Magmatic degassing at East African Rift volcanoes: evaluating geothermal resources and hazards

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Key Words

volcano; rift; geothermal; hazards; geochemistry

Overview

Volcanic calderas represent major geological hazards, and yet many also host significant untapped geothermal resources. The East African Rift system (EARS) hosts numerous large (>10 km diameter) silicic calderas, and unlike similar-sized volcanoes in developed nations, none of the EARS calderas are permanently monitored (Hutchison et al. 2016). This a major problem because many of these calderas also host large hydrothermal systems and thus recoverable geothermal energy resources (which could bring tremendous economic benefits to the region).

Ethiopia is particularly well endowed with geothermal resources (Younger, 2014). The country's economy is also growing rapidly and there is a great demand for increased energy access and development of these resources. One of the best geothermal energy prospects (Fig. 1) is the Abaya Volcanic field in the southern Main Ethiopian Rift (Fig. 1). Surface exploration by Reykjavik Geothermal suggests that there is a massive recoverable resource (on the order of 1000 MW) potentially making it one of the largest geothermal centres globally.

Figure 1. *Field photograph of a fault scarp at Abaya Volcanic field, the focus of this PhD project. Fumaroles and surface alteration are visible in the foreground.*

While little is known of the eruptive history and architecture of Abaya, recent geophysical surveys have built up an understanding of the subsurface. Magnetotelluric imaging indicates a shallow low resistivity clay cap underlain by a large geothermal reservoir (at depths of 200–2000 m and with temperatures around 200–300 °C). Low resistivities have also been observed at greater depths (~8000 m) and are linked to melt accumulation (i.e. the magmatic heat source).

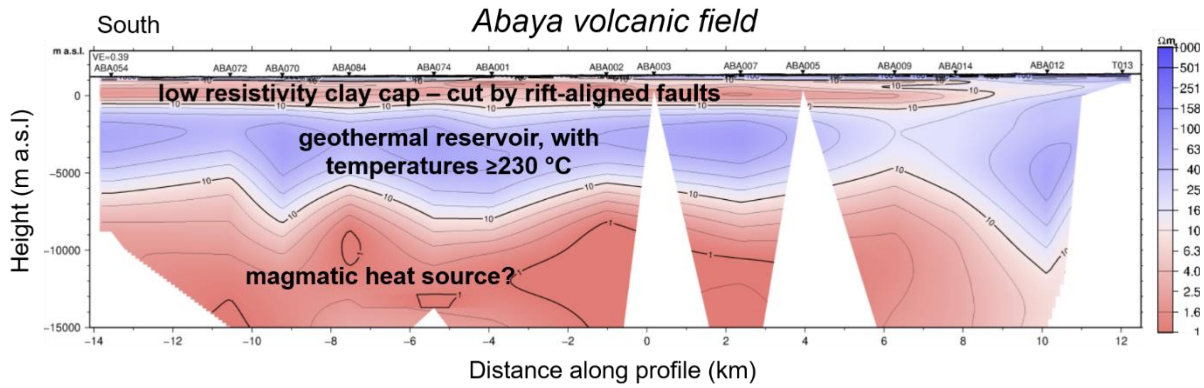

Figure 2. *Magnetotelluric models for the subsurface of Abaya volcanic field (courtesy of Reykjavik Geothermal). The observed resistivity structure is analogous to resistivity zoning observed in high enthalpy geothermal fields. The shallow layer is interpreted as a clay cap, overlying the main geothermal reservoir. The deeper structure at ~8 km is interpreted as the magmatic heat source for the system. In this project gas fluxes and chemistry will be analysed and used to evaluate permeable structures and understand fluid origins and evolution.*

Although these surveys provide useful insights into the architecture of the magmatic-hydrothermal system (Samrock et al. 2015), they are coarse, km-scale scale observations which cannot reveal the connectivity between magmatic and geothermal reservoirs, nor the 10–100 m scale permeable structures for drilling and long-term geochemical monitoring. The aim of this project is to use measurements of volcanic gases to illuminate the sub-surface architecture of Abaya Volcanic field and extend this knowledge to other rift-related geothermal resources in the EARS.

The main objectives of this study are:

1) **Undertake a high-spatial resolution soil-gas CO_2 survey of the Abaya Volcanic Field.** This will be used to identify high-permeability structures and determine the relative importance of volcanic vs. tectonic structures at controlling gas and fluid ascent.
2) **Geochemical characterisation of the volcanic gases.** Targeting zones of highest gas flux, samples will be acquired for bulk gas and stable and noble gas isotope analysis. Bulk gas and C, O, H and He isotopes will be used to understand gas-fluid-rock interactions within the geothermal reservoir (such as phase separation and crustal contamination). He, Ne and Ar isotopes will provide constraints on the mantle source.
3) **Build up a time-series of volcanic gas geochemistry.** The key degassing areas (from 2) will be visited several times throughout the project, either by the student or by project partners (Reykjavik Geothermal). Gas chemistry and isotopes will be analysed and used to understand whether there are temporal changes and whether these are linked to seasonal changes in the aquifer, and/or the delivery of new magmatic gases into geothermal system (Hutchison et al. 2016). Through Reykjavik Geothermal there will

be potential to analyse gas chemistry at other volcanoes such as Tulu Moye and Corbetti.

4) **Compare the gas flux to other rift volcanoes.** It is unclear whether gas flux (e.g. CO_2 emission) and chemistry varies between different rift volcanoes. The final objective of this project is to calculate the C flux from Abaya and evaluate how this compares to other rift volcanoes (e.g. Aluto, Corbetti and Tulu Moye, Hutchison et al. 2015). This will improve estimates of the C flux during continental rifting and will allow us to explore how variable gas emissions are in different magmatic systems.

We expect the project to provide valuable new insights into the origins and migration of gas and hydrothermal fluids through highly fractured rift volcanoes. It will be of wide interest to volcanologists and those interested in exploring and monitoring active geothermal resources.

Methodology

Objective 1: Fieldwork and gas surveying. The CO2 flux will be measured using an infrared gas analyser use the accumulation method. Maps of soil CO2 flux will be generated from the discrete point measurements using GIS methods.

Objectives 2 and 3: Gas samples will be collected in copper tubing. Analysis of bulk gas, stable and noble gas isotopes will be undertaken at the Scottish Universities Environmental Research Centre (SUERC, with Prof. Fin Stuart).

Objective 4: We will use a sequential Gaussian simulation (sGs) method to calculate the flux maps. We will calculate the mean and standard deviations of all simulations and use this to calculate total CO2 release at Abaya and evaluate the associated uncertainty (Cardellini et al., 2003). Re-analysis of CO2 flux at other rift volcanoes (Aluto, Tulu Moye and Corbetti) will also be conducted and used to provide robust estimates of C release from the Ethiopian Rift.

Timeline

Year 1: Literature review, fieldwork in Ethiopia and gas surveys. Training in CO2 flux instrumentation, gas sampling and mass spectrometry methods (SUERC).

Year 2: Further gas sample collection. Bulk gas, stable and noble gas isotope analysis (SUERC). Analysis of new data, and draft initial paper(s). Present results at national meeting (e.g. Volcanic and Magmatic Studies Group).

Year 3 to 3.5: Further gas chemistry analysis at SUERC. Complete analysis of all new datasets and compare these with other gas datasets from across the EARS to evaluate gas fluxes and origins at rift scale. Focus on publication and thesis writing. Present results at international meeting (AGU, EGU and/or Goldschmidt). Finalize written manuscripts and write thesis.

Training & Skills

This project would suit a student with an excellent BSc/MSc geoscience background and interests in magmatic processes, rifting and geochemistry. Previous field work experience in Africa is advantageous but not essential. The student will gain new expertise in soil gas surveys, gas sampling and geochemical analysis. They will be working with experts in these techniques (Hutchison et al. 2015; Györe et al. 2015) and will be trained in all field, laboratory and remote sensing techniques. They will also gain transferable skills such as scientific writing, statistics and data analysis, and problem-solving, as well as time management and working towards a long-term goal.

The student will join a burgeoning volcanology group at St Andrews and will interact with the St Andrews Isotope Geochemistry Group (StAIG). They will also make frequent visits to SUERC and form strong collaborations with Prof. Stuart's gas geochemistry group. This will develop complementary research skills and widen their network of collaborators. They will be encouraged to attend major international conferences (e.g. AGU and Goldschmidt) and present their research.

References & Further Reading

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