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Geology and Hydrothermal Alteration of Recently Drilled Five Wells at Aluto Langano Prospect, Ethiopia

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ABSTRACT

The Aluto Langano Geothermal Field is one of the various geothermal prospects in Ethiopia. The prospect is located in the central part of the Main Ethiopian Rift system. It has been the subject of various geothermal investigations. Early investigations in the prospect included: surface explorations, the drilling of eight deep exploratory wells in the 1980's and the drilling of additional two appraisal deep wells in the 2010's.

The initial exploratory drillings have discovered sufficient steam in four productive wells which have been running a pilot plant of 7.3 MW. The reservoir is liquid dominated with maximum temperature of 335 ^{o}C.

Current project at Aluto includes: the drilling of 10 production wells for potential steam discovery for 35 MW unit and the drilling of two exploratory wells as part of an extension to an additional 35 MW. The five deep wells drilled under this project so far and their measured depth in meter from rotary table include: LA 11 D1 (3000), LA 12 D2 (2700), LA12 D3 (2750), LA 13 D2 (2875) and LA13 D1(2961). The wells have been drilled directionally from 29 May 2021 to March 21, 2022 using two deep drilling rigs. The drilled wells have been tested to have 21.5 MW in total so far with maximum measured temperature of 346^{o}C.

The penetrated lithological units in these wells include; pyroclastic deposits (pumice, glass shards, variable silicic tuffs, lithic tuffs and rare vitreous tuff), rhyolites, volcanogenic lacustrine sediments, welded ignimbrites, basalts, scoria, intermediate rock units, fault breccia, crystal-rich ignimbrites and pre/syn rift basalt formation.

Hydrothermal alteration facies observed in the wells showed evidence of prograde alteration sequence with five distinctive alteration zones with depth; shallow unaltered zone, smectites-zeolite zone, chlorite-illite zone, epidote-chlorite-illite zone and actinolite-epidote-chlorite-illite zone, typical of high temperature geothermal systems.

1. INTRODUCTION

1.1 Background and Location

Ethiopia is located in the horn of Africa between 3.5°N and 14° N and 33°E and 48° E. The country is endowed with large geothermal potential. The geothermal resources are located in the Ethiopian Rift Valley, which is part of the East African Rift System. The geothermal sites in Ethiopia are geographically distributed from the south western part of the Ethiopian Rift up to the north eastern part with a total of over 25 high temperature prospects, among which Aluto Langano is one .The Aluto Langano prospect is located in the central part of the Ethiopian Rift known as the Main Ethiopian Rift, 200 km south of Addis Ababa (Figure 1).

2. SUMMARY OF PREVIOUS WORKS

2.1. Geological and Structural Setting

Aluto Langano geothermal field is located within the central part of the Main Ethiopian Rift (MER). MER is a major regional geological structure exhibiting a NE-SW direction (Figure 1), whose rifting started about 8 Ma ago. In the early stages, the rifting was accompanied by the development of several central volcanoes which emitted large volumes of pyroclastic products of the Nazret Group. Rejuvenated volcanism along the axix of the rift in Quaternary has been followed by Caldera collapses. The oldest rocks of the Aluto Volcano are dated at about 150 Ka, while some of the post/Syn caldera rocks are dated at about 55 Ka: this means that the caldera collapse took place at a time much younger than 150 Ka, presumably approximately 50 to 80 Ka (Hutchison et al.(2016); ELC (2016); Kebede et al.(1985).

The youngest volcanic products of the Aluto volcanics are mainly porphyritic obsidian lava flow or domes, with an age lower than 10 Ka. Areal distribution of these very young products, together with the associated hydrothermal manifestations and the structural pattern, are important indicators of the favorable geological conditions of these sectors from the point of view of geothermal energy exploration. In the case of the Aluto Volcano, the hydrothermal manifestations are located preferentially around or very close to the caldera rim, in particular in its eastern and western extremes, ELC (2016).

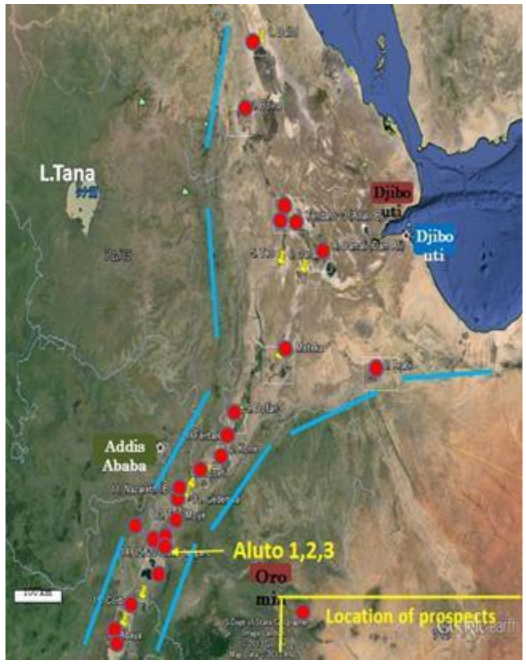

Figure 1: Location Map of Aluto Langano prospect in relation to other prospects

2.2 Subsurface Stratigraphy of Past Deep Drillings

The Aluto Langano prospect has been the subject of several geothermal investigations since the year 1969. Following early surface investigations, a program of deep exploratory drilling in the 80's, drilled eight deep exploratory vertical wells (LA 1 to LA 8), which led to the discovery of a geothermal field of commercial interest and brought in line the installation of a 7.3 MW steam/binary pilot power plant in 1998. Two additional deep appraisal directional wells have also been drilled in 2013 – 2014 (LA 9 D and LA 10 D), to evaluate the resource and install an additional 5 MW well head turbine,West Jec (2015). Geological logging of the eight drilled wells on top of the volcano, have outlined the stratigraphy and characteristics of the drilled formations (Figure 2).

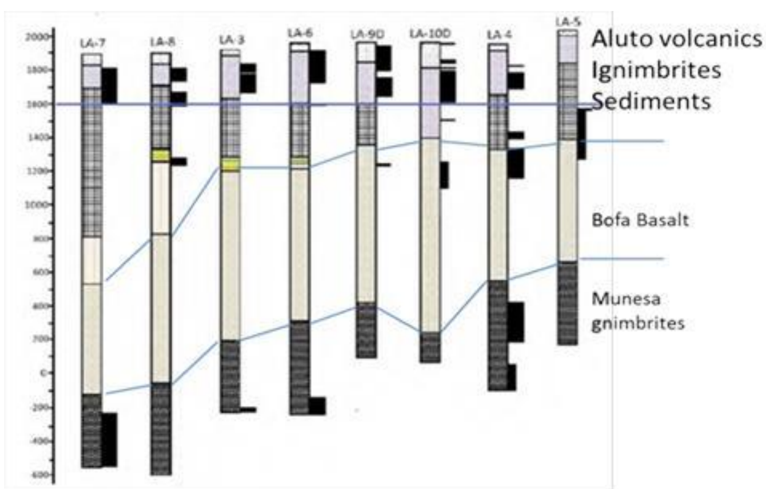

Figure 2: Simplified correlation diagram from LA 3 to LA 10D (Wells projected on E-W profile)

The top part of the stratigraphy is constituted by Aluto volcanics followed by Huloseyyno ignimbrites, which in some of the wells is underlain by Lake sediments. The thickness and elevation of these formations has varied from well to well. The major unit underlying these formations is Boffa basalt which has various thicknesses and appeared in all the drilled wells. The deepest formation in previous drillings is Munesa ignimbrite (a sequence of crystalline ignimbrites with some intercalation of rhyolites and basalt breccia's). A shallow permeable zone was usually encountered at 100-300m depths. The productive permeable zones are mostly located within the crystalline ignimbrite at zones of interlayered formation contact zones or where major fault zones have created fracture secondary permeability. Major hydrothermal alterations were found mainly in the Bofa basalts including high temperature minerals such as epidote.

2.3 Surface Explorations for Additional Wells Siting

A more detailed surface exploration of the prospect has been carried out in 2015 – 2016, focusing on the main anomaly areas , Aluto 1, 2 and 3 (Figure 3), with the objective of identifying the most favorable sectors within the Aluto volcanic complex for the implementation of further underground production and exploration drillings.

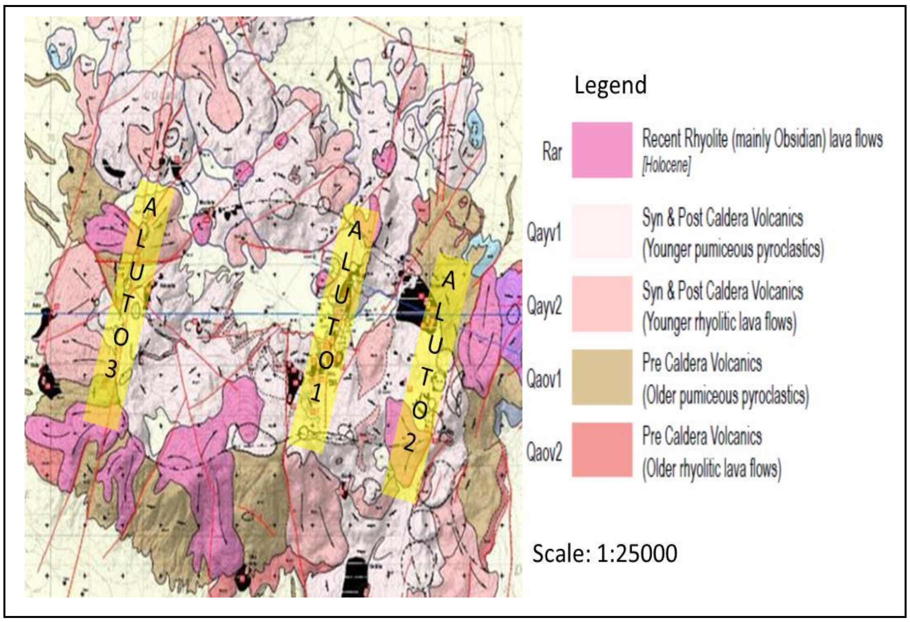

Figure 3: Geological Map of Aluto Volcano (modified from ELC (2015)

To achieve the objectives of additional well siting, geological, geochemical and geophysical survey (gravity, geo electrical and micro seismic) have been conducted. The integrated interpretation of the results of these surveys led to the following conclusions: (i) the geo volcanic situation may create an intense, wide and shallow thermal anomaly, (ii) the main element controlling the configuration of the geothermal system is represented by NNE-NNW trending faults, (iii) the other structural elements of major importance are elongated in a W-E direction over an extension of 8.5 x 5 km caldera (Figure 3), (iv) from resistivity survey clay caps corresponding to the top of reservoir have been identified in the central part of the volcano (Aluto 1) and the eastern portion of the volcano (Aluto 2) (Figure 3), and these two areas were selected for further drilling, (v) The two areas were expected to have a power out put of at least 70 MW and (vi) the reservoir fluids are of Na-HCO3-Cl type with average total salinity of 100 meq/kg and non-condensable gas content of 6-8 % in the steam, with low scaling and corrosion potential, ELC (2016). On the bases of these results six directional production drilling sites have been located at Aluto 1 targeting the main NNE trending main fault zone and two exploratory wells were located at Aluto 2 (Figure 4). Five of the selected wells (LA 11D1, LA12 D1 and D2, LA13 D1 and D2) at Aluto 1 have been drilled so far. This paper summarizes the geological findings obtained by logging and studying the drilled formations in the five wells.

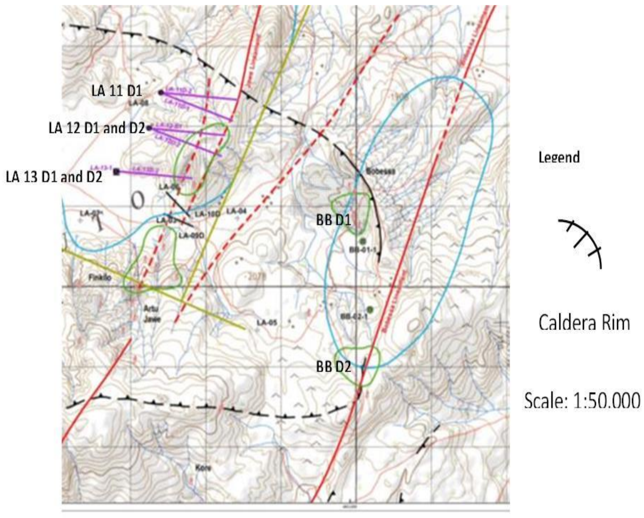

Figure 4: Location map of recently drilled five wells

3. OBJECTIVES OF PRESENT STUDY

The overall objective of the recent drilling program at Aluto was to exploit the geothermal resource along the NNE trending fault zone at Aluto 1 and 2 with the purpose of electricity generation. The geological assistance given during drilling had specific objectives of: (i) logging of the type and nature of the subsurface formations to assist in decision of casing programs and drilling parameters, (ii) to assist in the identification of permeable zones and to identify the type and rank of alteration, to advice on cap rocks and production zones.

4. METHODOLOGY USED IN THIS STUDY

During drilling rock cuttings were sampled every 4m and washed and analyzed using stereo- microscope for Identification of the lithology and minerals. Part of the samples has been dried using an oven and after crushing and powdering and mixing it with sulfuric acid and methlynblue, the smectite content has been determined. There has been no XRD studies conducted to identify the type of clay alteration minerals and also identification of some of the minerals was not supported with petrographic studies.

5. RESULTS

5.1. Drilling Performance

The five deep wells have been drilled from end of May, 2021 to early June 2022 and the main drilling data of the drilled wells is indicated in Table1. The wells have been drilled directionally to intersect a major NNE trending fault zone which is considered to be an upflow zone for hot geothermal fluids, already discovered by previous drillings. Three pads have been used to drill the five wells, which include pad 11 (only one well has been drilled) and pad 12 and 13 (two wells have been drilled from each of them).

The drilled five wells measured depth ranges from 2700m to 3000m and the horizontal distance attained by the directional drilling ranges from 808m to 1099m (Table 1). On the bases of geological findings during drilling various depths have been selected to land the surface casings, the anchor casings and the production casings in each of the wells.

Well Name	Measured Depth (m)	Kick off point (m)	Horizontal Departure (m)	Drift Angle (°)	Azimuth (°)	Drilling time (days)
LA -11D-1	3000	657	977	26.0	122	121
LA -12D-2	2700	615	857	26.8	173	100
LA -12D-3	2750	589	808	14.6	125	70
LA -13D-1	2875	664	1099	37.0	113	78
LA -13D-2	2961	610.4	1091	31.1	130	96

Table 1: Main drilling data of five recently drilled wells, EEP (2022).

5.2. Stratigraphy and Lithology

The lithological units penetrated during drilling are quite variable and from the oldest to youngest include, : syn - pre rift basalts (basalts interlayered with basaltic breccias, rhyolites and tuff), Munesa ignimbrite (quartz crystal rich, highly welded ignimbrites with interbeds of rhyolite, basalt and ash), Boffa basalt (a sequence of basalitic flows with various colour and texture interbeded with rhyolitic flows, scoraceous zones and tuffaceous material), Hulo seyno ignimbrites (with beds of lacustrine sediments in some of the wells) and Aluto volcanics (rhyolites, pumiceous breccia, variable silicic and lithic tuffs).

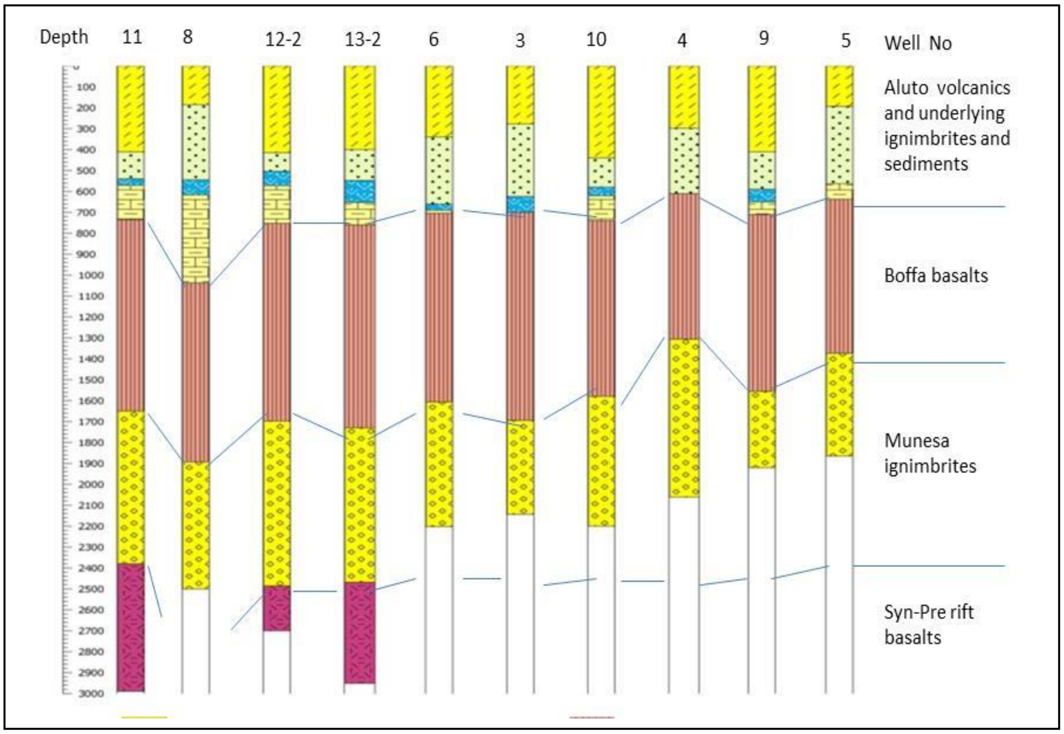

Figure 5: Depth correlation diagram of recent and old wells drilled at Aluto (depth from cellar top)

The pre/syn rift basalts have been encountered in all the five wells drilled under the current project, while absent in the older wells drilled in the past, which were not deep enough.

5.2. Permeability of Drilled Formations

The shallow formations down to 500 m are generally permeable with significant circulation loses during drilling, which are related to shallow fissures and fractures and blocky nature of some of the Aluto volcanics. However, permeability pathways within the reservoir, usually below 2000m depth, are largely controlled by faulting (brecciated zones), inter-bed permeability networks and to a lesser extent the interstitial matrix permeability commonly occasioned by pervasive hydrothermal alteration. Drilling through production zones recorded partial to full circulation loses within the brecciated zones, except in 11 D1. The brecciated zones sometimes are partly filled with gouge materials often compromising the cumulative fluid circulation pathways FSDC (2021). The Artu-Jawe fault zone is one of the major structural features considered to provide permeability within the wellbore having developed as result of localized kinematic strains associated with axial Wonji faulting episode. Therefore, permeability at deeper levels of the wells has been proven by complete circulation losses and partial losses observed during drilling, except in 11 D1 which appeared to have low permeability at depth.

5.3. Hydrothermal Alteration

Hydrothermal alteration facies observed in all the five wells show progressing alteration sequence typified by five notable alteration zones and the depth to the alteration boundaries varies from well to well and an average depth is considered (Table 2). The first appearance of crystalline epidote was observed at a depth below 1000 m in all the wells, depicting paleo-temperature condition in the reservoir of above 240 ^{o} C. The epidote-chlorite zone is followed by actionolite-epidote zone below 2100 m with estimated mineral temperature of minimum 280 ^{o}C, indicating propylitic alteration mineral assemblages and prograde alteration pattern, typical of high temeperature geothermal systems.

No	Average depth (m) (CT)	Alteration Zone	Estimated Mineral Temp (°C)
1	0-75	Unaltered	< 100
2	75-600	Smectite-Zeolite	180
3	600-1070	Chlorite Illite	200
4	1070 - 2100	Epidote - Chlorite	240
5	2100 – Total depth	Actinolite- Epidote	280

Table 2: Alteration zones in the wells.

The estimated mineral temperatures and the measured temperatures in the wells (as high as 346 °C) are in good agreement indicating that the reservoir is still in equilibrium with the indicated minerals and the geothermal system is still active enough.

6. CONCLUSION AND RECOMENDATION

6.1. Conclusion

Based on subsurface lithological characterization and alteration zones and drilling fluid loses the following has been concluded;
The lithology and hydrothermal alteration patterns of all the wells are generally similar to each other and also show good agreement with the wells drilled in the past.

Alteration patterns show pro-grade alteration consistent with a high temperature field. A high temperature geothermal system exists within the Aluto Volcanic Complex which is is characterized by phyllic alteration followed with depth by propylitic alteration pattern of high temperature minerals. The estimated mineral temperatures and the measured temperatures in the wells are in good agreement indicating that the reservoir is still in equilibrium with the indicated minerals and the geothermal system is still active enough.

Permeability fluid pathways in the wellbore appear fairly restricted and controlled by fracturing and faulting (fault breccias & fractured rock units) and hydrothermal alteration intensity and rank is higher along lithological contacts. The fault fractured Munesa ignimbrites and interbeding layers are considered the main reservoir rocks of the system, as evidenced by their better circulation loss during drilling.

6.2. Recommendation

Detailed petrographic analysis has to be conducted to characterize the mineralogical, mcro textures and structures of important rock units

XRD analysis is also recommended for detailed characterization of hydrothermal clays present in the well.

Chemical analysis of selected samples will be useful to understand the chemistry and gneiss of some of the major formations.

The geothermal conceptual model has to be updated with the newly acquired subsurface borehole data using 3D soft wares and has to be integrated with measurement and well test data, inorder to guide further exploitation targets within the field.

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