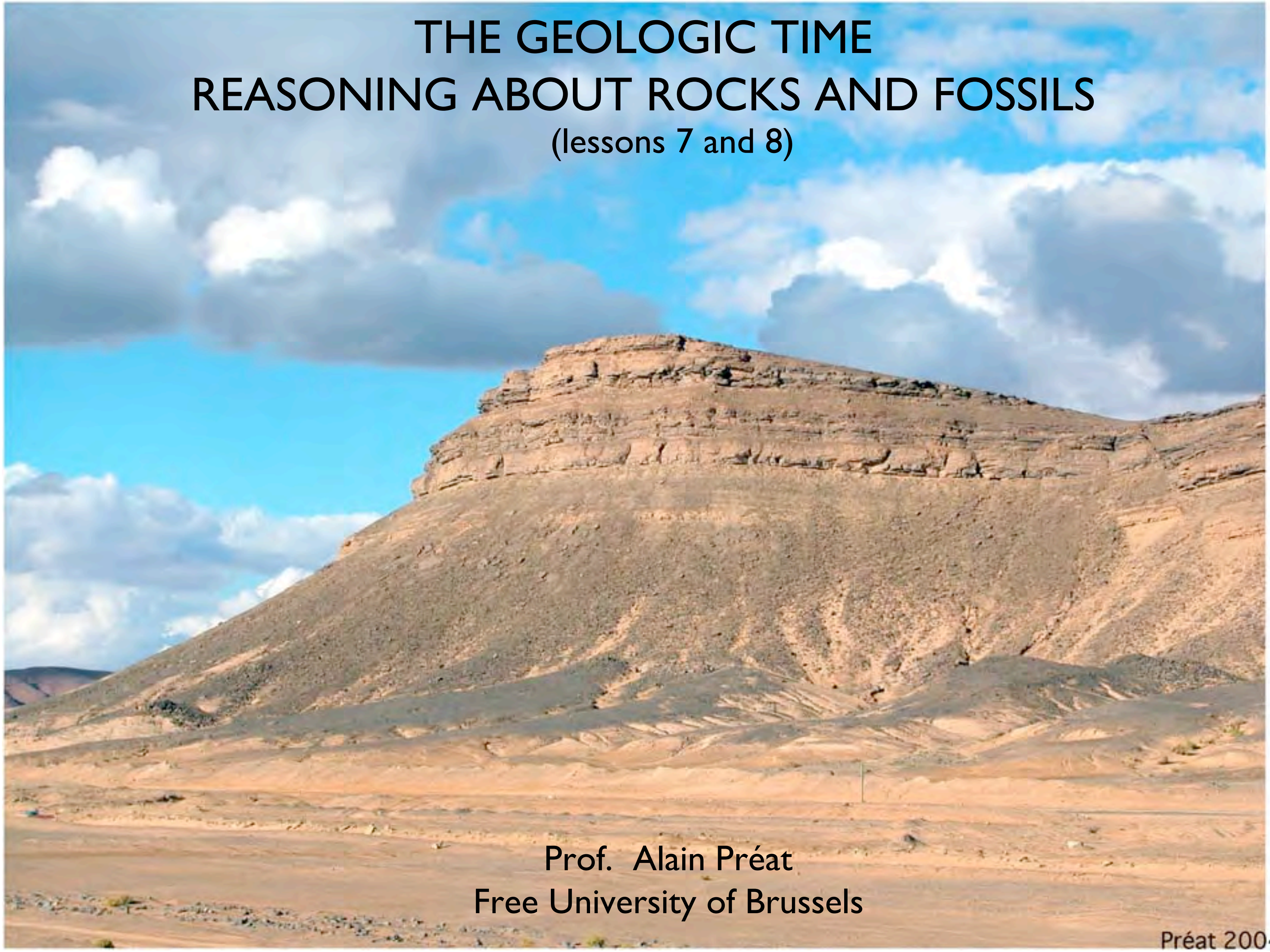
THE GEOLOGIC TIME
REASONING ABOUT ROCKS AND FOSSILS
(lessons 7 and 8)

GEOL.F.203



Prof. Alain Préat
Free University of Brussels

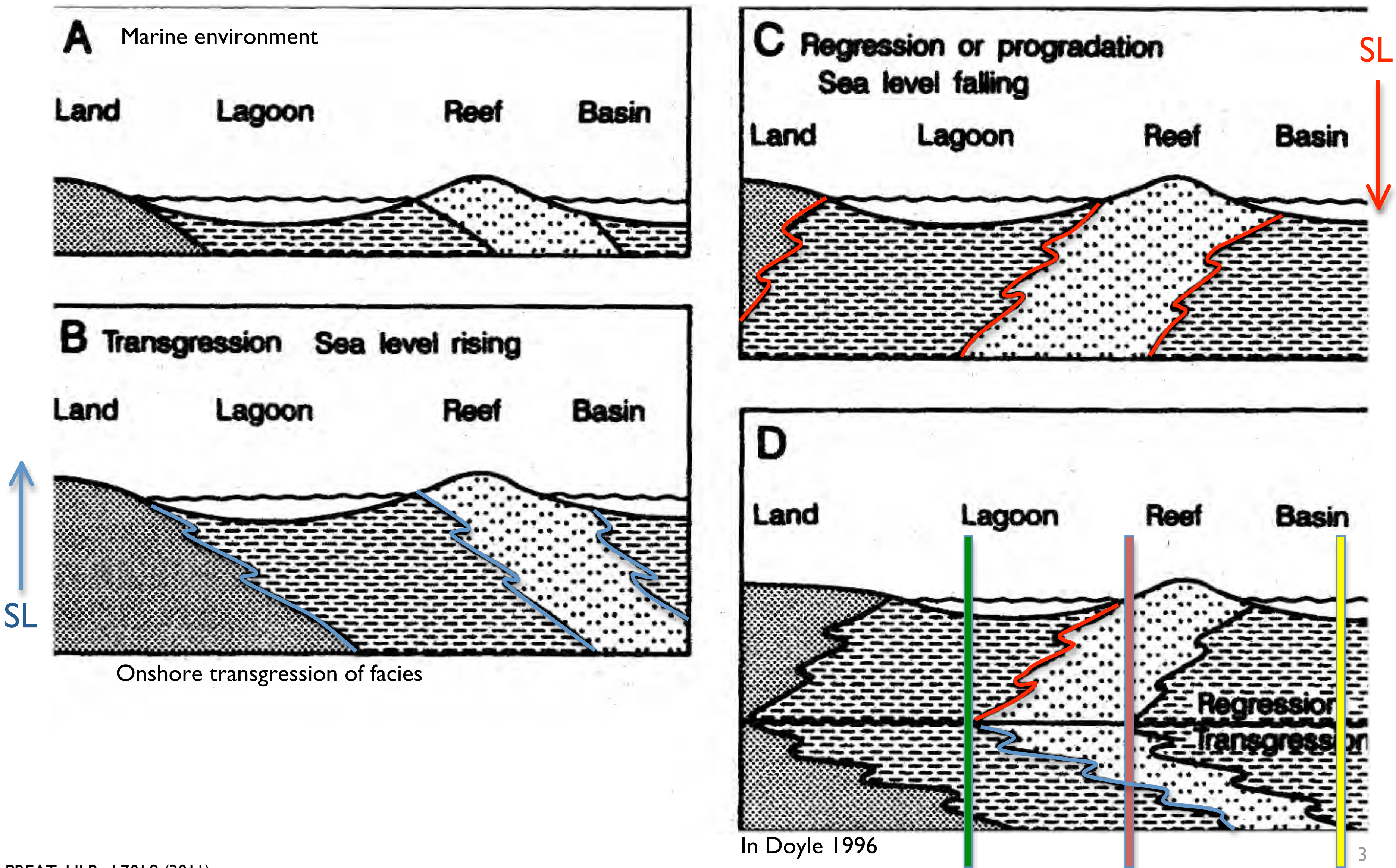
Préat 2004

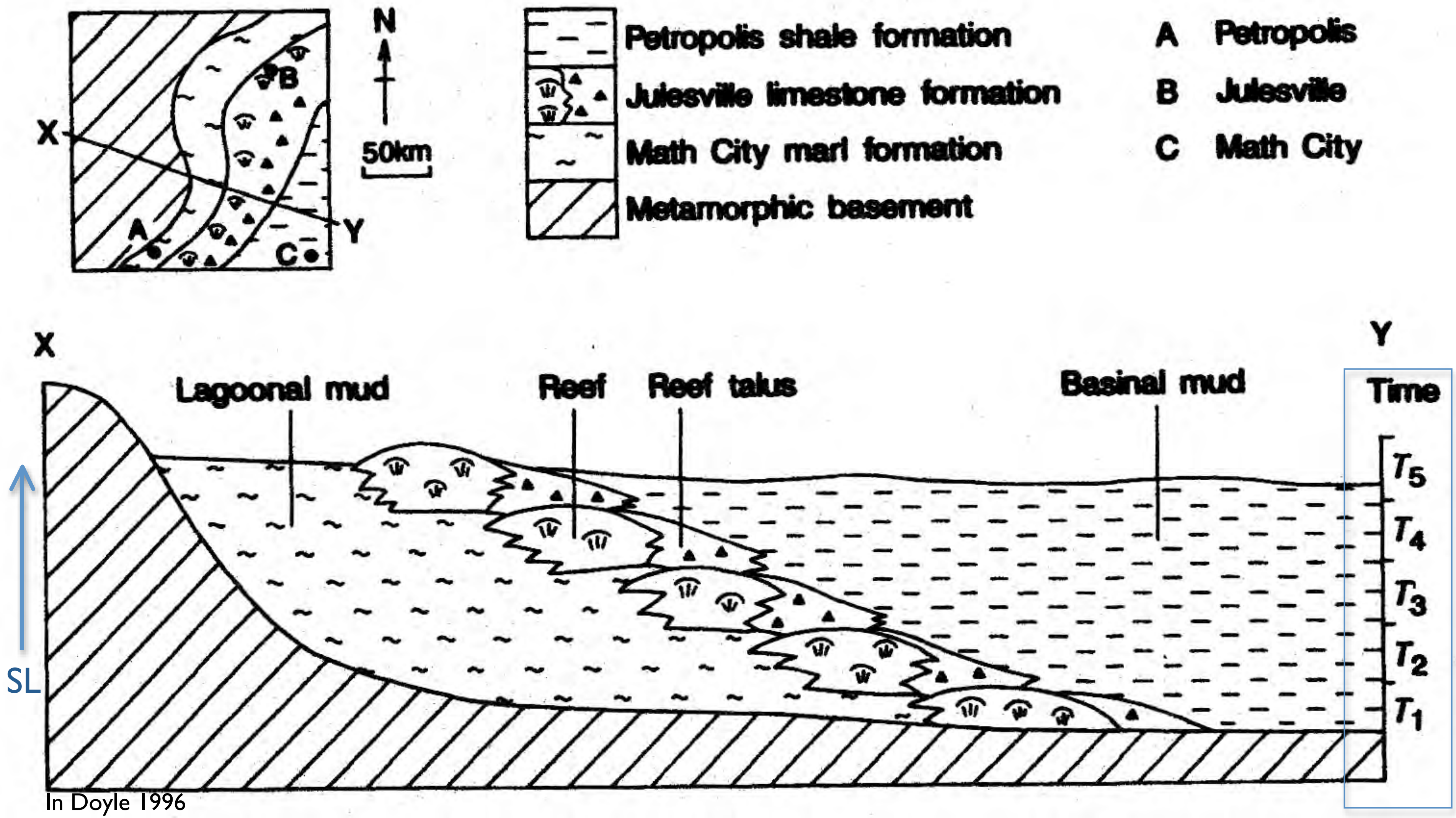
The basic unit in biostratigraphy BIOZONE

• BIOZONES are strata organized into stratigraphical units on the base of their content of guide (micro)fossils => may be recognized on LOCAL or REGIONAL scales

• The primary goal of biostratigraphy is to enable **CORRELATION** of local rock sequences => provides a method fro determining the RELATIVE chronology of a given set of rock units and therefore a given set of evolving environments

A set of evolving environments

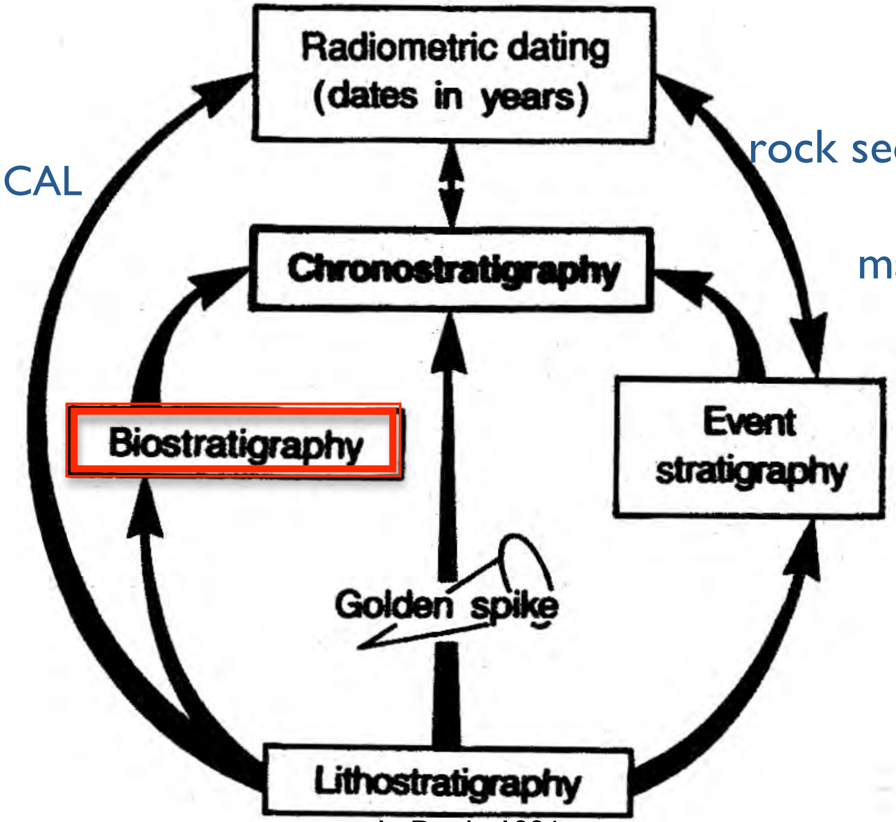




CONCEPT OF DIACHRONISM

The concept of **BIOZONE** was developed by Albert OPPEL (1856).
He recognized that the vertical stratigraphic range of fossils was time-significant and independant of the lithology
⇒ he subdivided the German (Wurtemberg) Jurassic System into 33 Ammonite Zones => each of Oppel's zones was formally defined and named from 10-30 species, and could be traced across continental Europe => still VALID today and recently found in Madagascar and South America!

Ultimate goal
=
CHRONOSTRATIGRAPHICAL UNITS
bodies of rock whose boundaries are time-significant
⇒ INTERNATIONAL AGREEMENT
(GSSP, Golden Spike)



In Doyle 1996

Correlation of rock sequences with this standard
=
mainly BIOSTRATIGRAPHY
and
EVENT STRATIGRAPHY

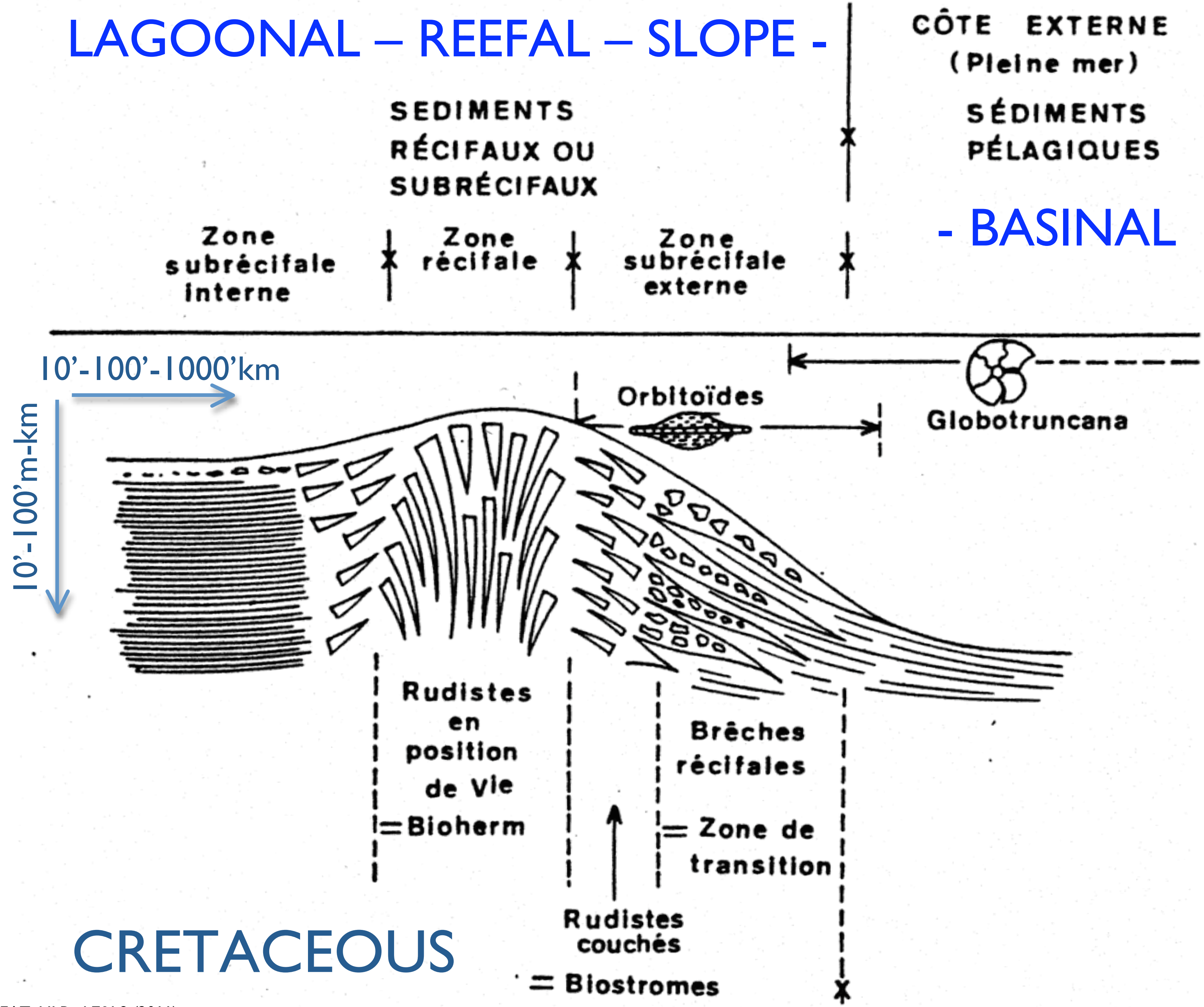
CONCLUSION : Most of the boundaries of chronostratigraphical units are determined using biostratigraphy, although other techniques are used.

Despite this, difficulties remain….

FIRST CASE : PARALLELISM BETWEEN STRATIGRAPHICAL SCALES BASED ON FOSSIL GROUPS IN DIFFERENTS BIOTOPES

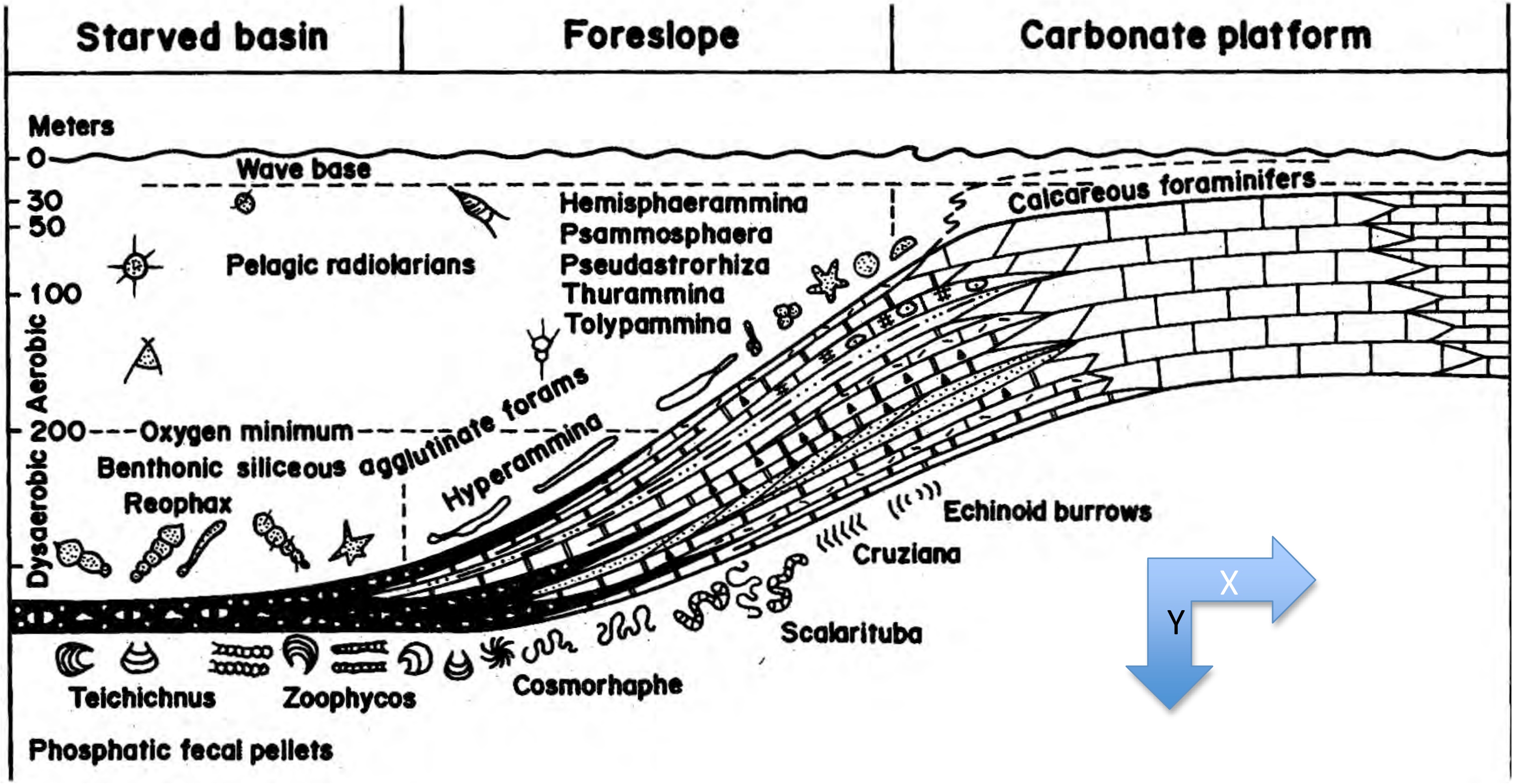
= PLATFORMS-REEFS (OR BARRIERS)-BASINS SYSTEMS

LAGOONAL – REEFAL – SLOPE - - BASINAL



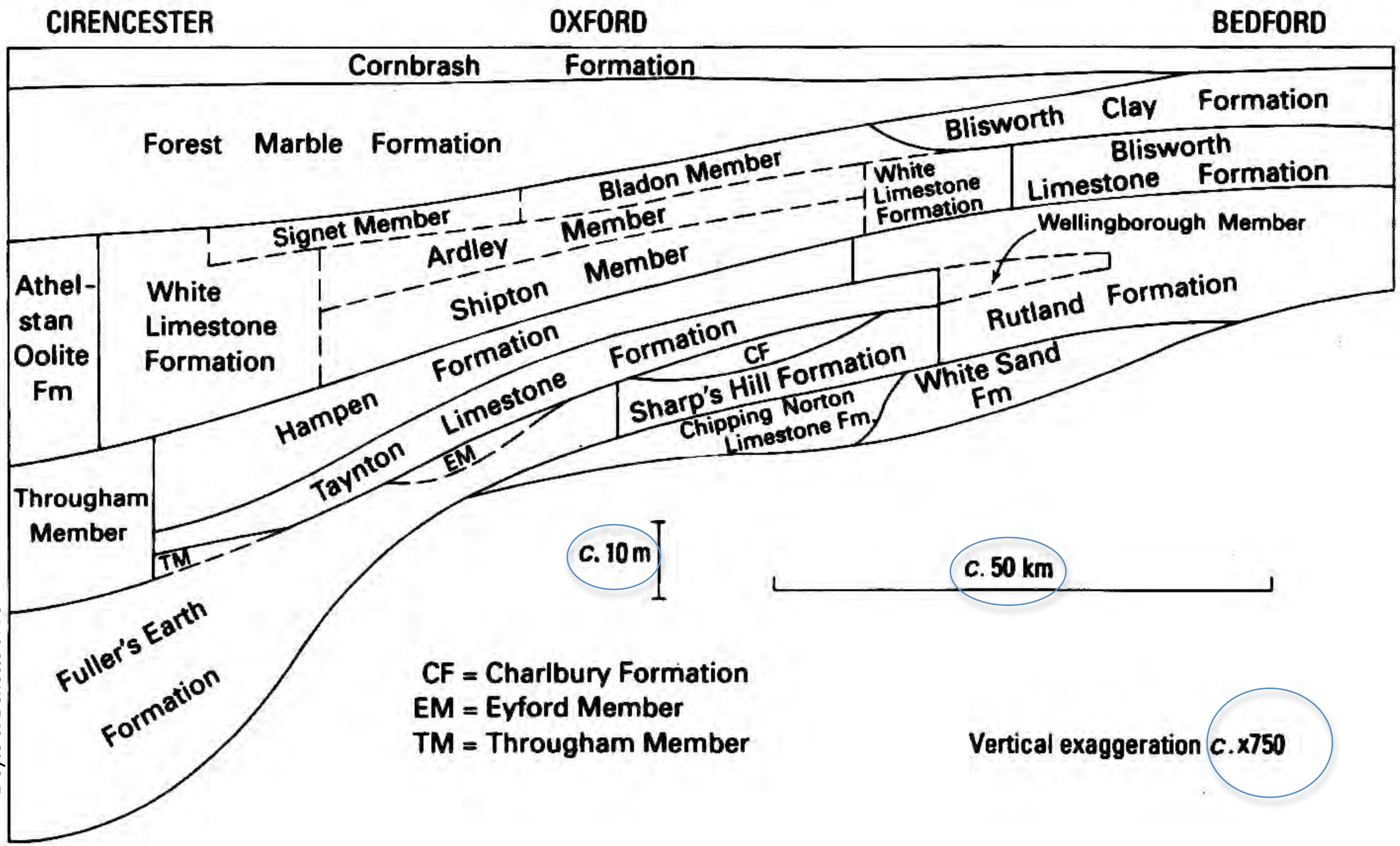
CRETACEOUS

Depositional environments and facies of the Deseret Limestone in Utah
Gutschik & Sandberg 1983



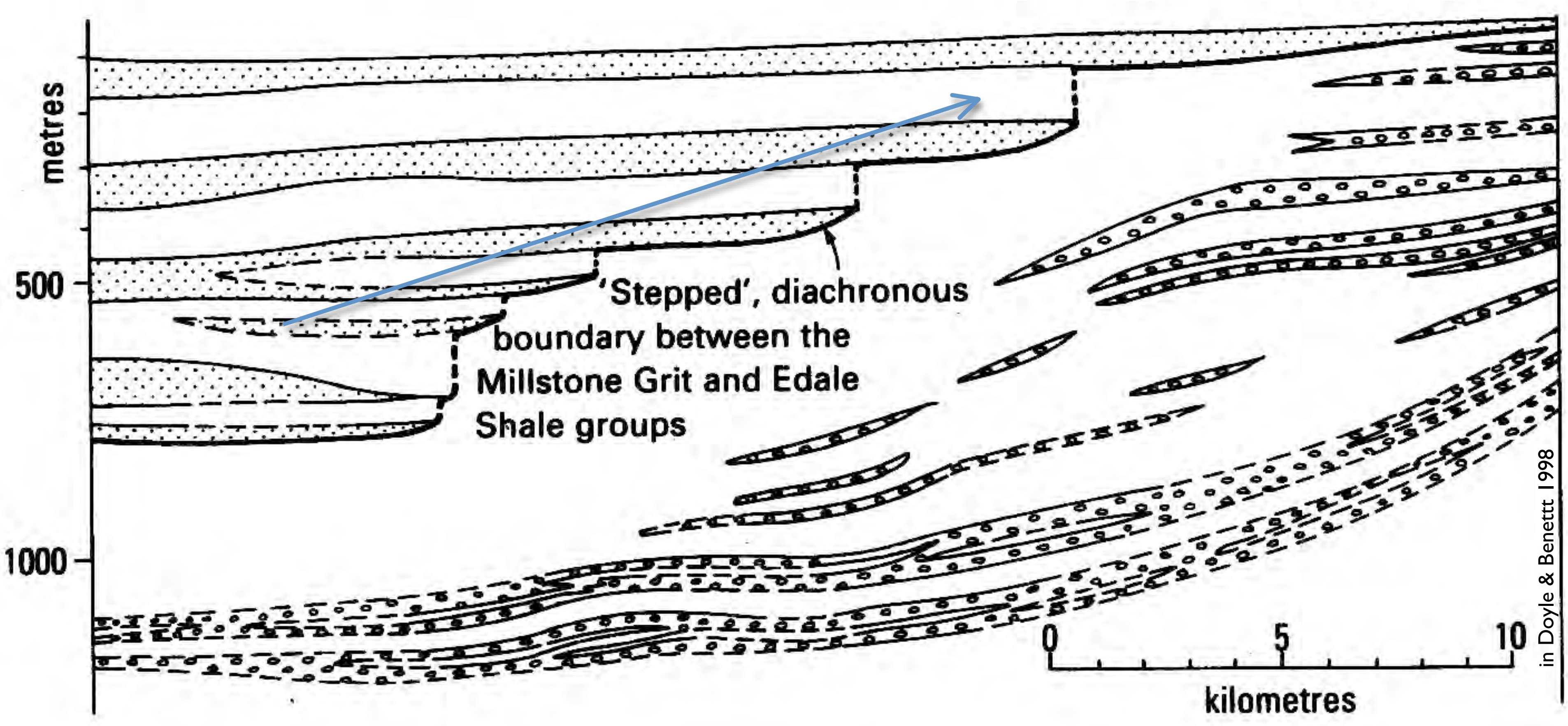
MISSISSIPPIAN

GREAT OOLITE GROUP, MIDDLE JURASSIC, SOUTH U.K.
Lithostratigraphical relationships



Doyle & Benett 1998

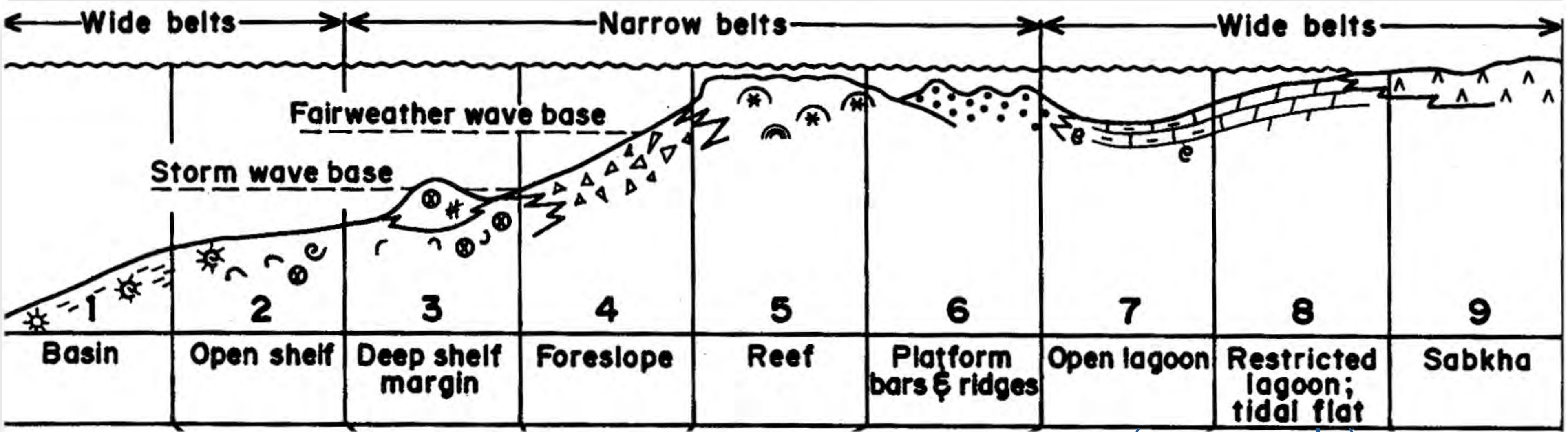
MILLSTONE GRIT and EDALE SHALE, CARBONIFEROUS, U.K.
Lateral boundaries



STANDARD CARBONATE FACIES BELTS

Wilson, 1975

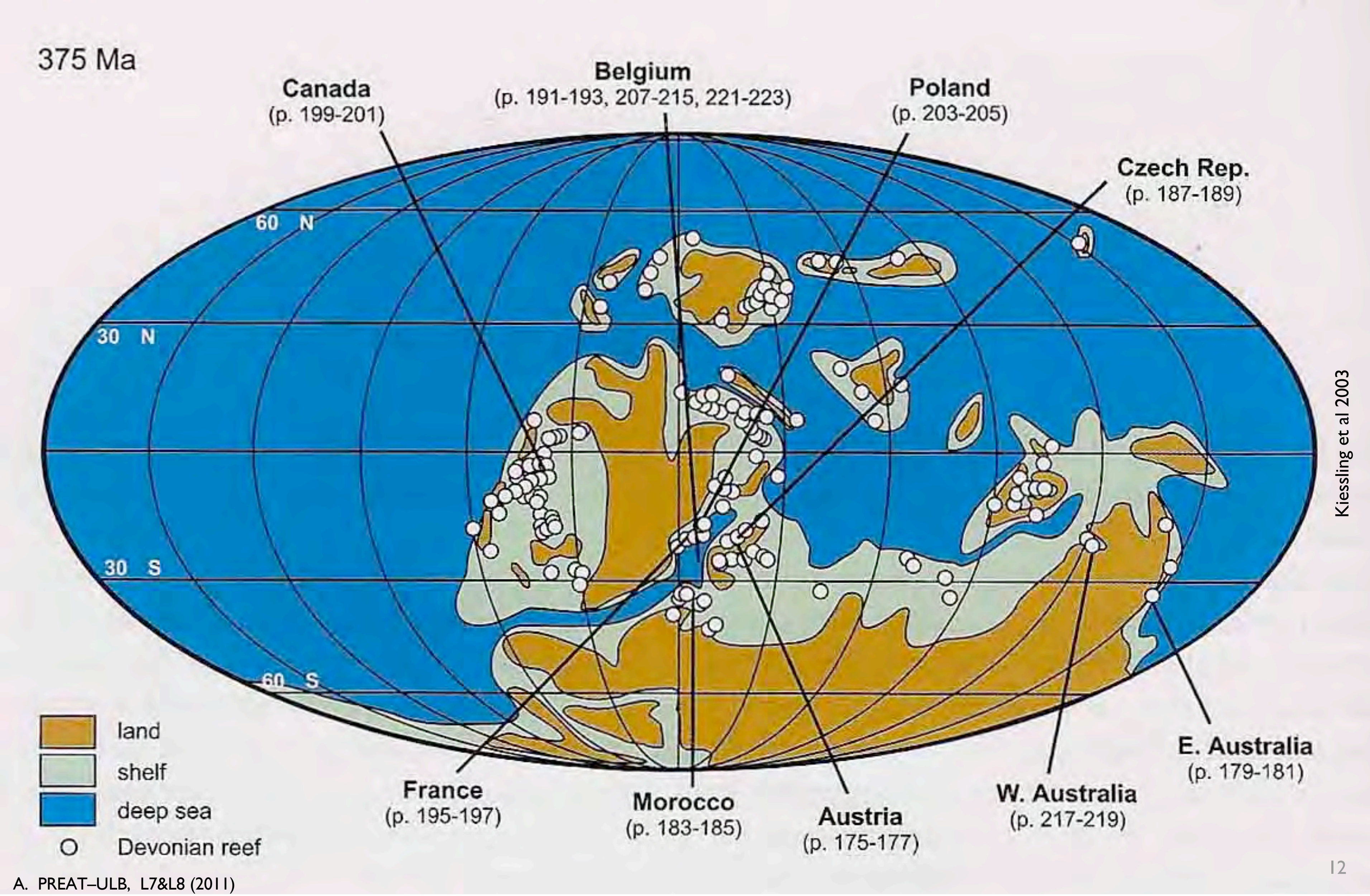
100-100km | 1-10km | 100-100km



source rocks | rock reservoirs | (source rocks) secondary reservoirs

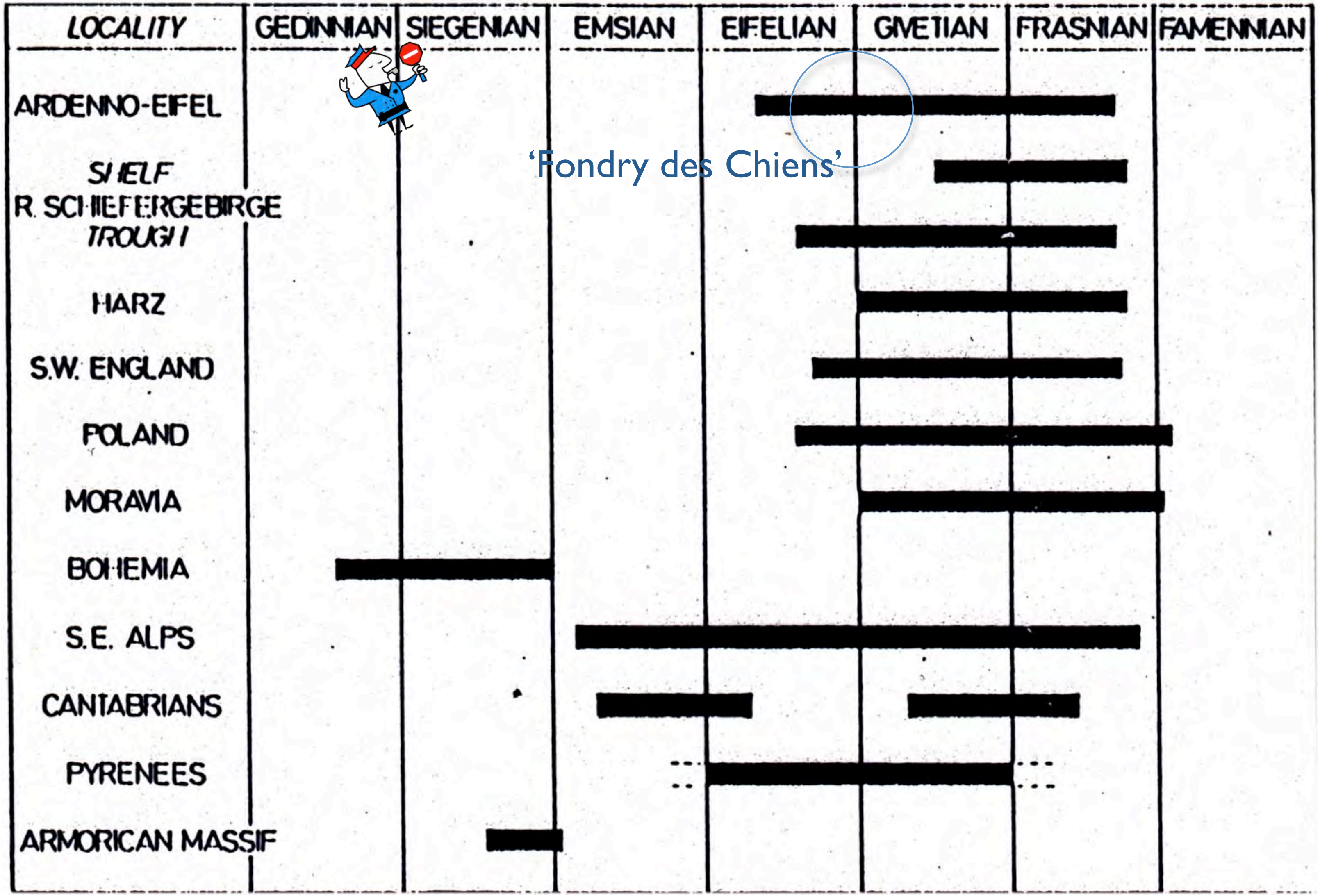
APPLICATION TO OIL GEOLOGY (very simplified)

PALEOGEOGRAPHIC SETTING OF THE DEVONIAN REEFS IN A GLOBAL RECONSTRUCTION



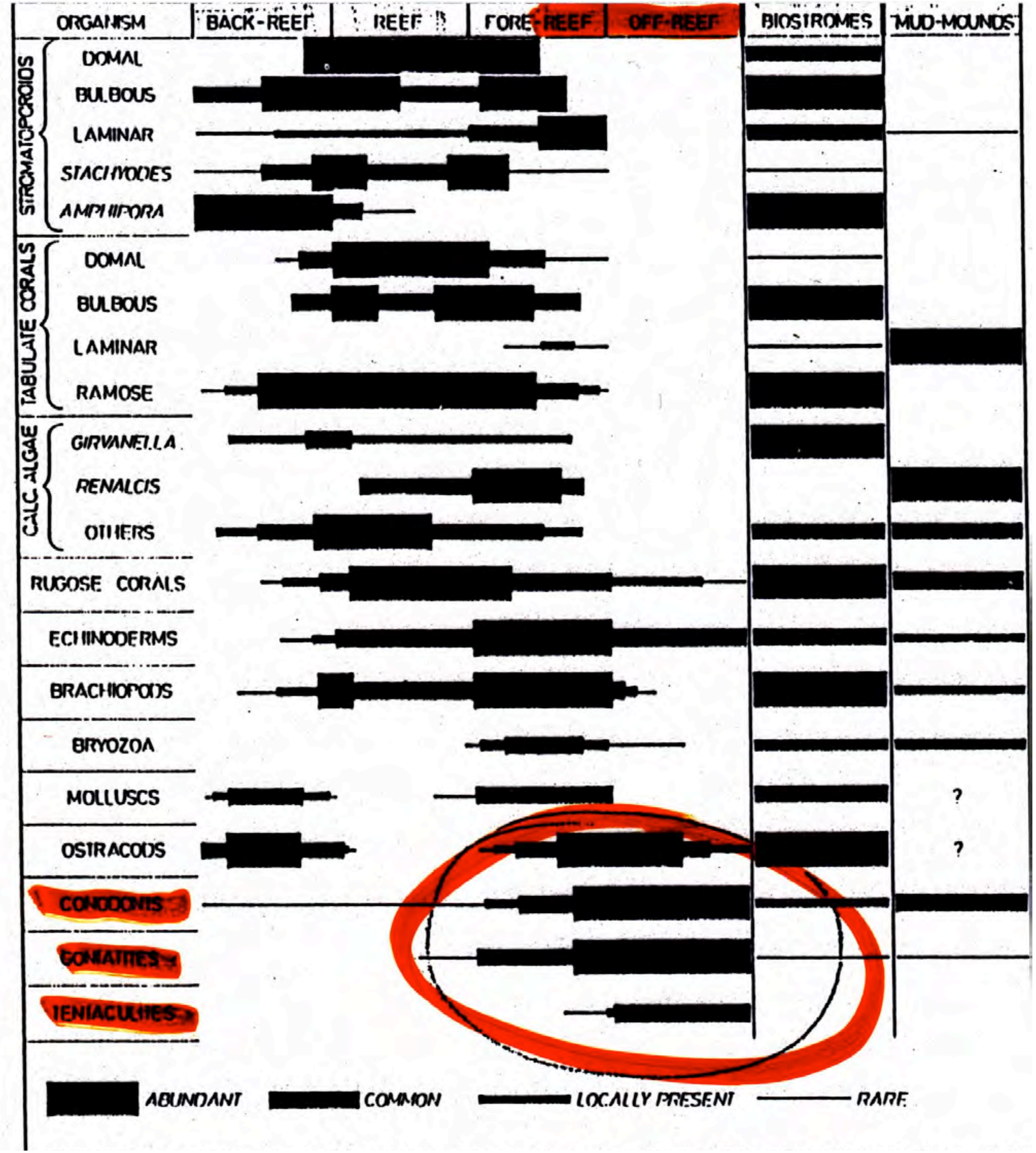
Kiessling et al 2003

STROMATOPOROID-CORALGAL REEFS IN EUROPE



FACIES-RELATED

'PELAGIC'



A. PREAT–ULB, L7&L8 (2011)

BELGIUM : M.G.M. NAMUR CONGRESS 1974

Micropaleontological Guide Markers

Base of ‘Couvinian’ ===> Late Viséan (V3c)

ZONE 1 ===============> ZONE 77

Today: National Commission of Stratigraphy => Subcommission

Namurian

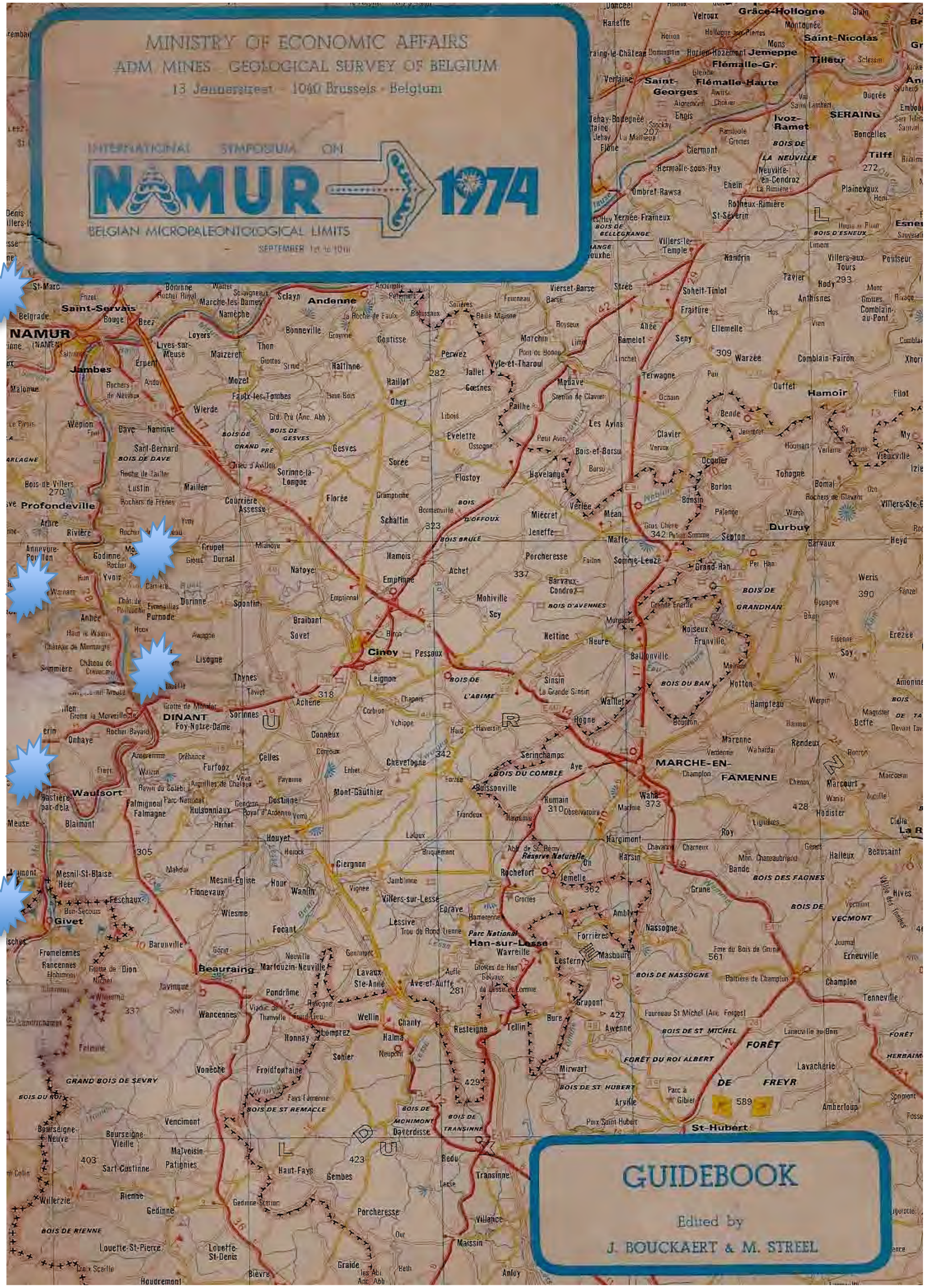
Yvoirian

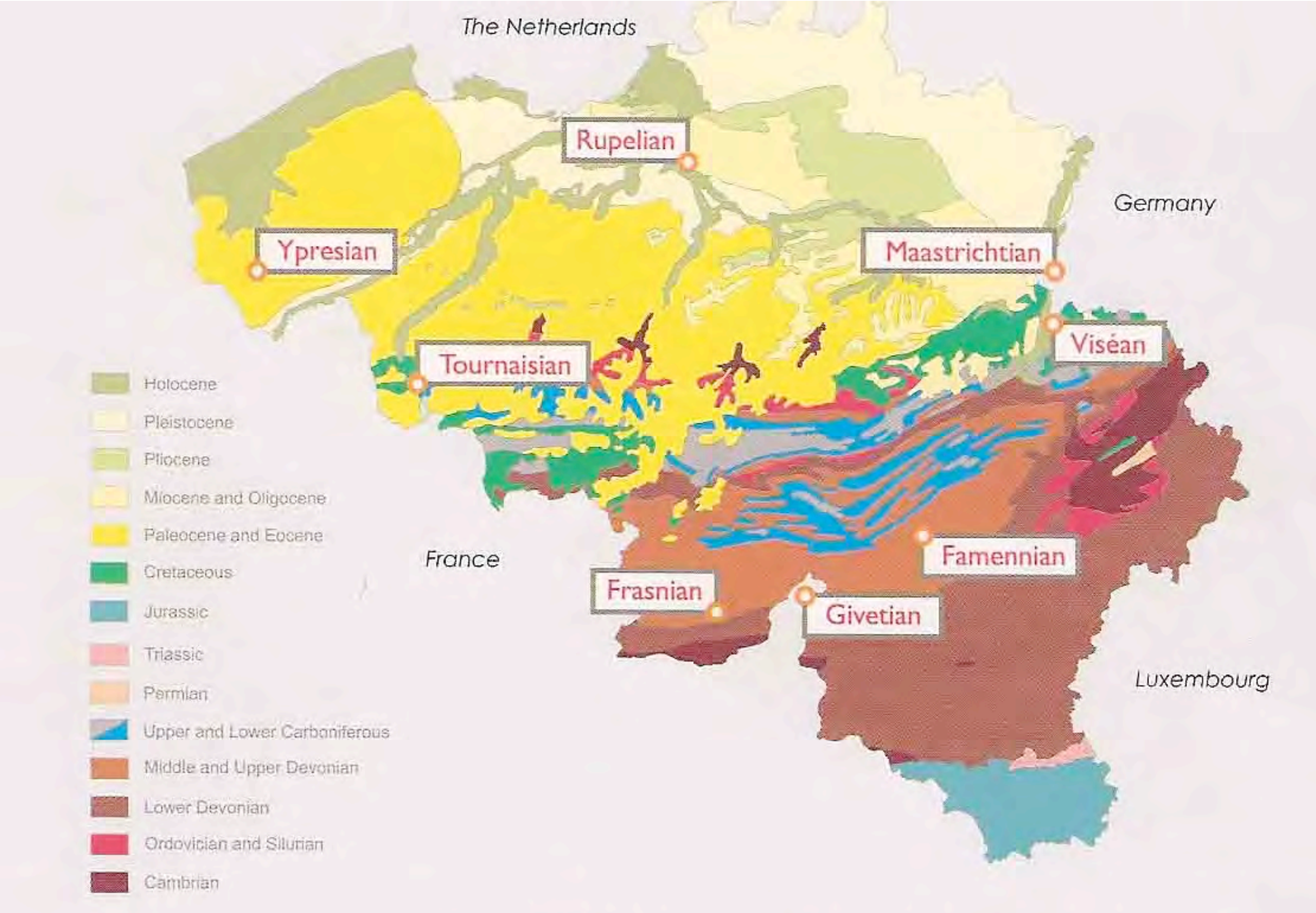
'Warnantian'

'Dinantian'

'Waulsortian'

Givetian

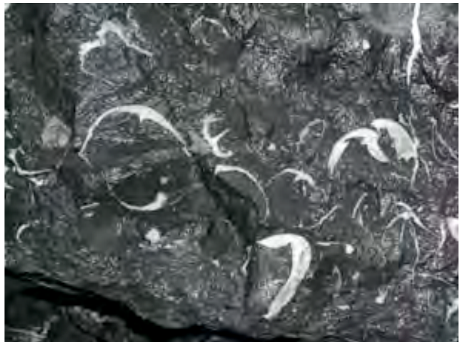




Chronostratigraphic units named from Belgium and adjacent areas

Fromelennes-Flohimont

Fromelennes-Flohimont



Resteigne

MACROFOSSILS

- Stromatoporoid: massive, lamellar, branching
- Tabulate: massive, lamellar, branching
- Rugose: massive, fasciculate, solitar

- Trilobites
- Bryozoa
- Gasteropoda
- Brachiopoda, Spiriferidae
- Goniatites
- Crinoids

Resteigne

MICROFOSSILS

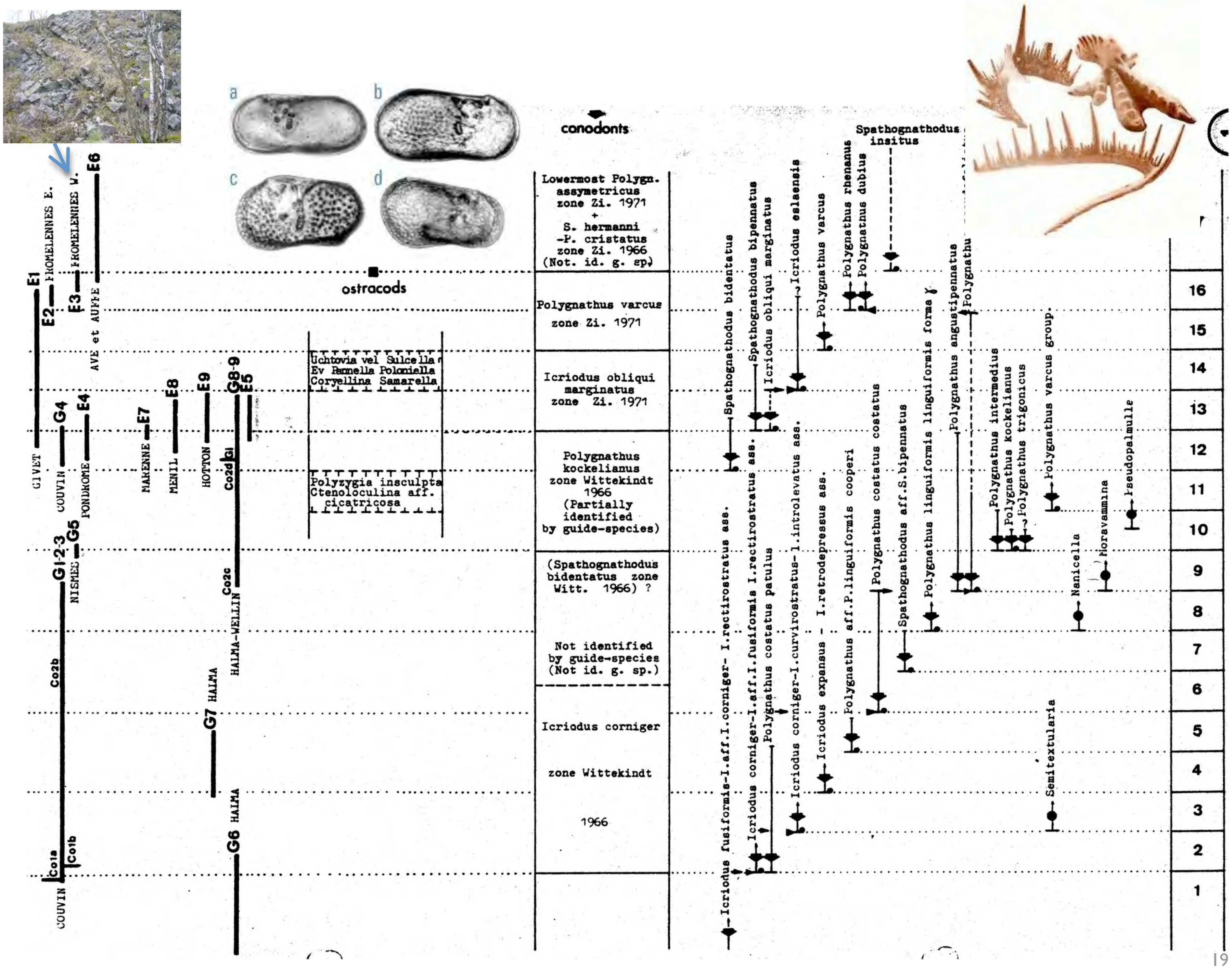
First occurence · ® reworked · barren sample

- Conodonts
- Ostracoda
- Foraminifera
- Algae
- Spores
- Acritarcha
- Tentaculitida

Beauchâteau-Senzeille

CORRELATION LINES

- precise limit in a succession of bio-characteristics
- correlation by similarity of bio-characteristics — here
- lithostratigraphic correlation line


a
b
c
d
ostracods
conodonts
Spathognathodus insitus
E1 FROMELENNES E.
E2
E3 FROMELENNES W.
E6
AVE et AUFFE
GIVET
G4 COUVIN
E4 PONDROME
MAKENNE E7
MENIL E8
HOTTON E9
G8-9
E5
Co2d
Gi
G1-2-3
G5 NISMES
Co2c
HALMA-WELLIN
Co2b
G7 HALMA
G6 HALMA
Co1a
Co1b
COUVIN
Uchtovia vel Sulcella
Ev Pennella Poloniella
Coryellina Samarella
Polyzygia insculpta
Ctenoloculina aff. cicatricosa
Lowermost Polygn. assymetricus zone Zi. 1971
+
S. hermanni -P. cristatus zone Zi. 1966
(Not. id. g. sp.)
Polygnathus varcus zone Zi. 1971
Icriodus obliqui marginatus zone Zi. 1971
Polygnathus kockelianus zone Wittekindt 1966
(Partially identified by guide-species)
(Spathognathodus bidentatus zone Witt. 1966) ?
Not identified by guide-species
(Not id. g. sp.)
Icriodus corniger
zone Wittekindt
1966
Icriodus fusiformis-I.aff.I.corniger- I.rectirostratus ass.
Icriodus corniger-I.aff.I.fusiformis I.rectirostratus ass.
Polygnathus costatus patulus
Spathognathodus bidentatus
Spathognathodus bipennatus
Icriodus obliqui marginatus
Icriodus eslaensis
Icriodus corniger-I.curvirostratus-I.introlevatus ass.
Icriodus expansus - I.retrodepressus ass.
Polygnathus varcus
Polygnathus aff.P.linguiformis cooperi
Polygnathus rhenanus
Polygnathus dubius
Polygnathus costatus costatus
Spathognathodus aff.S.bipennatus
Polygnathus linguiformis linguiformis forma γ
Polygnathus angustipennatus
Polygnathu
Polygnathus intermedius
Polygnathus kockelianus
Polygnathus trigonicus
Polygnathus varcus group
Semitextularia
Nanicella
Moravammina
Pseudopalmulle
16
15
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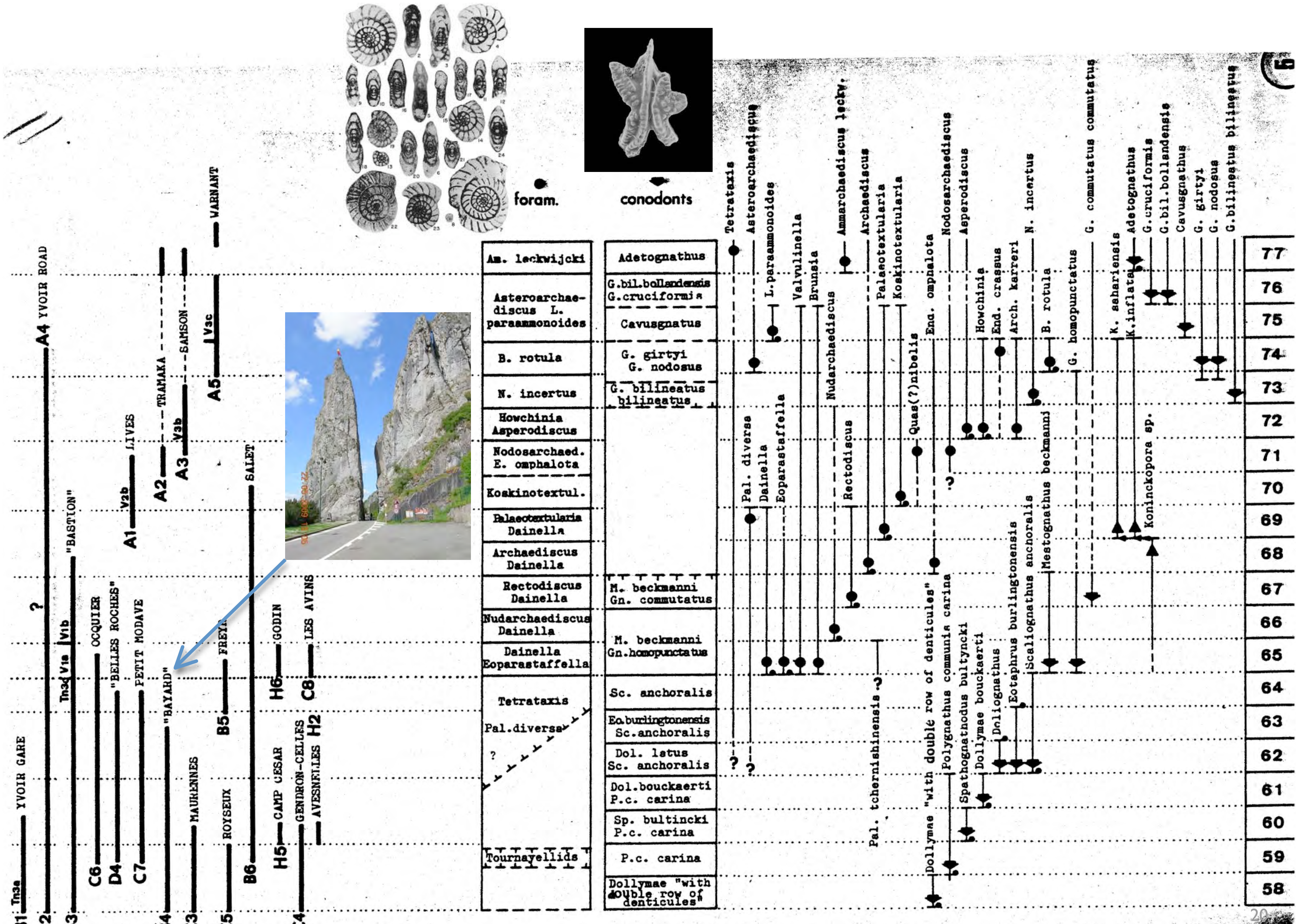
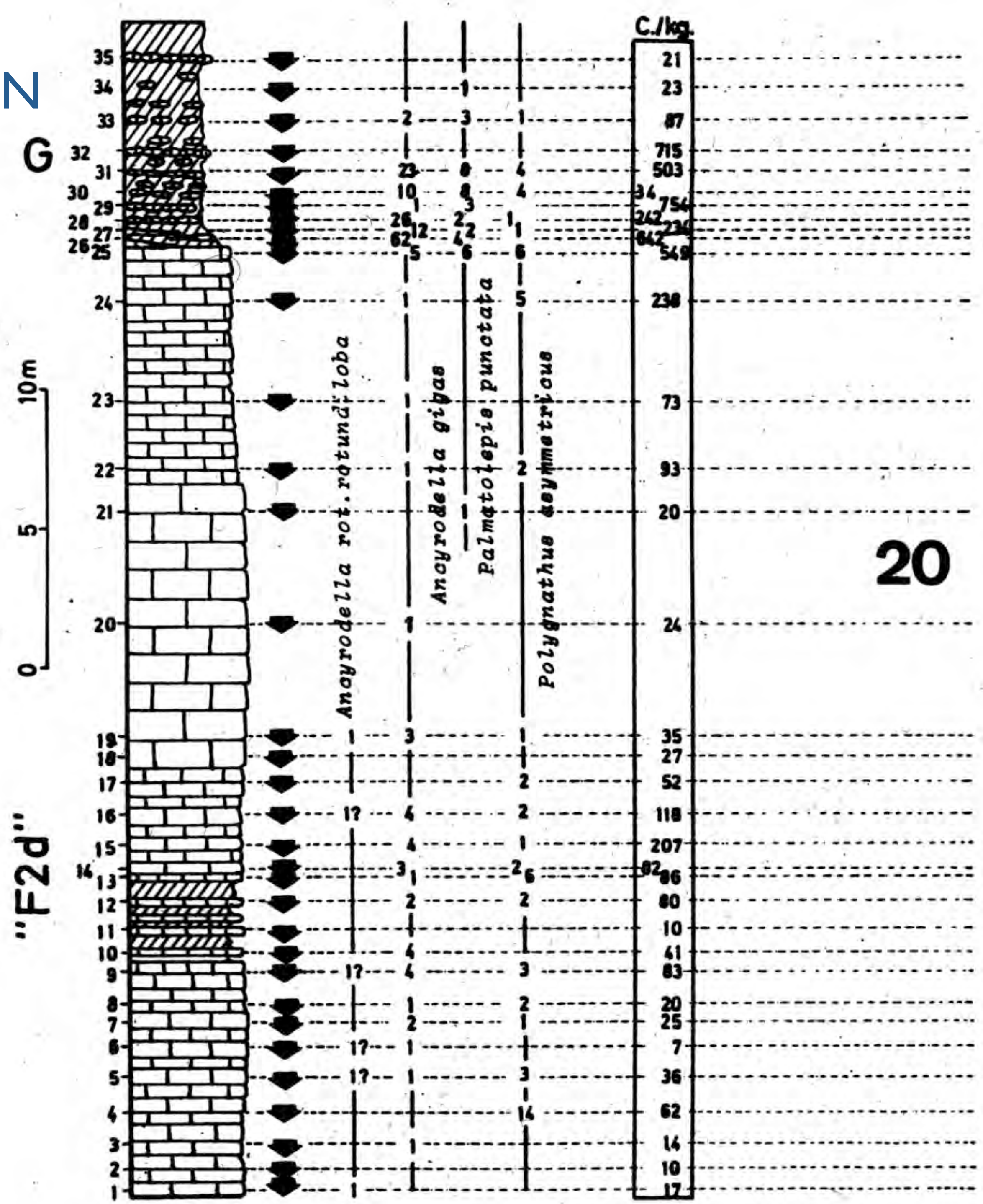
5
4
3
2
1

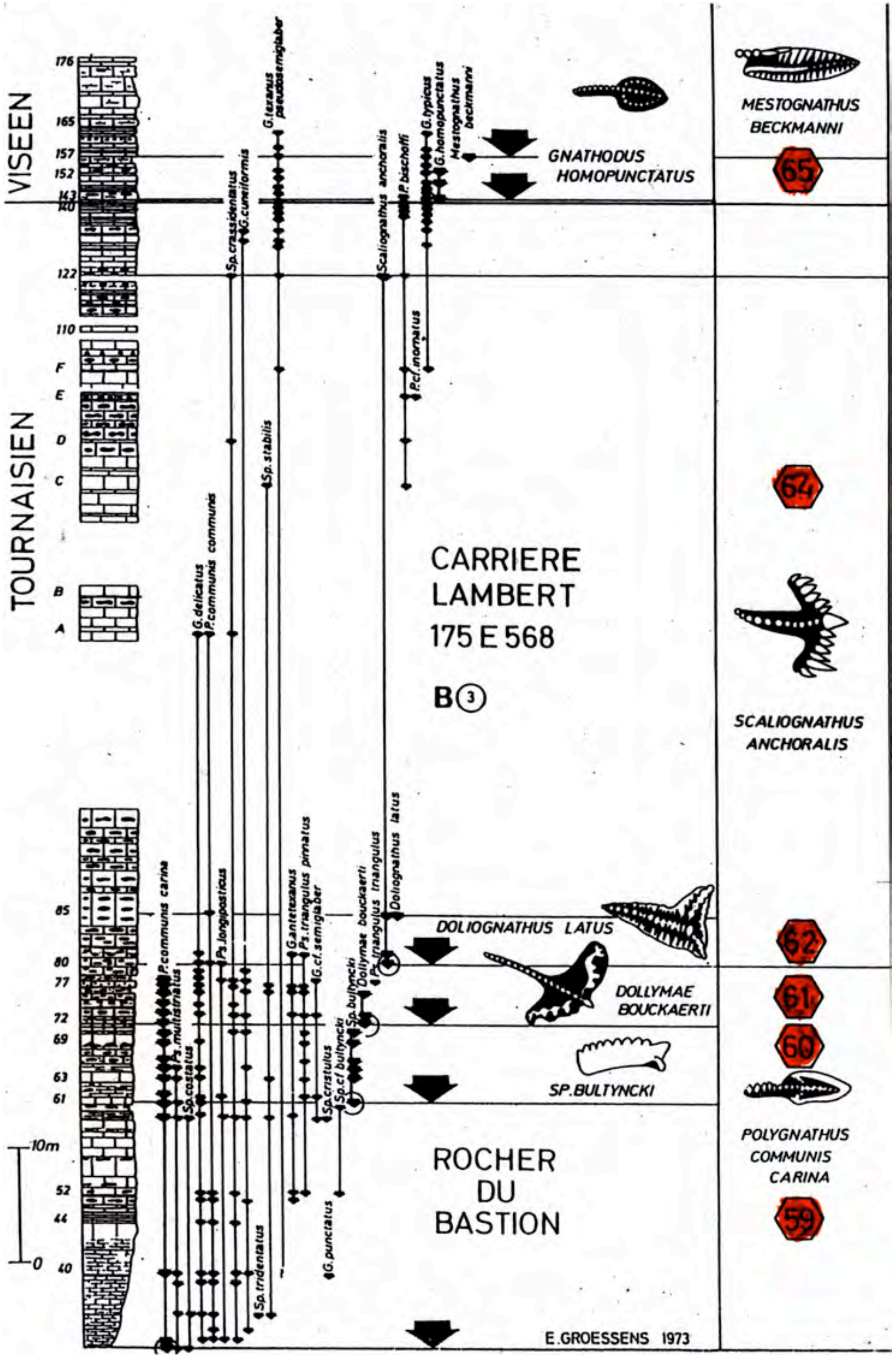


foram.
conodonts
Am. leckwijcki
Asteroarchaediscus L. paraammonoides
B. rotula
N. incertus
Howchinia Asperodiscus
Nodosarchaed. E. omphalota
Koskinotextul.
Palaeotextularia Dainella
Archaediscus Dainella
Rectodiscus Dainella
Nudarchaediscus Dainella
Dainella Eoparastaffella
Tetrataxis
Pal.diversa
Tournayellids
Adetognathus
G.bil.bollandensis G.cruciformis
Cavusgnatus
G. girtyi G. nodosus
G. bilineatus bilineatus
M. beckmanni Gn. commutatus
M. beckmanni Gn.homopunctatus
Sc. anchoralis
Eo.burlingtonensis Sc.anchoralis
Dol. latus Sc. anchoralis
Dol.bouckaerti P.c. carina
Sp. bultincki P.c. carina
P.c. carina
Dollymae "with double row of denticules"
77
76
75
74
73
72
71
70
69
68
67
66
65
64
63
62
61
60
59
58
YVOIR GARE
YVOIR ROAD
"BASTION"
OCQUIER
"BELLES ROCHES"
PETIT MODAVE
"BAYARD"
MAURENNES
ROYSEUX
FREYR
SALET
CAMP CESAR
GODIN
GENDRON-CELLES
AVESNELLES
LES AVINS
LIVES
TRAMAKA
SAMSON
WARNANT

NISMES SECTION



ZONE 20 (MGM20) FRASNIEN Dinant Basin


VISEEN
TOURNAISIEN
GNATHODUS HOMOPUNCTATUS
CARRIERE LAMBERT 175 E 568
B③
DOLIOGNATHUS LATUS
DOLLYMAE BOUCKAERTI
SP.BULTYNCKI
ROCHER DU BASTION
E.GROESSENS 1973
MESTOGNATHUS BECKMANNI
65
64
SCALIOGNATHUS ANCHORALIS
62
61
60
POLYGNATHUS COMMUNIS CARINA
59
10m
0

<table>
<tr><th>Etages</th><th>Formations</th><th colspan="2">Conodontes</th></tr>
<tr><td>GIVETIEN</td><td>F. de TROIS-FONTAINES
(base du Calcaire de Givet)</td><td>Apparition
d' Icriodus obliquimarginatus</td><td rowspan="3">Zone
à
Polygnathus ensensis</td></tr>
<tr><td rowspan="3">EIFELIEN

(COUVINIEN)</td><td>F. d'HANONET</td><td rowspan="2">Occurrence de
Polygnathus ensensis</td></tr>
<tr><td>FORMATION X</td></tr>
<tr><td>F. de JEMELLE</td><td></td><td>Zone à
Tortodus kockelianus</td></tr>
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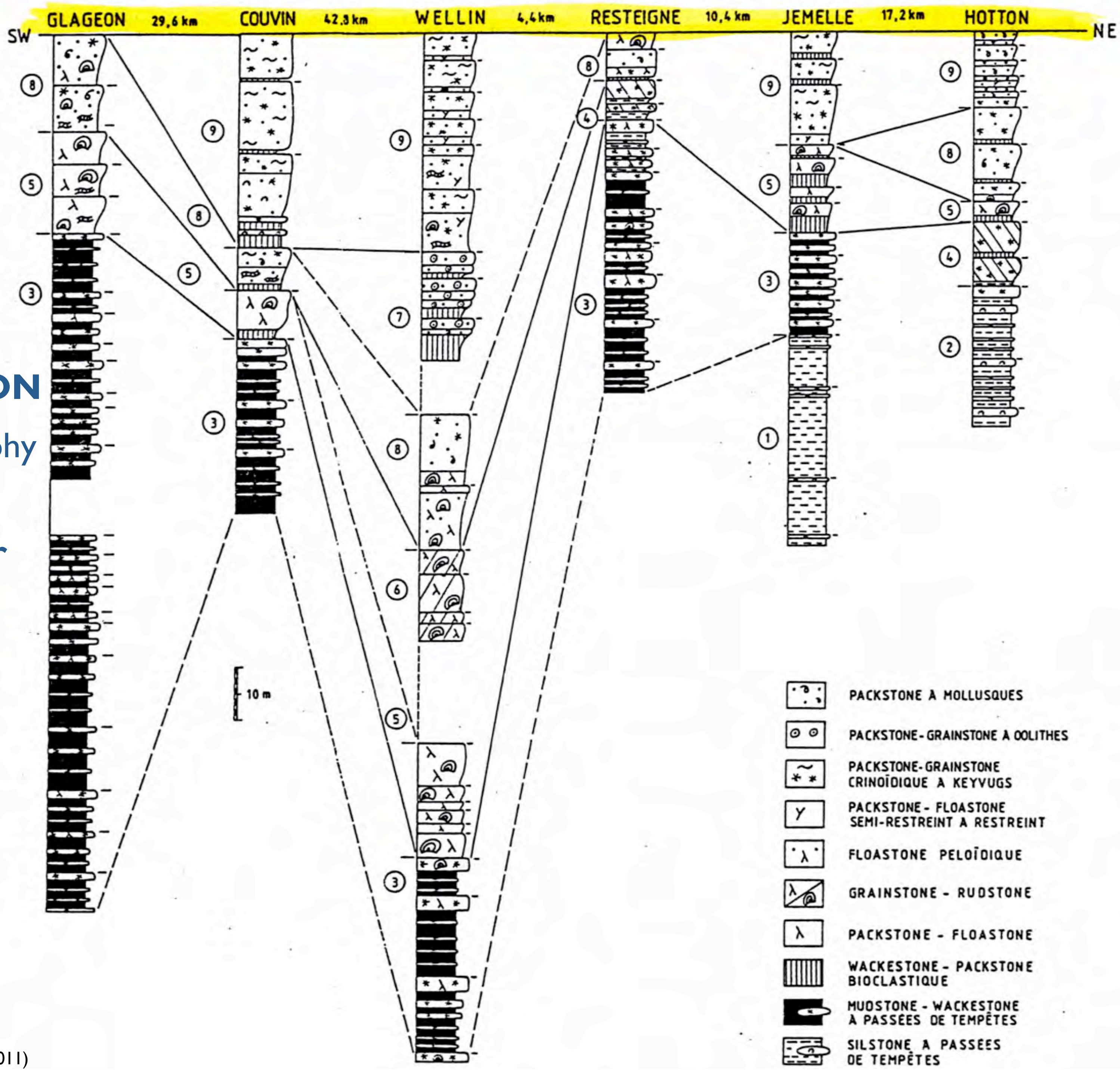
EIF/GIV TRANSITION

cyclostratigraphy

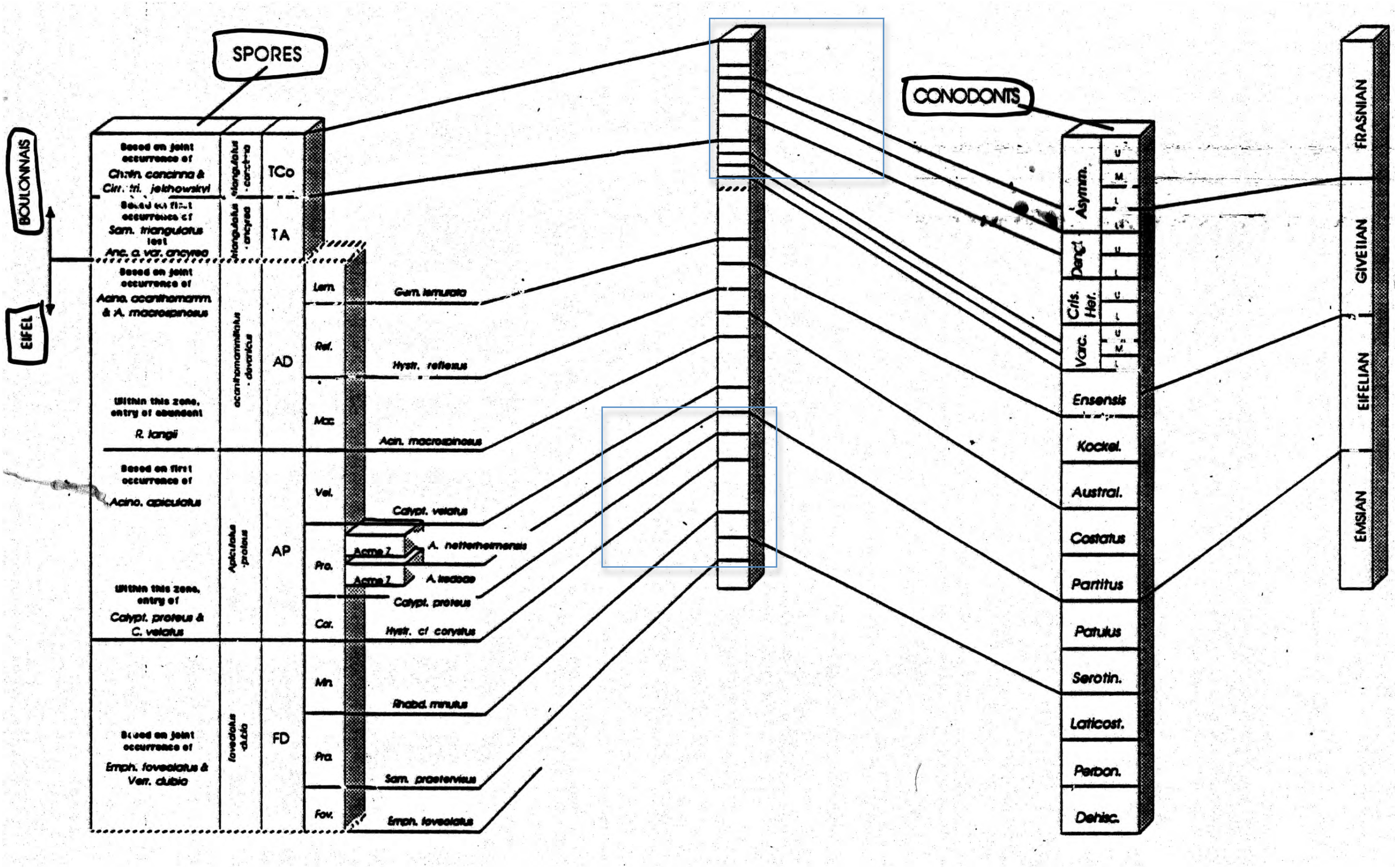
1 cycle

14-53 kyr

± 15 m



Kasimi & Préat 1996


SPORES
CONODONTS
BOULONNAIS
EIFEL
TCo
TA
AD
AP
FD
Lem.
Ref.
Mac.
Vel.
Pro.
Cor.
Min.
Pra.
Fov.
Gem. lemurata
Hystr. reflexus
Acin. macrospinosus
Calypt. velatus
A. netterheimensis
A. ledoae
Calypt. proteus
Hystr. cf coryitus
Rhabd. minutus
Sam. praetervisus
Emph. foveolatus
Asymm.
Dengl.
Varc.
Ensensis
Kockel.
Austral.
Costatus
Partitus
Patulus
Serotin.
Laticost.
Perbon.
Dehisc.
FRASNIAN
GIVETIAN
EIFELIAN
EMSIAN

… Finally temporal resolution are almost always insufficient
Examples: conodonts (±0.5-1.5 or more myr), trilobites (5 myr)…

⇒ **need of other techniques**
• sedimentology
• cyclostratigraphy
• …
• chemostratigraphy
• magnetic susceptibility
…

Application (example)
Belgian Frasnian mud mounds ('F2ij')
6 phases (SL) = 3 biozones (corals) = 2 biozones (conodonts)
…

BIOZONES : TIME RESOLUTION

CENOZOIC : < and << 500 000 yr

MESOZOIC : 500 000 – 750 000 yr

PALEOZOIC : myr and > myr

PRECAMBRIAN : no biozones, > 10-100 myr

FRENCH-BELGIAN DEVONIAN
ca. 2 km, ca. 16 conodont biozones/ 23 myr
⇒ one biozone ca 1.5 myr/100-200m
⇒ (one year = 0.06mm?)
GRAND CANYON
1.2 km/ca 500myr => 1yr = 0.0024mm

THE 'CHAMPION' = AMMONITES (JURASSIC)
100 000 yr and < (50 000 yr in biohorizon)

Despite this, difficulties remain….

FIRST CASE : PARALLELISM BETWEEN STRATIGRAPHICAL SCALES BASED ON FOSSIL GROUPS IN DIFFERENTS BIOTOPES

= PLATFORMS-REEFS (OR BARRIERS)- BASINS SYSTEMS

CONCLUSION

STRATIGRAPHICAL FOSSILS *vs* FACIES FOSSILS

Despite this, difficulties remain….

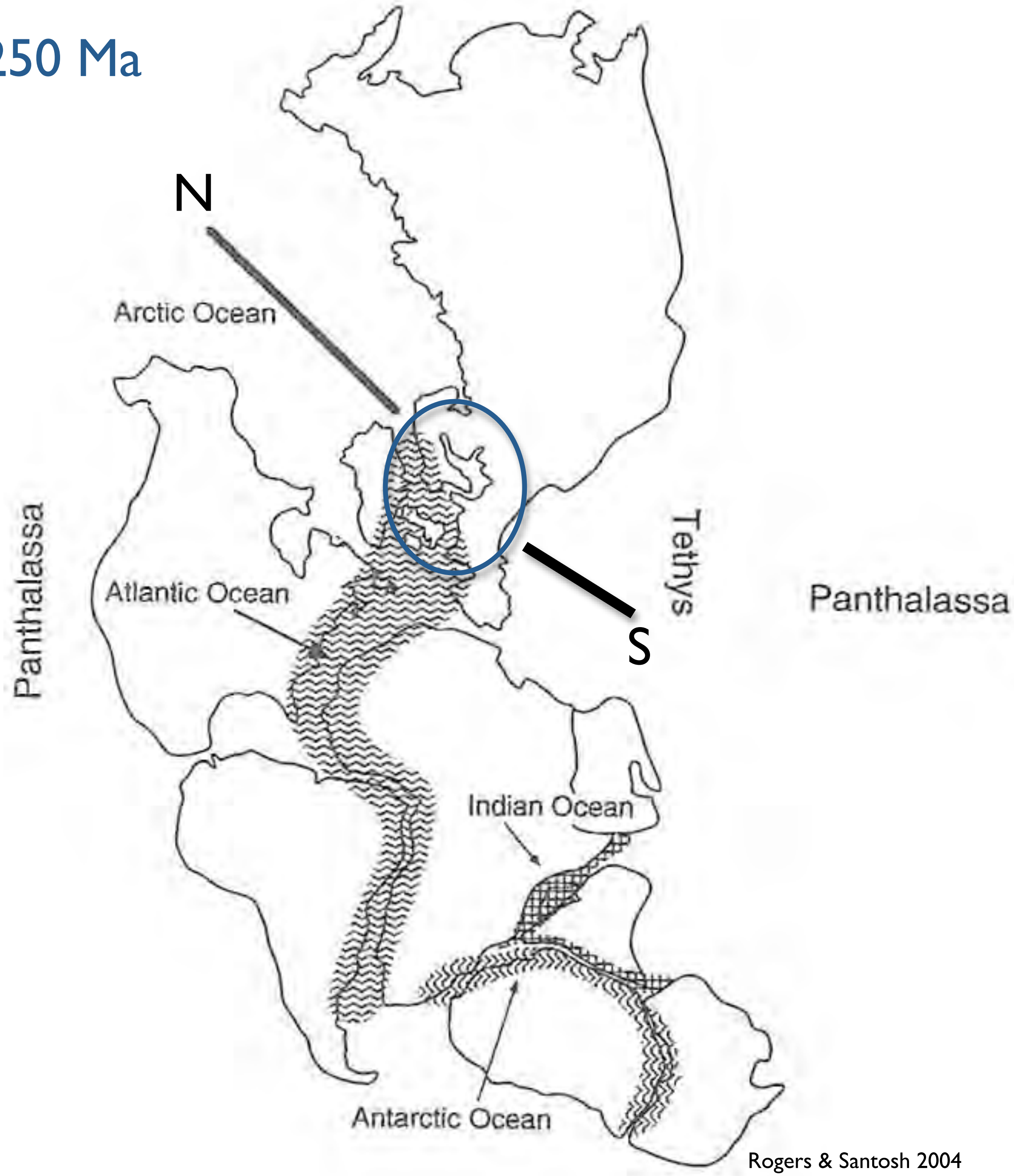
SECOND CASE : EXISTENCE OF FAUNAL-FLORAL PROVINCES SEPARATED FROM EACH OTHER BY GROUPS WITH NO RELATION(S) BETWEEN THEM

= PLATFORMS-REEFS (OR BARRIERS)- BASINS (SYSTEMS)

Similar to the previous case with notion of PROVINCES
=> palaeoecological and stratigraphical approaches

The boundary between these provinces is located to the SE-SW of France => TRANSITION ZONES

Pangea at *ca.* 250 Ma



Rogers & Santosh 2004

BOREAL PROVINCE (N)

ONLY A FEW COMMON RELATIONS

MESOGEAN PROVINCE (S)

Orbitolines **AND** Ammonites
SW Paris basin, 'mid' Cretaceous

Rudists **AND** Ammonites
Aquitaine basin, 'mid' Cretaceous

Parallelism RUDISTS//AMMONITES

Very important to date 'coeval' or synchronous events in different basins
Here : opening TETHYS => 'CENTRAL ATLANTIC' (starting in the Jurassic)
Idem at a worldwide scale.

Despite this, difficulties remain….

FIRST CASE : PARALLELISM BETWEEN STRATIGRAPHICAL SCALES BASED ON FOSSIL GROUPS IN DIFFERENTS BIOTOPES

SECOND CASE : EXISTENCE OF FAUNAL-FLORAL PROVINCES SEPARATED FROM EACH OTHER BY GROUPS WITH NO RELATION(S) BETWEEN THEM

THIRD CASE : EXISTENCE OF CONTINENTAL SERIES

- No stratigraphical fossils! => on the contrary = (paleo)climatic fossils
  => warm cool faunas/floras
  example: climatic evolution during the Quaternary based on molluscs, mammals, spores…
- need to search for 'transitional zones' with the marine domain
  example : Carboniferous => paralic basins (deltas) with continental series (with Plants) intercalated with a few marine incursions
  ==> FLORIZONES with PTERIDOPHYTA and PTERIDOSPERMAE interlayered with marine biozones (very useful for coal mining in Europe, India….)
- Continental series
  => MACROFLORAS = 'Houiller' (coal beds, Carboniferous)
  ⇒ MACROFAUNAS = VERTEBRATES : Tertiary, Quaternary
  ⇒ MICROVERTEBRATES (systematic separation) : Tertiary, Quaternary
  ⇒ MICROFAUNAS = Ostracodes…
  ⇒ SPORES : Palynology

••••

FOURTH CASE =>

FOURTH CASE : PROBLEM OF THE 'AZOIC' SERIES

• by definition, no paleontological criteria
⇒ other criteria that 'work'

(1) Sedimentary 'azoic' series : sedimentological criteria
⇒heavy minerals (Belgian Lower Devonian?, French Armorican massif …)
⇒palynology
[also area source or provenance]
⇒chemostratigraphy (Precambrian …)
⇒magnetic susceptibility
⇒uranium and radioactive peaks (well logging)
…
(2) Volcanic series = chronological criteria
(3) Granitic series : absolute dating
(4) Metamorphic series: microtectonic i.e. geometrical arguments, relation between foliation and axial plane in the folds + radiochronology

1-2-3-4 : search also transitional zones with dated or known sedimentary series
=> 'relative chronology'

FINALLY: EVERYTHING IS GOOD AS LONG AS IT 'WORKS!
Example : forms of pottery (archaeology), …. initially conodonts!

In conclusion, the principle of paleontological identity **is questionable** in **itself** because the (micro) faunal and (micro)-floral migrations may have occured (= paleo-bio-geography), therefore the age of a species is not necessarily the same at the end of the migration if compared with its beginning => possible diachronism?

- well-studied in the DSDP => to track the opening of the paleo-oceans

- complementarity with absolute chronology (despite a weaker precision)

PRINCIPLES 1 – 2 – 3

=

STRATIGRAPHICAL SCALE
BY SEARCH OF 'DISCONTINUITIES'

ANALYSIS OF CONTINUITY-THICKNESS OF SEDIMENTARY SERIES

TWO MAIN COMPLEMENTARY CATEGORIES OF SERIES

(A) COMPREHENSIVE and CONDENSED

No relation between thickness and duration

(B) CONTINUOUS and DISCONTINUOUS

Notion of lacuna or hiatus

Question? Thickness *vs* Time (duration)

Answer: no relation

cf. sedimentation rates Reefs *vs* Basin

cf. preservation potential (erosion syn-postdepositional)

Result: everything is possible in the sedimentary series …

=> **Example of two extreme cases = (A) Comprehensive and Condensed Series**

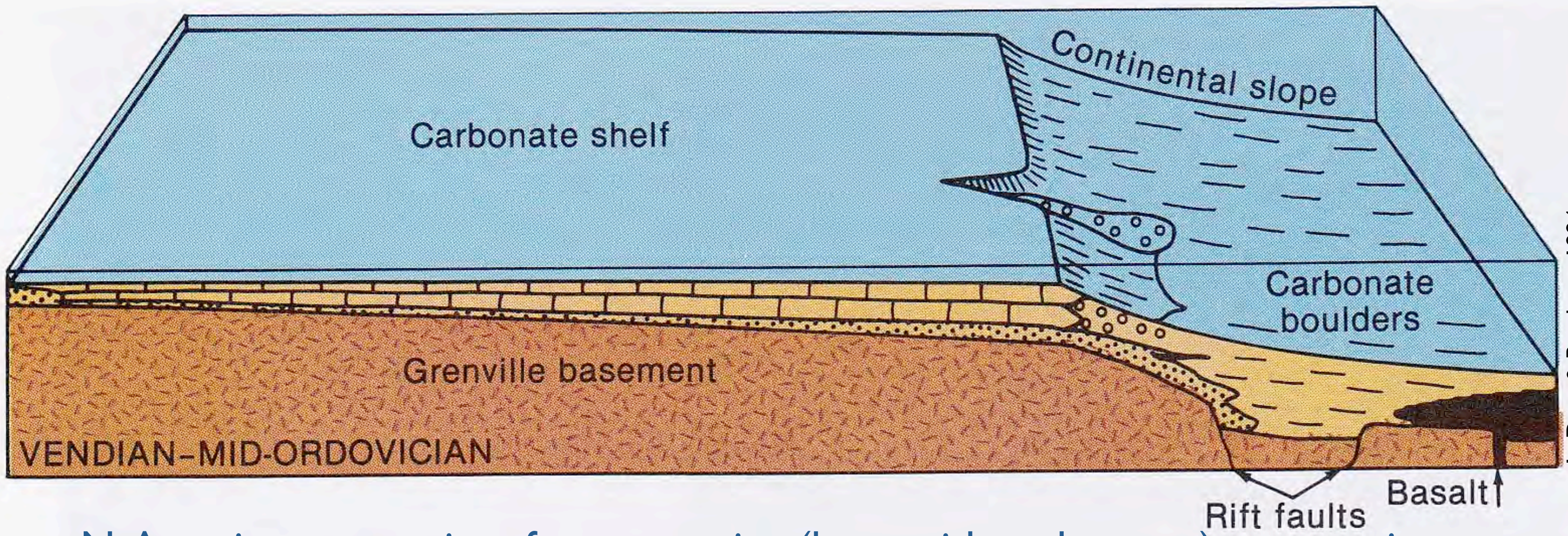
(A) COMPREHENSIVE and CONDENSED

Thick (up to km') 'monotonous' successions rapidly deposited

⇒**FLYSCH** ('fliessen' = flowing, sliding = Swiss term, 1853)

Thick marine succession of rhythmically bedded mudstones and graded muddy sandstones, today partially synonymous with deep-water turbidite

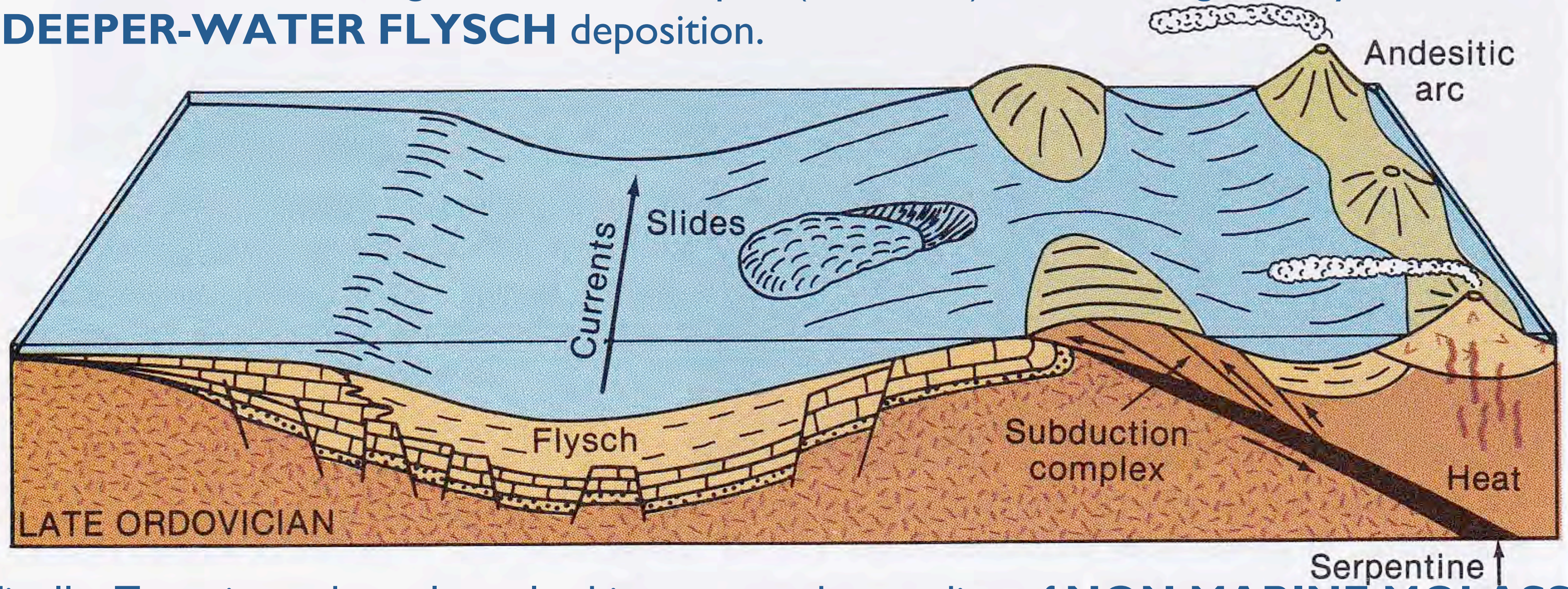
It is contrued as a **PRE-OROGENIC** or **SYN-OROGENIC FILL** of a tectonically trough or furrow



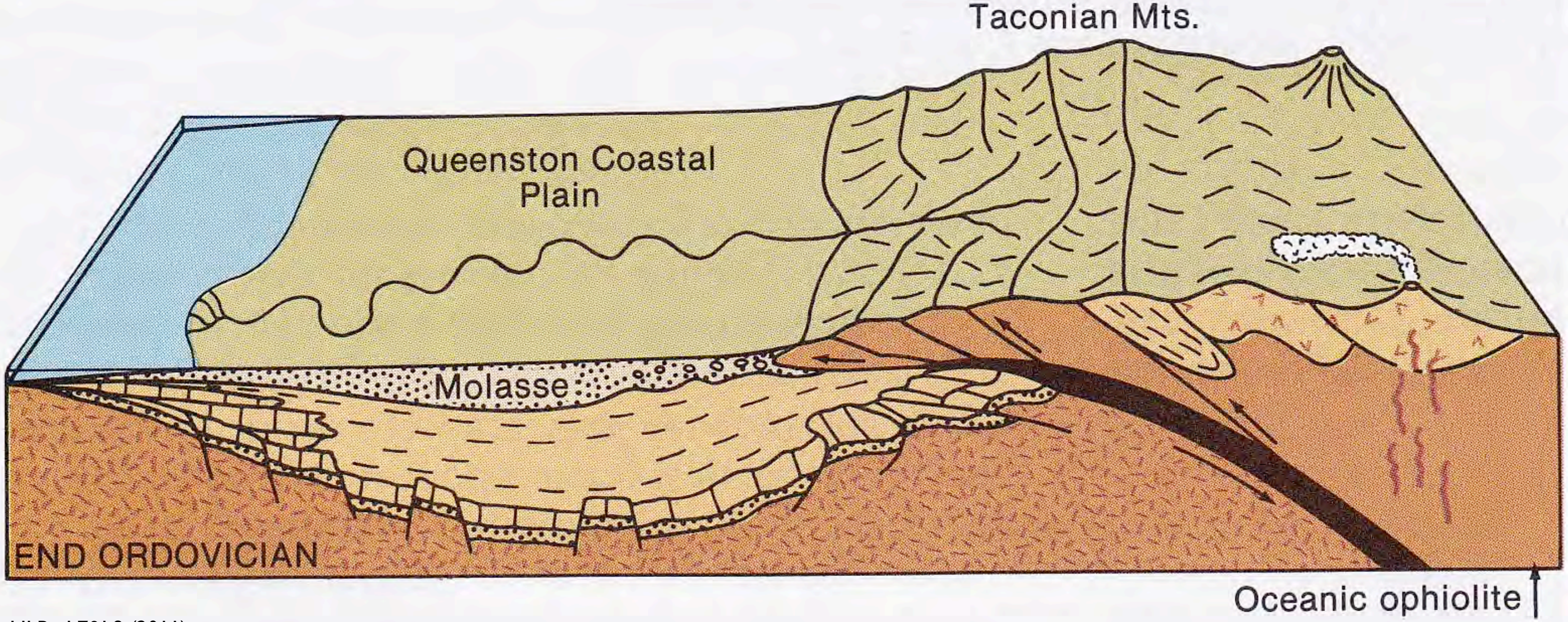
In Dott & Prothero 1994

Eastern N-America restoration, from a passive (here with carbonates) to an active continental margin culminating in arc collision = causing the TACONIC orogeny (Ordovician)

As the continental margin was downwarped (Late Ord), carbonate gave way to **DEEPER-WATER FLYSCH** deposition.

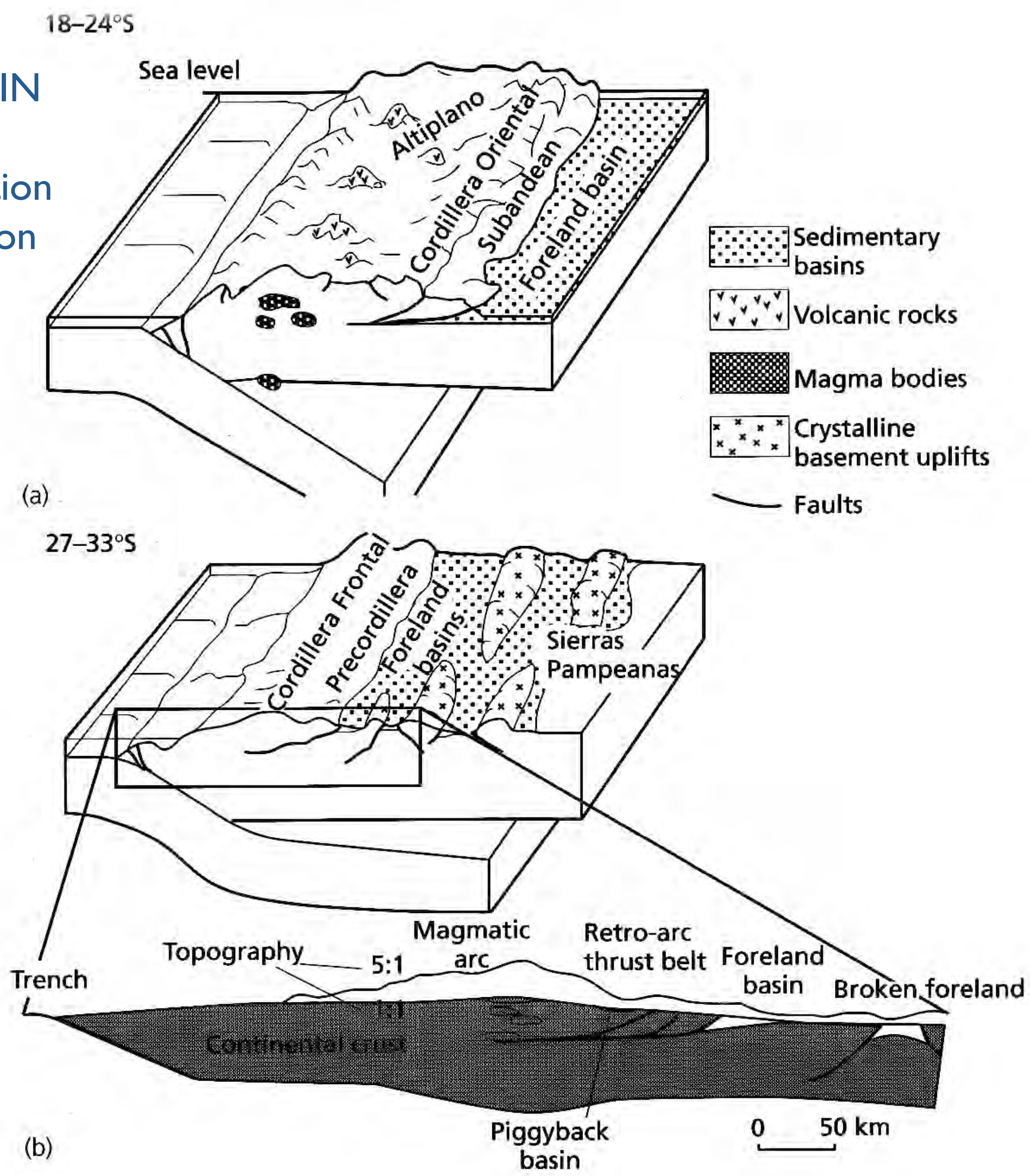


Finally, Taconian upheaval resulted in westward spreading of **NON MARINE MOLASSE**



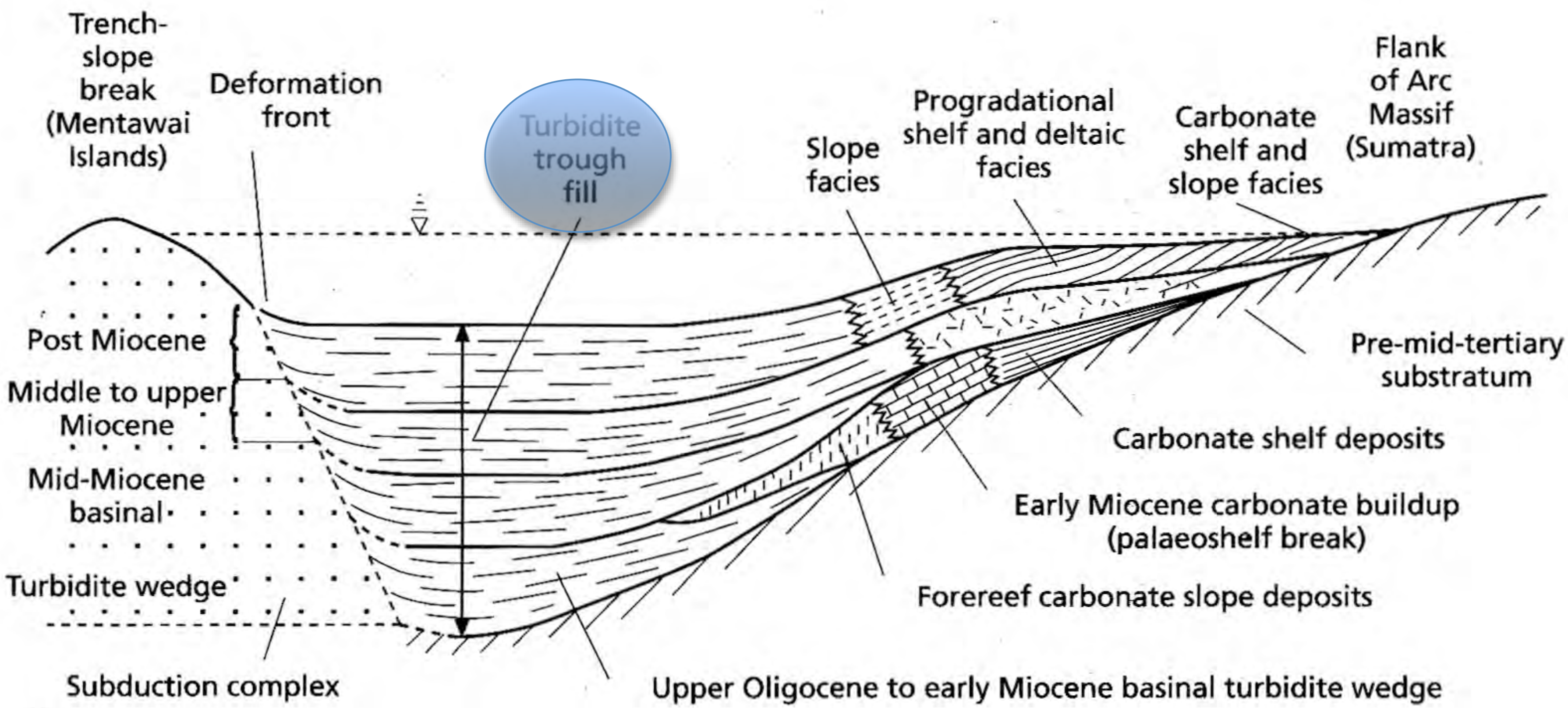
In Dott & Prothero 1994

FORELAN BASIN
ANDES
(a)northern section
(b)central section



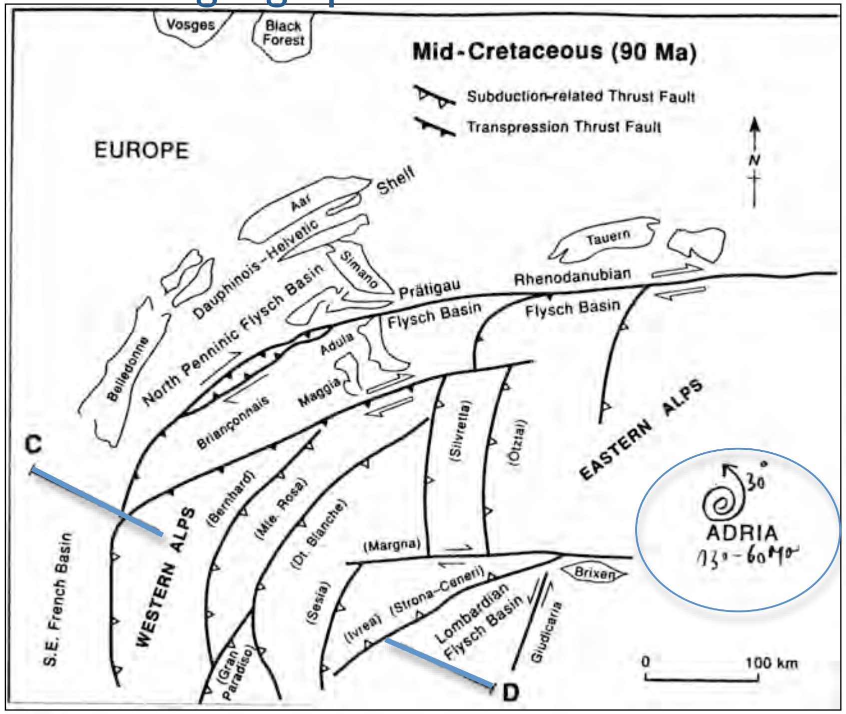
FACIES AND ENVIRONMENTS OF THE SUNDA FORE-ARC, INDONESIA

> 100 km, thickness up to1000's m

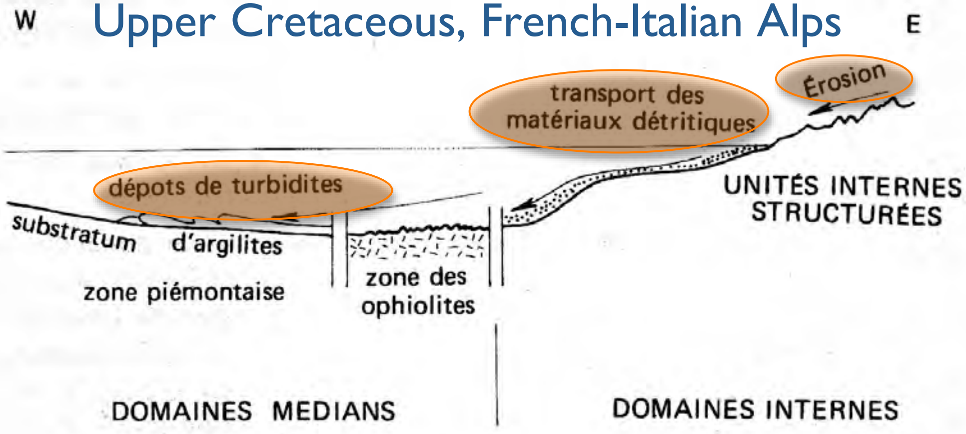


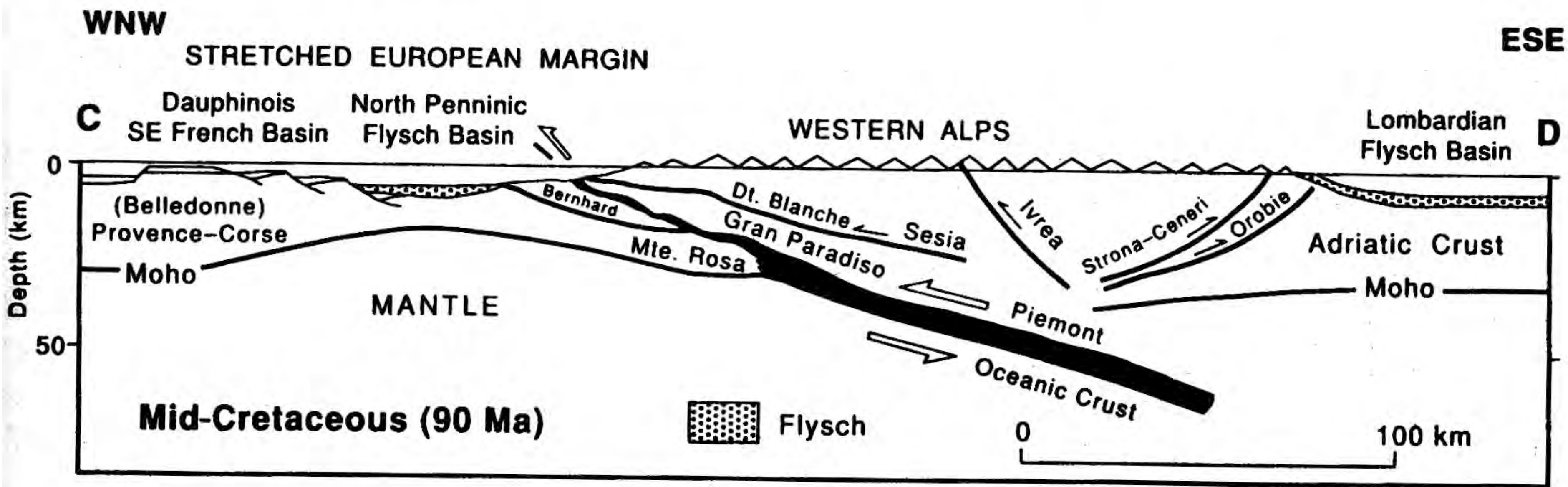
Dickinson 1995

Paleogeographic reconstruction : 'N-S' thrusting with shortening/uplifiting in a continent-continent collision



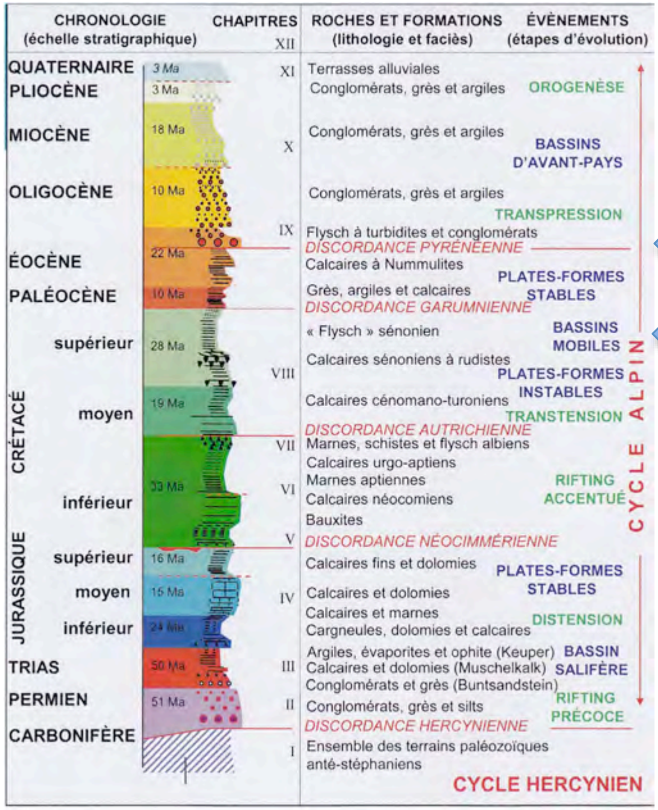
Upper Cretaceous, French-Italian Alps





'Eo-Alpine' subduction: the stretched European margin is about to collide with the Adriatic Microplate (Pfiffner 19992)

FLYSCHS ARE RELATED TO THE 'ALPINE CYCLE' FOREDEEPS TO THE N AND S RECEIVED CLASTIC SEDIMENTS FROM THE RISING ALPINE MOUNTAIN CHAIN



Folded Eocene Limestone FLYSCH (Pyrénées,N-Spain)

In Canerot 2008

= FORELAND BASIN(S)

Uplifting thrust fronts may act as major sediment suppliers

FORELAND BASIN(S)

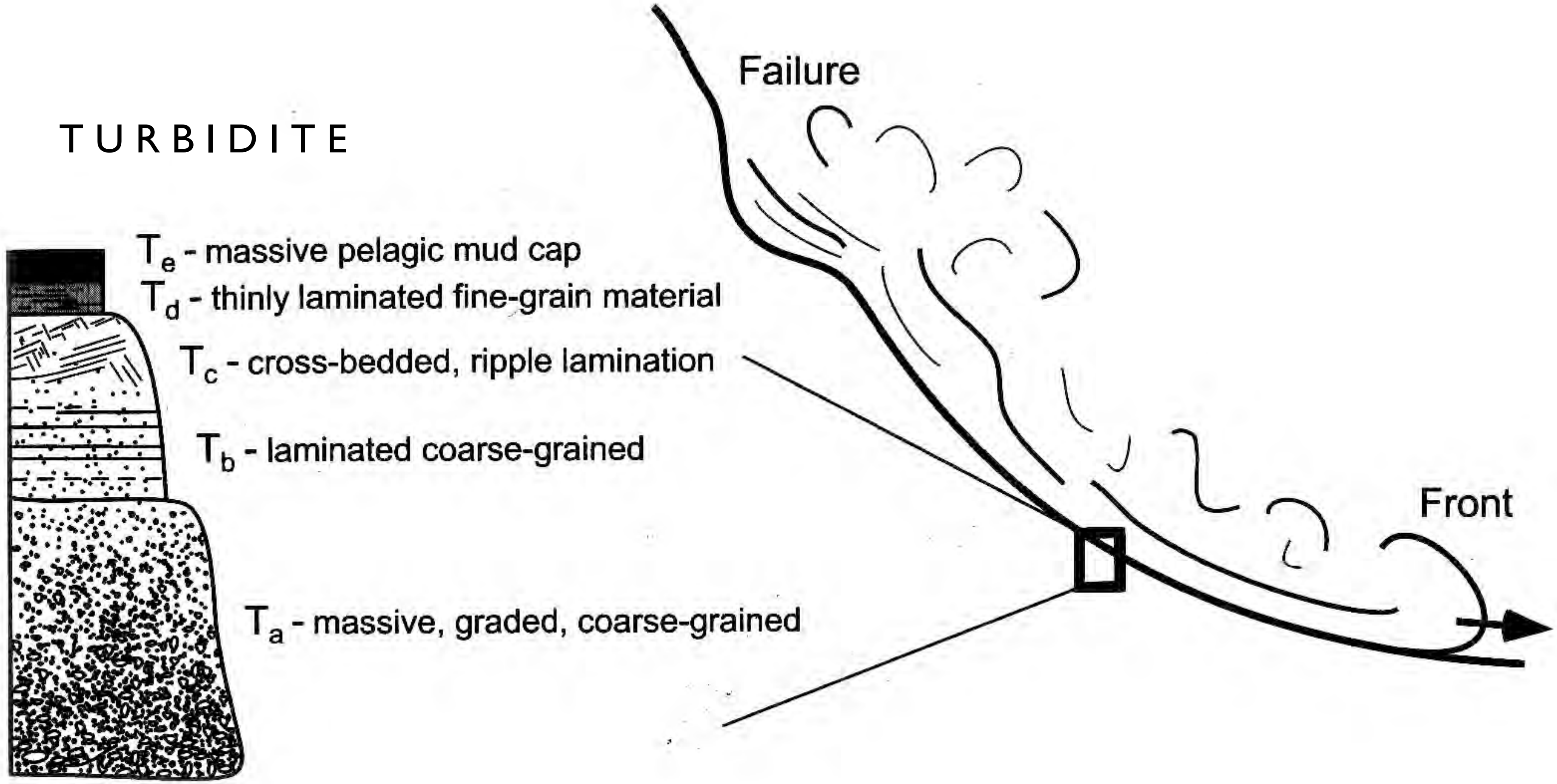
MONOTONOUS DETRITAL STACKINGS

- conglomerates, sandstones, pelites with carbonate intercalations
- = **TURBIDITES** in conformity with underlying stata
- often incorporated in important 'thrust nappes or 'thrust slices'
- sedimentation mode : **deep dea fans** in a basin ahead of the active thrust system (= in a **foredeep setting**) ⇔ discovery due to the sequential destruction of telegraph cables, lying along the continenal slope and rise in the Atlantic! – 1929 'Grand Banks' earthquake and failure)

TURBIDITE = **BOUMA SEQUENCE** (from medium-grained turbidites)
Represents a single catastrophic flow with a scoured base overlain by a massive graded bed **(A)** which corresponds to the coarsest material to settle out of suspension as the turbidity current slowed. Above this is plane lamination **(B)**= high-flow regime, then ripples and wavy laminations **(C)** = lower flow-regime. Unit **(D)** is laminated silt and **(E)** is laminated mud that settle out of suspension during the waning of the turbidity current. In some cases, unit E is topped by laminated hemipelagic mud **(Eh)** that settled from suspension in the episodes between the turbidity currents.

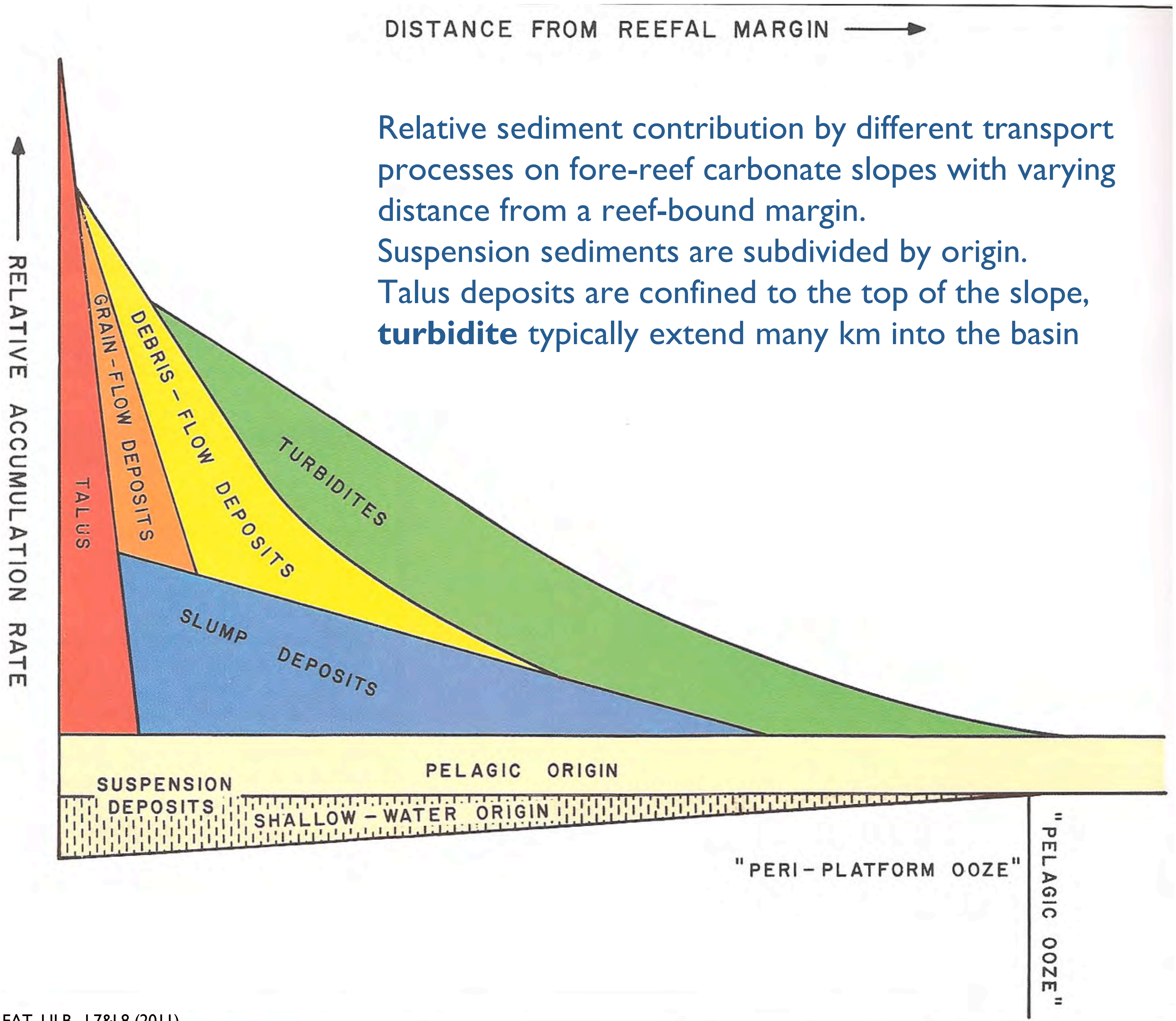
GRAVITY FLOW GENERATED FROM A FAILURE SUCH AS THE GRAND BANKS SLIDE

TURBIDITE



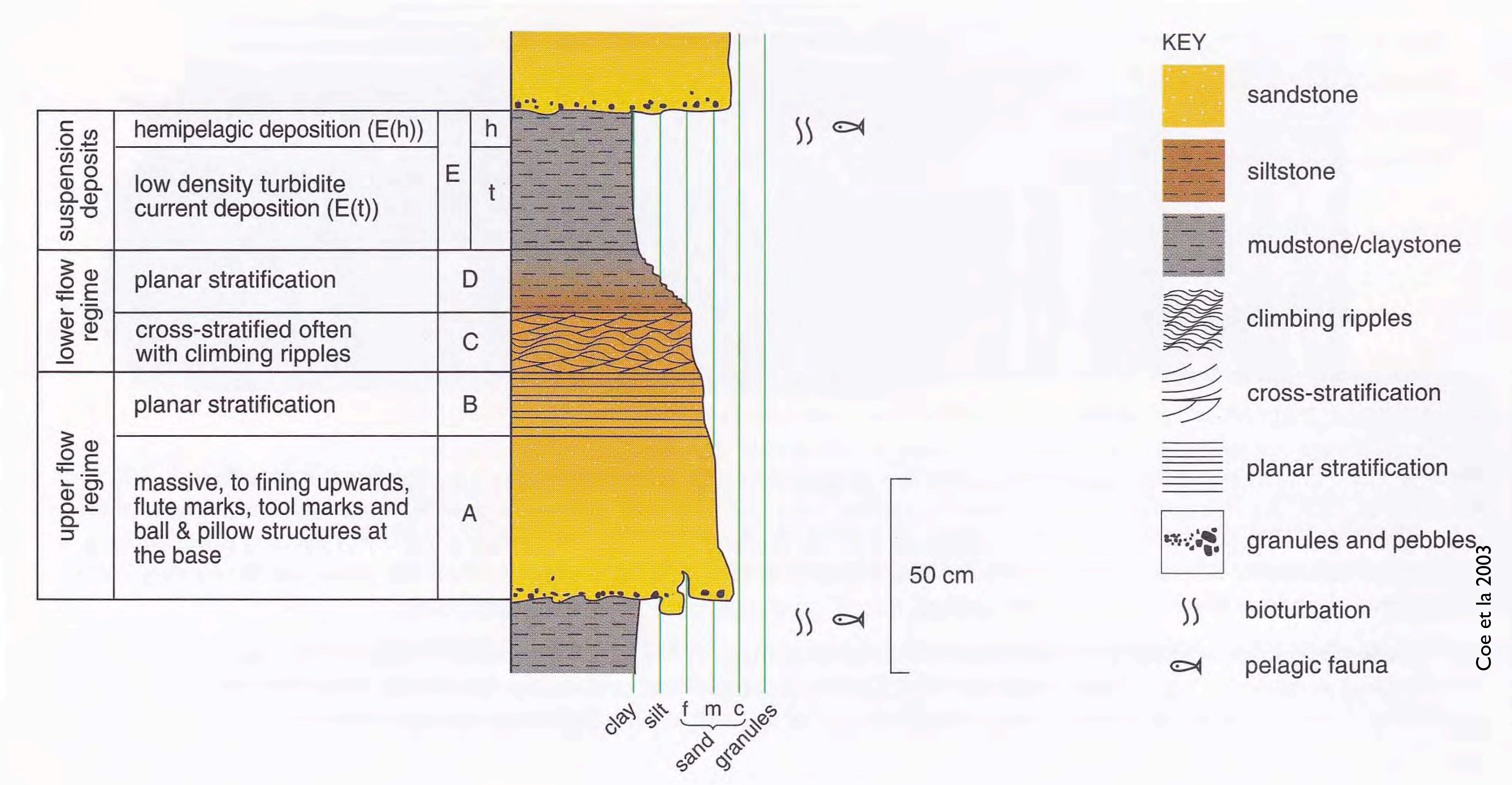
Bouma 1962

Relative sediment contribution by different transport processes on fore-reef carbonate slopes with varying distance from a reef-bound margin.
Suspension sediments are subdivided by origin.
Talus deposits are confined to the top of the slope, **turbidite** typically extend many km into the basin



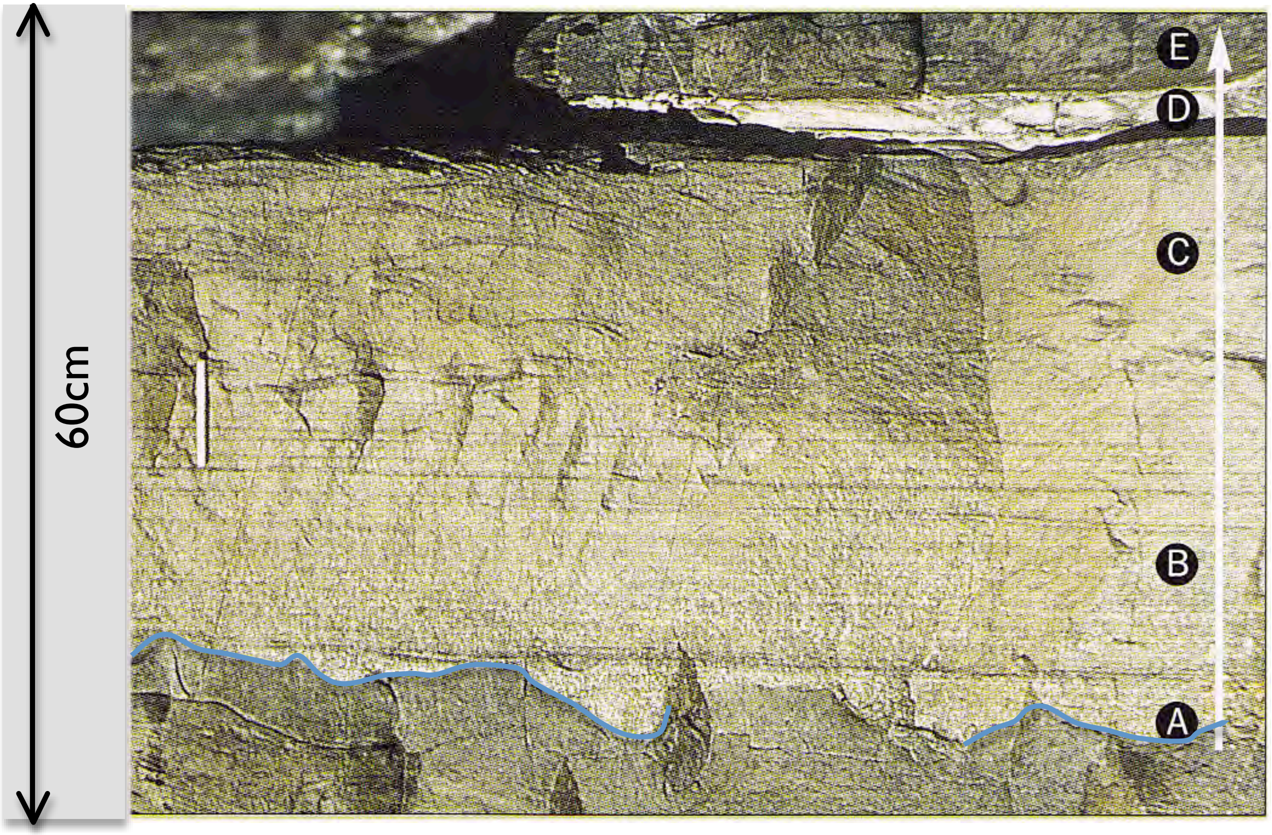
Scholle et al 1983

Turbidite sequences (A-E) accumulate as broad sheets and lobes of sediment that spread out from submarine canyon and built extensive **submarine fan** complexes



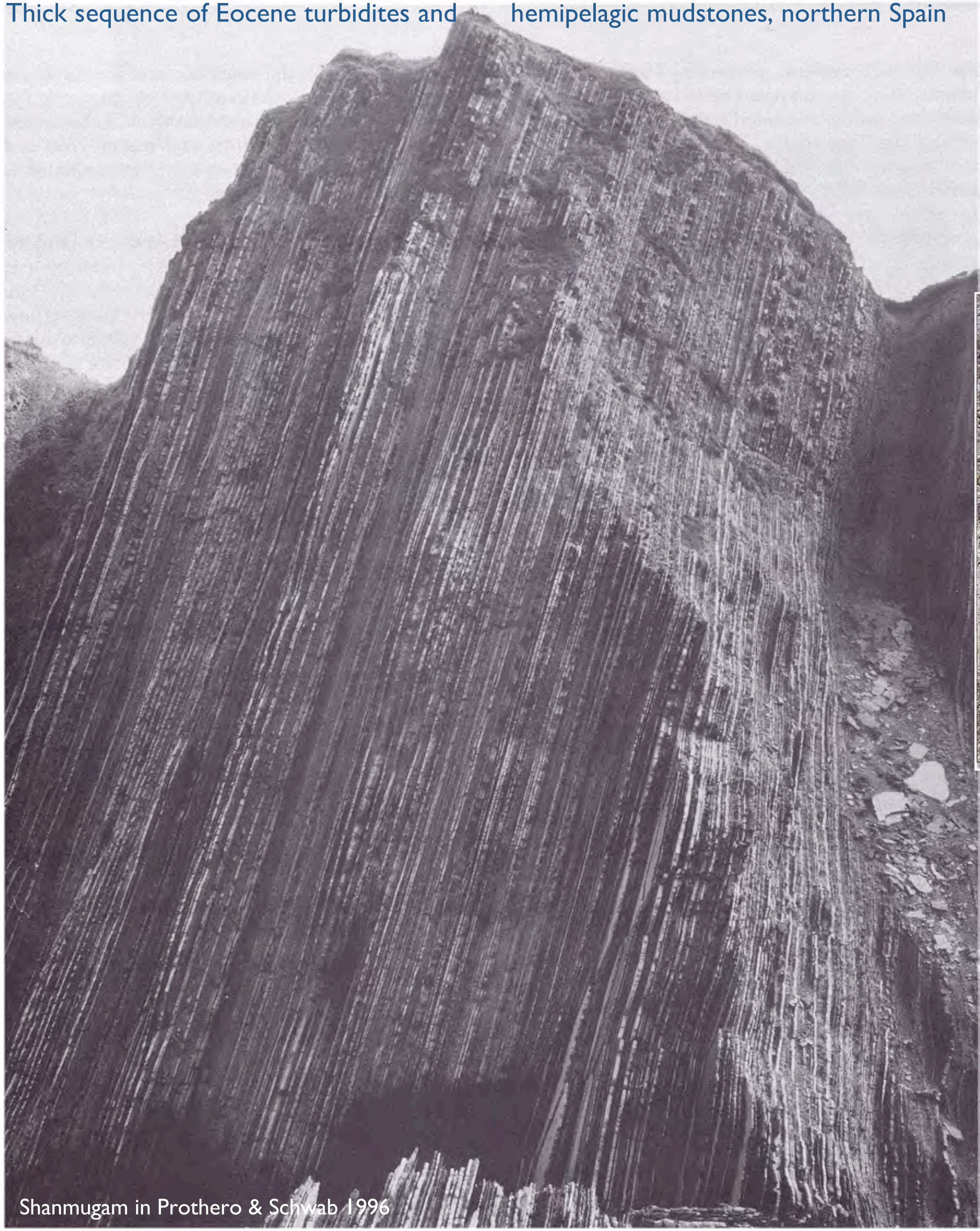
Turbidite sequences (A-E) are **rarely complete**, they are truncated….

A TYPICAL BOUMA SEQUENCE



Lithic muddy sandstone (lithic greywacke) **TURBIDITE BED** (A up to E), showing **erosive base**, **normal grading** and standard Bouma sequence (A-E). Ordovician, Southern Uplands, Scotland (from Stow 2005).

Thick sequence of Eocene turbidites and hemipelagic mudstones, northern Spain



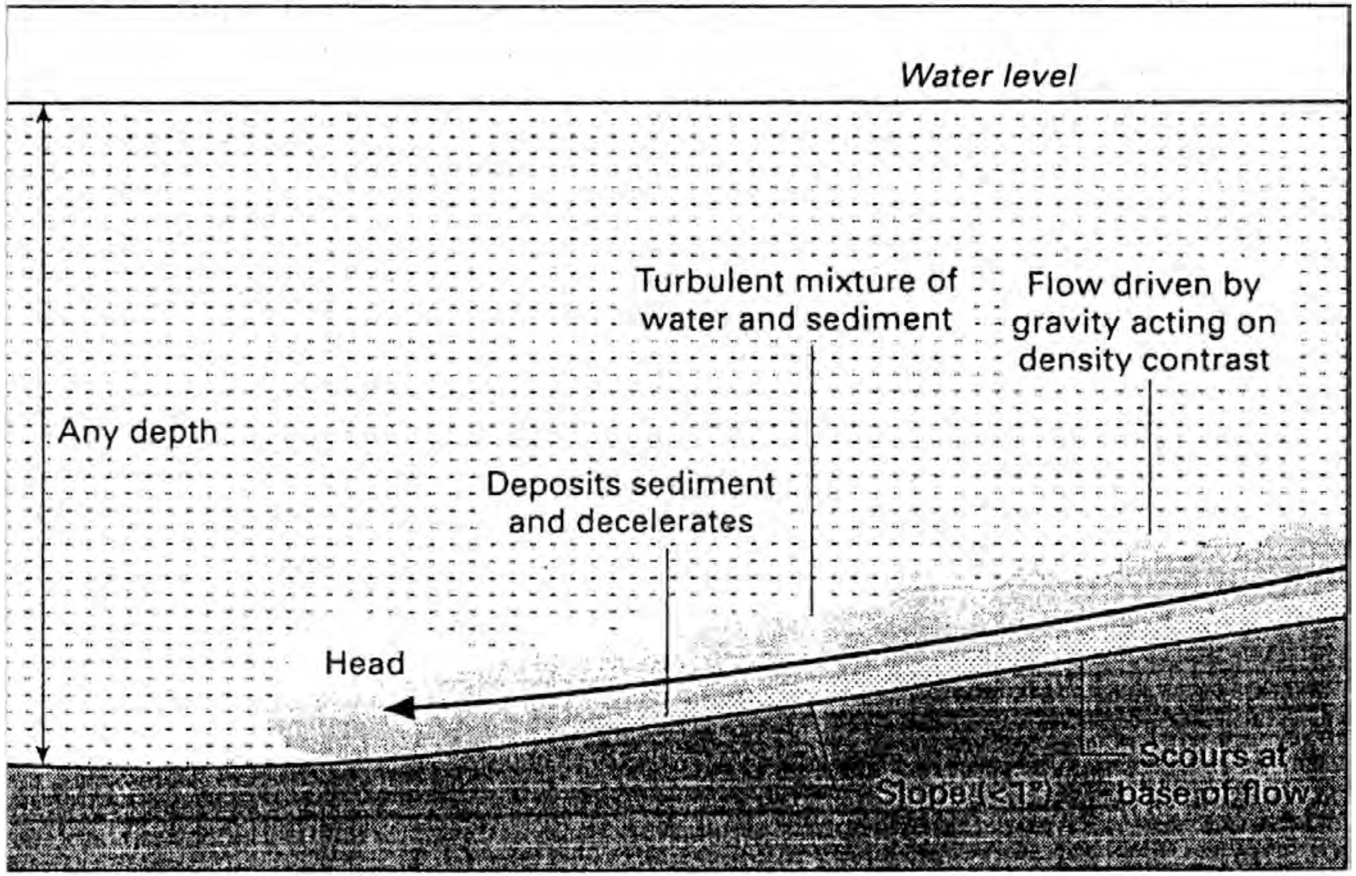
Shanmugam in Prothero & Schwab 1996

Interbedded turbidites (arrows) and hemipelagites (note low angle reverse faulting due to tectonic compression). Mio-Pliocene, near Tokyo, Japan. From Stow, 2006.

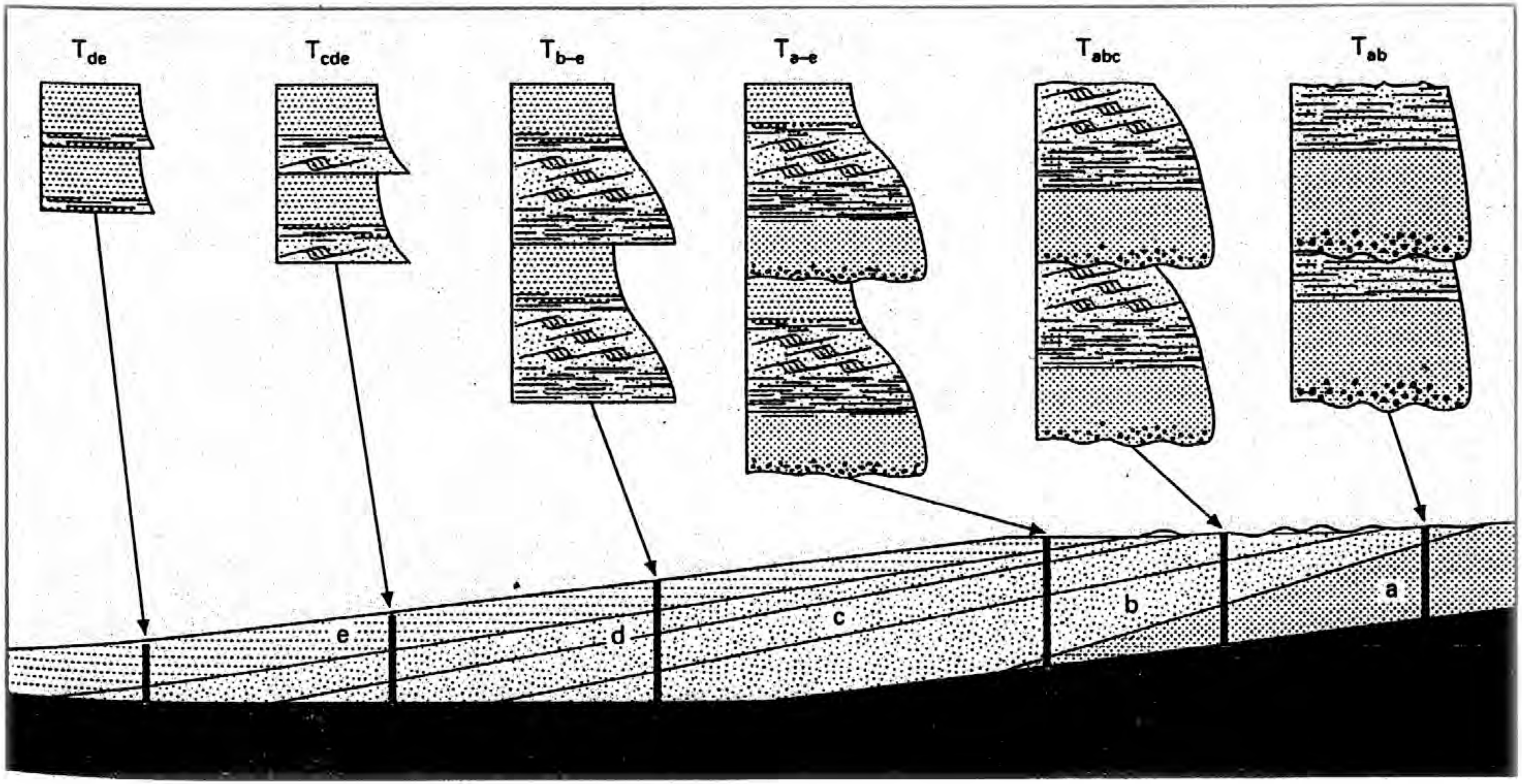
APPLICATION

- geopetal criteria (Stavelot massif, Belgium)

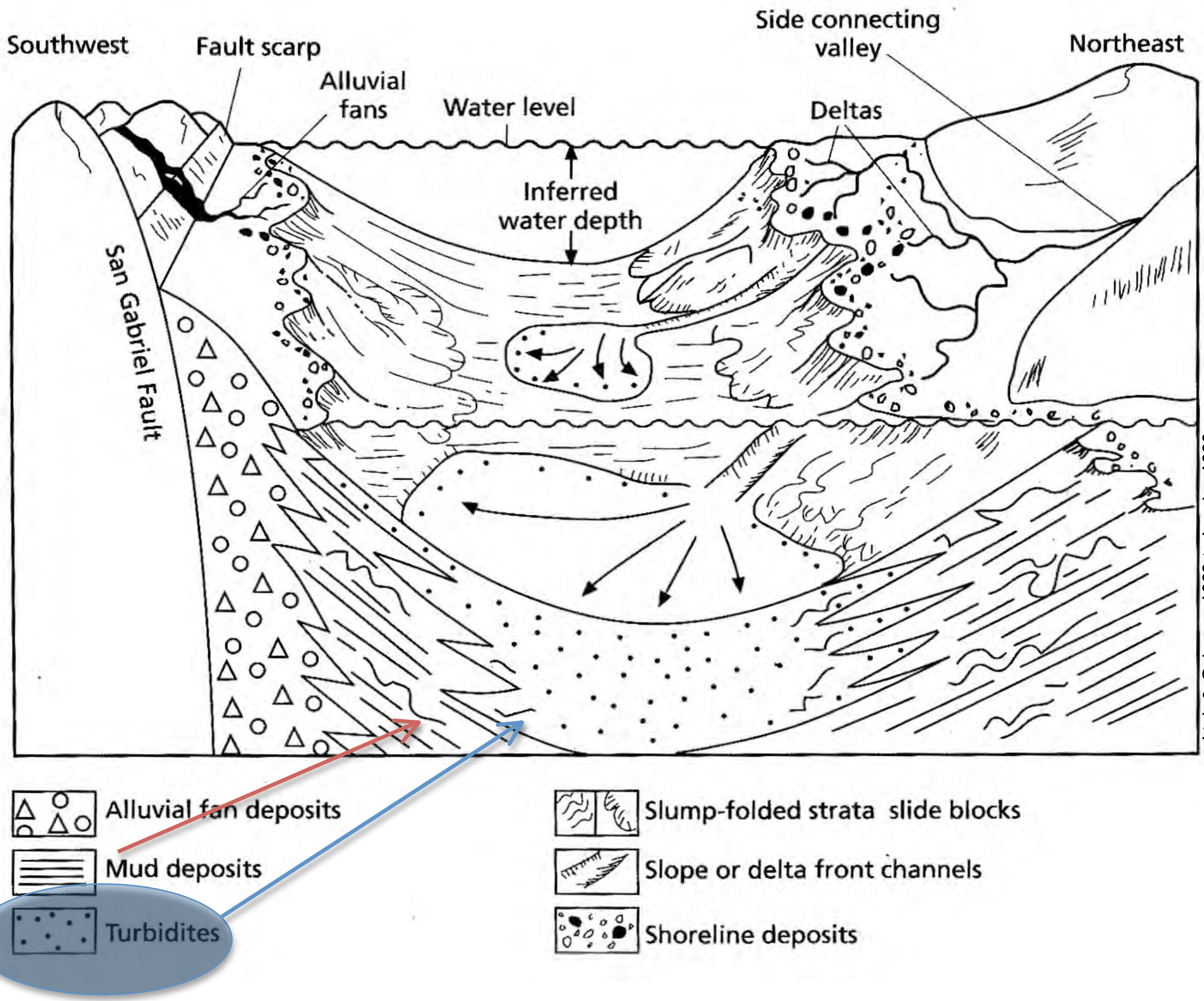
- paleogeographical reconstruction
 => **PROXIMAL** (A,B) vs **DISTAL** (C,D,E) FLYSCHS



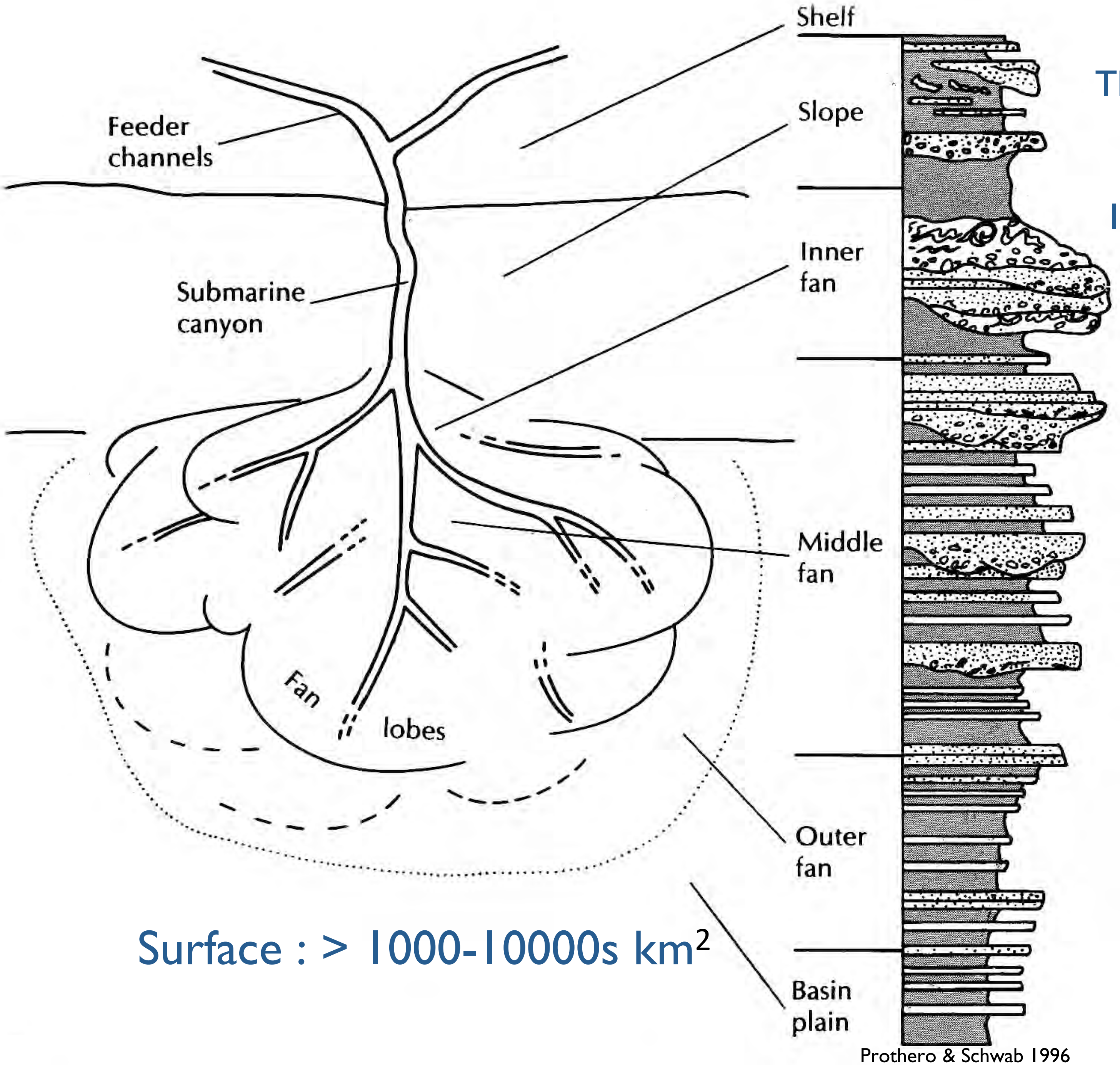
DISTAL PROXIMAL



Depositional environments, Ridge Basin, California

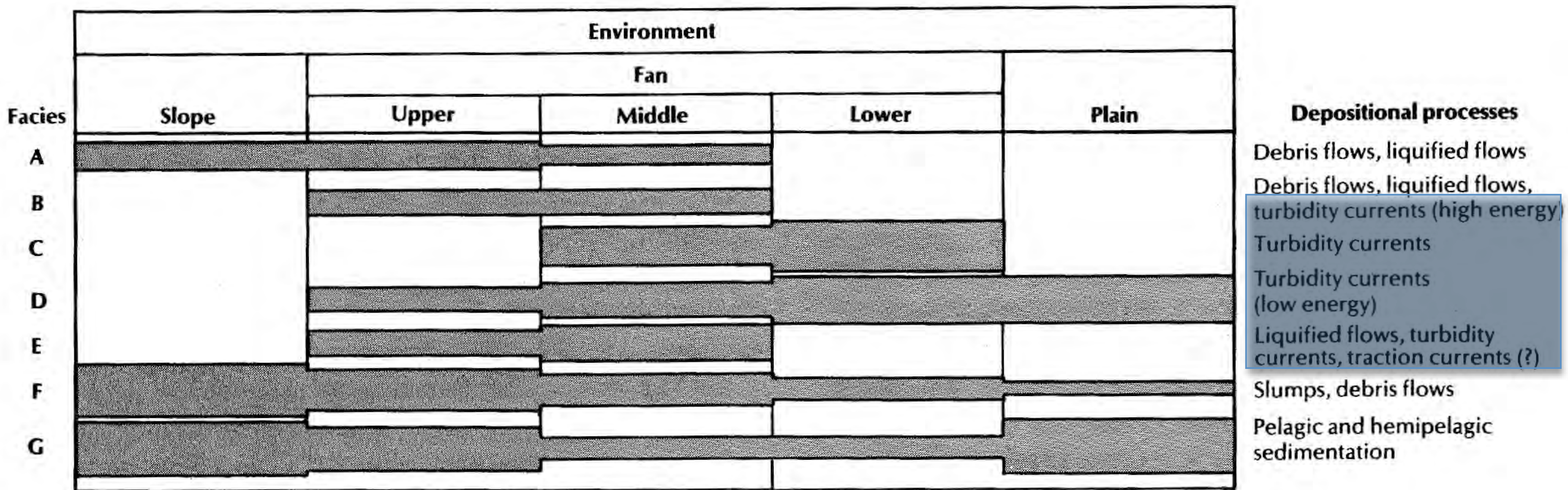


Link & Osborne 1982 in Leeder 1999



Thickness 100s m up to 1000s m

Surface : > 1000-10000s km^2



Prothero & Schwab 1996

Every turbidites

=> ALLOCHTHONOUS DETRITAL inputs

continental platform

⇒ AUTOCHTHONOUS PELAGIC inputs

planktonic 'rain' => **DATATION** is possible

Extensive paleogeographic domains

The term 'flysch' originally was applied to a formation of the Tertiary Period

In the northern Alpine region, but it now denotes similar deposits of other ages and places

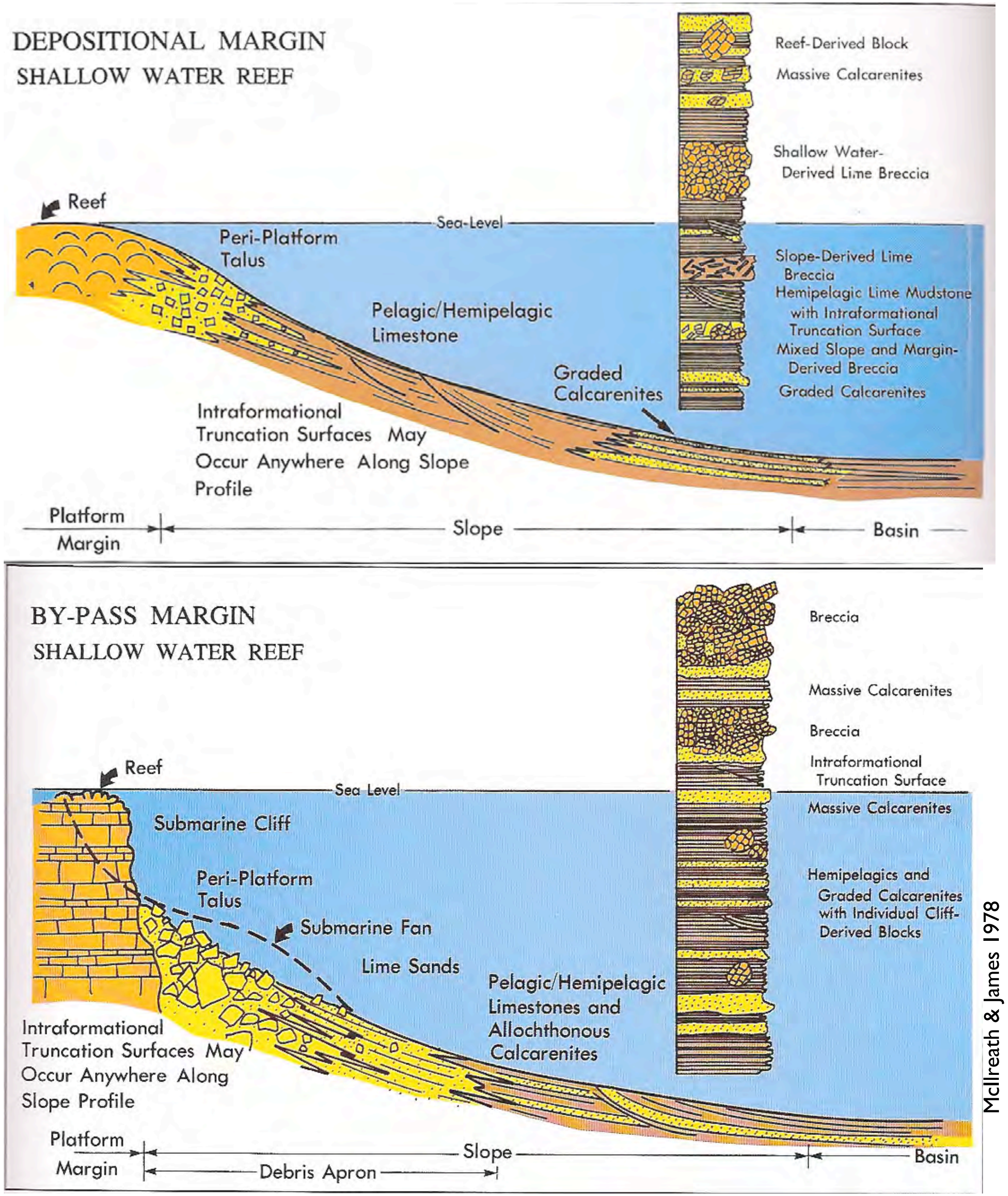
Examples :

FLYSCH AND MOLASSE IN KURDISTAN, NE IRAQ
CONCURRENT AND LATERAL DEPOSITION OF FLYSCH AND MOLASSE IN THE FORELAND BASIN OF UPPER CRETACEOUS AND PALEOCENE FROM NE-IRAQ, KURDISTAN REGION
Kamal Haji Karim (1) Ali M. Surdashy (2) and Sherzad Tofeeq Al-Barzinjy(1)

…

TODAY: CONGO CANYON, MONTEREY CANYON (USA) ….

SLOPE MODELS



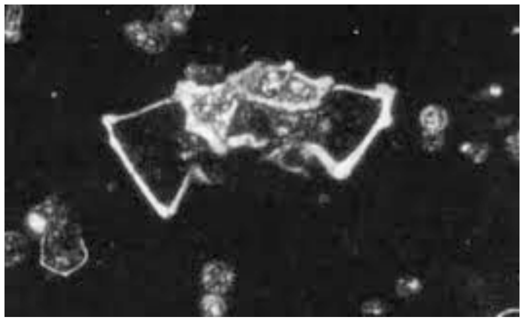
McIlreath & James 1978

Flysch deposits have been defined in Europe => foreland of the Alps, the Pyrenees, Carpathian … Italy, Greece, Cyprus …
Then found 'everywhere': Tunisia, Algeria, Indonesia etc.…

- Upper Eocene, Paris basin : a few dozen metres
- **Upper Eocene: the French-Italian (Western) Alps**
  same age but > 1000 m
  it is one of the best-known flysch series
  (ranging between 900 – 1500 m)

HELMINTHOID FLYSCH NAPPE

Ichnofossil (worm?)
= facies, no age

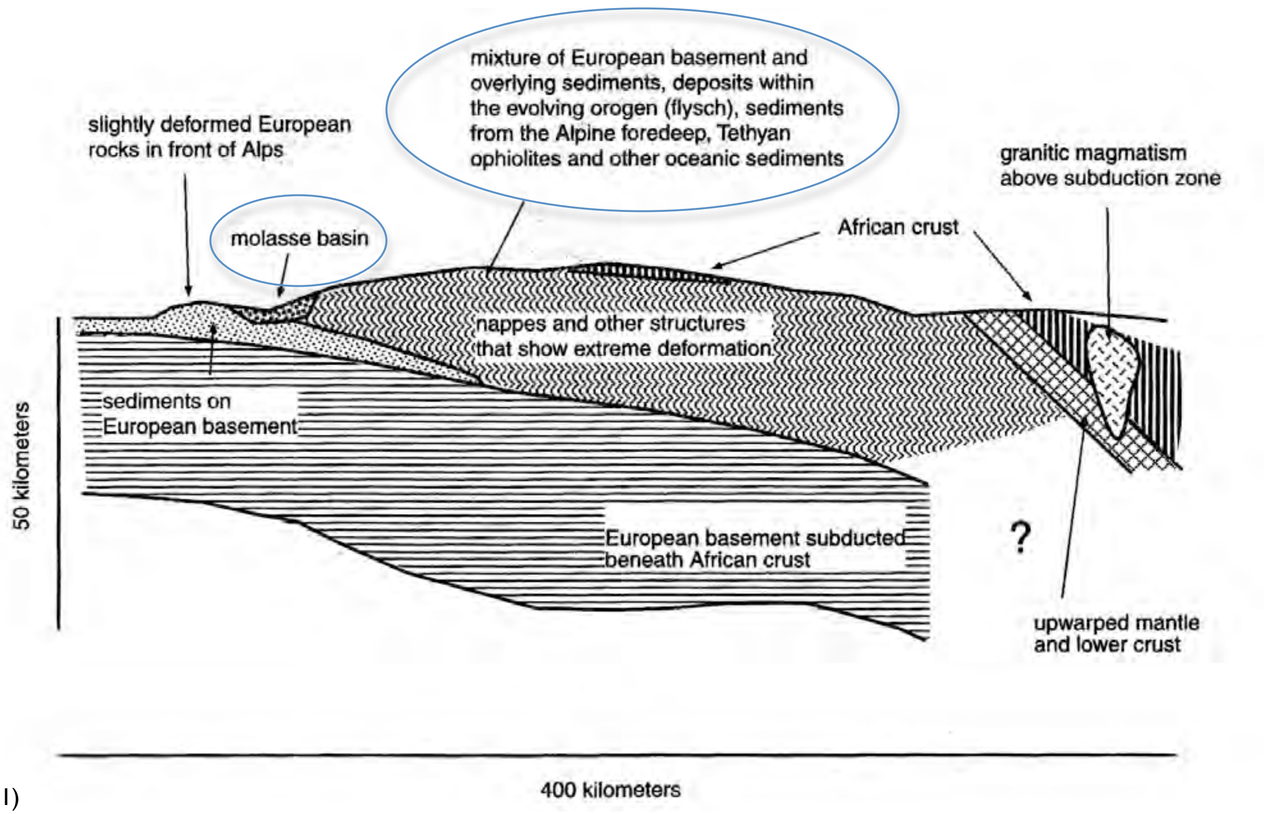


With microfossils
GLOBOTRUNCANES
(plurilocular foraminifers)
⇒ accurate K biozones =
⇒ Late Senonian
= (Campanian/Maastrichtian)

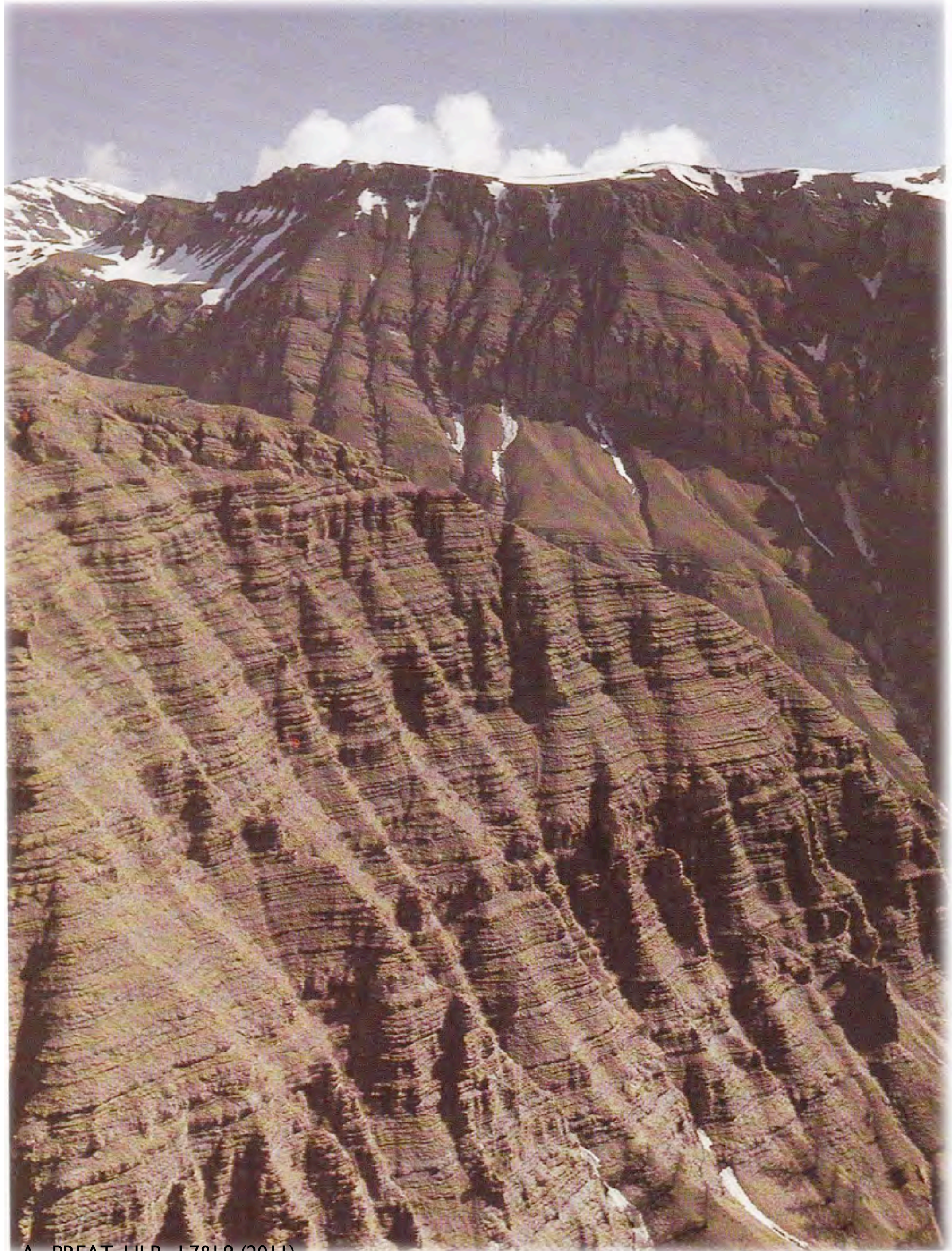
HELMINTHOID FLYSCH **NAPPE**

Why a 'NAPPE'? : the Alpine orogen (=descending European slab before colllision with Africa) was so intense that the series of the suture zone were THRUST upward and northward instead of remaining as a linear suture between the colliding blocks.

The intensity of the collision was sufficient to thrust some parts of the African continent across both the European block and the Tethyan suites.



Schmid & Kissling 2000



Helminthoid Flysch ('Hautes-Alpes')
(Embrun – Guillestre)

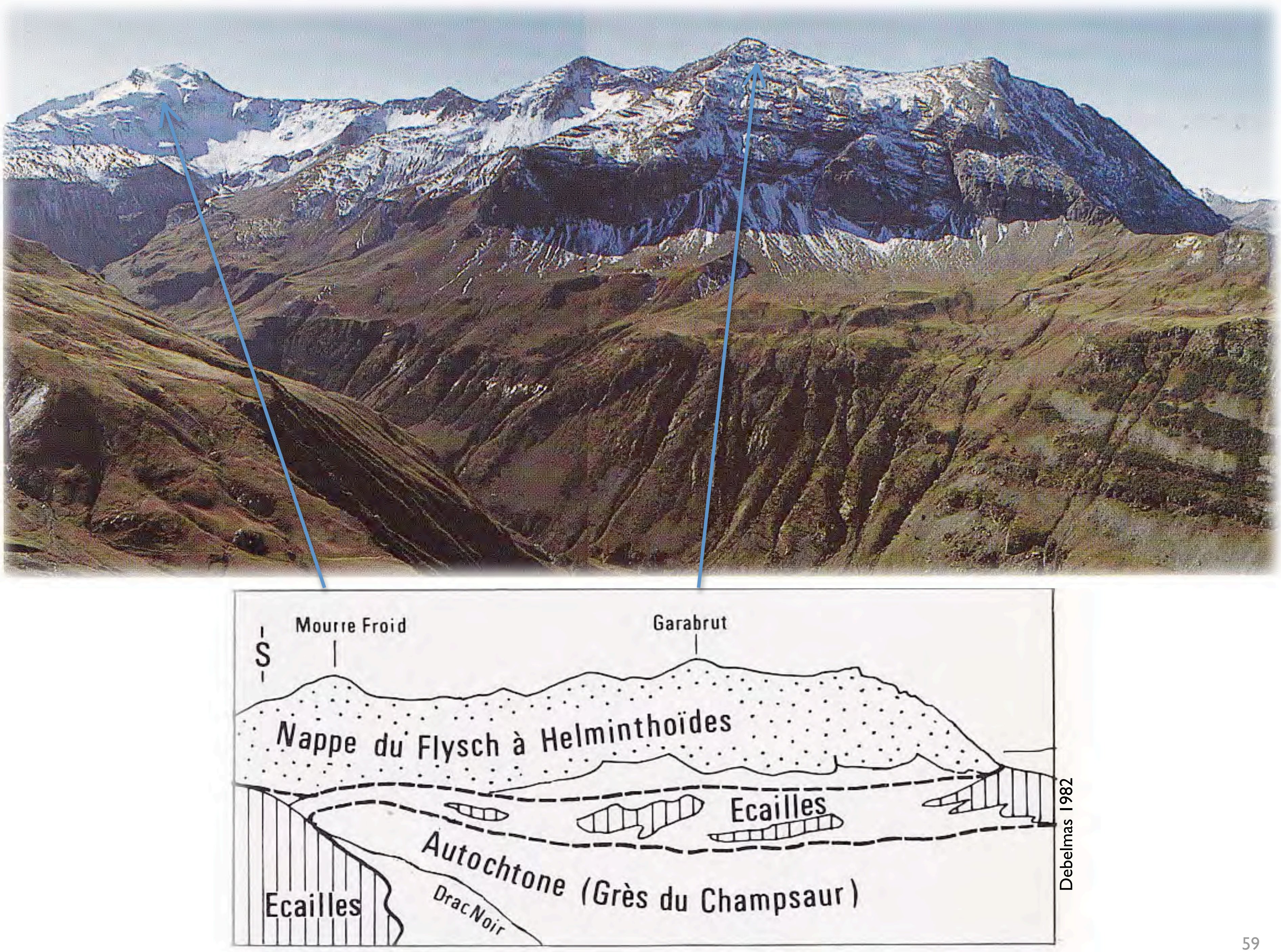
Upper Cretaceous

Debelmas 1982

reptation trace : worm?, gastropod?

=(PALEO)ICHNOLOGY

A. PREAT–ULB, L7&L8 (2011)



Debelmas 1982

Flysch = sediments deposited within an orogen undergoing active deformation
Molasse refers to sediments that were deposited either after active deformation had stopped or in areas outside the zone of deformation

HELMINTHOID FLYSCH NAPPE

base

a. lower part : >200m 'basal shaly complex' [complexe schisteux basal]
= indurated black clays, No apparent stratification + a few dm beds of fine-grained colored (by Fe, Mn) sandstones

b. a few 10s m = 'versicolored shales' [schistes colorés versicolores]
siltstones (20-70µm)

c. laminated limestones [calcaires plaquettés] thickness from a few m => 100m
= alternation dm beds of very fine-granied sdst/lmst/brown-black shales

d. HELMINTHOID FLYSCH ss >500m
either limy (limestones) or sandy (sandstones) with ca. 700 sequences (turbidites) without paleontological markers
=> at the base, rare beds with *Globotruncana*

top ==> Upper Cretaceous (Senonian): Campanian/Maastrichtian

ORIGIN OF THE DEPOSITIONAL ENVIRONMENT?

ORIGIN OF THE DEPOSITIONAL ENVIRONMENT?

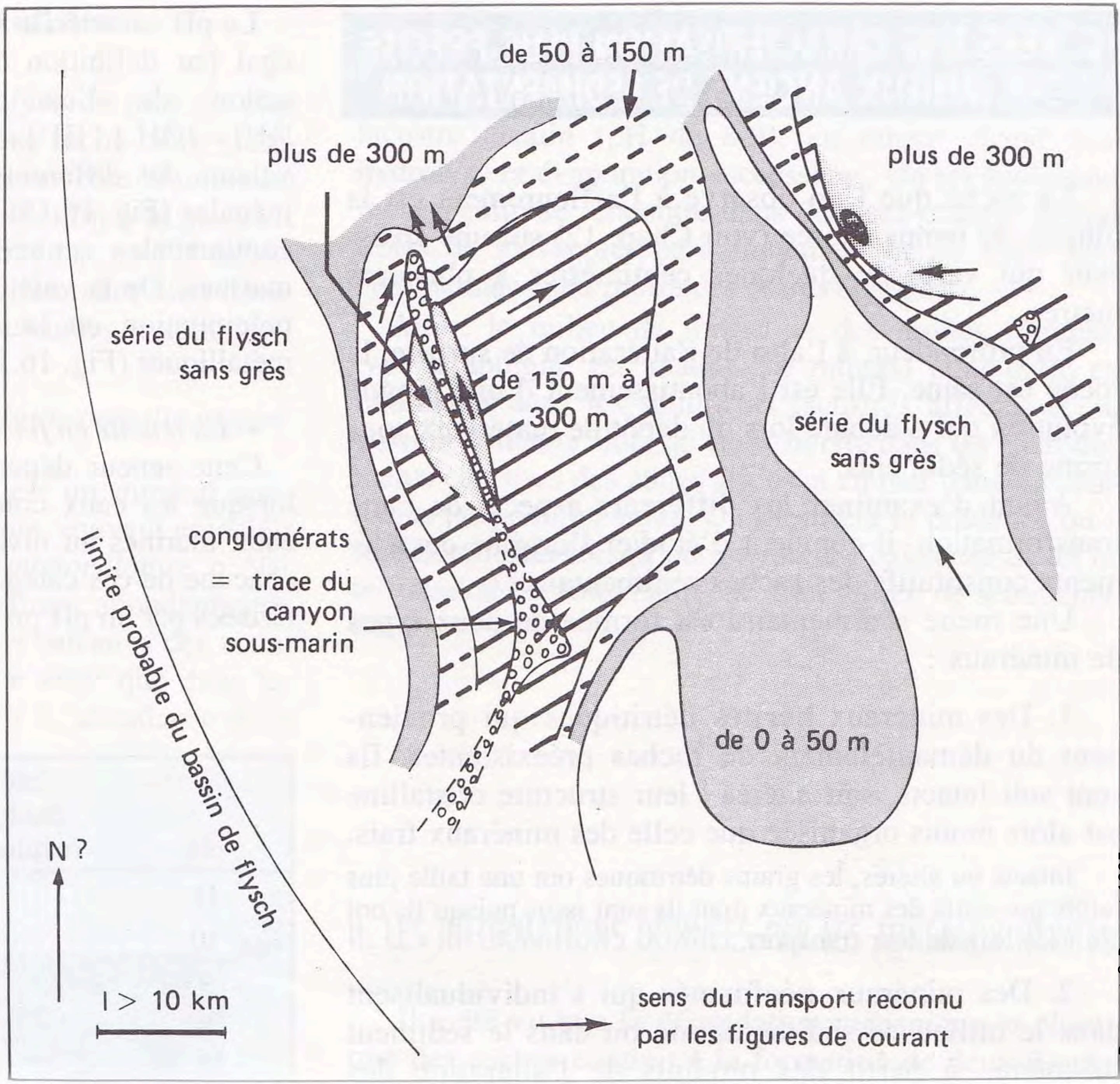
1. Poverty of microfaunas in the limestones and clays
   => 'pelagic' and great depth as absence of carbonate planktonic tests due to dissolution ⇔ CCD (lysocline)
   nb: CCD locally variable, event today. Generally > 2000m, today 4500-5000m
2. Brownish-darkish clays rich in Fe and Mn
   Today = Atlantic and Pacific > 1000 m
3. Turbiditic sequences => deep environments

- paleogeographical reconstructions
- lateral thickness varitaions of the sequences
- vertical variation of grain-size (cgt/sdst/clays)

the maximum thickness of sandstones = inside a N-S trough (60kmX10km)
the conglomerates (> 2cm) are associated with the thickest sandstones
…..

Recognition of a submarine canyon oblique in the through, with a S-N transport of the detrital sediments

IN THE NAPPE!



Dercourt & Paquet 1995

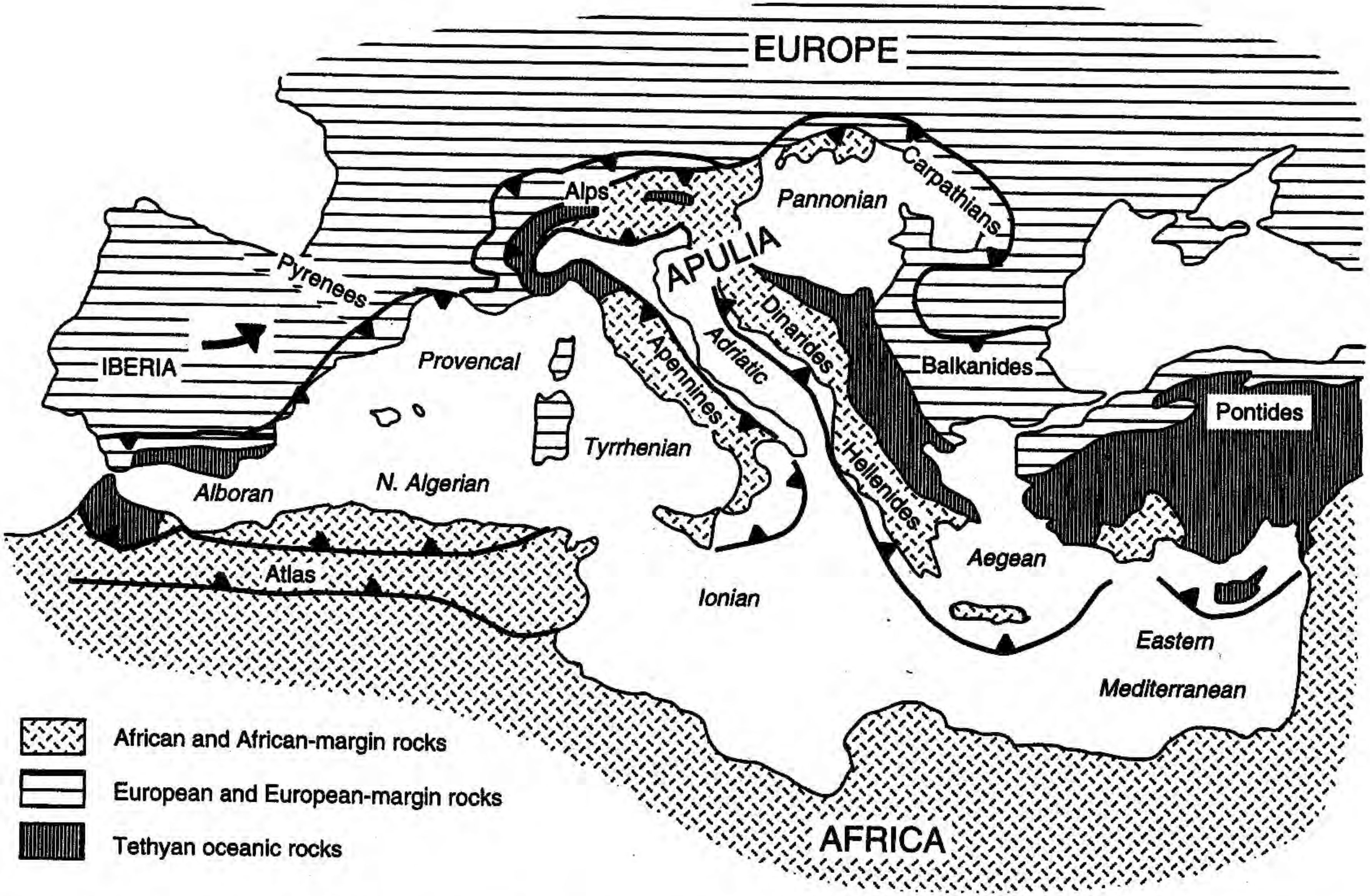
ORIGIN OF THE DETRITAL MATERIAL?

Sedimentary petrography (thin section, then geochemistry)
⇒ possible to infer the nature of the emerged areas which have been eroded
==> example from the CONGLOMERATES

- granitic and ryolitic pebbles
- arkosic pebbles
- flysch source = emerged, eroded, granitized are without sedimentary cover
- clay types ⇔ 'paleoalterites' ⇔ paleoclimates
- geochemistry of granites ⇔ plate tectonics (margin types)
- …

The FLYSCHS are well represented in the troughs of the Alpine Chains (foreland basins) => ALPS, PYRENEES, HELLENIDS, APENNINES ….. N-Africa (ATLAS…..) and far to the East (Himalaya, TIBET…)

Age : Cretaceous - Eocene



Rogers & Santosh 2004

Figure 9.9. Evolution of Mediterranean Sea. Subduction zones are shown by conventional symbols. Basins are in italics and mountain ranges in normal font. Iberia is shown rotating counterclockwise because of opening of the Bay of Biscay to the north. The Alps are further discussed in chapter 2.

FLYSCH AND MOLASSE IN KURDISTAN, NE IRAQ
CONCURRENT AND LATERAL DEPOSITION OF FLYSCH AND MOLASSE IN THE FORELAND BASIN OF UPPER CRETACEOUS AND PALEOCENE FROM NE-IRAQ, KURDISTAN REGION
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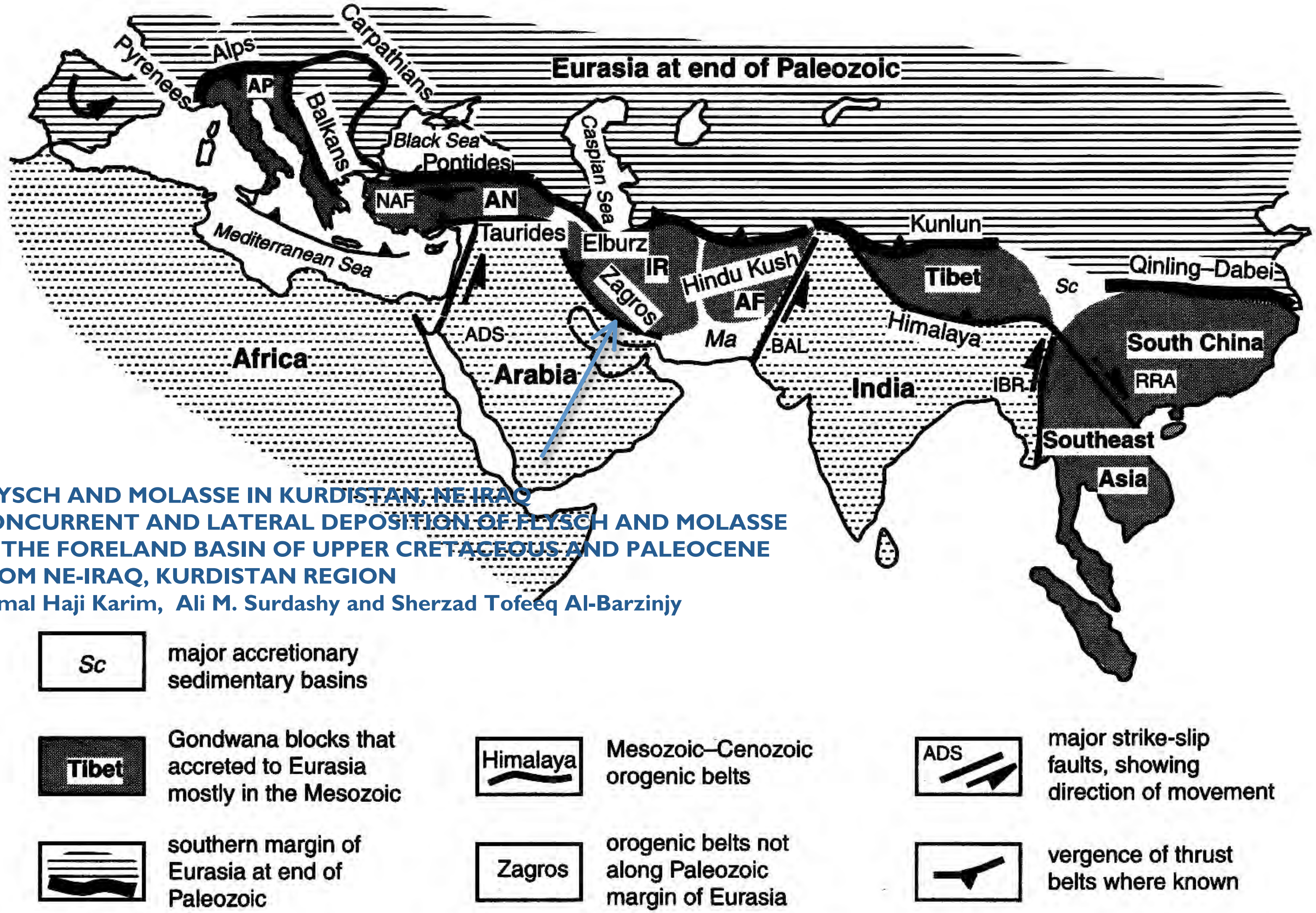


Rogers & Santosh 2004

Figure 10.2. Compression along the southern margin of Eurasia. The Iberian peninsula is shown rotating counterclockwise. Abbreviations are: AP, Apulia plate; NAF, North Anatolian fault zone; AN, Anatolia; IR, Iran; AF, Afghanistan; Sc, Southwest China flysch basin; ADS, Aqaba–Dead Sea fault zone; Ma, Makran accretionary prism; BAL, Baluchistan fault zone; IBR, Indo-Burman ranges; RRA, Red River–Ailongshan fault zone. Three mountain ranges are discussed in more detail elsewhere: Alps, chapter 2; Zagros, chapter 5; Himalaya, chapter 5.

FLYSCH = ‘TECTOFACIES’ related to an orogen

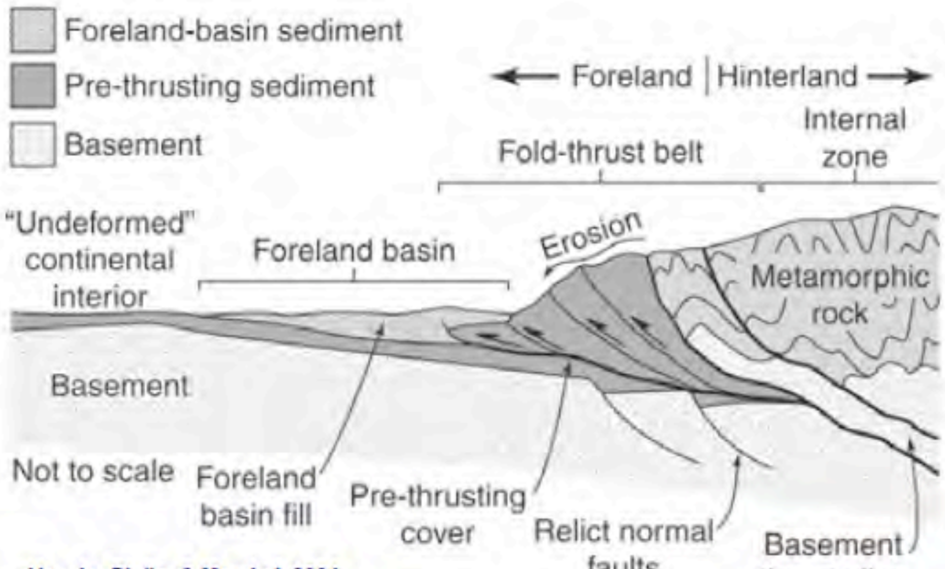
⇒ **FACIES CULM or (KULM)** : Lower Carboniferous (UK, Germany, Belgium, S-France…) related to the Hercynian or Variscan orogeny (collision of Laurasia and Gondwana) => many Central European ‘Culm’ basins with ‘Kulm greywackes’ …

⇒‘**FLYSCHOID**’ in orogenic Precambrian cycles

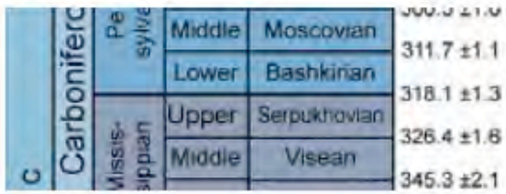
nb Flysch = sediment accumulation => offshore progradation of a talus
Today: ‘Talus landais, France’: 60 km far of the coast. During the Eocene the talus was located 160 km to the east => progradation of 200km/50myr ==> 1m/250yr

nb FORELAND BASINS = OIL INTEREST-PROSPECT

'CULM' FACIES IN BELGIUM



Van der Pluijm & Marshak 2004



C	Carbonifero	Pe sylva	Middle	Moscovian	311.7 ±1.1
			Lower	Bashkirian	318.1 ±1.3
		Missis-sippian	Upper	Serpukhovian	326.4 ±1.6
			Middle	Visean	345.3 ±2.1

(A) COMPREHENSIVE and CONDENSED

Thick (up to km') 'monotonous' successions rapidly deposited

⇒FLYSCH

It is contrued as a **PRE-OROGENIC** or **SYN-OROGENIC FILL** of
A tectonically trough or furrow

=>MOLASSE (also defined in the Alps, Swiss)

deposited after active deformation or in zones outside the deformation
they are ± **POST-OROGENIC** with or near an **ANGULAR DISCONFORMITY**

Despite this apparent 'evident' characteristics it is VERY DIFFICULT to distinguish flysch and molasse on the field…

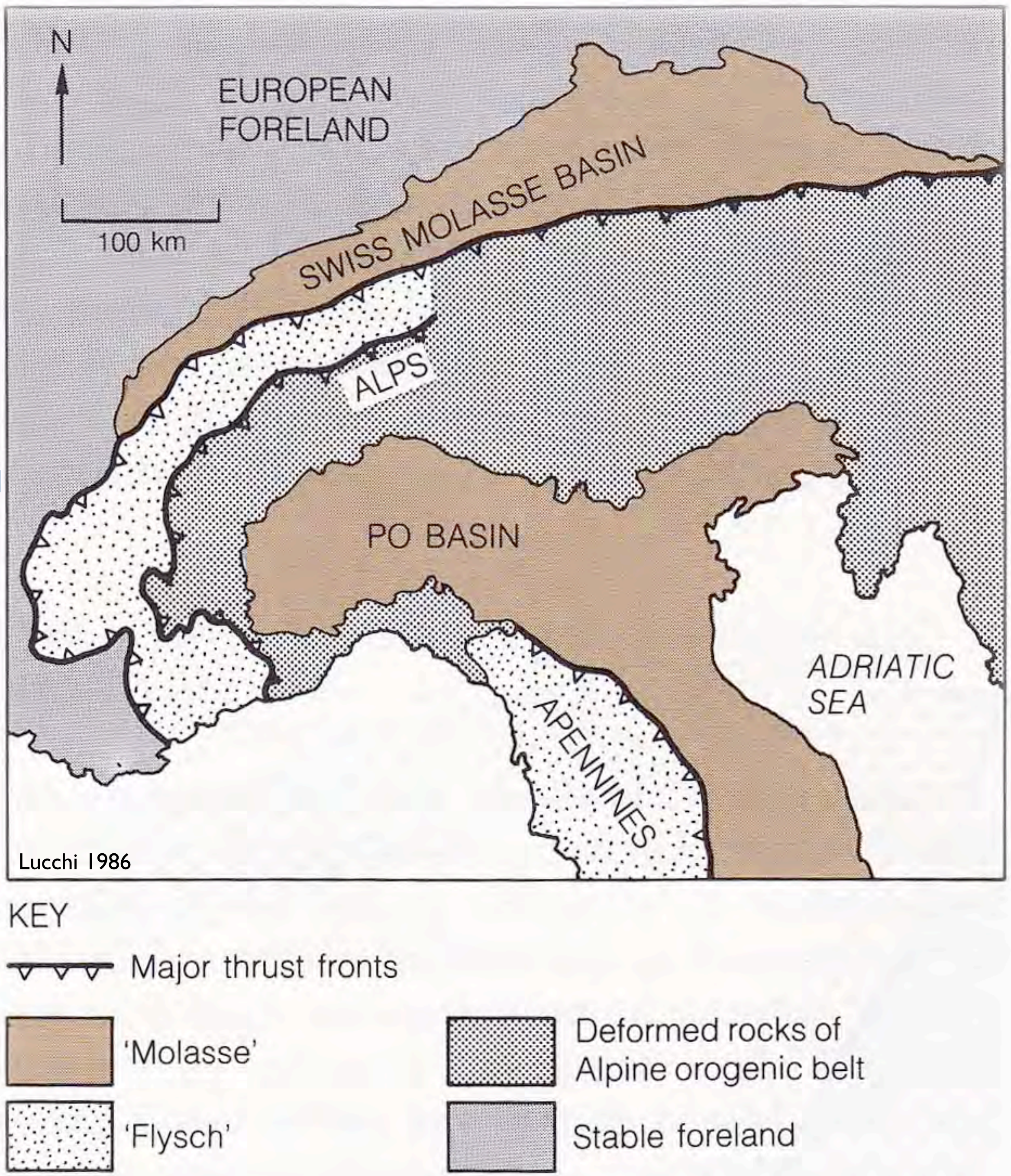
MOLASSE (100s-1000s metres)

• as uplift 'ends' the foreland basin is filled and the water depth decreases
⇒ shallower-marine deposition and sedimentation in rivers and lakes (freshwater)
Example: the **Swiss Molasse Basin** = 100s metres of shallow-marine and freshwater sediments (deltas, beaches, tidally-influenced sand bars, large alluvial fans) formed against the mountain front, fringing a broad plain of river and lake following the emplacement of thrust nappes in the Alps => post-orogenic

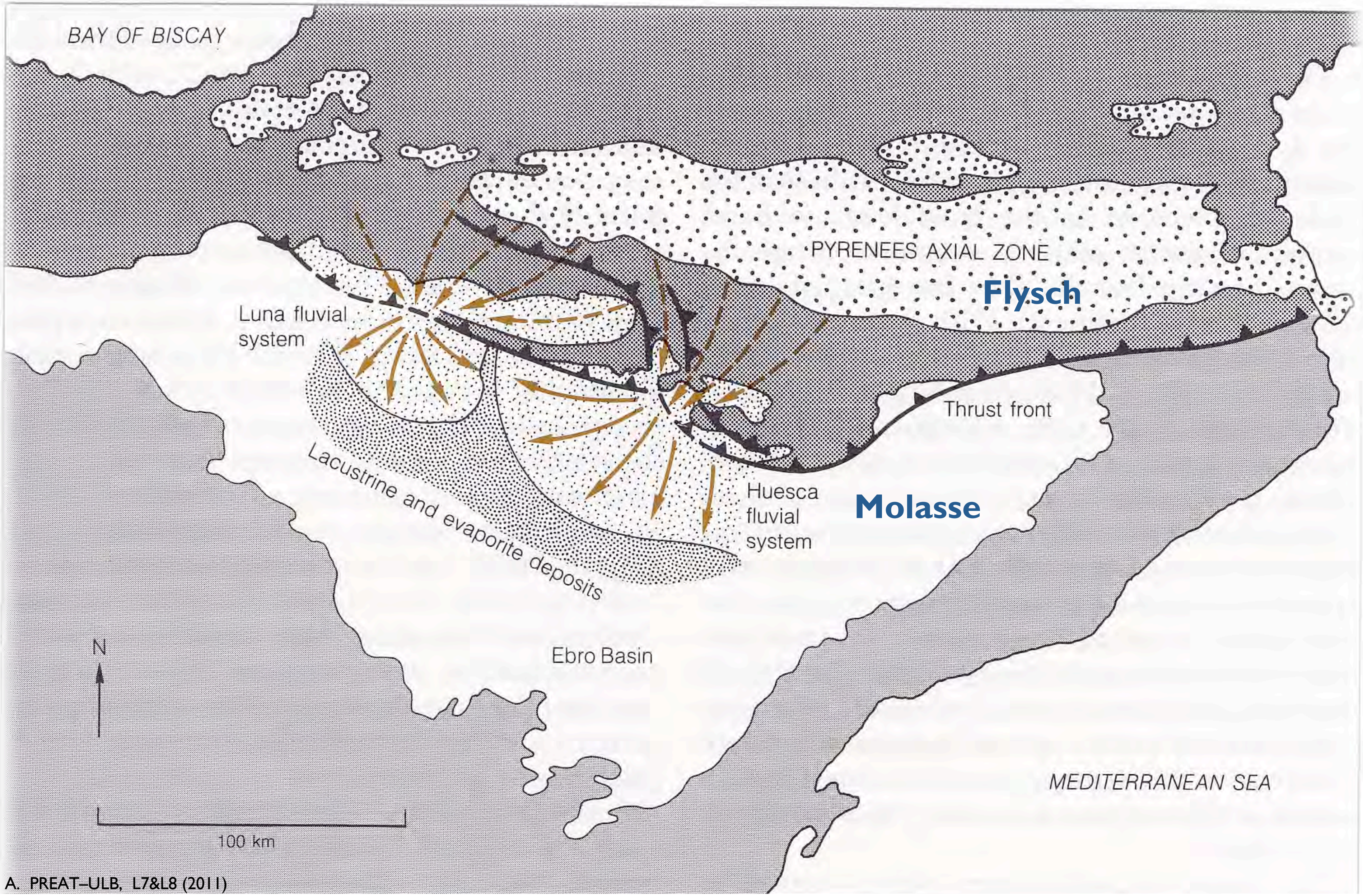
• Result : thick detrital or clastic formations composed with turbiditic AND non-turbiditic sequences with a fining-upward evolution => more or less same characteristics of those observed in the flyschs but with great variations

• Petrography: quartzitic sandstones with carbonate cements and abundant shells (molluscs) + bryozoans. Clays, marls and lignite

Sedimentary basins associated with the Alps land Apennines. North of the Alps the early foreland basin deposits (deep water flysch) have been deformed by later thrusting, at a later stage **the Swiss Molasse Basin** developed (shallow marine and continental deposition)



Oligo-Miocene alluvial distribution patterns controlled by the structure of the thrust front along the N margin of **the Ebro Basin** – foreland basin, Spain (Hirst & Nichols 1986)



MOLASSE

- origin: **freshwater** (continental) and marine waters (deltaic plain...)
- Designation form foreland basin **north of the Alps** => 10km of sediments in the Late Mesozoic and Early Cenozoic.
  Mainly from Late Oligocene (±25Ma) to Miocene (±5Ma)
- Examples: Berne-Fribourg ('tidal bundles', Swiss), Carcassone (France), Paros (Greece), Huesca (Spain), N-Africa etc.

North of the Alps

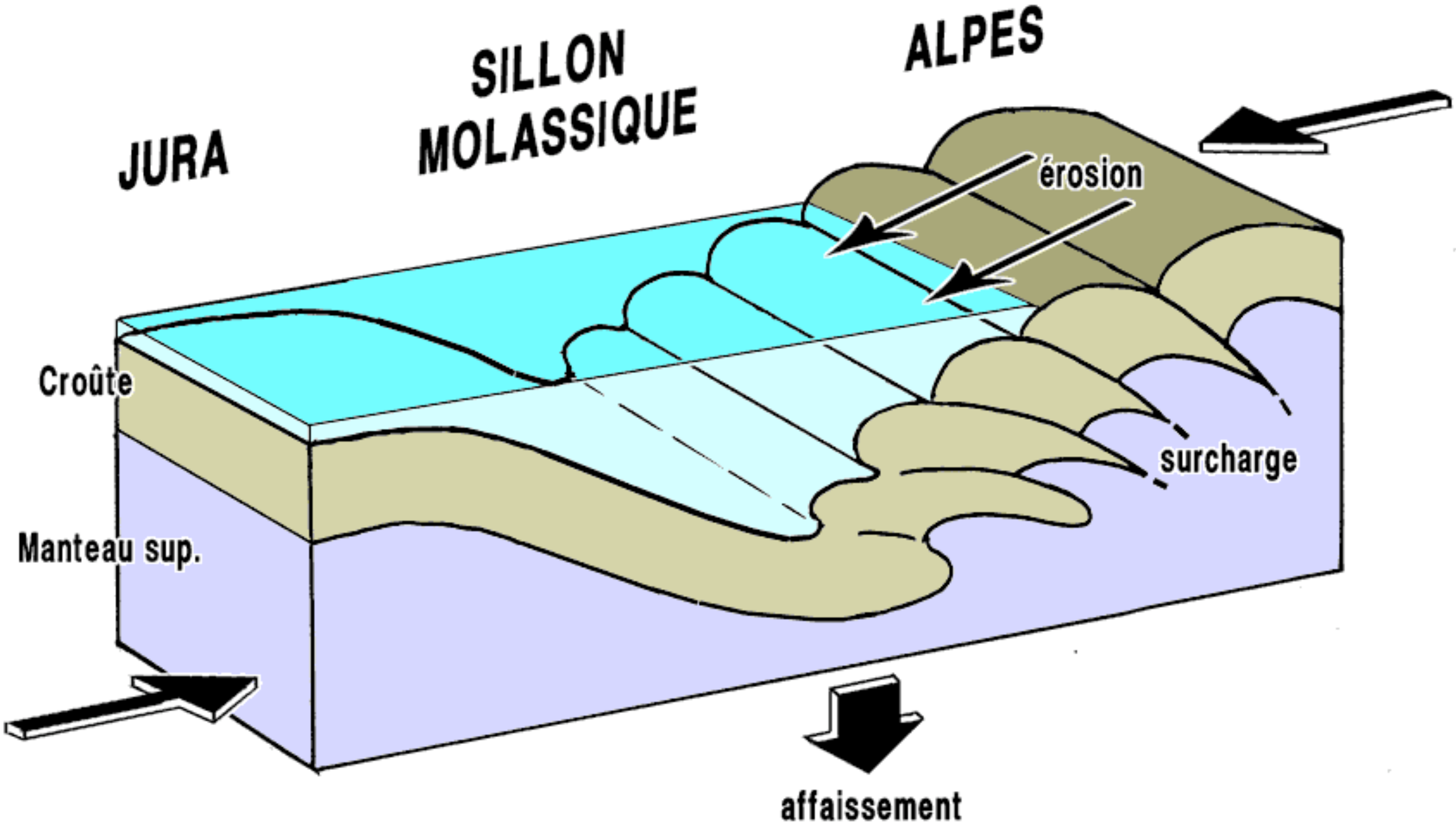
- Example 1 : Miocene, thickness =km's of detrital sediments contrasting with a few 10's metres in the north 'Aquitaine basin' (same age, same sediment types)
- Example 2 : Oligocene French-Italian Alps, 1 to 1.5km thick = cgts/marls/sdsts
  Analysis of the pebbles
  = erosion of ophiolites ⇔ subduction ⇔ active margin
  = Triassic limestones and dolomites => sedimentary 'substratum'
  = granitic and metamoprhic rocks => 'true substratum'
  = *Helminthoid* flysch (Eocene here and pre-orogenic)

In front of the Hercynian and Appalachian orogens

-NRS and ORS 'Coal Measures Carboniferous', 'Castkill Formation (Devonian)

…

PERI-ALPINE TRHOUGH (extremely simplified)



www.geol-alp.com/alpes_francaises/alpes_zones.html summary flysch/molasse

(A) COMPREHENSIVE and CONDENSED

Thick (up to km') 'monotonous' successions rapidly deposited

FLYSCH

refers to 'deep-water' clastic sediments deposited during **PRE-OROGENIC** or **EARLY-OROGENIC** conditions.
It commonly passes up stratigraphically into

MOLASSE

a shallow-marine to nonmarine deposit formed under **LATE-OROGENIC** to **POST-OROGENIC** conditions

TWO MAIN COMPLEMENTARY CATEGORIES OF SERIES

(A) COMPREHENSIVE and **CONDENSED**

No relation between thickness and duration

(B) CONTINUOUS and DISCONTINUOUS

Notion of lacuna or hiatus

CONDENSED SERIES

Long period of time being represented by a small thickness of sediment.
= pelagic carbonate sedimentation which is considerably **slower** than shallow marine accumulation rates, resuling in much **thinner** layers in a given period of time => condensed sections (they may have as many myr of accumulation in them as shallow water deposit two or three orders of magnitude thicker.

Condensed sections

-pelagic to hemipelagic sedimentation
-presence of apparent hiatuses
-burrowed horizons
-burrowed-perforated hardgrounds with or without Fe-Mn
-authigenic minerals (glauconite, phosphate, siderite)
-high faunal abundance (if not anoxic)
-high faunal diversity (if oxic)
-low faunal diversity (if hypoxic)
-deposition of organic-rich black shales => gamma-ray reading
-large regional extent and expending time from coastal to basinal
-important horizons of correlations within sedimentary basins

Condensed Sections are **abnormally thin** but nominally complete sections i.e. those enclosing all (or almost all) subdivisions of the Global Time Scale of the corresponding rank, embracing large stratigraphical intervals (several biostratigraphic zones, a substage, a stage) that originated due to a sharp decline in the sedimentation rate (condensed if < 1 cm/ka or ultracondensed if < 0.5 cm/ka), whose accumulation was interrupted by intervals of nondeposition, erosion, and other synsedimentary or early diagenetic events.

Example : **The whole Jurassic and Cretaceous of the 'Briançonnais area' (France) in the western Alps = a few tens metres (10-50m) of nodular-pelagic limestones**

while

at the **same time**, J+K = 3000m in the 'Dauphinois area' located at <100 km in the Alps.

Western Alps Jurassic and Cretaceous

comprehensive
(external domain)

condensed
(ext/median domain)

FLYSCH
upper Eocene

Jur+Cret.
shallow-subsident area

EVAP
Triassic

Jur+Cret.
'High'
reduced or no sedimentation

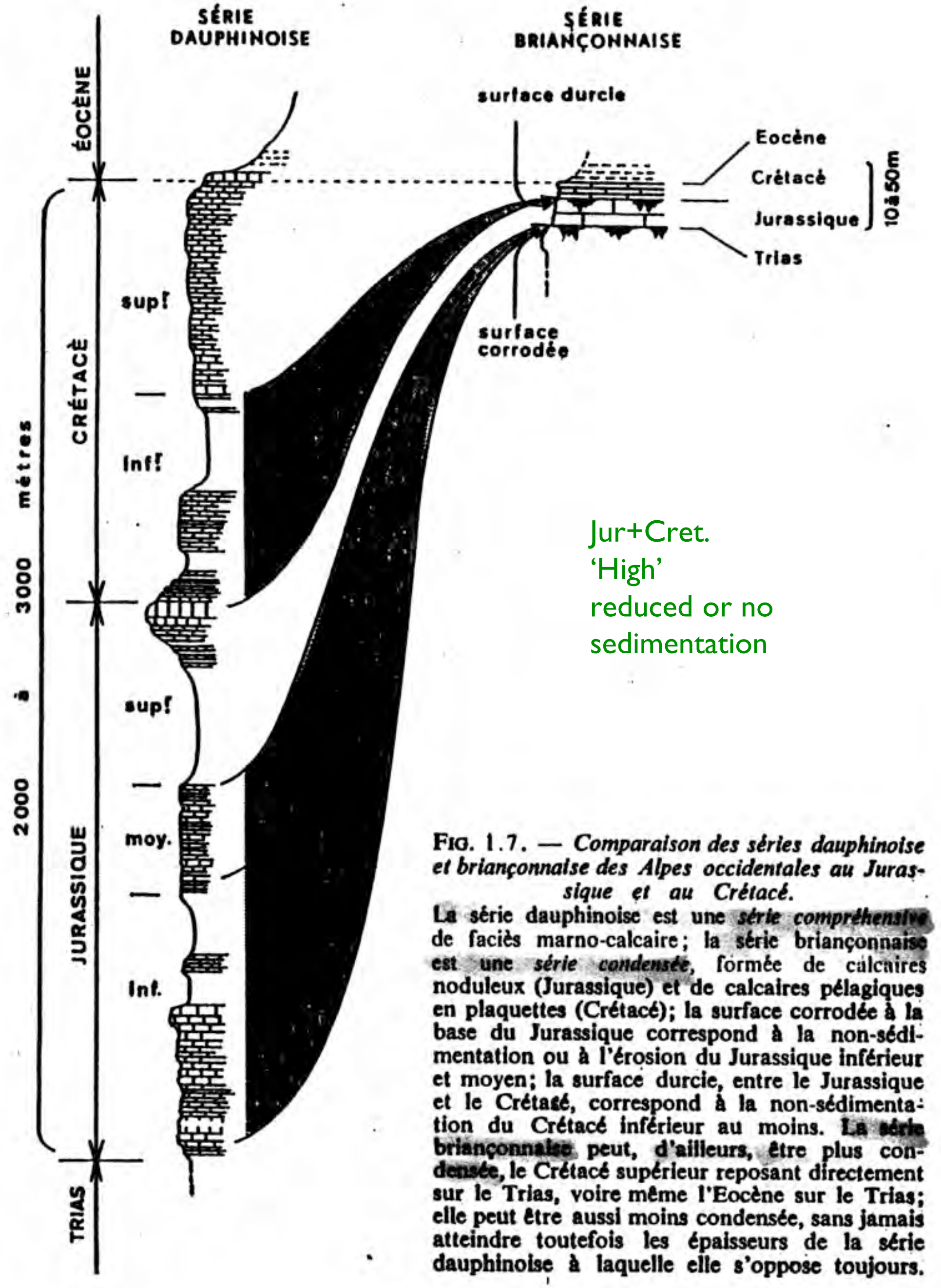
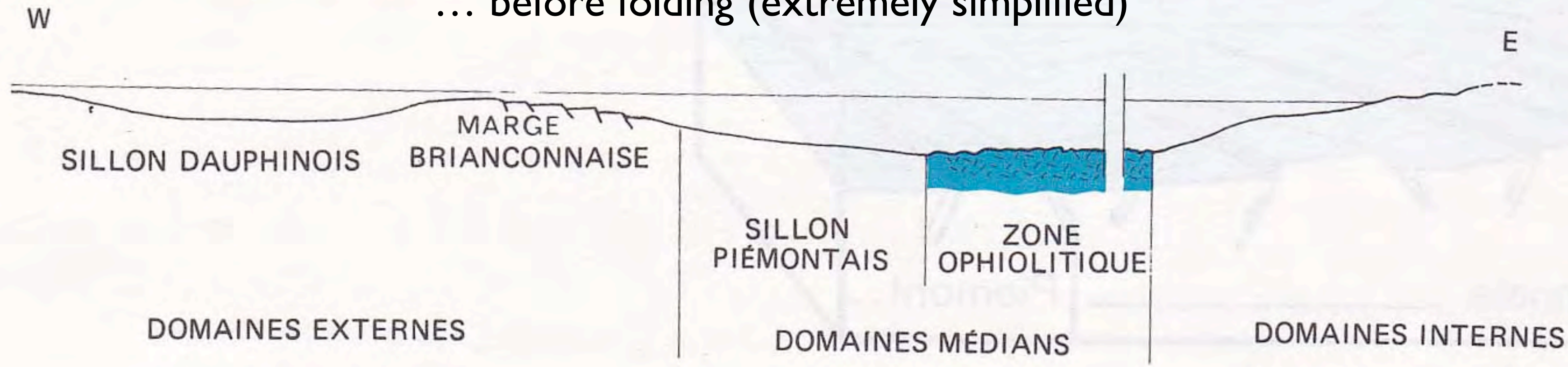
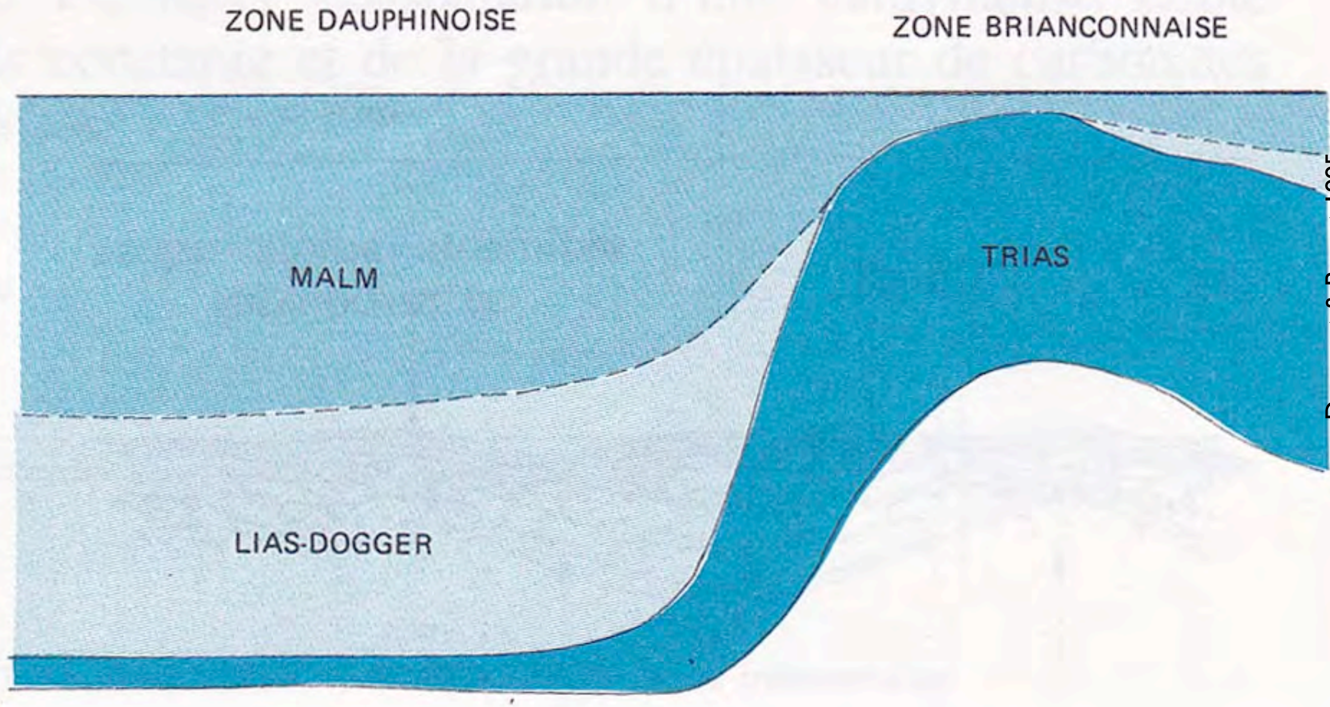


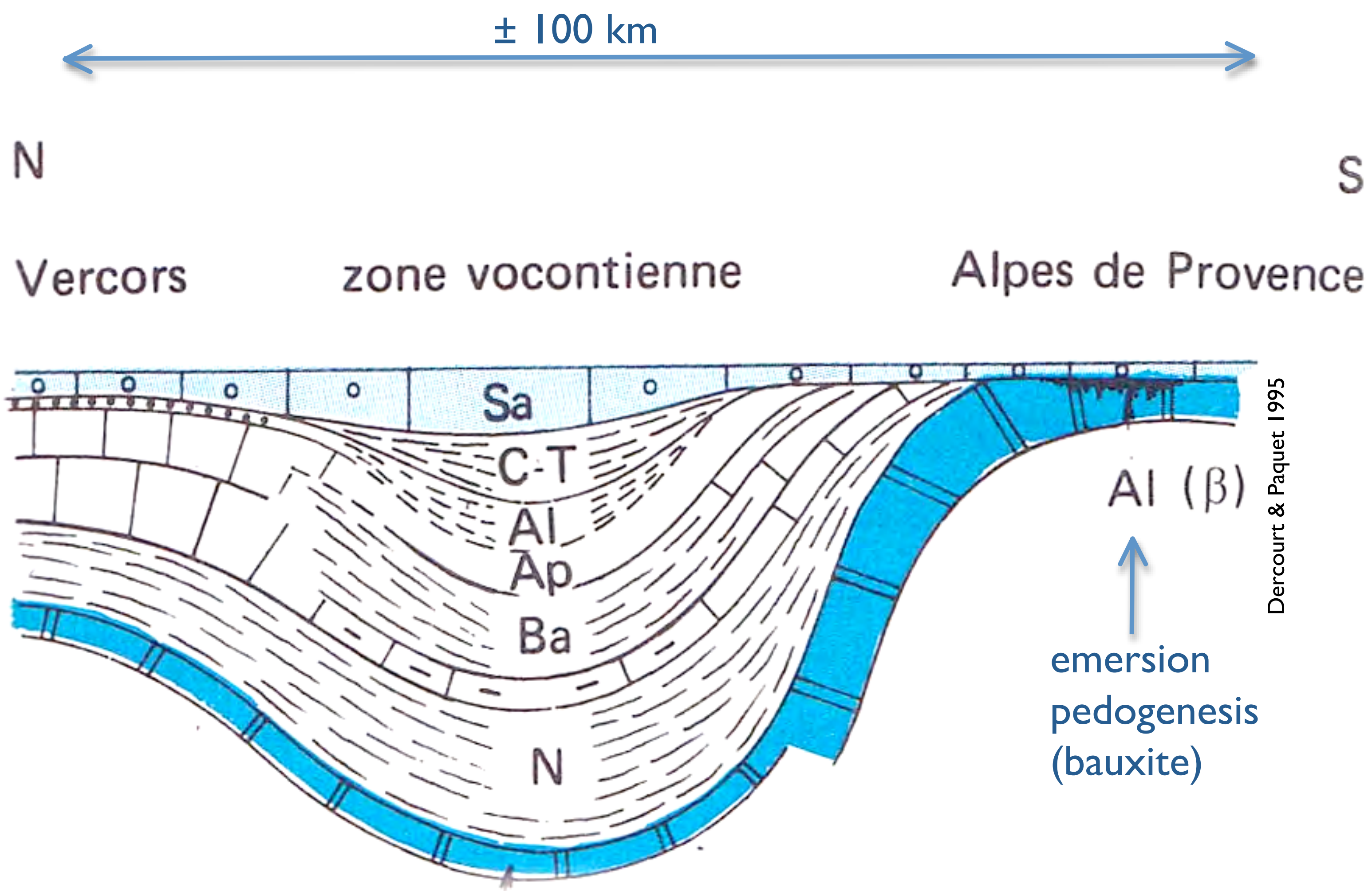
FIG. 1.7. — *Comparaison des séries dauphinoise et briançonnaise des Alpes occidentales au Jurassique et au Crétacé.*
La série dauphinoise est une *série compréhensive* de faciès marno-calcaire; la série briançonnaise est une *série condensée*, formée de calcaires noduleux (Jurassique) et de calcaires pélagiques en plaquettes (Crétacé); la surface corrodée à la base du Jurassique correspond à la non-sédimentation ou à l'érosion du Jurassique inférieur et moyen; la surface durcie, entre le Jurassique et le Crétacé, correspond à la non-sédimentation du Crétacé inférieur au moins. La série briançonnaise peut, d'ailleurs, être plus condensée, le Crétacé supérieur reposant directement sur le Trias, voire même l'Eocène sur le Trias; elle peut être aussi moins condensée, sans jamais atteindre toutefois les épaisseurs de la série dauphinoise à laquelle elle s'oppose toujours.

… before folding (extremely simplified)





Dercourt & Paquet 1995



± 100 km
N
S
Vercors
zone vocontienne
Alpes de Provence
Sa
C-T
Al
Ap
Ba
N
Al (β)
emersion
pedogenesis
(bauxite)
Dercourt & Paquet 1995

Condensed Sections are abnormally thin

How are they formed?

• one mechanism is storm activity in shallow seas

⇒ storms agitate the sea floor to unusally great depths and winnow finer sediment (carbonate…) from coarser benthonic shell debris ==> the shells are broken, abraded and concentrated into a coquina (bed)

Example with vertebrates = 'bone bed' : series with 2-20 layers in a single outcrop, individual beds up to 20 cm thick, lateral extension up to 50,000 km^2

Example with high energy: oolite or bioclastic barriers (Carboniferous, Belgium, France… Cretaceous Spain, Angola … etc

• '**true**' condensed sections are different = they are characterized by **slow accumulation** over long period of time. Example are abyssal deposits far from terrigenous sediment sources. Other examples are shallow depocenters protected from terrigenous influx and limestone formation.

Black shales of Devonian-Mississippian (S.E. USA) formed by slow deposition = 'Chattanooga Shale' with 10 m accumulated over a period of 14 myr (0.0007mm/yr) = **PELAGIC ORIGIN** with development of **nodular** facies

PELAGIC ORIGIN => 'basin hiatuses'

• due to the presence of deep or bottom water capable of transport and erosion (currents are ubiquitous along the deep ocean floor due to the Earth's rotation, temperature and salinity variations => velocities up to 50cm/sec i.e. 2km/hr have been measured and are high enough to move quartz sand)

• differential rates of planktonic production => regional variations in sedimentation rates (it is controlled by water temperature, ecologic factors ….)

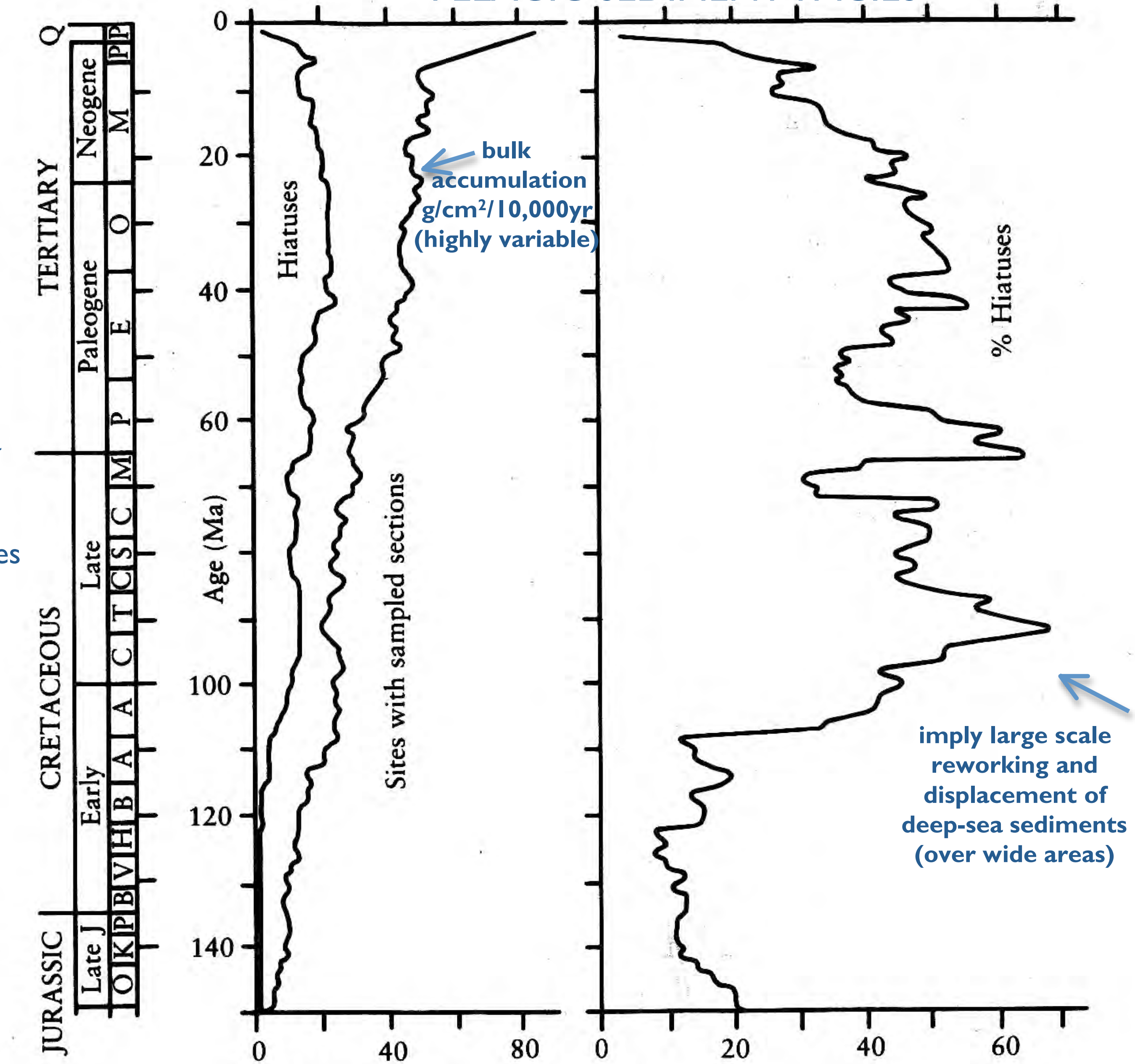
• coincidence of regions of low rates of plankton production and sedimentation with regions of high rates of dissolution at the sediment-water interface (for example due to cold corrosive current or buildup of CO_2 as a result of slow mixing and ponding of oceanic deep water

RESULT : incompleteness of the stratigraphic record

'The most complete' sections are almost all '**empty space**' when long period of geologic time are considered …

PELAGIC SEDIMENT FACIES

- Distribution of hiatuses in the N-Atlantic deep-sea drill sites (DSDP)
- Hiatus distribution in absolute and relative figures Ehrmann & Thiede 1985

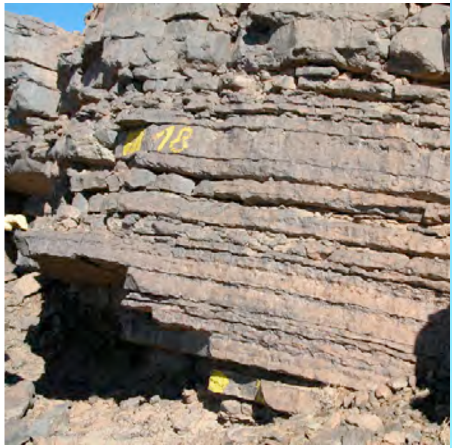


TYPICAL-WELL KNOWN 'CONDENSED' SERIES

CALCAIRES GRIOTTES ('GRIOTTE LIMESTONES')

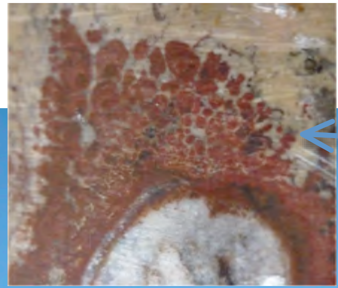
griotte is a cherry variety => colour is important to characterize this facies

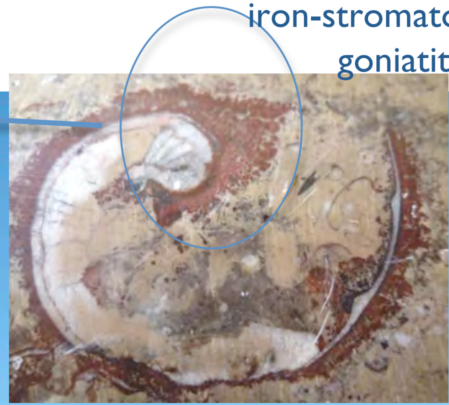
Paleozoic => nodules = Goniatites



Full of small-sized goniatites

Morocco, Anti-Atlas, Upper Devonian, Préat 2004





ORIGIN THE RED-REDDISH-PINK COLOUR?

Morocco, Anti-Atlas, Upper Devonian, Préat 2004

ORIGIN THE RED-REDDISH-PINK COLOUR?

Morocco, Anti-Atlas, Upper Devonian, Préat 2004

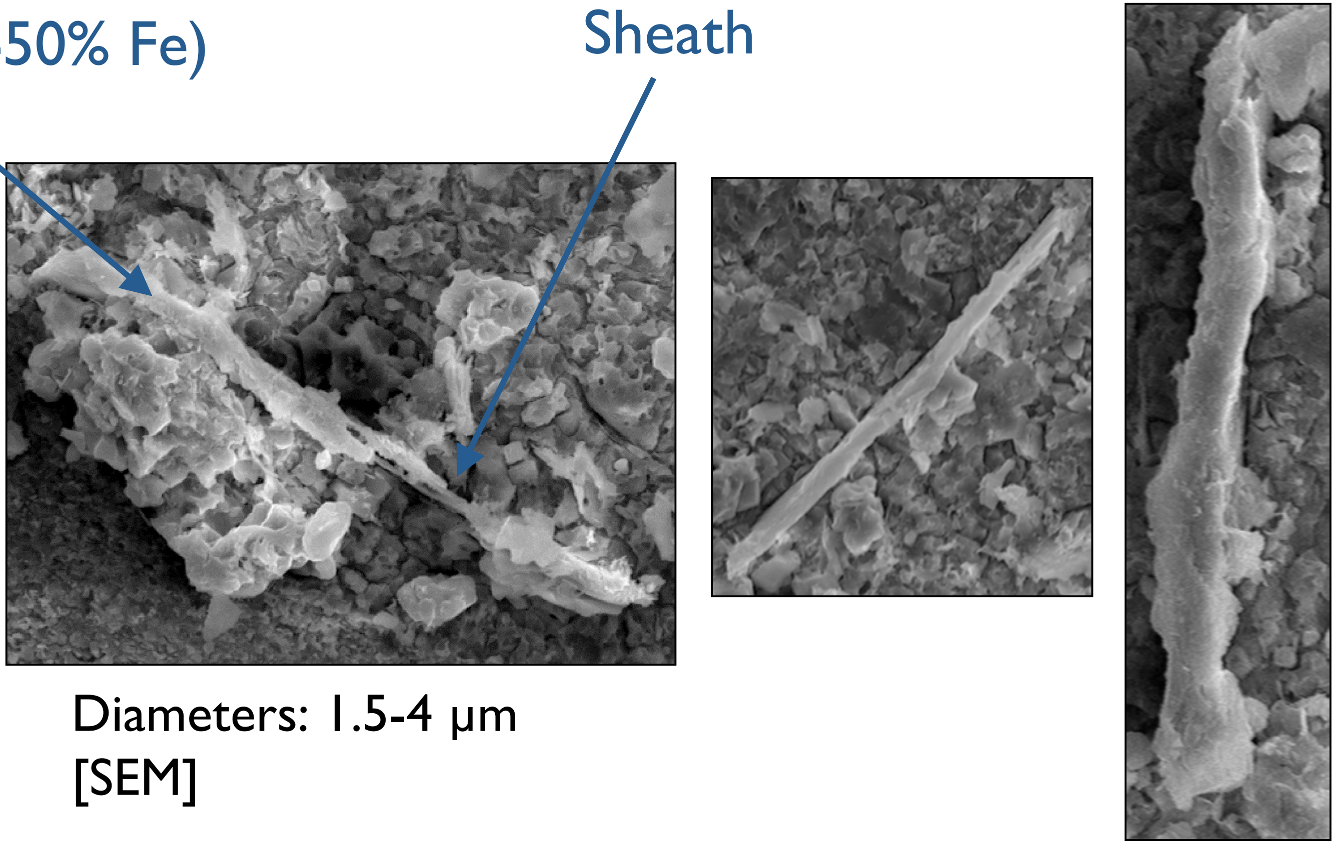
Three processes are possible

1.DETRITAL
2.CHEMICAL
3. BIOLOGICAL

Filamentous iron bacteria

Iron encrustation
(25-50% Fe)

Sheath



Diameters: 1.5-4 µm
[SEM]

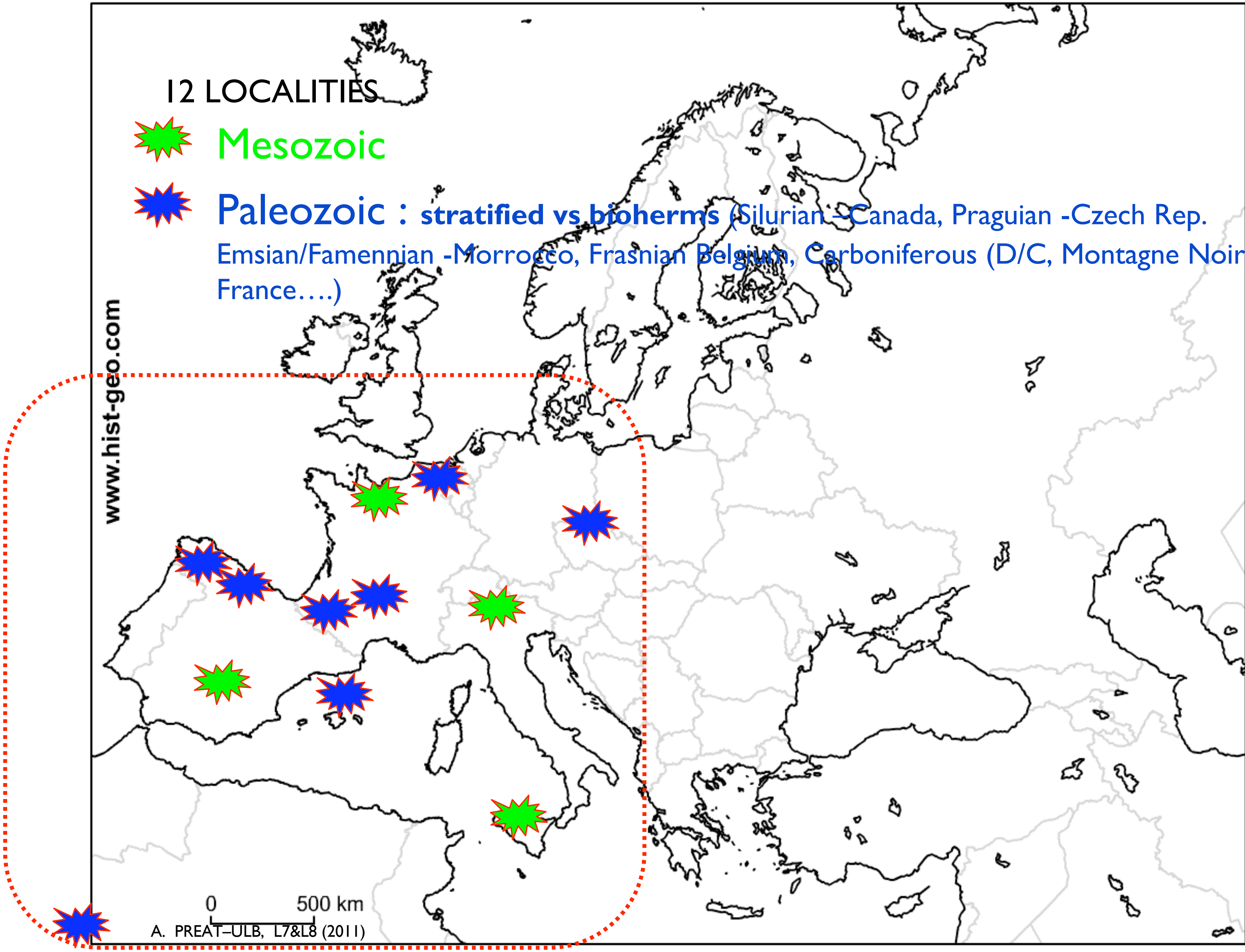
Mamet, Préat 2007

OBSERVED MICROFACIES OF DIFFERENT AGES AND LOCALITIES

12 LOCALITIES

Mesozoic

Paleozoic : **stratified vs bioherms** (Silurian -Canada, Praguian -Czech Rep. Emsian/Famennian -Morrocco, Frasnian Belgium, Carboniferous (D/C, Montagne Noire, France….)



A. PREAT–ULB, L7&L8 (2011)

Our studied Red limestones …

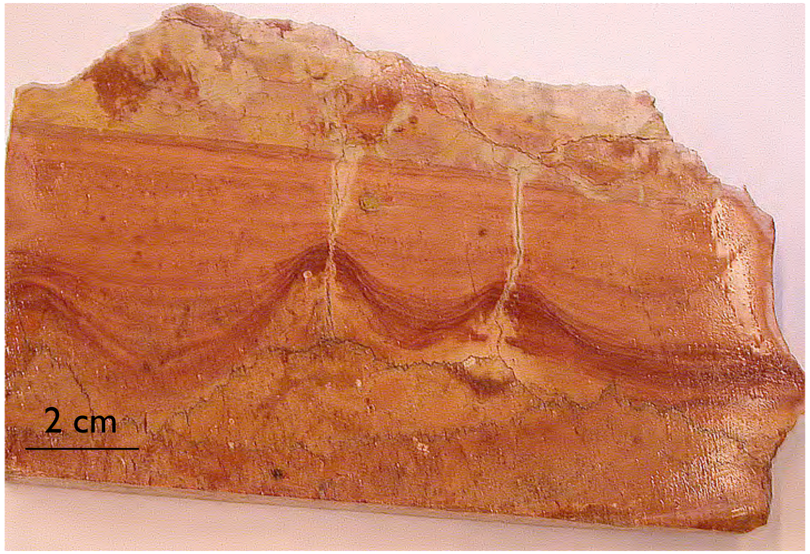
shallow

- ‘Oolite Ferrugineuse de Bayeux’ mid-Jurassic Normandy = ‘LITTORAL’
- ‘red marbles’ Devonian (Praguian), Czech Republic = INNER RAMP
- griottes Devonian S-France, Viséan N-Spain = SHALLOW PF + OUTER RAMP
- ‘red marbles’ Devonian (Frasnian), Belgium = OUTER RAMP
- red lenses in slope Carboniferous (Bashkirian), N-Spain = SLOPE
- Ammonitico Rosso Jurassic, N-Italy, S-Spain, Sicily = (HEMI)-PELAGIC
- red condensed series Devonian (F/F), Morocco = PELAGIC

deep

AMMONITICO ROSSO – JURASSIC

(Italy, Spain, Austria, Bulgaria, Morocco, Algeria….)



Northern Italy

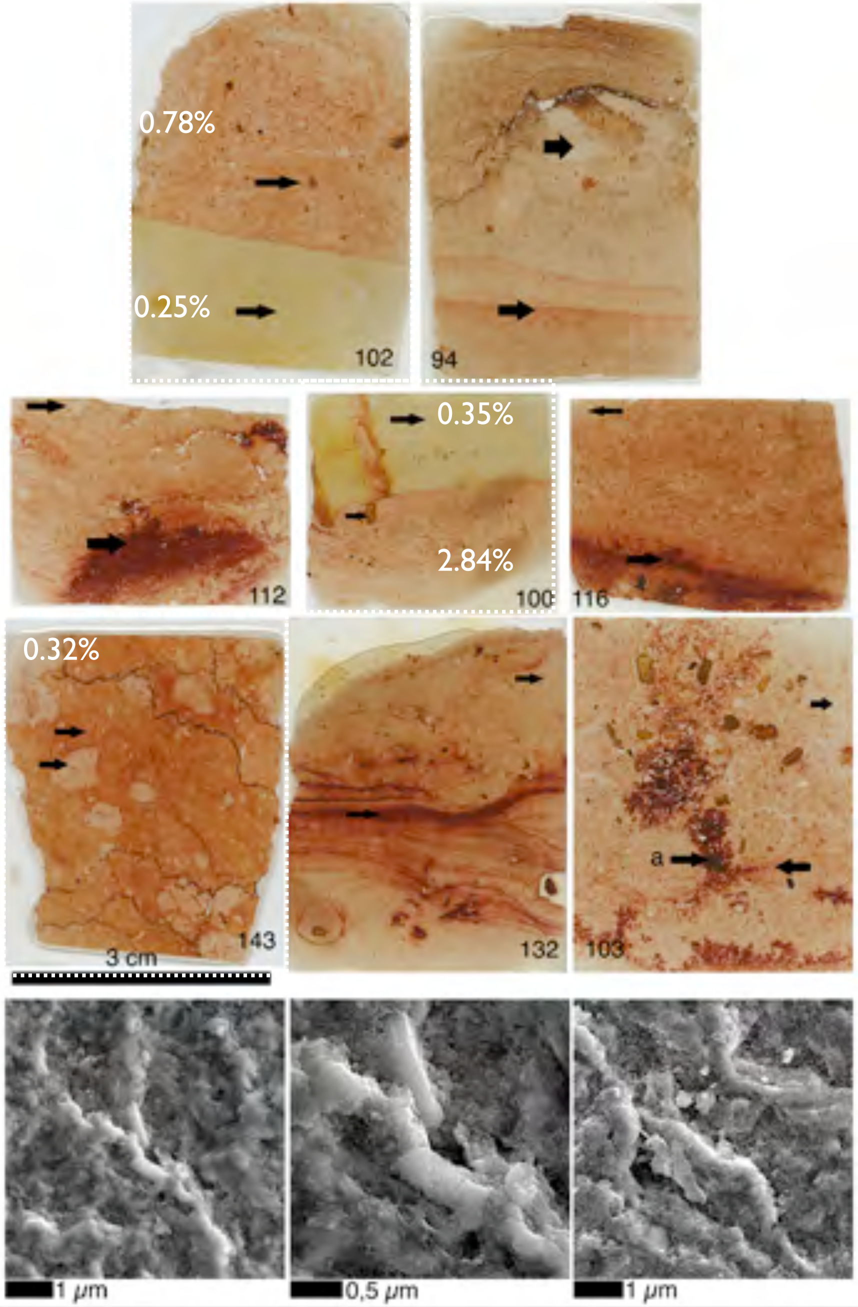
Jurassic Ammonitico Rosso

AMMONITICO ROSSO – JURASSIC

SICILY

- thinly and well bedded
- NODULAR facies

AMMONITICO ROSSO – ITALY



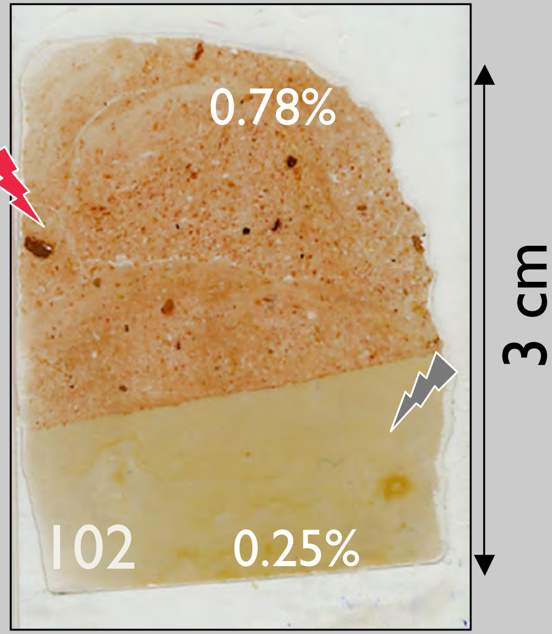
PREAT et al. 2008

total Fe_2O_3

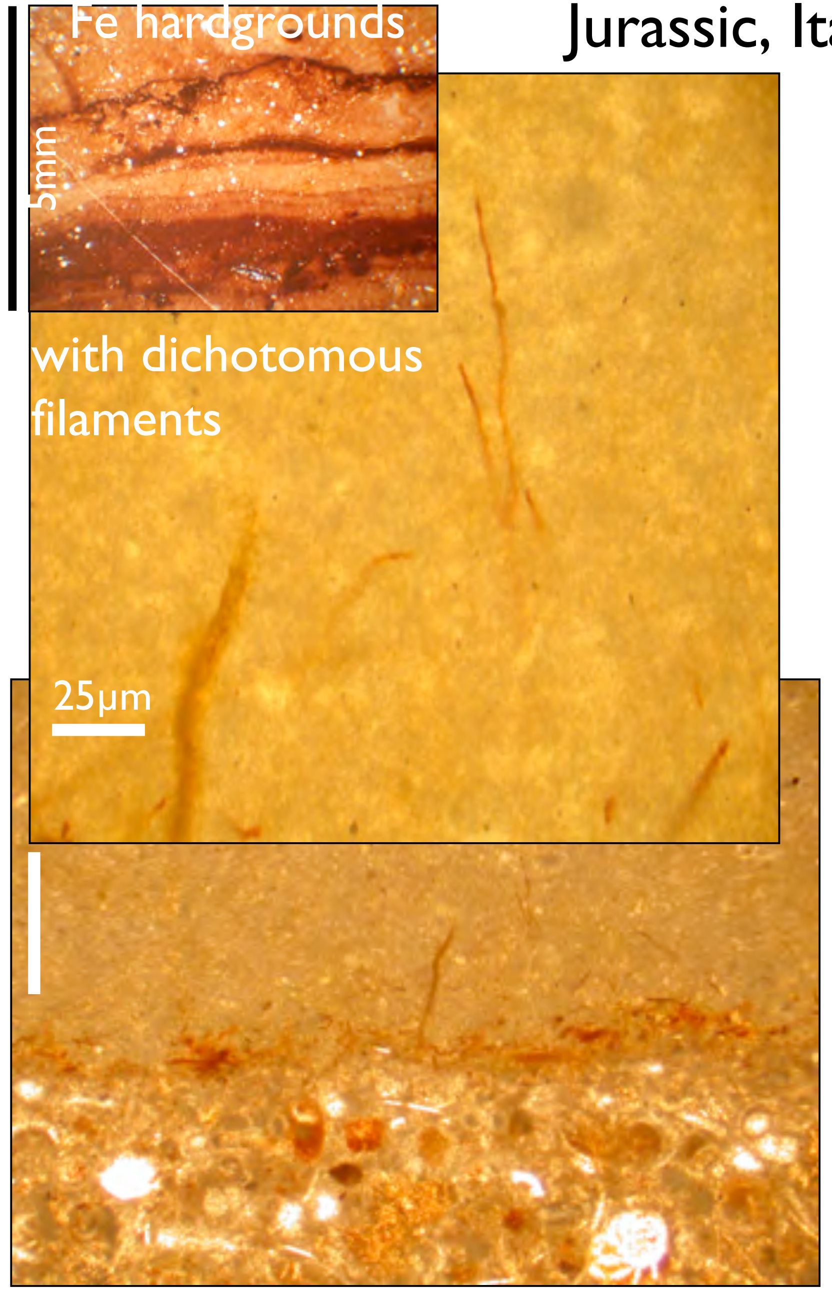
100G = 0.35%
100R = 2.84%

102G = 0.25%
102R = 0.78%

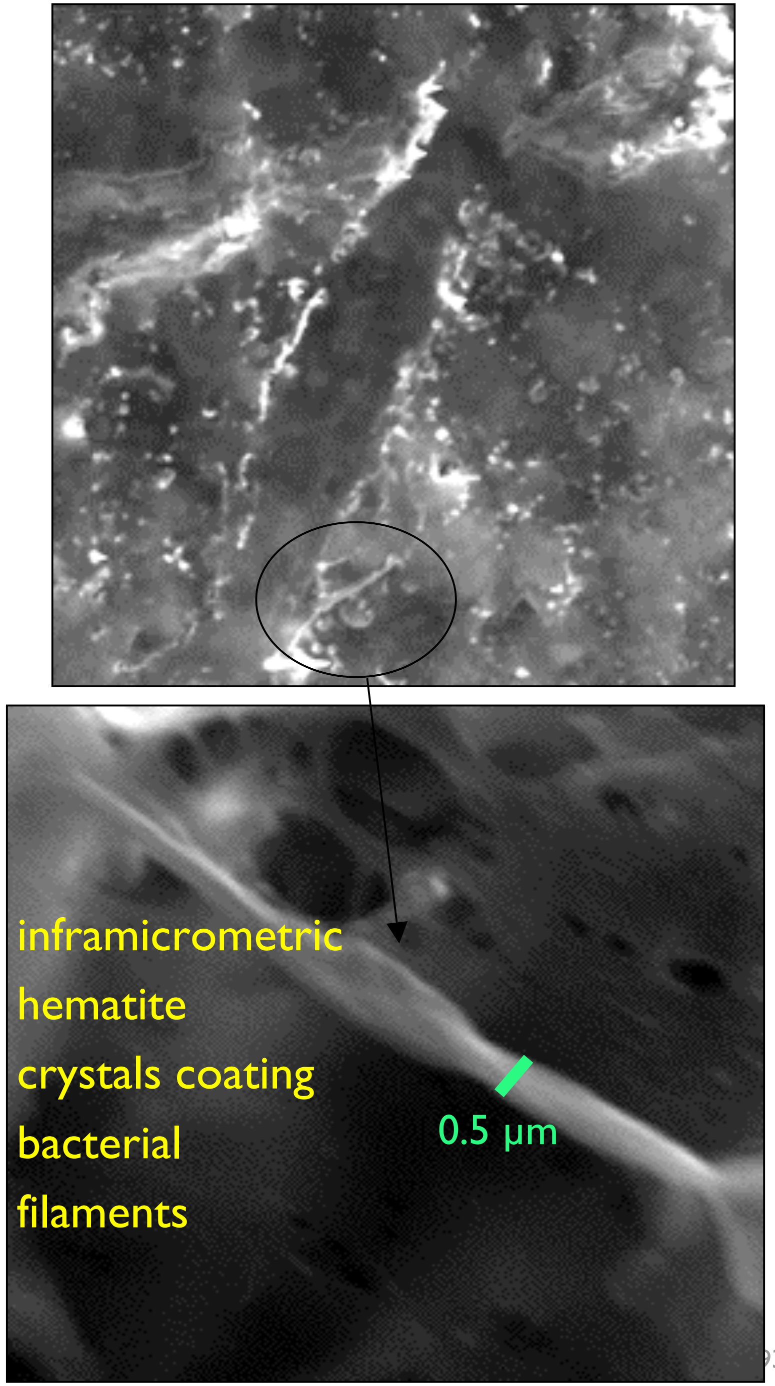
143R = 0.32%



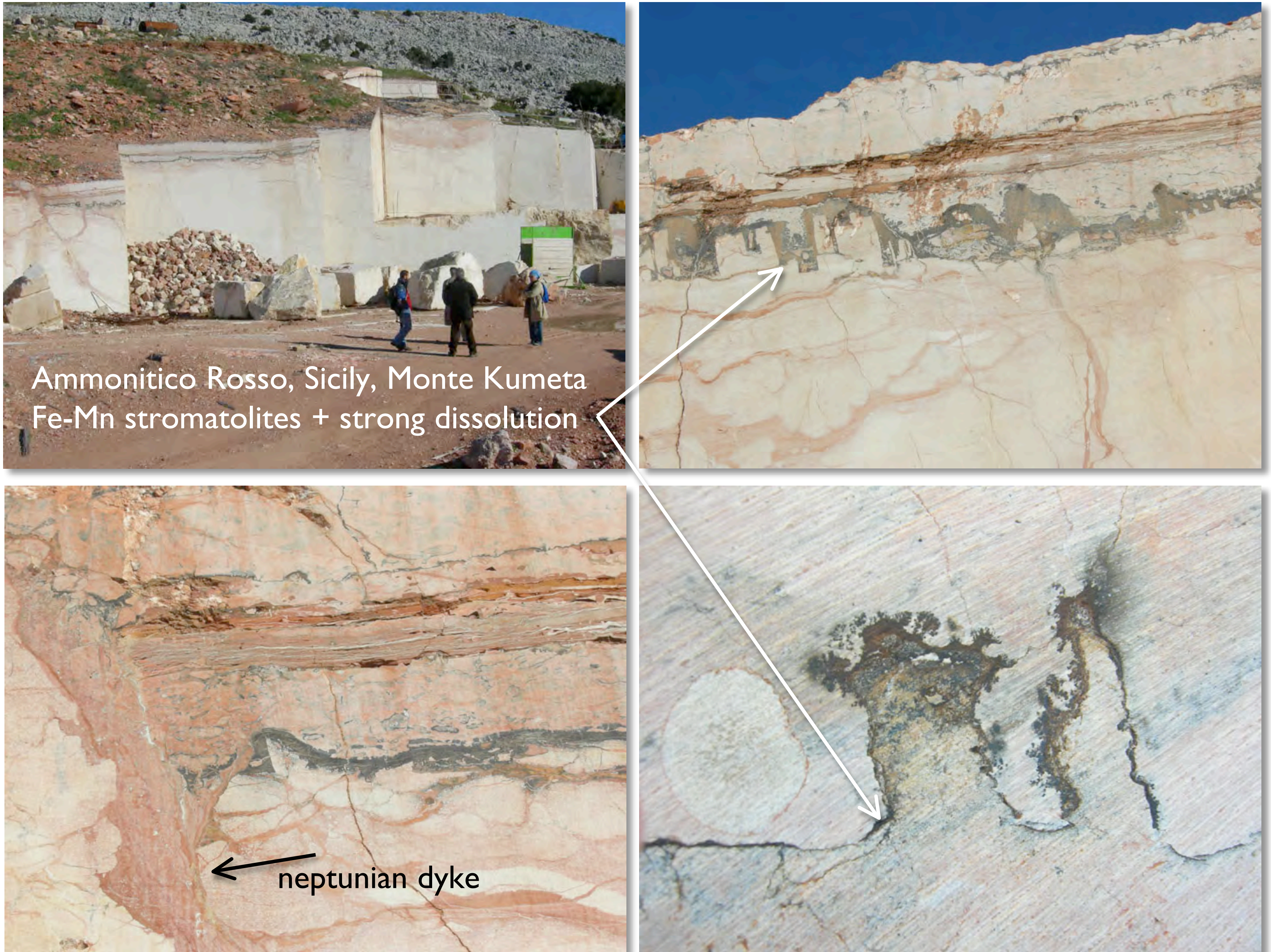
Ammonitico Rosso
Jurassic, Italy



SEM



Ammonitico Rosso, N Italy
Heavily burrowed

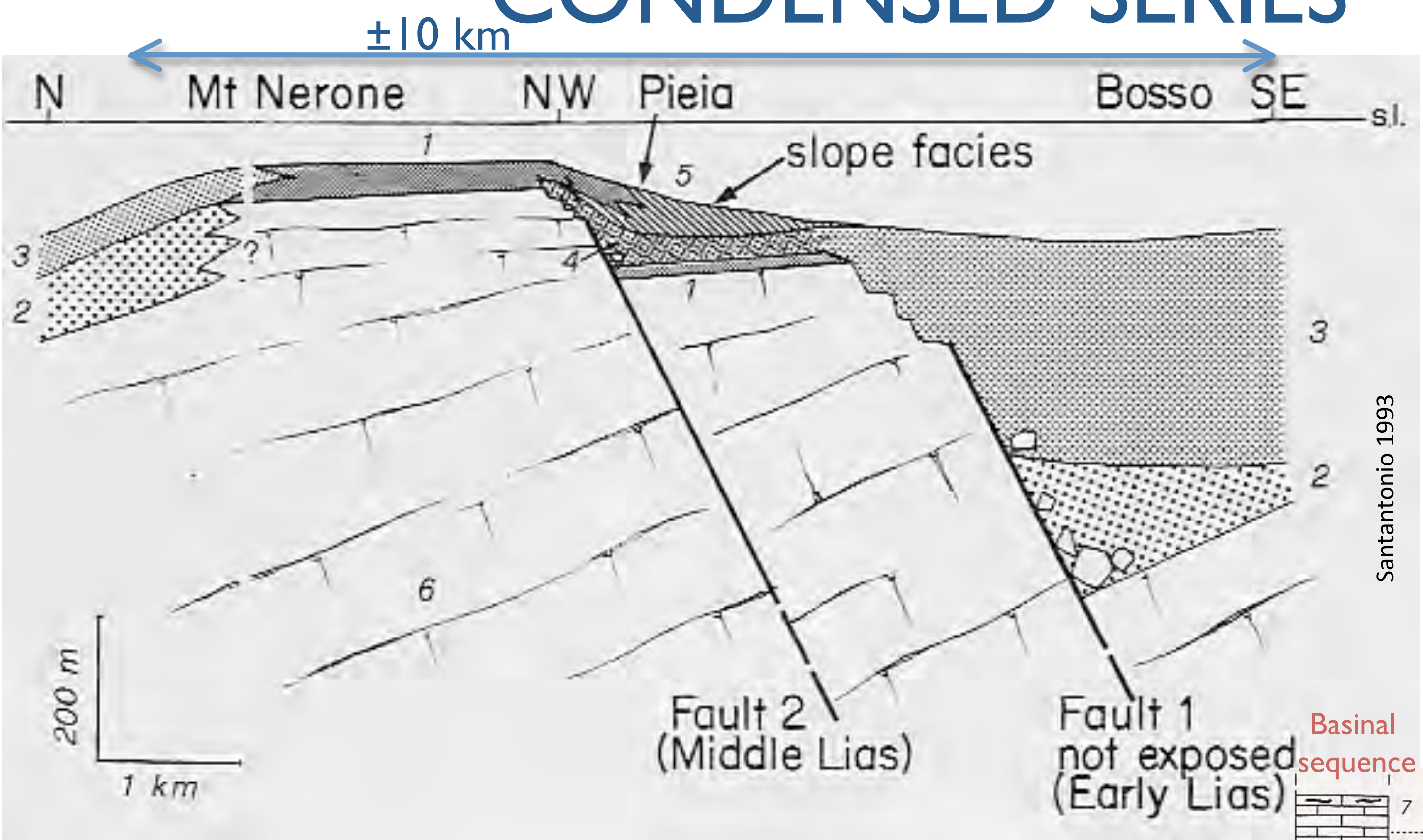

Ammonitico Rosso, Sicily, Monte Kumeta
Fe-Mn stromatolites + strong dissolution
neptunian dyke

Ammonitico Rosso, Sicily, Monte Kumeta
Fe-Mn stromatolites + strong dissolution

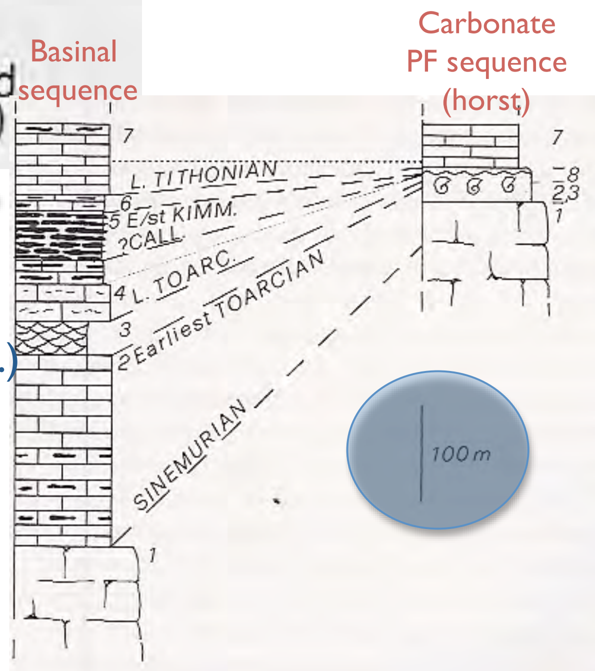

Sicily : Mn-oncoids-nodules


Italy : Fe-stromatolites

CONDENSED SERIES



UMBRIA-MARCHE APENNINES, ITALY



Early Tithonian 1-5

1 condensed pelagic (ammonites, belemnites, corals…)

2 interbedded pelagic and **resedimented** neritic (id. +crinoids, mollusks;..)

3 pelagic and **resedimented** pelagic

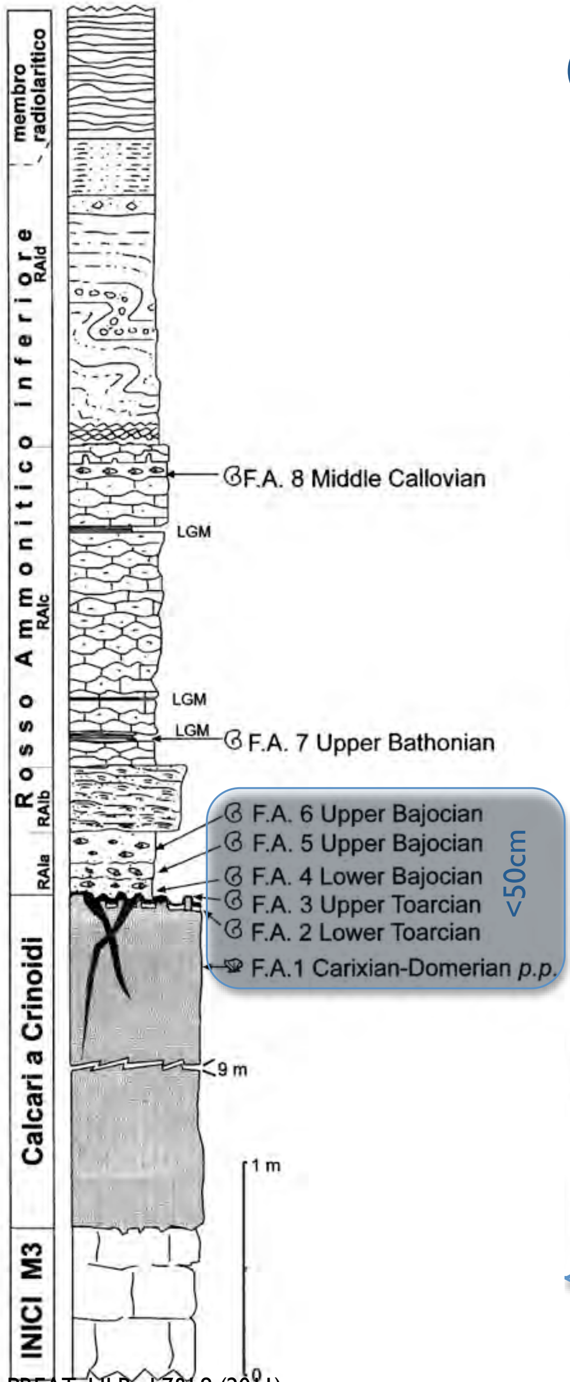
4 'perched basin' deposits

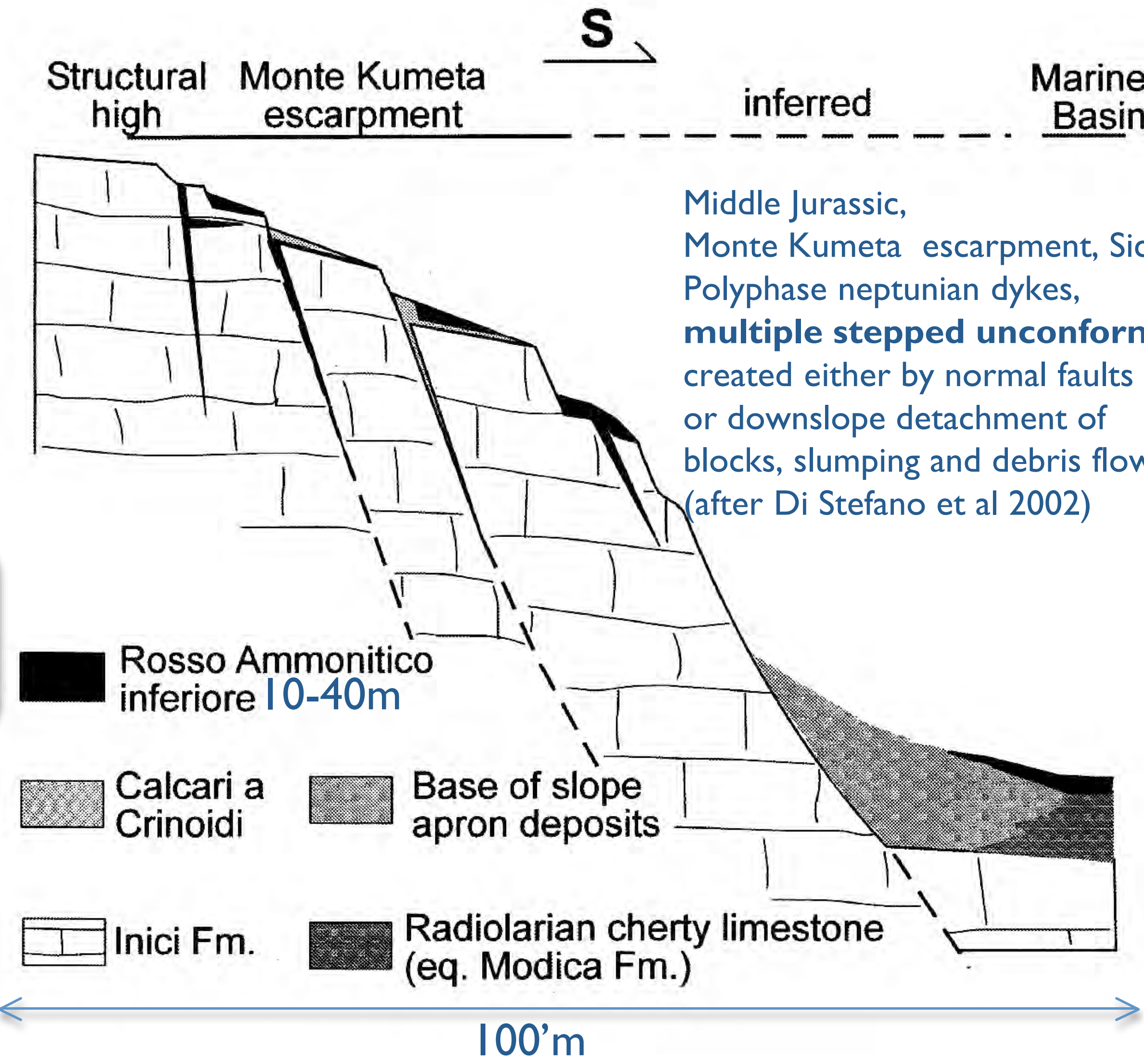
5 mainly **resedimented** pelagic

6 pre-drowning, peritidal carbonate platform deposits

(exaggerated vertical scale)

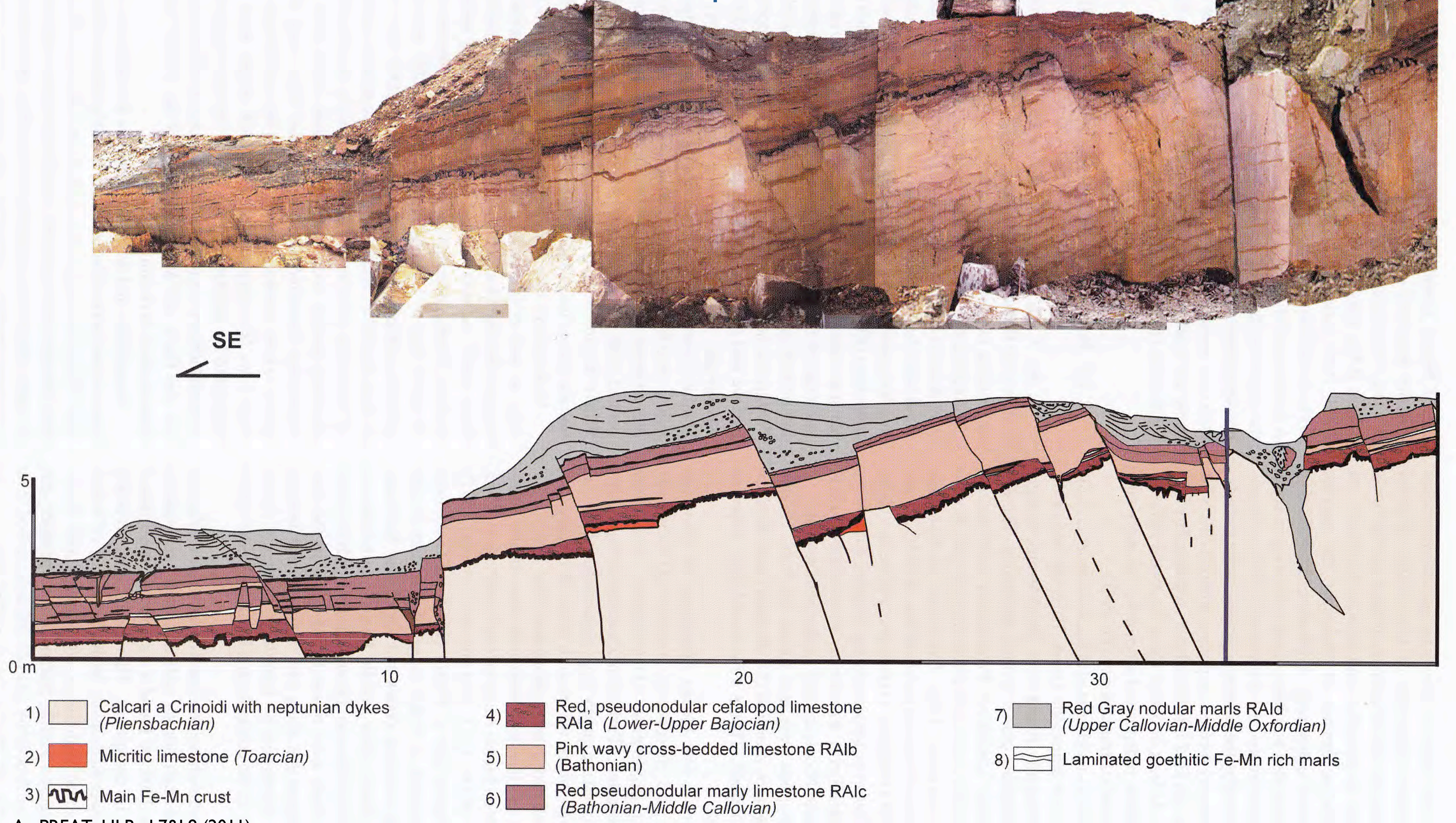
CONDENSED SERIES





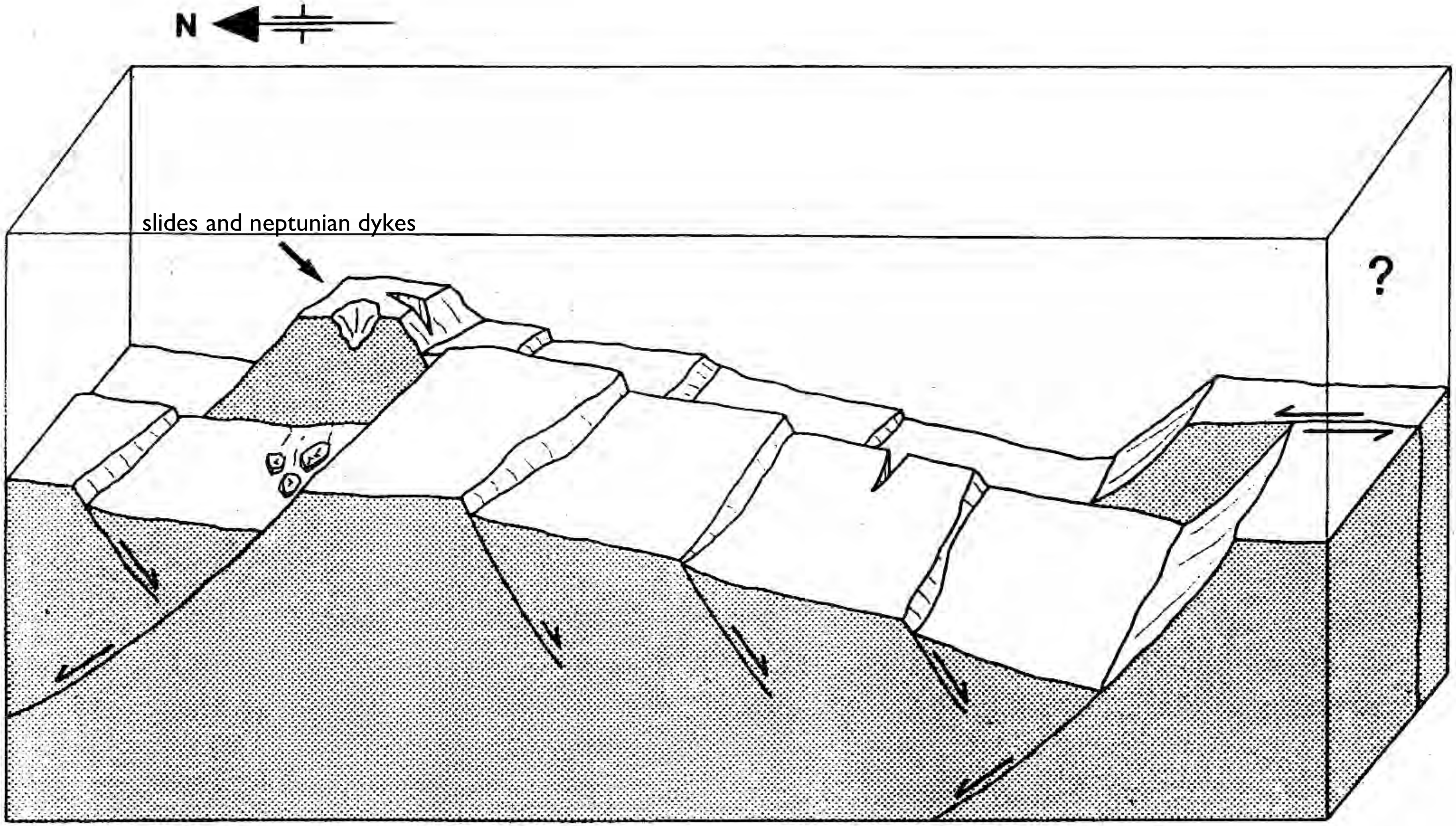
Middle Jurassic,
Monte Kumeta escarpment, Sicily
Polyphase neptunian dykes,
multiple stepped unconformities
created either by normal faults
or downslope detachment of
blocks, slumping and debris flows
(after Di Stefano et al 2002)

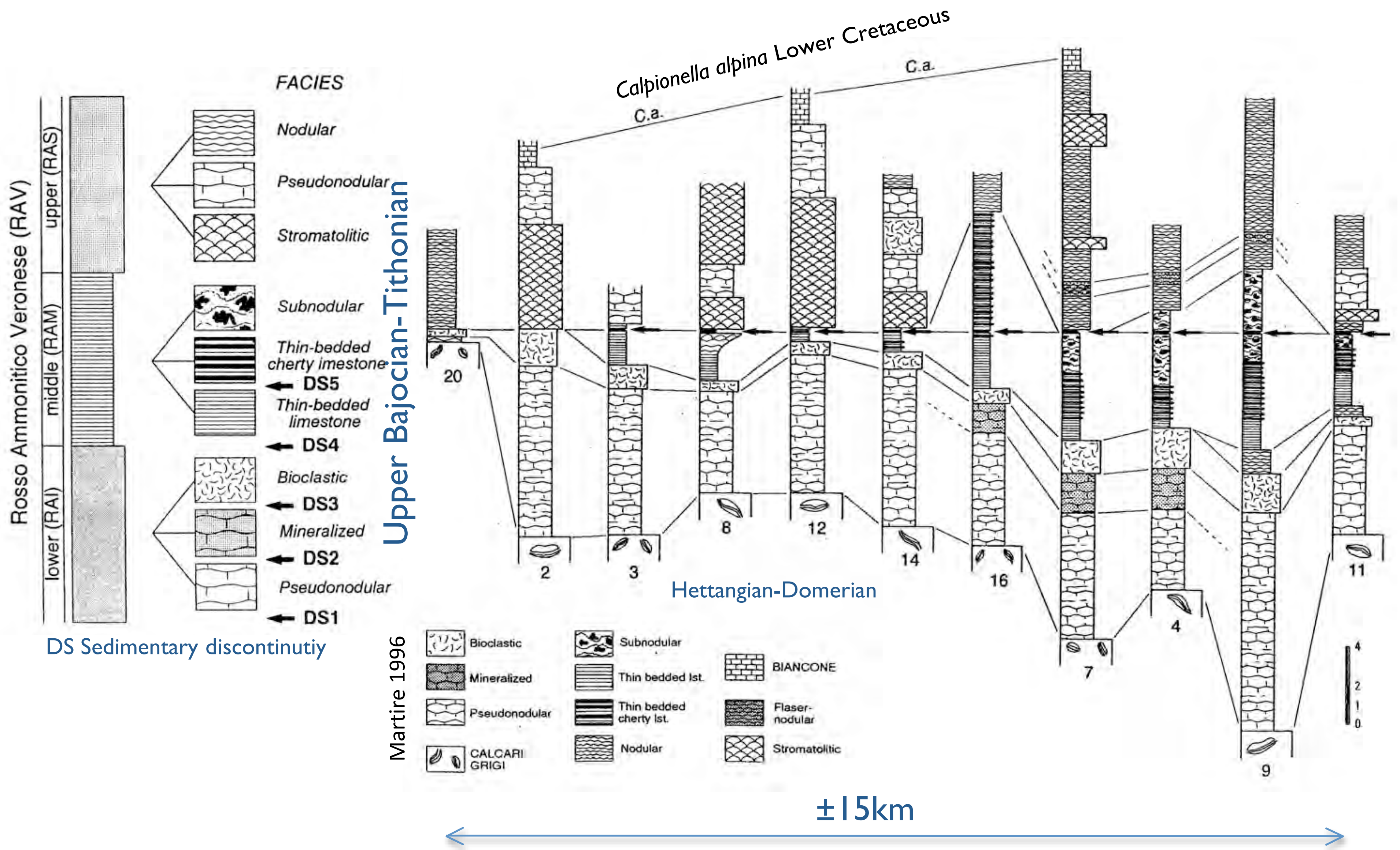
Main discontinuity surface between the Calcari a Crinoidi and the RAI (Monte Kumeta). The RAI geometries accomodate an irregular paleotopography on the Calcari a Crinoidi, which was further enhanced by repeated brittle deformations. The most
spectacular postades the RAIc including downslope gravity-driven soft deformation in the RAId nodular marls and debris flow phenomena. Di Stefano et al 2002



CONDENSED SERIES

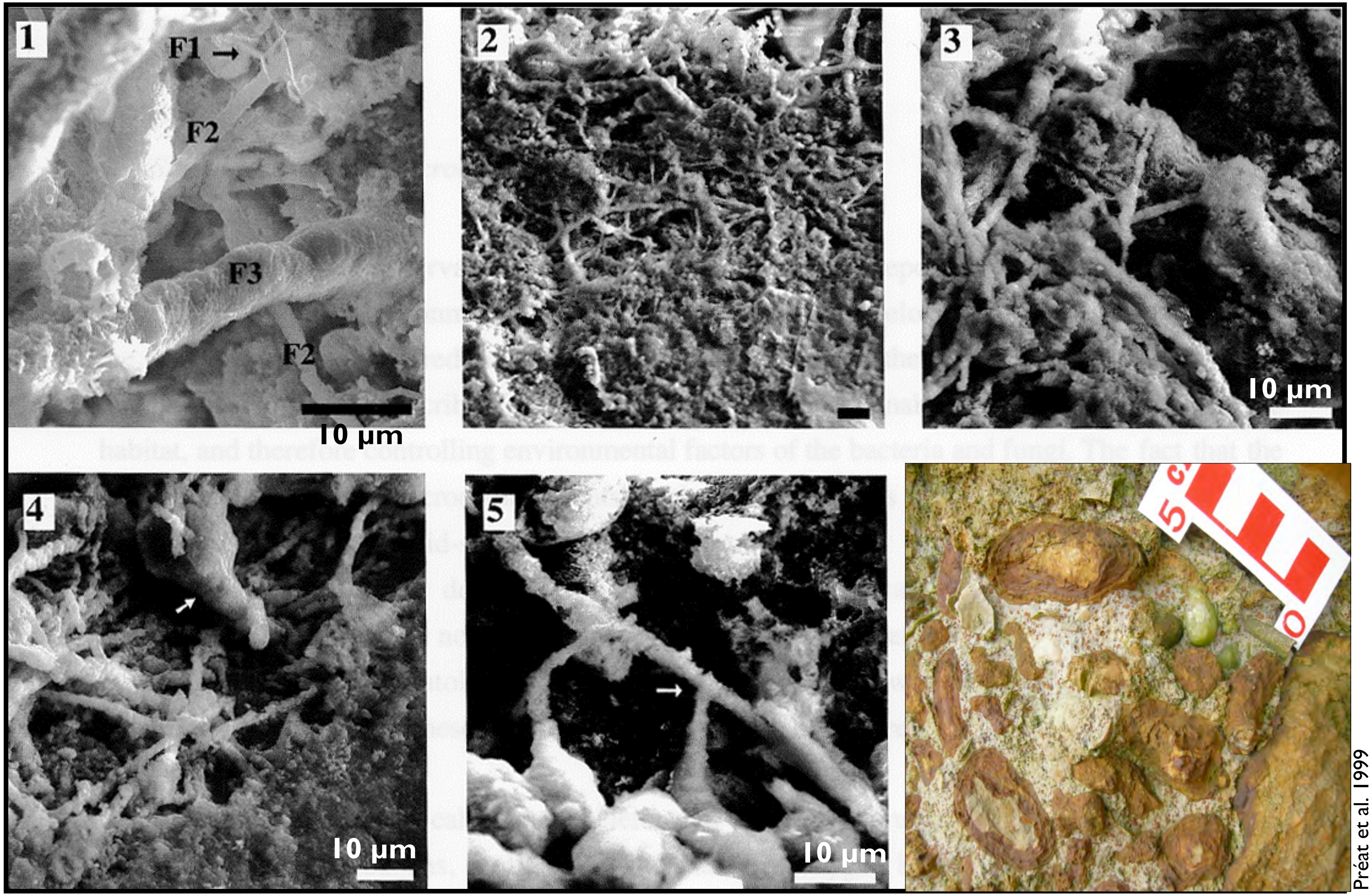
Hypothetical reconstruction of the structural framework of the Altopiano di Asiago NE Italy) in the Late Callovian (Martire1996)

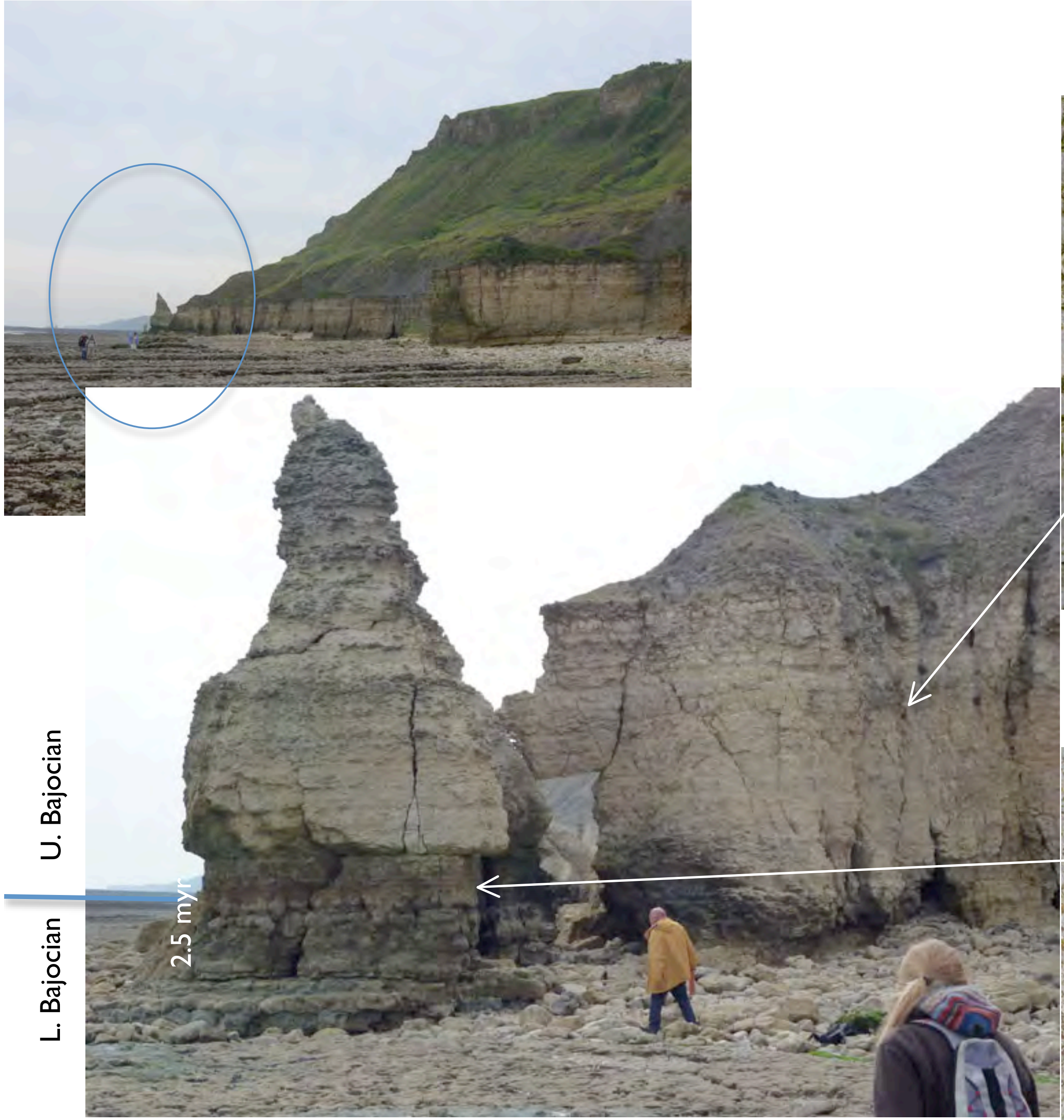




FACIES
Rosso Ammonitico Veronese (RAV)
upper (RAS)
middle (RAM)
lower (RAI)
Nodular
Pseudonodular
Stromatolitic
Subnodular
Thin-bedded cherty limestone
DS5
Thin-bedded limestone
DS4
Bioclastic
DS3
Mineralized
DS2
Pseudonodular
DS1
DS Sedimentary discontinutiy
Upper Bajocian-Tithonian
Calpionella alpina Lower Cretaceous
C.a.
C.a.
20
2
3
8
12
14
16
7
4
9
11
Hettangian-Domerian
Martire 1996
Bioclastic
Mineralized
Pseudonodular
CALCARI GRIGI
Subnodular
Thin bedded lst.
Thin bedded cherty lst.
Nodular
BIANCONE
Flaser-nodular
Stromatolitic
±15km

BAJOCIAN GSSP, SAINTE-HONORINE-DES-PERTES, FRANCE
Inside a Fe-oncoid... (nucleus is a small ammonite)

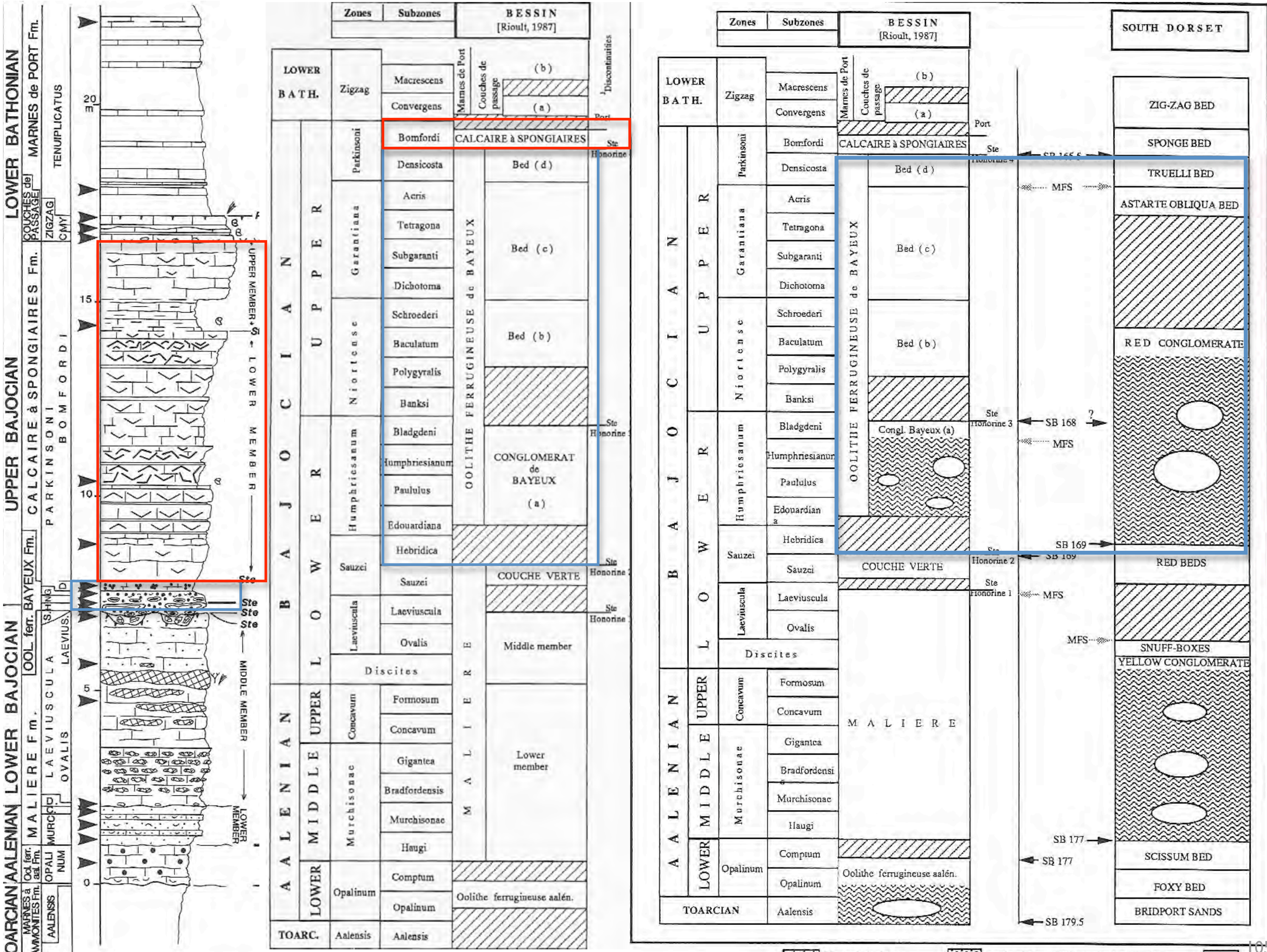




Sponges

Fe-oolites and ammonites

BAJOCIAN GSSP



Rioult et al 1991

MAJOR CONCLUSION

THE THICKNESS OF A SERIES IS NOT USEFUL TO ESTABLISH STRATIGRAPHIC SUBDIVISIONS

Example : Trois-Fontaines Formation (Givetian)
’high’ *vs* subsidence along the south border of Dinant basin
‘basin’? *vs* platform (Givet) *vs* ‘continent’ (paleosoils, Ronquières)
(para)stratotype *vs* lectostratotype *vs* limitotype

etc

= basin structuration (cf. seismic approach)

ANALYSIS OF CONTINUITY-THICKNESS OF SEDIMENTARY SERIES

TWO MAIN COMPLEMENTARY CATEGORIES OF SERIES

(A) COMPREHENSIVE and CONDENSED

No relation between thickness and duration

(B) CONTINUOUS and DISCONTINUOUS

Notion of lacuna or hiatus