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Managing Expectations in the Development of Geothermal Resources in East Africa

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ABSTRACT

East Africa is blessed with a substantial geothermal potential. In Kenya the geothermal resources have been under development for decades with impressive activities and more than 400 MW_{el} online. The Olkaria site is often seen as an example and a blueprint of geothermal development in East Africa. Here geothermal development started in the 1950s. In the other countries of the East African Rift System (EARS) geothermal development is still at an earlier stage.

Geothermal resources are not distributed equally in the East African Rift. There is a significant difference between the eastern and western branches. While the eastern branch is marked by a number of active volcanos and abundant geothermal features, the western Rift shows only a few active volcanos and minimal surface geothermal activity. The geothermal potential of the eastern branch of the Rift is considered to be about ten times higher than the potential of the western branch. There is also a difference between the northern and the southern parts of the Rift as geothermal potential generally decreases toward the south.

Along with the geothermal potential of a region, other factors impact the development and use of geothermal energy. During exploration, volcanic-related reservoirs require different exploration strategies and methods than geothermal aquifers in sedimentary basins or geothermal brine rising through faults to the surface from deep aquifers/reservoirs.

Lower temperatures in the western branch and in the south of the Rift require changes in the power generation technologies used: Smaller binary plants produce less electricity than high temperature, direct steam turbine plants. The production cost per MWh of geothermal electricity produced also changes - with higher costs in the West and the South. In the geothermally most favorable regions in the North and the eastern branch of the Rift, prices of below 10 USct/kWh can be realized. In the south and western branches of the Rift, prices of more than 10 USct/kWh, sometimes even more than 18 USct/kWh, depending on temperature and drilling depth, can be expected.

Olkaria is the best example of geothermal development in the East Africa Region: A high output in MW at low cost, generated by experienced personnel who understand the resource and learned how to exploit it. Olkaria has been visited by many people from around the world. The many visitors have developed certain expectations, returned home and want to follow one or more of the Kenya examples.

Geothermal experts are needed in the East Africa Region to explain the differences between reservoir and resource types, the most suitable technologies, the relationship between electricity outputs and price variations in the different countries and therefore to manage these expectations. As a simple guideline, the two orientations North to South and eastern to western branches of the Rift can help until in-depth studies of the geothermal resources of the countries have been completed. Guidelines are under development by international agencies defining a common standard for the evaluation of geothermal potential for worldwide use.

Understanding the different types of geothermal resources, their regional distribution, as described above, and the relationship between power plant size and price will help the governments in the East Africa as well as the international donor community to assist, manage, finance and encourage private sector participation in geothermal development.

To support and finance geothermal development, a fund for all East African countries should be initiated by the donor community to give grants for the exploration drilling phase to reduce drilling risks and costs and therefore help overcome the major obstacle of geothermal development. The grant amounts can be calculated taking in account the reservoir type with all its characteristics and the likely sale price of the geothermal electricity. On the basis of this concept, projects in the North and in the eastern branch of the Rift could receive smaller grants while projects in the South and the western branches of the Rift would be eligible to receive larger grants. Following that concept, all projects would sell the geothermal electricity for a defined and acceptable price and the geothermal development would be equally attractive and distributed throughout all of the East African countries.

The situation discussed above is based on current technology and current prices. New developments in technology and efficiency can be foreseen in the future. New exploration methods, drilling and exploitation technology, Enhanced Geothermal System (EGS) technology, and more efficient power plants will allow the exploitation of the geothermal resources in the EARS countries to a much larger extend. The total potential might be 10 times higher than today's expectations. The development of these technologies will take time as well as reducing the price of their application from more than 25 USct/kWh down to less than 15 USct/kWh. Until these new technologies will be developed and can be applied, the EARS counties will use the time to develop the resources cost effectively with today's technologies. For example, within the next 10 years Tanzania can be expected to develop up to 500 MW_{el} until new technologies will allow the generation of more than 4000 MW_{el}.

1. INTRODUCTION

Geothermal Energy will play an important role in the development of power supply in East Africa. As a local renewable energy it will also help to reduce dependence and cost from imported conventional fuel and will reduce the CO_2 footprint of the electrification in East African countries.

Geothermal development started in the 1950s in Kenya with the first power plant going online in Olkaria in 1981. In the more than 60 year long history of geothermal development and experience in Kenya local expertise and human resources have been established and are now the base of the current dynamic activities of both GDC and KenGen.

In the other countries of the EARS, except some singular geothermal power plant activities which were not enduring (e.g. D.R. Congo and Zambia), the development of geothermal energy has just started. In the absence of experience with geothermal development there is a lack of local expertise, human resources, laws and regulations.

In the last years, with the help of international funding, expertise and support, Rift Valley countries are focusing more and more on the development of their geothermal resources. These activities are moving in the right direction but need to reflect the geological and geothermal situations in the EARS. There is still some misunderstanding about the particular regional geothermal situation which leads to unrealistic expectations by decision-makers e.g. politicians, funding agencies, regulators and even private development companies.

One reason for the unrealistic expectations is the fact, that Olkaria in Kenya is often seen as a shining example and the only blueprint for geothermal development in East Africa. KenGen and Ormat's progress at Olkaria has been successful and, in many respects, demonstrates both public and private sector models from which lessons can be learned. However, they do not represent all of the geothermal development options that may be applicable in the EARS.

Current technologies only allow the exploitation of a fraction of the heat that is stored in the subsurface of the EARS countries.

2. RESOURCE TYPES

The amount of energy that can be extracted from the subsurface as well as the price of geothermal power production, which are two decisive characteristics of geothermal use, depend mainly on the resource depth and other attributes. Resource types can be defined and differentiated based on their geological setting. This can be seen in detail e.g. in a publication by Moeck (2014). Within this paper, it is sufficient to look at a simplified presentation of general ranges of reservoir temperatures (Table 1). For the different temperature intervals some typical examples of resource types are presented.

Table 1: Simplified scheme of geothermal resources by temperature according to Benderitter and Corny (1990)

Temperature Range	Temperature [°C]
Low enthalpy	< 100
Medium enthalpy	100 - 200
High enthalpy	> 200

Low enthalpy reservoirs are for direct heat use and can be found in all the resource types present in the EARS. Direct heat use is not yet in the focus of geothermal development, even though waste heat of geothermal power plants is already used e.g. for agriculture. **The economic and ecological benefit of geothermal heat should be used more widely in the EARS countries. Low temperature** resources are abundant throughout the Rift valley and they are easier to exploit because of comparatively shallow drilling depths and lower demands in production rates (kg/s) compared to power projects to supply an economic feasible amount of heat. All geothermal resource types are suitable to be used for low enthalpy direct heat use.

Medium enthalpy resources can be found in the vicinity of volcano-related resources. But also deep sedimentary basins like the Rufiji basin in Tanzania can contain such hot reservoirs. Here a temperature of about 140°C can be found in a sandstone reservoir in a depth of about 1.200 m (Kraml et al., 2014). Faults reaching into deep seated hot reservoirs allow hot water to rise and feed hot springs lined up along the fault line as it is the case at the Mbaka fault in Tanzania (Kraml et al. 2012, 2013, 2014). From chemical analysis of the hot spring water a resource temperature of about 160 to 180°C can be estimated.

High enthalpy resources require a magma chamber not far below the surface. This is the case in areas like Olkaria and Menengai in Kenya and Corbetti in Ethiopia. In these examples, temperatures of above 300°C can be found and the geothermal field can be exploited even more efficiently by installing a high number of wells. These volcanic areas are often marked by active volcanism as well as geothermal surface manifestations like steam from fumaroles. The Ngozi volcano in Tanzania also seats a magma chamber. The usually high geothermal gradient above the reservoir is masked by high precipitation (Kraml et al, 2010, 2014; see also Delvaux at al., 2010 and Kalberkamp et al. 2010 for resource assessment).

Using EGS technologies, not only permeable rocks with natural steam and brine content can be used to produce electricity, but also rocks with low matrix and fracture permeability as long as they feature physical properties that allow the successful application of hydraulic stimulations. These rocks are abundant in the EARS countries and add to the total geothermal resource potential in East Africa.

3. THE EAST AFRICAN RIFT VALLEY

After the EARS had been identified as a geothermal resource area the development started in Kenya as described above. In 1982 McNitt presented an assessment of the geothermal potential of East Africa and South Africa (McNitt, 1982). Table 2 shows an excerpt from his table presenting the geothermal potential in MW_{el} of ten countries in the EARS. The countries are aligned from North to South. The potential of each country is also related to the size of the country. In Djibouti the geothermal potential is low compared to Ethiopia and Tanzania, because Djibouti is a much smaller country in comparison.

In several countries assessments have been made and the geothermal potential has been updated. But for many countries McNitt's values are still used even in most recent papers and press articles, especially if no new assessments have been made or published since 1982. This is true e.g. for Tanzania, Malawi, D.R. Congo and Mozambique.

The results from new assessments suggest that the eastern branch of the EARS has been underestimated. This is especially true for Kenya and Ethiopia. The high enthalpy reservoirs are able to produce more power than McNitt's assessment shows. For the western branch McNitt's assessment seems to show the correct values or even a slight overestimation of the geothermal potential.

How much of a technical potential can actually be exploited also depends on economics. Due to access or infrastructural reasons a resource might not be exploited because costs to overcome these obstacles are too high. Also the probability of realizing an economically feasible project depends on the availability and pricing of competing energy sources. For example, almost 5900m high Kilimanjaro in Tanzania contains a magma chamber. It is located beneath the highest elevated crater of the volcano. To install a power plant near the top of the volcano or drilling deflected from the slope into the geothermal resource is technically challenging and may be too risky and expensive. Also nature preservation and tourism may stand against the realization of a geothermal power plant.

Table 2: Geothermal Potential in Eastern and South Africa. Excerpt from McNitt (1982) and correlation to the branches of the EARS and in the regional setting. N = North, M = Middle, S = South, E = Eastern branch of EARS, W = Western branch of EARS

Country	N-M-S	E - W	McNitt 1982 [MWel]
Djibouti	N	E	500
Ethiopia	N	E	4600
Kenya	N/M	E	1700
Tanzania	M	W/E	650
Uganda	M	W	450
Rwanda	M	W	100
Burundi	M/S	W	50
Zambia	S	W	50
Malawi	S	W	50
Mozambique	S	W	25

3.1 The Eastern and Western Branch of the EARS

The geothermal situation inside the EARS is controlled by the geological and structural setting. One main characteristic when comparing the geothermal potential of the countries in East Africa is the difference between the eastern and western branch of the Rift. Both branches are described and analyzed in Hochstein (2005). Figures 1 and 2 in Hochstein (2005) that illustrate the different features in the eastern and the western branch can be found at the end of this paper.

As a result of the comparison between the eastern and the western branch of the Rift system, the geothermal potential of the eastern branch is about ten times higher than the geothermal potential of the western branch.

This is also shown in Table 2. In the third column the East African countries are allocated to their position in the Rift system. Only in Tanzania both branches are represented and intersect in the area of the Ngozi volcano. Northern Tanzania shows active high enthalpy geothermal e.g. at the Kilimanjaro. Ngozi is the southernmost manifestation of the eastern branch as well as of a high enthalpy reservoir. It shows an estimated reservoir temperature of 220 to 240°C and might have a geothermal potential of about 100 MW_{el}.

Uganda is located at the western branch of the EARS. As a result of its location, the estimated value of 450 MW_{el} (McNitt 1982) seems to exaggerate the geothermal potential that can be realistically expected.

3.2 EARS from North to South

There is also a change in volcanic activity and geothermal features going from North to South along the EARS. This is also shown in Table 2.

In the northern part of the Rift, the eastern branch is predominant with the highest geothermal potential in Ethiopia and Kenya. The area is characterized by active volcanism and therefore high enthalpy resource types exist in addition with also medium and low enthalpy resources.

The countries located in the middle section can feature either high or low potentials. The geothermal potentials depend on their position on the eastern or western branch of the Rift. The western branch is characterized by medium to low temperature resource types.

In the south only the western branch exists and the geothermal potential is generally low. Only low to medium enthalpy resource types exist here.

Using new technologies like EGS, new and efficient drilling methods, and more efficient power plants will add to the geothermal potential of the entire Rift. EGS is more or less independent of location and can be used in volcanic as well as non-volcanic resources. Refined drilling technologies will allow to drill closer to hot volcanic reservoirs while more efficient drilling techniques will allow to drill deeper into sedimentary reservoirs and therefore to produce higher temperature brine. Using these new technologies the spatial distribution of the geothermal potential will be basically the same as with current technologies, but in all of the EARS the technical potential will be increased by 10 times or more.

4. CONSEQUENCES OF THE REGIONAL DISTRIBUTION OF RESOURCE TYPES

The different resource types with their distinct characteristics regarding geological settings and temperature ranges and their specific location in different areas of the EARS as shown in section 3 show significant consequences when it comes to geothermal potentials, technologies and production prices for geothermal electricity.

4.1 Technology

Depending on the temperature range of the geothermal resource, the conversion technology changes which is utilized for electricity production. For high enthalpy resources geothermal steam is directly used in a flash turbine cycle to produce electricity. The higher the temperatures, the more efficient becomes the power generation.

Medium enthalpy resources need a binary cycle power plant to generate electricity. To increase efficiency of the power generation, a different working fluid that evaporates at lower temperatures than water is utilized. Common methods are ORC and Kalina cycle power plants. The efficiency of binary power plants is also depending on temperature.

With a constant production rate of 100 kg/s a high enthalpy direct steam power plant produces about 17 MW_{el} at a temperature of 300°C. A binary power plant with the same production rate of 100 kg/s will only generate about 3,5 MW_{el} electricity at a temperature of 150°C.

4.2 Exploration

A volcano-related reservoir can be detected by surface manifestations (typically fumaroles) and its subsurface dimensions are usually explored by using geophysical methods like MT (magnetotellurics) and TEM (transient electromagnetics). With these geophysical methods, the physical differences in material characteristics between the clay alteration zone at the top of a geothermal reservoir, the geothermal reservoir itself and the surrounding rocks can be detected and modelled.

Other exploration methods have to be used in a medium or low enthalpy resource type that consists of a reservoir in a sedimentary basin or up streaming hot water along a fault. Beside also necessary geological and geochemical surveys, e.g. a seismic survey is the appropriate geophysical technique to be used (Kraml, 2008).

Planning and executing a MT or TEM in low to medium enthalpy resources, where no high temperature alteration is present, is not appropriate at all. There have been several cases in the southern part of the EARS where tenders from funding agencies as well as proposals from exploration companies were asking for or were offering especially MT and TEM services to explore the resource, even though only low to medium enthalpy resource types exist in that area and no active shallow volcanic activities are present.

4.3 Megawatts

The difference in conversion technology as described in section 4.1 means that the total geothermal electricity production from a project will be significantly less in the Western branch and the southern part of the Rift when compared to a project in the eastern branch or in the northern part of the Rift.

A large geothermal resource like the Olkaria field in Kenya allows drilling many wells to build a centralized geothermal power plant. Plant sizes of 20, 50 or even more than 100 MW_{el} are installed. Medium enthalpy resource types usually allow drilling of only 2 or 3 production wells. The sizes of the binary power plants in these resource types are therefore smaller and typical plant sizes will range between 1 and 10 MW_{el}.

Small ORC binary power plants with up to 500 kW_{el} can be installed where hot water with a temperature between 80 and 120°C is produced. The flow rates from shallow wells define the size of the plant. Only minimal flow rates of less than 15kg/s are needed for a single ORC module. With higher flow rates extra modules can be added. These easy to develop projects may play an important role in the future when it comes to rural electrification in the East African countries.

4.4 Price

The price of geothermal power production is defined by the CAPEX, especially by drilling and infrastructure costs. The decisive factors of the economic feasibility of a geothermal project are the temperature in °C and the flow rate in kg/s of geothermal steam

or brine. Drilling costs depend on the depth of the reservoir and the number of wells. Project sites at the slope of volcanos, in remote areas or at protected sites (e.g. national parks) increase the CAPEX and therefore raise the price per kWh of electricity produced.

The cost per MW of geothermal electricity produced also changes with smaller projects and thus higher costs in the West and the South of the EARS. In the geothermally most favorable regions in the North and the eastern branch of the Rift prices of below 10 USct/kWh can be realized. In the South and the western branch of the Rift prices of more than 10 USct/kWh, sometimes even more than 18 USct/kWh depending on temperature and drilling depth can be expected.

Small geothermal ORC binary power plants using low temperatures as described in section 4.3 need a sales price above 18 USct/kWh. In rural areas, where electricity is mostly generated by using diesel generators, these small geothermal installations are still competitive and avoid CO_2 emissions.

Using new and more efficient technologies the current prices will be reduced by a higher productivity of steam and / or brine and a lower CAPEX because of more efficient drilling and power plant technologies. The price per kWh of geothermal electricity using new technologies is currently above 25 USct/kWh. Therefore their development and use is limited to countries like the US and Europe which fund R&D and the application with high feed-in tariffs. When the price has come down to below 15 USct/kWh the application of new technologies will be possible in the EARS countries.

4.5 Example Tanzania

Geothermal Power Tanzania Ltd. started to develop geothermal projects in different regions of Tanzania.

The Ngozi volcano project has an expected potential of up to 100 MW_{el}. The project development is planned in stages starting with a 10 MW_{el} plant on the basis of three production and one injection well. The expected temperatures are between 220 to 240°C. A first slim hole well into the top of the reservoir shall prove the temperature and give an idea about the permeability of the reservoir. In the economic model the production rate in kg/s is the decisive factor for the price of the electricity produced. Depending on the flow rate a realistic price will be in a range of 10 to 16 USct/kWh.

In the Rufiji basin temperatures of 140°C have been proven by drilling in a sandstone aquifer in a depth of 1200 m. Several small binary power plants of up to 5 MW_{el} could be installed within the basin. The permeability of the geothermal reservoir has not yet been tested. The price of the electricity produced with this temperature is expected to be above 16 USct/kWh depending on the flow rate.

Along Mbaka fault several hot springs with temperatures above 50°C can be found. Chemical geothermometry shows reservoir temperatures of up to 180°C. Depending on the flow rate from about 800 m deep production wells and their number, binary power plants of up to 5 MW_{el} may be installed. With small binary power plants the price for the geothermal electricity produced will be about 16 USct/kWh.

The northern part of Tanzania has not yet been sufficiently explored. High enthalpy resources exist, especially at Mount Kilimanjaro. Several medium temperature resources exist as well. On the information available the possible geothermal potential of the northern region and price estimates therefore cannot be given at the moment.

The 650 MW geothermal potential estimated by McNitt (1982) is based on current technologies. With new technologies in geothermal exploration and exploitation the technical geothermal potential of Tanzania will be above 4000 MW.

5. MANAGING EXPECTATIONS

The information given above show that the overall geothermal potential of a country, the sizes of power plants and their specific output as well as the prices for the electricity produced from power plants is very different between and even within the several countries that are situated in the EARS. These variations are caused by the geological setting of the Rift system and the specific location of country in the Rift. Being located on the western or eastern branch of the Rift as well as being located in the north or in the south of the Rift makes the difference.

To understand Kenya with its power plants in Olkaria as a blueprint for the whole region of the EARS based on current technology is not appropriate and misleading. Any decision maker, politician, investor or fund manager should base his expectations on the simple scheme given above. The task of geothermal experts is to substantiate these findings. Stakeholders in the geothermal development of East Africa have to develop an understanding of the realistic potential and situation of geothermal energy production. Once that understanding is given, appropriate mechanisms, legal frameworks, funding mechanisms and feed-in tariffs can be designed. Also new technologies and their application in the EARS have to be kept in mind.

The definition of resource types as well as using international codes and standards on the assessment of resources is fundamental to manage the expectations. National stakeholders, international funding agencies as well as investors depend on the adequacy and accuracy of the results.

An international effort is on its way by different international stakeholders to define geothermal resource types and classifications and to design reporting codes. The goal is to set international standards which will be appropriate for all countries and accepted by all stakeholders in the geothermal world. The activities of the International Geothermal Association (IGA) are part of this effort. The assessment of the geothermal potential and situation in the EARS shall follow these standards to build a foundation of common understanding of the geothermal resources in the EARS.

6. FUNDING SCHEME FOR GEOTHERMAL DEVELOPMENT IN THE EARS

The geothermal development in the EARS is based on funding mechanisms and programs by national and international agencies like the World Bank, the African Development Bank, KfW, DEG, JICA, ICEIDA and many other national development agencies.

The different programs are focusing mainly on basic structures like legal framework, capacity building and preliminary exploration. In Kenya also the construction of power plants as well as the installation of national companies and their activities have been funded.

The Geothermal Risk Mitigation Facility (GRMF) is funding surface exploration and first drilling activities and will help starting projects in the East African region.

Out of intrinsic reasons funding agencies are focusing on large projects and large funding volumes. Even though all the countries of the EARS are on the list to be supported by the agencies, only a few will receive project funding, because many projects will be too small or do not require a large budget. The countries that will be in the focus of project funding can be deducted from the simple scheme presented above. There are countries in the EARS which have a realistic potential of less than 50 MW from several small rural geothermal binary power plants. However, with a current total power supply of about the same amount even the first 3 MW produced by a geothermal power project would make a difference.

Based on the understanding of the distribution of the geothermal potential, the size of projects and the electricity price of power generation an appropriate funding mechanism can be designed to cover all of the EARS countries. This mechanism could promote geothermal of all resource types in the medium and high enthalpy range.

The basic structures of the proposed mechanisms are:

- The funding should be grant funding to allow for a defined and acceptable price for the kWh of produced geothermal power.
- The grant should be given in the drilling phase.
- The size of the grant should be defined based on a financial model with input parameters depending especially on resource type (high, medium or low enthalpy, drilling depth), resource quality (temperature and production rate) and CAPEX (infrastructure, power plant and drilling costs). The target to define the grant size would be a specified and acceptable price for the kWh of produced geothermal power.
- The grants should be paid out by a fund, which is funded and managed by the international donor community.
- The grant should be open to government entities, PPP and private developers.

A national geothermal development company may be a good solution in one country, but might not fit in another country, especially when it only has few and small resources. The authors believe from their experience, that a PPP between a government entity and an experienced private developer taking the lead is the best choice to develop geothermal resources in most countries of the EARS in a fast and efficient way.

The GRMF program also uses a financial model to define the amount of grants to the projects. This experience can be used in the proposed funding mechanism.

The advantages of the proposed mechanism are:

- A defined and acceptable electricity price from geothermal power production which is independent of the type and quality of the geothermal resources present in the country.
- A promotion of geothermal development in all of the countries located in the EARS.
- The grants will be small in countries which are blessed with abundant and high enthalpy resources and large in the countries with medium enthalpy resources. The amount of an individual grant for a medium enthalpy geothermal project will be relatively small, since the number of wells drilled for a single power plant compared to a high enthalpy resource is limited.
- Grants in the drilling phase will relief the project of an investment barrier, which is mainly seen in drilling risk.
- The experience in project development and the understanding of resources is shared inside the program and helps to eliminate mistakes.

7. CONCLUSION

Understanding the geological setting of the East African Rift System discloses the differences in resource types, geothermal potential, expected amount of electricity (MW_{el}) produced and electricity price between the countries of the EARS.

This is the basis to manage expectations present in the different countries.

Based on this understanding, support mechanisms to promote the development of geothermal resources in the EARS can be designed appropriately.

The implementation of new technologies in geothermal in the EARS countries will be of high importance for the future development of geothermal power production as it will enable all of the countries also in the South and the western branch of the Rift to implement geothermal power to a considerable extend into their electrification scheme.

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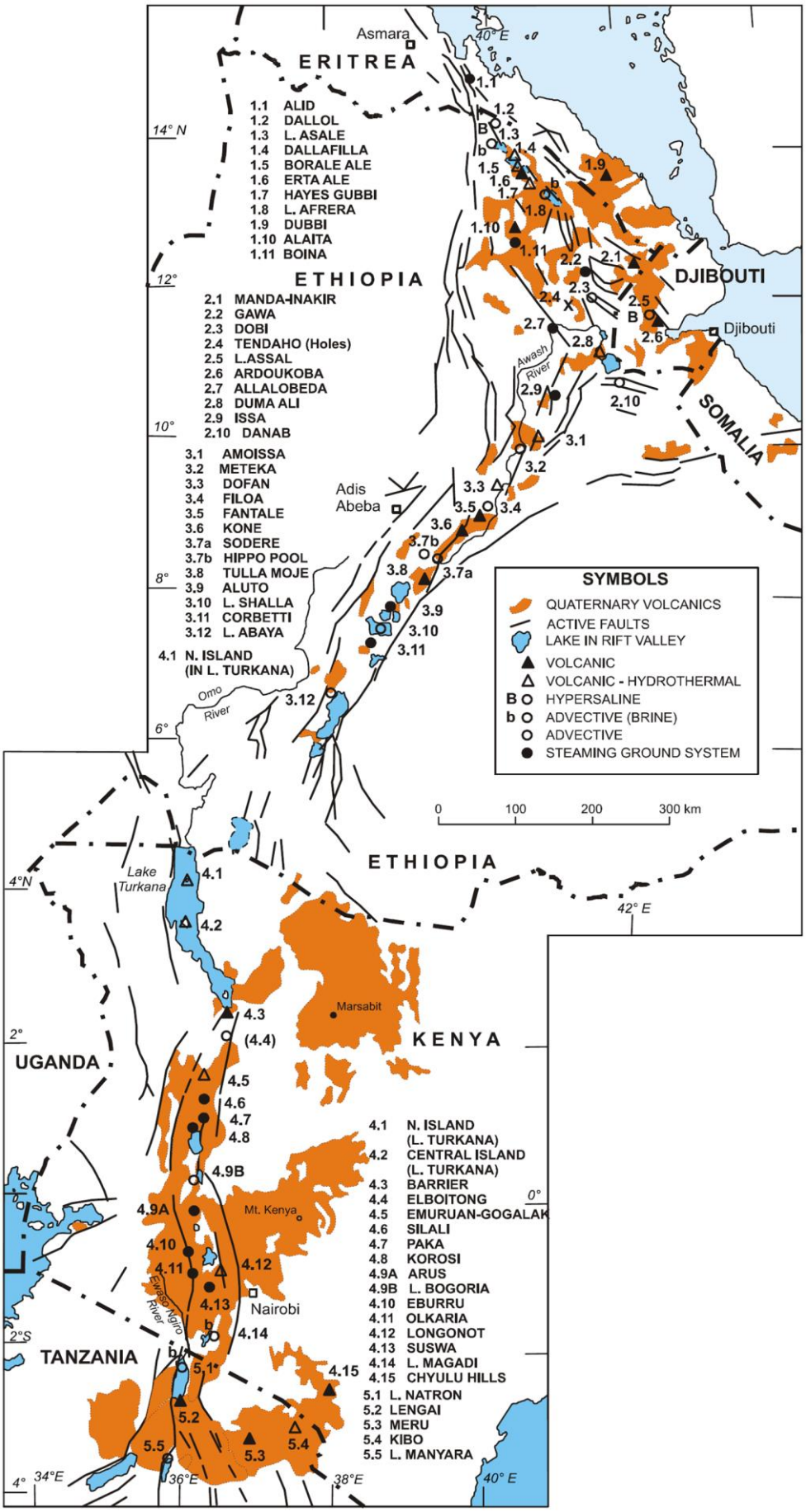

Figure 1: Location of major geothermal systems along the Eastern Branch of the East African Rift System (Hochstein 2005).

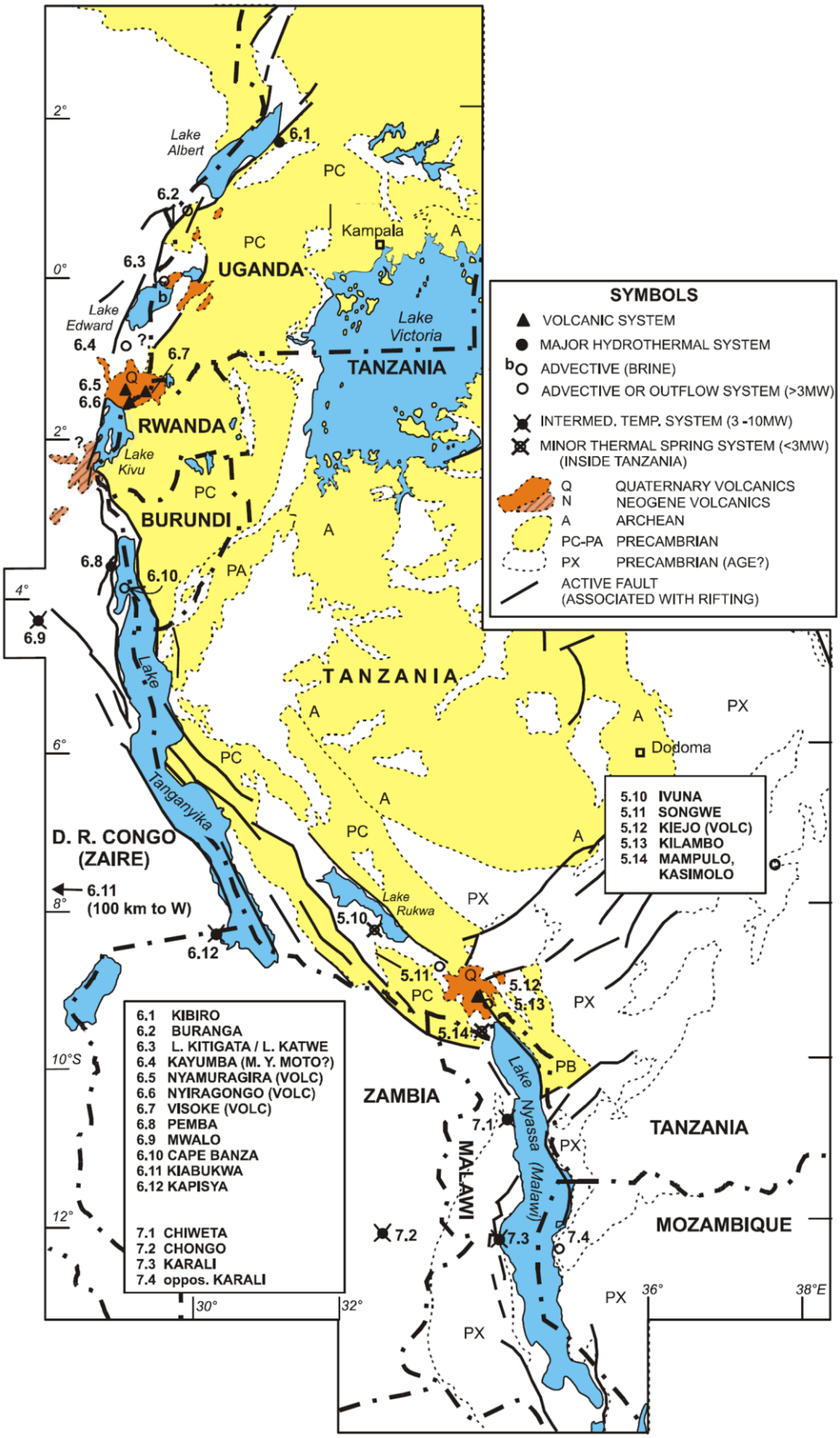

Figure 2: Location of major geothermal systems along the Western Branch of the East African Rift System (Hochstein 2005).