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Harnessing Geothermal Energy in Antsirabe: A Path Towards Sustainable Development

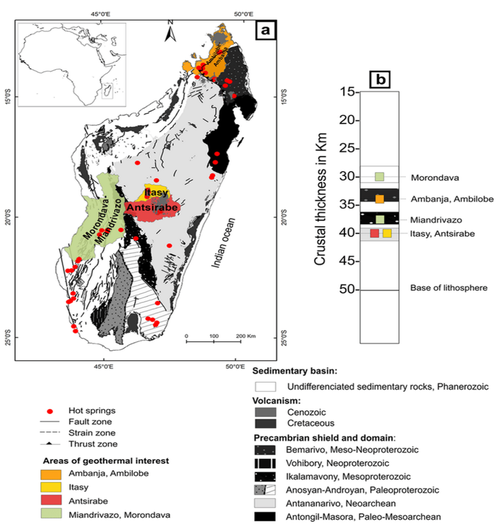
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INTRODUCTION

Madagascar hosts **ten geothermal regions**, categorized into **volcanic terrains, faults zones and sedimentary basins.** Two main geothermal system types can be distinguished: (1) Magmatic systems, heated by underground magma and (2) Extensional systems, controlled by tectonic fault.

Among these provinces, the **Antsirabe** region in central Madagascar stands out due its complex geological framework, combining volcanic formation, fractured sedimentary sequences, and active tectonic structures. Geochemical and geothermometric date indicate reservoir temperatures ranging between **75° C** and **152°C**, corresponding to estimated depths of **2.4-5.5 km**. Despite its potential, the Antsirabe geothermal field remains **under explored and under documented**. This study aims to characterize the **geological and structural controls of geothermal circulation** within the Antsirabe basin and to provide a scientific basis for **sustanaible resource valorization** in Madagascar's energy transition.



Modified from Roig et al., 2012; Tucker et al., 2014; Besairie, 1959; Gunnlaugsson et

METHODS

All Investigations at Vohimalaza (site 1), Ivohitra (site 2) and Mandray mountain (site 3) in the Antsirabe regions, focused on their structural and hydrothermal features within the Ankaratra volcanic system, integrating complementary field and remote methods:

(1) Geological mapping: Spatial distribution of the rock

(2) Structural observations: Measured faults and fractures (Orientation, connectivity and density)

(3) Drone photogrammetry: captured high resolution image 3D topography; Geolocated sampling point and suface manifestation

(4) Integration/3D modelling: Data will feed into a preliminary 3D geological and geothermal model; model visualize reservoir, fluids pathways and heat transfers mechanism.



Study area and investigated sites in the Antsirabe region

PRELIMINARY RESULTS

1-Field observation:

Initial investigation at Vohimalaza, Ivohitra and Mandray reveal constracting lithologies shaped by volcanic, sedimentary and tectonics interactions. Outcrops show variables degrees of fracturation, alteration and permeability., which directly influence fluid circulation.

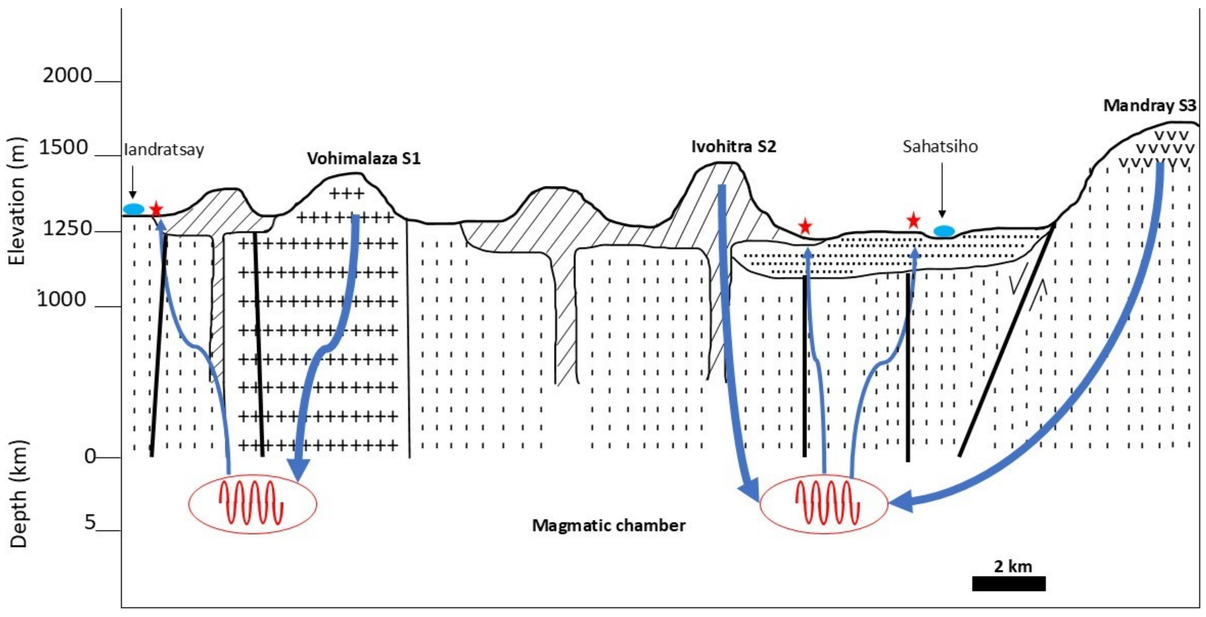


Figure 1. Conceptual geological crosse-section of thermal recharge in Antsirabe region

2– Structural analysis:

Fault and fracture mapping reveal a **dominant N–S structural trend**, with **secondary NW–SE orientations** that may correspond to reactivated older structures, consistent with the complex tectonic setting of the Ankaratra region. Measured fractures show high connectivity within volcanic units, indicating efficient pathways for fluid flow, while sedimentary layers display more localized fracture networks. Several structures exhibit signs of reactivation, supporting ongoing geothermal circulation

3– Hydrothermal signatures by sites:

Hydrothermal signatures identified at multiple site:

Site 1 Vohimalaza: no surface manifestation but linked to hot spring discharge 3km downstream the Iandratsay river (35°C)

Site 2 Ivohitra: Red clay and volcanic residues with fractures and hydrothermal manifestations appear 2km towards Antsirabe

Site 3 Mandray: Fractured sandstone and quartz vein indicate paleo-fluid pathaways, first manifestation appear 3km downslope the Sahatsio river.

DISCUSSION

The preliminary observations from the three investigated sites reveal that the geothermal behaviour of the **Antsirabe** basin is largely governed by the **regional extensional** setting. Rather than isolated features, the mapped fractures, fault orientations and hydrothermal traces collectively point to a structurally connected system where permeability is strongly inherited from the **Ankaratra tectonic** framework.

The contrasting responses of **volcanic, sedimentary and basement lithologies** underline the importance of geological layering in controlling **fluid pathways**. **Volcanic** units act as efficient shallow conduits, while sedimentary and basement formations appear to channel deeper or older circulation. This spatial organisation supports a conceptual model where **recharge occurs** on elevated **volcanic ridges and fluids** are forced to migrate laterally and vertically along fault-controlled corridors.

The downstream emergence of **hot springs** several kilometres from the **recharge zones** suggests a system where topography, fault geometry and lithological boundaries interact to produce delayed or displaced **surface manifestations.** This behaviour is consistent with previous estimates of **reservoir depth and temperature**, reinforcing the potential of Antsirabe as a **hybrid geothermal system**.

These findings highlight the need for continued 3D structural modelling to define reservoir geometry more accurately and to support sustainable development strategies for the region's

CONCLUSION

This study provides new structural and geological insights into the **geothermal dynamics** of the **Antsirabe** basin. The results highlight the key role of **fault-controlled permeability** and **lithological** contrasts in shaping fluid pathways from **volcanic recharge zones** to downstream discharge areas. The identification of connected structural corridors and hydrothermal traces supports the presence of a **hybrid geothermal system** with both shallow and deeper circulation components.

These findings confirm the significant yet **under-explored geothermal potential** of the region and emphasize the need for continued structural analysis, 3D modelling and targeted subsurface investigations. Such work will be essential to guide future exploration strategies and to develop sustainable geothermal solutions that align with **Madagascar's energy transition** goals.

Acknowledgements

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