State of Oregon
Oregon Department of Geology and Mineral Industries
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THERMAL GRADIENT DRILLING PROGRAM

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2013

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THERMAL GRADIENT DRILLING PROGRAM

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1.0 INTRODUCTION

The Oregon Department of Geology and Mineral Industries (DOGAMI), together with the states of Idaho, Utah, and Nevada formed the Great Basin Consortium, and as participants in the National Geothermal Data System (NGDS) project, this consortium received supplemental federal assistance funds from the US Energy Department's (USDoE) Geothermal Technologies Program through the Arizona Geological Survey for new geothermal data collection (expanding Task 2.4 of the project objectives). DOGAMI's portion of the federal assistance funds supported the following work:

- A pilot study employing airborne thermal infrared (TIR) and co-acquired Lidar (an acronym for light detection and ranging) directed at detecting potentially small-magnitude, geothermally-elevated ground temperatures.
- The drilling of three thermal gradient wells.

This report was prepared by DOGAMI to partially satisfy the Scope of Work, Task 2 and document the process that led to drilling of three boreholes, each completed as a thermal gradient well. The results of the TIR/Lidar pilot study are published in two separate reports, see Niewendorp and others (2013) and Madin and others (2013).

The project to drill the wells advanced through five (5) phases that included site selection, development of the initial proposal, State and federal permitting, bidding, drilling the wells, and plugging and abandonment (P&A) of the wells. A compilation of these phases is part of the documentation presented below.

For the convenience of the reader, this report is divided into four chapters as follows:

- Chapter 1 is this current chapter and describes the project participants, scope, site selection process, locations of drilling the wells, agency required permits and clearance, and contracting.
- Chapter 2 describes the drilling and related activities which includes details of the drilling operations.
- Chapter 3 describes well sampling and temperature logging activities.
- Chapter 4 is well plugging and abandonment followed by Chapter 5 (Acknowledgments) and Chapter 6 of selected references.

1.1 PROJECT PARTICIPANTS

Work described in this report was conducted by the following participants:

- DOGAMI handled the management of the project and closely monitored drilling activities, P&A of the wells, and site restoration.
- Bidding, procurement, and contacting were carried out by the Oregon Department of Administrative Service, Enterprise Goods and Services/Procurement Services.

- Welsco Drilling Corp (Welsco) of Fallon, Nevada was a vendor retained to drill the boreholes, complete the wells, and P&A,/site restoration.
- The United States Geological Survey (USGS), Energy Resources Program, contributed equipment and personnel towards temperature mapping of the wells, including temperature data analysis.

1.2 SCOPE

This report summarizes the drilling of three boreholes completed as thermal gradient wells, well construction details, and P&A. The primary objective of the drilling activities was to drill and install three thermal gradient wells, each 1,000 feet below ground surface (bgs), and collect thermal gradient measurements. Secondary objectives were to log the drill cuttings and provide descriptive rock names to the cuttings based on normalized major oxide analysis plots.

Three temperature-gradient wells have been drilled as of May 9, 2013. Drilling started April 16, 2013. Two of the wells reached 305 m/1,000 ft, while the other reached 239 m/960 ft. Each location of drilling the well is on and in state-owned land. Post-installation activities consisted of two rounds of temperature-depth measurements and P&A/site restoration.

The project plan also included a task to conducted geologic characterization of the immediate area in and around each locations of drilling the wells. This work was completed as of July of 2012 and consisted of reconnaissance geologic mapping of four separate 7.5-minute quadrangles: Summer Lake, Elgi Rim, Sand Rock, and Folly Farm. Volcanic rock samples were collected in each of the aforementioned quadrangles, together with selected well cuttings, for X-Ray fluorescence (XRD) analyses of their whole-rock and trace element geochemistry. Normalized major element analysis plots established descriptive rock names and correlation of volcanic rock units. Also, ground magnetometer surveys at each of the drilling sites augmented the geologic mapping. The results of this geologic characterization is a companion to this report.

1.3 SITE SELECTION

The selection of target areas for the locations of drilling the wells needed to be within Oregon's portion of the Great Basin and Range, on public lands, areas lacking geothermal information or areas with an indication of geothermal potential, and near or reasonably close to transmission power lines. Equally as important in the selection of target areas was the criteria used to exclude certain areas, such as:

- Areas of active and inactive geothermal leases.
- Presence of past geothermal exploration prospect drilling.
- Environmental restrictions, such as Sage Grouse habitat and wilderness study areas.

Figure 1.1 shows the locations of the three target areas for the locations of drilling the wells that emerged from the aforementioned evaluation process. The geologic context for selecting these sites is summarized as follows:

- Baker Pass of the Steens Mountain's eastern escarpment, Malheur County

    - Baker pass is parallel to what may be a zone of extensional transfer faulting (i.e. cross-faults) between two range-fault segments of the Steens eastern escarpment: the Crowley fault section to the north and Mann Lake fault section to the south (Personius, 2002a). This zone is marked by tilted fault blocks of Steens basalt and the association of structural basins filled with Quaternary sediments.

    - These observations attracted our attention for it was quite evident that elsewhere in Oregon similar structural relationships of extensional transfer faulting between two range-front fault segments were an important control of geothermal fluids, e.g. Alvord Valley, southern Malheur County and Paisley, Lake County.

- Eastern Margin of the Christmas Lake Valley, Lake County

    - The geologic context for the assessment of the eastern margin of the Christmas Lake Valley is two-fold: it provides thermal gradient information where none existed and little is known about eastern margin of the valley in terms of its subsurface geology.

    - Of interest are a group of unnamed faults which form the eastern margin of the Christmas Lake Valley (Personius, 2002c). These faults are coincide with Wildcat Butte which consists of Pliocene through late Pleistocene basaltic maar volcanoes.

- Picture Rock Pass of North Summer Lake, Lake County

    - The Summer Lake graben and its western margin (Winter Ridge) has areas where active geothermal features occur, such as hot and warm springs, and other evidence of geothermal processes such as fossil tuffa mounds and sinter deposits. These features all occur within a 5-mi radius of the Picture Rock Pass.

    - The pass between Summer Lake basin and Fort Rock basin to the north is underlain by the Picture Rock basalt. The general water-bearing properties of the Picture Rock Basalt are good because of scoriaceous flow tops and bottoms. Also, this basalt has been deformed into a broad anticlinal fold or warp. Coincident and parallel to its fold axis are northerly trending, down-to-the-east normal faults. These faults are continuous throughout the Winter Ridge section (escarpment) and part of the Winter Rim fault system (Personius, 2002b). Furthermore, there are also short active faults at the northern end of the Summer Lake graben as well.

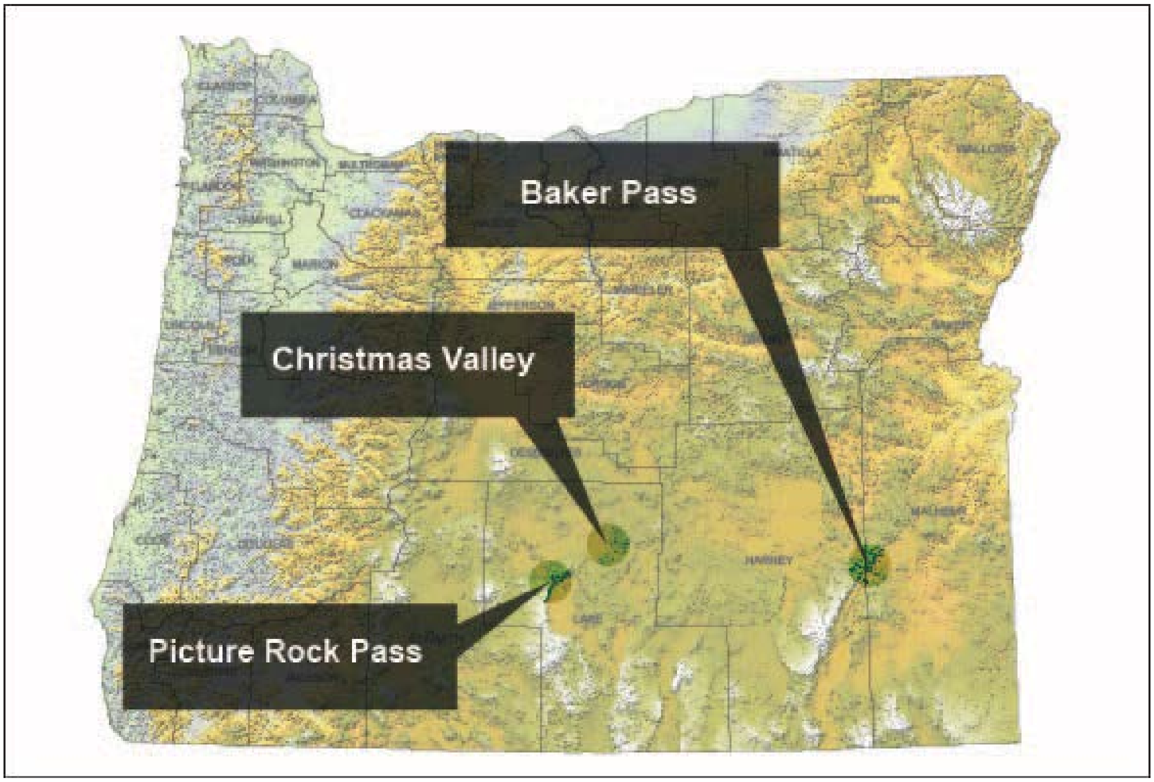

Figure 1.1: Shaded Relief Map of Oregon showing the locations of the three target areas selected for drilling thermal gradient wells

- The Picture Rock Pass attracted our attention for it was quite evident that the northern portion of the Summer Lake is an area where geologic characteristics indicated a geologic environment favorable for a geothermal resource occurrence.

Within the target areas described above, we then looked for locations of drilling the wells. Three separate sites to drill the wells emerged. Each was land owned by or under the control of the State of Oregon in which the land surface had already been disturbed. Table 1.1 lists each of these sites and their accompanying location information. A brief narrative follows giving driving directions to each location of drilling a well.

1.4 LOCATIONS OF DRILLING THE WELLS

Crowley-Riverside Road Stockpile Area, Malheur County

This site is an active gravel stockpile area off Crowley-Riverside Road at its intersection with Highway 78 (Rome-Princeton or Steens Highway) (Figure 1.2). The Oregon Department of Transportation (ODOT) leases ±0.77-acres (340 ft by 100 ft) from the Oregon Department of State Lands (ODSL). The stockpile area lies near the foot of Baker Pass in Sunrise Valley, Malheur County, Oregon between the MP-65 and MP-66 on Steens Highway (78/442) heading east.

Table 1.1: Site location information

Site Name	Crowley-Riverside Road Stockpile Area	Oregon Military Department	Picture Rock Gravel Pit
Well Name	ARRA FF-1	ARRA OMD-1	ARRA SL-1
PLSS	SE¼ NW¼, Sec. 16, T. 29 S., R. 37 E.	SW¼ SW¼, Sec. 31, T. 26 S., R. 20 E.	SW¼ NE¼, Sec. 36, T. 29 S., R. 16 E.
Latitude*	43.053288	43.270575	43.016038
Longitude*	-118.183184	-120.366657	-120.770717
Ground Elevation (m/ft)	1237.5/4060	1310.6/4300	1360.9/4465
County	Malheur	Lake	Lake
7.5' quadrangle	Foley Farm	Sand Rock	Egli Rim

* Locations of drilling the wells; decimal degree, WGS 84

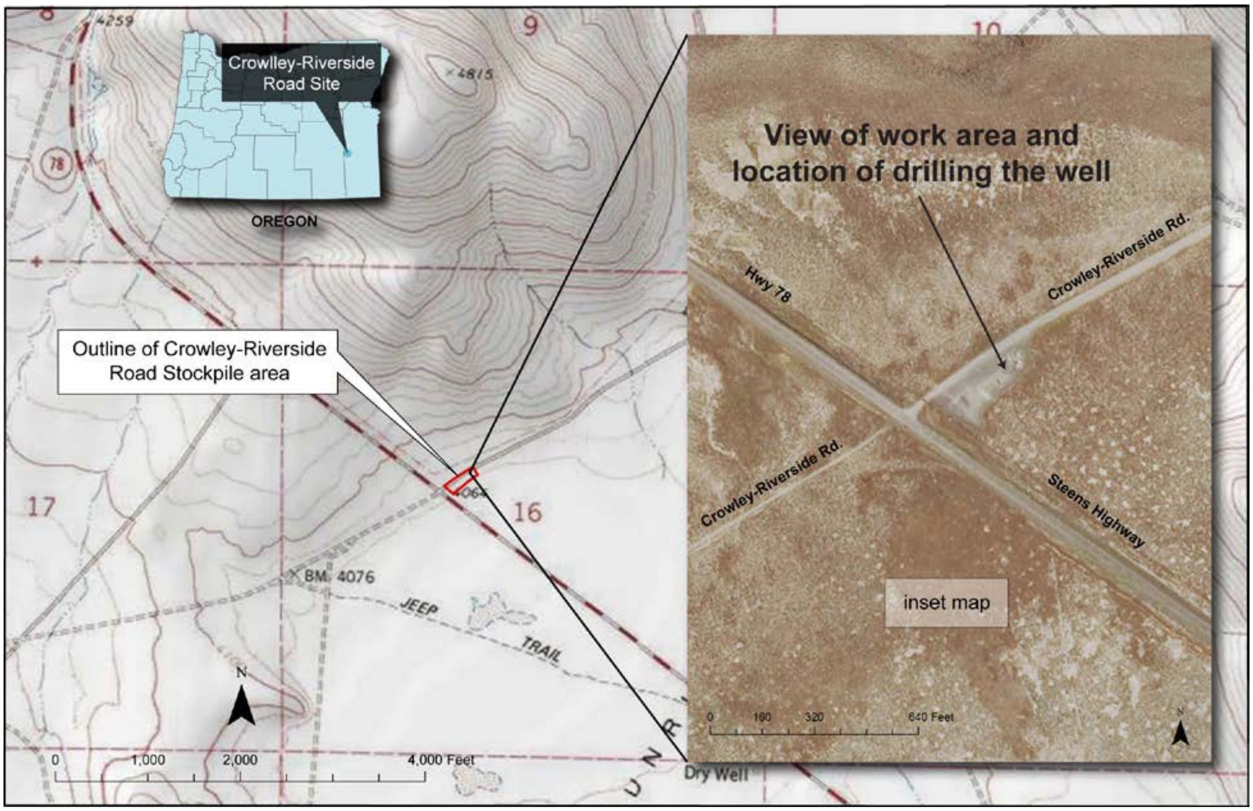

Figure 1.2: Map of the Crowley-Ridge Road gravel stockpile area in Sunrise Valley at the bottom of Baker Pass, Malheur County, Oregon. Map base is the Foley Farm 7.5-minute quadrangle. The red outline is the approximate boundary of the stockpile area. In the inset map, the arrow points to the approximate location of drilling the well (ARRA FF-1).

Oregon Military Department, Lake County

The Oregon Military Department (OMD) acquired part of the former USAF Over The Horizon Backscatter Radar air defense system in Christmas Valley, Lake County, Oregon. Figure 1.3 is an oblique aerial photograph of the southern-most radar antenna, called Sector 6. This site is located 16 miles east of the community of Christmas Valley. Travel east on Wagontire Road (County Rd., No. 5-14) and then turn left (north) on County Rd., No. 5-14f. Continue on the gavel road another 1.5 miles at which point the road leading to the Sector 6 area is to the right.

Figure 1.3: An oblique aerial view of the Oregon Military Department site, Lake County, Oregon. View is looking east- northeast. In the inset map, the arrow points to the approximate location of drilling the well (ARRA OMD-1)

Picture Rock Gravel Pit, Lake County

This site is an active gravel pit covering ±50.5-acres. ODOT owns and operates the pit, which lies near milepost MP-66.2, heading south on Highway 31-19 (Freemont Highway) towards Summer Lake, Lake County, Oregon. As can be seen in Figure 1.4, the gravel pit is immediately east of the highway near the foot of Picture Rock pass.

1.5 AGENCY REQUIRED PERMITS AND CLEARANCE

Below is a list of permits authorizing the drilling activities:

- An ODSL geothermal exploration permit for each location to drill the well.

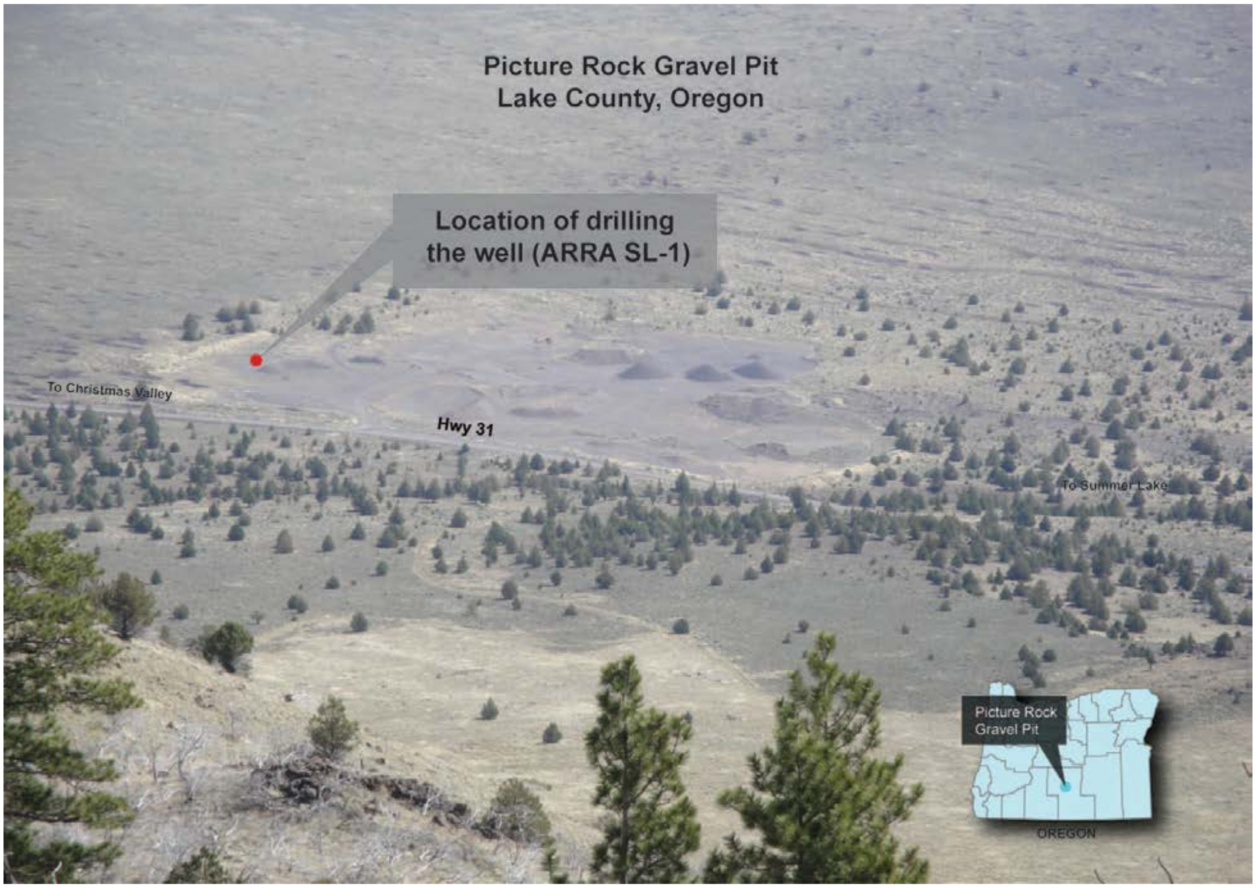

Figure 1.4: Photograph of the Picture Rock Gravel Pit, Lake County, Oregon (middle of photograph). View is looking to the east from Winter Rim. The red dot is the approximate location of drilling the well (ARRA SL-1)

- An ODOT encroachment permit (utility) for work in the Picture Rock Gravel Pit.
- National Environmental Policy Act (NEPA) scrutiny and clearance through US DoE.
- A site clearance letter for each location of drilling the well from the Oregon Parks and Recreation Department, State Office of Historic Preservation (SHPO).

The reader can follow a hyperlink in Appendix A to download a copy of the contract between DOGAMI and the Vendor.

1.6 CONTRACTING

The Oregon Department of Revenue, Enterprise Goods and Services/Procurement Services coordinated the solicitation for well drilling services. A Request for Proposals or RFP, which contained a description of the work, was published on ORPIN (Oregon Procurement Information Network), which is administered by the State Procurement Office. Timeline of the RFP process is listed in Table 1.2. The reader can follow a hyperlink in Appendix A to download a copy of the RFP 102-1899-12R.

Table 1.2: RFP timeline

Date	Description
7/27/2012	Solicitation for RFP 120-1899-02, Thermal Gradient Wells; ORPIN posting
9/7/2012	Solicitation for RFP 120-1899-02, Thermal Gradient Wells closed
9/11/2012	Re-post of solicitation RFP 102-1899-12R, Thermal Gradient Wells; ORPIN posting
10/15/2012	Re-posted solicitation RFP 102-1899-12R, Thermal Gradient Wells closed
11/16/2012	Negotiations with three bidders begins
1/23/2013	Reached positive negotiations with Welsco
3/11/2013	Executed Contract and Notice to Proceed-Contract #3378 for Thermal Gradient Well Drilling Services
3/25/2013	Kickoff meeting
4/16/2013	Spud-in of first borehole

2.0 DRILLING AND RELATED ACTIVITY

This section describes the drilling operation and related activity. The procedures and setup used to drill, complete, and P&A the three thermal gradient wells are similar to the general nature of drilling for a water well. The information presented below was compiled from logbooks, drilling logs, and daily activity summaries.

2.1 DRILLING OPERATIONS

A Schramm T130XD Telemast rig bored the holes. This drill rig is a heavy duty, heavy hoist, carrier mounted drill rig. It's important specifications are listed below:

- 130,000 lbs. (59,090 kg) actual pull-up
- 28 in (711 mm) table opening
- Detroit 2000 760 hp deck engine
- 1350/350–150/500 variable volume compressor
- 50 ft (15.25 m) of clear head travel
- Range III casing

An overall working area of approximately 50 ft wide by 100 ft long was needed to accommodate the drilling equipment. Support vehicles for the drilling included a 3,800 gal capacity water truck, pipe trailer, trailer mounted mud tank and separate mud pump, and service/fuel truck. The well pads were flat lying; no dirt work was necessary to prepare any of the three pads.

The following sources provided drilling/well construction water:

- ARRA FF-1: A rancher's pivot irrigation water
- ARRA OMD-1: Hydrant water from the community of Christmas Valley.
- ARRA SL-1: Well water from an artesian well near Anna Reservoir.

The boreholes were drilled using a mud rotary method. However, the entry hole for ARRA FF-1 was air rotary drilled. General details of well construction are summarized below. Table 2.1 lists these details and is followed by Figure 2.1. The Figure shows the relative position of casing strings and construction of each thermal gradient well.

- All entry holes were tri-coned, 10¾ inch diameter for the installation of flush joint surface casing, 8⅝ inch diameter. Cement was placed around the casing using a tremie pipe to fill the annular space.
- Rotary drilling of a 6⅛ in diameter borehole continued to final depth.
- Each borehole was lined with 2⅜ in threaded black steel pipe. Cement was pumped through the pipe and filled the annulus around the pipe from the bottom of the borehole up to the surface. The pipe was then plug at the bottom, filled with water to the collar, capped, and allowed to remain static.

- The ‘stickup’ of the pipe above grade is approximately 0.3 m (1 ft) and fitted with a lockable cap. The cap prevents liquids from entering or escaping the pipe and to discourage tampering with the well.

Table 2.1: Well construction details

WELL NAME	ARRA FF-1	ARRA OMD-1	ARRA SL-1
Site Name	Crowley-Riverside Road Gravel Stockpile area	Oregon Military Department	Picture Rock Gravel Pit
Spud Date	April 16, 2013	April 26, 2013	April 30, 2013
Ended Drilling Date	April 23, 2013	April 29, 2013	May 8, 2013
Entry Hole Depth (m/ft)*	36/120	12/40	12/40
Total Depth* (m/ft)	305/1,000	305/1,000	293/960
Surface Casing (m/ft)	36/120	12/40	12/40
Pipe (m/ft)	305/1,000	305/1,000	293/960†

* below ground surface
† Top of lost circulation zone

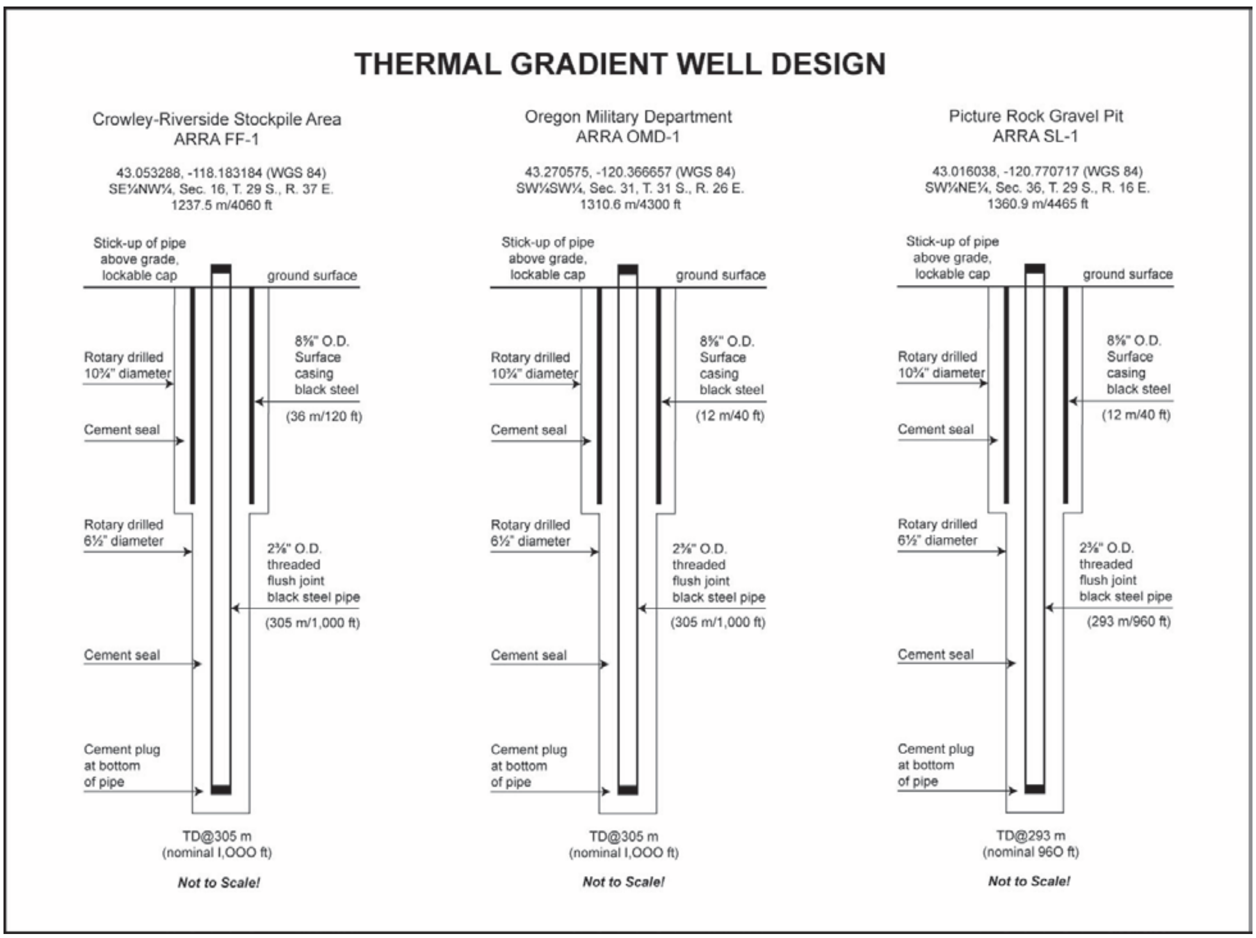

Figure 2.1: Diagram showing relative position of casing strings and construction of each thermal gradient well

2.2 LOST CIRCULATION MATERIALS (LCM)

During the drilling of all three boreholes, loss of circulation to the formation was routinely encountered. The remedial procedures and techniques used to restore circulation are summarized below:

- In ARRA OMD-1, drilling ahead restored circulation when the drilling fluid failed to return cuttings to the surface.
- The remedy in ARRA FF-1 (approximately 210 ft bgs) was the addition of gravel to the mud.
- To achieve plugging action in ARRA SL-1 (260-365 ft and 965 ft bgs), a slurry of drilling mud, gravel, and saw dust and walnut hulls was used. These additives were able restore circulation in the upper section of the borehole but was ineffective at the 965 ft bgs.

3.0 WELL SAMPLE AND TEMPERATURE LOGGING

This section addresses the primary and secondary objectives of the project, which are respectively the measurement of temperature gradients and the logging of the drill cuttings, together with geochemical characterization of selected cuttings utilizing normalized major oxide analysis plots.

3.1 TEMPERATURE GRADIENT LOGGING

To log the three wells for their temperature gradients, the USGS contributed equipment and personnel. Logging occurred on two separate dates: June 8, 2013 and August 20, 2013. The purpose of re-logging each well twice was to see how the well's temperature profile evolve as the borehole equilibrated.

Figure 3.1 shows the use of the USGS's portable temperature-measuring system. Its components are as follows:

- Laptop computer and 12-volt battery.
- An electrical signal processor that converts changes in resistance to a readout calibrated in temperature units.
- Four-conductor wire and calibrated digital thermistor thermometer (typically accuracy of 0.1ºC and precision of 0.01ºC).
- Hydraulically dampened cable reel to lower the sensor in the well.
- Calibrated depth counter in tenths of feet mounted on the well head.

Figure 3.2 illustrates the temperature vs. depth profiles of the wells for the June's log run, while the profiles of temperature vs. depth for log run in August are shown in Figure 3.3. The reader can follow a hyperlink in Appendix A to download a copy of the electronic temperature vs. depth data (Excel® spreadsheet).

Figure 3.1: View of Fredrick Grubb (USGS, Sacramento, CA.) conducting temperature measurements in ARRA OMD-1, Oregon Military Department site, Lake County. The calibrated depth counter is mounted on the well (middle-left in the photograph); the cable reel is next to Fredrick's leg; and the 12-volt battery-electrical signal processor-laptop computer are pictured between the reel and the truck. The red chainsaw engine is used to power the reel to hoist the logging cable and sensor out of the hole

3.2 WELL CUTTINGS/ LOGS

As each borehole was deepened, a sample of the well cuttings was retrieved at 10 foot intervals. Sample collection was delegated to a member of the drilling crew, while DOGAMI's well-site geologist was responsible for supervision of the sampling. Approximately one-quart by volume of well cuttings from each interval was caught at the shale shaker, bagged, and labeled.

DOGAMI geologists logged the cuttings and prepared a lithologic log of each borehole. A sampling of the cuttings was washed and then examined under a binocular microscope. The reader can follow a hyperlink in Appendix A to download a copy of the lithologic log for each borehole.

3.3 WHOLE-ROCK/MAJOR (TRACE) ELEMENT RELATIONS

Table 3.1 lists the selected zones of volcanic rock in ARRA FF-1 and ARRA SL-1 sampled for XRF whole-rock oxide and major (trace) element analysis. The well cuttings from ARRA ODM-1 were not sampled. The purpose of the analysis was to provide a descriptive name to selected cutting intervals based on normalized major oxide analysis plots. It is also a means to compare the whole-rock geochemistry of the intervals to rocks at the surface. The reader can follow a hyperlink in Appendix A to download an Excel® spreadsheet which contains the results of the whole-rock/major element analysis.

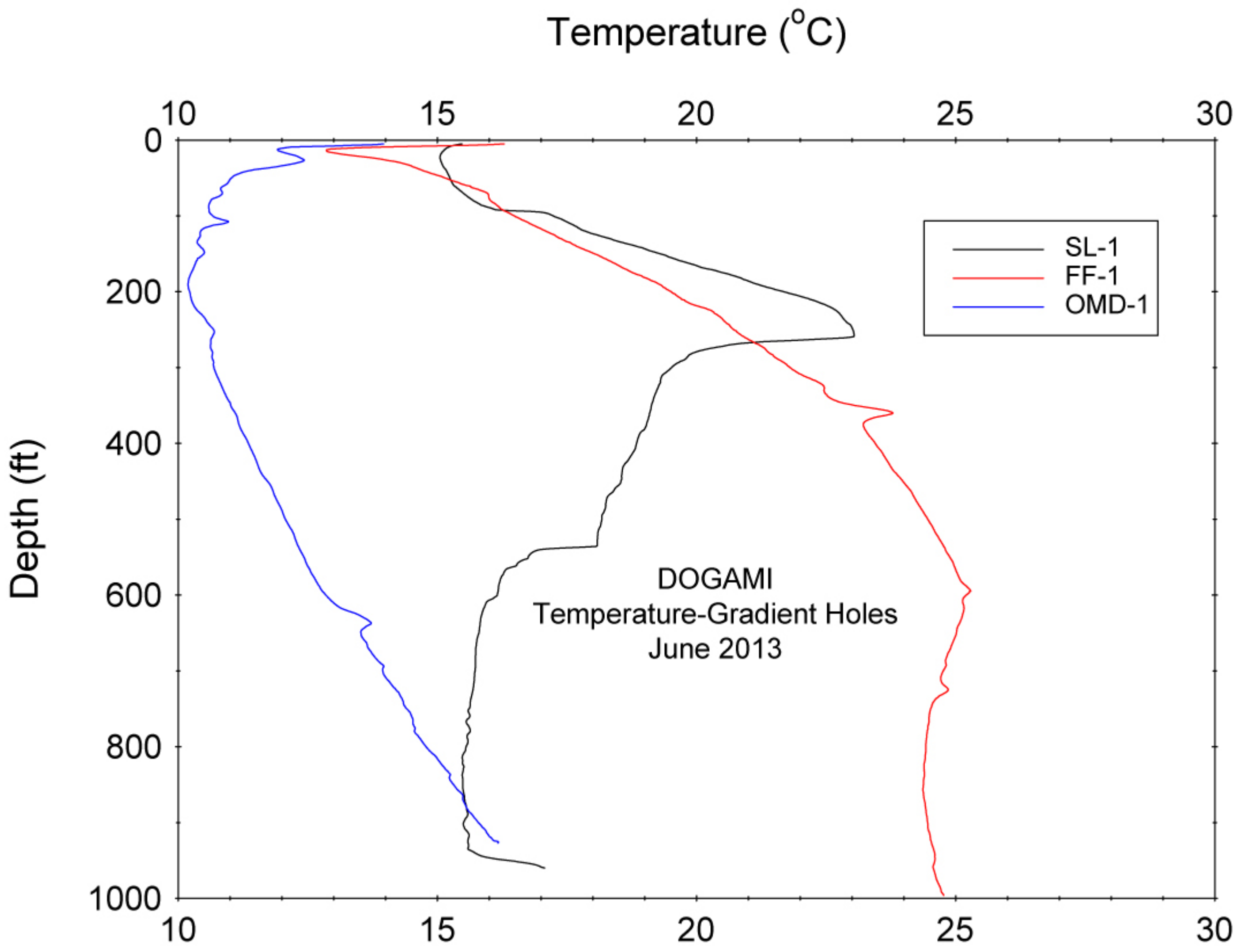

Figure 3.2: The June 8, 2013 temperature profiles of ARRA FF-1 (red), ARRA OMD-1 (blue), and ARRA SL-1 (black). The measurements occurred 28 days after the last well was complete. The unusual profile of ARRA SL-1 maybe due to a strong counter flow of water at different temperatures in 3 or 4 different zones in the well (David Blackwell, written communication, 7-1-2013). There is, however, a warmer water zone at approximately 220 ft bgs in ARRA SL-1. He also pointed out that a slightly warmer water zone occurs at approximately 600 ft bgs in ARRA FF-1 and flow of colder water occurs over the entire length of ARRA OMD-1

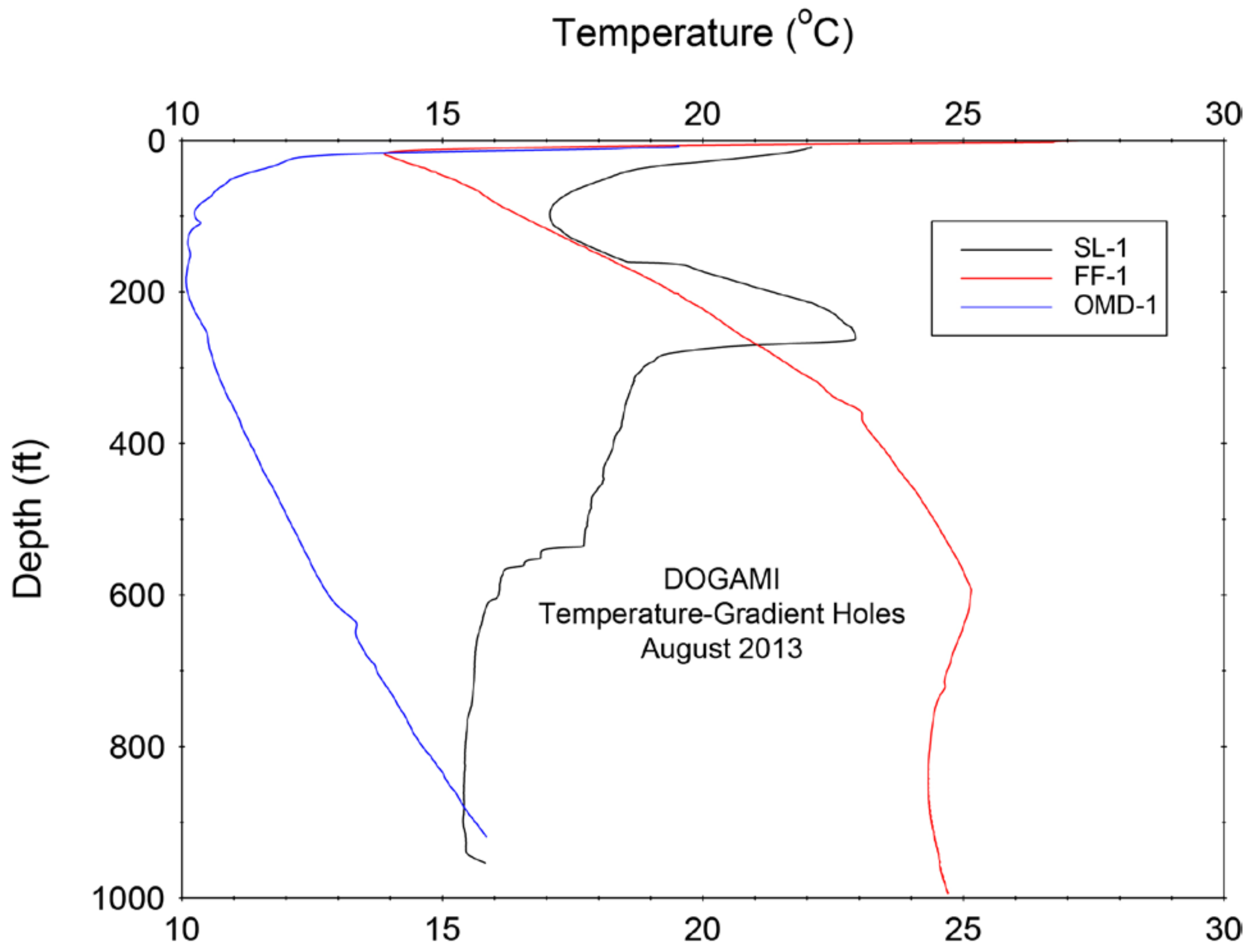

Figure 3.3: The August 20, 2013 temperature profiles of ARRA FF-1 (red), ARRA OMD-1 (blue), and ARRA SL-1 (black). The temperature gradients of the water in the wells for the August 2013 (second) log run exhibit the same profiles as those from the first log run in June 2013 (Figure 3.2). The exceptions are the starting temperatures (air) and the static water levels in each well fell particularly in SL-1.

Table 3.1: Sample intervals in ARRA FF-1 and ARRA SL-1

SAMPLE NUMBER	DEPTH*	WELL NUMBER	SITE NAME
FF1-250	250	ARRA FF-1	Crowley-Riverside Road Stockpile area
FF1-330	330	ARRA FF-1	Crowley-Riverside Road Stockpile area
FF1-475	475	ARRA FF-1	Crowley-Riverside Road Stockpile area
FF1-530	530	ARRA FF-1	Crowley-Riverside Road Stockpile area
FF1-640	640	ARRA FF-1	Crowley-Riverside Road Stockpile area
FF1-710	710	ARRA FF-1	Crowley-Riverside Road Stockpile area
SL1-65	65	ARRA SL-1	Picture Rock Gravel Pit
SL1-230	230	ARRA SL-1	Picture Rock Gravel Pit
SL1-510	510	ARRA SL-1	Picture Rock Gravel Pit
SL1-570	570	ARRA SL-1	Picture Rock Gravel Pit
SL1-640	640	ARRA SL-1	Picture Rock Gravel Pit
SL1-830	830	ARRA SL-1	Picture Rock Gravel Pit

* below ground surface

All samples were analyzed by XRF at the Department of Geosciences, Franklin and Marshall College, Lancaster, Pennsylvania, under the direction of S.A. Mertzman. Detailed analytical procedures for the Franklin and Marshall X-ray laboratory are described by Boyd and Mertzman (1987) and Mertzman (2000) and a copy of the procedures are available online at http://www.fandm.edu/ x7985.

4.0 WELL PLUGGING AND ABANDONMENT

The thermal gradient wells were abandoned and plugged (P&A) in-place. Well abandonment was conducted in accordance with Oregon Department of Water Resources requirements (ORS 536.090 & ORS 537.505 - ORS 537.795) and expertise readily available through Welsco Drilling Corp. The three wells were plugged and abandoned during September 2, 2013 through September 5, 2013, as follows:

- Dug-out well head to ±4 ft bgs; abandonment completed at that depth.
- The surface casing and 2⅜ in threaded black steel pipe was severed at ±4 ft bgs. The 2⅜ in threaded black steel pipe was filled with cement grout.
- The well head was backfilled to grade and drilling pad returned to a near pre-drilling status. No markers were left at the surface.

5.0 ACKNOWLEDGMENTS

This material is based upon work supported by the Federal Department of Energy's (USDoE) Geothermal Technologies Office and between the Arizona Geological Survey (AZGS; Sponsor working on the behalf of the American Association of State Geologists (AASG)) and the Oregon Department of Geology and Mineral Industries (DOGAMI; Subrecipient) under Award Number(s): Prime Award No. DE_EE0002850 and Sub Award No. OR-EE0002850, American Recovery and Reinvestment Act of 2009. The contents of the report are disseminated in the interest of information exchange.

The author would like to thank the following organizations and individuals for their advice and assistance in the completion of this work:

Oregon Department of Geology and Mineral Industries	Tom Wiley, Deb Scheuller
Federal Department of Energy	Arlene Anderson
Arizona Geological Survey	Kim Patton
U.S Geological Survey	Colin Williams, Frederick Grubb
Oregon Department of State Lands	Shawn Zumwalt
Oregon Department of Transportation	Bob Morrow
Oregon Department of Administrative Services	Lori Doke
Oregon Military Department	Gary Vandrew, Kris Mitchell

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APPENDIX A

Hyperlinks to Thermal Gradient Drilling Project Documents

Hyperlink	Documents
http://www.oregongeology.org/sub/gtilo/data/supplemental/ARRA_NEPA.pdf	NEPA clearance from USDoE
http://www.oregongeology.org/sub/gtilo/data/supplemental/ARRA_DSL_Permit.pdf	Department of State Land – Geothermal Exploration Permits
http://www.oregongeology.org/sub/gtilo/data/supplemental/ARRA_ODOT_Permit.pdf	Oregon Department of Transportation Department – Permit to Occupy or Perform Operations upon a State Highway
http://www.oregongeology.org/sub/gtilo/data/supplemental/SHPO.pdf	Oregon Parks and Recreation Department, State Historic Preservation Office – Clearance Letter
http://www.oregongeology.org/sub/gtilo/data/supplemental/RFP_102_1899_12R.pdf	Solicitation for RFP 120-1899-02, Thermal Gradient Wells
http://www.oregongeology.org/gtilo/ngds/well/ARRA_FF-1_Lith.pdf	Borehole log for ARRA FF-1
http://www.oregongeology.org/gtilo/ngds/well/ARRA_SL-1_Lith.pdf	Borehole log for ARRA SL-1
http://www.oregongeology.org/gtilo/ngds/well/ARRA_OMD-1_Lith.pdf	Borehole log for ARRA OMD-1
http://www.oregongeology.org/sub/gtilo/data/supplemental/ARRA_TempData.xlsx	Temperature vs. depth data
http://www.oregongeology.org/sub/gtilo/data/supplemental/Oregon_WellCuttingsChemistry_Supplemental.xlsm	XRF whole-rock/major element geochemistry of well cuttings