Rivers and Rifting: Interaction of Normal Faulting, Erosion and Sediment Dispersal in the Corinth Rift*

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Abstract

Rivers are key agents of mass flux in rift basins. The evolution of these rivers, and thus the distribution of their deposits, is strongly influenced by the development of normal fault systems. Rivers and their deposits can be used to understand the behavior and growth of fault systems while, conversely, the growth of normal fault systems influence the spatial distribution of river sediments. The Corinth rift in Greece provides a unique opportunity to study both the interaction of present day rivers with a rapidly opening rift and to trace the behavior and influence of the same drainage system back through a rifting history of around 4 million years.

Three stages are recognized in this rift's development: (a) Early Rift: The influence of inherited landscape and an antecedent drainage system on early rift structure and sediment dispersal (Pliocene Early Pleistocene). The standard evolutionary model for normal fault systems and related rift stratigraphy assumes that, in the initial pre-rift state, a homogenous crust has a flat upper surface and that the landscape and drainage system derives uniquely from the tectonic and climatic activity during rifting. But if, as occurs in the Corinth rift, rifting is superimposed on a complex pre-existing landscape with a well established drainage network, how will the early fault network evolve and how will sediments be distributed in early depocentres? (b) Mid Rift: Interaction of major normal faults with a well established antecedent drainage system during accelerated extension. At around 2-1.8 Ma the dynamics of rifting changed and the drainage system became subordinate to faulting. In the west, fault activity migrated northward and concentrated upon a single major fault (Ford et al., 2007) while in the east, northward migration of fault activity was more progressive (Rohais et al., 2007). Giant Gilbert deltas were deposited in the main depo-centers and track the life and death of controlling faults. (c) Recent Rift: Erosion power of antecedent rivers during accelerated uplift - at around 0.7 Ma fault activity migrated

north again and became focused on major coastal faults that control the current Gulf. The northern Peloponnesos began to uplift at a rate between 1 and 1.5 mm/a. In the west, rivers continued to flow northward, eroding into their own conglomeratic L-M Pleistocene deltas to redeposit them in the Gulf. Further east, many north flowing rivers were forced to flow south into endorheic basins.

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RIVERS AND RIFTING: interaction of Normal Faulting, Erosion and Sediment dispersal in the Corinth Rift

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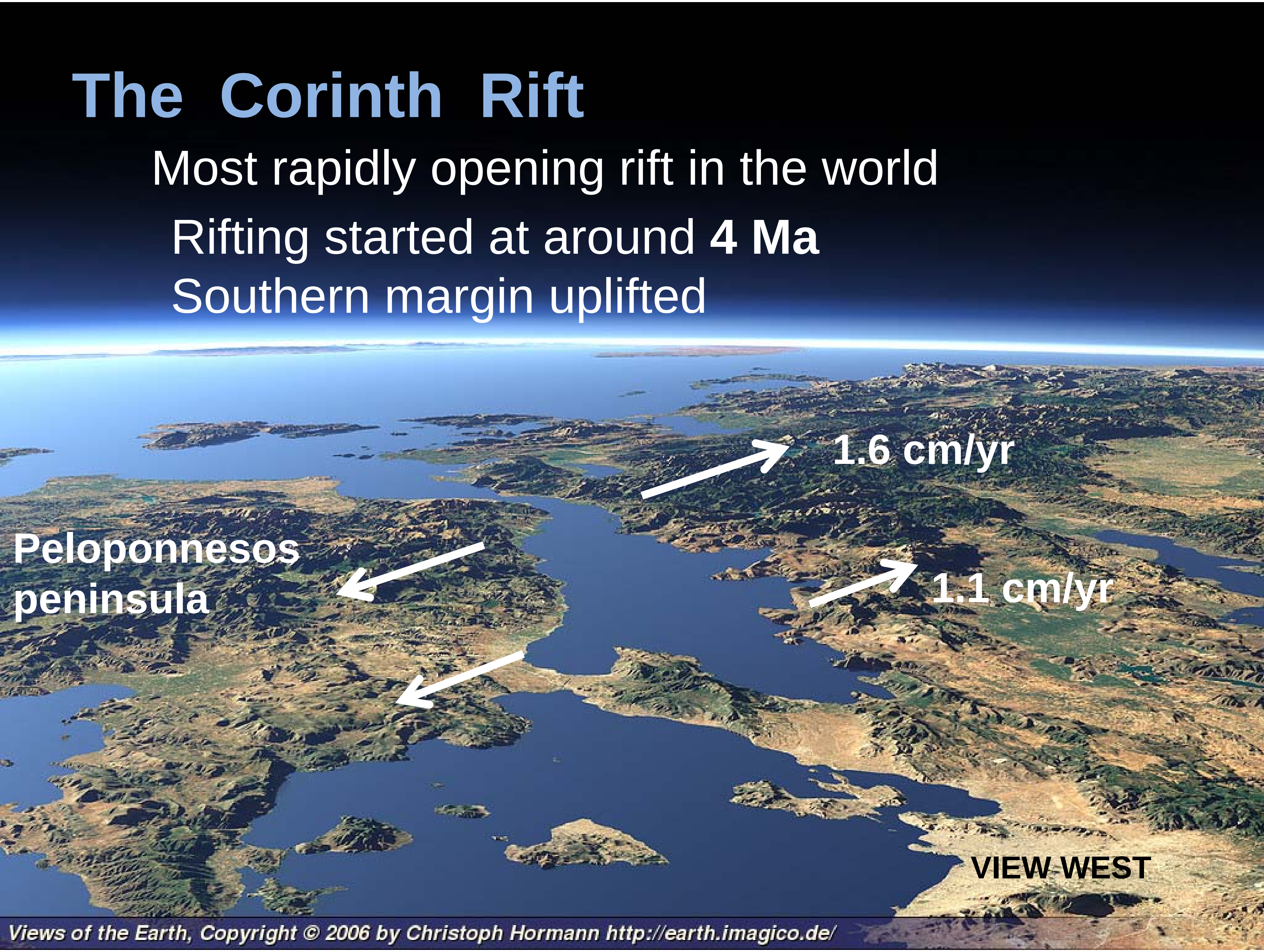
The Corinth Rift

Most rapidly opening rift in the world

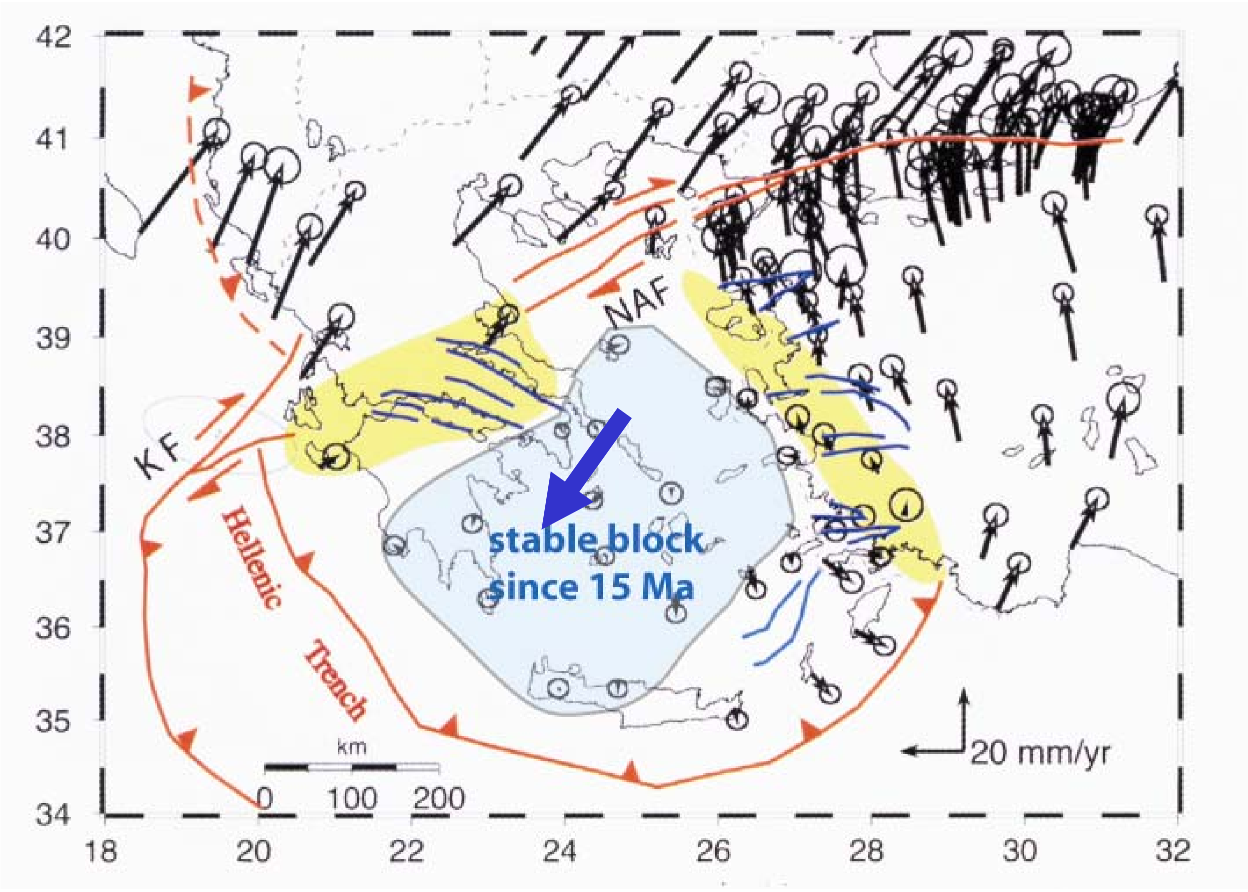
Rifting started at around **4 Ma**

Southern margin uplifted



Geodynamic setting

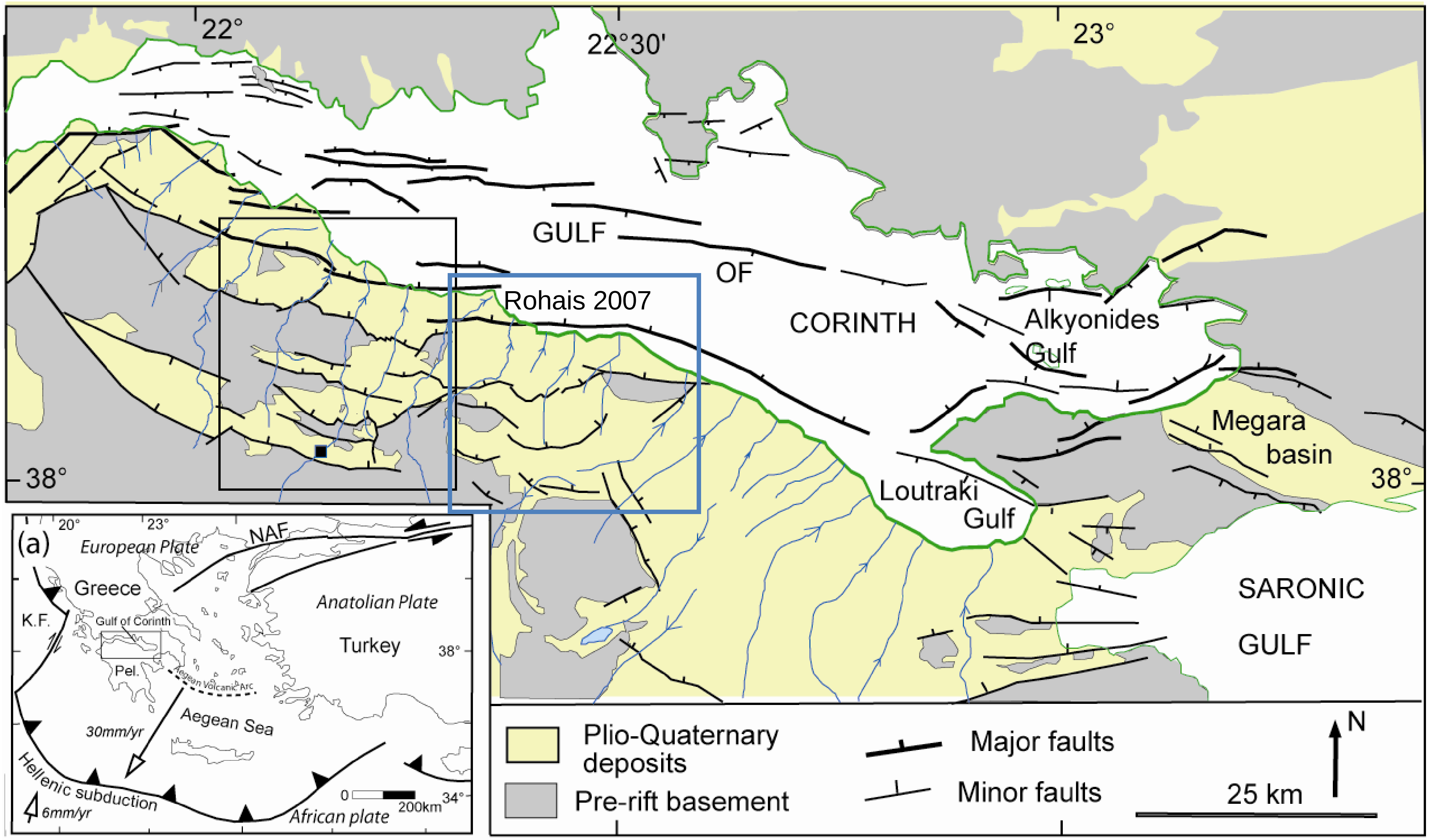
Lies within a rapidly evolving, diffuse plate boundary linking the Kefalonia fault (KF) with the North Anatolian fault (NAF).
Lies above the NW subducting African plate
Superimposed on the N-S trending Oligo-Miocene Hellenide fold and thrust belt



Yellow areas are actively extending (N-S)

B.C. Burchfiel, MIT, 2003 GSA Presidential address, 2008

Corinth Rift



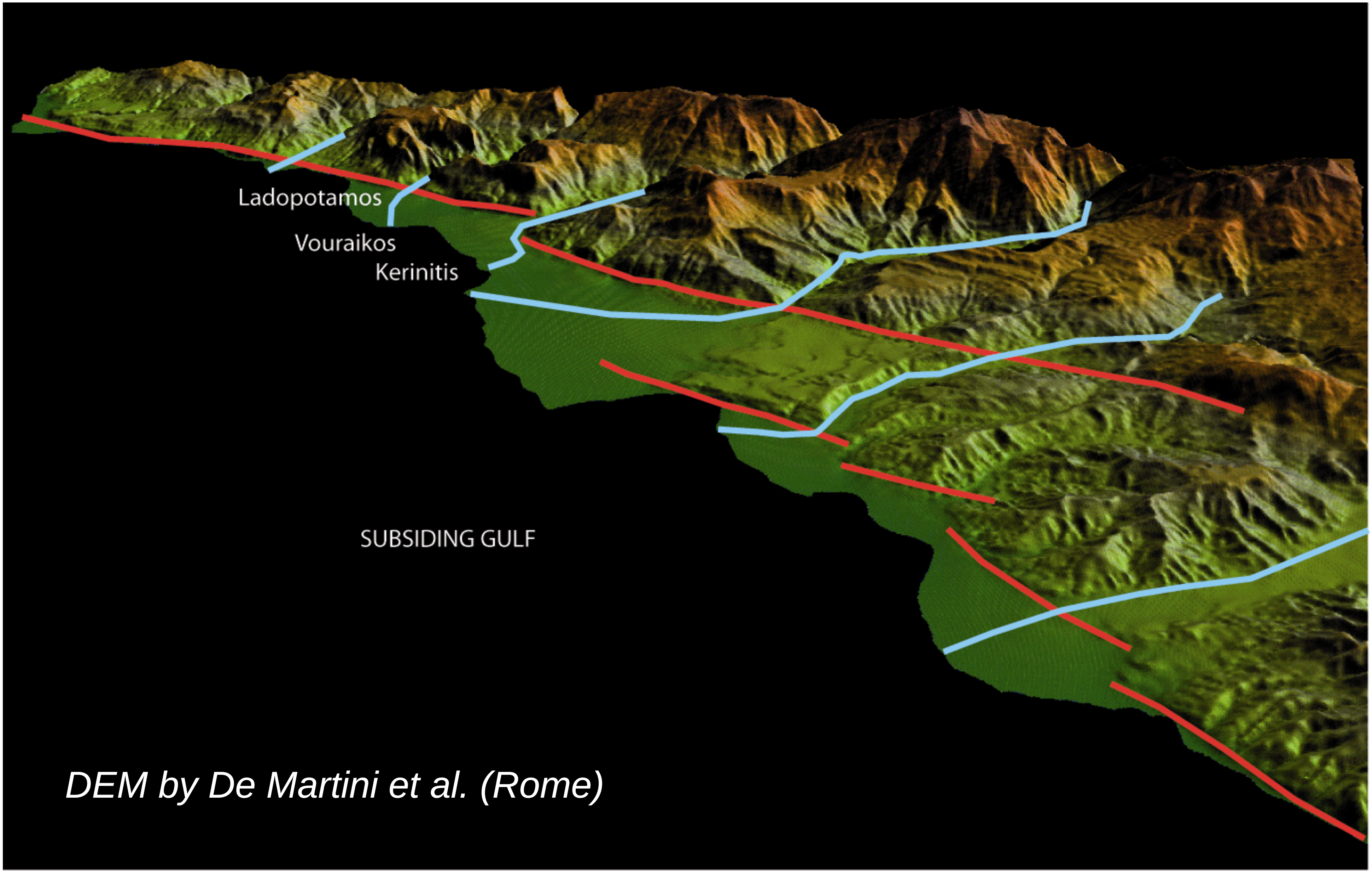
Main points on Corinth rifting

1. **Three phase rift history recording increasing Rate of Extension and Fault Migration**

2. **Major antecedent river system controlled sediment supply throughout rifting in western rift**
   - controlling mass flux
   - maintaining high sediment supply

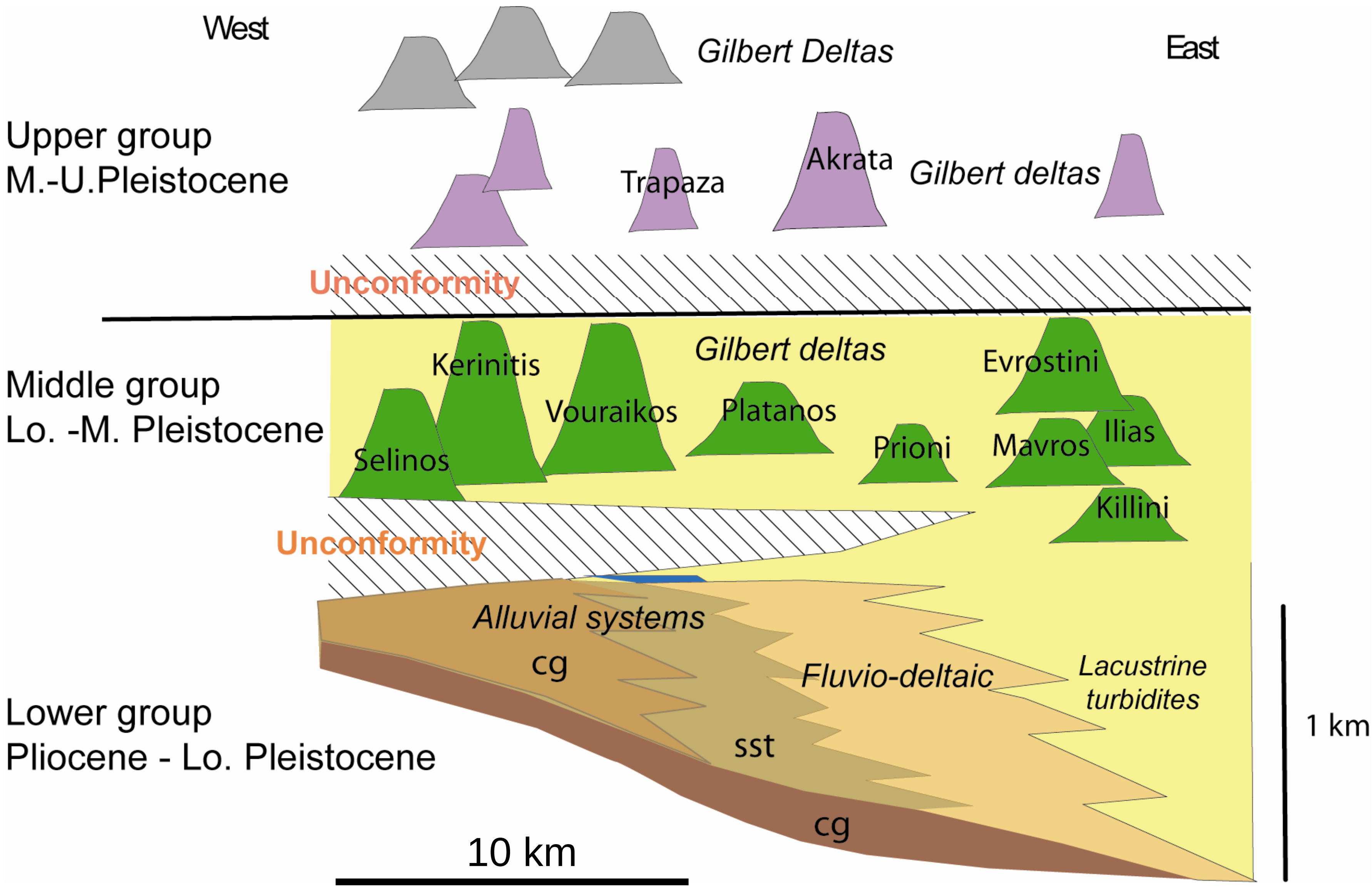
3. **Pre-existing relief** influenced sediment routing pathways especially during early rifting

Today's rivers in western Gulf

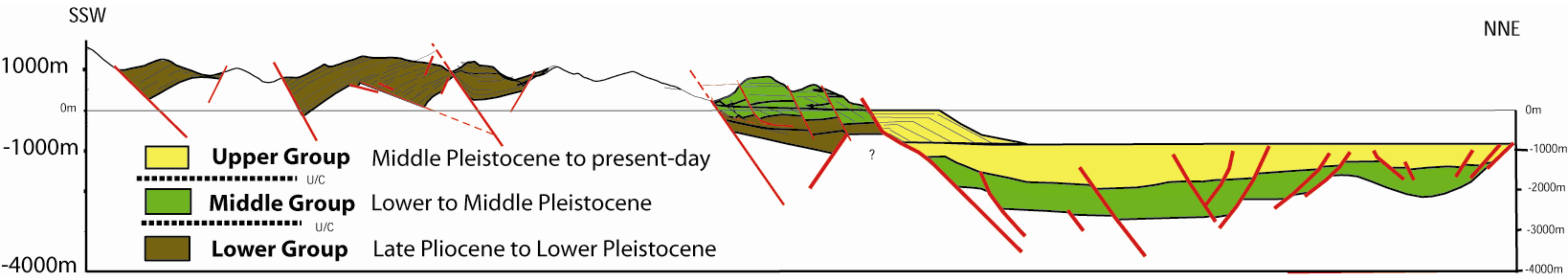


ONSHORE SYN-RIFT STRATIGRAPHY

Along-strike correlations



Extension rates during rifting



Minimum total NS extension across whole rift is approx 11 km (Beta 1.2).

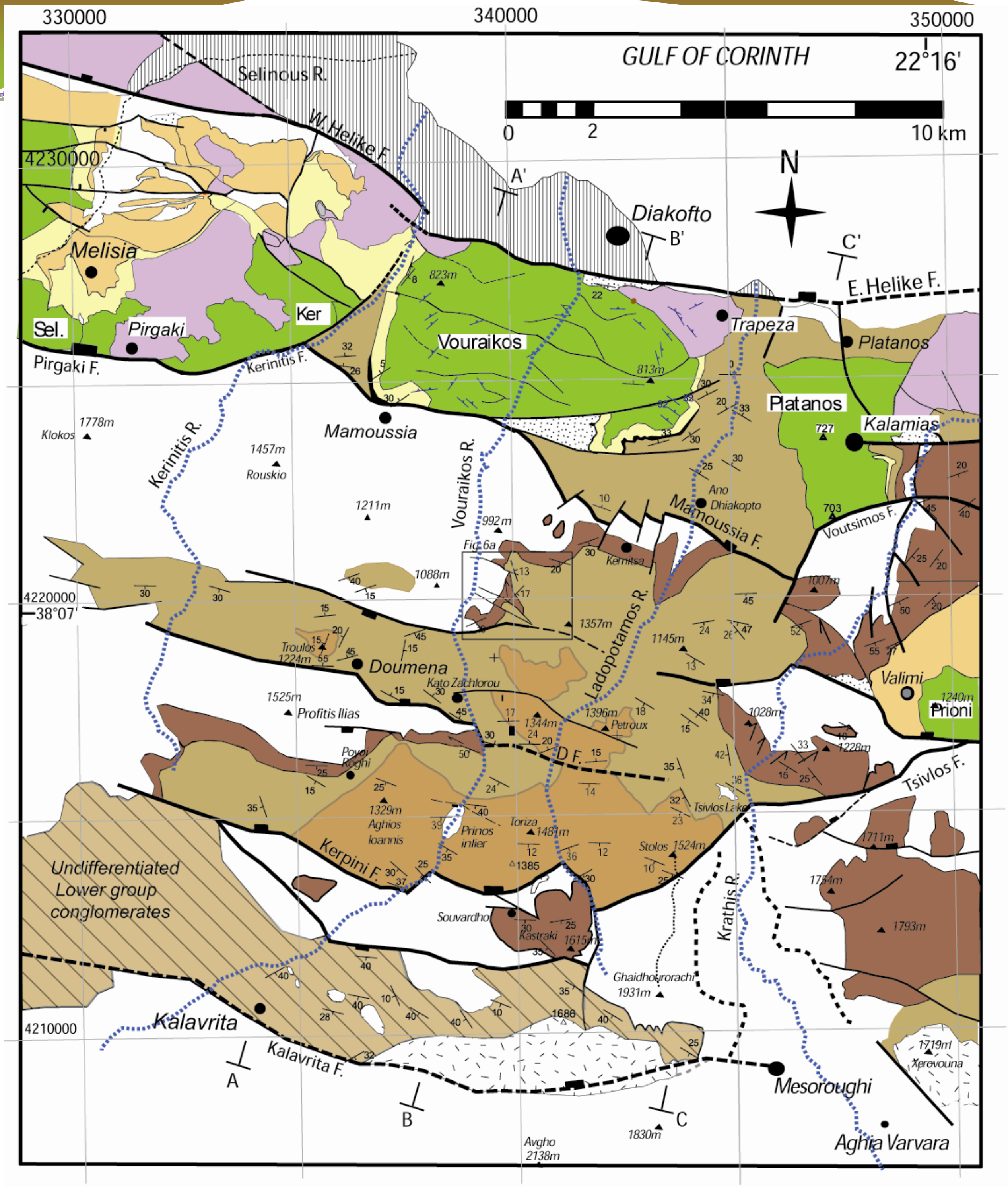
Assuming rifting began around 4 Ma, average extension rate =2.75 mm/a.

Present-day extension rate in the western gulf =16 mm/yr (Bernard et al. 2006) and 11 mm/yr in the eastern gulf (Briole et al. 2000).

If extrapolated back through 4 Myr rifting history, total extension would be 44 to 64 km.

Extension rate must therefore have accelerated significantly during rifting.

When and why did this acceleration occur?



Upper Group

- Present coarse conglomeratic Gilbert deltas
- Middle-Up Pleistocene Gilbert deltas
- Slope breccias

Unconformity

Middle Group

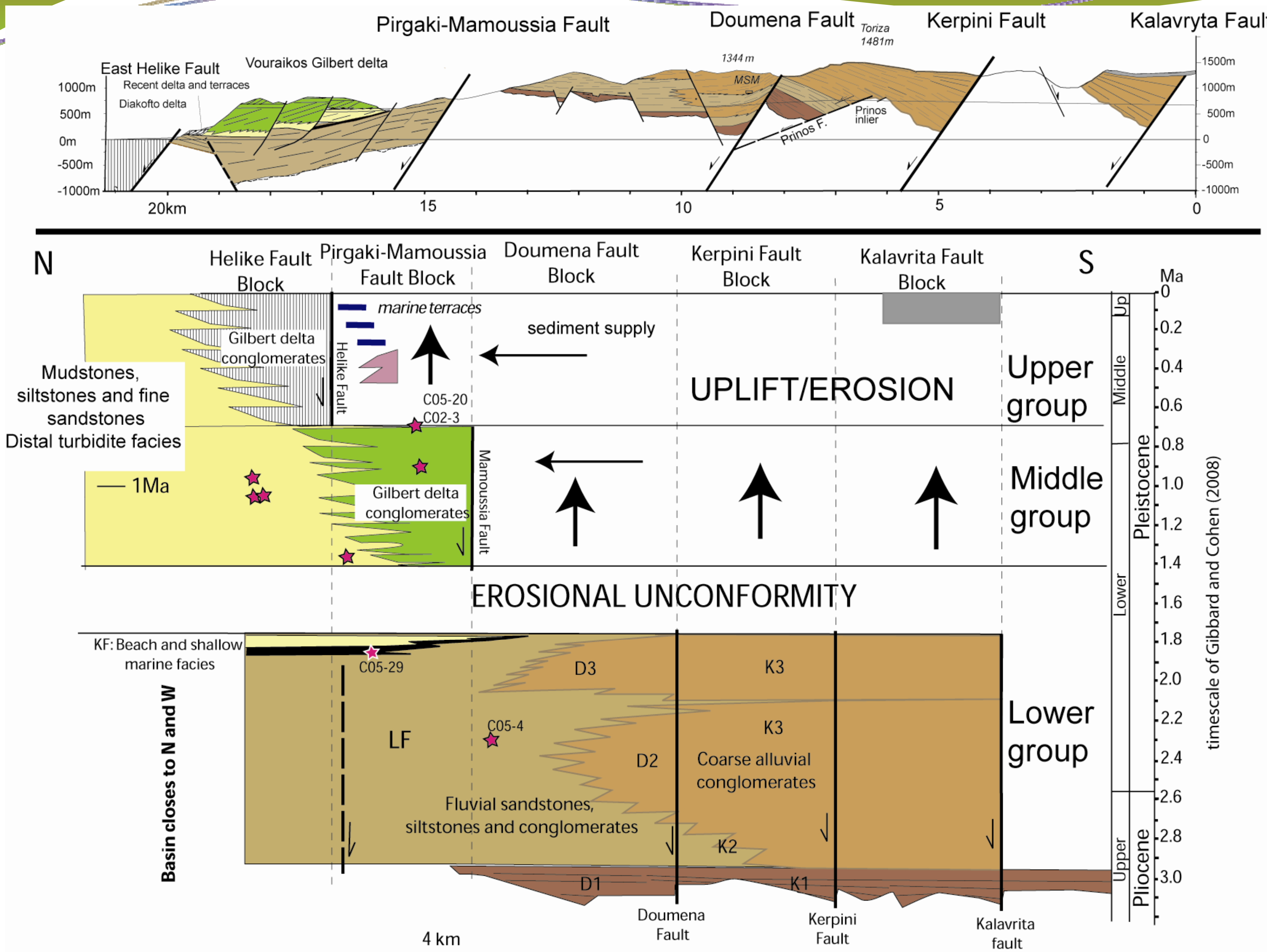
- Coarse Conglomeratic Gilbert Deltas
- Derveni Fm

Unconformity

Lower Group

- Derveni Fm
- Katafugion Fm
- Fluvio-deltaic sandstones and siltstones
- Fluvial sandstones and conglomerates
- Coarse alluvial conglomerates
- Basal conglomerates

- Pre-rift Pindos thrust sheet

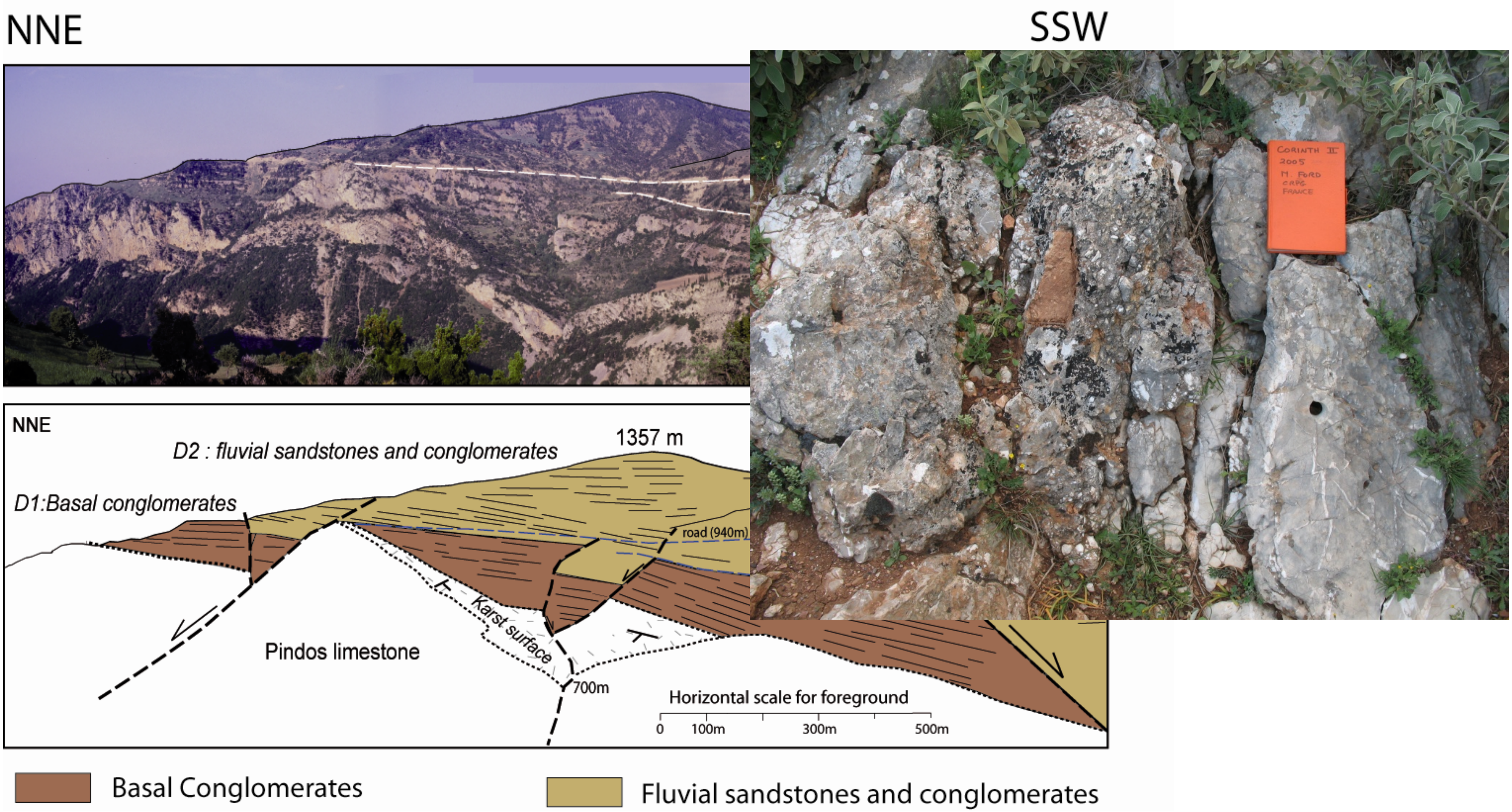


Pirgaki-Mamoussia Fault
Doumena Fault
Toriza 1481m
Kerpini Fault
Kalavryta Fault
East Helike Fault
Vouraikos Gilbert delta
Recent delta and terraces
Diakofto delta
1344 m
MSM
Prinos F.
Prinos inlier
1500m
1000m
500m
0m
-500m
-1000m
20km
15
10
5
0
N
S
Helike Fault Block
Pirgaki-Mamoussia Fault Block
Doumena Fault Block
Kerpini Fault Block
Kalavrita Fault Block
Ma
marine terraces
sediment supply
Gilbert delta conglomerates
Helike Fault
C05-20
C02-3
Mudstones, siltstones and fine sandstones
Distal turbidite facies
1Ma
UPLIFT/EROSION
Upper group
Middle group
Lower group
Mamoussia Fault
EROSIONAL UNCONFORMITY
KF: Beach and shallow marine facies
C05-29
D3
K3
LF
C05-4
D2
Coarse alluvial conglomerates
Fluvial sandstones, siltstones and conglomerates
K2
D1
K1
Basin closes to N and W
Doumena Fault
Kerpini Fault
Kalavrita fault
4 km
Up
Middle
Lower
Upper
Pleistocene
Pliocene
timescale of Gibbard and Cohen (2008)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0

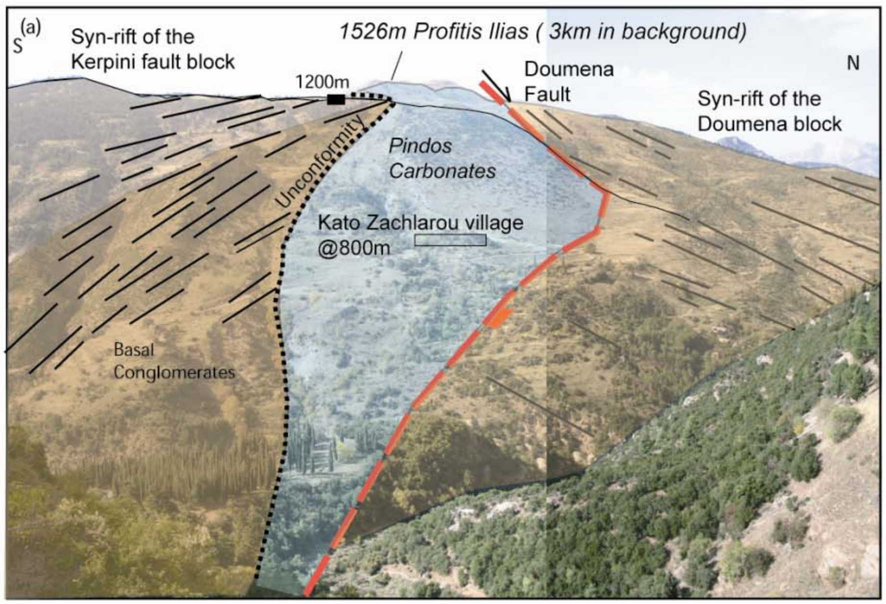
Basal unconformity: Inherited relief

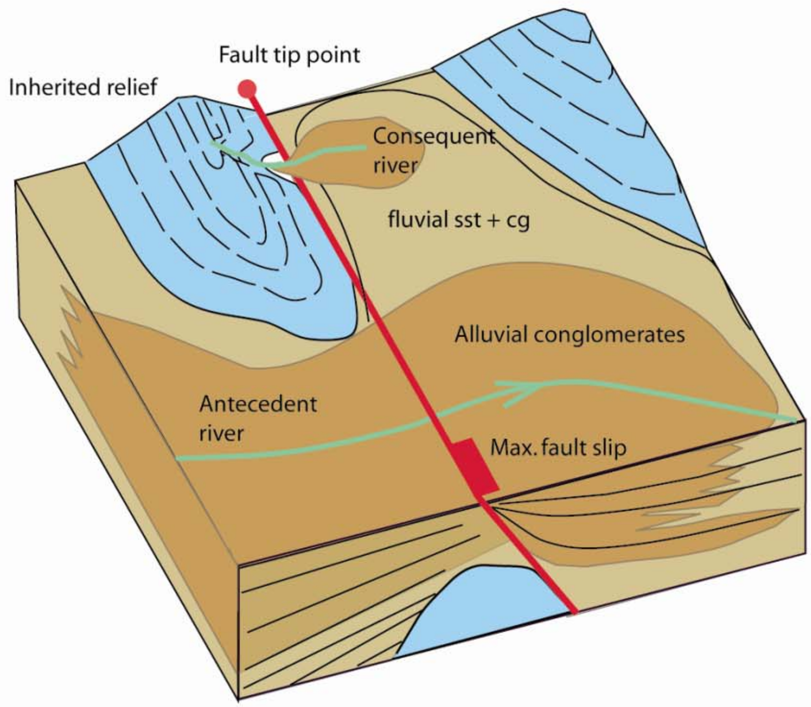
Lower group : Alluvial conglomerates and sandstones

Time gap of 15-20Ma since end of Hellenide orogen



Basal unconformity: Inherited relief





Paleorelief up to 800m on basal unconformity

Implications

(1) Footwall topography is NOT only related to fault displacement

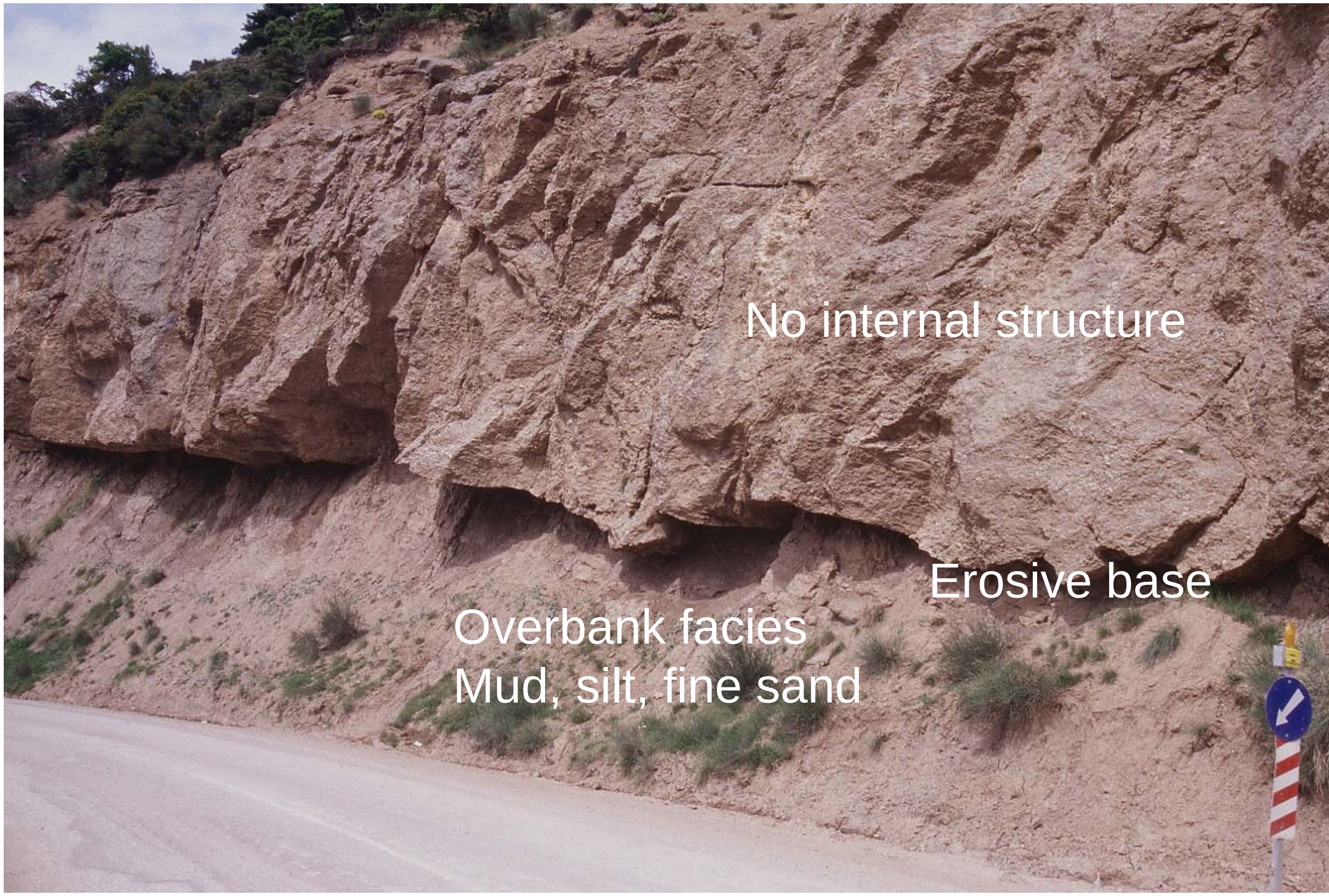
(2) Basal unconformity is NOT flat

(3) Fault displacement difficult to estimate

Amalgamated massive conglomerates

- Massive very thickly bedded, cobble, clast-supported conglomerates with little to no internal structure

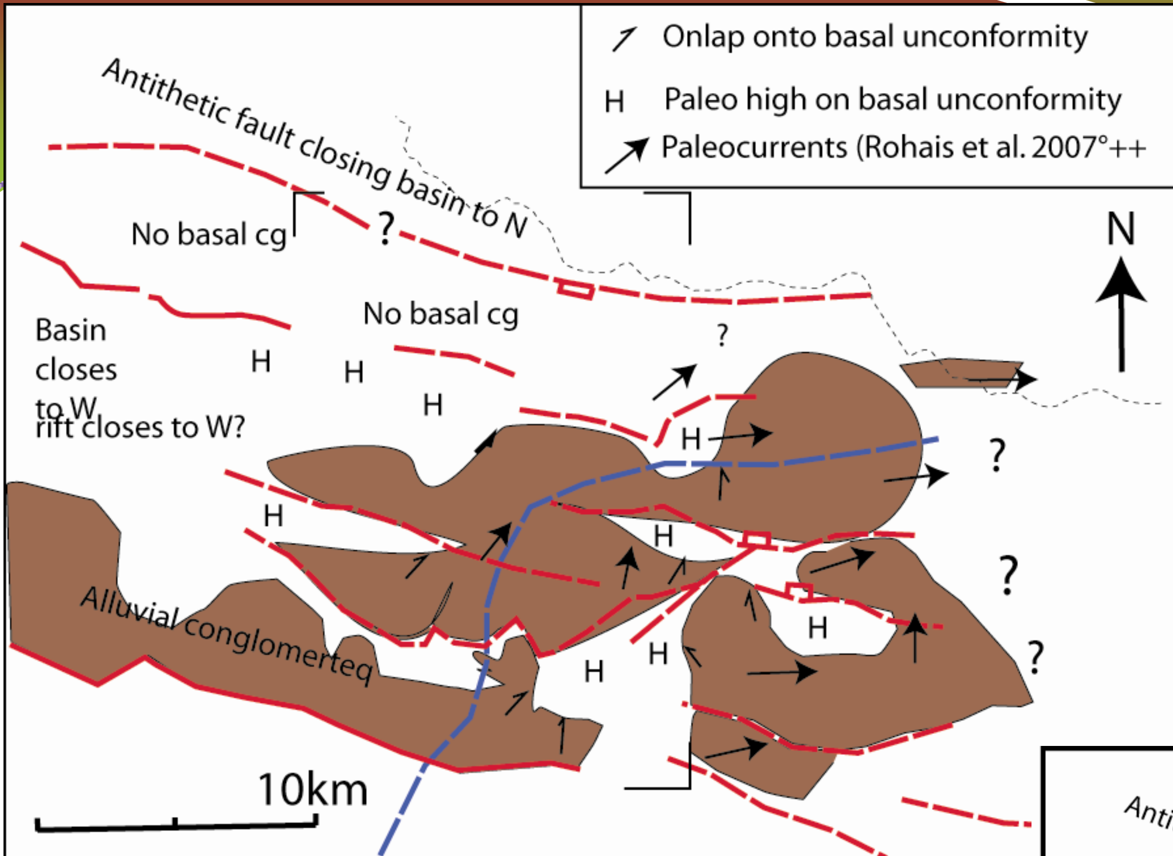
Gravely rivers and their floodplains



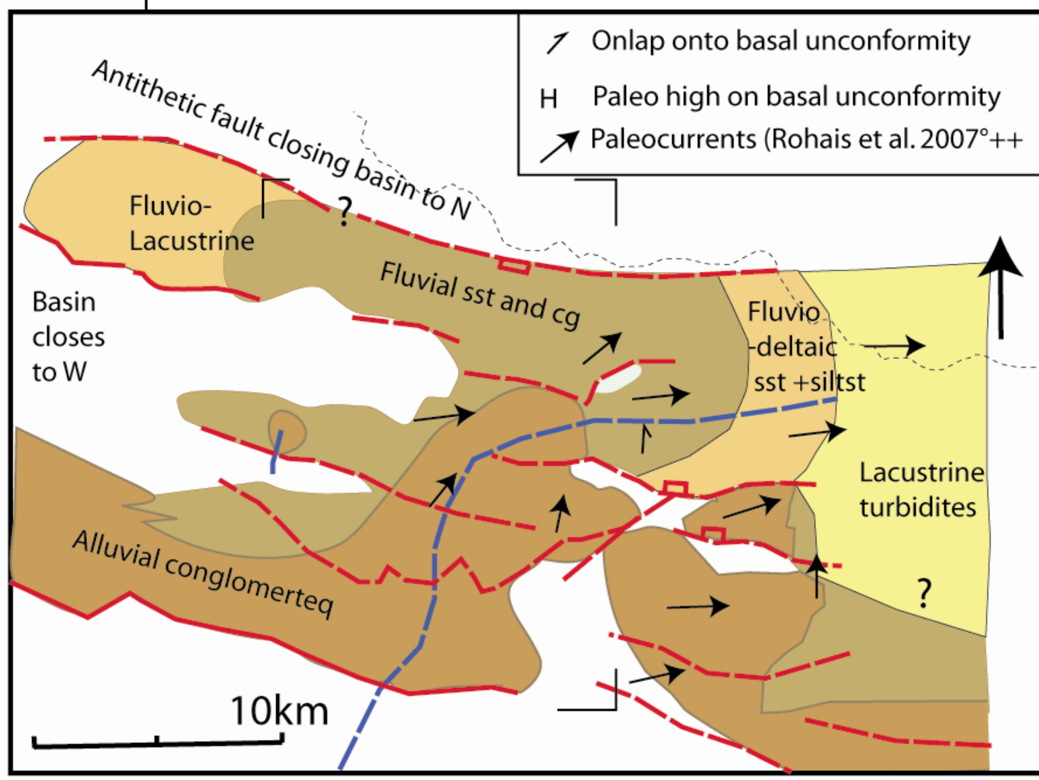
n=67

- Well developed orange-red siltstones, pebbly sandstones
- Tabular coarse conglomerate bodies several metres thick (up to 10 m), with internal bar-form surfaces
- Rare lignites and lacustrine fossils

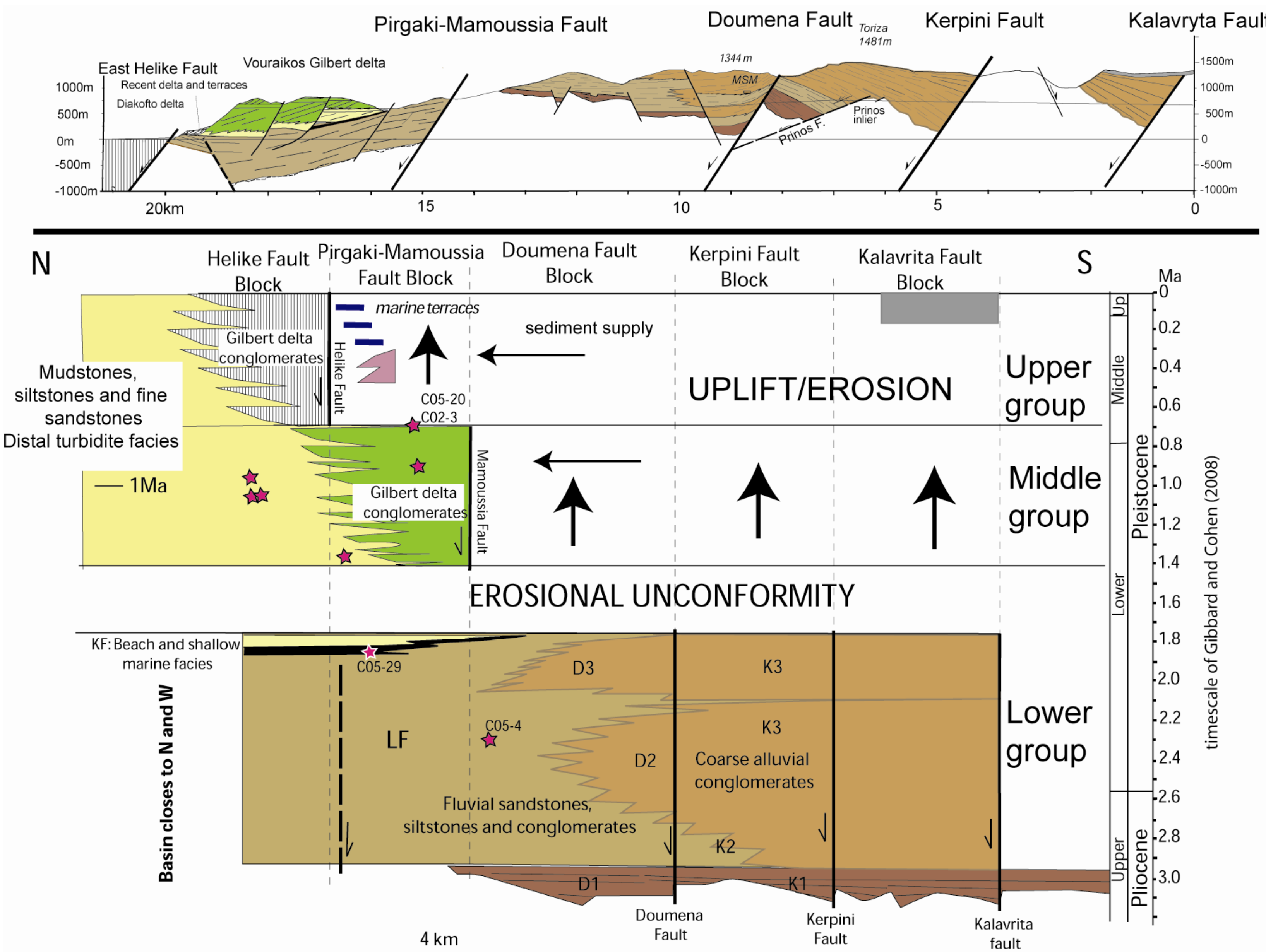
Basal conglomerates



Main Lower group alluvial systems



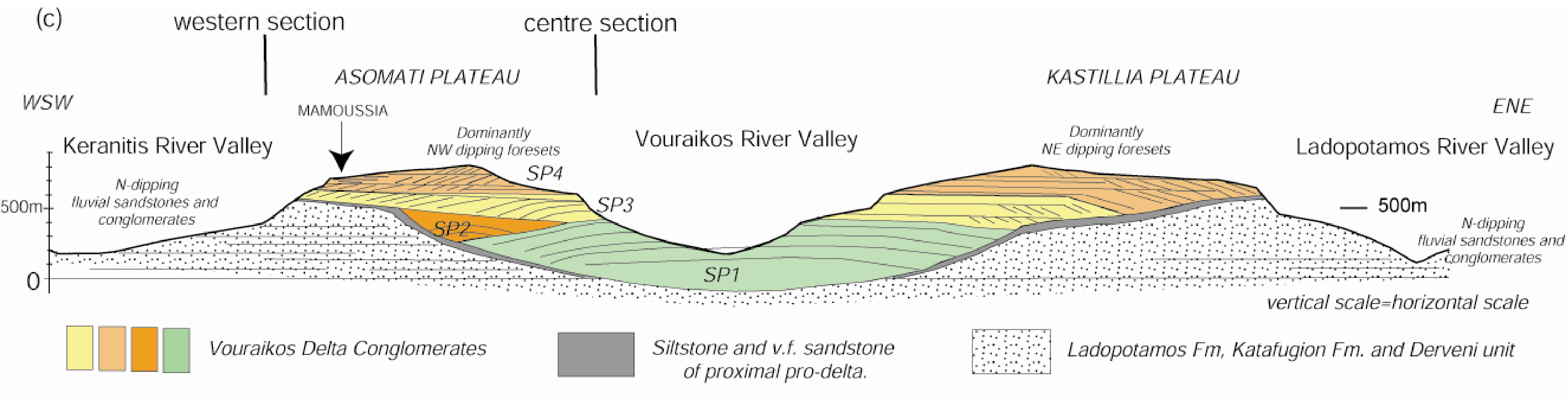
Middle Group: Lower to Middle Pleistocene, 1.4-0.7 Ma



Base Middle group: Major erosional event

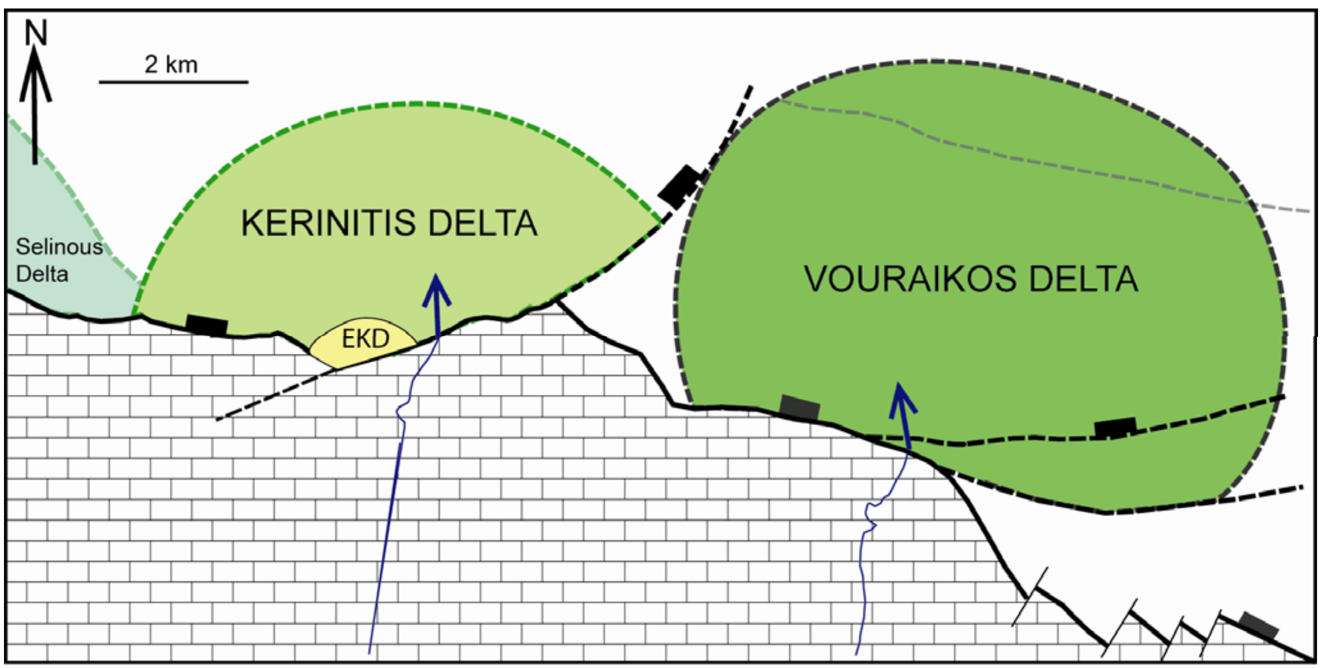
– deltas infill paleovalleys up to 300m deep

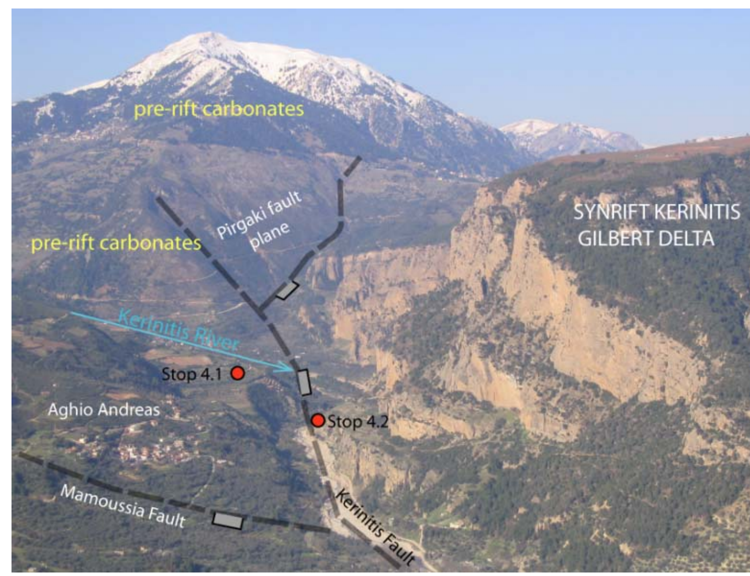
Vouraikos delta



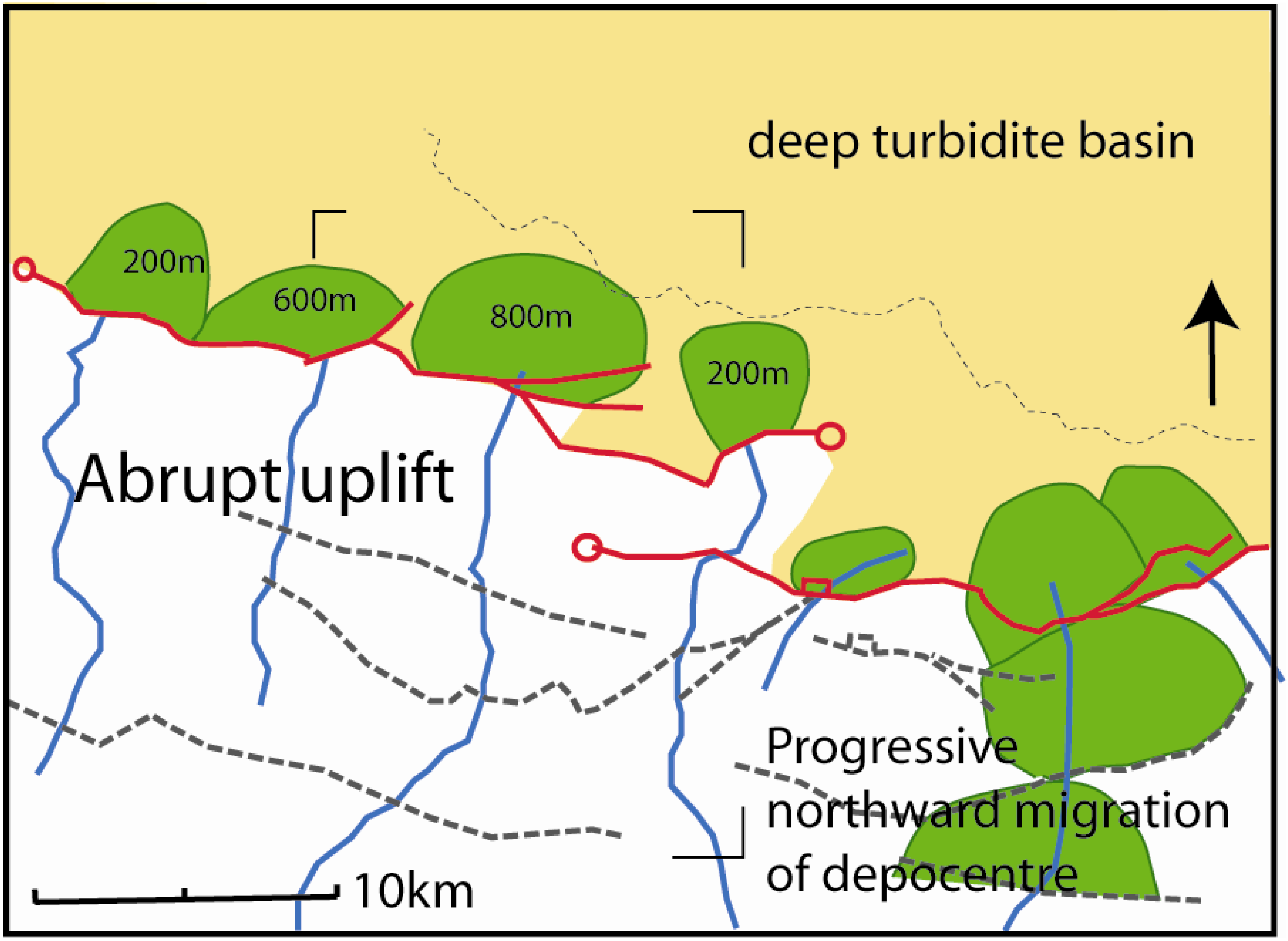
Middle Group

- Marine basin with giant Gilbert deltas sourced from the S.
- Rivers turn to flow north
- Sediment supply increases and subsidence increases
- Depocentre migrates north abruptly in W, gradually in E
- Extension rate increases to 4 mm/yr.

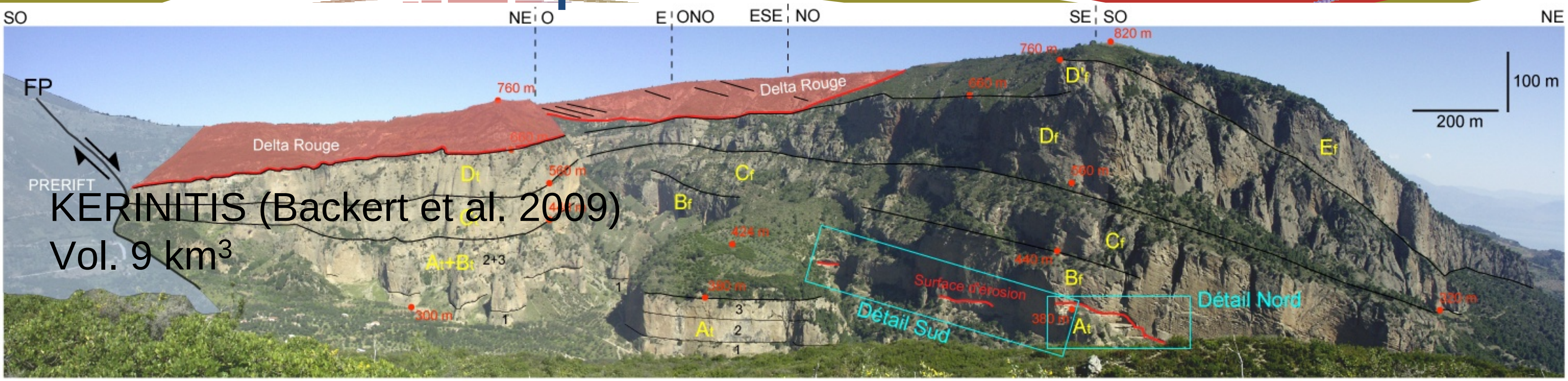




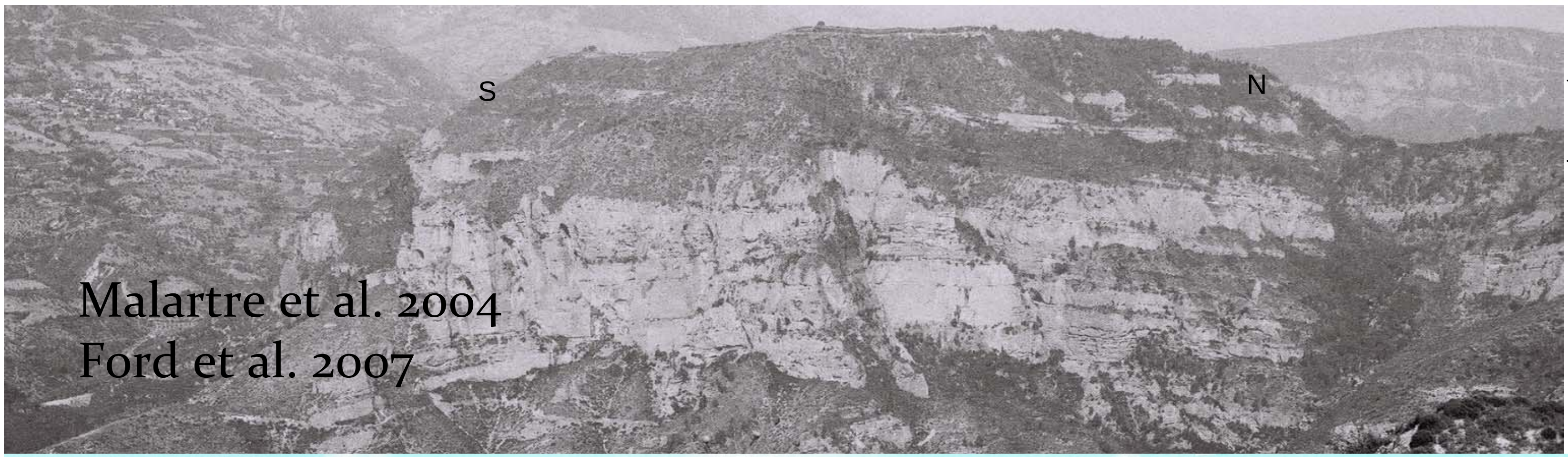
Middle group : paleogeogqphy



Middle Group: Giant Gilbert deltas

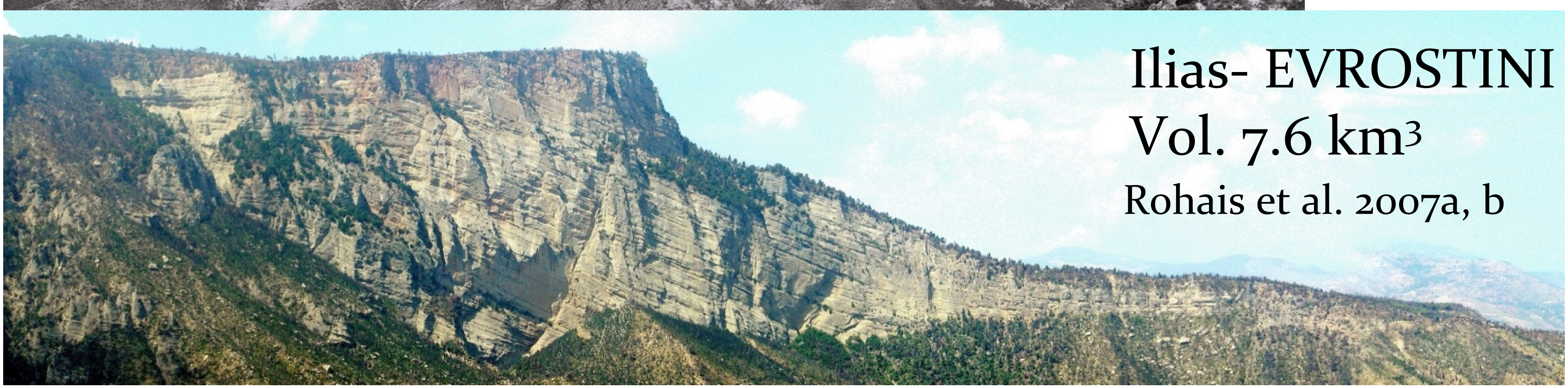


KERINITIS (Backert et al. 2009)
Vol. 9 km³



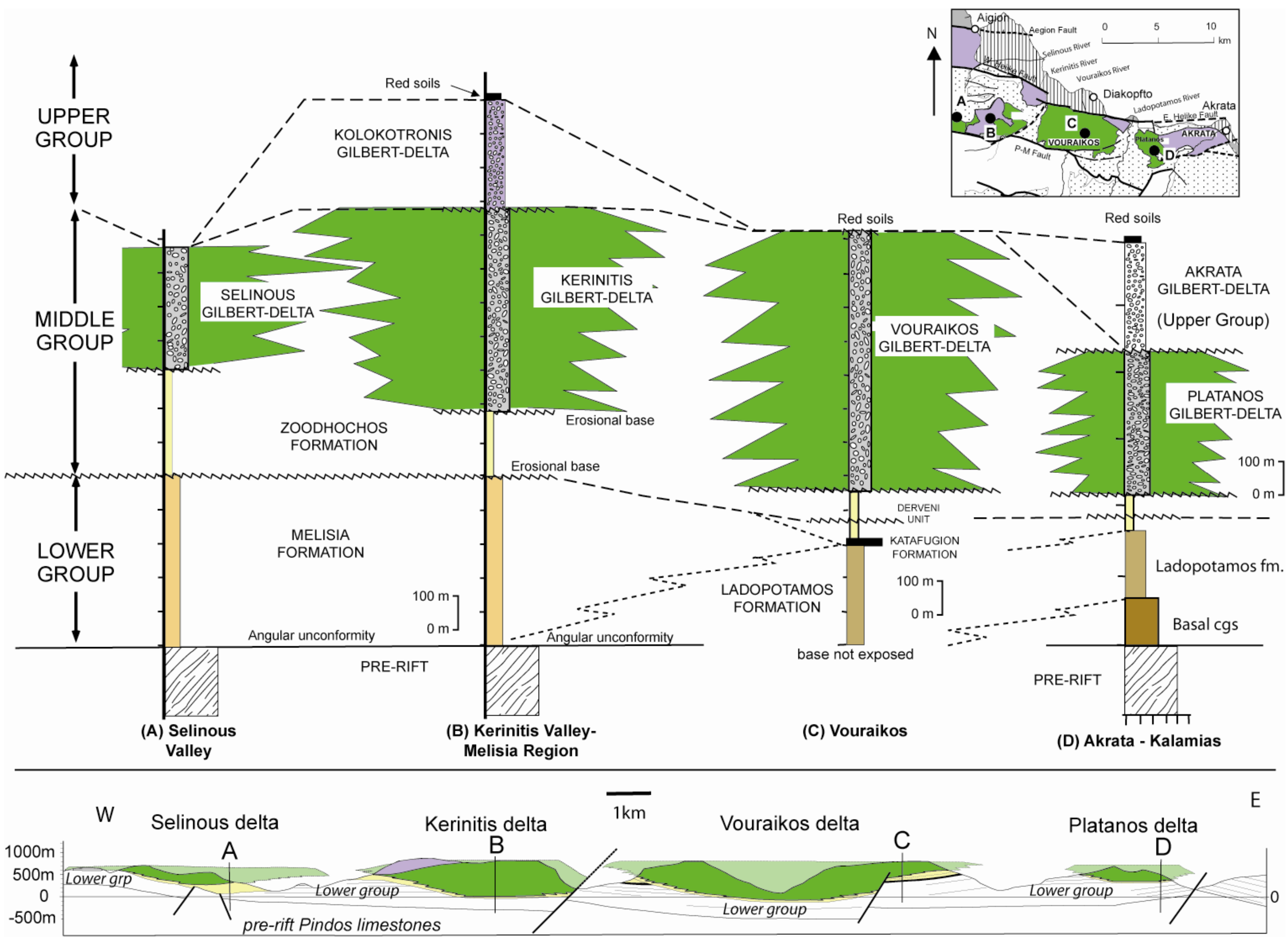
Malartre et al. 2004
Ford et al. 2007

VOURAIKOS
Vol. 12.6 km³



Ilias- EVROSTINI
Vol. 7.6 km³
Rohais et al. 2007a, b

Pirgaki-Mamoussia Fault block

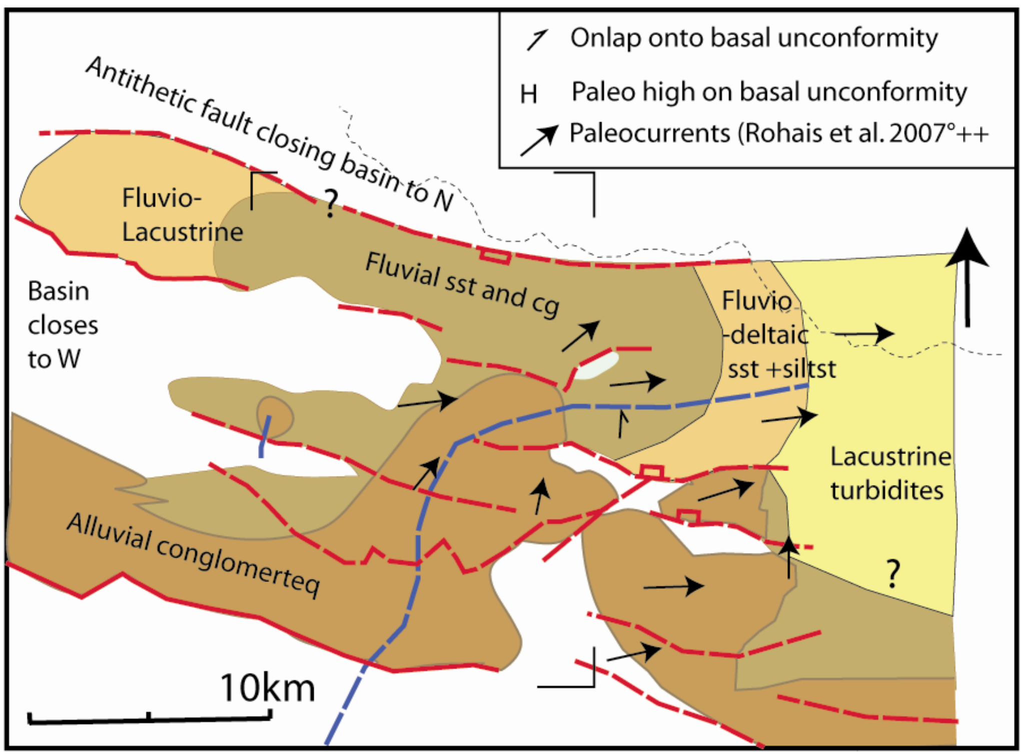


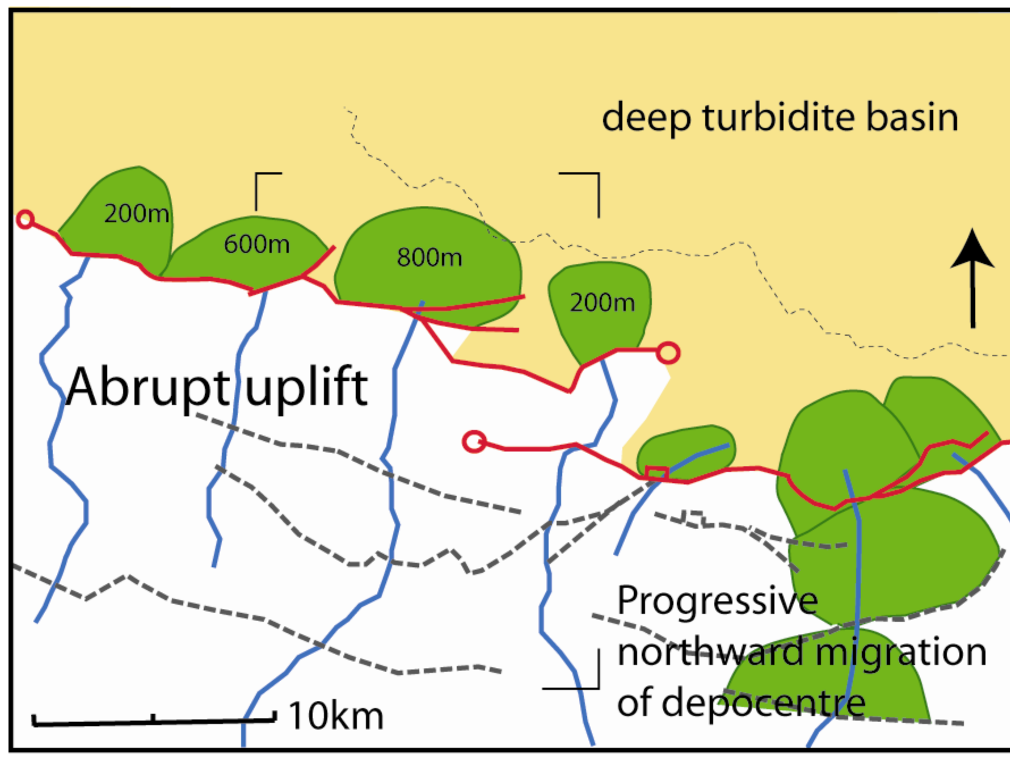
Summary of phase 1 and 2

Total N-S extension = 11 km = 3.8 km onshore + 7.2 km offshore

•**Lower group** :
•Pliocene-Early Pleistocene, 4 ? -1.4 Ma
•Alluvial-fluvial clastics up to 1.6 km thick, sourced from SW, fining to east.
•Extension 3.4-3.8 km.
•Extension rate 1.3-1.5 mm/a, **Slow**
• Dominated by high sediment supply

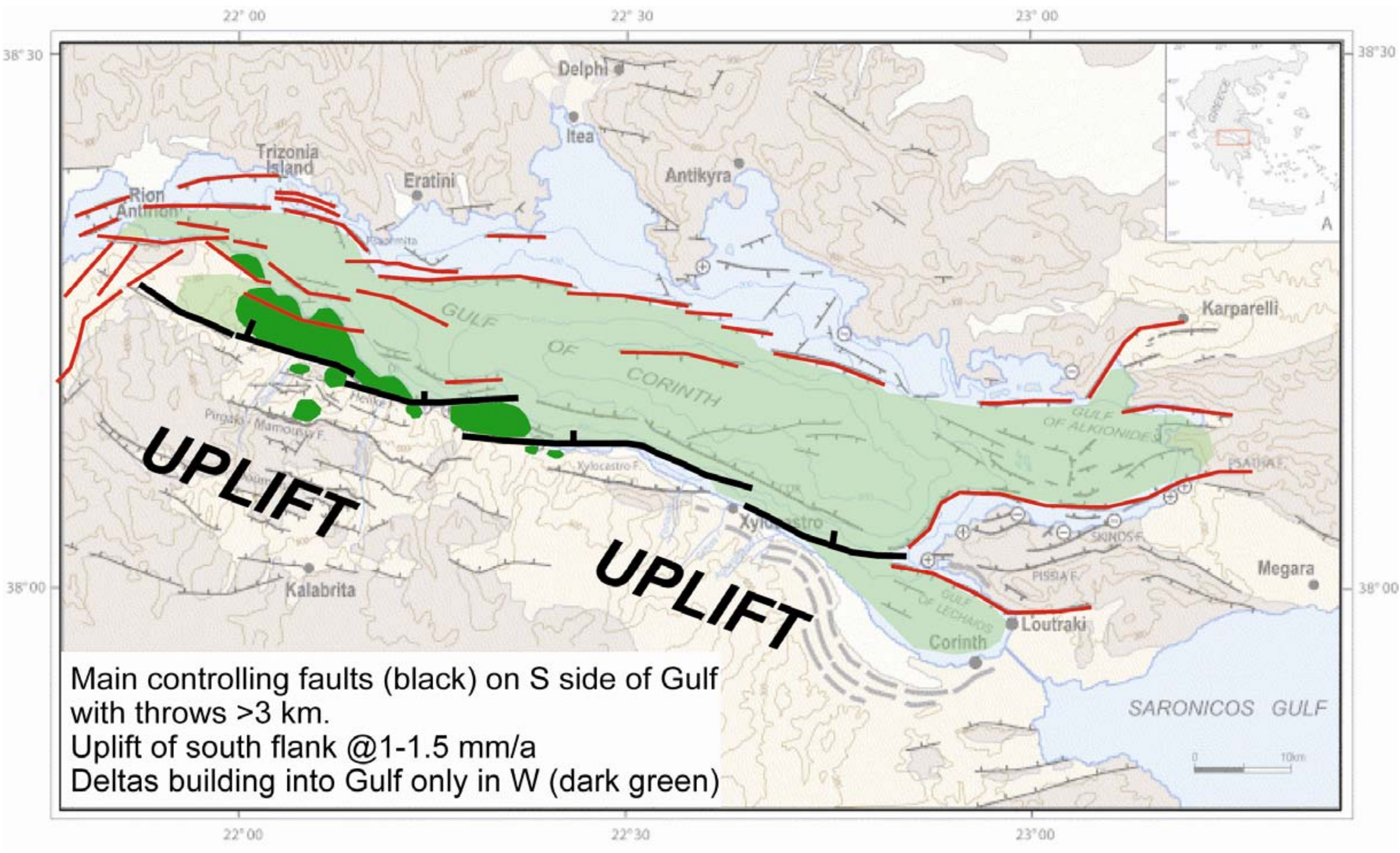
•**Middle group** :
•Early-Middle Pleistocene, 1.4 – 0.7 Ma
•Coarse giant Gilbert deltas up to 800 m thick, building north.
•Extension 3.2 km
•Extension rate 4 mm/a
• High accommodation+ high sed supply





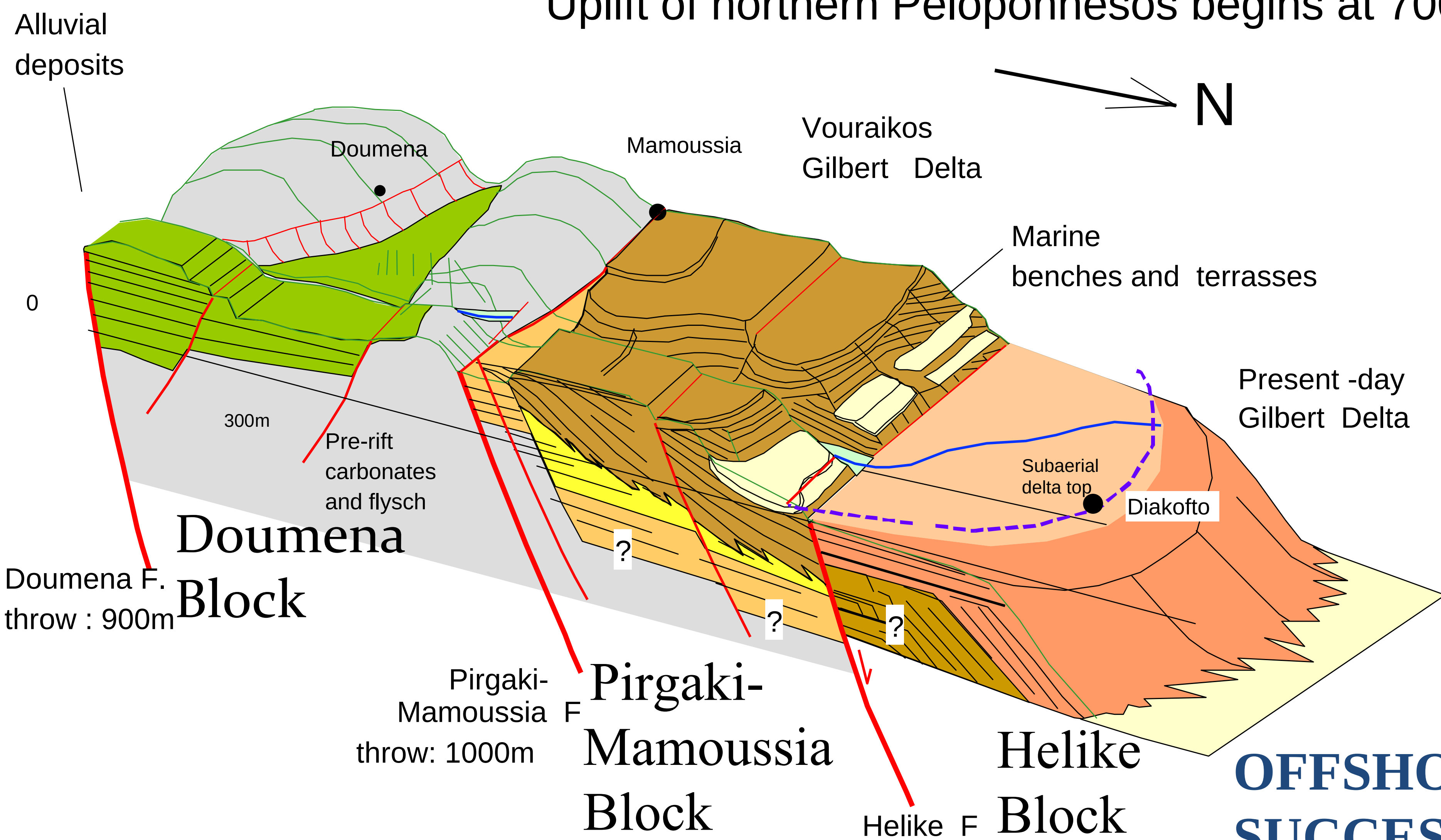
Phase 3: Upper Group: 700 ka - present

Rift narrows.
Gilbert deltas in west. Alternating lacustrine and marine turbidites offshore
Rapid uplift to south at rates of 1-1.5 mm/a
Rivers continue to flow N in western rift, but turned south in east
Extension accelerates and concentrates on a few large faults along south coast. 4.5 km of extension on the Helike Fault,
Average extension rate of 6.5 mm/a.



Upper group 700ka - present

Uplift of northern Peloponnesos begins at 700 Ka



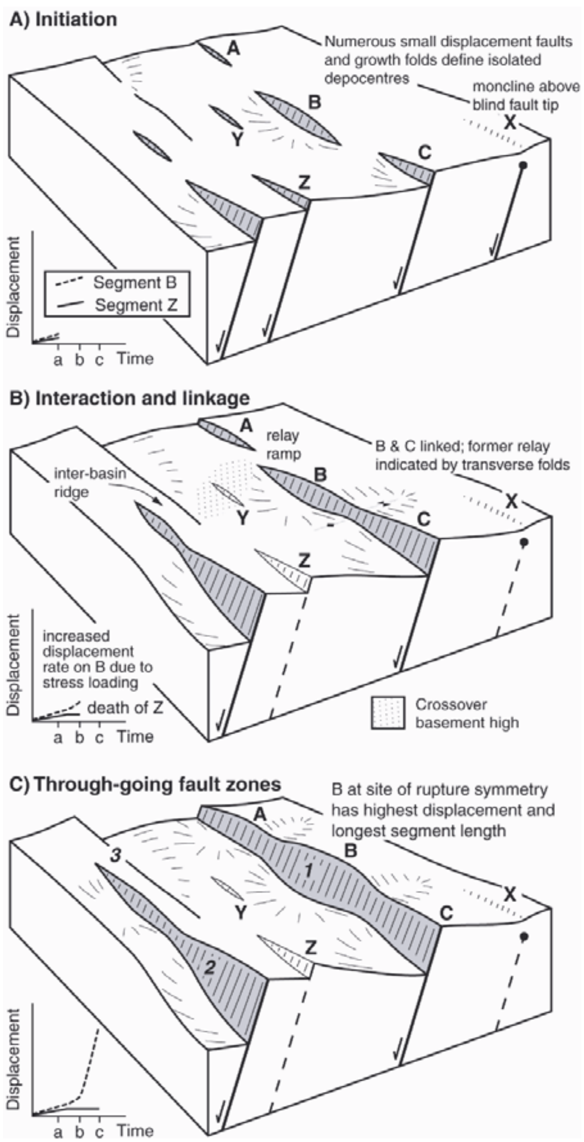
OFFSHORE SUCCESSION

Main Points

Antecedent conditions (relief and major rivers) imposed major controls on sediment supply, sediment routing pathways and depocentre distribution during early rifting

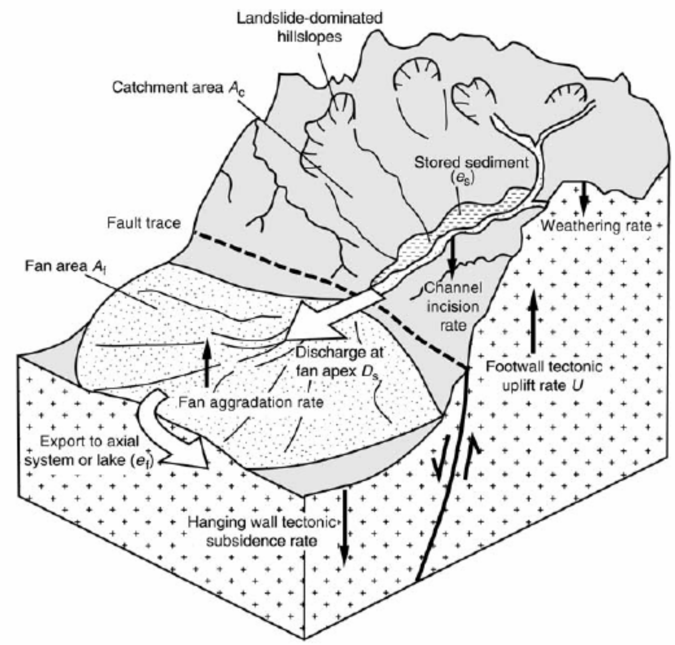
- Main sediment source to the SW – main control on facies distribution in rift.
- High supply of coarse sediments by antecedent rivers overwhelmed early faults
- Same rivers continued to supply western rift and kept pace with uplift (due to their coarse bedload? Cowie et al. 2008)
-

Assumptions in Standard Models for rift evolution and fault growth and linkage



Gawthorpe and Leeder 2000

Flat initial relief



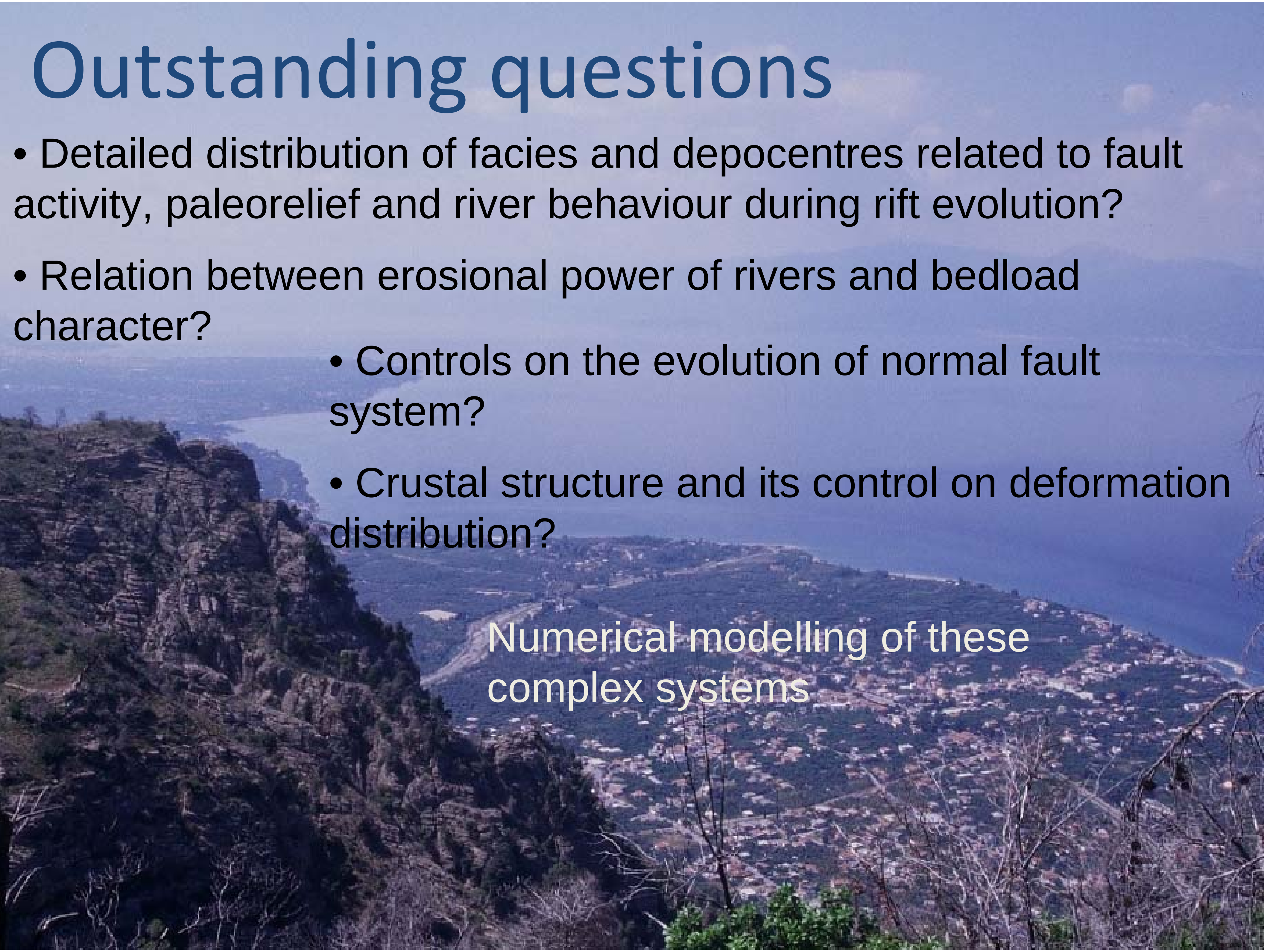
Consequent drainage generated during footwall uplift (e.g. Allen 2008)

However, antecedent conditions can be more complex………

Main Points: Rifting

- Three phases of accelerating rifting
- Migrates north in two distinct stages in western rift but more gradually in east
- Deformation distributed on many faults in earliest phase
- Deformation concentrates on fewer and larger faults with time
- Rate of extension increases through time **but especially since 0.7 Ma**

Outstanding questions



• Detailed distribution of facies and depocentres related to fault activity, paleorelief and river behaviour during rift evolution?

• Relation between erosional power of rivers and bedload character?

• Controls on the evolution of normal fault system?

• Crustal structure and its control on deformation distribution?

Numerical modelling of these complex systems