

THE ETHIOPIAN LANDMASS: Under the influence of the East African Rift System

By:
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- PLACE:
- University of Vienna,
- Vienna, AUSTRIA

OUTLINE

- INTRODUCTION
- INTRODUCTION TO CONTINENTAL RIFTING
- TECTONIC SETTING OF THE AFAR DEPRESSION
 - The Dallol Hydrothermal Field
 - The Erta'Ale Magmatic Shields
 - The Dabbahu Crustal Rupture
- THE AFAR ANTHROPOLOGICAL SITE
- ETHIOPIA: AFRICA'S WATER TOWER“
- FUTURE OF THE AFRICAN LANDMASS (SUMMARY)
- ACKNOWLEDGMENTS

GENERAL INTRODUCTION

The oldest standing structure in Sub-Saharan Africa



ቤተ-መቐደስ ዮሐ/
Yeha Temple
800 BC

From the
trachytic plugs
of the area

ETHIOPIA:

- ~125 million people,
- 86 Ethnic groups,
- 1.1 million km²
- Moderate temperature (5 – 30 °C) except Afar
- Rainfall: 850 mm/y
- **Ancient nation** (> 3000 years)

GENERAL INTRODUCTION

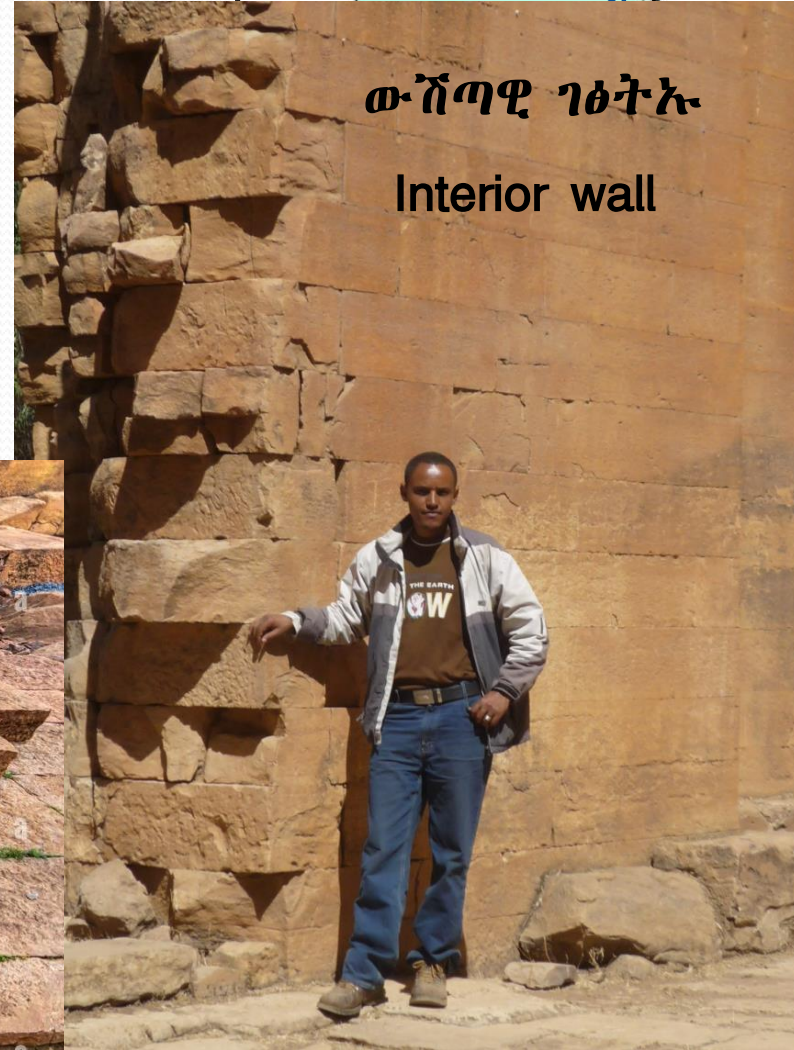
The oldest standing structure in Sub-Saharan Africa



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Yeha Temple
800 BC



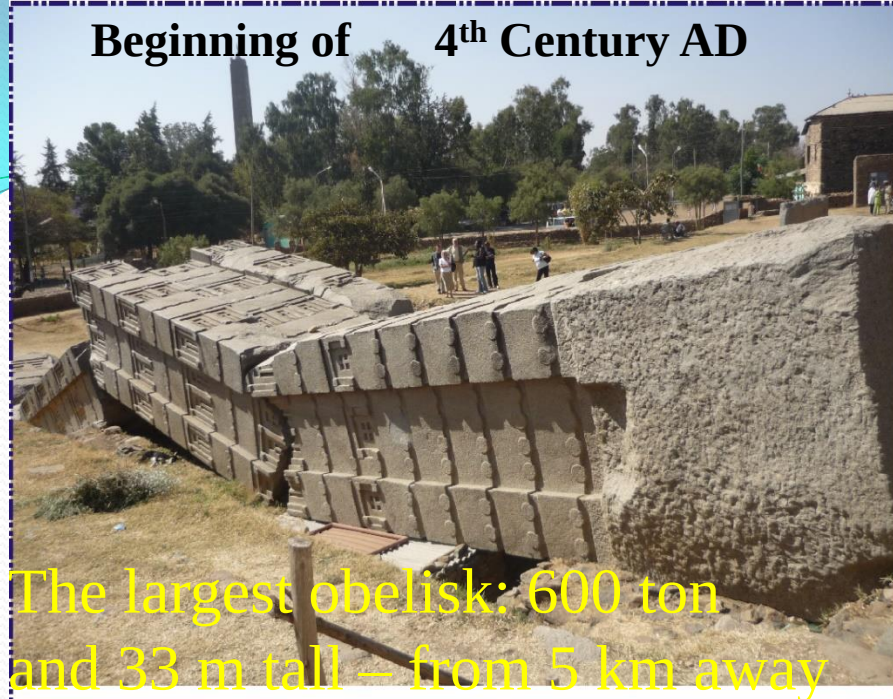
ውስጣዊ ገፅትኡ
Interior wall



Floor



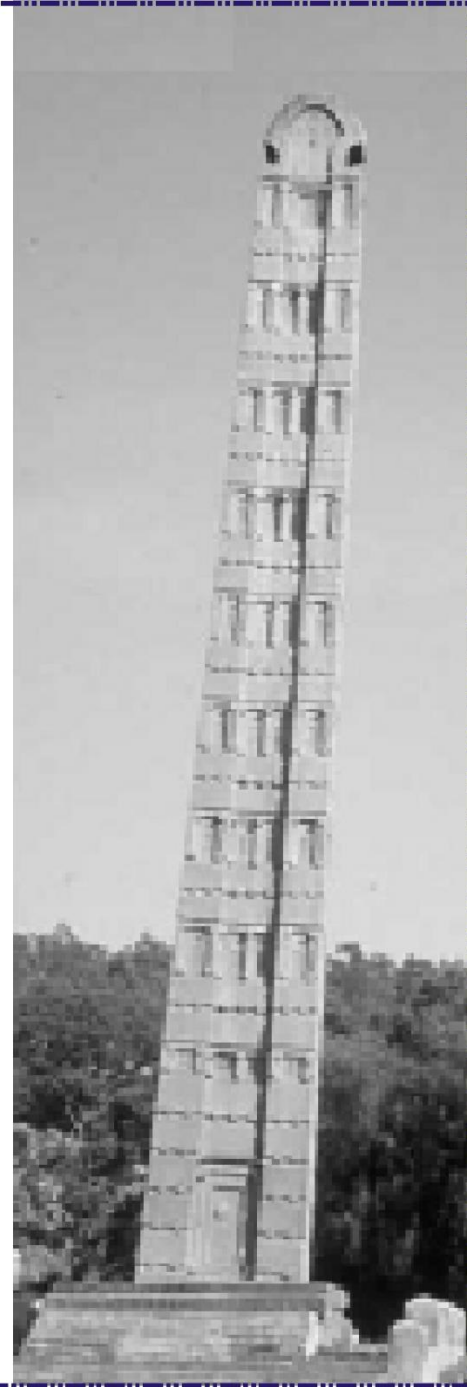
Beginning of 4th Century AD



The largest obelisk: 600 ton
and 33 m tall – from 5 km away



24 m / 160 ton



Rock hewn churches

- A rock church carved from welded pyroclastics,
- A three-story church,
- Built/ carved in the late 12th and early 13th century from a single monolithic rock.



THE ETHIOPIAN LANDMASS:...

GENERAL INTRODUCTION

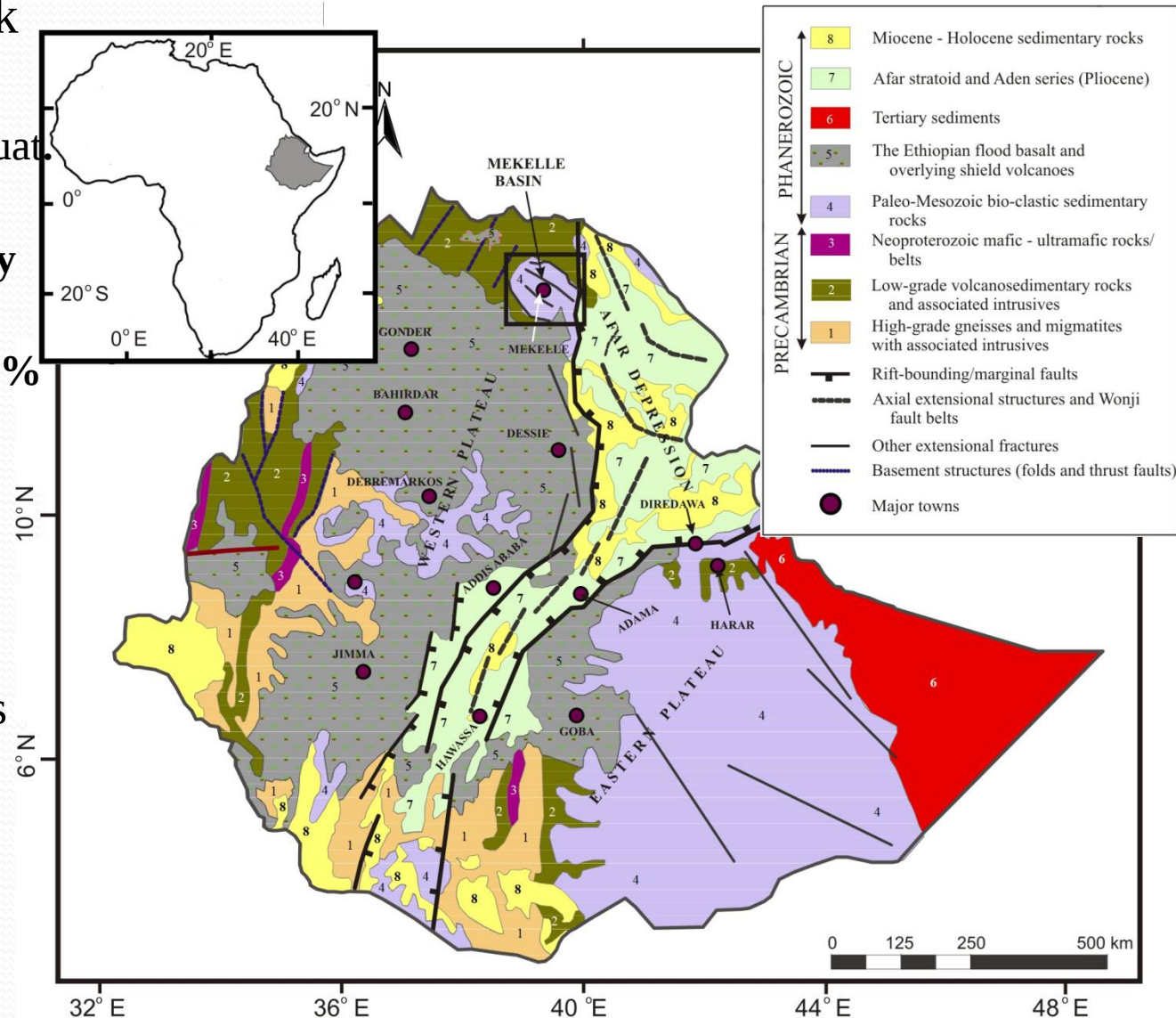
GEOLOGY

Ethiopia is home to highly diversified rock formations

- **Volcanic rocks** and Quaternary sediments (~56%)
- **Mesozoic sedimentary rocks** (~26%)
- **Basement rocks** (~18% of the country)

Huge mineral resources:

- Gold & base metals
- Industrial minerals
- Dimension stones
- Gemstones

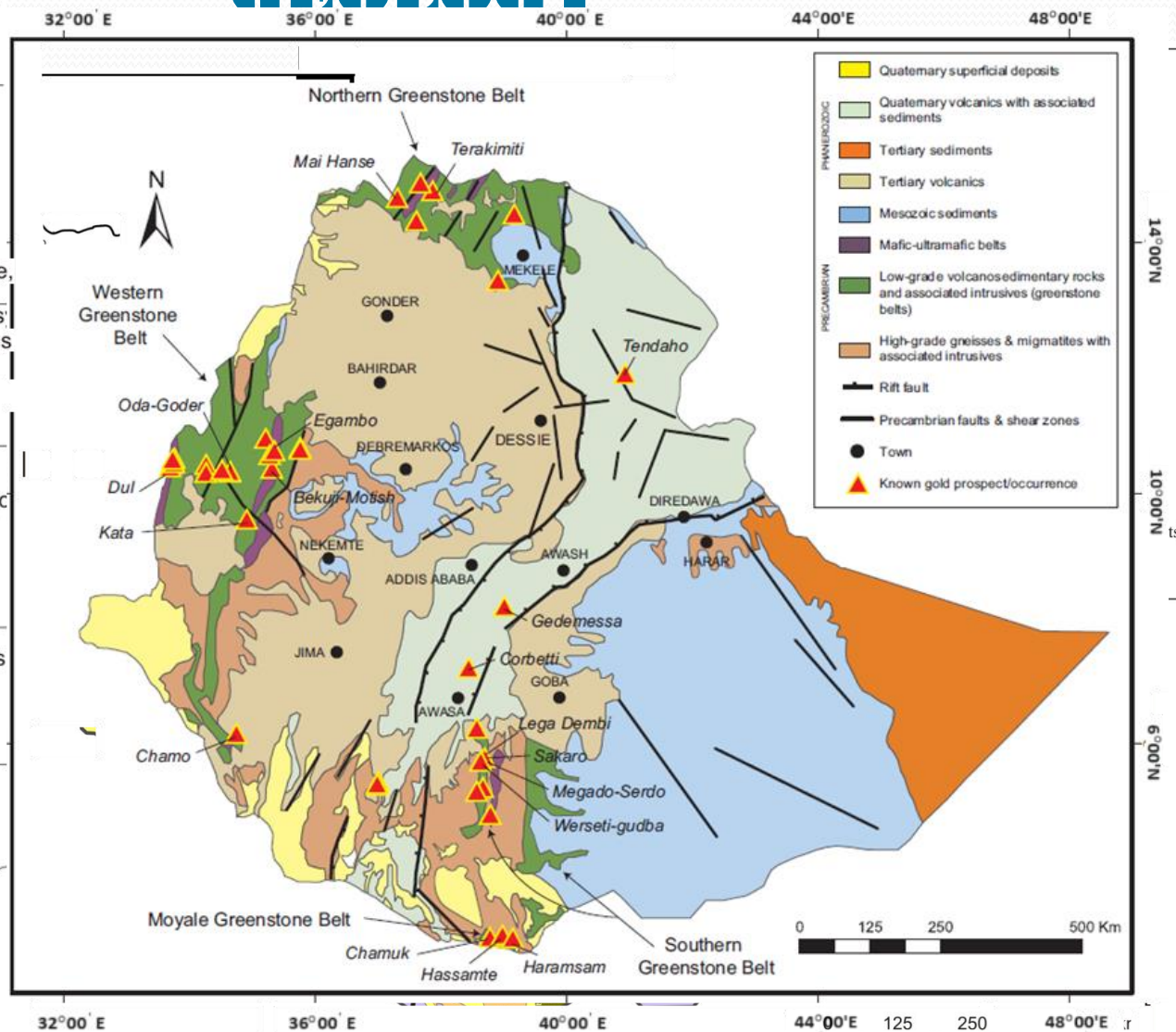


GENERAL INTRODUCTION

COMPOSITE SECTION OF ETHIOPIA

GEOLOGY

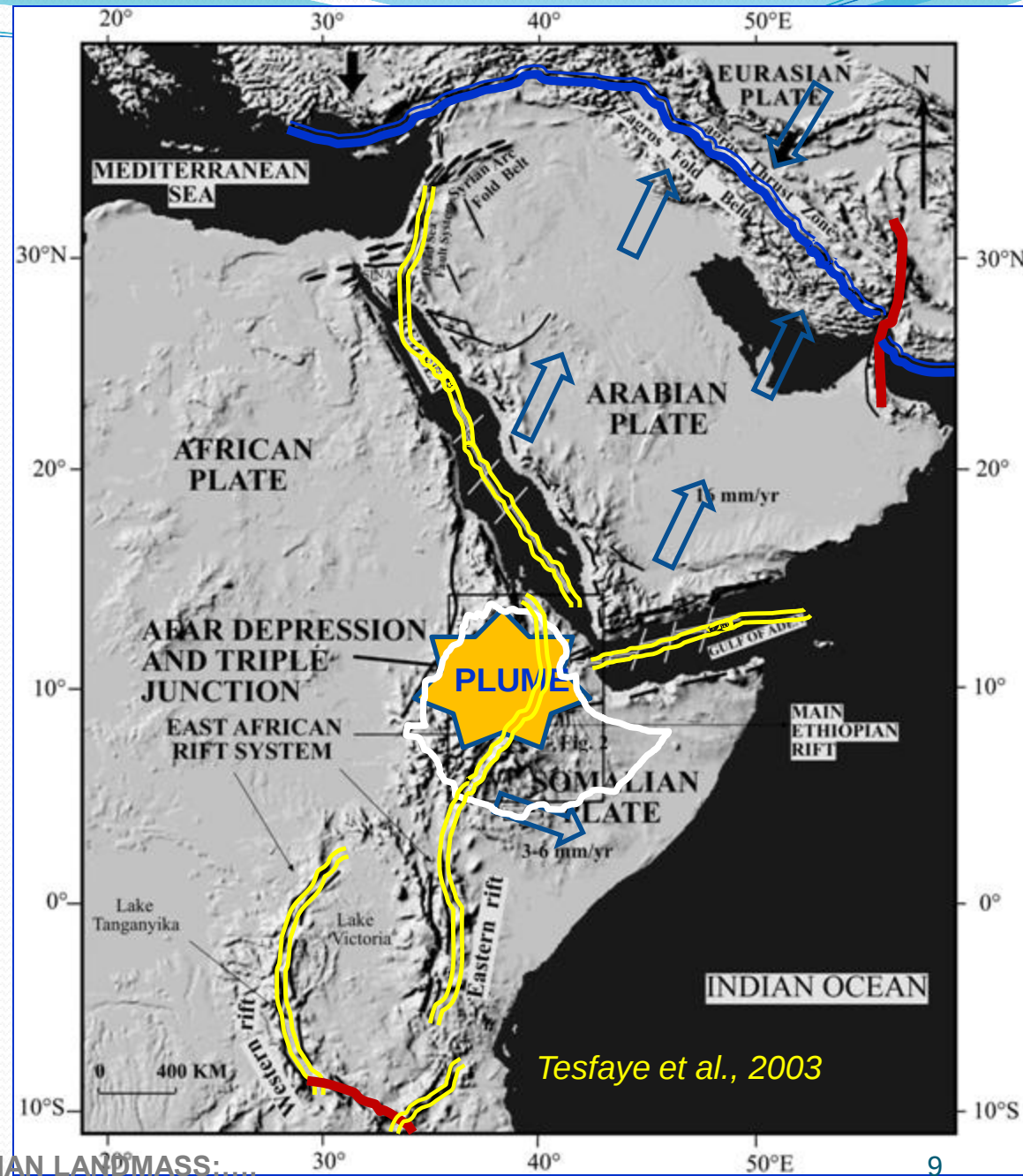
Age	Lithology	Lithologic description
CENOZOIC	Quaternary sediments (0 - 200m)	Quat. sedimentary deposits
	Ethiopian flood basalt (Oligo) (Thickness: 0 - 500m)	Mekelle dolerite Tholeiitic - alkaline volcanic rocks
MESOZOIC	Amboimian fm. (0 - 90m) (Thickness: 0 - 500m)	Immature & mottled sandstone.
	Antalo super-sequence (Thickness: 0 - 500m)	Agula'e shale - shale - marl - mudstone - gypsiferous - limestone intercalations Micritic - cryptocrystalline lst
	Adigrat sandstone (Thickness: 200 - 500m)	White and highly friable Fine - medium-grained with cyc deposition characterized by fining-upward sequence Intercalation of cemented and uncemented sst.
	Edaga Arbi tillite (Thickness: Max. 180)	Variegated color (Purple, reddish gray), laminated shale with granitic boulders
PALEOZOIC	Enticho sandstone (max. 110 m)	Upper section: with boulders of various origin Lower section: massive,
	Unconformity	
NEOPROTEROZOIC	Arabian-Nubian Shield (Tsaliet and Tambien groups)	Metavolcanics & meta-sediments,



The distribution of principal gold prospects and occurrences in Ethiopia.
(information from the Geological Survey of Ethiopia and the Ministry of Mines and Energy)

INTRODUCTION TO CONTINENTAL RIFTING

- East African Rift System (EARS) is:
 - extensional continental structure
 - Syria – Mozambique extending ~6000 km.
 - The EARS provides:
 - far-field stress &
 - plume-driven continental rifting; and
 - evolution of segmentation as continental rifting progresses to **seafloor spreading**
- (Furman et al., 2004)



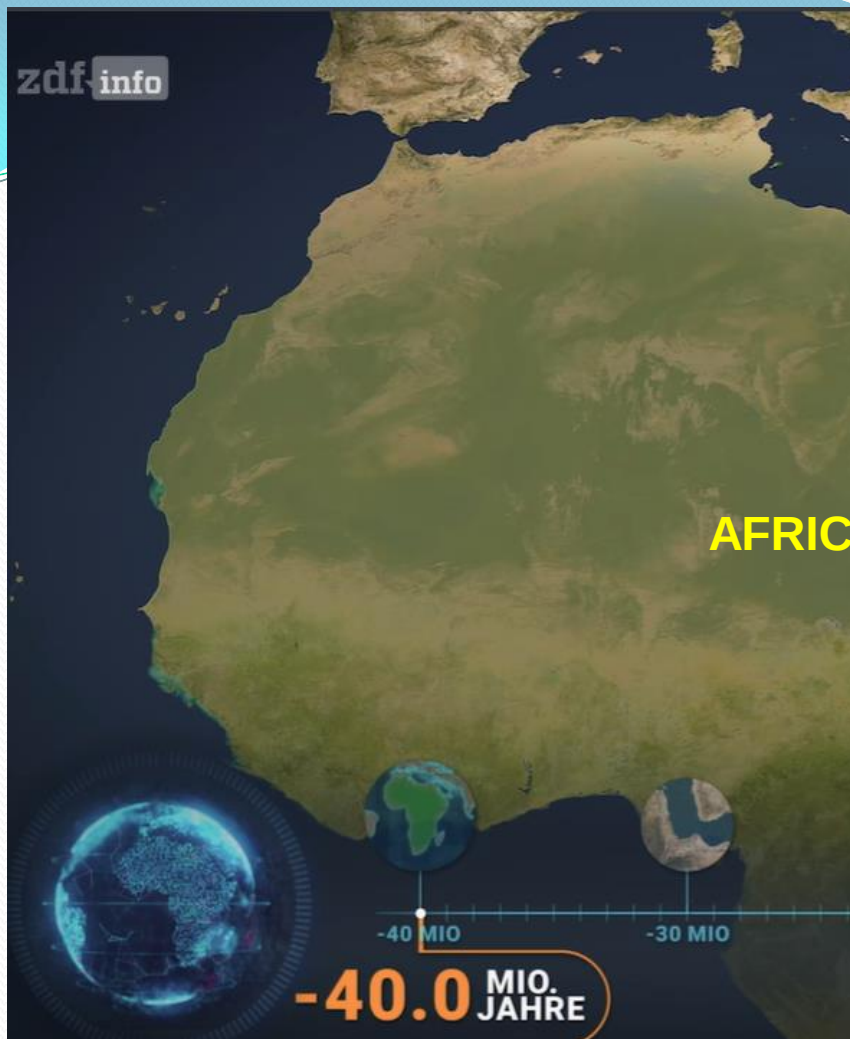


EVIDENCE:

- Similar eruption history and composition on both plates

...

- Similar shore line geometry,
- Fossil evidence, and
- Syn-rift sediments



EVIDENCE:

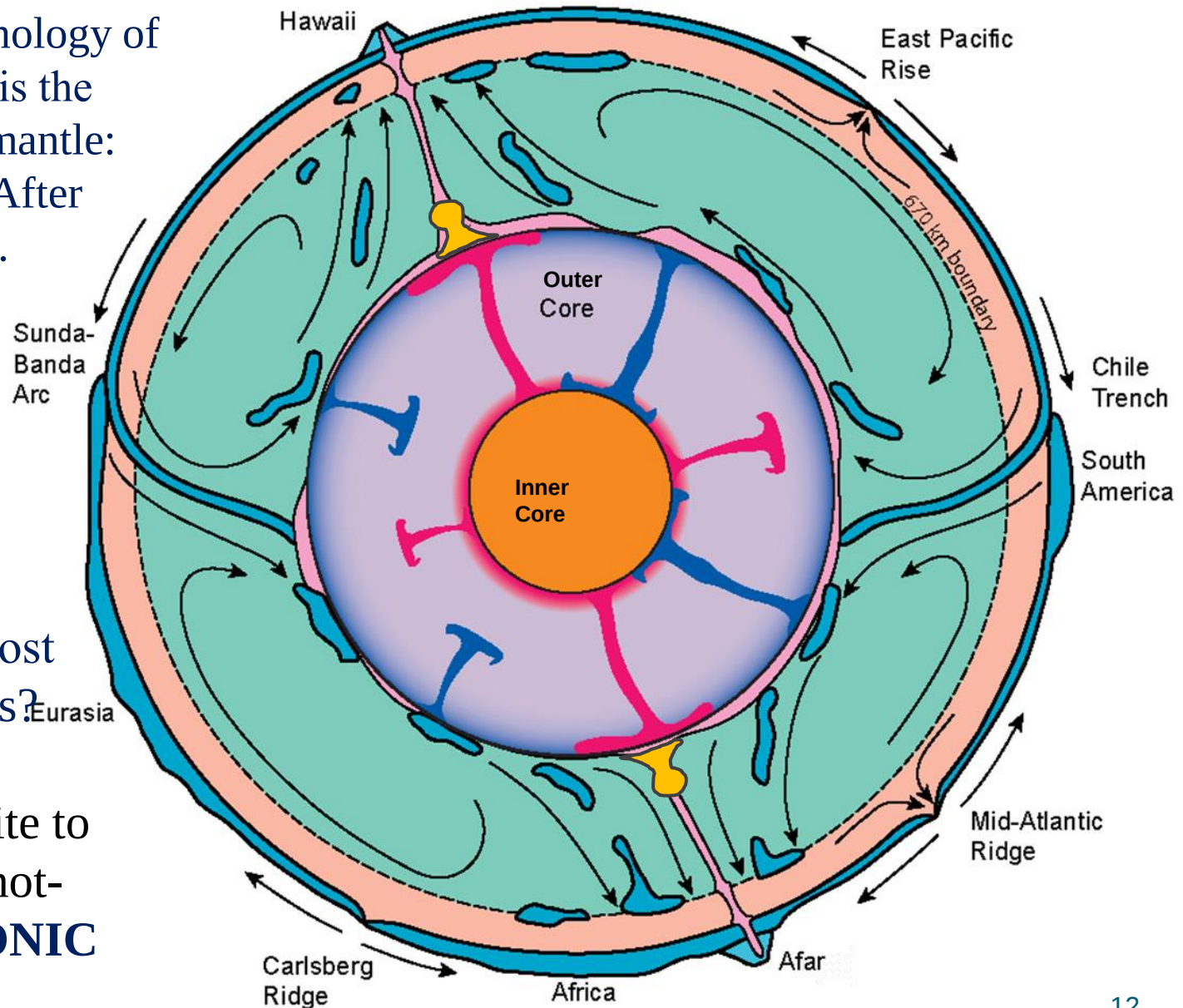
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MANTLE DYNAMICS

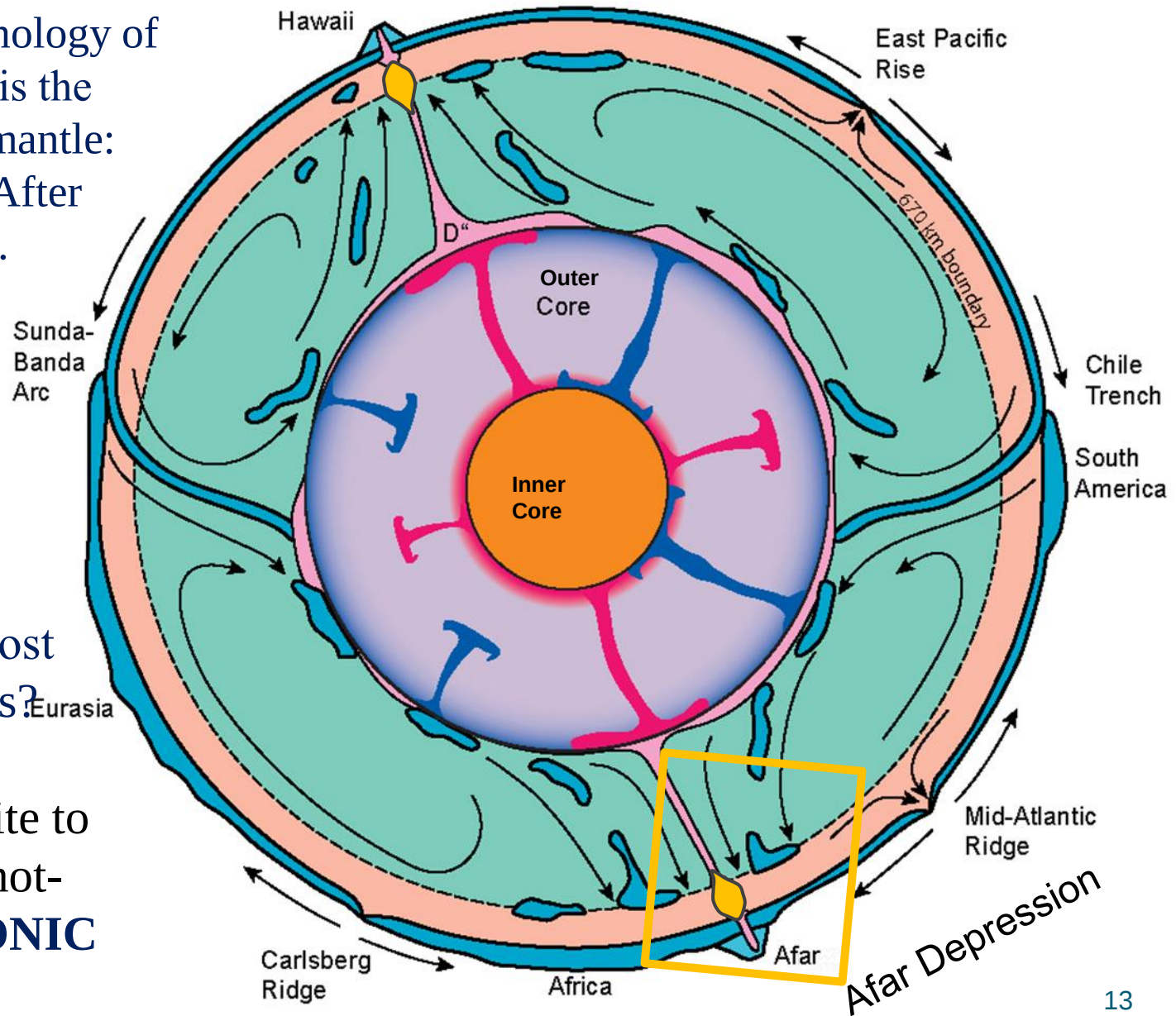
The driving force that regulate the morphology of the earth's surface is the convection of the mantle: **mantle dynamic**. After Silver et al. (1988).



- The world's most active hot spots?
- Afar is located directly opposite to the Hawaiian hot-spots: **TECTONIC POLE**

Mantle Dynamics

The driving force that regulate the morphology of the earth's surface is the convection of the mantle: **mantle dynamic**. After Silver et al. (1988).



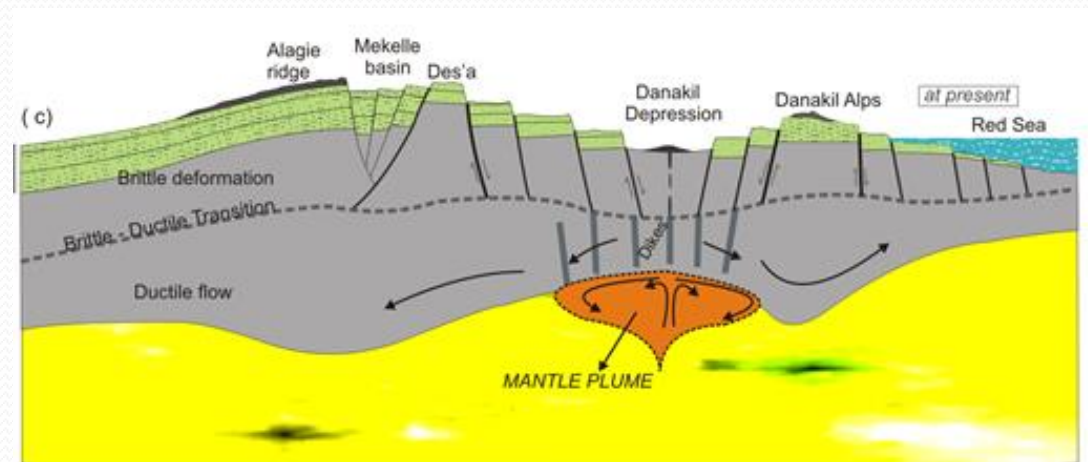
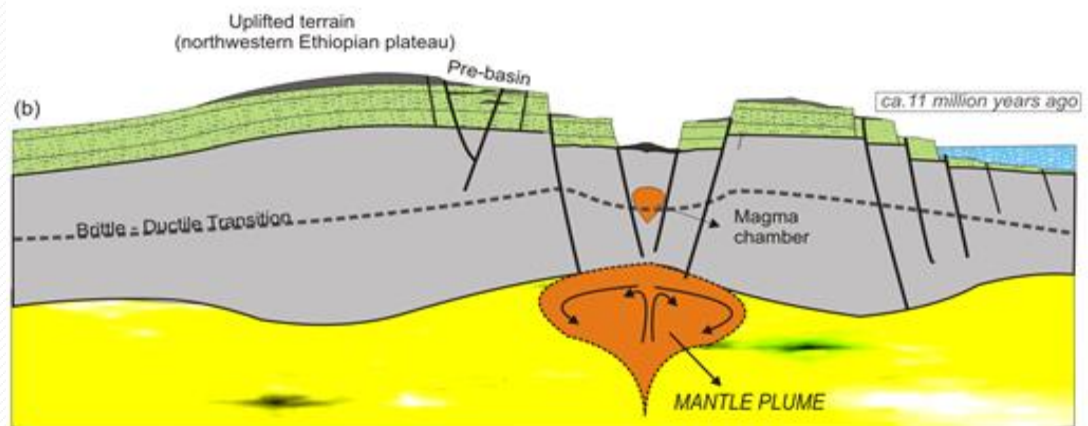
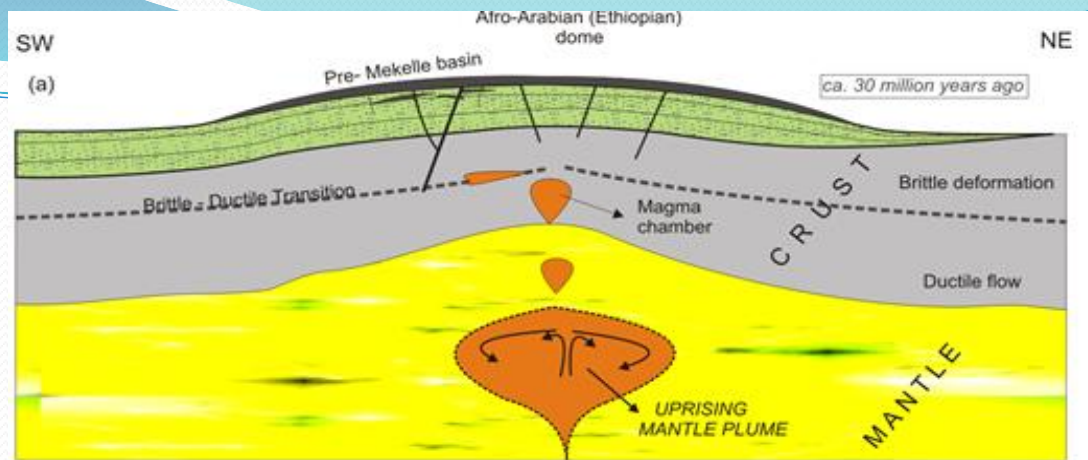
- The world's most active hot spots?
- Afar is located directly opposite to the Hawaiian hot-spots: **TECTONIC POLE**

The Afar mantle plume:

During the Oligocene –
Up- doming
and volcanism

Miocene:
Rifting and
subsidence

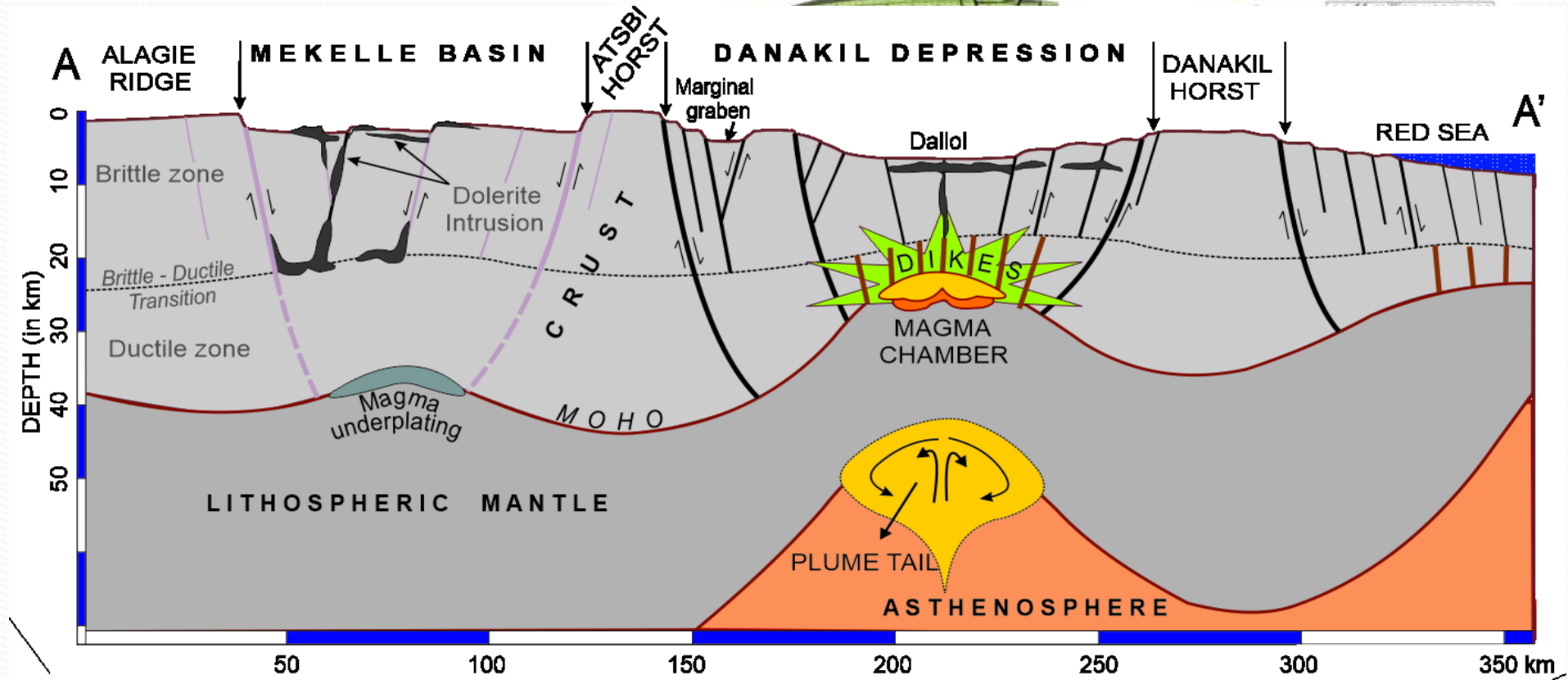
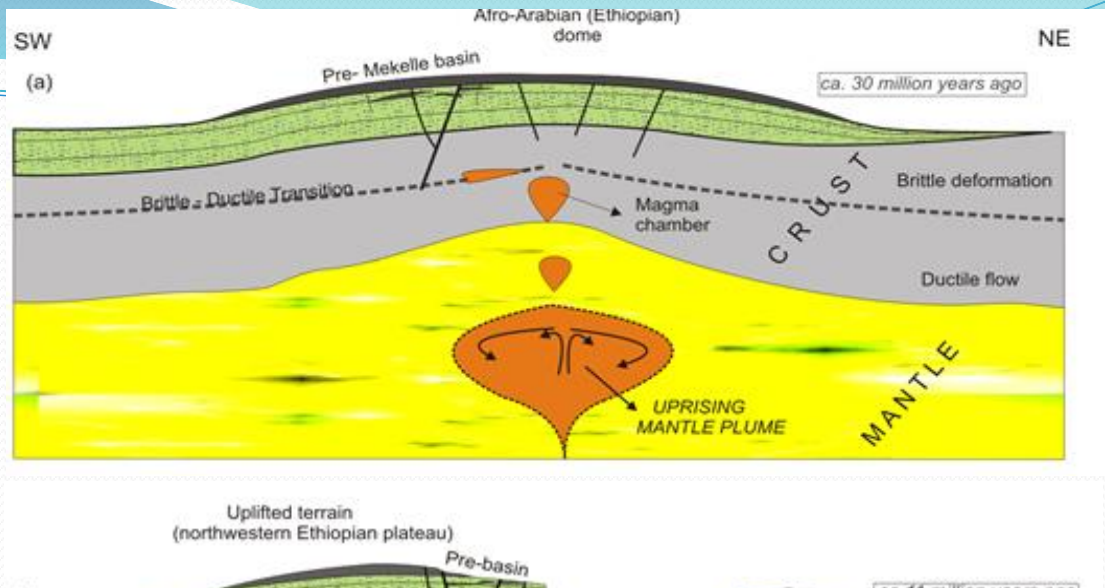
- Formation of Afar Depression
- Development of marginal basin



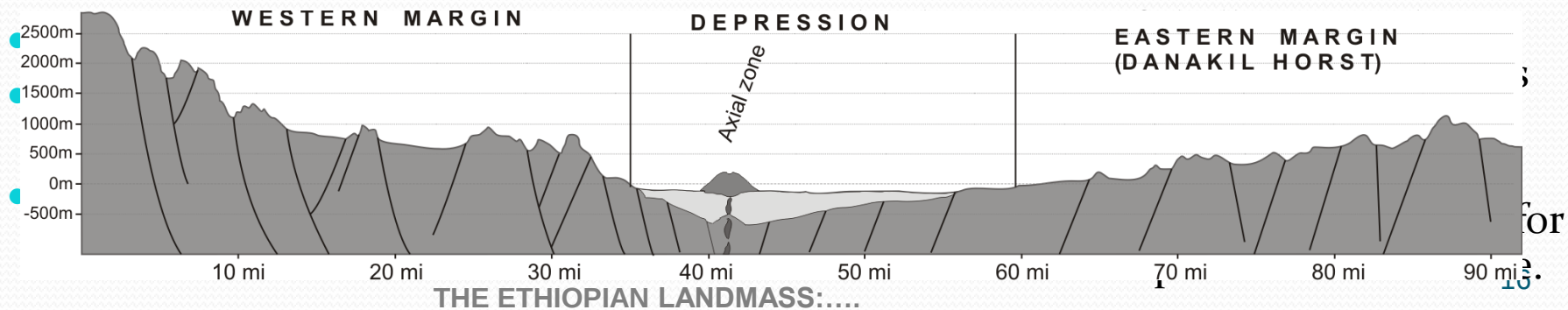
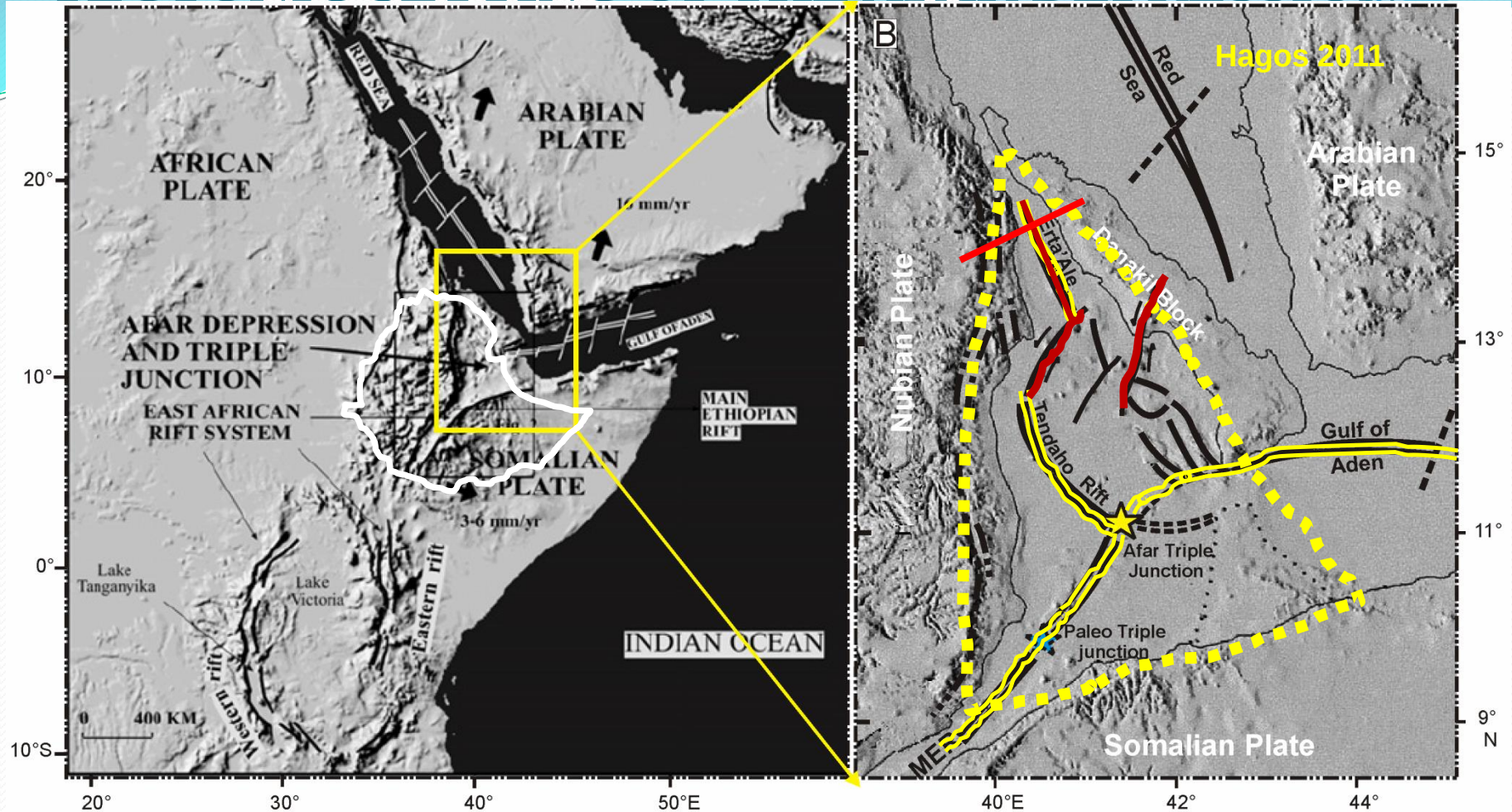
Mantle Plume

The Afar mantle plume:

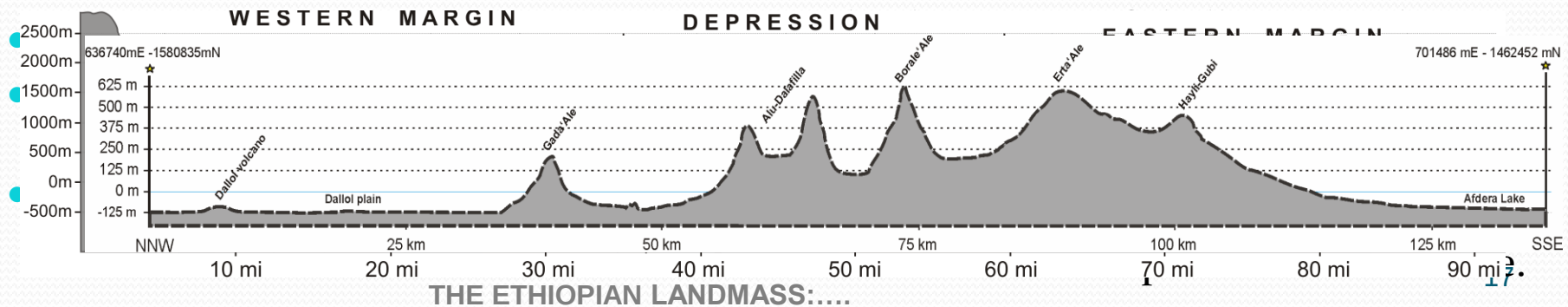
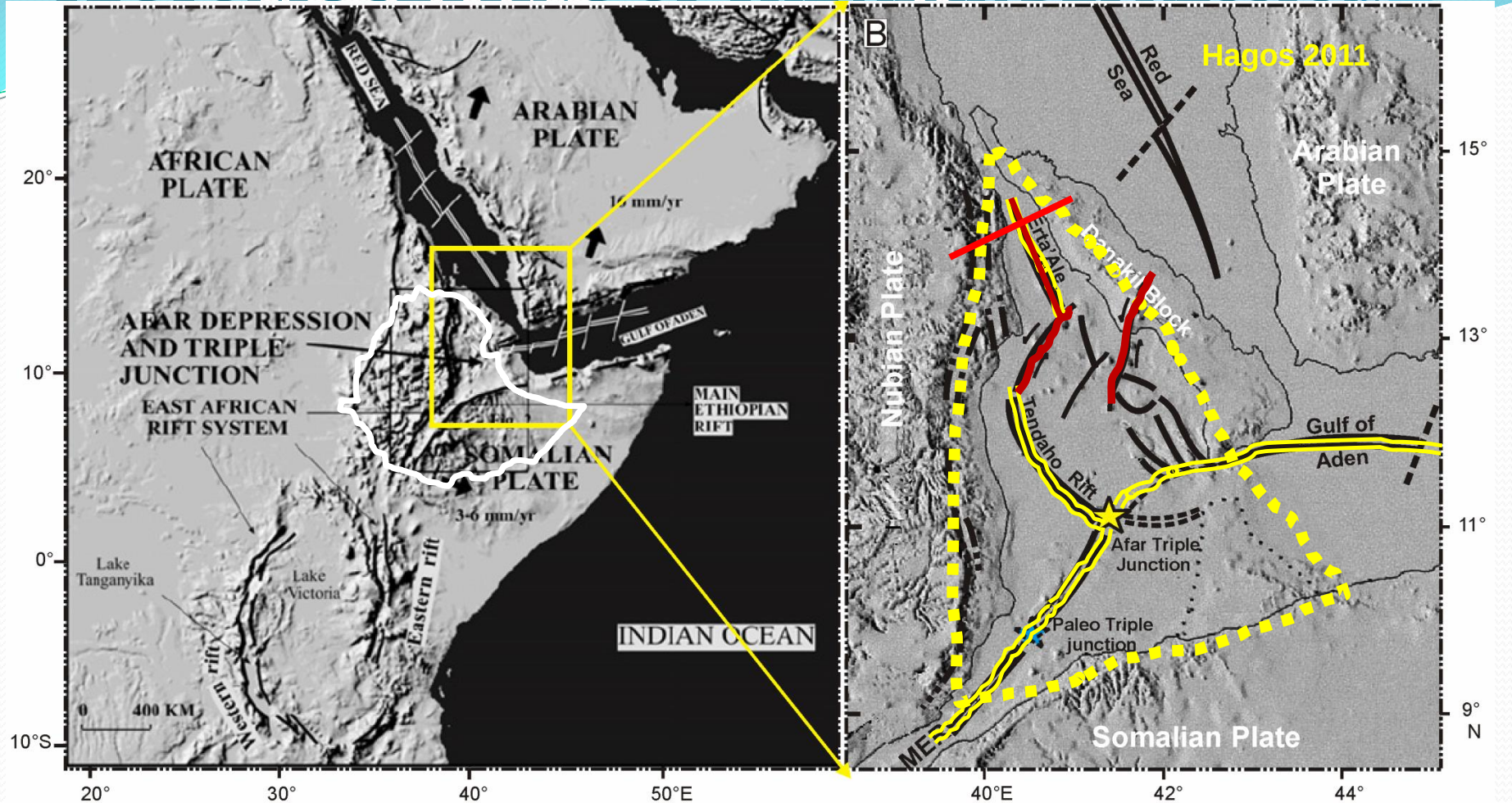
During the Oligocene – Up-doming



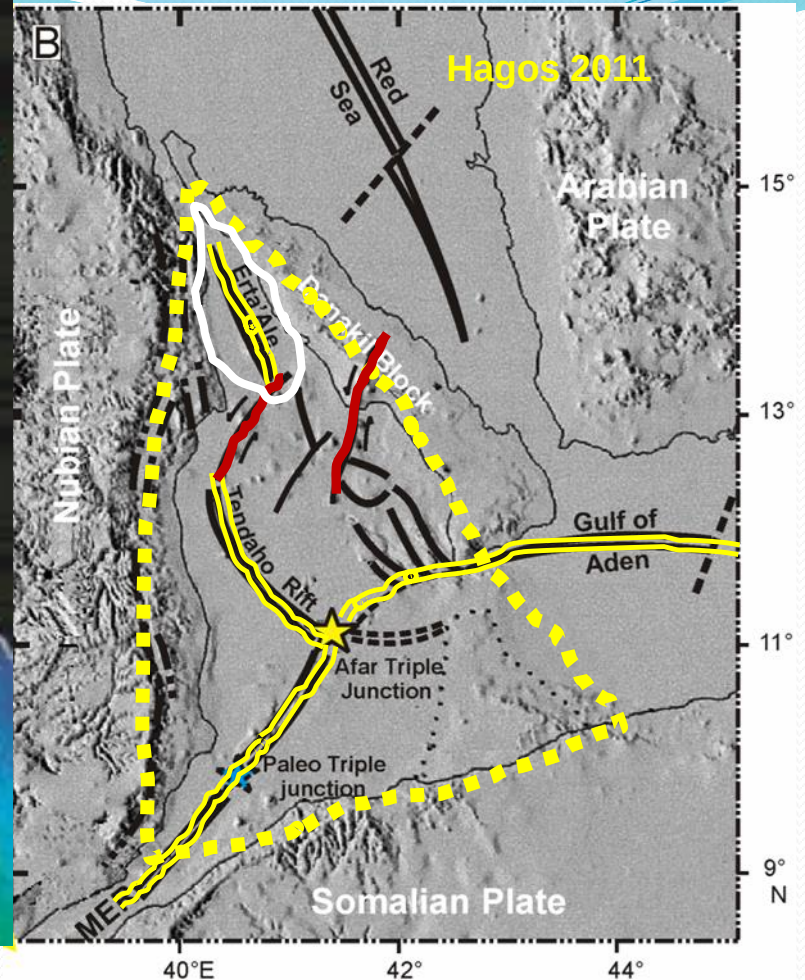
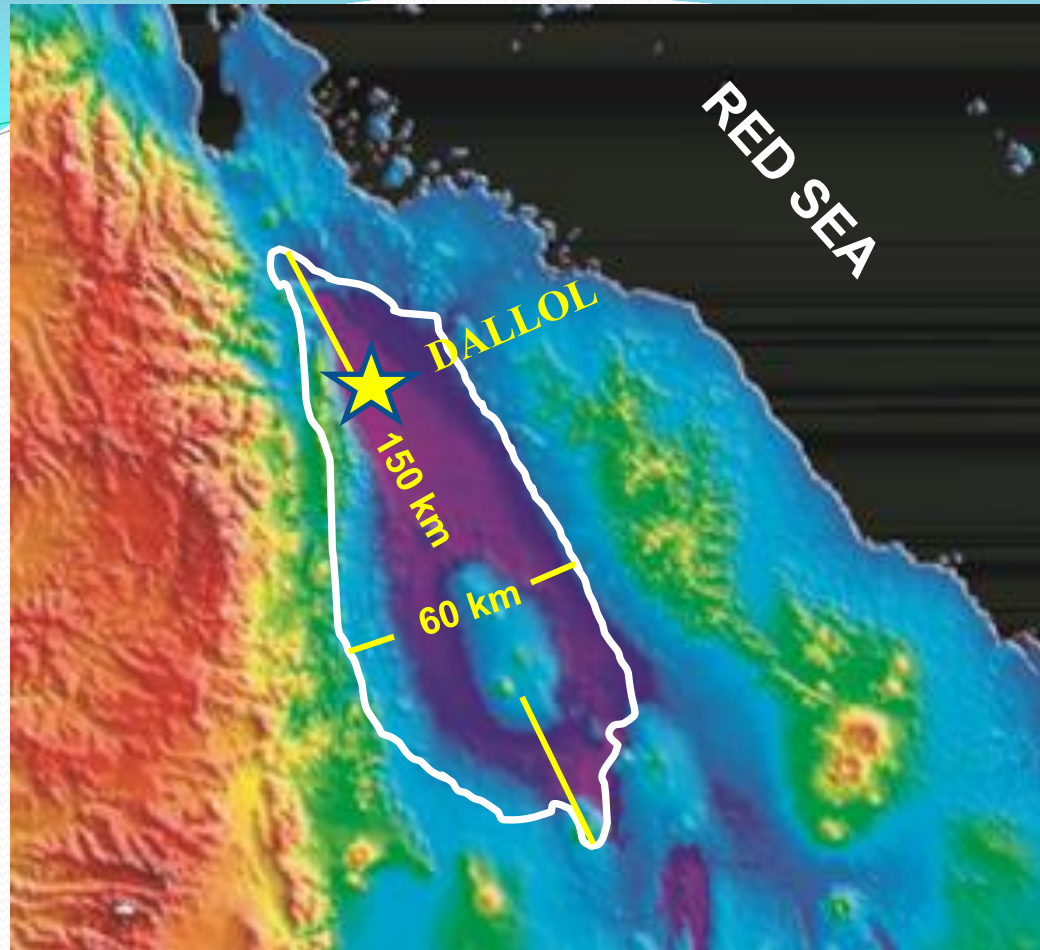
TECTONIC SETTING OF THE AFAR DEPRESSION



TECTONIC SETTING OF THE AFAR DEPRESSION



TECTONIC SETTING



- It is a triangular-shaped depression.....
- Elevation drops from 4000 m a s l to ~120 m b s l.
- Early Miocene– to early Pliocene syn-rift Red-bed series and lacustrine sediments
- The deposition of shallow water limestone, marine clays, and submarine volcanoes indicate that:
 - Large area of the Danakil Depression was once covered by marine environments for at least some part of Miocene time.

• The Sub-Aerial Oceanic crust--DALLOL

The wonder of Dallol

What makes Dallol so special?

- **It is the hottest year-round place on Earth.**
- **It is the most hostile place on Earth and conditions are similar to those on some planets.**
If life forms are found here, they could exist in other worlds. Planetary scientists are researching the geology and geomorphology of Dallol to determine if life is possible.
- **You are now standing more than 120m below the sea level on a buried active volcano.**
The ground is dropping as three tectonic plates separate and as the Earth's crust opens you can see what there is beneath it. This has been a sea and eventually the waters of the Red Sea will flood this depression and a new sea will be formed.

What can you see at Dallol?

The hot springs form pools of very acidic fluids and the gasses that emanate are toxic. Avoid any contact with the fluids and avoid inhaling the gasses for extended periods.

A thick salt crust is what remains of a sea that evaporated 25 million years ago. Buried active volcanos lie under this salt crust.

Hot springs of salt-saturated groundwater form geysers and fumaroles and pools of very hot magmatic fluids with bubbling carbon dioxide and other volcanic gases. The amazing colours are due to iron oxide, iron hydroxide and sulphur deposits on the salt.



Dallol is a Mars analogue environment

Millions of years ago Mars could have looked like Dallol.

Planetary scientists study the geology and geomorphology of Dallol to prepare for future missions to Mars.

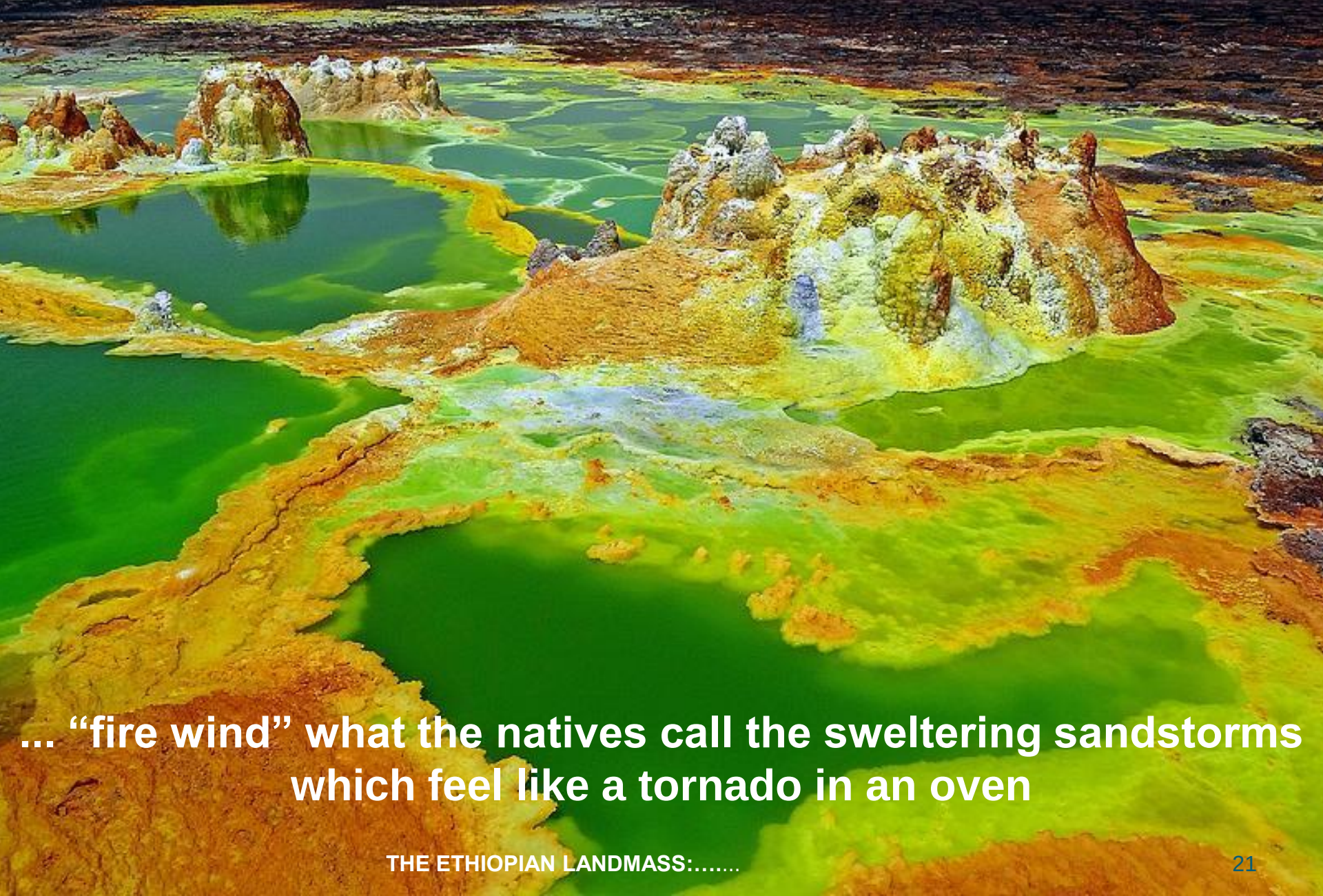
It is an ideal ground for testing equipment that will travel to Mars.

Is life possible?

Astrobiologists wonder if life is possible in harsh environments such as Dallol.

If they find life here it could mean that some life form could exist or have existed when Mars was like Dallol

... the beauty and the danger seem to go together!



**... “fire wind” what the natives call the sweltering sandstorms
which feel like a tornado in an oven**

One of 15 of the world's most colorful landscapes

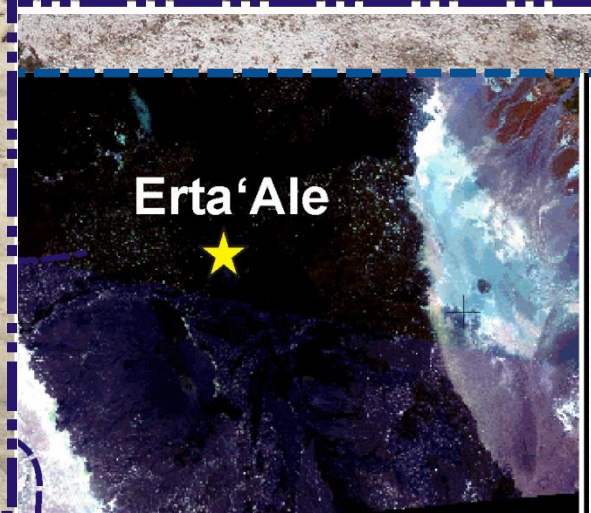
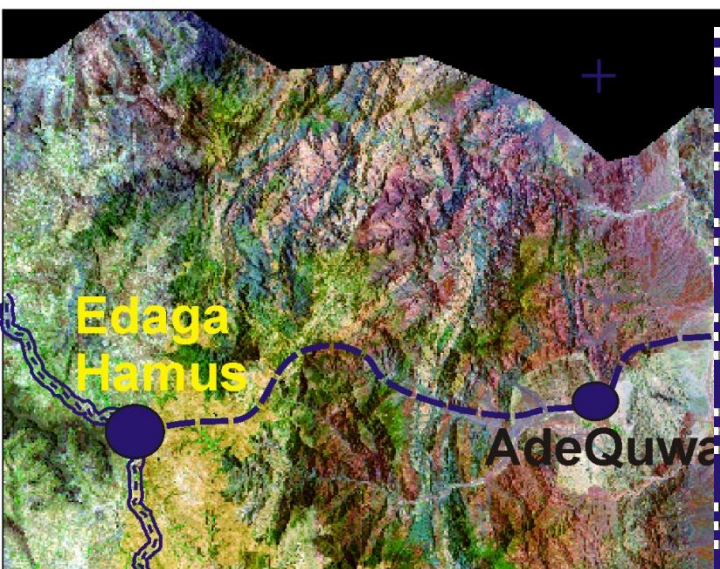


<http://edition.cnn.com/2014/12/25/travel/gallery/world-most-colorful-landscapes/>

THE ETHIOPIAN LANDMASS:.....

Traditional Salt Mining: Dallol Depression

- There is no clearly defined time frame:
 - when the tradition of hacking salt slabs from the earth's crust and transporting them by camel started.
- But it has been a practice for several centuries.
- Salt has been mined and transported with camels “camel caravans” for several hundred km.
- With the construction of a road to the area, the traditional destination of the camel caravan has been shortened.
- The camel caravans traveled only 40 km (from Dallol to Berahel), which was previously from Dallol to Mekelle and even beyond.
- Now Dallol has been connected with Mekelle by level-one asphalt road and the fate of camel caravans and traditional salt mining is questionable.



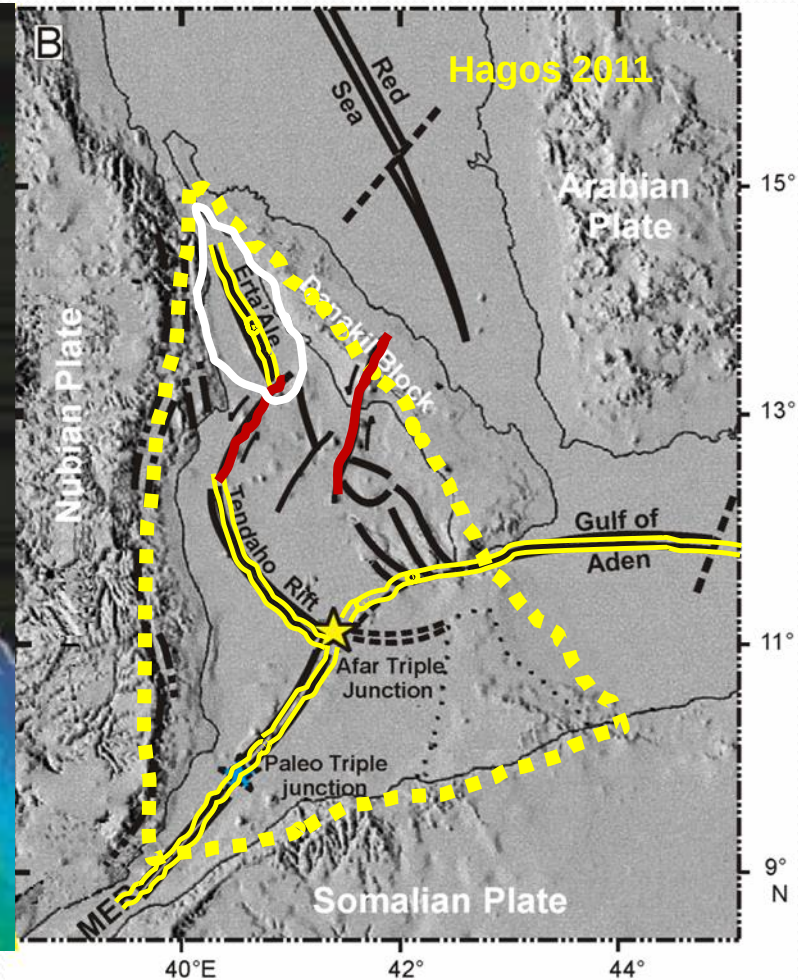
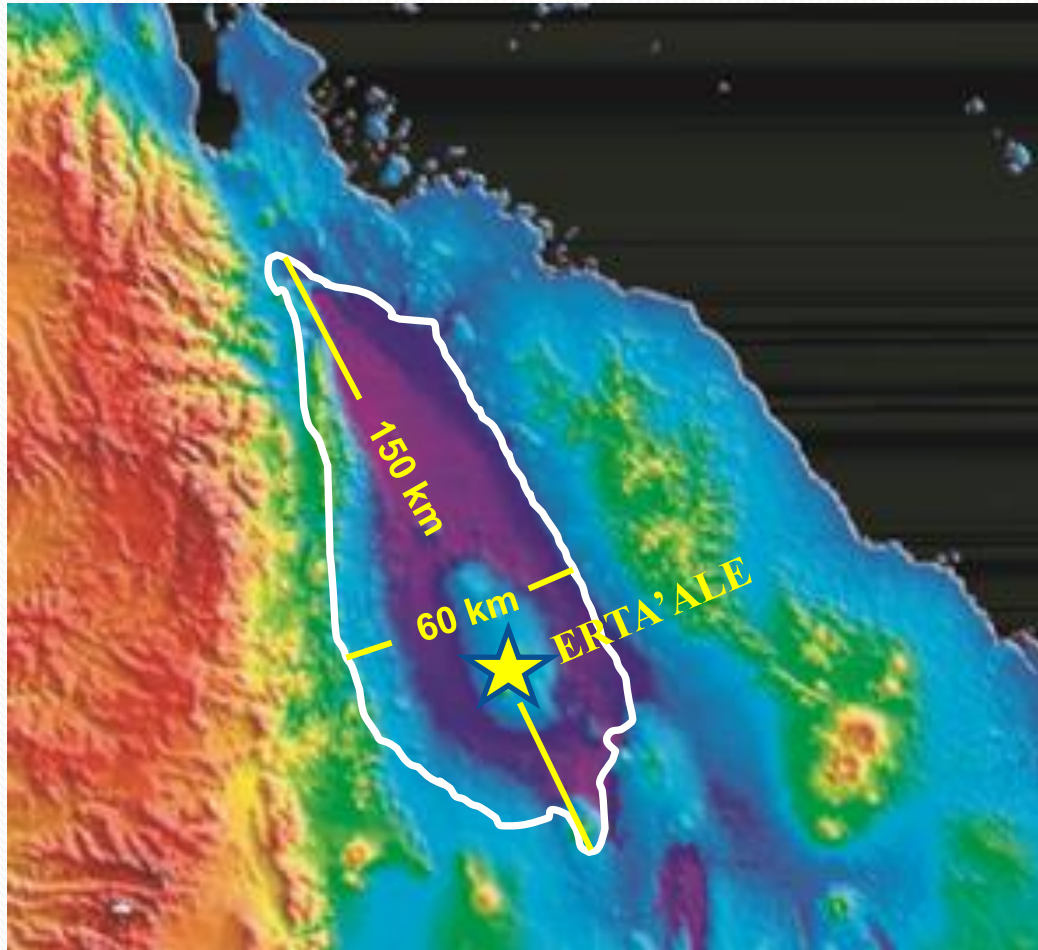
Edaga
Hamus

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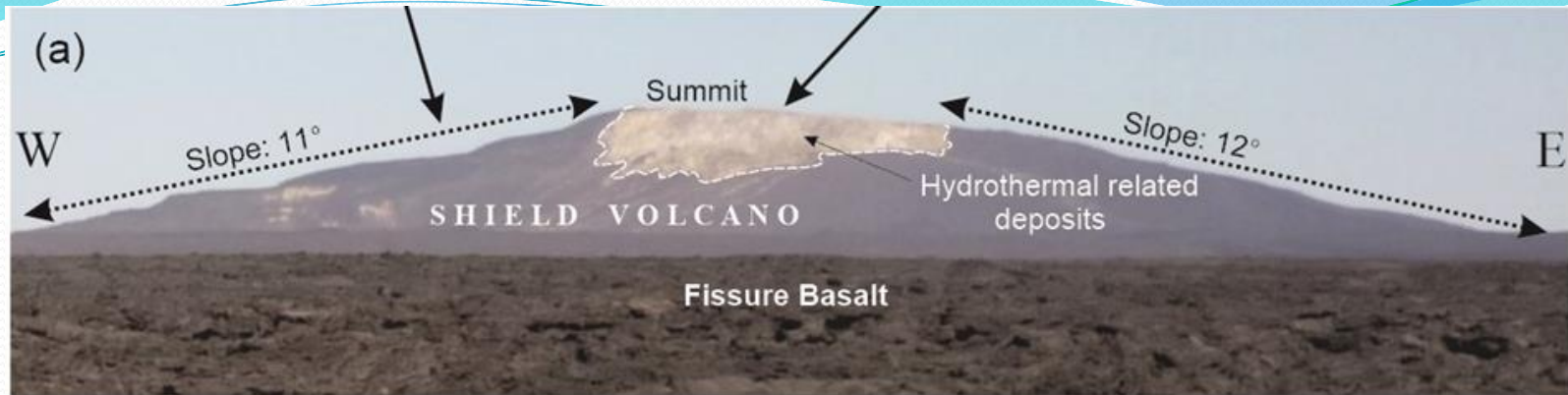
Transportation (Camel Caravan)



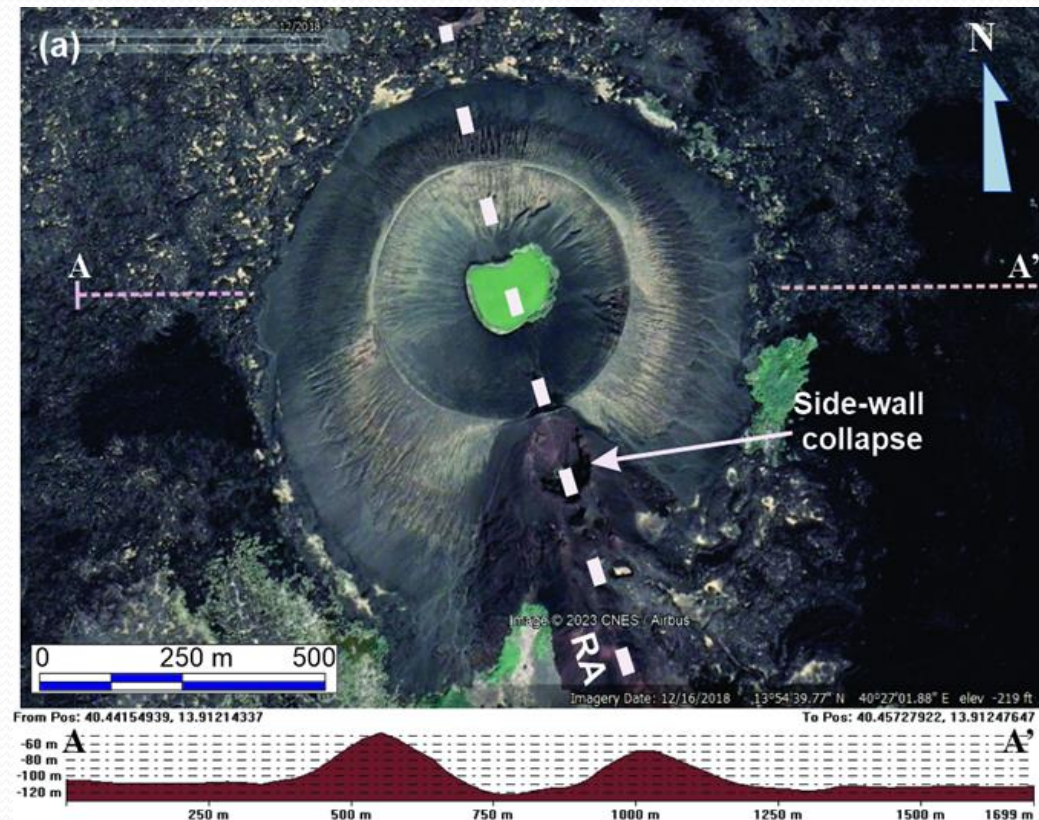
The Volcano-Tectonics of Erta'Ale



The Erta'Ale Shield volcanoes (Gada'Ale)



- There are plenty of things to see and do in Ethiopia,
- But visiting the Erta'Ale is a single reason to be there.
- Multiple shield volcanoes of Erta'Ale, occupying most of the depression floor.
- Maar and ring structures

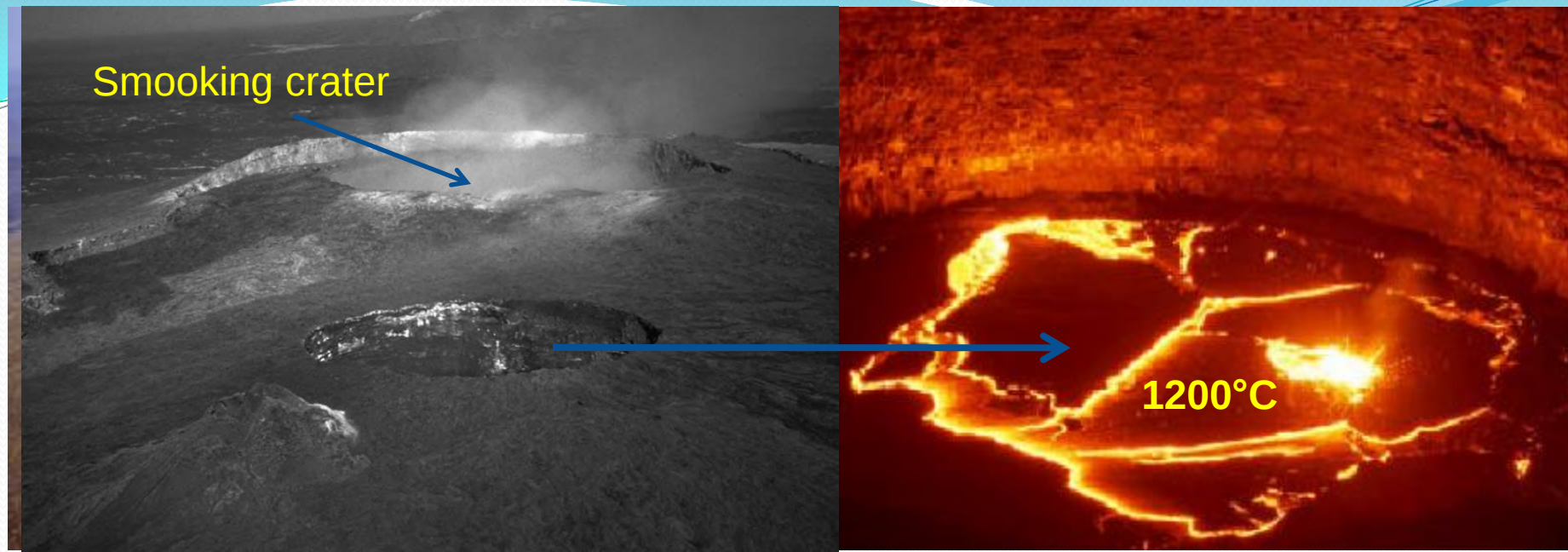


The Erta'Ale Shield volcanoes (Active lava-lake)

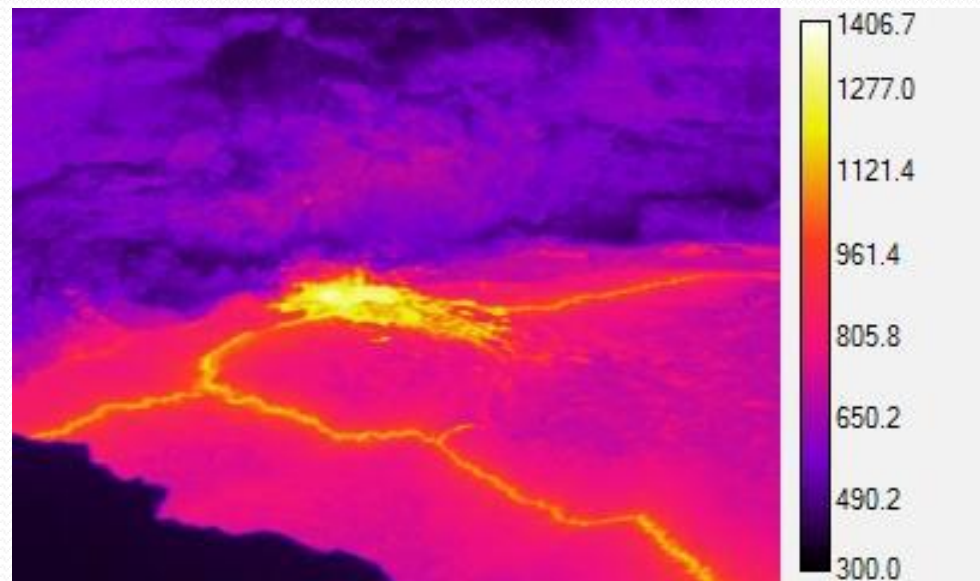
- The Erta'Ale lava lake:
 - It has been permanently active (~120 years)
 - Dynamically changing its intensity
 - The contraction and expansion
 - It is the most frequently visited site in Ethiopia.

Photograph of the Erta' Ale showing the lava lake with an elevated rim (Nov. 2020. Source: Google images).

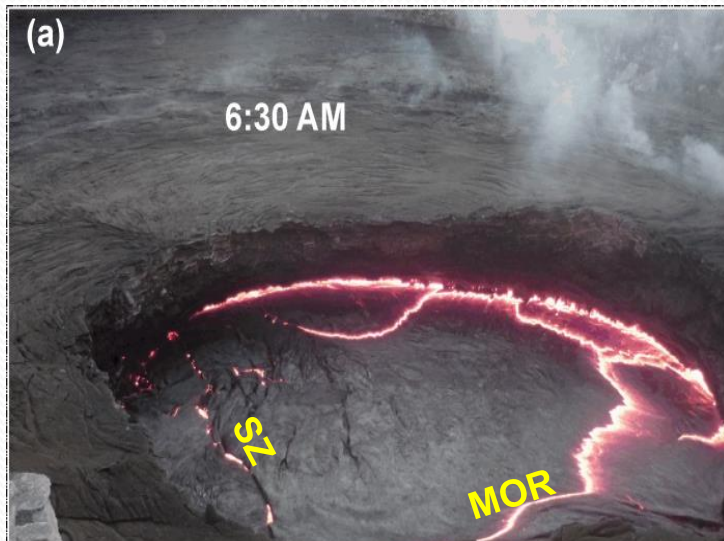




- *The larger the magma chamber, the larger is the thermal resource, which is a measure of the amount of economically useful energy.*



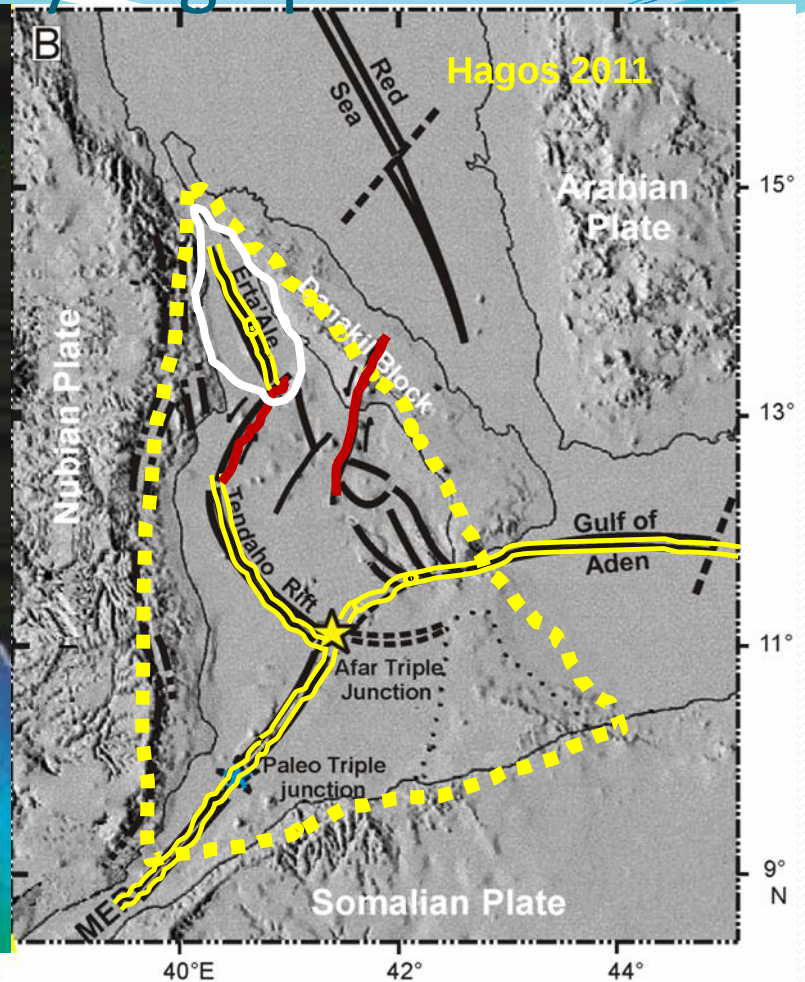
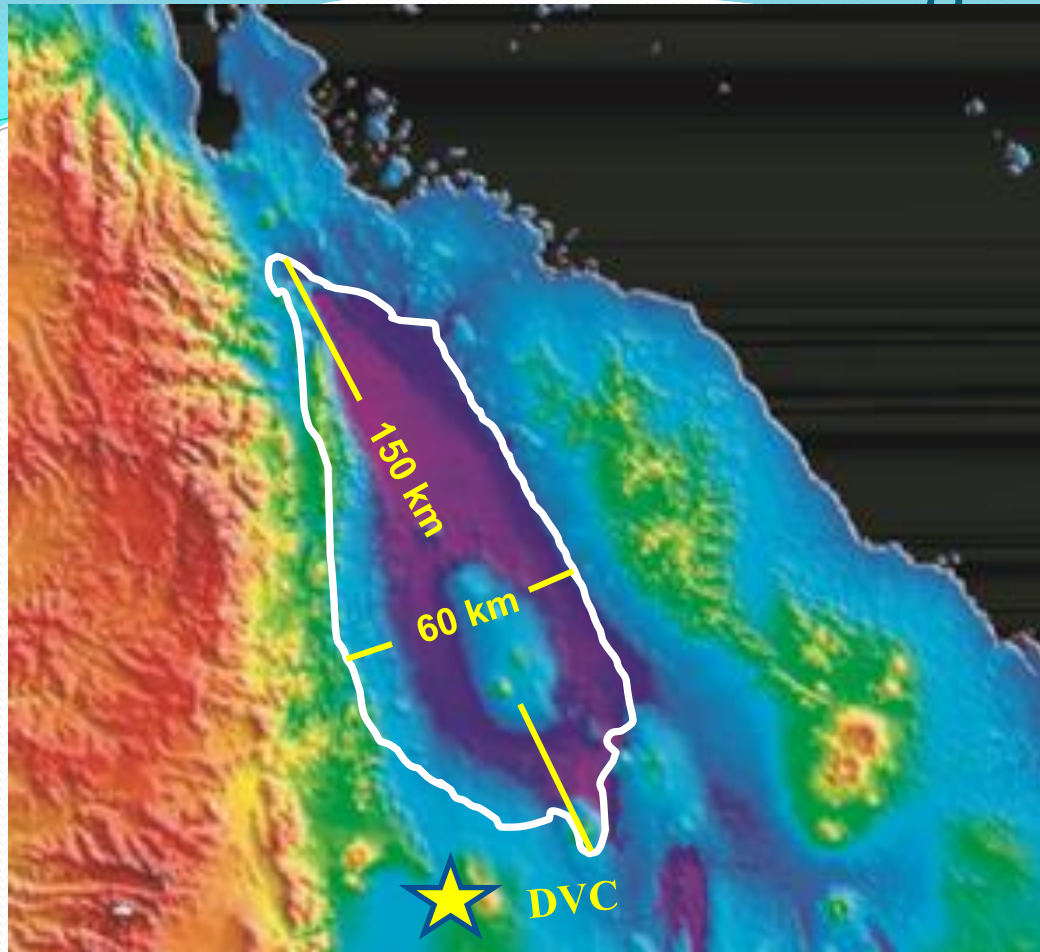
- The magma dynamics at the Erta'Ale crater is a model of plate tectonics: Mid Oceanic Ridges (MORs) and Subduction Zone (SZ)







The Dabbahu Mega-dyking Episode



- Sea-floor spreading is a very slow process,
 - 5 cm – 18 cm /year
- But, there are sporadic events that accelerate the rate:
- The Afar dyking/rifting episode:
 - Ruptured the floor up to 60 km long and 8 m wide in a single day,
 - This is one of the mega-tectonic structures in a rift system.

Dyke swarms and open fractures



Dyke swarms and open fractures



Dyke swarms and open fractures



The Afar Anthropological Site

French geologist, **Maurice Taibe**, discovered the **Hadar Formation of Afar**.

- The Afar Depression in general and northern Afar /Danakil Depression has many potential sites for Geo-heritage:

- The central Afar is home of ancient hominids



LUCY... well known to the paleo-anthropologists!

Human being!
Where all began
Just at 3.2 Ma



It is a rarely visited place but absolutely extraordinary in many ways.

Donald Johansen, Anthropologist

The Afar Geoheritage

- **Selam:** the 2nd femal hominin, “*Australopithecus afarensis*”, whose bones were first found in Afar in 2000 nicknamed **Lucy's baby**, the specimen has been dated at 3.3 million years ago.



SELAM... features of the skeleton suggest adaptation to walking upright (bipedalism) as well as tree-climbing,



Selam (*Australopithecus afarensis*) model at California Academy of Sciences

It is rarely visited place but absolutely extraordinary in many ways.

Zeresenay Alemseged,
Anthropologist

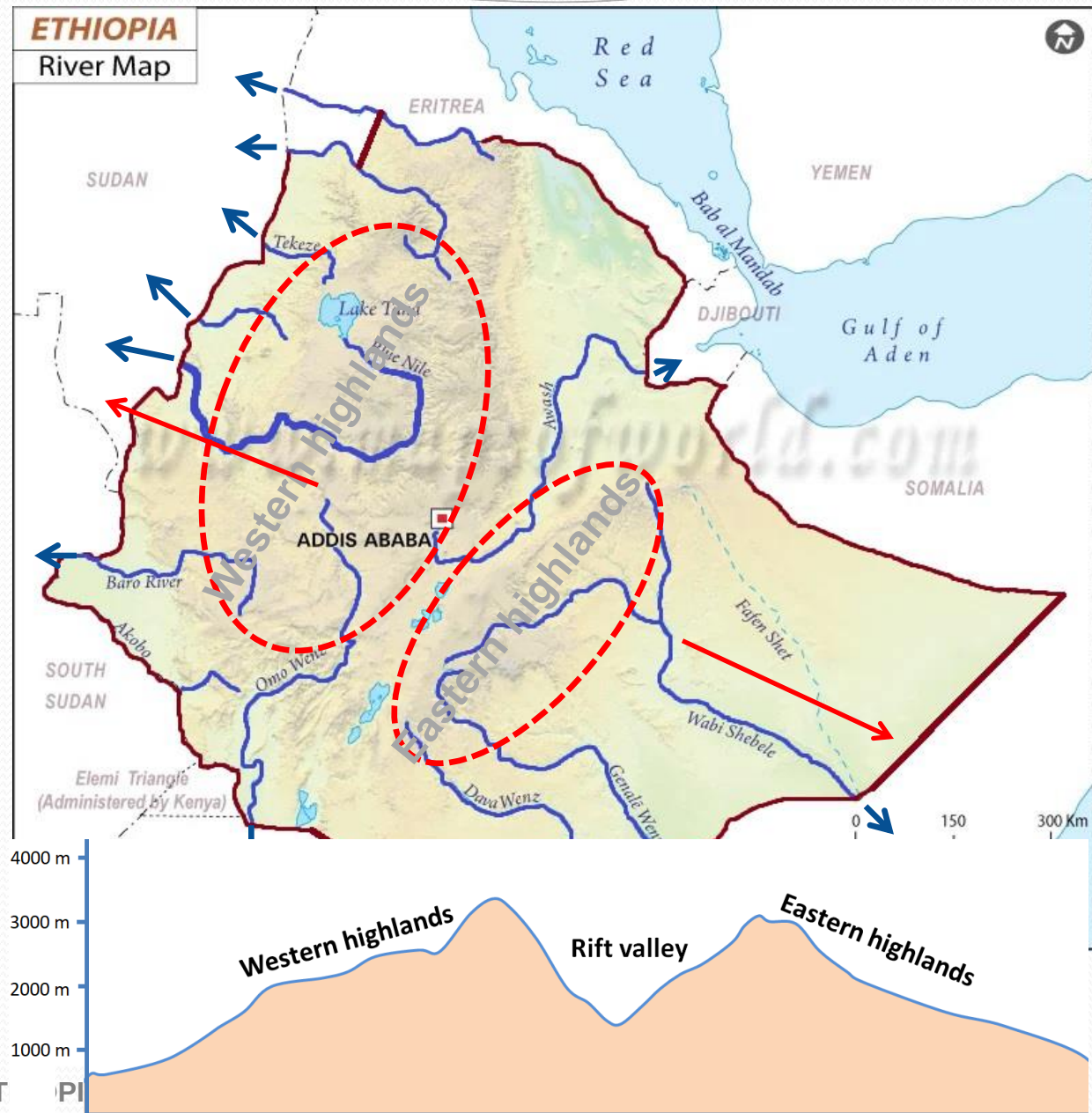
ETHIOPIA: "AFRICA'S WATER TOWER"

- Ethiopia receives high amount of rainfall (850 mm/year) over a vast area.
- Because of the high precipitation volumes that land on its highlands,
- it discharges about 45- 50 billion m³/y or 50 % of its water to the neighboring countries and beyond.

Gebrehiwot & van der Veen, 2013

<https://www.fao.org/4/W4347E/w4347eok.htm>

THE ET





The closest you can get to the falls!

Source: <https://www.brilliant-ethiopia.com/regions/blue-nile-falls>



The Blue Nile Falls is the most spectacular waterfall in Ethiopia

Source: <https://www.brilliant-ethiopia.com/regions/blue-nile-falls>

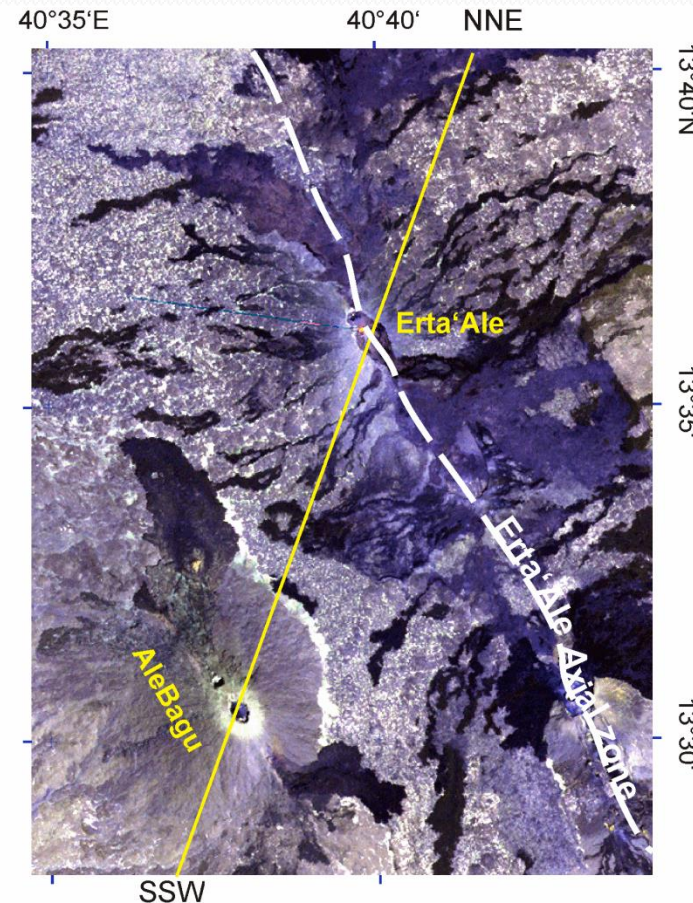
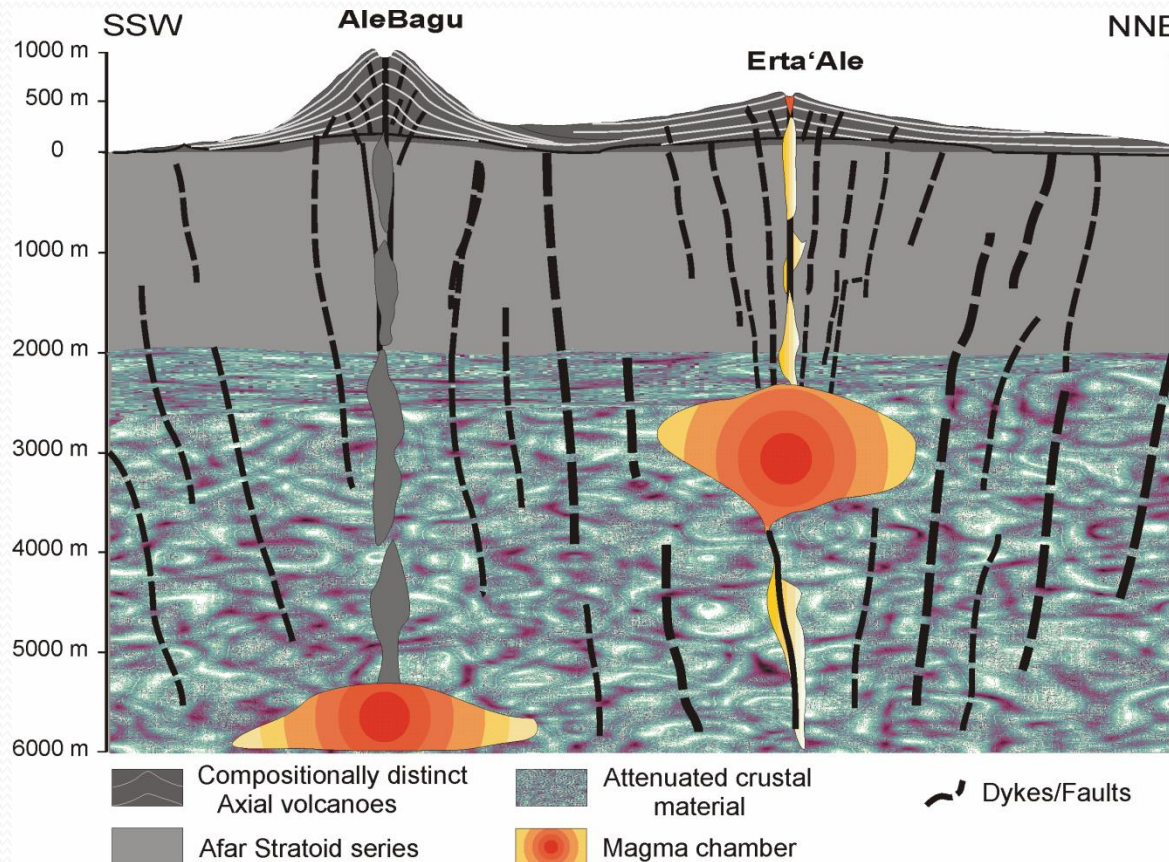


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FUTURE OF THE ETHIOPIAN/ AFRICAN LANDMASS

(Summary)

- The depth of magma chambers beneath the Afar Depression is very shallow,
- Volcano-tectonic activities take place at shallower depth (2 – 5 km deep)



THE ETHIOPIAN LANDMASS:.....

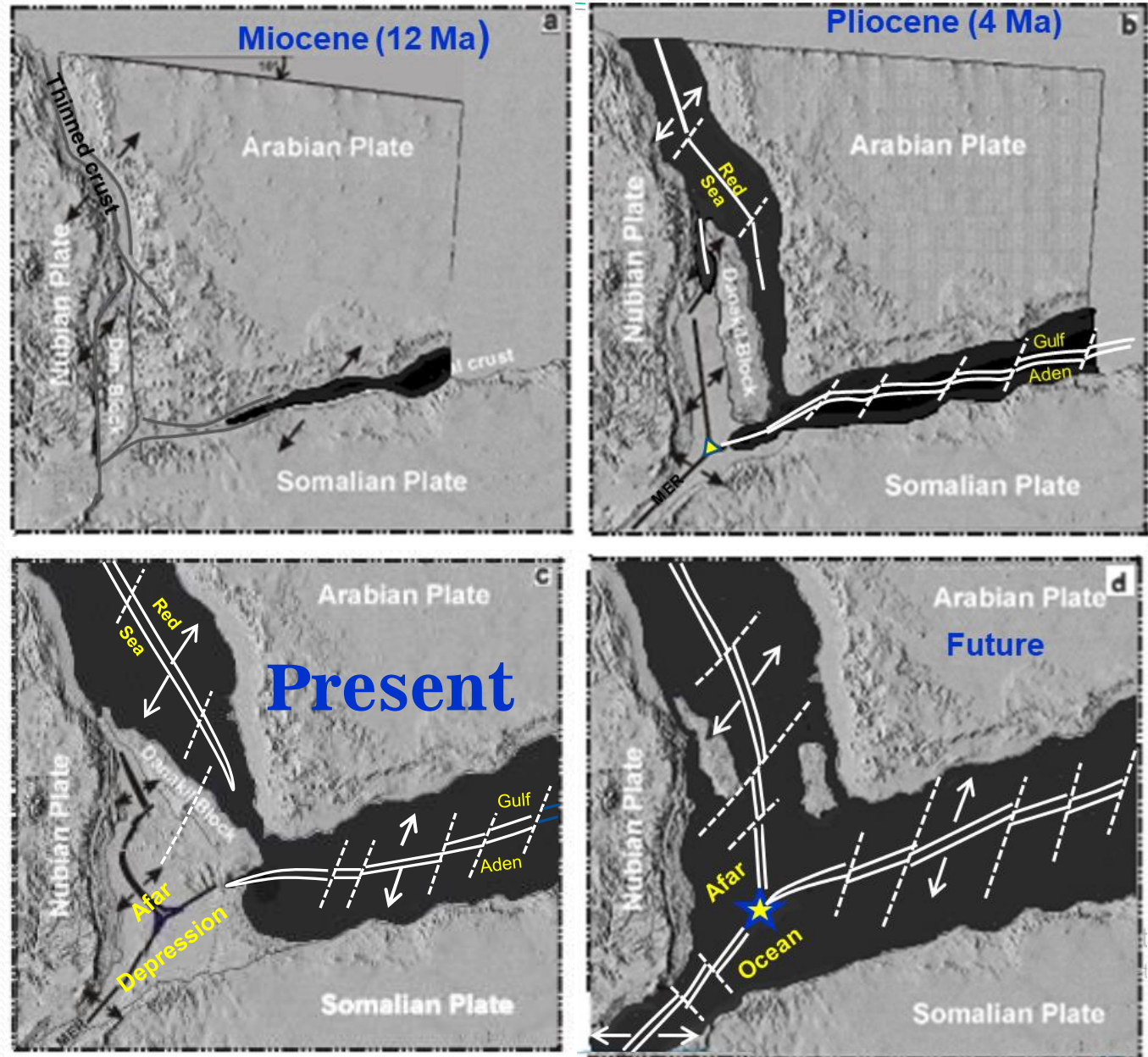
“The present is the key to the past”

“James Hutton”

- By observing the geological activities at present,
- We can reconstruct the past.

“The present is the key to the past and the future as well”

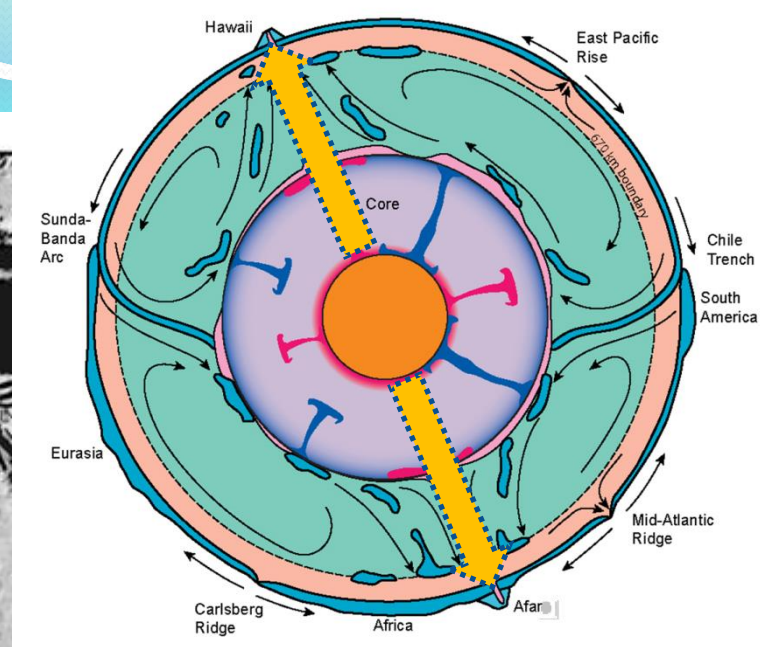
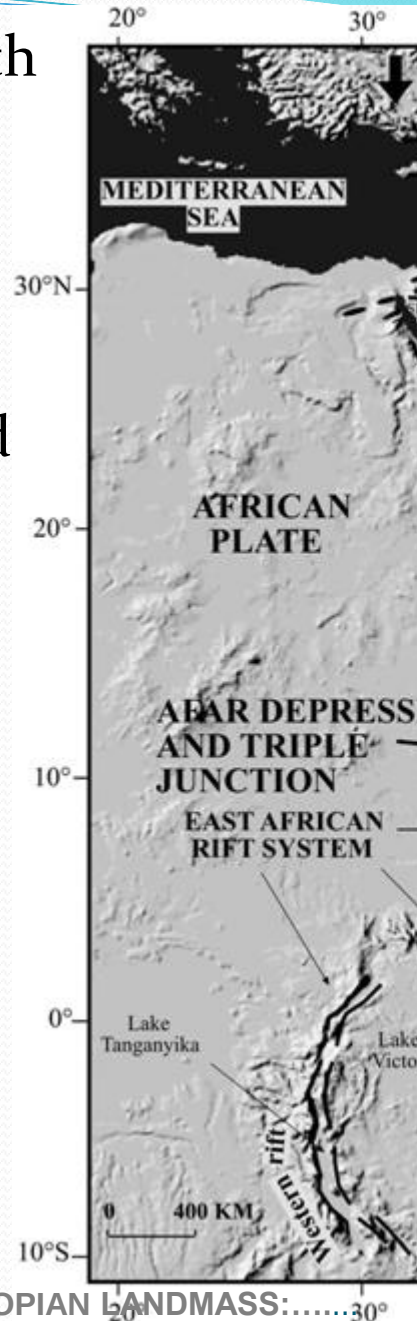
- We can also predict about the future,



THE ETHIOPIAN LANDMASS:.....

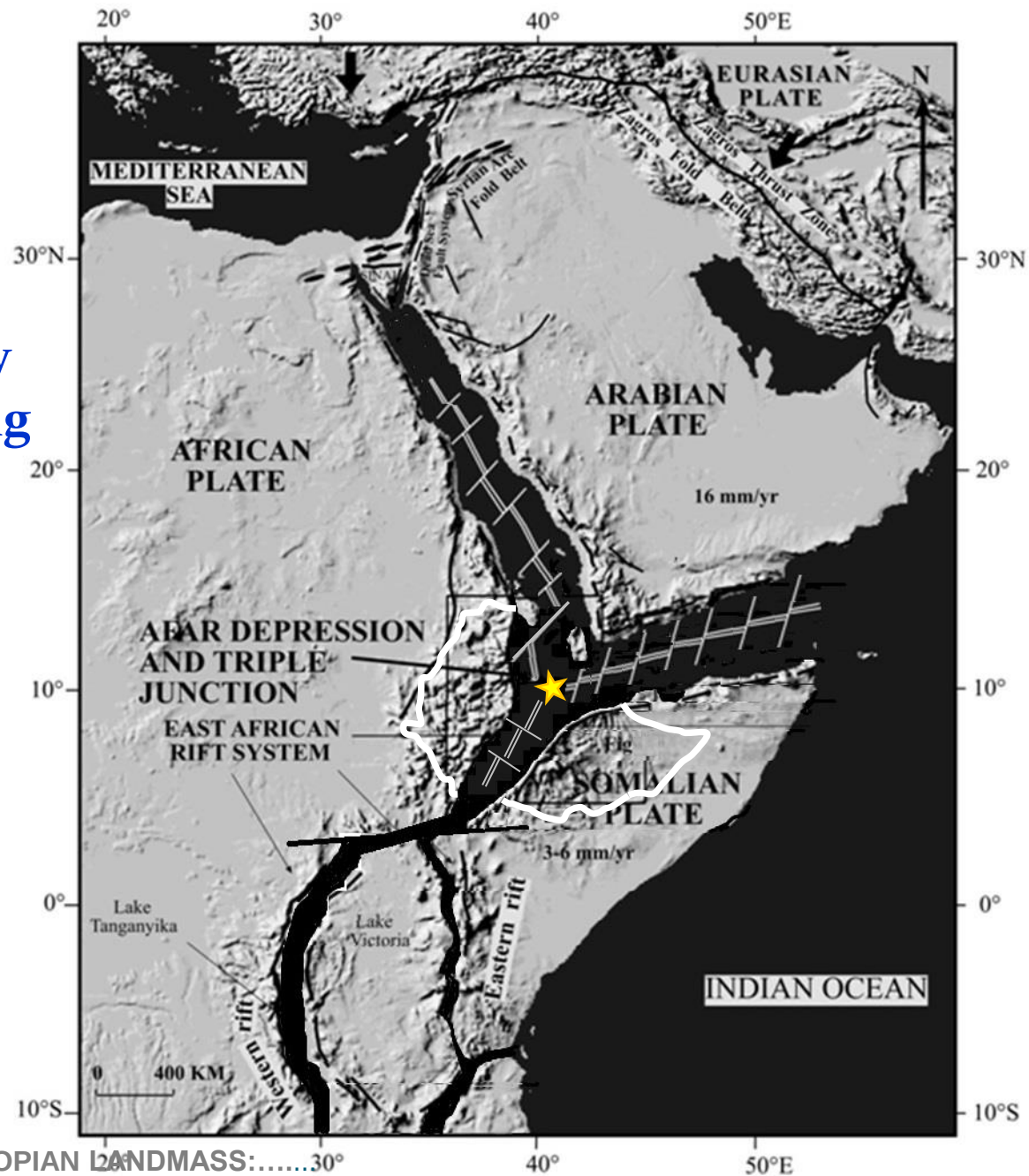
FUTURE OF THE ETHIOPIAN.....

- Crust is very thin beneath Afar, about 14 km,
- Crustal stretching or spreading rate is sporadically very high,
- Afar Depression is found at the opposite pole of Hawaii: TECTONIC POLE
- All its nature is closer to ocean basin than continental surface,
- So



FUTURE OF THE ETHIOPIAN

- So “the birth of a new ocean and the splitting of Africa into two or more plates” is imminent!!



Acknowledgments!

- My heartfelt thank goes to the **Austrian Academic Sciences (ÖAW)** for fully sponsoring and supporting the visit program and creating this platform.
- I greatly appreciate the help of **Dr. Bruckman Victor** for his valuable discussions, review of the lecture abstract and coordinating the whole program.
- I am also most grateful to my former supervisor and now colleague, **Professor Christian Koeberl**, for his tremendous professional support, encouragement and for showing me his limitless hard work.

A landscape photograph showing a vast, dry lake bed with a small, irregular pool of blue water in the foreground. The surrounding ground is cracked and reddish-brown. In the background, a range of flat-topped mountains or mesas stretches across the horizon under a clear sky.

**THANK YOU
ALL!**