Annað veldi ehf

Geothermal Provinces of Kenya

David Köndgen and Skuli Johannsson

September 29, 2009

OUTLINE

- Overview Geology of Kenya
- Excursus: The Wilson Cycle
- How do rifts form?
- The world of Platetectonics and Hotspots
- Hotspots and heat anomaly
  - 1. How is the heat obtained?
  - 2. Mantle transition zone structure
  - 3. Edge-driven convection model
  - 4. Rift geothermal model
- Geothermal regions of Kenya and temperature gradient in the Rift Valley
- Southern Rift Valley
  - Olkaria volcanic complex
  - Eburru geothermal field
  - Longonot geothermal field
  - Suswa volcano
- Central and Northern Rift Valley
  - More potential and projects
- Conclusions
- References

Overview Geology

- The **Kenyan Rift**, which is part of the **East African Rift System (EARS),** is the most important geological feature of Kenya:
  - Classic example of a **continental rift** – modern, actively spreading
  - **Volcanic** activity related to the rift started ca. 30 Ma (<u>M</u>illion years <u>a</u>go) in northern Kenya, moving southwards, reaching northern Tanzania around 8 Ma
  - Volcanism especially in northern **Kenya** continues to the present

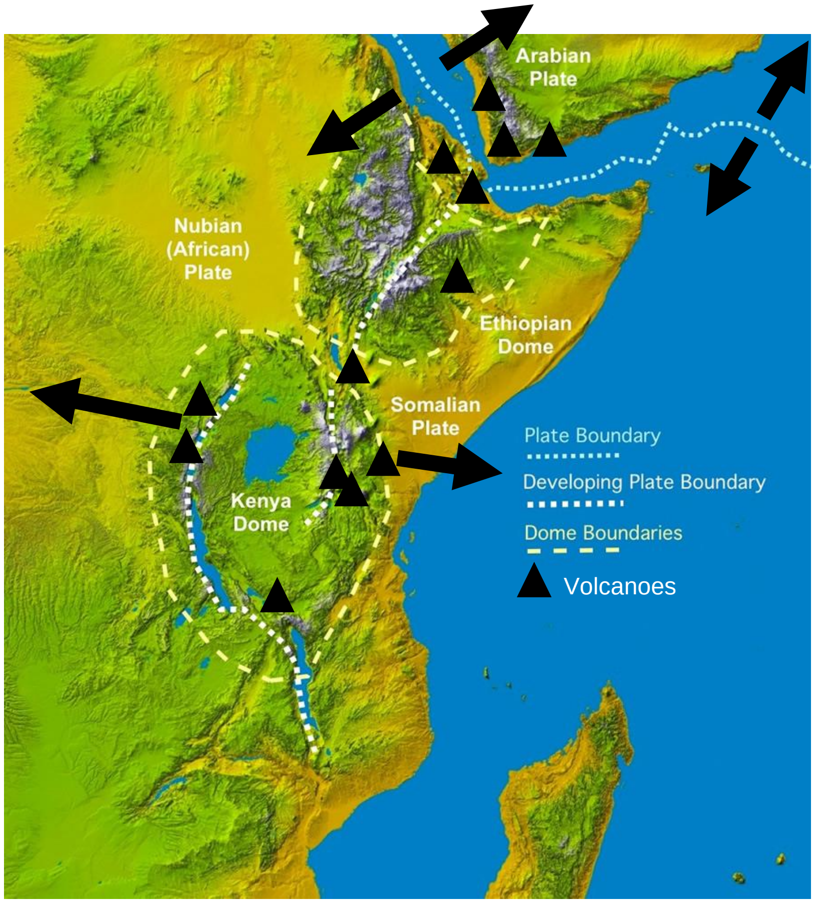


Fig. 1: The East African Rift System, modified after Wood and Guth

Excursus: The Wilson Cycle

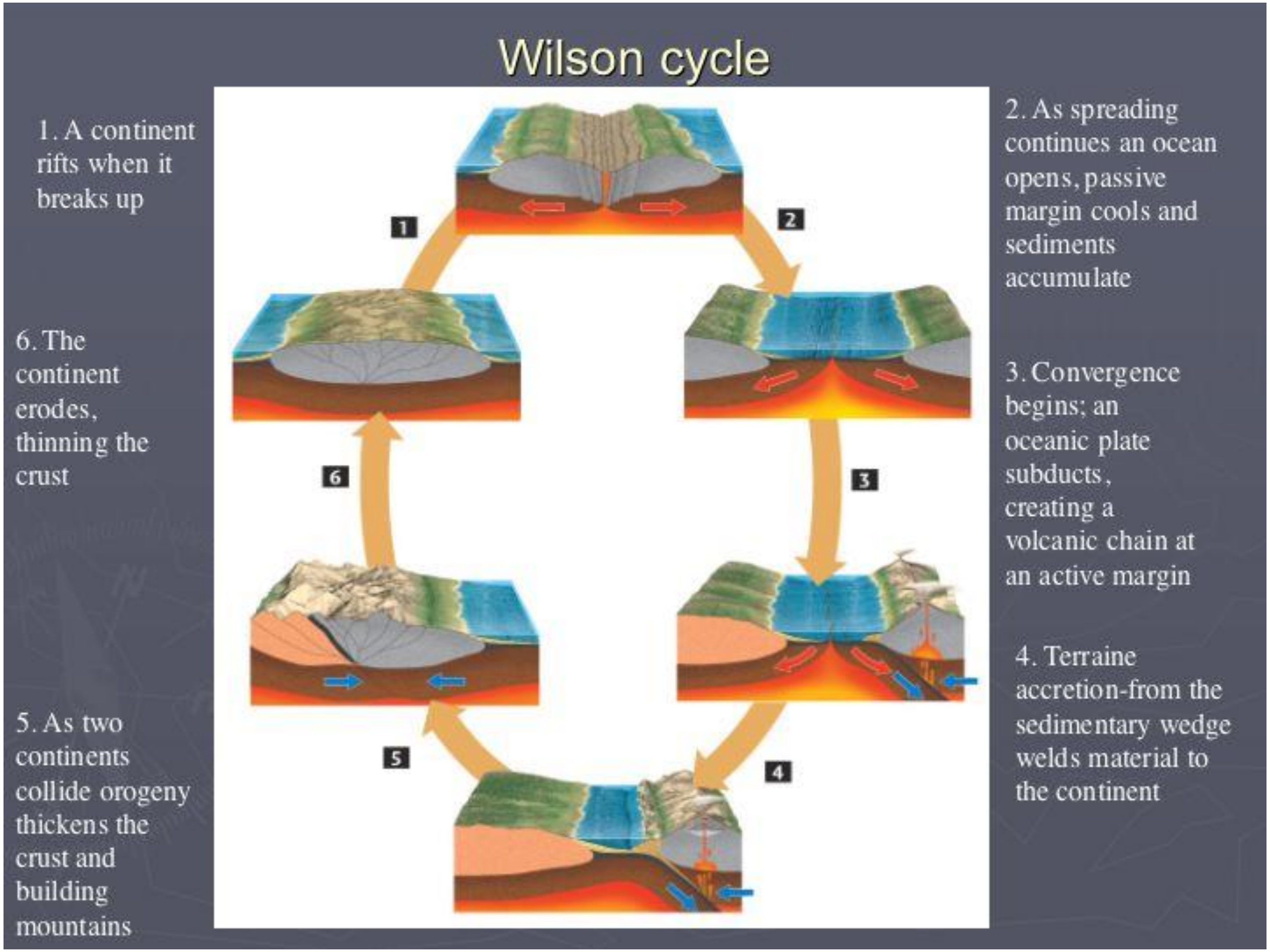


Fig. E: The Wilson Cycle, showing stages of rifting and ocean formation, from futura-sciences.com

How do rifts form?

- The **Kenyan Rift**, which is part of the **East African Rift System (EARS),** is the most important geological feature of Kenya:
  - Popular model assumes elevating heat flow from the mantle
  - Causing a pair of thermal “bulges”in **central Kenya** and **Arfar** (**Kenya** and **Ethopian Dome,** respectively)
  - “Bulges” are initiated by plumes heating the overlying crust
  - Streching and fracturing → Horst and Graben structure
  - Ideally three branches occur from one point with an angular separation of 120° → that point is called a **triple junction**

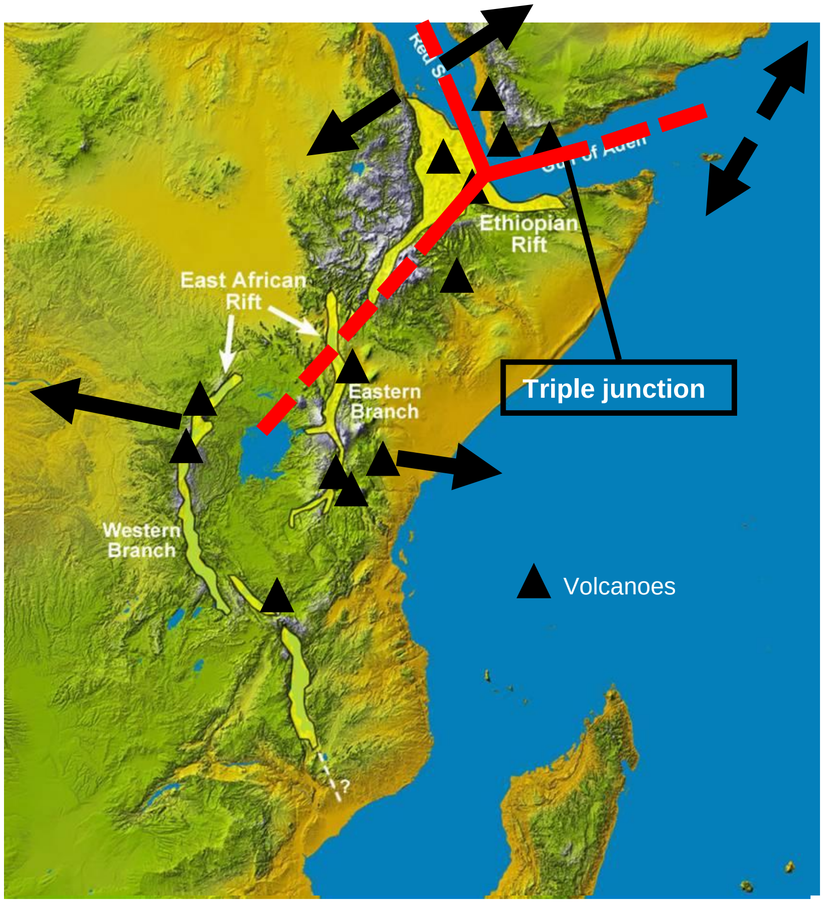


Fig. 2: The East African Rift System, showing different branches modified after Wood and Guth

How do rifts form?

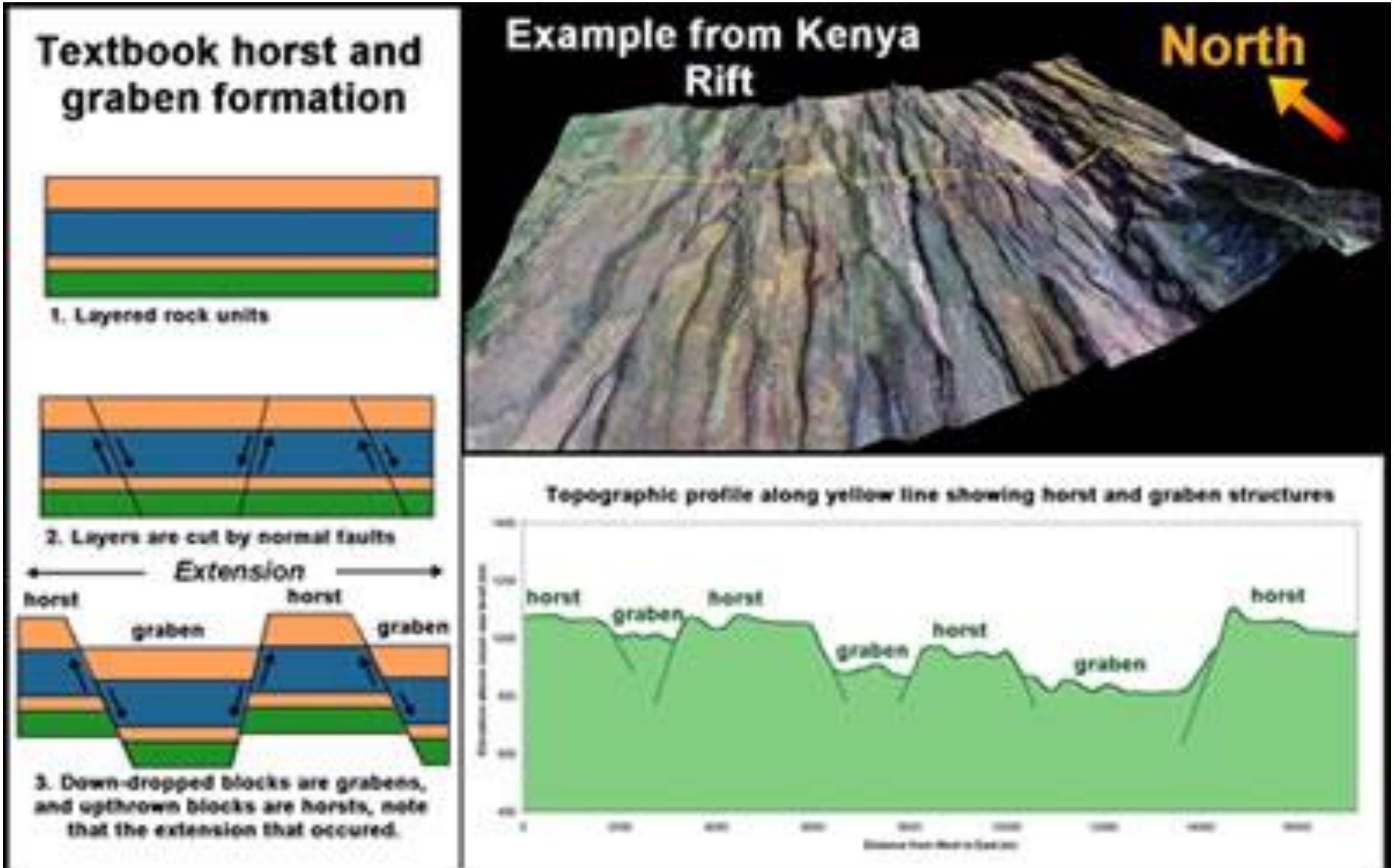
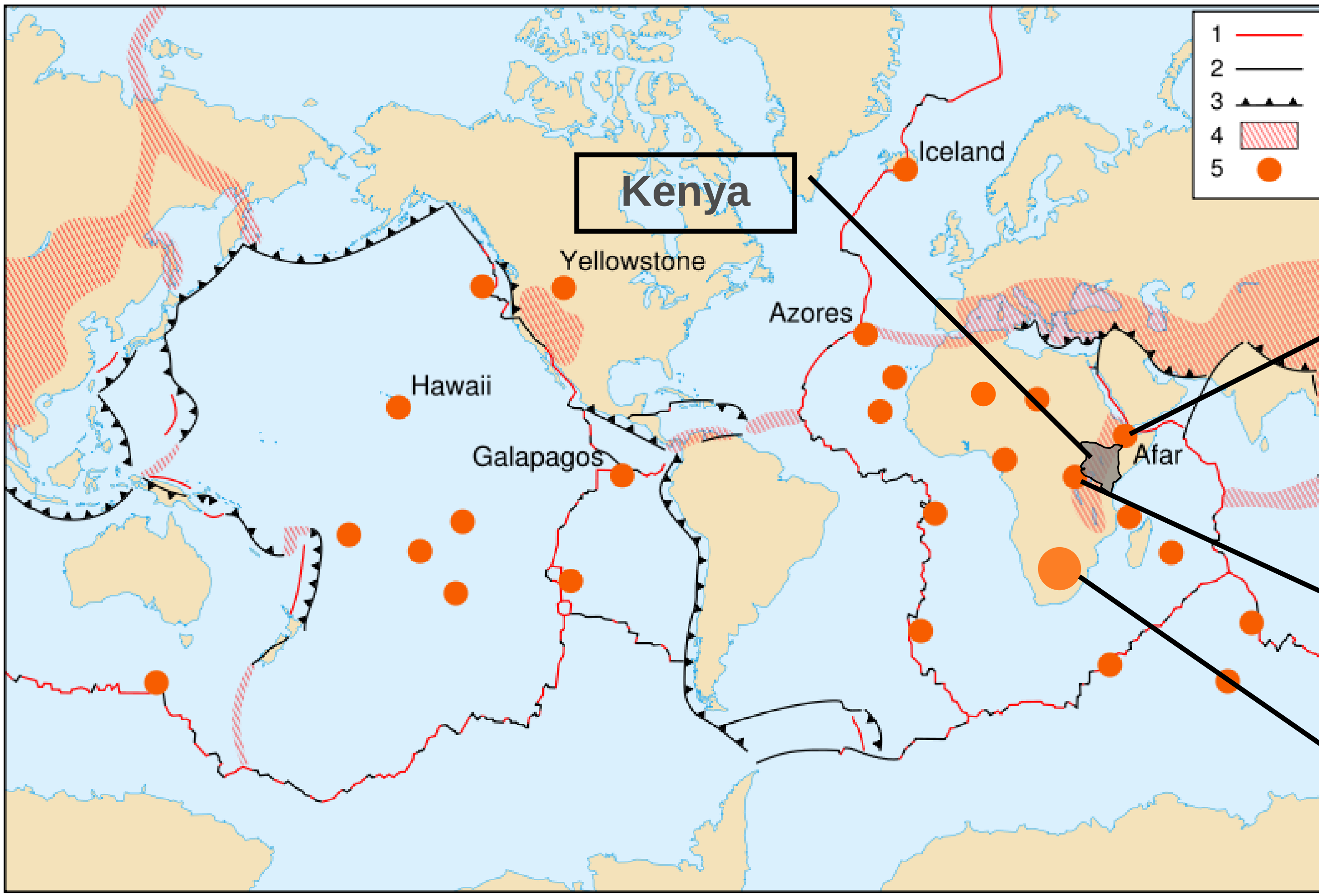


Fig. 3: Textbook horst and graben formation, from Wood and Guth

The world of Platetectonics and Hotspots



Divergent plate boundaries
Transform plate boundaries
Convergent plate boundaries
Plate boundary zones
Selected Hotspots

Afar Hotspot

Turkana Plume

South African Superplume

Fig. 4: World overview of selected Hotspots and plate boundaries, after wikipedia.org

Ingredients of a geothermal field

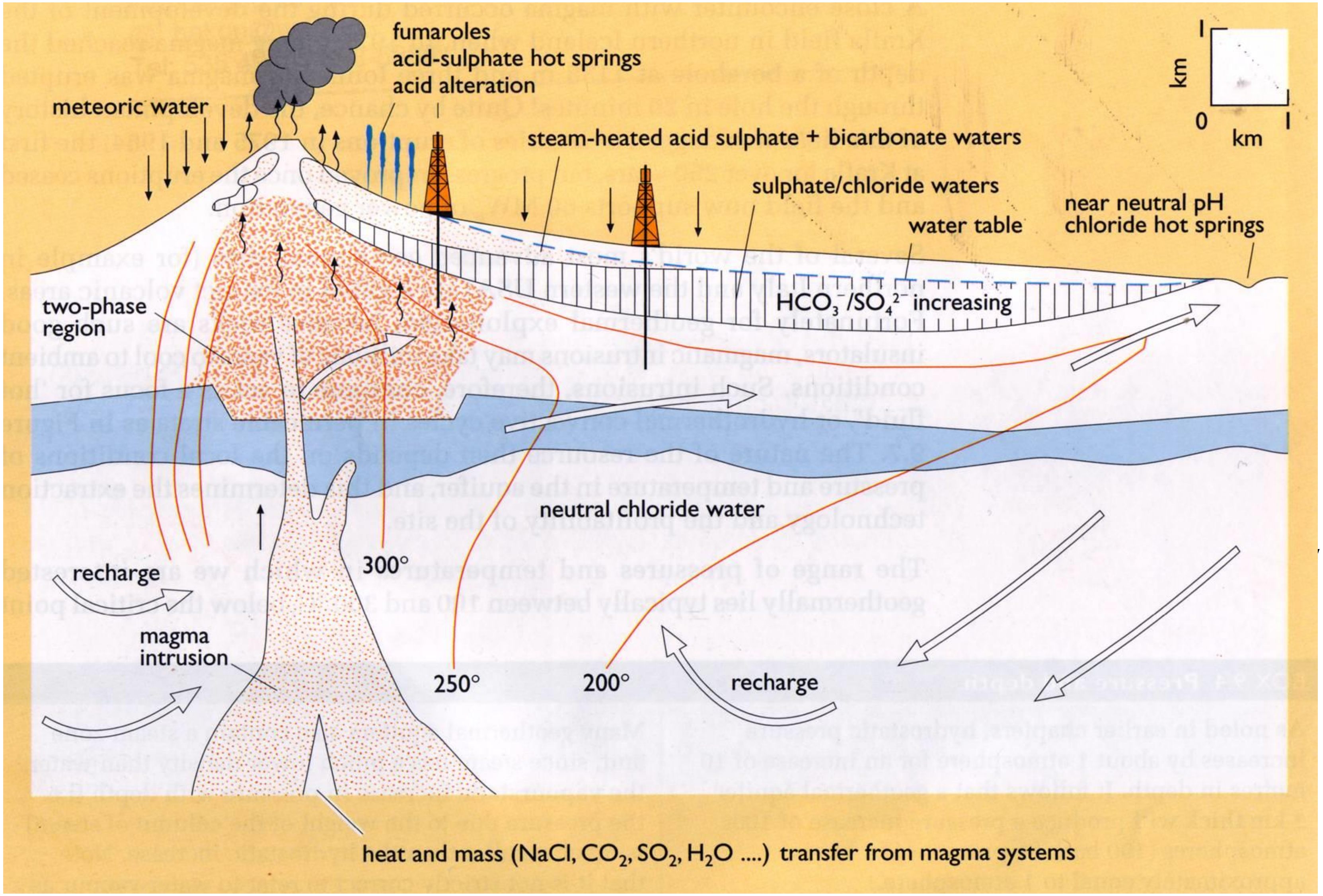


Fig. 5: Conceptual model of a typical volcanic geothermal system, Boyle (2004)

Ingredients of a geothermal field

- An Aquifer and a cap rock
    - Aquifer
        - Porous rocks that can store water
    - Cap rock
        - Prevents fluid escaping upwards
        - Mudrocks, clays and unfractured lavas are ideal
        - Given time, many geothermal fields develop there own cap rocks → not always the youngest volcanic areas are the most productive for geothermal
            - » rocks are such good insulators → magmatic intrusions stay hot for millions of years
            - » Such intrusions, therefore, act as a focus for „hot fluid“
- A heat source

Hotspots and heat anomaly

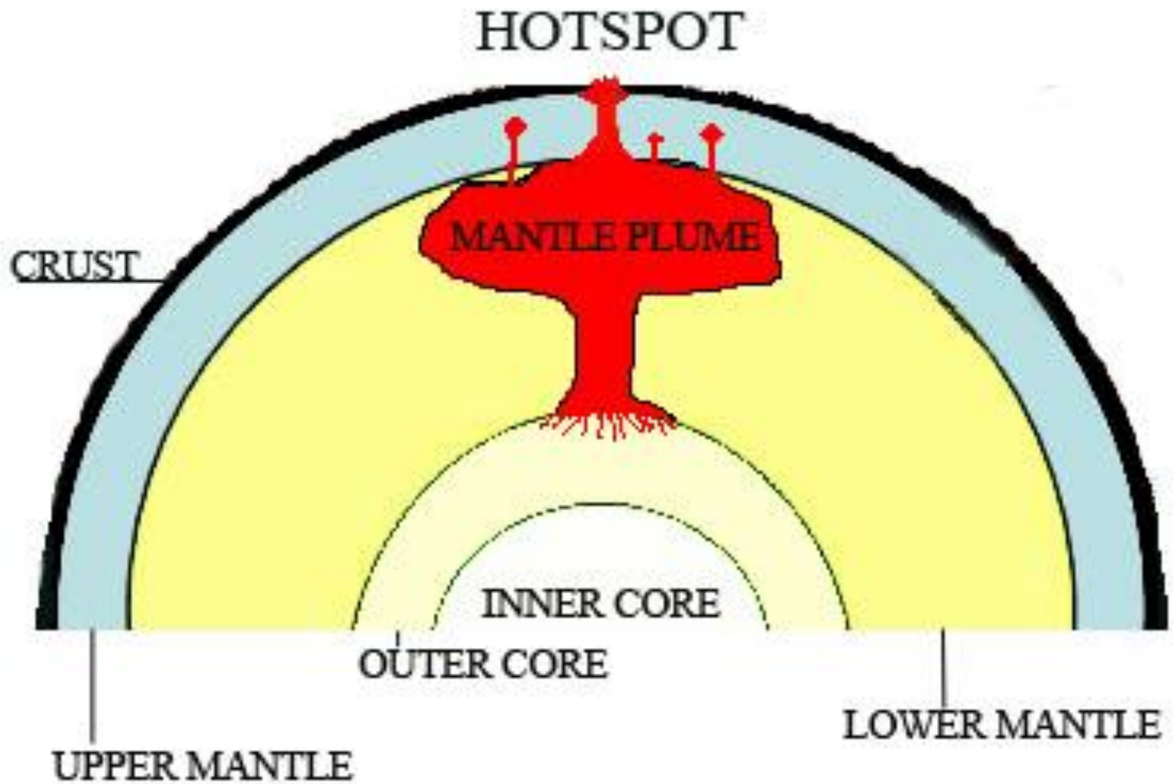
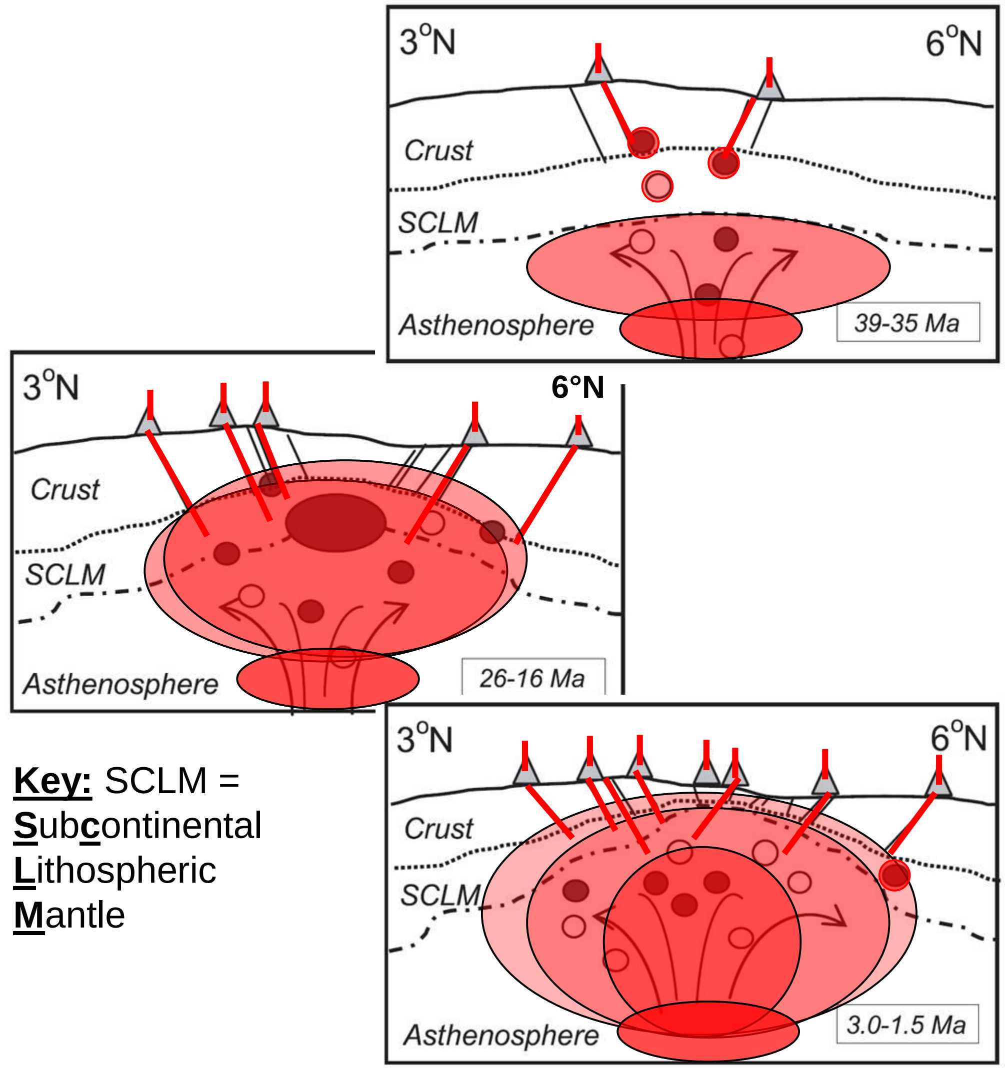


Fig. 6: Hotspot, David Köndgen

- Arfar Hotspot
- Plume under Turkana Depression
- South African Superplume

1. How is the heat obtained?

- Situation in northern Kenya (**Turkana depression**)
  - Distinctive crustal **extension** leads to a progressive thinning of the lithosphere and a 150 km wide fault zone
  - Underlying and **hot** Asthenosphere is now closer to the surface
  - Creation **volcanoes** and rising of **geothermal gradients**



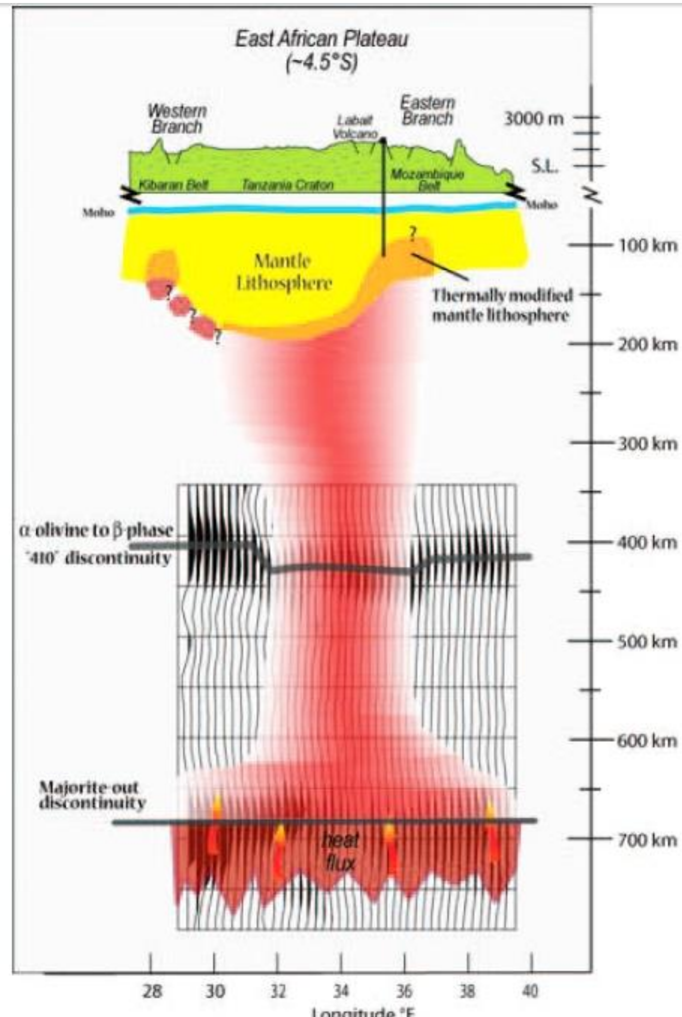
Key: SCLM = **S**ub**c**ontinental **L**ithospheric **M**antle

Fig. 7: Linked evolution of Turkana rifting and magmatism, after T. Furman

2. Mantle transition zone structure

- Seismic studies of wave-traveltimes have delineated velocity anomalies beneath Kenya
- Localized **350°C thermal anomaly** at the 410 km discontinuity
- Discontinuity beneath the rift in Kenya and northern Tanzania depressed 30-40 km → **increase in temperature**
- Thermal anomaly down in the mantle is much broader than at the top, extending all over east Africa (1000-1500 km wide)

→ **Diffusion of heat** connected to thermal upwelling (which will be explained next)



re

Fig. 8: Schematic cross-section showing receiver function stacks of mantle transition zone and cartoon of the associated thermal upwelling, Huerta et. al (2009)

3. Edge-driven convection model

- Occurence in small-scale along **Cratons** (regions of continent, which have been stable for >1 billion years)
- Estimated seismic velocity in the picture shows regions of downwelling **(cold thermal anomalies, blue)** and upwelling **(hot thermal anomalies, red)**
- Hotspots (located in Arfar and underneath Turkana), the **South African Superplume** and volcanism in Eastern Africa might be connected to this down- and upwelling

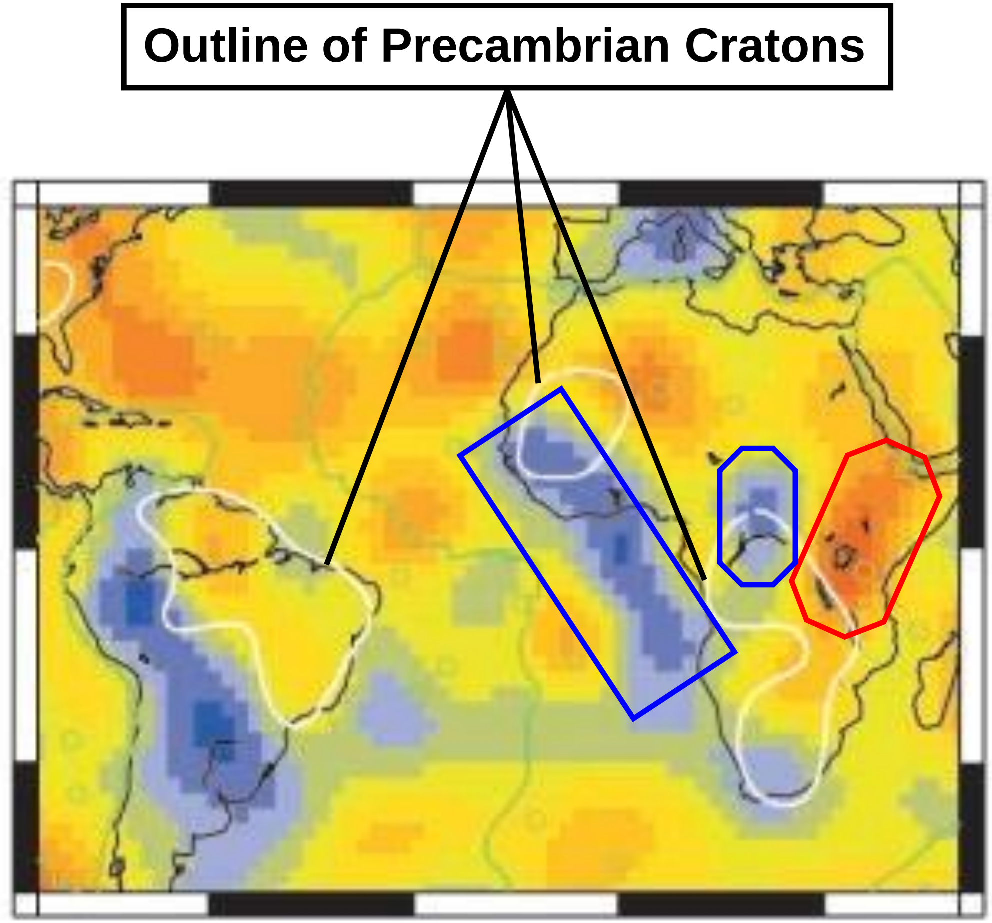


Fig. 9: Heat generation due to edge-driven convection, depth: 600 km, showing high- and low-velocity regions (blue and red,respectively), after King (2000)

4. Rift geothermal model

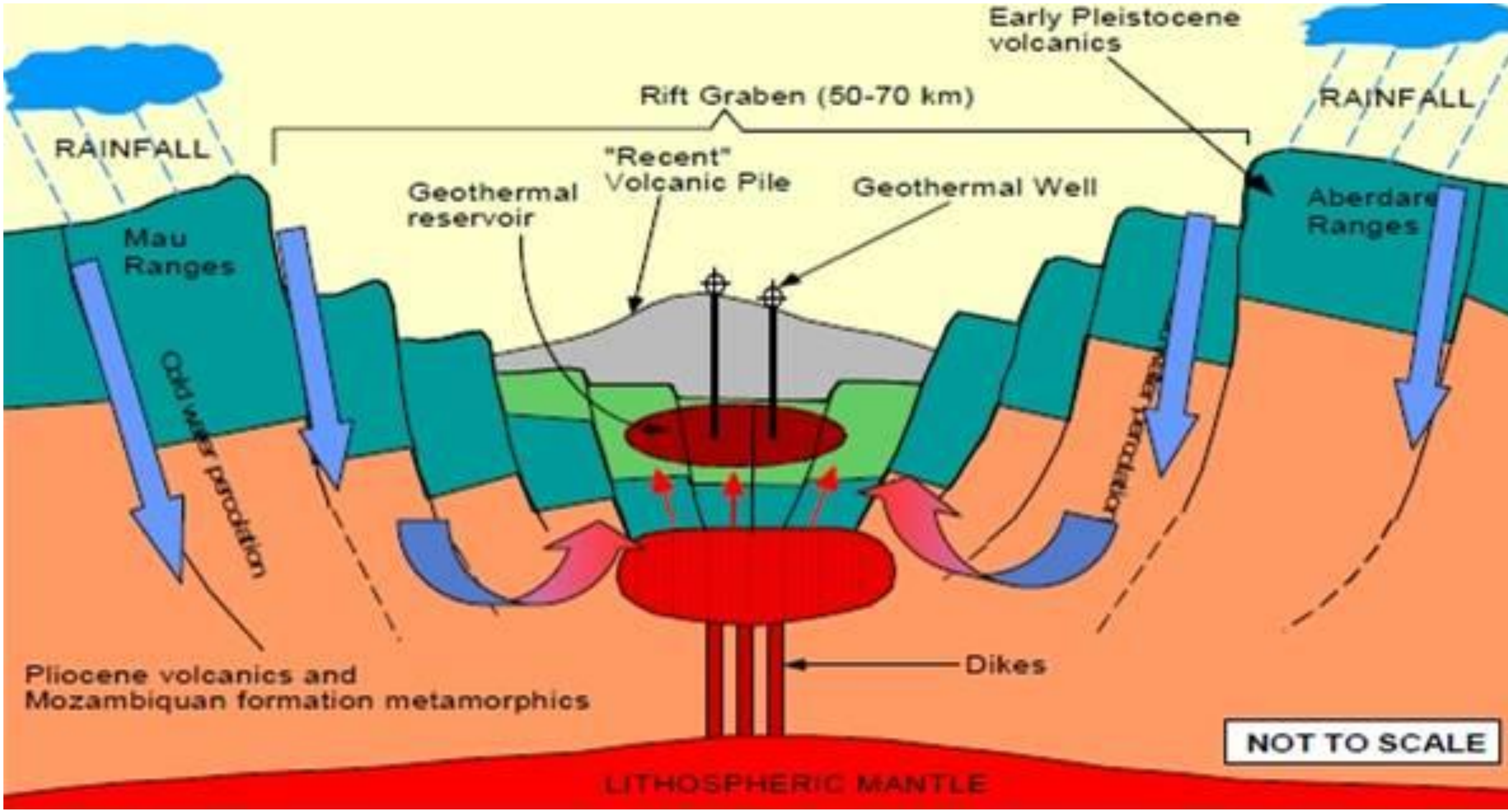


Fig. 10: Rift geothermal model, Mwangi (2006)

Geothermal regions

Northern Rift Valley

Central Rift Valley

Southern Rift Valley

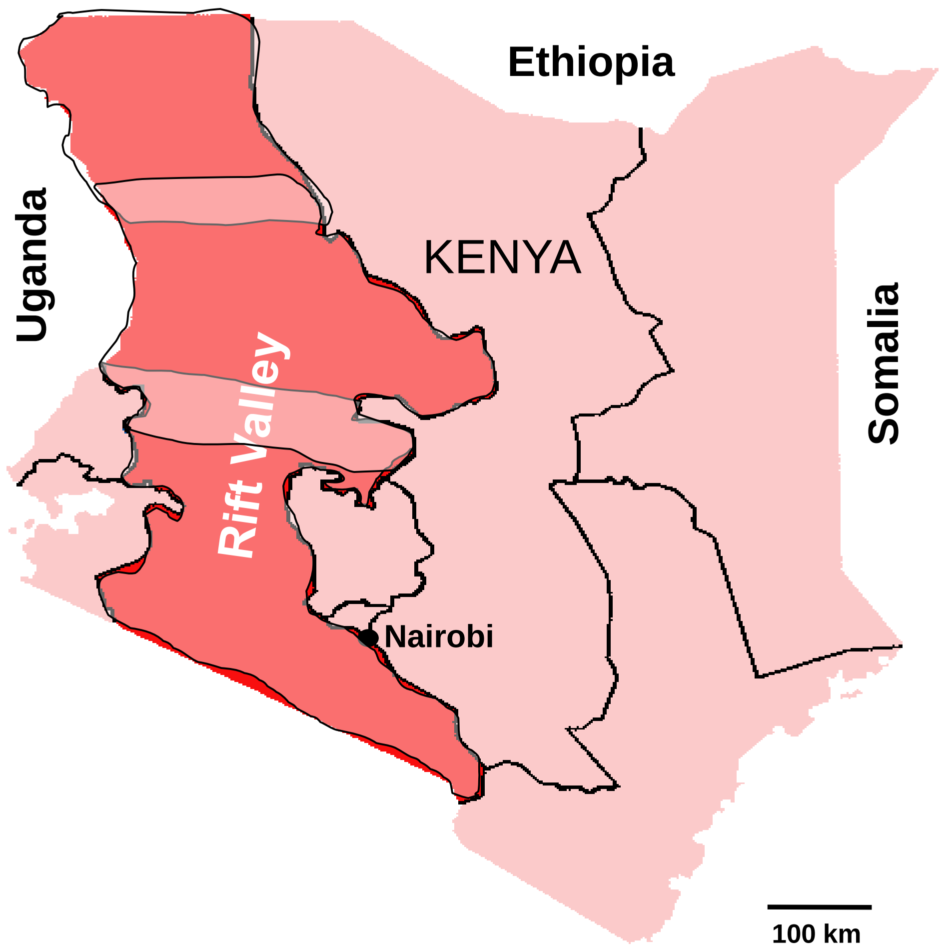


Fig. 11: Kenyan geothermal regions, after www.commons.wikimedia.org

Geothermal gradient

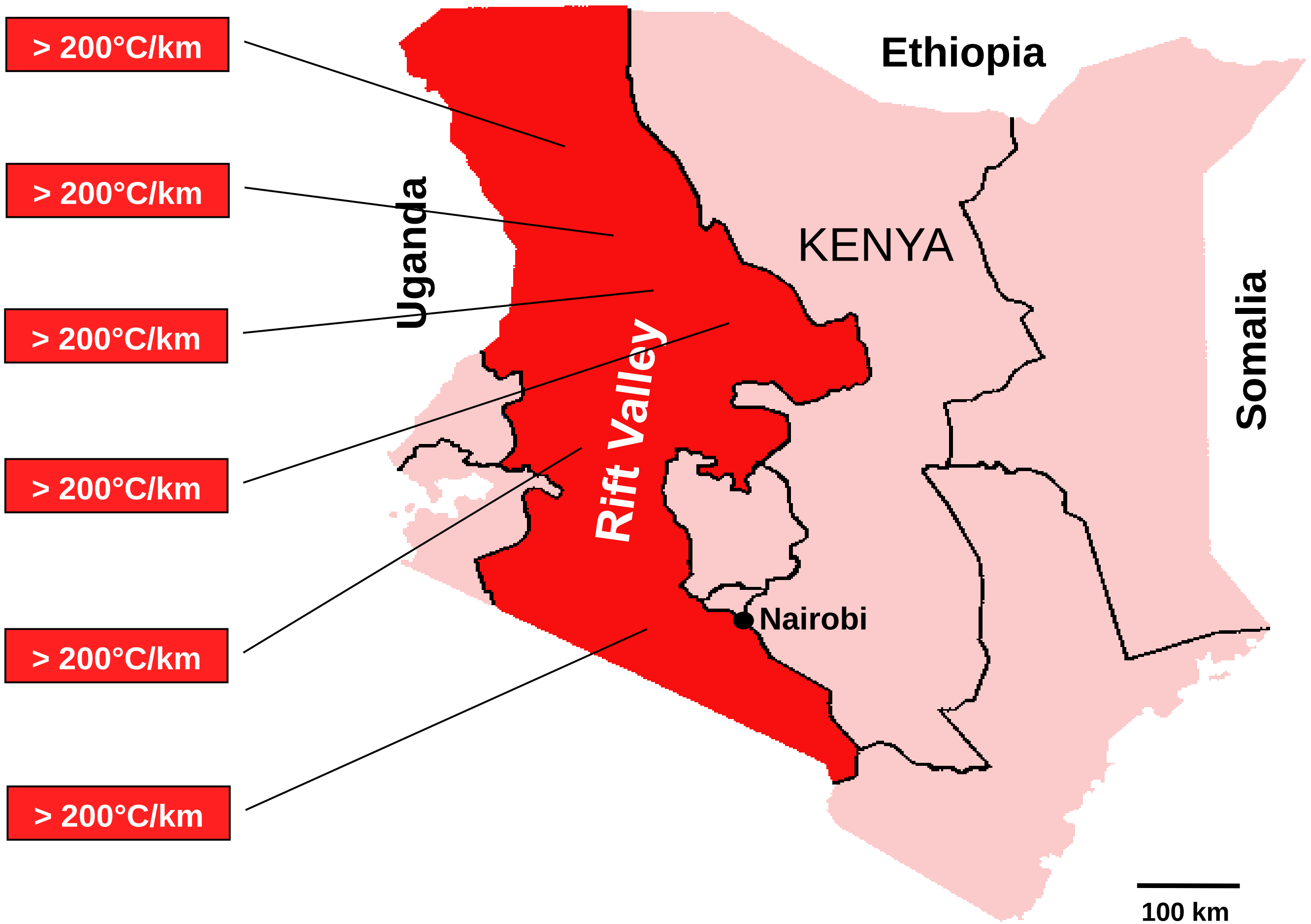


Fig. 12: Kenyan geothermal gradient in Rift Valley, after www.commons.wikimedia.org

Southern Rift Valley

Fig. 13: Southern Rift Valley, after www.commons.wikimedia.org

Olkaria volcanic complex

- Most interesting geothermal area:
  - Thermal gradient: > **200°C/km**
  - Reservoir depths: **750-900 m** (steam dominated) and **1100-1300 m** (richer in water)
  - Reservoir temperature: **340°C**
  - Covered area: about **80 km²**
  - **110 wells** drilled so far
- Exploration started 1956: **Olkaria I**
- Increasing interest in 1970´s leads to initial production start in 1981
- Situation in 2009: **129 MW** installed
  - **Olkaria I** producing 45 MW
  - **Olkaria II** producing 70 MW
  - **Olkaria III** producing 12 MW
  - **Planned: 576 MW** until 2025

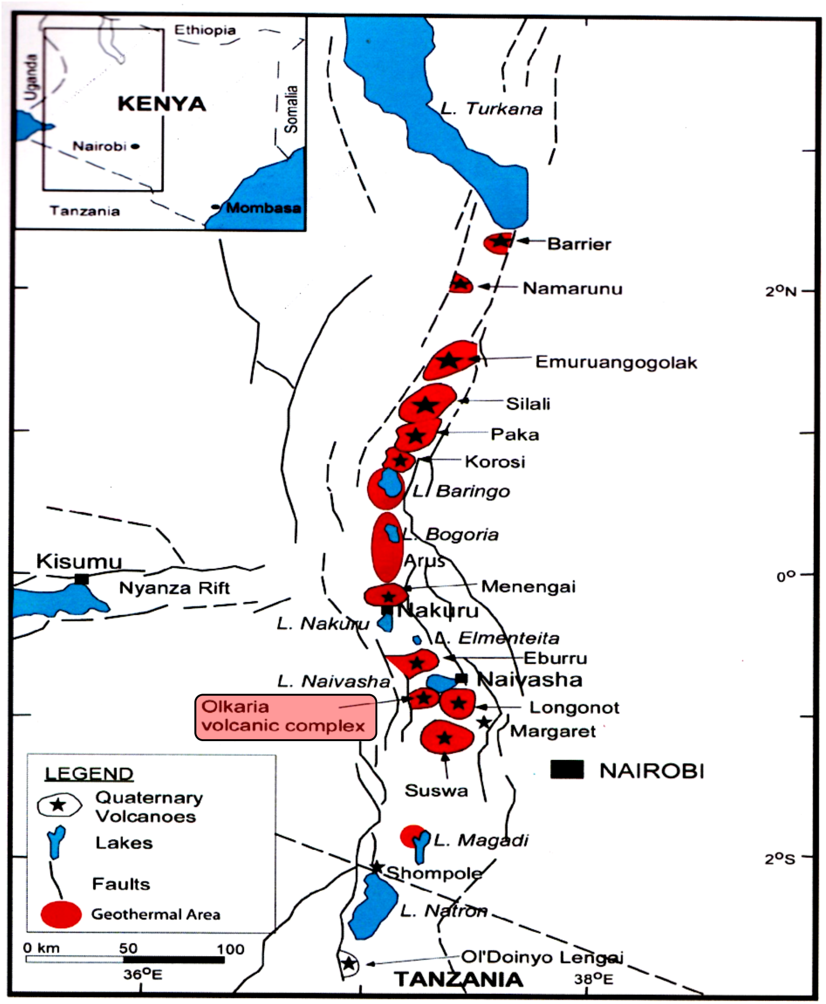


Fig. 14: Overview of geothermal prospects within the Rift Valley of Kenya, after J. Were, KenGen (2009)

Olkaria volcanic complex

- Most interesting geothermal area:
  - Thermal gradient: > **200°C/km**
  - Reservoir depths: **750-900 m** (steam dominated) and **1100-1300 m** (richer in water)
  - Reservoir temperature: **340°C**
  - Covered area: about **80 km²**
  - **110 wells** drilled so far
- Exploration started 1956: **Olkaria I**
- Increasing interest in 1970´s leads to initial production start in 1981
- Situation in 2009: **129 MW** installed
  - **Olkaria I** producing 45 MW
  - **Olkaria II** producing 70 MW
  - **Olkaria III** producing 12 MW
  - **Planned: 576 MW** until 2025

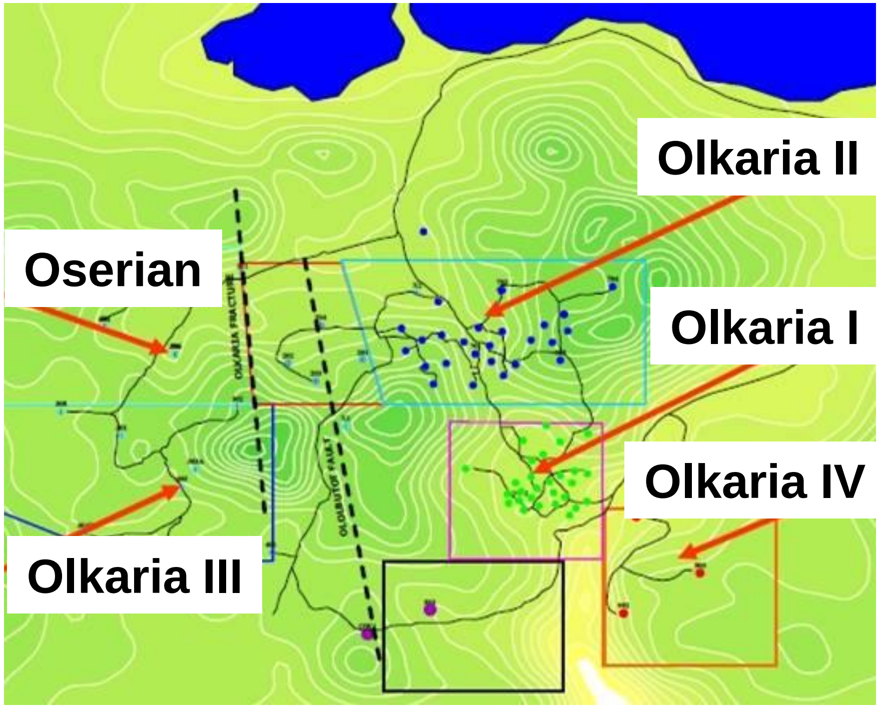


Fig. 15: Olkarian fields in the area of Olkaria volcanic complex (about 80 km^2), Oserian is a green house complex (2 MW Binary power plant), growing flowers to be shipped by air to Europe, after J. Were, KenGen (2009)

KenGen = Kenya Electricity Generating Company, Government Company, licensed in 1982

Olkaria volcanic complex

- Most interesting geothermal area:
  - Thermal gradient: > **200°C/km**
  - Reservoir depths: **750-900 m** (steam dominated) and **1100-1300 m** (richer in water)
  - Reservoir temperature: **340°C**
  - Covered area: about **80 km²**
  - **110 wells** drilled so far
- Exploration started 1956: **Olkaria I**
- Increasing interest in 1970´s leads to initial production start in 1981
- Situation in 2009: **129 MW** installed
  - **Olkaria I** producing 45 MW
  - **Olkaria II** producing 70 MW
  - **Olkaria III** producing 12 MW
  - **Planned: 576 MW** until 2025

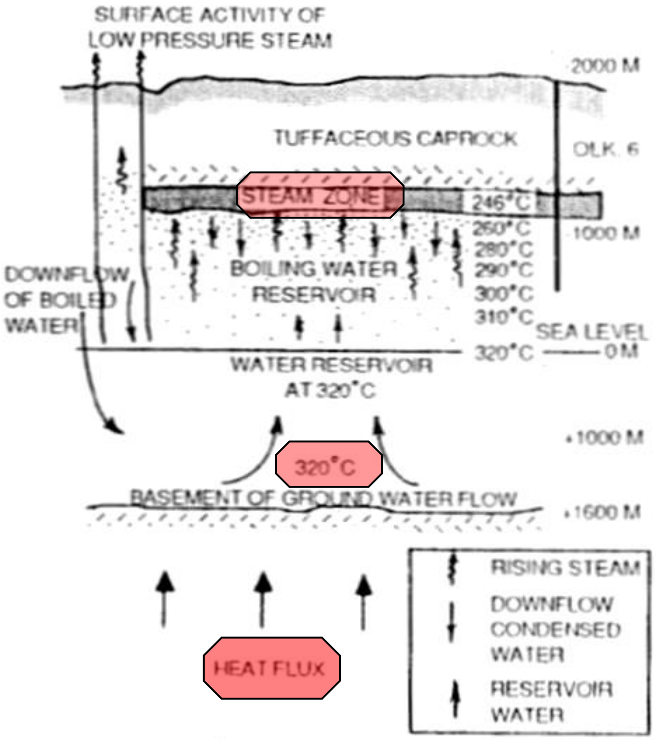


Fig. 16: Schematic cross section through Olkaria reservoir, after Bhogal (2000)

Eburru geothermal field

- Interesting geothermal area:
  - Thermal gradient: > **200°C/km**
  - Reservoir depths: **2400-2700 m**
  - Reservoir temperature:
    131-156°C, max. 279°C
  - High enthalpy area: about **2 km²**
  - **Wells** drilled in six thermally anomalous areas
- Proven geothermal resource:
  20 MW
- Current situation: **5 MW binary geothermal power plant**, KenGen
- Previous use: drying pyrethrum and domestic water supply via condensers

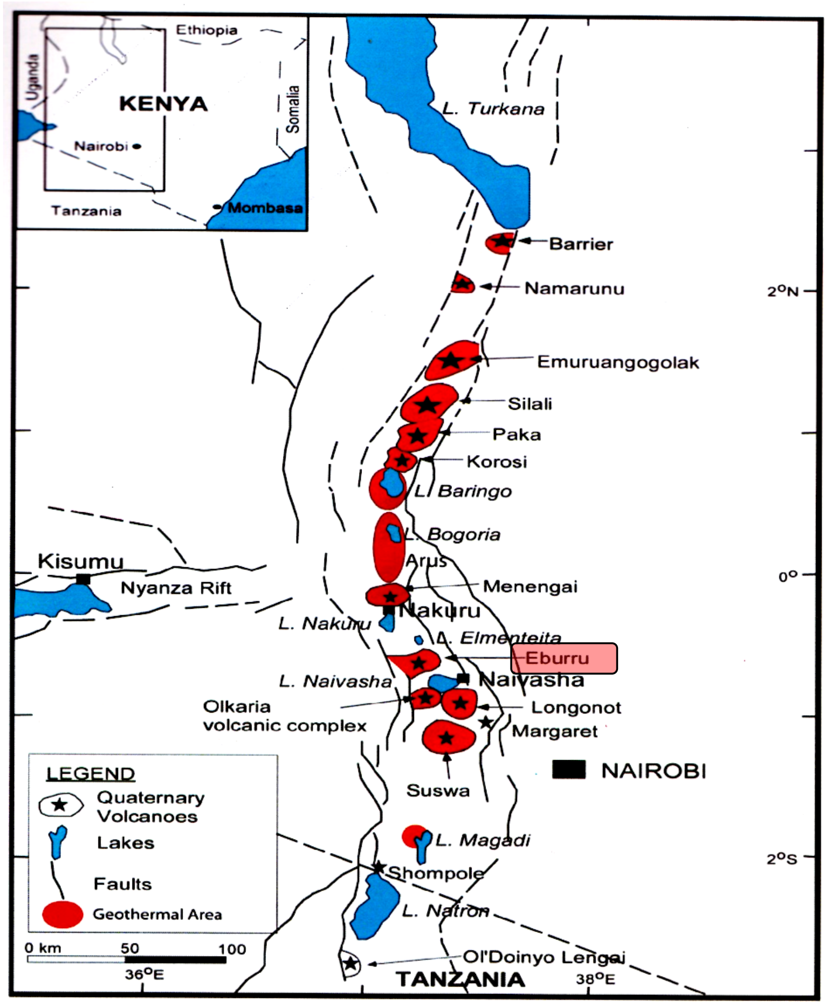


Fig. 14: Overview of geothermal prospects within the Rift Valley of Kenya, after J. Were, KenGen (2009)

Eburru geothermal field

- Interesting geothermal area:
  - Thermal gradient: > **200°C/km**
  - Reservoir depths: **2400-2700 m**
  - Reservoir temperature:
    131-156°C, max. 279°C
  - High enthalpy area: about **2 km²**
  - **Wells** drilled in six thermally anomalous areas
- Proven geothermal resource:
  20 MW
- Current situation: **5 MW binary geothermal power plant**, KenGen
- Previous use: drying pyrethrum and domestic water supply via condensers

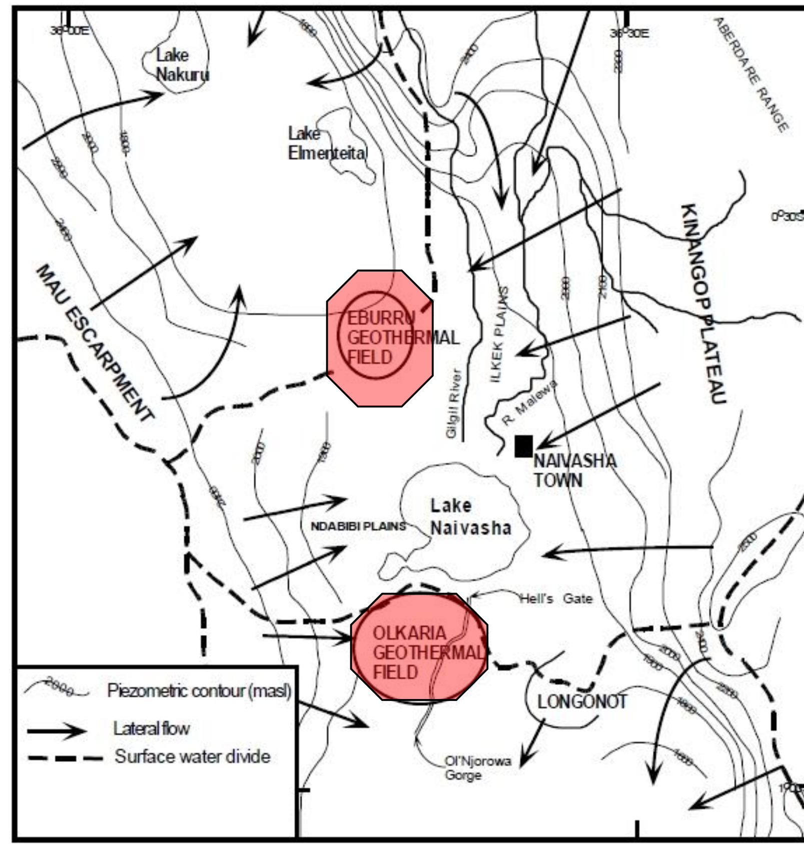


Fig. 17: Piezometric map of Southern Kenya Rift, showing Eburru and Olkaria geothermal fields, after J. Lagat (2003)

Longonot geothermal field

- Interesting geothermal area:
  - Thermal gradient: > **200°C/km**
  - Reservoir depths: **about 1500 m**
  - Reservoir temperature (under the volcano): **> 250°C**
  - Prospect area: about **60 km^2**
  - **Well** drilled to 55 m, half a kilometer south of Longonot recorded a bottom hole temperature of **200°C**
- Geothermal resource (KenGen):
  approximately 200 MW
- Joint Geophysical Imaging study in 2004, African Rift Geothermal initiative (Argeo) plans **pilot plant this year**

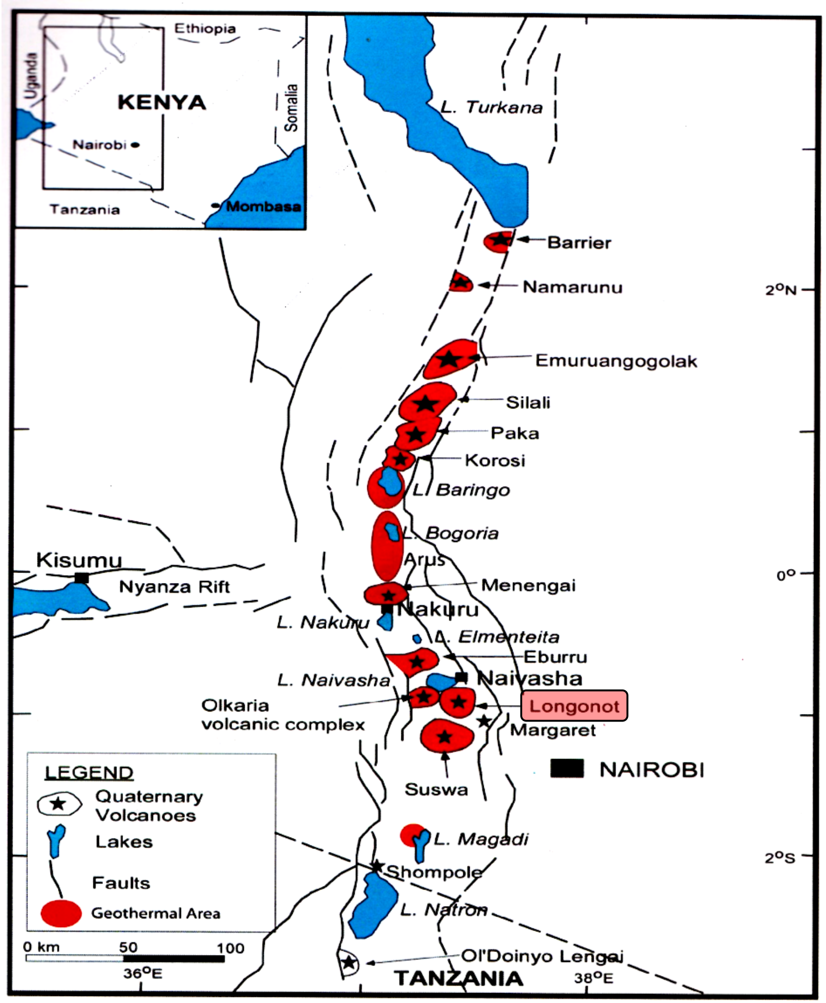


Fig. 14: Overview of geothermal prospects within the Rift Valley of Kenya, after J. Were, KenGen (2009)

Suswa volcano

- Good prospect:
  - Thermal gradient: > **200°C/km**
  - Reservoir temperature:

    >250°C (caldera), range between **270°C** and **>300°C** (fumarole geothermometry studies)
  - Two calderas area: **120 km²**
- Geothermal resource (KenGen):

  approximately 200 MW
- Detailed scientific studies by KenGen in 1992-1993, possibly shallow heat source under the caldera

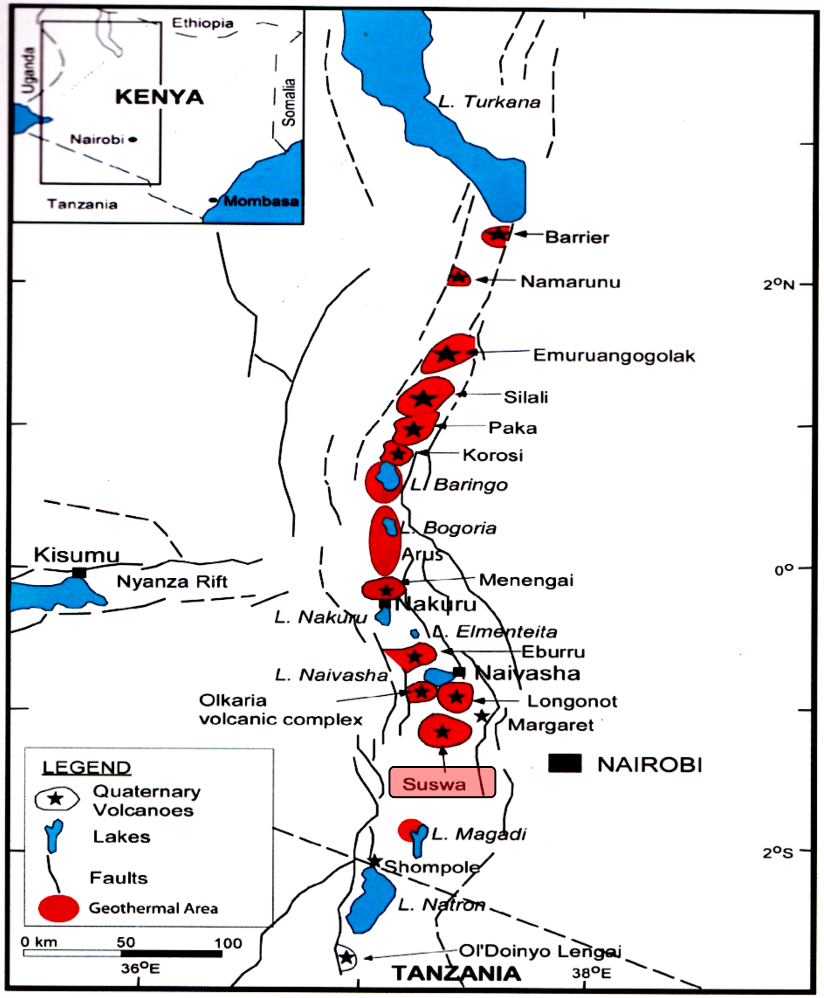


Fig. 14: Overview of geothermal prospects within the Rift Valley of Kenya, after J. Were, KenGen (2009)

Central and Northern Rift Valley

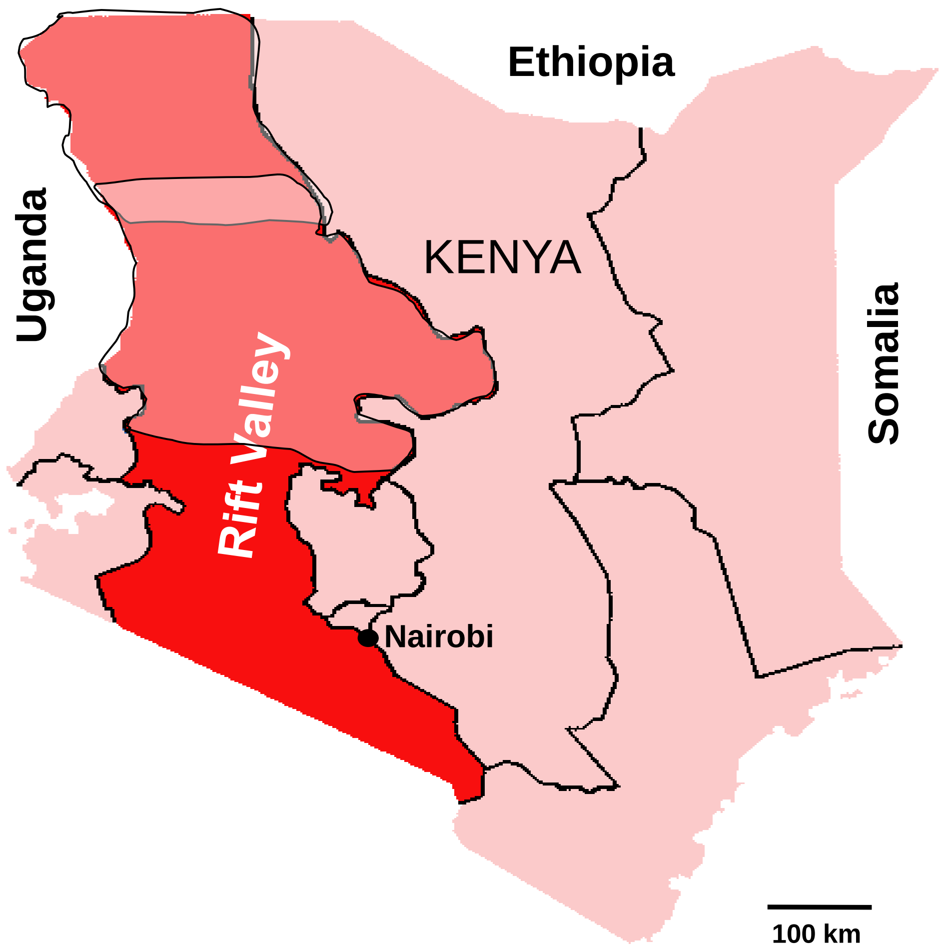


Fig. 18: Central and Northern Rift Valley, after www.commons.wikimedia.org

More potential and projects

	Geothermal Area	Detail Survey	Drilling	Max. Temp °C
1	L. Magadi	No	No	140^+
2	Suswa	Yes	No	250^+
3	Longonot	Yes	No	$>250^+$
4	Olkaria	Yes	Yes	340
5	Eburru	Yes	Yes	279
6	Menengai	Yes	No	$>250^+$
7	Arus/Bogoria	Yes	No	$115\text{-}190^+$
8	Baringo	Yes	No	$>170\text{-}210^+$
9	Korosi/Chepchuk	Yes	No	>220-250
10	Paka	Yes	No	$>250\text{-}300^+$
11	Silali	No	No	$250\text{-}300^+$
12	Emurangogolak	No	No	$210\text{-}290^+$
13	Namarunu	No	No	
14	Barrier volcano	No	No	220-296
	Note: + Geothermometer			

Fig. 19: Overview of geothermal projects, Rift Valley of Kenya, after J. Were, KenGen (2009)

Conclusions

- Kenya has a really huge potential of geothermal regions due to ist geological situation (EARS):
  - Very good potential
    - Shallow lithosphere-asthenosphere boundary
    - General high heat flow
    - Anomalous geothermal gradient of >200°C/km
    - Higher temperatures at shallower depths
- A lot of research and drilling done yet
- Successfully operating powerplants at Olkaria

References

- **Bhogal, P. S. (2000):** Reservoir models of the Olkaria geothermal project (1975-1985), *Proceedings World Geothermal Congress 2000, Kyushu-Tohoku, Japan.*
- **Boyle, G. (Edt.) (2004):** Renewable Energy – Power for a sustainable future, *Oxford University Press with the Open University*, Milton Keynes.
- **Furman, T. et. al (2006):** Tertiary Mafic Lavas of Turkana, Kenya: Constraints on East African Plume Structure and the Occurrence of High-m Volcanism in Africa, *Journal of Petrology, 47 (6): 1221–1244*, doi:10.1093/petrology/egl009.
- **Furman, T., et. al (2004):** East African Rift System (EARS) plume structure: insights from Quaternary mafic lavas of Turkana, Kenya. *Journal of Petrology,* 45, 1069-1088.
- **Huerta, A. et. al (2009): Mantle transition zone structure beneath Kenya and Tanzania:more evidence for a deep-seated thermal upwelling in the mantle,** *Geophys. J. Int.* (2009), doi: 10.1111/j.1365-246X.2009.04092.x.
- **Karekezi, S. and Kimani, J. (no year):** Renewable Energy Technology Transfer in Africa: The Value of Demonstration, The Case of Bagasse-based Cogeneration and Geothermal, Powerpoint Presentation, Nairobi ,Kenya.
- **King, S. and Ritsema, J. (2000):** African Hot Spot Volcanism: Small-Scale Convection in the Upper Mantle Beneath Cratons, *Science 10 (290), 5494, 1137–1140, doi: 10.1126/science.290.5494.1137.*
- **Lagat, J. (2003):** Geology and the geothermal systems of the southern segment of the Kenya Rift, *International Geothermal Conference (September 2003, session #4),* Reykjavík, Iceland.
- **Lin, S-C et. al (2005):** Thermal plume models and melt generation in East Africa: A dynamic modeling approach, *Earth Planetary Science Letters*.
- **Mwangi, M. (2006):** Geothermal development in Kenya: The indegenous, renewable, green option, Kenya Electricity Generating Company Ltd. (KenGen), Nairobi, Kenya.
- **Ni, S., et. al (2004):** Three-dimensional structure of the African superplume from wavefront modelling, *Geophys. J. Int. (161) 283-294, doi: 10.1111/j.1365-246X.2005.02508.x.*
- **No names, (2006(?)):** Geothermal potential in Kenya.
- **Nyblade, A., et. al (2000):** Seismic evidence for a deep upper mantle thermal anomaly beneath East Africa, *Geology, 28, 599-602*.
- **Were, J. and Mwangi, M. (2009):** An overview of geothermal development in Kenya, Kenya Electricity Generating Company Ltd. (KenGen), Nairobi, Kenya.

- http://geology.com/articles/east-africa-rift.shtml (James Wood and Alex Guth - Michigan Technological University)
- http://www.futura-sciences.com/fileadmin/Fichiers/images/Terre/cyclewilson.jpg
- http://www.worldbank.org/html/oed
- http://www.kengen.co.ke/

- First picture (Mount Kenya) from: http://www.myeverestchallenge.com