Sulfur Geochemistry of Igneous Rocks from the Central Kenya Peralkaline Province, East Africa Rift

Peter A. Omenda, Nicholas Mariita, Joel Muhanga, Anthony Marrufo, Benjamin Brunner, Elizabeth Y. Anthony
Geological Setting

• The Kenya rift is a classical “continental rift” measuring 30 – 60 km diameter and extending from MER to northern Tanzania

• Volcanism includes basalt – trachyte – rhyolite systems (central volcanoes)
Study area

- Focus area include the following:
  - Olkaria
  - Eburru
  - Menengai
  - Suswa
- The volcanoes are trachyte – rhyolite suite and are also important geothermal prospects
- Rock samples were used in the study
Why use Sulfur Isotopes?

• Sulfur species are often abundant in magmatic systems
• Sulfur behaves as an incompatible element during magma fractional crystallization processes
• Common stable isotopes of sulfur ($^{34}\text{S}, \ ^{32}\text{S}$) are good tracers

• Fractionation of the species depends on”
  – Fugacity of oxygen ($fO_2$) in the magma melt
  – Exsolution of SO$_2$ from magma during its evolution, ascent, and storage
  – Molecular weight of the sulfur species
Sulfur Isotope Measurement

Pyrocube and IRMS setup

• The High Temperature Elemental Analyzer is on the left, and this is where our samples are dropped and combusted. Water traps are also shown.

• In the middle, copper tubes allow the SO$_2$ gas to travel to the Isotope Ratio Mass Spectrometer, important parts such as magnet and collector are also depicted.

• Data is analyzed on the desktop computer. Five different gases (H$_2$, CO, N$_2$, CO$_2$, SO$_2$) can be monitored using this set up.
Data for comparison:

- **Mount Etna** is an active stratovolcano on the east coast of Italy. It lies above the convergent plate margin between the African Plate and the Eurasian Plate.

- **Krakatau** is a strato-volcano situated in the between the islands of Java and Sumatra in Indonesia.
Graph showing the sulfur concentration (x-axis) and isotope composition (y-axis) of samples collected from the volcanoes in the Central Kenya Peralkaline Province.

- Error bars are depicted to show two standard deviations for sulfur concentration and isotope composition.
- Standardized against Vienna-Canyon Diablo Troilite (VCDT)
- Mount Etna is shown as a square shape for comparison.
Results - 2

- The samples from Suswa and Longonot have high sulfur concentrations but low $\delta^{34}S$ within range of Mt Etna volcano
- Eburru has low Sulfur and low $\delta^{34}S$ concentrations
- Olkaria and Menengai lavas have low sulfur concentrations and high $\delta^{34}S$ similar to Krakatau
Interpretation - 1

• The sulfur content is explained by magmatic differentiation from a mafic, mantle-derived magma during which sulfur, as an incompatible element, increases in concentration.

• The shift to higher $^{34}\text{S}$ for Olkaria and Menengai, may be the result of magmatic outgassing, as interpreted for a similar trend for samples from Krakatau.

• Possible influence of crustal anataxis could also be a factor at Olkaria and Menengai.
Interpretation - 2

- The shift to higher $\delta^{34}$S would require that the magma-fluid system experienced a high oxidation state ($fO_2$) in the magma chamber during closed-system crystallization at low pressure.

- Associated decrease in temperature resulting in increased Sulfate/sulfide ratio in the magma.
The highly oxidized state of the magma reflects sudden degassing of volatile phases associated with instantaneous, irreversible, transient degassing of the magma chamber.

This is postulated to occur during periods of sudden decompression induced by fracturing of the volcanic edifice associated with paroxysmic activity and edifice collapse.
The Conceptual Model

Model based on Deep well cross-section and model of Aluto magmatic-hydrothermal system (Hutchinson et al., 2016):

- This sketch of a magmatic-hydrothermal system shows the exsolution of sulfur dioxide gas from a magmatic chamber.
- Ensuing sulfur disproportionates once the gas comes in contact with groundwater.
Implications

• In SAR images: Interferometric Synthetic Aperture Radar. Overlay multiple SAR images. Elevation changes are recorded as a change in phase of satellite radar signal.
• For example: 21 cm uplift of Paka (2006-2007).
• These data, along with geophysical and drilling data constrain the depth to the magma chamber. Best fit: Horizontal “penny-shaped” crack at 2-5 km.

Biggs, Anthony, Ebinger, 2009, Geology 37, 979-982.
Future Studies

- This hypothesis, although intriguing, requires additional data for interpretation. A principal focus of our ongoing research is to evaluate these complex magma-fluid processes and pathways.

- Our goal is to elucidate whether the variations are more closely correlated with the caldera structures or the north-south trending faults that cut through the area.

- Further analyses will elucidate the 3-D distribution of magmatic and meteoric fluids and the pathways for their mixing and upwelling.

- Analyses of \( ^{34}\text{S} \) for gas and water samples will be undertaken for fluid samples at geothermal wells at Olkaria, Eburru and Menengai to provide further information.
Acknowledgments

We would like to thank Levi Shako of Geothermal Development Company Ltd for help with the GIS project and Sadock Josepha and Douglas Onyancha for very helpful reviews of the manuscript.