Lectures in the Geology of Egypt
"Tectonic Framework"

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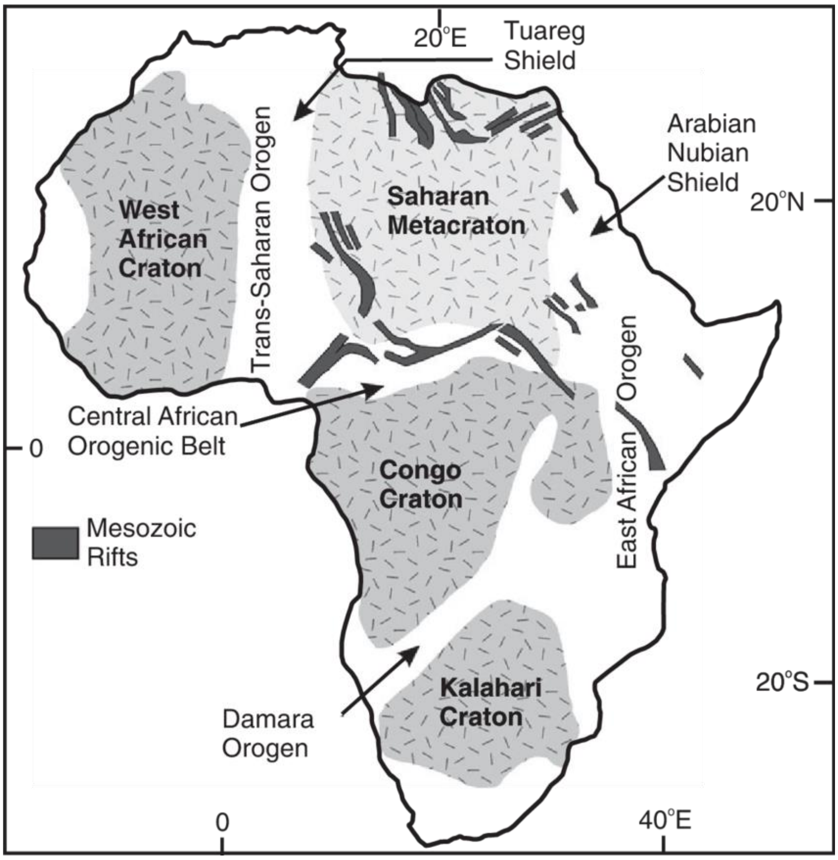
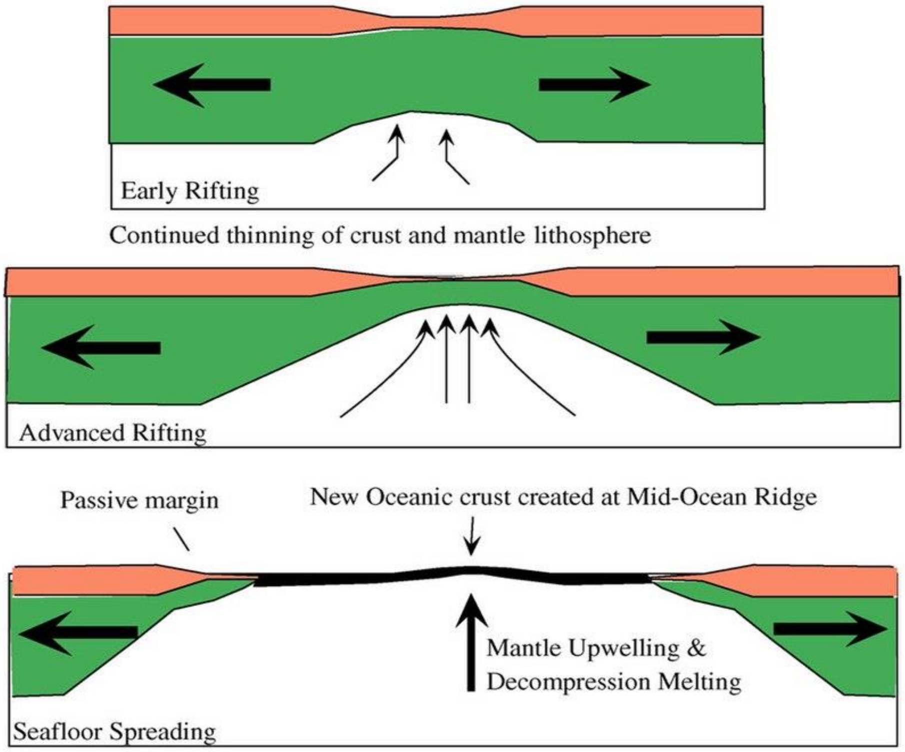
1-Saharan Craton or Meta-craton???

- The term ‘‘craton’’ refers to a stable part of the continent, composed of ancient crystalline basement rocks, that has been only slightly deformed for a prolonged period, henceacting as a stable interior during orogenic events at its margin. This can be linked to the acquisition of a thick lithospheric mantle, including a cold lower crust, strong crust–mantle coupling and an elastic thickness due to strong lithosphere that prevent later deformation. Examples of cratons include five cratons that make up the African plate (West African craton, Conog craton, Kalahari craton, Saharan metacraton, and Tanzanian craton).



- Margins of the present cratons behaved during Neoproterozoic orogenic events as passive margins; the transition between oceanic and continental lithosphere that is not an active plate margin. These margins are characterized by accumulation of sedimentary sequences dominanted by clastic sedimentary rocks such as sandstone and shale.



- A craton may be decratonized (meta-craton) when the passive margin turns into an active margin due to subduction initiation. In this case, when collision occurs, only traces of the craton will be preserved within the orogenic belts. So, the term ‘‘metacraton’’ to refer to a craton that has been remobilized during an Orogenic event but that is still recognizable dominantly through its rheological, geochronological and isotopic characteristics.
- As such example, the Saharan meta-craton that occupies the north-central part of Africa covering more than 5,000,000 km2. It extends from the Arabian Nubian Shield in the east to the Tuarge shield (Algeria,

Niger, Mali) and from the Congo craton in the south to the Phanerozoic cover of the northern margin of Africa in southern Egypt and Libya. The Saharan meta-craton is a part of the Rodinia super-continent (the motherland assembeled 1.1-0.9 Ba ago and broken up 750-633 Ma ago) and then rearranged into the Gondwana super-continent (550 Ma).

- Others name were given for this meta-craton like the Nile craton, but the Nile is at the extreme eastern margin of the meta-craton. Also, the Saharan-Congo craton, which implies that this crust is the northern continuation of the Congo craton; however, the Saharan meta-craton does not contain Neoproterozoic basement complex unlike the Congo craton.
- The question that has to be asked is why the Saharan basement complex is a meta-craton and not a craton???
    - The Saharan meta-craton are completely covered by the phanerozoic sedimentary cover all over Egypt, with an exception for the basement rocks at Gebel Uweinate (southwesetrnmost Egypt) are considered to be the oldest dated rocks (2673 Ma) in Egypt.
    - These rocks consist of charnockitic gneiss metamorphosed to granulite facies. The latter is only found under high temperature and pressure conditions of the regional metamorphism. Accordingly, these rocks were subjected to a continent-continent collision during Archean.
    - The geochronological studies by Rb/Sr and U/Pb isotopes indicate the presence of pre-Neoproterozoic continental crust.
- Two main structural trends dominate in the Saharah meta-craton; ENE-WSW (early trend) and younger N-S trend. The early trend represents folding system (Zalingei folded zone) recoreded in many places such as G. Uweinate and Darfur. It is thought to be inherited from the early Neoproterozoic collisons. The younger folding trend (N-S) constitutes

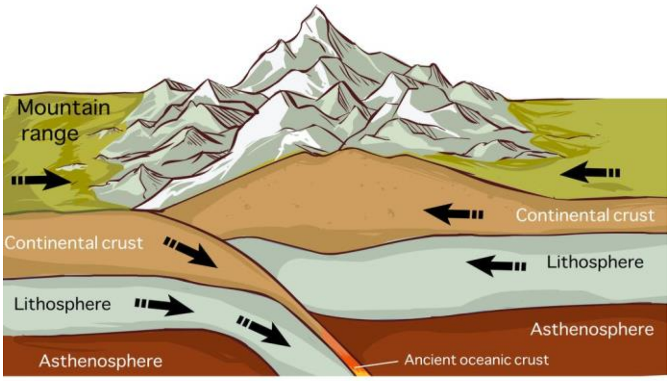
upright folds along the eastern margin and are deformed by shear zones (N-NW-trending strike-slipe faults).

- *What happened to the Sahara meta-craton during the Neoproterozoic???*
    1. *Collision process: the Sahara meta-craton was remobilized during the Neoproterzoic time by continent-continent collision between the Sahara meta-craton and Congo craton that is represented by the ENE-WSW-trending orogenic belt "Central African Orogenic Belt".*
    2. *Delamination of the sub-continental mantle lithosphere occurred at about 700Ma due to the high heat flows, causing collapse of the lower mantle crust.*
    3. *Extension tectonic within the Sahara meta-craton is due to the high heat flows associated with uplift of the lower mantle crust, resulting in A-type granitic intrusions and low-pressure, high-temperature metamorphism through the Neoproterozoic orogenic belts in northen Africa. Also, the occurrence of Jebel Rahib ophiolite in the interior of Sahara meta-craton indicates opening and closing of Red Sea-type restricted oceans.*

2- <u>What does the term orogeny mean?</u>

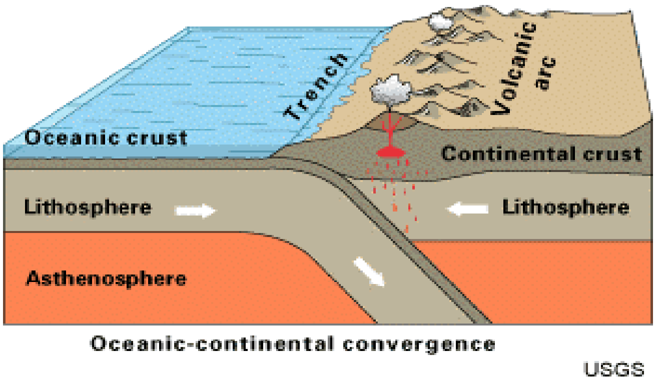
- In general, Orogeny (or orogenesis) derives from the Greek *oros*, which means mountain, and *genesis*, which means origin or mode of formation. The term mountain building implies that the rate of surface uplift is greater than the rate of erosion such that, over time, a lowland area evolves into *a mountain system* that is a group of mountain ranges with similarity in form, structure, and alignment that have arisen from the same cause (e.g. Saint Catherine mountain ranges in Sinai and Eastern Desert Mountain ranges).
- From the plate tectonic point of view, the term orogeny refers to uplifting of the Earth's surface when two continental plates are pushed together in opposite

directions. When this happens, the intense pressure of the edges pushing together forces the plate material upward since there's nowhere else for it to go. This would be like you taking two pieces of bread and sliding them across a surface into each other from opposite directions. As the edges of the bread are compressed together, they rise upward, forming a sort ofbread mountain. This process is called the fold-mountain (e.g. Himalayas in South Asia).



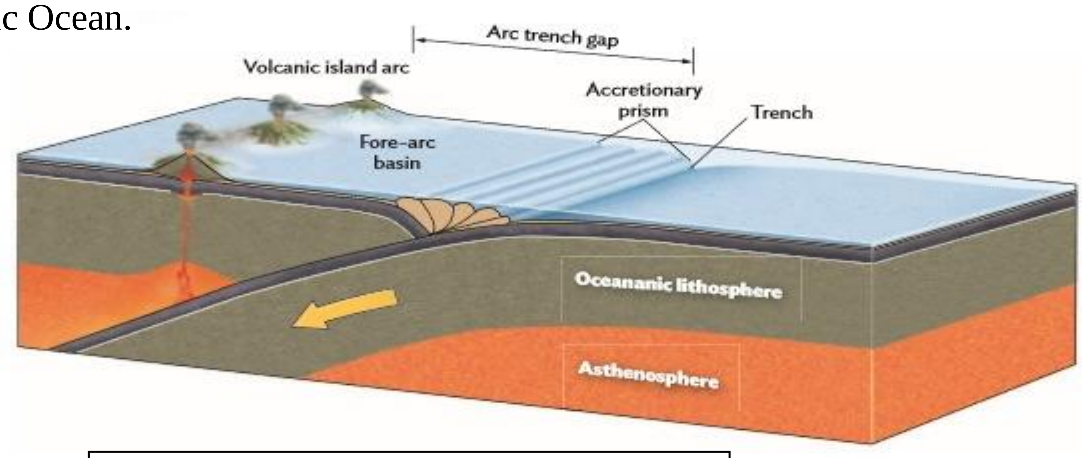
Continental collision-induced mountain formation

- Sometimes, oceanic plates run into continental plates, and when this happens, we also get mountain formation, but it's a bit different because the oceanic crust is much denser than the continental crust. Because of this, the oceanic crust sinks down below the continental crust, a process *known as subduction*. The crust material gets heated and then rises to the surface as magma, pushing upward and forming a volcano. As volcanic eruptions spew their material out, the material builds up around the ground, forming the mountain itself. This is why we find many of the world's volcanoes along oceanic-continental boundaries, like the area known as the Ring of Fire.



Volcanism-induced mountain formation

- Oceanic plates may also collide with other oceanic plates, and when this happens, the older one is subducted under the younger one because the older one is denser. This type of plate compression results in a volcanic island arc. As the name implies, these are mountainous islands made of volcanoes. Japan is one such set of mountainous islands along oceanic plate boundaries in the Pacific Ocean.

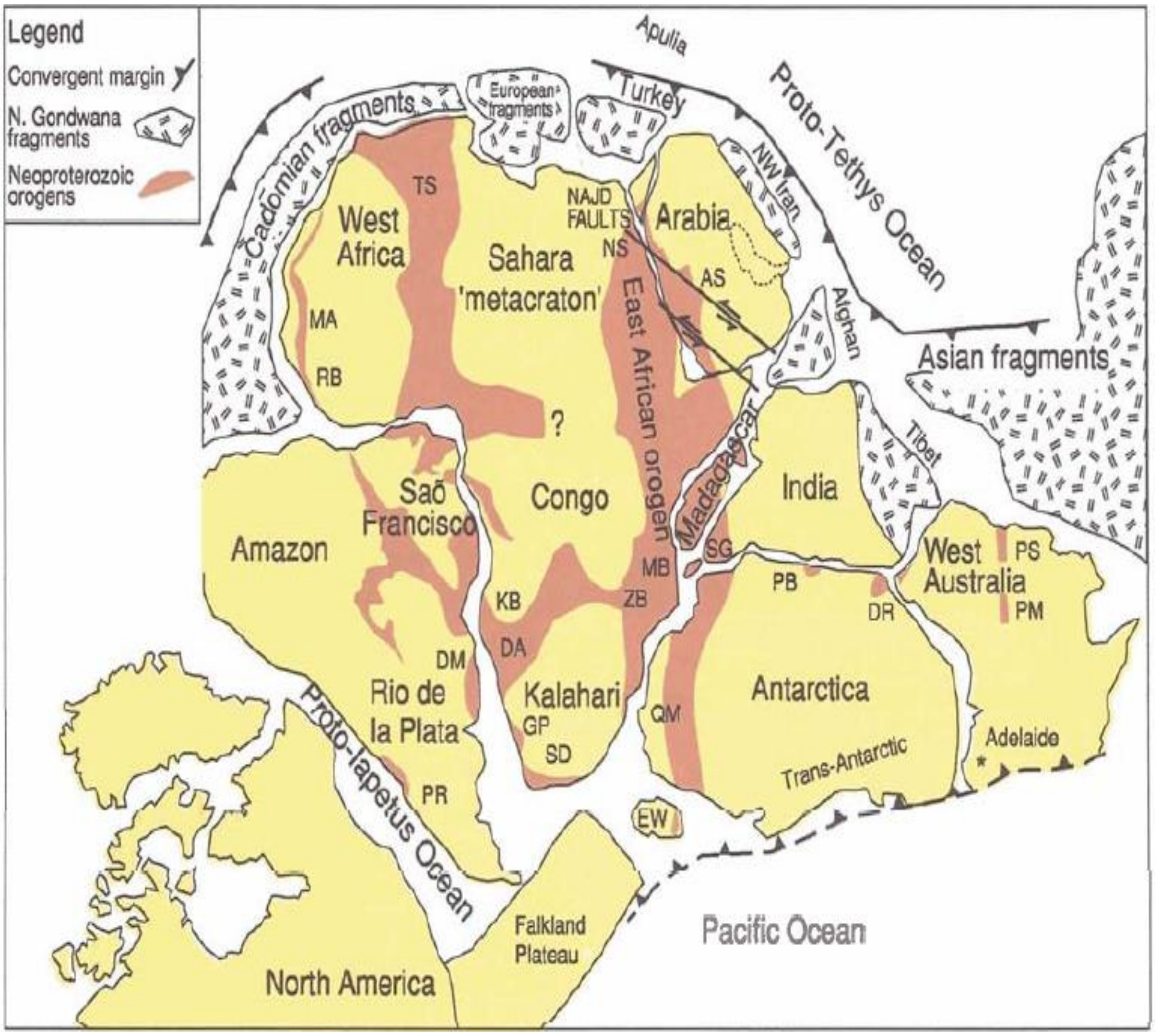


Subduction-induced mountain formation

3-Pan-African Orogeny

- The Pan-African Orogeny is defined as a tectonic, magmatic and metamorphic activity occurred during the Neoproterozoic-earliest paleozoic age (870-500 Ma), causing a number of mobile belts to form and surround the older cratons.
- The Pan-African even cannot be a single orogeny but must be a protracted orogenic cycle associated with opening and closing of large oceanic realms as well as accretion and collision of the buoyant crustal blocks. This stems from the global distribution of the Pan-African Orogeny.
- The Neoproterozoic oceans include the Mozambique Ocean between East Gondawan (Australia, Antarctica, southern India) and West Gondwana (Africa, South America), the Adamstor Ocean between the Kalahari and Congo cratons, and the Trans-Sahara Ocean between the West African Craton and the Sahara Meta-Craton.
- The Pan-African Orogeny culminated in the formation of the Late Neoproterozoic supercontinent Gondwana (800-550Ma).

- Within the Pan-African domains, two broad types of mobile belts can be distinguished:
    1. The first one type involves the upper-middle crustal parts and consists dominantly of Neoproterozoic supracrustal and magmatic assemblages as well as diagnostic features of ophiolites, subduction- or collision-related granites, island arc and passive margins assemblages (e.g. the Arabian-Nubian Shield, the West Congo belt of Angola and Congo Republic, and the Trans-Sahara belt of West Africa).
    2. The second type represents the lower crustal parts and comprises high-grade metamorphic rocks (e.g. the Mozambique belt of East Africa).



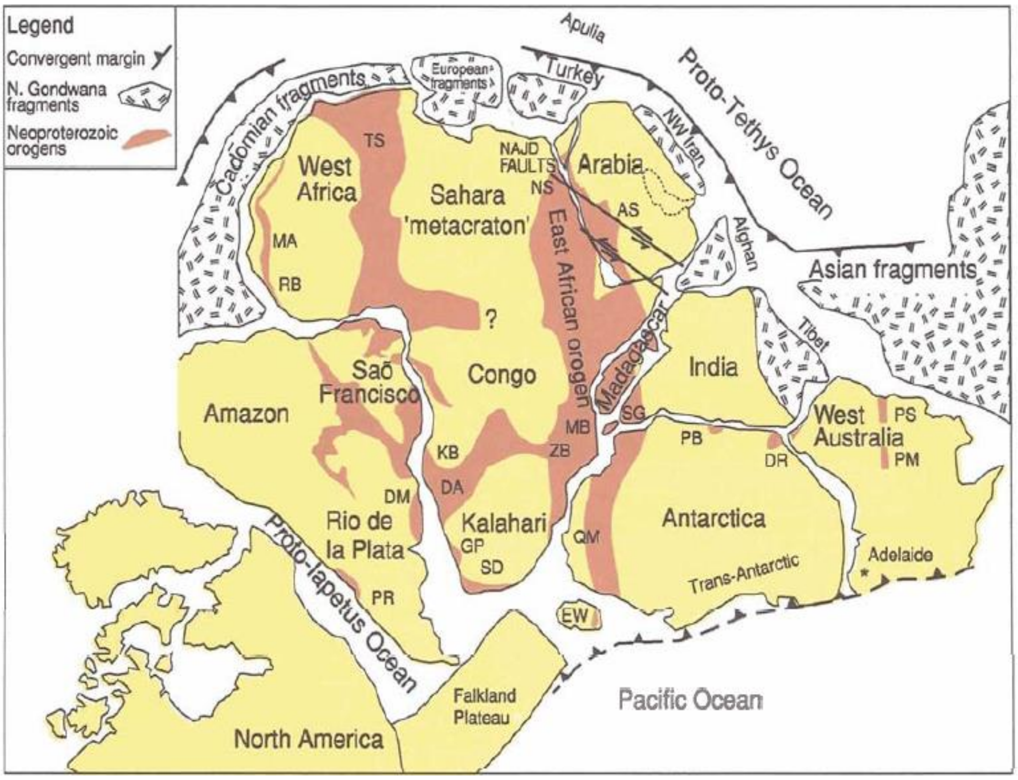
Supercontinent Gondwana containing the Pan-African Orogenic belts

LECTURE#2

Arabian-Nubian Shield

1-What is the Arabian-Nubian Shield????

- The Arabian-Nubian Shield is one of the Neoproterozoic mobile belts that formed during the Pan-African Orogeny.
- The Arabian–Nubian Shield (ANS) is part of an accretionary orogen exposed on either side of the Red Sea and Gulf of Aden in Northeast Africa (Nubian Shield) and the western part of the Arabian Peninsula (Arabian Shield).
- It represents the suture between the East and West Gondwana at the northern end of the East African Orogeny. The eastern part is preserved in the Arabian plate while the western part is a segment of the African plate.
- It extends about 3000km from north to south and >500km on either side of the Red Sea. Also, it can be tracted from southern Jordan south as far as Ethiopia and Yemen and from the east in Saudi Arabia to the west in Egypt.
- The Arabian-Nubian Shield is composed of Neoproterozoic rocks including gneisses, migmatites, meta-sediments, volcano-sedeimentary terrans (calc-alkaline basalts, andesites, rhyolites, tuffs, and pyroclastics), and ophiolites.
- The Neoproterozoic rocks formed during a supercontinent cycle bracketed by the 900–720 Ma break-up of Rodinia and the 650–530 Ma multiphase assembly of Gondwana concurrent with East African Orogeny.
- During this period, the Earth system was affected by remarkable changes in biology, chemistry and structure. These include the rapid evolution of the eukaryotic organisms (e.g. green algae), the reappearance of the banded iron formations, three episodes of the continental glaciation (717-660Ma, 641-635Ma, and 580Ma) due to the huge CO^2 emissions by volcaneoes, and the creation of juvenile crustal blocks of which the ANS is the largest.


Legend
Convergent margin
N. Gondwana fragments
Neoproterozoic orogens
Apulia
Proto-Tethys Ocean
Cadomian fragments
European fragments
Turkey
NW Iran
Afghan
Tibet
Asian fragments
West Africa
Sahara 'metacraton'
NAJD FAULTS
Arabia
East African orogen
Madagascar
India
Amazon
São Francisco
Congo
West Australia
Rio de la Plata
Kalahari
Antarctica
Trans-Antarctic
Adelaide
Proto-Iapetus Ocean
Falkland Plateau
North America
Pacific Ocean
TS
NS
AS
MA
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DR
PS
PM
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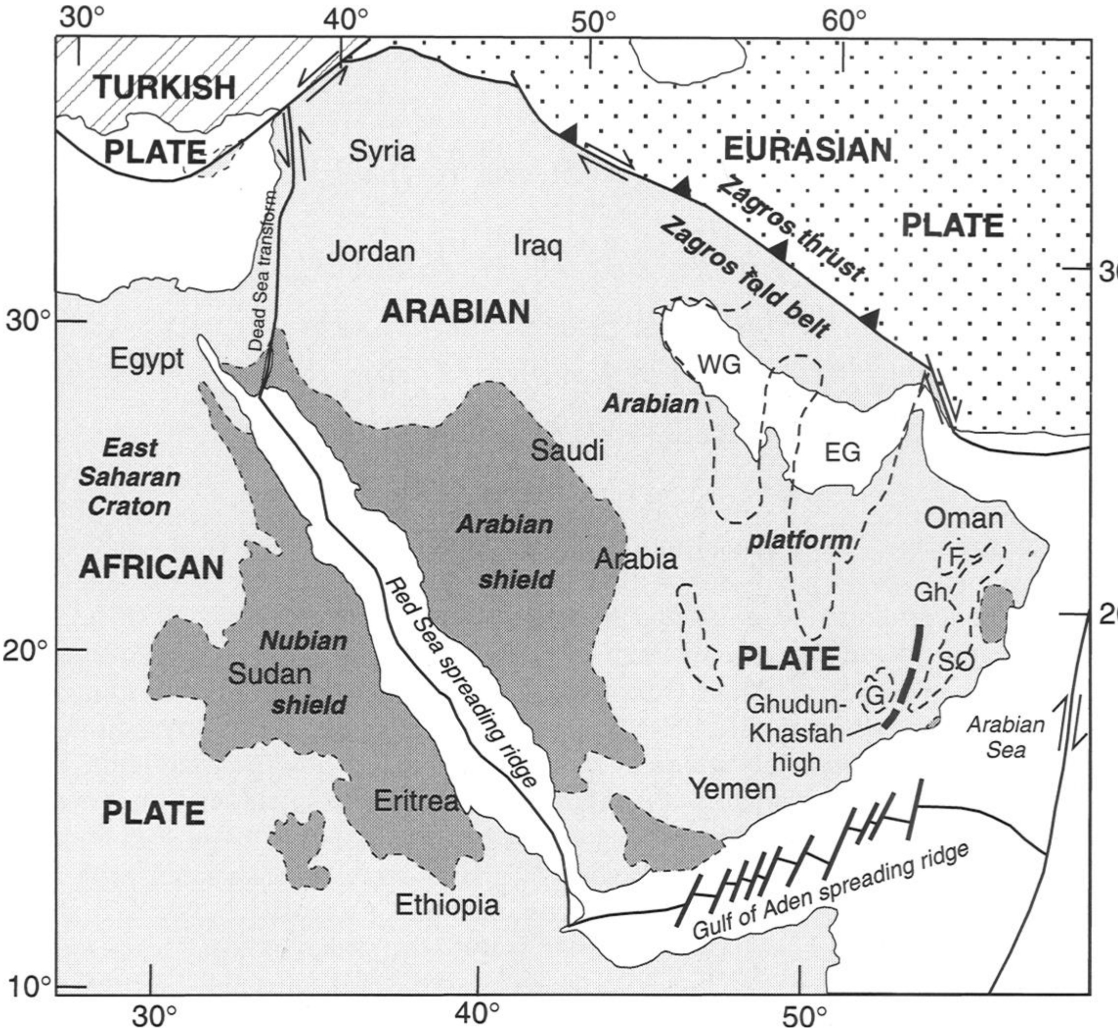
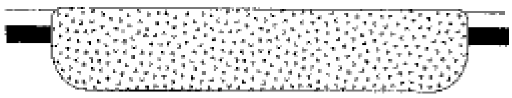
EW

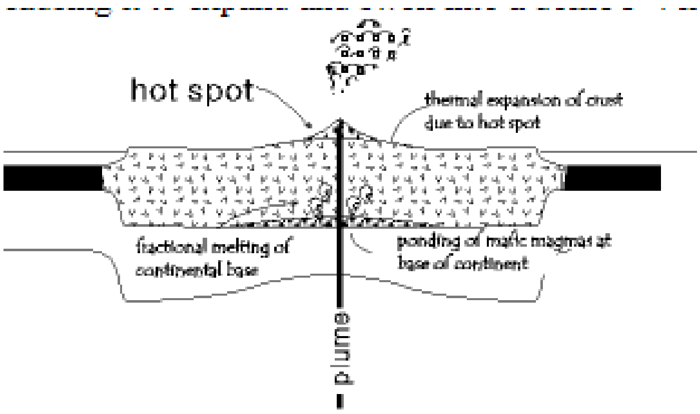

TURKISH PLATE
EURASIAN PLATE
ARABIAN PLATE
AFRICAN PLATE
Syria
Jordan
Iraq
Egypt
Saudi Arabia
Oman
Sudan
Eritrea
Ethiopia
Yemen
Dead Sea transform
Zagros thrust
Zagros fold belt
East Saharan Craton
Arabian shield
Nubian shield
Arabian platform
Red Sea spreading ridge
Gulf of Aden spreading ridge
Arabian Sea
Ghudun-Khasfah high
WG
EG
F
Gh
SO
G
30°
40°
50°
60°
20°
10°

2-Development of the Arabian-Nubian Shield

- The ANS formed over a period of about 340 million years, between 870 Ma and 530 Ma, and its growth reflects complex crustal evolution as part of the Rodinia–Gondwana supercontinent cycle.
- The formation of the ANS is related to Wilson cycle of supercontinets rifting and assembly.
  - Stage A: a tectonically stable continental craton bordered by ocean basins all around. The continent is eroded down nearly to sea level everywhere.

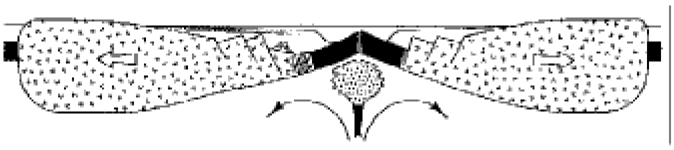


  - Stage B: Into the peaceful stable continent of Stage A comes a disturbance. From deep in the mantle a plume of hot mafic or ultramafic Magma, rises toward the surface and ponds at the base of the continent creating a hot spot. Heat from the hot spot warms the continental crust causing it to expand and swell into a dome 3-4 kilometers high and about a thousand kilometers in diameter. As the dome swells it thins and stretches like pulled taffy (or silly putty) until the brittle upper surface cracks. Here, the initial rifting forms, and the original continent is splitted into two pieces, west and east, although they are still connected at this stage. The axila rifting is a block-fault graben with listric-type normal faults. Also, Mafic (hot spot) volcanoes are common and appear as vent volcanos and/or flood basalts from fissure volcanos in the rift. Commonly the intense heat of the hot spot will fractionally melt the lower continental crust composed of Granodiorites or Plagiogranites. The results are Alkali Granitic magmas that rise to emplace as batholiths, frequently sending conduits to the surface to create large felsic volcanoes.



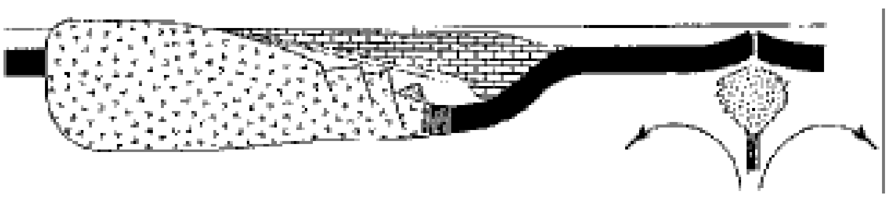
- Stage C: A string of hot spots joined together and a large number of basaltic dikes are injected into the thinned and stretched continental crust. As the volcanic activity continues, the two pieces of the original continent begin to drift apart and the gap between them fills with mafic igneous rock; the seawater trangresses across the new oceanic crust.

Creation of New Oceanic Crust: Early Divergent Margin

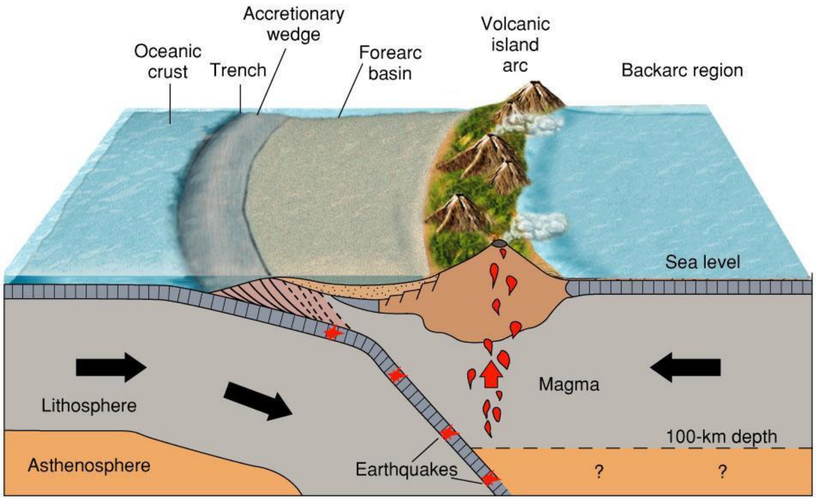


- Stage D: Heat rising to the surface from the convection cells remains concentrated at the rifting site in the center of the new ocean basin, so as the ocean basin widens the newly formed continental margin (now called a divergent continental margin [DCM], or a passive continental margin because it is geologically passive) moves away from the heat source.

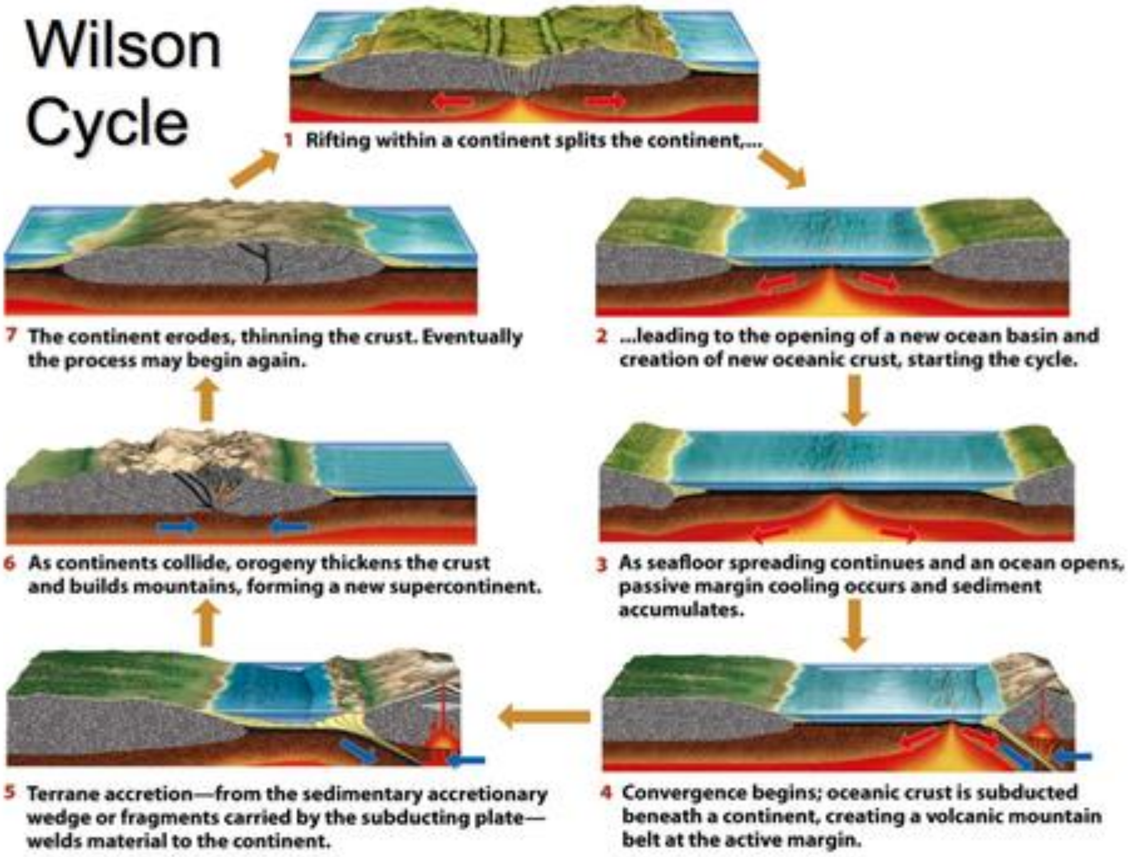
Full Divergent Margin



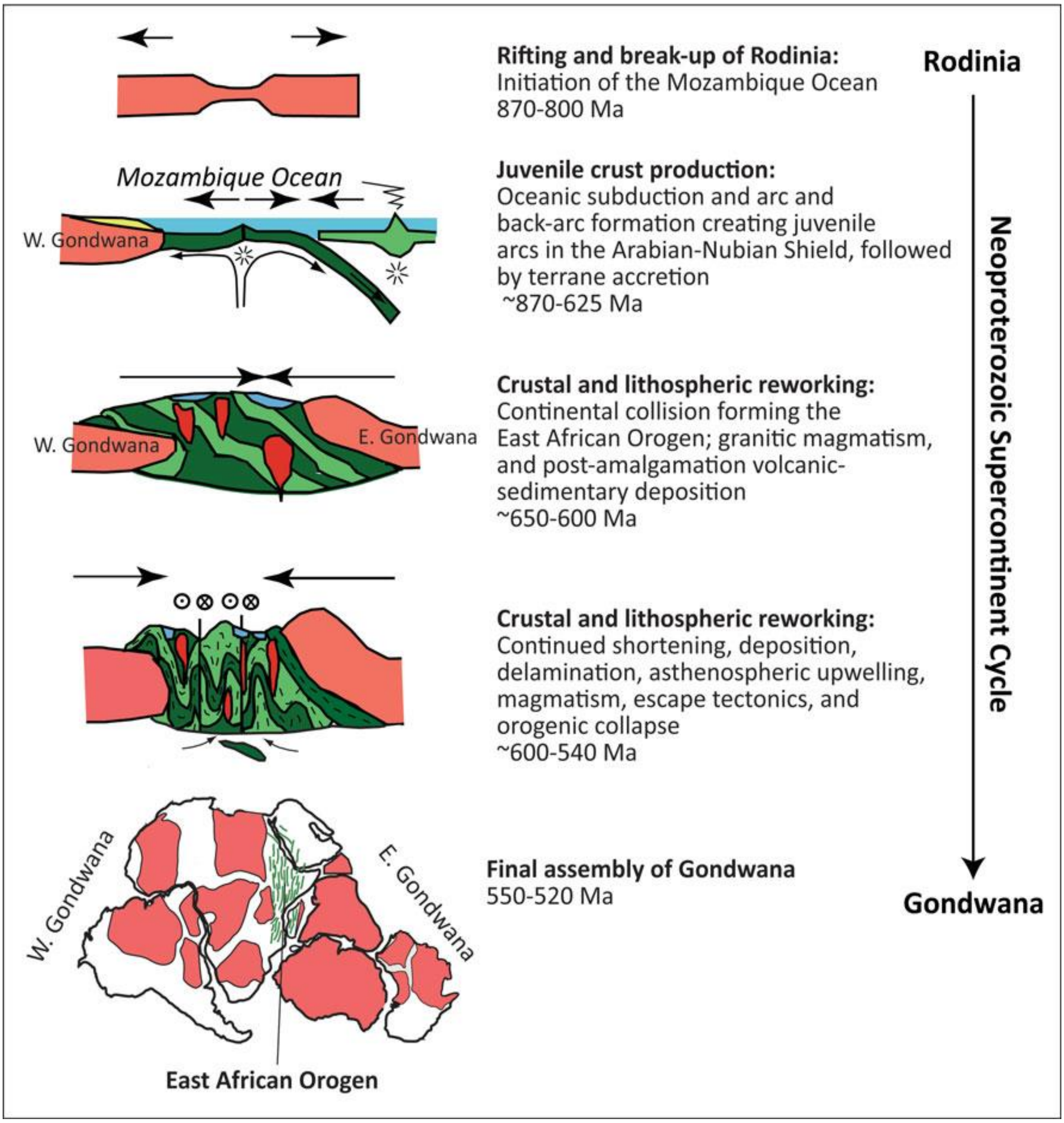
- Stage E: Convergence begins when oceanic crust decouples, that is, breaks at some place and begins to descend into the mantle along a subduction zone. This leads the volcanic island arcs to form.



- Stage F: During this stage island arc-continent collision and continent-continent collision occur due to the continuous subduction of the oceanic lithosphere. Finally, the ocean once opened is now closed.



- For the Arabian-Nubian Shield:
- Its rocks formed in the Mozambique ocean, an ocean basin between the Saharan meta-craton, Congo–Tanzania, and Indian cratons created by Rodinia break-up (870-800Ma).



LECTURE#3

Shear Zones in the Egyptian Nubian Shield

1-What is the shear zone????

- Shear zones are tabular zones of intense ductile deformation in which the rocks are highly strained than the surrounding wall rocks.
- The ductile deformation occurs as a response to the lateral movement of wall rocks in opposite directions.
- Shear zones, like faults, cause offsets of the older structures (e.g. dikes, veins, folding….etc). However, unlike faults, shear zones are not brittle fracturing.
- Shear zones are the deep equivalents of fault zones. In other words, rocks are cold (<300 C) in the upper crustal levels, and hence they can be strained or deformed by fracturing and faults-related displacement. In the deeper parts of the Earth's crust, rocks are so hot (300-800C) and their strain is expressed as a ductile or flow deformation. As such example, the choclate bar can be easily snapped after cooling, while it starts flowing under warm conditions. Anothher example is represented by steel shaping on heating.
- So, shear zones are formed under three main conditions:
    - Brittle deformation at/or near the surface where faults form.
    - Intermediate deformation between the upper and lower crustal levels.
    - Ductile deformation at the lower crustal levels (folding, foliation, lineation…etc).
- Shear zones vary in length and displacement from centimeters to few thousands of kilometers; they are also much longer than thicker.
- Shear zones can be classified regarding its continuity into: Continuous (gradual increase of ductile strain) and discontinuous (abrupt increase of ductile strains, resulting in fracturing.

Shear zones and faults

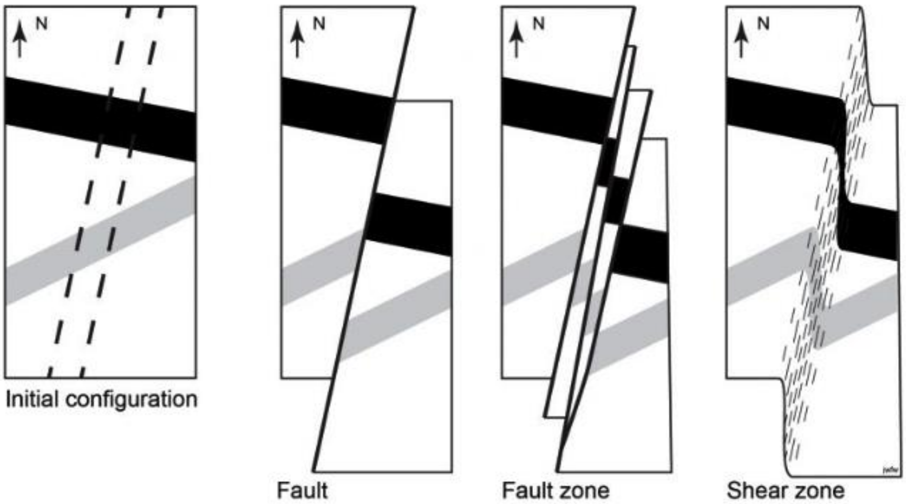
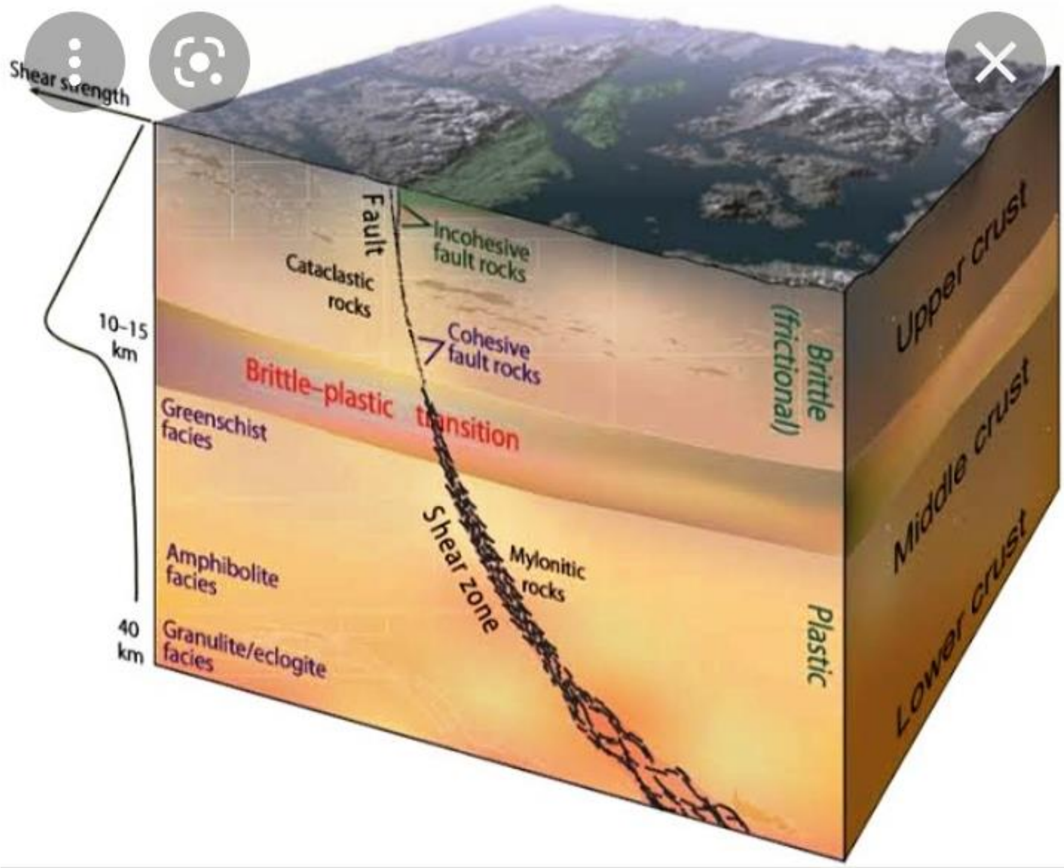
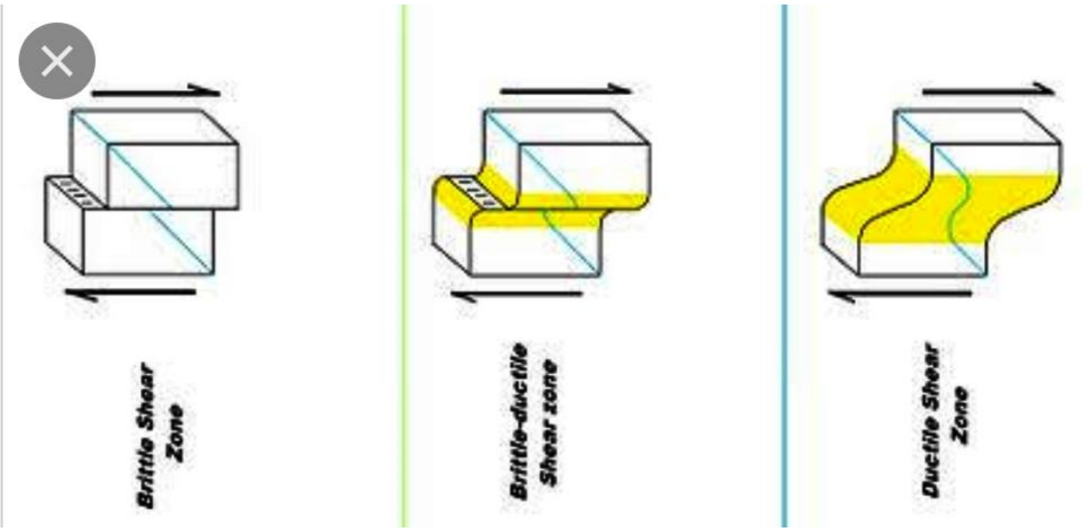
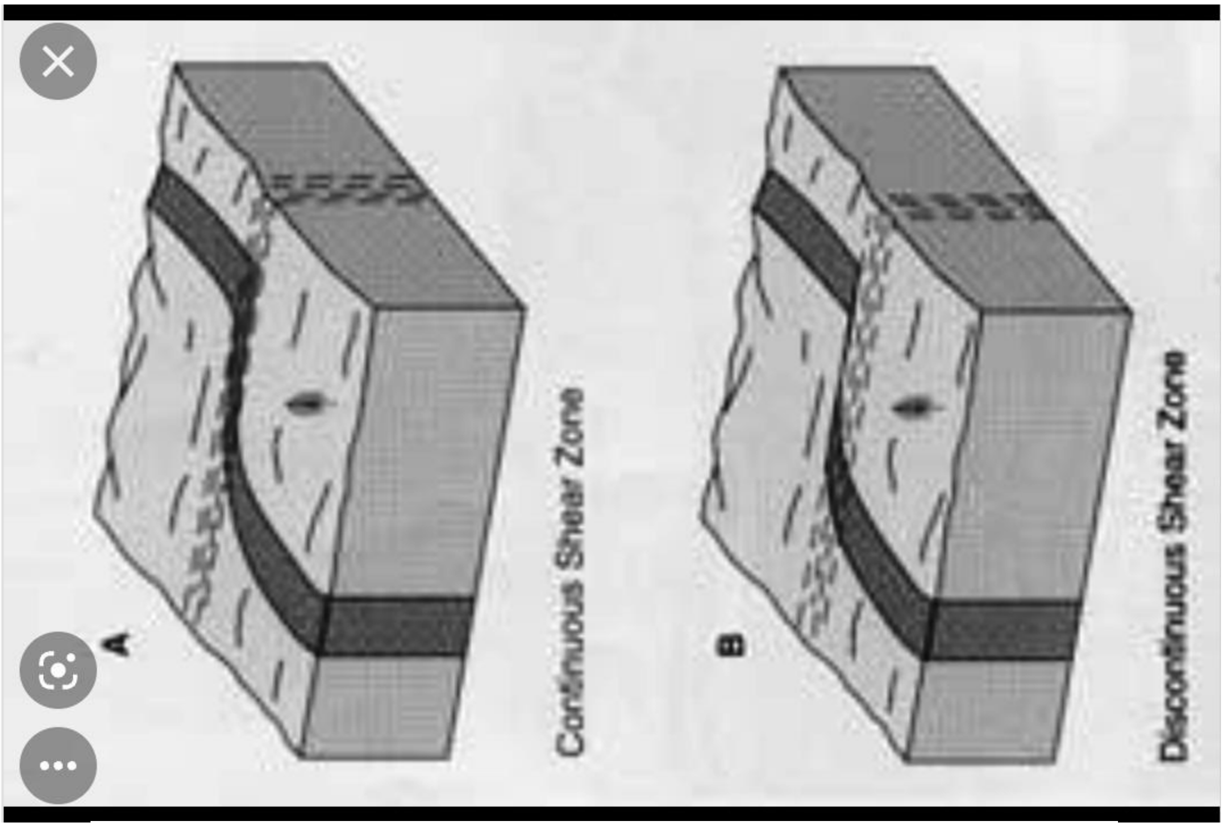
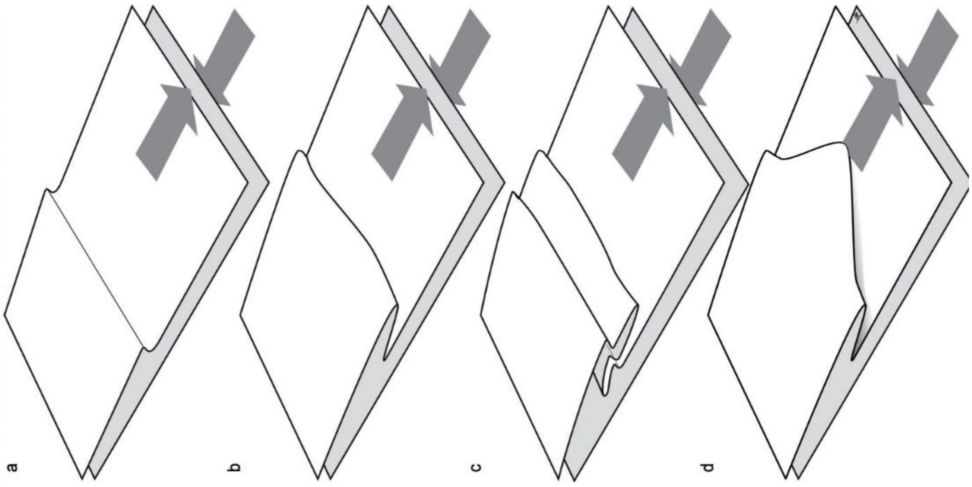


Figure 1. Fault, fault zone, shear zone.




Brittle Shear Zone
Brittle-ductile Shear zone
Ductile Shear Zone


A
Continuous Shear Zone
B
Discontinuous Shear Zone

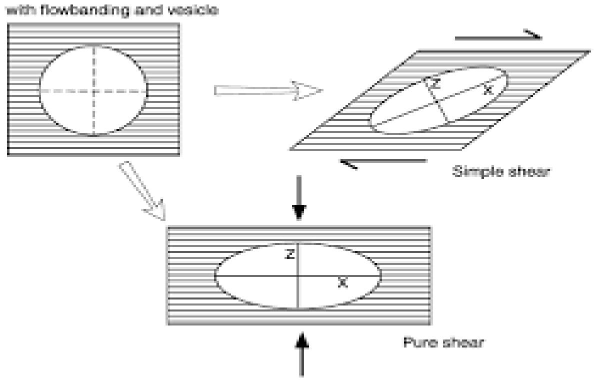

a
b
c
d

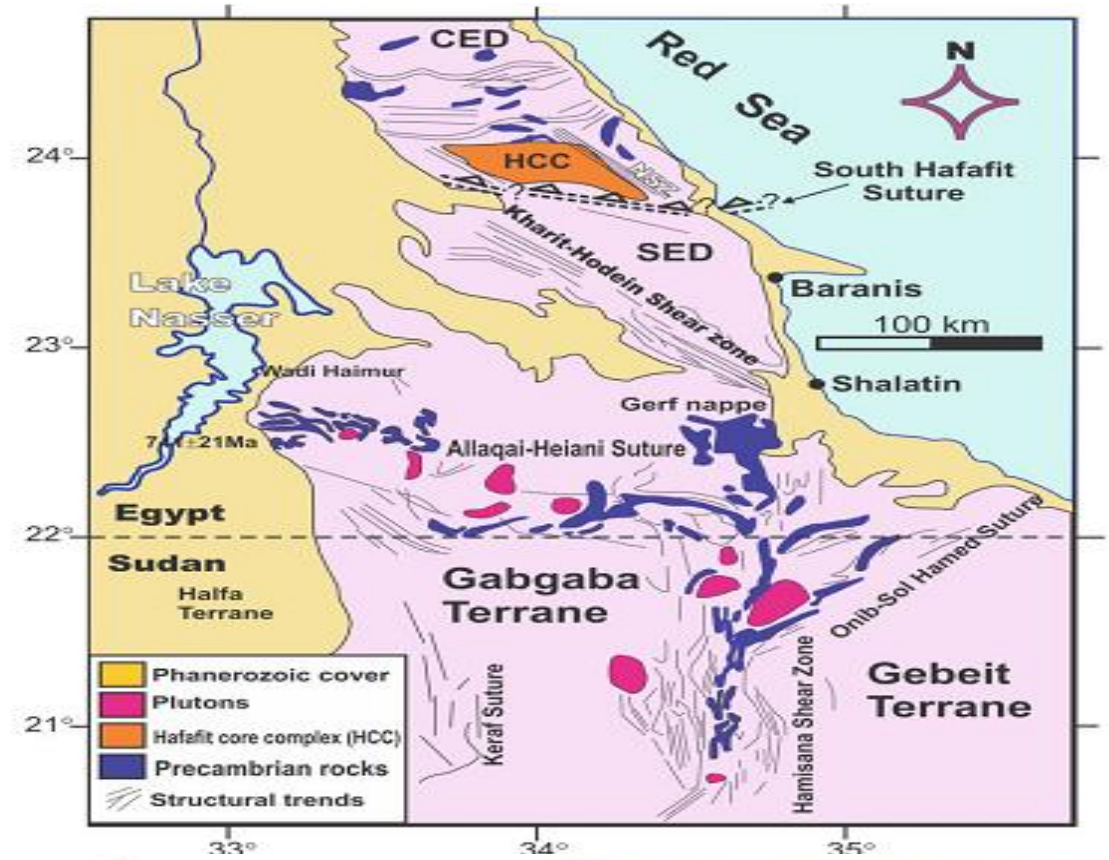
2-Types of shear zones in the Egyptian Nubian Shield

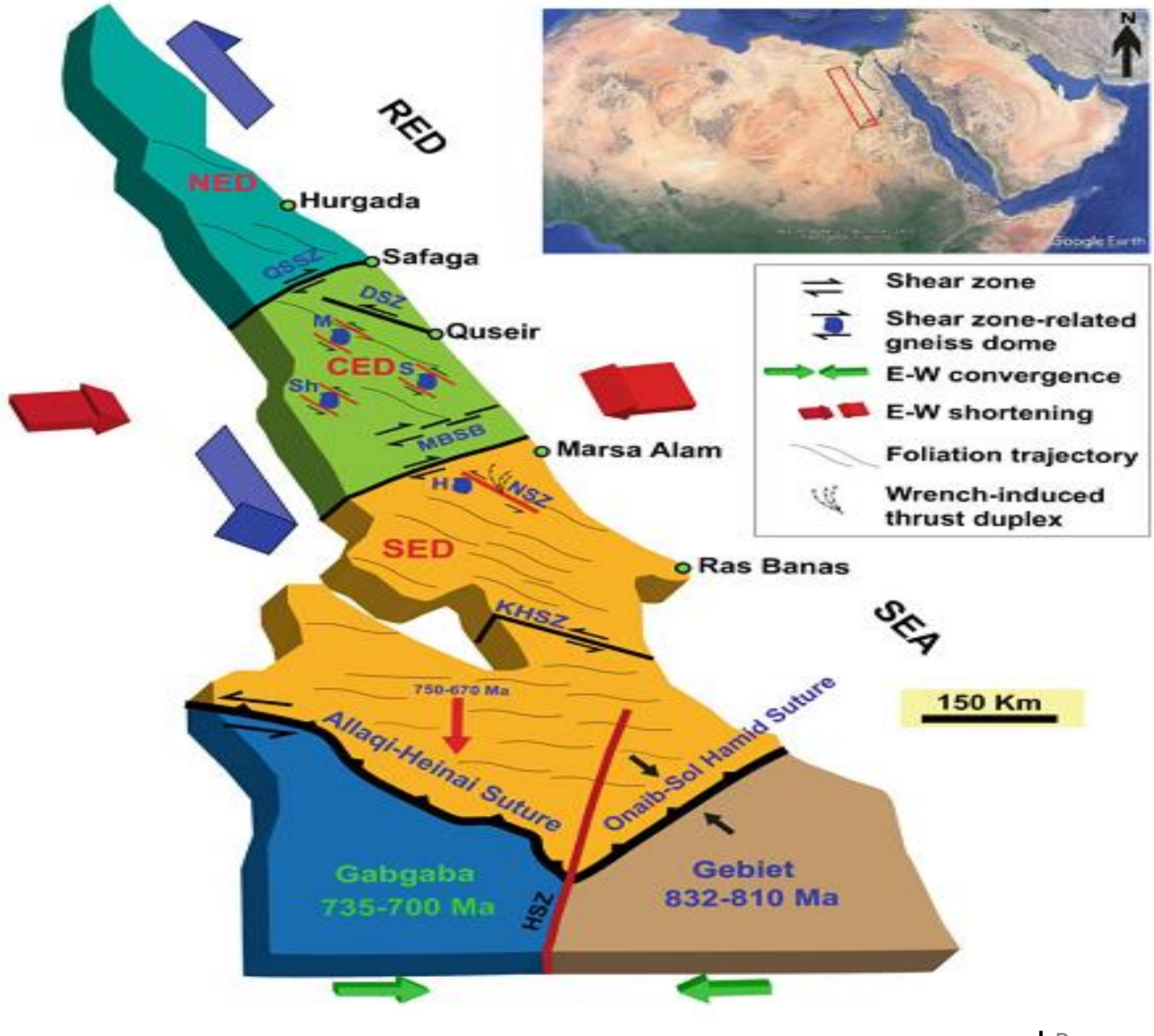
Three main shear zone types are found in the Egyptian Nubian Shield, including syn-accretion shear zones, post-accretion shear zones, and shear zones-related gneiss domes.

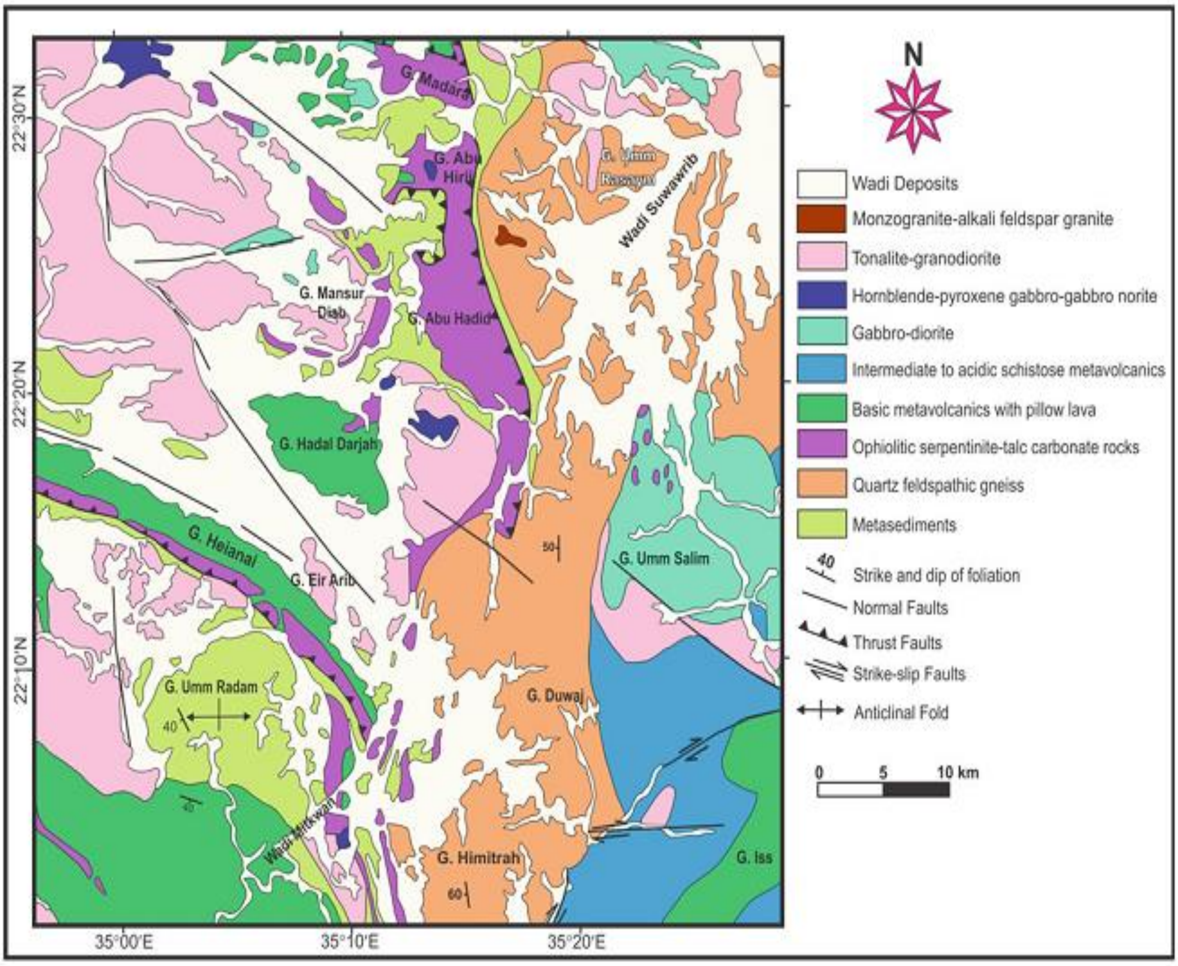
A-Syn-accretion shear zones:

- Syn-accretion shear zones are of intense ductile deformation that was concurrent with the accretion of islnad arcs. This accretion resulted from the arc-arc collision (760 and 690 Ma) during the closing stage of Mozambique ocean. This collision is due to the continuous convergence beteen E. Gondwana and W.Gondwana, leading to terminate the ocean crust subduction.
- In central and southern ANS, the collision between E- and W-Gondwana is expressed ultimately as typically N–S trending belts of intensely foliated and isoclinally upright folded rocks.
- Typical example of these belts is **the Hamisana Shear Zone**. The major HSZ covers an area of about 15,000 km^2 in southeastern Egypt and northeastern Sudan. The Hamisana shear zone comprises gneissic and schistose rocks (foliations and lineations due to shearing processes) and isoclinally folded slivers of ophiolites derived from the Allaqi-Heiani suture. It is sinistral in motion.
- Regarding kinematics, deformation in the HSZ is dominated by pure shear (the body is elongated in one direction while being shortened perpendicularly) under upper greenschist/ amphibolite grade metamorphic conditions, producing E–W shortening, but with a strong N–S-extensional component, resulting in many upright folding.




CED
Red Sea
N
24°
HCC
NSZ
South Hafafit
Suture
Kharit-Hodein Shear zone
SED
Baranis
Lake
Nasser
100 km
23°
Wadi Haimur
Shalatin
Gerf nappe
7??±21Ma
Allaqai-Heiani Suture
Egypt
22°
Sudan
Halfa
Terrane
Gabgaba
Terrane
Onib-Sol Hamed Suture
Phanerozoic cover
Plutons
Hafafit core complex (HCC)
Precambrian rocks
Structural trends
Keraf Suture
Hamisana Shear Zone
Gebeit
Terrane
21°
33°
34°
35°


RED
NED
Hurgada
Safaga
QSSZ
DSZ
Quseir
M
CED
S
Sh
MBSB
Marsa Alam
H
NSZ
SED
Ras Banas
KHSZ
SEA
750-670 Ma
Allaqi-Heinai Suture
Onaib-Sol Hamid Suture
150 Km
Gabgaba
735-700 Ma
HSZ
Gebiet
832-810 Ma
Shear zone
Shear zone-related
gneiss dome
E-W convergence
E-W shortening
Foliation trajectory
Wrench-induced
thrust duplex



B-Post-accretion shear zones:

1-Najd-Related NW-Trending Shear Zones

- The Najd Fault System is a complex set of post-accretion, left-lateral strike-slip faults and brittle-ductile shear zones that strike NW-SE across the northern part of the Arabian-Nubian Shield.
- This system was developed during the interval 540-620 Ma. It is up to 300 km wide with a total length of 2000 km. so, it is considered to be the largest proterozoic shear system on Earth.
- It was formed as a result of squeezing of the ANS between E- and W-Gondwana.

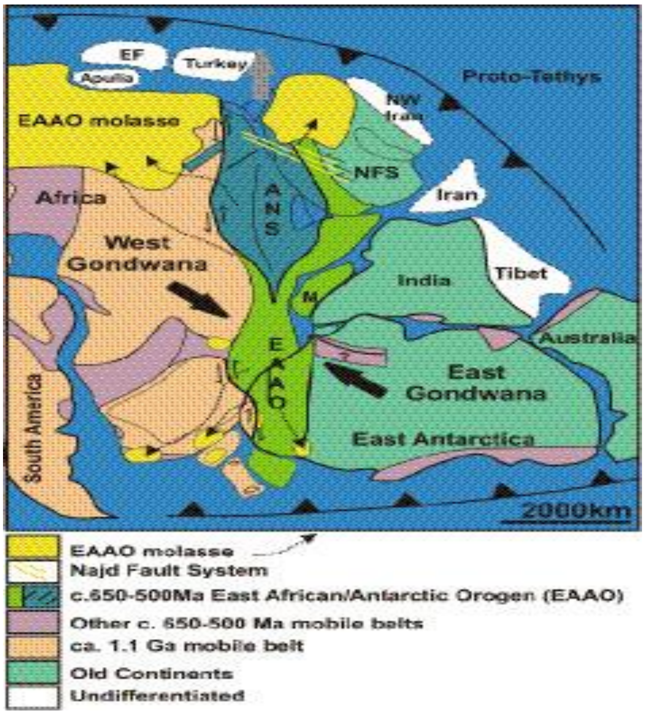


Figure showing the formation of NFS as a result of the squeezing the ANS between E- and W-Gondwana.

- Najd fault zone is enclosed between the Duwi shear zone in the Northern Eastern Desert "NED" and Kharit-Hodein shear zone in the Southern Eastern Desert "SED".

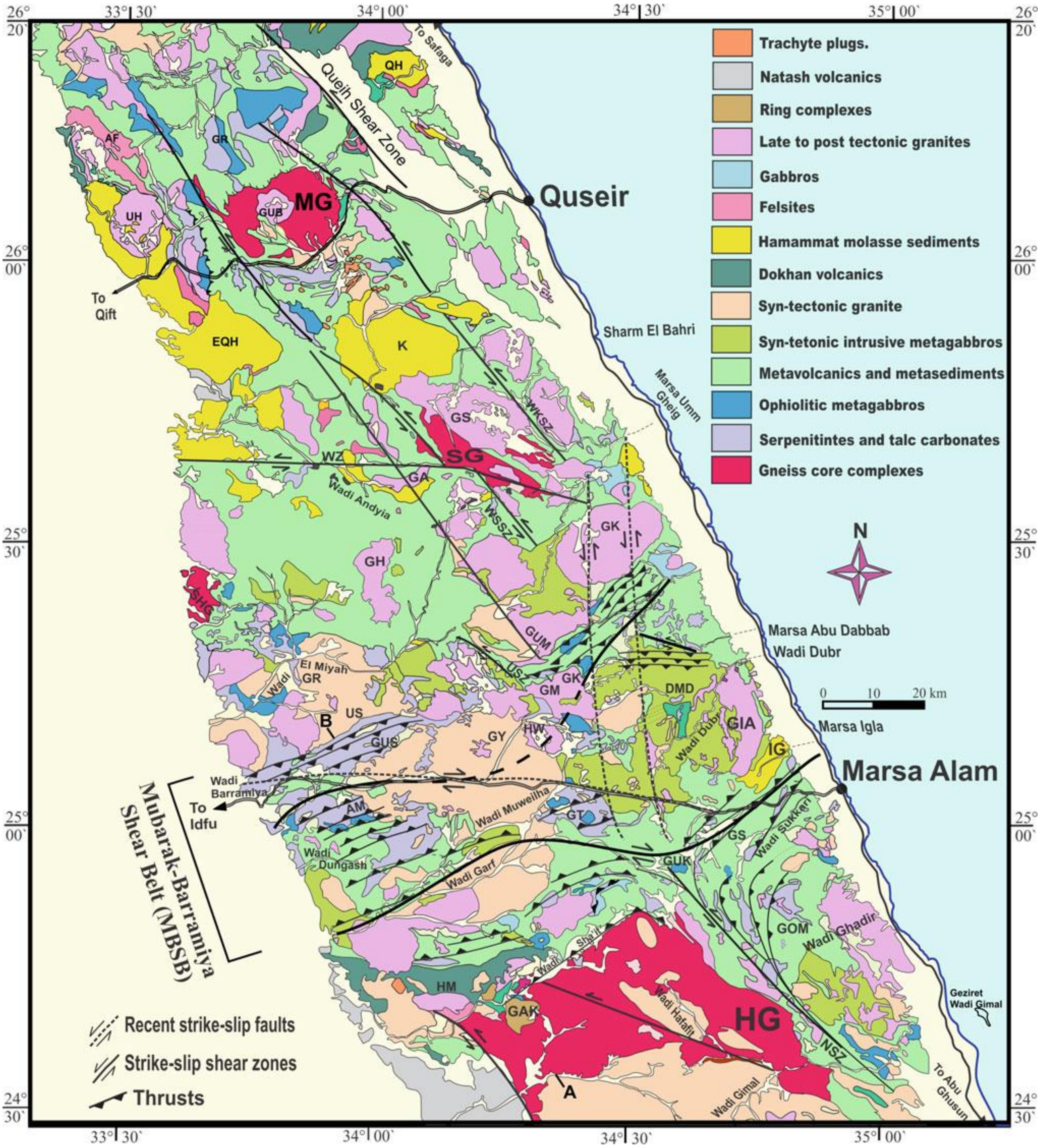
- Four shear zones are related to the Najd fault system: *Duwi shear zone, Atalla shear zone, Nugrus shear zone, and Kharit-Hodein shear zone*.

2-ENE- (to E-) Trending Shear Zones

These are post-accretion, dextral shear zones, including Qena-Safaga shear zone, Idfu-Marsa Alam shear zone, Mubarak-Barramiya shear zone.

C-Shear Zone-Related Gneiss Domes

- The gneiss domes in the Eastern Desert terrane (e.g., Meatiq, Sibai, El-Shalul and Hafafit) have been interpreted as metamorphic core complexes exhumed in extensional settings.
- The exhumation of these gneissic domes is confined to the oblique movement of the Najd Fault System.



Trachyte plugs.
Natash volcanics
Ring complexes
Late to post tectonic granites
Gabbros
Felsites
Hamammat molasse sediments
Dokhan volcanics
Syn-tectonic granite
Syn-tetonic intrusive metagabbros
Metavolcanics and metasediments
Ophiolitic metagabbros
Serpenitintes and talc carbonates
Gneiss core complexes
Quseir
Marsa Alam
Queih Shear Zone
Sharm El Bahri
Marsa Umm Gheig
Marsa Abu Dabbab
Wadi Dubr
Marsa Igla
Geziret Wadi Gimal
To Abu Ghusun
To Safaga
To Qift
To Idfu
Mubarak-Barramiya Shear Belt (MBSB)
Recent strike-slip faults
Strike-slip shear zones
Thrusts
MG
SG
HG
EQH
K
GS
WZ
GA
GH
GK
GUM
GM
DMD
GIA
IG
GY
HW
GT
GUK
GOM
HM
GAK
NSZ
WKSZ
WSSZ
Wadi Andyia
Wadi El Miyah
Wadi Barramiya
Wadi Muweilha
Wadi Dungash
Wadi Garf
Wadi Sukkari
Wadi Ghadir
Wadi Hafafit
Wadi Gimal
Wadi Sha'it
N
0 10 20 km
26° 20`
26° 00`
25° 30`
25° 00`
24° 30`
33° 30`
34° 00`
34° 30`
35° 00`

LECTURE#4

Mesozoic-Cenozoic Deformation History of Egypt

كن جميلا ترى الوجود جميلا

1-How many Mesozoic-Cenozoic deformation phases occurred in Egypt???

Due to divergence and convergence movements between the African plate and the surrounding Arabian, Eurasian, and South America plates, Egypt was affetced by four main deformational phases, comprising extentional and compressional deformations, during the Mesozoic-Cenozoic times. These deformational phases include the following:

1-Tethyan Rifting (Middle-Late Triassic-Early Cretaceous).

2-NW-SE to WNW-ESE rift basins (Cretaceous-Early Tertiary).

3-Inversion of the Tethyan extentional basins (Santonian-Miocene).

4-Gulf of Suez-Red Sea Rift (Late Oligocene-Miocene).

The following lines will take you for an excited journey through each of the above mentioned deformational phases. So, tight your seat ☺

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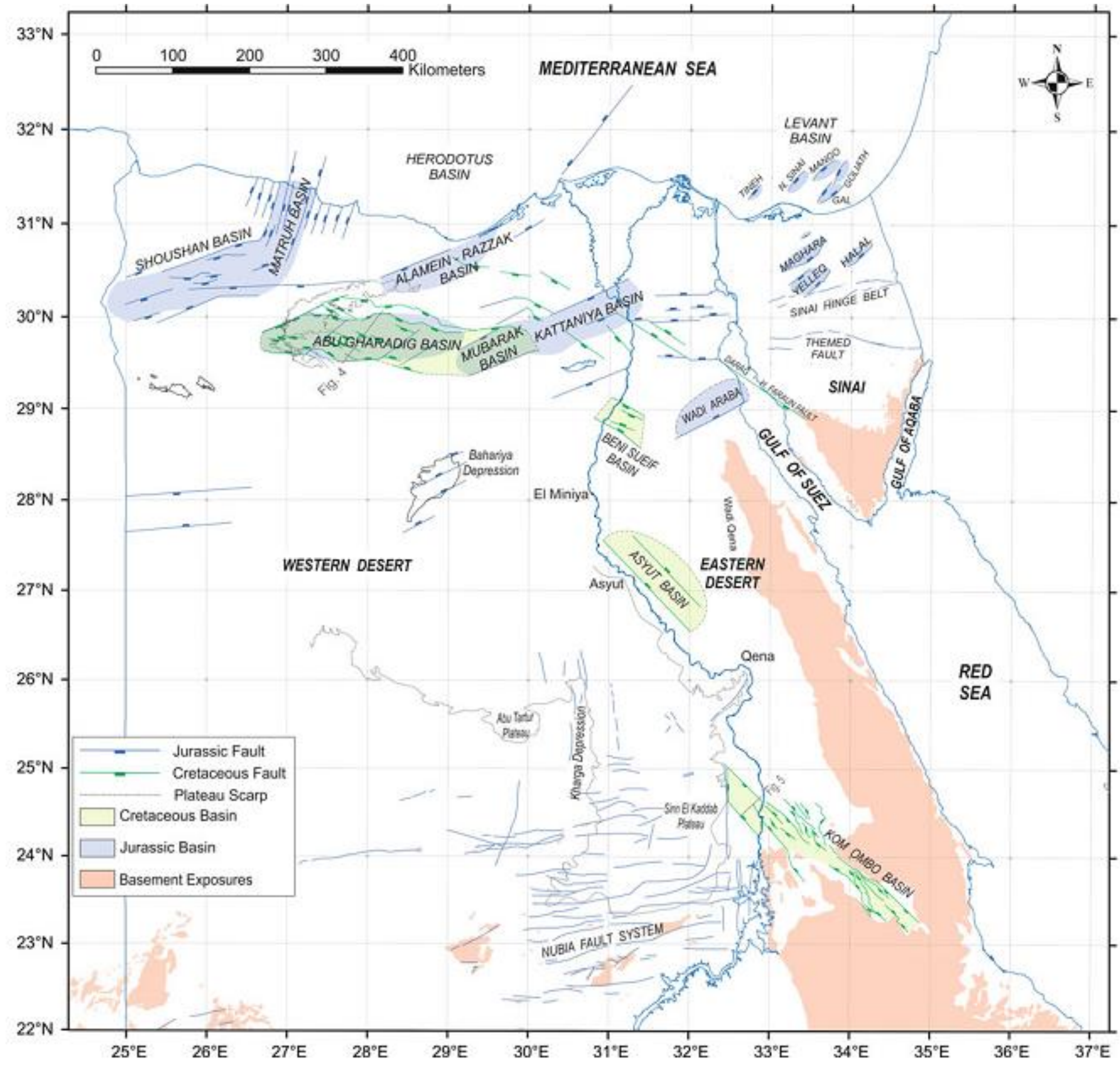
1- **Tethyan Rifting (Middle-Late Triassic-Eraly Cretaceous)**

- Tethyan rifting is attributed to the divergent movement between the Afro-Arabian and Eurasian Plates.
- Tethyan rifting affected the northern onshore and offshore areas of Egypt and led to opening of NE-SW to ENE-WSW oriented basins/sub-basins in the northern areas and formation of normal faults of the same orientation in the central and southern areas of Egypt.

- Detailed subsurface mapping of the northern Western Desert using 3D seismic and borehole data helped identification of several Tethyan extensional basins such as Kattaniya, Mubarak, Alamein-Razzak, Matruh and Shoushan Basins.
- The NE to ENEoriented basins had half graben geometry with NNW tilt and are bounded by major normal faults on their northwestern sides.
- In the Eastern Desert itself, as well as in northern Sinai, similar NE to ENE oriented extensional basins were also formed but with opposite polarity where the major basin-bounding faults lie on the southeastern sides of the basins. As such example, Wadi Araba and Shabraweet area basins in the northern Eastern Desert and Maghara, Yelleg and Halal basins in northern Sinai.



- Tethyan rifting-related extentional deformation affected also some central and southern areas, leading to NE-ENE oriented normal faults like that of the Bahariya and Farafra oases (Central Western Desert) and the Nubia Fault System (Southern Western Desert).
- The Triassic-Cretaceous syn-rift sedimentary successions are composed of clastic (siltstone, sandstone and shale) and carbonate units, sometimes with thin coal beds and basalt sills.

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2- <u>Cretaceous-Early Tertiary Rifting</u>

- Subsurface mapping for hydrocarbon exploration led to the recognition of several Cretaceous rift basins in the northern Western Desert as well as in the Eastern Desert and Nile Valley. These basins include the Abu Gharadig Basin, Beni Sueif Basin, Asyut Basin, and Kom Ombo Basin.
- These basins clearly show Cretaceous syn-rift rocks thickening toward NW-SE to WNW-ESE oriented normal faults.
- Tilted fault blocks in these half-graben basins dip toward the NE (e.g. Abu Gharadig and Kom Ombo Basins) or SW (Beni Sueif and Asyut Basins).
- Reactivation of the Najd Fault System (NW-SE trend) may be behind the Cretaceous rifting.

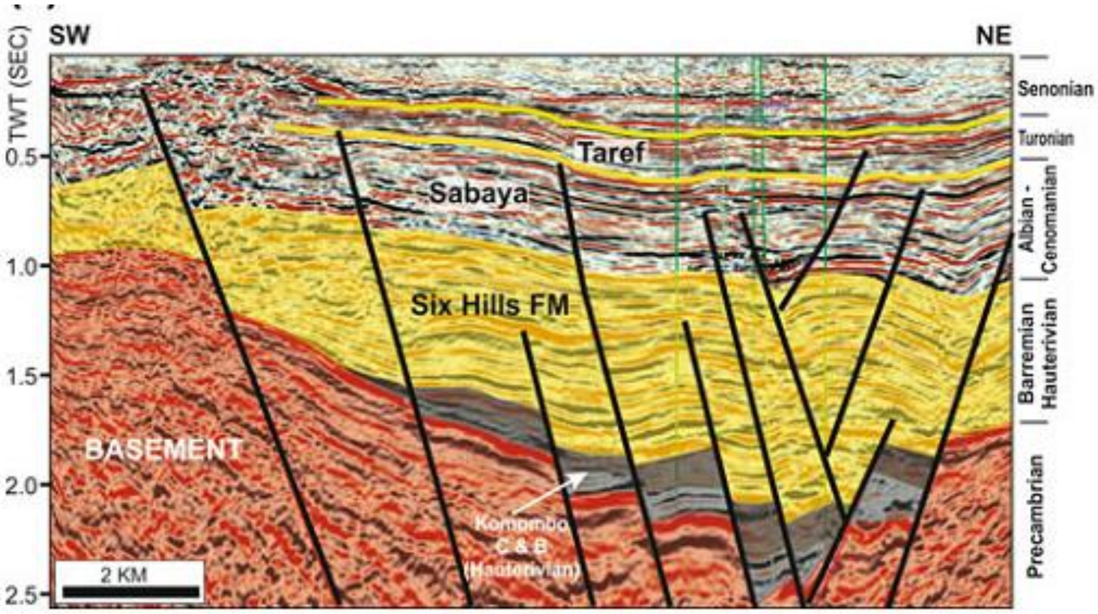
1. <u>Abu-Gharadig Basin:</u>

- Abu-Gharadig basin is WNW-ESE- trending extentional basin, with 300 km lateral extending in E-W direction.
- The main faults active during Cretaceous time within the basin are oriented WNW-ESE but the northern basin-bounding fault has a general E-W orientation that clearly shows the effect of pre-existing E-W faults on the general orientation of the basin.

- Consistent NE and NNE tilting of the Cretaceous and older rocks in the rift is obvious.
- Detailed structural mapping of the basin indicates NE-SW oriented faults of Jurassic age within the basin and were later inverted in Late Cretaceous-Early Tertiary time.

2. Kom Ombo Basin:

- Kom Ombo Basin extends for about 300 km in the southern Eastern Desert and extends northwestward across the Nile Valley to the eastern edge of Sin El Kaddab Plateau.
- Its orientation is dominated as NW-SE.
- Seismic reflection data indicate the half graben geometry of the basin with predominant NE dipping Cretaceous rocks.
- The basin fill of Kom Ombo Basin includes Lower Cretaceous non-marine sediments followed by marine deposition during the Albian/Cenomanian (sandstone and shale) and Upper Cretaceous-Early Tertiary (carbonates).



Seismic section across the KomOmbo basin, note that the main subsidence is toward the NE direction

3. **Beni Sueif Basin**

- The Beni Sueif Basin has WNW-ESE orientation and is crossed by the present-day Nile Valley at Beni Sueif and Maghagha towns.
- The main subsidence is along the southwestern basin-bounding fault, indicating a SW dipping half-graben at Cretaceous time.
- Basin initiation was at Albian time. Extension ceased at the end of Cretaceous time but was resumed during the Eocene resulting in the deposition of more than 1500 m thick carbonate rocks.

4. **Assiut Basin**

- Assiut Basin lies to the south of Beni Sueif Basin and extends east of the Nile Valley from Miniya to the north of Qena in the NW-SE direction.
- Like Beni Sueif Basin, Assiut Basin was opened in Early Cretaceous time. The basin has half graben geometry with SW tilt.
- The presence of Oligo-Miocene basalts along some of the faults of Assiut Basin (e.g. in the area east of Miniya; EGSMA 1981) might indicate reactivation of the Assiut Basin faults at Oligo-Miocene time.

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3- Inversion of the Tethyan extentional basins (Santonian-Miocene)

- During the Late Cretaceous-Recent times a change in the direction of movement of the African and Eurasian Plates led to convergent movement of the two plates and the development of compressional structures (e.g. Anticlines and reverse faults).
- The earliest record of convergence is obvious in the Late Cretaceous-Early Tertiary folds affecting the Mesozoic exposures in northern Egypt. These include the folded Mesozoic rocks exposed in northern Sinai, the northern Eastern Desert, as well as the folds of Abu Roash area and the Bahariya Oases in the Western Desert.
- Surface and subsurface folds in northern Egypt are oriented NE-SW and are associated with faults of different orientations and types.
- The onset of folding was in the Late Cretaceous specifically in the Santonian-Campanian time and is considered to have been of maximum magnitude at that time but continued mildly during the Tertiary.

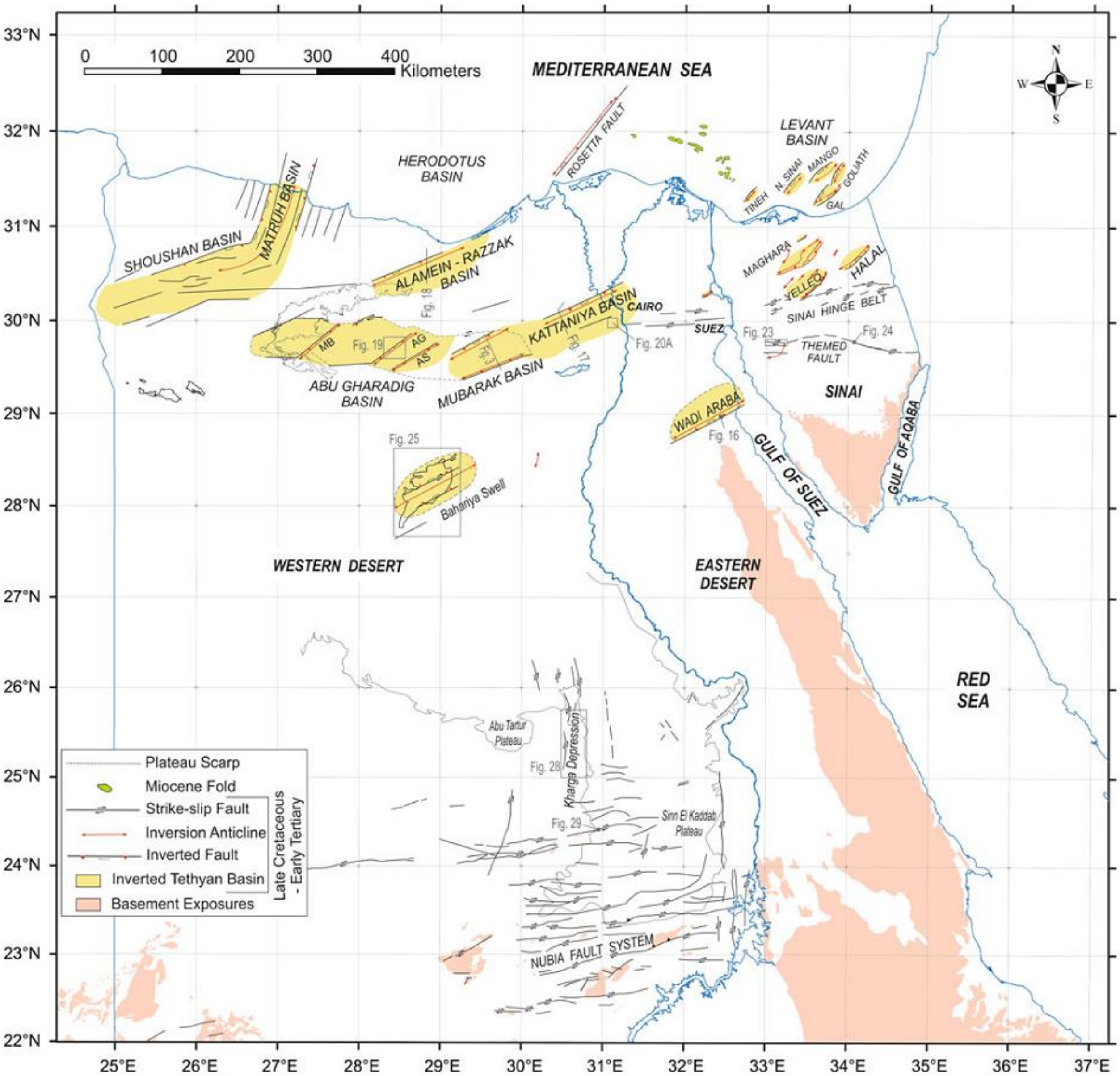


Fig. 7.6 Late Cretaceous-Recent compressive structures of Egypt. Abbreviations in the Abu Gharadig Basin stand for Mid-Basin Arch (MB), Abu Gharadig Anticline (AG), and Abu Sennan Anticline (AS)

Inversion Folds at the surfacial exposures:

1. Northern Sinai (Gebel Maghara, Gebel Yelleg, and Gebel Halal).
2. Northern Eastern Desert (WadiAraba and Gebel Shabrawet).
3. Western Desert (Abu Roash area and Bahariya Oases).

Northern Sinai Folds (Gebel Maghara, Gebel Yelleg, and Gebel Halal).

- ✓ A belt of NE-SW oriented doubly-plunging, SE vergent anticlines is well exposed in northern Sinai.
- ✓ This belt includes three major highly asymmetric folds at Gebel Maghara, Gebel Yelleg, and Gebel Halal; each with length of about 40–60 km and average width of about 15 km.

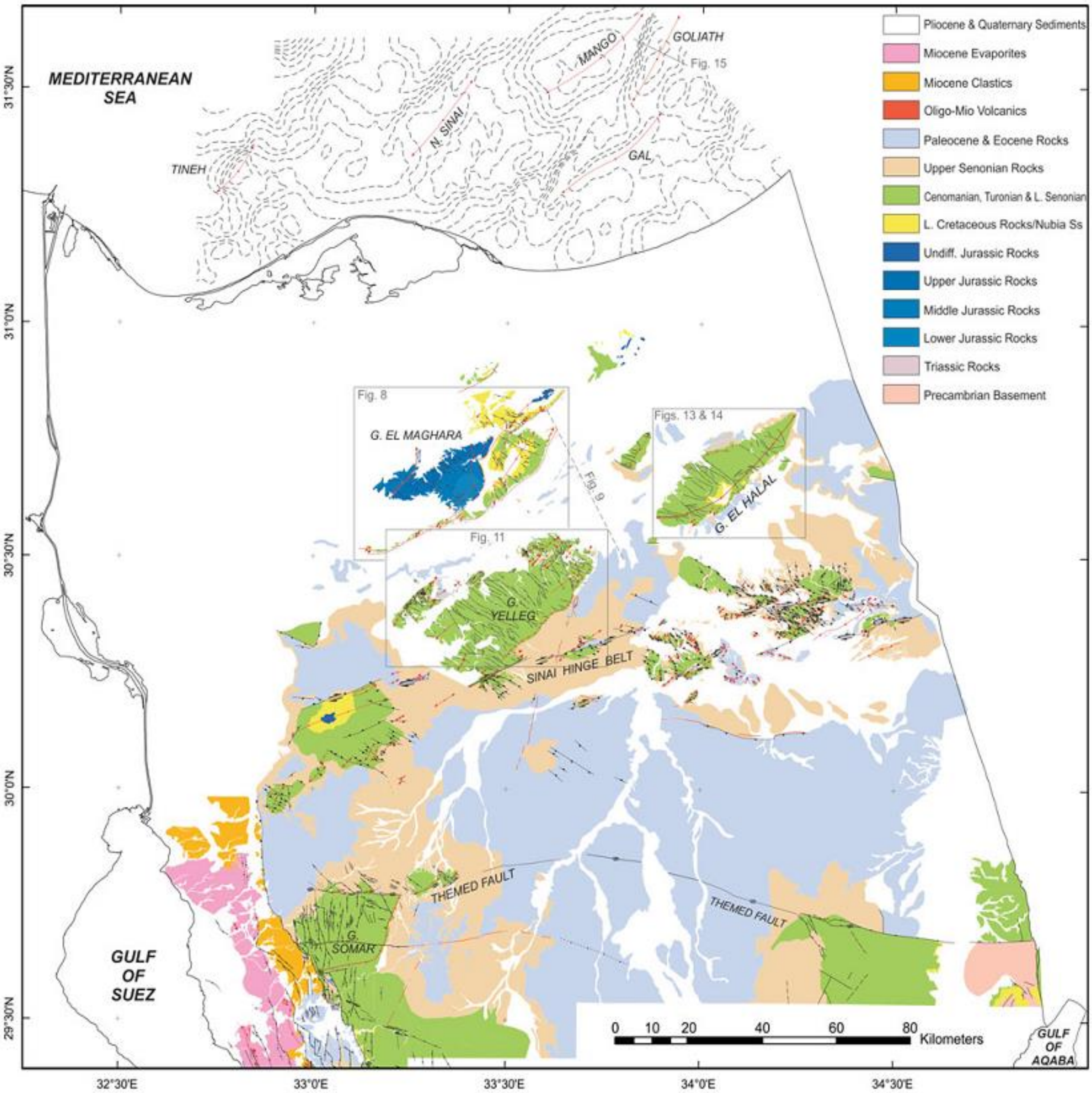


Fig. 7.7 Geological map of northern Sinai (compiled from Moustafa 2004, 2014; Abd-Allah et al. 2004; Moustafa and Khalil 1994; Moustafa and Fouda 2014, and Moustafa et al. 2014) showing the inversion structures of Gebel Maghara, Gebel Yelleg, and Gebel Halal as well as the Sinai Hinge Belt and Themed Fault. Structure contours in offshore northern Sinai are top Coniacian two-way-time structure contours (after Yousef et al. 2010) representing the offshore inversion folds

1.Gebel Maghara Structure:

- ✓ Gebel Maghara structure is about 60 km long and 15 km wide deforming the exposed Jurassic and Cretaceous rocks.
- ✓ It has the highest structural relief among the northern Sinai folds with about 2-km thick Jurassic section exposed in itsbreached core.
- ✓ Detailed structural mapping shows that this structure is made up of four main NE-SW oriented, asymmetric anticlines bounded on their southeastern sides by reverse faults dipping at 50–73° NW. The amount of reverse slip of these faults reaches 1250 m.
- ✓ The Gebel Maghara anticlines are dissected by transverse, steeply dipping (>65°) normal faults with relatively small amounts of throw (few tens of meters).
- ✓ The southernmost fault bounding the outer side of Gebel Maghara structure (Um Asagil Fault)is 55 km long and is the main bounding fault of an inverted Jurassic half graben basin.
- ✓ Surface geological data indicate that inversion started in the Santonian and continued into the Middle Eocene. Breaching of the inversion anticlines started at Paleocene time as indicated by syn-tectonic debris flow derived from Jurassic rocks and deposited in the lower part of the Paleocene sediments on the southern side of Gebel Maghara.
- ✓ Most of the Maghara inverted structure stood high above the Paleocene and Eocene sea levels, allowing deposition of the Lower Tertiary sediments on the outer margins of the inverted structure.

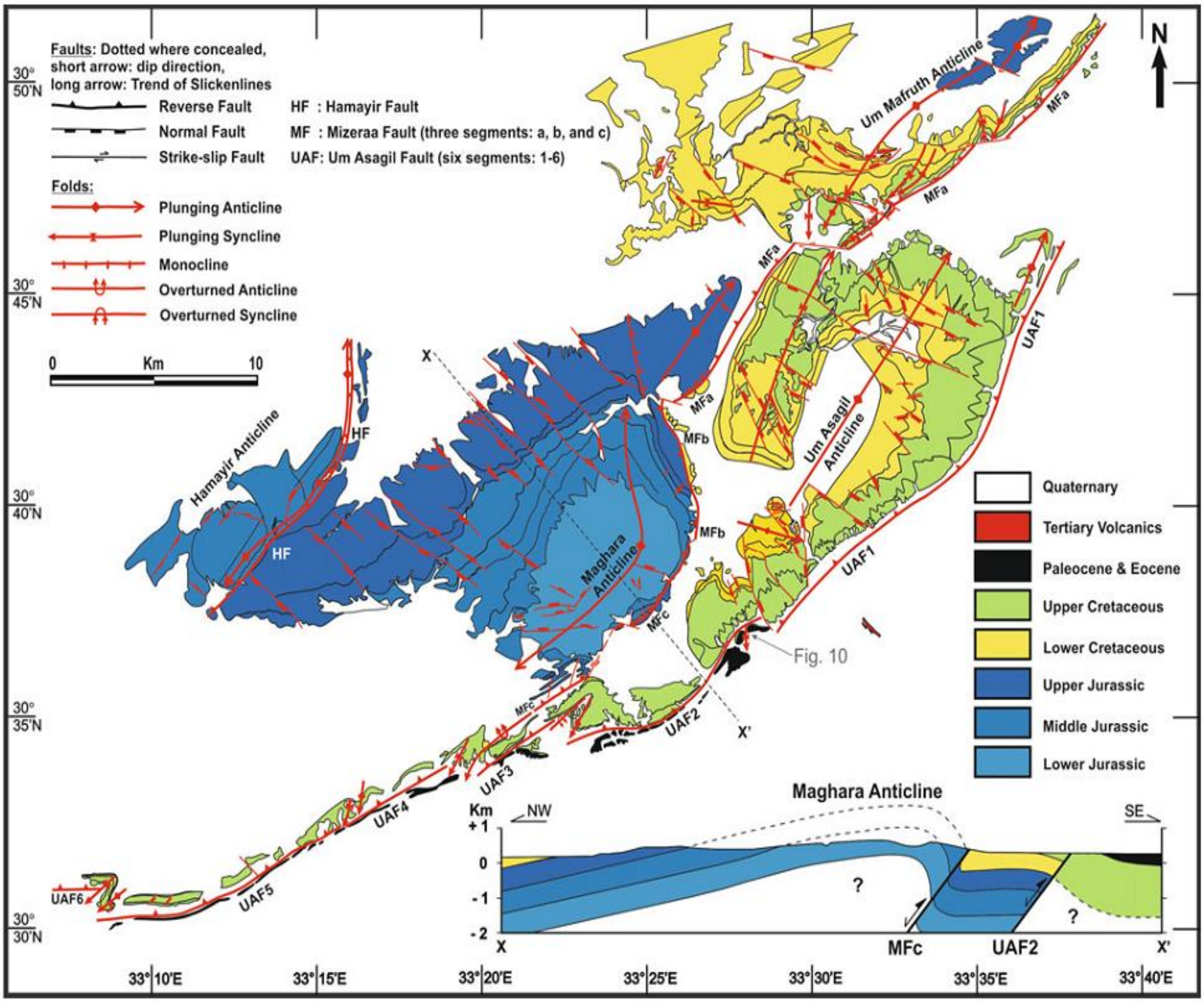


Fig. 7.8 Detailed geological map and structural cross section of Gebel Maghara area after Moustafa (2014)

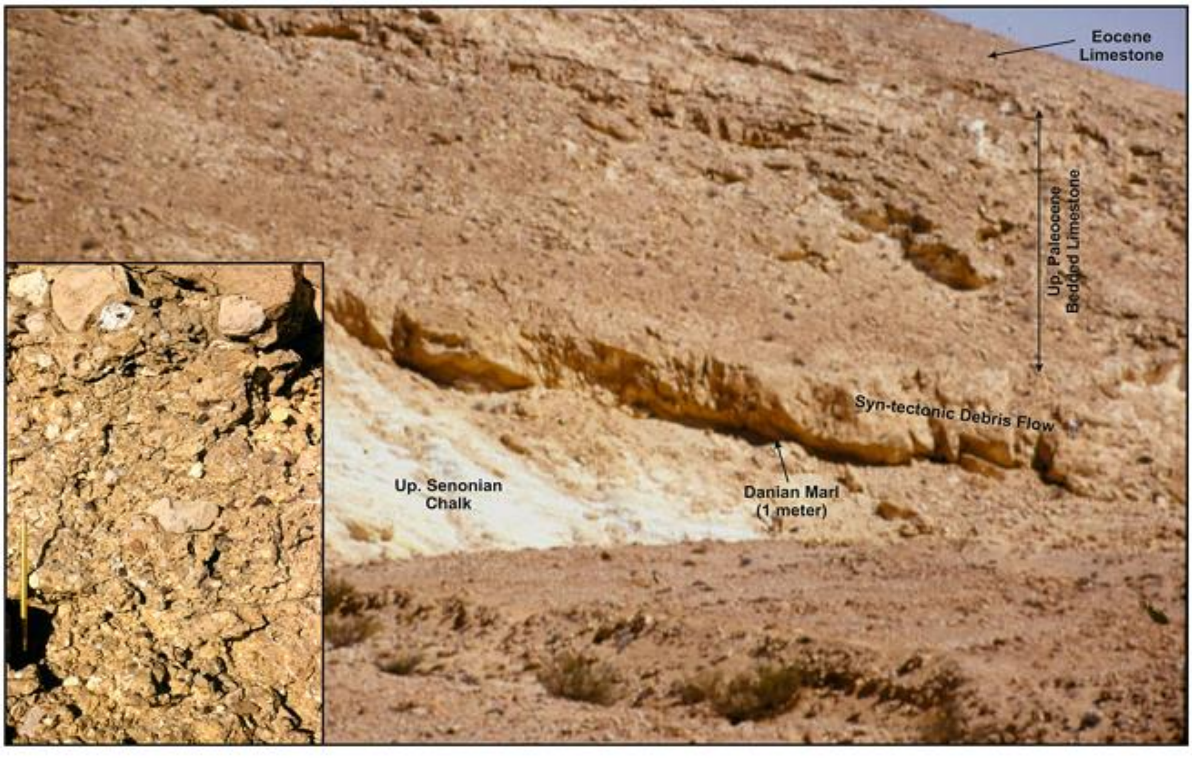
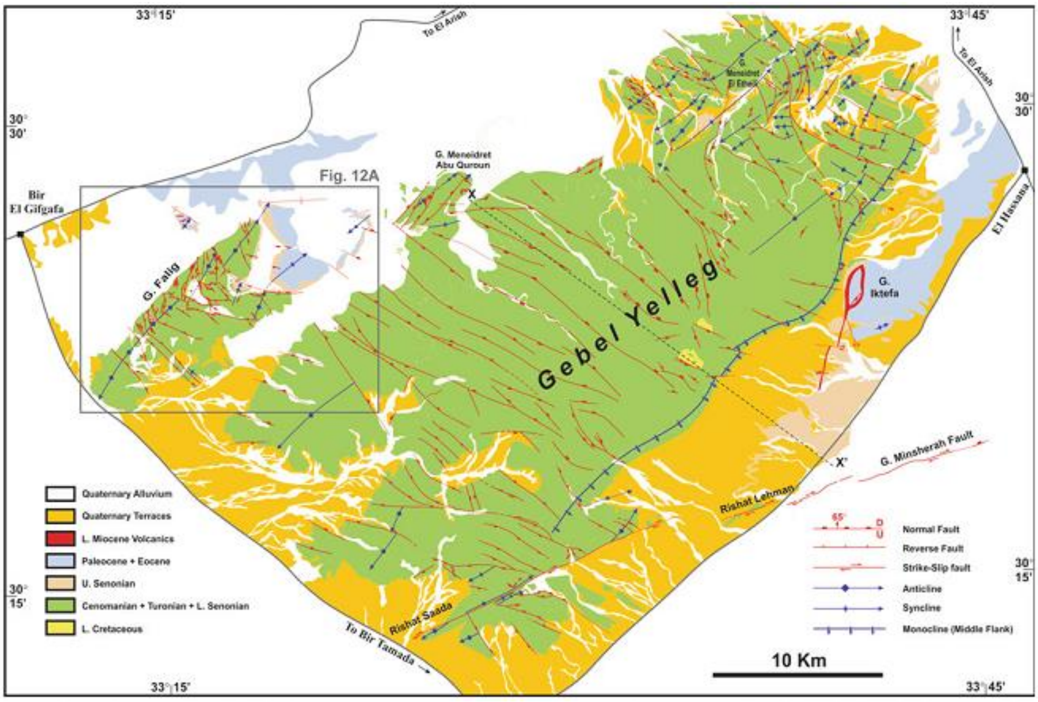


Fig. 7.10 Field photograph of the southern flank of Gebel Maghara Anticline showing debris flow unit in the lower part of the Paleocene rocks. Inset photo is a close-up view of the debris flow showing clasts derived from the Jurassic rocks. See Fig. 7.8 for location

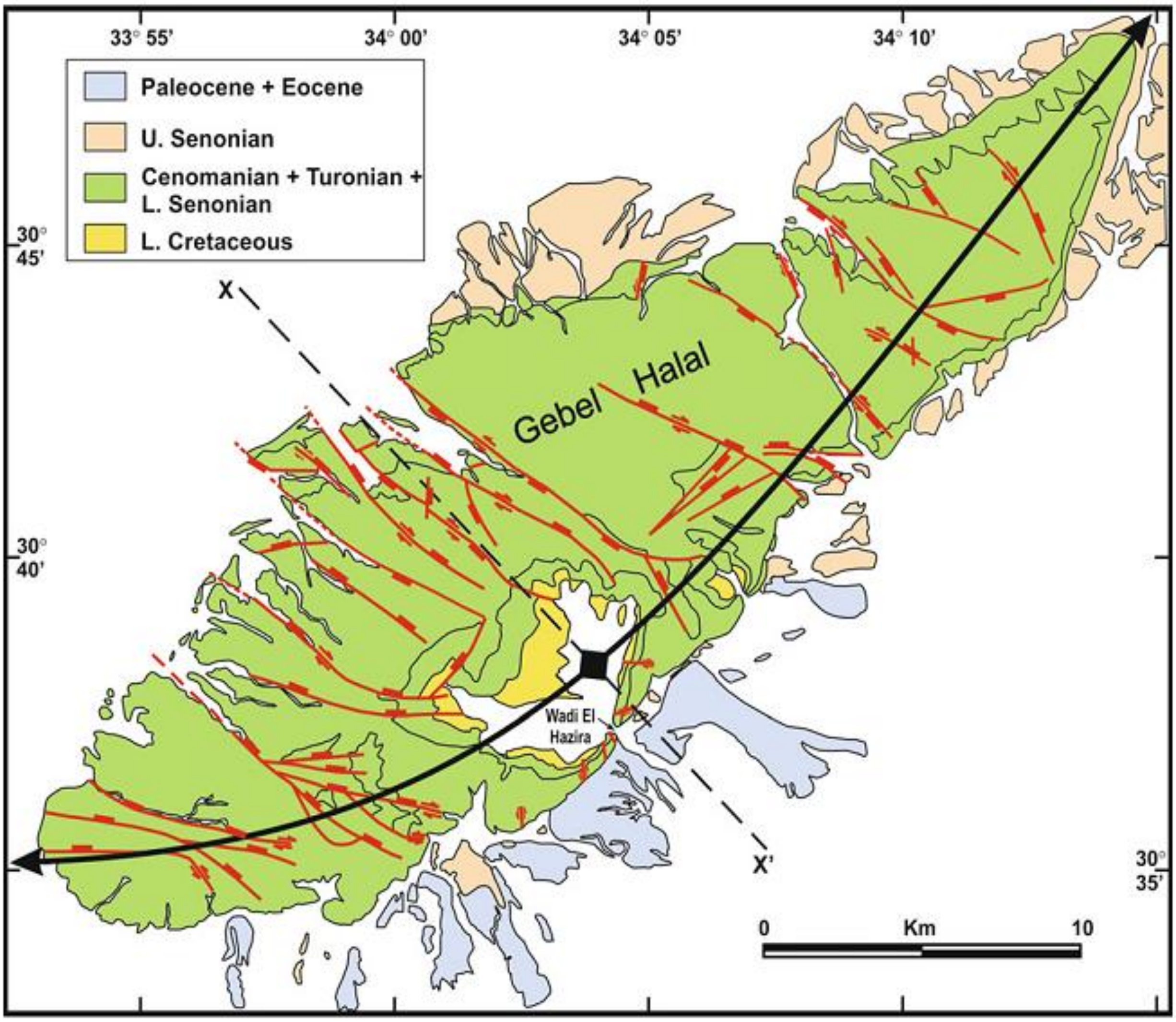
2.Gebel Yelleg Structure:

- ✓ The Gebel Yelleg NE-SW oriented anticline deforms the exposed Upper Cretaceous rocks and is 45 km long and 18 km wide.
- ✓ Detailed structural mapping indicates that the Gebel Yelleg anticline is doubly plunging with SE vergence.
- ✓ This anticline is pervasively dissected by steep (up to 79°) NW-SE oriented normal faults with 5 km average length and tens of meters throws.
- ✓ Seismic section at the northeastern downplunge area of the YellegAnticline indicates that the Gebel Yelleg folds overlie an asymmetric graben. This graben contains thicker Jurassic rocks.
- ✓ The surface and subsurface structures of Gebel Yelleg area indicate three phases of deformation; a Jurassic extensional phase, a Late Cretaceous-Early Tertiary compressional phase, and an Early Miocene extensional phase associated with volcanicity.
- ✓ The Jurassic extensional phase led to the development of NE-SW oriented asymmetric graben with thicker Jurassic section. The compressional phase led to positive inversion of the graben and development of the surface-mapped folds and associated faults.



3.Gebel Halal Structure:

- ✓ The Gebel Halal NE-SW oriented doubly plunging anticline deforms the exposed Cretaceous rocks and is 43 km long and 14 km wide.
- ✓ Detailed structural mapping indicates the SE vergence of the anticline.
- ✓ Like Gebel Maghara and Gebel Yelleg folds, the Gebel Halal Anticline is pervasively dissected by a large number of transverse NW-SE oriented normal faults that have steep dip (average 74°), long length (average 5 km), and relatively small throws of few tens of meters.



Northern Eastern Desert (WadiAraba and Gebel Shabrawet).

1-Wadi Araba Structure

- ✓ WadiAraba Anticline is a prominent structure in the northern Eastern Desert.
- ✓ It is oriented ENE-WSW, with breached core occupied by WadiAraba where the oldest (Carboniferous) rocks are exposed.
- ✓ The northern flank of WadiAraba Anticline dips very gently (few degrees) toward the NNW whereas the southern flank has very steep SE dip represented by nearly vertical Upper Cretaceous rocks at the northern scarp of the South Galala Plateau with excellent exposure at St. Anthony Monastery.
- ✓ Nearly vertical Turonian and Lower Senonian rocks at this locality are unconformably overlain by nearly flat Campanian and younger carbonate rocks indicating Santonian age folding.
- ✓ The WadiAraba Anticline continues further east into the offshore area of the Gulf of Suez.
- ✓ The steep flank of the fold was interpreted to overlie a steep NW dipping reverse fault and the WadiAraba Anticline is a fault-propagation fold.
- ✓ The development of WadiAraba Anticline affected the facies of the Eocene sediments in vicinity of its steep southeastern flank indicating that Eocene sediments are part of the syn-inversion sequence.

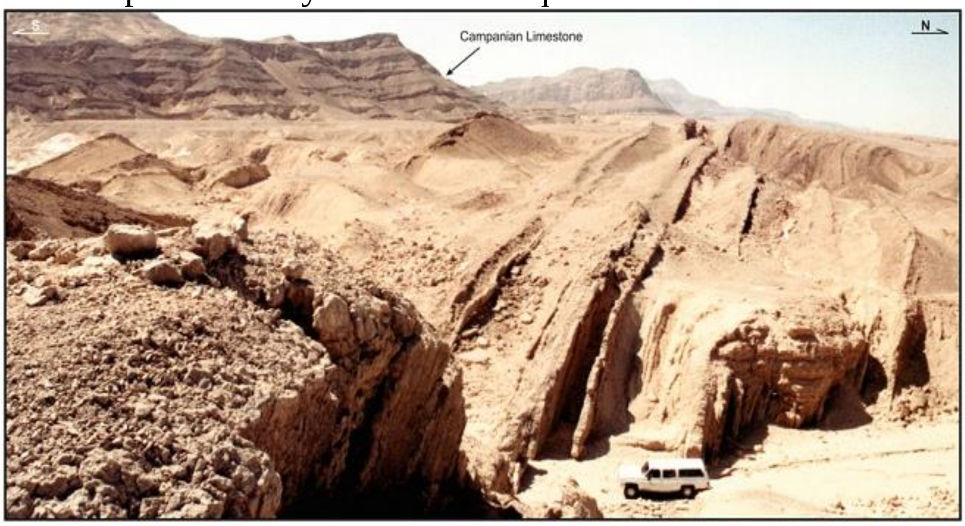


Fig. 7.16 Field photograph of the southern steep flank of Wadi Araba Anticline at St. Anthony Monastery showing nearly vertical Turonian and Lower Senonian rocks unconformably overlain by flat-lying Campanian limestone beds. See Fig. 7.6 for location

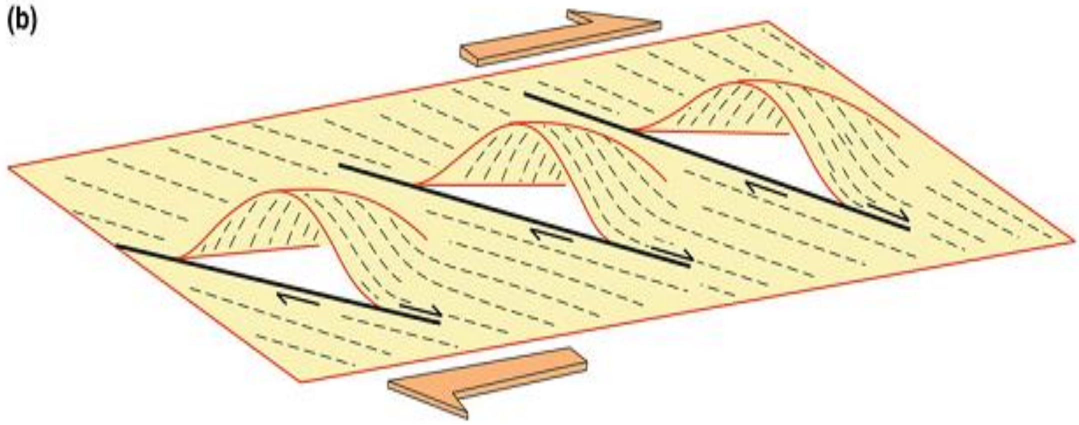
2-Gebel Shabrawet Structure

- ✓ About 150 km to the north of WadiAraba, Cretaceous rocks exposed at Gebel Shabrawet are folded by an ENE-WSW oriented anticline with an overturned southeastern flank bounded by a northward dipping reverse fault.
- ✓ These folded rocks are unconformably overlain by gently dipping Middle Eocene rocks with a hiatus represented by Campanian-Maastrichtian, Paleocene, and Lower Eocene rocks indicating post-Santonian to pre-Middle Eocene folding time.
- ✓ This anticline marks the southern side of an inverted basin most of which is now in the subsurface to the north of Gebel Shabrawet.

Western Desert (Abu Roash area and Bahariya Oasis).

1-Abu Roash Area Structure

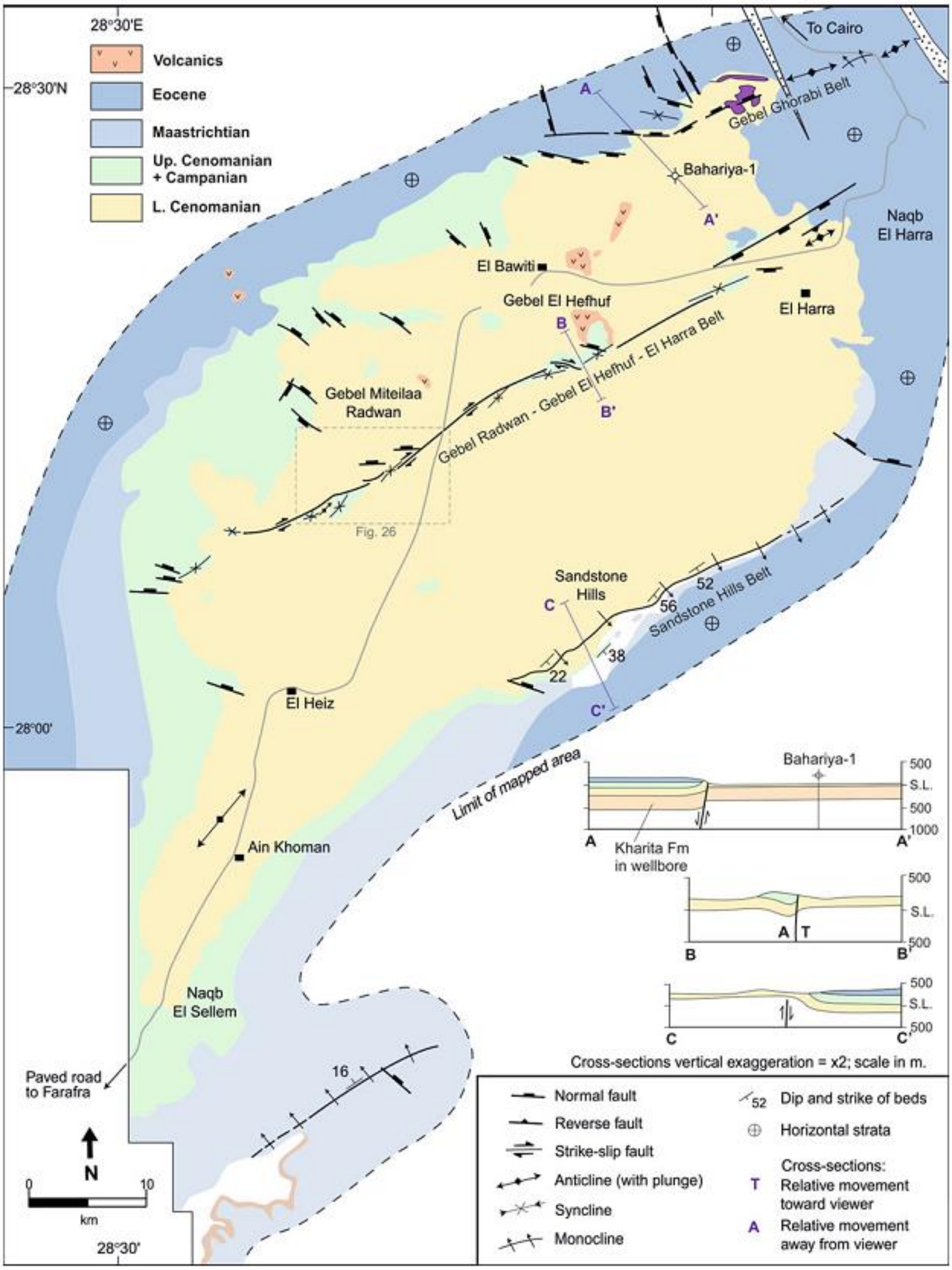
- ✓ At Abu Roash area, SW of Cairo, the Upper Cretaceous rocks represent the only Cretaceous exposure in the northern Western Desert.
- ✓ The structure of Abu Roash area is made up of three main NE-SW oriented folds, the most prominent of which is dissected by WNW-ESE oriented, right-lateral, strike-slip faults.
- ✓ It has been interpreted the Abu Roash structures as push-up folds resulting from E-W oriented, left-stepping, en echelon, right-lateral strike-slip faults where the NE-SW faults form push-up structures between left-stepping E-W faults.



Formation mechanism of the Abu-Roash push-up structures.

2-Bahariya Oasis

- ✓ The Bahariya Oases area (central part of the Western Desert) shows the base Campanian parallel unconformity where Cenomanian marine sediments of El Heiz Formation are directly overlain by Campanian marine sediments of El Hefhuf Formation with a notable hiatus represented by the Turonian-Santonian rocks.
- ✓ This unconformity is perhaps related to uplift of the central Western Desert and non-deposition and/or erosion of the missing rocks coeval with the onset of Late Cretaceous inversion of the northern basins.
- ✓ It displays folded Upper Cretaceous rocks due to Late Cretaceous-Early Tertiary deformation. The deformation is attributed to reactivation of pre-existing ENE-WSW oriented faults by NW compressive stress.
- ✓ Three well-defined ENE-WSW oriented structural belts were mapped in the area; Gebel Ghorabi Belt, Gebel Radwan– Gebel El Hefhuf–El Harra Belt, and the Sandstone Hills Belt.



El-Bahariya Folded Belts.

Inversion Folds at the sub-surfacial exposures:

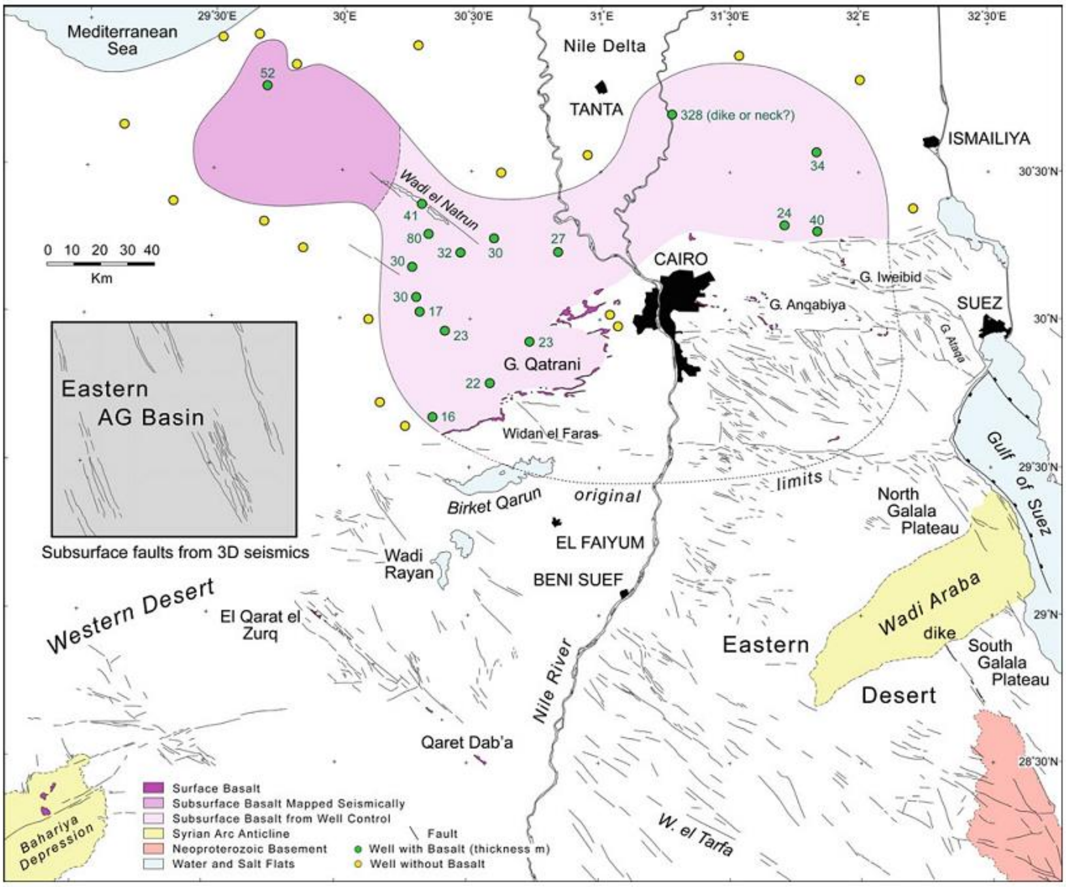
1. Northern Western Desert (Kattaniya, Alamein-Razzak, Mubarak, Abu Gharadig, and Matruh-Shoushan Basins).
2. Offshore northern Sinai (e.g. Mango and Goliath folds).
3. Rosetta fault area on the western side of the Nile Cone.

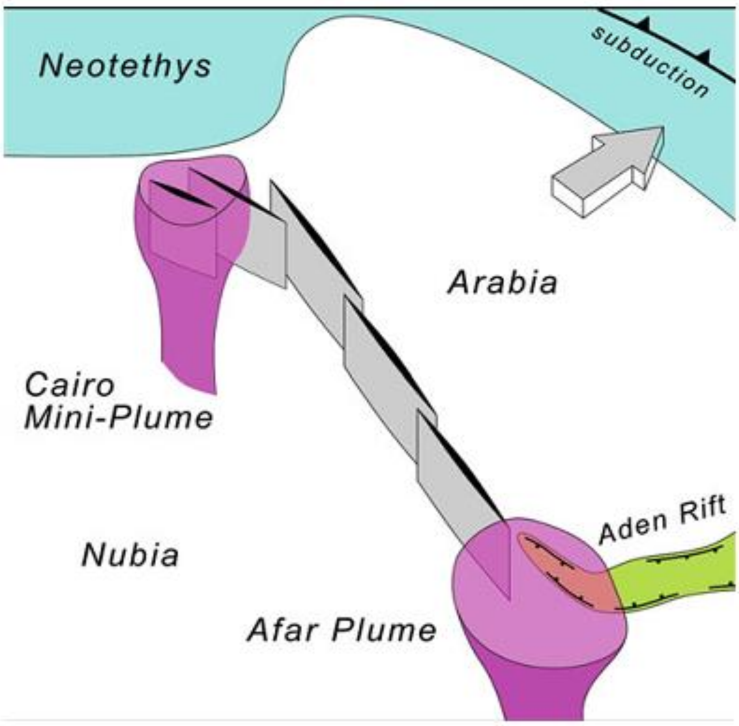
4- Red Sea Rifting (Late Oligocene-Miocene)

Causes behind the Red Sea opening???

- The Late Oligocene-Miocene rifting in and the subsequent formation of the Gulf of Suez and Red Sea are triggered by the divergent movement between the African and Arabian plates.
- The extensional rifting was oriented as NNW-SSE.
- It also causes reactivation of the Early Mesozoic NNE-SSW fault bet forming the Dead Sea left-lateral transform fault.
- Regarding the driving force of the divergent movement of the Afro-Arabian plate, it has been suggested that the normal continental lithosphere may be too strong to rift without magmatic dike intrusion, and therefore, there must be an appropriate combination of regional extension and a source of sufficient magma. Also, it has been claimed that both the Red Sea and Ethiopian Rift developed as magma-assisted rifts, whereas the model is difficult to apply to the Gulf of Aden where syn-rift dikes are absent. Bosworth et al. considered the trigger for rifting to be the impingement of the Afar plume at 31 Ma, and the actual onset of full-length Red Sea rifting the 24–22 Ma dike event.
- Besides Afar mantle-driven plumes, the 22-24Ma basaltic volcanism at northern Egypt is thought to played a critical role in the generation of Red Sea rift. It is covered 15,000 km2 with 30 m total thickness.

- The Cairo mini-plume "22-24Ma" may have acted as a trigger for the last phase of Red Sea rift propagation, similar to the role proposed for the Afar plume for Gulf of Aden continental rifting. The basalts may have helped control the direction of the rift as it shot north from Eritrea.





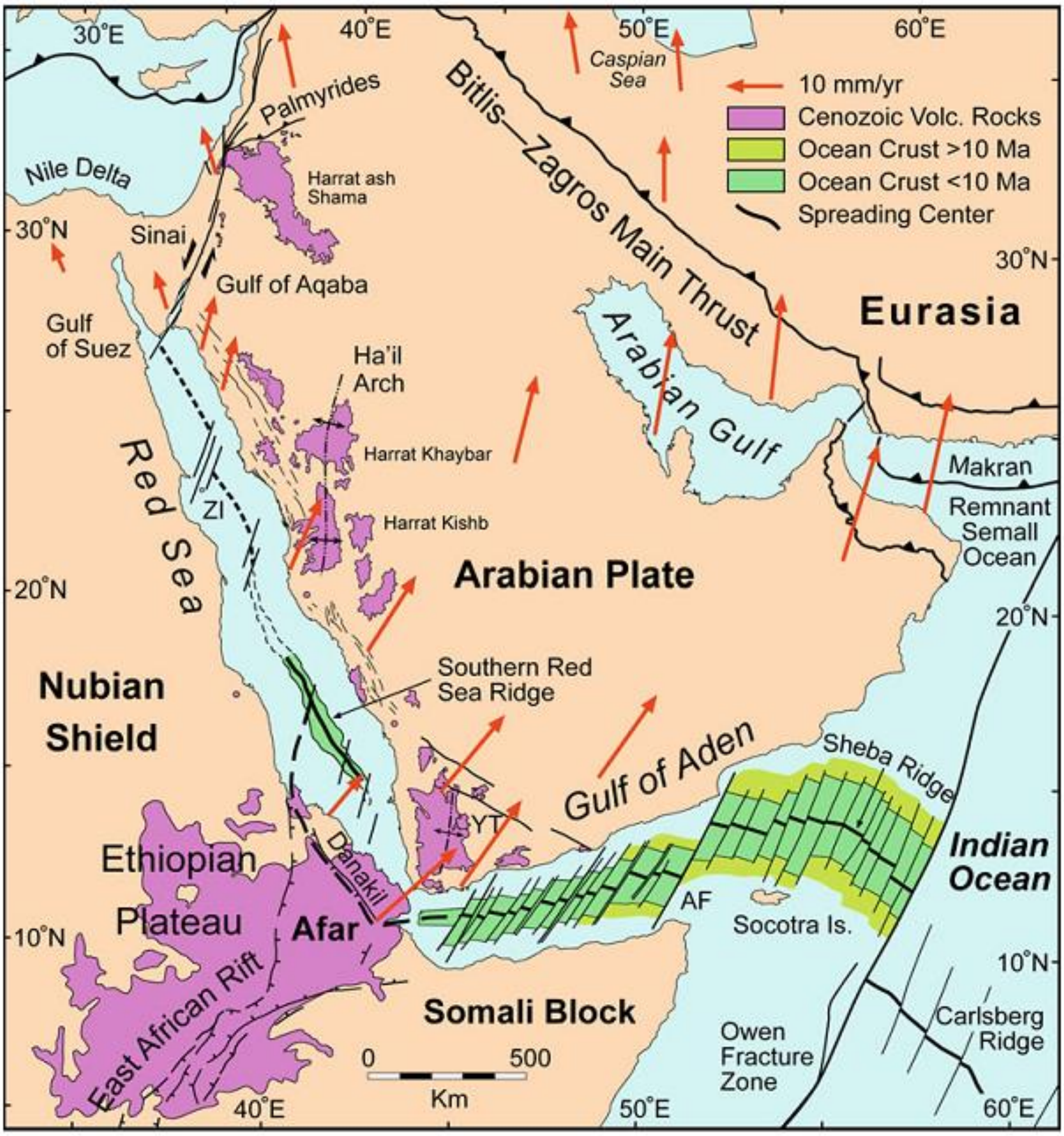
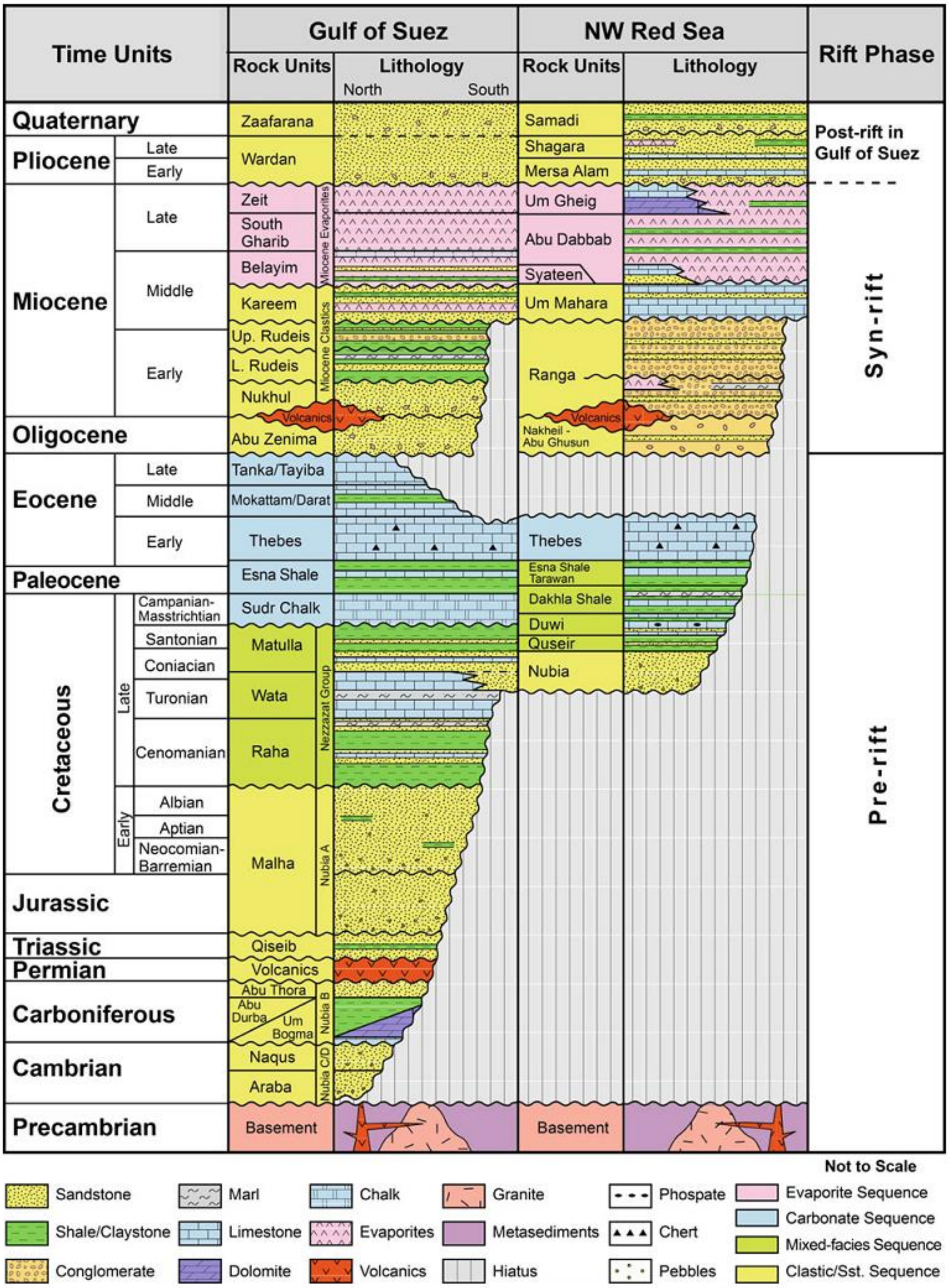


Plate tectonic setting of the Gulf of Suez-Red Sea rift???

- The Gulf of Suez-Red Sea basin is a world class rift basin and an area showing the evolutionary stages of continental breakup and transition from continental rifting to seafloor spreading and formation of new ocean basins.
- It involves three evolutionary stages: rifting; drifting; seafloor spreading.
- Both of the Gulf of Suez and Red Sea started as continental rifts at the initial phases of separation of Arabia from Africa. After a certain period of continental extension, they were separated from each other by ***the Dead Sea***

Transform that allowed continued extension in the Red Sea and abortion of the Suez Rift.

- Continued extension of the Red Sea led to increased crustal attenuation and seafloor spreading.
- After activation of the NNE-SSW Dead Sea transform fault, NNE-SSW oriented transform faults were formed in the Red Sea, the northernmost of them (Zabargad Transform or Zabargad Fracture Zone) passes through Zabargad Island "Northern Red Sea".
- The total rate of opening of the northern Red Sea is currently 7.5–9.5 mm/yr.
- The crust of the northern part of the Red Sea as far south as the Zabargad Fracture Zone is still continental and highly attenuated where crustal thickness in the main trough is 5– 8.5 km. However, some places in the northern Red Sea show the formation of basic igneous rocks at local centers. Gabbroic rocks cut by doleritic dykes exist at the Brothers Islands.
- Seafloor spreading in the southern Red Sea and Gulf of Aden allows north-northeastward movement of the Arabian Plate and its collision with the Eurasian Plate at the Bitlis-Zagros Suture.


Time Units
Gulf of Suez
Rock Units
Lithology
North
South
NW Red Sea
Rock Units
Lithology
Rift Phase
Quaternary
Pliocene
Late
Early
Miocene
Late
Middle
Early
Oligocene
Eocene
Late
Middle
Early
Paleocene
Cretaceous
Late
Campanian-Masstrichtian
Santonian
Coniacian
Turonian
Cenomanian
Early
Albian
Aptian
Neocomian-Barremian
Jurassic
Triassic
Permian
Carboniferous
Cambrian
Precambrian
Zaafarana
Wardan
Zeit
South Gharib
Belayim
Kareem
Up. Rudeis
L. Rudeis
Nukhul
Volcanics
Abu Zenima
Miocene Evaporites
Miocene Clastics
Tanka/Tayiba
Mokattam/Darat
Thebes
Esna Shale
Sudr Chalk
Matulla
Wata
Raha
Nezzazat Group
Malha
Nubia A
Qiseib
Volcanics
Abu Thora
Abu Durba
Um Bogma
Nubia B
Naqus
Araba
Nubia C/D
Basement
Samadi
Shagara
Mersa Alam
Um Gheig
Abu Dabbab
Syateen
Um Mahara
Ranga
Volcanics
Nakheil - Abu Ghusun
Thebes
Esna Shale Tarawan
Dakhla Shale
Duwi
Quseir
Nubia
Basement
Post-rift in Gulf of Suez
Syn-rift
Pre-rift
Not to Scale
Sandstone
Shale/Claystone
Conglomerate
Marl
Limestone
Dolomite
Chalk
Evaporites
Volcanics
Granite
Metasediments
Hiatus
Phospate
Chert
Pebbles
Evaporite Sequence
Carbonate Sequence
Mixed-facies Sequence
Clastic/Sst. Sequence