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3D RESISTIVITY INVERSION FOR GEOTHERMAL RESOURCE MODELLING: INSIGHTS FROM KIEJO-MBAKA GEOTHERMAL PROSPECT, SW TANZANIA.

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ABSTRACT

The Kiejo-Mbaka geothermal prospect in southwestern Tanzania is a structurally complex system comprising fault-controlled and volcanic features with promising geothermal potential. This paper presents integrated geoscientific investigations geological, geochemical, and geophysical undertaken to characterize the subsurface and guide resource development. Emphasis is placed on the application of Magnetotelluric (MT) resistivity surveys, whose 3D inversion and modeling have significantly enhanced well targeting and drilling strategies. A conceptual geothermal model was developed by synthesizing multidisciplinary datasets, enabling the strategic placement of Temperature Gradient Wells (TGWs) and Slim Wells (SLWs) for resource confirmation. MT imaging delineates the Mbaka fault system as low-resistivity sedimentary rocks to the west and high-resistivity Precambrian basement to the east. The Kiejo volcanic system exhibits a thickening low-resistivity layer eastward, likely due to sediment accumulation and/or hydrothermal alteration. Recent MT data acquired in 2022 by TGDC and Jacobs reveal a high-resistivity zone extending beyond 3 km depth, coinciding with exposed Precambrian basement. This feature suggests a clear subsurface separation between the Kiejo and Mbaka systems, potentially governed by cold, impermeable formations or permeable zones with descending cool fluids. These insights are critical for refining the geothermal development strategy in the region.

1. INTRODUCTION

The Kiejo–Mbaka geothermal prospect is located within Busokelo District in Rungwe, Mbeya Region, southwestern Tanzania (Figure 1). The area lies within the Rungwe Volcanic Province (RVP), which forms part of the East African Rift System (EARS). This region is situated at the junction of three major rift basins: the Rukwa, Usangu, and Karonga basins (Delvaux and Barth, 2010; Shillington et al., 2020; Scholz et al., 2020).

A range of geoscientific investigations has been undertaken in the prospect area, including geological mapping, geochemical sampling, gravimetric surveys, and electromagnetic studies (ELC Electroconsult and TGDC, 2017; TGDC and JACOBS, 2022). The Kiejo–Mbaka prospect is located approximately 90 km southeast of Mbeya town, along the southern segment of the Mbaka fault system within the Karonga rift basin (ELC Electroconsult and TGDC, 2017).

The prospect is considered one of the most promising geothermal areas in Tanzania, together with the Songwe–Ngozi and Luhoi prospects. These systems were identified during a national geothermal resource assessment and subsequently proposed for detailed investigation under international development initiatives (Delvaux et al., 2010; Kraml et al., 2012). In recent years, multiple collaborative projects have focused on advancing the understanding and development potential of these priority geothermal sites (TGDC, 2021; TGDC and JACOBS, 2022).

From a geothermal perspective, the Kiejo–Mbaka prospect exhibits several important characteristics. It is associated with relatively recent basaltic volcanism, particularly in the vicinity of Kiejo Volcano, indicating a potential heat source (Delvaux et al., 2010). Additionally, surface geothermal manifestations are present, including hot springs aligned along the Mbaka fault zone (e.g., Kilambo–Kajala), as well as cold gas emissions observed at Lufundo on the footwall block of the fault (Kraml et al., 2012; ELC Electroconsult and TGDC, 2017).

However, the prospect is located within an active tectonic setting of the EARS, characterized by both historical and ongoing seismicity, which reflects continued crustal deformation and fluid migration pathways (Delvaux and Barth, 2010; Shillington et al., 2020). Furthermore, the region is underlain by relatively thick continental crust, exceeding 40 km, and a deep seismogenic layer extending to approximately 35–40 km. This structural configuration suggests that major fault systems penetrate deeply into the crust, facilitating the circulation of geothermal fluids (Scholz et al., 2020; Shillington et al., 2020).

This study contributes to geothermal exploration at the Kiejo–Mbaka prospect by presenting a three-dimensional resistivity inversion model, which delineates subsurface structures and provides critical information for identifying zones with high geothermal potential.



Figure 1: The location of Kiejo-Mbaka prospect with reference to Tanzania largest city, Dar es Salaam; source, Google map.

2. GEOLOGY AND STRUCTURAL SETTING

2.1 Regional geological setting

The Rungwe Volcanic Province (RVP), covering approximately 1,500 km^2, is part of the East African Rift System (EARS). The RVP is located at the northern end of Lake Nyasa, where the EARS splits up into its Western and Eastern branches around the Tanzanian craton (Figure 2).

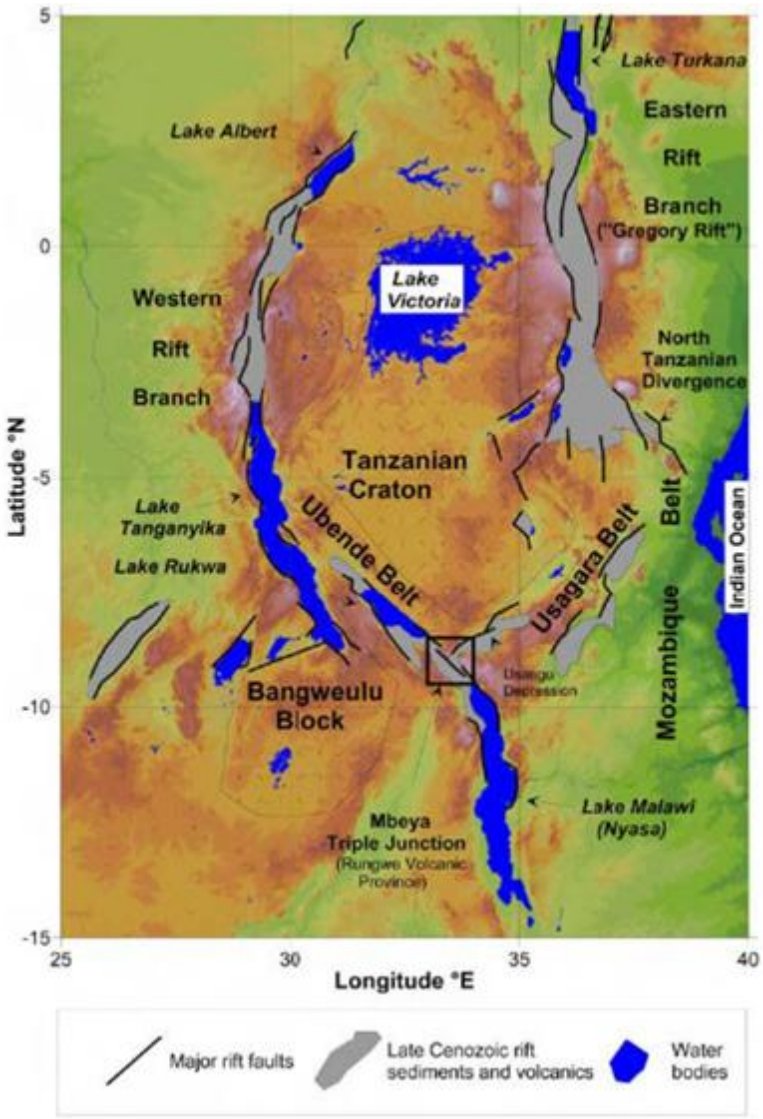


Figure 2: Location of RVP (Mbeya Triple Junction) regarding the Basement and the rift structure, on the background of colour-coded SRTM DEM (from Delvaux et al., 2010).

The project area is situated close to the triple junction of Rukwa, Usangu, and Karonga rift basins which are part of the EARS (Figure 3). The northernmost sub-basin of the Nyasa rift, the Karonga basin, is an asymmetric graben, which is limited to the NE by the prominent NW-SE trending Livingstone border fault and is affected by the intra-basin Mbaka transfer fault. The two faults have slightly different strike and are seismically active. During the kinematic rifting history, several successive phases occurred, due to the partial superimposition of a Cenozoic rifting on older Permian-Triassic and Mesozoic rift structures.

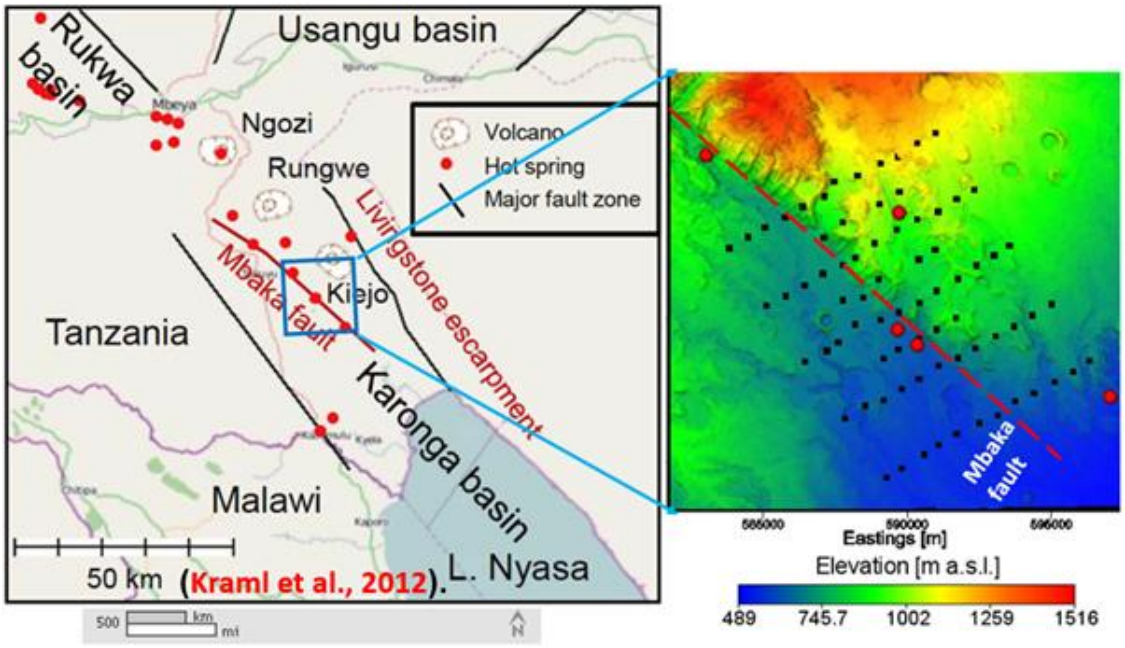


Figure 3:A major geological element of the study area (from Kraml et al., 2012). Blue square is focal area of study zoomed. Black dots are MT stations (ELC and TGDC, 2016); red spheres are geothermal manifestations.

2.2 Local geology and structure

The focus area of Kiejo-Mbaka is underlain by Pre-Cambrian products of the metamorphic-intrusive complex, consisting mostly of biotitic gneisses and schists, amphibolites and metagabbroid bodies as shown in Figure 4. The complex is sub-outcropping in the central portion of the focal area (Mbaka ridge) and is covered by a thick sequence of clastic sediments westwards and eastwards.

Several fault systems have been recognized, among which the most important ones are NW-SE and N-S. The Mbaka fault, which controls the hot spring locations and delimits to the west the Mbaka ridge, belongs to the NW-SE system and is associated with a series of vicariate parallel structures extending in the plain. The Kisyelo fault, which delimits to the east of the Mbaka ridge, trends N-S to NNW-SSE.

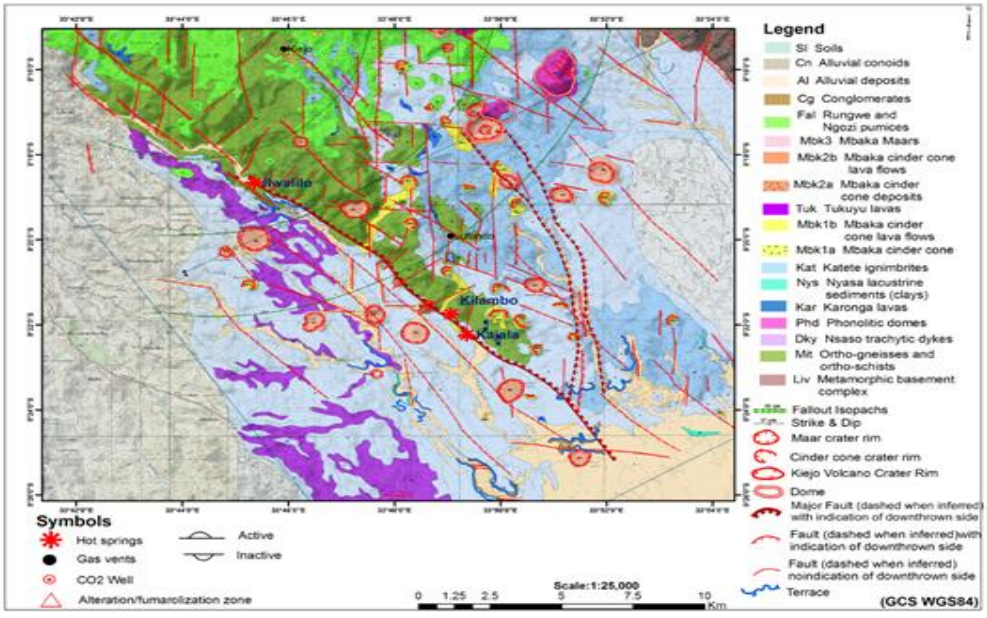


Figure 4: The geological map showing main structural features of the focal area; ELC and TGDC, 2016.

3. DATA AND METHODS

3.1 Magneto telluric survey

The magneto telluric (MT) survey was carried out in the Kiejo-Mbaka geothermal prospect in the period of September 18, 2016 to October 31, 2016 by ELC and TGDC as counterpart with a total of 76 MT stations. Followed by an addition of 84 MT stations in 2022 by TGDC and JACOBS as consultant for the program, mainly focusing on data re-processing, modelling, presentation and interpretation. This paper is not meant to detail the methodology applied, rather it enhances the understanding of the results obtained during this work. Figure 5 shows MT stations distribution for the survey campaign within the focus area of study.

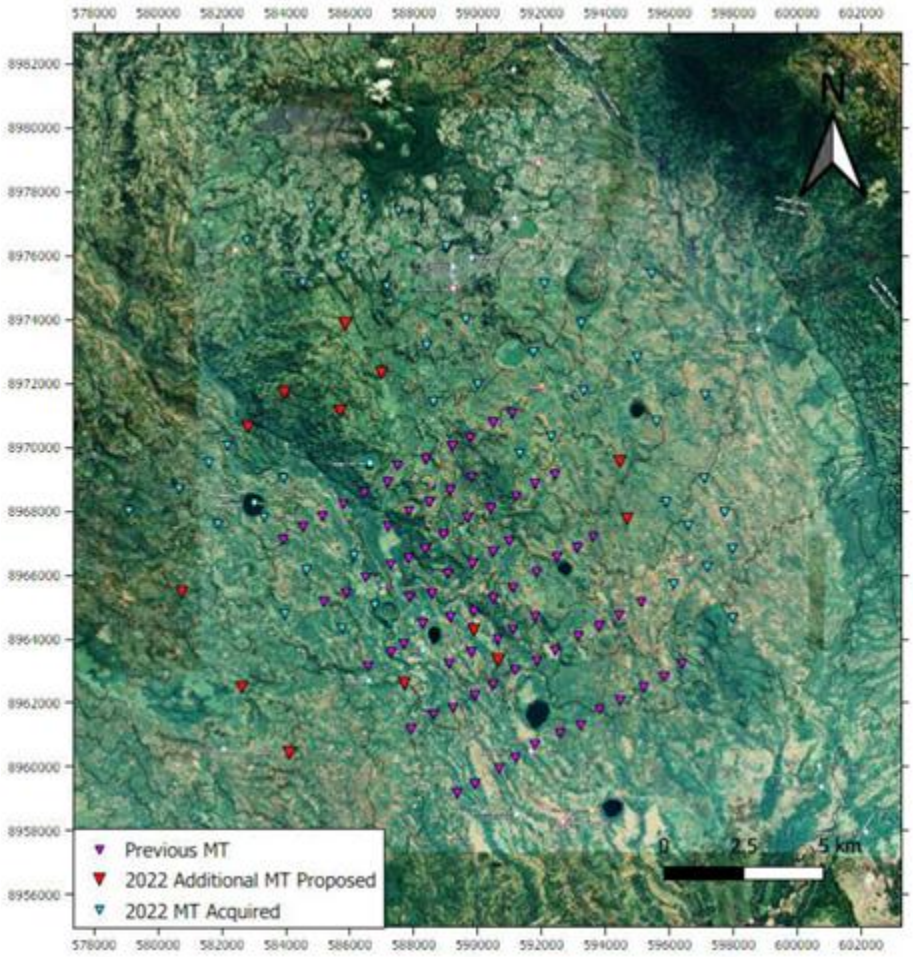


Figure 5: Map showing MT stations distribution within the study area TGDC and JACOBS, 2022.

3.2 Survey coverage

Data coverage is good for the main aims of assessing the fault system associated with hot springs and testing extent and thickness of conductor over the south side of the Kiejo volcano. It is recommended that data coverage over the Kiejo volcano be improved and infill stations acquired between Kiejo and Rungwe.

3.3 Data quality and static shifts

Data quality assessment was classified in four (4) groups (A-D). Group A to B being data with high-quality with most stations imaging the base of conductor effectively. Several low-quality stations grouped as C to D, particularly around the populated areas due to EM noise sources were observed as shown in Figure 6. Static shifts were not a major problem for the collected stations by ELC, 2016 campaign as the stations were having the co-located TEM measurements. MT stations collected by TGDC in 2022 do have static shift problems and did not include TEM measurements for static shifts correction. This introduces some uncertainty in the Kiejo volcano area however it is thought that the 3D inversion has been corrected for this.

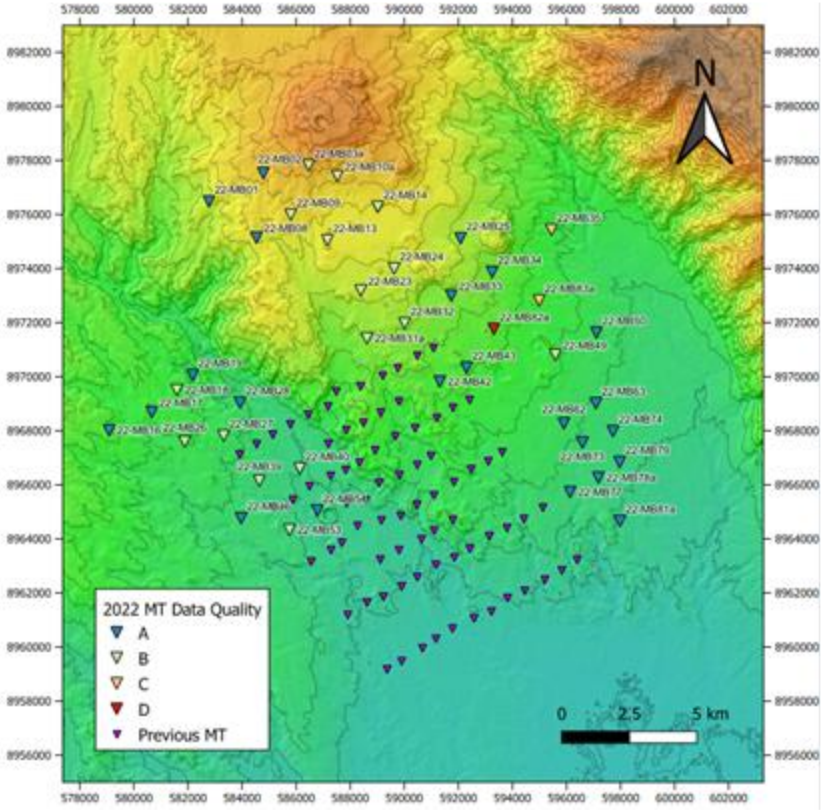


Figure 6: Map showing data quality distributions in the focal study area. TGDC and JACOBS, 2022.

Static shift was a major problem observed in most stations as the 2022 MT geophysical campaign did not have co-located TEM stations (Figure 7). Low apparent statics (1-1.5) were observed within the westward and east sector of focal study area. Moderately apparent statics (1.5-3) were observed in the center of the study area in the outcropping intrusive metamorphic basement toward the North of the prospect and South of Kiejo mountain/volcano. High apparent statics (3-5) occurred in the populated area due to EM noise sources and toward Kiejo volcano owing to topographical effects. Also, extremely high apparent statics (5-12) were evident for few stations North and south of Kiejo mountain due to topographical and possibly current channeling.

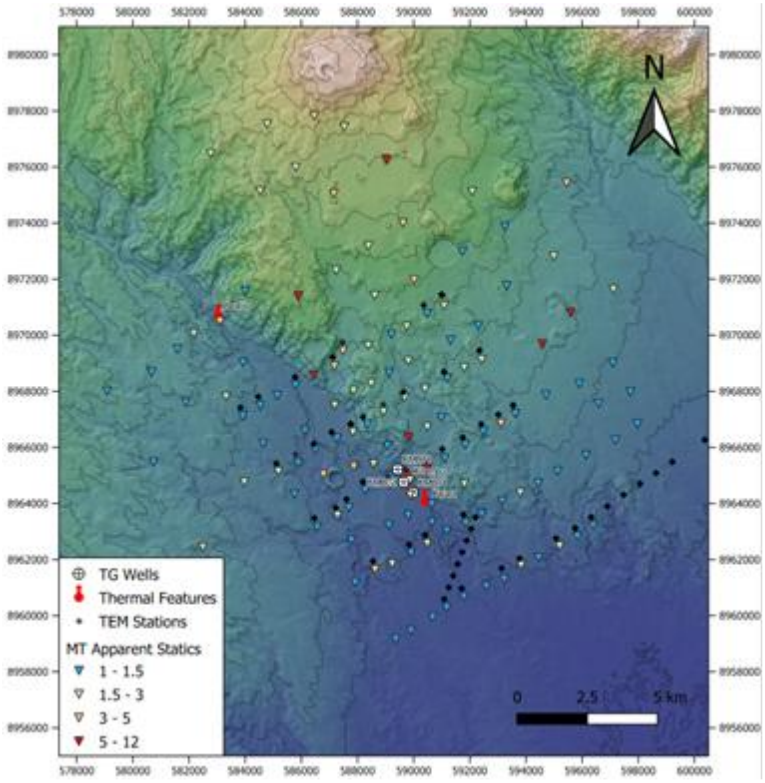


Figure 7: Map showing apparent statics distributions in the focal study area. TGDC and JACOBS, 2022.

3.4 Data processing and editing

3.4.1 Data processing

As MT data was being collected in the field at Kiejo-Mbaka in August 2022, the preliminary data was shared with Jacobs geophysicist Steven Sewell and suggestions made regarding possible issues and improvements that could be made to the survey. Support from Jacobs continued through 2023, with the QA and 1D TE mode inversion of all MT data and below.

3.4.2 Data editing and masking

Data editing and masking was conducted as shown in Figure 8 where station MB10a appear to have data truncated below 3s. Other stations not shown here were processed, edited and masked the noise during post-processing stage. MB82a appears to be way off the data points as shown in Figure 8 below.

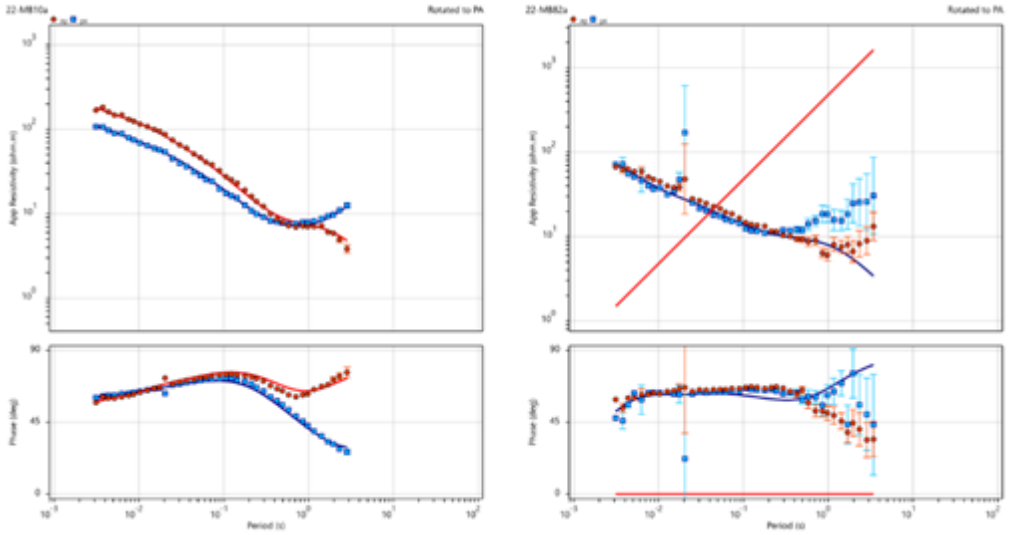


Figure 8: MT stations MB10a (left) and MB82a (right

3.5 3D Inversion by CGG-EM

The 3D grid mesh prepared for the 3D inversion overlaid with Temperature Gradient Wells (TGW) and Slim Wells (SLW) is shown in Figure 9. The 3D inversion was carried out using Geotool software from CGG-EM, data preparation was conducted and shared to CGG-EM clouds, inversion calculation was performed under the same, and result downloaded after 59 iterations. A final RMS misfit of 2.1 was reached after the inversion run. Figure 10 presents the transversal profile lines (P01, P02, P05, P06 and P09) that were used to plot the 2-D resistivity cross-sections extracted from 3D inversion which are shown in Figures 11 and 12.

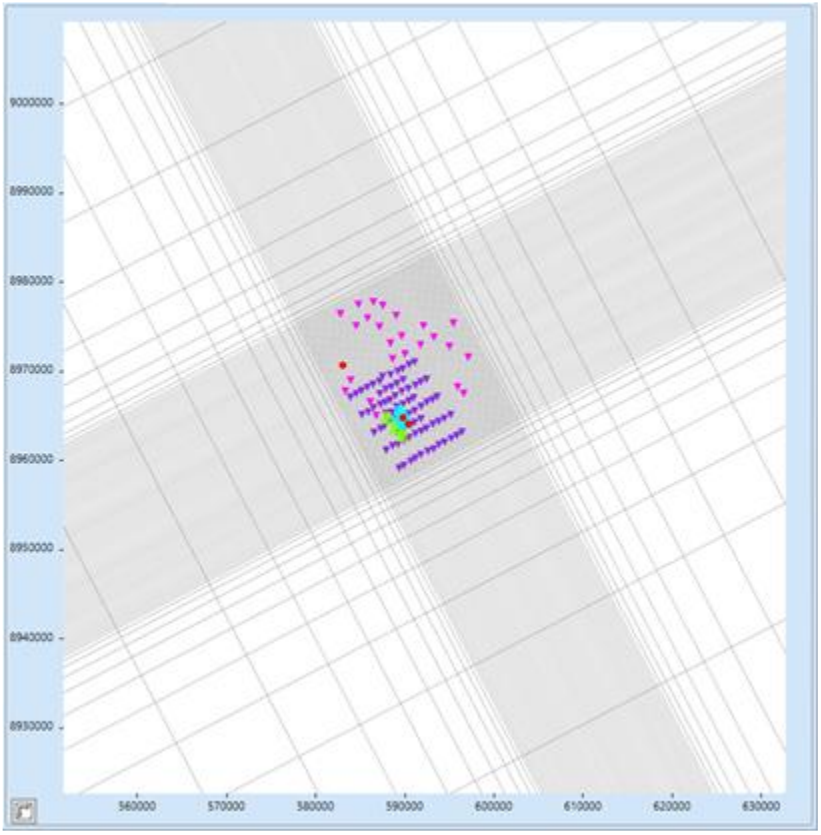


Figure 9: 3D grid mesh used for the 3D inversion. MT stations are shown by pinkish and purple triangles. Red dots are geothermal manifestations. TGW and SLW are also overlaid.

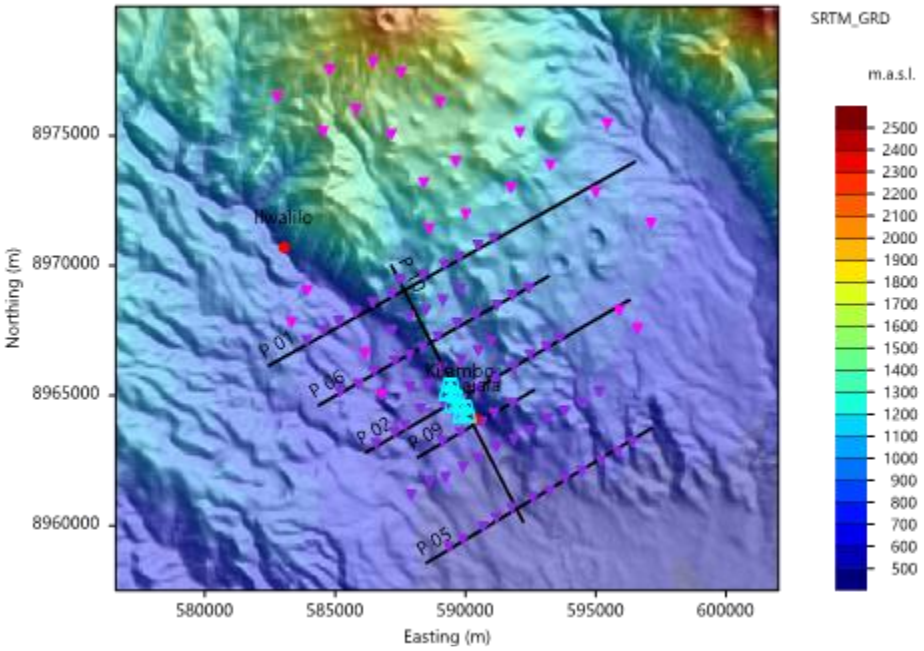


Figure 10: Map showing the transversal profile lines (P01, P02, P05, P06 and P09) used to extract 2-D resistivity cross sections resulted from 3D inversion. Purple and pinkish triangles are MT stations acquired in 2016 (ELC and TGDC), and in 2022 (TGDC and JACOBS) respectively, red dots are Kilambo, Kajala and Ilwalilo hot springs. TGW are shown by green symbols.

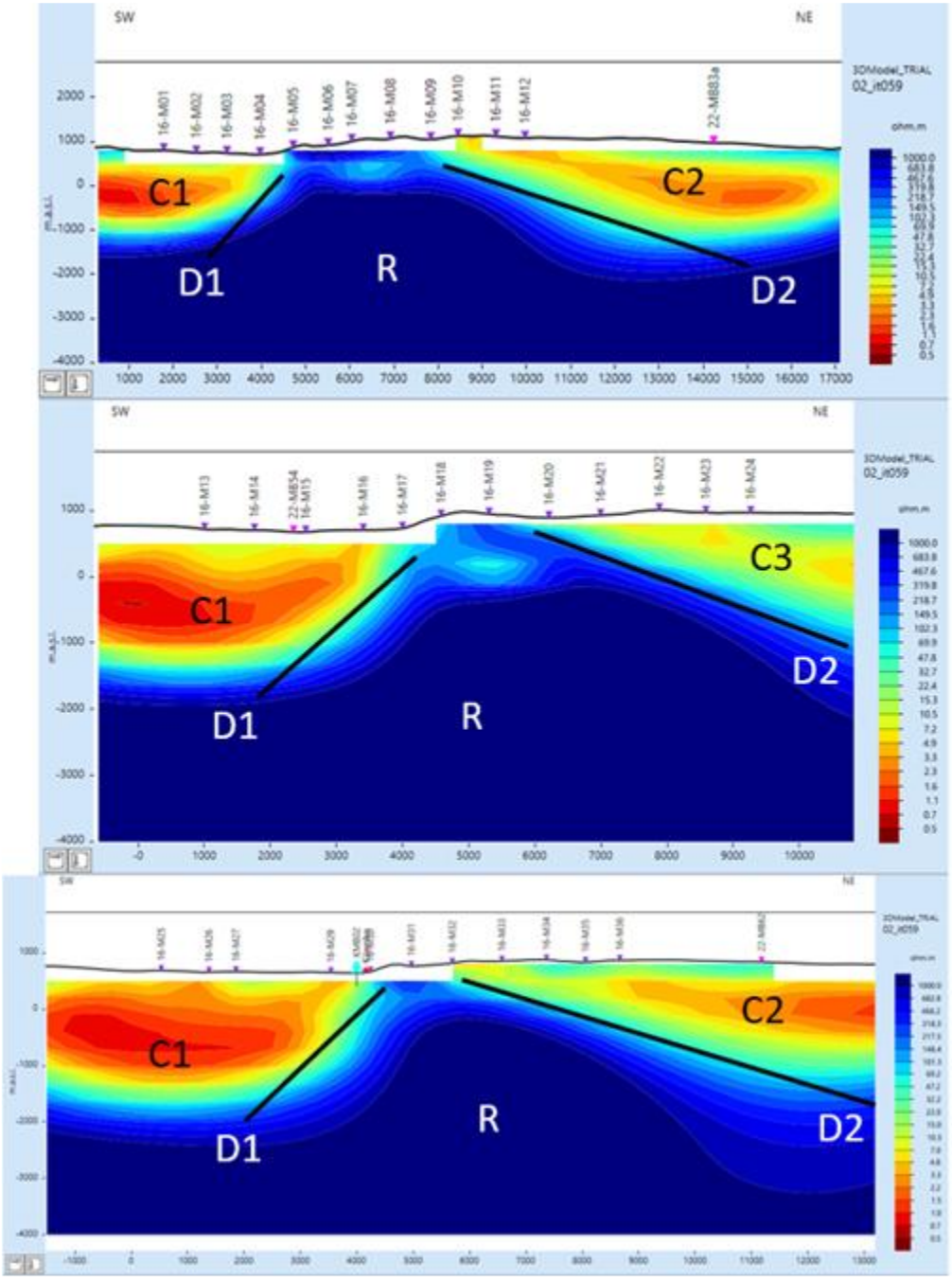


Figure 11: Map showing the SW-NE 2-D resistivity cross sections resulted from 3D inversion extracted from transversal profile lines P01(top), P06(middle) and P02(bottom). Red dots mark Kilambo hot spring while TGW is shown by green symbol.

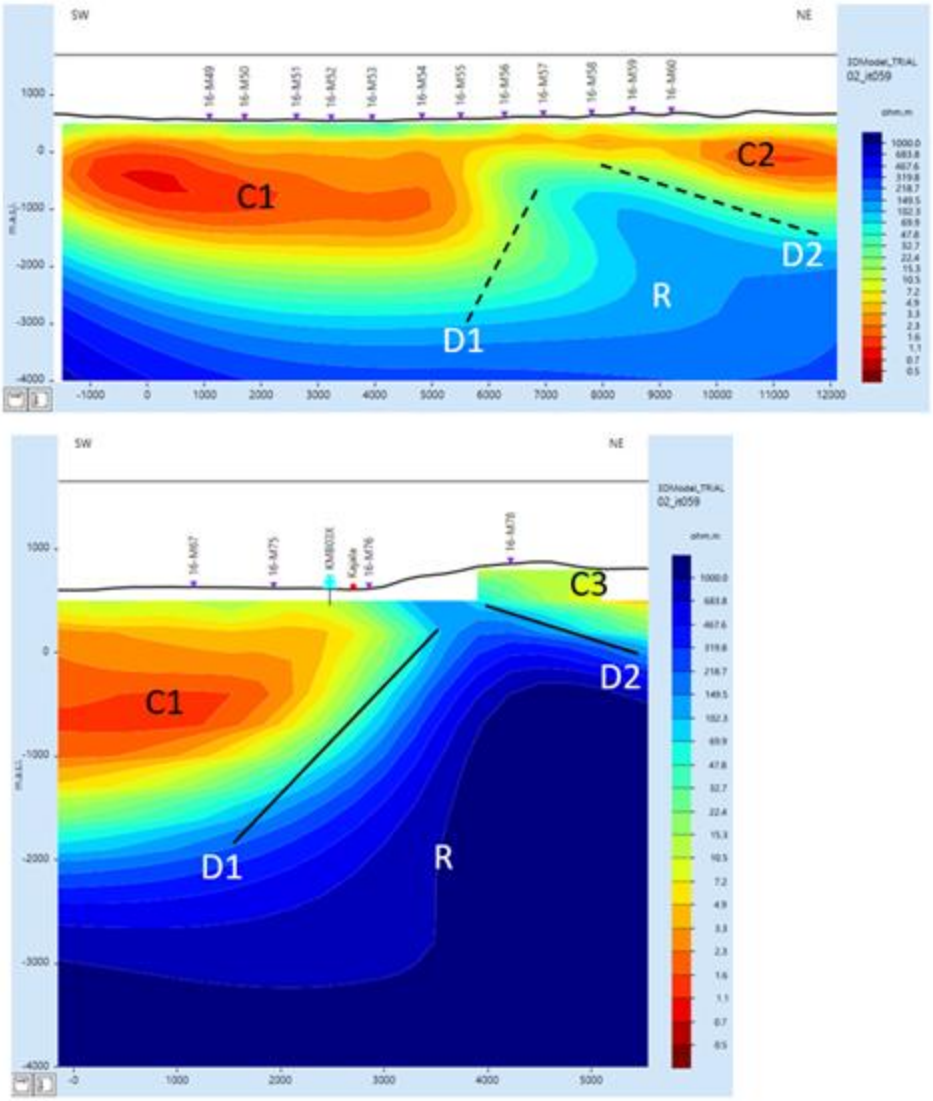


Figure 12: Continued; P05(top) and P09(bottom). Red dot marks Kajala hot spring while TGW is shown by green symbol.

4. RESULT COMPARISON FOR 1D, 2D AND 3D RESISTIVITY MODELS FROM MAGNETO TELLURIC SURVEY

The comparison between 1D, 2D and 3D inversion (Figure 13) are similar in general. The very 2D nature of the geology and resistivity structure in the Mbaka area means that emphasis for deeper interpretation must be placed on the 2D and 3D methods, but 2D models are easily impacted by parameter choices as can be seen with differences of 2D models in Figure 12. Overall, emphasis is placed on the 3D resistivity model.

From the previous subsection in 3.5 (3D inversion by CGG-EM), the Magneto telluric (MT) survey identified the existence of a block characterized by a high resistivity (**R**). Such block corresponds to the Mbaka ridge, where the basement is either outcropping or sub-outcropping. While in the plain which extends west of the Mbaka fault a conductive unit with an average thickness of about 1,000 m, a resistivity as low as about 0.5 Ohm m with a tendency to get thicker moving westward and southward was observed.

The modelling revealed that the Precambrian metamorphic intrusive “basement” complex outcropping east of Kilambo hot spring has very high resistivity. This is overlaid in the west by a deep sequence of volcanic sediments and basalt flows >2 km thick that forms a conductive cap westward from the Mbaka fault and which were clearly imaged as low resistivity by the MT. The sediments possibly have some relict hydrothermal alteration caused by low-temperature alteration processes over time. On the east side of the basement block the conductive layer gradually thickens and deepens to the east, indicating a gradual thickening of sediments in this area.
Given the gravity patterns that show a possible large offset on Mbaka Fault, downthrown west, the large offsets in lake Nyasa, and the observations of volcanic products infilling the basin at surface - it seems more likely that a thick pile of younger volcanic and sedimentary materials in this west of the Mbaka Fault, and that the low resistivity is due to some sediment clays but also probably low-grade alteration of them, possibly over a long period. We also note that lowest resistivity is in the zone closest to the Mbaka fault and known hot spring activity, which suggests that thermal activity is increasing the alteration in this pile of younger material. Also, temperature has a direct impact on resistivity of these materials, higher temperature lowers the resistivity.

The most remarkable features observed in the sections are:

(a) The sections are characterised by a central resistive core (indicated as "**R**") corresponding with the outcropping Precambrian basement. The high resistivity values it reaches may be a consequence of the extreme 3D effects observed in this area.
(b) **C1** is a thick and quite continuous conductor within the rift basin westward of the Mbaka fault; this layer shows locally very low resistivity values (about 1 Ohm m) and would be interpreted as volcanic and mixed fluvio-lacustrine Neogene sediments in the rift basin.
(c) **C2** is thin, considering the geological mapping, gravity patterns, rotation that is seen on the basement blocks in Lake Nyasa, the sediments on top of a tilted block are more interpreted being volcanic and mixed fluvio-lacustrine Neogene sediments in the rift basin. Its minimum resistivity is about 2-4 Ohm m.
(d) **C3** is shallower and discontinuous; it could be related to volcanic and mixed fluvio-lacustrine Neogene sediments in the rift basin. The minimum resistivity is about 6-8 Ohm m.
(e) The discontinuity **D1** is in correspondence of the Mbaka fault and marks a border between the conductive layer in the plain (**C1**) and the resistive rift shoulder (**R**) constituted by Livingstone gneiss.
(f) The discontinuity **D2** marks a border between the resistive zone "**R**" and the more conductive zone toward East (comprising **C2** and **C3**).

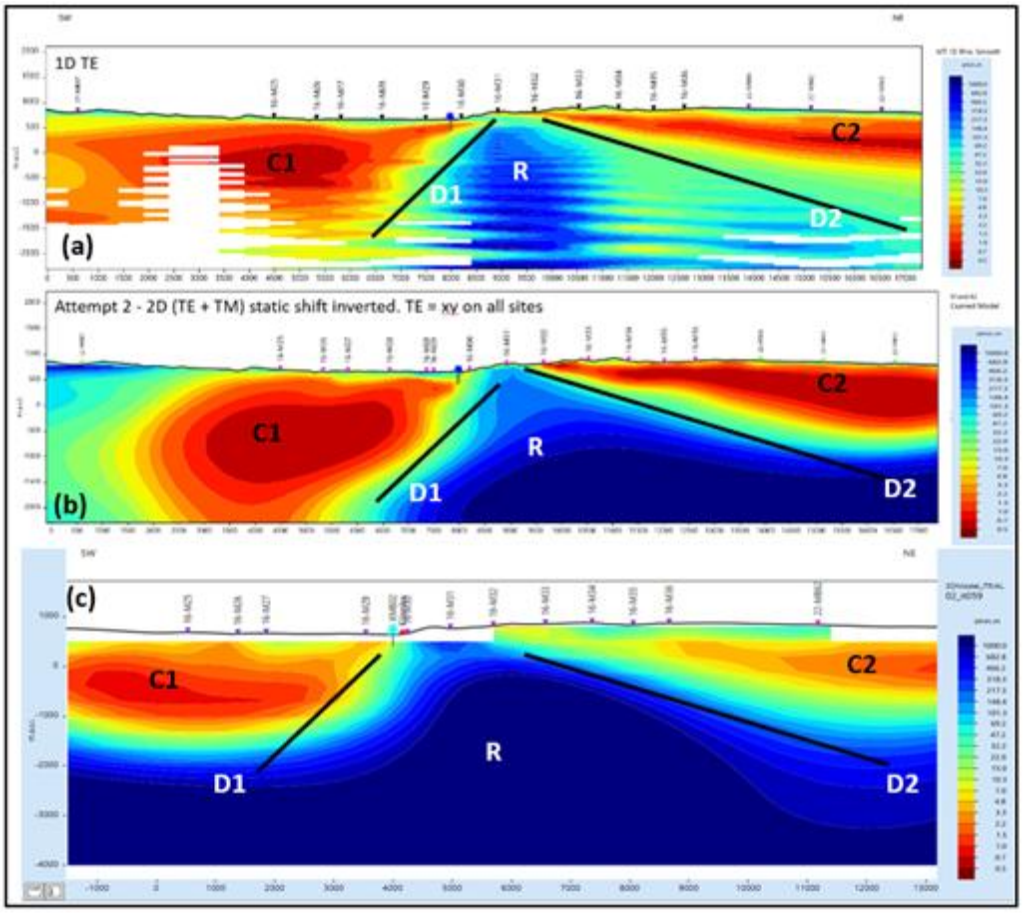


Figure 13: Comparison of 1D, 2D and 3D inversion profiles (refer profile map, line (P02) in figure 10) of the obtained resistivity models. (a) is 1D TE-mode, (b) 2D (TE+TM-mode), and (c) 3D (Z+Tz).

4.1 Geophysical models versus geological model

A useful reference for major basement structural patterns in the Nyasa Rift is provided by seismic surveys conducted in Lake Nyasa to the south of Mbaka. Shillington et al., (2020) interpreted major intra-rift faulting oriented along the rift with downthrow on the west side. The velocity models indicate basement rocks with high velocity are overlain with younger materials of much lower velocity. Offsets range from 1.2 to 2.4 km, on faults up to 50 km in length (Figure 14).

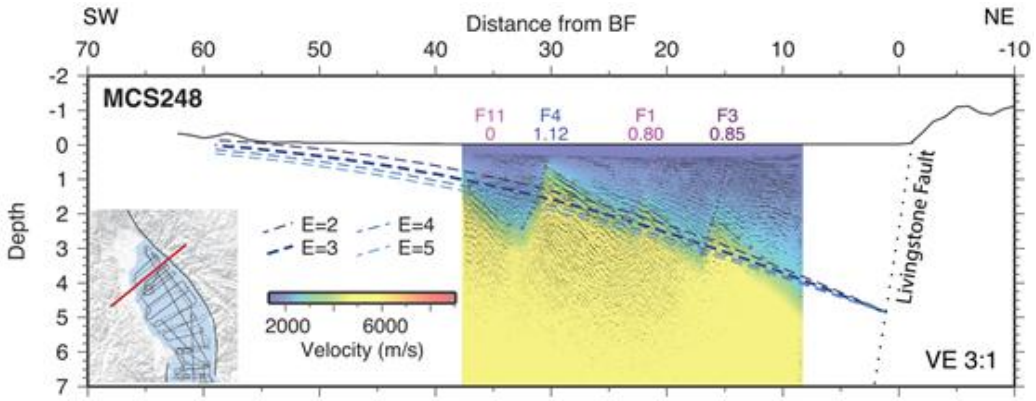


Figure 14: Faulting patterns in the northern part of Lake Nyasa (from Shillington et al, 2020).

4.1.1 Interpretation of the Mbaka system

To summarize the interpretation of the Mbaka system.

- Resistivity structure is typical of a fault-based system.
- Thick low resistivity layer on the western side of the Mbaka Fault? Transitions sharply to high resistivity across the Kiejo fault.
- Area of high resistivity from surface between Kiejo and Mbaka systems = no clay cap. Coincides well with area of outcropping pre-Cambrian.
- Comparing TG well, geology, alteration and temperature agree with each other.
- Low resistivity (clay cap) layer thickens from the western edge of pre-Cambrian rocks to the east-northeast.
- Consistent dip of the low resistivity layer suggests a sedimentary origin, and this agrees with seismic data in nearby areas.
- Low resistivity may also be in part due to hydrothermal alteration.
- In either case, the low resistivity layer will act as a cap over any underlying geothermal system.
- Low resistivity layer is 500-1000m thick extending from Kiejo volcano summit to the southeast which would provide a good cap for underlying system.

Geological model Figure 15 has revealed a good correlation to the geophysical model obtained from MT results. A general observation from the two models are a high resistive anomaly imaged by MT corresponds to an outcropping intrusive basement complex from the geological viewpoint, overlined by a low resistive anomaly, which could be undifferentiated sediments within the rift basin possibly as a result of low-Temperature hydrothermal alterations including some fluvio-lacustrine Neogene sediments in the basin.

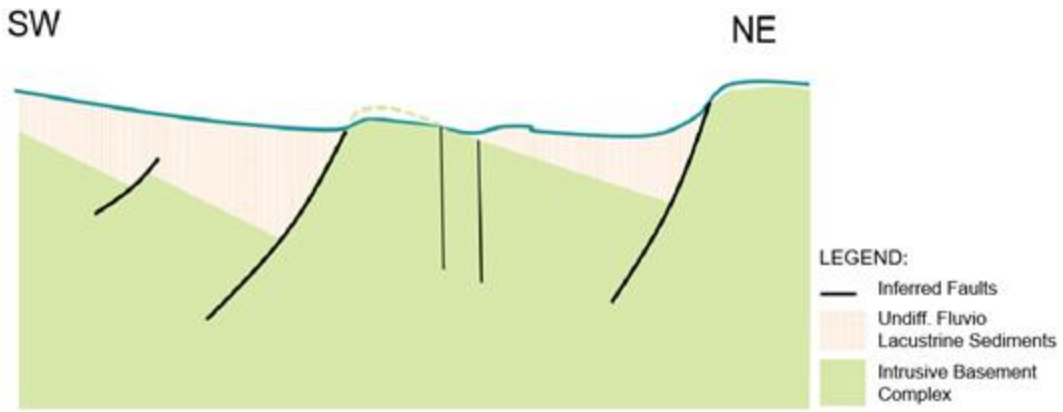


Figure 15: A simplified geological model for the focal study area. TGDC and JACOBS, 2022.

4.2 Possible drilling targets needed to test concept model

This paper presents an updated geophysical concept model delivered from MT results showing possible drilling targets for Slim Wells where two (2) vertical Slim Wells namely KM02 and KM06 out of seven (7) Slim Wells proposed by ELC, 2017 with depth to about 1,500m are initially proposed and presented in this work. Three (3) previously drilled Temperature Gradient Wells (TGW) by TGDC, 2021 namely KMB01X, KMB02 and KMB03X are presented as well (see Figures 17) whereas, a geological model superimposed with isotherm lines from geothermometers is shown in Figure 65 below.

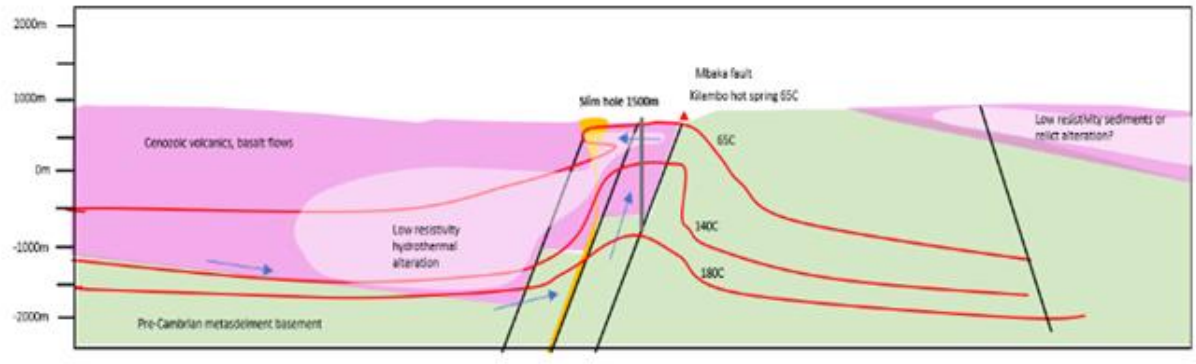


Figure 16: A geological model superimposed with isotherm lines from geothermometers. TGDC and JACOBS, 2022.

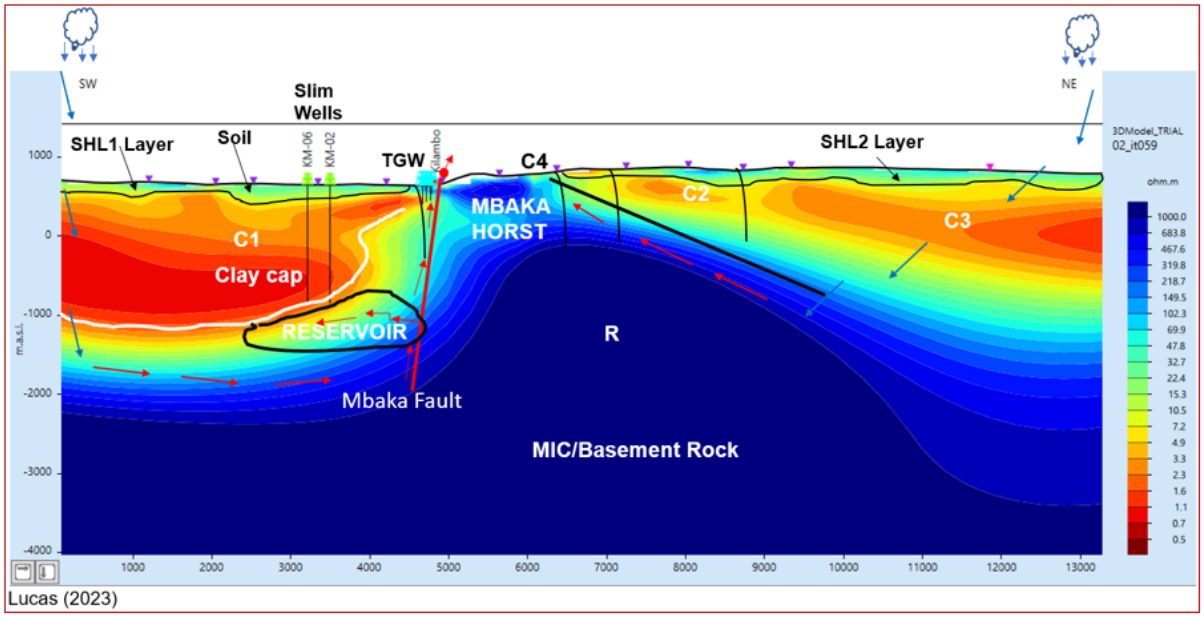


Figure 17: Updated geophysical concept model delivered from MT results showing possible drilling plans for Slim Wells (SLW) and Temperature Gradient Wells (TGW) for the Kiejo-Mbaka geothermal system.

5. CONCLUSIONS

The Kiejo-Mbaka geothermal prospect represents a structurally complex, fault-controlled hydrothermal system with significant potential for sustainable energy development in southwestern Tanzania. Integrated geoscientific investigations geological, geochemical, and geophysical—have advanced the understanding of subsurface processes and refined exploration strategies. Magnetotelluric (MT) surveys and their 3D resistivity inversion have proven invaluable in delineating the Mbaka fault system, distinguishing low-resistivity sedimentary basins from high-resistivity Precambrian basement, and clarifying the separation between the Kiejo and Mbaka geothermal systems.

The updated conceptual geothermal model, strengthened by multidisciplinary datasets, has enabled strategic placement of Temperature Gradient Wells (TGWs) and Slim Wells (SLWs), thereby

enhancing confidence in resource confirmation and drilling success. Recent MT data highlight critical resistivity contrasts that not only validate earlier findings but also provide new insights into sediment accumulation, hydrothermal alteration, and potential impermeable barriers at depth. The exploration drilling supported by expanded geophysical coverage, improved data acquisition over Kiejo volcano, and targeted studies within the Mwakareli Caldera will be essential to fully characterize the geothermal system. These efforts will strengthen Tanzania's geothermal development strategy, positioning the Kiejo-Mbaka prospect as a cornerstone for advancing renewable energy in the East African Rift System.

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REFERENCES

Delvaux, D., & Barth, A. (2010). African stress pattern from formal inversion of focal mechanism data. Tectonophysics, 482, 105–128.

Delvaux, D., Kraml, M., Sierralta, M., Wittenberg, A., Mayalla, J. W., Kabaka, K., & Makene, C. (2010). Surface exploration of a viable geothermal resource in Mbeya area, SW Tanzania: Part I—Geology of the Ngozi–Songwe geothermal system. Proceedings World Geothermal Congress 2010, Bali, Indonesia.

ELC Electroconsult & TGDC. (2017). Kiejo-Mbaka Geological Report.

Kraml, M., Kreuter, H., Robertson, G., et al. (2012). Small-scale rural electrification and direct use of low-temperature geothermal resources at Mbaka fault in SW Tanzania. Proceedings 4th African Rift Geothermal Conference, Nairobi, Kenya.

Scholz, C. A., Shillington, D. J., Wright, L. J., Accardo, N., Gaherty, J. B., & Chindandali, P. (2020). Intrarift fault fabric, segmentation, and basin evolution of the Lake Malawi (Nyasa) Rift, East Africa. Geosphere, 16(5), 1293–1311.

Shillington, D. J., Scholz, C. A., Chindandali, P. R., Gaherty, J. B., Accardo, N. J., Onyango, E., & Nyblade, A. A. (2020). Controls on rift faulting in the north basin of the Malawi (Nyasa) Rift, East Africa. Tectonics, 39(3), e2019TC005633.

TGDC. (2021). Kiejo-Mbaka Shallow Wells Drilling Project.

TGDC & JACOBS. (2022). Kiejo-Mbaka Geophysical Report and Training Services.