Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Results of Surface Exploration in the Corbetti Geothermal Area, Ethiopia

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Keywords: Corbetti, Ethiopia, geothermal, geothermometry, resistivity, MT, TEM, clay cap layer.

ABSTRACT

The surface exploration studies that Reykjavik Geothermal has carried out in the Corbetti caldera in Ethiopia, indicate a geothermal resource that exceeds 100 km^2, temperatures in the workable range of 250-350°C and expected capacity of over 1000 MW. If proven, this makes Corbetti among the world's largest geothermal reservoirs.

The Corbetti prospect is located some 200 km south of Addis Ababa and hosts a large volcanic complex of basaltic to silicic composition. Numerous fumaroles and thermally altered grounds are seen on surface. Three major geological structures are present, a 155 km^2 elliptical caldera ring form, a 50-60 km long and 10 km wide N-S fissure swarm, and a WNW-ESE trending volcanic belt in the middle of the caldera, with summits of Mt. Urji and Mt. Chebi as local magma centres. Shallow exploration wells coupled with lake levels indicate a lateral flow of groundwater from south to north. As this groundwater flows across the northern half of Corbetti, a change is observed in heat flow from a linear gradient type to convective and steaming behaviour. A substantial recharge of heat and mass is therefore taking place from a deep geothermal reservoir underneath Corbetti.

A consistent pattern of chemical signature is observed in the 12 fumaroles gas samples. These yield 260-360°C deep reservoir temperatures, based on CO_2 type geothermometers. Other studies conducted earlier in Corbetti show similar results. Water samples in the shallow exploration wells also suggest high recharge temperatures.

Reykjavik Geothermal has mapped the Corbetti caldera and surroundings by 127 MT- and 119 TEM resistivity soundings. The MT and the TEM data are jointly inverted for a 1-D resistivity model underneath each station pair, and then interpolated into a 3-D resistivity model down to about 25 km depth. Three major resistivity structures are identified. Firstly conductive 500-1000 m thick clay cap layer encountered at about 500 to 1500 m depth inside the northern half of the caldera and deepening to the north. Secondly a deep conductive and probably hot layer is seen at 5-15 km depth. Thirdly there is an abrupt vertical change in the resistivity distribution across a WNW-ESE line through the caldera centre, here attributed to a buried strike-slip structure and recharge of cold groundwater that has prevented the upper part of the southern caldera to develop into a high temperature geothermal resource. Other structures are also seen, like a correlation of the increased thickness of the conductive clay cap layer to the northern caldera rim, and a 50-100 m thick shallow low resistivity tongue away from the Mt Urji summit here interpreted as outflow of hot geothermal fluids.

The bottom of the clay cap layer is interpreted to show the boundary of well conductive clay minerals (like smectite) and higher temperature alteration minerals (like chlorite and epidote) which occurs at about 250°C. This interface is thought to represent a 250°C isotherm, provided that the thermal alteration is in equilibrium with the temperature. The depth to this proposed isotherm is about 500 meters beneath Mt. Urji in central part of the Corbetti Caldera and down to 2000 meters outside the caldera. Based on this the reachable area of temperatures >250°C is more than 100 km^2, which means over 1000 MW using the rule of thumb of 10 MW/km^2.

1. INTRODUCTION

Reykjavik Geothermal, a geothermal development company, acquired a reconnaissance permit from the relevant authorities of the Corbetti geothermal prospect, located in the Mid Ethiopian Rift (MER), about 200 km south of Addis Ababa. Surface exploration commenced in April 2011 and where completed in October 2012 (Gislason et al, 2012). This paper summarises the main findings of the exploration survey.

2. GEOLOGY

The Corbetti caldera is located in the MER, the southern-most large active central volcano in Ethiopia. MER is characterized by volcanic systems, roughly arranged north-south in an echelon fashion. Many of these systems have developed a large central volcanos, some of which have reached the advanced stage of caldera formation.

Commonly the material produced in fissure eruptions are of basaltic composition, but the central volcanos are usually situated over a shallow magma chamber where silicic magma develops through magmatic differentiation (DiPaola 1972). The Corbetti prospect is such a volcanic centre, with a large caldera, the longer axis (E-W) being 16 km and a 10 km long N-S axis. A fissure swarm enters the SW corner of the caldera and continues centre-north of it towards Lake Shala. North of the caldera several basaltic craters are located, but the intensive post caldera infill eruptions are rhyolitic, both as obsidian lavas and thick layers of course, whitish pumice. The rock formation of pre- and syn-caldera age can be seen in the western (welded tuffs) and southern (peralkaline lava flows) caldera wall, as well as extensive layered pumice pyriclastics to the SW of the caldera (Figure 2). The time of the caldera collapse has not been dated but Altaye (1984) reports it as late Pleistocene – early Holocene, i.e. 10,000 – 12,000 years old.

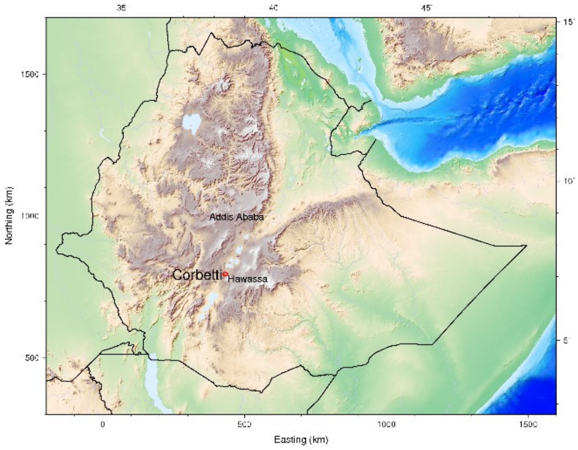

Figure 1: The location of the Corbetti caldera in the Main Ethiopian Rift

The post caldera activity has been concentrated in several volcanic centres. Firstly two major volcanos namely Mt. Urji in the centre of the caldera and Mt. Chebi near the eastern caldera rim. Secondly by obsidian lavas that covers the SE caldera rim and thirdly by products from other smaller volcanos (Danshe and Borama) that mantle the eastern and north-eastern caldera rim and are shown by dashed caldera outline on Figure 2. The centre of post-caldera volcanic activity is on a WNW-ESE stretching belt containing the Urji and Chebi volcanos as well as numerous craters and intersecting faults as well as surface geothermal manifestations (Figure 2).

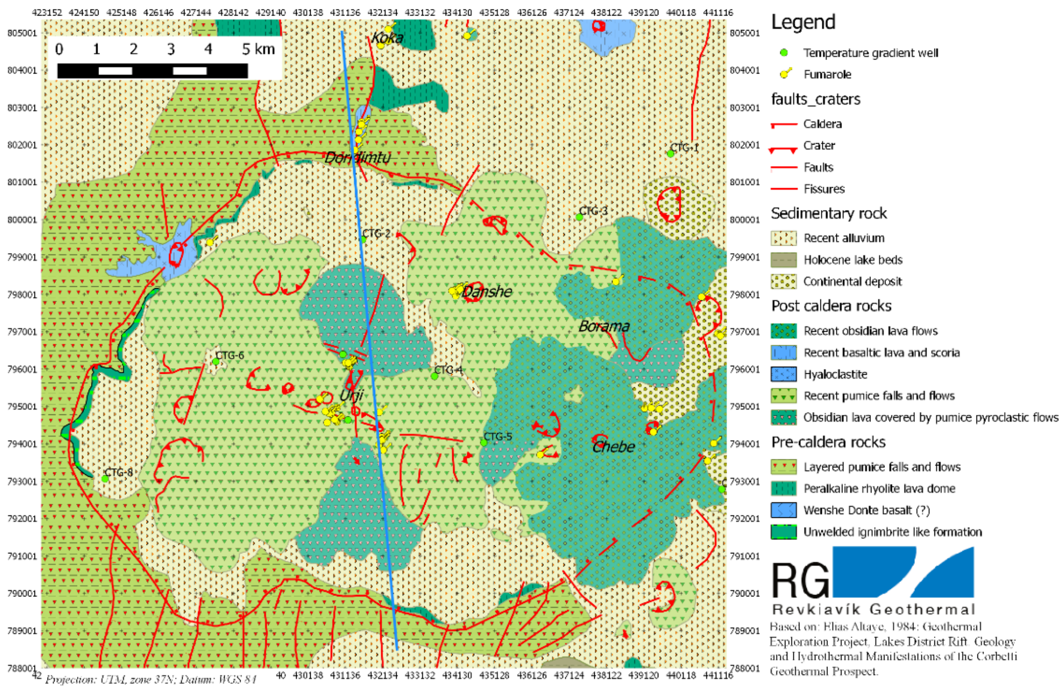

Figure 2: Geological map of the Corbetti caldera. Blue line shows the profile location in Figure 3

To a large extent the current project has relied on earlier geology mapping work, mostly by Geological Survey of Ethiopia (GSE), for geological information (DiPaola 1972, Altaye 1984, Altaye et al. 1986). The observations made by the RG science team in co-operation with their GSE counterparts has in general terms been in agreement with the earlier work. Currently the structural map of the caldera is being upgraded by use of remote sensing technique, soil gas flux measurement and infield verification work. Surface manifestations, in the form of steaming ground and low-scale thermal alteration, are generally structurally controlled (Altaye et al. 1986, Gislason et al. 2012), i.e. on the caldera rim, the NNE-SSW, the WNW-ESE volcanic axis or an intersection of those (Figure 2).

3. GROUNDWATER STUDIES

Eight shallow exploration wells, up to 184 m deep, were drilled in the Corbetti area in 1987 (Kebede and Abdulkadir, 1987). Their locations are shown on Figure 2. The wells stratigraphy includes felsic volcanics (ignimbrite and rhyolite), basalt lava, lake sediment, and younger volcanic (hyaloclastite, ignimbrite, rhyolite and pumiceous breccia). Only three wells reached the water level (CTG-2, 3 and 7) with ~96 °C hot water, the boiling temperature at the altitude (1610 – 1650 m a.s.l.). The regional groundwater flow is from north (Lake Hawassa, 1685 m a.s.l) to north (Lake Shala, 1558 m a.s.l) (Beles and VSO 2011) and controls the water table in the caldera. Measurement in the wells shows that the temperature in the southern section is normal ambient temperature (24-28 °C), whereas the northern section is boiling and the rock formations above the watertable is filled with steam at 96 °C (Kebede and Abdulkadir, 1987).

Downhole water samples were collected in wells CTG-2, 3 and 7 by Kebede and Abdulkadir, (1987) and reinterpreted by Gislason et al. (2011). The water is found of bicarbonate – sodium type, and calculated to be in water-rock equilibrium at 120 - 150 °C (Na/K geothermometers) or 160 to 210 °C (Qtz geothermometers).

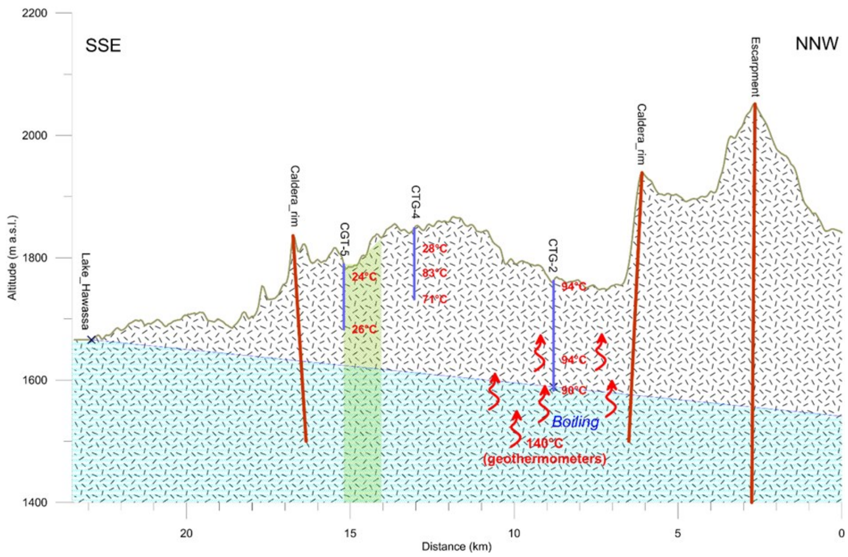

Figure 3: Model of the groundwater and heat flow. See location on Figure 2 (blue line)

Figure 3 is a simplified model of the shallow groundwater (Gislason et al. 2012). It shows the inflow of cold water from Lake Hawassa from the south, being heated by steam flow as it flows above the underlying high-enthalpy system, reaching partial water-rock equilibrium at ~140 °C. At the south shore of Lake Shala, about 20 km north of the Corbetti caldera, hot springs emerge from fissures of the rifting fissure swarm from Corbetti. This may well be a surface manifestation of the steam-heated groundwater from Corbetti

4. GAS GEOCHEMISTRY

No water springs were seen within or close to the Corbetti caldera, neither cold nor warm. All samples collected are therefore of steam. Generally the steam flow is weak and orifices suitable for sampling had to be carefully selected. Extensive exploration survey on the steam composition was carried out under a Government of Ethiopia (GoE)/United Nations Development Programme (UNDP) in the 1970's (UN Mission report, 1973; Gizaw, 1985), and a study by GSE in 1988 (Gizaw, 1996; Darling et al., 1996). In 2011 and 2012 the RG team resampled most of the old sampling sites, and the results were remarkably similar.

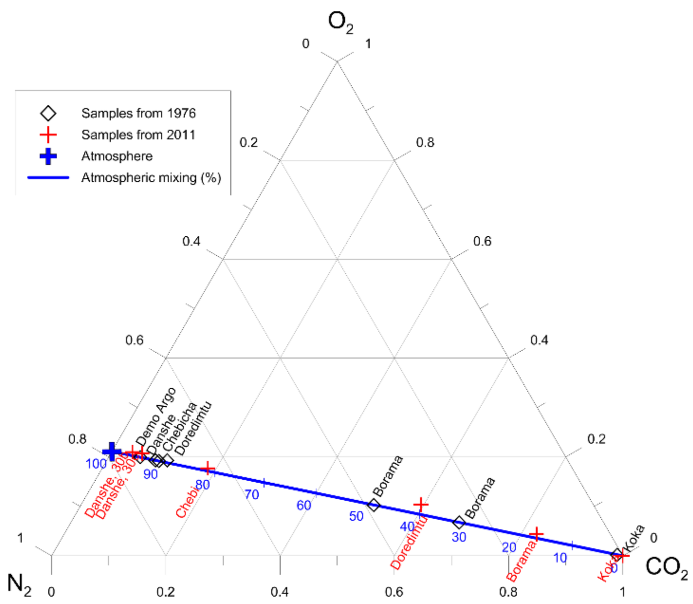

Figure 4: CO2-atmosphere mixing in Corbetti

Figure 4 shows the mixture of atmospheric gases (the N_2-O_2 axis) with the CO_2 geothermal gas in the Corbetti fumaroles. The blue line present the mixture with constant N_2/O_2 ration (79/21). The sampled analysed, both from 1976 (black diamonds) and from 2011 (red crosses) fall on the mixing line, showing that loss of oxygen due to oxidation is negligible. The plot also shows that the mixing is similar in 1976 and 2011. All the samples from within the caldera have high atmospheric mixing (80 – 98%) whereas samples from fumaroles on the caldera rim or outside it have mixing from 0 – 50% mixing. The location with the lowest or no mixing (Koka) is 4.5 km north of the caldera rim. The atmospheric mixing as removed H_2S through oxidation. Only Koka was reported with a detectable H_2S. It is also the only location where a trace of methane (CH_4) and with C_3H_6 up to 6.7 % was measured (Gislason et al. 2012). The large volume of atmospheric gases in the caldera steam is interpreted as a result of the low water level of the boiling ground water. Ascending rain water and inflowing surface water (saturated with dissolved atmospheric gas) degas as it is heated, and the released gases mixes with the rising geothermal steam. It is further anticipated that the situation is different in the fault zone north of the caldera (Koka and Doredimtu) and on the caldera rim (Borama) as atmospheric mixing is less or not observed in these places.

Table 1: Calculated CO_2 geothermometer temperature

Location	Year	T_{CO2}	Location	Year	T_{CO2}
Outside caldera			***Inside caldera***		
Borama	1976	313	Demo Argo	1976	315
Borama	1976	311	Chebicha	1976	320
Borama	2011	342	Danshe	1976	312
Doredimtu	1976	318	Danshe	2011	259
Doredimtu	2011	360	Danshe	2011	292
Koka	1976	333	Danshe	2011	279
Koka	2011	353	Chebi	2011	311
Koka	2011	338	Chebi	2011	304
			Urji	2011	359

The mixing of geothermal and atmospheric gases in the unsaturated zone above the regional groundwater table, poses a challenge when interpreting the analytical results of Corbetti steam samples into deep reservoir conditions. For example only the empirical CO_2 geothermometer is applicable for the Corbetti steam chemistry data set. Despite this limitation, the results achieved are nevertheless very promising (Table 1). They strongly suggest that the Corbetti geothermal prospect hosts a high-enthalpy reservoir with temperatures around and above 300°C.

5. RESISTIVITY SURVEY

Both Transient Electro-Magnetic (TEM) and magnetotelluric (MT) methods were applied in this study. The MT data from Corbetti has penetration depth of several tens of km while the TEM soundings have much less depth of penetration or less than 1 km. The main purpose of applying TEM at the same locations as the MT sites is to correct the MT data for the so called static shift. The TEM surveys also allow for observing in detail the shallowest resistivity structures. After acquisition, the collected data was pre-processed and a 1-D inversion for each sounding performed. By 1-D (one dimensional) we mean that the resistivity of the ground only varies with depth, and the inversion is an “automatic” computer process which finds a 1-D resistivity model whose response fits the measured data.

In the TEM soundings, electrical current is transmitted into a 200x200 m loop of wire laid on the ground. This current produces a magnetic field. When the current is abruptly turned off a decaying magnetic field causes induction currents in the ground propagating downward. The strength of the induced currents is dependent on the resistivity structure below the survey site. The ground response is measured by a small receiver coil in the centre of the transmitting loop. The time decaying signal is measured from about 20 µs and up to 200 ms from the current cut-off time. A 10 kW TEM transmitter was used, powered by a generator and transmitting generally 35-40A. The depth of resolution of the TEM data is 500-800 meters.

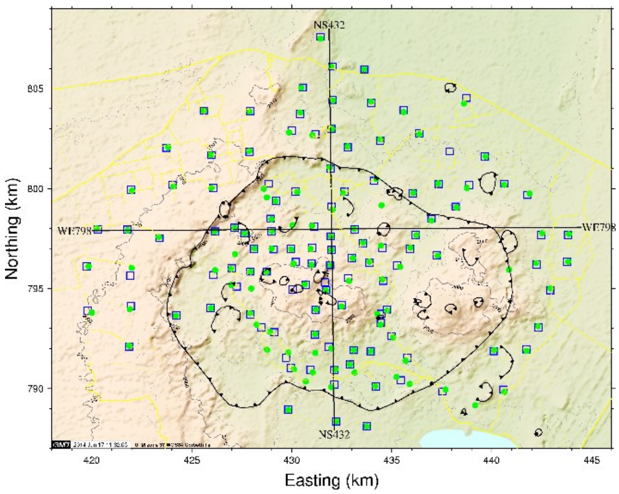

Figure 5: Location of MT (green filled circles) and TEM (blue squares) data points. Yellow lines are road or tracks. The black lines show location of cross section in Figure 6 and Figure 7

In the MT method, the natural fluctuation of the earth's magnetic field is used as current source. Those fluctuations induce currents in the ground. Those currents are measured on the surface with two horizontal and orthogonal electrical dipoles (Ex and Ey) while the incoming magnetic field is measured in three orthogonal directions (Hx, Hy and Hz). It is customary to set the x direction to the magnetic north direction. Five complete MT instruments where used. One instrument was kept running continuously 40 km east of the survey area (base site) and the data used for remote reference data processing in order to achieve higher quality result. Each MT station was kept running over night, for a total of about 20 hours, and MT data in the range of 320 Hz (0.003 sec) to about 1000 seconds. This gave resolution depth to about 20 km. A total of 127 MT soundings and 119 TEM soundings were performed, their location is shown on Figure 5.

The MT and TEM data from the same location are jointly inverted for 1-D resistivity model, where the static shift factor in the MT data is one of the inversion parameter. The MT data used are apparent resistivity and phase derived from the determinant of the impedance MT tensor. These models are then compiled into a 3-D resistivity structure by triangular interpolation. The end results are iso-resistivity maps at different elevations, and vertical resistivity cross sections. Figure 6 shows a south to north resistivity cross section through Mt. Urji in the western part of the caldera. The upper part of the figure show the upper portion of the cross section down to 2 km b.s.l, whereas the lower portion extends down to 20 km b.s.l. The conductive layer (red) in the upper figure is interpreted to be the so called clay cap layer, a region where the geothermal water has altered the rock matrix and for basaltic rocks conductive minerals such as zeolites and smectite are generated. Those minerals are formed in the temperature range of 100-230°C, while at 230-250°C the smectite is transformed into chlorite which is a resistive minerals. At still higher temperatures, exceeding 250°C, epidote is formed which is also a resistive mineral (Kristmannsdottir, 1979; Árnason et al., 2000). This interpretation of the clay cap layer can be used map the 100°C isotherm as the top of the clay layer and what is more useful the 250°C isotherm as the base of it. Those temperatures are only valid if the alterations are in equilibrium with the temperature. In the event that a geothermal system cools down, the same resistivity zoning would be seen. At the same token it will take some time for the alteration to form for a young geothermal system. This kind of resistivity zoning has been detected in many high enthalpy region around the world (e.g. Arnarson et al., 1987, Árnason et al., 2000; Johnston et al.; 1992; Eysteinsson et al., 1994; Pellerin et al., 1996; Cumming and Mackie, 2010, Gislason et.al. 2012; Eysteinsson 2013).

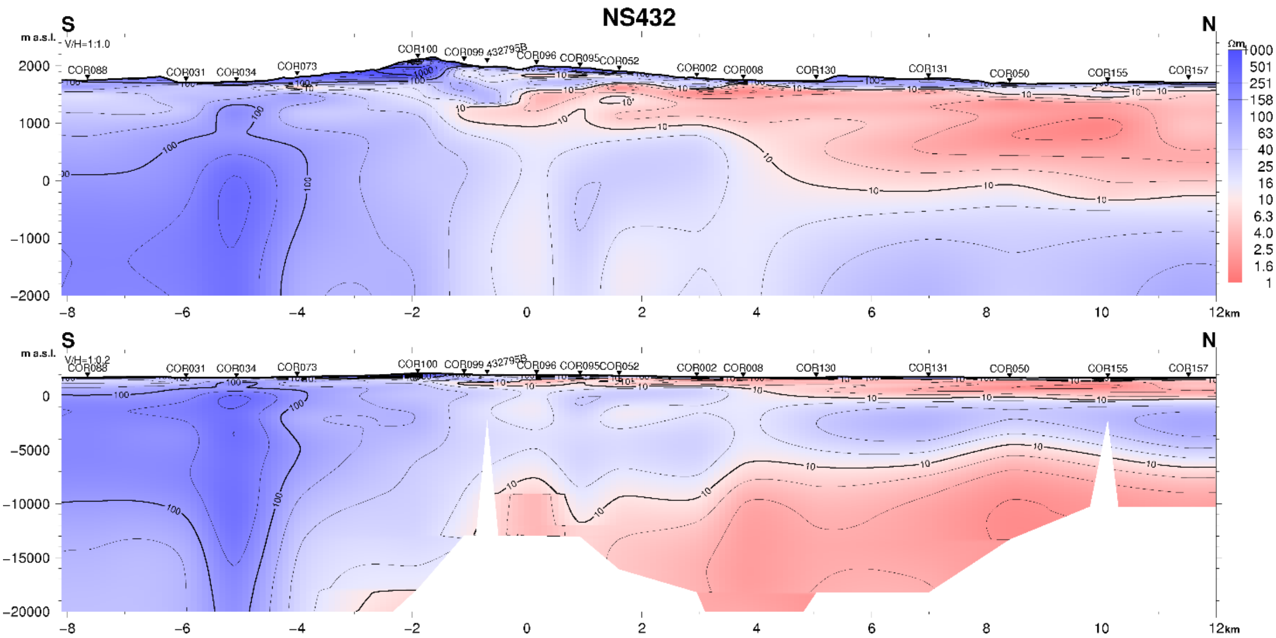

Figure 6: Resistivity cross section NS432. The southern and northern caldera rim is located at about -6 and +5 km horizontally, respectively. Mt. Urji is located between -2 and -1 km horizontally. Upper figure is down to 2 km below sea level, whereas the lower figure extends down to 20 km below sea level

As shown on Figure 6 the top of the clay cap layer (using the 10 Ωm isoline) is only at about 100-200 meters depth north of Mt. Urji whereas the base of the layer (i.e. 250°C isotherm) is at roughly 1000 m depth within the caldera and deepens to some 1700 m outside the caldera. The clay cap layer disappears south of Mt. Urji. This is a WNW-ESE vertical resistivity boundary to be discussed later. In the lower part of Figure 6a second low resistivity layer is observed, that also truncates south of Mt. Urji. Such a deep low resistivity layer is often found beneath high enthalpy geothermal fields (i.e. Iceland and Kenya). Its nature is not known but the most plausible explanation could be partly molten magma region i.e. the heat source for the geothermal system. Such a deep conductive magma body has been observed by another MT survey in the northern part of the Ethiopian rift and interpreted as partly molten magma layer at about 20 km depth (Whaler and Hautot, 2006.)

Figure 7 shows another resistivity cross section from west to east through the northern part of the caldera. It location is shown on Figure 5. As on Figure 6 the upper cross section shows the resistivity down to 2 km b.s.l. while the lower half extends down to 20 km b.s.l. The shallow conductive layer (i.e. the clay cap layer) is observed beneath the whole profile, 24 km in length. The base part of the layer (i.e. the interpreted 250°C isotherm) is shallowest within the caldera at 500-1000 m depth. West of the caldera it is at about 1500 m depth and at the eastern most site it is slightly deeper or 1800 meters depth. In the eastern part of the profile the are two low resistivity layers, the second one is interpreted as the clay cap layer while the upper one is interpreted to be horizontal flow of geothermal fluid from within the caldera. The base of the clay cap layer is deeper in the eastern portion of the cross section or at roughly 2200 meter depth. The deep conductor is at roughly 10 km b.s.l. (~12 km depth) except in the eastern part of the cross section where one sounding (COR113) shows it at only 4 km depth. Note that there is a large gap in data coverage between sites COR113 and COR043 which is due to rough terrain at and around Mt. Chepe (see also Figure 5). This increased elevation of the deep layer (heat source layer!) close to Mt Chepe may well be related to the enhanced magma production in that area. Reykjavik Geothermal plans to fill up this data gap in in the near future.

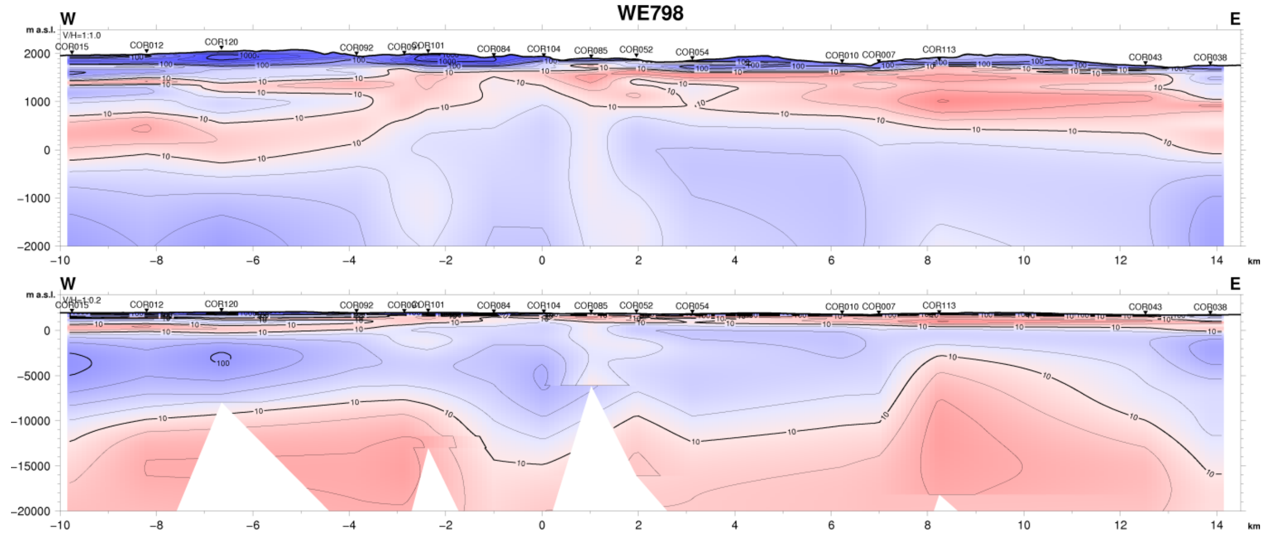

Figure 7: Resistivity cross section WE798. The west and east caldera rim is located at about -5 an +11 km horizontally, respectively

Figure 8 shows the resistivity at different elevations. The top left ma is at 1700 m a.s.l., i.e. close to the surface since the mean elevation within the caldera is about 1800 m. At this elevation the resistivity is high but at several places the clay cap layer is starting to show up. At 300m deeper, on the top right map, the clay cap layer is observe<d in all the northern half of the caldera. The WNW-ESE vertical resistivity boundary through the caldera coincides with the maximum post-caldera volcanic built-up between Mt Chebe and Mt Urji (see Figure 3). Limited seismicity information indicate enhanced seismicity on the same line, especially east of the caldera (Wilks, et.al. 2013). As seen on the bottom right map on Figure 8 the vertical boundary along this line is deep rooted, at least within the caldera and east of it, the boundary extend to more than 10 km depth. It is here postulated that this boundary is transform fault within the rift zone.

At 400 m a.sl. (centre left map of Figure 8) the resistivity within the caldera has increased by about one order of magnitude, i.e. below the clay cap layer where we expect temperatures higher than 250°C. Outside the caldera the clay we are within the clay cap layer showed by the red colour surrounding the caldera. There we expect the temperature to not reach the 250°C boundary, but just below this depth is the base of the clay cap layer. From this map it is clear that base of the clay cap layer (250°C) is reachable by drilling over the whole caldera and most of the area north of the WNW-ESE vertical resistivity boundary. Further survey, especially to the north and east is required to see the edge of the proposed geothermal reservoir. At 1500 m b.s.l. (centre right map of Figure 8) the resistivity is high and we are well below the base of the clay cap layer. At 4 km b.s.l. (bottom left map, Figure 8) we start to see the top of the deep conductive layer in the north eastern part of the survey area, just north of Mt. Chebe. Note there are no data points between this area and Mt. Chebe (difficult accessibility) and therefore this area of shallow depth to the deep conductor may well extend south to the mountain. At 10 km b.s.l. (bottom right map of Figure 8) the deep conductor is found to be located beneath most of the northern half of the caldera as well as west, north and east of it.

It should be noted that the soundings are interpreted by 1-D resistivity models, which is believed to be reasonable for most of the soundings since the MT data is quite 1-D in nature. However some of the soundings show 2-D or even 3-D signs. Those are mainly soundings close to the WNW-WSE boundary. Therefore finer interpretation using 3-D inversion might change the result somewhat, especially around this vertical resistivity boundary, especially the deeper portion of the resistivity model.

Figure 9 shows the elevation of the 10 Ωm isotherm at the base of the clay cap layer. According to the above discussion on the relationship between resistivity and alteration, this is the inferred elevation of the ~250°C isotherm. This layer is not found in the southern part of the survey area and is therefore not coloured on the figure. For some soundings close to the WNW-ESE resistivity boundary, a higher resistivity value than 10 Ωm has been used. This surface is at sea level or deeper outside the caldera and rises to about 1.5 km a.s.l. (i.e. 400 m depth) north of Mt. Urji. There appears to be an N-S striking elevated ridge of this surface extending northwards from Mt. Urji. Another shallow area to this surface is west of Mt. Chebe. There is a sharp deepening of this layer at the eastern and north eastern edge of the caldera.

Figure 10 shows the elevation down to the top of the deep conductor, using the 10 Ωm isoline as measure of the depth to this layer. This layer is not observed south of the WNW-ESE vertical resistivity boundary line. It is shallowest to this layer in the north eastern part of the survey area where the elevation is around 5 km b.s.l. (~7 km depth). East of the caldera and within it the elevation is around 10km and down to 15-20 km close to the WNW-ESE line. As previously stated the 1-D interpretation of MT/TEM data located close to this boundary line should be treated with care especially for the deeper part of the resistivity model.

The nature of this deep conductive layer is not known. However such a deep conductive layer is observed beneath many of the major high enthalpy system in the world, such as in Iceland and Kenya. The most plausible explanation is partially molten material. The molten stage portion need not to be high, probably not more than few % to 15% (e.g. Satao and Ida, 1984; Maumus, et.al. 2005), as long as the molten phase is somehow interconnected through a large volume. As such the deep conductor is here interpreted as the heat source layer for the geothermal system above. This heat source layer is apparently extending over larger area hen the current survey area, probably over some hundreds of km^2. It is worth noting that such a layer is not observed beneath the Aluto geothermal system some 75 km NNE of Corbetti, where the only geothermal power plant in Ethiopia is operating (Samrock, et.al. 2014).

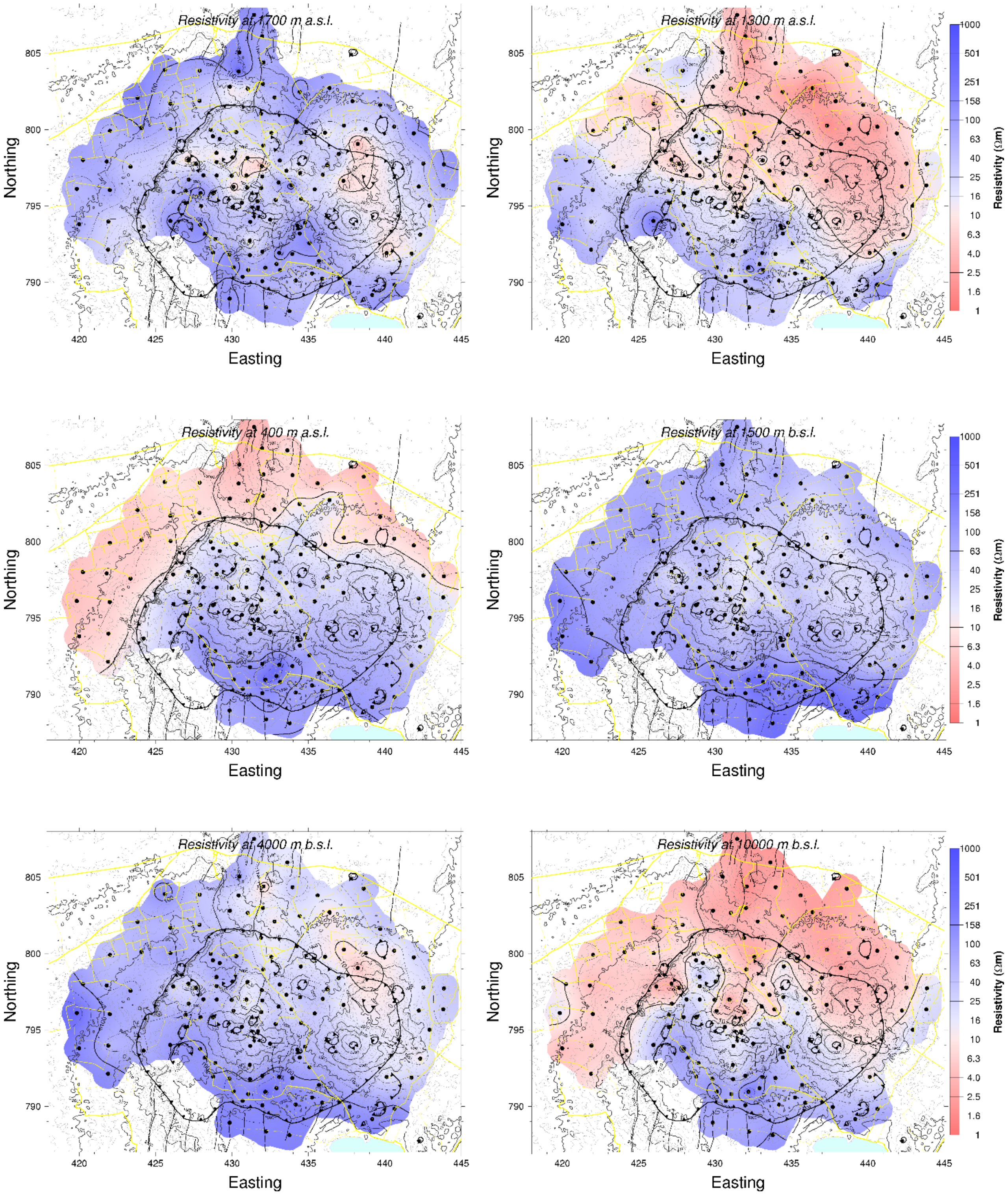

Figure 8: Resistivity at different elevations.

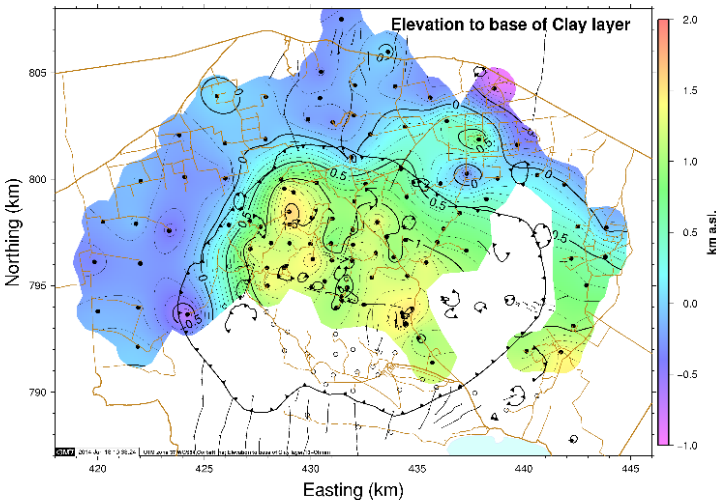

Figure 9: Elevation of the base of the clay cap layer (using 10 Ωm isoline)

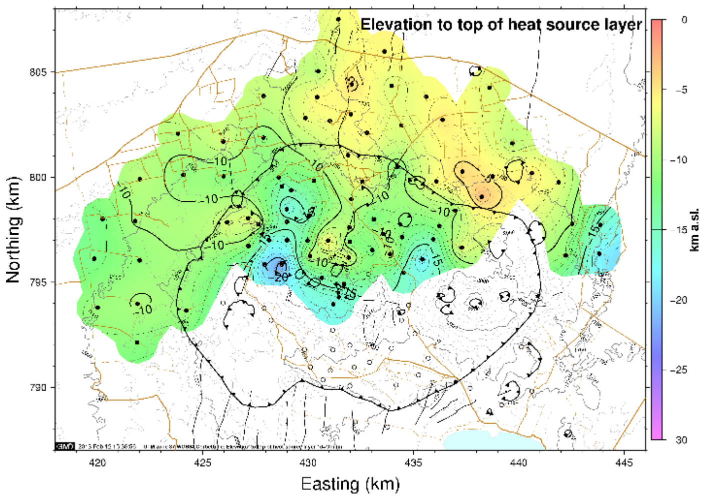

Figure 10: Elevation to the top of the deep conductor in km a.s.l. (i.e. down to the 10 Ωm isoline).

6. CONCLUSION

The surface exploration work carried out to date in Corbetti, in conjunction with earlier studies, allows the RG team to put forward a conceptual reservoir model for this large geothermal reservoir. This model is shown schematically in Figure 11. It is following a resistivity cross section NS432 from S to N, through the Urji volcanic centre (see location on Figure 2). The cross section is featuring the following:

- A deep upflow of hot fluid coincides with the shallowest depth to the heat source layer in Corbetti, right underneath the Mt Urji peak. Surface manifestations (steam vents and alteration) are present over the predicted high-enthalpy upflow.
- The lateral S to N pressure gradient of the shallow groundwater reservoir is also extended into the geothermal reservoir, resulting in a lateral outflow of the hot upwelling fluid to the North.
- The clay cap, shown in red on the figure, is here regarded as the cap rock of the geothermal reservoir. It is generally found at about 1600-1700 m a.s.l., coinciding with the watertable. The geothermal reservoir is encountered at the base of this layer, where the resistivity goes up again, above 10 Ωm. The resistive boundary is believed to occur where the clays of the cap rock become unstable because of rising temperature with depth, and are replaced by less conductive minerals (epidote and chloride) which are stable at temperatures above 250 °C.
- The shallow groundwater flow from south may recharge the deep geothermal reservoir through the caldera faults and rifting faults in the southern section of the caldera.
- The groundwater flow flowing at shallow level north of the WNW-ESE volcanic belt (Chebi-Urji) is heated by hot steam and water from depth. This hot fluid is floating on top of the groundwater lens, due to low density. This layering is picked up by the resistivity models as thin and horizontal tongues flowing to the north from Mt Urji, the clay cap layer.

- The hot reservoir fluid is escaping to surface as steam around and to the north of Mt Urji, and has been sampled for chemistry. All of those are conservatively indicating deep geothermal reservoir temperatures in the 250-300°C range.
- The shallow exploration well CTG-3 is on the cross section and its 93°C temperature coincides with top boundary of the clay cap. The geothermometers indicate resource temperature close to 140 °C, as is to be expected.
- The south part of the caldera rim may conduit colder fluids to greater depths and recharge the deep geothermal reservoir.
- Other explanations may apply for the abrupt WNW-ESE change in resistivity across the centre of the Corbetti caldera. But if the resistivity is reflecting a temperature contrast, the reservoir under the Demo Argo peak may have commercial permeability and thus resemble similar volumes as in Olkaria geothermal area in Kenya, where most of the best producers are drilled.
- To the north, at the caldera rim, the clay cap gets thicker. Possibly the lateral discharge from depth is here diverted to surface and thereby is less able to heat up the deeper formations, resulting in greater depth to the top of the 250°C geothermal reservoir.

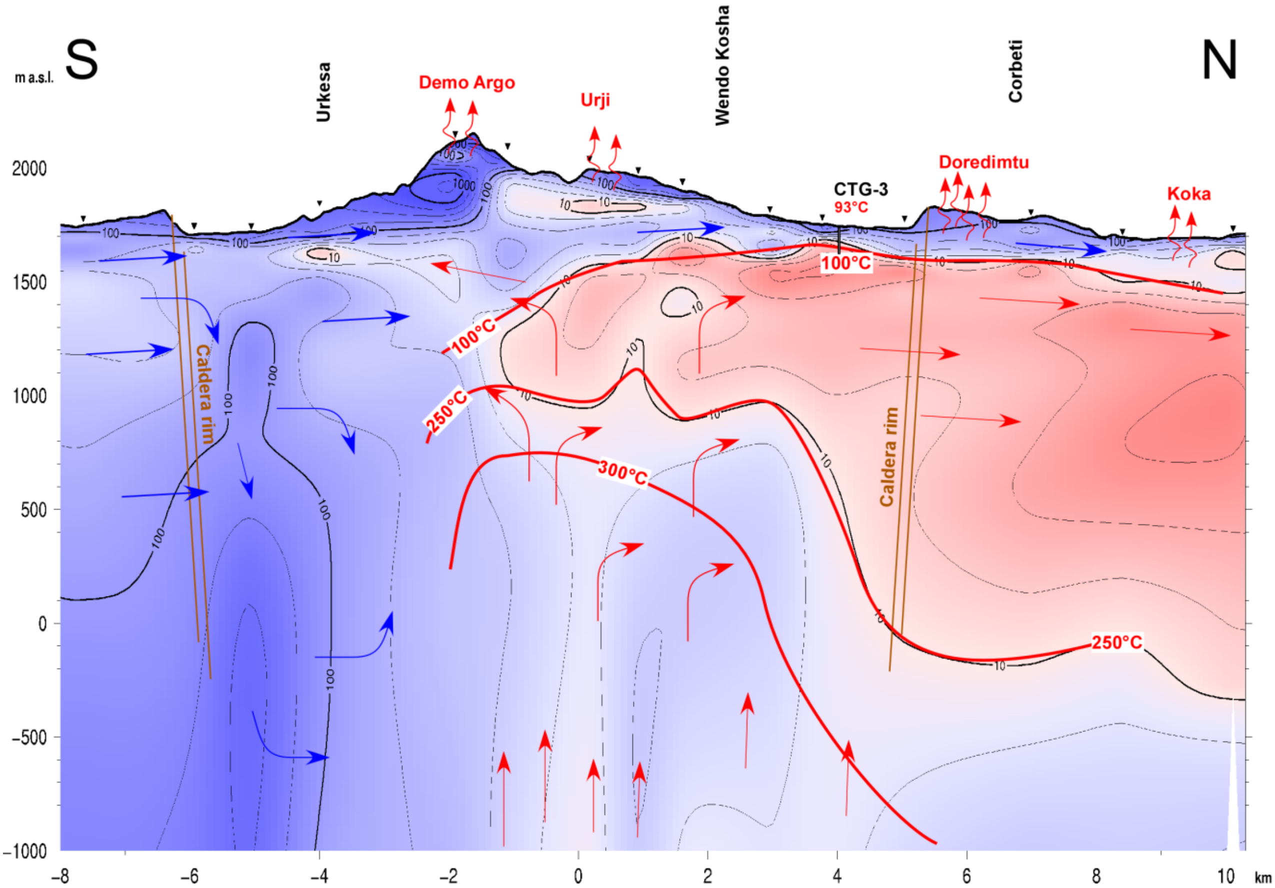

Figure 11: A conceptual reservoir model for the Corbetti geothermal system.

The lateral extent of the high temperature reservoir conceptualized on Figure 11 is conservatively set as 12 km, but may extend much farther north as indicated by the Koka fumaroles area (see Figure 2). Here the geothermal gas thermometry is of high quality and is indicating reservoir temperature in excess of 300°C.

The conceptual model has been accepted by RG and the relevant authorities in Ethiopia and two drilling sites been selected north and south of Mt Urji. Initial 5 well drilling plan is in place and drilling expected to commence late 2014. The wells will be directionally drilled, with production casing down through the clay cap layer to the predicted top of the reservoir. The anticipated depth of the first exploration wells is 2500 m.

Reykjavik Geothermal has agreed with the Government of Ethiopia on the development of up to 1,000 MW in the Main Ethiopian Rift. It is expected that the project will be split in two phase development of 500 MW each. The planned project will utilize geothermal energy from three different resources in MER; at Corbetti, Tulu Moyer and Abaya. Each of the resource will be developed in stages; in Corbetti the first stage is a 20 MW well head units and expanding to 70 MW in a single unit. The power of the planned plants will be sold to the state energy company of Ethiopia, Ethiopia Electric Power (EEP). With the first plant, the annual power production is expected to deliver about 4,000 GWh to the national grid.

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