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PROGRESS OF RECENT EXPLORATION AT COVE FORT-SULPHURDALE, UTAH

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ABSTRACT

Surface exploration and well drilling began at Sulphurdale, Utah in 2001 after a ten-year hiatus. Electrical resistivity measurements were taken in a previously untested area west of the producing field to help identify and rank potential well sites. A 601 m well was drilled and cased to 396 m and a preliminary temperature survey run. The well has already yielded some information for comparison with geologic and resistivity models of the area. The temperature results are encouraging but not definitive. More testing is planned upon the return of favorable weather and surface access. The new well was completed without trouble and within budget in twelve days using a conventional rotary rig. Hole and casings sizes will permit deepening and commercial production if budgets and technical indicators warrant doing so.

PROJECT BACKGROUND

Cove Fort is the name given to a pioneer travelers' way station and telegraph relay office built in 1867 near Cove Creek. The fort is located near the intersection of Interstate Highways 15 and 70, about 300 km south of Salt Lake City. Five km south of the fort is an ancient native sulphur pit named Sulphurdale by the Caucasian settlers. The producing geothermal field adjoins the sulphur pit area.

The Cove Fort-Sulphurdale geothermal area is located on the eastern margin of the Basin and Range province, near the junction of the Pavant Range and the Tushar Mountains. These highlands form part of the High Plateau subprovince that marks the transition between the Colorado Plateau and the Basin and Range provinces. The geothermal system is one of the largest thermal anomalies in the western United States and includes an area of about 60 km^2 with temperature gradients above 200 C/km (Ross & Moore [1985]).

In the late 1970s and early 1980s several geothermal companies conducted extensive exploration programs. Union Oil Company of California mounted the largest campaign. Union drilled twenty-four temperature gradient wells and four production-size wells. Three of the latter were drilled under the auspices of the US Department of Energy's Industry Coupled Program. Union's large wells were drilled north of the present bore field. Even though Union did not find adequate production to proceed with development, one of its wells (42-7) is now the project injection well, and a large amount of data was made available to subsequent operators (Ross & Moore[1985]).

The power plant, Cove Fort Station #1, is set back in the foothills of the Tushar Range, approximately 2-1/2 km east of I-15 and three km south of I-70. The plant began operating in 1985 as a pure binary system. It now comprises two parts: a condensing turbine rated at 8.5 MW and an Ormat binary plant with four 750 kW units. Three of the binary units are normally in operation with the fourth in reserve.

Mother Earth Industries (MEI) and the City of Provo worked together in the early 1980's to get the project started. The plant was designed to provide Provo with 10 MW of base-load capacity, utilizing five steam wells. Two of the wells are on Federal property and three on private land. When the plant was completed in 1990 it was named for Bud Bonnett, a long-time Provo city utility manager.

The City of Provo also joined the Utah Municipal Power Agency (UMPA) in the early 1980's. UMPA consists of six Utah cities, Provo being the largest. Once the plant came on line, the power produced was incorporated into UMPA's power sales to its agency members. When the larger condensing turbine was brought on line in 1990 it required the largest share of the steam produced. Nearly immediate declines in steam pressure and flow rate were recognized. A hot water well, P91-4, was drilled in 1991 to help supplement the steam flow but was not used until after UMPA was asked by the City of Provo to take over operation of the plant in 1994. MEI's interest in the geothermal field was purchased by UMPA in 1994 also.

When UMPA began operating the plant and managing the field in 1994, its first priority was to stabilize the declining field production. By 1996 the P91-4 hot water well was producing about 126 l/s of 152 C water. This water is flashed at high and low pressures in two different vessels. The high-pressure steam is mixed with the steam from the field and sent to the condensing turbine. The low-pressure steam flows to the binary units. The field steam supply has nearly stabilized since 1996. A small continuing decline requires that UMPA look at further increasing hot water production to support and increase plant generation.

The combination of an attractive exploration prospect near an operating geothermal plant with readily available capacity made UMPA a logical participant in the US Department of Energy's "Geopowering The West" initiative. UMPA's application was successful and provided the necessary encouragement for the agency to look more closely at its geothermal project's potential.

PRODUCTION CHARACTERISTICS

Steam is supplied to the Bonnett power plant by six production wells. Five of the wells discharge dry steam from a fractured sandstone of likely Mesozoic age that lies immediately below Tertiary ash-flow tuffs. The depth to the top of the sandstone and the top of the steam cap decreases from north to south. The two deepest dry steam wells 34-7A (aka Olga) and 34-7B (Linda) produce steam from depths of 339-351 m. These wells had initial temperatures of 147-151 C. P89-1 (Mary), located at the southern end of the field produces steam from 256-265 m. The sandstone appears to have a thickness of about 60 m. The full lateral and vertical extent of the vapor-dominated cap, however, has not yet been defined by drilling.

P91-4 produces water from the underlying liquid resource. This well was drilled to a depth of 745 m. P94-1 is reported to have encountered steam at 258 m, the water table at 314 m, and a maximum temperature of 163 C. The water table appears to be located near the top of the limestones immediately below the sandstone. Below 600 m, P94-1 encountered weakly altered intrusive rocks. Liquid water is presently produced at a temperature of 152 C from depths below 485 m. After flashing, the remaining water is injected into well 42-7 where it enters the reservoir at the base of the volcanic section between depths of 588 and 716 m. Well 42-7 was originally drilled to a depth of 2358 m and recorded a maximum temperature of 178 C near its TD. To date, this is the highest temperature recorded in the field.

GEOLOGIC SETTING

The stratigraphy and characteristics of the volcanic rocks in the Cove Fort-Sulphurdale area were described by Steven & Morris (1979, 1983) and by Ross and Moore (1985). Their studies indicate that the area has been the site of repeated structural, intrusive, volcanic, and hydrothermal activity since late Cretaceous time. Pre-volcanic basement rocks consist mainly of Paleozoic to Mesozoic limestones and sandstones that are exposed in a northeast trending belt north of Cove Creek. At depth, these rocks host the modern geothermal system throughout the area. Volcanic activity began at ~30 Ma, with the eruption of intermediate composition lava flows, breccias, and ash-flow tuffs related to a volcanic center near Cove Fort. A succession of ash-flow tuffs and the emplacement of monzonite to latite intrusions followed this early volcanism.

Six major ash-flow tuffs have been recognized in this area. They are (1) the Wales Canyon Tuffs (dacite, Oligocene), (2) the 27 Ma-old Three Creeks Tuff Member of the Bullion Canyon Volcanics (dacite), (3) the densely welded Tuff of Albinus Canyon, (4) the poorly welded Zeolitic Tuff (clinoptilolite-bearing), (5) the 22.4 Ma-old Osiris Tuff (dacite) and (6) the 19 Ma-old Joe Lott Tuff Member of the Mt. Belknap Volcanics (rhyolite). Younger basaltic andesite flows erupted 0.5 Ma ago, producing the broad shield volcano at Cove Fort. These younger flows and alluvium cover the Tertiary volcanic and older sedimentary units west of Sulphurdale.

Quartz monzonite and shallow latite porphyry stocks and dikes intruded the Zeolitic Tuff and the underlying rocks between 27 and 22 Ma ago. Intrusive rocks are exposed east of Sulphurdale, and were encountered in wells 42-7 and P91-4. Geophysical data suggests that a large intrusion is also centered under the productive portion of the geothermal field at Sulphurdale.

The distribution of permeability within the Cove Fort-Sulphurdale geothermal system is the result of several generations of faulting and tectonic activity. The oldest structures are thrust faults produced by the Mesozoic Sevier Orogeny. Basin and Range tectonism is represented by large-scale gravitational glide blocks bounded by low-angle faults and steeply dipping northerly- and easterly-trending normal faults. The glide blocks form a low permeability cap over the southeastern part of the system, southeast of Cove Fort. The glide blocks have had a profound effect on the distribution of surficial alteration, shallow thermal gradients, and the distribution of rock types within the Sulphurdale area.

The glide blocks are bounded on the north by the steeply dipping Clear Creek Fault. North of the fault, intense argillic alteration, active gas seeps, and native sulfur deposits are present at several locations along Basin and Range faults.

The reservoir is developed mainly in Mesozoic and Paleozoic sandstones and limestones, although carbonate units dominate the section. Within the geothermal well field, dry steam is produced from fractured sandstone. P91-4 produces water from the underlying carbonate rocks. The intrusive rocks in this well are only weakly altered and do not appear to be productive. Deep drilling has shown that the thermal water table occurs at a depth of 366 m throughout this area. No overlying aquifers were encountered during the drilling of the geothermal wells even though cold springs discharge to the east and perched aquifers are found to the west of the field.

Hydrothermal alteration at Sulphurdale was caused by several different events. Intense argillic alteration, deposition of native sulfur and acid leaching in the Sulphurdale pit is related to boiling of the reservoir fluids and the formation of acid-sulfate waters. These waters form above the water table when hydrogen sulfide oxidizes to sulfuric acid in steam condensate. An older episode of alteration appears to be related to the intrusion of the quartz monzonite. In the deepest part of 42-7, recrystallization of the limestones and formation of metamorphic minerals has occurred. Despite the large size of the thermal anomaly and the abundance of active and extinct fumaroles, no evidence has been found of hot spring deposits that would indicate thermal waters ever reached the surface.

GEOPHYSICAL RELATIONSHIPS

The diverse rock types and major geologic structures of this geologic setting are well expressed in the geophysical data and have been described in some detail (Ross & Moore [1985]). Two electrical resistivity surveys completed in the late 1970s defined an area of more than 4 km^2 typified by low (4 ohm-m) electrical resistivity at depths of 460-610 m. This low resistivity zone includes a large area of altered volcanic tuff and the steam production zone. The low resistivity area is confirmed by a CSAMT survey and extended by other resistivity work. Ross, et al. (1997) completed detailed self-potential surveys and recorded five significant SP anomalies associated with the low-resistivity area, including a small dipolar anomaly within the steam production zone. Cove Fort has been an area of active seismicity since monitoring began in the mid-1970. A magnitude 3.6 earthquake with a source east of the power plant in the Tushar Mountains was recorded as recently as December 2001.

New geophysical surveys were completed in 2001 to improve the geophysical characterization of the geothermal resource and to aid in site selection for an exploration well, Bonnett01-1 (Ross & Mackelprang [2001]). A detailed ground magnetic survey of 576 stations was completed for an area of about 3.25 km^2 west of and adjacent to the developed steam field. The survey provided additional support for the interpretation of several faults associated with the east margin of the Cove Fort - Beaver graben, and two east-trending structures that project into the production area.

Four new dipole-dipole resistivity lines were completed, and numerically modeled to better define the resistivity structure west of the steam field and across the hot water production well P91-4. The selection of profile locations was somewhat compromised by the presence of power lines, pipelines, and other grounded structures but important new results were obtained. The numerical models of these profiles define a low resistivity body (LRB) about 2000 m long (NNE) by 1100 m wide (ESE) at depths of 450-600 m west of well P91-4. The very low resistivity modeled for the body (0.5 to 2.5 ohm-m) is most likely due to geothermal fluids and associated alteration minerals (Ross & Mackelprang [2001]).

EXPLORATION WELL BONNETT01-1

The Bonnett01-1 (B01-1) site is on the low hills west of the Sulphurdale sulfur pit and the production wells. B01-1 used an existing drill pad with a 76 cm conductor pipe already in place, along the eastern margin of the LRB. The pad was constructed by Union Oil but never drilled. The site represents a compromise of several considerations including proximity to existing facilities, costs of site preparation and environmental surveys, and desire to test the LRB. Additional key considerations were the approaching federal fiscal year-end and the cost increases associated with winter drilling operations.

The drilling technology used on this job could best be described as carefully low-tech. A low cost approach was dictated by the fact that drilling rig day rates increased in Utah more than 50% between the time proposals were submitted to DOE and when drilling could begin. It quickly became apparent that attempting to reach the original target of 900 m depth within the original budget would require taking unacceptable risks with barely adequate equipment.

The well program was redesigned to use a larger rotary rig than originally planned, and larger but less expensive casing. The extra capacity provided an additional margin of safety, as did the use of very experienced rig crews. The larger casing left a large enough hole to be used for scientific studies, later deepening or liner installation and eventual use of a shaft driven pump. The well now has a string of 27.3 cm casing cemented from surface to 393 m. The open 21.6 cm hole from 393 m to total depth of 598 m was drilled and completed with no fill or sloughing problems.

GEOLOGY OF B01-1

Well B01-1 was drilled entirely within volcanic and intrusive rocks. It was sampled at 3 m depth intervals from 12-398 m. Three units have been identified, as shown in Figure 1. The uppermost part of the well, to a depth of 125 m, consists of latite porphyry. Between 125 and 189 m, the well encountered the Joe Lott Tuff Member of the Mount Belknap Volcanics. Below 189 m, the rocks appear to consist of The Three Creeks Tuff Member of the Bullion Canyon Volcanics.

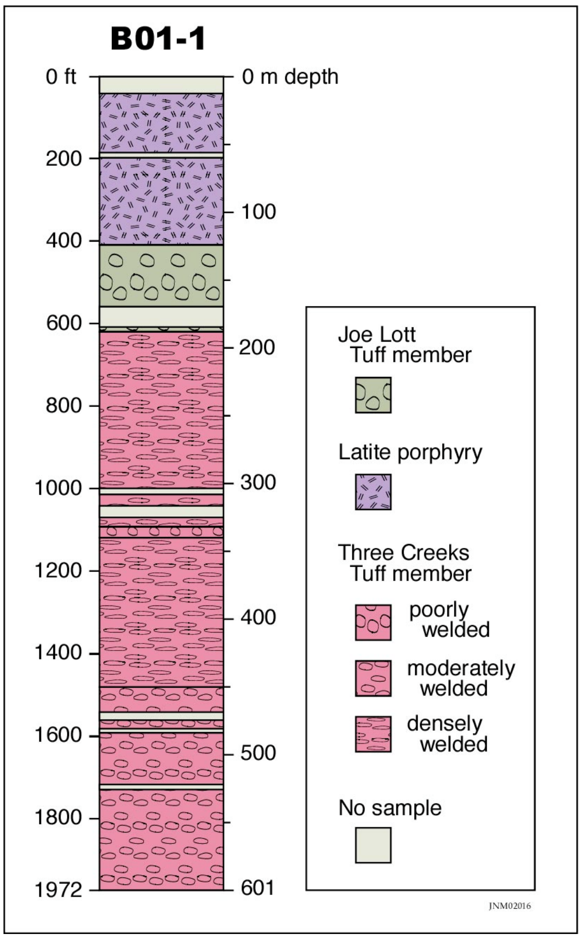

Figure 1. Lithology Log of Bonnett01-1 [depths measured from 3.7 m KB]

The latite porphyry is fine grained and white to reddish brown. Chips display flow banding. The matrix of the rock has been devitrified to a mixture of potassium feldspar and quartz. Phenocrysts of feldspar and pyroxene are present in some chips but they are not abundant.

The Joe Lott Tuff Member of the Mount Belknap Volcanics is a poorly welded pink ash flow tuff. The rock contains abundant shards but few phenocrysts or lithic fragments. The phenocrysts consist primarily of quartz and feldspar. This ash flow tuff was produced during the collapse of the Mount Belknap Caldera, located on the crest of the Tushar Mountains. Thick sections of ash flow tuff are exposed in Clear Creek Canyon. On the western side of the Tushar Mountains, it is relatively thin.

In contrast to the Joe Lott Tuff Member, the Three Creeks Tuff Member of the Bullion Canyon Volcanics is a moderately welded crystal-rich ash flow tuff. It is dacitic in composition and contains nearly 50% phenocrysts of plagioclase, hornblende, biotite, sanidine, magnetite, and quartz. Lithic fragments are common. The quartz characteristically displays bipyramidal crystal forms. The presence of these quartz crystals associated with biotite is diagnostic of the unit. The source area for this ash flow tuff is the Three Creeks Caldera, located just north of I-70, approximately half way between Cove Fort and Monroe. Here, the ash flow tuff consists of three major cooling units that differ primarily in their degree of welding.

Hydrothermal alteration is generally weak. A few calcite veins are present in the latite porphyry and between 12 and 18 m, there is some oxidation and iron staining. However, the feldspars in the matrix of the rock are relatively fresh. Feldspar phenocrysts in the ash flow tuffs display weak to moderate alteration to sericite, but the biotite crystals appear relatively fresh in hand specimen

Although B01-1 is located near the producing steam and water wells, the section it penetrated differs in several respects from that found in those wells. First, neither the Joe Lott Tuff Member nor the latite porphyry were encountered in the upper parts of the other wells, although intrusive rocks were found in the lower part of P91-4. Second, the Three Creeks Tuff Member is much thicker in B01-1 than in the producing steam and water wells. On the other side of the producing area, injection well 42-7 did encounter approximately 450 m of the Three Creeks Tuff Member before penetrating 150 m of the underlying lava flows and ash-flow tuffs. These differences suggest that B01-1 is located on the downthrown side of a major northwest-trending fault that passes between P91-4 and B01-1. This fault is exposed in the range to the southeast and exhibits a well-defined aeromagnetic signature, but is covered by alluvium near Sulphurdale.

The distribution of rock types in B01-1, with the Joe Lott Tuff Member (19 Ma) occurring below the older intrusive rocks (22-27 Ma), indicates that the two units are in fault contact. Reverse faults are not common. It is more likely that the contact between the Joe Lott Tuff Member and the intrusive rocks is a low angle normal fault at the base of a gravitional glide block. The distribution of major faults mapped in the surrounding area and inferred from geophysical data is shown in Figure 2.

Hydrothermal alteration of the volcanic rocks in B01-1 is also weaker than it is in the producing wells. Within the bore field, argillic alteration is generally more intense and small amounts of pyrite are common. The more intense alteration in the production wells may reflect leakage of CO_2 and H_2S from the underlying steam reservoir and the formation of slightly acidic steam condensate in the overlying volcanic rocks.

In contrast to B01-1, all of the production wells are located in a triangular shaped horst bounded by an easterly-trending fault on the north, the northwesterly-trending fault on the southwest, and northerly-trending Basin and Range structures to the east. The shallow depth of the sandstone within the horst allows it to serve as a reservoir for the steam cap. Outside the block, the sandstone may be an important aquifer for the deeper, liquid-dominated resource.

DRILLING AND GEOPHYSICAL RESULTS

There is some disagreement between the lithology observed in B01-1 and the surface electrical resistivity interpretation. Two of the 2001 resistivity profiles trend easterly nearby. Profile 1-01 (305 m dipole length) crosses about 75 m north of the drill hole. The numerical model, which assumes a two-dimensional geology, suggests moderate resistivity, 5-10 ohm-m, to depths of about 300 m, then 2.5 to 1 ohm-m to about 600 m depth. Much higher resistivity, 40 ohm-m, is indicated about 120-430 m east of the drill hole, at depths of 600 and 400 m. No electrical resistivity logs have been completed for this drill hole for comparison with the surface electrical surveys. Inspection of the drill cuttings does not indicate argillic alteration of a degree and rock volume that would correspond to the low (1-2.5 ohm-m) resistivity zone indicated in the model.

Profile 3-01 is a 152 m dipole line which trends easterly about 210 m south of B01-1. The modeled resistivity distribution, which should be a fair generalized representation of the resistivity distribution to depths of about 305 m in a near two-dimensional geometry, shows resistivity of 10-20 ohm-m to depths of about 230 m. A layer of 0.5

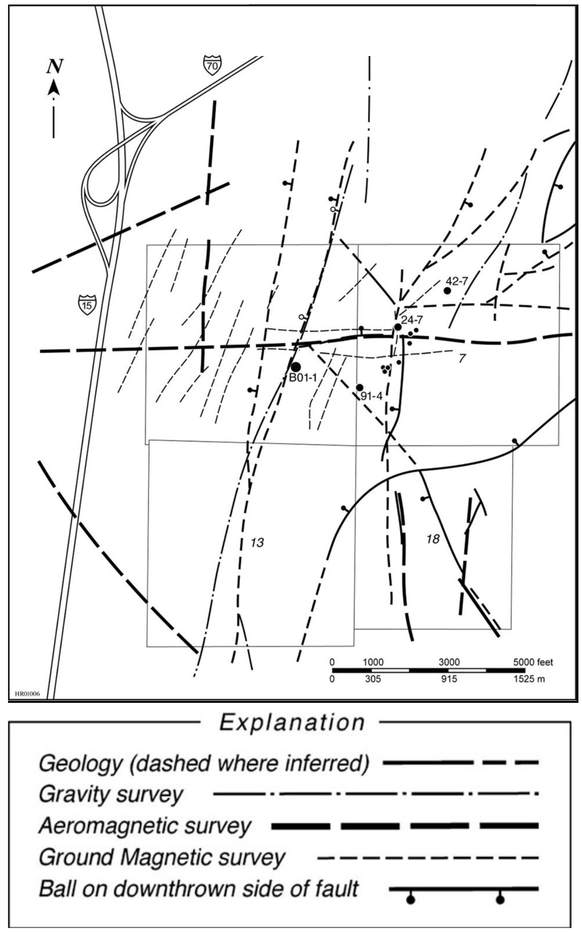

Figure 2. Summary of interpreted faults in the Cove Fort-Sulphurdale, Utah area. [Steven & Morris (1981), Ross & Moore (1985), Ross & Mackelprang(2002)]

ohm-m that is more continuous east of the well underlies this unit. The upper, moderate resistivity seems consistent with the drill cuttings, but the very low resistivity (0.5 ohm-m) layer at about 230 m is not indicated in the cuttings.

Although the moderate to strong argillic alteration found in short intervals in the cuttings could, if saturated with low-resistivity fluids, give rise to low bulk resistivity, they could not reduce the bulk resistivity of large rock volumes to the degree indicated by the numerical models of nearby resistivity lines.

There are several plausible explanations for the apparent disagreement. Two of the most likely are: 1) the resistivity lines are relatively close to, but do not directly cross the drill site, and 2) the numerical resistivity models are two-dimensional, whereas the geologic structure of the area is far from two-dimensional.

The low-resistivity response recorded by the profiles is due in part to low- resistivity distributions lateral to the profiles, and not directly beneath the profile. Major low-resistivity bodies are known to occur east of B01-1 (sulfur pit and alteration area), and north and west of B01-1 (the LRB) as defined by additional resistivity profiles.

TEMPERATURE MEASUREMENTS

Fluids were last circulated in well B01-1 on November 15, 2001. A temperature log of B01-1 was recorded on January 10, 2002 during a minor thaw in midwinter weather. Howard Ross and Robert Blackett used an N.P. Instruments high-precision (+/- 0.01 C) thermistor probe to log the cased hole, with the results graphed in Figure 3.

The air temperature varied between 0 and 4^oC during the logging period. The first temperature observation, at 1 m below the surface, was made in air and required a long time (10 minutes) before the temperature measurement stabilized at 4.6 C. Subsequent temperature measurements were made in air down to 200 m depth. These measurements were made in air as indicated by recording times of 6 to 10 minutes without reaching complete stability. The temperatures recorded for these depths are minimum temperatures, since waiting for complete equilibrium would have required substantially more time than was available in daylight hours. The temperature probe resistance stabilized immediately at 300 m, indicating the probe was in drilling fluid rather than air. Thus the fluid level in B01-1 was somewhere between 200 and 300 m subsurface.

The line shown on Figure 3 represents a temperature gradient in the wellbore of 227 C/km. The absence of any significant permeability in the uncased part of the hole suggests that the conductive temperature gradient observed in Figure 3 is likely to persist to the well's present total depth of 598 m. If that is correct, the bottom hole temperature in B01-1 may be about 157 C, or 5 C hotter than the water now being produced from P91-4. This suggests that temperatures could approach the 178 C level found in well 42-7 on the other side of the field. If the 227 C/km gradient persisted only another 27 m beyond the 598 m TD the temperature would equal the maximum recorded in P91-4. Unfortunately, we will be unable to confirm these speculations until a larger temperature tool can be run. The tool used is about 1.3 cm in diameter and was unable to pass over the 1.5-2.0 cm ledge at the shoe of the casing.

CONCLUSIONS

Well B01-1 is suitably constructed for scientific use or for eventual service as a production well. The well shows signs of usefully high temperatures that need to be verified by logging. Inconsistencies between the formations drilled and geophysical model predictions suggest that additional well logs and surveys may help resolve the complex structure.

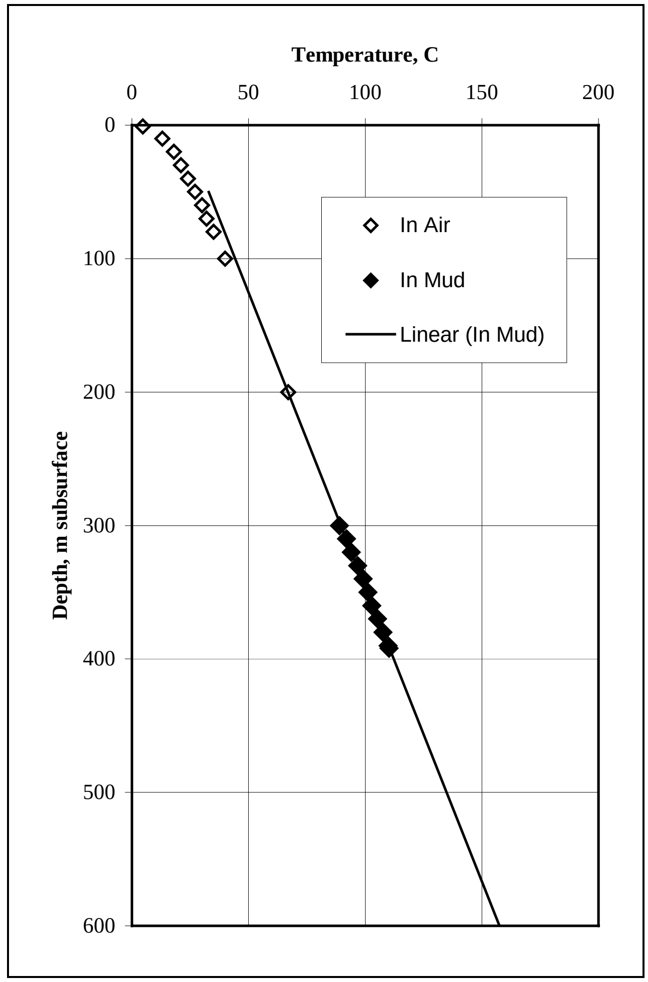

Figure 3. Static temperatures in well B01-1. Points above 300m are measured in air and not fully stabilized (see text). Line is best fit to points in liquid, 300-400 m.

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