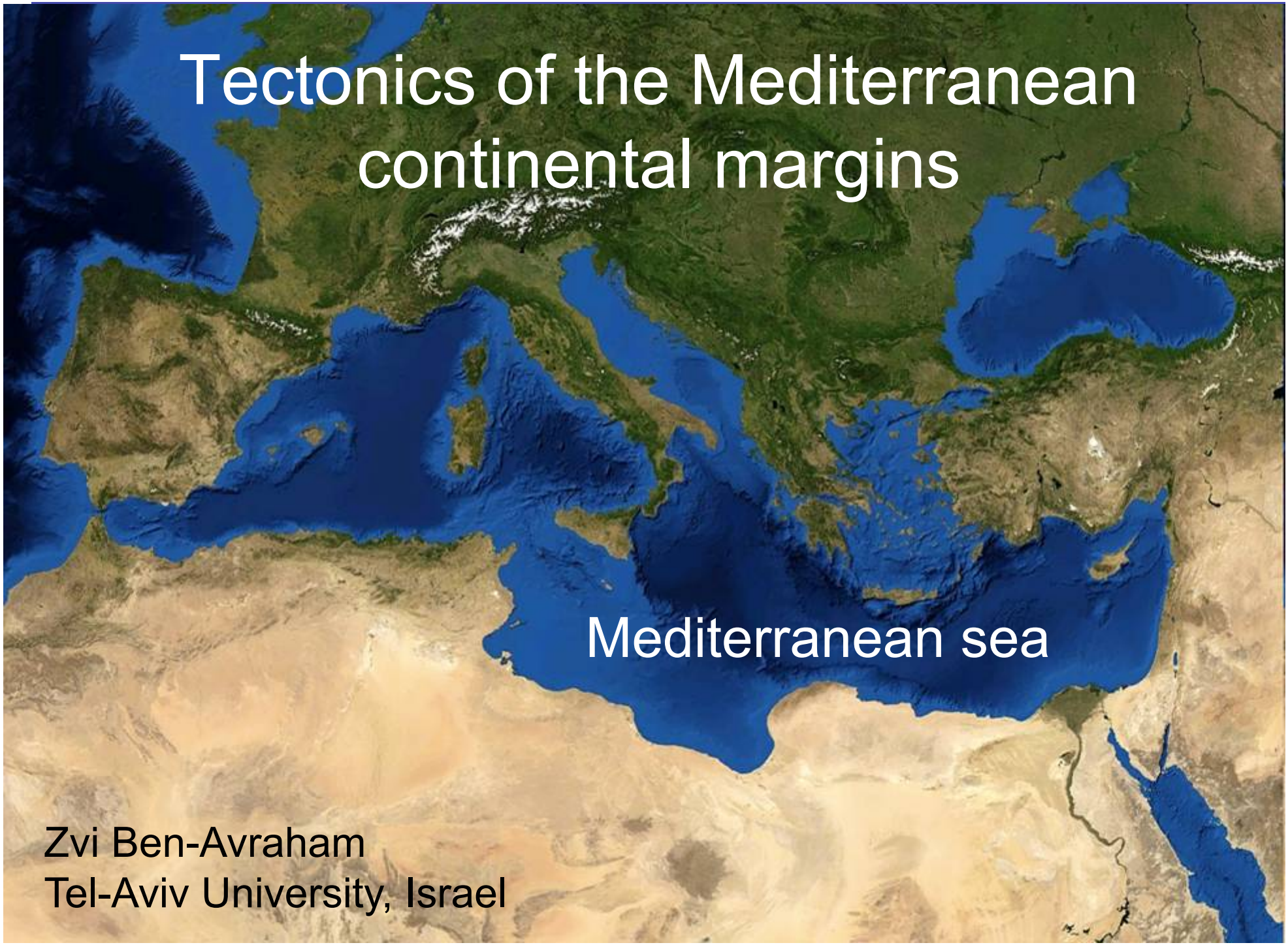
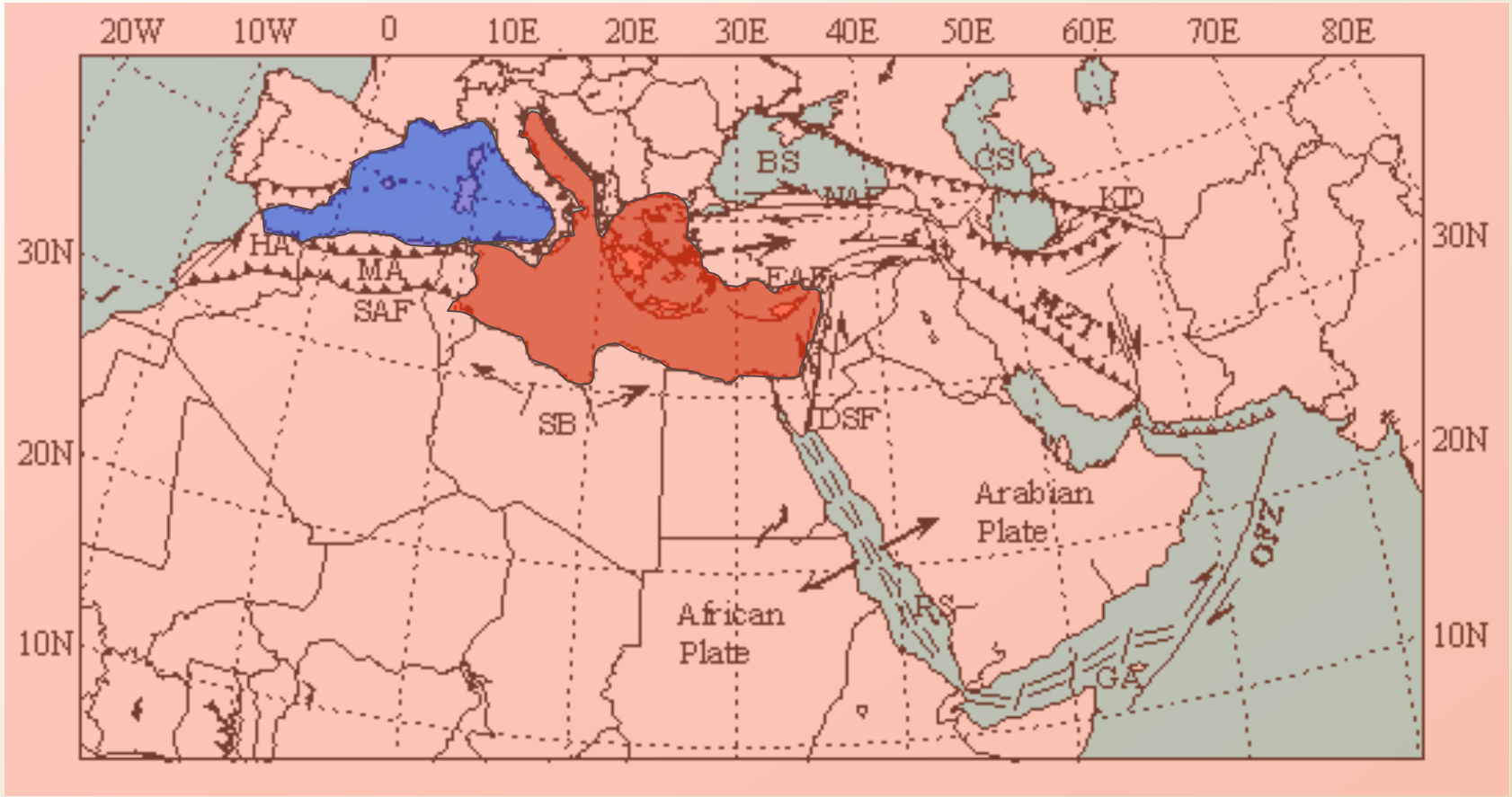
Tectonics of the Mediterranean continental margins



Zvi Ben-Avraham
Tel-Aviv University, Israel

the **Mediterranean** occupies only **1%** of the World Ocean

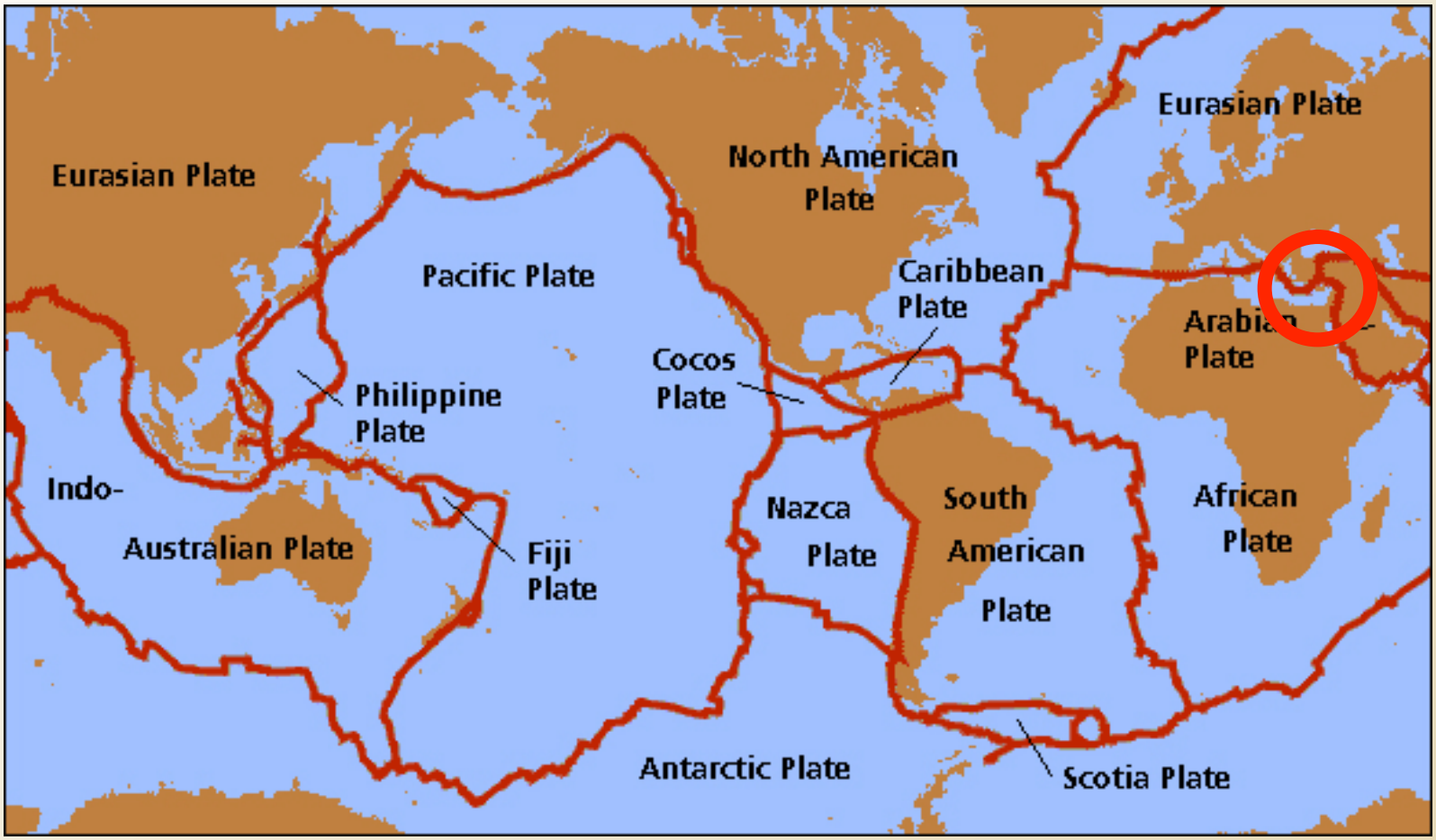

IRL
GBR
NLD
BEL
DEU
POL
BLR
KAZ
ATLANTIC
OCEAN
Celtic Sea
English Channel
LUX
CZE
UKR
RUS
SVK
AUT
MDA
Sea of Azov
FRA
CHE
HUN
Bay of Biscay
SVN
HRV
ROU
BIH
GEO
Black Sea
Ligurian Sea
SRB
Adriatic Sea
ITA
AND
BGR
PRT
ESP
MKD
Balearic Sea
Tyrrhenian Sea
Sea of Marmara
Thracian Sea
ALB
TUR
GRC
Aegean
Mediterranean
Strait of Gibraltar
Alboran Sea
Ionian Sea
Myrtoan Sea
Cilician Sea
SYR
CYP
Sea of Crete
LBN
IRQ
MLT
MAR
Libyan Sea
Sea
ISR
JOR
TUN
SAU
DZA
EGY
Red Sea
LBY
Tropic of Cancer
MRT
MLI
SDN
0°
10°E
20°E
30°E
40°E
30°N

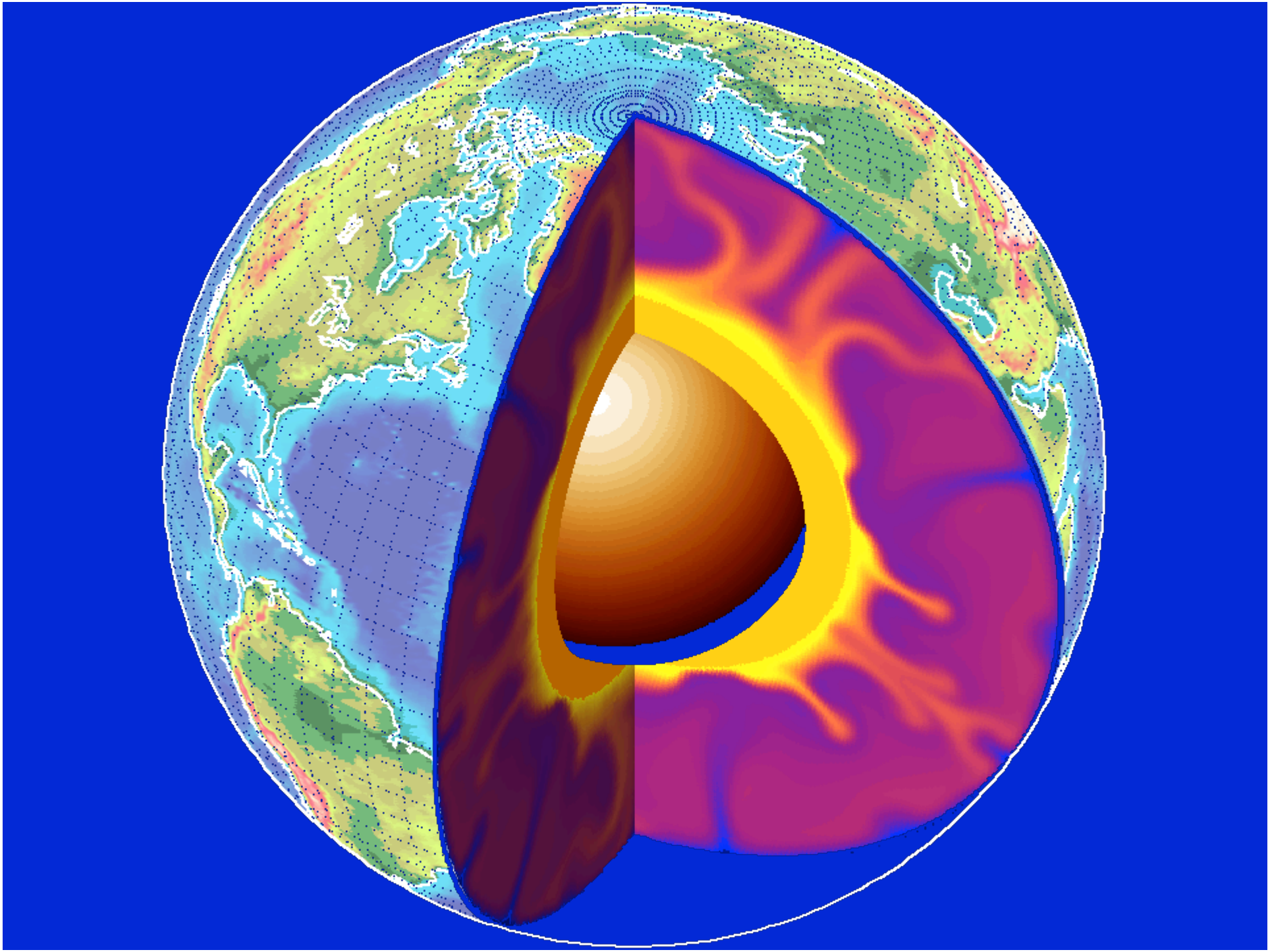

20W
10W
0
10E
20E
30E
40E
50E
60E
70E
80E
30N
20N
10N
BS
CS
KF
HA
MA
SAF
EAF
MZT
SB
DSF
Arabian
Plate
African
Plate
RS
GE
ZFO


Eastern Mediterranean Basin

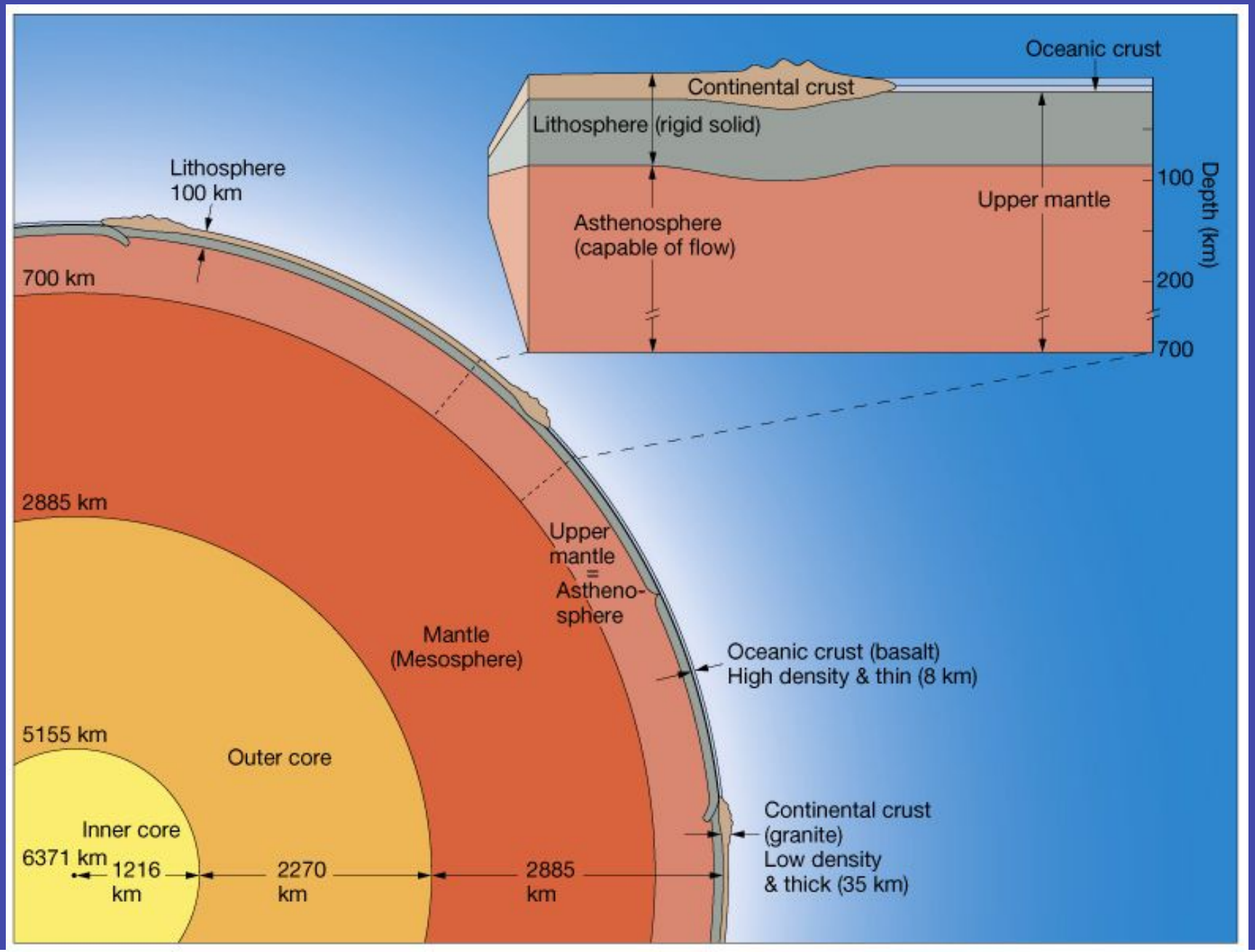
Marine geosciences

- Geological history
  - A detective story into Earth's past
  - Combining many small details to a coherent picture of multiple spatial and temporal processes that interact
- Geological principles = our tools for understanding phenomenon, even if their shape has changed over time
- Products
  - Maps and cross-sections – 2D view
  - Relation between Earth surface processes and its interior – 4D view


Eurasian Plate
North American Plate
Eurasian Plate
Pacific Plate
Caribbean Plate
Arabian Plate
Cocos Plate
Philippine Plate
Indo-
Australian Plate
Fiji Plate
Nazca Plate
South American Plate
African Plate
Antarctic Plate
Scotia Plate

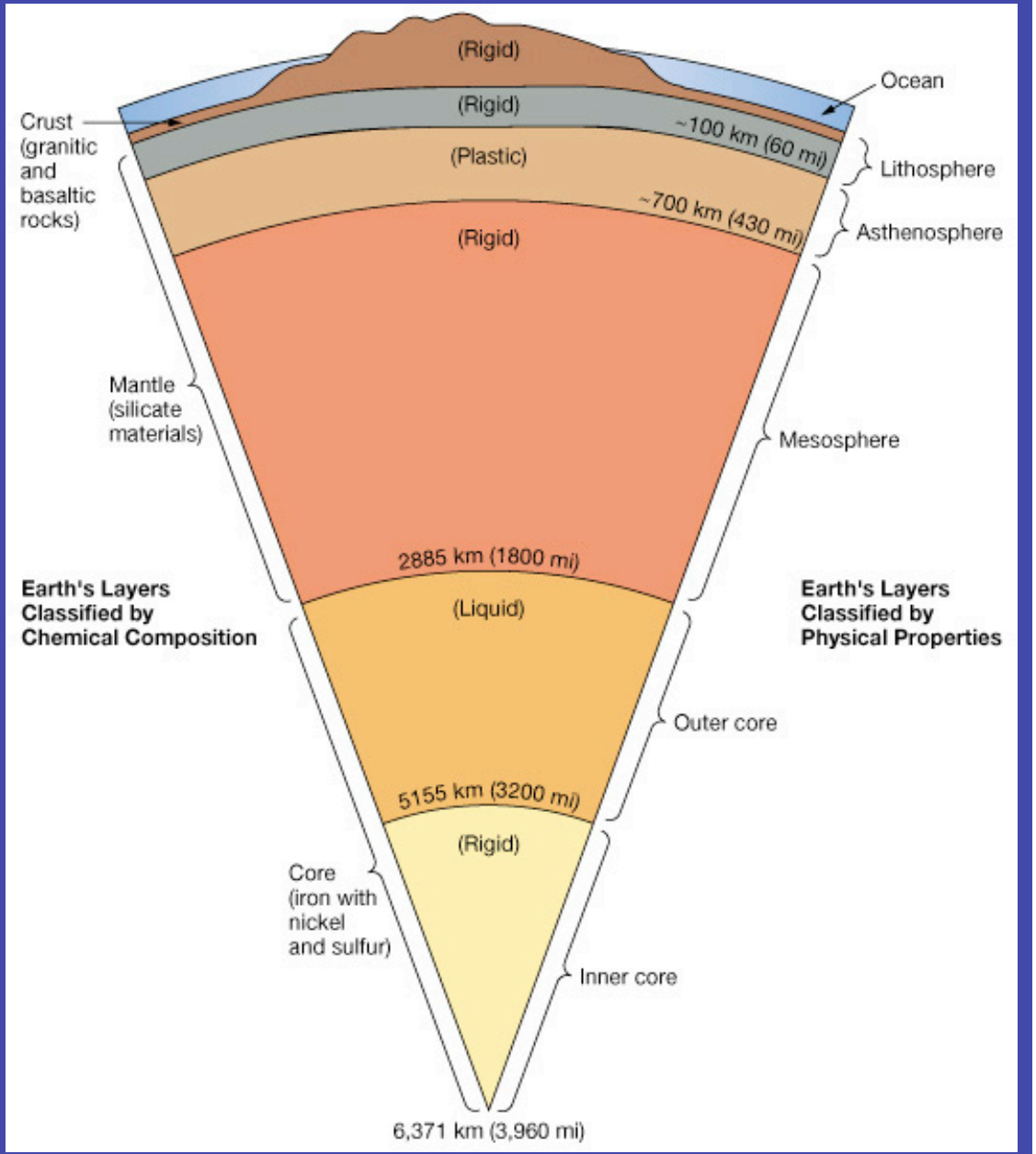


Earth internal

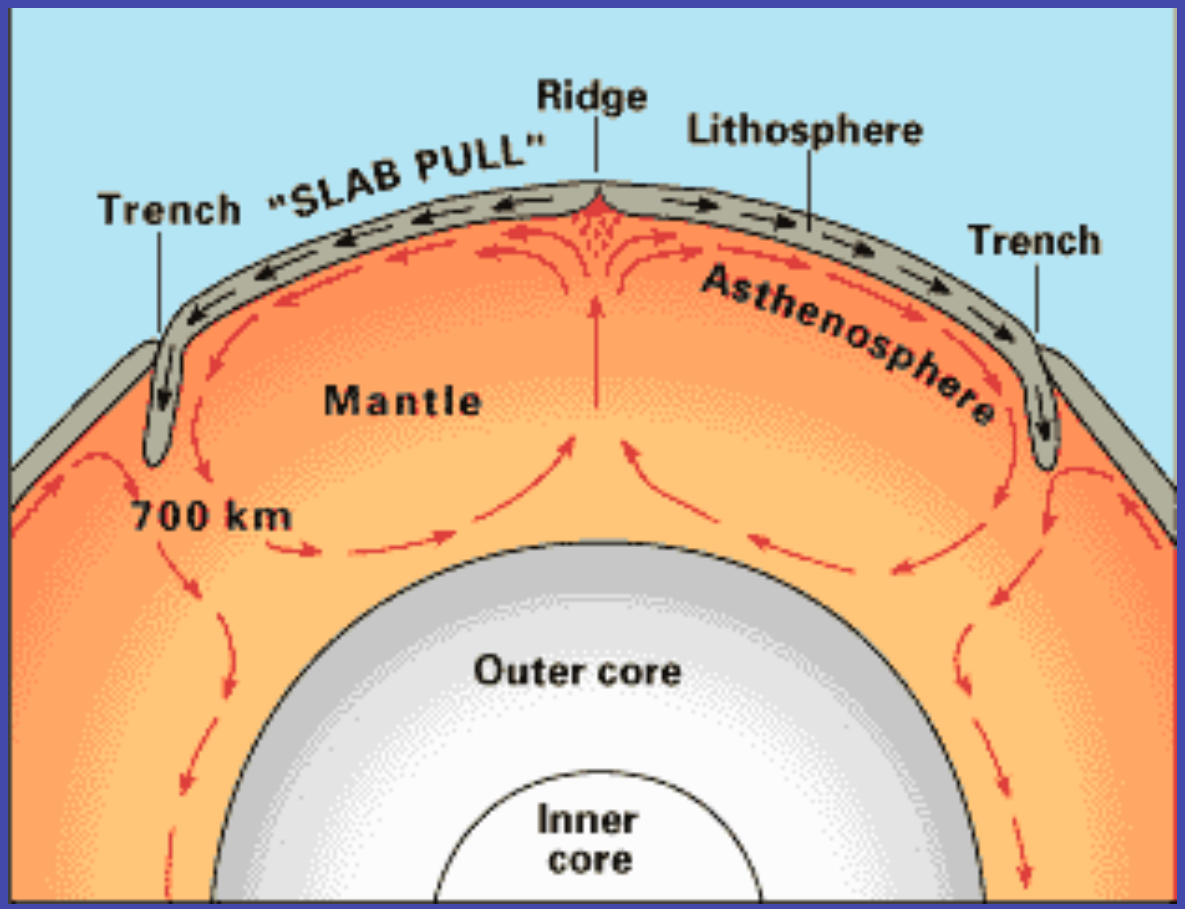


Earth structure

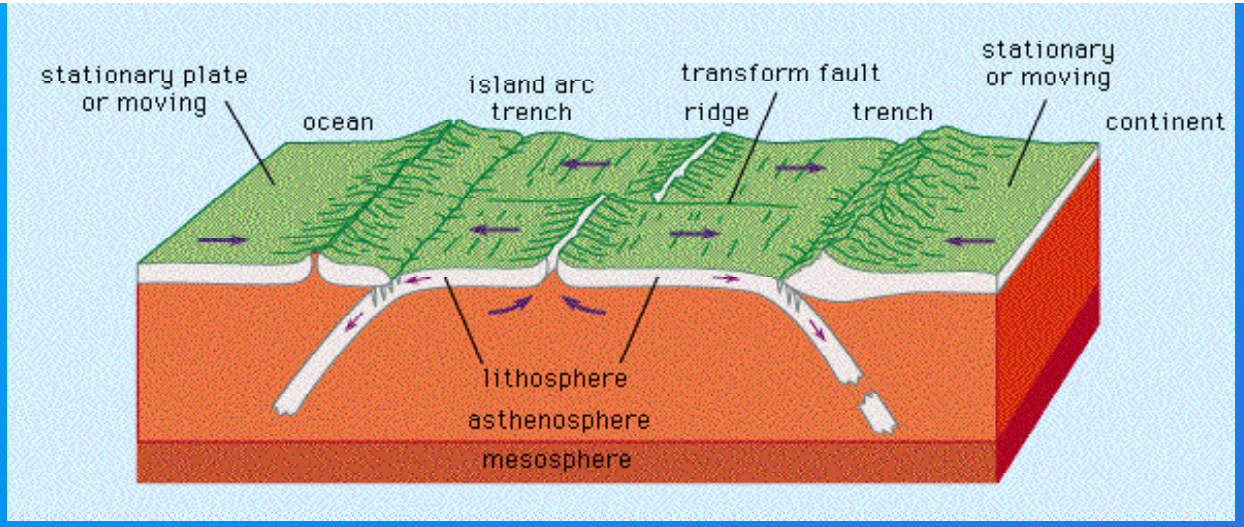
- Chemical composition
  - Crust
  - Mantle
  - Core
- Physical properties
  - Lithosphere
  - Asthenosphere
  - Mesosphere
  - Outer core
  - Inner core

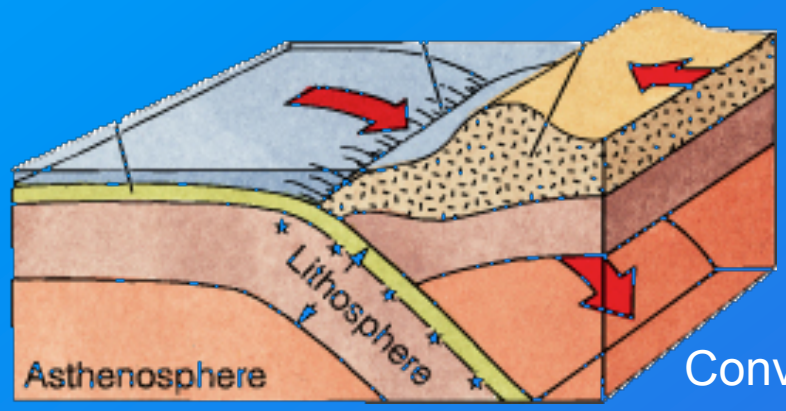


Driving forces of Plate Movement

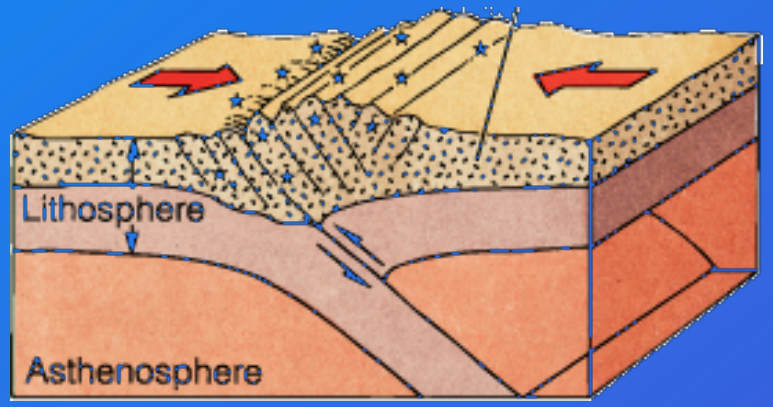


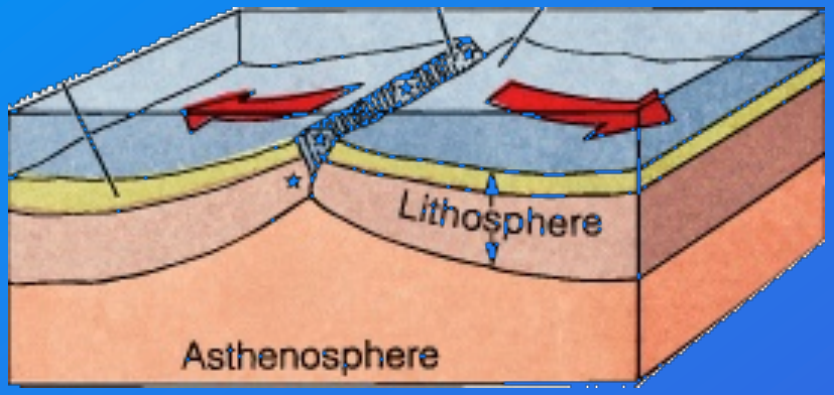
Convection Currents



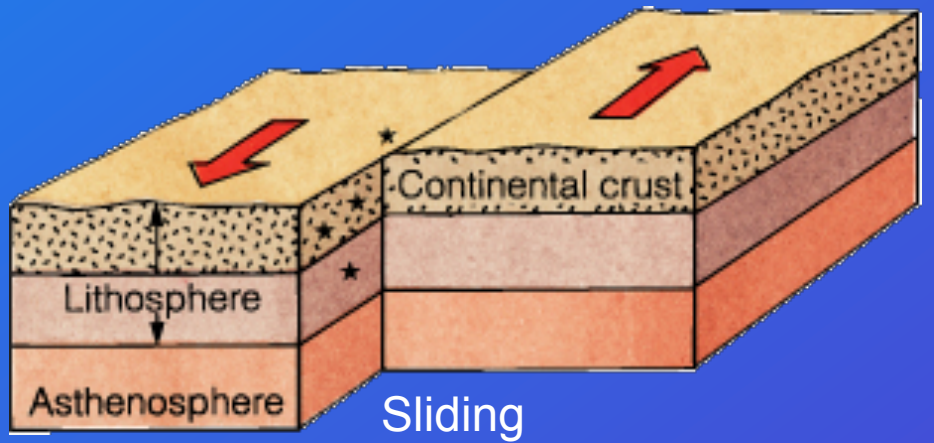


Convergence



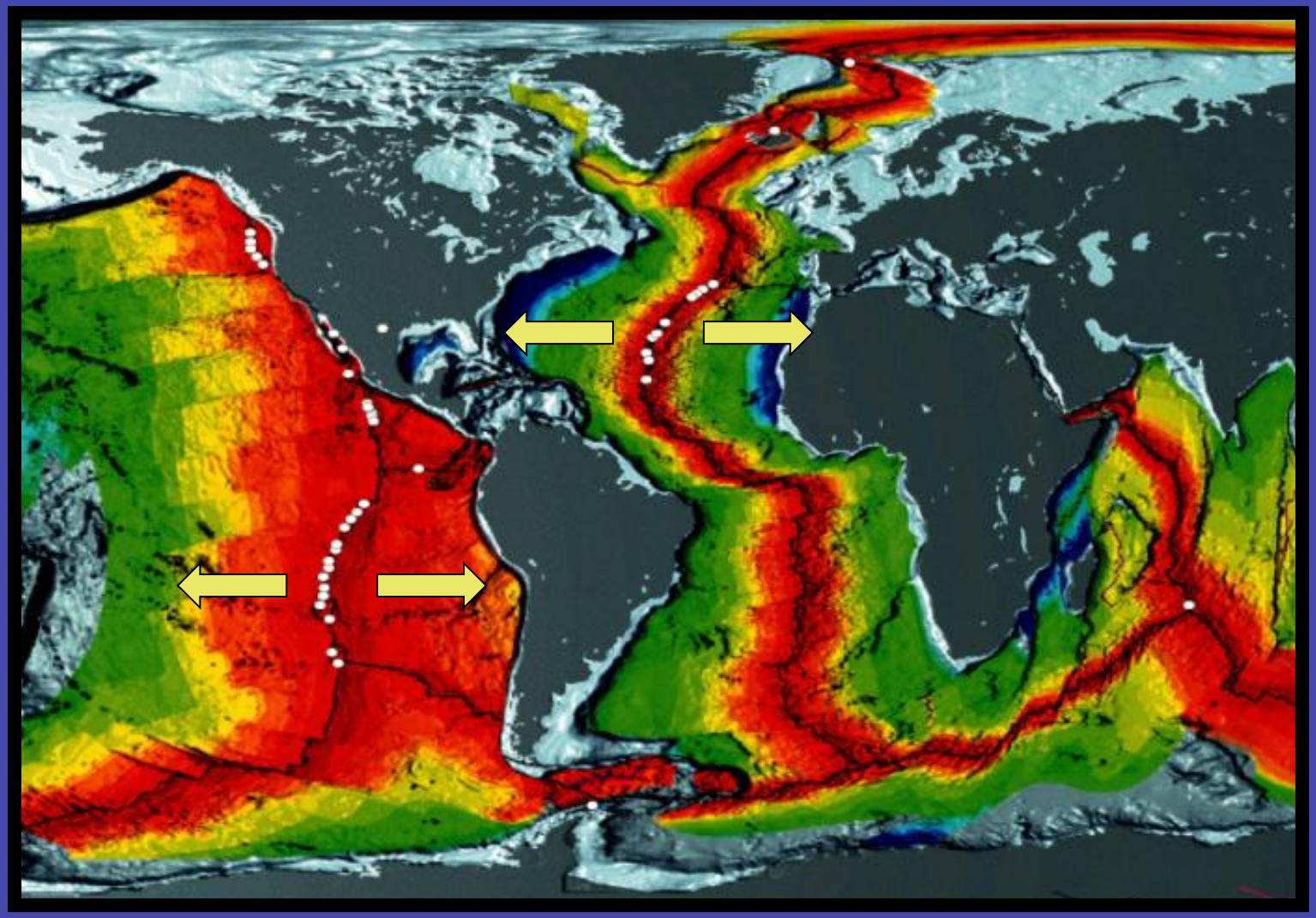


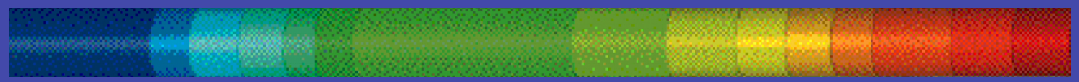
Divergence



Sliding

Age of the seafloor

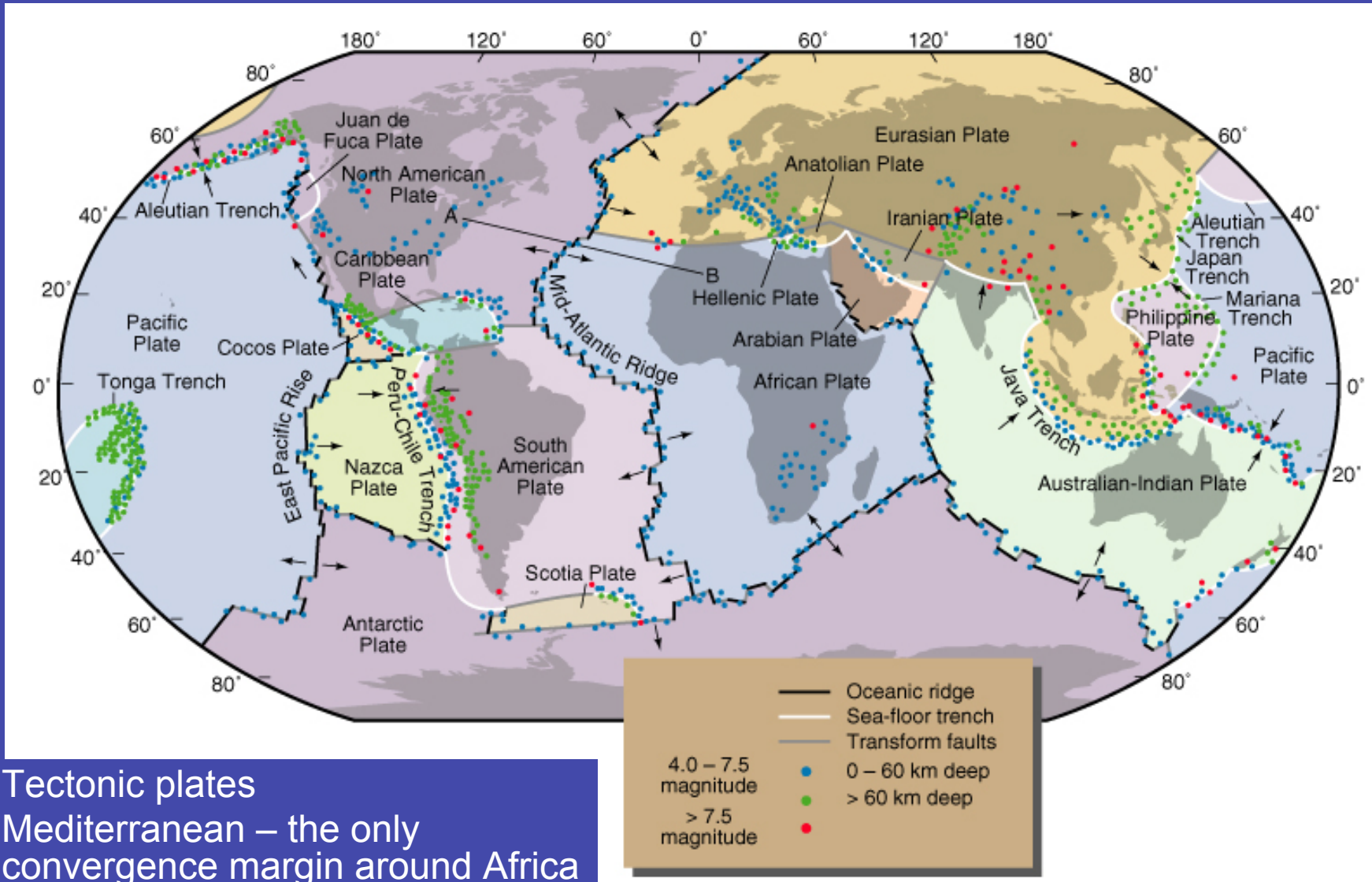




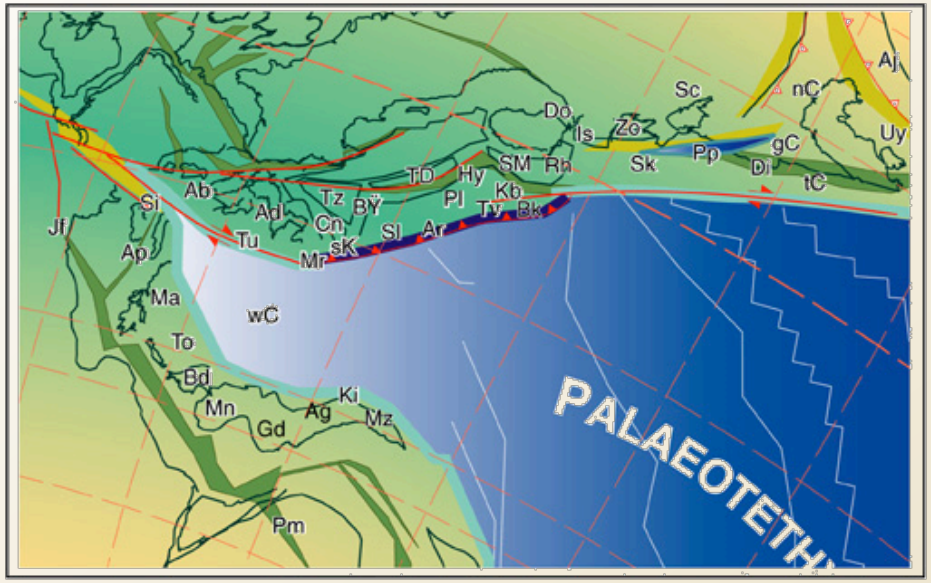
180 120.4 83.5 47.9 0

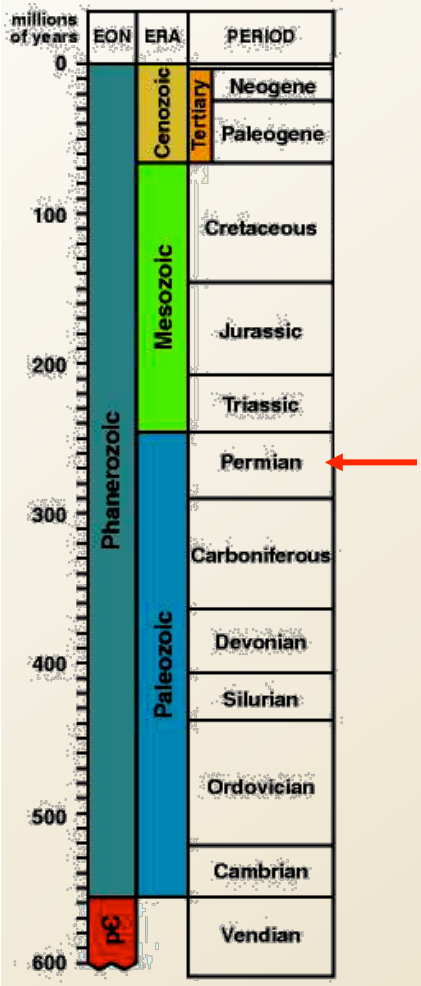
Million of years before present

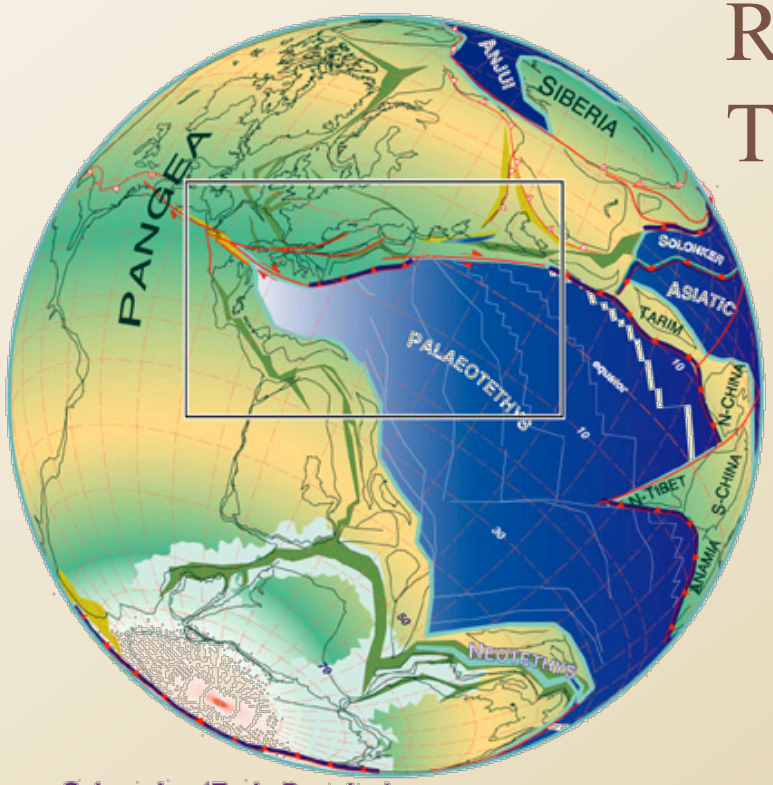
Tectonic location



- Tectonic plates
- Mediterranean – the only convergence margin around Africa
- Change with time



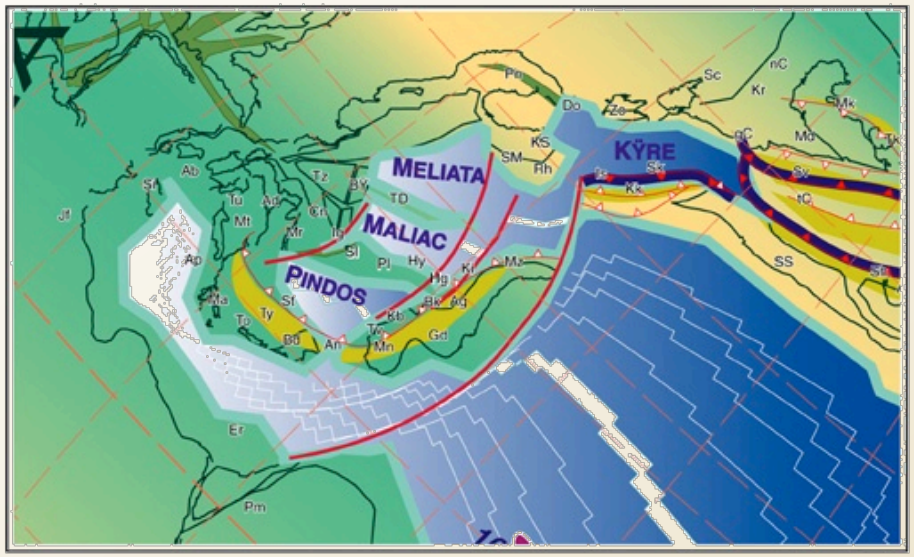


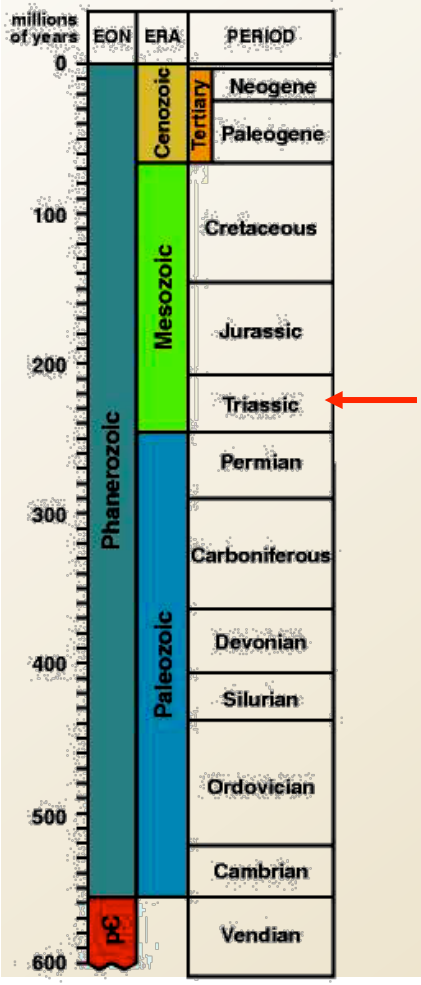


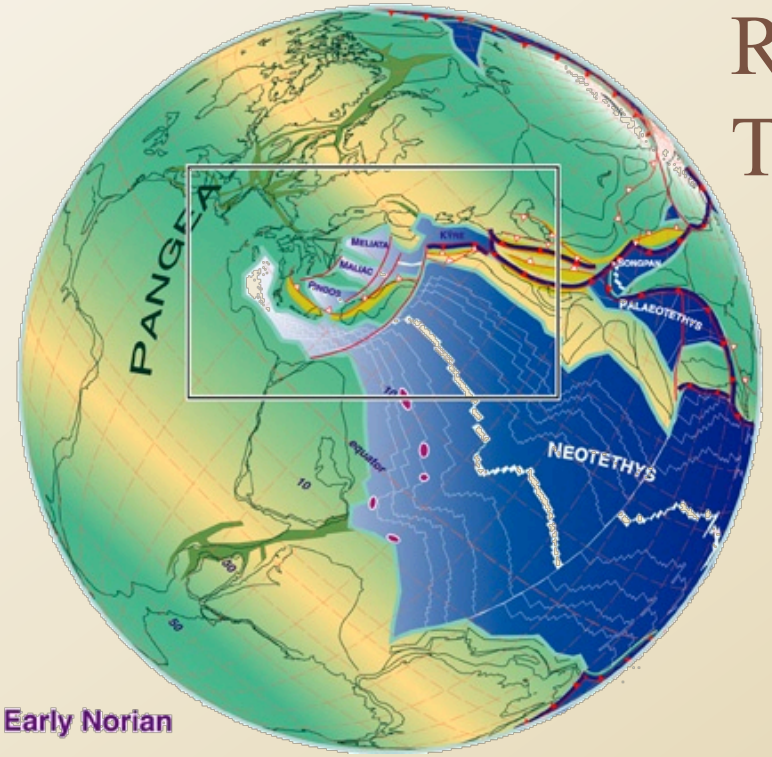
Sakmarian (Early Permian)

Remains of the Tethys Ocean

Stampfli et al., 2002



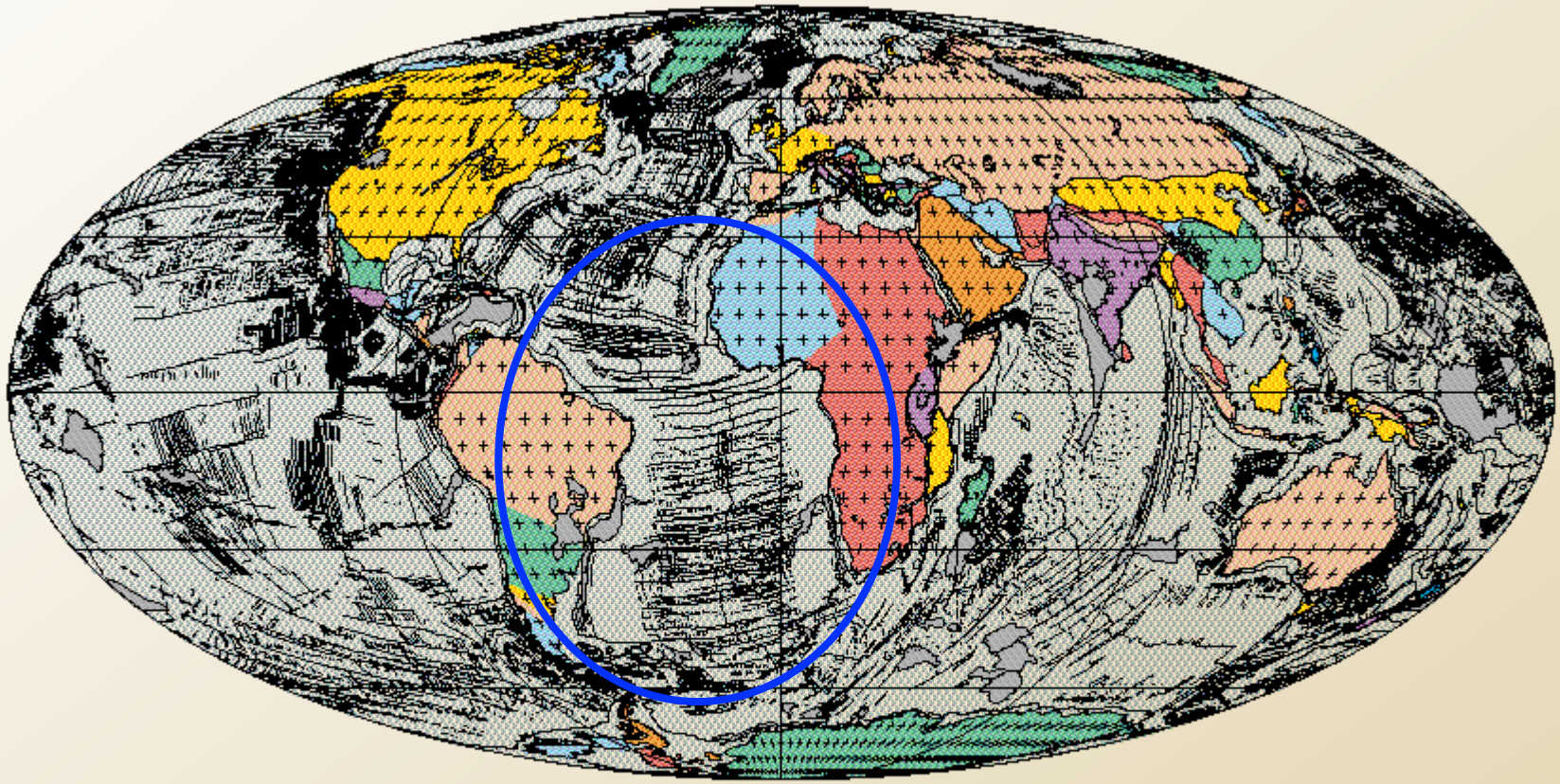




Early Norian

Remains of the Tethys Ocean

Stampfli et al., 2002

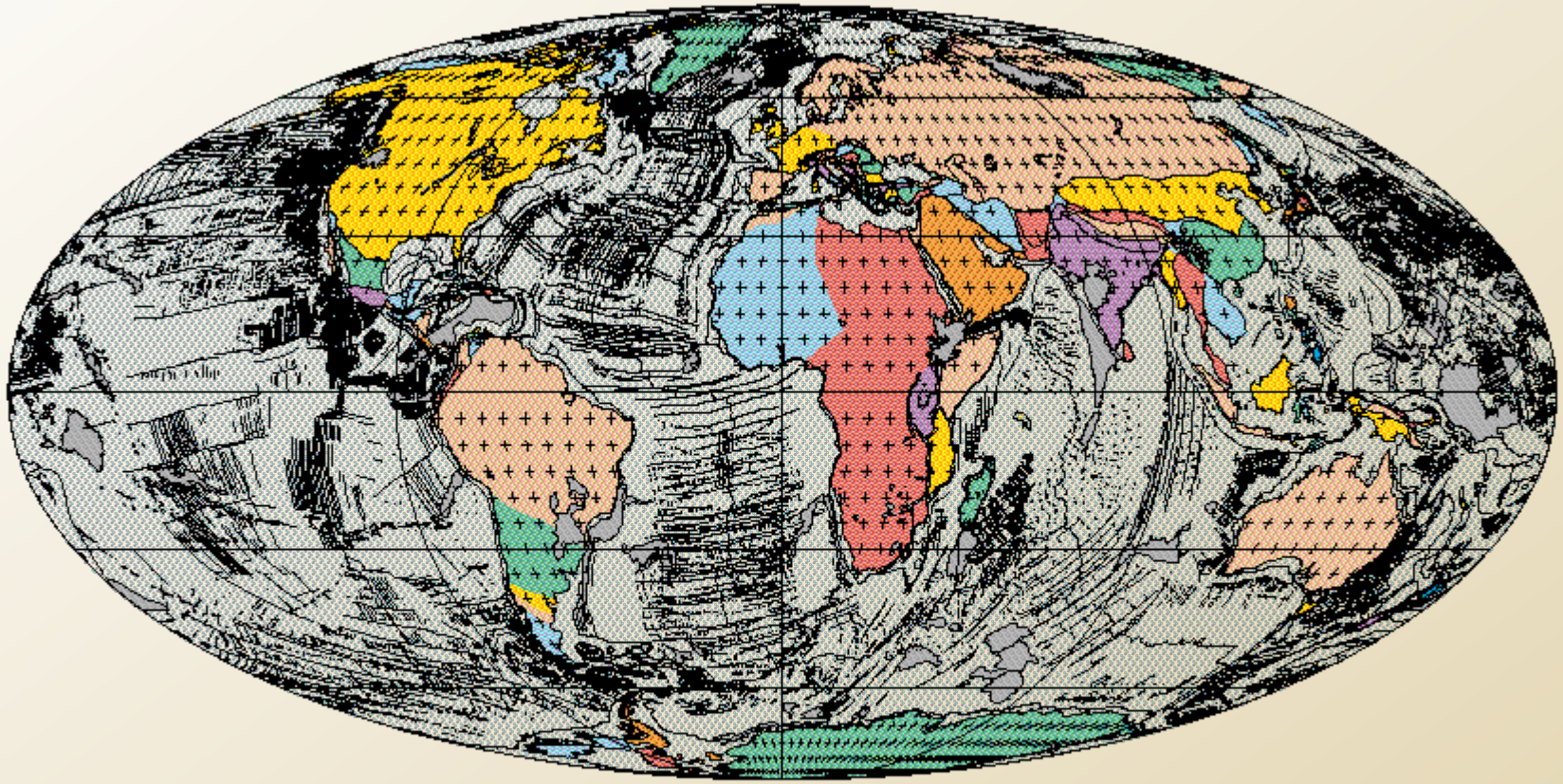


0 Ma
Present Day

PLATES/UTIG
July 1999


South America
Africa

Global Plate Tectonics

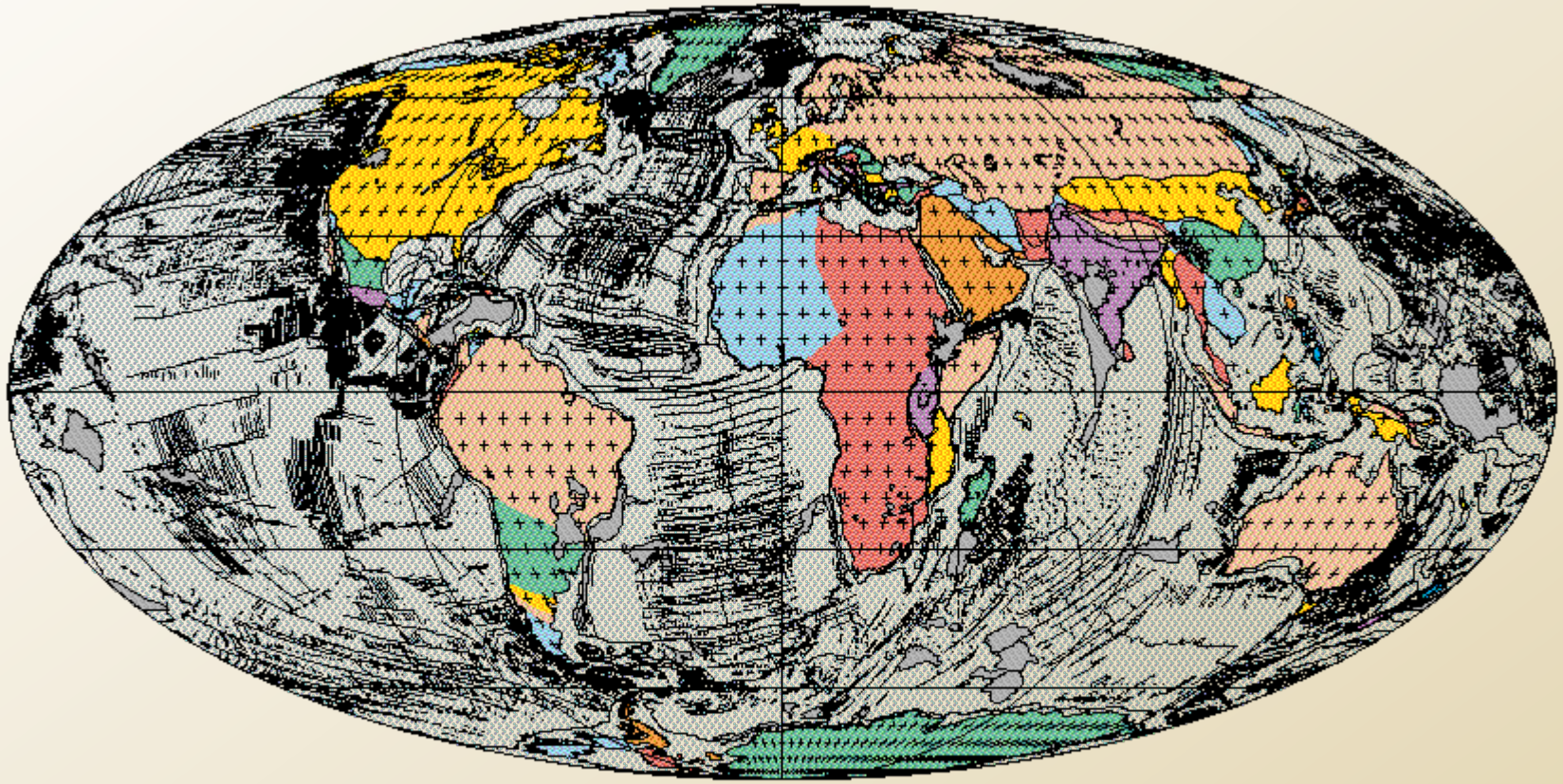


0 Ma
Present Day

PLATES/UTIG
July 1999

Lawver et al., 2001

Global Plate Tectonics

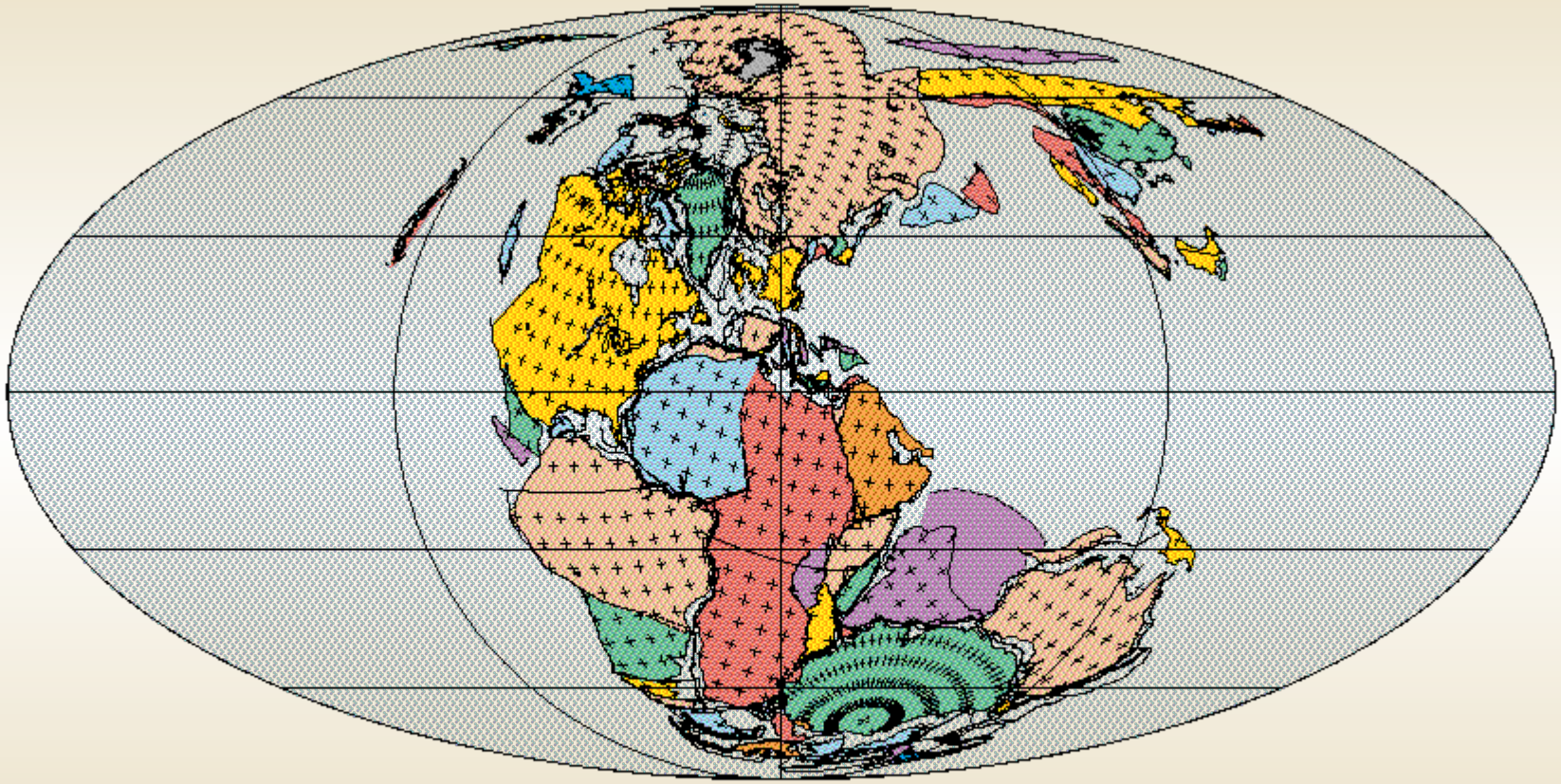


0 Ma
Present Day

PLATES/UTIG
July 1999

Lawver et al., 2001

Global Plate Tectonics …

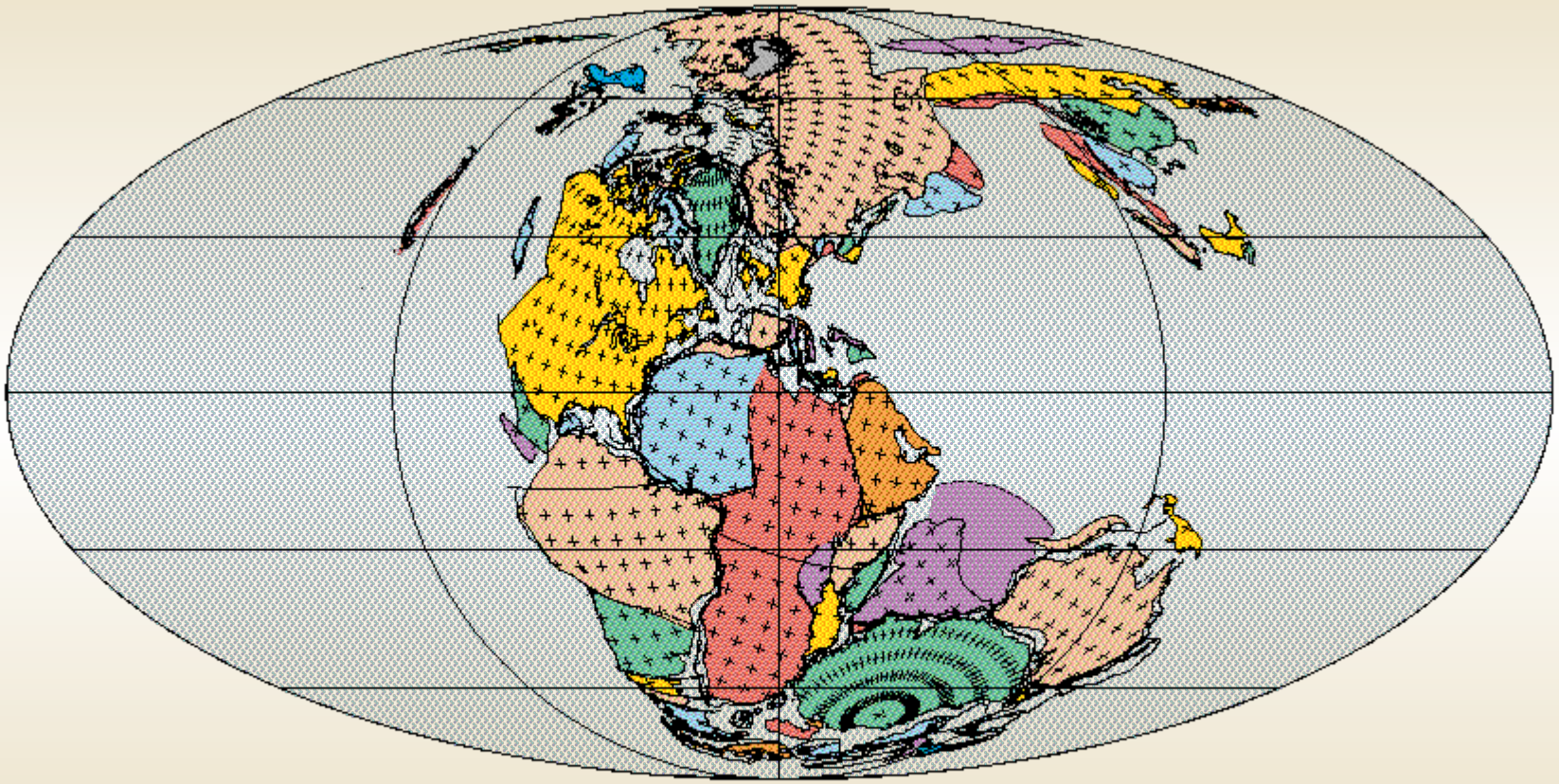


200 Ma
Sinemurian (Early Jurassic)

PLATES/UTIG
July 1999

Lawver et al., 2001

Global Plate Tectonics ...

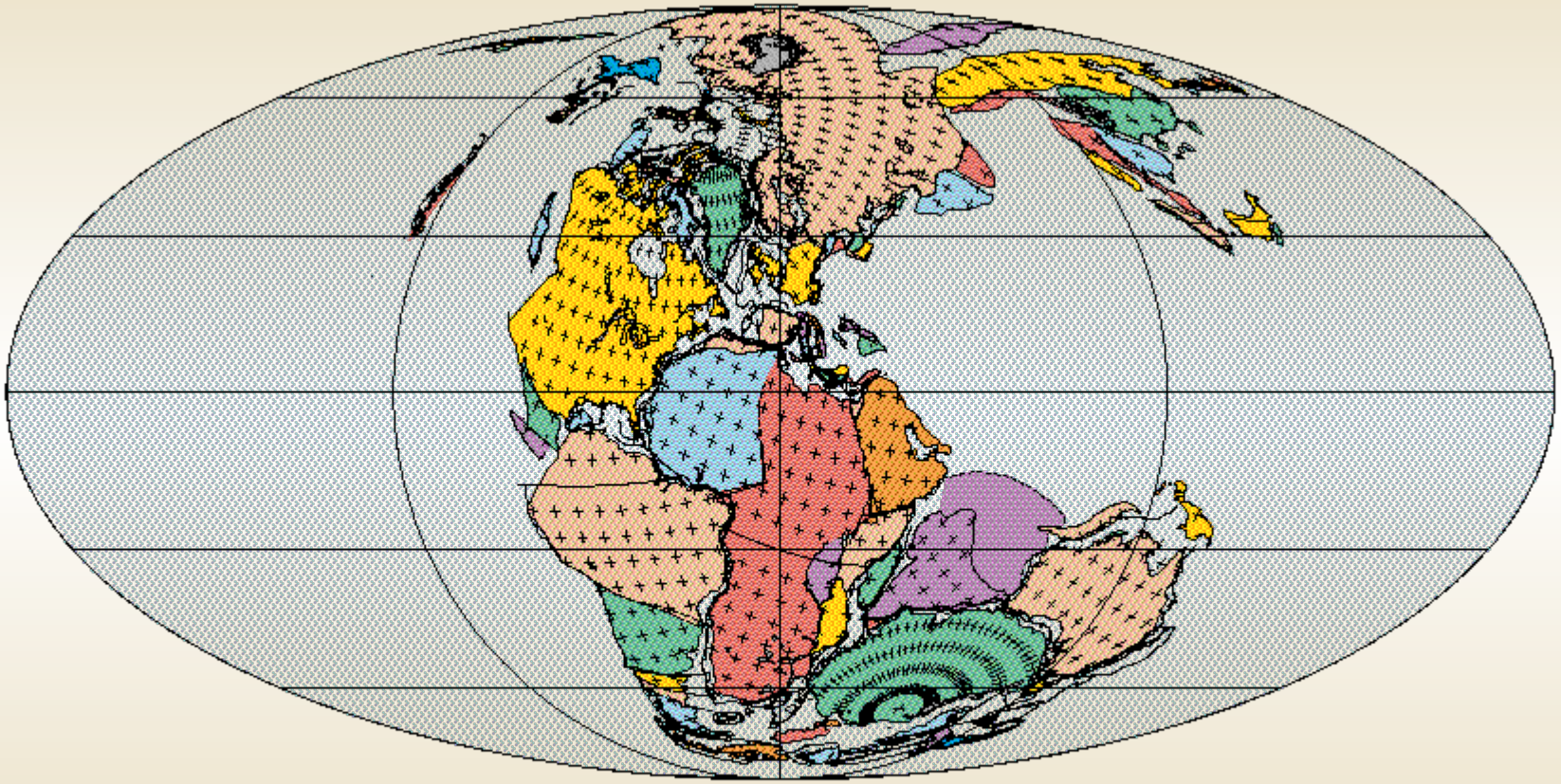


190 Ma
Pliensbachian (Early Jurassic)

PLATES/UTIG
July 1999

Lawver et al., 2001

Global Plate Tectonics ...

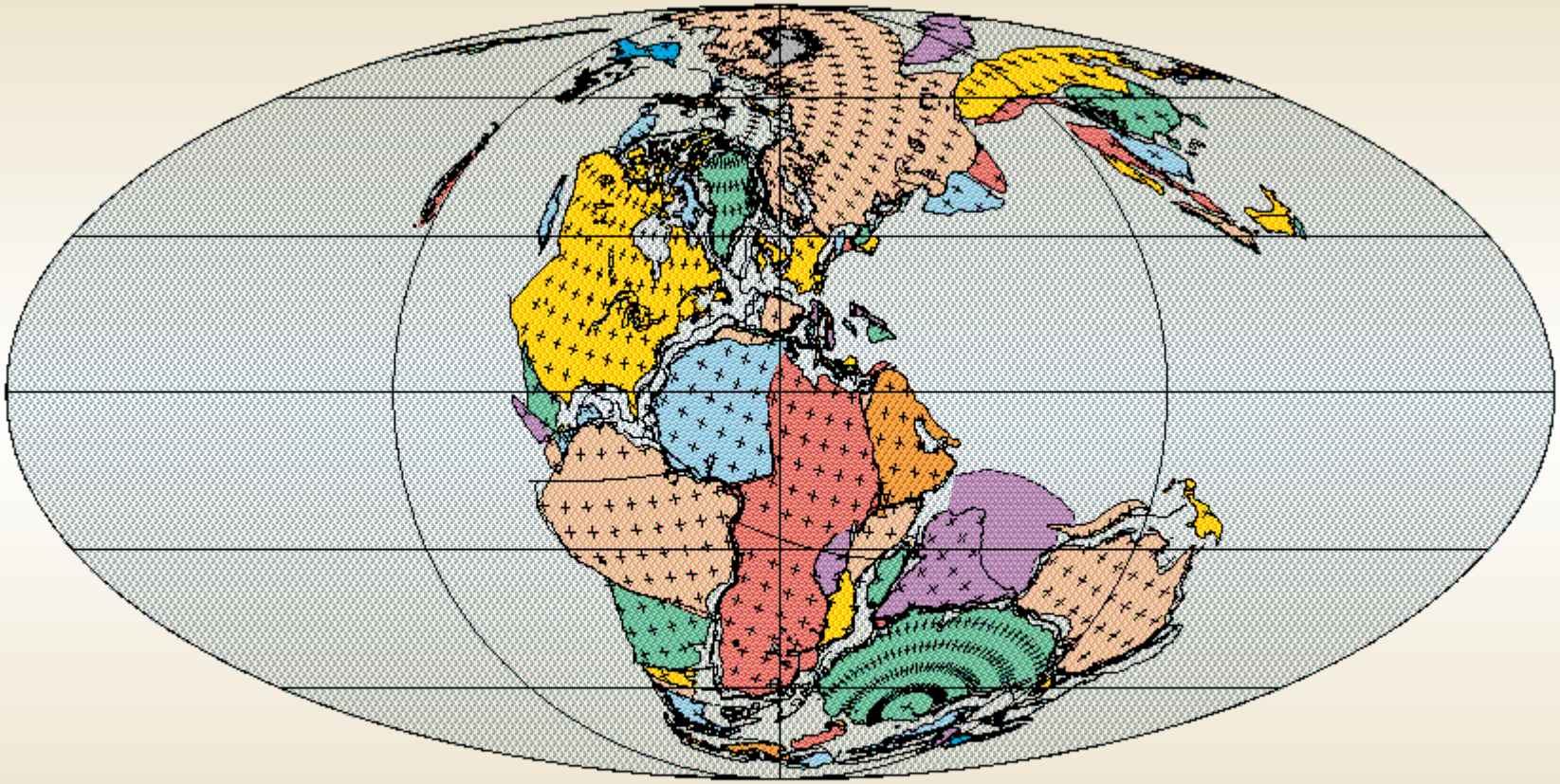


180 Ma
Aalenian (Middle Jurassic)

PLATES/UTIG
July 1999

Lawver et al., 2001

Global Plate Tectonics ...

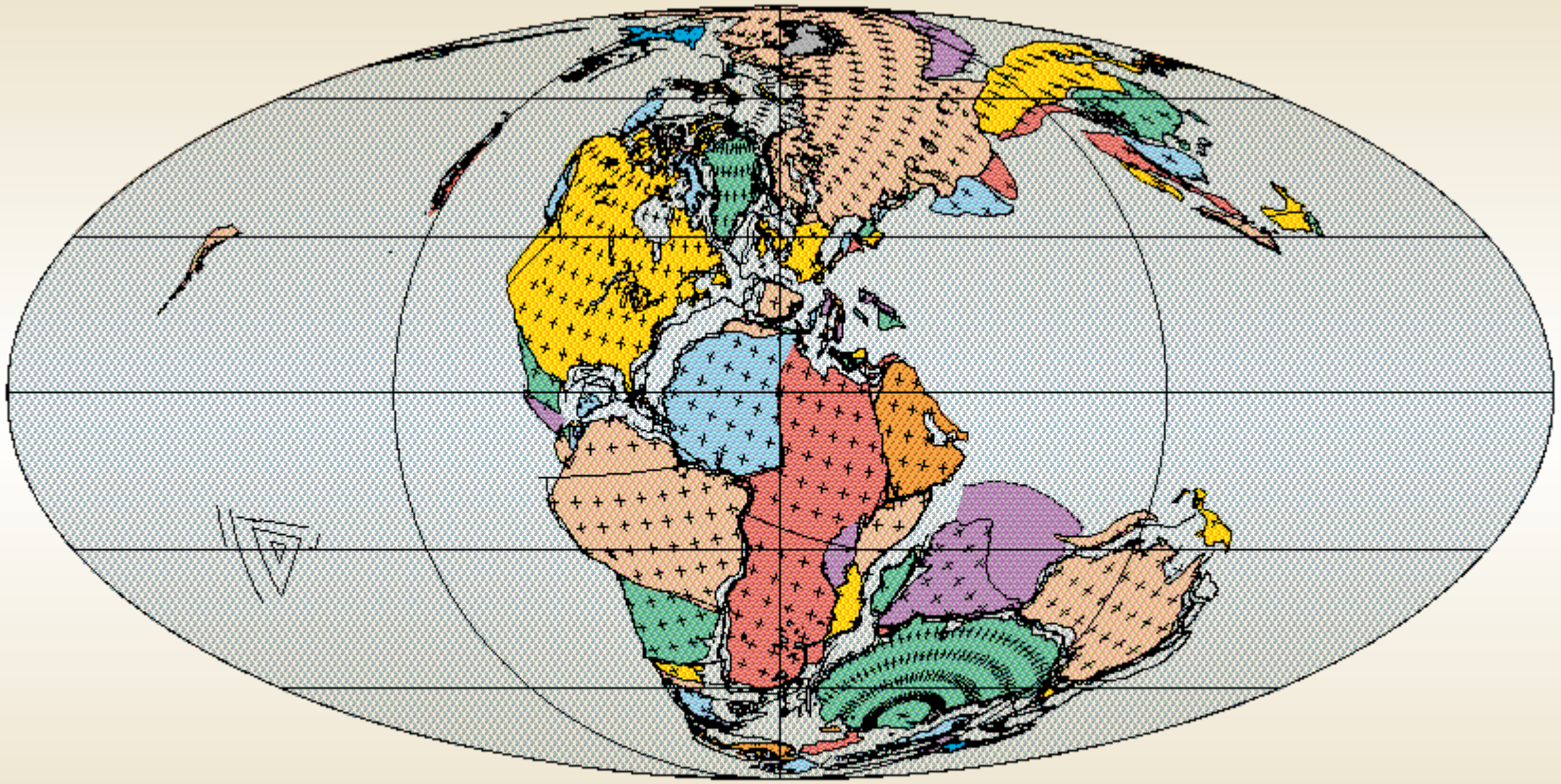


170 Ma
Bajocian (Middle Jurassic)

PLATES/UTIG
July 1999

Lawver et al., 2001

Global Plate Tectonics ...

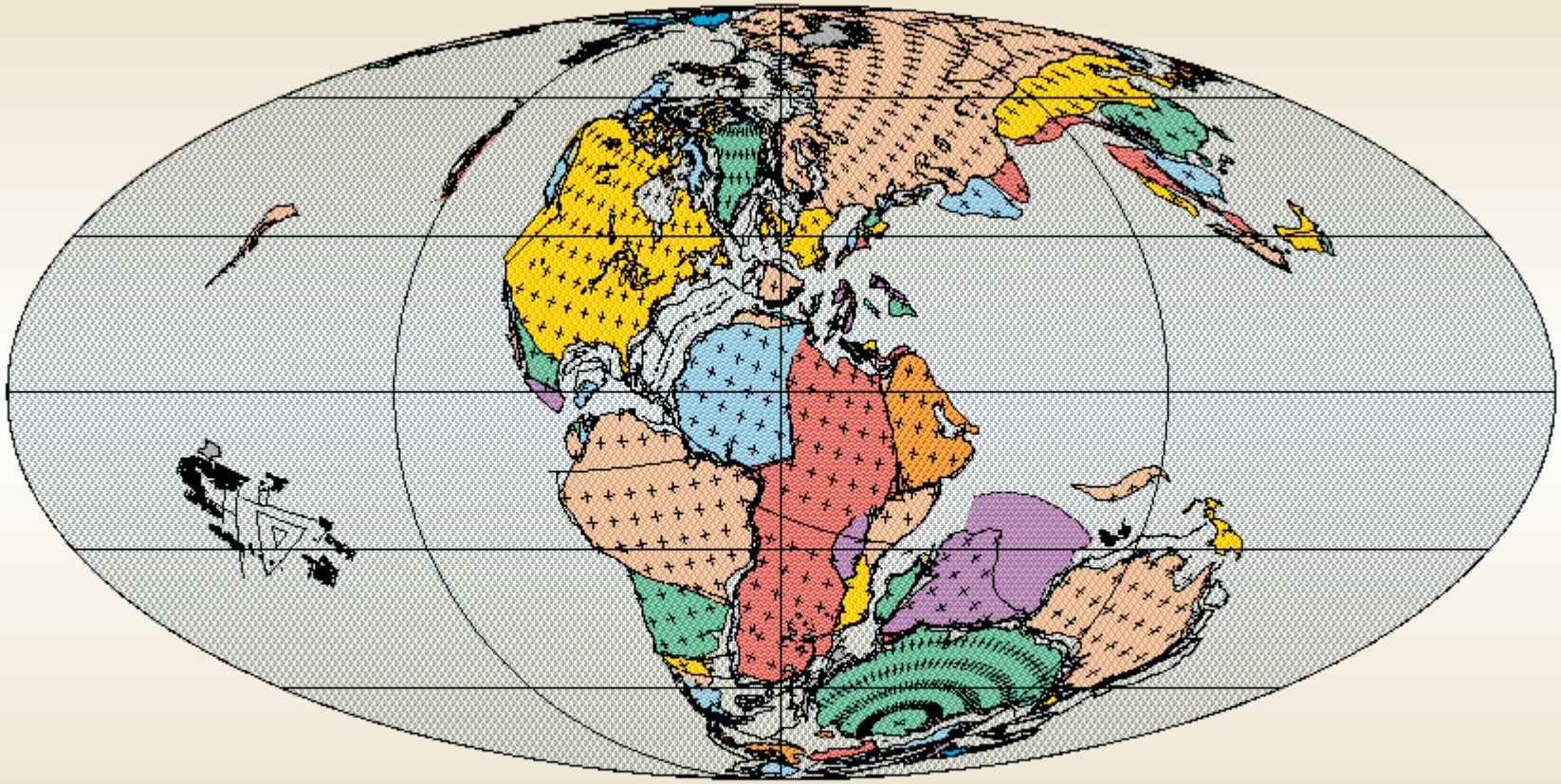


160 Ma
Callovian (Middle Jurassic)

PLATES/UTIG
July 1999

Lawver et al., 2001

Global Plate Tectonics ...

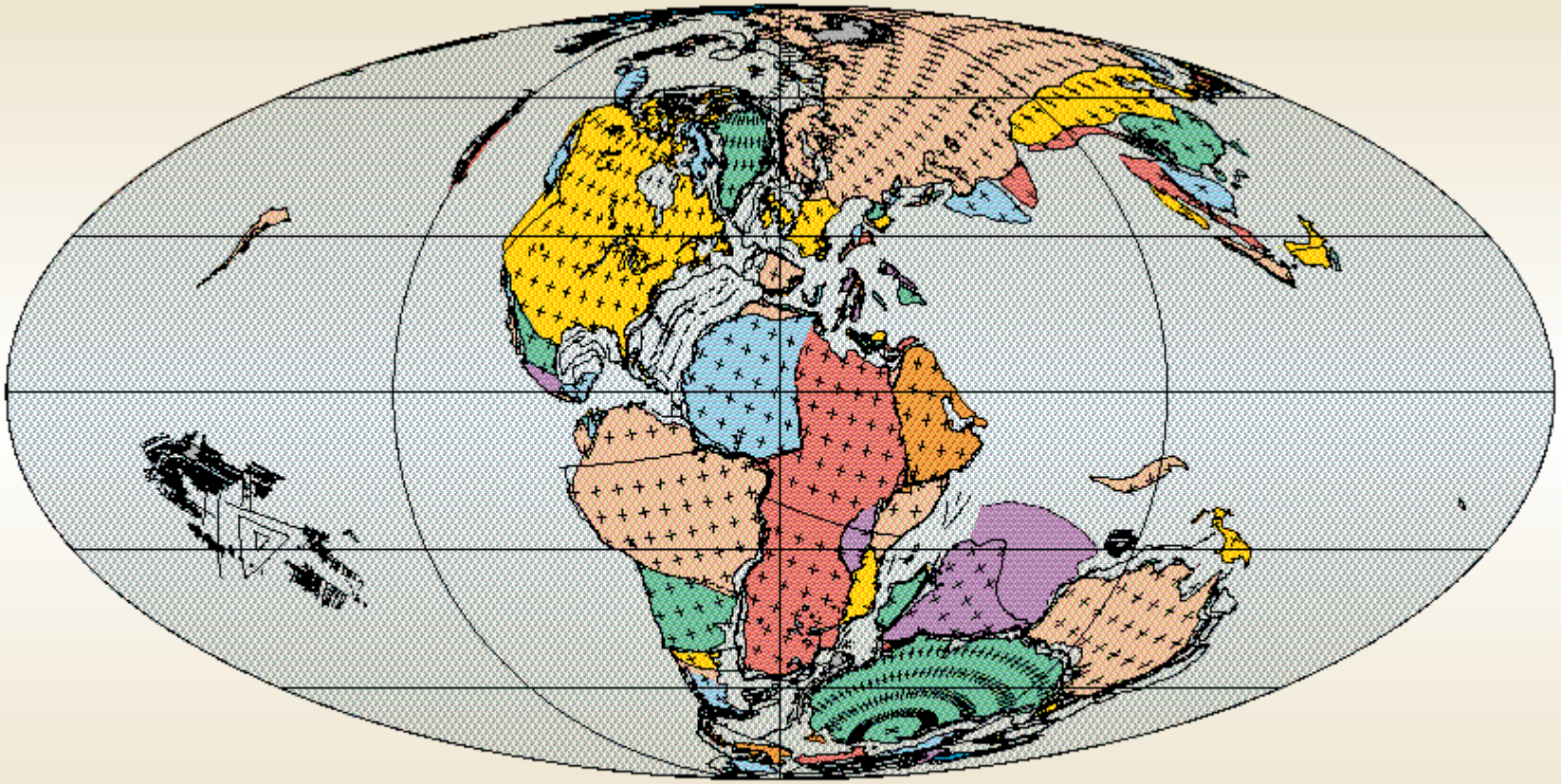


150 Ma
Volgian (Late Jurassic)

PLATES/UTIG
July 1999

Lawver et al., 2001

Global Plate Tectonics ...

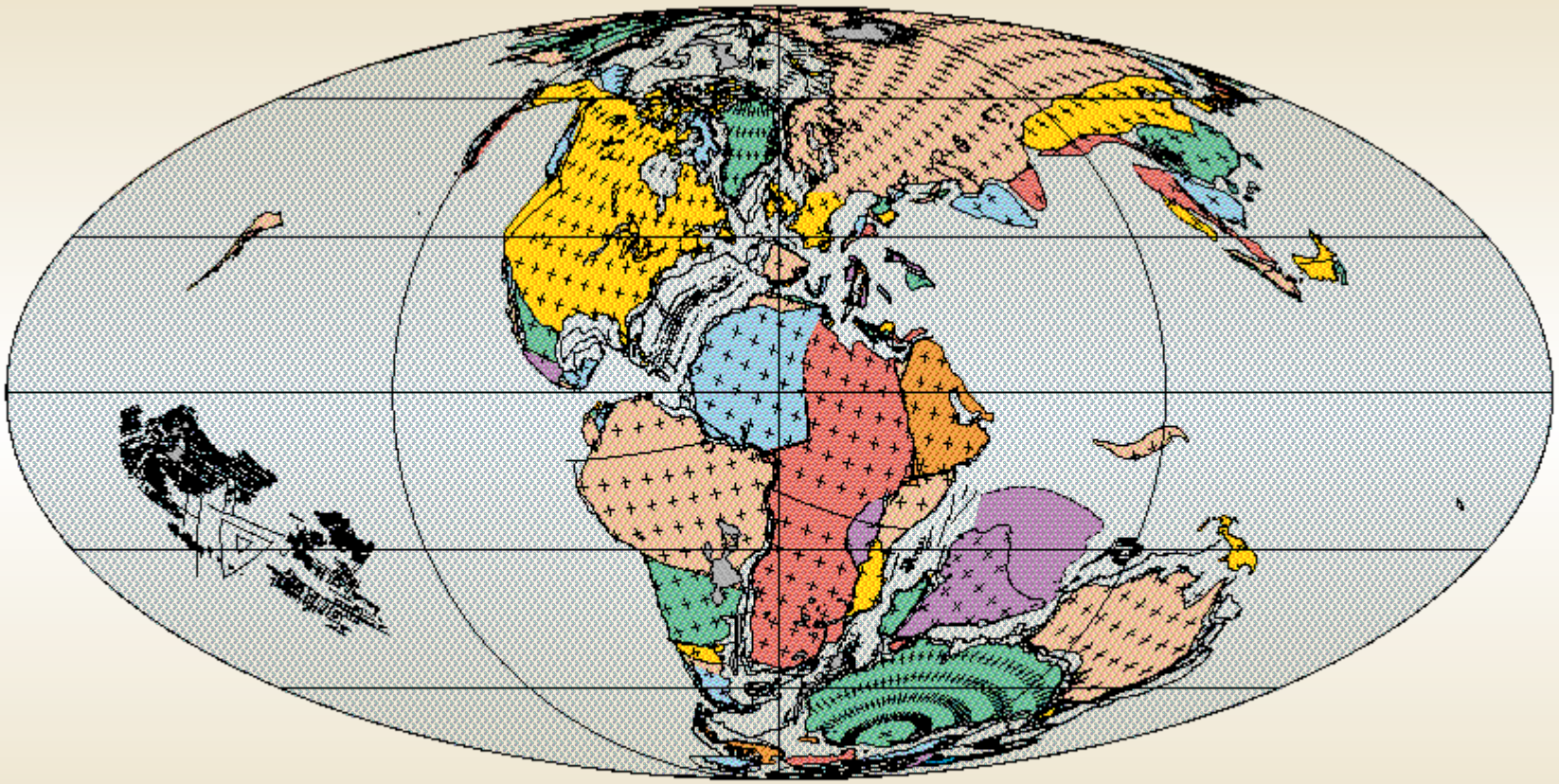


140 Ma
Ryazanian (Early Cretaceous)

PLATES/UTIG
July 1999

Lawver et al., 2001

Global Plate Tectonics ...

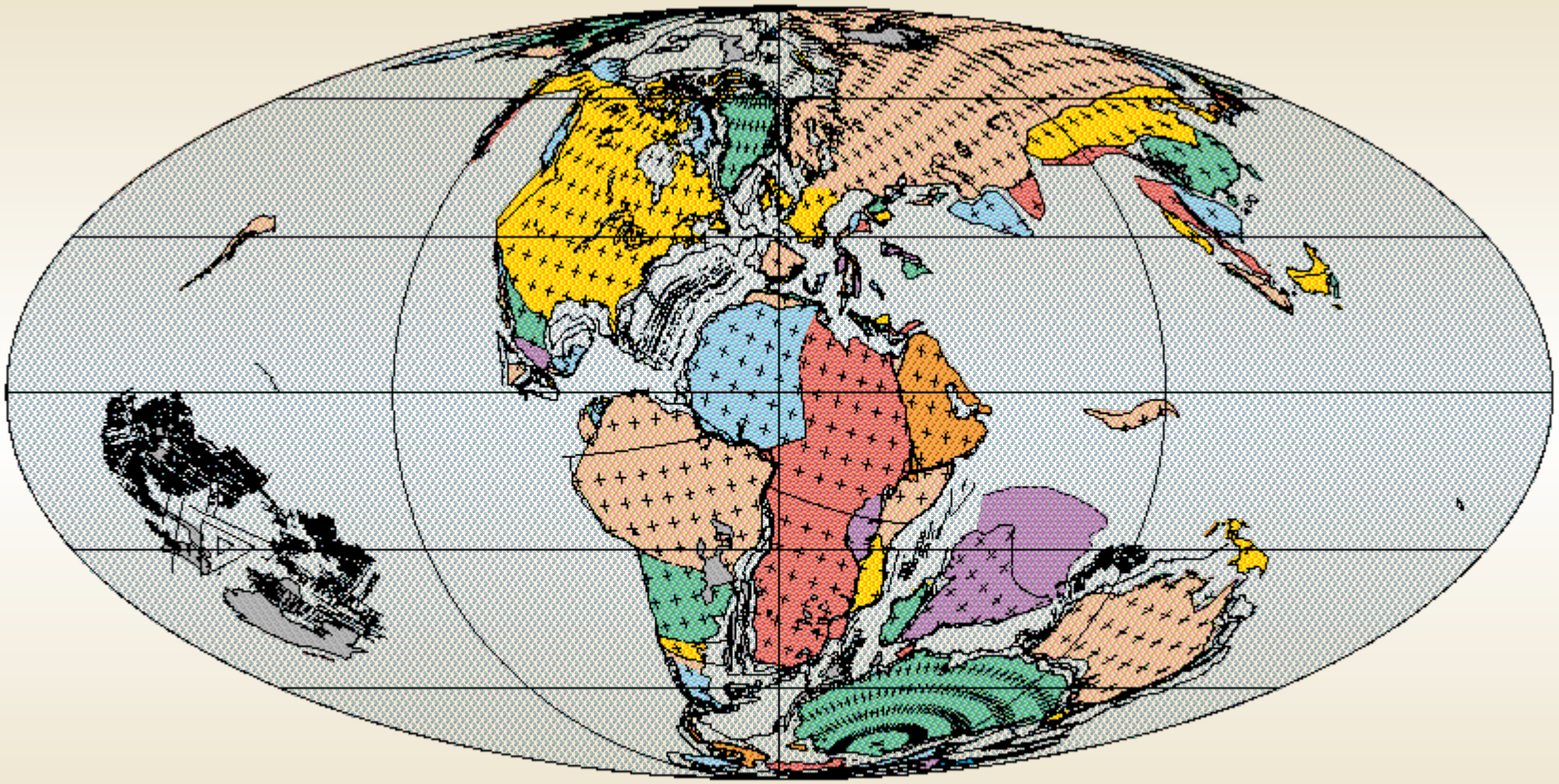


130 Ma
Hauterivian (Early Cretaceous)

PLATES/UTIG
July 1999

Lawver et al., 2001

Global Plate Tectonics ...

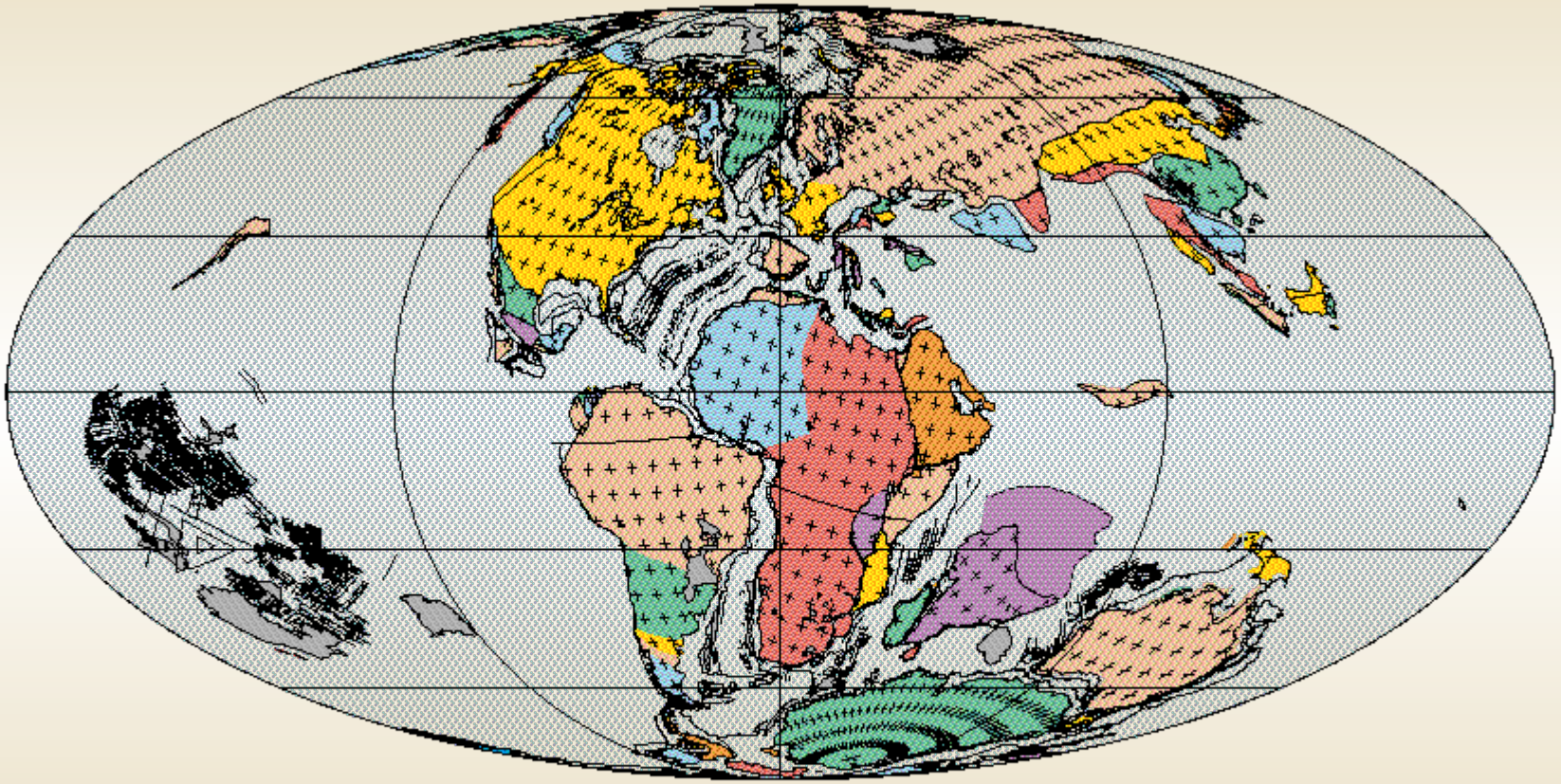


120 Ma
Aptian (Early Cretaceous)

PLATES/UTIG
July 1999

Lawver et al., 2001

Global Plate Tectonics ...

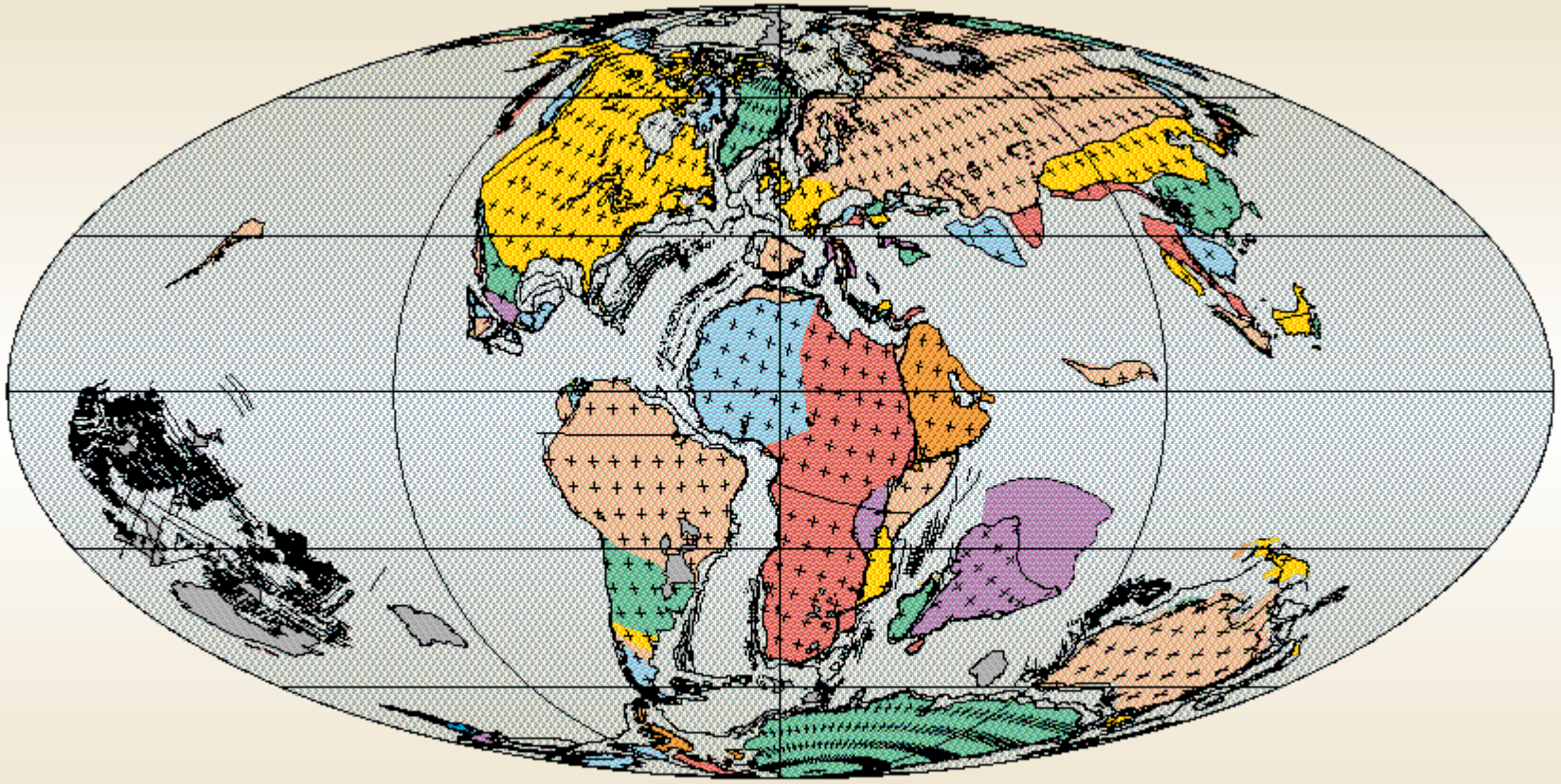


110 Ma
Early Albian (Early Cretaceous)

PLATES/UTIG
July 1999

Lawver et al., 2001

Global Plate Tectonics ...

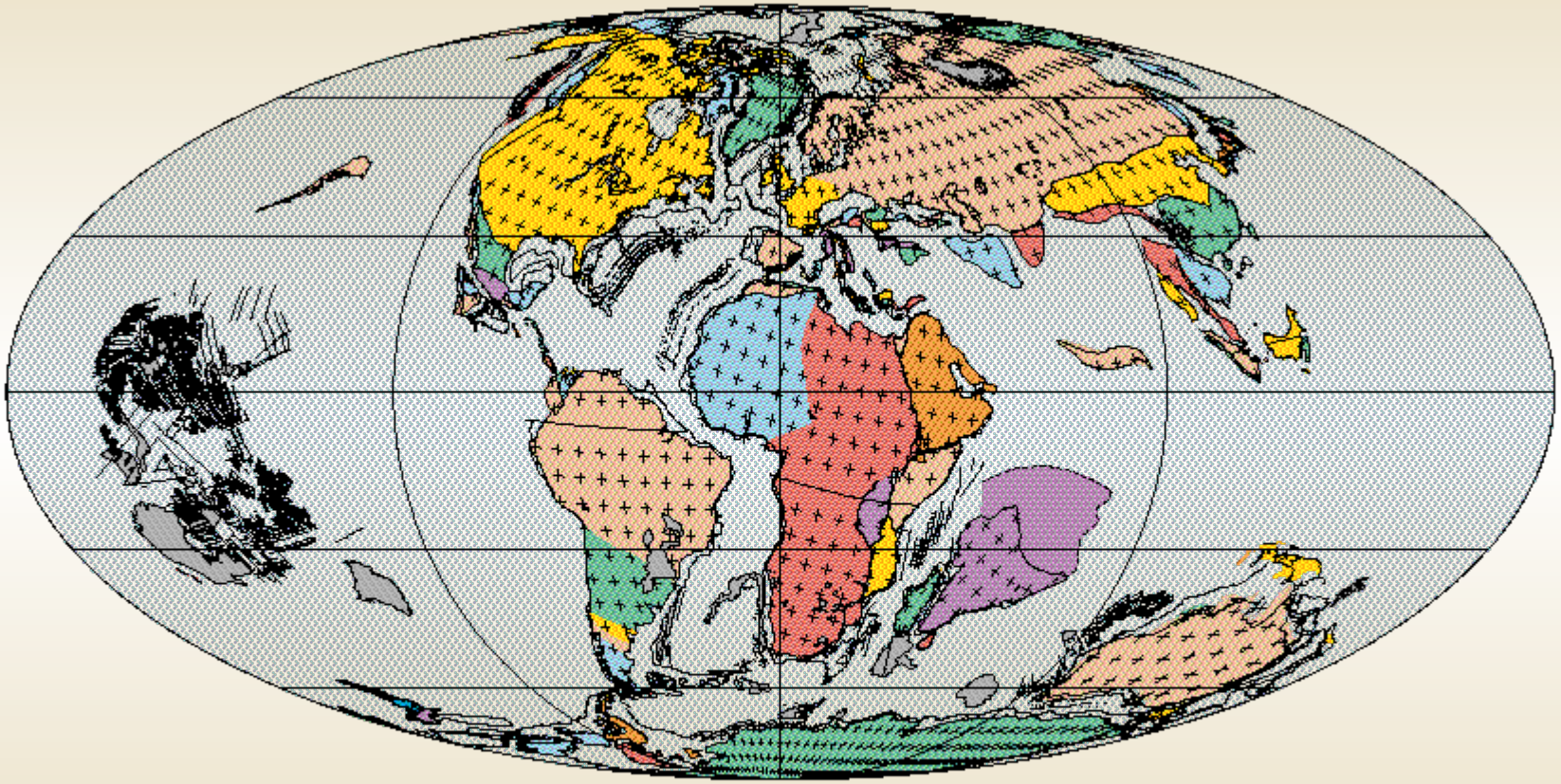


100 Ma
Late Albian (Early Cretaceous)

PLATES/UTIG
July 1999

Lawver et al., 2001

Global Plate Tectonics ...

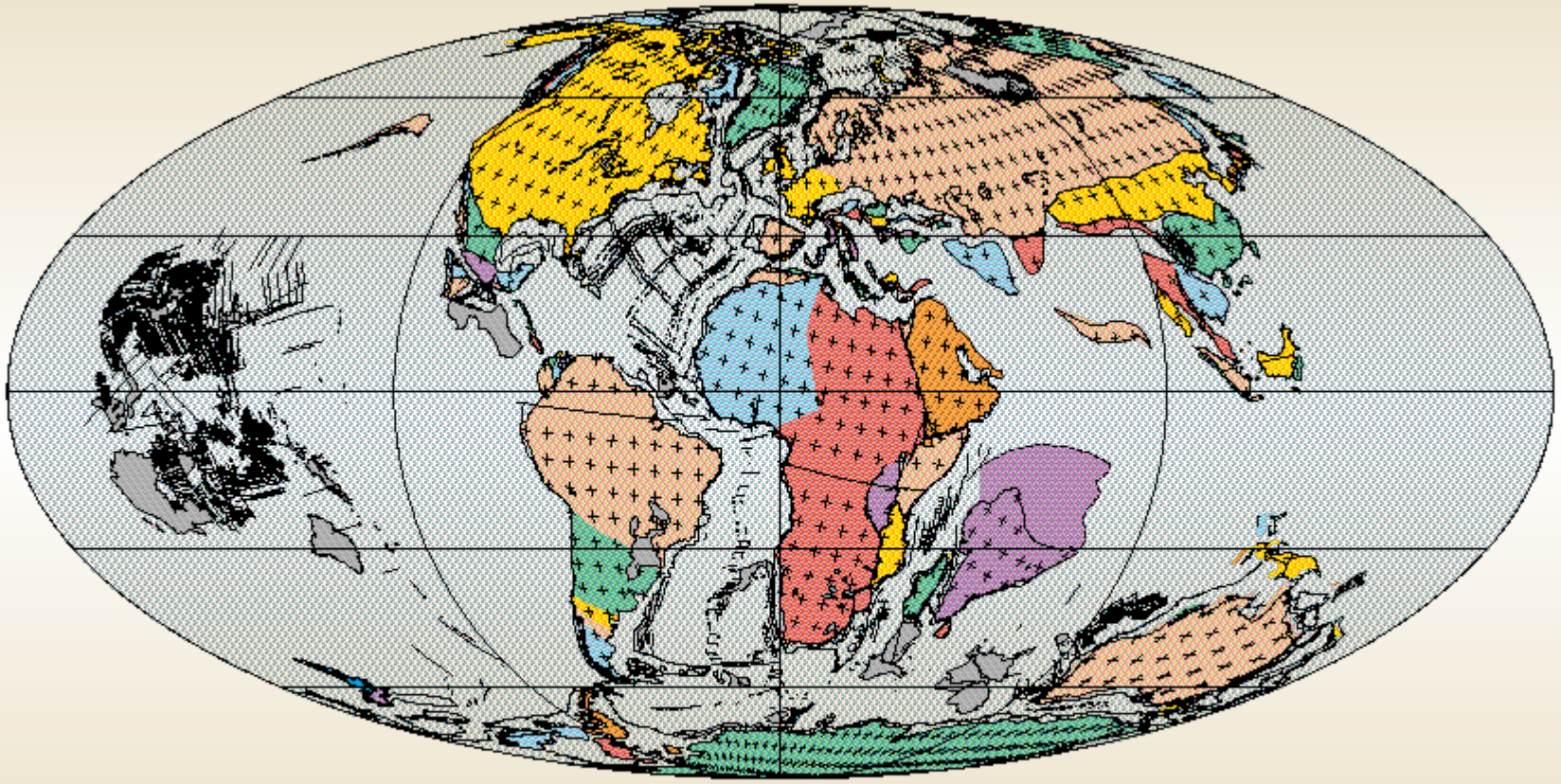


90 Ma
Turonian (Late Cretaceous)

PLATES/UTIG
July 1999

Lawver et al., 2001

Global Plate Tectonics ...

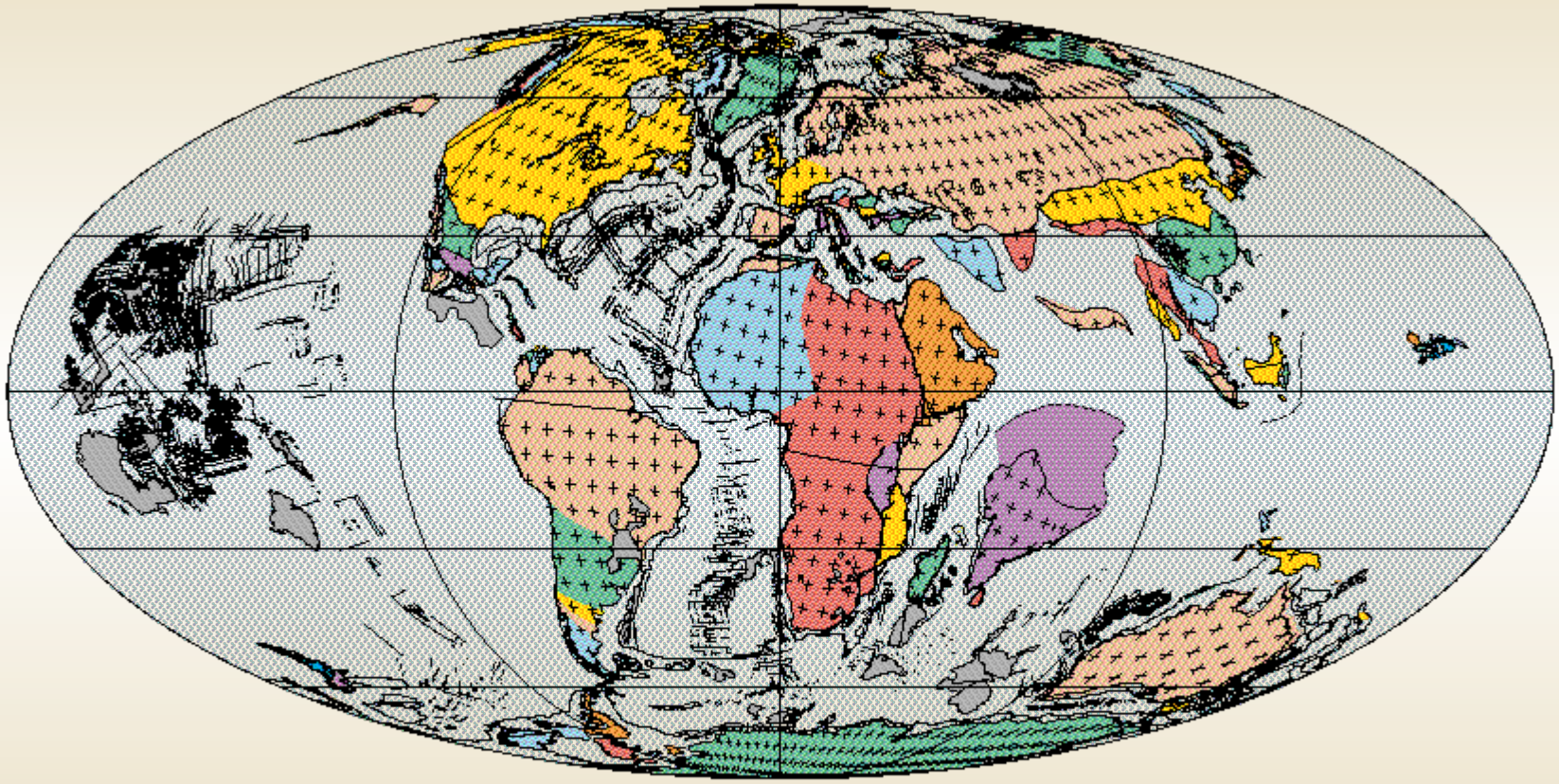


80 Ma
Campanian (Late Cretaceous)

PLATES/UTIG
July 1999

Lawver et al., 2001

Global Plate Tectonics ...

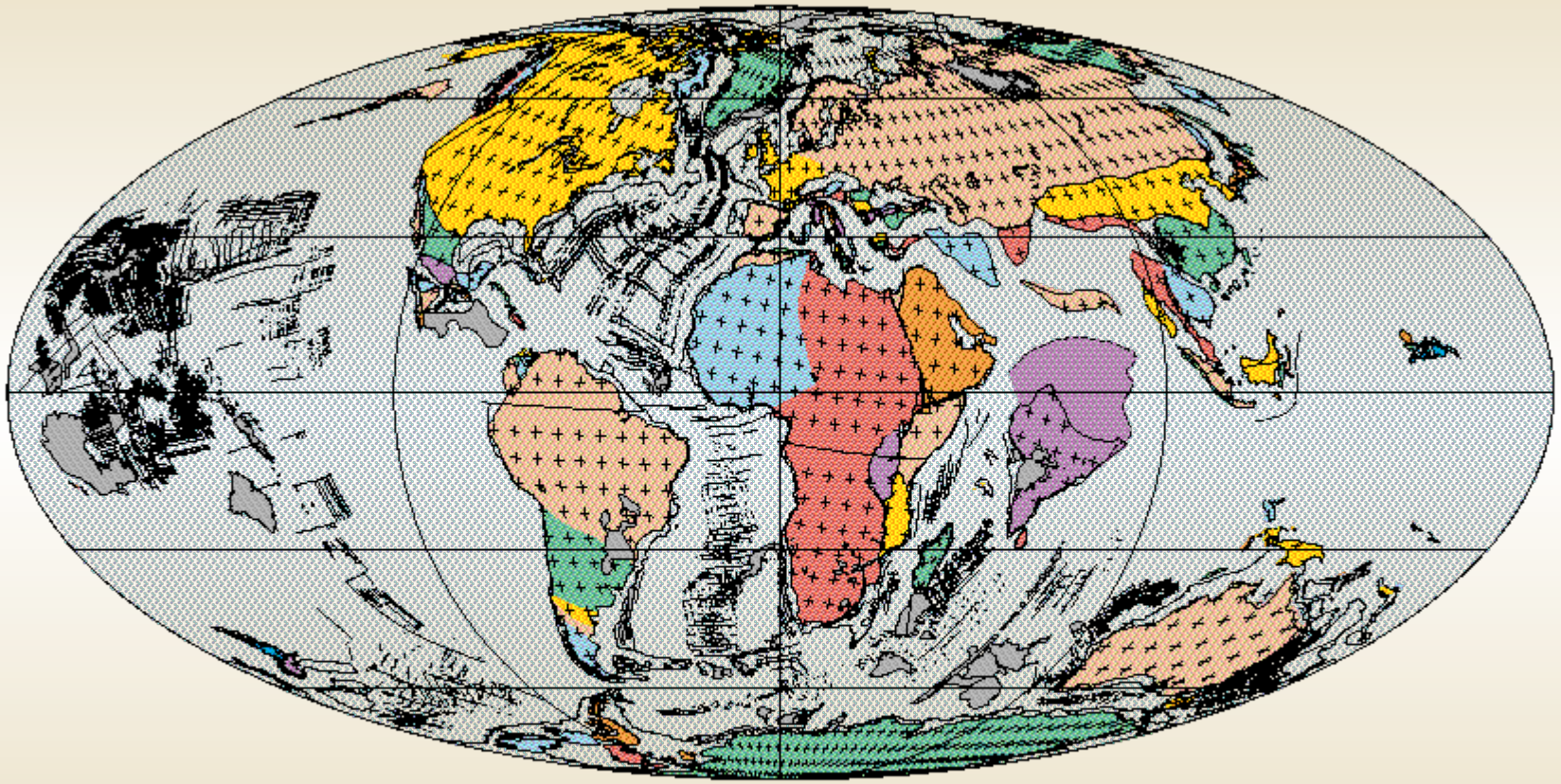


70 Ma
Maastrichtian (Late Cretaceous)

PLATES/UTIG
July 1999

Lawver et al., 2001

Global Plate Tectonics ...

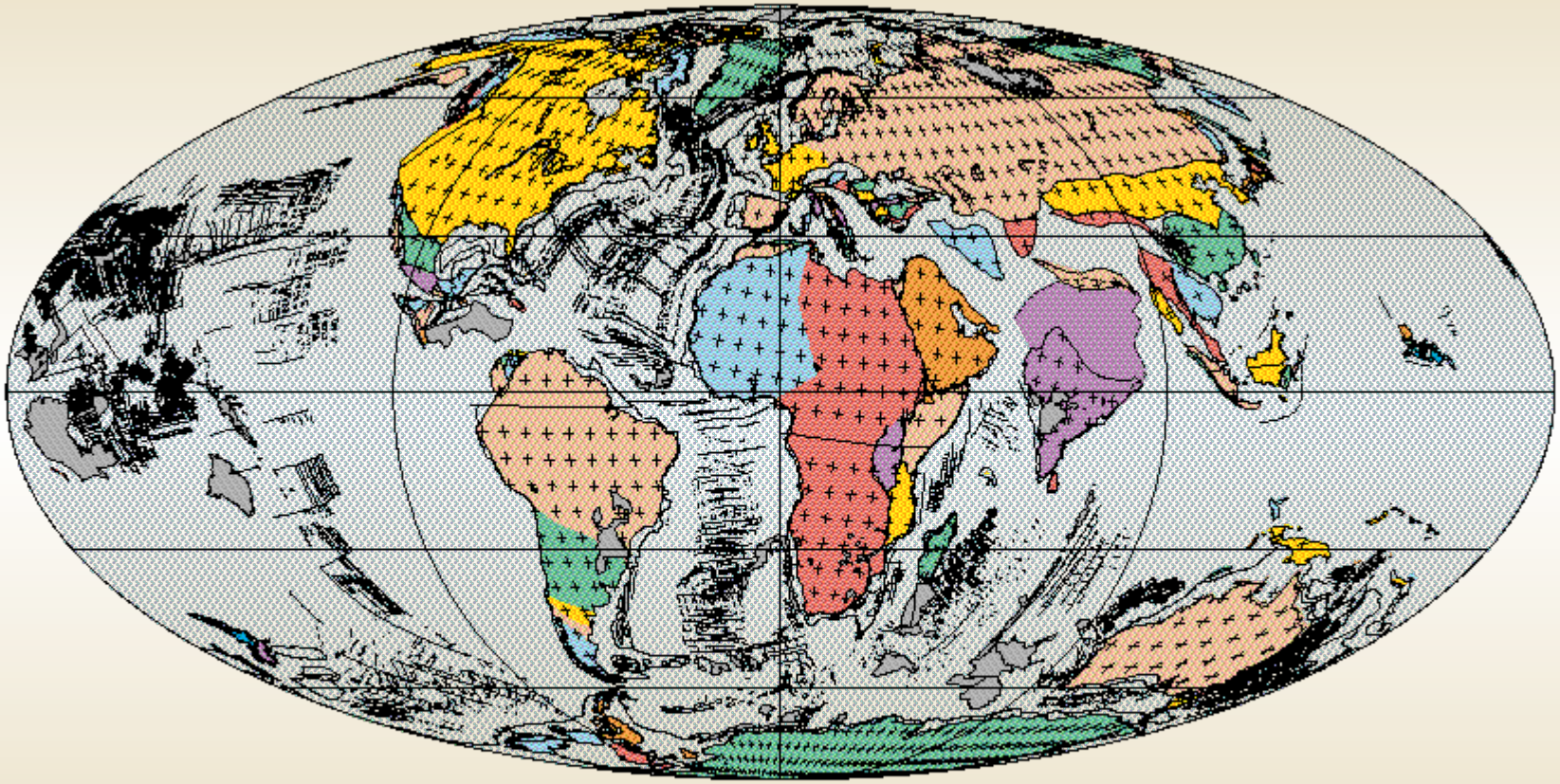


60 Ma
Late Paleocene

PLATES/UTIG
July 1999

Lawver et al., 2001

Global Plate Tectonics ...

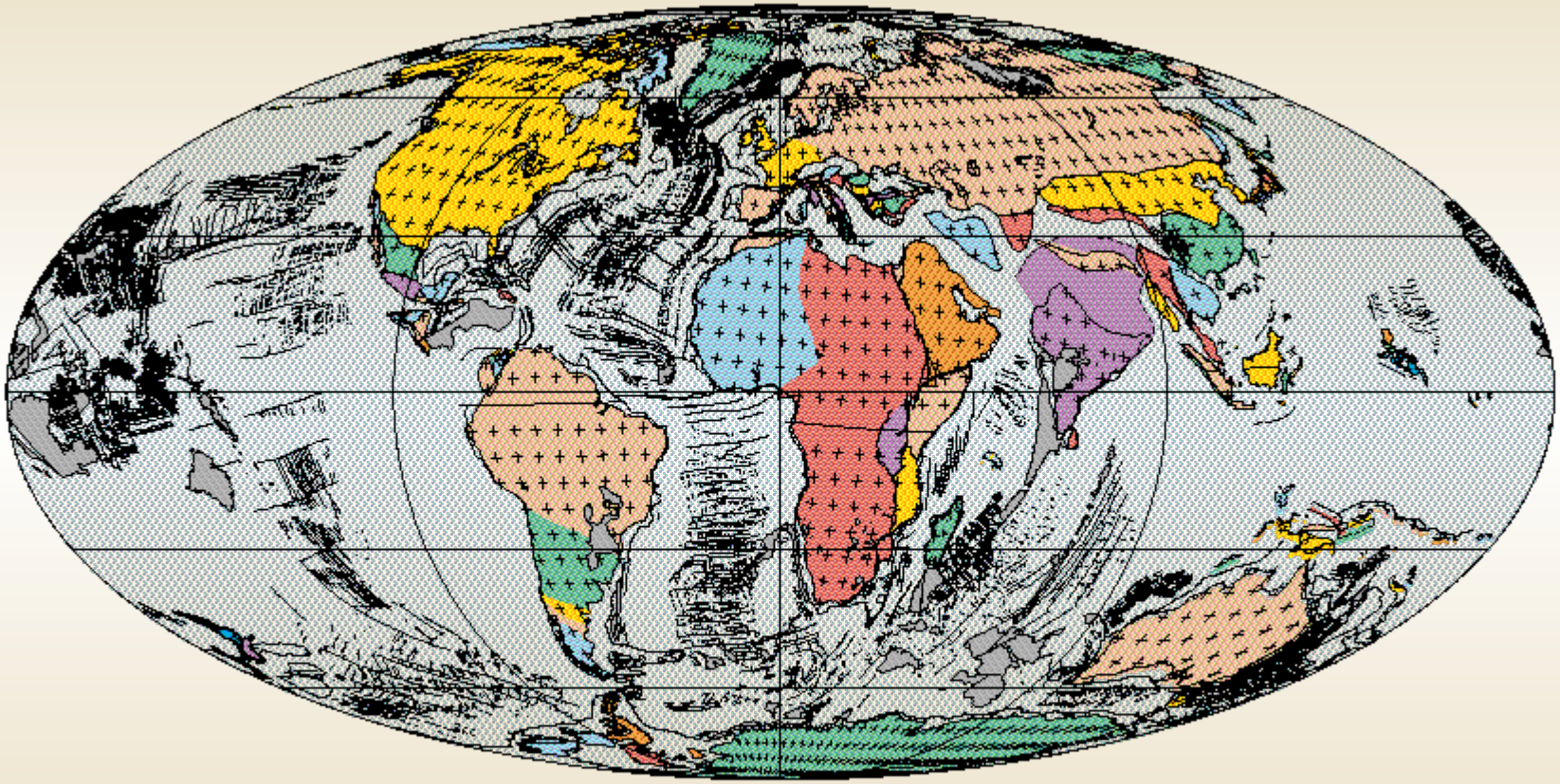


50 Ma
Early Eocene

PLATES/UTIG
July 1999

Lawver et al., 2001

Global Plate Tectonics ...

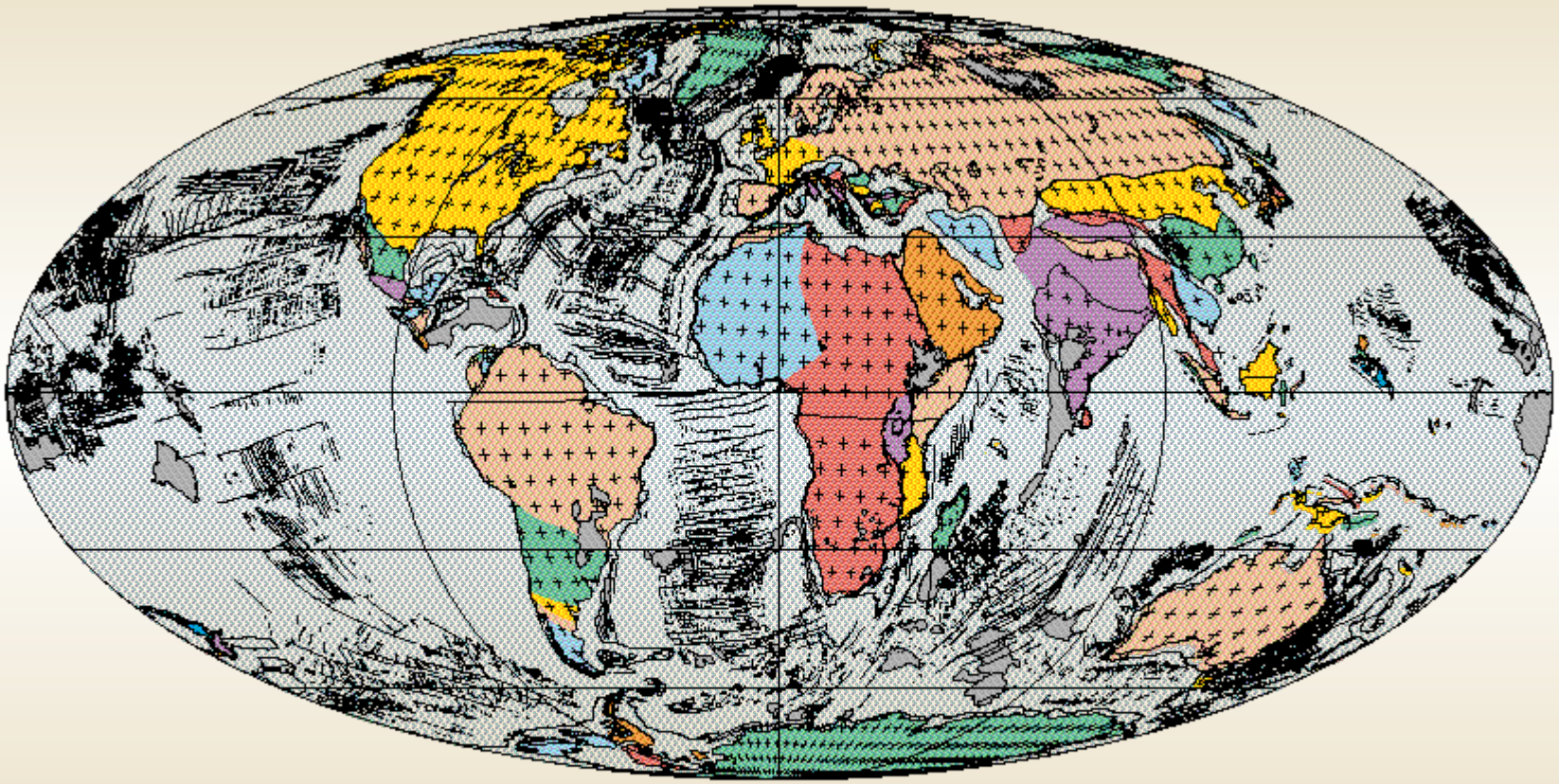


40 Ma
Middle Eocene

PLATES/UTIG
July 1999

Lawver et al., 2001

Global Plate Tectonics ...

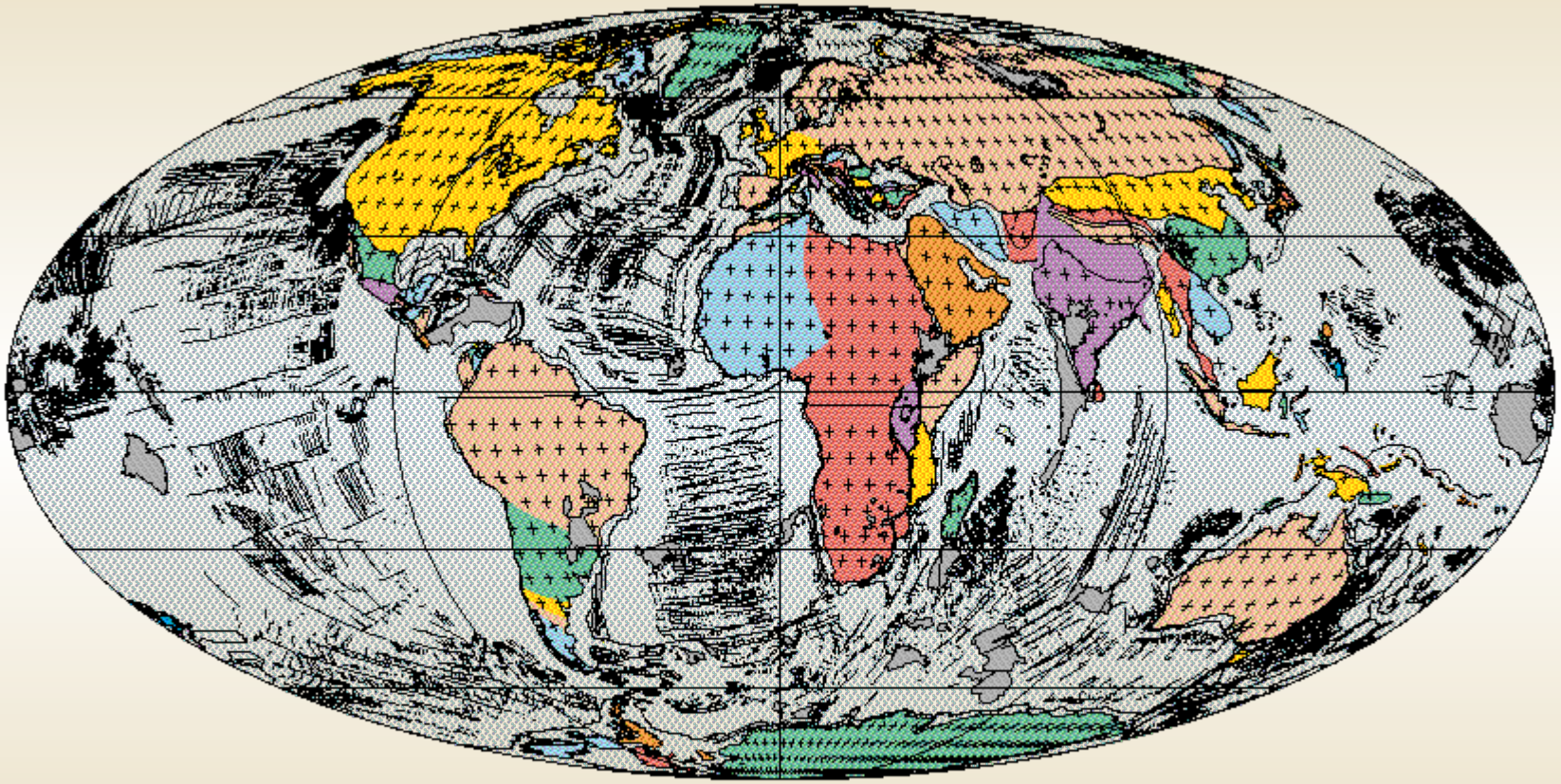


30 Ma
Early Oligocene

PLATES/UTIG
July 1999

Lawver et al., 2001

Global Plate Tectonics ...

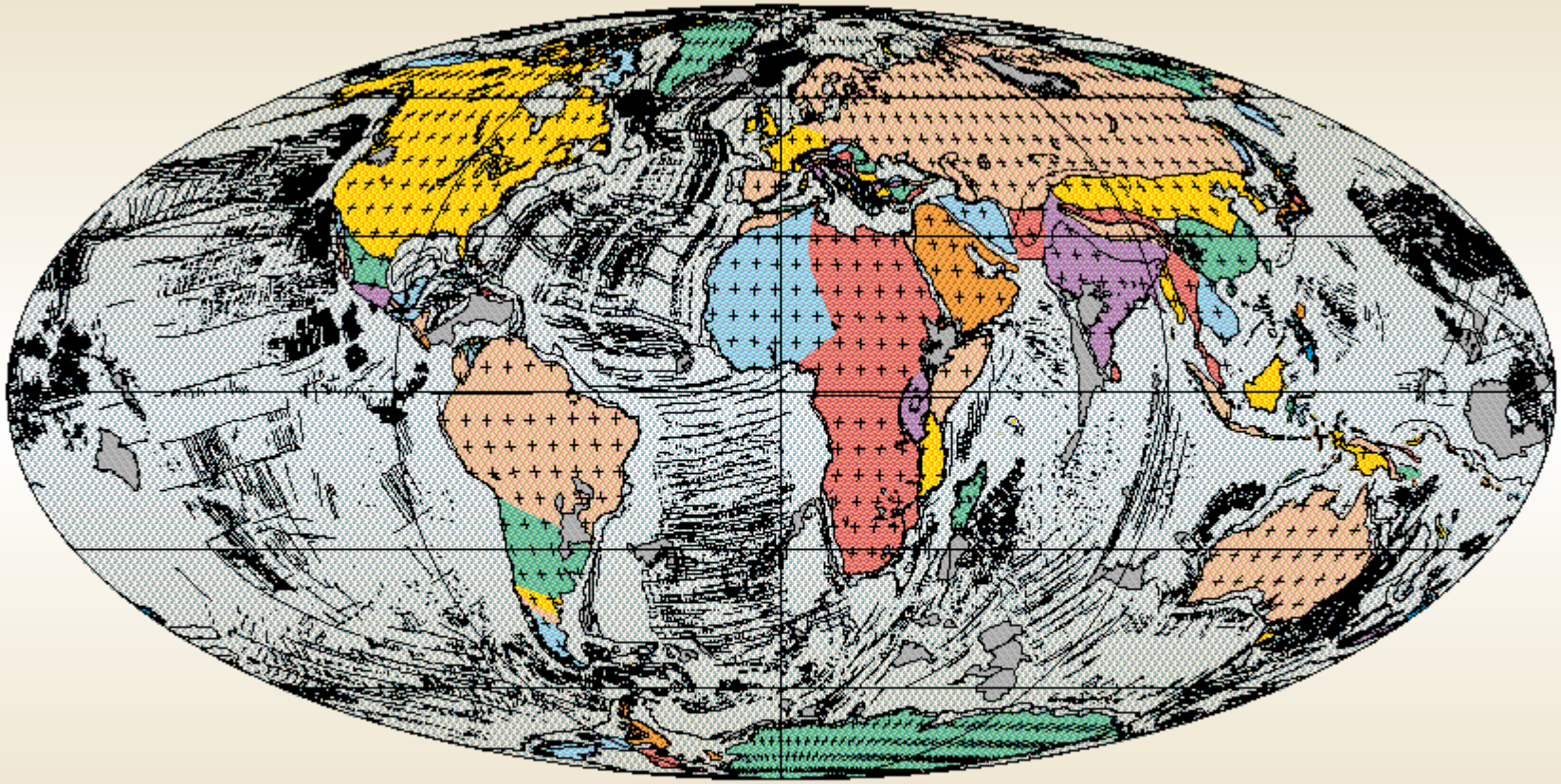


20 Ma
Early Miocene

PLATES/UTIG
July 1999

Lawver et al., 2001

Global Plate Tectonics ...

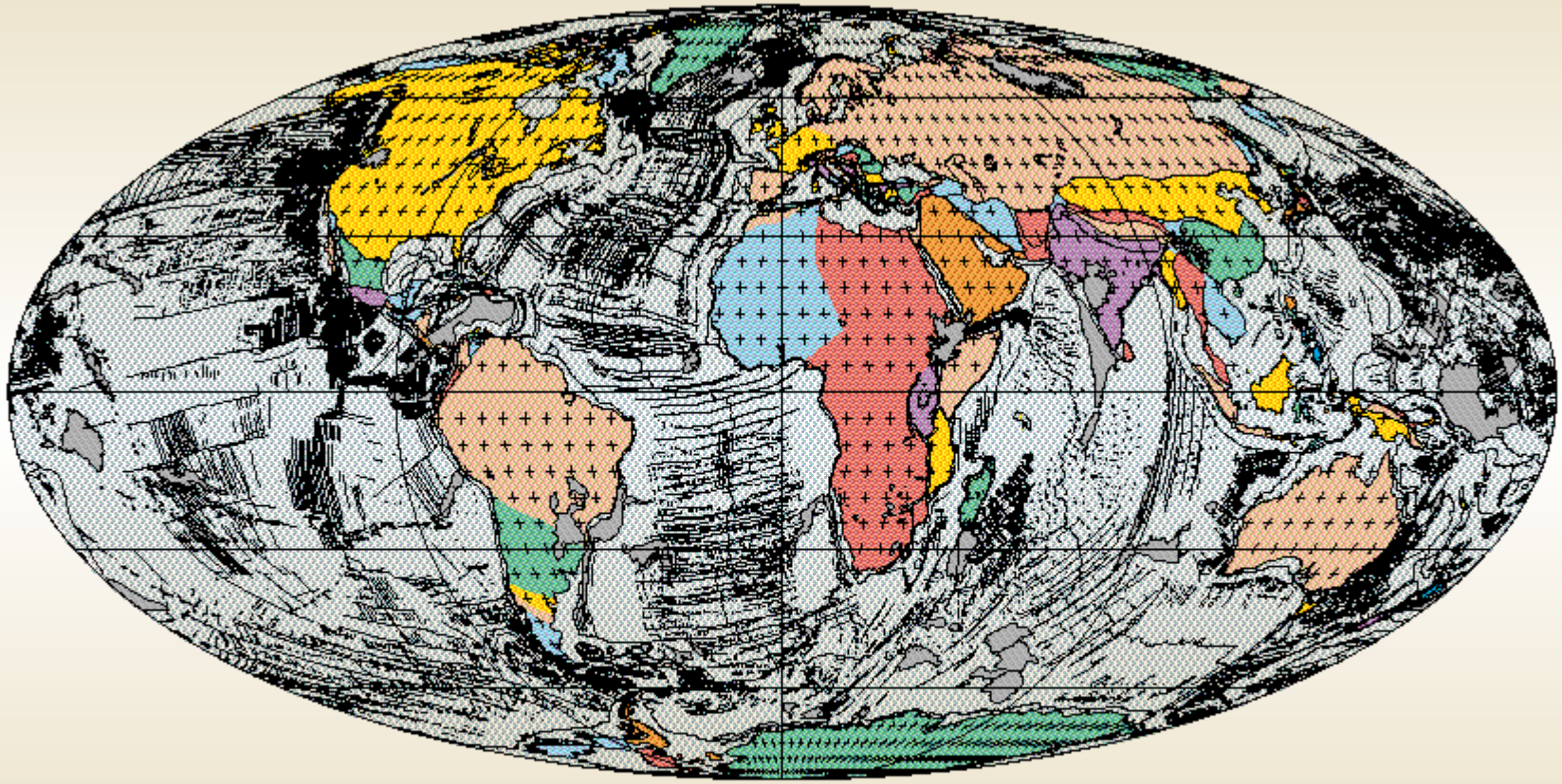


10 Ma
Late Miocene

PLATES/UTIG
July 1999

Lawver et al., 2001

Global Plate Tectonics ...



0 Ma
Present Day

PLATES/UTIG
July 1999

Lawver et al., 2001

Evolution of the Mediterranean subduction belts and back-arc basins

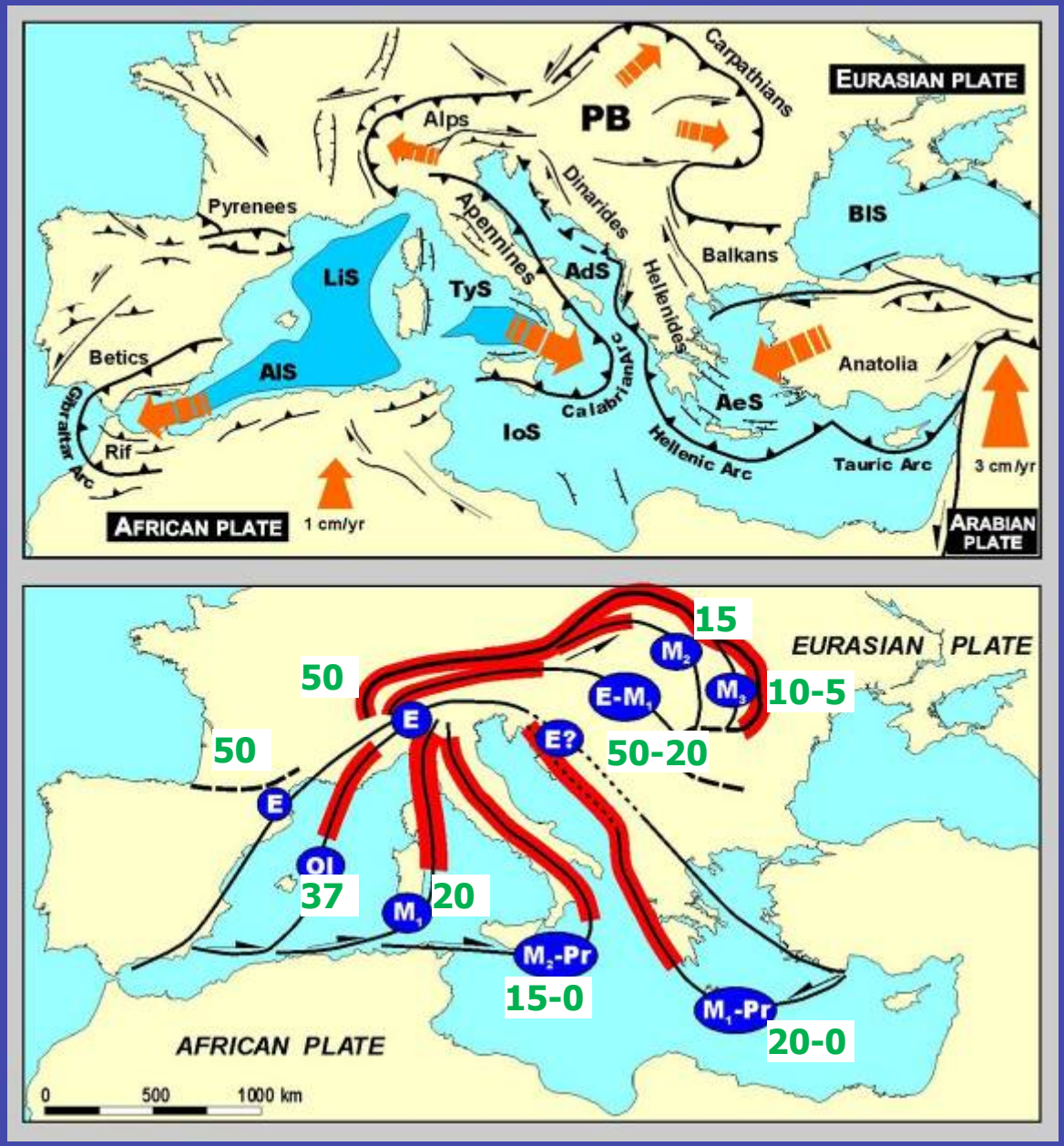
Present

Miocene 23-5 My
- **3** upper
- **2** mid
- **1** lower

Oligocene 37-23 My

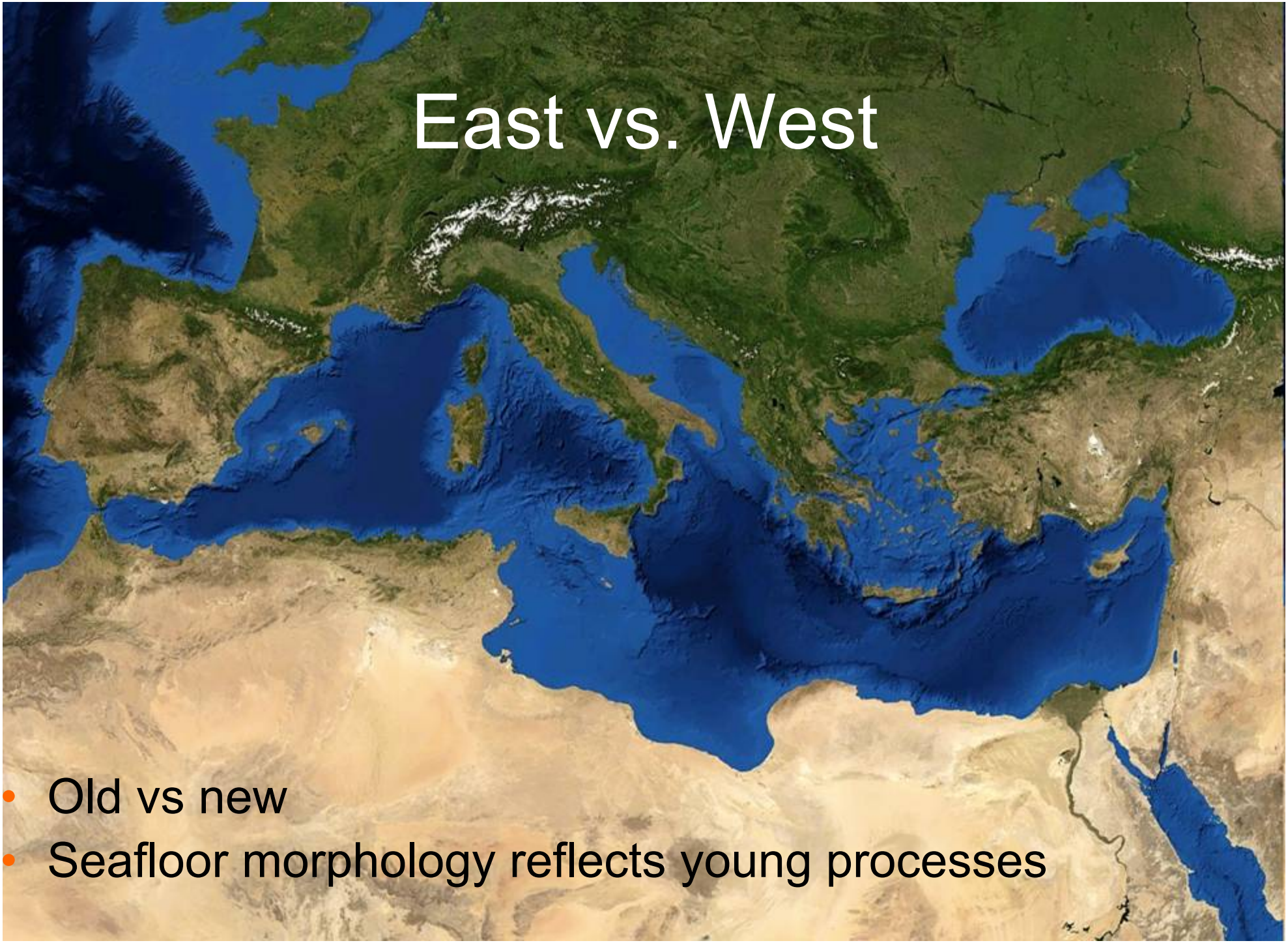
Eocene 50-37 My

Time before present (My)



Wortel & Spakman, 1992

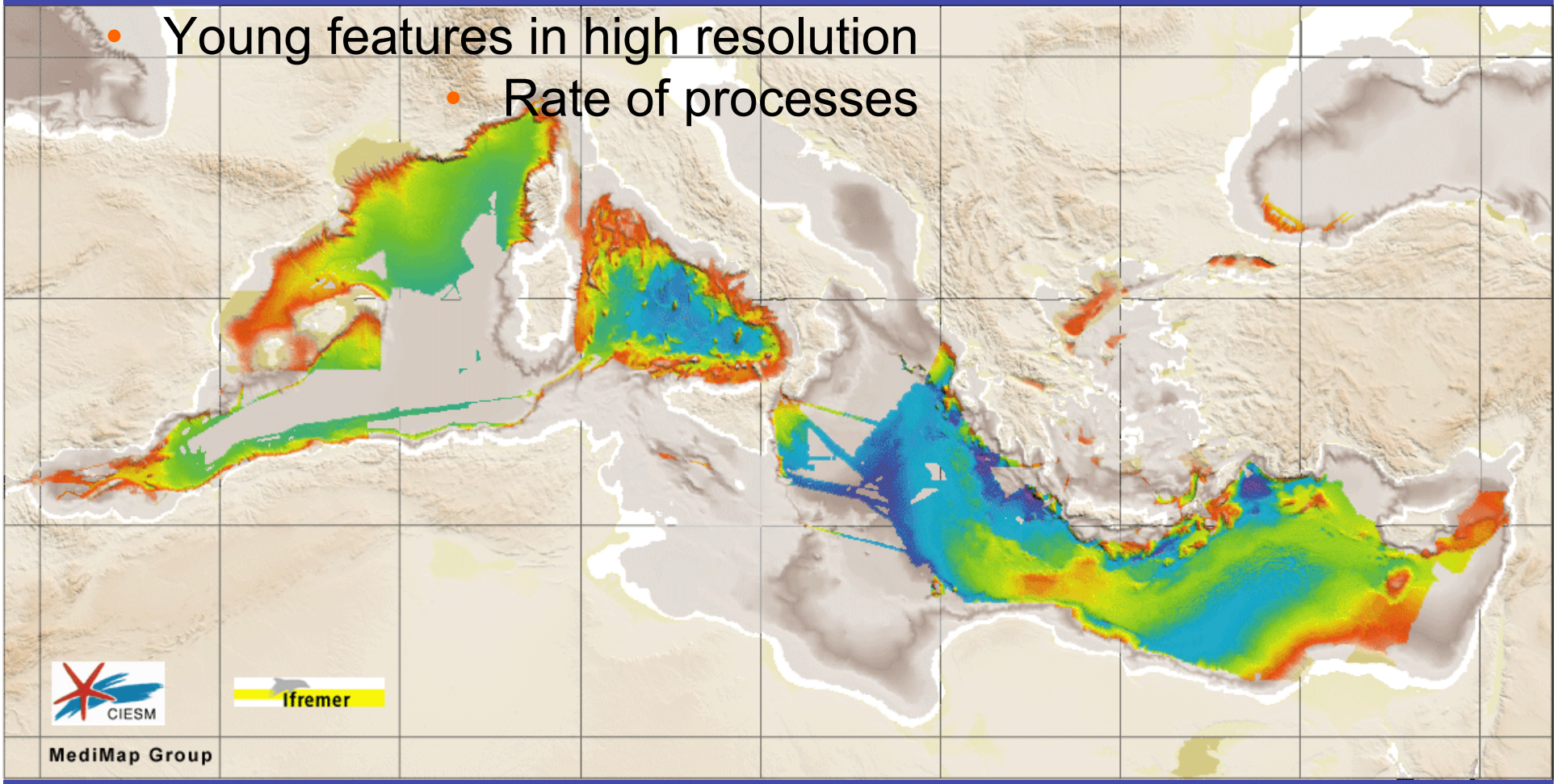
East vs. West



- Old vs new
- Seafloor morphology reflects young processes

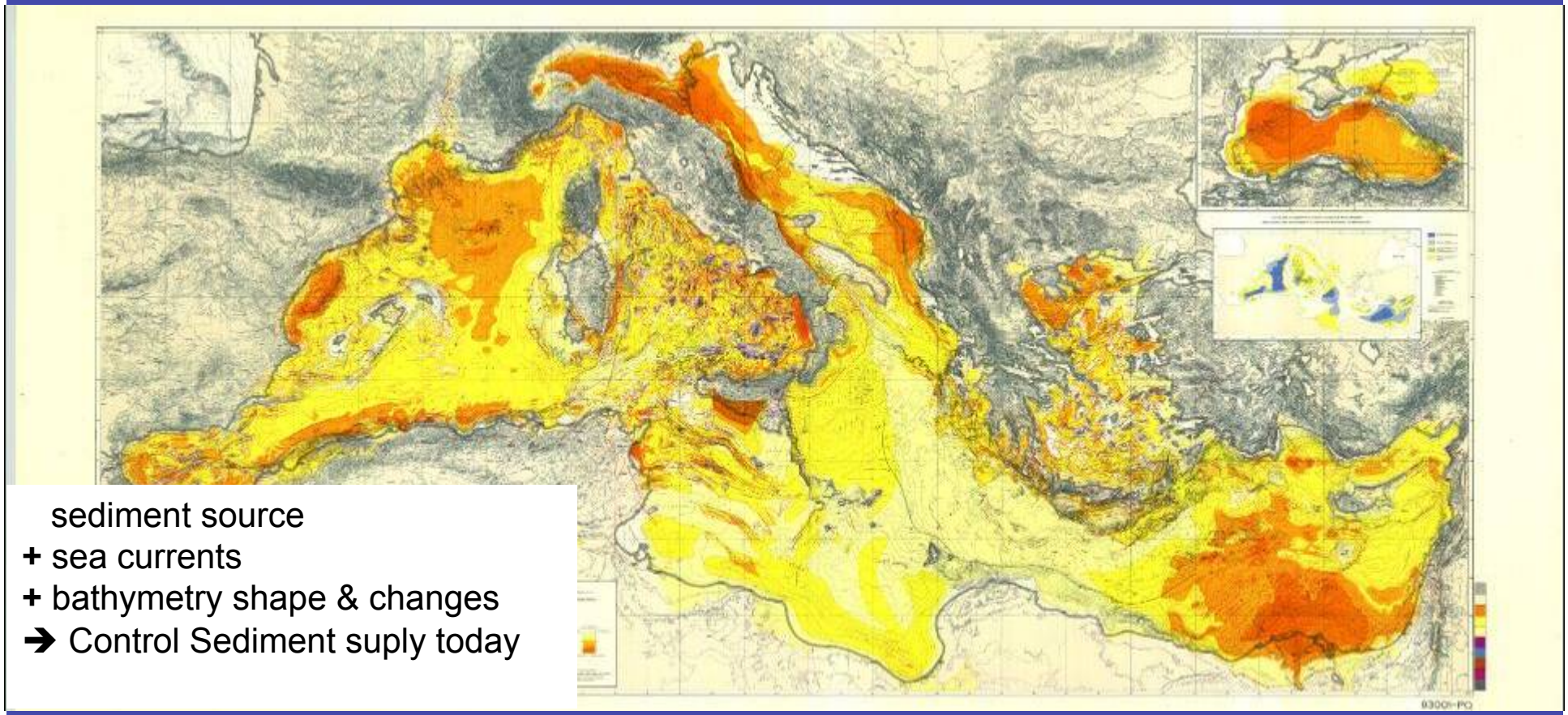
Bathymetry – seafloor morphology

- Young features in high resolution
  - Rate of processes



Multibeam bathymetric data recorded between 1992 and 2002 during several scientific surveys of the Ifremer oceanographic vessels L'Atalante and Le Suroit, and recently supplemented by swath data from both the French Navy Hydrogaphic Office vessel Beautemps-Beaupré and the research vessel Aegaeo of the Hellenic Centre for Marine Research, have been merged to produce a morpho-bathymetric synthesis of the eastern Mediterranean Sea.

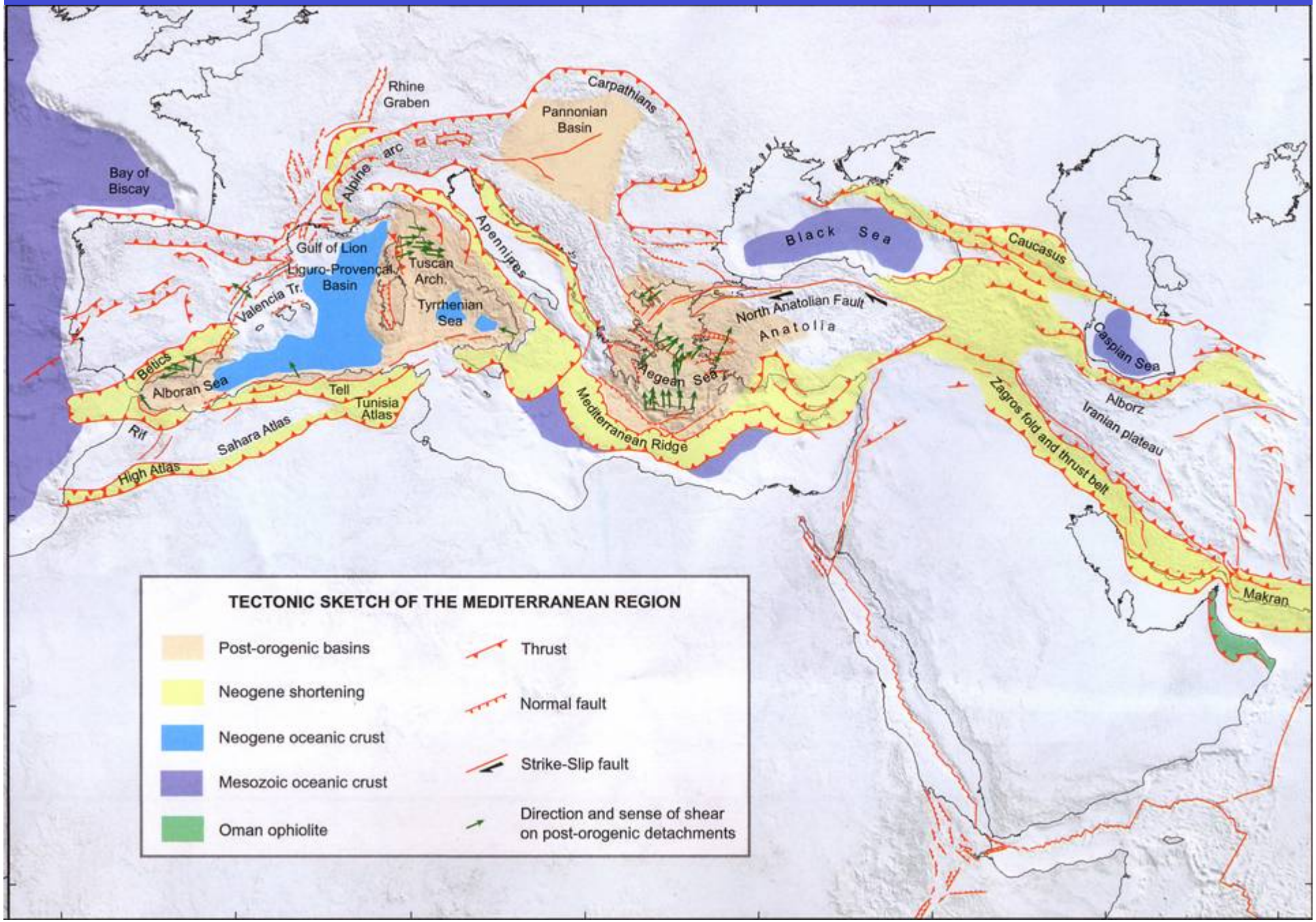
Continental sediment supply…today



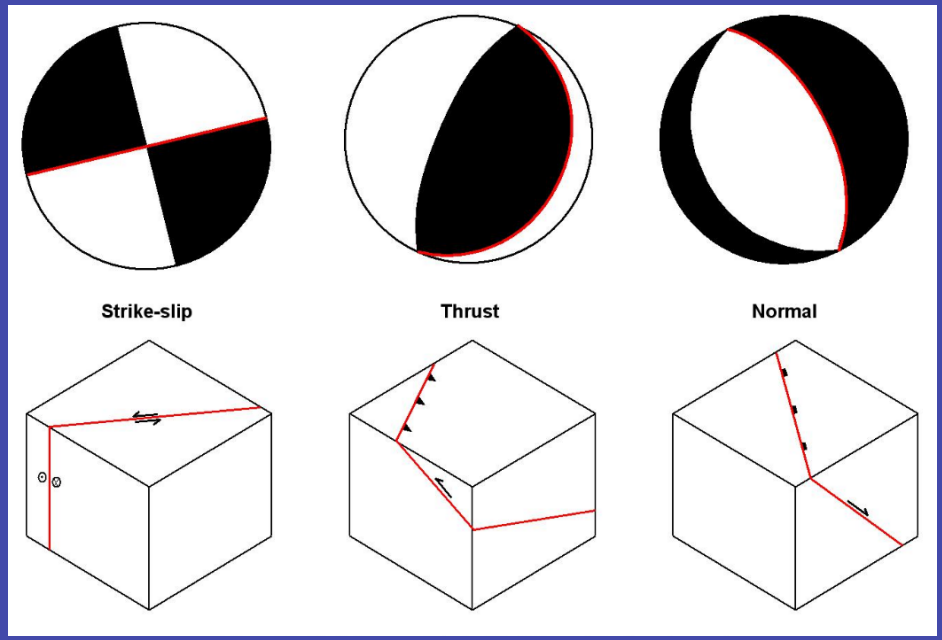
sediment source
+ sea currents
+ bathymetry shape & changes
➔ Control Sediment suply today

- The present is a key for understanding the past
- Each region is a key for understanding another one at a different geological time
- Warmer colors – higher sediment supply

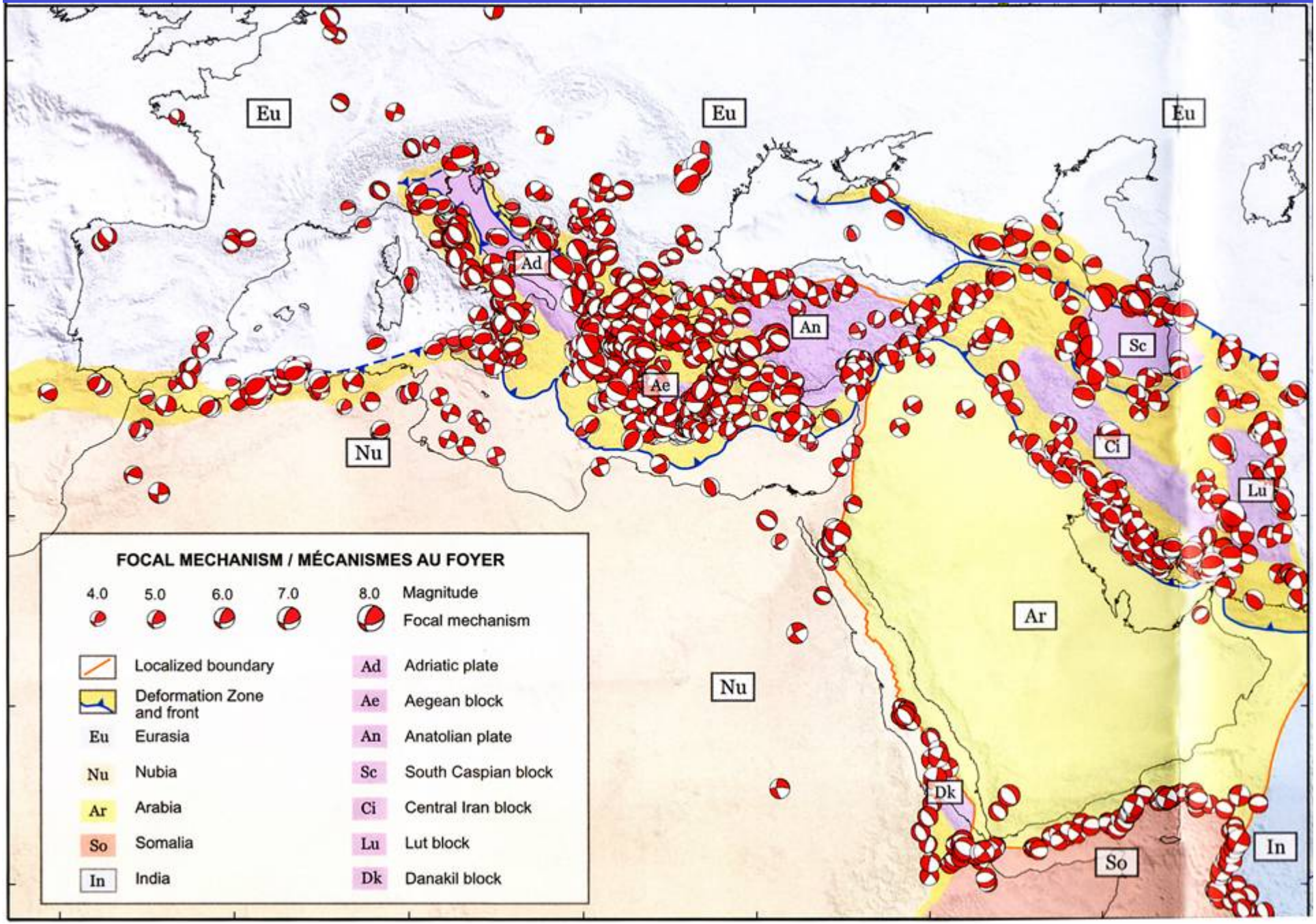
Present day plate tectonics of the eastern Mediterranean



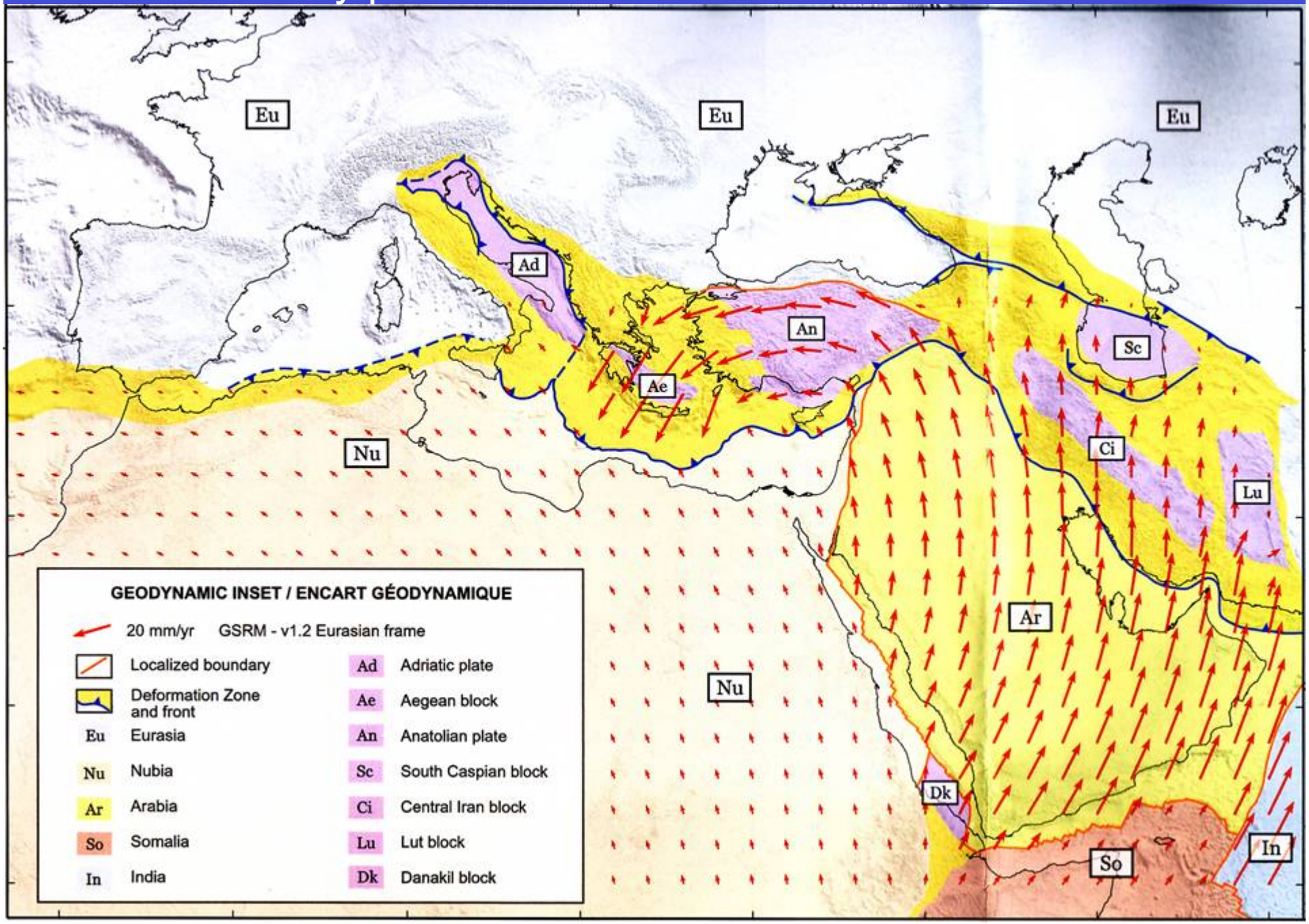
Types of faults

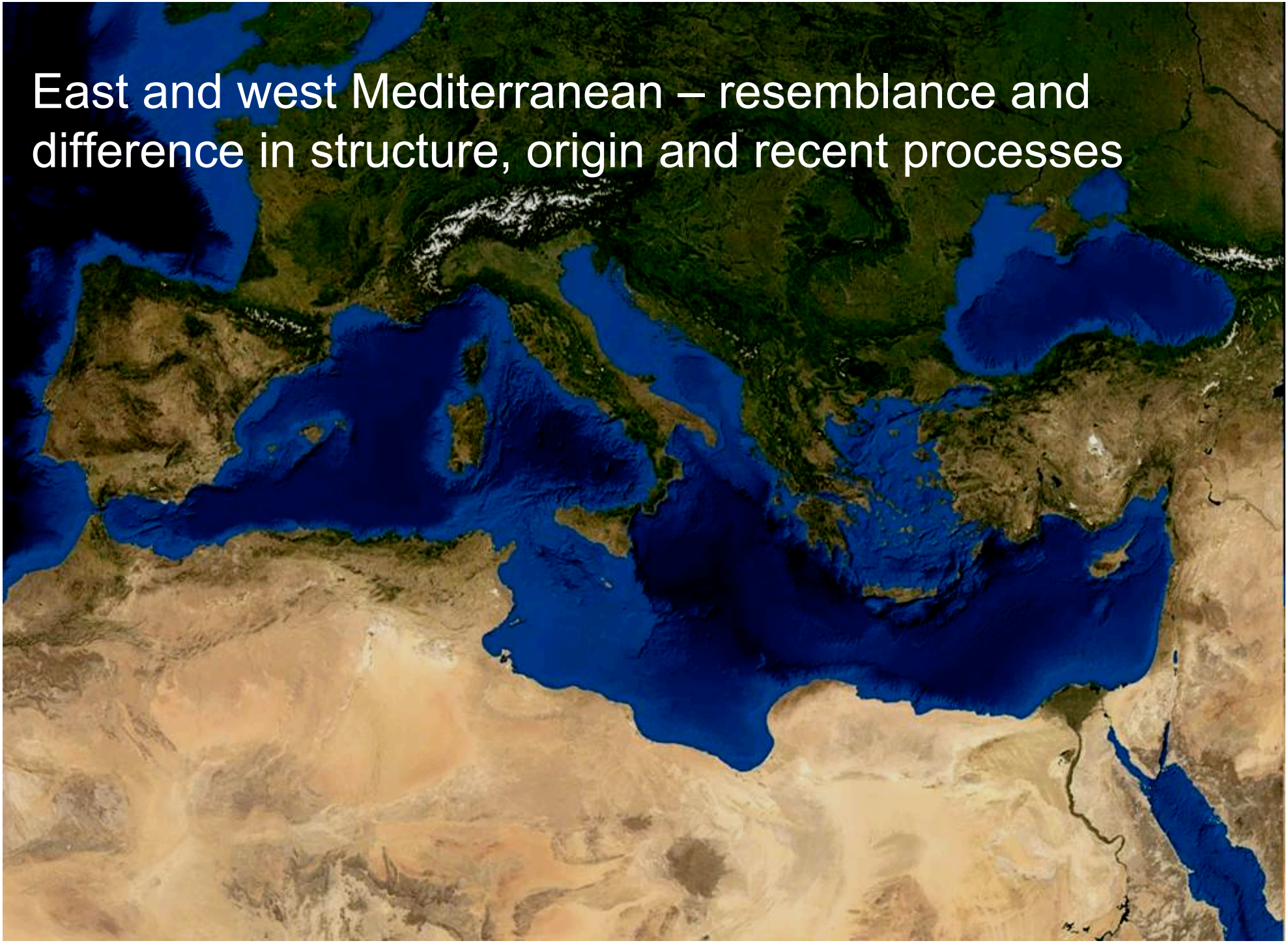


Present day plate tectonics of the eastern Mediterranean



Present day plate tectonics of the eastern Mediterranean




East and west Mediterranean – resemblance and difference in structure, origin and recent processes


METEOR
planeterde

Instruments and Methods

Seismics

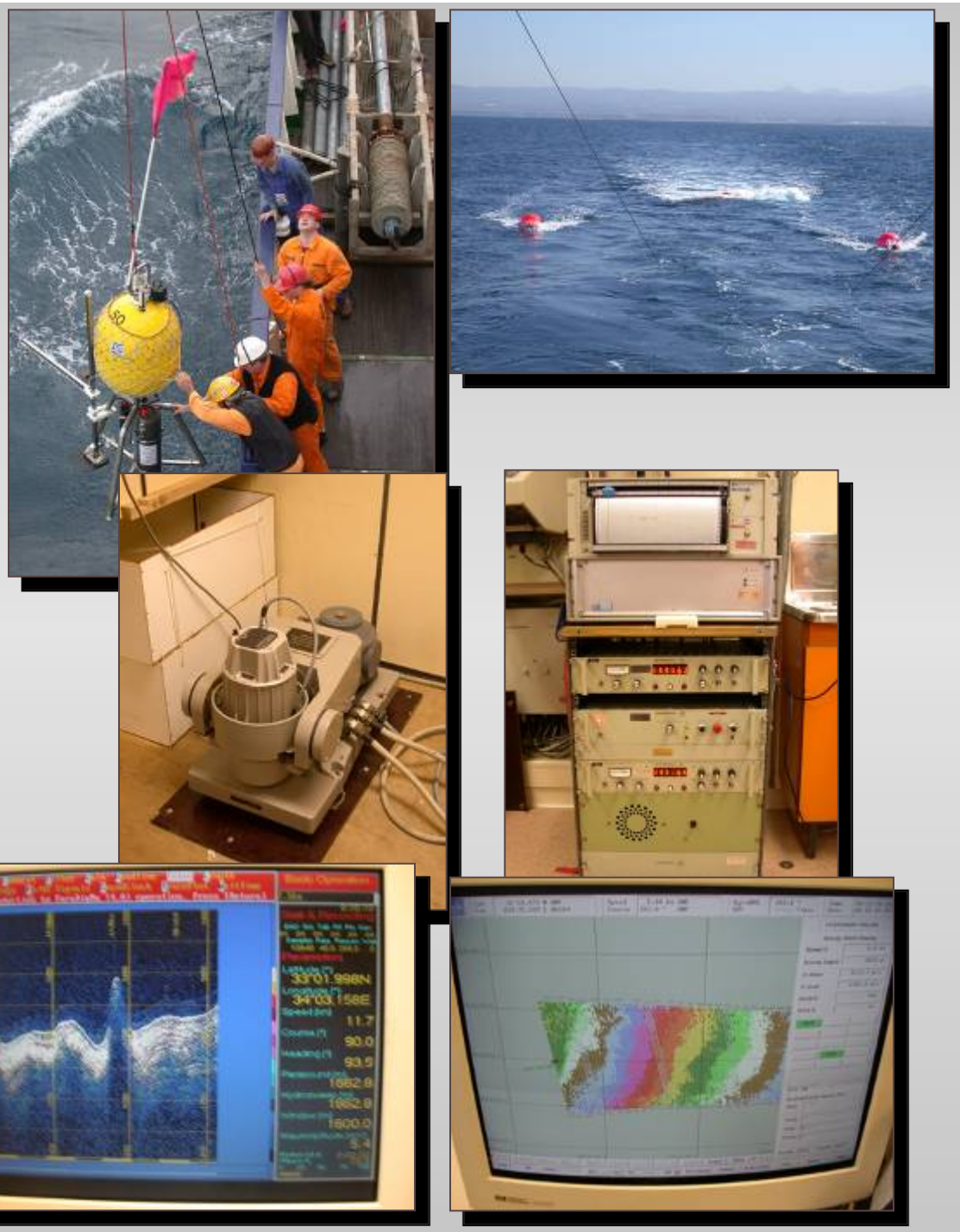
- Multichannel reflection
- Refraction

Potential field

- Gravity
- Magnetics

Hydroacoustics

- Parasound
- Hydrosweep



Basins of the Mediterranean

- Marine – continental geology interrelations
- Significant straights
- Different seas and their formation processes
- Seafloor is dynamic and reflects young processes
- Coastal structure reflects geological processes (magnitude, time, rigidity)

Gibraltar

- Connection to Atlantic
- Min. width 14 km
- Avg. depth 700 m
- Tectonics of African and Iberian plates
- Complex processes of Alboran Sea and Atlantic
- Messinian event
- Migration of Man and animals

The Messinian Salt Crisis

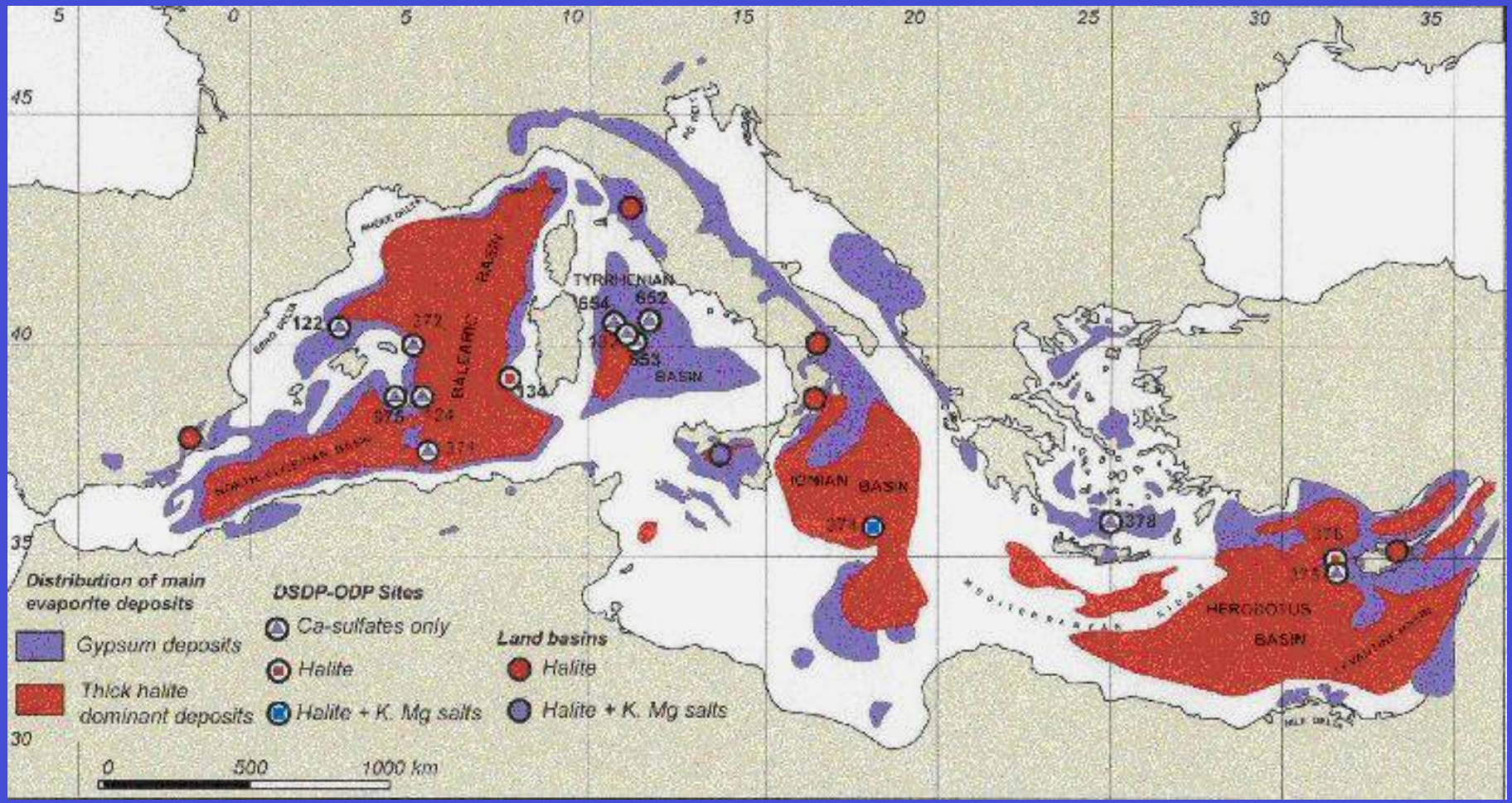
Giant salt crystals found in cave in Spain thought to formed during the Messinian Salt Crisis

Messinian salinity crisis

5.96 Ma cutoff; relative sea-level drop between 200m-1000m

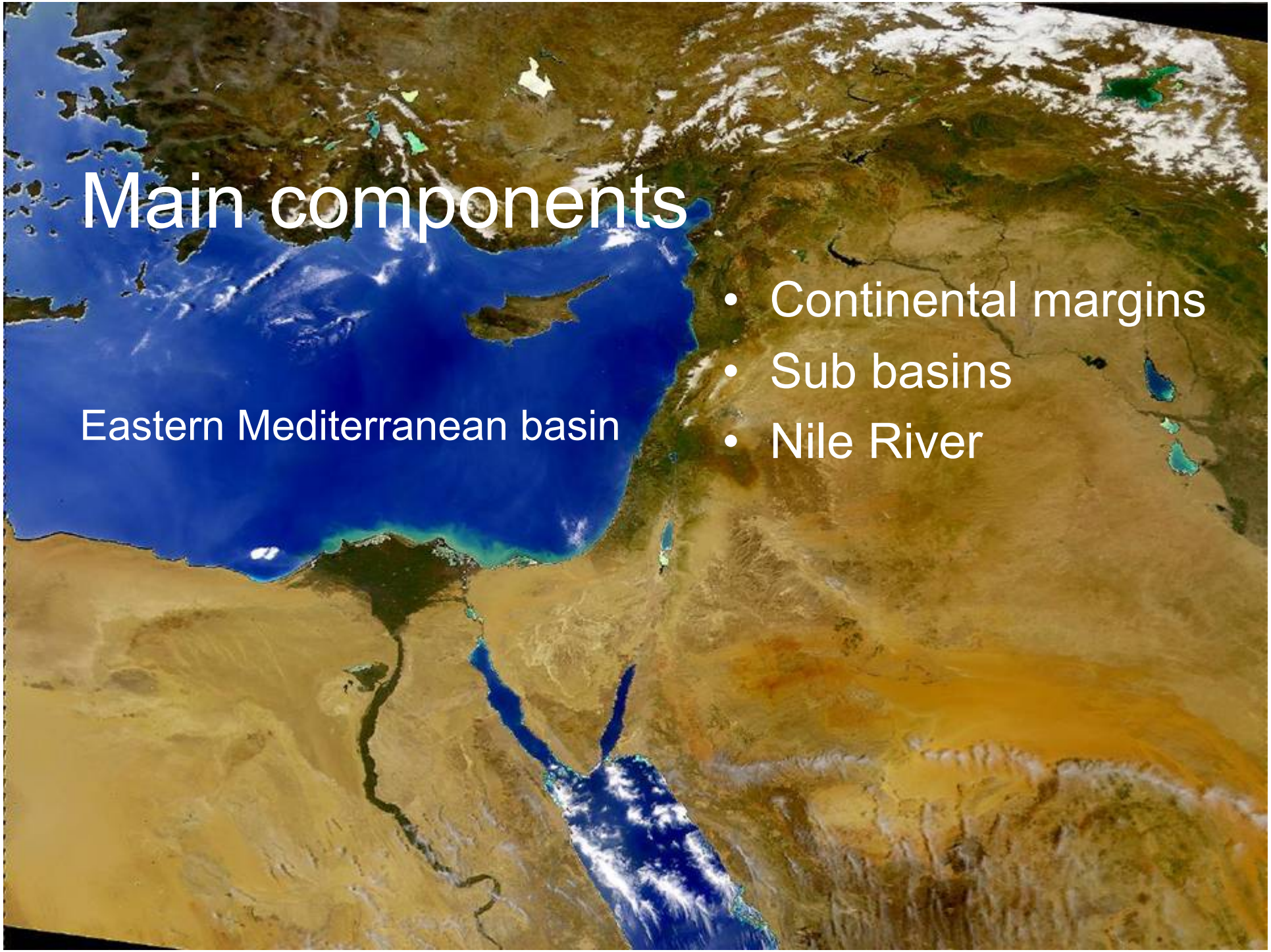
5.8 – 5.5 Ma complete isolation

5.33 Ma abrupt return to full marine conditions

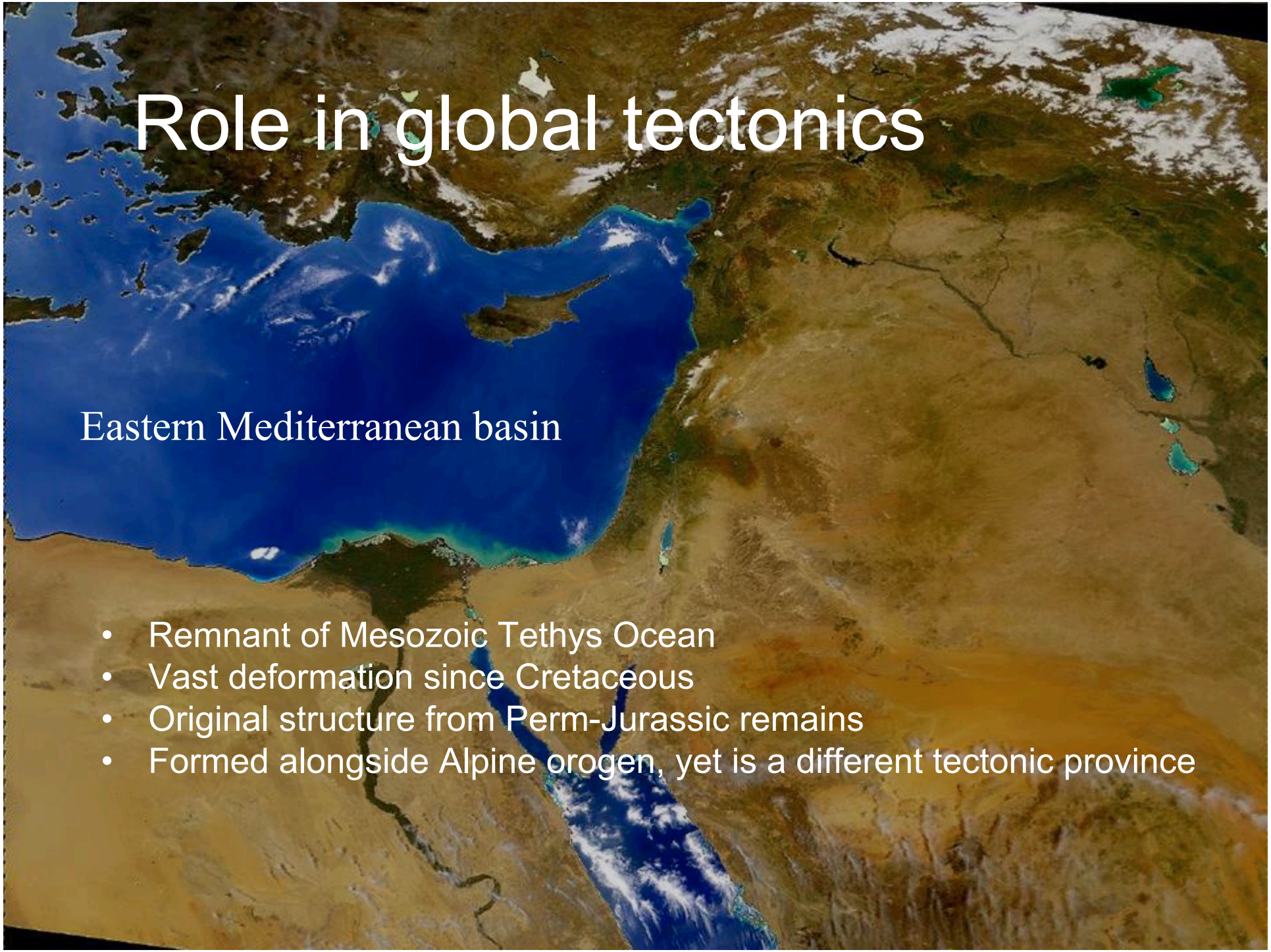


Four mechanisms have been proposed to explain the isolation of the Mediterranean during the Messinian, including:

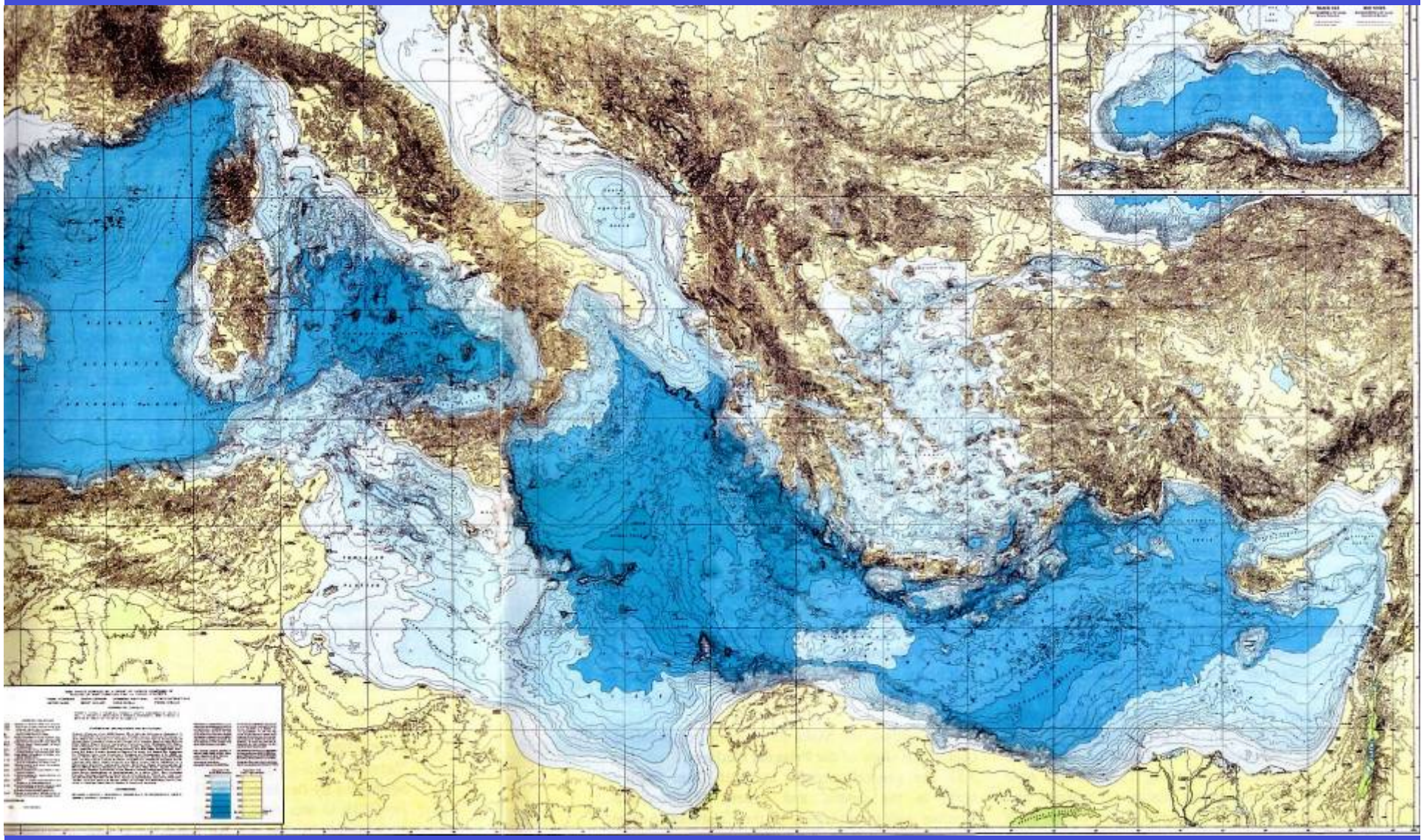
1) a 60 m global drop in sea level due to glaciation
2) horizontal squeezing
3) tectonic uplift
4) volcanism


Main components
Eastern Mediterranean basin
• Continental margins
• Sub basins
• Nile River

Role in global tectonics



- Remnant of Mesozoic Tethys Ocean
- Vast deformation since Cretaceous
- Original structure from Perm-Jurassic remains
- Formed alongside Alpine orogen, yet is a different tectonic province



Morelli et al., 1997

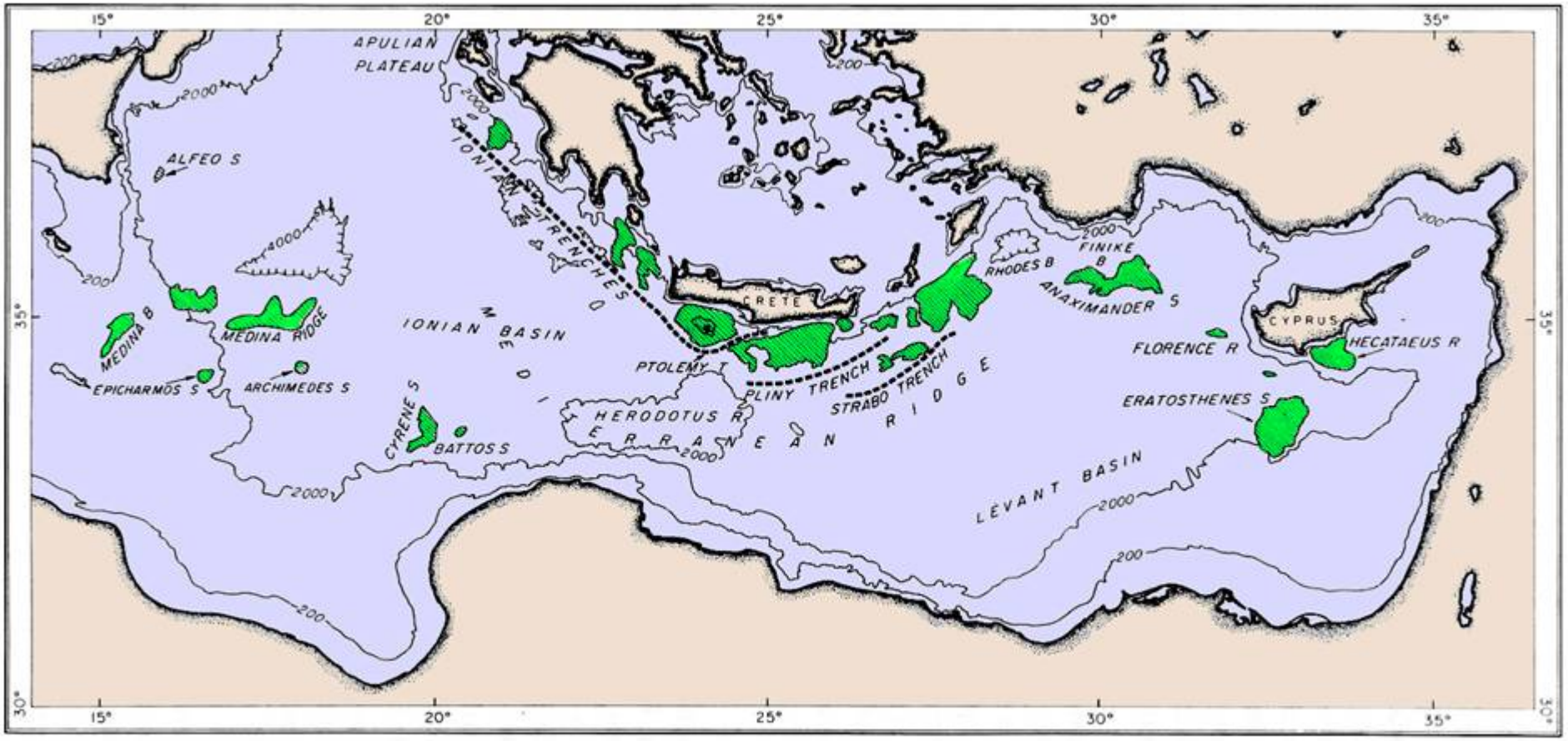
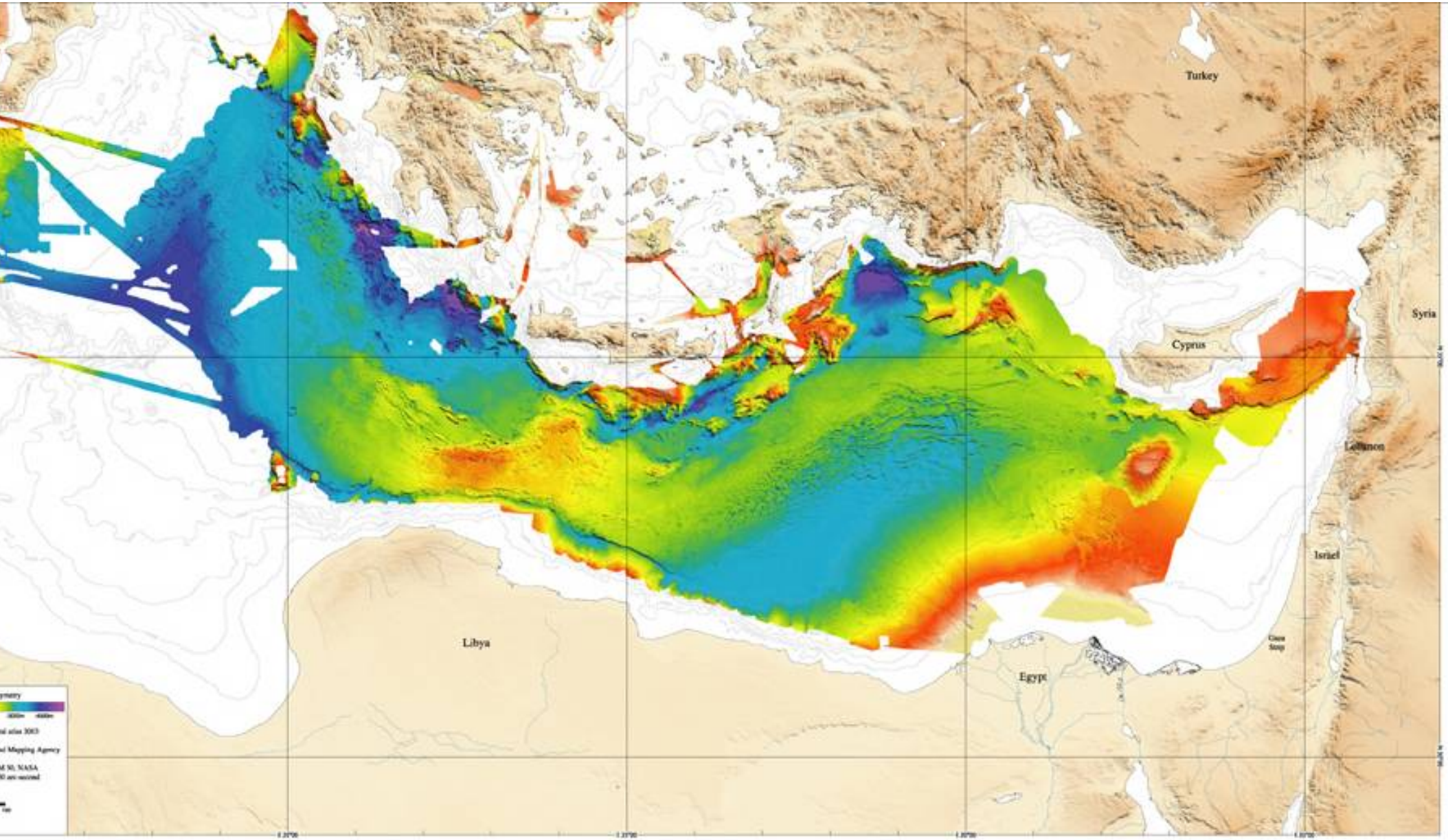
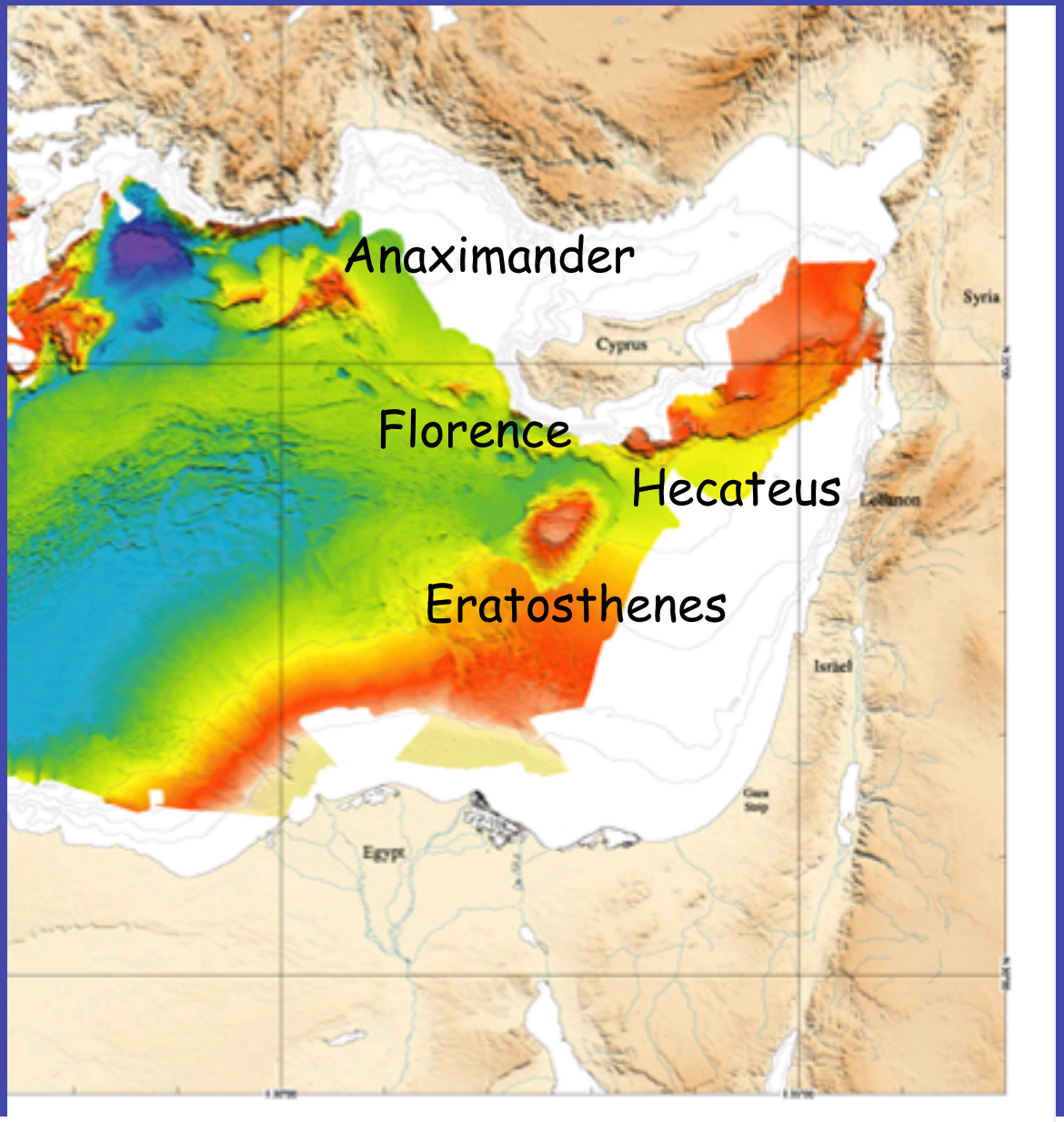


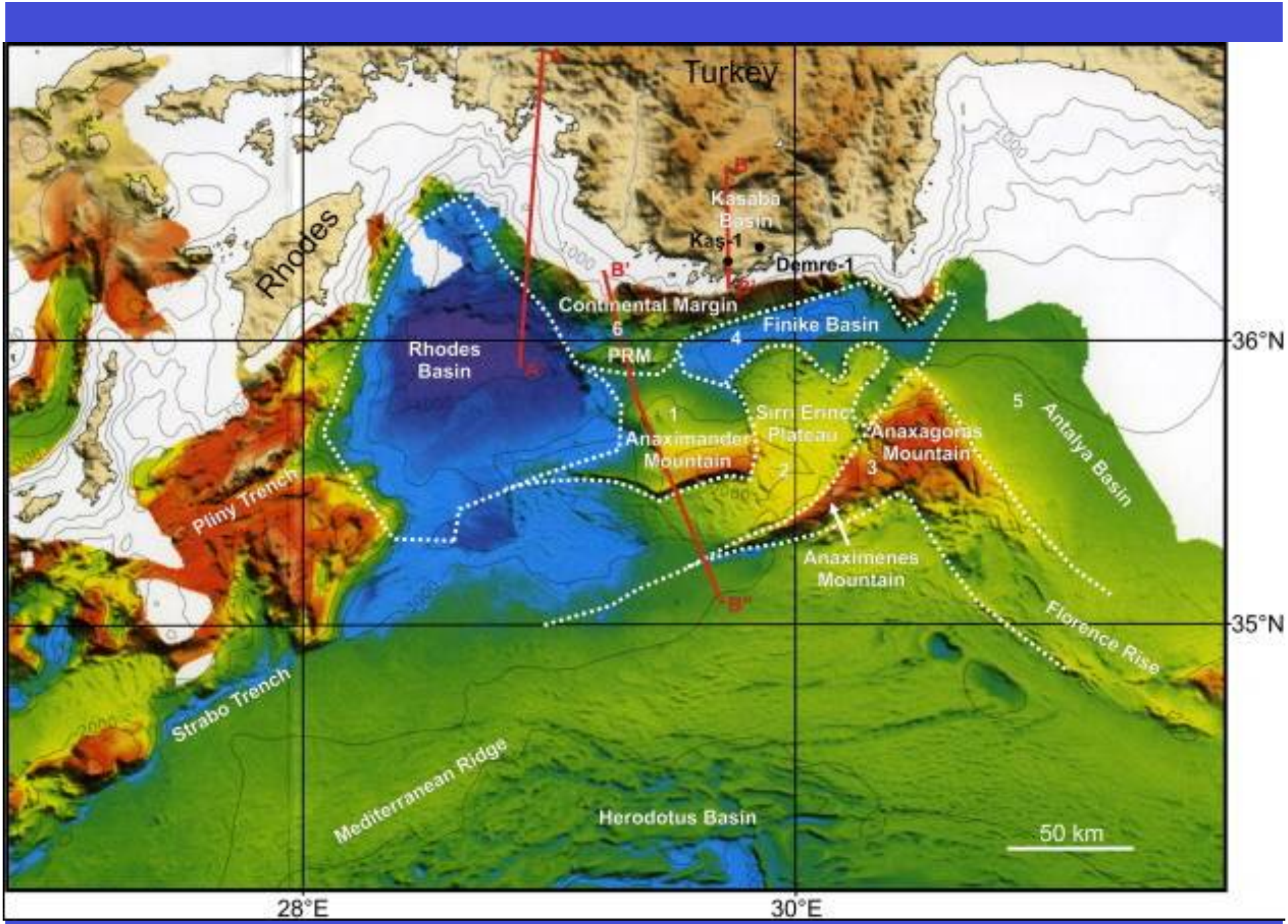
Fig. 1. The eastern Mediterranean. General bathymetric outline is shown by the 200, 2000 and 4000 m contours. Oceanic plateaus are marked by hatched area. Heavy, broken lines denote schematic outline of active and inactive subduction trenches.

Rotstien and Ben-Avraham 1985

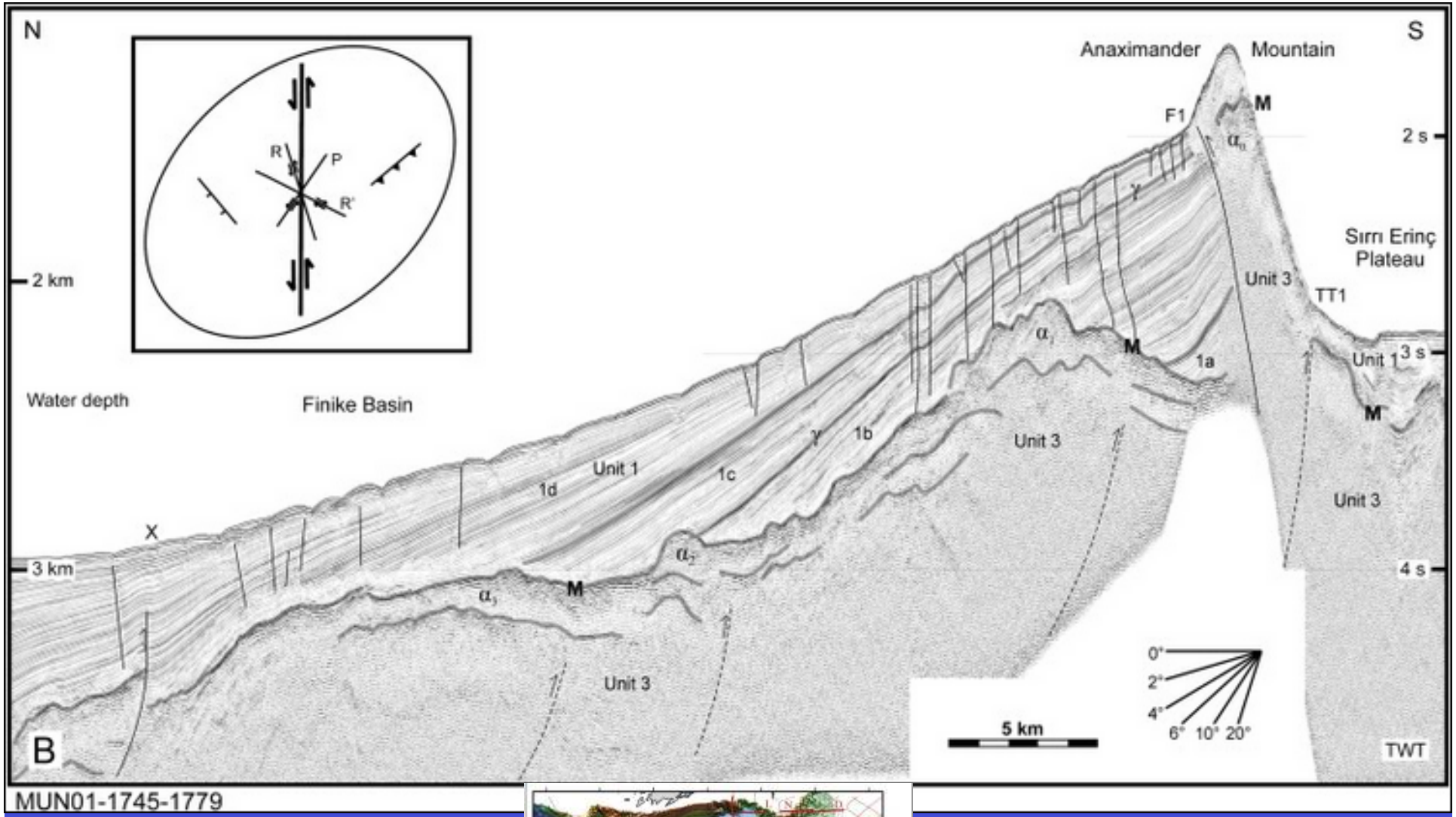

Turkey
Syria
Cyprus
Lebanon
Israel
Libya
Egypt
Gaza Strip

Seamounts

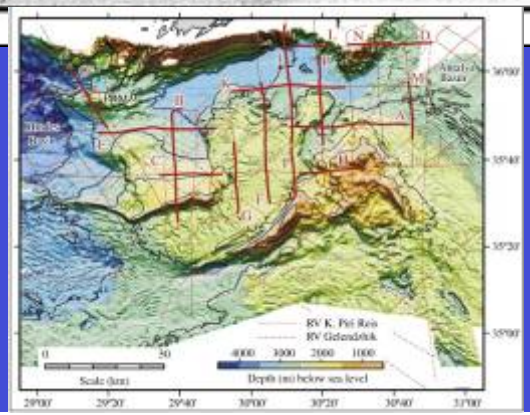

Anaximander
Florence
Hecateus
Eratosthenes
Syria
Cyprus
Israel
Egypt



Aksu et al., 2009

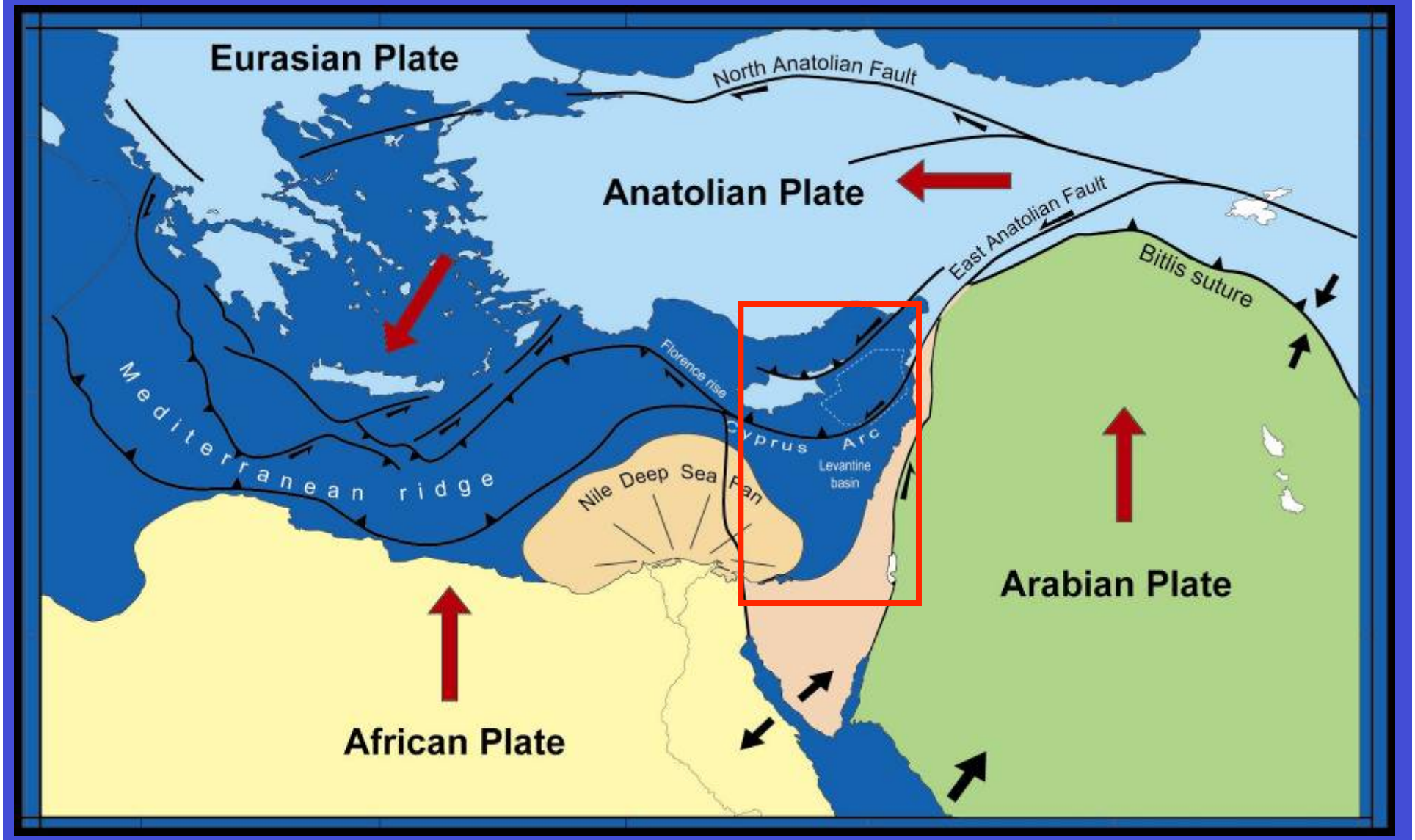


MUN01-1745-1779

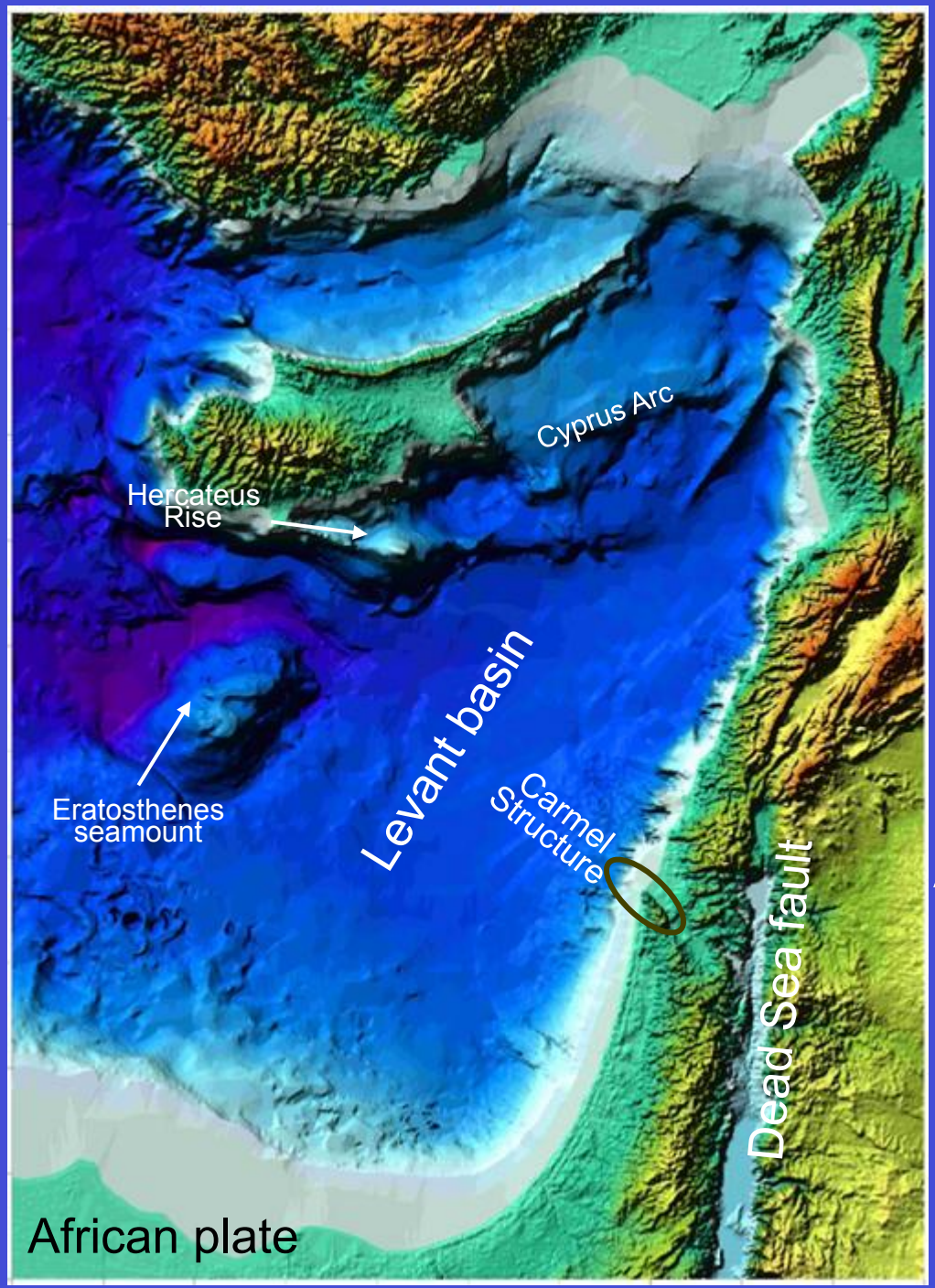


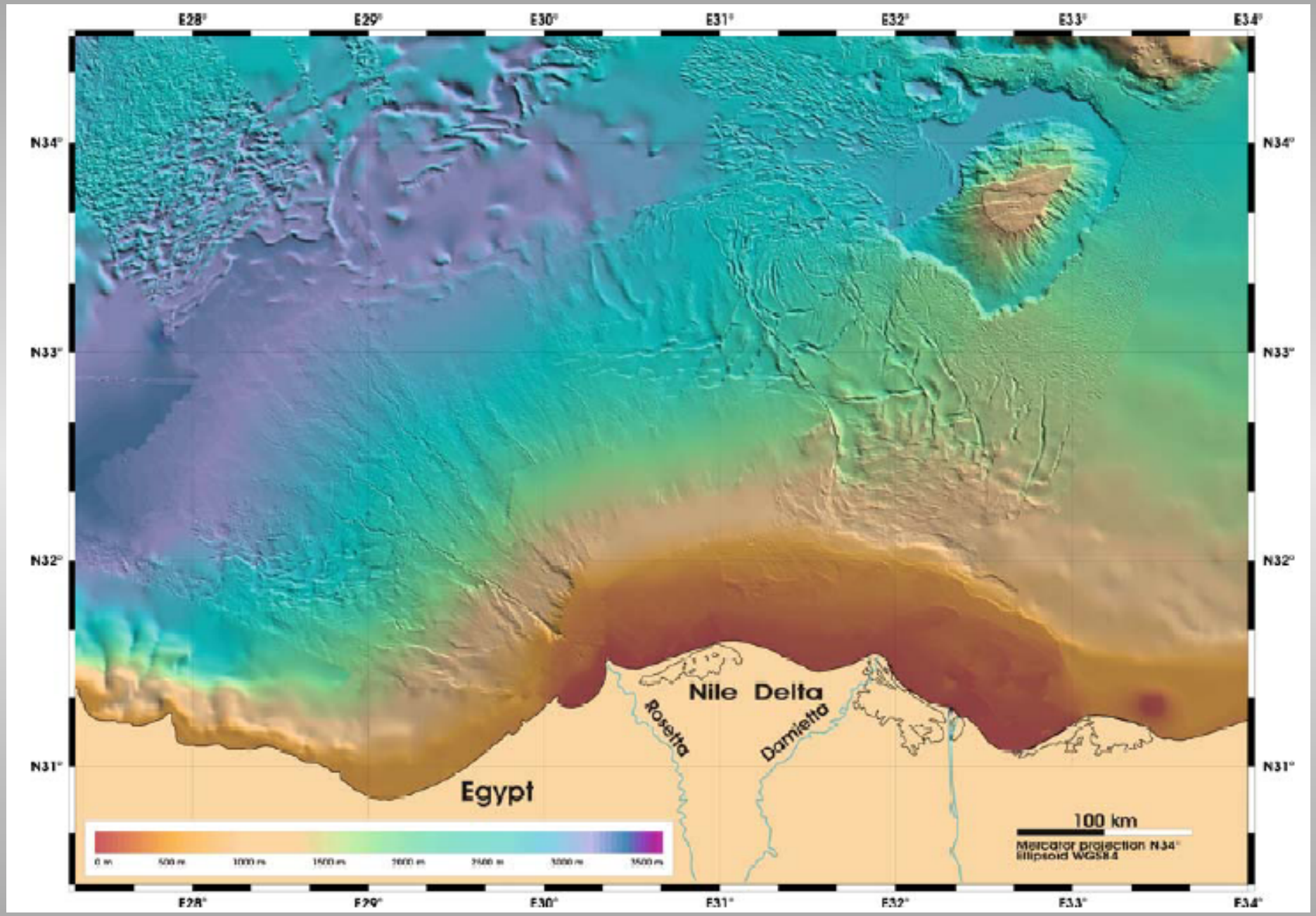
Aksu et al., 2009

Present day plate tectonics of the eastern Mediterranean

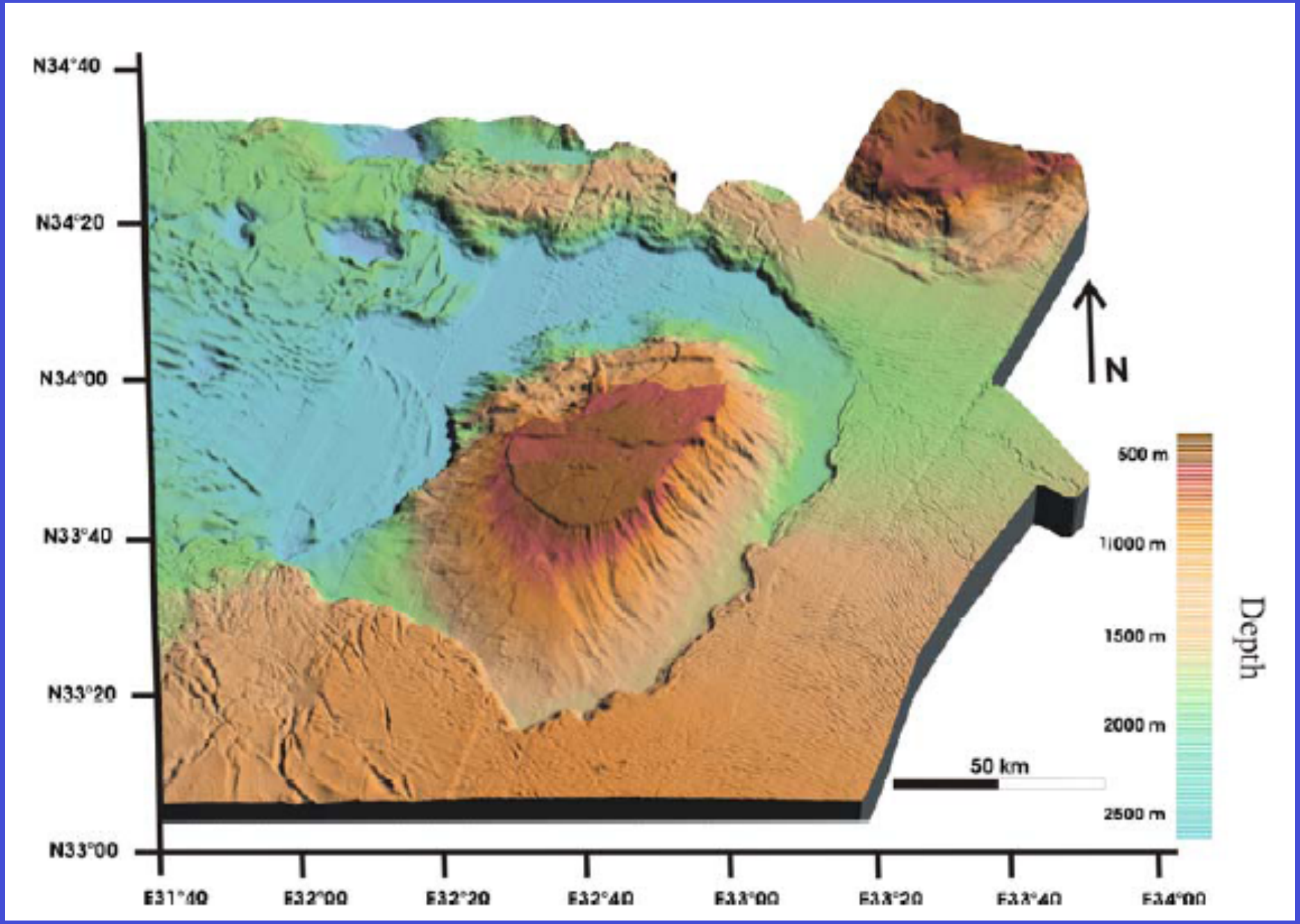


Eastern Mediterranean Main players





Mascle et al., 2006



Mascle et al., 2006

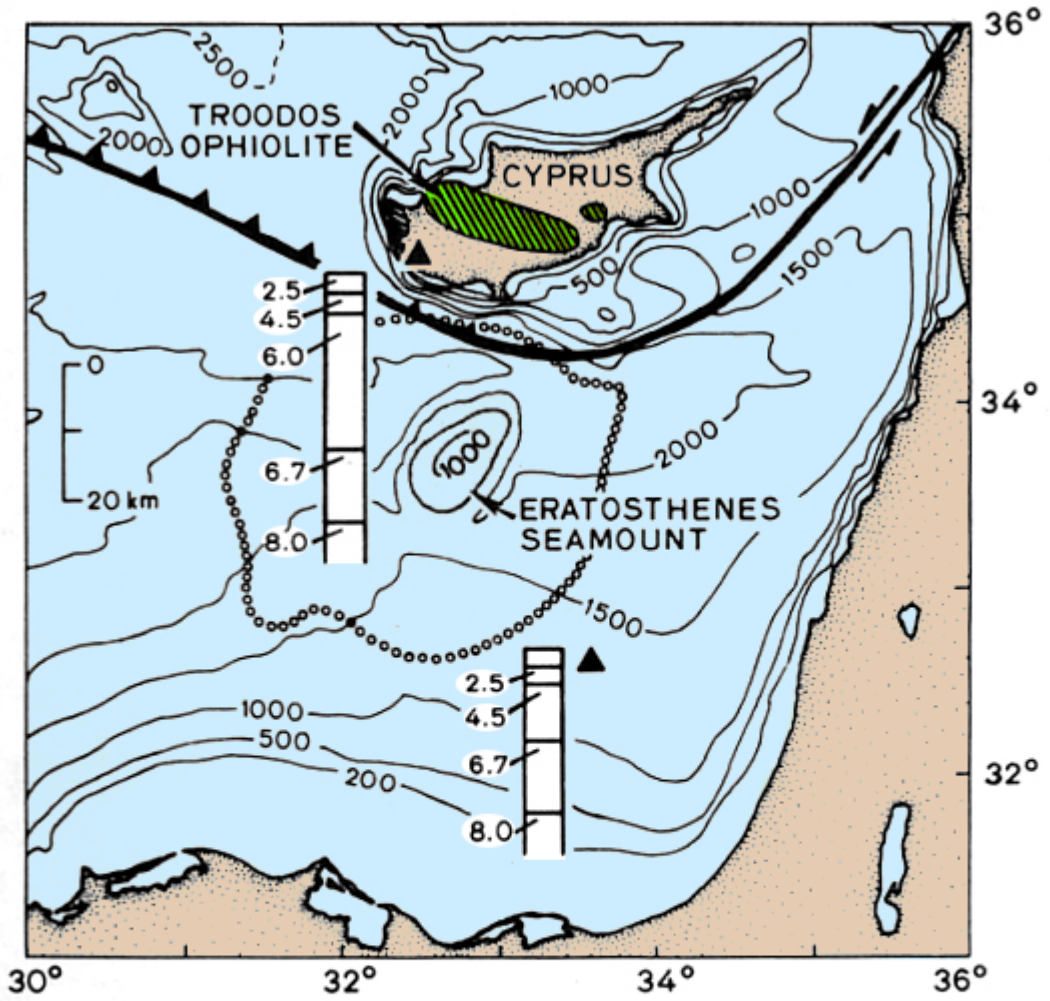
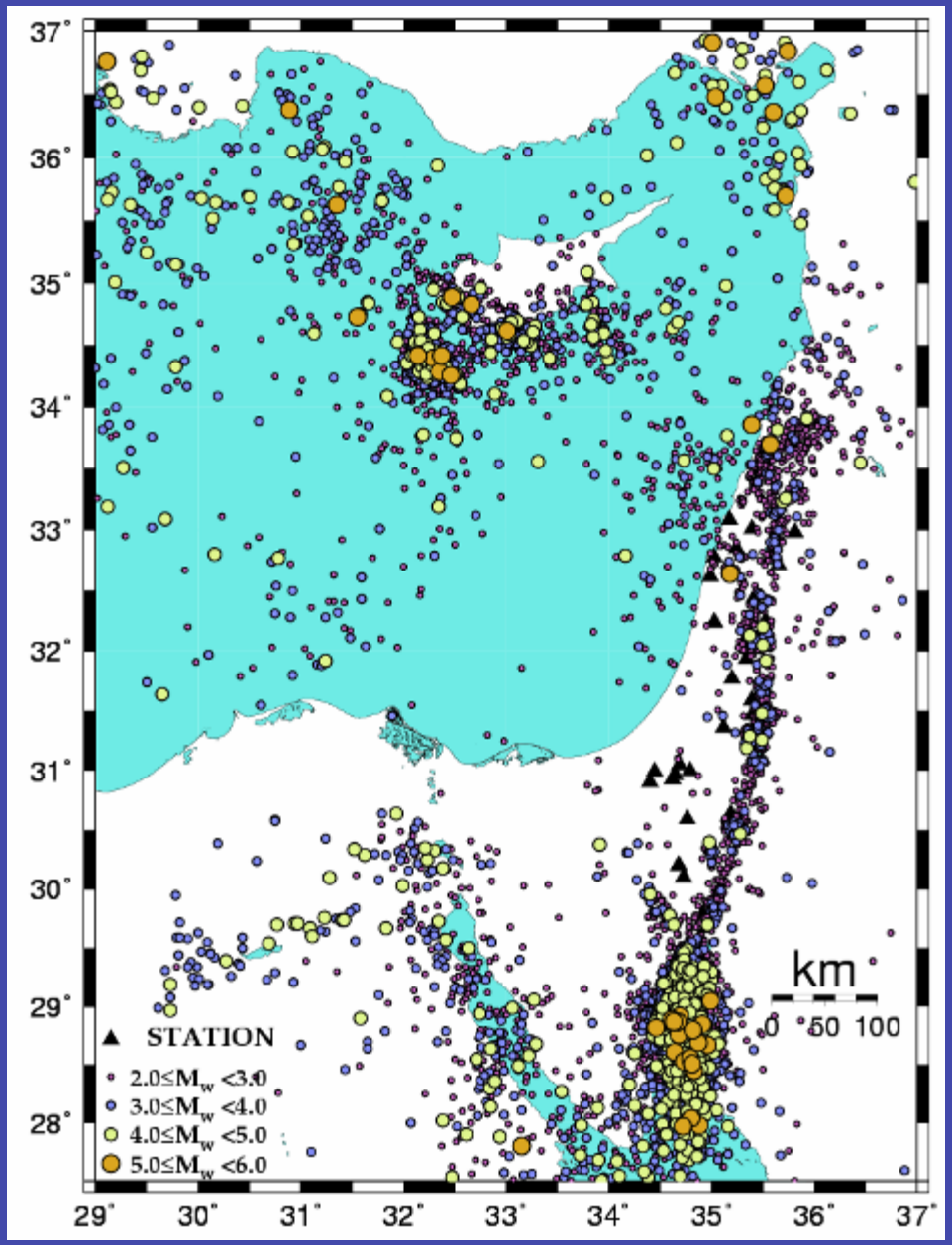


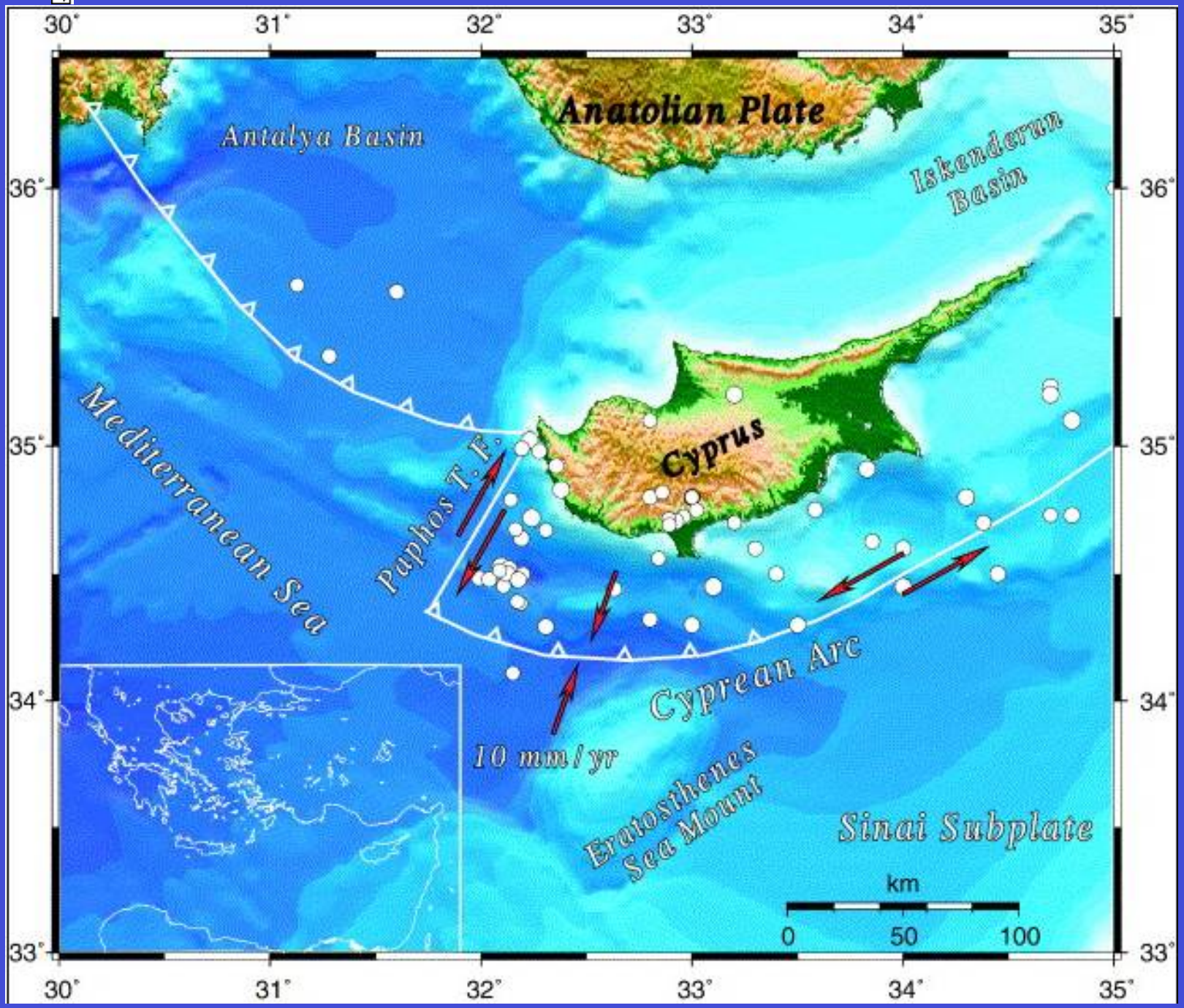
Fig. 1. The Troodos ophiolite complex on Cyprus and the Eratosthenes seamount in the eastern Mediterranean. Velocity sections of Cyprus and eastern Mediterranean are in km/s, and their location is marked by triangles [after *Ben-Avraham et al.*, 1979]. Open circles show the boundary of the subbottom structure which produces the Eratosthenes magnetic anomaly [after *Ben-Avraham et al.*, 1976].

Ben-Avraham et al 1982

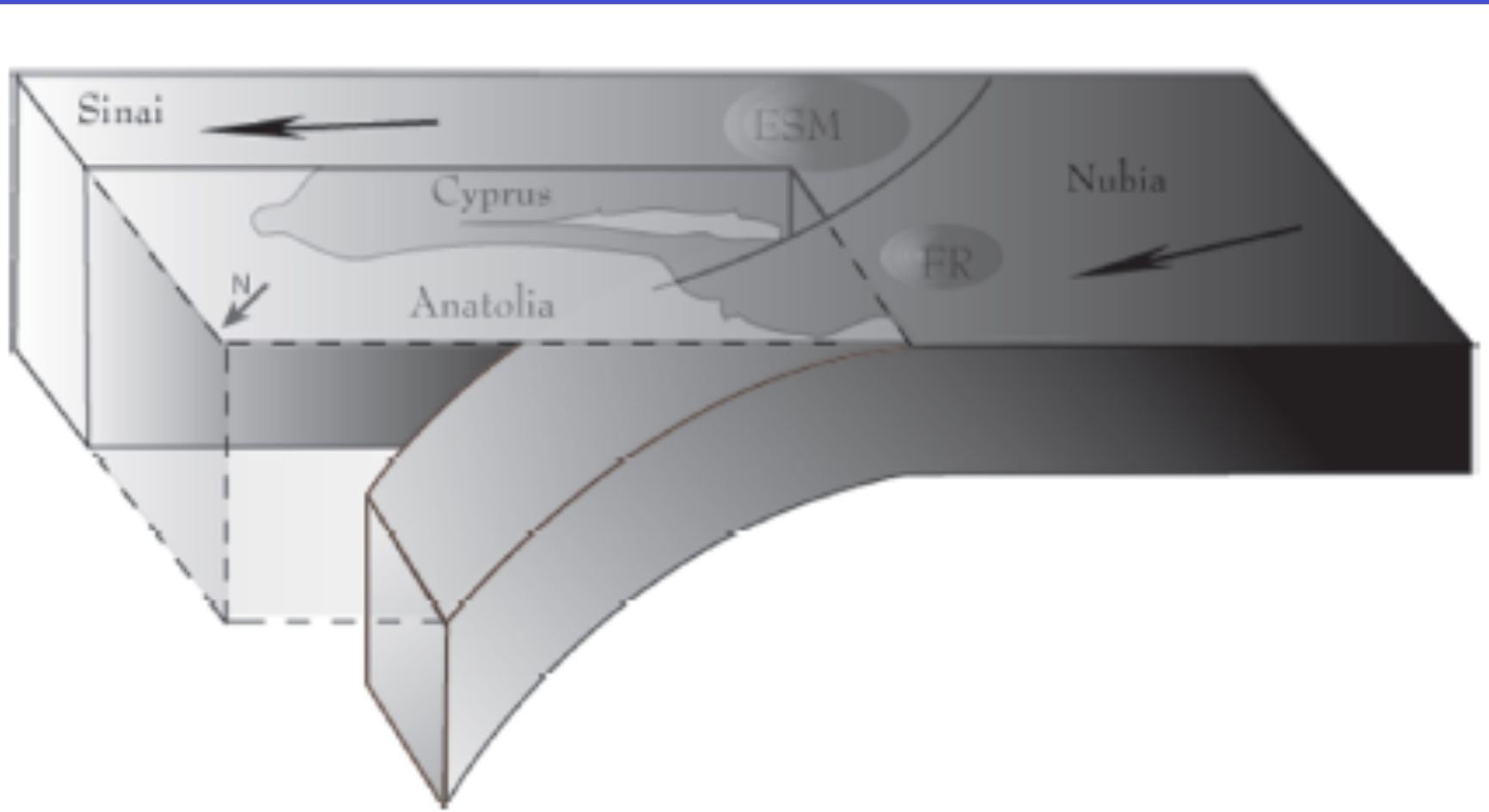


EARTHQUAKES IN AND AROUND ISRAEL 1984-2003

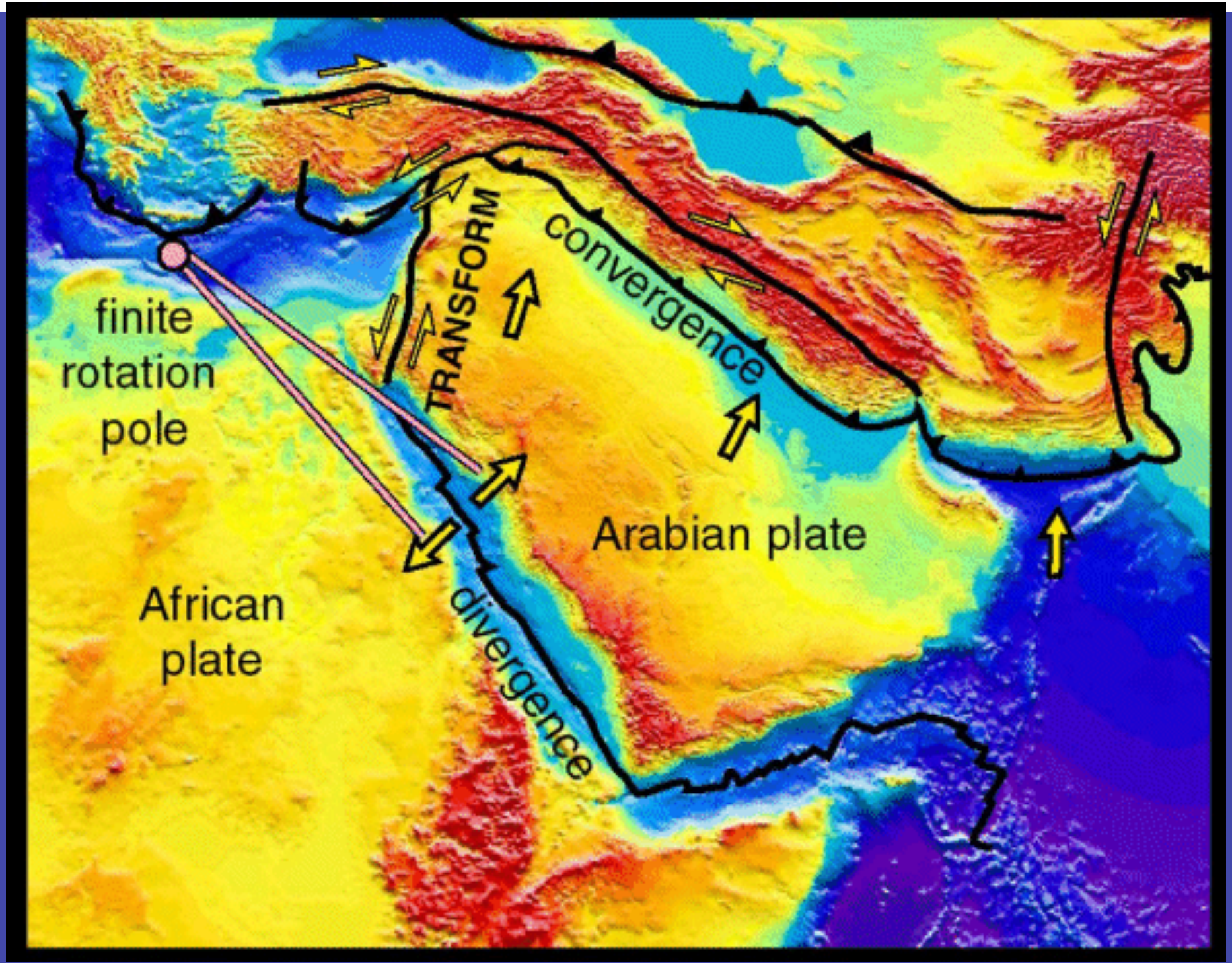
Geophysical Institute of Israel



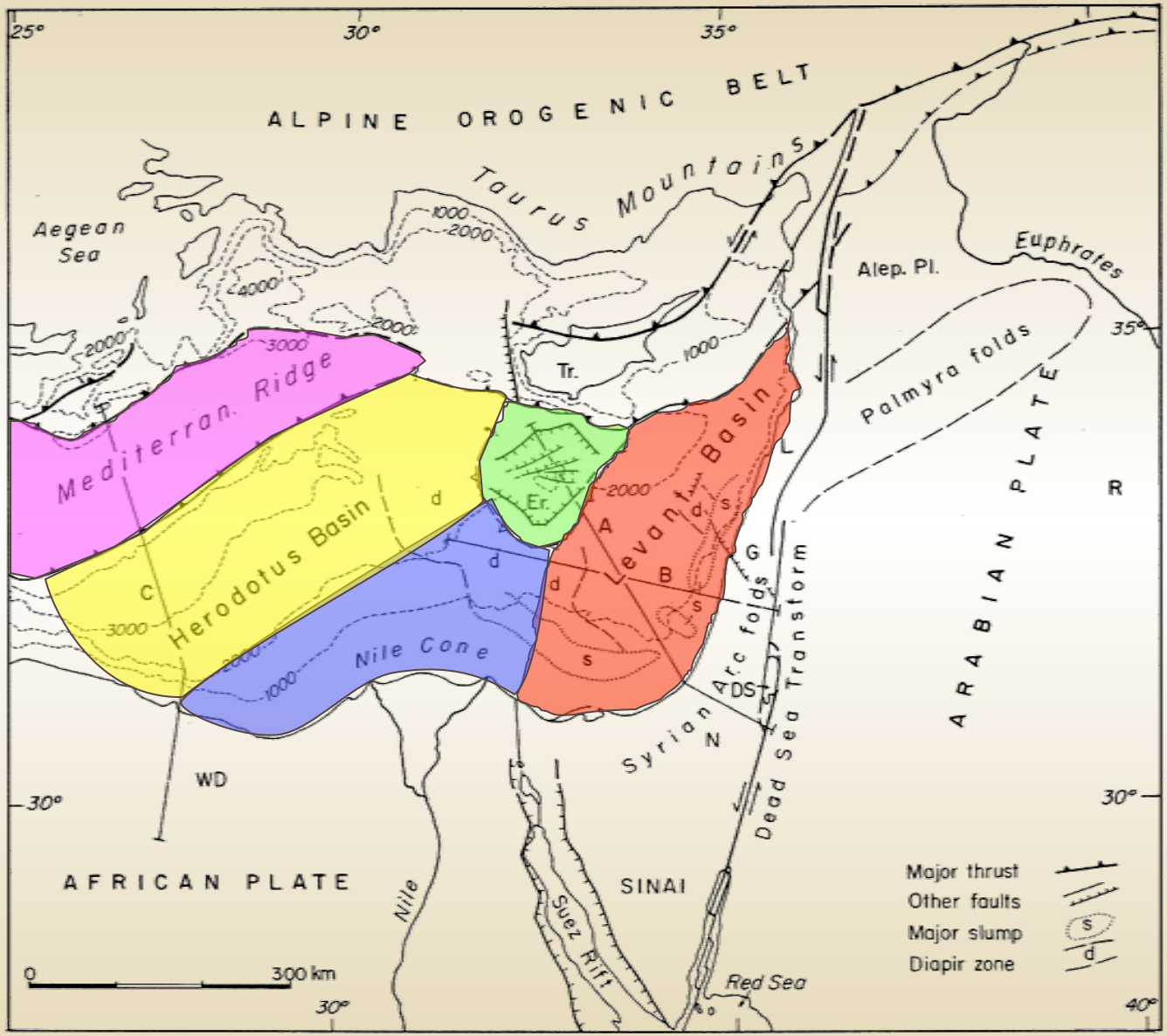
Papadimitriou and Karakostas, 2006



Wdowinski et al., 2006


finite
rotation
pole
TRANSFORM
convergence
Arabian plate
African
plate
divergence

Sub basins



Garfunkel, 1998

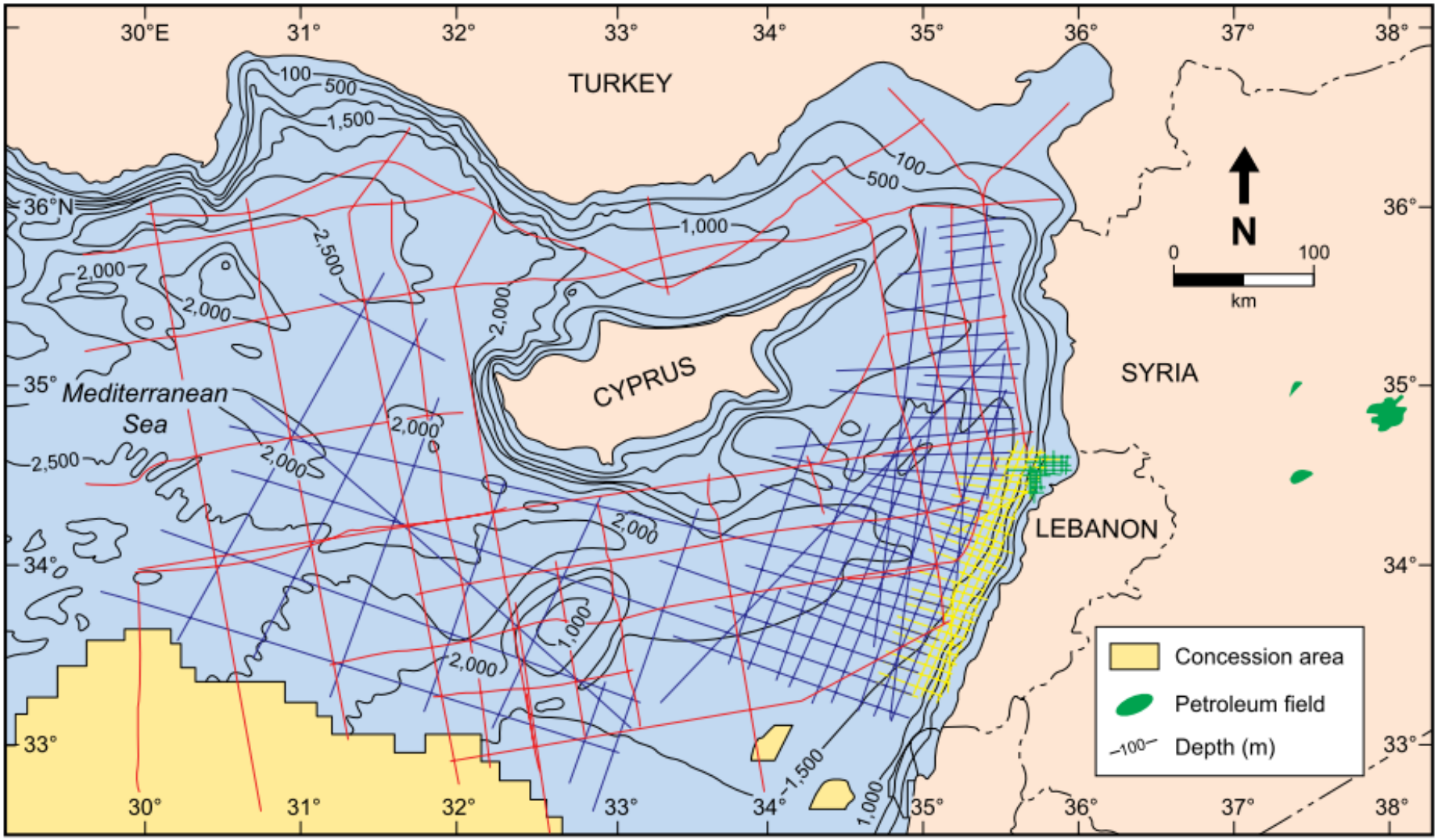


Figure 2: East Mediterranean area showing the GGS-Spectrum 2-D seismic coverage available for this paper. The Emed-2000 survey was acquired with a 7,200 metre streamer and recorded to 12 seconds, whilst the LEB-02 survey was recorded with a 6,000 m streamer to 9 seconds.

Roberts and Peace, 2007

GGS-Spectrum Seismic Surveys		
1975 Reprocessed	:	7,834
GL-93	:	508
Emed-2000	:	12,303
Leb-02	:	2,000
Total (km)		22,645

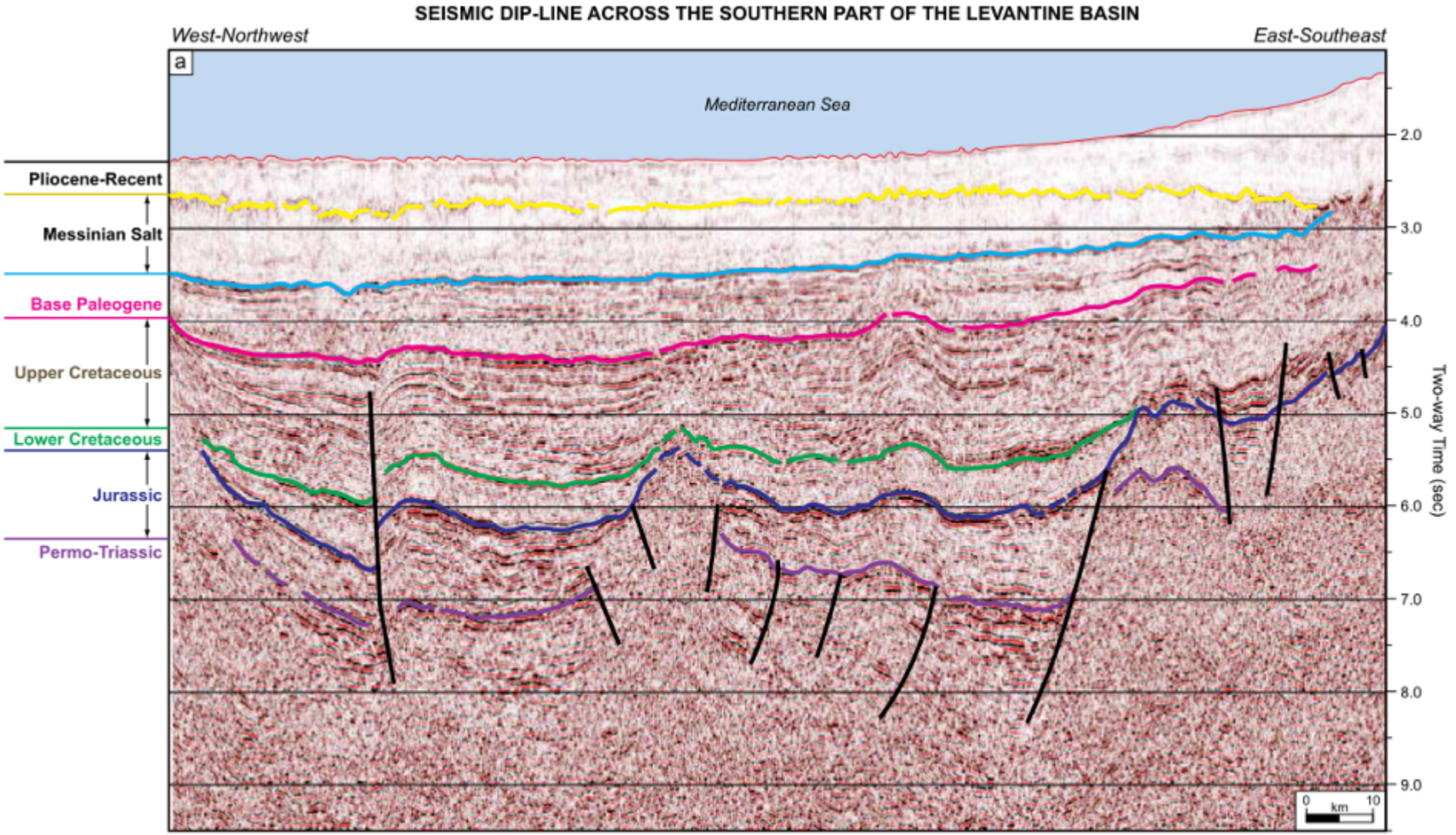


Figure 3: (a) WNW-ESE seismic line over the southern part of the Levantine Basin showing a Triassic-Jurassic rifted terrain (including a pop-up structure in the centre of the Basin) overlain by rocks of Cretaceous to Neogene age. Section width approximately 160 km.

Roberts and Peace, 2007

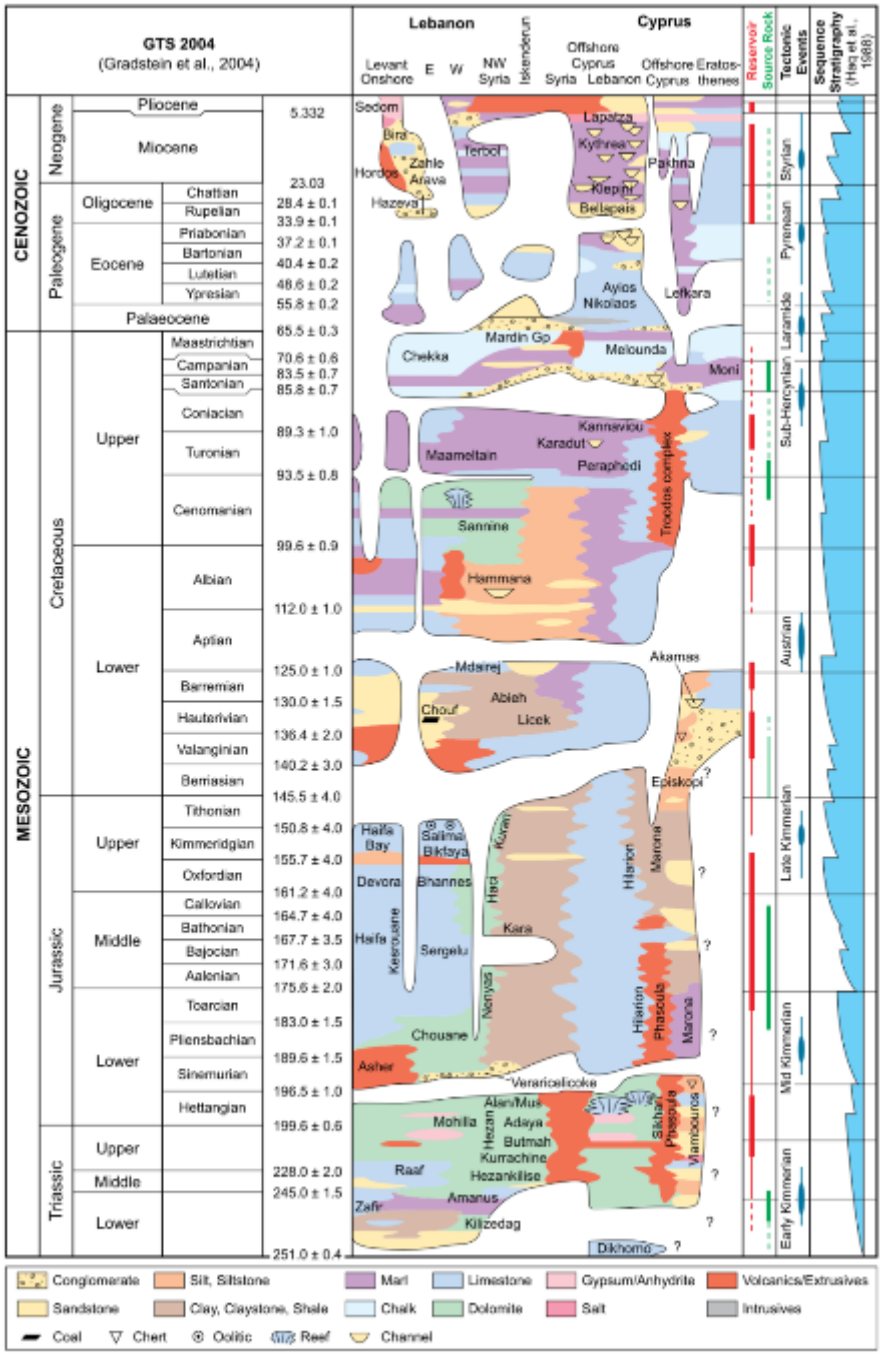
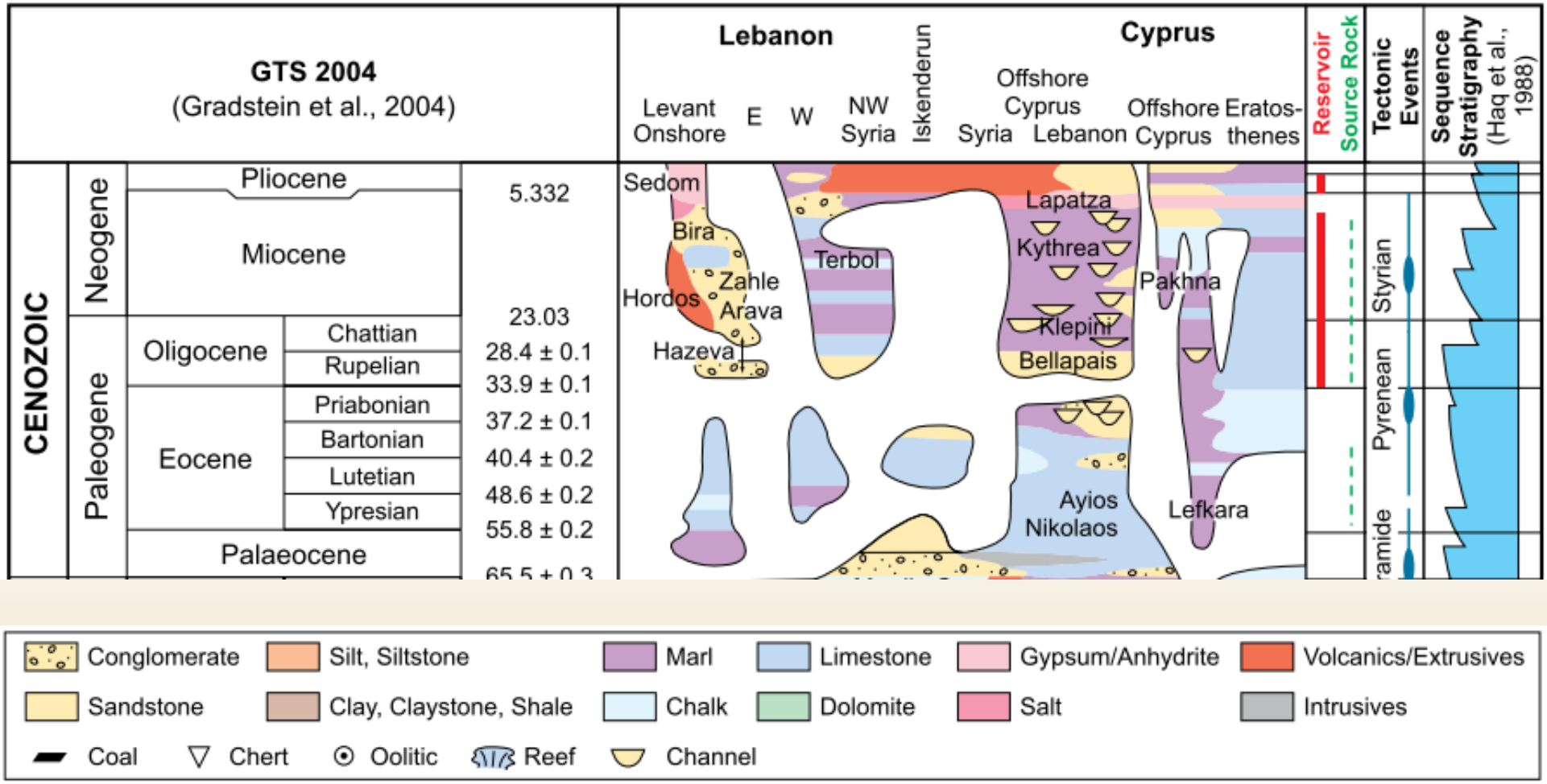


Figure 4: The stratigraphy of the nothern part of the Levantine Basin is indicated in the column below Offshore Cyprus/Syria/Lebanon, where the relationship between shelf and basin deposition is indicated by the different lithologies.

Roberts and Peace, 2007



Roberts and Peace, 2007

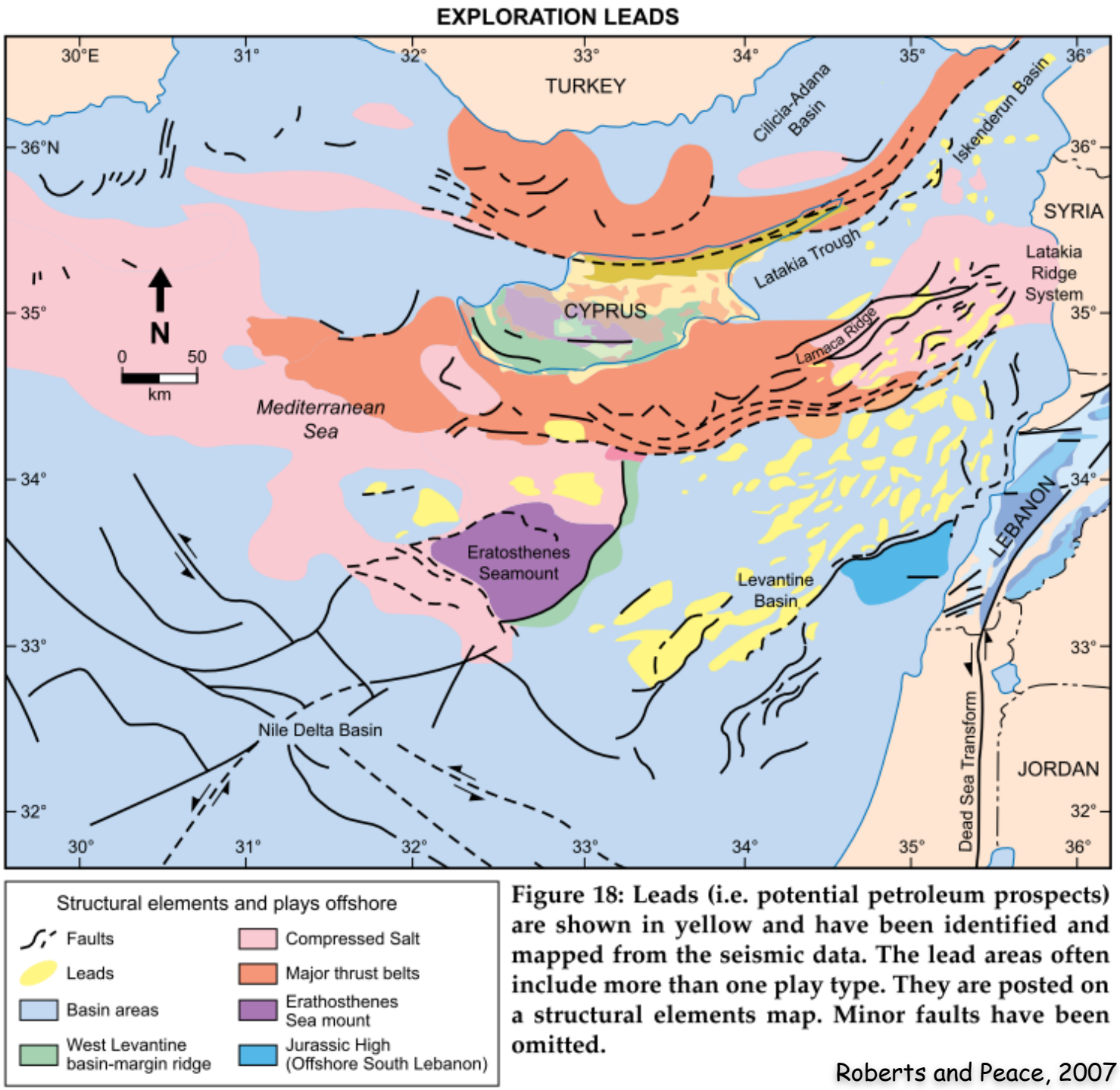


Figure 18: Leads (i.e. potential petroleum prospects) are shown in yellow and have been identified and mapped from the seismic data. The lead areas often include more than one play type. They are posted on a structural elements map. Minor faults have been omitted.

Roberts and Peace, 2007

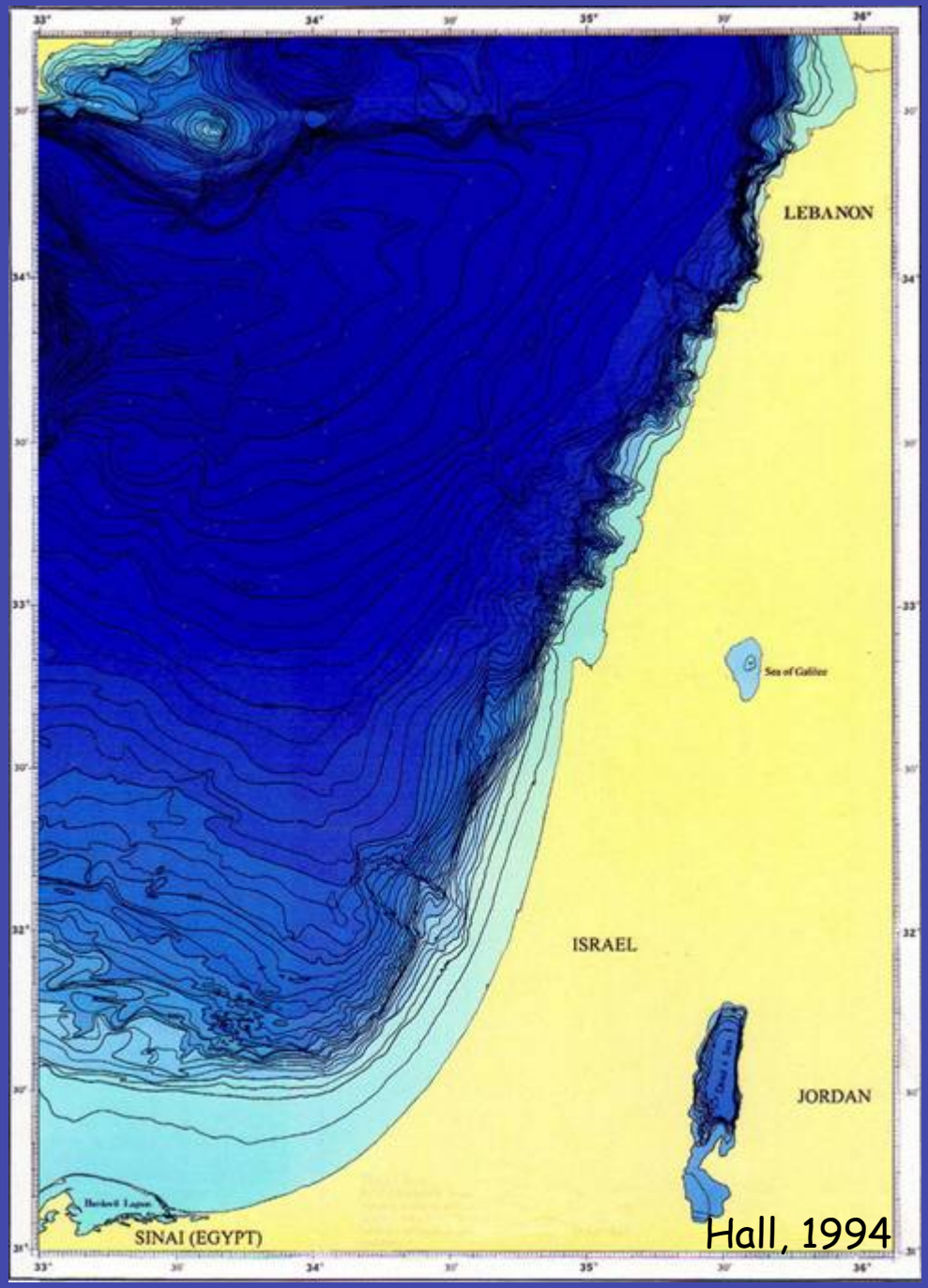
(marine) Geological research

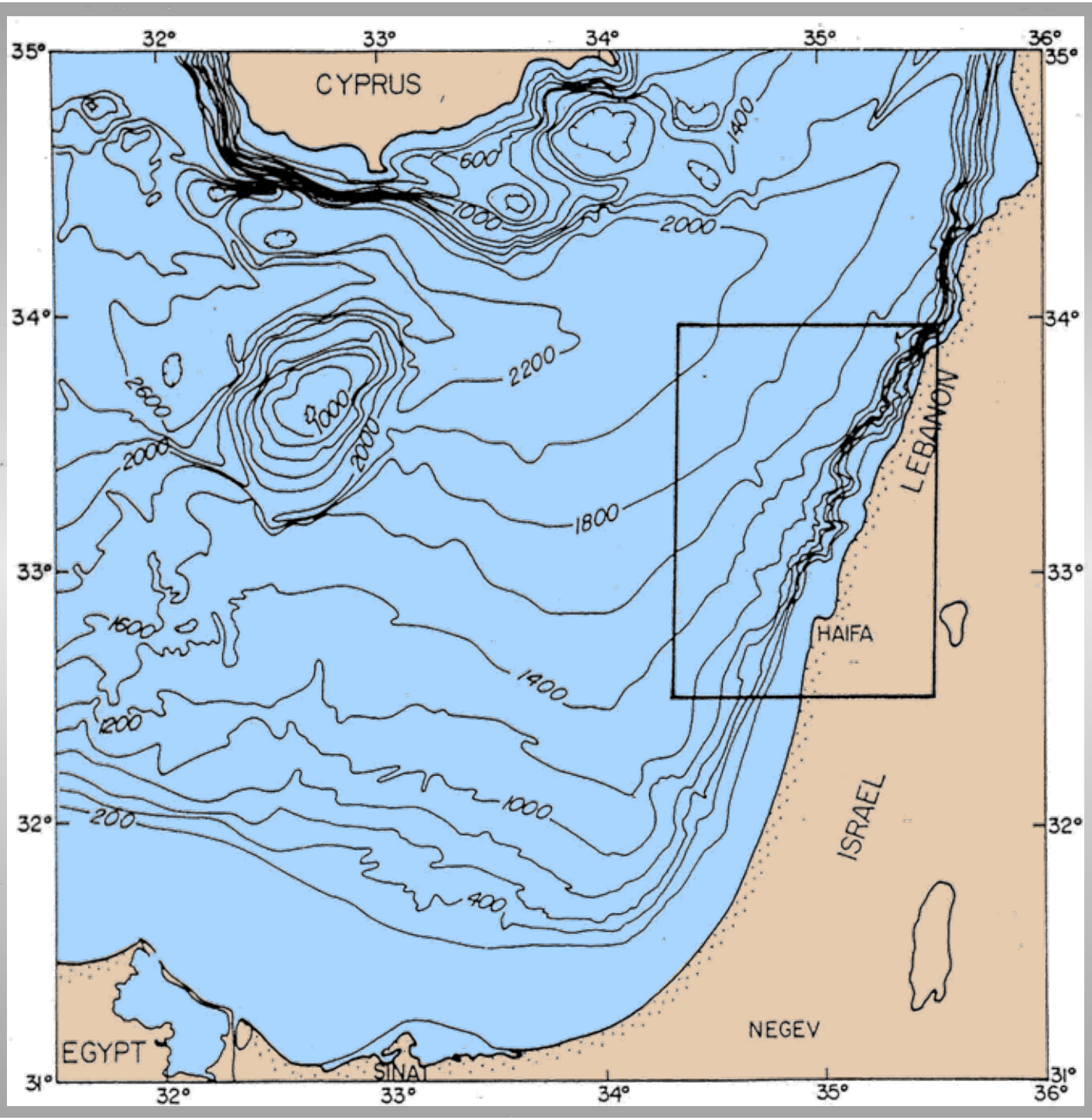
- goal: understanding of geological **processes**
- Subjects: geological **phenomena**
- **+**
- their formation **rates**
- deeper crust | shallow subsurface | surface

- **generalization**: integration of numerous **phenomena** and **rates** to deduce **complex processes**

What's strange about the E Med continental margin?

What's strange about the E Med continental margin?




32°
33°
34°
35°
36°
35°
34°
33°
32°
31°
CYPRUS
LEBANON
HAIFA
ISRAEL
NEGEV
EGYPT
SINAI
200
400
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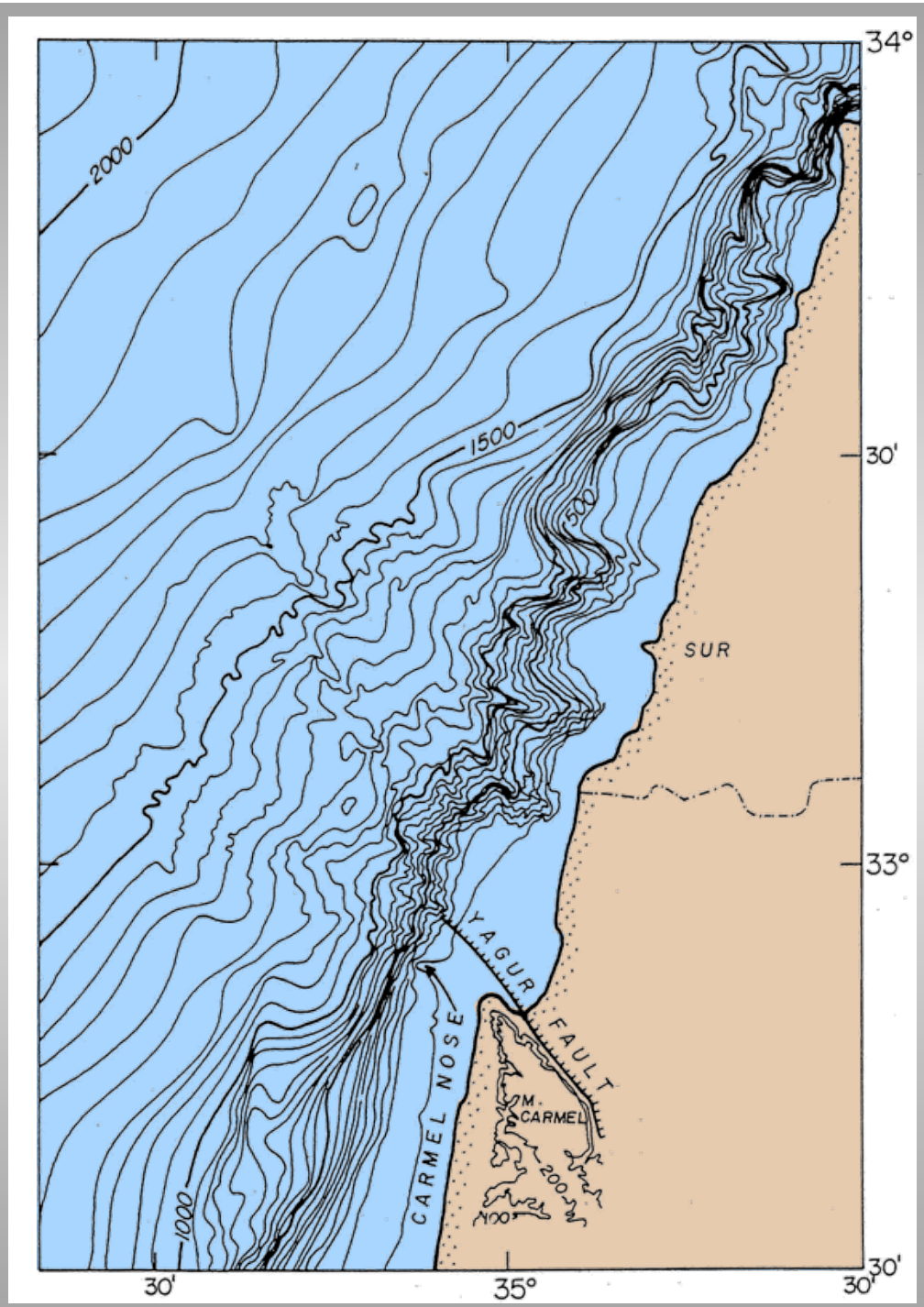
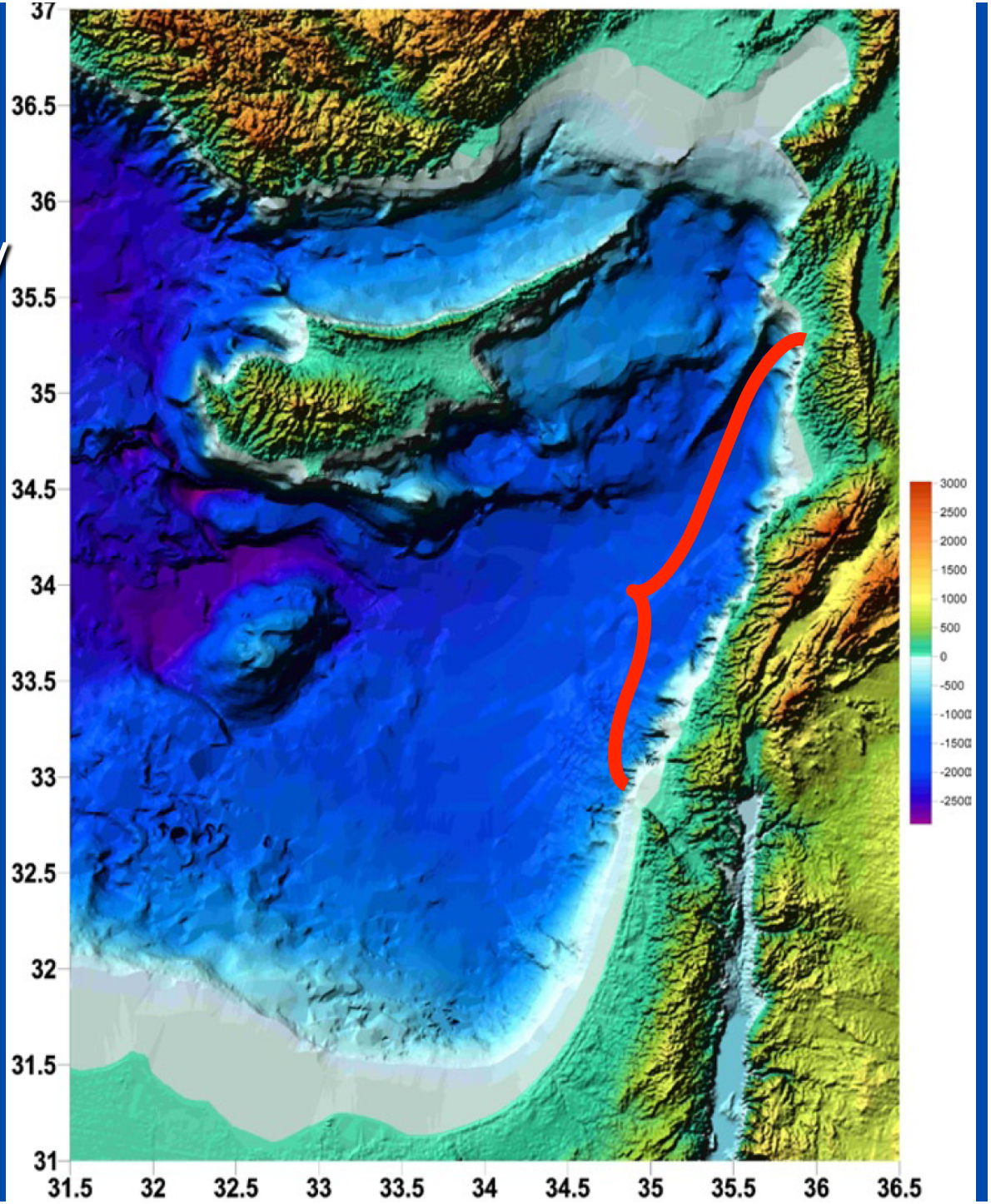
1000
1200
1400
1600
1800
2000
2200
2600

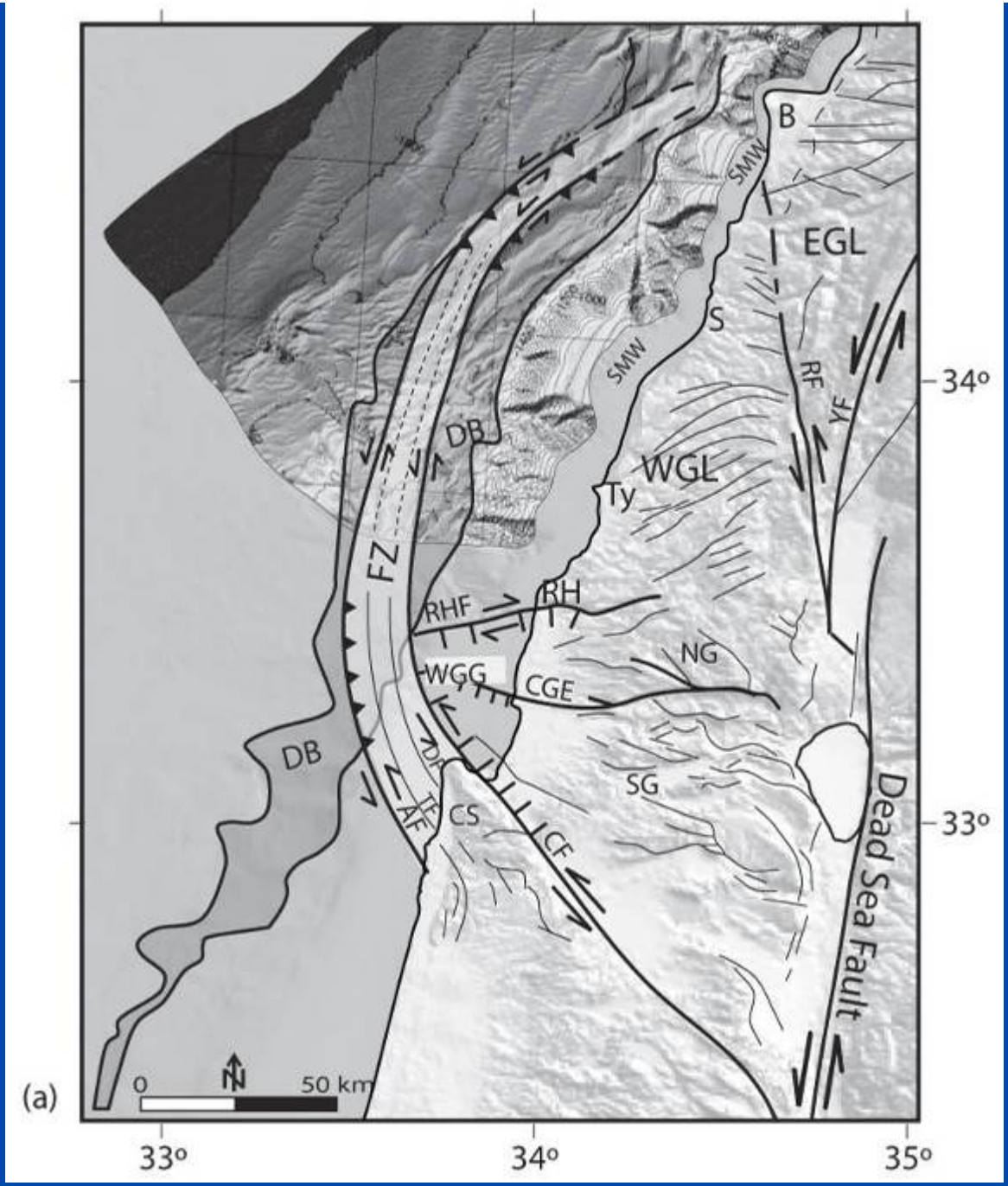
Ben-Avraham


34°
30'
33°
30'
30'
35°
30'
2000
1500
500
1000
SUR
YAGUR FAULT
CARMEL NOSE
M. CARMEL
200
400

Effect on the present day structure of the continental margin

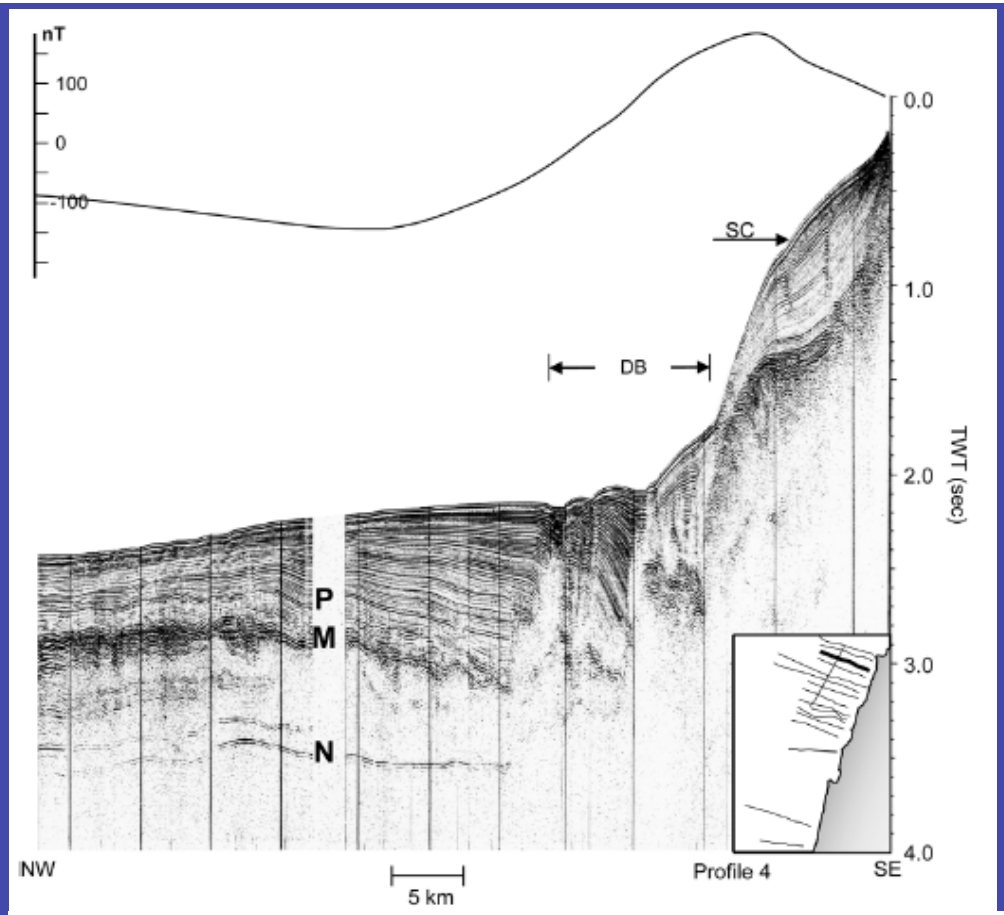


Marine extension of the Carmel fault

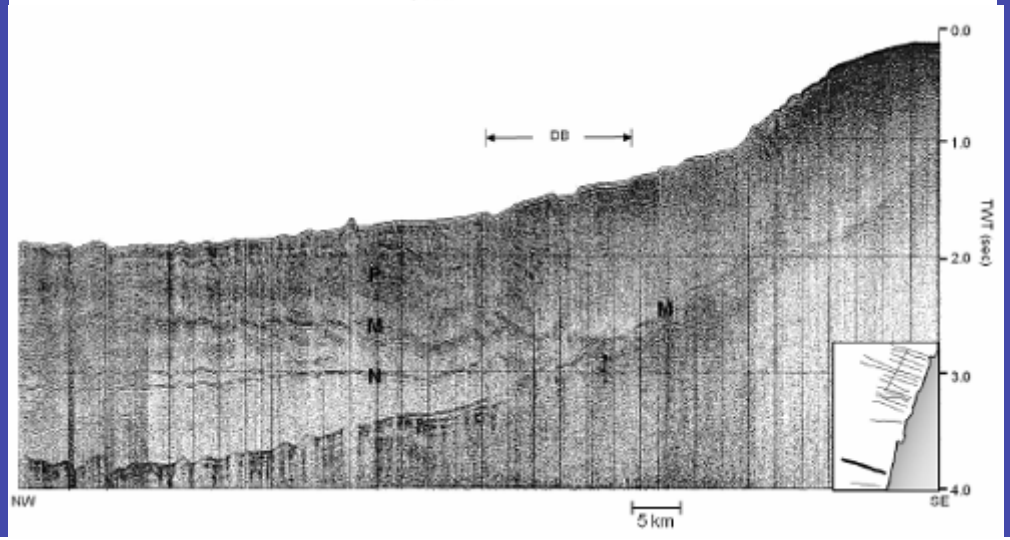


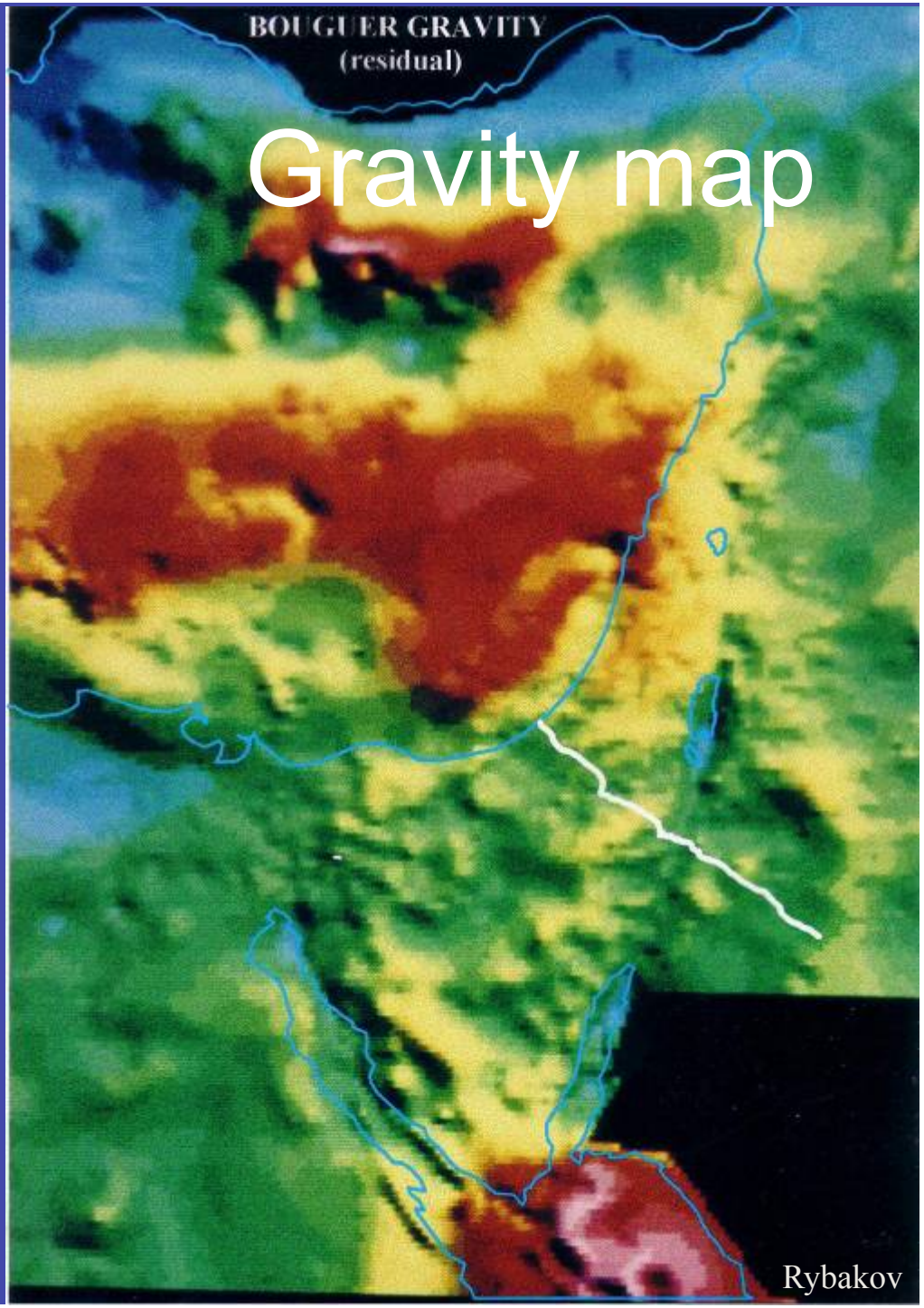
Schattner et al., 2006

Offshore Lebanon

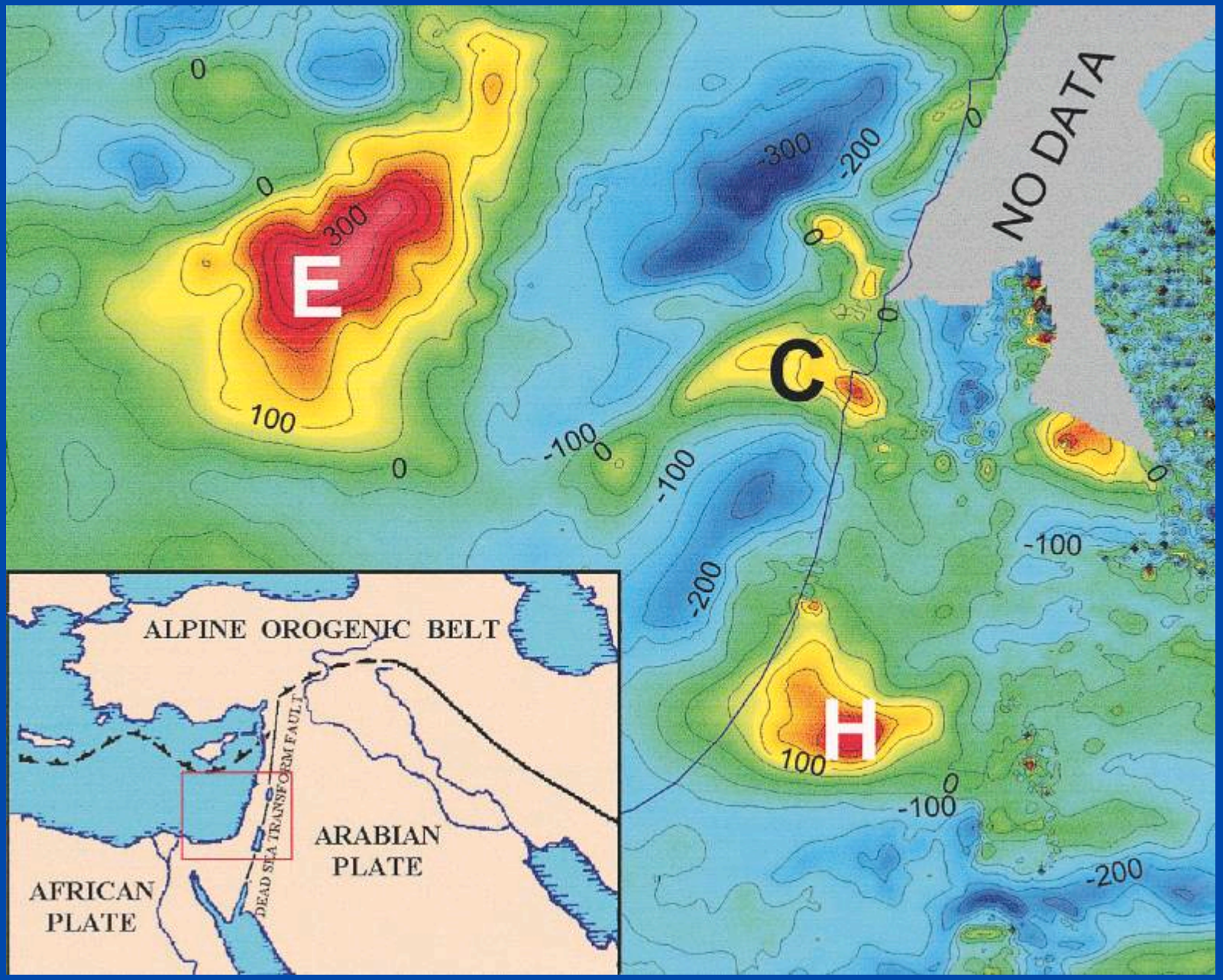


Offshore Israel

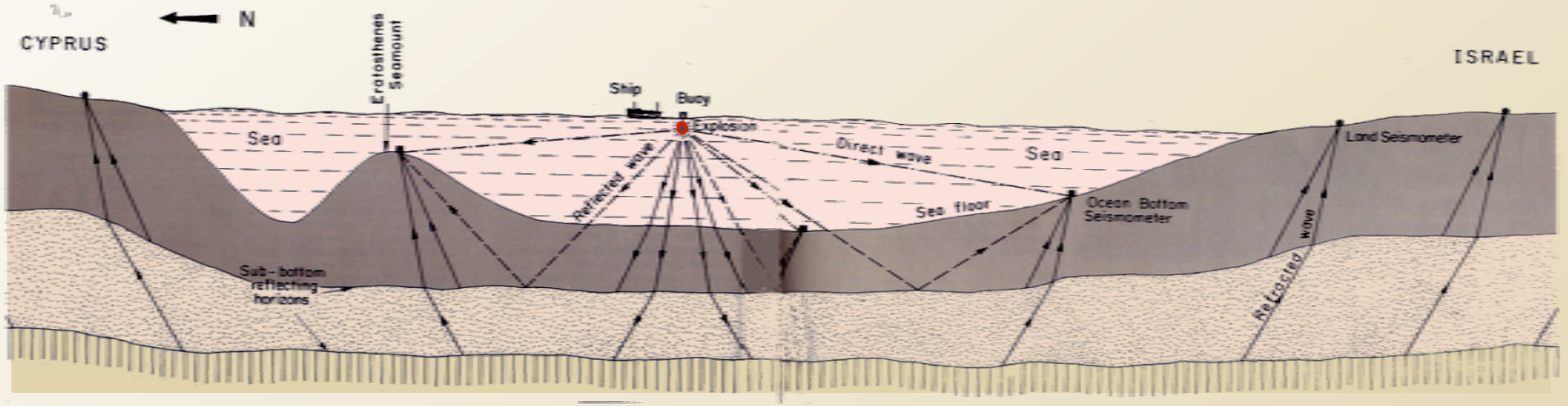


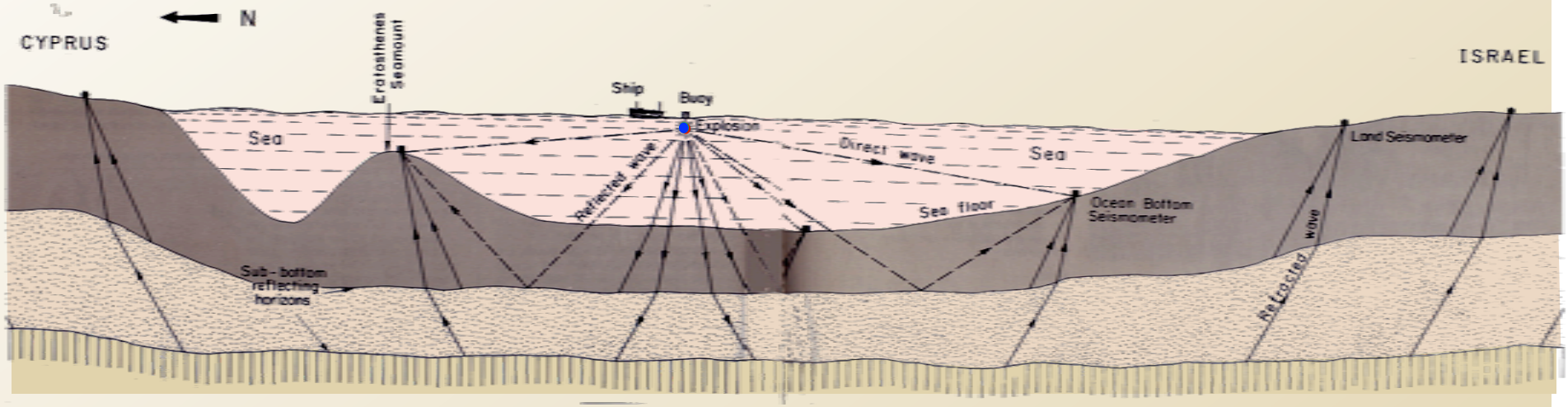

BOUGUER GRAVITY
(residual)
Gravity map
Rybakov

Magnetic Anomalies

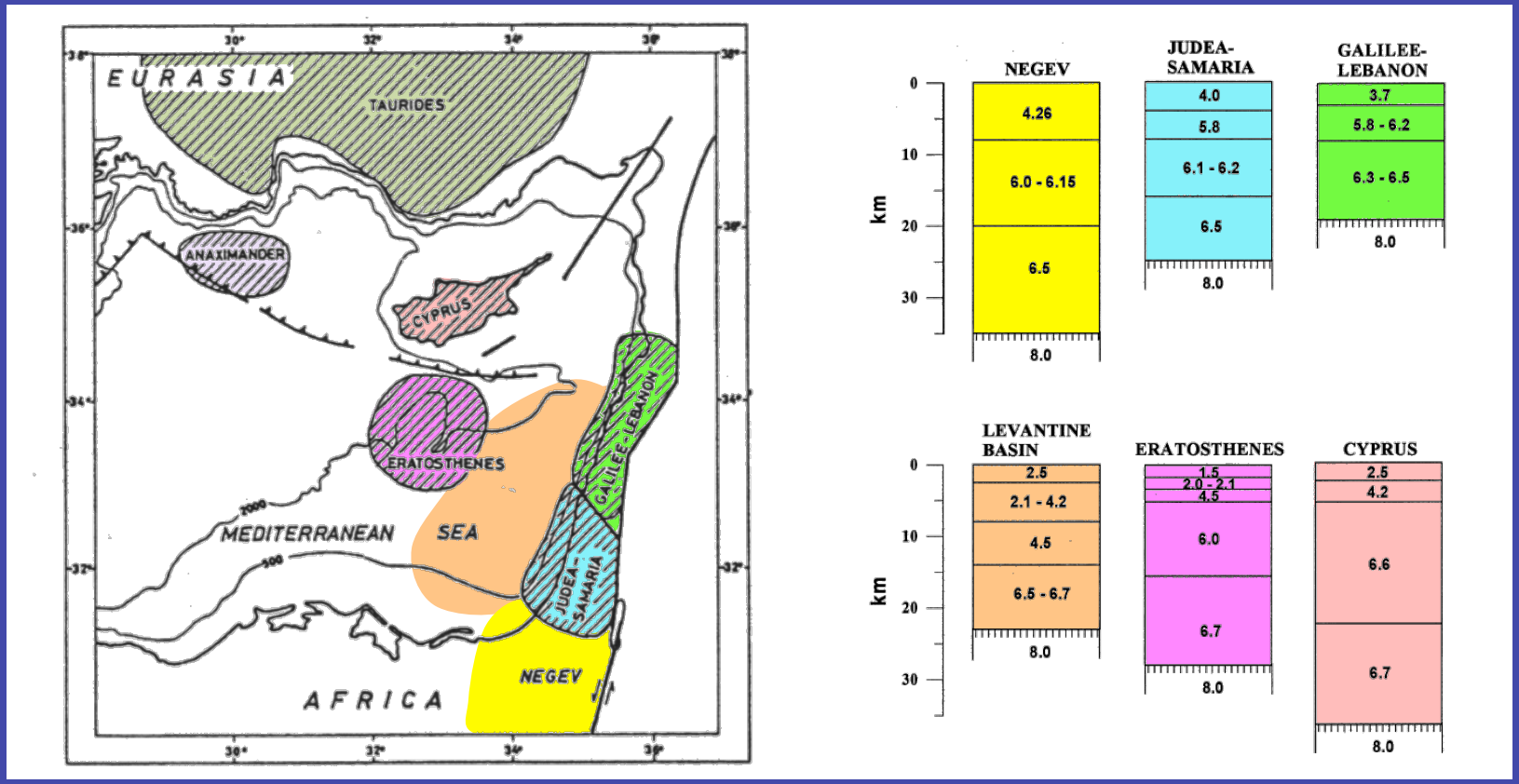


Rybakov et al., 2000


N
CYPRUS
ISRAEL
Eratosthenes Seamount
Ship
Buoy
Explosion
Sea
Direct wave
Sea
Land Seismometer
Reflected wave
Sea floor
Ocean Bottom Seismometer
Sub-bottom reflecting horizons
Reflected wave

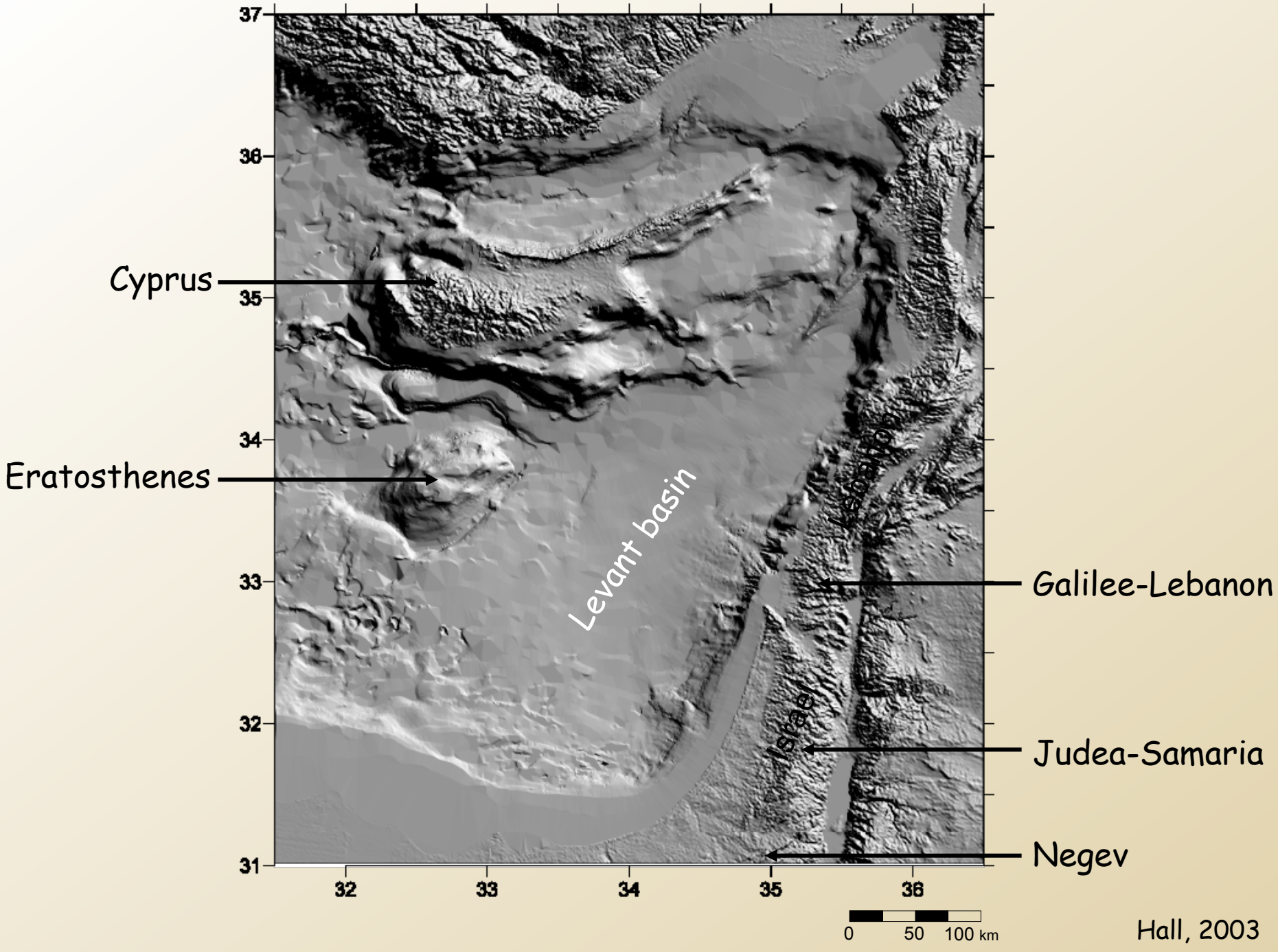

CYPRUS
N
Eratosthenes seamount
ISRAEL
Ship
Buoy
Explosion
Sea
Direct wave
Sea
Land Seismometer
Reflected wave
Sea floor
Ocean Bottom Seismometer
Sub-bottom reflecting horizons
Refracted wave

Crustal Provinces



Ben-Avraham and Ginzburg, 1990

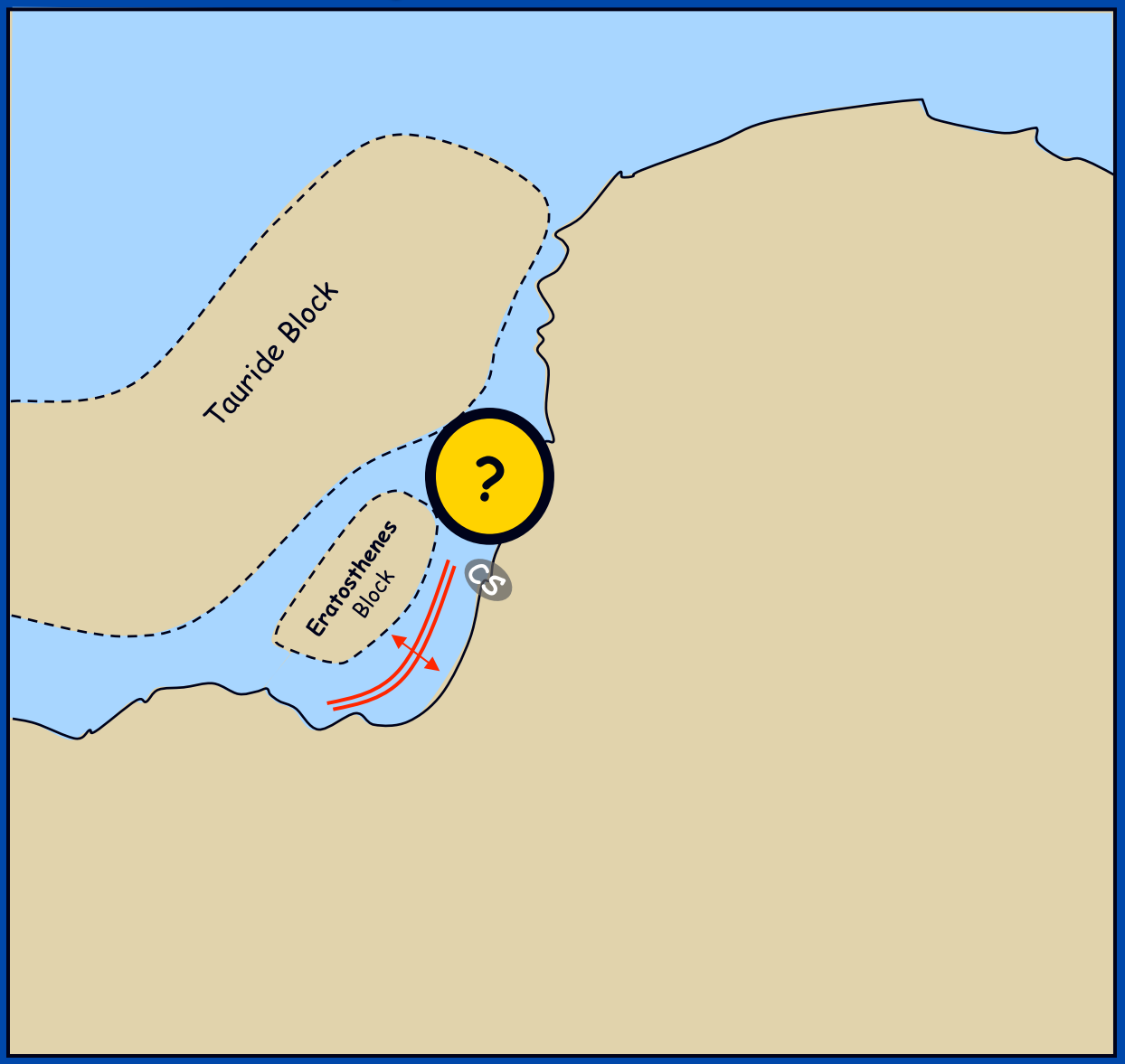
Ben-Avraham et al., 2002


37
36
35
34
33
32
31
32
33
34
35
36
Cyprus
Eratosthenes
Levant basin
Israel
Galilee-Lebanon
Judea-Samaria
Negev
0
50
100 km
Hall, 2003

Continental breakup

After Garfunkel, 1998

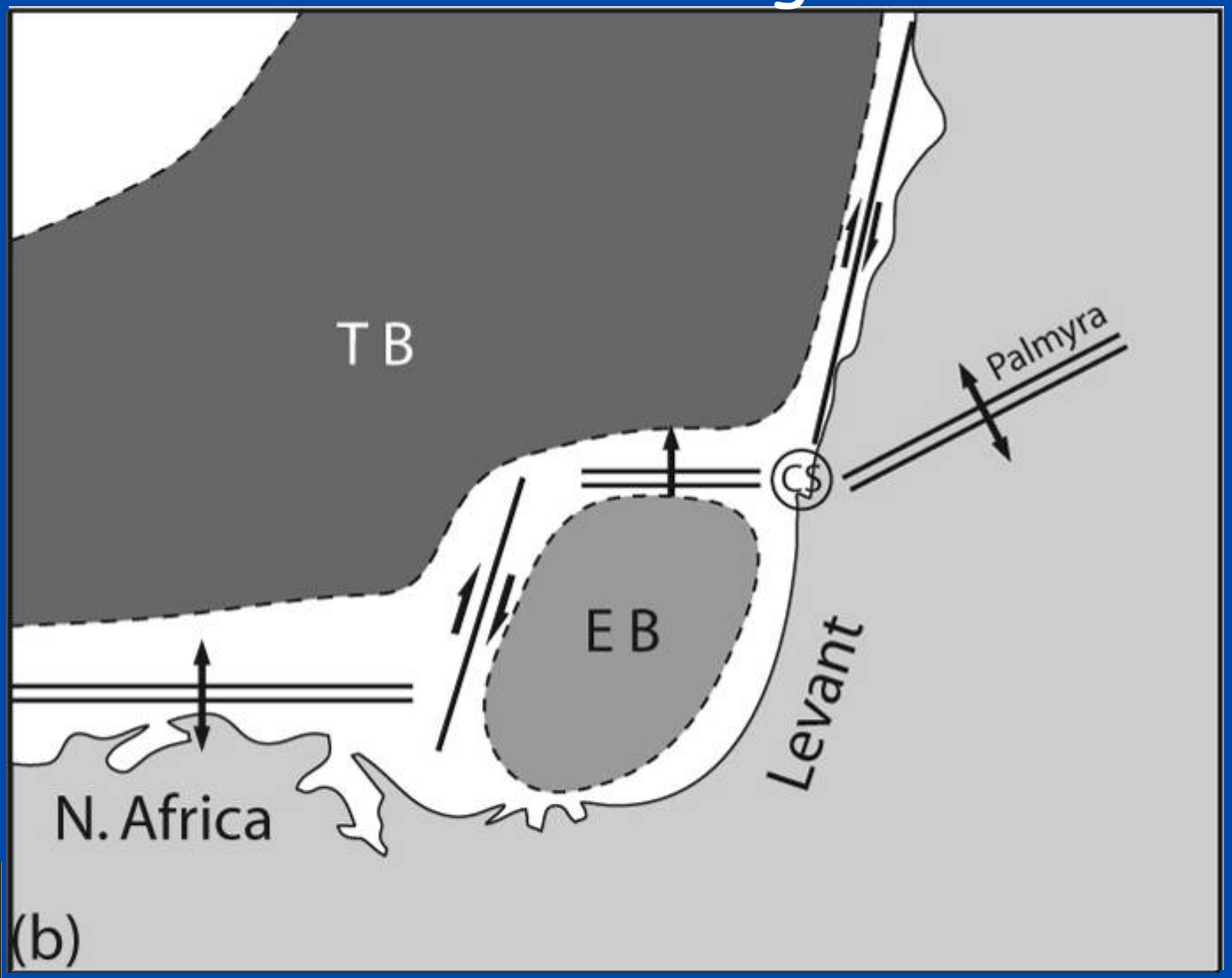
Major questions



After Garfunkel, 1998

I ~ Mid Permian
II ~ Triassic

Initial Phase II Settings

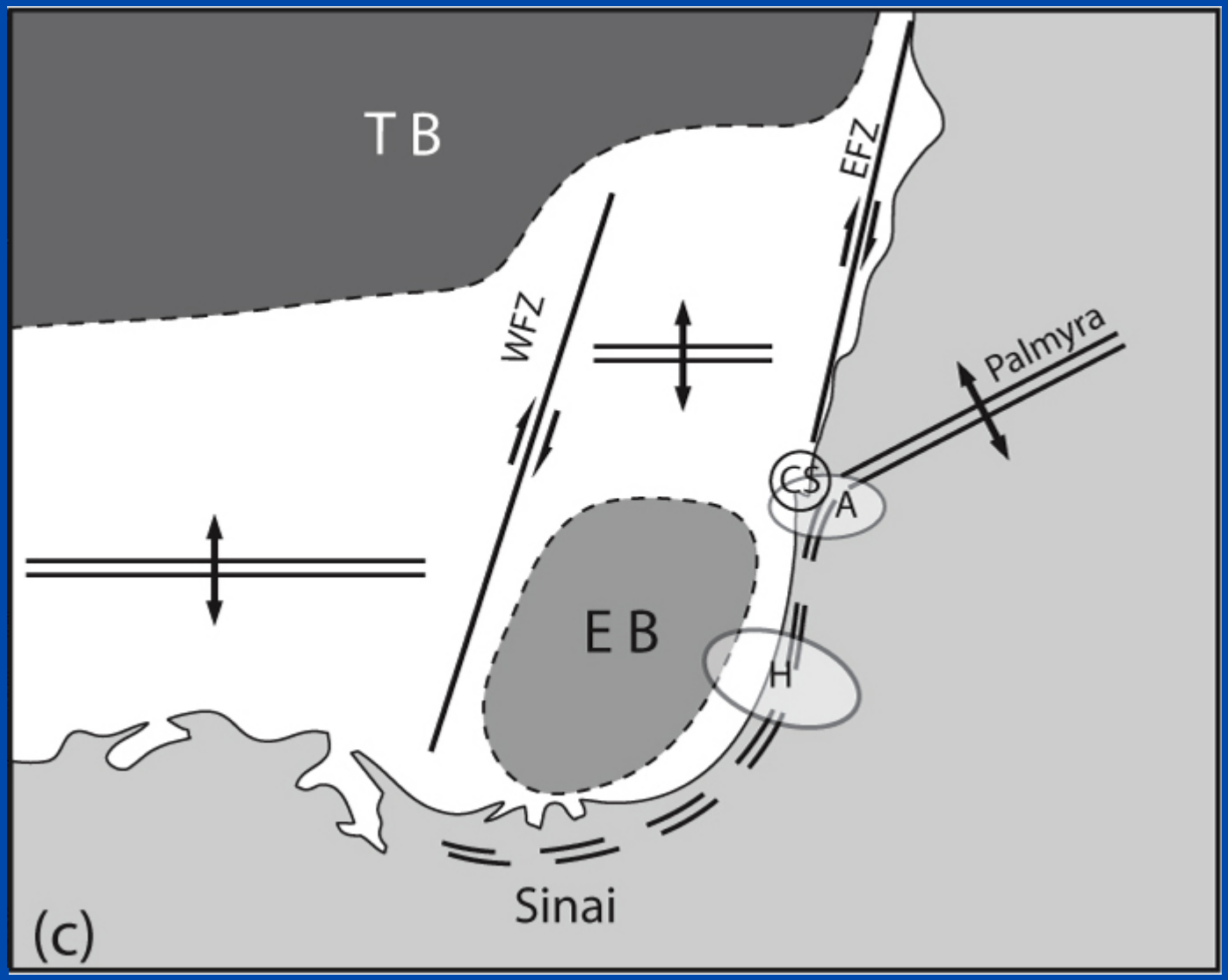


Legend
- Rift / Spreading center
- In-active Rift
- Fracture Zone
- Transform fault
- Magmatic center
- fold

TB=Tauride Block
EB=Eratosthenes block

Schattner and Ben-Avraham , 2006

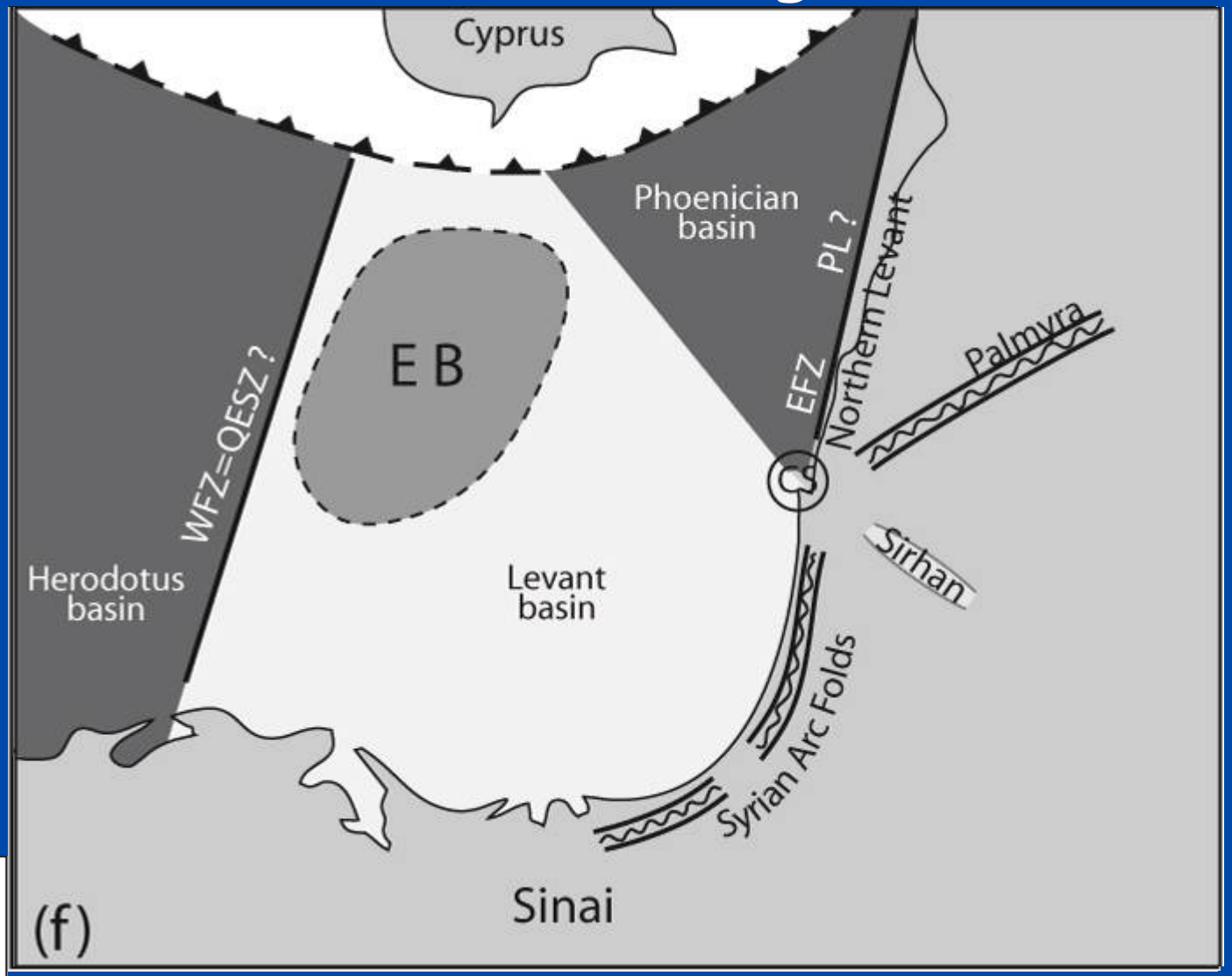
Phase I



Legend
- Rift / Spreading center
- In-active Rift
- Fracture Zone
- Transform fault
- Magmatic center
- fold

Schattner and Ben-Avraham , 2006

Final Settings



Legend
- Rift / Spreading center
- In-active Rift
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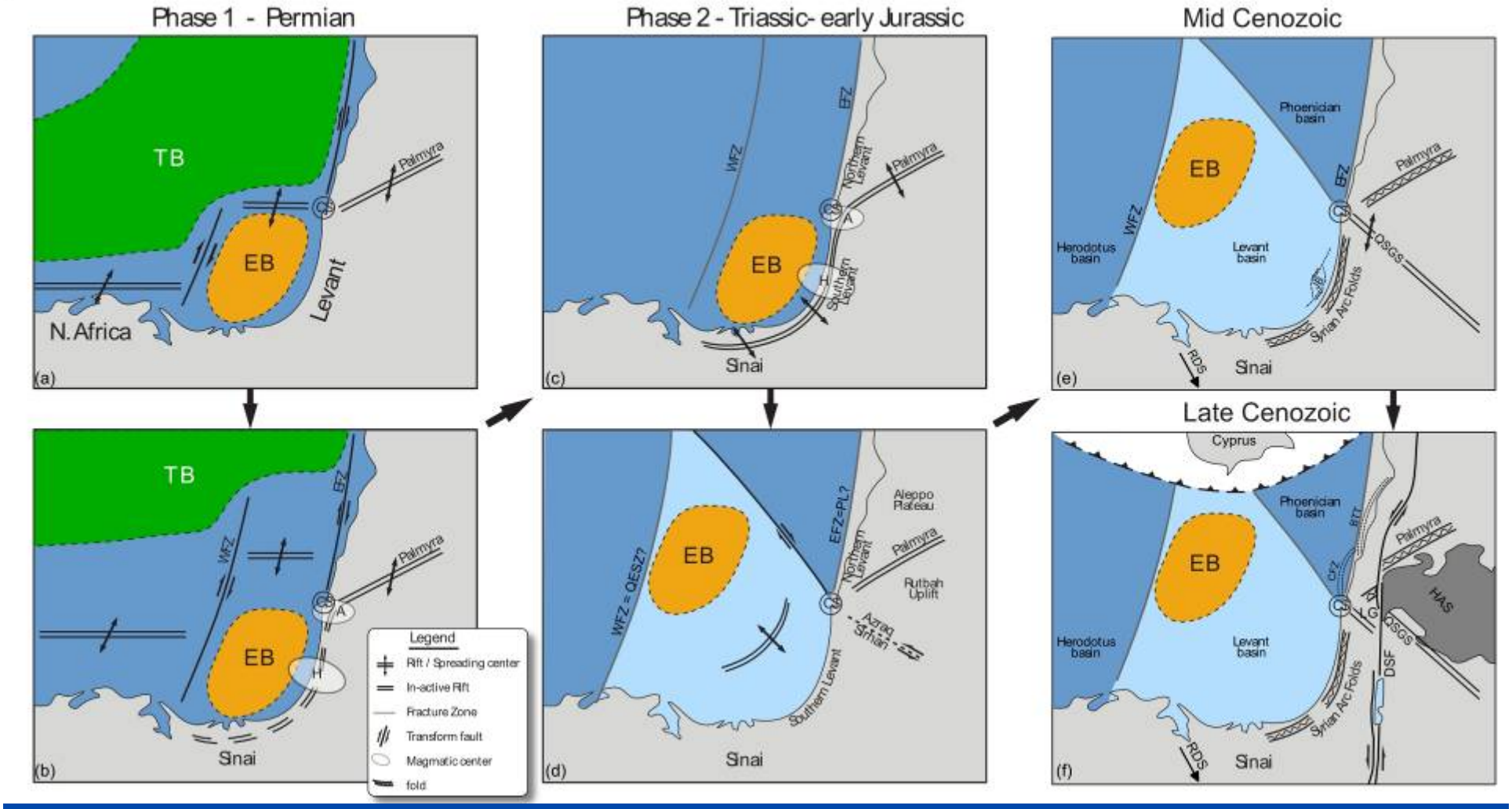
- Magmatic center
- fold

Schattner and Ben-Avraham , 2006

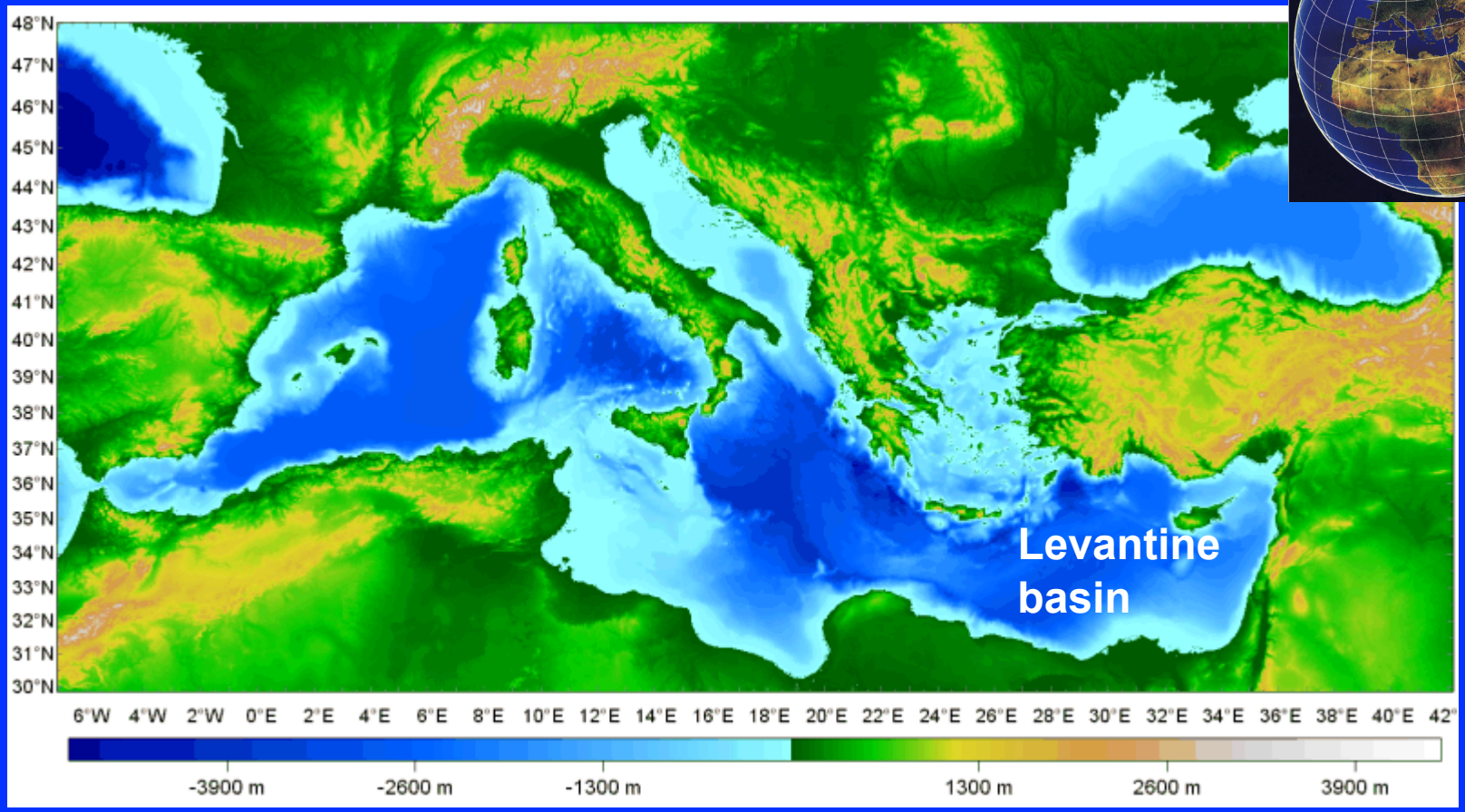
I ~ Mid Permian
II ~ Triassic



TB=Tauride Block
EB=Eratosthenes block

Schattner and Ben-Avraham , 2010

The Mediterranean Sea



- The Mediterranean Sea is a marginal, landlocked Sea
- The most distal Levantine basin, is a sensitive recorder of paleoclimate / paleoceanographic variations, amplifying the global signal

Uniqueness of the eastern Mediterranean

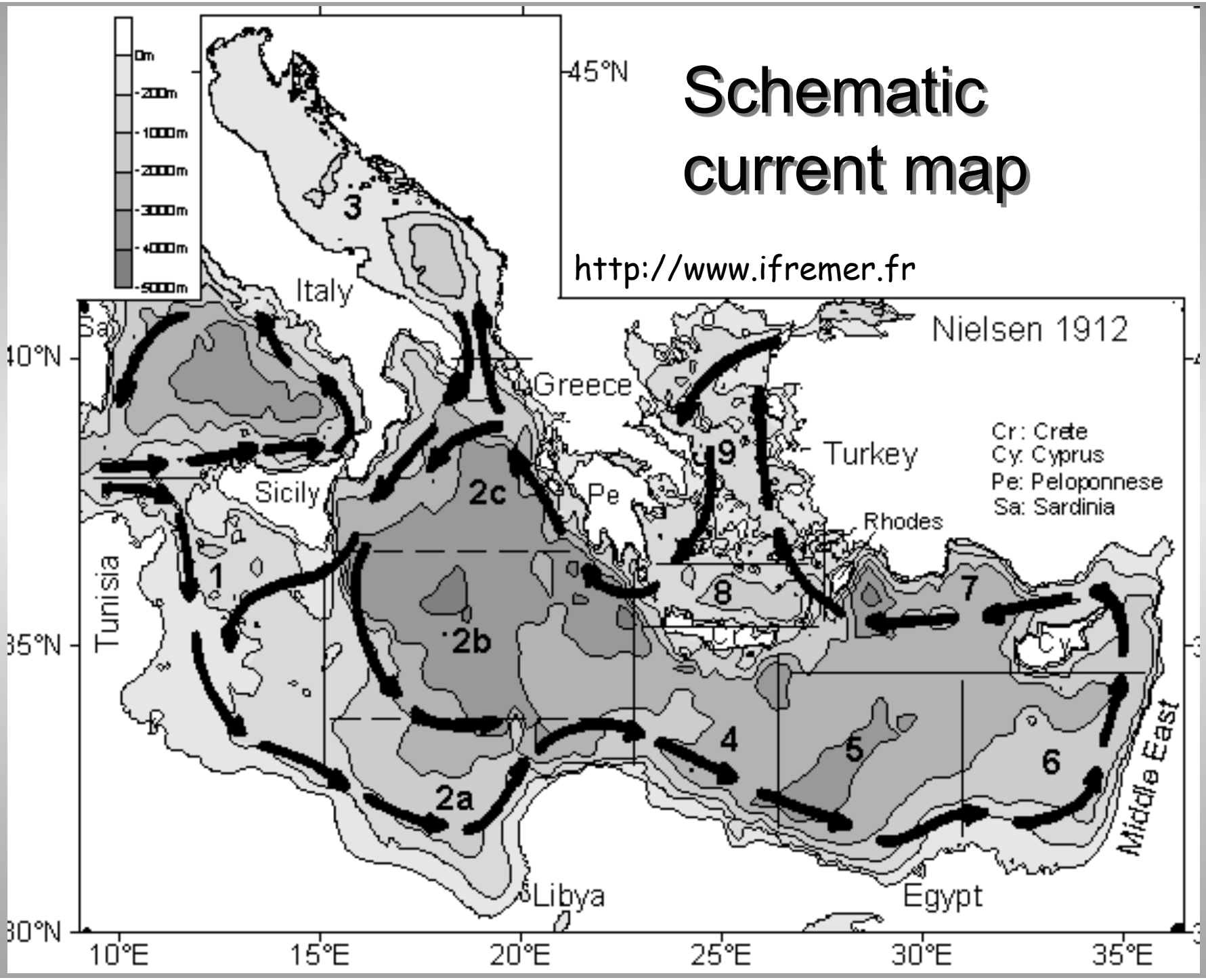
The Mediterranean is/was:

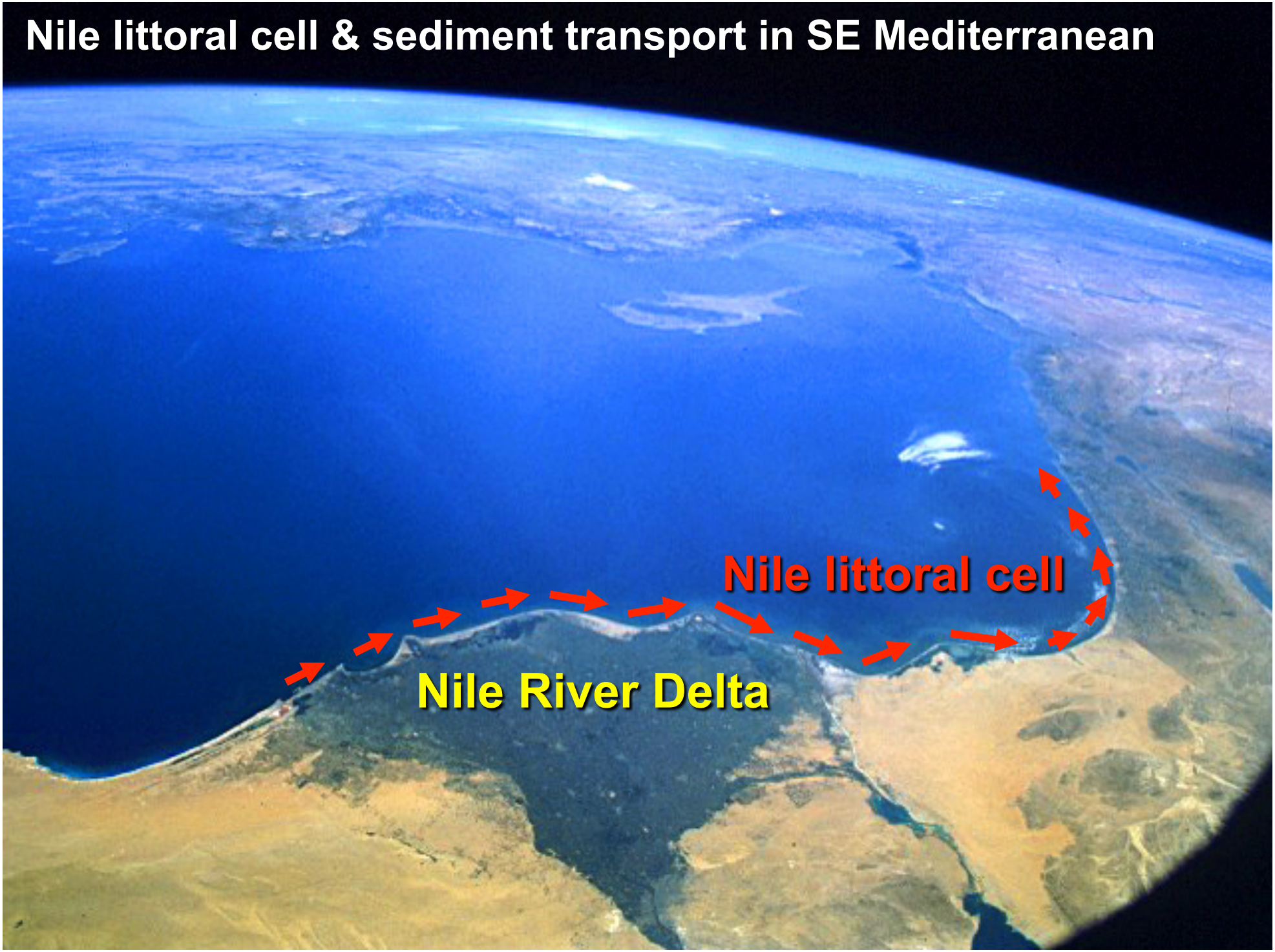
- a closed sea
- the cradle of marine civilization
- Many of the Mediterranean civilizations were reliant on shipping and seafaring
- Maritime navigation was developed here
- Fishing is a major activity
- The shores of the Med are very densely populated, highly utilized, centers of tourism and underline the need for integrated coastal zone management
- Introduction of exotic/invasive species from the Red Sea to the Med Sea (Lessepsian migration) is a growing problem that is most acute along Israeli Med coast


Some of the issues in the eastern Mediterranean:
•Pollution
•Fishing
•Sand shortage – Aswan Dam
•Exploitation – gas (oil?)
•Tourism and recreation
•Water desalinization
•Expansion – artificial islands

Schematic current map

http://www.ifremer.fr




Nile littoral cell & sediment transport in SE Mediterranean
Nile littoral cell
Nile River Delta

Mediterranean Sea

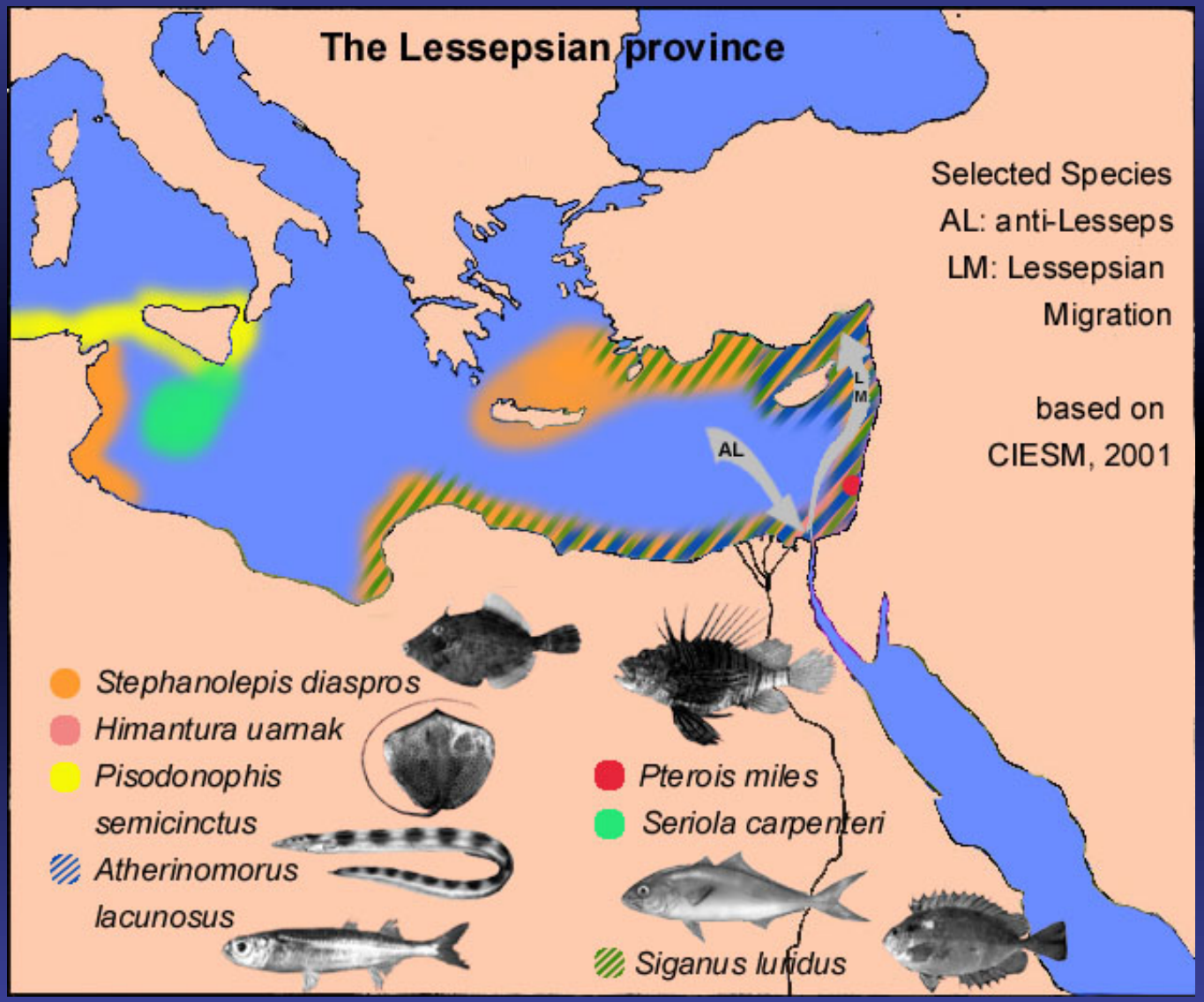
Suez Canal
1869

- One-way invasion: Red Sea to Eastern Mediterranean
- ~10% of all living species in eastern Mediterranean are of an Erythrean origin (Por, 1970)
  - Among Fish 90% are invaders

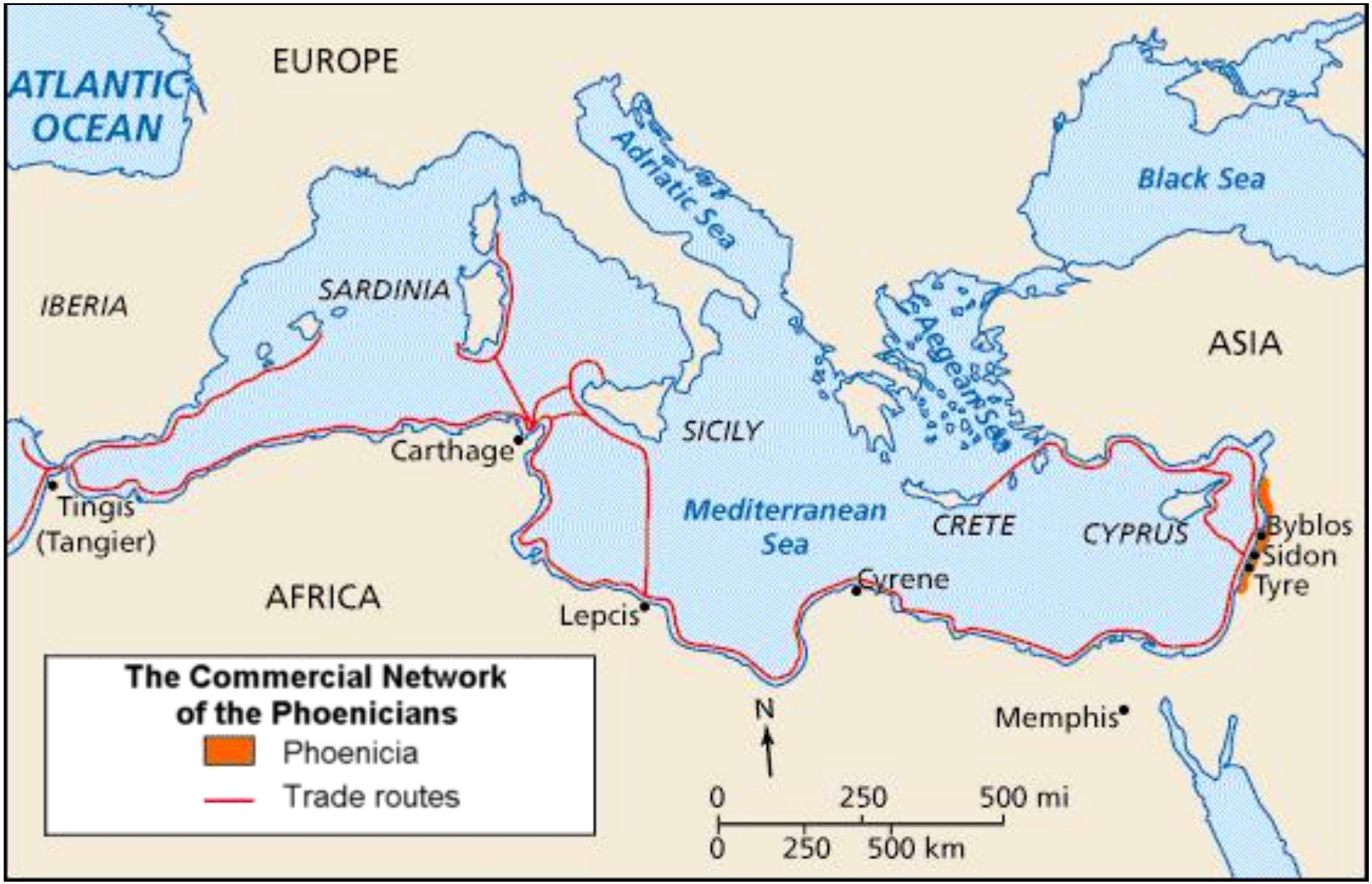

Ferdinand de Lesseps

Gulf of Suez

Lessepsian Fish



Phoenician seafaring (~900 – 350 BCE)

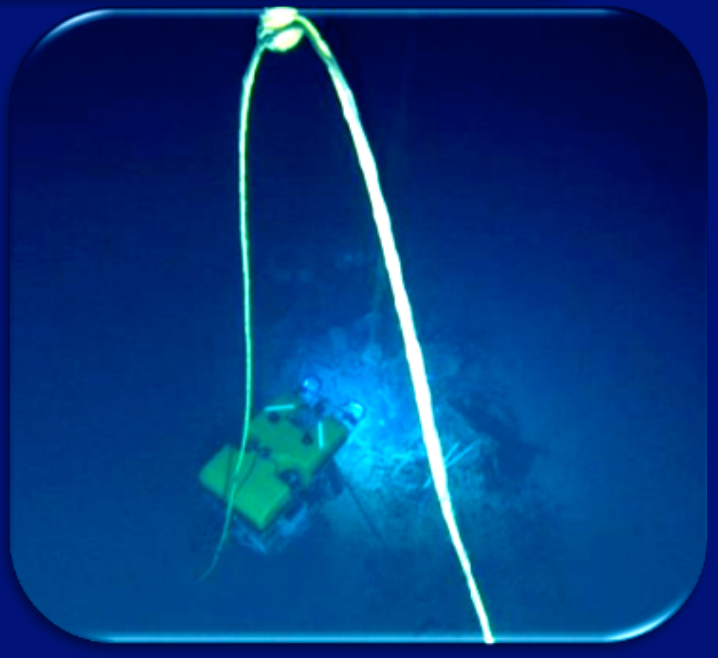


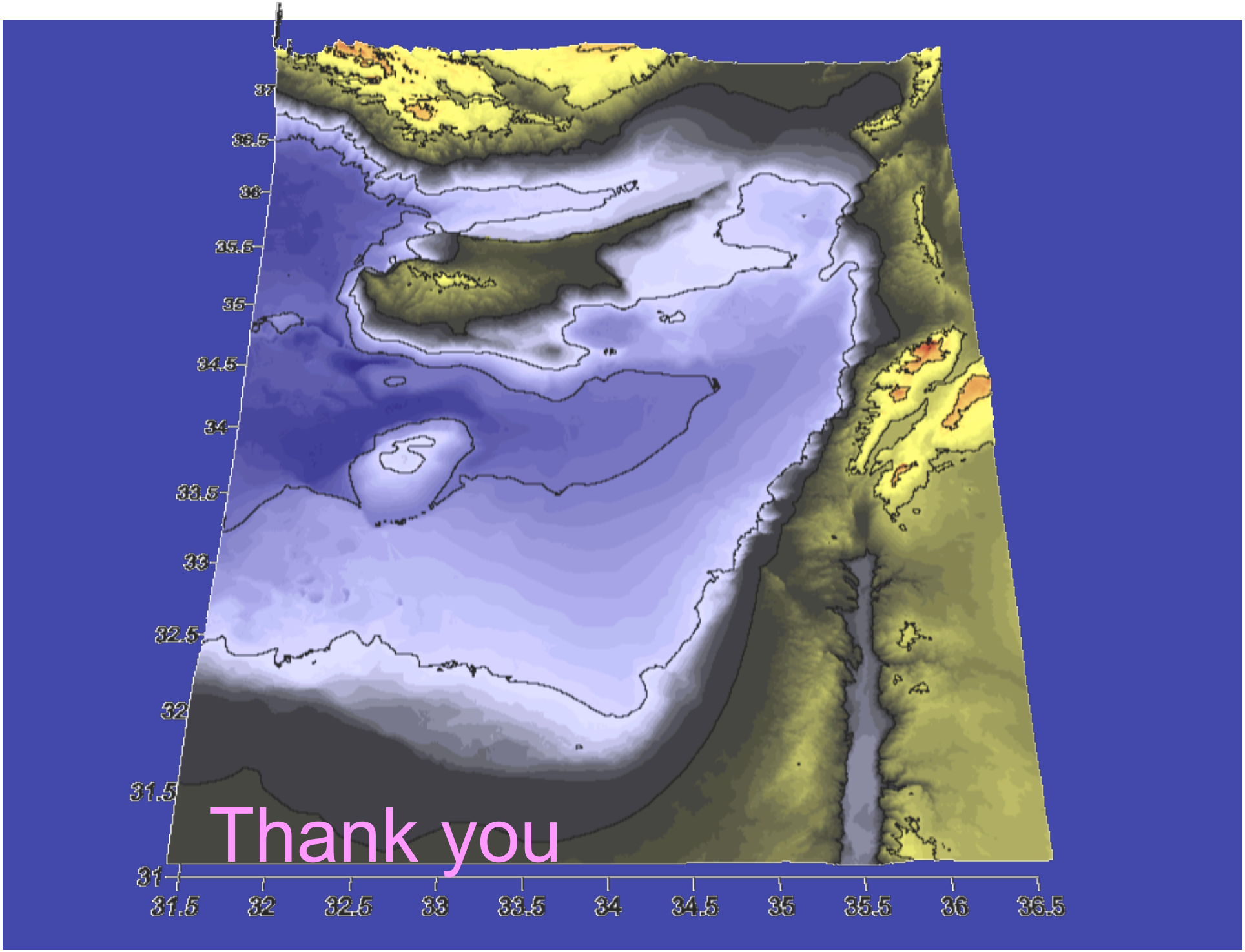

Troy
Mycenae
Messinia
Crete
Cyprus
Anatolia/Turkey
Syria
Lebanon
Egypt

Ma'agan Mikha'el ship, 5th century BCE

One of the most ancient & best preserved shipwrecks

Marine research – a bridge for peace

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Thank you