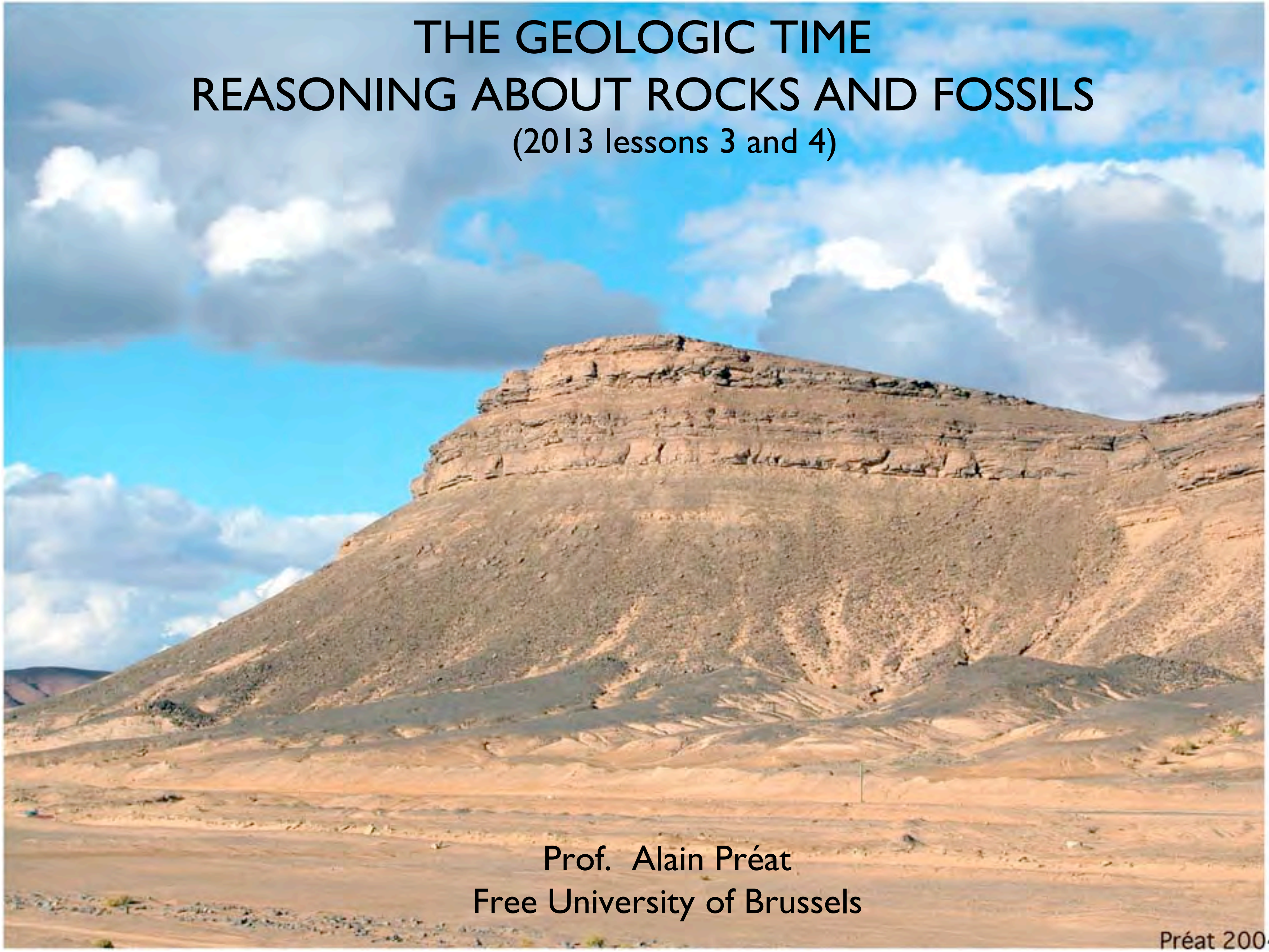
THE GEOLOGIC TIME
REASONING ABOUT ROCKS AND FOSSILS

(2013 lessons 3 and 4)

GEOL.F.104



Prof. Alain Préat
Free University of Brussels

1.GEOMETRY =>2. REL/ABS TIME =>3. KINETICS

1. REL/ABS TIME =>2.GEOMETRY =>3. KINETICS

2. GEOMETRY

>1960

Time lines are generally oblique (sedimentary bodies)
Then the series is folded, thrusted ('jagged')

1a. ABSOLUTE AND RELATIVE TIME

<1800

Both remain necessary

>1900

3. RATE

The kinetics of the phenomena depends of time resolution

>1980-1990

the

GOAL

ESTABLISH A CHRONOLOGY or A CHRONOSTRATIGRAPHY

= infer the event chronology having affected the Earth

= establish synchronisms between coeval formations (same age) which are geographically separated, and display various features (lithological or others)

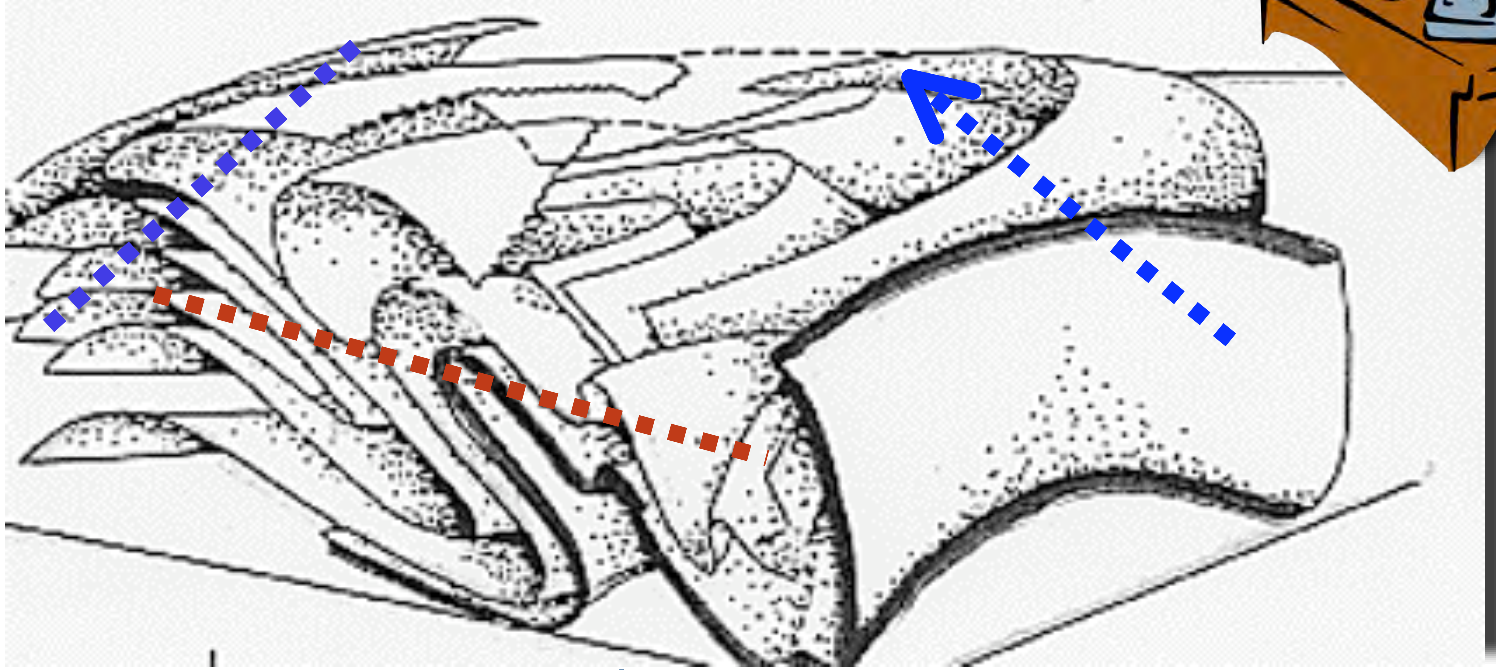
OUTCROPS

=folded notebook,

jagged... =mapping

Outcrops = folded, jagged notebook
…. first is mapping => its result is already
VERY incomplete at this stage

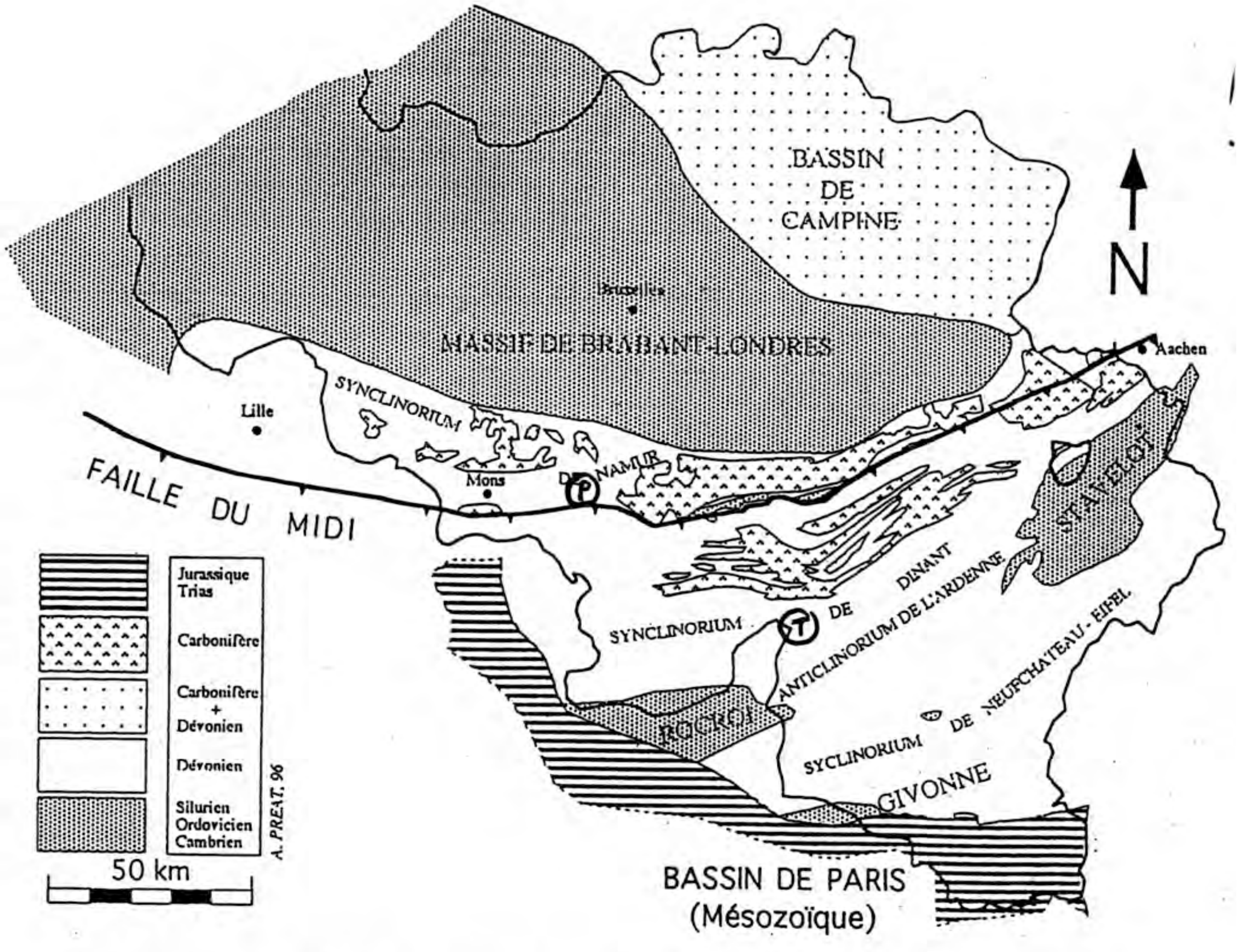
MAPPING GEOLOGY



metamorphism <==> compression
South APPALACHIAN (Caroline)
The foldings are so often complex
that is difficult to represent them
even as diagrams!

STRUCTURAL GEOLOGY

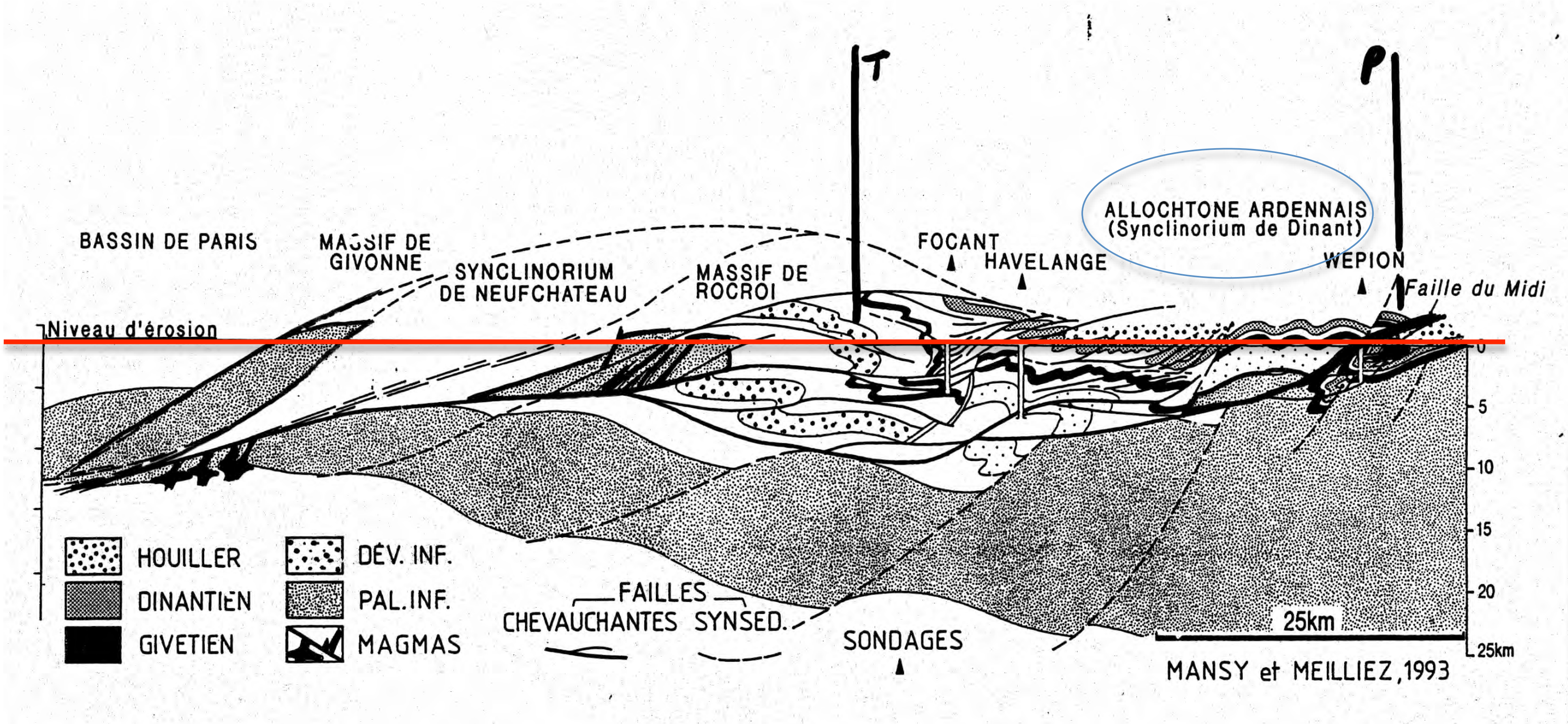
Major Paleozoic structural units in Belgium



PRINCIPALES UNITES STRUCTURALES DU PALEOZOIQUE DE BELGIQUE

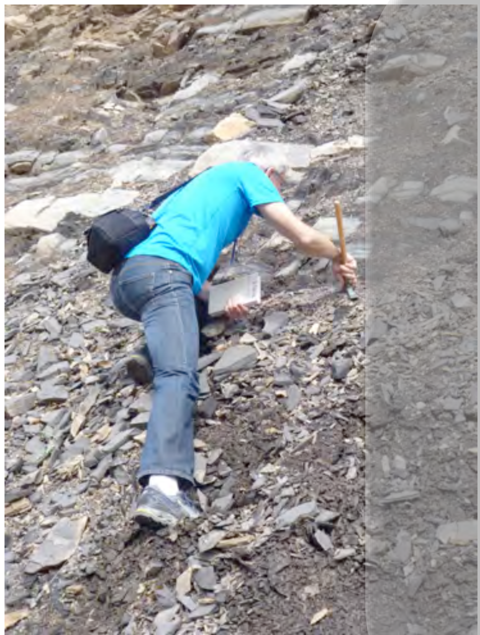
Nb: 'Historical Stratotypes: Givet = Givetian, Frasnes = Frasnian, Famenne = Famennian, Tournai = Tournaisian, Visé = Viséan, Dinant = Dinantian …. . Ypres = Ypresian …..

Major Paleozoic structural units in Belgium



How many basins? One, two or three…..
Two 'worldwide' paleozoic orogenic cycles : Caledonian and Hercynian

# of what consists the first work for a geologist?

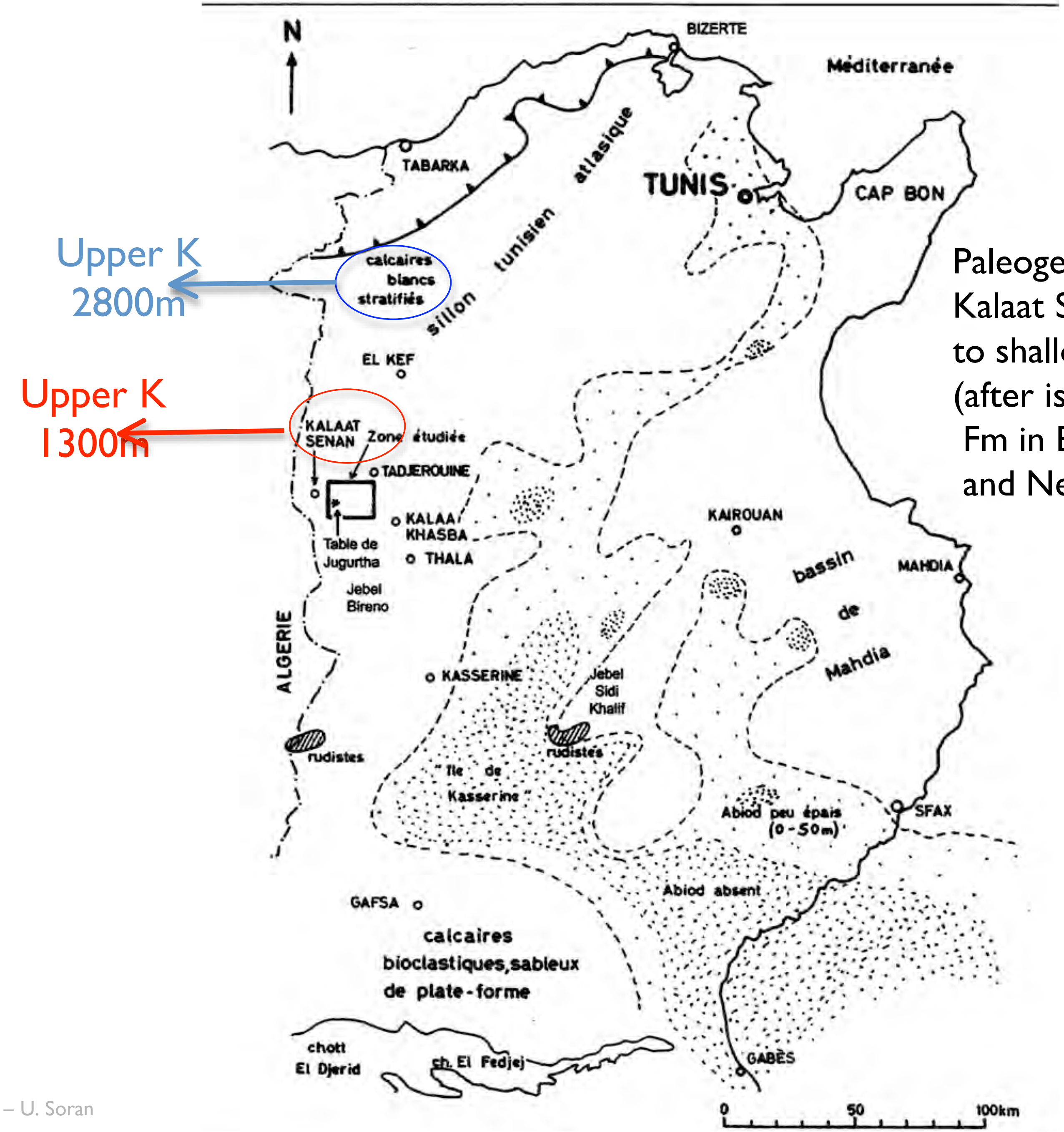


Of course = field work

⇒ Observation (…)
⇒ Lithologic column in one place

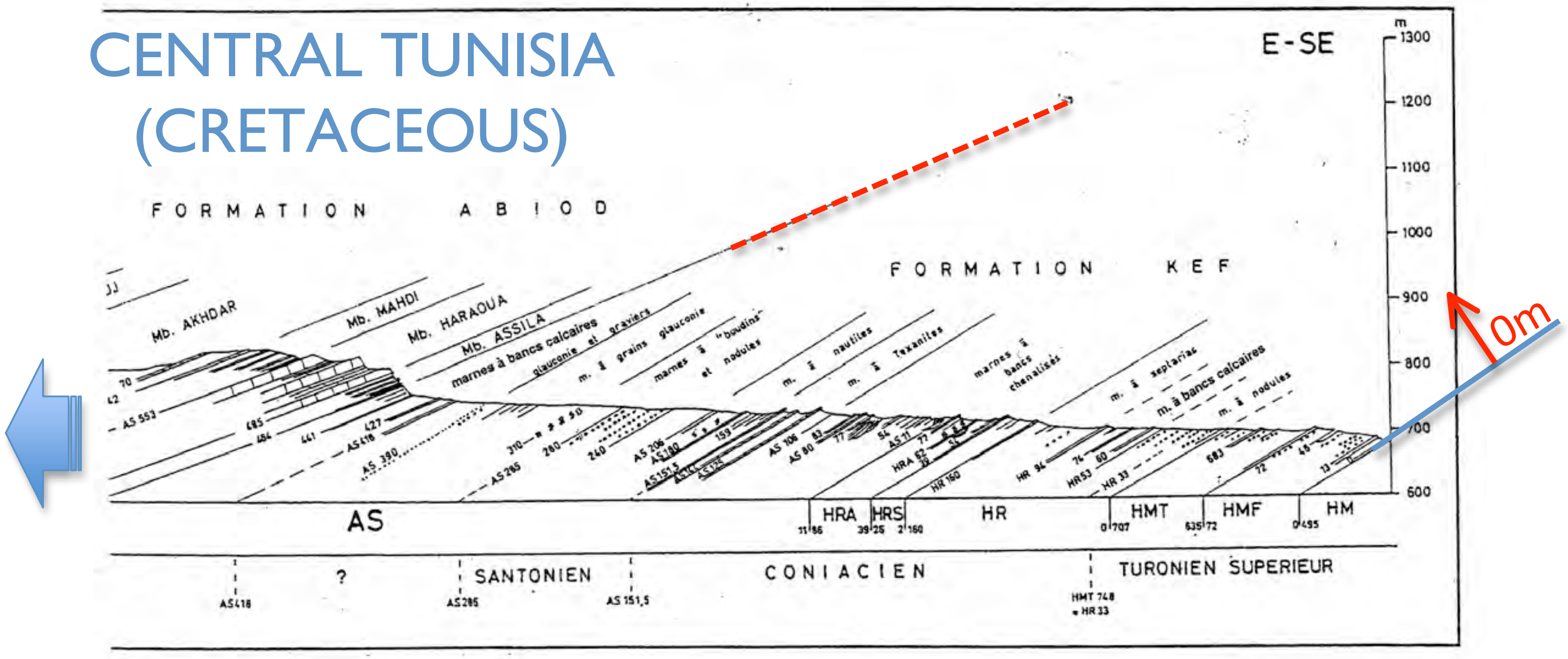
(Then in other places
=> Mapping, Correlation …)

# of what consists the first work for a geologist?

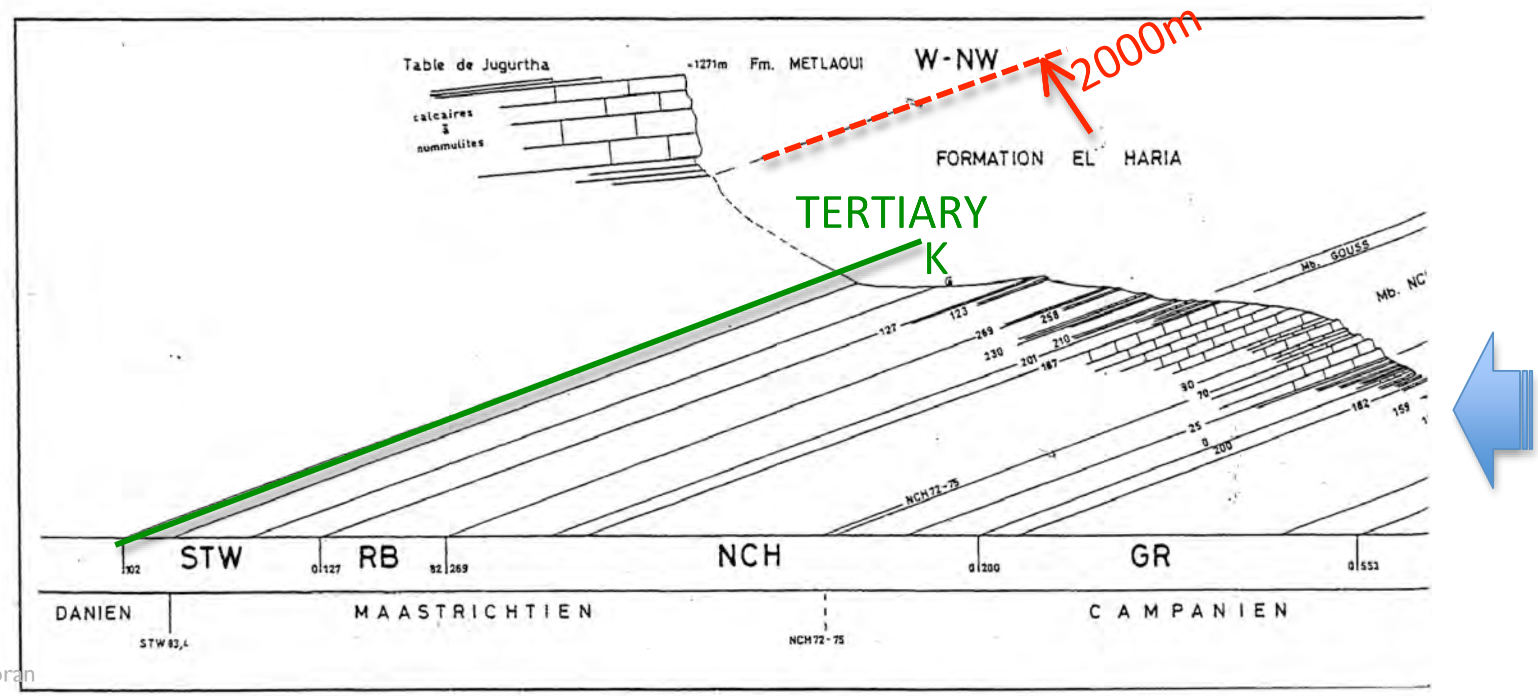


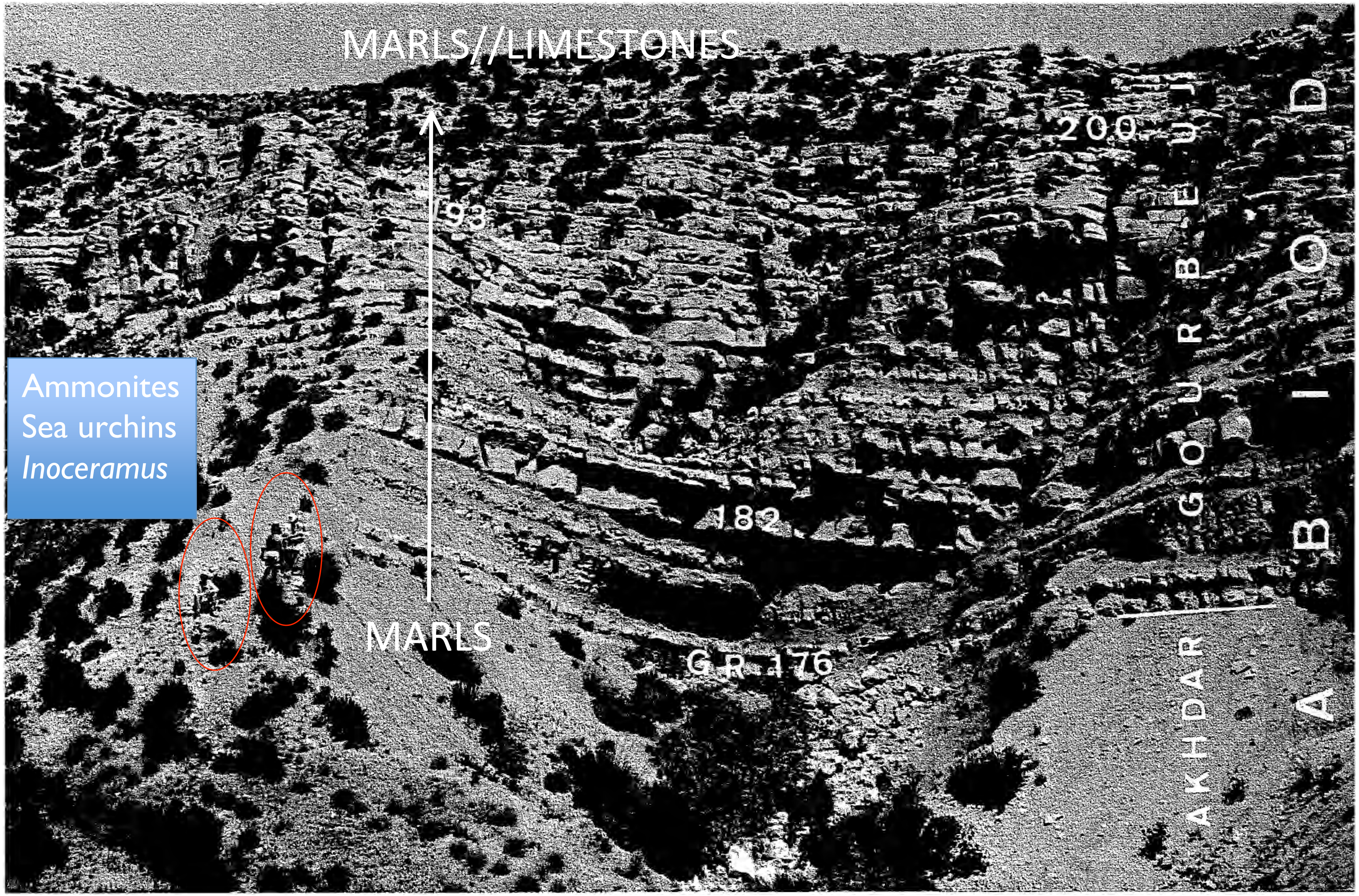
Paleogeographical situation of the Kalaat Senan region with regard to shallow or emerged areas (after isopach map of the Abiod Fm in Boltenhagen (1985) and Negra & Mrabet (1994)

CENTRAL TUNISIA (CRETACEOUS)

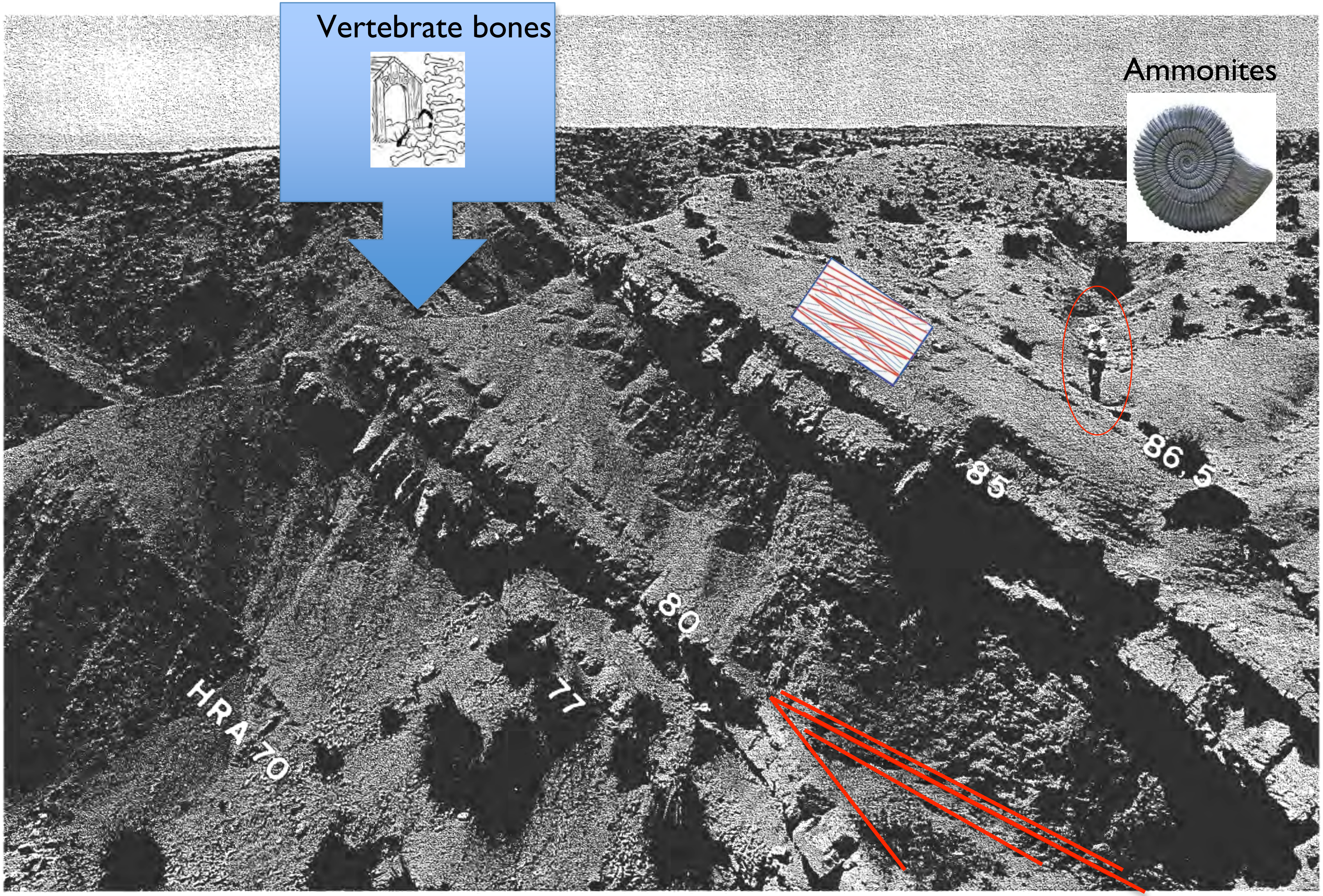


Transverse section WNW-ESE from the Upper Turonian to the Maastrichtian succession

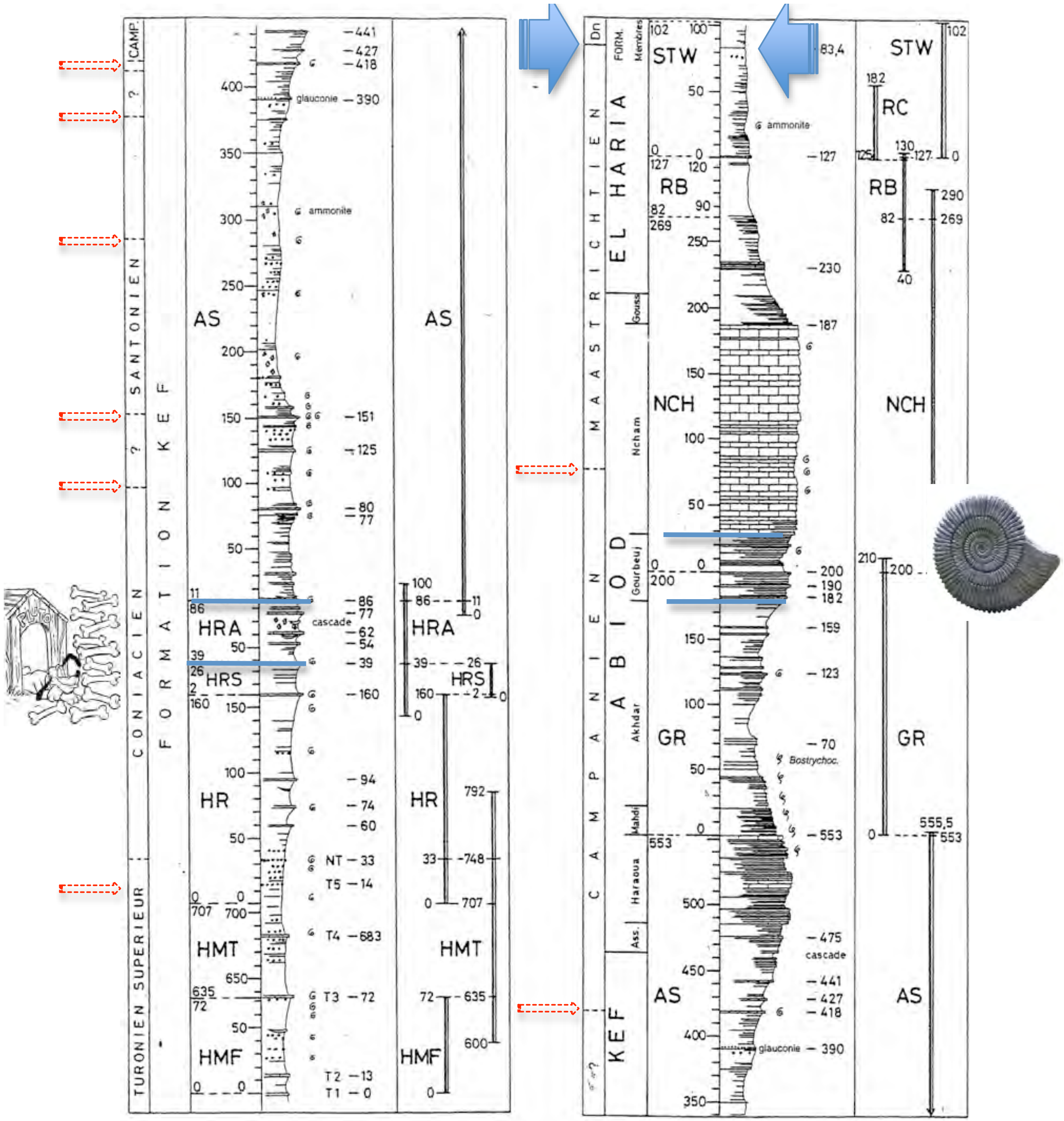




Wadi Gourbeuj, upstream and waterfall. Transition of Akhdar marls to Gourbeuj Mbr alternations (upper part of the Campanian)



Wadi Haraoua, Kef Fm, Coniacian grey marls with interbedded channelised limestones

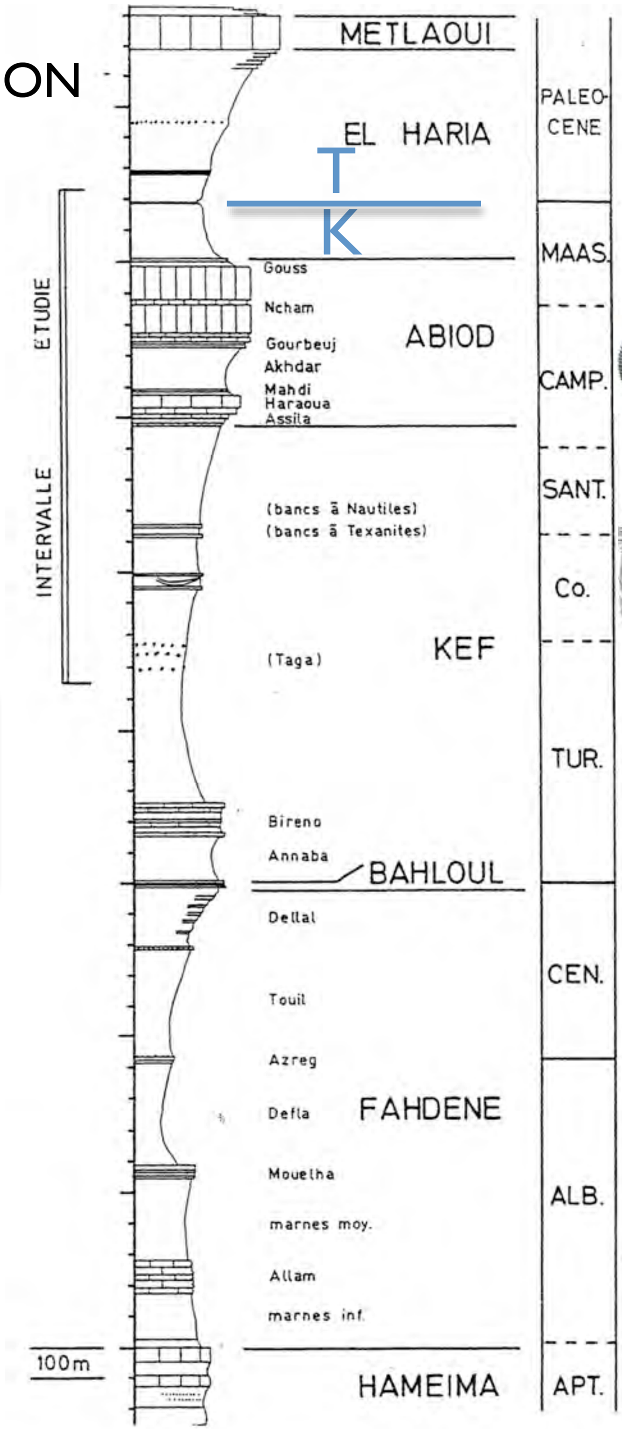


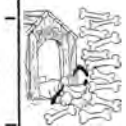
COMPOSITE lithological succession of the Coniacian to the Maastrichtian and relative position of **PARTIAL** sections (the numbers correspond to metres)

VERY IMPORTANT CONCLUSION

Fm subdivisions
Lithology > < Stratigraphy

Here
1300m
Distal platform
Ammonites, Foraminifers,
Nannofossils …



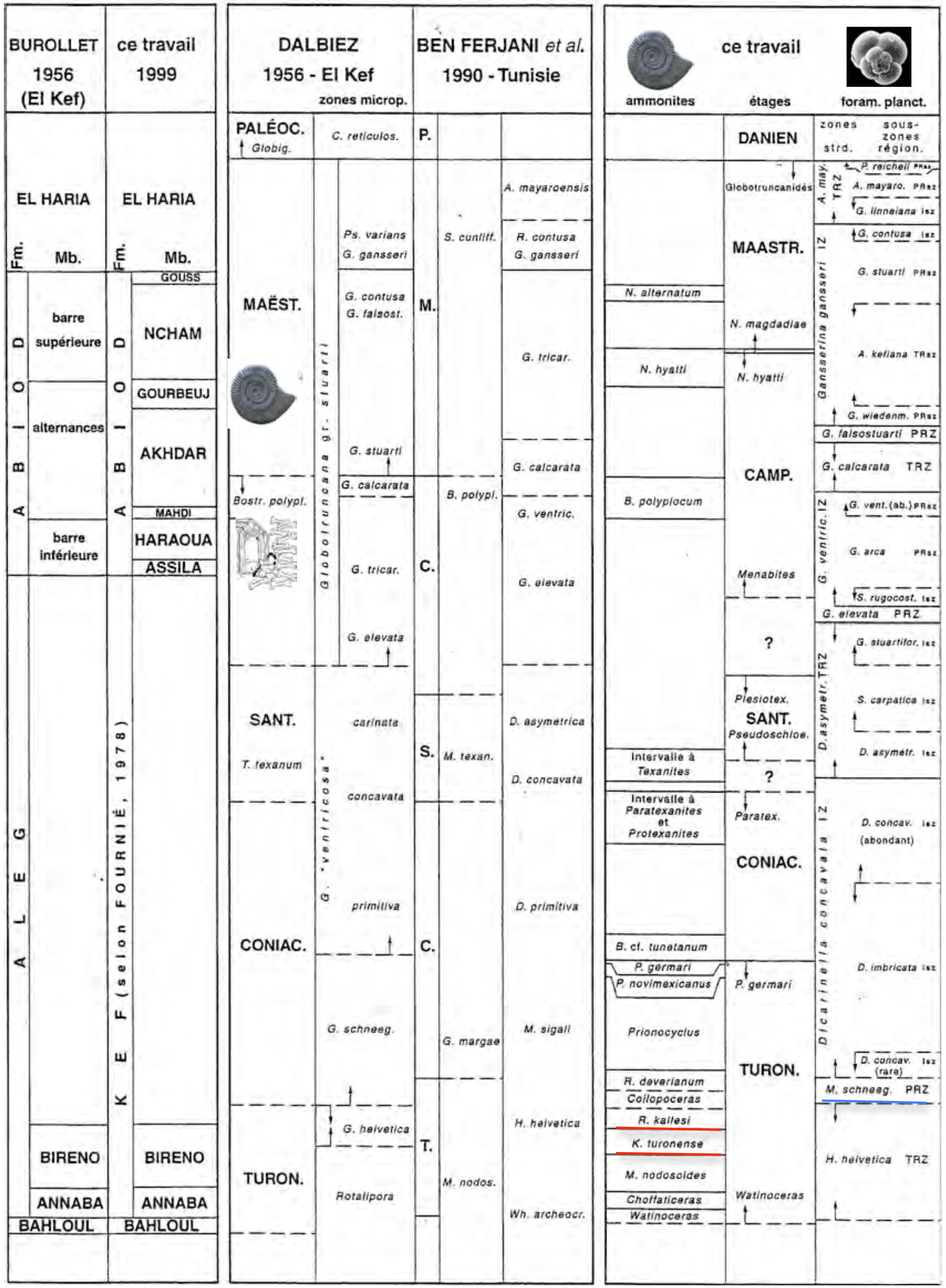


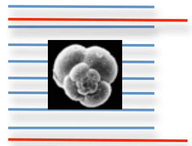
T
K

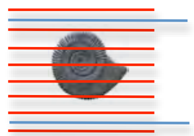
FROM **COMPOSITE** SECTIONS

± 50 myr

FIRST SUBDIVISIONS STARTED IN **1901**

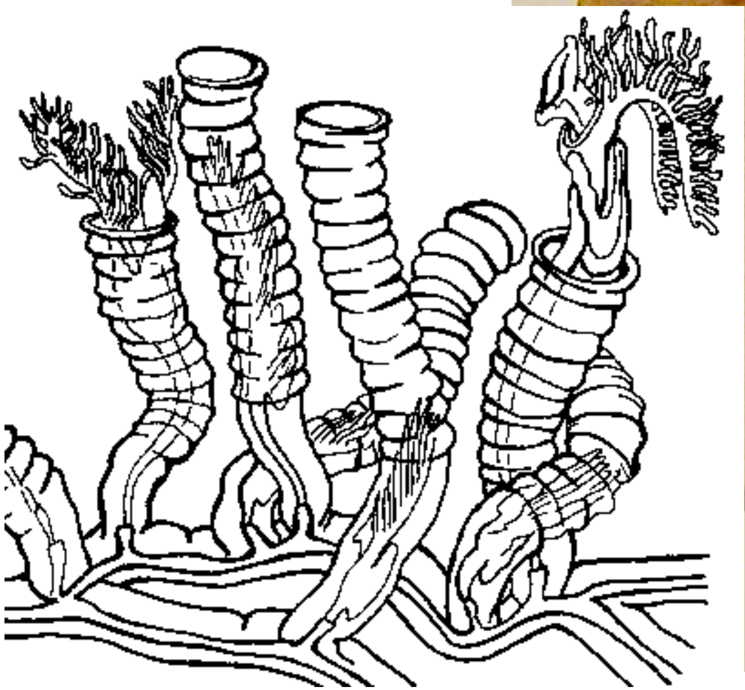






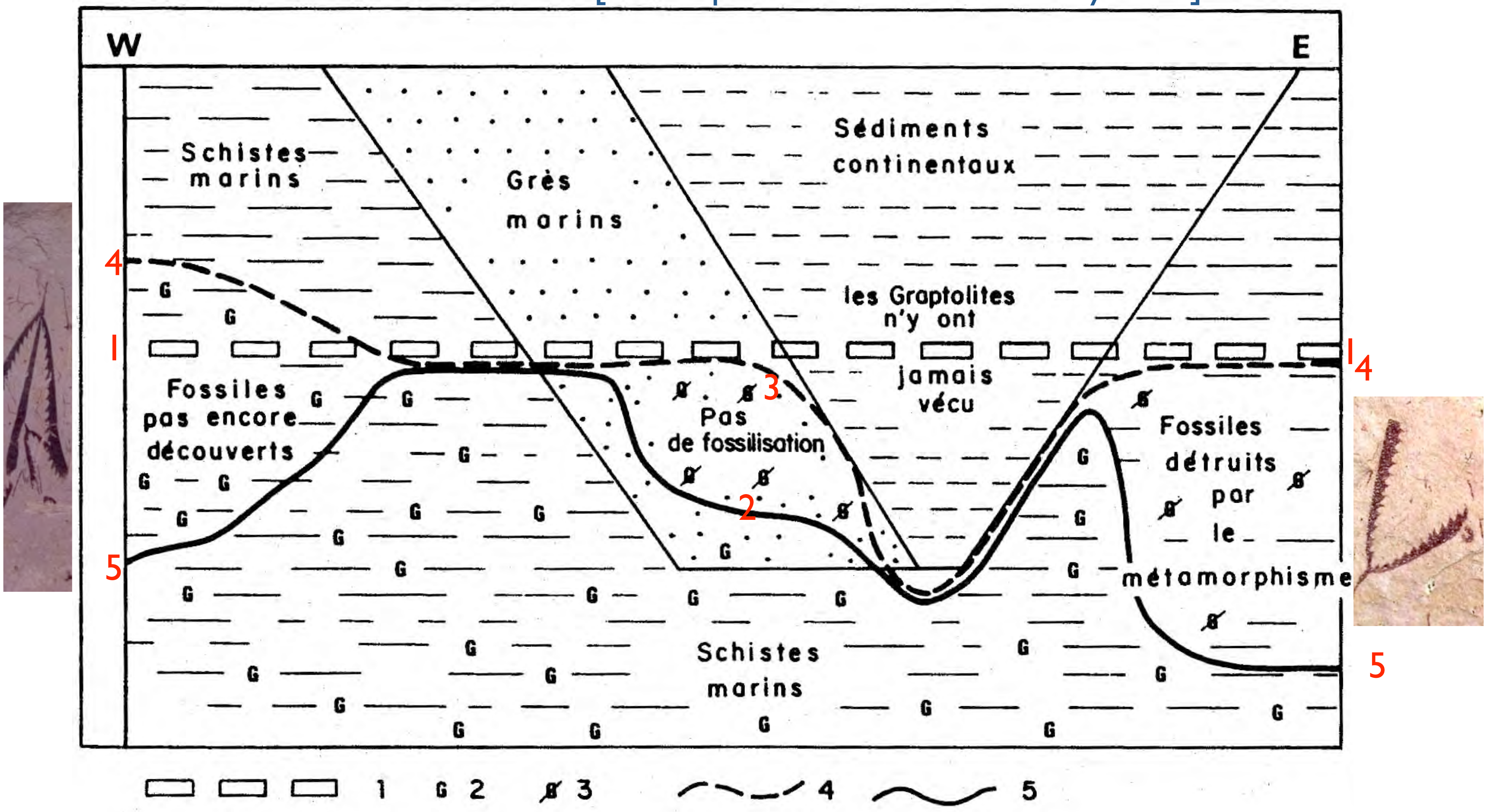
GRAPTOLITES : Cm-Early Cferous

Hemichordata (Primitive Invertebrates)
(colonial, zooids)
Floating animals = **PLANKTONIC**
Very useful for worldwide correlation
GSSP : Silurian (Czech Republic)



‘μΔt’

4 => 5 ==>1 [nb Graptolite biozones: a few myr 5-6!]



3. Ideal isochron surface 4. Upper limit of original graptolite deposition

5. Upper limit where graptolites have been discovered

G: Fm where graptolites lived

G/: Fm where graptolites lived, but no fossilization

ÉTAGE	SOUS-ÉTAGE	zones d'ammonites	nautiles	zones de brachiopodes	échinides	foraminifères
CALLOVIEN	sup.	19 Lamberti 18 Athleta	*Pseudaganides aganaticus*	Compacta Flexuosa	*Collyrites acuta*	
	moy.	17 Coronatum 16 Jason	*Cymatonautilus julii*	Dorsoplicata Orbignyana Aromasiensis Dominula	*Collyrites elliptica*	
	inf.	15 Gracilis 14 Macrocephalus	*Pseudocenoceras calloviense*	Almerasi Tenuiformis Spathica Divionensis		*Dorothia osowiensis*
BATHONIEN	sup.	13 Discus 12 Retrocostatum	*Pseudoceras verciacense*	Boueti Globata, Circumda	*Pygomalus ovalis* « *Tithonia* » *blondeti*	*Valvulina fusca*
	moy.	11 Subcontractus		Whatleyensis Bivallata	*Clypeus nugii*	*Lenticulina reticulata* *L. batrakiensis*
	inf.	10 Zigzag	*Digonioceras dispansum*	Bugeysiaca Dumortieri	*Acrosalenia marioni*	*Triplasia bartensteini* *Meyendorffina bathonica*
BAJOCIEN	sup.	9 Parkinsoni 8 Garantiana 7 Subfurcatum	« *Cenoceras* » *foordi* *Digonioceras excavatum*	Voultensis Ferryi Phillipsi, Craneae	*Paracidaris zschokkei*	
	moy.	6 Humphriesia		Parvula	*Coenocidaris cucumifera*	
	inf.	5 Sauzei 4b Laeviuscula 4a Discites	« *Cenoceras* » *obesus*	Pallas, Cortonensis Mühlbergi, Latovalis		
AALENIEN	sup.	3 Concavum	« *Cenoceras* » *lineatus* et *Pseudaganides vaceki*	Ingens, Subangula		*Planiinvoluta carinata*
	moy.	2 Murchisonae		Leckhamptonensis Trilineata		
	inf.	1 Opalinum		Prava, Ruthenensis	*Coen. roysi*	*Lenticulina d'orbignyi*

Time Lines?

'isochrons'
'isochrons'
'isochrons'

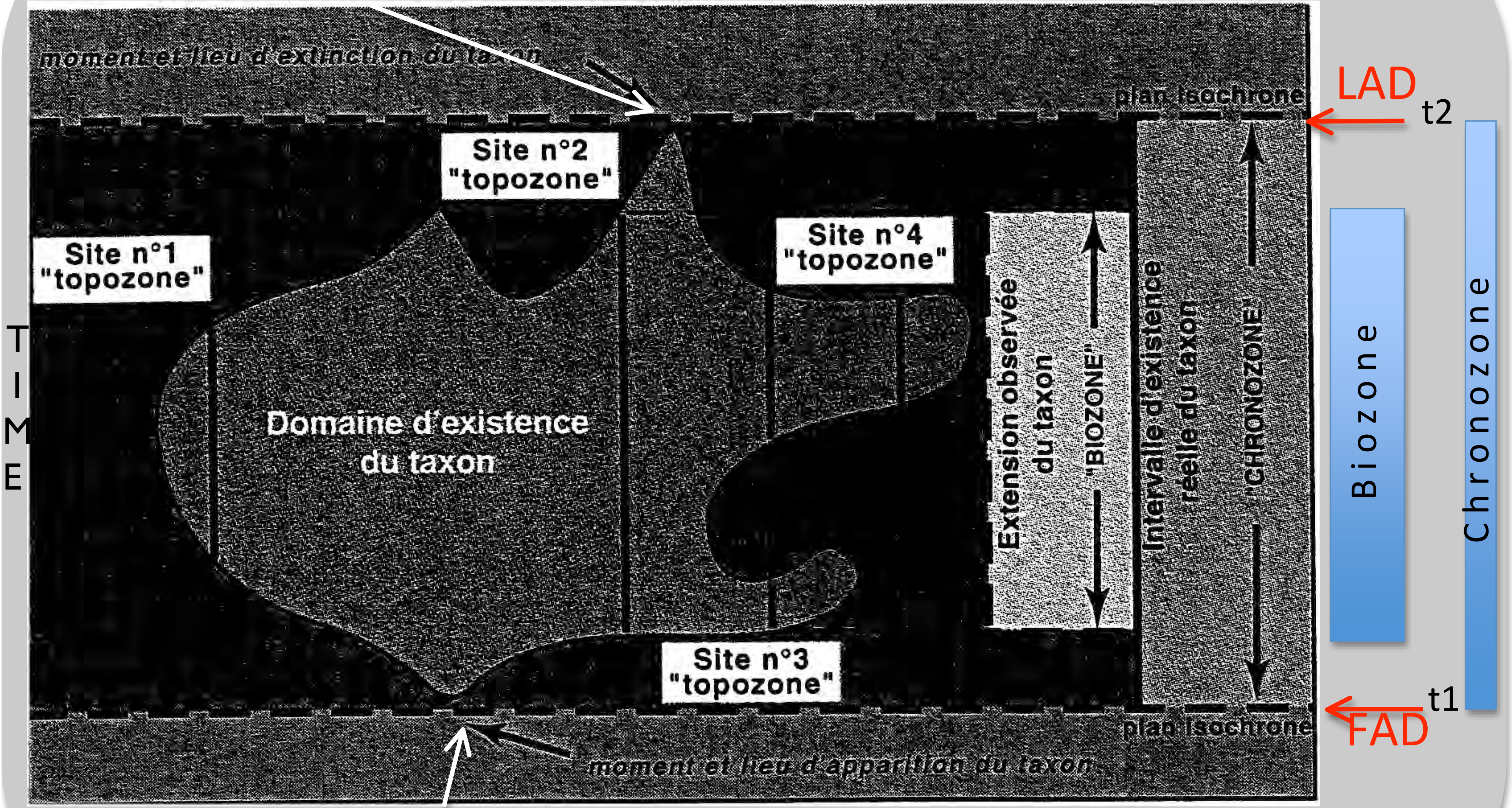
Time Lines?

'isochrons'
'isochrons'
'isochrons'

Tableau 2 – Échelles parallèles établies dans le Jurassique moyen.

Geographic area ‘2D’ => ?3D

Time AND Place

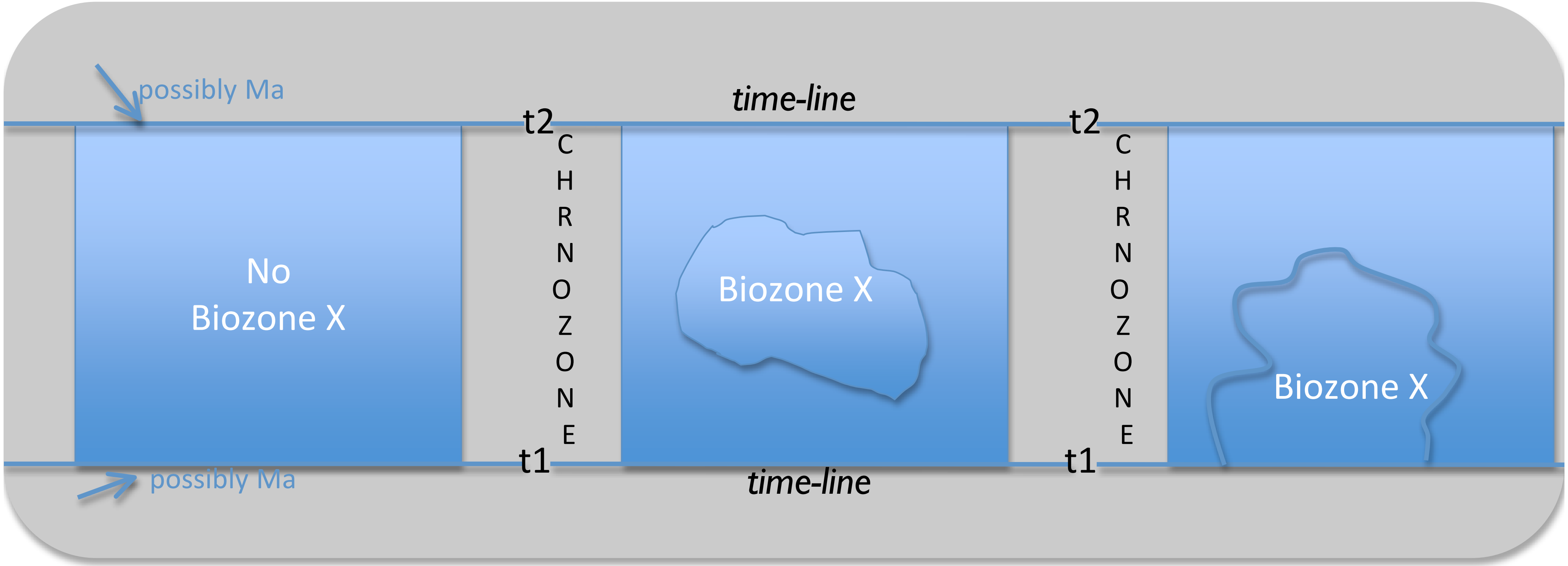


Time AND Place

nb oil geology LAD + FAD…

FIRST and LAST APPEARANCES OF A DATUM

BIOZONE(S) *vs* CHRONOZONE(S)
(relative vs absolute)



BIOZONE

⇒ Biostratigraphy : organisation of stratigraphical units based on their **guide** fossils contents (= subdivision of rock units on the basis of fossil content)

CHRONOZONE

⇒ Chronostratigraphy : study of rock units bounded by **time planes**

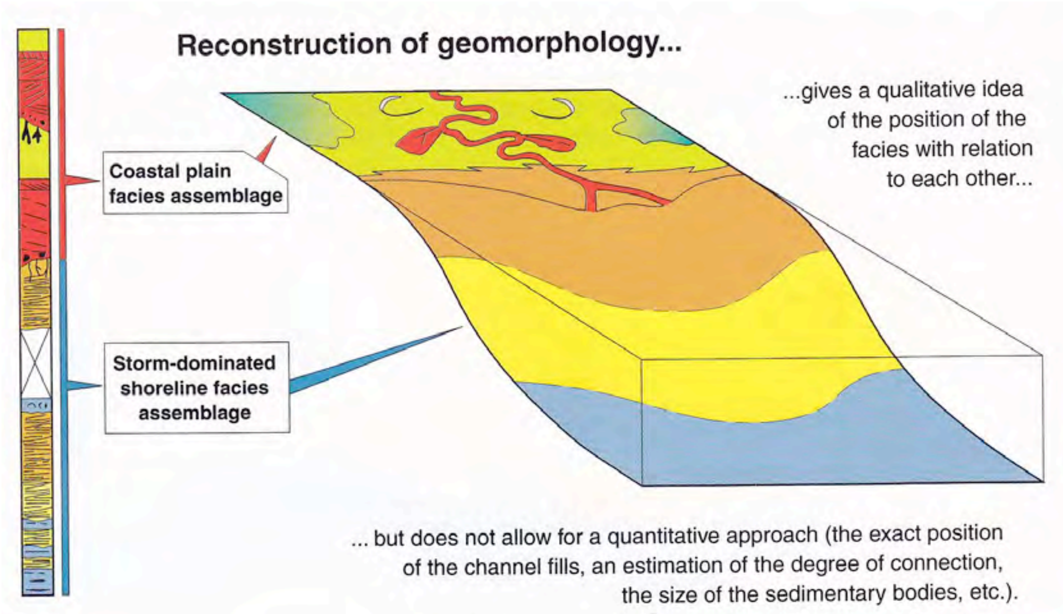
==> estabishment of a global standard or chronology of geological units = GTS

GTS = Geological Time Scale (Chronostratigraphical Scale)

BIOSTRATIGRAPHY is the basis for the CORRELATION or comparison, **in time**, of lithological units

⇒ it provides the time framework for interpreting sedimentary rock units as the product of interfingering environments

Homewwod et al 2000

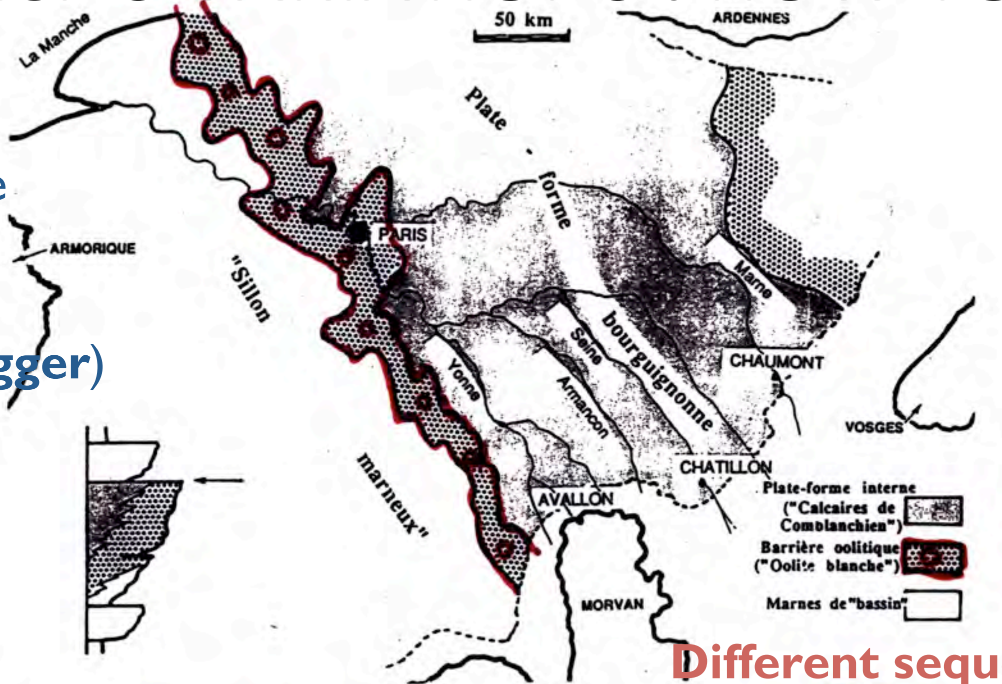


WHY?

Lateral Facies Variation(s)

LATERAL FACIES VARIATIONS : HOW TO MANAGE?

Palaeogeography of the Paris basin (platform) during the Bathonian **Middle Jurassic (Dogger)**

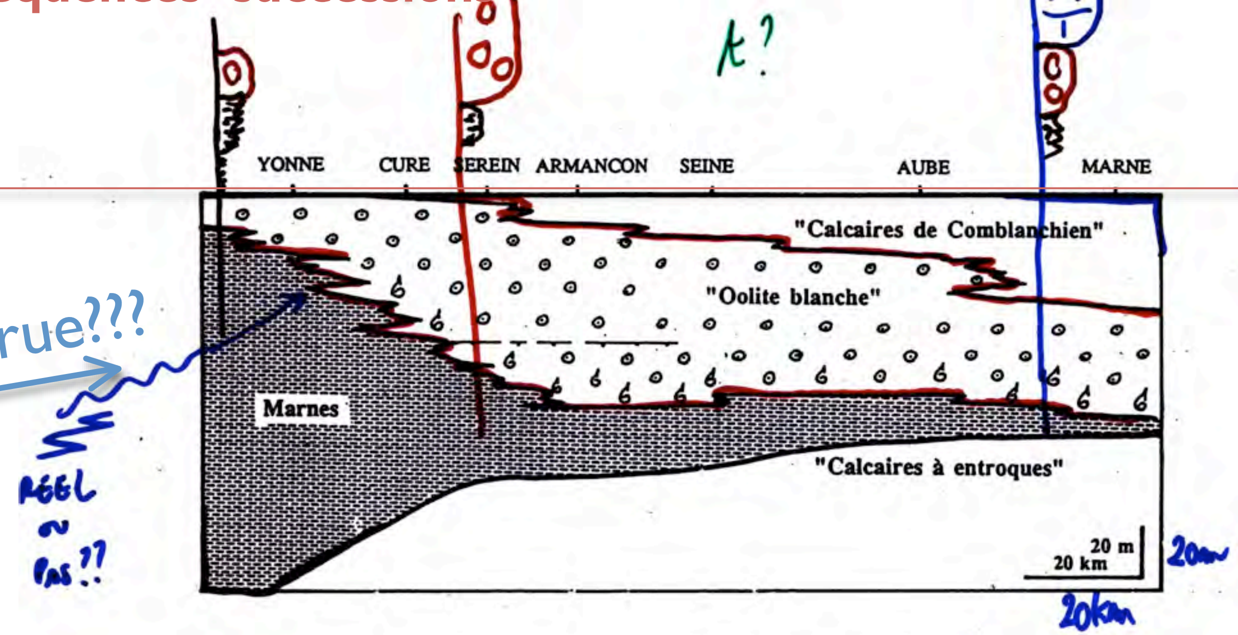


Different sequences -successions

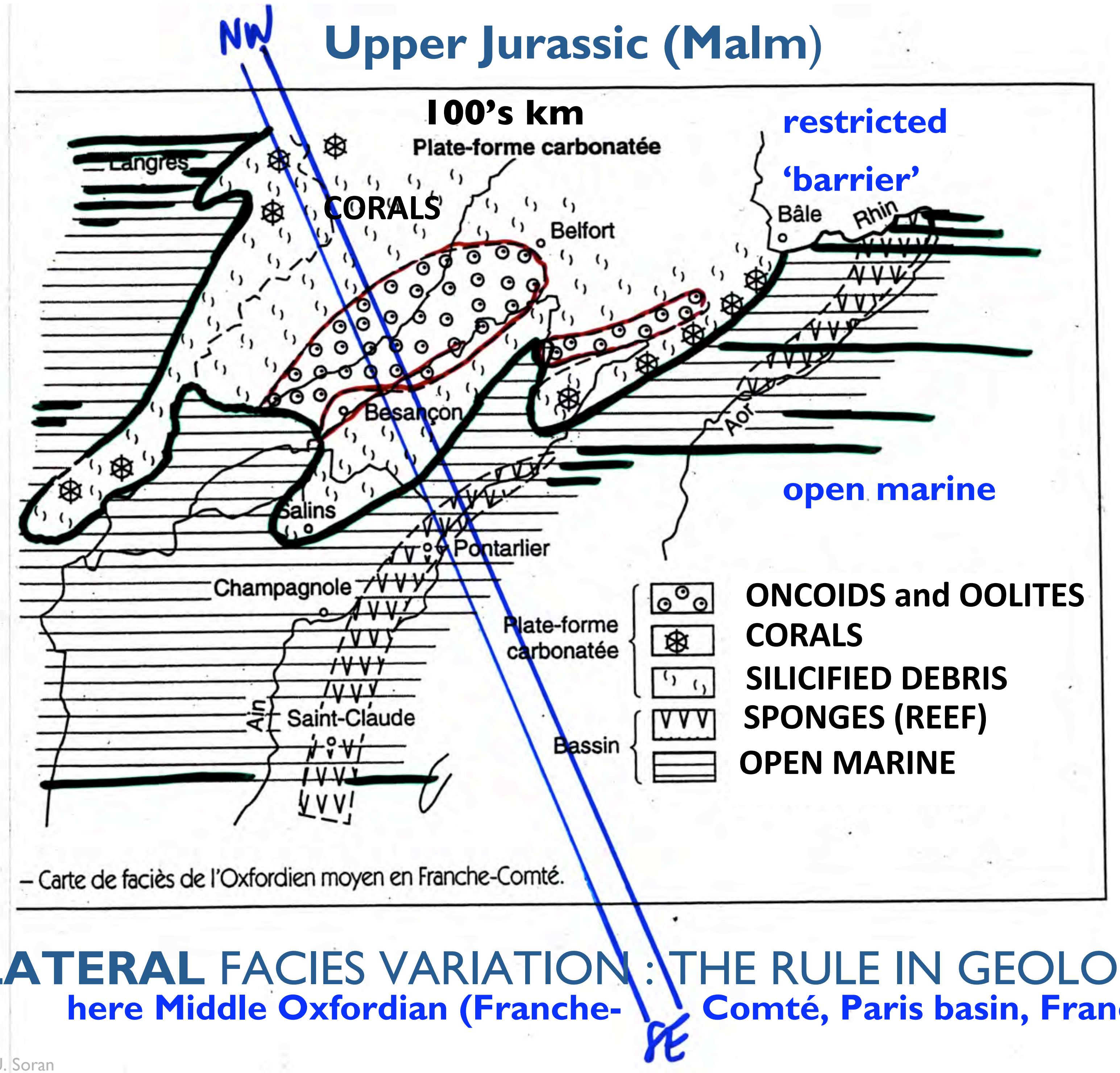
Fig. 37 - Paléogéographie de la plate-forme pariso-bourguignonne au sommet de la séquence "bathonienne". Selon B.H. Purser.

Different sequences -successions

Is it true???



Upper Jurassic (Malm)



LATERAL FACIES VARIATION : THE RULE IN GEOLOGY

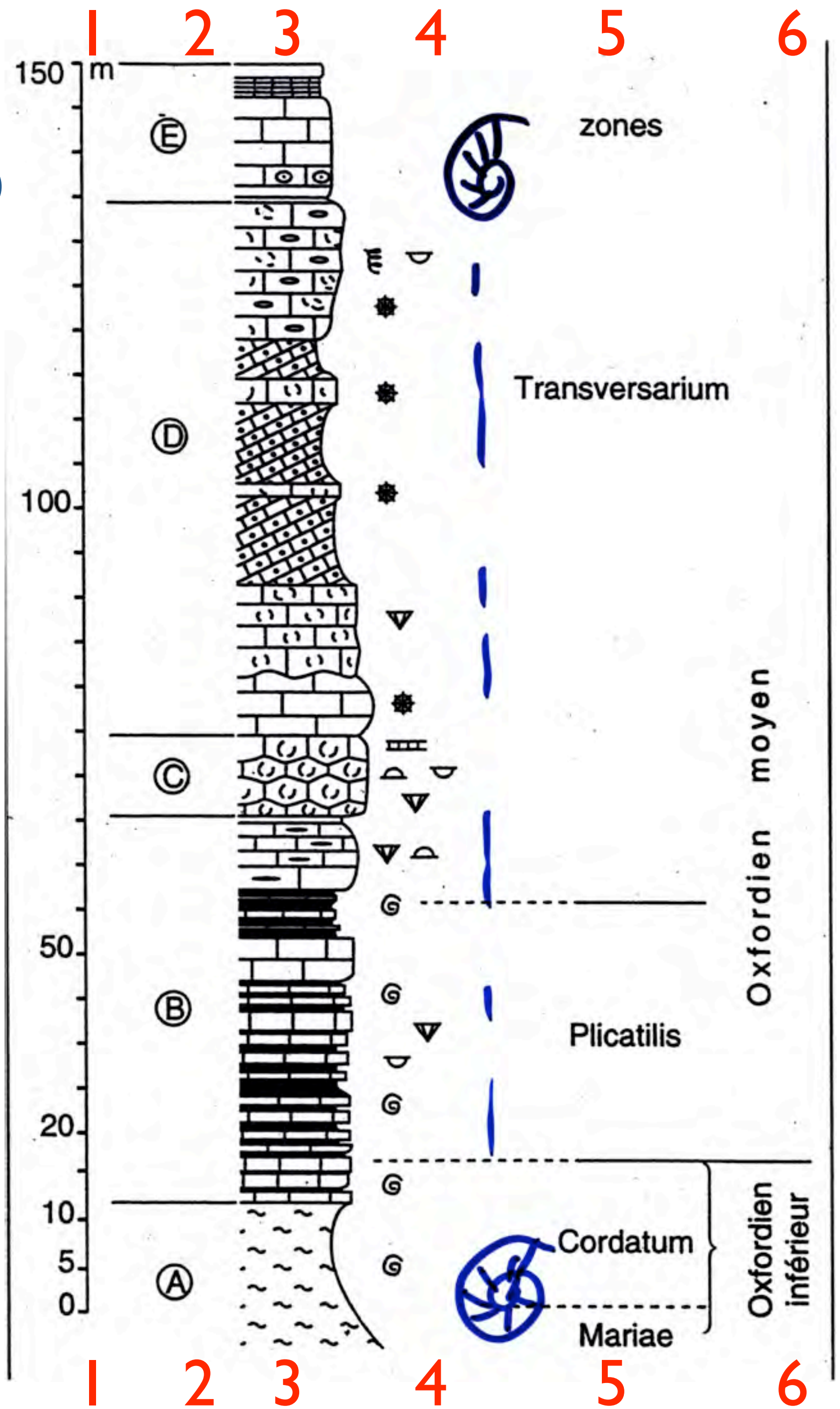
here Middle Oxfordian (Franche-Comté, Paris basin, France)

Upper Jurassic (Malm)

northern JURA France

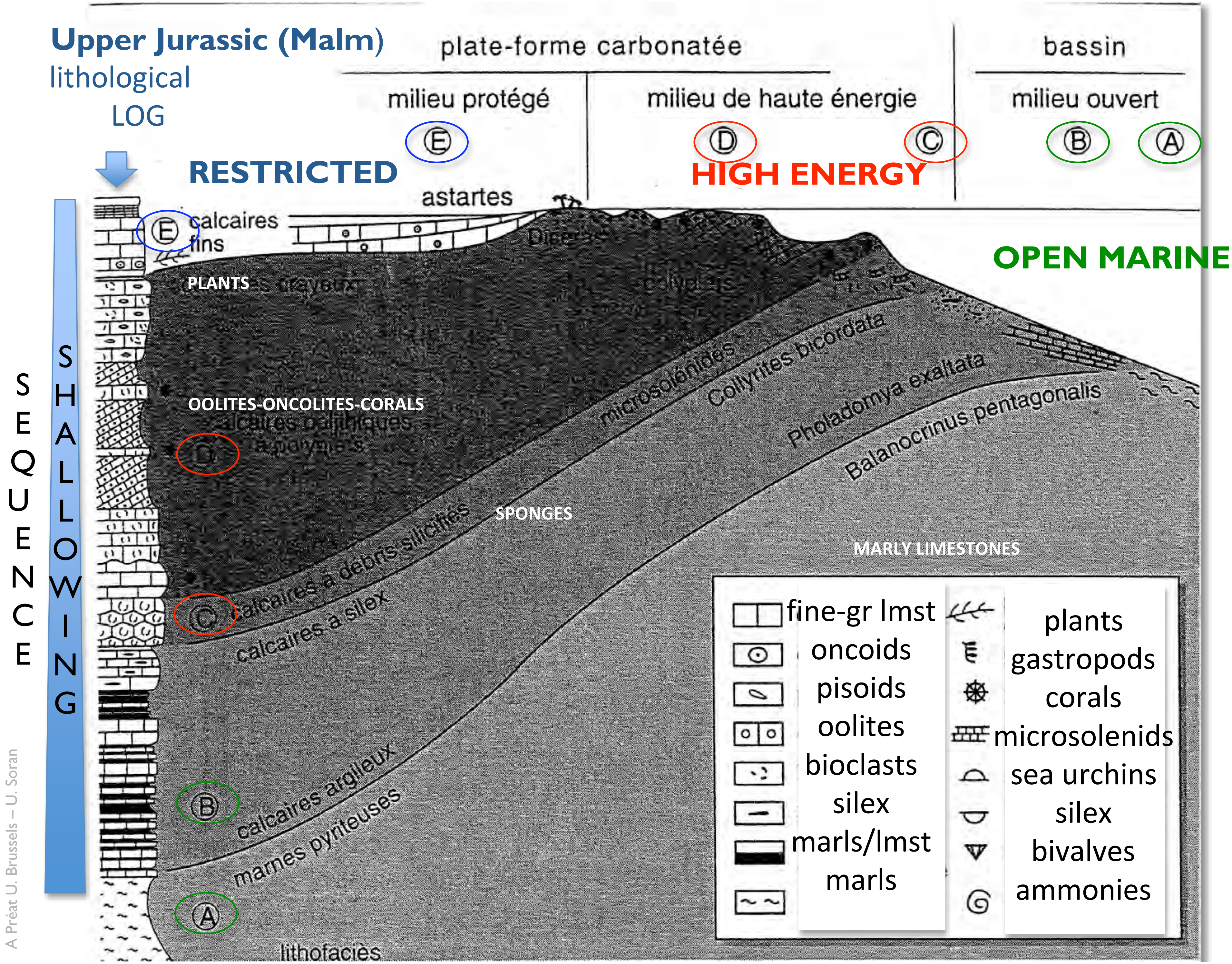
Synthetic data or information in **LOGS**

what is a log?
it is the record of any…



Upper Jurassic (Malm)

lithological LOG



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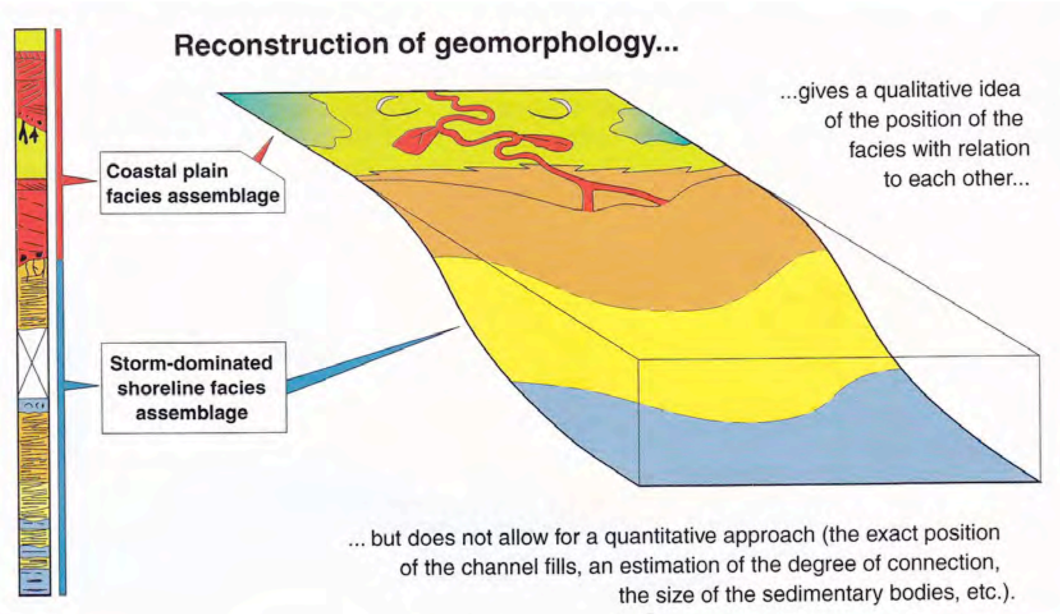

Homewwod et al 2000

Lateral Facies Variation(s)

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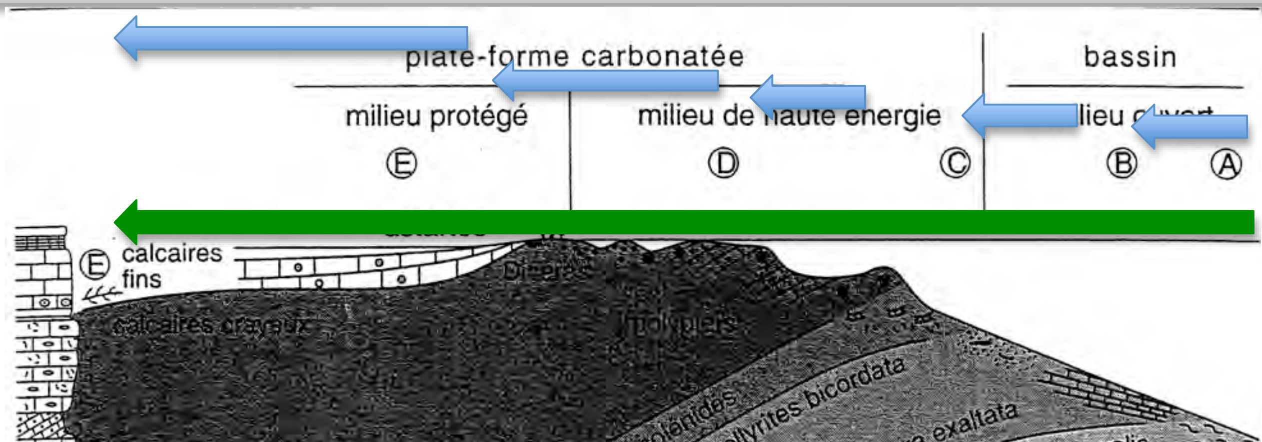
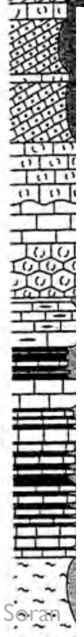


A
E

A
B
C
D
E



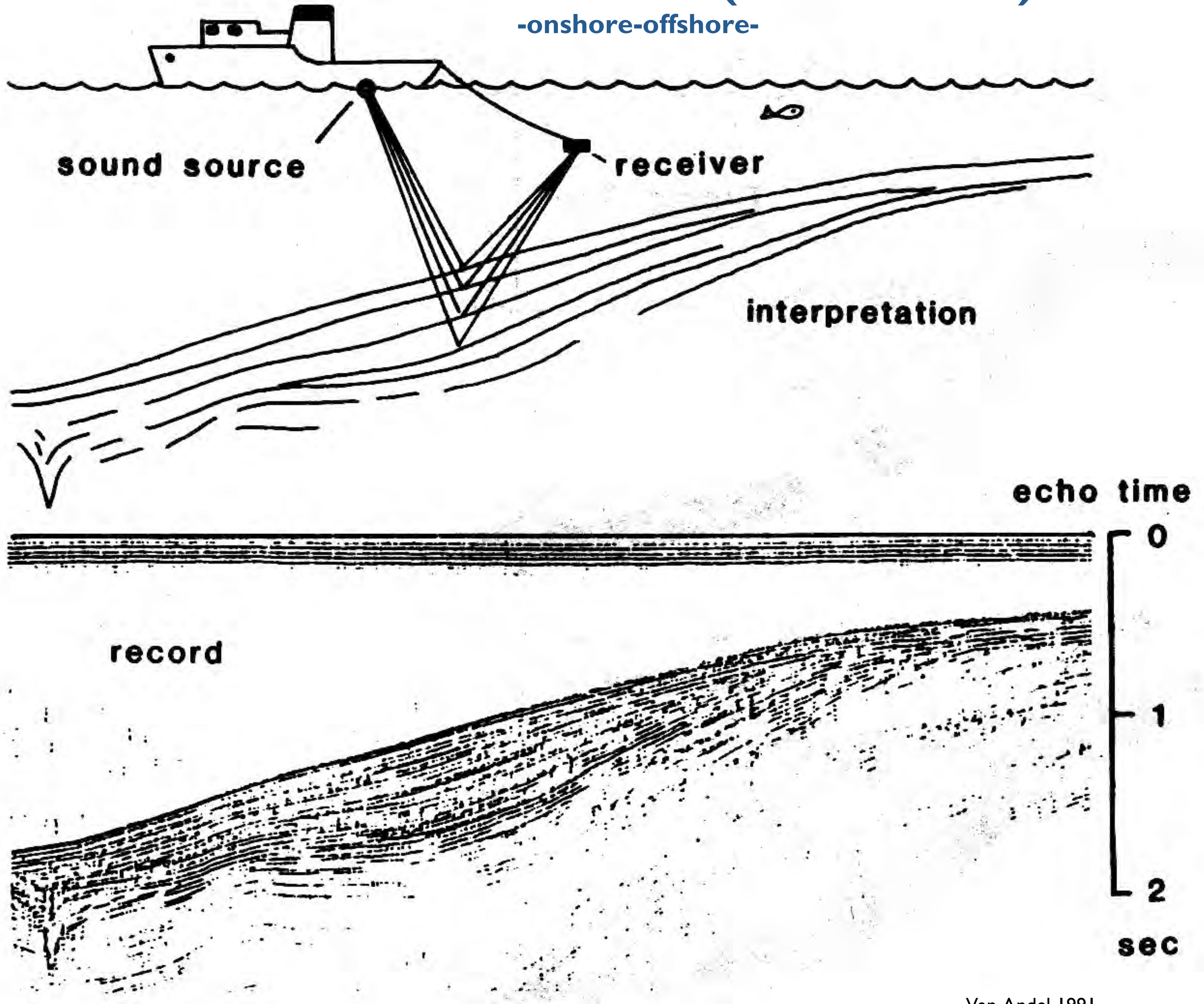
THIS IS A SEDIMENTARY MODEL

Q? what happens if sea level increases?

Answer = …

SEISMIC PROFILING (SIMPLIFIED)

-onshore-offshore-



Van Andel 1991

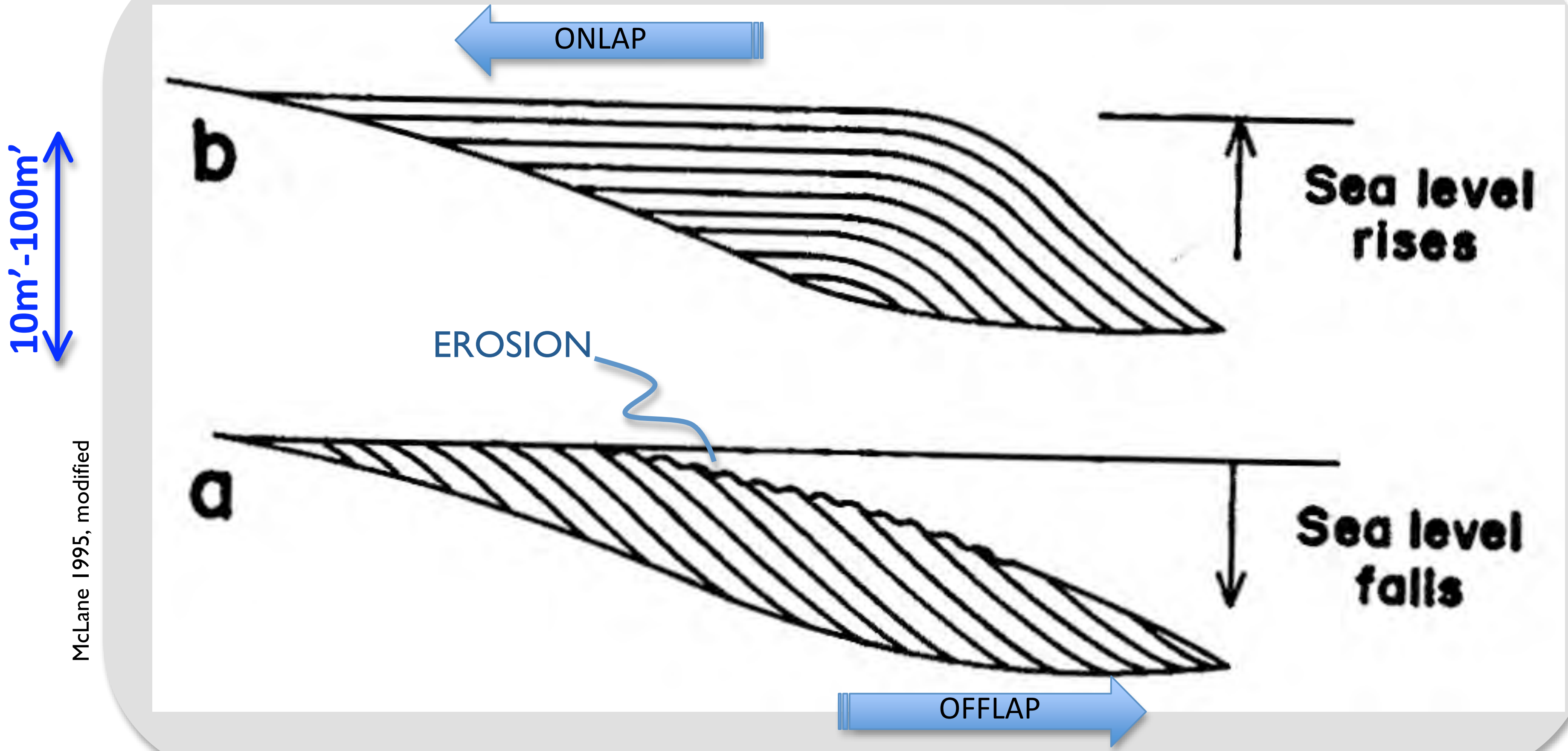
km-10km'-100km'

LANDWARD BASINWARD

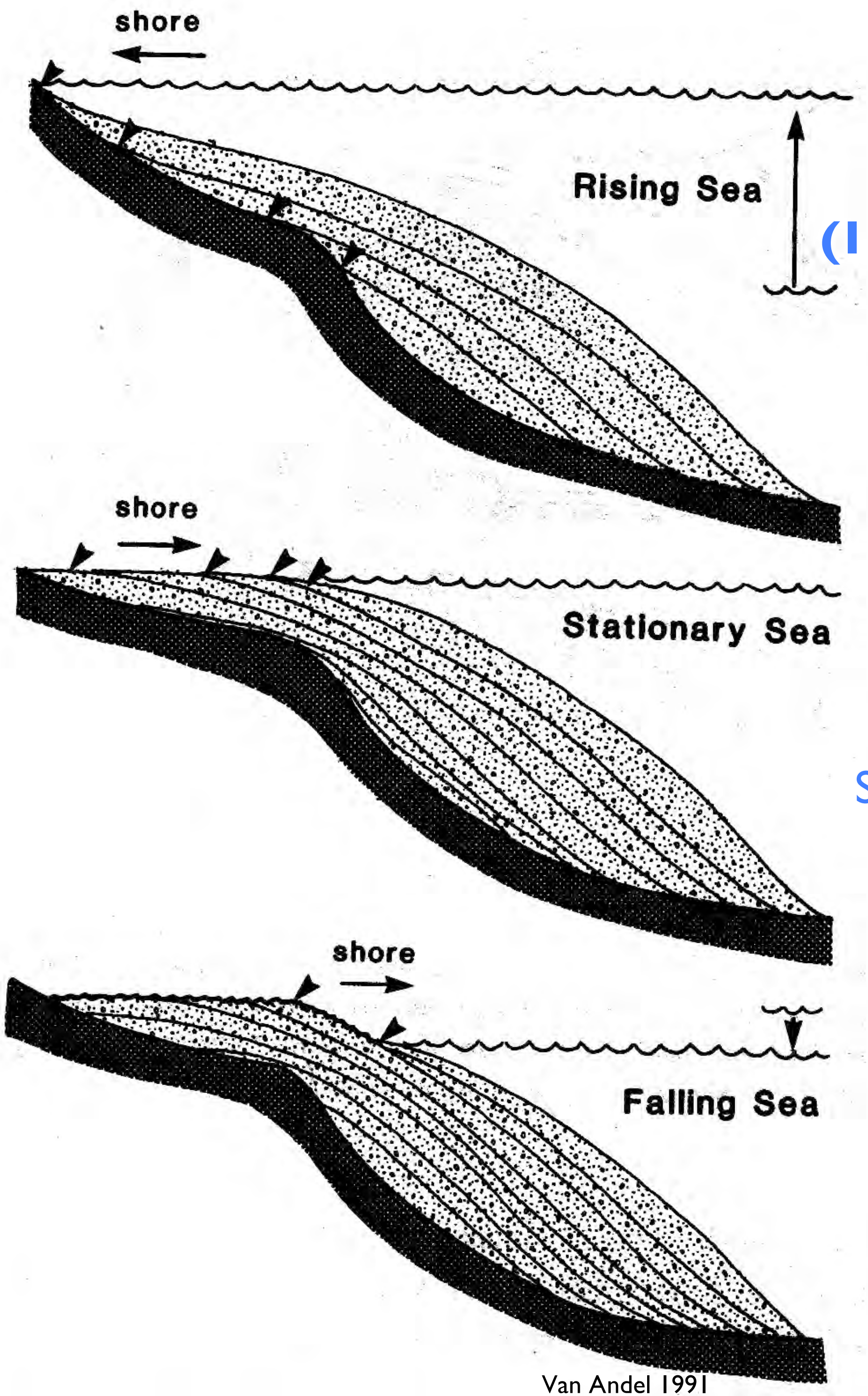
= **GEOMETRIC** TERMS FROM SEISMIC

… => 'SEQUENCE STRATIGRAPHY'

THE 'LAYER-CAKE' MODEL IS WRONG…



McLane 1995, modified



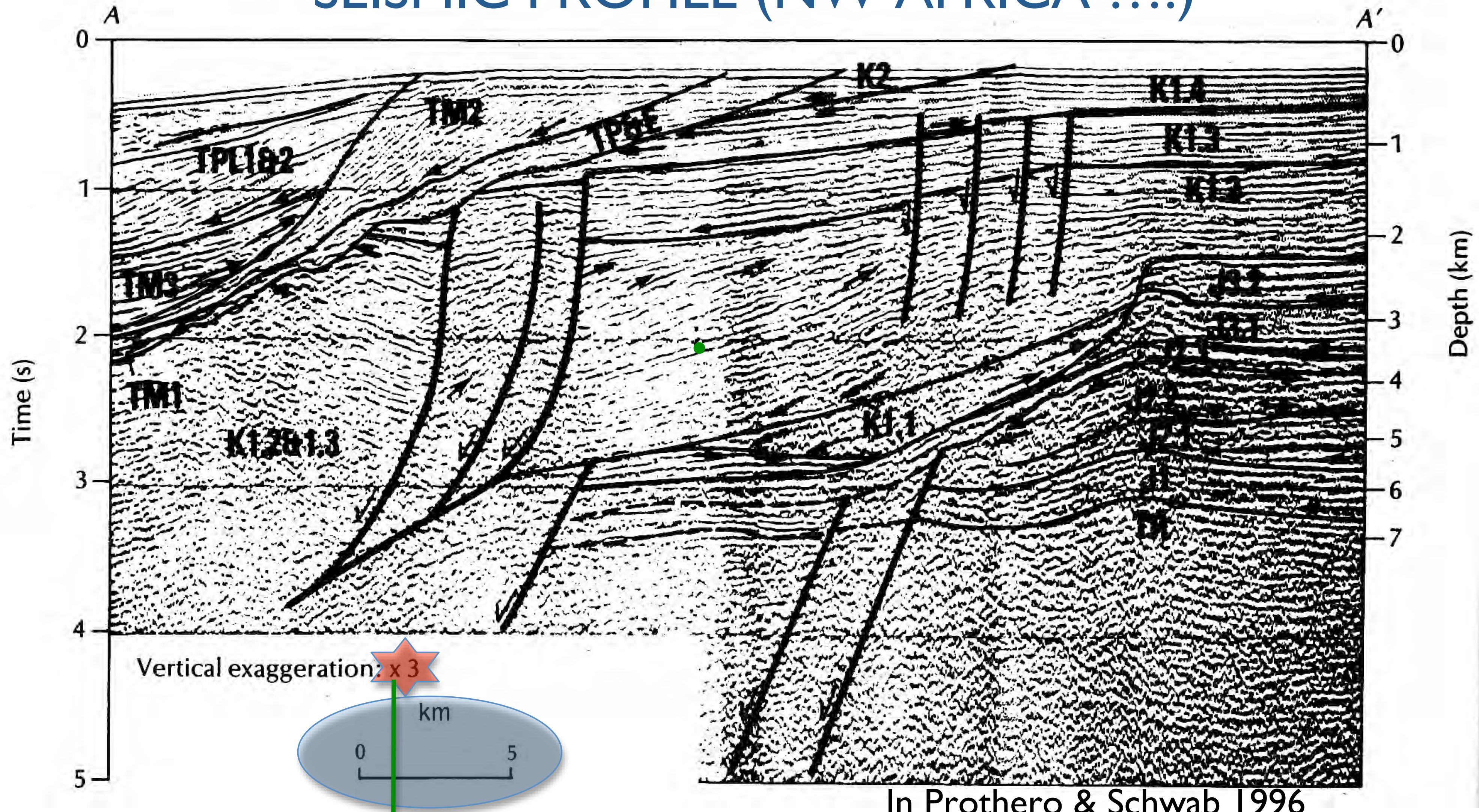
Van Andel 1991

GEOMETRY (1-100km x10-100'm)

Reflectors of seismic profile can record relative sealevel fluctuations
=
SEQUENCE STRATIGRAPHY 1990s

PROGRADATIONAL WEDGES OF SEDIMENTARY BODIES

SEISMIC PROFILE (NW AFRICA ….)

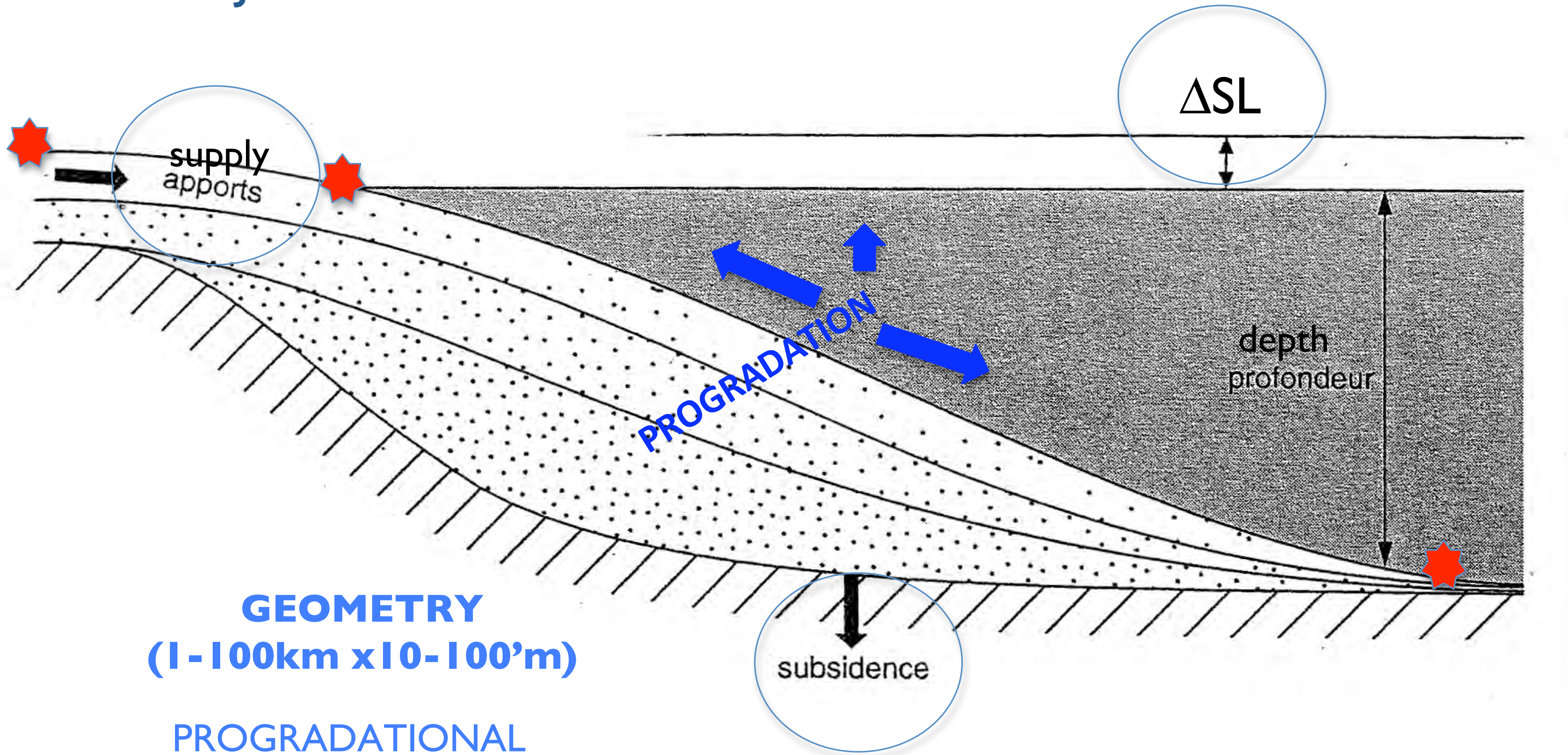


In Prothero & Schwab 1996

±100m

MOST OF THE LAYERS ARE **NOT** HORIZONTAL

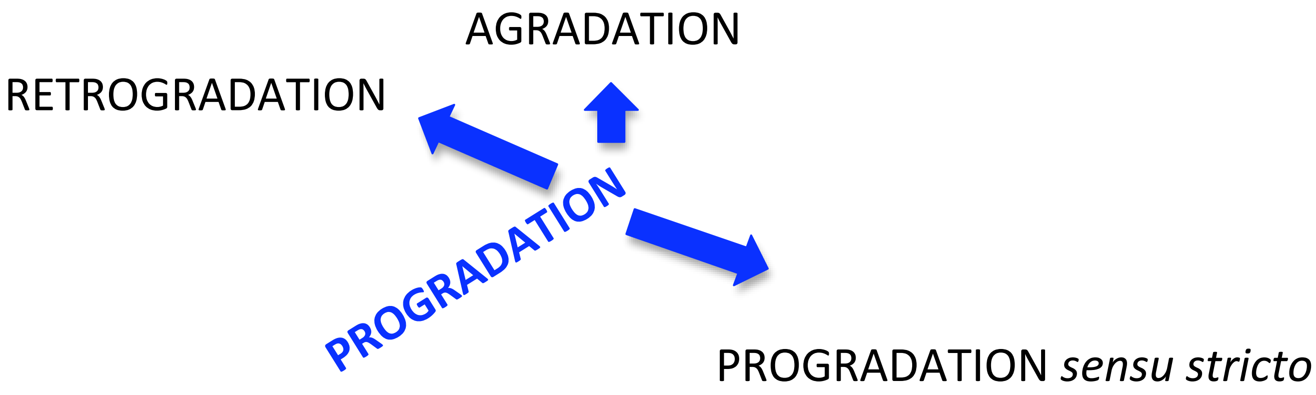
MAJOR FACTORS CONTROLLING SEDIMENTATION



GEOMETRY
(1-100km x10-100'm)

PROGRADATIONAL
WEDGES OF
SEDIMENTARY BODIES

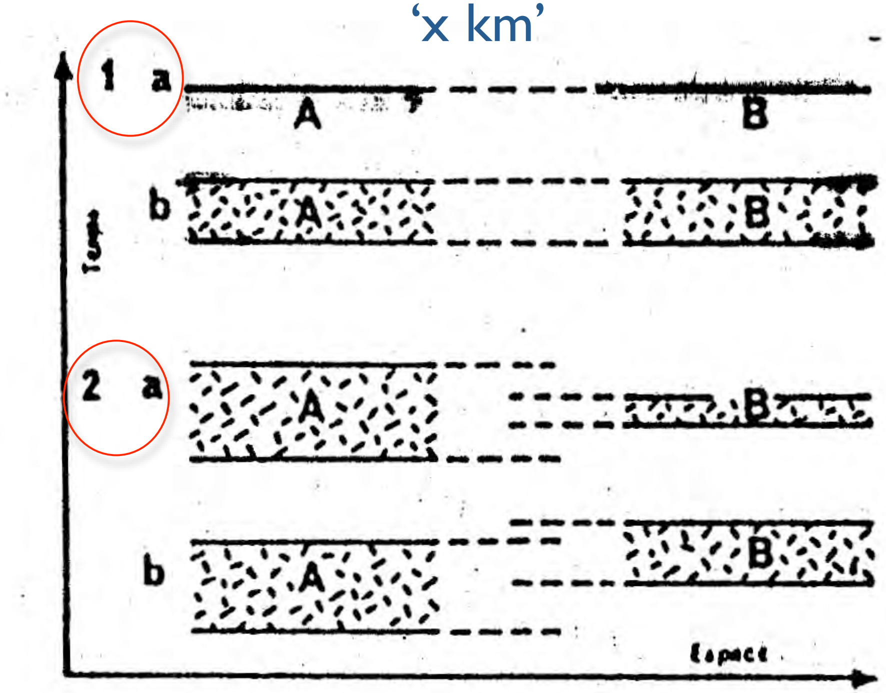
RELATIVE SEA LEVEL VARIATION(S)

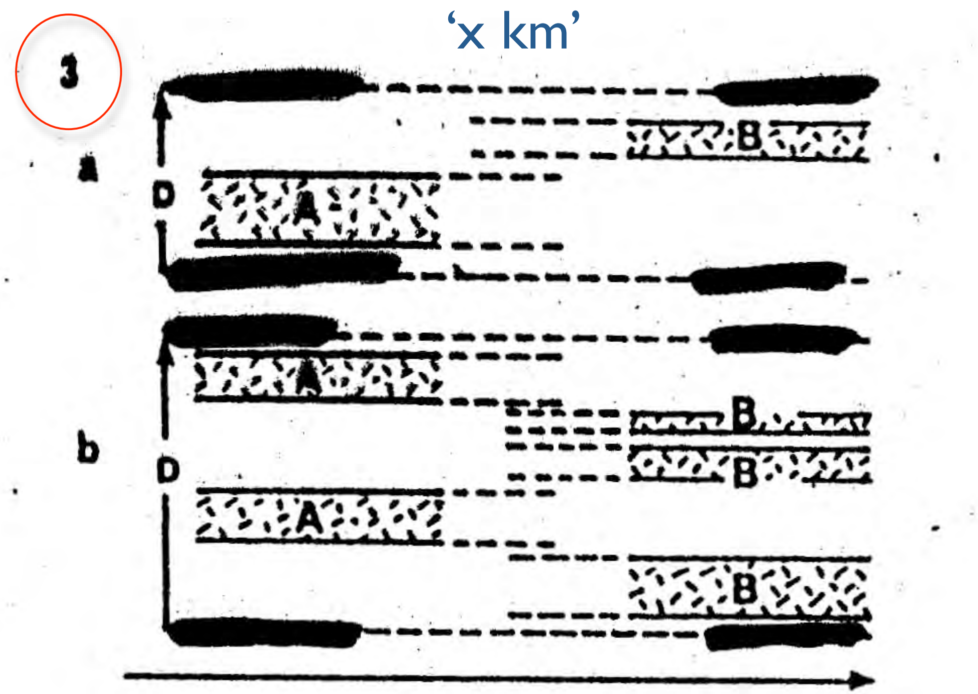


‘CHRONOZONES’

Étage	Zones (environ 1 Ma)	Sous-zones (0,5 Ma)	Horizons (0,25 Ma)
AALÉNIEN (environ 4 Ma)	Concavum	Formosum	
		Concavum	
	Murchisonae	Bradfordensis	Gigantea
			Bradfordensis
		Murchisonae	Murchisonae
			Haugi
	Opalinum	Bifidatum	Bifidatum
			Lineatum
		Opalinum	Opalinum
			Subglabrum

DESPITE THE PERFORMANCES OF THE SEQUENCE STRATIGRAPHY WE STILL NEED THE CHRONOZONES IN ORDER TO CORRELATE…





1 PERFECT CORRELATION (ex: ash/cinerite…)
2 PARTIAL CORRELATION **very common**
3 NO SIMULTANEITY **very common**

The geologist <u>**HAS**</u> TO CORRELATE!

WALTHER'S LAW (1893) of FACIES or LAW of CORRELATION FACIE 1860-1937

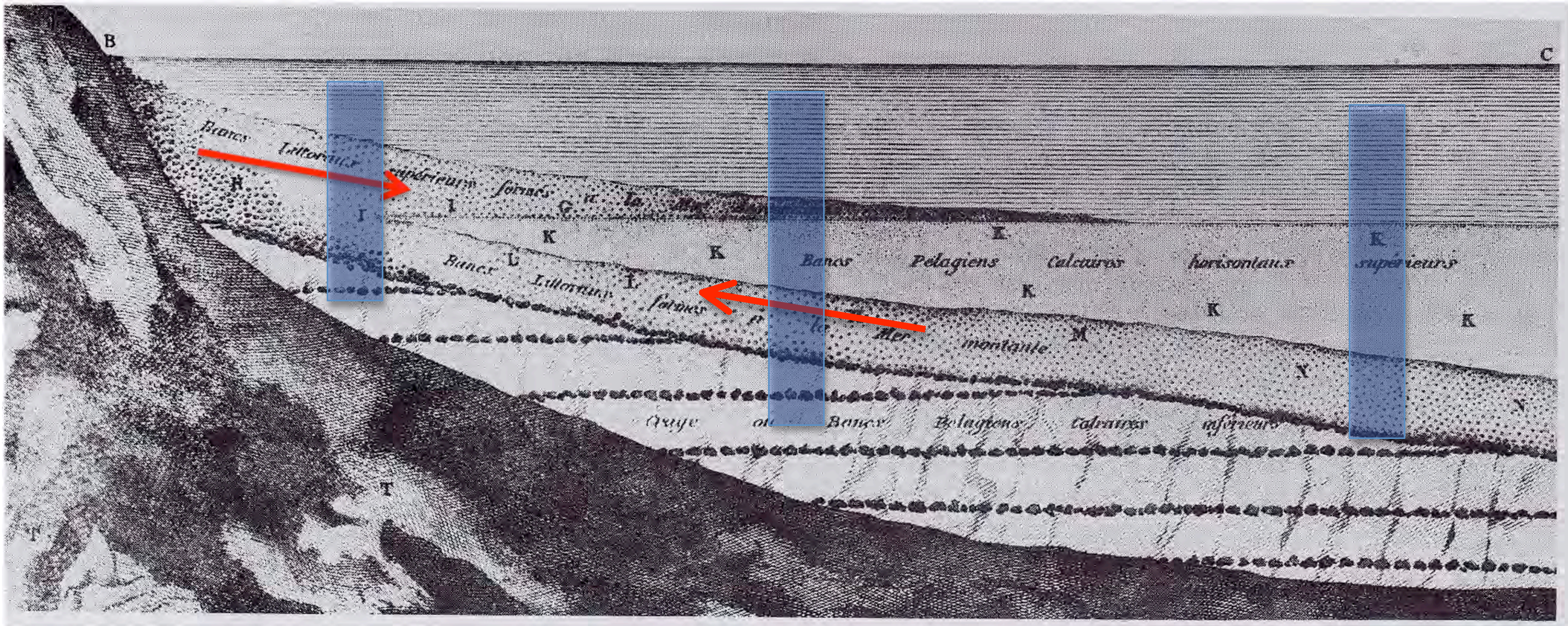
The vertical succession of facies reflects lateral changes in (paleo)environment => when a depositional environment 'migrates' laterally, sediments of one depositional environment come to lie of another.

In geology **facies** are a body of rock with specified characteristics. Ideally, a facies is a distinctive **rock unit** that forms under certain conditions of sedimentation, reflecting a particular process or environment.

The term **facies** was introduced by the Swiss geologist **Amanz Gressly** in **1838** and was part of his significant contribution of modern stratigraphy.

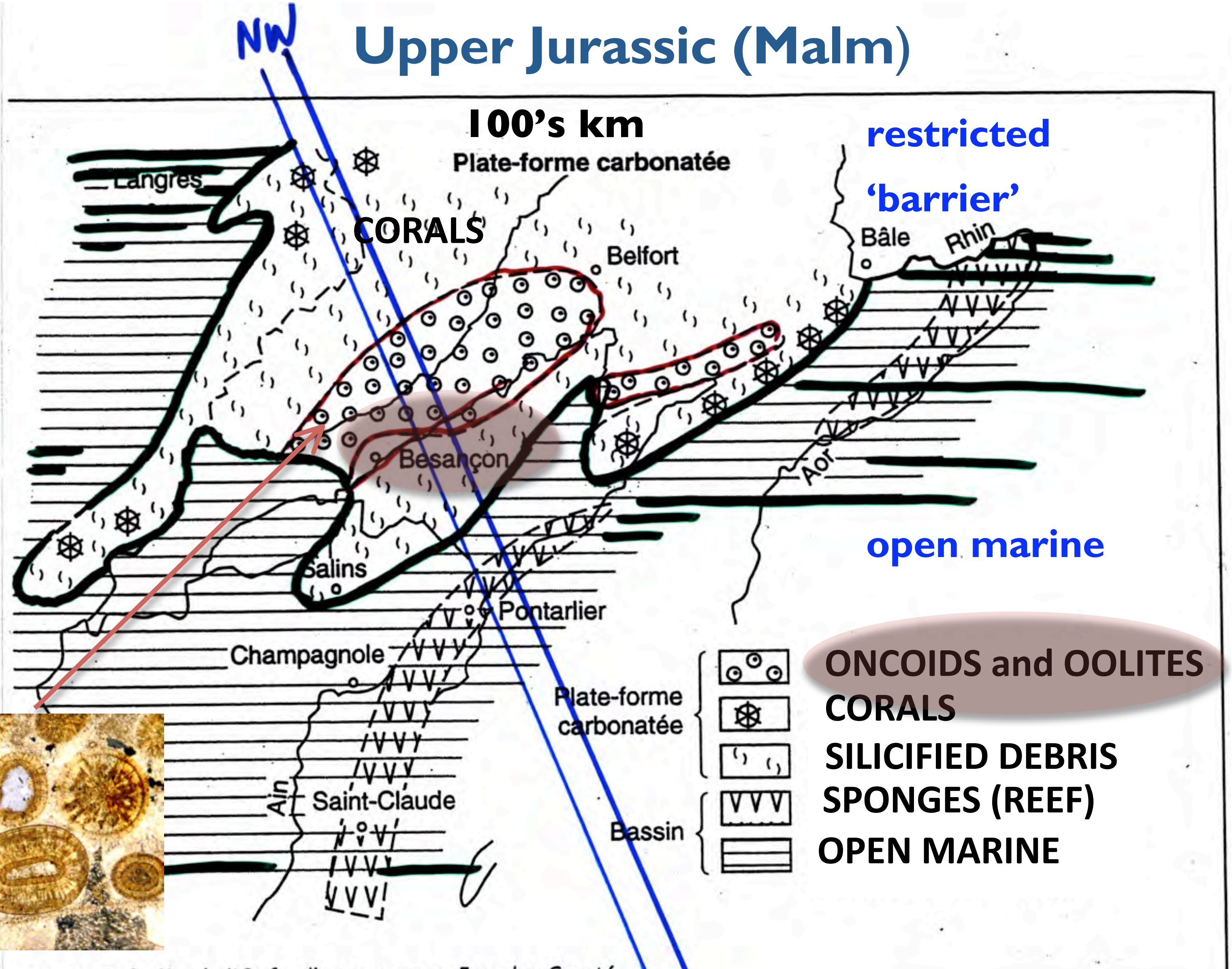
'LAYER CAKE' GEOLOGY and FACIES CHANGE

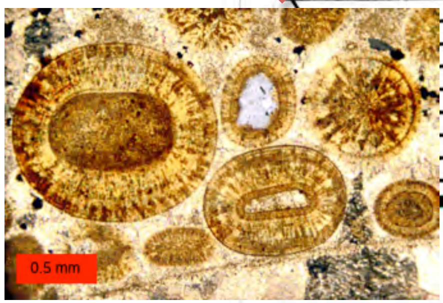
1700s-early 1800s catastrophist geology **thought that the rock record had been laid down in uniform sheets over the whole world** during Noah's flood => if true, the same rock layer would be evenly distributed over Earth everywhere with little difference in lithology or thickness ==> 'layer cake' geology… (ex. the Grand Canyon?) = **WRONG**



Antoine Lavoisier's diagram (1789) of the relationsphips of coarse littoral (*bancs littoraux*) and finer pelagic *(bancs pélagiens)* sediments to the northern French coastline. <u>Lavoisier recognized that gravel can be moved only by waves near the shore whereas fine sediments can be carried into deeper water</u>. He also saw that distinctive organisms inhabited each environment. <u>If sea level rose *(mer montante)* **=> landward migration**…, if sea level fell *(mer descendante)*,</u> **seaward shift**..

Upper Jurassic (Malm)





– Carte de faciès de l'Oxfordien moyen en Franche-Comté.

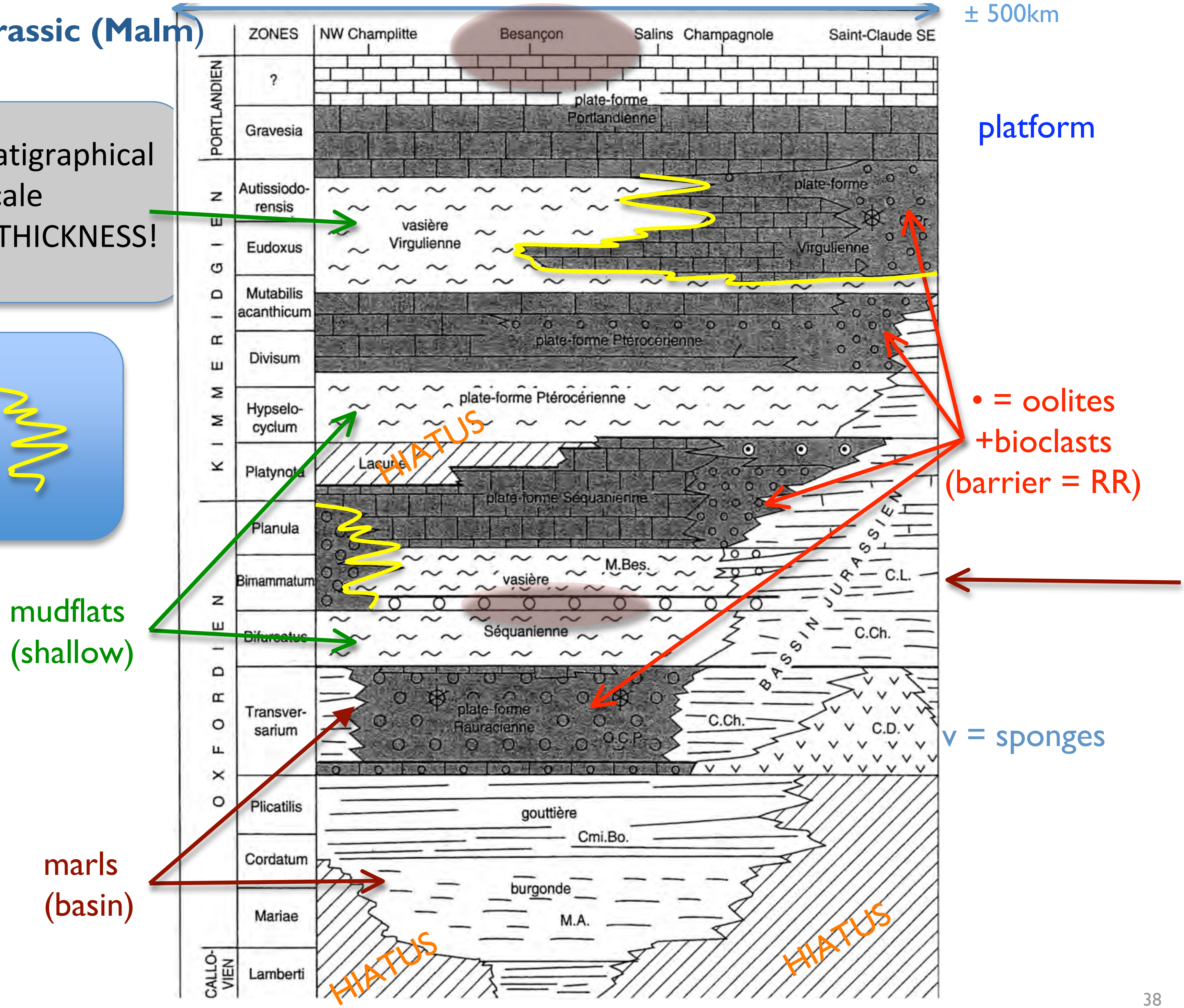
LATERAL FACIES VARIATION : THE RULE IN GEOLOGY

here Middle Oxfordian (Franche-Comté, Paris basin, France)

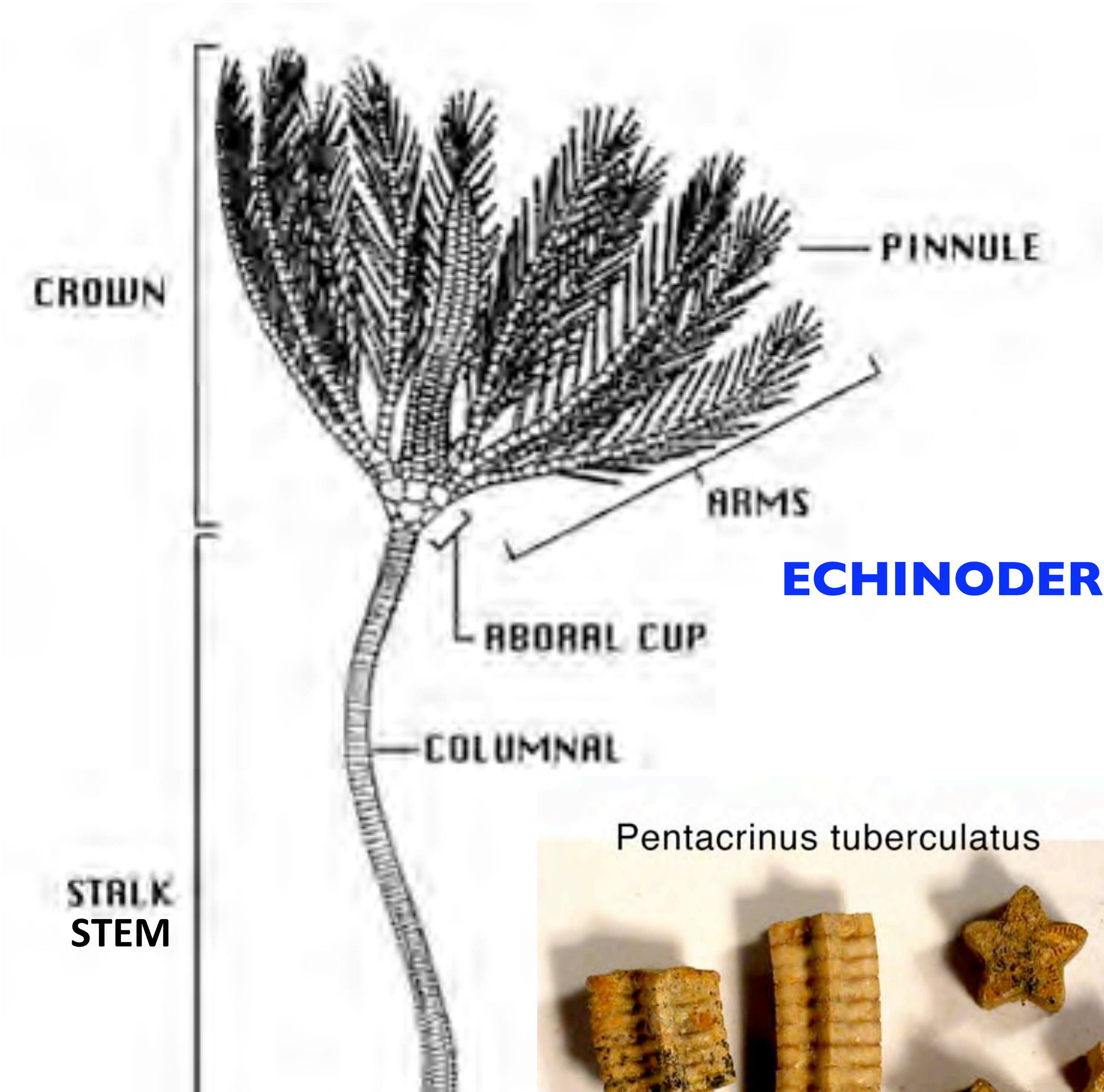
Upper Jurassic (Malm)

Chronostratigraphical scale
=> NO Fm THICKNESS!

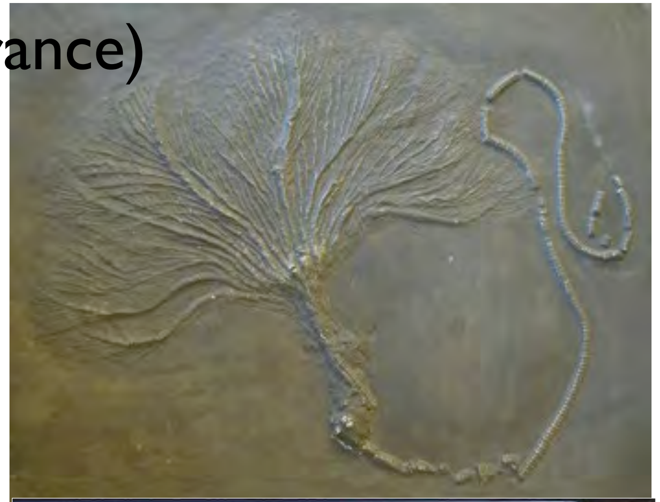
zig zag line(s)



Bajocian crinoidal limestones of Burgundy (France)

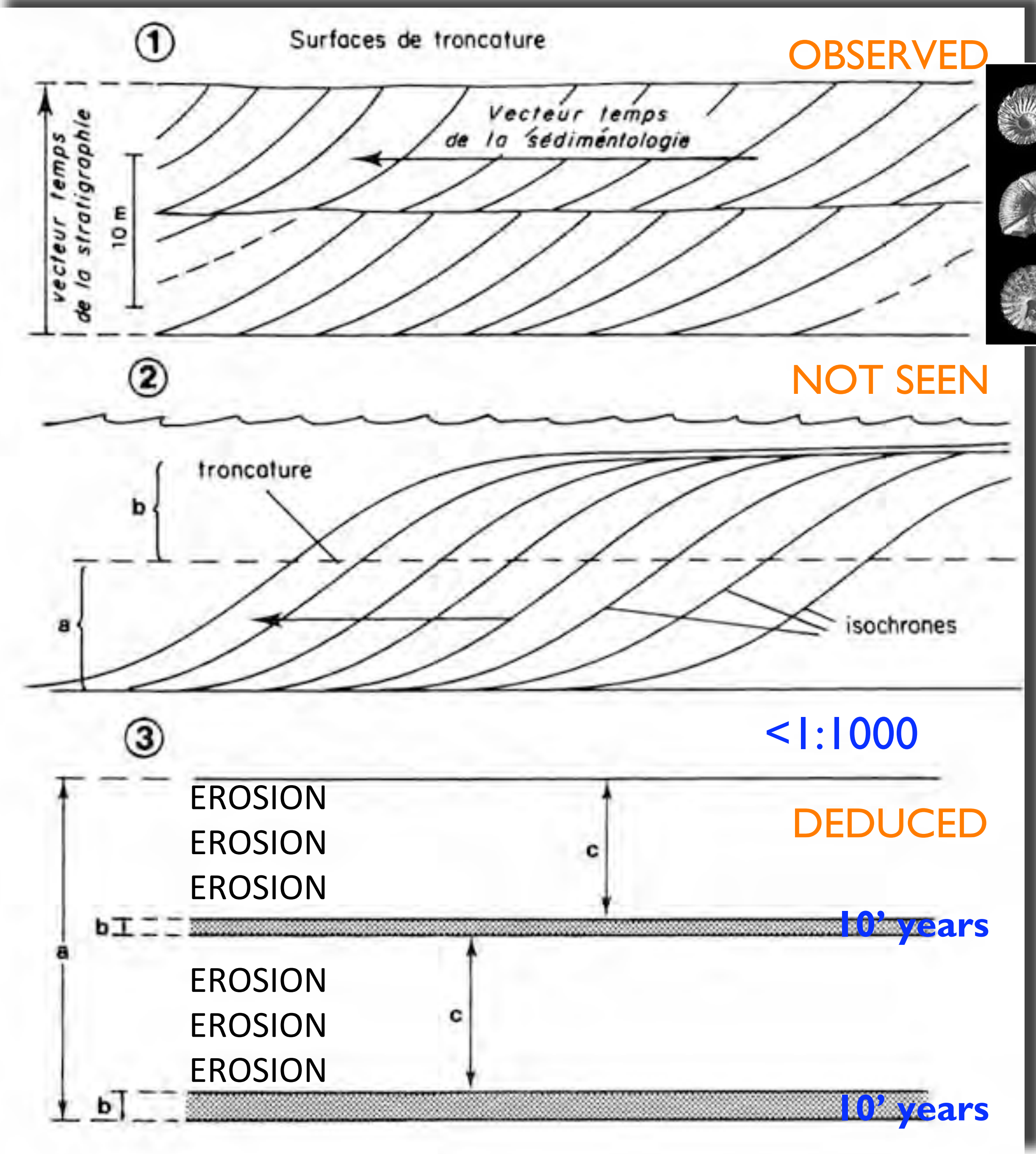


ECHINODERMS



Pentacrinus tuberculatus

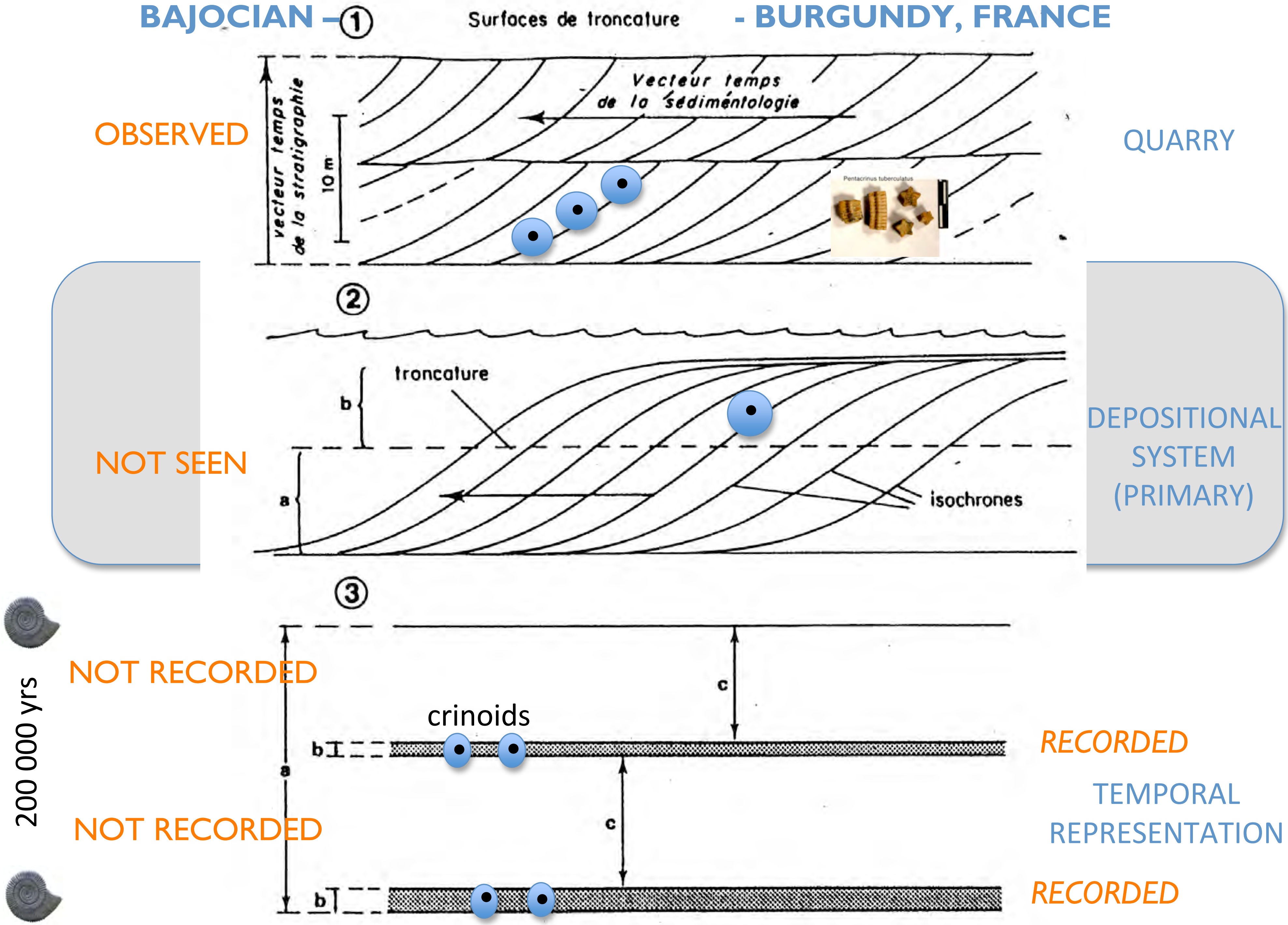
Bajocian crinoidal limestones of Burgundy (France)



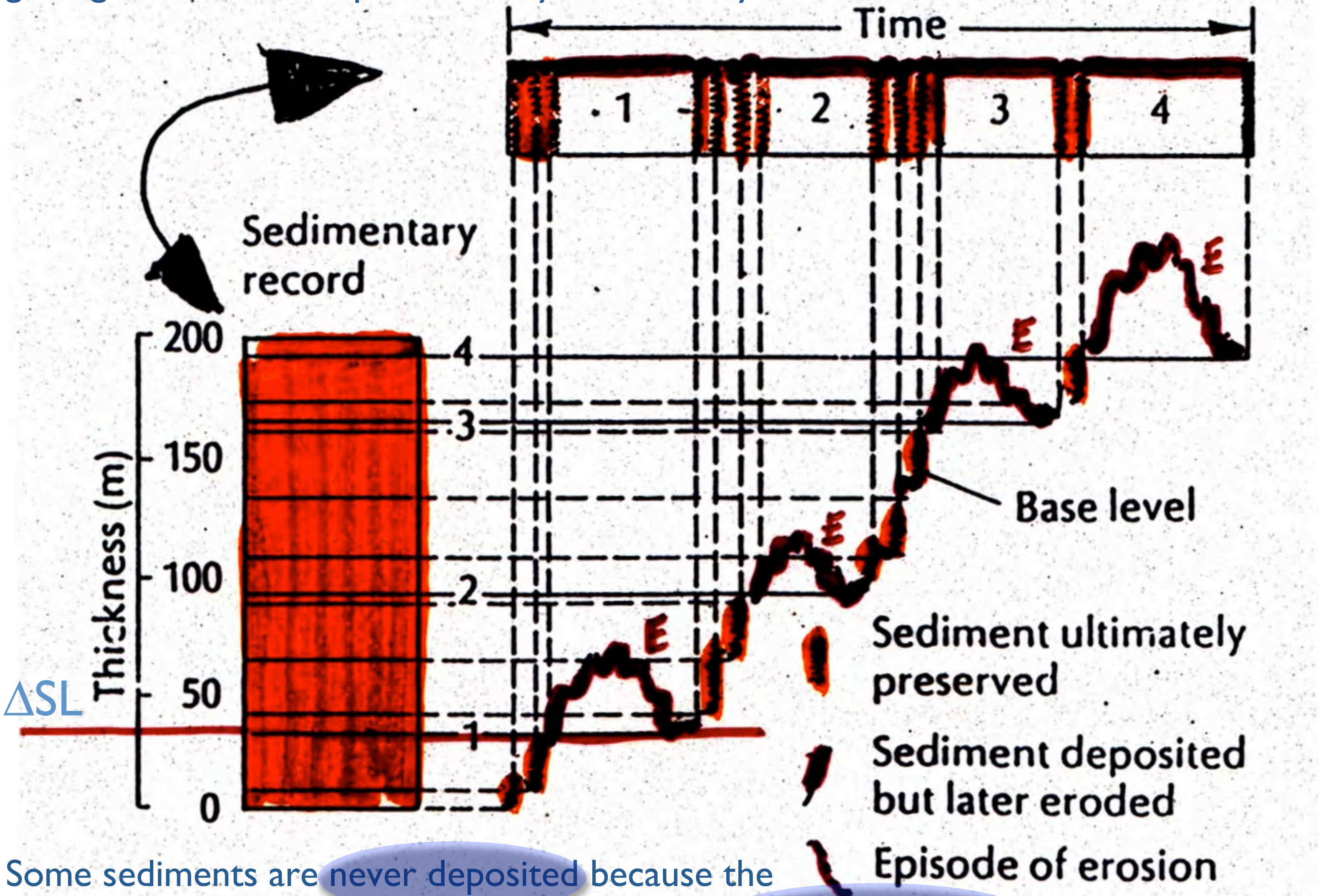
200 000 years

Pomerol et al 1987

BAJOCIAN – BURGUNDY, FRANCE



BARRELL **1917** : diagram showing the relationship between the sedimentary record and the actual time represented by it. Because base sea level fluctuates up and down, most geologic time is not represented by sedimentary record.



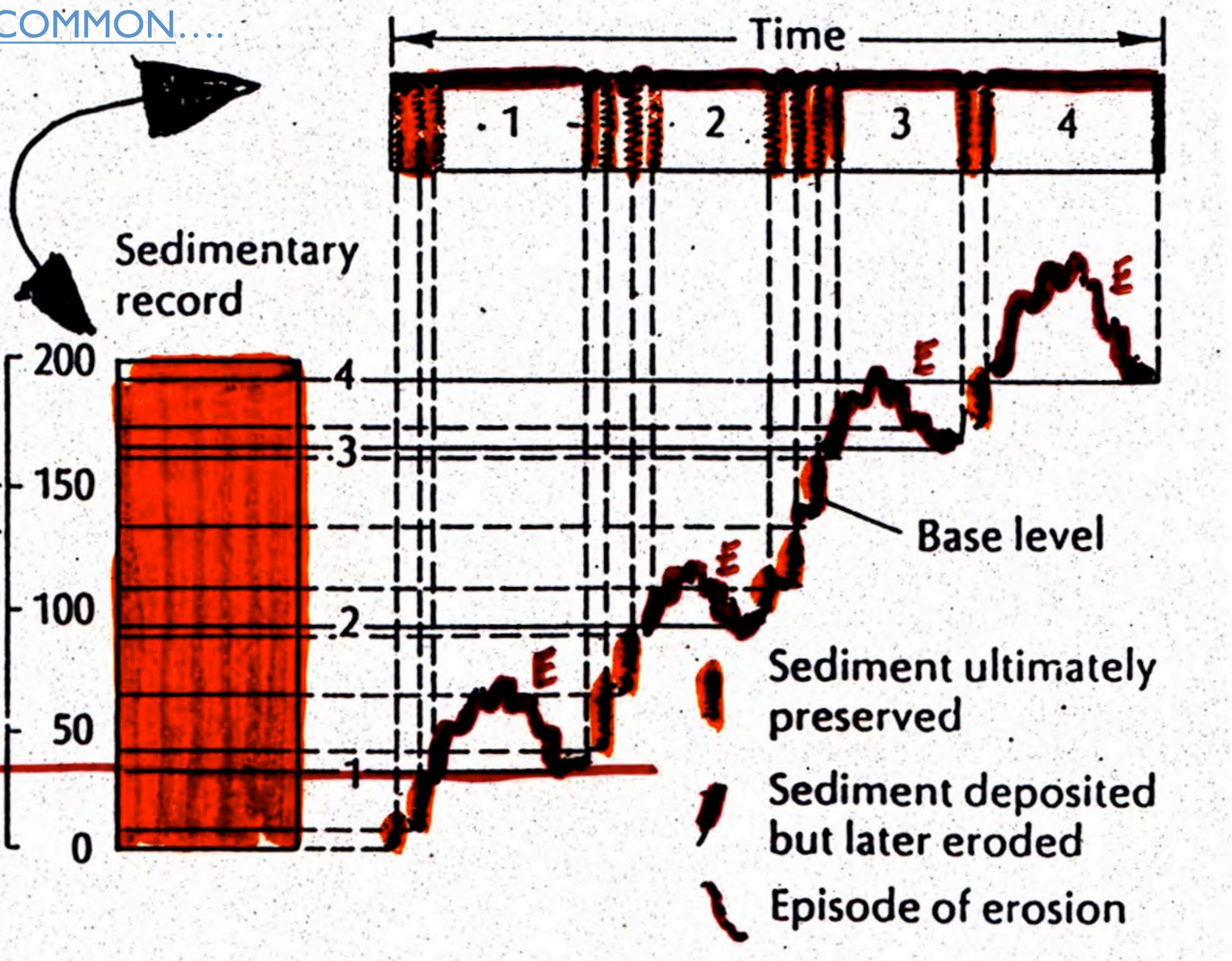
Some sediments are never deposited because the basins have a low base level (dashed lines), and others are eroded (solid lines)

DIASTEMS or **CRYPTIC UNCONFOMITIES** (Hutton, 1795)

Between bedding planes : breaks in the stratigraphic record

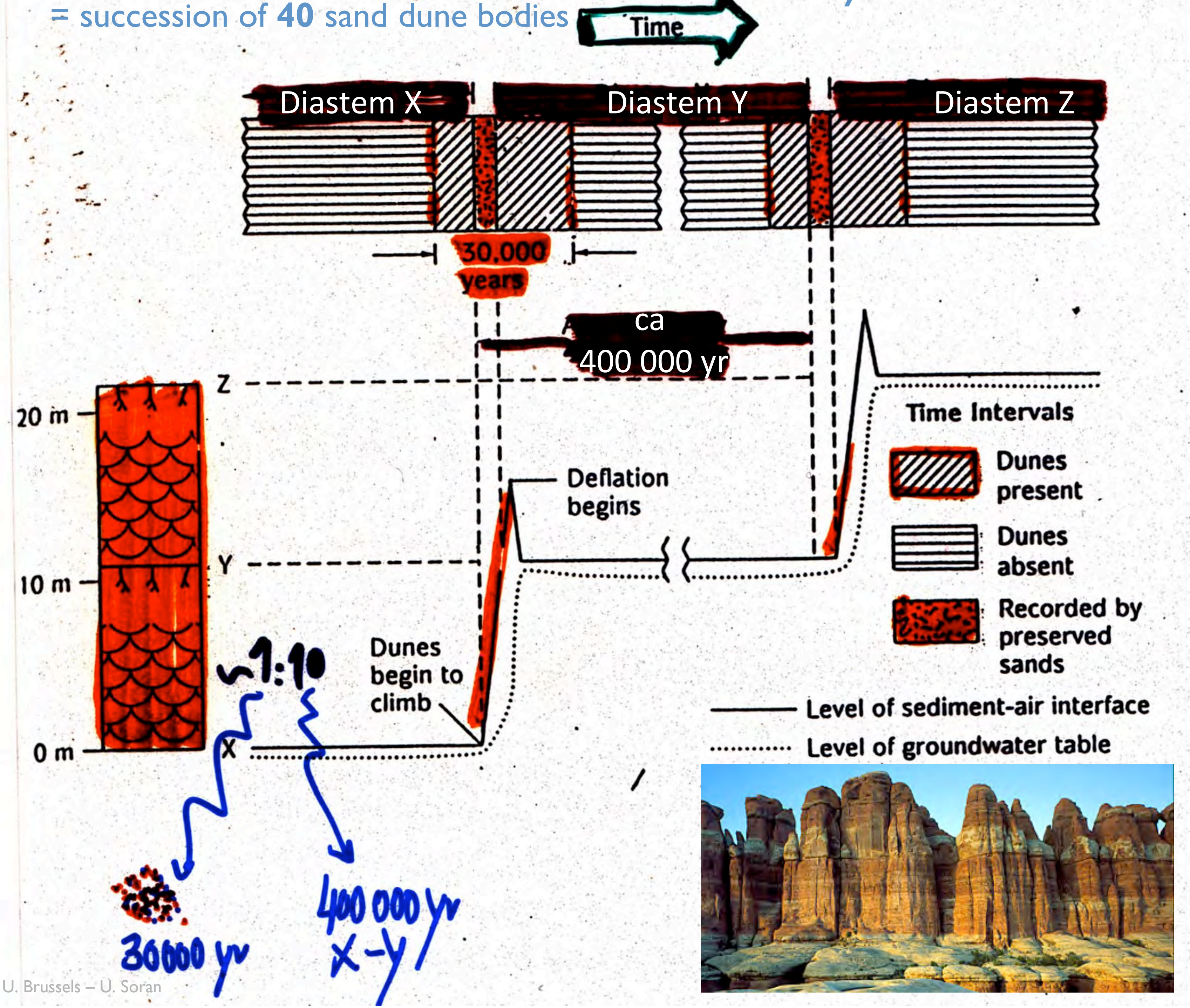
=> pause in sedimentation or local erosion

VERY COMMON….

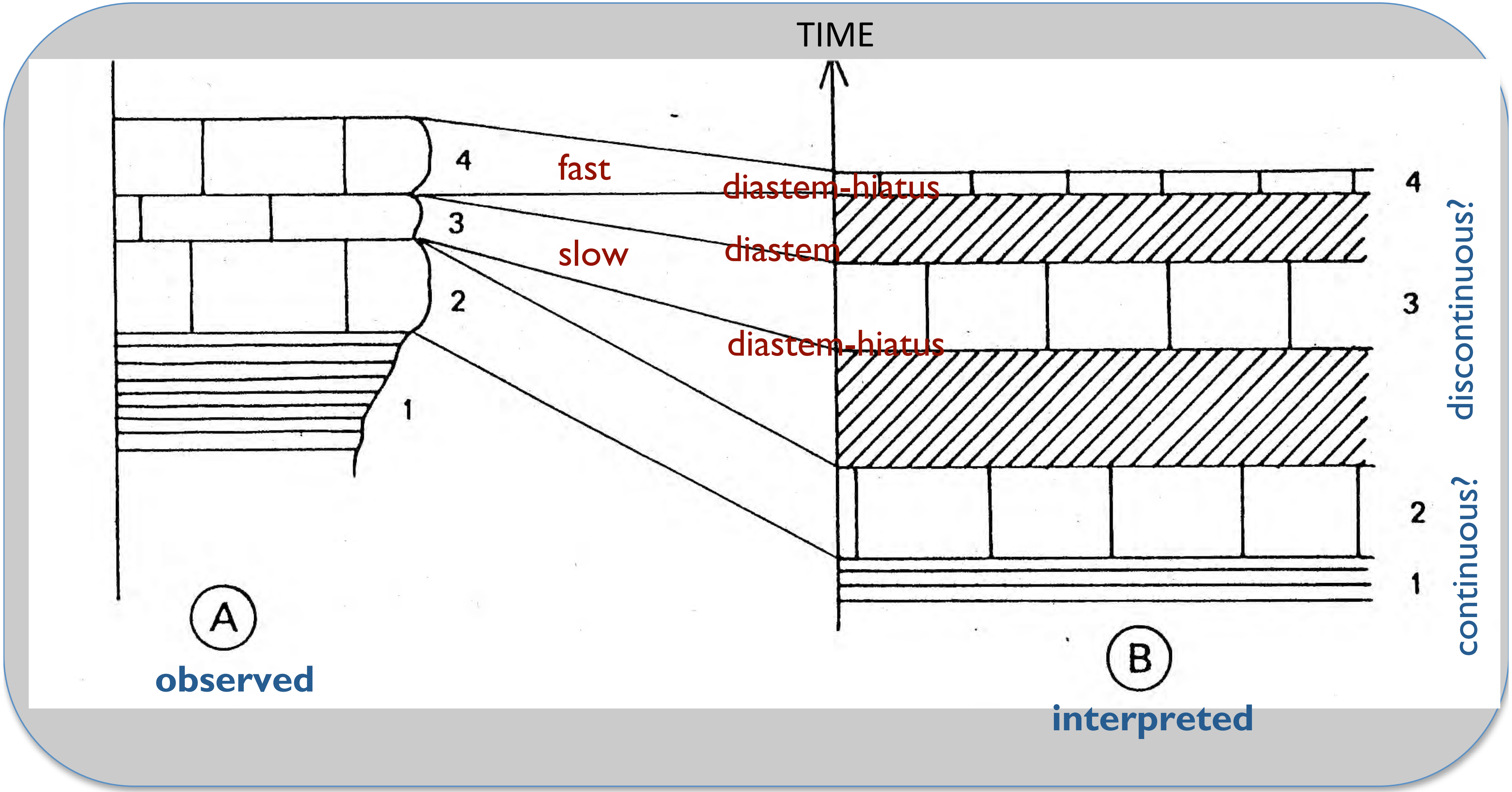


Cedar Mesa Sandstone of Utah – U. Pennsylv. - L. Permian

= succession of **40** sand dune bodies

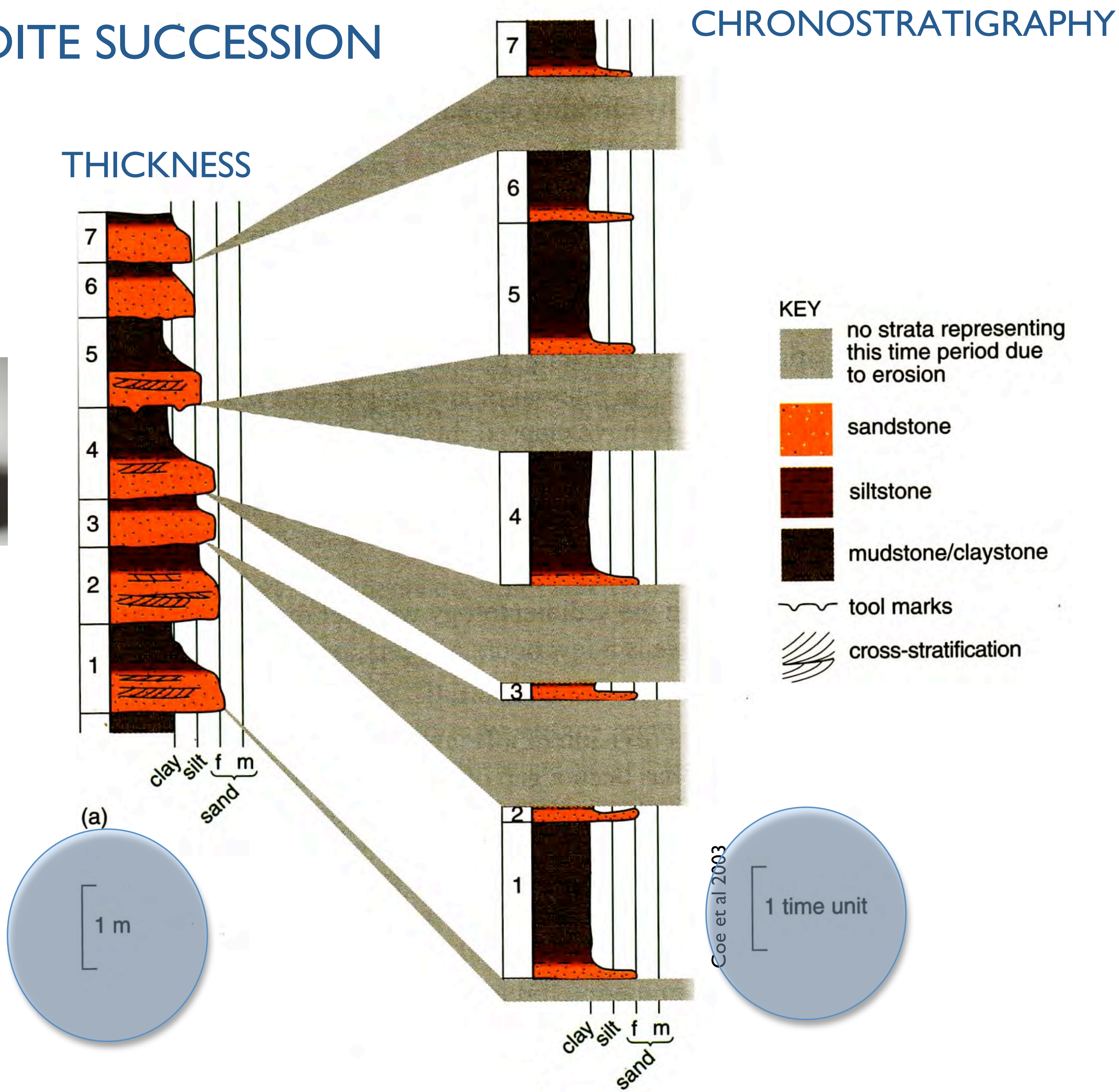


‘CONTINUOUS SECTION’



TURBIDITE SUCCESSION

Tool marks are (cast) of scratches on stream bed made by moving of sticks or rocks

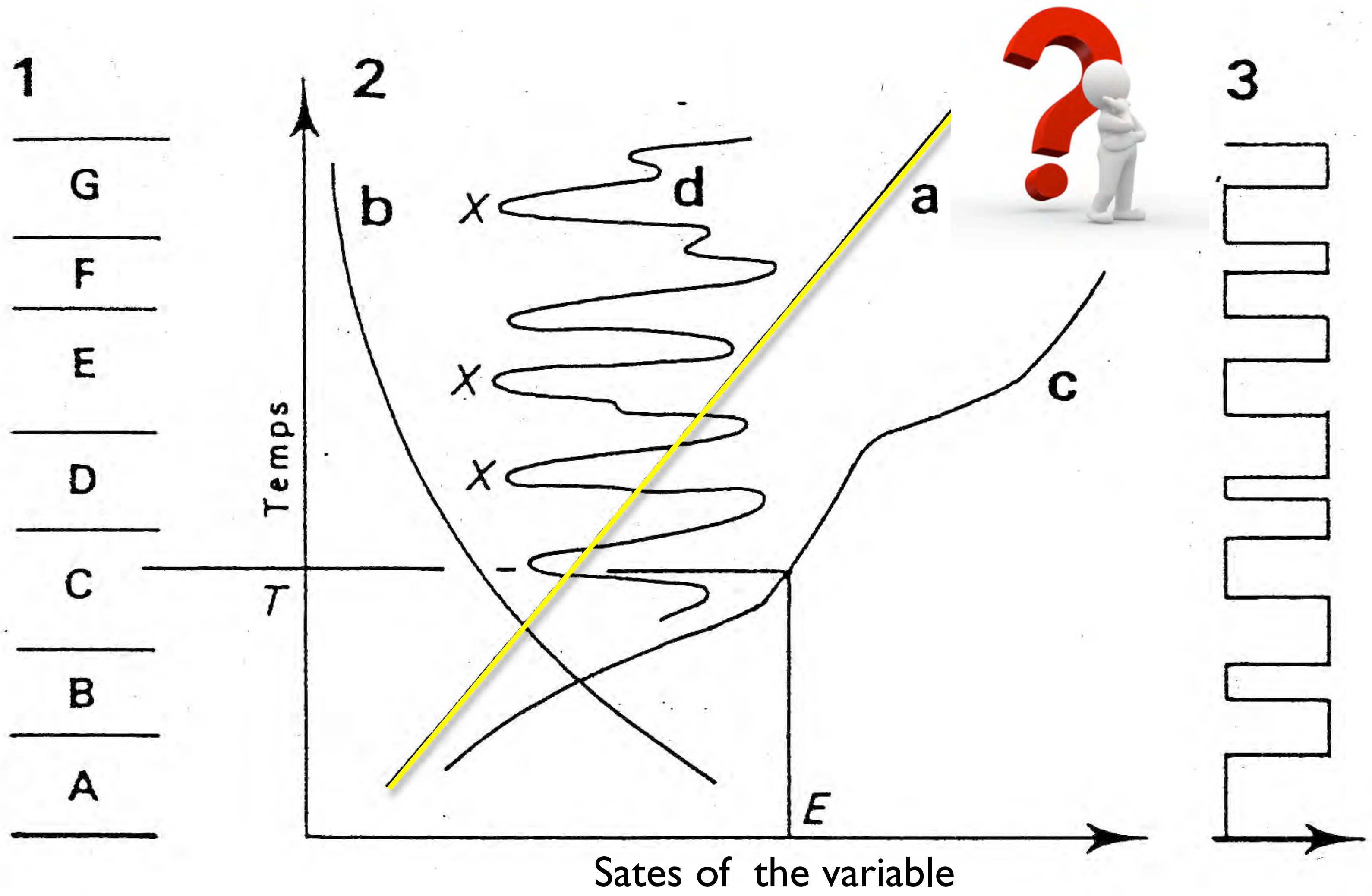


A **CONTINUOUS** SECTION-PROFILE DOES NOT EXIST
IT APPEARS 'CONTINUOUS'…

- Hiatus of observation
- Hiatus of erosion
- Hiatus of non deposition

All scales are possible
All time gaps are possible

ANYTHING IS POSSIBLE…



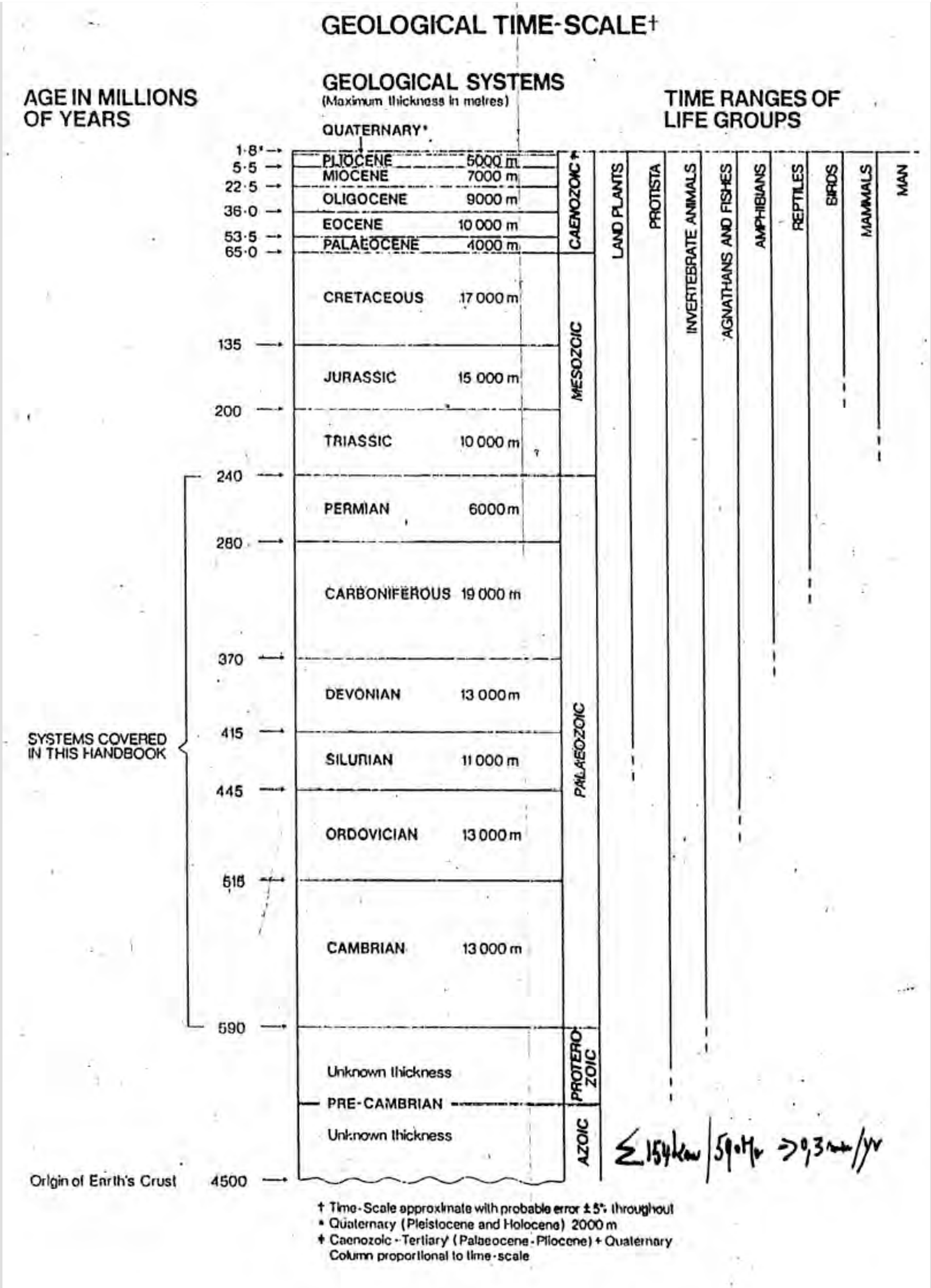
'a' is INTUITIVE : thickness pp time

FINALLY…

What would be the most continuous sedimentation?
(**i.e. the less discontinuous**)
and
the fastest
(i.e. maximal)
AT A REASONABLE GEOLOGIC SCALE?

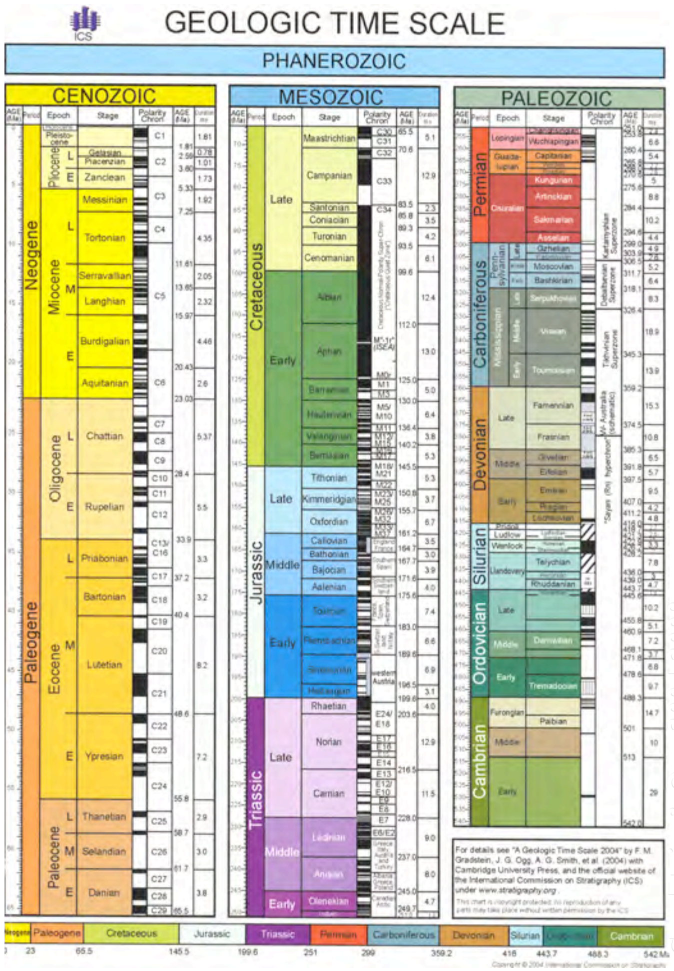
ARGUE BY CONTRADICTION
(i.e. not geo-logic…)

154km/542 myr
= 0.28 mm/yr



WHAT IS 'GOOD' SEDIMENTARY RECORD??

> REASONING BY THE ABSURD … <u>NOT</u> GEOLOGICAL!



PHANEROZOIC

(Holocene) 0
(Pleistocene)
Pliocene
Miocene …km
Oligocene
Eocene
Paleocene
Cretaceous 15.8km
Jurassic
Trias

Permian …km
Carboniferous
Devonian 11.7km
Silurian …km
Ordovician 13.8km
Cambrian 11.8km
542Ma

MAX

154Km = 0.28 mm/yr

including 'gaps' and discontinuities

i.e. ± 0.3 mm/yr

(in place of 1mm/yr)

0.3 mm/yr

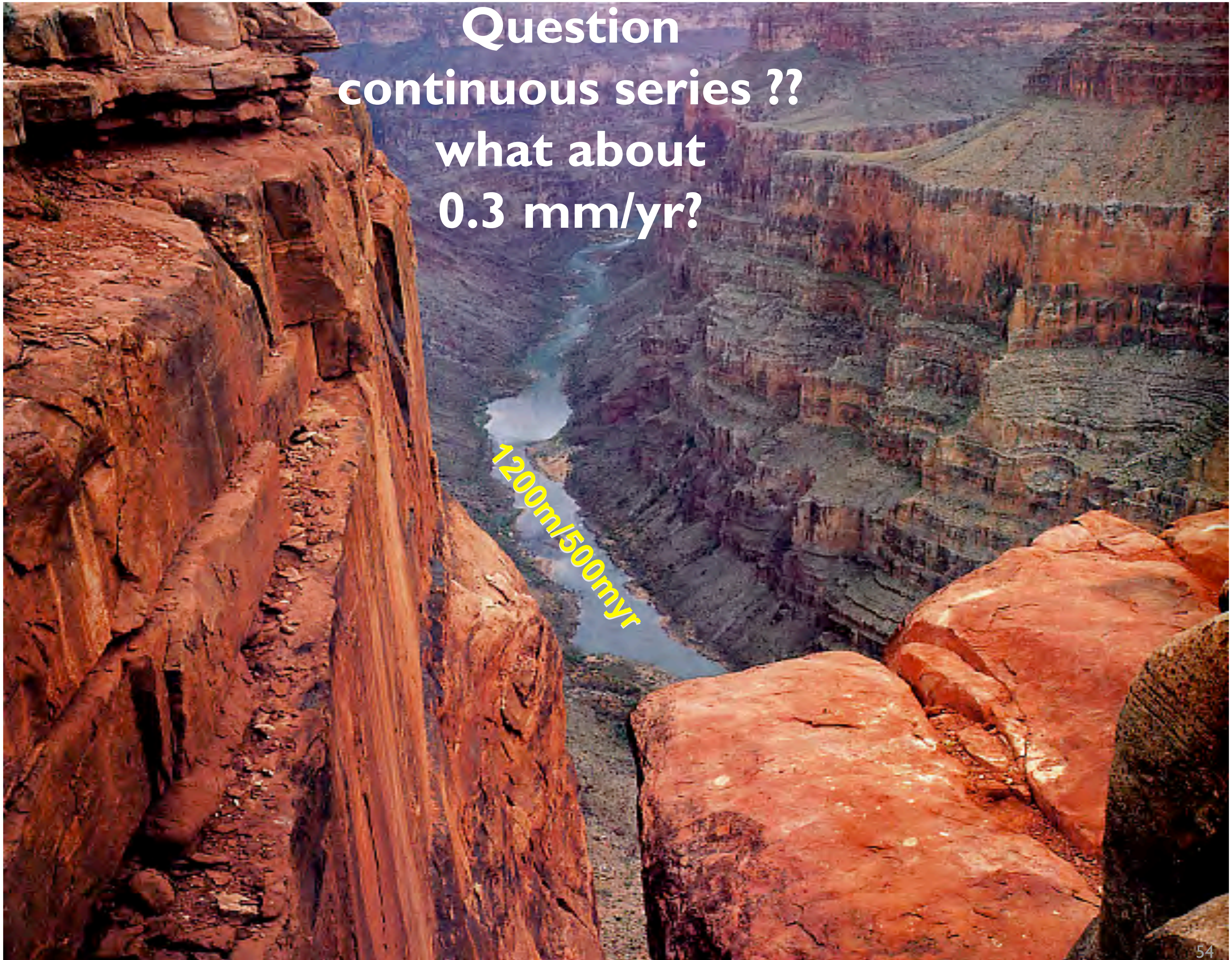
No compaction
No erosion
Less orogens

System	Maximum recorded sediment thickness (km)	Length of period (Ma)	Average maximum sedimentation rate (km/Ma)
Neogene and Quaternary	13.0	26	0.50
Palaeogene	20.9	39	0.54
Cretaceous	15.8	71	0.22
Jurassic	13.1	54	0.24
Triassic	8.8	35	0.25
Permian	6.2	55	0.11
Carboniferous	13.8	65	0.21
Devonian	11.7	50	0.23
Silurian	8.9	35	0.25
Ordovician	13.8	70	0.20
Cambrian	11.8	70	0.17
Phanerozoic eon	137.8	570	0.24

0.5 mm/yr

0.2 mm/yr

GRAND CANYON

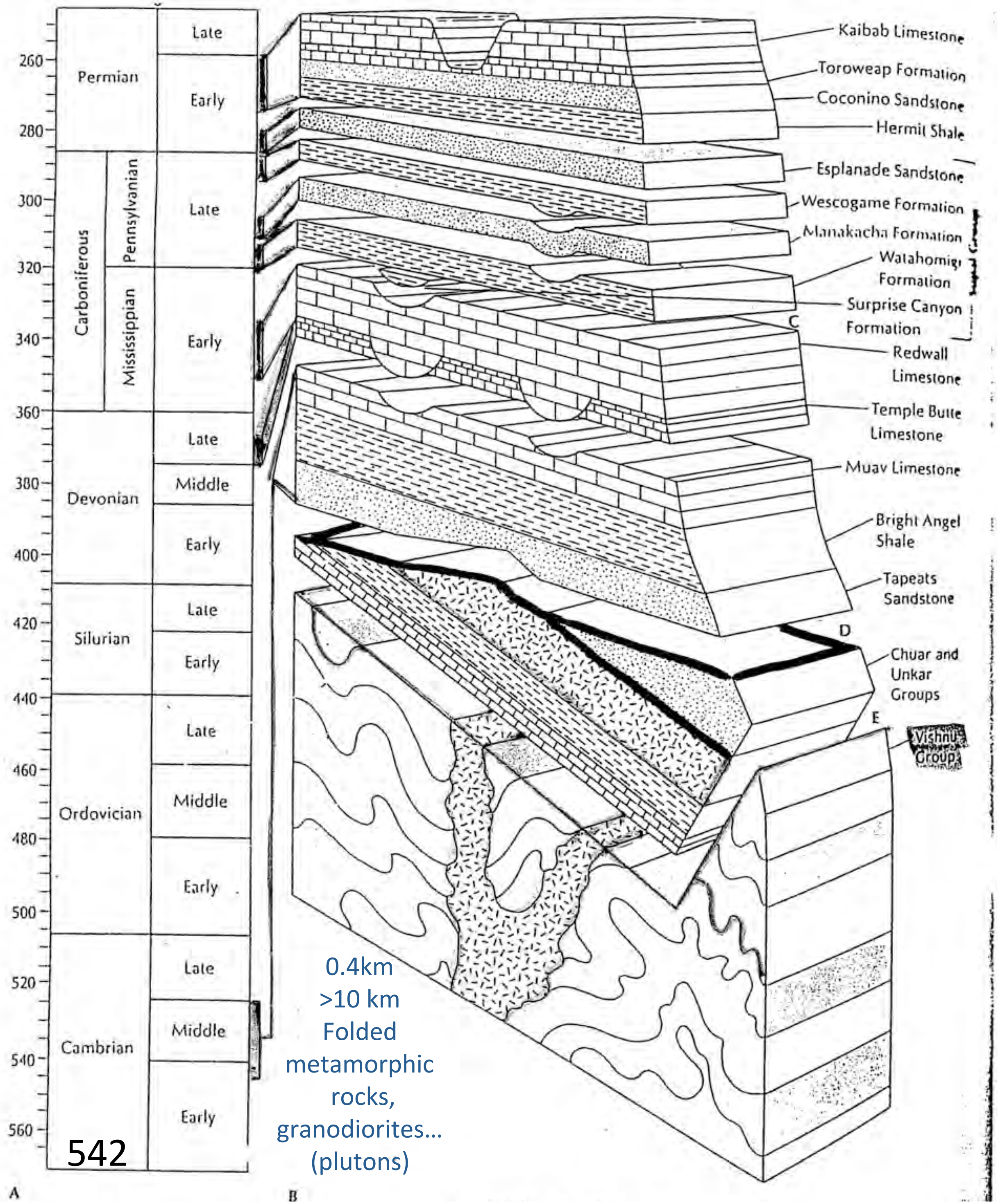


GRAND CANYON-USA

1.6 km

1.2km
Paleozoic
(ca. 500 Ma)

PHANEROZOIC
542
PROTEROZOIC
2500
ARCHEAN



M
A
X

PHANEROZOIC

154km = 0.28 mm/yr

including 'gaps' et discontinuities

the most realistic situation

GD CANYON (USA)

1.2Km = 500 myr

1yr = 0.0024 mm excluding the PCm

~100x LESS!

~1000x LESS!

If compared with RECENT

PHANEROZOIC
154km = 0.3 mm/yr
including 'gaps', diastems ...

Example 1 : carbonate platform Belgium-France: ±4myr/400m **=> 0.1 mm/yr** (biological productivity)
Example 2 : present day carbonates (Bahamas, Persian Gulf): tidal flat **1 mm/yr [0.3-3.0mm]**
Example 3 : Central Tunisia (first part of the course):
Tadjeroune 50myr /1300m => **0.03mm/yr**
El Kef 50 myr/2600m => **0.06mm/yr**
Example 4 : GRAND CANYON
1.2km/±500myr => **0.0024 mm/yr**
= 100 times less than the maximal rate of **recorded** sedimentation

short term vs long term

today — **most of the geologists**

Estimates of the Age of the Earth based on estimates of maximum thickness of sedimentary rocks

NOT A GOOD WAY …

Date	Author	Maximum Thickness (feet)	Rate of Deposit (years for 1 foot)	Time (millions of years)
1860	Phillips	72,000	1.332	96
1869	Huxley	100,000	1,000	100
1871	Haughton	177,200	8,616	1,526
1878	Haughton	177,200	?	200
1883	Winchell	—	—	3
1889	Croll	12,000[1]	6,000[2]	72
1890	de Lapparent	150,000	600	90
1892	Wallace	177,200	158	28
1892	Geikie	100,000	730–6,800	73–680
1893	McGee	264,000	6,000	1,584
1893	Upham	264,000	316	100
1893	Walcott	—	—	45–70
1893	Reade	31,680[1]	3,000[2]	95
1895	Sollas	164,000	100	17
1897	Sederholm	—	—	35–40
1899	Geikie	—	—	100
1900	Sollas	265,000	100	26.5
1908	Joly	265,000	300	80
1909	Sollas	335,000	100	80

0.03 mm/yr

3 mm/yr

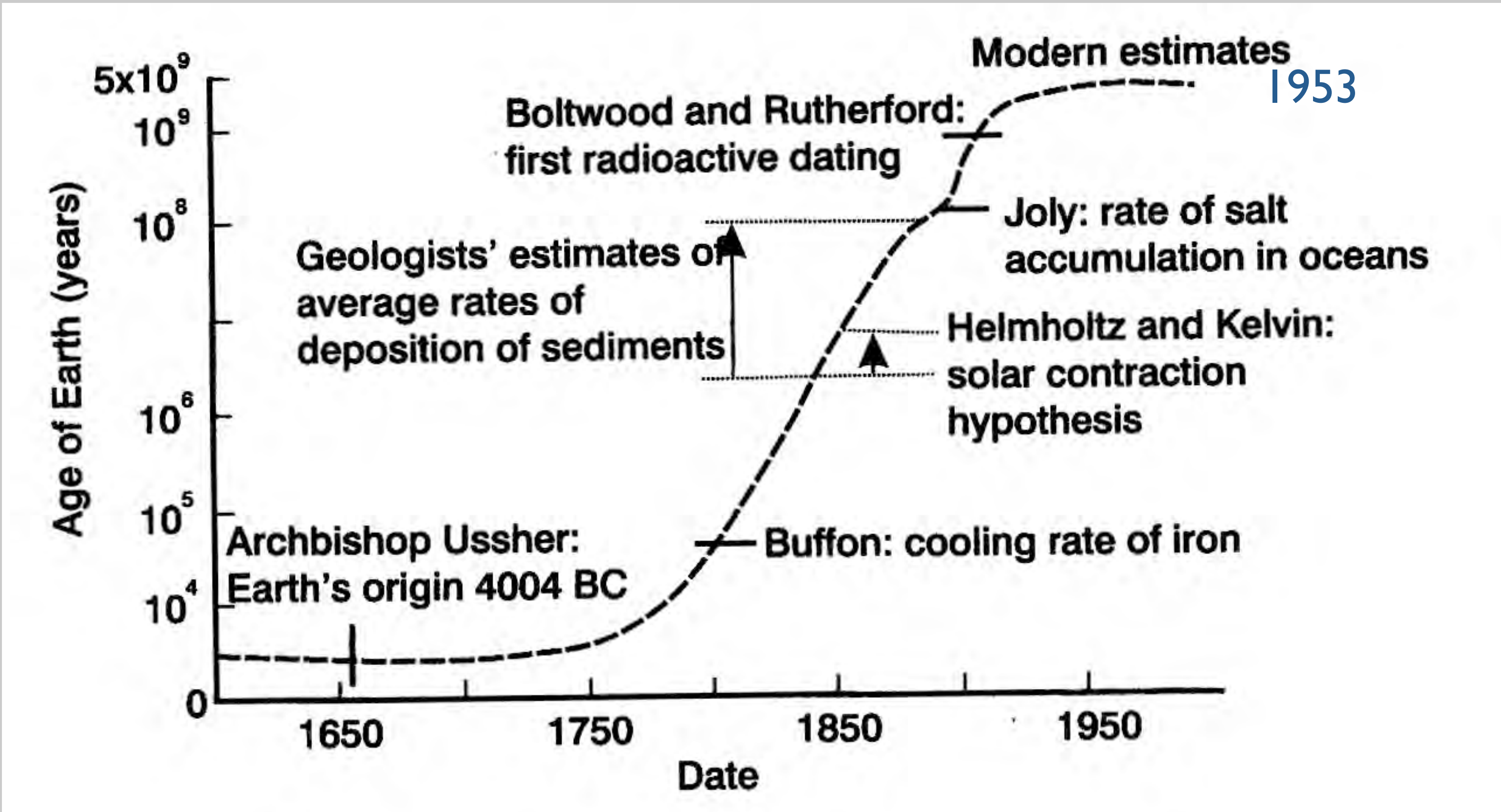
1:100

[1] Spread evenly over the land areas.

[2] Rate of denudation.

* Based on estimates of maximum thicknesses of sedimentary rocks.

After Arthur Holmes, 1913.



18th century : a few 10^3 years (Bible -6006yr, Oct 23th, 9 am, Archbishop Ussher)

19th century : rate of salt accumulation => a few myr

19th century : thermal appraisal => 100 myr (Lord Kelvin, 1862) => 24 myr (id., 1897)

1905 **RUTHERFORD : radioactive minerals could be used to date rocks**

1953 **Earth age defnitively established = 4.5 Ga**

RUTHERFORD 1905

⇒ relation radioactivity and radioactive desintegration of unstable elements

⇒ INTERNAL TIMER

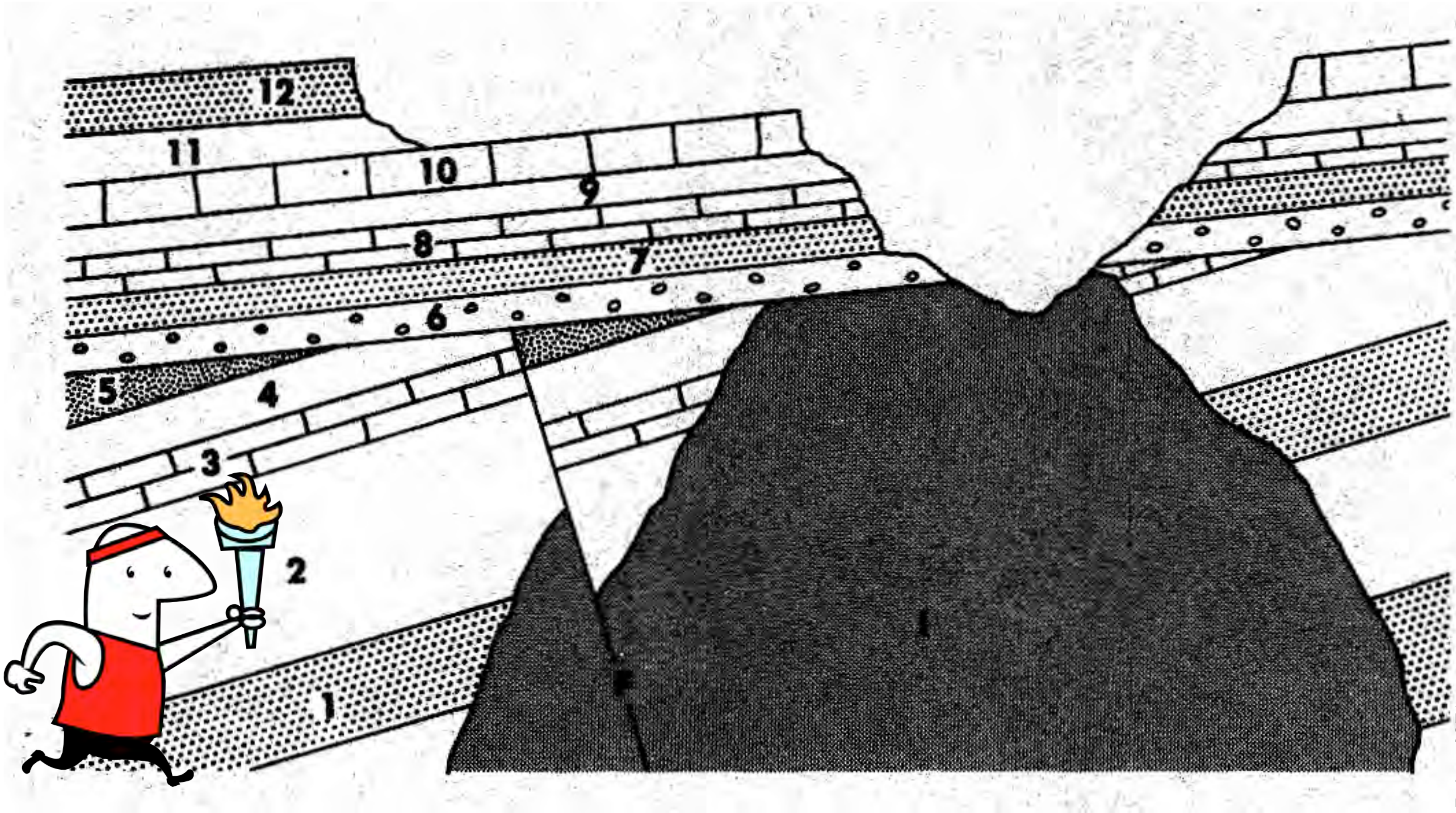
⇒ ABSOLUTE GEOCHRONOLOGY (RADIOMETRIC DATING)

Advantage : succession of hierarchized time slices independent of the content, i.e. the deposition and the processes

BUT… inadequate precision (a few Ma increasing with time)
>< relative chronology
Example: Givetian, duration 7 myr ± 3 myr

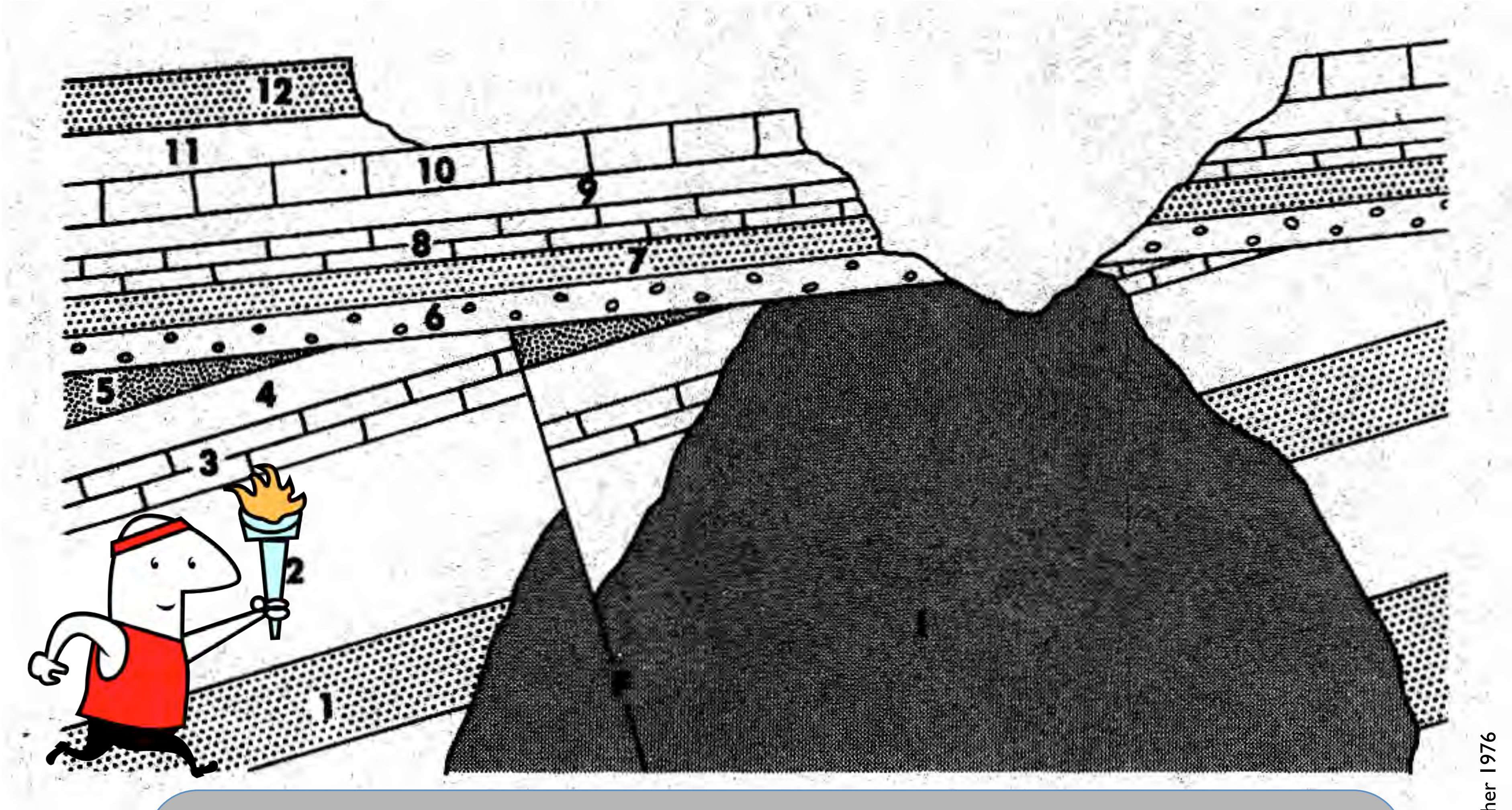
Nb ABSOLUTE and RELATIVE CHRONOLOGIES
= SEDIMENTARY BASIN DYNAMICS

WHAT IS THE SEQUENCE OF EVENTS?



Eicher 1976

WHAT IS THE SEQUENCE OF EVENTS?

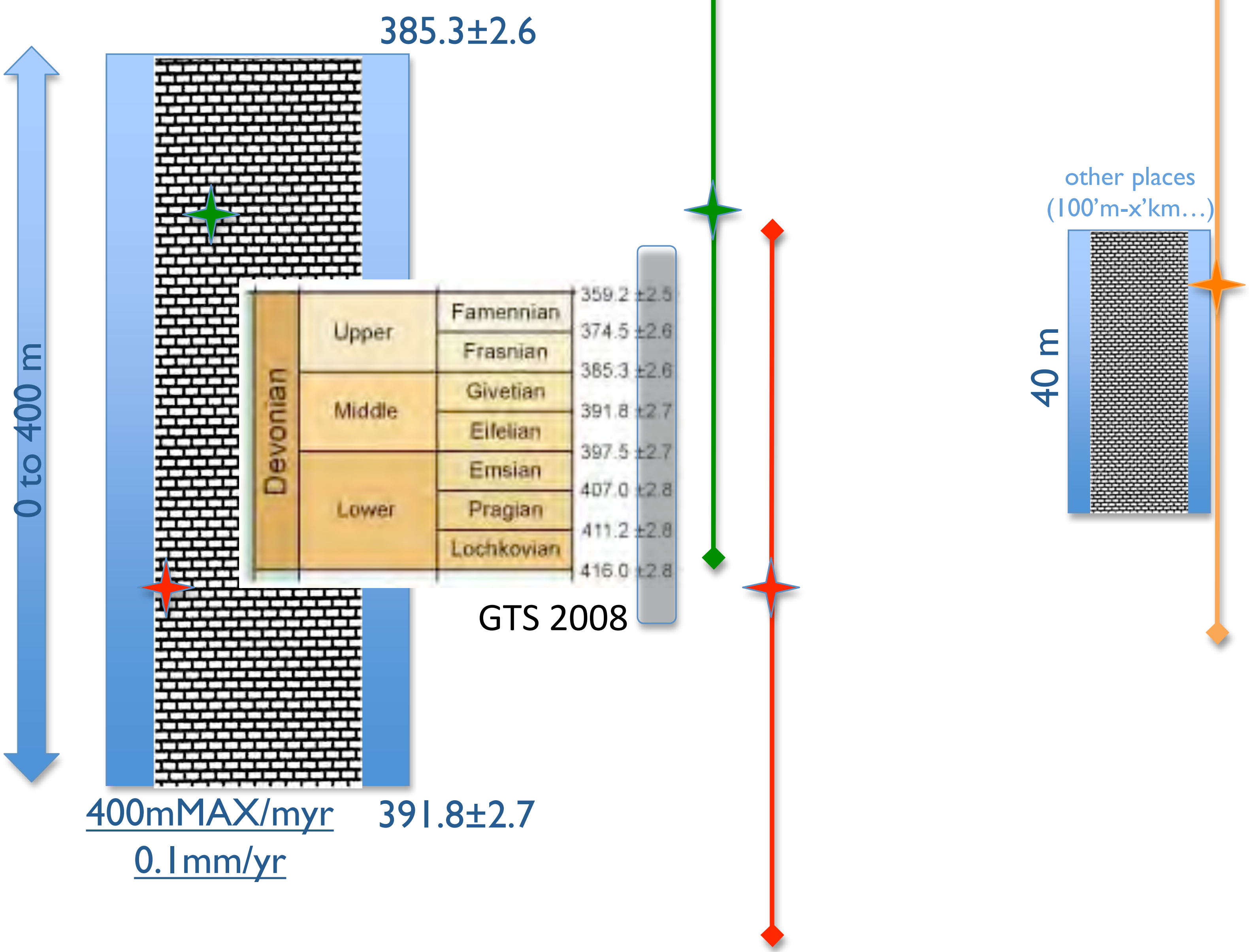


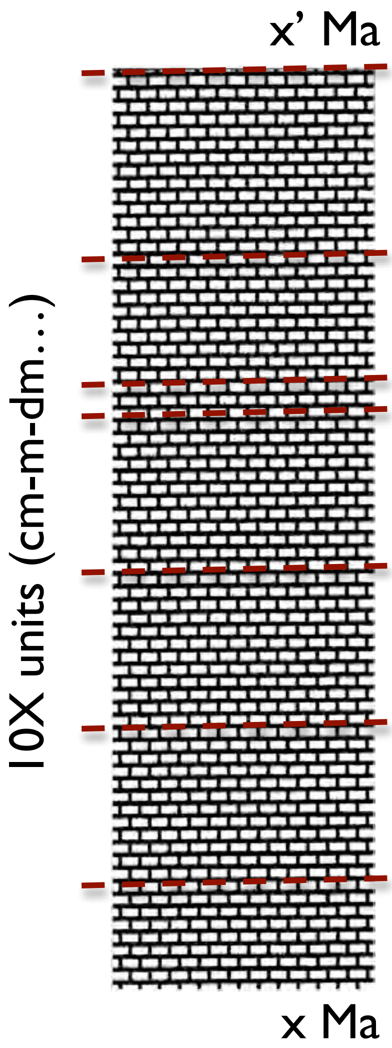
Eicher 1976

1. Deposition of beds 1 through 5.
2. Igneous intrusion
3. Faulting
4. Deposition of beds 6-12,
5. Uplift and Erosion

Time between events?
= relative AND absolute chronologies

EXAMPLE OF THE GIVETIAN (BELGIUM) IDEM FOR ALL GEOLOGICAL STAGES





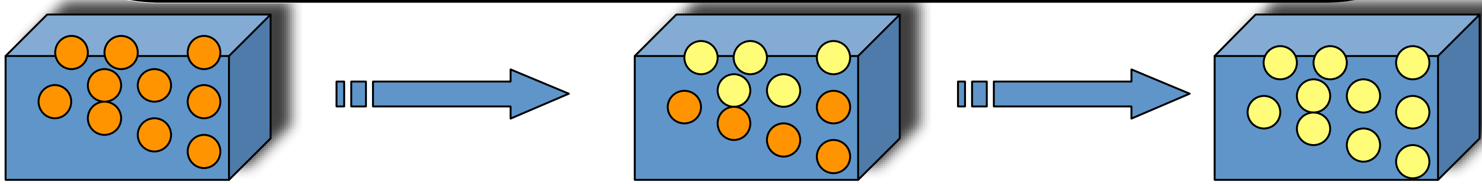
Clayey seams/diastems….
<< 10% of thickness
>> 70-90% of time

ABSOLUTE or ISOTOPIC CHRONOLOGY

^{138}La ===> ^{138}Ce (2.67 x10^{11} years)
^{87}Rb ===> ^{87}Sr (5 x10^{10} years)
^{232}Th ===> ^{208}Pb (13.9 x10^{9} years)
^{40}K ===> ^{40}Ar (11.9 x10^{9} years)
^{238}U ===> ^{206}Pb (4.6 x10^{9} years)
^{235}U ===> ^{207}Pb (7 x10^{8} years)
^{234}Th ===> ^{230}Th (250 000 years)
^{230}Th ===> ^{226}Ra (75 200 years)
^{14}C ===> ^{14}N (5 568 years)
^{3}T ===> ^{2}H (12.26 years)

PRECISION

REL. CHR



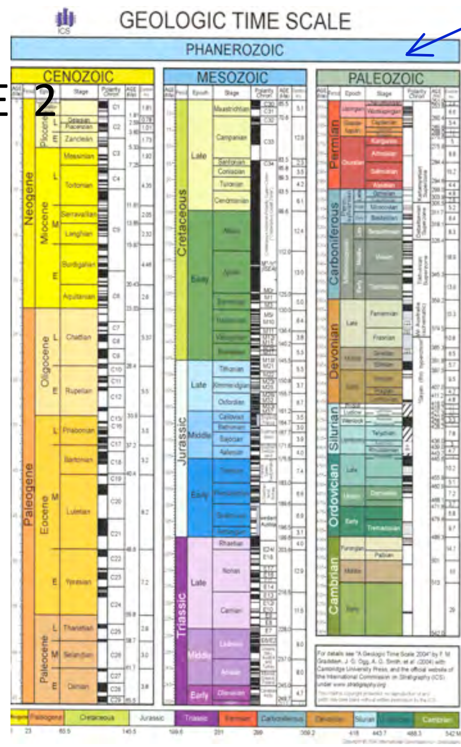
The system has to be closed ... all the time (= new problem)

VOLUME 2
1144 p.

www. stratigraphy.org

DERNIERE MISE A JOUR: 08-2012

387.7±0.8 (2012)



Août 2004-2008

Giv 391.8

Eif ± 2.7

et non plus 380 Ma! ± 5

(en 1995)

PROCHAINE MISE A JOUR: 08-2016

www. stratigraphy.org

CHRONOSTRATIGRAPHY

Space type = Lithostratigraphy (geometry of rocks)

Relative Time type = Chronostratigraphic (‘old *vs* young’)

Numerical Time = Geochronologic (ages *in* years)

CHRONOLOGIC SCALE : concerns the periods (of time)

STRATIGRAPHIC SCALE : concerns the strata i.e. the rocks

Nb Biostratigraphy = **combined** rock and relative-time subdivisions (were used by the first classifiers of the geologic column : rock and fossil changes were thought to occur at the same time)

HIERARCHY OF THE UNITS

GEOCHRONOLOGIC-GEOCHRONOMETRIC UNIT (temporal)
CHRONOSTRATIGRAPHIC UNITS (strata i.e. the rocks)

EON	ERA	PERIOD	EPOCH	AGE
Pcm	I,II,III,?IV	Devonian	Lias	
Phaner.	Paleoz.	…	Dogger	
	Mesoz.	Jurassic	Malm	
	Cenoz.	….	…	
	?Pleist.	?Quaternary*	Eocene	
	?Holocene			

EONOTHEM	ERATHEM	SYSTEM	SERIES	STAGE
idem	Idem	20-70myr	±15myr	±5myr [2-10]
		T/J/K	lower/middle/upper	+SUPERSTAGE
		…	Ex= Ks	+SUBSTAGE
		+SUBSYSTEM	Ex Dn = Tn+Vn	
		Cferous = Miss+Penn	+Lias/Dogger/Malm	
		+SUPERSYSTEM	….	
		Karoo Cferous-J		
		+ **		

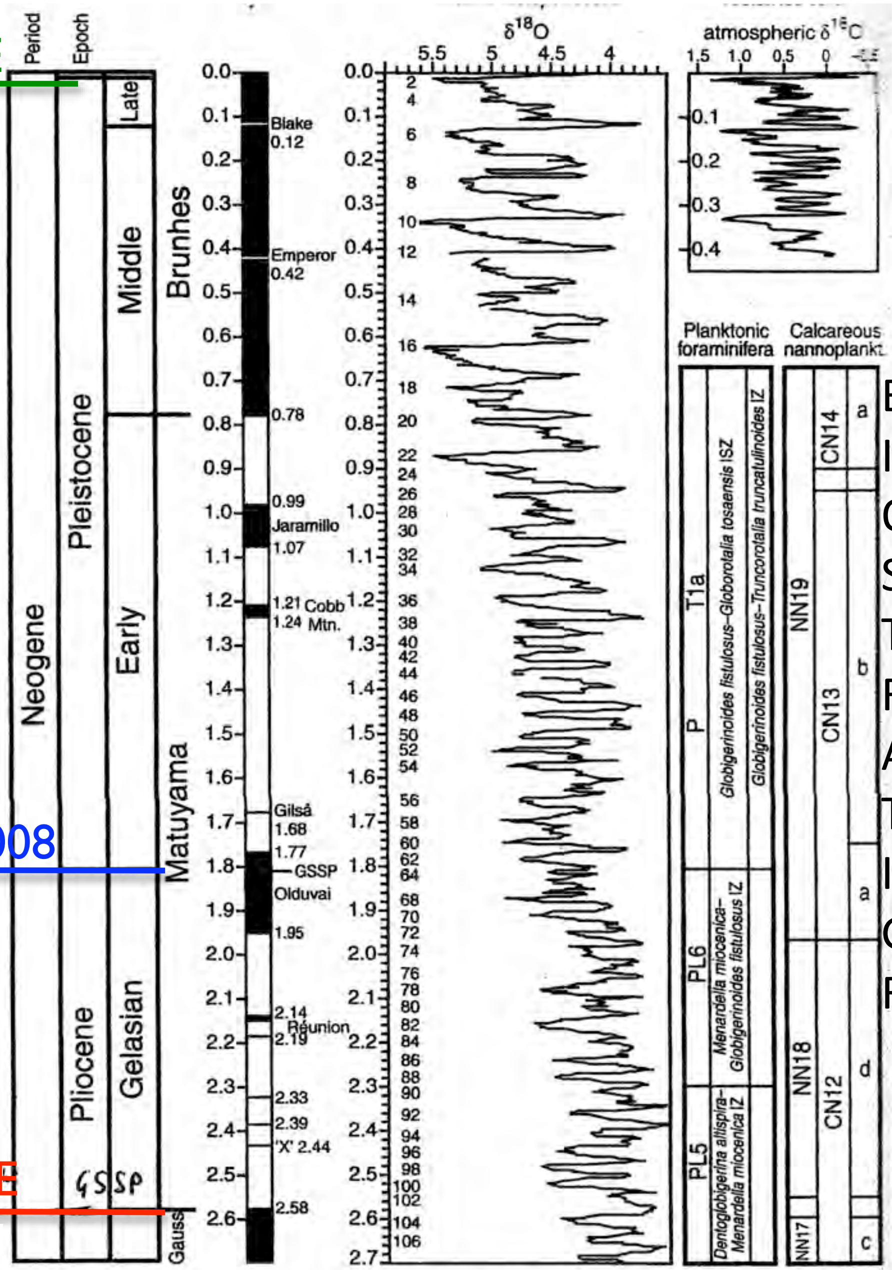
CHRON
hemera

CHRONOZ
epibole

*Related to human evolution and Arctic glaciations
** Some Systems (Cm = 70myr) > one Era (IIIr, 65 myr)

-11700yr -2kAD
GSSP North Grip
Ice ore (Central Groenland)
Depth: -1492.45m

HOLOCENE



BIOSTRATIGRAPHY

IVr 2004…2008
IIIr 1.806Ma

GSSP
MONTE SAN NICOLA
SICILY (GELA)
Initial cooling 2.7-2.4Ma
(mid point choosen)

30 June 2009

IVr 2.588 PLEISTOCENE
IIIr PLIOCENE

GSSP

Figure 22.1 The Pleistocene-Holocene and upper Pliocene time scale. The Global Stratotype Section and Point (GSSP) for the base of the Pleistocene Epoch is indicated. The calibration of the geomagnetic polarity time scale is from oceanographic data collected and processed by S. J. Crowhurst (Delphi Project 2002) and modified from Funnell (1996). The composite marine $\delta^{18}O$ isotope sequence is from the Delphi Project (database at http://131.111.44.196 at Godwin Laboratory, University of Cambridge, UK). The micropaleontological zonations are from Berggren *et al.* (1995a). The atmospheric oxygen isotope curve from the Vostok ice coring is from Petit *et al.* (2001, Vostok Ice Core Data for 420, 000 Years, IGBP PAGES/World Data Center for Paleoclimatology Data Contribution Series #2001-076, at NOAA/NGDC Paleoclimatology Program, Boulder, CO, USA; original reference is Petit *et al.*, 1999).

IUGS

June 30, 2009

Prof. Paul R. Bown,
Secretary, International Commission on Stratigraphy (ICS)
Department of Geological Sciences
University College London
Gower Street
London WC1E 6BT
United Kingdom

RE: Ratification of the definition of the base of Quaternary System/Period (and top of the Neogene System/Period), and redefinition of the base of the Pleistocene Series/Epoch (and top of the Pliocene Series/Epoch).

Dear Professor Bown,

This is to confirm the receipt of your Commission's request of June 2, 2009 for ratification of its recommendation that:

1) the base of the Pleistocene Series/Epoch be lowered such that the Pleistocene includes the Gelasian Stage/Age and its base is defined by the Monte San Nicola GSSP, which also defines the base of the Gelasian;
2) the base of the Quaternary System/Period, and thus the Neogene-Quaternary boundary, be formally defined by the Monte San Nicola GSSP and thus be coincident with the bases of the Pleistocene and Gelasian, and
3) with these definitions, the Gelasian Stage/Age be transferred from the Pliocene Series/Epoch to the Pleistocene.

I am pleased to report that these recommendations were approved by a majority vote of the IUGS Executive Committee on 29 June 2009.

Sincerely yours,

A. Riccardi

Prof. Alberto C. Riccardi
President
International Union of Geological Sciences

cc: Stan Finney, President, ICS
Shanchi Peng, Vice President, ICS
IUGS Executive Committee

www.iugs.org

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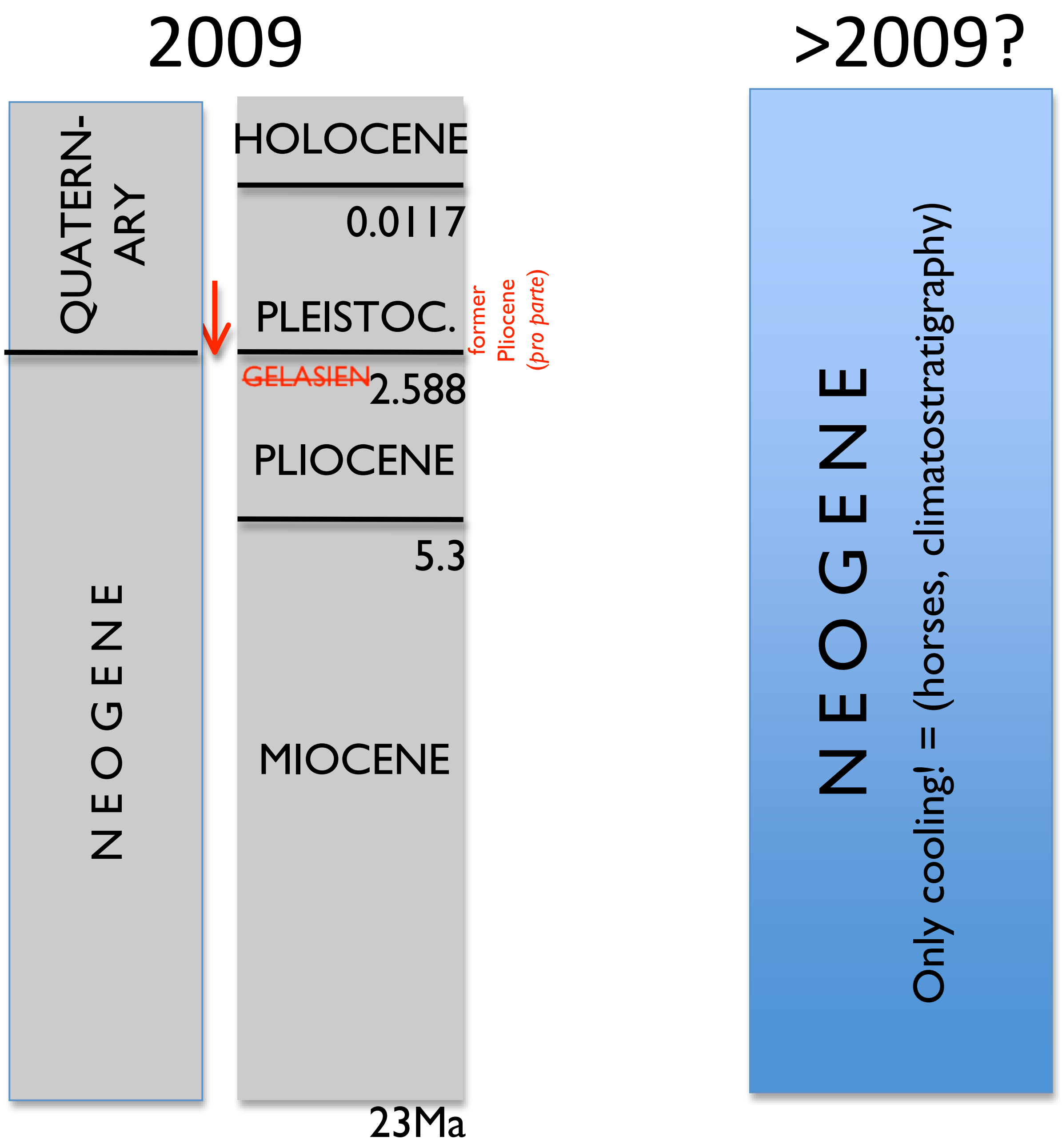

2009
QUATERN-
ARY
NEOGENE
HOLOCENE
0.0117
PLEISTOC.
former
Pliocene
(pro parte)
GELASIEN
2.588
PLIOCENE
5.3
MIOCENE
23Ma
>2009?
NEOGENE
Only cooling! = (horses, climatostratigraphy)

a *annum*	y *year*
ka	kyr
Ma	myr
Ga	

BP 1950

POSTAPOCALYPSE STRATIGRAPHY: SOME CONSIDERATIONS AND PROPOSALS
GEOLOGY, 1985, 13, 4-5

EONS
- *Archean*
- *Proterozoic*
- *Phanerozoic*
- *HYSTEROZOIC*

(hystéros = after)

→

ERA
- *Paleozoic*
- *Mesozoic*
- *Cenozoic*
- *TELOZOIC*

(télos= 'end of life')

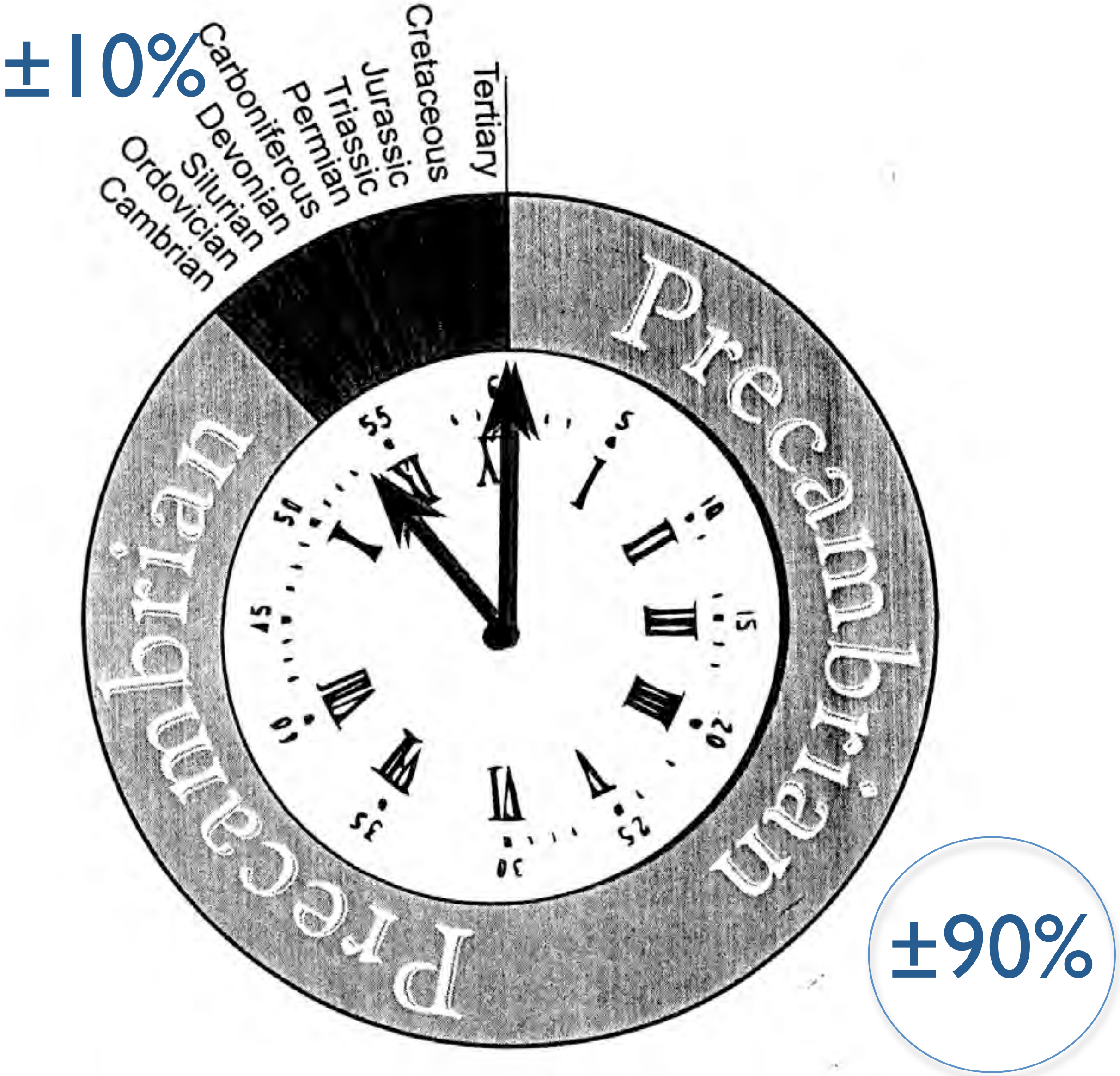
PERIODS
- …
- *QUINTINARY???*

EPOCHS
- *Paleocene*

…
- *Holocene*
- *KEROCENE*

(kéros = 'dead')

New Precambrian time scale : comments *Episodes 1992, 15,122-125*
A proposal for the revision of chronostratigraphic nomenclature *Episodes 1992, 17, 57-59*



Geological time.
To give an idea of the enormity of Precambrian time, the table opposite can be displayed as a clock where the Precambrian is seen to occupy almost ninety per cent of geological time. Man appears a few seconds before midnight.

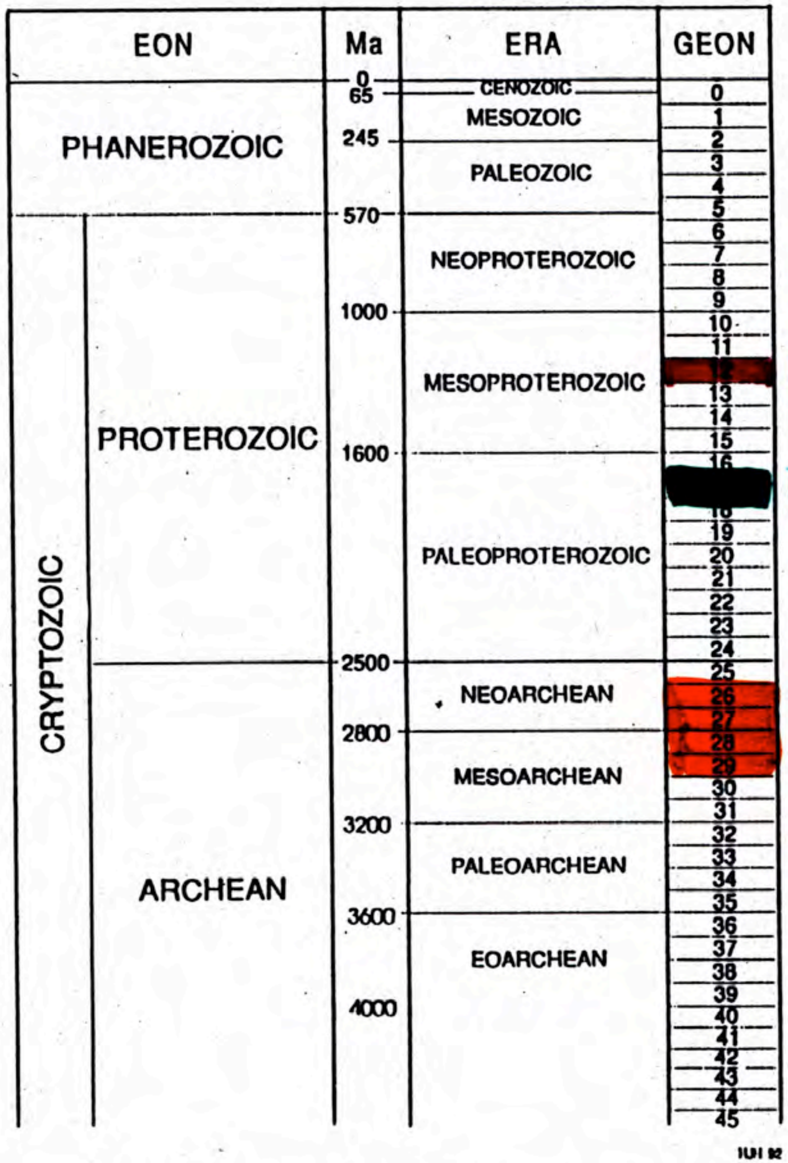
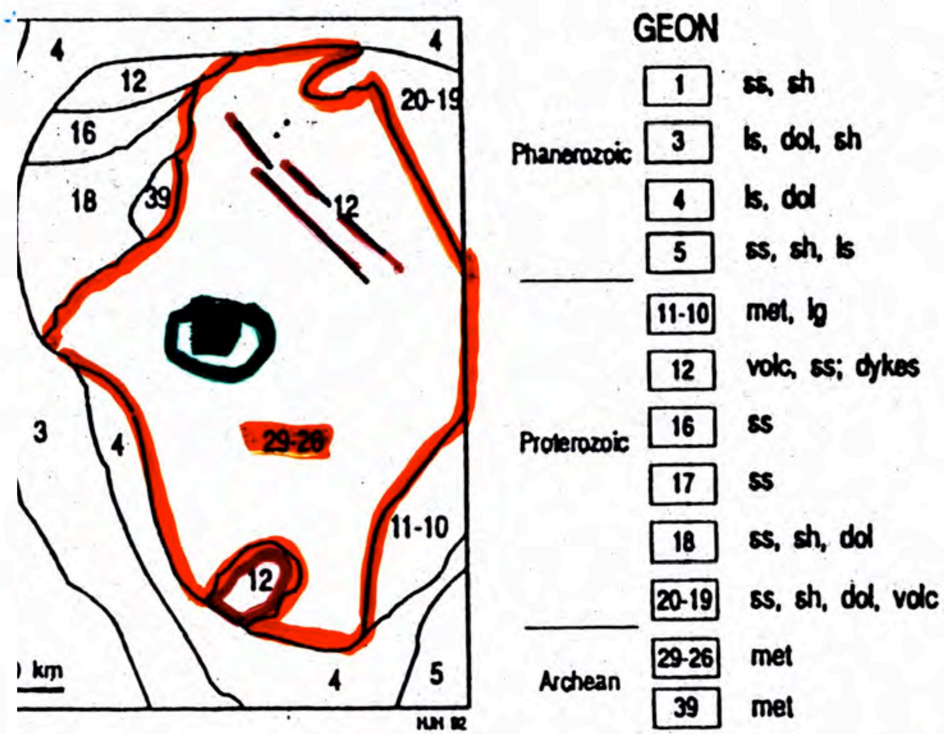


Figure 1.—Time divisions for the Precambrian using geon units. For example, a unit dated at 770 Ma belongs to geon 7; one of 2,740 Ma belongs to geon 27 (modified from Hofmann, 1990, fig.1). The scale includes eras recently recommended by the SPS for the Archean (Lumbers and Card, 1991).

NOT A GOOD PROPOSAL



2.—Hypothetical geologic map using geon units. Lithologic and map symbols are intentionally in order to show only time relationships (modified from Hofmann, fig. 1).

NOT A GOOD PROPOSAL

Table 1 Eons and eras. The nomenclature of IUGS(1989) compared with the proposals in this paper (new terms shown in bold type).

IUGS (Cowie and Bassett, 1989)			This proposal	
Era – Erathem	Eon – Eonthem	Geochronometry Ma BP	Eon – Eonthem	Era – Erathem
Cenozoic Mesozoic Paleozoic	Phanerozoic		**Phanerozoon**	Cenozoic Mesozoic Paleozoic
		570		
Neoproterozoic	Proterozoic	1000	**Cryptozoon**	**Mesophytic**
Mesoproterozoic		1600		**Paleophytic**
Paleoproterozoic				**Proterophytic**
		2500		
	Archean		**Azoon**	**Archeophytic**
		4000		
			Geogenon	**Geogenic**

Table 2 Periods of the Phanerozoic (new terms in bold type).

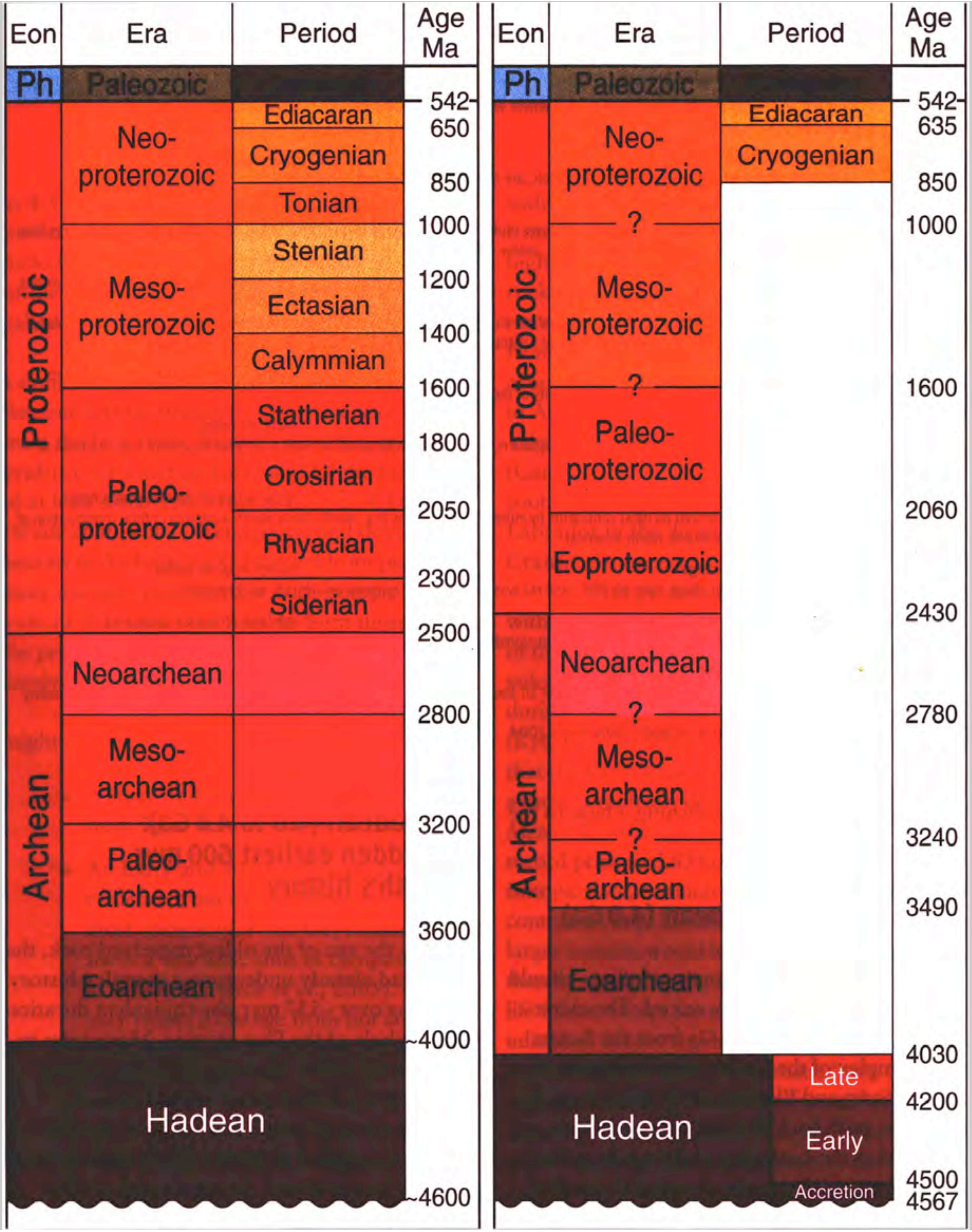
Era – Erathem	Period – System
Cenozoic	**Hologene** Neogene Paleogene
Mesozoic	**Cretacic** Jurassic Triassic
Paleozoic	Permian **Carboniferan** Devonian Silurian Ordovician Cambrian

NOT A GOOD PROPOSAL
NOT A GOOD PROPOSAL
NOT A GOOD PROPOSAL
NOT A GOOD PROPOSAL
NOT A GOOD PROPOSAL
NOT A GOOD PROPOSAL
NOT A GOOD PROPOSAL
NOT A GOOD PROPOSAL

OF CLOCKS AND ROCKS – THE FOUR AEONS OF EARTH
EPISODES 1991,14, 327-329

	PHANEROZOIC = 'visible' life (multicellular)
0.542Ga	**PROTEROZOIC** = 'middle' period of life
2.5Ga	**ARCHEAN** = 'early' life history
4Ga	**HADEAN** = prebiotic

Current International Stratigraphic Chart
2008
(Ogg et al. 2008)



Possible changes under consideration
(Ogg et al. 2008)

Current International Stratigraphic Chart
2012

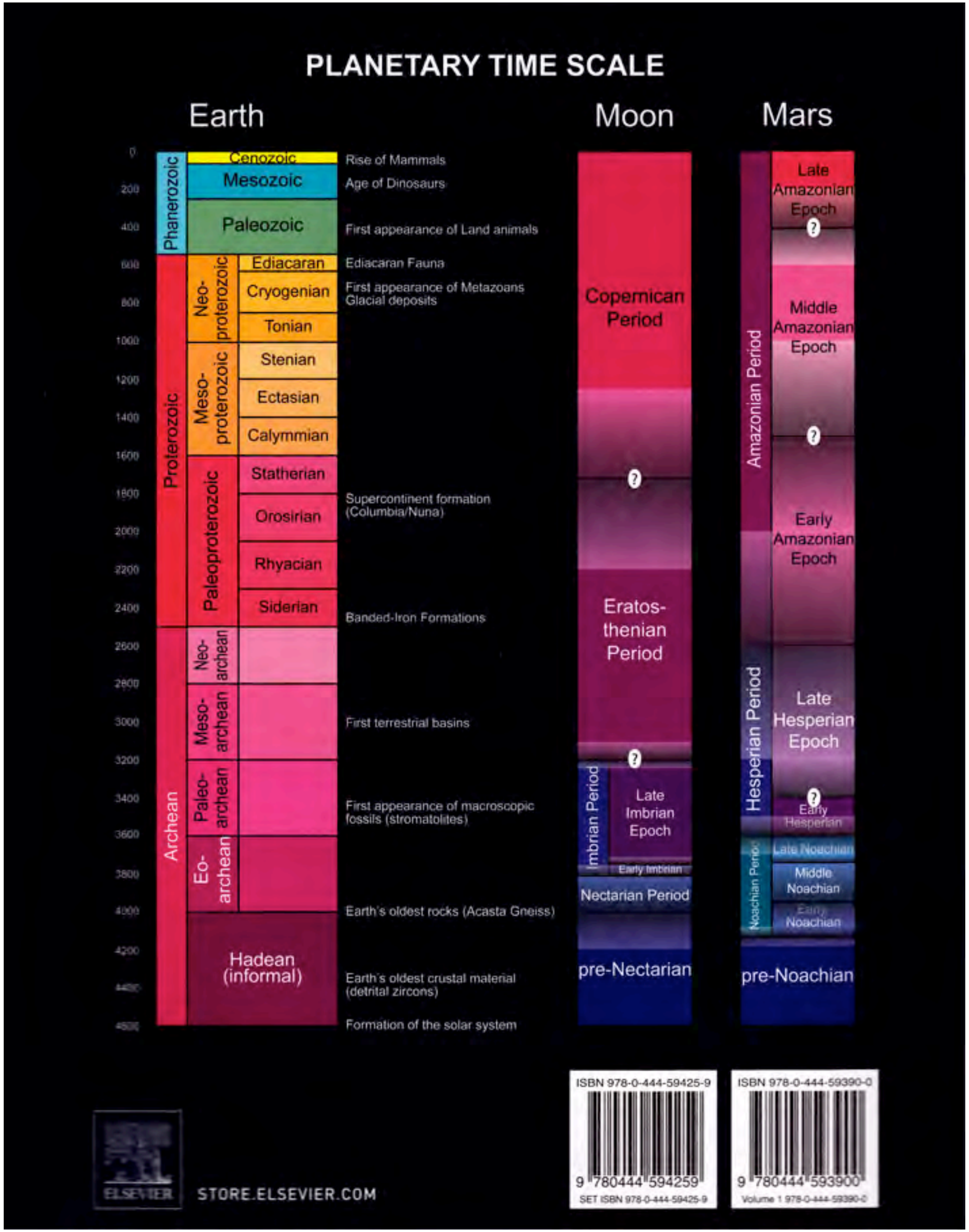
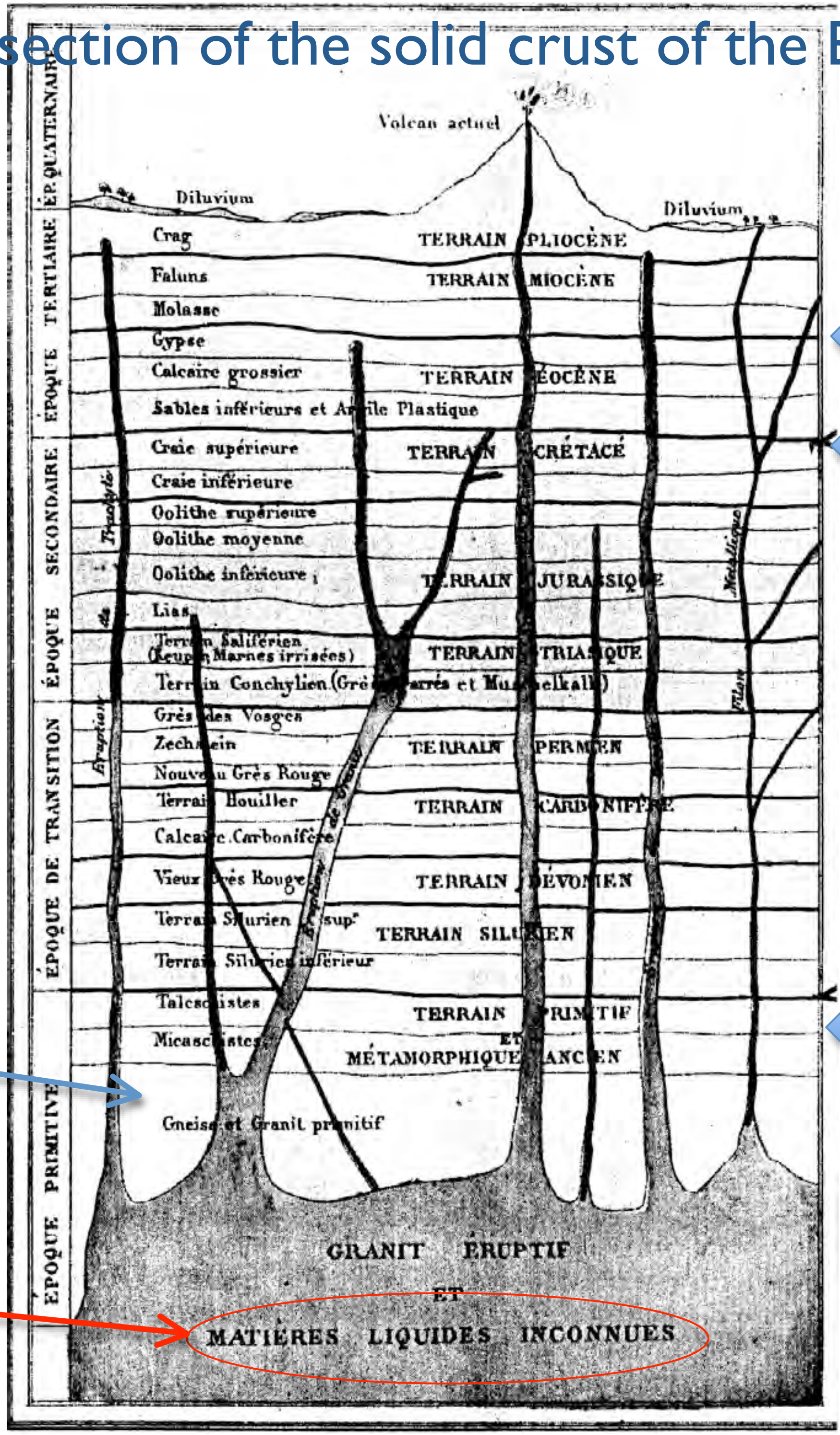


Table 3.1 Explanation of nomenclature used at the period level in the Proterozoic Eon

Period name	Derivation and geological process	
Ediacaran	Australian Aborigine term referring to a place where water is or was present close by	*Earliest metazoan life*
Cryogenian	*Cryos* = ice; *genesis* = birth Glacial deposits, which typify the late Proterozoic, are most abundant during this interval	*Global glaciation*
Tonian	*Tonas* = stretch Further major platform cover expansion (e.g., Upper Riphean, Russia.; Qingbaikou, China; basins of northwest Africa), following final cratonization of polymetamorphic mobile belts, below	
Stenian	*Stenos* = narrow Narrow polymetamorphic belts, characteristic of the mid-Proterozoic, separated the abundant platforms and were orogenically active at about this time (e.g., Grenville, Central Australia)	*Narrow belts of intense metamorphism and deformation*
Ectasian	*Ectasis* = extension Platforms continue to be prominent components of most shields	*Continued expansion of platform covers*
Calymmian	*Calymma* = cover Characterized by expansion of existing platform covers, or by new platforms on recently cratonized basement (e.g., Riphean of Russia)	*Platform covers*
Statherian	*Statheros* = stable, firm This period is characterized on most continents by either new platforms (e.g., North China, North Australia) or final cratonization of fold belts (e.g., Baltic Shield, North America)	*Stabilization of cratons; cratonization*
Orosirian	*Orosira* = mountain range The interval between about 1900 Ma and 1850 Ma was an episode of orogeny on virtually all continents	*Global orogenic period*
Rhyacian	*Rhyax* = stream of lava The Bushveld Complex (and similar layered intrusions) is an outstanding event of this time	*Injection of layered complexes*
Siderian	*Sideros* = iron The earliest Proterozoic is widely recognized for an abundance of BIF, which peaked just after the Archean–Proterozoic boundary	*Banded-iron formations* (BIF)

Ogg et al. 2008

Ideal section of the solid crust of the Earth 1864!



oligocene

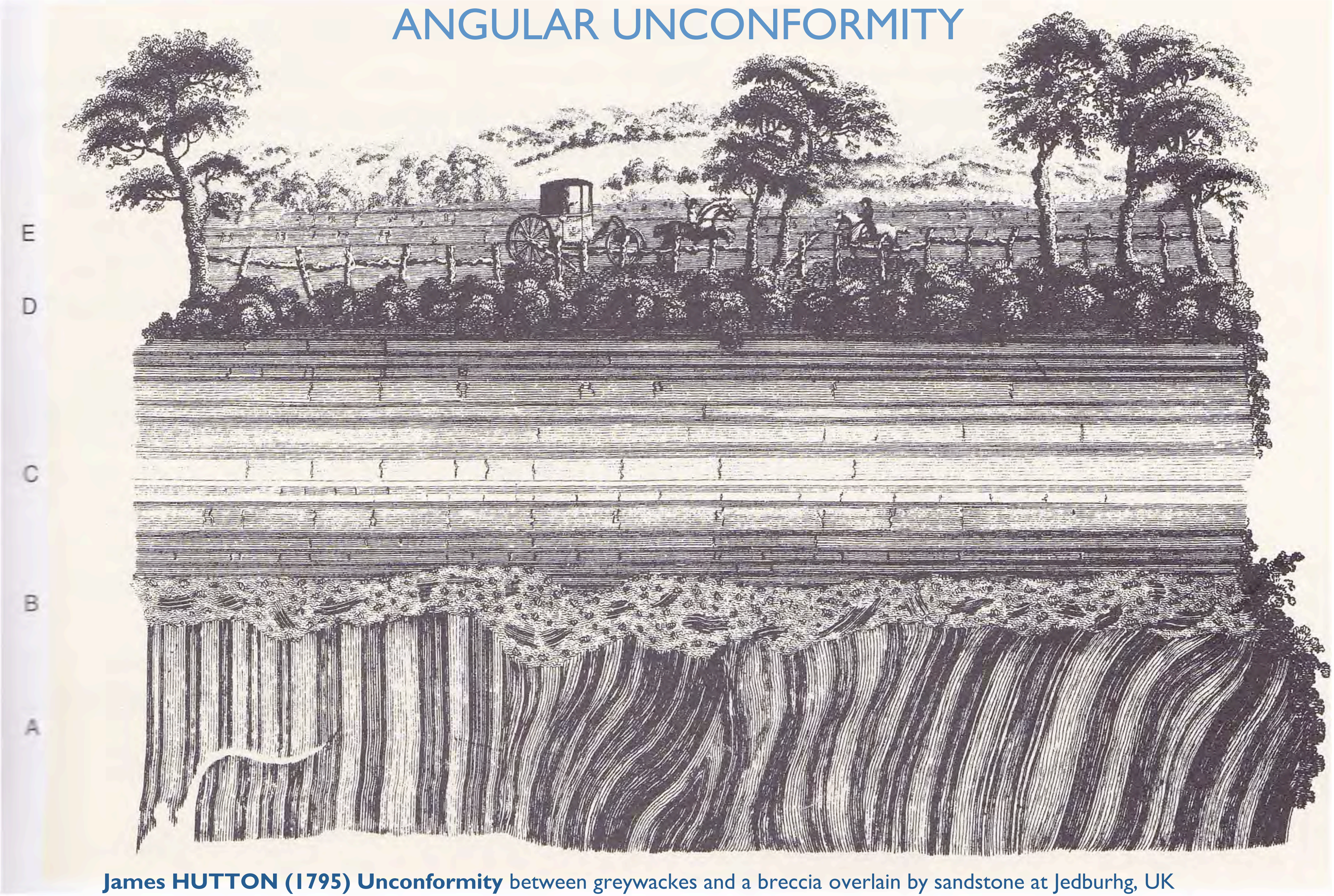
paleocene

ordovician
cambrian

considered to be
formed
in one time

unknown liquids

ANGULAR UNCONFORMITY

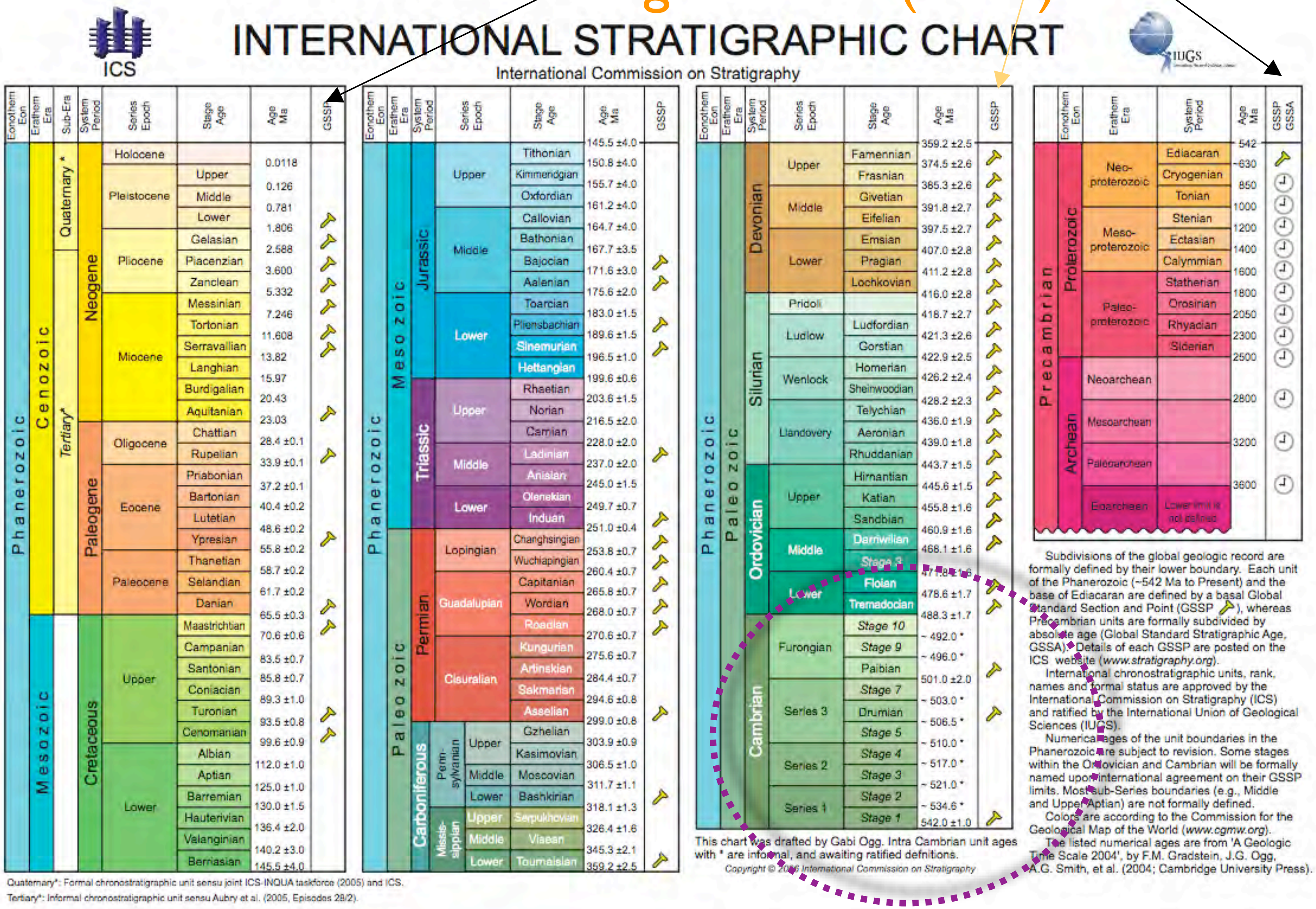


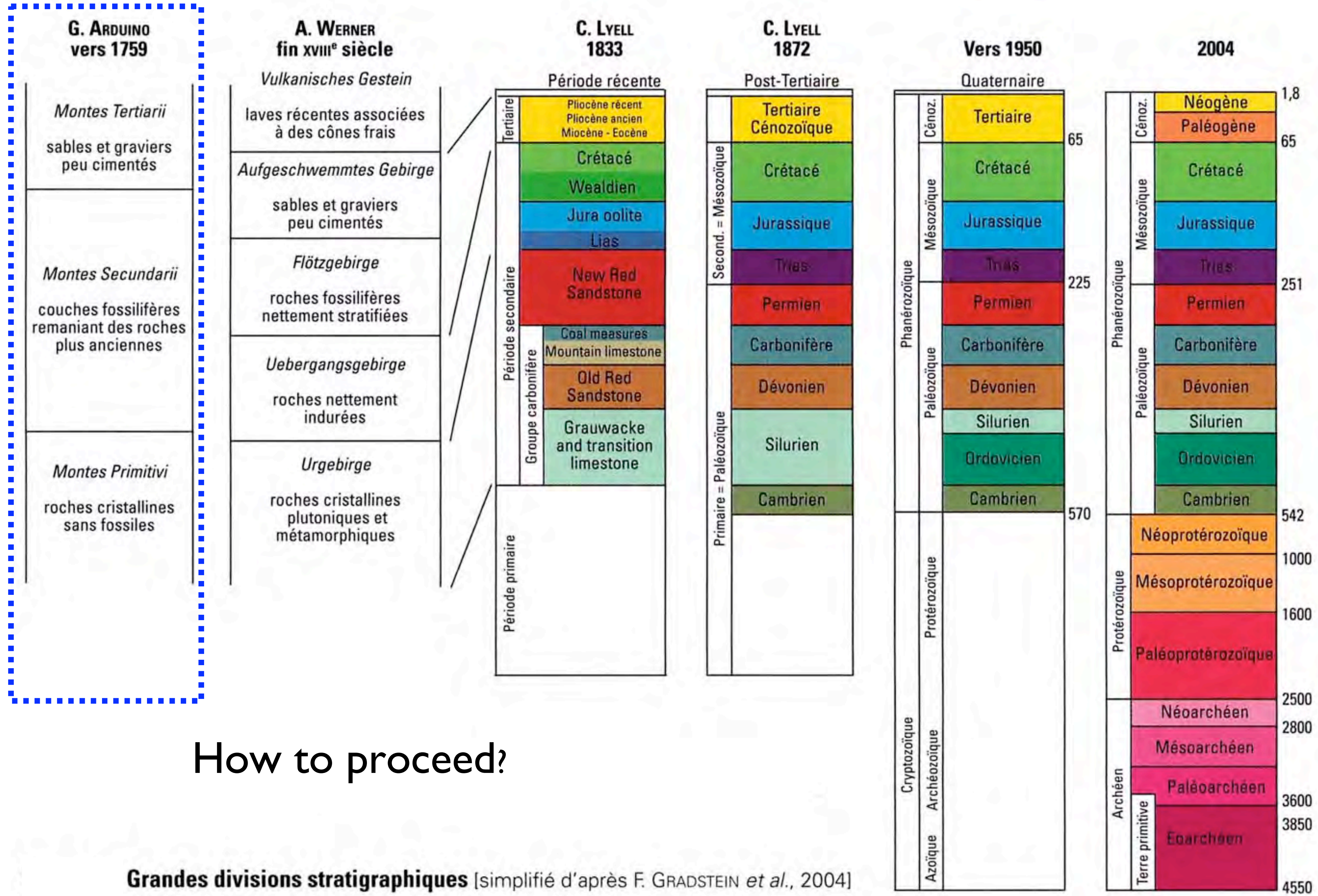
James HUTTON (1795) Unconformity between greywackes and a breccia overlain by sandstone at Jedburhg, UK
« section of a bank of mineral strata in River near Jedburg . ***A*** *The Shistus standing upright* ***B*** *The bed of Pudding-stone composed of The wreck(?) of the Shistus* ***C*** *Beds of red and marley sandstone, deposited above it* ***D*** *The line or Level of the Road cut out of the Bank* ***E*** *The beds of red marle Sandstone seen above th Rood »*

SICCAR POINT-ANGULAR UNCONFORMITY
HUTTON – 1788 East Coast Scotland
(ORS sandstone/greywacke)

GOLDEN SPIKE

GTS August 2004 (2008)





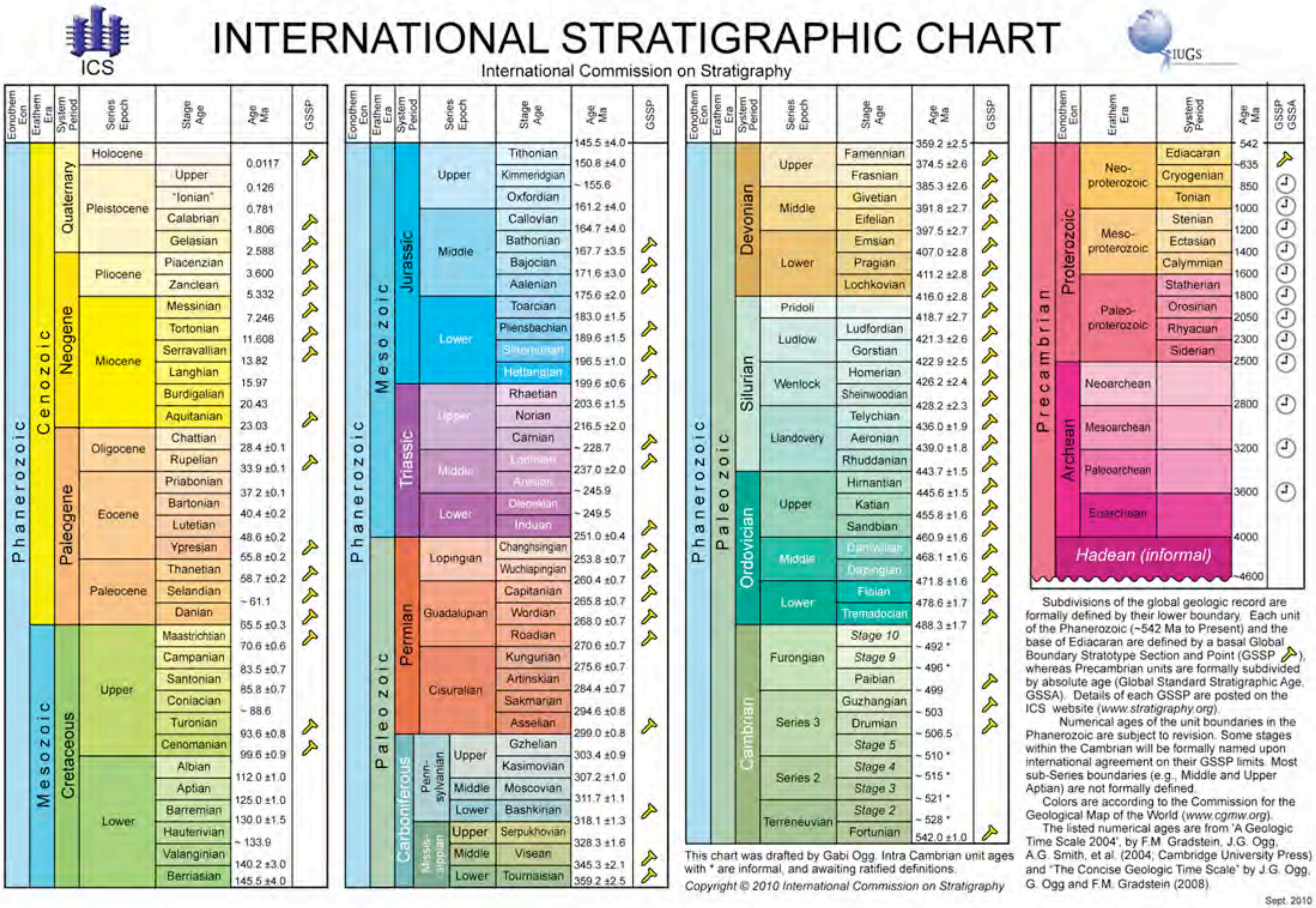
How to proceed?

In Mascle 2008

Chronostratigraphic standardscale

Approved and planned GSSPs

Eonothem	Erathem	System	S.s. Series	Stage	GSSP approved	GSSP Planned
Phanerozoic	Cenozoic	Quaternary	Holocene			
			Pleistocene		GSSP/85	
		Neogene	Pliocene	Gelasian	GSSP/96	
				Piacenzian	GSSP/97	
				Zanclean		<2000
			Miocene	Messinian		<2000
				Tortonian		<2000?
				Serravallian		?
				Langhian		?
				Burdigalian		?
				Aquitanian	GSSP/96	
		Palaeogene	Oligocene	Chattian		1998
				Rupelian	GSSP/93	
			Eocene	Priabonian		1998
				Bartonian		1999
				Lutetian		1998
				Ypresian		1998
			Paleocene	Thanetian		1998
				Selandian		1998
				Danian	GSSP/91	
	Mesozoic	Cretaceous	Upper	Maastrichtian		1998
				Campanian		2000
				Santonian		1999
				Coniacian		1998
				Turonian		1998
				Cenomanian		1998
			Lower	Albian		2000
				Aptian		1999
				Barremian		1998
				Hauterivian		1998
				Valanginian		1999
				Berriasian		2000
		Jurassic	Upper (Malm)	Tithonian		(2000+)
				Kimmeridgian		1999
				Oxfordian		1999
			Middle (Dogger)	Callovian		(2000?)
				Bathonian		1999
				Bajocian	GSSP/96	
				Aalenian		1999
			Lower (Lias)	Toarcian		(2000+)
				Pliensbachian		(2000++)
				Sinemurian		2000
				Hettangian		(2000+)
		Triassic	Upper	Rhaetian		
				Norian		
				Carnian		
			Middle	Ladinian		
				Anisian		
				Olenekian		
			Lower	Induan		
	Palaeozoic	Permian	Lopingian	Changhsingian		1998(2000)
				Wuchiapingian		1998(1999)
			Guadalupian	Capitanian		1998(2000)
				Wordian		1998(2000)
				Roadian		1997(1998)
			Cisuralian	Kungurian		2000
				Artinskian		2001
				Sakmarian		2000
				Asselian	GSSP/96	
		Carboniferous	Up.	Gzhelian		?
				Kasimovian		?
				Moscovian		?
				Bashkirian	GSSP/96	
			Lo.	Serpukhovian		?
				Viséan		2000?
				Tournaisian	GSSP/91	
		Devonian	Upper	Famennian	GSSP/93	
				Frasnian	GSSP/91	
			Middle	Givetian	GSSP/95	
				Eifelian	GSSP/85	
			Lower	Emsian	GSSP/96	
				Pragian	GSSP/89	
				Lochkovian	GSSP/77	
		Silurian	Přídolí		GSSP/85	
			Ludlow	Ludfordian	GSSP/85	
				Gorstian	GSSP/85	
			Wenlock	Homerian	GSSP/85	
				Sheinwoodian	GSSP/85	
			Llandovery	Telychian	GSSP/85	
				Aeronian	GSSP/85	
				Rhuddanian	GSSP/85	
		Ordovician	Upper			1999
						1999
			Middle	Dariwillian	GSSP/97	
						1999
			Lower			1998
						1998
		Cambrian	Upper			IGC(2000)
			Middle			IGC(2000)
			Lower		GSSP/94	

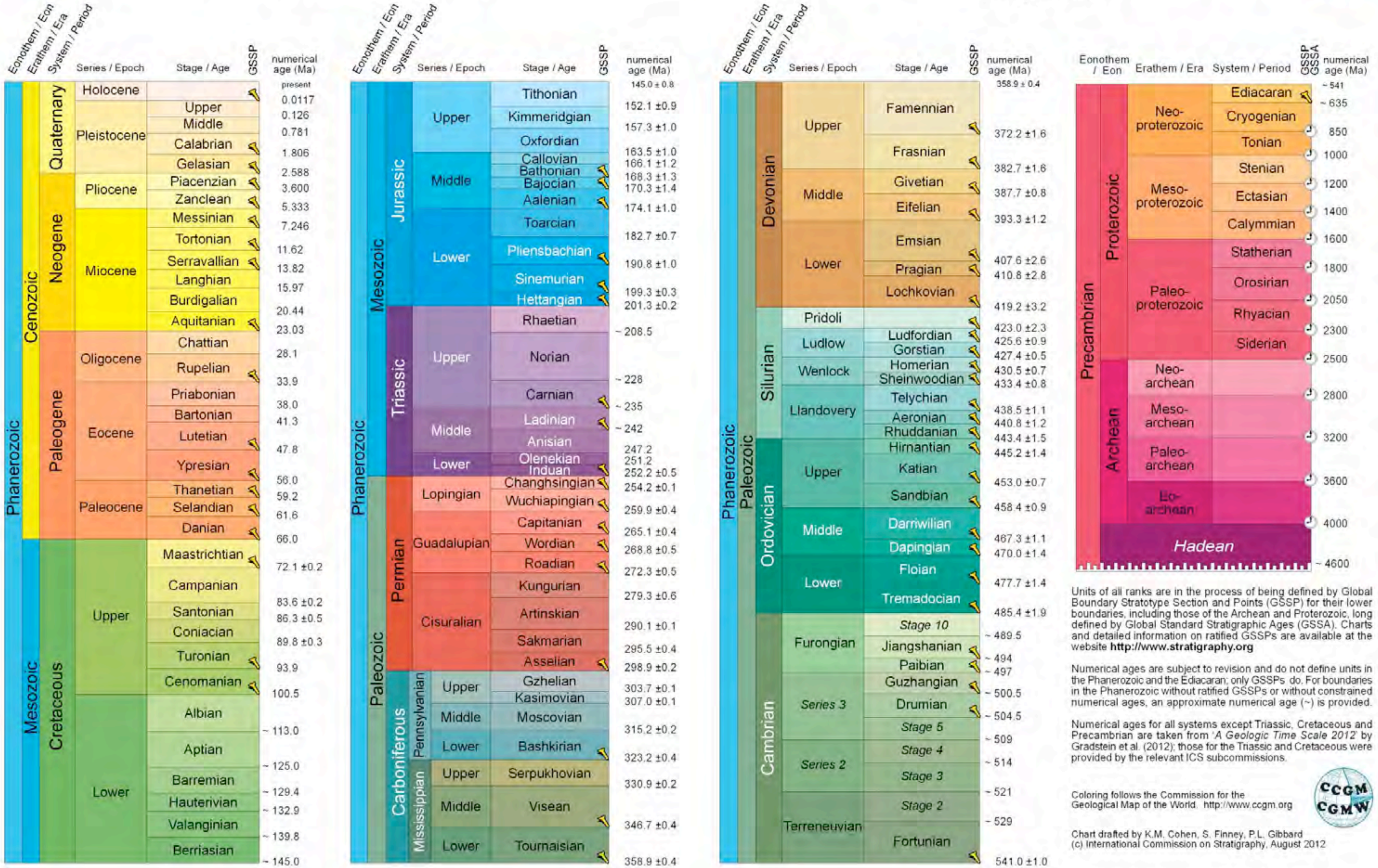

ICS
INTERNATIONAL STRATIGRAPHIC CHART
International Commission on Stratigraphy
IUGS
Subdivisions of the global geologic record are formally defined by their lower boundary. Each unit of the Phanerozoic (~542 Ma to Present) and the base of Ediacaran are defined by a basal Global Boundary Stratotype Section and Point (GSSP), whereas Precambrian units are formally subdivided by absolute age (Global Standard Stratigraphic Age, GSSA). Details of each GSSP are posted on the ICS website (www.stratigraphy.org).
Numerical ages of the unit boundaries in the Phanerozoic are subject to revision. Some stages within the Cambrian will be formally named upon international agreement on their GSSP limits. Most sub-Series boundaries (e.g., Middle and Upper Aptian) are not formally defined.
Colors are according to the Commission for the Geological Map of the World (www.cgmw.org).
The listed numerical ages are from 'A Geologic Time Scale 2004', by F.M. Gradstein, J.G. Ogg, A.G. Smith, et al. (2004; Cambridge University Press) and "The Concise Geologic Time Scale" by J.G. Ogg, G. Ogg and F.M. Gradstein (2008).
This chart was drafted by Gabi Ogg. Intra Cambrian unit ages with * are informal, and awaiting ratified definitions.
Copyright © 2010 International Commission on Stratigraphy
Sept. 2010

INTERNATIONAL CHRONOSTRATIGRAPHIC CHART

IUGS

www.stratigraphy.org

International Commission on Stratigraphy
August 2012



Units of all ranks are in the process of being defined by Global Boundary Stratotype Section and Points (GSSP) for their lower boundaries, including those of the Archean and Proterozoic, long defined by Global Standard Stratigraphic Ages (GSSA). Charts and detailed information on ratified GSSPs are available at the website **http://www.stratigraphy.org**

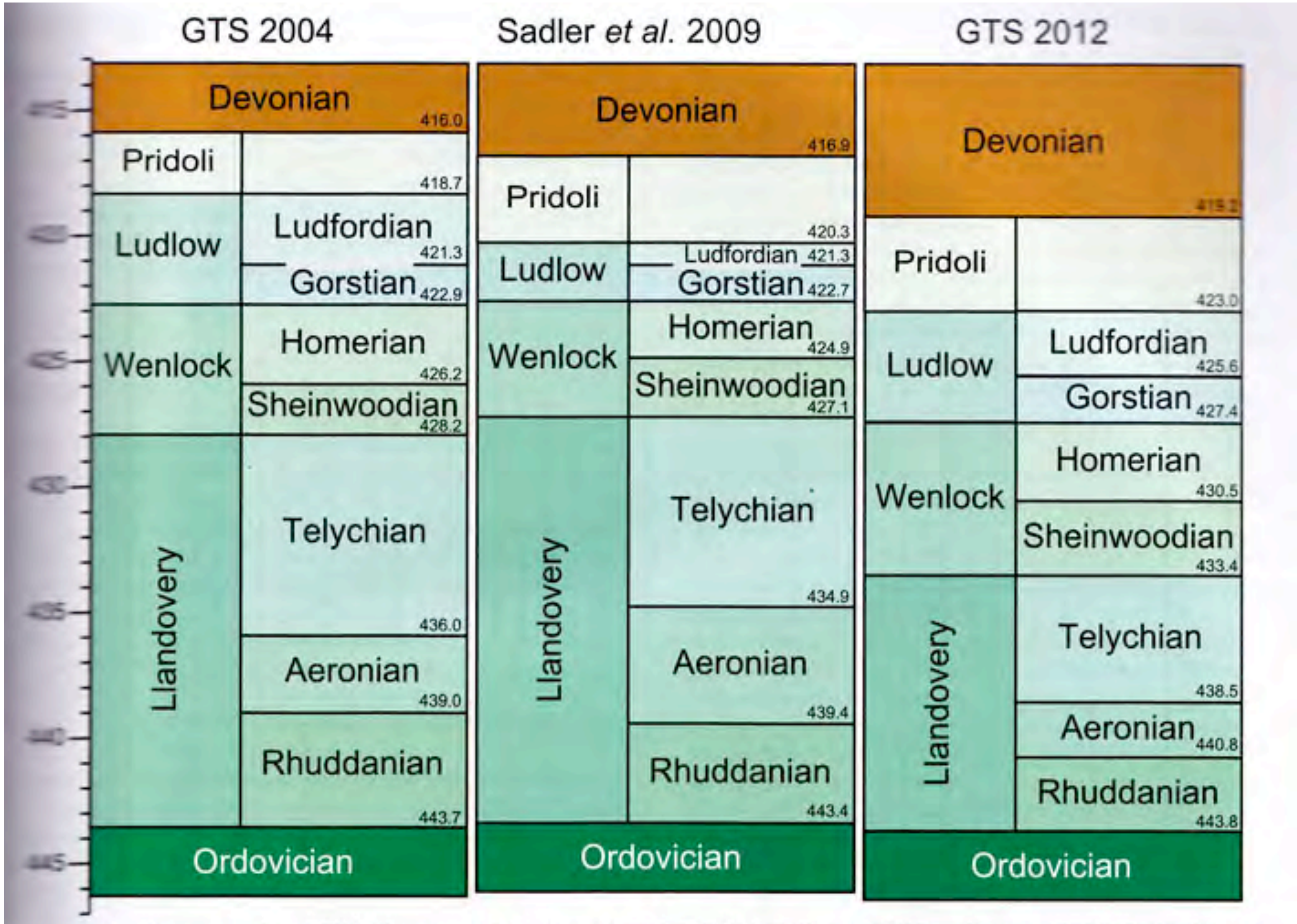
Numerical ages are subject to revision and do not define units in the Phanerozoic and the Ediacaran; only GSSPs do. For boundaries in the Phanerozoic without ratified GSSPs or without constrained numerical ages, an approximate numerical age (~) is provided.

Numerical ages for all systems except Triassic, Cretaceous and Precambrian are taken from '*A Geologic Time Scale 2012*' by Gradstein et al. (2012); those for the Triassic and Cretaceous were provided by the relevant ICS subcommissions.

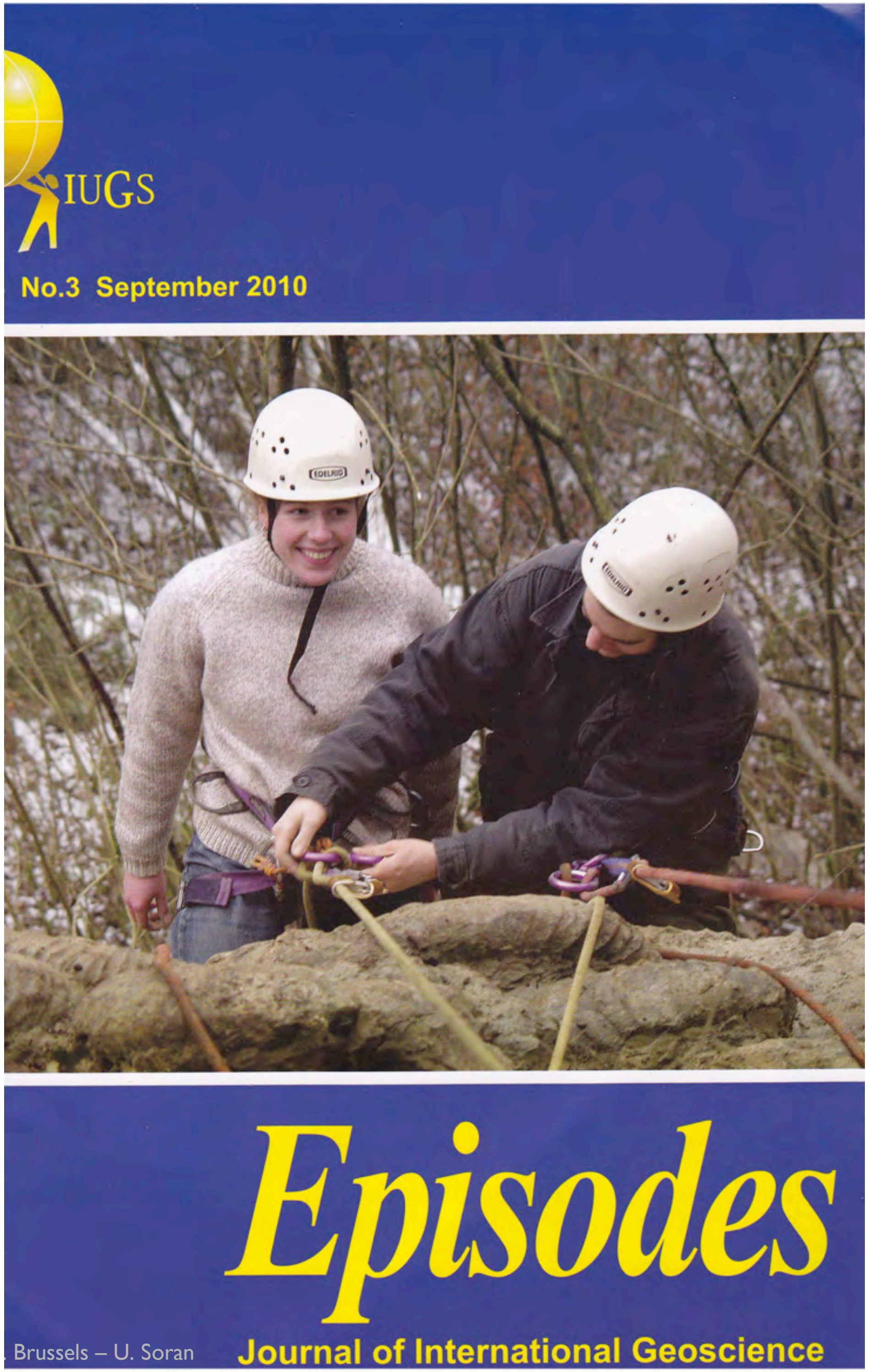
Coloring follows the Commission for the Geological Map of the World. http://www.ccgm.org

CCGM CGMW

Chart drafted by K.M. Cohen, S. Finney, P.L. Gibbard



Comparison of the CONOP time scales of Melchin *et al.* (2004, GTS2004), Sadler *et al.* (2009), and present (GTS2012), showing series and stages. Note that in the Melchin *et al.* (2004) and Sadler *et al.* (2009) papers, the base of the Wenlock was drawn at a level correlative with the base of the *C.* ... Zone, whereas in the GTS2012 column it is drawn at the base of the overlying *C. murchisoni* Zone (see text for explanation).



Contents

September 2010
Vol.33, No.3

Episodes

Published by the International Union of Geological Sciences

Cover

Front: Excavations by "roping" at the giant ammonite Puzosia accumulation from the Late Cenomanian (Upper Cretaceous) in Germany (top view). Photo: © PaleoLogic.

Back: The tectonically deformed ammonites after the preparation of the lower layer (lateral view), Late Cenomanian, Germany. Photo: © PaleoLogic.

The newly-ratified definition of the Quaternary System/Period and redefinition of the Pleistocene Series/Epoch, and comparison of proposals advanced prior to formal ratification

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by Stanley C. Finney

Formal definition of the Quaternary System/Period and redefinition of the Pleistocene Series/Epoch

Chair – International Commission on Stratigraphy (IUGS); Department of Geological Sciences, California State University at Long Beach, Long Beach CA 90840, USA. *E-mail: scfinney@cslb.edu*

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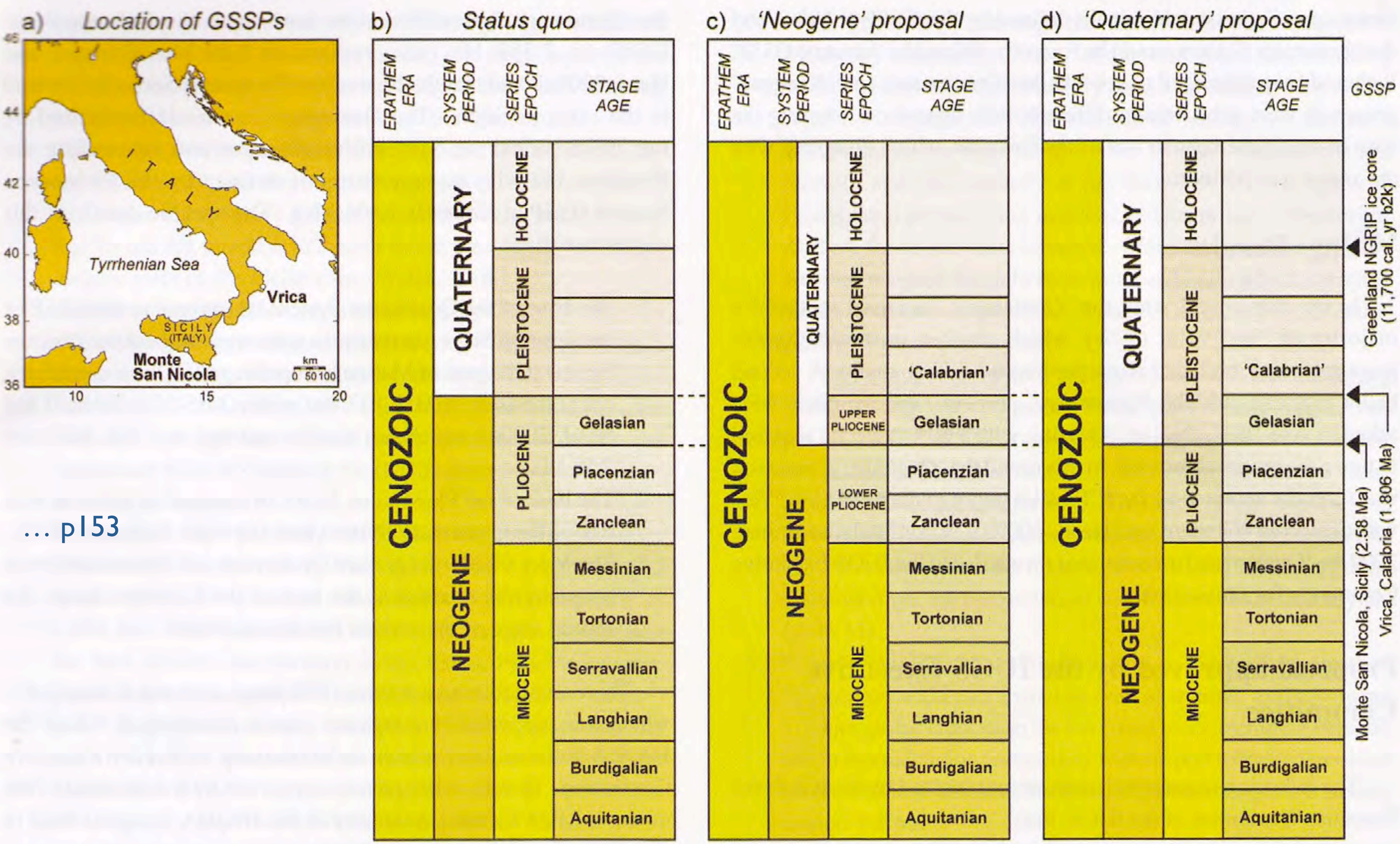

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Figure 1. (a) Location of the two Global Stratotype Sections and Points (GSSPs) discussed in the text: the Monte San Nicola GSSP now defining the base of the Gelasian Stage, Pleistocene Series and Quaternary System, and the Vrica GSSP having previously defined the base of the Pleistocene Series and still available to define the base of the 'Calabrian' Stage. (b) The status quo scheme represents the most recent previous IUGS-sanctioned time scale (Remane, 2000) as a fall-back position had neither the 'Quaternary' nor 'Neogene' proposal been successful. (c) The defeated 'Neogene' proposal has the Quaternary depicted as a subsystem, and the Pliocene Series is split into two separate series, a Lower Pliocene and an Upper Pliocene. (d) The 'Quaternary' proposal represents the now official scheme in the IUGS-sanctioned geological time scale. Although no stratigraphic units below the Quaternary were mentioned in this proposal, they are included here to illustrate the current IUGS-sanctioned time scale for the Cenozoic. The position of the GSSP defining the base of the Holocene Series (Walker et al., 2009), dated at 11,700 calendar years before AD 2000, is also shown.

ESTIMATES OF THE DURATION OF THE DEVONIAN AND THE GIVETIAN BY THE **BEST** SPECIALISTS (in HOUSE, 1985)

Author	Devonian duration (Ma)	Givetian duration (Ma)	Givetian as a percentage of Devonian duration
Harland *et al.* 1982	40	6	12.5
Palmer 1983	48	6	12.5
Odin 1985	40	5	12.5
McKerrow *et al.* 1985	58	11	18.96
Snelling 1985	50	(10)	(20)
Harland *et al.* 1989	46	3.4	7.39
Cowie & Bassett 1989	55	–	–
Menning 1989	46	–	–
Odin & Odin 1990	50	5	10.0
Fordham 1992	44	*c.* 8.7	19.8

GREAT CONSEQUENCES….

RELATIVE

1975	M.R.H. Gon.	G.K. Conod.	J.T.D. Brach.	W.A. O. Corals	A.R.O. Trilobites	1982 Absol.	1989 Absolute
Famennian	23.0%	22.9%	20.4%	15.0%	14.6%	14.6%	9.8%
Frasnian	15.3	18.7	14.2	13.3	16.6	14.6	22.6
Givetian	15.3	12.5	14.2	16.6	18.7	12.5	7.4
Eifelian	15.3	12.5	10.2	16.6	12.5	14.6	11.3
Emsian	7.7	12.5	20.4	8.3	20.8	14.6	9.5
Praguian	15.3	8.3	10.2	16.6	4.2	14.6	12.8
Lochkovian	7.7	12.5	10.2	13.3	12.5	14.6	26.5

ABSOLUTE

ABSOLUTE

	1986	1990	1982	1989	2008
Famennian	13 Ma	10	7	13	15.3±2.5
Frasnian	9	5	7	9	10.8±2.6
Givetian	12		6	12	6.5±2.7
Eifelian	7		7	7	5.7±2.7
Emsian	6		7	6	9.5±2.7
Praguian	4		7	4	4.2±2.8
Lochkovian	9		7	9	4.8 ±2.8

359.2

416.0

GTS

359.2 Ma | 360.7 Ma

	1986	1990	1982	1989	2008	2006
Famennian	13 Ma	10	7	13	15.3±2.5	15.4±2.7
Frasnian	9	5	7	9	10.8±2.6	7.6±3.6
Givetian	12		6	12	6.5±2.7	4.4±3.1
Eifelian	7		7	7	5.7±2.7	3.8±2.6
Emsian	6		7	6	9.5±2.7	17.2±3.4
Praguian	4		7	4	4.2±2.8	3.2±3.8
Lochkovian	9		7	9	4.8 ±2.8	5.8±3.0

416.0 Ma | 418.1.0 Ma

Kaufmann 2006

U-Pb method on zircon and monazite (volcanic ashes = bentonites-K)

57.4±5.4 for 57 conodont biozones
=> 1 bioZ = ± myr (0.6-5.5)

The geological series is therefore **FULL** of temporal gaps (like Swiss cheese!)

MANY CONSEQUENCES

- ‘Massive’ Extinctions
- Speciation
- Meteoritic impact
- Volcanic eruption
- Clathrates degassing
- Correlations
- .... metallogeny, hydrology etc ...

PRELIMINARY CONCLUSION

STAGE → CHRONOZONES

VARIES FROM A FEW m (also= 0 m! i.e. non existing) UP TO A FEW km
SCALE TIME AMPLITUDE : 10^{17} (10^{9} to 10^{-7} i.e. 3 sec)

=> stacking pattern with 5 orders… cf. phenomena or processes

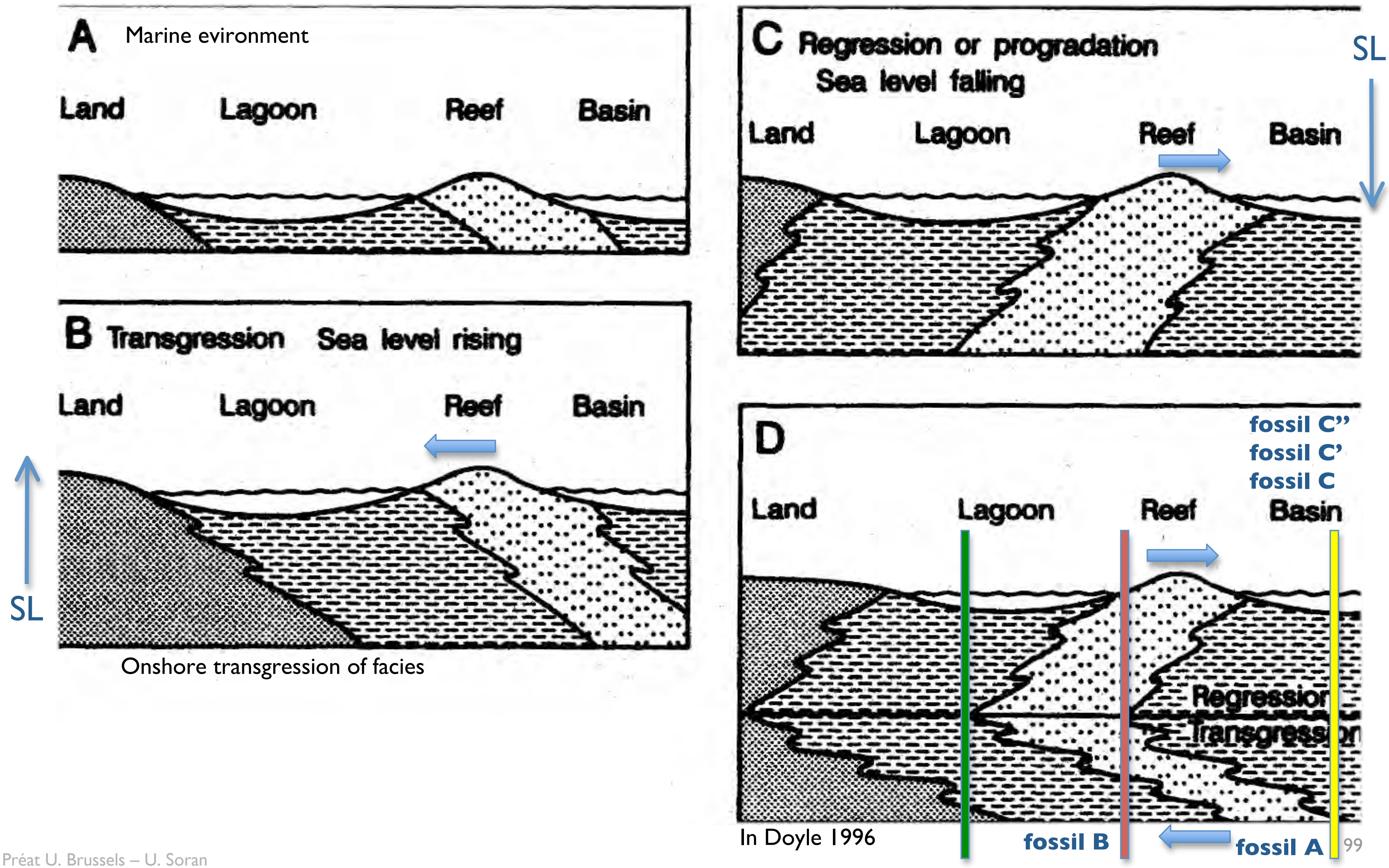
STAGE → BIOZONES

The basic unit in biostratigraphy
BIOZONE

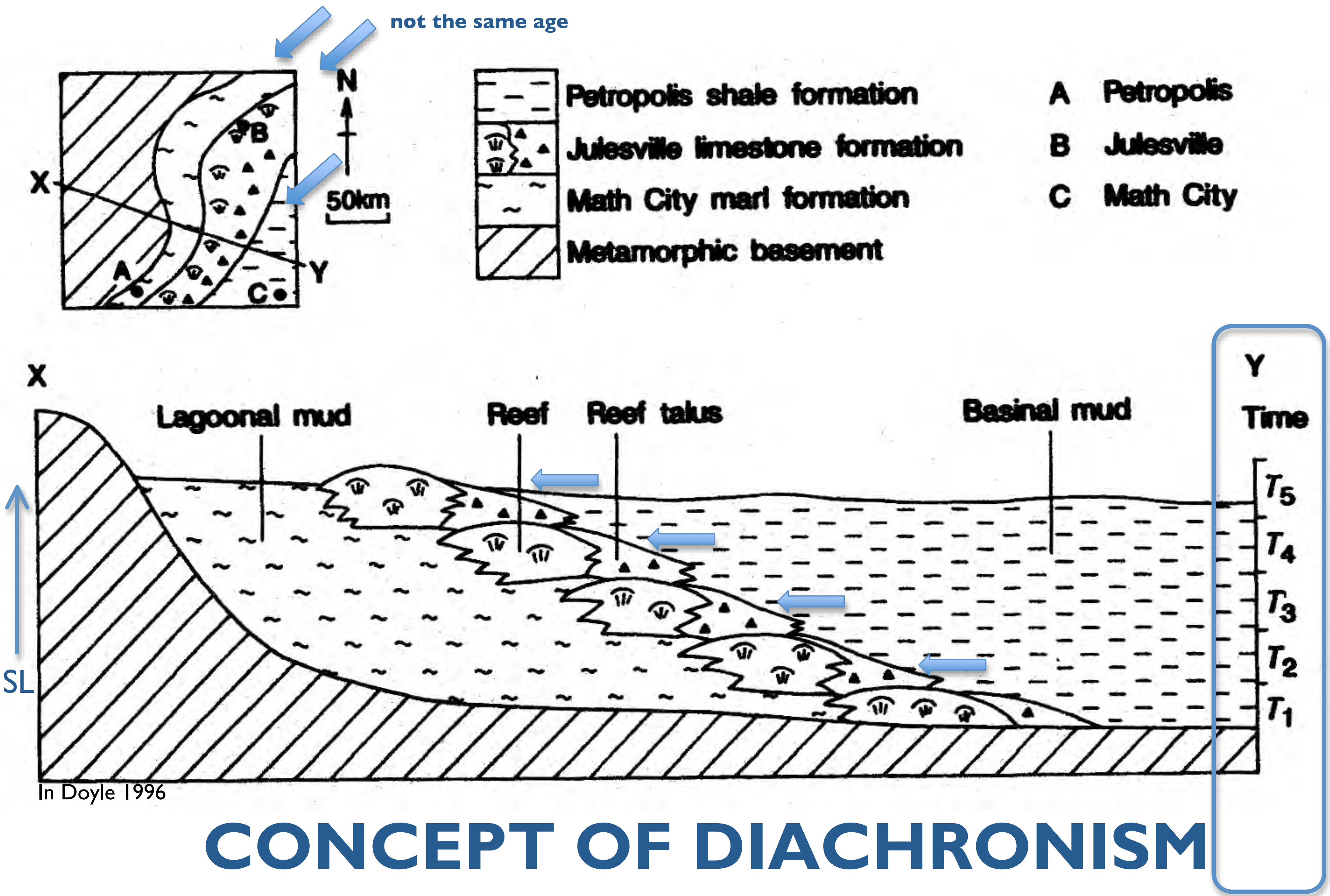
• BIOZONES are strata organised into stratigraphical units on the base of their content of **guide** (micro)fossils => may be recognized on LOCAL or REGIONAL scales

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

A set of evolving environments



In Doyle 1996



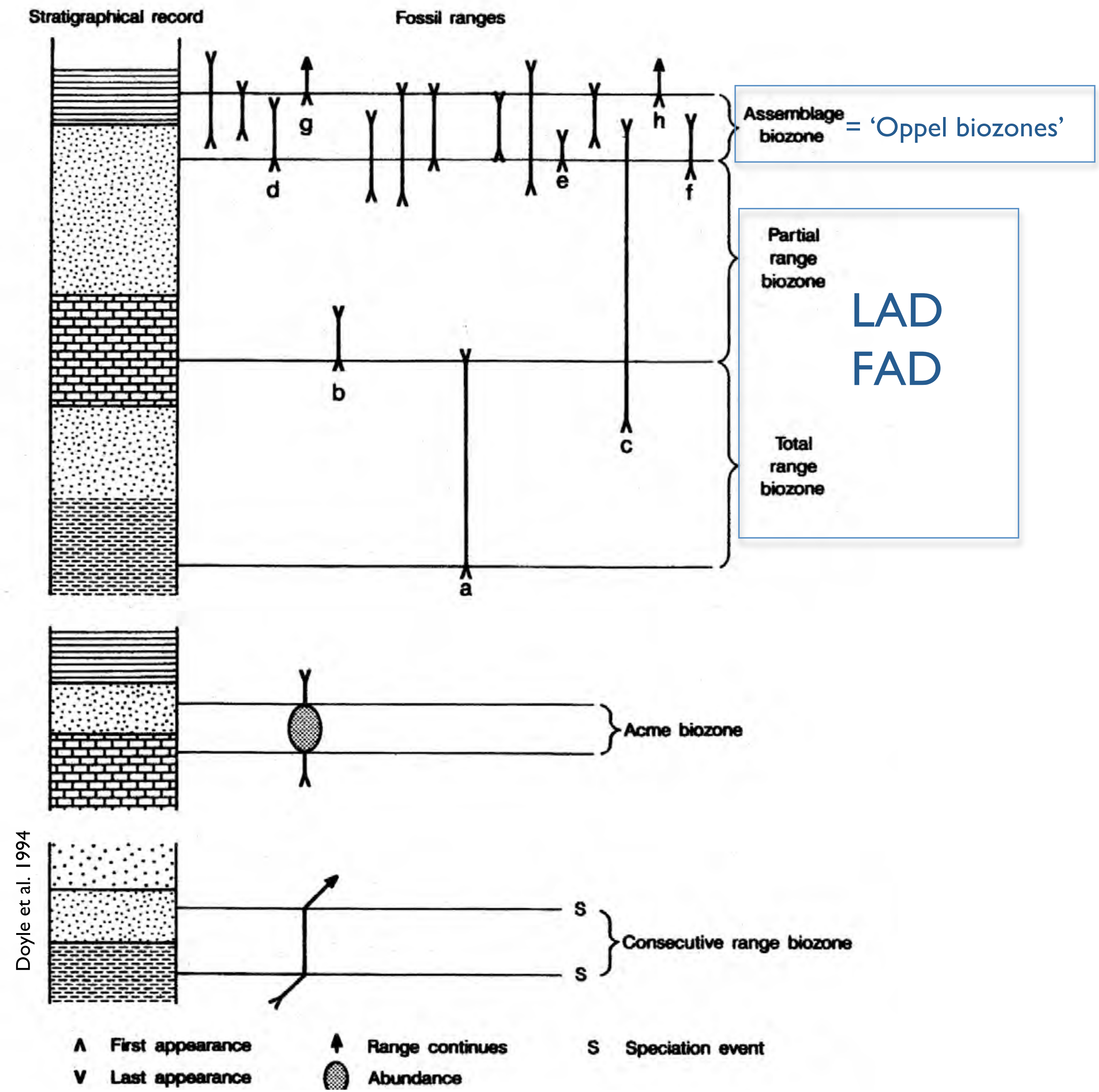
In Doyle 1996

CONCEPT OF DIACHRONISM

BIOZONES

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!

- **ASSEMBLAGE** biozone : vertical range<u>s</u> of a number of (micro)fossils utilized where there are few good **guide** fossils available, as is often the rule where most of the fossils have a benthonic (bottom-dwelling) rather than planktonic (free-floating) or nektonic (free-swimming) mode of life
- **RANGE** biozone (PARTIAL or TOTAL) : total (or partial) range of a single 'guide' (micro)fossil => FAD and LAD
- **ACME** biozone : based on an abundance of a fossil group
- **CONSECUTIVE** (RANGE) biozone : evolutionary lineage or line when the relpacement of species is directly related to the evolution…
- **INTERVAL** biozone : does not contain fossils => between the other biozones


Stratigraphical record
Fossil ranges
g
h
d
e
f
b
c
a
Assemblage biozone
= 'Oppel biozones'
Partial range biozone
LAD
FAD
Total range biozone
Acme biozone
S
S
Consecutive range biozone
Doyle et al. 1994
First appearance
Last appearance
Range continues
Abundance
S Speciation event

The basic idea of any biozonation scheme is that biological changes recorded in the scheme should be synchronous across the world…

- An ASSEMBLAGE biozone is often limited in use because it relies on the recognition of a number of fossils
- PARTIAL RANGE biozones utilise part of the total vertical range of a fossil, particularly of organisms which were relatively slow to evolve
- ACME biozones are more difficult to recognize in practice because of the overall imperfection of the fossil record
- CONSECUTIVE RANGE biozones need detailed stratigrapical study and are hard to prove (cf. also 'migration of species') => for specialists

MANY CONSEQUENCES

Example of representation of diagrams

(including the 'rock-time' vocabulary)

LITHOSTRATIGRAPHY

SERIES	FORMATION	
Upper Cretaceous	*Obscura* Shale	400 m
	Perfecta Sandstone	150 m
	disconformity	
Upper Jurassic	*Horrorosa* Formation	350 m

CHRONOSTRATIGRAPHY

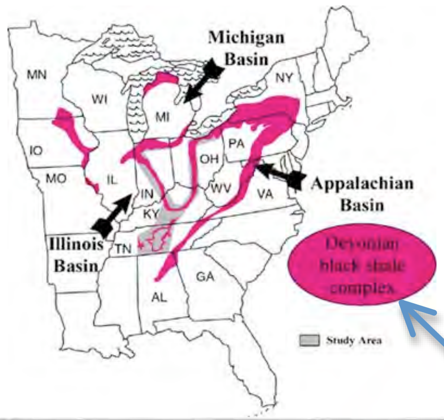
	EPOCH	FORMATION
_70Ma _100Ma	Late Cretaceous 30 myr	*Obscura* Shale *Perfecta* Sdst
	Early Cretaceous	HIATUS
_140Ma _180Ma	Late Jurassic	*Horrorosa* Fm

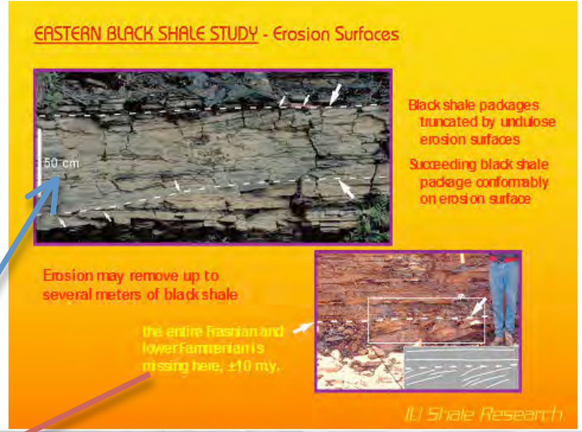
observed

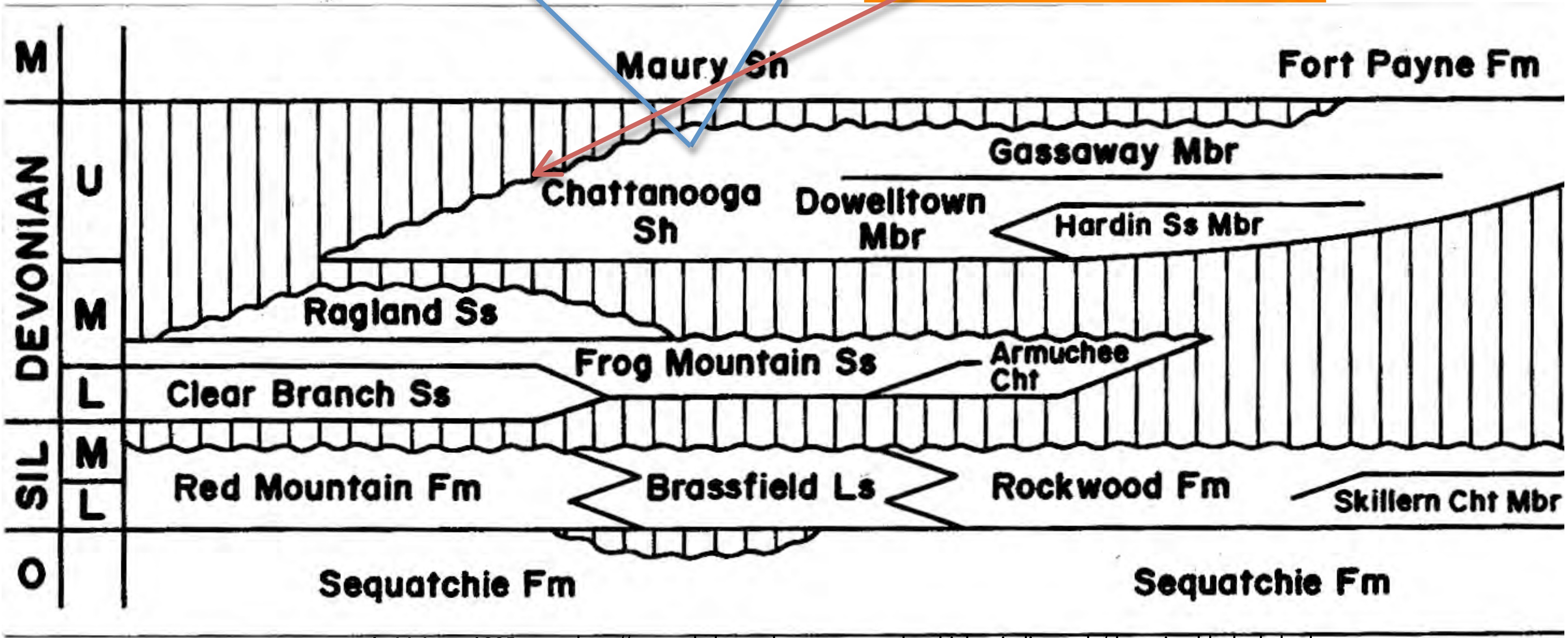
not observed

deduced

CORRELATION CHART WITH **APPROXIMATE** TEMPORAL RELATIONS AMONG THE FORMAL ROCK UNITS OF DIFFERENT REGIONS





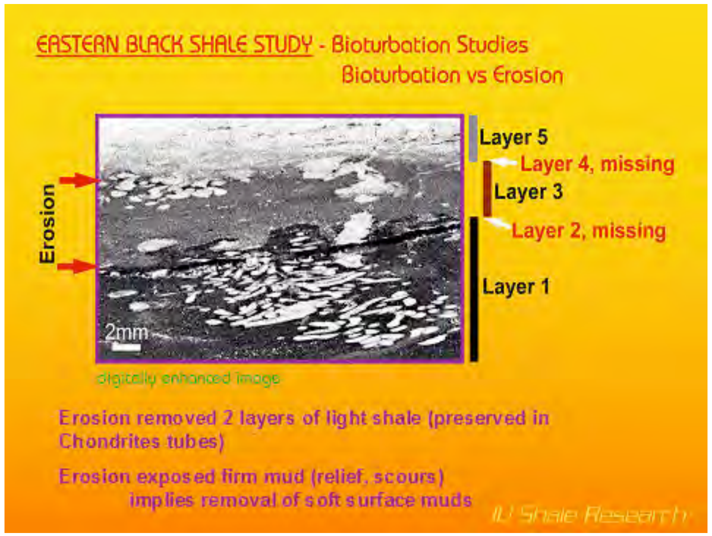


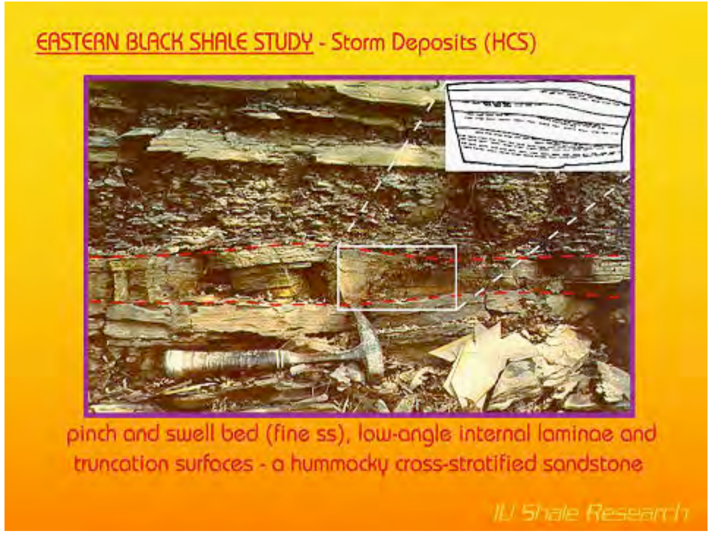
In McLane 1995 http://www.shale-mudstone-research-schieber.indiana.edu/devonian-black-shales.htm

Large scale erosion surfaces, traceable over large distances, partition the Devonian black shale succession into successively deposited packages. These erosion surfaces reflect intermittent sea level drops followed by transgression and renewed black shale deposition. They are the basis for a coherent sequence stratigraphic framework for all of these shales.

Erosion can be documented (and is common) at any scale, from sub-mm scours, over removal of cm-scale shale beds (see picture), local truncations at the dm-scale, to deep m-scale erosion that is traceable for 100's of kilometers.

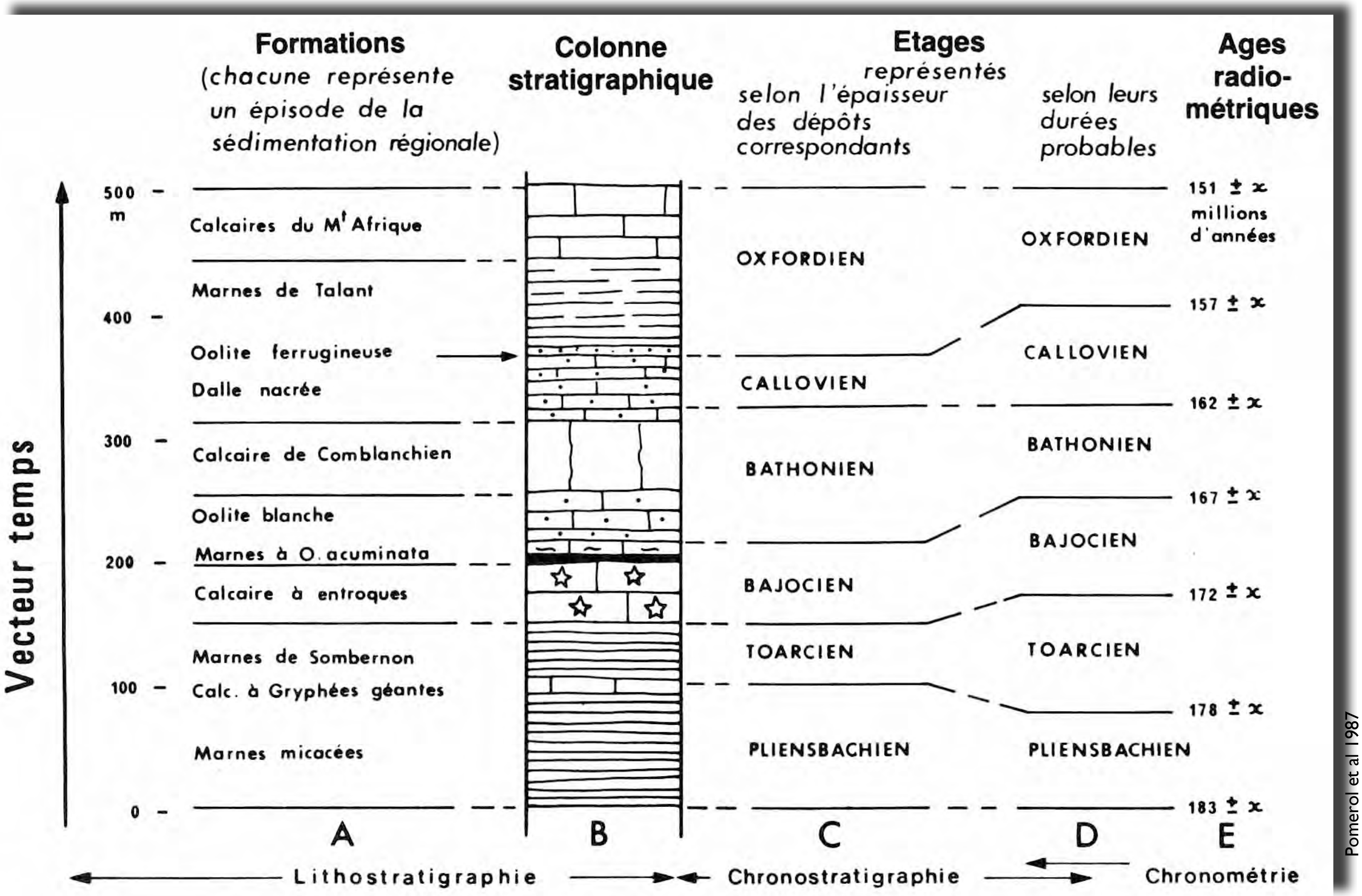
http://www.shale-mudstone-research-schieber.indiana.edu/devonian-black-shales.htm





TO CONCLUDE…tentatively…

Observed	'Not observed'



Pomerol et al 1987

Upper Jurassic (Malm) GEOMETRY => 3D?

SEQUENCE STRATIGRAPHY from SEISMIC STRATIGRAPHY

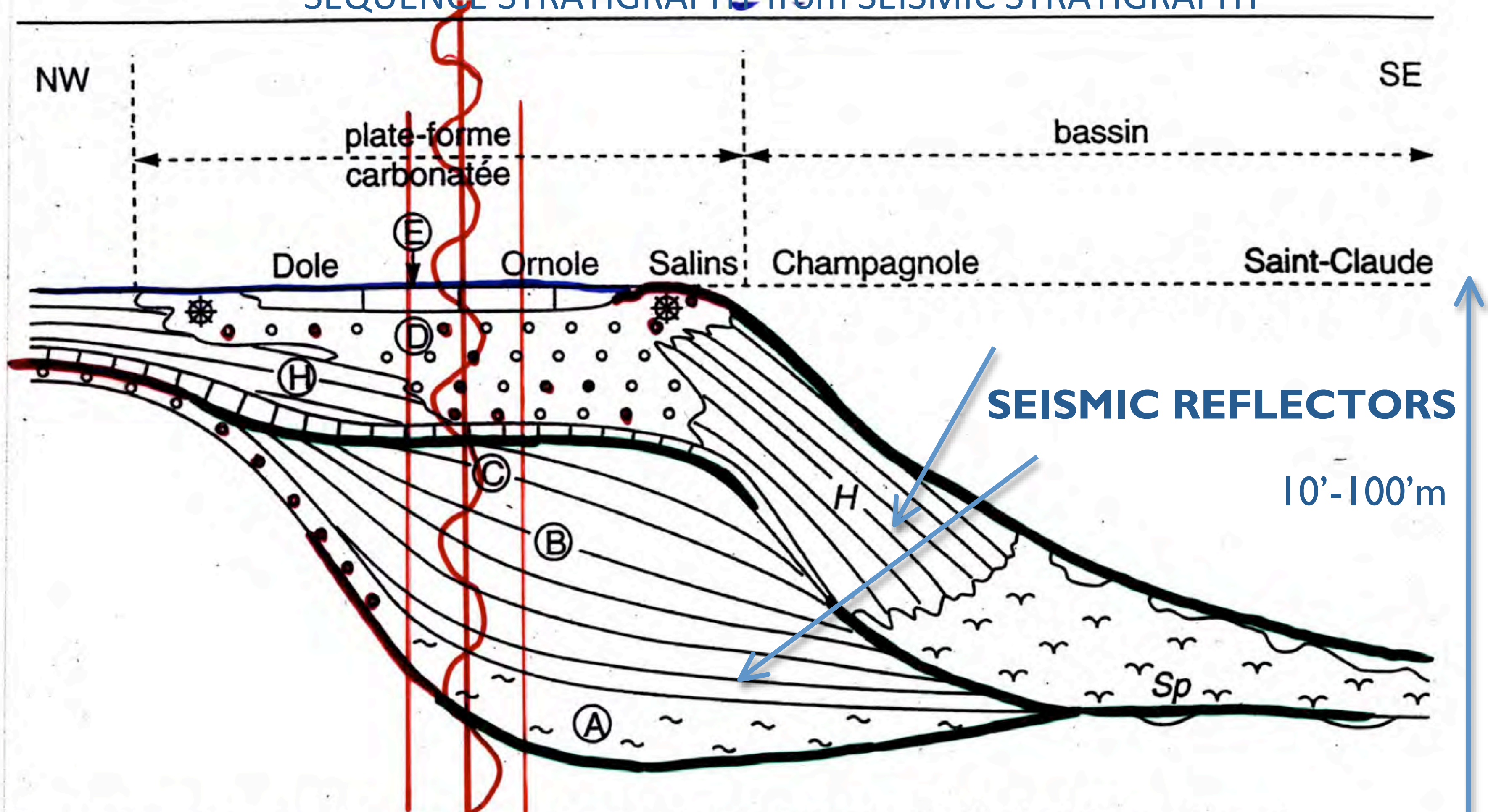


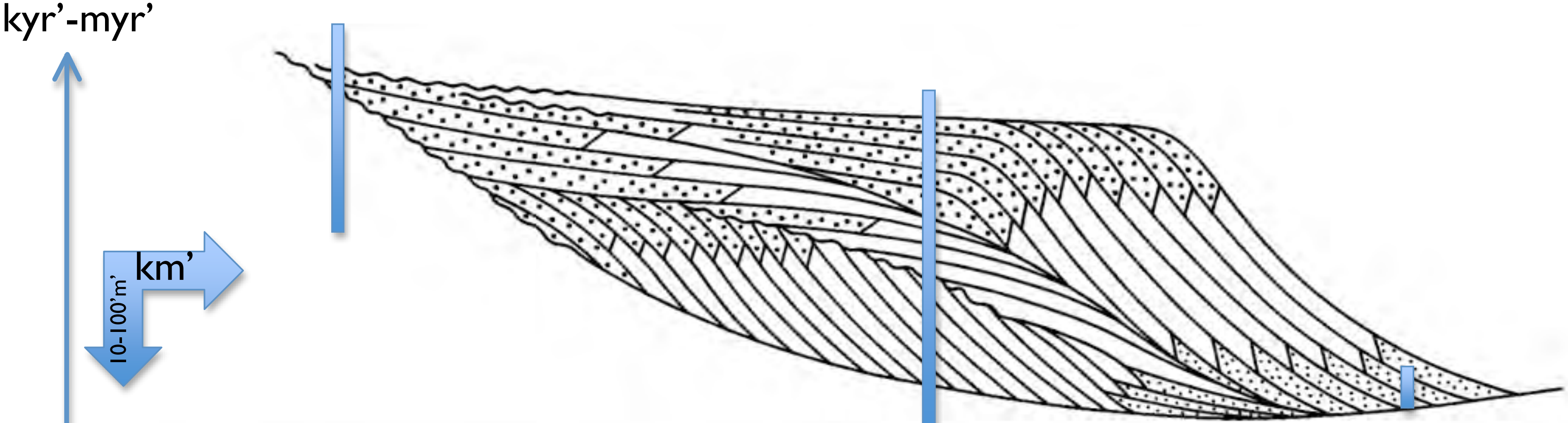
Fig. 3 – Disposition géométrique et bathymétrique relative des faciès dans l'Oxfordien inférieur et moyen.

Ⓐ : Marnes d'Arc-sous-Montenot ;
Ⓑ : Calcaires marneux de Bonnevaux ;
Ⓒ : Calcaires de Dole ;
Ⓓ : Oolithe corallienne de Pagnoz ;
Ⓔ : Calcaire de Clerval ;
Ⓗ : Calcaires de Champagnole.
Sp : couches à spongiaires.

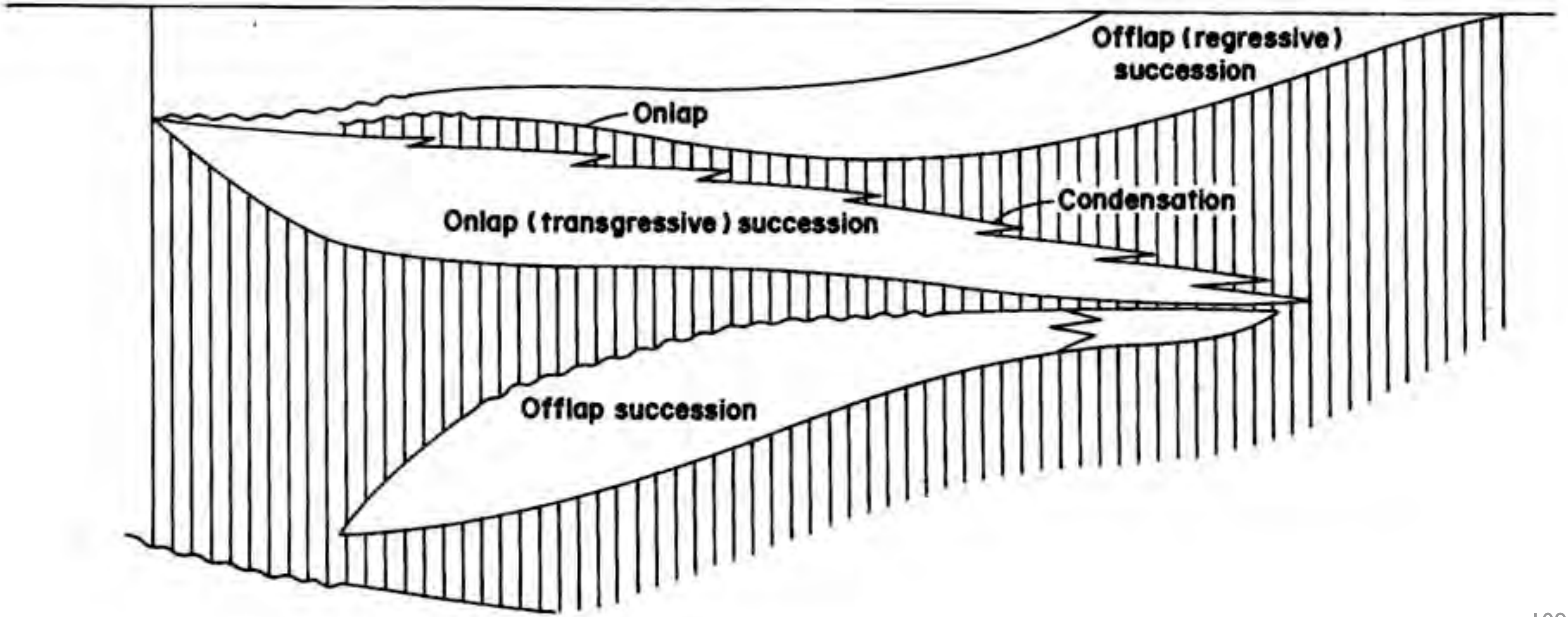
10'-100'km

A **stack** of 'depositional sequences ' and its Wheeler's diagram

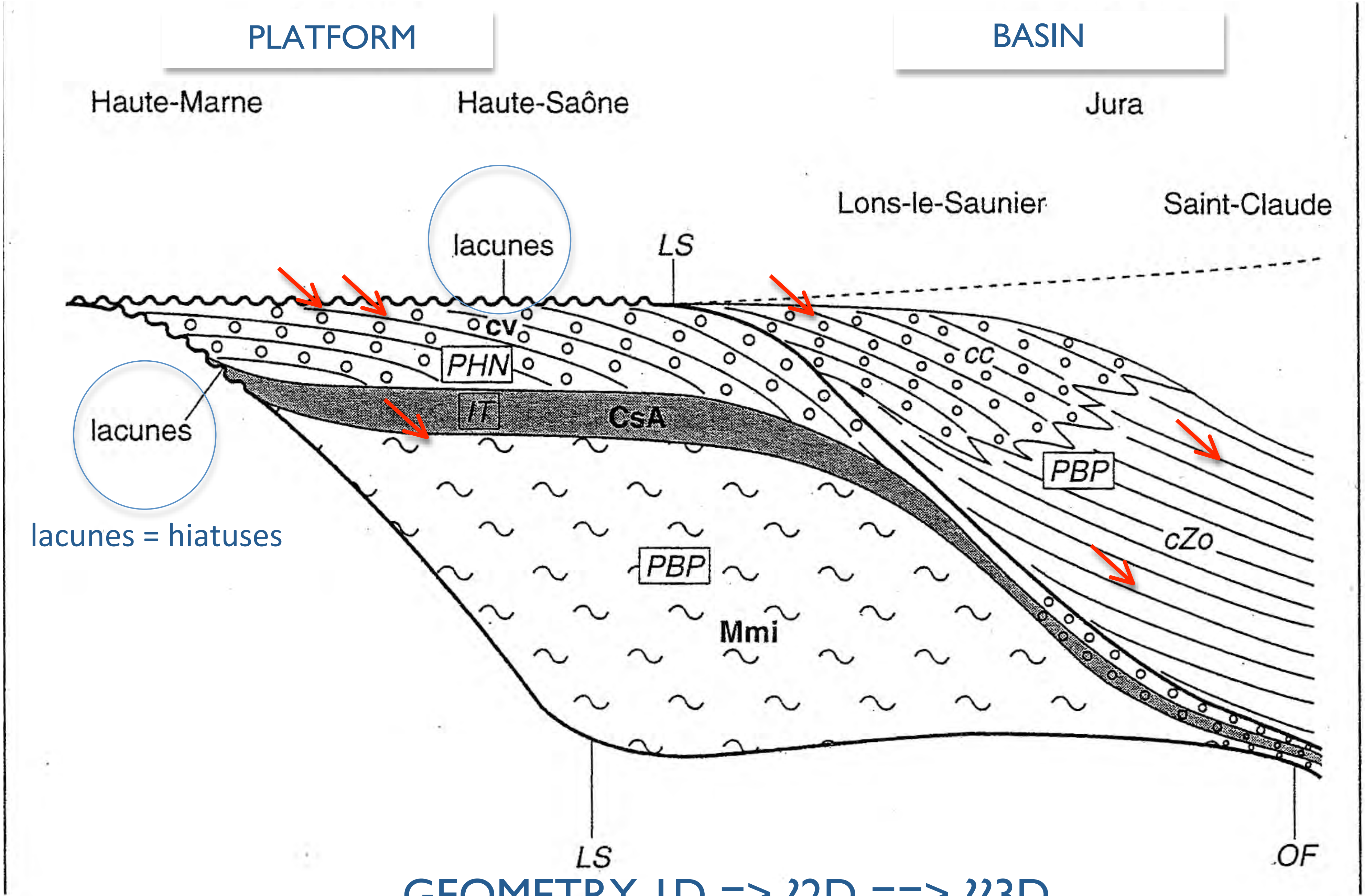
(in McLane 1995, modified)



THE 'LAYER-CAKE' MODEL IS WRONG…



AALENIAN-TOARCIAN SEQUENCE : FRANCHE-COMTE (FRANCE)



GEOMETRY 1D => ??2D ==> ??3D