Geothermal Exploration of the Barrier Volcanic Complex, Kenya

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ABSTRACT

The Barrier Volcanic Complex (BVC) is one of the northern-most geothermal prospects in the Kenyan rift system. Olsuswa Energy Limited (OEL) is a Kenyan independent private developer that was licensed to develop the 136km² prospect. Two major historical works have been conducted at the BVC. In the early 1990s, the British Geological Survey carried out a regionally-extensive geological mapping program in northern Kenya, while in 2011, the Geothermal Development Company (GDC) conducted geoscientific reconnaissance studies at the site. Both surveys were significant in establishing BVC’s positive geothermal potential. Driven by the energy demands of the country to providing affordable, green and stable power in light of the increased industrial growth of the economy, OEL embarked on a greenfield development of the BVC by employing geological, geochemical and geophysical techniques in its surface exploration project. The main objective of the exercise was to identify well targets for exploration drilling. Field methodologies applied in the 30-day surface studies included lithological and structural mapping, geochemical sampling and geophysical measurements. These were focused in a 67km² priority area. Geological and geochemical data analyses and interpretation indicated the presence of a high-temperature, caldera-hosted geothermal system with calculated geothermometry temperatures in excess of 300°C. Through geophysics (resistivity, gravity and seismic methods), it was established that the study area is an active volcanic system defined by an intrusion-heated, shallow reservoir. Integration of geological, geochemical and geophysical data sets informed on the priority siting of four drilling targets. From the exploration program, it was recommended that exploration drilling be undertaken to confirm the resource potential of the Barrier Volcanic Complex.
1. Introduction

Olsuswa Energy Limited (OEL) is a Kenyan-based energy company that was incorporated in 2011. The company was awarded a Geothermal Resource License in 2016 by the Ministry of Energy to explore, develop and exploit geothermal resources at the Barrier Volcanic Complex (BVC).

The backbone of OEL’s formation and participation in the clean energy space was in keeping allegiance with the green agenda on both the international and national fronts. On the latter’s case, gradual year-on-year Gross Domestic Product (GDP) growth had ushered Kenya into a lower-middle-income status (Odhiambo, 2015). This in effect created a demand for affordable, sustainable and clean energy. The Least Cost Power Development Plan (LCPDP) published by the Government of Kenya (2018) spells that the nation had seen an average annual increase of 6% in the demand for electricity in the last 7 years to 2017.

More importantly, it was projected that in a “high” scenario, the gross electricity consumption was expected to grow from 10,465GWh in 2017 to 57,990GWh in 2037 (Government of Kenya, 2018), representing an annual growth of 8.8% per annum. This reflects an electricity demand of 9,790MW in 2037 from a peak demand of 1,754MW in 2017. The key driving factors of demand are population growth, urbanization, GDP growth and implementation of the Kenya Vision 2030 projects.

Buoyed by the above needs and gap, OEL embarked on developing the BVC. The first stage, on which this paper is based, was to conduct a detailed surface exploration program in March 2019. This was an advancement of previous works conducted by the British Geological Survey (BGS) and Geothermal Development Company (GDC) whose studies had been done on a broader regional scale. Preparations began on paper and involved many consultation meetings with the technical, logistics, administrative and community affairs teams.

Due to its lean structure, OEL contracted KenGen (Kenya Electricity Generating Company Ltd.) and ISOR (Iceland Geosurvey) through competitive international bidding to undertake the detailed geoscientific surface exploration and provide consultation services respectively. A similar approach was used in outsourcing for transport, security and camp services. 30 days were spent to complete field investigations. A 100-man militariesque canvas-tented camp was put up to accommodate the multi-disciplinary labour force of scientists and support-service staff. Given the arduous terrain, helicopters were the most appropriate means of transport for the work.

The purpose of the exploration studies was to further understand and define the geothermal resource characteristics of the BVC through geological, geochemical and geophysical angles. This would subsequently aid in estimating the potential of the study area and importantly fulfill the main objective of locating well targets for exploratory drilling by developing a geothermal conceptual model.

Specific objectives were as follows; detailed lithological and structural mapping, identification of geothermal surface manifestations, estimation of the reservoir temperatures using solute/gas geothermometers, establishing of fluid origin, carrying out electromagnetic surveys to outline possible geothermal reservoir boundaries, conduct gravity surveys to understand geothermal heat source patterns and carrying out micro-earthquake surveys to define fracture zones that may be associated with tectonic activities.

The scope of the exploration program was to review historical geological works and conduct detailed geological, geochemical and geophysical studies. A few challenges were experienced
in the exploration programme: the unforgiving, rugged landscape of the BVC through which arduous long traverses were made; lack of road infrastructure which subjected the company to use helicopters for transit services; and soaring day temperatures of between 37°C to 48°C. On some occasions, highs of up to 60°C would be encountered.

2. The Barrier Volcanic Complex

2.1 Regional Geological Setting

The Barrier Volcanic Complex is located in the Kenyan rift section of the East African Rift System (EARS). Chorowicz (2005) considered EARS as an intra-continental ridge system that comprises an axial rift. Its form at the surface is that of a series of several thousand kilometers-long aligned successions of tectonic basins generally bordered by uplifted shoulders. Morley et al. (1999) gave a more intimate description of the EARS, describing it as a 50-150 km wide elongate system of normal faults that stretches for approximately 3,500 km in a submeridian direction (figure 1).

Figure 1: A Digital Elevation Model (DEM) location map of the East African Rift System showing the major features. Adapted from Chorowicz (2005).

The Afar Triangle (shown in figure 1) which is a triple junction between the African, Arabian and Somalian plates (Chorowicz, 2005), is an important structure in the entire rift interplay as
it connects the EARS to two oceanic rift systems; the Red Sea and Gulf of Aden. Large-scale volcanological topography of the EARS was explained by Morley et al. (1999) to be marked by the Afar mantle plume dome in the north and East Africa mantle plume domes in the south (figure 2). These are separated by the relatively low-lying Turkana depression (600 m). Within the East Africa dome are the smaller Kenya and Kivu domes that are responsible for the strong geothermal signatures observed in the rift setting (figure 2).

Figure 2: A map showing the distribution of topographic domes with relation to the rift structure in East Africa. The Bouguer gravity anomaly cross-sectional profiles of the Afar and East African Domes have been provided in the two map inserts. Adapted from Morley et al. (1999).

The Kenyan (Gregory) rift together with the Ethiopian rift, comprise the 2,200-km eastern branch of the EARS that runs from the Afar triangle in the north to the basins of the north-Tanzanian divergence in the south (Chorowicz, 2005), and features some of the highest free-standing volcanic peaks in the world, in particular, Mts. Kenya and Kilimanjaro (figure 3). The Kenyan rift, as shown in figure 2, corresponds to the Kenyan dome.

The northern Kenya rift is developed in the northern part of the dome. Most of the exposed section is either volcanic flows, igneous intrusives or volcaniclastic sediments (Morley et al., 1999). It is worthy to note of the correlation that can be drawn on the formational developments between the Kenyan and Ethiopian rifts.
Kandie (2014) explains, the former depicts “continental rifting” therefore providing an insight into the early developments of the Ethiopian rift. The author further asserts that the Kenyan rift is endowed with many volcanic tectonic features that have been assessed to have geothermal potential, among them, the BVC.

Figure 3: Location map for the Kenyan Rift which begins from Lake Turkana in the north stretching down to south of Lake Magadi. The red star (symbol) indicates the location of the Barrier Volcanic Complex. The bordering Precambrian basement on either side of the rift is also shown. Most of the geophysical studies done in the Kenyan rift are a product of the Kenya Rift International Seismic Project (KRISP) which started in 1968. Adapted from Morley et al. (1999).
2.2 Local Geological Setting

The BVC is an iconic East-West-oriented Quaternary provenance that forms a natural barrier between Lake Turkana and the Suguta valley, which Lake Logipi is a part of (figure 4). The Complex is 20 km in length and 15 km wide, and as described by Dunkley et al. (1993), is a composite structure composed of four distinct volcanic centers; Kalolenyang, Kakorinya, Likaiu West and Likaiu East, named from west to east.

Figure 4: Location of the Barrier Volcanic Complex.

Rock units in Barrier Volcanic Complex are largely dominated by trachytes, basalts, phonolites and pyroclastics. Rocks of intermediate compositions are rarely found in the area. Rock types in the area have been broadly classified into three eruptive episodes; the pre-caldera, syn-caldera and post-caldera formations. The last episode of the inner caldera collapse evolution is dated approximately 92,000 years ago and was proceeded by resurgent magmatic activities involving phonolitic eruptions (Dunkley et al., 1993).

The most recent activities in the BVC area involved the 1921 eruption of basaltic lava flows of Teleki’s and Andrew’s cone located north and south of Kakorinya caldera respectively. The oldest rocks (pre-caldera formation) in the area are associated with development of Kakorinya edifice dated at about 0.2Ma (Dunkley et al., 1993).

Sigurdsson et al. (2000) classify the BVC as a shield volcano with a Volcanic Explosivity Index (VEI) of 3 whose most recent eruption, and latest one in Kenya, was in 1921. They additionally point out that seven eruption episodes within the BVC area preceded the 1921 event, all with a VEI≤3. These occurred in the years 1871, 1888, 1895, 1897, 1906, 1917 and 1920.
2.3 Previous Works

BVC is one of the least studied geological terrains along the Kenyan rift. A team from the British Geological Survey (BGS) in the early 1990s are credited to providing a berth of geoscientific information on this area including the structural and geological frameworks as well as gas/fluid geochemical mapping and geothermal mapping, albeit on a regional scale. Dunkley et al. (1993) illuminated and provided crucial evidences in the potential of BVC to harboring geothermal potential especially around the Kakorinya caldera.

More recently, the Kenyan Paraastatal Geothermal Development Company (GDC) conducted geological, geochemical and geophysical surface exploration surveys in 2011 at the BVC. The main objective of conducting this activity was to assess the presence, extent and resource potential using available scientific techniques in an aim to qualify the prospect for further exploration through drilling. The activity was in line with part of GDC’s mandate to develop geothermal resources in Kenya. Similar to the BGS study, GDC’s results indicated the existence of a geothermal resource at the BVC.

3. Materials and Methods Used in the BVC Surface Exploration

3.1 Geology

3.1.1 Fieldwork

Prior to the exploration program, a reconnaissance fieldwork had been conducted to assess the topographic profiles, identify possible traverse networks and familiarize with the weather conditions. Desktop studies were conducted and these involved a review of previous works on the study area, such as Dunkley et al. (1993) and GDC (2011). Other geological reports studied were sourced from the Mines and Geology Department of the Ministry of Mining. These included Walsh and Dodson (1969).

Maps and satellite imagery were analysed to help decipher the geological structures influencing groundwater flux. In addition, Digital Elevation Models (DEM) from a high-precision LiDAR survey that OEL had earlier conducted were analysed to identify the local and regional structural trends. Available hydrogeological data was employed to comprehend the general aquifer parameters and characteristics in the BVC.

A technical review meeting involving OEL, ISOR and KenGen was held before the start of the 30-day geoscientific fieldwork to discuss on the general approaches to be employed. Out of the 136km² BVC license area, OEL prioritized an area of 67km² for the surface studies. This was primarily because it was the most prospective resource area given its location in the central Kakorinya caldera as detailed in previous reports and data.

Moreover, the one-month time allocation of the activity for the initial exploration phase would be well utilized in this smaller but high-potential geothermal area. By utilizing this exploration strategy, OEL would be able to expand its geothermal development organically throughout its license area.

The approach employed for geological and structural mapping included; measurements of fault attributes (to understand the orientation and relationships of different structures that might have an influence on the geothermal resource), description of geothermal manifestations (to plot and understand their correlation to structures and geophysical aspects with relation to a geothermal existence), sampling of rocks and clays (to understand the mineralogical signatures critical to determining a geothermal system), descriptions of
lithological units (to understand stratigraphy and the geological makeup of the BVC) and fault kinematic analyses that are important in discovering blind geothermal systems (Mwania et al., 2019).

During fieldwork, litho-structural data was collected along planned traverses and recorded on field note books. For ease of complementing field mapping observations with the existing detailed map by Dunkley et al. (1993), locational data was recorded using the Arc 1960 UTM 37N coordinate system. This would be transferred daily in the Microsoft Excel format and plotted as points in ArcGIS.

3.1.2 Sample Analysis

As standard procedure, clay samples were first analysed at the BVC site to determine their in-situ physical properties. They were dried during field work and taken to an XRD laboratory for clay analysis thereafter. Analyses were carried out using the Shimadzu equipment. The PowDLL software was used to convert the XRD Shimadzu Raw data type to Brucker type while the DiffracPlus EVA software displayed and evaluated the peak graphs of different clay types (Mwania et al., 2019).

In the rock petrography sections, confirmation of rock types, alteration minerals and alteration mineral sequences were determined. Thin sections were analyzed at the KenGen’s petrographic laboratory, using the Olympus BX51 and Leitz Wetzlar petrographic microscopes with a magnification range of between 4x and 50x.

3.2 Geochemistry

3.2.1 Fieldwork

Previous BVC geochemical data was reviewed and compared with the subsequent field and laboratory results conducted by KenGen. The historical works that were used included Allen et al. (1989), Dunkley et al. (1993), Darling and Talbot (1991), GDC (2011) and Auko (2013). The studied data set according to Wafula and Kamunya (2019) included major aqueous cation components (Na, K, Ca, Mg, Fe, Al and Li), major aqueous anion components (SO$_4$, Cl, F, and HCO$_3$), gas components (CO$_2$, H$_2$S, CH$_4$, H$_2$, N$_2$, O$_2$, He and Ar) and isotopes ($\delta^{2}$H, $\delta^{18}$O and He).

The methodology adopted for geochemical survey and sampling was three-fold (Wafula and Kamunya, 2019), and the overall objective was to obtain surface composition of the fluids in the BVC geothermal system and use the information to determine subsurface temperatures, fluid origin and flow direction. The first of the three involved sampling of non-thermal fluids which were cold springs, domestic water boreholes and lake waters. The second was sampling of thermal fluids; hot springs and fumaroles, where the steam and gases associated with the steam were targeted in the latter. Sampling of the surface fluids was carried out in accordance with procedures for sampling geothermal fluid as outlined by Ólafsson (1988).

The third, soil gas survey, was done by measuring concentration of two gases; CO$_2$ and Radon-222. The CO$_2$ flux rate to the surface was measured. An Orsat apparatus was used to sample % CO$_2$, Durridge 7 radon meter for Radon-222 measurements and a West Systems Gas flux meter equipped with a CO$_2$ sensor for the CO$_2$ flux rate.

% CO$_2$ in the soil gas was measured in the suitable predetermined E-W grid of 500m by 1000m. Survey points were established in a map of the area using the ArcGIS software and their coordinates extracted from the map. Reading of the grid-established 155 % CO$_2$ soil gas
points would be followed by measuring the concentration of Radon-222 in the soil at the same location using the Durridge 7 radon meter. Soil temperature measurements were also done in the same sample sites as the %CO₂ and Radon-222 measurements by means of digital thermocouple with a 1m long K-type probe (Wafula and Kamunya, 2019).

Diffuse CO₂ soil flux measurements were carried out to delineate permeable fractures. The survey was conducted within a rectangular grid covering 67km² in an E-W traverse that cut across the structural orientation of the BVC, mostly covering the high potential area including the Kakorinya caldera. A 1000m (line spacing) x 50m (sample spacing) grid was established, running approximately 10 km E-W, and designed to lie between the CO₂ and Radon traverse lines. 1,138 soil flux measurements were recorded, including infill points that were done within the high potential caldera area to finely define the anomalous area.

3.2.2 Sample Analysis

Liquid samples from hot and cold springs, lakes and steam condensate from fumaroles were obtained for determination of pH, SiO₂, B, Na, K, Ca, Mg, Fe, Al, Cl, F, CO₂, H₂S, and isotopes (δD and δ¹⁸O). Dissolved H₂S in the liquid samples was analysed on site by Hg-precipitation titration using dithizone as an indicator whereas pH and CO₂ was analysed in the laboratory using a combination of electrode and modified alkalinity titration (Wafula and Kamunya, 2019).

Concentrations of major cations (Na, K, Ca, Mg, Al, Li and Fe) were determined using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES). SiO₂, B, SO₄ and Cl <5ppm was analysed using Ultraviolet-Visible Spectroscopy (UV-Vis). F was analysed using ion selective electrode while Cl>5 ppm was analysed by titration with silver nitrate with potassium chromate indicator. CO₂ and H₂S collected into gas flasks were analysed using modified alkalinity titration and Hg-acetate precipitation titration respectively, with dithizone as an indicator while H₂, CH₄, N₂ and O₂ in the headspace were analysed using gas chromatography.

3.3 Geophysics

3.3.1 Fieldwork and Data Analysis

OEL carried out the geophysical survey as part of its surface exploration programme given the discipline’s role in delineating the extent of a geothermal resource through measurements of earth’s physical properties. These have been established to infer parameters that point to sub-surface temperatures, fluid content of rocks and structures that influence the occurrence of a geothermal system.

The measurements were carried out using three techniques; electromagnetic resistivity surveys (magnetotellurics (MT) and transient-electromagnetics (TEM)) to infer the temperature and fluid content of the rocks of the geothermal system, gravity surveys to delineate the spatial density variation that assist in understanding heat source and micro-earthquake monitoring for studying sub-surface tectonic activities (Omiti et al., 2019).

As with the geological and geochemical studies, previous works were important in guiding the geophysical surveys. In this regard, publications on the regional and local areas were reviewed. These included Dugda et al. (2005), GDC (2011), Keller et al. (1994), Pointing et al. (1985), Perez and Mayra (2018), Simiyu and Malin (2000), Foulger (1982) and Dunkley et al. (1993).
49 MT soundings were acquired in the BVC study area using the Phoenix MTU-5A equipment and processed using the manufacturer’s Synchro-Time Series Viewer program (SSMT2000 program). Static shifting of MT data was corrected by carrying out TEM soundings for a one-dimensional (1-D) joint inversion of both data sets. In total, 49 TEM soundings were collected in close proximity of the MT stations using a Zonge GDP32 system.

As explained by Omiti et al. (2019), the raw TEM data was processed by the TemxUSFZ program for Zonge data while 1-D inversion was carried out using the TEMTD program. The designed two-dimensional grid upon which the resistivity soundings were based comprised of 7 E-W line profiles and 8 N-S line profiles. A remote reference station was located at about 43 km from the BVC.

In the second methodology, a CG-5 Scintrex Autograv gravimeter was used to acquire 135 gravity readings in the field at regular interval of 1 km along the proposed cross-traversing, 9 E-W profiles. Location data was acquired and referenced to a local base using the Arc1960 datum. Gravity data processing involved algorithmic calculations to correct for instrumental drift, mean gravity measurement, latitude, free-air, terrain and Bouguer effects. The Bouguer anomaly was obtained by applying all these corrections.

The third technique involved the deployment of a five-station micro-earthquake monitoring network to record the seismic activity of the area (Omiti et al., 2019), which was comprised of REFTBEK 151B-30sec three component broadband seismometers, GPS and a data logger. Data acquisition was set on continuous recording at a sampling rate of 200 samples/second (200/1). Servicing and data retrieval from the loggers was carried out on a weekly basis (Omiti et al., 2019).

The REFTBEK data would be downloaded directly from the memory card into the PC and then converted from the rt-format to miniseed-format. The miniseed waveform data would be checked for data quality using the PQL II program and later archived into the Seiscomp3 programme for interactive processing and analysis.

3.4 Data Quality

OEL put controls in place to ensure that the collected geological, geochemical and geophysical information and processed data was of the highest standard and would neither undermine the integrity nor decisions of the entire program. In addition to ensuring that sample analyses and data collection/processing were aligned to the agreed industry conventions, measures were taken to calibrate the various KenGen equipment before commencing the exploration program. OEL carried out a physical audit of these equipment and sought for their inspection certificates to ascertain that they were in good working condition.

Furthermore, it was also ensured that all the personnel involved in data handling at the different stages of the project (field to laboratory) were of the desired experience. ISOR supervised the entirety of KenGen’s scope of work and spent a few days in the field observing the data collection activity. They also maintained quality assurance/quality control (QAQC) by running selected test-samples in their Icelandic laboratory and comparing the results to KenGen’s output. All the data was found to be coherent.
4. Results of the BVC Surface Exploration Programme

4.1 Geological and Structural Mapping

Rocks in the BVC area can be classified on their eruptive episodes as follows; pre-caldera, syn-caldera and post-caldera formations. The most recent activities were the eruption of basaltic lava flows from Teleki’s and Andrew’s cones to the north and south of the Kakorinya caldera respectively. The pre-caldera formation includes trachytes and associated pyroclastic deposits.

Brecciated tuffs, welded tuffs and trachytes largely comprise the syn-caldera formation, and these were mapped northwest of the outer Kakorinya caldera. The post-caldera formation was formed after Kakorinya caldera collapse and constitutes trachytes, basalts, mugearites and phonolites dated between 0.05Ma to recent (Mwania et al., 2019). Lithological mapping was consistent with the work conducted by GDC (2011) as shown in figure 5.

![Figure 5: Simplified geological map of the Barrier Volcanic Complex. The dashed red outline shows the priority area within the BVC license where geological mapping and other geoscientific investigations were carried out. Map adopted from Dunkley et al. (1993).](image)

Evidence of hydrothermal activity was confirmed through the observation of fumaroles, hot altered ground, silica sinters, calcite precipitates and sulphur deposits on the surface (Mwania et al., 2019). These surface manifestations are prevalent in Kakorinya volcano and are key to identification of an existence of a geothermal system as they predicate occurrence of heat and thermally-mineralized fluids at shallow depth.
It was established that the study area is dominated by a framework of extensional structures namely; normal faults, tensile fractures, fissures, micro-grabens and lineaments trending in a general N-S direction with offsets to NNW-NW and NNE to NE. Normal faulting in Kakorinya volcano as shown in figure 6, is characterized by series of N-S, NNE-SSW, NW-SE and NNE-SSW trending faults (Mwania et al., 2019).

Figure 6: Structural map of Kakorinya volcano showing major structural trends and fault-controlled volcanic activities.

The NNE faults strike direction varying from 10-20°. Fractures, fissures and geomorphic lineaments are also common in the BVC. Components of the fault kinematics were studied to include fault termination patterns, multiple overlapping en-echelon faults, strike-slip shears and segregation mechanisms.

4.2 Hydrogeology

The bulk recharge in BVC is largely supplied by deep groundwater circulating system that has a direct bearing to deeply incised listric faults. Mwania et al. (2019) posit that thermal waters from the flanks are largely channeled towards the main rift graben by lateral fault system. Other possible limited sources of groundwater component include local infiltration and axial flows of meteoric waters which may not have hydraulic linkage with deep geothermal reservoir.
4.3 Geochemical Sampling and Surveys

Soil-gas data including both CO₂ concentration and flux, Radon-222 and temperature were jointly interpreted to delineate anomalous areas and possible up-flow and outflow zones (Wafula and Kamunya, 2019). The highest %CO₂ concentrations are found in the inner floor of Kakorinya caldera and in the outer caldera to the west.

These are associated with the NNE faults cutting the caldera thus making them sources of permeability. Anomalous Radon (Rn) counts of 1000-3000 cpm were also mapped within the Kakorinya caldera floor and to the west of the outer caldera. High Rn counts represent high-permeability areas.

Temperature measurements indicated three populations in the data set with the most anomalous ranging between 50°C and 95°C. The CO₂ flux anomalies coincide with locally mapped fault orientations (Wafula and Kamunya, 2019). All BVC water samples were generally found to be bicarbonate-rich with some chloride content often interpreted to be produced by water-rock interaction (figure 7).

From a triangular diagram of major cations, it was deduced that thermal waters are sodium-rich whereas non-thermal waters are preferentially enriched in sodium with appreciable amounts of alkali-earth metals.

![Figure 7: Triangular diagrams of major anions for the water samples from BVC area. Modified from GDC (2011).](image)

4.4 Geophysical Measurements and Soundings

The 1-D joint inversion of the MT and TEM results defined a conductive layer (clay cap) as the most dominant feature beneath the top of the unaltered formation therefore providing a useful indicator of the location and extent of the underlying higher temperature reservoir (Omiti et al., 2019). Geo-electric sections from the resistivity survey indicated an extensive conductive layer with varying thickness across the caldera with the thinnest and shallowest zones occurring at the eastern boundary of the caldera system.

The profiles that traverse the center of the caldera show enhanced conductivity beneath the central caldera (Omiti et al., 2019). By a positive correlation to the resistivity survey conducted by GDC (2011), figure 8 shows a profile at 3,000 mbsl which denotes a low resistivity anomaly in the areas Kakorinya caldera, and Likaiu to the east of the prospect.
Gravity measurements indicated the presence of deep, dense bodies interpreted to be possible localized heat sources beneath the Kakorinya caldera system. A micro-earthquake event distribution map revealed a hypocenter trend along the caldera rim with the high-magnitude event occurring at the western side of the rim, thus signaling permeable zones. Most events were on average located to a focal depth of 5 km below ground level, which marked the brittle-ductile transition zone that can be associated with the heat source.

5. BVC Geothermal Conceptual Model

Based on the findings of the exploration programme, it was concluded that a high-temperature, caldera-hosted geothermal system exists in the BVC study area, with an estimated reservoir temperature in excess of 300°C. Fracture-controlled permeability is defined by NNE-trending faults dominating the up-flow and outflow in the system. The reservoir rocks at a depth of between 2,000m and 3,000m are inferred to be fractured and highly altered trachytes whereas recharge into the geothermal system is provided by master rift faults with minor components from the axial rift flow.

6. Conclusions

Geological and geochemical data analyses and interpretation at the BVC indicated the presence of a high-temperature, caldera-hosted geothermal system with calculated geothermometry temperatures in excess of 300°C. Through geophysics, it was established that the study area is an active volcanic system defined by an intrusion-heated, shallow reservoir.
In consideration of the positive results and resource indications arising after exploration studies at the Barrier Volcanic Complex, it was recommended that exploration drilling be carried out to further evaluate the potential of the area. Four well site locations were identified, guided by the integrated geoscientific data.

The drilling activity will take a phased-approach with spudding of the first well in 2021, such that the performance of the first priority well will inform subsequent drilling targets. Olsuswa Energy remains optimistic that the success of exploration drilling will usher in production drilling in the not-so-distant future.

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