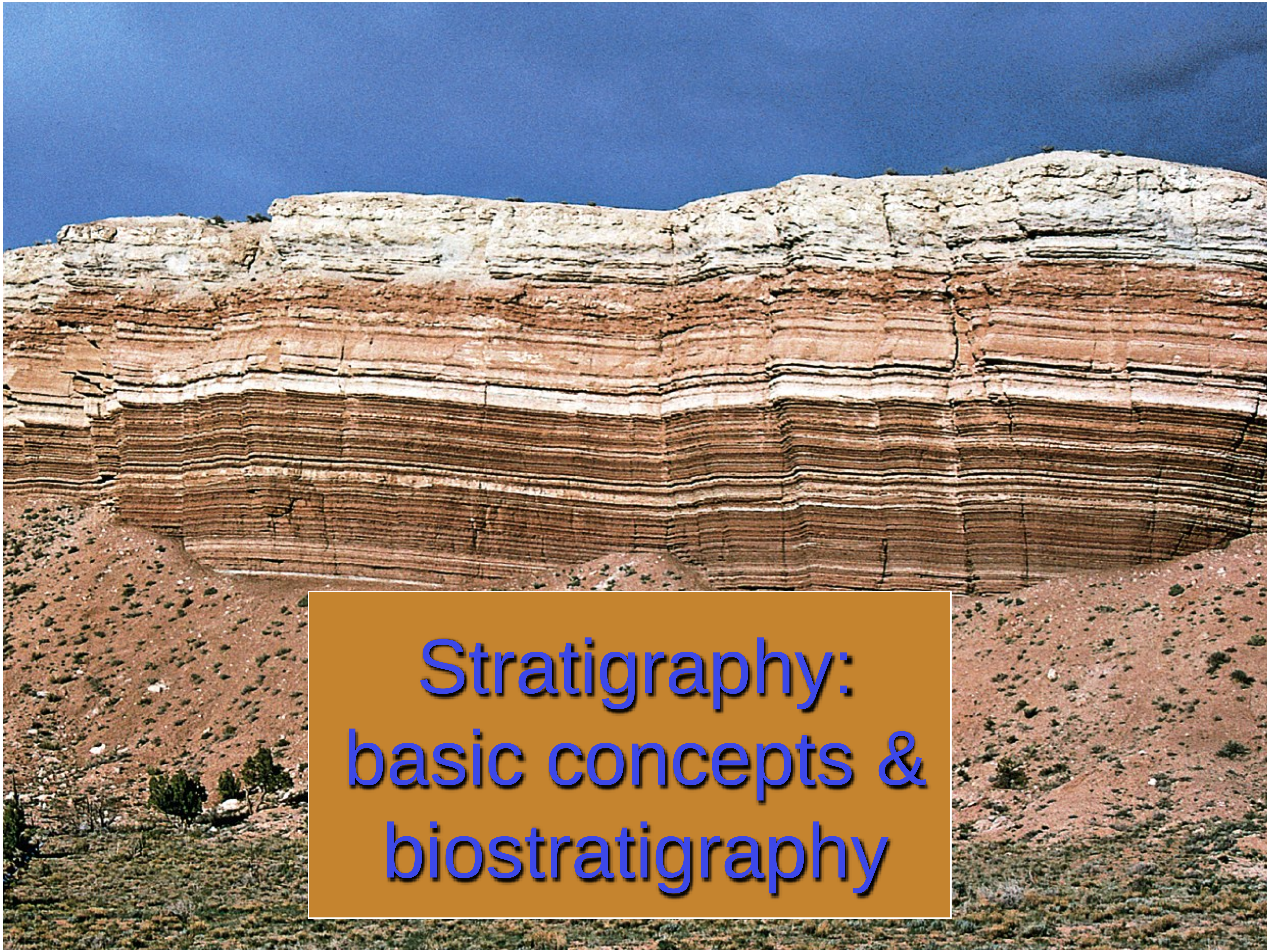


Stratigraphy: basic concepts & biostratigraphy

Sedimentary rocks and Stratigraphy

Sedimentary rock is a type of rock that is formed by **sedimentation** of material at the Earth's surface and within bodies of water. Sedimentation is the collective name for processes that cause mineral and/or organic particles (detritus) to settle and accumulate or minerals to precipitate from a solution. Particles that form a sedimentary rock by accumulating are called **sediment**. Before being deposited, sediment was formed by weathering and erosion in a source area, and then transported to the place of deposition by water, wind, mass movement or glaciers which are called agents of denudation.The study of the sequence of sedimentary rock strata is the main source for scientific knowledge about the Earth's history, including palaeogeography, paleoclimatology and the **history of life**.

Stratigraphy is a branch of geology that studies rock layers and layering (stratification). It is primarily used in the study of sedimentary rocks.

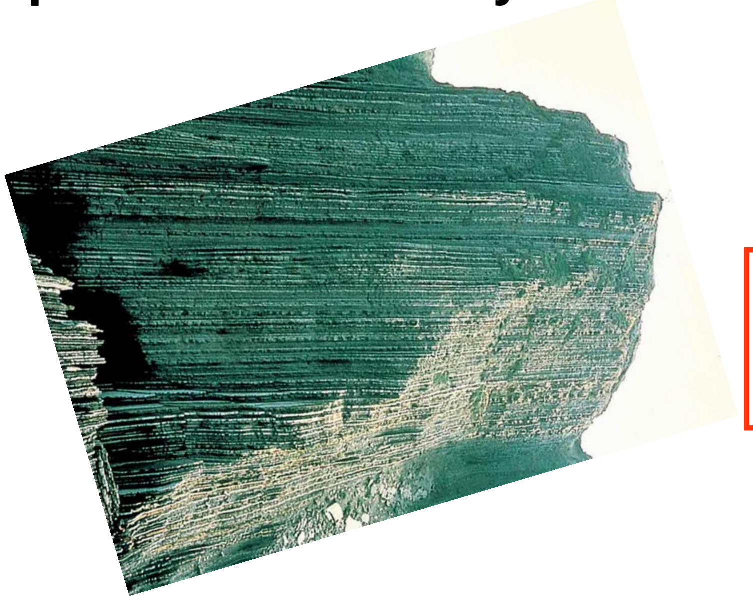
Our observations about rocks need to be set in the context of a time framework if we are to use them to understand Earth processes and history. That framework is provided by stratigraphy, and it is one of the oldest disciplines of the geological sciences. Stratigraphy is primarily concerned with the following issues: the recognition of distinct bodies of rock and their spatial relationships with each other; the definition of lithostratigraphic units and the correlation of lithostratigraphic units with each other; the correlation of rock units with a chronostratigraphic standard, which is a formal time-framework to which all of Earth geology can be related. Lithostratigraphy forms the basis for making geological maps and by correlating lithostratigraphic units it is possible to reconstruct the changing palaeogeography of an area through time.

Lithostratigraphy deals with the physical lithologic change both vertically in layering of varying rock type and laterally reflecting changing environments of deposition, known as facies change. Key elements of stratigraphy involve understanding how certain geometric relationships between rock layers arise and what these geometries mean in terms of depositional environment.

A body of rock can be distinguished and defined by its characteristics and its stratigraphic position relative to other bodies of rock: these are lithostratigraphic units. Lithostratigraphic units are the starting point of any stratigraphic study.

A lithostratigraphic unit conforms to the **principle of original horizontality**, the **law of superposition**, and the **principle of lateral continuity** introduced by **Nicolas Steno** (Danish: Niels Stensen; Latinized to Nicolaus Stenonis, Italian Niccolo' Stenone) (11 January 1638 – 25 November 1686), a Danish pioneer in both anatomy and geology.

The **principle of original horizontality** states that layers of sediment are originally deposited **horizontally** under the action of gravity. **The principle is important to the analysis of folded and tilted strata.**



Original horizontal layering

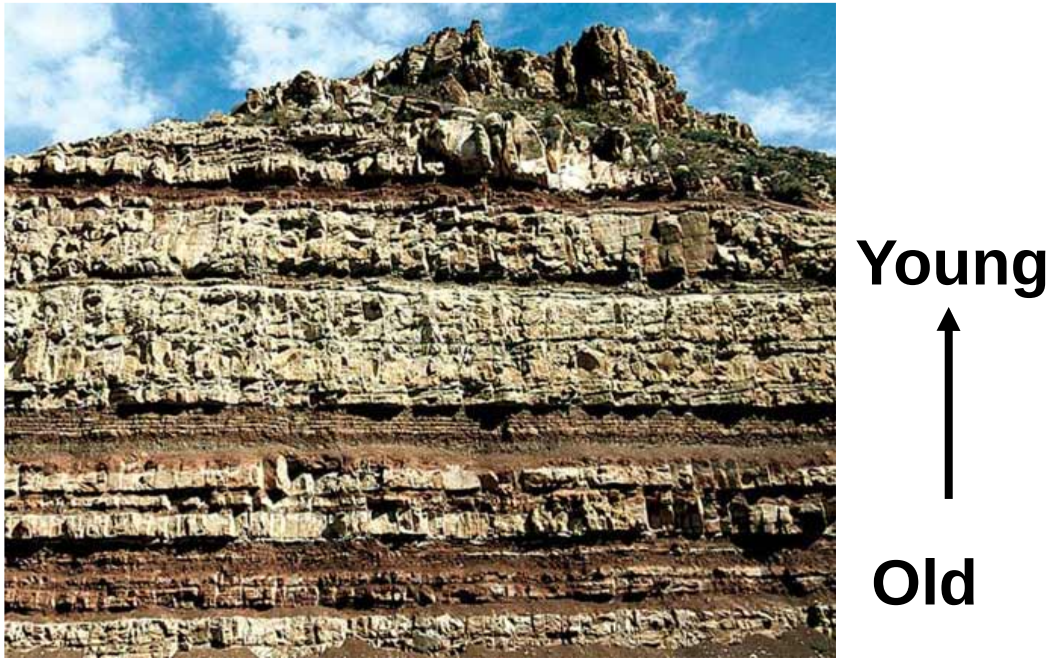
Tectonic event

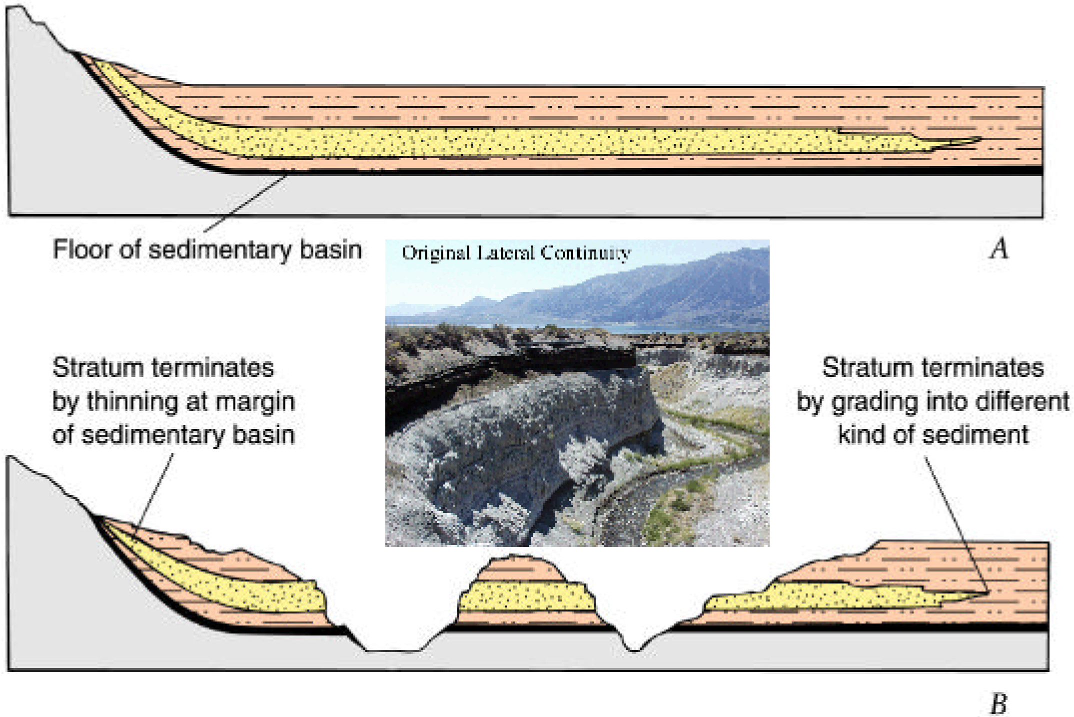
Strata tilted by tectonics

The **law of superposition** states that in any succession of strata, not disturbed or overturned since deposition, **younger rocks lies above older rocks**.

The **principle of lateral continuity** states that layers of sediment initially extend laterally in all directions - they are laterally continuous. Rocks that are similar, but are now separated by a valley or other erosional feature, can be assumed to be **originally continuous**.

Layers of sediment do not extend **indefinitely**. They thin out against the margins of the **sedimentary basin**.

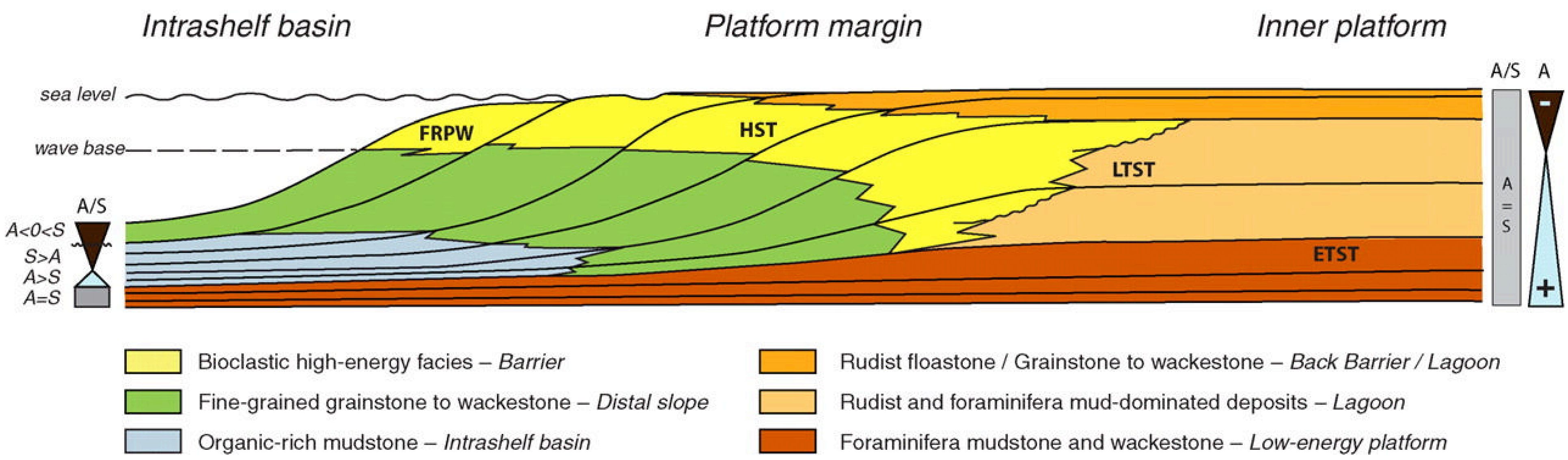




Steno's Principle of Original Horizontality served well in the nascent days of geological science. However, it is now known that not all sedimentary layers are deposited purely horizontally.

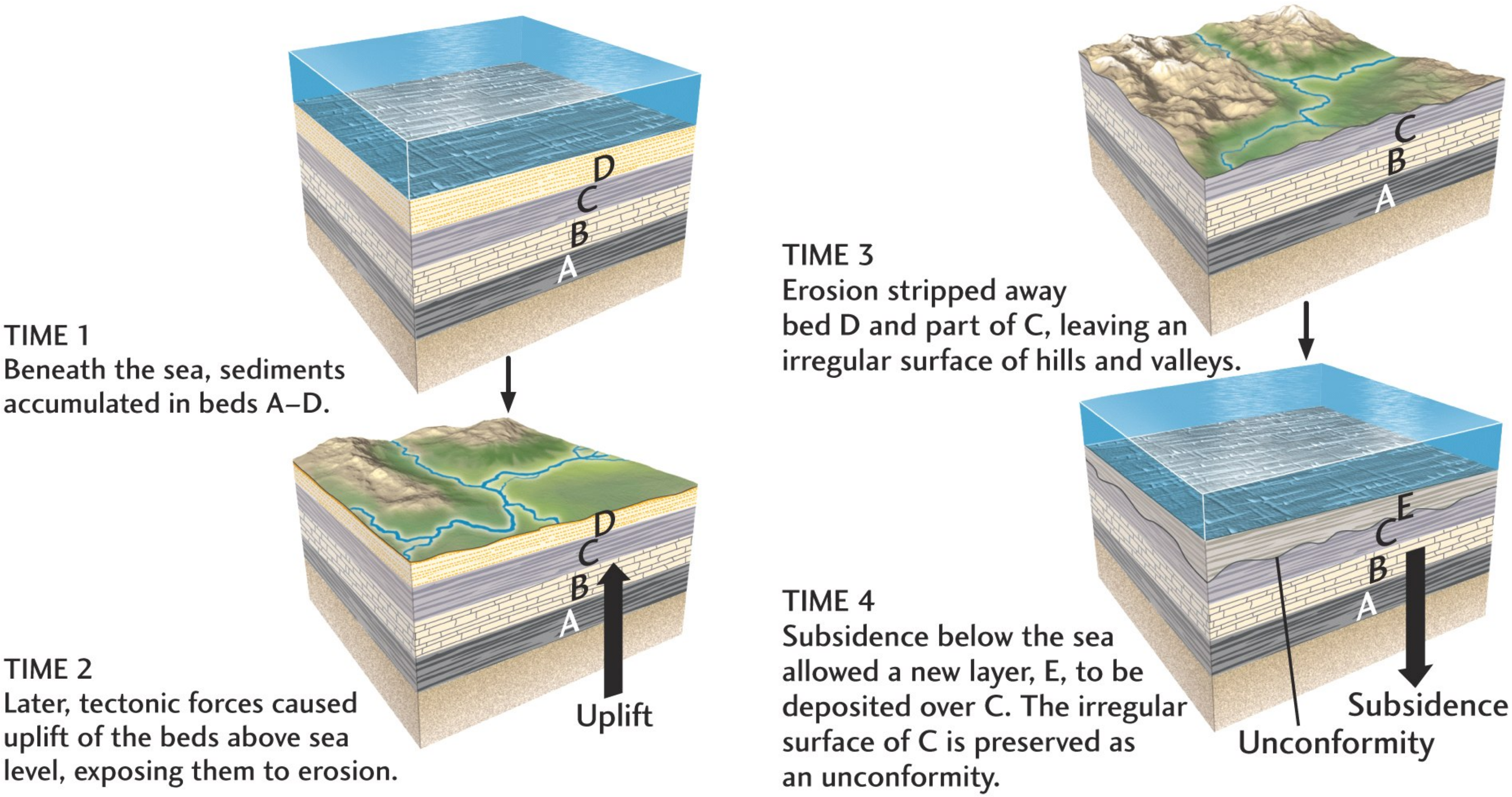
For instance, coarser grained sediments such as sand may be deposited at angles of up to 15 degrees, held up by the internal friction between grains which prevents them slumping to a lower angle. This is known as the **angle of repose**, and a prime example is the surface of sand dunes.

Another example is provided by carbonate platforms, where the inner platform is connected to the adjacent basin by **clinoforms**.

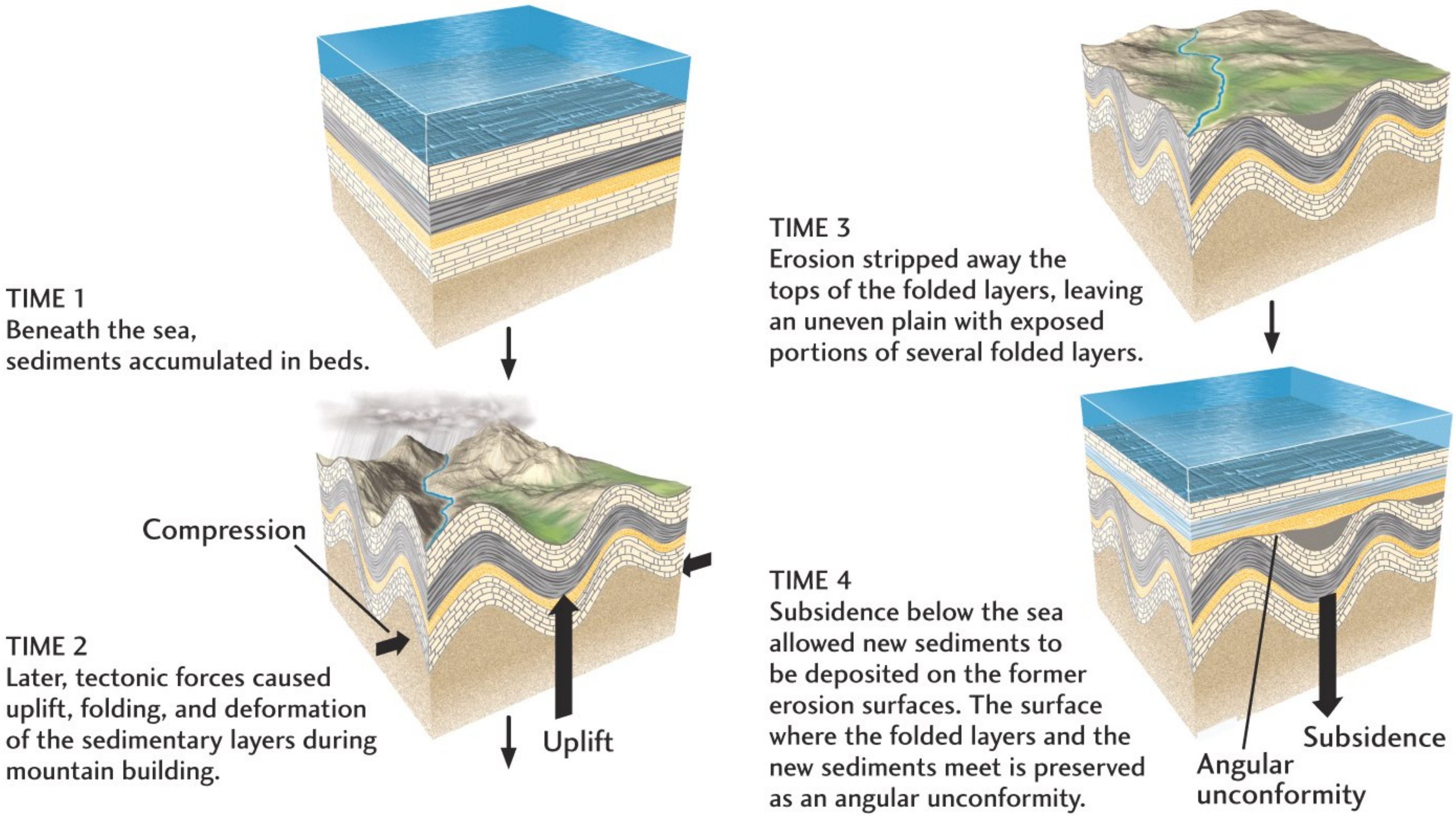


A sequence of lithostratigrapic units can contain **unconformities** (*discordanze*) which are **breaks in sedimentation** due to **erosion**. All rocks which lie above the unconformity must be younger than those below.

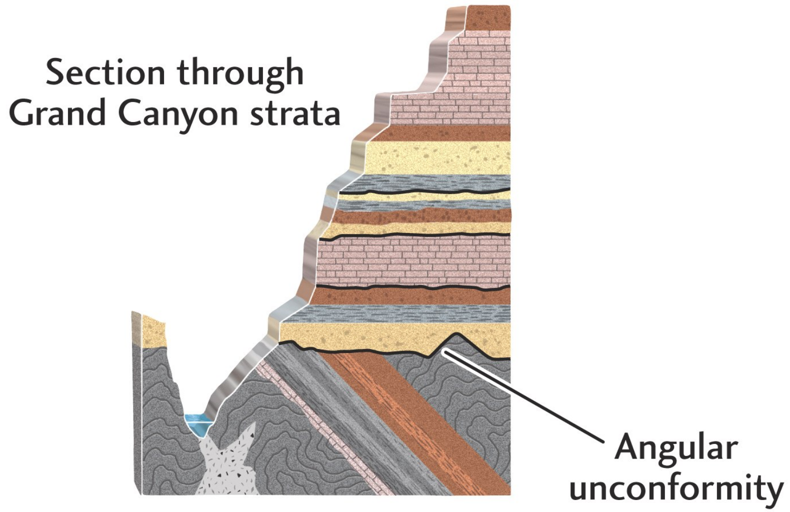
A **disconformity** (*paraconcordanza*) marks a break in sedimentation and some erosion, but without any deformation of the underlying strata.



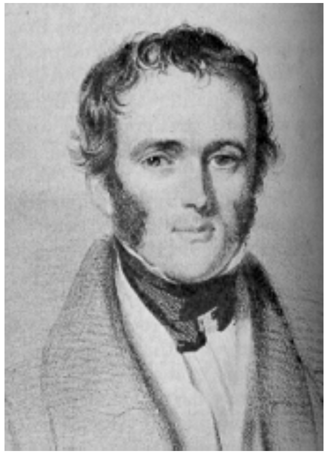
In cases where strata have been deformed and partly eroded prior to deposition of the younger beds, an **angular unconformity** (*discordanza angolare*) is formed.



Angular unconformity

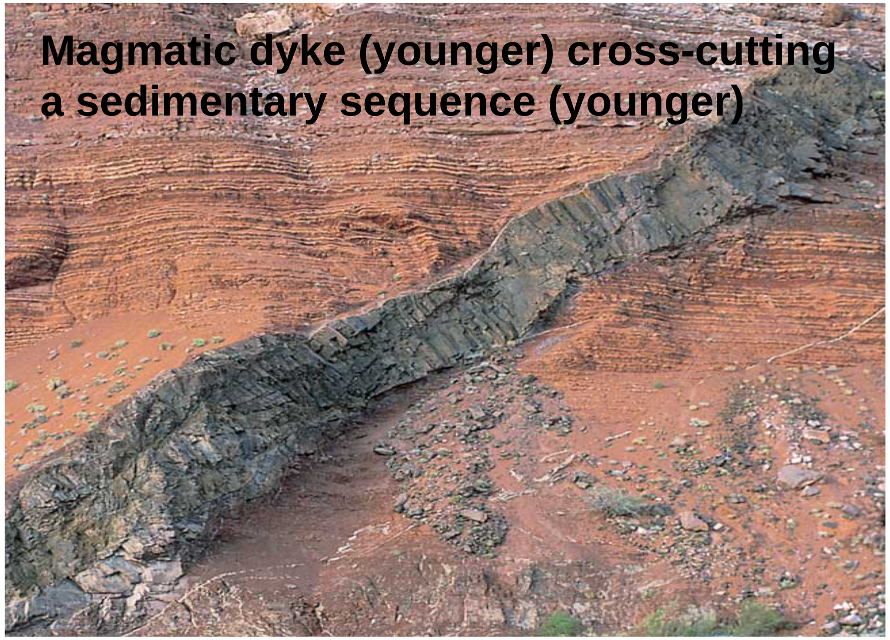


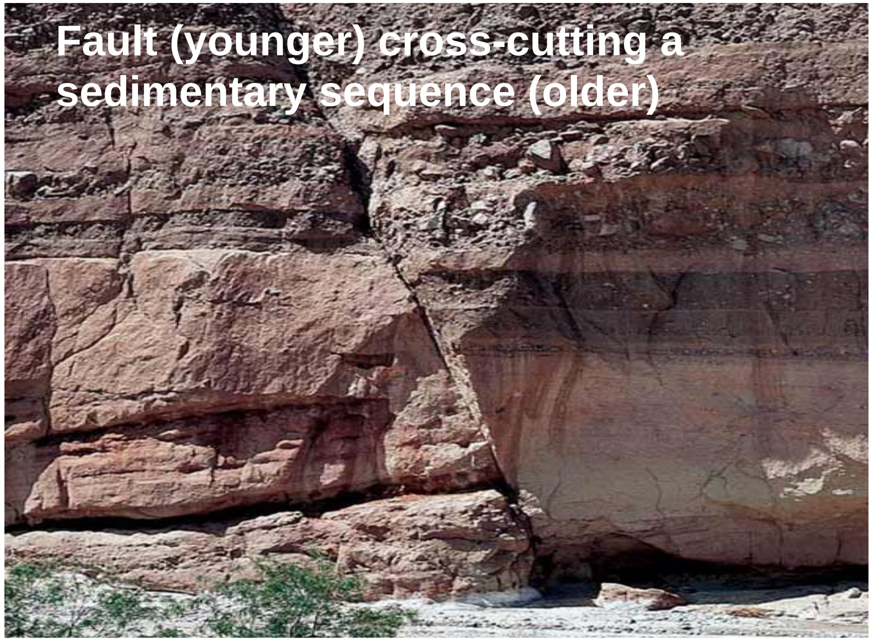
The relationships of lithostratigraphic units with other geologic features are described by the **Cross-cutting principle** and the **Inclusion principle** introduced by Charles Lyell in *Principles of Geology* (1830) and based on James Hutton *Theory of the Earth* (1795).



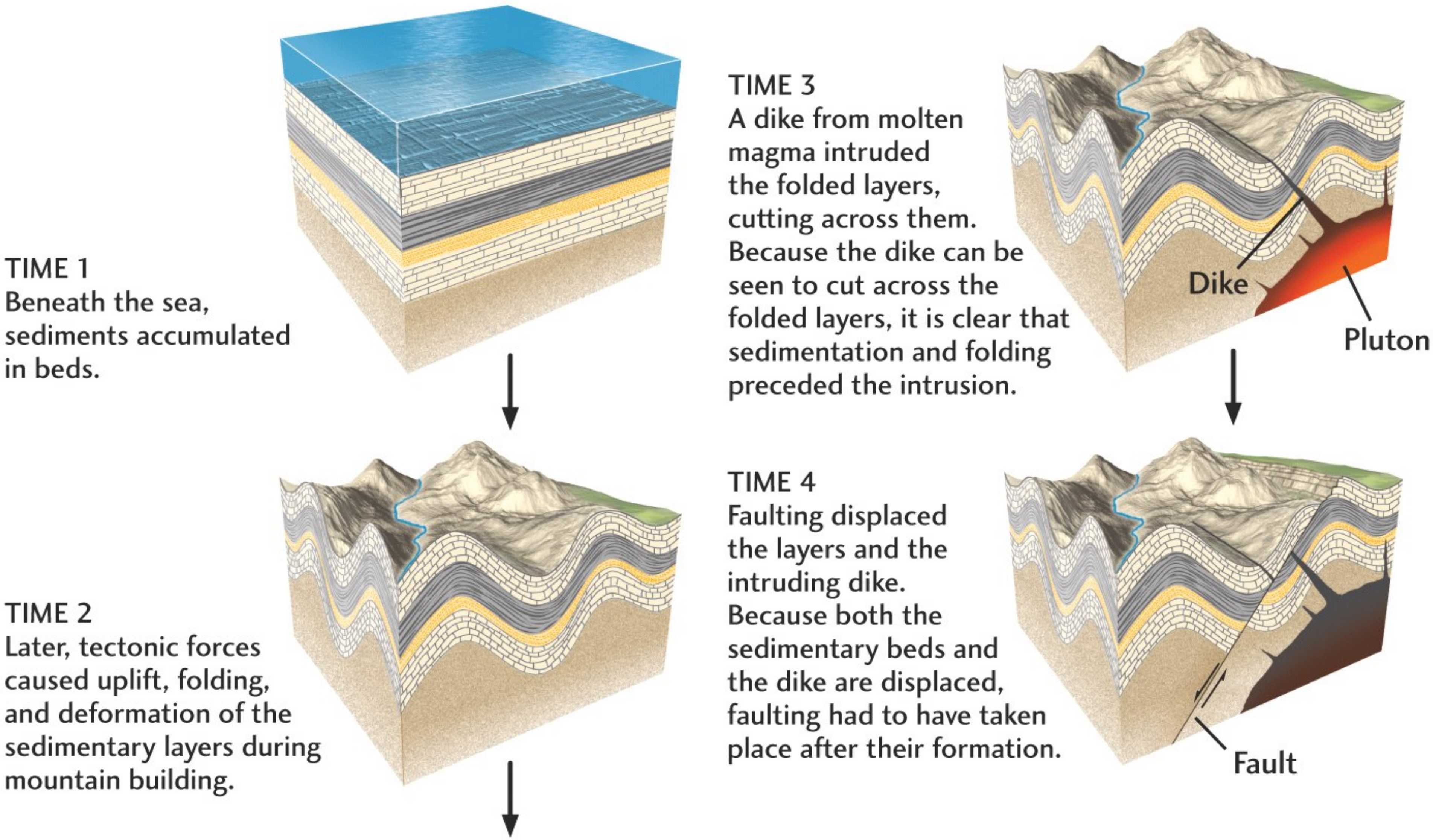
Charles Lyell
1797-1875

Cross-cutting principle: Any unit that has boundaries that cut across other strata must be younger than the rocks it cuts. This is most commonly seen with **intrusive bodies** such as batholiths on a larger scale and **magmatic dykes** on a smaller scale. This relationship is also seen in **sedimentary dykes** that form by younger sediments filling a crack in older rocks. This relationship is also seen in **faults**.

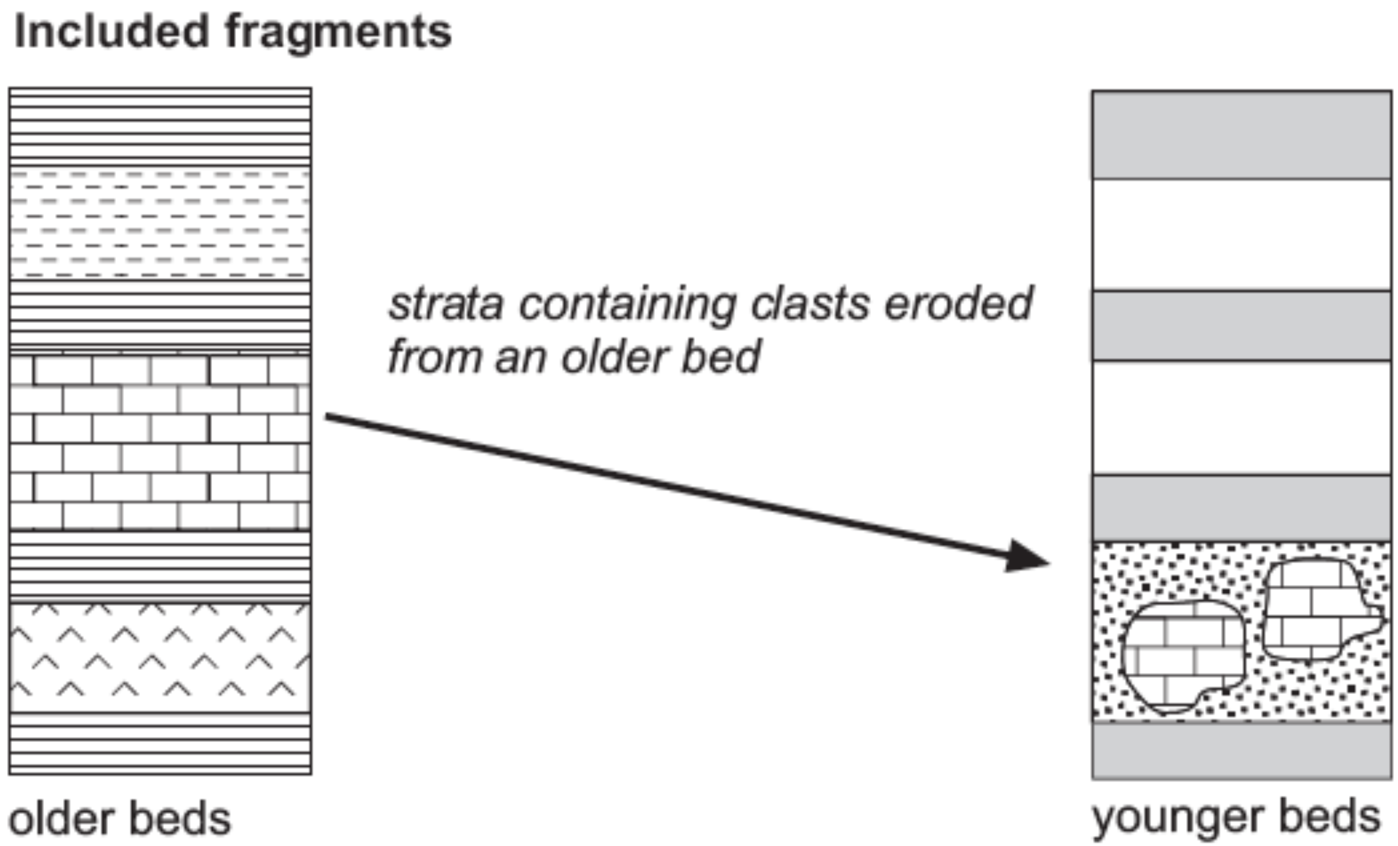


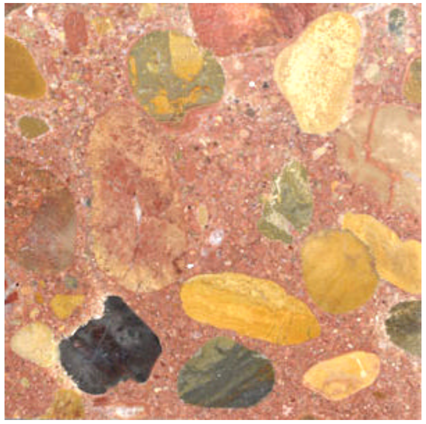


Cross-cutting of dykes, batholiths, and faults



Inclusion principle. **The fragments in a clastic rock must be made up of a rock that is older than the strata in which they are found**. The same relationship holds true for igneous rocks that contain pieces of the surrounding country rock as **xenoliths** (literally ‘foreign rocks’). This relationship can be useful in determining the age relationship between rock units that are some distance apart. Pebbles of a characteristic lithology can provide conclusive evidence that **the source rock type was being eroded by the time a later unit was being deposited** tens or hundreds of kilometres away.



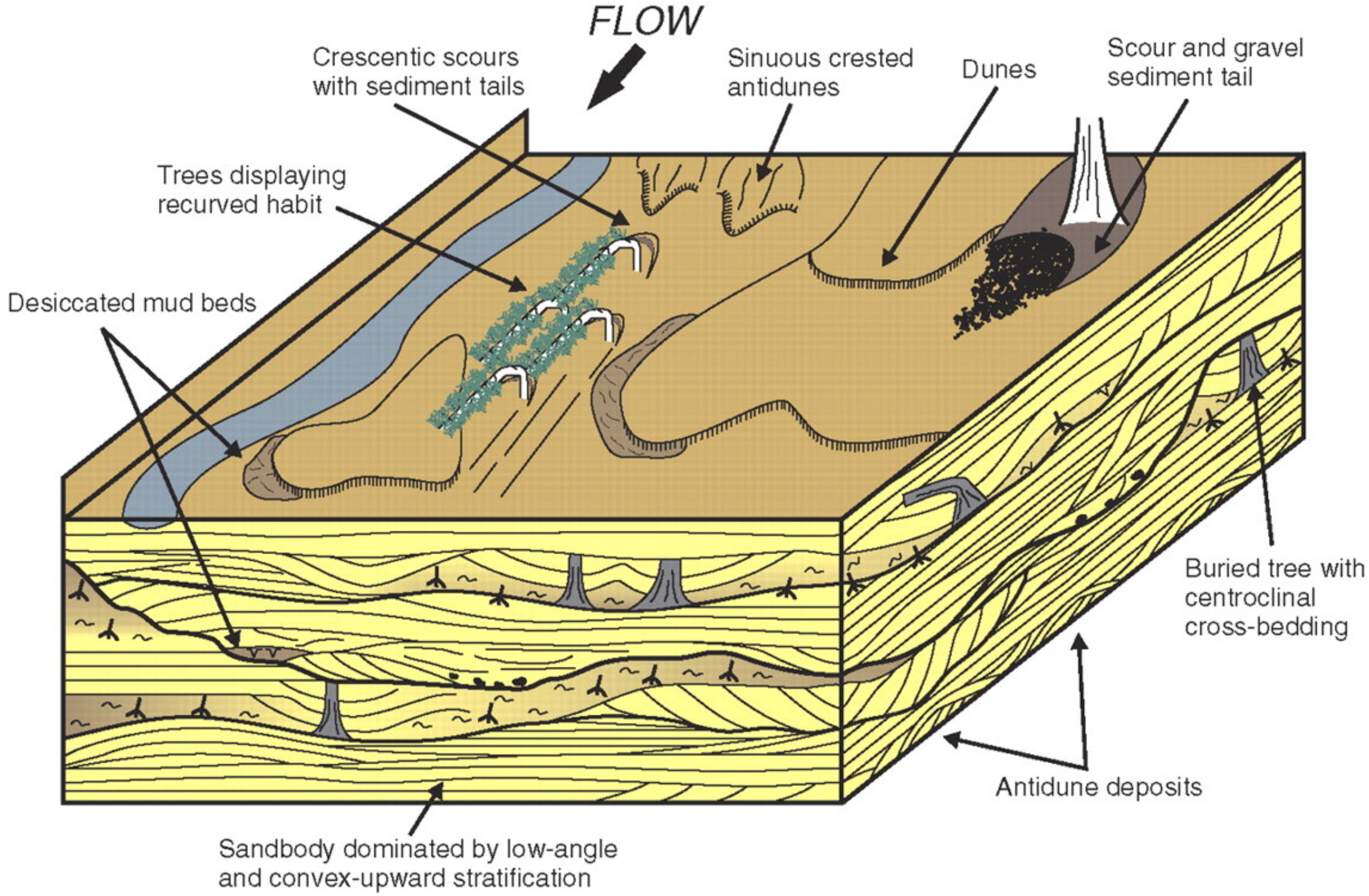


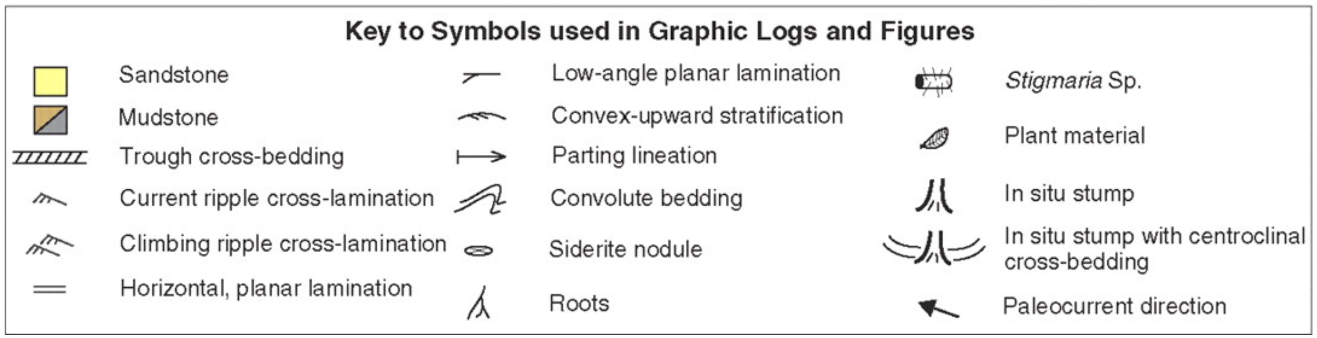
In Stratigraphy, a **facies** is a body of physical characteristics that allow to attribute a sediment to a specific **depositional environment** for distinction from adjacent sediment deposited in a different depositional environment. Sedimentary facies reflect **depositional environment**.

For example, a **sandstone** is a sedimentary rock composed mainly of sand-sized minerals or rock grains. Its body of characteristics such as **grain size, sorting and composition** as well as **sedimentary structures** and outcrop **geometry** contribute to define the environment where it is deposited, which include:

1. Rivers (levees, point bars, channel sands)
2. Alluvial fans
3. Glacial outwash
4. Lakes
5. Deserts (sand dunes and ergs)
6. Deltas
7. Beach and shoreface sands
8. Tidal flats
9. Offshore bars and sand waves
10. Storm deposits (tempestites)
11. Turbidites (submarine channels and fans)

Annotated block diagram summarizing essential elements of proposed facies model for subhumid to semiarid tropical and subtropical fluvial deposits, and key to symbols used.





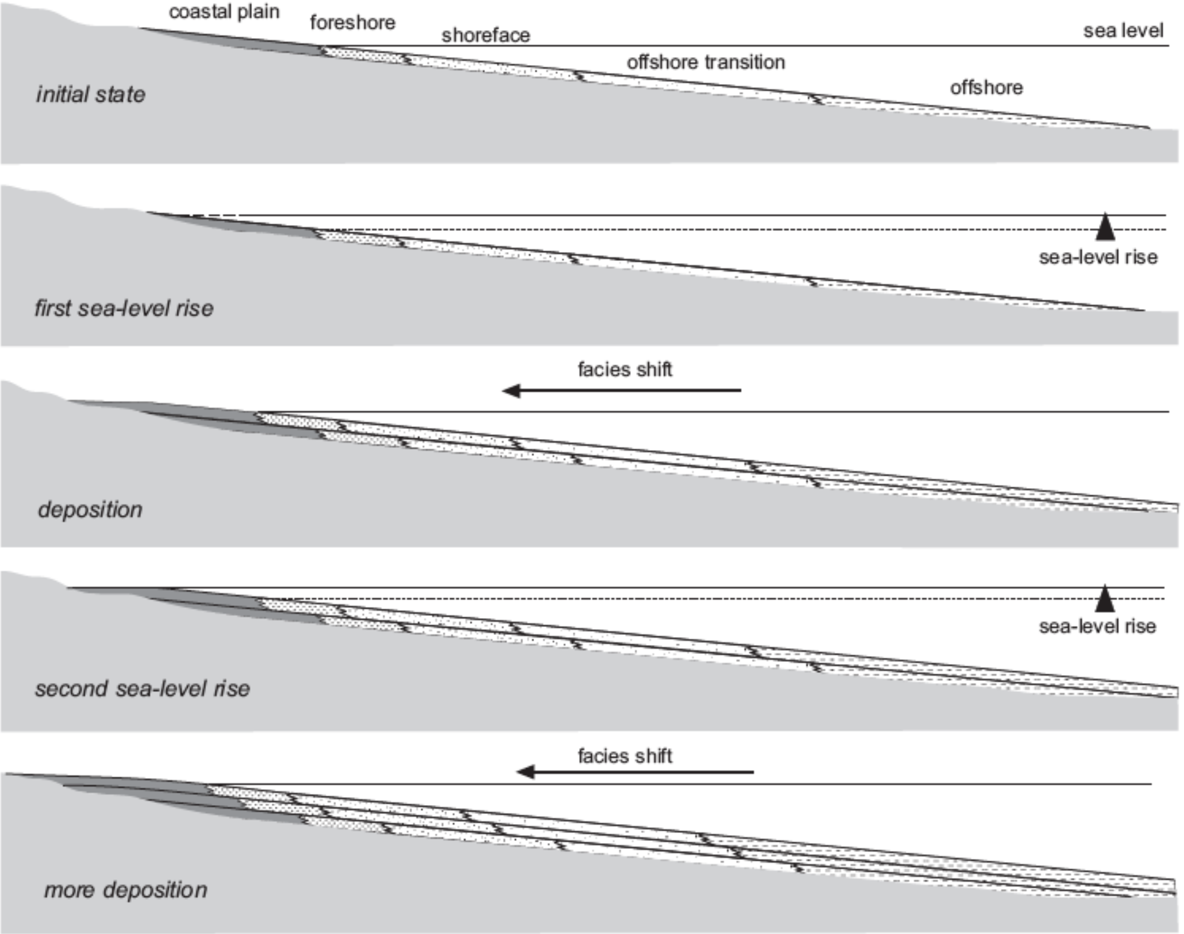
Fielding C R et al. Geology 2009;37:623-626

THE GEOLOGICAL SOCIETY OF AMERICA

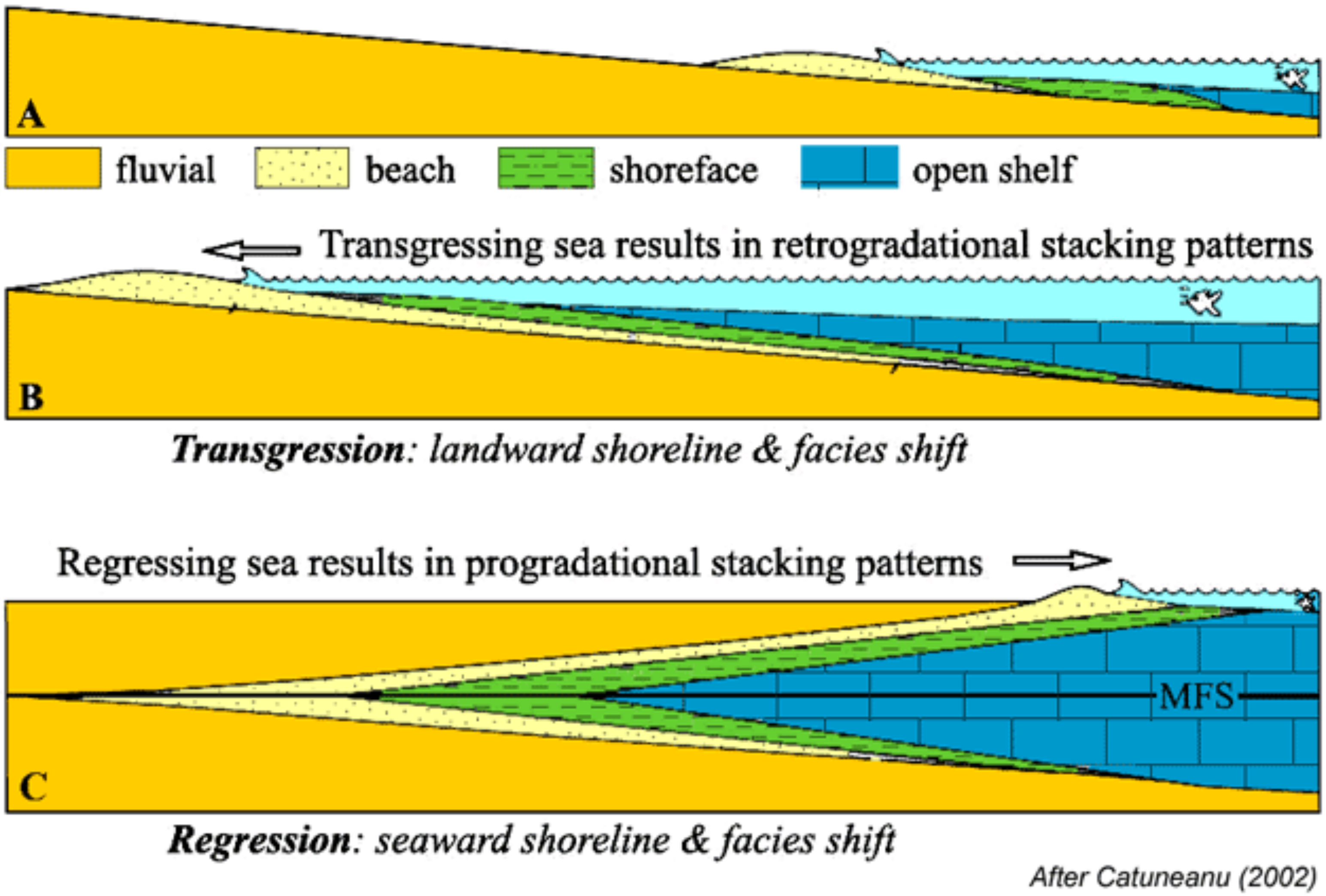
Walther's Law of Facies, named after the geologist Johannes Walther (1860-1937), states that **the vertical succession of facies reflects lateral migrations in environment** because when a depositional environment migrates laterally, **sediments of one depositional environment come to lie on top of another**. A classic example of this law is the vertical stratigraphic succession that typifies marine trangressions and regressions.

Consider a coastline where a sandy beach (foreshore) lies between a vegetated coastal plain and a shoreface succession of mudstones.

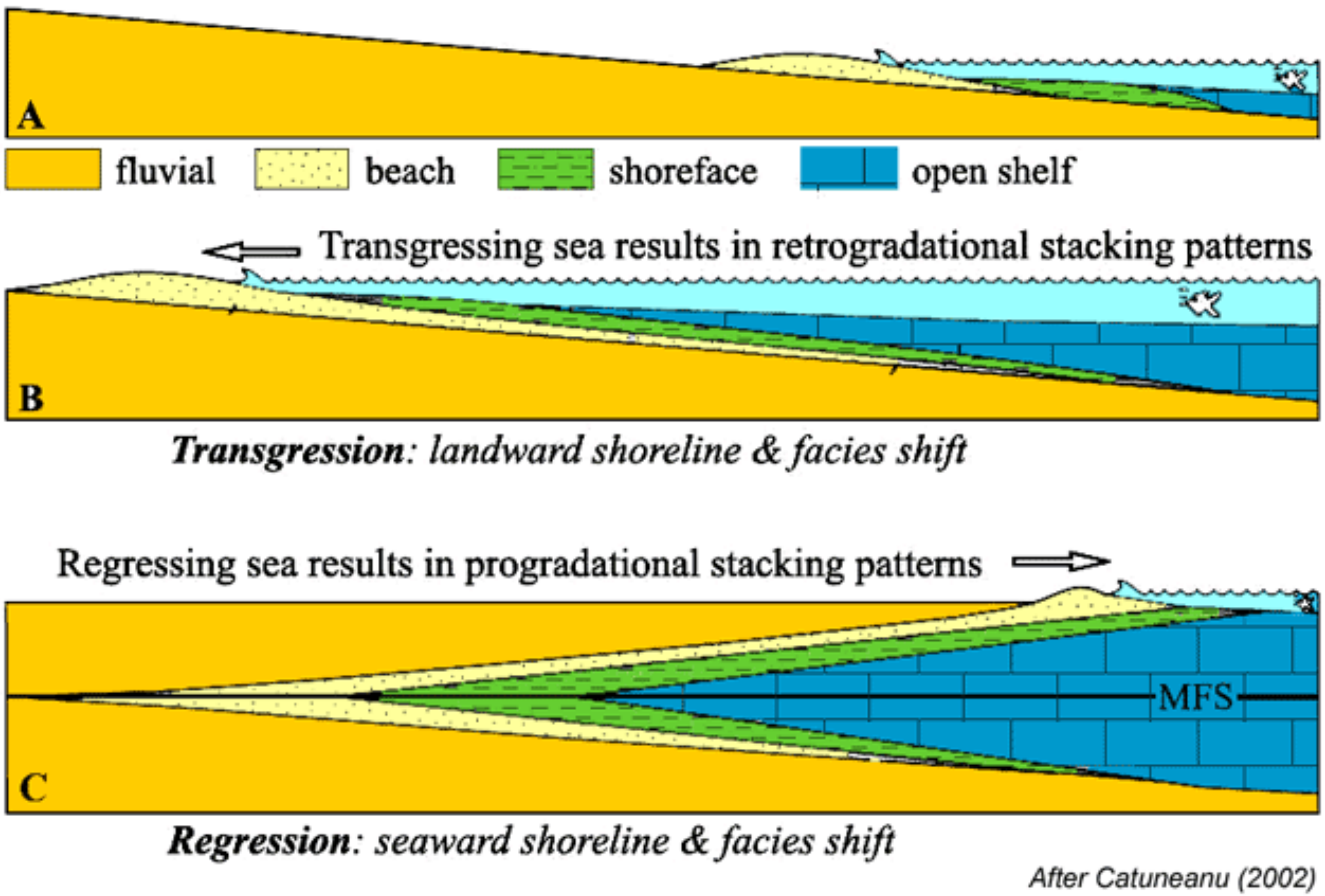
If sea level slowly rises the shoreline will move **landwards** and **on top of** previous coastal plain deposits. The same would be true for all other units.



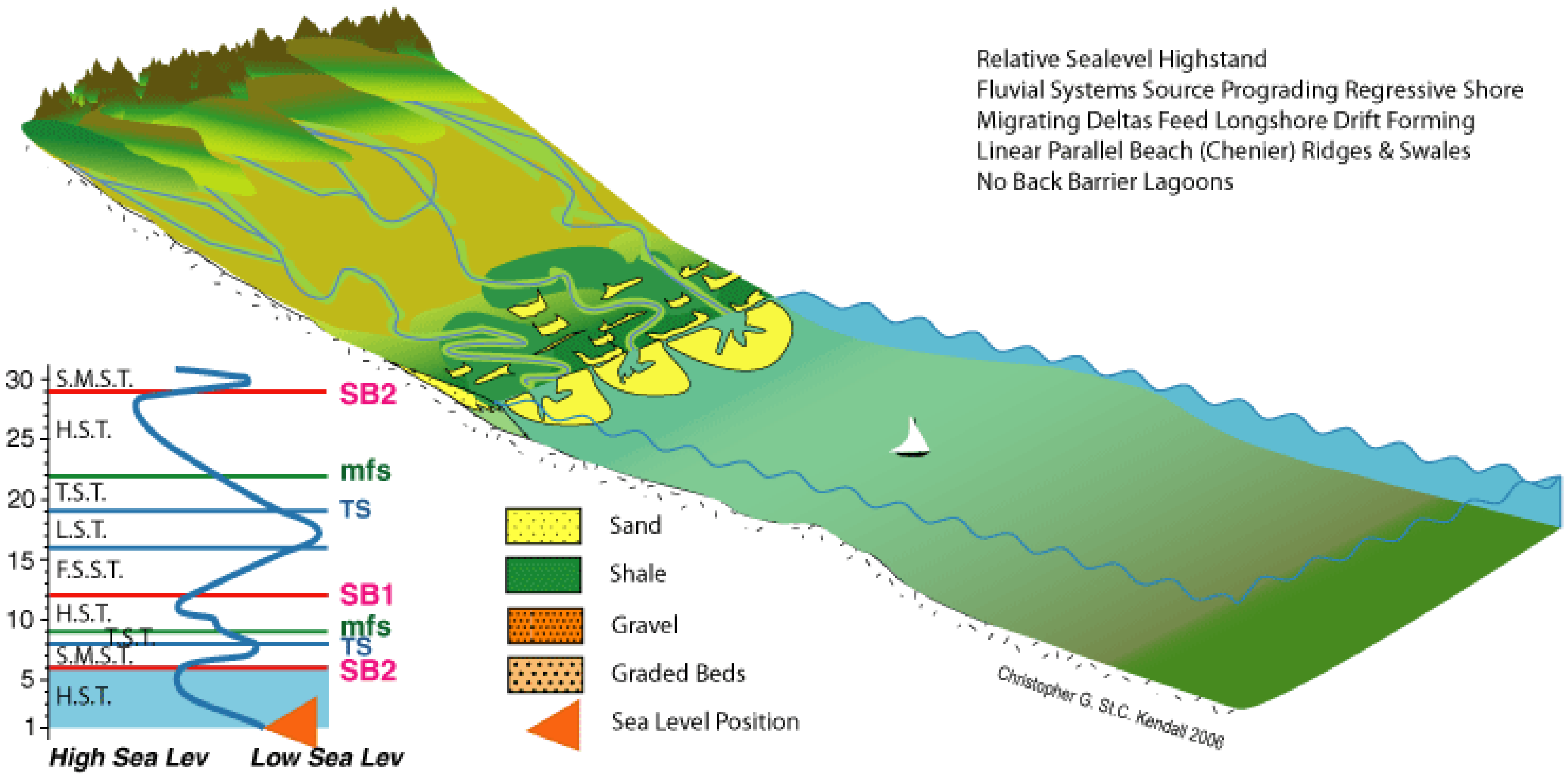
A **transgression** occurs when the rate of sea level rise landward exceeds the rate of sediment input and causes an increase in accommodation, initiating the development of a transgressive surface over which the trangressive sediments of the transgressive systems tract onlap and retrograde.



A **regression** occurs when when sedimentation rates outpace the rates of base-level rise at the shoreline, or when base-level falls.

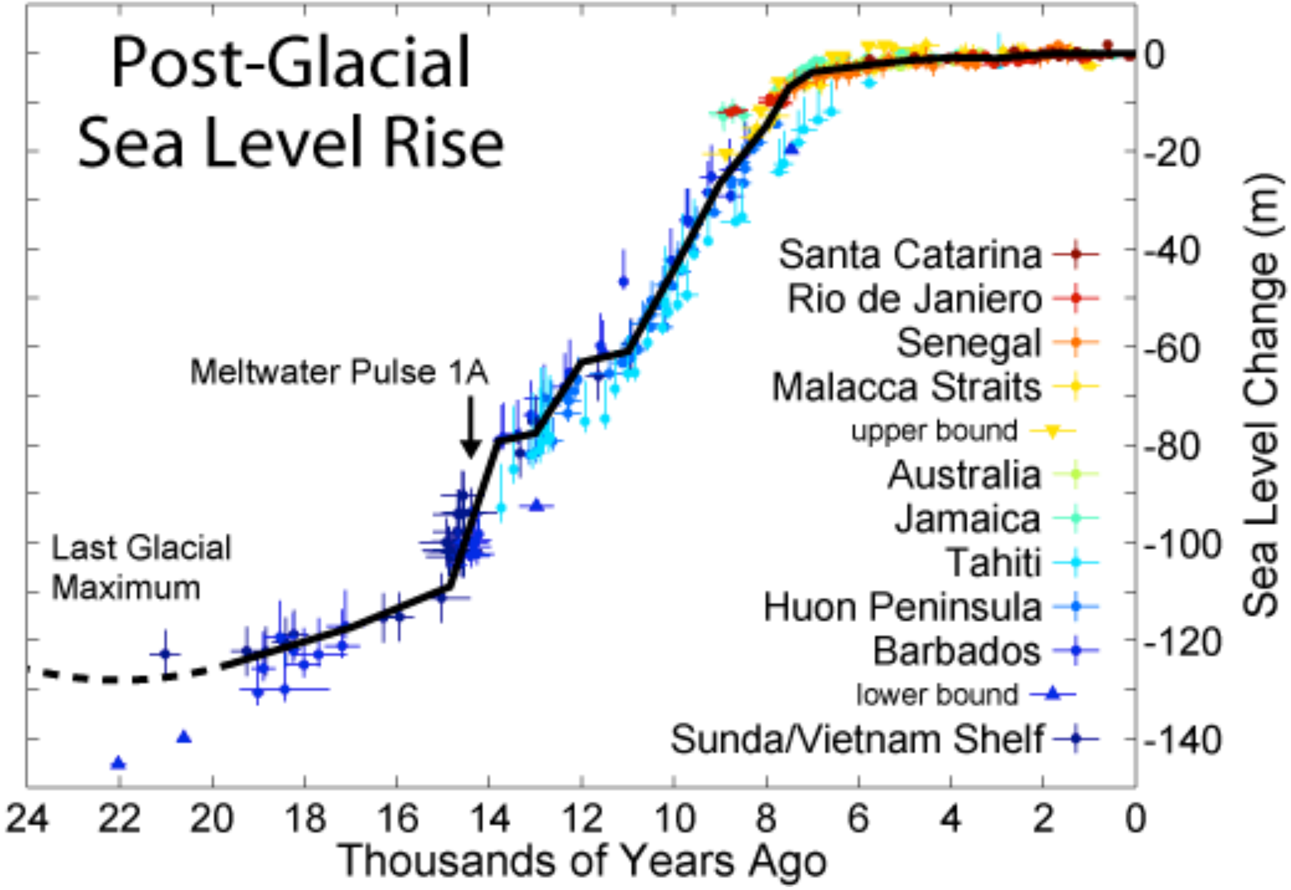


Walther's Law ***the vertical succession of facies reflects lateral migrations in environment*** **in a movie.**

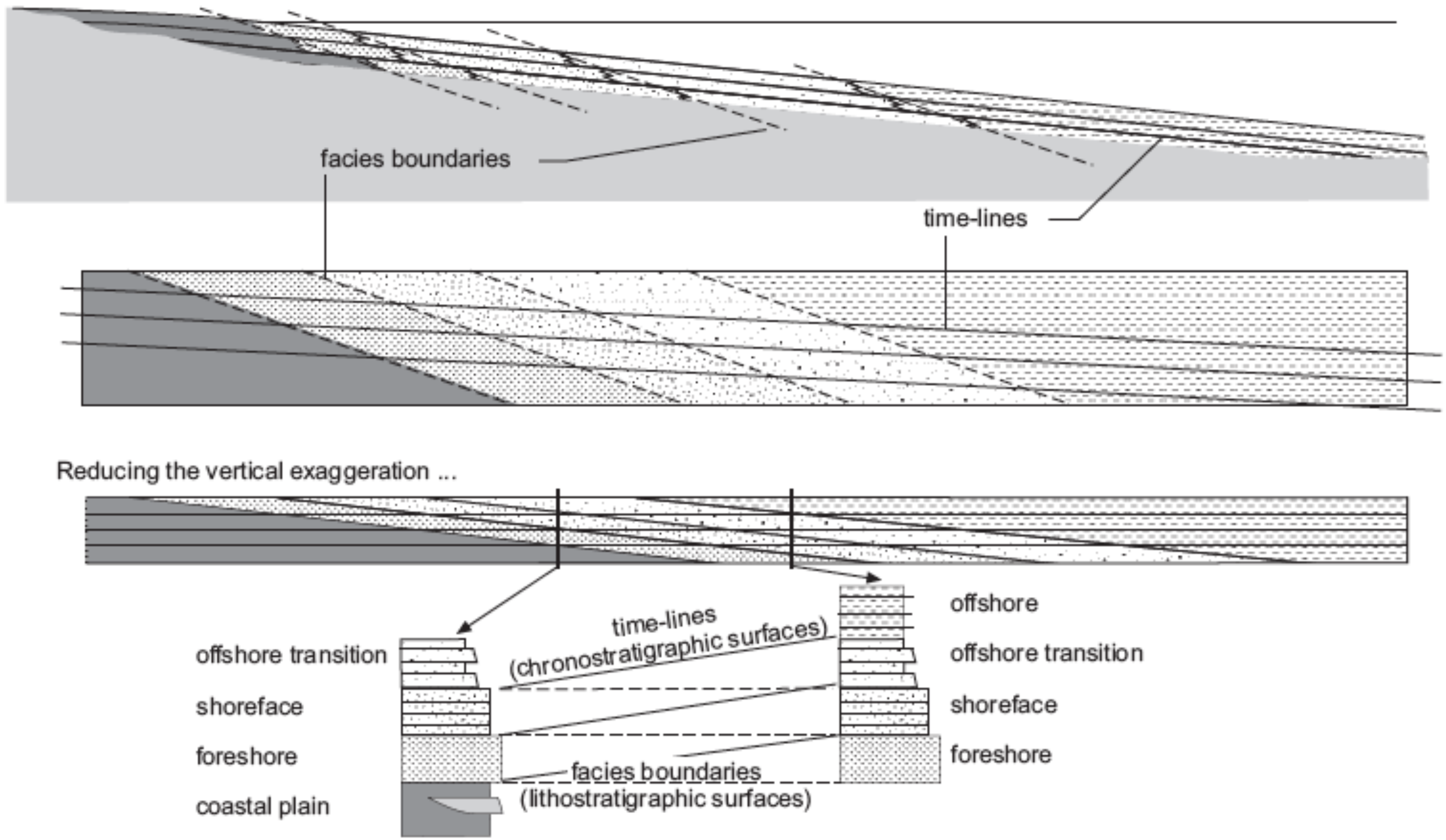


Facies lateral migrations occur essentially because **sea level has changed** over geologic time. For example, during the most recent ice age (at its maximum about 20,000 years ago) the world's sea level was about **130 m lower** than today, due to the large amount of sea water that had evaporated and been deposited as snow and ice, mostly in the Laurentide and Fennoscandian ice sheet. The majority of this had melted by about 10,000 years ago.

Hundreds of similar glacial cycles have occurred throughout the Earth's history. Geologists who study the positions of coastal sediment deposits through time have noted dozens of landward or basinward shifts of shorelines due to **sea level rise (transgression) or sea level fall (regression).**



This implies that the boundaries separating lithostratigraphic units of a given facies (e.g., shoreface sandstones, coastal plain mudstones etc.) **do not necessarily represent <u>chronostratigraphic time-lines</u>** (imaginary lines drawn across and between bodies of rock which represent **a moment in time**). Lithostratigraphic correlations **do not** coincide with chronostratigraphic correlations.



Correlation in stratigraphy is usually concerned with considering rocks in a **temporal framework**, that is, we want to know the time relationships between different rock units – which ones are older, which are younger and which are the same age.

Correlation on the basis of lithostratigraphy alone is difficult because, as discussed before, **lithostratigraphic units are likely to be diachronous**. In the example of the lithofacies deposited in a beach environment during a period of rising sea level the lithofacies has different ages in different places. **Therefore the upper and lower boundaries of this lithofacies will cross time-lines**.

If we can draw a time-line across our rock units, we would be able to reconstruct the distribution of palaeoenvironments at that time across that area.

To carry out this exercise of making a palaeogeographic reconstruction **we need to have some means of determining the age of rock units.**

Biostratigraphy is the branch of stratigraphy which focuses on correlating and assigning **relative ages** of rock strata by using the **fossil assemblages** contained within them. It can assign a **numerical age** to rock strata by correlation to a geochronologically calibrated reference **time scale**.

Magnetostratigraphy is the branch of stratigraphy which focuses on correlating and assigning **relative ages** of rock strata by using the sequence of normal and reverse polarity reversals of the Earth's magnetic field registered within them by magnetic minerals. It can assign a **numerical age** to rock strata by correlation to a geochronologically calibrated reference **time scale (**that includes marine magnetic anomalies).

Chemostratigraphy is the branch of stratigraphy which focuses on the changes in the relative proportions of trace elements and isotopes (mainly carbon and oxygen) within and between lithologic units. It can be used for correlating and assigning **relative ages** of rock strata, demonstrating that a particular horizon in one geological section containing a particular isotopic excursion represents the same period of time as another horizon at some other section containing a similar isotopic excursion.

Cyclostratigraphy is the branch of stratigraphy which focuses on astronomically forced climate cycles within sedimentary successions due to the gravitational interaction of the Earth's orbit with other masses within the solar system. Due these interactions, solar irradiation differs through time on different hemispheres, and these insolation variations have influence on Earth's climate and on the deposition of sedimentary rocks. It can be used to assign a **numerical age** to rock strata when used in conjunction with geochronology.

Geochronology is the science of determining the **numerical age** of rocks, fossils, and sediments by measuring the amount of decay of a radioactive isotope with a known half-life.

Biostratigraphy and fossils. A (very little bit) of history

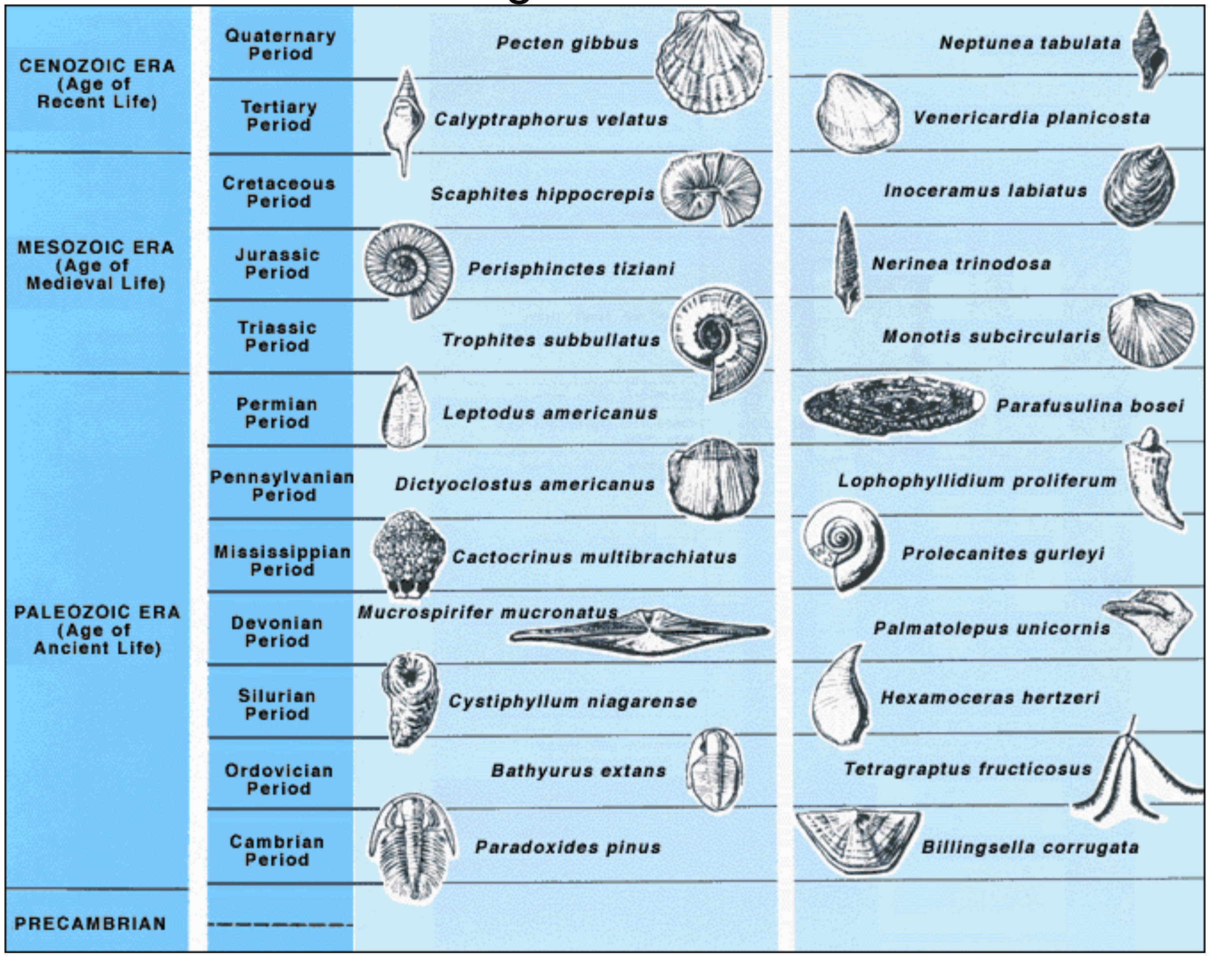
Leonardo Da Vinci (1452-1519) postulated that the deluge - a mythical story of a great flood sent by a deity to destroy civilization as an act of divine retribution - could not have caused the presence of fossils in the Italian Apennines.: *"Della stoltizia e semplicità di quelli che vogliono che tali animali fussin in tal lochi distanti dai mari portati dal diluvio. Come altra setta d'ignoranti affermano la natura o i celi averli in tali lochi creati per infrussi celesti....E se tu dirai che li nichi [le conchiglie] che per li confini d'Italia, lontano da li mari, in tanta altezza si vegghino alli nostri tempi, sia stato per causa del diluvio che lì li lasciò, io ti rispondo che credendo che tal diluvio superassi il più alto monte di 7 cubiti - come scrisse chi 'l misurò! - tali nichi, che sempre stanno vicini a' liti del mare, doveano stare sopra tali montagne, e non sì poco sopra la radice de' monti....*"

William Smith (1769-1839) formulated the principle of faunal succession based on the observation that sedimentary rock strata contain fossilized flora and fauna, and that these fossils succeed each other vertically in a specific, reliable order that can be identified over wide horizontal distances: *"…each stratum contained organized fossils peculiar to itself, and might, in cases otherwise doubtful, be recognized and discriminated from others like it, but in a different part of the series, by examination of them."*

Biostratigraphy uses fossils for correlating and dating sediments

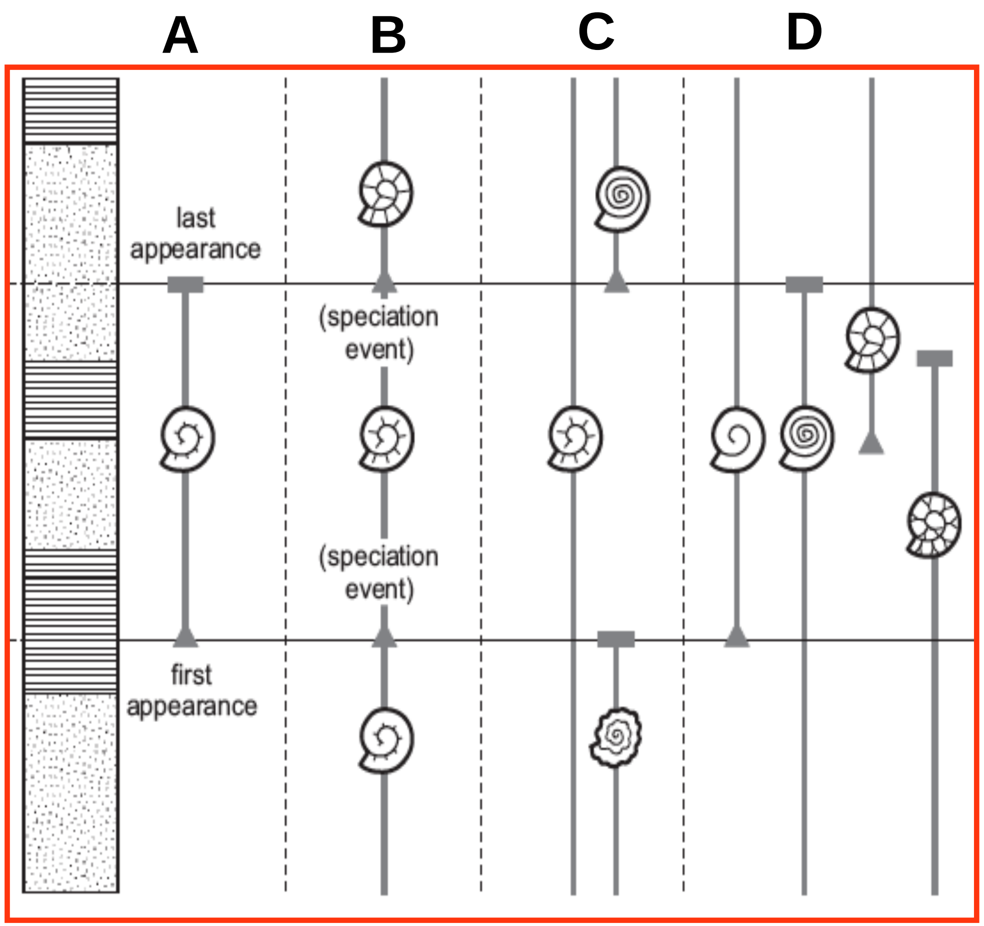
Sediments of the same age can look completely different because of local variations in the sedimentary environment. For example, one section might have been made up of clays and marls while another has more chalky limestones, but if the **fossil species** recorded are similar, the two sediments are likely to have been laid down at the same time. Different fossils work well for sediments of different ages.

Ammonites, graptolites, archeocyathids, and trilobites are index fossils that are widely used in biostratigraphy. Microfossils such as acritarchs, chitinozoans, conodonts, dinoflagellate cysts, pollen, spores and foraminiferans are also frequently used. **Refer to the Paleontology class you took!**



In 1856 **Albert Oppel** introduced the concept of **biozone** to describe strata characterised by the overlapping range of fossils. A biozone represents the interval between the **appearance** of species at the base of the zone and the appearance of other species at the base of the next zone. Oppel's zones are named after a particular distinctive fossil species, called an **index fossil**.

There exist different types of biozones:



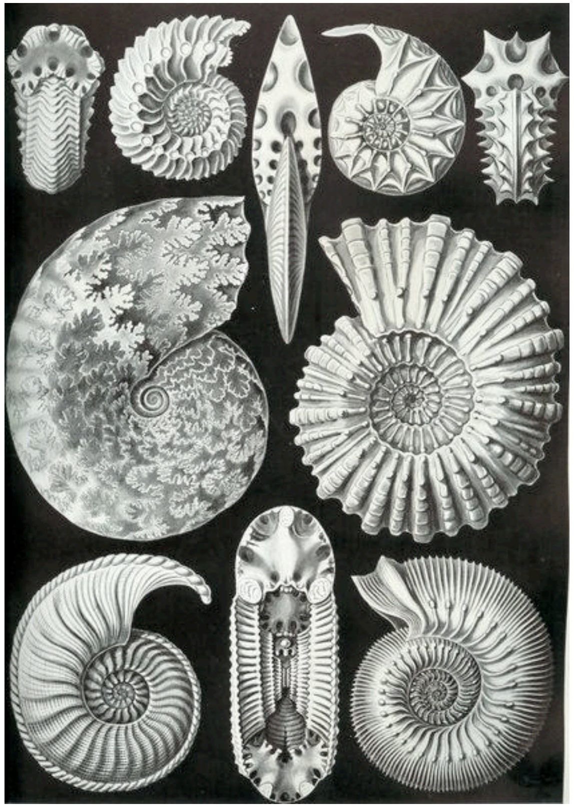
Taxon range biozone representing the range of occurrence of a single taxon (**A**).
Lineage biozone representing a specific segment of an evolutionary lineage (**B**).
Concurrent range biozone representing the concurrent range of two taxa (**C**).
Assemblage biozone representing a unique association of three or more taxa (**D**).

Biozones are based on **index fossils**.
As previously stated, although different sediments may look different depending on the conditions under which they were laid down, they may include the remains of the same species of fossil. **If the species concerned were short-lived** (in geological terms, lasting a few hundred thousand years), **then it is certain that the sediments in question were deposited within that narrow time period**. The shorter the lifespan of a species, the more precisely different sediments can be correlated, and so rapidly evolving types of fossils are particularly valuable.

To be useful in biostratigraphy index fossils should be:

- *Rapidly evolving (short-lived)*
- * **Independent of their environment**
- * **Geographically widespread**
- * **Abundant (easy to find in the rock record)**
- * **Easy to preserve in the rock record**
- * **Easy to identify**

Ammonites

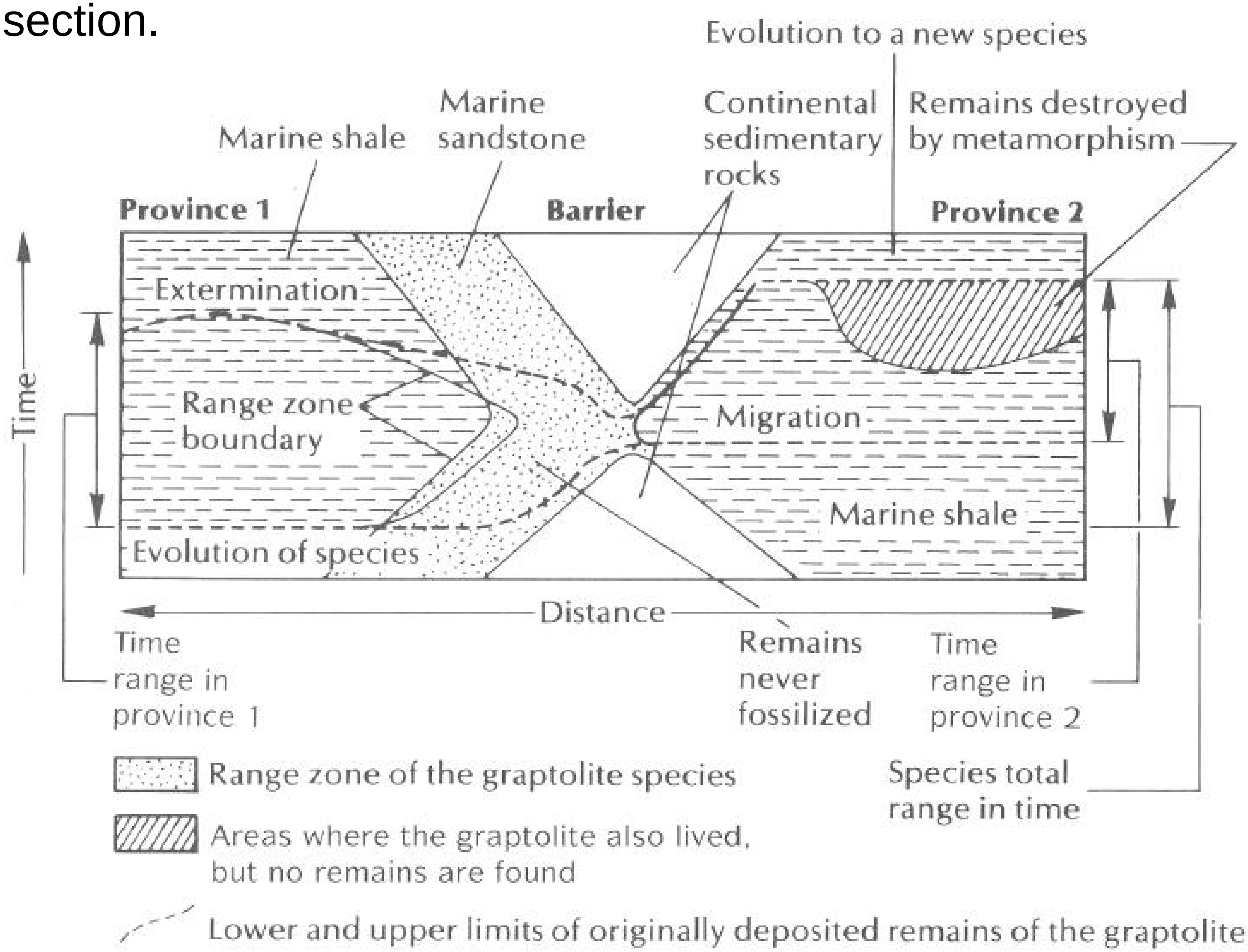


One of the most commonly used biozones in biostratigraphy is the **Taxon range biozone** representing the range of occurrence of a single taxon. This range is comprised between the **First Appearance Datum (FAD)**, which designates the first (oldest) **appearance on Earth** (**speciation event**) of the taxon, and the **Last Appearance Datum (LAD)**, which designates the last (youngest) presence on Earth of that taxon and consequently its disappearance from Earth (**extinction event**).

However, the fossil record is inherently imperfect (only a very small fraction of organisms become fossilized) and sediments do not always register faithfully speciation events that occur through time because sediments may contain hiata (absence of deposition, erosion) or be affected by changing environmental conditions that are variably favorable to that particular taxon. Therefore, the appearance or disappearance of a zone fossil in the rock record may be due to **changes in environment rather than be true speciation or extinction events**.

Hence, when dealing with rocks, biostratigraphers use the terms **First Occurrence (FO)** and **Last Occurrence (LO)** of a taxon to **approximate** its FAD (speciation) and LAD (extinction).

Reason why FAD&LAD ≠ FO&LO: Biogeography. If the depositional environment has remained the same, the appearance of a taxon may be due to a speciation event. However, species may have already existed for a period of time in a different geographical location before **migrating** to the area of the studied section.



Reason why FAD&LAD ≠ FO&LO: Lazarus Effect

a Lazarus taxon is a taxon that disappears from one or more periods of the fossil record, only to appear again later. Lazarus taxa are **observational artifacts**: they disappear from the geologic record to reappear later in the geologic record because of **locally changing environmental conditions**, for example a regression that superposes continental sediments above marine sediments, followed by a transgression that re-establishes marine sedimentation.

Lazarus taxa may also be **sampling artifacts** due to incomplete sampling of a rock succession or changing preservation efficiency of organisms during fossilization.

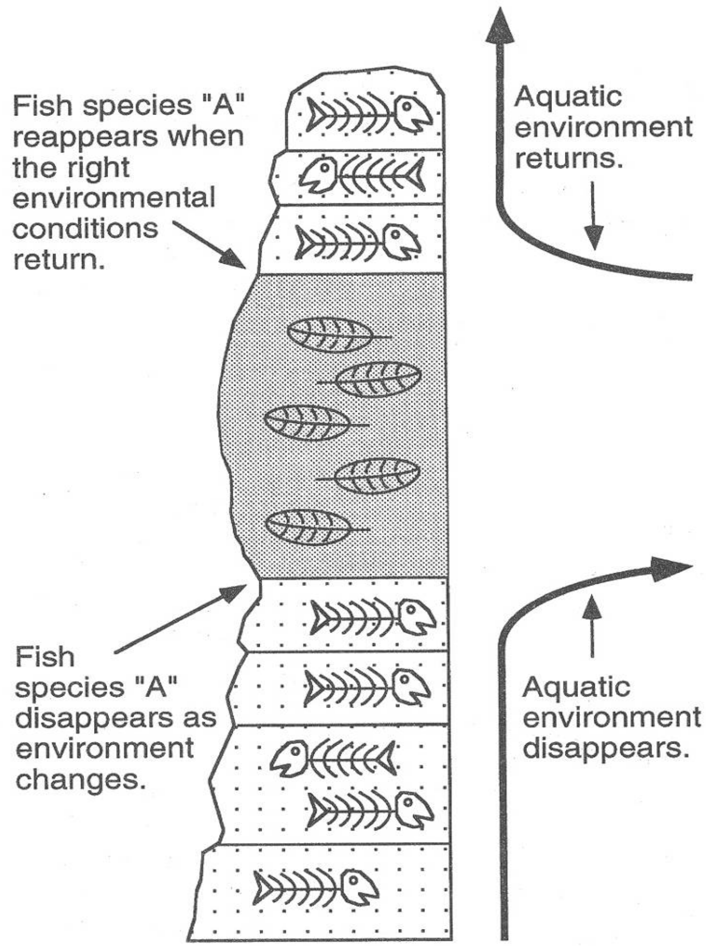


figure 10.12 The Lazarus effect. When a taxon disappears from the record, it is not necessarily its final extinction. It may have simply migrated out of the local region, or may be restricted to a refugium where it is not fossilized. It can then reappear higher in the section when the appropriate conditions return, like Lazarus rising from the dead. This is particularly critical for studies that focus on the taxa that disappear at a mass extinction level, and do not look higher in the section to see if the "extinct" taxon later reappears. (From Archibald, 1996a.)

Reason why FAD&LAD ≠ FO&LO: Zombie Effect

a Zombie taxon refers to a fossil that was washed out of old sediments (by erosion) and re-deposited in sediments millions of years younger.

When this occurs the fossil is described as **reworked,** meaning that it comes from older sediments and from an evolutionary viewpoint, it has **nothing to do** with the age of the sediment where it is actually found.

Zombie taxa, if not understood for what they really are (i.e., reworked), can lead to huge mistakes in the interpretation of the age of the sediment.

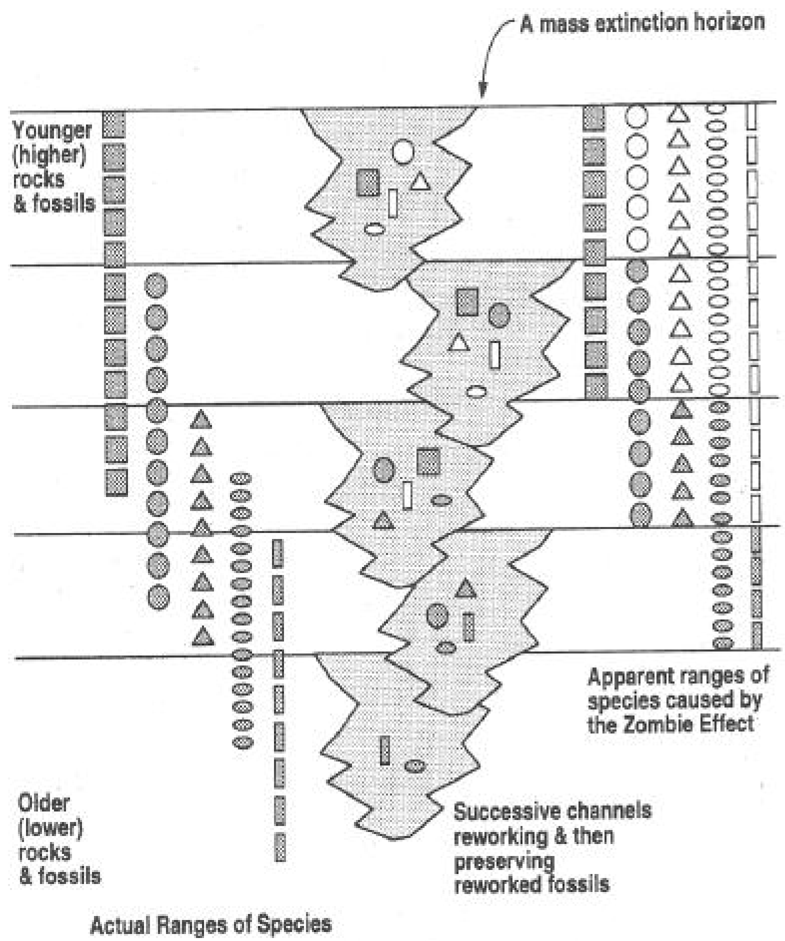


figure 10.13 The Zombie effect. Some fossils are remarkably durable when eroded out of older deposits, so that they can be redeposited into younger beds long after the original organism is extinct. This gives the false impression that they survived longer than they actually did. Fossils deposited during the time the organism lived are shown with the filled shapes in the channels; those reworked from older beds are indicated by unfilled shapes. (From Archibald, 1996a.)

Reason why FAD&LAD ≠ FO&LO: Infiltration Effect

Introduced or infiltrated fossils are younger fossils introduced into older rocks by fluids, through animal burrows or root cavities, or by sedimentary dikes or diapirs. They should be distinguished from indigenous fossils in biostratigraphic zonation.

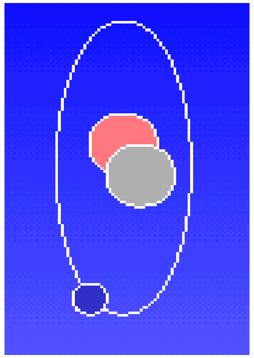
Reason why FAD&LAD ≠ FO&LO: Condensation

Effects of stratigraphic condensation. Extremely low rates of sedimentation may result in fossils of different ages and different environments being mingled or very intimately associated in a very thin stratigraphic interval, even in a single bed.

Stratigrafia Isotopica

Gli ISOTOPI di uno stesso elemento hanno lo stesso numero di protoni (e quindi di elettroni) ma un diverso numero di neutroni N. Quindi hanno lo stesso numero atomico Z (detto anche numero protonico, o numero di protoni) ma un diverso numero di massa A (protoni + neutroni).

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt									
				58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
				90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr



In natura esistono circa 1700 ISOTOPI

Quando
n neutroni/n protoni circa 1
isotopi STABILI
(non radioattivi)

la loro composizione nucleare rimane inalterata nel tempo

Hanno un diverso peso:
stesse proprietà chimiche,
diverse proprietà fisiche,
utili nello studio del clima

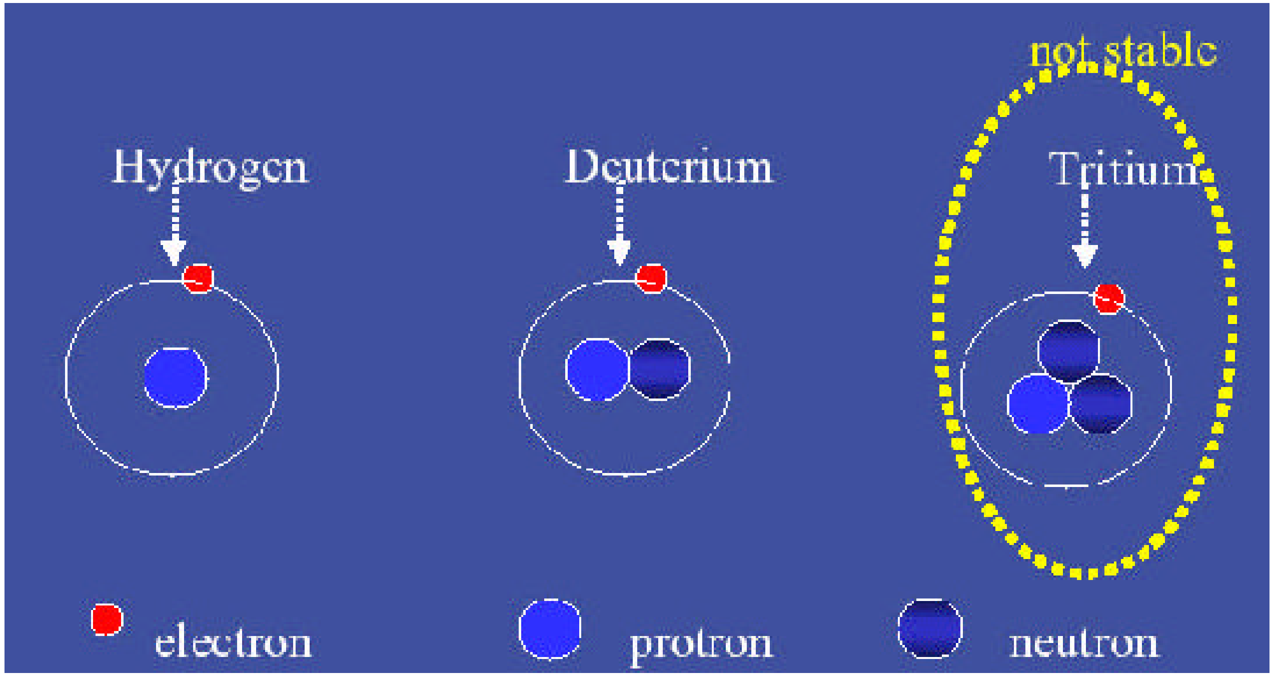
Quando n neutroni/n protoni molto diverso da 1, isotopi INSTABILI (radioattivi)

si trasformano spontaneamente fino ad assumere una configurazione stabile

Hanno altre applicazioni, ad esempio le datazioni (^{14}C, U/Th)

Esempio dell'idrogeno:

I tre isotopi dell'idrogeno hanno proprietà chimiche molto simili, ma masse differenti. Questa piccola differenza di massa si traduce in una piccola differenza nella forza dei legami quando questi si legano ad altri elementi (per esempio con l'O nell'H_2O)



n neutroni/n protoni diverso da 1
INSTABILE

n neutroni/n protoni = 1
STABILE

Tra i principali isotopi stabili studiati dalla geochimica isotopica vi sono C e O

Carbonio: ^{12}C= 98,89% ^{13}C= 1,11%

Ossigeno: ^{16}O= 99,763% ^{17}O= 0,0375%

^{18}O= 0,1995%

Il numero indica il numero di massa (A) = protoni + neutroni

Oxygen-isotope systematics

Oxygen has 3 stable isotopes: ^{16}O, ^{17}O and ^{18}O

Most scientists report the ratio between ^{18}O and ^{16}O

The ubiquitous presence of water, in solid, liquid and vapour form on the planet means that numerous reactions involving isotopic fractionation take place

Notation and Standards

$$\delta^{18}O = \frac{\{(^{18}O/^{16}O)\ \text{sample} - (^{18}O/^{16}O)\ \text{standard}\} \times 1000}{(^{18}O/^{16}O)\ \text{standard}}$$

The usual standard for carbonates is PDB, a belemnite from the Cretaceous Peedee Formation in North America. Because this material no longer exists, secondary standards, calibrated to PDB, now have to be used. The term 'V-PDB' (Vienna PDB) is sometimes used to denote use of the most commonly used secondary standard (NBS 19), after an agreement reached at an international meeting in Vienna in 1995. Fluids are reported with respect to Standard Mean Ocean Water (SMOW) or V-SMOW.

The $\delta^{18}O$ value of NBS 19 relative to V-PDB is -2.2‰

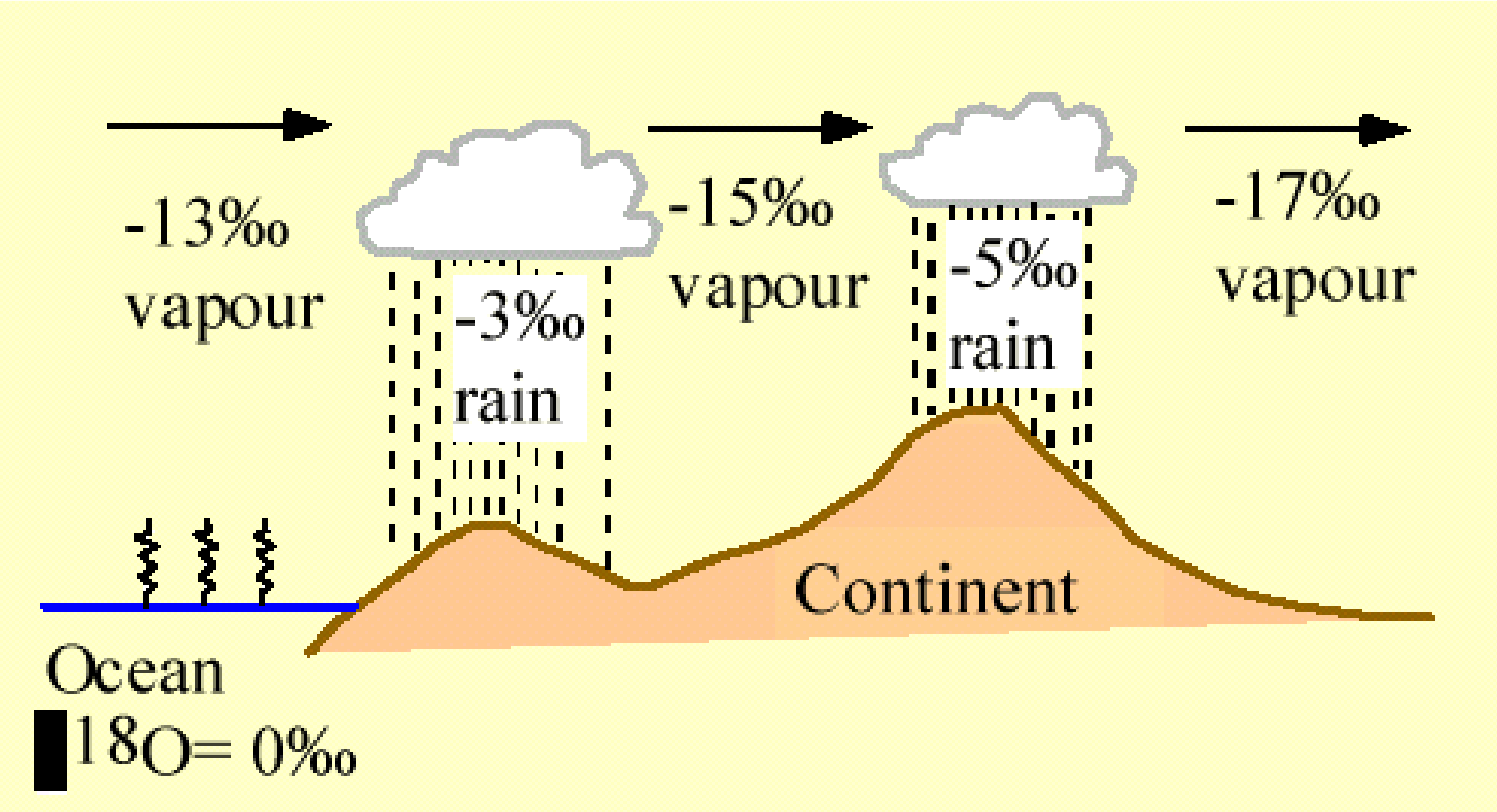
Isotopi diversi hanno diverso peso (numero di massa): stesse proprietà chimiche, diverse proprietà fisiche (capacità termica, pressione di vapore, punto di fusione).

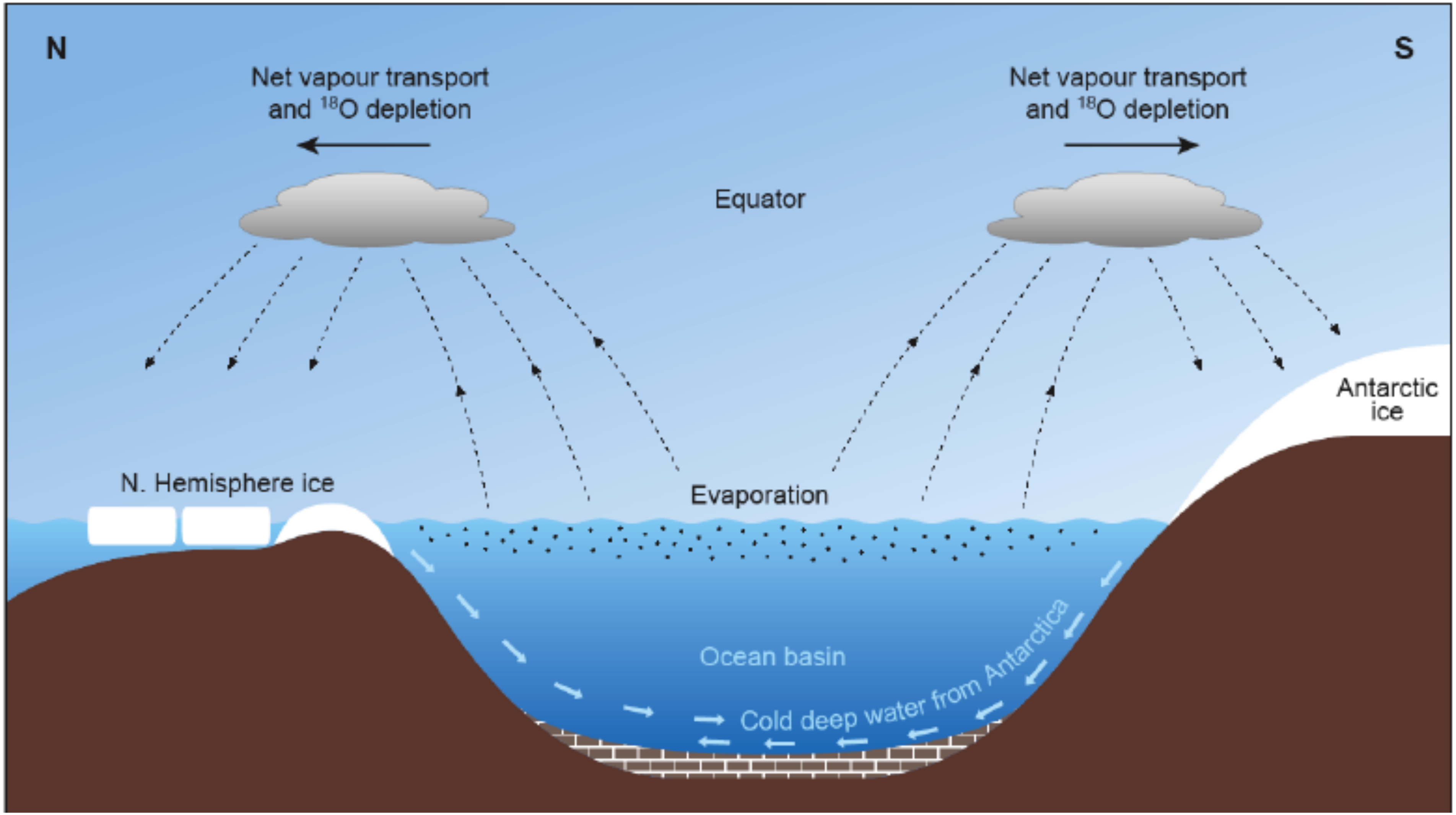
L'isotopo più pesante reagisce più lentamente

In natura le stesse molecole con differenti isotopi reagiscono in modo differente ai cambiamenti di fase:

si parla di **frazionamento isotopico** tra le due fasi

Ad esempio nel passaggio di stato da H_2Oaq ad H_2Ovap: H_2Ovap sarà più o meno ricco di ^{16}O rispetto all'acqua di partenza? Nella trasformazione da liquido a gas, H_2Ovap si arricchisce di ^{16}O (diventa più negativa, più leggera) per frazionamento cinetico. Nel ritrasformarsi in liquido (pioggia) nelle nubi, H_2Oaq prende ^{18}O (più pesante) per frazionamento di equilibrio. Il vapore rimanente è ancora più negativo.




N
S
Net vapour transport
and ^{18}O depletion
Net vapour transport
and ^{18}O depletion
Equator
Antarctic
ice
N. Hemisphere ice
Evaporation
Ocean basin
Cold deep water from Antarctica

Archivi di dati isotopici:

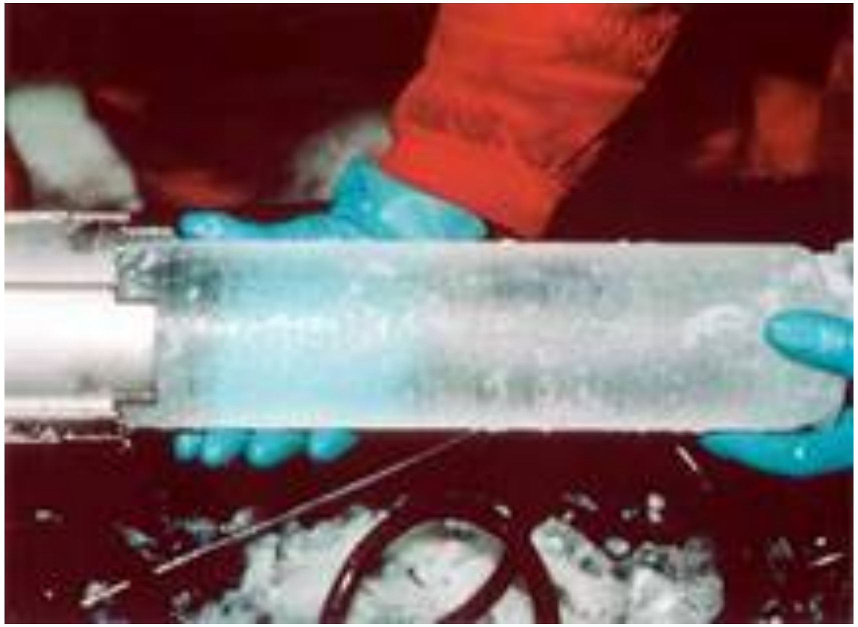
Gusci di foraminiferi

Coralli

Carote di ghiaccio

Depositi lacustri

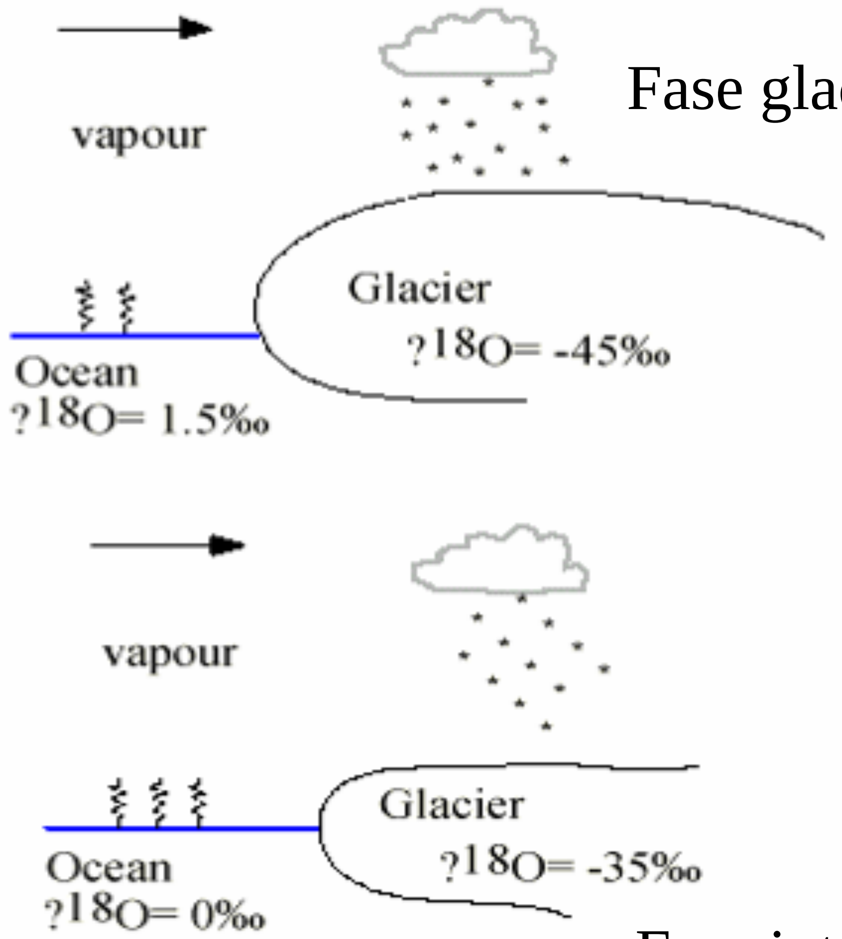
Speleotemi



Stalagmite GL-S1 from Golgotha Cave, southwest Western Australia will be used to construct 1000 years of rainfall proxy data.

Dagli archivi isotopici si evince che la composizione isotopica della sorgente del vapore (oceani) non è rimasta invariata durante il Pleistocene, soprattutto durante le fasi glaciali e interglaciali degli ultimo ~900 mila anni.

Durante una fase glaciale, il rapporto $^{18}O/^{16}O$ dei gusci dei foraminiferi (cioè dell'acqua marina in cui vivono) **AUMENTA** (^{16}O trasferito nei ghiacci continentali). Durante una fase glaciale, il rapporto $^{18}O/^{16}O$ del ghiaccio continentale **DIMINUISCE** (^{16}O ricevuto nei ghiacci continentali). Attenzione quindi: dobbiamo sapere se abbiamo a che fare con sedimenti marini o carote di ghiaccio!



Fase glaciale

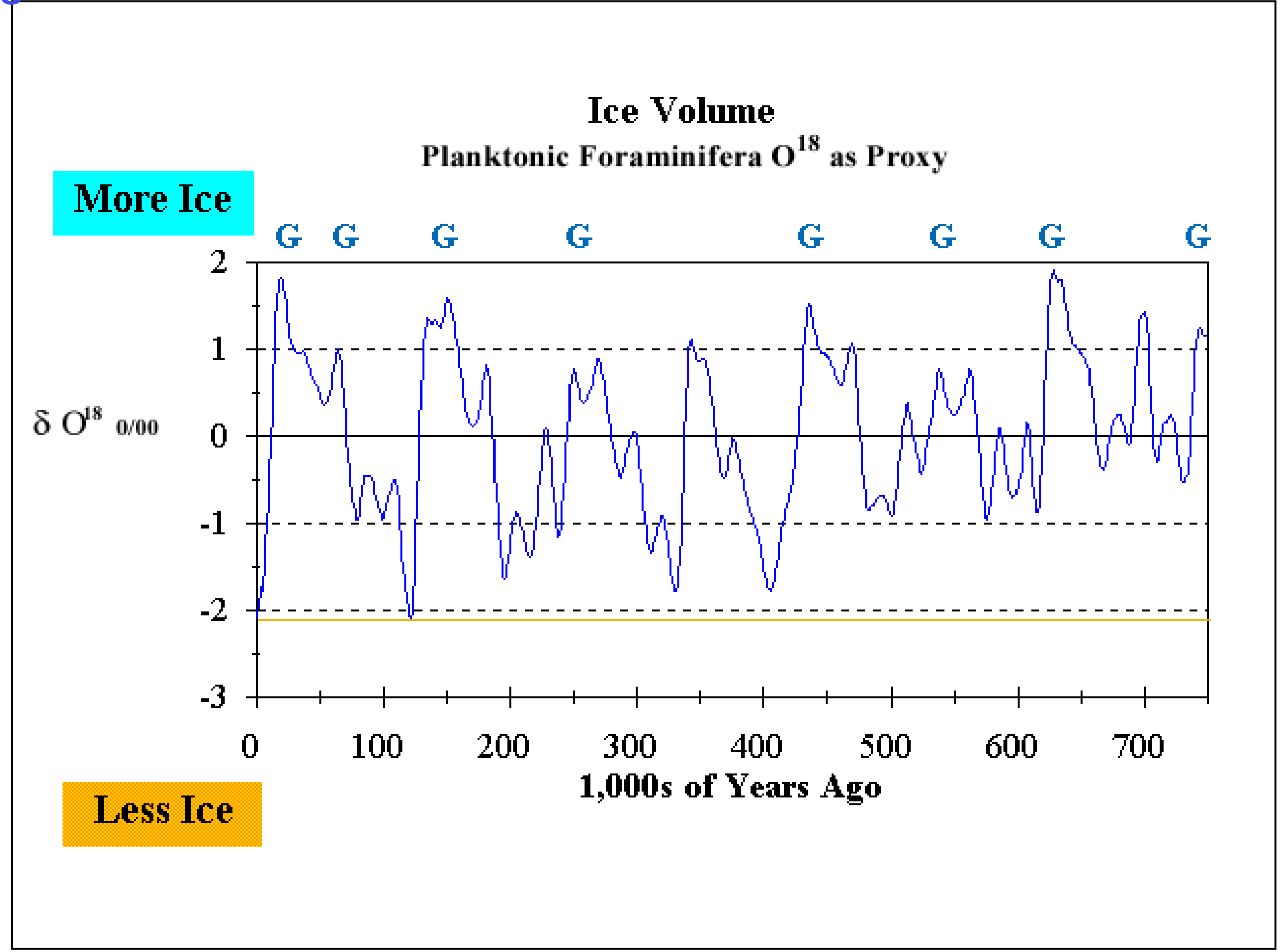
Fase interglaciale

Cesare Emiliani (1922-1995): the founder of paleoceanography

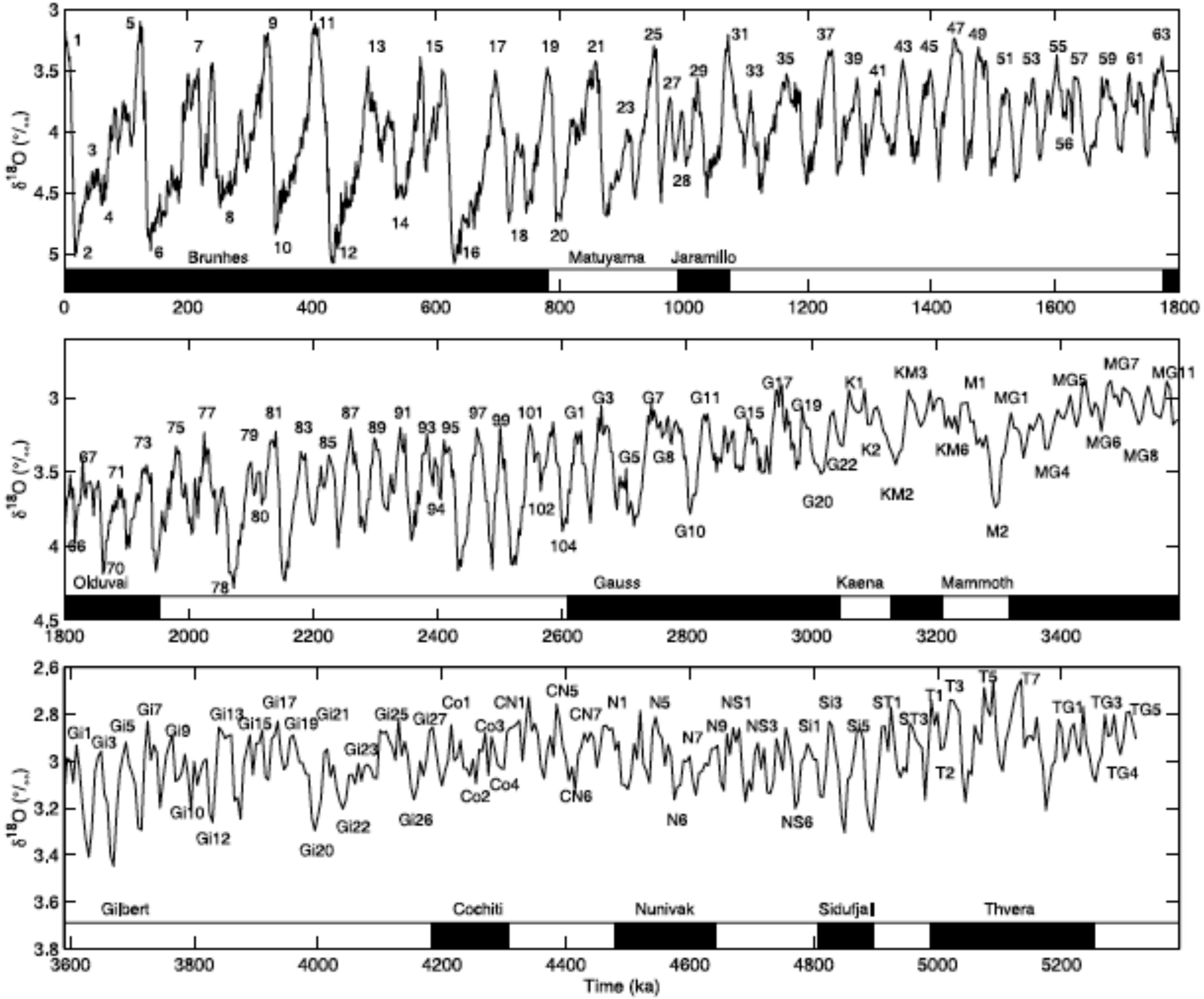
Emiliani analyzed the oxygen-isotope composition of planktonic foraminifers.

Urey had already established that the ratio between two different isotopes of oxygen atoms (O-16 and O-18) within carbonate shells is a measure of the temperature during which the shell-forming organism grew

Curva **SPECMAP**. 18O/16O da foraminiferi bentonici: rapporto 18O/16O alto = fasi glaciali, rapporto 18O/16O basso = fasi interglaciali



Benthic foraminiferal $\delta^{18}O$ data can be used for global correlation



Lisiecki and Raymo, 2005

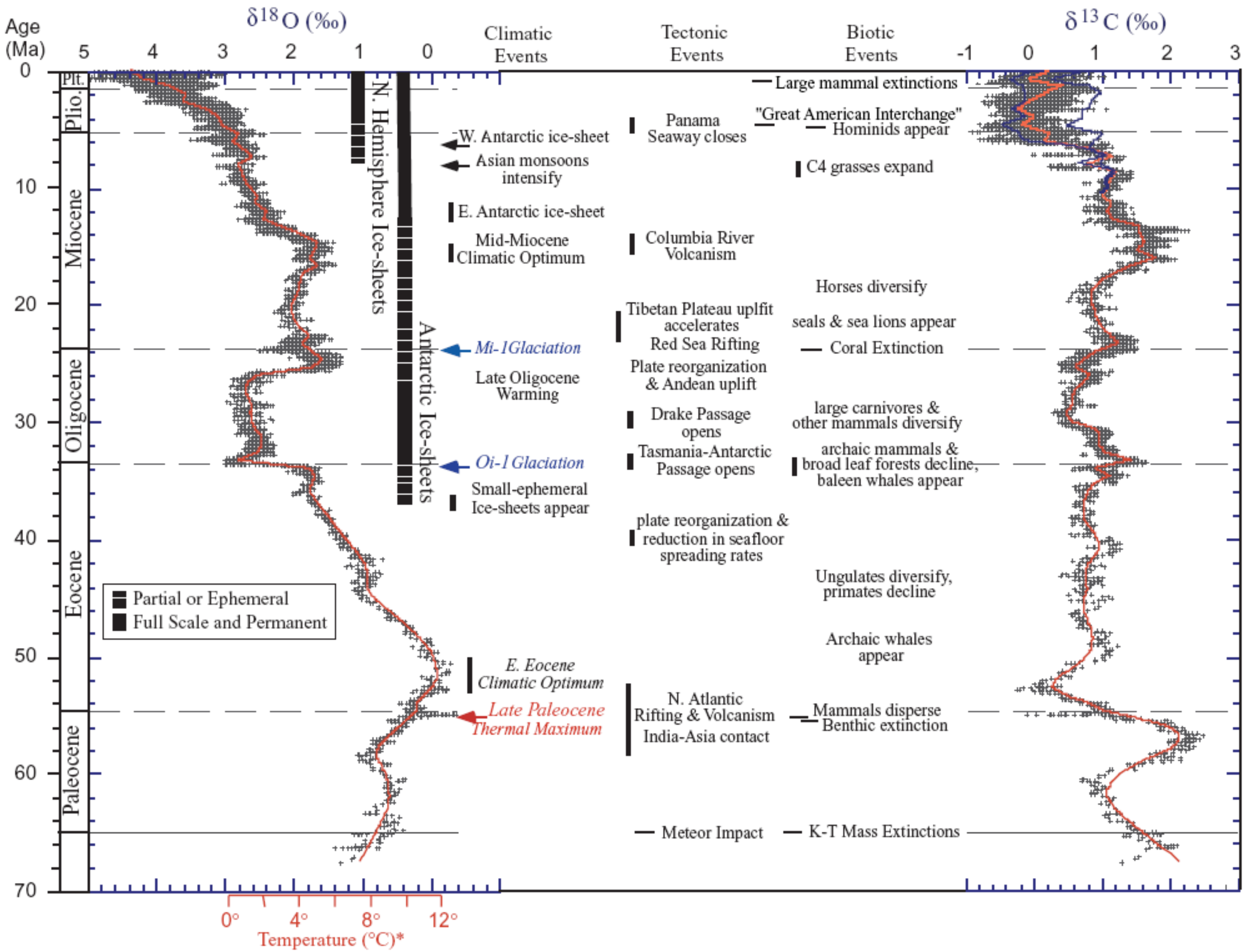
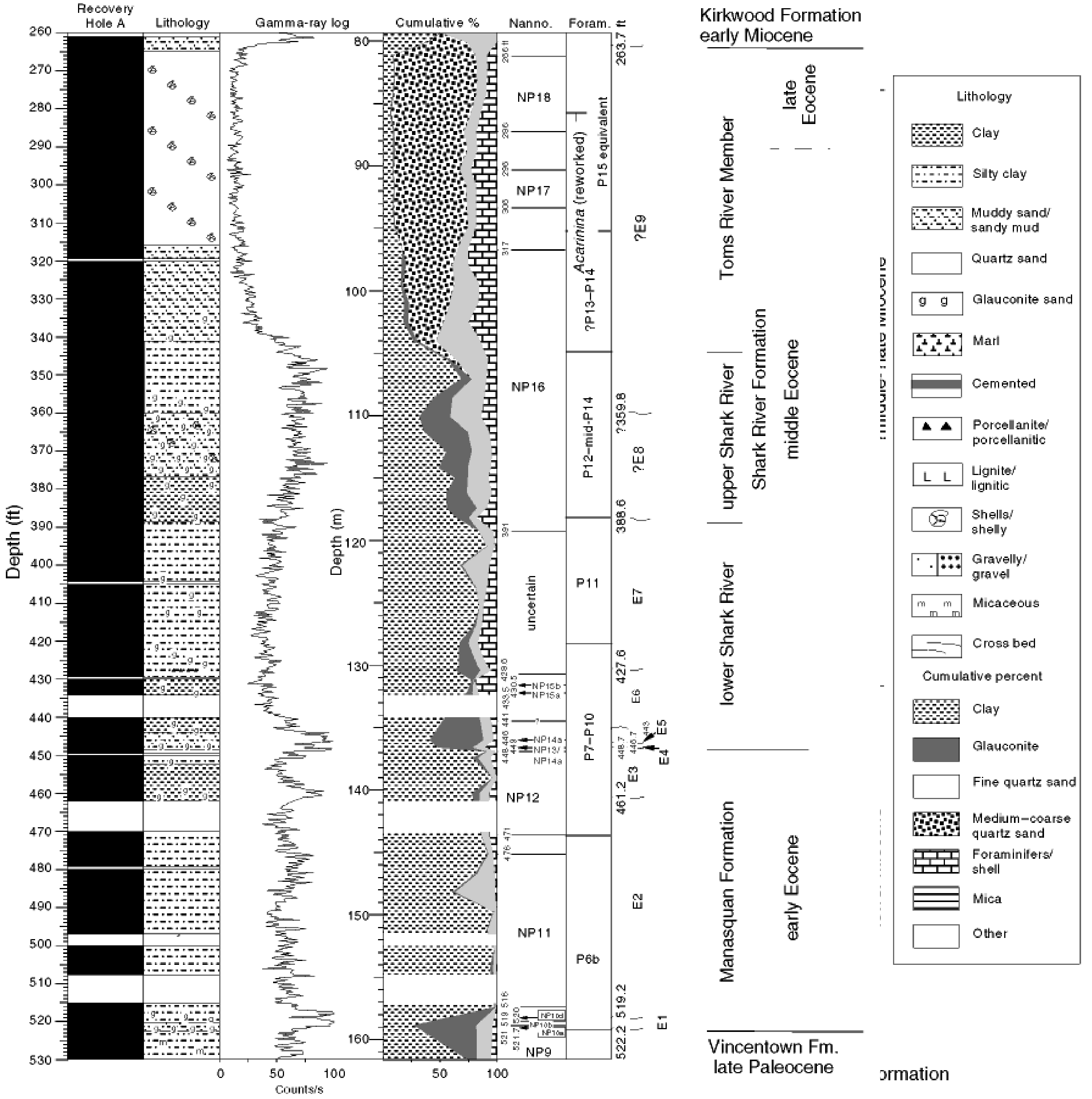


Fig. 2. Global deep-sea oxygen and carbon isotope records based on data fractionation that exceeds ~1.0‰ in some intervals. Prior to 15 Ma,



Example of integrated lithostratigraphy and nannoplankton biostratigraphy

Ocean Drilling Project, Texas A&M University.

Example of integrated lithostratigraphy, magnetostratigraphy, and nannoplankton biostratigraphy from the Eocene of the Southern Alps (Agnini et al., EPSL 2006)

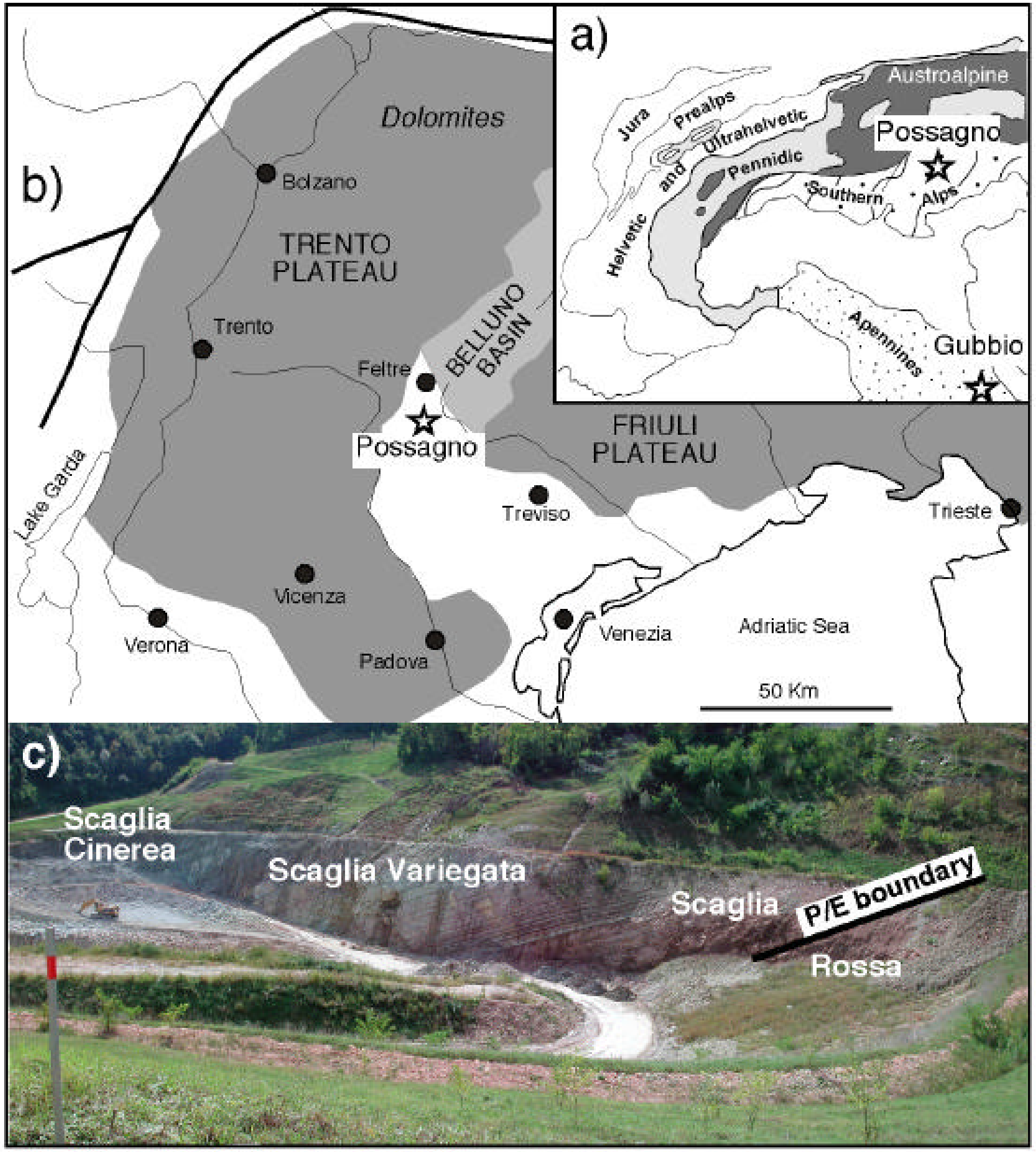
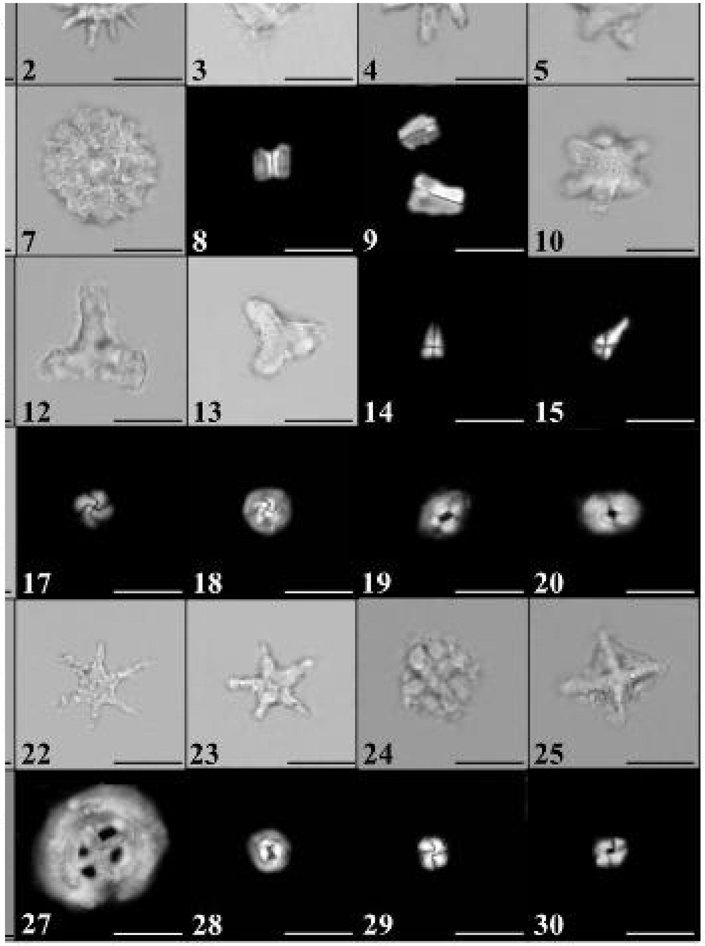
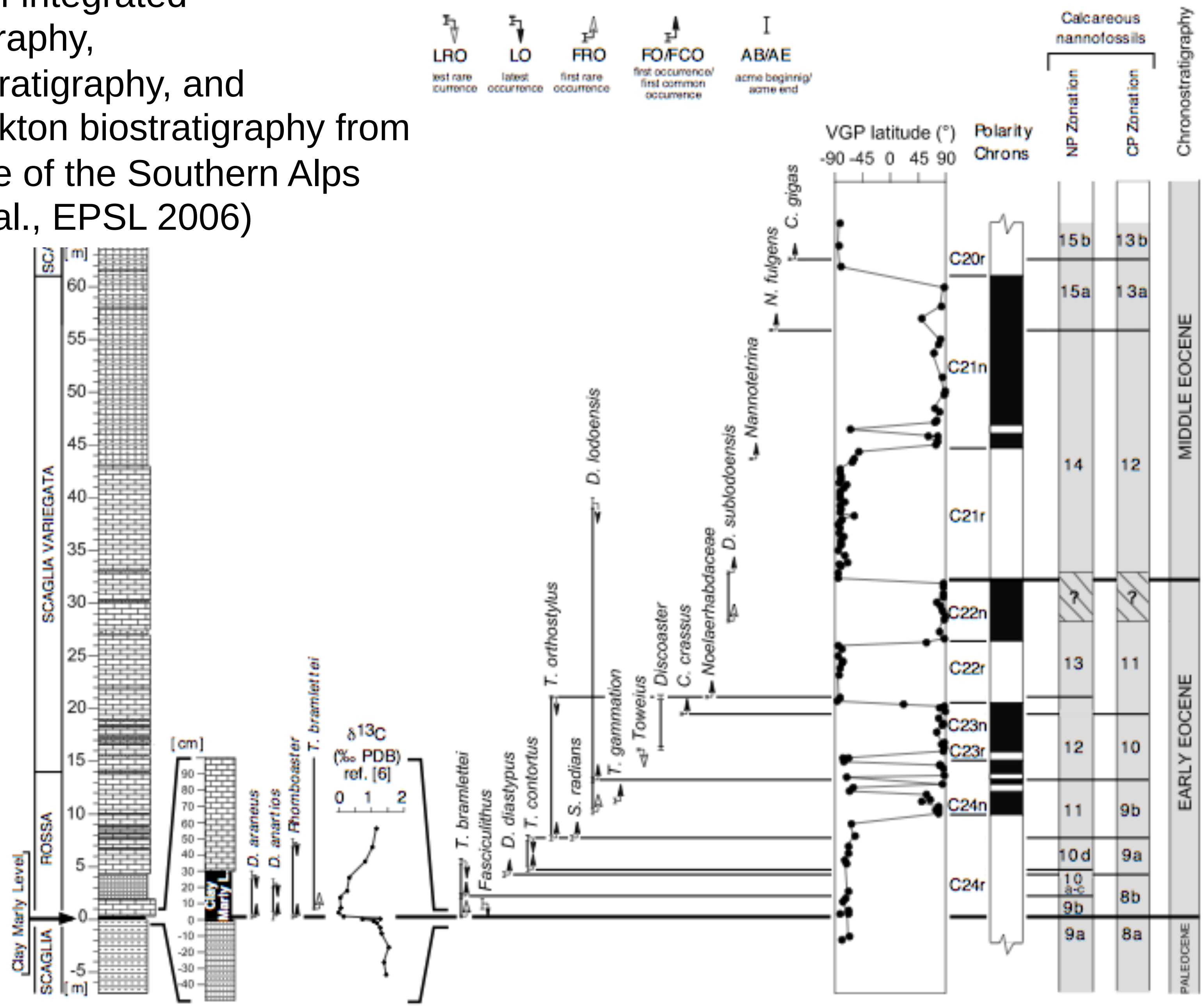


Fig. 1



Example of integrated lithostratigraphy, magnetostratigraphy, and nannoplankton biostratigraphy from the Eocene of the Southern Alps (Agnini et al., EPSL 2006)

Fig. 2



The ultimate aim of Stratigraphy is to construct a reference **time scale** where Earth’s time is ordered and ranked in geochronologic units: **Era, Period, Epoch, Age, Chron**. Each geochronologic unit is provided with a sequence of biozones (**biostratigraphy**) correlated with a sequence of magnetic polarity reversals (**magnetostratigraphy)** and with isotopic curves (**chemo-stratigraphy**), all of which are numerically dated using **geochrono-logy** in combi-nation with **cyclo-stratigraphy**.