Hydrology Across Scale: Sensitivity of Kenya Rift lakes to climate change

Lydia Olaka
Dept of Geology, University of Nairobi

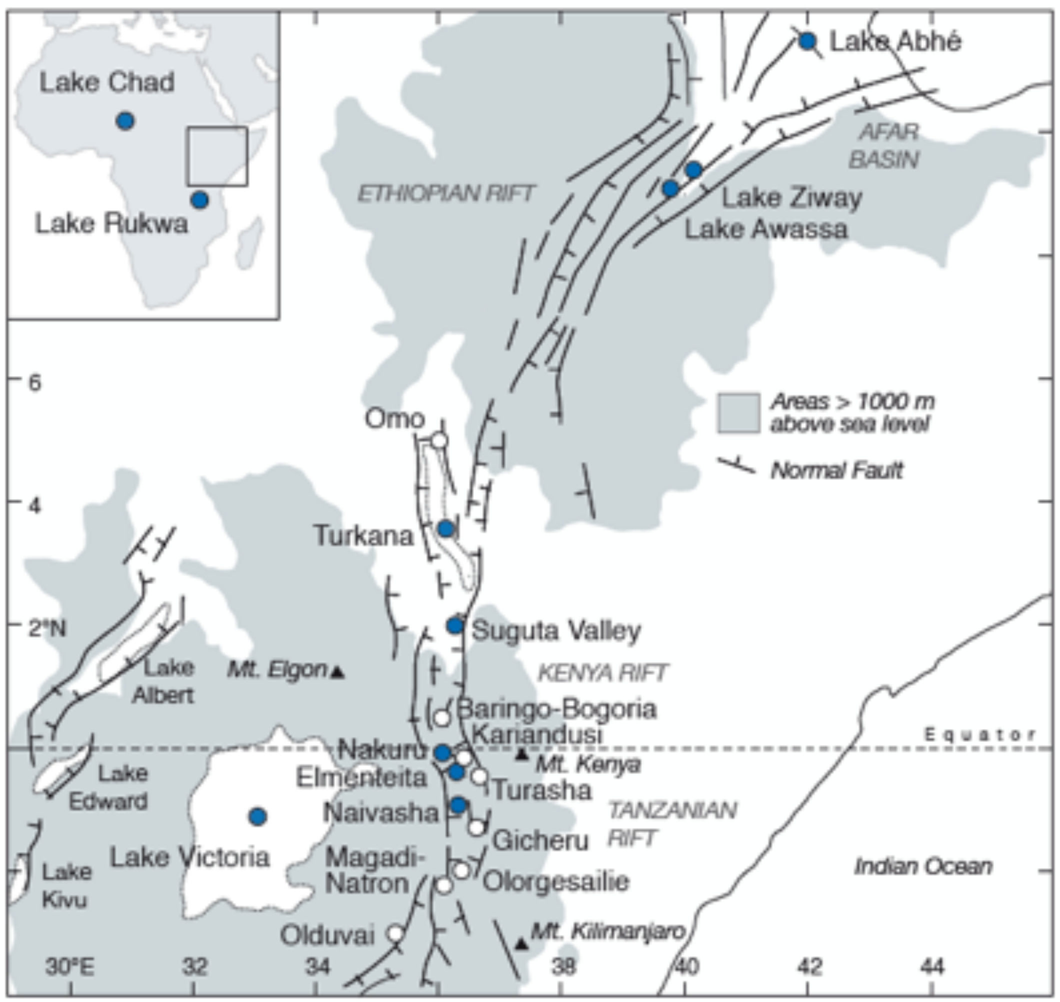
3rd Research week Keynote presentation (CBPS) 15th Oct 2020

Talk Outline

- History of formation and characteristics of Kenya rift Lakes
- Hydrology across scales– Spatial and Temporal
- Climate
- Interconnectivity –Groundwater
- Amplifier lakes
- Recent lake level changes

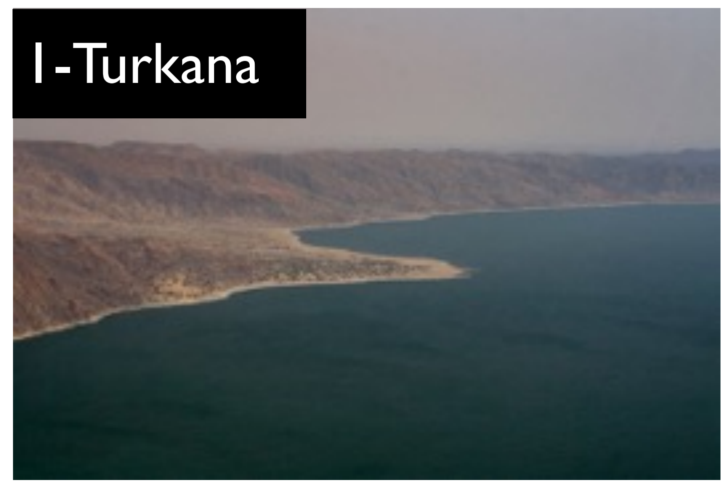
Lakes

Rift graben and crater lakes



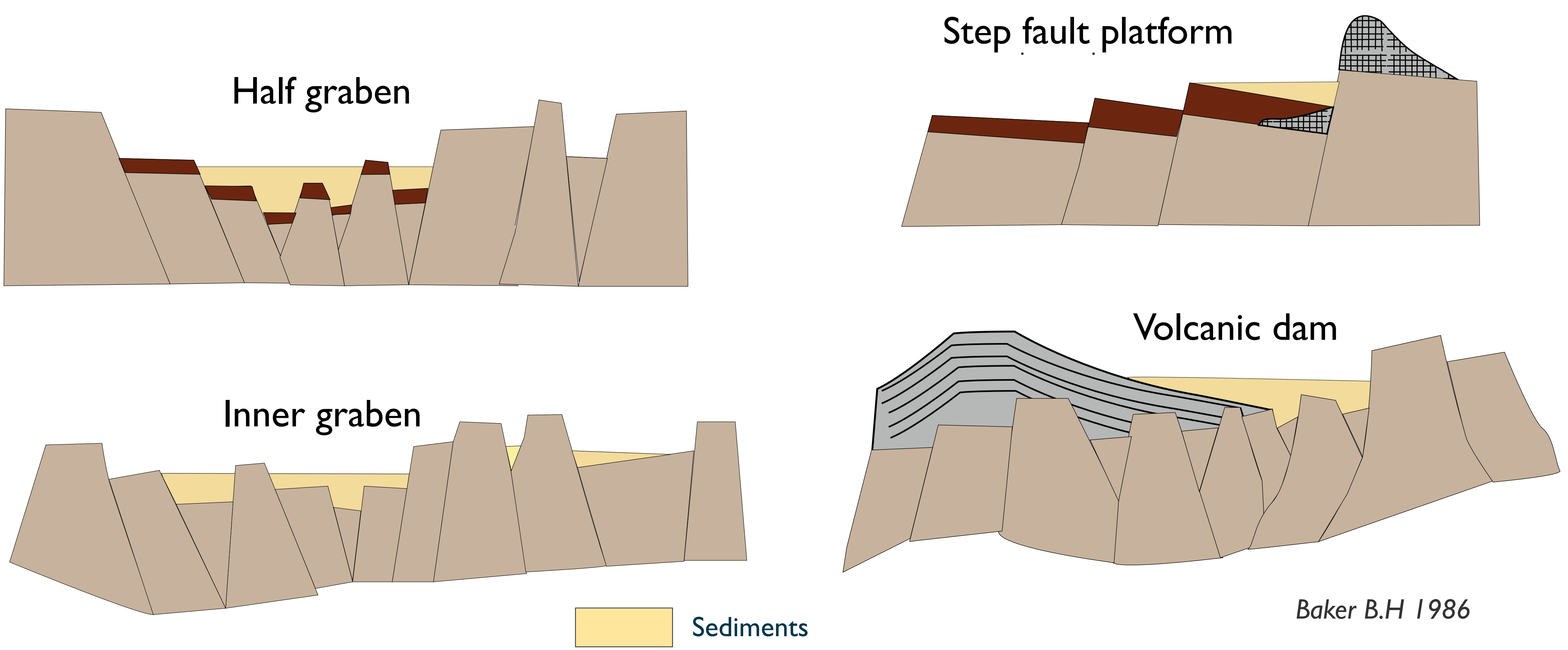
200 km

Trauth et al 2010

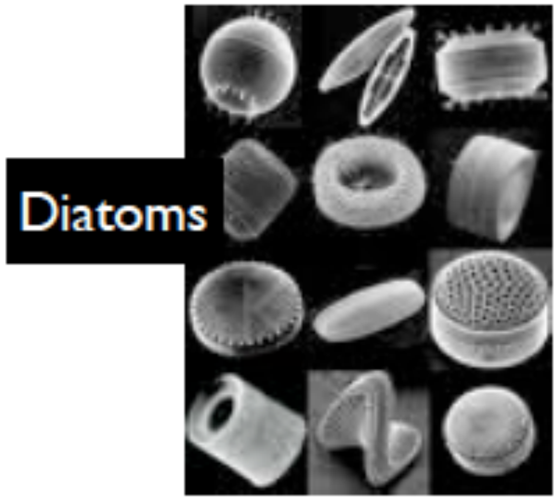


Basins Setting

- created by **subsidence** of the central block or **tilting** of one block to **damming by volcanos**, filled volcanic craters.
- Good archives.
- Varied erosion-deposition environments as a result of ongoing tectonic and volcanic activity initiated about 40 Ma

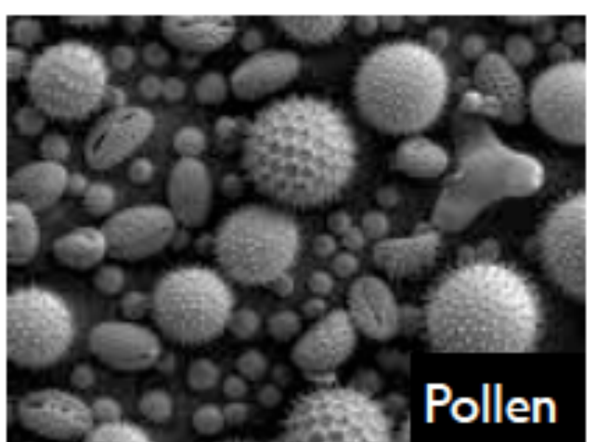


1.2 Climate proxies



Biological and geochemical indicators
water chemistry e.g. diatom inferred salinity

Geomorphological
aerial extent of paleolakes

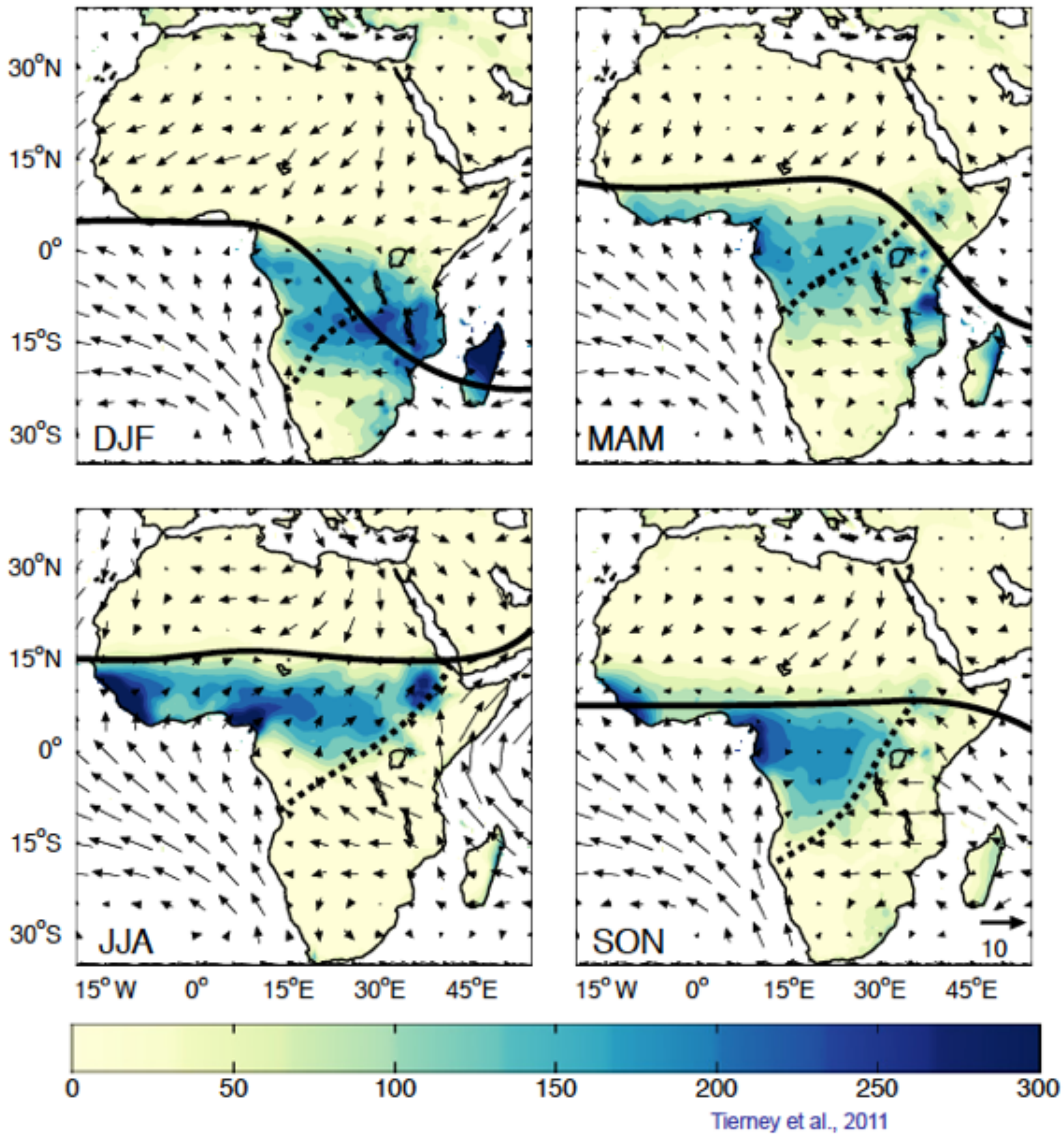


Terrestrial pollen-
lake catchment conditions

2. Hydrology

- Over 10 lakes:
  Small - Large; Deep - Shallow; fresh - saline.
- Occur at varied elevation: climatic regimes.
- “Closed” lakes
- Most rift lakes are connected with the GW systems
  Recharge and discharge
- Complex geology, geomorphology, Hydrology and climate at different temporal and spatial scales
- Support various livelihoods and sectors of the Economy

3. Climate: Modern Rainfall Distribution



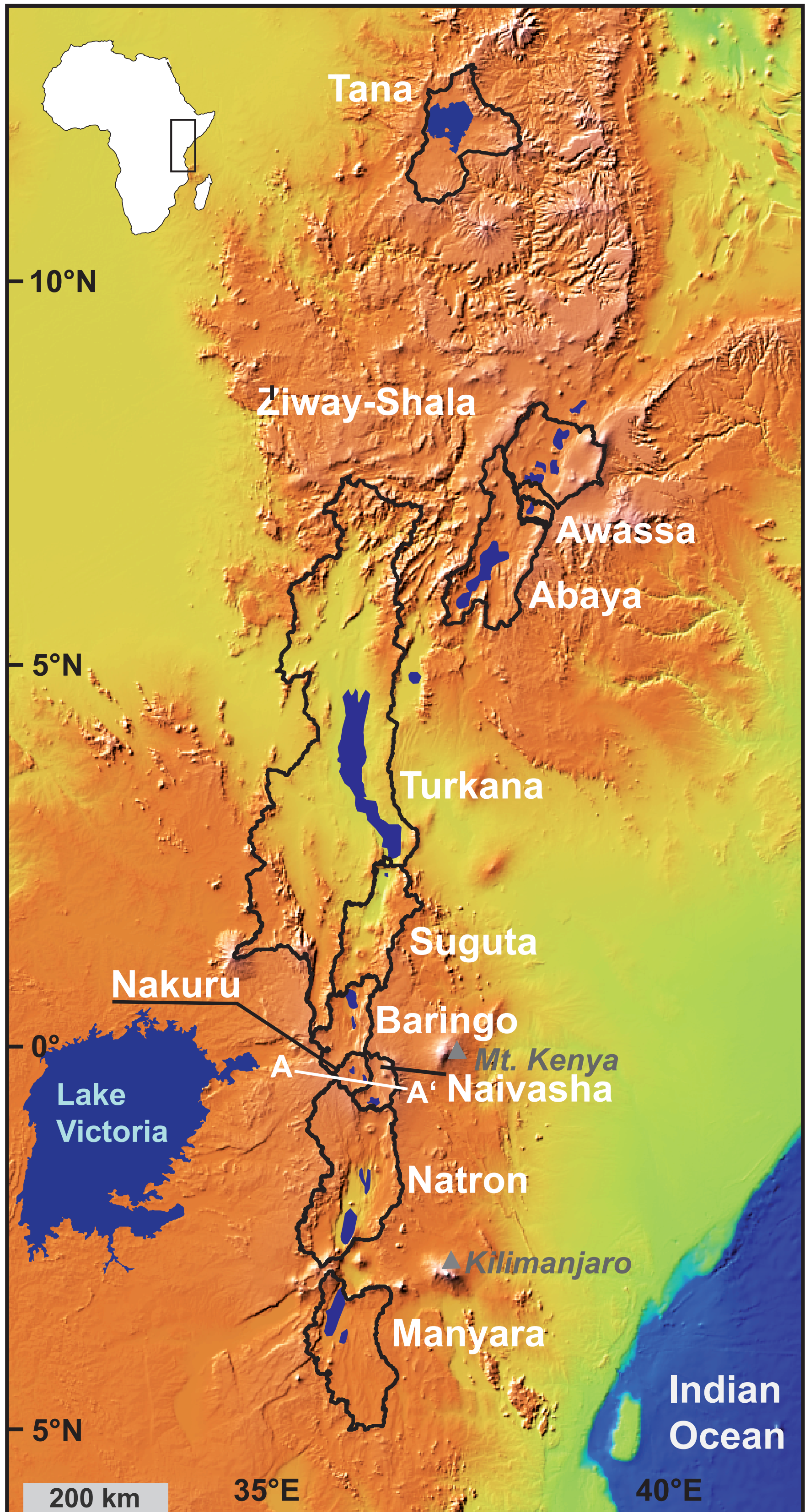
ITCZ ——

CAB ----

Tierney et al 2011

Rainfall in EA is linked to the passage of the ITCZ and CAB modified by topography causing a strongly **bimodal** annual cycle

3. Characteristics of Catchment's



Influencing climate mechanisms

ITCZ, CAB, ENSO/IOD, ISM

Orographic effects

0 m to >5000 m asl

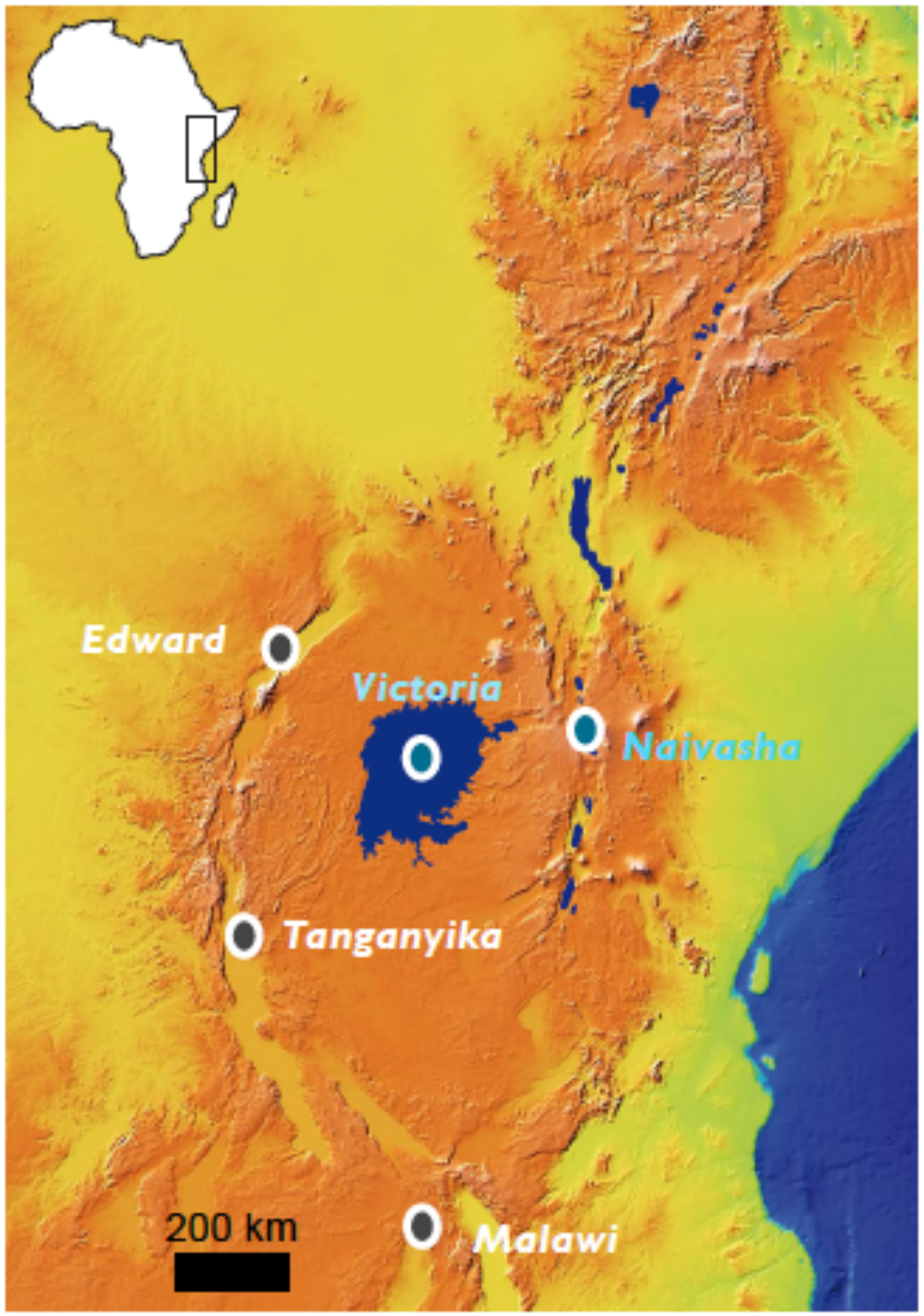
Large lake Surface areas

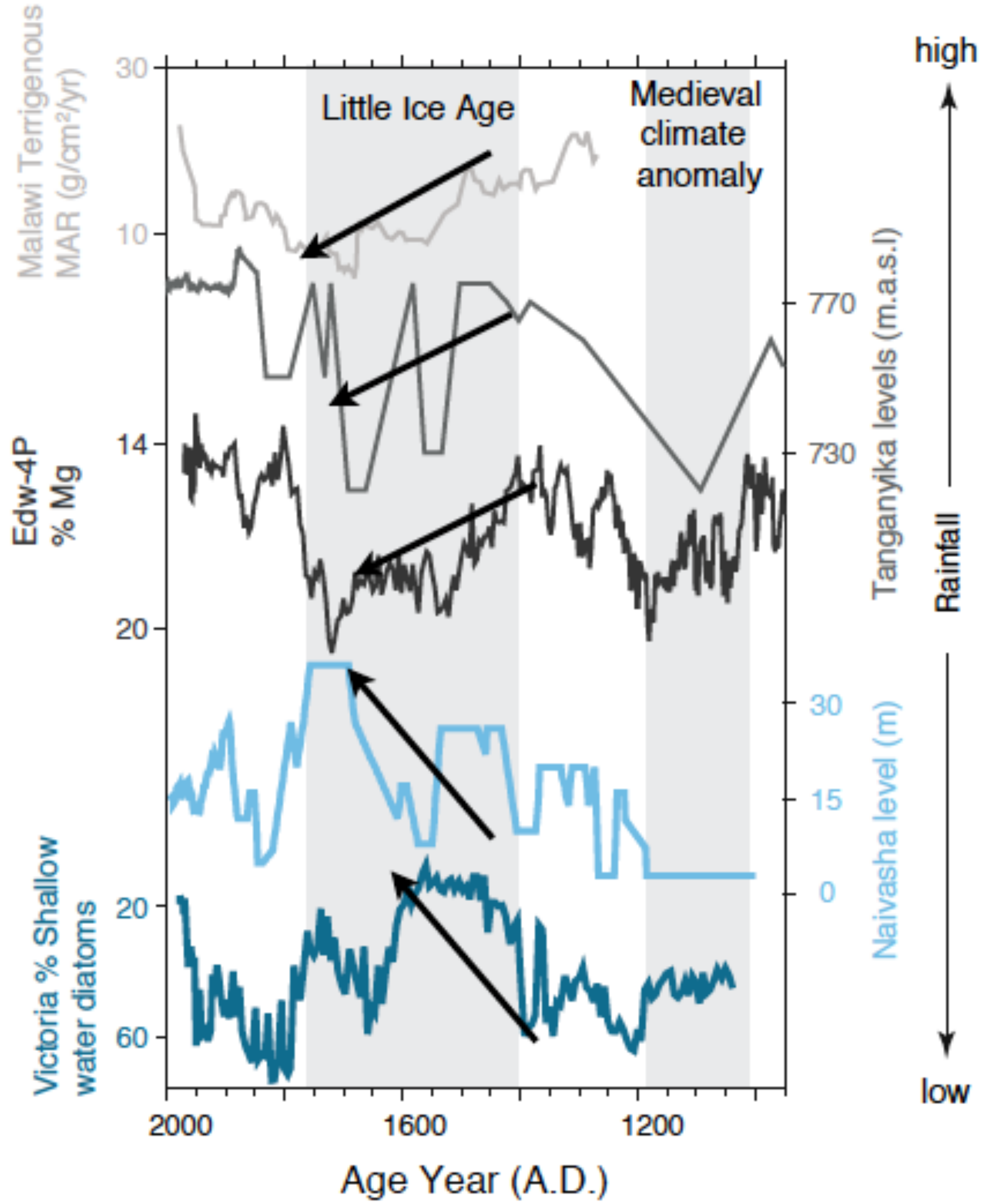
(e.g. Victoria: 68,800 km^2)

Basins elongate along the rift

3. Lake History -Variability

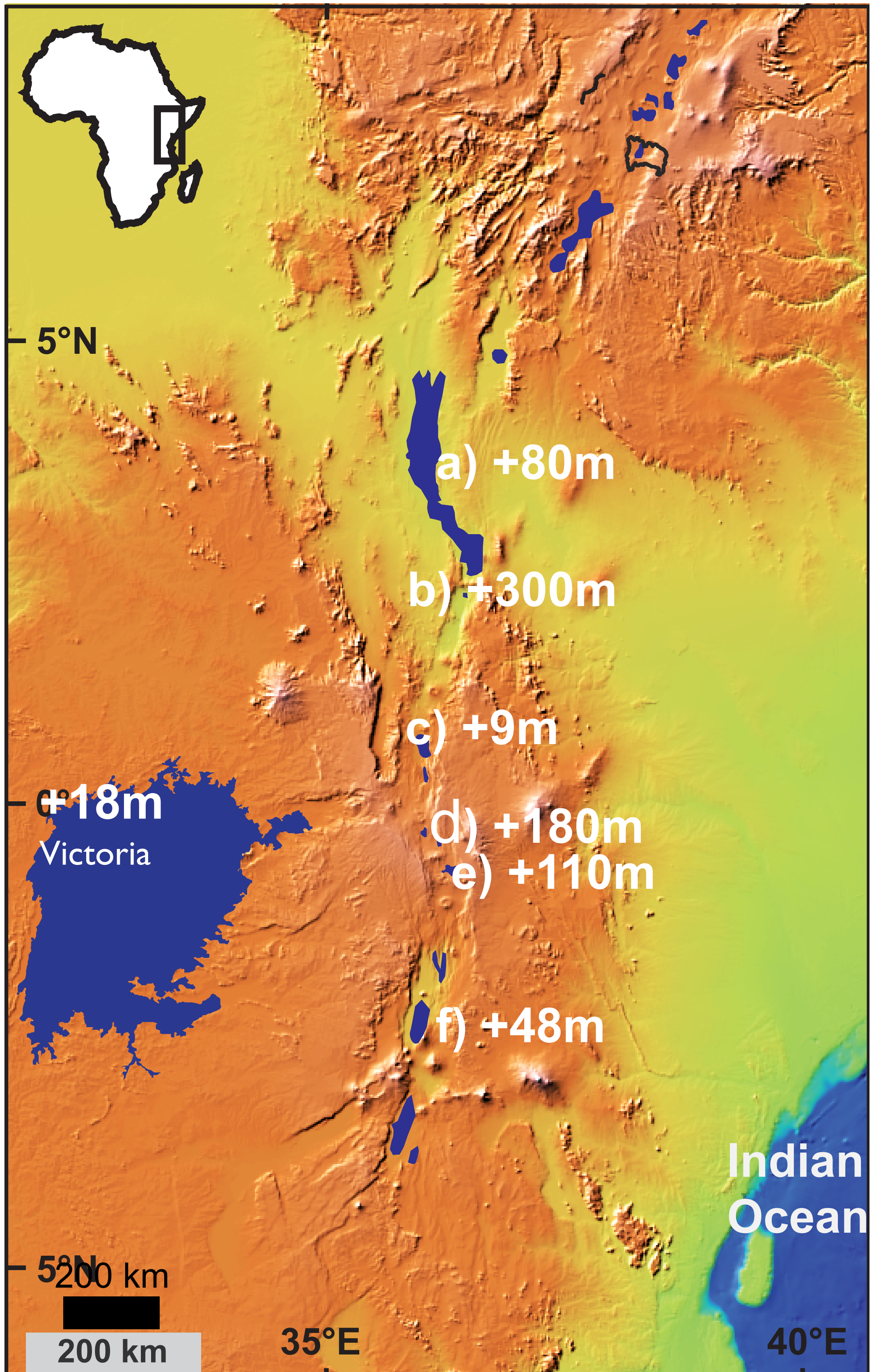
Anti correlated behaviour during Little Ice Age

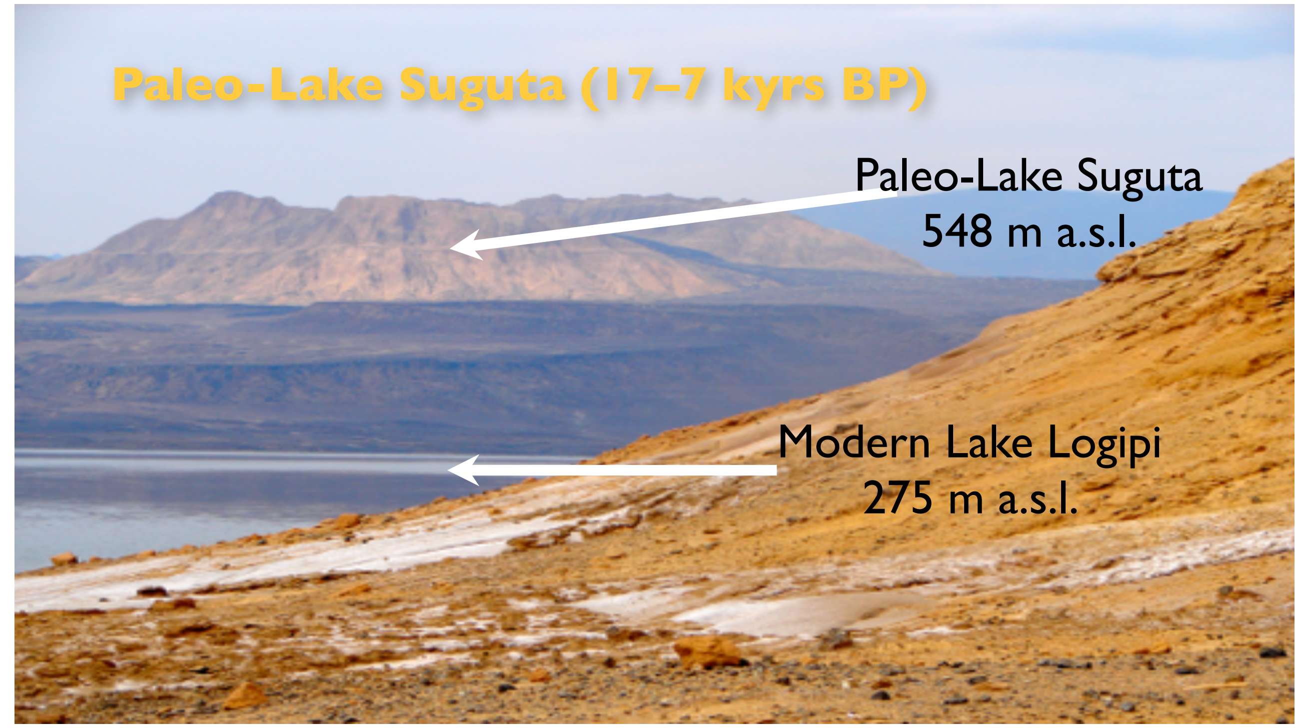


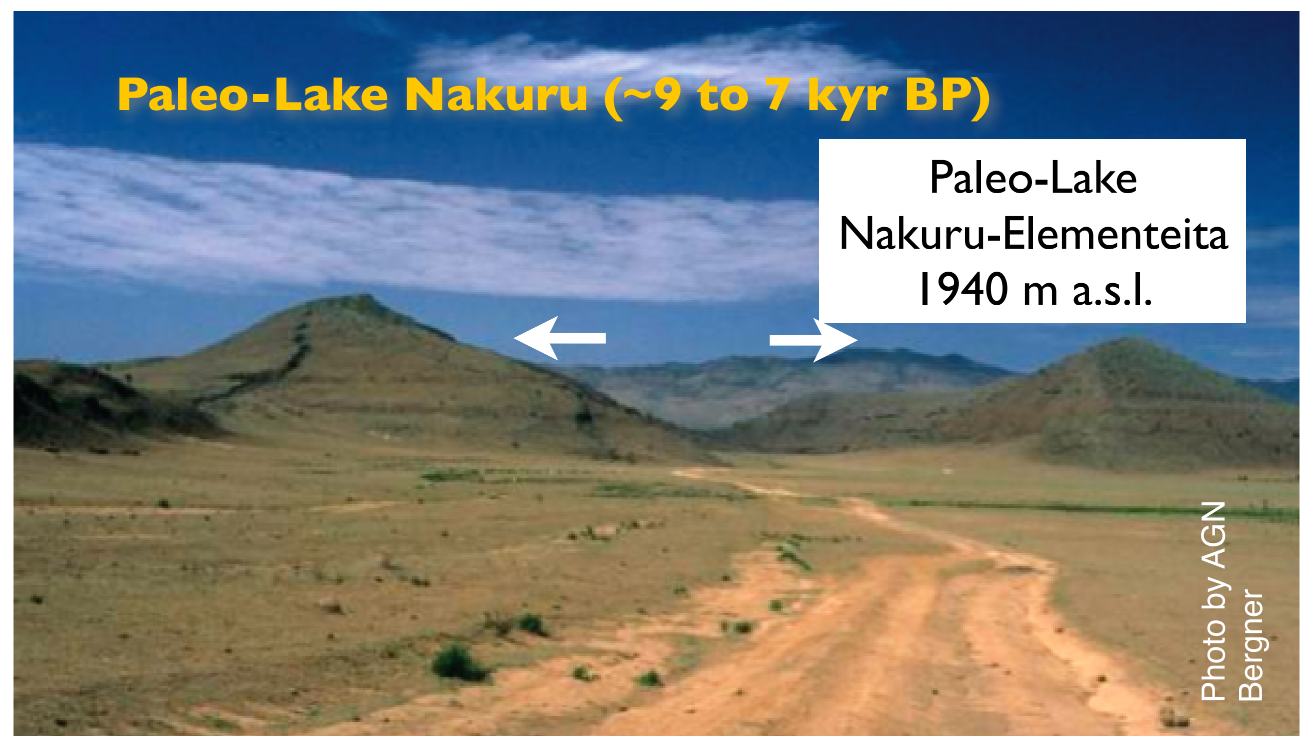


Verschuren et al. 2000; Alin and Cohen 2003; Russell et al. 2003; Stager et al. 2005

3.1. EARS Paleolakes African Humid Period lake highstands 15-5kyr



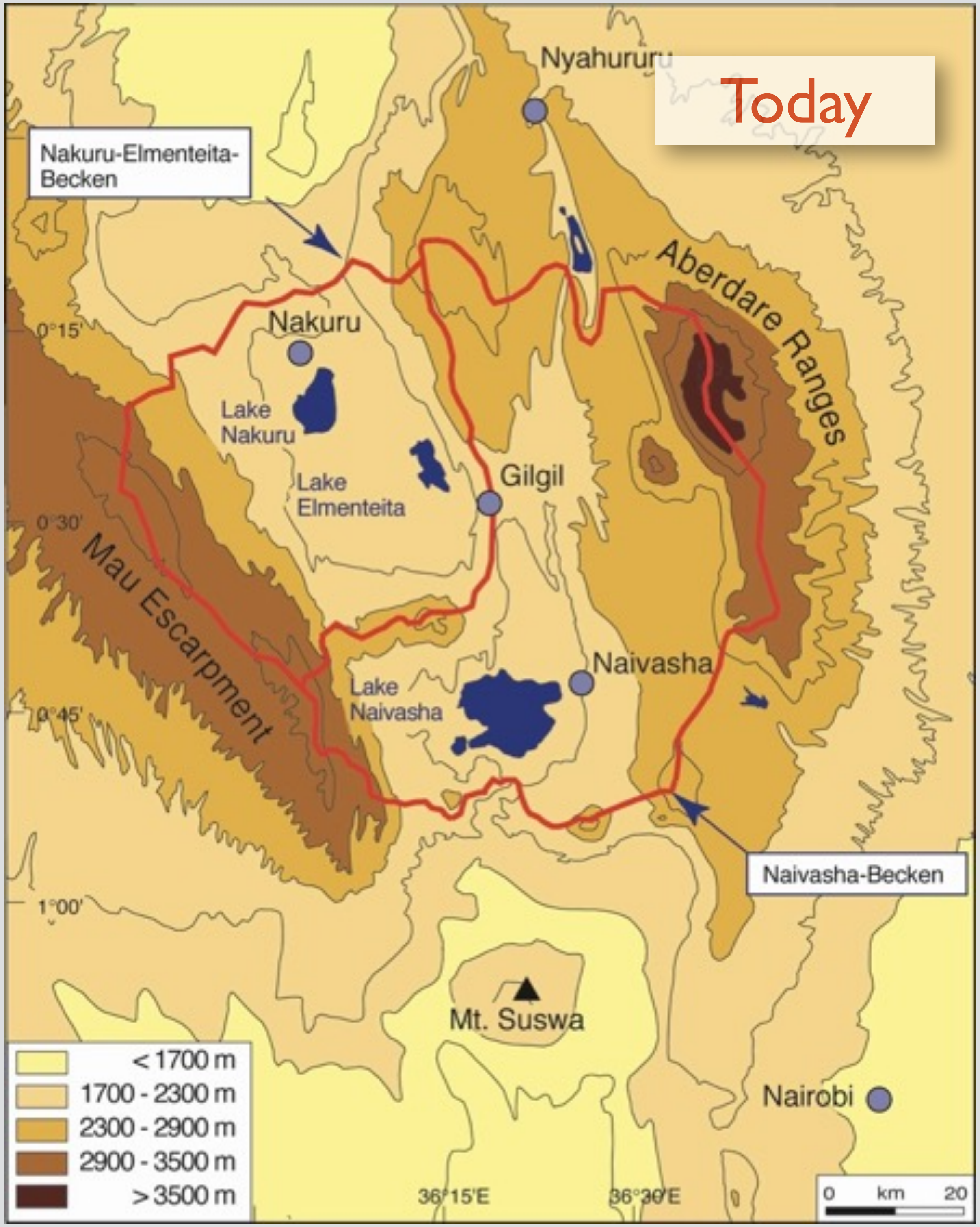




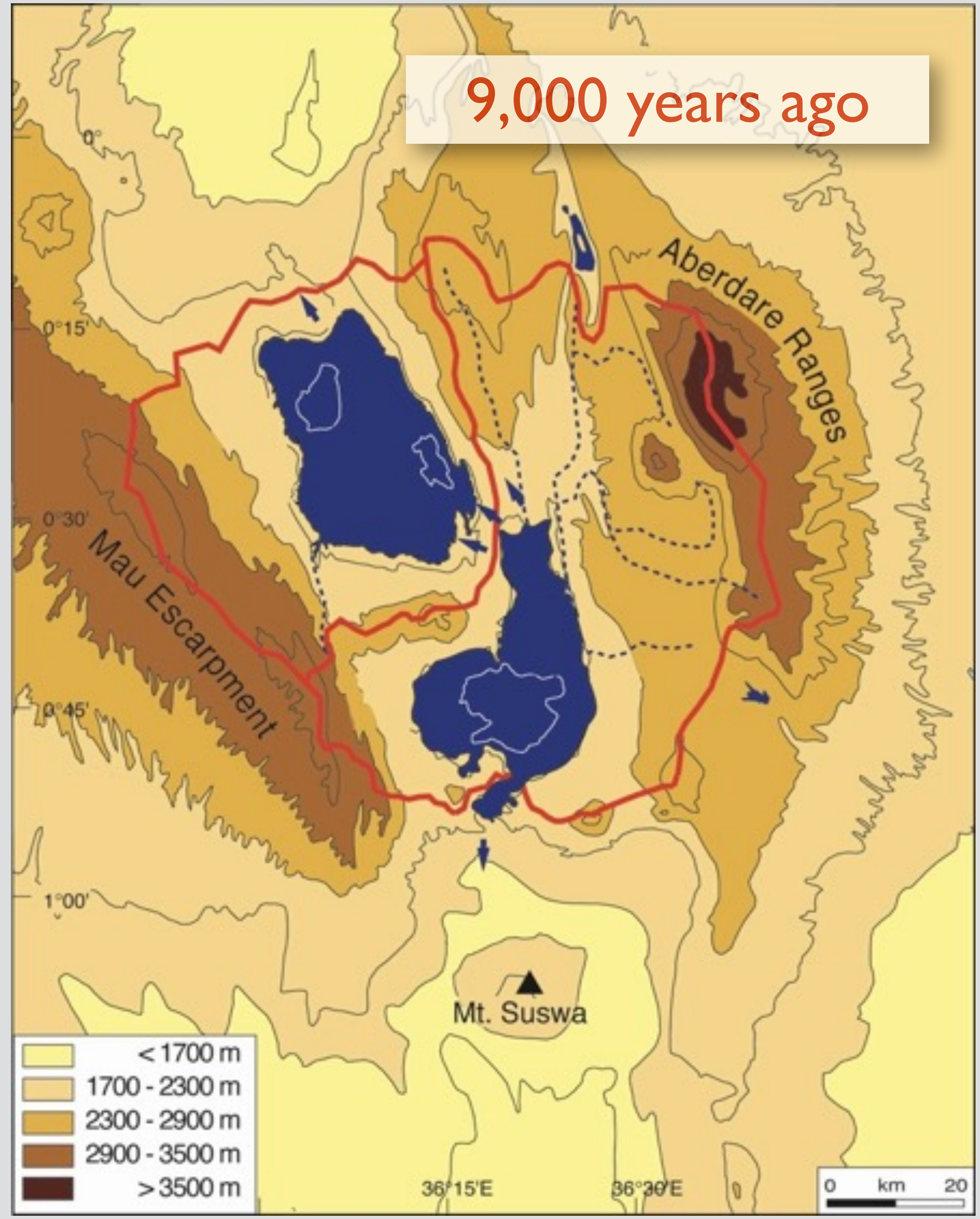
NORTH -SOUTH **a.** Turkana, **b.** Suguta, **c.** Baringo-Bogoria, **d.** Nakuru-Elementeita, **e.** Naivasha, **f.** Magadi- Natron,

Washbourn 1967, 1970; Butzer, 1972; Casanova et al. 1988; Vincens et al. 1986; Gillespie et al. 1983; Renault and Owen 1991; Dunkley et al. 1993;Garcin et al 2009

3.2 CKR Paleo and modern Lake Extent



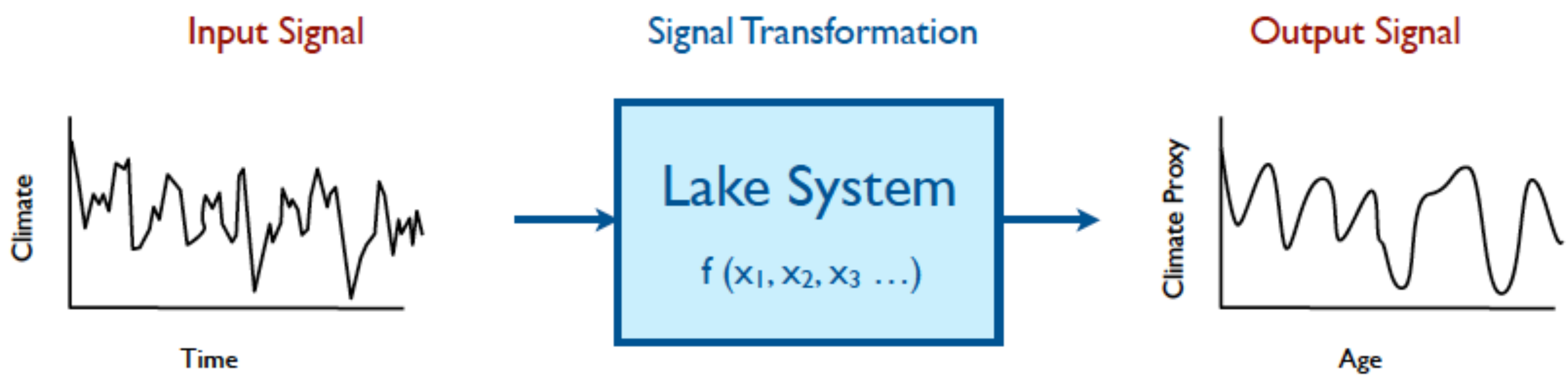
NV. Area, 140 Km2
NK-EL Area 72 +20 km 2



NV. Area, 685 Km2
NK-EL Area 755km 2

Bergner et al 2009

4. Lake Variability



where

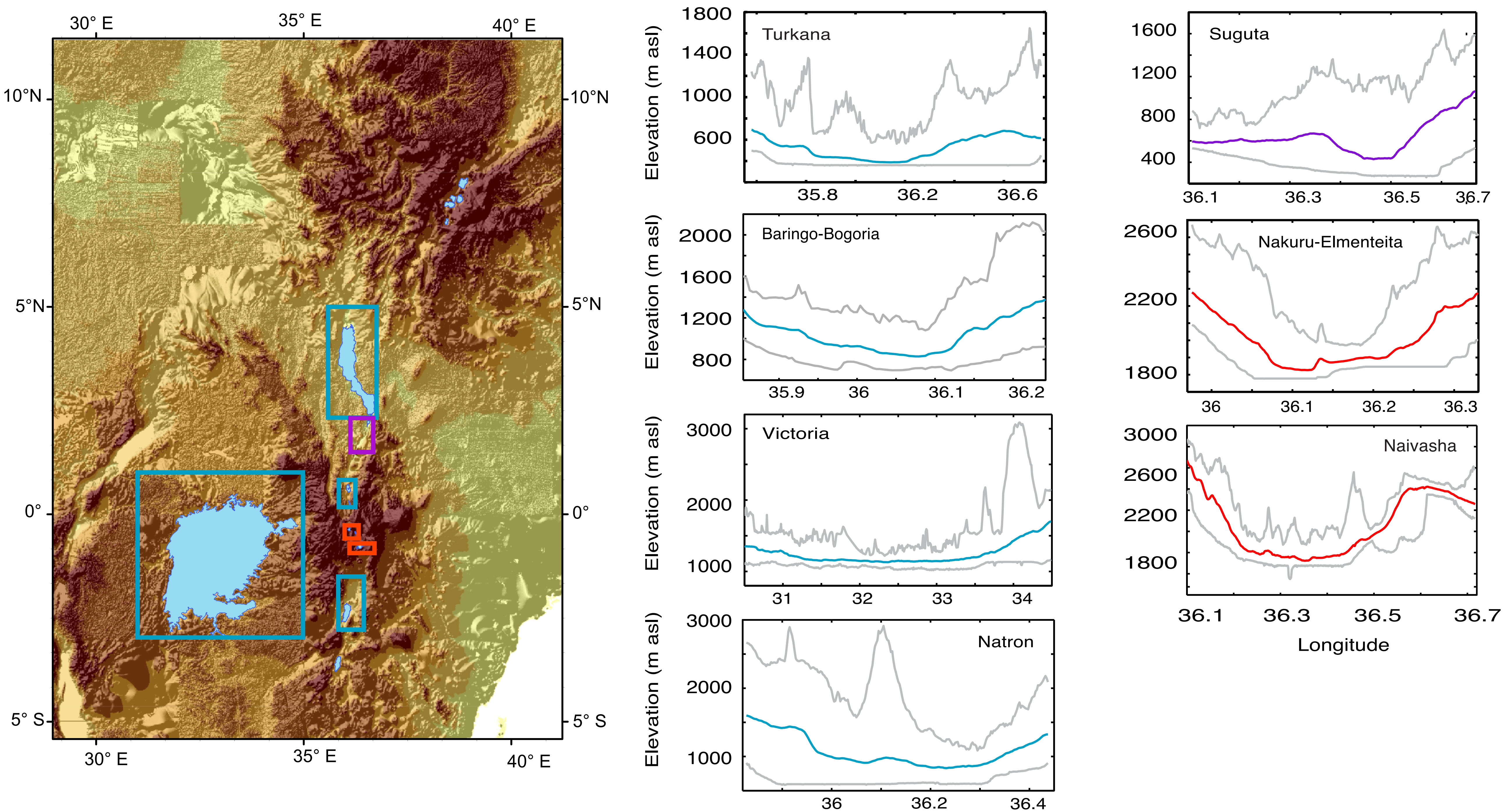
x_1 = geomorphology
x_2 = groundwater
x_3 = local / regional climate
etc.

Lakes interpose a significant filter between the external climate driver and the sedimentary record

Lake Morphometry

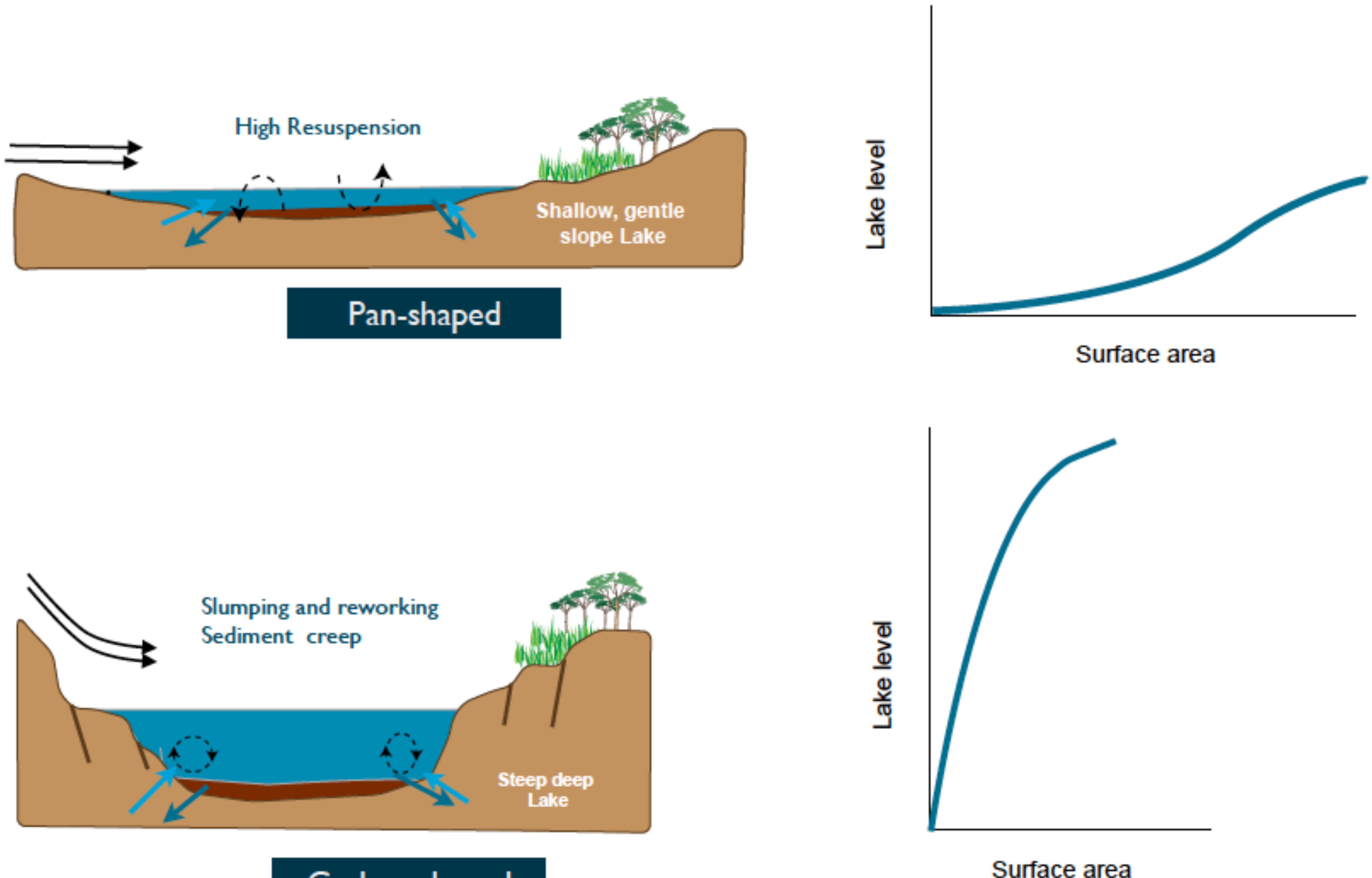
Graben shaped

Pan shaped



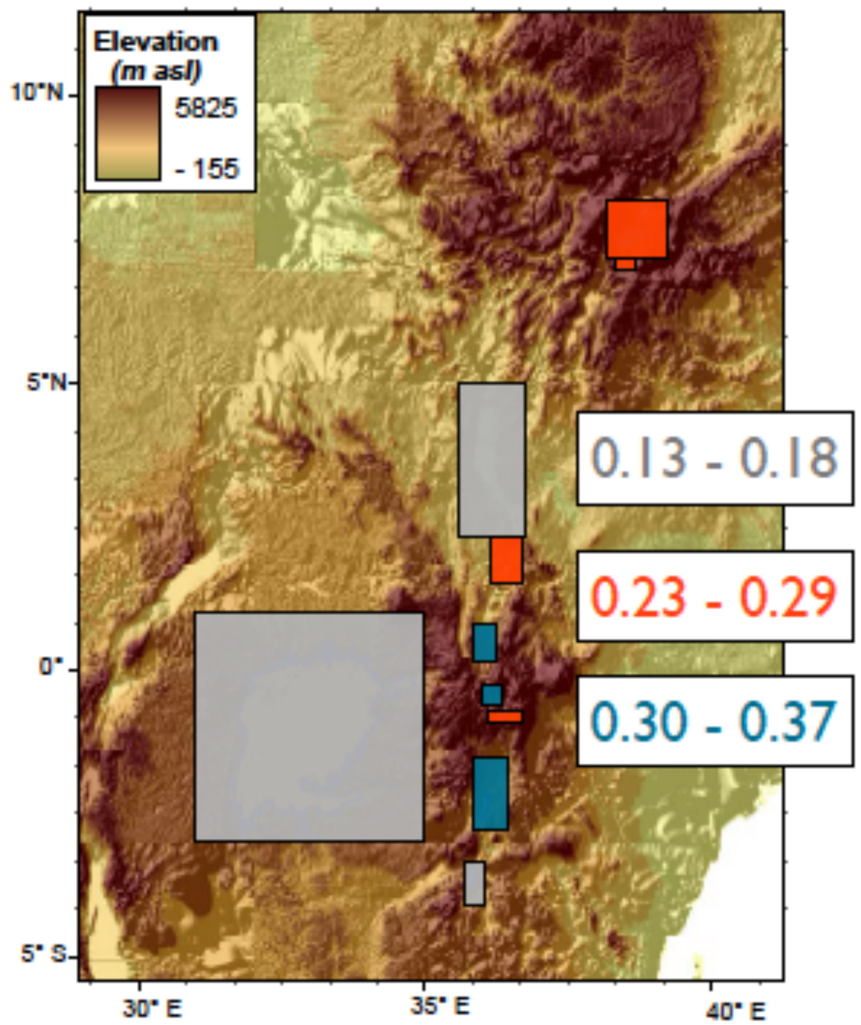
Olaka et al., 2010, JOPL

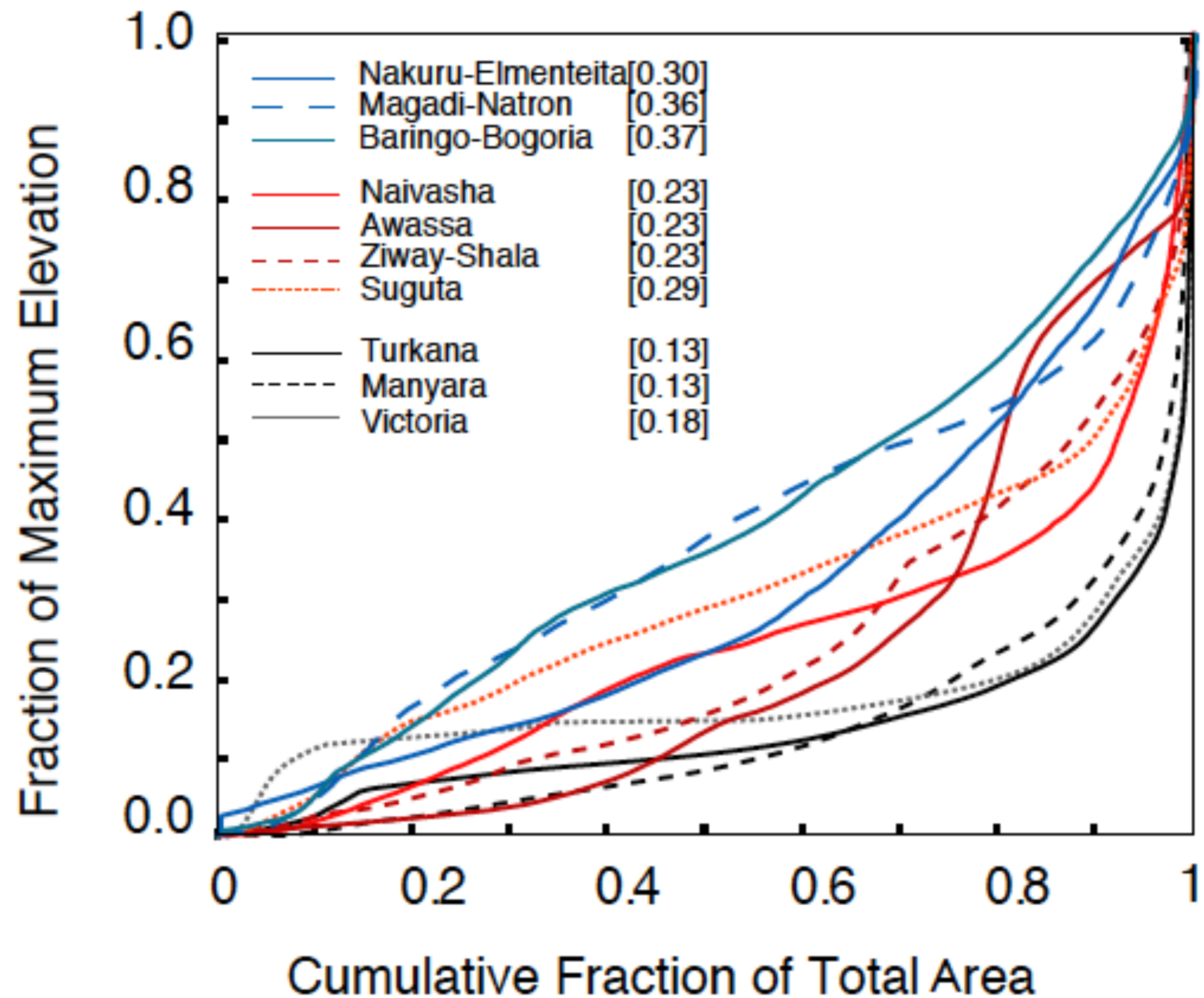
5.1. Lake Responses



Olaka et al 2011 PhD thesis

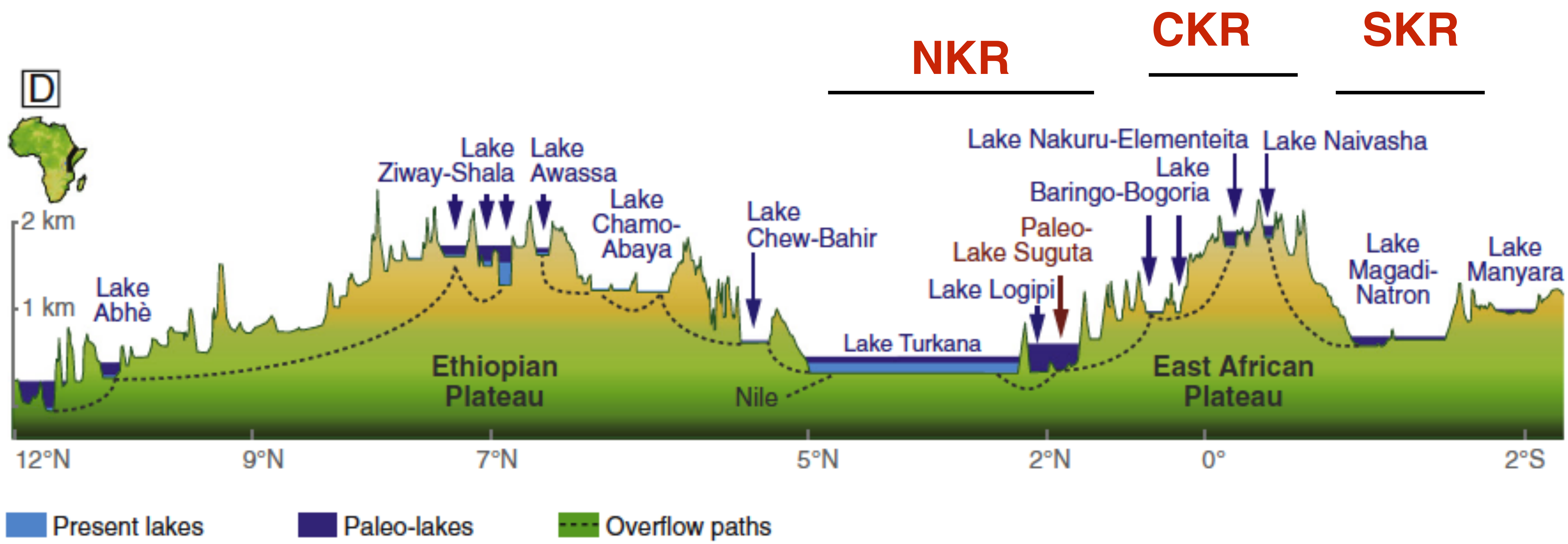
Hypsometry





Olaka et al., 2010, JOPL *Olaka et al 2011 PhD thesis*

6. Groundwater

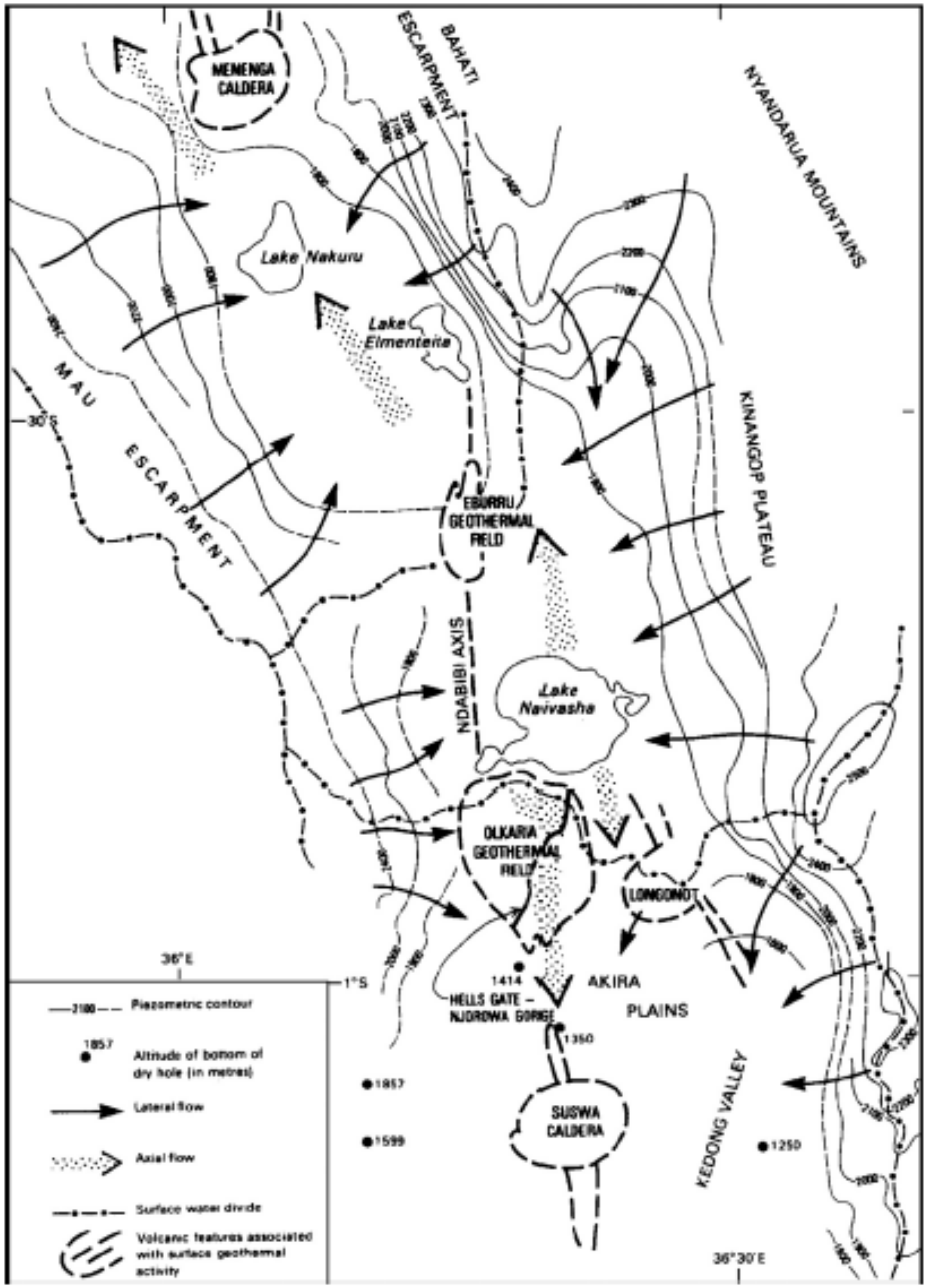


Hydraulic Gradient of the EARS Basins

- Hydraulic gradient
- Flow pathways, Faults

Olaka et al., 2010 ,Junginger et al 2014

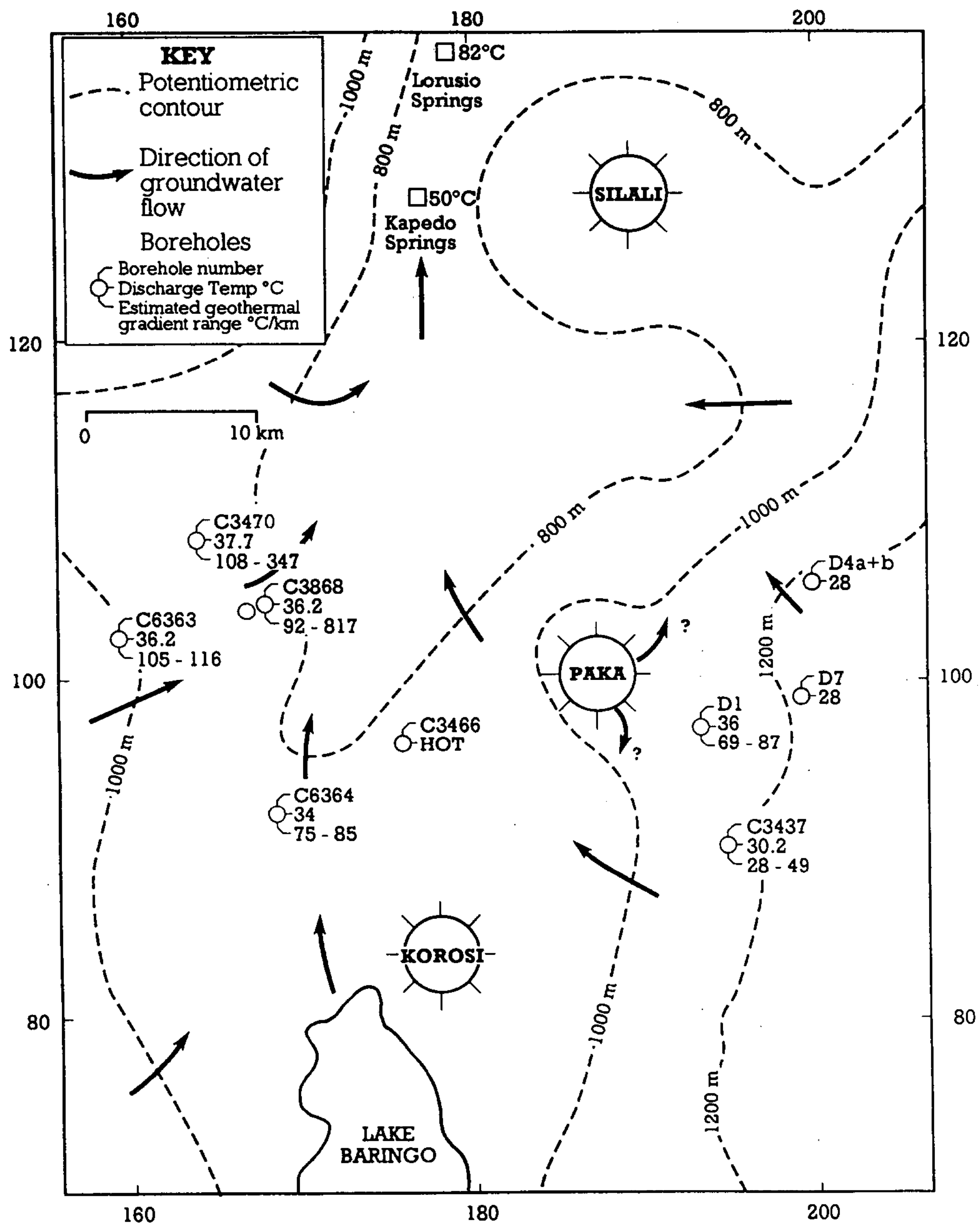
6.1. Ground Water Flow in the CKR



Rift axis flow to the south and north

Clarke et al 1990

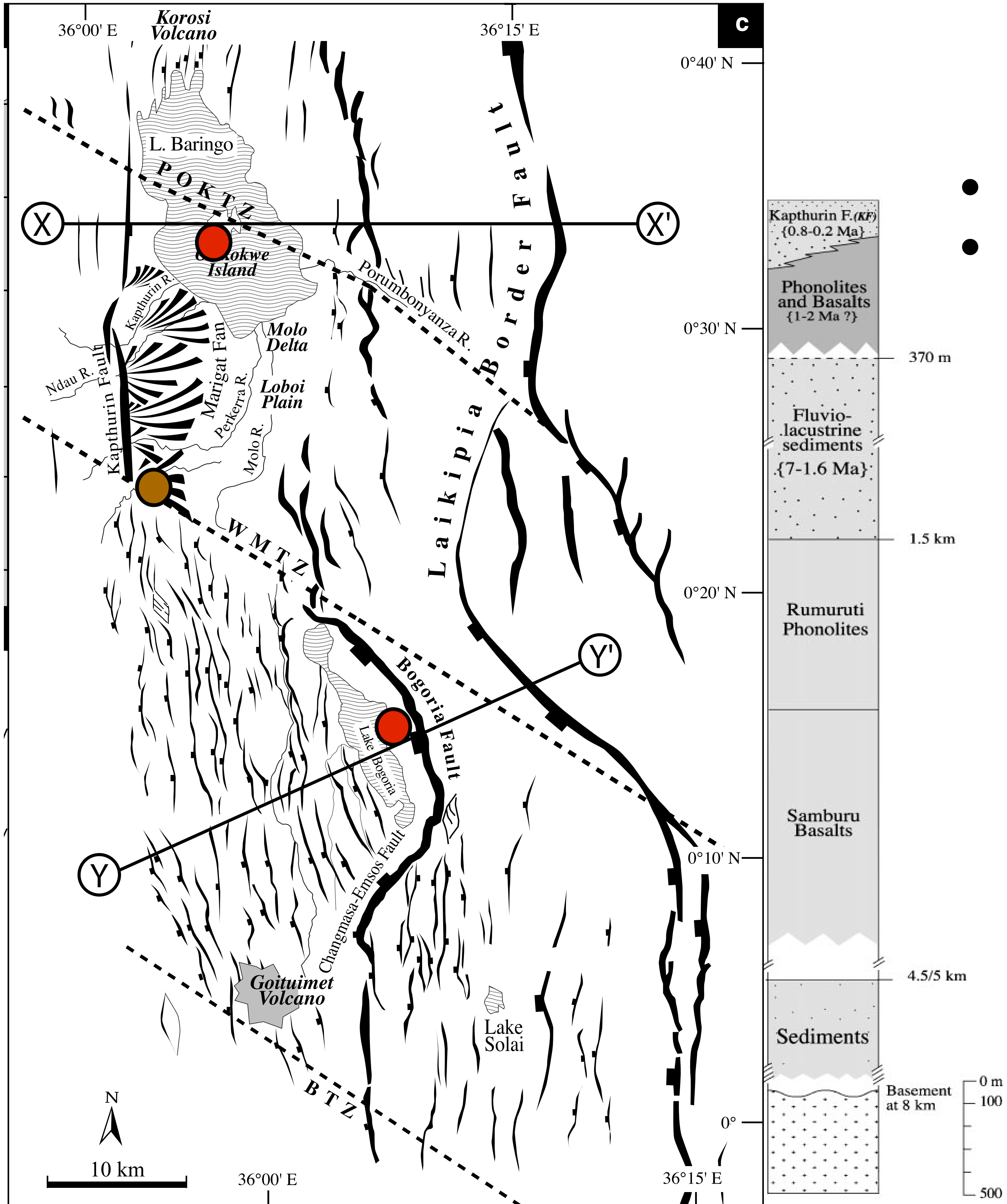
6.2 Groundwater flow NKR



- Groundwater flow North of Baringo
- Geochemical composition of the Lake Baringo waters reflects two physical processes:
- **evaporation** and the **binary mixing** between river water and hydrothermal fluids(*(Tarits et al 2006)*

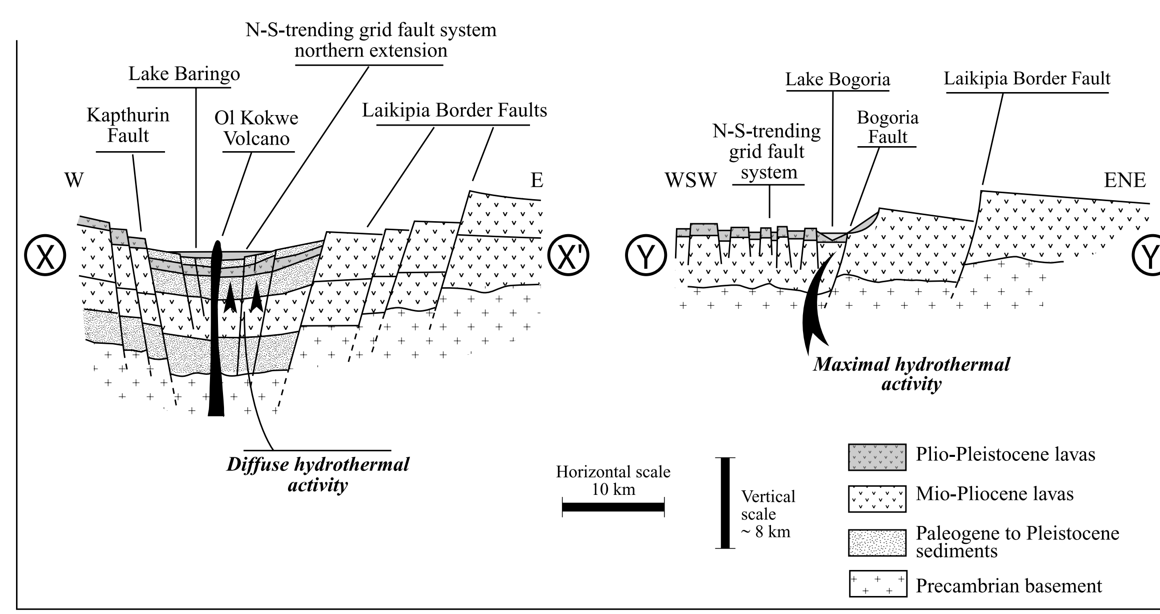
Area North of Baringo, showing groundwater potentiometric contours and schematic flow direction *(after Allen and Darling, 1992, Darling et al., 1996)*

6.3 Baringo Bogoria- Structures, Geology



- areas of minor hydrothermal activity
- areas of maximal hydrothermal activity

- Lake in basin formed by 8km deep fault
- Numerous faults forming the Islands

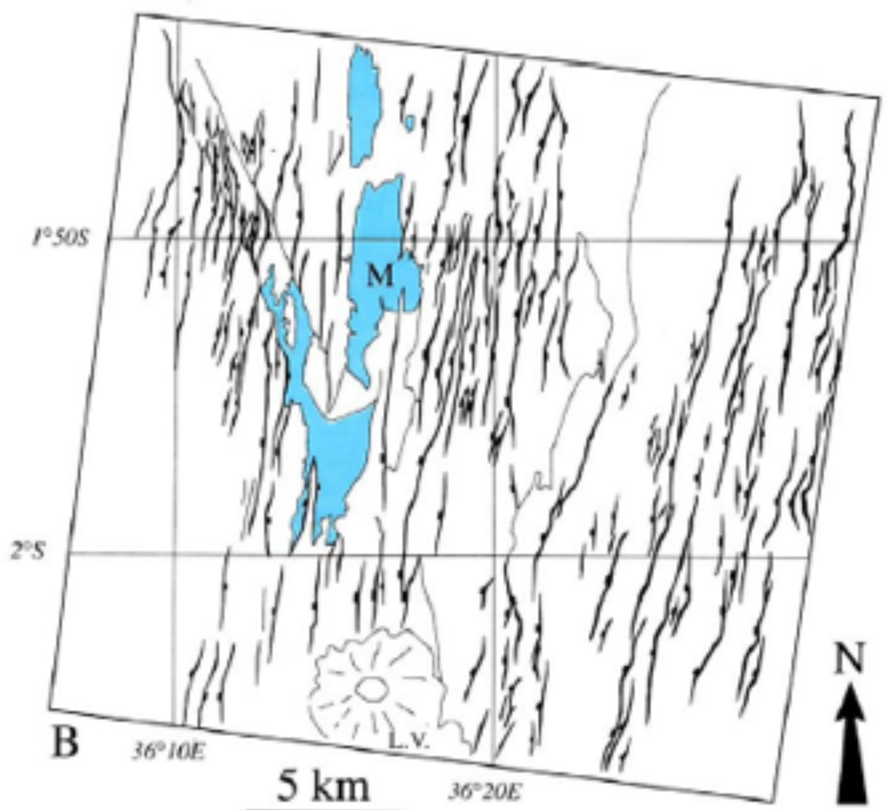


Legal et al., 2000;Tarits et al., 2006

6.4 Hydrology Magadi-Geochemistry

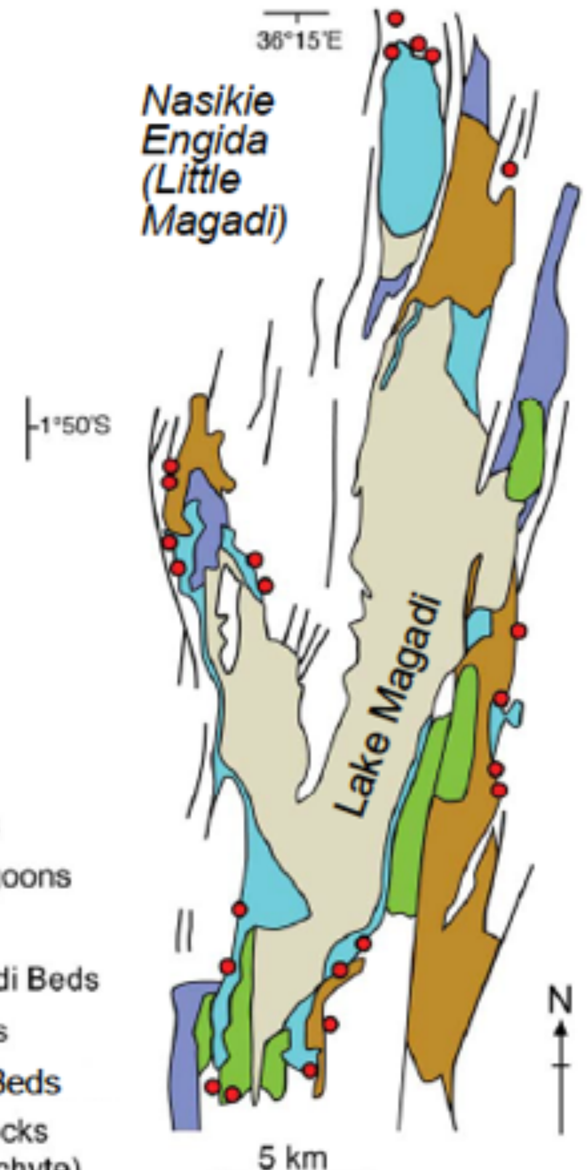
Geochemistry

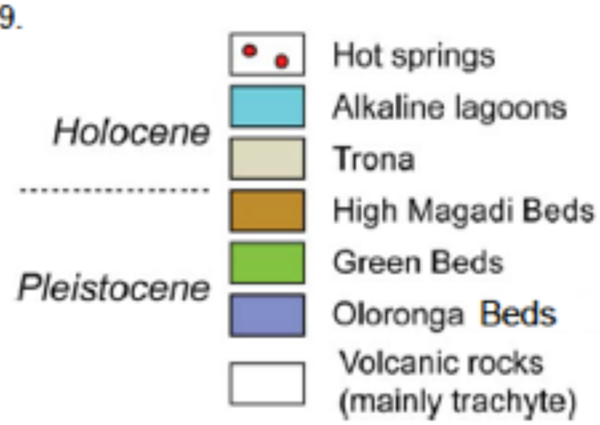
Hypersaline- Na-CO_3- Cl brine fed mainly by hot, alkaline (40-80^{o}C) springs that discharge along lake marginal faults covered by thick bed of Trona (renault et al..)



(after Le Turdu et al., 1999. AAPG Stud. Geol. 44)

(after Allen et al.,1989, BGS Rep SD89 and Behr 2002, SEPM Spec. Pub 73)

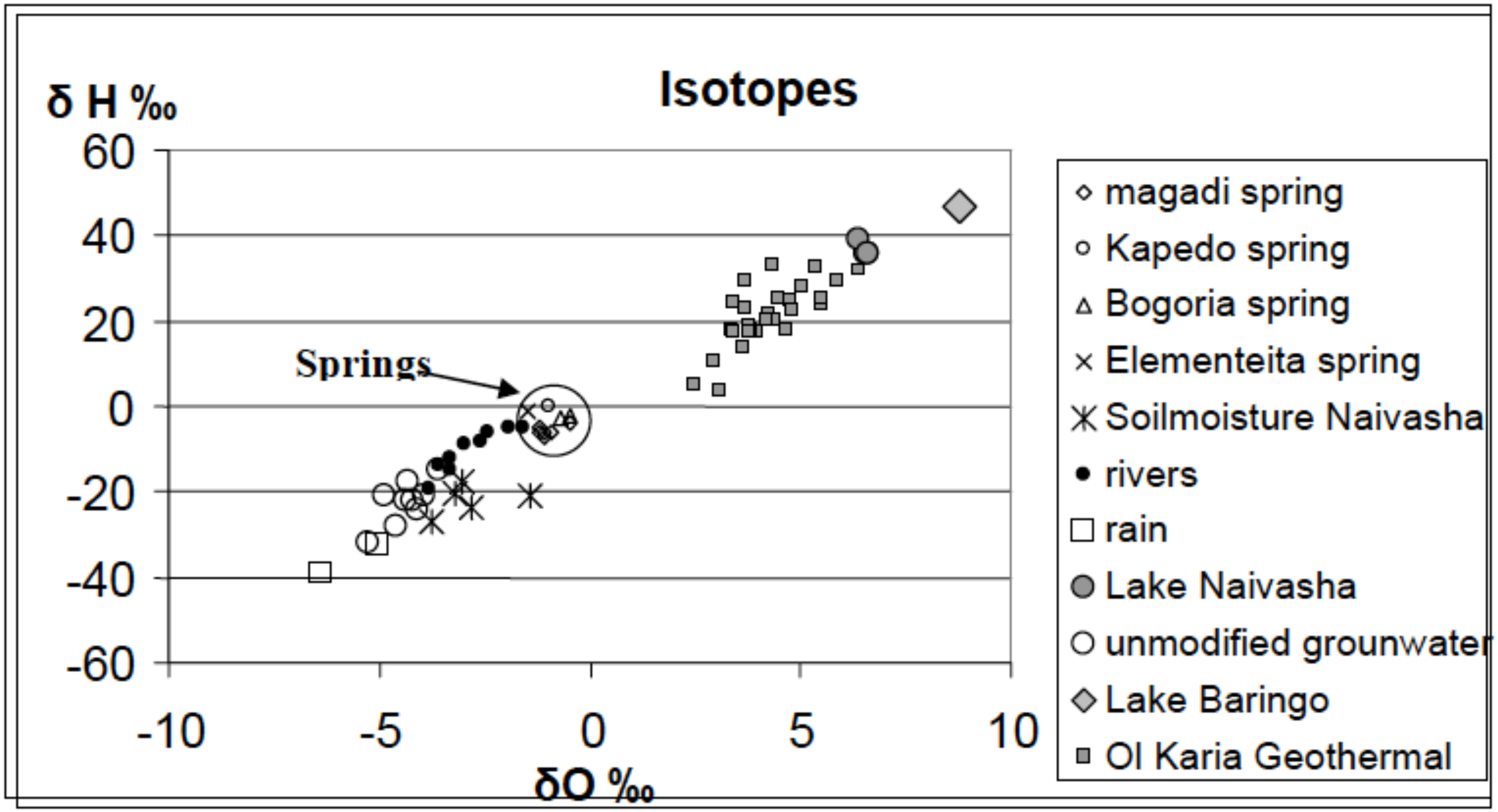




Geological setting of the axial graben

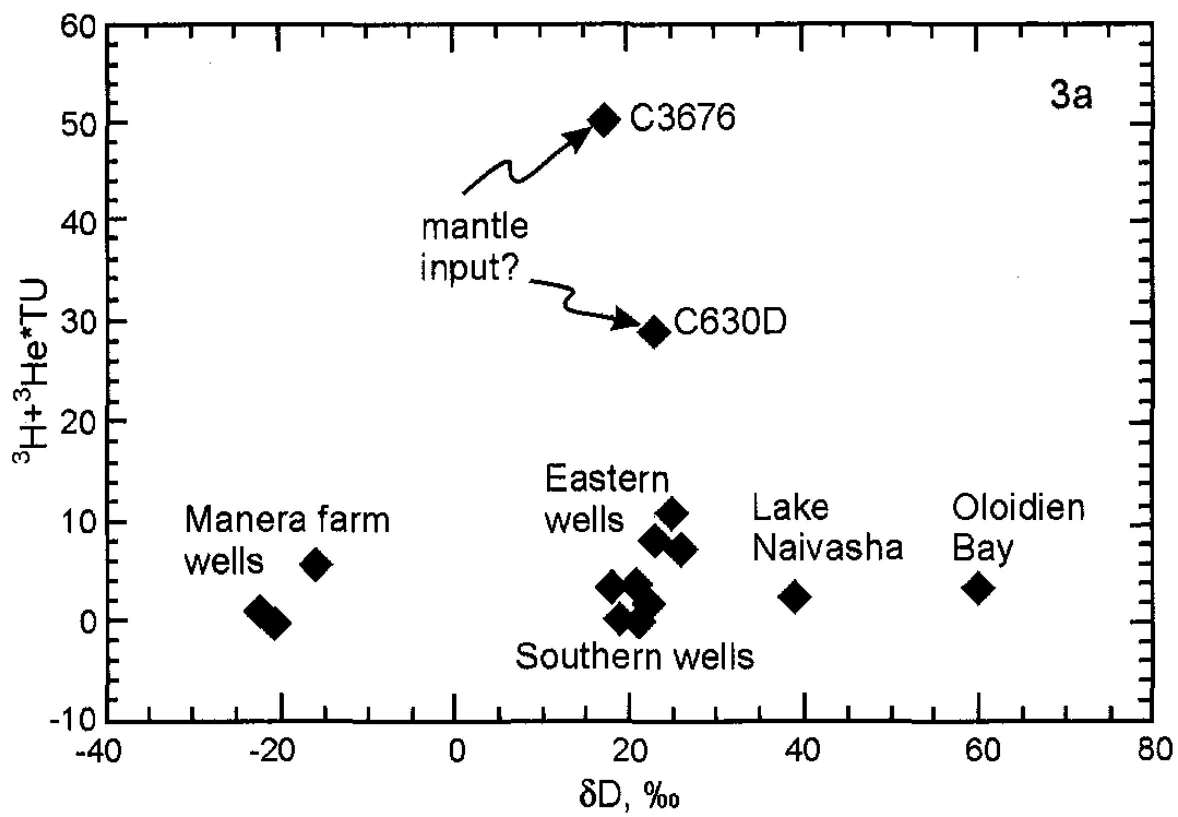
figure from Renault et al

6.5 Isotopic Evidence of gw connection

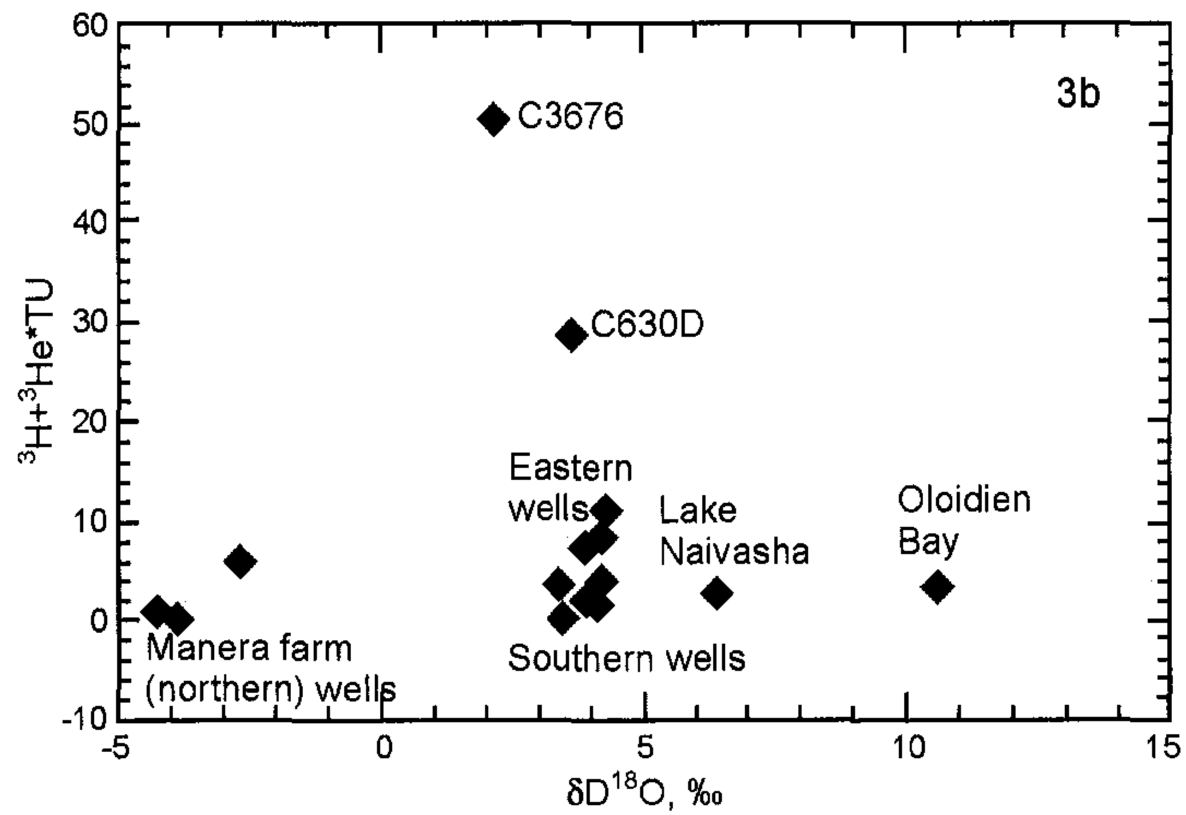


Becht et al 2005

7.1 Groundwater Recharge and flow



Plot of $^3H+^3He$ versus δD for ground water from Lake
Naivasha region.

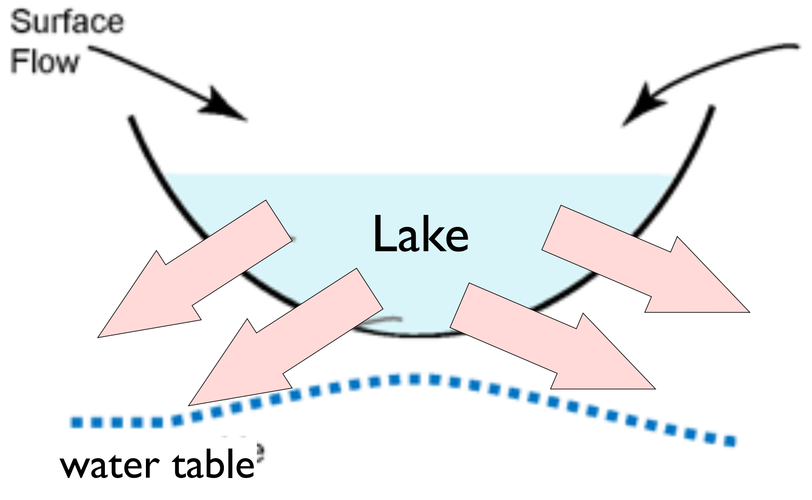


Plot of $^3H+^3He$ versus $\delta^{18}D$, **%o** for ground water from Lake Naivasha region.

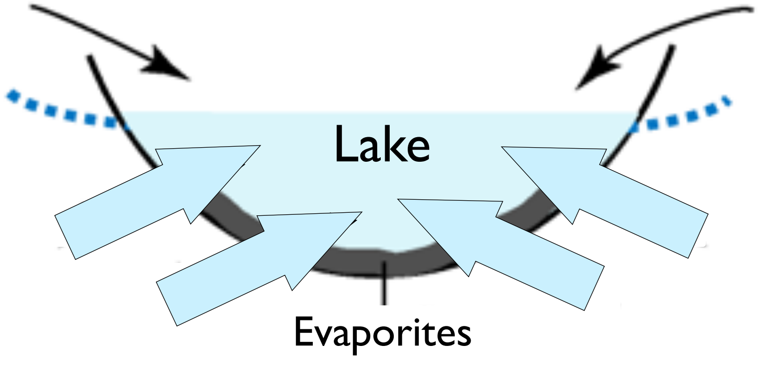
Ojiambo et al., 1996

6.6 SW- GW interconnection

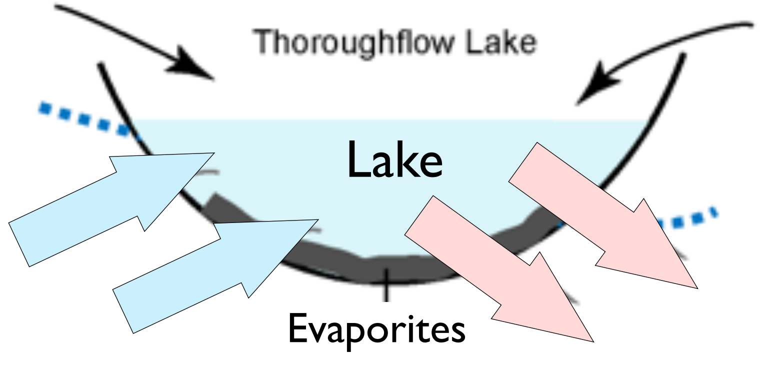
- Both Surface and Groundwater contribute to the lake budget-
  - input for closed lakes -rivers, rainfall, springs, hydrothermal,



1. Recharge lake



2. Discharge lake



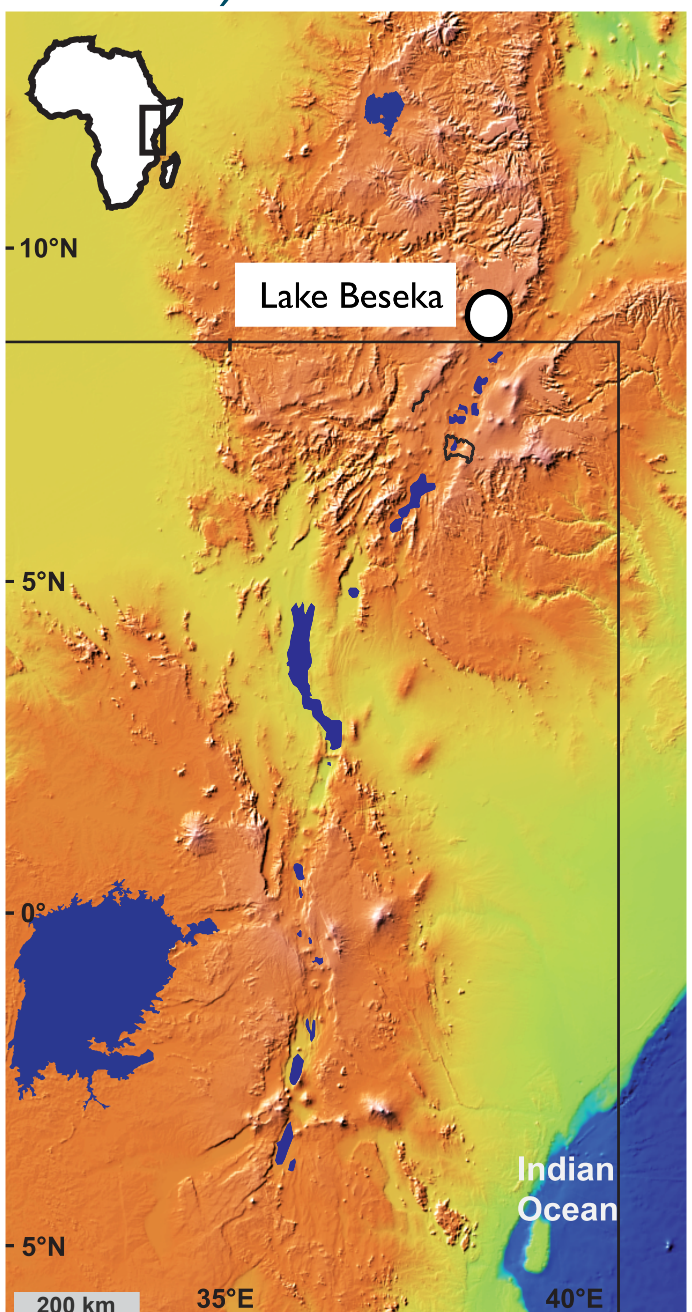
3. Throughflow lake

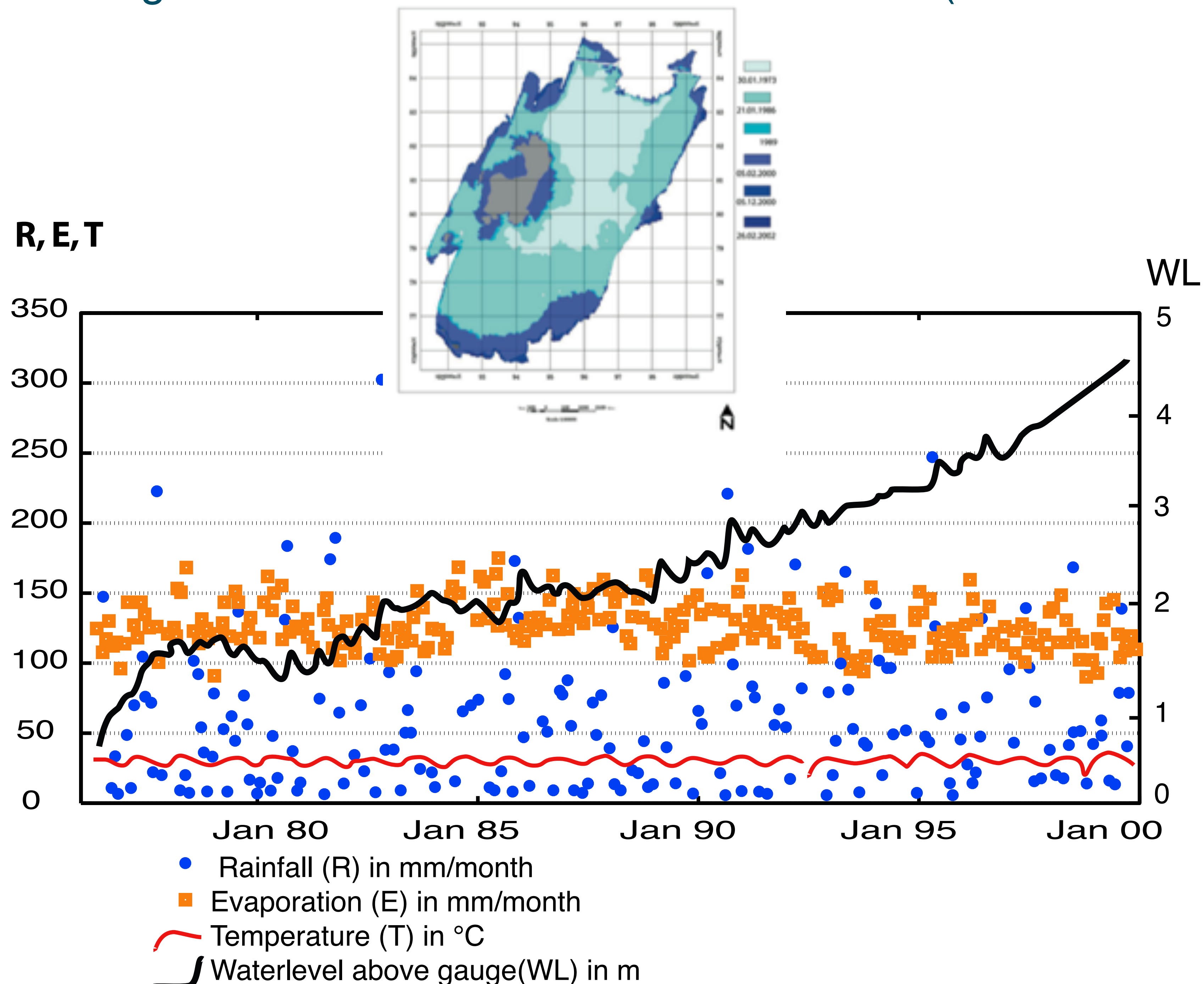
Tweed et al. 2010

6.6 SW- GW interconnection

1. Lake Beseka, Ethiopia

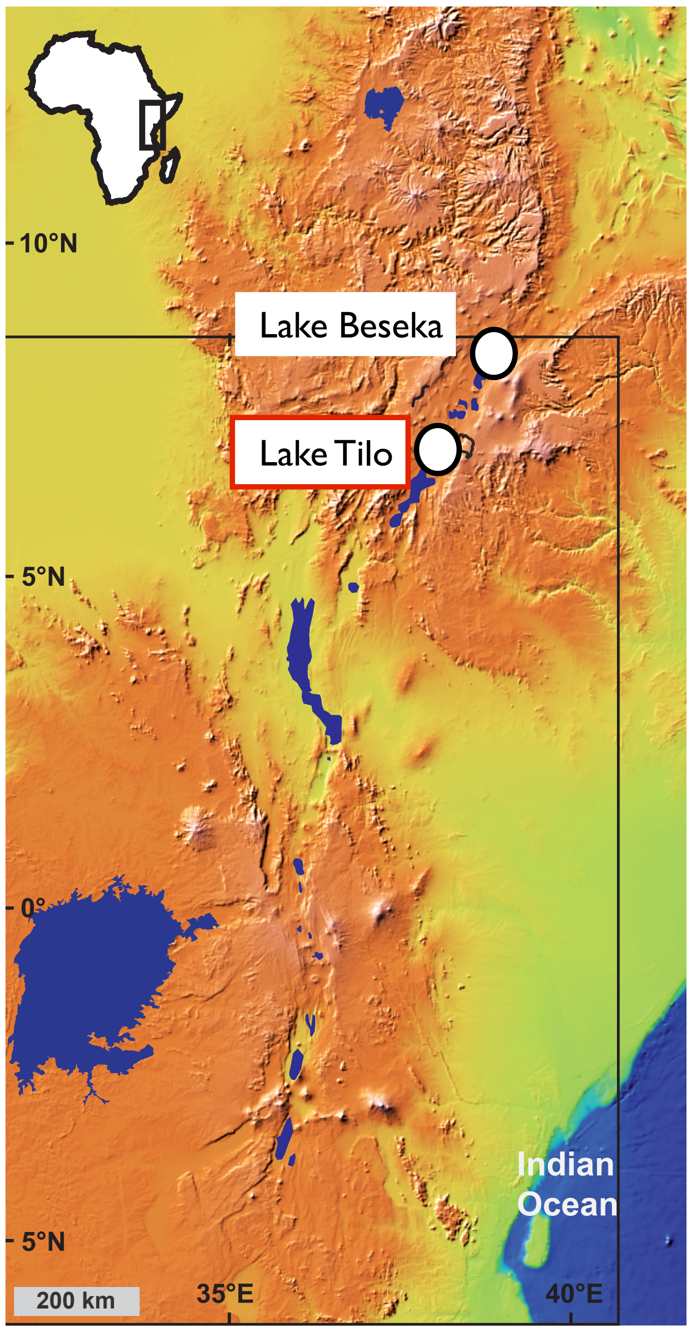
the lake's surface area quadrupled from 11.1 km² in 1973 to 39.5 km² in 2002 attibuted to increased groundwater recharge: Damming or **increased tectonics**?-(*Goerner et al., 2008)*



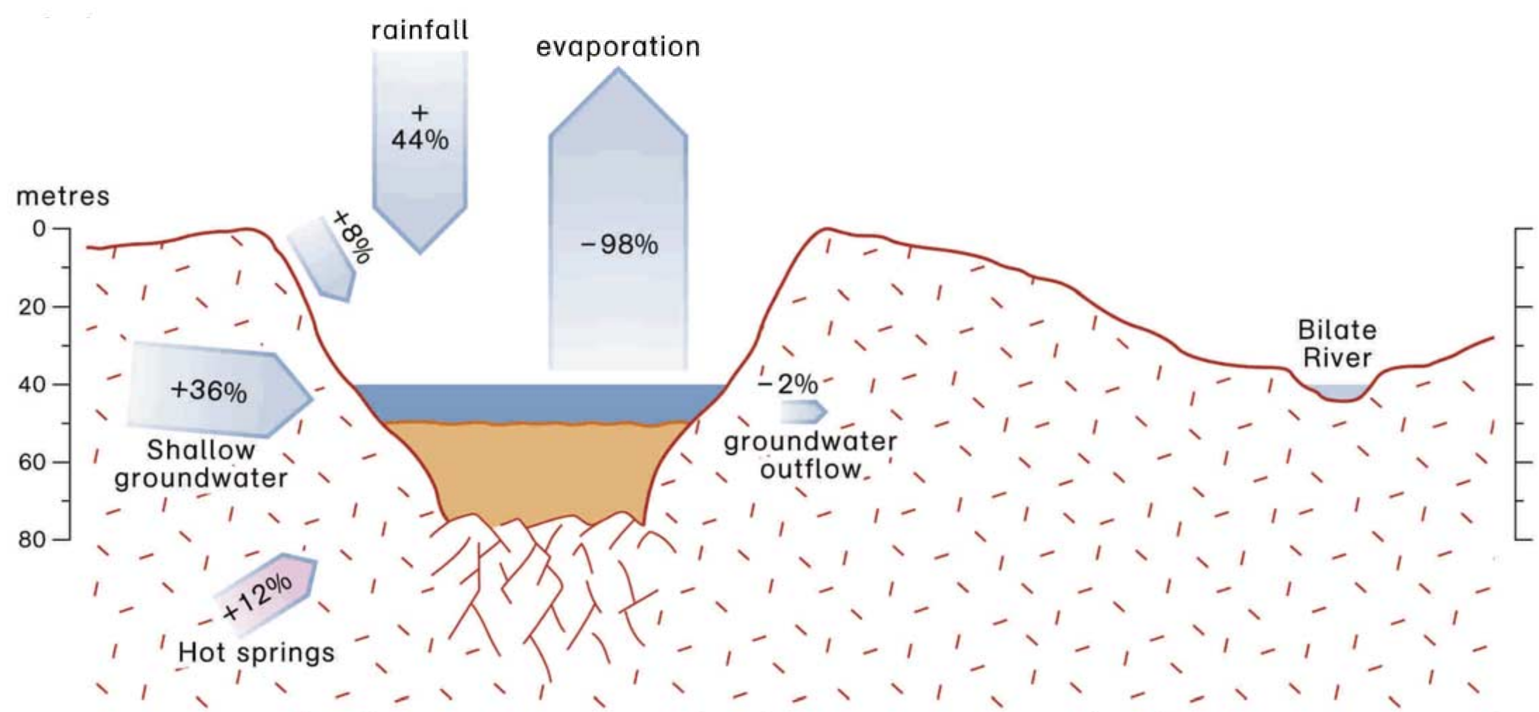


6.6. SW- GW interconnection

2. Lake Tilo, Ethiopia

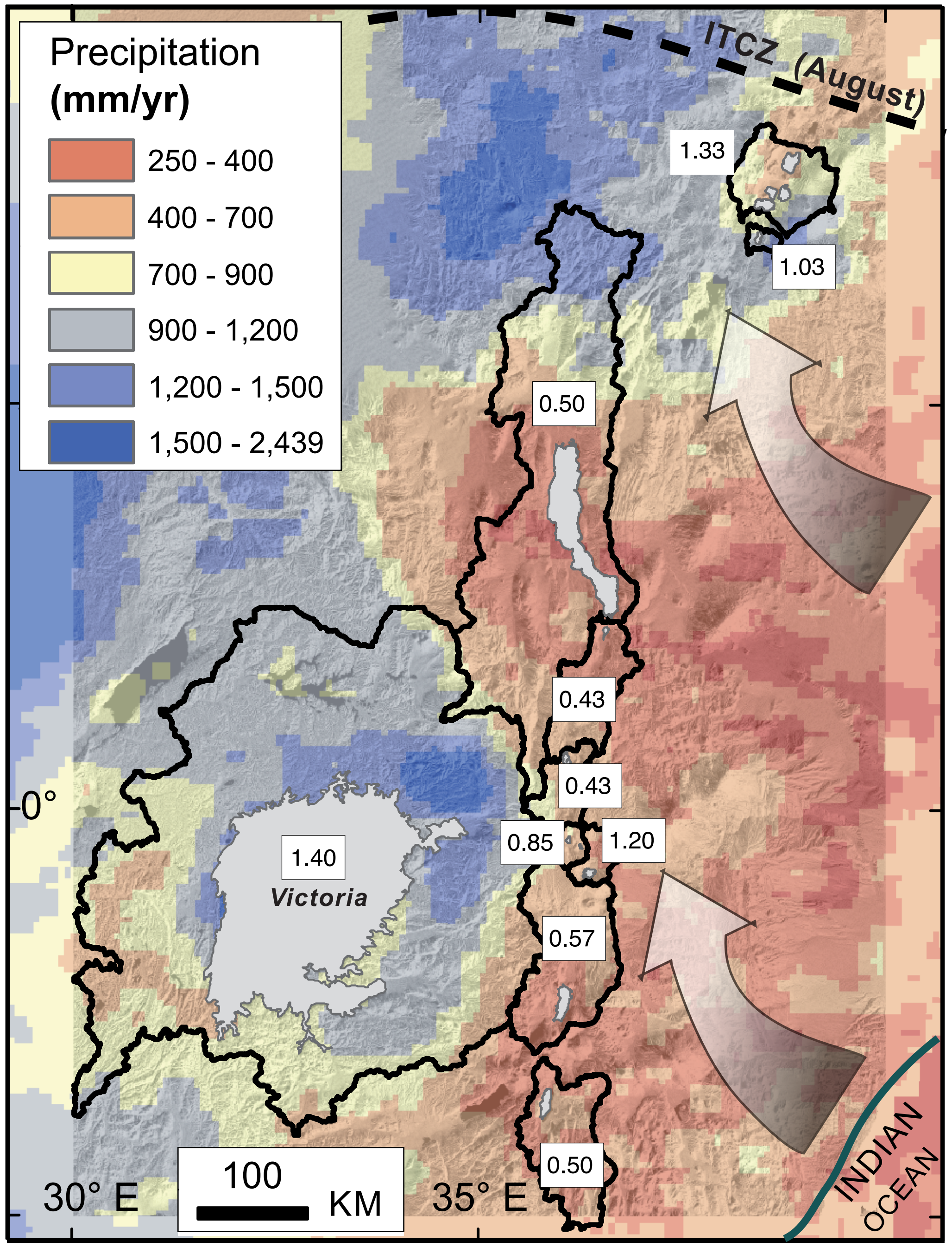


- Observed high diatom inferred salinity at the same time all paleoshoreline proxies show high lake levels
- Change to saline conditions at 4500 yr B.P. due to increased Geothermal groundwater flux

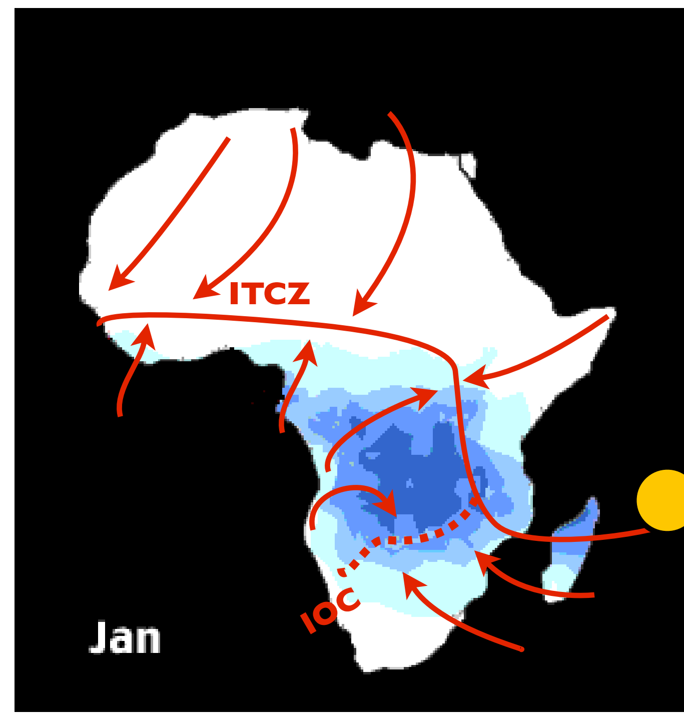


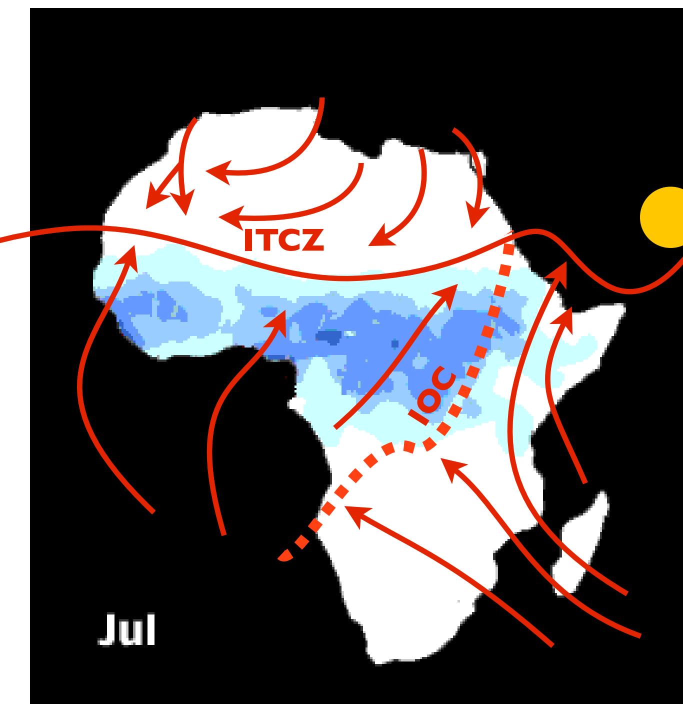
Telford et al., 1999; Lamb, 2001

7 Aridity index



Olaka et al., 2010, JOPL

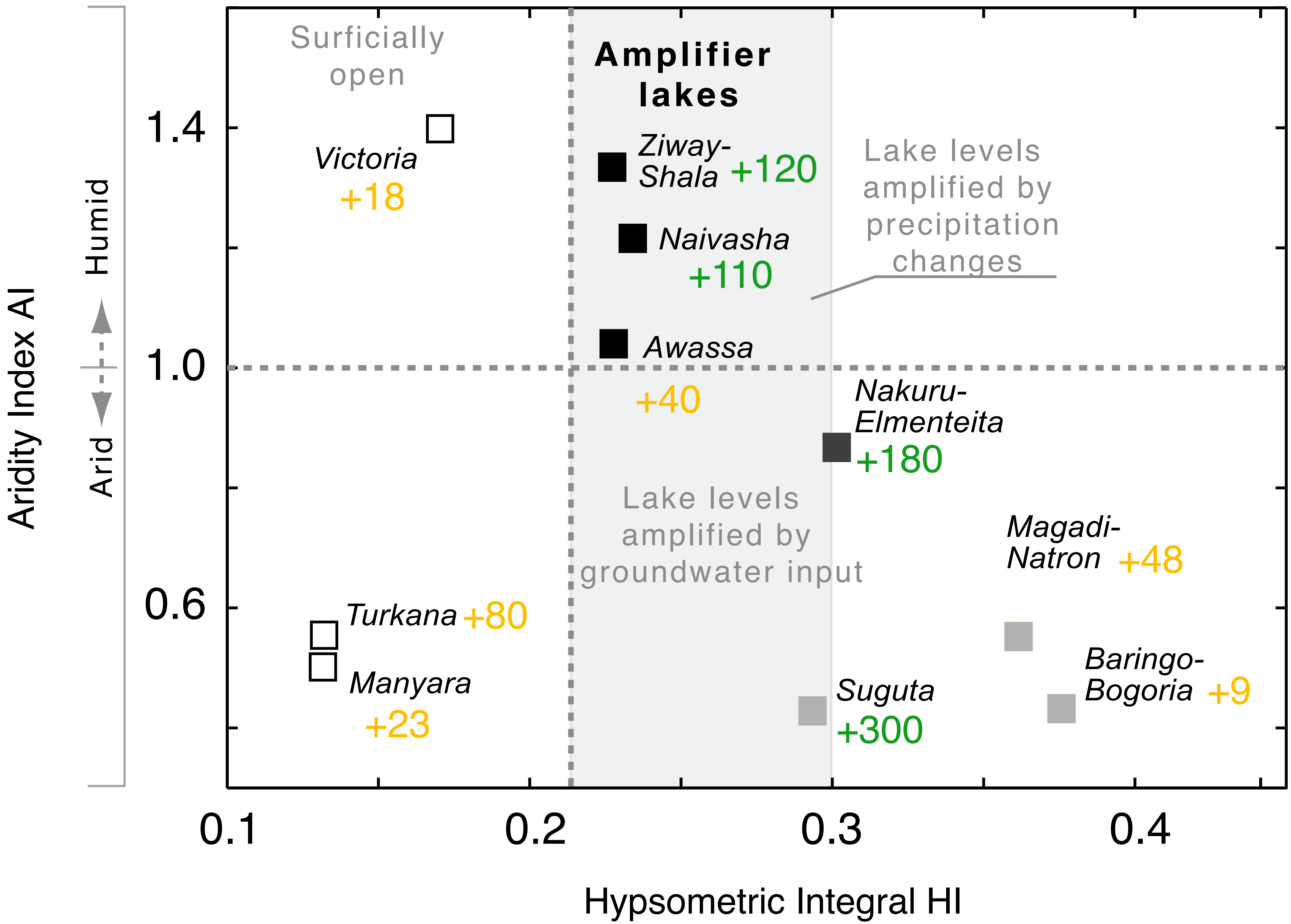




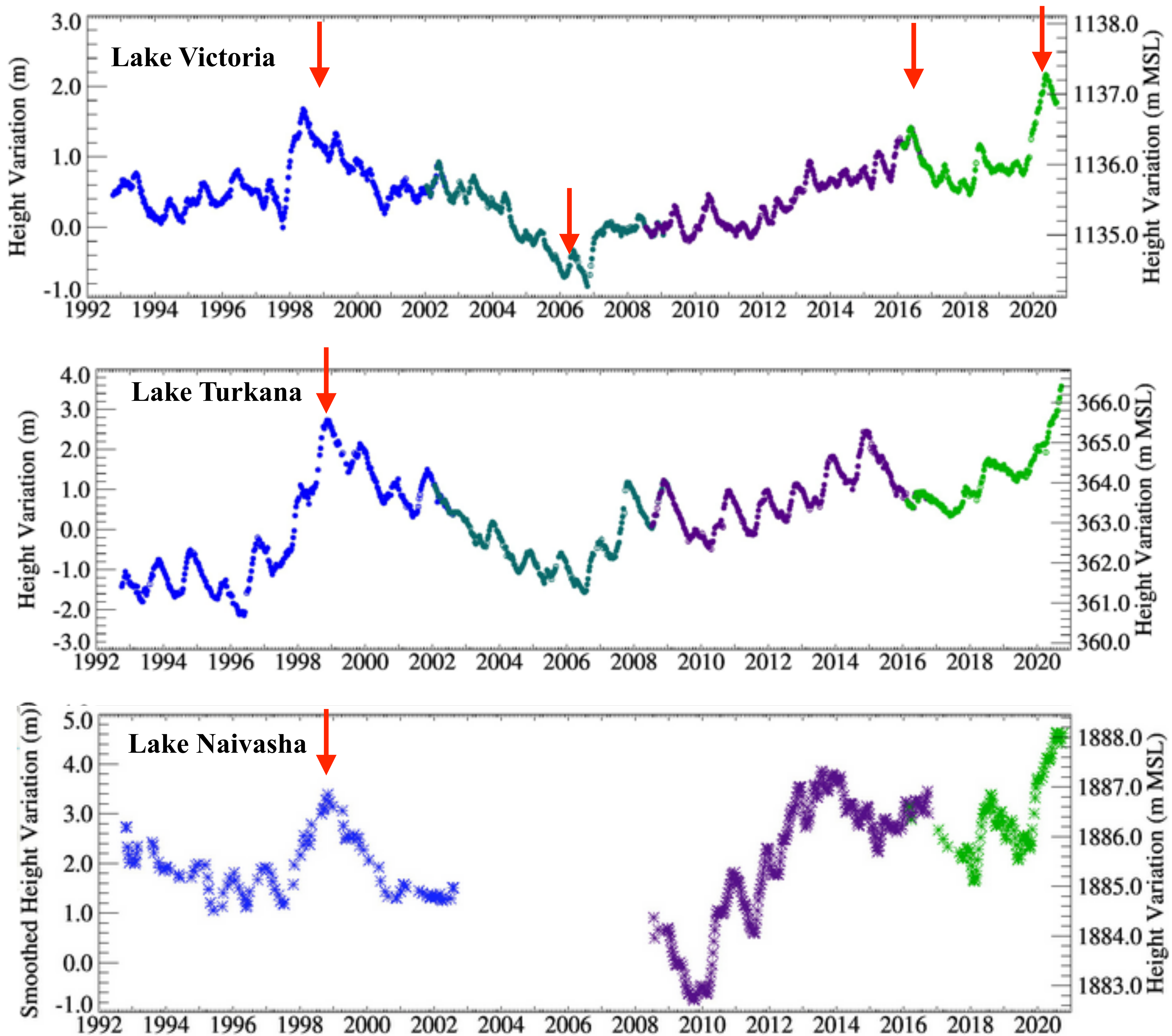
Aridity Index values for the EARS rift lakes

- Humid > 1
- Arid < 1

8. Amplifier lakes

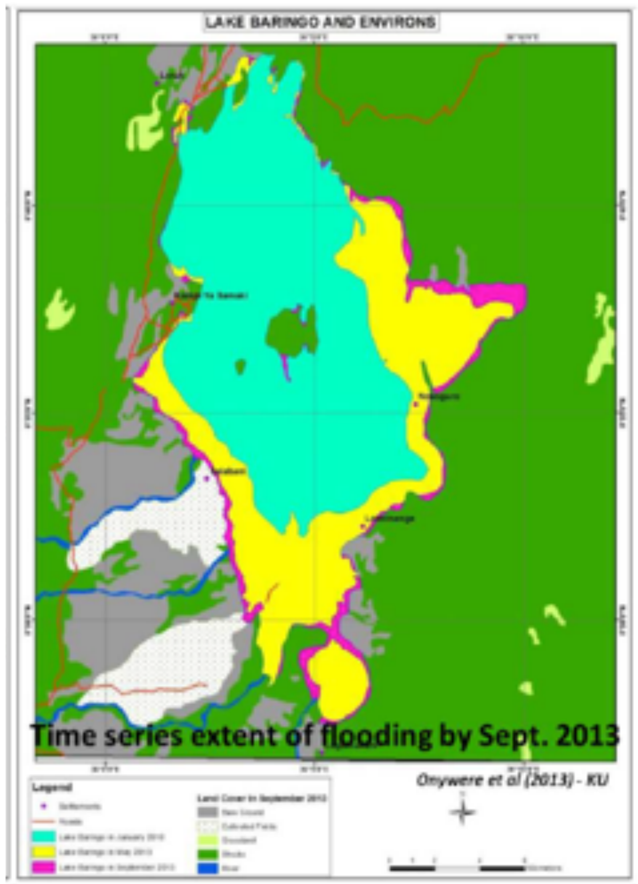


9. Recent Lake level changes 1992-2020

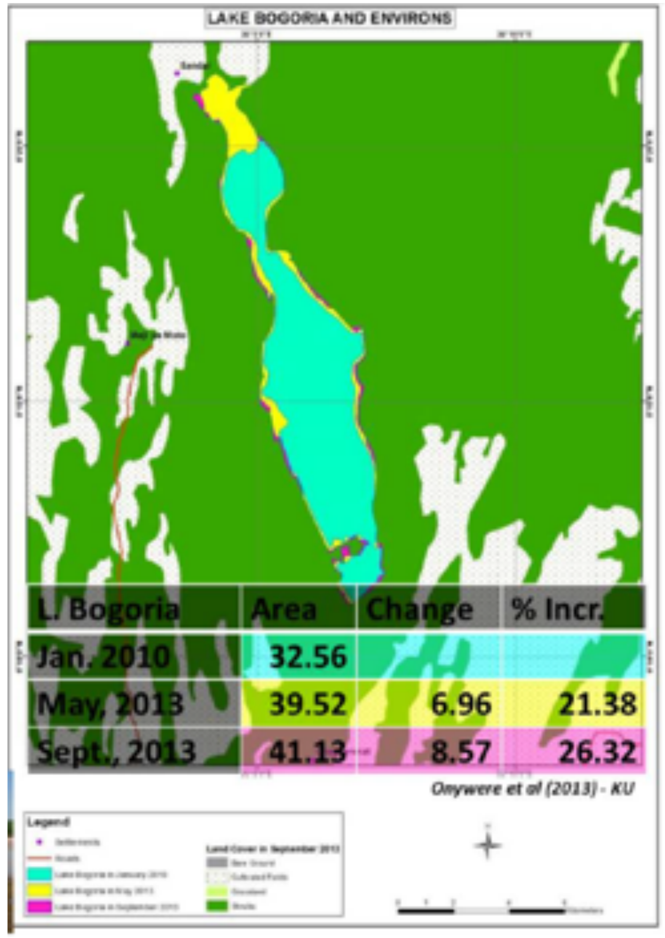


TOPEX /POISEDON
USDA

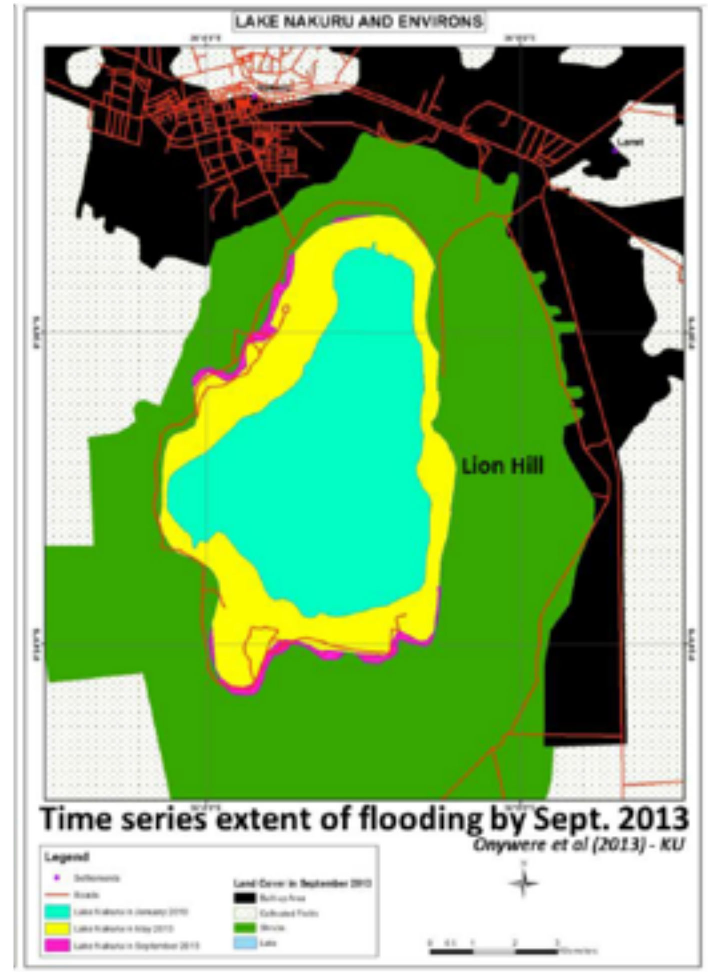
9.1 lake surface area changes jan2010- 2013



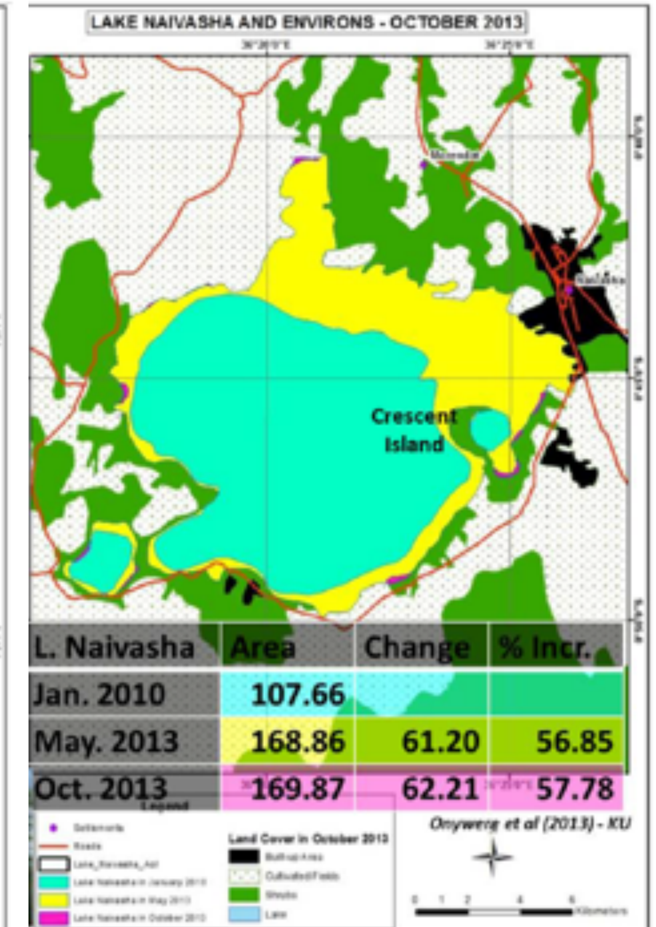
Baringo 61.2 %



Bogoria, 26.3%



Nakuru, 71.9%



Naivasha, 57.8%

Onywere et al 2013

9.1. Impact of lake level changes in rift lakes

- Destruction of property
- changes in the geochemistry of the lake water
- impact on the biodiversity, - flamingo, tourism, extremophiles in Bogoria,

Summary

- Lakes are Highly sensitive to climate shifts.
- Connection of Ground and surface water is high - structures, geothermal activity
- a combination of regional-scale (e.g. climatic) and site-specific local factors- topography,Groundwater modify lake level and surface area

Recommendations

1. Enhanced monitoring network of the Hydroclimatic parameters (evaporation, groundwater)
2. Flood models for the lakes need to be developed, considering the projected climate changes
3. Exploring Adaptation options
4. Landuse planning

Acknowledgements

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- DFG
- VolkswagenStiftung
- Martin Trauth, Manfred Strecker, Eric Odada, Dan Olago
- University of Nairobi

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Thank You

lydiaolaka@uonbi.ac.ke
Dept of Geology

END

Summary

	Nakuru Elementeita	Naivasha
Drainage area [km^2]	2,390	3200
Modern lakes		
Lake level m.asl	1760, 1780	1880
Conductivity [mS/cm]	25,000, 30,000	250
Holocene lakes		
Max. lake level m.asl	1940	2000

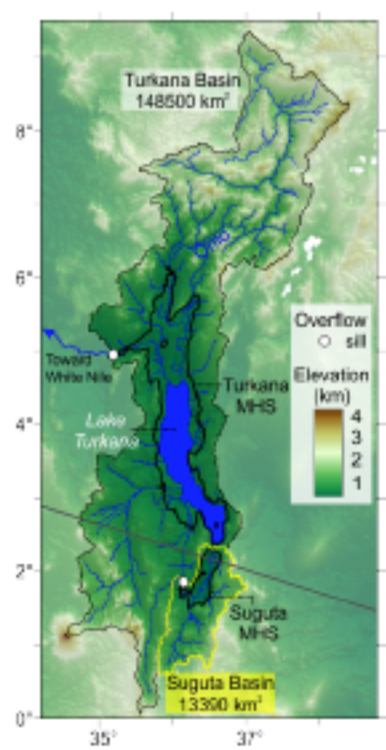
African Humid Periods
Protracted lake highstands

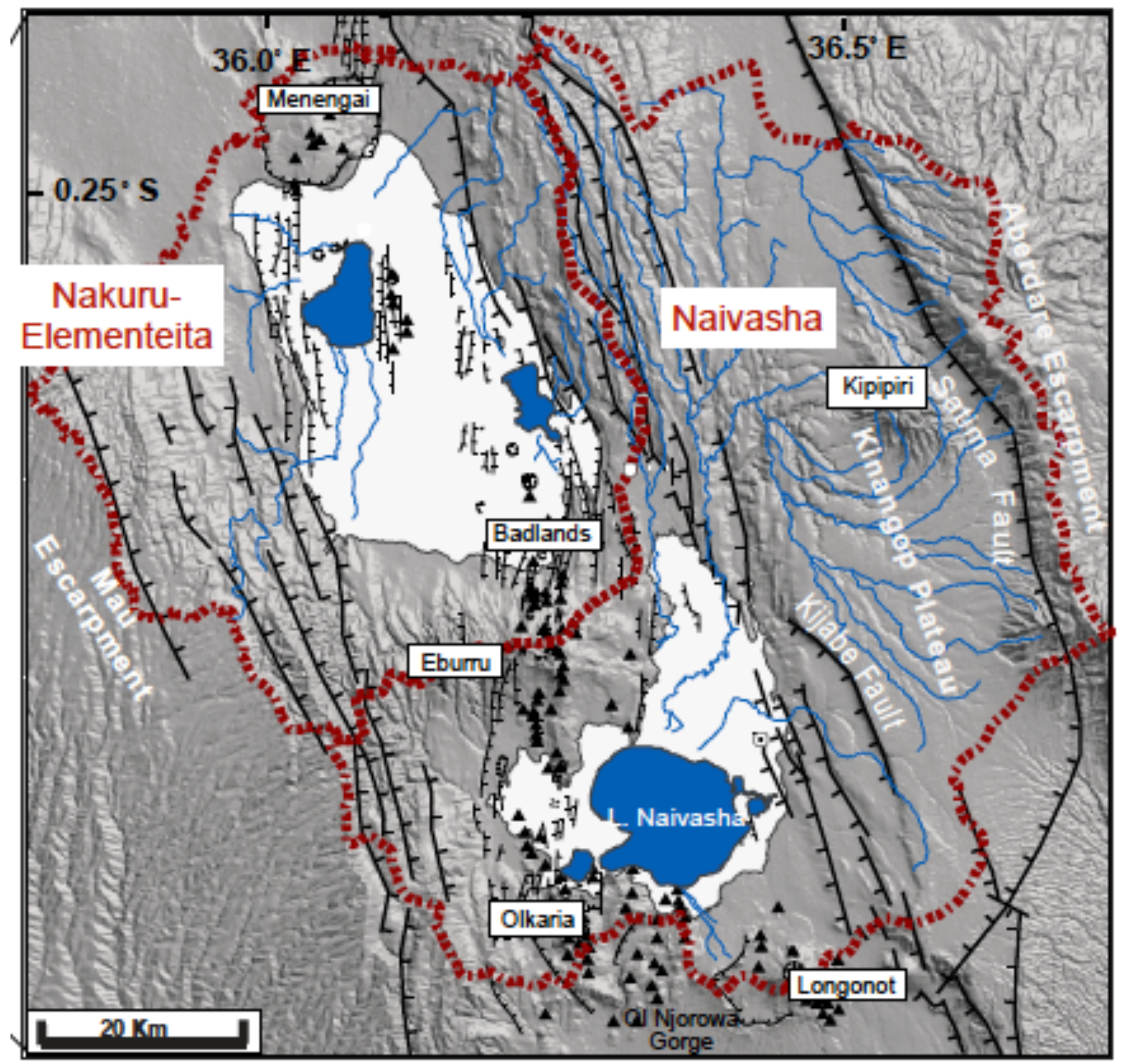
- Lake Turkana highstand ~11-5 ka

- Paleo Lake Suguta ~14-6 ka

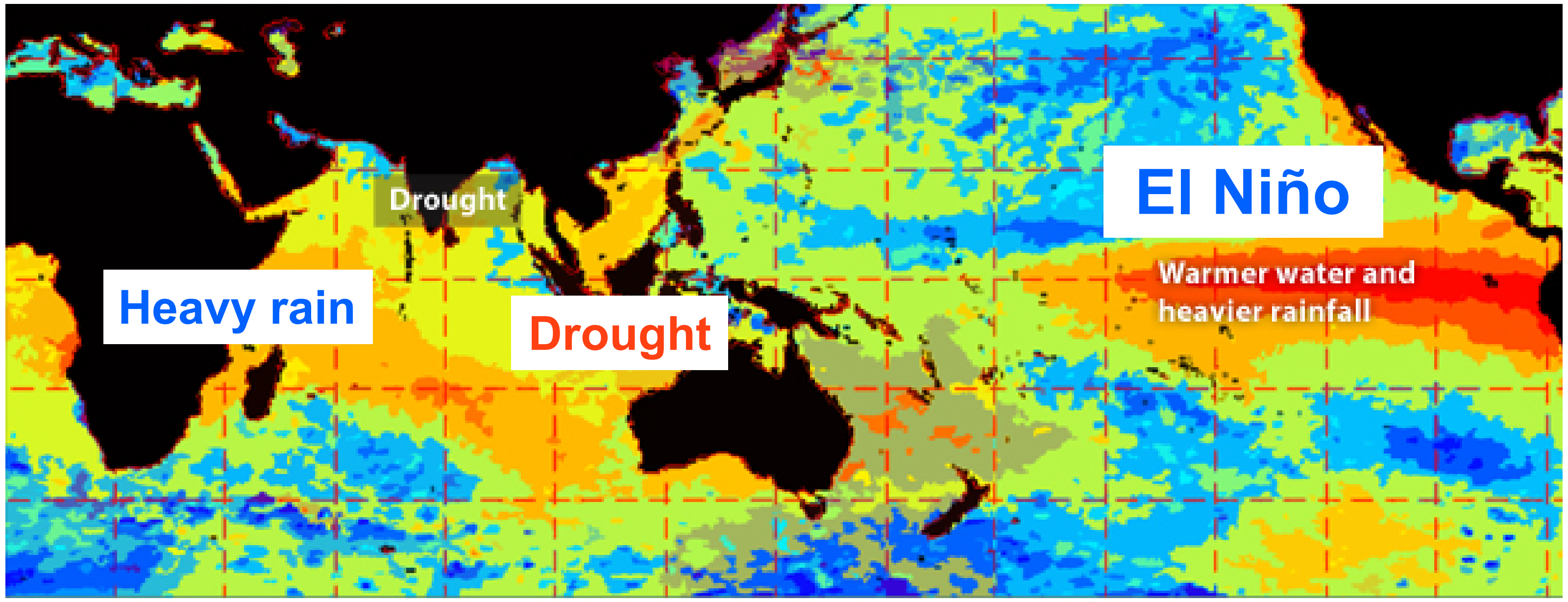
Both lakes where overflowing

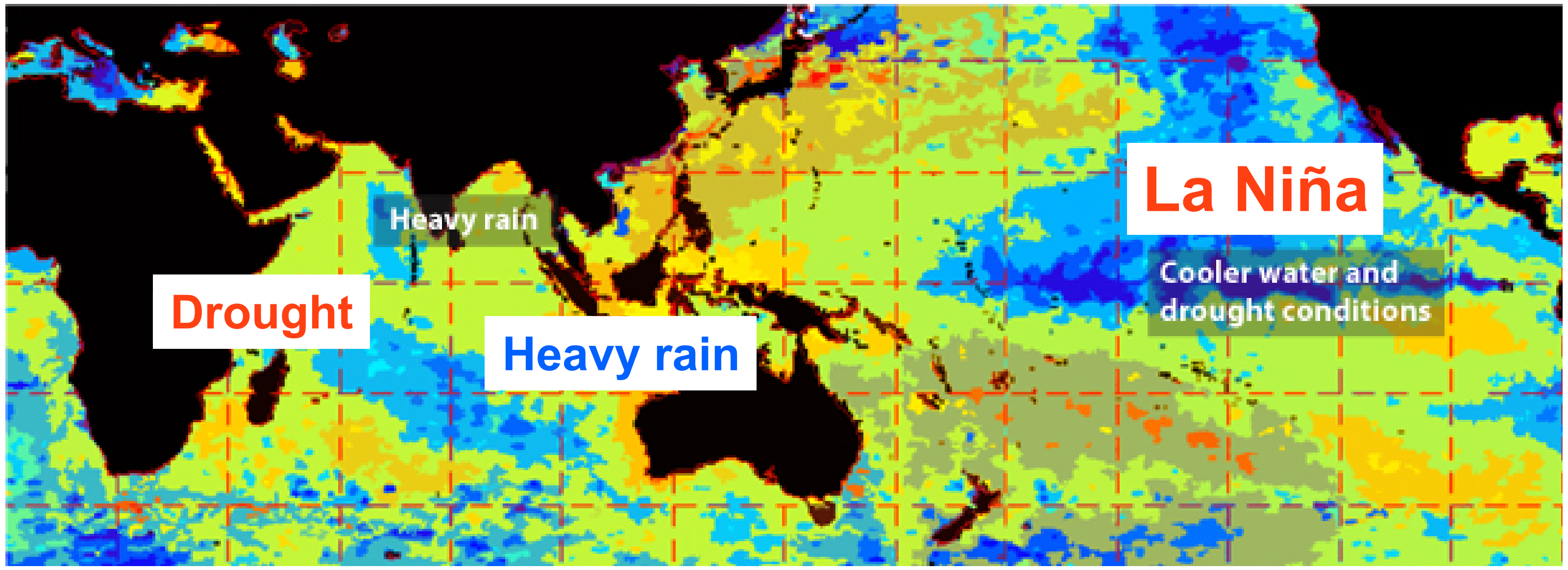
Harvey and Grove, 1982; Owen et al., 1982; Johnson, 1987; Garcin et al., 2009, QSR





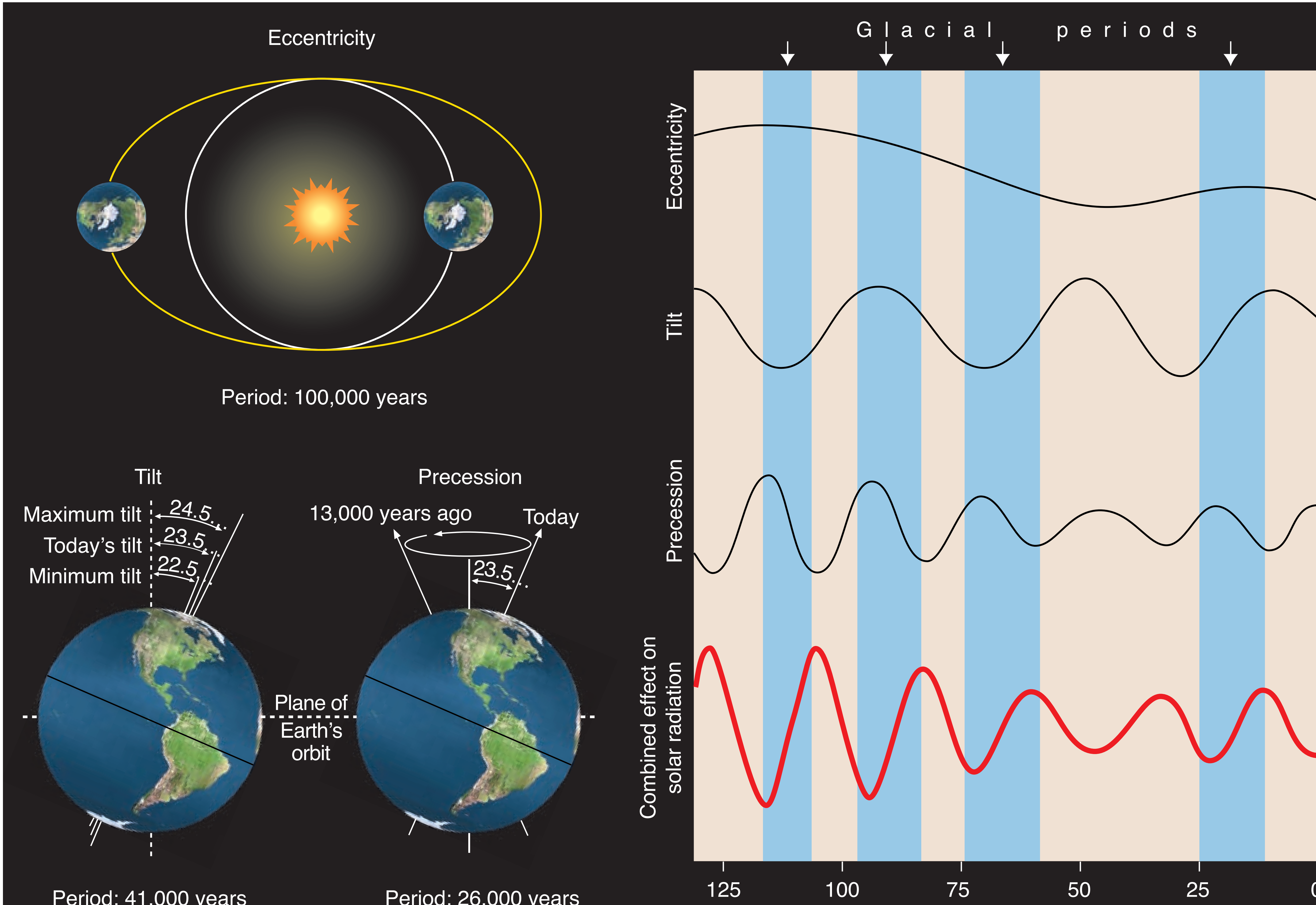
Climate variability Drivers





- **Rainfall across Africa are known to resonate with the coupled Ocean-Atmosphere phenomena of ENSO and IOD**
- **ENSO (El Nino Southern Oscillation) 3-7 year cycle**
- **IOD (Indian Ocean Dipole) ca. 2 year cycle**

Milankovitch Cycles



Characteristics

	Longitude	Latitude	Altitude	Lake Area	Basin Area	Basin Area/ Lake Area	Hypsometric Integral	Precipitation	Potential Evaportrans piration	Aridity Index
	deg	deg	m	km^2	km^2			mm/yr	mm/yr	
Nakuru-Elmenteita	36.08	-0.37	1,770	60	2,390	39.83	0.30	1,200	1,400	0.85
Naivasha	36.34	-0.77	1,885	180	3,200	17.78	0.23	1,500	1,250	1.20
Awassa	38.43	7.03	1,680	129	1,455	11.28	0.23	1,028	1,000	1.03
Suguta	36.55	2.22	275	80	12,800	160.00	0.30	1,000	2,309	0.43
Ziway-Shala	38.76	7.59	1,558	1,222	14,600	11.94	0.23	1,200	900	1.33
Magadi-Natron	36.26	-2.33	600	440	10,930	24.84	0.36	1,000	1,750	0.57
Baringo-Bogoria	36.06	0.63	967	215	6,200	34.98	0.37	1,000	2,309	0.43
Manyara	35.80	-3.62	960	12,000	23,207	1.93	0.13	1,000	2,000	0.50
Turkana	36.05	3.66	375	7,300	130,860	17.92	0.13	1,400	2,560	0.55
Victoria	36.26	-2.33	1,134	68,800	184,000	2.67	0.18	2,400	1,690	1.40