Project Development in Tanzania: Geothermal Resources, Surface Exploration, Conceptual Models and Potential—Status Report

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Keywords

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ABSTRACT

Tanzania's geothermal potential was estimated in the early 1980th based on analogy method. The high- and low-temperature systems mainly occur within the eastern and western branch of the East African Rift System (EARS). Outside the EARS only low-temperature systems occur in the Precambrian Tanzanian Craton and in the sedimentary basins of the coastal area. Viable high-temperature systems are related to Kilimanjaro, Ngozi and maybe Meru volcano. From those volcanoes Ngozi was investigated in detail by a Tanzanian-German government to government technical cooperation program resulting in a conclusive conceptual model for the Ngozi geothermal system. Subsequent surface exploration by private company Geothermal Power Tanzania Ltd. (GPT) resulted in a first conceptual model for the low-temperature geothermal system at Mbaka fault which is also situated within the rift-rift-rift triple junction in Mbeya area (SW Tanzania). Two shallow exploration wells at Mbaka fault were drilled in 2013 revealing the lithological and hydrological conditions expected in the planned deep exploration / production well. Currently GPT is planning to drill a first exploration well at Ngozi volcano. GPT's activities will soon lead to a refinement in estimation of the geothermal potential and has advanced the discussion on energy policy issues of Tanzania.

Introduction

Tanzania reveals a significant geothermal potential for high- and low-temperature geothermal systems. A first assessment in the early 1980th based on analogy method gave a potential of 650 MW for electricity generation in the country (Figure 1, McNitt 1982).

Potential Geothermal Prospects

Three major areas have been identified for geothermal project development:

Northern Tanzania with a section of the eastern branch of the East African Rift System (splay) and its prominent volcanoes Ngorongoro, Mount Meru and Kilimanjaro (Figure 2,3,4) being characterized by evolved rock compositions and caldera formation. Gas geo-thermometric results of fumarole samples from the top of Kilimanjaro (Kibo caldera) gave clear indications of a high-temperature geothermal system (Giggenbach 1997).

Unique Ol Doinyo Lengai with its current natro-carbonatitic activity and also neighboring carbonatitic Kerimasi volcanoes are special cases and the role of their "magma chamber" acting as heat source for sustainably driving a geothermal system is questionable. Recent fluid inclusion investigations by Carmody et al. (2012) suggest a deeper origin for the carbonatitic melt based on fluid trapping pressures equivalent to the lower crust at ~30 km, which is at a much greater depth than the proposed magma-storage system for Ol Doinyo Lengai volcano.

	Volcanic Systems		Non-Volcanic Systems		
Country	Potential Based on Number of Active Volcanic Centers, MW	Potential Decreased Because of Absence of Acidic Volcanism, MW	Potential Based on Areal Extent of Hot Spring Occurrences, MW	Potential Decreased Because of Absence of Cover Rocks, MW	Totals, MW
Tanzania	450	---	200	---	650

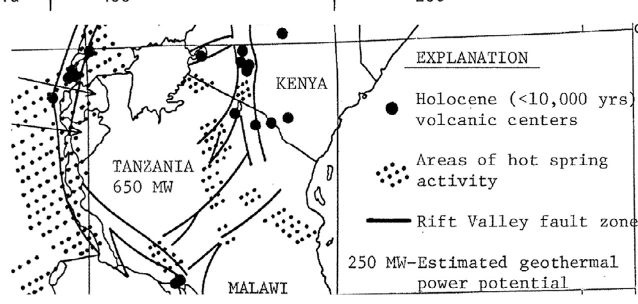

Figure 1. Geothermal potential of Tanzania as estimated by analogy method (McNitt 1982).

Fumaroles at Mount Meru caldera are so far not investigated. Lacking fumaroles at Ngorongoro caldera (widest diameter of 22 km) caused doubt that a geothermal system currently exists (lukewarm springs gave no convincing evidence; Hochstein et al. 2000). Additional to missing surface manifestations, the old age of 2.3 to 2.0 Ma for the entire volcanic activity period of Ngorongoro volcano (Mollel 2007) also supports a currently no more active geothermal system.

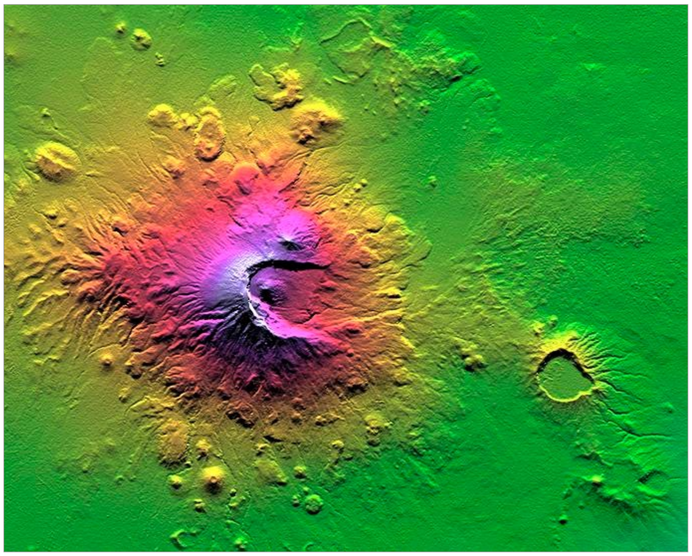

Figure 2. Mt. Meru stratovolcano (3.25°S, 36.75°E within Arusha National Park) with 3.5 km wide breached caldera. The volcano experienced a major sector collapse and its last eruption occurred in 1910 (Wilkinson et al. 1986). The slopes of 4566m high Mt. Meru are covered by forest that hosts diverse wildlife. (Source: http://photojournal.jpl.nasa.gov/catalog/PIA03356; SRTM data February 2000).

Eastern Tanzania in the coastal area of Rufiji basin and Dar es Salaam platform. There, some prominent hot springs occur as surface expression of low-temperature geothermal activity in the subsurface. A potential of >100MW has been estimated for a modeled block of 90×45km areal extent (MEM 2004).

South-Western Tanzania (Mbeya area between Lake Nyasa and Mbeya town) Mbeya area is part of a triple-junction of the East African Rift System with its Quaternary Rungwe volcanic

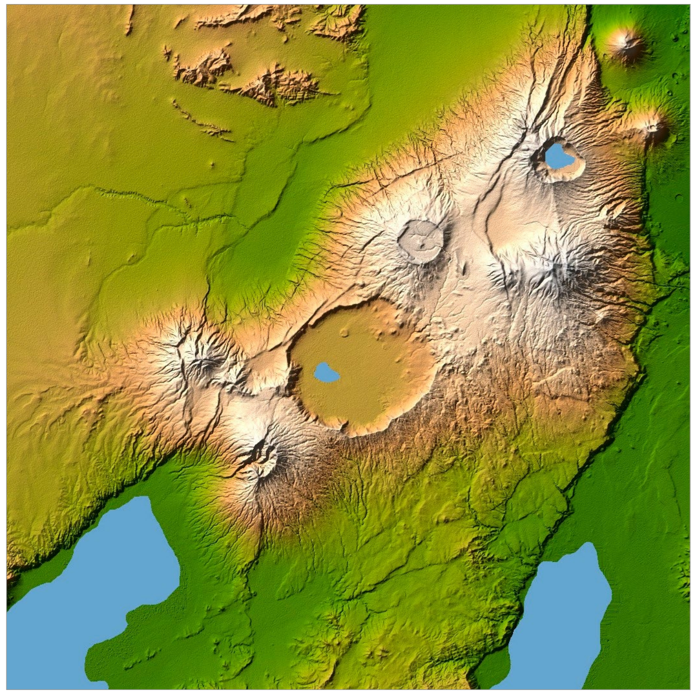

Figure 4. Ngorongoro is characterized by a >20km wide caldera which is 400 to 610m deep and the elevation of the caldera rim ranges from 2,280 to 2,440m a.s.l. (Pickering 1994). The caldera (3.15°S, 39.30°E) is located within the Ngorongoro Conservation Area an UNESCO World Heritage Site (>75,000 animals; Ngorongoro Conservation Area includes Lake Eyasi & Lake Manyara south of the caldera; shaded and colored SRTM data February 2000) (source: http://earthobservatory.nasa.gov/IOTD/view.php?id=4705).

province. There, high- and low-temperature resources exist e.g. at Ngozi volcano and at Mbaka fault, respectively (Kraml et al. 2010).

Beside major geothermal activity in the three areas described above, minor geothermal resources exist in the NW of Tanzania near Lake Victoria (e.g. Maji Moto; Figure 5 and 7) and in the center of the country (area N of Dodoma; Figure 6) where mainly fault related hot springs occur as surface expression of low-temperature systems within the Precambrian Tanzanian Craton.

In summary, only one high-temperature hydrothermal system is known in Northern Tanzania (Kilimanjaro in extremely high elevation causing logistical difficulties in development of the

Figure 3. 5895m high Kilimanjaro consists of three overlapping stratovolcanoes with 2.4×3.6 km wide caldera at Kibo ice-caped summit (3.07°S, 37.35°E within Kilimanjaro National Park - UNESCO World Heritage Site). Its last eruption occurred during Pleistocene with possibly Holocene nested summit craters (Nonnotte et al. 2008). (Source: http://photojournal.jpl.nasa.gov/catalog/PIA03355; SRTM data plus Landsat-7 image and artificial sky added; elevation exaggerated).

Figure 5. Fluid sampling (water, gas and noble gas) at Maji Moto hot springs in NW Tanzania (January 2013) by a joint team of Geological Survey of Tanzania (GST), University of Dar es Salaam (UDSM) and GPT. GPT assisted in gas and noble gas sampling (copper tube technique). Please note that noble gas sampling took place after sunset.

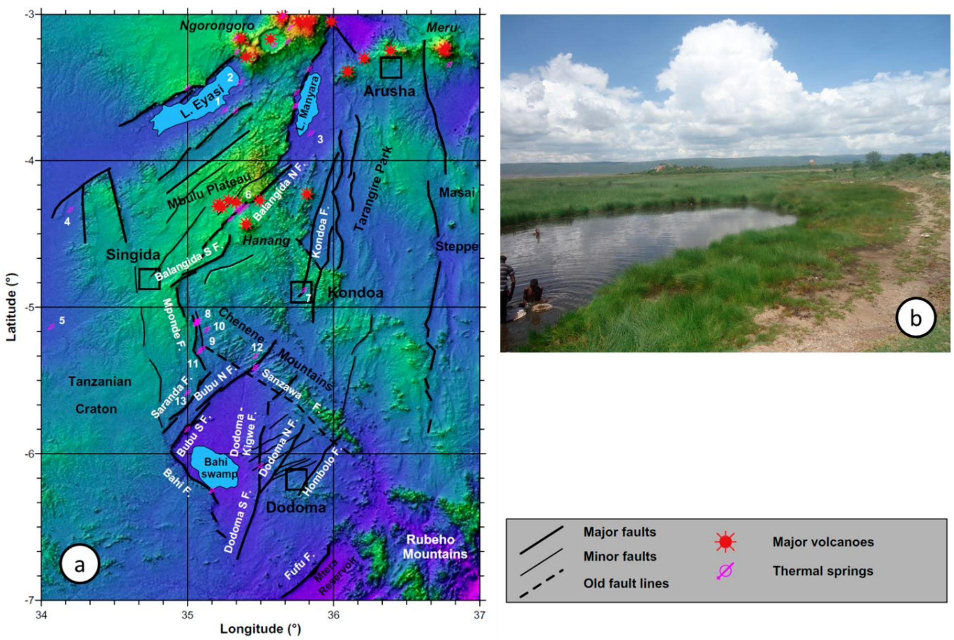

Figure 6. (a) Digital elevation model (map view) with occurrences of hot springs in central Tanzania (Macheyeki et al. 2008) showing their fault-related nature (b) Photography (courtesy of N. Mwalija) of one of the Balangida hot springs with *Fimbristylis exilis* (= "geothermal grass").

resource) and two additional high-temperature systems (Mount Meru and Ol Doinyo Lengai) are assumed to reflect an immature status (Hochstein et al. 2000; Figure 7).

Additionally, all possible high-temperature prospects in Northern Tanzania are situated in ecological sensitive areas (National Parks, Conservation Areas, UNESCO Heritage sites) and are of utmost importance for tourism industry. Since no geothermal law is in place for utilization of geothermal resources in National Parks etc., no project development is expected to take place in Northern Tanzania.

The prospects in North-Central and NW Tanzania are fault-related low-temperature systems. Their geothermal development potential is very limited. Most of those springs are characterized by high helium concentrations of up to >10% (see Macheyeki et al. 2008 for compilation and references therein). The high helium concentrations can be explained by accumulated crustal helium from decay of U and Th in Precambrian reservoir rocks (Kraml et al. unpublished data). Those high helium concentrations gave hope for enhancing the economy of geothermal projects utilizing low-temperature resources by producing helium as by-product. However, low gas flow-rates lead to a factor of 1,000 to 10,000 lower production rates compared to the economic viable threshold value. Due to the negligible concentration of helium in the fluid, it is not possible to enhance production by separating helium from the fluid phase. Therefore, it is not expected that the fault-related low-temperature geothermal resources in that area can be utilized economically under current boundary conditions.

Surface Exploration and Conceptual Models

Two areas are so far intensively investigated in Eastern and South-Western Tanzania:

1. Rufiji basin/Dar es Salaam platform: In the frame of hydrocarbon exploration during drilling of a hydrocarbon well, hot water of 140°C was found in 1179m depth indicating a Mesozoic aquifer with lateral fluid flow within the sedimentary basin (MEM 2004). Supplementary surface exploration was done by GPT (Figure 8).
2. Mbeya area: Intense surface exploration by GEOTHERM technical cooperation programme of BGR, Hannover, Germany including a TEM/MT survey at Ngozi and subsequent surface exploration by private company Geothermal Power Tanzania Ltd. (GPT) at Mbaka fault indicates a high-

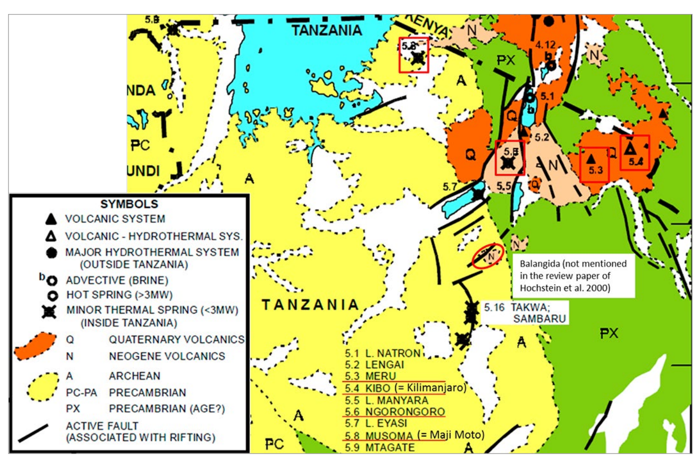

Figure 7. Synopsis of possible geothermal sites in northern and north-central Tanzania (Hochstein et al. 2000, modified).

Figure 8. Sampling of noble gas at Nyongoni hot spring at active travertine mount in September 2012 by GPT. Beside noble gas also fluid samples mainly for stable isotope analyses and gas samples for species and isotope analyses were taken.

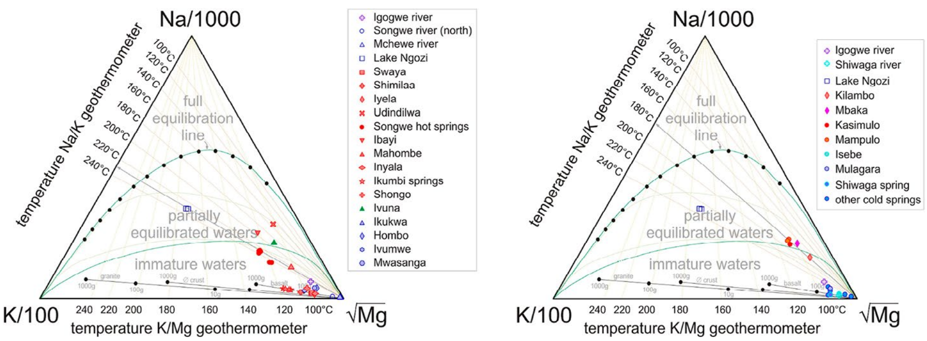

Figure 9. Na-K-Mg ternary diagram showing water samples of Ngozi high-temperature system (left; Ngozi, Songwe and Mahombe hot spring) and Mbaka low-temperature system (right; Mbaka and Kilambo hot spring) (Kraml et al. 2010).

temperature system (≥220°C) at Ngozi volcano and a low-temperature system (≥160°C) at Mbaka fault both with fracture-controlled fluid-flow within the East African Rift (Kraml et al. 2010, Delvaux et al. 2010, Kalberkamp et al. 2010, Kraml et al. 2012; Figure 9 and 10).

In late 2011 six prospecting licenses were granted to GPT in those two areas (one at Dar es Salaam platform low-temperature resource; two at Ngozi high-temperature resource; three at Mbaka/ Livingstone fault low-temperature resources). Due to sufficient surface exploration data already acquired at Ngozi volcano (Figure 11) and Dar es Salaam platform, the major focus of GPT in 2012 was surface exploration for enhancing the data base which enables the creation of the still missing conceptual model for Mbaka fault (Figure 12).

After presenting the first conceptual model of Mbaka fault in November 2012 (at ARGeoC4 conference in Nairobi), GPT drilled two exploration wells at Mbaka fault in the first quarter of 2013 together with its German joint-venture partner Geothermal Engineering GmbH (GeoT) and the drilling company AAA based in Tanzania. While the first well exposed the stratigraphy of the Tertiary cover (continuous drill core, Figure 13), the second well discovered thermal water in shallow depth and provided valuable hydrological conditions (artesian pressure) to be expected in the future production well. Within the next months a deep exploration well, drilled with a Hanjin Rig D&B 45D, shall determine the potential productivity of the reservoir at Mbaka fault.

Further surface studies are planned to clarify open questions in the conceptual model of Mbaka fault to help identify a suitable area for re-injection. Further field work and sampling campaigns (Figure 14) as well as detailed investigation of the drill cores will enhance the data base and related reliability of the Mbaka model. Presently it is evident that the stratigraphy of the Plio-/Miocene covering volcano-sedimentary unit can be revised with major implications for the tectonic development of the rift in the area.

The first exploration well at Ngozi (>2000m) will be drilled after completion of the deep exploration well at Mbaka fault.

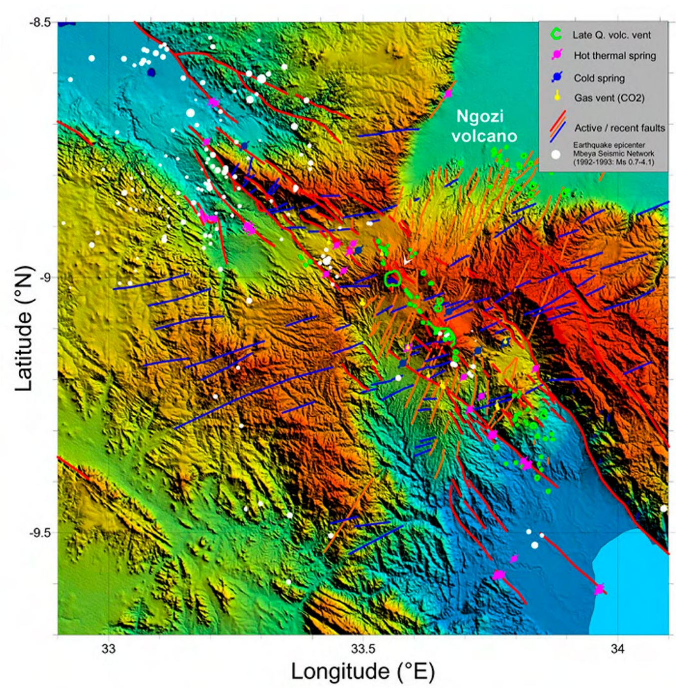

Figure 10. Active faults responsible for fluid flow in rift-rift-rift triple junction of Mbeya area (Delvaux et al. 2010).

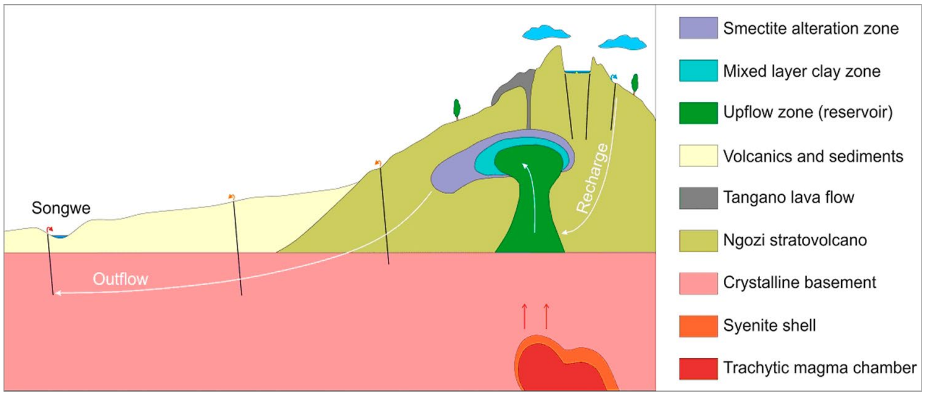

Figure 11. Conceptual model of Ngozi high-temperature geothermal system (Kraml et al. 2008, Kalberkamp et al. 2010).

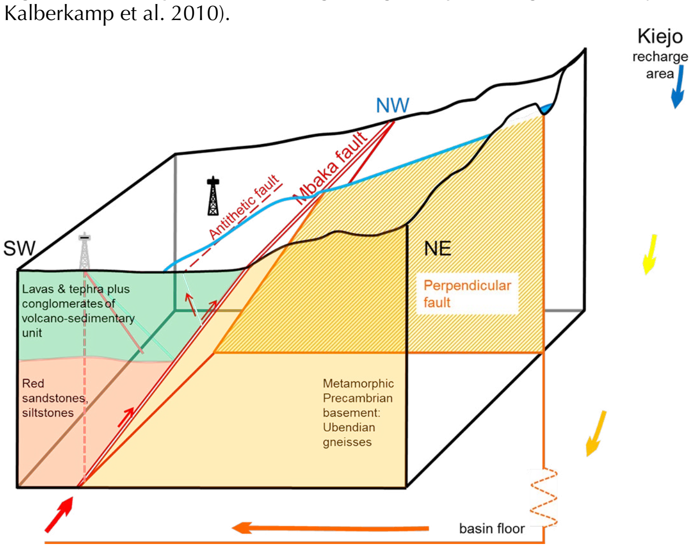

Figure 12. Conceptual model of Mbaka fault at Kilambo geothermal site (Kraml et al. 2012, strongly modified) with exploration drilling concept.

Figure 13. First 150m of continuous drill core at Mbaka fault.

Conclusions

The geothermal potential of Tanzania as estimated by McNitt (1982) will soon be updated once the two low-temperature resources at Mbaka fault and Rufiji area as well as promising high-temperature resource at Ngozi are further characterized by exploration wells.

With the first geothermal development in Tanzania implemented in Mbaka area, GPT has advanced the discussion on energy policy issues of Tanzania, as the country still lacks legal regulations for geothermal development.

Figure 14. Sampling of a cold spring for isotope hydrological assessment of the recharge area.

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