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How plate tectonics is recorded in Chalk deposits along the eastern English Channel in Normandy (France) and Sussex (UK)

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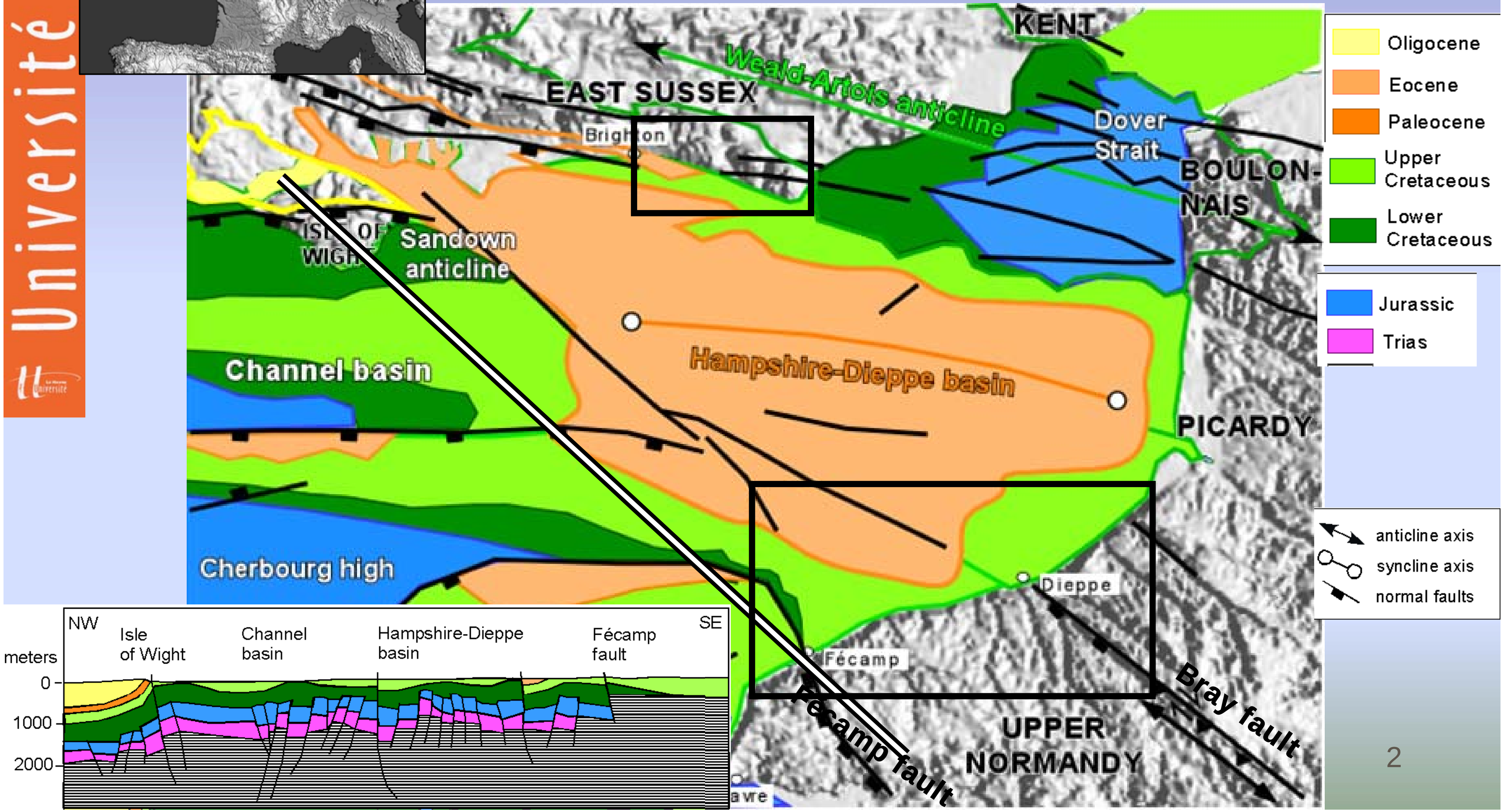
The Eastern Channel simplified geology



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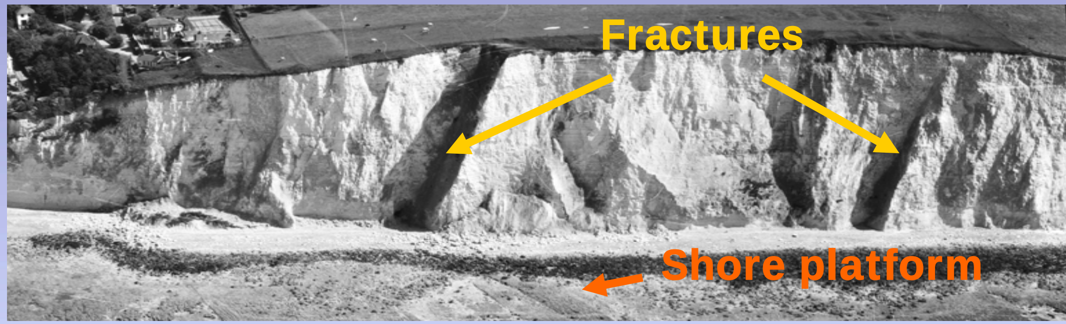
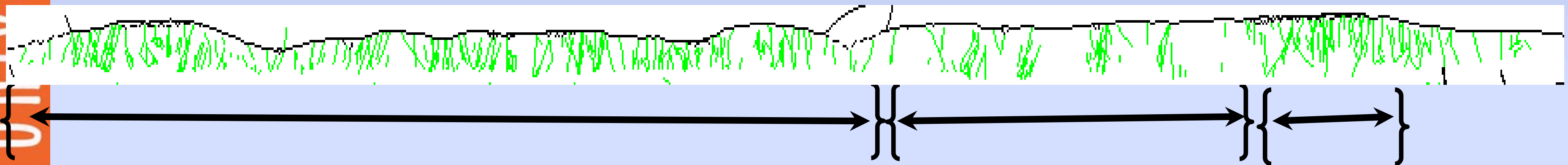
Spatial analysis of meso-scale fractures on cliff face

- Oblic aerial photographs

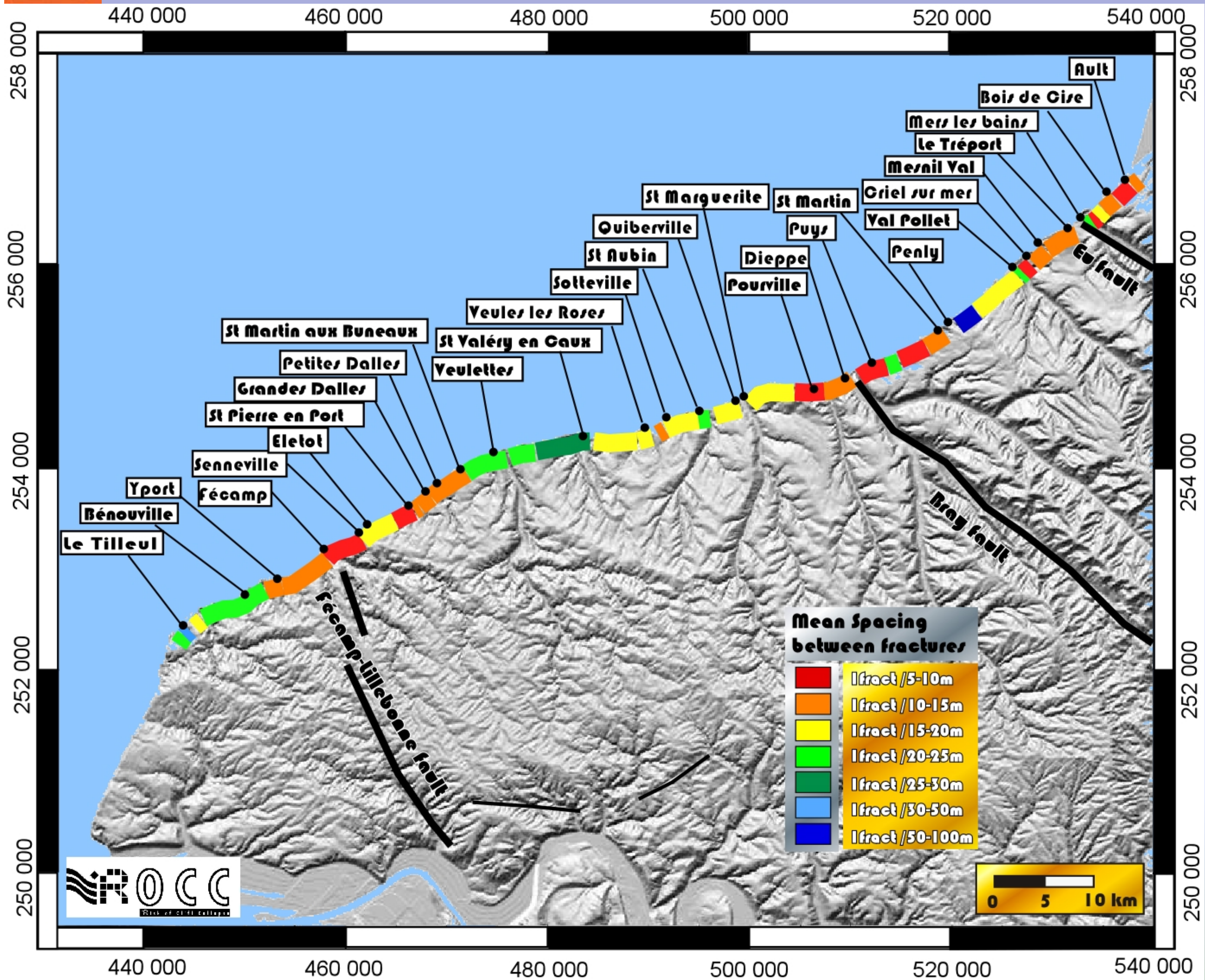




	Sector N	Sector N+1	N+2
Linear fracture density (fract./m)	d=0.094	d=0.059	d=0.137
Mean spacing between fractures (m)	sp=10.6	sp=14	sp=7

- Division into sectors by visual estimation
- Numbering per sector with Mapinfo software (GIS)

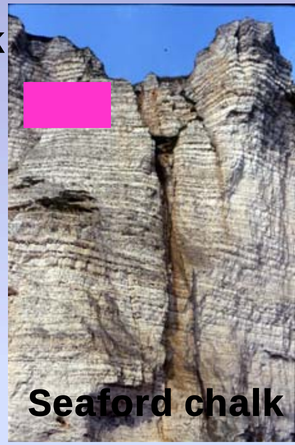
Meso-scale fracture density in Normandy



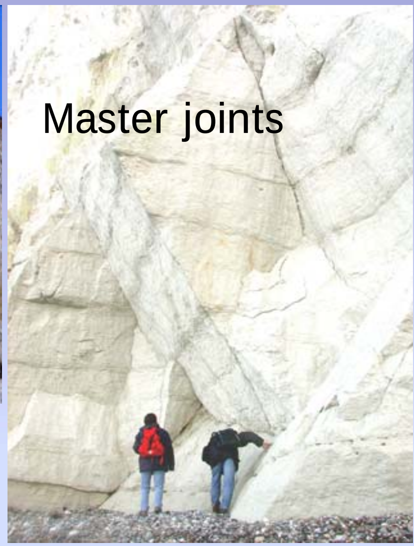
- Sectors of apparent fracture density on the chalk cliffs
- Low fracturation degree in Normandy
  - Higher degree
    - 1 fract/5-10m
- High fracture degree sectors are located near large-scale fracture

Anglo-Paris basin Chalk lithostratigraphy concept

Stage	Members	Local unit	Key markers
Campanian	Culver Chalk Fm		
	Newhaven Chalk Fm		Meeching marl
			Peacehaven marl
			Old Nore marl
			Friar's bay marl
			Buckle marl
Santonian	Seaford Chalk Fm	Fécamp para-moudra	Whitaker's three inch
			Bedwell's columnar flint
			Cuckmere beds
Coniacian			BelleTout beds
			Seven sisters flint
	Lewes Chalk Fm		Shoreham marls
			Etretat HG
		Etretat chalk	Navigation marl
Turonian			Lewes marl
			Chalk rock HG
			Mers HG
			Southerham Marl
			Glynde Marl
	New Pit Chalk Fm		New Pit marl
			3 Tilleul HG
	Holywell Chalk Fm		Antifer Hardground
			Plenus marl-Antifer HG
Cenomanian	craie de Rouen		



Meso-scale Fracture type on the chalk cliffs



- Fracture type
  - Normal fault (mode II)
    - with offsets varying from a few cm to 1 m
  - Shear fault (Mode III)
  - Master joint (mode I)
    - Length varying from 10 to 100m
  - Joints (mode I)
    - A few meters in length

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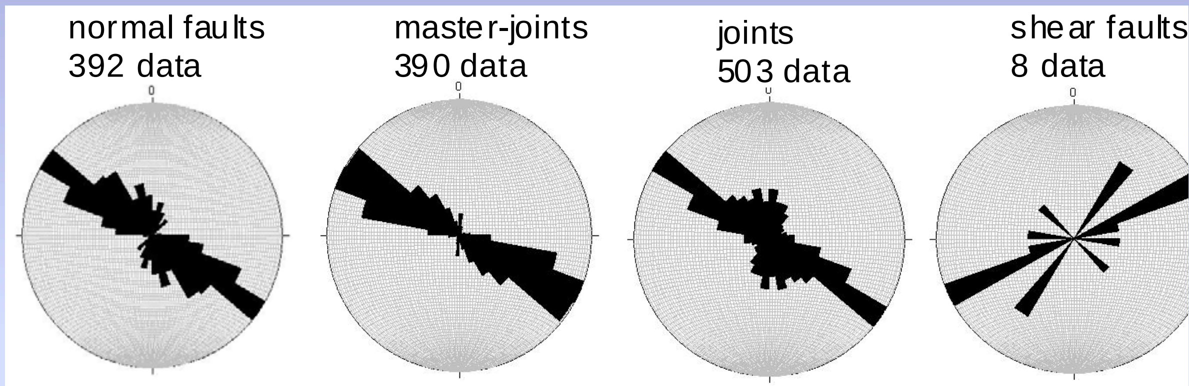
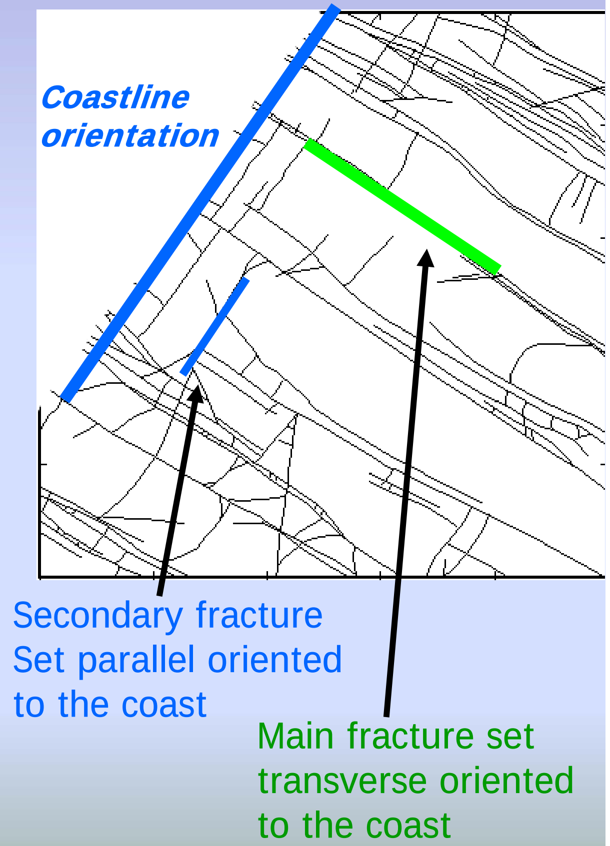
Meso-scale fracture azimuts in Normandy

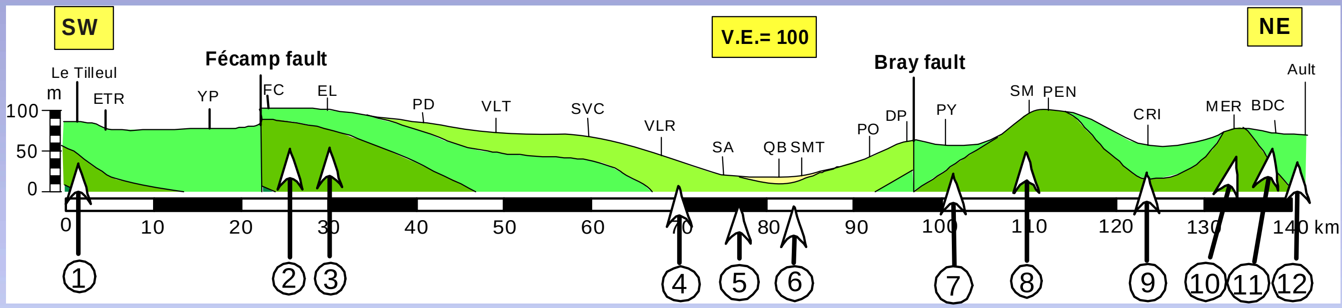


- 24 studied sites
- 1296 fracture data
- The most common azimut is N120 (NW-SE)
- 68 faults with slickenslides were treated using Angelier's inversion method
- Paleostresses are correlated with chalk units datations using the chalk lithostratigraphy concept

Ladder fracture Pattern (plan view)



Paleo-state of stresses in Normandy



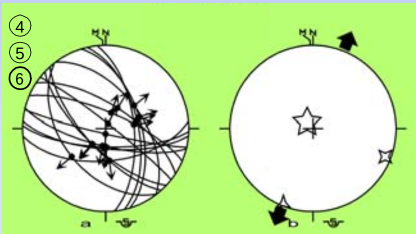
Stratigraphy

- Campanien (75-84 Ma)
- Santonien (84-86 Ma)
- Coniacien (86-89 Ma)
- Turonien (89-94 Ma)
- Cénomanien (94-99 Ma)

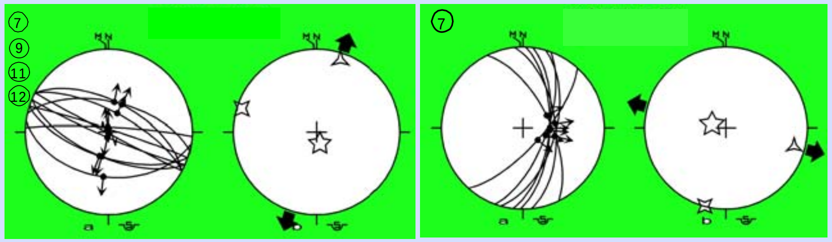
Chronology

- Phase I : extension NE-SW (Turonian)
- Phase II : extension WNW-ESE (Turo-Coniacian)
- Phase III : extension NNE-SSW (Turonian-Campanian)

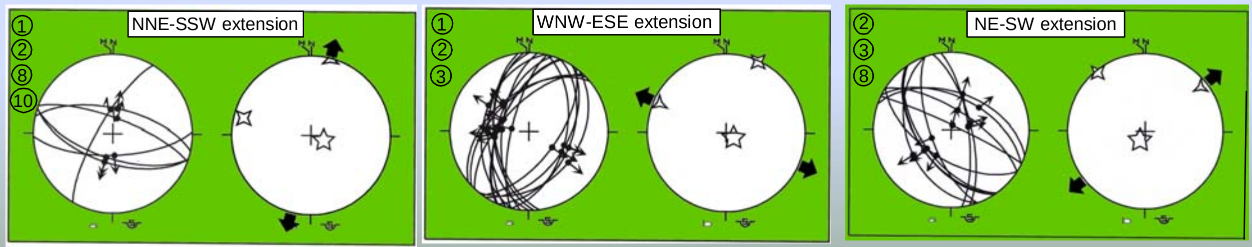
Santonian



Turo-Coniacian



Turonian



Phase III Phase II Phase I

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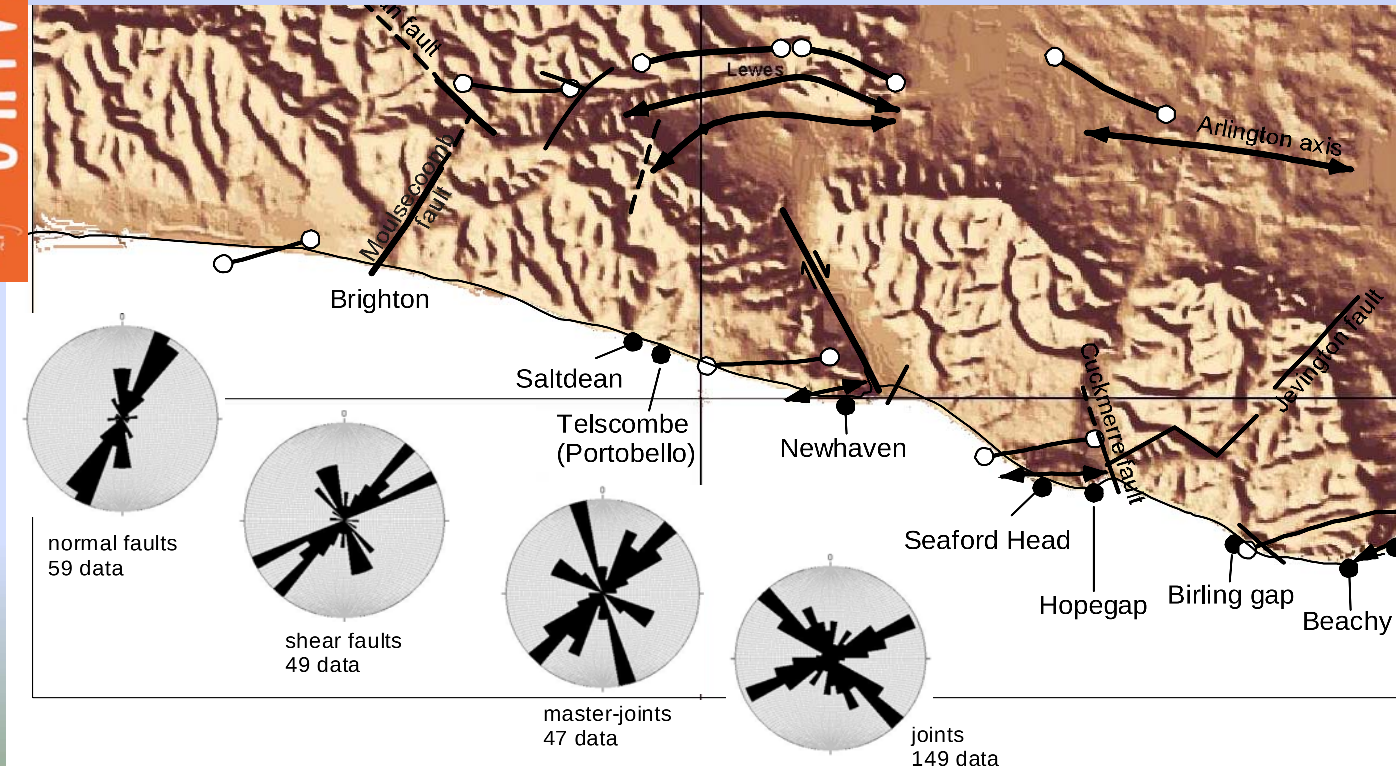
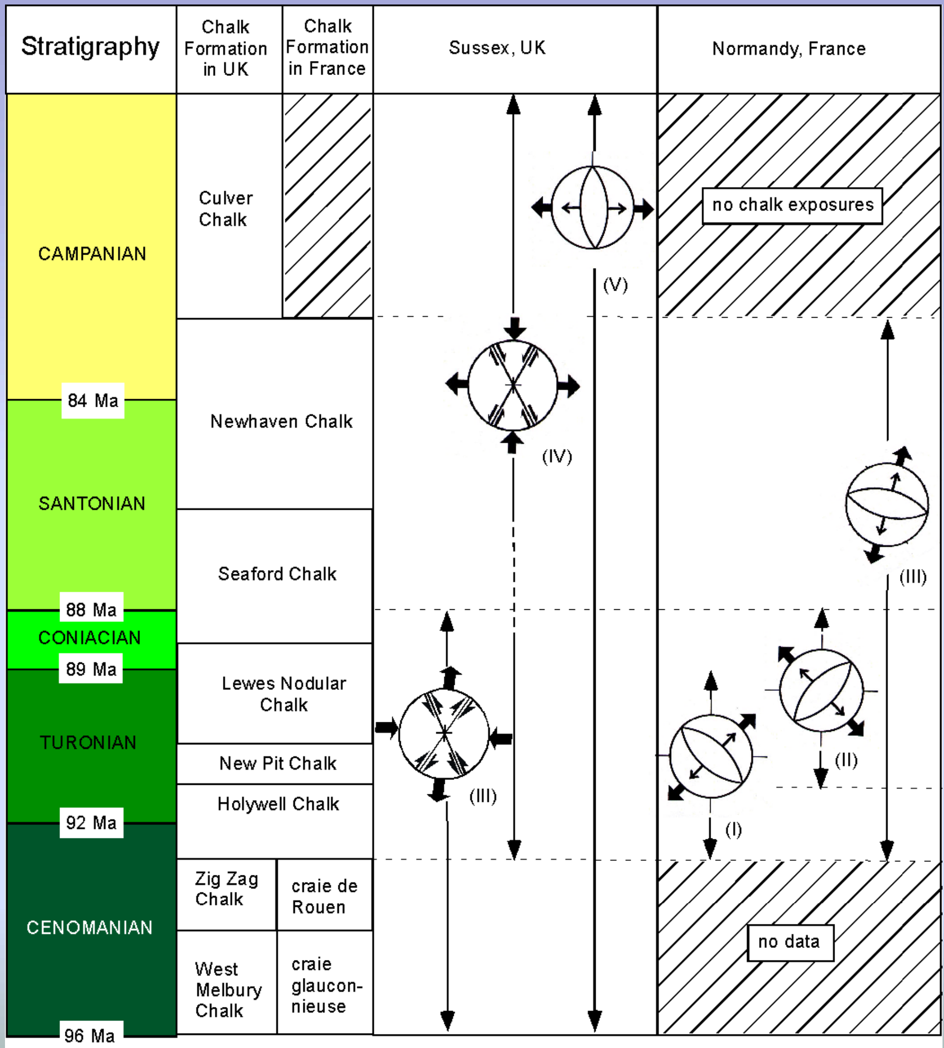
Meso-scale fractures, East Sussex, UK

- 12 studied sites
- 304 fracture data
- 43 fractures with slickenslides were treated using Angelier’s method
- The most common azimuts are N30 (NF), N50/N170 (SS) and N150
- Numerous conjugate fault systems



Paleo-stresses recorded in the Chalk of NW Europe



Chronology

- Phase I : NE-SW extension
- Phase II : NW-SE extension
- Phase III :
  - NNE-SSW extension / ESE-WNW compression
- Phase IV :
  - N-S compression/E-W extension
- Phase V : E-W extension

Normandy (France)

- Successive extensive brittle tectonics recorded since Paleocene

In Sussex (UK)

- Younger compressive and extensive brittle tectonics recorded since Oligocene

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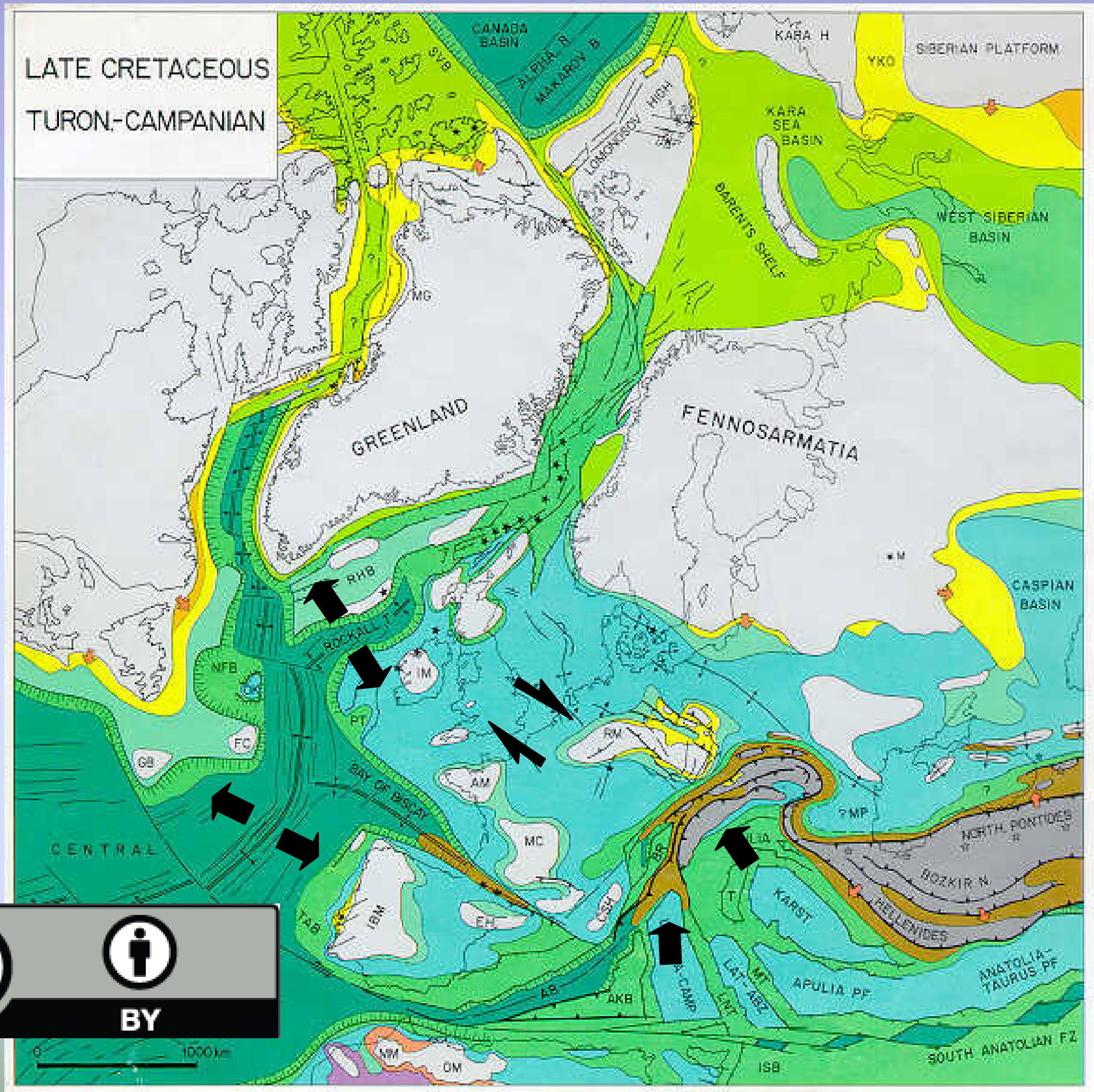
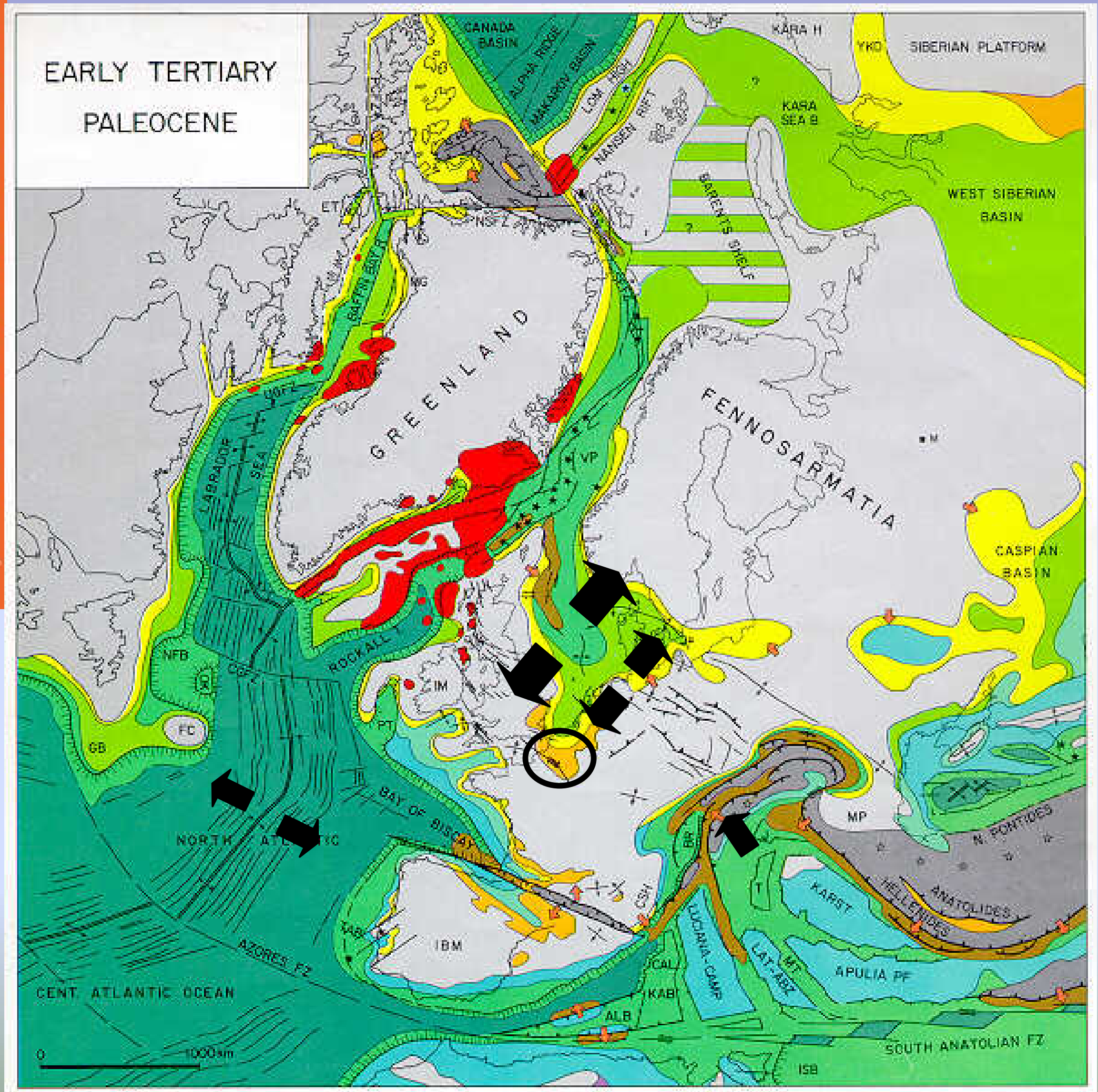
Paleogeography during Upper Cretaceous

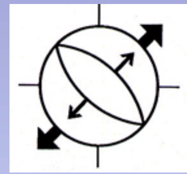


- **During the Chalk sedimentation**
- Atlantic opening
- Tethysian dynamics
- NW Europe appears as a relay zone, where compressional events periodically reactivated large-scale structures of the ante-Mesozoic basement

from Ziegler, 1989

Paleocene



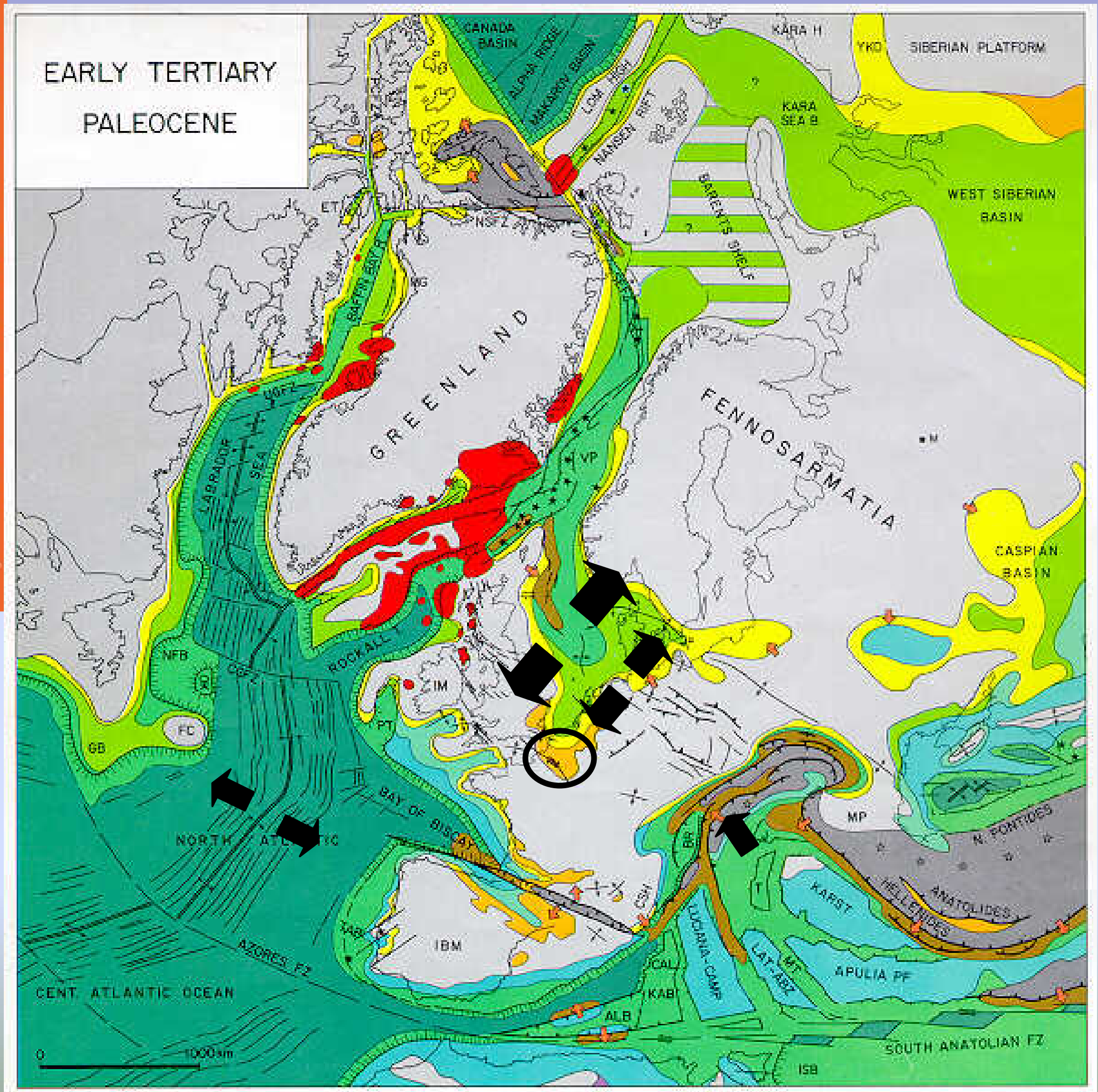


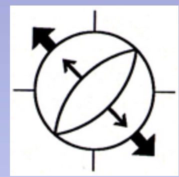
NE-SW extension

- **Phase I**
- Extension mainly recorded in Normandy
- The Southern North Sea and Lower Rhine grabens opening

from Ziegler, 1989

Paleocene



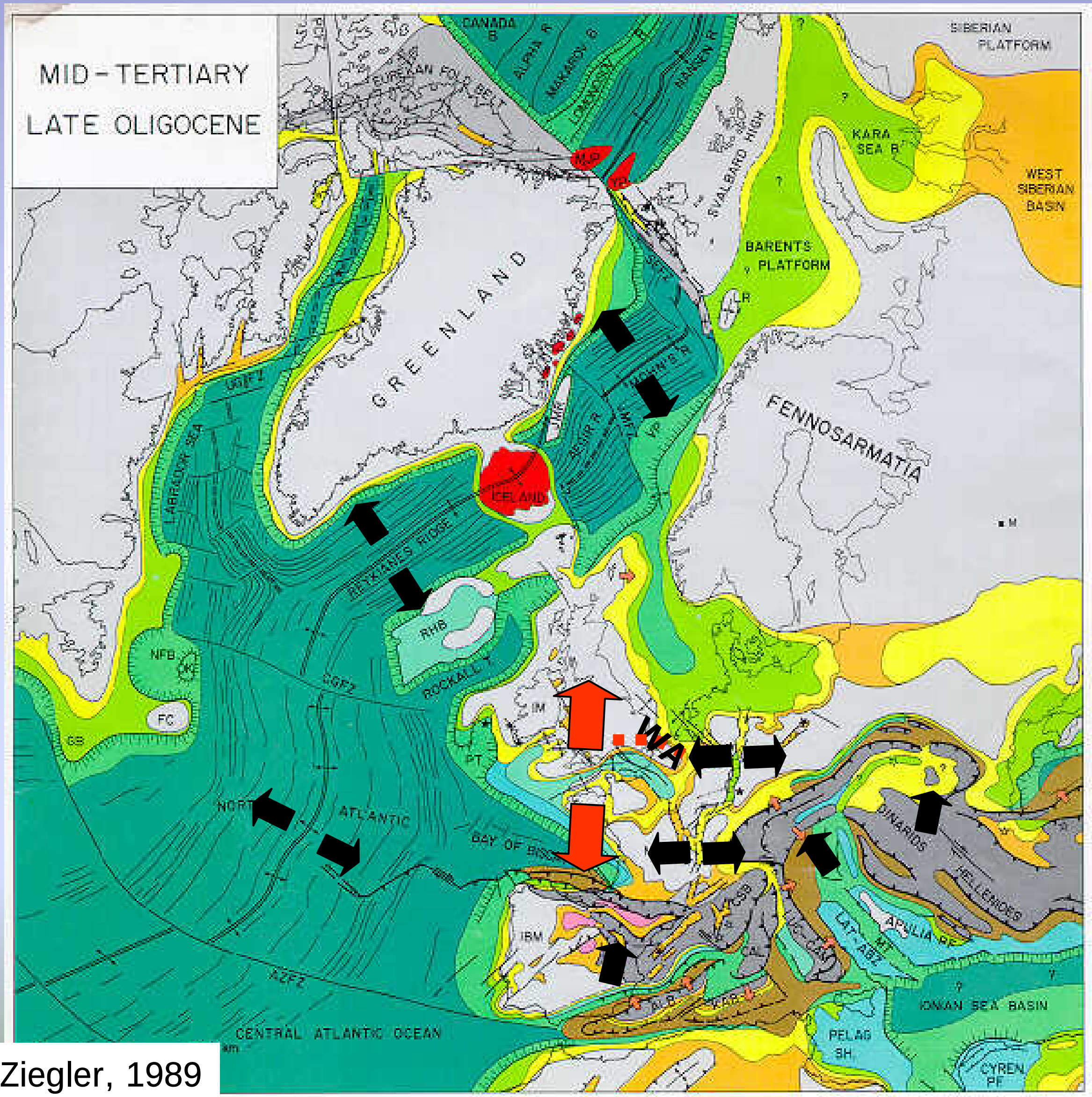


NW-SE extension

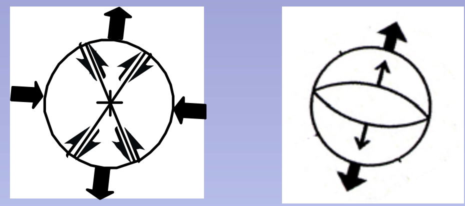
- **Phase II**
- Tensor axis inversion?
- Differential subsidence to the center of the Chalk basin (towards the SW) ?

from Ziegler, 1989

Late Oligocene



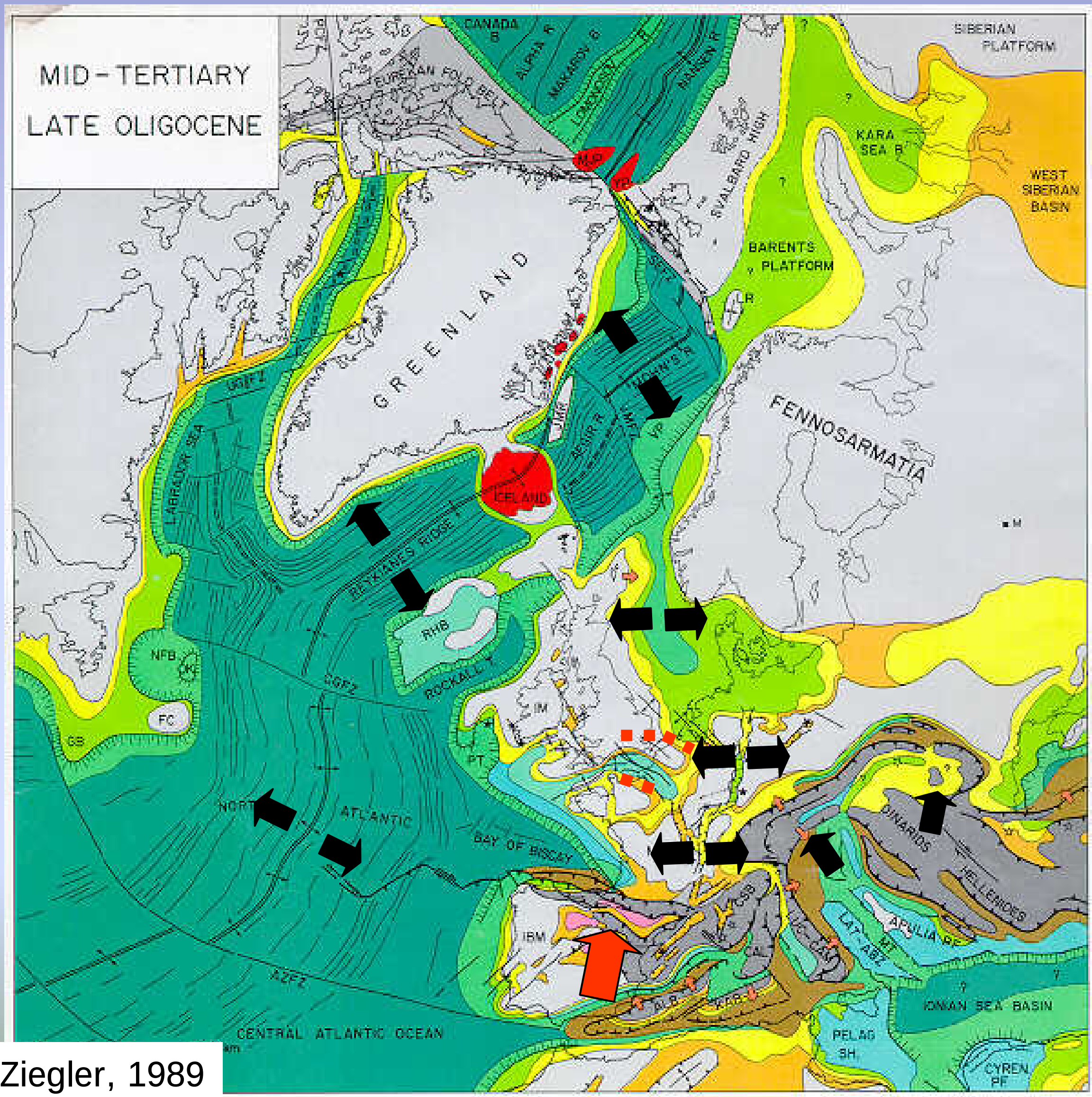
from Ziegler, 1989



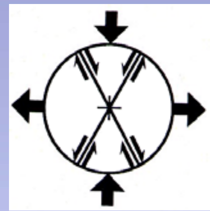
NNE-SSW extension

- **Phase III**
- Recorded in Normandy and Sussex
- Western approaches opening in the English Channel
- The Weald Artois axis uplift stopped the influence of Upper Rhine graben opening in Normandy basin and favoured stress propagation in Sussex

Late Oligocene



from Ziegler, 1989



N-S compression / E-W extension

- **Phase IV**
- N-S compression is recorded in Sussex
- also in the Chalk of the Isle of Wight
- Pulses of Pyrenean tectonics
- Amplified by large-scale folded structures (Weald- Artois anticline)
- not recorded in the Chalk basin (Normandy, Belgium)

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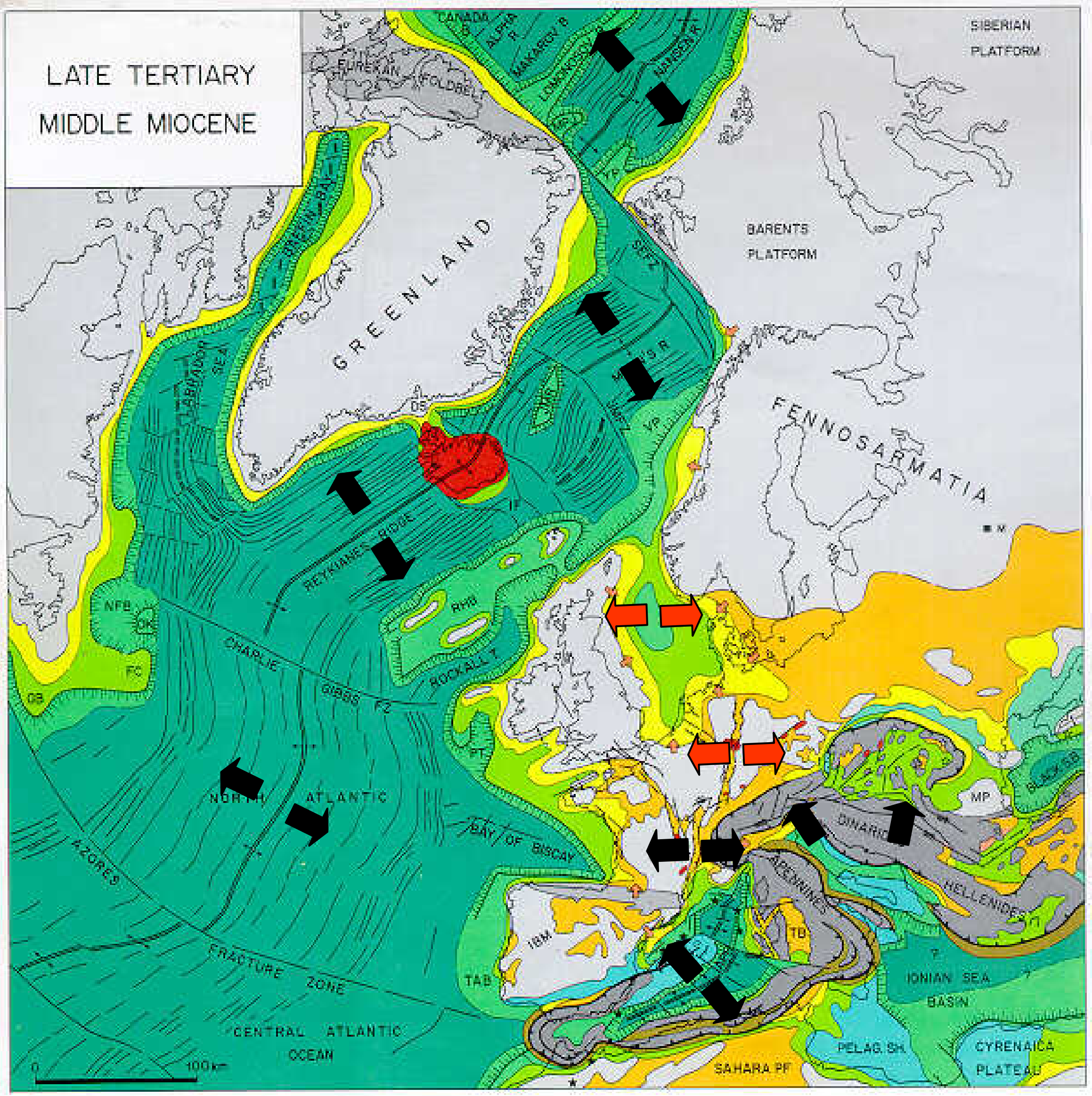
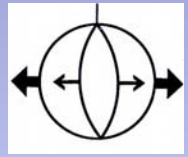
Middle Miocene





E-W extension

- **Phase V**
- E-W extension recorded in Sussex
- Opening of the north of the North Sea and the Upper Rhine Graben
- Also guided by the Weald Artois anticline
- Not recorded in the Chalk basin (Normandy)

from Ziegler, 1989

Conclusion- Normandy

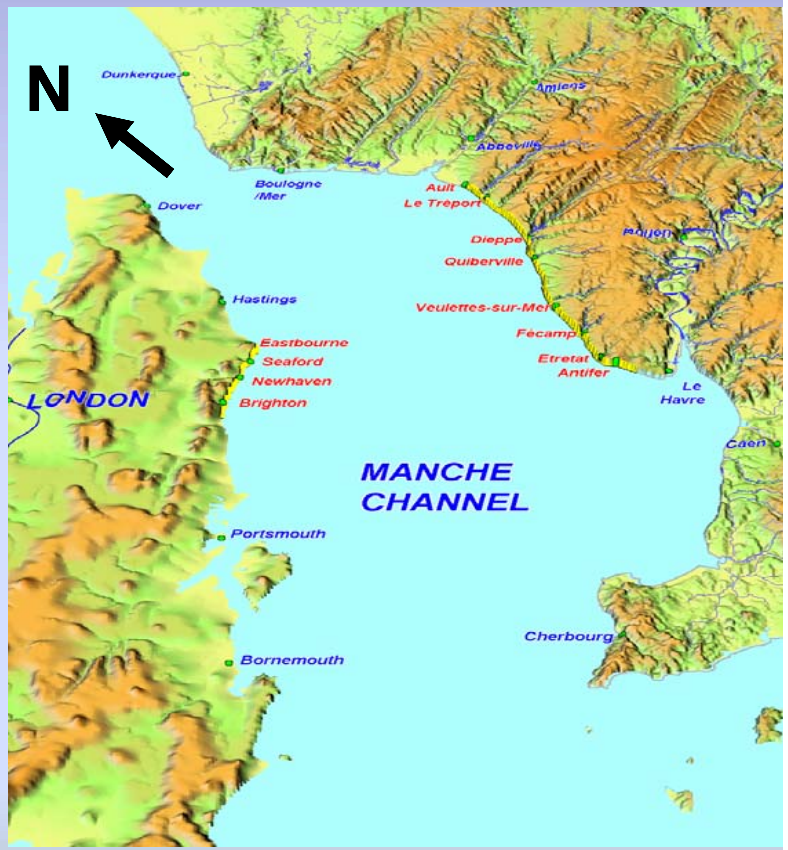
In Normandy (France)

- Normandy is located in the center of the Chalk basin with high chalk thickness and low folding

- The Chalk is sensible to the Western approaches opening

- Meso-scale fractures are concentrated near large scale faults (Bray and Fécamp-Lillebonne faults), that are not reactivated during cenozoic events

- Deep transverse structures (Armorican massif, Weald-Artois anticline) protect the Chalk of the Pyrenean tectonics and of the Upper Rhine graben opening



Conclusion- Sussex

- **In Sussex (UK)**
  - East Sussex is located in the border of the Chalk basin with *en-échelon* folded Chalk in relation with large-scale transverse burried lineaments.
  - The Chalk is more sensitive to far field extensive and compressive stresses
  - The Chalk recorded the Pyrenean pulses and the North Sea and Upper Rhine Graben opening, guided by the Weald-Artois structure