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A Review of the Aluto Langano Geothermal Project and Recent Temperature and Pressure Logging

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ABSTRACT

The Aluto Langano geothermal field covers an area of at least 8 km² in the central part of the Aluto volcanic complex, a rhyolitic volcanic field in the main Ethiopian Rift Valley. The first two wells drilled south and west of the complex penetrated through a low temperature outflow. The last six wells drilled in the complex, and centered on the Wonji Fault Belt found temperatures of 200 to 334 °C. Four of these wells have been used for production and one for injection. High temperatures are offset by low to moderate permeability. A 7.28 MW net power plant operated briefly but was shut down due to numerous power plant and resource problems. Efforts have now been underway for one year to refurbish and restart the power plant. Caliper logging has shown that the two hottest production wells are in good mechanical condition. One cooler well is largely blocked by carbonate scale and the other cooler production well, which still has a good flow rate, has a major blockage at a depth of 701m. New precision digital temperature and pressure logs agree well with many older mechanical logs and show new details regarding permeable intervals in the wells. Pressure logs show very large downhole pressure drops when the hottest wells are flowed, which is in agreement with past interpretations of these wells having low permeability.

Introduction

The Aluto Langano geothermal field is located in the Lakes District, between Lakes Ziway and Langano, within the main Ethiopian rift valley about 200 km south of Addis Abbaba. Aluto Langano is one of 13 geothermal prospects that have been evaluated to varying degrees by the Geological Survey of Ethiopia (Figure 1). The Aluto-Langano geothermal field is located within the Aluto rhyolitic volcanic complex. Access is via a paved two lane highway to the small town of Bulbulla and then via about 25 km of gravel road to the power plant, scenically located within a high internally drained valley.

A geothermal power plant was constructed and briefly operated before being shut down due to a number of power plant and resource problems. Recently the Ethiopian Electric Power Company contracted with Geothermal Development
Associates to evaluate the power plant and steamfield and to return them to an operable condition.

**Geology**

The Aluto volcanic complex, as it is currently named, is a Quaternary rhyolitic eruptive center covering 100 km² and rising to over 700m above the eastern part of the main rift valley floor which has an elevation of about 1600m. The largest feature in the complex is an elliptical, flat-bottomed and internally drained central valley surrounded by rhyolite domes. Workers, who spent little time in the field in the 1970s and early 1980s, referred to the central valley as a caldera but the absence of any significant ignimbrite deposit within or around the volcanic complex has led to the current interpretation that the complex is a cluster of Quaternary overlapping rhyolitic domes, glassy lava flows, pumiceous cones, and craters (Kebede et al., 1984) (Figure 2). Only the youngest obsidian flows are not extensively mantled with relatively thin unconsolidated pumice deposits. The closest geological analogies to a United States geothermal field would be with the rhyolitic domes at Coso or the Mono Craters.

It has been proposed that the Aluto Volcanic Complex is located along, and localized by, the Wonji Fault belt, an en echelon belt of Quaternary north-northeast trending extensional faulting and fissure volcanism located within the Rift Valley. Due to the young age of the volcanic rocks there are few features which can be readily recognized as faults near the geothermal field. The most obvious normal fault in the Aluto volcanic complex is located about 0.5 km east of the Aluto power plant where two strands of a normal fault have uplifted the eastern part of the central valley floor by about 100m (Figure 3). These scarps have been interpreted to be part of the Wonji Fault Belt. The more eastern of the two fault scarps exposes unconsolidated pumice and, in places, is more or less vertical with a height of 20-25 m. This scarp has yet to be incised by a substantial ephemeral stream and so must be very recent. The western scarp is much more subdued but of similar height. The highest temperatures yet measured are located along these scarps. There is a striking alignment of craters along the general trend of these scarps towards the north-northeast. These scarps and the alignment of craters have been described as defining part of the Wonji Fault belt.

**Surface Manifestations**

The Aluto Volcanic Complex has no surface water, other than ephemeral streams during the rainy season. There are no hot or cold springs. Water is so precious that steam is condensed from fumaroles on cut brush by the local people for drinking water. It has been estimated that 17.5 million cubic meters per year of rainfall percolates into the volcanic complex (Hochstein, 1983). There are boiling thermal springs located south of the volcanic complex near the shore of Lake Langano and on an island in Oitu bay in Lake Langano. There are abundant small low pressure fumaroles clustered primarily in the eastern and southern parts of the volcanic complex. A few scattered fumaroles are present in the western part of the complex (Kebede et al., 1984).

**Exploration and Development History**

Geothermal exploration in Ethiopia commenced in 1969 as a joint effort between the branch of the Ethiopian Government now known as the Geological Survey of Ethiopia and the United Nations Development Program (GSE, 2002). Reconnaissance exploration techniques identified a number of potential high-temperature geothermal resources in the main Ethiopian rift valley in the southern part of the country and

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Figure 2. Photo of part of a geologic map of the Aluto Volcanic Complex by Kebede et al., 1984.

Figure 3. Photograph looking north of the Wonji Fault Belt located just east of the power plant near the center of the photo. The road switchbacks up across the main fault scarp. The fault scarp either terminates or disappears beneath the large pumice cone complex to the north of the road. The pumice cone complex also defines part of the Wonji Fault Belt. Well LA-4 is located at the far right edge of the photo and LA-8 is located off to the left of the photo. Wells LA-3 and 6 are located near the center of the photo.
the Afar triple junction area in the eastern part of the country (Figure 1). In the mid 1970s more detailed exploration identified the Aluto area as the first priority for deep, large diameter exploratory drilling. In part this was due to the accessibility of the area and its proximity to the national power grid; only 15 km of new power line was needed to connect the geothermal power plant to the grid.

Between Nov. 1981 and March 1985 eight exploration and development wells were drilled to between depths of 1317 and 2501 m. The first two were located in easily accessible low elevation and low-resistivity areas to the south and west of the Aluto volcanic complex where thermal springs produced water as hot as 95°C and the chemical geothermometers indicated subsurface temperatures of at least 180 to 200°C (Hochstein, 1983). Unfortunately, these first wells encountered a maximum temperature of only 103°C above a depth of 1500 m. In 1981 there was no road access to the higher portions of the Aluto area but it is telling that none of the United Nations individuals involved in siting the first two wells had actually visited the upper portions of the volcanic complex. A classical mistake was made in misinterpreting outflow zones as an upflow zone (Hochstein, 1983).

Following the completion of the second well, roads were quickly bulldozed up into the volcanic complex and 18 temperature-gradient holes were drilled in areas where the geology indicated holes could be quickly completed to depths of 50 m. These holes generally encountered high temperatures and/or temperature gradients and suggested a total heat loss of the Aluto geothermal system to be greater than 120 to 130 MW (Hochstein, 1983). This temperature-gradient hole program, along with some additional work in locating fumaroles, led to the siting of LA-3, the discovery well which was drilled during the first half of 1983. LA-3 is located between the two previously mentioned fault scarps. The eastern scarp now has some small and weak fumaroles, one of which was previously described as “impressive” by Hochstein (1983).

Following the successful completion of LA-3, five additional wells were drilled with a spacing of 1 to 2 kilometers around LA-3 (see Figure 2 for locations of wells LA-3 through 8). Two of the four production wells, LA-3 and LA-6, are located a short distance west of the obvious fault scarp (Figures 2 and 3). The other two production wells, LA-4 and 8, are located on the flat valley floor not close to any fumaroles and were apparently not targeted on any particular structure. The four production wells originally had an average megawatt output of about 2 MW/well. Well 7 has been utilized as the sole injection well for the power plant. Only well LA-5 was unsuccessful in that it was unproductive, but it did encounter temperatures over 200°C.

The proven productive area at Aluto is on the order of 8 km² (Figure 2) but this is a highly tentative number as the margins of the geothermal system are basically undefined. It is important to note that the drilling success rate after LA-2 was very good without the need of targeting one specific structure. This strongly implies an areally extensive reservoir and hopefully a substantially larger resource than that proven to date. All of the wells that were capable of flowing were extensively tested and logged. No drilling or exploration work has occurred over the past 22 years.

**Power Plant Design and Operations**

In 1986 a recommendation by ElectroConsult (1986) was made to construct a 3.5 MW back-pressure steam turbine plant to utilize the existing wells. In 1995, after investigating five different power plant cycle combinations, a recommendation was made to construct a 5.8 MW power plant utilizing a condensing turbine (GENZL, 1995). Instead, a combined steam and binary cycle unit rated at 7.28 MW (net) was constructed and began operations in May 1998. The power plant only reached about 50% of its rated capacity and ceased operating in 2002 due to numerous issues with the power plant, gathering system, and production wells. In 2004 a competitive tender was offered by the Ethiopian Electric Power Company to evaluate the entire project and, in late 2005, Geothermal Development Associates commenced work to evaluate the current condition of the geothermal resource and to refurbish and restart the power plant. The geothermal combined cycle unit (a steam turbine) was restarted in early June 2007.

**Steamfield Reassessment**

**Well Drilling**

Drilling times for individual wells ranged from as long as 220 days for LA-1, the first well drilled, to 99 days for LA-7, one of the last wells drilled (Figure 4, overleaf). Drilling was challenging in a number of aspects. Developing and maintaining a reliable water supply required pumping water from Lake Ziway to the upper parts of the Aluto volcanic complex. It could take weeks to get drilling supplies or equipment to the site. The most difficult drilling problems were borehole stability and lost circulation problems at shallow to intermediate depths. This required repeated cementing and redrilling due to unconsolidated pumice deposits. Cementing all casing strings generally required more than one pumping effort and usually involved a “top job”.

It took anywhere from 40 to 106 days to begin continuously drilling below a depth of 1000 m. Once all of the wells were below 1000 m progress was rapid to near the total depth of the well where another set of rig repair, fishing, and waiting for equipment delays were common.

**Well Design and Completion**

The wells were drilled according to common geothermal drilling practices of the early 1980s with 13 3/8 inch surface casing, 9 7/8 inch production casing and 7 inch liners. The 7” liners ranged from being mostly blank or unslotted to all slotted and were simply set on the bottom of the well. None of the liners are hanging. No attempts were made to cement any part of the 7” liners in place.

**Caliper Logging**

The two hottest wells, LA-3 and LA-6 have shown little or no loss in open diameter or depth in the 20 plus years since they were completed.

The coolest production well, LA-4, has shown a major decrease in diameter at depths between about 700 and 1100 m
between 1996 and 2006. Some soft white scale fragments that appear to be calcium carbonate scale were recovered from two of the 2006 go-devils. Currently the minimum open diameter in LA-4 at depths near 1085m is between 1.75 and 3.0 inches (4.45 and 7.62 cm). LA-4 has flowed for several hundred days so this is a relatively modest scaling rate.

Well LA-8 has had a possible history of producing pumice sand. In May 2006 this well was discovered to be blocked by an obstruction at a depth of 701m to the point that a 1.3 inch (3.3 cm) sinker bar would not pass. This obstruction is within the unslotted or blank part of the 7” liner and is actually above the bottom of the 9 7/8” casing. LA-8 is still capable of producing at reasonable flow rates.

Well LA-7, the single injection well for the geothermal field, has also lost some open diameter being completely blocked at a depth of 1462m in May 2006. The nature of this blockage is not known.

**Static Temperature Logging**

A few hundred temperature and pressure logs were run in the Aluto Langano wells between 1982 and 1990 with mechanical tools. The spacing between stops was generally 50 to 100m and most of these were run while the well was in the process of thermally equilibrating. A few logs were run while the well was “bleeding” or flowing a small amount of fluid. Only one log was run under wide open flowing conditions in LA-3. No traversing logs were run during injection tests at the time the wells were completed. In 2006 a digital Kuster K-10 temperature and pressure memory logging tool was purchased and the first detailed logs were run under static and flowing conditions. The static temperature logs show a complex subsurface fluid flow pattern with temperatures as high as 334°C in LA-6 below a depth of 2000m (Figure 5). The static logs show that the highest temperatures are located along the Wonji Fault Belt and suggest that even higher temperatures may be found beneath the pumice cone complex located north of LA-6 (Figure 3) and at greater depths.

Presuming the temperatures in the deeper parts of LA-1 and LA-2 represent regional background conditions with temperatures near 100°C at a depth of about 1500m, then the temperatures below a depth of 2200m in LA-7 also must be more or less representative of background thermal conditions (Figure 5). This means that the bottom part of well LA-7 is completely beneath the geothermal reservoir. Similarly, if the decreasing temperatures in the lower parts of LA-4, 5, and 8 are extrapolated to depths somewhere below 2500m they should also be near regional background temperatures. Therefore, the static temperature logs show that the deep geothermal resource is located in the vicinity of wells LA-3 and 6 and has relatively limited extent in the east-west direction at depths below 2000m. This is in agreement with previous interpretations of the geothermal system being localized by the Wonji Fault Zone. At depths above 2000m hot fluids from the Wonji fault flow laterally both east and west to provide the production from wells LA-4 and 8.

**Flowing Temperature Logging**

In December 2006 three of the four production wells at Aluto Langano were briefly flow tested and logged under flowing conditions. Only the data from LA-3 are presented here but similar logs were obtained from LA-6 and 8 (to its open depth of 701m). LA-4 was not flow tested because it is largely locked by carbonate scale. Testing in this condition would not provide meaningful data.

Comparison of flowing, static, and injecting temperature logs can usually definitively locate permeable intervals in a well, especially with the amount of data available from modern digital logging tools. In LA-3 a comparison of static and bleeding logs indicates that the primary permeable intervals are below 1980m on the static log and below 1900m on the flowing log as shown by the small temperature inflections (Figure 6).
During flow LA-3 has two phase conditions to the bottom of the well. So above the permeable zones the temperatures are controlled by the saturation pressures and are actually 31°C lower than shown on Figure 6. The flowing temperature data from LA-6 were similar to that shown for LA-3.

Static and Flowing Pressure Logs

The static pressure logs from LA-3 (Figure 7) show a noncondensible gas cap which can be as high as 50 to 60 bars in the upper few hundred meters of the well and a liquid pressure gradient below the gas cap. Under bleeding conditions the noncondensible gas cap does not exist and sub hydrostatic two phase conditions are present to the bottom of the well. As the flow rates increase both the wellhead and downhole pressures decrease until, at wide open flow, the wellhead pressure is only a few bars and the downhole pressures are as low as 21 bars. The total pressure change in LA-3 between static and wide open flowing condition is 138 bars, which demonstrates very low overall permeability. The initial pressure falloffs and buildups at the bottom of LA-3 were also recorded by the logging tool but only a few hours of data could be recorded at temperatures above 310°C.

A similar large pressure drop was measured in LA-6 between static and bleeding conditions. LA-8 appears to show a much more modest pressure drop of 17 bar at a depth of 700m. Therefore, at Aluto, the two hottest wells also have the lowest permeability. This is confirmed by relatively low total mass flow rates from LA-3 and 6 as compared to LA-4 and 8.

The static pressure logs from all the wells show a similar overall pattern to the temperature logs in that the highest pressures are found in LA-3 and 6, along the Wonji Fault Belt.

Conclusions

A lengthy exploration history and the drilling of 8 large diameter exploration wells has shown that a significant geothermal resource underlies the central part of the Aluto volcanic complex. Two wells drilled outside the volcanic complex confirmed the presence of lower temperature outflow zones but all six wells; drilled 1 to 2 km apart within the volcanic complex, found temperatures ranging from 200 to 334°C. Static temperature and pressure logs show the geothermal system is centered on the north-north east trending Wonji Fault Belt. However, cooler wells to the east and west of the Wonji Fault Belt may actually be more productive. The permeability of the productive wells is low to moderate with short term well outputs averaging near 2 megawatts. Temperature and pressure logs obtained with a digital Kuster K-10 logging tool in 2006 have largely confirmed that earlier mechanical logs of the wells are of reasonable quality but the digital data show details which allow for an improved understanding of the wells.

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Figure 6. Static and bleeding temperature logs from well LA-3.

Figure 7. Static, bleeding, and flowing pressure logs from well LA-3.

References


