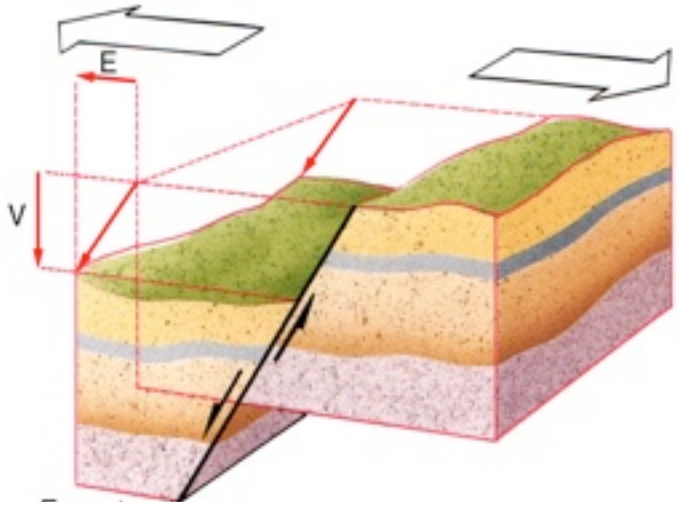
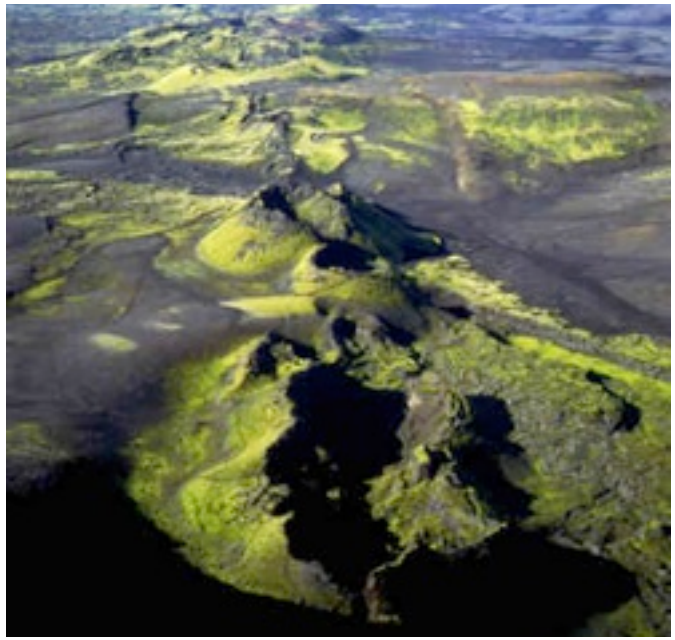
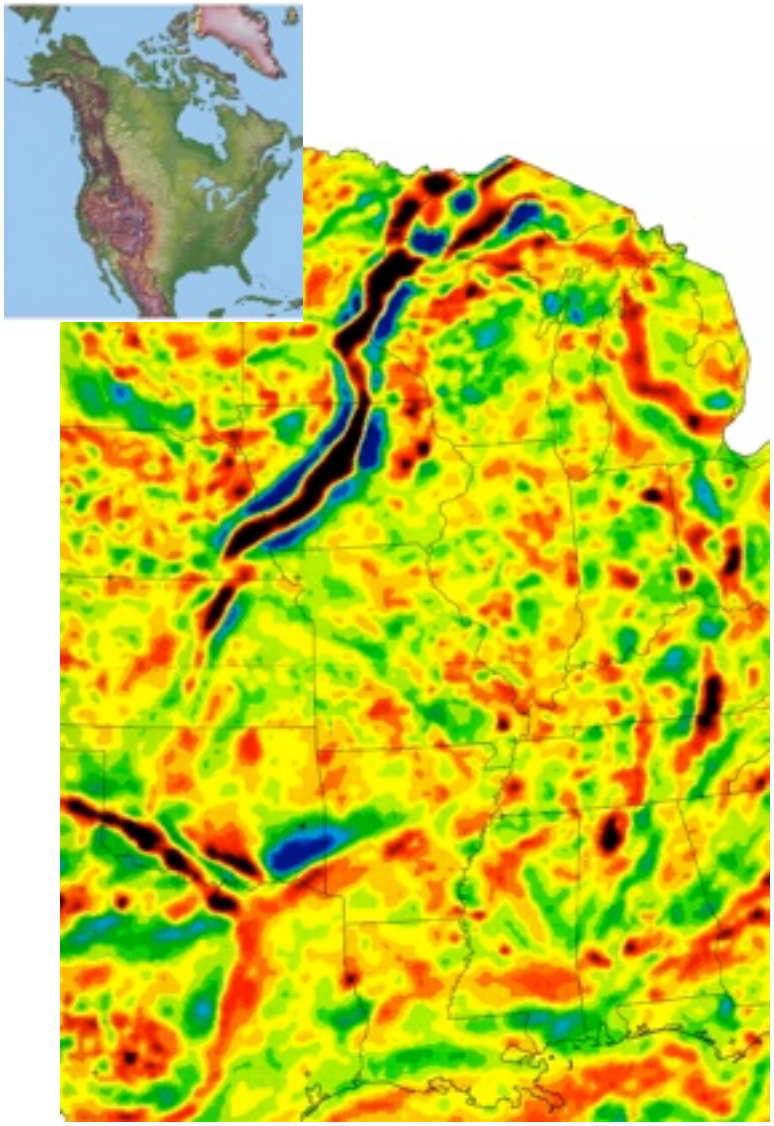


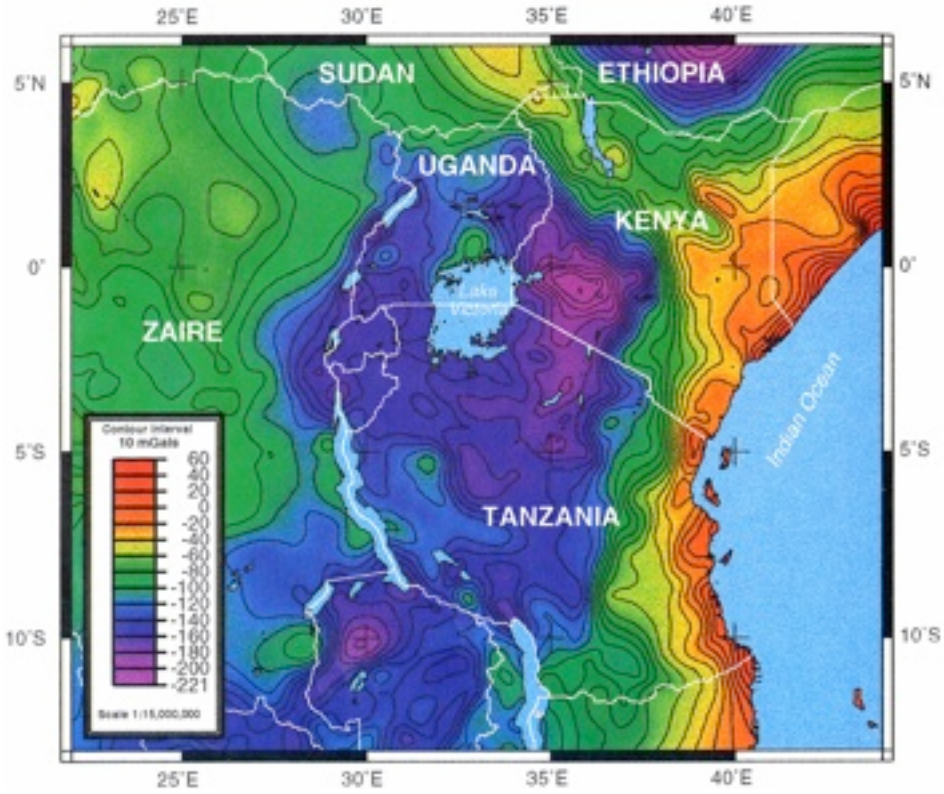
Extensionszonen

Aktive & Passive Rifts, Bruchausbreitung

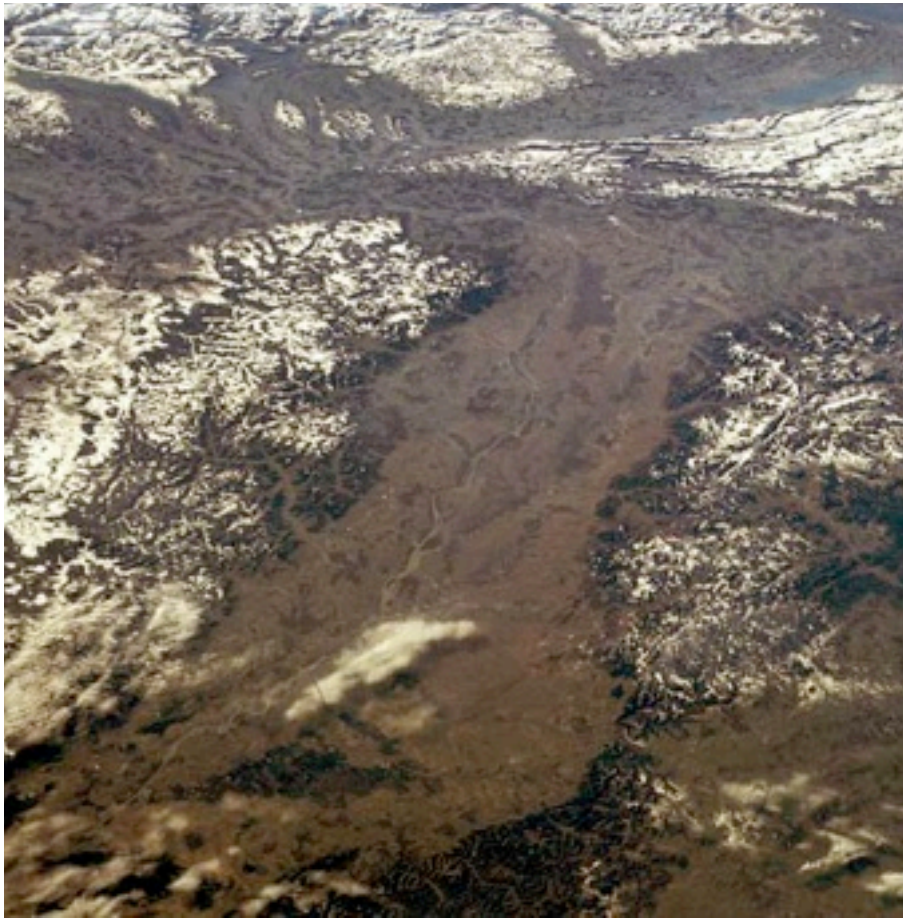


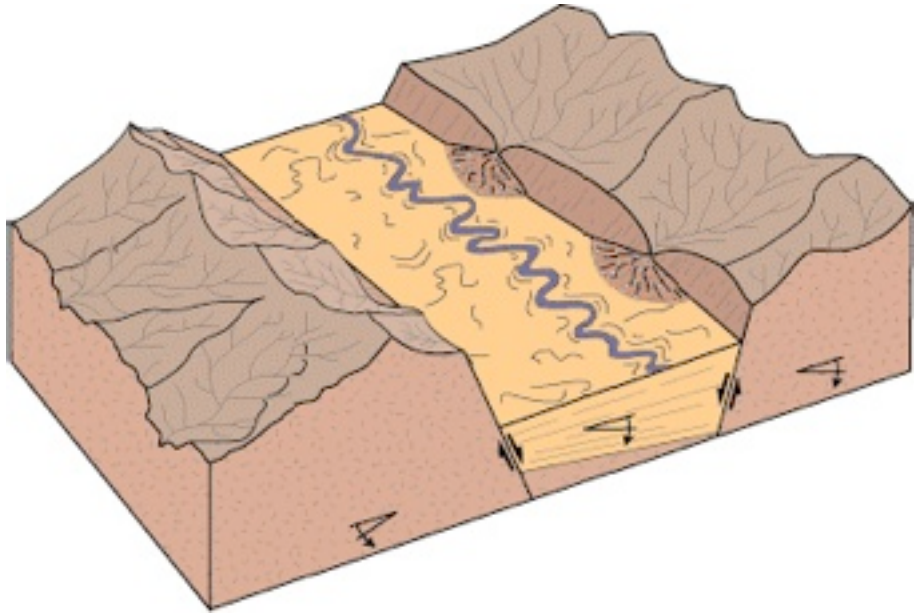
Gravity anomalies in rifts



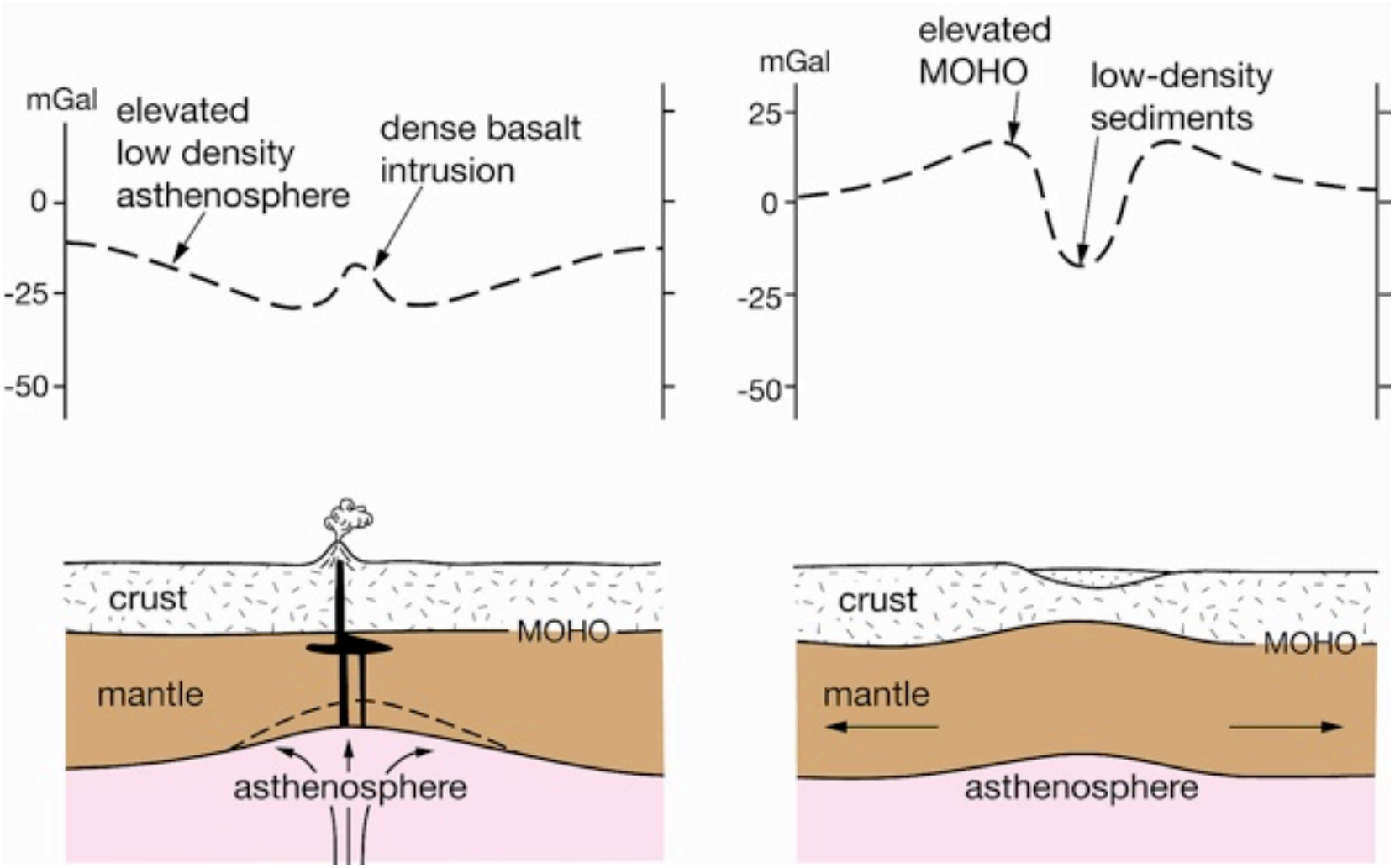


Extension without pronounced volcanism: Rhine and Baikal rifts

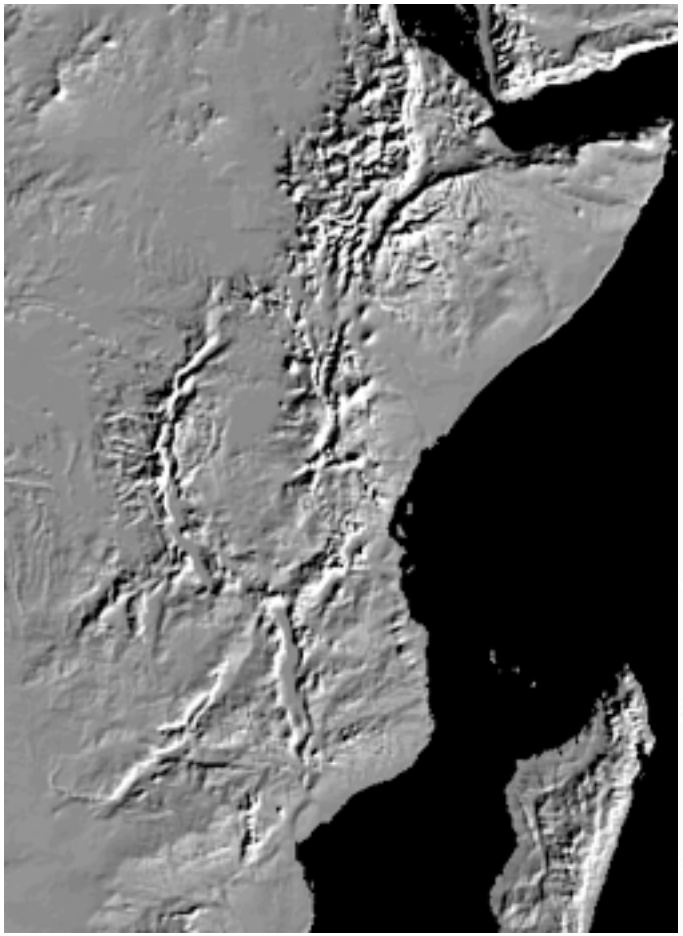


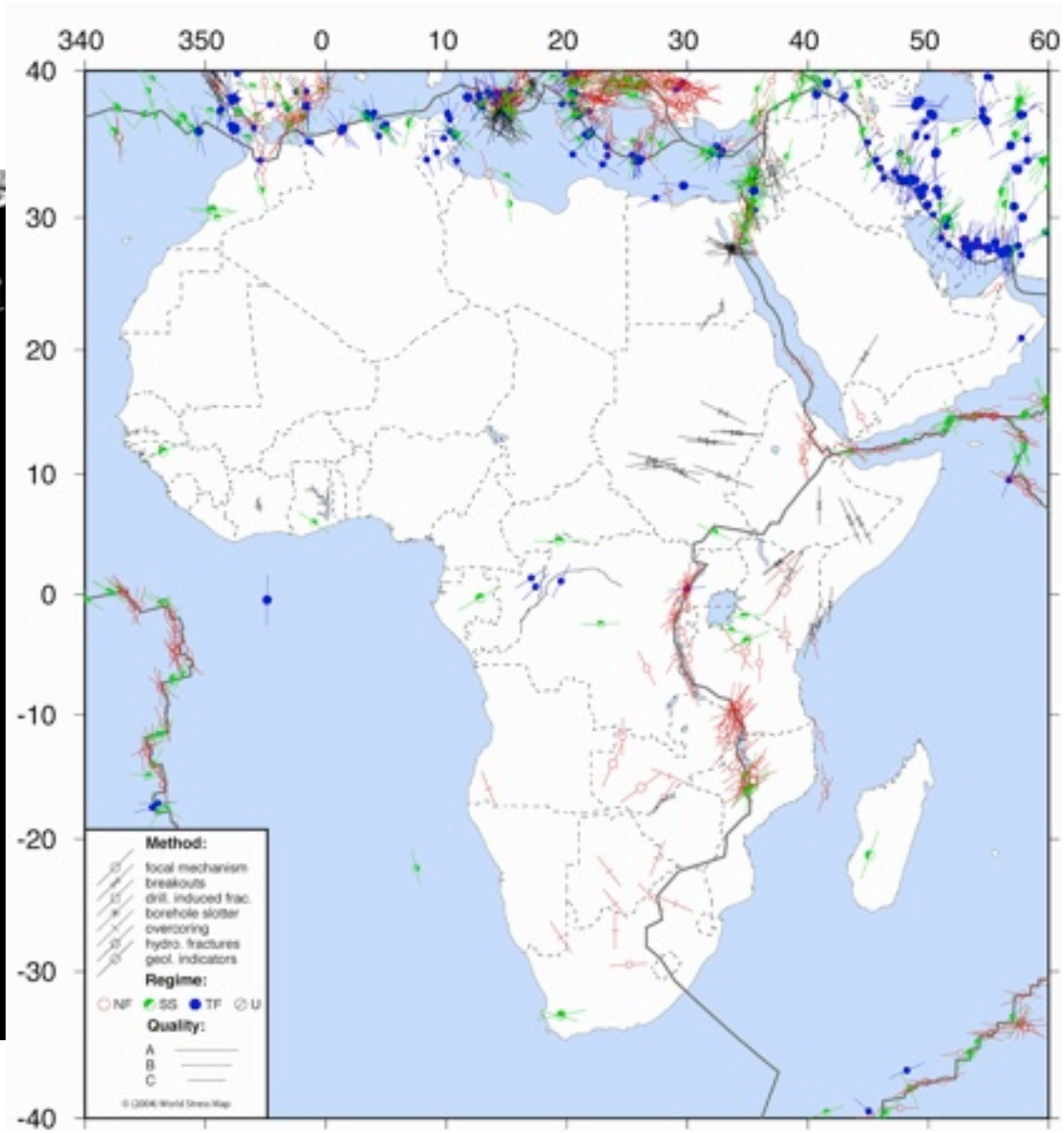


Active vs. passive Rifts

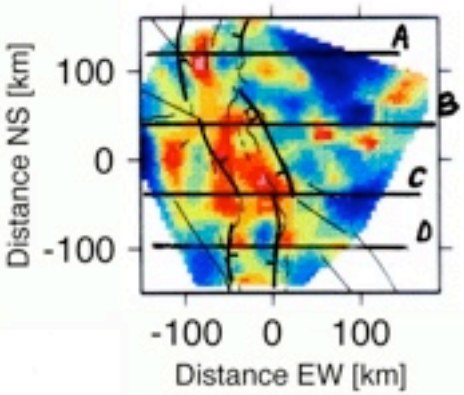


Active rifting in East Africa

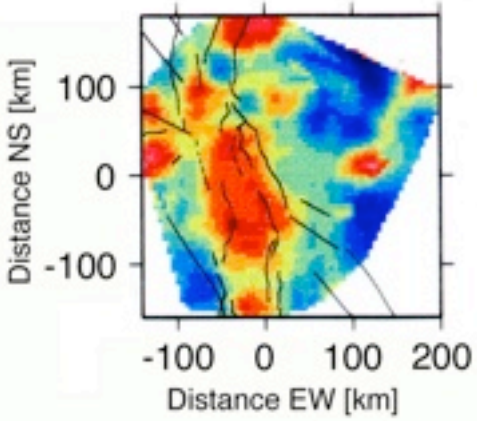




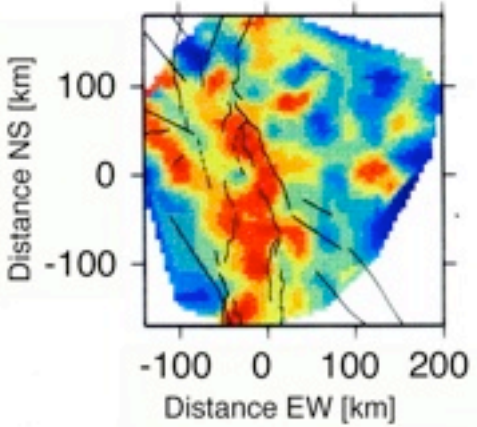
layer 2 [10-35km]

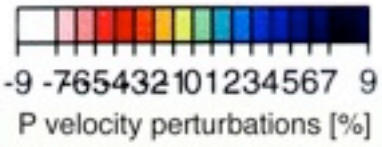


layer 3 [35-65km]

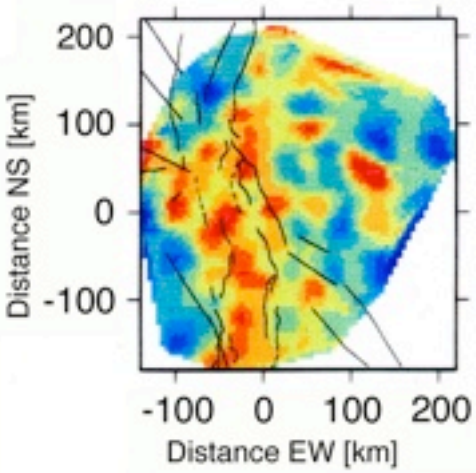


layer 4 [65-95km]

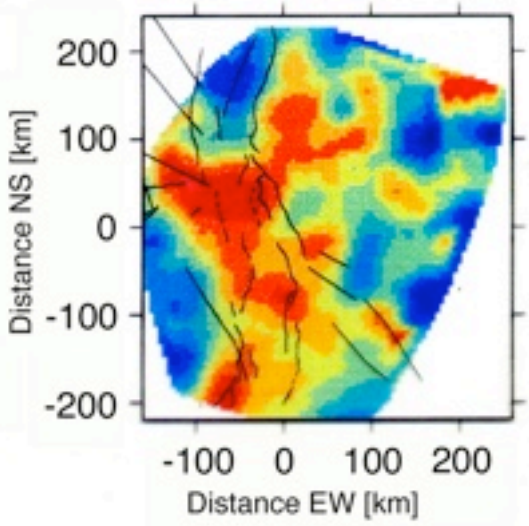




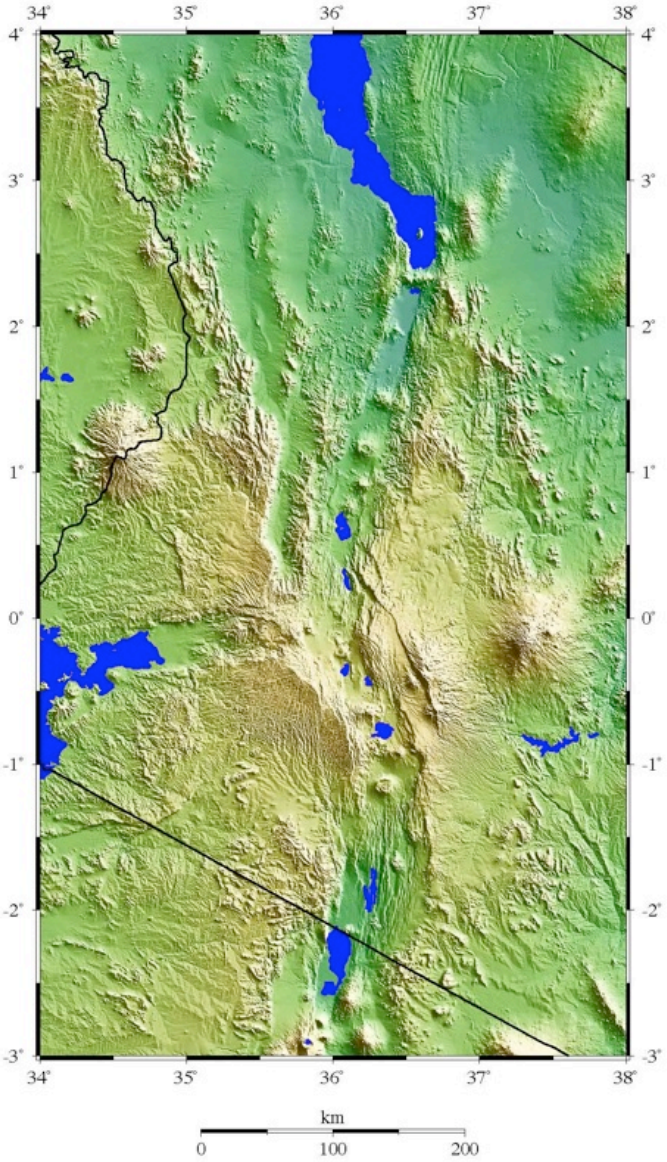
layer 5 [95-125km]

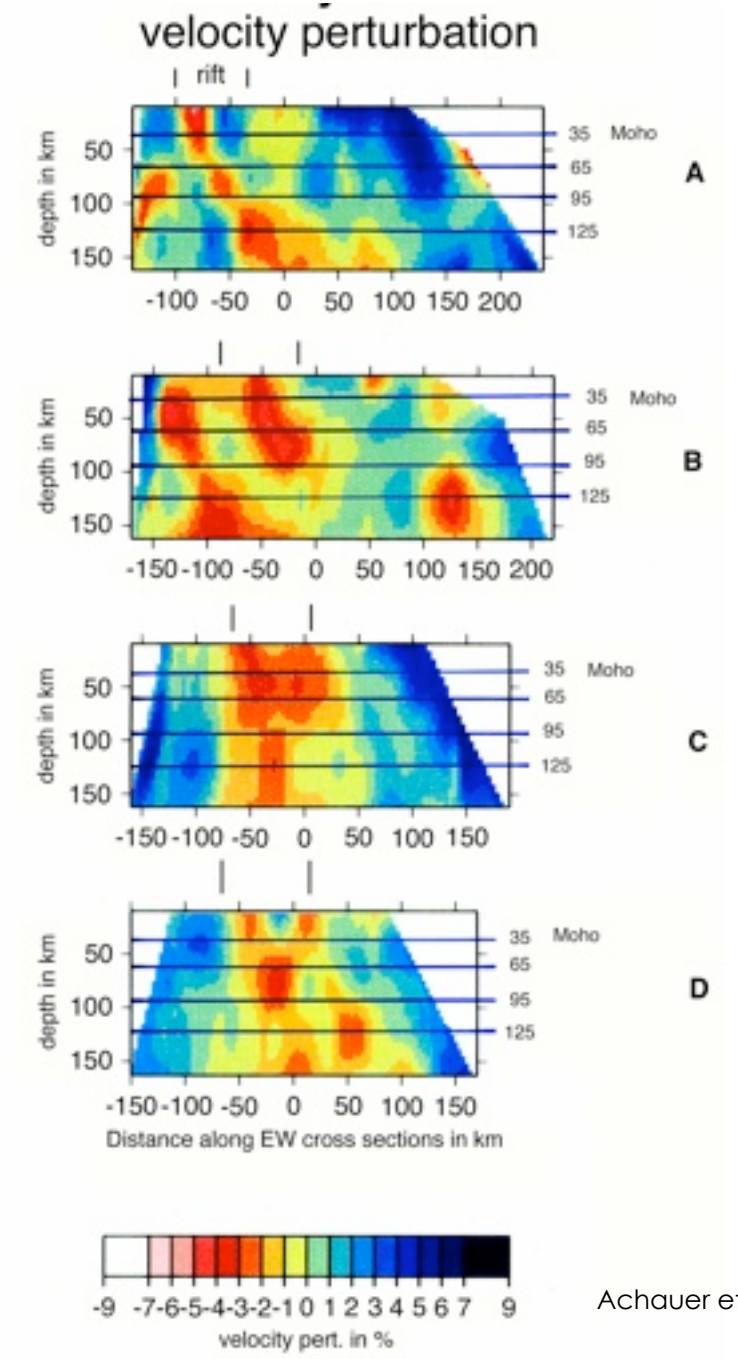


layer 6 [125-165km]



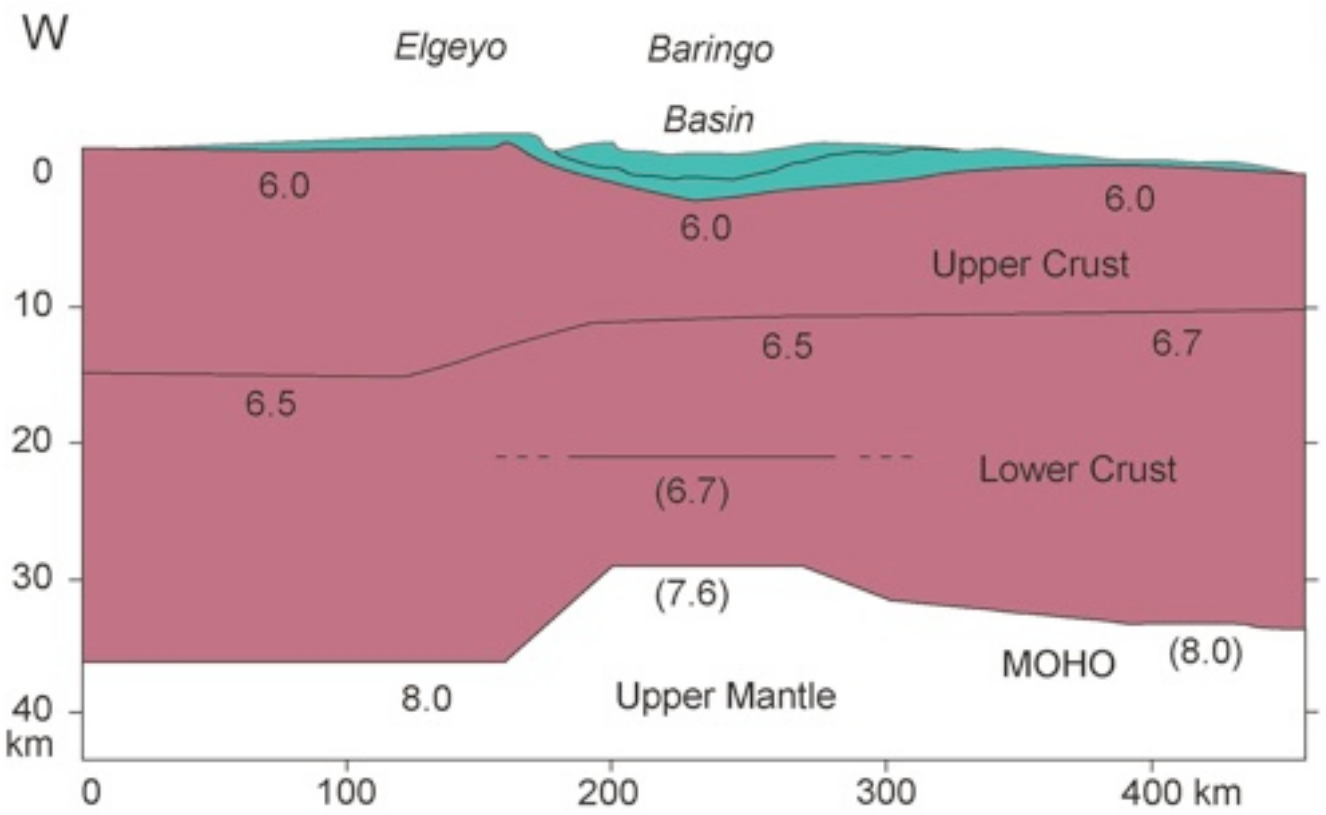
Teleseismic data

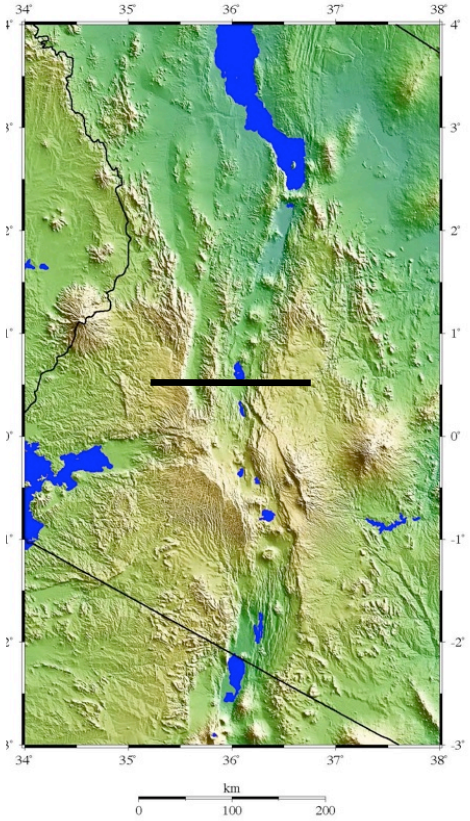




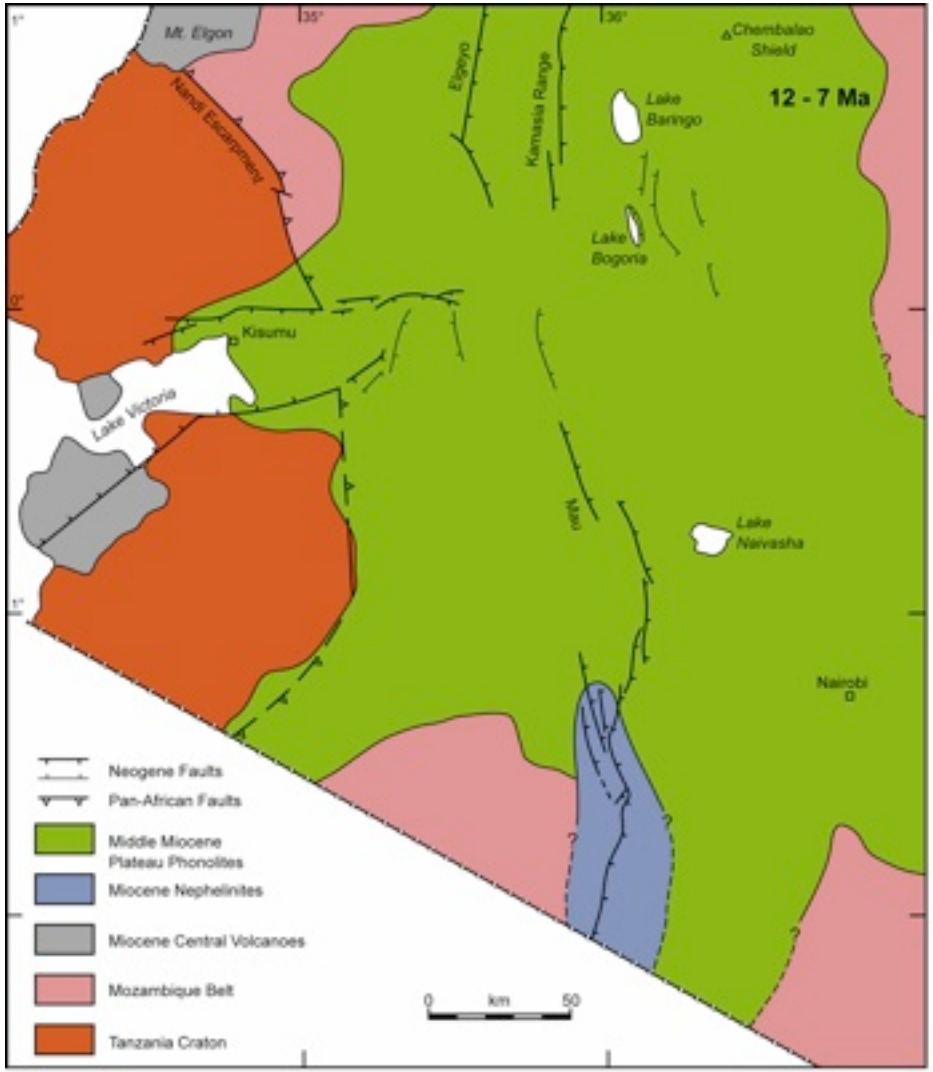
Achauer et al., 1994

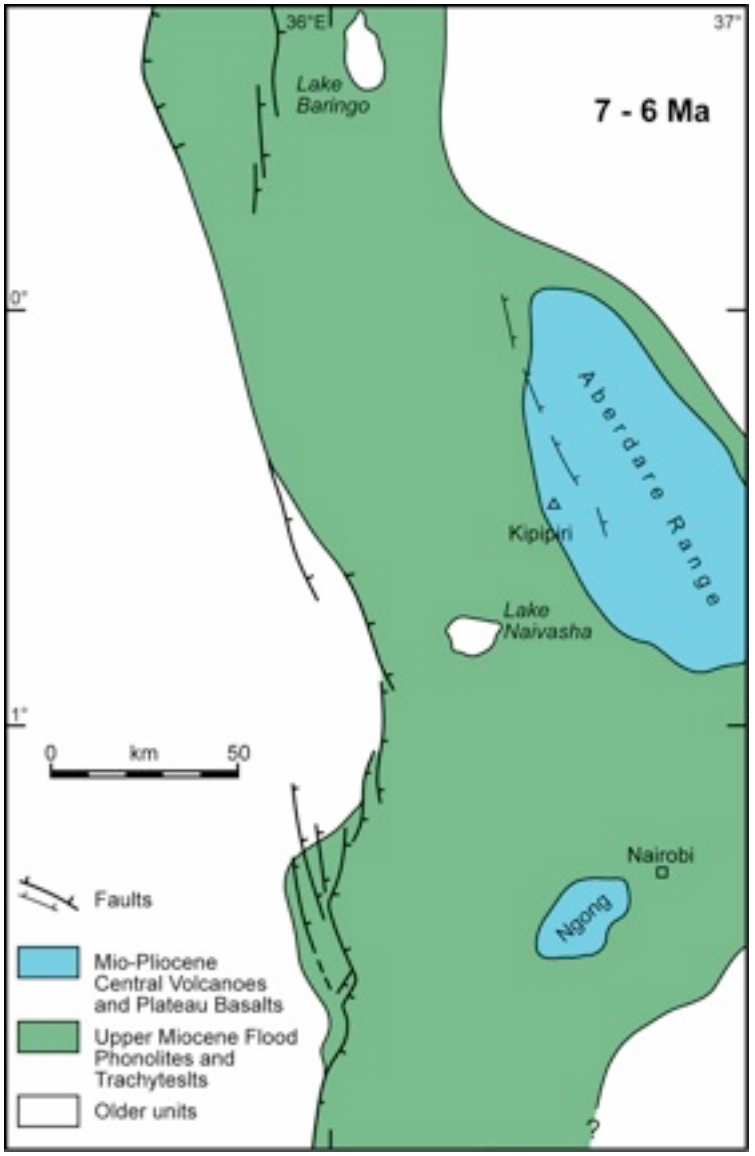
Active rifting: seismic refraction data indicates anomalous upper mantle

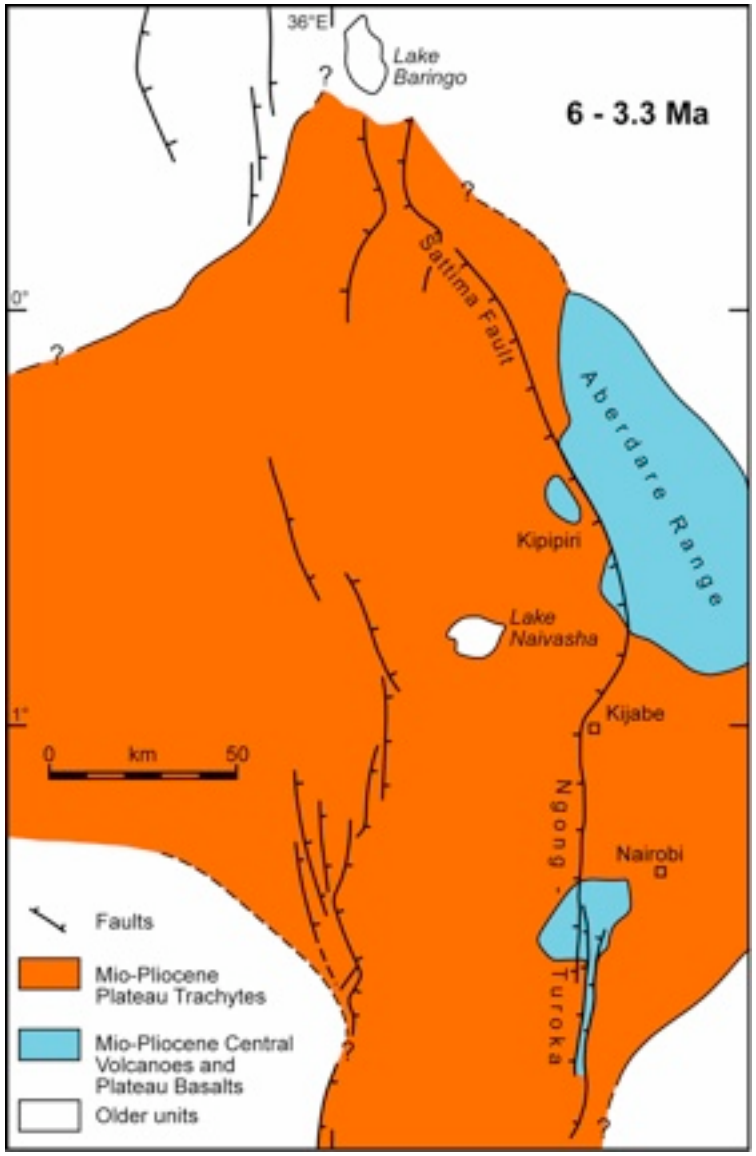


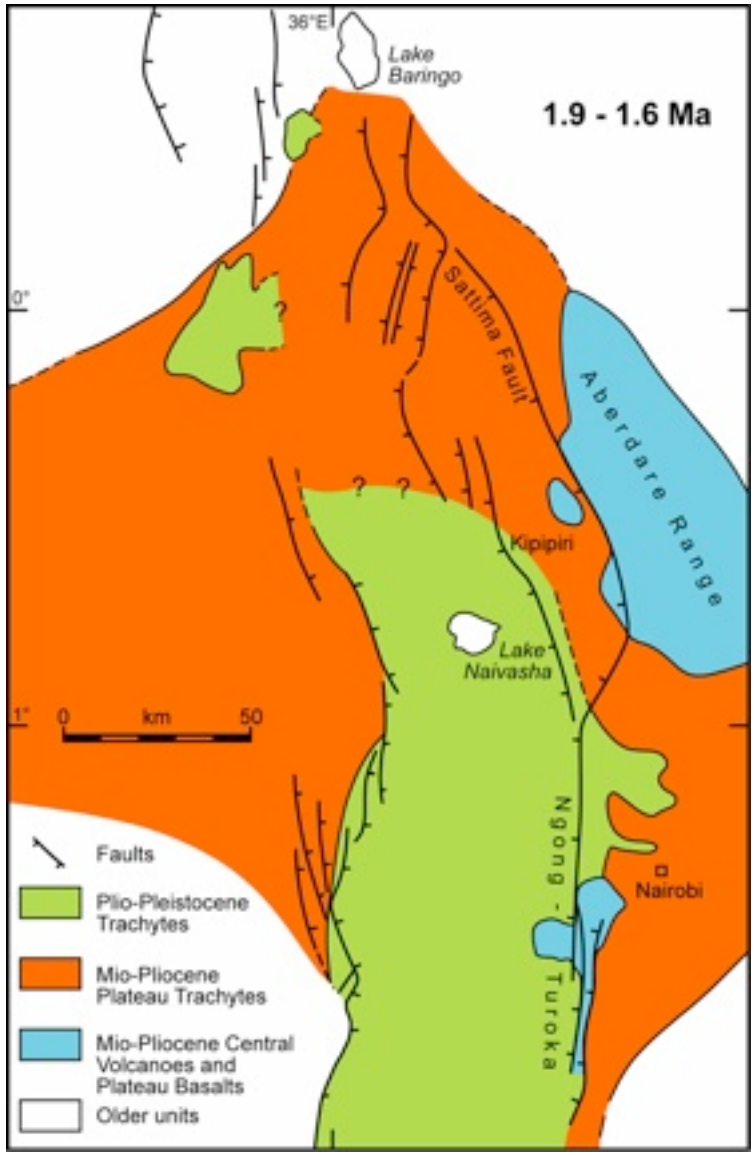


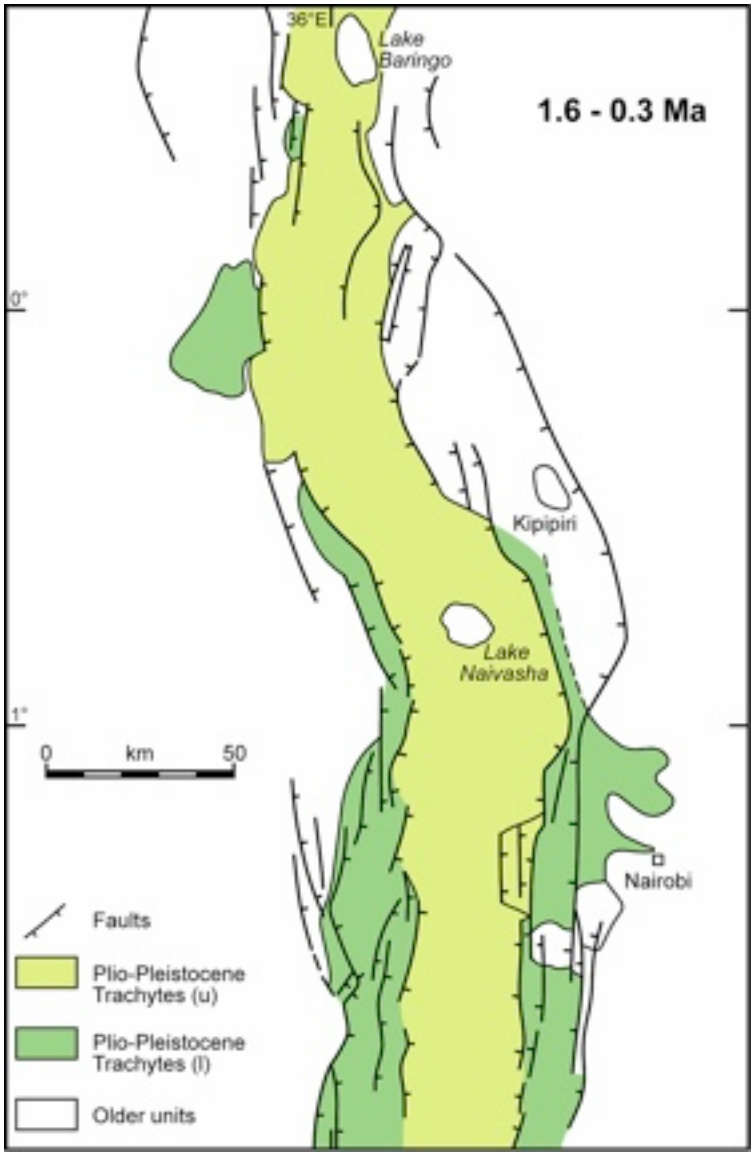
Mechie et al., 1994; 1997; Maguire et al., 1994

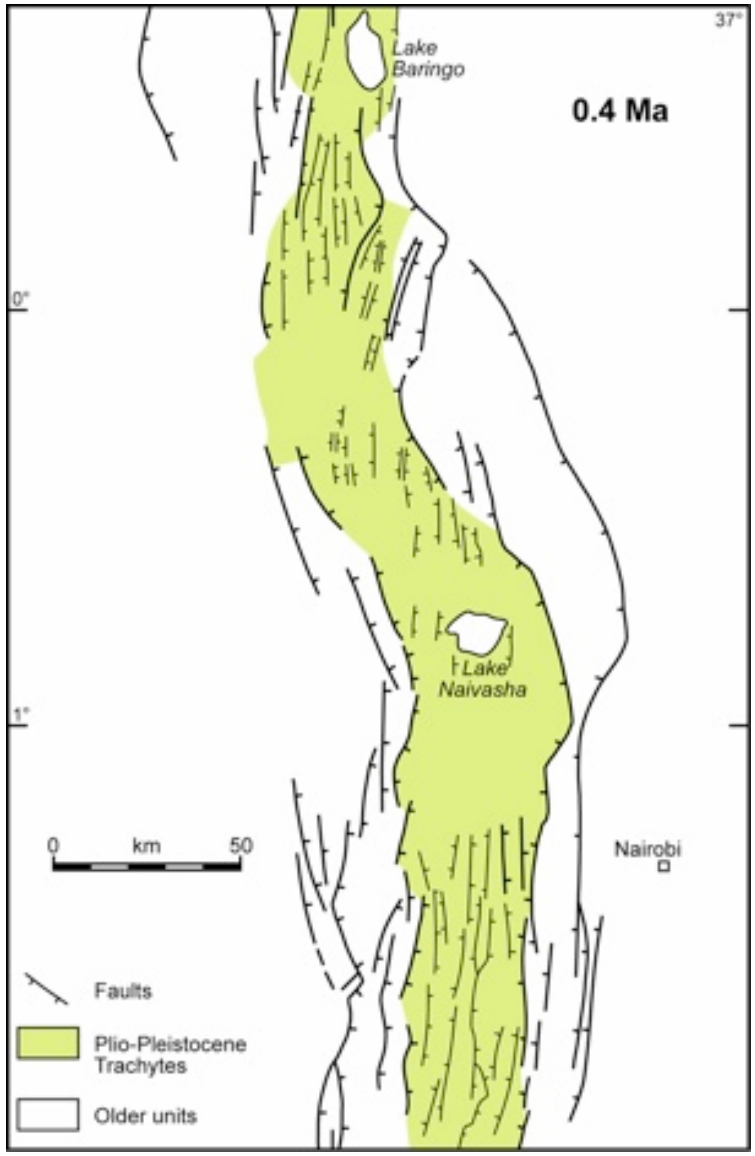

1°
35°
36°
Mt. Elgon
Chembalao Shield
Nandi Escarpment
Elgeyo
Kamasia Range
Lake Baringo
12 - 7 Ma
Lake Bogoria
Kisumu
Lake Victoria
Kenia
Lake Naivasha
Nairobi
Neogene Faults
Pan-African Faults
Middle Miocene Plateau Phonolites
Miocene Nephelinites
Miocene Central Volcanoes
Mozambique Belt
Tanzania Craton
0 km 50

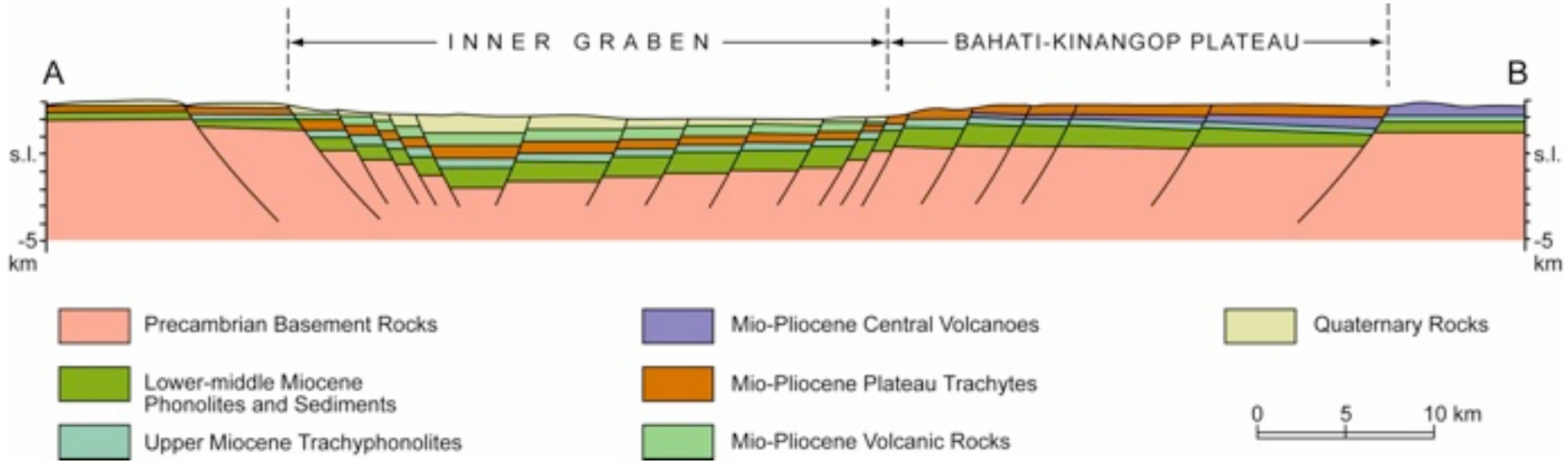

36°E
37°
Lake Baringo
7 - 6 Ma
0°
Aberdare Range
Kipipiri
Lake Naivasha
1°
0 km 50
Nairobi
Ngong
Faults
Mio-Pliocene Central Volcanoes and Plateau Basalts
Upper Miocene Flood Phonolites and Trachyteslts
Older units

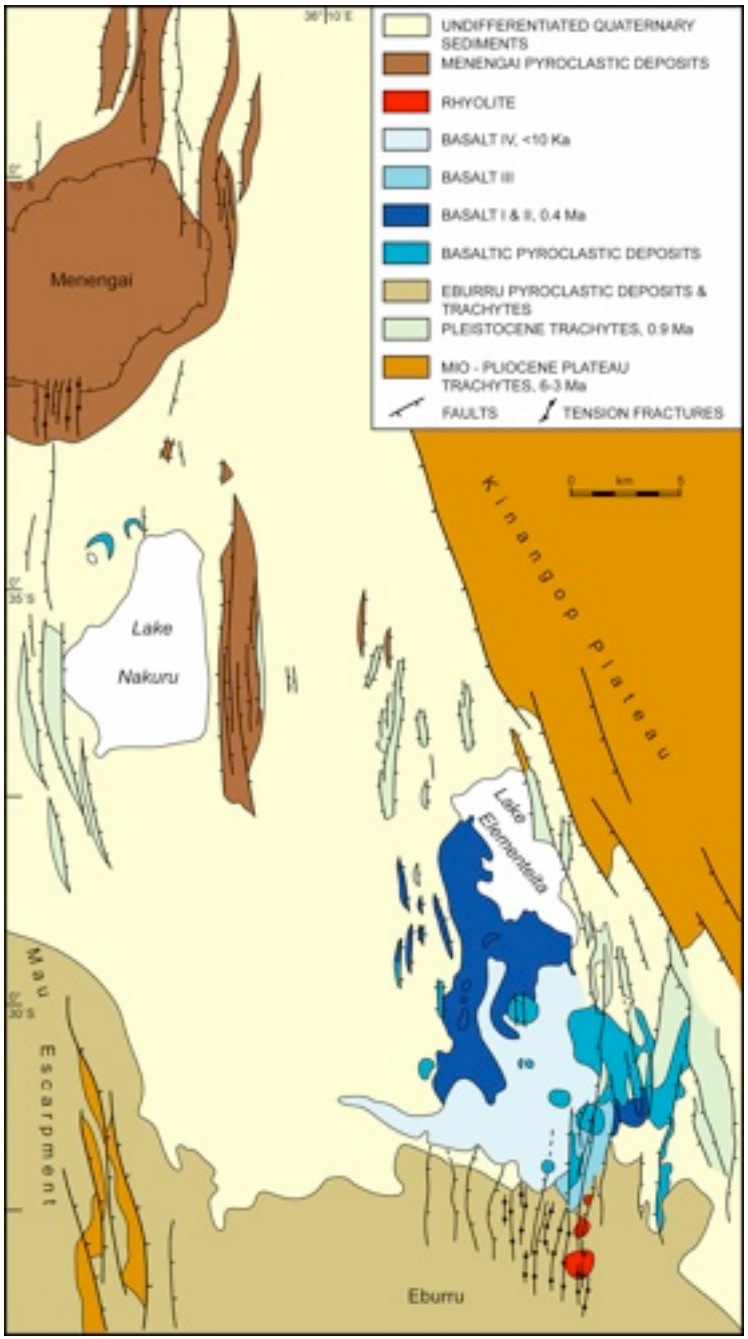

36°E
Lake Baringo
6 - 3.3 Ma
0°
Suttima Fault
Aberdare Range
Kipipiri
Lake Naivasha
1°
0
km
50
Kijabe
Ngong - Turoka
Nairobi
Faults
Mio-Pliocene Plateau Trachytes
Mio-Pliocene Central Volcanoes and Plateau Basalts
Older units

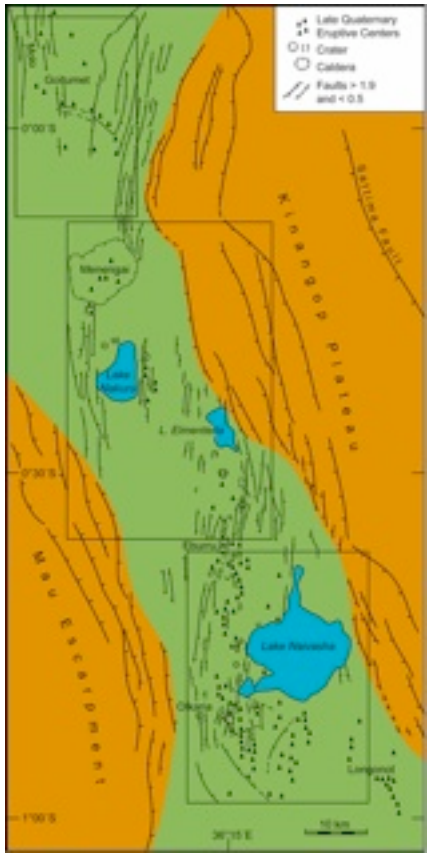

36°E
Lake Baringo
1.9 - 1.6 Ma
0°
Suttima Fault
Aberdare Range
Kipipiri
Lake Naivasha
1°
0
km
50
Ngong - Turoka
Nairobi
Faults
Plio-Pleistocene Trachytes
Mio-Pliocene Plateau Trachytes
Mio-Pliocene Central Volcanoes and Plateau Basalts
Older units

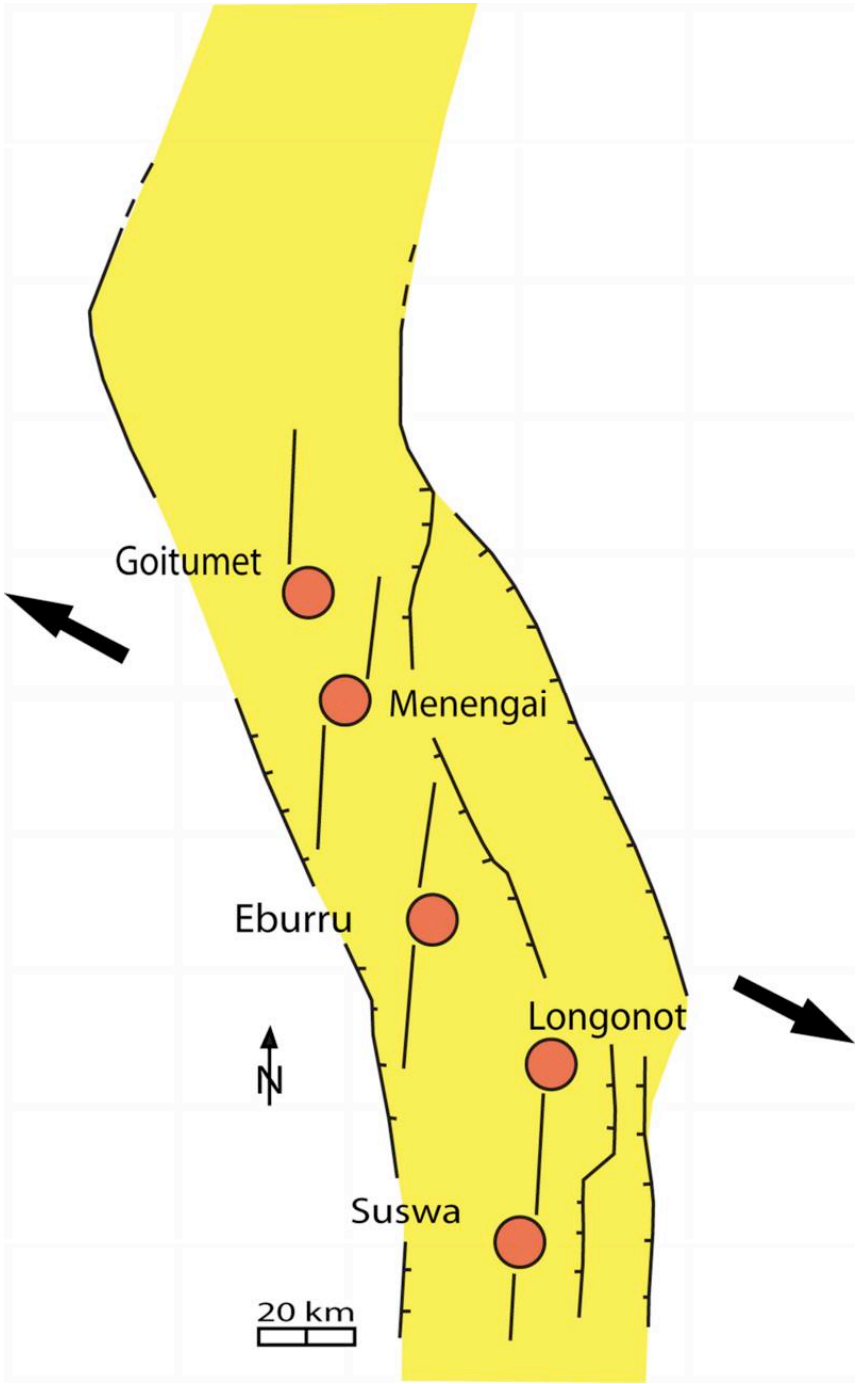

36°E
Lake
Baringo
1.6 - 0.3 Ma
0°
1°
Kipipiri
Lake
Naivasha
0
km
50
Nairobi
Faults
Plio-Pleistocene
Trachytes (u)
Plio-Pleistocene
Trachytes (l)
Older units

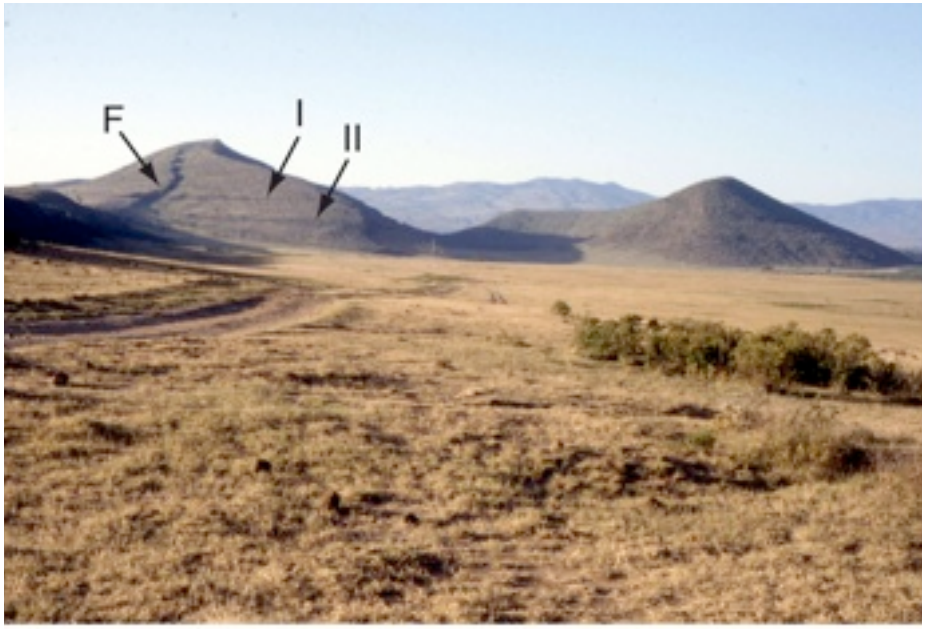

37°
Lake
Baringo
0.4 Ma
0°
1°
Lake
Naivasha
0
km
50
Nairobi
Faults
Plio-Pleistocene
Trachytes
Older units


INNER GRABEN
BAHATI-KINANGOP PLATEAU
A
B
s.l.
-5
km
s.l.
-5
km
Precambrian Basement Rocks
Lower-middle Miocene
Phonolites and Sediments
Upper Miocene Trachyphonolites
Mio-Pliocene Central Volcanoes
Mio-Pliocene Plateau Trachytes
Mio-Pliocene Volcanic Rocks
Quaternary Rocks
0
5
10 km

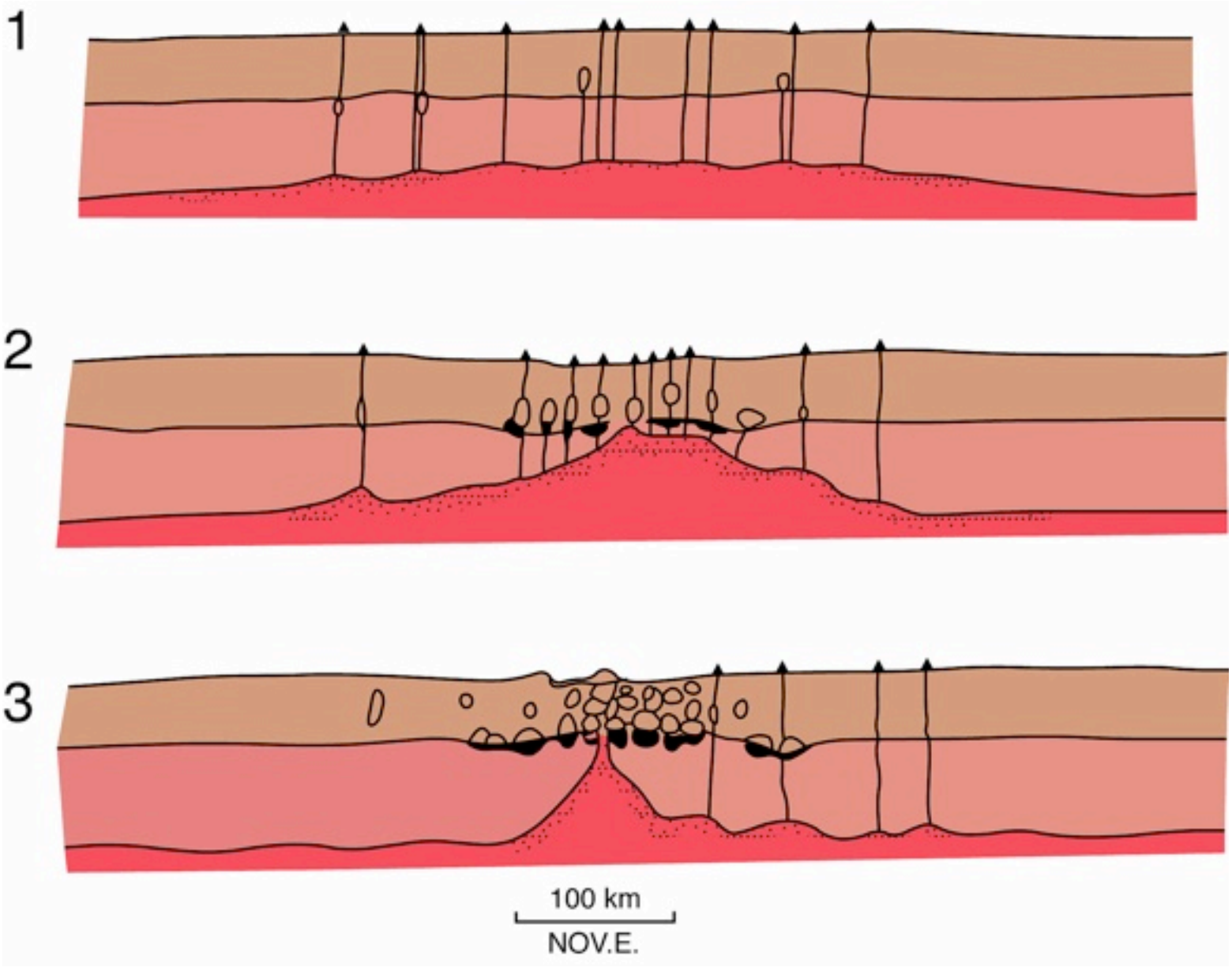

UNDIFFERENTIATED QUATERNARY SEDIMENTS
MENENGAI PYROCLASTIC DEPOSITS
RHYOLITE
BASALT IV, <10 Ka
BASALT III
BASALT I & II, 0.4 Ma
BASALTIC PYROCLASTIC DEPOSITS
EBURRU PYROCLASTIC DEPOSITS & TRACHYTES
PLEISTOCENE TRACHYTES, 0.9 Ma
MIO - PLIOCENE PLATEAU TRACHYTES, 6-3 Ma
FAULTS
TENSION FRACTURES
Menengai
Lake Nakuru
Lake Elementeita
Kinangop plateau
Mau Escarpment
Eburru


Late Quaternary Eruptive Centers
Crater
Caldera
Faults > 1.9 and < 0.5
Kinangop plateau
Mau Escarpment
Lake Naivasha

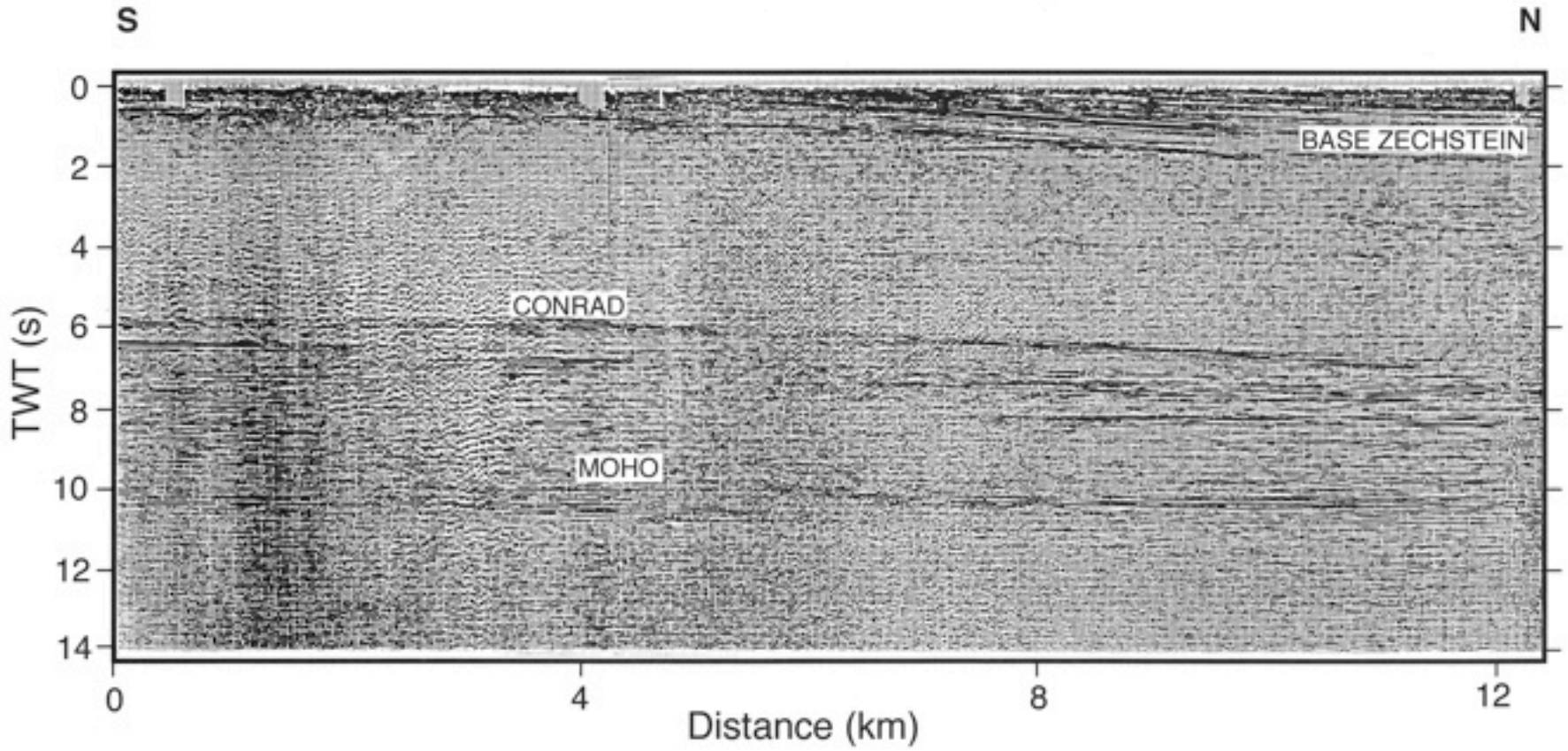

Goitumet
Menengai
Eburru
Longonot
Suswa
N
20 km


F
I
II

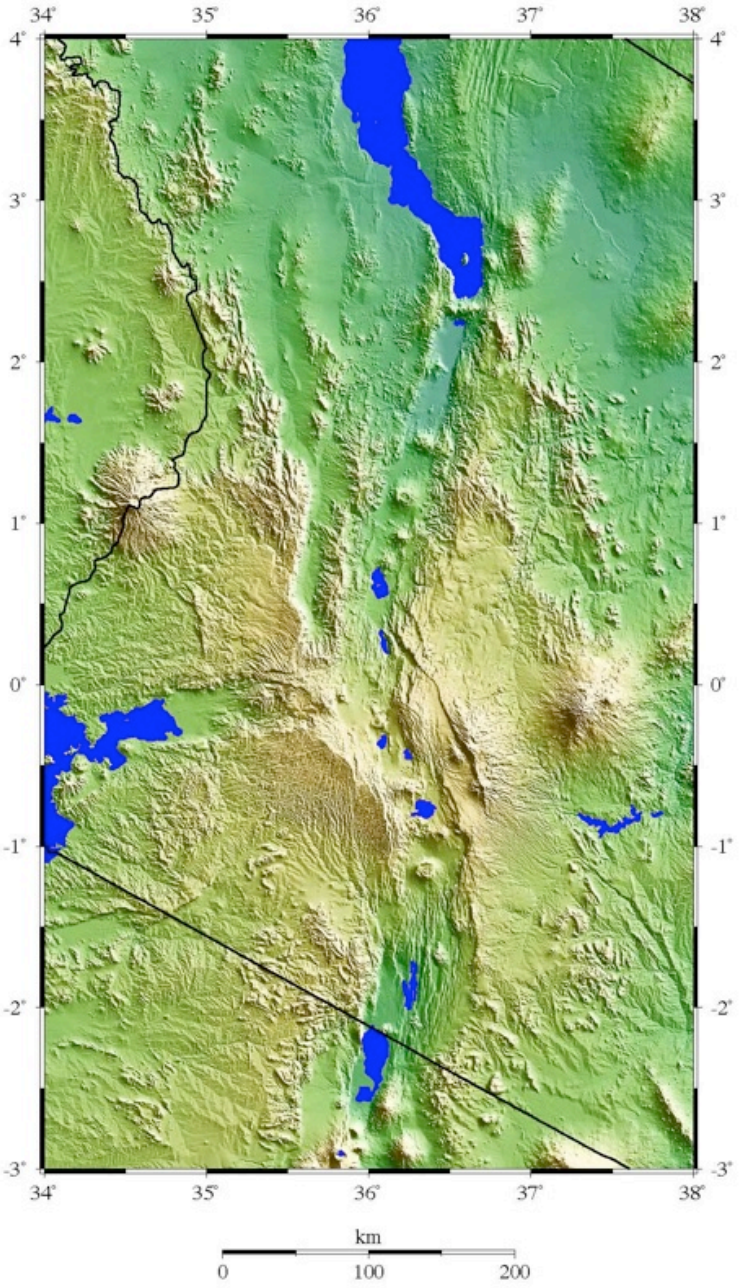
Thermal processes and underplating

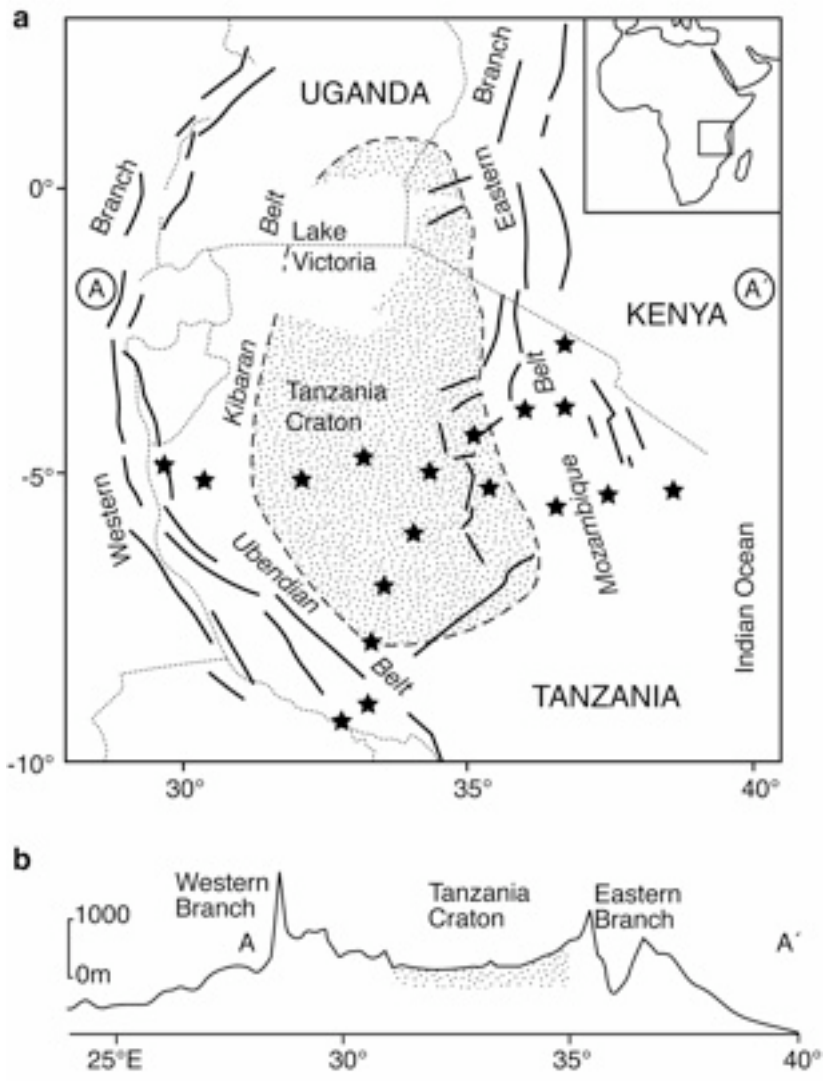


Conrad discontinuity

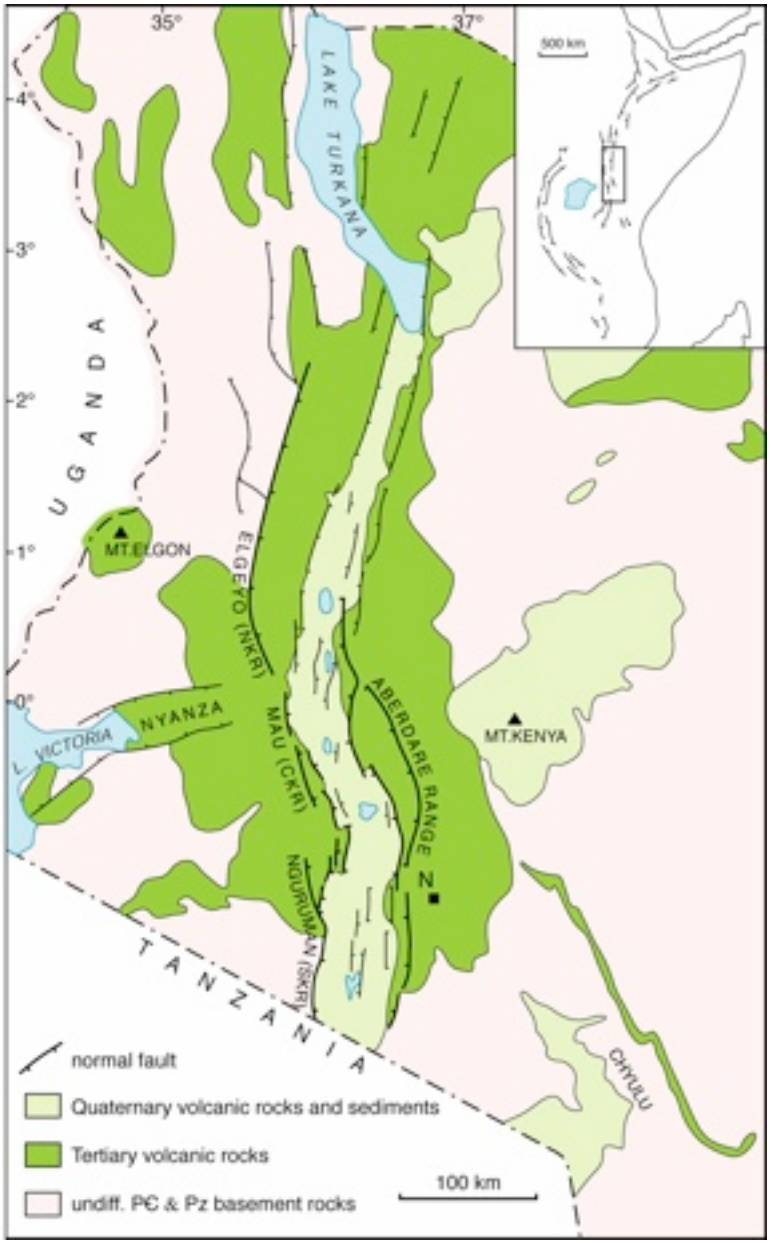


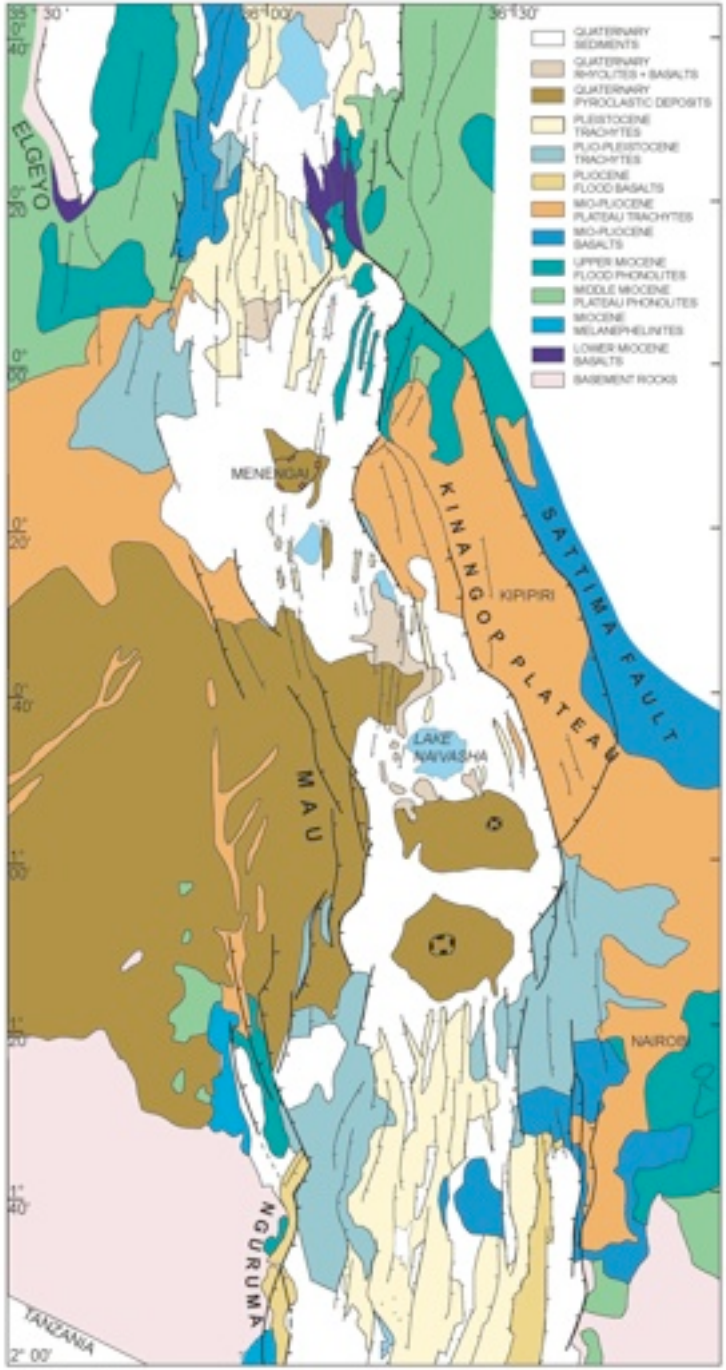
Inherited structure and first-order rift segmentation



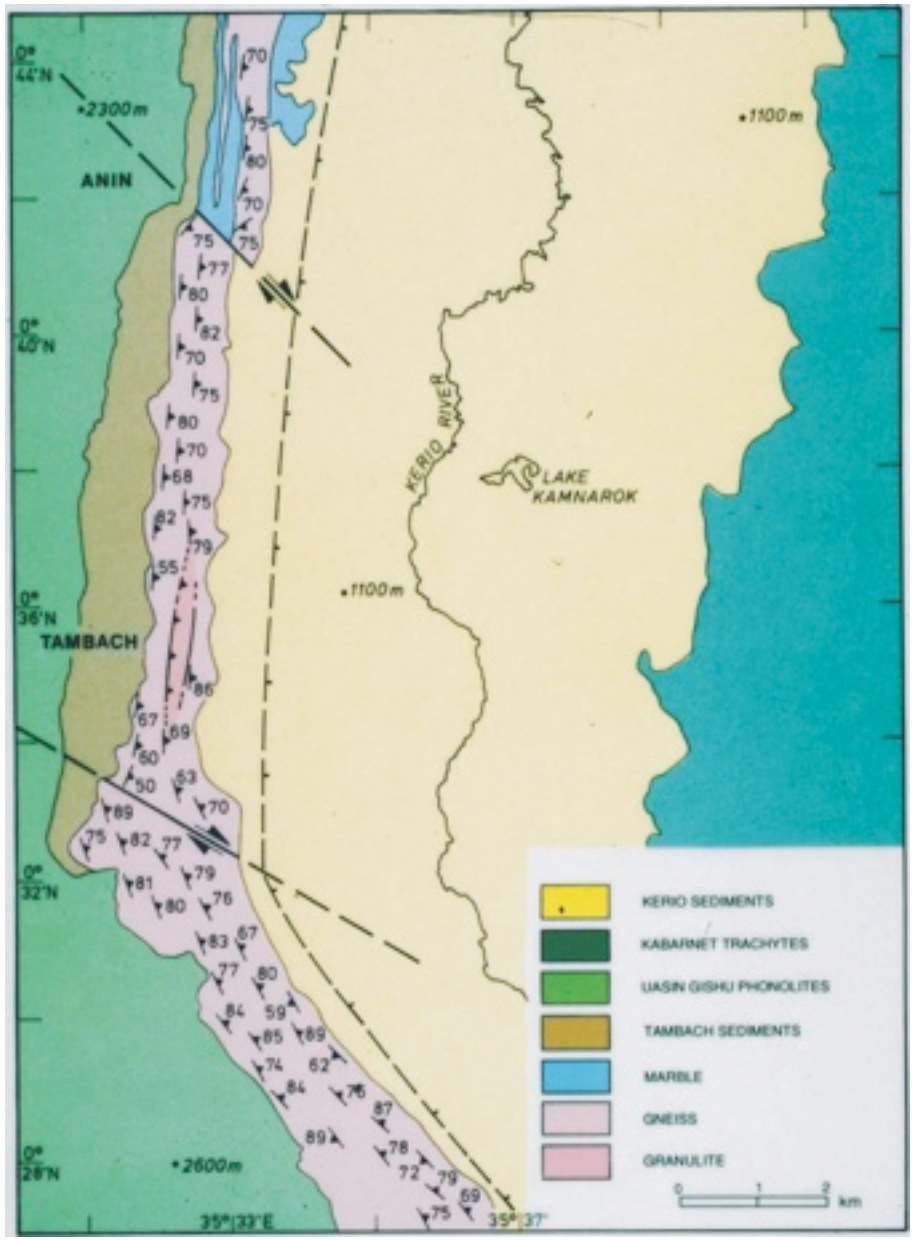


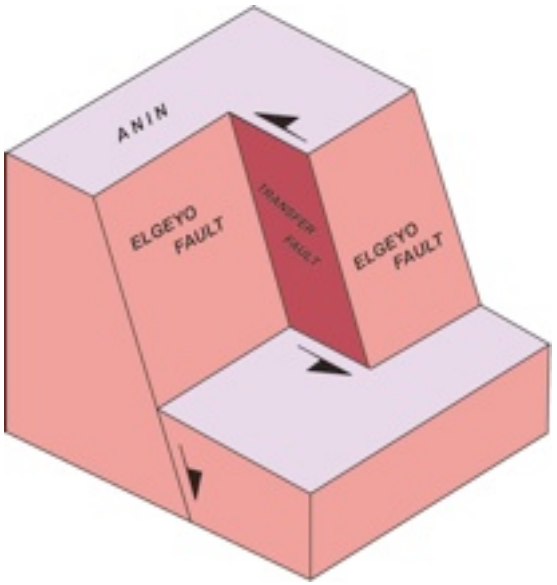
Geological Survey of Kenya, 1970


35°
37°
4°
3°
2°
1°
0°
LAKE TURKANA
500 km
UGANDA
MT.ELGON
ELGEYO (NKR)
MAU (CKR)
NYANZA
VICTORIA
ABERDARE RANGE
MT.KENYA
NGURUMAN (SKR)
TANZANIA
CHYULU
normal fault
Quaternary volcanic rocks and sediments
Tertiary volcanic rocks
undiff. PЄ & Pz basement rocks
100 km

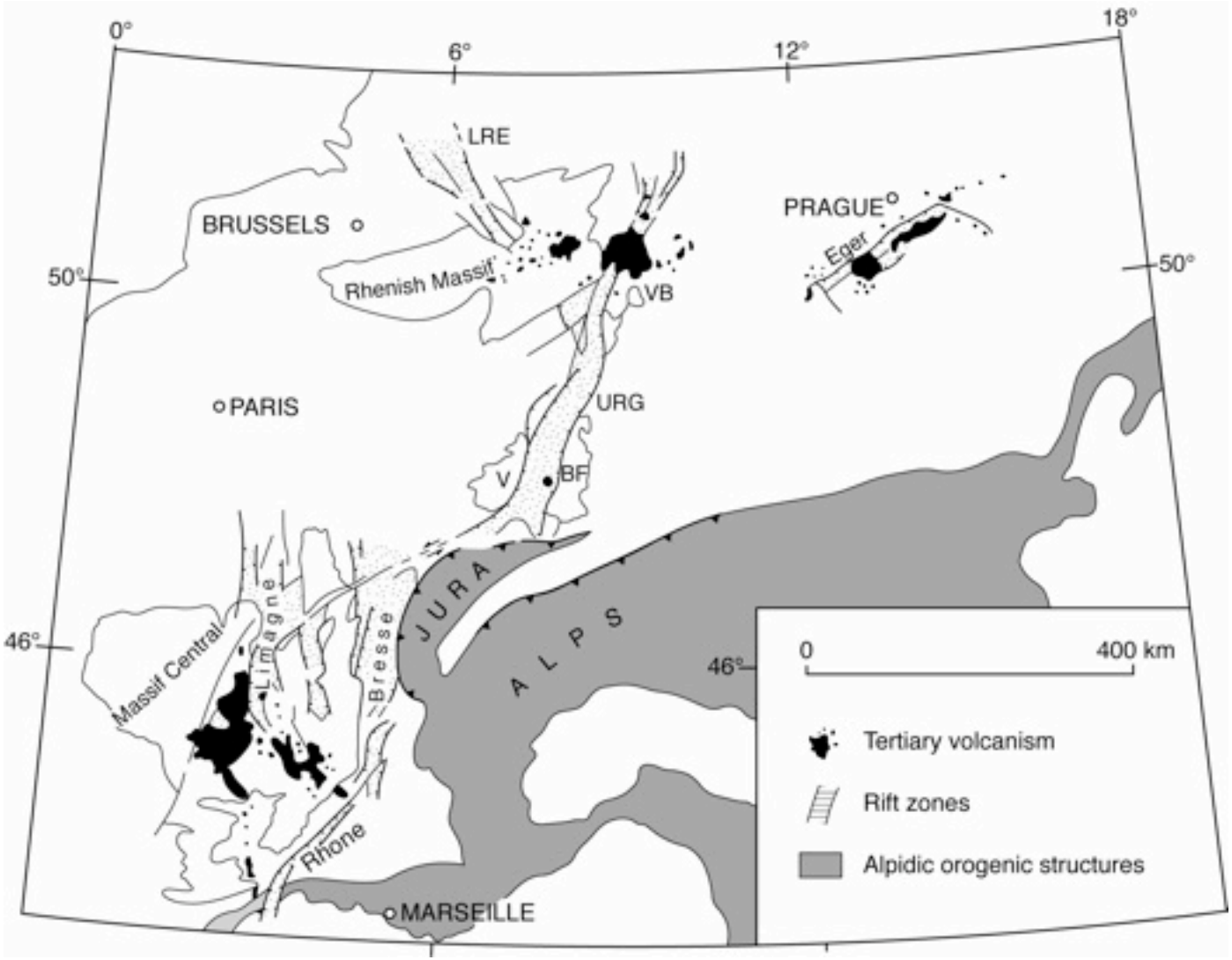

35° 30'
36° 00'
36° 30'
1° 00'
0° 30'
0° 00'
QUATERNARY SEDIMENTS
QUATERNARY RHYOLITES + BASALTS
QUATERNARY PYROCLASTIC DEPOSITS
PLEISTOCENE TRACHYTES
PLIO-PLEISTOCENE TRACHYTES
PLIOCENE FLOOD BASALTS
MIO-PLIOCENE PLATEAU TRACHYTES
MIO-PLIOCENE BASALTS
UPPER MIOCENE FLOOD PHONOLITES
MIDDLE MIOCENE PLATEAU PHONOLITES
MIOCENE MELANEPHELINITES
LOWER MIOCENE BASALTS
BASEMENT ROCKS
ELGEYO
MENENGAI
KINANGOP PLATEAU
KIPIPIRI
SATTIMA FAULT
LAKE NAIVASHA
MAU
NAIROBI
NGURUMA
TANZANIA
2° 00'

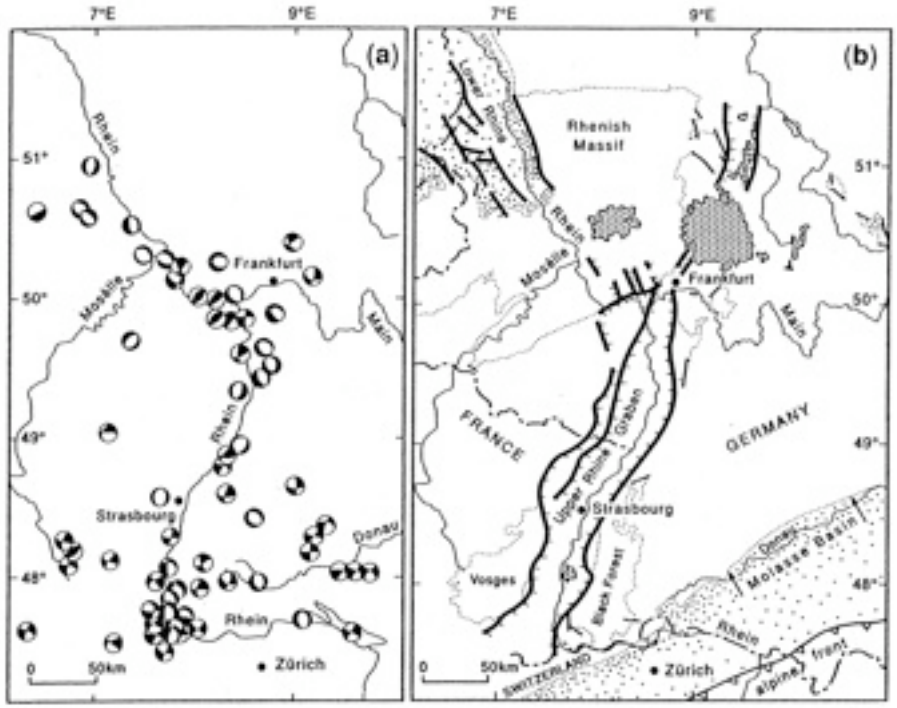
Basement-controlled transfer zones

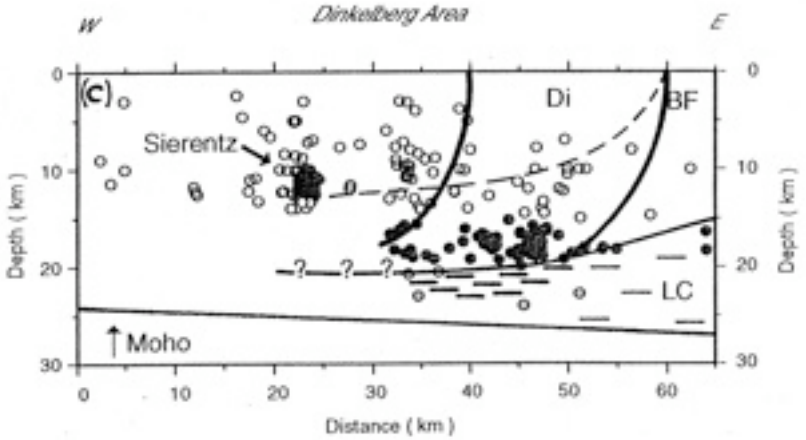


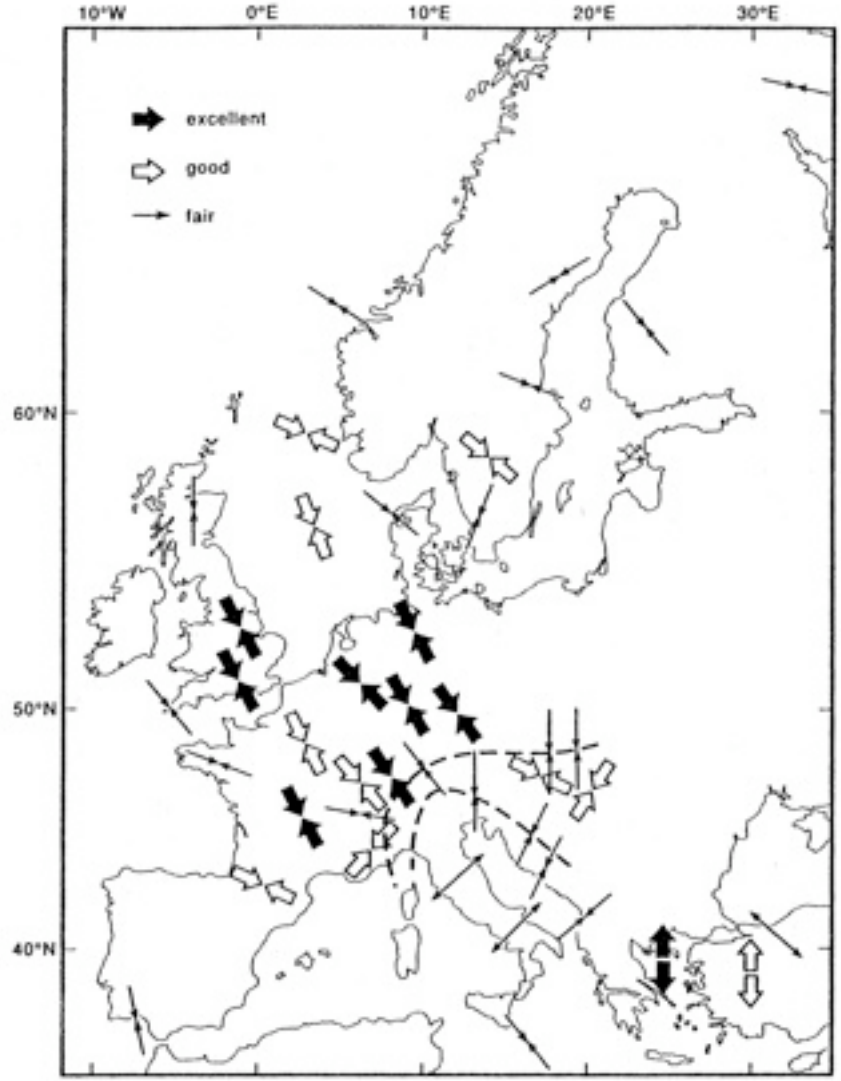


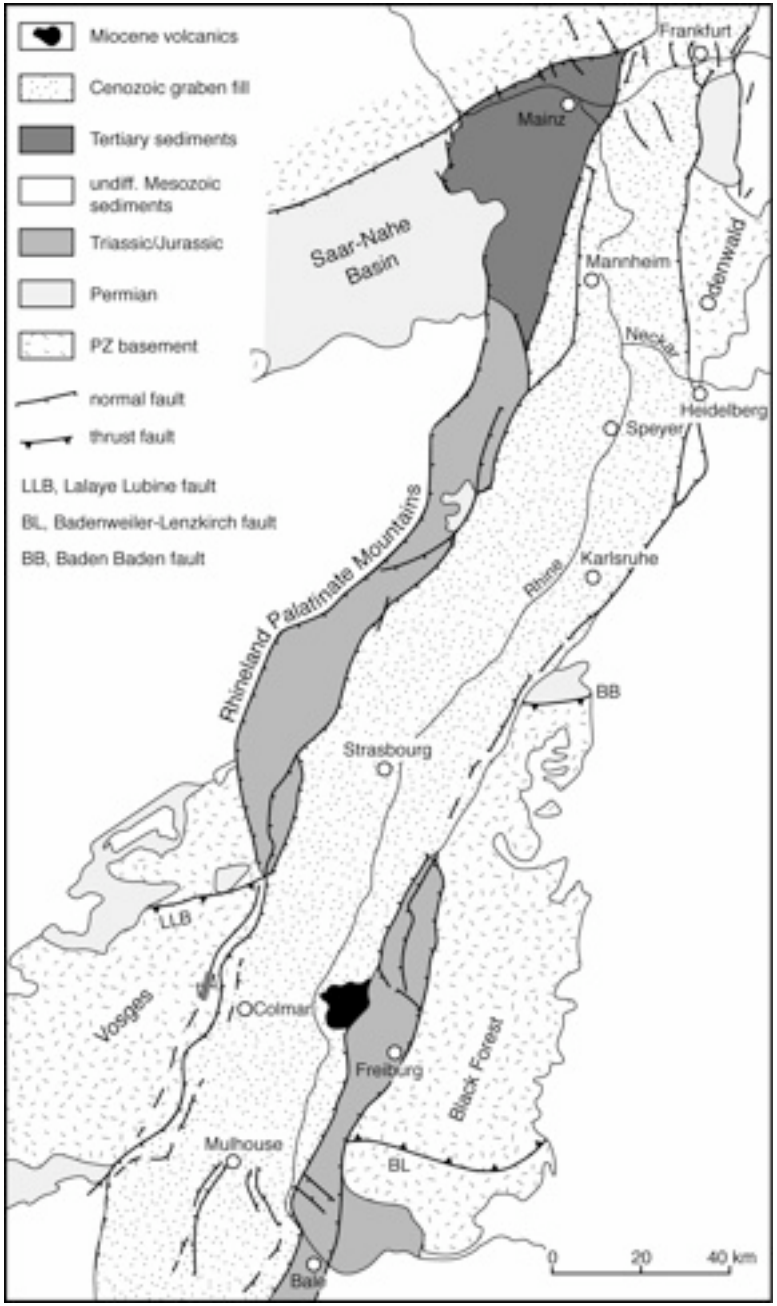
The Rheingraben Rift: a passive rift

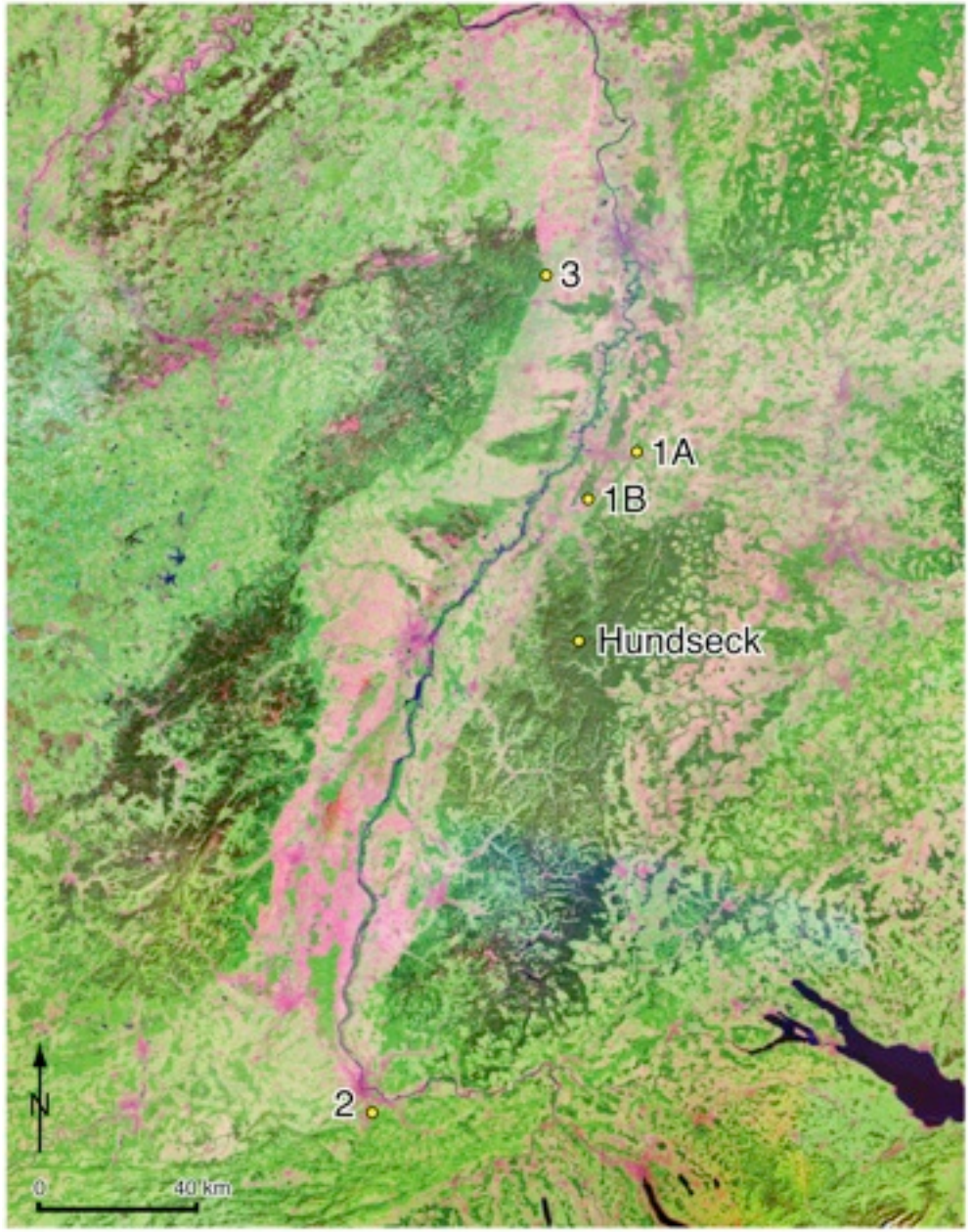


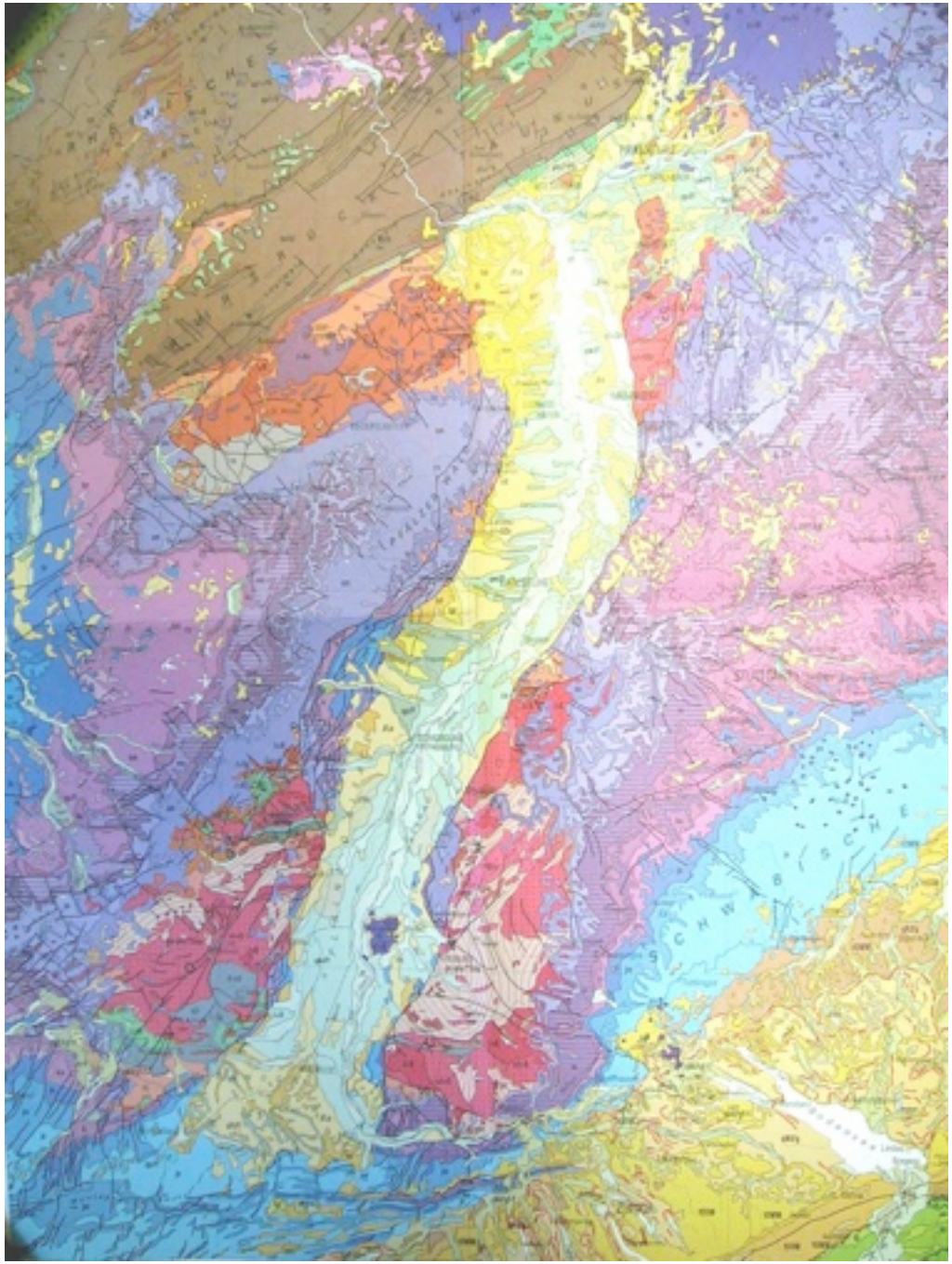

7°E
9°E
(a)
(b)
Rhein
Frankfurt
Mosel
Main
Strasbourg
Donau
Zürich
0
50km
Lower Rhine
Rhenish Massif
Upper Rhine Graben
FRANCE
GERMANY
Vosges
Black Forest
Molasse Basin
SWITZERLAND
alpine front

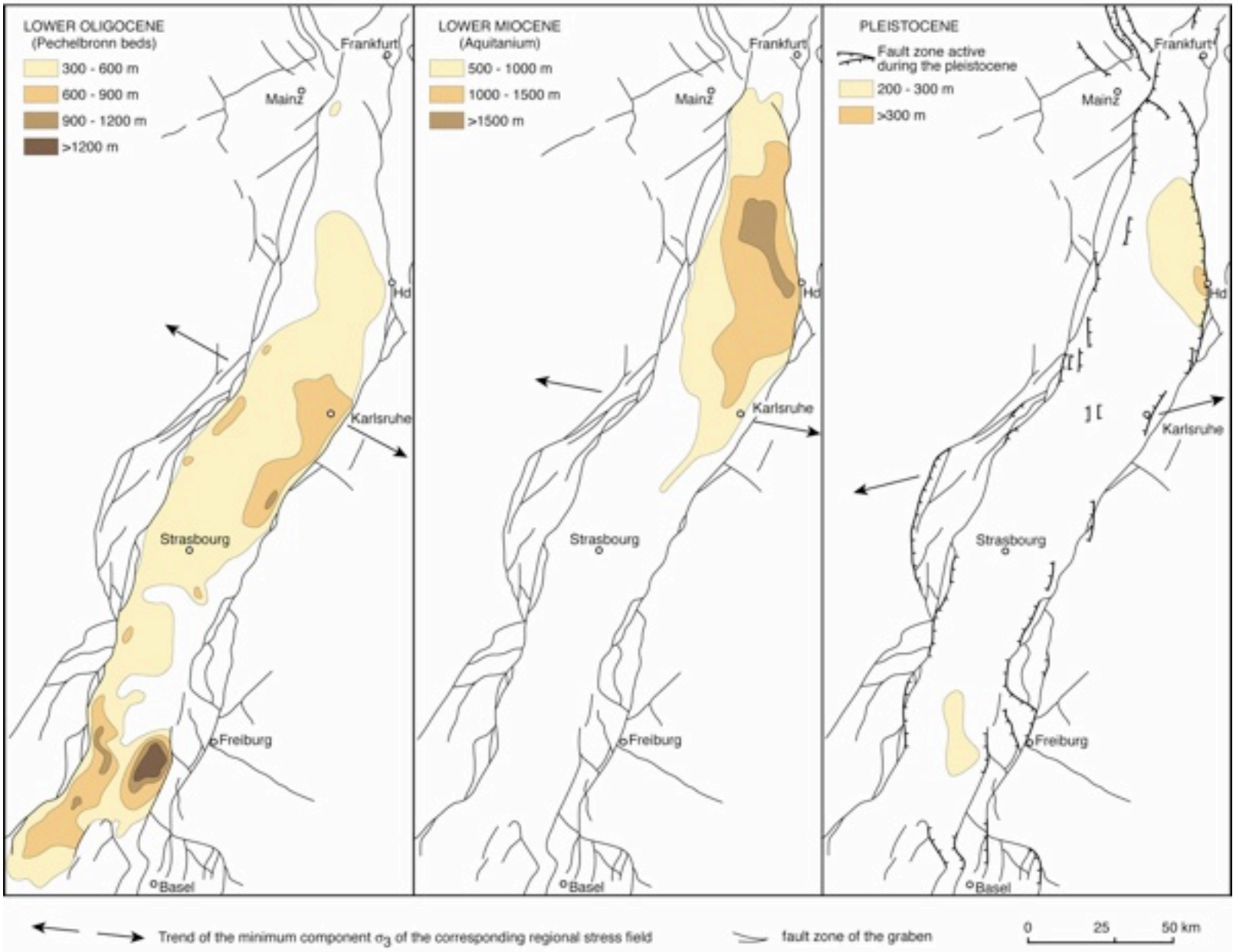

W
Dinkelberg Area
E
(c)
Sierentz
Di
BF
LC
Moho
Depth (km)
Distance (km)

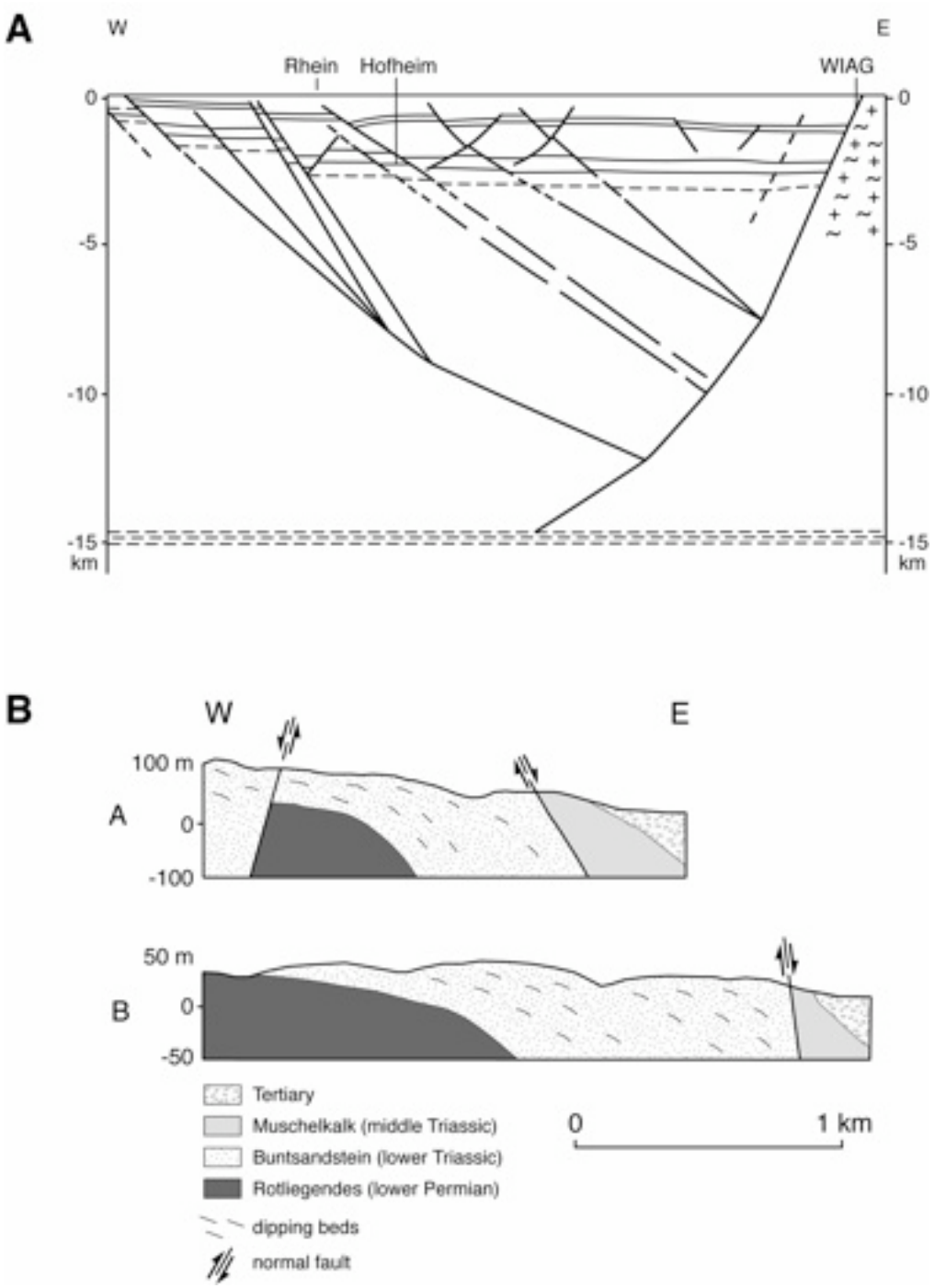

10°W
0°E
10°E
20°E
30°E
60°N
50°N
40°N
excellent
good
fair

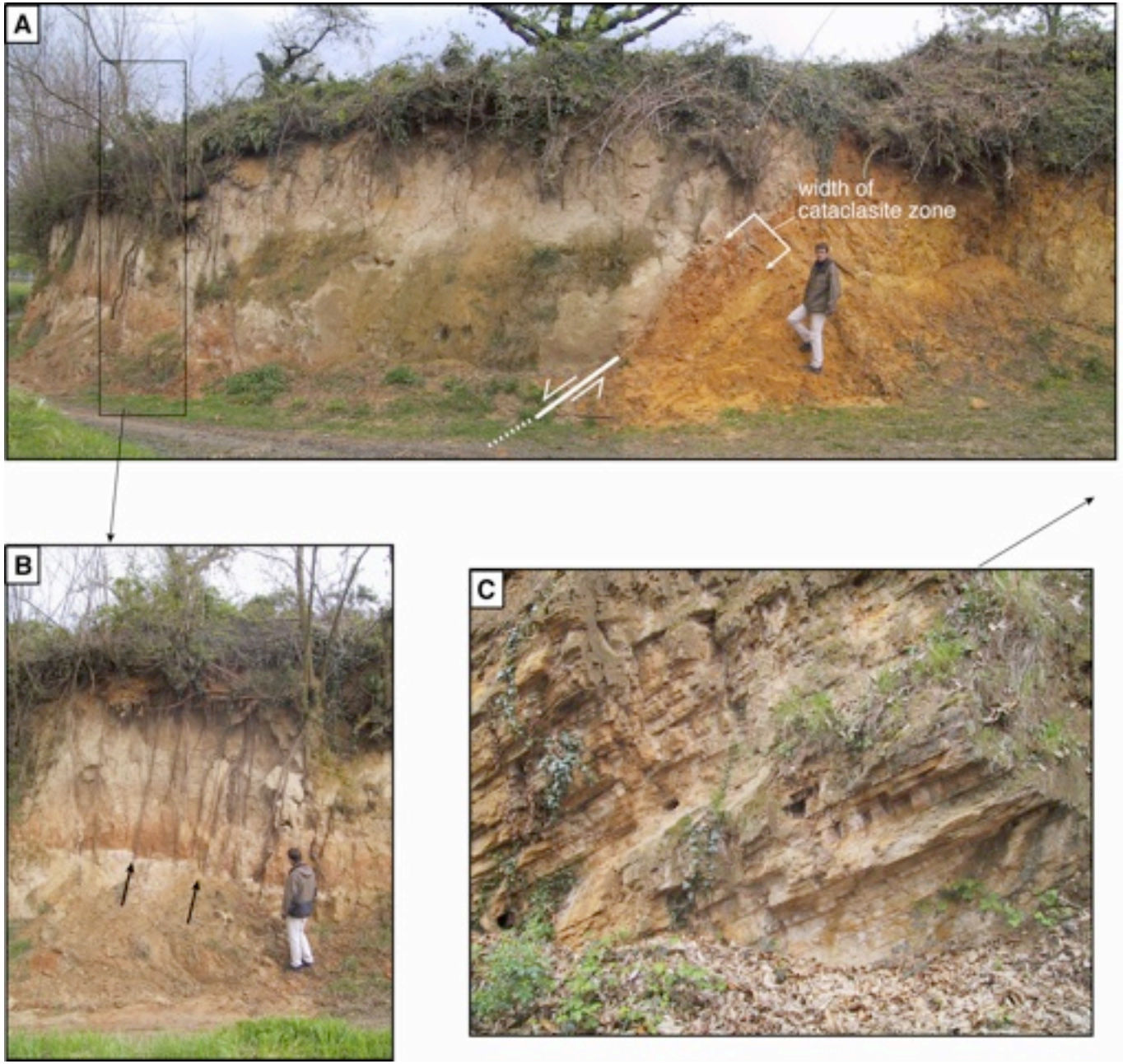

Miocene volcanics
Cenozoic graben fill
Tertiary sediments
undiff. Mesozoic sediments
Triassic/Jurassic
Permian
PZ basement
normal fault
thrust fault
LLB, Lalaye Lubine fault
BL, Badenweiler-Lenzkirch fault
BB, Baden Baden fault
Frankfurt
Mainz
Saar-Nahe Basin
Mannheim
Odenwald
Neckar
Heidelberg
Speyer
Rhineland Palatinate Mountains
Rhine
Karlsruhe
BB
Strasbourg
LLB
Vosges
Colmar
Freiburg
Black Forest
Mulhouse
BL
Basle
0
20
40 km

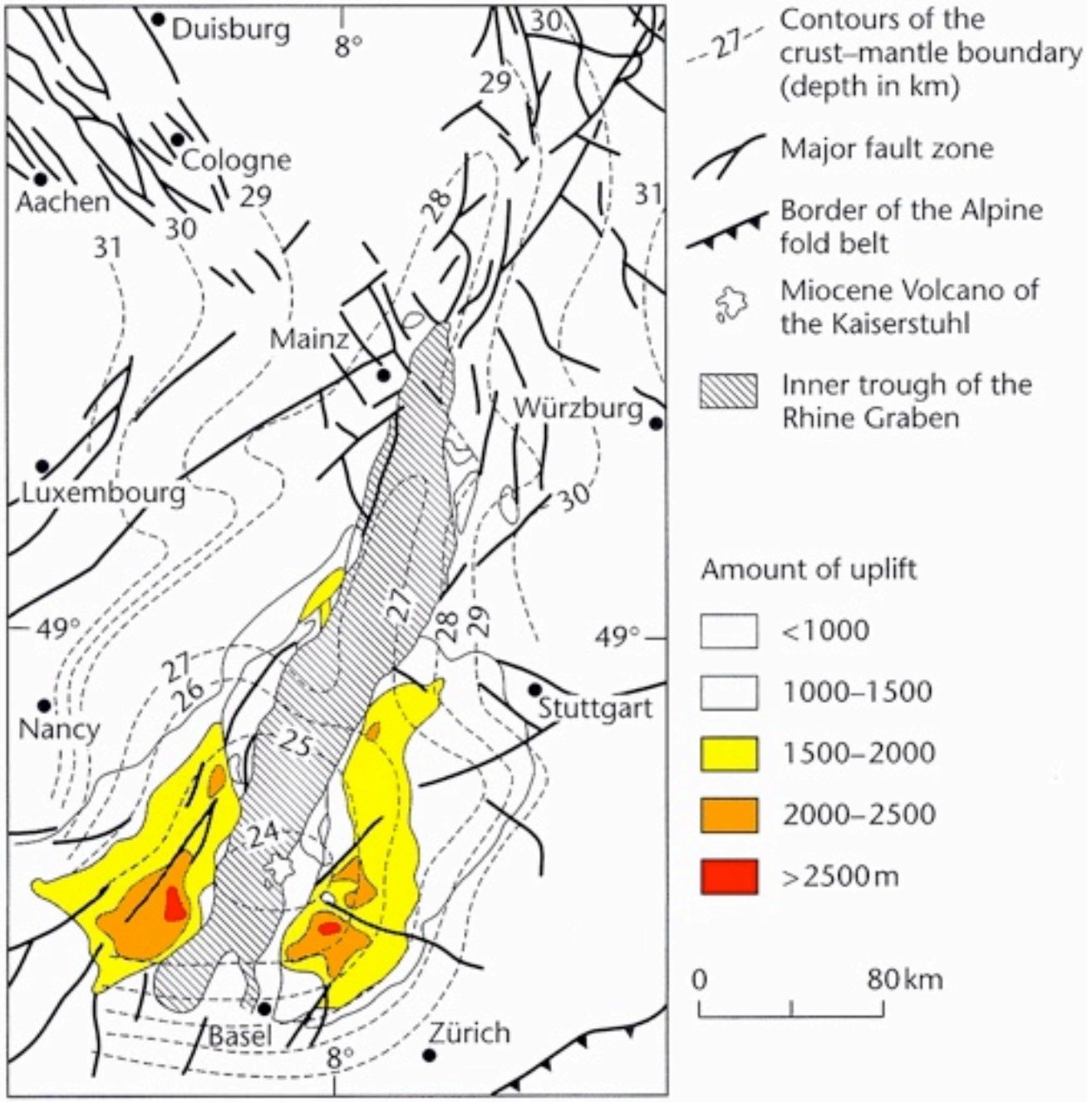

3
1A
1B
Hundseck
2
N
0
40 km



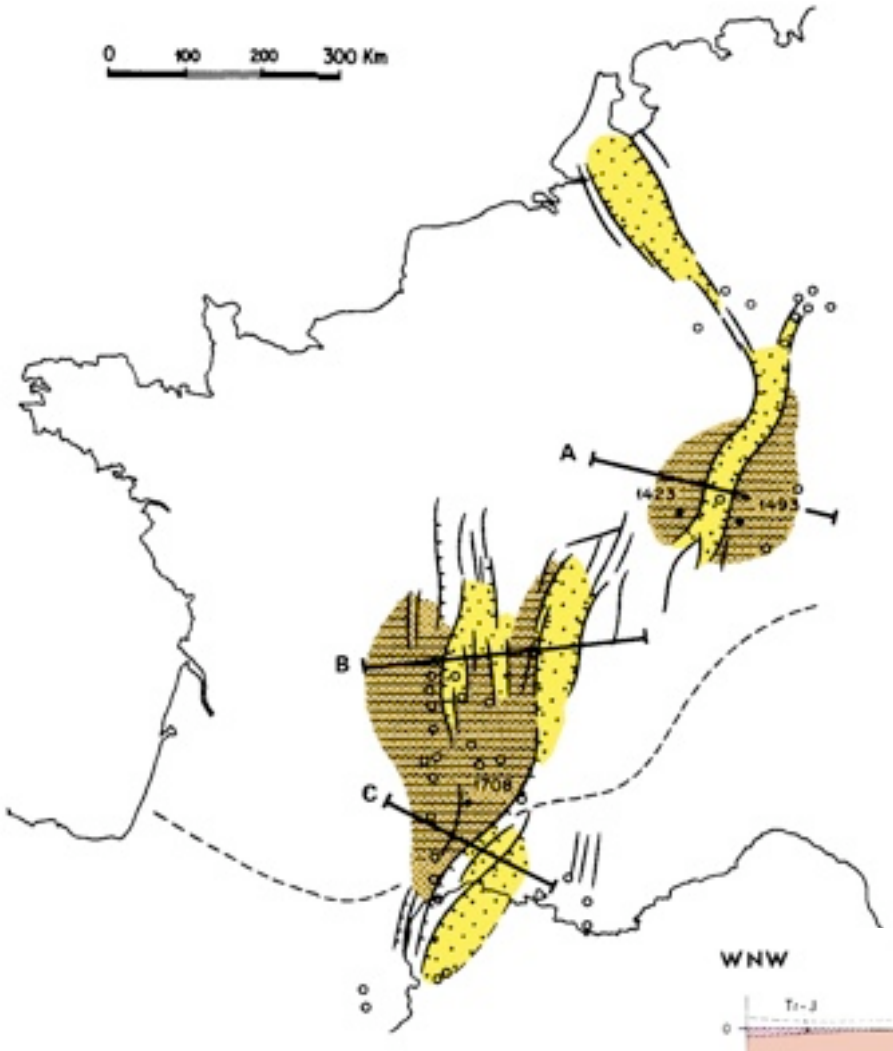

LOWER OLIGOCENE
(Pechelbronn beds)
300 - 600 m
600 - 900 m
900 - 1200 m
>1200 m
LOWER MIOCENE
(Aquitanium)
500 - 1000 m
1000 - 1500 m
>1500 m
PLEISTOCENE
Fault zone active during the pleistocene
200 - 300 m
>300 m
Frankfurt
Mainz
Hd
Karlsruhe
Strasbourg
Freiburg
Basel
Trend of the minimum component σ3 of the corresponding regional stress field
fault zone of the graben
0
25
50 km

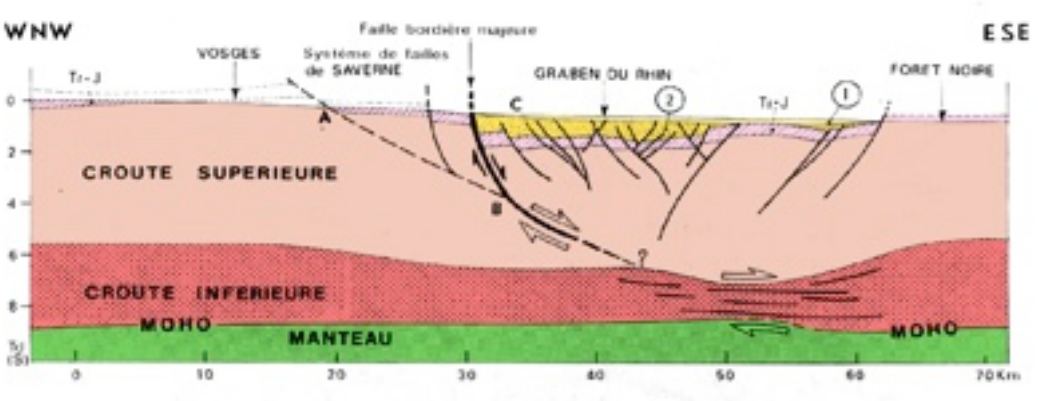

A
W
E
Rhein
Hofheim
WIAG
0
-5
-10
-15
km
B
W
E
100 m
A
0
-100
50 m
B
0
-50
Tertiary
Muschelkalk (middle Triassic)
Buntsandstein (lower Triassic)
Rotliegendes (lower Permian)
dipping beds
normal fault
0
1 km


A
width of
cataclasite zone
B
C

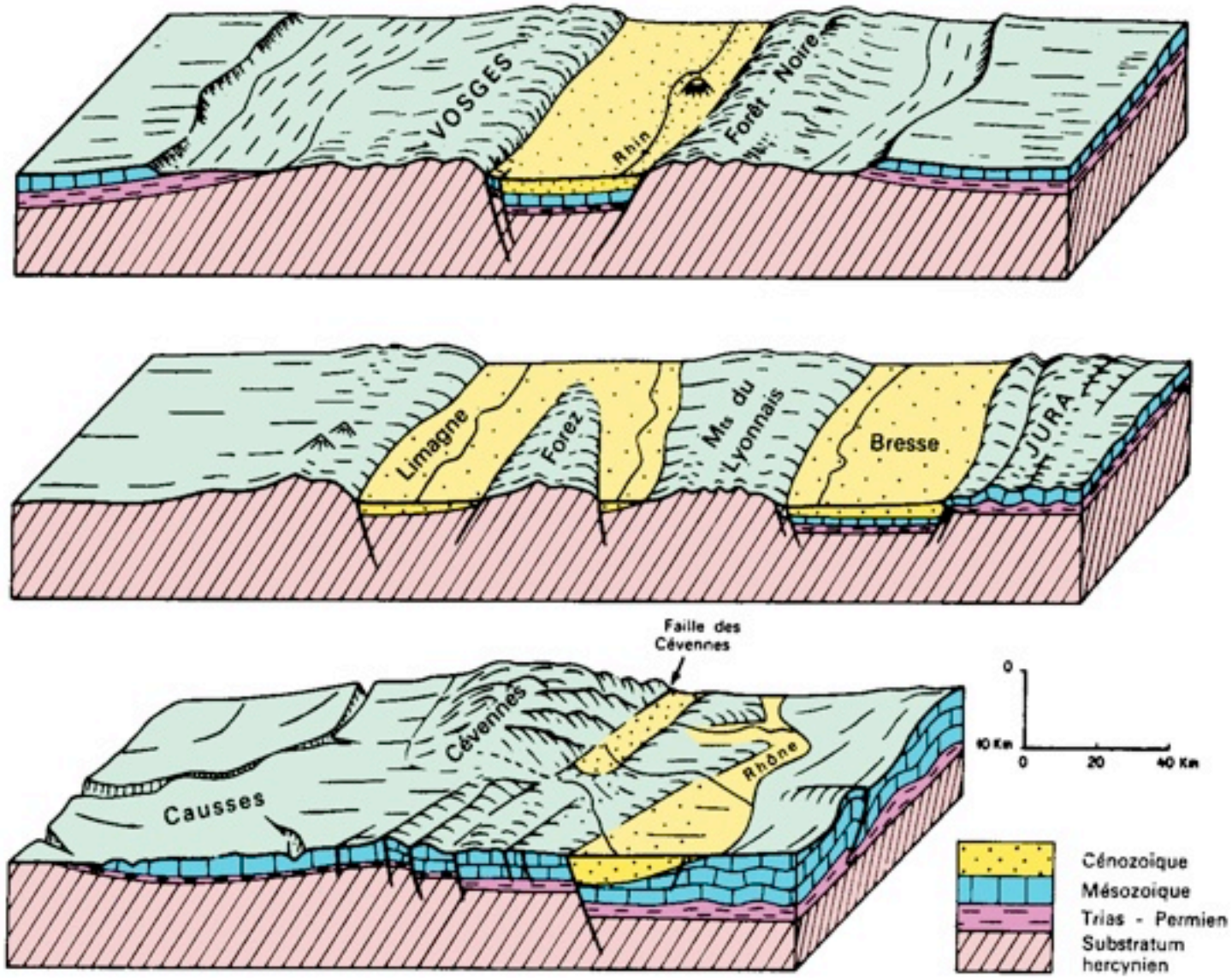

Duisburg
8°
30
29
Cologne
Aachen
29
28
31
30
31
Mainz
Würzburg
Luxembourg
30
49°
27
28
29
49°
27
26
Stuttgart
Nancy
25
24
Basel
Zürich
8°
27
Contours of the crust–mantle boundary (depth in km)
Major fault zone
Border of the Alpine fold belt
Miocene Volcano of the Kaiserstuhl
Inner trough of the Rhine Graben
Amount of uplift
<1000
1000–1500
1500–2000
2000–2500
>2500m
0
80km

Transfer zones

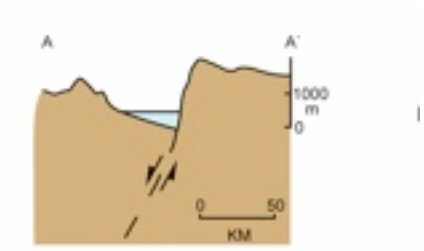


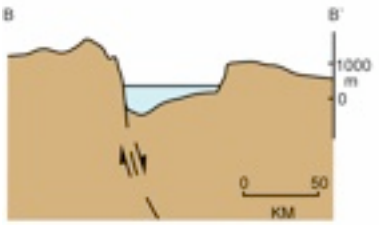


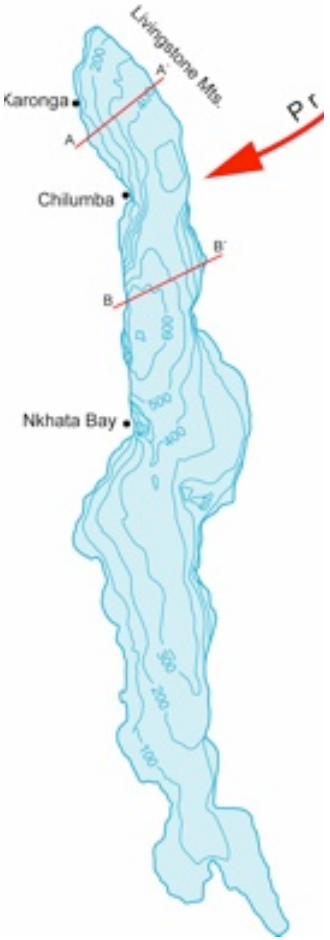
The Rhine Rift

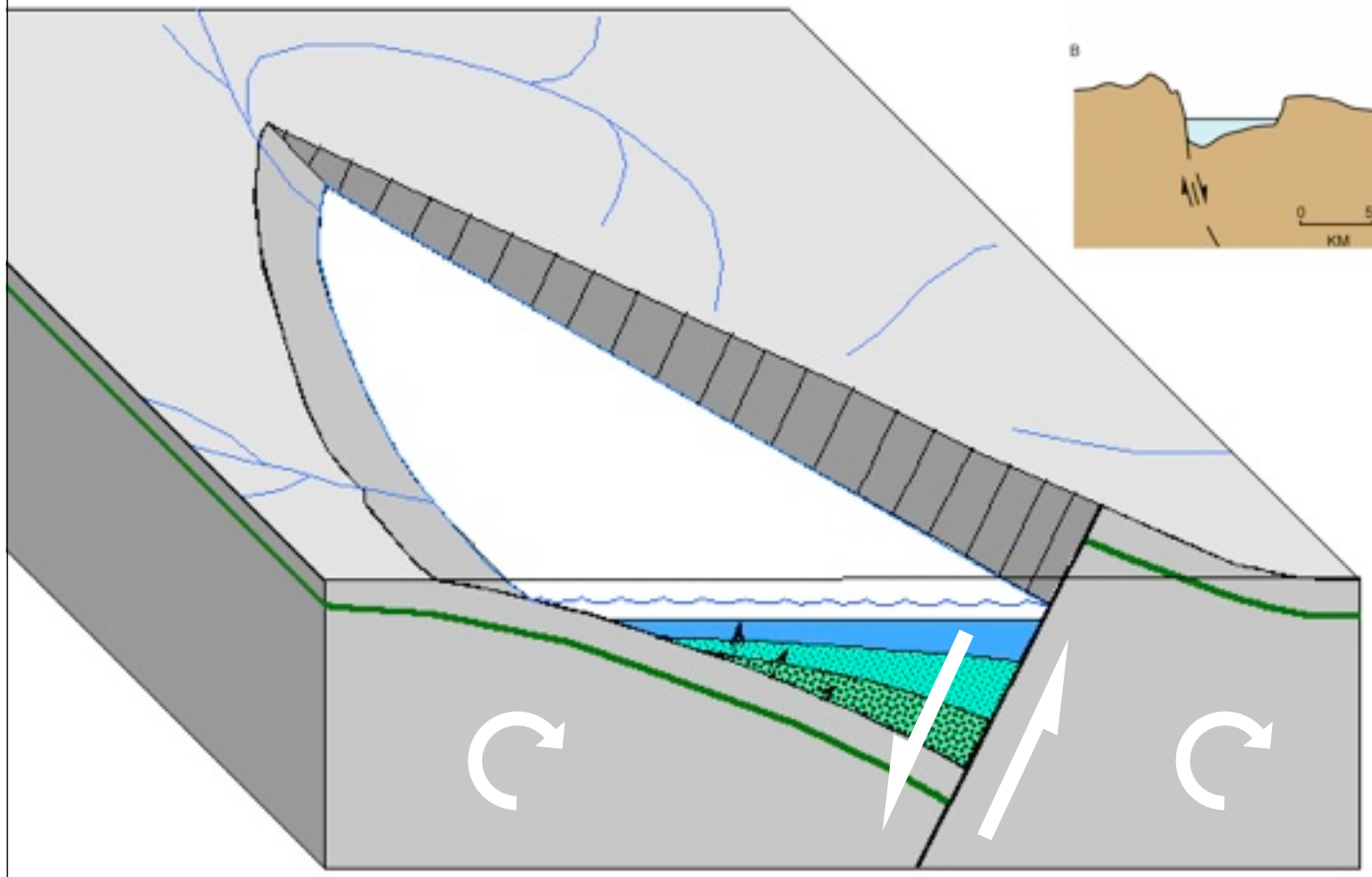


Lake Malawi: halfgraben with alternating polarity

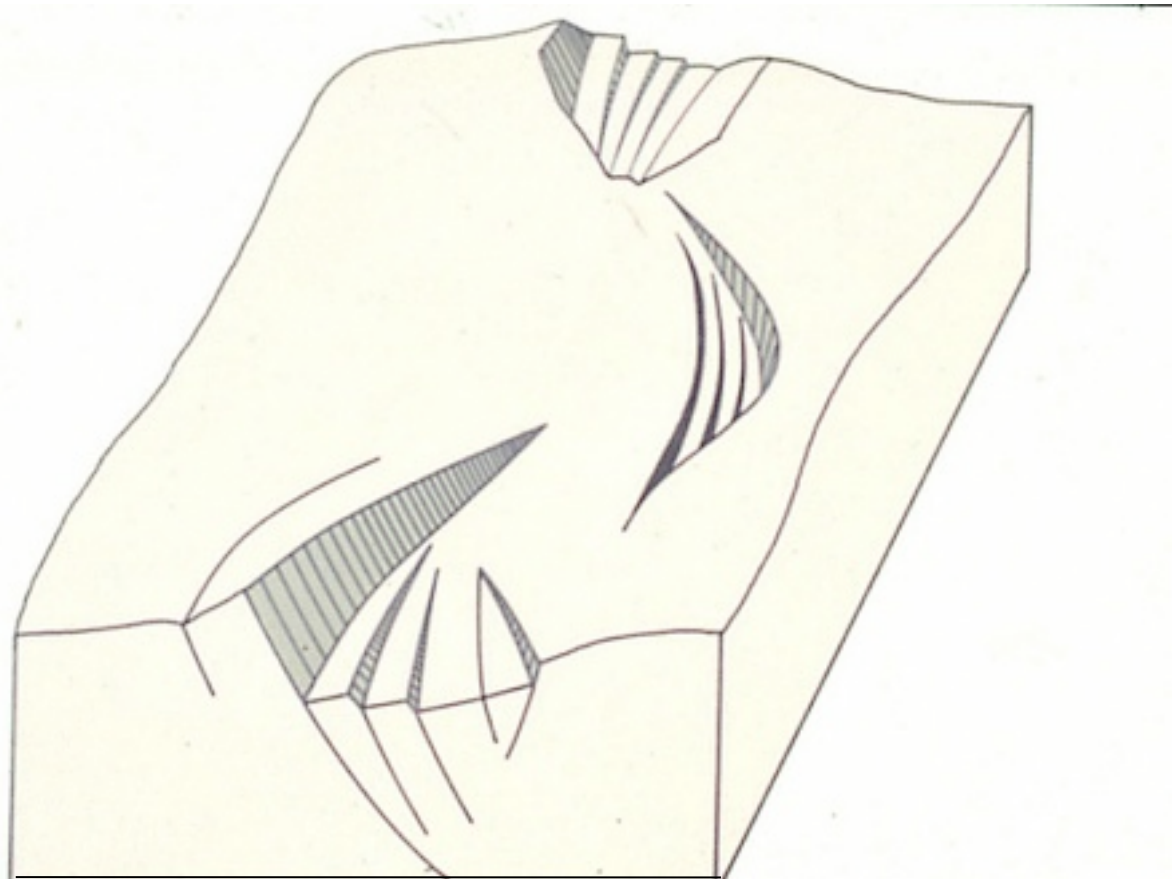


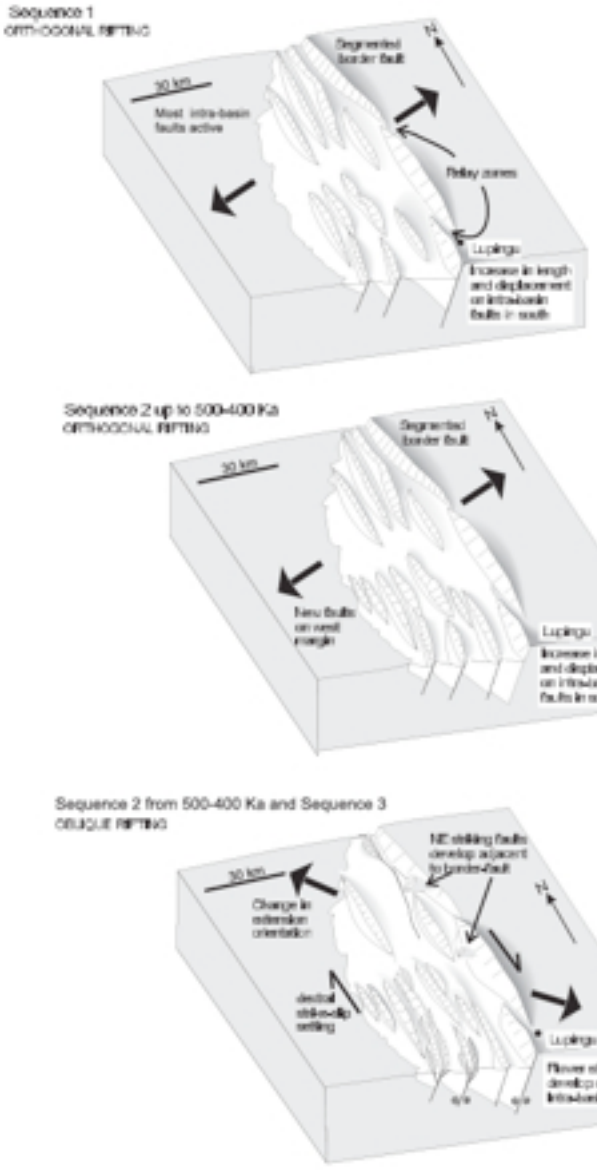




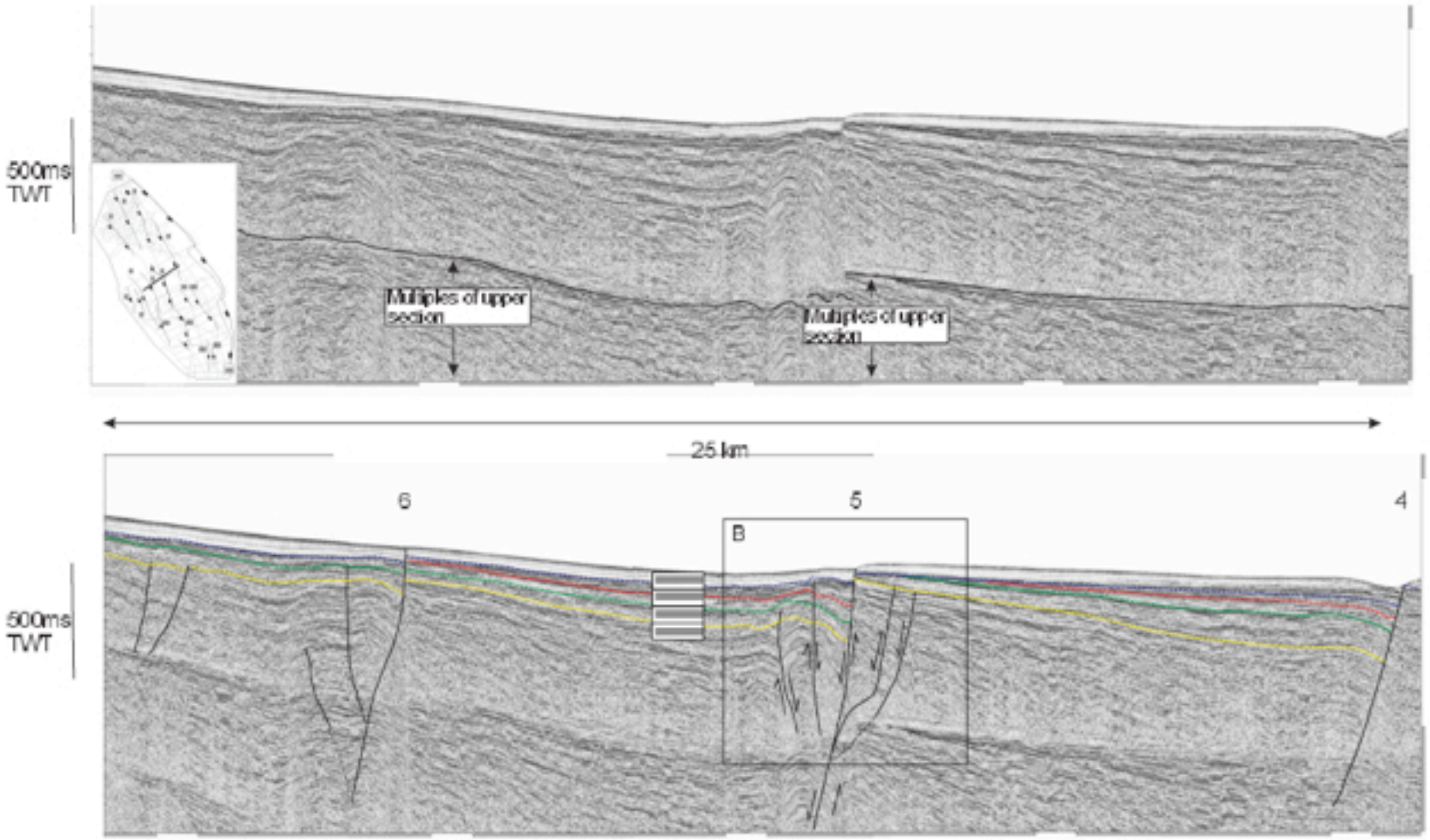


Lake Malawi



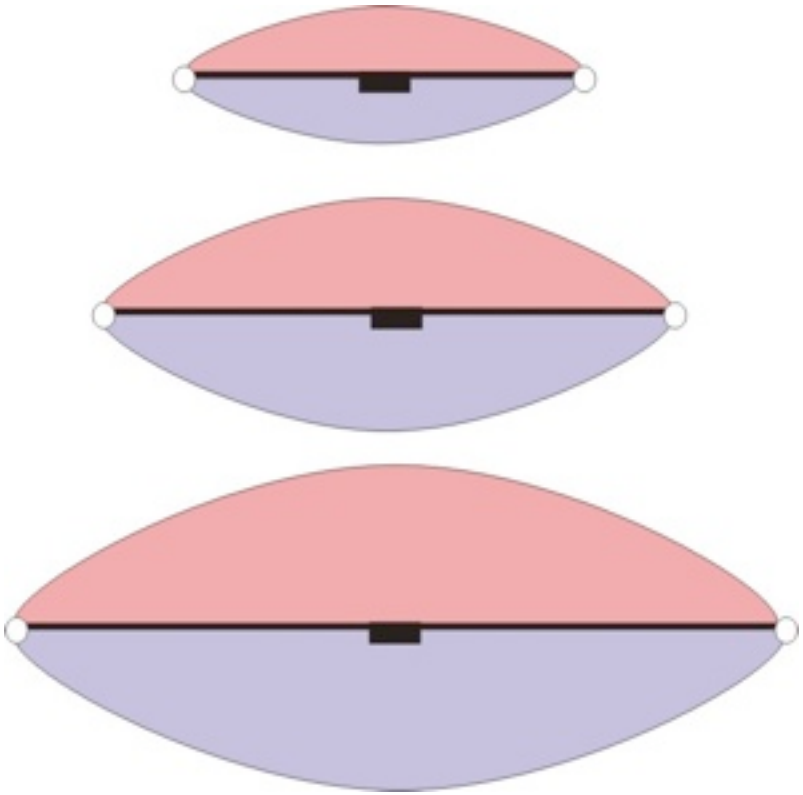

Sequence 1
ORTHOGONAL RIFTING
30 km
Most intra-basin faults active
Relay zones
Lupingu
Sequence 2 up to 500-400 Ka
ORTHOGONAL RIFTING
30 km
New faults on west margin
Lupingu
Sequence 2 from 500-400 Ka and Sequence 3
OBLIQUE RIFTING
30 km
Change in extension orientation
Lupingu


Arabian Peninsula
Red Sea
AFRICA
Gulf of Aden
Afar Lowlands
Indian Ocean
Rift valeys
Lake Victoria
Mt. Kenya
Mt. Kilimanjaro
Lake Tanganyika

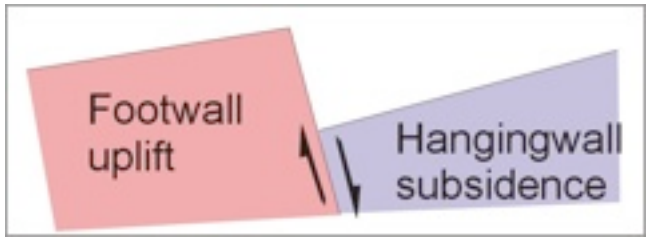

500ms
TWT
Multiples of upper section
Multiples of upper section
25 km
6
5
4
B
500ms
TWT

Isolated fault growth by radial tip propagation

Plan view



Fw uplift generally < Hw subsidence

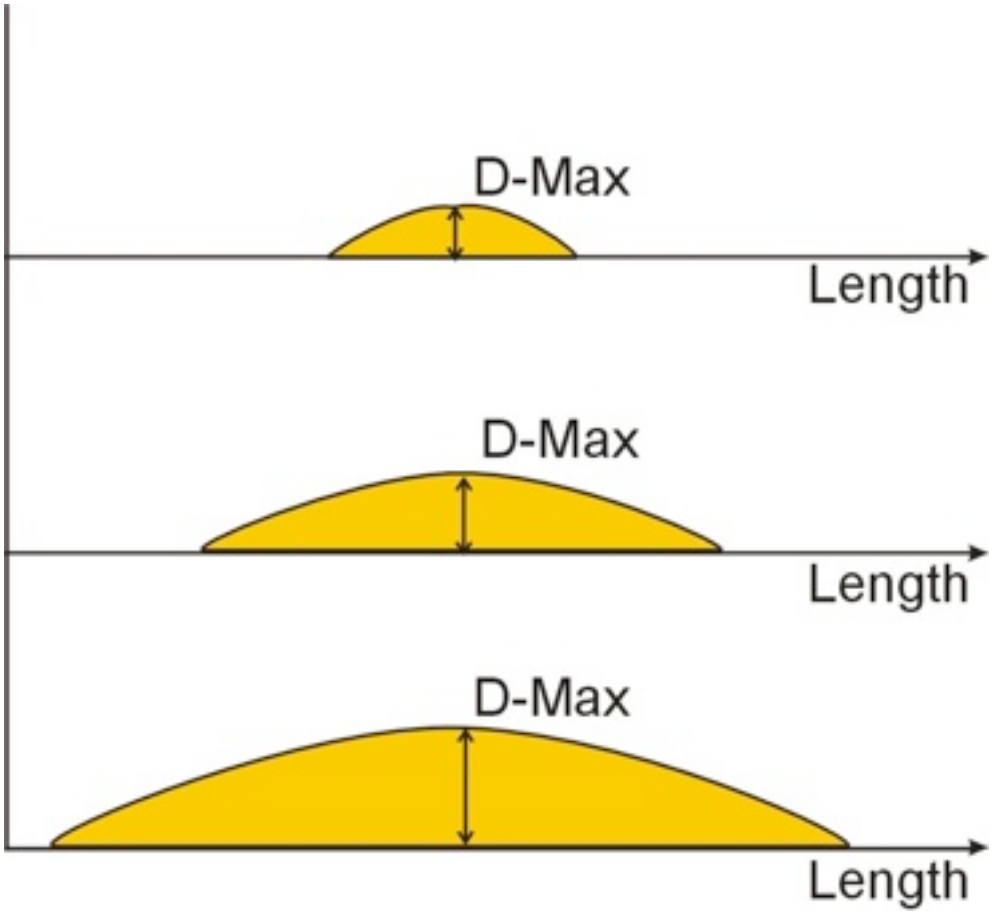


Area affected by footwall uplift

Area affected by
hanging wall subsidence

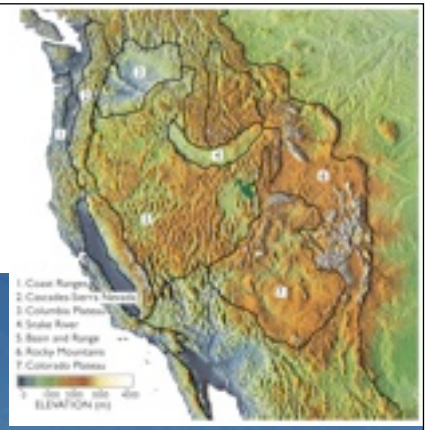
Isolated fault growth by radial tip propagation: D-L scaling

•Fault development with characteristic bell-shaped D-L (displacement-length) profiles

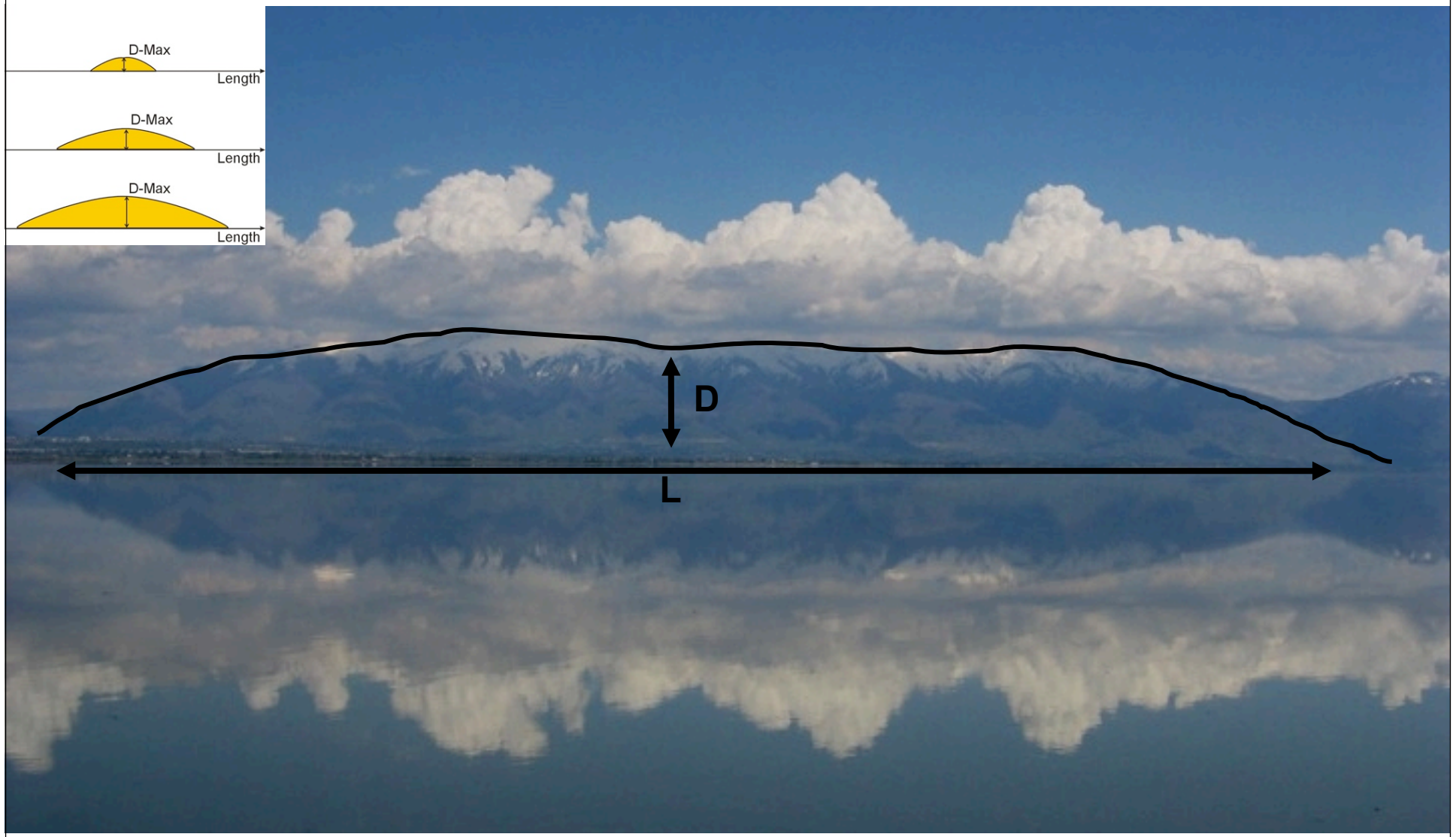


After Cartwright, Trudgill, Mansfield, 1995

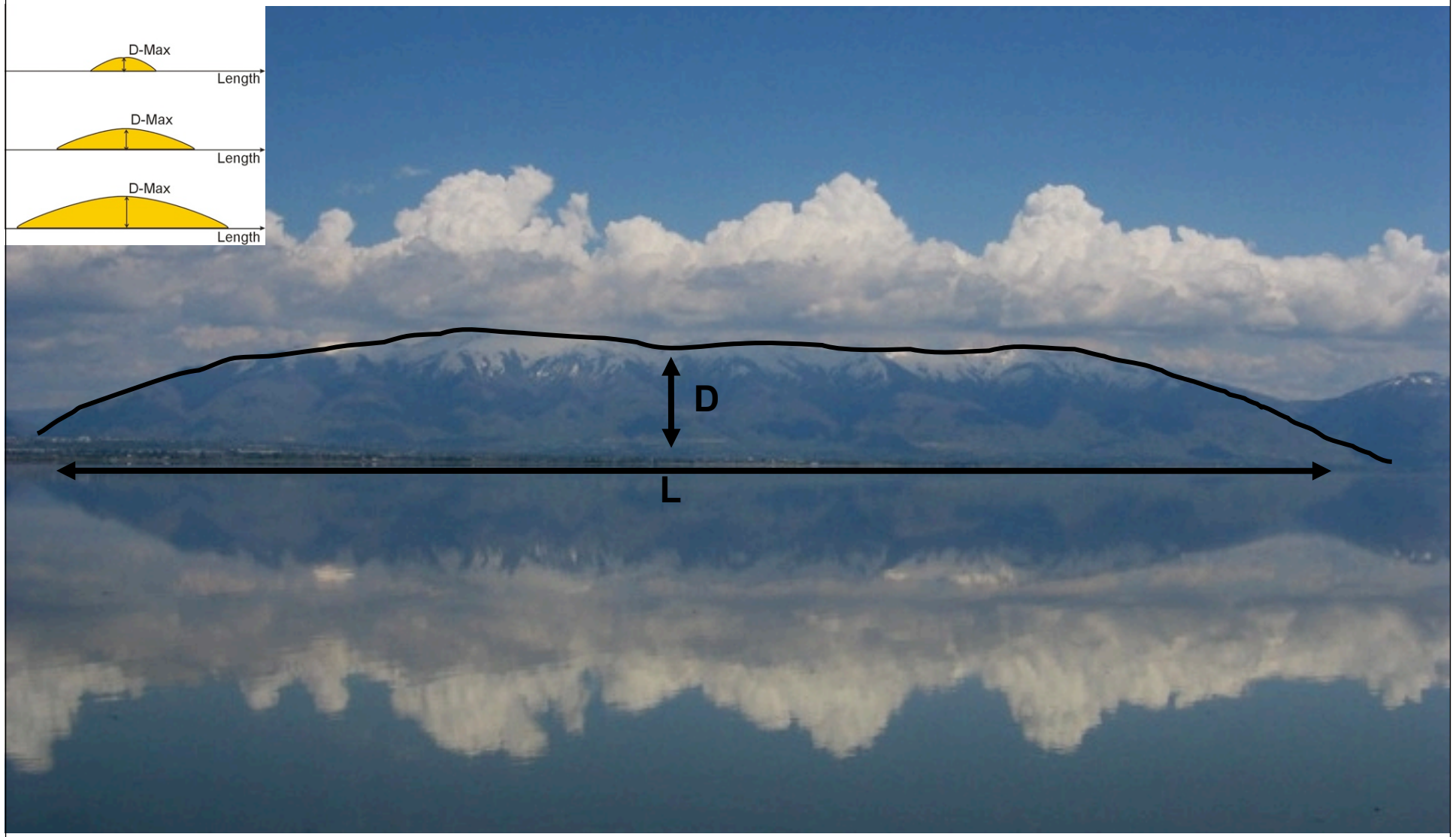
Wasatch Fault, Utah



Wasatch Fault, Utah

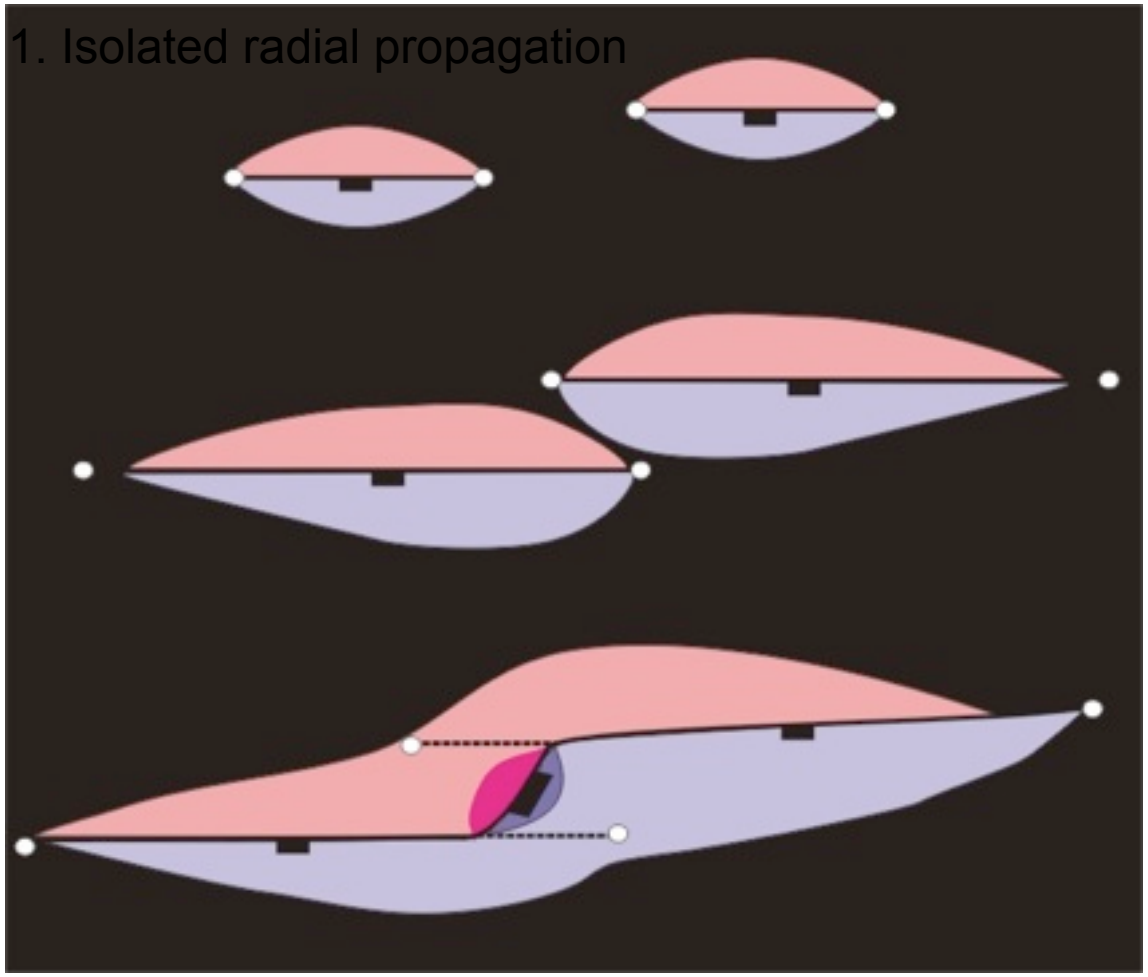


Wasatch Fault, Utah

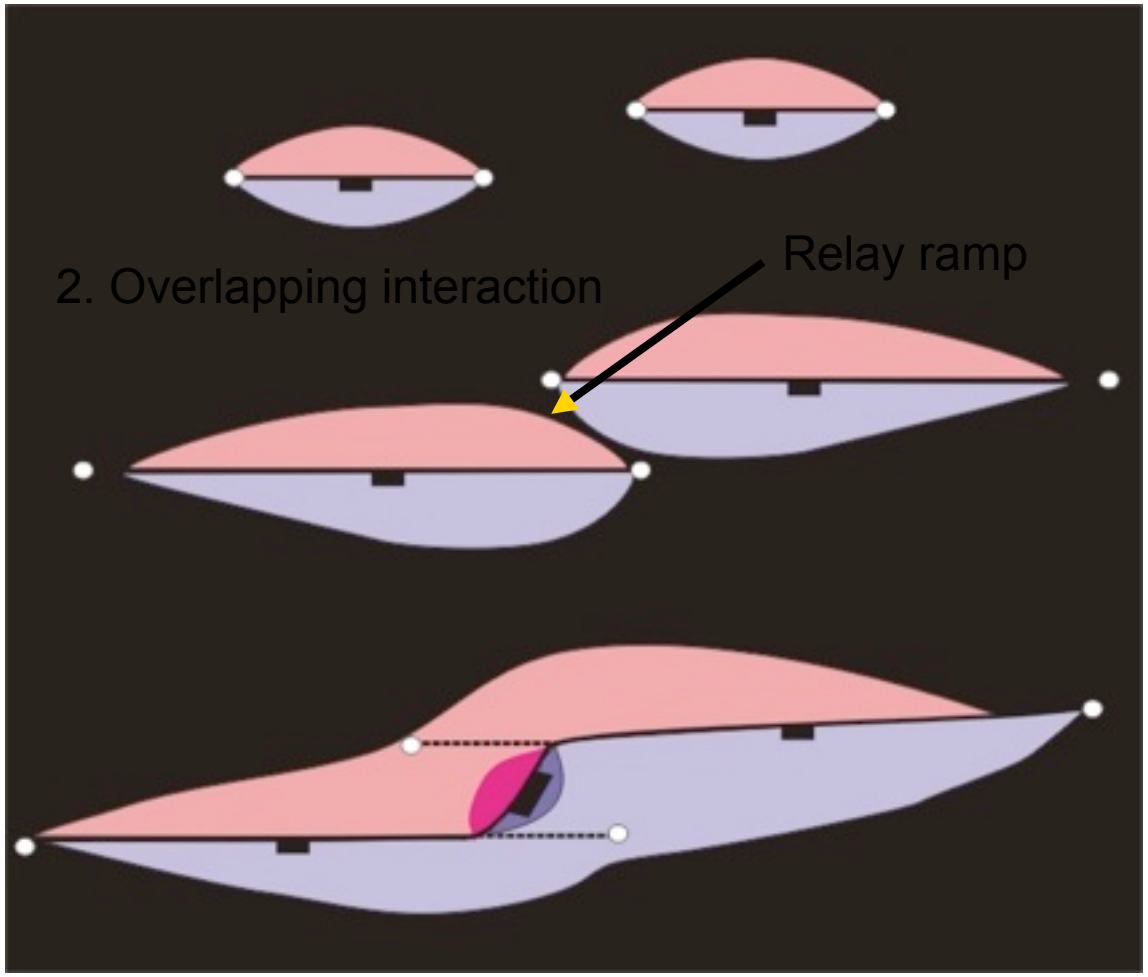


Wasatch Fault array

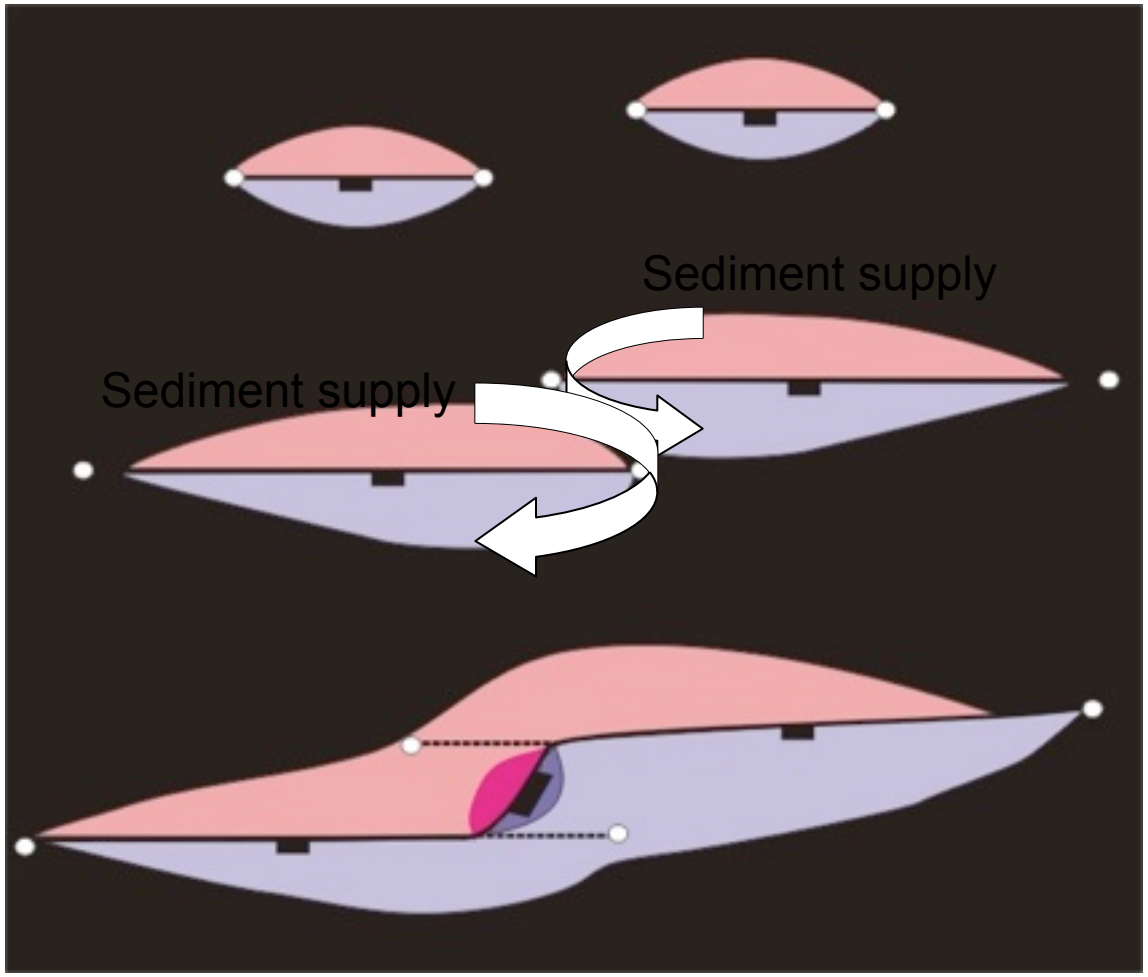
Segment linkage model



Segment linkage model



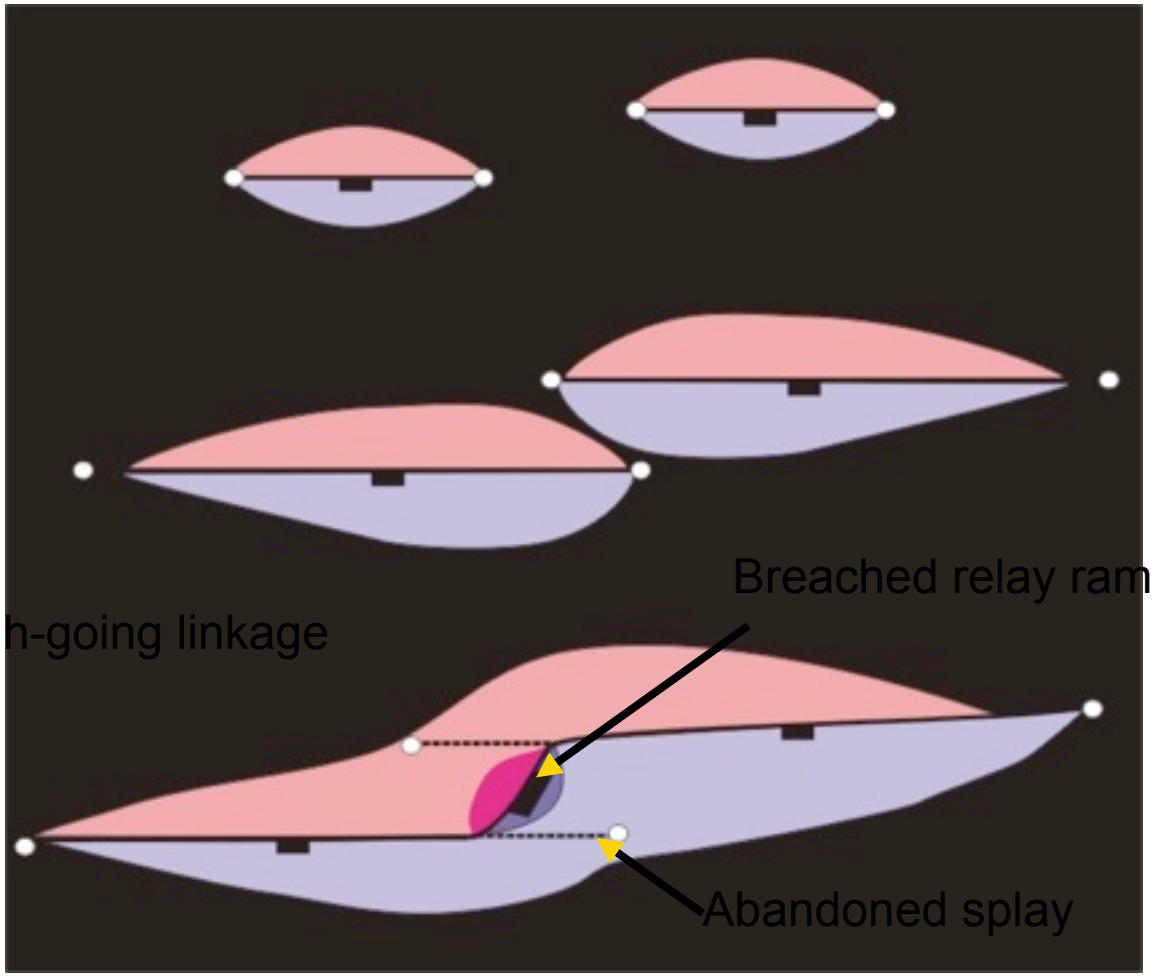
Segment linkage model



Relay ramps can be important in sediment supply

Segment linkage model

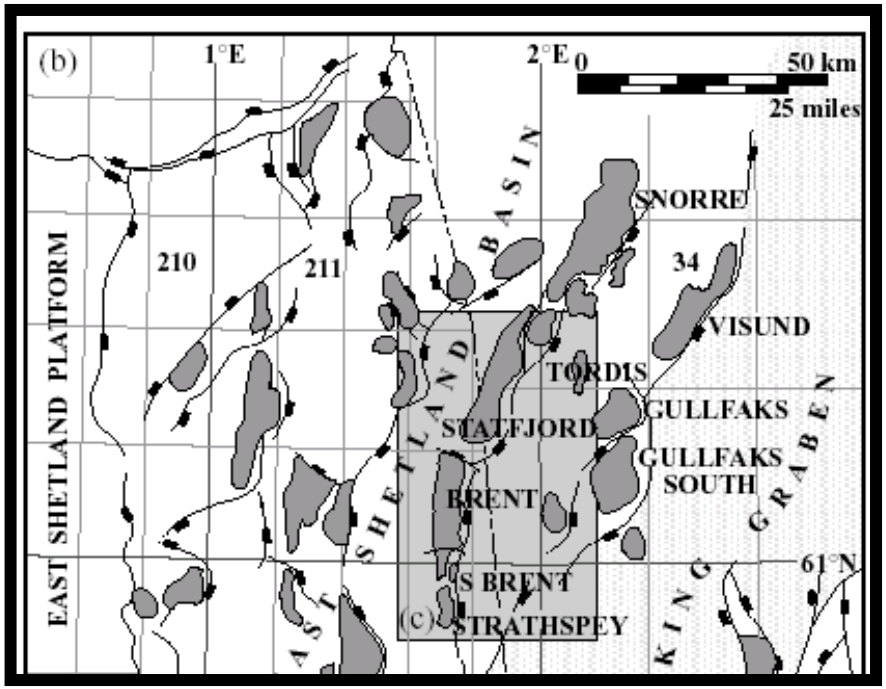
3. Through-going linkage



Normal fault growth

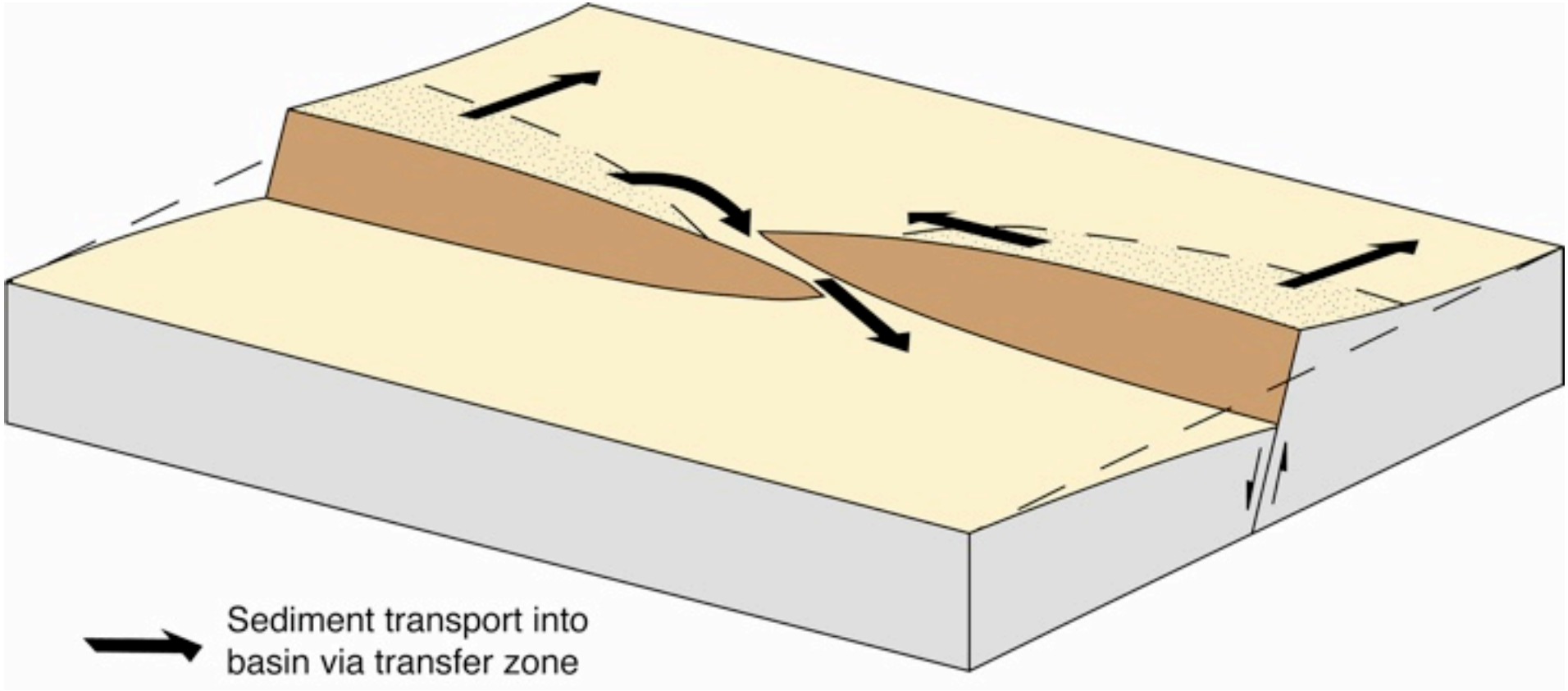
- Many studies (field, sub-surface, analogue, numerical) suggest that extensional systems show a complex interplay of linkage and propagation

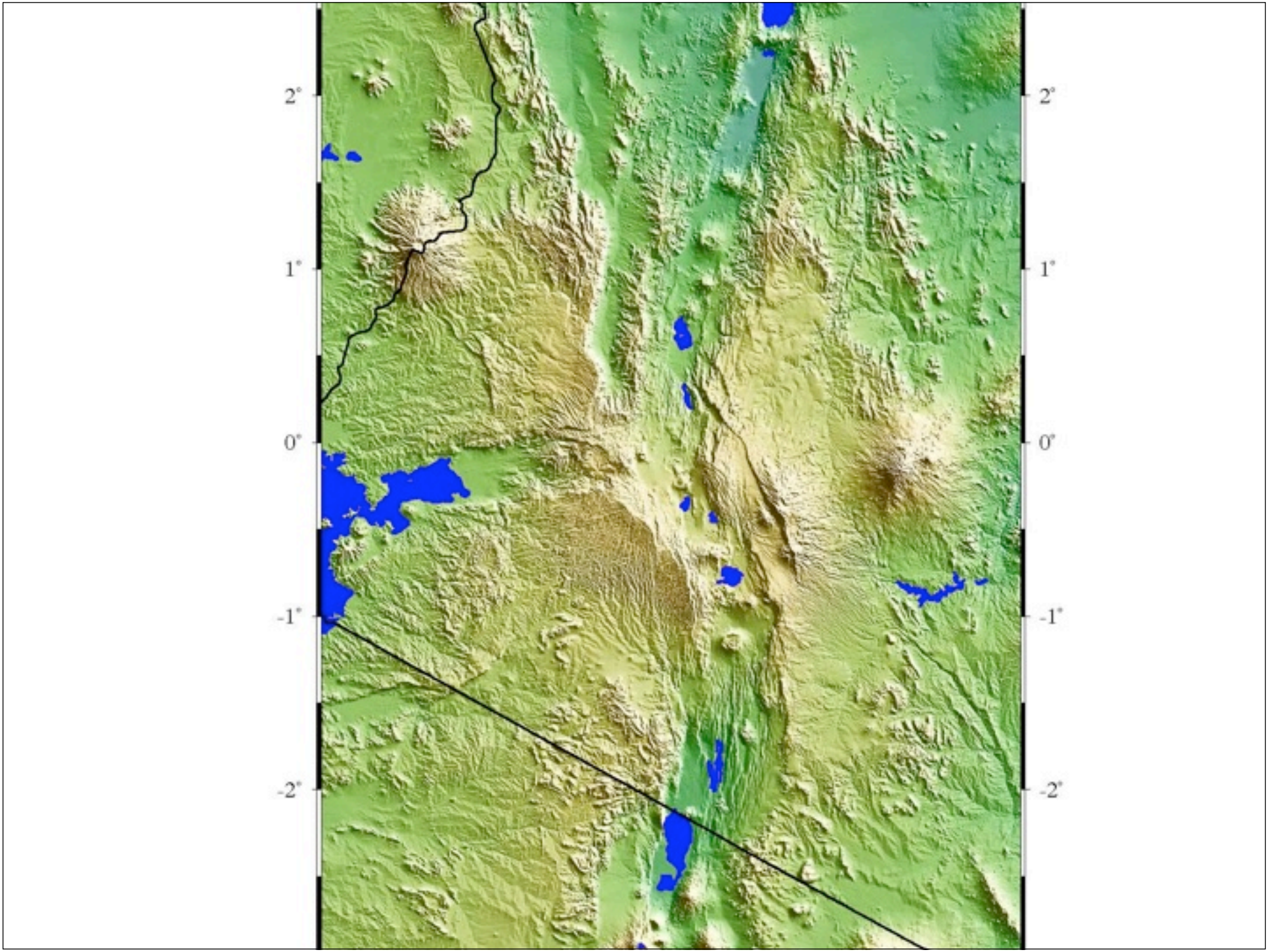
Volcanic Tablelands
Dawers et al., 1993

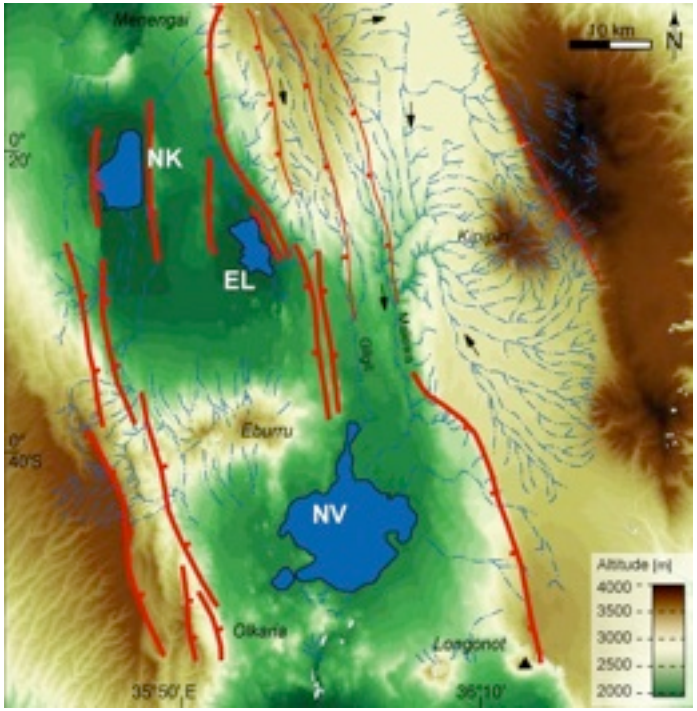


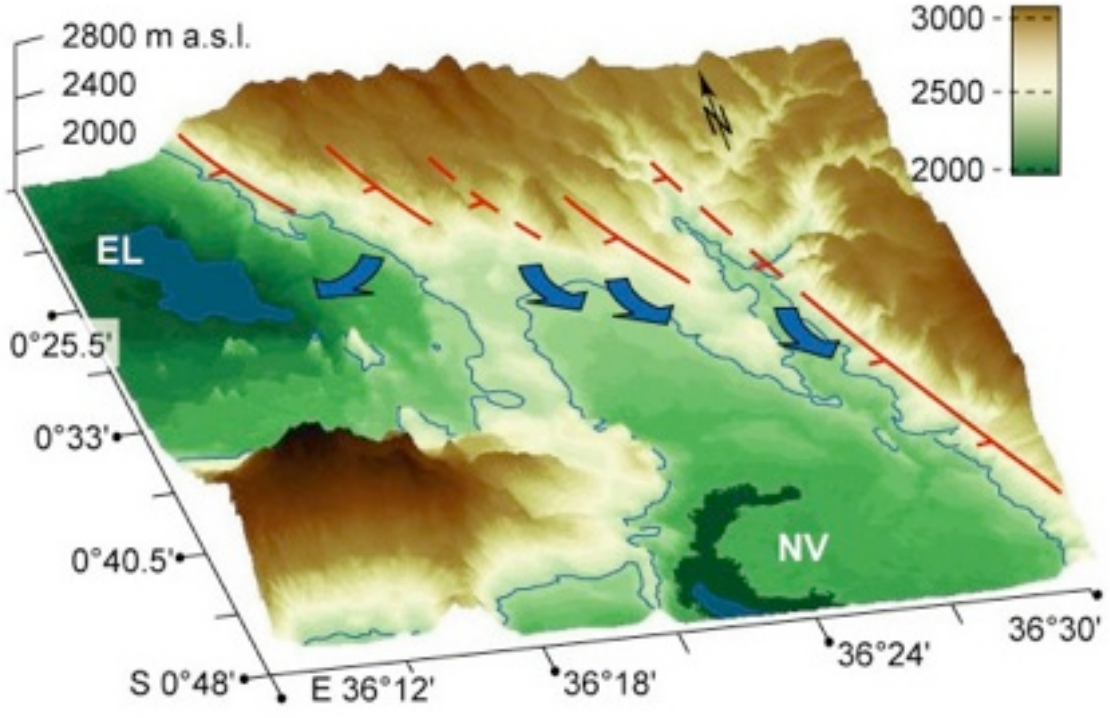
North Sea Basin

Sedimentation in normal-faulting environments




2°
1°
0°
-1°
-2°
2°
1°
0°
-1°
-2°

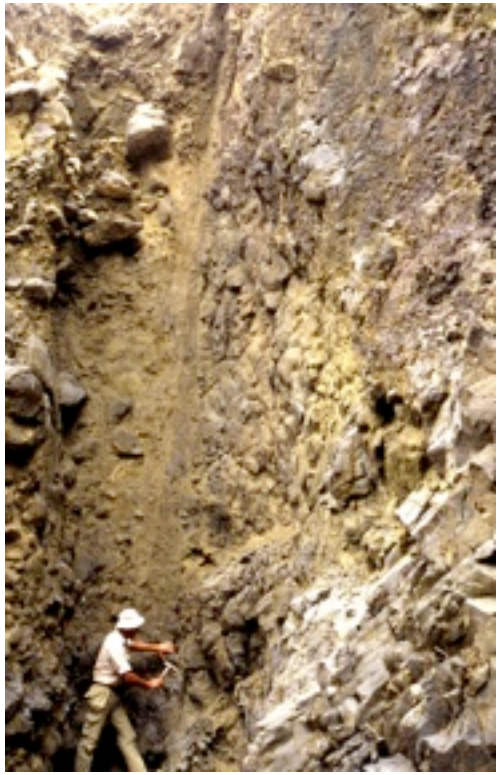

Menengai
10 km
N
0°
20'
NK
EL
Kijabe
Uasin
Gishu
0°
40'S
Eburru
NV
Altitude [m]
4000
3500
3000
2500
2000
Olkaria
Longonot
35°50' E
36°10'

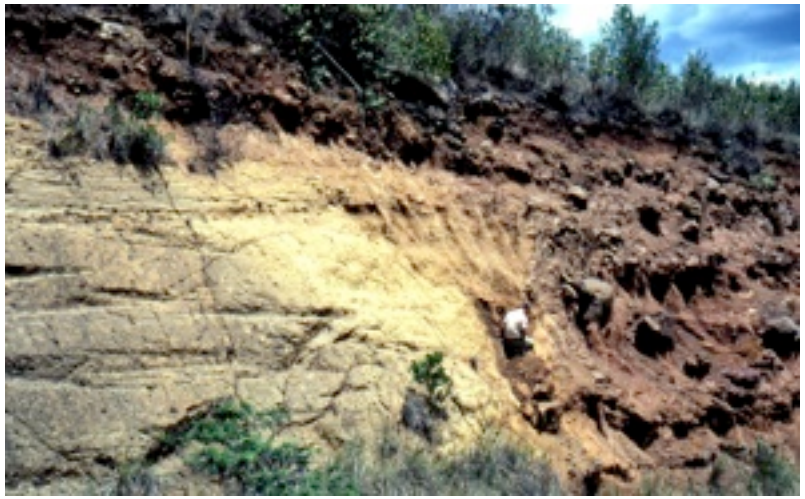

2800 m a.s.l.
2400
2000
3000
2500
2000
N
EL
0°25.5'
0°33'
0°40.5'
NV
S 0°48'
E 36°12'
36°18'
36°24'
36°30'

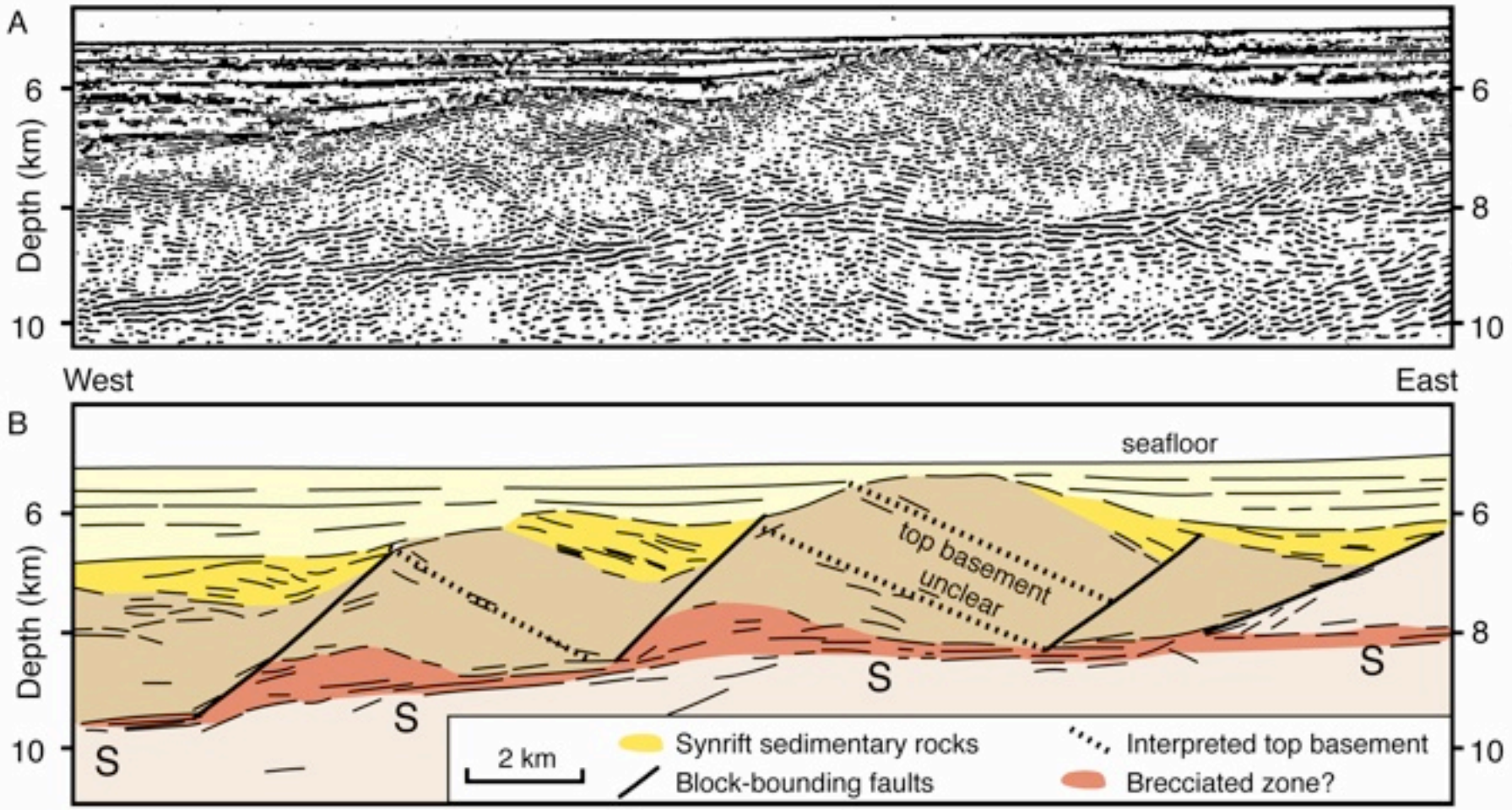
Streckungsmodelle, Abschiebungsgeometrien

Von kontinentalen zu ozeanischen Rifts

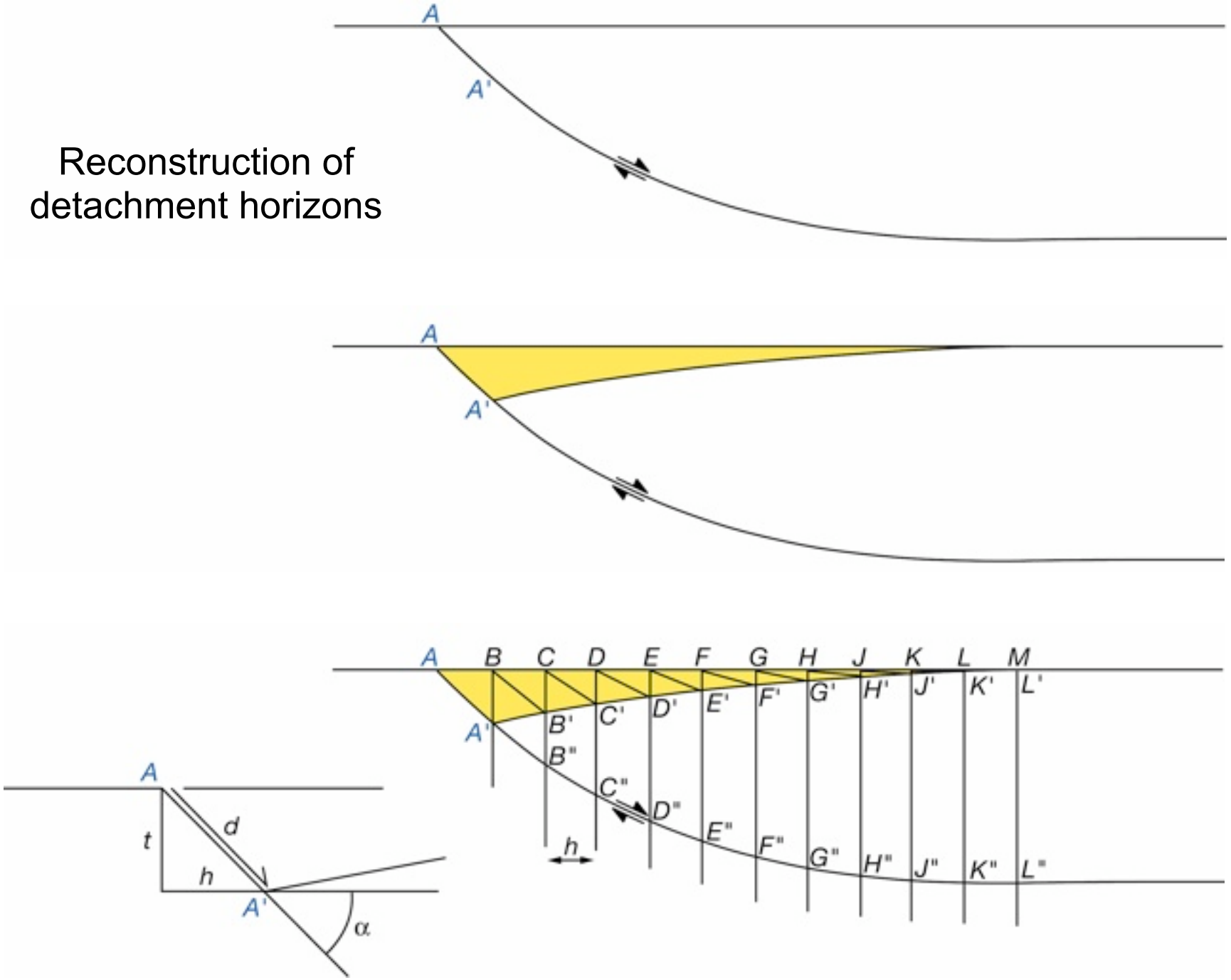
Planar vs. listric faults

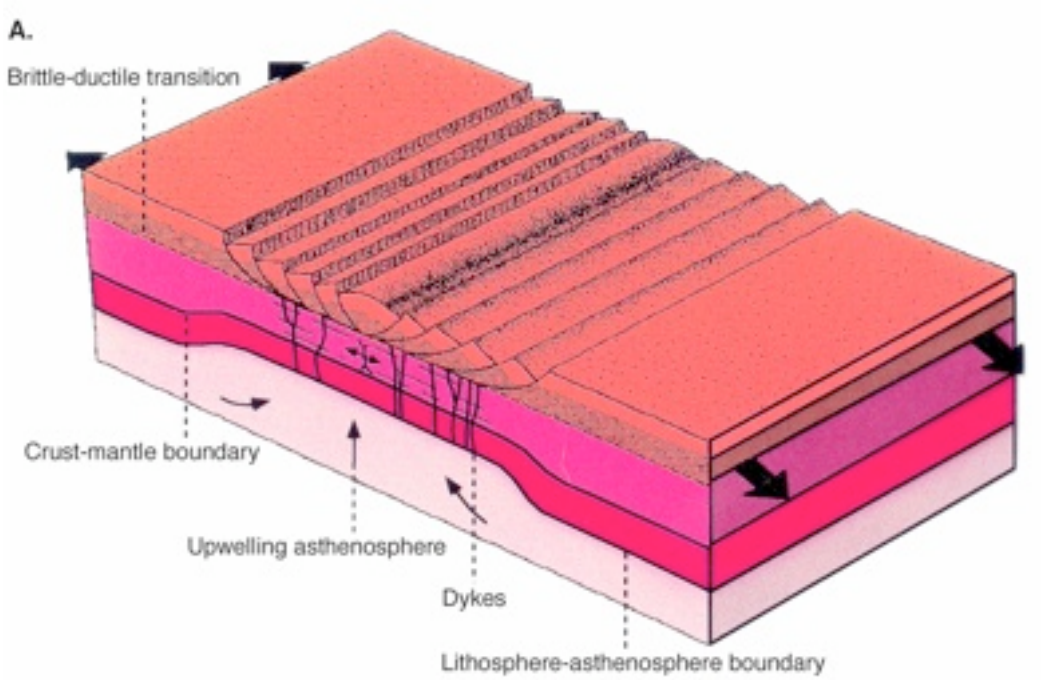





A
Depth (km)
6
10
6
8
10
West
East
B
Depth (km)
6
10
seafloor
top basement
unclear
S
S
S
S
2 km
Synrift sedimentary rocks
Block-bounding faults
Interpreted top basement
Brecciated zone?

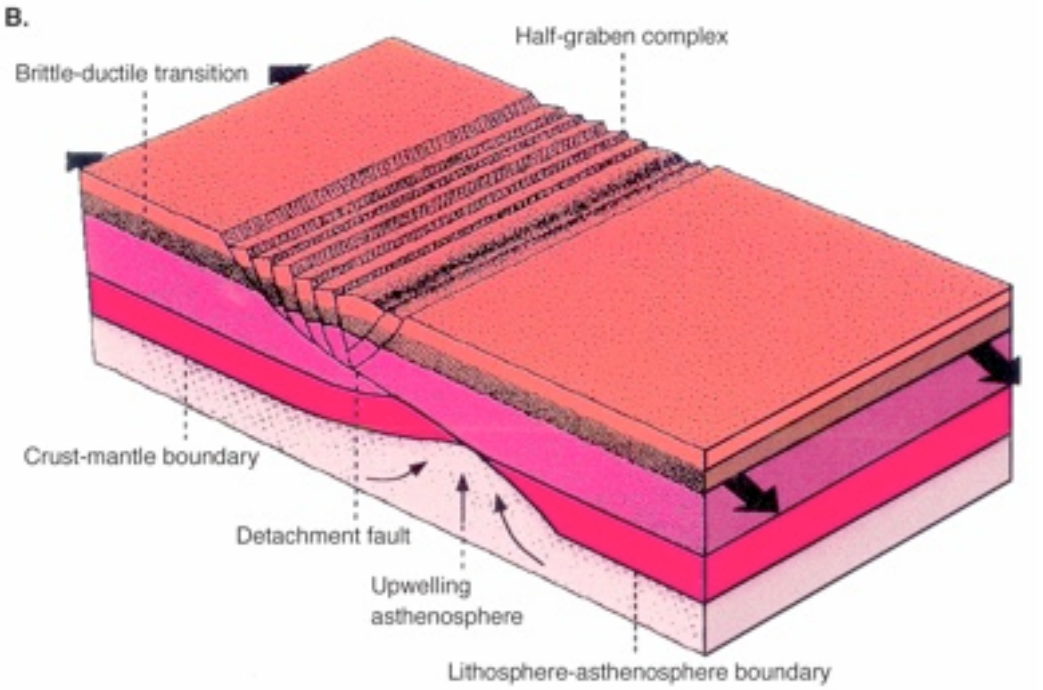
Reconstruction of detachment horizons





Lithospheric stretching model - pure shear

(McKenzie, 1987)

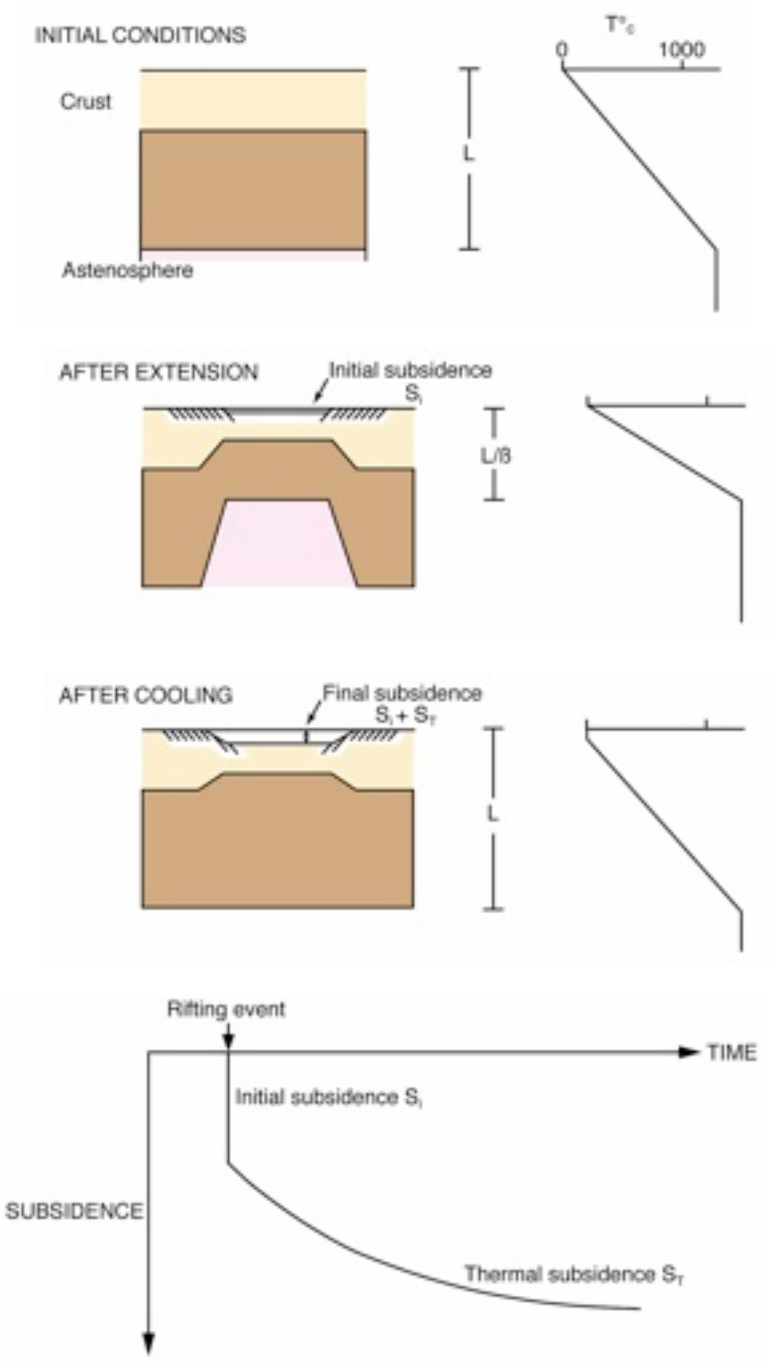


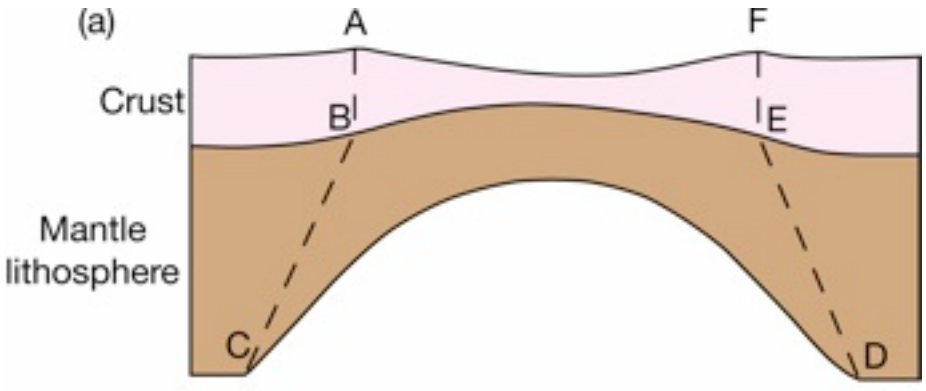
Lithospheric stretching model - simple shear

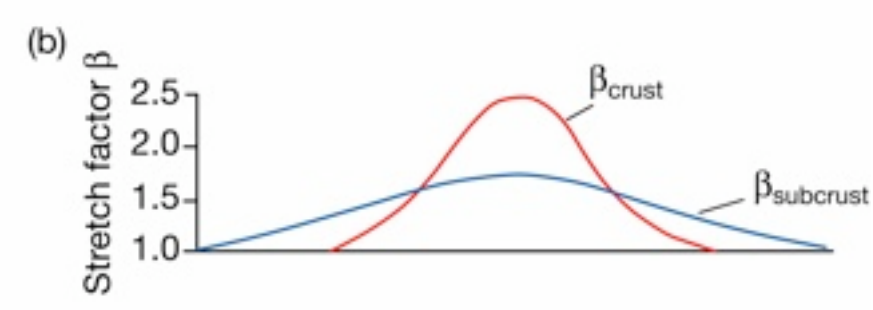
(Wernicke, 1985)

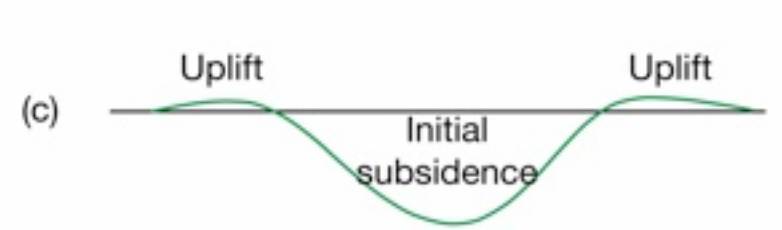
Stretching models

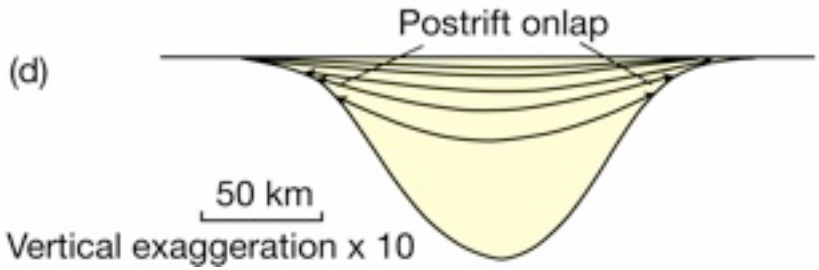
Pure-shear model




(a)
A
F
Crust
B
E
Mantle
lithosphere
C
D

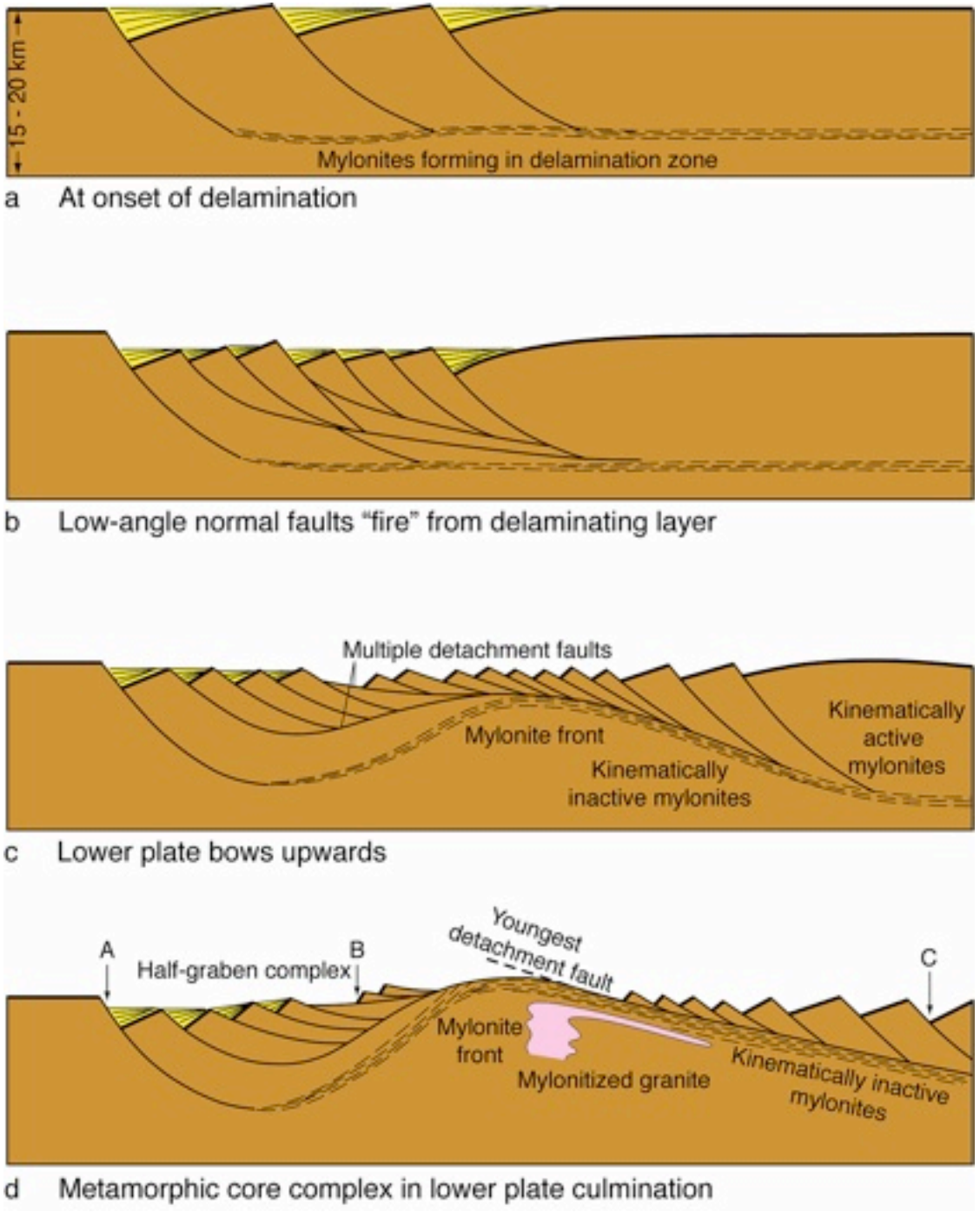

(b)
Stretch factor β
2.5
2.0
1.5
1.0
βcrust
βsubcrust

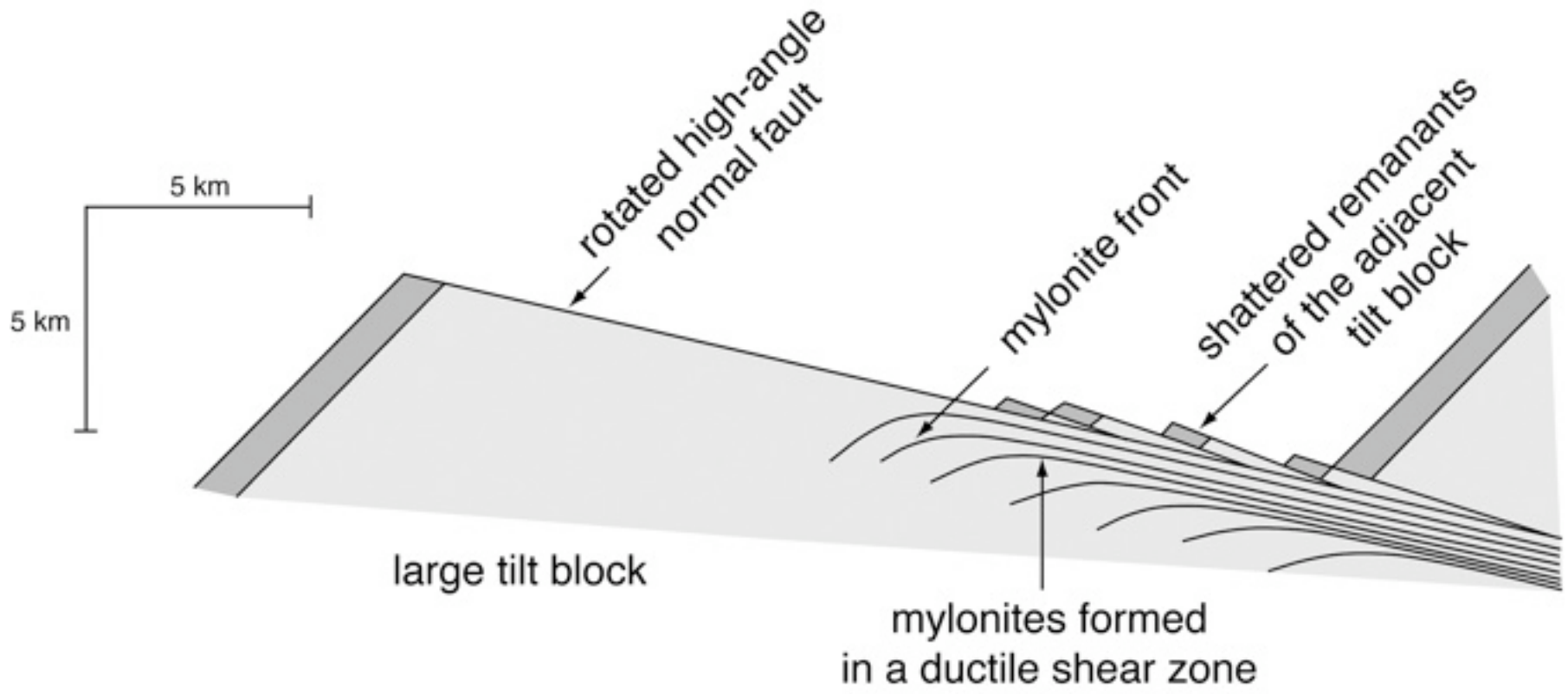

(c)
Uplift
Uplift
Initial
subsidence

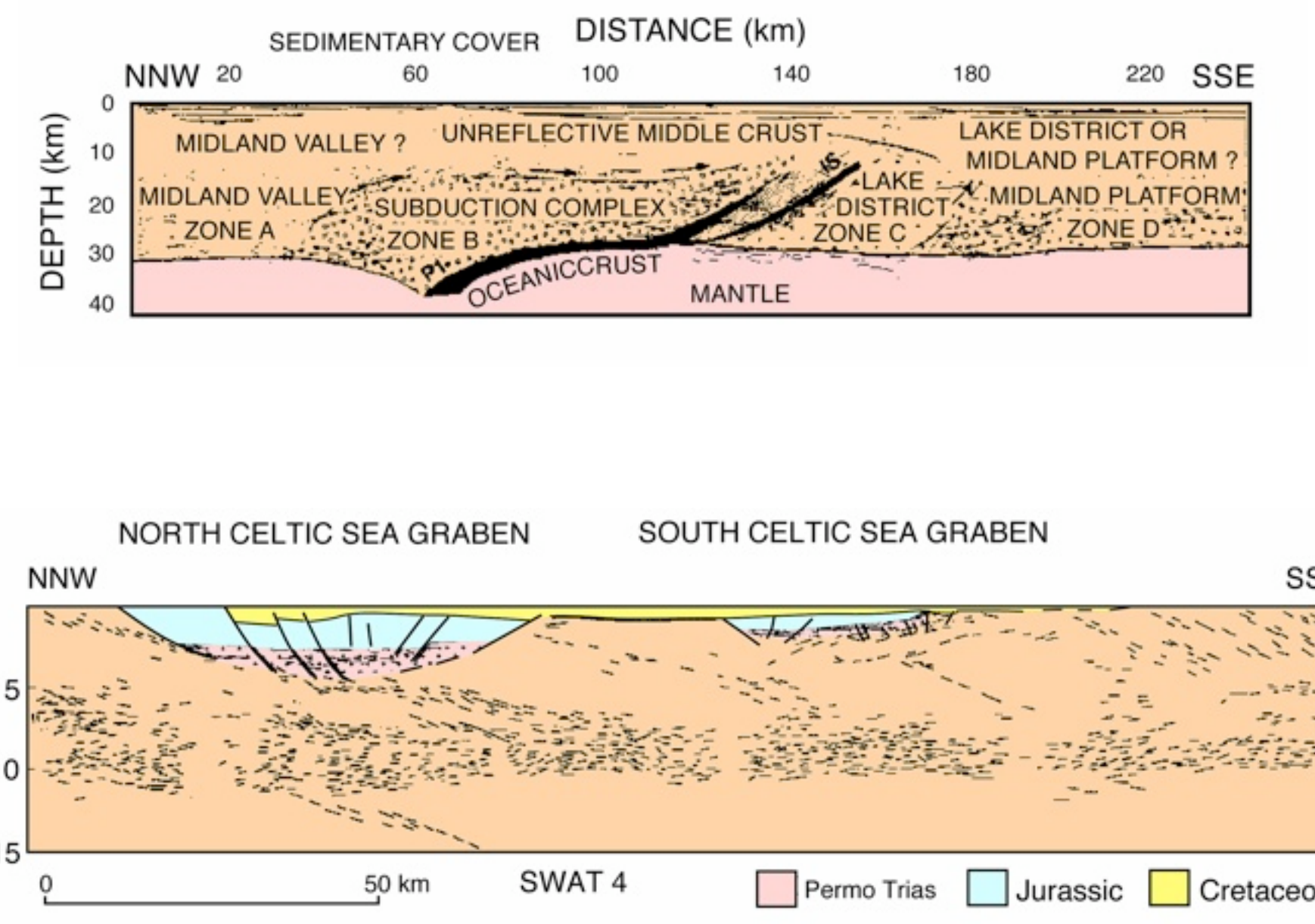

(d)
Postrift onlap
50 km
Vertical exaggeration x 10

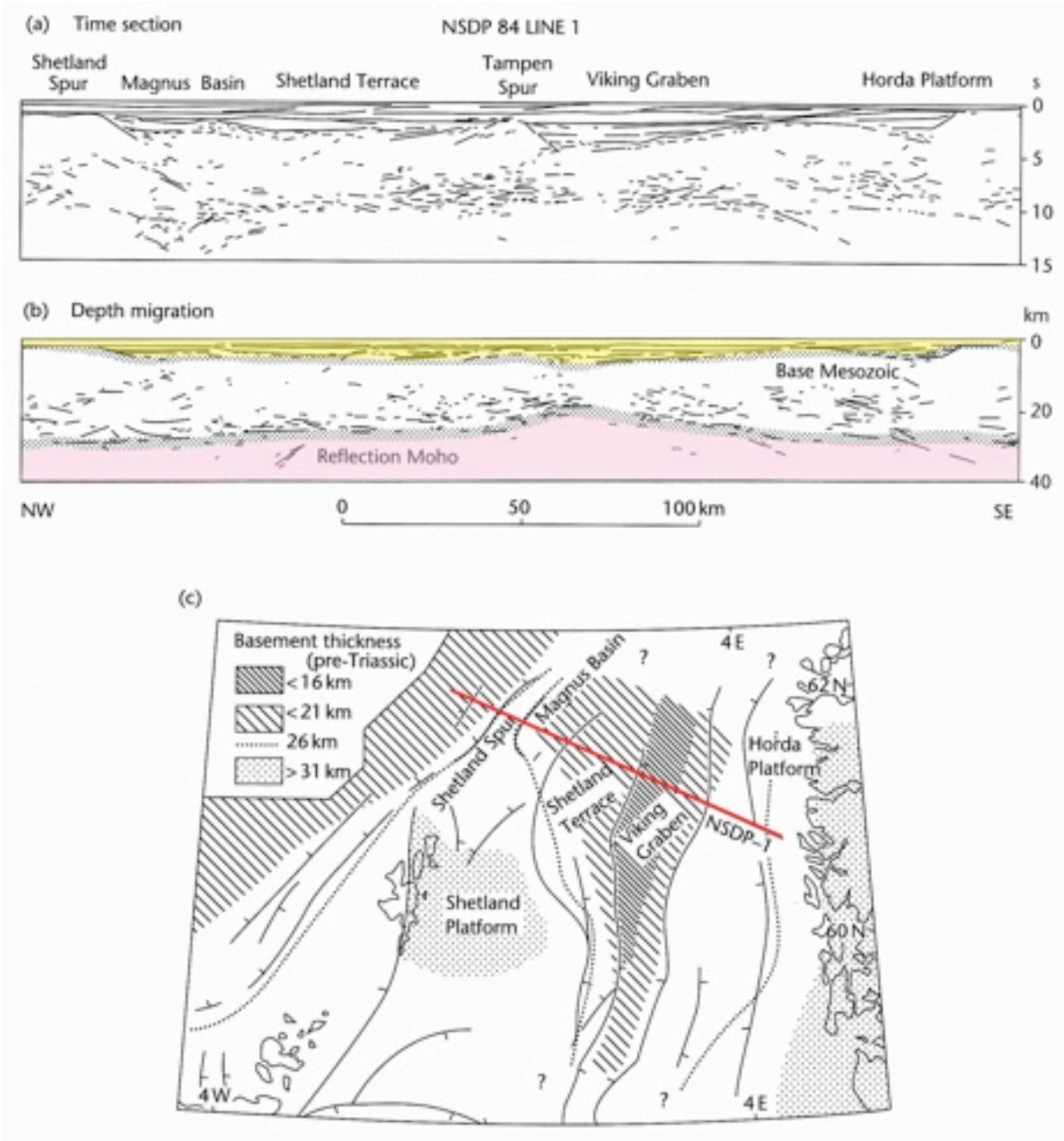
Non-uniform stretching

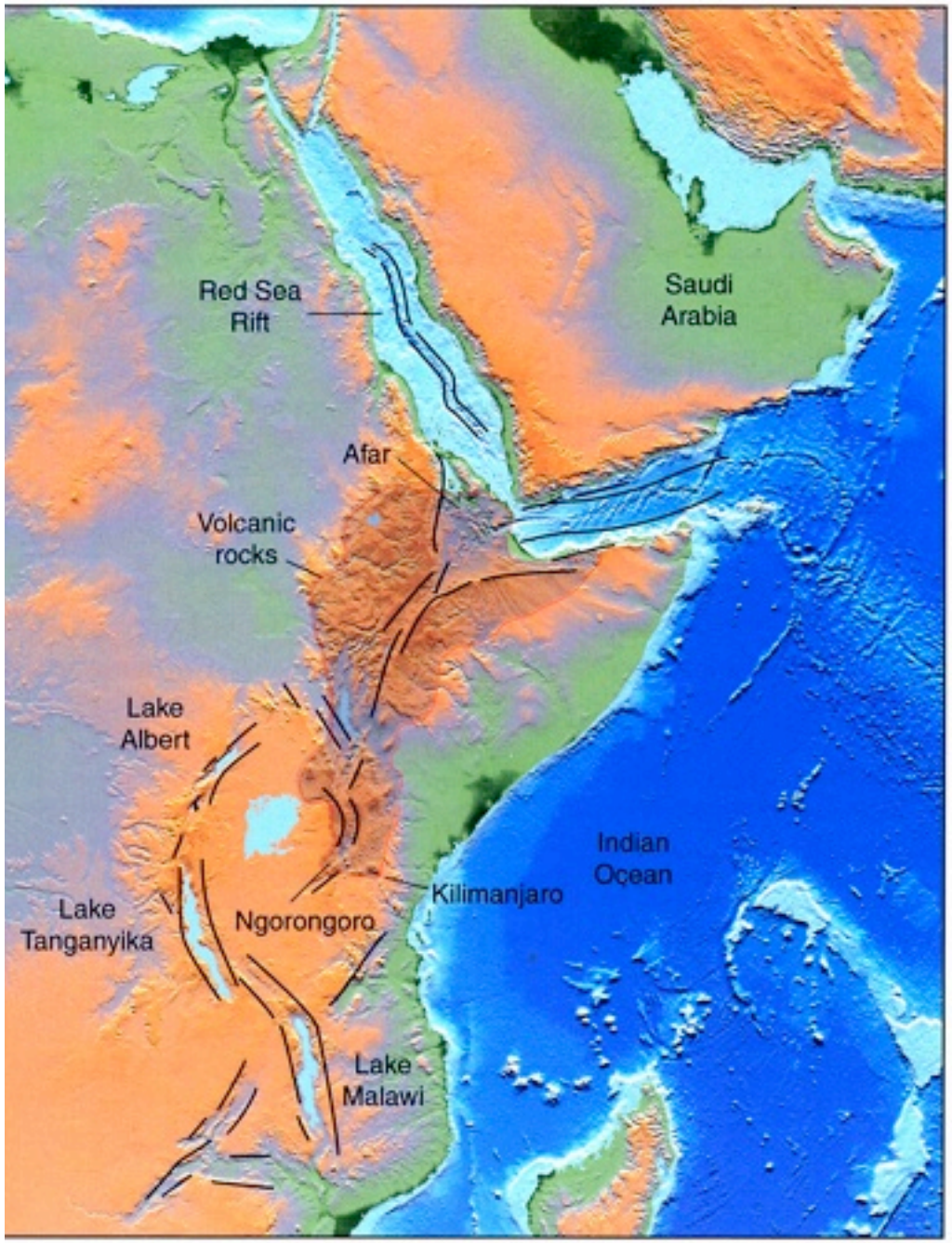
Simple-shear model



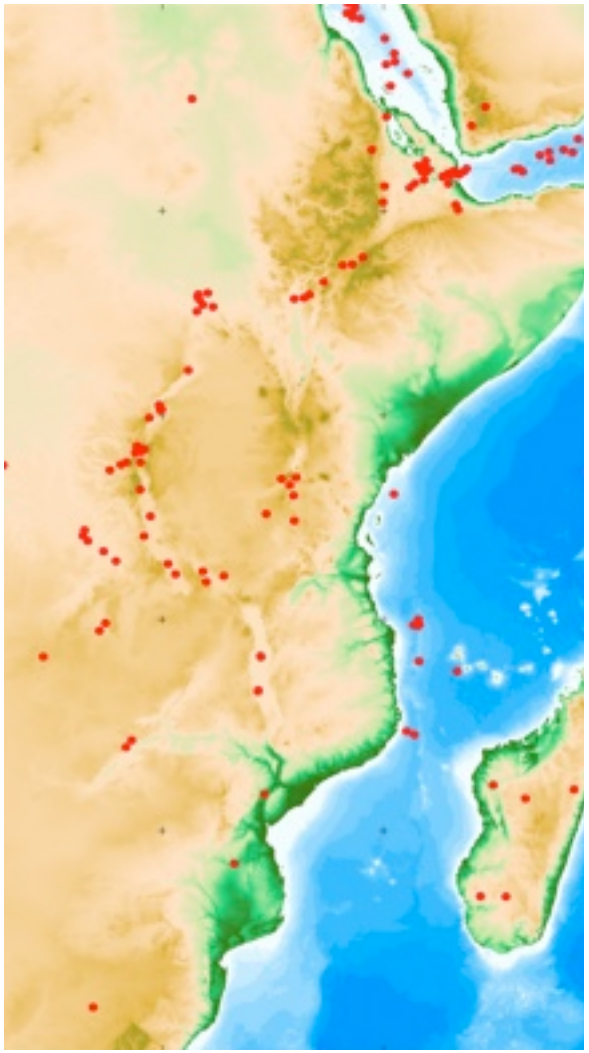

5 km
5 km
rotated high-angle
normal fault
mylonite front
shattered remanants
of the adjacent
tilt block
large tilt block
mylonites formed
in a ductile shear zone

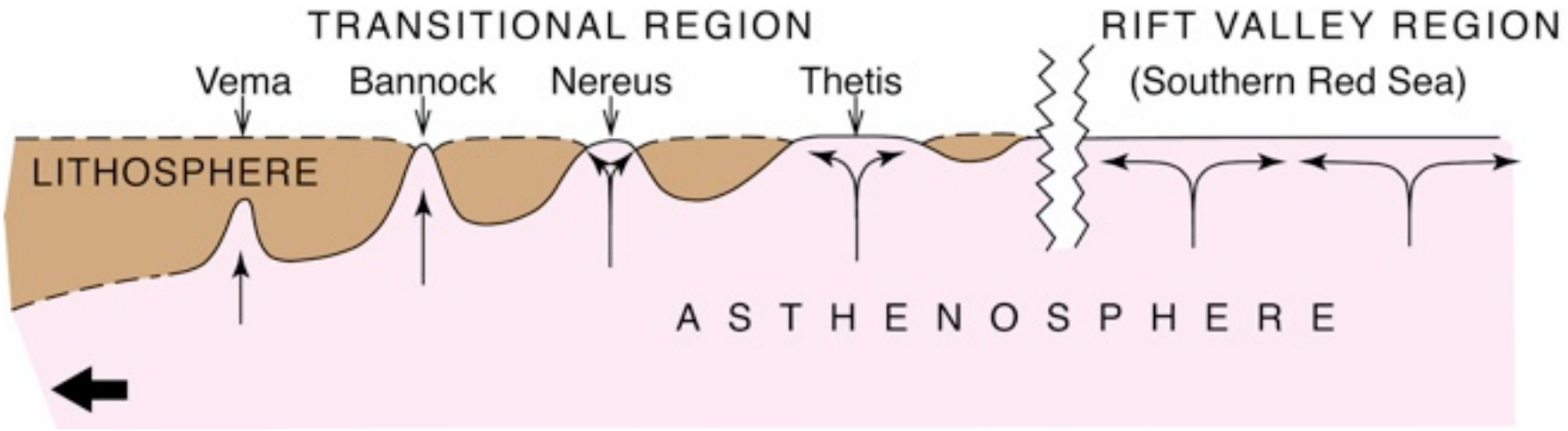

SEDIMENTARY COVER
DISTANCE (km)
NNW
20
60
100
140
180
220
SSE
DEPTH (km)
0
10
20
30
40
MIDLAND VALLEY ?
UNREFLECTIVE MIDDLE CRUST
LAKE DISTRICT OR
MIDLAND PLATFORM ?
MIDLAND VALLEY
ZONE A
SUBDUCTION COMPLEX
ZONE B
LAKE
DISTRICT
ZONE C
MIDLAND PLATFORM
ZONE D
IS
P1
OCEANICCRUST
MANTLE
NORTH CELTIC SEA GRABEN
SOUTH CELTIC SEA GRABEN
NNW
SSE
5
10
15
0
50 km
SWAT 4
Permo Trias
Jurassic
Cretaceous

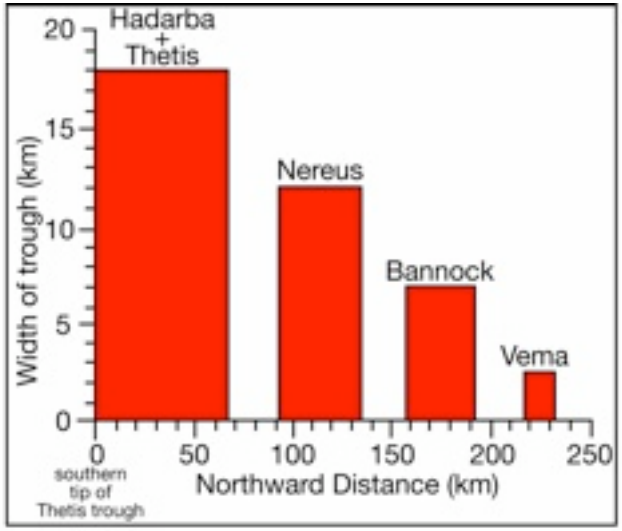

(a) Time section
NSDP 84 LINE 1
Shetland Spur
Magnus Basin
Shetland Terrace
Tampen Spur
Viking Graben
Horda Platform
s
0
5
10
15
(b) Depth migration
km
0
Base Mesozoic
20
Reflection Moho
40
NW
0
50
100 km
SE
(c)
Basement thickness (pre-Triassic)
< 16 km
< 21 km
26 km
> 31 km
Shetland Spur
Magnus Basin
Shetland Terrace
Viking Graben
NSDP-1
Horda Platform
Shetland Platform
62 N
60 N
4 W
4 E
?

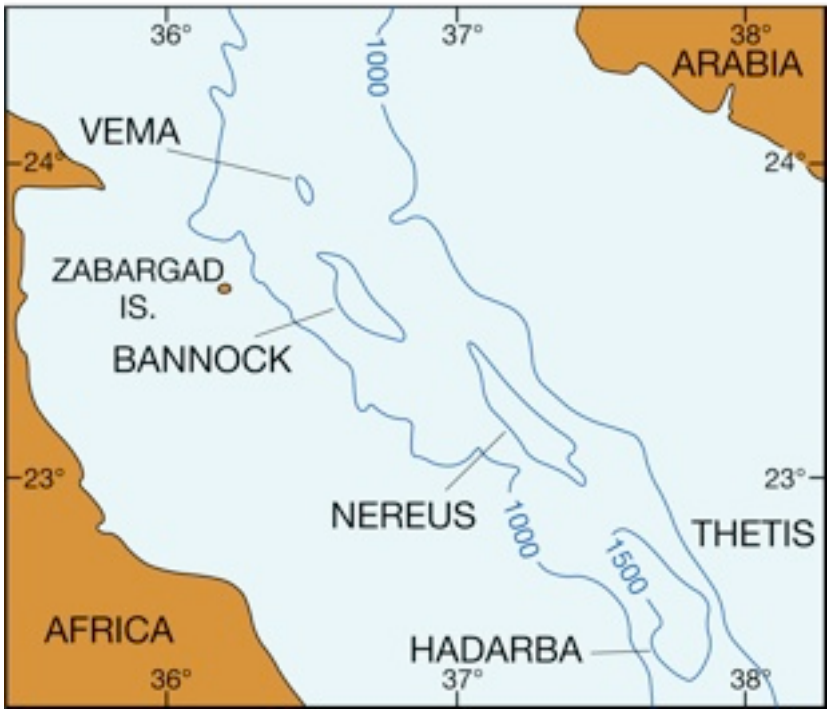


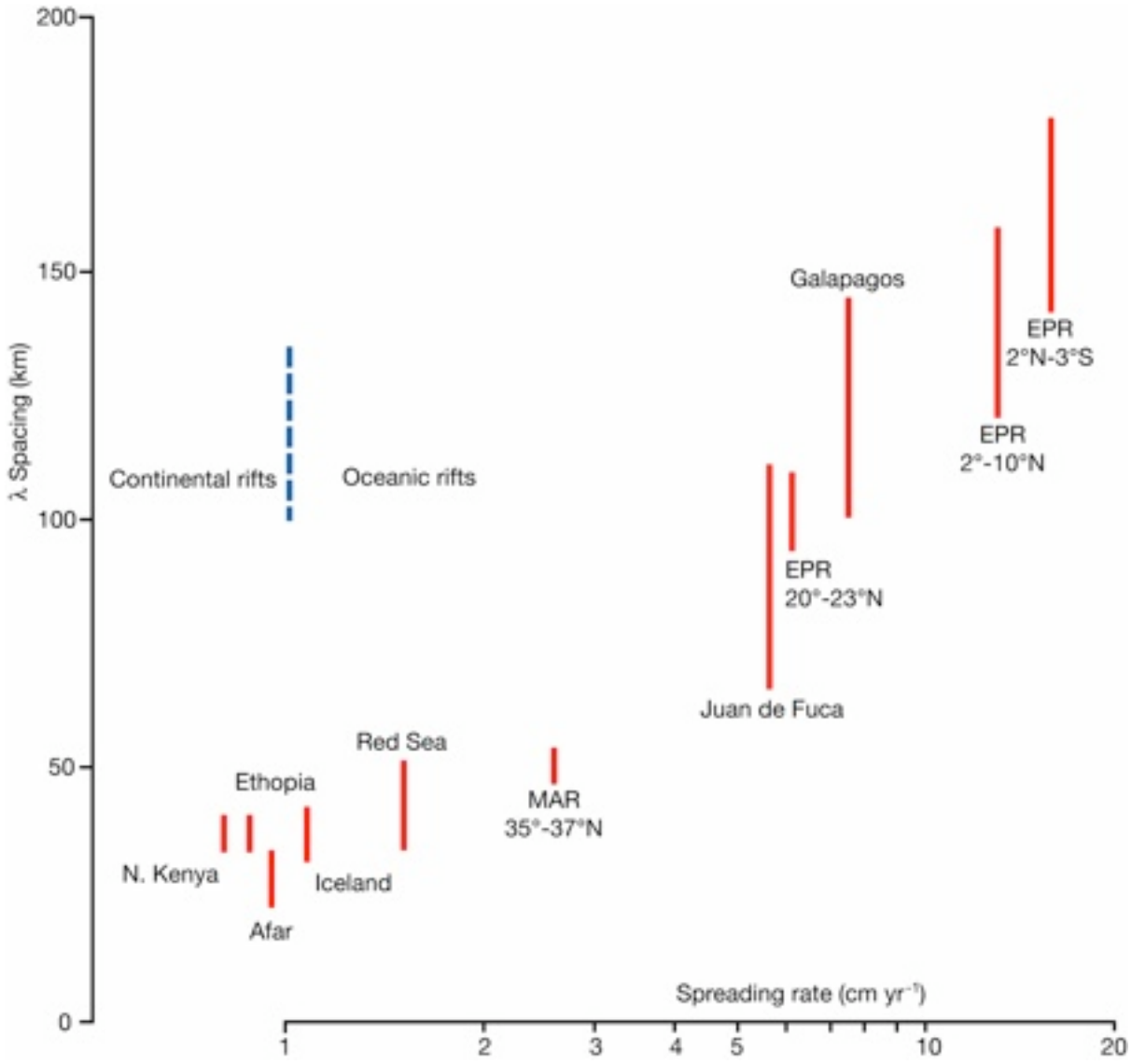
From continental to oceanic rifting




TRANSITIONAL REGION
RIFT VALLEY REGION
Vema
Bannock
Nereus
Thetis
(Southern Red Sea)
LITHOSPHERE
ASTHENOSPHERE


Hadarba
+
Thetis
Nereus
Bannock
Verna
Width of trough (km)
20
15
10
5
0
0
50
100
150
200
250
southern
tip of
Thetis trough
Northward Distance (km)


36°
37°
38°
ARABIA
1000
VEMA
24°
24°
ZABARGAD
IS.
BANNOCK
23°
23°
NEREUS
1000
1500
THETIS
AFRICA
HADARBA
36°
37°
38°


200
150
100
50
0
λ Spacing (km)
Continental rifts
Oceanic rifts
Galapagos
EPR
2°N-3°S
EPR
2°-10°N
EPR
20°-23°N
Juan de Fuca
Red Sea
Ethopia
MAR
35°-37°N
N. Kenya
Iceland
Afar
Spreading rate (cm yr⁻¹)
1
2
3
4
5
10
20