Energy Research and Development Division
FINAL PROJECT REPORT

ASSESSMENT OF GEOTHERMAL RESOURCES IN THE WILBUR HOTSPRINGS AREA,COLUSA AND LAKE COUNTIES, CALIFORNIA

Appendices

Prepared for: California Energy Commission
Prepared by: Renovitas, LLC

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RENOVITAS

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PREFACE

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Assessment of Geothermal Resources in the Wilbur Hot Springs area, Colusa and Lake Counties, California is the final report for the Geothermal Grant and Loan project (grant number GEO-10-003) conducted by Renovitas, LLC . The information from this project contributes to Energy Research and Development Division's Renewable Energy Technologies Program.

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ABSTRACT

This report presents the results of mapping, rock and water sampling, and geophysical surveys conducted by Renovitas and its project partner, the Sacramento Municipal Utility District, to assess the geothermal resource potential in the Wilbur Hot Springs area and vicinity. The mapping, sampling and surveys were conducted on Bureau of Land Management and California Department of Fish and Game land located in Colusa and Lake Counties in northern California, on property with mineral rights owned by the Trebilcot family.

The goal of this project was to conduct the preliminary resource assessment, geologic mapping and geophysical surveying work necessary to site future temperature gradient or slim-hole geothermal wells in the area. The results from this project provided data needed to determine if the Wilbur Hot Springs area is a viable geothermal resource. The data will be used to plan for future work to ascertain if there is sufficient geothermal potential in the project area for power plant development.

The project work included analysis of existing literature; geological, geochemical and geophysical sampling activities; and development of an exploratory drilling work plan. Data generated by the mapping and geophysical surveys allowed the project team to develop a conceptual model of the geothermal system in the project area. This conceptual model indicated that the geothermal resource in the project area may have geothermal temperatures sufficient for binary power production. However, further exploration and slim-hole well drilling will be required to generate the additional data needed to fully assess the resource. Recommendations for future work are to conduct outreach to stakeholders, prepare California Environmental Quality Act documents and obtain permits for drilling, drill slim-hole wells to further evaluate the resource and prepare a feasibility assessment for power development.

Keywords: Geothermal, Wilbur Hot Springs, Sulphur Creek Mining District, Geothermal Power Development, Colusa County, Lake County, Northern California, Rock Sampling, Water Sampling, Geochemical Survey, Geophysical Survey

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GEOLOGICAL AND GEOCHEMICAL WORK PLAN FOR THE SMUD-RENOVITAS PROJECT, COLUSA COUNTY, CALIFORNIA

FINAL

for

SACRAMENTO MUNICIPAL UTILITY DISTRICT

and

RENOVITAS LLC

in support of

Exploration Drilling and Assessment of Geothermal Resources,

Colusa County, California

California Energy Commission GRDA Grant #GEO-10-003

by

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1. INTRODUCTION

The Sacramento Municipal Utility District (SMUD) is interested in developing a geothermal power project in the Wilbur Hot Springs area of Colusa County. Renovitas LLC (Renovitas) has obtained partial funding from the California Energy Commission (CEC) to undertake certain geothermal exploration and resource characterization activities. GeothermEx is providing guidance for this project and conducting exploration and characterization activities.

The project area (shown on Figure 1) has long been known to have geothermal resources, and previous investigations of these geothermal resources have been undertaken by various parties. The project area is also known to be situated within a former mercury mining district, and there are several abandoned mines within and nearby the area of interest. Certain efforts are underway by other parties [including the Central Valley Regional Water Quality Control Board (CVRWQCB)] to identify and characterize areas of mercury mining waste (*e.g.*, tailings piles), and to develop and implement plans to remediate the associated environmental impacts.

In this context, exploration and other work in the project area must be undertaken in a way that: 1) avoids disturbing areas of mining waste; 2) is consistent with identification, characterization and remediation efforts; and 3) provides data valuable for SMUD's geothermal exploration and characterization activities.

1.1 Purpose and Scope

GeothermEx is tasked with preparing a work plan for the project exploration program that includes details of how geologic and geochemical exploration efforts will be conducted in the area without disturbing mining waste that is known to be present. The work plan is presented herein with details on the means by which work will be conducted while avoiding disturbance of mining waste. It is GeothermEx's understanding that this plan will be reviewed by CEC and the CVRWQCB and that work will begin after receiving approval from both.

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1.2 Background

GeothermEx's activities to date on the project have included developing a GIS-based map of land ownership in the area, including surface and the mineral estates and their boundaries. As noted by ownership type in the legend of Figures 1[1], 2, and 3, there are numerous land owners in the area, with several combinations of property rights, including:

- ownership of both the surface and mineral rights by a single entity (either public or private); and
- multiple cases of split property ownership, with surface and mineral rights held by separate entities (either public or private).

SMUD and its land experts have evaluated property rights and ownership in the project area to identify areas within which it could develop a geothermal project. SMUD reports that it has obtained the geothermal (mineral) rights to the property previously held by Trebilcot. The mineral rights of this property (which are now held by SMUD) are shown as a black diagonal pattern on Figure 1. As can be seen, the surface rights are not owned by SMUD, but instead by other entities, including the US Bureau of Land Management (BLM), the California Department of Fish and Game (CDFG), and certain private parties.

The BLM has been consulted on this project and advises that exploration activities such as geologic mapping, geochemical sampling and geophysical surveying on BLM land are classified as "casual use" and do not require a permit. GeothermEx is seeking to confirm whether exploration activities on CDFG land would also be considered casual use (e-mails from Mr. Logan Hackett of GeothermEx to Mr. Josh Bush of CDFG, dated 23 May and 7 June 2012). However, at the time of this report, CDFG is clarifying surface ownership of the land, and has

[1] Because of the lack of recent land surveys in this area, the GIS shape files provided by various entities (including BLM) do not always align well with other information, resulting in uncertainty with respect to the boundaries of some land parcels.

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not provided clarification on whether an access permit must be issued to conduct geologic mapping, geochemical sampling and geophysical surveying in the area where CDFG holds the surface rights. GeothermEx is continuing to follow up on this request.

Other activities, particularly any drilling activities (temperature-gradient wells, slim holes and full-diameter production wells) will require permits, and there are certain restrictions on where such activities can take place. However, this work plan is focused solely on surface exploration activities (*i.e.*, geologic mapping, geochemical sampling, and geophysical surveying) that will help understand the potential for finding an economically productive geothermal resource within the area of mineral rights controlled by SMUD.

During this phase of exploration in the project area, GeothermEx intends to undertake geologic reconnaissance and geochemical sampling exploration activities, both of which are non-invasive and result in little or no disturbance to the study area, where all mine workings and waste will be avoided, and a 100-foot buffer zone will be maintained at all times. During these activities, GeothermEx will adhere to the to the fieldwork procedures outlined in Section 3, and will avoid and report any previously undocumented mining features, as outlined in Section 4.

In areas where private land access can be obtained, geologic and geochemical exploration activities will also take place to better assess geothermal resources on properties where the mineral rights are held by SMUD.

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2. ACCESS AND ITS RELATIONSHIP TO THE WORK PLAN

GeothermEx is allowed to undertake exploration work on public lands (the BLM has given clearance without the need for a permit, and the level of clearance needed is presently being clarified with CDFG, as described in Section 1.2). In addition, GeothermEx can use public roads to gain access to these public lands. However, permission must be obtained from landowners to work in areas beyond public lands. With assistance from SMUD and with information provided by the CVRWQCB and CEC, GeothermEx has contacted local landowners and has requested permission to access their lands for mapping and sampling efforts.

The work that GeothermEx plans to conduct on public lands, and on private land where access is granted, is discussed by individual property in Section 3. Following the submission of this document and receipt of responses from private landowners, a final memo summarizing property access will be generated and submitted on 11 July by GeothermEx to clarify the scope of field work.

Figure 2 (on a shaded topography base) shows the public roads, mines, known areas of mining waste, and hot springs in the area of interest. The same map is presented on a satellite image base as Figure 3. All information related to mining activities, including mine locations, tailings, waste rock, cuts, and adits was digitized and reviewed using maps and information available in multiple evaluation and engineering documents (CDC/CGS, 2003; Tetra Tech, 2003; CVRWQCB, 2007; ERM, 2010). Sections 3 and 4 present a detailed discussion on the means by which GeothermEx field work personnel will avoid areas of mines and mine waste.

For reference, Table 1 (below) summarizes public and private lands on which GeothermEx hopes to have access, the respective access-granting party, and the status of access at the time of issuance of this work plan.

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Property	Party Granting Access	Status
Public Land		
BLM	**BLM**	**Granted**
CDFG	**CDFG**	**Clarifying ownership and awaiting grant**
Colusa County	**not applicable**	**No Permit Required**
Lake County	**not applicable**	**No Permit Required**
Private Land		
Abbott and Turkey Run Mines	**unknown land trust**	**Seeking contact information**
Wide Awake Mine (central)	**Merced General Construction, Inc.**	**Requested**
Wide Awake Mine (peripheral)	**David Brown**	**Seeking contact information**
Bailey Minerals	**Dr. Richard Miller**	**Requested**
Wilbur Hot Springs	**Dr. Richard Miller**	**Requested**

Table 1. Summary of project area properties and access status

In regard to private land access, GeothermEx is particularly interested in conducting the following activities:

- A focused mapping and structural study of Wilbur Hot Springs and the surrounding area, including locating and recording the field characteristics of each spring. This work will be aimed at understanding the flow paths of the hot spring source fluids, and it will require permission from Dr. Richard Miller (owner of the Wilbur Spring Resort) to access this property (GeothermEx is seeking this permission now).
- Geochemical sampling of 4 or 5 hot springs, including Wilbur Hot Springs and surrounding hot springs [*e.g.*, the Jones Fountain of Life Spring, located on the Bailey Minerals (Bailey) Property]. Sampling these springs will depend on obtaining access permission from Dr. Richard Miller, who purchased this land from the American Land

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Conservancy (GeothermEx is seeking permission from Dr. Miller now). GeothermEx's goal at the hot springs is to sample the hot spring fluids and make field measurements of temperature, pH, conductivity, and flow rate and potentially to collect geochemical analysis samples, as outlined below in Section 3.1.

- Focused mapping and a structural study of the areas surrounding the Abbott and Turkey Run Mines, including locating and recording the field characteristics of any springs near these mines. This work will be aimed at understanding the flow paths of the hot spring fluids. GeothermEx's ability to undertake this work will depend upon obtaining permission from the landowner (an unknown trust; GeothermEx has asked SMUD and CEC/CVRWQCB to provide contact information for this landowner). The mine workings and waste will not be included in this investigation, and a 100-foot buffer zone will be adhered to by field work personnel to avoid disturbing existing or identified mine features.
- Geochemical sampling of the Abbott Mine Hot Spring, as outlined for the Wilbur Hot Springs and others above. It is presently unclear from the available mapping and property data whether there are one or two hot springs in this vicinity, and whether the Abbott Hot Spring is located on public or private land. The number of springs accessed and sampled depends on whether the spring is on public or private land, and whether access will be granted by the landowner (presumably, the same unknown trust as mentioned above, for which GeothermEx has asked SMUD and CEC/CVRWQCB to provide contact information). The mine workings and waste will not be included in this investigation, and a 100-foot buffer zone will be adhered to by field work personnel to avoid disturbing existing or identified mine features, even if springs are located within the buffer zone.
- Focused mapping and structural study of the Wide Awake Mine area, as for the Abbott and Turkey Run Mines above. Access will need to be granted by the landowners,

identified as 1) Merced General Construction, Inc. (GeothermEx has requested this permission and are awaiting a response) and 2) a Mr. David Brown (GeothermEx has asked SMUD and CEC/CVRWQCB to provide contact information for this landowner). The mine workings and waste will not be included in this investigation, and a 100-foot buffer zone will be adhered to by field work personnel to avoid disturbing existing or identified mine features.

Gaining access to private lands would improve the geochemical sampling effort by allowing evaluation of the Wilbur Hot Springs, Jones Fountain of Life, and possibly the Abbott Springs (if on private land). It would also facilitate the geological evaluation of the Wide Awake, Abbott, and Turkey Run Mine properties, which will contribute to the overall understanding of the controls on geothermal fluid flow in the area. During field work activities, GeothermEx personnel will avoid all mine features and will adhere to a 100-foot buffer zone around known and identified mine workings and mine waste. Sections 3 and 4 present detailed discussions of the means by which GeothermEx field work personnel will avoid areas of mines and mine waste.

None of the activities outside the already-granted BLM land activities will occur until CEC and CVRWQCB approve this plan.

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3. WORK PLAN

3.1 Exploration Activities

GeothermEx has compiled available public geologic and geochemical data for the project area, including:

- Data from wells previously drilled in the area by Magma, Shell, and Cordero Mining
- Mine histories from the Sulfur Creek Mining District
- Several published geologic maps of the area
- Data from geochemical surveys by the U.S. Geological Survey and other researchers

This information has been reviewed to develop the data collection strategy presented in this work plan, as outlined below. The field-collected data will be analyzed to help inform later exploration decisions and field development strategies. The overall purpose is to characterize subsurface conditions in the area, including stratigraphy and geologic structure, heat flow, subsurface temperatures, fluid chemistry, and drilling conditions. The field data collection program is designed to supplement the existing data and fill in knowledge gaps, as opposed to duplicating already existing data. The work conducted will not impact or disturb mine workings or mine waste in any way.

During this phase of exploration in the project area, GeothermEx intends to undertake geochemical sampling and geologic mapping, both of which are non-invasive and result in little or no disturbance to the study area, where all mine workings and waste will be avoided. Available documentation indicates that mining waste is not present on public lands that will be accessed by GeothermEx in its field work. However, on both public and private lands, GeothermEx will adhere to the procedures for geochemical sampling and geologic mapping (as outlined in Sections 3.1 and 3.2), and it will identify, avoid, and report any non-documented mining waste (as outlined in Section 4).

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1. Geochemical Sampling. This work consists of taking water samples from hot springs and warm springs to characterize the geochemistry of the geothermal system. In addition, a few water samples will be collected at cold springs and streams to characterize the contribution of meteoric water to the geothermal system. Temperature, pH, electrical conductivity, and sometimes chloride content are measured at each site. A Global Positioning System (GPS) unit is carried with field personnel to determine the precise location of each sampling site. A few small bottles of sample water and perhaps gas (all less than one liter) may be collected at each sample site. There is no disturbance to the land surface in the process of chemical sampling. Samples will be collected by field personnel by walking from the access road to the spring or other fluid source with sampling equipment. Field personnel will then collect the sample and leave the area without creating any soil disturbance. In cases of springs with extremely low flow rates, it is typical to move a few rocks to enable the spring waters to flow into a small, temporary pool (about 10 cm in diameter and up to 5 cm deep) from which water is then sampled using a siphon. After sampling, the rocks are moved back to their original position. During these activities, a 100-foot buffer zone will be adhered to by GeothermEx field work personnel around all mine workings and mine features.

2. Geologic Mapping and Structural Studies. This work is aimed at ground-truthing and improving existing maps. It is accomplished by assessing the study area, collecting mapping data (strike and dip measurements) and taking occasional hand samples of rocks from outcrops to assist with identification and description of rock types in the study area. These samples are ideally taken directly from exposed outcrops using a rock hammer, providing confidence that the formation itself has been sampled. In cases where no obvious outcrop is present, samples are simply picked up from the ground surface. Collecting these samples will not involve any digging or disturbance of sediment. In addition, field personnel will collect structural information (strike and dip data on bedding and faults) using a Brunton compass. Again, a GPS unit is used to

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record the location of each sample or measurement. Rock samples collected will be analyzed using standard petrographic techniques to determine textures and mineralogical compositions (including hydrothermal alteration mineralogy). During these activities, a 100-foot buffer zone will be adhered to by GeothermEx field work personnel around all mine workings and mine features.

The GPS unit used by field personnel will be pre-loaded with all relevant maps and data, including topographic maps, geologic maps and (importantly for this project) maps showing areas of mining waste. These maps include the 100-foot buffer zones around all known and identified mine features on all lands (the importance of this buffer zone and how it will be dealt with in the field is discussed further in Sections 3.2 and 3.3). GeothermEx field work personnel who will conduct this work have first-hand experience with identification and delineation of historic and active mine features. This experience will be used to avoid areas of known mining features and to identify areas not previously cataloged. A detailed discussion on the nature and extent of mining waste in this mining region and how new mining waste will be identified is discussed in Section 4.

If any new areas of mining waste are found, a GPS reading and a photograph will be taken. These data will be provided to the CVRWQCB for incorporation into their maps and databases in the form of updates to Figures 4 through 7 contained herein, and as a GIS database if requested.

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Geologic and geochemical data will be collected in the field with an eye to particular information, including:

- Addressing and resolving conflicts between the different geologic maps related to SMUD's exploration project
- Supplementing existing mapping with detailed geothermal-specific mapping of areas with hydrothermal-related mineralization and alteration
- Identifying and characterizing potential reservoir rock units and important geologic structures
- Collecting additional strike and dip data to supplement existing data on bedding and fault attitudes (geologic structure)
- Collecting rock samples in support of the mapping and structural analysis
- Collecting additional fluid samples to fill in gaps in the existing fluid geochemistry database

The fluid samples will be sent to a qualified geothermal laboratory (Thermochem in Santa Rosa, CA) for analyses of major cations and anions (using the standard suite of analyses for geothermal waters). In addition, isotopic analyses may be made, likely including deuterium (^{2}H) and ^{18}O in water, and ^{18}O in sulfate (SO_4). Springs will also be evaluated for the presence of gas, which may warrant additional sampling of the gases for evaluation of gas geothermometers. Following data collection, GeothermEx will begin to evaluate and summarize the geological and geochemical results of the field exploration activities. This evaluation will consider chemical geothermometers, fluids type, evidence of mixing, evidence of fluid origins at depth, etc., such that the information generated can be used in developing a conceptual model of the geothermal resource. A report will be prepared and submitted, which presents all of the raw and processed data, relevant maps, graphs and conclusions. After commentary and feedback from SMUD and CEC, the report will be edited as needed and issued in final form with recommendations for continued exploration.

Depending on the results of the initial investigations, geologic mapping and geochemical sampling might be followed by several types of geophysical surveys (gravity, magnetic, resistivity and seismic are among the most common), although these types of surveys are not always performed. At present, GeothermEx is considering a combination of MT resistivity and gravity mapping in the project area; however, this is subject to revision based on the results of geological and geochemical analyses. Therefore, the geophysical survey plan will be presented at a later date.

3.2 Focused Work Plan for BLM and CDFG Land

Exploration of BLM (and CDFG land, if granted) is expected to consist primarily of geologic mapping and structural studies, as described above. Only limited geochemical sampling is anticipated, as there are few known hot springs on BLM/CDFG land. As described in Section 4 of this report, GeothermEx will be mindful of mining waste in the study area and will not disturb any mining-waste-related lands during the brief time GeothermEx needs to spend in these areas (approximately one to two full days). In addition, a 100-foot-wide buffer zone will be adhered to around all identified mine features on public lands.

Unless access is granted to CDFG land, this property will not be accessed at any time during this study.

3.2.1 Access to BLM and CDFG Land

Access to BLM (and CDFG land, if granted) will be obtained using public roads that pass through both BLM and private land. Unless access is granted to private land that abuts public roads, GeothermEx will not venture beyond the right-of-way granted by public roads. For this field effort, GeothermEx will adhere to a right-of-way that is defined as no more than 10 ft beyond the roadside edge.

3.2.2 Geochemical Sampling

On BLM land, the following springs are expected to be visited and potentially sampled during work:

- The Blank and Manzanita Mine Springs – 2 to 4 samples possible
- The Abbott Mine Spring (potentially on BLM land) – 1 to 2 samples possible

There is some inconsistency in the property boundaries of BLM and private lands in the area of these springs. Because of this, GeothermEx field personnel will not venture onto private land to access sampling sites where permission has not been granted. Property boundaries will be displayed on a GPS system showing an area specific map and will be adhered to at all times by field personnel.

If additional hot or warm springs are discovered during exploration activities on public land, these features will be assessed, coordinates of the spring will be recorded, and the feature may be sampled following the description in Section 3.1 above.

3.2.3 Geological Mapping

The documentation available indicates that mining waste is not present on public lands that will be accessed by GeothermEx while conducting geologic mapping activities. However, GeothermEx will adhere to the procedures for geologic mapping outlined in Section 3.1, and will identify, avoid, and report any non-documented mining waste, as outlined in Section 4.

As noted previously, access to BLM land for geologic mapping purposes will be obtained using public roads that pass through both BLM and private land (as shown on Figures 2 and 3). Unless access is granted to private land, GeothermEx will not venture beyond the right-of-way on public roads (as discussed in Section 3.2.1). Further, because of some uncertainties about the property boundaries between BLM and private land in this area, the field personnel will not venture on to private land that abuts public land to access thermal features. Property

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boundaries will be displayed on a GPS system showing an area specific map and will be adhered to at all times by field personnel.

3.3 Focused Work Plan for Private Land

Private land access may be granted on a case-by-case basis to assess geologic conditions and collect rock and fluid samples. As noted above, with assistance from SMUD and using information provided by the CVRWQCB and CEC, GeothermEx has approached property owners for access to conduct this study. The status of access permission at the time of this work plan is summarized on a case-by-case basis below. Further, to clarify property access issues to all concerned parties, GeothermEx will generate and submit a final memo on 11 July summarizing the status of access to each property to clarify the scope of field work.

If access permission is granted, all work conducted on private land will be done while: 1) adhering to the procedures of geochemical sampling and geologic mapping outlined in Section 3.1; and 2) identifying and avoiding areas of mining waste in Section 4. As indicated on Figures 4 through 7, a 100-foot-wide buffer zone will be adhered to around all previously known and newly identified mine features on all private lands.

The intended work activities on each property for which GeothermEx seeks access are specifically summarized below, by property.

3.3.1 Work Plan and Access to Miller Private Land

Access to the Miller property has not yet been granted. GeothermEx hopes to conduct a focused mapping and structural study of Wilbur Hot Springs, the additional smaller springs, and the surrounding area, including locating and recording the field characteristics of each spring. This work will be aimed at understanding the flow paths of the hot spring source fluids. The Wilbur Hot Springs will be sampled, and if hot or warm springs are discovered during exploration activities on this land, these features will be assessed, coordinates of the springs

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will be recorded, and the features may be sampled. Therefore one to possibly five springs would be sampled on this property.

Approximately one to one and a half full days of fieldwork would be planned for this land. Access to the Miller Property and Wilbur Hot Springs will be through the public road that leads to the Wilbur Hot Springs Resort (Figures 2 and 3).

3.3.2 Work Plan and Access to Bailey Minerals Private Land

Access to the Bailey Minerals property has not yet been granted. GeothermEx hopes to conduct a focused mapping and structural study of the Jones Fountain of Life Spring and the surrounding area, including locating and recording the field characteristics of the spring. This work will be aimed at understanding the flow paths of the hot spring source fluids. The Jones Fountain of Life Spring would likely be sampled, and if hot or warm springs are discovered during exploration activities on this land, these features will be assessed, coordinates of the springs will be recorded, and the features may be sampled. Therefore possibly one to two springs would be sampled on this property. During these activities, a 100-foot buffer zone will be adhered to by GeothermEx field work personnel around all mine workings and mine features.

If the Blank and/or Manzanita Mine Springs are found to be located on Bailey Minerals private land, GeothermEx will refrain from accessing this land to assess these springs unless permission is granted.

Approximately one full day of fieldwork would be planned for this land. Access to the Bailey Minerals property and the Jones Fountain of Life Spring would be through the public road that leads past the Wilbur Hot Springs Resort, and by walking access from the Miller property (if granted). Unless access is granted to the Bailey Minerals property, this property will not be accessed at any time during this study.

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3.3.3 Work Plan and Access to Wide Awake Mine Private Land

Access to the Wide Awake Mine private land has not yet been granted. GeothermEx hopes to conduct a focused mapping and structural study of the area surrounding the Wide Awake Mine private land, including locating and recording the field characteristics of any springs identified. Additionally, if any hot or warm springs are discovered during exploration activities on this land, these features will be assessed, coordinates of the springs will be recorded, and the features may be sampled. During these activities, a 100-foot buffer zone will be adhered to by GeothermEx field work personnel around all mine workings and mine features.

Approximately one half day of fieldwork would be planned for this land. Access to the Wide Awake Mine private land would be through the public road that leads through the Bailey Minerals property, and by walking access from the BLM and the Bailey Minerals property (if granted). Unless access is granted to the Wide Awake Mine private land, this property will not be accessed at any time during this study.

3.3.4 Work Plan and Access to Abbott and Turkey Run Mines Private Land

Access to the Abbott and Turkey Run Mines private land has not yet been granted. GeothermEx hopes to conduct a focused mapping and structural study of the area surrounding the Abbott and Turkey Run Mines private land, including locating and recording the field characteristics of any springs identified. Additionally, if any hot or warm springs are discovered during exploration activities on this land, these features will be assessed, coordinates of the springs will be recorded, and the features may be sampled. Therefore, possibly one to two springs would be sampled on this property. During these activities, a 100-foot buffer zone will be adhered to by GeothermEx field work personnel around all mine workings and mine features.

It is presently unclear if the Abbott Mine Spring is located on public or private land; if the spring is located on Abbott Mine private land where access has not been granted, GeothermEx will refrain from accessing this land to assess this spring.

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Approximately one half day of fieldwork would be planned for this land. Access to the private lands that host the Abbott and Turkey Run Mines private land would be through the public road that leads from Highway 20, and by walking access from BLM land. Unless access is granted to the private land around the Abbott and Turkey Run Mines, these properties will not be accessed at any time during this study.

3.4 Schedule

Per the agreement between Renovitas and CEC, as outlined in the email from Jodie Crandell on 28 June 2012, a final memo summarizing property access will be generated by GeothermEx and delivered to the work group 11 July 2012. Following this, fieldwork will be conducted and a results and evaluation report will be prepared and submitted in draft form by 24 August 2012, with the final report delivered by 21 September 2012.

GeothermEx is in agreement with and can provide the necessary services to accommodate this schedule. Following approval of this work plan, the fieldwork effort should be begin as soon as possible to meet the requested 24 August, 2012 deadline, as: 1) two weeks are required for fieldwork preparation and execution; 2) five weeks is commonly required for laboratory sample analysis and reporting; and 3) three weeks is required for data evaluation and reporting.

Any need for schedule modification will be discussed with CEC, SMUD, and Renovitas following submission of this work plan and the execution of fieldwork.

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4. RECOGNIZING AND AVOIDING AREAS WITH MINING WASTE

The CEC and the CVRWQCB have requested additional assurance within this work plan indicating that GeothermEx is sufficiently aware of the historic mining sites and associated waste in the Sulphur Creek Mining District, which coincides with the project study area. It is GeothermEx's intention to avoid disturbing any and all public and private land mine sites and associated waste during the geothermal exploration efforts. As shown in Figure 2, there are a number of documented historic mining sites in this area, and most have known mining waste. The location of this mining waste will be loaded into the field team's GPS unit, and hardcopy maps will be taken into the field, assuring that GeothermEx personnel know their location at all times relative to any areas of mining activity. Additionally, as indicated on Figures 4 through 7, a 100-foot buffer zone will be maintained around all known and identified mine features on all public and private lands (*i.e.*, there will be no walking, rock sampling or exploration activity of any kind around any area of mining waste, including the100-foot buffer).

The historic mining sites that have been catalogued in the Sulphur Creek Mining District in the vicinity of the geothermal exploration area are listed below and shown in Figures 2 and 3, with smaller scale maps of mine workings and mine waste on both a topographic base and on an aerial photograph in Figures 4 through 7.

- Central Mine
- Manzanita Mine
- West End Mine
- Cherry Hill Mine
- Empire Mine
- Wide Awake Mine
- Abbott Mine

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- Turkey Run Mine

The indented and italicized paragraph below is an excerpt from the CDC/CGS (2003) document which summarizes the history of mining in the Sulfur Creek Mining District:

> *The mines* [as indicated above] *were initially discovered in the 1860s and 1870s and were worked intermittently, some until the early 1970s. Mining operations in the district were mostly by underground methods with limited surface mining activity…The Abbott-Turkey Run is the largest underground mine in the district and has between one and two miles of underground workings distributed over a 500-foot vertical interval. It also had the largest mercury production in the district, probably in excess of 1.8 million kilograms. Total district mercury production is approximately 2 million kilograms.*

During fieldwork, GeothermEx will use Figures 2 and 3, in coordination with the smaller scale Figures 4 through 7 to note and avoid locations of mine workings and waste. In addition, GeothermEx field personnel will note, describe, and take GPS readings at any previously undocumented locations, and will provide updated maps during reporting.

There are a number of additional historic mining sites in the Sulphur Creek Mining District which are more than 2-1/2 miles north and northwest of the area of interest. These areas will not be visited; thus, they are not depicted in figures in this work plan.

GeothermEx personnel who will be involved in exploration activities in the Sulfur Creek Mining District have been made aware of these historic mining sites and their features to ensure they will avoid disturbing any mining related waste. In addition to the documented historic mining sites, it is possible that additional undocumented mining sites will be found during the course of the exploration work; these will be documented as described above.

GeothermEx has reviewed documentation authored by CalTrans (2008) which provides detailed descriptions of the archeological features associated with hard rock mining and history and procedures of mining in California, so that our personnel may accurately identify and avoid any such areas encountered. The pertinent excerpt from the CalTrans (2008) document will be

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reviewed by GeothermEx field personnel in advance of conducting fieldwork. The pertinent sections of the CalTrans (2008) document have been included as an Appendix to this work plan.

One of the two GeothermEx staff members assigned for this field work is an experienced mining geologist who has worked in various mining areas in California, Washington, Alaska, Utah and Montana. The two staff members will work together during field work, primarily for safety reasons, but also to enable the experienced GeothermEx mining geologist to provide guidance to the second staff member on how to recognize the signs of mining in unmapped areas. The second staff member assigned to the project is a geologist with pertinent experience in historic mining cleanup and remediation.

The team will be equipped with GPS units loaded with maps similar to those presented herein, helping them maintain an acute awareness of where they are and what mining features may be nearby. If any new areas of mining waste are found (locating new test pits with waste rock is possible), a GPS reading and a photograph will be taken. These data will be provided to the CVRWQCB for incorporation into their maps and databases in the form of updates to Figures 4 through 7 contained herein, and as a GIS database if requested.

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5. REFERENCES

California Department of Conservation (CDC) and California Geological Survey (CGS), 2003. An Assessment of Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed, CALFED Bay-Delta Mercury Project, Task 5C1: Assessment of the Feasibility of Remediation of Mercury Mine Sources in the Cache Creek Watershed. Final Report and Appendices, September.

California Depratment of Transportation (CalTrans), 2008. A Historical Context and Archeological Research Design for Mining Properties in California. Chief, Cultural and Community Studies Office, CalTrans Division of Environmental Analysis, P.O. Box 942874, MS-27, Sacramento, CA 94274-0001

ERM, 2010. Mining-Related Materials Characterization and Remediation work plan, Sulphur Creek Mining District, Central Group and Wide Awake Mines, Colusa County, California, September.

Central Valley Regional Water Quality Control Board (CVRWQCB), 2007. Central Valley Region, Sulphur Creek TMDL for Mercury. Final Staff Report, January.

Tetra Tech EMI., 2003. CALFED-Cache Creek Study, Engineering Evaluation and Cost Analysis for the Sulphur Creek Mining District, Colusa and Lake Counties, California. Final. September.

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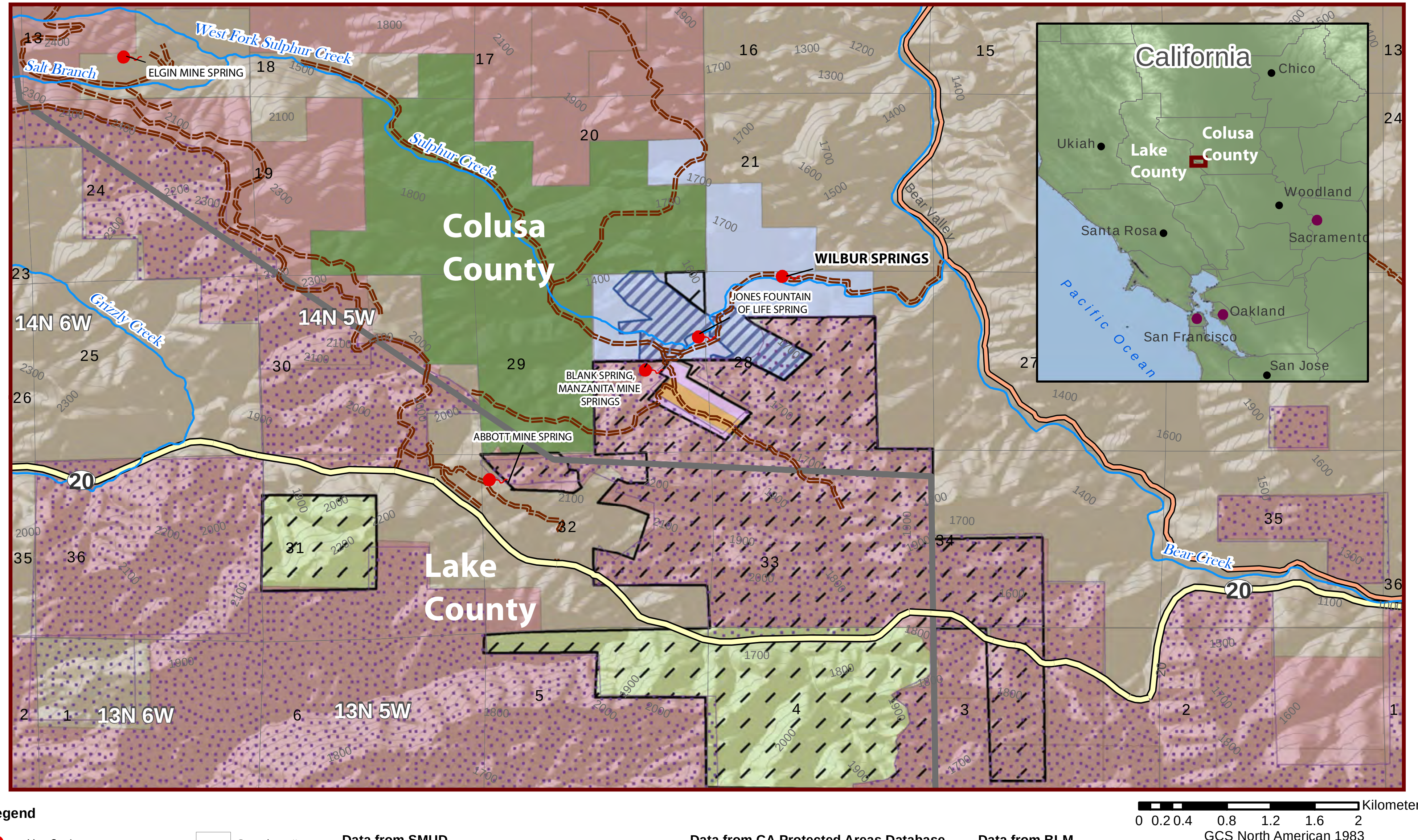
FIGURES



Legend

- Hot Spring
- Rivers & Streams
- County Line
- Township & Range
- Section #s
- Highway 20
- Bear Valley Road
- Local Public Road

Data from SMUD

- Trebilcot Property (Mineral)
- Bailey Property (Mineral)
- David Brown (Mineral & Surface)
- Merced General Construction (Mineral & Surface)

Data from CA Protected Areas Database

- Private - Unknown
- California Dept. of Fish and Game (Surface)
- US Bureau of Land Management (Mixed)

Data from BLM

- Cache Creek Management Area Plan
- Miller Property (Surface)
- Miller & American Land Cons. Trust (Surface)

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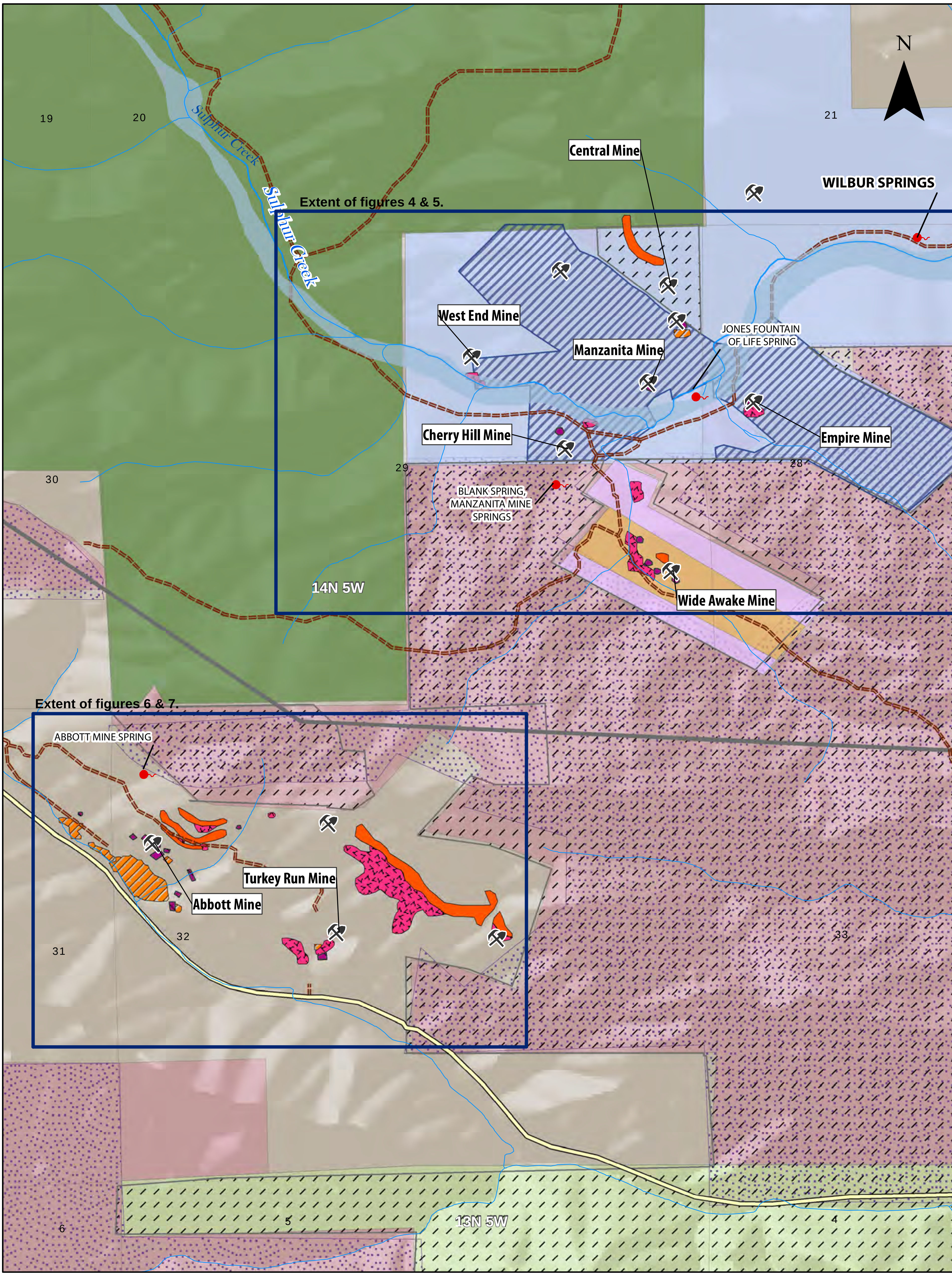
Figure 1: Location map showing surface and mineral ownership near Wilbur Springs, California

CLIENT: SMUD	PROJECT: Wilbur Work Plan
JOB: 051993.P TASK: 1	DRAWN: RR CHECKED: ART
DATE: 5/4/2012	FIGURE: WorkPlan.mxd



GCS North American 1983

0 0.125 0.25 0.5 0.75 1 Kilometers

Legend

- Hot Spring
- Mine
- Rivers & Streams
- County Line
- Township & Range
- Highway 20
- Bear Valley Road
- Local Public Road
- Section #s

Data from BLM

- Cache Creek Management Area Plan

Data from SMUD

- Trebilcot Property (Mineral)
- Bailey Property (Mineral)
- David Brown (Mineral & Surface)
- Merced General Construction (Mineral & Surface)
- Miller Property (Surface)
- Miller & American Land Cons. Trust (Surface)

Data from FEMA

- 100 year Flood Zone

Data from CA Protected Areas Database

- Private - Unknown
- California Dept. of Fish and Game
- US Bureau of Land Management

Mine Features from Tetra Tech 2003

- Open Cut
- Mine Structures
- Mine Tailings
- Waste Rock

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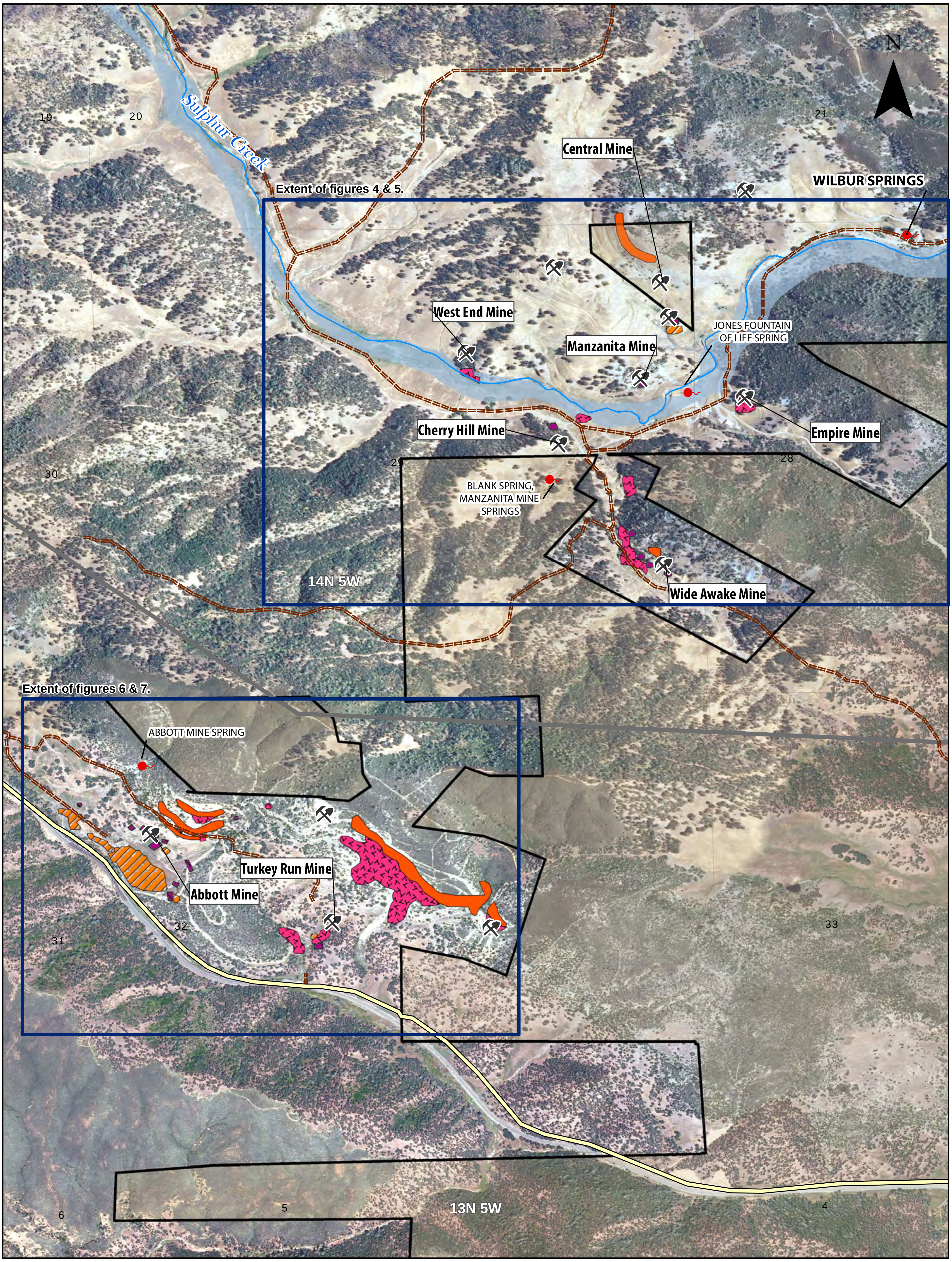
Figure 2: Roads, mines, known areas of mining waste and hot springs, Wilbur Springs, CA (shaded relief background)

CLIENT: SMUD	PROJECT: Wilbur Work Plan
JOB: 051993.P TASK: 1	DRAWN: RR CHECKED: ART
DATE: 6/19/2012	FIGURE: WorkPlan.mxd



GCS North American 1983

0 0.125 0.25 0.5 0.75 1 Kilometers

Legend

- Hot Spring
- Mine
- Rivers & Streams
- County Line
- Township & Range
- Highway 20
- Bear Valley Road
- Local Public Road
- Section #s

Mine Features from Tetra Tech 2003

- Open Cut
- Mine Structures
- Mine Tailings
- Waste Rock

Data from SMUD

- Trebilcot Property (Mineral)

Data from FEMA

- 100 year Flood Zone

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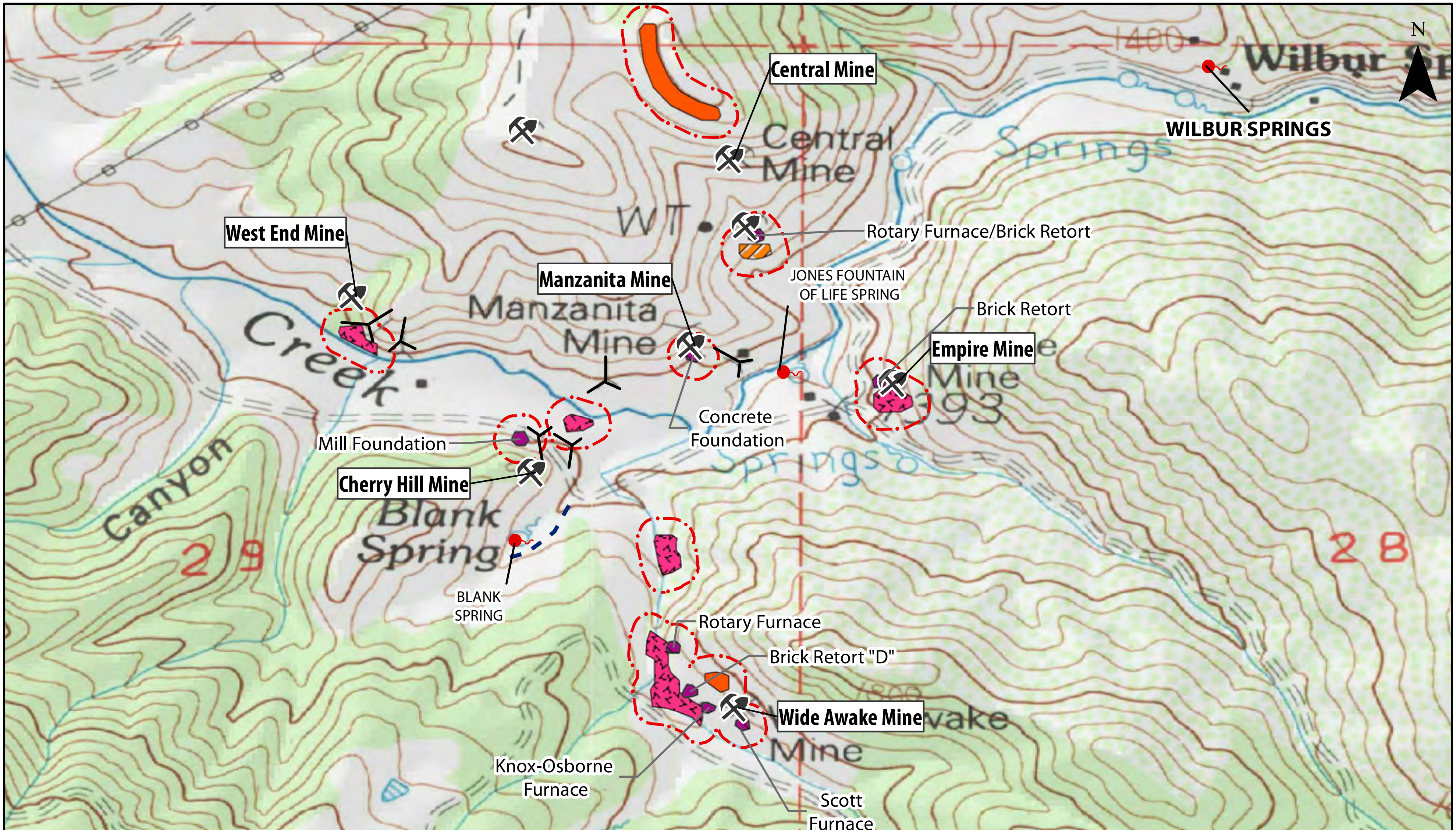
Figure 3: Roads, mines, known areas of mining waste and hot springs, Wilbur Springs, CA (satellite image background)

CLIENT: SMUD	PROJECT: Wilbur Work Plan
JOB: 051993.P TASK: 1	DRAWN: RR CHECKED: ART
DATE: 6/19/2012	FIGURE: WorkPlan.mxd



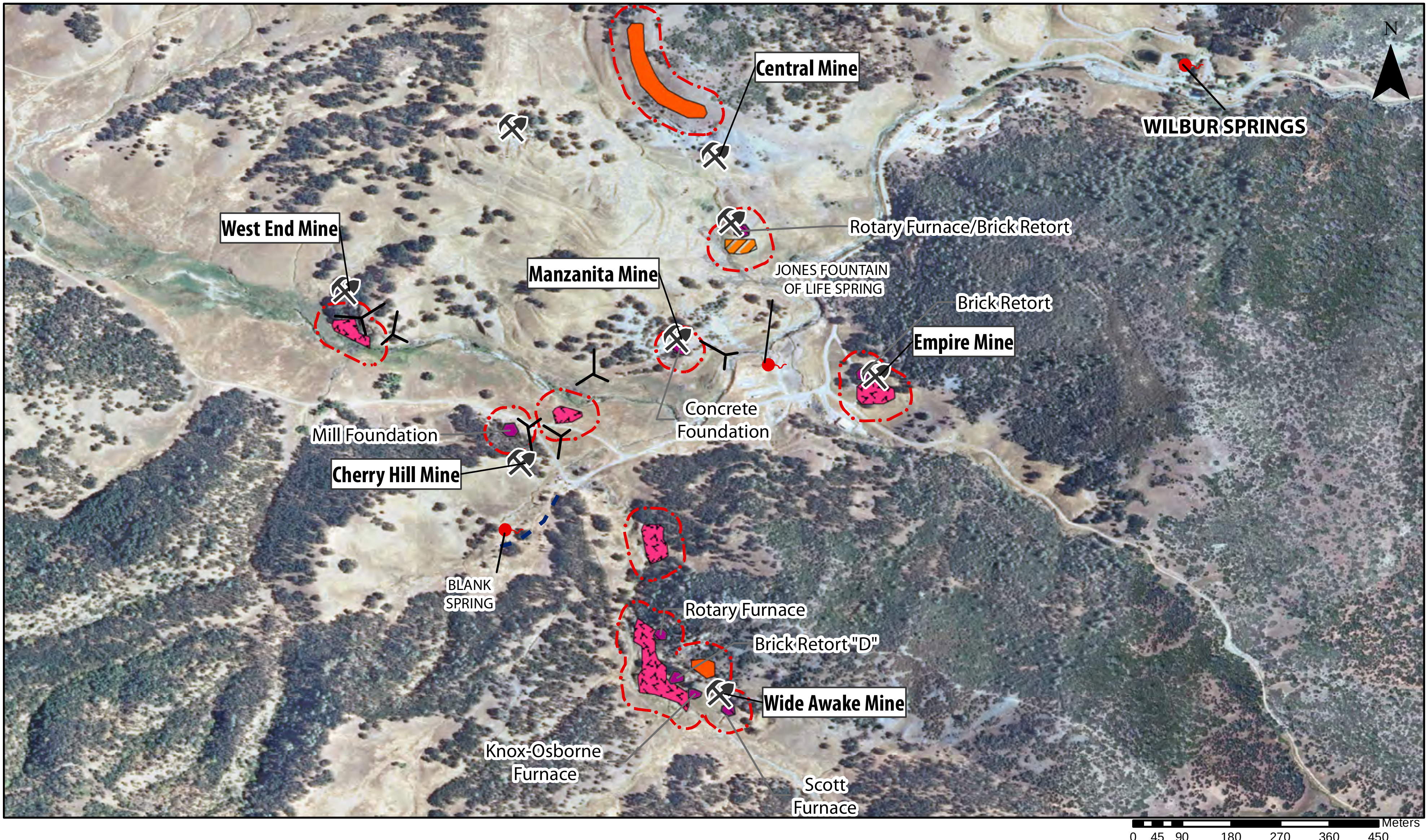
Meters
0 45 90 180 270 360 450

GCS North American 1983

Legend

Mine	Adit	Open Cut	Mine Tailings	100 ft. Buffer Zone
Hot Spring	Diversion	Mine Structures	Waste Rock	***Mine features replicated from Tetra Tech 2003**

GeothermEx A Schlumberger Company	Figure 4: Mine Features, Wilbur Springs Area Mines	
	CLIENT: SMUD	PROJECT: Wilbur Work Plan
	JOB: 051993.P TASK: 1	DRAWN: RR CHECKED: LH
	DATE: 5/24/2012	FIGURE: WorkPlanDetailTopo.mxd



GCS North American 1983

Legend

Mine — Adit — Open Cut — Mine Tailings — 100 ft. Buffer Zone

Hot Spring — Diversion — Mine Structures — Waste Rock — ***Mine features replicated from Tetra Tech 2003**

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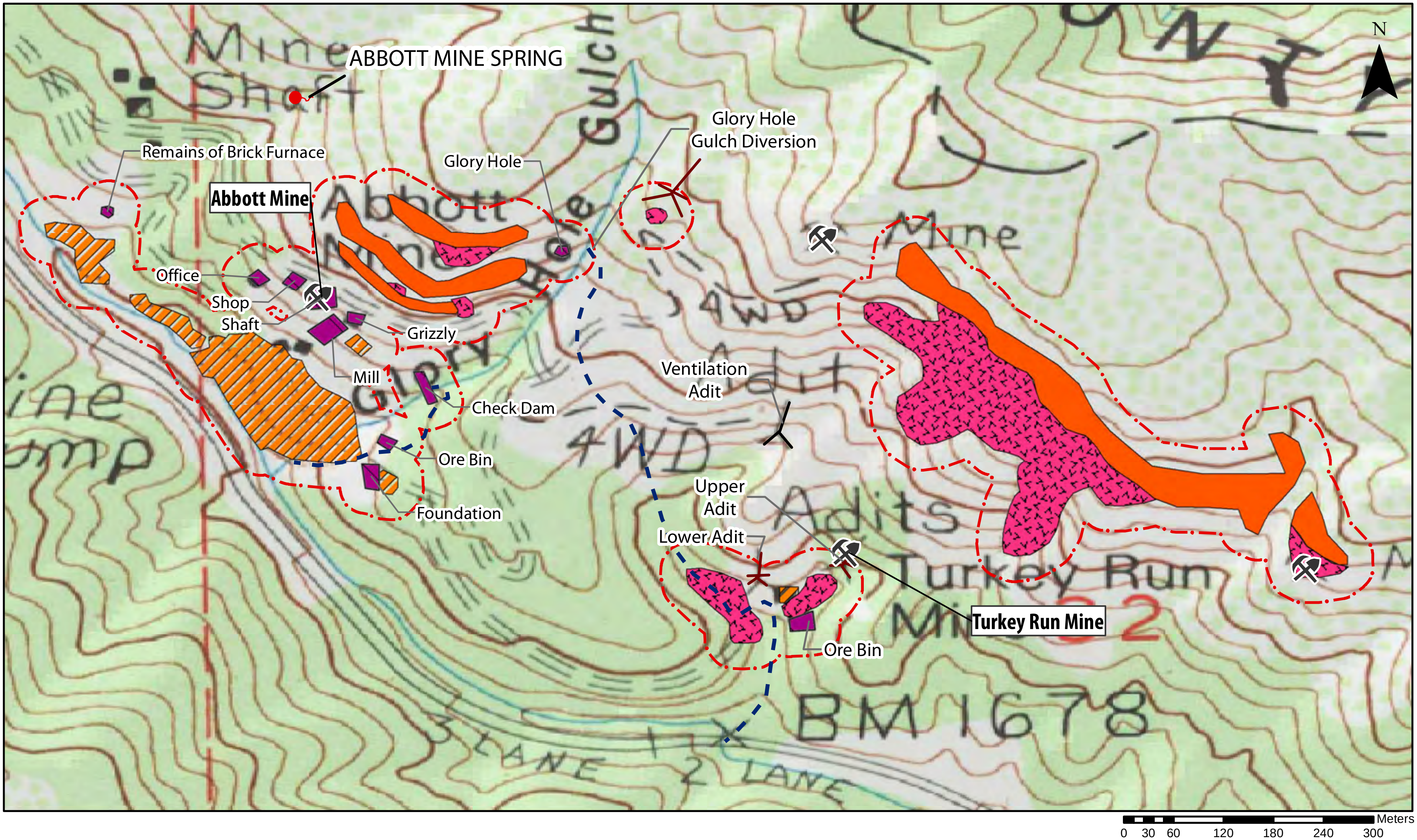
Figure 5: Mine Features, Wilbur Springs Area Mines	
CLIENT: SMUD	PROJECT: Wilbur Work Plan
JOB: 051993.P TASK: 1	DRAWN: RR CHECKED: LH
DATE: 5/24/2012	FIGURE: WorkPlanDetailTopo.mxd



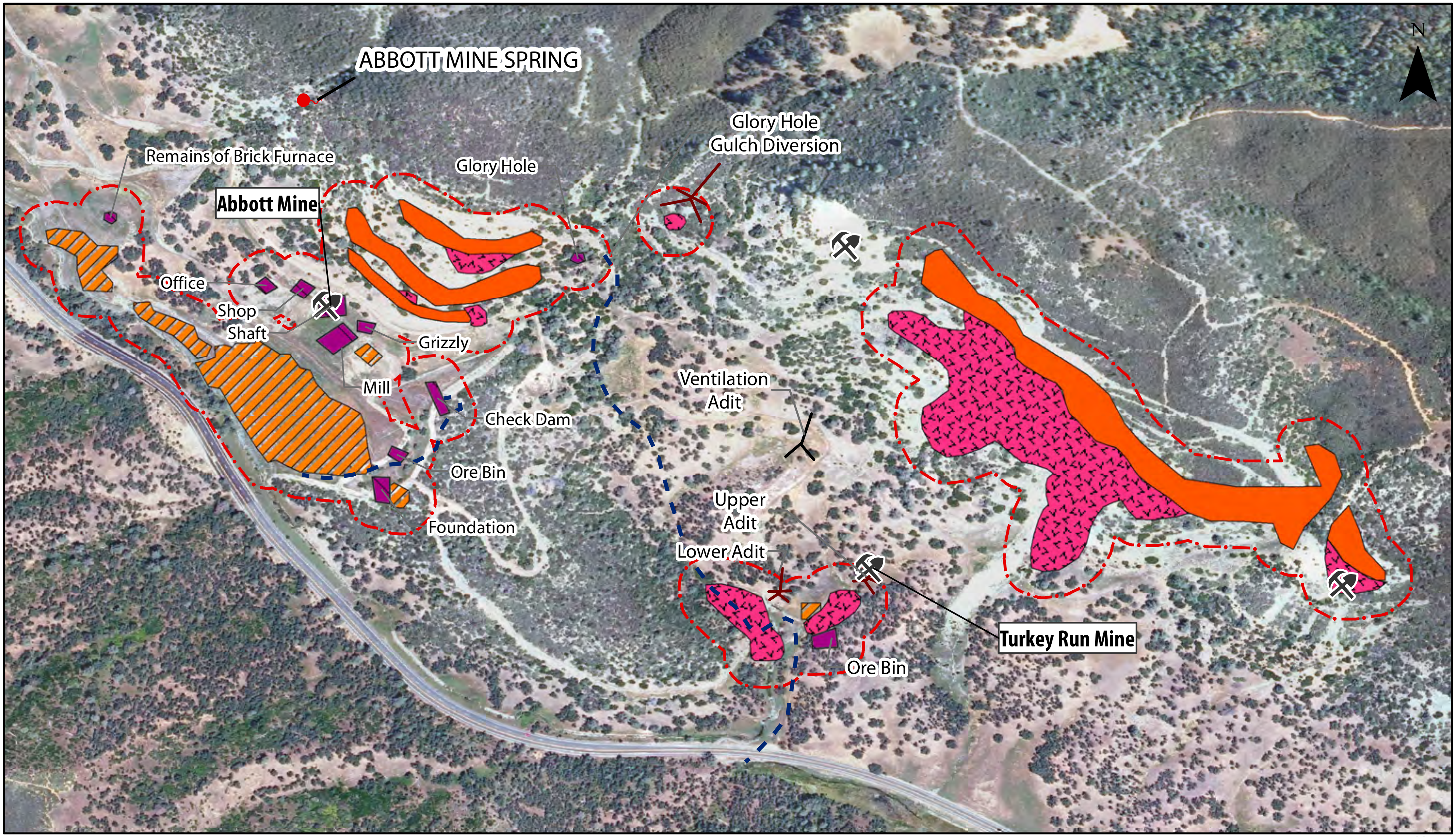
GCS North American 1983

Legend

Mine
Hot Spring
Adit
Caved Adit
Diversion
100 ft. Buffer Zone
Open Cut
Mine Structures
Mine Tailings
Waste Rock

***Mine features replicated from Tetra Tech 2003**

GeothermEx A Schlumberger Company	Figure 6: Mine Features, Abbott and Turkey Run Mines			
	CLIENT: SMUD		PROJECT: Wilbur Work Plan	
	JOB: 051993.P	TASK: 1	DRAWN: RR	CHECKED: LH
	DATE: 5/24/2012		FIGURE: WorkPlanDetailTopo.mxd	



Meters
0 30 60 120 180 240 300

GCS North American 1983

Legend

Mine	Adit	Diversion	Open Cut	Mine Tailings
Hot Spring	Caved Adit	100 ft. Buffer Zone	Mine Structures	Waste Rock

***Mine features replicated from Tetra Tech 2003**

GeothermEx
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Figure 7: Mine Features, Abbott and Turkey Run Mines

CLIENT: SMUD	PROJECT: Wilbur Work Plan
JOB: 051993.P TASK: 1	DRAWN: RR CHECKED: LH
DATE: 5/24/2012	FIGURE: WorkPlanDetailTopo.mxd

APPENDIX

CHAPTER 3. PROPERTY TYPES

INTRODUCTION TO PROPERTY TYPE CATEGORIES

This chapter introduces types of archaeological resources associated with historic mining processes. These property types do not exist in isolation, but must be identified and interpreted within their functional and historic context. As used here, property types include the individual building blocks of mining sites such as prospect pits, shafts, mills, and tailings ponds. Simple sites may have only one or two property types while complex sites may have many, linked by function and time. These linked property types are what Donald Hardesty referred to as "feature systems" on mining sites in Nevada to distinguish "a group of archaeologically visible features and objects that is the product of a specific human activity" (1988:9). This is a useful way to tie together different features into a functional process. In general, site significance increases with the size, complexity, visibility, and focus of these systems: focus indicates the clarity with which the story of archaeological remains can be "read," while visibility refers to the quantity of remains present (Deetz 1996:94). The concepts of visibility and focus are discussed further in Chapter 5.

A similar, process-based approach to identifying property types is recommended in the National Park Service's *Guidelines for Identifying, Evaluating, and Registering Historic Mining Properties* (Noble and Spude 1997).

Accurate interpretation of property types and feature systems - establishing function and context - is critical. Determining whether a pile of rocks is the result of placer or hard-rock mining, or that it dates to the gold rush or Depression-Era, forms the basis for determining site significance. In addition, because many of these sites may be affected by development projects, this identification may constitute their last examination and recording by archaeologists and historians. It is important that our final record of this mining activity be accurate. Interpretation is made more difficult when mining occurs over a long span of years and subsequent mining overlays original development. For sites with several property types or feature systems, interpretation is facilitated by physically reconstructing deduced mining processes on a map, and perhaps in a flow chart, to ensure an accounting for all the potential resources and their relationships. For complex sites, a mining engineer and/or geologist can contribute much to this exercise.

The links between processes or activities and the common types of archaeological mining resources are drawn below, grouped under five categories:

1. prospecting and extraction;
2. ore processing;
3. intra-site ancillary facilities;
4. domestic remains pertaining to social, non-technological elements of mining; and
5. larger, regional linear properties, such as water conveyance systems that support the mining endeavor.

In this chapter, a description of the process that created the physical remains is provided, visual representations have been added to assist interpretation, and common tangible remains for each is summarized. Mining sites can contain multiple property types from multiple categories.

PROSPECTING AND EXTRACTION PROPERTY TYPES

Mining involves locating and extracting minerals from naturally occurring deposits. Prospecting is the act of searching for new mineral deposits and testing or determining their potential value (Fay 1920:540). The two primary forms of deposits are lode and placer. Lode deposits are the original mineral occurrence within a fissure through native rock, also variously known as vein or ledge. Hard rock and quartz mining are two common terms referring to mineral extraction from lode deposits. Extracted lode minerals, especially those deep underground, generally require additional refinement, called beneficiation (discussed in Ore Processing Property Types below). Placer deposits are sedimentary formations containing minerals that have eroded from their parent lode into a variety of natural contexts, both shallow and deeply buried. The ubiquitous image of a 49er panning for gold along a gravel bar is well known, although hydraulic, drift, and dredge mining also targeted this type of deposit. Placer minerals are generally "free" from parent material and do not require additional refinement once separated from worthless sediment. Placer miners followed "color" up drainages looking for the source, or parent outcroppings of lode ore. They also discovered eroding ancient riverbeds, now elevated above the modern landscape, which contained naturally deposited placer gold as well. Later, geology played a larger role in locating minerals. Miners often used ingenuity and innovation to tailor their operations to local conditions for both lode and placer deposits. Prospecting and extraction technology differed for the two types of mineral deposits.

PLACER MINING PROPERTY TYPES

Placer Mining Property Types include:

- Tailings Piles
  - Small Piles of Placer Tailings
  - Oblong Piles of Placer Tailings
  - Long Lines of Placer Tailings
  - Pits with Placer Tailings
  - Surface Exposures of Placer Rock
- Cut Banks, Channels and Placer Tailings
- River Diversion
- Dredge Tailings
- Drift Mining Remains

The primary means of separating free gold from auriferous sediments relies on water and gravity. Water flow is used to move and agitate gravel, and gold's specific gravity ensures that it naturally settles under proper conditions. Dry placering, such as winnowing, may have been used in the absence of water; here wind blows the lighter component to the side while heavier material drops. One of the most comprehensive references regarding placer mining is C.V. Averill's *Placer Mining for Gold in California* (1946), but there are many others (Wilson 1907; Boericke

1936; Peele 1941; Wells 1969; Rohe 1986; Silva 1986; Meals 1994; Tibbetts 1997; and Lindström et al. 2000).

The simplest placer prospecting is typically done with a metal gold pan, a round shallow dish with flat bottom and slanted sides sometimes improvised from common kitchen supplies; wooden *bateas* and baskets were also used in the earliest years. Panning involves swirling a small amount of dirt and gravel with water in a manner that allows the lighter material to rise to the top for removal while the heavier fraction, particularly the gold, concentrates at the bottom. Panning can be carried out at the location of a placer deposit, or auriferous sediment can be collected using a variety of hand tools and taken to a convenient panning location. For example, gravel can be scraped out of crevices, with various kinds of metal bars, into a bucket and taken to a bar along a creek where it can be easily panned. The method is limited to coarse gold, as fine particles tend to be lost with the gravel. The gold pan has endured, however, and metal and plastic versions can still be found in modern supply stores. Because of its simplicity, the pan is used for prospecting, as an extraction tool, and in combination with other technologies discussed below. Although widely used, evidence of panning in archaeological contexts is generally limited to the presence of the pan itself. Any evident changes to the ground surface would have been so minor that, combined with natural processes, they would have been erased. Hand tools such as picks, shovels, buckets, and wheelbarrows were the dominant method of extracting and transporting placer deposits to separating devices.

Tailings Piles

The most distinctive indicator of a placer mining site is the waste rock, or tailings piles, left from prospecting or mining. These rock piles – located in creek drainages, along bars and riverbanks, or at locations of ancient, exposed river deposits – consist of water-worn rocks and a general lack of soil. Tailings piles come in different shapes and sizes, as noted below, depending on where they are on the landscape and how they were separated from gold-bearing gravels. Boulders and cobbles were often moved out of the way and piled or stacked to the side, while gravel and smaller cobbles were generally processed for gold. Water, necessary to wash the deposits, could, for small operations, consist of seasonal runoff or include short water diversions from nearby drainages. Large-scale mining might involve large ditch systems bringing water from afar. Both short- and long-term placer mining areas may include habitation sites or features. The complexity of these habitation sites or features is generally related to the duration of the mining operation, and the physical relationship of the mining operation to areas suitable for habitation.

Small Piles of Placer Tailings

A placer deposit worked by a rocker or cradle exhibits an undulating ground surface formed of piles of uniform-sized gravel and cobbles where the hopper was emptied. Piled or stacked cobbles and boulders may also have been moved out of the gravel bed. Metal, perforated screens (riddle plates or grizzlies) are diagnostic artifacts that are typically square, and range "16 to 20 inches on each side with one-half inch openings" (Silva 1986:3).

The rocker, or cradle, is one of the simplest mining tools and can be operated by one individual. Named for its likeness to a baby cradle, it is essentially a wooden trough

Figure 41: Rocker Clean-out Pile, Prairie Diggings Placer Mining District (PDPMD), Locus 20, Sacramento County (courtesy Judith D. Tordoff).

with a screened hopper on top and a handle that allows the operator to rock the device. Auriferous gravel is dumped into the hopper and enough water poured in to transport the finer sediments through the sieve, across an apron, and through a series of riffles. "Dry washers" were similar devices that did not require the use of water. Cobbles and gravel caught in the screen are cleaned out and dumped to the side (Figure 41). The apron, which was historically made of a cloth-like material such as canvas or burlap, collects coarse gold and directs fine material to the head of the riffle-lined trough, where fine gold settles. Riffles are a series of parallel slats of various designs fixed to the bottom of collection troughs that "retard the gravel and sand moving over them, and so give the gold a chance to settle" (Boericke 1936:62). Material collected from behind riffles was typically panned. The entire device is relatively portable, typically two to five feet long, one to two feet wide, and less than two feet in height. It was popular in California by 1849, and although designs continue to circulate in modern mining books, they are no longer widely used.

Oblong Piles of Placer Tailings

The use of long toms leaves a landscape similar to that of rockers, although the rock and gravel removed from the longer troughs create linear or oblong piles of uniform-sized gravel and cobbles, as much as 15 to 20 feet long. Other associated artifacts may include the flared, perforated sheet-iron plate.

The long tom operates much like a rocker. Gravel is dumped into an open, inclined trough and drains through a screen into another box fitted with riffles. Coarse gold settles into perforated sheet iron that lines the initial trough, while the finer particles are captured in the riffle box below the sieve. The device relies on a steady current of gravity-fed water to move material instead of rocking, and no pressure, or head, is necessary. The flow is controlled, and must be stopped during frequent cleanouts. Material collected from behind riffles was typically panned. Widespread adoption of long toms in 1851 depended upon development of a necessary water supply system (Rohe 1986:136). Perforated metal used in long toms may vary in dimensions, although designs generally include a flared riffle plate uncommon in other collection devices (Boericke 1936:60; Silva 1986:7; Lindström et al. 2000:68). As described by Wilson (1907:39), "the feed end of the tom is about 18 inches wide, while the discharge end is about 32

Lines of Placer Tailings

The use of sluice boxes resulted in a landscape similar to that of a long tom, although straight linear piles of tailings usually exceeded 20 feet in length. Metal grates or angle iron riffles might be present. Steep cut banks are absent.

inches wide, and terminates in a perforated sheet-iron plate." Common water systems include penstock, hose, flume, and ditch, or a combination of these.

Figure 42: Ground Sluice Tailings, Alder Creek Corridor Placer Mining District (ACCPMD), Sacramento County *(courtesy Judith D. Tordoff).*

A box or board sluice is a wooden, riffle-lined trough that operates much like a long tom, although typically 12-foot sections were interconnected to construct much longer devices (Peele 1941:10–561; Rohe 1986:137; Figures 42 and 43). As with the long tom, the chain of sluice boxes was supplied with a controlled source of water, and was constructed to a suitable grade for collection, often requiring trestles. Water and gravel were introduced at the head, gold and heavy sediment collected behind riffles, and water and gravel—and fine minerals—exited the tail into a dump.

Flow had to be stopped periodically to clean out concentrate from behind the riffles. Material collected from behind riffles was typically panned. Gravel could be shoveled in manually, or brought to the feed sluice by wheelbarrow and then shoveled in. Various means were employed to

Figure 43: Sluice Tailings, PDPMD, Locus 20, Sacramento County *(courtesy Judith D. Tordoff).*

Pits with Placer Tailings

Small-scale prospecting of slope deposits resulted in an undulating landscape of depressions and mounds located on hill-sides and ridges formed of ancient river channels. The depressions are less than ten feet in diameter and cobbles and other river rock are piled adjacent. Abundant pits with large adjacent rock piles may indicate an area of coyoting.

prevent clogging and damage by large rocks, such as a mud box fitted with a grizzly, or metal grate; "oversize material and boulders are forked out and thrown to one side after having been cleaned" (Boericke 1936:55). Undercurrents were used to increase collection of finer, gold-bearing sediments by diverting finer material through a grate along the bottom of the sluice to a large box designed to slow the flow of water enough to allow fine gold to settle. Sluice boxes were widely used by 1852 (Rohe 1986:137). Various metal grates or sieves were used to help screen gravel and riffles were generally wood, although there are some metal designs such as angle iron (Peele 1941:10–566; Silva 1986:7). A water conveyance system would be present, although exclusive use of the sluice box would not result in steep cut banks, which would indicate ground sluicing or hydraulic technology. Sluicing resulted in impressive, distinctive landscapes (Figure 44).

Hillsides composed of the eroding remains of ancient river channels could be prospected by surface prospecting and by ground sluicing (see below). Small, shallow pits were excavated into the ground surface, and the soils removed for processing in a pan, cradle, or other sorting device. Water did not need to be brought to these prospecting locations. The pits were usually less than eight feet in diameter and only a few feet deep. A pattern of small, deep prospects is called "post-holing." Archaeologically they survive as shallow depressions with small adjacent piles of stream-washed cobbles. Where buried gold deposits were located, either in exposed modern river bottoms or elevated ancient ones, prospects were enlarged by "coyoting" (mining in irregular

Figure 44: Sluice-mining landscape created in the 1850s –1860s, McCabe Creek, Butte County *(Courtesy Anthropological Studies Center, image no. 27-03-D136-05).*

openings or burrows into the auriferous gravels; also see discussion below on Adits and Tailings). Dry placering employed this method as well. The work was considered quite dangerous as the ground matrix was unstable and cave-ins common. Archaeologically these prospects have collapsed and eroded and are distinguished from pit prospects only by the size of the adjacent tailings piles.

Figure 45: Bedrock Drains in Ground Sluice System, PDPMD, Locus 19, Sacramento County *(courtesy Judith D. Tordoff).*

Cut Banks, Channels, and Placer Tailings

Combinations of cut banks, channels, and stacked or piled rocks are the result of ground sluice or hydraulic operations, or a combination of these methods. Both processes of excavating auriferous deposits relied on collection technologies described above. Disposal methods for large quantities of water and waste material from the operations are evident in the archaeological remains. The feature systems resulting from sluicing and hydraulicking methods are similar.

A ground sluice is a channel or trough in the ground through which auriferous earth is washed. It may require carving into the bedrock to obtain the correct slope or grade for the bottom of the channel (Wilson 1907:40; Figure 45). Ground sluicing is also the act of caving-in and eroding the ground into a prepared channel using a steady stream of water and hand tools to remove overburden (Peele 1941:10–541). In all respects, what sets ground sluicing apart from box or board sluicing is the large quantities of water needed to excavate the ground. Booming is a variation in which the water was impounded nearby and released suddenly to cause a powerful gush of water against a bank or over a ground surface. A variety of material can be used for riffles in a ground sluice, including natural irregularities in the channel, cobbles, and wood poles. Cleaning out the concentrate from a ground sluice took place as needed. It involved removing all riffles and large stones, collecting all the sediment, and often extracting a few inches of bedrock; the result was an empty channel. The collected material would then typically be run through a board sluice, long tom, or rocker, and eventually the pan. It was also common to use board sluices at some phase of ground sluicing operations, including at the tail or in place of a ground sluice. Like the board sluice, ground sluicing became common in the early 1850s, and relied on dependable

Cut Banks, Channels, and Placer Tailings

Ground sluicing and hydraulic mining produce similar landscapes characterized by substantial water conveyance features, and the presence of steep cut faces of varying heights at the edge of the worked area.

sources of water.

Hydraulic mining is a method in which a bank of auriferous material is washed away by a powerful jet of water and carried into sluices (Fay 1920:352). As the name suggests, an abundant water supply—and the means to build sufficient head, or pressure—is necessary. Water is typically conveyed from high on an adjacent hillside into a metal pipe (penstock) to build head, and then into canvas hoses fitted to a metal nozzle, or monitor, which directs the jet of water. In large operations giant monitors were hooked directly to penstocks to contain the high pressure. Gold was collected in extensive sluice systems, often similar to the ground sluicing described above (Figure 46).

Figure 46: Stewart Mine Hydraulic Cut, Dutch Flat, Placer County *(I-80 in foreground) (courtesy Anmarie Medin).*

Low-pressure models were developed in the 1850s, although substantial technological developments in high-pressure water wheels and delivery systems were accompanied by far greater gold production beginning in the early 1870s (Limbaugh 1999:34). Far greater dumping of processed waste sediment (i.e., mining debris) in waterways was another result. Judge Sawyer’s 1884 decision in Woodward vs. North Bloomfield led to the 1893 Caminetti Act, federal legislation controlling hydraulic discharge into public waterways. Large-scale operations that could not control their discharge for whatever reason began closing down.

Lindström et al. (2000:62) noted the difficulty in differentiating hydraulic and ground sluice operations in archaeological interpretation, particularly for small-scale operations. In large-scale hydraulic mines, pressurized water systems, steep cliffs, and abundant tailings in noticeable hydraulic pits and dumping grounds should be apparent. Typically small operations elevated a monitor on a stable platform to keep it dry and above flowing gravel and water. Archaeologically this looks like a flattened rock pile in front of a concaved bank; there is no equivalent need for such a feature in ground sluicing, whereby the water is delivered via a race, or ditch, above the cut face. Peele (1941:10–551) describes ideal monitor placement for larger operations.

River Diversion

Mining the beds of rivers and streams required special techniques. One historically popular method involved turning a river from its bed in order to process the underlying gravels, popularly accomplished by wing dams, flumes, and channel diversion. A wing dam was constructed down a stretch of river, parallel to the bed, connecting upper and lower cross dams in a manner that would box a segment of riverbed (Figure 47). The flow that continued down behind the wing dam sometimes operated a pump (often called a Chinese pump) that would continue draining the contained portion of the riverbed in order to allow mining below the level of the river. Fluming involved construction of a head and tail dam, and a flume erected between them, thereby exposing an entire width of a river segment. In channel diversion, a parallel channel was made for the river alongside the natural one, and the river diverted into it. A stream course could be moved back and forth across a drainage over a period of mining. River mining was widely practiced in California beginning in the early 1850s (Rohe 1986:140), and reached its peak in the mid-1850s (Meals 1994:10), although miners used these methods as late as the 1880s.

***Figure 47: Remains of a wing dam along the Stanislaus River** (Courtesy Julia Costello).*

River Channel Diversion

While a river will typically reclaim its course and obliterate evidence of this activity, some elements of the diversion means may survive along banks, such as dams and ditches. For smaller courses, evidence of parallel channels and stacked-rock retaining walls may indicate a temporary channel diversion. Sedimentation may have partially buried some elements.

Dredge Tailings

Dredge mining provided the means to access areas laden with deep auriferous gravels using amphibious vessels, and in turn allowed the profitable recovery of gold-bearing material that paid as little as five cents per cubic yard. Successfully used in California by 1898, and continuing into the 1960s, the bucket-line dredge consists of a "mechanical excavator and a screening and washing plant, both mounted on a floating hull" (Peele 1941:10–577). The dredge, anchored by a spud or post that could be raised or lowered at the stern of the hull, was floated in an artificial pond where it excavated a channel in deep gravel plains. Gravel was processed through a series of gold-saving devices, and the large volume of waste cobbles deposited by conveyor into a series of uniform tailings piles. The dredge would pull forward, following the excavated channel and leaving the tailings to fill in behind. Large-scale models were adapted to California's gravel plains, particularly where the Feather, Yuba, and American rivers, flowing from the Sierra Nevada, entered the Sacramento Valley (Figure 48).

Dredge Tailings
Large, multiple piles of river cobbles with little or no soil covering, extending over a large area.

Bucket-line
Vast tailings fields with high, rounded, parallel rows of cobbles.

Dragline
Clusters of conical, or rounded, individual piles; a pond was once present.

Dry-land dredge
Clusters of conical, or rounded, individual piles; no pond present.

Figure 48: Bucket-line Dredge Tailings, Yuba River *(courtesy Jim Woodward and Judith D. Tordoff).*

The dragline or doodlebug dredge was developed in the 1930s and operated for about a decade in California. The dredging unit consists of two parts: a shore-based power shovel equipped with a dragline bucket, and a floating washing plant, similar to but smaller than the one on a bucket-line dredge. The dragline works from the edge of the bank above the pond where the washing plant is floating. The bucket was cast into the pond, hitting the bottom teeth-first. Then it was rotated and filled by pulling it toward the power shovel with the dragline. When the bucket was hoisted up it was swung over the hopper on the washing plant and dumped; then the cycle started again. The bucket cut away the bank on which the dragline sat, so it had to move backwards as the pond and washing plant advanced toward it. Dragline dredges were "generally well suited to relatively small, shallow deposits which are too small to amortize a bucket-line dredge or too wet or low grade to be profitably worked by hand or other small-scale methods" (Wells 1966:12).

When the washing plant is mounted on wheels or skids, the dredge is called a dry land dredge (Wells 1966:13). These machines were only used in special situations such as places where the ground had to be put back to its original state by returning the tailings into the pit, leveling it over and planting it. The existence of very shallow deposits would also make it more appropriate because it could only dig about half as deep as the draglines. These dredges operated in California in the 1930s and 1940s.

Figure 49: Bucket-line Dredge Landscape along the Feather River, Oroville, Butte County *(Courtesy Anthropological Studies Center, image no. 27-03-D30-14).*

The signal outcome of bucket-line dredging is vast tailings fields that encompass hundreds of acres (Figure 49). Tailings left by bucket-line dredges are distinctive in that they consist of high rounded rows of cobbles created by the arc of the stacker as the dredge pivoted on its spud. The rows angle away from the forward direction of the plant and each one represents a single pass. Ponds, dredge parts, and wire rope are also items that may be noted in an abandoned dredge field.

Dragline dredge tailings are deposited in large individual piles, rather than in continuous arcs. They are usually conical, unless they have weathered down to more rounded shapes. They are often in clusters, or in rows if the dredge was following a stream course. Because of their size, shape, and configuration, dragline dredge tailings are easily distinguished from bucket-line dredge tailings, but not from dry-land dredge tailings. Also found in clustered and conical piles, dry land dredge tailings can be confused with those from a dragline (Figure 50). The most reliable way to differentiate between the two would be by determining whether or not a pond was present, which would indicate the presence of a dragline. Mining company records would be helpful as well.

Figure 50: Dry-land Dredge Tailings, PDPMD, Locus 3, Sacramento County *(courtesy Judith D. Tordoff). .*

Drift Mining Remains

Accessing buried placer deposits using underground mining techniques of adits and shafts is called drift mining. Prospecting for bench or Tertiary placer deposits elevated above drainages or locked beneath ancient volcanic flows often results in a pock-marking of small pits spread over a hillside. When fertile ground was found, larger excavations included coyoting or drift mining into the old river channels (see discussion above on pits). The “paystreak” is reached through an adit or shallow shaft and wheelbarrows or small rail-cars may be used for transporting the gravel to a sluice on the surface. If large, the paystreak can be taken in a series of regular cuts or slices. Drift mining is more expensive than sluicing or hydraulicking and is consequently used only in rich ground (Thrush 1968:351). Substantial drift mines were operating across California by the mid-1850s (Rohe 1986:146–147). The method reached its peak in the 1870s, before virtually ceasing, only to be revived after 1933 (Peele 1941:10-606). Excavated sedimentary material deposited near a drift mine is distinguished from a lode mine's angular waste rock by its water-washed cobbles and gravels. Openings into the ground may be barely noticeable slumps, or extend into the slope a measurable distance and could include drifts, shafts, or adits (Wells 1969:127). Rail or hoist remains may be present. The facilities for processing gravel, most likely a sluice, could be on-site, or some reasonable distance away depending on the transportation methods and water source.

Drift Mining Remains

Drift mines will be located in geological deposits containing old riverbeds. Waste rock will look like placer tailings, composed of cobbles. The adits and shafts may have caved in. Water is not required on site so ditches may not be present. Ore car routes may be evident.

HARD ROCK (LODE) MINING PROPERTY TYPES

Hard Rock (Lode) Mining Property Types include:

- Small Pits, Crosscuts, and Surface Vein Workings
- Waste Rock Piles
- Shafts, Adits, and Inclines
- Mills and other Processing Units
- Underground Workings
- Open Pit Mines

Lode refers to a mineral deposit located in fissures in country rock, and is nearly synonymous with the term vein as used by geologists. Lode deposits are tabular and clearly bounded, with orientations measured by their "dip" (angle from the horizontal) and "strike" (angle from the vertical). Although lodes may extend to the surface, they primarily lie underground and are accessed by excavations such as shafts and adits, or by open pit mines. Ore (mineral-bearing rock) extracted from the lode is usually processed first through crushing and then by physical or chemical separation devices. Lode sites produce waste rock (excavated rock that is not ore) and tailings (the discharge of unwanted processed material from mills and separators). Good discussions of lode technologies are found in Peele (1941), Hardesty (1988), Bailey (1996), Pearson (1996) Bunyak (1998), Limbaugh and Fuller (2004), and Twitty (2005).

Lode deposits, varying greatly, define the nature of the extraction and milling technologies applied to them. They are often grouped into geologic occurrences identified as zones, the most famous of which in California is the Mother Lode, extending through five counties. Lode deposits can vary greatly in depth and width, with some surface quartz leads pinching out within a few hundred feet of the surface while a few extended to a depth of more than six thousand feet with widths sometimes exceeding fifty feet. Most lode miners on the Mother Lode did not encounter major ore bodies until their workings reached five hundred or more feet in depth (Limbaugh and Fuller 2004:42–43).

Lode mining tends to be more complex than placer mining, requiring advanced technologies, skilled personnel, and substantial capital investment. Also, unlike placer gold, extracted ore requires processing to free its minerals. Surface ore was naturally oxidized and its values could often be retrieved through simple crushing and physical separation. As veins extended deeper into the earth, however, gold was typically chemically bound with sulfides and other mineral compounds. Miners developed various chemical processes to separate them (discussed below in Section 2: Ore Processing). Although extraction and processing technologies evolved over time, older techniques continued where newer ones were too expensive or inappropriate for the scale of the effort. What was the state-of-the-art in the industry was not necessarily what was practiced on the ground. As pointed out by Mother Lode historian Ronald H. Limbaugh and geologist Willard P. Fuller:

> It must be remembered that many goldmines on the Mother Lode and most of those on the adjacent belts were small operations too poorly financed to afford trained staff and the most recent improvements in mining machinery. In general, California mines probably modernized slower than those in other western districts, partly because of the size and cost factors, and partly because of a traditional conservatism among Mother Lode mine owners and operators that persisted down nearly to the present day (2004:183–184).

Many hard-rock miners worked only seasonally, on weekends, or between jobs. The ingenuity and inventiveness of these frugal miners also produced unique solutions to mining problems. One example includes Rancher James D. McCarty who set up a two-stamp mill on his Defiance claim in 1910, putting a tractor-boiler up on blocks to supply steam power (Figure 51).

The range of hard rock technologies is vast and complex and will not be detailed in this section; instead, a description of the types of features commonly present on sites is described and some examples provided. Examples of mines from the Copperopolis district in Calaveras County, recorded for the Historic American Engineering Record (HAER), are available online (HAER 2007).

Small Pits and Surface Vein Workings

Surface vein workings are among the oldest evidence of hard-rock mining in California. During even the earliest years of the gold rush, placer miners were following “color” (gold) up gulches and encountering outcrops of quartz veins. Although “bull” veins (those without ore) were the most common, traces of gold were evident in some outcroppings and prospectors learned to search these out. Float, mineralized rock broken out from eroding veins, indicated a nearby source, and ‘gossans’ – surface mineralizations of iron-heavy deposits- signified mineral veins underneath. Prospecting tools included picks, bars, and shovels and, in larger operations, wheelbarrows and ore cars to move ore and waste rock.

Small Pits and Surface Vein Workings

This includes pits with adjacent quarried rocks (not stream cobbles), or exposures of uplifted strata of country rock with excavated-out veins. Adits and other evidence of hard-rock mining and exploration will likely be in the vicinity. On larger workings, an arrastra or small mill might have been located nearby.

Figure 51: Tractor-boiler that Supplied Power to Two-stamp Mill at Defiance Claim (*Library of Congress, HAER Photo by Alice Olmstead*).

Typically, an exposed vein was simply followed down into its outcropping, leaving an exposed rock stratum with its center gouged out like a cavity in a large tooth. The sides of these excavations are usually uneven as digging simply ceased at the limits of the ore. The floors of these workings have generally filled in over the years with silt and natural debris, but larger examples often exhibit an "exit" on a downhill side for removal of rock, or a platform for a windlass or hoist in deep excavations. Waste rock will be conveniently disposed of near the workings. Included in the waste rock may be chunks of bull quartz, a good sign that the excavators were following a vein.

Some kind of crusher was required to pulverize the recovered ore to release the gold or other minerals. This might have been a small stamp mill (two to five stamps) or an arrastra (see discussion below). The facility might have been near the vein workings, or next to a source of water with the ore transported to its location. If the mining is productive, and the vein deepens, there might be an adit driven in on the lode further down the hillside. At Carson Hill, on the Stanislaus River, the original 1850s surface vein workings that led to nearly a century of rich mining operations are still extant on the crest of a ridge.

Waste Rock Piles

Perhaps the most visible evidence of underground workings is waste rock. In following a vein, the vast majority of excavated rock is that surrounding the ore, and this waste rock is discarded immediately at the opening to the mine, allowed to accumulate in a downhill, gravity-formed mound or dump. Piles of waste rock not only indicate the location of uphill shafts and adits (which may be caved in and therefore not easily identifiable), but the size of the pile reflects the extent of the underground workings. Waste has also been used for roadbeds and other improvements, however, so the size of the pile should be viewed with caution.

Waste Rock Piles

Country rock dumped into gravity-formed piles with little or no topsoil and vegetation. Their presence indicates the locations of mine portals and under-ground workings.

Figure 52: Waste rock Pile in Canyon, San Bernardino County, with Cabin Ruins in Foreground
(Courtesy, JRP Historical Consulting Services).

Waste dumps are visible as unnatural contours on hillsides and for the lack of soil development and vegetation. For larger operations, waste-rock piles may be formed by dumping rock from ore cars, producing a long, flat-topped ridge that begins at the mine portal and is extended as the workings deepen. Mines that operated for a long time often incorporated waste rock dumps into later development, terracing them for placement of buildings or other facilities (Figure 52). As mineral-recovery techniques improved over time, old waste rock with low mineral values was (and still is) processed to extract its values.

Shafts, Adits, and Facilities in their Vicinity

The entrance to underground workings is called a portal, and opens into either a shaft or an adit, providing access to the lode. Shafts sink down into the ground from the surface and can be vertical or on an incline, while adits are driven horizontally into hillsides (adits are often referred to as "tunnels," however, among miners this latter term is reserved for horizontal passages that have an entrance and an exit, as along roads and railroad grades). Shafts and adits vary according to the size of mining operation and the nature of the surrounding rock. Portals will often be first identified by their associated waste-rock piles (see discussion above) as their openings may have caved in or been closed by dynamiting. Shaft-like openings that do not have any associated waste rock are likely air vents connected to deeper workings, or daylight stopes (where ore excavations break the surface). When cut into a stable matrix, shafts are typically square while adits may have a curved ceiling. Where the surrounding rock is unstable, square shoring is used to reinforce the sides.

Shafts, Adits and Facilities in their Vicinity

Shafts are square (or caved in) holes in the surface and may have surrounding footings for head frames and hoists. An adit's entrance into a hillside may be evident, or appear as a caved-in trench. Shafts and adits are accompanied by waste rock piles on their downhill sides. Shafts without waste rock may be air vents or daylight stopes.

Shafts and adits require mechanisms for removal of underground waste rock and ore, and remains of these facilities are commonly present around the openings. Adits most frequently have ore cars running on tramways, or just a dirt path for wheelbarrows on smaller operations. Shafts require a hoisting device to raise the excavated material. While small shafts may operate with hand-run windlasses, larger operations require head frames with cables, buckets, and drum hoists (Figure 53). Footings for head frames straddle the shaft opening and remains typically consist of concrete bases topped with metal plates or bolts. Adjacent to these would be similar footings for the hoist drum. As mines deepened, devices such as Cornish pumps were installed to both ventilate and de-water the underground workings. Hoist power was provided by animals, steam, water, fossil fuel, and, later, electricity. Evidence for the power source might be found in massive boiler footings, a compressor, or engine mounts run by imported electricity or a generator.

The openings to deep shafts were usually collared with timbers and planks (Figure 54), or concrete (after the 1880s) to stabilize the work area, although collapse of these openings after abandonment often makes them appear as large craters. In ranchlands, abandoned shafts are often surrounded with fencing to keep out livestock. ***The bottoms of these large depressions are very unstable – often consisting of only a thin soil developed over fallen timbers and tree limbs – and should never be entered.***

Figure 53: Small Head Frame with Chute, Inyo County *(Courtesy JRP Historical Consulting Services).*

Underground Workings

Examination of underground workings is very dangerous and is prohibited by Caltrans. Indicated by shafts, adits, and waste rock dumps, they are NOT to be explored but must be studied through documents.

Underground Workings

Figure 54: Isolated Shaft Collar, Inyo County *(Courtesy, JRP Historical Consulting Services).*

Shafts and adits are built to access underground workings, a series of excavations providing access to the lode. Drifts (horizontal connectors) link various parts of the mine while mining the ore body itself is frequently referred to as stoping. Underground miners sort the material they are sending to the surface into waste rock and ore so those at the top can handle each ore car lode efficiently. The size, nature, and surrounding geology of mines are vital to understanding their history. This information may be most efficiently found in documentary records.

Open Pit Mines

Open Pit Mines

Large pits excavated in stepped layers with haul roads. They may have facilities nearby. Glory holes remove ore and rock underground from the center of the pit.

Low-grade ores located near the surface could be mined through an open pit system, much like a large quarry where rock is removed systematically in stepped benches. Excavation is generally by controlled blasting, the ore separated and hauled to the mill and the waste disposed of nearby. In modern times both ore and rock are typically loaded with large shovels and carried out by truck. Support facilities include a road system, machine shop or garage, and office. Some open pit mines used a leaching system to extract gold, and such ponds may be located nearby. Pit excavations are also sometimes called "glory holes," although this term more accurately indicates surface excavations where the rock and ore are gravity-fed out from the bottom, as in a funnel, and removed through an adit. In that case, waste rock, milling, and transport systems will accumulate near the adit portal and not the excavation area.

ORE PROCESSING (BENEFICIATION) PROPERTY TYPES

Once ore has been removed from a mine, valuable minerals must be separated from the gangue (undesired minerals). Beneficiation is a broadly applied term and can include crushing, stamping, screening, flotation, amalgamation, and smelting (Cowie et al. 2005:13–24). The technology of beneficiation developed diverse and sophisticated processes over past centuries and only those most commonly found on sites in California are discussed below. Milling sites often contain innovative and complex technologies that were added to and modified over time. Interpretation of these site types should rely upon official mining reports and documents or those solicited by the mining company, and frequently requires the help of mining engineers.

ORE PROCESSING PROPERTY TYPES:

- Arrastras
- Mills: Industrial Foundations, Pads, and Machine Mounts
- Mill Tailings

Arrastras

An arrastra (or arrastre) is a shallow circular pit, rock-lined on its sides and flat bottom, in which broken ore is pulverized by drag stones (Figure 55). These are attached to horizontal poles fastened to a central pillar and typically rotated by use of animal or human power, although later machine-powered examples can be found. The base or floor stones are usually of a hard material such as marble and exhibit a polished surface. The upper drag stones also have a polished, smooth undersurface and evidence of a bolt attachment imbedded on top. Although not commonly encountered in the field, these simple grinding devices are significant indicators of early mining activities and were also used into the twentieth century in remote areas of the state or where capitalized mining was not prudent or cost-effective (Figure 56).

Introduced by Mexican miners (arrastrar = to drag), they could be constructed with materials at hand and were quite effective in reducing ore to a powder, from which gold could be recovered by amalgamation or other simple separation processes. This type of milling is most productive for surface vein workings, where the ore has been naturally oxidized and does not require chemical processes for mineral recovery. Arrastras are rarely found intact as, upon abandonment, the floor stones were typically pulled up and the underlying soils panned to retrieve gold that sifted between the cracks. Discussions of arrastras are found in Kelly and Kelly (1983) and in Van Bueren (2004).

***Figure 55: Remains of Twentieth-century Arrastra, Inyo* County** (Courtesy JRP Historical Consulting Services).

Arrastra

A shallow, flat-bottomed circular depression typically less than 20 feet in diameter, lined on its edges and floor with stones. The base and drag stones are of a hard quality and exhibit polished surfaces.

Figure 56: Remains of Arrastra Floor, Amador County *(Courtesy Thad Van Bueren).*

Mills: Industrial Foundations, Pads, and Machine Mounts

Mills are not necessarily constructed adjacent to mine portals, although they may be. Mills require a power source and a steady supply of water, and it may be more expedient to locate the mill in the best place to access those requirements and transport the ore. Mills may also be centrally located to serve a series of mines.

The first step in ore processing at a mill is crushing the rock into a powder that can be treated. The most common technology for accomplishing this was the stamp mill, where ore was fed into a cast-iron mortar box located under a battery of heavy vertical rods (see also discussion of arrastras above). Through use of overhead cams, the rods were repeatedly raised about six inches and then allowed to fall, their heat-treated shoes falling on the mortar dies. The camshaft was rotated eighty to one hundred times a minute

Mills

The remains of these sites generally appear as large terraces on hillsides, the size reflecting the number of stamps present. The stamp terrace has a large back wall to stabilize the stamps, and footings for the batteries may be evident. The lower terrace is for concentrating the pulp, and mill tailings will be found below. Various pads and machinery mounts around the mill reflect necessary support devices. A water source and method of transporting ore to and from the mill may be evident.

by a belt-driven bull wheel, powered initially by water or steam (Limbaugh and Fuller 2004:65). Small, mobile, one- or two-stamp mills were effective on small sites, although batteries of five stamps were soon found to be the most effective. Stamp mills often grew in increments of two five-stamp batteries as operations expanded, resulting in some large mills of 100 and 120 stamps.

Archaeological evidence of mill sites increases with their size and permanency. Small, early mills were relatively ephemeral and temporary, leaving few traces. Unless the stamp mill itself was abandoned—leaving cast-iron shoes, cams, rods, and hopper-mortars in place—their short-term operations may not be identified. Larger stamp mills can involve large excavations of earth and leave distinctive terraces, often with equipment mounts or foundations (Figure 57). They were nearly always built into hillsides, taking advantage of gravity feed to move ore through the stages of processing. At the uppermost level, ore was delivered to the facility by tram or other vehicle, stored in bins and then fed into the hopper of a primary crusher where it was reduced to a uniform size. Jaw crushers were initially preferred, later largely replaced by ball mills (Figure 58), where ore was rotated with iron balls in large barrel-like devices (worn iron balls often mark these locations). Crushed ore was then fed through a grizzly (screen) into the stamps, where it was pulverized with the controlled use of water, creating pulp. The number of stamps is documented by footings for the batteries, grouped into five or ten per footing. The width of the stamping floor often defines the width of the mill building itself.

Below the stamps, the lower level of the mill contains the amalgamation or concentrating tables. Here the discharged pulp, with the addition of small amounts of mercury (“quicksilver”), was processed to recover the gold. This level has drains to carry off excess water from the wet processing area. Below the amalgamation level, pulp may be further processed in chlorination or cyanide tanks, or other innovative device, for final recovery. After 1870, various devices were introduced to improve this process and maximize the recovery of free gold in the concentrates, the vanner being among the most important (Limbaugh and Fuller 2004). The amalgam was then retorted to drive off (and then recapture) mercury, with the resulting gold “sponge” shipped to a mint or smelter; sometimes ingots were prepared on site. The final discards were dumped downhill as tailings.

Figure 57: Remains of the Royal Consolidated Mill *(Library of Congress, HAER Photo by Alice Olmstead).*

Simple amalgamation worked well with free-milling gold, but not with refractory ores where gold was tightly bonded with other metallic minerals. In these, while gold was often clearly visible in ore samples, milling and the use of mercury did not permit its recovery. It took years of experimentation before solutions were found, and many tailings piles from early mills were later reworked to recover their gold or silver with improved processing. In the 1870s, chlorination was the first breakthrough, but even this was expensive and relatively ineffective and was only productively used on large ventures. Cyanide was used with some success in the early 1900s, applied to reground slimes from ore initially treated with chlorination. Later flotation methods subjected the treated pulp to a frothing agent which separated the minerals in cell-like devices. Heap leaching of chunk ore was also sometimes successful in recovering values from low-grade ores. No single recovery method worked in all mills, however, because of the different composition of local ores.

Figure 58: Hendy Ball Mill at Mountain King Mine *(Library of Congress, HAER Photo by Alice Olmstead).*

For most mines, the final step was smelting through the application of heat. Prior to 1863, copper was shipped to the east coast or Swansea, Wales, for smelting; after that time it was sent to a facility at Antioch and later to the only West Coast smelter in Tacoma, Washington. California's only major smelter (for gold, silver, copper, lead and zinc) was started in San Francisco but soon moved to Selby, immediately east of Martinez along the margin of Suisun Bay. The Selby smelter was the only one operating in 1940 (USBM 1941:230; Limbaugh and Fuller 2004:66–67, 80, 176–191).

In the early years, mills were run by steam, produced in boilers or furnaces, and by water-powered impulse wheels, modeled on those made by Pelton and Knight. Impulse wheels revolutionized the industry by creating an inexpensive power source for air compressors, which ran machine drills, mills, hoists, pumps, and other equipment (Limbaugh and Fuller 2004:181). Remains of boilers may be evident adjacent to mill sites and are distinguished by rectangular platforms of brick or other refractory insulating material which encompassed large, iron horizontal-boilers. Furnaces also powered steam plants and compressors and their remains may be accompanied by a below-grade slot, or "well," to accommodate the fly wheel. Pelton-type wheels were often installed along the side of a mill where they would turn a bull wheel. They required heavy foundations and mounts, and a "well" to accommodate the wheel's rotation. A steady stream of pressurized water, delivered by an adjacent ditch or canal, blasted "buckets" at the end of the spokes, and remains of these devices will include channels for runoff.

In the 1890s electrical power plants began to be built, sometimes by independent entities and sometimes by the mining interests themselves. Engine mounts in mills are characterized by raised concrete footings topped by heavy bolts. Evidence of electrical power may also be evident in wire conduits, switch boxes, and insulators. In later years, on remote sites, local generators may also have been used.

Mill Tailings

The undesired portion of the ore discharged from mills is identified as tailings. They were generally in the form of slurry, and for most of the nineteenth century were allowed to run down adjacent creeks and gullies. A federal anti-debris law, the Caminetti Act of 1893, prohibited miners from dumping their waste into rivers and streams. While aimed primarily at hydraulic mining debris, this act also addressed lode mine tailings. As a result, mills began constructing impound areas. These tailings ponds were typically formed by constructing a dam across a downstream ravine and allowing the tailings to build up behind it. Heavier portions of the tailings settled into flat, meadow-like formations while the water portion ran over a spillway. Abandoned with their mills, the dams for these holding ponds were typically breached in later years, allowing the stream to cut through the accumulated tailings and reach its bed once again. These breached ponds can be identified by the cliff-like sides of the stream exposing mineral-colored fines unlike the surrounding soils, and remnants of the flat pond surface preserved along the sides of the drainage.

Tailings could also be carried as slurry to neighboring ravines and pond locations some distance from the mill. This is the case in Jackson, where the unique Kennedy Tailing Wheels lifted mill tailings to a retention pond over an adjacent ridge. Mill tailings contain high levels of minerals and are often distinguished not only by their coloration but by an absence of vegetation. At the New Melones Reservoir at low water a valley filled with stark white tailings from the Carson Hill Gold Mines mill is visible from Highway 49 (Figure 59). Many modern reclamation efforts are designed to contain old tailings and prevent water from leaching their often toxic contents into waterways.

Figure 59: Tailings at New Melones Reservoir,Stanislaus River Drainage*.* *The mill tailings were slurried to a neighboring valley resulting in the white fill visible in background.* (Courtesy Calaveras County Historical Society).

ANCILLARY MINING PROPERTY TYPES

These are other site-specific facilities and systems that are commonly found in association with extraction and beneficiation activities. They represent important internal components assisting mining and milling operations.

ANCILLARY MINING PROPERTY TYPES:

- Structural Remains (ruins)
  - Office
  - Change Room
  - Blacksmith/Mechanic Shop
  - Shed/store/warehouse
  - Garage
  - Stable/corral
- Site-Specific Transportation Features (ruins)
  - Ore car routes, trestles, tramways
  - Trails, paths, walkways
  - Roads, haul roads
  - Railways
- Site-Specific Water Conveyance Systems
  - Dam/reservoir
  - Ditch/flume/conduit/siphon/penstock
  - Tanks/cisterns
  - Drains

Structural Remains

Mining sites may contain a myriad of buildings related to their mining and milling operations. Although some may be identifiable by distinctive artifacts, construction techniques, or locations, identification of most is achieved through comparing documentary records (mine inventories, photographs, and maps) with remains on the ground. Long-operating mines periodically upgraded or revamped their operations, and over time buildings may have been moved, demolished, or changed in function. Every building or structure in evidence on a site may not have been functioning at the same time.

Building remains may be from offices, sheds, storage buildings, stables and shops, locations of which may be indicated by concrete or stone foundations or simply leveled pads and retaining walls. Wooden structures were often covered with metal sheeting and may be evidenced by lumber, cut or wire nails, building hardware, or fragments of window glass. Assay offices may be distinguished by the remains of furnaces or retorting facilities, as well as fragments of crucibles and cupules.

Change rooms, where company gear and workers' personal equipment could be stored, are located next to mine portals or mills and later may have featured concrete floors and piped water for showering. These facilities were installed not only for the convenience of the workers, but to prevent high-grading (theft) of ore by employees

Powder houses stored the mine's explosives and were usually located some distance from other structures. These were usually small windowless rooms, often semi-subterranean (commonly built into a hillside) and featured thick walls of stone, brick, or concrete.

Other Structural Remains

Foundations or pads located around mining or milling sites represent various functions, some of which may be evident from the related artifacts. Those with domestic artifacts are discussed under Mining Community below.

Blacksmith shops maintained a mine's equipment and vehicles, and their former locations may contain various pieces of worked metal, raw materials, coal or coke, and slag from forging; the remains of the forge may also be evident. One of a mine blacksmith's principal duties was sharpening miners' drills. Nineteenth-century mines had stables and corrals for livestock used to haul ore cars and wagons. Stone foundations and wood posts with wire fence lines may be evident. At the Empire Mine, mules were stabled underground. More recent mines required a garage and shop which may feature tanks for oil and gasoline, grease pits, and vehicle parts. Structural remains with domestic artifacts (ceramics, bottles, and cans) are discussed below under "Mining Community."

Site-Specific Transportation Features

Within a mining site, transportation systems were needed to move ore, waste rock, and people. On the simplest sites, hauling was done by the miners themselves or by pack animals on single-track trails. Even modest development, however, had to address how to remove waste rock from lode mines and deposit it out of the way. Ore cars were often utilized within underground workings to move excavated material toward the surface. For adit portals, tramways for ore cars commonly ran out the entrance along a level grade to the adjacent waste rock dump, both being extended as the mine deepened. Tramways were also used to haul ore to mills for processing, either run along prepared grades or on trestles. The ore cars could be powered by animals, gravity, fossil fuels, or electricity. One of the earliest gravity-fed trams in use during the 1860s, was at Hite's Cove along the South Fork of the Merced River. In the 1890s before the Royal Mill was constructed, tram mules followed ore cars downhill from the Royal shaft to the Pine Log Mill, returning on their own with empty cars for a ration of oats (HAER 2007: Document No. CA-81). Tramways can be recognized by their uniform grades and the presence of rails and ties. Overhead tramways with buckets suspended on cables connected mines in inaccessible locations to mills or transportation facilities (Figure 60).

Trails, Roads, and Tramways

These linear features are visible as continuous grades leading to critical areas of the mine or mill. Tramways feature rails and ties. Aerial tramway sites where artifacts have survived are typified by cables, head frames, and buckets.

Roads were always present to connect mine facilities, and grew in importance when trucks replaced tramways for hauling both ore and waste rock.

Site-Specific Water Conveyance Systems

Figure 60: Tramway Header, Star of the West Mine, Inyo County *(Courtesy JRP Historical Consulting Services).*

Water played an important role both in placer mining and in processing lode ore. For placer mining, refer to its role in the placer extraction section above. Water was required for all types of milling; conveyance and storage systems will also be present on sites. Reservoirs, cisterns, and water tanks may be found above mills to allow for gravity feed while distribution may have been done in pipes. Remains of old riveted penstock systems may be present. Drains and methods to direct run-off from the mills will also be in evidence.

Water conveyance systems bringing water to a mill from distant sources (outside of the site boundaries) are recorded separately as individual sites. They may have tapped resources many miles away and served several mines or communities in the vicinity. These are discussed below under Inter-Site Mining Support types. Water conveyance systems for mines are also described in detail, with recordation methods and registration requirements, in the JRP/Caltrans publication *Water Conveyance Systems in California* (JRP and Caltrans 2000).

Water Conveyance Systems

Reservoirs, cisterns and tanks are located uphill of mills to allow for gravity feed. Ditches, pipes and penstocks were used to move water around the facility. Drains removed spent water from the mill area.

MINING COMMUNITY PROPERTY TYPES

Miners often lived at the mines, and this property type addresses facilities related to the domestic residential activities of the miners, the mine’s support staff, and their families. Although often marked by impermanence, mining-camp residents created distinct communities that are integral to the study of the mining site (Douglass 1998:106). The domestic property types discussed below must be physically and historically associated with prospecting, extraction, or milling activities. Resources related to mining-site residences, if present, are generally found integrated within or adjacent to mineral operations. Metal detection can help identify associated sheet refuse useful for interpreting foundations. There may be numerous remains of structures on mining sites, especially more developed ones that generally fit the architectural remains described below (see Structural Remains under Ancillary Mining Property Types). However, the residential property types addressed here must be distinguished by one or more of the following:

1. presence of sufficient quantity of domestic artifacts (e.g., more than a few),
2. distinctive domestic features such as hearths or baking ovens, or
3. identification as residence-related in documents.

In many respects the mining community reflects a work camp composed for mining. Communities brought together primarily for the mineral industry may also grow into townsites, with diminished connections to their mining roots. Modern towns along the Mother Lode's Highway 49 amply demonstrate this evolution. Mining community resources can resemble types discussed in the Work Camps and Town Sites Research Designs, and additional discussions of these types of resources may be found in those companion documents. Isolated residential sites may also be found along water conveyance, transportation, or utility lines, as well as in areas of agricultural development. Such sites should be addressed by research designs appropriate to those topics, although they may share many attributes of Mining, Work Camp, and Townsite properties.

MINING COMMUNITY PROPERTY TYPES:

- Domestic Structural Remains (residential and/or service)
  - Earthen pads
  - Foundations
  - Cuts/dugouts
  - Chimney/oven
- Domestic Artifact Deposits
  - Sheet refuse
  - Hollow-filled features
- Domestic Landscape Features

Domestic Structural Remains

The simplest temporary dwelling form is the tent, or lean-to with a canvas or shake-roof. An improvement was a half-walled version where the lower sides of a one-room dwelling were made of logs, milled lumber, or fieldstone, and if a canvas roof was employed, the roof could be rolled down to close the walls. Another version was a semi-subterranean space cut into a hillside with a superstructure covered by canvass, brush, or split logs. Located on natural earthen flats or leveled pads, these simple dwellings required only modest site improvements and the canvas and wood members could easily be transported to another mining location. A tent flat may be barely noticeable if located on a naturally level area but on slopes may be distinguished by a small retaining wall (as minimal as one row of stones) on the downhill side. Improved earthen pads may be surrounded on one or more sides by a shallow ditch created by building up the pad; these also provided drainage. Where semi-subterranean features are identifiable, hill slopes were dug by hand and often supported by rubble fieldstone walls. Sparse sheet refuse is usually found on the location of the tent or cabin pad, sometimes extending downhill away from the shelter. In many cases the only

Earthen Pads

Located close to placer mining remains, these leveled pads may have a downhill retaining wall and a stone hearth. They are characterized by a sparse scatter of domestic artifacts as sheet refuse.

Foundations
All the types below are associated with domestic artifacts or have been identified as domestic facilities through historical research. Any may be located on natural level areas or on prepared structure platforms with retaining walls and may have evidence of fireplaces. Structures over 30 feet long may be bunkhouses or dining halls.

Stone Piers or Perimeter Foundations
Arranged symmetrically to support a frame building.

Stone, Adobe, or Rammed-Earth Walls
Collapsed or partially standing stone building; adobe or rammed-earth may have "melted," leaving an earthen berm.

Concrete Piers or Perimeter Foundations
Generally post-dating 1900, they have bolts, sill boards, or other devices to affix the overlying frame building.

feature visible is the collapsed remains of a fieldstone chimney or fireplace. Metal detection can help identify associated sheet refuse. The presence of a few large stones may indicate a U-shaped hearth or fire ring. These hearths may consist of flat stones set on end to form firebreak, or a few courses of stacked local rock. Stone oven remains have also been found associated with placer mining tent pads (see discussion below). These types of dwellings are generally found in close proximity to small-scale placer mining remains (more extensive placering and hard-rock mining required greater investment in developing the mine and housing was similarly more permanent).

More substantial dwellings employed stone foundations to raise wooden walls and floors above ground level; these can include stone piers to support posts or floor joists as well as complete stone perimeter foundations. Flat stones used as post footings on a flat, such as those used for simple cabins like the ubiquitous, two-room miners' cottage, can be barely noticeable (Bell 1998:31). Post-and-pier construction was used into the early-twentieth century for frame dwellings as well as for bunkhouses and dining halls found on some mining sites. Domestic structures with stone masonry walls, or of adobe or rammed-earth, may also be present (Figure 61). A full or partial cellar, typically reinforced with stone masonry, may have been incorporated. Roofs were commonly of metal or wood. Supervisors or managers may have resided on-site in large or unique structures, possibly higher in elevation or across from the housing of common laborers.


Figure 61: Star of the West Mine, Inyo County: Partially Standing Stone Cabin *(Courtesy JRP Historical Consulting Services).*

Later, poured concrete slabs and perimeter foundations were used for housing. Concrete constructions are common on well-developed mining sites after 1890. Board-formed poured foundations date to after the First World War, although smaller sites may have continued using simple stone technologies. Sites dating to the twentieth century show increasing evidence over time of off-site utilities for electric lighting, telephone, and domestic water supply.

On more extensive mines, evidence of large foundations (exceeding 30 feet in length) in association with personal domestic debris may represent bunkhouses or other collective housing. Community dining halls and kitchens will be distinguished by large refuse piles containing tablewares; large quantity cans, bottles, and jars; and faunal remains.

Cuts/Dugouts

Commonly appear as collapsed cuts into the hillside, or basement-like areas, possibly stone-lined, associated with domestic house-hold artifacts.

A dugout describes an open, often rock-lined cavity in a hillside, usually the size of a single room (Figure 62). In the mining community these generally served the same functions as discussed above for foundations: they were used as dwellings as well as for other functions such as storage. Most simply they can appear as a single slumped-in cut into the hillside. Better-developed examples were fully excavated and may have been lined with stone, poured concrete, or milled lumber framing, and supported metal or wood roofing. Wood construction elements, if not entirely decayed, will likely be collapsed within. Dugouts are typically at least partially filled-in, often burying structural elements and living surfaces. For large dugouts, the removed fill should be visible around the structure.

Figure 62: Remains of a Masonry-lined Dugout, Butte County *(Courtesy Anthropological Studies Center, image no. 27-03-D136-05.).*

Figure 63: Large Stone Oven, Chili Junction, Calaveras County. *The 1850s mining camp of Chili Junction was populated by miners from Chile (Courtesy Julia Costello).*

Some mining residence areas may contain cooking features, and any of the features described below may be found on domestic mining sites. Simple hearths are discussed above under "earthen pads." More developed residences may contain evidence of a stone fireplace with a chimney. The hearth itself was typically made of stone, and the chimney of stone, mud-and-stick, or pipe. Similarly, a separate area for preparing food or a more formal cookhouse may have contained a dome-shaped bake oven. Where collapsed, these appear as roundish piles of stones, about 10–15 feet in diameter, with the centers collapsed into a cavity and stones typically resting at steep angles (Figure 63). In the Mother Lode, these are most commonly associated with Italians, although they were also constructed and used by French, German, and Hispanic residents (Costello 1981; Wegars 1991). In later years, they incorporated modern materials such as brick, concrete, and cast-iron doors. A distinctive curved free-standing wall – an asado – was used by Chileans and Peruvians to cook flayed cattle. Overseas Chinese also constructed U-shaped stone hearths in the vicinity of their diggings (Tordoff and Seldner 1987; Tordoff and Maniery 1989; Medin 2002) identified by the presence of ceramics and other artifacts from their homeland. Often these suspected piles of stone must be carefully excavated to reveal their original forms and functions.

Domestic Artifact Deposits

Domestic artifact deposits are also discussed in the *Agricultural*, *Work Camps* and *Townsites* thematic studies. The examples below identify those commonly found on mining sites.

Domestic Sheet Refuse

Domestic artifacts found in the vicinity of a dwelling, conveniently deposited on the surface by the occupants.

Domestic sheet refuse describes a horizontal scattering of discarded items typically found around a dwelling, and is one of the most common types of domestic artifact deposits on rural mining sites. Artifact accumulation results from unintended loss as well as intentional waste disposal such as casting debris away from a dwelling. Sheet refuse may be found throughout the living area of a dwelling, or as deposit located adjacent to and downhill from the residence area. Disposal of debris into natural features such as gullies may create vertical interfaces similar to the "hollow filled features" discussed below. Metal detection is helpful in identifying boundaries of discrete surface deposits.

In both situations, sheet refuse may retain a form of horizontal stratigraphy that represents unique activities or episodes; one occupant may have discarded debris one direction, while another may have tossed debris in another, thereby creating distinguishable deposits. Don Hardesty (1987:85) noted this quality on mining sites, recognizing that some site components may be organized horizontally instead of vertically. The implications of this for research and integrity have been recognized as an important element of evaluations (Cowie et al. 2005:62).

Hollow-Filled Feature

Concentrated deposits of artifacts disposed of in features such as trash pits, prospects, privies, cellars, or other abandoned features.

Developed mines with sedentary communities that resemble a town more than a camp may exhibit more intentional methods of refuse disposal, such as designating a communal dump. Artifact deposits are found buried or partially eroding from features such as trash pits or prospect pits, or from privies, wells, dugouts, cellars, or ditches abandoned at the time of disposal. It should be noted that artifacts found in abandoned features, such as basement depressions, likely reflect activities after the facility was abandoned, not the period of use. These hollow-filled features potentially offer a rich assemblage of artifacts with traditional vertical stratigraphy. Many of these types of features are buried, however, and must be explored through excavation or use of documents. The location and excavation of these types of features is discussed in the Town Sites Research Design.

Domestic Landscape Features

Besides improvements to the physical characteristics of the mines themselves, miners and members of the mining community attempted to create a domestic environment for themselves by planting vegetable gardens and ornamentals. Surviving features may include ornamental ground cover, shrubs, and trees. Vinca major, roses, black locust, and *ailanthus*, or Chinese Tree of Heaven, are particularly common throughout the Mother Lode region. In certain instances miners terraced hillsides, built fieldstone retaining walls, and walkways.

Plantings
Exotic plantings that can survive untended such as bulbs, trees, and rose bushes.

Stonework
Lined paths, retaining walls, and terraces.

INTER-SITE MINING SUPPORT PROPERTY TYPES

These are separate, distinct sites that may extend many miles, creating a link between the mining site and the outside world. They represent linear systems for delivery of services or access and are recorded as individual and distinct entities. The nexus of these common property types with a particular mine, however, is a contributing element of that mining site.

INTER-SITE MINING SUPPORT PROPERTY TYPES:

- Inter-site Transportation Features
    - Trails
    - Roads

- Inter-site Water Conveyance Systems
    - Ditch, Canal or Flume
- Inter-site Utilities

Inter-site Linear Transportation Features

Early access to mines was by way of single-track trail, such as the network of mule trails that quickly developed to service mining camps during the first years of the gold rush. Such trails are narrow and often have stone masonry retaining walls; their width is most accurately measured at switchbacks and outcrops. Segments of trails are often completely erased by later activities. Wagon, freight, and stage roads replaced portions of these systems as some areas grew into viable settlements. These typically have stone masonry and a berm on the downhill side from grading, and often replace the steeper grades of trails with longer routes. Over time, additional road improvements such as oiling, macadam, or paving, became a standard practice. Earthen and paved roads form a network across the rural landscape. Mining operations patched into existing transportation networks or financed their own service connections. Large, capitalized operations, in particular, typically improved road systems linking to the larger transportation network. Byrd (1992a) provides a general history of road development to 1940, while Bethel (1999) offers an overview specifically for nineteenth-century gold mining.

Trails and Roads

Trails were narrow and often marked with downhill rock retaining walls on hillsides. Wagon roads were wider and less steep, and later roads for motorized vehicles were often paved.

Inter-site Water Conveyance Systems

Water is necessary for many aspects of mining, and when an intra-site supply was not developed (see discussion above for intra-site, ancillary mining property types), operations depended on an inter-site water conveyance system for its delivery. The mining company may have developed its own water supply and storage system by buying up and improving on earlier claims and systems or purchasing water from the owner of a ditch system. These linear systems can be quite large, extending for miles beyond a mine. Typical components include catchment or take-out, storage, and delivery features. Elements are discussed at length in the JRP/Caltrans (2000) report on water conveyance systems, and by Shelly Davis-King (1990); both documents provide the general features of mining ditches. Intra-site water conveyance systems typically took water from an inter-site system, often first directing water into the mine's own storage feature via a ditch, flume, or penstock. The history of a mining site's water system is vital to understanding its development, and the source of water should be identified for each operation.

The primary feature that will be archaeologically visible in the vicinity of a mine is an earth-berm ditch, possibly with associated stone or concrete masonry or penstock. Ditch segments may be filled with sediment, or in places entirely eroded away. As the grades of ditches remained steady, their routes can be determined across a landscape even when large segments are no longer extant. Natural gullies were often used to move water quickly to a lower elevation, where it would be picked up again by a lower section of ditch.

Remains of parallel ditches are often found in close proximity and may represent water from the same source being taken to different destinations, or an improvement in the grade of a ditch at a later period of time. Small side-hill ditches – long, narrow reservoir-like hillside features – caught seasonal surface runoff and supplied mining operations below. Flumes of any antiquity are usually in disrepair if extant at all; more likely they exist as an alignment of fasteners. Remains of gates, pipes, or penstock may survive as ferrous metal and poured concrete reinforcement. During World War II many abandoned segments of riveted pipe were collected for scrap and shipped to coastal shipyards. Water storage features were developed in concert with ditches or canals. The storage reservoir was generally built upslope from the mine or mill and through penstocks and gravity water pressure was generated to power a variety of machinery.

Ditches
Paths of streams of water excavated across the landscape on contours; downhill berms are typical and may be reinforced with rock.
Reservoirs
Dams were typically made of stone and earth.
Flumes
Often no longer extant, may be indicated by missing segments of ditches over creeks or steep hillsides.
Pipes
Riveted iron pipe carried water down hillsides, or siphoned over creeks.

Inter-site Utilities

Some mining operations required utilities, particularly electricity. The development of electrical generating plants in the 1890s was pioneered by mining companies to supply their needs as they had both capital and incentive (Limbaugh and Fuller 2004:182). Power companies supplied mines with electricity to operate head frame hoists, compressors, underground lights, etc. As telephone companies expanded their service beyond the principal metropolitan areas of California, mines and other industrial facilities established telephone communications at their facilities. Utility poles might be present, although lines were often hung from existing trees fitted with insulators. The mines near Copperopolis, Calaveras County, were, in 1901, linked by a telephone service run partially along the barbed wire of fences (Fuller et al. 1996:69).

Poles

Cut or standing poles and glass and ceramic insulators.

APPENDIX B:
GEO-10-003 Geologic and Geochemical Evaluation of Geothermal Resources for Geothermal Power Development, Colusa and Lake Counties, California

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GEO-10-003 GEOLOGIC AND GEOCHEMICAL EVALUATION OF GEOTHERMAL RESOURCES FOR GEOTHERMAL POWER DEVELOPMENT

COLUSA AND LAKE COUNTIES, CALIFORNIA

FINAL

for

Renovitas, LLC and

The Sacramento Municipal Utility District (SMUD)

Sacramento, California

REGISTERED PROFESSIONAL ENGINEER
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Appendices

A Photos from Field Visit to Project Area

B Down Hole Summary Plots for Project Area Wells

C Thermochem Laboratory Reports for Samples Collected During August, 2012 Fieldwork

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EXECUTIVE SUMMARY

The Sacramento Municipal Utility District (SMUD) is interested in evaluating geothermal potential with the goal of developing a geothermal power project in the Wilbur Hot Springs area of Colusa County. Renovitas LLC (Renovitas) has obtained partial funding from the California Energy Commission (CEC) to undertake certain geothermal exploration and resource characterization activities. On behalf of SMUD and Renovitas, GeothermEx is providing guidance for this project and conducting exploration and characterization activities.

The purpose of this investigation is to evaluate the potential of the project area for developing electric power from geothermal fluid using Trebilcot land mineral rights that are presently held by SMUD. To support this investigation, GeothermEx prepared and carried out a Geological and Geochemical Work Plan. This work plan outlined 1) the conditions under which field work may be conducted in the investigation area which has a history of mercury mining and associated mining waste, and 2) the methods and practices of data collection implemented to collect geologic data and geochemical samples to support development of the geologic model. The results of the field work outlined in the above work plan are contained in this evaluation document.

A GeothermEx field team conducted fieldwork efforts 21 – 24 August, 2012. The field team collected information related to the lithological and structural setting in the project area. Information collected has been used to better understand lithologic contacts and the behavior of surface thermal water outflows and subsurface formations that have been interpreted to control the migration of geothermal fluid. Geochemical samples were collected from two locations on Bureau of Land Management (BLM) land. No sampling was conducted on either private or California Department of Fish and Game (CADFG) land as permission for sample collection was not available at the time of fieldwork efforts.

Historical and recently collected geochemical sample data indicate that the Sulphur Creek area has a stratified water system in which deeper waters at the historic Bailey Min. #1 well are a heated chloride (Cl) enriched Great Valley sequence type that lacks abundant carbon dioxide (CO_2) while the thermal waters at the shallower wells and hot springs are a heated Cl enriched Great Valley sequence type that is charged with abundant CO_2. In general, Cl rich waters that display a shift of oxygen and hydrogen isotopes with respect to meteoric water emerge from Great Valley sequence rocks in the eastern part of the region, and the Cl content of these waters generally increases from west to east as Great Valley sequence marine sandstone and shale formations increase in thickness. Most, but not all, of the high Cl waters also display elevated bicarbonate (HCO_3) produced by addition at depth of carbon dioxide (CO_2) and relatively high levels of hydrogen sulfide (H_2S), ammonia (NH_3, mostly present as NH_4^+), and boron (B), which like CO_2 are relatively volatile species.

Based on the geothermometry discussion presented in this report, GeothermEx believes that the 170°C (340°F) Na/K temperature of reservoir waters that make outflow near the Elgin mine is a reasonable lower limit to assign to the deep hot spring resource, with some evidence suggesting that temperatures may be up to about 190°C (374°F). Coincidentally, 170°C is the maximum temperature reported from the historic Bailey Min. #1 test well in the vicinity of Wilbur Hot Springs.

A key observation that can be made from the geologic maps contained in this report is that the hot springs of the Sulphur Creek District occur, geologically, near the base of the Knoxville Formation on the SW flank of the Wilbur Springs anticline. We believe one of two possible scenarios explain this:

1. Fluid rises diagonally upward, from SE to NW, along the line of axial plunge of the Wilbur Springs anticline, within fractured Franciscan sandstone, and beneath an impermeable serpentine cap rock. This possibility is plausible and appears to be the preferred interpretation of earlier investigators, or
2. Fluid migrates up-dip in permeable strata located on the W flank of the Wilbur Springs anticline. Based on the model presented in this report, we prefer this possibility.

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The next stage of this investigation is designed to assess and validate these scenarios. Presently, a geophysical investigation utilizing both magnetotelluric (MT) and gravity methods is planned for the Trebilcot lands located to the west, southwest, and south of Wilbur Hot Springs. MT geophysical methods will be used to identify low-resistivity anomalies which may represent areas of hydrothermal alteration in the subsurface, and therefore may be associated with a hydrothermal reservoir. Gravity geophysical methods will be used to better understand the structural behavior of the anticline in the subsurface.

Due to limited surface geology exposure in the area, the use of geophysical methods for subsurface lithology, structure, and hydrothermal alteration will provide valuable information to calibrate the geologic model. Of particular interest for a geophysical investigation is the axis and western flank of the southeastward-plunging Wilbur Springs Anticline beneath the study area that is thought by some researchers to be the primary fluid migration control mechanism for surface outflows of geothermal fluid.

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1. INTRODUCTION

The Sacramento Municipal Utility District (SMUD) is interested in evaluating geothermal potential with the goal of developing a geothermal power project in the Wilbur Hot Springs area of Colusa County. Renovitas LLC (Renovitas) has obtained partial funding from the California Energy Commission (CEC) to undertake certain geothermal exploration and resource characterization activities. GeothermEx is providing guidance for this project and conducting exploration and characterization activities.

The project area (shown by Figures 1 and 2a) has long been known to have geothermal resources, and previous investigations of these geothermal resources have been undertaken by various parties. The project area is also known to be situated within a former mercury mining district, and there are several abandoned mines within and nearby the area of interest. Certain efforts are underway by other parties [including the Central Valley Regional Water Quality Control Board (CVRWQCB)] to identify and characterize areas of mercury mining waste (*e.g.*, tailings piles), and to develop and implement plans to remediate the associated environmental impacts.

The purpose of this investigation is to evaluate the potential of the project area for developing electric power from geothermal fluid using Trebilcot land mineral rights that are presently held by SMUD.

The project area is located in northern California about 90 miles north of San Francisco, and 19 miles southwest of the Central Valley town of Williams (Figure 1). The area contains a number of mercury mines that comprise the Sulphur Creek Mercury District, which is geologically unique because there is a close spatial association of mercury and gold mineralization with hot springs and methane gas seeps. Partially because of this association, a number of geologic investigations, including four separate geologic mapping projects, have been undertaken in the area. In addition to these studies, many reports have been published on the mining activity, which took place in the later part of the 19th and first part of the 20th centuries.

The border of the Trebilcot property and the distribution of mines and hot springs in the Sulphur Creek District are shown on Figure 2a. The Wilbur Springs area and its associated hot springs are located in the SE part of the District and along Sulphur Creek. In most of this report the group of springs that are clustered in the Wilbur Hot Springs area at the SE end of the Sulphur Creek District are referred to collectively as Wilbur Springs, even though the majority of the springs have individual names that are differentiated (as shown on Figures 2a and 2b). Additionally, the Abbott Mine, which also has associated hot springs and is included in the District, is located about a mile SW of the Wilbur Springs group on the SW side of the ridge that bounds Sulphur Creek on the SW (Figure 2a).

Interest in developing geothermal power in the District began in 1964 when 11 shallow holes, 127 to 292 feet deep, were drilled by Worldwide Geothermal Exploration Company in and around Wilbur Springs for the purpose of measuring temperature gradients. The location of the holes and the contoured gradient values are shown on Figures 2a and 2b; the 8°C/100 ft contour encircles the Wilbur Springs group. Following an interpretation of temperature gradients from these wells, Magma Power Company in 1965 drilled an exploration hole (the Magma well) in the center of the temperature gradient anomaly to a depth of 1,226 feet. This was followed by the drilling of the Cordero #1 well in 1968 by the Cordero Mining Company to 3,400 feet, and the Bailey Minerals #1 well in 1980 by the Sunoco Energy Development Company to 9,100 feet. All these wells were drilled at the Wilbur Springs area within the 8°C/100 ft gradient contour (Figures 2a and 2b), yet the temperatures and flow rates encountered were considered to be non-commercial. In Chapters 4 and 5 of this report, the information obtained from these holes is described and interpreted, and well test results are evaluated.

To support the current investigation, GeothermEx prepared and carried out a Geological and Geochemical Work Plan (GeothermEx, 2012). This work plan outlined 1) the conditions under which field work may be conducted in the investigation area which has a history of mercury mining and associated mining waste, and 2) the methods and practices of data collection implemented to collect geologic data and geochemical samples to support development of the geologic model. The results of the field work outlined in the GeothermEx (2012) document are contained in this evaluation document. The strategy of the current investigation is to develop a model of the project area through analysis of available geologic and geochemical data to support further exploration work for geothermal power development.

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2. GEOLOGIC SETTING

Though numerous geological investigations have been conducted in the northern Coast Range region of California over the past 70 years, some aspects of the geology of the region have yet to be resolved. The main obstacle to producing a well-substantiated geologic map of the region is that it is underlain by a stratigraphic section of very similar sedimentary rocks that is tens of thousands of feet thick and yet contains few marker horizons. Defining geologic structures in such a thick sequence, without a detailed and easily recognizable stratigraphic section, is difficult. This is particularly true in attempting to map the locations of faults that occur entirely within a single stratigraphic unit. The location of bedding folds is less ambiguous because the folds are defined not only by the outcrop pattern of marker horizons, but also by the distribution and orientation of bedding attitudes, which are more easily demonstrated.

With these caveats in mind, a simplified version of regional geology surrounding the Sulphur Creek Mining District is shown on Figure 3, with a legend presented on Figure 4. This figure is a 1:70,000-scale enlargement of the appropriate segment of the 1:250,000 Ukiah Sheet of the State of California geologic map series (1960). The boundary of the Trebilcot property and the location of the Wilbur hot springs are included on the map.

The outcrop areas of the following stratigraphic units are shown on Figure 3. The Franciscan assemblage, designated "Kjf," consists mainly of highly consolidated and, in some areas, metamorphosed (re-crystallized) sandstone. This is the deepest and probably oldest group of rocks in the sequence, except for a sheet of variable thickness ultrabasic rock (serpentinite), designated as "ub" on Figure 3, which once may have comprised an underlying part of the ocean floor and now overlies the Franciscan assemblage along what is considered to be a gently-to-steeply-dipping folded thrust fault (the regional Coast Range Thrust). Another thrust fault, the Stony Creek Thrust, is thought to separate the sheet of serpentinite from the overlying Great Valley sequence, which is comprised of the Jurassic Knoxville shale ("Jk") and a

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thick overlying sequence of alternating sand and shale of lower Cretaceous age (“Kl”). West-northwest of Wilbur Springs, a layer of submarine basalt (“Kjfv”) occurs at or near the base of the Knoxville. This layer is of variable thickness and in some places is absent. In the SW corner of the map, young sediments of the Cache Formation (“QP”) un-conformably overlie the older faulted and folded rocks. Very young volcanic rocks of the Clear Lake volcanic series (“Qrv”) intrude into the Cache Formation west of the mapped area.

Two fold structures are shown by the outcrop pattern in Figure 3: the Wilbur Springs anticline and the Grizzly Creek syncline. Both folds trend NW and plunge to the SE; the axes of these two folds are separated by about 2.5 miles. These folds are not only defined by outcrop pattern, but also by a large number of measured bedding attitudes, as shown on Figure 5.

On the geologic map shown in Figure 5, most of the boundaries between stratigraphic units, and between the stratigraphic units and the serpentinite, are shown as faults, with the exception of the Knoxville-lower Cretaceous (Jk-Kl) boundary, which is depositional. Because proposed thrust faults define the upper and lower bounding surfaces of the serpentinite, and because these faults do not offset the body itself, for the purposes of this report they can be treated as stratigraphic boundaries. The presence of high angle faults in the Sulphur Creek area will be discussed in Chapters 5 and 6.

The distribution of hot springs in the Wilbur Hot Springs area is displayed on Figure 2a, with a larger display hot springs in the Wilbur Hot Springs area displayed on Figure 2b. Hot springs issue at a variety of flow rates and temperatures from less than 1 liter per minute (lpm) at the Abbott Hot Springs to more than 40 lpm at the Elgin Mine Springs, and 24°C at Abbott Hot Springs to 67°C at the Elgin Mine Springs. A key observation that can be made from Figures 3 and 5 is that the hot springs of the Sulphur Creek District occur, geologically, near the base of the Knoxville Formation on the SW flank of the Wilbur Springs anticline. As discussed more in Section 2.1, the base of the Knoxville Formation and its contact with the underlying serpentinite

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is noted as the zone of hydrothermal alteration and resulting mineralization associated with thermal water outflows in the Wilbur Hot Springs area.

2.1 Results of Historic Mining Activities

Historic mining documents provide valuable information on the geology and structure of the mines in the Wilbur Springs area, where available. These are relevant to the current geothermal investigation as most of mercury and/or gold mines contain deposits directly related to the geothermal fluids. An understanding of the geometry of these ore deposits provides insight into subsurface fluid flow pathways in the area. Mines in the project area as discussed below are located on Figures 2a and 2b.

Abbott and Turkey Run Mines

These mines consist of extensive underground workings that include a series of shafts, tunnels, open cuts, and glory holes, all located along the main ore bearing zone. Workings of the Abbott and Turkey Run Mines extend nearly 3,000 feet laterally to a maximum depth of about 500 feet below surface where the underground workings of the two mines are connected. Mined ore at the Abbott and Turkey Run mines is hosted in fracture fillings in silicified and altered serpentine breccia, and rarely in the shale within a few feet of the silicified serpentine breccia (Wiebelt 1949). The deposits of the Abbott group are mainly concentrated along the upper contact of a thick “dike” of detrital serpentinite (Main dike), oriented southeast-northwest, and located in the southern part of the district. The lower contact of the Main dike varies in dip from 45° to the southwest at the surface to nearly vertical at depth. The dip along the upper contact is 60° to the southwest near the surface and 80° at the 300-foot level.

At least one thermal spring was intersected in the workings of the Abbott Mine. The discharge was estimated at approximately 17 gpm (Crawford 1894, 1896). A flowing spring has previously been observed emanating from the collapsed lower adit at the Turkey Run Mine and is estimated to be about 15 gpm.

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Wide Awake Mine

Early production was from shallow workings and later, in the 1870s, a 470- to 500-foot vertical shaft with levels at 190, 290, and 390 feet was sunk which cut off nearby Blank Spring. After the shaft filled with water to within 56 feet of the collar the spring was flowing again, but its temperature had dropped to 39.5°C instead of its former 42.2°C (Bradley, 1916a).

Elgin Mine

Ore mined at the Elgin Mine occurs in a serpentinite body that trends northwest to southeast where the ore deposit occurs in a silicified body of serpentinite along the upper contact with the shale. Siliceous sinter resembling deposits at the Geysers has been reported (Waring 1915).

Numerous springs were observed in the Elgin Mine area. At least one of these has been intersected by the underground mine workings and is now emanating from the collapsed main adit. Flow from the collapsed main adit was reported to be about 28 gpm with a temperature of 59°C, with a second nearby spring up the hill from the adit having a temperature of 67°C. Waters were noted to be strongly saline.

Summary

Evidence from all the mines in the Wilbur Springs area where historic data are available suggests that fluid flow is occurring predominantly along the lithologic contact between the top of mapped serpentinite and the overlying shale, which is the lithologic margin where mined ore in Wilbur Springs area mines have historically excavated hydrothermally associated ores.

The noted serpentinite sheet, indicated as KJgs on Figure 5, strikes NW – SE and dips to the SW, a relationship characteristic of the SW flank of the Wilbur Springs Anticline in the general vicinity of the mines discussed above and SW of Wilbur Hot Springs. Dip angles at the surface on the serpentinite range from 45 to 60° at the Abbott Mine to as much as 80° from the regional geologic map (McLauglin et al., 1990), and at depth (also noted at the Abbott Mine) appears to increase in dip angle to the SW.

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3. RESULTS OF FIELD WORK

Fieldwork was conducted in the Wilbur Hot Springs area by Mr. Logan Hackett and Mr. Scott Herman of GeothermEx during 21-24 August, 2012. The visit included: 1) logistical reconnaissance for access to the Wilbur Hot Springs area with regard to future exploration activities, 2) geologic data collection, and 3) geochemical sample collection.

A fieldwork field summary is presented below, with more detailed notes and pictures contained in Appendix A.

3.1 Areas of Mine Waste and How They Were Avoided

The CEC and the CVRWQCB requested demonstration within the work plan issued by GeothermEx on 2 July 2012 (GeothermEx 2012) of sufficient awareness and appropriate methods of avoidance of historic mining sites and associated waste in the Sulphur Creek Mining District, which coincides with the project study area.

During fieldwork, GeothermEx avoided all mine sites and associated mining waste located on public and private lands during the field exploration. This was accomplished by the following:

- The location of mining waste was loaded into the field team's GPS unit, and hardcopy maps were taken into the field, assuring that GeothermEx personnel knew their location at all times relative to any areas of mining activity, and
- A 100-foot buffer zone was maintained around all known and identified mine features on all public and private lands (i.e., there was no walking, rock sampling or exploration activity of any kind around any area of mining waste, including the 100-foot buffer).

Additionally, due to the field team's awareness of the presence of mine waste, new areas of previously unmapped waste were identified, and photographs and coordinates of this mine waste were taken. This information is presented in Appendix A, Photographs 2 through 4.

3.2 Geologic Mapping

During field work efforts conducted 21 – 24 August, 2012, the GeothermEx field team collected information related to the lithological and structural setting in the Wilbur Hot Springs area. Information collected was used to better understand lithologic contacts and the behavior of surface thermal water outflows and subsurface formations that have been interpreted to control the migration of geothermal fluid. Strike and dip information of geologic formations was collected where appropriate to advance the geologic model. This information is presented in Figure 3 as 'GEx Mapped Strike and Dip' locations and is summarized below in Table 1. All geologic field data collected have been integrated into the geologic model presented in Chapter 6.

Table 1. Coordinates and Strike and Dip Information Collected During Field Activities.

Lat/Long	Strike/Dip
10N E 549680.25, N 4317915.27	S: 53 W, D: 100 SW
10N E 549406, N 4317998	S: 79 W, D: 40 SW
10N E 549448, N 4317971	S: 105 W, D: 30 SW
10N E 549976, N 4319634	S: 90 W, D: 72 S
10N E 549692, N 4319769	S: 40 E, D: 82 SE

3.3 Geochemical Sampling

Samples were collected from two locations on BLM land, as follows. No sampling was conducted on either private or California Department of Fish and Game land as permission for sample collection was not available at the time of fieldwork efforts.

- Sample 120823-1200—Wide Awake Upper Seep: This sample was collected from a spring that emanated from a fault SW of the Wide Awake Mine at coordinates (10N)

4319823.5 N; 549235.3 E. Field parameter data collected at this spring is summarized on Table 1 and a picture of the sample location is presented in Appendix A.

- Sample 120823-153—Abbott Hot Springs: This sample was collected from the Abbott Hot Springs at coordinates (10N) 4319408.6 N; 548036.1 E. Field parameter data collected at this spring are summarized on Table 1 and a picture of the sample location is presented in Appendix A.

Results and interpretation of analytical data from these samples is presented in Section 4.

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4. GEOCHEMISTRY

4.1 Introduction

4.1.1 Background

Numerous academic/scientific publications have reported and discussed the chemistry of thermal and cool mineral spring waters in the greater Geysers-Clear Lake region, which includes the Wilbur Hot Springs (Sulphur Creek) area at its eastern edge (see References in Chapter 8). In general, chloride (Cl) rich waters that display a shift of oxygen and hydrogen isotopes with respect to meteoric water emerge from Great Valley sequence rocks in the eastern part of the region, and the Cl content of these waters generally increases from west to east as Great Valley sequence marine sandstone and shale formations increase in thickness.

Most, but not all, of the high Cl waters also display elevated bicarbonate (HCO_3) produced by addition at depth of carbon dioxide (CO_2) and relatively high levels of hydrogen sulfide (H_2S), ammonia (NH_3, mostly present as NH_4^+), and boron (B), which like CO_2 are relatively volatile species. All four of these species can migrate in high-temperature steam, and it has been at times suggested that the elevated levels manifest a deep-seated, high-temperature steam reservoir. This claim is tenuous, because elevated CO_2 is common throughout the California Coast Ranges, probably coming from deep in the earth's crust or mantle, and the other species may originate from decomposition of sedimentary organic matter.

Table 2 is a compilation of Sulphur Creek area thermal water data taken from various sources (see References in Chapter 8[1]) and including samples most recently collected by GeothermEx in August, 2012. Table 3 lists chemical geothermometers calculated from the water compositions (see discussion in Section 4.3 below). Table 4 lists analyses of non-condensable gases (NCG) at

[1] Several spring analyses from Tetra Tech (2003) are not included in Table 1 because they do not report sulfate, silica and boron.

the springs and wells. Figures 7 to 10 comprise various graphical illustrations of the water and gas chemistry, which are discussed below.

Locations of the springs and wells listed in the tables are included in Figure 3, excepting four points outside the immediate Sulphur Creek area. Two of these are Cl enriched waters of the Great Valley sequence type:

- Wilbur Oil Test well water (sample WO1), drilled into cool Great Valley Sequence rocks east of Wilbur Hot Springs.
- Grizzly Springs water, which issues at 19.4°C about 4.5 miles (7.5 km) southwest of Sulphur Creek, from the western edge of the exposure of Great Valley Sequence rocks that extends in that direction. This water also contains relatively high CO_2 and B.

The other two points are waters elsewhere that have chemical similarities to the waters commonly found in the Great Valley sequence:

- Sulfur Bank mine well water, Bradley Minerals #1. This former sulfur and mercury mine is located at the eastern tip of Clear Lake, where an active hydrothermal system reaches temperatures at depth as hot as 220°C (425°F). The thermal water that was produced by the well is more dilute than thermal waters of the Wilbur Hot Springs area and is believed to come from rocks of the Franciscan Formation, but it shows a similar isotope shift and also contains elevated CO_2 and B.
- Hot spring water from Ngawha (in New Zealand), the location of a geothermal reservoir and power plant and also characterized by elevated CO_2, B and NH_3.

4.1.2 Data Quality

All of the chemical analyses in the data tables are from sources that can be considered reliable in terms of documentation and quality (precision and accuracy) of the data, but for various technical reasons the analyses of B, silica (SiO_2), potassium (K), NH_3 and H_2S (in water) are likely

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to be the least accurate, especially among older analyses. Technical reasons for reduced reliability and caveats are as follows (see also the annotations on lower graphs of Figure 7 and occasional comments on data quality in the rest of this Chapter):

- Of the SiO_2 and K analyses from Cordero #1, only the last ("Best Cordero #1" by the USGS) should be considered reliable, as other Cordero #1 analyses report lower SiO_2 and K probably due to a failure to preserve the samples correctly. It is assumed that the "Best Cordero #1" sample likely underwent only minor concentration due to boiling, based on ion concentrations and recorded bottom hole temperatures. All of the Cordero #1 samples were analyzed in 1968 and the precision of Mg values reported at low levels (=<2 mg/l) may be relatively low.

- Of the SiO_2 and K analyses from Bailey Min. #1, only the two collected in 1982 ("Best Bailey Min. #1" by the USGS) should be considered reliable, though these may also have been concentrated somewhat due to boiling.

- Of the remaining silica analyses, there are five from hot springs that are attributed by Thompson (1993) to a PhD Thesis done by E.K. Peters at Harvard University in 1990 (annotated "P" on Figure 7). These five show higher SiO_2 than reported from various analyses by the USGS, by a factor that is most commonly about 1.5 to 1.7, suggesting a systematic error in handling the data. Therefore, these data should be considered suspect.

- There is only one SiO_2 analysis that matches the high level reported by Peters, this being a sample from the Elgin Mine hot springs collected by the USGS in 1956. Three other Elgin samples contain SiO_2 at about 150 mg/l, including one collected in 2008

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with 159 mg/l SiO_2 that we have confirmed was properly diluted to preserve it for analysis. One other Elgin sample contains SiO_2 at 198 mg/l[2].

After removing the Peters data, which is pertinent specifically to public data from the Elgin Mine, the remaining irregularities of SiO_2 at Elgin suggest that re-sampling of the springs for this analysis at some future opportunity may be warranted.

4.1.3 Principal Issues

The two questions of principal interest for this evaluation are:

- What variations exist among the water and gas compositions that may help lead to and be compatible with the conceptual model of the geothermal system that is discussed in Chapter 6?
- What does the thermal water composition say about possible maximum temperatures in the hydrothermal system that discharges nearby to Wilbur Springs that may be accessible for geothermal development?

4.2 Variations of Composition

Salient characteristics of the data set include:

1. The hot waters of Wilbur, Jones' Fountain, Elbow, Blank's and Elgin springs and of the Magma and Cordero wells are all very similar in terms of ratios among the major anions and cations (see analytical data on Table 1 and tri-linear diagrams on Figure 7), whereas the waters from Abbott Hot Spring show distinct ion ratios in comparison to other thermal waters in the Wilbur area.
2. These waters also contain very similar levels of overall salinity, but patterns of dilution with meteoric water show small differences as illustrated by graphs of B vs Cl, the

[2] The lower right graph of Figure 7 (silica vs. Cl) includes several analyses not listed in the data tables or shown on other graphs but obtained after they were compiled, from Thompson (1979).

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stable isotopes of hydrogen and oxygen (Deuterium and ^{18}O) and stable isotopes of oxygen plotted against Cl.

a. Wilbur, Jones', Elgin and Magma well waters have the most similar levels of Cl, whereas Blank's is diluted somewhat, and Elbow and Cordero #1 are somewhat more concentrated.

b. B plotted vs. Cl falls into four groups in terms of the ratio B/Cl: (i) Magma well and Cordero #1 (USGS sample) with highest B; (ii) Wilbur, Jones', Blank's and Elbow with intermediate B; (iii) Elgin with the moderately low B in the grouping; and (iv) the lowest (with similarity to the cool waters of Grizzly Springs, the Abbott HS and Wide Awake Seep) show low B and Cl, indicating a large degree of meteoric water mixing. The differences between clustered data groups are small but distinct enough to probably be real. They also correspond to the different geographic locations and elevations of the three sets.

3. Na/K is a temperature-sensitive parameter that tends to decrease as the deep source temperature of a hot spring increases (see section 4.3). Slightly lower Na/K was found at Blank's, Elgin and Cordero #1 than was found at Wilbur, Elbow and Jones', and this is a tentative indication that fluids are cooling as they move generally from SW to NE. The low concentrations of Na and K seen at Abbott HS are an indication of a predominant meteoric outflow.

4. The concentration of SiO_2 is also temperature-sensitive, increasing with temperature at depth (although with possible complications in this area which are discussed in section 4.3). Silica also adjusts to cooling (and heating) more quickly than does Na/K. Among the sources discussed above, Cordero #1 (the 'best sample only'), Wilbur and Elgin, and Blank's show a linear relationship between SiO_2 and Cl that could be related to dilution, but the higher SiO_2 and Cl of Cordero #1 could be an artifact of some boiling. The

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samples from Jones', Magma well and Elbow show lower SiO_2 that probably is related to a loss during cooling at shallow aquifer levels.

5. Stable isotopes of Abbott HS show an oxygen (del ^{18}O) value that is not uncharacteristic of local cool meteoric water, but show a large depletion in deuterium and deviation from the meteoric water line, which may be associated with water-rock interaction at a low flow rate.

6. The deep water from Bailey Min. #1 was obtained after drilling and casing to a depth of 7,372 feet and is distinct from the shallower waters above:

    a. Alkalinity (HCO_3) is very low and Ca is very high. Both are similar to alkalinity and Ca at the Wilbur Oil Test well to the east.

    b. Although the stable isotopes of water appear to show a mixing trend that coincides with the shallower waters, the deep well water lies on a different oxygen isotope vs. Cl trend.

    c. In terms of B the deep Bailey water is more similar to Wilbur Oil Test than the other waters.

    d. Na/K is distinctly lower and SiO_2 is distinctly higher than at the other sources, undoubtedly as a result of higher temperatures.

7. Gases sampled at Wilbur and Elgin hot springs are mostly CO_2, levels of methane (CH_4) being only 2.5 ~ 4.5 vol.% of the dry gas at Wilbur and <1 vol.% of the dry gas at Elgin. In contrast, the dry gas at Cordero #1 was about 14 vol.% CH_4 and the dry gas at Jones' has varied from about 44 to 60 vol.% CH_4, showing evidence of mixing between high

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CO_2 and high CH_4 components (Figure 10)[3]. Correction of the Cordero #1 gas sample for a probable loss of H_2S (Figure 10) suggests that the gases at this well are also a mixture of high CO_2 and high CH_4 components.

8. Gases obtained along with the deep Bailey Min.#1 water were predominantly CH_4 with CO_2 being virtually absent. This is consistent with the high Ca and low bicarbonate that are also observed. Elsewhere in this report, the distribution of methane in the well is discussed, showing that most of it probably is concentrated above the level from which the deep waters were sampled, but essentially below the level of high-CO_2 waters found in the Cordero #1 well (see Figures 7 and 8). The rocks deep in Bailey Min.#1 are considered to be Franciscan Formation, and overall the Franciscan comprises rocks (including the basalts penetrated in Bailey Min. #1) that are not considered to be a significant source of CH_4. However, a significant source of methane has been demonstrated to exist in Franciscan rocks at the very southern end of the Geysers steam field, as illustrated by Figure 10.

9. The cool, saline water of Grizzly Springs (Figure 7) has characteristics of Great Valley sequence water diluted by meteoric water, but contains particularly high magnesium (Mg) along with high alkalinity due to charging with CO_2. It also has somewhat elevated SiO_2 compared to the measured temperature, yet very high Na/K due to low K, which is characteristic of low temperatures. The elevated Mg and SiO_2 are probably obtained from dissolution of serpentine (a hydrous magnesium silicate) that underlies the Great Valley sediments in the area of the spring.

[3] Jones' Fountain is the discharge of a 120 ft deep well that erupts on a more-or-less regular cycle. This behavior has been attributed, reasonably, to variations of pressure in the aquifer caused by mixing between the two gas sources.

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4.3 Fluid Temperatures at Depth

The chemical composition of a geothermal fluid (water and gases) is determined in part by a combination of rock chemistry and temperature at depth, and the fluid-rock chemical reactions that take place equilibrate most rapidly at high temperatures, slowing as the fluid ascends and cools. As a result, a hot spring or hot well tends to have a composition that reflects its temperature history. Chemical geothermometers are mathematical equations that take advantage of this fact, relating geothermal water or gas composition to the equilibrium reactions that most likely have taken place at depth.

Several kinds of geothermometers are commonly in use, based on:

(a) dissolution of silica (SiO_2) minerals quartz, chalcedony, or volcanic glass

(b) ion exchange reactions involving Na, K, Ca and Mg in silicate minerals, as formulations with common names such as Na/K, Na-K-Ca, Na-K-Ca-Mg and K-Mg, most of these having more than one possible calibration[4]

(c) solubility of anhydrite ($CaSO_4$) or calcite ($CaCO_3$), both of which become decreasingly soluble as temperature increases

(d) oxygen isotope exchange between co-existing sulfate and water, and

(e) various chemical reactions among non-condensible gas species with sulfide and oxide minerals in the rocks.

Given the right conditions and appropriate calibrations, all of the geothermometers listed above can be applied across a wide range of temperatures, from near 0°C to over 300°C, with the exception of Na/K, which is generally considered to be unreliable (or insufficiently reliable for general use) at conditions below ~150°C.

[4] Other combinations of cations exist, including forms with lithium (Li), but the ones listed are the most reliable and accurate.

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The geothermometer equations can be further divided into two groups according to how they are calibrated. In general, the water species equations have been calibrated using actual thermal fluid compositions (from springs, wells and/or laboratory experiments) and, as a rule-of-thumb, the better water equations can be considered "accurate" (for a particular calibration) to about ±25°F (15°C). This is approximately the standard deviation of the calibration data set relative to the equation curve fit, so it must be realized that larger deviation errors are possible.[5] This is partly because the cation geothermometers are sensitive to rock mineral composition. Each available calibration depends more than a little upon the examples of geothermal fluids used and just where they came from, even though most of the calibrations that have been published (including those used here) have attempted to use a variety of samples from a range of geologic settings.[6]

The gas species equations have more commonly been calibrated using thermodynamic data that describe the ideal equilibrium condition, with exceptions that are based on actual thermal fluids. In general, the gas equations are prone to be less accurate than the water equations, and there is no simple rule-of-thumb regarding their accuracy.

Any interpretation of chemical geothermometry has two complications that must be considered:

First, there is the possibility that the fluids sampled have been altered by mixing with fluids of shallower origin, and/or by reactions with minerals in rocks near the discharge point (the spring

[5] ±25°F (15°C) is an approximate value that should not be over-emphasized. In general, the geothermometers are linear functions with respect to the inverse of temperature (1/T). As a result, calibration accuracy usually increases as temperature increases. The K-Mg geothermometer used here has been calibrated (Fournier, 1990) using a data set that includes a number of oil field brines coming from production zones at 35°C to about 160°C, and the scatter of measured data relative to the calibration is smallest at the upper end of this range.

[6] This report uses a K-Mg geothermometer that was calibrated by Fournier(1990) using a data set that included a number of oil field brines (similar to the Wilbur-Elgin waters) coming from production zones at 35°C to about 160°C, along with other geothermal waters at higher and lower temperatures. The precision of the Fournier calibration (scatter of measured temperatures relative to calculated) was highest (errors smallest) at temperatures near the upper end of the 35°C - 160°C range.

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location or production zone in a well) that are not representative of the rocks in the deeper reservoir.

Second are the relative rates of adjustment of the geothermometers to changes of temperature, because the geothermometers that adjust most slowly are most likely to reflect the highest (usually deepest) temperatures in a geothermal circulation system. As a general rule, it is expected that reaction rates proceed in the following sequence (slowest to fastest): sulfate-water isotope < gas reactions in general (with differences in detail) < Na/K =< Na-K-Ca < (Na-K-Ca-Mg, K-Mg) < silica. According to one available set of estimates, at 250°C the half-life for re-equilibration of the sulfate-water isotope thermometer is 500 years, for Na/K and Na-K-Ca 0.3 years, and for silica 1 to 100 hours.

Water Temperatures

Aqueous geothermometers of the data set are listed in Table 3, and Figure 9 provides a graphical representation of Na/K and K-Mg temperatures. The table and figure represent calibrations of Fournier and of Fournier and Potter, which we consider most likely to be accurate in the Sulphur Creek setting, although there is reason to believe that the Fournier Na/K calibration may be yielding under-estimates (see below). Among the silica geothermometers, at the temperature ranges found here, the chalcedony (chal) form is much more likely than quartz (qtz) to be accurate. Ad (adiabatic) indicates a temperature corrected for boiling with maximum steam loss, and cond (conductive) indicates a temperature that assumes no boiling. The only samples that may have boiled are those of the Magma, Cordero #1 and Bailey Min. #1 wells, but it is relatively unlikely under the conditions in which the wells were sampled that any of these experienced maximum possible steam loss.

We estimated the anhydrite temperature of the Elgin Mine springs (nearby and to the NW of Wilbur Hot Springs) and found that the water is so greatly under-saturated with anhydrite that the resulting extremely high temperature estimates are not reasonable. This simply indicates

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that the rocks in the hydrothermal system probably do not contain anhydrite. The calcite temperature cannot be meaningfully estimated because subsurface CO_2 pressure is not known, but the water is not far from saturated at the discharge temperature (suggesting that calcite may be present in the upflow zone). Data for the sulfate-water isotope temperature have not been collected.

Results can be summarized as follows, listing °C (°F) rounded to the nearest 5°(10°). The Na/K calibration of Giggenbach (Gig.) is listed as well as that of Fournier (Four.), because in this case it may be more accurate (see below).

Table 5. Wilbur Hot Springs area calculated geothermometers.

Source	Max Meas. Temp °C (°F)	Na/K (Four.)	Na/K (Gig.)	Na-K-Ca	Na-K-Ca-Mg	K-Mg (Four.)	Chal-cedony
Magma hole	122° (252°) BHT	160° (320°)	175° (350°)	240° (460°)	155° (310°)	165° (330°)	95° (200°)
Cordero #1 (C4)	134°~140° (273°~284°)	185° (360°)	200° (390°)	265° (510°)	265° (510°)[a]	225° (440°)[a]	155° (310°)
Abbott Spr	23.8° (75°)	252°	241 (486°)	cool	cool	cool	83 (181°)
Bailey Min.#1	171° (340°)	195° (380°)	210° (410°)	200° (400°)	200° (400°)	185° or 270°[b] (360° or 520°)	190° (370°)
Blank's Spr	44°(111°)	180°(360°)	197.5°(400°)	245°(480°)	70°(160°)	145° (290°)	120° (250°)
Elbow Spr	62° (144°)	160° (320°)	180° (360°)	250° (480°)	200° or 240°[b] (390° or 470°)	190° (370°)	90° (190°)
Elgin Mine Sprs	68° (154°)	170° (340°)	190° (370°)	240° (460°)	135° (280°)	160° (320°)	140° (280°)
Jones' Fountain	62° (144°)	165° (330°)	185° (360°)	240° (460°)	120° (250°)	155° (310°)	100° (210°)
Wilbur Hot Spr	58° (136°)	165° (330°)	185° (360°)	240° (460°)	90° (190°)	150° (300°)	150° (300°)
Wilbur Oil Test	cool	70° (150°)	90° (190°)	100° (210°)	85° (185°)	55° (130°)	cool

(a) These very high values are the result of very low Mg which may be under-reported (analysis done in 1968)

(b) Two analyses having different Mg values that yield large differences in temperature

(c) BHT = bottom hole temperature

Thompson (1979) has pointed out that there is some risk to applying the Na-K-Ca-Mg, K-Mg and silica geothermometers to the hot springs of Sulphur Creek because the ascending thermal water may be passing through serpentine rock or altered serpentinites and picking up both Mg and SiO_2. There is evidence that this happens, because Elbow Spring and Jones' Fountain are nearly adjacent and chemically identical except that the latter shows dilution by meteoric water (as seen in the Cl vs isotopes plot on Figure 8) yet bears distinctly higher Mg and slightly higher SiO_2. The same process may be affecting Elgin, which resembles Jones' more than Elbow.

Mg and SiO_2 have opposite effects on geothermometry. Higher Mg decreases the Na-K-Ca-Mg and K-Mg temperatures, but higher SiO_2 increases the silica temperature. The two Mg-based geothermometers of Elgin (Na-K-Ca-Mg and K-Mg) indicate conditions at 135° to 160°C (280° to 320°F), and the chalcedony geothermometer indicates 140°C (280°F). Given the uncertainty in the estimates, this can be taken as an overlapping prediction. It also can be interpreted to suggest that the water at depth reaches temperatures of at least 135° to 160°C (280° to 320°F) and, if it does reach temperatures above 135°~140°C (280°F), it subsequently resides for some time at 135°~140°C (280°F) or below during ascent.

Even without effects of mixing and/or shallow level reactions, the Mg-based and silica geothermometers are prone to indicate effects of cooling during ascent, and the Na/K and Na-K-Ca temperatures are more likely to indicate higher temperatures at greater depth. In some high-temperature geothermal systems the Na/K and Na-K-Ca temperatures are in agreement within a few tens of degrees Celsius; the samples from Bailey Min. #1 show such an agreement between the two, at 195°~210°C.

The Great Valley sequence waters, in contrast, show a relatively large difference between Na/K temperatures (160° - 185°C according to Fournier and 175° - 200°C according to Giggenbach) and notably higher Na-K-Ca temperatures (240° - 265°C). This seems to be a characteristic of moderately-high to high-temperature waters in which particularly high CO_2 (combined with buffering of pH by silicate reactions) has suppressed Ca to very low levels, and in such cases we have evidence that Na/K temperatures are more reliable than Na-K-Ca temperatures, as follows. Although theoretically speaking the amount of CO_2 should not significantly affect the Na-K-Ca temperature, the data set that was used by Fournier and Potter to calibrate the Na-K-Ca geothermometer actually didn't contain any examples of waters with Ca as low, (relative to Na) as found along Sulphur Creek (except the deep waters in Bailey Min.#1). Four well-known, commercially produced geothermal fields that have particularly high CO_2 and low Ca are São Miguel (Azores), Kizildere (Turkey), Germencik (Turkey) and Ohaaki-Broadlands (NZ), and in the first three of these, the Na/K temperatures of water samples (either calibration) are closer to measured production zone temperatures than the Na-K-Ca temperatures, which are higher. (At Ohaaki-Broadlands, the two geothermometers yield similar values that compare reasonably well with measured temperatures.)

Thompson (1979) argued that the Na-K-Ca temperatures of the Sulphur Creek thermal waters should be considered valid, but later (Thompson, 1993) dropped this point of view and instead favored the K-Mg temperatures, and by extension the similar Na/K temperatures, obtained using a figure analogous to Figure 9. We think that the un-corrected Na-K-Ca temperatures are indeed unreasonably high (although not impossible), given the evidence from other high CO_2 fields discussed above combined with three observations: (a) the area nearby lacks a really young volcanic heat source that is exposed at the surface; (b) helium isotope ratios (Table 3, column $^3He/^4He$) are low, which indicates an absence of magmatic input and (c) none of the springs in the area are hotter than 68°C in spite of modestly high flow rates. A substantial flow rate (estimated to be about 250 gpm) is needed for a spring water to lose virtually no heat during ascent, and to boil vigorously if hotter than 100°C (212°F) at depth. The highest flow rate reported from Elgin springs is about 20 gpm, but this may not represent total discharge, which is currently being measured by monitoring the flow rate and Cl in Sulphur Creek downstream.

Considering the calibration data used by Fournier for the Na/K temperature (Table 2 and summarized above), his form of the equation should be giving reasonable estimates for the Sulphur Creek waters. Giggenbach calibrated his Na/K geothermometer (summarized in Table 5 but not in Table 2) using a data set that was significantly biased towards very high temperature reservoirs (230° - 330°C) in young volcanic settings, so we usually do not favor Giggenbach's Na/K calibration for settings such as Sulphur Creek.

In this case, however, there is tentative evidence that the Fournier Na/K values may be somewhat low. Referring to Figure 9, it is noted that the common low Mg of Cordero and Elbow stands in contrast to other waters on the same Na/K trend, and this low Mg is at odds with the position of the "full equilibrium" line (along which the two geothermometers are equal), because it yields higher K-Mg temperatures than Na/K temperatures. As explained above, it is possible that Elgin and Jones' (and more likely that Wilbur and Blank's) carry Mg that comes from near-surface processes related to the presence of serpentine (hydrous Mg silicate). If so, and if Cordero and Elbow do not carry this Mg, then it follows that the Na/K and K-Mg calibration of Fournier that is illustrated by Figure 9 may be inaccurate. This is because the full equilibrium line would then more likely pass through Cordero and Elbow than close to Elgin and Jones' Fountain. If the data on Figure 9 are instead plotted on a tri-linear diagram that uses the Na/K and K-Mg calibrations of Giggenbach (not shown here), the full equilibrium line lies closer to the group of Cordero, Elbow, Elgin, Jones', etc. and shows evidence of excess Mg (due either to cooling or to a shallow source). In the temperature range of the Sulphur Creek waters, Giggenbach's K-Mg temperatures are about 10°C (20°F) higher than Fournier's and Giggenbach's Na/K temperatures are about 20°C (40°F) higher.

Gas Temperatures

Table 3 lists the D'Amore-Panichi geothermometer temperatures (T-DAP) of the gas samples, excluding the methane gas at Bailey Min. #1, to which the geothermometer does not apply.

The T-DAP temperatures listed are those given by the sources of the analyses, except for Elgin Mine, which we calculated (we also verified the Wilbur estimates).

Two of the samples from Wilbur contain enough oxygen (probable contamination during collection) to be unreliable, and the rest indicate a temperature of 140~145°C (285°~295°F) at Wilbur and Elgin and about 135°C at Jones' Fountain. This agrees reasonably well with the Na/K temperatures, which probably are more accurate.

However, the T-DAP geothermometer often gives large errors, both because it is both very sensitive to input values, and because it depends upon an assumed partial pressure of CO_2 at depth. The 143°C temperature calculated for Elgin assumes that H_2 (reported at <0.144 vol.%) is 0, and the calculation uses a 10 bar default value of CO_2 pressure (chosen because H_2 is very low relative to CH_4 and H_2S). However, if the CO_2 pressure were 5 bar, the result would be 129°C. If H_2 were instead 0.1 vol.%, the result would be 248°C, or if 0.01 vol.% the result would be 190°C.

Two other geothermometers that can be applied to spring gases are the CO_2-Ar and CH_4-CO_2 forms of Giggenbach, which yield 334°C and 285°C at Elgin. Conditions for applying the CO_2-Ar form are not likely to be met in the Elgin hydrothermal system. The CH_4-CO_2 form has some chance of being applicable. However, if Elgin gases contain some CH_4 from a source beneath and vol.% CH_4 is reduced to compensate, the CH_4-CO_2 temperature increases. Since 285°C is already a suspiciously high value, we conclude that the CH_4-CO_2 geothermometer is also unreliable in this case.

4.4 Summary

The sample data discussed above indicate that the Sulphur Creek area has a stratified water system in which deeper waters at Bailey Min. #1 well are a heated, chloride-enriched Great Valley sequence type that lacks abundant CO_2. Thermal waters at the shallower wells and hot springs are also a heated, chloride-enriched Great Valley sequence type, though charged with

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abundant CO_2. The source of CO_2 is probably very deep and may be very hot[7], and so more likely to lie SW or W of the area (towards the Clear Lake Volcanic Field) than to the E or NE. It is therefore inferred that the water feeding the hot springs also comes from the SW or W, with residence at higher temperatures occurring during ascent. Chemical geothermometry of the waters is consistent with greater heating of the deeper (Bailey) water than the shallower hot spring waters, although the shallower waters may have adjusted to cooling more than the deeper waters and still could be hotter at some ultimate source depth.

Considering the preceding discussion of geothermometry factors, we think that the 170°C (340°F) Na/K (Fournier) temperature of reservoir waters that make outflow at Elgin is a reasonable lower limit to assign to the deep hot spring resource, with some evidence suggesting that temperatures may be up to about 190°C (374°F). Coincidentally, 170°C is the maximum temperature reported from Bailey Min.#1 in the vicinity of Wilbur Hot Springs. This is a “best” estimate that may be inaccurate in either direction.

The levels of CO_2 present in the hot spring and shallower well waters will need to be measured and taken into account very carefully during future drilling and well testing, because high dissolved CO_2 limits the depths and rates from which water can be pumped without causing cavitation of the pump.

[7] Thompson (1993) summarized carbon isotope data for the CO_2 in Sulphur Creek area hot springs and concluded that some 80% of the CO_2 is likely to come from the earth’s mantle, with 20% coming from the overlying crust.

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5. PREVIOUS GEOTHERMAL EXPLORATION DRILLING

Figure 5 is a detailed map showing geology, spring locations, and the surface and subsurface locations of the three Wilbur Springs area exploration wells, adapted from mapping by McLaughlin et al. (1990). The Magma and Bailey #1 wells were drilled vertically, but the original hole (OH) of the Cordero well is deviated to the NE. The surface trace of the deviated course of the Cordero well, including ticks showing the location of elevation points along the trace, is shown on the map insert. The OH reached a measured depth (MD) of 3,757 feet, but a true vertical depth (TVD) of only about 2,600 feet. Due to this severe deviation, the well was then side-tracked at about 2,000 ft depth in an effort to drill a more vertical hole. The surface trace of the side-track (ST) is also shown on the map, as are elevation ticks. The ST reached a measured depth of 3,713 feet and a true vertical depth of about 3,450 feet.

Appendix A contains Downhole Summary Plots of these wells showing, where available, completion information, lithology, permeable intervals, methane entry locations, and temperature profiles, all plotted against both elevation and depth.

The severe deviation of the two legs of the Cordero well makes it possible to construct a 2,300 foot long, NE-trending cross section through Wilbur Springs to a depth of 3,500 feet, based on information from the two vertical wells and the two legs of the deviated wells (cross section A-A`, Figure 11). The surface location of cross section A-A` is shown on Figure 5.

5.1 Geologic Interpretation

Correlation of stratigraphic boundaries, including the top and bottom of the sandstone unit and the top of basalt above -1,000 feet to mean sea level (msl) in the Bailey #1 well and -500 feet (msl) in the Cordero well, indicates the stratigraphic section has an apparent dip of 30° to 40° to the SW[8]. This is consistent with the NE orientation of the section and its location on the SW flank of the Wilbur Springs anticline. The deeper clastic (siltstone/mudstone) unit, which appears to produce most of the methane in the Bailey well, was not encountered up-dip in either leg of the Cordero well, where only basalt was found in the intervals between elevations of -300 and -1,800 feet (msl). Consequently, a fault has been inserted in section A-A` that accounts for this discontinuity.

This same fault accounts for the juxtaposition of sediments against serpentine at the land surface, at the NE end of A-A`, although the position of this exposed serpentine body in the stratigraphic succession is actually uncertain. The faulted juxtaposition shown on A-A` is between sedimentary unit KJg and serpentinite unit KJgs on Figure 11, but KJgs has been mapped as both igneous (i.e., an intrusion) and detrital (i.e. erosion products rather than an in situ rock mass), depending on the person doing the mapping. Because of this uncertainty, the relative movement on the postulated fault is also uncertain. In our opinion it is probably a SW-dipping fault that is down-thrown to the SW, as shown on the section.

5.2 Location of Permeability

There is no drilling history available for the Magma well. The drilling histories of the Cordero and Bailey #1 wells, however, are available, and reveal some important differences.

The location of permeability in the Cordero well was detected by fluid entries because the hole was drilled with air and, therefore, was under-pressured. In the Bailey #1 well, permeability was detected by the loss of drilling fluid because the well was drilled in the more typical over-pressured mode (i.e., with mud as the circulating fluid), which helped to control gas entries.

The main permeability in the Cordero well occurs in basalt between elevations of -900 and 1,800 feet (msl) (Appendix B); this permeable zone provided large flow rates during testing, as

[8] The apparent dip is the dip along the section line, which may be somewhat different than the true dip of these boundaries.

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described in Section 5.4. In contrast, permeability (defined by drilling fluid losses) was not encountered in Bailey #1 above a depth of about 7,000 feet (Appendix B), although the losses encountered below that depth were mainly, again, in basalt. The fact that no permeability was found in the shallow basalt in Bailey #1, as compared to the Cordero well, may be related to the proposed fault shown on Figure 11. The presence of the fault implies that the basalt encountered in the Cordero well is different from the shallow basalt found in the Bailey #1 well, and possibly has different physical properties.

Although fluid losses in the Bailey #1 well were not encountered in the clastic unit located between elevations of -1,700 and -2,300 feet (msl) (immediately above the serpentine), the methane entry log (Appendix B) shows that this unit was the main gas contributor to the Bailey #1 well and, therefore, must have some permeability. Evidently, the gas was under sufficient pressure to prevent the loss of circulating drilling fluid.

5.3 Temperature Distribution

Temperature contours have been superimposed on the geologic cross-section A-A` (Figure 11) in degrees Celsius. The temperature distribution is based on the most stable (February 24, 1981) temperature profile of Bailey #1 well, and the combined profiles from the Magma well. The temperature profiles measured in the two legs of the Cordero well were taken shortly before or after air-induced flow and are not considered to be representative of stable rock temperature. Therefore, for the Cordero well, only the highest temperature measurements in the two legs, presumed to be at the points of fluid inflow, were used in constructing the temperature cross section.

Section A-A‘ shows that, on the SW side of the fault, the isotherms dip to the SW, more or less parallel to the dip of the strata, and that temperature increases both downward and to the NE. The fact that the 138°C isotherm crosses the fault may reflect fluid flow crossing the fault from the methane-bearing clastic unit and entering the permeable basalt on the NE side. This relationship between geologic structure and temperature distribution suggests that the methane-bearing stratigraphic unit, rather than the fault, is controlling thermal fluid flow. The location and orientation of flow paths, and the direction of flow, are considered in Chapter 6.

5.4 Flow Test Results

Historical flow data for the Cordero ST well were analyzed using a two-phase wellbore simulation model, which matches observed data using wellbore flow theory by adjusting input parameters within reasonable ranges until a match is obtained. To accomplish this simulation the static reservoir pressure was estimated from the reported shut-in artesian wellhead pressure of 88 psig. The resulting match to historical flow rate indicates that the productivity index (PI) of the well[9] was about 1 gpm/psi. This value is at the low end of the range of PIs observed in commercial geothermal wells.

Using the data from the wellbore simulation, the performance of a large diameter pumped well with the same properties encountered in the Cordero ST well was then calculated. In these calculations, a thermodynamic model of a generic binary power plant and typical production pump efficiency values were utilized. Results from this analysis suggest that similar wells drilled into the shallow portion of this part of the reservoir would be expected to have a generation potential of 0.5 MW net.

A similar analysis was undertaken for the Bailey Minerals #1 well, which was drilled into the deeper portion of the reservoir. A measured static bottom-hole pressure was available for this well, which suggests static liquid level at a depth of 980 feet. This is a significant difference from the Cordero ST well where artesian conditions (static level above the well head) were reported. Another difference is that well records indicate that the Bailey Minerals #1 well was not capable of steady production, whereas the Cordero ST was able to flow unassisted.

[9] PI is a measure of flow rate achieved per unit of pressure drawdown.

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Contained in the Bailey #1 well records is a comment that low reservoir pressure (i.e., deep static liquid level), coupled with moderate reservoir temperature, was responsible for the well's surging behavior during flow attempts. Wellbore modeling supports this conclusion. Even at high PI values, the wellbore model predicted that wellhead pressures and flow rates would be low.

The fact that the Bailey Minerals #1 well flowed at all suggests that the PI of this well is at least as high (and possible higher) than calculated for the Cordero ST well. Using the measured static bottom-hole pressure and an assumed PI of 1 gpm/psi, the performance of a large diameter pumped Bailey #1- type well completed in the deeper portion of the reservoir was calculated. The results indicate that such a well has a slightly higher generation potential than the Cordero ST-type well (approximately 0.8 MW net). This increase is due primarily to the increased resource temperature. If the PI was higher, say 10 gpm/psi, modeling results (not shown here) indicate that a generation capacity of 4.5 MW (net) might be possible. Note that these calculations are "net" in that they account for the power required for production pumping. The additional power needed to operate the power plant is not considered.

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6. CONCEPTUAL MODEL OF GEOTHERMAL SYSTEM

The objectives of developing a geologic model are to provide bases for estimating the power potential of the Wilbur Hot Springs geothermal system and to design an exploration program. Herein we present the model developed for the Wilbur Springs area to guide further exploration.

In Chapter 5, the geology and temperature distribution beneath Wilbur Springs was shown in cross section A-A` (Figure 11) down to an elevation of only about -3,000 feet (msl), reflecting the depth to which the Cordero well had been drilled. The Bailey #1 well, however, reached an elevation of -7,670 feet msl, providing a one-point source of geologic and temperature information 4,000 feet below the bottom of section A-A'.

The Downhole Summary Plot of Bailey #1 (Appendix B) shows that the well penetrated a 5,400-foot thick sequence of alternating serpentine and basalt below the bottom of the clastic unit, which lies at an elevation of -2,200 feet (msl). Penetrating such a large thickness of igneous rock had not been anticipated. The well had been sited to penetrate a 1,000 to 2,000 foot-thick serpentine layer and enter Franciscan sandstone, assumed to be present in the core of the Wilbur Springs anticline. It was hoped that in such a structural position, the sandstone would be fractured and contain a geothermal reservoir, as at The Geysers, where the reservoir is contained in fractured Franciscan sandstone. Encountering this great thickness of poorly permeable igneous rock, instead of the Franciscan assemblage, was not predicted from surface mapping.

McLaughlin *et al.* (1990), the latest group to publish a map of the area, have provided an interpretation of geologic conditions below the anticline. The authors had access to information from the Bailey #1 well and used it in part to construct a deep, NE-trending cross section drawn about ¾ mile NW of the Wilbur Springs wells. The location of the cross section, labeled B-B', is shown on Figure 5 and the relevant portion of the section itself, drawn to -

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10,000 ft msl, is reproduced herein as Figure 12. The unit labeled "Km" by McLaughlin *et al.* on cross section B-B' is the same "siltstone/mudstone" unit that occurs below the first basalt, and that produced the most amount of methane, in the Bailey # 1 well. (See cross section A-A`, Figure 11).

McLaughlin *et al.* define the Km unit as a mixture of Great Valley sediments and various rocks from the Franciscan assemblage. The authors propose that the mixing of these two major units occurred from movement on the Great Valley Thrust Fault, which they show as the upper boundary of the unit, and the Stony Creek Thrust Fault, which they show as the lower boundary of the unit (Figure 5).

The crux of developing an acceptable geologic model of Wilbur Springs hinges on deducing the most probable thermal fluid flow path and, consequently, the distribution of subsurface temperature, in cross section B-B'. The three likely possibilities to explain this fluid movement are:

1. Thermal fluid rises vertically upward on faults located along the axis of the Wilbur Springs anticline. This does not appear to be supported by deep drilling data; nevertheless, many geologists have a bias toward this kind of model.
2. Fluid rises diagonally upward, from SE to NW, along the line of axial plunge of the Wilbur Springs anticline, within fractured Franciscan sandstone, and beneath an impermeable serpentine cap rock. This possibility is plausible and appears to be the preferred interpretation of earlier investigators.
3. Fluid migrates up-dip in permeable strata located on the W flank of the Wilbur Springs anticline. For the reasons discussed below, we prefer this third possibility.

As shown on the Downhole Summary Plot of Bailey #1 (Appendix B), the most stabilized of the temperature profiles (24 Feb. '81) shows that temperature increases downward along two gradients, a shallow, higher gradient of about 3.2°F (2.0°C)/100 ft, and a deeper, lower gradient

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of about 1.4°F (0.8°C)/100 ft. These two gradients intersect at an elevation of about -2,400 feet (msl), which is only 250 feet below the base of the lowest clastic unit (which corresponds to Km). If heat flow were purely conductive, this discontinuity in the pattern of heat flow would only indicate a difference of conductivity of the rocks above and below the discontinuity. The fact that the discontinuity is located just below unit Km, a possible thermal fluid and methane-containing aquifer, suggests the temperature discontinuity is instead due to local heating by fluid flowing in unit Km. The presence of thermal fluid flowing upward in the dipping aquifer would decrease conductive heat flow beneath the aquifer, thereby decreasing the thermal gradient, and increase conductive heat flow above the aquifer, thereby increasing the thermal gradient. It is proposed that this stratigraphic unit provides the flow path of thermal fluid from the bottom of the Grizzly Creek syncline upward, and eastward, to the western flank of the Wilber Springs anticline.

The proposed model of up-dip migration of thermal fluid in a SW-dipping stratigraphic horizon, rather than from a steeply dipping fault, explains many of the geologic and geochemical characteristics of the Wilbur area, and also provides a basis for estimating subsurface temperature distribution to the SW. By assuming the geochemically estimated reservoir temperature of about 188°C (370°F) is the probable temperature at the presumed depth of unit Km near the axis of the Grizzly Creek syncline (*i.e.*, at its deepest point), and combining this information with the measured temperatures in Bailey #1, it is possible to construct a probable pattern of temperature distribution on the NE flank of the syncline. This postulated temperature distribution is superimposed on the geologic section B-B' (Figure 12), giving an approximation of the variation of temperature with depth within the section.

This model is supported by the chemical composition of the Sulphur Creek thermal fluids (Chapter 4), which indicates an origin in Great Valley sequence sedimentary rocks, rather than Franciscan assemblage or igneous rock, as does the association of methane gas with both the Wilbur Springs and Elgin spring areas.

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Well testing has shown a large pressure potential difference between the shallow artesian production zones encountered in the Cordero well as compared to the relatively low potential found in entries below an elevation of -6,000 feet (msl) in the Bailey well (see section 5.4). This indicates that vertical up-flow of fluids from depth beneath Wilbur Springs is unlikely.

Almost all of the springs in the Wilbur group are located in the alluvium of Sulphur Creek, making it difficult to identify the specific bedrock structures from which they flow. Previous workers have interpreted the NE direction of Sulphur Creek, where it flows through the Wilbur Springs group, to indicate the presence of a NE-trending fault from which thermal water is conducted to the surface. This theory is hard to defend, however, because no discontinuity has been mapped displacing the NW trend of lithologic contacts on either side of the creek and because the zones of mercury mineralization, with which the springs are associated, all follow a NW trend. Mineralized zones in both the Wide Awake and Abbott mines, located just S and about a mile SE, respectively, of the Wilbur Springs group, strike NW and dip SW. Dewatering of the Wide Awake Mine caused a hot spring, located about ¼ mile to the NW, to cease flowing.

At the Elgin Mine, however, the springs flow directly from exposed strata on the side of a steep hill. The trend of springs and patches of hydrothermally altered rock form a well-defined line that is about 2,250 feet long and curves across the face of the hill following the same path that a SW-dipping plane would follow across the hillside. If a methane seep located in the creek SE of the mine is included with the spring and altered rock locations, the total combined length of the alteration, hot spring, and methane seep trend line is about 3,200 feet. The dipping feature could be either a fault or a stratigraphic unit. As the direction of dip corresponds to the direction that strata are dipping toward the axis of the Grizzly Creek syncline, it is probable that the springs emerge from the exposed edge of a permeable stratigraphic unit.

Unit Km appears to be the conduit for deep up-flow beneath the Wilbur Springs area, because the basalt that overlies Km at Wilbur does not outcrop up dip (SW) of the Elgin hot water aquifer. The Elgin Mine aquifer, however, does occur in a stratigraphic position that is similar, if

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not exactly equivalent, to that of unit Km. Both thermal aquifers (at Wilbur and Elgin) are near the base of the Great Valley sequence and, therefore, the Stony Creek Thrust. McLaughlin *et al*. (1990) locate unit Km immediately beneath the thrust (Figure 5). The Wilbur-Elgin aquifer is just up dip from (*i.e*., stratigraphically above), a SW-dipping basalt located across Sulphur Creek from the Elgin mine. This relationship is shown on the geologic map (Figure 5). The basalt underlies sediments of the Great Valley sequence, including the Elgin aquifer, and overlies the Coast Range serpentine from which it is separated by the Stony Creek Thrust.

This geologic model of up-dip flow from the SW, combined with the inferred aquifer temperatures illustrated on section B-B’, will be used to outline a geophysical exploration strategy for the project area to assess prospective drilling targets for development of geothermal fluids.

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7. NEXT STEPS IN EXPLORATION AND DEVELOPMENT

Presently, a geophysical investigation utilizing both magnetotelluric and gravity methods, is planned for the Trebilcot lands south-southwest of Wilbur Hot Springs.

Due to limited surface geology exposure in the area, the use of geophysical methods for subsurface lithology, structure, and hydrothermal alteration will provide valuable information to calibrate the geologic model. Regionally, both structural faults and folds and lithologic zones of impermeability are believed to control subsurface geothermal fluid movement. Of particular interest for a geophysical investigation is the axis and western flank of the southeastern plunging Wilbur Springs Anticline beneath the study area that is thought by some researchers to be the primary fluid migration control mechanism for geothermal fluid surface outflows. The geophysical survey should be designed to

- 1) use MT to identify low resistive anomalies which may represent areas of hydrothermal alteration in the subsurface, and therefore may be associated with a hydrothermal reservoir, that are seen to correlate with our understanding of the structural behavior of the anticline in the subsurface, and
- 2) use gravity to better understand the structural behavior of the anticline in the subsurface.

Details of the planned geophysical survey will be outlined in the final Wilbur Hot Springs Area Geophysical Survey Work Plan that will be issued by GeothermEx in early November, 2012. This work plan will demonstrate that field work will not impact mine sites and associated waste, etc., as with the GeothermEx (2012) work plan developed for geologic and geochemical field evaluation efforts. Results of this geophysical work will be integrated into the existing geologic model, as outlined in this report, and presented in the draft Gravity and Electrical Methods Geophysical Surveys Report that will be issued by GeothermEx in early December 2012, and in

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the draft Temperature Gradient Well Drilling Work Plan that will be issued by GeothermEx in mid-January 2013.

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TABLES

Table 2.: Chemical analyses of geothermal waters from the area of Wilbur Hot Springs and vicinity

						mg/l concentrations																										
Code	name	Date	T°C	Flow (gpm)	pH	Na	K	Ca	Mg	SiO2	Alk HCO3	Alk CO3	Talk HCO3	SO4	Cl	Li	Fe	Sr	F	B	NH4	H2S	Br	I	Sum -	Sum+-	% Dif/Sum	TDS (sum)	δD	$\delta^{18}O$	Ref	Comments
A1	Abbott Hot Spring	8/23/2012	23.8	<1 lpm	7.97	4.17	1.02	7.56	384	62.48	1920	1	1920	31.6	15.1		0.01			1.2					32.296	32.554	-0.397	1456.34	-102.7	-8.074	Collected by Mr. Logan Hackett, GeothermEx	
M1	Magma Hole	4/12/1968			7.5	10000	460	2.2	18	78	7900	0	7900	153	11200	1.3	0.14	1.3		350	270	65	34	25	449.05	912.59	1.58873	27968.64			USGS GEOTHERM (Barnes)	as "Wilbur Hot Springs area - Magma well"; sample collected "at depth of 30 m"; temperature logged to 755 ft (93.6°C)
C1	Cordero #1 2525 ft (OH)	6/25/1968			8.6	8920	302	5	25	34	5560	660	6902	76	11640		0.24		6.80	170	264				443.44	856.13	-3.5909	25592.12			Ultrachem, Walnut Cr CA	Sample received at lab 2 July; sample date inferred from drilling depth. Hole being drld w/air, making water at same rate since water found at 625 ft
C2	Cordero #1 3045 ft (OH)	7/2/1968			9.0	10860	482	0	1	84	3709	1850	7472	1080	14000		0.26		4.00	300	190				540.11	1035.5	-4.3218	31999.8			Ultrachem, Walnut Cr CA	Sample received at lab 2 July; sample date inferred from drilling depth. Hole cased at 2656 ft; being drld w/air, 'trace of water to 2745ft, sl.incr at 2745ft to 100B/hr at 2885ft' no incr of water rate after
C3	Cordero #1 3445 ft (SideTr)	7/31/1968	134		8.8	10000	440	1	2	133	5170	1170	7550	263	14400				16.00	400	275	148			536.29	997.95	-7.4778	31407.81			Ultrachem, Walnut Cr CA	Lab report says water smpl recd 21 July but well not at this depth until July 28; other info suggests sample collected 31 July and sent to lab same day. T svy 274°F across 2850~3200 ft (24 hr SI on 30 July)
C4	Cordero #1 4000 ft	07/1968			9.0	9500	630	1.7	1.7	205			8230	46	12900	1.6	0.12	0.5		400	205	200	35	29	500.19	941.39	-6.2672	25651.62			USGS WRD Menlo Park (J.Rapp, #1966)	Also in USGS GEOTHERM (barnes)
B1	Bailey Min.#1 DST#1	8/1/1980			7.8	6010	896	486	1.58	401	699	0	699	360	9990	3.48		19.7	0.16	125					300.78	610.43	1.45177	19187.11				Drld dpth 8562 ft; hole cased to 7372ft, packer in csg at 7264ft.. Solids settled by flocculation from raw, acidified sample, leaving clear gasoline-colored liquid.
B2	Bailey Min.#1 DST#2	8/17/1980			8.1	5060	1110	470	15	218	560	0	560	325	8430			12.7	0.24	120	14.6		40.9	39.9	253.77	526.95	3.68314	16552.32				Drld dpth 9055ft; hole cased to 7372ft, packer in csg at 7164ft. Sample a translucent brown color with moderate load of suspended sediment. Sample collected after 23 hours flow.
B3	Bailey Min.#1	8/30/1980	169																												Pruett Wireline 8-30-80	
B4	Bailey Mineral Well	6/28/1982	88			5470	457	449	0.16	277	324	0	324	84	9820			18	0.38	85	1.2	-0.01			284.1	556.63	-2.0797	17195.47	-12.5	8.1	Thompson(1993)	
B5	Bailey Mineral Well	6/29/1982				5920	412	493	5.39	308	247	0	247	104	10110			20	0.33	99					291.44	584.99	0.36247	18029.09	-5	11.4	Thompson(1993)	
Bk1	Blank's Spr	8/15/1987	44			6900	469	4	77	174	6100	0	6100	10	8200				1.3	173	220	212			331.58	662.45	-0.1064	19996.8	-33	2.1	Thompson(1993)	
Bk2	Blank's Spr	6/5/1992	44			7590	438	3	44.5	119	7090	0	7090	27	9360			5.4	1.92	257		110			380.91	726.21	-4.9043	22471.99	-26	3.8	Thompson(1993)	
Eb1	Elbow Spr	8/15/1987	62			11000	510	1	11.9	198	8600	0	8600	10	12800				0.2	324	230	294			502.26	1007.6	0.30368	30750.5	-16	8.5	Thompson(1993)	
Eb2	Elbow Spr	6/17/1990	59			9200	459.8	1.2	3	67.4	7382	0	7382	182	11880			1.4	6.58	294	370				460.26	893.07	-3.0742	27398.31	-14.6	9.03	Thompson(1993)	
E1	Elgin Mine		64		7.4						7320	0	7320	69	11200						271	110			437.36	452.39	-93.358	15148.76			Robertson & Whitehead (1961)	
E2	Elgin Mine Spr No.1	10/5/1956	59.5	76 lpm	8.1	9440	572	8	24	140	7210	0	7210	275	11500			8.9		240					448.32	876.16	-2.3366	26818.43			USGS GEOTHERM (white)	
E3	Elgin Mine Spr No.2	10/5/1956	68.5	38 lpm	7.4	9110	506	5.9	29	244	7240	0	7240	6.8	11000	10	0.04	3.7	3	240	243	170	30	25	429.65	856.55	-0.3206	26026.76			USGS GEOTHERM (white)	
E4	Elgin Mine Spr No.1	3/27/1957	58	41 lpm	8.2			4	27		7220	0	7220		11500										442.75	445.17	-98.912	15090.46			USGS GEOTHERM (white and others)	In Knoxville SS at serpentine contact.
E5	Elgin Mine Spr No.2	3/27/1957	68		7.5			8	24		7330	0	7330		11200		0.04								436.09	438.47	-98.917	14845.73			USGS GEOTHERM (white)	
E6	Elgin Mine	9/18/1958	64.4		7.8						7320	0	7320	69	11200										437.36	437.36		14877.76			USGS GEOTHERM (roberson and whitehead)	
E7	Elgin Mine	8/25/1966	40		7.7	9720	479	3.5	27	21	7420	71	7564	0.2	11600	14	0.23	1.3		244	221	22			451.22	902.99	0.06102	27133.89			USGS GEOTHERM (white)	
E8	Elgin Mine Spr	2/15/1985	67			8900	478	4.16	24	150	8270	0	8270	90	11000			1.4	2.6	220	360	0.8			447.87	869.41	-3.0276	26275.27	-16.4	6.06	Thompson(1993)	
E9	Elgin Mine Spr	8/15/1987	67			8970	508	4	26.7	234	7200	0	7200	10	11300				1.7	216	340				437.08	861.51	-1.4682	26110.4	-18	6.4	Thompson(1993)	
JM1	Judge Moore Tunnel (nr. Elgin)		60			304	7.4	162	104	119		182	370	910	209		26								30.919	61.972	0.21743	2023.4			USGS GEOTHERM (waring 1915)	
J1	Jones Hot Spr (well)	3/25/1953	61	8 lpm	8.6	10790	556		19		5890	1210	8351	150	12430	14				317					490.65	977.81	-0.3567	29784.57			USGS GEOTHERM (waring 1915)	
J2	Jone's Fountain of Life	8/15/1987	58			9400	510	2	34	126	7200	0	7200	10	11300				1.7	281	290	258			437.08	877.99	0.43692	26740.7	-22	6.5	Thompson(1993)	
J3	Jone's Fountain of Life	9/7/1988	56			9770	475	2.23	31.3	78	7470	0	7470	112	11430			1.2	4.4	340	420	198			447.44	910.58	1.72427	27842.84	-20	6.5	Thompson(1993)	
J4	Jone's Fountain of Life	9/17/1990	59			9339	461	4.4	32.2	85	7113	0	7113	168	10720			1.1	5.6	288	351	60.9			422.79	863.17	2.03895	26229.21	-22	7.5	Thompson(1993)	
J5	Jone's Fountain of Life	3/9/1991	62			9740	513	5.6	41	89	8250	0	8250	170	11210			1.1	5.15	300	218				455.26	907.83	-0.2967	27680.1	-22.6	6.99	Thompson(1993)	
J6	Jone's Fountain of Life	6/5/1992	56			9450	461	3.7	23.4	85	7680	0	7680	336	11500			3	2.68	269		56.6			457.43	882.47	-3.6703	27103.62	-18	6.9	Thompson(1993)	
W1	Wilbur Springs		57		7.2	9140	460	1.4	58	190	7390	0	7390	23	11000					292		178			431.91	846.1	-2.0941	26092.47				
W2	Wilbur Spring	08/1978	55		7.5	8700	408	2.5	45	176	6900		6900	356	9980	11.6	0.17	3.5	2.4	233	294	165	19	12	402.41	813.17	1.02809	24639.07				
W3	Wilbur Main Spring	9/7/1988	53			8520	452	2.26	41.3	168	6690	0	6690	39	10310			2	2.5	312	290	40			401.44	803.25	0.04642	24810.03	-34	5	Thompson(1993)	
W4	Wilbur Main Spring	8/15/1987	54			8500	430	2	41.3	282	6710	0	6710	10	9930				1.5	259	250	248			390.39	788.49	0.97817	24153.43	-21	5	Thompson(1993)	
W5	Wilbur Main Spring	6/6/1990	52			8420	359	1.61	37.7	140	6959	0	6959	40	10651			3.5	3.9	296	121	125			415.56	800.98	-3.7631	24806.9	-21	6.08	Thompson(1993)	
W6	Wilbur Main Spring	3/9/1991	56			8580	460	5.6	54.8	199	7375	0	7375	157	10710			2	3.32	285	214				426.45	828.14	-2.99	25560.6	-25.2	6.01	Thompson(1993)	
W7	Wilbur Main Spring	6/5/1992	58			8560	451	3.3	30.6	185	7060	0	7060	14	11150			5.4	1.65	269					430.63	817.33	-5.3756	25334.13	-20	6.3		
WO1	Wilbur Oil Tst S27,T14N,R5W	3/19/1970	cold		8.6	6700	55	580	92	0.5	62	2	66	72	11400				0.4	23	17		41		324.13	653.5	0.80112	19054.67			White et al (1973) usgs menlo	
SBM	SulfurBnkMine BradleyMn#1					770	70	2	-1	295	1439	0	1439	10	990				2	500	-2	33			51.827	87.211	-18.853	5548.427				
NGA	Ngawha NZ - Jubilee Pool					830	63	7.8	2.5	178	340	0	340	347	1250				0.3	911	178	6			48.079	96.258	0.10409	7943.62				
GR1	Grizzly Spring	3/9/1991	19		7.05	2686	45	52.3	686	90	4845	0	4845	12	3750	3.8		13	0.4	167	16.5		16.1		185.47	363.34	-2.089	9709.885	-36.5	0.14	Thompson(1993)	
S1	Wide Awake Upper Seep	8/23/2012	19.9	<1 lpm	7.23	285	16.8	11.9	3.92	42.37	484	1	484	72.9	141		0.02			6.3					13.749	13.432	1.16682	813.732	-102.5	-8.087	Collected by Mr. Logan Hackett and Mr. Scott Herman, GeothermEx	

Table 3: Chemical thermometers of geothermal waters from the area of Wilbur Hot Springs and vicinity

						mg/l concentrations					Temperatures, °C										
											Na-K-Ca				Na-K-Ca-Mg			Silica			
Code	name	Date	T°C	Flow (lpm)	pH	Na	K	Ca	Mg	SiO2	Beta 1/3	Beta 4/3	SQR (Ca/Na)	Choice	Final	KMgf	Na/Kf	Chal-f (ad)	Chal-f (cond)	Qtz-f (ad)	Qtz-f (cond)
A1	Abbott Hot Springs	8/23/2012	23.8	<1 lpm	7.97	4.17	1.02	7.56	384	62.5	154	26	45.11	154			252		83	112	113
M1	Magma Hole	4/12/1968			7.5	10000	460	2.2	18	78	239	863	0.02	239	157	165	158		96	122	124
C1	Cordero #1 2525 ft (OH)	6/25/1968			8.6	8920	302	5	25	34	207	600	0.03	207	93	145	139		54	86	85
C2	Cordero #1 3045 ft (OH)	7/2/1968			9.0	10860	482	0	1	84						226	156	103	100	126	128
C3	Cordero #1 3445 ft (SideTr)	7/31/1968	134		8.8	10000	440	0	2	133						207	155	125	129	148	154
C4	Cordero #1 4000 ft	1968-07			9.0	9500	630	1.7	1.7	205	267	1049	0.02	267	267	226	184	152	161	172	182
B1	Bailey Min.#1 DST#1	1980-08-01			7.8	6010	896	486	1.16	401	246	316	0.42	246	246	253	254	201	221	214	235
B2	Bailey Min.#1 DST#2	1980-08-17			8.1	5060	1110	470	15	218	271	333	0.49	271	260	203	295	156	166	175	187
B3	Bailey Min.#1	1980-08-30	169																		
B4	Bailey Mineral Well	1982-06-28	88			5470	457	449	0.16	277	207	262	0.44	207	207	270	202	173	186	190	204
B5	Bailey Mineral Well	1982-06-29				5920	412	493	5.39	308	197	251	0.43	197	197	184	188	181	196	196	213
Bk1	Blank's Spr	1987-08-15	44			6900	469	4	77	174	250	714	0.03	250	57	141	186	141	148	163	171
Bk2	Blank's Spr	1992-06-05	44			7590	438	3	44.5	119	244	756	0.03	244	87	148	174	119	122	143	147
Eb1	Elbow Spr	1987-08-15	62			11000	510	1	11.9	198	251	1143	0.01	251	198	177	159	149	158	170	180
Eb2	Elbow Spr	1990-09-17	59			9200	459.8	1.2	3	67.4	250	1007	0.01	250	244	200	164		88	115	117
E1	Elgin Mine		64		7.4																
E2	Elgin Mine Spr No.1	10/5/1956	59.5	76	8.1	9440	572	8	24	140	241	675	0.03	241	155	168	177	128	133	151	157
E3	Elgin Mine Spr No.2	10/5/1956	68.5	38	7.4	9110	506	5.9	29	244	238	691	0.03	238	130	160	171	164	175	182	195
E4	Elgin Mine Spr No.1	3/27/1957	58	41	8.2			4	27												
E5	Elgin Mine Spr No.2	3/27/1957	68		7.5			8	24												
E6	Elgin Mine	9/18/1958	64.4		7.8																
E7	Elgin Mine	8/25/1966	40		7.7	9720	479	3.5	27	21	237	775	0.02	237	130	160	163		33	66	66
E8	Elgin Miner Spr	1985-02-15	67			8900	478	4.16	24	150	239	735	0.03	239	140	161	169	132	137	155	161
E9	Elgin Miner Spr	1987-08-15	67			8970	508	4	26.7	234	244	759	0.03	244	138	162	173	161	172	179	192
E10	Elgin Mine #1	2008-04			7.54	8620	497	6.44	27.2	159	238	669	0.03	238	134	161	174	135	142	158	165
JM1	Judge Moore Tunnel (nr. Elgin)		60			304	7.4	162	104	119	109	57	4.81	57		-15	120	119	122	143	147
J1	Jones Hot Spr (well)	3/25/1953	61	8	8.6	10790	556		19							171	166				
J2	Jone's Fountain of Life	1987-08-15	58			9400	510	2	34	126	250	915	0.02	250	122	158	170	122	125	145	151
J3	Jone's Fountain of Life	1988-09-07	56			9770	475	2.23	31.3	78	242	868	0.02	242	119	157	162		96	122	124
J4	Jone's Fountain of Life	1990-09-17	59			9339	461	4.4	32.2	85	234	719	0.03	234	113	155	163	103	101	126	128
J5	Jone's Fountain of Life	1991-03-09	62			9740	513	5.6	41	89	237	709	0.03	237	104	155	168	105	103	128	131
J6	Jone's Fountain of Life	1992-06-05	56			9450	461	3.7	23.4	85	235	751	0.02	235	137	161	162	103	101	126	128
W1	Wilbur Springs		57		7.2	9140	460	1.4	58	190	248	964	0.01	248	73	145	164	146	155	167	177
W2	Wilbur Spring	1978-08	55		7.5	8700	408	2.5	45	176	235	783	0.02	235	79	145	160	141	149	163	172
W3	Wilbur Main Spring	1988-09-07	53			8520	452	2.26	41.3	168	245	834	0.02	245	95	150	168	138	146	161	169
W4	Wilbur Main Spring	1987-08-15	54			8500	430	2	41.3	282	243	844	0.02	243	91	149	165	175	188	191	206
W5	Wilbur Main Spring	1990-06-06	52			8420	359	1.61	37.7	140	233	831	0.02	233	81	144	153	128	133	151	157
W6	Wilbur Main Spring	1991-03-09	56			8580	460	5.6	54.8	199	235	672	0.03	235	74	146	169	150	158	170	180
W7	Wilbur Main Spring	1992-06-05	58			8560	451	3.3	30.6	185	240	757	0.02	240	117	155	168	145	153	166	175
WO1	Wilbur Oil Tst S27,T14N,R5W	1970-03-19	cold		8.6	6700	55	580	92	0.5	99	134	0.41	99	86	56	68				
SBM	SulfurBnkMine BradleyMn#1					770	70	2	-1	295	228	358	0.21	228			209	178	192	194	209
NGA	Ngawha NZ - Jubilee Pool					830	63	7.8	2.5	178	204	269	0.39	204	151	132	194	142	150	164	173
GR1	Grizzly Spring	3/9/1991	19			2686	45	52.3	686	90	131	189	0.31	131	cool	11	100	106	104	129	132
S1	Wide Awake Upper Seep	8/23/2012	20	<1 lpm	7.23	285	16.8	11.9	3.92	42.4	166	150	1.40	150	94	74	176		64	95	95

Table 4: Wilbur Hot Springs area analysis of non-condensible gases

Code	Name	Date	Time	Sample T°C	Dry gas vol.% CO2	H2S	NH3	Ar	N2	CH4	H2	C2H6	He	O2	Tot. Vol.%	3He/4He R/Ra	T-DAP °C	Refs.
B1	Bailey Min.#1 DST#2	17-Aug-80	11:30 AM		<1		0.0018		1.5	97	<1	2.7		<1	101.20			LFE Environmental
B2	Bailey Min.#1 DST#2	17-Aug-80	3:30 PM		<1		0.0010		10.5	87	<1	2.4		2.5	102.40			LFE Environmental
B3	Bailey Min.#1 DST#2	17-Aug-80	3:30 PM		<1		0.0016		2.5	93	<1			<1	95.50			LFE Environmental
B4	Bailey Min.#1	30-Aug-80	11:25		0.077	0.0010			74	1.09	7.7			19	94.17			LFE Environmental
C1	Cordero #1 (OH)	3-Jul-68			84.7	0.00095	1.43			13.8		0.0230		0	99.95			Ultrachem, Walnut Crk, CA
E1	Elgin Mine H.S. (Uppermost pool)	23-Jun-08			96.7	2.50	<0.00995	0.000794	0.0793	0.743	<0.144				100.02		143	TCI 13481 (Ormat)
J1	Jones (Fountain of Life) H.S.	16-Aug-78		60	32.5	0.001	0.182	0.0135	2.95	60.4	0.145	<DL	<DL	0.104	96.350			Thompson(1993)
J2	Jones (Fountain of Life) H.S.	1988		58?	45.2	0.770	0.013	0.042	4.06	49.6	0.24	0.000	0.00095	0.013		1.6	126	Goff and Janik(1993)
J3	Jones (Fountain of Life) H.S.	9-Mar-91		61.9	40.7	0.369	0.0024	0.0353	6.76	51.9	0.0353	0.147	0	0.0943		1.7	136	Goff and Janik(1993)
J4	Jones (Fountain of Life) H.S.	9-Mar-91		61.9	47.2	0.600		0.0118	2.26	51.1	0.108	0.103	0.0013	0.144		1.7	157	Goff and Janik(1993)
J5	Jones (Fountain of Life) H.S.	2-Jun-92		57	53.3	0.976	0.149	0.0000	2.22	44.0	0.184	0.0872	0	0.0000			121	Goff and Janik(1993)
W1	Wilbur H.S.	1988		54?	91.2	2.80	0.3	0.021	1.17	4.49	0.0014	0	0.00033	0.0000	99.98	1.3	140	Goff and Janik(1993)
W2	Wilbur H.S.	1977		~55	95.6	2.92		<0.02	0.26	3.58	<0.01	<0.05	<0.02	0.04	102.40			Goff and Janik(1993)
W3	Wilbur Main Spr	11-Dec-77			54.2	2.66	0.622	0.319	29	2.36	0.000936	<DL	<DL	4.19	93.35		188	Thompson(1993)
W4	Wilbur Main Spr	11-Dec-77			69.3	2.94	0	0.217	18.8	3.33	0.00266	<DL	<DL	1.26	95.85		211	Thompson(1993)
W5	Wilbur Main Spr	16-Dec-77		53	76.7	2.92	0.0324	0.188	15.1	3.28	0.000108	<DL	<DL	0.634	98.85		143	Thompson(1993)

References:

Goff, F. and C.Janik (1993). Gas geochemistry and guide for geothermal features in the Clear Lake Region, California. In: Active Geothermal Systems and Gold-Mercury Deposits in the Sonoma-Clear Lake Volcanic Fields, California. Soc.Economic Geologists Guidebook Series Vol.16, p.207-261. Ed. J.J. Rytuba.

Thompson, J.M. (1993). Chemical and isotopic constituents in the hot springs along Sulphur Creek, Colusa County, California. In: Active Geothermal Systems and Gold-Mercury Deposits in the Sonoma-Clear Lake Volcanic Fields, California. Soc.Economic Geologists Guidebook Series Vol.16, p.190-206. Ed. J.J. Rytuba.

T-DAP = D'Amore-Panichi geothermometer

Code	Comment
B1	Alkanes as Hexane 1610 ppmv, Aromatics as Xylene 812 ppmv
B2	Alkanes as Hexane 20600 ppmv, Aromatics as Xylene 3330 ppmv
B3	Alkanes as Hexane 2090 ppmv, Aromatics as Xylene 121 ppmv
B4	Alkanes as Hexane 74 ppmv, Aromatics as Xylene <2 ppmv
C1	Sample with 20.1 vol% O2 corrected to 0% air. Propane 46 ppmv. Uncorrected sample contained 4.6 vol.% CO2, 0.75 vol.% CH4. Collected from port on top of 18 inch discharge line while drilling with air (hot making water) at ~3200 ft. H2S and NH3 collected with absorption impingers. CO2, N2, O2 and HCs analyzed on dry gas sample.
E1	Gases collected with caustic. Other geothermometers: Giggenbach CO2-Ar 334°C, CH4-CO2 285°C
J1	
J2	Gases collected with caustic
J3	Gases collected with caustic
J4	Flow-through gas sample
J5	Gases collected with caustic
W1	Gases collected with caustic
W2	Flow-through gas sample
W3	
W4	
W5	

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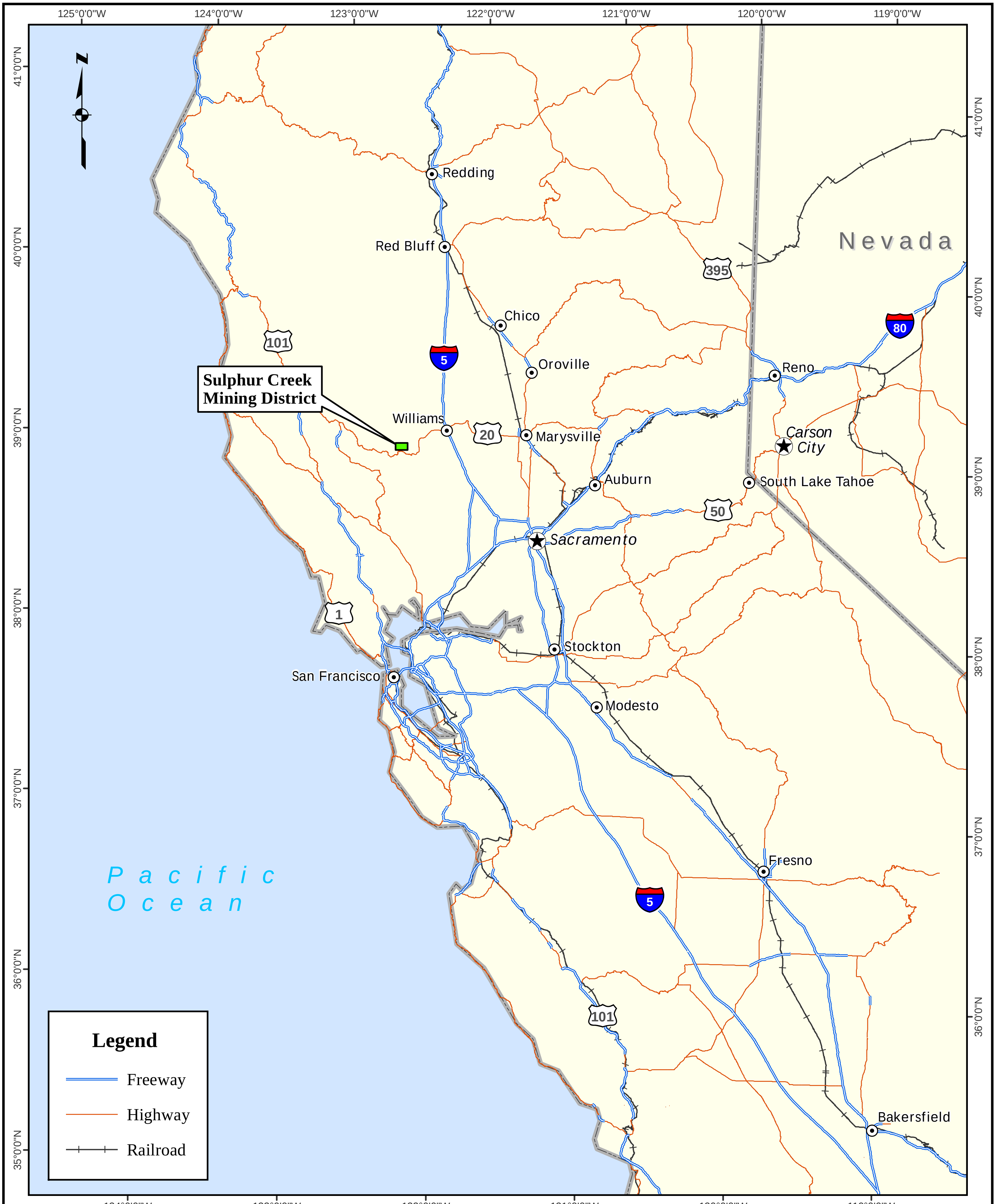
FIGURES



Projection:
NAD27 Lamber
Conformal Conic

0 20 Miles
1:3,000,000

Figure 1: Location of Sulphur Creek Mining District, Colusa Co., California

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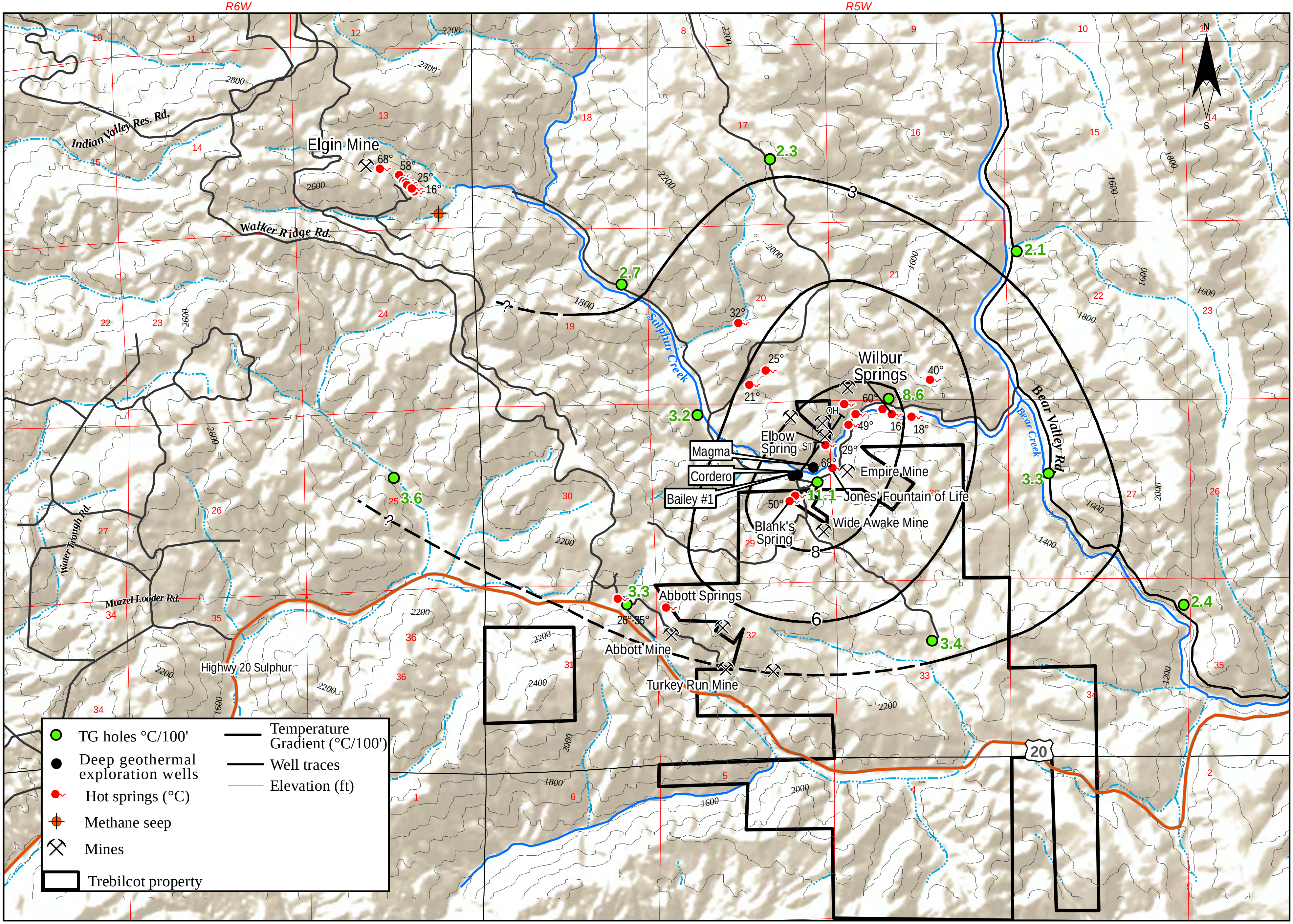

Projection:
NAD83 UTM Zone 10N
Plot Date:
July 21, 2009

0 0.55 Miles
1:45,000

Figure 2a: Locations of hot springs, mines, temperature gradient anomoly, and deep exploration holes, Sulphur Creek Mining District

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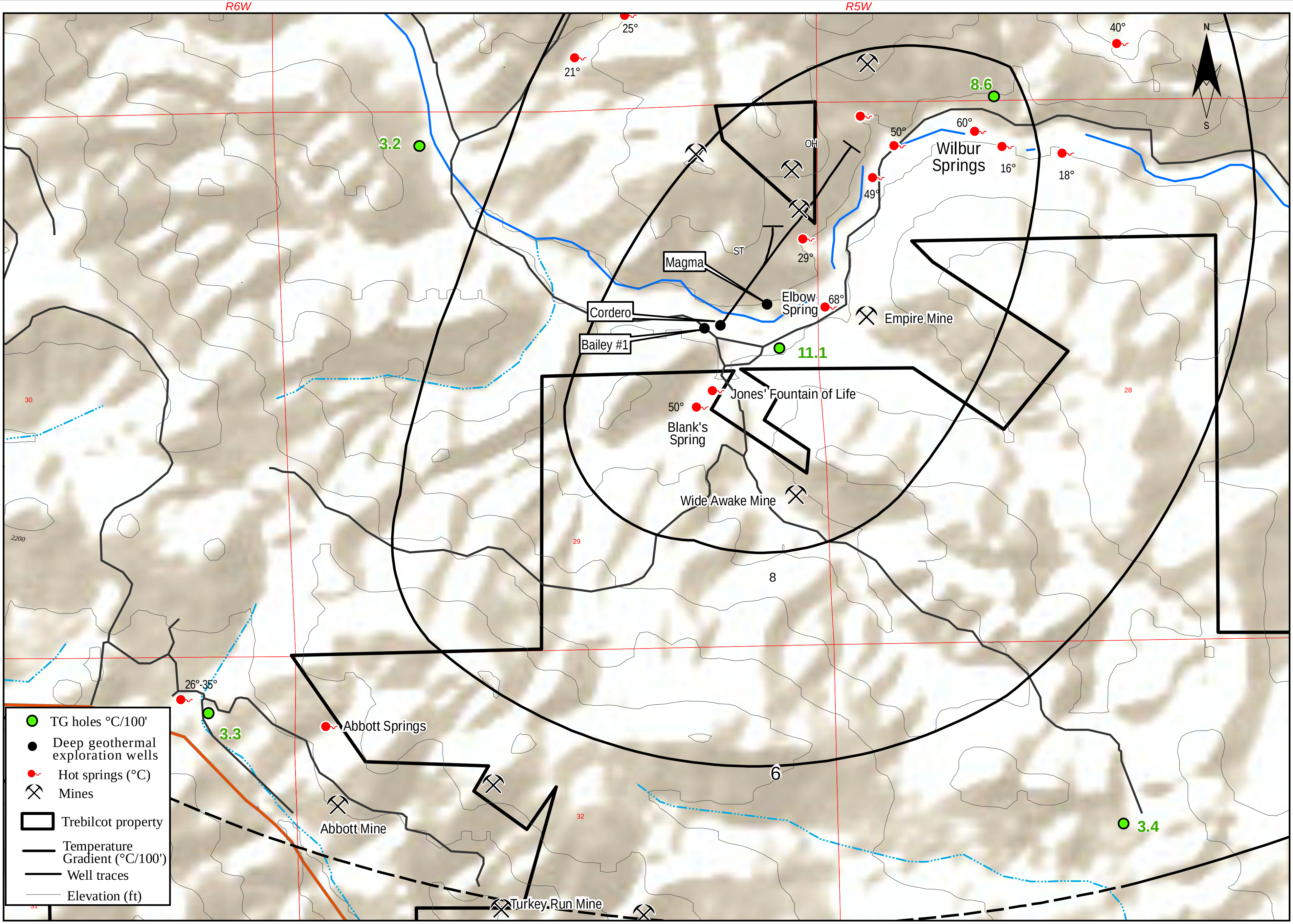

Projection:
NAD83 UTM Zone 10N
Plot Date:
July 21, 2009

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1:15,000

Figure 2b: Detailed map of hot springs, mines, temperature gradient anomaly, and deep exploration holes, in the Wilbur Hot Springs Area

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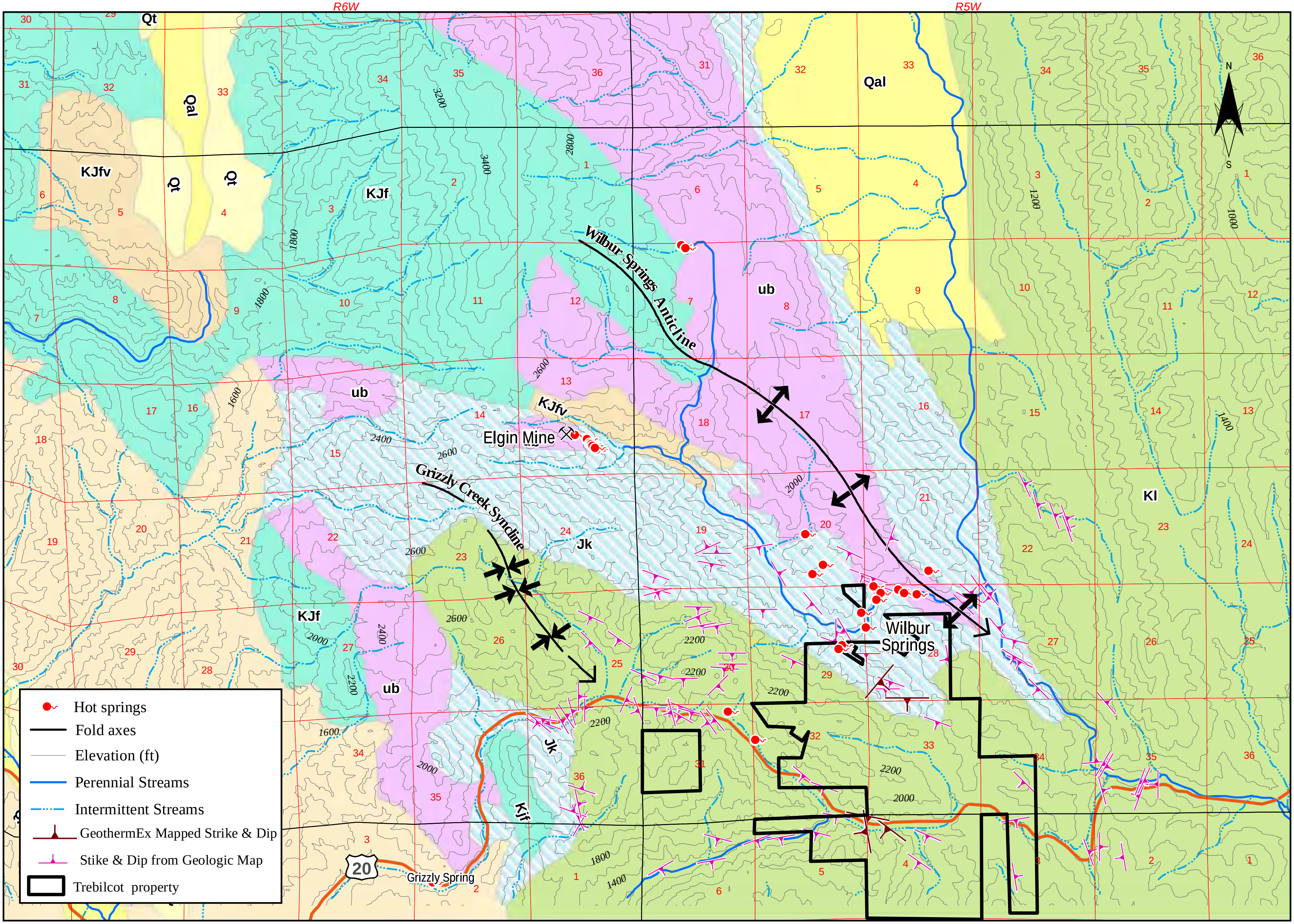

Figure 3: Regional geologic map of area surrounding the Sulphur Creek District

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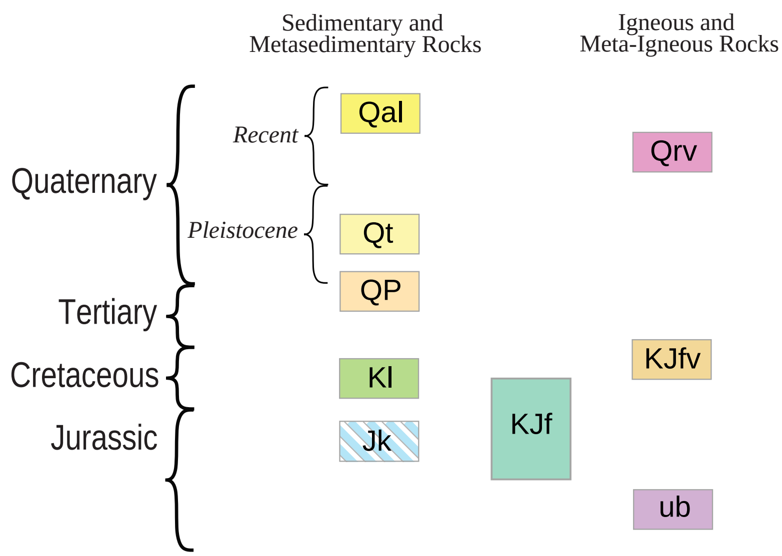
Geologic Legend



Qal	Alluvium
Qt	Quaternary nonmarine terrace deposits
QP	Plio-Pleistocene nonmarine
Qrv	Recent volcanic - rhyolite, andesite, basalt, and pyroclastic rocks
Kl	Lower Cretaceous marine
KJf	Franciscan formation
KJfv	Franciscan volcanic and metavolcanic rocks
Jk	Knoxville formation
ub	Mesozoic ultrabasic intrusive rocks

(Jennings and Rudolph, 1960)

Figure 4: Legend for Geologic map figure 3

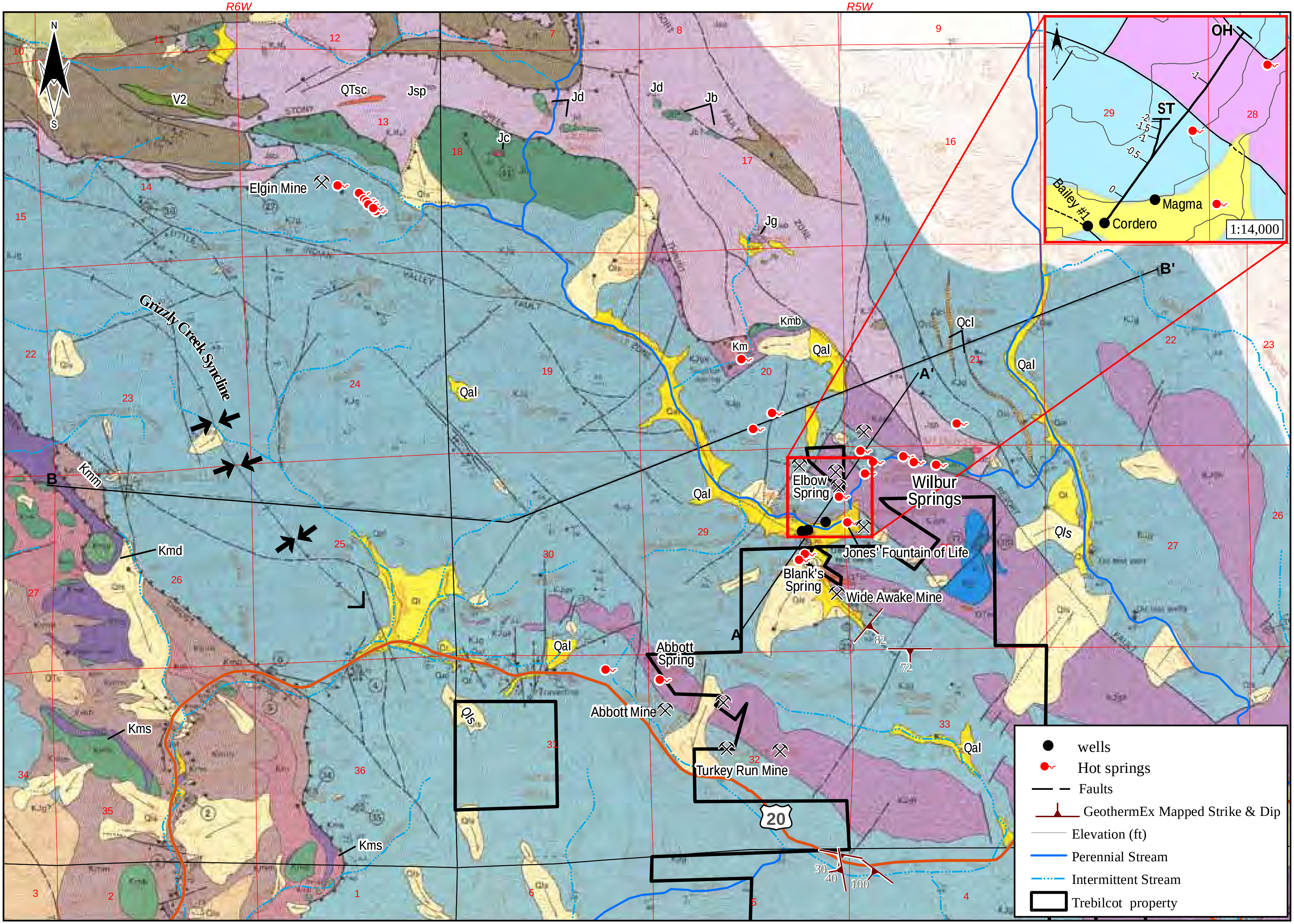
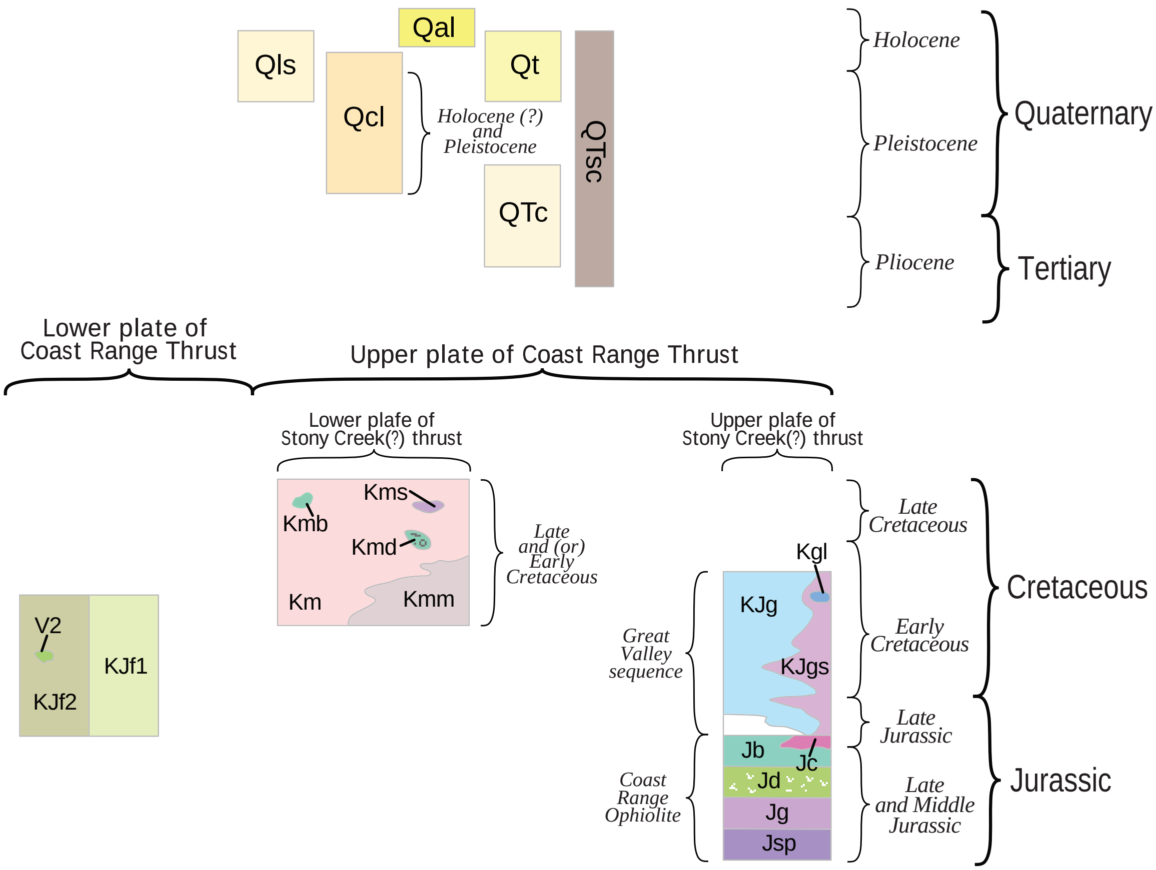


Figure 5: Geologic map showing the locations of springs, exploration wells and cross-sections A-A' and B-B', Sulphur Creek Mining District

Geologic Legend



Qal	Alluvium - Unconsolidated to semiconsolidated rock and soil debris deposited by modern streams	Jd	Diabase - Fine to coarse-grained equigranular to porphyritic; locally with secondary brown to green amphibole replacing pyroxene
Qls	Landslide deposits - Unconsolidated to semiconsolidated rock and soil debris, rock blocks moved downslope by creep, flow, or rotational slumping	Jg	Gabbro - Fine to coarse-grained, layered olivine and orthopyroxene-bearing gabbro ; locally cut by diabase dikes and by dikelets of hornblende-albite pegmatite or plagiogranite
Qt	Terrace deposits - Unconsolidated to semiconsolidated rock and soil debris deposited by streams; minor lacustrine siltstone and mudstone	Jsp	Serpentinite - Penetratively sheared dunite and peridotite, partly to completely altered to chrysotile ± lizardite ± clinochrysotile
Qcl	**Clear Lake Volcanics** - Olivine basalt, basaltic andesite, dacite intrusives and flow rocks	Km	**Melange of Grizzly Creek** - Penetratively sheared, chaotic mixture of rocks incorporated from Coast Range ophiolite and lower Great Valley sequence
QTsc	Silica carbonate rocks - Hydrothermal alteration of serpentinite; occurs locally along faults	Kmb	Basalt
QTc	**Cache Formation** - Semiconsolidated to consolidated pebble to boulder conglomerate, silty sandstone and siltstone; poorly sorted and deposited in alluvial fans and streams	Kmm	Mudstone and sandstone - Mudstone locally contains carbonate concretions with mollusks of Late Jurassic age
KJg	**Great Valley Sequence** - Black, olive-gray-weathered shale and mudstone, brown to gray fine to coarse-grained lithic sandstone; locally conglomeratic; mudstone and shale; carbonate concretions	Kmd	Diabase breccia
Kgl	Limestone	Kms	Serpentinized dunite and peridotite
KJgs	Detrital serpentinite	KJF2	Metasandstone, metachert, and metavolcanic rocks, reconstituted to textural zone 2 of Blake and others (1967). Chiefly composed of sandstone and argillite, but locally includes minor:
Jc	Coast Range ophiolite - Radiolarian chert; intercalated masses of manganiferous red radiolarian chert or green to black tuffaceous radiolarian chert	V2	Volcanic rocks - Metamorphosed; includes basaltic tuff, flows, and intrusive rocks
Jb	Basalt - Pillow flows, flow breccia and tuff	KJF1	Argillitic rocks - Rocks reconstituted to textural zone 1 of Blake and others (1967); isoclinally folded, with prominent slaty cleavage; abundant mollusks of Late Jurassic through Early Cretaceous age

(McLaughlin et al., 1990)

Figure 6: Legend for Geologic map figure 5

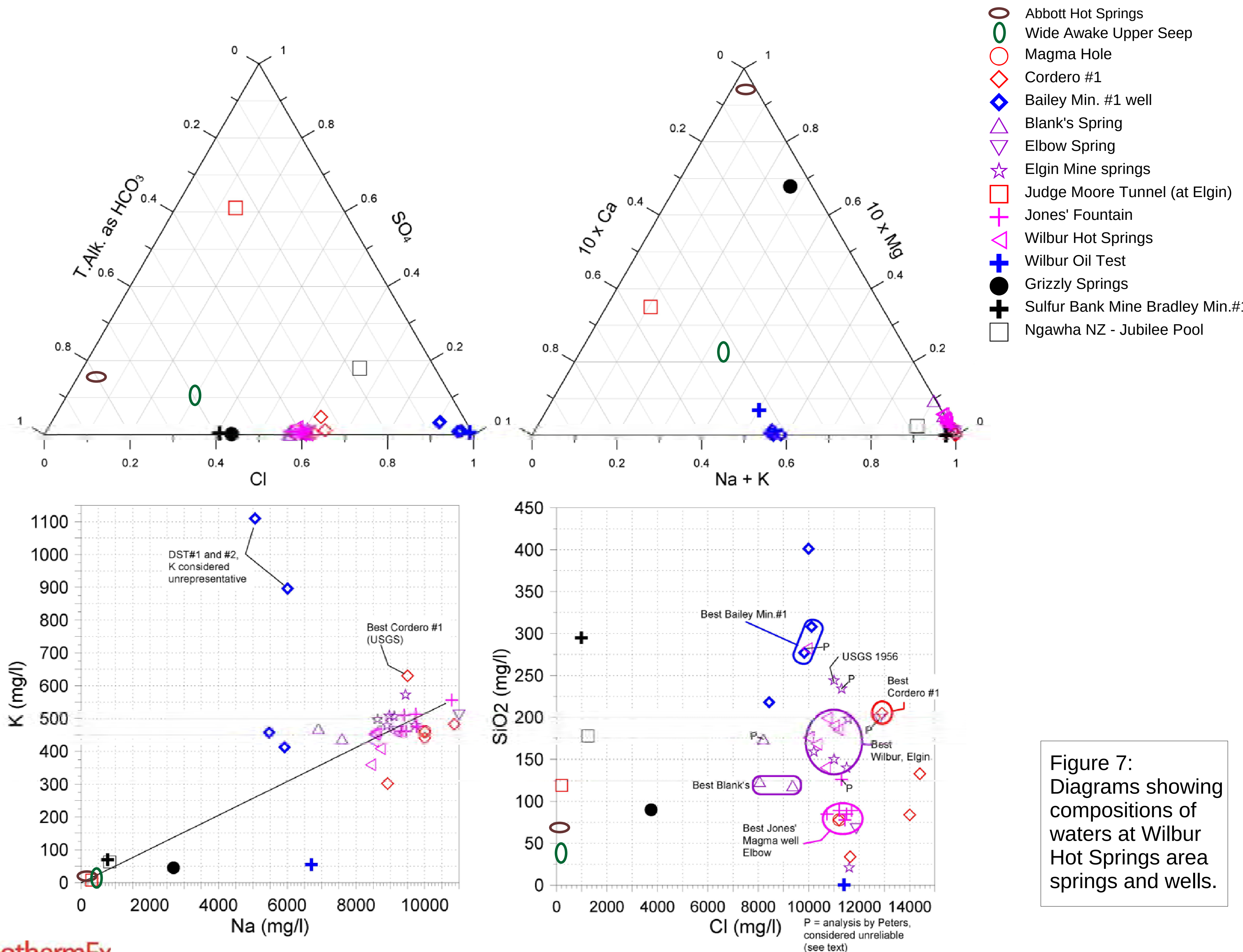


Figure 7: Diagrams showing compositions of waters at Wilbur Hot Springs area springs and wells.

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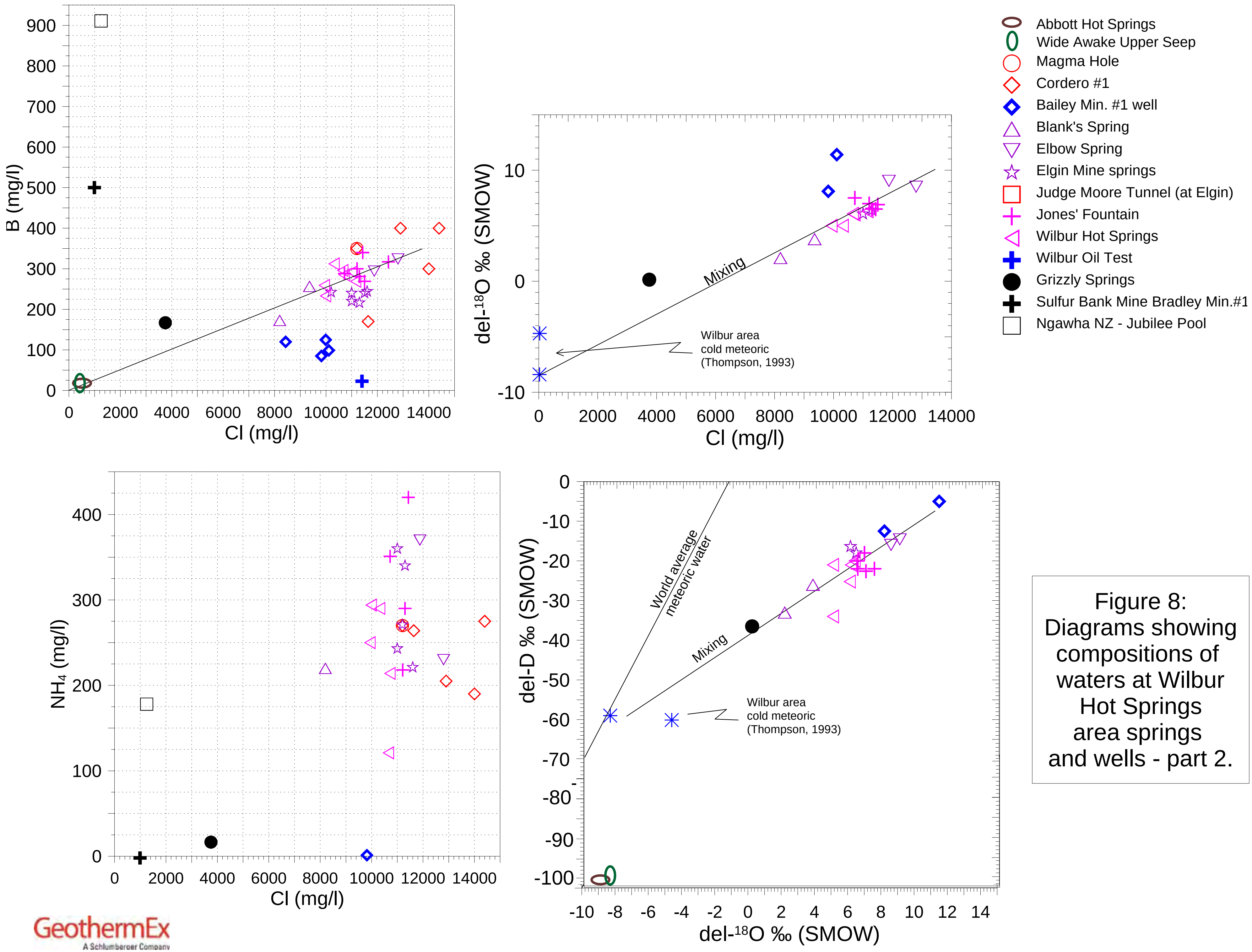

Figure 8: Diagrams showing compositions of waters at Wilbur Hot Springs area springs and wells - part 2.

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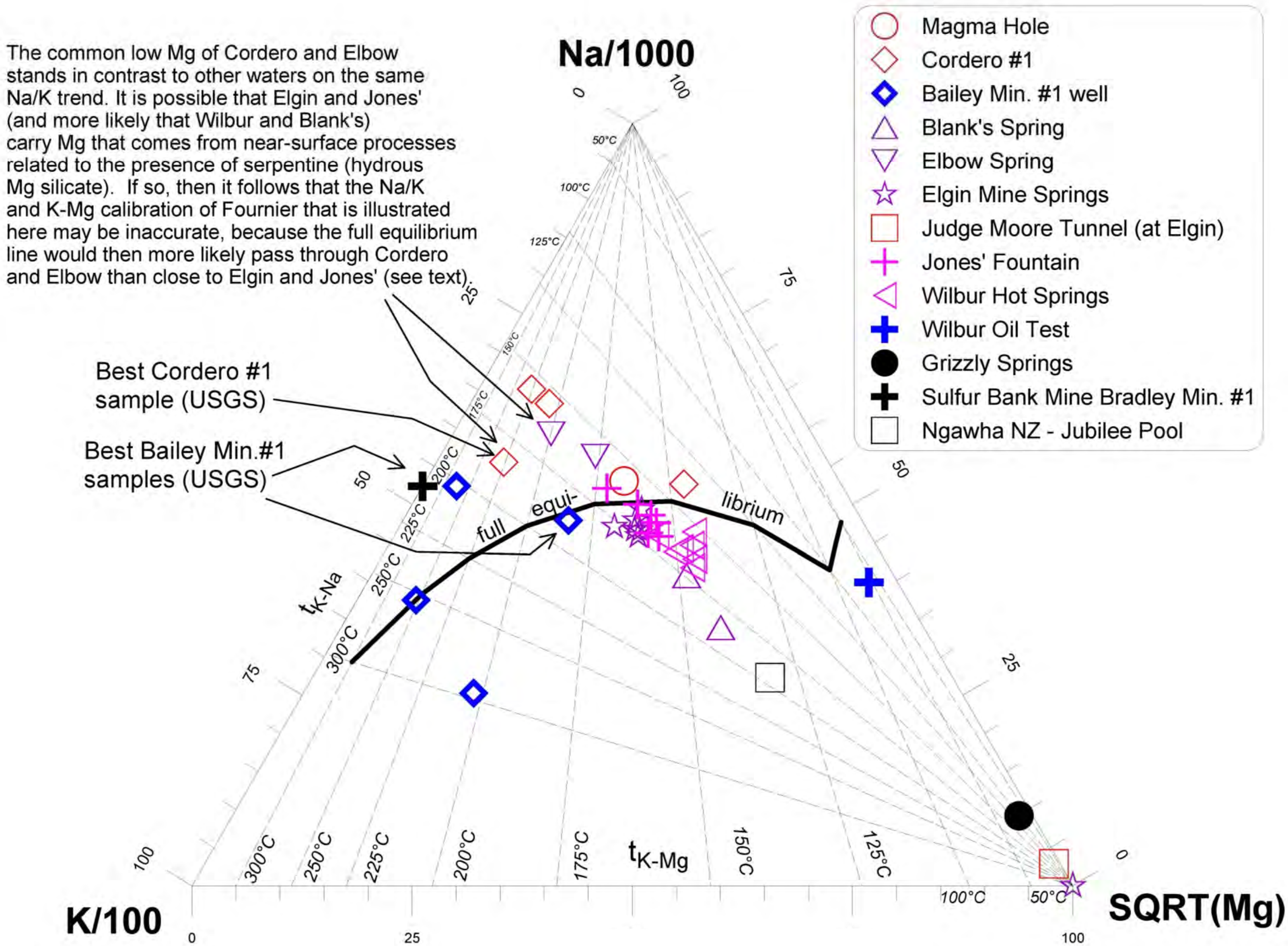
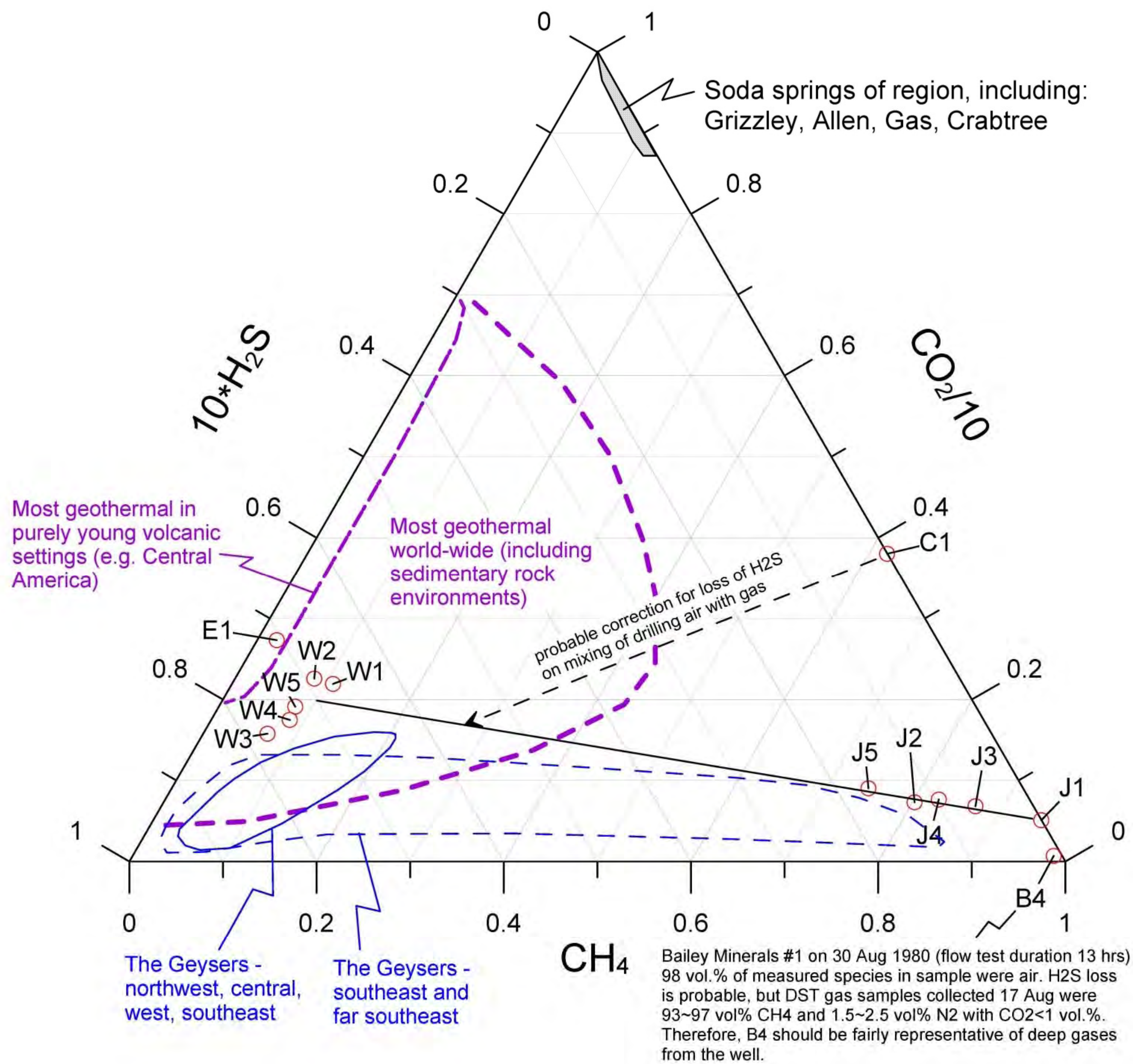
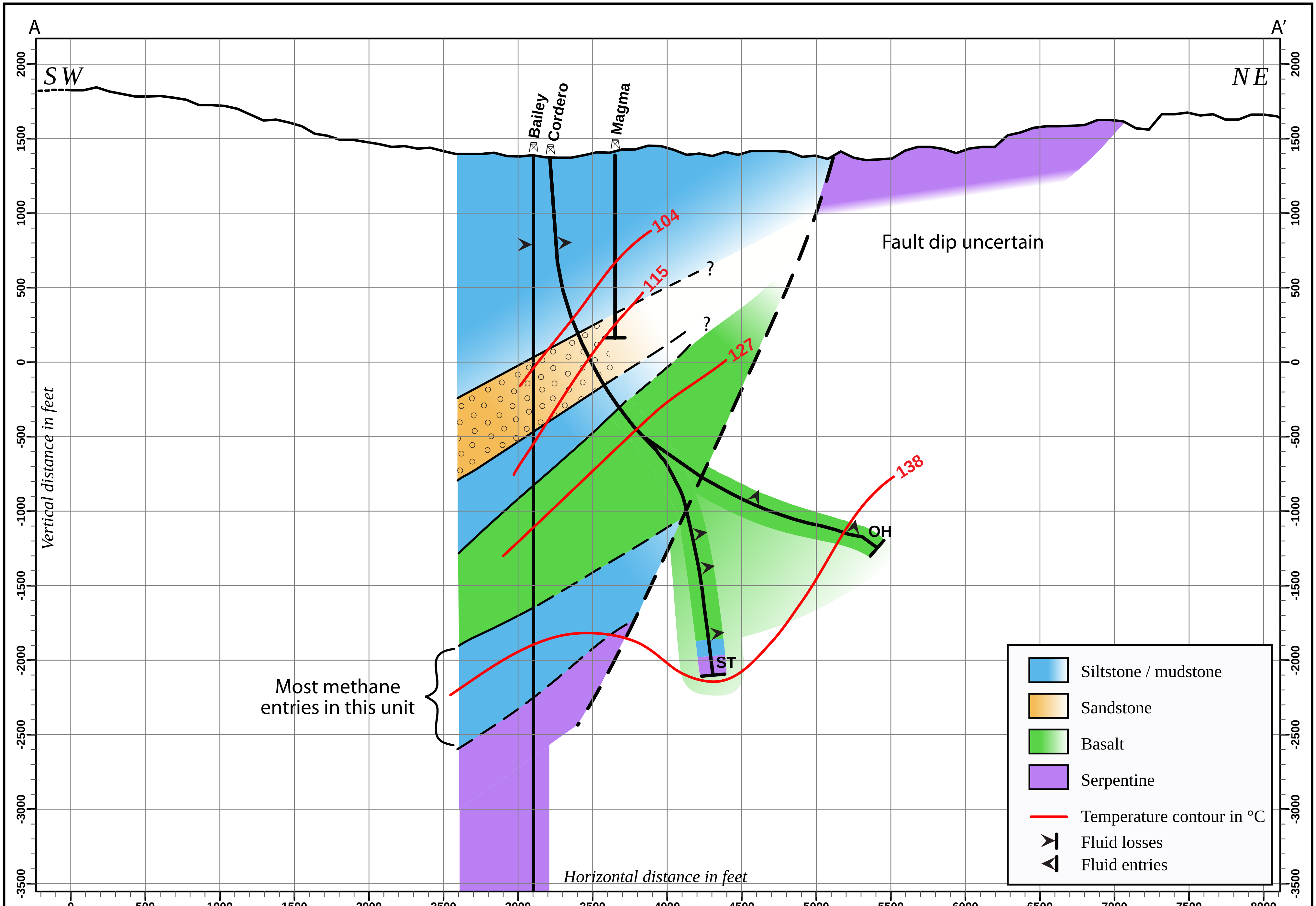


Figure 9:
Graph showing relative concentrations of Na, K and Mg, and Na-K (Fournier 1979) and K-Mg (Fournier 1990) geothermometers

Figure 10: Compositions of NCG at Wilbur Hot Springs area springs and wells





Projection:
NAD27 State Plane Zone 2
Plot Date:
July 13, 2008

Figure 11: Geologic and temperature cross-section A-A' to -3,500 ft msl

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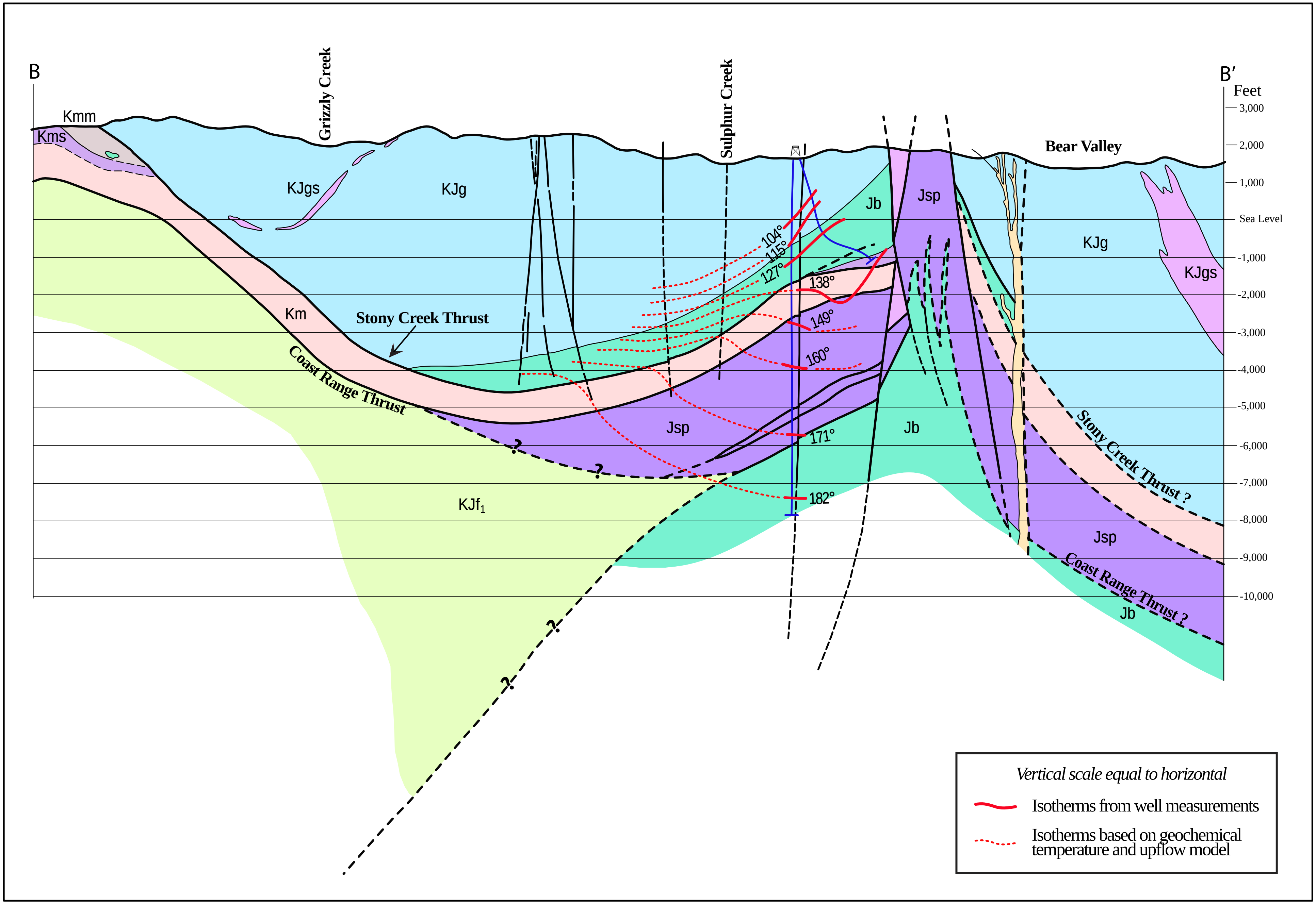

Plot Date:
July 24, 2009

Figure 12: Geologic and temperature cross section B-B' to -10,000 ft msl

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APPENDIX A:

Photos from Field Visit to Project Area

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APPENDIX A:

NOTES AND ASSOCIATED PICTURES FROM FIELDWORK IN WILBUR HOT SPRINGS AREA

PICTURE 1: Walker Ridge pullout looking east toward Trebilcot/BLM land. Abbott mine to left foreground of picture.

a. Coordinates of picture location: +39.0235°, -122.4527°

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PICTURE 2: Unknown tailings pile found in stream valley that is not identified on Tetra Tech (2002) tailings location maps. Additional smaller tailings piles, including a graded road, noted to the SE of picture location.

a. Coordinates of picture location: +39.0215°, -122.4413°

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PICTURE 3: Additional picture of tailings not mapped on Tetra Tech (2002) maps.

a. Coordinates of picture location: +39.0213°, -122.4414°

PICTURE 4: Additional picture of tailings not mapped on Tetra Tech (2002) maps.

a. Coordinates of picture location: +39.0214°, -122.4413°

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PICTURE 5: Area of open terrain SE from Abbott Spring Hiking Location

a. Coordinates of picture location: +39.0197°, -122.4279°

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PICTURE 6: Roadcut in Great Valley Sequence near Route 20

a. Coordinates of picture location: +39.0096°, -122.4293°

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PICTURE 7: Subparallel faulting in conglomerate units of the Great Valley Sequence, SE of Wide Awake mine

a. Coordinates of picture location: +39.0243°, -122.4226°

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PICTURE 8: Sample (120823-1200-Wide Awake Upper Seep) – seep located SW of the Wide Awake mine

a. Coordinates of picture location: +39.0261°, -122.4312°

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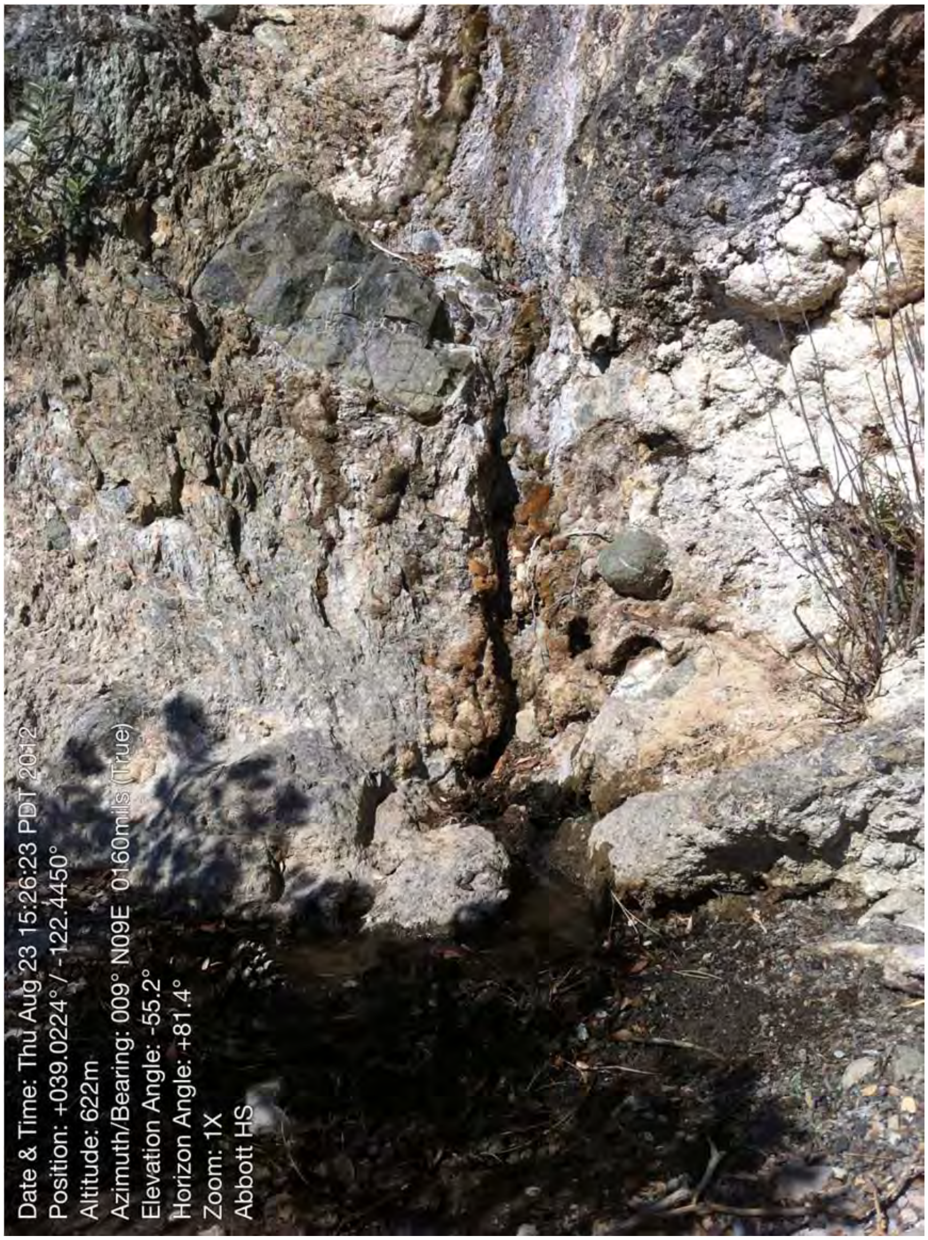
PICTURE 9: Sample (120823-1530-Abbott Hot Springs) – sample taken from Abbott Hot Springs



a. Coordinates of picture location: +39.0224°, -122.4450°

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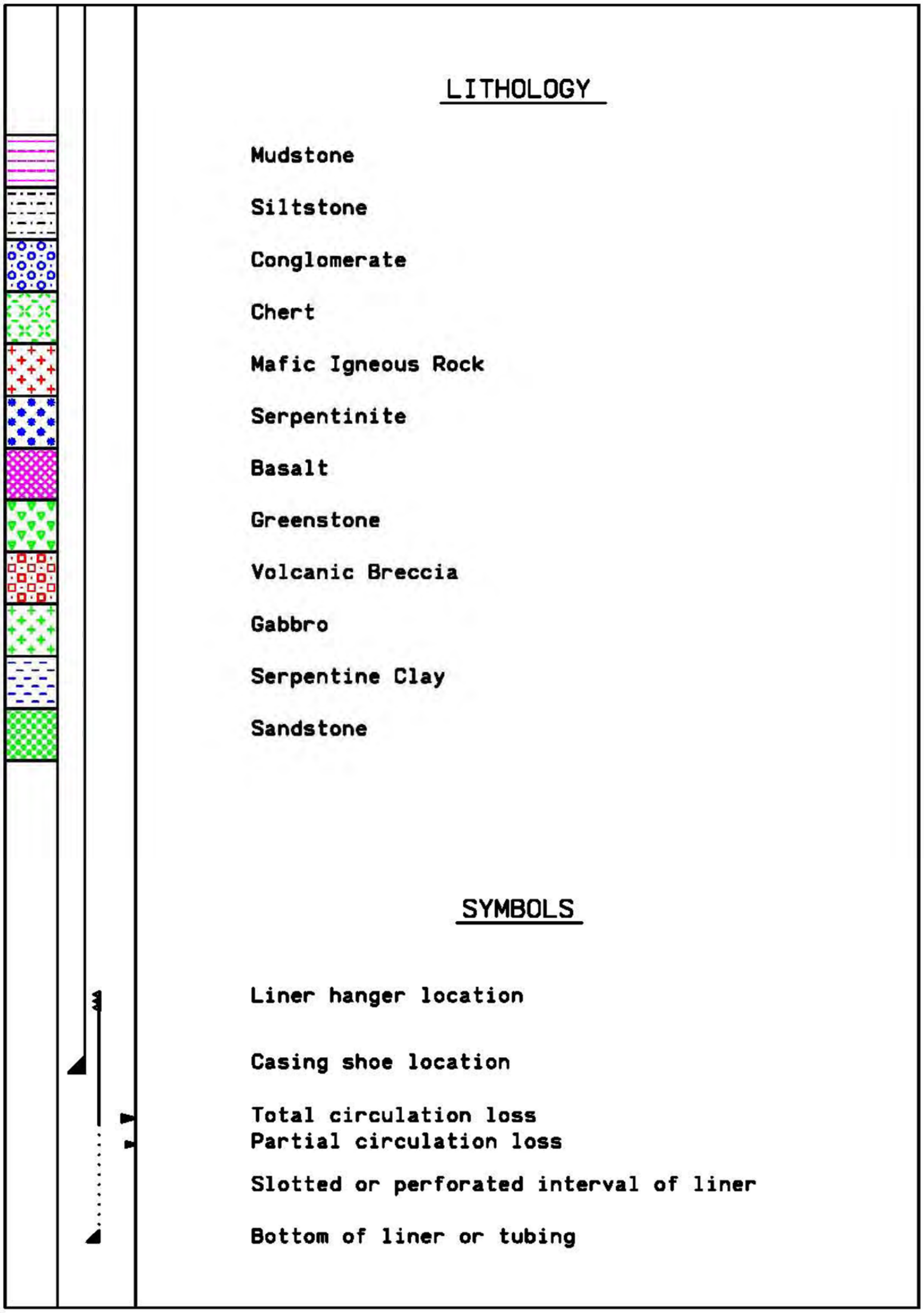
APPENDIX B:

Down Hole Summary Plots for Project Area Wells

EXPLANATION FOR WILBUR HOT SPRINGS DOWNHOLE SUMMARY PLOTS



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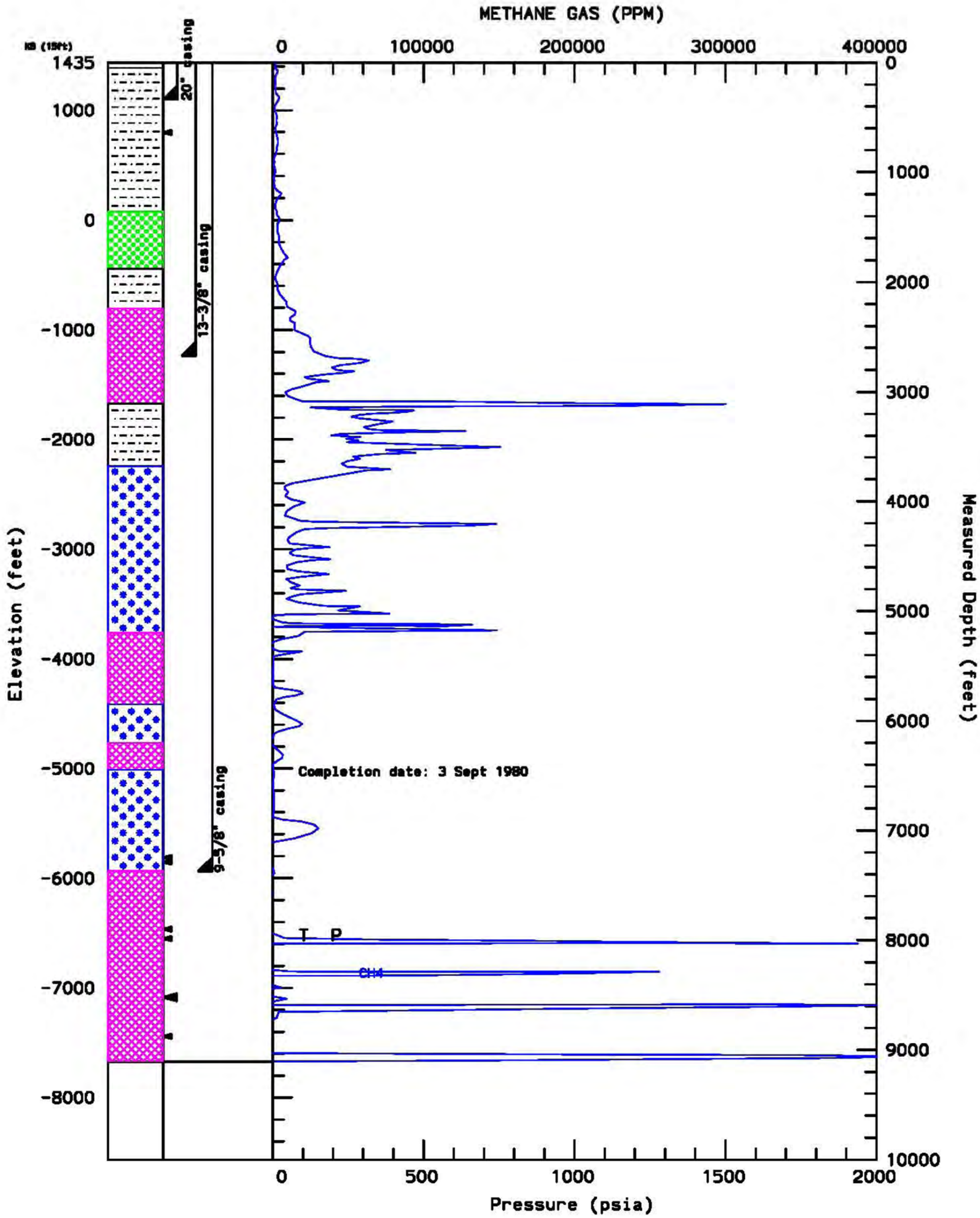
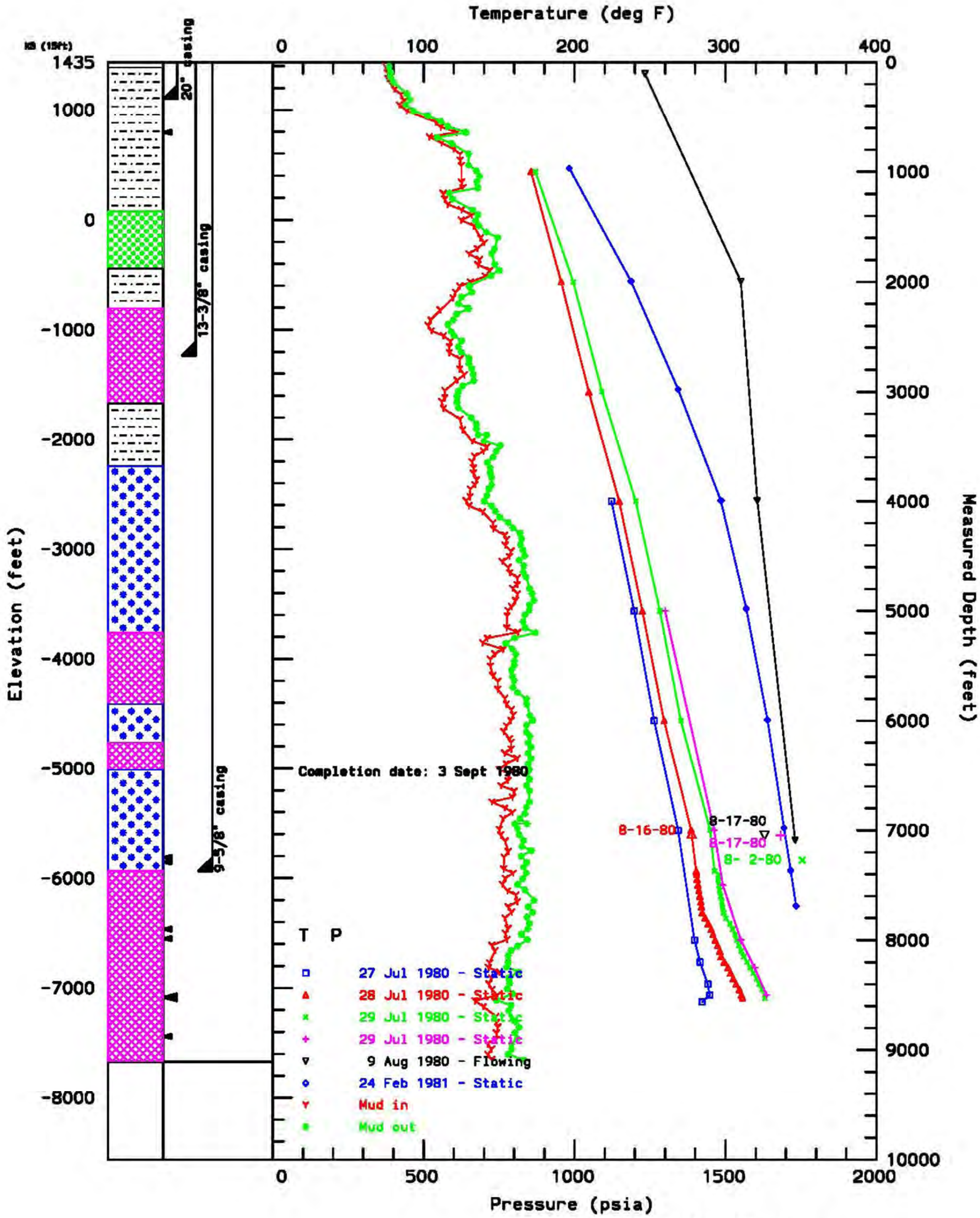
DOWNHOLE SUMMARY - WILBUR HOT SPRINGS WELL BAILEY #1



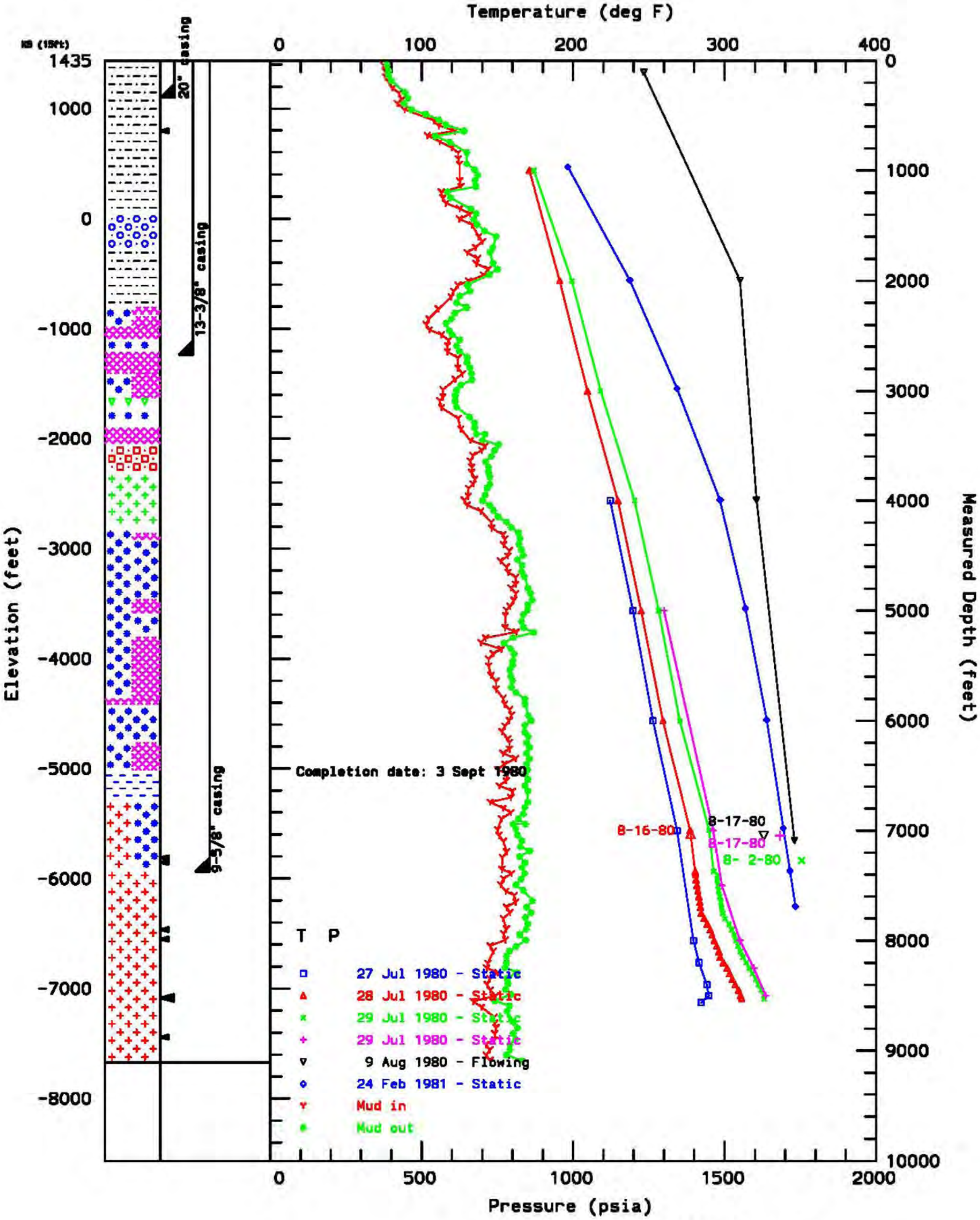
GeothermEx, Inc.

DOWNHOLE SUMMARY - WILBUR HOT SPRINGS WELL BAILEY #1



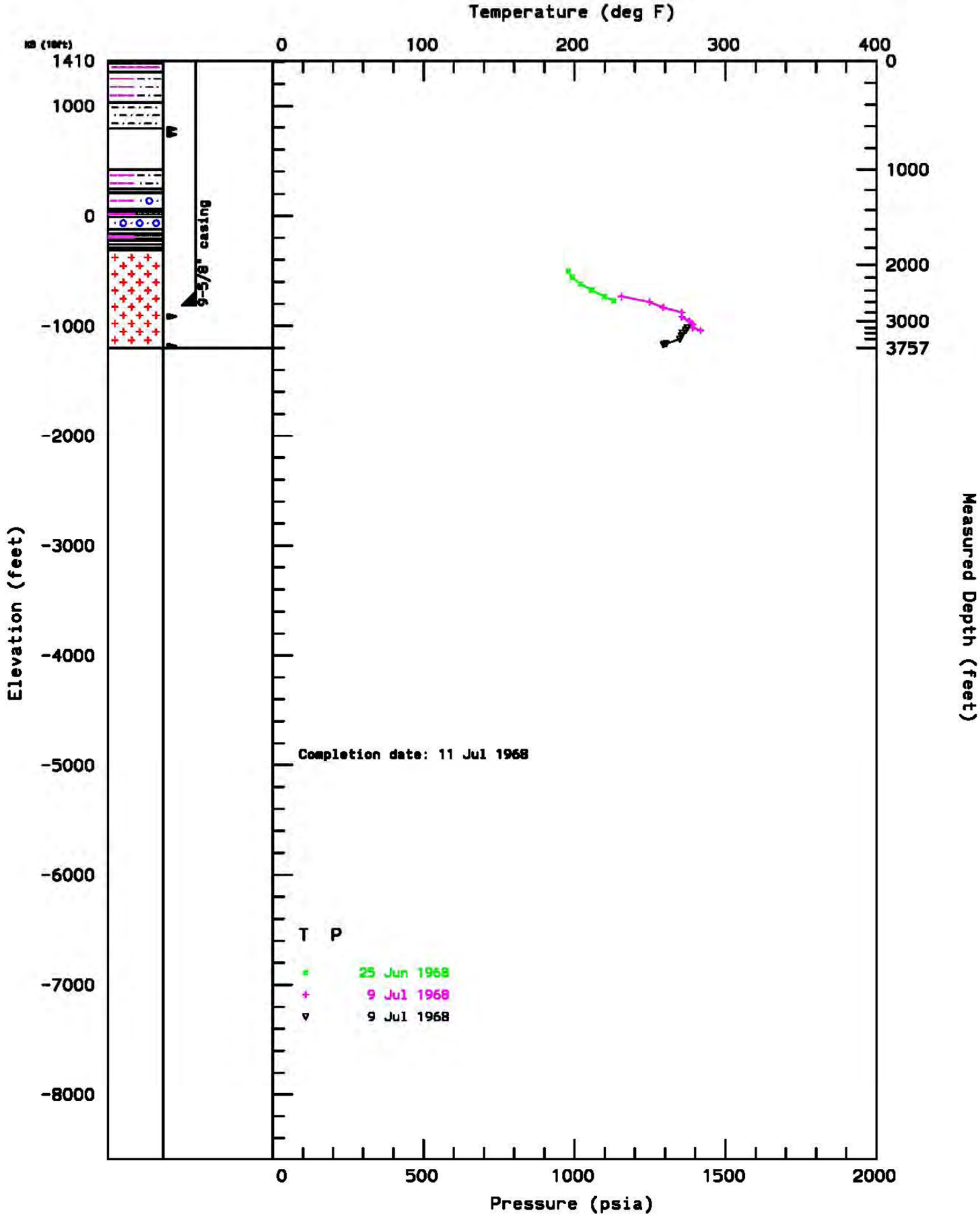
GeothermEx, Inc.

DOWNHOLE SUMMARY - WILBUR HOT SPRINGS WELL BAILEY #1



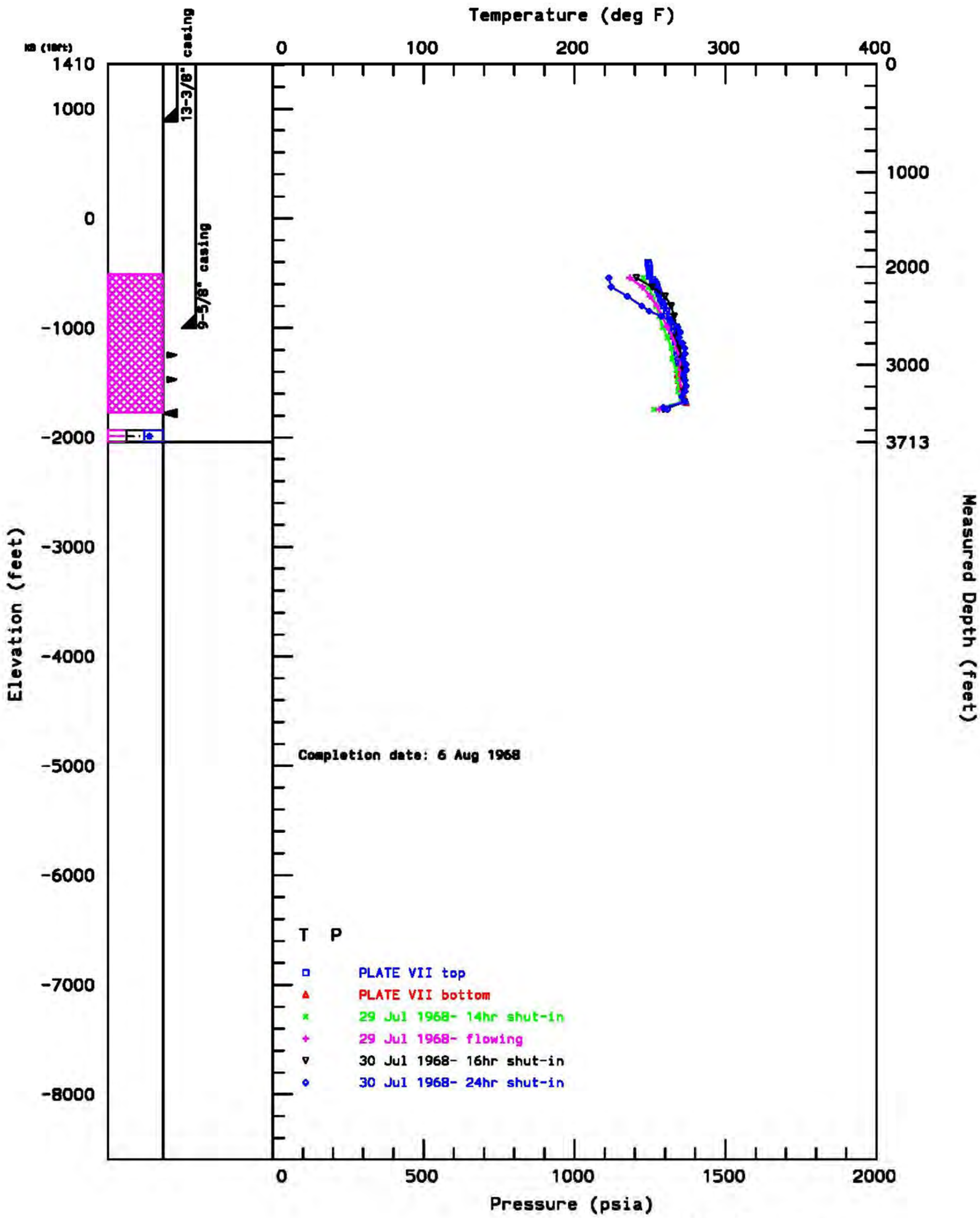
GeothermEx, Inc.

DOWNHOLE SUMMARY - WILBUR HOT SPRINGS WELL CORDERO OH

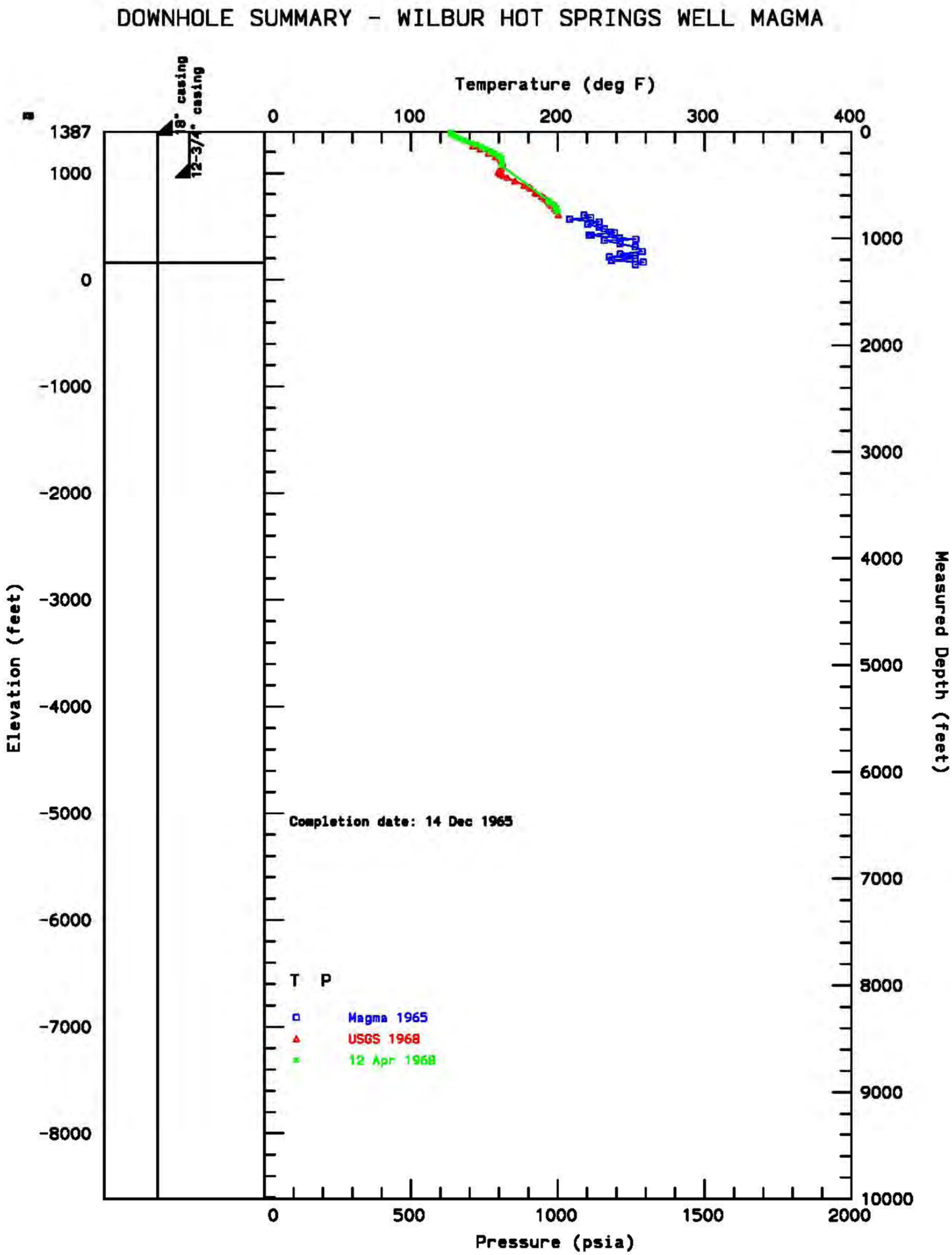


GeothermEx, Inc.

DOWNHOLE SUMMARY - WILBUR HOT SPRINGS WELL CORDERO ST



GeothermEx, Inc.



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APPENDIX C:

Thermochem Laboratory Reports for Samples Collected During August, 2012 Fieldwork

GeothermEx
Wilbur Springs

Report of Analysis

Lab Number: 16718 - 1

Descriptor: Wide Awake - Upper Seep Brine 8-23-12 12:00
Seep from draw SW of Wide Awake mine

Analyte	mg/kg
Sodium	285
Potassium	16.8
Calcium	11.9
Magnesium	3.92
Iron	0.016
Boron	6.33
Silica	19.8
Chloride	141
Sulfate	72.9
Total Alkalinity (as HCO3-)	484
Carbonate Alkalinity (as CO3=)	<2
Bicarbonate Alkalinity (as HCO3-)	484
TDS (Calculated)	1040
Lab pH (units)	7.75

GeothermEx
Wilbur Springs

Report of Analysis

Lab Number: 16718 - 2

Descriptor: Abott HS Brine 8-23-12 15:30

Analyte	mg/kg
Sodium	4.17
Potassium	1.02
Calcium	7.56
Magnesium	384
Iron	<0.01
Boron	1.21
Silica	29.5
Chloride	15.1
Sulfate	31.6
Total Alkalinity (as HCO3-)	1920
Carbonate Alkalinity (as CO3=)	<2
Bicarbonate Alkalinity (as HCO3-)	1920
TDS (Calculated)	2390
Lab pH (units)	8.09

16719 (1-2) October 5, 2012

GeothermEx
Wilbur Springs

Report of Analysis

Lab Number	Descriptor	δ ^{2}H (‰), H_2O V-SMOW [1]	δ ^{18}O (‰), H_2O V-SMOW [1]
16719 - 1	Wide Awake, Upper Seep Brine 8-23-12 12:00 Seep from draw SW of Wide Awake mine	-102.5	-8.074
16719 - 2	Abott HS Brine 8-23-12 15:30	-102.7	-8.087

1. Measurements relative to V-SMOW = 0 with uncertainty of +/-1.0% for δ ^{2}H and +/-0.1% for δ ^{18}O

   V-SMOW = Vienna distribution of water sample representing Standard Mean Ocean Water

APPENDIX C:
Geophysical Work Plan for the SMUD-Renovitas Project, Colusa County, California

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GEOPHYSICAL WORK PLAN FOR THE SMUD-RENOVITAS PROJECT, COLUSA COUNTY, CALIFORNIA

FINAL

for

SACRAMENTO MUNICIPAL UTILITY DISTRICT

and

RENOVITAS LLC

in support of

Exploration Drilling and Assessment of Geothermal Resources,

Colusa County, California

California Energy Commission GRDA Grant #GEO-10-003

by

GeothermEx, Inc.

Richmond, California, USA

9 NOVEMBER, 2012

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1. INTRODUCTION

The Sacramento Municipal Utility District (SMUD) is interested in developing a geothermal power project in the Wilbur Hot Springs area of Colusa County. Renovitas LLC (Renovitas) has obtained partial funding from the California Energy Commission (CEC) to undertake certain geothermal exploration and resource characterization activities.

This document describes the follow-on effort to further evaluate geothermal resources for geothermal power development in Colusa and Lake Counties, California. Activities to date include the preparation and approval of a "Geologic and Geochemical Work Plan for the SMUD-Renovitas Project (FINAL)" (GeothermEx, 2012a) and geologic and geochemical fieldwork with subsequent reporting of findings in the "Geologic and Geochemical Evaluation of Geothermal Resources for Geothermal Power Development (FINAL)" document (GeothermEx, 2012b).

The geophysical work outlined in this document is intended to aid in development and validation of the Wilbur Hot Springs area geothermal resource model, which will in turn be used to develop an exploration drilling strategy. Due to limited surface geology exposure in the area, the use of geophysical methods for collection of data on subsurface lithology, structure, and interpreted areas of hydrothermal alteration will provide valuable information to calibrate the model. Regionally, structural faults, folds, and lithologic zones of impermeability are believed to control subsurface geothermal fluid movement. Of particular interest for a geophysical investigation is the axis and western flank of the southeastward plunging Wilbur Springs Anticline beneath the study area that is thought to be the primary structure controlling fluid migration for geothermal fluid surface outflows, as further discussed in GeothermEx (2012b).

GeothermEx is providing guidance for geophysical surveys to take place in late-November, 2012.

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The project area (shown on Figure 1[1]) has long been known to have geothermal resources, and previous investigations of these geothermal resources have been undertaken by various parties. The project area is also known to be situated within a former mercury-mining district, and there are several abandoned mines within and nearby the area of interest. Certain efforts are underway by other parties [including the Central Valley Regional Water Quality Control Board (CVRWQCB)] to identify and characterize areas of mercury-mining waste (*e.g.*, tailings piles), and to develop and implement plans to remediate the associated environmental impacts.

In this context, the execution of this work plan in the project area must be undertaken in a way that: 1) avoids disturbing areas of mining waste; 2) is consistent with identification, characterization and remediation efforts; and 3) provides geophysical data valuable for SMUD's geothermal exploration and characterization activities.

1.1 Purpose and Scope

The purpose of this document is to develop a work plan for a geophysical exploration program that includes details of how geophysical surveys will be conducted in the area without disturbing mining waste that is known to be present. The work plan is presented herein with details on the means by which work will be conducted while avoiding disturbance of mining waste. It is GeothermEx's understanding that this plan will be reviewed by the California Energy Commission (CEC), the California Department of Fish and Game (CDFG), and the CVRWQCB, and that work will begin after receiving approval from these agencies.

[1] Because of the lack of recent land surveys in this area, the Geographic Information System (GIS) shape files provided by various entities (including BLM) do not always align well with other information, resulting in uncertainty with respect to the boundaries of some land parcels.

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1.2 Background

As an initial step for exploration activities in the Wilbur Hot Springs area, GeothermEx developed a GIS-based map of land ownership, including surface and mineral estates and their boundaries. As noted by ownership type in the legend of Figures 1, 2, and 3, there are numerous land owners in the area, with several combinations of property rights, including:

- ownership of both the surface and mineral rights by a single entity (either public or private); and
- multiple cases of split property ownership, with surface and mineral rights held by separate entities (either public or private).

SMUD has evaluated property rights and ownership in the project area to identify areas within which it could develop a geothermal project. SMUD reports that it has obtained the geothermal (mineral) rights to the property previously held by the Trebilcot estate. The mineral rights of this property (which are now held by SMUD) are shown as a black diagonal pattern on Figure 1. As can be seen, the surface rights are not owned by SMUD, but instead by other entities, including the US Bureau of Land Management (BLM), the CDFG, and certain private parties.

The BLM has been consulted on this project and advises that the planned geophysical exploration activities on all BLM lands, regardless of mineral ownership, are classified as "casual use" and do not require a permit. GeothermEx has obtained appropriate permission from BLM for conducting the planned work, as per the email issued by Mr. James P. Haerter of BLM, on 18 October, 2012.

The CDFG was also consulted on this project, as some of the surface land adjacent to the BLM land is under its jurisdiction. In the meeting held on 17 October, 2012, GeothermEx presented the proposed project, including all available and current data on land areas and surface ownership to CDFG. CDFG agreed to review this work plan and to make the decision on whether to grant access for the proposed work plan without the need for a permit. GeothermEx will continue to submit inquiries for access with CDFG until fieldwork begins in late-November, 2012. Unless access is granted to CDFG land, this property will not be accessed at any time during this study.

Other activities, particularly drilling (temperature-gradient wells, slim holes and full-diameter production wells) will require permits, and there are certain restrictions on where such activities can take place. However, this work plan is focused solely on geophysical surface exploration activities that do not require permits (*i.e.*, no drilling activity) to understand the potential for finding an economically productive geothermal resource within the area of mineral rights controlled by SMUD.

During this phase of exploration in the project area, GeothermEx intends to supervise a geophysical survey, to be carried out by Western Geco, which is non-invasive and results in no disturbance to the study area. This work will avoid all known areas of mine workings and waste, maintaining a 100-foot buffer zone of these areas at all times. During this activity, GeothermEx and Western Geco will adhere to the fieldwork procedures outlined in Section 3, and will avoid and report any previously undocumented mining features, as outlined in Section 4.

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2. ACCESS AND ITS RELATIONSHIP TO THE WORK PLAN

GeothermEx is allowed to undertake exploration work on all public lands held by BLM. The BLM has given clearance without the need for a permit, and the level of clearance needed is presently being clarified with CDFG, as described in Section 1.2. In addition, GeothermEx can use public roads to gain access to these public lands. No landowner permission is required to access public lands where the study will be conducted. Therefore, no request for access to private parties has been issued. For reference, Table 1 (below) summarizes public lands on which GeothermEx has gained or hopes to have access, and private party lands that will not be accessed. Table 1 also indicates the respective access-granting party and the status of access at the time of issuance of this work plan.

Property	Party Granting Access	Status
Public Land		
BLM	**BLM**	**Granted**
CDFG	**CDFG**	**Awaiting determination**
Colusa County	**not applicable**	**No Permit Required**
Lake County	**not applicable**	**No Permit Required**
Private Land		
Abbott and Turkey Run Mines	**unknown land trust**	**Will not be accessed**
Wide Awake Mine (central)	**Merced General Construction, Inc.**	**Will not be accessed**
Wide Awake Mine (peripheral)	**David Brown**	**Will not be accessed**
Bailey Minerals	**Dr. Richard Miller**	**Will not be accessed**
Wilbur Hot Springs	**Dr. Richard Miller**	**Will not be accessed**

Table 1. Summary of project area properties and access status

The work that GeothermEx plans to conduct on public lands is further discussed in Section 3.

Figure 2 (on a shaded topography base) shows the public roads, mines, known areas of mining waste, and hot springs in the area of interest. The same map is presented on a satellite image base as Figure 3. All information related to mining activities, including mine locations, tailings,

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waste rock, cuts, and adits, was digitized and reviewed using maps and information available in multiple evaluation and engineering documents [California Department of Conservation (CDC) and California Geological Survey (CGS), 2003; Tetra Tech, 2003; CVRWQCB, 2007; ERM, 2010]. Sections 3 and 4 present a detailed discussion on the means by which GeothermEx and Western Geco field personnel will avoid known areas of mines and mine waste.

With regard to public land access, GeothermEx is particularly interested in conducting the following geophysical activities:

- a focused magneto-telluric (MT) survey on combined Trebilcot and BLM land in the Wilbur Hot Springs area, where the geophysical survey strategy is depicted on Figure 4 along with property boundaries and areas of known mine workings and waste. This work will consist of 75 stations that cover approximately 9.9 km^2, and will be aimed at better understanding resistivity properties in the subsurface, and
- a focused differential-global-positioning-system (dGPS) and gravity survey utilizing the same 75 stations, as these measurements will be taken in parallel with the MT measurements, and will be aimed at better understanding density properties in the subsurface.

There are no known areas of mine waste on BLM and CDFG land where field activities will be conducted. Any discovered areas of mine workings and waste on BLM and CDFG land will not be included in this investigation, and a 100-foot buffer zone will be implemented and adhered to by field work personnel to avoid disturbing existing or identified mine features.

None of the geophysical survey activities outlined in this document on BLM (and possibly on CDFG) land will occur until CEC, CDFG, and CVRWQCB approve this plan.

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3. WORK PLAN

3.1 Exploration Activities

GeothermEx has compiled available geologic and geochemical data for the project area, including:

- Fieldwork for this project, including geologic evaluation and geochemical sampling, as conducted by GeothermEx in August, 2012 and summarized in the 1 November, 2012 document titled "GEO-10-003 Geologic and Geochemical Evaluation of Geothermal Resources for Geothermal Power Development (FINAL)" (GeothermEx, 2012b)
- Data from wells previously drilled in the area by Magma, Shell, and Cordero Mining
- Mine histories from the Sulfur Creek Mining District
- Several published geologic maps of the area
- Data from geophysical surveys by the U.S. Geological Survey and other researchers

This information has been reviewed to develop the data-collection strategy presented in this work plan, as outlined below. The field-collected data will be analyzed to help inform later exploration decisions and field-development strategies, including the upcoming exploration-drilling work plan. The overall purpose is to characterize subsurface conditions in the area, including stratigraphy, geologic structure and potential reservoir boundaries. The program for collecting field data is designed to supplement the existing data and fill in knowledge gaps, as opposed to duplicating already-existing data. The work conducted will not impact or disturb known or unknown mine workings or mine waste in any way.

During this phase of exploration in the project area, GeothermEx intends to oversee non-invasive geophysical surveying with no disturbance to the study area, where all discovered mine workings and waste on public land will be avoided. Available documentation indicates that mining waste is not present on public lands that will be accessed by GeothermEx and Western

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Geco personnel in its field work. However, all personnel will adhere to the procedures for geophysical surveying (as outlined in Sections 3.1 and 3.2), and will identify, avoid, and report any non-documented mining waste (as outlined in Section 4). No work access has been granted on private land; therefore areas of mining waste known to be present on private land will be avoided during this survey.

3.2 Procedures for MT, dGPS, and Gravity Surveys

Two geophysical surveys will be conducted over a period of approximately 20 days. Survey days will be used for 1) reconnaissance of the field area: scouting and sensor testing for a duration of 2 – 3 days; and 2) conducting the geophysical investigation: consisting of an MT survey, and a dGPS and gravity survey including 75 measurement sites for a duration of 16 days. The timetable and schedule of deliverables from Western Geco is presented in Table 2 (below) and is outlined in the proposal by Western Geco in Appendix A.

Component of Geophysical Survey	**Date of Completion**
Reconnaissance of field area: scouting and sensor testing	20 November
Begin geophysical data acquisition	23 November
Complete geophysical data acquisition	8 December
Deliver 3-D modeling results and draft operations report, under expedited delivery (includes all details needed for geophysical evaluation report)	20 December
Western Geco delivery of final modeling report (no expected difference in content from 20 Dec draft)	60 days following fieldwork completion

Table 2. Geophysical survey and subcontractor report delivery schedule

The combined MT and dGPS/gravity measurements will be collected at a rate of approximately 5 to as many as 8 stations per day (depending on terrain and access). A total of 3 surveying crews consisting of 3 people for each crew (1 operator and 2 field assistants) will conduct the

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MT geophysical surveys. One surveying crew consisting of 2 people total (1 dGPS operator and 1 gravity operator) will conduct the dGPS and gravity geophysical surveys.

Survey locations will be roughly 0.20 to 0.25 miles apart (both the MT and dGPS/gravity surveys utilize the same 75 sites), as shown on Figure 4 and presented in Appendix A. In the event these pre-determined locations cannot be accessed due to terrain, road conditions, vegetation, mine waste, or the required 100 foot buffer zone, the site will be moved to a new location that is accessible, maintains the survey integrity, and provides sufficient data density. If permission to access CDFG land is not granted, then the 8 stations planned on CDFG land will be moved to alternate locations on BLM land, as shown on Figure 4.

GPS units are carried with field personnel to determine the precise location of each surveying station. Geophysical survey measurements will be collected by field personnel by walking from the access road to the survey station locations with the necessary surveying equipment. Field personnel will then lay out the surveying equipment at the determined location, only disturbing a maximum ground area 30 cm wide x 85 cm long x 50 cm deep for setting the survey equipment temporarily in place at each station in order to obtain measurements. Disturbed soil will be replaced after the survey at that station is completed.

During these activities, a 100-foot buffer zone will be adhered to by GeothermEx and Western Geco field work personnel around any identified mine workings and mine features. The GPS units used by field personnel will be pre-loaded with all relevant maps and data, including topographic maps, geologic maps and (importantly for this project) maps showing areas of mining waste, as shown on Figures 2, 3, and 4. These maps include the 100-foot buffer zones around all known and identified mine features on all lands (the importance of this buffer zone and how it will be dealt with in the field is discussed further in Sections 3.2 and 3.3). It is anticipated that no areas of mine waste will be encountered while working on BLM land; however, GeothermEx will provide guidance to Western Geco on avoidance of mine waste and establishment of a buffer zone should waste be discovered. GeothermEx and Western Geco

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field work personnel who will conduct this work have first-hand experience with identification and delineation of historic and active mine features. This experience will be used to avoid areas of known mining features and to identify areas not previously cataloged. A detailed discussion on the nature and extent of mining waste in this mining region and how new mining waste will be identified is provided in Section 4.

If any new areas of mining waste are found, a GPS reading and a photograph will be taken. These data will be provided to the CVRWQCB for incorporation into their maps and databases in the form of updates to Figures 2 and 3 contained herein.

3.3 Focused Work Plan for BLM and CDFG Land

Exploration of BLM and CDFG land will consist primarily of MT, dGPS, and gravity surveys, as described above. As described in Section 4 of this report, all personnel will be mindful of mining waste in the study area and will not disturb any mining-waste-related lands during the time GeothermEx and Western Geco are in the field (approximately twenty days). In addition, a 100-foot-wide buffer zone will be adhered to around all identified mine features on public lands.

GeothermEx will continue to submit inquiries for access with CDFG until fieldwork begins in late November, 2012. However, unless access is granted to CDFG land, this property will not be accessed at any time during this study. If permission to access CDFG land is not granted, then the 8 stations planned on CDFG land will be moved to alternate locations on BLM land, as shown on Figure 4.

3.2.1 Access to BLM and CDFG Land

Access to BLM and CDFG land will be obtained using roads that pass through public land, specifically Highway 20, as shown on Figure 1. During field activities, field personnel will not venture onto private land to access survey sites at any time. Property boundaries will be displayed on a GPS system showing an area-specific map and will be adhered to at all times by field personnel.

The documentation available indicates that no known areas of mining waste are present on public lands that will be accessed by GeothermEx and Western Geco while conducting geophysical survey measurements. All personnel will adhere to the procedures outlined in Section 3.1 to identify, avoid, document, and report all known mining waste, as outlined in Section 4.

3.4 Schedule

It is anticipated that the fieldwork will be conducted and a results and evaluation report will be prepared and submitted in draft form by 28 December 2012, with the final report delivered by 11 January 2013.

GeothermEx and Western Geco can provide the necessary services to accommodate this schedule. Following approval of this work plan, the fieldwork effort should begin as soon as possible to meet the deadline of 28 December 2012, as: 1) approximately two to four weeks are required for advance notice to the geophysical subcontractor, 2) 20 days are required for fieldwork activities, and 3) 12 days are required for preliminary data evaluation and reporting, where Western Geco has agreed to an expedited data delivery schedule to accommodate the established 28 December, 2012 deadline.

Any need for schedule modification will be discussed with CEC, SMUD, and Renovitas following submission of this work plan and execution of the fieldwork.

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4. RECOGNIZING AND AVOIDING AREAS WITH MINING WASTE

The CEC and the CVRWQCB have requested this work plan to ensure that project activities do not impact mine features or mining waste, thereby preventing project-related water-quality impacts or possible liability under environmental and waste cleanup laws. It is the intention of both GeothermEx and Western Geco to avoid disturbing any and all public and private mine sites and associated waste during the geothermal exploration efforts. As shown in Figure 2 and 3, there are a number of documented historic mining sites in this area, and most have known mining waste. The location of this mining waste will be loaded into the field teams' GPS units, and hardcopy maps will be taken into the field, assuring that all field personnel know their location at all times relative to any areas of mining activity. Additionally, as indicated on Figures 2 and 3, a 100-foot buffer zone will be maintained around all known and identified mine features on all public and private lands (*i.e.*, there will be no walking, ground disturbance or exploration activity of any kind around any area of mining waste, including the 100-foot buffer).

The historic mining sites that have been catalogued in the Sulphur Creek Mining District in the vicinity of the geothermal exploration area are listed below and shown in Figures 2, 3, and 4.

- Central Mine
- Manzanita Mine
- West End Mine
- Cherry Hill Mine
- Empire Mine
- Wide Awake Mine
- Abbott Mine
- Turkey Run Mine

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The following paragraph is an excerpt from the CDC/CGS (2003) document which summarizes the history of mining in the Sulfur Creek Mining District:

> *"The mines* [as indicated above] *were initially discovered in the 1860s and 1870s and were worked intermittently, some until the early 1970s. Mining operations in the district were mostly by underground methods with limited surface mining activity…The Abbott-Turkey Run is the largest underground mine in the district and has between one and two miles of underground workings distributed over a 500-foot vertical interval. It also had the largest mercury production in the district, probably in excess of 1.8 million kilograms. Total district mercury production is approximately 2 million kilograms".*

During fieldwork, all field personnel will use Figures 2 and 3, in coordination with electronic and hardcopy versions of the geophysical survey strategy on Figure 4, to note and avoid locations of mine workings and waste. In addition, all field personnel will note, describe, and take GPS readings at any previously undocumented mine workings.

All field personnel will be equipped with GPS units loaded with maps similar to those presented herein, helping them maintain an acute awareness of where they are and what mining features may be nearby. If any new areas of mining waste are found (locating new test pits with waste rock is possible), a GPS reading and a photograph will be taken. These data will be provided to the CVRWQCB for incorporation into their maps and databases in the form of updates to Figures 2 and 3 contained herein, and as GPS coordinates if requested.

There are a number of additional historic mining sites in the Sulphur Creek Mining District which are more than 2-1/2 miles north and northwest of the area of interest. These areas will not be visited; thus, they are not depicted in figures in this work plan.

All field personnel who will be involved in exploration activities in the Sulfur Creek Mining District will be made aware of these historic mining sites and their features to ensure they will avoid disturbing any mining related waste. In addition to the documented historic mining sites,

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it is possible that additional undocumented mining sites will be found during the course of the exploration work; these will be documented as described above.

GeothermEx has reviewed documentation authored by the California Department of Transportation (CalTrans, 2008) which provides detailed descriptions of the archeological features associated with hard-rock mining history and procedures of mining in California, so that all personnel may accurately identify and avoid any such areas encountered. The pertinent excerpt from the CalTrans (2008) document will be reviewed by GeothermEx and Western Geco field personnel in advance of conducting fieldwork. The pertinent sections of the CalTrans (2008) document have been included as Appendix B to this work plan.

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5. REFERENCES

California Department of Conservation (CDC) and California Geological Survey (CGS), 2003. An Assessment of Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed, CALFED Bay-Delta Mercury Project, Task 5C1: Assessment of the Feasibility of Remediation of Mercury Mine Sources in the Cache Creek Watershed. Final Report and Appendices, September.

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ERM, 2010. Mining-Related Materials Characterization and Remediation Work Plan, Sulphur Creek Mining District, Central Group and Wide Awake Mines, Colusa County, California, September.

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Tetra Tech EMI, 2003. CALFED-Cache Creek Study, Engineering Evaluation and Cost Analysis for the Sulphur Creek Mining District, Colusa and Lake Counties, California. Final. September.

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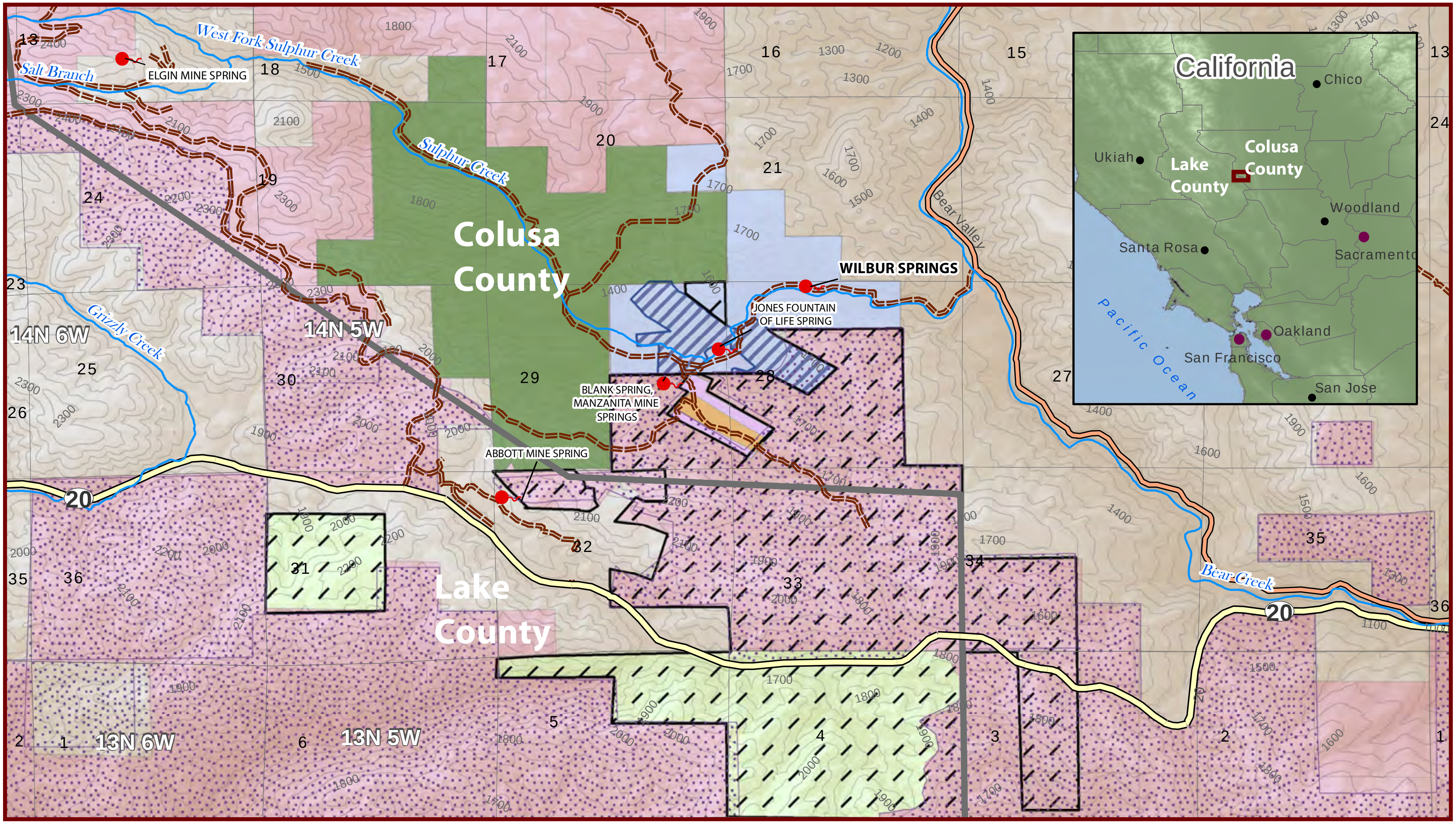
FIGURES



0 0.25 0.5 1 1.5 Miles

GCS North American 1983

Legend

- Hot Spring
- Rivers & Streams
- County Line
- Township & Range
- Section #s
- Highway 20
- Bear Valley Road
- Local Public Road

Data from SMUD

- Trebilcot Property (Mineral)
- Bailey Property (Mineral)
- David Brown (Mineral & Surface)
- Merced General Construction (Mineral & Surface)

Data from CA Protected Areas Database

- Private - Unknown
- California Dept. of Fish and Game (Surface)
- US Bureau of Land Management (Mixed)

Data from BLM

- Cache Creek Management Area Plan
- Miller Property (Surface)
- Miller & American Land Cons. Trust (Surface)

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Figure 1: Location map showing surface and mineral ownership near Wilbur Springs, California

CLIENT: SMUD / Renovitas	PROJECT: Geophysics Work Plan
DATE: 10/25/2012	FIGURE: WorkPlan.mxd

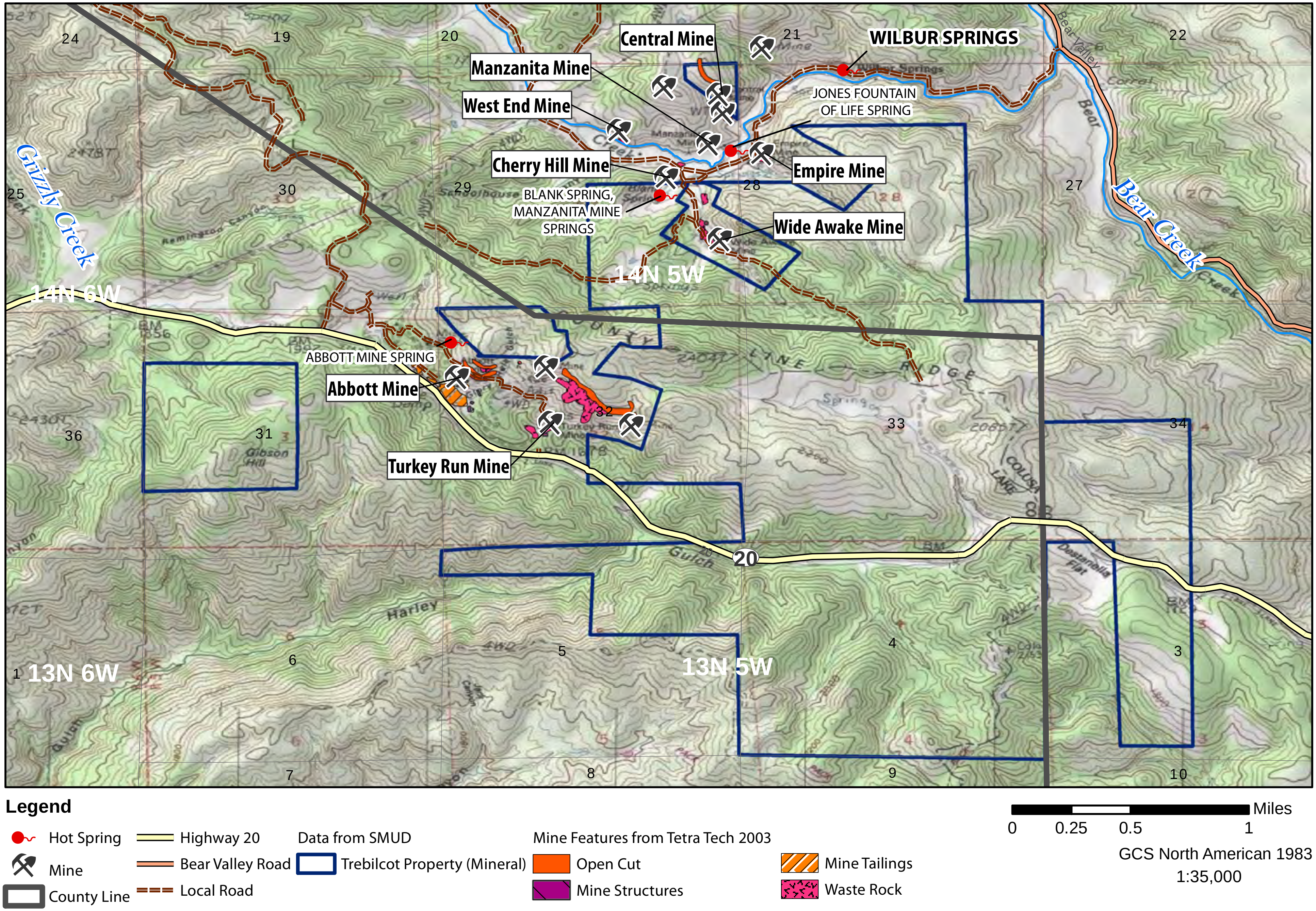

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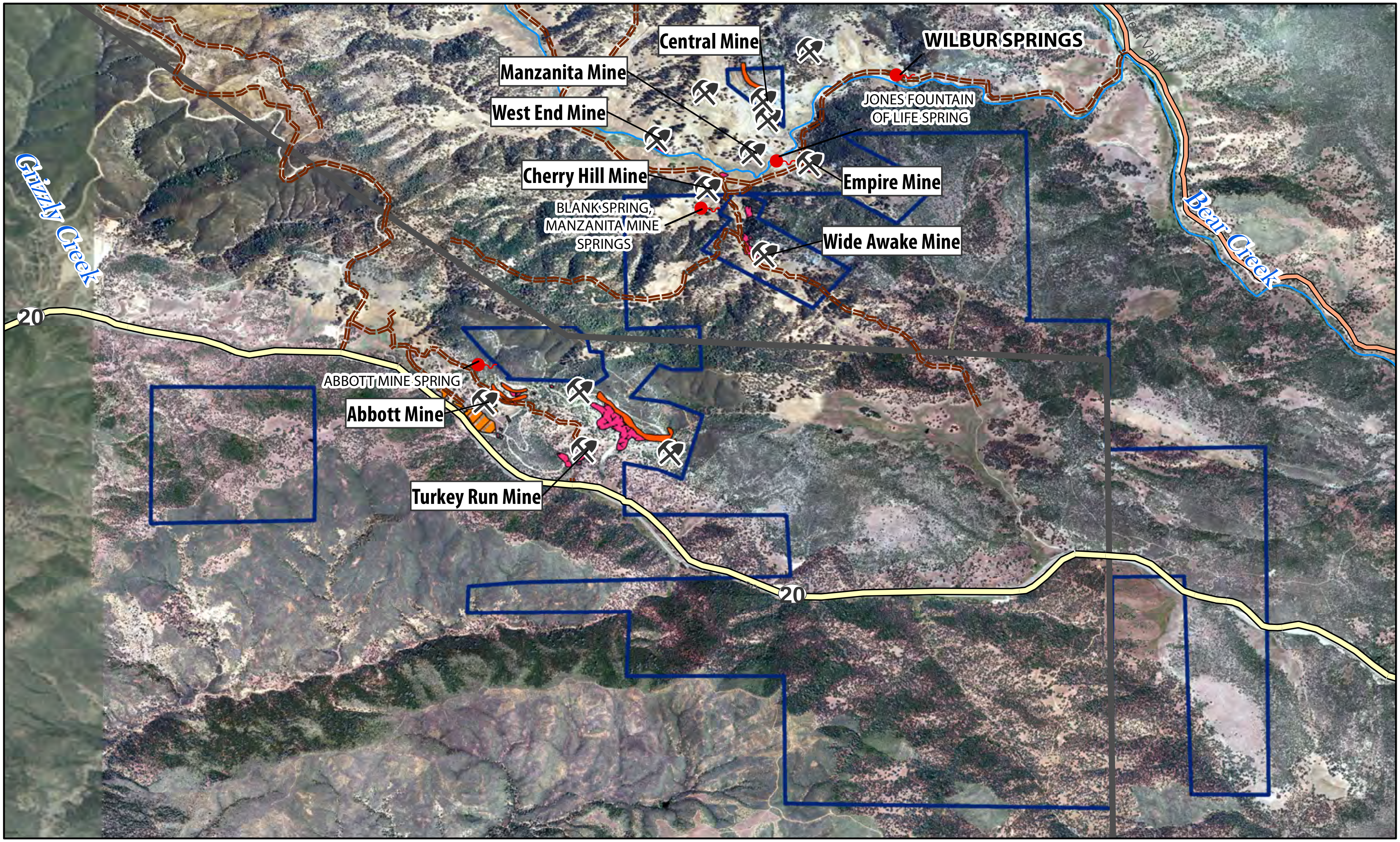
Figure 2: Roads, mines, known areas of mining waste and hot springs in the study area, Wilbur Spring, CA (topographic background)

CLIENT:	SMUD / Renovitas	PROJECT:	Geophysics Work Plan
DATE:	10/25/2012	FIGURE:	GeoWorkPlanAerialFig2.mxd



Legend

Hot Spring
Mine
County Line
Highway 20
Bear Valley Road
Local Road
Data from SMUD
Trebilcot Property (Mineral)
Mine Features from Tetra Tech 2003
Open Cut
Mine Structures
Mine Tailings
Waste Rock

Miles
0 0.25 0.5 1

GCS North American 1983
1:35,000

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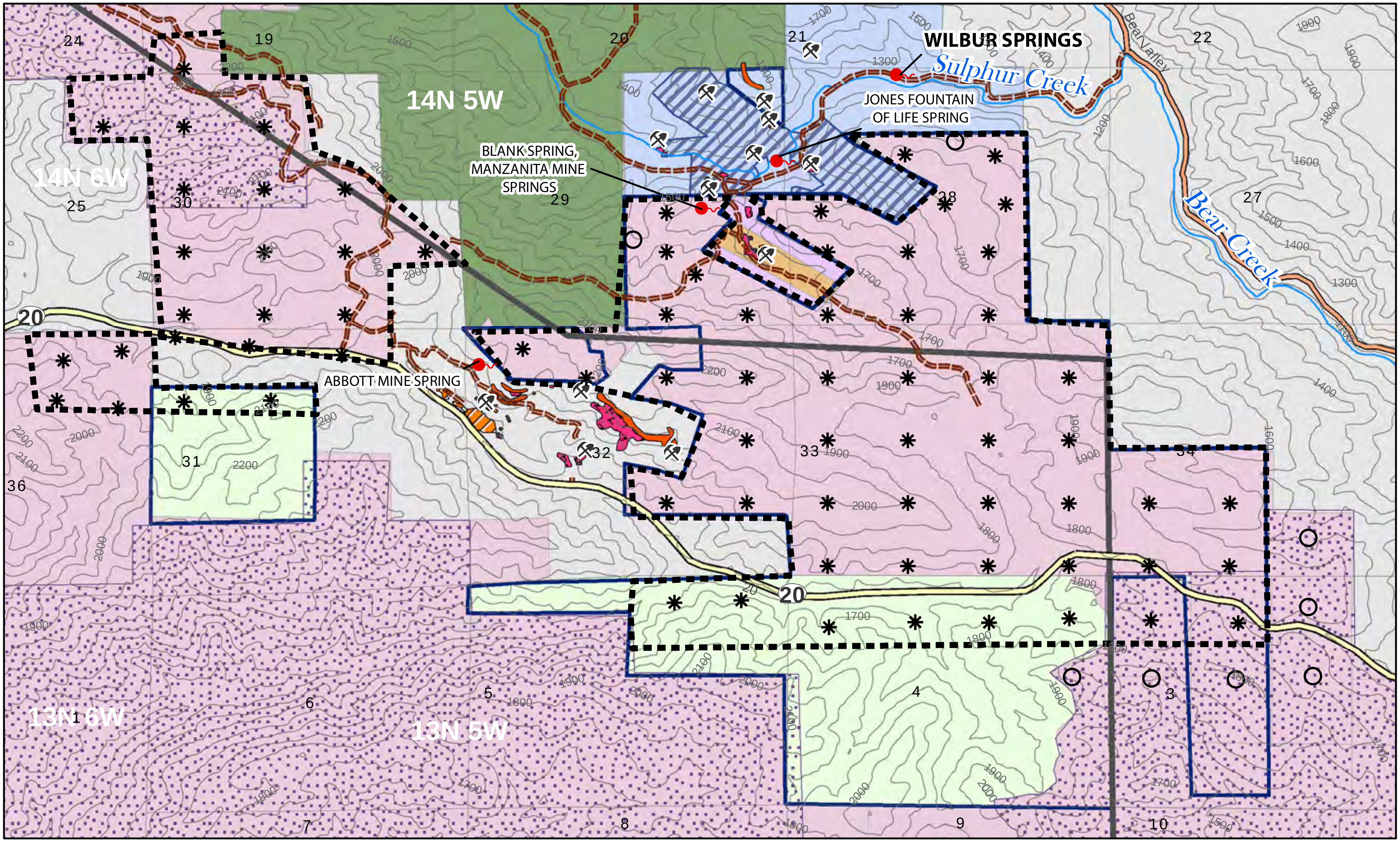
Figure 3: Roads, mines, known areas of mining waste and hot springs in the study area, Wilbur Spring, CA (satellite image background)

CLIENT: SMUD / Renovitas	PROJECT: Geophysics Work Plan
DATE: 10/25/2012	FIGURE: GeoWorkPlanAerialFig3.mxd



Legend

- Hot Spring
- Mine
- County Line
- Highway 20
- Bear Valley Road
- Local Road
- Geophysics Study Area
- MT / Gravity Stations
- Alternate Stations

Mine Features from Tetra Tech 2003
- Open Cut
- Mine Structures
- Mine Tailings
- Waste Rock

Data from SMUD
- Trebilcot Property (Mineral)
- Bailey Property (Mineral)
- David Brown (Mineral & Surface)
- Merced General Construction (Mineral & Surface)

Data from CA Protected Areas Database
- Private - Unknown
- California Dept. of Fish and Game
- US Bureau of Land Management

Data from BLM
- Miller Property (Surface)
- Miller & American Land Cons. Trust (Surface)
- Cache Creek Management Area Plan

Miles: 0, 0.25, 0.5, 1

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Figure 4: Geophysical Investigation Strategy

CLIENT:	SMUD / Renovitas	PROJECT:	Geophysics Work Plan
DATE:	10/25/2012	FIGURE:	GeoWorkPlanAerialFig4.mxd

GCS North American 1983
1:35,000

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APPENDIX A:

Western Geco Proposal for Geophysical Survey

TECHNICAL PROPOSAL

for

MT AND GRAVITY
DATA ACQUISITION, PROCESSING, 3D INVERSION

WILBUR HOT SPRINGS CALIFORNIA, USA

Prepared for

SACRAMENTO MUNICIPAL UTILITY DISTRICT (SMUD)

By

WESTERNGECO

November 7th, 2012

Table of Contents

SCOPE OF SERVICES

The scope of services is based on the information provided by GeothermEx. The survey area is located at Wilbur Hot Springs, approximately 25 miles south west of Williams California (Figure 1).

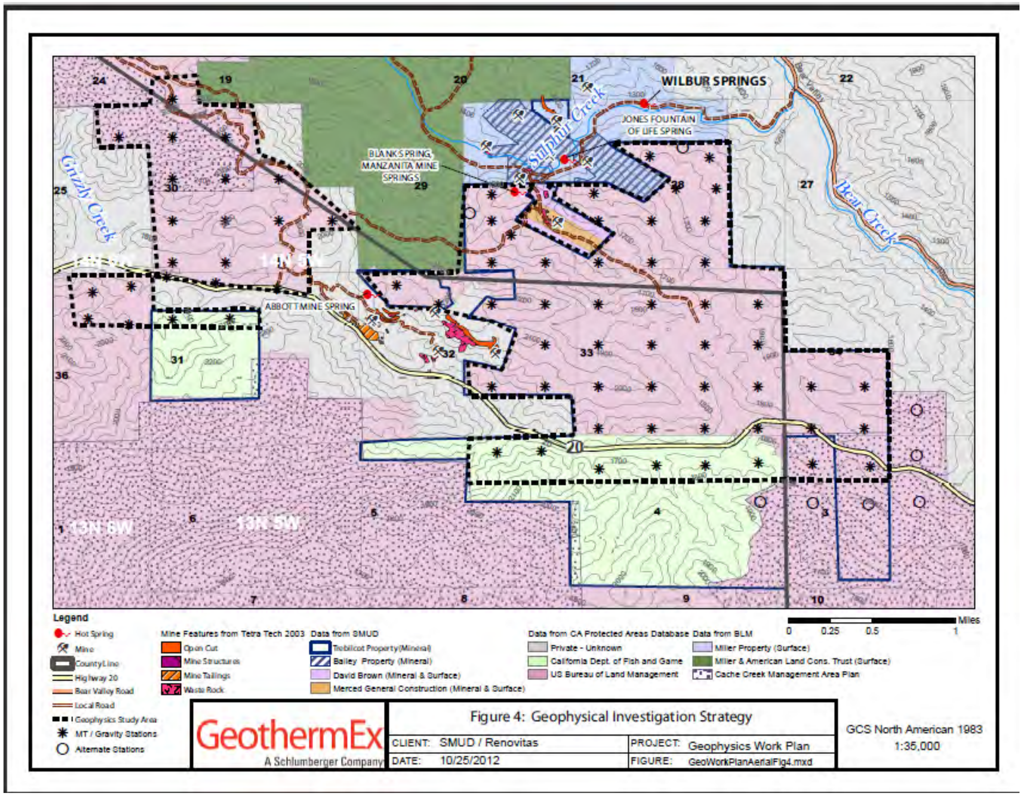


Figure 1. Proposed station locations for MT and gravity surveys.

In the event these pre-plot locations can't be accessed due to terrain, road conditions or vegetation the site will be moved to a new location that is accessible and maintains the survey integrity.

Detailed information about our acquisition, processing and inversion methodology is given in the following sections, but in summary our work plan comprises:

- Acquisition of approximately 50 dGPS and gravity measurements.
  - Trimble GPS-rtk receivers
  - Gravity instrumentation Scintrex CG-5 or LaCoste & Romberg G-meter.
  - Processing of gravity data to Bouguer anomaly.
- Acquisition of approximately 50 full-tensor MT sites.
  - MT instrumentation Metronix ADU-07/ADU-06 or Phoenix MTU-5 with Metronix broadband MFS-06/07 coils.
  - Overnight MT recordings providing 12-14 hours of data.
  - Bandwidth 7 decades from 10,000Hz down to 0.001Hz.
  - Processing and 1D inversion of MT data.
- Optional 3D inversion on MT data
- Optional integrated modelling of MT and gravity data through Simultaneous Joint Inversion (SJI)
- Optional geologic interpretation and structural restoration in the survey areas.

Survey Plan and Timing

We propose deploying 3 MT crews and 1 dGPS/Gravity crew. The independent field crews will be supported by a Party Chief from the field office and Senior Operator who will be available on the survey grid to respond quickly to issues for smooth operations. The remote reference MT system will be operated by the base crew. QHSE support will be provided by our QHSE supervisor either from the field (project start-up and occasional visits as necessary) or the office.

Each MT crew will comprise 1 operator and 2 field assistants. Field reconnaissance will be conducted for 2 to 3 days before the survey is to begin. For the survey, each MT crew will aim to lay out 2-3 new MT sites per day for overnight recording. The total MT production rate is expected to average 5 to 8 stations per day (allowing for areas of rough terrain with difficult access and necessary repeats because of noisy data), taking around 16 days to complete 75 MT sites. The survey is expected to start November 23rd and be completed by the 8th.

The dGPS and gravity surveys will be conducted in parallel with the MT survey. The dGPS crew will start 1-2 days in advance of the gravity crew. Each dGPS and gravity crew will comprise 1 operator. The total gravity production rate is expected to average ~15 stations per day (allowing for areas of rough terrain with difficult access and necessary repeats because of noisy data), taking around 5 days to complete 75 Gravity sites.

Contractor's Project Personnel and logistics support (minimum)

Field Unit means:
1 × Party Chief
1 × Senior Operator
3 × MT crews
- 1 × Operator per crew (including Senior Operator)
- 2 × Field Assistants per crew

1x Gravity crew
- 1 × Gravity operator per crew

1 × dGPS crew
- 1 x dGPS operator per crew

All our key field personnel have relevant and recent technical and practical experience in MT and/or Gravity surveying with Contractor. CVs of key personnel are provided along with this proposal.

- Field Party Manager: Pietro Miglio, Andrea Vella, Christopher Jones, Jesus Barrious or Russell Ketchum (based on personnel availability at the time of contract award)
- Assistant Party Chief / Senior Operator : Trey Firestone or equivalent (based on personnel availability at the time of contract award)
- Office-based daily operations supervision: Jairo Sedano, Operations Manager
- Office-based daily QHSE supervision: Alessandra Flaminio, QHSE Manager
- 3D Inversion and Intepretation overview: Carlo Ungarelli (PhD), Senior MT Geophysicist, and Andrea Lovatini, EM DP&I Manager.

Client's Responsibilities

Client will supply the following logistics and support for project:
- 1:25,000 or 1:50,000 scale topographic maps
- All national, state, ministry, local government, environmental and other permits required

METHODOLOGY AND TECHNICAL SPECIFICATIONS

MT SURVEY

Scouting, EM Noise Sources, and Equipment Conformance

Prior to the survey, and in collaboration with the Client, a reconnaissance of the field area will identify the main access routes, meeting points, and the likely EM noise sources. A suitably quiet and secure MT remote reference site will also be chosen. Before survey start-up, an overnight conformance recording of all instrumentation will be performed with the sensors laid out in parallel. Non-compliant equipment is removed from the equipment pool.

MT Data Acquisition

Each MT crew operates three 5-channel MT (Figure 2) systems, recording, picking up, moving and laying out so that each MT crew deploys 2-3 overnight MT recordings (12-14 hours duration) per 24 hours (allowing for occasional repeat soundings and variable access/move times).

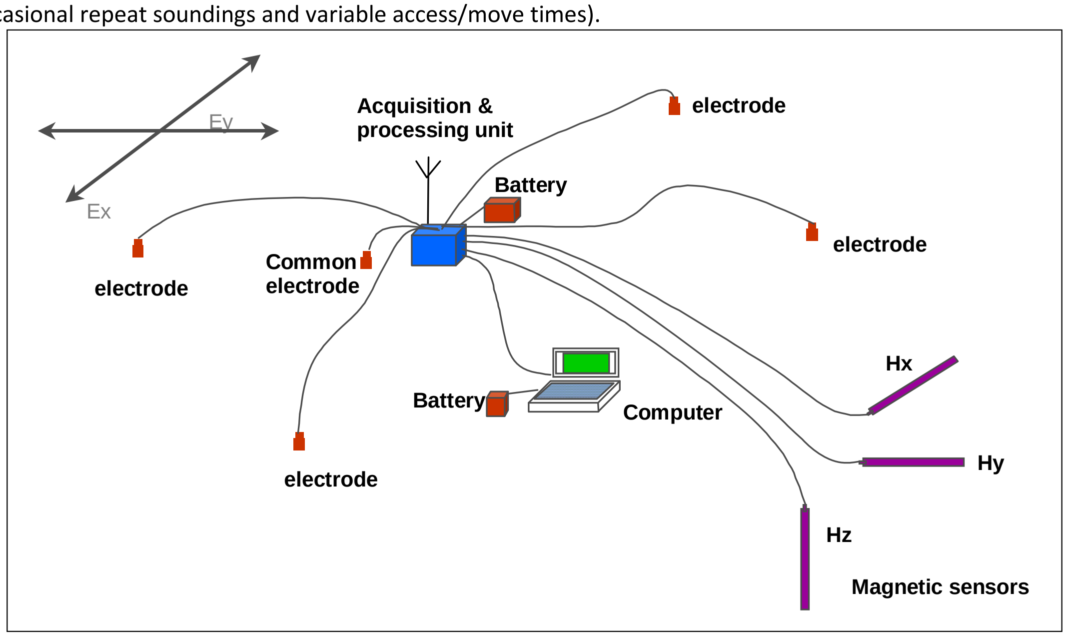


Figure 2: 5-channel MT layout diagram (schematic). The total system weight is 45kg, including the 12V 24Ah sealed battery. The field computer is present only during site set-up and data downloading, otherwise remaining with the operator. Auxiliary tools include machete, shovel and pick, water jugs, backpacks.

Layout Procedure (MT)

Arriving at the overnight site, the operator checks for signs of damage by animals or obvious interference during the recording (chewed and pulled cables etc.), and downloads data onto rugged laptop PC or USB key. The site is examined to ensure all 5 components were correctly recorded, and once given the all clear the site is “pulled” for transport to the successive site. The coil and electrode holes are back-filled, replacing the previously cut and conserved earth sods in order to restore the site to its original state.

Arriving at the new site, the operator reviews the terrain to decide the optimum layout position and directions, offsetting the site position as necessary to avoid steep or dangerous terrain, and adjusting the dipole lengths accordingly. Precise site location is not as important as suitability of location. The first course of action is to extend the orthogonal dipoles (4×50m wires, single conductor PVC insulated, with a diameter of 1.5mm) and install the electrodes to allow sufficient time for stabilization. Each electrode consists of a small sealed cylinder, with a diameter of about 7cm and a height of 15cm. The lower part of this is buried in a small hole (about 15cm diameter and 15cm deep) to which water is added (in order to ensure good electrical contact). A fifth, central electrode acts as the ground, and inserted next to the ADU recording unit.

Magnetic fields are measured by induction coils, which have the external form of a plastic tube 85cm long and a diameter of 8cm. The two horizontal coils are buried in trenches about 20cm deep and 25cm wide, and positioned usually within 15m of the center of the site (ADU). The vertical coil is emplaced by using a post-hole digger or narrow shovel to make a hole of about 30cm diameter to a depth of 50cm. The coils are inserted, and the hole back filled with earth. The objective of this is to minimize wind vibration and to provide thermal stability. Coil positions are chosen in open locations to minimize plant damages, and as far as reasonably possible from tree roots (possible vibration sources). Any protruding part of the vertical coil will be covered by a garbage pail and weighted down with rocks or soil.

The total MT system weight, including battery, computer, water for electrodes and digging tools is 45kg, of which no one component weighs more than 10kg. One system is therefore comfortably portable by 2-3 persons over the distances considered here, and as the equipment is left recording overnight, in the morning and evening the crew only carries in/out the fresh/old 12V battery and laptop. The final mode of operation/access will ultimately depend on the results of the scouting and access routes.

MT Equipment

Contractor proposes to use the following (minimum) equipment (Table 1), reserving the right to employ equivalent or superior equipment having advised Company in advance:

Table 1 MT equipment for two-three crews plus 1 × remote reference, plus spare units.

Unit Function	Manufacturer and Model	Units for Field Use Incl R.Ref	Spare Units
MT Recording unit (5 channel, GPS synch)	Metronix ADU-06 / 07, or Phoenix MTU-5a	10	1
MT Acquisition software	MTU-5a and ADU-06/07 firmware	1	1
MT Magnetic sensors Hx, Hy, Hz coils	Metronix MFS-06/07 broadband induction coils	21	3
MT Electrodes	Wolf non polarizable PbPbCl	50	15
Field computers	Panasonic MF34 (to view ADU if required)	4	1
Other Spare Parts	Spare GPS antenna Spare power supply Spare Coil leads		4 4 5
Miscellaneous	Compasses, eTrex GPS units, levels, all weather notebooks, electrical tape, backpacks, battery chargers, 2 x PC, drives, back-ups, office supplies.		

MT Data Processing

MT field data (Time Series) will be processed using the Larsen and Chave codes as implemented by Contractor (Table 2). The Larsen code uses a sophisticated robust remote-reference approach, including pre-filtering to remove harmonic noise (line frequencies from powerlines) and de-spiking to remove the effects of very close (non-plane wave) lightning spikes, if present. The output files are stored in standard SEG EDI format. Data will be processed to EDI within 24 hours of acquisition, and e-mailed to our offices in Milan for analysis and interpretation. All MT data plots will be reviewed by Company Representative prior to Contractor demobilizing.

Table 2 MT PROCESSING and INTERPRETATION TOOLS

Task Description	Name and Version	Developed By	Licensed to
Time Series Viewer	WinGLink Tools	WesternGeco	WesternGeco
Field Data QC	WinGLink Tools	WesternGeco	WesternGeco
Robust, Remote Reference MT Processing	Larsen, Chave	Larsen, Chave, WesternGeco	WesternGeco
X-Power Editor, or equivalent Impedance Editor, merge to final EDI	Combine EDI Tool, WinGLink	WesternGeco	WesternGeco
MT 1D modeling (layered earth, Bostick and Occam)	MT 1D Soundings, WinGLink	WesternGeco	WesternGeco
MT Modeling 2D Smooth	2D MT Inversions, WinGLink	Rodi and Mackie, WesternGeco	WesternGeco
MT Modeling 3D Smooth	MT3Dinv, WinGLink	Rodi and Mackie, WesternGeco	WesternGeco
Integration of Well Control, gravity,etc.	WinGLink	WesternGeco	WesternGeco

MT Intepretation

The processed MT data, in the form of EDI files, will be e-mailed to WesternGeco Milan for analysis and 3D modeling:

1. edit each MT sounding to mask data distorted by powerlines or other cultural interference, digitizing and plotting all cultural features on the MT database maps and sections;
2. Static shift using TDEM data (if available), option for 1D modeling;
3. Apparent resistivity maps;
4. Post-survey: Integration with existing data, and interpretation in terms of target-related properties;
5. 3D inversion: up to 10 runs per model in order to fine tune resistivity model sensitivity to target area (smoothing, horizontal vs. vertical structure weighting, mesh detail, boundary conditions).

3D inversions will be carried out using our <u>unique</u> and <u>proprietary</u> code that utilizes the full tensor as input (Zxy, Zyx, Zxx, Zyy, and Tzx, Tzy) and include detailed topography in the model to compute correct, full responses as seen in the measured data.

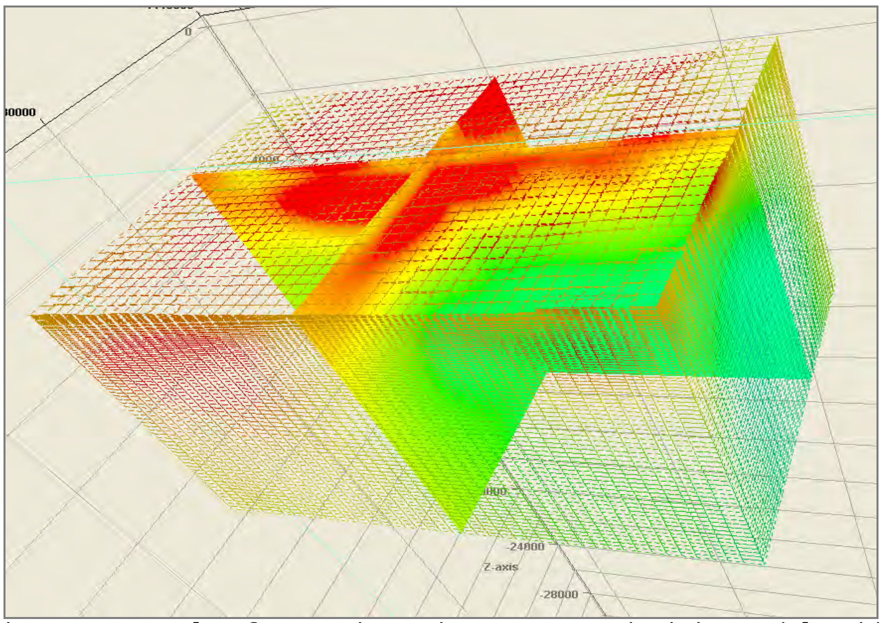


Figure 3. Example of 3D MT inversion output resistivity model grid.

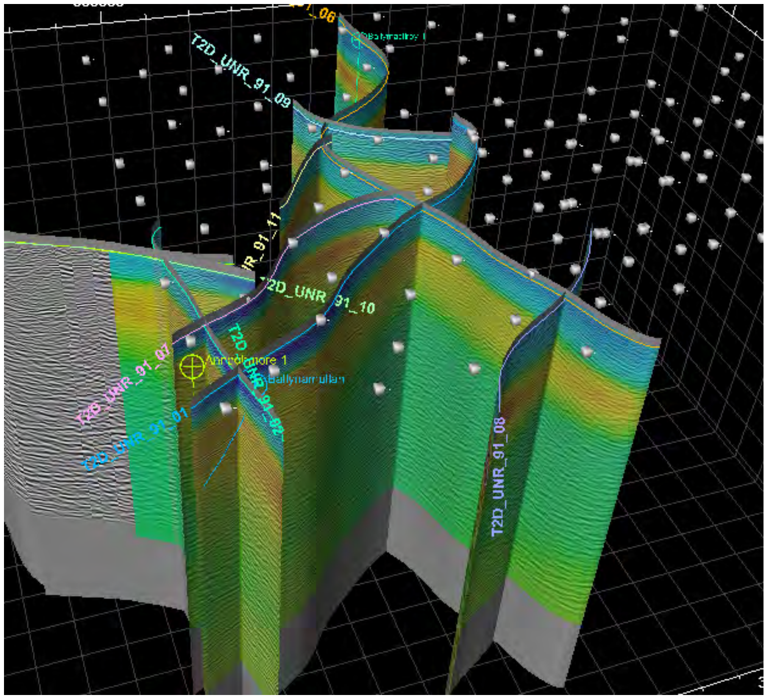


Figure 4. Example integration of existing 2D seismic data, and well logs, with resistivity from 3D MT inversion model (colour grid, red is conductive, blue near surface are resistive basalts).

<u>Station Coordinates</u>

The MT processing and interpretation do not require centimeter accurate station positioning, and single site GPS receivers are adequate. The crews shall locate sites using Garmin single point GPS units (eTrex 12 models), loaded with the pre-plot locations. Each geophysical recording crew shall independently confirm their position using similar, single site GPS measurements accurate to within 15m. Elevations will be taken from 3D GPS solutions, and checked against DEM-derived topographic heights.

<u>Reporting and deliverables</u>

A list of standard available, digital deliverable products is given in Table 3; file examples are immediately available on request. The final deliverables list will depend on COMPANY's requirements, and may be agreed at survey start-up.

<u>Preliminary Results</u>

The preliminary results of the 3Dmodeling and operations report will be delivered by December 20th.

<u>Acquisition, Processing and Data</u>

Within 21 days of demobilizing the field crew, Contractor will provide three copies of a comprehensive Operational Report covering acquisition, processing, HSE and operations. This provides a summary and details of the processed data, a list of station locations, large scale map(s) showing these locations, and a summary of logistics, operations, HSE statistics, equipment, instrumentation, procedures and personnel, for each area. All final processed results shall be plotted in a manner agreed by Contractor and Company, including full MT impedance and quality parameter plots. The Operational Report shall include:

- Documentation explaining the content and format of the data files.
- DVDs containing the raw MT time series.
- CD with the final processed MT EDI files including all computed parameters.

<u>Modeling & Inversion</u>

The final modeling report, delivered by the Contractor to the Company within 60 days of demobilizing the field crew, shall include details of the inversion modeling and error estimates. The report is accompanied by documentation explaining the content and format of the model files, the processes described and a CD with the grid and input and computed MT files and a pdf copy of the final report.

Table 3 DELIVERABLES (minimum list)

File Type	Brief Summary of File Nomenclature	Generated by Program / Vers.	Reference to File Format
MT – Time Series *.TS	One ASCII- binary file per time series band, per site	MTU-5 firmware	Phoenix MTU-5 Manual & int.. Reports
MT – EDI *.EDI	Single ASCII file per site, containing all impedance and Tipper information in SEG standard format	WinGLink MT Combine Tools	Wight (1988)
MT 1D models	Single ASCII file per site	WinGLink MT 1D export	WinGLink manual / int docs
MT 3D Model, resistivity mesh and inversion log *2D.data	ASCII grid and listing files	WinGLink 3D models	WinGLink manual / int docs
Database Manager: WinGLink	Visual Basic driven database containing all raw and edited and modeled MT and well data.	WinGLink	WinGLink manual / int docs
Maps and Cross Sections	In digital images to be coordinated with Client	WinGLink IVM (montage mapping and cross section tool)	WinGLink manual / int docs

GRAVITY AND DGPS SURVEY

Overview

The dGPS crew will precede the Gravity crew by 1-2 days and will be equipped with on vehicle, Trimble R7/R8 dGPS receiver and a handheld GPS unit for auxiliary navigation. The Gravity crew will comprise one vehicle, an operator and one assistant equipped with Scintrex CG-5 AutoGrav or LaCoste & Romberg G-meter, a handheld GPS unit for auxiliary navigation, and autonomous safety/recovery equipment including mobile phone and satellite phone where required. All equipment is highly portable in backpacks, with the heaviest component weighing 8kg, so for stations not on drivable access, the equipment can be carried to site walking to and from the sites.

Within the noted limits of the rugged terrain, the tentative grid of gravity stations will be laid out on an approximately 3D grid. Quasi-equidistant spacing between all adjacent sites provides optimum layout for eventual gridding of potential field data, and offers flexibility in acquisition planning. A reference base GPS configuration will be used to allow true triangulation processing of every control station. The gravity crew will therefore complete the survey in blocks, served by one central GPS Control Point; in this fashion, the baseline length is always less than 20km.

At project start-up, the gravity crew will establish the GPS control and gravity base network via industry standard triangulation methods, each tied to the primary gravity and geodetic networks respectively. The gravity-GPS base network, and the use of block surveying rather than strict along line surveying, provides for repeat measurements, cross-loop checks, and total survey network analysis. During the survey, at least 5% of stations will be repeated, making repeat measurements on stations from independent data loops (i.e. from different day's work).

We propose making dGPS readings in Rapid Static mode at each station where required. Rapid Static recordings will be made for a minimum of 10 minutes at each site, during which time the operator is making the gravity and terrain correction readings. In summary, the crew is poly-functional as proposed here.

Gravity and dGPS Instrumentation and maintenance

Table 4 Gravimeters, and dGPS equipment. WesternGeco will deploy this equipment, or equivalent or superior equipment as available at the time of LOA.

Unit Function	Manufacturer (Make) and Model	Quantity
Gravity Meter	Scintrex CG-5 or LaCoste & Romberg G-meter	1
GPS-rtk receivers (base and rover)	Trimble R7 / R8	2

Station Coordinates (dGPS)

Differential GPS in post-processed, Rapid Static mode will be used to achieve 10cm vertical position spec.

Gravimeter Calibration and Drift rate

Following a 48-hour warm-up period upon arrival in-country, the meters will undergo a 24-hour cycling test to establish rate and linearity of drift. During the survey the drift rate will be monitored and updated using the routine repeat measurements at base stations.
Gravimeter calibration details will be provided in advance of survey, and in addition all instruments will undergo a parallel, double run in-country between at least two gravity base stations differing by at least 30mGal.

GPS unit calibration

Absolute calibrations are determined by the manufacturer, but at project start-up, all receivers will be run over a very short (meter length) baseline to ensure inter-receiver consistency to less than 5cm.

Instrument Maintenance

Weekly gravimeter checks will include a long-term drift adjustment via an overnight cycling run, and X,Y tilt meter accuracy and sensitivity measurements at the base. The temperature compensation potentiometer is adjusted as necessary to ensure the digital output is within the prescribed ±1mK range.

Routine maintenance of all GPS equipment will be carried out on a weekly basis to ensure base and rover units are kept dust and static free as far as possible. Weekly checks are made on magnetometers to ensure the sensor heads are clean and fluid levels and cable contacts are in order.

Base Networks

Gravity Base Network

Absolute Gravity will be transferred to the operational base at the beginning of the survey, from the nearest reliable IGSN station. Secondary bases are established in each survey sector to allow daily loop closures as necessary. The bases are tied together by a series of independent double run gravity loops (A-B-A-B-A), so that each base is connected to at least two other bases, and network adjusted using the least squares method, thus providing a tight Gobs base network. All A-B-A closures will be made within 12 hours to reduce drift. All gravity stations of the base network shall obtain a standard deviation $\sigma < |0.01|$ mGal.

Where practical, the gravity bases will also be tied to the GPS Control points in order to provide joint gravity and topographic reference datum for present and future use.

Geodetic dGPS Control Network

The survey area will work off two GPS Control stations, set out in advance of the gravity crew equipped with three dual frequency GPS receivers operating in Differential-phase Static mode. Firstly, the site is selected and rebar set, and only surveyed after a sufficient stabilization period. A triangulated network is constructed, where each control point is connected to at least two others, facilitating rigorous loop closure checks. Control points will be established with a central re-bar or galvanized pole survey mark protruding 2cm above the concrete and marked by an adjacent stake, positioned always 1m north of the survey mark.

In Post processed differential-phase static mode, the dGPS systems provide baseline accuracy of 1cm +0.5ppm (vertical) over baselines <50km. To facilitate the local geoid improvement (if required), this dGPS control station base network will be tied into all available trigonometric points from the national survey (if available).

Gravity-dGPS Operational Procedure

The daily program is decided by the Party Chief, coordinating all crews. Operators make a gravity reading at the gravity bases at least at the beginning and end of each survey day, and a control GPS reading at the check point adjacent to the GPS bases also. Pre-survey, the Pre-plot station positions from regular grid filling each block are studied for position on maps relative to evident obstructions and noise sources, and moved within the defined tolerance (25m). Stations requiring further offset are put to Client for approval prior to surveying stations. Final agreed pre-plot station positions are pre-loaded into the GPS units. During the survey day, crews walk a point within 25% spacing radius of pre-plot location, but suitable for gravity measurement (i.e. >50m from extreme topography), using the dGPS receiver for final coordinates. The crews are specifically equipped with GPS and gravity backpacks for this purpose. At site, the assistant marks the station with biodegradable flagging, marking a reference point for future re-measurement of GPS and gravity.

The gravimeter is leveled on the standard tripod in normal conditions, or on a tripod adapted with extended legs for use over the soft ground. At least three readings are made, checking for stability and making further measurements if readings differ by more than 0.03mGal. The height of the gravimeter relative to the stake mark is measured and recorded. During the gravity readings the operator is free to record the rapid static GPS coordinates, and make local terrain estimates using a clinometer (details below).

The GPS receiver antennae will be pole mounted, where the pole is fixed to a light tripod base to allow the operator freedom. Vertical distance to survey marker is determined at every station in order to avoid positional errors in sloping topography.

Terrain Corrections

The operator will make all reasonable effort to locate the gravity station as far from steep terrain as possible. In the hills and vegetation, the objective will be to use the terrain as far as possible to improve GPS coverage as well as reduce the terrain correction. The terrain effect will be calculated from:

1) Local terrain corrections out to Hammer Zone C estimated in-field by use of Suunto clinometers. The gravity stations will be located so that the terrain in Zone A (to 2m radius) is always flat, and the unevenness in Zones B and C (out to 53m radius) is minimized. The number of sectors in each of zones B-C will be decided by the operator; minimum 4 and up to 8, depending on terrain complexity.
2) Digital elevation model (DEM), as available from SRTM.

The local, inner and outer (DEM) terrain corrections will be calculated using the using WinGLink[1] software, incorporating the sloping prism formula for the near-station corrections.

Data Repeatability

Repeat measurements of gravity and dGPS position are made to check gravimeter drift and GPS repeatability, between measurements made on different recording loops, on different days. The total number of repeats will be sufficient to provide ≥ 3% repeat rate. These repeats are in addition to the opening and closing readings made at the operational base station (gravity and GPS). The following observed data QC standards will be met.

Earth Tide Corrected residual Gravity drift on any loop not to exceed 0.1mGal/hr.
Drift and Tide corrected Observed Gravity repeatable to 0.1mGal.
Vertical Position repeatable to 0.3m
Horizontal Position repeatable to 2m

Repeatability tolerance levels are taken as one standard deviation. This would mean that at the 95% confidence level data points are repeatable to within 2 standard deviations. Any data repeat reading outside two standard deviations will therefore require re-measurement of that loop.

Data Processing and Interpretation

The in-field office processed gravity and dGPS data, in the form of gravity and coordinate data listings files, are QC'd at the field office.

Data processing, reduction, terrain corrections and final QC can be carried out within 48 hours of acquisition at the field office, so that the anomaly definitions may be used to optimize the gravity station layout, fill-in and schedule.

Table 5 Gravity Processing and Interpretation Tools

Task Description	Name and Version	Developed By	Licensed to
GPS processing	Trimble or Leica Office	Trimble / Leica	WesternGeco
Gravity Tools, Data Reduction	WinGLink	Geosystem	WesternGeco
Gravity. Terrain and Bouguer Corrections, Image Processing, Residuals	WinGLink	Geosystem	WesternGeco
Gravity 2D inversion	2.75-D Models, WinGLink	Geosystem	WesternGeco
Gravity 3D inversion	Grav_3D_JIPP	Geosystem	WesternGeco
Integration of Well Control,	WinGLink	Geosystem	WesternGeco
Image Processing, Maps, Sections, Plots	WinGLink Petrel	Geosystem	WesternGeco

[1] **WinGLink™** Geophysical data processing, modeling and interpretation software, integrating MT, TDEM, CSEM, DC, gravity, magnetics and ancillary data including well logs, in the Windows environment; developed and marketed by WG.

Gravity and dGPS Processing

Gravity data are processed in WinGLink Tools and core modules, including base station networks, data reduction, terrain corrections (from field data and/or digital elevation models, DEM), full Bouguer anomaly including curvature, isostatic residuals, polynomial and high-low-band-passed filters, upward continuation, horizontal and vertical gradients.

GPS processing is performed in Trimble Office Solutions. Nominal parameters for GPS processing include; baselines <25km, recording sample rate <3seconds, maximum PDOP<6, Max HDOP<4, minimum satellites 5, mask angle 15° above horizon.

Gravity data reduction

LaCoste G-meter data is logged in and transferred to PC the same evening. Scintrex CG3/5 data are dumped to PC every day, and checked immediately for anomalous drift or tares. Final Bouguer anomalies are processed within 48 hours of acquisition, incorporating residual drift, latitude, free-air, terrain and Bouguer corrections, using. Earth Tides, tilt, temperature correction and long-term drift are calculated by the AutoGrav internally. Gravity will be referenced to absolute gravity at operational base station. Bouguer and Terrain Corrections at 3 reduction densities are updated daily, to provide profiles and maps for QC purposes.

The isostatic residual anomaly will be calculated using the digital topographic and bathymetric model (ETOPO-2) to calculate MOHO relief over an extended area (250×250km) assuming variable lithospheric strength models. Other residuals (polynomial, low pass, band pass) can be easily created in WinGLink.

dGPS data reduction

From the dGPS survey, in-field receiver raw data may also be stored in-field for downloading and post-processing using the Standard Trimble software. The database Manager facilitates individual and final survey loop and least squares network adjustment for Static Rapid Static GPS data (for the Control station network), individual vector processing, orthometric heights from latest geoidal models.

Output station coordinates in ASCII are directly read by WinGLink for gravity data reduction, full terrain corrections, QC, Bouguer anomaly and image analysis, filtering etc.

Gravity Interpretation

Image processing, 2.75-D and 3D inversion modeling and interpretation of the gravity data will be carried out within WinGLink and on Milan Cluster. Structure and Basement depths may be estimated through 2.5 and 2.75-D modeling, in conjunction with Werner and Euler solutions as qualitative guides.

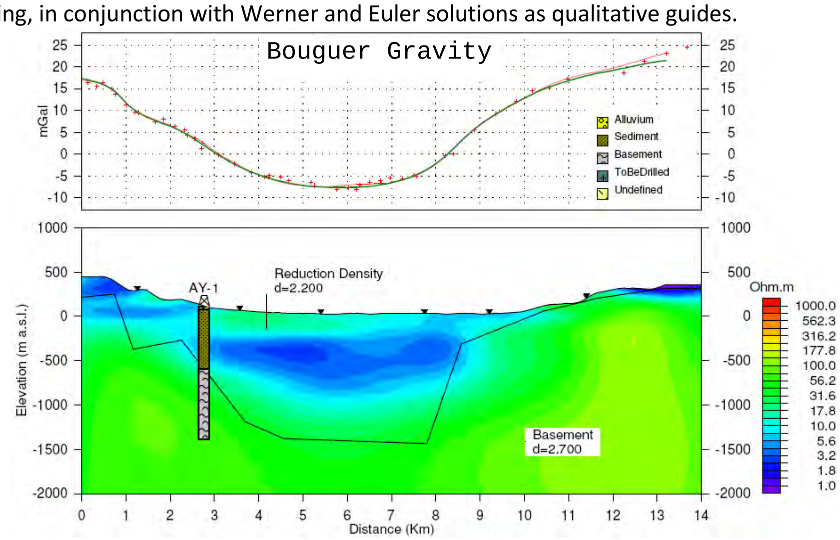


Figure 5 Example 2.75-D Gravity model across graben, superimposed on resistivity from 3D MT inversion, and production well lithology (WinGLink).

Stand-alone 3D gravity inversion is carried using propriety WesternGeco software. The inversion process includes the ability to strip anomalies from shallower structure defined by seismic horizons for example. All MT and gravity products are integrated within WinGLink or Petrel, as required.

Gravity Reporting and deliverables

Daily reporting via e-mail includes progress and HSE report and processed data. A list of WesternGeco standard final digital deliverable products is given in
Table 6, for reference.

Table 6 Deliverables Examples

File Type	Brief Summary of File Nomenclature	Generated by Program / Vers.
Database Manager: WinGLink	Visual Basic driven database containing all raw and edited and modeled MT and TDEM and well data.	WinGLink
Maps and Cross Sections	In digital images to be coordinated with CLIENT	WinGLink IVM (montage mapping and cross section tool)
Site Coordinates	Table of listings	
Maps and Cross Sections	In digital images to be coordinated with CLIENT	WinGLink IVM (montage mapping and cross section tool)
Raw Gravity Data	Instrument dump files (mixed binary and ASCII)	Scintrex CG3/5 or LaCoste & Romberg G-meter
Raw GPS data (Rinex)	Day Files (mixed binary and ASCII)	Trimble, Leica and Magellan
Final Coordinates	As per spec, in orthometric heights.	WinGLink and GNNS Solutions
Processed Gravity, QC and GPS Data	ASCII listings with coordinates, Gobs, corrections Free Air, and Bouguer anomalies Maps and Sections	WinGLink and GNNS Solutions

Reporting of Preliminary Results and Final Report

The preliminary results of the 3Dmodeling and operations report will be delivered by December 20th. Within 21 days of the end of acquisition we will provide copies of a comprehensive operational report covering acquisition, processing and HSE operations. This provides a summary and details of the processed data, a list of station locations, large scale map(s) showing these locations, and a summary of logistics, operations, HSE statistics, equipment, instrumentation, procedures and personnel. All final processed results shall be plotted in a manner agreed by WesternGeco and Client, including data listings, and full quality parameter plots. The final report shall include details of the interpretation methodology, error estimates, the auxiliary geophysical and geological well log data integrated, and maps and cross-sections with wells and integrated data overlays, demonstrating the results, and accompanied by:

- documentation explaining the content and format of the data files.
- DVDs containing the raw data.
- DVD with the final processed files including all computed parameters such as 2D models, meshes, depth map and X-section grids in a variety of industrially-accepted formats.
- Integration and Interpretation grids,
- documentation explaining the content and format of the model files.
- copy of the final report document.

In case of 3D gravity inversion and/or joint inversion of gravity with MT data, a final interpretation report will be delivered within 60 days from the end of acquisition, covering all aspects of modeling and inversion methodology and results.

Schlumberger

Western Geco

INTEGRATED MODELING OF MT AND GRAVITY DATA

Multiple measurements of the subsurface properties via seismic, electromagnetic and gravity methods should produce a more accurate earth model via Simultaneous Joint Inversion (SJI).

The term joint inversion is commonly used in the oil and gas industry to indicate a wide range of technologies and workflows that aim to integrate different measurements for geophysical exploration. Dell'Aversana (2001) integrated seismic and electromagnetic data for structural imaging; Li and Oldenburg (1996b) used borehole and surface magnetic data to invert for susceptibility; De Stefano and Colombo (2007) inverted linked data within a single cost function. This approach is called simultaneous joint inversion (SJI), given that the workflow integrates the measurements in the inversion phase, and it is not simply an alternating sequence of single measurement inversions.

Common applications of SJI involve seismic (surface, refracted, or reflection) and non seismic measurements (EM, gravity, magnetic); In this optional unpriced proposal we focus on SJI of MT with gravity data, each time minimizing a single objective function (in contrast to an approach in which multiple objective functions are inverted in separate domains). We propose to apply this technology as a test on a small number of gravity and MT stations and, depending on the success of the results, to formulate a commercial proposal for the application to the whole dataset.

Considering the above, we propose performing multi-measurement modelling through SJI of MT and gravity data, as per the following workflow:

1. Geological model definition in cooperation with SMUD: using all available geological and geophysical data, a geological model of the survey area is defined.
2. Property model building: the geological model is translated into the appropriate property model (density and resistivity) for each methodology. A few different scenarios will be modeled and evaluated.
3. Synthetic response computation: for each property model, 3D single domain forward modeling is run to compute synthetic responses of the relative methodology.
4. Anomaly detectability analysis: for each methodology, synthetic data from different scenarios are compared to determine anomaly detectability.
5. Single domain inversion of MT and single domain gravity inversion are run. The resulting models will be used as benchmark for the improved models coming from SJI inversions.
6. 3D SJI inversions obtaining inverted property models, inversion statistics and data misfit, to check how the model is recovered by SJI. To define the result reliability, sensitivity and uncertainty will be analyzed comparing SJI models and single domain results obtained in step 5.

Input data

- Existing and new geophysical data: gravity, MT and any other available data (seismic, magnetic, etc.)
- Existing geological data: geological models, maps, remote sensing data

Deliverables

- Property models (density and resistivity model) based on actual geological and geophysical data in addition to the SJI results.
- SJI Inversion parameters and statistics

Software

WesternGeco uses proprietary technology for modeling and survey design studies that includes:

- Petrel software for complex earth model building and integrated interpretation of geophysical data
- WinGLink software for processing and modeling gravity and MT data; visualization with seismic horizons and sections and well data
- 3D gravity inversion
- 3D MT inversion
- Simultaneous Joint Inversion of MT with gravity data.

SIMULTANEOUS JOINT INVERSION METHODOLOGY

Simultaneous Joint Inversion (SJI) offers an elegant and analytical approach to geophysical data integration, suitable for application to large volumes of data in a production data processing environment. The benefits of seismic-gravity-electromagnetic SJI applied to complex velocity distributions have been demonstrated via synthetic and real data sets either in the pre-migration and/or post-migration domains (for Pre-Stack Depth Migration) with applications spanning from Northern Oman thrust-belt to the basalt-covered Columbia River Basin, Washington. More recently, SJI applications have been extended to the analysis of shallow complex velocity distributions, where SJI of seismic and gravity, as well as integration of seismic and TDEM data, have been successfully applied for time and depth seismic processing.

Having recognized the added value of geophysical data integration, difficulties arise in the definition of analytic and quantitative workflows for performing such an operation. Traditional integration approaches rely on iterative procedures with data conversion from one geophysical domain to the other while performing modeling and/or inversion in each separate domain Figure 6, top). Such interactive approaches involve large user discretion in the generation of appropriate results among a wide range of possible solutions. This makes these approaches difficult to generalize for large-scale applications.

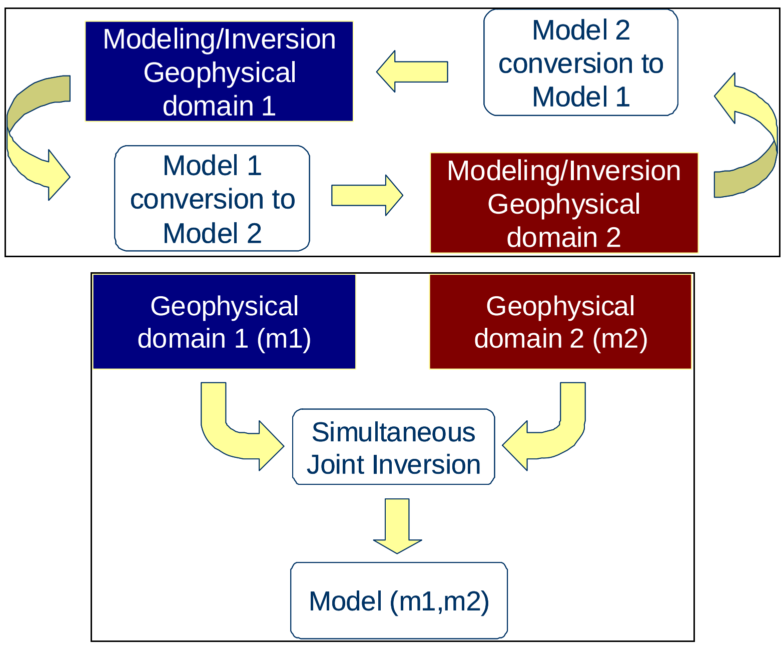


Figure 6:Traditional sequential integration approach (top) and simultaneous Joint Inversion approach (bottom).

Another disadvantage relies in the progressive loss of information when converting from one geophysical domain to the other, an operation typically governed by empirical transformation equations, which are valid only within restricted experimental conditions.

An alternative approach is provided by a scheme of simultaneous Joint Inversion where the inversion equations and cross-links among parameters of multiple geophysical domains are probabilistically evaluated to generate simultaneously the models of multiple geophysical parameters (Figure 6, bottom). The advantages of such a procedure consist of a quantitative and analytic geophysical integration scheme, the reduction of non-uniqueness in the inversion results and the availability of cross-correlated geophysical parameter models.

GEOLOGIC INTERPRETATION AND STRUCTURAL RESTORATION

Introduction

A good and precise geologic understanding of a study area is one of the key requirements in order to properly set up an integrated project, carry out a controlled DP flow and minimize E&P risks and play evaluation uncertainties.

At the earliest stages, Geology can contribute to the precise definition of the project scope and objectives, avoiding waste of time and money from both sides and promoting the delivery of a true GeoSolution. During the DP phase, it can help in defining a geologically-driven DP flow that allows the identification of the geologically consistent solutions, among all the correct numerical possibilities. Once at the E&P planning phase, it is the key to minimize the exploration risks and localize the main uncertainties, for a good target evaluation and a successful production phase.

Geologic advice and interpretation followed by structural restoration can effectively improve the quality of the final products, driving the model building and providing important information in terms of play location, structural geologic setting (both at regional and local scale), preferential paths for fluid migration etc.

Since late ‘80s many studies in the O&G industry have been conducted using this type of approach; more recently, it has been introduced in the Mining, Geothermal and CCS (Carbon Capture and Storage) industries as well. In the majority of the cases a substantial gain has been recorded, both in terms of actual increasing in productivity/decreasing of costs and in terms of general knowledge advancement (i.e. publication of papers on international scientific journals).

In case of interest in this type of services, we can formulate a commercial proposal for the application to the survey area.

The project set up: a geological perspective

Taking Geology in account during the project set up allows the early identification of the key targets, giving more perspective and breath to the project in itself and avoiding “bad surprises” with respect to the expected results. The geologic advice and “control” can likely occur all along the project development, through the DP phase until the E&P part. This procedure will bring to the delivery of a true and complete GeoSolution.

Geologic constraints during the DP phase: the geologic box

Placing soft geologic constraints during the DP phase corresponds to the building of a geologically consistent “box” around a project. Within this box any numerically valid solution represents an acceptable scenario, while any numerically correct solution that appears consistent in itself but stands outside this box will be the object of further investigations, and eventually discarded.

The contribution of Geology in this phase of a project is a novel approach that has many applications. It can help in identifying and minimizing potential issues immediately after they arise, giving a strong control on the outcomes and providing, at the end of the data processing, an extremely high-quality result. It can be also used as “extra-input” during the processing phase, to provide geologic consistency to numerically valid data. Geologic advice can also be helpful for an integrated interim data estimation and evaluation.

Examples of “soft geologic constraints” during the DP phase are:

- Existing literature evaluation

  Checking the existing scientific publications it is a really important step to start understanding an area. Any deposit has its own characteristics and a deep comprehension of the main issues is fundamental for a successful exploration phase.

- Evaluation of test results

  With a process similar to the WDS (Well-Driven Seismic) control, it is possible to check – in collaboration with other experts - the outcomes from test results with a “geologic eye”. This contributes to the improvement of the data quality.

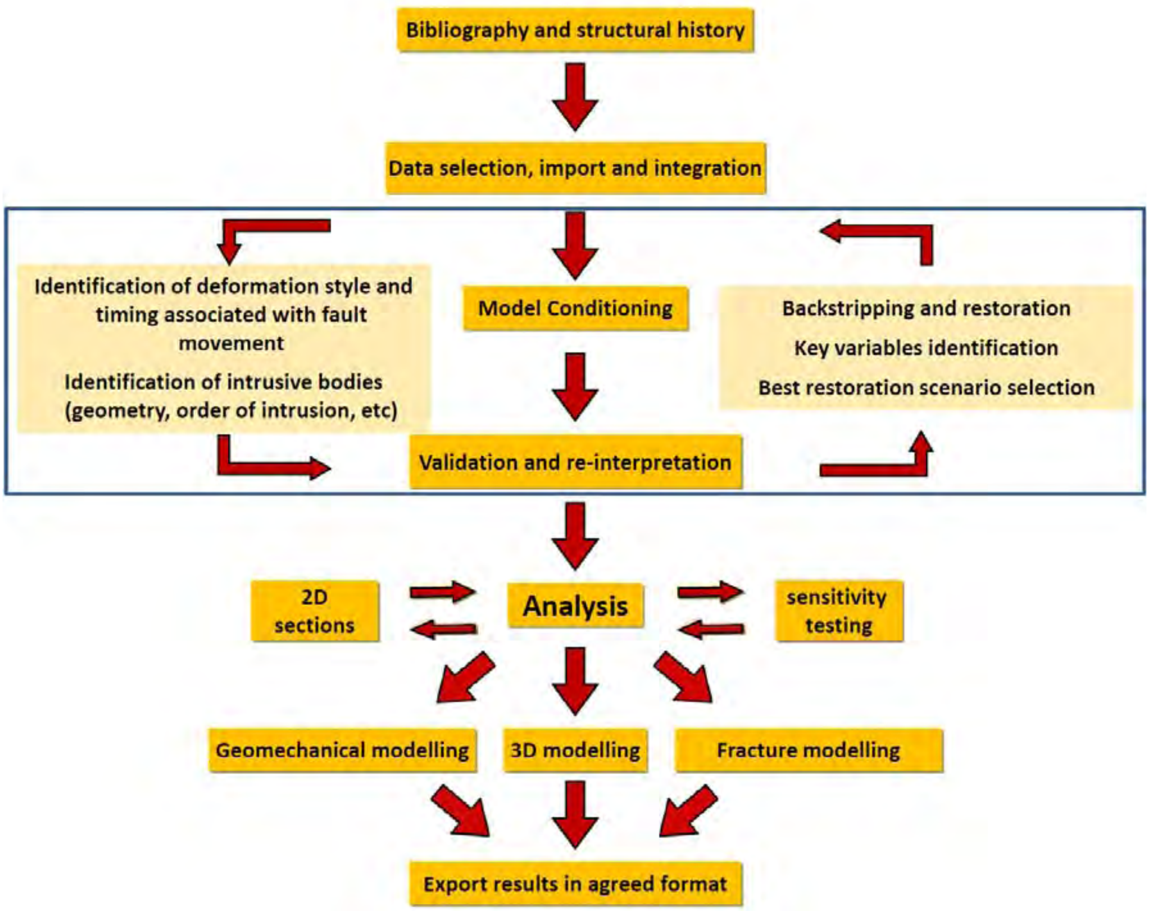
- Parameter estimation from geologic interpretation

  Integration of Geology during the DP phase can refine the definition of the values for physical parameters (e.g. velocity, resistivity, magnetic susceptibility, porosity, permeability, etc) that will be used as input to build up the corresponding model.

The resulting geologically acceptable scenarios will then be analyzed during the subsequent E&P phase.

Geologic interpretation and structural restoration: the uncertainty reduction

Each numerically valid solution (i.e. embedded in the "geologic box" mentioned above) represents a potential scenario to test. A geologic interpretation followed by a structural backstripping and restoration is the most powerful tool to assess the internal consistency of a geologic model. With this technique it is possible to precisely assess the surface shape and position (both in 2D and 3D), determine the timing of the tectonic deformation at basin scale and possibly reconstruct the present-day position of key features (deep ore bodies, fluid flow channels, etc) on the basis of their reconstructed palaeo-position. The detailed workflow in case of a project involving 2D lines is highlighted in the diagram below. 3D



More in detail, this technique allows:

- Precise definition of shape and position of every surface defined in the model (depositional and erosional surfaces, faults, etc). An important consequence of this exercise is that the obtained calibrated surfaces are a realistic and geometrically valid representation of the true geologic situation, both qualitatively and quantitatively.
- Reconstruction of the movement along faults back in time, subdividing the study area in sub-regions of "equal deformation" and recovering the motion along each specific surface to reach the pre-deformation state. The main consequence is that, at the end of this iterative process, each fault surface will have a dedicated and precise motion timing. This is of fundamental importance in the exploration phase.
- Geomechanical reconstruction of selected surfaces and non-deterministic fracture network generation. With this technique it is possible to generate a consistent DFN (Discrete Fracture Network) model, together with a number of parameters, such as porosity, permeability, fracture connectivity, stress/strain partitioning, etc., which can be subsequently used during the E&P phase.

WESTERNGECO EXPERIENCE AND KEY PERSONNEL

Experience

WesternGeco's EM group has more than 27 years experience as an EM and potential fields contractor. Our Land EM group provides acquisition and interpretation services to the Geothermal, Mining and Oil & Gas industries and has conducted exploration operations in more than 35 countries.

WesternGeco is the industry leader in the acquisition and interpretation of MT data in the exploration industry, focusing on developing and delivering practical solutions with state-of-the-art 24-bit instrumentation, robust processing and both 2D and 3D inversion modeling. Our MT-Xpress software provides the most modern in-field data QC and processing techniques, while our WinGLink® software is the worldwide industry standard for MT data modeling and inversion.

Our data interpretation capabilities extend beyond qualitative methods to full 3D inversion modeling using our unique and proprietary software. The inversions can be constrained using seismic or other available G&G information. During the last 5 years alone we have carried out 3D modeling and interpretations of over 150 MT surveys in diverse environments from the geothermal, mining and petroleum sectors.

Moreover, we acquire, process and interpret different types of EM data, such as time-domain EM (TDEM), controlled-source EM (CSEM), DC soundings and induced polarization (IP). We also have extensive experience with gravity and magnetic data acquisition and modeling (including 3D gravity and magnetic inversion).

Our unique strength actually resides in geophysical data integration. We employ proprietary algorithms for simultaneous joint inversion (SJI) of seismic, MT, CSEM, gravity and magnetic data in order to provide multi-property earth models and reduce uncertainty in exploration decisions.

Representative broadband MT and gravity surveys. 3D inversion was carried out for 85% of these surveys. Geothermal surveys are shown in **bold**.

Year	Client, Area, Country	# MT Soundings	# Gravity (+/- mag) stations,
2012	**ENEL, Italy (mobilizing)**		
2012	**MasPo Energy, Turkey (ongoing)**		
2012	**Magma Energy, Italy (ongoing)**		
2012	**Gesto Energy, Italy (ongoing)**		
2011-12	Rio Tinto, Peru	316	
2011	**SyR, Ecuador**	**195 +90TDEM**	
2011	**Chevron, Indonesia**	**90**	**300**
2011	**Derin Jeotermal, Turkey**	**182**	
2011	**R2E2, Armenia**	**150**	**300**
2011	**Interlink Capital, Java, Indonesia**	**90**	
2011	**Chevron, Philippines**	**10**	**25**
2011	**SMGP, Sumatra, Indonesia**	**200**	
2011	KOC, Kuwait (2 projects)	500+ TDEM, CSEM	15,000
2011	ONGC, Gujarat State, India (Cambay Basin)	250	
2011	Saudi Aramco. 3D Mabruq with uniQ seismic	640 TDEM	4,000
2010-11	**Four geothermal companies. Western Turkey**	**2,100**	

Year	Client, Area, Country	# MT Soundings	# Gravity (+/- mag) stations,
2010-11	**Energía Andina, Chile (Colpitas, Juncalito)**	**201**	
2010-11	RioTinto-Northparkes, NSW, Australia	510	
2010-11	**TerraGen, NV, USA (4 areas)**	**396**	
2010	Freeport McMoRan, Superior W., AZ, USA	510	
2010	**LBNL, Raft River Idaho – EGS CSEM survey with MT**	**65 (CSEM, MT)**	
2010	RioTinto-Kennecott, UT, USA (Bingham, Big Hill)	120	
2010	**Gradient Resources, NV, USA**	**50**	
2010	**Magravitya, NV, USA**	**40**	
2010	**Turkerler. Western Turkey**	**122**	
2010	RioTinto-Kennecott, AK, USA	184	
2010	CHEVRON-KGOC Joint Operations, PZ, Kuwait (2D)		614
2010	Vale-Inco, Thompson, Canada (fill in from 2009)	650	
2010	Saudi Aramco. 3 areas, A/MT, TDEM, GR	250	4,500
2010	Vale-Inco, Thompson, Canada	650	
2010	**Magravitya Energy, Chile**	**80**	
2010	**AGIL, Longonot, Kenya**	**100**	
2010	Chevron Joint Operations, PNZ, Kuwait		19,200
2010	**4 clients. Taupo Volcanic Zone, 8 survey areas New Zealand**	**400**	
2009-10	**Energia Andina, Chile**	**170**	
2009	**KSL, Spremberg, Germany**	**82**	
2009	**Sierra GeoPower, Silver Peak + Alum, NV, USA**	**148**	
2009	P.D.O., Wa'ad 3D, South Oman	210	4,337
2009	Kennecott, Bingham, UT, USA	251	
2009	**Petratherm, Tenerife, Spain**	**80**	
2009	**Akutan, Alaska, USA**	**51**	
2009	**Nevada Geothermal Power, Blue Mountain, NV, USA**	**48**	
2009	**BM Muhendislik Insaat A.S. Western Turkey**	**503**	
2009	**DETI-GSNI, Lough Neagh Basin, Northern Ireland**	**96**	
2009	**Magravitya, Laguna del Maule, Chile**	**75**	
2009	Vale-Inco, Thompson, Canada	852	
2009	ONGC, Cambay Basin, India	500	
2008	Petrobras, San Antonio, Bolivia	303	
2008	**Vulcan Power, Patua, NV, USA**	**106**	
2008	MOL, Hawasina Window, Oman	275	390
2008	PTTEP, Oman	16	624
2008	**Sumatra, Indonesia, (3 areas)**	**560**	
2007	**ENEL Western USA**	**210**	
2007	**ENEL Guatemala**	**160**	**600**
2007	**ENG, Chile**	**90**	
2007	**Vulcan Power, Salt Wells, NV, USA**	**66**	
2007	DevonCanada, Foothills, Alberta	42	160
2007	GSC Sub-Basalt Frontier, British Colombia, Canada	1075	
2007, 2008	**BM Mühendislik & Insaat A. S., Western Anatolia, Turkey (2 surveys)**	**814**	**10,590 (interp.)**
2007	Exxel Energy Corporation, CRB, WA, USA	138	
2007	Delta Petroleum Corporation, CRB, WA, USA	93	
2007	Savant Resources LLC, WA, USA	120	
2006	Trident USA Corp, CRB, WA, USA	450	
2006	Delta Petroleum Corporation, CRB, WA, USA	300	
2006	Savant Resources LLC, CRB, WA, USA	139	
2005	**Türkiye Petrolleri A.O. (TPAO), Abdulaziz, Hatay, TURKEY**	**348**	

Year	Client, Area, Country	# MT Soundings	# Gravity (+/- mag) stations,
2005	Savant Resources LLC, CRB, WA, USA	221	
2005	MEDUSA OIL AND GAS (POLAND) SP. ZO, POLAND	82	
2004-6	Encana Oil & Gas (USA) Inc., WA, OR	1035	1017
2005	Pluspetrol Bolivia Corp. SA BOLIVIA (Entre Rios)	85	
2005	Pluspetrol Bolivia Corp. SA, BOLIVIA (Bermejo)	111	
2005	Consorcio Yacimiento Ramos, ARGENTINA (Ramos)	112	
2005	Petrobras Bolivia SA , BOLIVIA (Ingre)	83	

Key Personnel

WesternGeco's field survey will be led by Pietro Miglio, Andrea Vella, Christopher Jones, Jennifer Livermore or Russell Ketchum (or someone with equivalent qualifications). The actual party chief can only be confirmed once the exact timing of the survey is known and is subject to personnel availability at the time of award.

Daily operations will be supervised from the office by our Operations Manager, while office-based daily QHSE supervision will be provided by Alessandra Flaminio, our QHSE Manager.

The office-based data processing and 3D inversion modeling will be overviewed by our senior MT geophysicist Carlo Ungarelli (PhD), assisted by our EM DP&I Manager, Andrea Lovatini.

CVs of key personnel are attached to this proposal.

CVs OF KEY PERSONNEL

Full Name:	**Andrea Lovatini**
Citizenship:	Italian
Languages:	Italian: native English: good Spanish: good
Country of birth	Italy
Date of birth	April 17, 1980

Position:

WesternGeco IEM DP manager, Senior geophysicist

Education:

2005	M.Sc. in Telecommunications Engineering, Politecnico of Milano, Italy

Professional experience:

Year(s)	Description
2005-present	**WesternGeco EM**
2010-present	**IEM DP&I Manager**, IEM CoE WG (Milan, Italy)
2008-2010	**Senior EM geophysicist**, on board DP manager WesternGeco EM - Geosystem srl (Milan, Italy) Marine CSEM-MT survey design Marine CSEM-MT survey DPI Marine CSEM-MT algorithm development heading
2007-2008	**EM geophysicist** WesternGeco EM - Geosystem srl (Milan, Italy) Marine CSEM processing and post-processing algorithm development Marine CSEM survey design Marine CSEM survey DPI
2005-2007	**EM geophysicist** Geosystem srl MMT processing from CSEM data marine FD CSEM processing algorithm development land TD CSEM processing algorithm development (transient EM, electro-seismic, seismoelectric) onboard QC and Client Rep, CSEM survey Chevron data processor, land MT survey, Turkey
2005	WG Tool TimeSeries, Maintenance and development
2005	Adaptation and development of software for Marine MT processing
2005	Politecnico of Milano: Development of a Coherence estimator with adaptive windows in SAR interferometry

Publications

- Rovetta, Lovatini, Watts, "Probabilistic joint inversion of TD-CSEM, MT and DC data for hydrocarbon exploration" Extended abstract, SEG 2008
- Lovatini, Umbach, Patmore, "3D CSEM inversion in a frontier basin offshore West Greenland", First Break, May 2009
- Umbach, Ferster, Lovatini, Watts, "Hydrocarbon charge risk assessment in a frontier basin using 3D CSEM inversion derived resistivity, offshore West Greenland", 2009 CSPG CSEG CWLS convention
- Lovatini, Watts, Umbach, Ferster, "3D CSEM Inversion Strategy - An Example Offshore West of Greenland", EAGE 2009. SBGF 2009
- Lovatini, Watts, Umbach, Ferster, Patmore, Stilling, "Application of 3D Anisotropic CSEM Inversion Offshore West of Greenland", SEG 2009

- Myers, Watterson, Campbell, Lovatini, "An integrated approach to exploration in the Potiguar Basin, offshore northeast Brazil -- the application of complementary measurements and techniques", IGC 2009
- Medina, Lovatini, Watts, "CSEM and MT data sensitivity analysis for 1D anisotropic inversions", EGM, 2010
- Lovatini, A., Myers, K., Watterson, P. and Campbell, T. "An integrated approach to exploration data in the Potiguar Basin, offshore Brazil." First Break, May 2010
- Lovatini, Medina, Campbell, Myers, "The use of CSEM within an Integrated Exploration Project" EAGE, 2010 & SBGF non-seismic method forum 2010.
- Lovatini, K. Myers, P. Watterson, and T. Campbell , "The Potiguar integrated exploration project: CSEM prospectivity assessment offshore Brazil", TLE 2010
- A.Zerilli, T.Labruzzo, M.P.Buonora, P.L.Menezes, L. F.Rodrigues, A.Lovatini, "3D inversion of total field mCSEM data: The Santos Basin case study",SEG 2010
- Bender, Bryant, Chhibber, Campbell, Lovatini, Mavridou, Palmowski, Schenk, Myers, Saragoussi, Xu, "Integrating Exploration Tools to Reduce Risk", Oilfield Review Summer 2010
- I.D. Bryant, A. Bender, A. Lovatini, B. Wygrala, P. Xu, "Integrated Modeling to Mitigate Risk in Frontier Exploration Offshore Brazil", EAGE Second Workshop on Exploration, Dec 2010
- L. Masnaghetti, F. Ceci, A. Lovatini, "Anisotropy Sensitivity Analysis with 2.5D CSEM Inversion of Broadside Data",
- EAGE2011 E.Tartaras, L.Masnaghetti, A.Lovatini, S.Hallinan, M.Mantovani, M.Virgilio, W.Soyer, M.De Stefano, F.Snyder, J.Subia, T.Dugoujard, "Multi-property earth model building through data integration for improved subsurfaceimaging", First Break, April 2011

Schlumberger WesternGeco

Full Name:	**Carlo Ungarelli**
Citizenship:	Italian
Languages:	Italian: native English: good French: good
Country of birth	Italy
Date of birth	April 12, 1968

Present position

Senior EM Geophysicist, Schlumberger WesternGeco

Education:

Year	*Degree*
1993	MSc with merits (Laurea con lode) in Physics, University of Rome "La Sapienza" (Italy).
1997	PhD in Physics, University of Pisa, Italy

Professional experience:

Year(s)	Description
2012 – present:	**WesternGeco EM**
2007-2011	Contract researcher, Institute of Geosciences and Earth Resources, CNR,Pisa (Italy)
2011	Scientific consultant, Water Research Institute,CNR, Rome (Italy).
2005-2007	Research fellow, Physics Department, University of Pisa (Italy).
2002-2005	Fixed- term lecturer, School of Physics and Astronomy,Un. of Birmingham (UK).
1999-2002	Research fellow, Institute of Cosmology and Gravitation, Un. Of Portsmouth (UK).
1998-1999	Research fellow, Max-Planck-Institut für Gravitationphysik, Potsdam (Germany).
1997-1998	Project Scientist, Information Engineering Department, University of Pisa (Italy).
1997	Scientific associate, Theoretical Physics Division, CERN, Geneva (Switzerland).
1997	Qualified scientific guide, CERN, Geneva (Switzerland).

Award and Honors:

2001-2002	PPARC fellowship, Portsmouth (UK).
1999-2001	University of Portsmouth Postdoctoral fellowship, Portsmouth (UK).
1998-1999	Max Planck Gesellschaft Fellowship, Potsdam (Germany).

Geophysical _field campaigns

- 02/2008-09/2008 SI.RI.Pro. project (Sicily, Italy)
- Magnetotelluric (MT) survey (receivers used: EMI-STRATAGEM, NIMS),
- 28 stations, 100 Km long pro_le.
- 07/2008-09/2008 Equi Terme area (Alpi Apuane, Tuscany, Italy)
- ERT and MT surveys (receivers used: Iris SYSCAL Pro, EMI-STRATAGEM);
- 10 MT stations, two 1-km long ERT pro_les.
- 2011-present Project Scientist, 4th CUIA Reseach Program
- (Exploration and use of medium-low enthalpy geotermal resources
- in the sub-andean area for the sustainable energy development
- of the town of Salta and the Jujuy province)
- 10/2009-05/2010 Montecatini-Monsummano hydrothermal area (Tuscany, Italy)

- MT survey (receiver used: EMI-STRATAGEM),
- 18 stations.
- 09/2010 Argentera Massif (Piemonte, Italy)
- MT survey (receiver used: EMI-STRATAGEM),
- 28 stations.

Books

- 1. \La geotermia"
- A. Manzella and C. Ungarelli,

Conference Abstracts

- Passive geophysical methods for geothermal exploration in the External Crystalline Argentera Massif of the Western Italian Alps: Gravity and Magnetotelluric", L. Guglielmetti et al.. Geophysical Research Abstracts, Vol. 13, EGU2011-8557-1, 2011.
- From the field to the interpretation of magnetotelluric data, integrated with geological, seismic and gravity data within the SI.RI.Pro project", A. Manzella, C. Ungarelli and R. Catalano. Abstracts of 29th National Congress of the Solid Earth Geophysical National Group (GNGTS), p. 567, 2010.
- Combined interpretation of acoustic velocity and resistivity models: the SI.RI.Pro project case", A. Maltese, C. Ungarelli, A. Manzella, R. Catalano, F. Accaino and C. Zanolla, Abstracts of 28th National Congress of GNGTS, p. 692, 2009.
- Towards the integration of magnetotelluric with geological, seismic and gravity data within the SI.RI.Pro project". A. Manzella, R. Catalano, C. Ungarelli, L. Coppo and C. Zanolla. Abstracts of 28th National Congress of GNGTS, p. 683-684, 2009.
- Electrical resistivity at the Travale geothermal _eld (Italy)". A. Manzella, C. Ungarelli, G. Ruggieri, C. Giolito and G. Gianelli. Conference Contributions of the I-GET Final Conference, E. Huenges and D. Bruhn (eds), p.28, 2009.
- A multidisciplinary approach to resistivity modeling at the Travale geothermal field". A. Manzella, C. Giolito, G. Ruggieri, C. Ungarelli and G. Gianelli. Conference Contributions of the I-GET Final Conference, E. Huenges and D. Bruhn (eds), p. 36, 2009.
- Two-dimensional magnetotelluric data modeling at the Travale geothermal field (Italy). A. Manzella, A. Bianchi and C. Ungarelli. Abstracts of 27th National Congress of GNGTS, p. 70-71, 2008.
- Three-dimensional magnetotelluric data modeling at the Travale geothermal field (Italy). A. Bianchi, A. Manzella and C. Ungarelli. Abstracts of the 19th International Workshop on Electromagnetic Induction in the Earth, p. 460, 2008.

Selected Publications

- Multidisciplinary Approach to the Study of the Relationships Between Shallow and Deep Circulation of Geofuids". A. Bianchi et al. Proceedings of the World Geothermal Congress, 2010.
- Electrical resistivity at the Travale geothermal _field (Italy)". A. Manzella, C. Ungarelli, G. Ruggieri, C. Giolito and A. Fiordelisi, Proceedings of the World Geothermal Congress, 2010.

Schlumberger Western Geco

Full Name:	**Alessandra Flaminio**
Citizenship:	Italian
Languages:	Italian: native English: good German: good
Country of birth	Italy
Date of birth	November 12, 1964

Present position

Land EM /IEM CoE QHSE Coordinator.

Education:

Year	*Degree*
1988	M.Sc. in Geology, University of Milan, Italy

Professional experience:

Year(s)	Description
1988 – present:	**WesternGeco EM - Geosystem**
2008- present	Westerngeco EM QHSE Coordinator – Schlumberger Driving Trainer – Schlumberge Injury Prevention Program Trainer – QHSE 2 Trainer – Quality and HSE Lead Auditor
2001 -2008	Geosystem srl: HSE Responsible and QA Director
1999-2000	Geosystem srl: Responsible for Safety and QA Director Assistant
1996-1998	Geosystem srl: QA Director Assistant
1994- 1995	Geosystem srl: MT Operator/ Data Processing in several projects in Italy, Turkey, Uk , Albania. Clients: AGIP, FINA, Total, Coparex, British Gas, Enel , Edison Gas, Rimin ENI, TPAO
1990-1994	Gravity and TDEM data acquisition and processing . Client: MINISTRY OF WATER RESOURCES, OMAN, Rimin ENI, TPAO, Enel, UK Nirex
1988-90	Detailed gravity survey and High-precision underground gravity surveys. Cross-hole seismic data interpretation for geotechnical purposes.
1987	CNR: Operator for regional seismic refraction surveys, Central ITALY.

Professional Qualifications:

2011	Nebosh International HSE Certificate.
2011	Schlumberger Driving Trainer
2010	Quality and HSE Lead Auditor
2009	QHSE Level 2 Trainer
2008	Schlumberger Injury Prevention Program Trainer
2008	First Aid and CPR Level 2

Schlumberger

WesternGeco

Full Name:	Christopher Lyman Jones
Citizenship:	U.S.A.
Languages:	English: mother tongue
Country of birth	U.S.A.
Date of birth	November, 23 1976

Present Position:

Geophysicist – MT, TDEM, GR-MG Party Chief and Data Processor

Education:

Year	*Degree*
1999	BA in Business - Univ. of Colorado at Boulder USA (incomplete)
1995	Bear Creek High School - Graduate

Professional experience:

Year(s)	*Description*
2005- present	**WesternGeco EM**
2012	Party Chief, MT Survey La Granja, Peru. Client Rio Tinto Exploration
2011	Party Chief, MT/TDEM Survey Chachimbiro/Chacana, Ecuador. Client SyR
2011	Party Chief , MT/GR/CSEM Survey South Ratqa, Kuwait. Client KOC (KUWAIT OIL CO)
2011	Party Chief , MT Survey Kalinga, Philippines. Client CHEVRON Geothermal Philippines Holdings, Inc.
2011	Party Chief , MT Survey Cambay, India. Client ONGC
2010	Party Chief , MT Survey Superior Arizona. Client Freeport McMoran.
2010	Party Chief , MT Survey Salt Lake City Utah. Client Kennecott Exploration.
2010	Party Chief, MT, TDEM Survey Fallon, Nevada. Client Gradiant
2010	Party Chief, MT Survey Fallon, Nevada. Client Magma Power
2010	Party Chief, MT Survey Fallon, Nevada. Client TerraGen Power
2010	Party Chief, Data Processor. MT, TDEM, Gravity-Mag Survey, Saudi Arabia, Client Saudi Aramco
2010	Party Chief, Data Processor. MT Survey, Taupo, New Zealand. Clients Genesis, MRP. Contact, Top Energy
2009	Party Chief, Data Processor. MT, TDEM, Gravity-Mag Survey, Oman, Client PDO
2009	Party Chief Assistant, Data Processor, MT Survey, Bingham. Client Kennecott
2009	Party Chief Assistant, Data Processor, MT Survey, Akutan. Client City of Akutan
2009	Party Chief Assistant, Data Processor, MT Survey, Baroda India. Client ONGC
2009	Party Chief, Data Processor, MT Survey Reporoa, New Zealand. Client Genesis
2008	MT Operator, Crew Chief . MT Survey, Bingham Mine, Utah, USA Client : Kennecott
2008	Party chief and GR Operator / Processor, GR Survey, Block58, Oman. Client : PTTEP
2008	MT Operator, Crew Chief . MT Survey, Tokkanu, New Zealand. Client : Genesis En.
2008	MT Operator, Crew Chief / Processor. MT, TDEM, GR, MG Survey, Block 43A, Oman. Client : Hawasina
2008	TDEM Operator, Crew Chief. TDEM Survey Dubai, UAE. Client Dubai Petroleum
2007	MT Operator, Crew Chief . MT Survey Cove Fort and Surprise Valley, USA . Client ENEL USA

2007	MT Operator and permitter, Long Period MT (NIMS) Earthscope Project, Western USA. Client IRIS
2007	MT Operator, MT Surveys, N. Alaska, USA. Client: Northern Dynasty Minerals
2007	MT Operator, MT Surveys, Washington, USA. Clients: Exxel, Delta Petroleum, Savant Resources
2006	MT Operator, MT survey Jadar Serbia, Client Rio Sava Expl.
2006	MT Operator, MT and TDEM Survey , Newberry Oregon. Client: Northwest Geothermal Company (NGC)
2006	MT Operator, MT and TDEM Surveys, North Island, New Zealand. Client: Mighty River Power Limited
2006	MT Operator, MT/TDEM, Oregon, USA. Client: Savant Resources
2005 -2006	MT Operator MT/TDEM surveys, Washington, USA. Clients : Encana USA, Trident, Delta Petroleum Corp., Savant Resources
2004-2005	EM Survey Crew Chief Montason Exploration, Angola, Africa.

Schlumberger **WesternGeco**

Full Name:	Pietro Miglio
Citizenship:	Italian
Languages:	Italian, English, French
Country of birth	Italy
Date of birth	9 May 1973

Present Position:

Party Chief, Crew Chief, Data Processor

Education:

2003	M.Sc in Geology, University of Milan, Italy
1992	Aeronautic construction and design.

Professional experience:

Year(s)	*Description*
2007-to present	**WesternGeco EM**
2011	Party Chief, Gravity, TDEM, MT, DGPS South Sumatra. Client, Chewron.
2011	Party Chief, Gravity, MT, Armenia. Client R2E2
2011	Party Chief, Gravity, TDEM Survey KSA , Client Saudi Aramco
2010	Party Chief, MT Survey Western Turkey , Client Demiroren
2010	Data Processor MT Survey Western Turkey , Client Derin Energy
2010	Party chief, Data processing for 2D gravity Kuwait, Client JointOperations
2010	Party chief, Data processing for 3D microgravity, Kuwait, Client JointOperations
2009	Party chief, Data processing for magnetic and gravity data Oman, Client PDO
2009	Crew Chief , MT Survey Tenerife, Client Petraterm.
2009	Crew Chief , MT Survey Western Turkey, Client BM Mühendislik & Insaat A.S.
2009	Crew Chief. MT Survey Baroda, India. Client ONGC
2008	Crew Chief, MT Operator. MT Survey, San Antonio , Bolivia. Client Petrobras
2008	Crew Chief , MT Survey Western Turkey. BM MUHENDISLIK & INSAAT A.S.
2008	Data processing for magnetic and gravity data, Journey Manager . MT, GR, MG Survey, Block 43A, Oman. Client : Hawasina
2008	Land operator for MEQ passive seismic survey in south Italy, TOTAL Italia S.p.A.
2007	Scouting, permitting for MEQ passive seismic survey in south Italy, TOTAL Italia S.p.A.
2007	Data Processing passive seismic survey Wayang Windu (Indonesia), Magma Nusantara Ltd.
2007	Party Chief passive seismic survey Wayang Windu (Indonesia), Magma Nusantara Ltd.
2007	Data Processing, Passive seismic survey, Usano Arakubi Area (Papua New Guinea), OIL SEARCH Ltd.
2007	Data analysis Start up passive seismic survey, Usano Arakubi Area (Papua New Guinea), OIL SEARCH Ltd.

2007	2D Seismic Pre-processing, Montegranaro, Client GAS PLUS ITALIANA.
2007	2D Seismic Pre-processing, Cuenta, Client PLUSPETROL VENEZUELA.
2007	2D Seismic Seismic Pre-processing , Wabah, Client INDAGO.
2007	2D Seismic Pre Processing, Jordan. Client Schlumberger
2002-2006	Geophysics, AKRON Srl, Milano. Project field engineer: project management, acquisition, analysis and data processing for engineering, geology and the applied geophysical (seismic refraction, seismic down hole, cross hole, seismic tomography, micro-seismic, non-destructive testing on concretes, metal and constructions materials, load tests, ultra-sound surface test, ultrasonic cross hole, ultra-sonic log, GPR, photometers scan log, mechanical admittance). Multi-frequency electromagnetic scan, ERT, sonic tomography, clinometers, environment monitoring, dynamic test for bridge and structure, vibrations monitoring, fracture analysis. Meteorological monitoring. Partially destructive tests: pull out, Windsor's probe. Landfill contamination characterization, direct and indirect survey methods. GPR (Ground Penetrating Radar) investigation from surface and borehole for engineering works, mapping of the subsurface for pipe location, nondestructive surveying and landfill management. Electrical resistivity tomography (ERT) for Hydrogeology studies. Sonic topographies. Structural tests, monitoring of (high speed, railway tunnels, galleries, lines, freeways), roads, dams. Load tests and dynamics test on buildings, railway and structures..
2006	**Freelance: Guide in Iceland for geological tour.**
2003	**Freelance: collaboration with the University of Milano** GPR survey for the determination of the" Plateau Rosà" (Cervinia)ice thickness.
2002	**Freelance, (I.D.P.A.) (C.N.R.) Milano.** Archaeological research with GPR method (Giardini di Porta Venezia, Milano).
1998-2001	**Geologia e Ambiente, Oleggio, Novara.** SPT tests , water infiltration tests, perforations, coring, stratigraphic analysis in quaternary sediments and SEV for water search.

Full Name:	**Andrea Vella**
Citizenship:	Italy
Languages:	Italian: mother tongue English: good
Country of birth	Italy
Date of birth	01-Nov-1975

Present Position:

MT-TDEM Crew Chief / Instrument Technican

Education:

Year	*Degree*
1999	Electrotecnical Diploma
1996	Specializacion in installer maintainer and test of electric devices
1995	Qualification in electrotecnic maintenaince, Milan

Professional experience:

Year(s)	*Description*
2003- present	**Schlumberger Italiana – WesternGeco – Geosystem**
2011	CSEM-MT Crew Chief, Kuwait. Client KOC
2010-11	Crew Chief. MT Survey WesternTurkey. Client Demiroren
2009	MT Operator, Crew Chief. Spremberger, Germany. Client KLS
2009	MT Operator, Crew Chief. Antrim, Nord Ireland.
2009	MT Operator, Crew Chief. Tenerife. Client Petratherm
2009	Crew Chief. MT Survey Baroda, India. Client ONGC
2008	MT Data Processor, Crew Chief. Gunung Wilis, East Java.
2008	Crew Chief, MT operator, MT Survey Sumatra, Indonesia. Client Supreme Energy
2008	MT-TDEM Operator, Crew Chief . Western Turkey, Client BM MÜHENDISLIK & INSAAT A.S
2007	MEQ Operator. Passive seismic, Basilicata Italy , Client Total
2004-05	MT-TDEM Operator, Crew Chief. MT – various international projects
2003	MT Operator. Calabria Italy, Client TOTAL Italia Spa.

Schlumberger WesternGeco

Full Name:	**Russell Jason Ketchum**
Citizenship:	U.S.A.
Languages:	English: native Spanish: (working knowledge)
Country of birth	U.S.A.
Date of birth	May 16, 1960

Position:

Geophysicist – MT-TDEM Operator and Crew Chief

Education:

Year	*Degree*
1978	Graduated Herbert Hoover HS

Professional experience:

Year(s)	*Description*
1999 to present	Geosystem – WesternGeco EM
1990 to 1998	Zephyr Geophysical Services
1987 to 1990	Phoenix Geoscience
1979 to 1986	Argonaut Enterprises

2010	
	Party Manager, MT Operator.MT Survey. Fallon, Nevada. USA. Client: Terra Gen
2010	MT Operator. MT Survey. Provo, Utah. USA. Client: Kennicott
	MT Operator, Crew Chief. Fallon, Nevada. USA. Client: Terra Gen.
2010	MT, TDEM, Gravity Operator. Crew Chief. Saudi Arabia Cliet: Saudi Aramco
2010	MT Operator, Crew Chief. MT Survey, Taupo, New Zealand.Client Top Energy
2010	MT Operator, Crew Chief. MT Survey, Taupo, New Zealand. Client MRP
2010	MT Operator, Crew Chief MT Survey, Taupo, New Zealand. Client Contact
2010	MT Operator, Crew Chief. MT Survey, Taupo, New Zealand. Client Genesis
2009	MT Operator, Crew Chief, QHSE coordinator. MT Survey, Alum-Silver Peak, NV. Client SGP
2009	MT Operator, Crew Chief. MT Survey, Bingham, UT: Client Kennecott
2009	MT Operator, Crew Chief. QHSE coordinator. MT Survey, Nevada: Client Nevada Geothermal Power
2009	MT Operator, Crew Chief. MT-TDEM Survey, Baroda India: Client ONGC
2008	MT Operator – CSEM layout supervisor, College Station, Texas; Pinedale, Wyoming, USA: Client Shell Expl.
2008	MT Operator, Crew Chief. MT Survey, Wadi Hawasina , Oman. Client: Hawasina LLC Oman Branch
2008	MT Operator, Crew Chief. MT Survey, South Sumatra, Indonesia. Client: Supreme Energy, PT
2007	MT Operator, Crew Chief. MT Survey Cove Fort and Surprise Valley, USA . Client ENEL USA
2007	MT Operator and permitter, Long Period MT (NIMS) Earthscope Project, Western USA. Client IRIS
2007	Crew Chief MT-TDEM Survey Nevada, USA. Client Vulcan Power.

2007	Crew Chief MT Survey Alaska State, USA. Client Northern Dynasty Minerals Ltd.
2007	Crew Chief MT Survey Washington State, Client Exxel Energy Corp.
2007	Crew Chief MT Survey Washington State, Client Delta Petroleum Corp.
2006	Pilot Project long period MT, Cascade Mountains Oaragon USA. Client IRIS
2006	Geosystem: MT-TDEM crew chief, Oregon, USA. Client: Savant Resources
2005-2006	Geosystem: MT-TDEM crew chief, WA State, USA. Client: Encana USA, Trident, Delta Petroleum Corp., Savant Resources
2004	Geosystem: Crew Chief, MT-TDEM survey. 5 prospects in Taupo Volcanic Zone, New Zealand. Client: Mighty River.
2004	Operator, MT/TDEM survey, Obrajuelo, El Salvador. Client: LAGEO SA
2004	Operator, MT/TDEM survey, Ahuachapan, El Salvador. Client: Enel Green Power
2004	Geosystem: MT-TDEM crew chief, Lihir, Papua New Guinea, Client: LMC
2003	Geosystem: MT-TDEM crew chief, WA State, USA. Client Savant
2000	Geosystem: MT crew chief, Terceira, Azores, client EDA
2000	Geosystem: MT crew chief, Chiltepe, Mombacho, Nicaragua, client GeothermEx
2000	Geosystem: AMT crew chief, Manitoba, client INCO
1999	Geosystem: MT crew chief, Wyoming, client Marathon
1999	Bar Geophysics: IP crew chief, Mexico multiple projects, client Phelps Dodge
1998	Zephyr: MT crew chief, Ethiopia, client Hunt Oil
1997	Zephyr: MT crew chief, Papau New Guinea, Baracuda Oil
1997	Zephyr: MT and CSAMT crew chief,, Western US petroleum and mineral exploration, clients Hunt Oil, Chevron
1996	Zephyr: MT crew chief, Papau New Guinea, Baracuda Oil
1996	Zephyr: MT crew chief, Western US petroleum and mineral exploration, clients Hunt Oil, Sante Fe.
1994-1995	Zephyr: MT crew chief, Saudi Arabia. Client ARAMCO.
1990-1993	Zephyr: MT crew chief, Papau New Guinea and western US, petroleum and mineral exploration. Clients Texaco, Exxon, several mineral companies.
1989-1990	Phoenix: MT crew chief, Petroleum exploration Venezuela. Client INTIVEP.
1987-1989	Phoenix: CSAMT, IP crew chief, Western US. Client Sante Fe Pacific, First Miss Gold.
1979-1986	Argonaut Enterprises: MT crew chief, Western US petroleum exploration. Clients AMOCO, Texaco, Exxon, Unocal, BP

Schlumberger   WesternGeco

Full Name:	**Ivan Guerra**
Citizenship:	Italian
Languages:	Italian: native English: very good French: very good Spanish: good
Country of birth	Italy
Date of birth	March 15, 1977

Present position

Senior Structural Geologist, WesternGeco

Education:

Year	*Degree*
2002	BSc in Geology, Milano University, Italy.
2004	MSc in Petrology and Structural Geology, Milano University, Italy.
2010	PhD in Structural Geology and Geochemistry, Lausanne University, Switzerland.

Professional experience:

Year(s)	Description
2012 – present:	**WesternGeco EM**

2010 – 2011 Structural/Project Geologist - Midland Valley Exploration Ltd

- Company responsible for SE Asia and Australia portfolios
- Company co-responsible for Radiaoctive Waste Disposal, Geothermics and Carbon Capture and Storage

2009 – 2010 Research Assistant – Stable isotope geochemistry
Institut de Minéralogie et Géochimie
Université de Lausanne
Switzerland

2006 – 2008 Teaching Assistant – General geology, Structural geology, Alpine geology (with field courses)
Institut de Géologie et d'Hydrogéologie
Université de Neuchâtel
Switzerland

2005 – 2006 Teaching Assistant – Sedimentary Geology
University of Victoria
School of Earth and Ocean Sciences
Canada

2002 – 2004 Field Geologist
"Progetto CARG – Cartografia Geologica 1:50000 – Foglio Merano". Italian program for National geological map renewing. My activity area (approximately 20 km2) was situated in the eastern Alps, in a portion of Alpine metamorphic basement with igneous intrusions. I produced a detailed (1:10000) structural-geological map, a PT-t-D path of that crustal portion and a final report of all activities.

2001 – 2002 Field Geologist
"Progetto CARG – Cartografia Geologica 1:50000 – Foglio Malonno". Italian program for National geological map renewing. My activity area (approximately 21 km2) was situated in the central Alps, in a portion of Alpine metamorphic basement. I produced a geological map (1:10000), a structural map and a final report of all activities.

Technical skills:

Structural geology modelling and analysis
Experienced user of Move (Move, 2DMove and 3DMove) and related modules (Sediment Modelling, Geomechanical Modelling and Fracture Modelling).
User of Petrel and Landmark.
Knowledges of KINGDOM, Vulcan and LithoTect.
GIS
Experienced user of ArcView and Global Mapper.
Geochemistry – Analytical geology
Excellent knowledge of the following facilities:
Finnigan MAT 253 Stable Isotope Ratio Mass Spectrometer
Oxygen-extraction line equipped with a Finnigan MAT 253 SIR-MS for normal dual inlet and carrier gas analyses, and on-line CO2-laser fluorination line for single grain and whole rock analyses as well as a UV-laser fluorination for insitu analyses of oxygen (and sulfur) isotope analyses.
Finnigan MAT Delta Plus XL
Automated extraction line equipped with a Finnigan MAT Delta Plus XL for carrier gas analyses and on-line TC/EA for H and O isotope analyses of solids (hydrous mineral, phosphates, sulphates, nitrates), liquids (waters) and gases, as well as a Gas-Bench for C and O isotopes of carbonates, dissolved inorganic carbon and oxygen isotope analyses of waters.
Automated (U-Th)/He Laser Extraction and QMS Line
All metal, ultra-high vacuum noble gas extraction and purification line for 4He measurements.
ID-TIMS (Isotope Dilution - Thermal Ionization Mass Spectrometry)
High precision measurement method (and related facility) for U-Th-Pb isotopes on U-bearing minerals.
Excellent knowledge of all modern techniques for mineral separation and sample preparation – crushing; water, magnetic and chemical separation; heavy liquids separation; picking; work in clean lab; thin, thick and polished section preparation; etc - related to different purposes (U/Pb and (U-Th)/He dating, O and C-O stable isotope measurements, EM measurements, SEM observations, etc).
Excellent knowledge of SEM, EM (WDS/EDS microanalysis) and optical microscope (transmitted and reflected light).

Publications and meetings
Accepted articles
Campani, M., Mancktelow, N., Seward, D., Rolland, Y., Müller, W and **Guerra, I.** (2010): Geochronological evidence for continuous exhumation through the ductile-brittle transition along a crustal-scale low-angle normal fault (Simplon Fault Zone, Central Alps), Tectonics, doi:10.1029/2009TC002582.
Guerra, I., Corfu, F., Stockli, D., Ruiz, G., Mancktelow, N., Negro, F., Vennemann, T. and Kalt, A. (2009): Integrated zircon U/Pb, (U-Th)/He, and oxygen stable isotope study of a normal fault zone (western Alps, Switzerland), Geochimica et Cosmochimica Acta, 73(13), 475.
Submitted articles
Guerra, I., Mancktelow, N., Negro, F. and Vennemann, T.: Brittle faulting in the Penninic Zone of Valais (western Alps, Switzerland), *submitted to Swiss Journal of Geosciences*
Articles in preparation
Guerra, I., Vennemann, T.W., Mancktelow, N., Negro, F. and Putlitz, B.: Fluid circulation and fluid-rock interaction along the Simplon Fault Zone (central-western Alps) inferred from oxygen and carbon stable isotope geochemistry
Guerra, I., Stockli, D., Corfu, F., Vennemann, T.W., Negro, F., Ruiz, G.M.H. and Mancktelow, N.: Integrated U/Pb, (UTh)/He and oxygen stable isotope study on zircon of a normal fault zone (western Alps, Switzerland)
Guerra, I., Corfu, F., Ruiz, G.M.H., Negro, F., Mancktelow, N., and Vennemann, T.W.: U/Pb absolute age determination on zircon of the Tsaté Nappe (western Alps, Switzerland)
Unpublished Ph.D thesis
Guerra, I.; "Fluid-rock interaction during late stages of the Alpine exhumation"; 2010, Université de

Lausanne, Institut de Minéralogie et Géochimie.

Unpublished M.Sc. thesis

Guerra, I.; "Metamorphic evolution of Campo Nappe near Oetztal Nappe and Ultimo-Tonale Complex (Meran, South Tirol)"; 2004, Università degli Studi di Milano, Dipartimento di Scienze della Terra « Ardito Desio ».

International meetings

Swiss Geoscience Meeting 2009 (Neuchâtel, Switzerland):

I. Guerra, D. Stockli, F. Corfu, T. Vennemann, F. Negro, G. Ruiz and N. Mancktelow; "Integrated U/Pb, (U-Th)/He, and oxygen stable isotope study on zircon of a normal fault zone (western Alps, Switzerland)"; 2009, Swiss Geoscience Meeting (Neuchâtel, November 20th – 21st), oral presentation.

F. Negro, C. M. Pellet, R. Bousquet, O. Beyssac, **I. Guerra** and F. Vils; "Thermal structure and metamorphic evolution of the Piedmont-Ligurian metasediments in the Western-Central Alps"; 2009, Swiss Geoscience Meeting (Neuchâtel, November 20th – 21st), poster presentation.

Goldschmidt 2009 (Davos, Switzerland):

I. Guerra, F. Corfu, D. Stockli, G. Ruiz, N. Mancktelow, F. Negro, T. Vennemann and A. Kalt; "Integrated zircon U/Pb, (U-Th)/He, and oxygen stable isotope study of a normal fault zone (western Alps, Switzerland)"; 2009, Goldschmidt (Davos, June 21st - 26th), oral presentation.

EGU meeting 2009 (Wien, Austria):

I. Guerra, T. Vennemann, N. Mancktelow, F. Negro and A. Kalt; "Fluid-rock interaction along the Simplon fault zone (central-western Alps): constraints from oxygen and carbon stable isotope geochemistry"; 2009, EGU General Assembly (Wien, April 19th - 24th), oral presentation.

F. Negro, C. M. Pellet, R. Bousquet, O. Beyssac, A. Lahfid, **I. Guerra** and J.P. Schaer; "Thermal structure of the Piedmont-Ligurian and Valaisan units in the Western-Central Alps"; 2009, EGU General Assembly (Wien, April 19th -24th), oral presentation. *Swiss Geoscience Meeting 2008 (Lugano, Switzerland):*

I. Guerra, T. Vennemann, N. Mancktelow, F. Negro and A. Kalt; "Interaction between meteoric and metamorphic water along the Simplon fault zone: constraints from oxygen and carbon stable isotope geochemistry"; 2008, Swiss Geoscience Meeting (Lugano, November 21st - 23rd), oral presentation.

International Geological Congress 2008 (Oslo, Norway):

I. Guerra, N. Mancktelow, T. Vennemann, F. Negro and A. Kalt; "Fluid circulation related to the Simplon Fault Zone (central western Alps): Constraints from oxygen isotope geochemistry"; 2008, International Geological Congress (Oslo, August 6th - 14th), oral presentation.

International Martin Burkhard conference 2007 (Neuchâtel, Switzerland):

I. Guerra, M. Burkhard, N. Mancktelow and A. Kalt; "Mineralization related to possible deep penetration of meteoric waters in late Alpine brittle faults developed during exhumation", 2007, International conference in Structural Geology and Tectonics in honour of Martin Burkhard (Neuchâtel, May 11th – 13th), poster presentation.

EGU meeting 2007 (Wien, Austria):

I. Guerra, M. Burkhard, N. Mancktelow and A. Kalt; "Mineralization related to possible deep penetration of meteoric waters in late Alpine brittle faults developed during exhumation"; 2007, EGU General Assembly (Wien, April 15th - 20th), poster presentation.

PRICES AND RATES

The following prices are based on the information already provided by GeothermEx.

Our prices are valid for a minimum program of 50 collocated MT and dGPS/gravity stations.

MT survey	Unit Price (USD)
1. Mobilization/Demobilization to/from Field Area	$44,000
2. Per MT sounding (including scouting, processing to EDI files and data/report deliveries) for 75 stations minimum	$1,975
3. Stand-by charge for 3 MT crews, per day	$5,400

Gravity/dGPS survey	Unit Price (USD)
4. Mobilization/Demobilization to/from Field Area	$20,000
5. Per dGPS/Gravity station (including scouting, processing to Bouguer anomaly and data/report deliveries) for 75 stations minimum	$175
6. Stand-by charge for 1 dGPS/Gravity crews, per day	$3,250

Modeling & Inversion	Unit Price (USD)
7. 3D modeling & inversion for up to 75 MT stations	$20,000
8. 3D modeling & inversion for up to 75 Gravity stations	$15,000
9. 3D SJI MT/Gravity (Items 7 & 8 must be done)	$20,000

Totals	Unit Price (USD)
10. 75 collocated MT/Gravity stations including mobilization, acquisition, processing and 1D inversion	$225,250
11. 75 collocated MT/Gravity stations including mobilization, acquisition, processing and 3D inversion	$260,000
12. 75 collocated MT/Gravity stations including mobilization, acquisition, processing, 3D inversion and 3D SJI	$280,250

Mobilization
All personnel air flights and salaries, equipment transport to/from survey area, the start-up induction, equipment testing and setup, ancillary equipment for the project (batteries, wire, tools and consumables) are included in the mobilization-demobilization costs.

Production
Includes personnel, equipment and project management necessary to conduct the scouting, acquisition, processing, 1D inversion, reporting and deliverables, as described herein.

Stand-by Rate, Full Crew (WG EM crew and equipment)
Applicable in the case of Company–requested stand-down, lack of access permits, standard *force majeure* conditions including inclement weather, and security issues. Full Crew rate is pro-rated for single crews.

Permitting
All government, state, exploration and similar licenses/permits are Company's responsibility.

Invoicing and Payment conditions:
100% of mobilization fee to be invoiced on Contract signing.
Production and standby charges to be invoiced on a monthly basis based on approved work.
100% of 3D inversion fee to be invoiced on receipt of final modeling report.

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APPENDIX B:

Excerpt from CalTrans 2008. A Historical Context and Archaeological Research Design for Mining Properties in California. Chapter 3, Introduction to Property Type Categories

CHAPTER 3. PROPERTY TYPES

INTRODUCTION TO PROPERTY TYPE CATEGORIES

This chapter introduces types of archaeological resources associated with historic mining processes. These property types do not exist in isolation, but must be identified and interpreted within their functional and historic context. As used here, property types include the individual building blocks of mining sites such as prospect pits, shafts, mills, and tailings ponds. Simple sites may have only one or two property types while complex sites may have many, linked by function and time. These linked property types are what Donald Hardesty referred to as "feature systems" on mining sites in Nevada to distinguish "a group of archaeologically visible features and objects that is the product of a specific human activity" (1988:9). This is a useful way to tie together different features into a functional process. In general, site significance increases with the size, complexity, visibility, and focus of these systems: focus indicates the clarity with which the story of archaeological remains can be "read," while visibility refers to the quantity of remains present (Deetz 1996:94). The concepts of visibility and focus are discussed further in Chapter 5.

A similar, process-based approach to identifying property types is recommended in the National Park Service's *Guidelines for Identifying, Evaluating, and Registering Historic Mining Properties* (Noble and Spude 1997).

Accurate interpretation of property types and feature systems - establishing function and context - is critical. Determining whether a pile of rocks is the result of placer or hard-rock mining, or that it dates to the gold rush or Depression-Era, forms the basis for determining site significance. In addition, because many of these sites may be affected by development projects, this identification may constitute their last examination and recording by archaeologists and historians. It is important that our final record of this mining activity be accurate. Interpretation is made more difficult when mining occurs over a long span of years and subsequent mining overlays original development. For sites with several property types or feature systems, interpretation is facilitated by physically reconstructing deduced mining processes on a map, and perhaps in a flow chart, to ensure an accounting for all the potential resources and their relationships. For complex sites, a mining engineer and/or geologist can contribute much to this exercise.

The links between processes or activities and the common types of archaeological mining resources are drawn below, grouped under five categories:

1. prospecting and extraction;
2. ore processing;
3. intra-site ancillary facilities;
4. domestic remains pertaining to social, non-technological elements of mining; and
5. larger, regional linear properties, such as water conveyance systems that support the mining endeavor.

In this chapter, a description of the process that created the physical remains is provided, visual representations have been added to assist interpretation, and common tangible remains for each is summarized. Mining sites can contain multiple property types from multiple categories.

PROSPECTING AND EXTRACTION PROPERTY TYPES

Mining involves locating and extracting minerals from naturally occurring deposits. Prospecting is the act of searching for new mineral deposits and testing or determining their potential value (Fay 1920:540). The two primary forms of deposits are lode and placer. Lode deposits are the original mineral occurrence within a fissure through native rock, also variously known as vein or ledge. Hard rock and quartz mining are two common terms referring to mineral extraction from lode deposits. Extracted lode minerals, especially those deep underground, generally require additional refinement, called beneficiation (discussed in Ore Processing Property Types below). Placer deposits are sedimentary formations containing minerals that have eroded from their parent lode into a variety of natural contexts, both shallow and deeply buried. The ubiquitous image of a 49er panning for gold along a gravel bar is well known, although hydraulic, drift, and dredge mining also targeted this type of deposit. Placer minerals are generally "free" from parent material and do not require additional refinement once separated from worthless sediment. Placer miners followed "color" up drainages looking for the source, or parent outcroppings of lode ore. They also discovered eroding ancient riverbeds, now elevated above the modern landscape, which contained naturally deposited placer gold as well. Later, geology played a larger role in locating minerals. Miners often used ingenuity and innovation to tailor their operations to local conditions for both lode and placer deposits. Prospecting and extraction technology differed for the two types of mineral deposits.

PLACER MINING PROPERTY TYPES

Placer Mining Property Types include:

- Tailings Piles
    - Small Piles of Placer Tailings
    - Oblong Piles of Placer Tailings
    - Long Lines of Placer Tailings
    - Pits with Placer Tailings
    - Surface Exposures of Placer Rock
- Cut Banks, Channels and Placer Tailings
- River Diversion
- Dredge Tailings
- Drift Mining Remains

The primary means of separating free gold from auriferous sediments relies on water and gravity. Water flow is used to move and agitate gravel, and gold's specific gravity ensures that it naturally settles under proper conditions. Dry placering, such as winnowing, may have been used in the absence of water; here wind blows the lighter component to the side while heavier material drops. One of the most comprehensive references regarding placer mining is C.V. Averill's *Placer Mining for Gold in California* (1946), but there are many others (Wilson 1907; Boericke

1936; Peele 1941; Wells 1969; Rohe 1986; Silva 1986; Meals 1994; Tibbetts 1997; and Lindström et al. 2000).

The simplest placer prospecting is typically done with a metal gold pan, a round shallow dish with flat bottom and slanted sides sometimes improvised from common kitchen supplies; wooden *bateas* and baskets were also used in the earliest years. Panning involves swirling a small amount of dirt and gravel with water in a manner that allows the lighter material to rise to the top for removal while the heavier fraction, particularly the gold, concentrates at the bottom. Panning can be carried out at the location of a placer deposit, or auriferous sediment can be collected using a variety of hand tools and taken to a convenient panning location. For example, gravel can be scraped out of crevices, with various kinds of metal bars, into a bucket and taken to a bar along a creek where it can be easily panned. The method is limited to coarse gold, as fine particles tend to be lost with the gravel. The gold pan has endured, however, and metal and plastic versions can still be found in modern supply stores. Because of its simplicity, the pan is used for prospecting, as an extraction tool, and in combination with other technologies discussed below. Although widely used, evidence of panning in archaeological contexts is generally limited to the presence of the pan itself. Any evident changes to the ground surface would have been so minor that, combined with natural processes, they would have been erased. Hand tools such as picks, shovels, buckets, and wheelbarrows were the dominant method of extracting and transporting placer deposits to separating devices.

Tailings Piles

The most distinctive indicator of a placer mining site is the waste rock, or tailings piles, left from prospecting or mining. These rock piles – located in creek drainages, along bars and riverbanks, or at locations of ancient, exposed river deposits – consist of water-worn rocks and a general lack of soil. Tailings piles come in different shapes and sizes, as noted below, depending on where they are on the landscape and how they were separated from gold-bearing gravels. Boulders and cobbles were often moved out of the way and piled or stacked to the side, while gravel and smaller cobbles were generally processed for gold. Water, necessary to wash the deposits, could, for small operations, consist of seasonal runoff or include short water diversions from nearby drainages. Large-scale mining might involve large ditch systems bringing water from afar. Both short- and long-term placer mining areas may include habitation sites or features. The complexity of these habitation sites or features is generally related to the duration of the mining operation, and the physical relationship of the mining operation to areas suitable for habitation.

Small Piles of Placer Tailings

A placer deposit worked by a rocker or cradle exhibits an undulating ground surface formed of piles of uniform-sized gravel and cobbles where the hopper was emptied. Piled or stacked cobbles and boulders may also have been moved out of the gravel bed. Metal, perforated screens (riddle plates or grizzlies) are diagnostic artifacts that are typically square, and range "16 to 20 inches on each side with one-half inch openings" (Silva 1986:3).

The rocker, or cradle, is one of the simplest mining tools and can be operated by one individual. Named for its likeness to a baby cradle, it is essentially a wooden trough

Figure 41: Rocker Clean-out Pile, Prairie Diggings Placer Mining District (PDPMD), Locus 20, Sacramento County *(courtesy Judith D. Tordoff).*

with a screened hopper on top and a handle that allows the operator to rock the device. Auriferous gravel is dumped into the hopper and enough water poured in to transport the finer sediments through the sieve, across an apron, and through a series of riffles. "Dry washers" were similar devices that did not require the use of water. Cobbles and gravel caught in the screen are cleaned out and dumped to the side (Figure 41). The apron, which was historically made of a cloth-like material such as canvas or burlap, collects coarse gold and directs fine material to the head of the riffle-lined trough, where fine gold settles. Riffles are a series of parallel slats of various designs fixed to the bottom of collection troughs that "retard the gravel and sand moving over them, and so give the gold a chance to settle" (Boericke 1936:62). Material collected from behind riffles was typically panned. The entire device is relatively portable, typically two to five feet long, one to two feet wide, and less than two feet in height. It was popular in California by 1849, and although designs continue to circulate in modern mining books, they are no longer widely used.

Oblong Piles of Placer Tailings

The use of long toms leaves a landscape similar to that of rockers, although the rock and gravel removed from the longer troughs create linear or oblong piles of uniform-sized gravel and cobbles, as much as 15 to 20 feet long. Other associated artifacts may include the flared, perforated sheet-iron plate.

The long tom operates much like a rocker. Gravel is dumped into an open, inclined trough and drains through a screen into another box fitted with riffles. Coarse gold settles into perforated sheet iron that lines the initial trough, while the finer particles are captured in the riffle box below the sieve. The device relies on a steady current of gravity-fed water to move material instead of rocking, and no pressure, or head, is necessary. The flow is controlled, and must be stopped during frequent cleanouts. Material collected from behind riffles was typically panned. Widespread adoption of long toms in 1851 depended upon development of a necessary water supply system (Rohe 1986:136). Perforated metal used in long toms may vary in dimensions, although designs generally include a flared riffle plate uncommon in other collection devices (Boericke 1936:60; Silva 1986:7; Lindström et al. 2000:68). As described by Wilson (1907:39), "the feed end of the tom is about 18 inches wide, while the discharge end is about 32

Lines of Placer Tailings

The use of sluice boxes resulted in a landscape similar to that of a long tom, although straight linear piles of tailings usually exceeded 20 feet in length. Metal grates or angle iron riffles might be present. Steep cut banks are absent.

inches wide, and terminates in a perforated sheet-iron plate." Common water systems include penstock, hose, flume, and ditch, or a combination of these.

Figure 42: Ground Sluice Tailings, Alder Creek Corridor Placer Mining District (ACCPMD), Sacramento County *(courtesy Judith D. Tordoff).*

A box or board sluice is a wooden, riffle-lined trough that operates much like a long tom, although typically 12-foot sections were interconnected to construct much longer devices (Peele 1941:10–561; Rohe 1986:137; Figures 42 and 43). As with the long tom, the chain of sluice boxes was supplied with a controlled source of water, and was constructed to a suitable grade for collection, often requiring trestles. Water and gravel were introduced at the head, gold and heavy sediment collected behind riffles, and water and gravel—and fine minerals—exited the tail into a dump.

Flow had to be stopped periodically to clean out concentrate from behind the riffles. Material collected from behind riffles was typically panned. Gravel could be shoveled in manually, or brought to the feed sluice by wheelbarrow and then shoveled in. Various means were employed to

Figure 43: Sluice Tailings, PDPMD, Locus 20, Sacramento County *(courtesy Judith D. Tordoff).*

Pits with Placer Tailings

Small-scale prospecting of slope deposits resulted in an undulating landscape of depressions and mounds located on hill-sides and ridges formed of ancient river channels. The depressions are less than ten feet in diameter and cobbles and other river rock are piled adjacent. Abundant pits with large adjacent rock piles may indicate an area of coyoting.

prevent clogging and damage by large rocks, such as a mud box fitted with a grizzly, or metal grate; "oversize material and boulders are forked out and thrown to one side after having been cleaned" (Boericke 1936:55). Undercurrents were used to increase collection of finer, gold-bearing sediments by diverting finer material through a grate along the bottom of the sluice to a large box designed to slow the flow of water enough to allow fine gold to settle. Sluice boxes were widely used by 1852 (Rohe 1986:137). Various metal grates or sieves were used to help screen gravel and riffles were generally wood, although there are some metal designs such as angle iron (Peele 1941:10–566; Silva 1986:7). A water conveyance system would be present, although exclusive use of the sluice box would not result in steep cut banks, which would indicate ground sluicing or hydraulic technology. Sluicing resulted in impressive, distinctive landscapes (Figure 44).

Hillsides composed of the eroding remains of ancient river channels could be prospected by surface prospecting and by ground sluicing (see below). Small, shallow pits were excavated into the ground surface, and the soils removed for processing in a pan, cradle, or other sorting device. Water did not need to be brought to these prospecting locations. The pits were usually less than eight feet in diameter and only a few feet deep. A pattern of small, deep prospects is called "post-holing." Archaeologically they survive as shallow depressions with small adjacent piles of stream-washed cobbles. Where buried gold deposits were located, either in exposed modern river bottoms or elevated ancient ones, prospects were enlarged by "coyoting" (mining in irregular

Figure 44: Sluice-mining landscape created in the 1850s –1860s, McCabe Creek, Butte County *(Courtesy Anthropological Studies Center, image no. 27-03-D136-05).*

openings or burrows into the auriferous gravels; also see discussion below on Adits and Tailings). Dry placering employed this method as well. The work was considered quite dangerous as the ground matrix was unstable and cave-ins common. Archaeologically these prospects have collapsed and eroded and are distinguished from pit prospects only by the size of the adjacent tailings piles.

Figure 45: Bedrock Drains in Ground Sluice System, PDPMD, Locus 19, Sacramento County *(courtesy Judith D. Tordoff).*

Cut Banks, Channels, and Placer Tailings

Combinations of cut banks, channels, and stacked or piled rocks are the result of ground sluice or hydraulic operations, or a combination of these methods. Both processes of excavating auriferous deposits relied on collection technologies described above. Disposal methods for large quantities of water and waste material from the operations are evident in the archaeological remains. The feature systems resulting from sluicing and hydraulicking methods are similar.

A ground sluice is a channel or trough in the ground through which auriferous earth is washed. It may require carving into the bedrock to obtain the correct slope or grade for the bottom of the channel (Wilson 1907:40; Figure 45). Ground sluicing is also the act of caving-in and eroding the ground into a prepared channel using a steady stream of water and hand tools to remove overburden (Peele 1941:10–541). In all respects, what sets ground sluicing apart from box or board sluicing is the large quantities of water needed to excavate the ground. Booming is a variation in which the water was impounded nearby and released suddenly to cause a powerful gush of water against a bank or over a ground surface. A variety of material can be used for riffles in a ground sluice, including natural irregularities in the channel, cobbles, and wood poles. Cleaning out the concentrate from a ground sluice took place as needed. It involved removing all riffles and large stones, collecting all the sediment, and often extracting a few inches of bedrock; the result was an empty channel. The collected material would then typically be run through a board sluice, long tom, or rocker, and eventually the pan. It was also common to use board sluices at some phase of ground sluicing operations, including at the tail or in place of a ground sluice. Like the board sluice, ground sluicing became common in the early 1850s, and relied on dependable

Cut Banks, Channels, and Placer Tailings

Ground sluicing and hydraulic mining produce similar landscapes characterized by substantial water conveyance features, and the presence of steep cut faces of varying heights at the edge of the worked area.

sources of water.

Hydraulic mining is a method in which a bank of auriferous material is washed away by a powerful jet of water and carried into sluices (Fay 1920:352). As the name suggests, an abundant water supply—and the means to build sufficient head, or pressure—is necessary. Water is typically conveyed from high on an adjacent hillside into a metal pipe (penstock) to build head, and then into canvas hoses fitted to a metal nozzle, or monitor, which directs the jet of water. In large operations giant monitors were hooked directly to penstocks to contain the high pressure. Gold was collected in extensive sluice systems, often similar to the ground sluicing described above (Figure 46).

Figure 46: Stewart Mine Hydraulic Cut, Dutch Flat, Placer County *(I-80 in foreground) (courtesy Anmarie Medin).*

Low-pressure models were developed in the 1850s, although substantial technological developments in high-pressure water wheels and delivery systems were accompanied by far greater gold production beginning in the early 1870s (Limbaugh 1999:34). Far greater dumping of processed waste sediment (i.e., mining debris) in waterways was another result. Judge Sawyer's 1884 decision in Woodward vs. North Bloomfield led to the 1893 Caminetti Act, federal legislation controlling hydraulic discharge into public waterways. Large-scale operations that could not control their discharge for whatever reason began closing down.

Lindström et al. (2000:62) noted the difficulty in differentiating hydraulic and ground sluice operations in archaeological interpretation, particularly for small-scale operations. In large-scale hydraulic mines, pressurized water systems, steep cliffs, and abundant tailings in noticeable hydraulic pits and dumping grounds should be apparent. Typically small operations elevated a monitor on a stable platform to keep it dry and above flowing gravel and water. Archaeologically this looks like a flattened rock pile in front of a concaved bank; there is no equivalent need for such a feature in ground sluicing, whereby the water is delivered via a race, or ditch, above the cut face. Peele (1941:10–551) describes ideal monitor placement for larger operations.

River Diversion

Mining the beds of rivers and streams required special techniques. One historically popular method involved turning a river from its bed in order to process the underlying gravels, popularly accomplished by wing dams, flumes, and channel diversion. A wing dam was constructed down a stretch of river, parallel to the bed, connecting upper and lower cross dams in a manner that would box a segment of riverbed (Figure 47). The flow that continued down behind the wing dam sometimes operated a pump (often called a Chinese pump) that would continue draining the contained portion of the riverbed in order to allow mining below the level of the river. Fluming involved construction of a head and tail dam, and a flume erected between them, thereby exposing an entire width of a river segment. In channel diversion, a parallel channel was made for the river alongside the natural one, and the river diverted into it. A stream course could be moved back and forth across a drainage over a period of mining. River mining was widely practiced in California beginning in the early 1850s (Rohe 1986:140), and reached its peak in the mid-1850s (Meals 1994:10), although miners used these methods as late as the 1880s.

Figure 47: Remains of a wing dam along the Stanislaus River *(Courtesy Julia Costello).*

River Channel Diversion

While a river will typically reclaim its course and obliterate evidence of this activity, some elements of the diversion means may survive along banks, such as dams and ditches. For smaller courses, evidence of parallel channels and stacked-rock retaining walls may indicate a temporary channel diversion. Sedimentation may have partially buried some elements.

Dredge Tailings

Dredge mining provided the means to access areas laden with deep auriferous gravels using amphibious vessels, and in turn allowed the profitable recovery of gold-bearing material that paid as little as five cents per cubic yard. Successfully used in California by 1898, and continuing into the 1960s, the bucket-line dredge consists of a "mechanical excavator and a screening and washing plant, both mounted on a floating hull" (Peele 1941:10–577). The dredge, anchored by a spud or post that could be raised or lowered at the stern of the hull, was floated in an artificial pond where it excavated a channel in deep gravel plains. Gravel was processed through a series of gold-saving devices, and the large volume of waste cobbles deposited by conveyor into a series of uniform tailings piles. The dredge would pull forward, following the excavated channel and leaving the tailings to fill in behind. Large-scale models were adapted to California's gravel plains, particularly where the Feather, Yuba, and American rivers, flowing from the Sierra Nevada, entered the Sacramento Valley (Figure 48).

Dredge Tailings
Large, multiple piles of river cobbles with little or no soil covering, extending over a large area.

Bucket-line
Vast tailings fields with high, rounded, parallel rows of cobbles.

Dragline
Clusters of conical, or rounded, individual piles; a pond was once present.

Dry-land dredge
Clusters of conical, or rounded, individual piles; no pond present.

Figure 48: Bucket-line Dredge Tailings, Yuba River (courtesy Jim Woodward and Judith D. Tordoff).

The dragline or doodlebug dredge was developed in the 1930s and operated for about a decade in California. The dredging unit consists of two parts: a shore-based power shovel equipped with a dragline bucket, and a floating washing plant, similar to but smaller than the one on a bucket-line dredge. The dragline works from the edge of the bank above the pond where the washing plant is floating. The bucket was cast into the pond, hitting the bottom teeth-first. Then it was rotated and filled by pulling it toward the power shovel with the dragline. When the bucket was hoisted up it was swung over the hopper on the washing plant and dumped; then the cycle started again. The bucket cut away the bank on which the dragline sat, so it had to move backwards as the pond and washing plant advanced toward it. Dragline dredges were "generally well suited to relatively small, shallow deposits which are too small to amortize a bucket-line dredge or too wet or low grade to be profitably worked by hand or other small-scale methods" (Wells 1966:12).

When the washing plant is mounted on wheels or skids, the dredge is called a dry land dredge (Wells 1966:13). These machines were only used in special situations such as places where the ground had to be put back to its original state by returning the tailings into the pit, leveling it over and planting it. The existence of very shallow deposits would also make it more appropriate because it could only dig about half as deep as the draglines. These dredges operated in California in the 1930s and 1940s.

Figure 49: Bucket-line Dredge Landscape along the Feather River, Oroville, Butte County *(Courtesy Anthropological Studies Center, image no. 27-03-D30-14).*

The signal outcome of bucket-line dredging is vast tailings fields that encompass hundreds of acres (Figure 49). Tailings left by bucket-line dredges are distinctive in that they consist of high rounded rows of cobbles created by the arc of the stacker as the dredge pivoted on its spud. The rows angle away from the forward direction of the plant and each one represents a single pass. Ponds, dredge parts, and wire rope are also items that may be noted in an abandoned dredge field.

Dragline dredge tailings are deposited in large individual piles, rather than in continuous arcs. They are usually conical, unless they have weathered down to more rounded shapes. They are often in clusters, or in rows if the dredge was following a stream course. Because of their size, shape, and configuration, dragline dredge tailings are easily distinguished from bucket-line dredge tailings, but not from dry-land dredge tailings. Also found in clustered and conical piles, dry land dredge tailings can be confused with those from a dragline (Figure 50). The most reliable way to differentiate between the two would be by determining whether or not a pond was present, which would indicate the presence of a dragline. Mining company records would be helpful as well.

Figure 50: Dry-land Dredge Tailings, PDPMD, Locus 3, Sacramento County *(courtesy Judith D. Tordoff). .*

Drift Mining Remains

Accessing buried placer deposits using underground mining techniques of adits and shafts is called drift mining. Prospecting for bench or Tertiary placer deposits elevated above drainages or locked beneath ancient volcanic flows often results in a pock-marking of small pits spread over a hillside. When fertile ground was found, larger excavations included coyoting or drift mining into the old river channels (see discussion above on pits). The “paystreak” is reached through an adit or shallow shaft and wheelbarrows or small rail-cars may be used for transporting the gravel to a sluice on the surface. If large, the paystreak can be taken in a series of regular cuts or slices. Drift mining is more expensive than sluicing or hydraulicking and is consequently used only in rich ground (Thrush 1968:351). Substantial drift mines were operating across California by the mid-1850s (Rohe 1986:146–147). The method reached its peak in the 1870s, before virtually ceasing, only to be revived after 1933 (Peele 1941:10-606). Excavated sedimentary material deposited near a drift mine is distinguished from a lode mine's angular waste rock by its water-washed cobbles and gravels. Openings into the ground may be barely noticeable slumps, or extend into the slope a measurable distance and could include drifts, shafts, or adits (Wells 1969:127). Rail or hoist remains may be present. The facilities for processing gravel, most likely a sluice, could be on-site, or some reasonable distance away depending on the transportation methods and water source.

Drift Mining Remains

Drift mines will be located in geological deposits containing old riverbeds. Waste rock will look like placer tailings, composed of cobbles. The adits and shafts may have caved in. Water is not required on site so ditches may not be present. Ore car routes may be evident.

HARD ROCK (LODE) MINING PROPERTY TYPES

Hard Rock (Lode) Mining Property Types include:

- Small Pits, Crosscuts, and Surface Vein Workings
- Waste Rock Piles
- Shafts, Adits, and Inclines
- Mills and other Processing Units
- Underground Workings
- Open Pit Mines

Lode refers to a mineral deposit located in fissures in country rock, and is nearly synonymous with the term vein as used by geologists. Lode deposits are tabular and clearly bounded, with orientations measured by their "dip" (angle from the horizontal) and "strike" (angle from the vertical). Although lodes may extend to the surface, they primarily lie underground and are accessed by excavations such as shafts and adits, or by open pit mines. Ore (mineral-bearing rock) extracted from the lode is usually processed first through crushing and then by physical or chemical separation devices. Lode sites produce waste rock (excavated rock that is not ore) and tailings (the discharge of unwanted processed material from mills and separators). Good discussions of lode technologies are found in Peele (1941), Hardesty (1988), Bailey (1996), Pearson (1996) Bunyak (1998), Limbaugh and Fuller (2004), and Twitty (2005).

Lode deposits, varying greatly, define the nature of the extraction and milling technologies applied to them. They are often grouped into geologic occurrences identified as zones, the most famous of which in California is the Mother Lode, extending through five counties. Lode deposits can vary greatly in depth and width, with some surface quartz leads pinching out within a few hundred feet of the surface while a few extended to a depth of more than six thousand feet with widths sometimes exceeding fifty feet. Most lode miners on the Mother Lode did not encounter major ore bodies until their workings reached five hundred or more feet in depth (Limbaugh and Fuller 2004:42–43).

Lode mining tends to be more complex than placer mining, requiring advanced technologies, skilled personnel, and substantial capital investment. Also, unlike placer gold, extracted ore requires processing to free its minerals. Surface ore was naturally oxidized and its values could often be retrieved through simple crushing and physical separation. As veins extended deeper into the earth, however, gold was typically chemically bound with sulfides and other mineral compounds. Miners developed various chemical processes to separate them (discussed below in Section 2: Ore Processing). Although extraction and processing technologies evolved over time, older techniques continued where newer ones were too expensive or inappropriate for the scale of the effort. What was the state-of-the-art in the industry was not necessarily what was practiced on the ground. As pointed out by Mother Lode historian Ronald H. Limbaugh and geologist Willard P. Fuller:

> It must be remembered that many goldmines on the Mother Lode and most of those on the adjacent belts were small operations too poorly financed to afford trained staff and the most recent improvements in mining machinery. In general, California mines probably modernized slower than those in other western districts, partly because of the size and cost factors, and partly because of a traditional conservatism among Mother Lode mine owners and operators that persisted down nearly to the present day (2004:183–184).

Many hard-rock miners worked only seasonally, on weekends, or between jobs. The ingenuity and inventiveness of these frugal miners also produced unique solutions to mining problems. One example includes Rancher James D. McCarty who set up a two-stamp mill on his Defiance claim in 1910, putting a tractor-boiler up on blocks to supply steam power (Figure 51).

The range of hard rock technologies is vast and complex and will not be detailed in this section; instead, a description of the types of features commonly present on sites is described and some examples provided. Examples of mines from the Copperopolis district in Calaveras County, recorded for the Historic American Engineering Record (HAER), are available online (HAER 2007).

Small Pits and Surface Vein Workings

Surface vein workings are among the oldest evidence of hard-rock mining in California. During even the earliest years of the gold rush, placer miners were following "color" (gold) up gulches and encountering outcrops of quartz veins. Although "bull" veins (those without ore) were the most common, traces of gold were evident in some outcroppings and prospectors learned to search these out. Float, mineralized rock broken out from eroding veins, indicated a nearby source, and 'gossans' – surface mineralizations of iron-heavy deposits- signified mineral veins underneath. Prospecting tools included picks, bars, and shovels and, in larger operations, wheelbarrows and ore cars to move ore and waste rock.

Small Pits and Surface Vein Workings

This includes pits with adjacent quarried rocks (not stream cobbles), or exposures of uplifted strata of country rock with excavated-out veins. Adits and other evidence of hard-rock mining and exploration will likely be in the vicinity. On larger workings, an arrastra or small mill might have been located nearby.

Figure 51: Tractor-boiler that Supplied Power to Two-stamp Mill at Defiance Claim (*Library of Congress, HAER Photo by Alice Olmstead*).

Typically, an exposed vein was simply followed down into its outcropping, leaving an exposed rock stratum with its center gouged out like a cavity in a large tooth. The sides of these excavations are usually uneven as digging simply ceased at the limits of the ore. The floors of these workings have generally filled in over the years with silt and natural debris, but larger examples often exhibit an "exit" on a downhill side for removal of rock, or a platform for a windlass or hoist in deep excavations. Waste rock will be conveniently disposed of near the workings. Included in the waste rock may be chunks of bull quartz, a good sign that the excavators were following a vein.

Some kind of crusher was required to pulverize the recovered ore to release the gold or other minerals. This might have been a small stamp mill (two to five stamps) or an arrastra (see discussion below). The facility might have been near the vein workings, or next to a source of water with the ore transported to its location. If the mining is productive, and the vein deepens, there might be an adit driven in on the lode further down the hillside. At Carson Hill, on the Stanislaus River, the original 1850s surface vein workings that led to nearly a century of rich mining operations are still extant on the crest of a ridge.

Waste Rock Piles

Perhaps the most visible evidence of underground workings is waste rock. In following a vein, the vast majority of excavated rock is that surrounding the ore, and this waste rock is discarded immediately at the opening to the mine, allowed to accumulate in a downhill, gravity-formed mound or dump. Piles of waste rock not only indicate the location of uphill shafts and adits (which may be caved in and therefore not easily identifiable), but the size of the pile reflects the extent of the underground workings. Waste has also been used for roadbeds and other improvements, however, so the size of the pile should be viewed with caution.

Waste Rock Piles

Country rock dumped into gravity-formed piles with little or no topsoil and vegetation. Their presence indicates the locations of mine portals and under-ground workings.

Figure 52: Waste rock Pile in Canyon, San Bernardino County, with Cabin Ruins in Foreground *(Courtesy, JRP Historical Consulting Services).*

Waste dumps are visible as unnatural contours on hillsides and for the lack of soil development and vegetation. For larger operations, waste-rock piles may be formed by dumping rock from ore cars, producing a long, flat-topped ridge that begins at the mine portal and is extended as the workings deepen. Mines that operated for a long time often incorporated waste rock dumps into later development, terracing them for placement of buildings or other facilities (Figure 52). As mineral-recovery techniques improved over time, old waste rock with low mineral values was (and still is) processed to extract its values.

Shafts, Adits, and Facilities in their Vicinity

The entrance to underground workings is called a portal, and opens into either a shaft or an adit, providing access to the lode. Shafts sink down into the ground from the surface and can be vertical or on an incline, while adits are driven horizontally into hillsides (adits are often referred to as "tunnels," however, among miners this latter term is reserved for horizontal passages that have an entrance and an exit, as along roads and railroad grades). Shafts and adits vary according to the size of mining operation and the nature of the surrounding rock. Portals will often be first identified by their associated waste-rock piles (see discussion above) as their openings may have caved in or been closed by dynamiting. Shaft-like openings that do not have any associated waste rock are likely air vents connected to deeper workings, or daylight stopes (where ore excavations break the surface). When cut into a stable matrix, shafts are typically square while adits may have a curved ceiling. Where the surrounding rock is unstable, square shoring is used to reinforce the sides.

Shafts, Adits and Facilities in their Vicinity

Shafts are square (or caved in) holes in the surface and may have surrounding footings for head frames and hoists. An adit's entrance into a hillside may be evident, or appear as a caved-in trench. Shafts and adits are accompanied by waste rock piles on their downhill sides. Shafts without waste rock may be air vents or daylight stopes.

Shafts and adits require mechanisms for removal of underground waste rock and ore, and remains of these facilities are commonly present around the openings. Adits most frequently have ore cars running on tramways, or just a dirt path for wheelbarrows on smaller operations. Shafts require a hoisting device to raise the excavated material. While small shafts may operate with hand-run windlasses, larger operations require head frames with cables, buckets, and drum hoists (Figure 53). Footings for head frames straddle the shaft opening and remains typically consist of concrete bases topped with metal plates or bolts. Adjacent to these would be similar footings for the hoist drum. As mines deepened, devices such as Cornish pumps were installed to both ventilate and de-water the underground workings. Hoist power was provided by animals, steam, water, fossil fuel, and, later, electricity. Evidence for the power source might be found in massive boiler footings, a compressor, or engine mounts run by imported electricity or a generator.

The openings to deep shafts were usually collared with timbers and planks (Figure 54), or concrete (after the 1880s) to stabilize the work area, although collapse of these openings after abandonment often makes them appear as large craters. In ranchlands, abandoned shafts are often surrounded with fencing to keep out livestock. ***The bottoms of these large depressions are very unstable – often consisting of only a thin soil developed over fallen timbers and tree limbs – and should never be entered.***

Figure 53: Small Head Frame with Chute, Inyo County *(Courtesy JRP Historical Consulting Services).*

Underground Workings

Examination of underground workings is very dangerous and is prohibited by Caltrans. Indicated by shafts, adits, and waste rock dumps, they are NOT to be explored but must be studied through documents.

Underground Workings

***Figure 54: Isolated Shaft Collar, Inyo County** (Courtesy, JRP Historical Consulting Services).*

Shafts and adits are built to access underground workings, a series of excavations providing access to the lode. Drifts (horizontal connectors) link various parts of the mine while mining the ore body itself is frequently referred to as stoping. Underground miners sort the material they are sending to the surface into waste rock and ore so those at the top can handle each ore car lode efficiently. The size, nature, and surrounding geology of mines are vital to understanding their history. This information may be most efficiently found in documentary records.

Open Pit Mines

<u>Open Pit Mines</u>

Large pits excavated in stepped layers with haul roads. They may have facilities nearby. Glory holes remove ore and rock underground from the center of the pit.

Low-grade ores located near the surface could be mined through an open pit system, much like a large quarry where rock is removed systematically in stepped benches. Excavation is generally by controlled blasting, the ore separated and hauled to the mill and the waste disposed of nearby. In modern times both ore and rock are typically loaded with large shovels and carried out by truck. Support facilities include a road system, machine shop or garage, and office. Some open pit mines used a leaching system to extract gold, and such ponds may be located nearby. Pit excavations are also sometimes called "glory holes," although this term more accurately indicates surface excavations where the rock and ore are gravity-fed out from the bottom, as in a funnel, and removed through an adit. In that case, waste rock, milling, and transport systems will accumulate near the adit portal and not the excavation area.

ORE PROCESSING (BENEFICIATION) PROPERTY TYPES

Once ore has been removed from a mine, valuable minerals must be separated from the gangue (undesired minerals). Beneficiation is a broadly applied term and can include crushing, stamping, screening, flotation, amalgamation, and smelting (Cowie et al. 2005:13–24). The technology of beneficiation developed diverse and sophisticated processes over past centuries and only those most commonly found on sites in California are discussed below. Milling sites often contain innovative and complex technologies that were added to and modified over time. Interpretation of these site types should rely upon official mining reports and documents or those solicited by the mining company, and frequently requires the help of mining engineers.

ORE PROCESSING PROPERTY TYPES:

- Arrastras
- Mills: Industrial Foundations, Pads, and Machine Mounts
- Mill Tailings

Arrastras

An arrastra (or arrastre) is a shallow circular pit, rock-lined on its sides and flat bottom, in which broken ore is pulverized by drag stones (Figure 55). These are attached to horizontal poles fastened to a central pillar and typically rotated by use of animal or human power, although later machine-powered examples can be found. The base or floor stones are usually of a hard material such as marble and exhibit a polished surface. The upper drag stones also have a polished, smooth undersurface and evidence of a bolt attachment imbedded on top. Although not commonly encountered in the field, these simple grinding devices are significant indicators of early mining activities and were also used into the twentieth century in remote areas of the state or where capitalized mining was not prudent or cost-effective (Figure 56).

Introduced by Mexican miners (arrastrar = to drag), they could be constructed with materials at hand and were quite effective in reducing ore to a powder, from which gold could be recovered by amalgamation or other simple separation processes. This type of milling is most productive for surface vein workings, where the ore has been naturally oxidized and does not require chemical processes for mineral recovery. Arrastras are rarely found intact as, upon abandonment, the floor stones were typically pulled up and the underlying soils panned to retrieve gold that sifted between the cracks. Discussions of arrastras are found in Kelly and Kelly (1983) and in Van Bueren (2004).

Arrastra

A shallow, flat-bottomed circular depression typically less than 20 feet in diameter, lined on its edges and floor with stones. The base and drag stones are of a hard quality and exhibit polished surfaces.

***Figure 55: Remains of Twentieth-century Arrastra, Inyo* County** (Courtesy JRP Historical Consulting Services).

Figure 56: Remains of Arrastra Floor, Amador County *(Courtesy Thad Van Bueren).*

Mills: Industrial Foundations, Pads, and Machine Mounts

Mills are not necessarily constructed adjacent to mine portals, although they may be. Mills require a power source and a steady supply of water, and it may be more expedient to locate the mill in the best place to access those requirements and transport the ore. Mills may also be centrally located to serve a series of mines.

The first step in ore processing at a mill is crushing the rock into a powder that can be treated. The most common technology for accomplishing this was the stamp mill, where ore was fed into a cast-iron mortar box located under a battery of heavy vertical rods (see also discussion of arrastras above). Through use of overhead cams, the rods were repeatedly raised about six inches and then allowed to fall, their heat-treated shoes falling on the mortar dies. The camshaft was rotated eighty to one hundred times a minute

Mills

The remains of these sites generally appear as large terraces on hillsides, the size reflecting the number of stamps present. The stamp terrace has a large back wall to stabilize the stamps, and footings for the batteries may be evident. The lower terrace is for concentrating the pulp, and mill tailings will be found below. Various pads and machinery mounts around the mill reflect necessary support devices. A water source and method of transporting ore to and from the mill may be evident.

by a belt-driven bull wheel, powered initially by water or steam (Limbaugh and Fuller 2004:65). Small, mobile, one- or two-stamp mills were effective on small sites, although batteries of five stamps were soon found to be the most effective. Stamp mills often grew in increments of two five-stamp batteries as operations expanded, resulting in some large mills of 100 and 120 stamps.

Archaeological evidence of mill sites increases with their size and permanency. Small, early mills were relatively ephemeral and temporary, leaving few traces. Unless the stamp mill itself was abandoned—leaving cast-iron shoes, cams, rods, and hopper-mortars in place—their short-term operations may not be identified. Larger stamp mills can involve large excavations of earth and leave distinctive terraces, often with equipment mounts or foundations (Figure 57). They were nearly always built into hillsides, taking advantage of gravity feed to move ore through the stages of processing. At the uppermost level, ore was delivered to the facility by tram or other vehicle, stored in bins and then fed into the hopper of a primary crusher where it was reduced to a uniform size. Jaw crushers were initially preferred, later largely replaced by ball mills (Figure 58), where ore was rotated with iron balls in large barrel-like devices (worn iron balls often mark these locations). Crushed ore was then fed through a grizzly (screen) into the stamps, where it was pulverized with the controlled use of water, creating pulp. The number of stamps is documented by footings for the batteries, grouped into five or ten per footing. The width of the stamping floor often defines the width of the mill building itself.

Below the stamps, the lower level of the mill contains the amalgamation or concentrating tables. Here the discharged pulp, with the addition of small amounts of mercury ("quicksilver"), was processed to recover the gold. This level has drains to carry off excess water from the wet processing area. Below the amalgamation level, pulp may be further processed in chlorination or cyanide tanks, or other innovative device, for final recovery. After 1870, various devices were introduced to improve this process and maximize the recovery of free gold in the concentrates, the vanner being among the most important (Limbaugh and Fuller 2004). The amalgam was then retorted to drive off (and then recapture) mercury, with the resulting gold "sponge" shipped to a mint or smelter; sometimes ingots were prepared on site. The final discards were dumped downhill as tailings.

Figure 57: Remains of the Royal Consolidated Mill *(Library of Congress, HAER Photo by Alice Olmstead).*

Simple amalgamation worked well with free-milling gold, but not with refractory ores where gold was tightly bonded with other metallic minerals. In these, while gold was often clearly visible in ore samples, milling and the use of mercury did not permit its recovery. It took years of experimentation before solutions were found, and many tailings piles from early mills were later reworked to recover their gold or silver with improved processing. In the 1870s, chlorination was the first breakthrough, but even this was expensive and relatively ineffective and was only productively used on large ventures. Cyanide was used with some success in the early 1900s, applied to reground slimes from ore initially treated with chlorination. Later flotation methods subjected the treated pulp to a frothing agent which separated the minerals in cell-like devices. Heap leaching of chunk ore was also sometimes successful in recovering values from low-grade ores. No single recovery method worked in all mills, however, because of the different composition of local ores.

Figure 58: Hendy Ball Mill at Mountain King Mine *(Library of Congress, HAER Photo by Alice Olmstead).*

For most mines, the final step was smelting through the application of heat. Prior to 1863, copper was shipped to the east coast or Swansea, Wales, for smelting; after that time it was sent to a facility at Antioch and later to the only West Coast smelter in Tacoma, Washington. California's only major smelter (for gold, silver, copper, lead and zinc) was started in San Francisco but soon moved to Selby, immediately east of Martinez along the margin of Suisun Bay. The Selby smelter was the only one operating in 1940 (USBM 1941:230; Limbaugh and Fuller 2004:66–67, 80, 176–191).

In the early years, mills were run by steam, produced in boilers or furnaces, and by water-powered impulse wheels, modeled on those made by Pelton and Knight. Impulse wheels revolutionized the industry by creating an inexpensive power source for air compressors, which ran machine drills, mills, hoists, pumps, and other equipment (Limbaugh and Fuller 2004:181). Remains of boilers may be evident adjacent to mill sites and are distinguished by rectangular platforms of brick or other refractory insulating material which encompassed large, iron horizontal-boilers. Furnaces also powered steam plants and compressors and their remains may be accompanied by a below-grade slot, or "well," to accommodate the fly wheel. Pelton-type wheels were often installed along the side of a mill where they would turn a bull wheel. They required heavy foundations and mounts, and a "well" to accommodate the wheel's rotation. A steady stream of pressurized water, delivered by an adjacent ditch or canal, blasted "buckets" at the end of the spokes, and remains of these devices will include channels for runoff.

In the 1890s electrical power plants began to be built, sometimes by independent entities and sometimes by the mining interests themselves. Engine mounts in mills are characterized by raised concrete footings topped by heavy bolts. Evidence of electrical power may also be evident in wire conduits, switch boxes, and insulators. In later years, on remote sites, local generators may also have been used.

Mill Tailings

The undesired portion of the ore discharged from mills is identified as tailings. They were generally in the form of slurry, and for most of the nineteenth century were allowed to run down adjacent creeks and gullies. A federal anti-debris law, the Caminetti Act of 1893, prohibited miners from dumping their waste into rivers and streams. While aimed primarily at hydraulic mining debris, this act also addressed lode mine tailings. As a result, mills began constructing impound areas. These tailings ponds were typically formed by constructing a dam across a downstream ravine and allowing the tailings to build up behind it. Heavier portions of the tailings settled into flat, meadow-like formations while the water portion ran over a spillway. Abandoned with their mills, the dams for these holding ponds were typically breached in later years, allowing the stream to cut through the accumulated tailings and reach its bed once again. These breached ponds can be identified by the cliff-like sides of the stream exposing mineral-colored fines unlike the surrounding soils, and remnants of the flat pond surface preserved along the sides of the drainage.

Tailings could also be carried as slurry to neighboring ravines and pond locations some distance from the mill. This is the case in Jackson, where the unique Kennedy Tailing Wheels lifted mill tailings to a retention pond over an adjacent ridge. Mill tailings contain high levels of minerals and are often distinguished not only by their coloration but by an absence of vegetation. At the New Melones Reservoir at low water a valley filled with stark white tailings from the Carson Hill Gold Mines mill is visible from Highway 49 (Figure 59). Many modern reclamation efforts are designed to contain old tailings and prevent water from leaching their often toxic contents into waterways.

***Figure 59: Tailings at New Melones Reservoir,Stanislaus River Drainage**. The mill tailings were slurried to a neighboring valley resulting in the white fill visible in background.* (Courtesy Calaveras County Historical Society).

ANCILLARY MINING PROPERTY TYPES

These are other site-specific facilities and systems that are commonly found in association with extraction and beneficiation activities. They represent important internal components assisting mining and milling operations.

ANCILLARY MINING PROPERTY TYPES:

- Structural Remains (ruins)
    - Office
    - Change Room
    - Blacksmith/Mechanic Shop
    - Shed/store/warehouse
    - Garage
    - Stable/corral
- Site-Specific Transportation Features (ruins)
    - Ore car routes, trestles, tramways
    - Trails, paths, walkways
    - Roads, haul roads
    - Railways
- Site-Specific Water Conveyance Systems
    - Dam/reservoir
    - Ditch/flume/conduit/siphon/penstock
    - Tanks/cisterns
    - Drains

Structural Remains

Mining sites may contain a myriad of buildings related to their mining and milling operations. Although some may be identifiable by distinctive artifacts, construction techniques, or locations, identification of most is achieved through comparing documentary records (mine inventories, photographs, and maps) with remains on the ground. Long-operating mines periodically upgraded or revamped their operations, and over time buildings may have been moved, demolished, or changed in function. Every building or structure in evidence on a site may not have been functioning at the same time.

Building remains may be from offices, sheds, storage buildings, stables and shops, locations of which may be indicated by concrete or stone foundations or simply leveled pads and retaining walls. Wooden structures were often covered with metal sheeting and may be evidenced by lumber, cut or wire nails, building hardware, or fragments of window glass. Assay offices may be distinguished by the remains of furnaces or retorting facilities, as well as fragments of crucibles and cupules.

Change rooms, where company gear and workers' personal equipment could be stored, are located next to mine portals or mills and later may have featured concrete floors and piped water for showering. These facilities were installed not only for the convenience of the workers, but to prevent high-grading (theft) of ore by employees

Other Structural Remains

Foundations or pads located around mining or milling sites represent various functions, some of which may be evident from the related artifacts. Those with domestic artifacts are discussed under Mining Community below.

Powder houses stored the mine's explosives and were usually located some distance from other structures. These were usually small windowless rooms, often semi-subterranean (commonly built into a hillside) and featured thick walls of stone, brick, or concrete.

Blacksmith shops maintained a mine's equipment and vehicles, and their former locations may contain various pieces of worked metal, raw materials, coal or coke, and slag from forging; the remains of the forge may also be evident. One of a mine blacksmith's principal duties was sharpening miners' drills. Nineteenth-century mines had stables and corrals for livestock used to haul ore cars and wagons. Stone foundations and wood posts with wire fence lines may be evident. At the Empire Mine, mules were stabled underground. More recent mines required a garage and shop which may feature tanks for oil and gasoline, grease pits, and vehicle parts. Structural remains with domestic artifacts (ceramics, bottles, and cans) are discussed below under "Mining Community."

Site-Specific Transportation Features

Within a mining site, transportation systems were needed to move ore, waste rock, and people. On the simplest sites, hauling was done by the miners themselves or by pack animals on single-track trails. Even modest development, however, had to address how to remove waste rock from lode mines and deposit it out of the way. Ore cars were often utilized within underground workings to move excavated material toward the surface. For adit portals, tramways for ore cars commonly ran out the entrance along a level grade to the adjacent waste rock dump, both being extended as the mine deepened. Tramways were also used to haul ore to mills for processing, either run along prepared grades or on trestles. The ore cars could be powered by animals, gravity, fossil fuels, or electricity. One of the earliest gravity-fed trams in use during the 1860s, was at Hite's Cove along the South Fork of the Merced River. In the 1890s before the Royal Mill was constructed, tram mules followed ore cars downhill from the Royal shaft to the Pine Log Mill, returning on their own with empty cars for a ration of oats (HAER 2007: Document No. CA-81). Tramways can be recognized by their uniform grades and the presence of rails and ties. Overhead tramways with buckets suspended on cables connected mines in inaccessible locations to mills or transportation facilities (Figure 60).

Trails, Roads, and Tramways

These linear features are visible as continuous grades leading to critical areas of the mine or mill. Tramways feature rails and ties. Aerial tramway sites where artifacts have survived are typified by cables, head frames, and buckets.

Roads were always present to connect mine facilities, and grew in importance when trucks replaced tramways for hauling both ore and waste rock.

Site-Specific Water Conveyance Systems

*Figure 60: **Tramway Header, Star of the West Mine, Inyo County** (Courtesy JRP Historical Consulting Services).*

Water played an important role both in placer mining and in processing lode ore. For placer mining, refer to its role in the placer extraction section above. Water was required for all types of milling; conveyance and storage systems will also be present on sites. Reservoirs, cisterns, and water tanks may be found above mills to allow for gravity feed while distribution may have been done in pipes. Remains of old riveted penstock systems may be present. Drains and methods to direct run-off from the mills will also be in evidence.

Water conveyance systems bringing water to a mill from distant sources (outside of the site boundaries) are recorded separately as individual sites. They may have tapped resources many miles away and served several mines or communities in the vicinity. These are discussed below under Inter-Site Mining Support types. Water conveyance systems for mines are also described in detail, with recordation methods and registration requirements, in the JRP/Caltrans publication *Water Conveyance Systems in California* (JRP and Caltrans 2000).

Water Conveyance Systems

Reservoirs, cisterns and tanks are located uphill of mills to allow for gravity feed. Ditches, pipes and penstocks were used to move water around the facility. Drains removed spent water from the mill area.

MINING COMMUNITY PROPERTY TYPES

Miners often lived at the mines, and this property type addresses facilities related to the domestic residential activities of the miners, the mine’s support staff, and their families. Although often marked by impermanence, mining-camp residents created distinct communities that are integral to the study of the mining site (Douglass 1998:106). The domestic property types discussed below must be physically and historically associated with prospecting, extraction, or milling activities. Resources related to mining-site residences, if present, are generally found integrated within or adjacent to mineral operations. Metal detection can help identify associated sheet refuse useful for interpreting foundations. There may be numerous remains of structures on mining sites, especially more developed ones that generally fit the architectural remains described below (see Structural Remains under Ancillary Mining Property Types). However, the residential property types addressed here must be distinguished by one or more of the following:

1. presence of sufficient quantity of domestic artifacts (e.g., more than a few),
2. distinctive domestic features such as hearths or baking ovens, or
3. identification as residence-related in documents.

In many respects the mining community reflects a work camp composed for mining. Communities brought together primarily for the mineral industry may also grow into townsites, with diminished connections to their mining roots. Modern towns along the Mother Lode's Highway 49 amply demonstrate this evolution. Mining community resources can resemble types discussed in the Work Camps and Town Sites Research Designs, and additional discussions of these types of resources may be found in those companion documents. Isolated residential sites may also be found along water conveyance, transportation, or utility lines, as well as in areas of agricultural development. Such sites should be addressed by research designs appropriate to those topics, although they may share many attributes of Mining, Work Camp, and Townsite properties.

MINING COMMUNITY PROPERTY TYPES:

- Domestic Structural Remains (residential and/or service)
  - Earthen pads
  - Foundations
  - Cuts/dugouts
  - Chimney/oven
- Domestic Artifact Deposits
  - Sheet refuse
  - Hollow-filled features
- Domestic Landscape Features

Domestic Structural Remains

The simplest temporary dwelling form is the tent, or lean-to with a canvas or shake-roof. An improvement was a half-walled version where the lower sides of a one-room dwelling were made of logs, milled lumber, or fieldstone, and if a canvas roof was employed, the roof could be rolled down to close the walls. Another version was a semi-subterranean space cut into a hillside with a superstructure covered by canvass, brush, or split logs. Located on natural earthen flats or leveled pads, these simple dwellings required only modest site improvements and the canvas and wood members could easily be transported to another mining location. A tent flat may be barely noticeable if located on a naturally level area but on slopes may be distinguished by a small retaining wall (as minimal as one row of stones) on the downhill side. Improved earthen pads may be surrounded on one or more sides by a shallow ditch created by building up the pad; these also provided drainage. Where semi-subterranean features are identifiable, hill slopes were dug by hand and often supported by rubble fieldstone walls. Sparse sheet refuse is usually found on the location of the tent or cabin pad, sometimes extending downhill away from the shelter. In many cases the only

Earthen Pads

Located close to placer mining remains, these leveled pads may have a downhill retaining wall and a stone hearth. They are characterized by a sparse scatter of domestic artifacts as sheet refuse.

Foundations
All the types below are associated with domestic artifacts or have been identified as domestic facilities through historical research. Any may be located on natural level areas or on prepared structure platforms with retaining walls and may have evidence of fireplaces. Structures over 30 feet long may be bunkhouses or dining halls.

Stone Piers or Perimeter Foundations
Arranged symmetrically to support a frame building.

Stone, Adobe, or Rammed-Earth Walls
Collapsed or partially standing stone building; adobe or rammed-earth may have "melted," leaving an earthen berm.

Concrete Piers or Perimeter Foundations
Generally post-dating 1900, they have bolts, sill boards, or other devices to affix the overlying frame building.

feature visible is the collapsed remains of a fieldstone chimney or fireplace. Metal detection can help identify associated sheet refuse. The presence of a few large stones may indicate a U-shaped hearth or fire ring. These hearths may consist of flat stones set on end to form firebreak, or a few courses of stacked local rock. Stone oven remains have also been found associated with placer mining tent pads (see discussion below). These types of dwellings are generally found in close proximity to small-scale placer mining remains (more extensive placering and hard-rock mining required greater investment in developing the mine and housing was similarly more permanent).

More substantial dwellings employed stone foundations to raise wooden walls and floors above ground level; these can include stone piers to support posts or floor joists as well as complete stone perimeter foundations. Flat stones used as post footings on a flat, such as those used for simple cabins like the ubiquitous, two-room miners' cottage, can be barely noticeable (Bell 1998:31). Post-and-pier construction was used into the early-twentieth century for frame dwellings as well as for bunk-houses and dining halls found on some mining sites. Domestic structures with stone masonry walls, or of adobe or rammed-earth, may also be present (Figure 61). A full or partial cellar, typically reinforced with stone masonry, may have been incorporated. Roofs were commonly of metal or wood. Supervisors or managers may have resided on-site in large or unique structures, possibly higher in elevation or across from the housing of common laborers.

Figure 61: Star of the West Mine, Inyo County: Partially Standing Stone Cabin *(Courtesy JRP Historical Consulting Services).*

Later, poured concrete slabs and perimeter foundations were used for housing. Concrete constructions are common on well-developed mining sites after 1890. Board-formed poured foundations date to after the First World War, although smaller sites may have continued using simple stone technologies. Sites dating to the twentieth century show increasing evidence over time of off-site utilities for electric lighting, telephone, and domestic water supply.

Cuts/Dugouts

Commonly appear as collapsed cuts into the hillside, or basement-like areas, possibly stone-lined, associated with domestic house-hold artifacts.

On more extensive mines, evidence of large foundations (exceeding 30 feet in length) in association with personal domestic debris may represent bunkhouses or other collective housing. Community dining halls and kitchens will be distinguished by large refuse piles containing tablewares; large quantity cans, bottles, and jars; and faunal remains.

A dugout describes an open, often rock-lined cavity in a hillside, usually the size of a single room (Figure 62). In the mining community these generally served the same functions as discussed above for foundations: they were used as dwellings as well as for other functions such as storage. Most simply they can appear as a single slumped-in cut into the hillside. Better-developed examples were fully excavated and may have been lined with stone, poured concrete, or milled lumber framing, and supported metal or wood roofing. Wood construction elements, if not entirely decayed, will likely be collapsed within. Dugouts are typically at least partially filled-in, often burying structural elements and living surfaces. For large dugouts, the removed fill should be visible around the structure.

Figure 62: Remains of a Masonry-lined Dugout, Butte County *(Courtesy Anthropological Studies Center, image no. 27-03-D136-05.).*

Figure 63: Large Stone Oven, Chili Junction, Calaveras County. *The 1850s mining camp of Chili Junction was populated by miners from Chile (Courtesy Julia Costello).*

Some mining residence areas may contain cooking features, and any of the features described below may be found on domestic mining sites. Simple hearths are discussed above under "earthen pads." More developed residences may contain evidence of a stone fireplace with a chimney. The hearth itself was typically made of stone, and the chimney of stone, mud-and-stick, or pipe. Similarly, a separate area for preparing food or a more formal cookhouse may have contained a dome-shaped bake oven. Where collapsed, these appear as roundish piles of stones, about 10–15 feet in diameter, with the centers collapsed into a cavity and stones typically resting at steep angles (Figure 63). In the Mother Lode, these are most commonly associated with Italians, although they were also constructed and used by French, German, and Hispanic residents (Costello 1981; Wegars 1991). In later years, they incorporated modern materials such as brick, concrete, and cast-iron doors. A distinctive curved free-standing wall – an asado – was used by Chileans and Peruvians to cook flayed cattle. Overseas Chinese also constructed U-shaped stone hearths in the vicinity of their diggings (Tordoff and Seldner 1987; Tordoff and Maniery 1989; Medin 2002) identified by the presence of ceramics and other artifacts from their homeland. Often these suspected piles of stone must be carefully excavated to reveal their original forms and functions.

Domestic Artifact Deposits

Domestic artifact deposits are also discussed in the *Agricultural*, *Work Camps* and *Townsites* thematic studies. The examples below identify those commonly found on mining sites.

Domestic Sheet Refuse

Domestic artifacts found in the vicinity of a dwelling, conveniently deposited on the surface by the occupants.

Domestic sheet refuse describes a horizontal scattering of discarded items typically found around a dwelling, and is one of the most common types of domestic artifact deposits on rural mining sites. Artifact accumulation results from unintended loss as well as intentional waste disposal such as casting debris away from a dwelling. Sheet refuse may be found throughout the living area of a dwelling, or as deposit located adjacent to and downhill from the residence area. Disposal of debris into natural features such as gullies may create vertical interfaces similar to the "hollow filled features" discussed below. Metal detection is helpful in identifying boundaries of discrete surface deposits.

In both situations, sheet refuse may retain a form of horizontal stratigraphy that represents unique activities or episodes; one occupant may have discarded debris one direction, while another may have tossed debris in another, thereby creating distinguishable deposits. Don Hardesty (1987:85) noted this quality on mining sites, recognizing that some site components may be organized horizontally instead of vertically. The implications of this for research and integrity have been recognized as an important element of evaluations (Cowie et al. 2005:62).

Hollow-Filled Feature

Concentrated deposits of artifacts disposed of in features such as trash pits, prospects, privies, cellars, or other abandoned features.

Developed mines with sedentary communities that resemble a town more than a camp may exhibit more intentional methods of refuse disposal, such as designating a communal dump. Artifact deposits are found buried or partially eroding from features such as trash pits or prospect pits, or from privies, wells, dugouts, cellars, or ditches abandoned at the time of disposal. It should be noted that artifacts found in abandoned features, such as basement depressions, likely reflect activities after the facility was abandoned, not the period of use. These hollow-filled features potentially offer a rich assemblage of artifacts with traditional vertical stratigraphy. Many of these types of features are buried, however, and must be explored through excavation or use of documents. The location and excavation of these types of features is discussed in the Town Sites Research Design.

Domestic Landscape Features

Besides improvements to the physical characteristics of the mines themselves, miners and members of the mining community attempted to create a domestic environment for themselves by planting vegetable gardens and ornamentals. Surviving features may include ornamental ground cover, shrubs, and trees. Vinca major, roses, black locust, and *ailanthus*, or Chinese Tree of Heaven, are particularly common throughout the Mother Lode region. In certain instances miners terraced hillsides, built fieldstone retaining walls, and walkways.

Plantings
Exotic plantings that can survive untended such as bulbs, trees, and rose bushes.

Stonework
Lined paths, retaining walls, and terraces.

INTER-SITE MINING SUPPORT PROPERTY TYPES

These are separate, distinct sites that may extend many miles, creating a link between the mining site and the outside world. They represent linear systems for delivery of services or access and are recorded as individual and distinct entities. The nexus of these common property types with a particular mine, however, is a contributing element of that mining site.

INTER-SITE MINING SUPPORT PROPERTY TYPES:

- Inter-site Transportation Features
    - Trails
    - Roads

- Inter-site Water Conveyance Systems
  - Ditch, Canal or Flume
- Inter-site Utilities

Inter-site Linear Transportation Features

Early access to mines was by way of single-track trail, such as the network of mule trails that quickly developed to service mining camps during the first years of the gold rush. Such trails are narrow and often have stone masonry retaining walls; their width is most accurately measured at switchbacks and outcrops. Segments of trails are often completely erased by later activities. Wagon, freight, and stage roads replaced portions of these systems as some areas grew into viable settlements. These typically have stone masonry and a berm on the downhill side from grading, and often replace the steeper grades of trails with longer routes. Over time, additional road improvements such as oiling, macadam, or paving, became a standard practice. Earthen and paved roads form a network across the rural landscape. Mining operations patched into existing transportation networks or financed their own service connections. Large, capitalized operations, in particular, typically improved road systems linking to the larger transportation network. Byrd (1992a) provides a general history of road development to 1940, while Bethel (1999) offers an overview specifically for nineteenth-century gold mining.

Trails and Roads

Trails were narrow and often marked with downhill rock retaining walls on hillsides. Wagon roads were wider and less steep, and later roads for motorized vehicles were often paved.

Inter-site Water Conveyance Systems

Water is necessary for many aspects of mining, and when an intra-site supply was not developed (see discussion above for intra-site, ancillary mining property types), operations depended on an inter-site water conveyance system for its delivery. The mining company may have developed its own water supply and storage system by buying up and improving on earlier claims and systems or purchasing water from the owner of a ditch system. These linear systems can be quite large, extending for miles beyond a mine. Typical components include catchment or take-out, storage, and delivery features. Elements are discussed at length in the JRP/Caltrans (2000) report on water conveyance systems, and by Shelly Davis-King (1990); both documents provide the general features of mining ditches. Intra-site water conveyance systems typically took water from an inter-site system, often first directing water into the mine's own storage feature via a ditch, flume, or penstock. The history of a mining site's water system is vital to understanding its development, and the source of water should be identified for each operation.

The primary feature that will be archaeologically visible in the vicinity of a mine is an earth-berm ditch, possibly with associated stone or concrete masonry or penstock. Ditch segments may be filled with sediment, or in places entirely eroded away. As the grades of ditches remained steady, their routes can be determined across a landscape even when large segments are no longer extant. Natural gullies were often used to move water quickly to a lower elevation, where it would be picked up again by a lower section of ditch.

Remains of parallel ditches are often found in close proximity and may represent water from the same source being taken to different destinations, or an improvement in the grade of a ditch at a later period of time. Small side-hill ditches – long, narrow reservoir-like hillside features – caught seasonal surface runoff and supplied mining operations below. Flumes of any antiquity are usually in disrepair if extant at all; more likely they exist as an alignment of fasteners. Remains of gates, pipes, or penstock may survive as ferrous metal and poured concrete reinforcement. During World War II many abandoned segments of riveted pipe were collected for scrap and shipped to coastal shipyards. Water storage features were developed in concert with ditches or canals. The storage reservoir was generally built upslope from the mine or mill and through penstocks and gravity water pressure was generated to power a variety of machinery.

Ditches
Paths of streams of water excavated across the landscape on contours; downhill berms are typical and may be reinforced with rock.

Reservoirs
Dams were typically made of stone and earth.

Flumes
Often no longer extant, may be indicated by missing segments of ditches over creeks or steep hillsides.

Pipes
Riveted iron pipe carried water down hillsides, or siphoned over creeks.

Inter-site Utilities

Some mining operations required utilities, particularly electricity. The development of electrical generating plants in the 1890s was pioneered by mining companies to supply their needs as they had both capital and incentive (Limbaugh and Fuller 2004:182). Power companies supplied mines with electricity to operate head frame hoists, compressors, underground lights, etc. As telephone companies expanded their service beyond the principal metropolitan areas of California, mines and other industrial facilities established telephone communications at their facilities. Utility poles might be present, although lines were often hung from existing trees fitted with insulators. The mines near Copperopolis, Calaveras County, were, in 1901, linked by a telephone service run partially along the barbed wire of fences (Fuller et al. 1996:69).

Poles

Cut or standing poles and glass and ceramic insulators.

APPENDIX D:
GEO-10-003-1 Gravity and Electrical Methods Geophysical Surveys Report, Colusa and Lake Counties, California

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GEO-10-003-01 GRAVITY AND ELECTRICAL METHODS GEOPHYSICAL SURVEYS REPORT

COLUSA AND LAKE COUNTIES, CALIFORNIA

FINAL

for

Renovitas, LLC and

The Sacramento Municipal Utility District (SMUD)

Sacramento, California

REGISTERED PROFESSIONAL ENGINEER
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EXECUTIVE SUMMARY

This report presents the results of activities carried out during the execution of the approved Geophysical Work Plan for this Grant (GeothermEx, 2012c). The overall objective of this Grant is to better understand the geothermal resource in the project area (defined below), to update and augment the resource model in the project area, and to further define whether the project area could support a geothermal power plant. This report focuses on results and evaluation of the geophysical surveys conducted in the project area.

The project area is located in northern California about 90 miles north (N) of San Francisco, and 19 miles southwest (SW) of the Central Valley town of Williams. The area has long been known to have geothermal resources, and previous investigations of these geothermal resources have been undertaken by various parties. The geophysical surveys were conducted in the project area using Trebilcot mineral rights that are presently held by the Sacramento Municipal Utility District (SMUD). At present, Trebilcot land can only be accessed via public roads, and nearly all Trebilcot land have surface rights held by federal and state agencies, including the Bureau of Land Management (BLM) and California Department of Fish and Game (CA DFG). However, a small parcel of Trebilcot land is located in the northeast corner of Section 29, and has privately held surface rights. Except for the Section 29 parcel, the Trebilcot land falls within the joint Cache Creek Coordinated Management Plan and Ukiah Resource Management Plan (CCCMP/URMP) areas administered by BLM and are subject to plan restrictions and any associated permit requirements.

The overall grant project consists of collecting field geologic, geochemical, and geophysical data and submitting a set of deliverables comprising three work plans and two final technical reports, which are outlined below in order of delivery:

- The Final Geologic and Geochemical Work Plan for the SMUD-Renovitas Project (GeothermEx, 2012a)

- The Final GEO-10-003 Geologic and Geochemical Evaluation of Geothermal Resources for Geothermal Power Development (GeothermEx, 2012b)
- The Final Geophysical Work Plan for the SMUD-Renovitas Project (GeothermEx, 2012c)
- The Final GEO-10-003-001 Gravity and Electrical Methods Geophysical Surveys Report (this document)
- The Final Exploration Drilling Work Plan for the SMUD-Renovitas Project

Field work to collect geophysical data was conducted in the Wilbur Hot Springs area by the GeothermEx subcontractor WesternGeco from November 22 to December 13, 2012. Field work activities included: 1) logistical reconnaissance for access to the Wilbur Hot Springs area to prepare for conducting the geophysical survey; 2) magnetotelluric (MT) resistivity survey equipment installation and data collection; and 3) differential-global-positioning-system (dGPS) and gravity survey equipment installation and data collection.

Geophysical survey points were located on BLM and CA DFG lands, as indicated within this report. The field area included land to the south (S) and west (W) of the Sulfur Creek Valley. Terrain in the study area is mountainous, with alternating clay and serpentine-rich soil cover and only occasional rock outcrop. Vegetation in the study area is a combination of scrub brush and pine trees. For both the MT resistivity and dGPS surveys, the survey area was covered by an irregular survey grid on a spacing of 500 meters.

MT equipment measures how much different rocks and formations conduct or resist electrical impulses. This is known as electrical resistivity and is a function of rock porosity. Correlating the resistivity distribution with known geological, lithologic, and structural units is an important step in this process. Resistivity data rarely directly identify deep drilling targets, as upflow zones in geothermal fields often do not have a clear resistivity signature, and therefore, resistivity data should be used in the context of the geologic model to plan drilling targets at greater depths than any low-resistivity signature, thus enabling wells to intersect inferred zones of thermal fluid upflow and outflow.

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The gravity survey uses the earth's gravitational field and the mass of the earth to measure changes in the gravity field that occur due to variations in subsurface materials. For geophysical evaluations, low-gravity values in geothermal systems may indicate rock that has experienced hydrothermal alteration (that is, rock altered by contact with hot fluids) resulting in decreased density at depth. Conversely, high-gravity values indicate higher density rocks at depth (and may indicate limited hydrothermal alteration). The differences in gravity may be used as a preliminary marker to help delineate a potential geothermal reservoir. However, it is noteworthy to mention that lithology changes (independent of alteration) can produce similar gravity results. Additional subsurface data (for example, examination of rock cuttings from drilling activities) will be required to help update and refine the gravity interpretation.

The stratigraphic sequence in outcrop within the study area is comprised of the Coast Range Ophiolite (CRO) and younger Great Valley Sequence (GVS) assemblages. Serpentinites (also referred to herein as serpentine) of the CRO are probably the oldest group of rocks in the local stratigraphic sequence, which once may have comprised an underlying part of the ocean floor and now overlies the Franciscan assemblage along what is considered to be a gently-to-steeply-dipping folded thrust fault (the regional Coast Range Thrust). Another thrust fault, the Stony Creek Thrust, is thought to separate the sheet of serpentine within the CRO assemblage from the overlying GVS, which is comprised of the Jurassic Knoxville shale and a thick overlying sequence of alternating sandstone and shale of lower Cretaceous age.

Two fold structures are shown by the outcrop pattern in the study area, the crest of the Wilbur Springs anticline and the trough of the Grizzly Creek syncline. Both folds trend northwest – southeast (NW – SE) and plunge to the SE; the axes of these two folds are separated by about 2.5 miles. In the case of a geologic setting with well-pronounced structural features and lithologic deformation such as the Wilbur Hot Springs area, thermal fluid upwelling likely occurs primarily within bedding surfaces and at lithologic contacts, as well as along fault and fracture planes.

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In general, the Wilbur Hot Springs survey area shows MT resistivity data relationships that partly match the structural setting of the Wilbur Hot Springs area. Near the northeast (NE) corner of the study area, the location of low-resistivity data is seen approximately at the mapped surface extent of a serpentine unit, which is interpreted to be a controlling mechanism for thermal water upwelling. However, along the axial plunge of the Grizzly Creek syncline, the MT resistivity data pattern does not match the inferred geologic structure, which may be a result of factors such as the clay distribution in GVS sediments, and/or edge effects on the survey that would not appear had a larger area been surveyed.

Low-resistivity and low-gravity data correlate within the NE portion of the study area to the nearby location of hot spring outflows at Wilbur Hot Springs, where resistivity data was collected just S – SW of the springs, in the down-dip direction of thermal outflows. However, subsurface hydrothermal alteration may not be the primary reason for low-resistivity and gravity values, because prominent resistivity and gravity lows closely correspond to the surface outcrops of serpentine rock. This is consistent with serpentine's unaltered physical properties as compared to the higher density and resistivity of the surrounding sandstone and shale.

Up-dip migration of fluid in permeable strata located on the west (W) flank of the Wilbur Springs anticline appears the most likely fluid migration scenario. This interpretation is based on information available from prior geologic, geochemical, and historic drilling data, combined with results of the geophysical survey. MT resistivity and gravity data observations that appear to further support this scenario include:

1. MT resistivity data showing a zone of low-resistivity extending from 250 meters below ground surface (m bgs) in the vicinity of survey point WS003a to greater depths in the SW (down-dip) direction (see Figures 13 and 14). This low-resistivity zone is inferred to be associated with serpentine and melange rock units, which have been previously mapped as dipping approximately SW, perpendicular to strike of the axis of the Wilbur Springs anticline.

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2. Low-gravity anomalies correlating to areas of low-resistivity, with anomalies noted S and SW of Wilbur Hot Springs and in the southern portion of the study area. The outcropping serpentine unit is inferred to be the source of these low-gravity signatures.

Surface-mapped outcrops of the serpentine unit in the study area show close correlation with low-resistivity and low-gravity anomalies, as seen in the NW and S portions of the study area. The resistivity cross-sections show, in most cases, that the serpentine lenses dip to the SW, which is consistent with the mapped attitudes of the sandstone and shale beds that enclose the serpentine. These linear, SW-dipping permeable stratigraphic horizons disclosed by the geophysical surveys support the geologic model of the Wilbur Hot Springs area, as proposed by GeothermEx (2012b) and summarized above.

The key to successful development of the geothermal resource in the project area is to drill to the proper depth to intercept fluid-bearing horizons. The selection of drilling targets at depth will be done with consideration of resistivity and gravity results alongside geologic, structural, and geochemical information.

The currently approved statement of work and schedule of products for the grant project includes the preparation of a temperature-gradient drilling work plan. However, based on GeothermEx's technical and regulatory understanding of the project area, it has been determined that temperature-gradient drilling would not be a suitable next-step exploration activity for the following reasons: 1) the CCCMP/URMP, which includes all of the Trebilcot property except the parcel of land in Section 29, does not allow exploration activities in the form of temperature-gradient wells, though a production slim-hole well may be allowed; and 2) the depth of the resource and the potential variability in the thermal conductivities of rocks above it would hamper the ability to extrapolate shallow temperature data to depth. Therefore, it is recommended that the program proceed to deeper exploratory wells in the form of slim-hole production wells. Details for a potential exploration drilling program are provided in the Final Exploration Drilling Work Plan.

As an initial step before staging any exploration drilling, consideration could be given to flying an aeromagnetic survey over the study area. This geophysical method could confirm the attitude of beds dipping W – SW from the Wilbur Springs anticline, thus helping to better identify prospective drilling targets. This survey, as with all data acquired by aircraft with aeromagnetic equipment, could be conducted without regard to land holdings and ownership, thus facilitating the extension of data from the Trebilcot land to the private land areas that have been previously drilled but are presently not accessible.

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1. INTRODUCTION AND BACKGROUND

This report presents the results of activities carried out during the execution of the approved Geophysical Work Plan for this Grant (GeothermEx, 2012c). The overall objective of this Grant is to better understand the geothermal resource in the project area (defined below), to update and augment the resource model in the project area, and to further define whether the project area could support a geothermal power plant. This report focuses on results and evaluation of the geophysical surveys conducted in the project area.

The project area is located in northern California about 90 miles north of San Francisco, and 19 miles southwest (SW) of the Central Valley town of Williams. The area (shown by Figures 1 and 2) has long been known to have geothermal resources, and previous investigations of these geothermal resources have been undertaken by various parties.

The activities conducted in execution of the approved work plan were completed in the project area using Trebilcot mineral rights that are presently held by the Sacramento Municipal Utility District (SMUD). At present, Trebilcot land can only be accessed via public roads and all Trebilcot land has surface rights held by federal and state agencies, including the Bureau of Land Management (BLM) and California Department of Fish and Game (CA DFG). However, a small parcel of Trebilcot land is located in the northeast corner of Section 29, and has privately held surface rights, as shown on Figure 2a and 2b. Except for the Section 29 parcel, the Trebilcot land falls within the joint Cache Creek Coordinated Management Plan and Ukiah Resource Management Plan (CCCMP/URMP) areas administered by BLM and are subject to plan restrictions and any associated permit requirements (CCCMP, 2004 and URMP, 2006).

This grant project consists of collecting geologic, geochemical, and geophysical data from the field and submitting set deliverables comprising three work plans and two final technical reports, which are outlined below in order of delivery:

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- The Final Geophysical Work Plan for the SMUD-Renovitas Project (GeothermEx, 2012c)
- The Final GEO-10-003-001 Gravity and Electrical Methods Geophysical Surveys Report (this document)
- Final Exploration Drilling Work Plan for the SMUD-Renovitas Project

This document, titled 'Final Gravity and Electrical Methods Geophysical Surveys Report', contains results and evaluation of the geophysical surveys conducted within the project area. In conducting the geophysical surveys, GeothermEx has prepared and carried out work according to the Geophysical Work Plan (GeothermEx, 2012c). This work plan outlined: 1) the conditions under which geophysical survey field work was to be conducted in the project area, which has a history of mercury mining and associated mining waste, and 2) the methods and practices of data collection implemented to collect geophysical data to support development of the resource model.

The strategy of this investigation is to develop a resource model for the project area through the collection and evaluation of geologic, geochemical, and geophysical data to support further exploration work that is expected to include exploration well drilling for potential geothermal power development, as permitted by the CCCMP/UMP.

The Trebilcot lease area (and the location of the 'project area') is located south – southwest (S – SW) of the WHS area. The location of the Trebilcot land, the location of WHS, and the distribution of mines and hot springs in the Sulphur Creek Mining District are shown on Figures 2a and 2b. The WHS area and associated hot springs are located in the southeast (SE) part of the Sulphur Creek Mining District. In most of this report, the group of springs that are clustered

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in the WHS area at the SE end of the Sulphur Creek Mining District are referred to collectively as WHS, though the majority of the springs do have individual names, as shown on Figures 2a and 2b. [Additional detail on spring names and locations is available in the Geological and Geochemical Evaluation Document (GeothermEx, 2012b)]. The WHS group is due north – northeast (N – NE) of the Trebilcot land, with geothermal resources beneath the Trebilcot land likely associated to some degree with outflows at WHS. Approximately 1 mile southwest of WHS in the Sulphur Creek Mining District is the Abbott Mine and its associated hot springs, located on the southwest side of the ridge that bounds Sulphur Creek to the southwest (Figures 2a and 2b).

Interest in developing geothermal power in the District began in 1964 when 11 shallow wells, 127 to 292 feet deep, were drilled by Worldwide Geothermal Exploration Company in and around WHS for the purpose of measuring temperature gradients. The location of the wells and the contoured gradient values are shown on Figures 2a and 2b; the 8°C/100 ft contour encircles the WHS group. Following an interpretation of temperature gradients from these wells, Magma Power Company drilled an exploration well in 1965 (‘Magma’ on Figure 2a and 2b) in the center of the temperature gradient anomaly to a depth of 1,226 feet below ground surface (ft bgs) [386 meters (m) bgs]. This was followed by the drilling of the Cordero #1 (‘Cordero’) well in 1968 by the Cordero Mining Company to 3,400 ft (1,036 m) bgs, and the Bailey Minerals #1 (‘Bailey #1’) well in 1980 by the Sunoco Energy Development Company to 9,100 ft (2,774 m) bgs. All these wells were drilled at the WHS area within the 8°C/100 ft gradient contour (Figures 2a and 2b), though the temperatures and flow rates encountered were considered to be non-commercial at the time. The information obtained from these wells and well test results are described and interpreted in detail to assist with preparation of the project area resource model, as presented in the GeothermEx (2012b) report.

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A correction to Figure 2b is noted in this report, where the correct location of Jones' Fountain of Life spring is shown on Figure 2b herein. This figure was previously included in GeothermEx (2012b; Figure 2b) with the location of the Jones' Fountain of Life spring incorrectly shown.

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2. GEOLOGIC SETTING

A simplified map of the regional geology surrounding the Sulphur Creek Mining District is shown in Figure 3, with a legend presented on Figure 4; this is a 1:70,000-scale enlargement of the appropriate segment of the 1:250,000 Ukiah Sheet of the State of California geologic map series (1960). Figure 5 presents an enlargement of the 1:24,000-scale local geologic map of the WHS area, with a legend on Figure 6. The boundary of the Trebilcot land and the location of WHS are included on the map in Figures 3 and 5.

As part of the effort associated with executing the Final Geologic and Geochemical Work Plan (GeothermEx, 2012a), geologic mapping was conducted, and the data from this effort was used with existing geologic map data (Jennings and Rudolph, 1960; Rich, 1971; and McLaughlin et al., 1990) to produce a more detailed geologic map of the project area. This fieldwork and data are summarized in GeothermEx (2012b).

Outcrops of the Coast Range Ophiolite (CRO) serpentinites (also referred to herein as serpentines) and units of the younger Great Valley Sequence (GVS) are found within the study area. Serpentines of the CRO are probably the oldest group of rocks in the local stratigraphic sequence, designated as “ub” on Figure 3 and “KJg” on Figure 5, which once comprised an underlying part of the ocean floor and now overlie the Franciscan assemblage (designated “KJfv” on Figure 3) along what is considered to be a gently-to-steeply-dipping folded thrust fault (the regional Coast Range Thrust). Another thrust fault, the Stony Creek Thrust, is thought to separate the sheet of CRO serpentine from the overlying GVS, which is comprised of the Jurassic Knoxville shale (“Jk” on Figure 3) and a thick overlying sequence of alternating sandstone and shale of lower Cretaceous age (“Kl” on Figure 3). Both of these units are referred to as “KJg” on Figure 5. West-northwest (W – NW) of WHS, a layer of submarine basalt (“Kjfv”) occurs at or near the base of the Knoxville. This layer is of variable thickness and absent in

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some places. In the SW corner of the map, young sediments of the Cache Formation ("QP") unconformably overly the older faulted and folded rocks. Young volcanic rocks of the Clear Lake volcanic series ("Qrv") intrude the Cache Formation west of the mapped area.

Two fold structures are expressed by the outcrop pattern in Figure 3: the crest of the Wilbur Springs anticline and the trough of the Grizzly Creek syncline. Both folds trend NW and plunge to the SE; the axes of these two folds are separated by approximately 2.5 miles. These folds are also defined by a large number of measured bedding attitudes, as shown on Figures 3 and 5. Some of the bedding attitudes were collected by GeothermEx during recent field work, as outlined in the Final Geologic and Geochemical Evaluation of Geothermal Resources for Geothermal Power Development document (GeothermEx, 2012b).

On the geologic map shown on Figure 5, most of the boundaries between stratigraphic units, and between the stratigraphic units and the serpentine, are shown as faults, with the exception of the Knoxville-lower Cretaceous boundary (shown as formations KJg and KJgs on this figure), which is depositional. Because proposed thrust faults define the upper and lower bounding surfaces of the serpentine, and because these faults do not offset the body itself, for the purposes of this report they can be treated as stratigraphic boundaries. The presence and importance of faults in the Sulphur Creek area and specifically within the Trebilcot project area will be discussed in Section 5.

A key observation that can be made from Figures 3 and 5 is that the hot springs of the Sulphur Creek Mining District occur near the base of the Knoxville Formation on the SW flank of the Wilbur Springs anticline.

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3. RESULTS OF FIELD WORK

Geophysical data collection in the field has been conducted in the WHS area by the GeothermEx subcontractor WesternGeco during November 22 to December 13, 2012. Field work activities included: 1) logistical reconnaissance for access to the WHS area in advance of conducting the geophysical survey; 2) magnetotelluric (MT) resistivity survey equipment installation and data collection; and 3) differential-global-positioning-system (dGPS) and gravity survey equipment installation and data collection. A field work summary is presented below.

During the course of geophysical survey field activities, only lands with surface rights held by the BLM and CA DFG were accessed for purposes of conducting the investigation. Field work personnel did not venture onto private land at any time.

Climate in the study area is hot in the summer, with temperatures reaching over 38°C, and cool in the winter, with temperatures approaching 0°C. Large rain events are possible in the area. Terrain in the study area is mountainous, with alternating clay and serpentine rich soil cover and only occasional rock outcrop. Vegetation in the study area is a combination of scrub brush and pine trees.

3.1 Areas of Mine Waste and How They Were Avoided and Access Conditions

Avoidance of mine wastes in the project area during field work by GeothermEx and WesternGeco was achieved by:

- GeothermEx providing the geophysical survey subcontractor with a site introduction and as-needed guidance on land boundaries and hazards information, including how to identify unmapped mine waste, to ensure that safe-work and mine-waste-avoidance practices were implemented,

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- The location of mining waste being loaded into the field team's GPS units, and additional hardcopy maps taken into the field, assuring that subcontractor personnel knew their location at all times relative to any areas of mining activity, and
- Maintaining a 100-foot buffer zone around all known and identified mine features on all public and private lands (*i.e.*, there was no walking, driving, surveying, or exploration activity of any kind around any area of mining waste, including within the 100-foot buffer).

During field work efforts conducted November 22 to December 13, 2012 no additional areas of mine waste were discovered.

Other conditions of access included the following:

- During this fieldwork effort, the BLM has provided permission for access to those lands on which the BLM holds the surface rights, allowing the geophysical investigation to be conducted. The BLM has provided access to all lands in Lake and Colusa Counties in the vicinity of the Trebilcot land, as shown on Figure 4 within the Final Geophysical Work Plan for the SMUD-Renovitas Project (GeothermEx, 2012c). The BLM has allowed access to these lands under the following conditions:
  - Fieldworkers must avoid unnecessary impact to serpentine soils, which are considered vegetation stressed. To accomplish this, GeothermEx and WesternGeco field crews avoided unnecessary vehicle and foot disturbance of these soils during both normal and inclement weather.
  - Fieldworkers must avoid any cultural resources in the area. To accomplish this, GeothermEx and WesternGeco field crews were required to note, report, and adapt the survey strategy to avoid any indications of cultural resources. During this fieldwork effort, no cultural resources were identified in the project area.

- During this fieldwork effort, the CA DFG has provided permission for access to those lands on which CA DFG holds the surface rights, allowing the geophysical investigation to be conducted. The CA DFG has provided access to lands S of Route 20, as shown on Figure 4 of GeothermEx (2012c). The CA DFG allowed access to these lands under the following conditions:
  - All findings shall be reported to CA DFG,
  - Consideration shall be given to other users including hikers, hunters, etc., and
  - CA DFG shall be notified when work is starting and ending.

GeothermEx satisfied CA DFG requests during and following field work activities.

3.2 Geophysical Surveying

The geophysical fieldwork consisted of the temporary installation of 75 co-located MT resistivity and dGPS/gravity stations for measuring data. The combined MT resistivity and dGPS/gravity measurements were made at a rate of approximately 5 to as many as 8 stations per day (depending on terrain and access) when weather did not prohibit field activities. A total of 3 surveying crews, consisting of 1 operator and 2 field assistants per crew, conducted the MT resistivity geophysical surveys. One surveying crew consisting of 1 dGPS operator and 1 gravity operator conducted the dGPS and gravity geophysical surveys utilizing the same station locations.

For both the MT resistivity and dGPS surveys, the survey area was covered by an irregular survey grid with a spacing of 500 m (see Figure 7). GPS units were carried with field personnel to determine the precise location of each surveying station, and all locations were independently confirmed by the dGPS survey crew.

Geophysical survey measurements were collected by field personnel by walking from the access road to the survey station locations with the necessary surveying equipment. Field personnel laid out the surveying equipment at each determined location, taking care to disturb no more than a volume of soil measuring 30 cm wide x 85 cm long x 50 cm deep when setting the survey equipment temporarily in place at each station. Disturbed soil at the station was replaced after the survey was completed and equipment was removed.

During the course of data acquisition, a remote reference station was established 40 km north of the field area to identify regional electromagnetic events that could affect survey data.

Heavy rainstorms resulted in two days of weather-related standby during the scheduled fieldwork activities. During these standby days, WesternGeco fieldwork crews did not mobilize to the project area.

Data processing and interpretation of geophysical MT resistivity and gravity survey data are presented in Section 4.

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4. GEOPHYSICAL DATA EVALUATION

4.1 Introduction

Both MT resistivity and gravity geophysical data was collected at 75 co-located stations during this fieldwork effort, as outlined in Section 3.2. Concepts of these survey techniques, their application to geothermal evaluation, and interpretation of survey results are presented here.

4.1.1 Magnetotelluric (MT) Resistivity Survey

MT equipment measures how much different rocks and formations conduct or resist electrical impulses. This is known as electrical resistivity and is a function of rock porosity, with results most often reported in Ohm-meters (Ωm). The electrical resistivity of a rock unit at depth is a basic petrophysical parameter used to evaluate subsurface reservoirs. For clay-rich rocks this relationship is more complex, since the clay itself is often electrically conductive, effecting the overall reading of the rock unit. Resistivity is also a function of temperature and thus resistivity methods can be a useful tool in geothermal prospecting. Commonly, resistivity is reduced by a factor of 10 as temperatures increase from 20°C to 200°C, suggesting that higher-temperature zones will have reduced resistivity values compared to equivalent rocks in cooler environments. As a general rule, resistivity readings are strongly affected by conditions of soil or rock saturation, temperature, porosity, and clay content.

The strategy for applying resistivity data in geothermal exploration is to utilize the data within the known geological framework to map thermal fluid outflow and the overlying cap rock or boundary (*i.e.*, 'clay cap') zones, as well as to identify discontinuities such as structural faults or folds. Correlating the resistivity distribution with known geological, lithologic, and structural units helps to guide exploration and develop drilling target areas. Resistivity data rarely directly identify deep drilling targets, as upflow zones in geothermal fields often do not have a clear resistivity signature. However, resistivity data can be used in the context of the geologic model to plan drilling targets at greater depths, thus enabling wells to intersect inferred zones of

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thermal fluid upflow and outflow. As a result of hydrothermal alteration processes, clays typically form near the upper part of a geothermal reservoir and act to hydraulically isolate and thermally insulate the hydrothermal system beneath. However, not all low-resistivity anomalies are signs of a geothermal system: a clay-rich sedimentary unit with average subsurface temperatures can produce a similar and misleading electrical signal. Therefore, low-resistivity readings from a survey of the project area might indicate a clay cap above a geothermal reservoir, but this cannot be determined unequivocally without additional data (*e.g.*, exploration drilling).

4.1.2 Gravity Survey

The gravity survey uses the earth's gravitational field and the mass of the earth to measure changes in the gravity field that occur due to variations in subsurface materials. Gravity data can be used to help evaluate subsurface structures in a survey area based on the relative densities of the underlying rocks. This method measures the gravity signal of earth material directly beneath a survey location, with gross characterization of rock properties possible, including: 1) depth to bedrock based on density differences between unconsolidated sediments and surrounding bedrock in a sediment-filled valley; and 2) the interpretation of gravity signatures of surface-mapped units, which can be used to then distinguish subsurface behavior of lithology, provided there is sufficient density variation between varied rock-types.

In geothermal systems, low-gravity signature values may indicate rock that has experienced hydrothermal alteration (that is, rock altered by contact with thermal fluids) resulting in decreased density at depth. Conversely, high-gravity signature values indicate higher density rocks at depth (and may indicate limited hydrothermal alteration). The differences in gravity may be used as a preliminary marker to help delineate a potential geothermal reservoir. However, if is noteworthy to mention that lithology changes (independent of alteration) can produce similar gravity results. Additional subsurface data (for example, examination of rock cuttings from drilling activities) will be required to help update and refine the gravity interpretation.

4.1.3 Geophysical Survey Operations and Data Processing

Field Data Collection

The data quality of the MT resistivity survey allows reliable estimates to be made of the relevant parameters (the "impedance tensor" and "tipper values", as defined below) over a wide frequency range, with specifics of frequency range outlined in Appendix A. The "impedance tensor values" are a function of a model of three-dimensional conductivity, which allows for measurement of all components of the electric and magnetic field as related to each other. Inaccurate impedance tensor values can result from background resistivity that is not indicative of survey point conditions. The "tipper values" refer to the measurement of the vertical component of the magnetic field out of the horizontal plane. Reliable results for both of these variables are required for survey data accuracy.

The main factor that affects the reliability of resistivity sounding curves at low frequencies is the daily variation of source signals, which produce some noise effects between 1 and 10 seconds (s). To improve the data quality in the low-frequency range, some sites were surveyed twice. All locations where data were collected once (as shown on Table 1) are indicated by a lower case 'a' following the survey point number, and locations where data were collected twice are indicated by a lower case 'b' following the point number.

The use of a remote reference location allows for a robust processing procedure to obtain estimates of the impedance tensor and tipper values between 0.001 and 100 s, appropriate for the subsequent data-modeling phase.

For the dGPS/gravity survey, the geophysical subcontractor reports that: 1) precise dGPS results were recorded for each co-located MT and gravity station as presented in Table 1; and

2) smooth acquisition of gravity data was possible at each location, and there was no requirement for repeat acquisition due to poor data quality.

Data Processing

In order to check the consistency of the sounding data over the survey area and to obtain some information about the resistivity distribution at depth, apparent resistivity and phase maps at different periods were prepared by WesternGeco. Maps showing the results of this effort are presented in Appendix A. The outcome of this data processing is as follows:

- The lateral consistency between adjacent resistivity soundings over the whole spectrum is generally quite good;
- The response for both XY and YX components (these components refer to the electrical field at the earth's surface) is quite similar for periods up to 1 s; hence, a one-dimensional behavior of the resistivity distribution was determined to be a legitimate approximation at shallow depths;
- There is a good consistency between apparent resistivity and respective "anticipated" phase response;
- The range of apparent resistivity values recorded during the survey is quite good, and is on the order of near 1 to greater than 60 Ωm, which provides a high – low data range that allows for adequate differentiation of low-resistive anomalies; and
- The YX resistivity maps provide a qualitative indication of the occurrence of a shallow conductive anomaly in the NE portion of the survey area.

After completion of the sounding-data quality control described above, WesternGeco prepared a preliminary three-dimensional (3D) inversion model of the MT resistivity data. Based on these model results WesternGeco determined that, for each site, the full impedance tensor should be inverted (that is, processed to prepare for modeling) over a frequency band equally spaced on a logarithmic scale (5 values per decade) ranging from 0.01 Hertz (Hz) to 1000 Hz.

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The 3D resistivity distribution obtained from the inversion of MT data turned out to be quite consistent with the sounding test data.

For gravity survey results, WesternGeco reported that data were amenable to routine processing, and two independent Bouguer gravity reduction densities of 2.4 gm/cm^3 and 2.67 gm/cm^3 were utilized to calibrate the results.

4.2 MT Resistivity Survey Results

Following data processing, WesternGeco has prepared a series of MT resistivity cross-sections and depth slices for the lateral and vertical distribution of MT resistivity data across the study area (Figures 8 – 16). The cross-section lines are displayed on Figure 7. Details on these figures are as follows.

- Figure 8 presents three cross-sections: A – A' (running southwest – northeast through survey points WS011a – WS006a – WS050b – WS002a); B – B' (running southwest – northeast through WS023a – WS018a – WS014a – WS009a – WS004a – WS001a – WS054b); and C – C' (running north – south through WS065a – WS057a – WS047b – WS043a – WS040a – WS038a – WS062a).
- Figure 9 presents two cross-sections: D –D' (running east – west through WS075a – WS050b – WS002a – WS051a – WS001a – WS055a); and E – E' (running north – south through WS053b – WS001a – WS004a – WS009a – WS015a – WS020b – WS026a – WS032a – WS071a).
- Figure 10 presents two cross-sections: F – F' (running east – west through WS023a – WS024a – WS025a – WS026a – WS027a – WS028b – WS029b – WS030a); and G – G' (running north – south through WS002a – WS050b – WS006a – WS012a – WS023a – WS074a).

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- Figure 11 presents one cross-section: H – H' (running east – west; WS043a – WS044a – WS045b – WS046a – WS061a – WS011a – WS012a – WS013b – WS014a – WS015a – WS016a – WS017a).
- Figure 12 presents a study area scale MT resistivity map at 250 meters below ground surface (m bgs)
- Figure 13 presents an MT resistivity map at 500 m bgs
- Figure 14 presents an MT resistivity map at 750 m bgs
- Figure 15 presents an MT resistivity map at 1,000 m bgs
- Figure 16 presents an MT resistivity map at 1,500 m bgs

Additional depth-slice MT resistivity maps are presented in the WesternGeco modeling report (Appendix A) for the depths of 2,000, 2,500, and 3,000 m bgs. These images are not referred to during interpretations of the MT resistivity model and therefore were not included as figures within the report. In general, the WHS survey area shows MT resistivity data relationships that partly match the structural setting of the WHS area. This is most clearly demonstrated by the following features:

- The location of low-resistivity data is seen approximately at the mapped surface extent of a serpentine unit near the NE corner of the study area, which is interpreted to be a controlling mechanism for thermal water upwelling.
- However, the MT resistivity data pattern does not match the inferred geologic structure along the axial plunge of the Grizzly Creek syncline, which may be a result of factors such as:
    - the clay distribution in Great Valley Sequence sediments and/or
    - edge effects on the survey that would not appear had a larger area been surveyed.

Salient characteristics from the MT resistivity and geologic models include the following:

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1. No resistivity stations were located in the actual area of hot springs due to access restrictions. Therefore, the resistivity response of near-surface alteration by thermal fluid has not been sufficiently demonstrated. Outflows at WHS do provide a known area of thermal water outflow which can be compared to nearby resistivity results, with the expectation that any subsurface hydrothermal alteration may extend beyond the area of surface outflows. As noted above, mature geothermal systems often have a low-resistivity clay cap, which can be formed above an upflow and along outflow zones. If present, this feature is commonly detected by a resistivity survey. However, a low-resistivity signature may not be detected in cases of a system in which alteration clays have not formed. WHS may be an example of the latter, where byproducts of alteration in serpentine may form silica-carbonates with a high-resistivity signature.

   It is noted that a relatively large low-resistivity anomaly occurs in the NE part of the survey area, S – SW of WHS. The occurrence of this low-resistivity anomaly is characterized on depth slice models at 250 and 500 m bgs (Figures 12 and 13, respectively) by MT resistivity values of ~1.5 Ωm focused beneath survey points WS001a, WS055a, extending W to WS003a and somewhat S to WS009a. This resistivity anomaly is noted to reduce in size and have a higher-resistivity signature at 750 m bgs, and it does not extend further south than WS009a at any depth.

   This same low-resistivity anomaly is noted on cross-sections B – B’, D – D’, and E – E’ (respectively, Figures 8 and 9) that are modeled through the area. On these cross-sections, the low-resistivity anomaly is seen to occur at an elevation interval from +400 to -400 m in reference to mean sea level (msl). This low-resistivity anomaly correlates to the mapped surface extent of serpentine, which forms a notable ridge in the study area S of WHS (this is the formation designated “Jsp” on Figure 5).

2. The resistivity survey covered sufficient ground to demonstrate a clear relationship between the SW – NE trend of the resistivity anomalies and the SW – NE trend of mapped

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geologic units. In the case of a geologic setting with well-pronounced structural features and lithologic deformation such as the WHS area, thermal fluid upwelling likely occurs primarily within bedding surfaces and at lithologic contacts, and along fault and fracture planes.

a) The lateral distribution of the low-resistivity anomaly discussed above supports this concept, where the W – SW dipping flank of the Wilbur Springs anticline may provide the lithologic control on the movement of geothermal fluids. Low-resistivity zones measured south of WHS extend deeper and W – SW of the anomaly noted at 250 m bgs on Figure 12, as is seen at 500 m and 750 m bgs on Figures 13 and 14, respectively.

b) A second low-resistivity anomaly occurs in the NE part of the survey area in the vicinity of Blank's Spring. The occurrence of this second low-resistivity anomaly is characterized on the 250 m bgs depth slice in Figure 12 beneath point WS003a by resistivity values of ~1.5 Ωm, and is distinct from the larger anomaly to the E – NE. Interestingly, the low-resistivity anomaly beneath point WS003 is modeled as 'merging' with the larger low-resistivity anomaly to the E on the 500 m bgs depth slice. This large zone of low-resistivity extends from WS009a NE toward the edge of the survey area and is displayed on cross-section B - B' in Figure 8.

c) Considering the approximate W – SW dip on beds in the vicinity of the low-resistivity zone seen beneath point WS003a at 250 m bgs, it is likely this zone is connected to the low-resistivity zone displayed on the 500 m bgs depth slice beneath points WS050b and WS052b, and to the low-resistivity zone noted beneath WS050b, WS052b, and WS006a on the 750 m bgs depth slice. It is noted that the surface expression of serpentine on the local geologic map (Figure 5) corresponds with the location of this low-resistivity anomaly at 250 m bgs. It is likely this W – SW dipping serpentine bed is also the cause of the low-resistivity signatures noted on the 500 and 750 m bgs depth slices.

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d) A third resistivity low is seen at 750 and 1,000 m bgs centered around point WS025a. The location of this low-resistivity zone shows a strong correlation with the mapped extent of serpentine that forms a NW – SE trending ridge in the southern extent of the study area. There are no known thermal springs nearby to this low-resistivity zone, though the Abbott and Turkey Run Springs are W – NW of this location at the edge of the study area. It is possible that this low-resistivity zone represents a 'blind' geothermal system, but without drilling data on which to independently verify and compare with these low-resistivity values, the cause of this low-resistivity zone is not yet clear.

3. Medium- to high-resistivity readings of subsurface materials (greater than ~5 Ωm) are indicative of areas with consolidated rocks (which have reduced porosity and therefore low water content) and without hydrothermal alteration (with decreased clay content and more unaltered rocks with a high-resistivity signature). Common low-end values of resistivity are 20 Ωm for unaltered shales and 100 Ωm for granites.

   A trend of medium-resistivity values (~15 – 40 Ωm) is seen running from NW to SE through the field area on the 250 and 500 m bgs depth slices (respectively, Figures 12 and 13). Based on the local geologic map (Figure 5), there appears to be a correlation between the location of this high-resistivity trend with the mapped surface extent of GVS rocks and overburden. High-resistivity values do not rule out the presence of conductive heating, but these values may mean that minimal thermal fluid flow is occurring through these areas where high-resistivity values were measured. Therefore, even if the presence of a heat anomaly is established in this region of the study area, high-resistivity data indicate that measured rock properties may not have sufficient permeability for economic production of geothermal fluid along this NW to SE trend through the study area, where GVS rocks and overburden are mapped at the surface.

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4.3 Gravity Survey Results

Figures 17 – 19 present gravity maps of the study area, as provided by WesternGeco following data processing and modeling. Gravity data were calibrated with two independent Bouguer gravity reduction densities of 2.4 gm/cm^3 and 2.67 gm/cm^3. Both models are evaluated herein; however modeling efforts with the 2.67 gm/cm^3 reduction density are seen to have generated the best high – low range. Figure 19 depicts gravity data modeling results using the 2.67 gm/cm^3 reduction density placed over the local geologic map.

Salient characteristics from the gravity and geologic models include:

1) The pattern of the gravity anomalies showing a similar trend to that of the resistivity anomalies, where there is a clear relationship between the NE trend of the resistivity anomalies and the NE trend of mapped geologic units.
   a) A low-gravity anomaly in the NE corner of the study area appears to correlate with the location of the low-resistivity anomaly located in the same vicinity (Figure 18). This gravity signature also correlates with the mapped surface extent of the serpentine ridge-former in the same area (Figure 19).
   b) A second relatively low-gravity anomaly in the NE corner of the study area, which is focused under the gravity point WS003a. This low-gravity reading appears to correlate with low-resistivity readings at 250 m bgs in the same area, and with the mapped surface extent of the serpentine bed.
   c) The third low-gravity anomaly occurs in the southern portion of the study area and is focused around point WS025a. This low-gravity reading appears to correlate nicely with the low-resistivity reading at 500 – 1,000 m bgs in the same area, and with the mapped surface extent of the serpentine ridge-former.
2) High-gravity readings in areas known to have volcanic and structural activity can be associated with specific geologic units that are likely hydrothermally unaltered and can be

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high-gravity signature rocks such as emplaced intrusives (*e.g.*, stocks, dikes, and basaltic bodies).

a) GVS rocks and overburden (KJg on Figure 19) produce a relatively consistent, medium-gravity signature across the study area in a NW – SE trend that is approximately correlative with the high-resistivity trend seen on Figures 12 and 13 at 250 to 500 m bgs.

b) The axial plunge of the Grizzly Creek syncline produces the highest gravity readings measured anywhere in the study area (Figure 19). These high-gravity readings are likely associated with a thick section of GVS rocks and overburden above the syncline axis, and possibly due to influence by the nearby Cretaceous age sandstones and basalts. Results from this area of the survey provide a valuable quality check of the collected geophysical data, whereas the Grizzly Creek syncline provides a unique structural feature against which to compare geophysical results.

4.4 Summary

In areas with extensive geologic faulting, structural deformation, and variation in lithology such as with this project area, variations in resistivity should first be scrutinized in terms of changes in the structural and lithologic setting. If these changes can be eliminated as the cause of resistivity signature changes, then geothermal fluid movement and the possible resulting hydrothermal alteration may be the explanation for low-resistivity anomalies.

Low-resistivity and low-gravity data correlate within the NE portion of the study area with the nearby location of hot spring outflows at WHS, where resistivity data was collected just S – SW of the springs, in the down-dip direction of thermal outflows. However, subsurface hydrothermal alteration may not be the primary reason for low-resistivity and gravity values, where prominent resistivity and gravity lows closely correspond to the surface outcrops of serpentine rock.

Observations made about MT resistivity and gravity data for the study area have been used to update the conceptual model of the geothermal system presented in Section 5.

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5. UPDATED CONCEPTUAL MODEL OF THE GEOTHERMAL SYSTEM

The objectives of further developing the WHS geologic model are to provide the basis for estimating the power potential of the WHS geothermal system and to design the next stages of an exploration program.

Developing an acceptable geologic model of the project area for further exploration hinges on deducing the most probable thermal fluid flow path and, consequently, the distribution of subsurface temperature. The two likely possibilities to explain fluid movement in the present geothermal model are:

1. Fluid rises diagonally upward, from SE to NW, along the line of axial plunge of the Wilbur Springs anticline, within fractured Franciscan sandstone, and beneath an impermeable serpentine cap rock.
2. Fluid migrates up-dip in permeable strata located on the W flank of the Wilbur Springs anticline.

Based on information available from geologic, geochemical, and historic drilling data, as previously outlined in GeothermEx (2012b), the second scenario appears the most plausible. Additionally, MT resistivity and gravity data appear to further support this scenario, as follows:

1. MT resistivity data show a zone of low-resistivity extending from 250 m bgs in the vicinity of survey point WS003a to greater depths in the SW (down-dip) direction [see 500 and 750 m bgs depth slices (Figures 12 – 14, respectively)]. This low-resistivity zone is inferred to be associated with units Km and Jsp, which have been previously mapped as dipping approximately SW, perpendicular to strike of the axis of the Wilbur Springs anticline.
2. Low-gravity anomalies are noted to correlate to areas of low-resistivity, with anomalies noted to the S and SW of WHS and in the southern portion of the study area. The

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outcropping Jsp serpentine unit is inferred to be the source of these low-gravity signatures.

In GeothermEx (2012a), the geology and temperature distribution beneath WHS was shown in cross section A – A` (as Figure 11 therein), which extends to an elevation of approximately -3,000 feet (-915 m) msl, reflecting the depth to which the Cordero well had been drilled. The Bailey #1 well, however, reached an elevation of -7,670 feet (-2,338 m) msl, providing a one-point source of geologic and temperature information 4,000 feet (1,219 m) below the bottom of section A-A'. Further details on these wells, including well data that allowed for creation of Downhole Summary Plots and plotting of wellbore temperatures on the A – A' cross-section, are contained in GeothermEx (2012b).

Geophysical MT resistivity data collected for this investigation has been used to extend the A – A' cross-section first presented in GeothermEx (2012b), which depicts the current understanding of subsurface conditions along a line which now extends from SW at the surface location of the geophysical survey point WS011a to NE through Blank's Spring, the Bailey #1, Cordero, and Magma explorations wells, and Elbow Spring. This cross-section has been designed to display the site-specific features most representative of subsurface conditions in the NE section of the Trebilcot land for the selection of an exploration drilling target. Currently, this is the only region of the study area with available subsurface data from drilling.

From this cross-section (Figure 20) and from the current geologic model, the following observations are made:

- Sandstones, siltstones and basalts of the GVS that were penetrated by the Bailey #1, Cordero, and Magma wells are offset by a fault to the NW of the well pads, with serpentine mapped at the surface and northeast of the fault. This fault provides the likely conduit for thermal surface outflows at Elbow Spring which, according to the present geothermal system model (that is, geothermal fluids moving NE up-dip toward the exposed nose of the Wilbur Springs anticline near WHS), is not a deep-seated fault,

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but one that provides the likely conduit from the serpentine body at depth, where thermal fluids are moving NE within the permeable serpentine horizon and up the flank of the anticline, and are then deflected by the shallow fault and ascend to the surface outflow at Elbow Spring. Based on the mapped surface expression of serpentine (specifically, along the A – A' cross-section), it is noted that the Blank's Spring outflows at a similar mapped fault contact between serpentine and GVS rocks to the SW of the Bailey #1 well in the vicinity and NE of geophysical survey point WS002a. The outflow of Blank's Spring at the mapped surface contact of serpentine and GVS rocks is a similar model to the shallow-fault-controlled system seen at Elbow Spring. Along the resistivity portion of the A – A' cross-section, the GVS rocks are those with a high-resistivity signature, and serpentine rocks are those having a low-resistivity signature.

- The SW trend of the low-resistivity anomaly on the A – A' cross-section shown on Figure 20 indicates that, if low-resistivity beneath WS052b and WS050b is associated with units Km and Jsp, then thermal fluids could be moving through SW dipping units in a path that runs approximately parallel to the A – A' cross-section shown in Figure 20. The aerial extent of this low-resistivity anomaly at various depths is seen on the 250, 500, and 750 m depth slices in Figures 12 – 14, respectively.

In GeothermEx (2012b), historical analytical data and the results of geothermometer calculations are presented for Blank's Spring. Results indicate consistent chemical temperatures of ~140 – 170°C, though Mg concentrations are higher than expected for an unmixed geothermal system. If chemical geothermometers show consistency, and if ion chemistries suggest geothermal input and flowing temperatures and flow rates are high, then cation geothermometer results can be representative of thermal water near-equilibrium in the reservoir. Conversely, a wide distribution of the temperature estimates suggests cooling effects, even if the magnitudes of cooling are uncertain. It is possible that the fault mapped at the contact between serpentines and the GVS rocks near Blank's Spring allows for cool, shallow water mixing with thermal water during ascent.

Surface-mapped outcrops of unit Jsp in the study area show close correlation with low-resistivity and low-gravity anomalies, as seen in the NW and S portions of the study area. This is consistent with serpentine rock's unaltered physical properties as compared to the higher density and resistivity of the surrounding sandstone and shale. The resistivity cross-sections show, in most cases, that the serpentine lenses dip to the SW, which is consistent with the mapped attitudes of the sandstone and shale beds that enclose the serpentine. These linear, SW-dipping permeable stratigraphic horizons disclosed by the geophysical surveys support the geologic model of the WHS area proposed earlier in GeothermEx (2012b) and discussed above.

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6. NEXT STEPS IN EXPLORATION AND DEVELOPMENT

The key to future geothermal exploration and development in the Wilbur Hot Springs area will be to drill to the proper depth to intercept possible fluid-bearing horizons. The selection of drilling targets at depth needs to be done with consideration of resistivity and gravity results alongside geologic, structural, and geochemical information.

To better refine the validity of the resistivity and gravity geophysics dataset at detecting zones of hydrothermal alteration, any drilling information collected from high-priority locations should be used to evaluate the correlation between measured temperature and permeability with resistivity and gravity readings.

This geologic model of up-dip flow in stratigraphic horizons from the SW, combined with the distribution of resistivity and gravity data, geochemical data, and inferred aquifer temperatures illustrated on cross-section A – A', outlines the strategy for continued exploration of the project area as described below.

The currently approved statement of work and schedule of products for the grant project includes the preparation of a temperature-gradient drilling work plan. However, based on GeothermEx's technical and regulatory understanding of the project area, it has been determined that temperature-gradient drilling would not be a suitable next-step exploration activity for the following reasons: 1) the CCCMP/URMP, which includes all of the Trebilcot land except the parcel of land in Section 29, does not allow exploration activities in the form of temperature-gradient wells, though a <u>production</u> slim-hole well <u>may</u> be allowed; and 2) the depth of the resource and the potential variability in the thermal conductivities of rocks above it would hamper the ability to extrapolate shallow temperature data to depth. Therefore, it is recommended that the program proceed to deeper exploratory wells in the form of slim-hole production wells.

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A proposed exploration drilling program will be designed to investigate areas within the Trebilcot mineral rights lease properties that appear to be most prospective and feasible for geothermal development. Analysis of the data collected to date, including the preliminary assessment of geophysical data presented herein, suggests that the following preliminary wells and drilling locations should be considered (see Figure 7):

1. A slim-hole production well S of geophysical survey locations WS050b and WS052b drilled to a depth of 1,700 m bgs, targeting the contact between projected W – SW dipping siltstone (containing methane) and serpentine beds that lay below an area of low-resistivity.
2. A slim-hole production well would optimally be located between survey locations WS001 and WS055, but due to terrain, the realistic location could be placed NE of survey location WS004a and drilled to a depth of 1,000 m bgs. This location would target the area beneath a low-resistivity anomaly at 500 m bgs that is within what are expected to be serpentine beds. This location is chosen to validate the applicability of the MT resistivity and gravity dataset for detecting geothermal fluid zones.
3. A third location is also suggested, but it would have a lower priority than locations 1 and 2, and would only be drilled following acquisition of temperature and permeability data at the two well locations described above in order to validate the applicability of the MT resistivity and gravity dataset for detecting geothermal fluid zones. This production slim-hole well would be located as close to survey location WS026a as possible, but due to terrain, the realistic location could be placed N – NW of survey location WS027a to a depth of 1,000 m bgs. This location would test an area of low-resistivity that is expected to be within serpentine beds.

Details of the proposed exploration drilling program will be provided in a Final Exploration Drilling Work Plan to be developed as part of the WHS assessment. The Final Exploration Drilling Work Plan for the SMUD-Renovitas Project document will contain access and staging

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details, well pad locations, and procedures for drilling the three production slim-hole wells outlined above. The Final Well Drilling Work Plan is scheduled for delivery January 25, 2013.

Finally, as an initial step before staging any exploration drilling, consideration could be given to flying an aeromagnetic survey over the study area. This geophysical method could confirm the attitude of beds dipping W – SW from the Wilbur Springs anticline, thus helping to better identify prospective drilling targets. This survey, as with all data acquired by aircraft with aeromagnetic equipment, could be conducted without regard to land holdings and ownership, thus facilitating the extension of data from the Trebilcot land to the private land areas that have been previously drilled but are presently not accessible.

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7. REFERENCES

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FIGURES

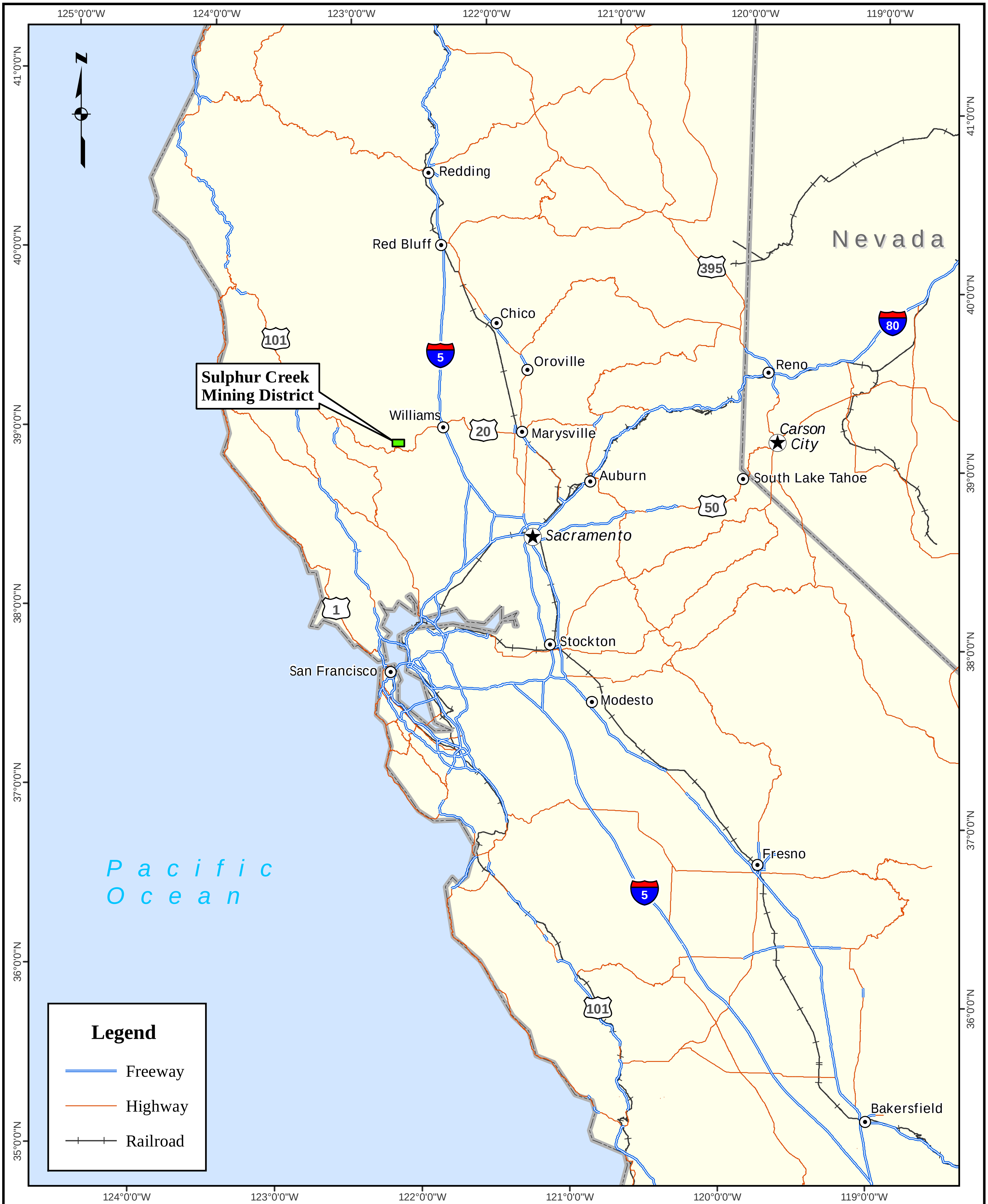

Figure 1: Location of Sulphur Creek Mining District, Colusa Co., California

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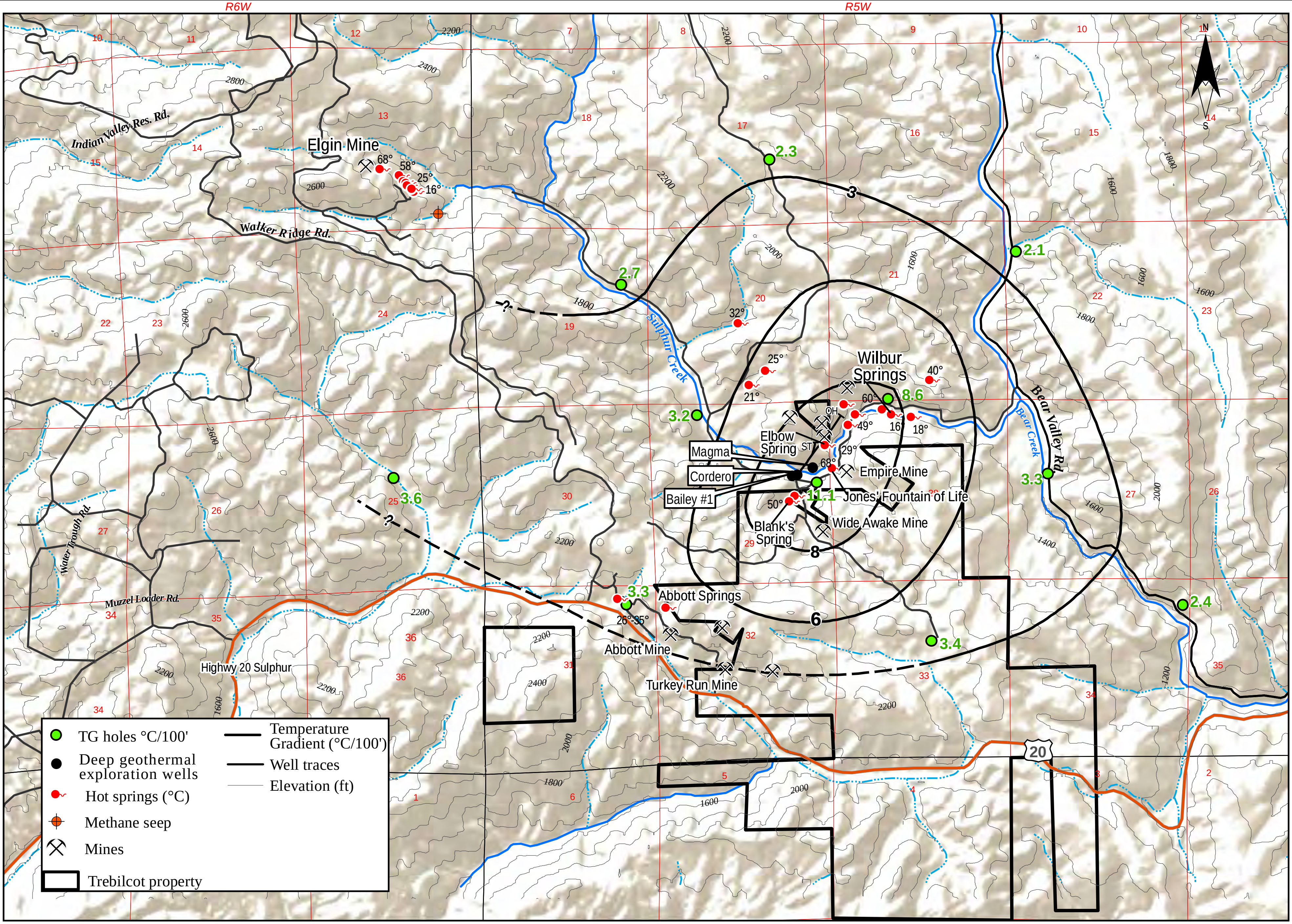

Projection:
NAD83 UTM Zone 10N
12/26/2012

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1:45,000

Figure 2a: Locations of hot springs, mines, temperature gradient anomoly, and deep exploration holes, Sulphur Creek Mining District

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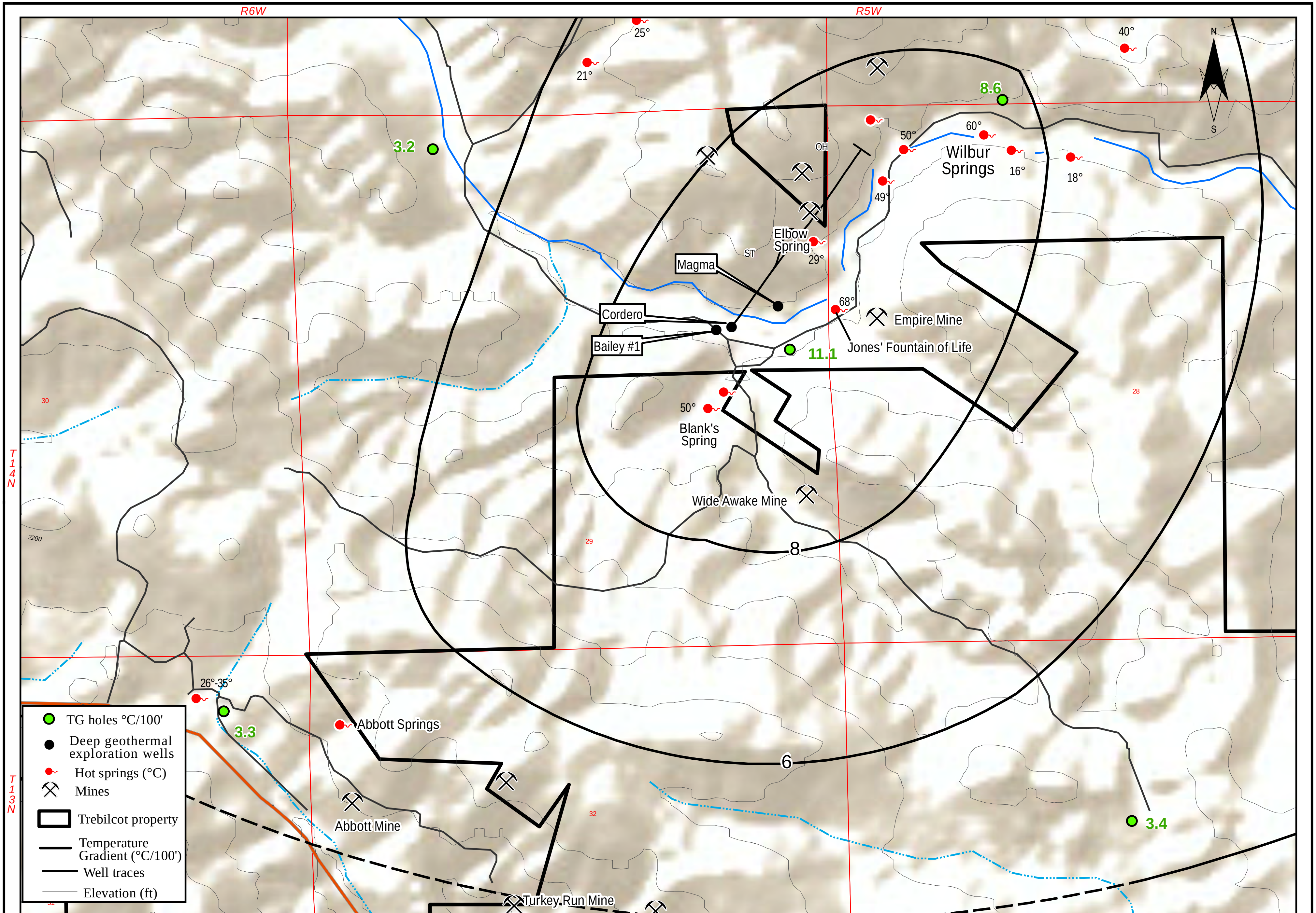

Projection:
NAD83 UTM Zone 10N
12/26/2012

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1:15,000

Figure 2b: Detailed map of hot springs, mines, temperature gradient anomaly, and deep exploration holes, in the Wilbur Hot Springs Area

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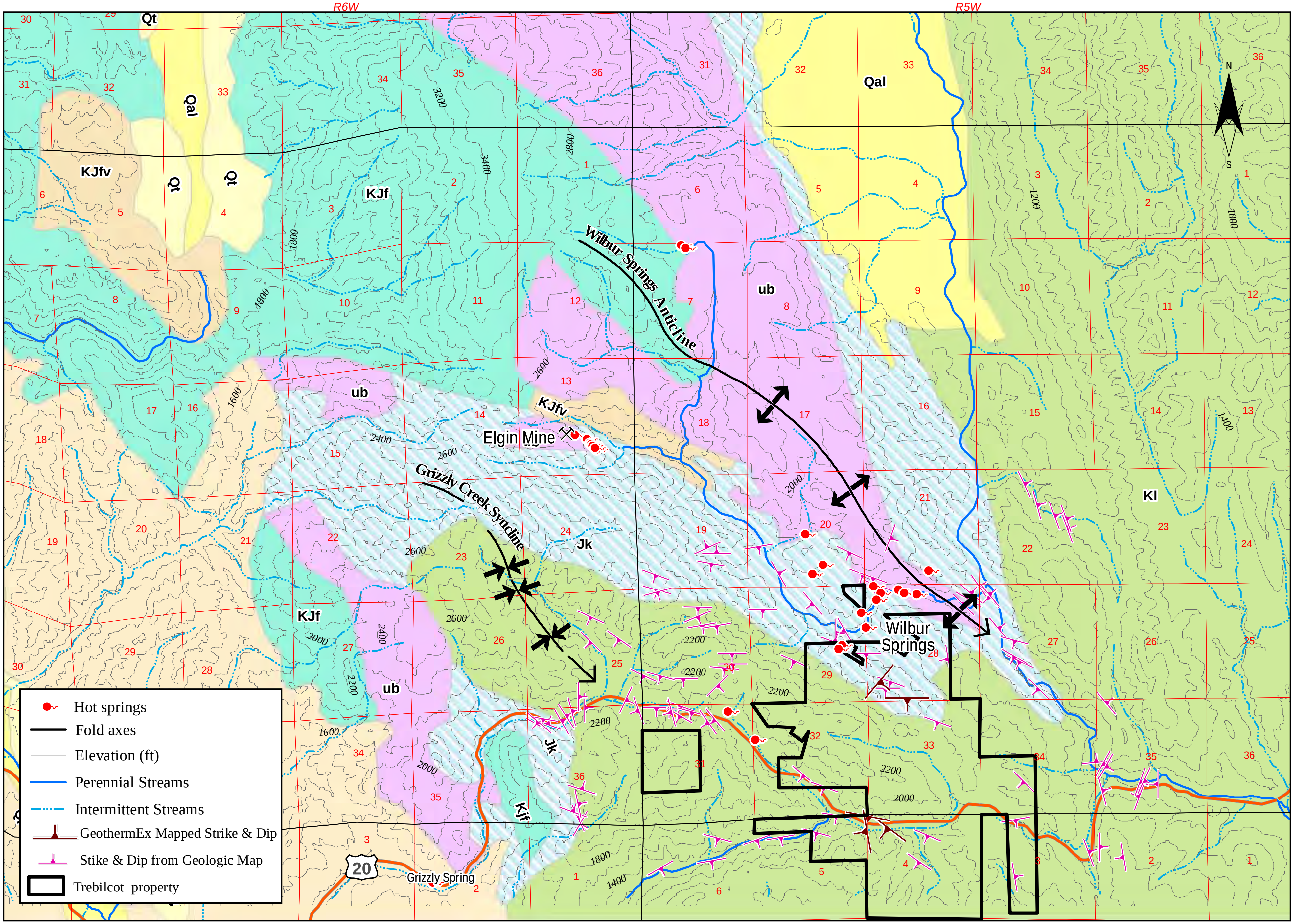

Projection:
NAD83 UTM Zone 10N

0 1 Miles
1:70,000

Figure 3: Regional geologic map of area surrounding the Sulphur Creek District

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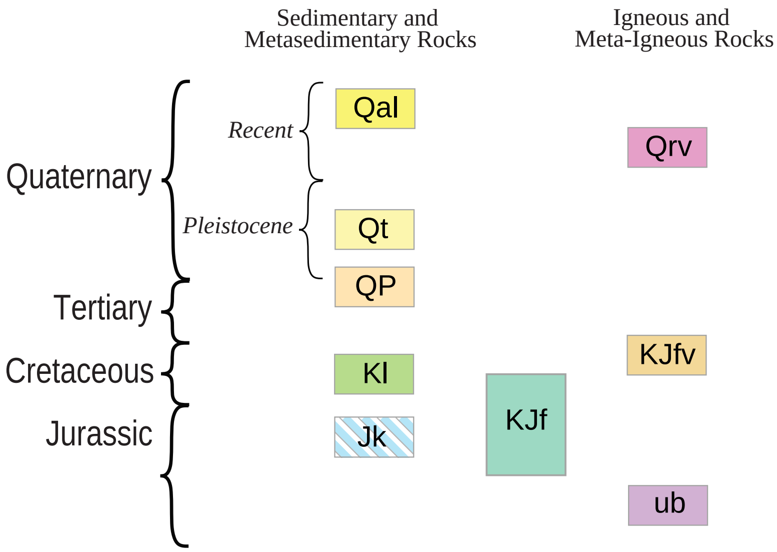
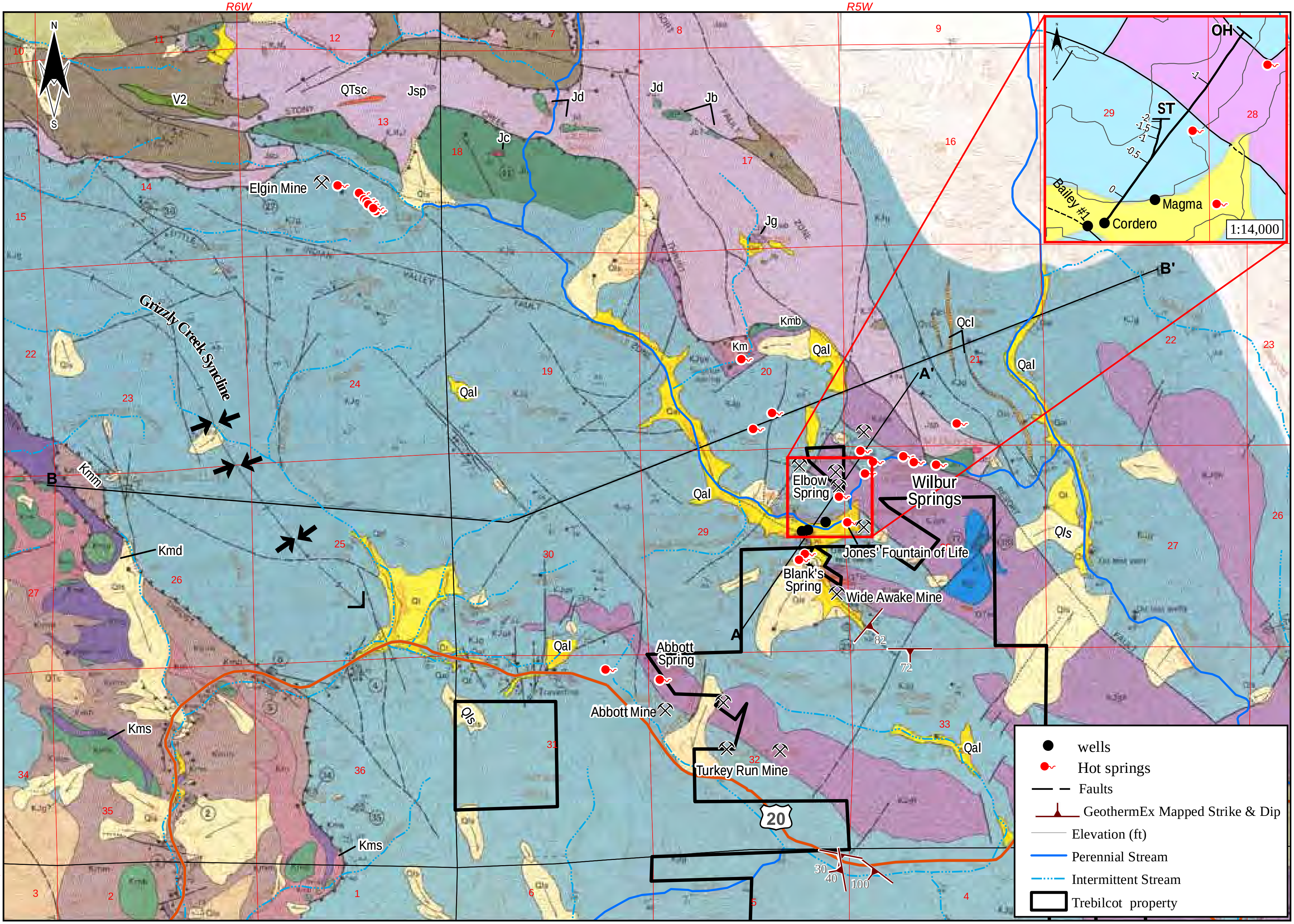
Geologic Legend



Qal	Alluvium
Qt	Quaternary nonmarine terrace deposits
QP	Plio-Pleistocene nonmarine
Qrv	Recent volcanic - rhyolite, andesite, basalt, and pyroclastic rocks
Kl	Lower Cretaceous marine
KJf	Franciscan formation
KJfv	Franciscan volcanic and metavolcanic rocks
Jk	Knoxville formation
ub	Mesozoic ultrabasic intrusive rocks

(Jennings and Rudolph, 1960)

Figure 4: Legend for Geologic map figure 3



Projection:
NAD83 UTM Zone 10N

0 0.5 Miles
1:40,000

Figure 5: Geologic map showing the locations of springs, exploration wells and cross-sections A-A' and B-B', Sulphur Creek Mining District

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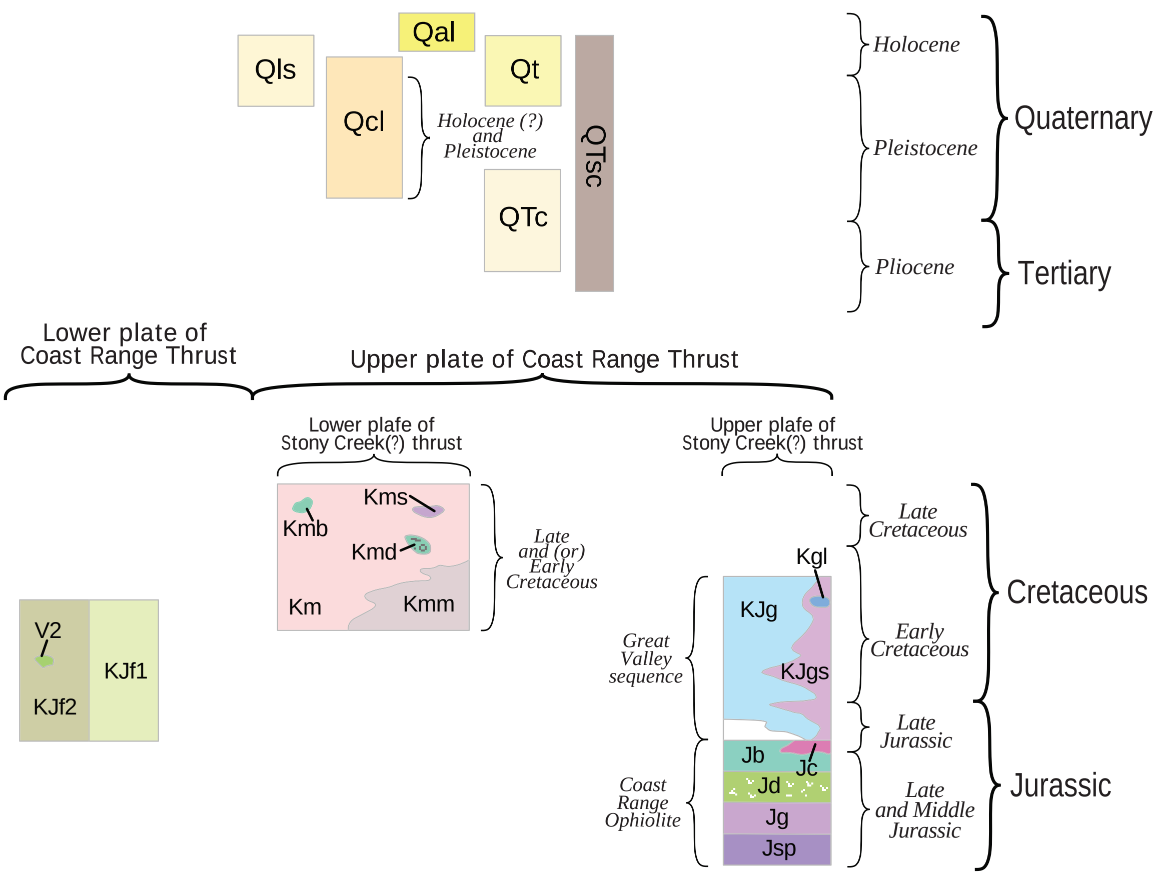
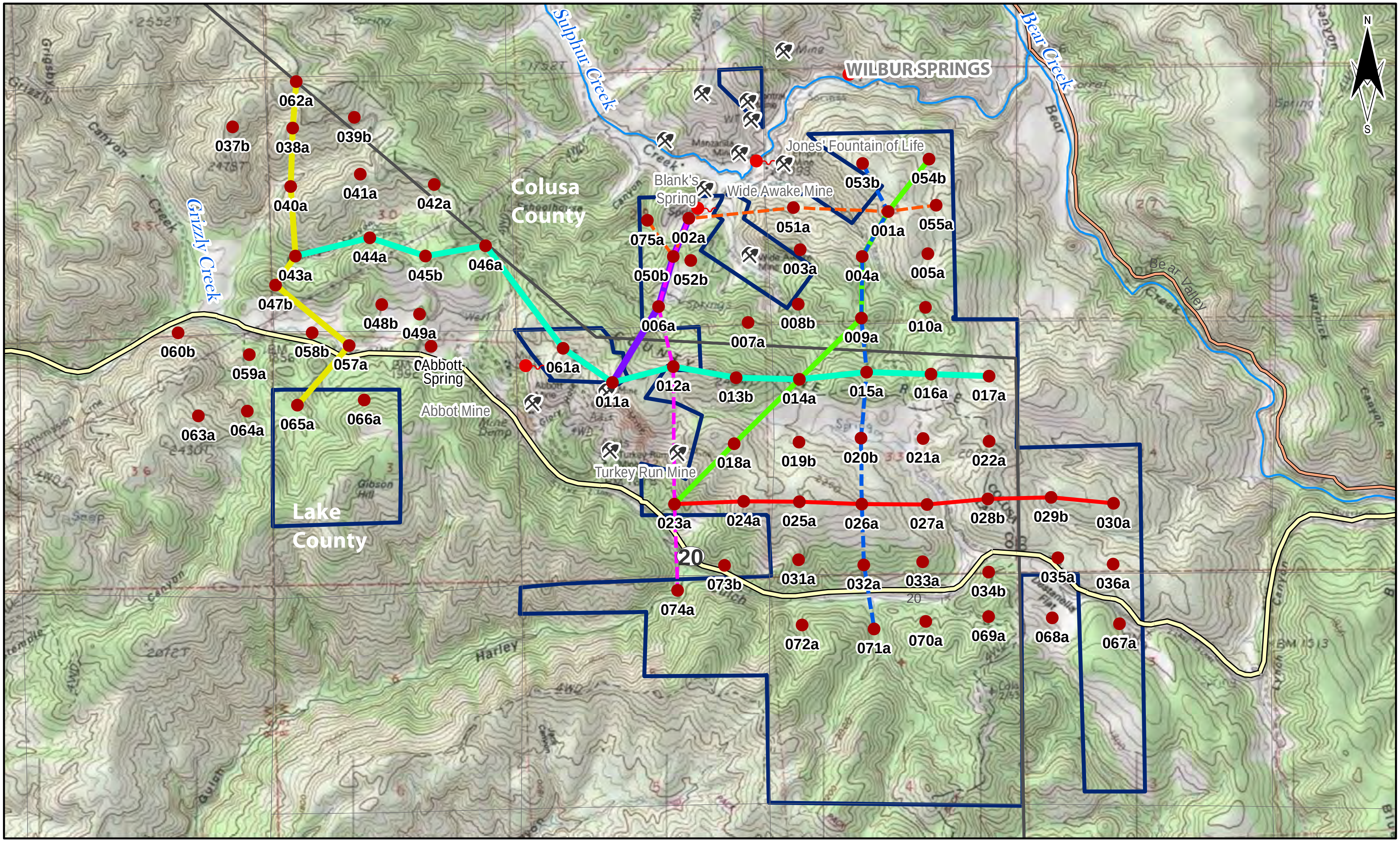
Geologic Legend



Qal	Alluvium - Unconsolidated to semiconsolidated rock and soil debris deposited by modern streams
Qls	Landslide deposits - Unconsolidated to semiconsolidated rock and soil debris, rock blocks moved downslope by creep, flow, or rotational slumping
Qt	Terrace deposits - Unconsolidated to semiconsolidated rock and soil debris deposited by streams; minor lacustrine siltstone and mudstone
Qcl	**Clear Lake Volcanics** - Olivine basalt, basaltic andesite, dacite intrusives and flow rocks
QTsc	Silica carbonate rocks - Hydrothermal alteration of serpentinite; occurs locally along faults
QTc	**Cache Formation** - Semiconsolidated to consolidated pebble to boulder conglomerate, silty sandstone and siltstone; poorly sorted and deposited in alluvial fans and streams
KJg	**Great Valley Sequence** - Black, olive-gray-weathered shale and mudstone, brown to gray fine to coarse-grained lithic sandstone; locally conglomeratic; mudstone and shale; carbonate concretions
Kgl	Limestone
KJgs	Detrital serpentinite
Jc	Coast Range ophiolite - Radiolarian chert; intercalated masses of manganiferous red radiolarian chert or green to black tuffaceous radiolarian chert
Jb	Basalt - Pillow flows, flow breccia and tuff
Jd	Diabase - Fine to coarse-grained equigranular to porphyritic; locally with secondary brown to green amphibole replacing pyroxene
Jg	Gabbro - Fine to coarse-grained, layered olivine and orthopyroxene-bearing gabbro ; locally cut by diabase dikes and by dikelets of hornblende-albite pegmatite or plagiogranite
Jsp	Serpentinite - Penetratively sheared dunite and peridotite, partly to completely altered to chrysotile ± lizardite ± clinochrysotile
Km	**Melange of Grizzly Creek** - Penetratively sheared, chaotic mixture of rocks incorporated from Coast Range ophiolite and lower Great Valley sequence
Kmb	Basalt
Kmm	Mudstone and sandstone - Mudstone locally contains carbonate concretions with mollusks of Late Jurassic age
Kmd	Diabase breccia
Kms	Serpentinized dunite and peridotite
KJF2	Metasandstone, metachert, and metavolcanic rocks, reconstituted to textural zone 2 of Blake and others (1967). Chiefly composed of sandstone and argillite, but locally includes minor:
V2	Volcanic rocks - Metamorphosed; includes basaltic tuff, flows, and intrusive rocks
KJF1	Argillitic rocks - Rocks reconstituted to textural zone 1 of Blake and others (1967); isoclinally folded, with prominent slaty cleavage; abundant mollusks of Late Jurassic through Early Cretaceous age

(McLaughlin et al., 1990)

Figure 6: Legend for Geologic map figure 5



Legend

Hot Spring
Mine
County Line
Highway 20
Bear Valley Road

Data from SMUD

Trebilcot Property (Mineral)

Geophysical Data from WesternGeco

Survey Stations
A-A'
B-B'
C-C'
D-D'
E-E'
F-F'
G-G'
H-H'

Miles
0 0.25 0.5 1

NAD 1983 UTM Zone 10N
1:35,000

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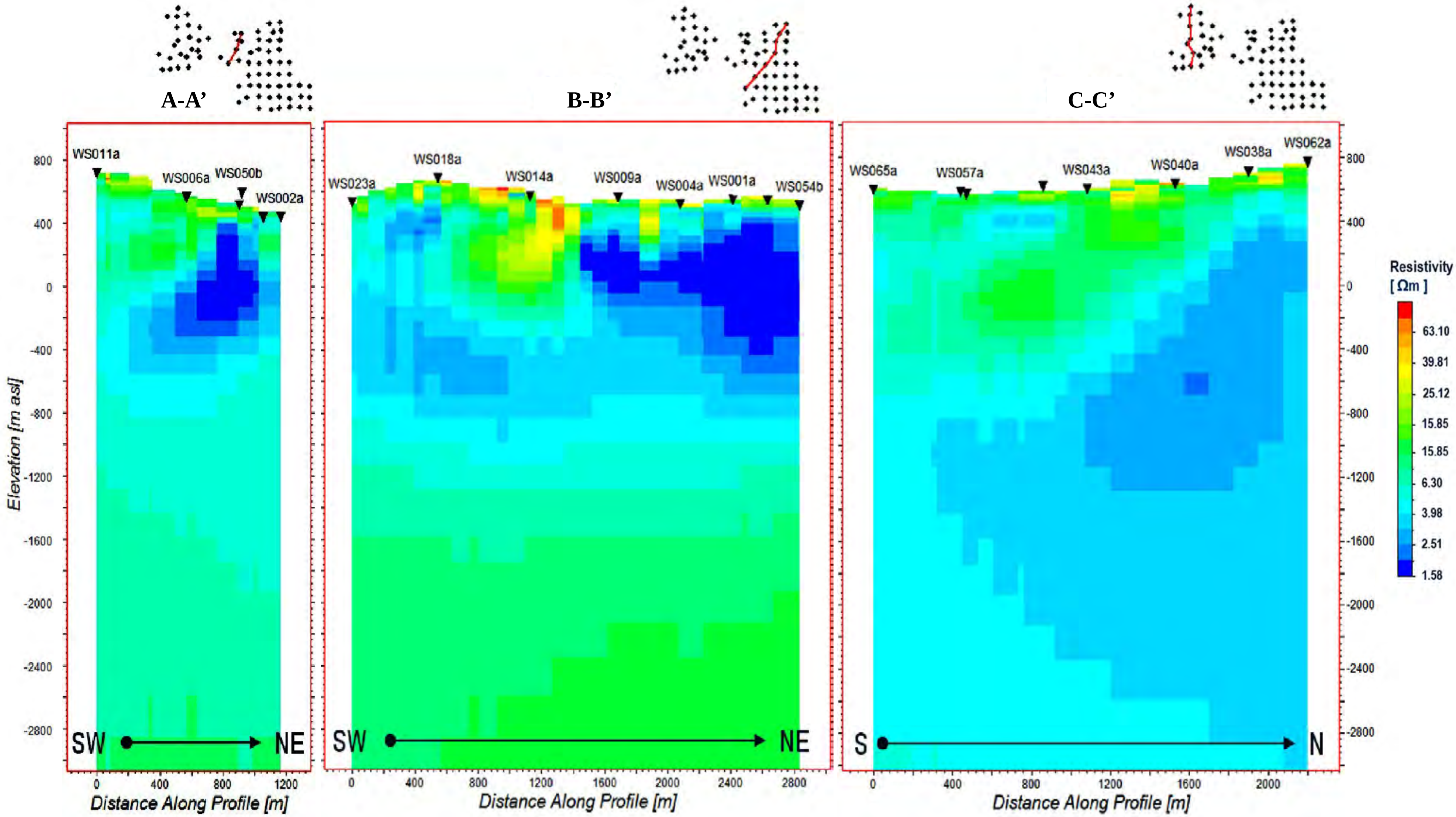
Figure 7: Map showing location of WesternGeco resistivity and gravity geophysical survey stations and resistivity cross-section lines, Wilbur Spring, CA

CLIENT:	SMUD / Renovitas	PROJECT:	Geophysical Evaluation
DATE:	12/26/2012	FIGURE:	Figure7.mxd



Source: WesternGeco
Preliminary Report
12/26/2012

Figure 8: Resistivity geophysics southwest – northeast cross-section A – A', southwest – northeast cross-section B – B', and north – south cross-section C – C'

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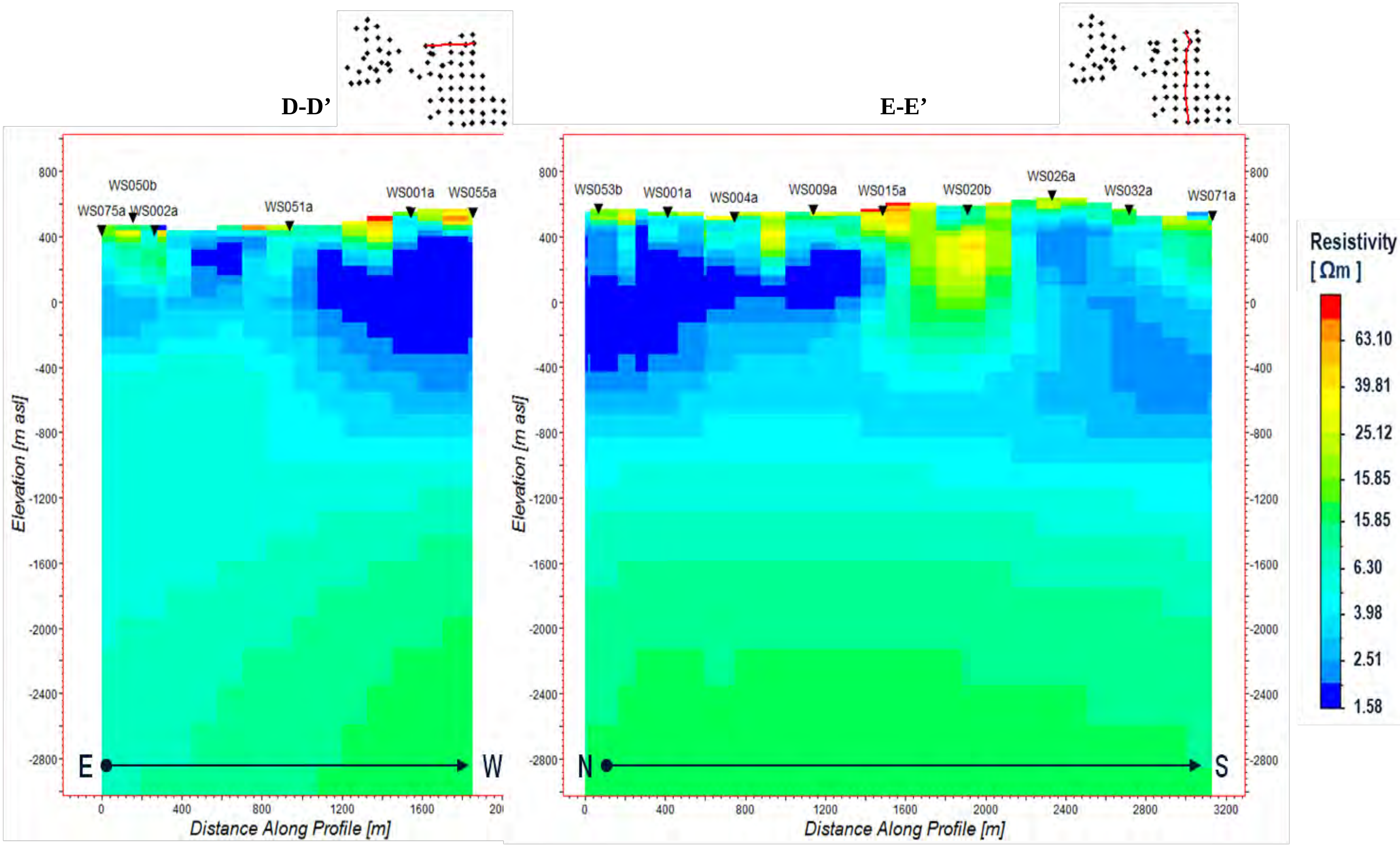

Source: WesternGeco
Preliminary Report
12/26/2012

Figure 9: Resistivity geophysics east – west cross-section D – D' and north – south cross-section E – E'

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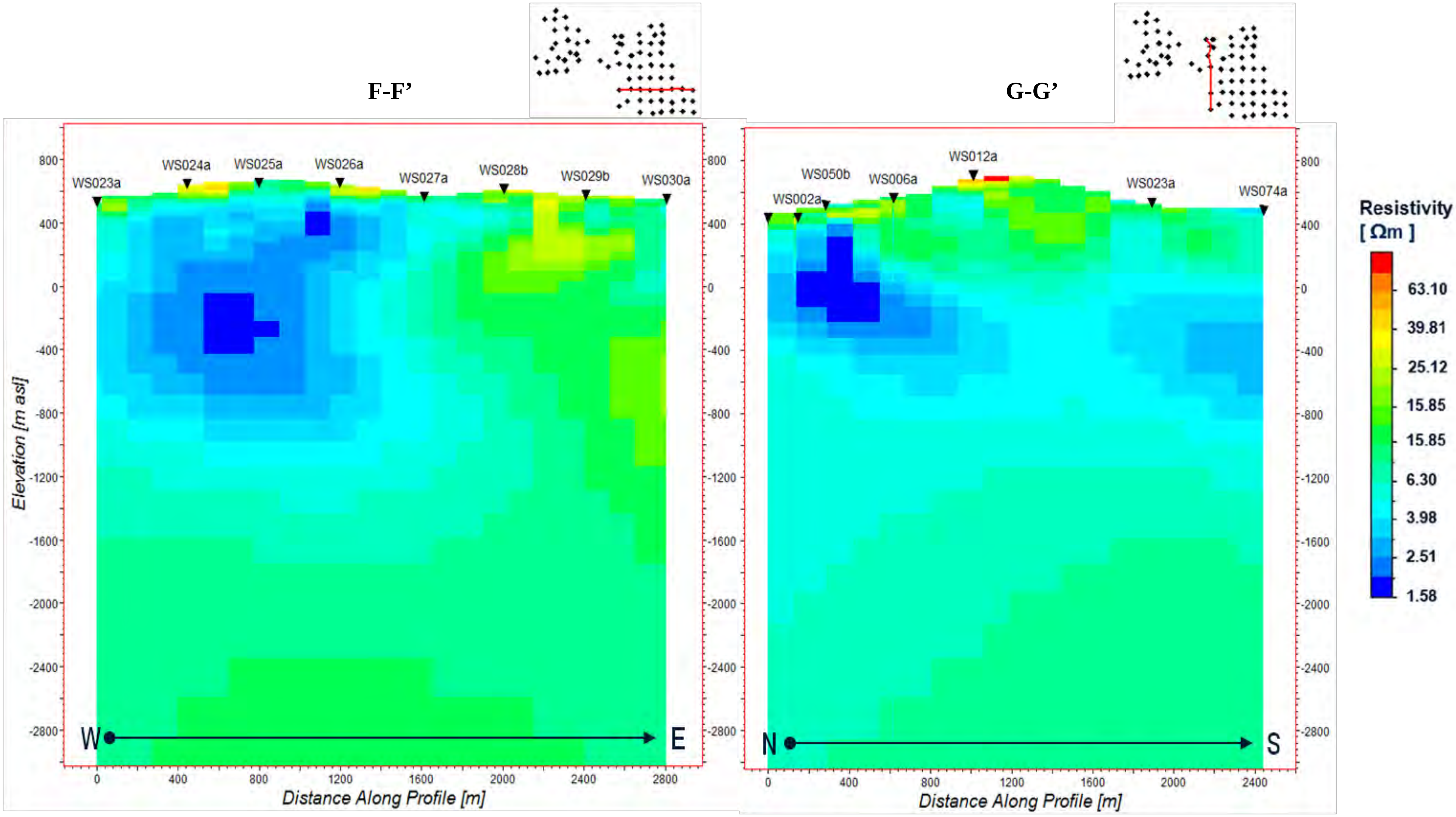

Source: WesternGeco
Preliminary Report
12/26/2012

Figure 10: Resistivity geophysics east – west cross-section F – F' and north – south cross-section G – G'

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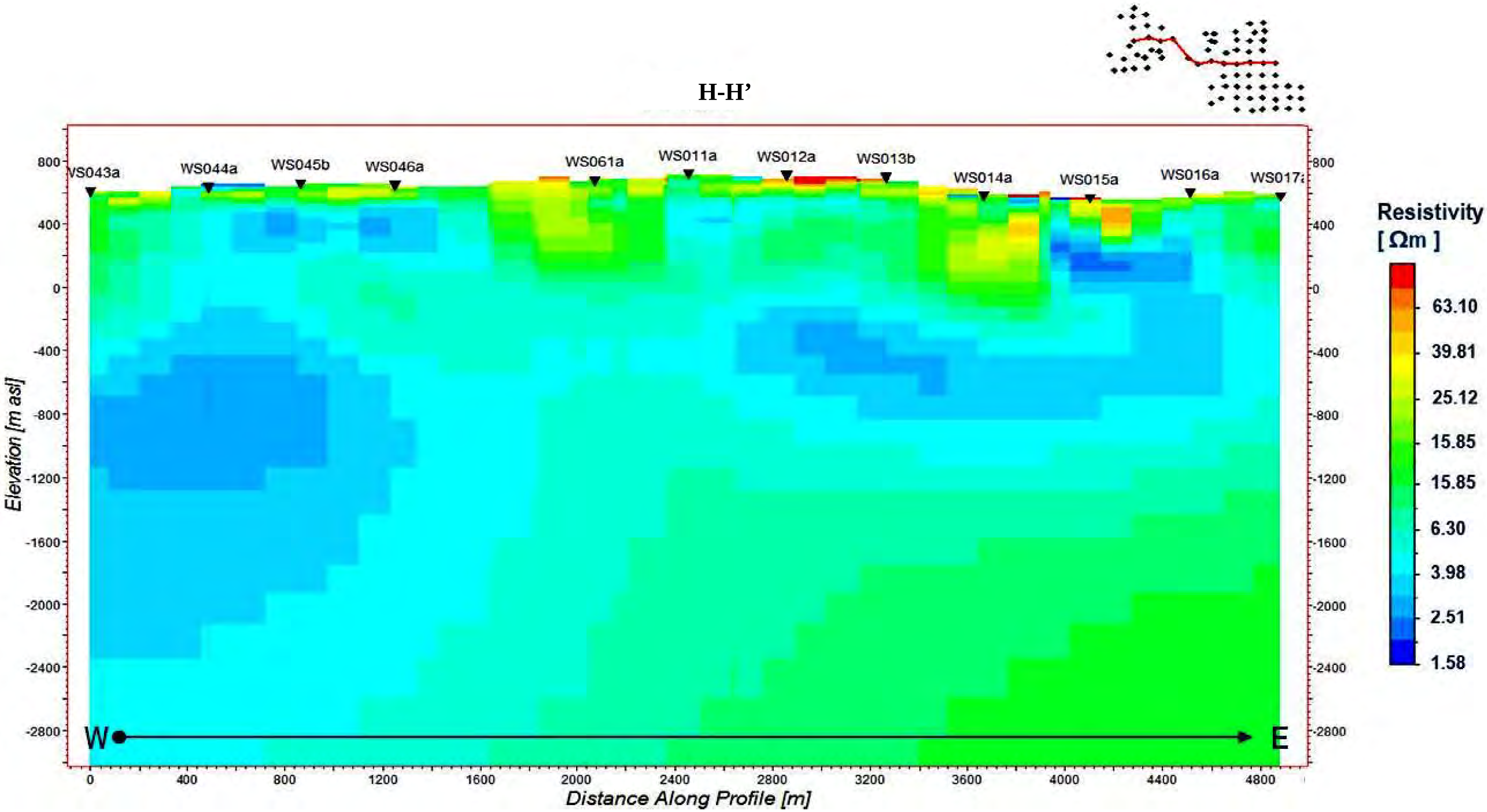

Source: WesternGeco
Preliminary Report
12/26/2012

Figure 11: Resistivity geophysics east – west cross-section – H – H’

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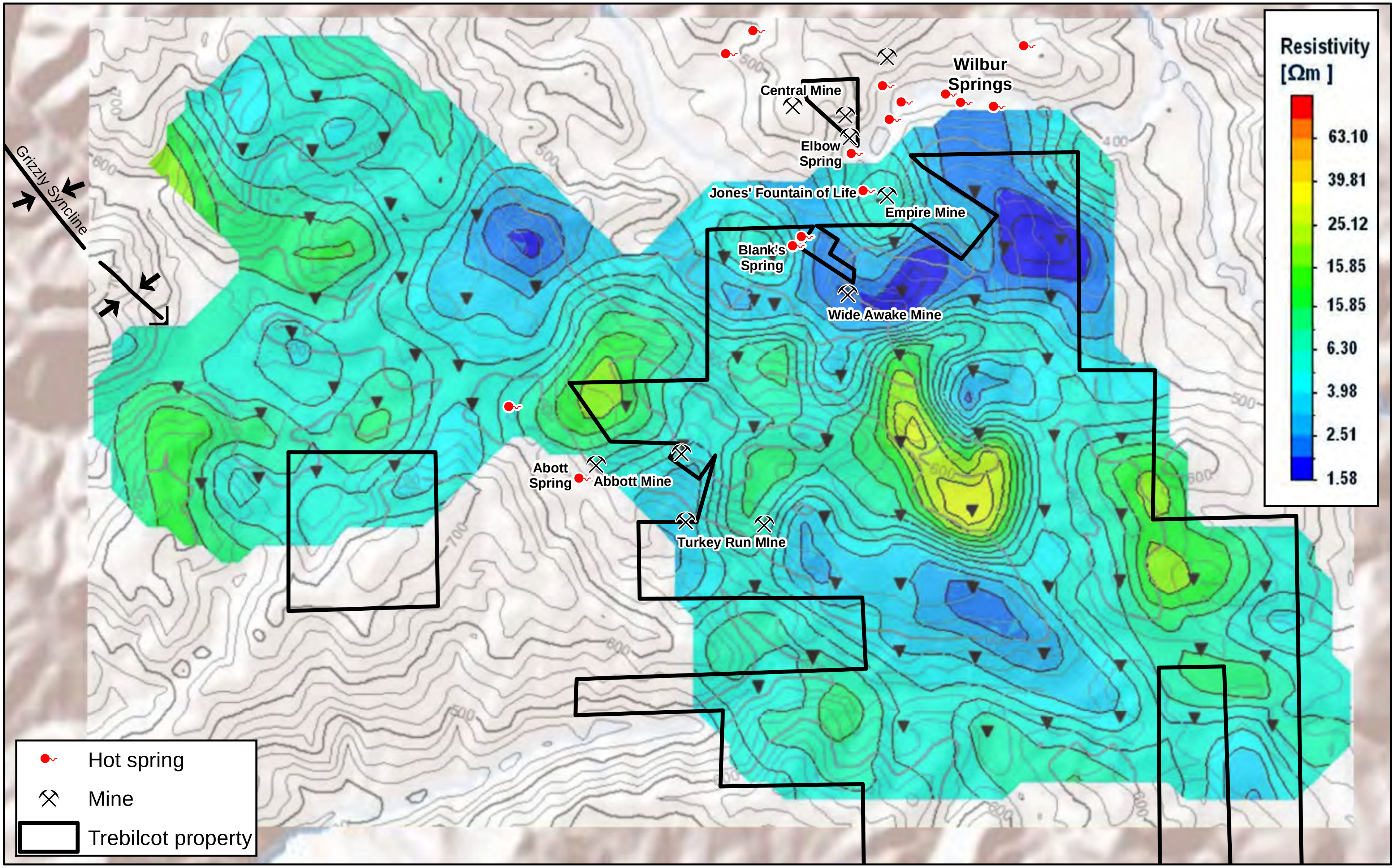

Source: WesternGeco
Preliminary Report
Projection:
NAD83 UTM Zone 10N

0 0.5 Miles
1:30,000

Figure 12: Study area resistivity map at 250 meters below ground surface (m bgs)

GeothermEx
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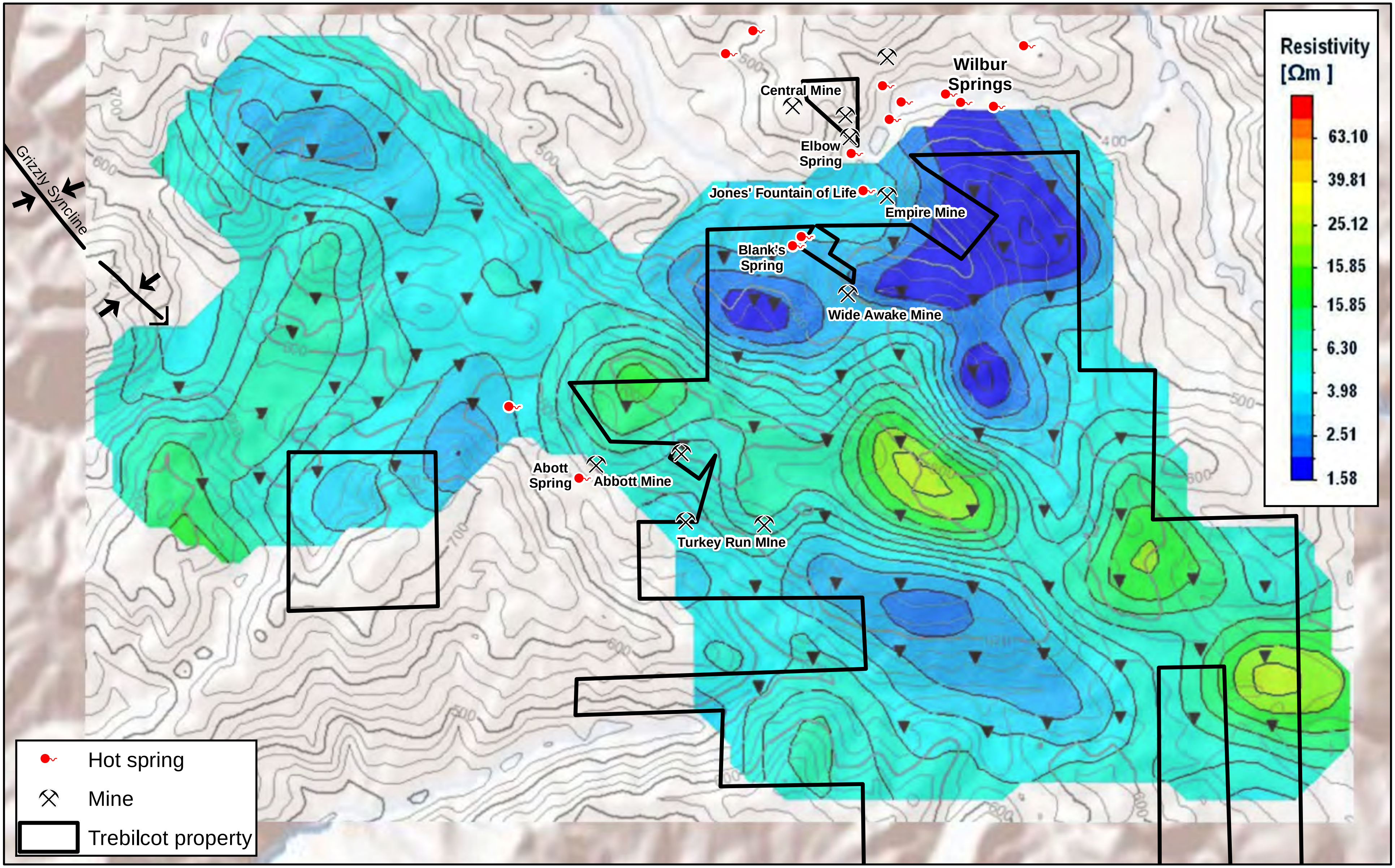

Source: WesternGeco
Preliminary Report
Projection:
NAD83 UTM Zone 10N

0 0.5 Miles
1:30,000

Figure 13: Study area resistivity map at 500 m bgs

GeothermEx
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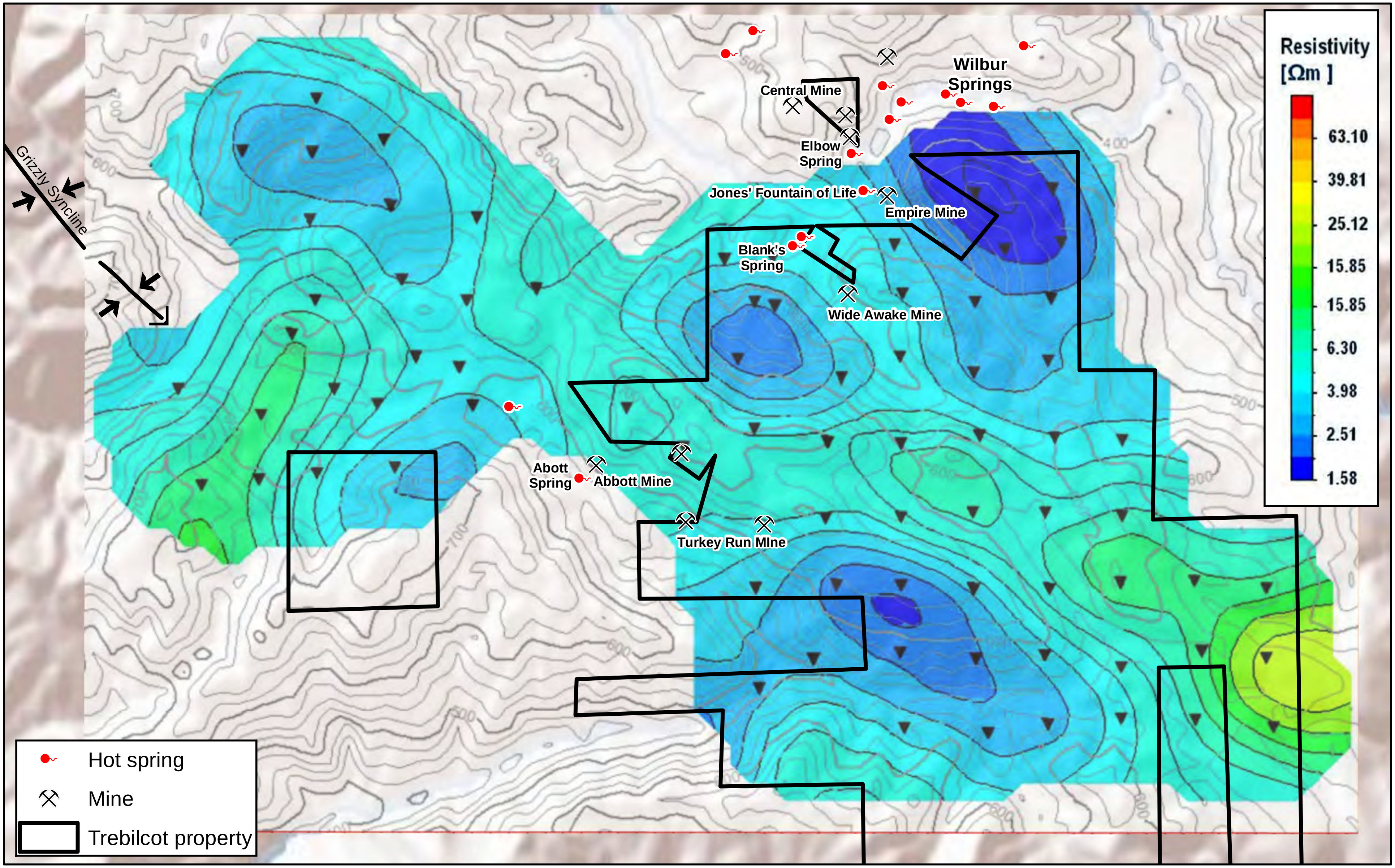

Source: WesternGeco
Preliminary Report
Projection:
NAD83 UTM Zone 10N

0 0.5 Miles
1:30,000

Figure 14: Study area resistivity map at 750 m bgs

GeothermEx
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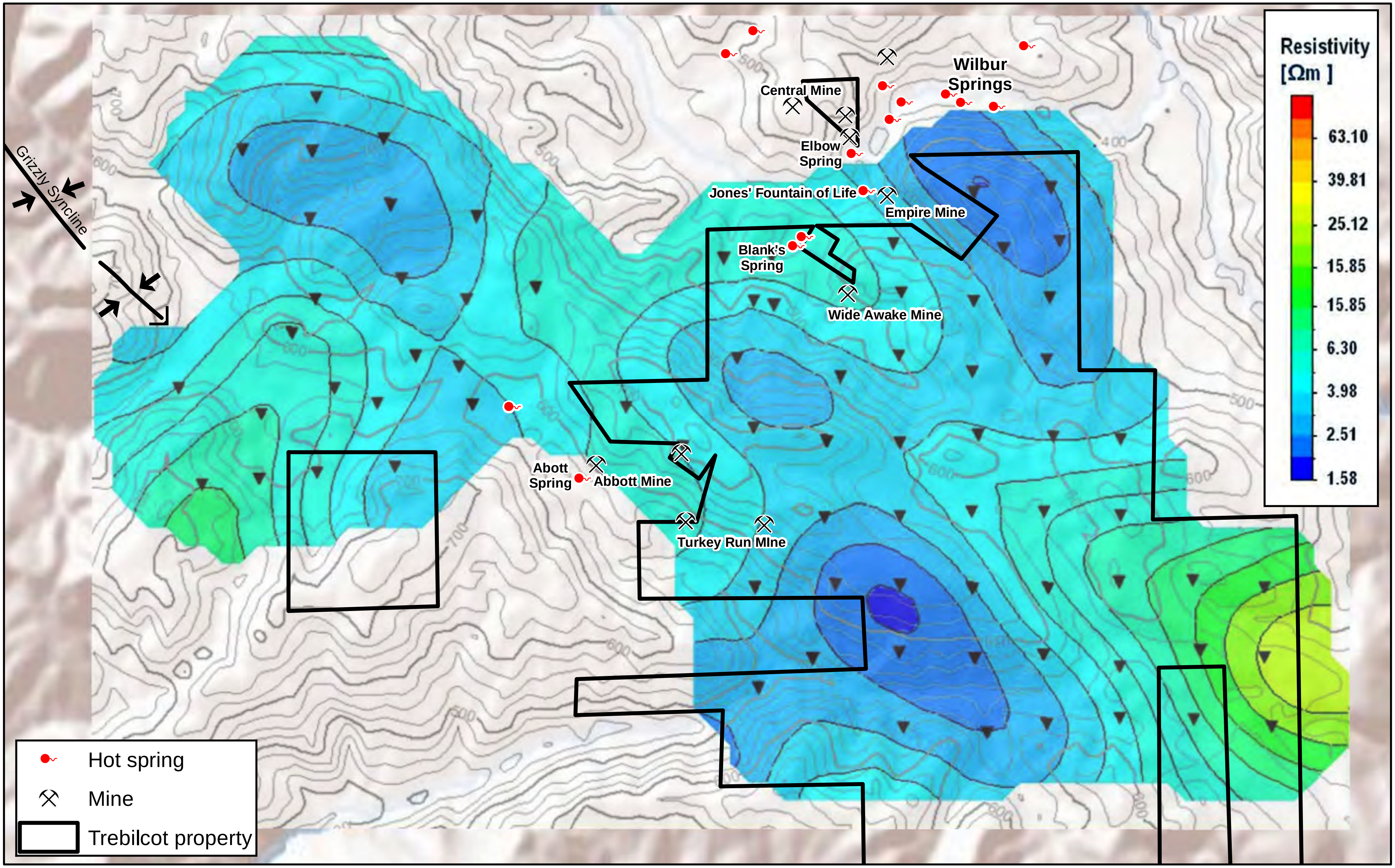

Source: WesternGeco
Preliminary Report
Projection:
NAD83 UTM Zone 10N

0 0.5 Miles
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Figure 15: Study area resistivity map at 1000 m bgs

GeothermEx
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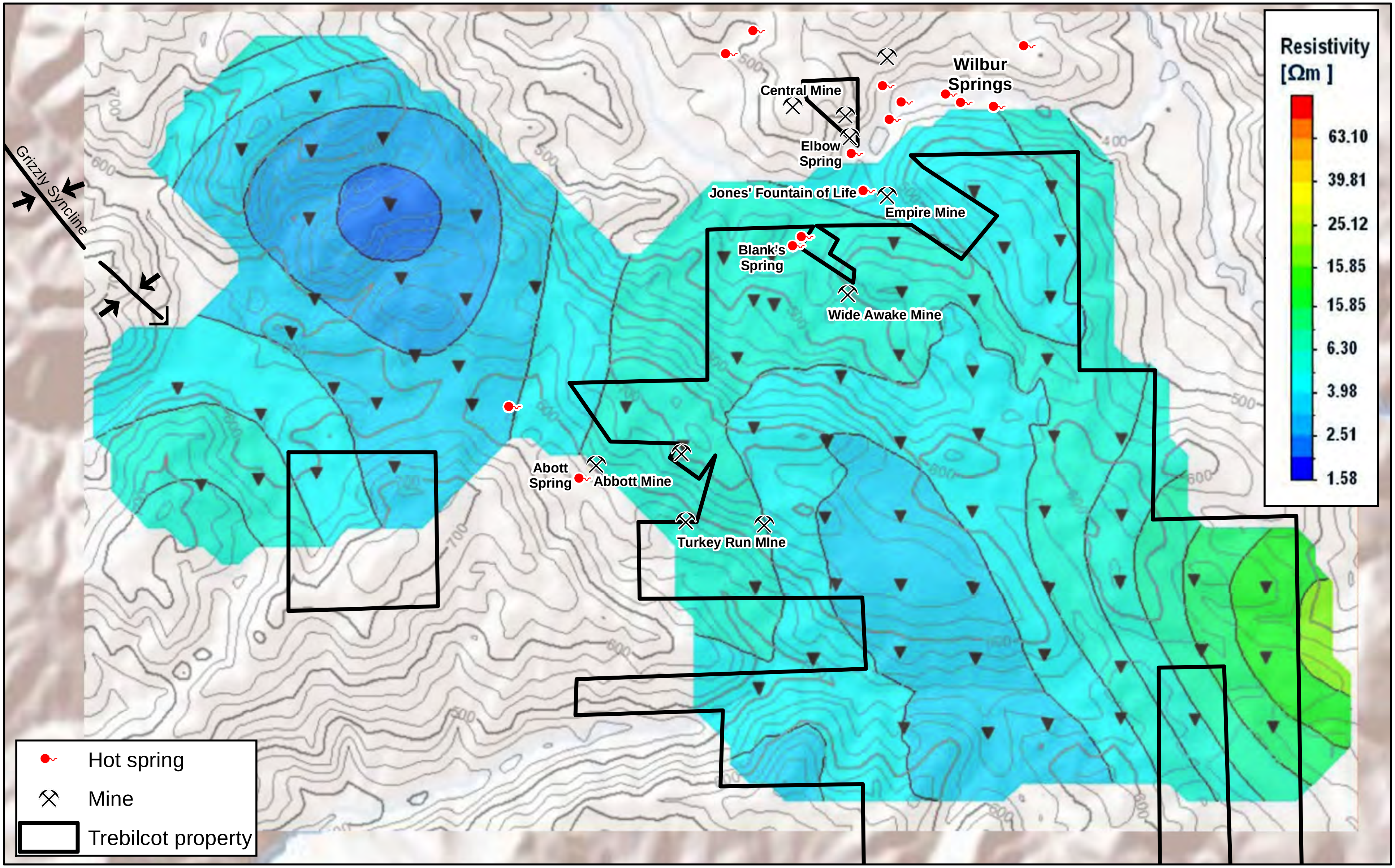

Source: WesternGeco
Preliminary Report
Projection:
NAD83 UTM Zone 10N

0 0.5 Miles
1:30,000

Figure 16: Study area resistivity map at 1500 m bgs

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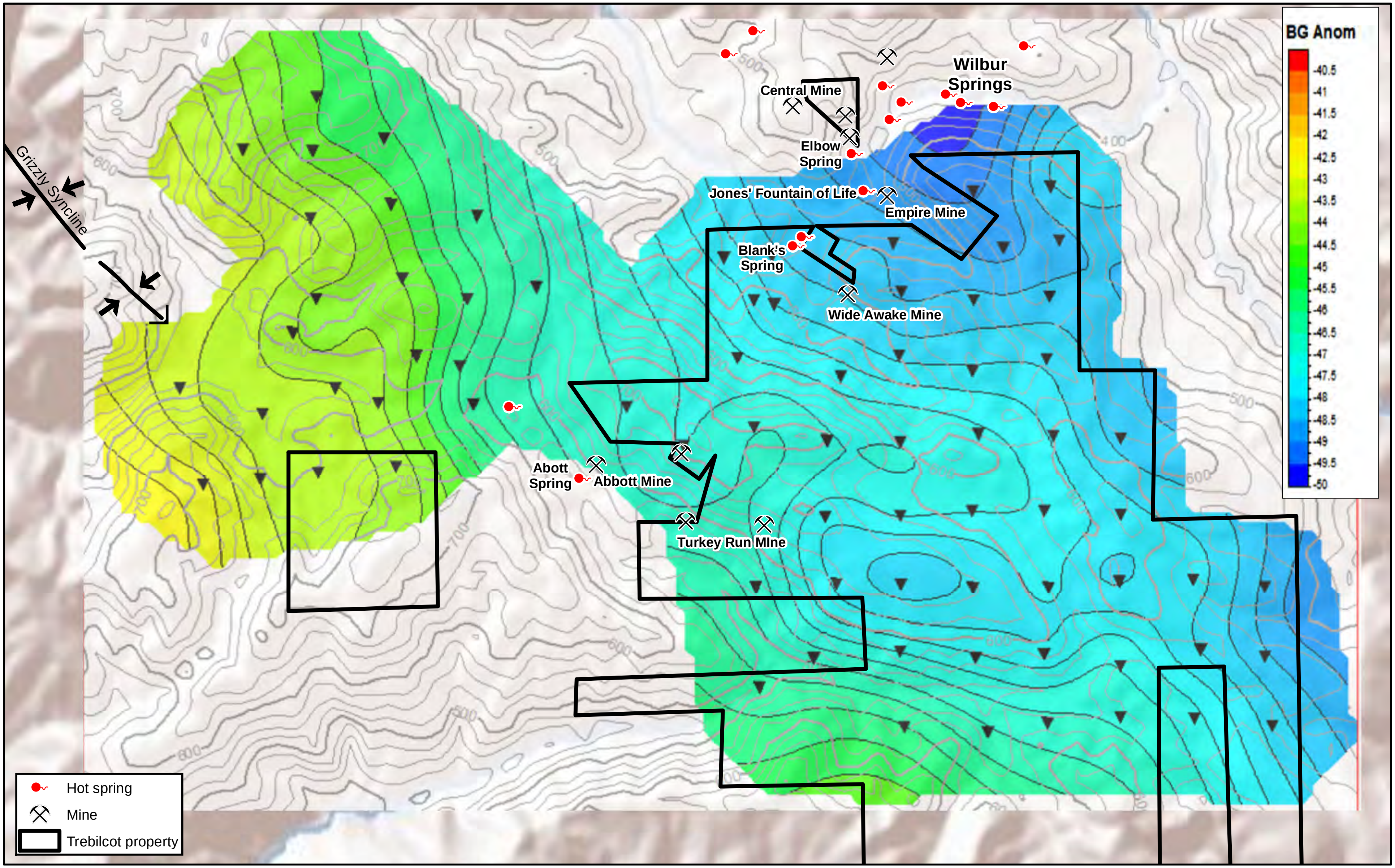

Source: WesternGeco
Preliminary Report
Projection:
NAD83 UTM Zone 10N

0 0.5 Miles
1:30,000

Figure 17: Bouguer gravity geophysics map, 2.4 gm/cm3

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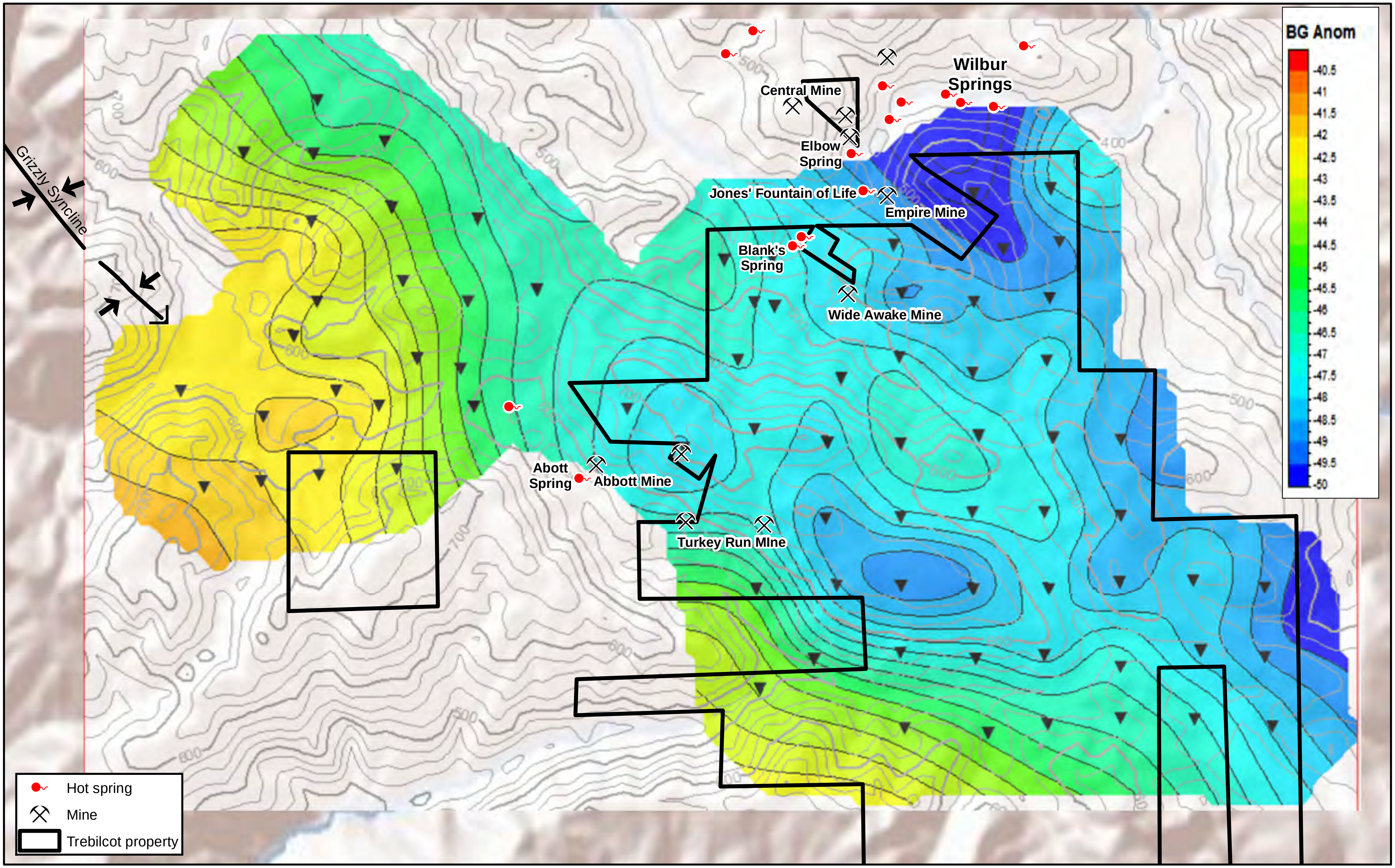

Source: WesternGeco
Preliminary Report
Projection:
NAD83 UTM Zone 10N

0 0.5 Miles
1:30,000

Figure 18: Bouguer gravity geophysics map, 2.67 gm/cm3

GeothermEx
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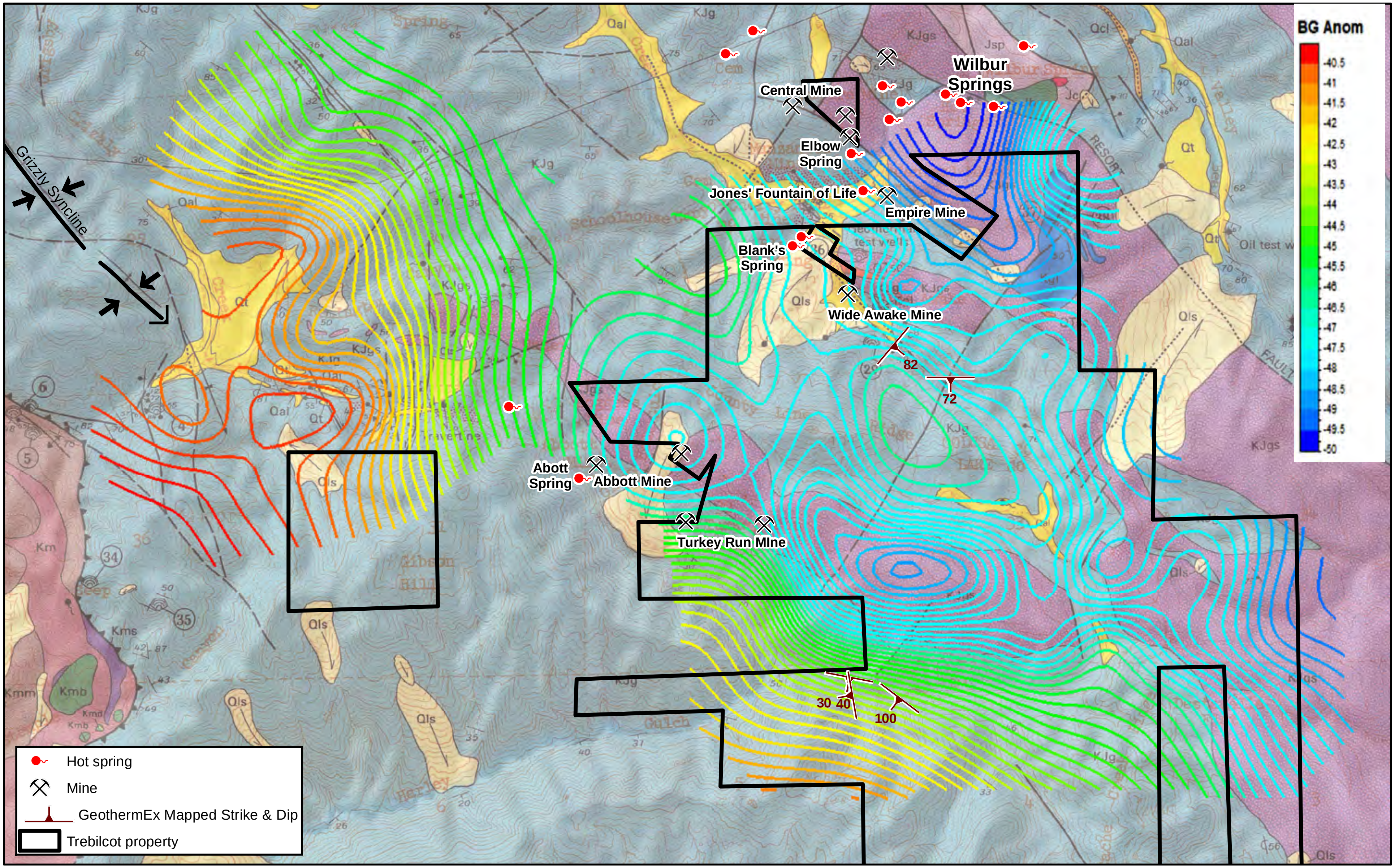

Source: WesternGeco Preliminary Report
Projection: NAD83 UTM Zone 10N

0 0.5 Miles
1:30,000

Figure 19: Bouguer gravity geophysics map, 2.67 gm/cm3 over local geologic map

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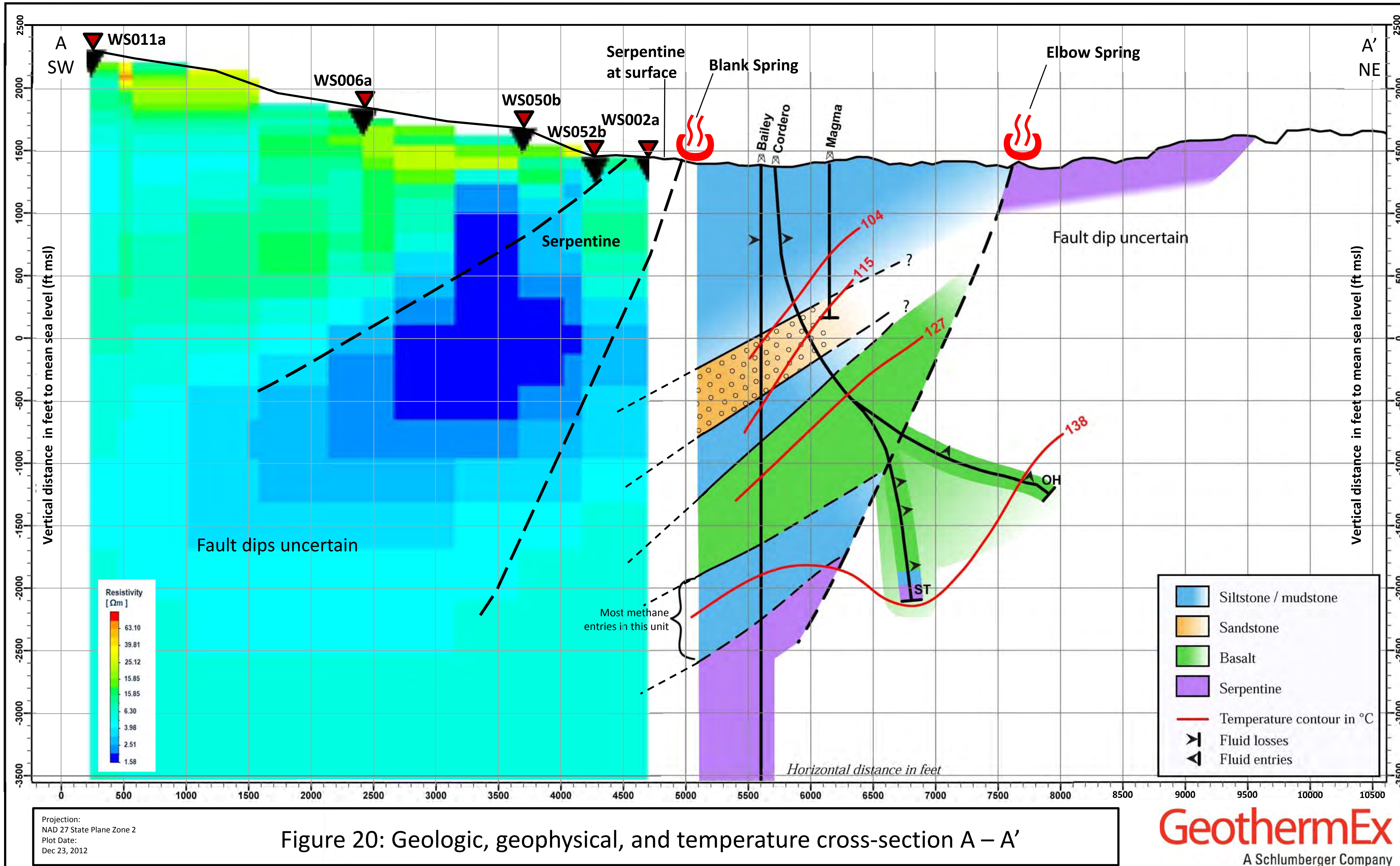

Figure 20: Geologic, geophysical, and temperature cross-section A – A'

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TABLES

Table 1. dGPS Acquired Coordinates of Co-Located Magnetotelluric and Gravity Survey Points

Site name	Long (deg)	Long (min)	Long (sec)	Lat (deg)	Lat (min)	Lat (sec)	Elev (m)
WS001a	-122	25	7.20	39	1	51.96	550
WS002a	-122	26	0.18	39	1	50.76	439
WS003a	-122	25	30.60	39	1	44.16	545
WS004a	-122	25	14.10	39	1	42.66	521
WS005a	-122	24	56.70	39	1	43.14	553
WS006a	-122	26	8.34	39	1	32.52	564
WS007a	-122	25	44.58	39	1	29.10	560
WS008b	-122	25	31.26	39	1	32.88	481
WS009a	-122	25	14.46	39	1	29.88	568
WS010a	-122	24	57.48	39	1	32.04	524
WS011a	-122	26	20.70	39	1	16.86	716
WS012a	-122	26	4.50	39	1	20.10	707
WS013b	-122	25	47.88	39	1	17.70	695
WS014a	-122	25	31.08	39	1	17.28	575
WS015a	-122	25	13.14	39	1	18.66	561
WS016a	-122	24	56.10	39	1	18.18	597
WS017a	-122	24	40.68	39	1	17.70	574
WS018a	-122	25	48.42	39	1	4.02	686
WS019b	-122	25	31.26	39	1	4.26	611
WS020b	-122	25	14.76	39	1	4.98	568
WS021a	-122	24	58.26	39	1	4.86	557
WS022a	-122	24	40.80	39	1	4.20	615
WS023a	-122	26	4.44	39	0	51.60	535
WS024a	-122	25	46.02	39	0	52.08	647
WS025a	-122	25	31.26	39	0	51.90	654
WS026a	-122	25	14.70	39	0	51.30	654
WS027a	-122	24	57.36	39	0	51.18	564
WS028b	-122	24	41.16	39	0	52.26	615
WS029b	-122	24	24.36	39	0	52.50	575
WS030a	-122	24	7.86	39	0	51.12	551
WS031a	-122	25	31.56	39	0	39.90	599
WS032a	-122	25	14.22	39	0	38.76	564
WS033a	-122	24	58.56	39	0	39.30	579
WS034b	-122	24	41.10	39	0	37.08	575
WS035a	-122	24	22.68	39	0	39.90	552
WS036a	-122	24	8.04	39	0	38.58	559
WS037b	-122	28	1.20	39	2	10.32	747
WS038a	-122	27	45.24	39	2	9.96	711
WS039b	-122	27	28.80	39	2	12.12	689
WS040a	-122	27	45.78	39	1	57.90	633
WS041a	-122	27	27.30	39	2	0.36	693
WS042a	-122	27	7.68	39	1	58.14	664
WS043a	-122	27	44.64	39	1	43.50	604
WS044a	-122	27	24.90	39	1	47.16	631

Table 1. dGPS Acquired Coordinates of Co-Located Magnetotelluric and Gravity Survey Points

Site name	Long (deg)	Long (min)	Long (sec)	Lat (deg)	Lat (min)	Lat (sec)	Elev (m)
WS045b	-122	27	10.08	39	1	43.32	655
WS046a	-122	26	54.18	39	1	45.36	644
WS047b	-122	27	50.04	39	1	37.50	619
WS048b	-122	27	21.78	39	1	33.30	627
WS049a	-122	27	11.82	39	1	31.32	602
WS050b	-122	26	4.32	39	1	42.90	518
WS051a	-122	25	32.34	39	1	52.86	466
WS052b	-122	25	59.70	39	1	42.06	590
WS053b	-122	25	13.92	39	2	1.98	573
WS054b	-122	24	56.28	39	2	2.76	513
WS055a	-122	24	54.42	39	1	53.22	549
WS056a	-122	27	8.82	39	1	24.60	592
WS057a	-122	27	30.60	39	1	24.90	583
WS058b	-122	27	40.38	39	1	27.54	570
WS059a	-122	27	57.12	39	1	23.10	574
WS060b	-122	28	15.96	39	1	27.72	583
WS061a	-122	26	33.72	39	1	24.00	673
WS062a	-122	27	44.16	39	2	19.62	770
WS063a	-122	28	10.74	39	1	10.44	686
WS064a	-122	27	57.72	39	1	11.40	593
WS065a	-122	27	44.40	39	1	12.54	596
WS066a	-122	27	26.64	39	1	13.56	675
WS067a	-122	24	6.42	39	0	26.16	537
WS068a	-122	24	24.30	39	0	27.54	544
WS069a	-122	24	41.16	39	0	27.84	566
WS070a	-122	24	57.90	39	0	26.94	568
WS071a	-122	25	11.58	39	0	25.44	530
WS072a	-122	25	30.66	39	0	26.34	558
WS073b	-122	25	51.24	39	0	38.82	502
WS074a	-122	26	3.72	39	0	33.66	486
WS075a	-122	26	11.16	39	1	50.40	438

Note: Stations with lower case 'a' were collected once. Stations with lower case 'b' were collected twice to improve data collection.

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APPENDIX A:

WesternGeco Magnetotelluric Survey, Wilbur Hot Springs, California, USA

MAGNETOTELLURIC SURVEY

Wilbour Hot Springs, California, USA

Preliminary Report

Volume 1 of 1

Prepared for

GeothermEx

By

WesternGeco
Integrated EM Center of Excellence
Milan, Italy

Effective date: December 2012

Revision History

Rev. No.	Effective Date	Description	Prepared by	Reviewed by	Approved by
01	21 December 2012	Draft version	Carlo Ungarelli		

CONTENTS

FIGURES

TABLES

1 INTRODUCTION

Project name:	27001_Wilbur_Hot_Spring
Survey areas:	Wilbour Hot Springs, California, USA
Survey Period:	22nd November- 13th December 2012
Survey Type:	Gravimetric and Full Tensor Magnetotelluric (MT) Survey
Client:	GeothermEx
Report Type:	Summary describing the acquisition, processing and preliminary modeling of MT data

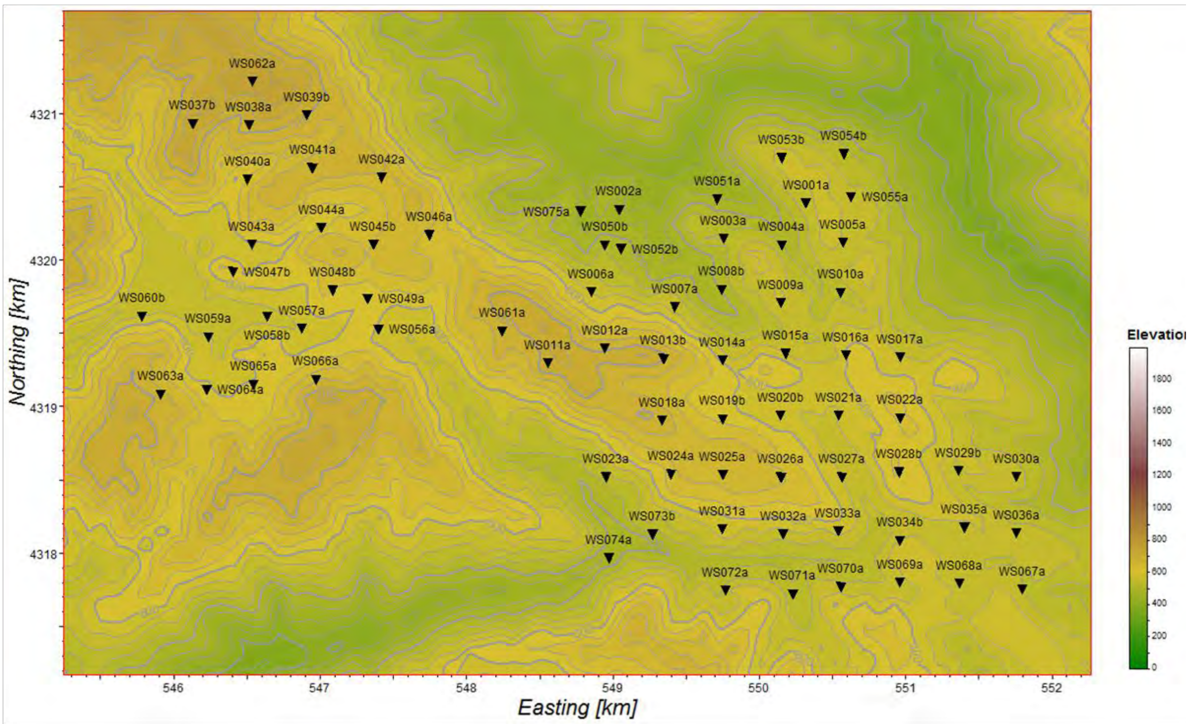

Figure 1. Survey area (measured sites locations are black triangles) superimposed on topography.

2 GENERAL SURVEY DETAILS

2.1 COORDINATES SYSTEM

Metric Coordinates:	Projection:	Transverse Mercator
	True Origin:	-123°00’ E, 0°00’ N
	Coordinates at Origin:	500’000.000m E, 0.000m N
	Datum:	North American 1983
	Spheroid:	Geodetic Reference System 1980
Geographic Coordinates:	Datum:	WGS84
	Spheroid:	WGS84
Elevation	Orthometric:	Extracted from 10m (SRTM) DEM, in meters relative to mean sea level

2.2 SURVEY GRID

Preplot stations:	75
MT station spacing:	500 m on an irregular grid
Remote reference location:	40 km north of the central area

3 SURVEY SPECIFICATIONS

3.1 MT ACQUISITION LAYOUT

Recording system:	5-channel, GPS synchronized, Phoenix MTU-5A.
Magnetic sensors (details in Appendix A):	H_x, H_y, H_z and Metronix magnetic sensors MFS-06.
Electric sensors (details in Appendix A):	2 x (E_x, E_y) orthogonal lines of 100m length, with 1×50m and 1 x100m dipole wires deployed for both the Ex and Ey dipoles. 5 ×non-polarisable Pb-$PbCl_2$ electrodes (including ground).
MT station layout (see Error! Not a valid bookmark self-reference.):	Varying setup azimuth. Convention after rotation: E_x - North (N 0°); E_y - East (N 90° E); H_x - North (N 0°); H_y - East (N 90° E). H_z - Vertical.

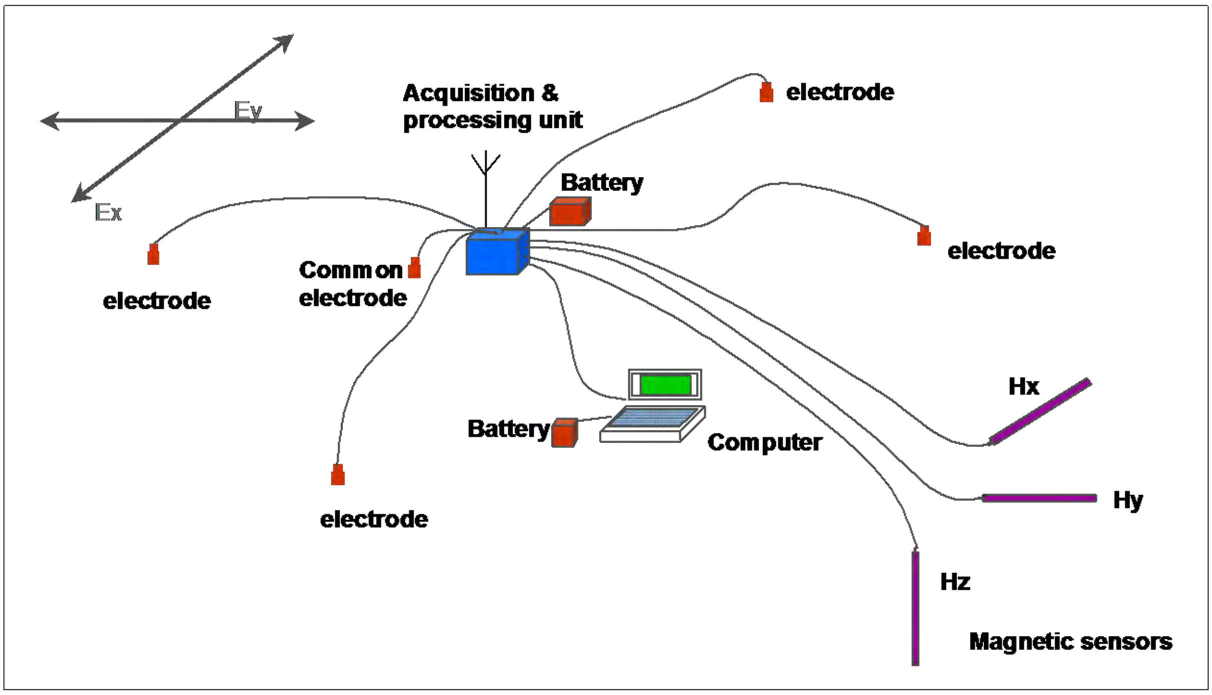

Figure 2. Five-channel MT layout diagram.

3.2 ACQUISITION PARAMETERS

Data acquisition:	Full Time series recorded.
Technique:	Broadband Full tensor MT with remote reference.
Data processing (see Appendix C):	Robust remote reference technique.
Frequency range:	0.001 – 10,000 Hz.
Recording parameters:	See recording schedule in Table 1.

Following the MTU-5a data acquisition scheme, all receivers continuously record data after being turned on and synchronized to the GPS timing. The recording schedule (**Error! Reference source not found.**) was designed to maximize data acquisition in the mid to long periods (TS4 band at 150Hz), and to provide high frequency bursts to catch windows of variable signal strength (TS2 and TS3 at 24,000Hz and 2,400Hz, respectively).

	Sampling Frequency	**Recording interval**
TS2	24000 Hz	2 records of 2400 points every 30 seconds, beginning at 20:00:00 and ending at 22:00:00. During this time the MFS magnetic coils have the chopper amplifier switched off for high frequency responses.
TS3	2400 Hz	4 records of 2400 points every 30 seconds, beginning at 10:00:00 and ending at 09:00:00 (+1 day) MFS magnetic coils have chopper amplifier turned on for the duration of this recording, except for the time period defined for TS2 during which the MFS chopper amplifier is turned off.
TS4	150 Hz	Continuous from 10:00:00 to 09:00:00 (+1 day) MFS magnetic coils have chopper amplifier turned on for the duration of this recording, except for the time period defined for TS2 during which the MFS chopper amplifier is turned off.

Table 1. MT recording frequency schedule used (local time).

3.3 QUALITY CONTROL

During-survey	Layout parameters (Appendix B.3)	Fieldbooks daily compiled
Post-survey	Field office control measure	Daily s/n and remote referencing controls

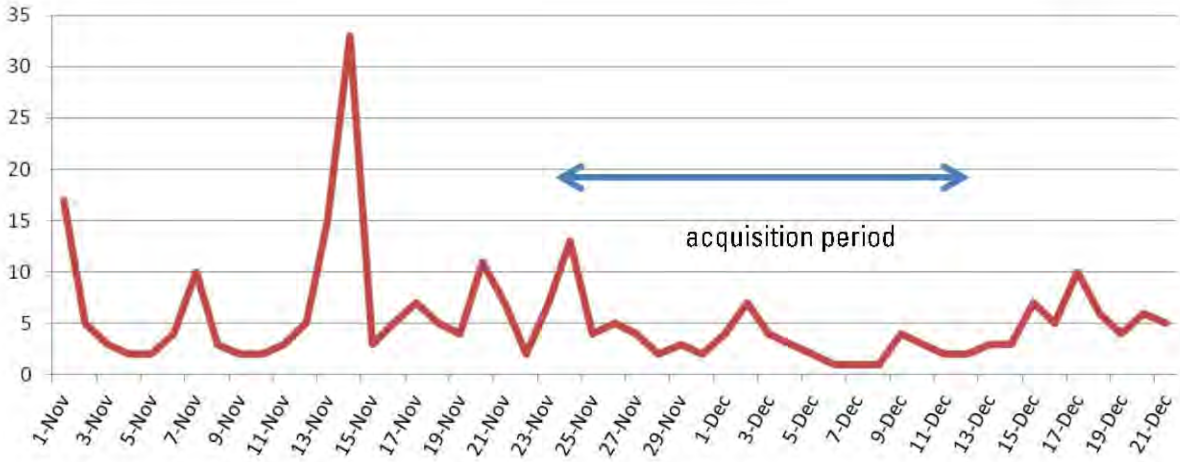

Figure 3. Geomagnetic planetary activity (Ap index) for the survey period. Dates are referred to UTC time.

Overall the data quality for the whole survey allowed to obtain reliable estimates of the impendance tensor and tipper values over a wide frequency range (see fig. 4). The main factor affecting the reliability of the sounding curves at low frequencies was related to the daily variations of source signals.(see figure 3), which produced some noise effects between 1 and 10 s. Hence, in order to improve the data quality in the low frequency some sites the data were surveyed twice (see figure 5). Given the job recording schedule adopted, the remote-reference robust processing procedure allowed to obtain estimates of the impedance tensor and tipper appropriate for the subsequent modelling phase between 0.001 and 100 s.

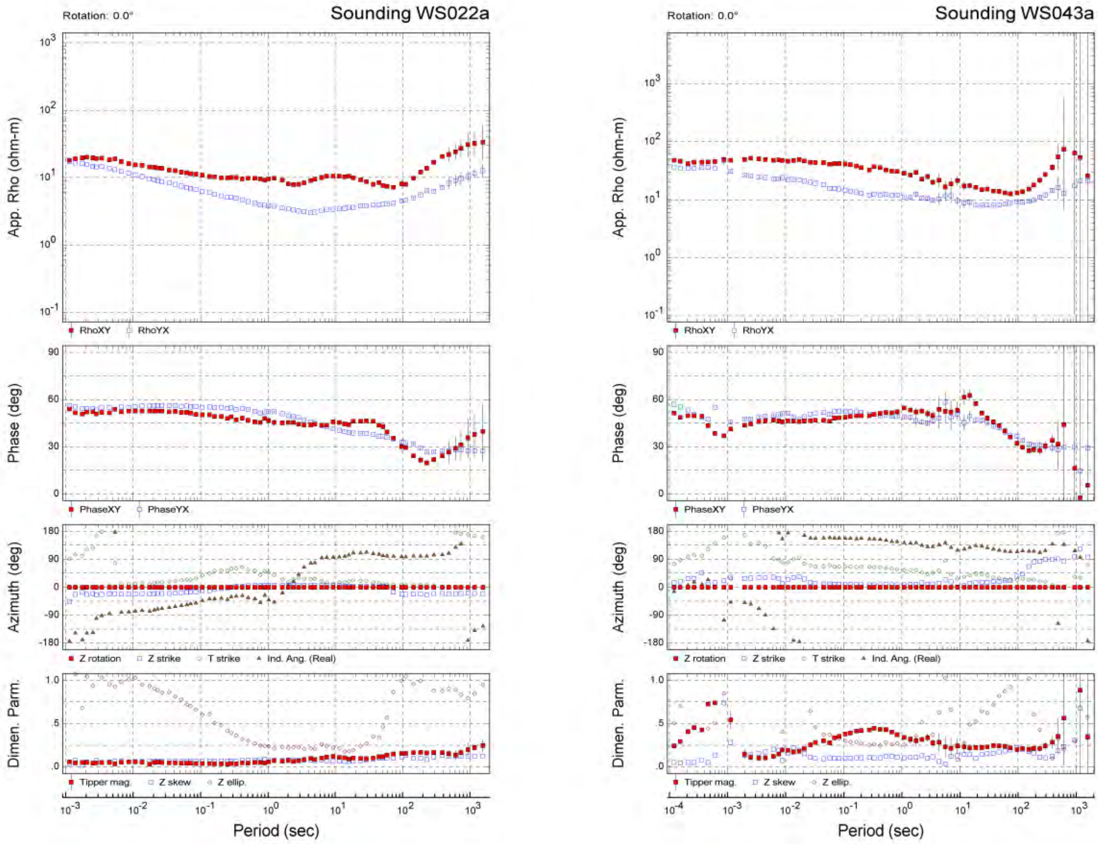

Figure 4. Example of principal impedance curves and interpretational quantities for the sites WS22a and WS43a. Data are rotated to 0°N.

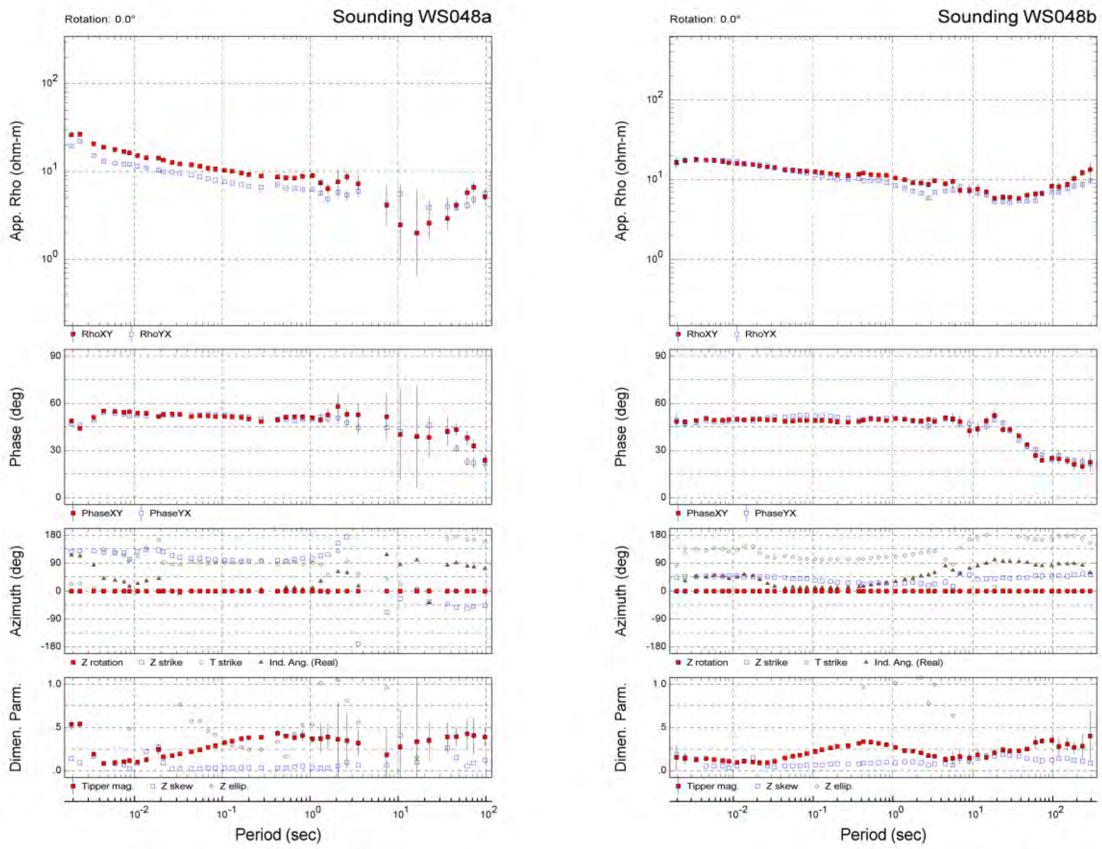

Figure 5. Site WS048. Comparison between the soundings obtained processing data from the first acquisition (left panel) and from the repeated acquisition (right panel)

3.4 DATA ANALYSIS: QUALITATIVE IMAGING

In order both to check the consistency of the souding data over the survey area and to obtain some information about the resistivity distribution at depth, apparent resistivity and phase maps at different periods have been estimates. The results are shown in figures 6-7. The outcome of such analysis can be summarized as follows:

- The lateral consistency between adjacent soundings over the whole spectrum is generally quite good;
- The response for both XY and YX components is quite similar for periods up to 1 s . Hence a 1D dimensional behavior of the resistivity distribution is a legitimate approximation at shallow depths;
- There is a good consistency between apparent resistivity and respective "anticipated" phase response
- The YX resistivity maps provide a qualitative indication of the occurrence of a shallow conductive anomaly in the NE portion of the survey area

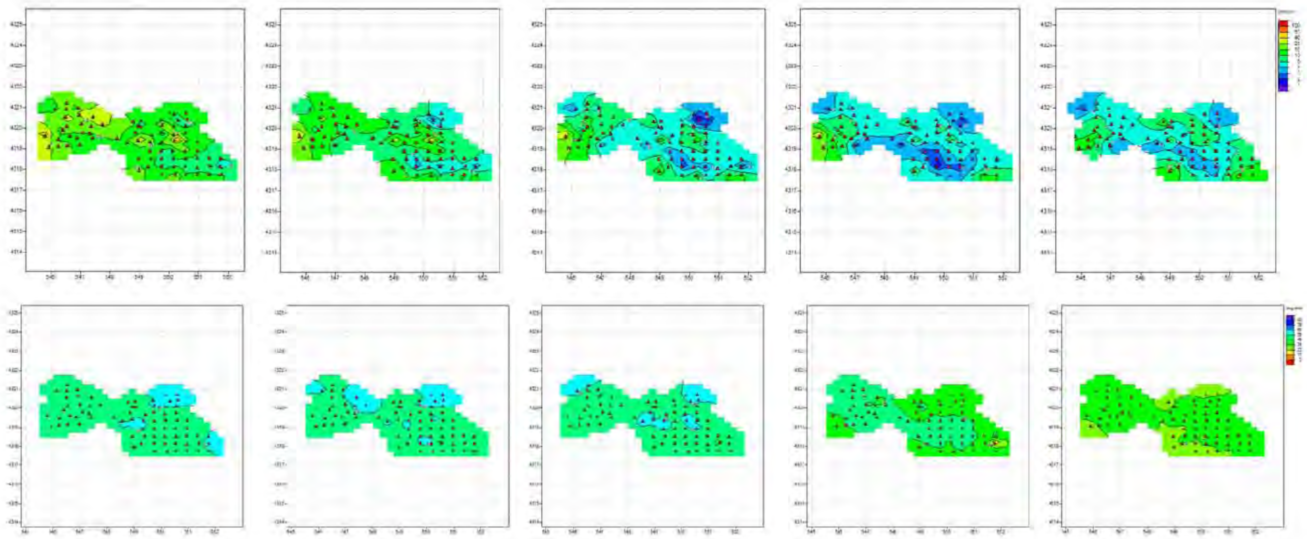

Figure 6. XY apparent resistivity (top panel) and phase (bottom panel) maps at different periods. Top panel, from left to right:0.01 s, 0.1 s, 1 s, 10 s and 100s. Bottom panel: 0.005 s, 0.05 s, 0.5 s, 5 s and 50 s. The sounding data are rotated to 0°N

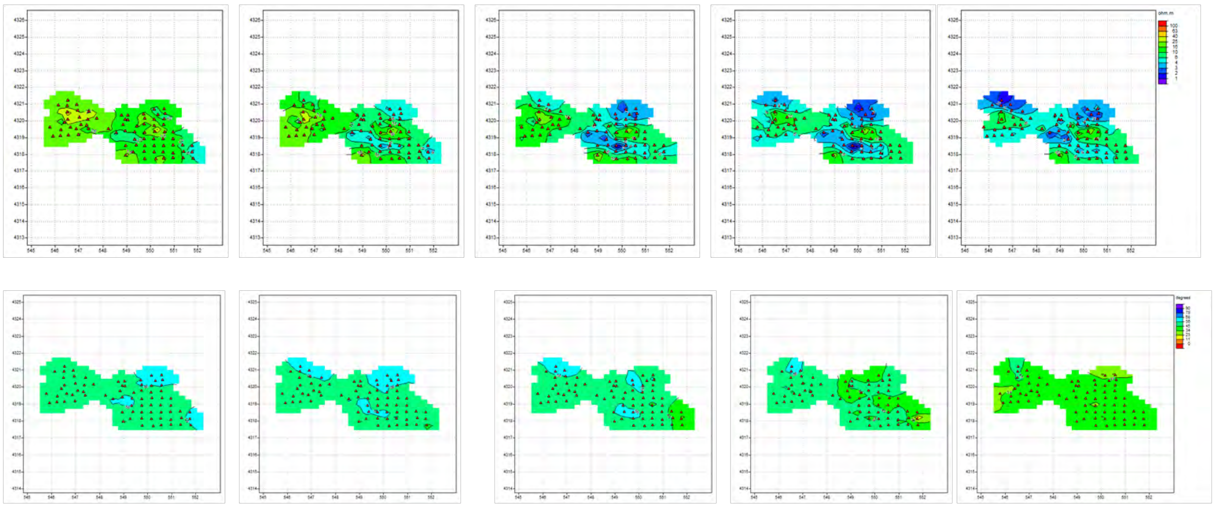

Figure 7: YX apparent resistivity (top panel) and phase (bottom panel) maps at different periods. Top panel, from left to right:0.01 s, 0.1 s, 1 s, 10 s and 100s. Bottom panel: 0.005 s, 0.05 s, 0.5 s, 5 s and 50 s. The sounding data are rotated to 0°N

4 PRELIMINARY MODELING

After the completion of the sounding data quality control, a preliminary 3D inversion of MT data was carried out. Following the results of the qualitative imaging analysis, the workflow for such preliminary modeling phase was set up as follows. For the starting resistivity model, we chose a uniform resistivity distribution with a value of 10 ohm.m; we then carried out two separate runs, using two values of the smoothness parameter τ (0.1 and 0.05, respectively). For each site, the full impedance tensor was inverted over a frequency band equally spaced on a logarithmic scale (5 values per decade) ranging from 0.01 Hz to 1000 Hz. The parameters used for the inversion are summarized in table 3.

The three-dimensional resistivity distribution obtained from the inversion of MT data turned out to be quite consistent with the sounding data, with a final RMS of 1.09 (see figures 8-9) The results of the 3D inversion are summarized in the figures 10-21. Figures 10-17 shows the resistivity maps at different depths, while figures 18-21 show resistivity cross section along various profile. The main feature that can be inferred from the results of such preliminary inversion is the occurrence, in the NE part of the survey area, of shallow conductive anomaly

Mesh dimensions: 83 x 62 x 74
Total number of cells: 380804
Minimum cell dimensions: 125m x 125m x 15m
Total inverted sites: 75
Inverting for: Impedences (Full Tensor)
Min freq: 0.01Hz
Max freq: 1000Hz
#freqs/decade: 5

RUN 01
Zxy/yx Amplitude Error floor: 3%
Zxy/yx Phase Error floor: 3%
Zxx Error floor: 10%
Zyy Error floor: 10%
Tau for model smoothness: **0.1**
Total Iterations: 50
RMS: 1.198

RUN 02
Zxy/yx Amplitude Error floor: 3%
Zxy/yx Phase Error floor: 3%
Zxx Error floor: 10%
Zyy Error floor: 10%
Tau for model smoothness: **0.05**
Total Iterations: 100 (50 +50)
Final RMS: 1.093

Table 2. Parameters for the 3D inversion. The resistivity value for the starting model is set to 10 ohm.m

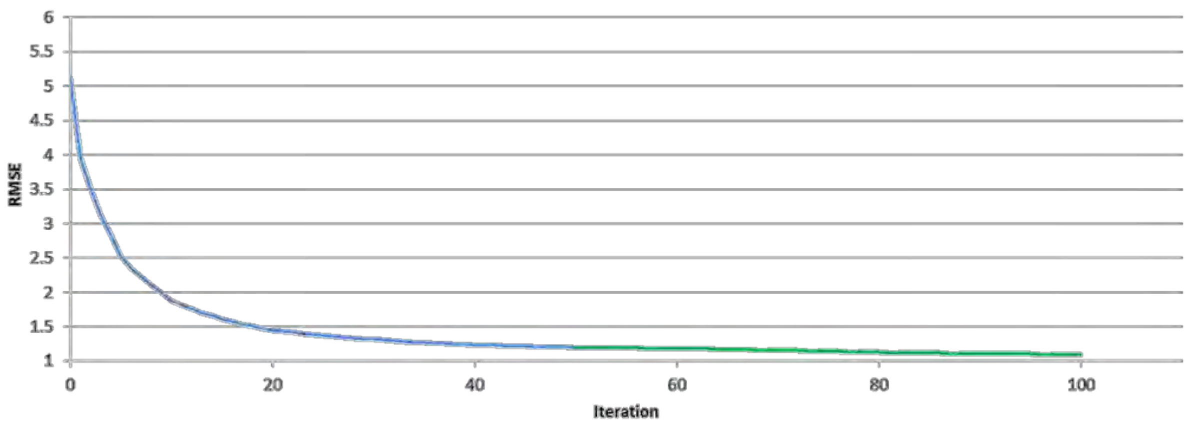

Figure 8. RMS as a function of the total number of iterations for both the first run (blue solid line) and the second run (green solid line). The resistivity value for the starting model is 10 ohm.m.

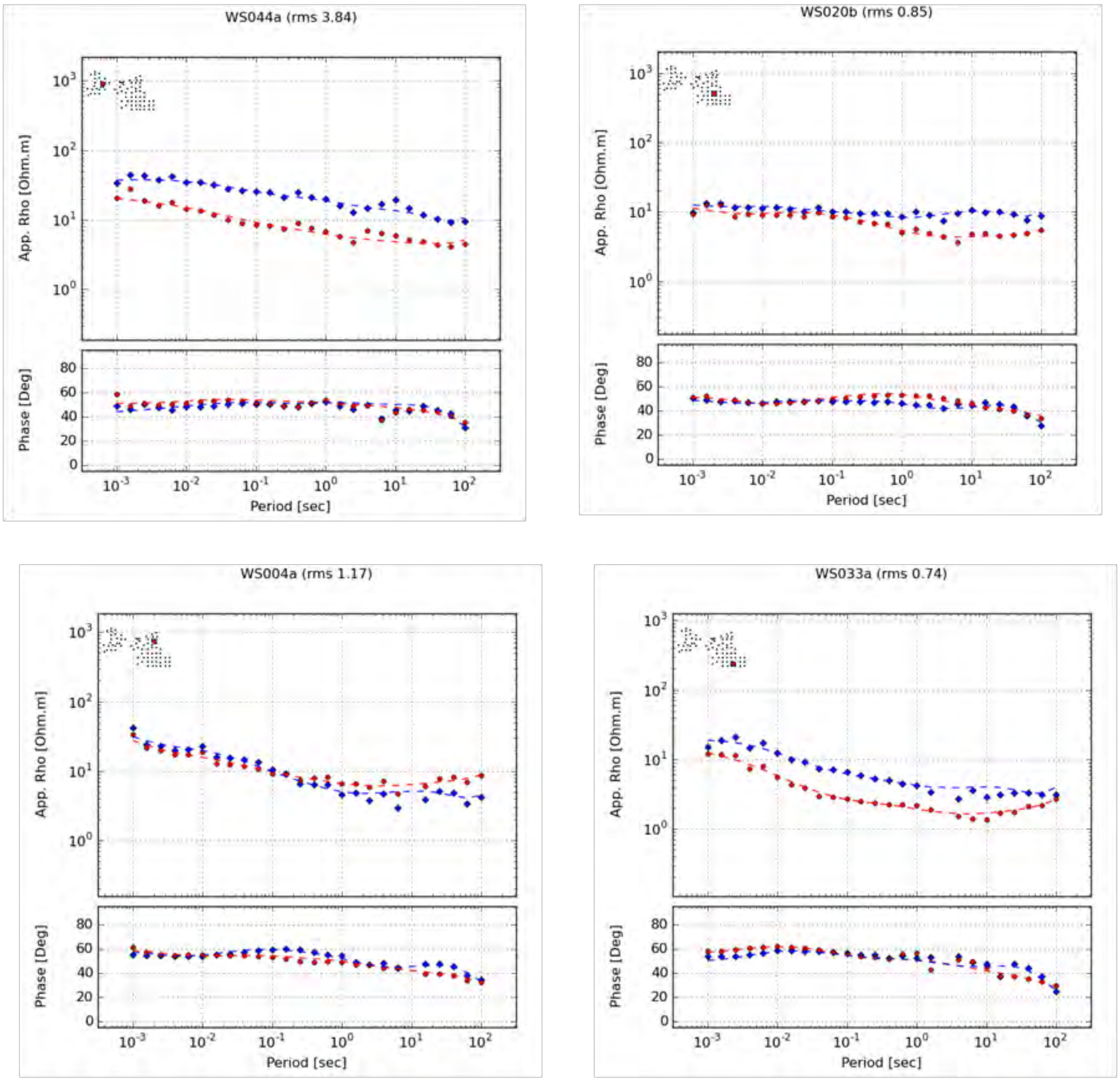

Figure 9. Comparison between model responses (dashed lines) and sounding data (points) for 4 sites. Red and blue curves refers to XY and YX components, respectively. Data are rotated °90N.

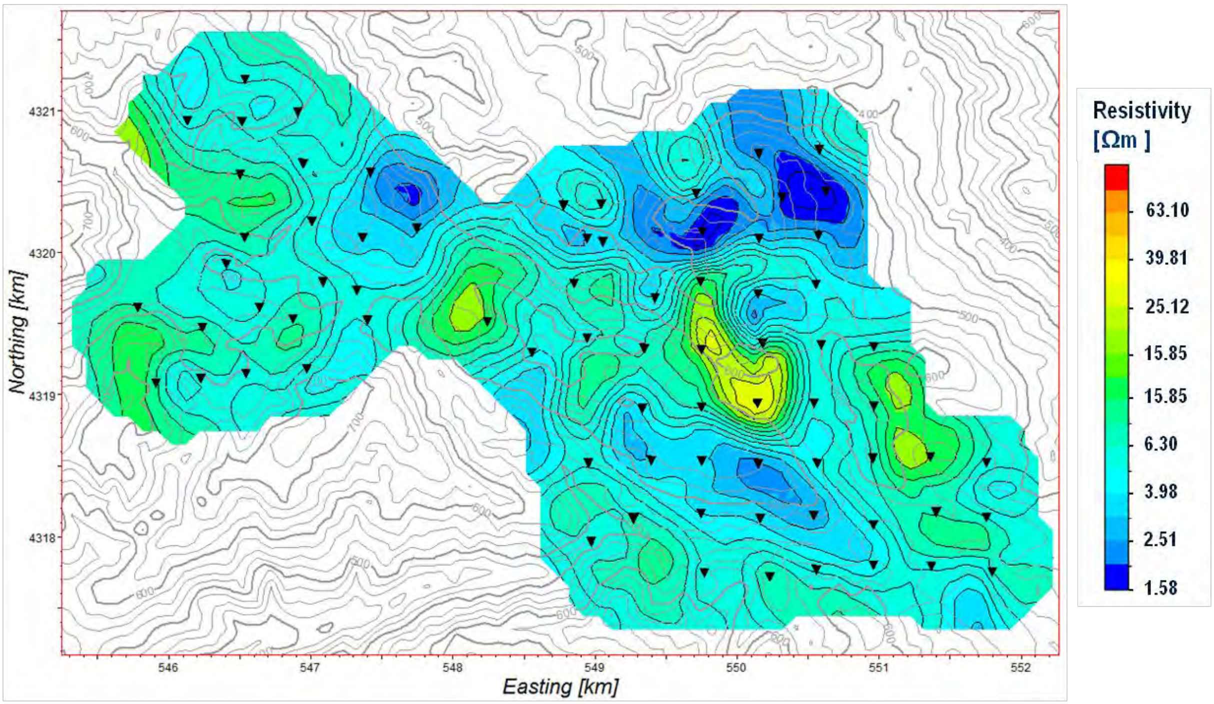

Figure 10. Resistivity map at 250 m depth.

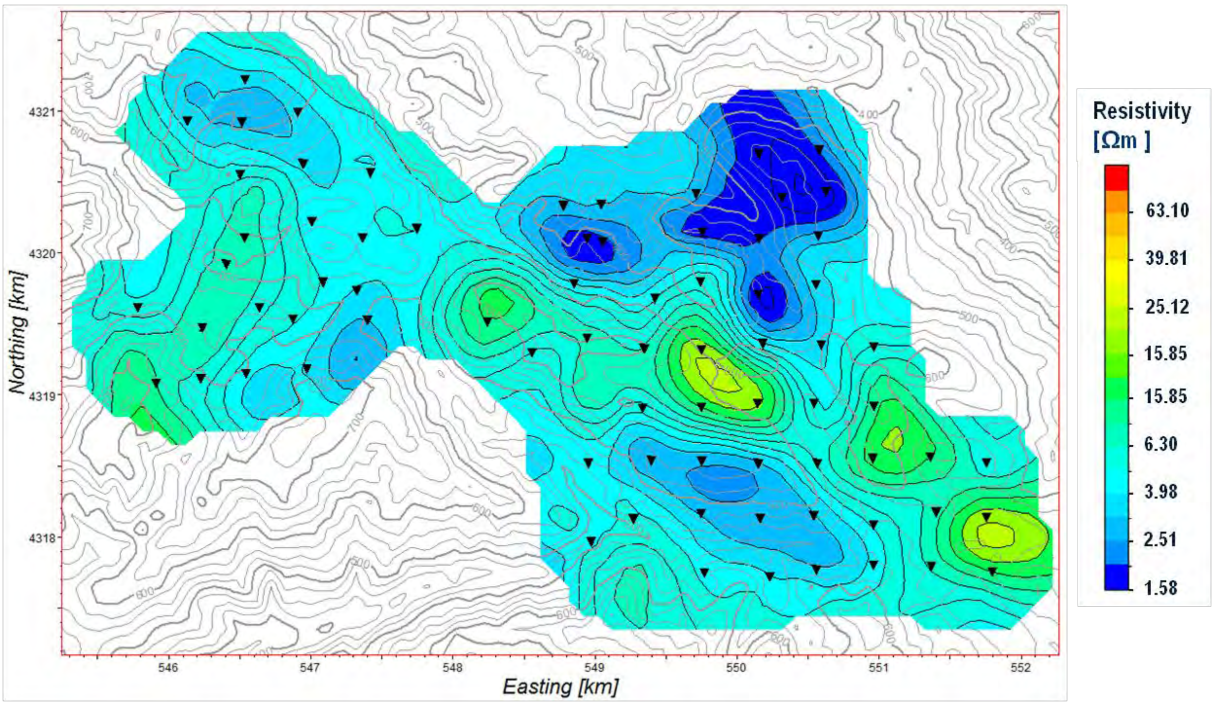

Figure 11 Resistivity map at 500 m depth.

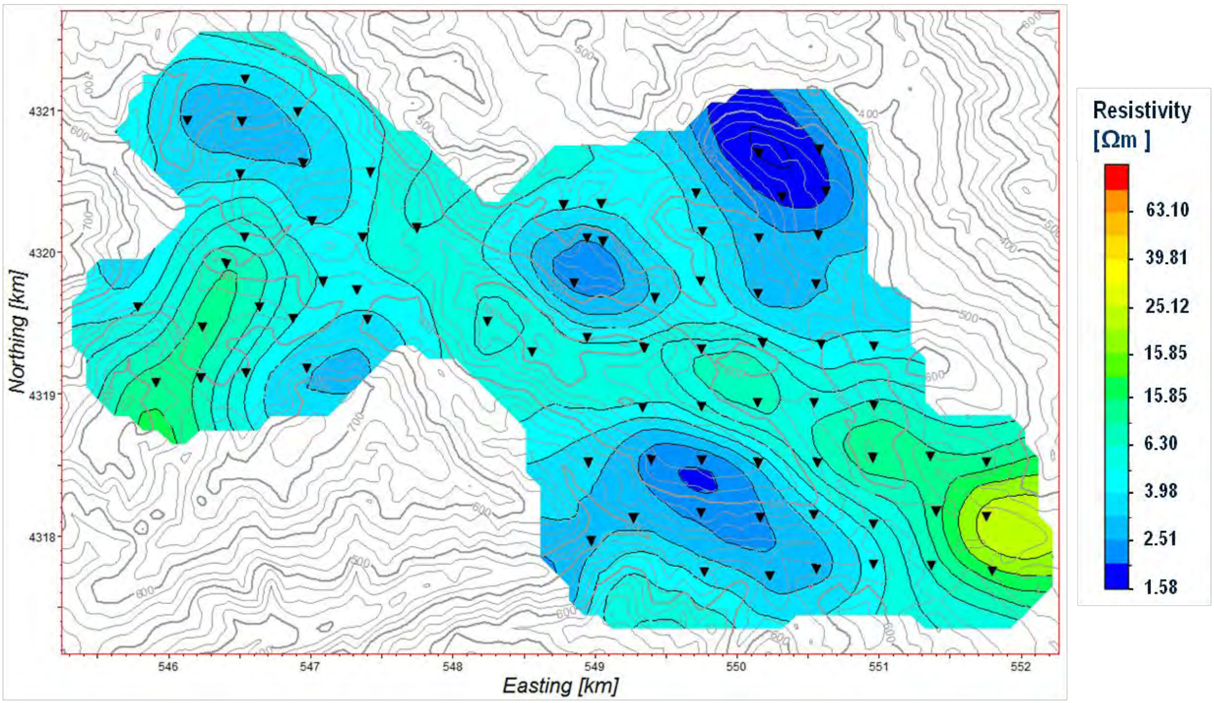

Figure 12 Resistivity map at 750 m depth.

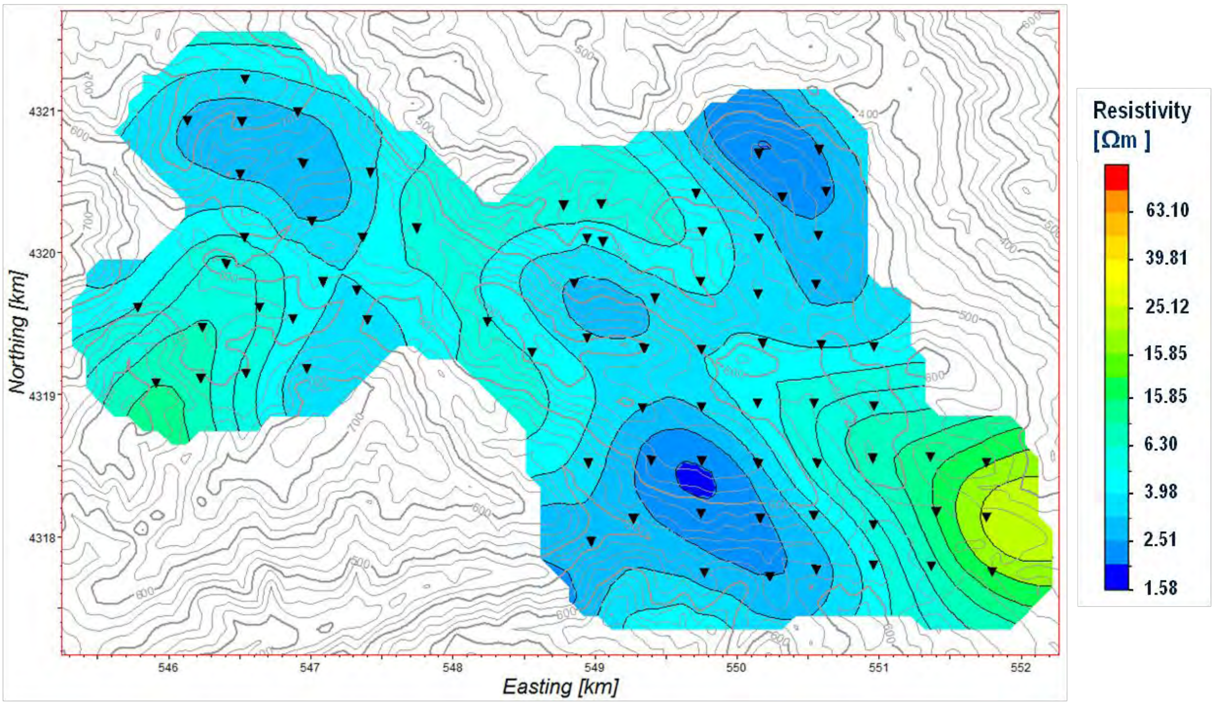

Figure 13 Resistivity map at 1000 m depth.

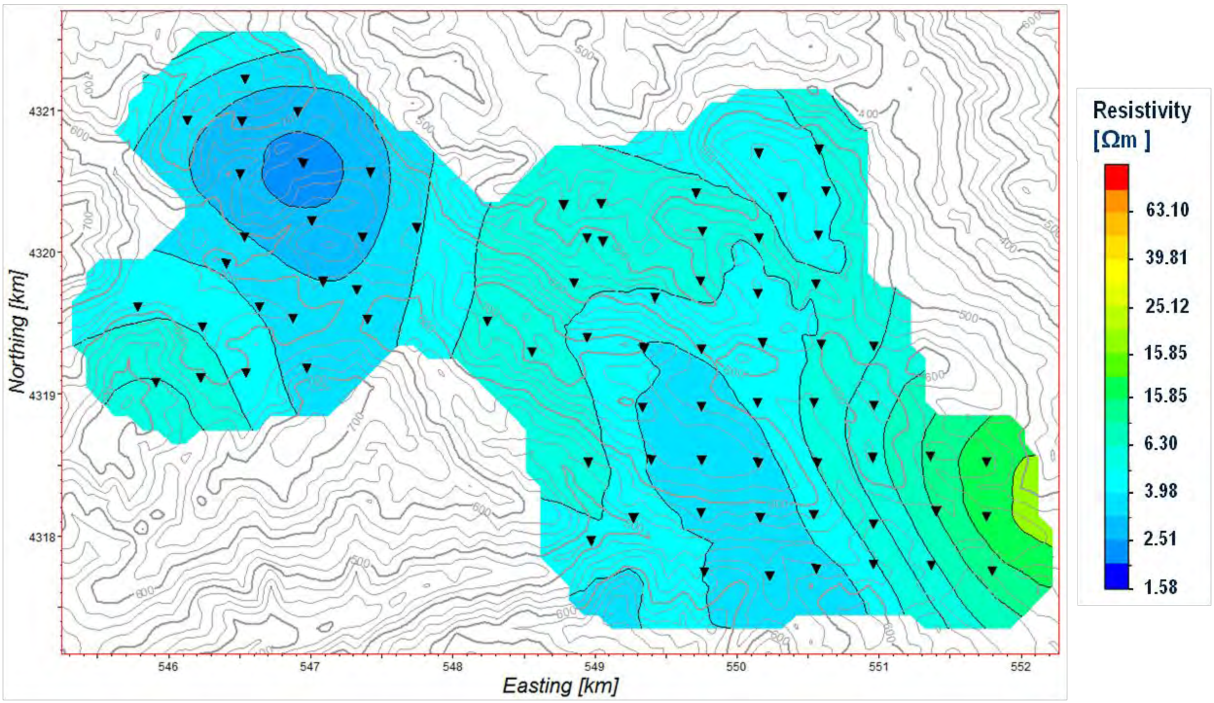

Figure 14 Resistivity map at 1500 m depth.

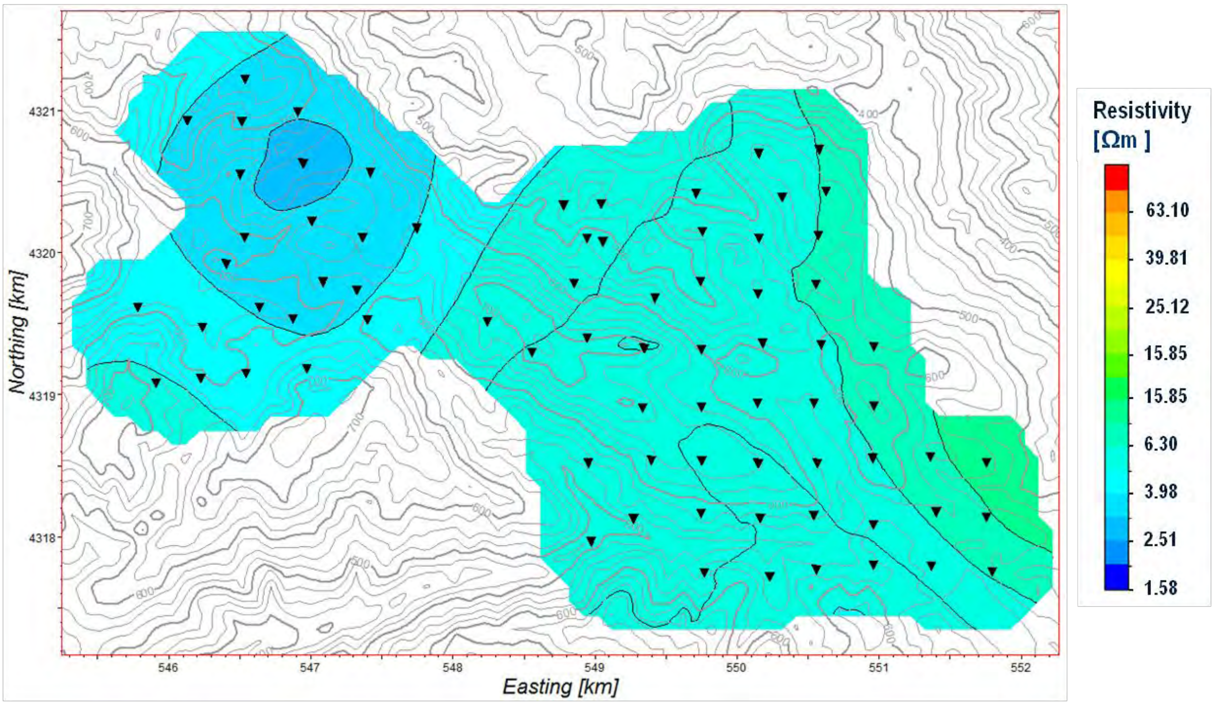

Figure 15 Resistivity map at 2000 m depth.

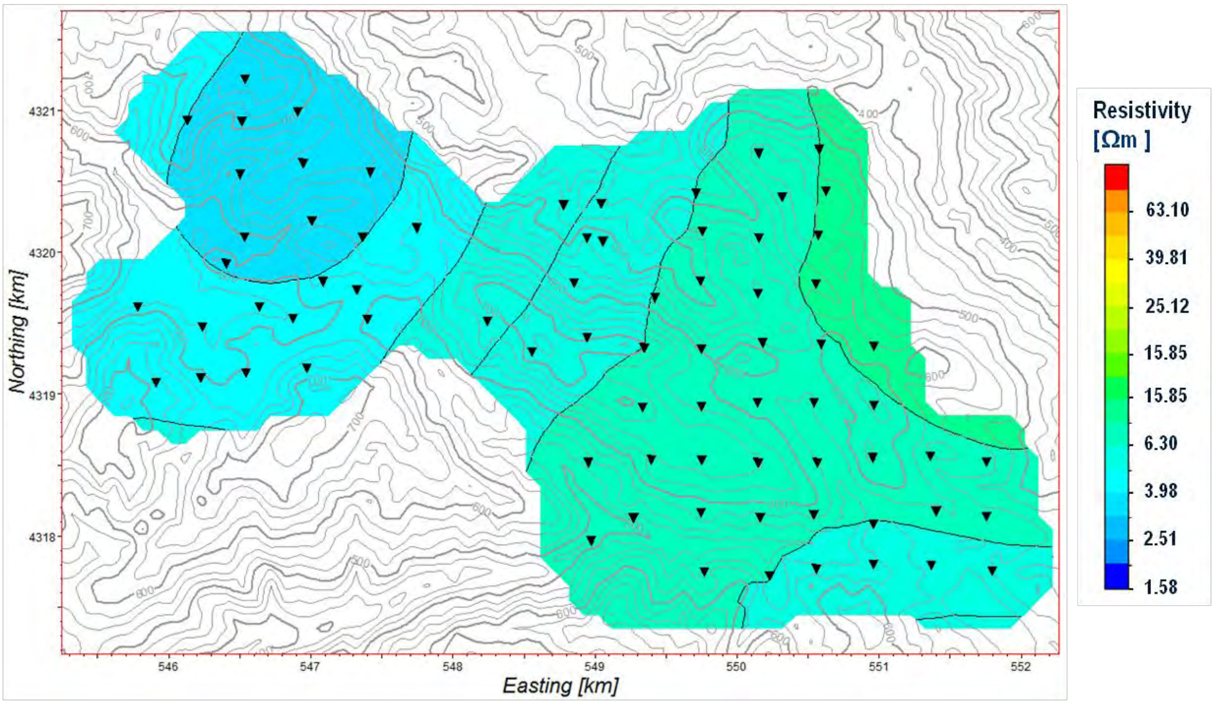

Figure 16. Resistivity map at 2500 m

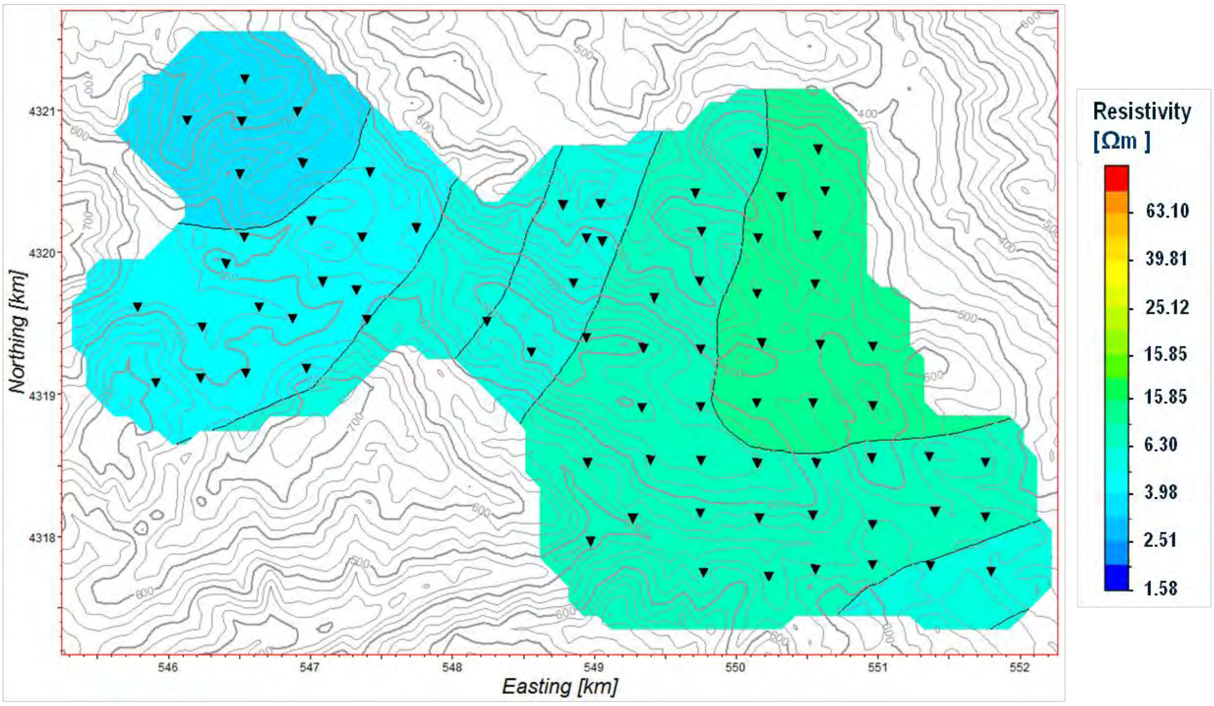

Figure 17. Resistivity map at 3000 m

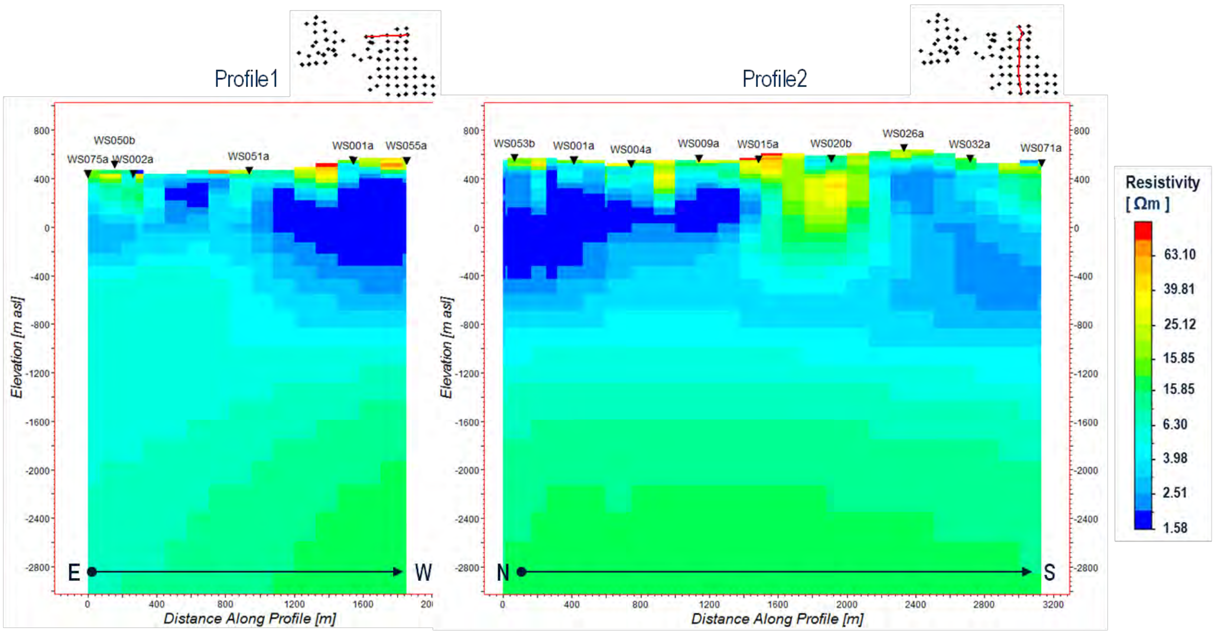

Figure 18. Resistivity cross sections along two profiles oriente EW and NS respectively.

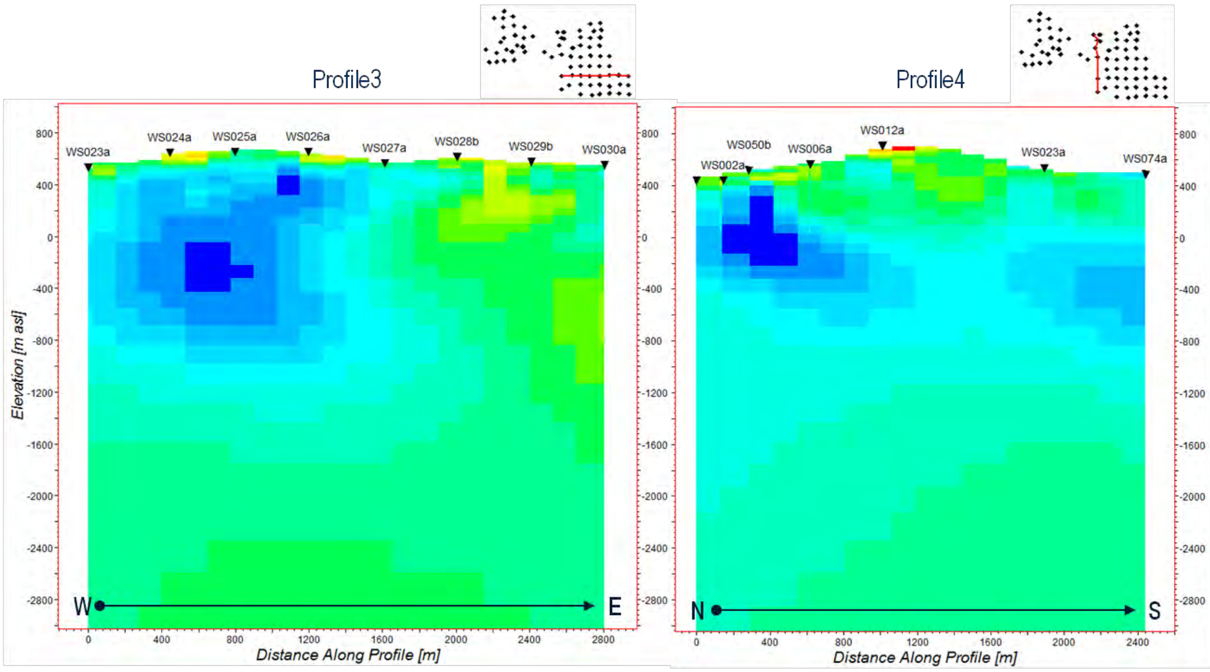

Figure 19 Resistivity cross sections along two profiles oriente EW and NS respectively

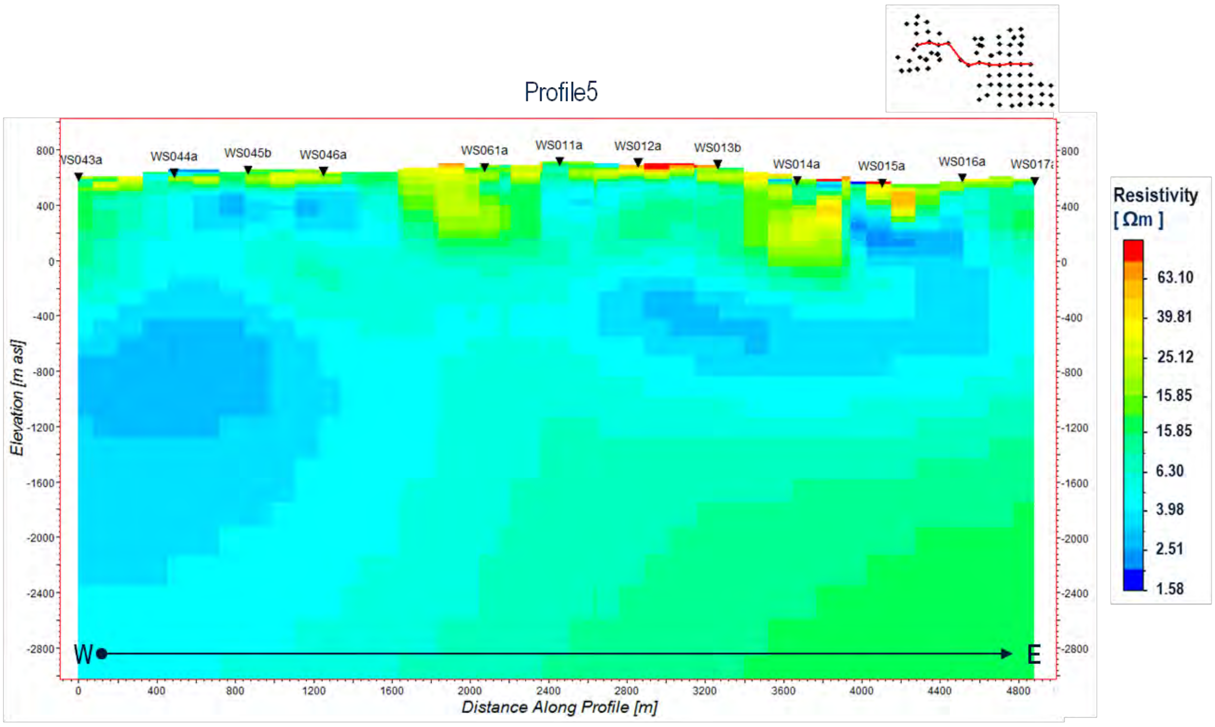

Figure 20 Resistivity cross sections along one profile oriented EW

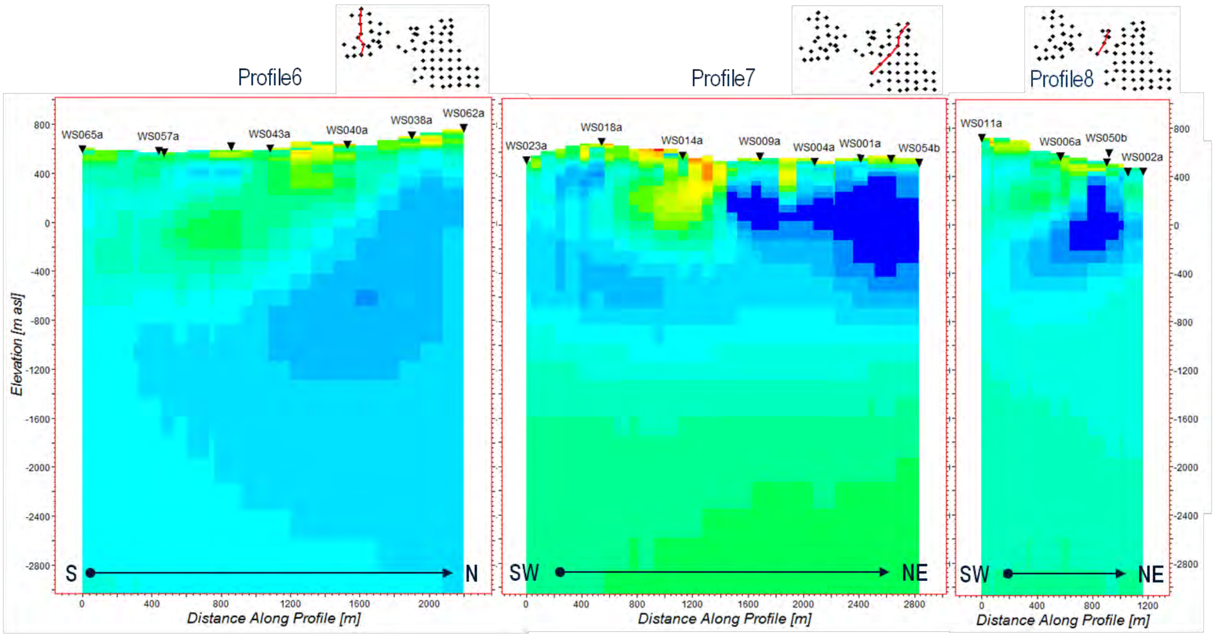

Figure 21 Resistivity cross sections along three profile oriented EW

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http://www.sec.noaa.gov/ftpmenu/indices/old_indices.html	2010	Geomagnetic A Index, Estimated Planetary
http://srtm.csi.cgiar.org/	2011	Shuttle Radar Topography Mission

APPENDIX A INSTRUMENTATION

A.1 TECHNICAL SPECIFICATIONS

Full tensor, 24-bit, GPS-synchronized Phoenix MTU-5A systems were deployed. At any one time, up to ten MT systems were in use on production, with one at the remote reference station. The deployed MTU-5A system consists of:

MT Equipment – MTU-5A System:

- 5 channel Phoenix MTU-5A acquisition systems, with GPS antenna for synchronization
- 3 Metronix MFS-07 magnetic sensors (H_x , H_y and H_z);
- 5 Pb-PbCl2 non-polarizing electrodes (Wolf, Hungary), per system;
- 300m AWG#16 wire (2x50m + 2x100m wires), per system;
- 1 sealed lead-acid battery, 12V/34Ah, per system;
- Connecting cables

MTU-5A (acquisition and processing unit):

Internal computer, 24 bit A/D converter, 15, 150 and 2400 sample/sec data rate, 26-pin circular connector to IEEE 1284 ECP bi-directional PC parallel port for communication with system computer. Data stored on a removable compact flash card.

Internal GPS receiver, and an oven controlled crystal oscillator clock, GPS precision is 1 •s or better, and $\pm$ $5x10^{-9}$ clock accuracy in case of GPS synchronization loss.

Magnetic Sensors:

H_x, H_y	Metronix MSF-07 (0.001 to 50,000 Hz).
	Sensitivity 0.02 V/(nT*Hz) (f«32 Hz); 0.64 V/nT (f»32Hz).
	At remote site location: Metronix MSF-06 (0.00025 to 10,000 Hz)
	Sensitivity 0.2 V/(nT*Hz) (f«4 Hz); 0.8 V/nT (f»4Hz), or:
H_z	Metronix MSF-07 (0.001 to 50,000 Hz).
	Sensitivity 0.02 V/(nT*Hz) (f«32 Hz); 0.64 V/nT (f»32Hz).

Electric Sensors:

150M dipoles (total length). AWG #16 cables with Pb-PbCl2 non-polarizing electrodes (Wolf, Hungary).

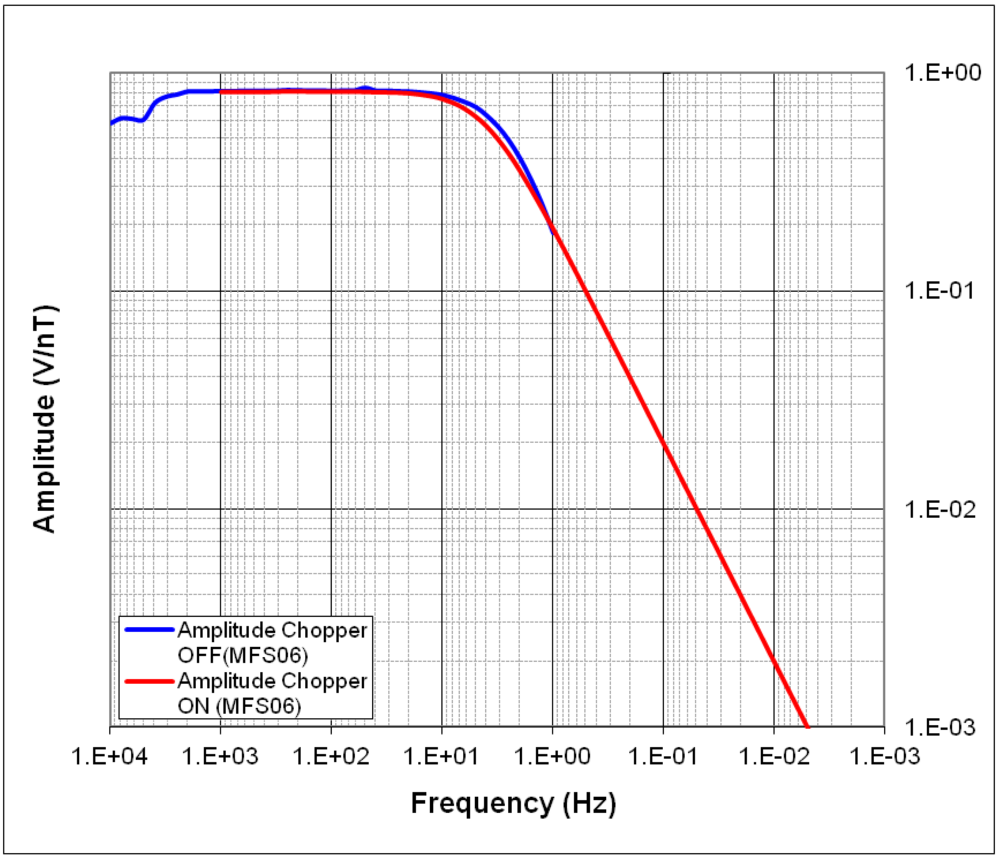
Environmental:

Power supply MTU-5A	1×12V 34Ah sealed lead-acid battery, 24 kg.
Operating temperature:	
MTU-5A	-20°C to +50°C
MFS-06, MFS-07	-25 to +70°C
Weights:	
MTU-5A	4.4 kg
MFS-06	8.5 kg
MFS-07	5.5 kg

A.2 CALIBRATION CURVES

Prior to shipment of the equipment to the survey area, Metronix magnetic sensors (MFS-06/07) were tested and checked by an engineer trained by Metronix GmbH. Example of calibration curves from coil MFS06-144 and MFS07-002 are shown in Figure 22 and Figure 23.

Note that there are two sets of curves for each magnetic sensor, corresponding to the high and low frequency ranges (chopper on and off).



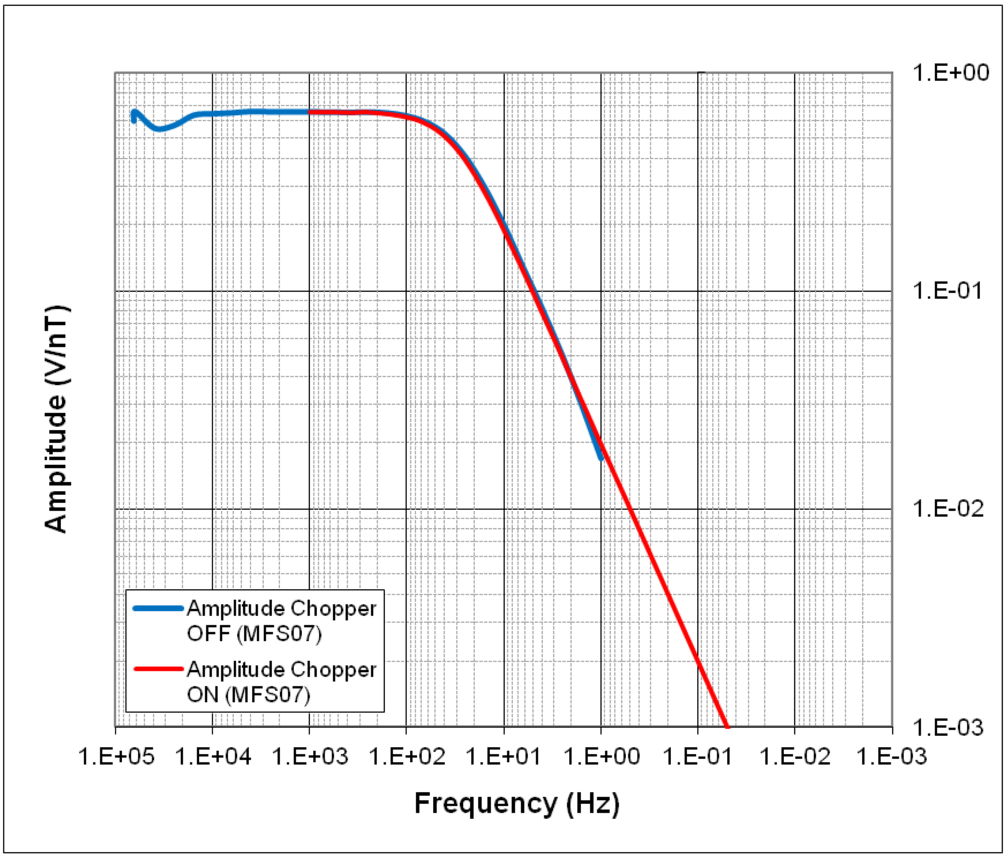
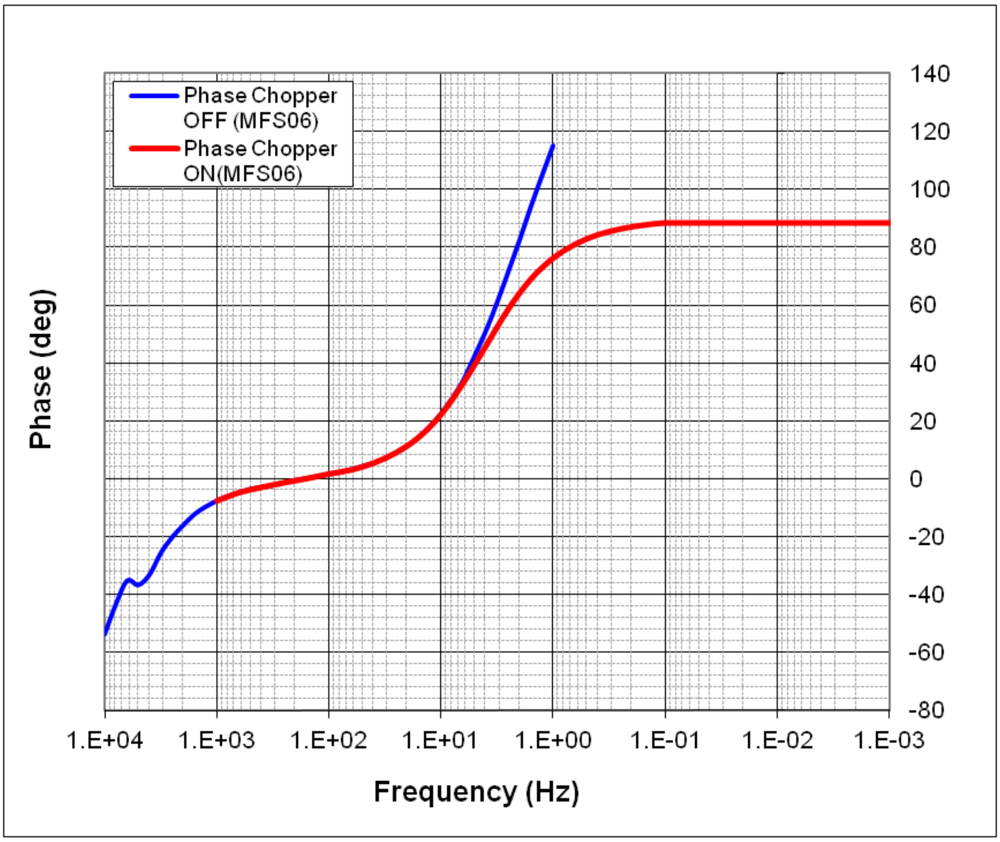


Figure 22. Calibration curves for Metronix coils MFS06-144.



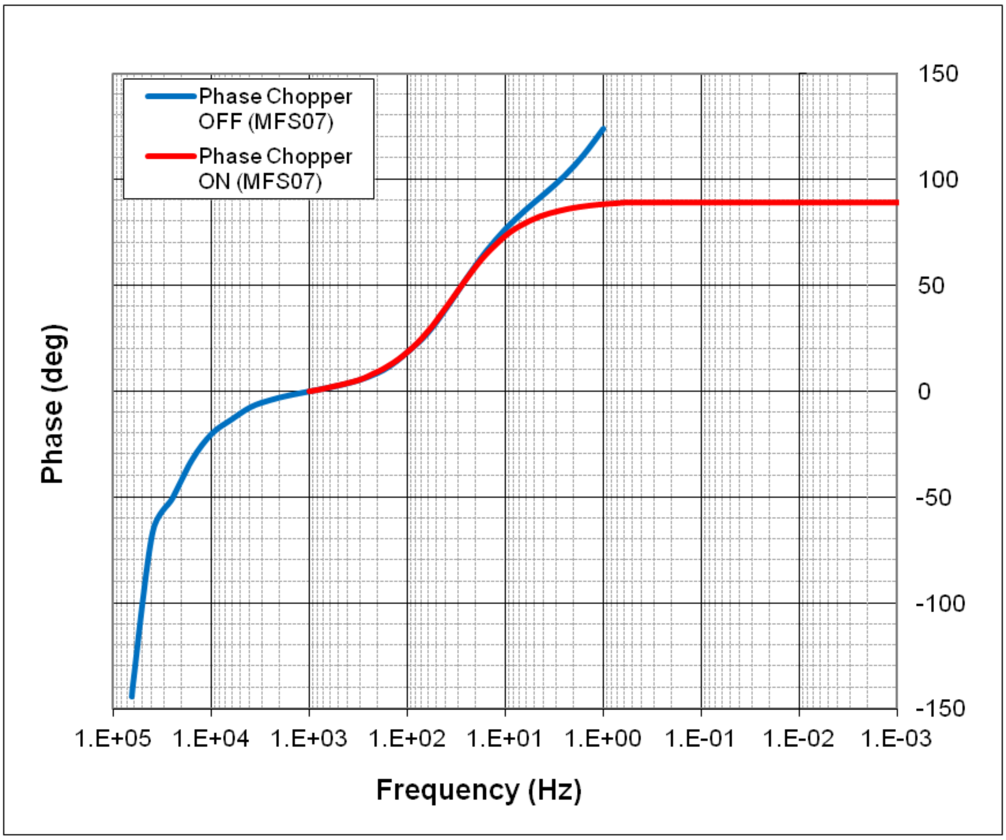


Figure 23. Calibration curves for Metronix coils MFS07-002.

APPENDIX B PROCEDURES: LAYOUT AND PROCESSING

B.1 PARALLEL SENSOR TEST

All coils and electrodes are checked in a series of parallel sensor tests at an accessible, electromagnetically quiet location.

The magnetic sensors are buried to depths of about 30cm, aligned North-South, and each is located parallel to and about 2m from its neighbour. The electric channels Ex and Ey on each MT receiver is then connected to the same single pair of electrodes, laid out at right angles to the coils. Given identical sensor and acquisition systems, one would expect to see very similar outputs both in time and frequency domain: with reasonable signal levels, the resulting coherencies should be greater than 0.9 between pairs of like sensors, and amplitude and phase transfer functions close to the theoretical values of 1.0° and 0.0° respectively. In this way both the magnetic coils and the individual MT receiver channel boards could be verified. Suspect sensors and components are re-tested and ultimately excluded from the production pool if still noisy or otherwise defective.

Electric dipole wires are checked for correct length (50m) and obvious external damage to the protective insulation. Coil cables are similarly tested for correct pin-to-pin continuity and the absence of cross-channel interference (partial grounding between pins).

B.2 SITE PREPARATION AND LAY-OUT

Crews located the new sites using a hand-held GPS unit pre-programmed with the proposed sounding locations, in conjunction with maps showing the sounding locations provided by the client representative. Each MT crew moved to the new sites upon completion of data downloading and retrieval of equipment from the previous recording site. Arriving at a new site, the first course of action was to select the site centre so as to minimize topographic relief between electrodes, avoid possible interference sources, extend the dipoles (4×50m wires) and install the electrodes to allow sufficient time for stabilization.

Trenches up to 30cm deep were dug to bury the horizontal coils, as well as a hole for the vertical coil, to minimize wind vibration and to provide thermal stability. Where rock outcropped at or close to the surface, the vertical coil was buried as far as possible and protected from wind noise by a plastic can held in place with earth and stones. The magnetic sensors were buried at a distance of 5m from the acquisition unit.

The dipole was extended for a nominal length of 100m. The operator measured SP (Self Potential) and contact resistance across the dipoles and recorded them in the field books, together with the magnetic sensor serial numbers and the dipole lengths. In case of high contact resistance, the electrodes were re-buried and re-watered in order to reduce the resistance.

The GPS antenna could be placed up to 2m from the MT recording unit to improve satellite coverage. The recording schedule and acquired data were loaded from and stored on a removeable USB flash stick that was switched daily by the operator.

B.3 QUALITY CONTROL

Quality control procedures were taken at each stage of data acquisition. The MT crews assessed the status of the equipment on a daily basis, as described above. Field records were kept, to track possible equipment problems, with the following information:

- Coordinates;
- Telluric lines lengths and azimuths (geographic North);
- Contact resistance and self-potential;
- Magnetic sensor and MT receiver serial numbers.

The field layout parameters and sketch are included with the archived time series data.

Further quality control measures were completed in the field office. Time series data from the same recordings were brought together on the processing computer and inter-channel correlation was checked. Any discrepancies noted were relayed to the operators, so that suspect equipment could be set aside until further testing was undertaken.

B.4 MT DATA PROCESSING

Data were processed at the field office within 48 hours of recording, using robust, remote techniques. All time series data is recorded and stored. For data processing the following procedures were used:

1. Visual inspection of time series segments using WinGLink, developed by Geosystem;
2. Chave and Thomson (2004) processing mostly to check for noise characteristics;
3. Robust processing of time series using Larsen code, by individual bands;
4. Merging of individual bands to form a complete sounding curve.

The robust, remote reference MT processing code described by Larsen et al. (1996), and subsequently implemented and upgraded by Geosystem, was used to estimate a smooth magnetotelluric transfer function (i.e. impedance) relating the electric and magnetic field data.

The original and decimated time series bands provided input data. The code first determines the transfer function between the remote and local magnetic fields, with the assumption that the remote magnetic field is noise free. This iterative process corrects the local magnetic field for outliers in both the frequency and time domains. The magnetic fields are then used in an iterative re-weighted method to determine the impedance tensor. During the iterations, the electric fields are corrected in both the frequency and time domains, utilizing a smooth MT transfer function to estimate the electric field data from the magnetic fields. This procedure is repeated for each time series band and the complete sounding file, spanning all the-decade frequency range, is obtained by merging the results. The final MT parameters are written to standard EDI files, one per sounding.

APPENDIX C MT PARAMETERS

C.1 OVERVIEW

The magnetotelluric method is a means of determining the resistivity distribution of the Earth through the measurement of time varying electric and magnetic fields at the surface. At each MT site, data from five channels are recorded as a function of time, which is referred to as time series. These channels are indicated in the following figure, and correspond to three orthogonal magnetic field components (designated Hx, Hy, and Hz), and two horizontal electric field components (designated Ex and Ey). Note that a right-hand coordinate system is used and z is positive downwards.

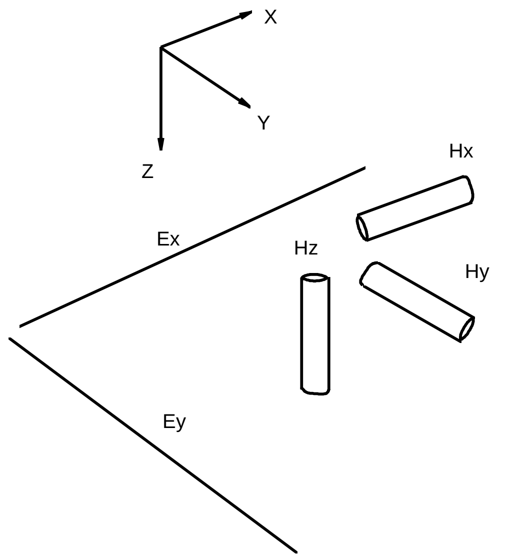


Figure 24. Coordinate axes and component identifications for 5-component MT site.

As an electromagnetic method, magnetotelluric depends on Maxwell's law stating that a time-varying magnetic field induces an electric field in a conductor. The source fields are the time-varying horizontal magnetic fields (Hx and Hy), which are generated by two distinct phenomena. The high frequency source fields, greater than 1Hz, are generated by lightning discharges of distant electrical storms. The low frequency source fields are generated by the interaction of charged particles, solar wind, with the earth's ionosphere. The output of the source fields convolved with the Earth consists of the horizontal electric field (Ex, and Ey) and the vertical magnetic field (Hz). Thus, ideally, the electrical nature of the Earth (i.e. the impedance) can be determined through the transfer function of the measured input and output signals.

C.2 MEASURED QUANTITIES

The actual parameters measured in the field are the time-varying voltage outputs of the electric and magnetic field sensors: Ex, Ey, Hx, Hy, and Hz.

Computed functions

The measured parameters, the electric and magnetic field values, are transformed into the frequency domain using FFT procedures, and convolved with the sensor responses to give the complex values of electric and magnetic fields at specific frequencies.

The resulting Fourier-transformed spectral estimates are combined into a spectral crosspower matrix relating all of the measured electromagnetic fields at discrete frequency values. If the spectral values of two channels at frequency fi in the channel bounded by frequencies between fj-m and fj+m are A and B (complex numbers), then

$$\left\langle A(f_j), A(f_j) \right\rangle = \frac{1}{2m+1} \sum_{k=j-m}^{j+m} A_k A_k^* = \left\langle A_k A_k^* \right\rangle$$

define the autopower $A_j A_j^*$; and

$$\left\langle A(f_j), B(f_j) \right\rangle = \frac{1}{2m+1} \sum_{k=j-m}^{j+m} A_k B_k^* = \left\langle A_k B_k^* \right\rangle$$

define the crosspower $A_k B_k^*$,where the * indicates the complex conjugate.

The impedance tensor is calculated directly from the crosspower matrix, via relationships of the form

$$Z_{xy} = \frac{\begin{vmatrix} \rangle E_x H_x^* \langle & \rangle E_y H_x^* \langle \\ \rangle E_x H_y^* \langle & \rangle E_y H_y^* \langle \end{vmatrix}}{\begin{vmatrix} \rangle H_x H_x^* \langle & \rangle H_y H_x^* \langle \\ \rangle H_x H_y^* \langle & \rangle H_y H_y^* \langle \end{vmatrix}}$$

The relationships between the five measured components at each site are contained in the impedance tensor (Zij) and the tipper transfer function (Ti), expressed by:

$$E_x = Z_{xy} H_y + Z_{xx} H_x$$

$$E_y = Z_{yx} H_x + Z_{yy} H_y$$

$$H_z = T_x H_x + T_y H_y$$

The impedance tensor and the crosspower matrix are used to derive more practical parameters for interpretation and data quality assessment.

Data interpretation parameters

The interpretation parameters are calculated using the standard definitions of Vozoff (1991), and are described here in simplified form:

Apparent Resistivity	Scaled magnitude of the ratio of each orthogonal E and H pair, with associated variances, i.e. $\rho_{ij} = \frac{1}{5f}\left\|Z_{ij}\right\|^2$
Impedance Phase	Impedance phase of each orthogonal E and H pair, with associated variances.
Impedance Rotation	Presents rotation direction of Zxy (i.e. it can be a fixed, user-specified rotation angle, or that defined as impedance strike).
Impedance Strike (θ)	Angle which minimizes: |Zxx(θ)|^2 + |Zyy(θ)|^2. In an ideal 2-D environment, one component will be parallel to strike (transverse electric, or TE mode), and the other will be perpendicular to strike (transverse magnetic, or TM mode).
Tipper Strike	Direction which maximizes the cross power of horizontal and vertical magnetic field components + 90 degrees.
Tipper Magnitude	Magnitude of the vertical magnetic field with respect to the total horizontal magnetic field. Tipper = SQRT($\|T_x\|^2 + \|T_y\|^2$)
Impedance Skew	Impedance tensor ratio, 3-D indicator, invariant with rotation. $\|Z_{xx}+Z_{yy}\|/\|Z_{xy}-Z_{yx}\|$
Impedance Ellipticity	Impedance tensor ratio, 3-D indicator, dependent upon rotation. $\|Z_{xx}(\theta)-Z_{yy}(\theta)\|/\|Z_{xy}(\theta)+Z_{yx}(\theta)\|$

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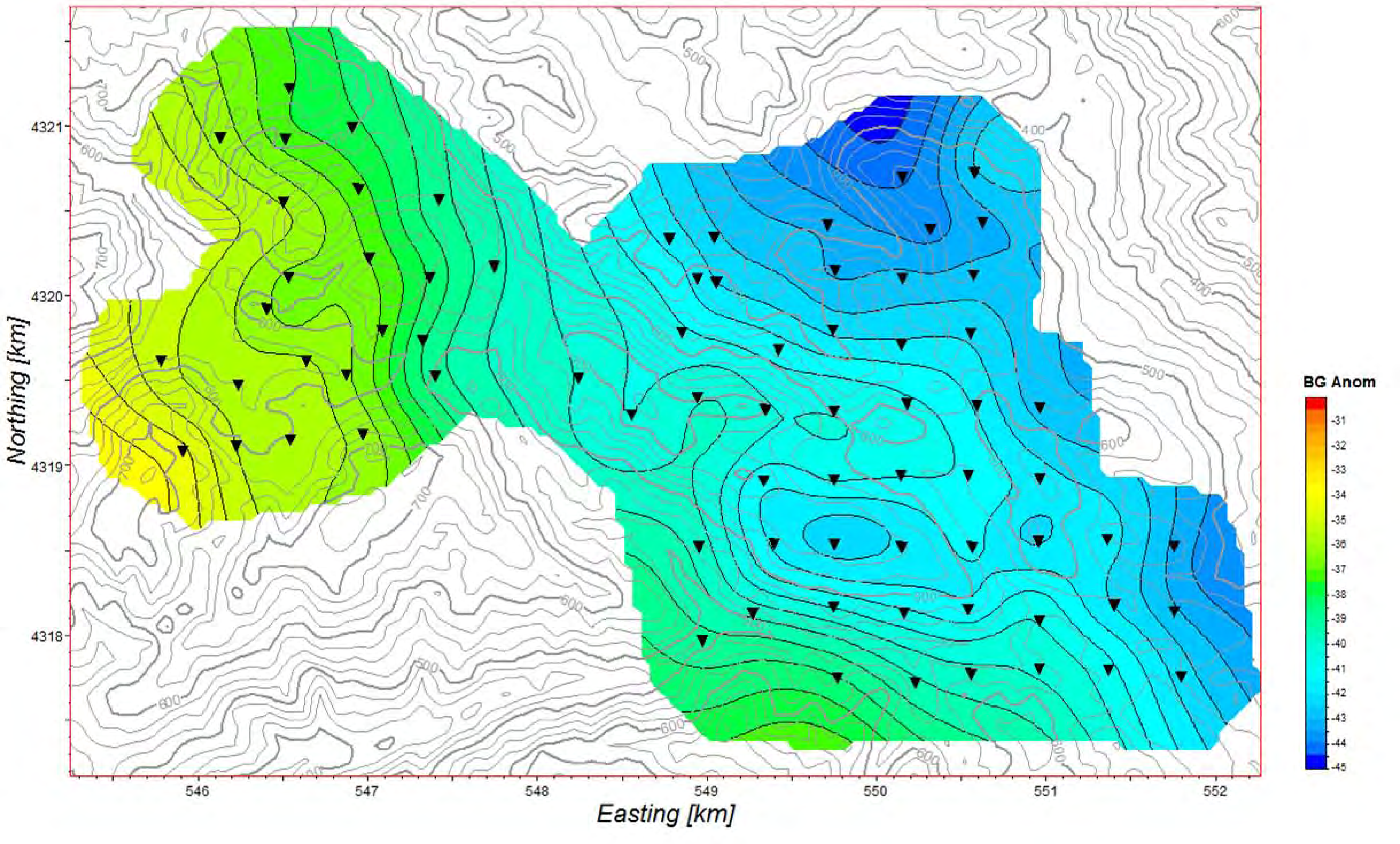
APPENDIX B:

WesternGeco Results of gravity modeling, Wilbur Hot Springs, California, USA

BG Anom 240 gcc



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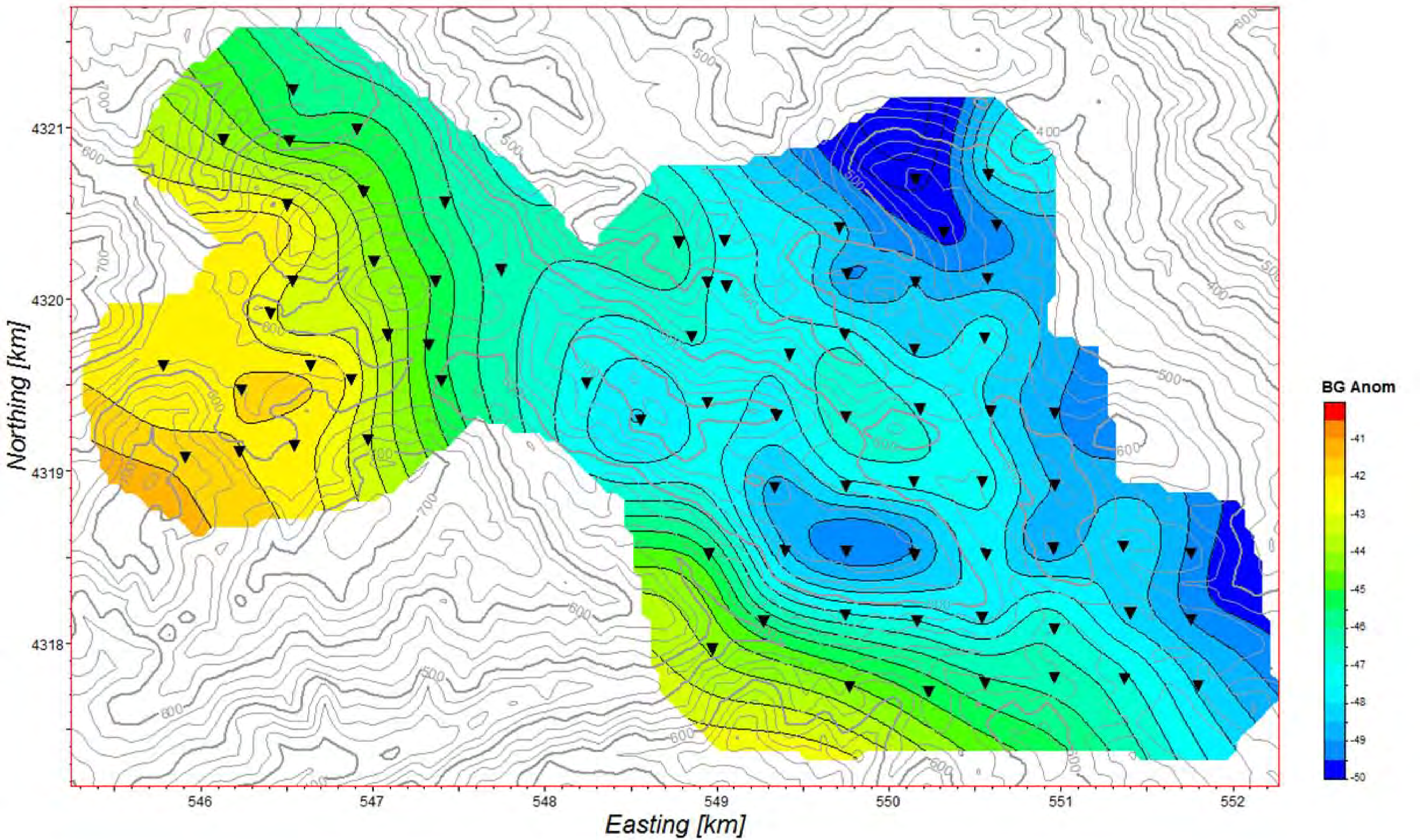

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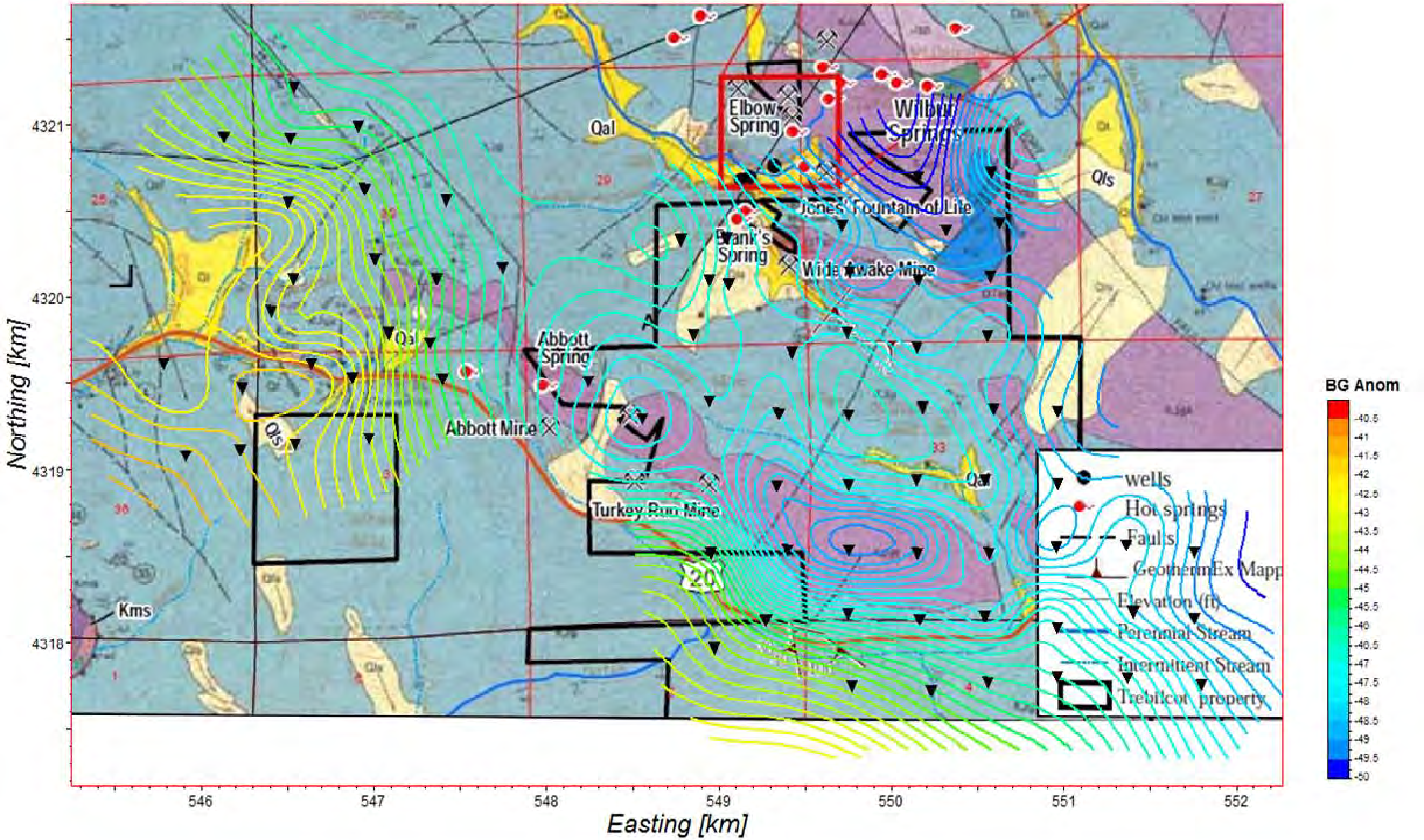

APPENDIX E:
GEO-10-003-1 Exploration Drilling Work Plan for the SMUD-Renovitas Project, Colusa and Lake Counties, California

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GEO-10-003-1 EXPLORATION DRILLING WORK PLAN FOR THE SMUD-RENOVITAS PROJECT

COLUSA AND LAKE COUNTIES, CALIFORNIA

FINAL

for

Renovitas, LLC and

The Sacramento Municipal Utility District (SMUD)

Sacramento, California

REGISTERED PROFESSIONAL ENGINEER
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EXP. 30 SEP 2013
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GeothermEx, Inc.

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JANUARY 25, 2013

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1. INTRODUCTION AND BACKGROUND

The Sacramento Municipal Utility District (SMUD) is interested in developing a geothermal power project in the Wilbur Hot Springs area of Colusa and Lake Counties, California. In partnership with SMUD, Renovitas LLC (Renovitas) obtained grant funding from the California Energy Commission (CEC) for a project to undertake certain geothermal exploration and resource characterization activities in the Wilbur Hot Springs area. On behalf of SMUD and Renovitas, GeothermEx is providing guidance for this project and conducting exploration and characterization activities.

This document describes an exploration well drilling work plan that will assist in further evaluating geothermal resources for geothermal power development in the Wilbur Hot Springs area. Activities to date include field geologic, geochemical, and geophysical data collection, two work plans and two technical report final deliverables, which are outlined below in order of delivery:

- The Final Geologic and Geochemical Work Plan for the SMUD-Renovitas Project (GeothermEx, 2012a)
- The Final GEO-10-003 Geologic and Geochemical Evaluation of Geothermal Resources for Geothermal Power Development (GeothermEx, 2012b)
- The Final Geophysical Work Plan for the SMUD-Renovitas Project (GeothermEx, 2012c)
- The Final GEO-10-003-01 Gravity and Electrical Methods Geophysical Surveys Report (GeothermEx, 2013)
- The Final GEO-10-003-1 Exploration Drilling Work Plan for the SMUD-Renovitas Project (this document)

The drilling program work outlined in this document, titled 'Final Exploration Drilling Work Plan for the SMUD-Renovitas Project' is intended to aid in the evaluation of the geothermal resource in the project area. Data and information gathered during the execution of this work plan will be used to plan the next stage of development work.

The project area is located in northern California about 90 miles north (N) of San Francisco, and 19 miles southwest (SW) of the Central Valley town of Williams. The area (shown by Figures 1 and 2) has long been known to have geothermal resources, and previous investigations of these geothermal resources have been undertaken by various parties. The purpose of the grant project is to evaluate the potential for developing electric power from geothermal resources in the project area using Trebilcot mineral rights that are presently held by SMUD. At present, the Trebilcot mineral rights properties (referred to herein as “Trebilcot land”) can only be accessed via public roads, and nearly all Trebilcot land has surface rights held by federal and state agencies, including the Bureau of Land Management (BLM) and California Department of Fish and Game (CA DFG). However, a small parcel of Trebilcot land located in the northeast corner of Section 29 has privately held surface rights. Except for the Section 29 parcel, the Trebilcot land falls within the joint Cache Creek Coordinated Management Plan and Ukiah Resource Management Plan (CCCMP/URMP) areas administered by the BLM and are subject to plan restrictions and any associated permit requirements (CCCMP, 2004 and URMP, 2006).

The execution of this work plan in the project area must be undertaken in a way that: 1) avoids disturbing areas of mining waste; 2) is consistent with identification, characterization, and remediation efforts; 3) is in agreement with public and private entity restrictions on the project area; and 4) allows execution of a drilling program that provides data valuable for SMUD’s geothermal resource exploration and characterization activities.

1.1 Purpose and Scope

The purpose of this document is to present a work plan for a drilling exploration program that outlines both proposed pre-drilling and drilling work requirements as well as how drilling will be conducted in the area without disturbing mining waste that is known to be present. It is GeothermEx’s understanding that this plan will be reviewed by the California Energy Commission (CEC), the California Department of Fish and Game (CA DFG), and the Central

Valley Regional Water Quality Control Board (CVRWQCB). The proposed drilling work outlined in this work plan is currently not funded but may be conducted at a later date.

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2. TEMPERATURE-GRADIENT WELL DRILLING

As part of the grant project, GeothermEx has collected and assessed geologic, geochemical, and geophysical data (GeothermEx, 2012b; 2013) and has evaluated logistical access to the project area for further development of the Wilbur Hot Springs area geothermal resource (as presented in this work plan).

The currently approved statement of work and schedule of products for the grant project includes the preparation of a temperature-gradient drilling work plan. However, based on GeothermEx's technical and regulatory understanding of the project area, it has been determined that temperature-gradient drilling would not be a suitable next-step exploration activity for the following reasons:

- Data compiled and interpreted by GeothermEx when preparing the Geologic and Geochemical Evaluation of Geothermal Resources for Geothermal Power Development document (GeothermEx, 2012b) and by GeothermEx and its subcontractor WesternGeco when preparing the Gravity and Electrical Methods Geophysical Surveys Report (GeothermEx, 2013) have been used to develop a model of the geothermal resource. To prepare this drilling work plan, GeothermEx has evaluated the resource model in the context of planning exploration drilling operations. The resulting evaluation of the resource model indicates that:
    1. The projected depth of the resource and the potential variability in the thermal conductivities of rocks above the resource would hamper the ability to extrapolate shallow temperature data (as collected by temperature-gradient drilling) to the depth of the resource; and
    2. The well-pronounced structural features and associated lithologic deformation in the project area make further refinement of the resource model through temperature-gradient well drilling of limited usefulness beyond the existing temperature-gradient data previously used to define the temperature anomaly

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in the area of Wilbur Hot Springs (as presented in GeothermEx, 2012b).

- The CCCMP/URMP, which includes all of the Trebilcot land except the parcel of land in Section 29, does not allow exploration activities in the form of temperature-gradient wells, though production slim hole wells may be allowed. The BLM's interpretation of the CCCMP and URMP documents and associated regulations precludes allowance of exploration activities requiring a permit, such as temperature-gradient holes (Title 43, Code of Federal Regulations, Section 3250.11(a))[1]. The CA DFG has indicated they have a similar interpretation of CCCMP regulations[2].

Based on the above, it is therefore recommended that the project proceed to deeper production well drilling in the form of slim hole production wells. Typical slim holes are commonly drilled from several hundred to over one-thousand meters depth, and are intended to penetrate the upper portion of the geothermal reservoir for the purpose of flow-testing the well. The bottom-hole diameter of a slim hole is designed to be sufficiently large for the well to self-flow or to be pumped, with the aim of testing and analyzing subsurface permeability, along with temperature and pressure. The diameter of the slim hole's production-casing interval

[1] During a meeting between BLM, SMUD, Renovitas, and CEC on April 24, 2012, Mr. Richard Estabrook of BLM indicated that exploratory drilling (in the form of temperature-gradient wells) on its land would be denied due to the fact that the project location falls in the land included in the CCCMP. Additionally, a letter from Mr. Richard Burns of BLM to Dr. Valentino Tiangco of SMUD, dated March 13, 2012 (BLM, 2012), indicated that "because of URMP closure, the BLM lands would be closed to exploration activities that require a permit, such as the drilling of temperature-gradient holes."

[2] At a meeting between CA DFG, Renovitas, and GeothermEx on October 16, 2012, Mr. Joshua Bush of CA DFG indicated that CA DFG is a party to the CCCMP via memorandum of consent and thus would not allow exploration drilling.

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would be large enough to allow the well to be used for production to a power plant, if sufficient temperature and permeability are encountered.

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3. PRE-DRILLING REQUIREMENTS

GeothermEx has been allowed to undertake "casual use" exploration field work (in the form of geologic mapping, geochemical sampling, and geophysical surveying) on all public lands held by BLM, without the need for a permit. Additionally, the CA DFG has allowed geologic mapping and geophysical surveying without the need for a permit (geochemical sampling on CA DFG lands had not been approved by CA DFG at the time the field work was performed).

As outlined in Sections 1 and 2, it is GeothermEx's understanding that exploratory drilling in the form of temperature-gradient wells is not permitted within CCCMP/URMP areas. It may, however, be possible to permit slim hole production wells on Trebilcot land within the CCCMP/URMP areas (where regulation against production wells may not be in place). Any agreement between BLM and a developer that allows the drilling of slim hole production wells would require the use of existing roads for drilling operations, because land modification to allow access would require compliance with the BLM's environmental assessment/environmental impact study (EA/EIS) process. Further confirmation and agreement with BLM regarding regulations, including CCCMP/URMP regulations and the EA/EIS process, would be required for permitting and environmental review compliance before drilling operations could proceed. In addition, compliance with the California Energy Quality Act (CEQA) would be required for the drilling activities proposed under this work plan. The California Division of Oil, Gas, and Geothermal Resources (DOGGR) is the lead state agency for CEQA review of geothermal drilling activities. In a January 18, 2012 letter to Renovitas regarding CEQA applicability and compliance, DOGGR requested an "initial study" be completed and submitted to DOGGR for its review and discussion. Associated DOGGR drilling permits would also be required to execute this work plan. Specific instructions for this work plan may need to be redefined to accommodate conditions of these permits.

Also, if drilling operations are to proceed, liability under California water law and the federal Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) will need to

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be addressed for those activities that could remobilize any mercury contamination present in the project area in natural deposits and/or mining waste.

No request for permission to access private land has been made for drilling program activities on the Trebilcot land. It is likely however, that agreement will need to be reached with the Wilbur Hot Springs Resort for access to the Wilbur Hot Springs Slim Hole-1 (WHS SH-1) and WHS SH-2 locations proposed in this work plan.

Figure 2 (on a shaded topography base) shows the following site features in the area of interest:

- Public roads, mines, known areas of mining waste, and hot springs,
- The wellhead location of the historic Magma, Cordero, and Bailey exploration wells and the surface trace of the Cordero well, and
- The proposed locations of four slim hole production wells.

The same map is presented on a satellite image base as Figure 3. All information related to mining activities (including mine locations, tailings, waste rock, cuts, and adits) was digitized and reviewed using maps and information available in multiple evaluation and engineering documents [California Department of Conservation (CDC) and California Geological Survey (CGS), 2003; Tetra Tech, 2003; CVRWQCB, 2007; ERM, 2010]. Section 5 presents a detailed discussion of how field personnel and equipment operators involved with drilling operations would recognize and avoid known areas of mines and mine waste. (The drilling operations that GeothermEx proposes to conduct on public lands are further discussed in Sections 3 and 4.) There are no known areas of mine waste near the proposed slim hole locations that are on BLM land (WHS SH-2, -3, and -4). Any discovered areas of mine workings and waste on BLM lands near these proposed locations would be avoided, the affected well location(s) would be moved accordingly, and a 100-foot buffer zone would be implemented and adhered to by field personnel to avoid disturbing existing or identified mine features.

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However, for WHS SH-1 (which is on private land) mine waste has been mapped near the proposed location (Figures 2 and 3). Reconnaissance is needed to determine if drilling operations at this location would be outside of the required 100-foot buffer surrounding mine waste. Advance approval and permitting of mitigation and reclamation techniques may also be needed to stabilize mine waste in order to perform drilling operations on this parcel of land.

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4. RATIONALE AND LOGISTICS FOR LOCATION OF WELLS

The locations for the first two slim hole production wells (WHS SH-1 and WHS SH-2) are based primarily on data from previous drilling and, secondarily, on the results of the geophysical surveys conducted under this agreement. These geology, geochemistry, geophysical, and drilling history data were first presented in two reports, the Geologic and Geochemical Evaluation of Geothermal Resources for Geothermal Power Development (GeothermEx, 2012b) and the Gravity and Electrical Methods Geophysical Surveys Report (GeothermEx, 2013). Data from these reports are used to present the rationale for drilling locations and depths.

Data provided by drilling consist of the geologic and temperature information obtained from the three holes previously drilled at Wilbur Springs: the Magma, Cordero [both the original hole (OH) and side-track (ST)], and Bailey, which were drilled in 1965, 1968, and 1980, respectively. The wellhead locations (as well as the surface trace of the Cordero OH and ST) are shown on Figures 2 and 3; the depths, reported lithologies, and temperatures of these wells are shown in Appendix A.

No follow-up work was undertaken after drilling these wells because, at that time, minimum temperatures of about 240°C were believed necessary for commercial development (for reference, 240°C is the approximate temperature of the nearby reservoir at The Geysers). Given today's pumping and generation technology, we have previously calculated that the Cordero and Bailey wells would have been be capable of producing on the order of one-half to one megawatt each (GeothermEx, 2012b). This figure would improve greatly by encountering better permeability in any new wells drilled.

A geologic and geophysical cross-section was presented in GeothermEx (2013) to illustrate the current interpretation of subsurface conditions along a line which extends from southwest (SW) (at geophysical survey point WS011a) to northeast (NE) (through Blank’s Spring, the Bailey, Cordero, and Magma explorations wells, and Elbow Spring). The surface location of this cross-section is displayed on Figures 2 and 3. The location of the first two proposed slim hole

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production wells (WSH SH-1 and WSH SH-2) have been added to this cross-section, as shown on Figure 4. The rationale for these locations and the logistics of drill rig staging are discussed below.

- WHS SH-1 would be drilled further to the NE of previous well locations, i.e. above and to the NE of Elbow Spring. This location is suggested by the 138°C isothermal contour rising in that direction (Figure 4). This option holds the possibility of encountering water in excess of 140°C at about 3,000 feet (ft) or 915 meters (m) below ground surface (bgs). For this location, surface modification for a well pad would be required, and direct access is not possible from the Trebilcot land. Access for this location would need to be from the road that runs along Sulphur Creek. Coordination with the surface rights holder (the Wilbur Hot Springs Resort, referred to by the owner's last name as 'Miller Property' on Figure 1) would be required to conduct this work. Additionally, mine waste has been mapped within this land parcel, as shown on Figures 2 and 3. Reconnaissance is needed to determine if drilling operations at this location would be outside of the required 100-foot buffer surrounding mine waste. Advanced approval and permitting of mitigation and reclamation techniques may also be required to stabilize mine waste in order to perform drilling operations on this parcel of land.
- WHS SH-2 would be drilled to the SW of Blank Spring to intersect the methane-bearing (inferred to have permeability) formation found in the Bailey well hole at a temperature of about 140°C. The well will also be drilled through an area of low resistivity, as shown on Figure 4. This would require drilling to about 5,000 ft (1,525 m) bgs. This location would be placed south (S) of geophysical survey locations WS050b and WS052b. For this location, direct access is not possible from the Trebilcot land, where previously existing roads at this location are washed-out, and the slope grade exceeds 30° when approaching from the S (this is not suitable for travel by a truck-mounted rig). Access for this location would need to be from the road that runs along Sulphur Creek. Surface

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modification may not be required, and a well pad could be built on the previously existing road at this location. Reconnaissance should be done to ascertain the condition of the road to the proposed well location in advance of mobilization.

The WHS SH-1 and WHS SH-2 drilling locations are logistically difficult to access because land along the NE extension of the Figure 4 cross-section is not accessible through the Trebilcot land. Surface rights at the points of access from the road along Sulphur Creek are held by the Wilbur Hot Springs.

Considering these access restrictions, a third proposed slim hole (WHS SH-3) may be a more feasible short-term drilling location. For this location, both the resistivity and gravity data (as reported in GeothermEx, 2013) show a NW-trending structure (inferred to be the western limb of the Wilbur Springs anticline) in the project area and, assuming this structure is controlling fluid flow, there is justification to extrapolate the temperature contours that exist below Elbow Spring to the SW onto the Trebilcot land. This provides justification for the WHS SH-3 location on Trebilcot land (Figures 2 and 3).

Further logistics and rationale for the location of the WHS SH-3 follows:

- The optimal location would be between survey locations WS001a and WS055a (Figures 5 and 6), but due to terrain, the realistic location could be placed NE of survey location WS004a and drilled to a depth of 3,300 ft (1,000 m) bgs. This location would target the area beneath a low-resistivity anomaly at 1,650 ft (500 m) bgs that is within what are expected to be serpentine beds. Little is known about the depth of the serpentine beds in this area, other than that regional dip of beds is perpendicular to the plunge of the Wilbur Springs anticline. This location has been chosen to validate the applicability of the magnetotelluric (MT) resistivity and gravity dataset for detecting geothermal fluid zones within serpentine beds, and to acquire borehole geologic information to further refine the subsurface geologic and resource models. For this location, no surface

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modification would be required, access can be gained, and the rig could be staged on the maintained road between Route 20 and the road along Sulphur Creek.

The rationale for the location of a fourth well (WHS SH-4) is as follows:

- WHS SH-4 is a lower-priority location than the above proposed wells, and would be drilled only if warranted following acquisition of temperature and permeability data at other well locations described above, in order to validate the applicability of the MT resistivity and gravity dataset for detecting geothermal fluid zones. This slim hole production well would be located as close to survey location WS025a as possible, but due to terrain, the realistic location could be placed north – northwest (N – NW) of survey location WS027a to a depth of 3,300 ft (1,000 m) bgs. This location would test an area of low resistivity (seen in Figure 6) to the SW that is expected to be within serpentine beds. For this location, surface modification would be required in the form of a road and a pad to gain access to the proposed well location. The road would be built from the closest intersection to the maintained road between Route 20 and the road along Sulphur Creek.

5. PROGRAM FOR DRILLING SLIM HOLE WELLS

5.1 Well Numbers and Coordinates

All proposed slim hole production wells would use the abbreviations 'WHS SH' for Wilbur Hot Springs Slim Hole. Coordinates presented are in WGS 84.

- WHS SH-1: 39° 2.210'N, 122° 25.696'W
- WHS SH-2: 39° 1.689'N, 122° 26.056'W
- WHS SH-3: 39° 1.764'N, 122° 25.223'W
- WHS SH-4: 39° 0.940'N, 122° 24.987'W

5.2 Target Well Depth

- WHS SH-1: 3,000 ft (915 m) bgs
- WHS SH-2: 5,000 ft (1,525 m) bgs
- WHS SH-3: 3,300 ft (1,000 m) bgs
- WHS SH-4: 3,300 ft (1,000 m) bgs

Note: All depths quoted in this work plan are measured with respect to ground level. Figure 7 shows the generic design for the slim hole production wells.

5.3 Objective

At each location, drill a new slim hole vertical well for resource confirmation and characterization, as well as for possible hot geothermal fluid production.

5.4 Summary and Geologic Prognosis

Wells WHS SH-1, -2, -3, and -4 are planned as slim hole wells with a diameter sufficiently large to allow for economic production of geothermal fluid. These wells are planned to assess subsurface conditions in the Wilbur Hot Springs project area and, if successful, to provide

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enough geothermal fluid production for reservoir characterization. The wells will be drilled from new pads to be constructed, as needed, on Trebilcot land (Figures 2 through 6). Existing roads will be used to avoid surface modification. However, at some locations, road and pad building is required, as described in Section 3. The final site selection will be made based on site accessibility (terrain and road limitations) as well as proximity to the proposed geographic coordinates. [Note: regulations may limit pad construction to areas with existing grading, such as roads.]

Details on prior drilling in the Wilbur Hot Spring area are presented in detail in GeothermEx (2012b). Specific details on these wells are included in the discussion below, as needed. Figures 2 and 3 show the location of three prior exploration wells drilled in the vicinity of Wilbur Hot Springs.

The regional and local geologic sequence is described in summary in Section 3 and in more detail within GeothermEx (2012b). The rationale for well-target selection is also discussed in Section 3.

Fluid entries and losses of circulation occurred during drilling of the Cordero well, and could potentially occur at any depth in wells proposed in this work plan. The main permeable zone in the Cordero well occurs in basalt between the elevations of -900 ft (274 m) and -1,800 ft (550 m) to mean sea level (msl), as shown on Figure 4. However, permeability (as defined by drilling fluid losses) was not encountered in the Bailey #1 well above a depth of about -5,600 ft (-1,700 m) msl (as shown in Appendix A), and the losses encountered below that depth were mainly in basalt. This same basal unit, and the methane-bearing siltstone/mudstone unit, may provide the permeability needed for thermal fluid extraction from the serpentine below. However, whether sufficient permeability exists to extract economic amounts of fluid from any of the units at the proposed drilling locations remains to be determined.

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5.5 Drilling Procedure

5.5.1. Prepare drilling pad and access road according to rig requirements and engineer's specifications (Figure 8). Soil compaction must be suitable to support the rig gross dead-weight plus 50,000-pound live loads. Access roads must be able to support heavy and frequent traffic. The area must be properly drained, avoiding accumulation of water around the work areas.

5.5.2. Drill an 18-inch hole to a depth of 20-30 m, using a rat-hole digging auger. Cement a 14-inch, Schedule 30, conductor pipe in the hole using ready-mix cement. Maintain the cement level in the annular space. Build cellar and mud sump per specifications from the drilling contractor.

5.5.3. Mobilize drilling equipment to the well site and rig up (see Table 1 for minimum rig specifications). Nipple up 14-inch flow diverter stack (Figure 9).

5.5.4. Make up 12-1/4-inch drilling assembly. Do not install nozzles on bit (see Table 2 for recommended bit selection).

5.5.5. Start drilling with low-viscosity spud mud (see Appendix B), adding lime as needed to reach the viscosity required to keep the hole clean.

5.5.6. Cure losses of circulation as they occur with lost-circulation material (LCM). Place cement plugs where LCM is not sufficient to cure the loss zones. If losses cannot be cured, drill ahead without returns.

5.5.7. Drill 12-1/4-inch hole to 100 m (approximately). Run 100 m of 9-5/8-inch, 36 lb/ft, K-55 buttress-threaded casing (Table 3). Cement casing with Class G or Class H cement and additives (silica flour, accelerant, dispersant) as specified by cementing contractor, using stab-in method. Follow instructions from cementing contractor for pumping the cement volumes as specified in Figure 10. (Note: cement calculations are provided in standard oilfield units to simplify field operations with cementing service companies.) Wait on cement for 6 hours. If full cement returns are not observed during the cementing operation, prepare wellhead equipment to conduct top cementing job. Fill the annulus with cement and wait 12 hours before cutting off the 9-5/8-inch casing at the desired level. If good cement returns are observed, but the cement top drops down the annulus, wait 8 hours and conduct a cementing job from the surface using tremmie pipe.

5.5.8. Weld on 9-5/8-inch x 10-inch casing head. Nipple up the 11-inch BOP equipment as shown in Figure 11. Pressure-test the BOP equipment with mud to 500 psi. Notify BLM representative or other appropriate regulator in time to witness the test. Document test on daily drilling report.

5.5.9. Make up 8-1/2” drilling assembly, equip bit with nozzles according to the hydraulic program. Drill out float shoe and cement with used mill-tooth bit and slick assembly; treat mud for cement contamination with sodium bicarbonate and soda ash. Pull out when the shoe and sufficient hole have been drilled to accommodate a stabilized string.

5.5.10. Run in hole with new 8-1/2-inch bit, reamer, 8-1/2-inch stabilizer, and 6-inch drill collars. Drill a straight hole to a depth of approximately 500 m (the final depth will be selected by the site geologist, drilling supervisor and drilling engineer based on observed conditions). Use a dispersed mud system, as recommended in Appendix B of this document. Cure losses of circulation as they occur with LCM. Place cement plugs where LCM is not sufficient to cure the losses. Maintain the verticality of the well within 3°, run periodic drift surveys to monitor drift angle. Adjust the bottom-hole drilling assembly and hydraulic parameters if deviation increases above 3°.

5.5.11. At the selected casing depth, circulate hole clean and short-trip collars. Tag bottom and circulate bottoms up before tripping out to run casing. Notify geophysical logging contractor and run geophysical logs before running casing.

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5.5.12. Run 7-inch, 23.0 lb/ft, K-55 (or L-80) BTC, R-3 casing to selected casing depth, filling casing every third joint. Tack-weld bottom 3 collars, and use thread-lock compound on first 3 collars.

5.5.13. Cement casing with Class G or Class H cement using stab-in method, per cementing program specified in Figure 12. Monitor returns and prepare to run 1-inch pipe into the annular space to do top-job-cementing, if required. If cement returns are observed and the cement level falls after the primary cementation, back-fill the annulus with cement immediately.

5.5.14. Wait on cement for 18 hours total. If a top job is required, wait on cement to set (12 hours), fill the annulus with cement slurry using tremmie pipe and wait 8 hours before cutting off the casing at the desired level.

5.5.15. Land 7-inch casing. Weld on 7-inch x 6-inch casing head equipped with 2-inch flanged and valved outlets. Weld the casing head according to the American Petroleum Institute (API) recommended procedure (Appendix C).

5.5.16. Install 6-inch master valve and 6-inch x 10-inch adaptor spool [or double-studded adaptor (DSA) flange]. Nipple up 11-inch blow-out preventer (BOP) equipment as shown in Figure 13. Pressure test BOP equipment to 1,000 psi with mud. Notify BLM representative or other appropriate regulator in time for him to witness the test. Document test on daily drilling report.

5.5.17. Make up 6-1/8-inch slick drilling assembly, installing nozzles on bit per hydraulics program. Drill out 7-inch float collar and cement. Treat mud with sodium bicarbonate and soda ash to control viscosity while drilling cement. Pull out when 7-inch shoe plus enough hole has been drilled to accommodate a stabilized assembly.

5.5.18. Run in hole with new 6-1/8-inch bit, reamer, 6-1/8-inch stabilizer and 4-1/4-inch drill collars. Start drilling the 6-1/8-inch hole using a dispersed mud system, as described

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in Appendix B of this work plan. Control hole deviation using a stiff bottom-hole assembly if required.

5.5.19. Drill until the presence of a permeable zone is indicated by a major loss of circulation. After the first loss of circulation is observed, change the circulating fluid to water and continue drilling. Pump high-viscosity mud sweeps if hole is not cleaning properly and fill is noticed on the bottom after connections. Follow the parameters for preparing viscous mud pills described in Appendix B of this program. Adjust the drilling procedure as required to mitigate any of the following conditions that may occur:

- excessive fill on bottom;
- significant torque and drag;
- inadequate water supply.

5.5.20. Drill to a depth of approximately 3,280 ft (1,000 m), adjusting the bottom-hole assembly and the fluid parameters to the conditions observed while drilling. If no indications of significant permeability are observed, the well may be deepened beyond this point, to a maximum depth of 5,000 ft (1,525 m) (the intended hole depth). The total depth of the well will be selected based on the resource and drilling conditions encountered.

5.5.21. Circulate hole clean. Notify logging contractor and run geophysical logs before running slotted liner.

5.5.22. Install 5-inch, K-55, 15.0 lb/ft, Hydril SFJ slotted liner to total depth, hanging it approximately 100 feet above the shoe of the 7-inch casing. The slotting pattern for the liner is shown in Figure 14. Flush the open portion of the well with clean water. Pull out of hole, laying down drill pipe.

5.5.23. A short logging period may be conducted after running the liner and before releasing the rig. In this case, water will be injected while running temperature/pressure/spinner logs as directed by the well test engineer.

5.5.24. Rig down and demobilize drilling equipment. Cleanup site.

5.6 Drilling Fluids and Corrosion Control

The mud program presented in Appendix B is to be used as a guideline only. Actual well conditions encountered during drilling will dictate the final type and rheological properties of the drilling fluid. Environmental permits issued by regulatory agencies may also require modification to activities conducted under this work plan. Mud drilling will be utilized until the first important loss of circulation occurs. Drilling will proceed using plain water below that point, pumping high-viscosity mud sweeps at every connection, or a combination of water and air, or water and mud. The following rheological conditions should be maintained while using a dispersed mud system:

5.6.1 Dispersed Mud

Weight	8.7 – 8.9 pounds per gallon (ppg)
pH	9.5 - 10.5
Marsh viscosity	35 - 38 seconds
Plastic viscosity	10 - 15 Centi Poise (cp)
Yield point	3 - 10 lbs/100 square feet (sq. ft.)
10 min Gel	10 lbs/100 sq. ft.
Water loss	5 - 7 cc/30 minute
Wall cake	0.5 - 1.0 millimeters (mm) (1/32")
Sand content	0.25% max. (control with desander/desilter)

Use chrome-free ligno-sulfonate / lignite products to condition and thin the mud. A polymer mud system may be used for drilling the 12-1/4-inch or the 8-1/2-inch holes, to improve rate of penetration and well cleanup, based on the observed drilling conditions.

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5.6.2. Aerated Water or Aerated Mud

In the event that aerated drilling is required or selected to deepen the well within the open-hole interval, the following procedure should be used.

A minimum water flow rate of 350 (gallons per minute (gpm) [or 1,300 liters per minute (lpm)] for the 6-1/4” hole is usually sufficient to provide adequate cuttings clearance as well as bit and hole cooling. Use a soap concentration of approximately 0.015% of the water flow rate (e.g. approximately 3 gal/hour in a water flow rate of 350 gpm).

The drilling supervisor will specify airflow volume and the corresponding liquid fraction to maintain balanced downhole pressures. The air volume will be in the range of 1,000 – 2,000 cubic feet per minute (cfm) at a boosted pressure of 3,000 pounds per square inch (psi).

Place string float valves (flapper or type G) at varying depths in the drill string, in order to minimize the time required to unload the drill string when making a connection.

When unloading the hole, approximately 1.5 gallons of soap solution should be poured into the drill pipe prior to connecting the kelly.

The strategy for unloading and the use of jet subs will be determined by downhole conditions, and will be specified by the air drilling engineer on site. Note: jet subs should not be placed in the drill string below the 7-inch casing shoe.

Keep to an absolute minimum the time periods in which the bit is left without fluid circulating in the hot hole. When tripping into the hole, break circulation with water on a regular basis. Maintain a flow of cold water down the backside at all times during trips.

Once circulation has been established and stabilized, the circulating fluid must be maintained at a pH of approximately 10. The returns will be tested on a regular basis and the pH will be recorded on the Daily Record Sheet. If the reservoir fluids give indications of high corrosion rates in the presence of air, use amine inhibitor to mitigate the problem by adjusting pH.

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6. RECOGNIZING AND AVOIDING AREAS WITH MINING WASTE

GeothermEx and any other subcontractor involved with execution of this work plan will avoid disturbing any and all public and private mine sites and associated waste during any geothermal drilling efforts.

As shown in Figure 2 and 3, there are a number of documented sites of prior mining in this area, and most have known mining waste. The location of this mining waste will be considered at all times during drilling activities, so that drilling work personnel know their location relative to any areas of mining activity. Additionally, a 100-foot buffer zone will be maintained around all known and identified mine features on all public and private lands (*i.e.*, there will be no walking, ground disturbance, or exploration activity of any kind around any area of mining waste, including within the 100-foot buffer).

The sites of prior mining that have been catalogued in the Sulphur Creek Mining District in the vicinity of the geothermal exploration area are listed below and shown in Figures 2 and 3.

- Central Mine
- Manzanita Mine
- West End Mine
- Cherry Hill Mine
- Empire Mine
- Wide Awake Mine
- Abbott Mine
- Turkey Run Mine

The following paragraph is an excerpt from the CDC/CGS (2003) document that summarizes the history of mining in the Sulfur Creek Mining District:

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> *"The mines* [as indicated above] *were initially discovered in the 1860s and 1870s and were worked intermittently, some until the early 1970s. Mining operations in the district were mostly by underground methods with limited surface mining activity…The Abbott-Turkey Run is the largest underground mine in the district and has between one and two miles of underground workings distributed over a 500-foot vertical interval. It also had the largest mercury production in the district, probably in excess of 1.8 million kilograms. Total district mercury production is approximately 2 million kilograms".*

All drilling personnel involved in exploration activities in the Sulfur Creek Mining District would be made aware of these historic mining sites and their features to ensure they would avoid disturbing any mining-related waste. During drilling operations, all field personnel would use Figures 2 and 3, or variations of these figures, to note and avoid locations of mine workings and waste.

GeothermEx staff has reviewed documentation authored by the California Department of Transportation (CalTrans, 2008) that provides detailed descriptions of the archeological features associated with hard-rock mining history and procedures of mining in California, so that all personnel may accurately identify and avoid any such areas encountered. GeothermEx would review the pertinent excerpt from the CalTrans (2008) document with field personnel and with any other subcontractor in advance of conducting fieldwork. The pertinent sections of the CalTrans (2008) document are included within the geological and geochemical and geophysical work plans (respectively, GeothermEx, 2012a; 2012c).

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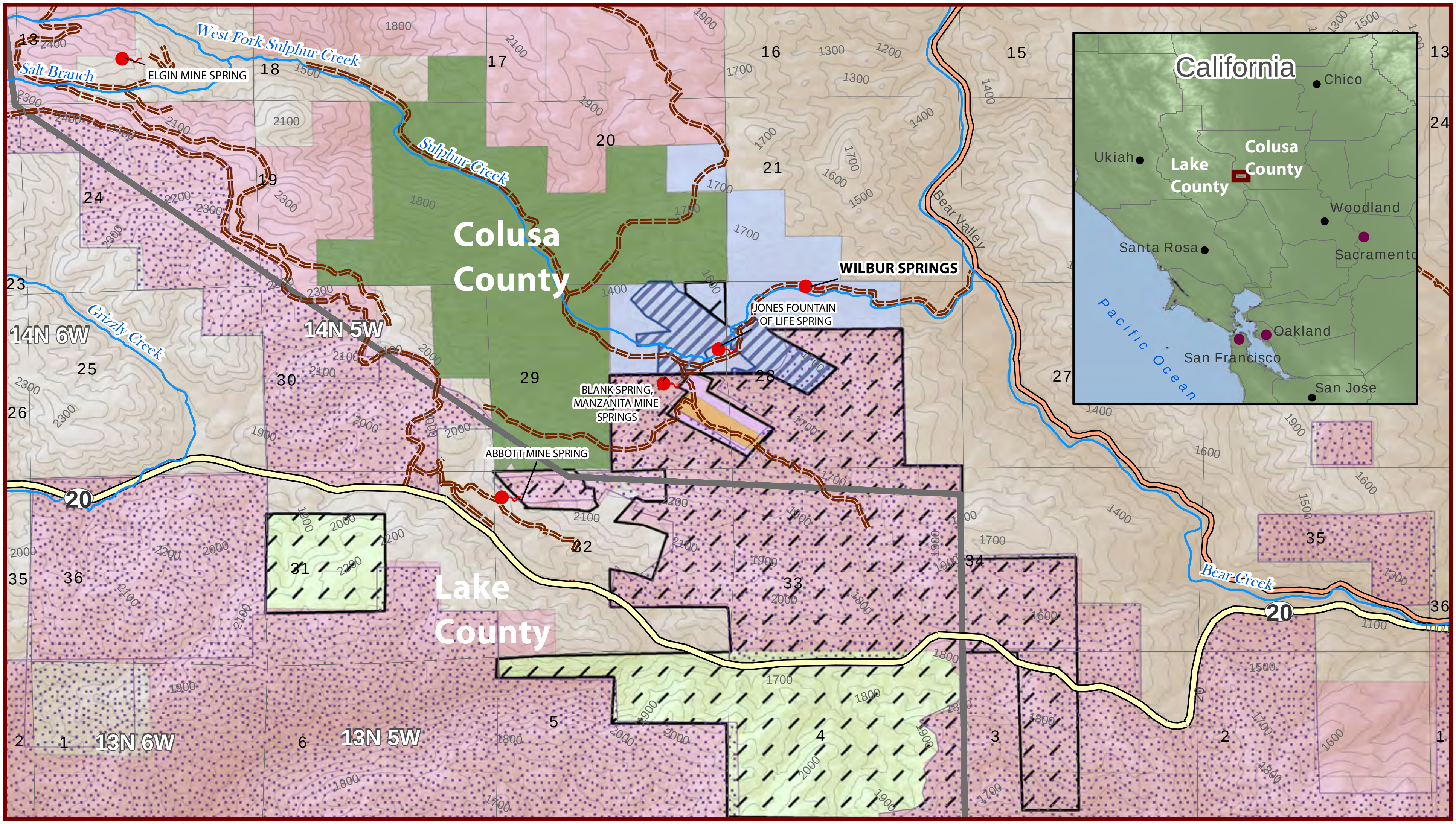
FIGURES



Miles
0 0.25 0.5 1 1.5
GCS North American 1983

Legend

- Hot Spring
- Rivers & Streams
- County Line
- Township & Range
- Section #s
- Highway 20
- Bear Valley Road
- Local Public Road

Data from SMUD

- Trebilcot Property (Mineral)
- Bailey Property (Mineral)
- David Brown (Mineral & Surface)
- Merced General Construction (Mineral & Surface)

Data from CA Protected Areas Database

- Private - Unknown
- California Dept. of Fish and Game (Surface)
- US Bureau of Land Management (Mixed)

Data from BLM

- Cache Creek Management Area Plan
- Miller Property (Surface)
- Miller & American Land Cons. Trust (Surface)

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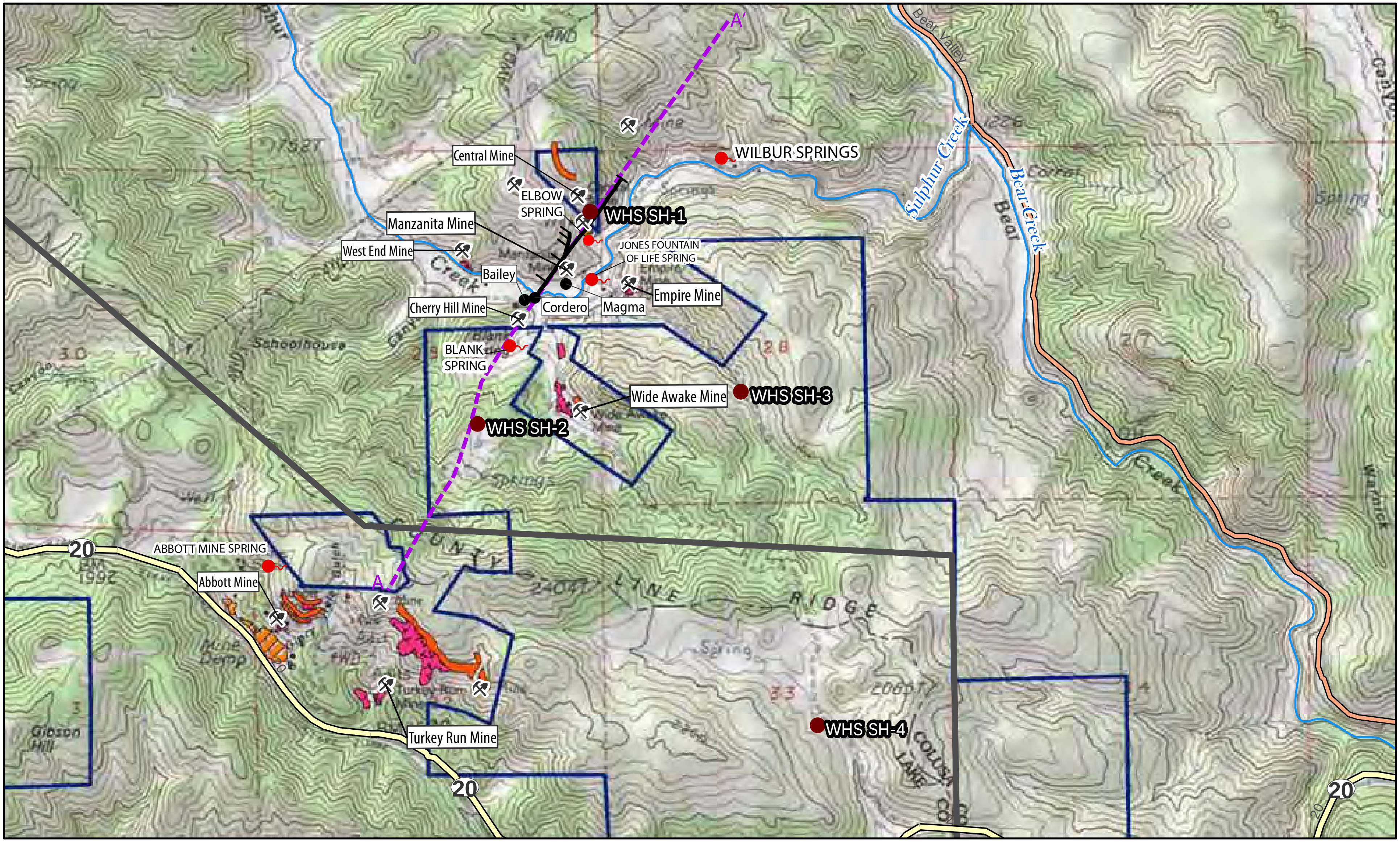
Figure 1: Location map showing surface and mineral ownership near Wilbur Springs, California

CLIENT: SMUD / Renovitas	PROJECT: Drilling Work Plan
DATE: 01/05/2013	FIGURE: WorkPlan.mxd



0 0.25 0.5 1 Miles

Legend

Hot Spring
Mine
County Line
Highway 20
Bear Valley Road
A-A'

Data from SMUD
Trebilcot Property (Mineral)

Mine Features from Tetra Tech 2003
Open Cut
Mine Structures
Mine Tailings
Waste Rock

Well traces
Deep geothermal exploration wells
Proposed Slimholes Well Locations

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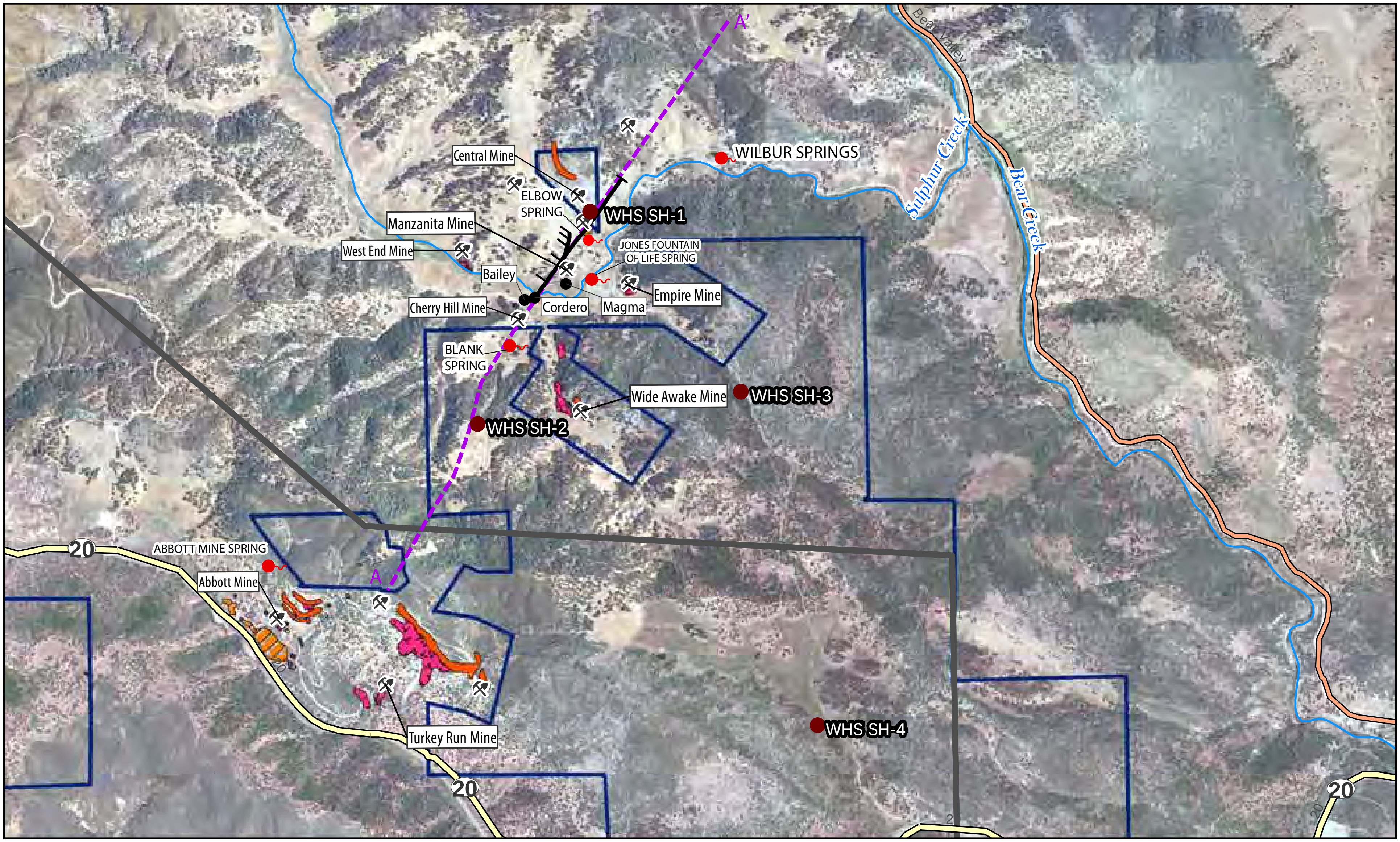
Figure 2: Project Area Features Wilbur Spring, CA (topographic background)	
CLIENT: SMUD / Renovitas	PROJECT: Drilling Program
DATE: 01/09/2013	FIGURE: DrillingProgramFig2.mxd

NAD 1983 UTM Zone 10N
1:25,000



0 0.25 0.5 1 Miles

Legend

Hot Spring
Mine
County Line
Highway 20
Bear Valley Road
A-A'

Data from SMUD
Trebilcot Property (Mineral)

Mine Features from Tetra Tech 2003
Open Cut
Mine Structures
Mine Tailings
Waste Rock

Well traces
Deep geothermal exploration wells
Proposed Slimholes Well Locations

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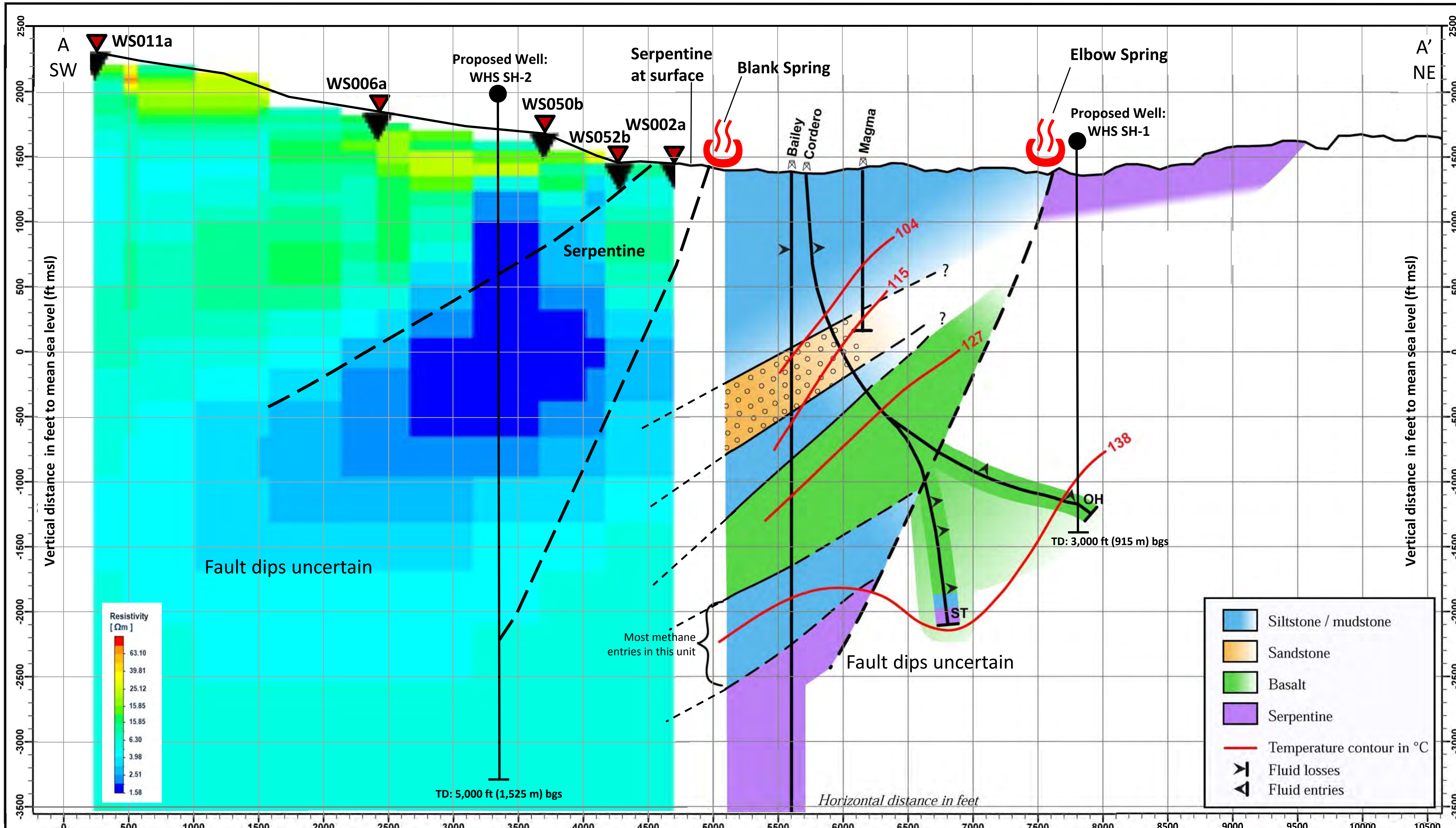
Figure 3: Project Area Features Wilbur Spring, CA (aerial photo background)

CLIENT:	SMUD / Renovitas	PROJECT:	Drilling Program
DATE:	01/09/2013	FIGURE:	DrillingProgramFig2.mxd

NAD 1983 UTM Zone 10N

1:25,000



Projection:
NAD 27 State Plane Zone 2
Plot Date:
Dec 23, 2012

Figure 4: A – A' cross-section with geologic, geophysical, temperature, and proposed slim-hole locations

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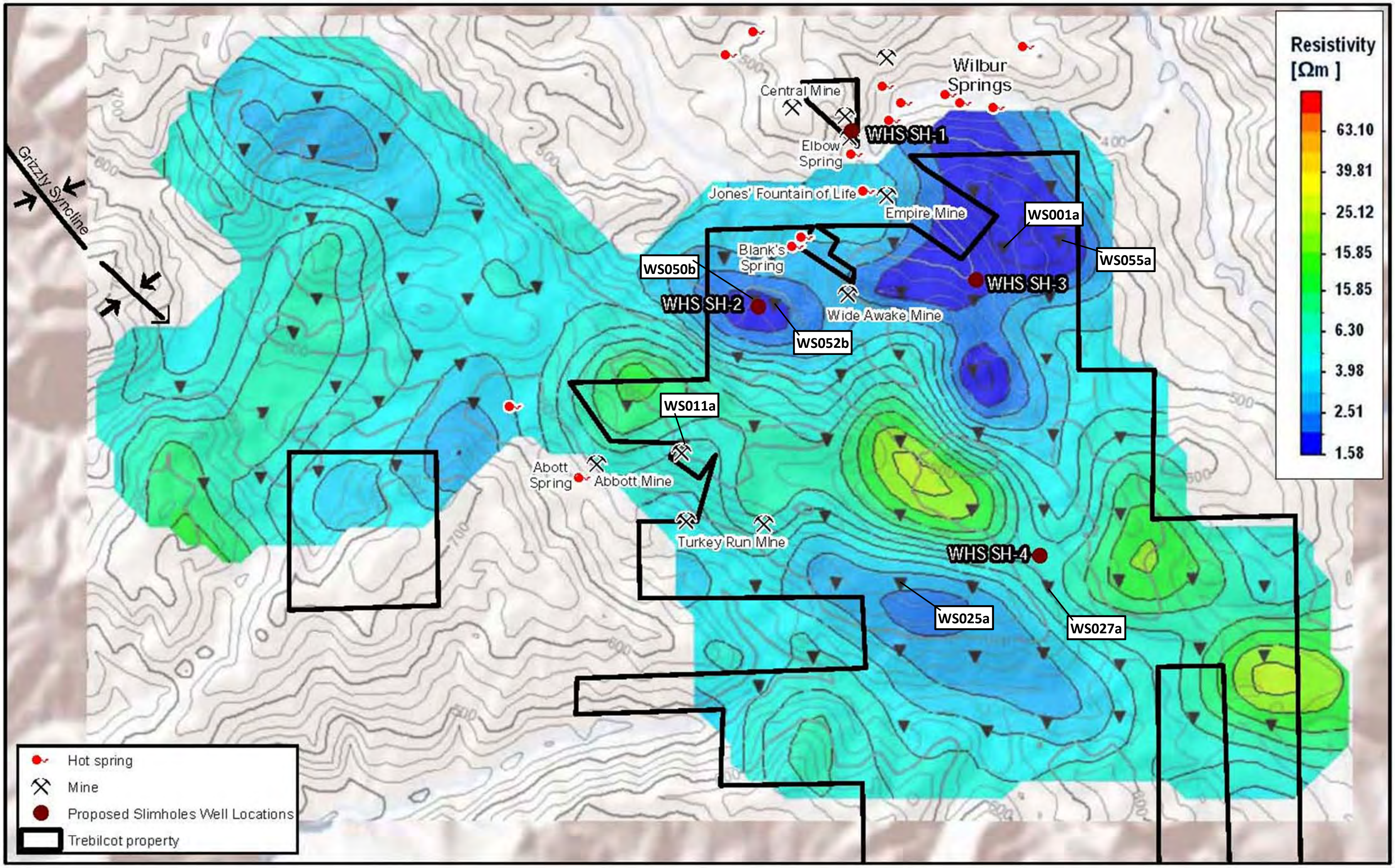
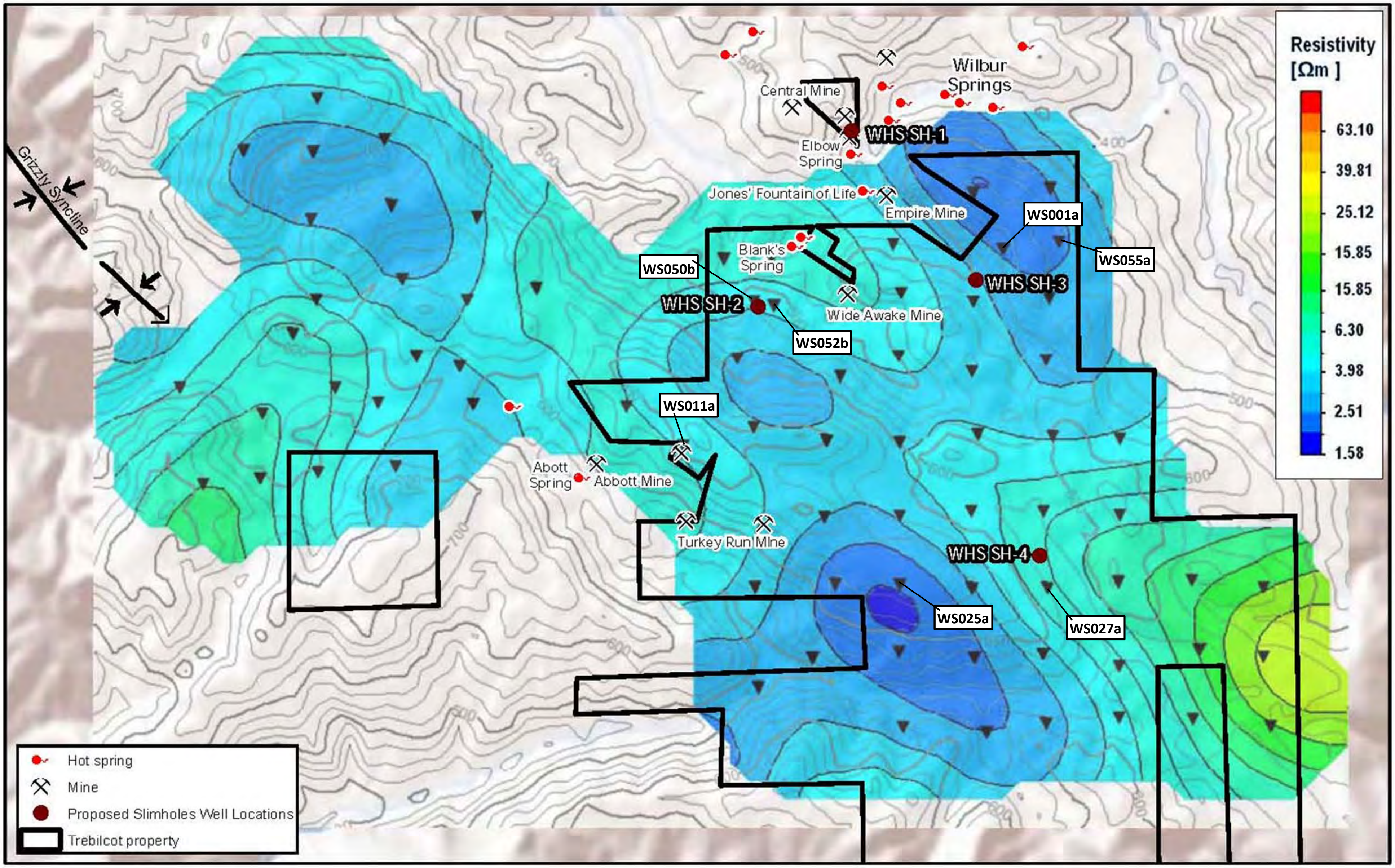


Source: WesternGeco Preliminary Report
Projection: NAD83 UTM Zone 10N

Figure 5: Study Area Resistivity Map at 500 m bgs



Source: WesternGeco
Preliminary Report
Projection:
NAD83 UTM Zone 10N

0 0.5
Miles
1:30,000

Figure 6: Study Area Resistivity Map at 1,000 m bgs

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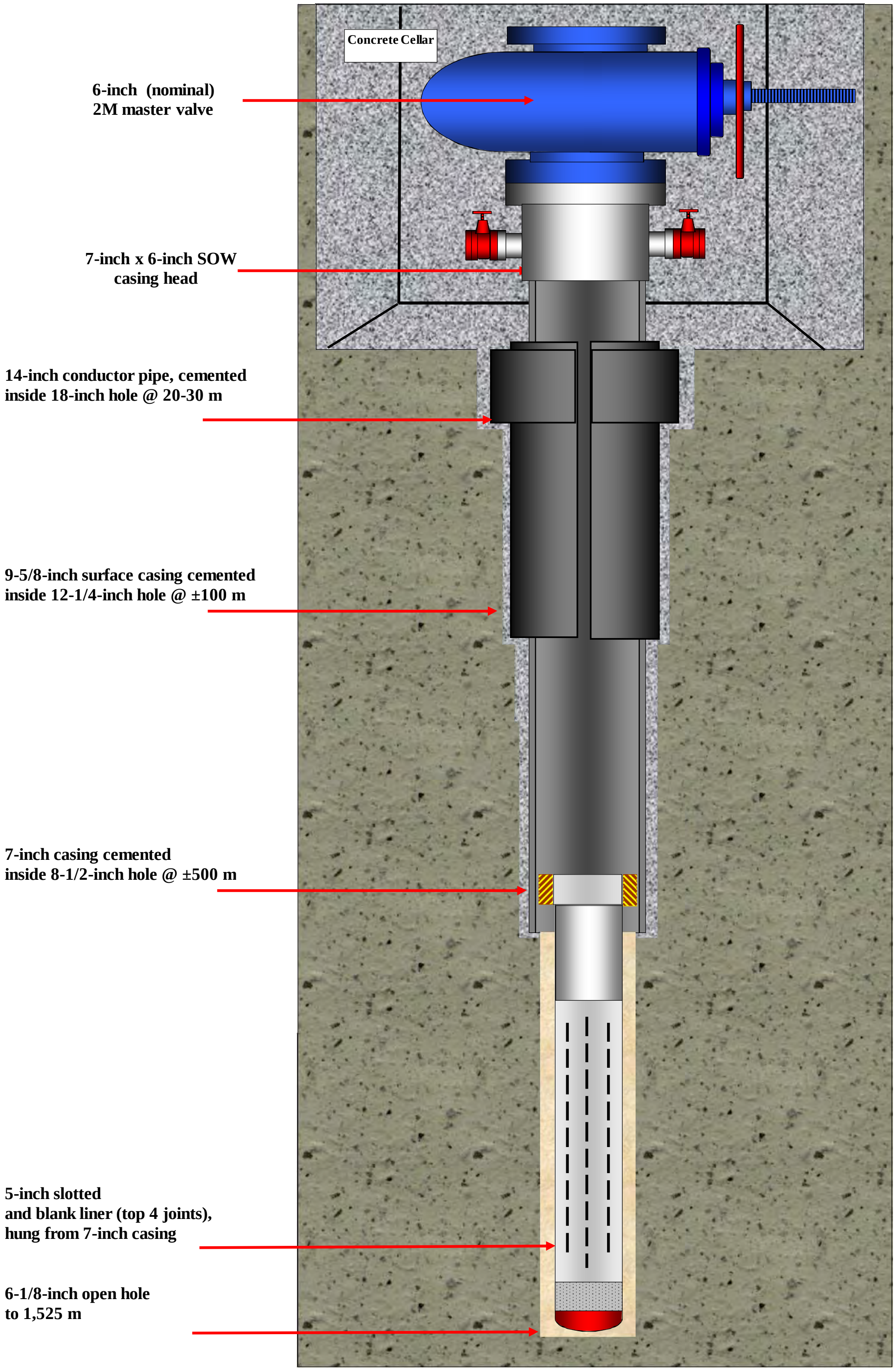
Figure 7. Wilbur Hot Springs Geothermal Project - Design of Exploratory/Production Slim Well



GeothermEx, Inc. 2013

Figure 8. Wilbur Hot Springs Slim Well - Drilling Pad Layout (Not to Scale)

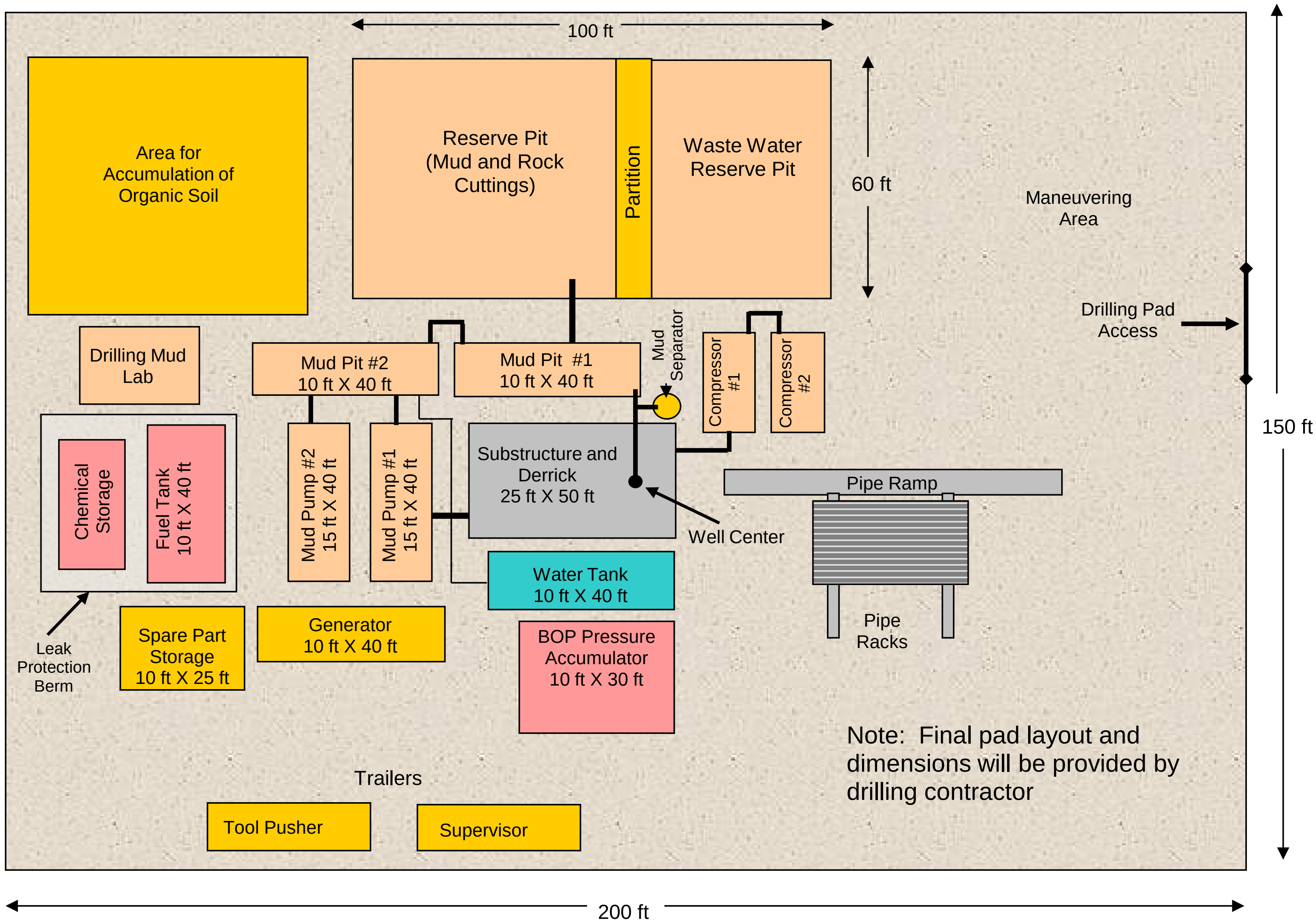


Figure 9. Equipment for Drilling Below Conductor Pipe

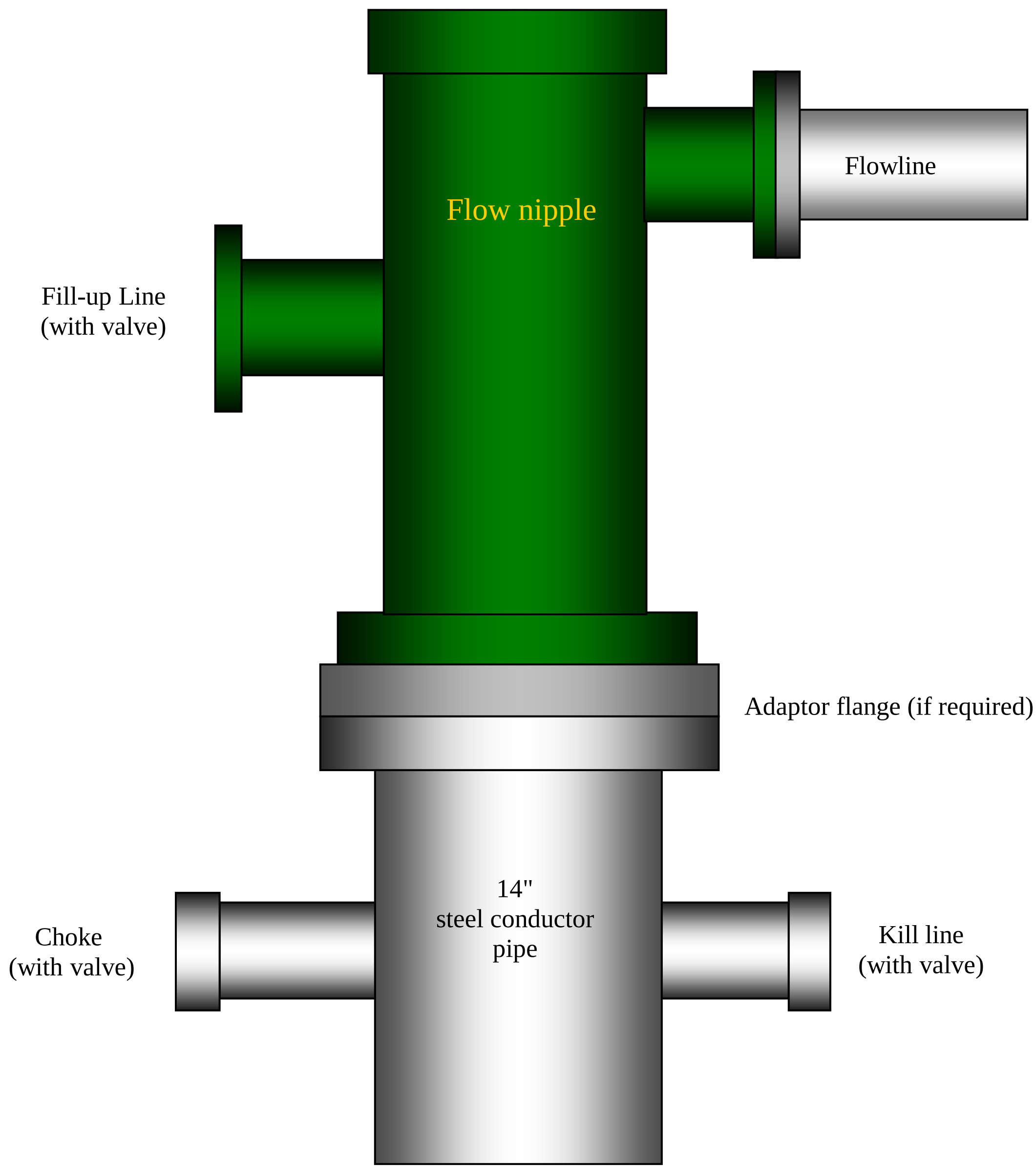


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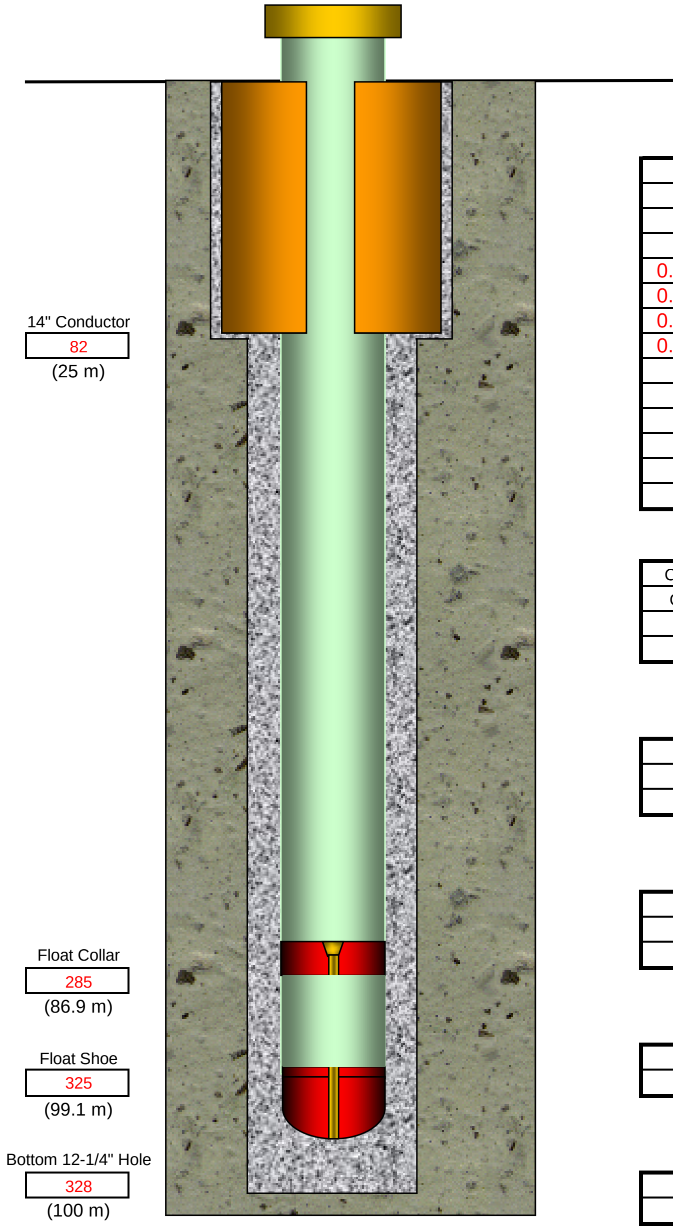
Figure 10. Cementing Calculations for 9-5/8-inch Surface Casing



Cement Worksheet

Initial Parameters

100	Feet of Tail Cement
100	% Excess Lead Cement in Open Hole
0	% Excess Lead Cement in Cased Hole
50	% Excess Tail Cement in Open Hole
0.04167	Drill Pipe Capacity (ft^3/ft)
0.43406	Casing Capacity (ft^3/ft)
0.33538	Volume Between Casings (ft^3/ft)
0.31319	Volume Bet.Csg & Open Hole (ft^3/ft)
1.34	Lead Cement Yield (ft^3/sk)
1.15	Tail Cement Yield (ft^3/sk)
6.3	Lead Water gal/sk
5.0	Tail Water gal/sk
14.8	Lead Cement Weight (lbs/gal)
15.8	Tail Cement Weight (lbs/gal)

Lead Slurry Calculations	**(ft^3)**
Calculated Lead Slurry in Open Hole	76.11
Calculated Lead Slurry Bet. Csngs.	27.50
Excess Lead Slurry in Open Hole	76.11
Excess Lead Slurry in Cased Hole	0.00

Tail Slurry Calculations	**(ft^3)**
Calculated Tail Slurry	31.32
Excess Tail Slurry	15.66
Slurry in Float Shoe/Collar	17.36

Calculated Totals	**(ft^3)**
Total Lead Slurry	179.71
Total Tail Slurry	64.34
Total Slurry for the Job	244.05

Displacement Water Volumes	**(ft^3)**
Wiper Plug Method	123.71
Stab-in Method	11.88

Cement Weight	**(lbs)**	**(sks)**
Lead Cement	12,606.63	134.11
Tail Cement	5,259.17	55.95
Total Cement	17,865.80	190.06

Slurry Water	**(bbl)**	**(gal)**
Lead Cement	20.12	844.91
Tail Cement	6.66	279.74
Total Water	26.78	1,124.66

Casing Details :

Tack-weld bottom three joints. Run centralizers as recommended by cement engineer

Cement Details :

Pump 200 cu. ft of water ahead, followed by 100 cu. ft of pre-flush.

Do not reciprocate casing while cementing.

Do not exceed 1,500 psi while cementing or displacing.

Pressure-test all lines to 2,000 psi before starting cement operation.

Use Class "G" cement, pre-hydrated gel, silica flour, cement retarder, friction reducer and defoamer as recommended by cementing operator.

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Figure 11. Blowout Prevention Equipment for Drilling Below 9-5/8-inch Casing

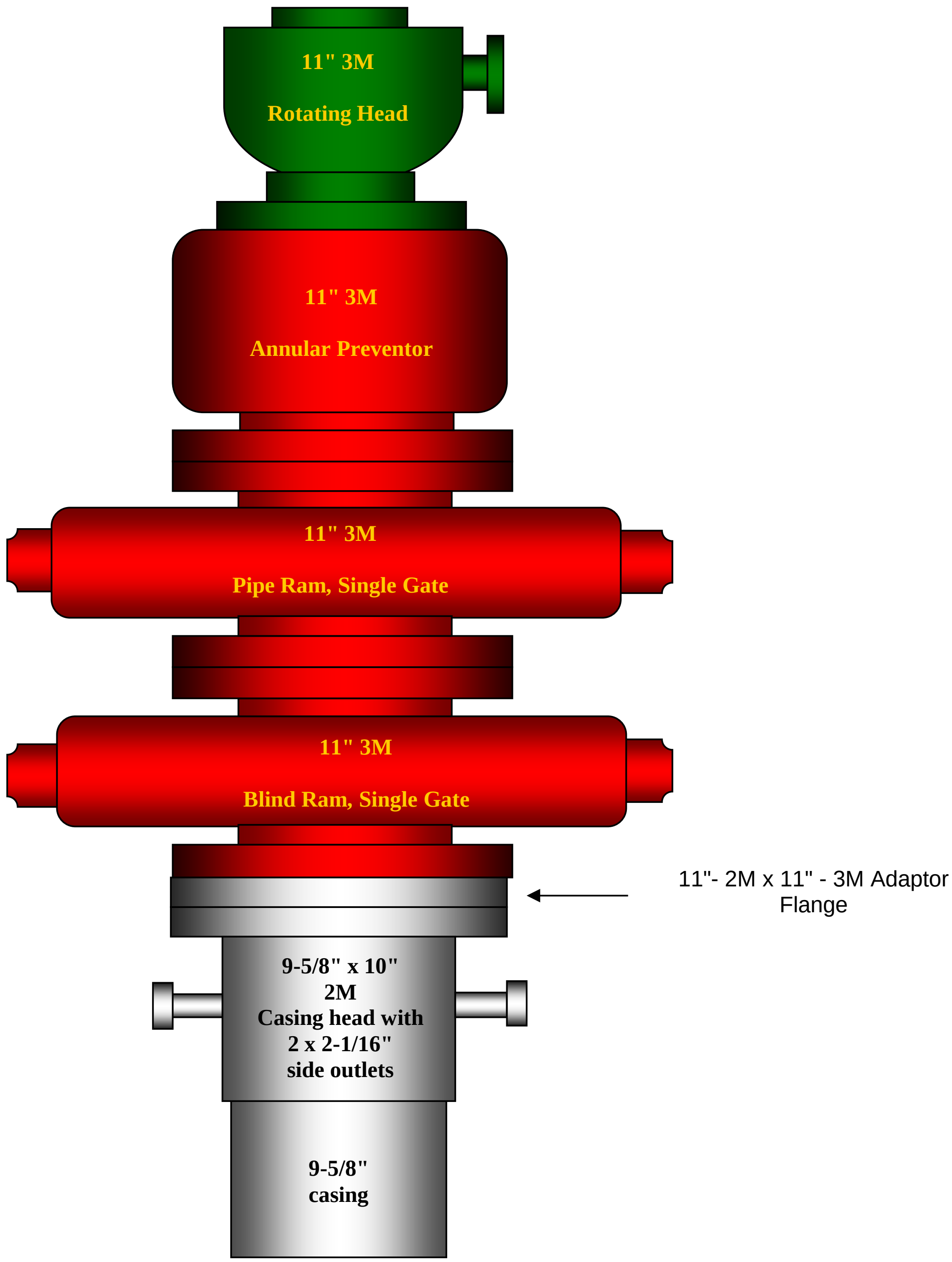

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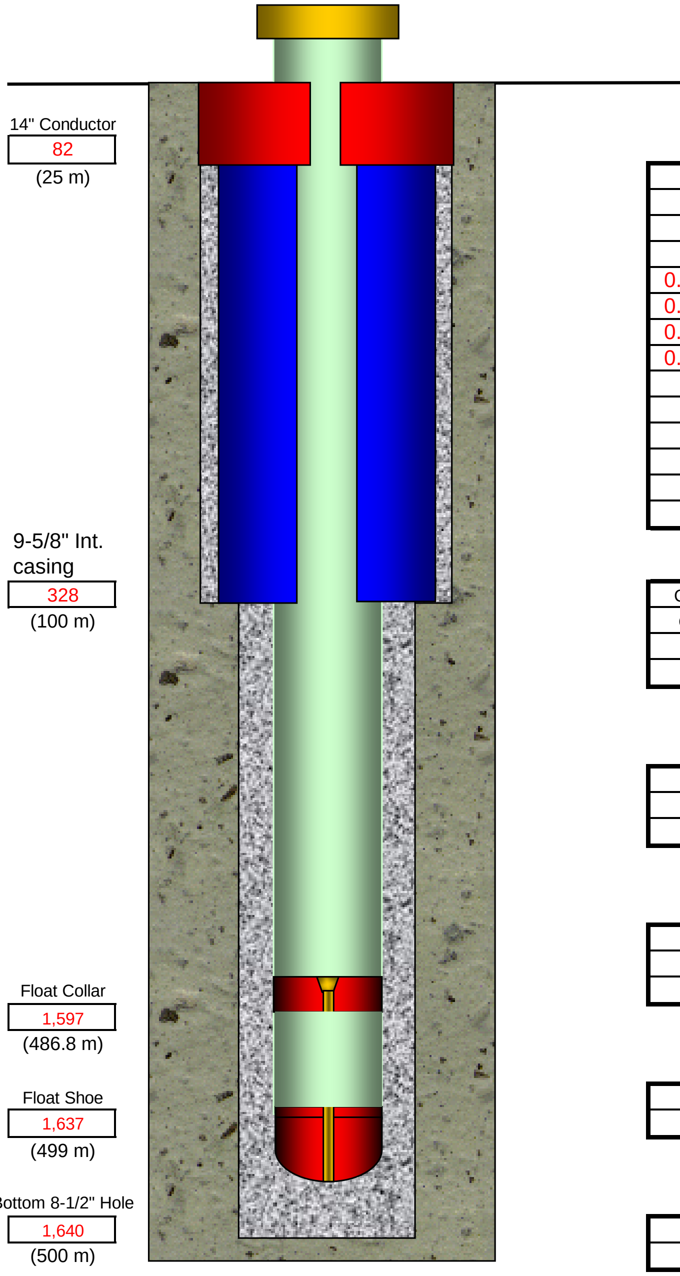
Figure 12. Cementing Calculations for 7-inch Production Casing



Cement Worksheet

Initial Parameters

200	Feet of Tail Cement
50	% Excess Lead Cement in Open Hole
0	% Excess Lead Cement in Cased Hole
50	% Excess Tail Cement in Open Hole
0.04167	Drill Pipe Capacity (ft^3/ft)
0.22103	Casing Capacity (ft^3/ft)
0.16681	Volume Between Casings (ft^3/ft)
0.12681	Volume Bet.Csg & Open Hole (ft^3/ft)
1.34	Lead Cement Yield (ft^3/sk)
1.15	Tail Cement Yield (ft^3/sk)
6.3	Lead Water gal/sk
5	Tail Water gal/sk
14.8	Lead Cement Weight (lbs/gal)
15.8	Tail Cement Weight (lbs/gal)

Lead Slurry Calculations	(ft^3)
Calculated Lead Slurry in Open Hole	165.99
Calculated Lead Slurry Bet. Csngs.	54.71
Excess Lead Slurry in Open Hole	83.00
Excess Lead Slurry in Cased Hole	0.00

Tail Slurry Calculations	(ft^3)
Calculated Tail Slurry	25.36
Excess Tail Slurry	12.68
Slurry in Float Shoe/Collar	8.84

Calculated Totals	(ft^3)
Total Lead Slurry	303.71
Total Tail Slurry	46.88
Total Slurry for the Job	350.59

Displacement Water Volumes	(ft^3)
Wiper Plug Method	352.98
Stab-in Method	66.55

Cement Weight	(lbs)	(sks)
Lead Cement	21,304.69	226.65
Tail Cement	3,832.27	40.77
Total Cement	25,136.96	267.41

Slurry Water	(bbl)	(gal)
Lead Cement	34.00	1427.87
Tail Cement	4.85	203.84
Total Water	38.85	1631.71

Casing Details :

Tack-weld bottom three joints. Run centralizers as recommended by cement engineer

Cement Details :

Pump 200 cu. ft of water ahead, followed by 100 cu. ft of pre-flush.

Do not reciprocate casing while cementing.

Do not exceed 1,500 psi while cementing or displacing.

Pressure-test all lines to 2,000 psi before starting cement operation.

Use Class "G" cement, pre-hydrated gel, silica flour, cement retarder, friction reducer and defoamer as recommended by cementing operator.

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Figure 13. Blowout Prevention Equipment for Drilling Below 7-inch Casing

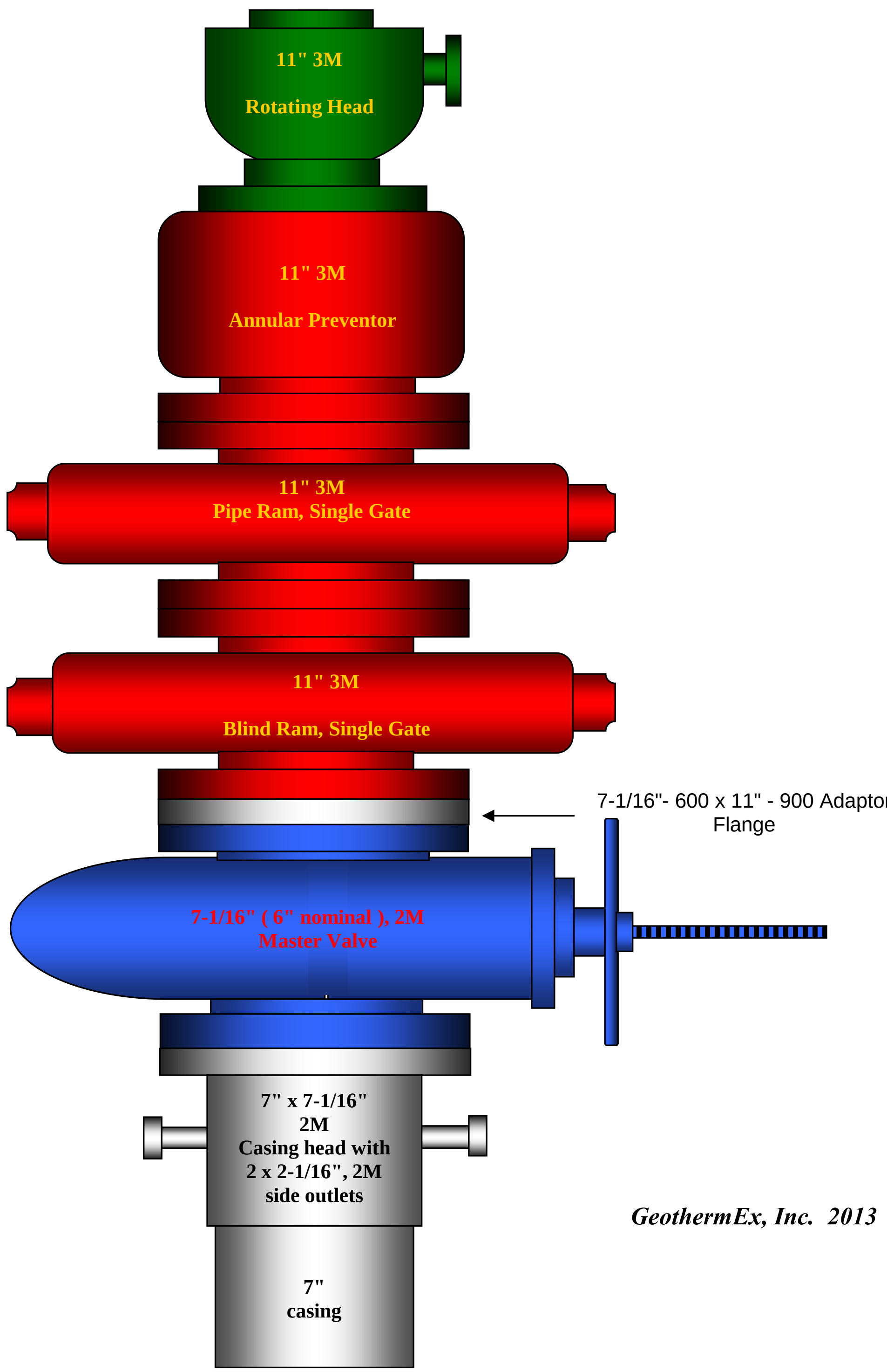
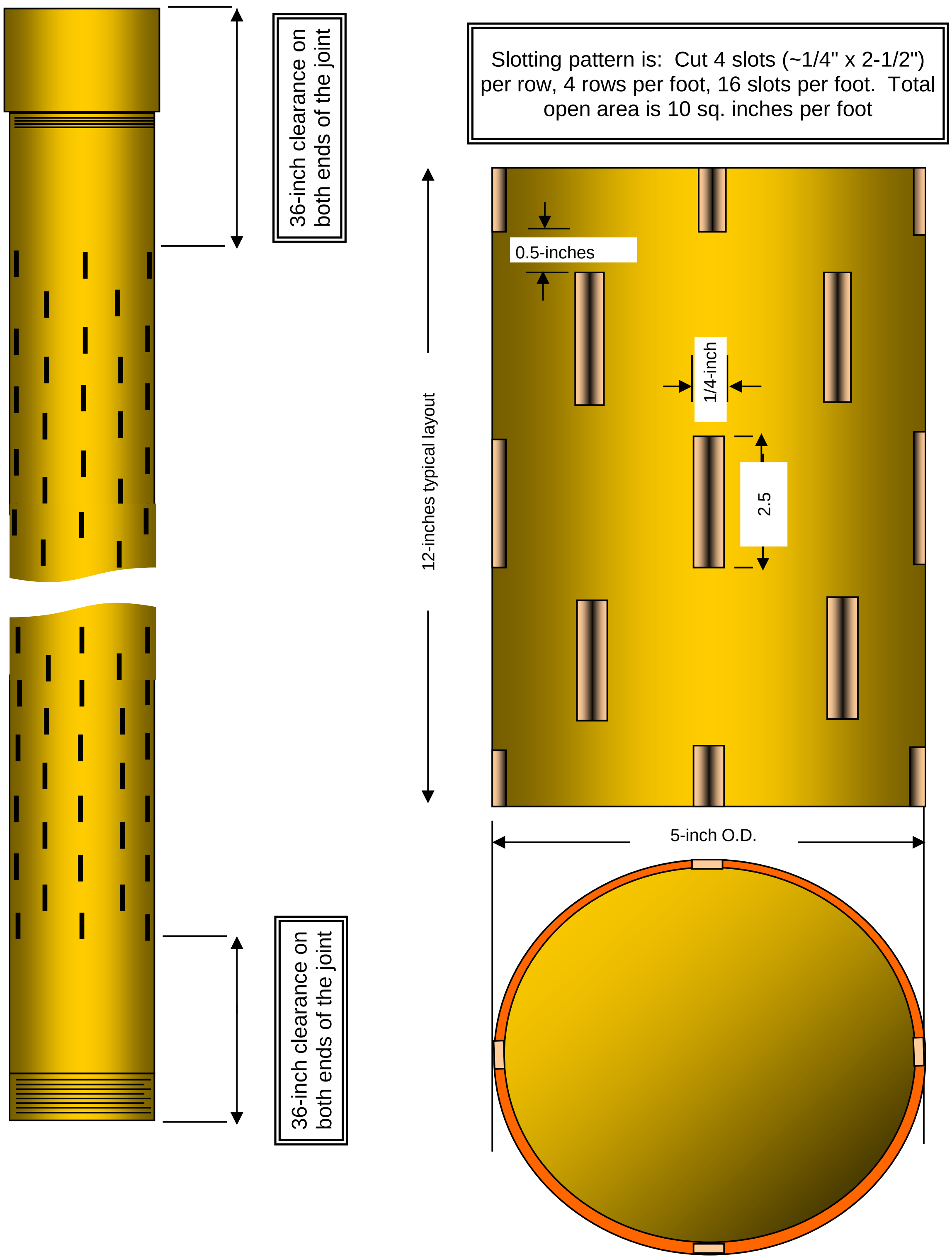


Figure 14. Recommended Slot Pattern for 5-inch Liner



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TABLES

Table 1

Specifications of Recommended Drilling Equipment for Drilling a Slim Hole at the Wilbur Hot Springs Geothermal Project
Rotary Rig - Depth Range: 5,000 - 8,000 FT

Depth Rating	Draworks		Derrick		Pumps		Rotary Table			Travelling Block / Hook		Blowout Prevention Equipment
	Rating	Single Line Capacity	Height	Capacity	Make & Model	Power Rating	Make & Model	Capacity	Opening	Make & Model	Rated Capacity	
(ft)	(HP)	(lbs)	(ft)	(lbs)		(HP)		(lbs)	(inches)		(lbs)	
8,000' with 3-1/2" D.P.	500	40,000	74	200,000	IDECO MM-300 GB (Two Units)	250	IDECO SR-12	180,000	11.5	IDECO DS-110	200,000	Annular: 11-inch REGAN Torus or Hydril (3M) Double Ram: 11-inch, 3M, Double Ram

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January, 2013

Table 2

Wilbur Hot Springs Geothermal Project
Recommended Drilling Bits

Quantity	Size (inches)	IADC Designation	Bit Type
2	12 1/4	6-1-7	GFi47HY
2	12 1/4	5-1-5	GFi23V
2	8 1/2	5-3-7	GF30
2	8 1/2	5-1-5	GF25
2	6 1/8	6-3-7	XR50
2	6 1/8	5-1-7	XRi20

Note: ***Recommended bit types are products marketed by Smith Bits. Equivalent products of the same IADC designation from other suppliers may be substituted.***

TABLE 3. MINIMUM RECOMMENDED CASING SPECIFICATIONS

DESCRIPTION	APPROXIMATE DEPTH (ft)	OUTSIDE DIAMETER	WEIGHT LBS/FT	NOMINAL I.D. (INCHES)	DRIFT I.D. (INCHES)	GRADE	THREAD TYPE	RANGE
Conductor Pipe	82 (25 m)	14-inch	Sch. 30	13.25	-	Black Iron	Welded	-
Surface Casing	328 (100 m)	9-5/8-inch	36	8.921	8.765	K-55	Buttress	3
Production Casing	1640 (500 m)	7-inch	23	6.366	6.241	K-55 or L-80	Buttress	3
Slotted Liner	1,542 - 5,003 (470 m - 1525 m)	5-inch	15	4.408	4.283	L-80	Flush Jointed	3

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APPENDIX A:

Down Hole Summary Plots for Project Wells

EXPLANATION FOR WILBUR HOT SPRINGS DOWNHOLE SUMMARY PLOTS

LITHOLOGY

Mudstone

Siltstone

Conglomerate

Chert

Mafic Igneous Rock

Serpentinite

Basalt

Greenstone

Volcanic Breccia

Gabbro

Serpentine Clay

Sandstone

SYMBOLS

Liner hanger location

Casing shoe location

Total circulation loss

Partial circulation loss

Slotted or perforated interval of liner

Bottom of liner or tubing

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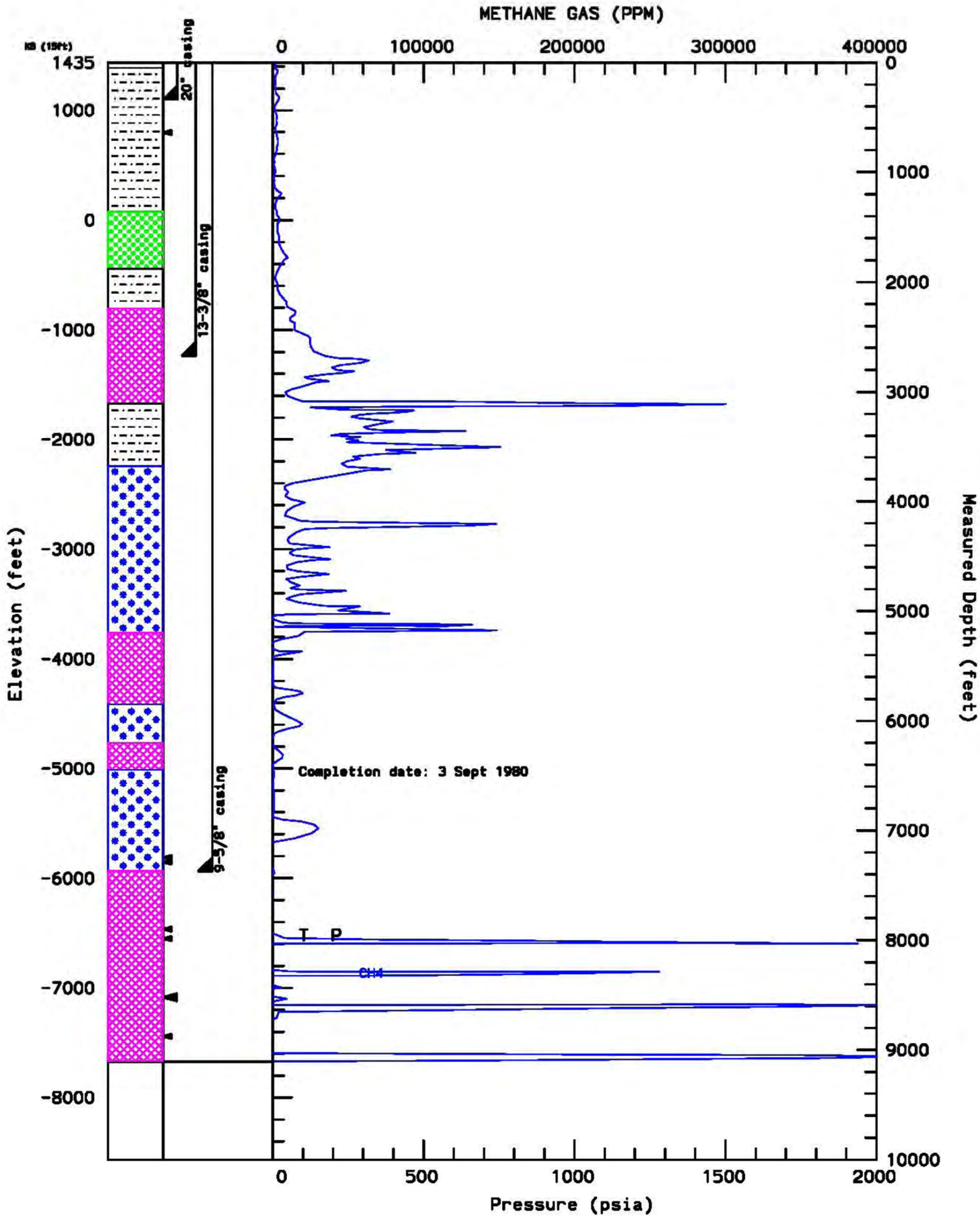
DOWNHOLE SUMMARY - WILBUR HOT SPRINGS WELL BAILEY #1



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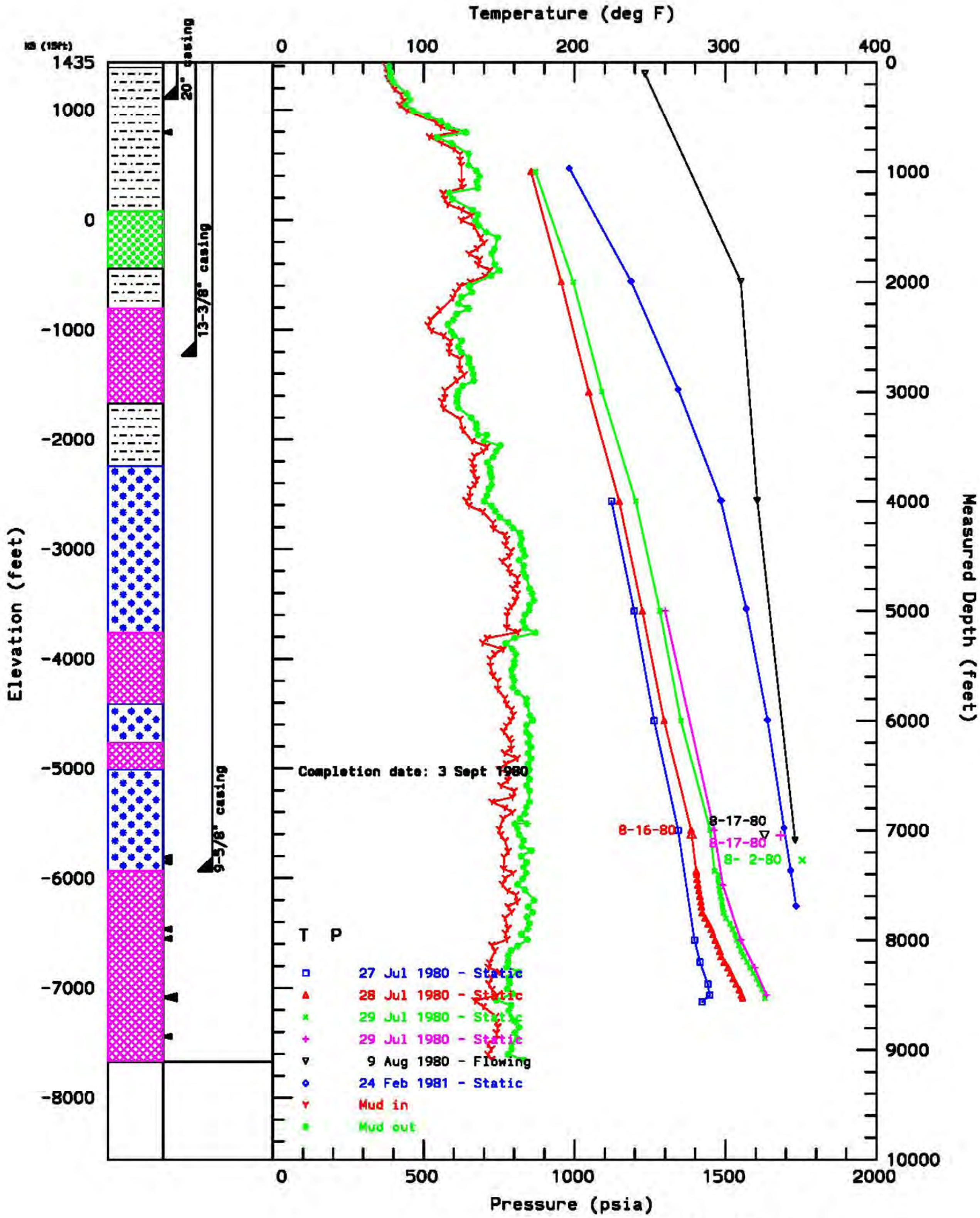
DOWNHOLE SUMMARY - WILBUR HOT SPRINGS WELL BAILEY #1



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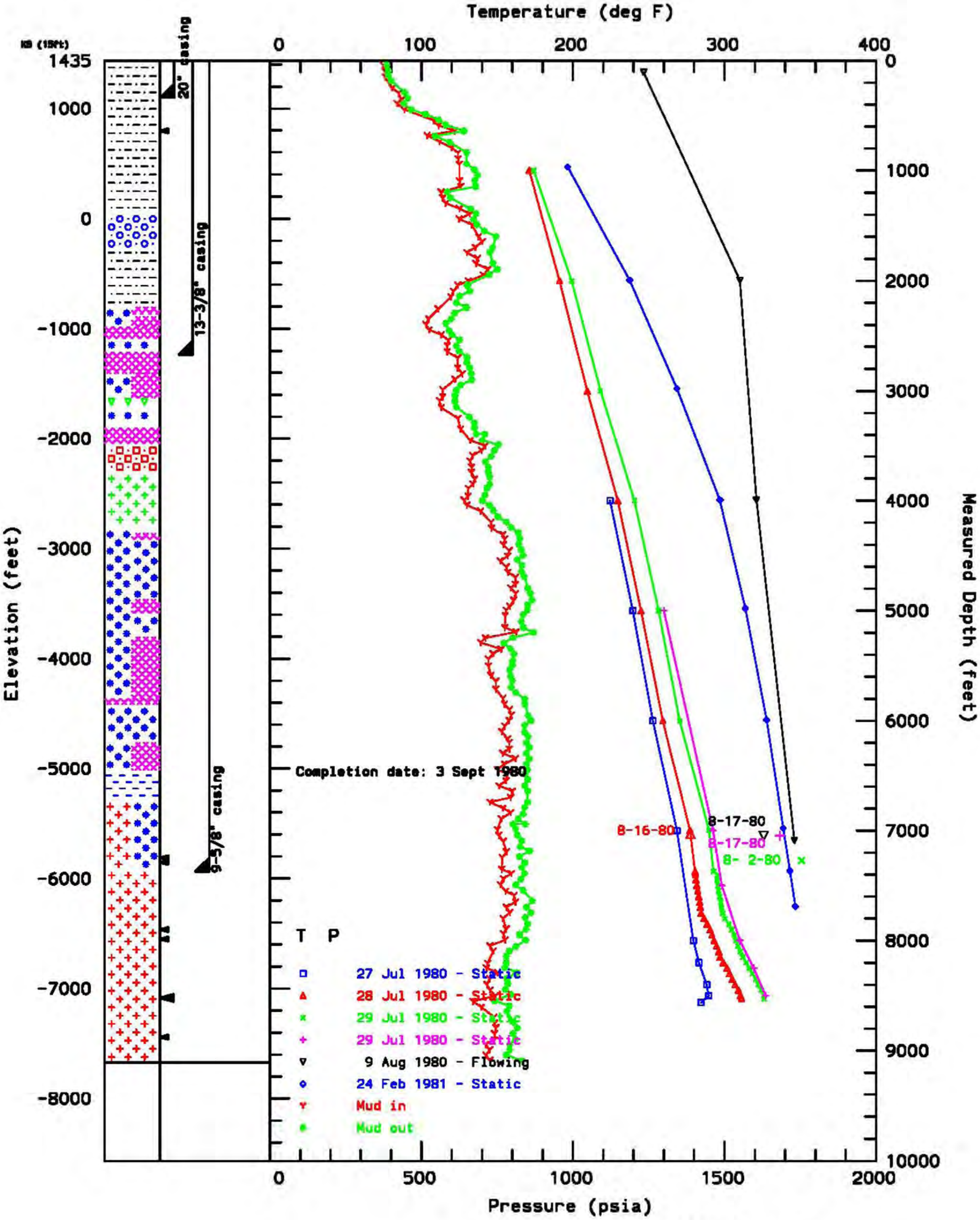
DOWNHOLE SUMMARY - WILBUR HOT SPRINGS WELL BAILEY #1



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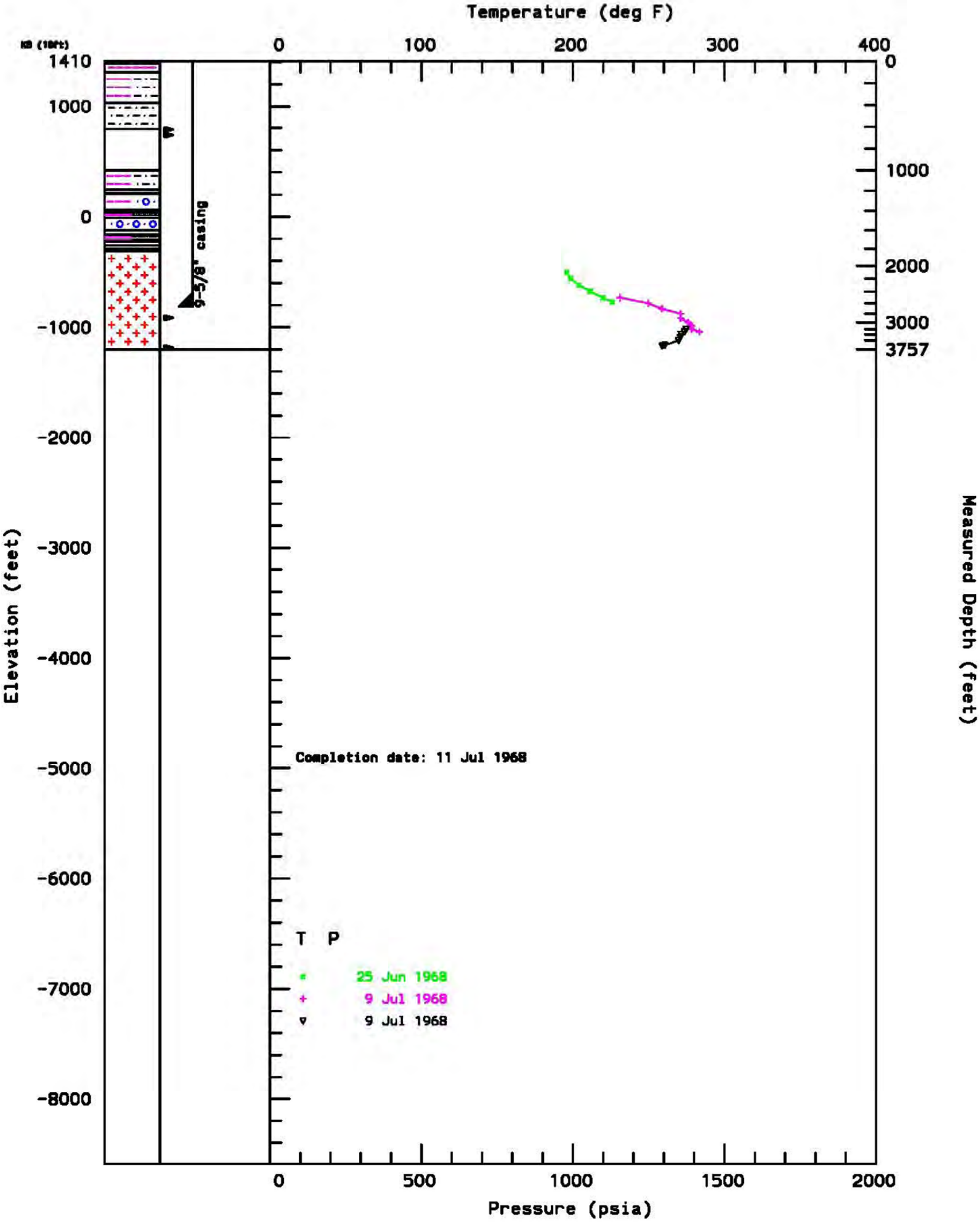
DOWNHOLE SUMMARY - WILBUR HOT SPRINGS WELL CORDERO OH



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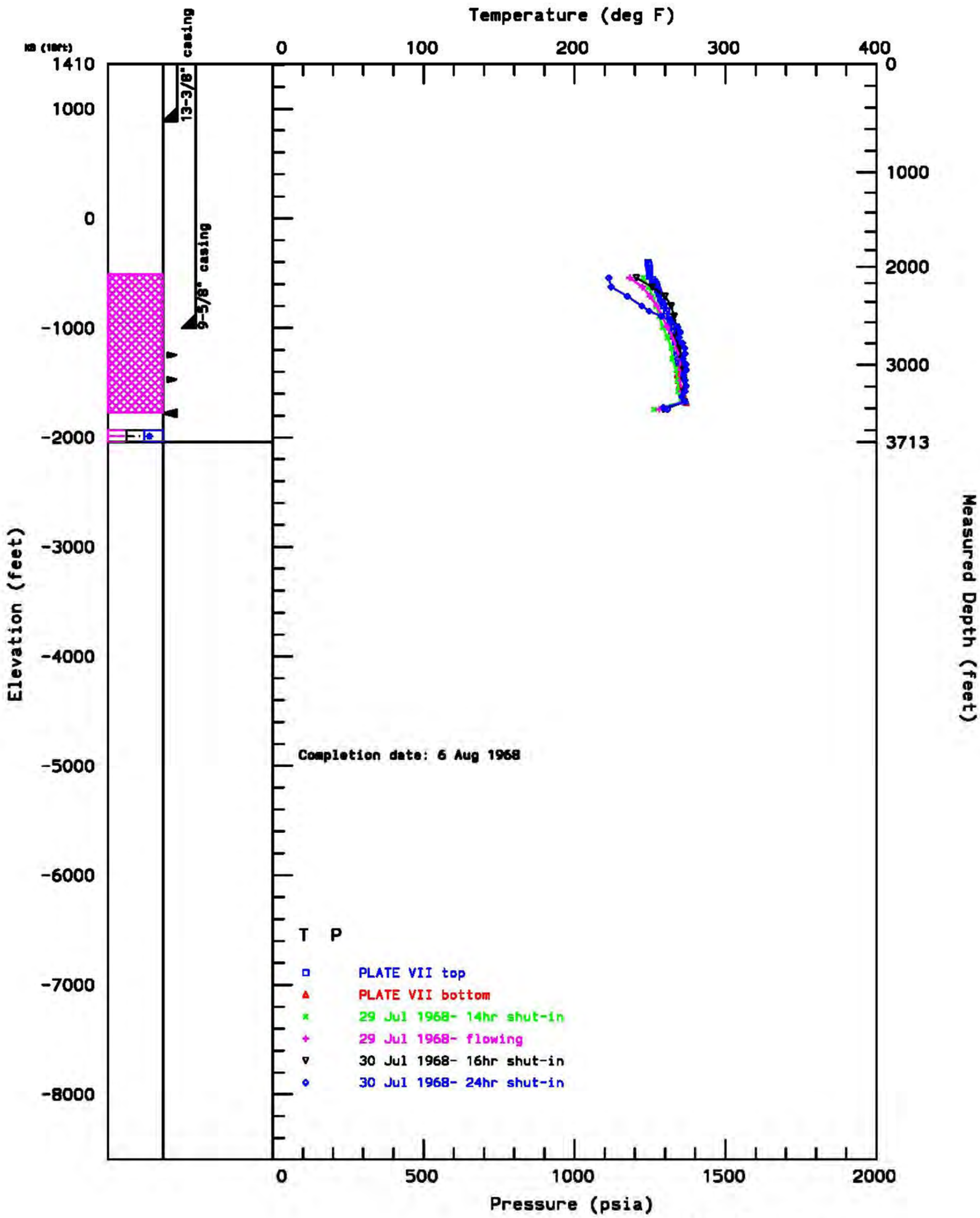
DOWNHOLE SUMMARY - WILBUR HOT SPRINGS WELL CORDERO ST



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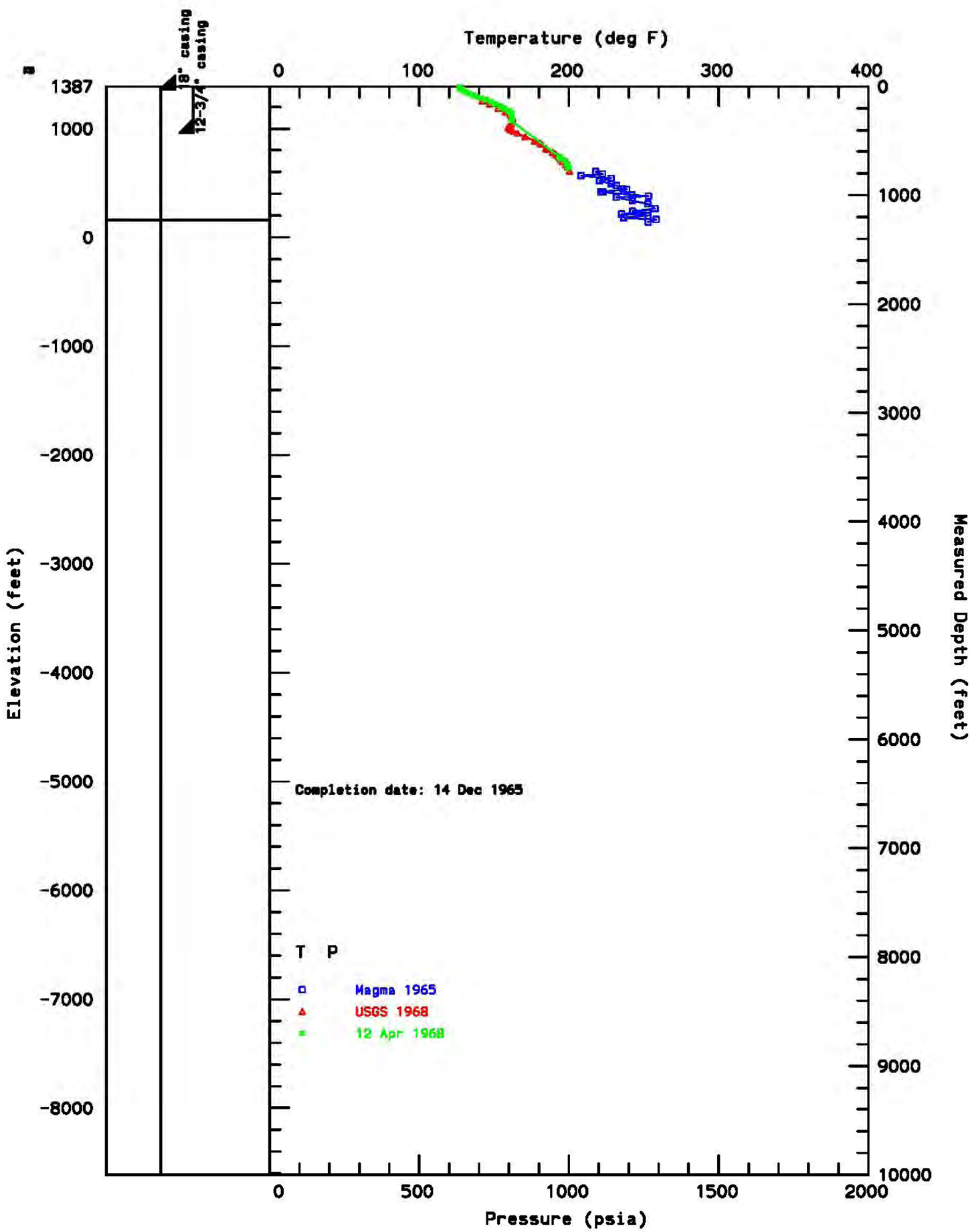
DOWNHOLE SUMMARY - WILBUR HOT SPRINGS WELL MAGMA



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APPENDIX B:

Recommended Mud Program for Drilling Slim Holes

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RECOMMENDED MUD PROGRAM FOR DRILLING SLIM WELL

12-1/4-inch PHASE (Surface - 100 m)

MUD TYPE:

GEL SPUD MUD

RECOMMENDED CHEMICAL CONCENTRATION:

BENTONITE:	28 lb/bbl
CAUSTIC SODA:	0.2 lb/bbl
LIME:	0.2 lb/bbl (TO INCREASE -IF NECESSARY- YIELD OF CLAY)
(This concentration may vary depending on shaker flow capacity)	

RECOMMENDED MUD PROPERTIES:

MUD WEIGHT:	8.6/9.5 ppg
VISCOSITY:	60/70 SEC
PH:	8.5/9
CA++:	<200 ppm

8-1/2-inch PHASE (100 m – 500 m)

MUD TYPE:

LOW SOLID-BENTONITE-POLYMER SYSTEM

RECOMMENDED CHEMICAL CONCENTRATION

BENTONITE:	18 lb/bbl
CAUSTIC SODA:	0.3-0.7 lb/bbl
MILPAC:	1.4 lb/bbl
MILTHIN OR TERMATHIN:	1 lb/bbl TO CONTROL RHEOLOGY IF NECESSARY
LIGCON:	1.4 lb/bbl FOR WALL CAKE IF NECESSARY
NEWDRILL:	0.7 lb/bbl TO IMPROVE LUBRICITY IF NECESSARY

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RECOMMENDED MUD PROPERTIES:

MUD WEIGHT:	8.7 / 10 ppg
VISCOSITY:	45/50 SEC
PH:	9/10
YP (Yield Point):	8-15 LB/100FT2
PV (Plastic Viscosity):	ALAP
GELS 10"/10":	2/10 LB/100FT2
API F.L. (Fluid Loss):	10 CC
FILTER CAKE:	0.5-1 mm

6-1/8-inch PHASE (500 m - 1,525 m, or up to the first important loss of circulation)

MUD TYPE:

LOW SOLID-BENTONITE-POLYMER SYSTEM

RECOMMENDED CHEMICAL CONCENTRATION

BENTONITE:	18 lb/bbl
CAUSTIC SODA:	0.35-0.7 lb/bbl
MILPAC:	1 lb/bbl
MILTHIN OR THERMATHIN:	1 lb/bbl TO CONTROL RHEOLOGY IF NECESSARY
LIGCON:	1 lb/bbl TO IMPROVE WALL CAKE IF NECESSARY
NEWDRILL:	0.7 lb/bbl TO IMPROVE LUBRICITY IF NECESSARY

RECOMMENDED MUD PROPERTIES:

MUD WEIGHT:	9.2 / 10 ppg
VISCOSITY:	40/50 SEC
PH:	9/10
YP:	8-15 LB/100FT2
PV:	ALAP
GELS 10"/10":	2/20 LB/100FT2
API F.L.:	10-15 CC
FILTER CAKE:	1 mm

Volumes of product usage during the preceding stages will depend on presence of circulation losses and the casing setting depth.

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6-1/8-inch PHASE (500 m – 1,525 m, below the first important loss of circulation)

AS AN OPTION, WATER COMBINED WITH HIGH-VISC PILLS PUMPED AT EVERY DRILL PIPE CONNECTION MAY BE USED DURING THE 6-1/8-INCH DRILLING PHASE.

RECOMMENDED COMPOSITION FOR HI VIS PILL

WATER : 50 bbl
MILVIS OR NEWDRILL : 3.5-5 lb/bbl TO HAVE 80-90 SEC OF VISCOSITY

OR

WATER : 50 bbl
BICARB : 0.7 lb/bbl
BENTONITE :18 lb/bbl TO HAVE 60-70 SEC OF VISCOSITY
LIME : 0.35 lb/bbl

RECOMMENDED COMPOSITION FOR LCM PILL

FROM 5 TO 25 bbl/hr OF LOSSES :

MILGEL MY : 7 lb/bbl
LIME : 0.18 lb/bbl
MICA FINE-MEDIUM 10%
NUT PLUG FINE : 10%
SAW DUST : 10%

FROM 30 TO 100 bbl/hr OF LOSSES :

MILGEL MY : 7 lb/bbl
LIME : 0.17 lb/bbl
MICA MEDIUM-COARSE : 20%
NUT PLUG MEDIUM : 20%
SAW DUST : 20%

APPENDIX C:

Procedure for Welding Casing Heads

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WELDING PROCEDURE FOR WELDING CASING HEADS

The welding of the casing head to the casing for all geothermal wells should follow the API standard 6A (fourteenth Edition, March 1983, Appendix B). A direct extraction of this standard follows, with comments and additions in bold and/or italic.

API RECOMMENDED PROCEDURE
FOR WELDING PIPE TO WELLHEAD EQUIPMENT

B1 INTRODUCTION AND SCOPE - The following recommended procedure has been prepared with particular regard to attaining pressure tight welds when attaching casing heads, flanges, etc., to casing. Although most of the high strength casing used is not normally considered suitable for field welding, some success may be obtained by using the following or similar procedures.

CAUTION: In some wellheads, the seal weld is also a structural weld and can be subjected to high tensile stresses. Consideration must therefore be given by competent authority to the mechanical properties of the weld and its heat affected zone.

The 20" surface casing is K-55, a mild steel that is suited for field welding. The wellheads are also made from mild steel with a Rockwell C hardness (HRC) of approximately 22.

Wellheads may occasionally be welded on L-80 casing (when the surface casing is 13-3/8", 9-5/8" OR 7"), a mild steel that has been heat treated for higher strength. Welding will reduce the pipe strength to the equivalent of a K-55 joint. This is generally not a problem because other factors cause the wellhead connection to be several time stronger than necessary, but the casing performance design should be checked to make sure that the joint will be strong enough if the casing head is welded onto high strength casing.

1) The steels used in wellhead parts and in casing are high strength steels that are susceptible to cracking when welded. It is imperative that the finished weld and adjacent metal be free from cracks. The heat from welding also affects the mechanical properties. This is especially serious if the weld is subjected to service tension stresses ***(such as changes in temperature in geothermal wellheads).***

2) This procedure is offered only as a recommendation. The responsibility for welding lies with the user and results are largely governed by the welder's skill. Weldability of several makes and grades of casing varies widely; thus placing added responsibility on the welder. Transporting a qualified welder to the job, rather than using a less skilled man who may be found at hand, will, in most cases, prove economical. The responsible operating representative should ascertain the welder's qualifications and, if necessary, assure himself by instruction or demonstration, that the welder is able to perform the work satisfactorily. ***(We recommend screening welders prior to the weld jobs.)***

B2 WELDING CONDITIONS – Unfavorable welding conditions must be avoided or minimized in every way possible, as even the most skilled welder cannot successfully weld steels that are susceptible

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to cracking under adverse working conditions, or when the work is rushed. Work above the welder on the drill floor should be avoided ***(stopped).*** The weld should be protected from dripping mud, water, and oil, also from wind, rain, or other adverse weather conditions ***(place tarp above the working area).*** The drilling mud, water or other fluids must be lowered in the casing and kept at a low level until the weld has properly cooled, ***(at least 3 ft below the top of the casing).*** It is the responsibility of the user to provide supervision that will assure favorable working conditions, adequate time, and the necessary cooperation of the rig personnel.

B3 WELDING – The welding should be done by the shielded metal arc or other approved process.

B4 FILLER METAL – After the root pass, low hydrogen electrodes or filler wires of a yield strength equal to the casing yield strength should be used. The low hydrogen electrodes include classes EXX15, EXX16, EXX18, EXX28 of AWS A5.1 (latest edition): Mild Steel Covered Arc-Welding Electrodes* and AWS A5.5 (latest edition: Low Alloy Steel covered Arc-Welding Electrodes*. Low hydrogen electrodes should not be exposed to atmosphere until ready for use. ***We recommend E6010 welding rod for the root pass and #7018 for the filler passes.***

B5 PREPARATION OF BASE METAL – The area to be welded should be dry and free of any paint, grease, scale, rust or dirt.

B6 PREHEATING – Both the casing and the wellhead member should be preheated to 250° - 400° F (121° - 204° C) for a distance of at least 3 inches (76.2 mm) on either side of the weld location, using a suitable preheating torch ***(our target is 392°F with a electric heat blanket).*** Before applying preheat, the fluid should be bailed out of the casing to a point several inches (mm) below the weld location, ***(at least 3 ft below the top of the casing).*** The preheat temperature should be checked by the use of the heat sensitive crayons ***(because temperature instruments are unreliable if not calibrated and maintained properly).*** Special attention must be given to preheating the thick sections of the wellhead parts to be welded, to insure uniform heating and expansion with respect to the relatively thin casing. ***The preheat treatment should include 1 hour soak after 200°C is achieved before proceeding with tack welding.***

Note: Preheating may have to be modified because of the effect of temperature on adjacent packing elements, which may be damaged by exposure to the temperatures of 200° F (93° C) and higher. Temperature limitations of the packing materials should be determined before the application of preheat, ***(does not apply for initial installation of 20 ¾" casing heads).***

B7 WELDING TECHNIQUE – Use a 1/8 or 5/32 inch (3.2 or 4.0 mm) E6010 electrode and step weld the first bead (root pas); that is, weld approximately 2 to 4 inches (50 to 100 mm) and the move diametrically opposite this point and weld 2 to 4 inches (50 to 100 mm). Then weld 2 to 4 inches (50 to 100 mm) halfway between the first two welds, move diametrically opposite this weld and so on until the first pass is completed. The second pass should be made with a 5/32-inch (4.0 mm) low hydrogen electrode of the proper strength and may be continuous. The balance of the welding groove may then be filled with continuous passes without back stepping or lacing, using a 3/16 inch (4.8 mm) low hydrogen electrode ***(E7018)***. All beads should be stringer beads with good penetration, and each bead after the root pass should be thoroughly ***cleaned*** before applying the next bead. There should be no undercutting and welds shall be workmanlike in appearance ***(we emphasize the importance of the workmanship and the wellsite supervisor will visually inspect the final welds. Ideally for a quality weld, four (4) inside passes and eight (8)***

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outside passes should be done. The outside passes should form a fillet approximately ½" on a side).

1) Test ports should be open when welding is performed to prevent pressure build-up with the test cavity.

2) During welding, the temperature of the base metal on either side of the weld should be maintained at 250° F (121° C) minimum ***(maintain the target of 392°F).***

3) Care should be taken to insure that the welding cable is properly grounded to the casing, but ground wire should not be welded to the casing or wellhead. Ground wire should be firmly clamped to the casing, the wellhead, or fixed in position between pipe slips. Bad contact may cause sparking with resultant hard spots beneath which incipient cracks may develop. The welding cable should not be grounded to the steel derrick, or to the rotary table base.

B8 CLEANING – All slag or flux remaining on any welding bead should be removed before laying the next bead. This also applied to the completed weld ***(again emphasis on workmanship).***

B9 DEFECTS – Any cracks or blowholes that appear on any bead should be removed to sound metal by chipping or grinding before depositing the next bead.

B10 POSTHEATING – For the removal of all brittle areas in high strength steel casing, a post heat temperature of 1050° - 1100° F (566° to 593° C) is desirable. It is recognized, however, that this temperature is difficult or impossible to obtain in the field, and that the mechanical properties of the wellhead parts and pipe may be considerably reduced by these temperatures. As a practical matter, the temperature range of 500° 900° F (260° to 482° C) has been used with satisfactory results ***(our recommended target is 800°F, with 1 hour soak after reaching target temperature.***

B11 COOLING – Rapid cooling must be avoided ***(after soak, bring temperature down to 392°F over a period of 1-1/2" hours with blanket on).*** To assure slow cooling, welds should be protected from extreme weather conditions (cold, rain, high winds, etc.) by the use of a blanket of asbestos or other suitable insulating material. Particular attention should be given to maintaining uniform cooling of the thick sections of the wellhead parts and the relatively thin casing, as the relatively thin casing will pull away from the head or hanger if allowed to cool more rapidly. The welds should cool in air to 250° F (121° C) (measured with a heat sensitive crayon) prior to permitting the mud to rise in the casing ***(allow casing head to cool to ambient temperature for weld inspection).***

<u>WELD INSPECTION</u>: After casing head is allowed to cool to ambient temperature, perform a pressure test using nitrogen with a freon tracer. Conduct the pressure test to 1000 psig for 10 minutes. Use a Freon detector or soapy water to locate any leaks if the pressure does not hold. When a successful pressure test is obtained and witnessed by the well site supervisor or drilling engineer, bleed off the pressure and install the port plug.

If either of these tests fail – fully grind the effected area of the base material. Re-weld the area using full pre-heat and post-heat procedures given above. Re-conduct the pressure and MPI tests.

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