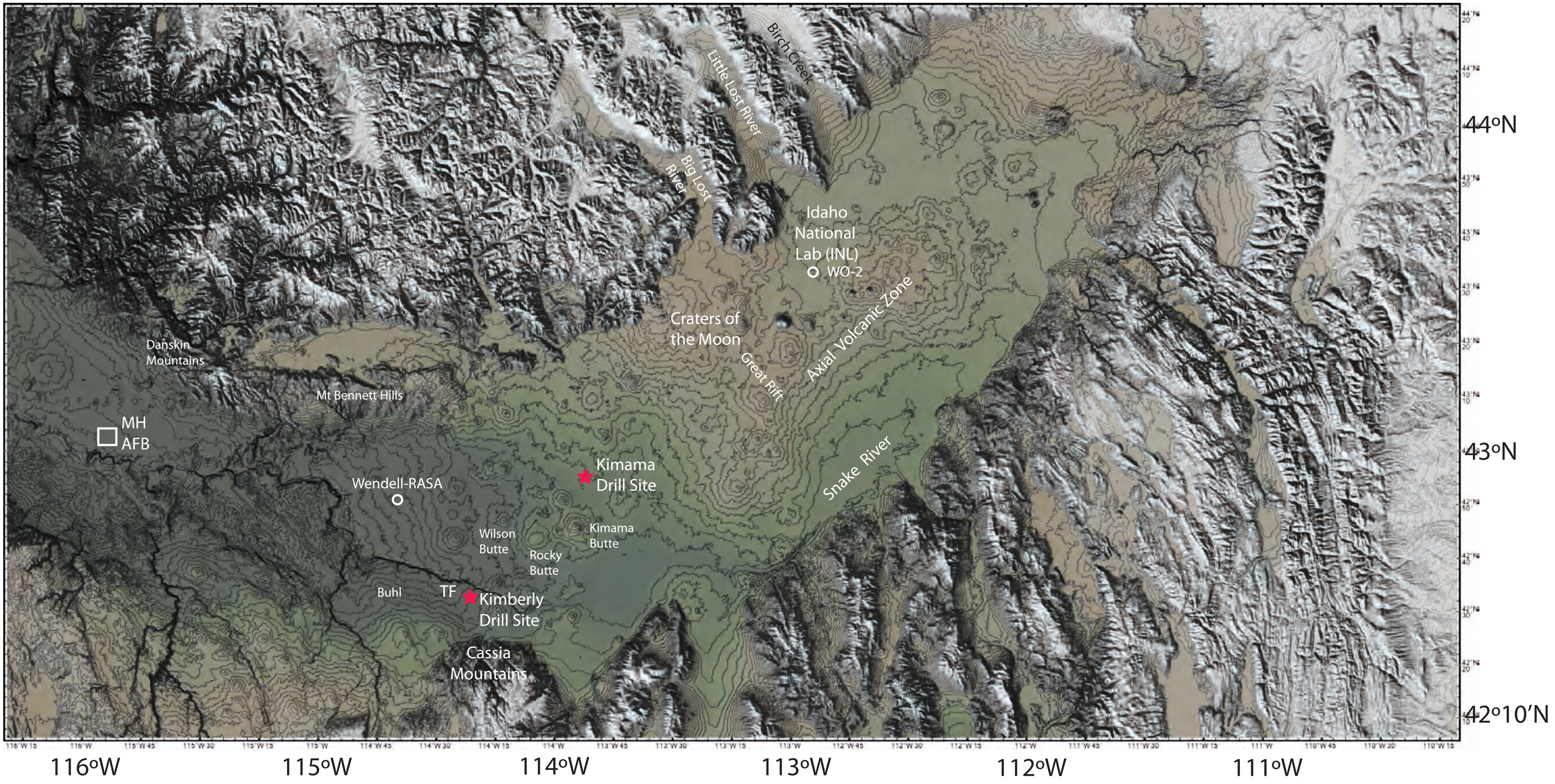
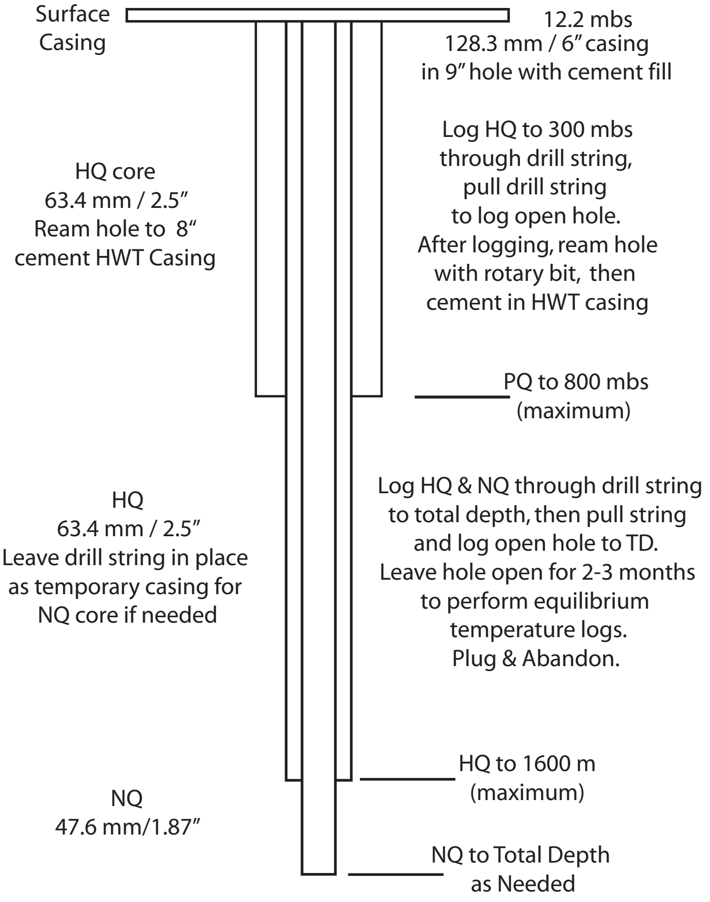


Figure 3. Shaded relief-topographic map of Snake River Plain, derived from NASA 10 m DEM data and contoured at 30 m intervals in GeoMap App. Lowest elevations are green, highest are white.

Figure 4. DOSECC's Atlas-Copco 4002 truck mounted drill rig, to used for both deep holes. It has a capacity of 18,000 kg and can lift 2450 m of NQ drill string.

Figure 5 (below). Drill Hole Plan for Kimama (1500 m) and Kimberly (1800 m) Test Wells



Log HQ to 300 mbs through drill string, pull drill string to log open hole. After logging, ream hole with rotary bit, then cement in HWT casing

Log HQ & NQ through drill string to total depth, then pull string and log open hole to TD. Leave hole open for 2-3 months to perform equilibrium temperature logs. Plug & Abandon.

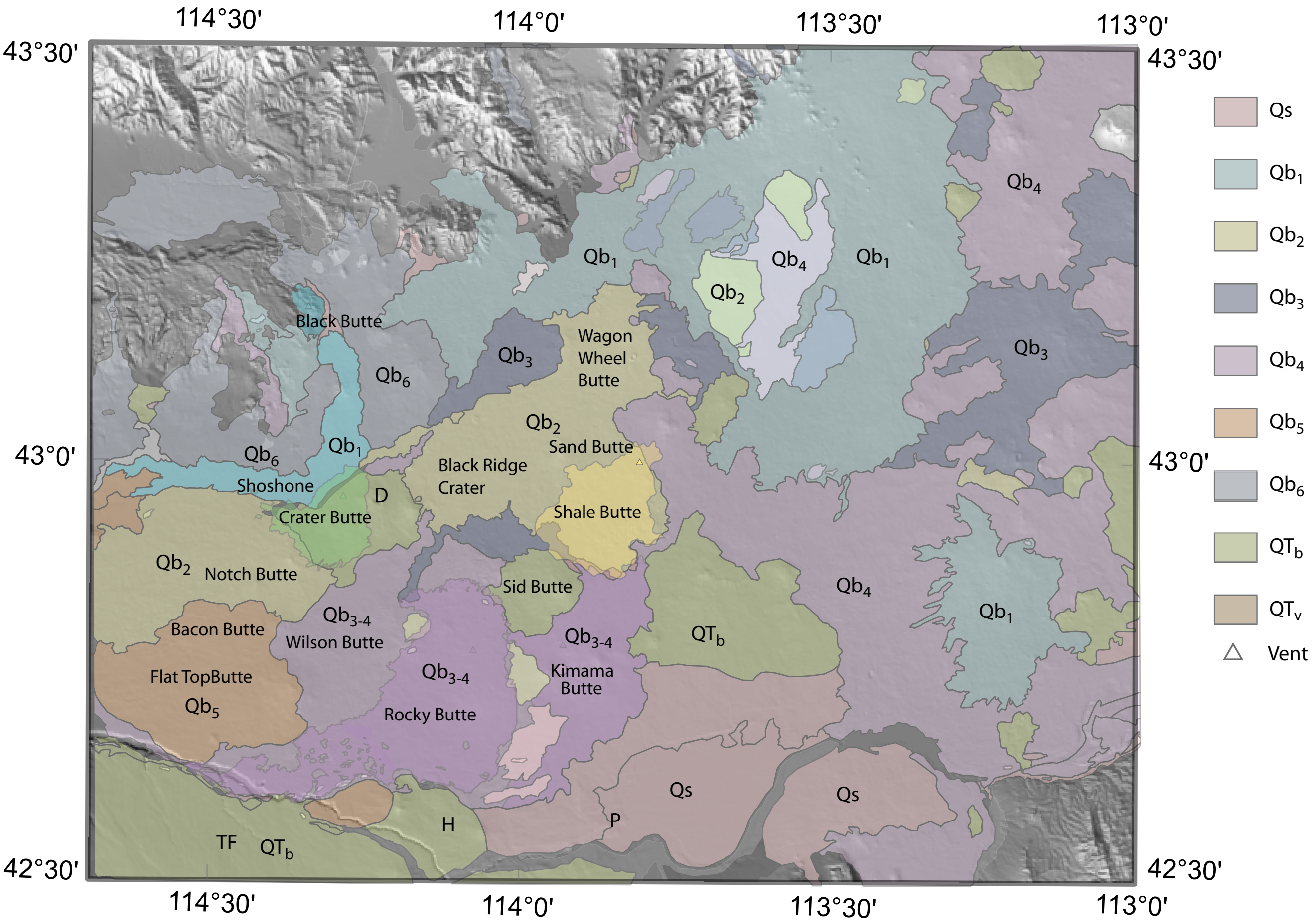


Figure 6. Partial compilation of basaltic vents in central Snake River Plain. Most vents north of the Snake River are < 780,000 years old, with one vent as young at ~10,000 Ka (Kuntz et al., 1992). Note the clustering of basaltic vents along the Axial Volcanic Zone, in which older vents are largely buried by younger flows. Compiled from Kauffman et al 2005, Shervais et al 2006c, 2006d, Cooke et al 2006a, 2006b, Matthews et al 2006a, 2006b, and Kuntz et al 2007, as well as from unpublished mapping by the PI and his students. Not all vents shown, many units combined for clarity.

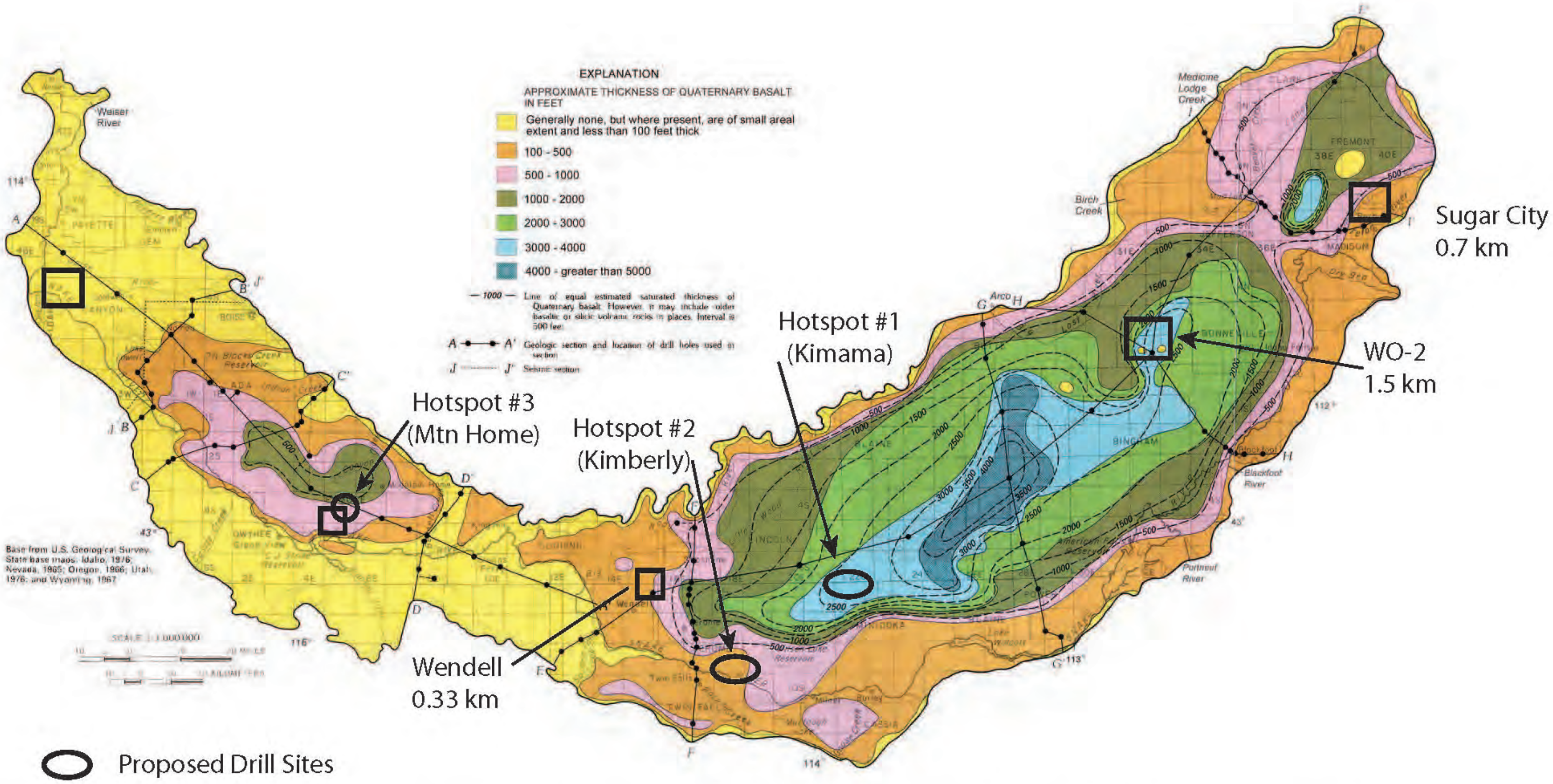


Figure 7. Basalt thickness estimated from resistivity surveys and well data. From Lindholm 1996, USGS Professional Paper 1408-A. Also shown are proposed drill sites and existing drill sites discussed in text.

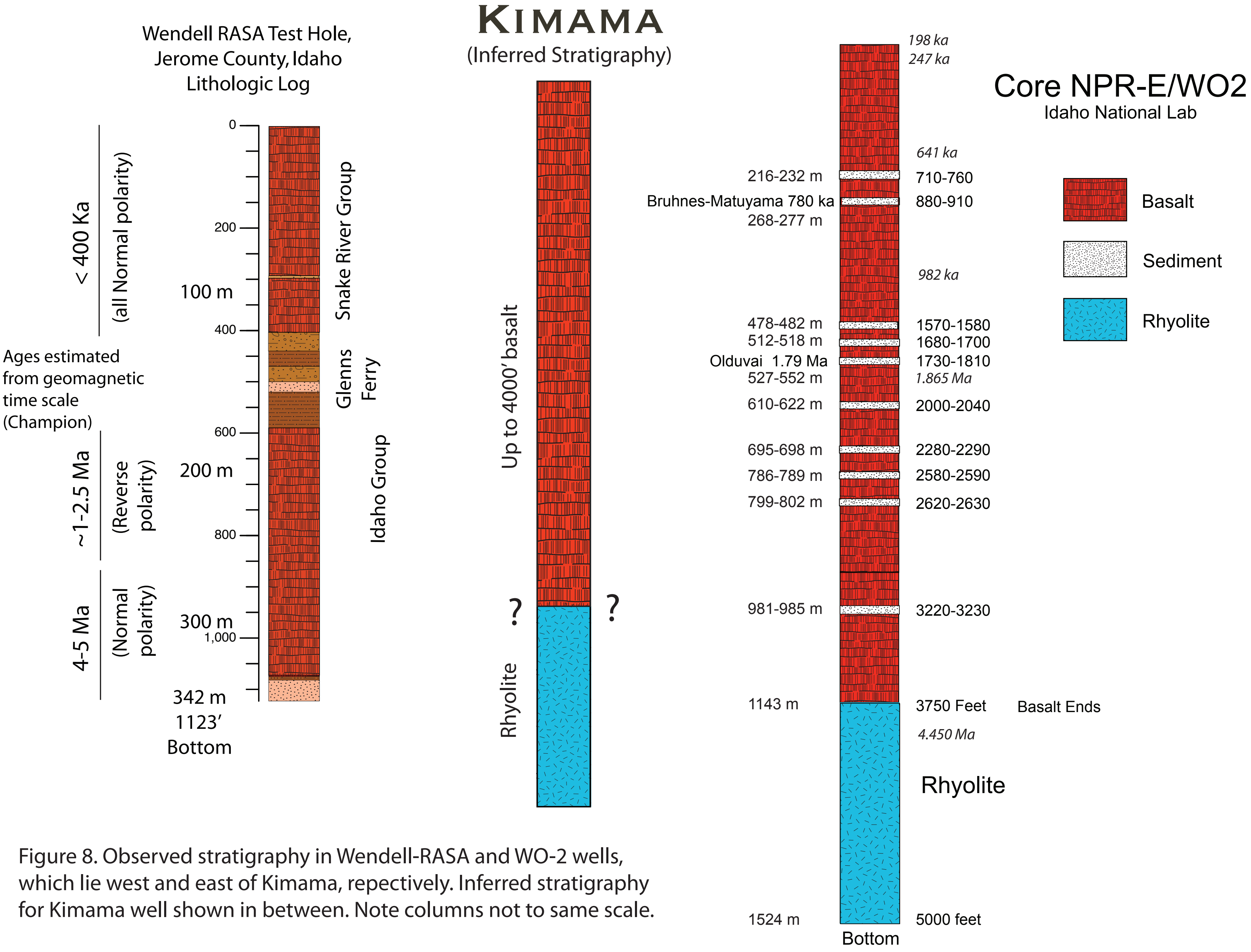


Figure 8. Observed stratigraphy in Wendell-RASA and WO-2 wells, which lie west and east of Kimama, repectively. Inferred stratigraphy for Kimama well shown in between. Note columns not to same scale.

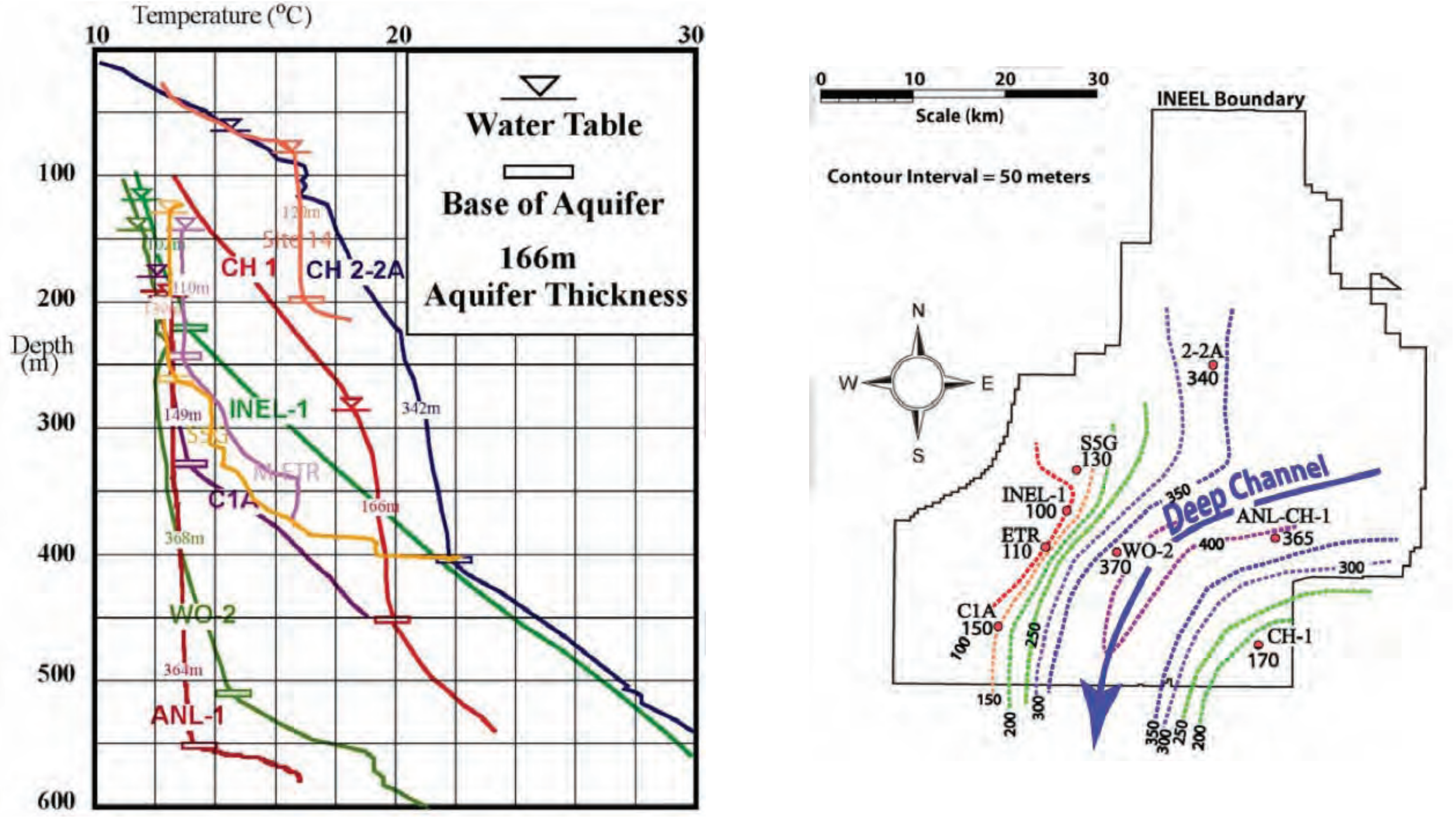


Figure 9. (a) Thermal profiles in deep wells at the INL site. Upper inflection from conductive to isothermal represents top of the Snake River aquifer; lower inflection from isothermal to conductive represents the base of the aquifer. (b) Aquifer thickness and the lower inflections define a deep channel that underlies the INL, caused by the influx of cold groundwater from the Centennial Mountains to the north. This cold water plume flows SW along the northern margin of the SRP. From Smith 2004 and Smith et al (submitted).

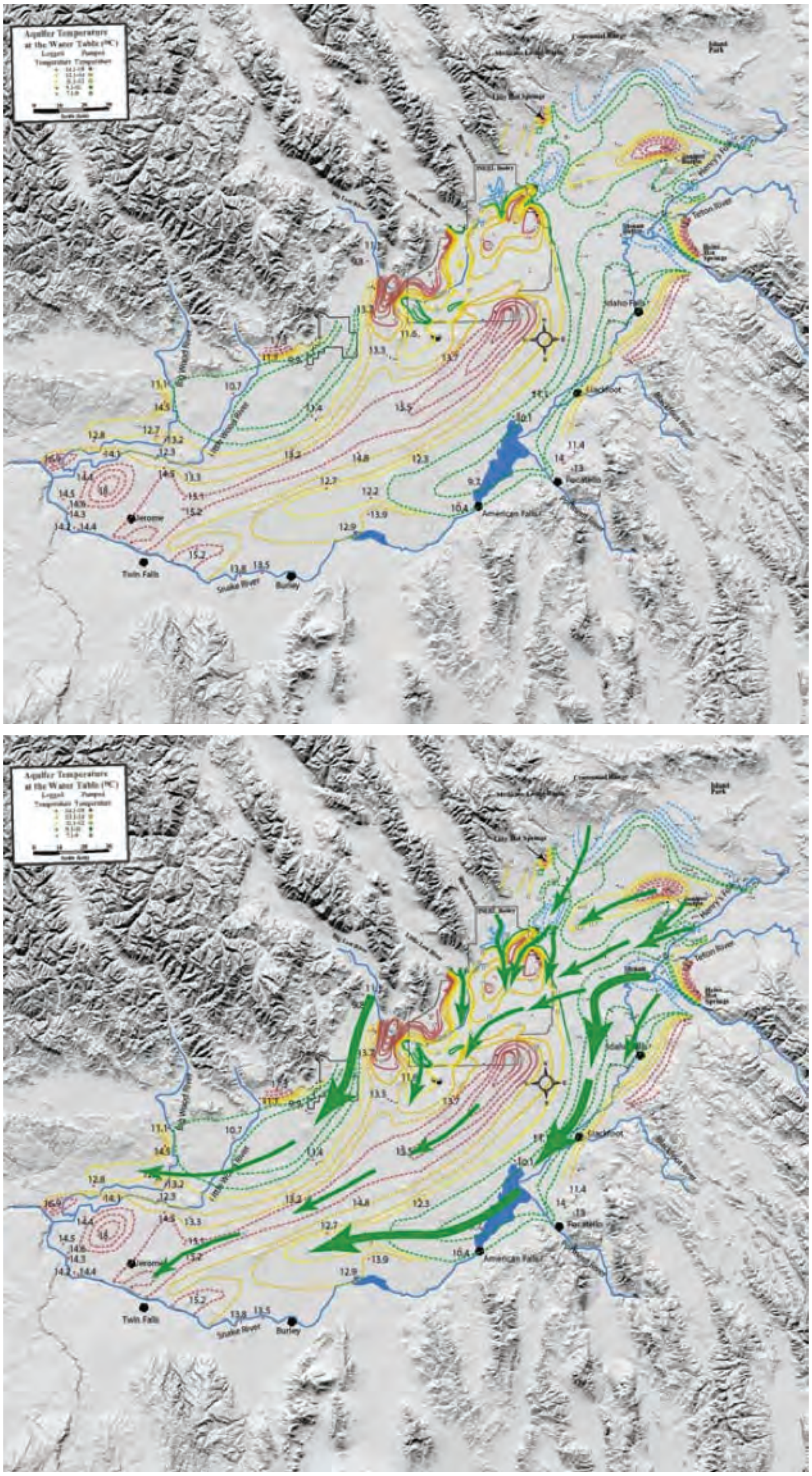


Figure 10. Groundwater temperatures and inferred flow paths, from Smith 2004 and Smith et al 2002, submitted. (a) groundwater temperatures contoured from cold (blue, green) to warm (yellow, red). Note axial zone of high groundwater temperatures that correspond to the central volcanic axis of the SRP; (b) Inferred flow paths for cold water in subsurface.

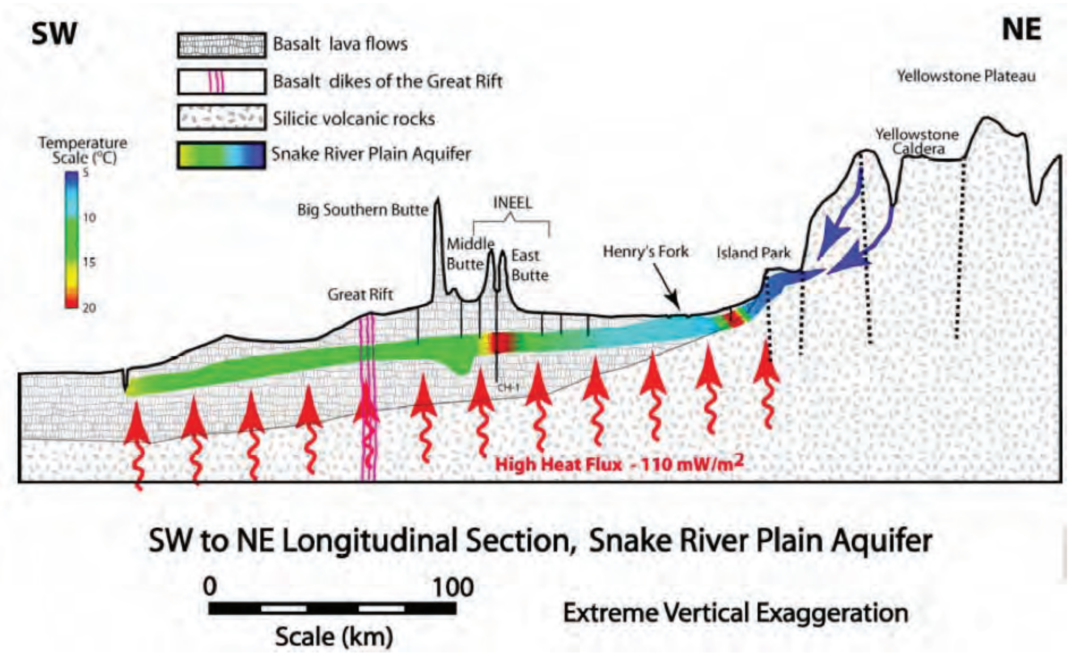


Figure 11. Model of groundwater flow under central axis of Snake River Plain, from Smith 2004. Cold water influx from mountains is warmed from below by conduction of high geothermal gradient, and by advection of heat in thermal fluids. Water becomes progressively warmer as it moves westward long the volcanic axis.

Figure 12. Photo looking west from Perrine Bridge in Twin Falls at Twin Falls Rhyolite lava flow. Flow contain typical rhyolite lava flow structures (ramps, platy cleavage) and has large scale undulations on upper surface (ogives) that may contain rhyolite breccia.

Figure 13. View looking North at north wall of Snake River Canyon in Twin Falls, at the Perrine Bridge. Lower half of photo (below bridge abutment) comprises grey-reddish Twin Falls rhyolite (aka Shoshone Falls rhyolite). Upper half of photo comprises basalts from Flat Top Butte (330 ka) and Wilson-Rocky Buttes (circa 95 ka; these have been mapped as "Sand Springs Basalt" by Malde). Between rhyolite and basalt is thin interlayer of fine grained fluvial/lake sediments, generally correlated with the Glens Ferry formation. Swales in top surface of the rhyolite are filled with rhyolite-obsidian breccia (e.g., just left of bridge abutment). This stratigraphy is typical of what is observed in deep wells and likely represents the upper section of what we will encounter in the Kimberly well.

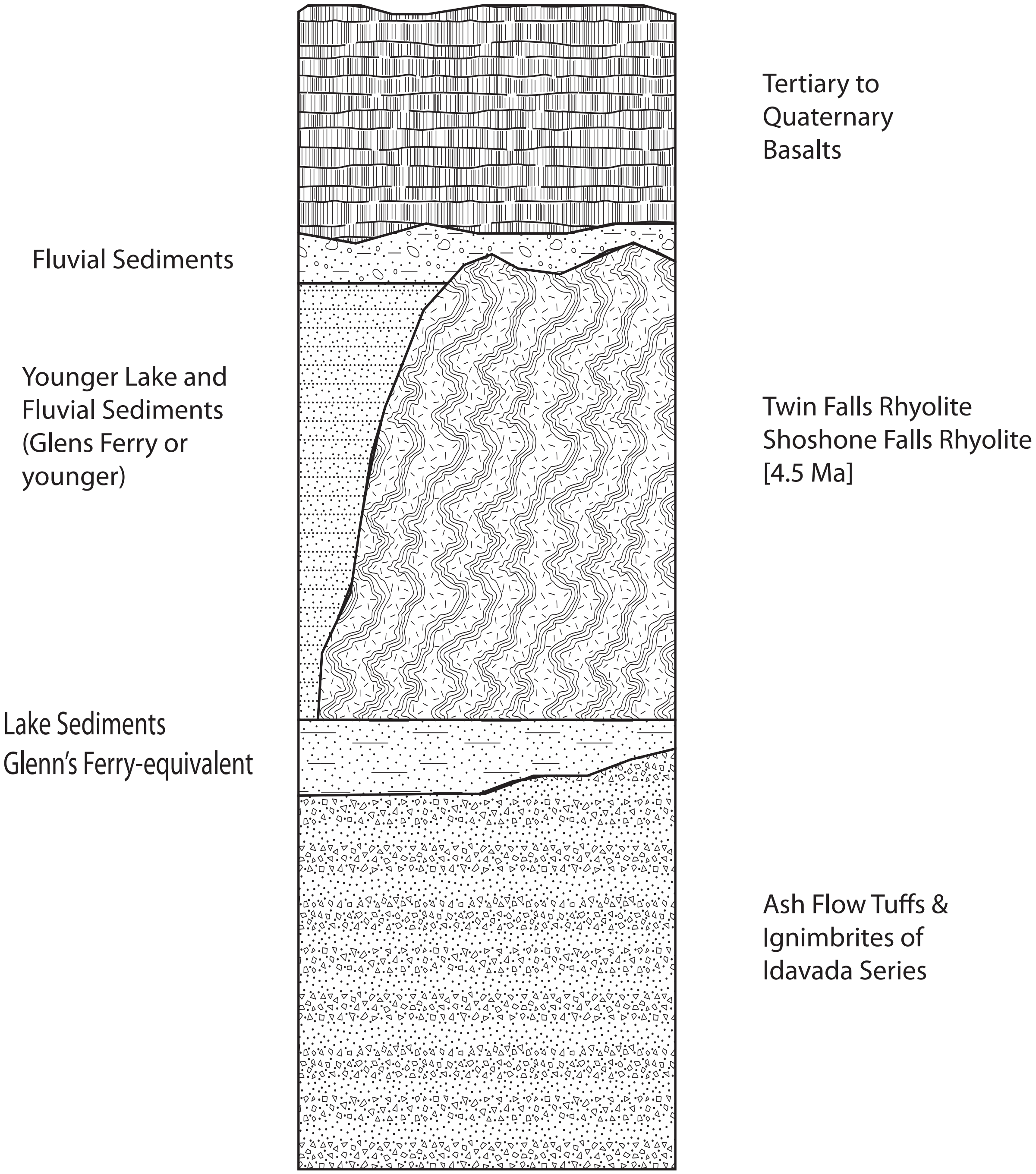


Figure 14. Representative stratigraphic column of Twin Falls area geothermal district. Modified from Street and DeTar (1987); based on drillers logs from shallow water and geothermal wells (up to 2200 feet deep).

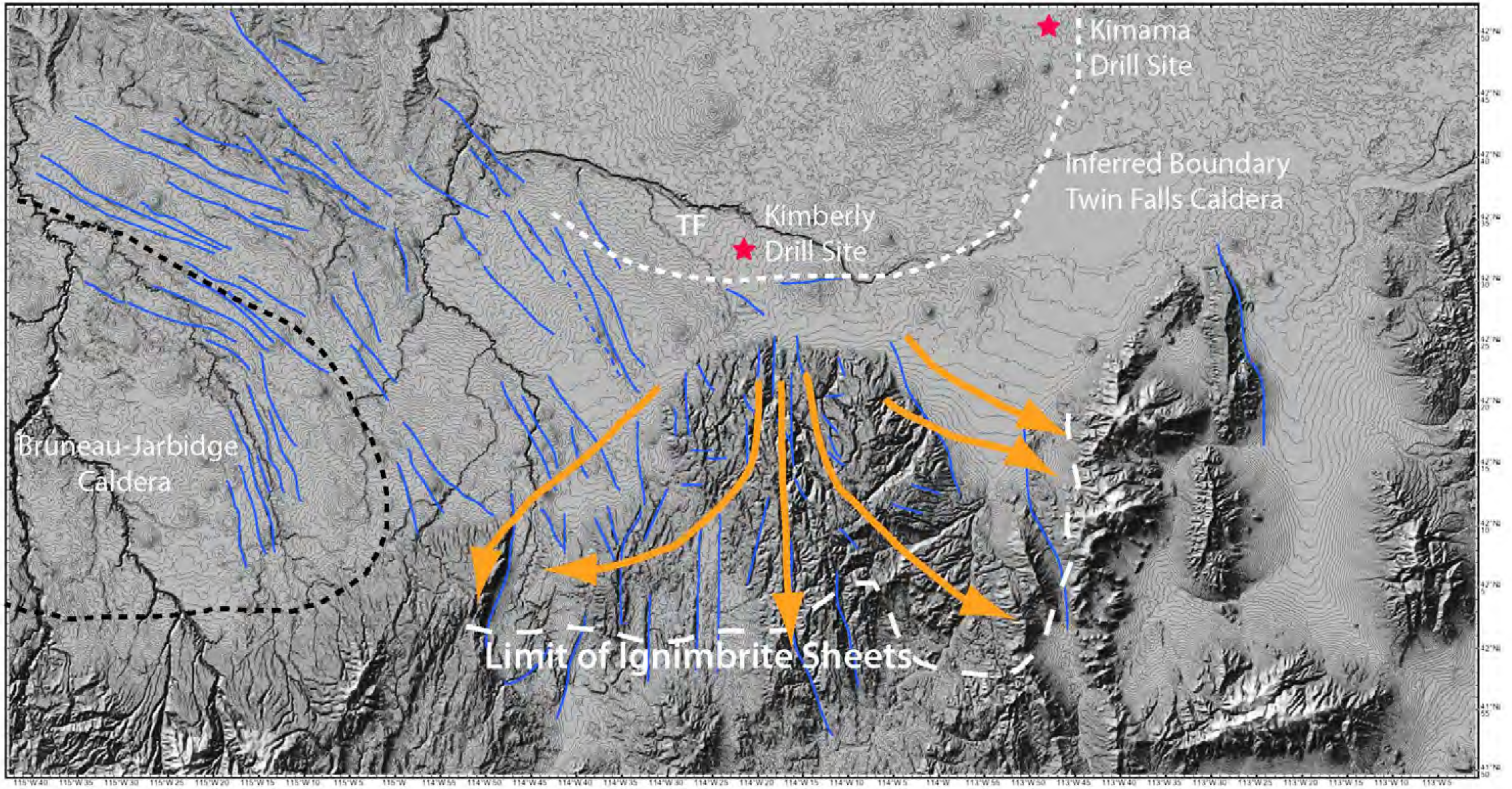


Figure 15. Shaded relief map of Twin Falls area, with 10m contours calculated from NASA 10 m DEM data in GeoMapApp. Blue lines show mapped faults from published maps or mapped from lineaments in 10 m data. Yellow arrows show flow directions on ash flow tuff sheets in Cassia Mountains, mapped by McCurry et al 1996, with southern extent of ash sheets marked by long-dash white line. Bruneau-Jarbidge caldera marked by short-dashed black line. Southern margin of the Twin Falls caldera complex, inferred from regional Bouger gravity anomaly, shown with dashed white line. Drill sites marked with red stars; TF = City of Twin Falls.

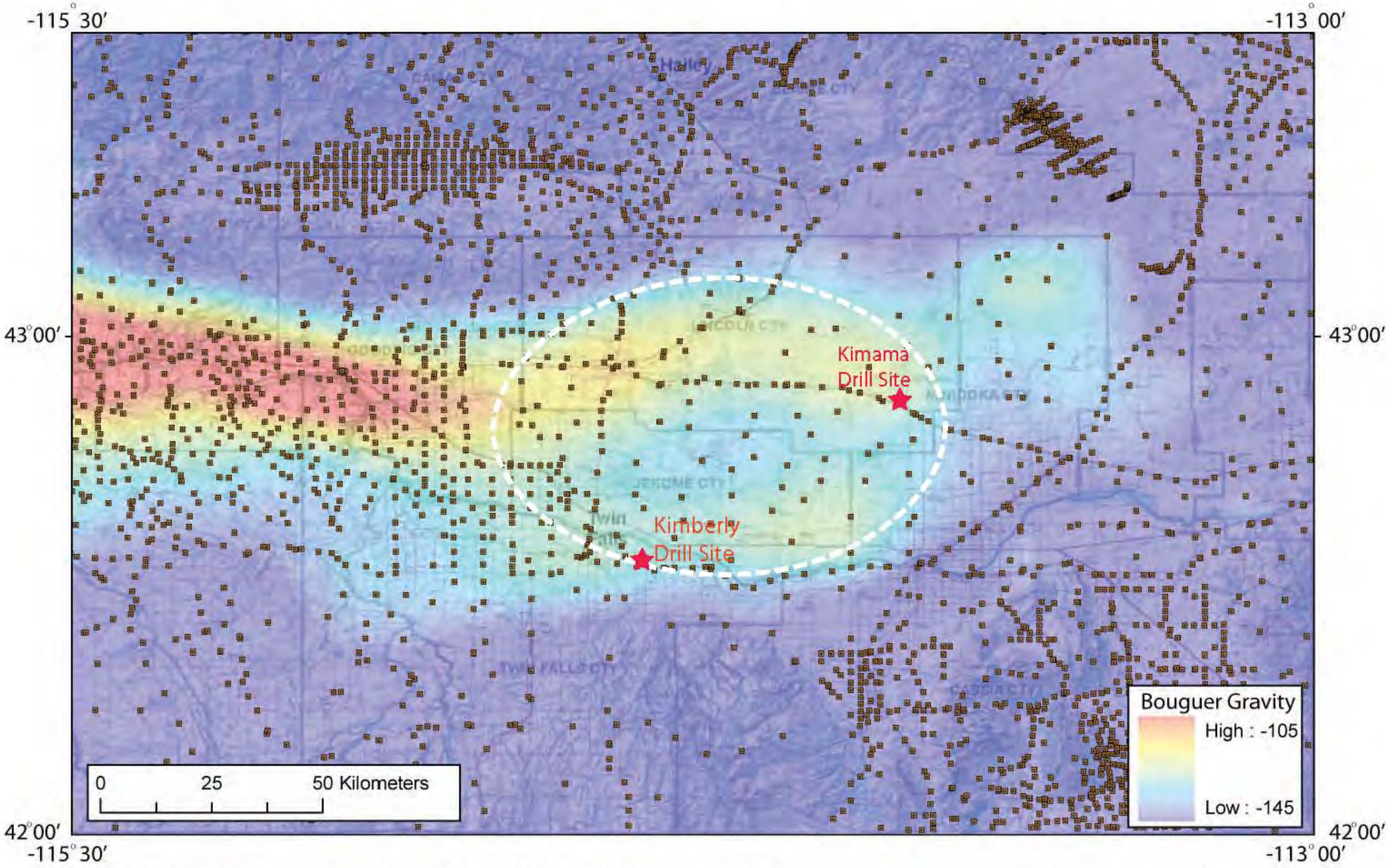
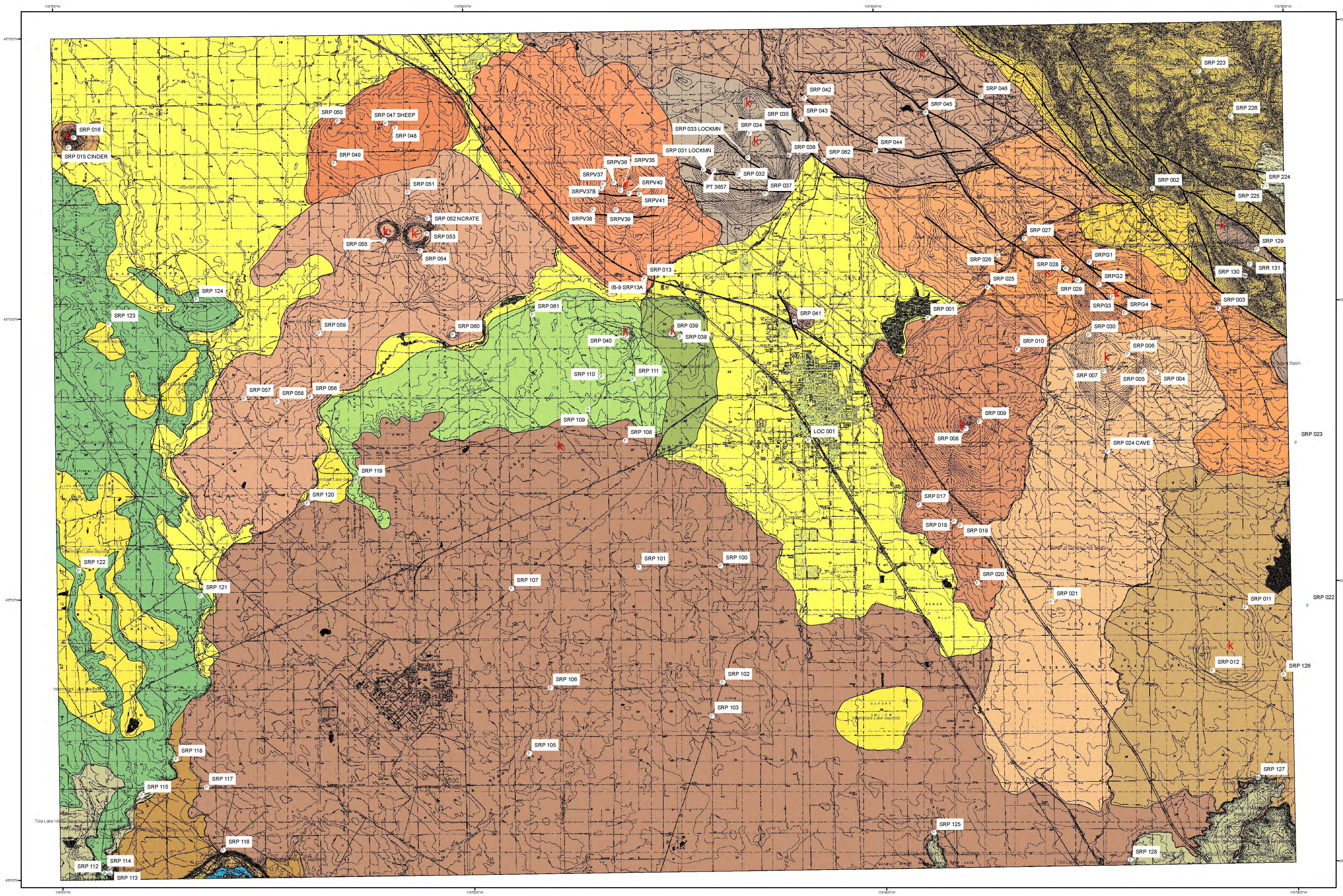


Figure 16. Bouger gravity map of central Snake River plain showing low gravity alon the margins (corresponding to sediment-filled basins, rhyolite ash flows, or Paleozoic carbonate basement. Pronounced gravity high to west continues beneath the western SRP, and may represent a buried horst block within the WSRP graben. North of Twin Falls is a prominent gravity low surrounded by a rim of slightly higher gravity material (dashed white line). We interpret this structure to represent a buried caldera complex associated with eruption of the Idavada rhyolite tuffs. The Kimberly drill site lies along the southern margin of this structure, while Kimama lies along the NE margin of this structure (red stars).



k Vents
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🟩 Qunw
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🟦 River

Figure 17. Geologic Map of Mountain Home area - SW corner of Mtn Home 1/100,000 sheet. Mapping by JW Shervais.

Geologic Map
Mountain Home Area
Elmore County, Idaho
by
John Shervais
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2010

SCALE 1:50,000
0 2,000 4,000 8,000 12,000 16,000 20,000 24,000 Feet
0 0.5 1 2 3 Miles
0 1 2 4 Kilometers
CONTOUR INTERVAL 40 FEET

Base from USGS 7.5' Quadrangles
Projected Coordinate System: NAD_1983_UTM_Zone_11N
Geographic Coordinate System: GCS_North_American_1983

GIS Work completed by Christopher Tressler

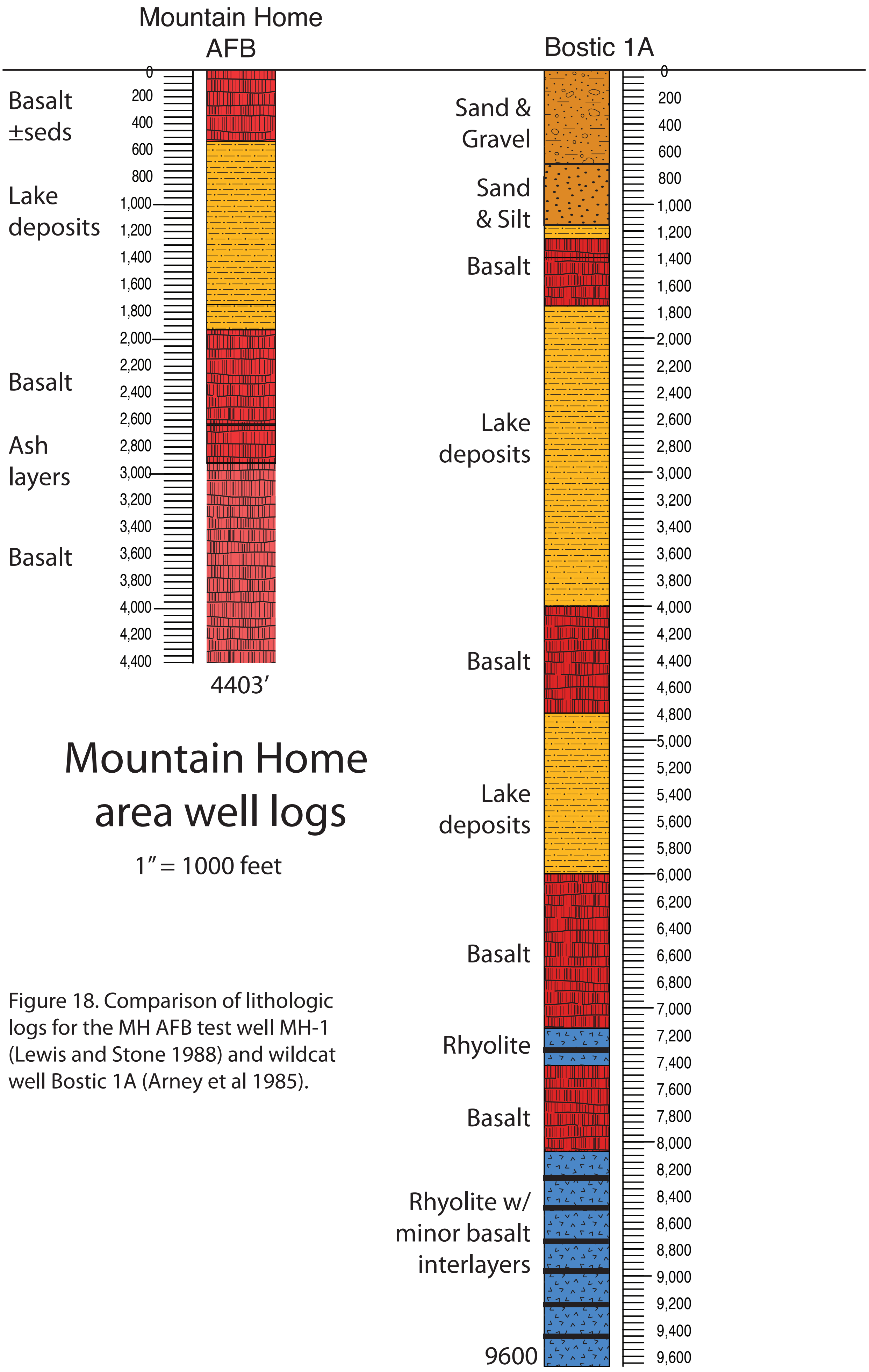


Figure 18. Comparison of lithologic logs for the MH AFB test well MH-1 (Lewis and Stone 1988) and wildcat well Bostic 1A (Arney et al 1985).

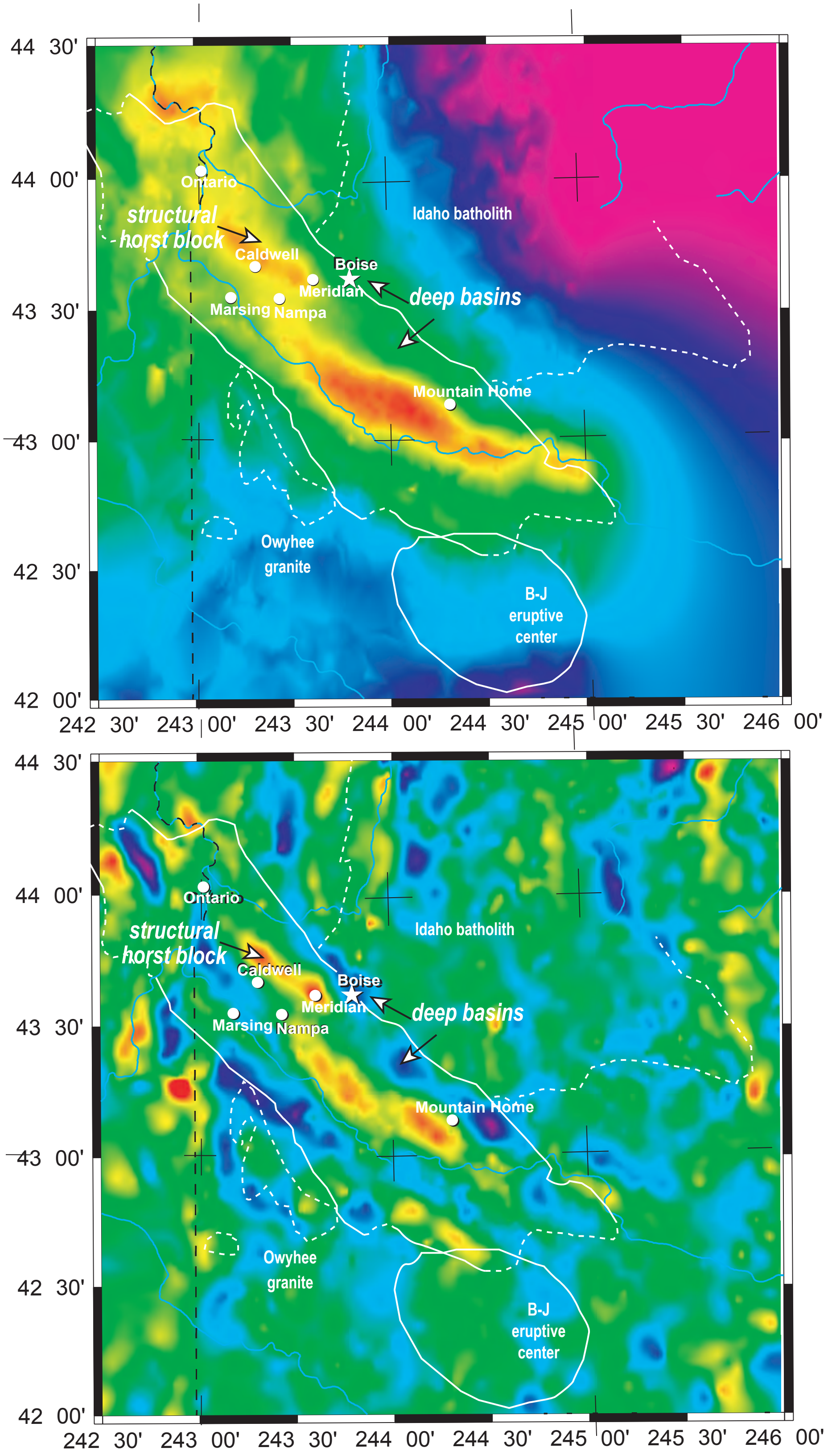


Figure 19. (a) Bouguer gravity anomaly map and (b) upward continued Bouguer gravity map, of the western Snake River Plain. The upward continued map emphasizes deeper crustal features, including deep basins along the margins of the WSRP and a prominent gravity high trending obliquely to its axis; we interpret this positive anomaly as a buried horst block.

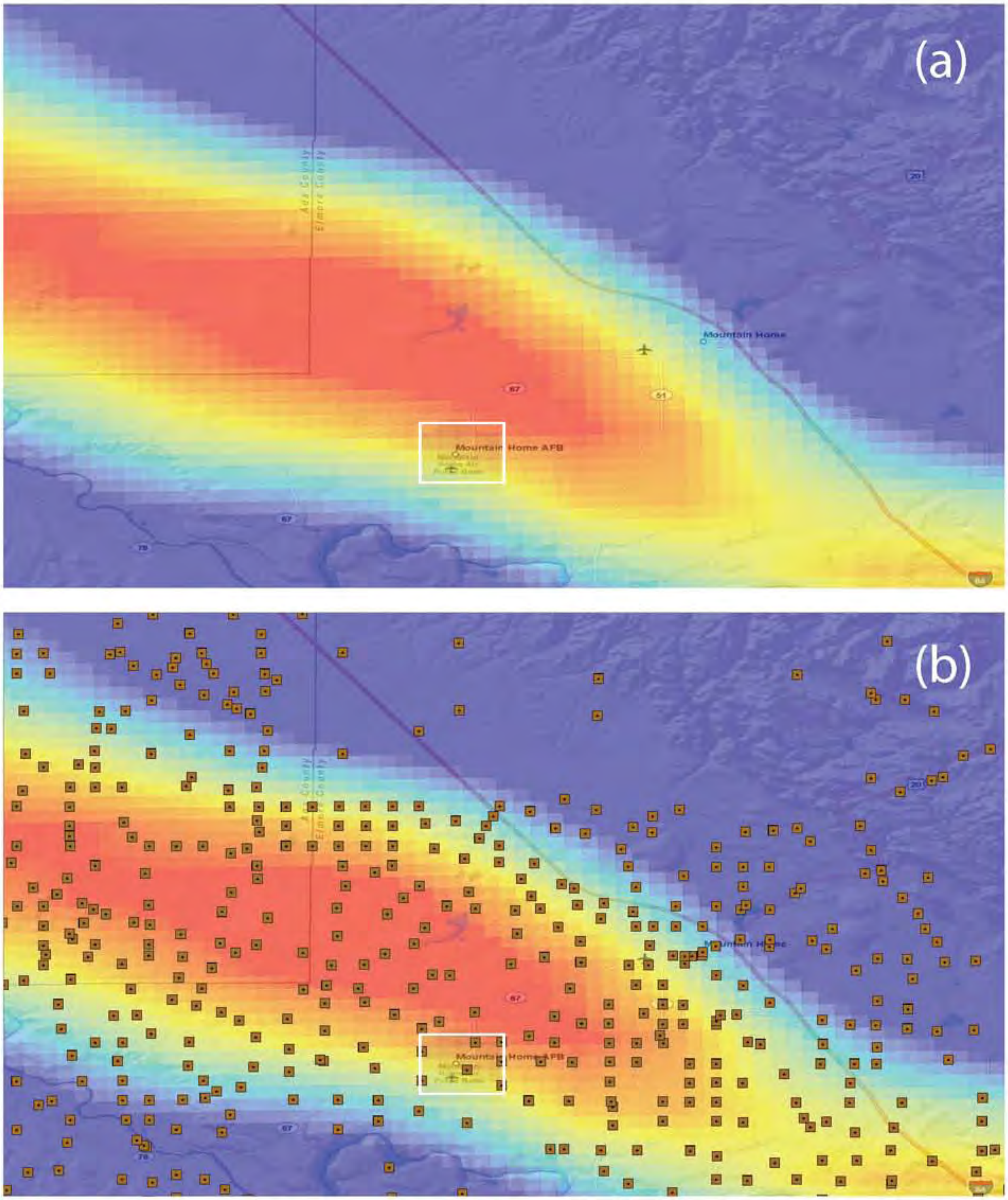


Figure 20. Bouguer gravity map of Mountain Home area (a) without gravity stations(shown and (b) with gravity stations shown. White box = outline of Mountain Home AFB. MH-AFB lies on the southern edge of a pronounced gravity high that has been interpreted by Shervais et al (2002) to represent a buried horst block with the larger western SRP graben. This interpretation is consistent with reflection seismic data from Boise-Caldwell area that documents a buried horst block below the Glens Ferry formation (Wood 1994).

gravity contour map with stations and proposed (pre-drill) seismic profiles

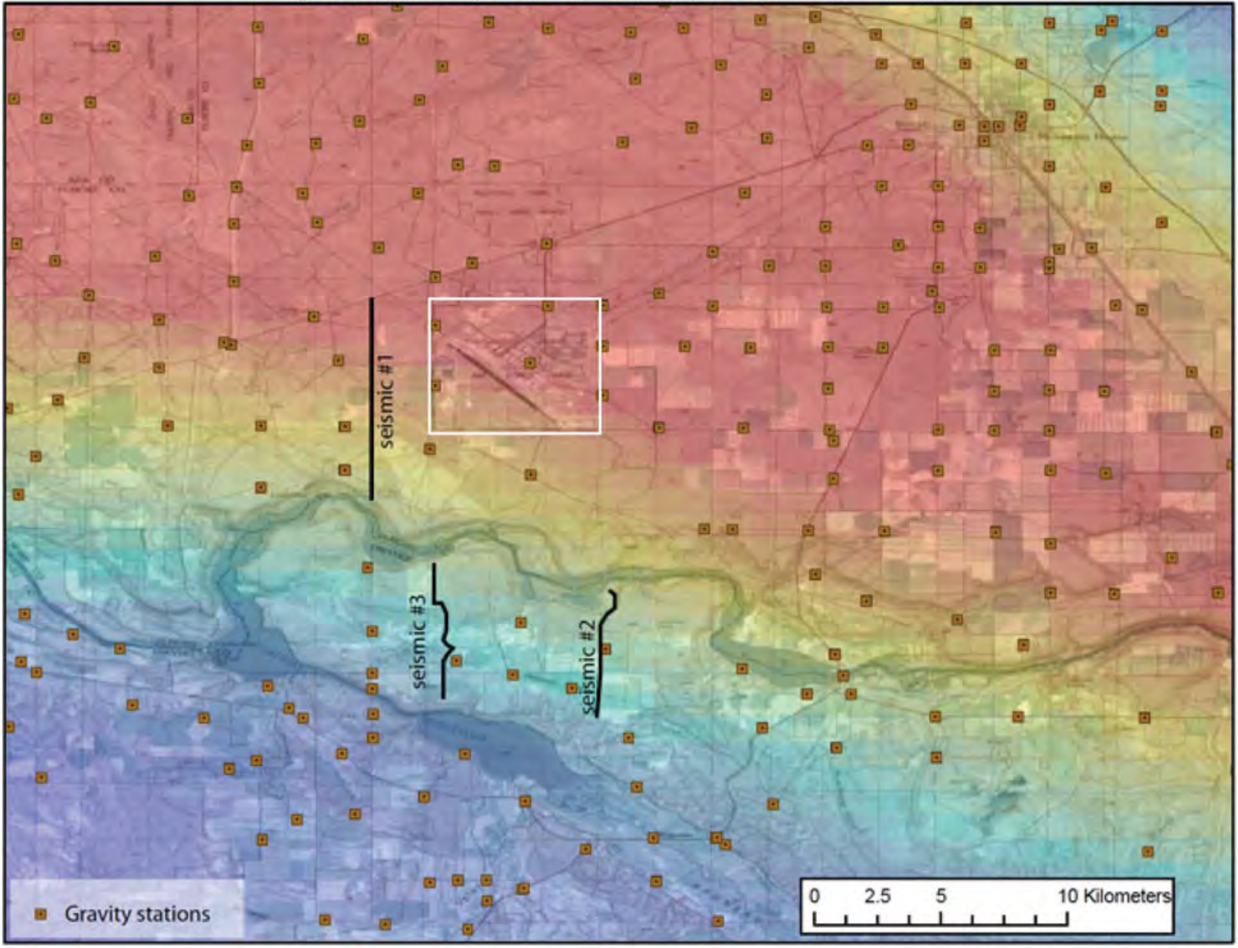


Figure 21. Gravity contour map of the Mountain Home AFB area, with gravity stations shown. MH-AFB is outlined by white box. Also shown are proposed seismic reflection profiles planned for September 2010. These reflection profiles should delineate basement structure in some detail and lead to a clearer understanding of the nature of the prominent positive gravity anomaly.

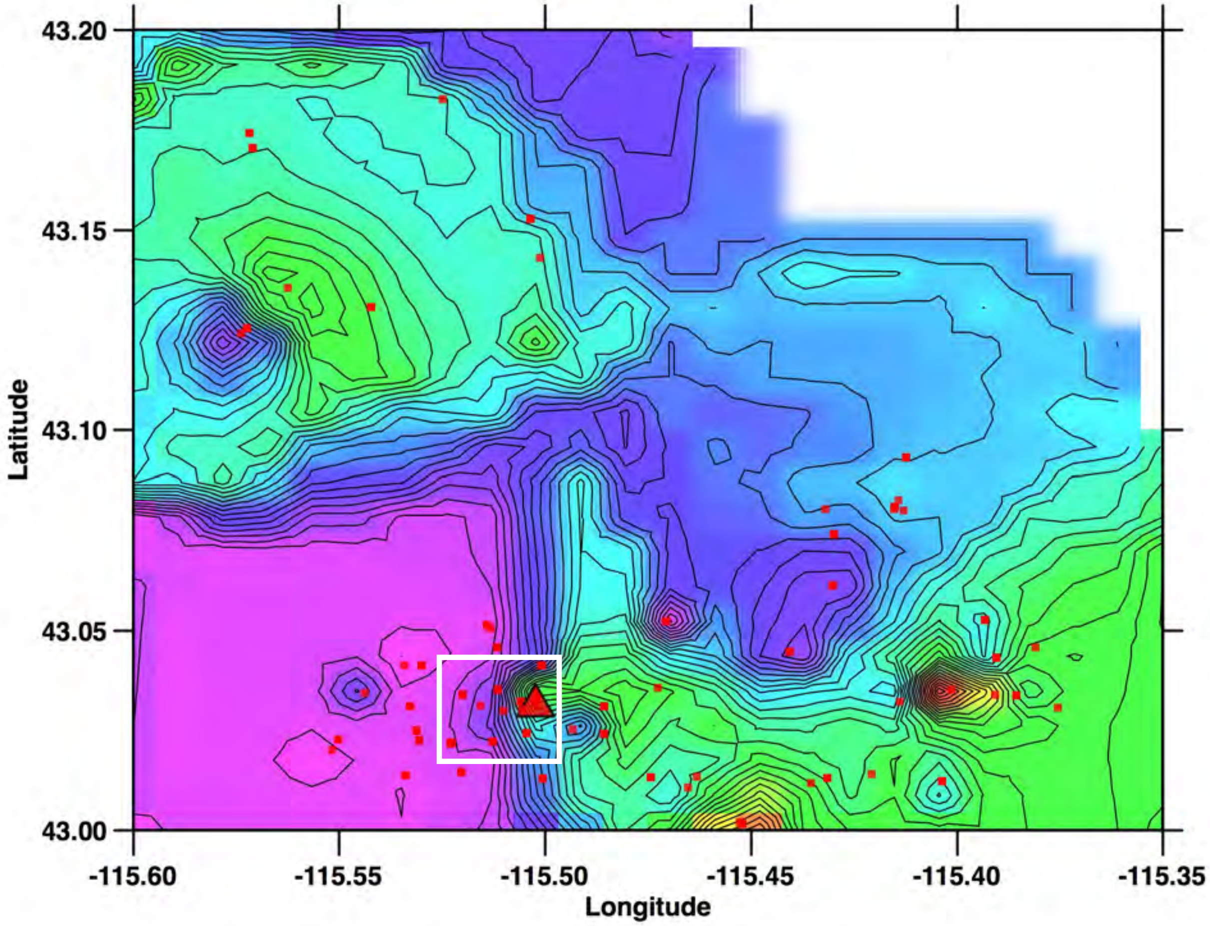


Figure 22. Map of groundwater temperatures in Mountain Home area, kriged using a next nearest neighbor algorithm with distance weighted proportional to 1/(D^2+1); purple and blue colors are low temperatures, greens/yellows/reds are progressively higher temperatures. Approximate location of Mountain Home AFB shown as white square. Red triangle = Mtn Home AFB geothermal test well (4404' total depth; 93°C). The data show warmer groundwater temperatures along the eastern side of the AFB, particularily towards the NE corner of the base, and a NW-trending zone of anomalously high groundwater temperatures that parallels the southern margin of the observed gravity high. The low groundwater temperatures in the SW portion of the map correspond to the Canyon Creek drainage, which traverses the area from SW to NE approximately, and provides a flux of cold water from the Danskin Mountains (to the north). Data from USGS groundwater temperature database (Parliman, personal communication, 2010).

John W. Shervais, Utah State University

Science / Exploration Objectives

Young volcanic active regions with high heat flow offer significant geothermal energy potential, and many of these areas have not been explored for economic resources. However, the application of traditional geophysical methods can be problematic -- especially in bi-modal volcanic terranes where young basalts impede seismic wave transmission and present challenges to detailed interpretations.

This project has as its focus an undeveloped "greenfield" region noted for its high heat flow and the common development of low-temperature passive geothermal, but which has not been developed for electrical generation.

Our goals are to [1] identify new geothermal resources in the undeveloped Snake River Plain region, or failing that, to [2] characterize the thermal regime at depth in such a way as to further exploration goals in more focussed efforts, and [3] to document specific exploration methods and protocols that can be used effectively in these terranes.

We plan to use a combination of traditional geologic tools (geologic mapping, petrologic studies, and geochemical investigations of rocks and water samples) and geophysical techniques (high-resolution active source seismic reflection-refraction surveys, detailed ground-based gravity and magnetic surveys), along with relatively deep test wells that allow us to document the underlying stratigraphy (ground truth), geothermal gradients below the surface aquifers, fracture densities, and hydraulic conductivities.

Our success will be defined by three standards applied to these goals:

[1] Our goal of identifying new geothermal resources in the Snake River Plain region will be successful if we are able to show that sufficiently high temperatures and hydraulic conductivities exist in areas we have identified for detailed study.

[2] Our goal of characterizing the thermal regime at depth in such a way as to further exploration goals in more focussed efforts will be considered a success if we are able to show in some detail how temperature and hydraulic conductivity vary within the SRP, for example, under the axial volcanic zone or within the proposed caldera ring complex.

[3] Our goal of documenting specific exploration methods and protocols that can be used effectively in these terranes will be successful if we are able to show that certain combinations of geologic and geophysical methods, with or without slimhole exploration wells, can be used to predict regions favorable for geothermal development.

Scientific/financial rationale for the determination of success or cessation of well operations.

The general standards of project success have been presented above. For both the Kimama and Kimberly holes, there are specific objectives that apply to the above standards and can be related to the drilling program.

The model of Smith, 2004 (Figure 11) shows the masking effect of the Snake River Aquifer (SRA) on the regional high heat flow of the Snake River plain. It is one of the principal objectives of this project to core through the SRA and evaluate this model. Note that the Kimama hole will be drilled in the center of the plain where the basalts are thought to be thickest, and the Kimberly hole will be drilled on the margins where we anticipate a thinner basalt section and are likely to be along the ring fracture system of the Twin Falls caldera. The evaluation will require temperature and water chemistry data as well as identification of the fluid flow character of the host rocks through lithologic and geophysical logging. This testing will be possible during the initial phases of coring to 1000' that we anticipate will penetrate the SRA into the underlying rocks.

Drilling Issues. We anticipate that there will be lost circulation and hole instability in this phase, but we should be able to solve these drilling problems using standard techniques. Drilling costs will be compared with the proforma budget during this phase with a budget and technical review at the end of the first phase of HQ drilling.

Success Criteria. It is critical for the success of the project that the SRA be penetrated and temperature measurements made in the rocks immediately (300') underlying the SRA. Every effort will be made to accomplish this, even at the expense of continuing the hole to its total planned depth.

A second objective of drilling is to evaluate the character of geothermal activity beneath the Snake River Aquifer. Different topics that are critical for this evaluation are as follows:

- Determine uniformity of high heat flow and the character of heat exchange, *i.e.,* is the high heat flow related solely to conduction or is there a significant convective mechanism? Is there a difference in the character in the central part of the plain (Kimama) vs. the margin (Kimberly)?
- If there is a significant convective component, is fluid flow controlled by regional faults, caldera structures or both?
- What is the character of the Twin Falls caldera? This can be determined by drilling through the ring fracture rhyolites into the underlying rocks. If this is a typical caldera, there should be little difference in the age of the rhyolites (4.8 Ma) and the underlying ash flow tuffs.

Drilling Issues. In order to continue coring past the first stage objective of approximately 1000 feet, the hole will be opened from HQ (3.8") to 6-1/2" from the surface through the bottom of the SRA (identified during the initial HQ drilling). During this opening, lost circulation will be cured to improve the chances for a competent cement job following the setting of 4-1/2" casing. Subsequently, the hole will be continued HQ to total depth, unless it is necessary to reduce to NQ. The highest risk operations will be associated with hole opening, curing lost circulation and setting and cementing 4-1/2" casing. The IDWR requires that casing be set to a minimum of 10% of hole depth (500' for Kimama; 600' for Kimberly) with a 1" cement annulus. However, they do not require a pressure test for a low-temperature well. Once the bottom hole temperature reaches 100^o C, the well is considered high-temperature by IDWR. At this point, the well must have a pressure test (IDWR requires 1000 psi) and an annular BOP must be installed. Should the well fail the pressure test, the well will be terminated since there is little opportunity to re-cement without considerable cost.

Well stability issues may occur at any time during the drilling. These often require hole conditioning, reaming or re-drilling sections, and reducing from HQ to NQ. Curing hole problems becomes a more significant issue as the well deepens and the cost approaches that of the well budget. The severity of the well problem must be evaluated in the context of the above drilling objectives. The hole must be left in a condition to allow geophysical logging, especially temperature and BHTV that together will allow the identification of permeable fracture zones and their orientation. The decision to fight hole stability problems must be made in the context of budget remaining and probability of stabilizing the well sufficiently to guarantee logging past the problem point. Should it be evident that the hole cannot be stabilized, the drilling will be terminated and the logging program will proceed.

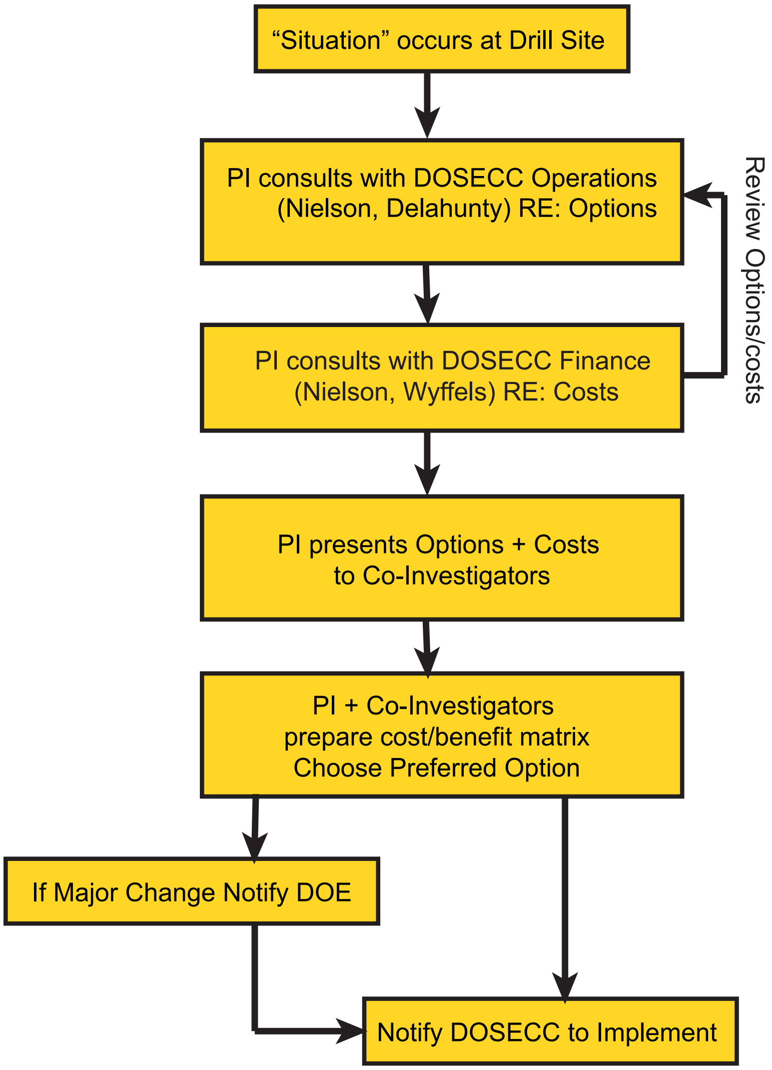
Success Criteria. The success for the lower part of the well will be:

- Penetration and sampling of units beneath the basalt to contribute to the understanding of the presence and character of the Twin Falls caldera.
- Well logs, especially temperature and BHTV in the section beneath the SRA to determine the conductive vs. convective heat transfer mechanism.

Risk Analysis

RISK FACTOR	PROBABILITY	MITIGATION, CORRECTIVE ACTION
Drilling Equipment Failure	Low	Spare Parts Inventory, Nearby Mechanical Services Mechanical inspection/upgrade prior to Mobilization
Availability of Drilling Services	Low	Water well services in Burley and Twin Falls; Core Services and Supplies in Salt Lake
Land Owner Relations	Low	Very Good relationship with land owner
Lost Circulation	High	Cure lost circulation using LCM and cement through planned cased section (surface to 600 feet). >600 feet open hole; lost circulation cure if cuttings buildup using LCM and cement.
Hole cave in	Moderate	LCM and cement to cure stability as above. Potential to reduce from HQ to NQ
Penetration Rate Lower than Planned	Moderate	Revise budget; Reduce from HQ to NQ
Stuck Pipe	Moderate	Work pipe; reduce to NQ
Fish in Hole	Low to Moderate	Bowen spear and Junk basket on site. Cement fish and kick off (wedge) if cost is scientifically warranted
Hole stability - open hole logging	Low to Moderate	Clean out bridge; redrill. Log out bottom of drill rod in depth increments
Hole stability - temperature logs	Low to Moderate	Set pipe
Geothermal fluid entry	Moderate	Casing prepared for pressure control as above. BOP equipment on site and standby. Daily logging of bottom hole T
Excessive Mud Utilization	Moderate	Cure lost circulation as above. Water well on site
Inclement Weather	High	Winterized Rig; Good Paved and Gravel Roads
Permitting	Low	Permits currently in place
Power Outage	Low	Would impact water supply; reserve tank on site; extended power grid outage unlikely

Decision Flow Line for Risk Response



DOE will receive daily drilling log reports and weekly reports from DOSECC that are sent to all PI's and funding agencies. Any issues that arise with potential impact will be noted in the daily drilling report.

The PIs, DOSECC, and funding agency representatives will have conference call at least once each month to discuss progress and issues that may impact drilling.

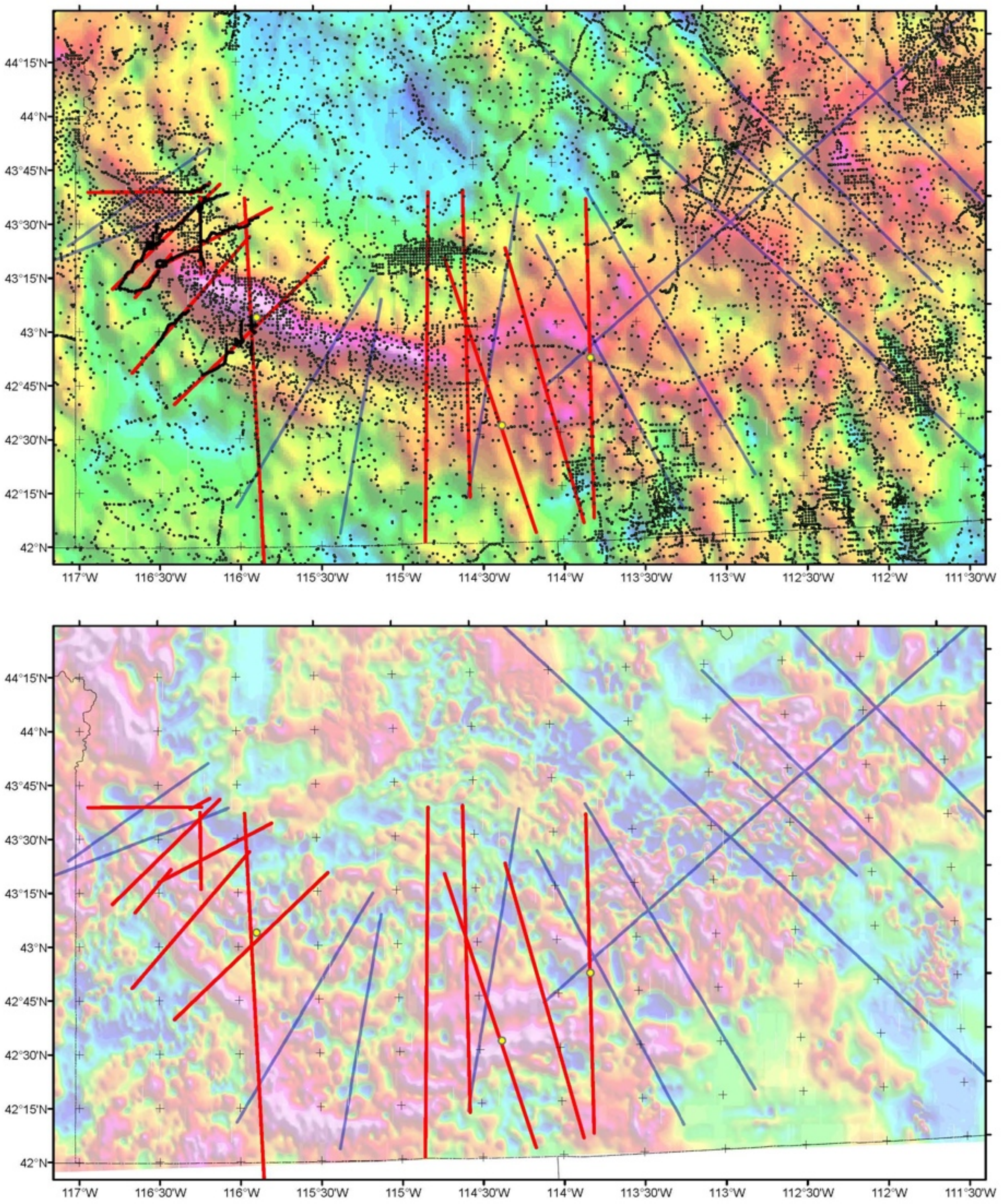
Choice of Drilling Contractor

DOSECC (Drilling, Observation, and Sampling of Earths Continental Crust) is the United States facility for continental scientific drilling. It is a non-profit consortium of some 50 US universities and colleges dedicated to continental scientific drilling as a tool for addressing the origin and evolution of continental crust.

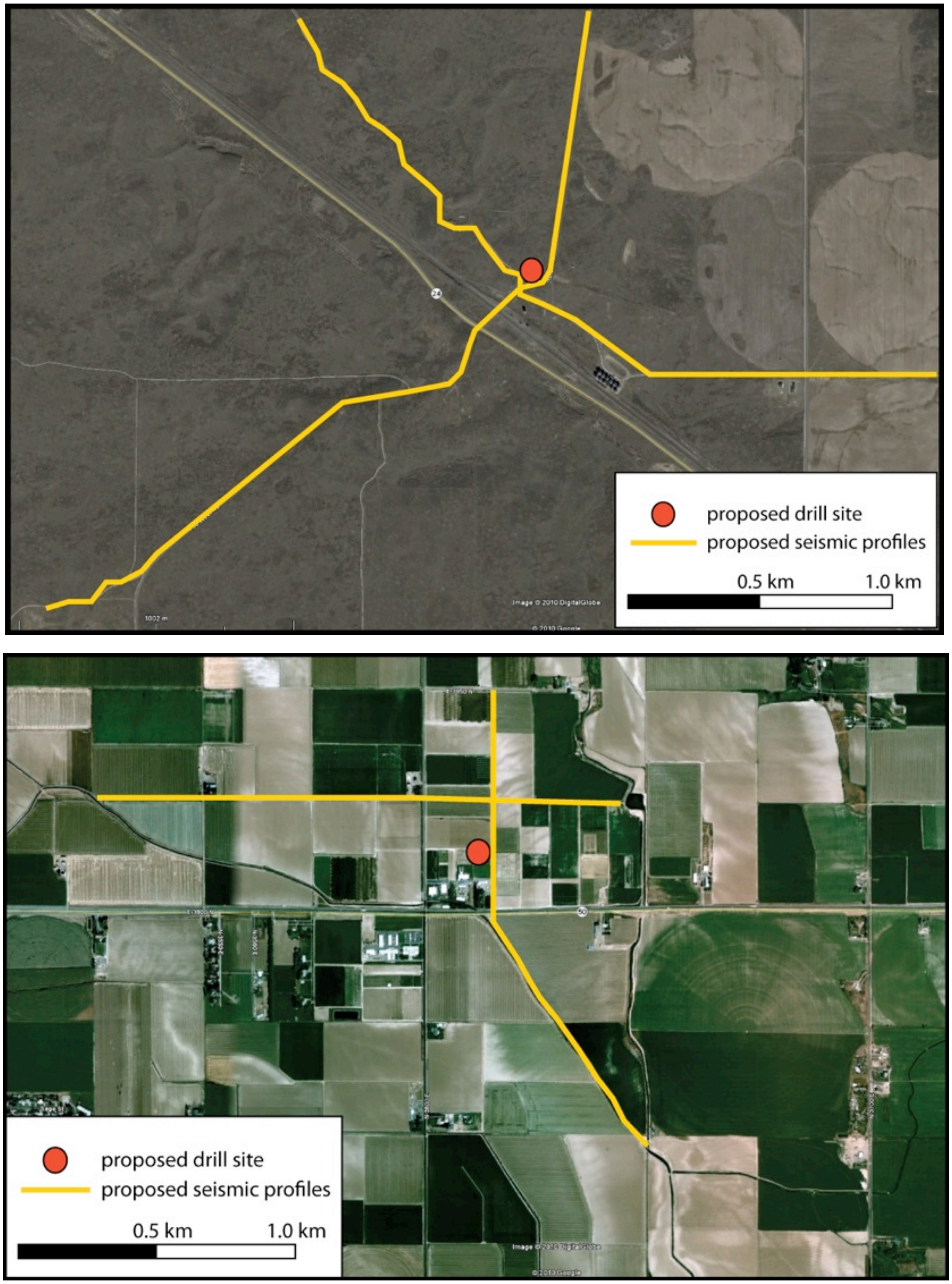
We have worked in partnership with DOSECC to develop our drilling plan in concert with the science plan interactively, so that we are able to meet our science goals in the most cost effective means possible, starting in 2005. This allows the science PI's to focus on their scientific goals while DOSECC addresses the technical and logistical aspects of continental scientific drilling. DOSECC is able to address the cost and time implications of different drilling plans and can present them to the PI's so that the scientists can make informed decisions about how to proceed.

The DOSECC CS 4002 drill rig was purchased with our project in mind, in order for DOSECC to have the capabilities we need in a small relatively inexpensive platform. Thus, our drilling plans have been developed with this particular drill rig in mind. Its ability to penetrate up to 2450 m into the crust and lift core from that depth provides us with the ability to target deep structures without the expense of a large industrial drill rig.

The PI has been associated with DOSECC for almost a decade and is personally acquainted with most of the science PI's on the large drilling projects its has carried out over the last two decades, including drilling in extreme environments (Siberia in winter, central Africa) and in basalt (several projects in Hawaii). Thus we have complete confidence in their ability to carry out this project in a timely and cost effective manner. A detailed presentation of DOSECC's personnel and their experience is presented at the end of this document.



Regional Bouguer gravity anomaly map (top) and magnetic anomaly map (bottom) for southern Idaho, showing lines of planned (in progress) gravity-mag traverses in red, and lines of potential gravity-mag traverses in blue. Note circular gravity anomaly in central SRP which may represent Twin Falls caldera complex. From Glen, USGS.



Proposed active source seismic reflection-refraction surveys in central SRP for Kimama (top) and Kimberly (bottom). Liberty, Boise State University and Schmitt, University of Alberta.

Information From Deep Wells

Blackwell, D.D., 1989, Regional implications of heat flow of the Snake River Plain, Northwestern United States, in Tectonophysics, v164, 323-343.

Blackwell, DD, Kelley, S., and Steele, JL, 1992, Heat Flow Modeling of the Snake River Plain, Idaho; Contract Report EGG-C91-103450, prepared under DOE contract DE-AC07-761DO1570, 109 pp.

Eastern SRP:

Average Surface Heat Flows in ESRP = 100 ±15 mWm^{-2} for all groupings

Subaquifer Heat Flow USGS G2A and INEL-1 = 107-110 mWm^{-2}

[Blackwell et al 1992, pages 40, 49]

Groundwater Temperatures ESRP:

Heat Loss above the Aquifer = 42.3 MW

Heat required to change GW temperatures in aquifer from 8ºC to 14.5ºC = 287.3 MW

Total Heat Flux from Below Aquifer = 329.6 MW

Required Heat Flow to Achieve this Flux = 190 mWm^{-2}

[Blackwell et al 1992, page 51]

Western SRP:

North side of WSRP: Bostic 1A = 195ºC at 2900 meters [north side of graben]
high heat flow, positive geothermal gradient

South side of WSRP: Anschutz Federal = 195ºC at 2900 meters [south side of graben]
high temperatures at shallow depths but not at deeper levels.

Information From Deep Wells

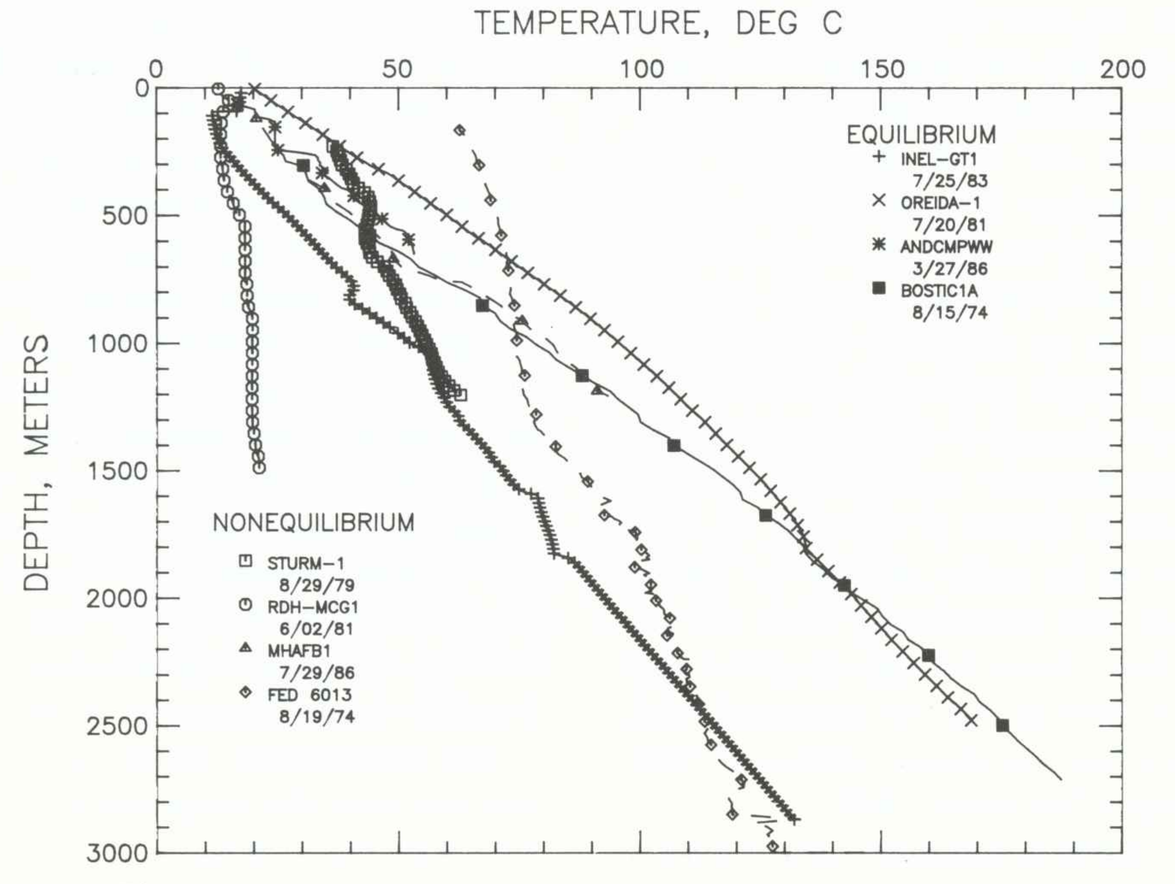


Fig. 10. Temperature–depth curves for deep wells in the Snake River Plain.

Figure 10, from Blackwell (1989) showing temperature gradient profiles from deep wells in eastern and western SRP. Note that the temperature gradient on Bostic 1A increases with depth, implying an increase in heat flow at depth. Note that MHAFB-1 follows similar high gradient trend, even though it is non-equilibrium and thus can be expected to increase in temperature over time at depth.

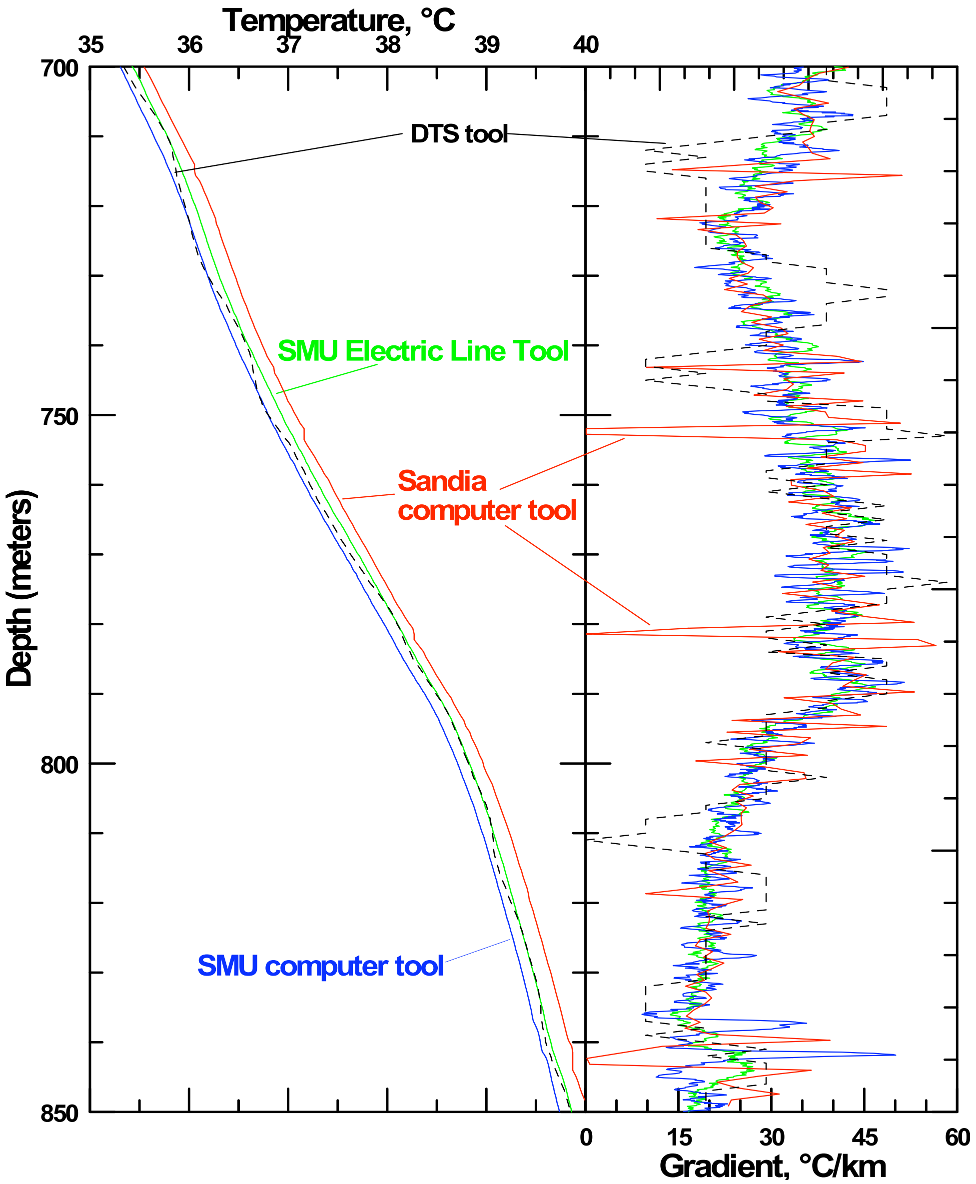
Anderson Camp (ANDCMPWW) is the closest well to Kimberly; it follows a high temperature gradient similar to Bostic 1A and MH-1, though it is much shallower. We expect Kimberly to be higher because it lies south of the river and outside the influence of the Snake River aquifer.

All three wells (Bostic, MH-1, Anderson Camp) project to temperatures ~200ºC at around 3 km depth.

Blackwell, D.D., 1989, Regional implications of heat flow of the Snake River Plain, Northwestern United States, in Tectonophysics, v164, 323-343.

Comparison of four state-of-the-art temperature logging systems: an analog electric line system, two pressure and temperature recording tools (in-hole computer systems: Sandia and SMU), and a distributed optical fiber temperature sensing (DTS) system.

Tools provide accurate, detailed resolution to 2 km and 200°C, with absolute temperature differences between the tools of ≤o.4°C.



Reference:

Wisian, KW, DD Blackwell, S. Bellani, JA Henfling, RA Norman, PC Lysne, A Forster, and J. Schrotter, 1998, Field comparison of conventional and new technology temperature logging systems; *Geothermics*, v27, n2, 131-141.

Vertical Seismic Profiles (VSP) Doug Schmitt, Univ Alberta

There are two major objectives for the VSP surveys. The first is to accurately calibrate the seismic traveltimes to different reflecting horizons, and as part of that to also examine what is the primary cause of difficulties in obtaining seismic reflection profiles over such basalt covered terranes. The second is to examine, via walk-a-way VSP, the P and S wave anisotropy to determine how this may be influenced by the 'layered' basalt flow structure as well as any subvertical joints or fractures that may exist.

The first objective will largely be accomplished by a 'zero-offset' VSP. A three component downhole geophone will be deployed in the holes; and 3-component seismic traces will be obtained at as close a spacing as is reasonable (to be evaluated based on drilling progress, etc.) but we expect that the data will be acquired at a 2-m spacing from bottomhole to near surface down the hole. This has previously been carried out in the ICDP Outokumpu well and allows for high resolution examiation of both the downgoing and upgoing seismic wavefields. Testing of the vibration sweep length will be tested but it is anticipated that a sweep from 10 Hz to ~ 200 Hz will be employed. We hope to be able to obtain a large shear wave vibrator that is available through the NEEP for scientific purposes.

The second objective will be accomplished by carrying out a series of walk-a-way VSP measurements. It is expected that these data will be acquired at the same time that the reflection seismic surveys are obtained in order to exploit the seismic source that will be required for these. We anticipate spacing of the receiver at ~500 m depth intervals down the hole (to be determined on the basis of additional core and geophysical logs), with the source activated along the proposed 2D seismic profiles at a nominal spacing of 20 m.

Water Sampling Protocol

The basic water sampling process will utilize a wireline packer as follows:

1. The wireline core inner barrel is retrieved and the drill string is lifted off the bottom to expose the test zone. Alternatively, a straddle packing approach can taken with the addition of a second open-hole packer is attached to the bottom of the standard packer assembly via a perforated pipe of predetermined length. This packer is inflated together with the other two packers thus isolatin g an open-hole zone between the two bottom packers. Sampling and permeability testing can then be carried out on this straddled zone as described below for the single open-hole packer.
2. A top seal assembly is then screwed on to the top of the coring string.
3. The wireline packer is connected to the rig wire line in place of the inner tube overshot and run through the seal assembly and coring string to the seat in the bit as shown.
4. The packers are inflated using either air or water via a small bore tube run from the surface in parallel with the rig wireline.
5. A small diameter tube is installed inside the drill string with an educator type fitting attached to the end.
6. Using compressed air lift mud and water from isolated sampling zone.
7. A mud “buster” type product can be added to the zone as necessary to help break up mud.
8. Field parameters of conductivity, pH, temperature, turbidity, etc. Will be monitored to evaluate purging of mud and drilling fluids. Purging will continue until field parameters stabilize.
9. A Bennett 1.8-inch diameter pump will be lowered in to the drill string and used to collect samples. Again, field parameters of conductivity, pH, temperature, turbidity, etc will be measured until they stabilize. Sample will be collected at the well head from the discharge manifold of the pump.

Purging may take as long as 24 hours or more, so sampling will probably only take place once or twice at most from individual wells. Most likely at the bottom or on the way out after coring is completed. We will likely take additional sample before P&A.

OSG has gas-tight water samplers for downhole use. These can be taken during wireline logging shorting after completion of well, and just before P&A.

We are planning to perform background work this fall and present it with the results of the Hotspot drilling water sampling. We will be looking at existing water chemistry (major anions and cations) for nearby geothermal springs and wells, along with different geothermometry calculations, to help provide some context for the water samples.

Cost Share Distribution for Mountain Home well site

The Mountain Home well will be drilled in two stages. The upper ~700m will be drilled using DOE and ICDP funds proportioned to maintain our cost share commitment at the required level as the project goes forward. This will also be the case for the Kimama and Kimberly wells, where costs will be apportioned to maintain the appropriate cost share distribution. The remainder of the Mountain Home well will be drilled as a separate project with Air Force funding -- that is, we will close out the DOE-ICDP funded project and transition to the USAF project, so that there is no co-mingling of funds or expenses on these two stages.

DRILLING CONTRACTOR CAPABILITIES

DOSECC is the Implementing Organization for Continental Scientific Drilling for the National Science Foundation. We have worked with the International Scientific Drilling Program (ICDP) that is providing co-funding for this project since that organization sponsored its first drilling effort (Hawaii Scientific Drilling Program; HSDP). DOSECC has been the drilling for the following projects that have similarities to the Hotspot project.

1. Long Valley Exploratory Well Phase III (continuous core from 7,178’ to 9,832’). Exploration drilling of the deep part of the resurgent dome of the Long Valley caldera.
2. Hawaii Scientific Drilling Program (continuous core from surface to 11,500’). Continuous coring through Kilauea into Mona Kea lava sequences
3. Koolau Scientific Drilling Project in Honolulu (continuous core 1,150 to 1,409’) through Koolau basalt sequence)
4. Core three holes on Kilauea Volcano for the installation of down hole monitoring instruments. All holes were in Recent basalt flows.
5. Coring six holes on the island of Montserrat for the installation of down hole monitoring instruments around an active volcano.

PERSONNEL

Dr. Dennis Nielson is the president of DOSECC. He has extensive experience in geothermal exploration as well as scientific drilling. From 1978 to 1996, he was a Research Professor at the University of Utah and was funded by the DOE to perform research on data and samples from active geothermal systems. Some of his activities during this time were as follows.

1. Detailed geological evaluation of the Roosevelt Hot Springs geothermal system in Utah.
2. Compilation of geothermal data from DOE's Industry Coupled Geothermal Program and publication of geothermal exploration strategies (with Drs. S. H. Ward and H.P. Ross)
3. Research in fracture permeability and hydrothermal alteration in the Valles caldera, New Mexico.
4. Member of DOE's technical review committee on the Baca Geothermal Project that provided oversight for Unocal's geothermal exploration and development activities.
5. Co-Principal investigator (along With Dr. Fraser Goff) for DOE-sponsored scientific drilling in the Valles caldera.
6. Manager of a DOE and US Air Force Project for geothermal exploration of Ascension Island in the South Atlantic Ocean. Geologic mapping and geophysics resulted in the drilling of 7 core holes to measure temperature gradients and investigate subsurface geology on the young volcanic island. The project drilled a deep geothermal production well that encountered temperatures of $>250^{o}$ C.
7. Scientific drilling and investigations of fracture permeability in The Geysers geothermal system.
8. Co-convener (with Dr. Duncan Foley) of an annual course in Yellowstone on "Calderas and Hydrothermal Systems". The course generally involved graduate students, teachers and geothermal professionals.

Dr. Nielson has also worked on many of the geothermal systems in the Basin and Range as well as Tiwi in the Philippines and Awibengkok in Indonesia.

Chris Delahunty is Director of Operations for DOSECC:

1.) BS Mathematics minor Physics 1997 Southern Utah
2.) MS Civil Eng specialty in Earthquake Engineering/Structures
3.) Civil/Mechanical Engineering design
4.) Fabrication of Hydraulics/Machinery/Electrical/Diesel
5.) IADC Well cap well control school
6.) Core drilling to 4000+
7.) MSHA Certification current
8.) Idaho Dept of Water Drill License 656
9.) Drilled in active volcano in Montserrat BWI. 2002
10.) Drilled Valles Caldera 2003
11.) Drilled Brazos River Texas2003
12.) Drilled Lake Sediments in Iceland2004
13.) Drilled Puna Geothermal Hawaii work over and production 2004
14.) Drilled lake sediments in Ghana 2005
15.) Drilled Lake Sediments China 2006
16.) Drilled basalts Washington 2006
17.) Ran operations for DOSECC 2001-2008
18.) Director of operations for DOSSECC 2008-Present
19.) Managed projects on 5 of 7 continents in logistically challenged areas
More on request.

Beau Marshall is DOSECC's Operations Manager:

1.) MSHA Certified
2.) CPR/First aid
3.) Supervised Core drilling jobs in Centeral America, North America, Europe,
4.) Relevant drilling experience is in gold exploration in Nevada where coring encountered highly fractured and hydrothermally altered rocks.
5.) Managed DOSECC Drill crews from 2007 to present

DOSECC's principal drillers:

Carl Heeren: 6 years as Driller, 10 years rig experience

1.) BOP certified/experience
2.) MSHA certified
3.) CPR/First aid
4.) Conventional mud/air rotary
5.) Core 5000+
6.) Directional
7.) Nevada Drilling experience
8.) Reverse Circulation
9.) Odex
10.) Coal Bed Methane
11.) Work over/cleanout
Worked for: Ledcor, DOSECC Exploration Services, Major, Kettle, Barrick Gold

Joseph A. Bolin: 3 years as driller, 10 years rig experience

1.) MSHA Certified
2.) First Aid / CPR Certified
3.) Diamond coring to 3000+
4.) Driller, lake sediments, volcanic formation collections Van, Turkey
5.) Driller, Ocean sediment collection New Jersey Margin
6.) Driller, Lake sediment collection (meteor impact) El Gygytgyn, Siberia.
7.) Driller, Lake sediment collection Lake Potrok Aike, Argentina
8.) Driller-in-Training – Earthquake/Fault Zone San Andres Fault Zone, Los Angeles
9.) Driller / Driller-in-Training / Helper – Hollister Gold Mine (Gold Exploration) Nevada (Apr. 2007 – present)
10.)LLC.Driller-in-Training / Helper – Hycroft Mine (Gold Exploration) Nevada (Apr. 2007 – present)
11.)Rotary Drilling (Natural Gas) 4 yearsDerrick Hand, Motor Man, Driller
12.)Derrick Hand, Motor Man Oil / Natural Gas (3 years**)** WARREN
Worked for: DOSECC Exploration Services, Pinnacle, Warren

Steven J. Cole: 1 year Drilling, 4 years rig experience

1.) MSHA Certified
2.) First Aid / CPR Certified
3.) First Responder Certified
4.) Core drilling 4000+
5.) Driller, lake sediments, volcanic formation collections Lake Van, Turkey
6.) Driller-in-Training, Ocean sediment collection New Jersey Margin
7.) Driller-in-Training / Lead Helper, Lake sediment collection (meteor impact studies) Lake Potrok Aike, Argentina
8.) Driller / Driller-in-Training / Helper – Hollister Gold Mine (Gold Exploration)
9.) Driller-in-Training / Helper – Hycroft Mine (Gold Exploration)

Worked for: DOSECC Exploration Services