Geothermal State of Play for East African Countries: Public and Private Sector Investment Opportunities in Djibouti, Ethiopia, Kenya, Rwanda, Tanzania and Uganda

Dr. Peter Omenda,
UNIDO Consultant
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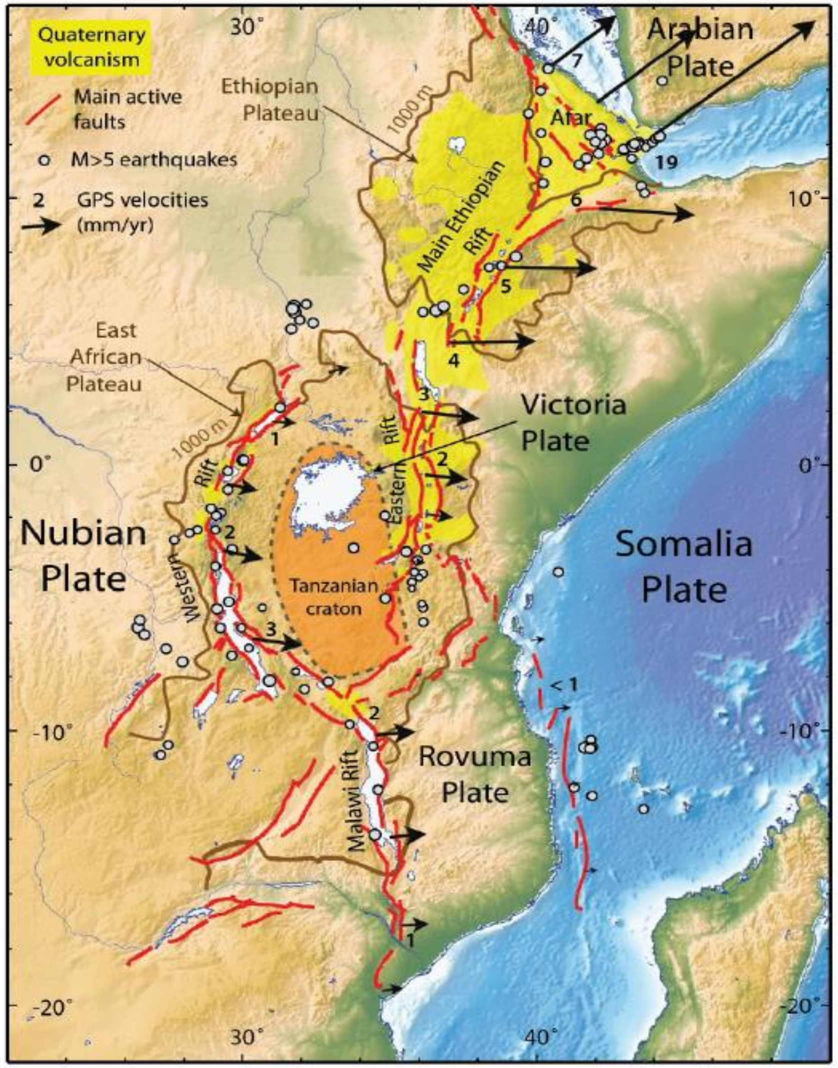
Regional Geological Setting

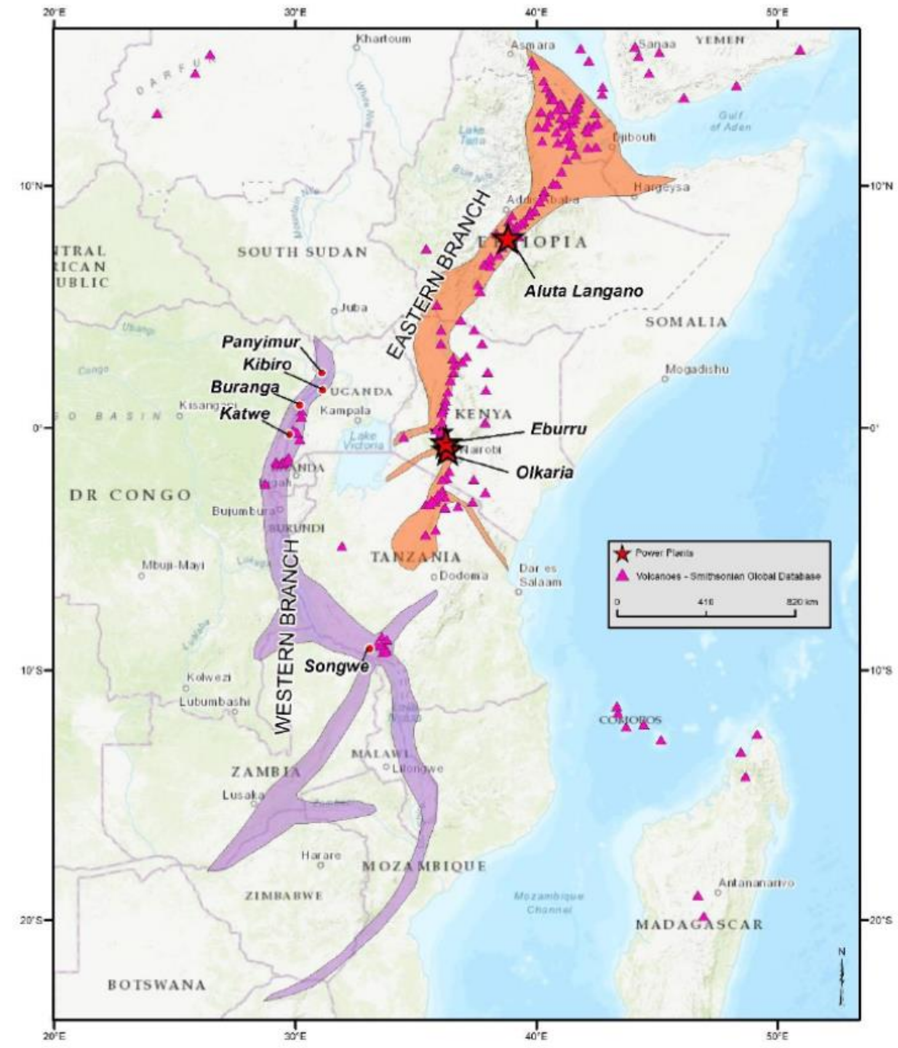


Adopted from Calais, 2016). Le rift est Africain, laboratoire de la rupture continentale. Geosciences 21

- The East African Rift System has an opening rate of up to 7 mm/y in the north and less than 1mm/year in the Kenya Rift and southwards
- Extension resulted in updoming of the asthenosphere under the rift which then produced magma bodies under the Quaternary volcanoes
- Geothermal resources in the rift are a product of the shallow magma bodies and elevated heat due to elevated asthenospheric mantle/thinned crust

East African Rift System Branches

- The East Africa African Rift System has two branches, namely, Eastern and Western Branch
- The Eastern Branch extends from Djibouti in the north through Ethiopia, Kenya and northern Tanzania
- The Western Branch extends from Uganda, Rwanda, DR Congo, Burundi, Tanzania, Malawi, Zambia and Mozambique
- The Eastern Branch is more volcanically active and has Quaternary Basalt-trachyte-rhyolite volcanoes
- The Western Branch is less active and has potassic basaltic eruptives, and less extension



Hinz, Nick & Cumming, William & Sussman, David. (2018). Exploration of fault-related deep-circulation geothermal resources in the western branch of the East African Rift System: examples from Uganda and Tanzania.

Geothermal Systems

Geothermal Type	Resource Temperature
Non-electrical grade	<100°C
Low temperature	100°C to <150°C
Medium temperature	150°C to 190°C
Medium-high temperature	190°C to <230°C
High temperature	>230°C to <300°C
Ultra-high temperature	>300°C

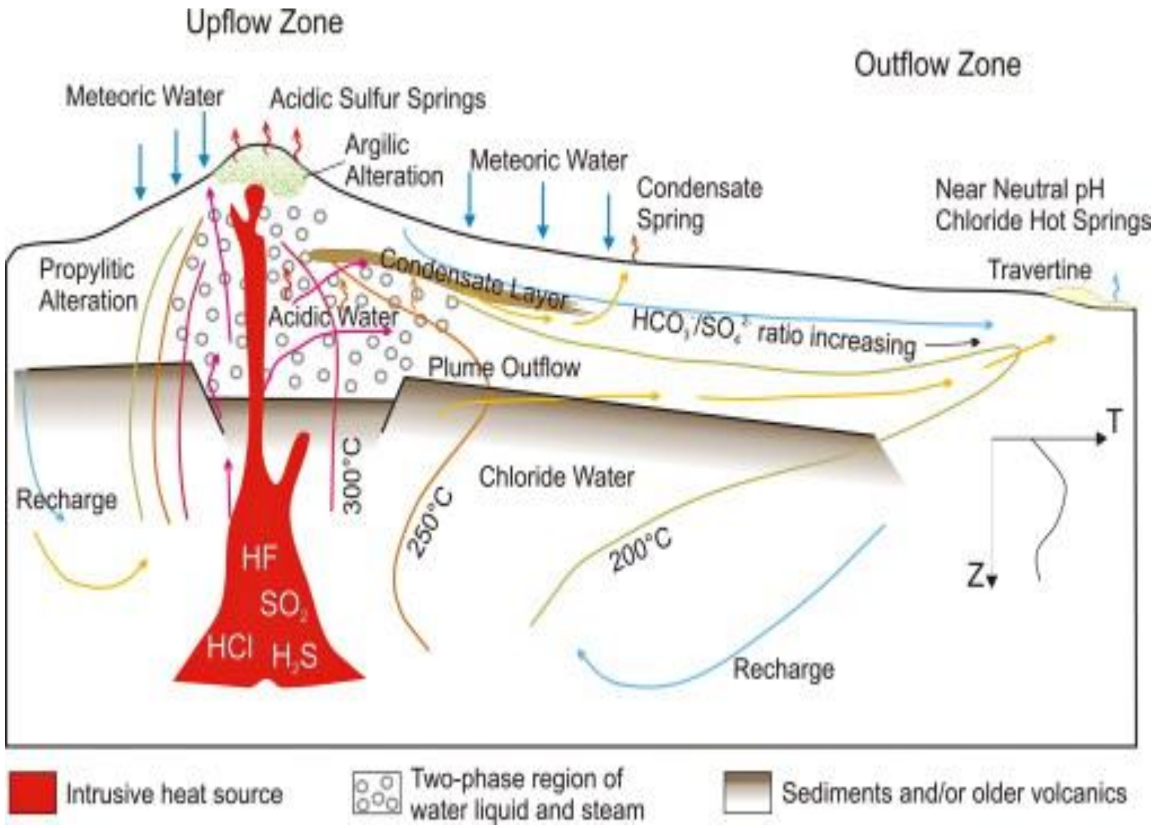
- The low temperature systems are suitable only for Direct use
- The medium temperature resources are usually liquid dominated and good for ORC and direct use
- The high-temperature and ultra-high temperature are suitable for all uses and all technologies

Sanyal, S. (2005). PROCEEDINGS, Thirtieth Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, January 31-February 2, 2005 SGP-TR-176

Geothermal Systems/Play Types in EARS

Volcanic hosted Geothermal systems

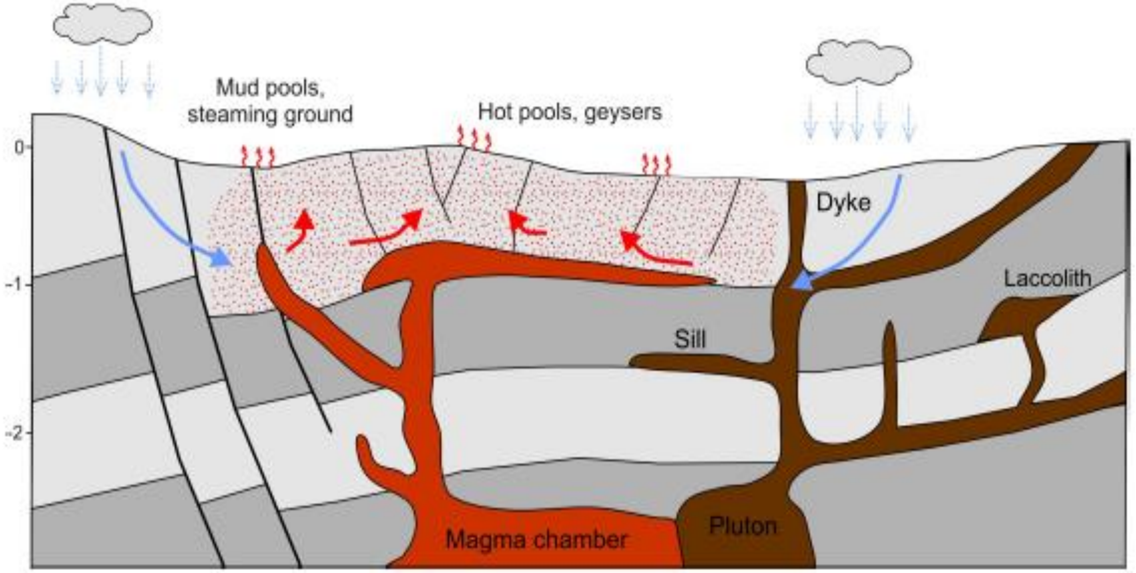
- Heat transfer is due to a convective reservoir driven by hot rocks or magma under the volcano with an up-flow zone under the mountain and outflows to the sides
- Type common in Djibouti, Ethiopia, Kenya, and Tanzania. Production at Aluto, Olkaria, Menengai, Eburru and Paka geothermal fields



From: IGA and IFC. (2014). Best Practices Guide for Geothermal Exploration (2nd ed.). Bochum: IGA Service Company GmbH

Magmatic intrusion type

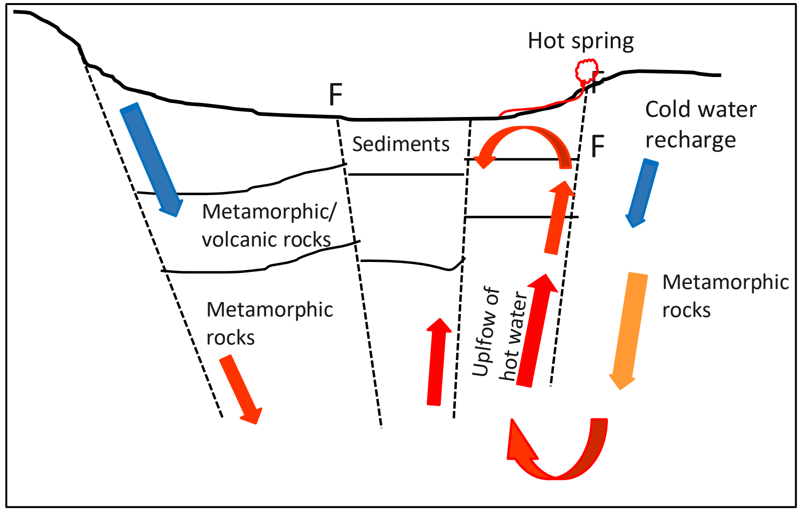
- Active magma chamber may not always produce volcanism, especially if magmatism is juvenile or if the magma is siliceous
- Magma chambers may exist underneath controlled by faults and fractures
- Active high and medium temperature geothermal systems may be generated by such heat sources
- Typical case is the Tendaho geothermal field in Ethiopia

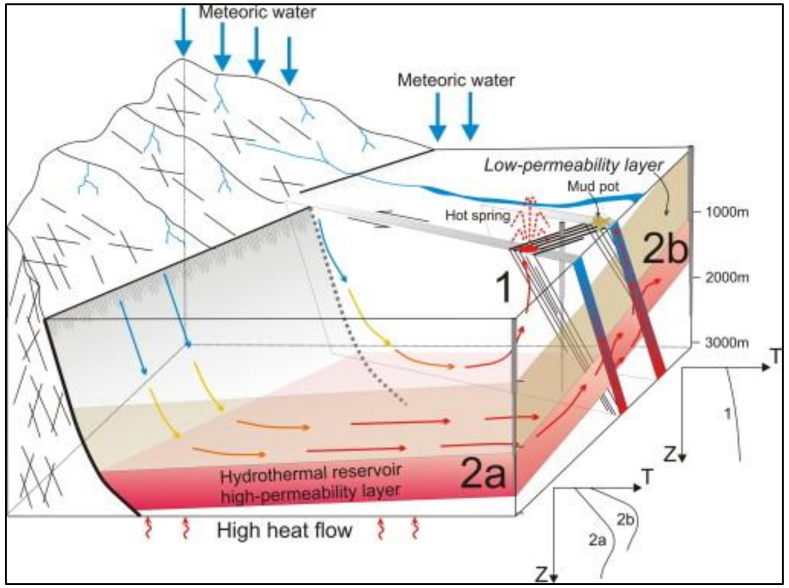


From: IGA and IFC. (2014). Best Practices Guide for Geothermal Exploration (2nd ed.). Bochum: IGA Service Company GmbH

Extensional Domain Play Type - Fault controlled

- Non-magmatic convection-dominated geothermal play systems are either fault controlled or fault-leakage controlled. In purely fault controlled play systems, convection occurs along the fault and is commonly combined with infiltration of meteoric water along the fault planes
- In fault-leakage play systems, the fluid leaks from the fault into a permeable concealed layer. In turn, fluids can move from a permeable layer into the fault zone and from there to the surface.
- Type commonly associated with the Western Branch of EARS and some locations in Eastern EARS





Moeck, I. S., 2014. Catalog of geothermal play types based on geologic controls. Renewable and Sustainable Energy Reviews, 37 (2014) 867–882

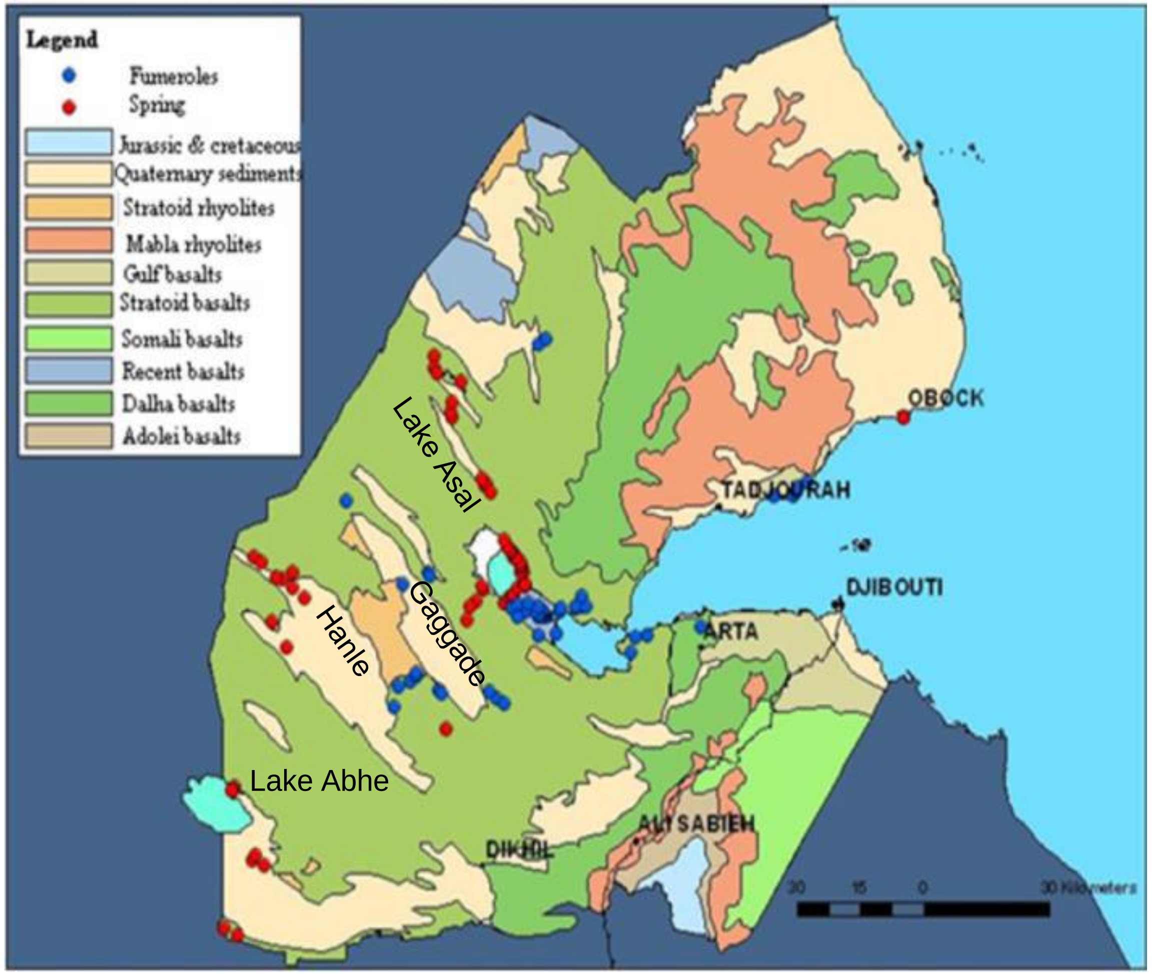
Geothermal Exploration Methods in East Africa

Method	Eastern branch	Western branch	Shallow resources
Characteristics	Volcano hosted, magma heat sources, distributed heat, deep anomalies	Fracture/fault-controlled, deep circulation, localised anomalies	Commonly low- to medium-temperature resources controlled by fault systems
Geological mapping	Lithologic and structural mapping and fault kinematics	Detailed structural and litho-stratigraphic mapping	Detailed structural and litho-stratigraphic mapping
Geophysics	Gravity, seismic (Vp/Vs), MT, TEM, heat flow, occasional TGH	Gravity, seismic, TEM, (optional MT), heat flow, TGH	Gravity, seismic, TEM, heat flow and TGH
Geochemistry	Fluid (hot spring), gas (fumaroles), soil gas (radon and CO_2)	Fluid (hot spring), soil gas (radon and CO_2)	Soil gas (CO_2 and radon surveys); fluid sampling and analysis

Geothermal Resources and Potential In East Africa

Djibouti

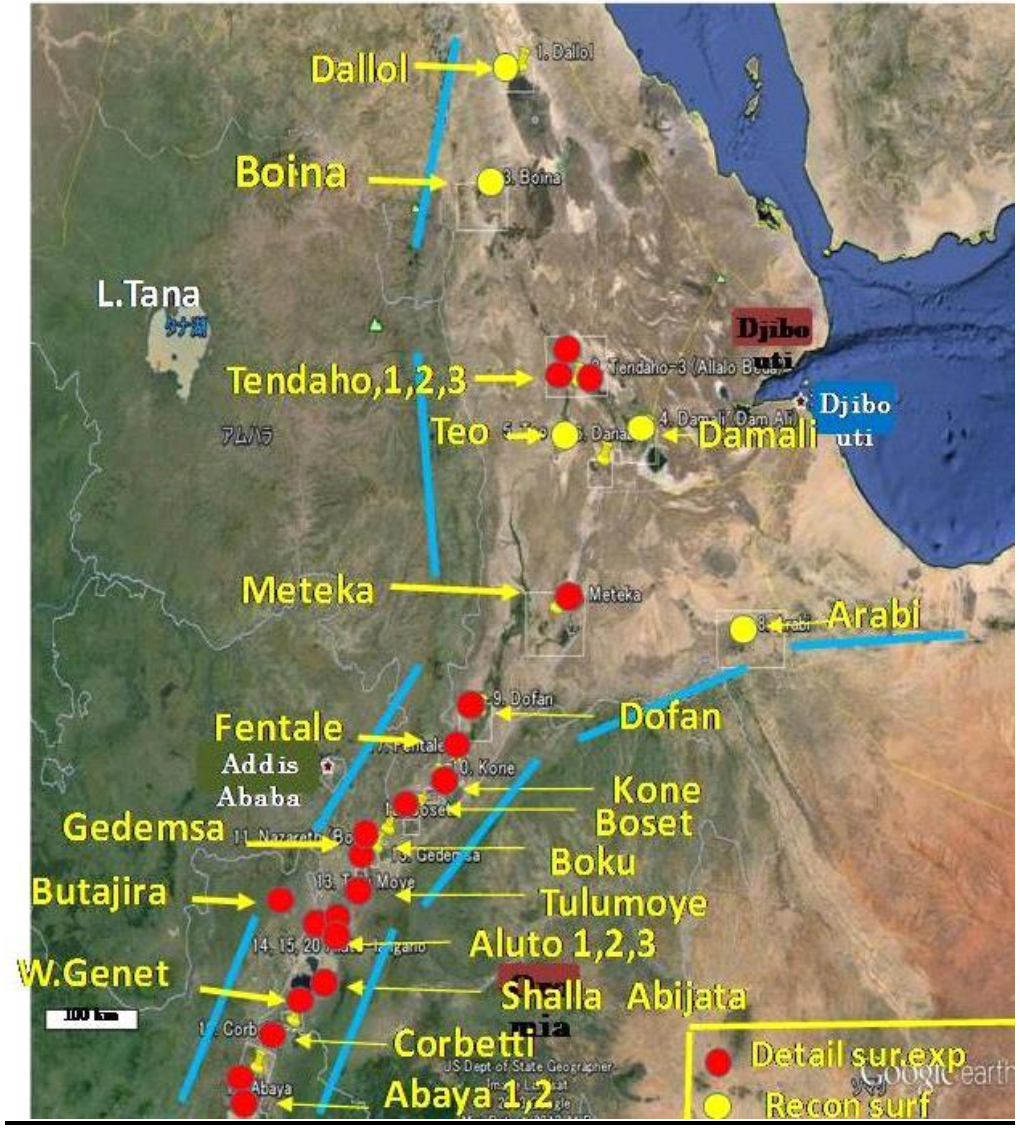
- The promising prospects lie along the main NW-SE active axis of spreading from the Gulf of Tadjoura
- The studies found potential area in the Asal, North Ghoubhet, Hanle Graben and Fiale, Gale La Koma, Hanle Garrabayis, and Gaggade prospects
- Most drilling has been undertaken within the Greater Asal field (Asal, Fiale, Gale La Koma)
- Reservoirs hot but – high salinity and temperature inversions common and low permeability



From: Moussa, O.A. and Souleiman, H., 2015. Country Report, Geothermal Development in Djibouti Republic. Proceedings World Geothermal Congress 2015. Melbourne, Australia, 19-25 April 2015

Ethiopia

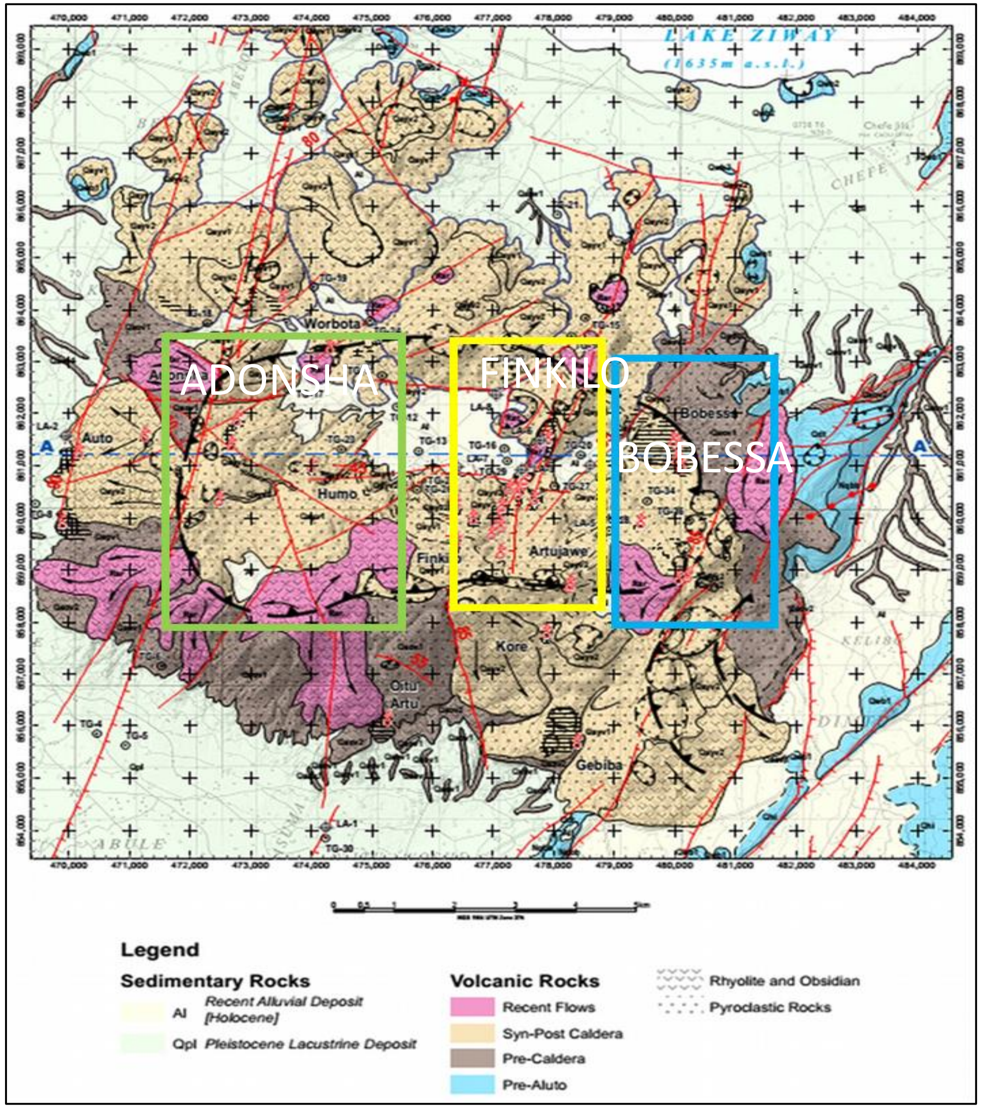
- Ethiopia has the longest section of the East African Rift system and the highest number of active volcanoes within the rift.
- Earliest recorded use of geothermal resources was in 1880 –wellness spas
- Aluto – Langano geothermal field is the best known



Map From: Fekadu, M. Kebede, S. and Kassa, T., (2022). Geothermal Exploration and Development in Ethiopia: a Country Update. Proceedings, 9th African Rift Geothermal Conference Djibouti, 3rd November – 5th November 2022

Aluto – Langano Geothermal Field

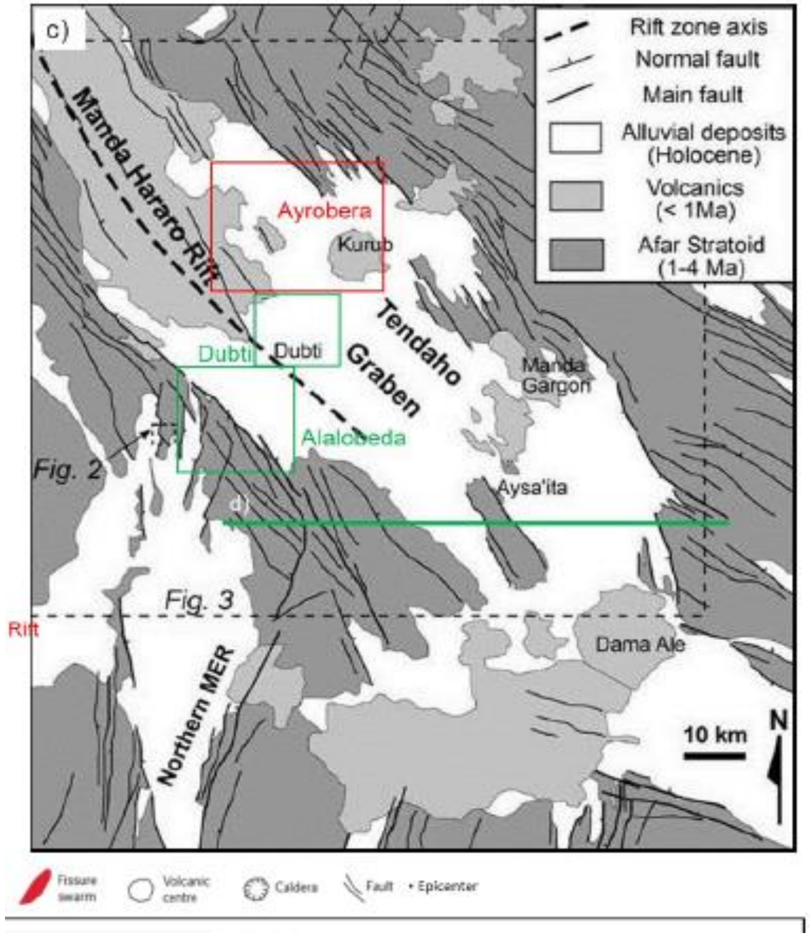
- Three sectors have been identified for development:
  - Finkilo – targeted for 35MW. Successful drilling along Artu Jawe fault zone ongoing.
  - Bobessa – One well drilled but still recovering. More wells planned. A 5 MW wellhead plant built and awaiting commissioning.
  - Adonsha - western sector. Fumaroles common along caldera rim. Drilling planned in the near future after Bobessa



Map from: Abebe, T., Pasqua, C., Kebede, S. 2016. Aluto Langano Geothermal Field (Ethiopia): Proposal of a new geo volcanological model by combining the existing data with modern studies. Proceedings, 6th African Rift Geothermal Conference, Addis Ababa, Ethiopia, 2nd – 4th November 2016

Tendaho

- Initial exploration of the Tendaho geothermal field took place in the 1970s and 1980s which culminated in the drilling of 3 deep exploration wells and 3 shallow wells (1993-1998)
- The Tendaho field has been divided into three sectors for ease of development, namely: Dubti, Ayrobeda, and Alalobeda
- The entire Tendaho field is estimated to have a potential of over 1,000MW.
- Drilling is planned in Alalobeda funded by AFD and World Bank
- Drilling in Ayrobeda is under consideration with funds from JICA



Stimac, J. Armadillo, E., Rizzello, D., and Mandeno, P. E., 2016. Geothermal Resource Assessment Report for Tendaho: Technical Review Report. UNEP and GSE

Tulu Moye and Corbetti Projects

- **Tulu Moye:**
  - Third area to have exploration wells drilled. It is under PPP development.
  - Five wells have been drilled after detailed feasibility studies
  - Most wells either have low reservoir temperatures or low permeability at depth. Temp inversions common. Still heating.
  - Two wells have good temperatures but low permeabilities and so unable to discharge
  - TMGO is considering next steps but the field is still considered viable despite the drawbacks

- **Corbetti:**
  - Potentially one of the largest geothermal prospects in Ethiopia with three large Quaternary volcanoes occurring as resurgent domes
  - High temperature has been modeled from surface studies (MT/TEM, Geology, geochemistry)
  - Exploration drilling was expected to commence in 2023 but may experience some delays

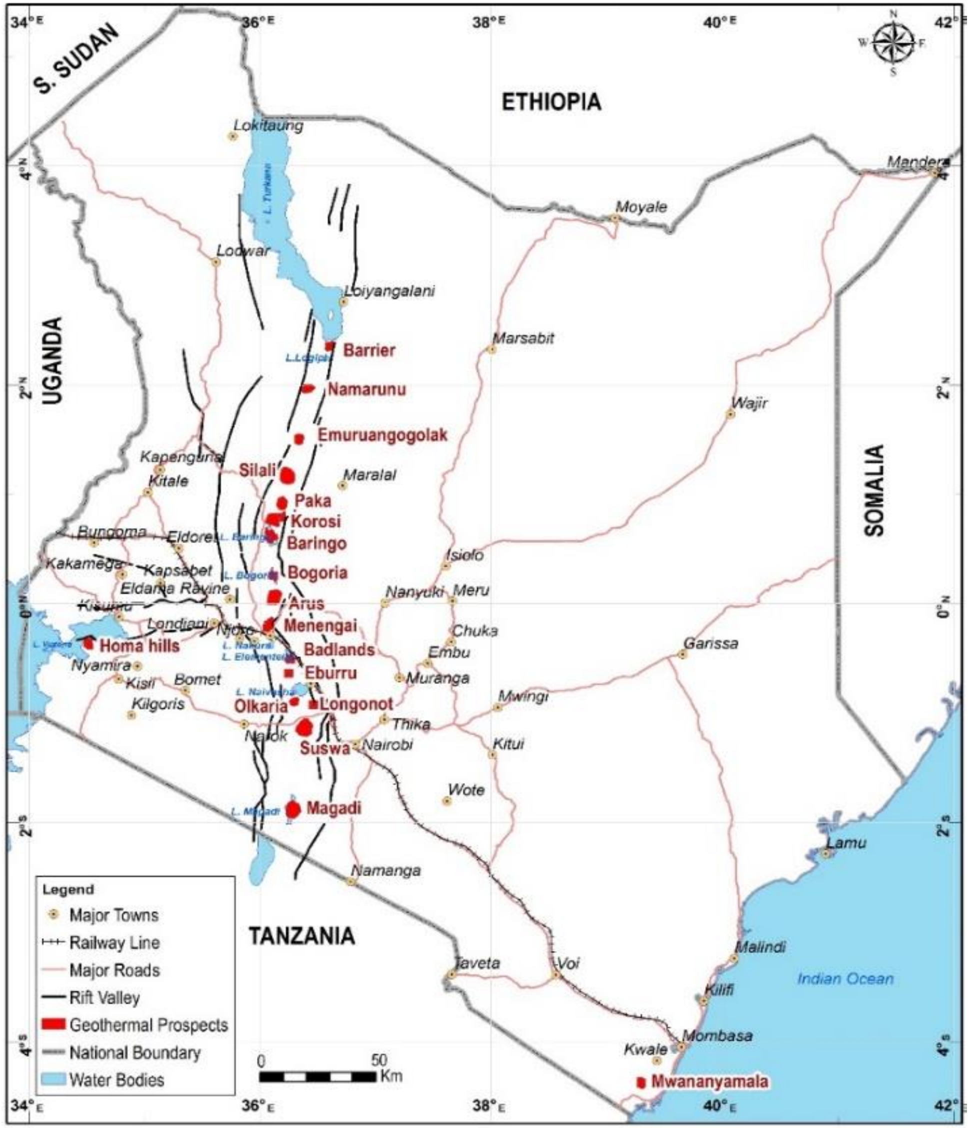
Power Generation Technologies

- **Aluto Combined Cycle and Wellhead plants**
- The 8.5 MW (7.3MW net) combined cycle pilot plant commissioned in 1998.
- The combined cycle Plant was developed by Ormat but hardly operated at full capacity
- Main challenges were: corrosion, probably un- appropriate design, lack of trained maintenance staff, insufficient O&M funds
- A 5 MW, Toshiba wellhead power plant has been constructed and is awaiting commissioning

Photos by Peter Omenda, 2023

Kenya

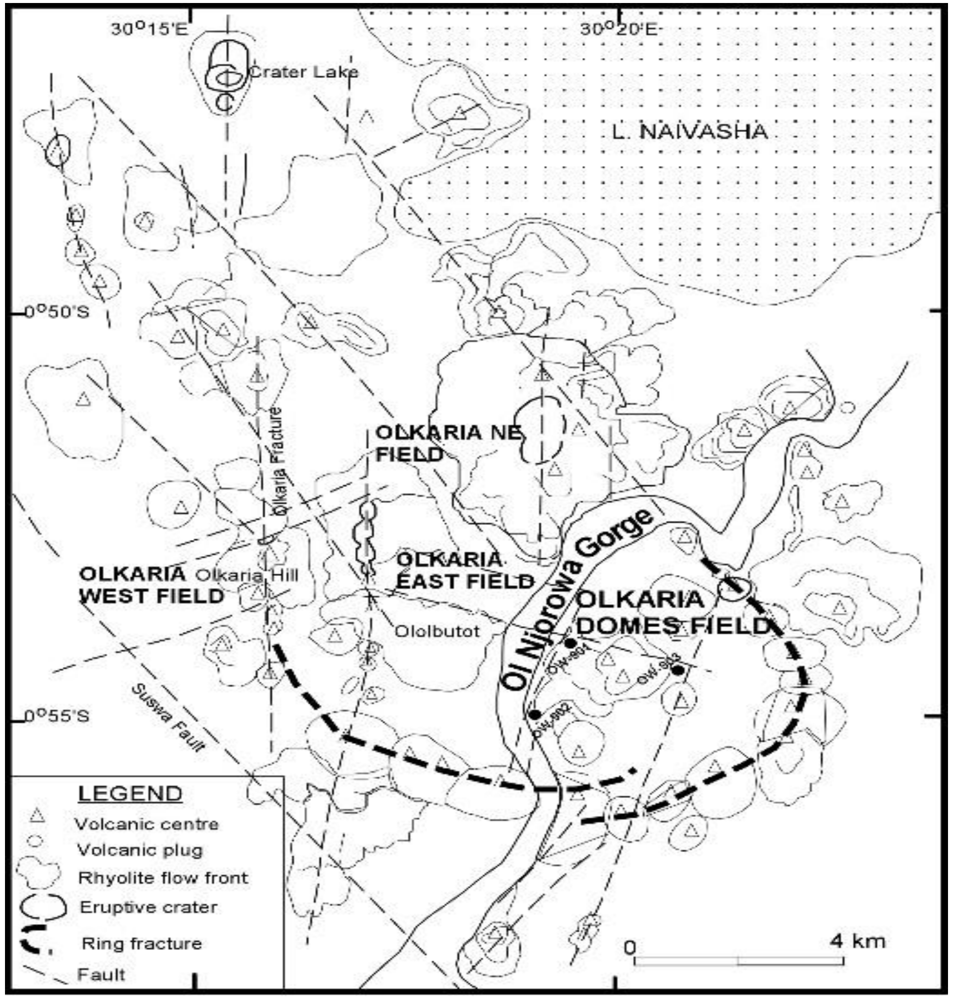
- The Kenya rift is part of the eastern EARS. The rift is well developed and at its axis occurs Quaternary caldera volcanoes most of which have geothermal potential
- The geothermal prospects and fields include the following:
  - Suswa,
  - Longonot,
  - Olkaria,
  - Eburru,
  - Menengai,
  - Paka,
  - Others: Korosi, Silali, Emuruepoli, Arus, Emuruangogolak, Namarunu, Barrier, Homa Hills



From: Geothermal Development Company

Olkaria Geothermal Field

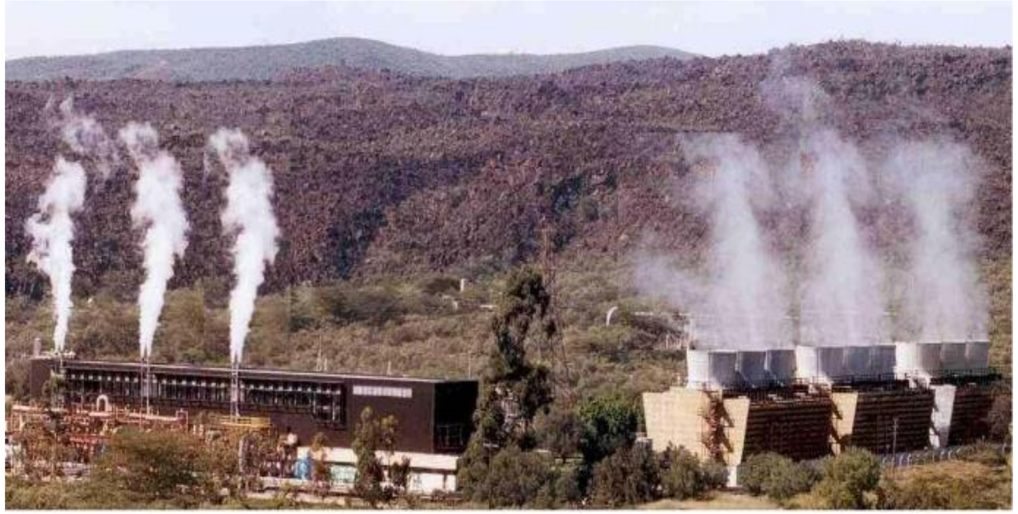
- The Greater Olkaria geothermal field is one of the largest geothermal fields in the world. Current installed capacity stands at 905MW.
- Additional 300MW and 58MW plants are close to commencement of construction
- Five power plants are in Operation:
  - Olkaria I Unit 4, 5, 6 (236MW)
  - Olkaria II – 1, 2, 3 (105MW)
  - Olkaria IV (150)
  - Olkaria V – 172MW
  - Olkaria III (155MW)
  - Oserian (3.6MW)



Omenda, P., Ofwona, C., Mangi, P.,, and Lupe, C. (2023). Country Update Report for Kenya 2020 – 2022: Proceedings World Geothermal Congress 2023, Beijing, China

Olkaria I and Wellheads

- Olkaria I, 3x15 (45 MW) (Mitsubishi turbine) that was commissioned in 1982-1985 has been decommissioned for rehabilitation to 63 MW funded by JICA
- 236 MW from 3 turbo-generators are operational with high efficiency. The new 86.88 MW plant is the largest single turbine in Kenya and with highest operational efficiency
- Olkaria 1AU 4&5 turbines are Toshiba while Unit 6 is Fuji turbine



Olkaria II and III Power Plants

- This field hosts the Olkaria II power plant. The plant consisting of 2X35MWe units was commissioned in 2003. A third 35MWe unit was commissioned in 2010. All three units are Mitsubishi turbines
- The geothermal field is home to Orpower4, Inc with installed capacity of 155MW (150MW net). This was the first geothermal PPP project in Kenya with first phase of commissioning in 2003. Ormat Energy Converter ORC units

Olkaria Domes field

- The Olkaria Domes field is home to Olkaria IV (150MW) plant and Olkaria V (172MW) plant and 37MW of well head plants. Olkaria IV turbines are Toshiba while Olkaria V is Mitsubishi (2x86.6)
- Wellhead power plants have a total installed capacity of 81MW and are operated at Olkaria I and Olkaria Domes fields. The wellhead power plants operate under FiT
- The equipment were manufactured and installed by GEG
- The Wellhead power plants have low efficiency compared to the large power plants

Eburru Geothermal project

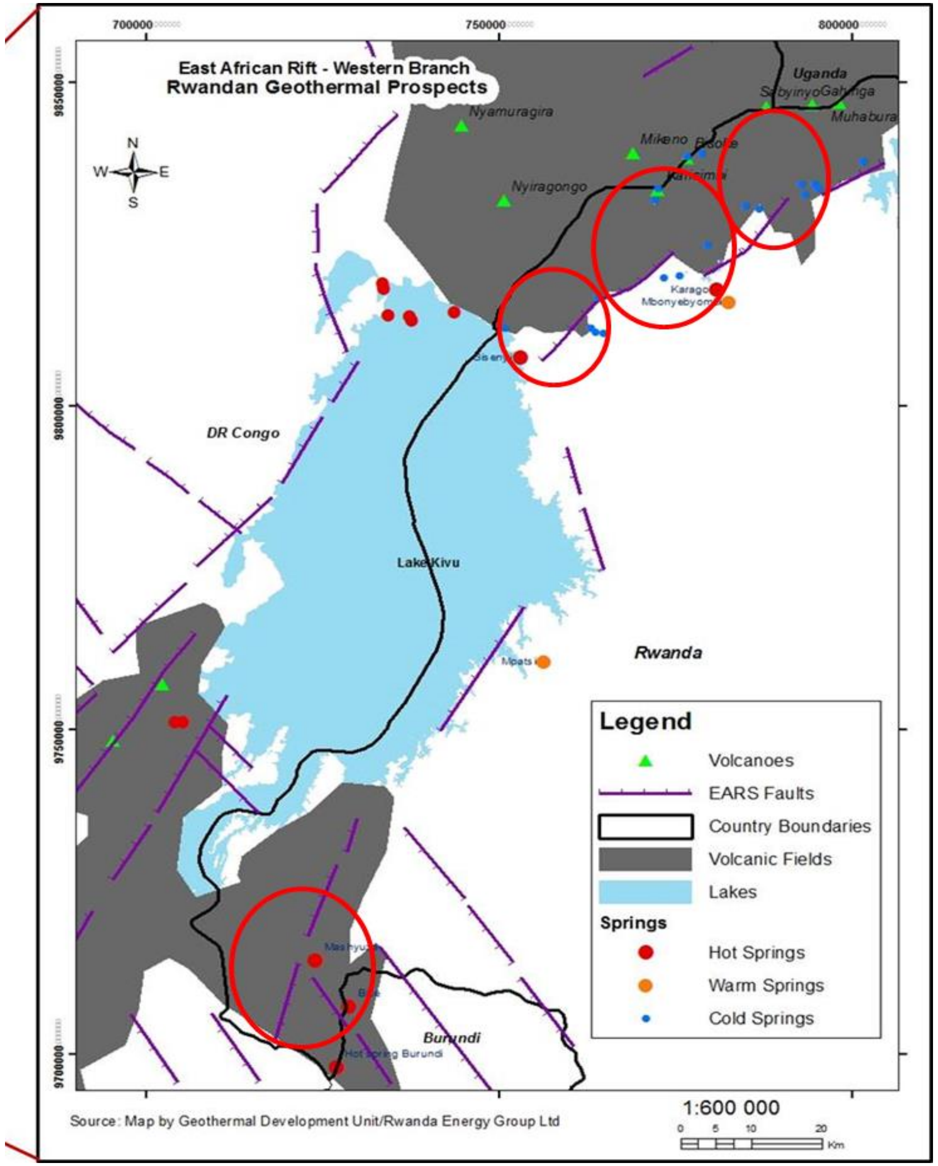
- Six wells were drilled in the prospect and out of which one intersected high temperature resource (1989-1991)
- A 2.40 MWe condensing pilot plant was constructed and commissioned in 2012 and feeds the 33 kV distribution line
- KenGen is drilling appraisal and production wells to upgrade the generation capacity to 25 MW
- The plant uses Elliott Turbine, USA.
- The plant has low efficiency due to various challenges

Menengai Geothermal field

- Production drilling at the Menengai geothermal field has proved steam equivalent to about 170MW on the wellhead.
- Three IPPs have entered into a steam sales agreement with GDC for power generation of 35 MWe each.
- The IPPs are Globeleq-Quantum Power East Africa Ltd., OrPower 22 Ltd (a consortium of Ormat, Civicon and Symbion Power) and Sosian Menengai Geothermal Power Ltd (SMGPL).
- 35MW SMGPL plant is undergoing commissioning – Screw Expander with ORC bottoming cycle

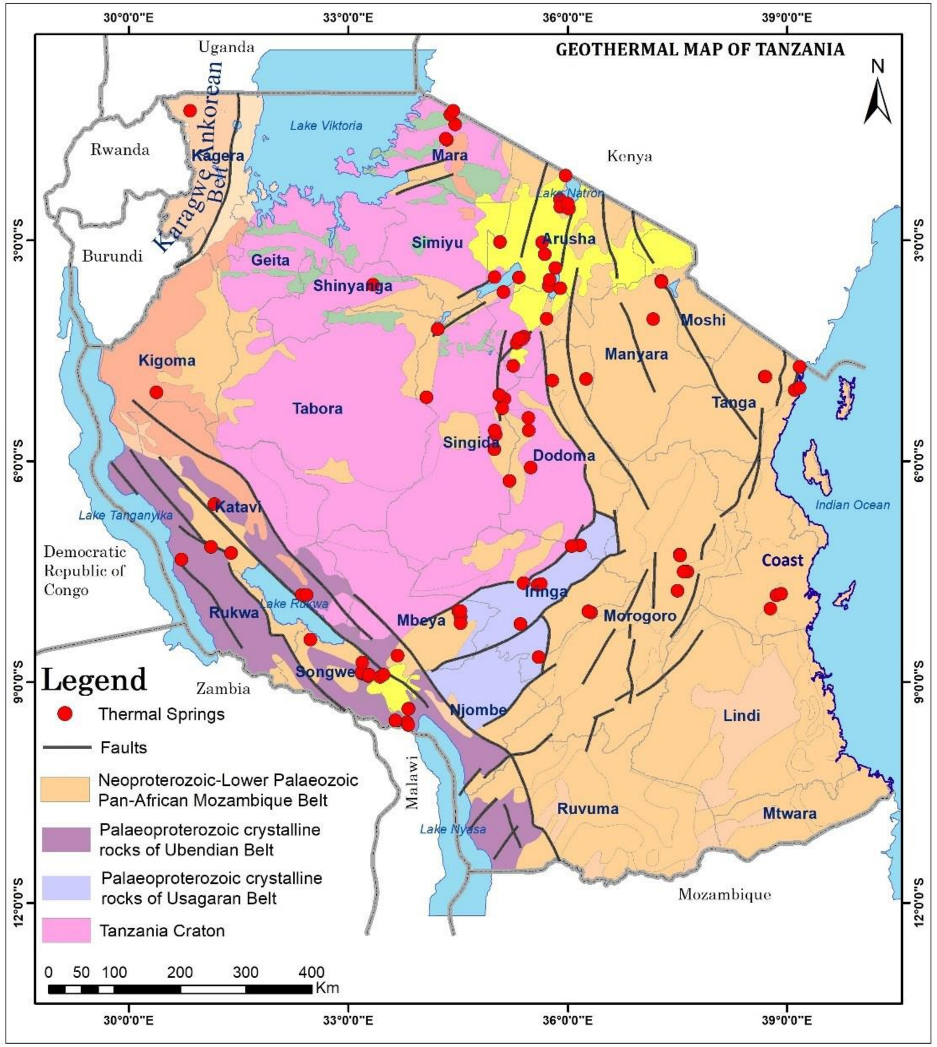
Rwanda

- Geothermal prospects in Rwanda are Gisenyi, Bugarama (Mashyuza), Kinigi, karisimbi, and Karago
- Drilling in 2013 at Karisimbi did not encounter a geothermal system
- Studies are ongoing to re-evaluate the resources for low to medium temp resource for small power generation and direct use
- Active research is currently ongoing in Mashyuza by the LEAPRE programme with funding from EU.



Tanzania

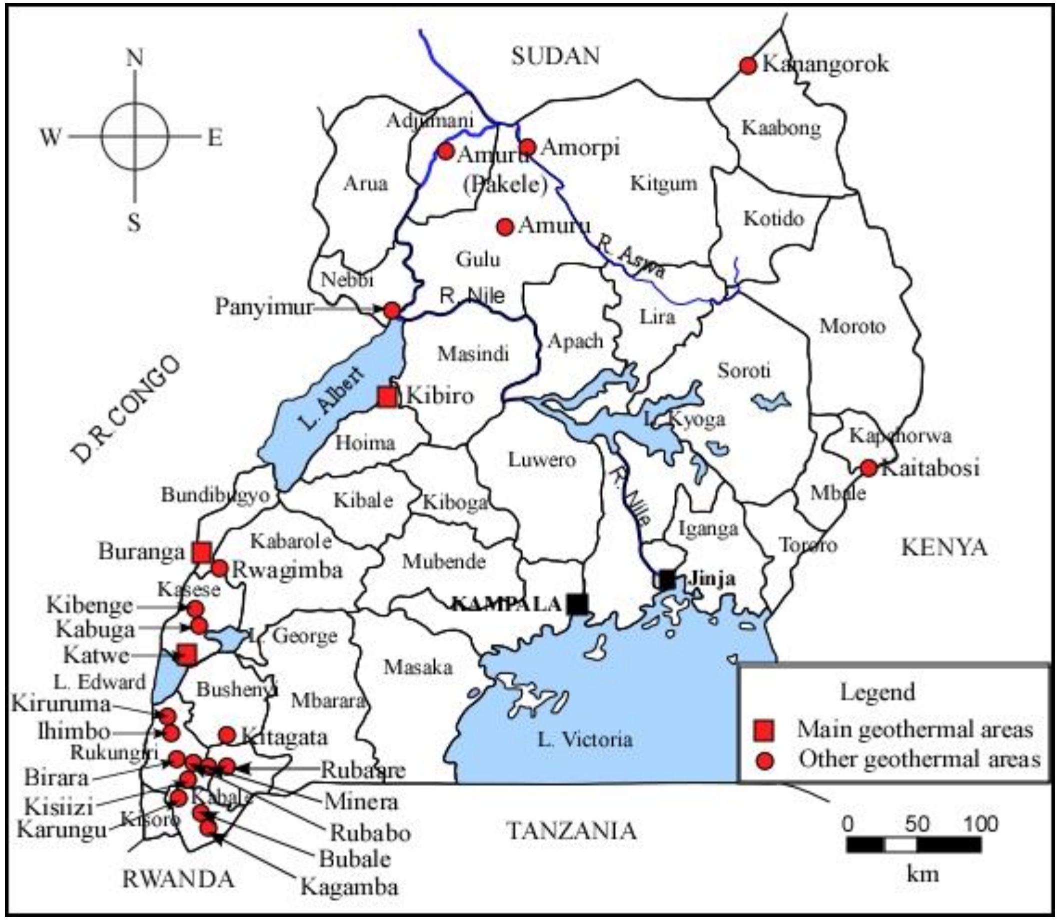
- Geothermal resources in Tanzania are associated with the East African Rift System
- Prominent sites are Ngozi, Lake Natron, Kiejo-Mbaka, Luhoi, and Songwe
- Exploration drilling is planned for Ngozi with spudding in August 2023. It is expected that high temp resource may be encountered.
- TGDC has tendered for EOI for IPPs to show interest in developing Ngozi prospect under PPP arrangement once slim hole drilling confirms a viable resource



Kajugus, S., Kabaka, K., and Mnjokava, T., 2021: Tanzania Geothermal Resources Development – Current Status. Proceedings World Geothermal Congress 2020+1, Reykjavik, Iceland, April - October 2021

Uganda

- All the prospective geothermal resources in Uganda are located along the Western Branch of EARS
- All the prospects in Uganda are fault controlled deep circulation systems
- Areas of focused activities are Kibiro, Buranga, and Panyimur
- Several TGH have been drilled at Kibiro with good results for resource derisking
- The country has licensed several prospects for private investment through PPP
- Development of commercial direct use projects are consideration at several sites



Bahati, G., (2007). Status of geothermal exploration in Uganda. Proceedings of the Short Course II on Surface Exploration for Geothermal Resources, organized by UNU-GTP and KenGen, at Lake Naivasha, Kenya

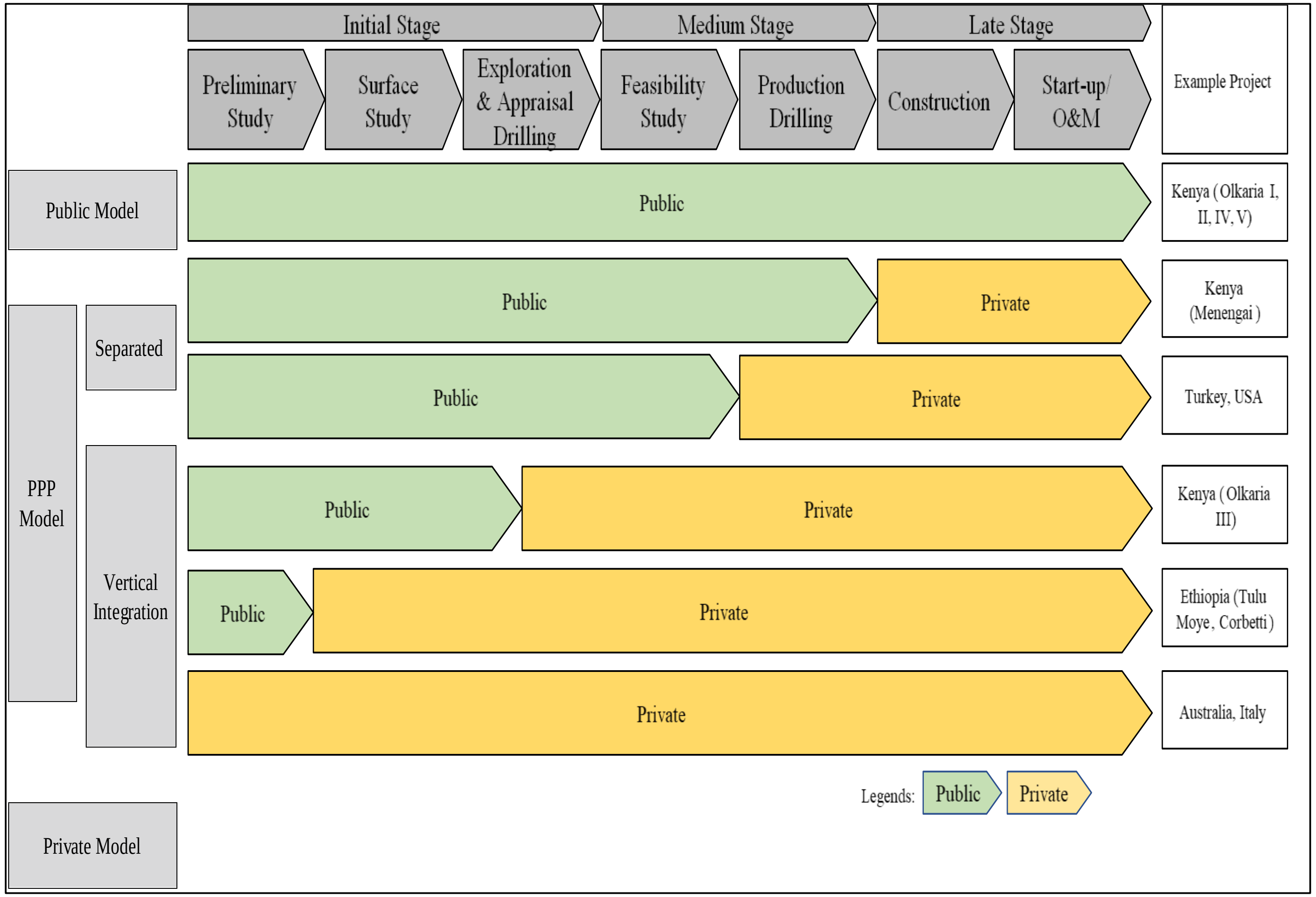
Policy and Regulatory Framework

- Ethiopia and Kenya developed Acts of parliament that guides licensing, and development of geothermal resources
- Kenya, Tanzania and Djibouti have dedicated institutions to spearhead geothermal projects. Ethiopia is moving towards setting up a geothermal dedicated company
- Uganda has a geothermal directorate
- All the targeted countries have active PPP regulatory framework to guide energy projects

- PPP projects developed or under development:
  - 155MW Orpower4, Inc
  - Menengai (3x35MW)
  - Tulu Moye
  - Corbetti
  - Ngozi under development
  - Olkaria 300MW IPP
  - Olkaria 58 MW wellhead leasing

PPP Models for Geothermal Development

- PPP model is partnership between the public sector and the private sector for the purpose of delivering a geothermal project.
- Separated and vertical integrated are the main models
- Many variations exist as shown in the diagram. Another variation is in the contractual arrangements



105MW Menengai PPP Model

RISK	GDC	IPP	KPLC	GOK
Fuel risk (steam)	Deemed payment obligation to the IPP / termination payment	N/A	N/A	N/A
Market Risk	N/A	N/A	Deemed payment obligation to the IPP / termination payment	N/A
Foreign exchange risk	N/A	N/A	Pass-through cost to the consumer	N/A
Financing risk due to long lead time between initial investment and start of revenue	Exploration, drilling, and steam gathering system	Development costs and investment during construction	N/A	N/A
Termination risk before financial close	Cost incurred	Cost incurred	Cost incurred	N/A
Termination risk after financial close	Related to fuel	Related to generation	Related to evacuation / demand	Termination due to political event
Short-term payment delay	GDC operations security	IPP operations security	Partial risk guarantee	Partial risk guarantee
Permits and authorization	Related to the steam field	Related to the power plant	Related to power offtake	Related to timely assurance
Construction delay	Steam gathering system	Power plant	Evacuation facilities	N/A
Technology risk	Steam gathering system	Power plant	Evacuation facilities	N/A
Operation and maintenance	Steam gathering system	Power plant	Evacuation facilities	N/A

Mwai A., 2016. Geothermal Development by Public Private Partnership- A Case Study Of Menengai 105 MW Project, Proceedings, 6th African Rift Geothermal Conference, Addis Ababa, Ethiopia (2016)

Risks in Geothermal Development

Level of Risk	High	Moderate	Low
Main Specific Risks	• No access road • Resource Risk • Technical Risk • Permitting Risk, etc	• Resource Risk • Technical Risk • Completion Delay Risk • Operational Risk, etc.	• Credit Risk of Offtaker/Steam Provider • Price Risk • Completion Delay Risk, etc.
Common Risks	• Political Risk • Organizational Risks • Financial Risk • Social and Environmental Risk • Force Majeure		

Risk Mitigation Measures

Public Sector Led

- Government Led exploration
- Cost-shared exploration and appraisal drilling
- Initial-stage fiscal incentives
- Structural improvement
- Portfolio exploration

- **Pubic and Private Led**
  - Resource viability research
  - Incremental/Stepwise approach
  - Insurance/Guarantees
  - Creditworthiness Analysis
  - Capacity building
  - Use of Climate finance
  - Lower interest loans
  - Technical assistance and use of experts

Financing Options for Geothermal Development

Pre-survey Construction | Surface Study& | Appraisal Expl ration Drilling | easibility Study | Production Drill ng

Risk	High	Medium	Low
Financing Options	• Balance Sheet Financing by Developer • Government Funds (capital cost sharing, • soft loan or guarantee) • Grants (GRMF, Grants from DFIs)	• Balance sheet financing, corporate debt or bonds issued by developer • Public equity issuance • Construction • (short/mid-term) debt • Loan guarantee from Gov. • Long-term debts or guarantee from DFIs • Soft Loan from Climate Finance	• Construction debt • Loan-term debt from commercial bank • Long-term debts from • DFIs • Partial risk guarantee or partial credit guarantee instruments from DFIs • Soft loan from Climate Finance

- Geothermal projects are capital intensive requiring more than US$4-5 million/MW
- Grants required to derisk early stages
- Accessing Funds from multiple sources including climate finance
- Payback period of less than 12 years are achievable

Conclusions

- Geothermal is a viable generation option for the targeted six East African countries of Djibouti, Ethiopia, Kenya, Rwanda, Tanzania and Uganda. Large size (>50MW) power plants using flash technology are feasible in Kenya, Djibouti, Ethiopia and Tanzania while smaller size plants using ORC can be developed in Rwanda, Uganda and Tanzania
- Geothermal PPP financing are already being used in Kenya and Ethiopia but there is room for expansion of its use in all the countries
- Government support is required during the early stages of drilling to derisk the projects and then allowing IPPs to take up the subsequent stages of development.

45 MW Olkaria I Power Plant operated for 40 Years. Decommissioned in March 2023 and will be replaced by 63MW plant to be commissioned in 2026