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Characterization of the Natron Geothermal System: Rift Basin Dynamics and Volcanic Influence

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INTRODUCTION

The Natron geothermal prospect, located in the Arusha Region of northern Tanzania, represents a significant target for geothermal exploration due to its complex tectonic setting and active volcanism. This prospect is being developed by the Tanzania Geothermal Development Company (TGDC), with preliminary studies conducted to create a conceptual model that will guide further detailed resource investigation and development.

The Natron Basin is characterised by recent volcanic and fluvial deposits, underlain by pyroclastics, trachyte, nepheline-carbonatite, and basaltic lava flows. Rift faults and volcanic features structurally define the area, particularly the Oldoinyo Lengai and Gelai volcanoes, which serve as the main heat sources for the geothermal system. The geothermal manifestations include hot springs with temperatures ranging from 45 to 55°C, and pH levels above 10.

Preliminary findings indicate that the reservoir is hosted within fractured basaltic units and volcanic sediments. The Gelai dyke, which is over 10 km long and associated with the 2007 Oldoinyo Lengai eruption, is considered a significant heat source. The Natron geothermal system is a magmatic, medium- to high-temperature reservoir associated with deep crustal heat sources and fault-controlled permeability. This geological framework underscores Natron's potential for geothermal energy development and and supports the need for undertaking detailed geophysical, geochemical, and resource confirmation (test drilling) programs.

METHODS

- Preliminary Geological Mapping: Field observations from the recent geological mapping conducted by TGDC in the Natron Basin, located in northern Tanzania underscore significant interest due to further exploring the geothermal resource in the area. Several key observations from the field highlight both geological and geothermal processes that characterize the area, providing valuable insights into the dynamic geothermal system. The rift valley's walls are formed by numerous basalt flows, which are steeper on the recently faulted western margin. Along the shores of Lake Natron, at least 20 warm saline springs with temperatures ranging from 32-52°C and flow rates between 30-300 l/s are present.

- Literature Review: The previous exploration efforts related to the Natron geothermal prospect, as discussed in this chapter, encompass the findings from reconnaissance surveys carried out by SWECO in 2005 and JICA in 2014 highlighted the following results; The geology surrounding Lake Natron is primarily dominated by Cenozoic volcanic activity, with basalt lava flows and more viscous alkali volcanics. The chemistry of the spring water in the area is heavily influenced by carbonatite volcanism. As a result, the spring water has an alkaline composition, with a pH range of 9-10 and a significant NaHCO3 content.The Silica thermometers show temperatures ranging from 69-140°C (SWECO 2005), while the Na-K-Ca thermometers report values between 159-172°C (JICA 2014) and 159 -257°C (SWECO 2005) respectively.

RESULTS

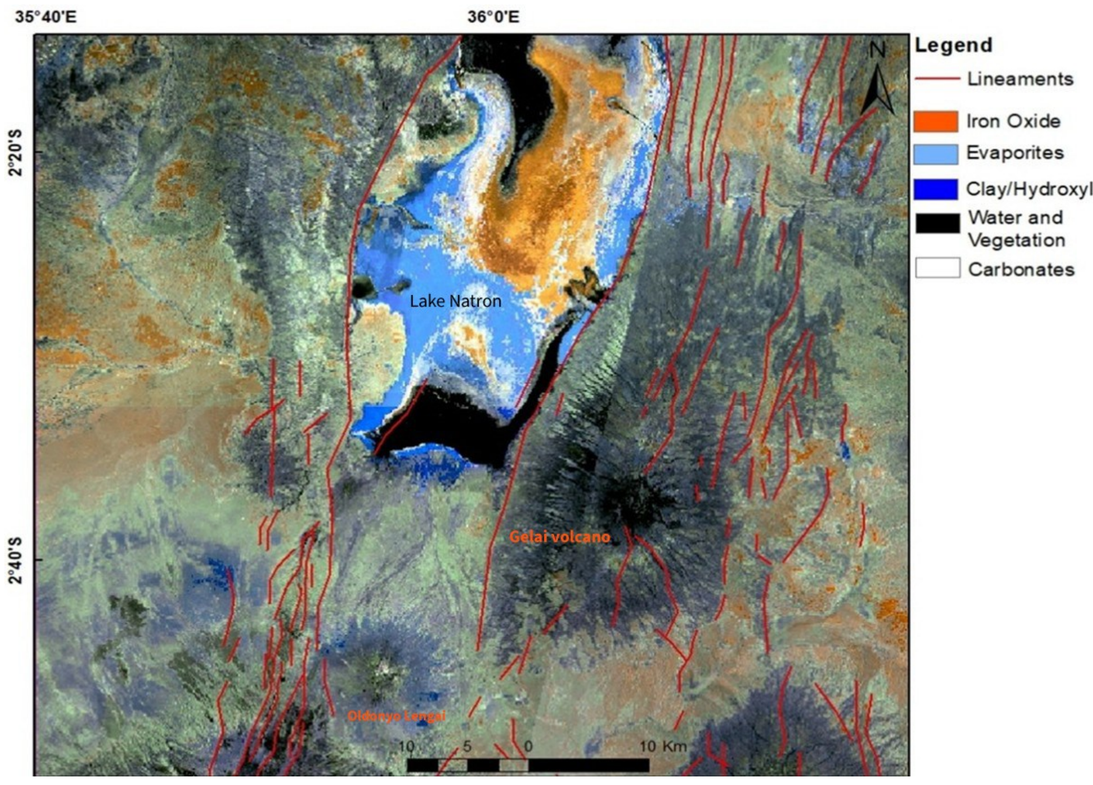


Figure 1: Digital Elevation Map (DEM) of the Natron basin showing hydrothermal alterations , rift scarps and Lineaments

The topography of Natron Prospect is largely controlled by its geological position, which includes volcanic eruptions and rifting/tectonic movement. It is regionally located in the Northern Tanzania Divergence zone of the EARS, which developed due to complex tectonics. The high relief is dominated by steep volcanoes, depositing pyroclastic materials, composed of nepheline-carbonatite lava and soda ash. Gelai and Oldoinyo Lengai are the major volcanic mountains and probably are the recharge areas for the Natron geothermal system (Figure 1). Several other eruption centres form part of the lowland of the Natron basin. The hot springs along the western escarpment exhibit significantly higher temperatures, often exceeding 45–55°C in contrast to the hot springs in the eastern segment of the basin, where the temperatures are generally lower, below 45°C.

The Natron Basin has two prominent volcanic features namely Oldonyo Lengai and Gelai volcanoes. Oldonyo Lengai, in particular, is a well-known active volcano in the region, renowned for its unique natrocarbonatite lavas, which are rich in sodium and potassium carbonates. Both of these volcanoes serve as significant heat sources for the geothermal system, whereas the Gelai dyke (Lava pipe) which is located 10km south of the Gelai volcano is likely the driving heat source that contributes to the overall thermal budget of the basin, enhancing the geothermal gradients observed in the hot springs (TGDC, 2024). The Gelai dyke, which is 50cm wide, trending 45-50°N direction is believed to occur contemporaneously with the Oldoinyo Lengai eruption in 2007.

Major structural features associated with the western border faults are typically truncated by lake sediments or terminate at the foot of the escarpment. These structural elements, including fault lines and associated fractures, are part of the larger tectonic framework that governs the rifting process within the East African Rift System .

DISCUSSION

The current understanding of the geothermal activity suggests that the Natron prospect is a magmatic, medium to high-temperature system, associated with a 10 km long dyke intrusion located south of Gelai volcano (TGDC, 2024). The estimated resource temperature in the Natron prospect based on Na-K-Ca geothermometers range from 159 °C to 257 °C. It is however likely that shallow cold water flow contaminate the deep-flowing thermal waters. This cools the up-flowing and out-flowing thermal waters, lowering the hot springs' discharge temperatures.

The thermal waters in the Natron prospect have been classified as NaCl-HCO3 type based on the anions and cations triangular plots. This composition has been interpreted as the intermediate depth reservoir and is fully matured waters based on the Giggenbach triangular diagram (SWECO, 2005, JICA 2014).

Generally, the Natron prospect represents a geologically complex and active region, shaped by a combination of fault dynamics, volcanic activity (basaltic and carbonatitic lava flows), and hot springs highlight distinctive geological environment and underscore the dynamics geothermal system. As TGDC prepares to advance geothermal development in the Natron prospect, detailed exploration program is recommended to be undertaken involving both classical and high-resolution satellite images to delineate geological structures (e.g., LiDAR/InSAR), detailed volcanology studies, MT/TEM resistivity surveys, and detailed geochemical surveys, i.e., CO2 flux and Radon.

CONCLUSION

In conclusion, based on the recent survey and existing literature, the following geological findings can be highlighted to characterize the Natron geothermal system;

- The Natron Basin is primarily covered by fluvial and lake sediments, with consolidated soda ash and trona deposits, resulting in limited surface evidence of rock or mineral alteration.
- Basement rocks, which are overlain by basaltic and carbonatitic lava flows, are prominently exposed along the scarps of the western and eastern border faults that define Lake Natron.
- The western fault escarpment is likely a key mechanism for both the recharge and outflow of the Natron geothermal system.
- Hot springs discharge along the footwalls of the border faults and the shoreline of the lake, with no evidence of hot springs within the lake floor.
- Hot springs in the western escarpment of the Natron Basin exhibit higher temperatures (T > 45–55°C) compared to those in the eastern segment, where temperatures are generally lower (T < 45°C).
- The hot spring waters are highly saline, with a pH >10, and are seasonally flooded by lake waters during periods of high rainfall.
- Major structural features along the western border faults are either truncated by lake sedi-

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