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The Fantale Geothermal Development Project, Ethiopia: An Update

Thomas P. Elliott[1], Matthew J. Sharp[1], George D. Percy[1]

1Cluff Geothermal Limited, Syon House, London Road, Brentford. TW8 8JF, United Kingdom

info@cluffgeothermal.com

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ABSTRACT

Cluff Geothermal Limited (CG) was awarded the Fantale Geothermal Exploration Licence in July 2015. The licence area is principally sited to take advantage of suspected high-enthalpy resources, totalling 400 MW_e, associated with Mt. Fantale, a prominent stratovolcano situated within the Main Ethiopian Rift near the town of Metehara. Since licence award, CG has undertaken a detailed surface studies campaign, the most significant milestone being the successful completion of a 246-station magnetotelluric (MT) survey in early 2016. All data have been collated and independently reviewed to produce a conceptual model of the subsurface, from which a series of exploratory drilling targets have been identified, and a conceptual development plan for an initial 150 MW_e of geothermal development devised. Confirmation of drilling activities remains subject to the signing of a Power Purchase Agreement (PPA) and Implementation Agreement (IA).

1. INTRODUCTION

Cluff Geothermal Limited (CG), a British geothermal exploration and development company, identified the area surrounding the Mt. Fantale volcano, a prominent stratovolcano situated within the Main Ethiopian Rift approximately 200 km east of Ethiopia's capital Addis Ababa, as a suitable site for geothermal exploration and power plant development (Figure 1). CG was awarded the Fantale Geothermal Exploration Licence in 2015.

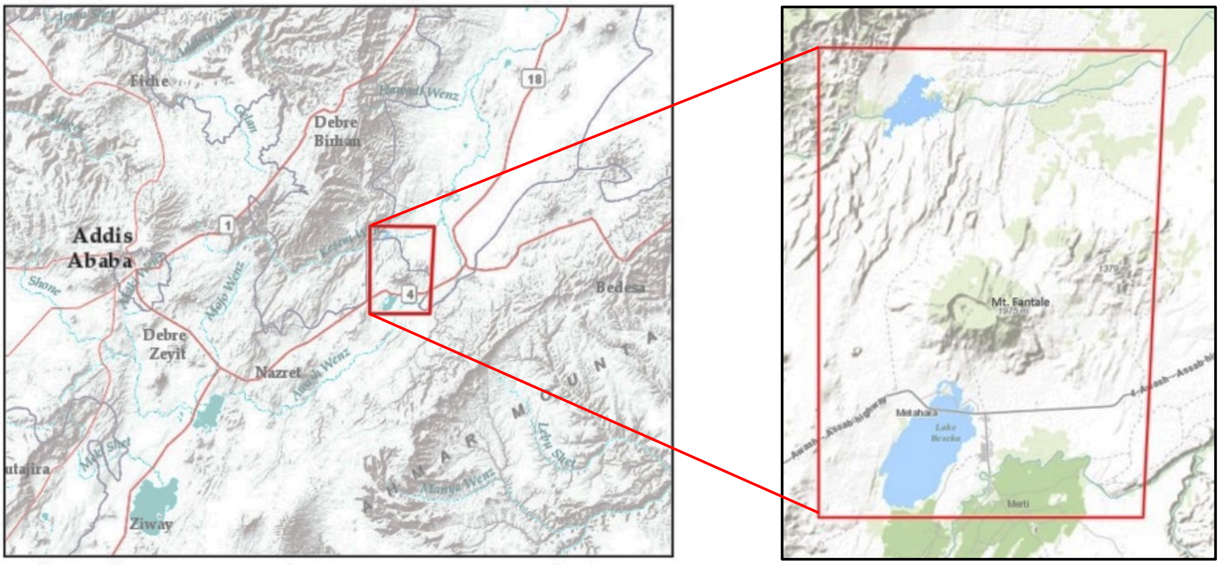

Figure 1: Fantale Geothermal Licence Area

Ethiopia has been undergoing geothermal exploration since the 1970s. A broad selection of potential geothermal prospects have been identified along the East African Rift System (EARS), with many early reconnaissance surveys being followed up by more detailed surface exploration activities. In the 1980s and 1990s, exploration drilling took place at two sites: Aluto Langano and Tendaho. This resulted in a 7.2 MW_e pilot plant being constructed at Aluto in the late 1990s. Since then, exploration licences issued by the Government of Ethiopia have encouraged significant private and public investment at numerous sites along the EARS (Kebede, 2016).

The Fantale concession is situated in the Main Ethiopian Rift at a triple junction of three national regional states: Amhara, Afar and Oromia. The 1,200 km^2 licence area is dominated by Mt. Fantale, a dormant stratovolcano lying in the centre of the concession with a maximum elevation of 2,007 m above sea level. It rises approximately 600 m from the surrounding plains and its summit is occupied by a large crater 2.5 km by 4 km across. The remainder of the licence area is comparatively flat, with Tinish Fantale (a heavily eroded former volcanic centre) rising about 100 m above the surrounding plain. To the west and east lie steep escarpments forming the Main Ethiopian Rift's boundaries. Drainage in the area is to the north, into the Kessem River, or to the south-east into the Awash River.

The Kessem River flows from the western escarpment towards the Sabure Sugar Plantation in the north of the licence area. Following Sabure, it joins the larger Awash River that flows for over 1,000 km across Ethiopia from the west of Addis Ababa into the desert of southern Afar. Also found within the licence area are two large lakes: Lake Beseka, a large saline lake located to the south of Mt. Fantale and the Kessem reservoir to the north.

CG carried out surface exploration works and analysis between 2015 – 2017. These included: remote sensing and geological mapping; water sampling and analysis; and a 246 station MT survey. The acquired data were interpreted and used to develop a detailed conceptual model of the area of interest's geothermal resource, which identified exploration drilling targets and a phased 400 MW_e field development strategy.

2. PREVIOUS WORK

The Fantale Geothermal Licence Area has been the subject of considerable geothermal exploration. Earlier geoscientific studies of the area prompted the initial 1987 reconnaissance study by ELC Electroconsult (ELC, 1987a-c). Further studies took place in the 2000s by the Geological Survey of Ethiopia (GSE) (Bekele et al., 2007). These early studies noted several features at Fantale which suggest the presence of a suitable geothermal resource. These include: a recent volcanic complex exhibiting caldera collapse and indication of a shallow heat anomaly; hot springs and surface manifestations; active tectonics; sufficient groundwater recharge; and the presence of a low permeability cap rock.

2.1 Regional Geology

The caldera-forming explosion of Mt. Fantale is dated at 170 ka. The mountain is one of a line of silicic Quaternary volcanoes which extend along the Main Ethiopian Rift. The Rift's graben structure produces two escarpments to the west and east of the licence area, while the terrain immediately surrounding the volcano is typical of a recently active volcanic environment.

In the west of the licence area, there are further examples of volcanic activity, with regular blister cones and NNE/SSW trending fault escarpments dominating the landscape. There is hot spring activity where some of these faults outcrop at the surface. To the south-west, scoria cones mark the existence of otherwise less-visible continuations of the NNE/SSW faulting structures (Williams, 2012). A shallow magma chamber is inferred beneath Mt. Fantale from geochemical evidence obtained from widespread surface manifestations; geophysical evidence of a high Bouguer gravity anomaly; a high-velocity seismic structure; and an extensive young dyke complex above its inferred location.

GSE geological investigations identified the Alaji and Bofa basalts as the main reservoir target strata (Bekele et al., 2007). Both are brecciated and expected to maintain high permeability at depth. The main extensional faults have been mapped and are estimated to extend to a maximum depth of 2 km. Mapping of surface features revealed the NNE/SSW trend of the Wonji Fault Belt, while a magnetic survey identified a second cluster of faults trending NW/SE. The two sets of faults intersect each other in a manner suggesting they serve to enhance secondary permeability in the target reservoir rocks. The overlying ignimbrites (and less extensive rhyolites and obsidians) are generally considered effective cap rocks. Although the total thickness of the cap-rock sequence has not been fully characterised, the Dino and Fantale ignimbrites are typically each around 30 m thick and are laterally extensive over a large area.

2.2 Geochemistry

In the 2000s the GSE identified up to 40 surface manifestations in the form of hot springs, mud pools, fumaroles and steaming ground (GSE, 2007). They are located throughout the licence area, with the most extensive manifestations in the Habilo region to the north-west of Mt. Fantale. The GSE carried out fluid sampling and analysis at seventeen locations, which included a selection of springs, boreholes and surface waters. The sampled fluids emanate from hot springs at 40-80 °C, and geothermometry calculations based on the chemistry of their discharge indicate a source temperature of around 250 °C (Teclu, 2002). The geochemistry is relatively consistent between the different sampling stations, implying that they share a common source.

2.3 Geophysics

Historical geophysical investigations comprised a series of seismic and micro-seismic studies, which highlighted the presence of anomalous high velocity structures beneath the axial rift. Additionally, reconnaissance gravity and resistivity surveys were carried out with 200 gravity stations and 53 VES data points recorded. The GSE augmented these results with new gravity, magnetic and electrical resistivity data. An elongated, low residual gravity anomaly to the north-west of the licence area was identified in these investigations, and surface manifestations are located at or around the margins of this anomaly. The magnetic survey mapped the north-west trending subsurface linear features, with their depth varying between 300 and 1,000 m (Bekele, 2007).

Low apparent resistivity values extend from the Habilo springs towards the south-west of the area. These could be caused by the combined effects of hydrothermal alteration, fluid circulation, or buried lacustrine sediments. The resistivity anomaly at the Filoha springs could be caused by alteration and the presence of hot water in the subsurface, while groundwater circulation patterns and lacustrine sediment bodies might explain the low resistivity around Sabure village.

2.4 Previous Data Review

The historic geological and geoscientific data point towards a valuable high enthalpy geothermal reservoir system. The inferred high permeability of the Alaji basalt at depth is sufficient to act as a suitable reservoir rock, with the Fantale and Dino ignimbrites providing a potential capping structure. The north-west/south-east trending faults visible at the surface and in the magnetic survey data extend to depth, so these would also enhance fluid flow within the target strata.

The ultimate heat source is anticipated to be a shallow magma chamber with additional heat generated from associated dyke intrusions. Geothermometry results are promising; pH values are benign and H_2S concentrations are low. This suggests that the geothermal fluids have been heated by the conduction of energy from a nearby magmatic heat source, rather than by direct contact. This would be consistent with the meteoric signatures of the hot waters.

The GSE produced a simple two-dimensional conceptual model cartoon of the predicted geothermal system (Figure 2), with water precipitating onto the rift escarpment, percolating through permeable rocks and open fault structures in the rift flank into the deep subsurface. Then, heated in close proximity to the magma chamber which promotes upwelling (along other fault systems in the rift floor). The target depth is the point at which this upwelling pathway coincides with the suggested reservoir rock (the Alaji basalt).

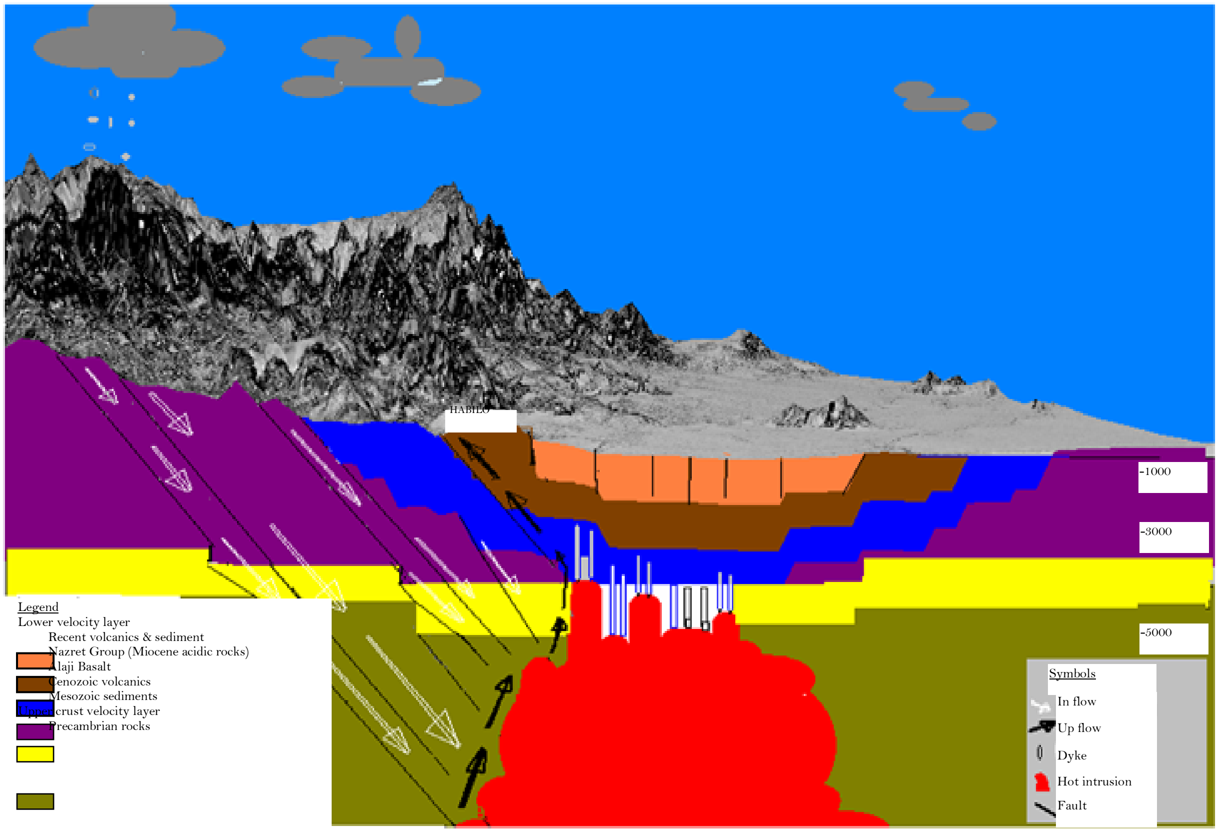

Figure 2: Geological Survey of Ethiopia Fantale Conceptual Model (Bekele et al., 2007)

2.5 Exploration Strategy

A critical review of the existing geoscientific data by GeothermEx Inc. concluded that further surface studies, notably a magnetotellurics (MT) survey, would significantly assist with determining suitable drilling targets for exploration boreholes. Geological structures surrounding the extensive faulting and surface manifestations at Habilo were the main targets for detailed surface investigation (GeothermEx, 2015). The surface targets for these surveys were along the predicted groundwater flow pathways between the geothermal heat source and the surface manifestations, most notably the north-western portion of the licence area around the Habilo springs. A MT survey grid would acquire data across this area to identify the most promising drilling targets. Exploration drilling target locations would be further clarified by additional geochemical and geological investigations.

3. CLUFF GEOTHERMAL'S EXPLORATION

Following licence award, CG carried out extensive exploration studies at Fantale building on results from past surveys. An emphasis was placed on verifying or improving existing datasets alongside the addition of a large MT survey. The two main items requiring verification and further investigation were the local geology and the region's fluid chemistry.

3.1 Remote Sensing

Structural and lithological mapping of the survey area was carried out using remote sensing techniques. Data used included Landsat 8 OLI (Operational Land Imager) images, SRTM DEM (Shuttle Radar Topography Mission Digital Elevation Model) and existing geological maps of the survey area (Sharp et al., 2020). Satellite imagery and DEM data were used to identify geological structures, which were then correlated with existing geological maps to produce a detailed geological and structural map of the area. A geological map for the region was created from the findings, which was ground-truthed to confirm prior lithological classifications owing to disparities between existing geological maps. The remote sensing survey highlighted numerous surface fault traces across the area of interest between Lake Kessem and Mt. Fantale, corroborating a previous study which suggests the target area has some of the highest lineament density in the Main Ethiopian Rift (Figure 3).

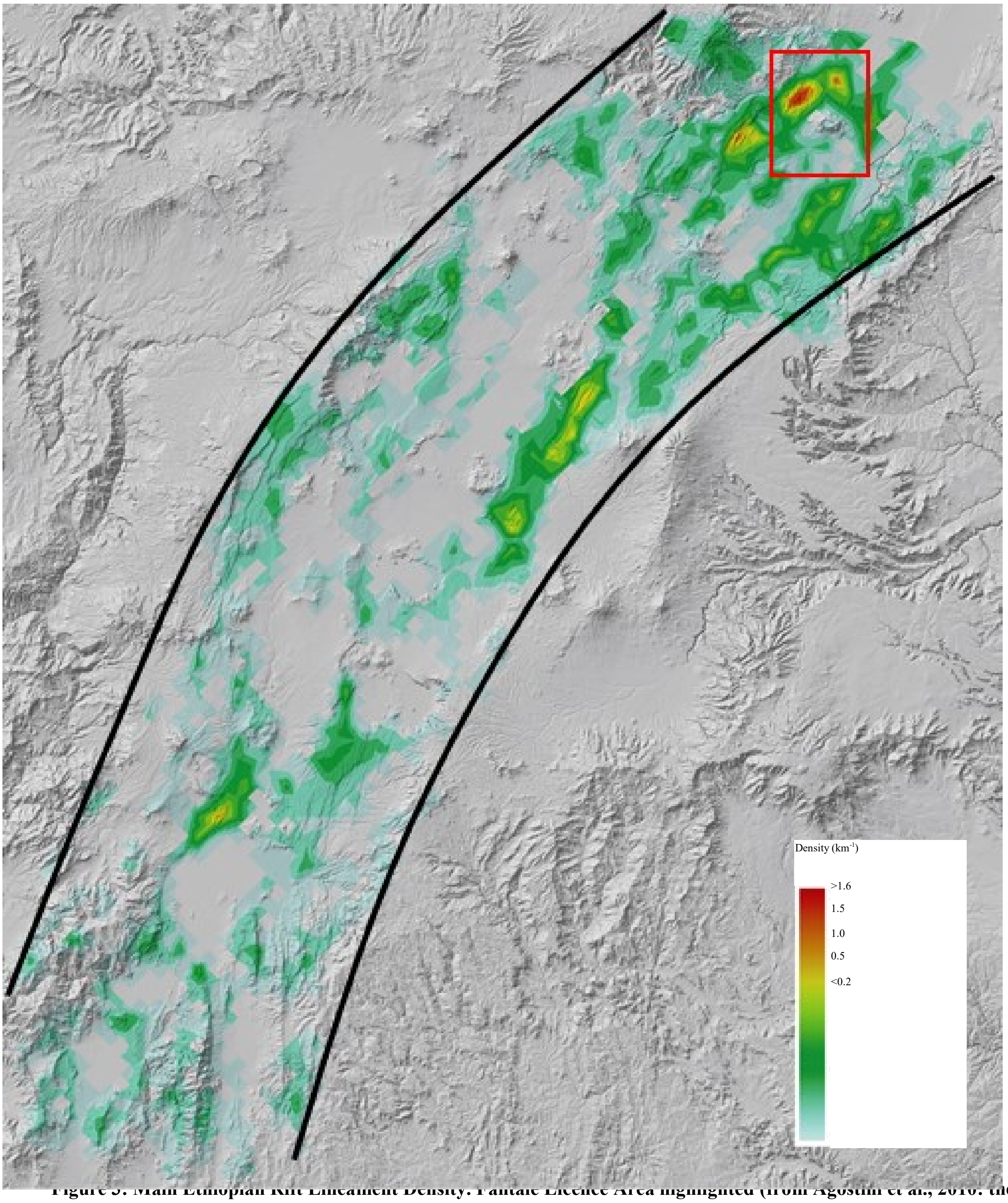

Figure 3: Main Ethiopian Rift Lineament Density. Fantale Licence Area highlighted (from Agostini et al., 2010: the density has been calculated for 5 km-sided square cells as the ratio between the cumulative length of faults contained in each cell and the area of the cell)

3.2 Geological Mapping

Geological mapping of the main area of interest was undertaken to ground-truth the lithologies and structures identified through remote sensing. Ground-truthing involved selecting localities for detailed investigation based upon previous work. The exercise critically evaluated the validity of the remote sensing map by testing lithologies, unit boundaries and structural features, centred on the Habilo spring (Sharp et al., 2020).

Ground truthing of the remote sensing map resulted in reclassification of some lithological units within the mapped area and confirmed the location of geological structures and faults initially identified through remote sensing. Discrepancies from the remote sensing map are unsurprising owing to the extensive weathering of the surface outcrops, making lithological identification difficult. Findings from the field mapping were combined with the results of the initial remote sensing and extrapolated across the survey area, leading to a final updated geological map. This exercise resulted in an improved understanding of the area of interest's lithological and structural make up.

3.3 Water Sampling and Analysis

Previous geochemical studies had identified numerous surface manifestations within the licence area. Monthly water sampling took place at six sites over an eight-month period. Four additional sites were also sampled on occasion. Not all sites were sampled every month owing to dry springs or flooded access roads.

Field analysis measured temperature, conductivity, total dissolved solids (TDS), pH, oxygen reduction potential (ORP), alkalinity and hardness. To ensure high-quality data collection, fluid sampling best practices were followed, including repeat measurements and regular calibration of equipment using standard solutions. Monthly data collection has allowed for consistency checks and identification of any seasonal geochemical variation, which was limited. Filtered samples were collected and major and trace element analysis took place in the British Geological Survey's (BGS) UKAS-accredited laboratory in Keyworth, United Kingdom. Care was taken to ensure samples were collected and transported in accordance with the laboratory's specifications.

CG's water sampling campaign for the most part validated the existing fluid chemistry dataset from the GSE, ELC and others (GeothermEx, 2016). The geochemistry of the Habilo hot spring in particular suggests that an exploitable hot resource is indicated in the area. The chemistry of the Habilo waters is benign, presenting no serious constraints to production. The geothermometer indications from the Habilo samples of 210 – 220 °C are considered to underestimate the deep temperature owing to cooling and re-equilibration occurring along the upflow (Jacobs, 2017a). To the north of Mt. Fantale, the waters from the Filoha hot springs appear representative of the system's outflow.

3.4 Magnetotelluric (MT) Survey

The MT survey at Fantale took place over a period of six weeks in early 2016. The project's aim was to acquire safely at least 210 high quality MT data points over a 40-day period to assist with determining the most appropriate sites for a future exploratory drilling campaign. The survey was undertaken by Quantec Geoscience alongside CG personnel. Quantec operated with a high level of quality control and scientific rigour, with sites repeated where necessary to ensure high quality data. All equipment used was standardised at the start of the survey through a parallel sensor test, and a selection of sites were repeated using different equipment sets as a further means of quality control. Mid-survey reviews of the preliminary MT data were conducted by Jacobs Consultancy to assess data quality and assist with the siting of supplementary MT stations. The assessments found high-quality data had been acquired owing to meticulous data collection and a low noise environment (Jacobs, 2016).

In total, 246 MT data points were collected during the 40-day survey period over an area of approximately 14 km × 20 km. The original aim to collect 210 MT data points was surpassed following efficient progress and excellent cooperation from the local community, allowing additional in-fill sites to be added. Preliminary interpretation of initial MT data helped to determine the location of these supplementary infill sites.

The 1D and 3D inversions were carried out by Quantec, and several highly conductive zones were resolved near the surface, two of which correlate with locations of known surface fumaroles and the Habilo hot spring. A near-surface, thin conductive layer at ≈100 m depth with thickness of a few tens of metres is observed. Beneath this a thick and nearly continuous conductive layer, extending across the entire survey area, with a nominal thickness of ≈1,000 m is resolved.

Due to the depth penetration of the MT method, two deep conductive anomalies are observed in the northern and southern parts of the survey grid extending to more than 5 km in depth. The findings from the MT survey and resulting interpretation of the subsurface, when analysed alongside the surface geology and geochemical signatures from manifestations in the region, have greatly assisted with understanding the geothermal system at Fantale (GeothermEx, 2016). All data and associated acquisition techniques were independently reviewed by Jacobs Consultancy, who carried out a peer review role throughout the surface exploration and interpretation phases (Jacobs 2017a).

4. CONCEPTUAL DEVELOPMENT PLAN

The MT survey marked the final part of CG's surface exploration at Fantale. It was concluded that there is sufficient good quality information available to justify a decision to commit funds for an exploration drilling programme (Jacobs, 2017b). The surface exploration campaign identified the Habilo Basin as the most attractive target for exploration drilling (Figures 4 and 5). As there has been no deep drilling in the region, the first exploration well will aim to identify the base of the inferred clay cap; determine the existence and characteristics of a geothermal resource; understand the reservoir rock characteristics; and if appropriate determine the reservoir unit's thickness. Subsequent exploration wells will be deviated and aim to prove an extended resource area. They will establish productivity potential by deviating perpendicular to the axis of maximum stress.

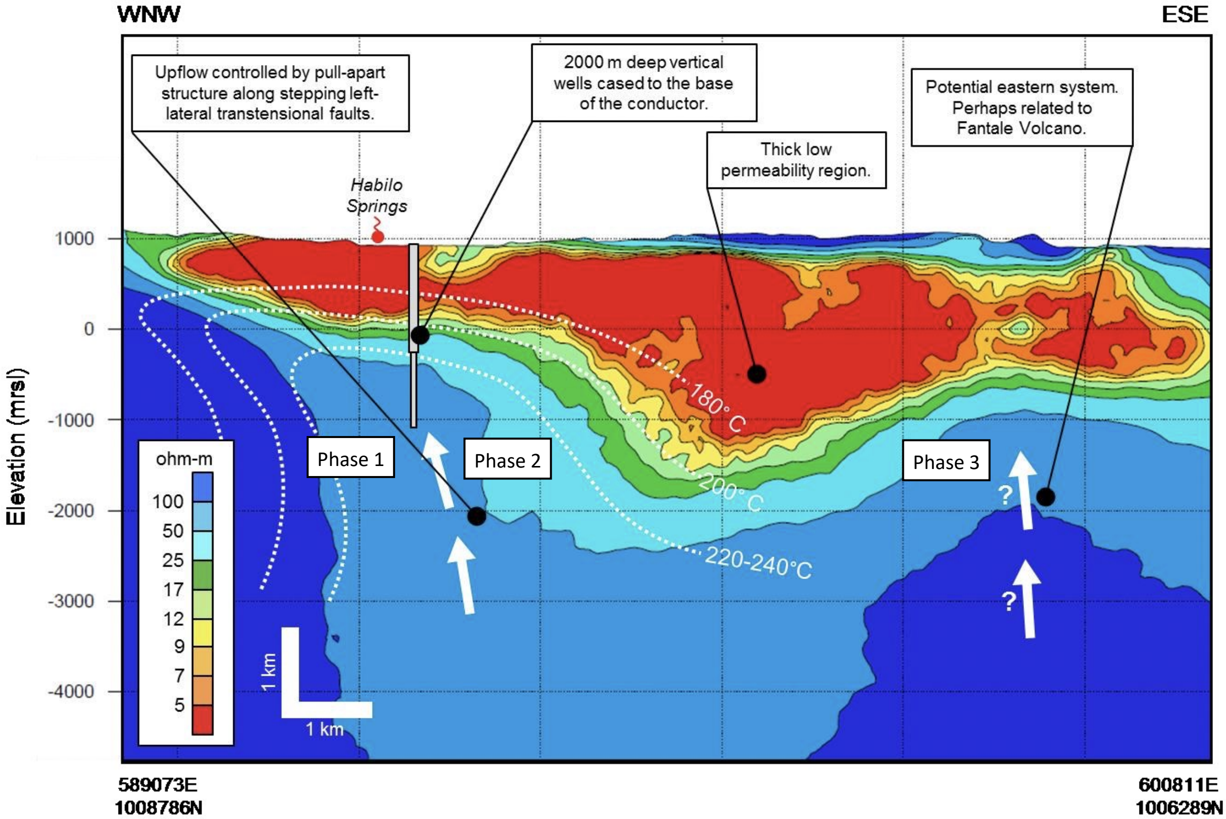

Figure 4: Cross-section through MT 3D inversion showing approximate targets of development Phases 1-3

To develop the Fantale prospect CG will follow a phased approach (Table 1). Each phase will provide new information to determine whether to proceed with further resource development. Given the current greenfield nature of the Fantale prospect, the Conceptual Development Plan has focused primarily on Phase 1 of the development. Phase 1 has been split into two parts: Phase 1a and 1b (Figure 5). Phase 1a of the Fantale Development has been set at 50 MW_e, which is close to the estimated P90 resource capacity for the Habilo Basin resource area, and as such is a logical first stage development capacity. The process of developing Phase 1a will start with exploring for and confirming the presence of an exploitable geothermal resource. The capacity of Phase 1b has been set at 100 MW_e. This is a logical second stage capacity as it would bring the total developed capacity to 150 MW_e which is close to the estimated P50 resource capacity for the Habilo Basin area.

Table 1: Fantale Geothermal Development Summary

Phase	Additional Capacity (MW)	Cumulative Capacity (MW)
1a	50	50
1b	100	150
2	100	250
3	150	400

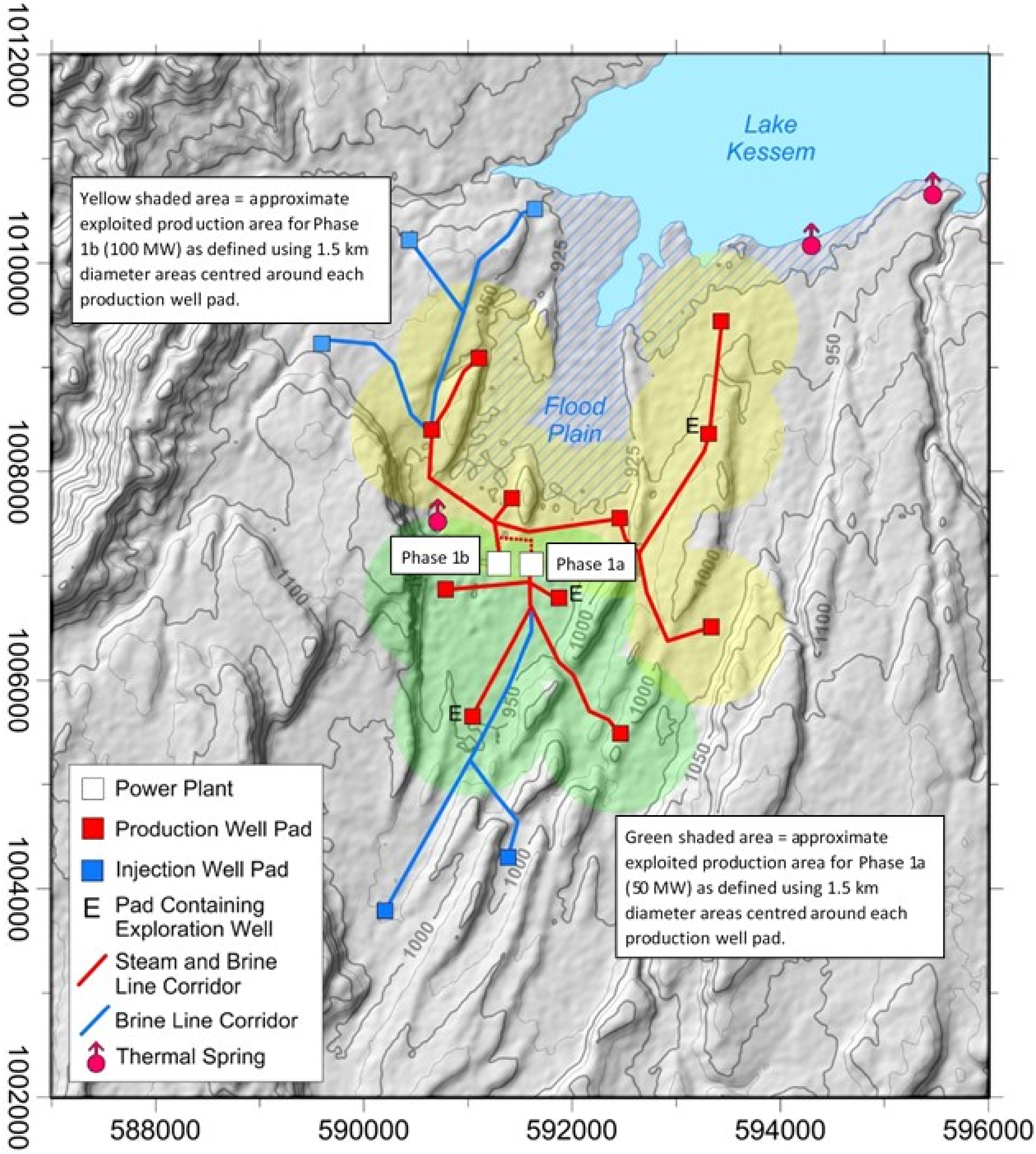

Figure 5: Fantale Phases 1a and 1b – Developing the Habilo Basin

After a suitable period of sustainable operation Phase 2, a further 100 MW_e, will explore the region to the east of the Habilo Basin, closer to Mt. Fantale (Figure 6). Phase 3 will explore a potential secondary system to the north of Mt. Fantale, highlighted by the MT survey (Figure 4). Phase 3, an additional 150 MW_e, would bring the cumulative installed capacity of the Fantale Development to 400 MW_e (Table 1 and Figure 6).

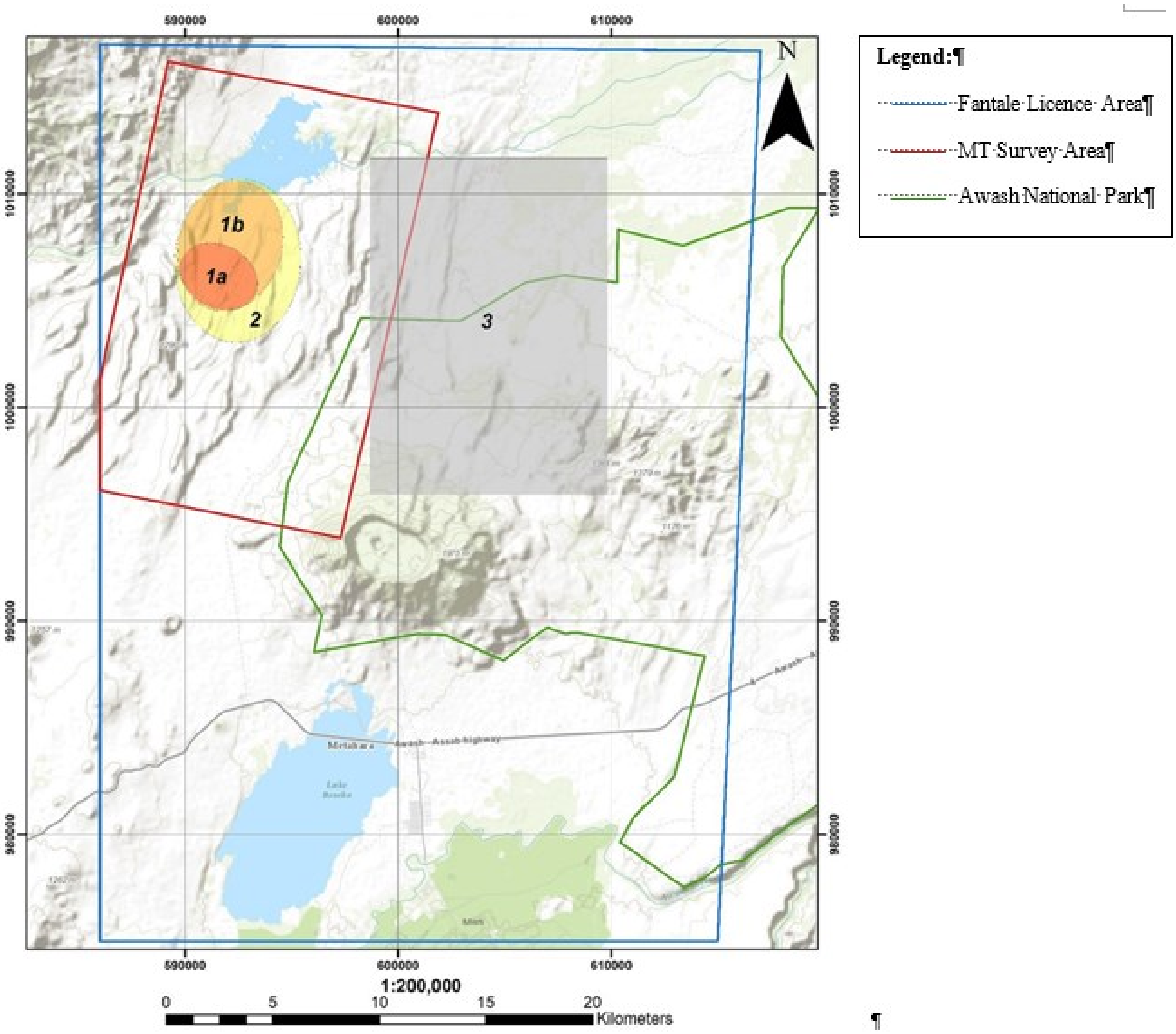

Figure 6: Fantale Geothermal Development: Phases 1 - 3

5. CONCLUSION

Both GeothermEx and Jacobs agree that there is a prospective geothermal resource in the Fantale study area. Waters analysed from the Habilo springs are of geothermal origin and have experienced low level of dilution and re-equilibration in their ascent from a deeper reservoir. The MT results indicate a clay capping structure in the vicinity of the Habilo springs, which is the primary target for exploratory drilling and Phase 1a of the development. Subsequent phases focus on testing the lateral extent of the primary upflow zone and exploring a potential secondary upflow zone identified by the MT survey to the north of Mt. Fantale.

CG has identified an excellent geothermal resource with the capacity to host commercial electricity production at Fantale. The resource is expected to provide up to 400 MW_e of baseload, renewable electricity into the Ethiopian grid. This would support Ethiopia's rapidly growing economy and help realise their laudable ambition for a low carbon grid portfolio. The next, crucial, phase for the Fantale project is the signing of a Power Purchase Agreement (PPA) and Implementation Agreement (IA) with the state-owned Ethiopian Electric Power (EEP) company and the Government of Ethiopia respectively. If the Fantale PPA and IA documents are concluded promptly, CG will be able to rapidly progress this exciting project to the drilling and power production phases, benefitting the Ethiopian energy sector and Ethiopia's economic prosperity. The Fantale project would be a prime example of a UK company working with African partners to deliver increased UK-Africa trade that benefits both the host country and UK business.

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