Stratigraphic Classifications

(Subdivision of Rock Record)

- **Classic Stratigraphy**
  1- Lithostratigraphy
  2- Chronostratigraphy and Geochronology
  3- Biostratigraphy
  4- Magnetostratigraphy

- **Modern Stratigraphy**
  1- Allostratigraphy
  2- Cyclostratigraphy
  3- Chemostratigraphy
  4- Sequence stratigraphy (Genetic Stratigraphy)

Grand Canyon- USA

Classic Stratigraphic Classifications

1- Lithostratigraphy

2- Chronostratigraphy and Geochronology

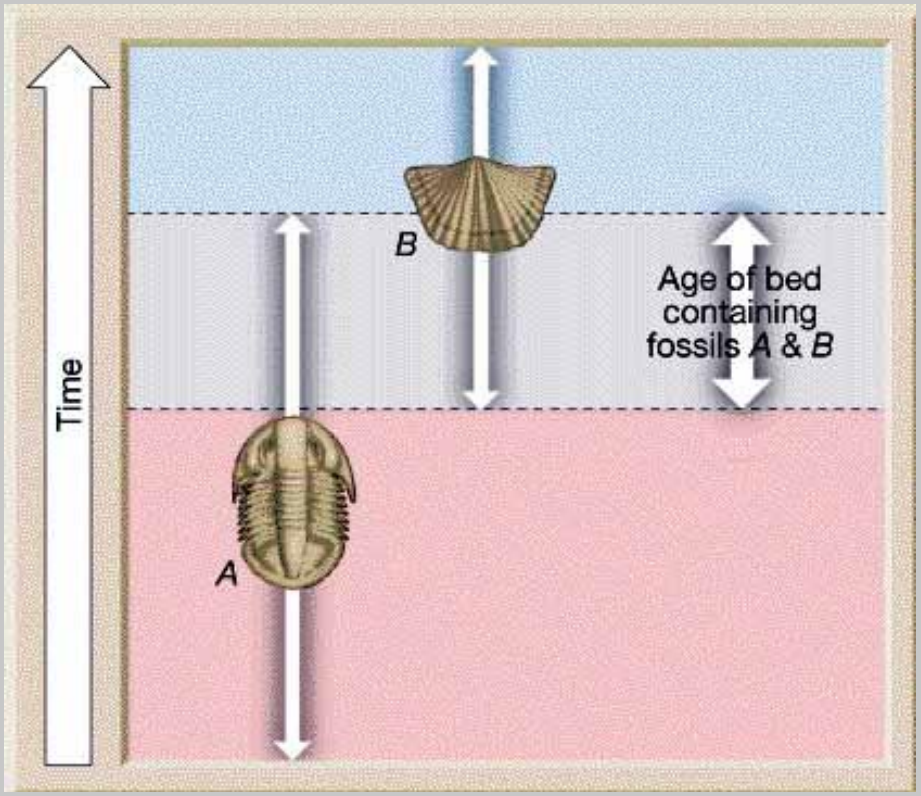
3- Biostratigraphy

4- Magnetostratigraphy

Biostratigraphy

Superzone - Biozones - *Subzones*

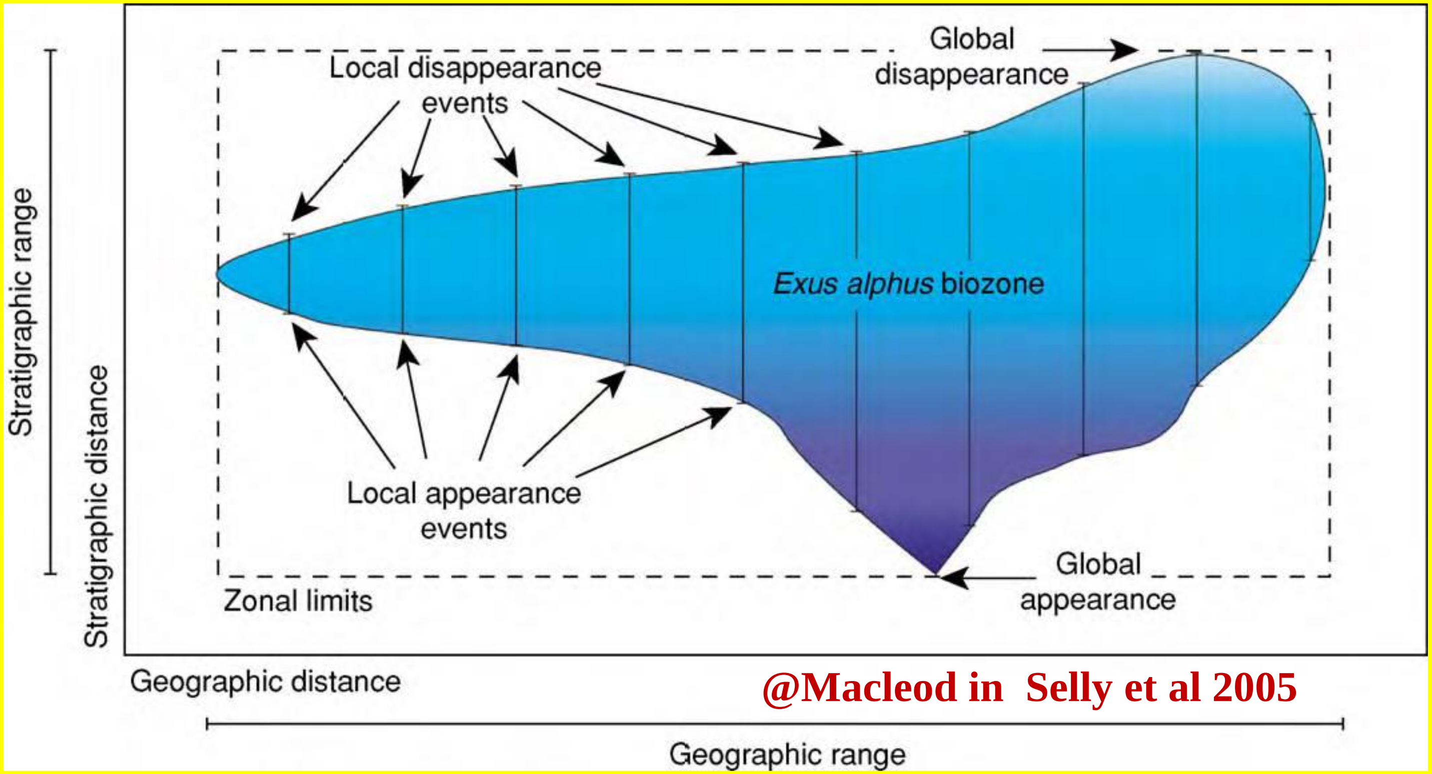
Biostratigraphic zone (Biozone) is a general term for any kind of biostratigraphic unit regardless of thickness or geographic extent, and represented time span.



Superbiozone (Superzone) is a grouping of two or more biozones with related biostratigraphic attributes.

Subbiozone (Subzone) is a subdivision of a biozone.

Biostratigraphic horizon (Biohorizon) is a stratigraphic boundary, surface, or interface across which there is a significant change in biostratigraphic character. A biohorizon has no thickness and should not be used to describe very thin and distinctive units.



@Macleod in Selly et al 2005

Barren intervals are stratigraphic intervals with no fossils common in the stratigraphic section.

Kinds of Biostratigraphic Units (Biozones)

Five kinds of biozones are in common use, which show no hierarchy:

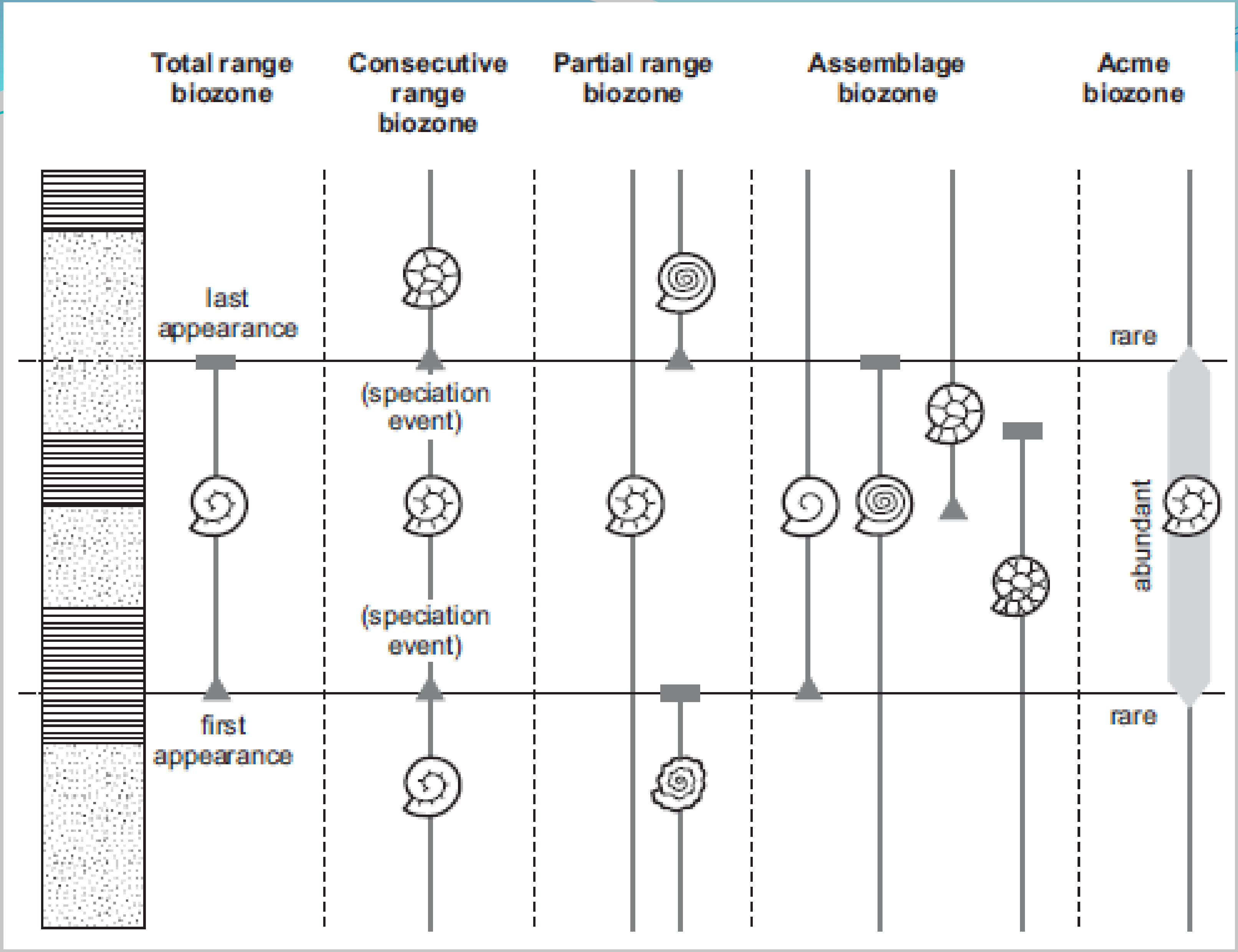
1. **Range Zone** (occurrence of a taxon or combination of two taxa)

2. **Interval Zone** (body of fossiliferous strata between two specified biohorizons)

3. **Lineage Zone** (body of strata containing specimens representing a specific segment of an evolutionary lineage).

4. **Assemblage Zone** (body of strata characterized by an assemblage of three or more fossil taxa)

5. **Abundance zone** (body of strata shows abundance of a particular taxon or specified group of taxa)



Zonation schemes used in biostratigraphic correlation
(Adapted from North American Commission on Stratigraphic Nomenclature 1983)

1. Range Zone

Range Zone is the body of strata representing the known stratigraphic and geographic range of occurrence of a particular taxon or combination of two taxa of any rank.

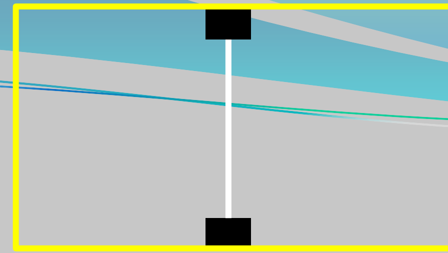
There are two principal types of range zones:

1.a- Taxon-range Zone:

It is the body of strata representing the known range of stratigraphic and geographic occurrence of specimens of a particular taxon. It is the sum of the documented occurrences in all individual sections and localities from which the particular taxon has been identified. The boundaries of a taxon-range zone in any one section are the horizons of lowest stratigraphic occurrence and highest stratigraphic occurrence of the specified taxon in that section. The taxon-range zone is named from the taxon whose range it expresses. The local range of a taxon may be specified in some local section, area, or region as long as the context is clear.

Taxon-range Biozone

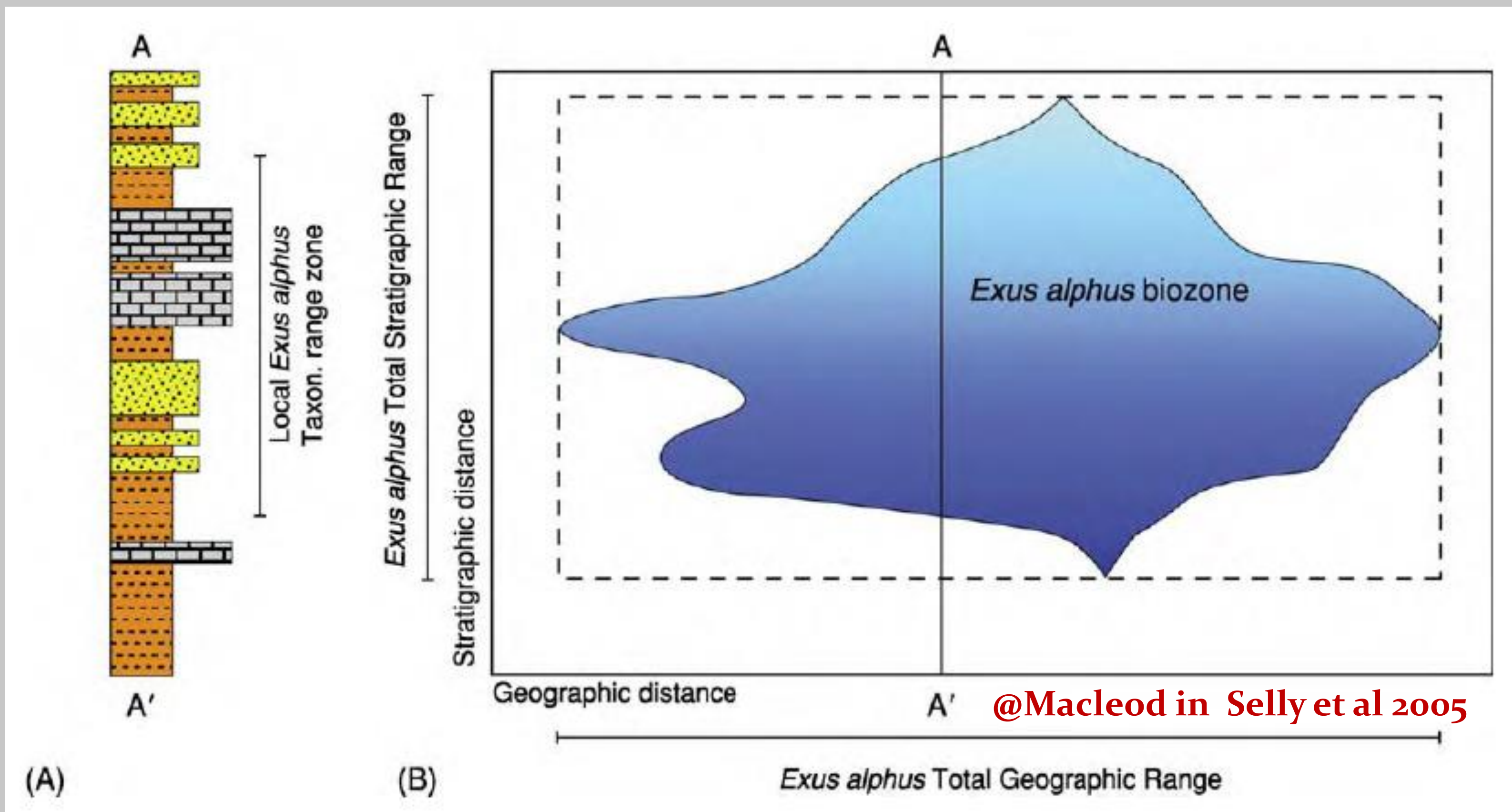
(Based on the range of a taxon)



Lower and upper range of taxon

Vertical range of taxon

Biozone boundaries (lower, upper, lateral)



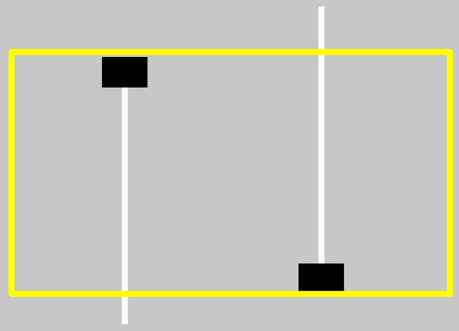
Taxon-range Zone Example:

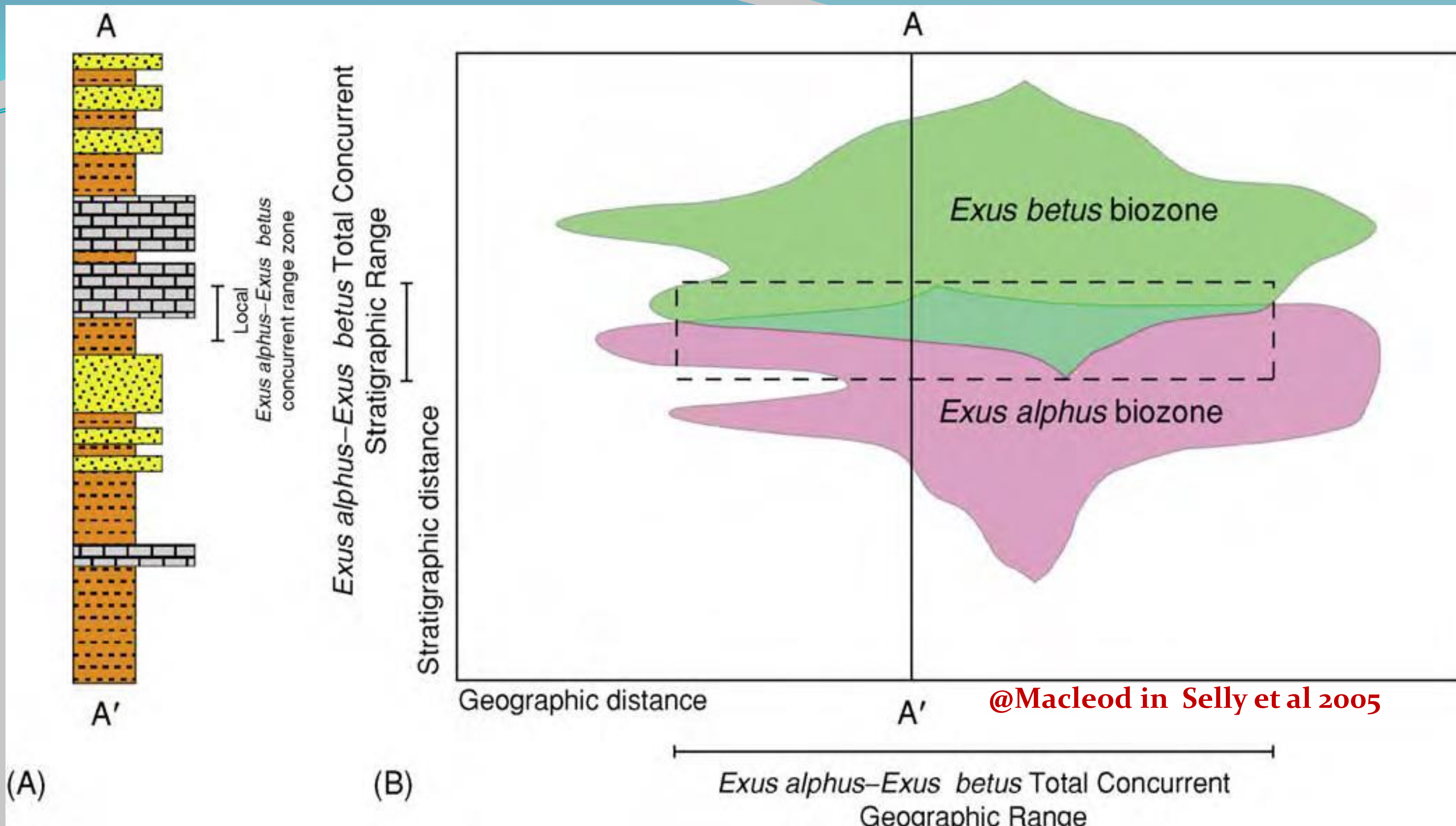
Interval between these two datums (lowest taxon's local first appearance and the local last appearance) represents the species' local biostratigraphic range. Note gaps in the appearance pattern can occur within the species' biostratigraphical range.

1.b. Concurrent-range Zone:

Concurrent-range zone (also referred to as an overlap zone or range-overlap zone) is the body of strata including the overlapping parts of the range zones of two specified taxa. This type of zone may include taxa additional to those specified as characterizing elements of the zone, but only the two specified taxa are used to define the boundaries of the zone. The boundaries of a concurrent-range zone are defined in any particular stratigraphic section by the lowest stratigraphic occurrence of the higher-ranging of the two defining taxa and the highest stratigraphic occurrence of the lower-ranging of the two defining taxa. A concurrent-range zone is named from both the taxa that define and characterize the biozone by their concurrence.

Concurrent-range Bizone
(Based on range of concurrent occurrence of two taxa)





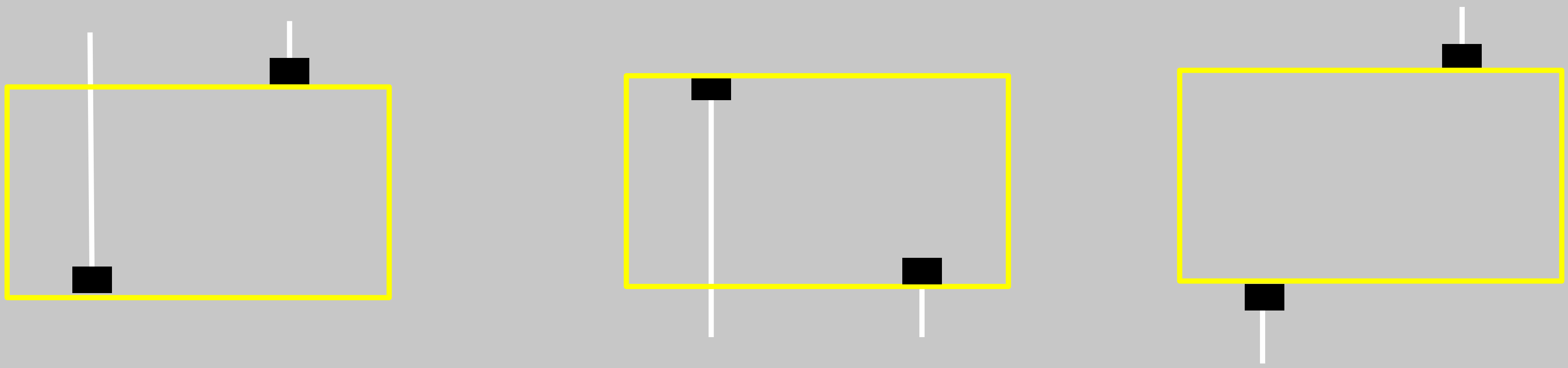
@Macleod in Selly et al 2005

Concurrent range Biozone example:

The zone encompasses all strata containing fossils assignable to the taxon range zones of *Exus alphus* and *Exus betus*. Globally, the speciation event of *Exus betus*, the extinction event of *Exus alphus*, and the geographic limits of the concurrent distribution of these two species' range biozones define a spatio temporal region within which the taxon's inferred Total Stratigraphic Range (vertical) and Total Geographic Range (horizontal) are defined (dashed box). Note the strong diachrony of the biozone boundaries.

2. Interval Zone

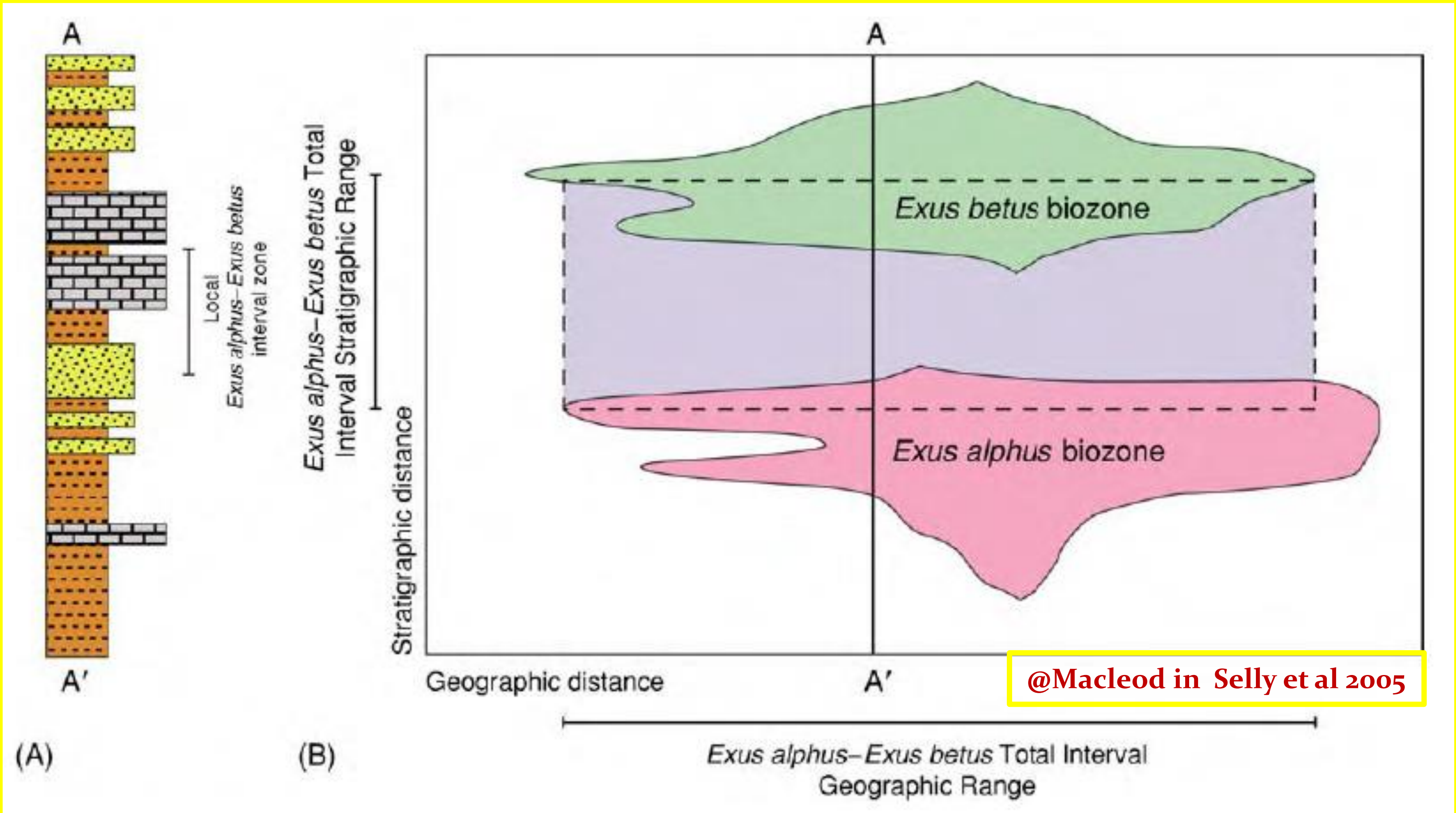
An **interval zone** (also referred to as an **interbiohorizon zone, gap zone, or a partial-range zone**) is the body of fossiliferous strata between **two specified biohorizons**. Such a zone is not itself necessarily the range zone of a taxon or concurrence of taxa; it is defined and identified only on the basis of its bounding biohorizons. The names given to interval zones may be derived from the names of the boundary horizons, the name of the basal boundary preceding that of the upper boundary; e.g., *Globigerinoides sicanus - Orbulina suturalis* Interval Zone.



A. Interval Biozone (based on lowest occurrences of taxa)

B. Interval Biozone (based on highest occurrences of taxa)

B. Interval Biozone (gabs between two taxa)



Interval Biozone example:

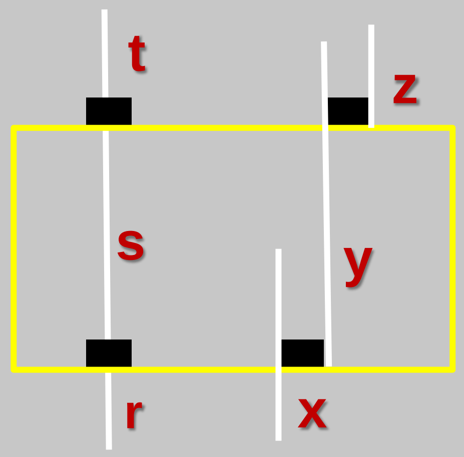
The zone begins at the geographic acme of the hypothetical species Exus alphus and encompasses all strata between this extinction datum and the overlying Exus betus geographic expansion datum. Globally, this interval between taxon range biozones defines a spatio-temporal region within which the interval biozone's inferred Total Stratigraphic Range (vertical) and Total Geographic Range (horizontal) are defined (dashed box). Note the strong diachrony of the biozone boundaries.

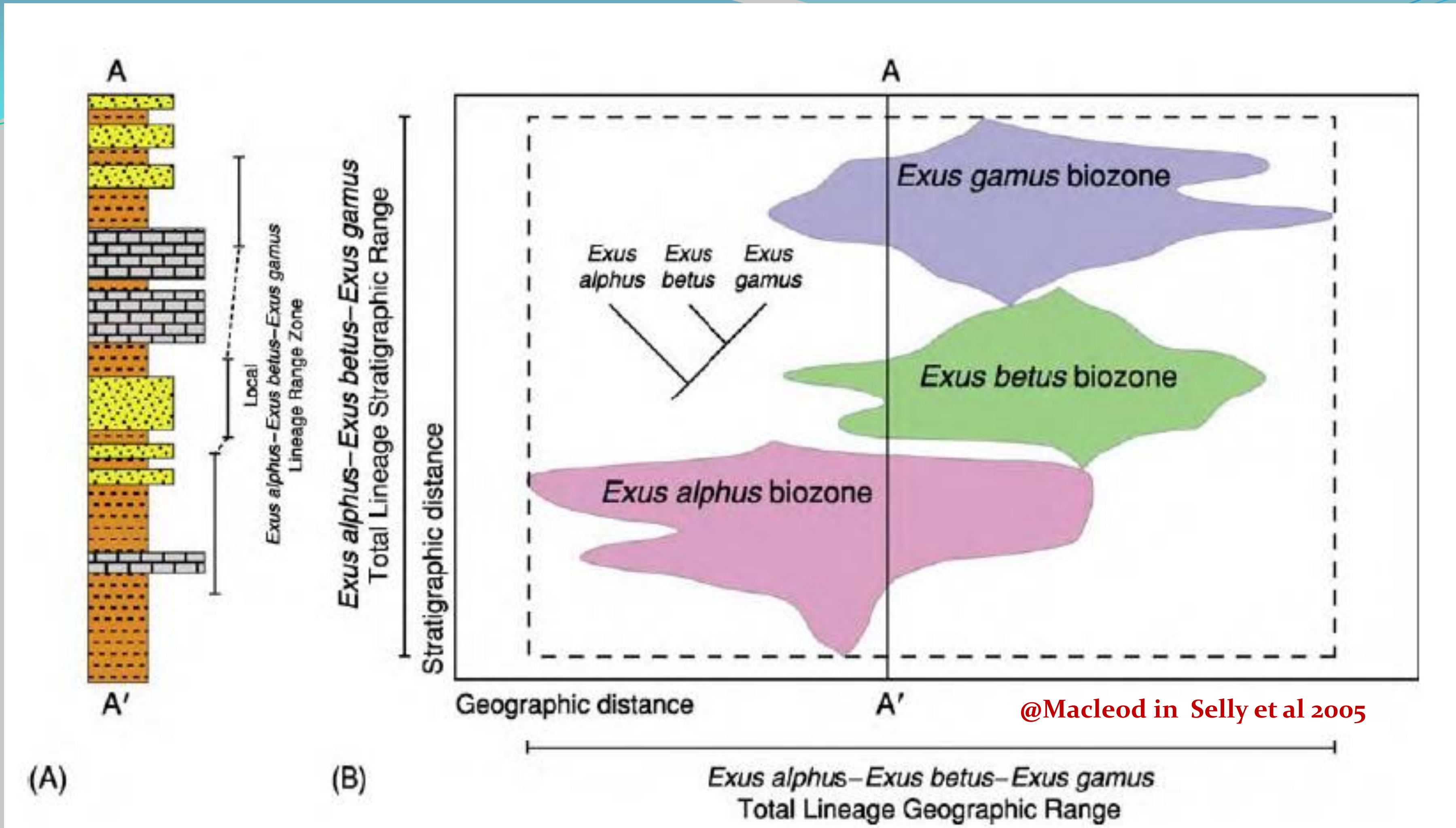
3. Lineage Zone

A lineage zone (also referred to as a phylozone, evolutionary zone, lineage zone, morphogenic zone, or phylogenetic zone) is the body of strata containing specimens representing a specific segment of an evolutionary lineage. It may represent the entire range of a taxon within a lineage or only that part of the range of the taxon below the appearance of a descendant taxon. The boundaries of a lineage zone are determined by the biohorizons representing the lowest occurrence of successive elements of the evolutionary lineage under consideration. A lineage zone is named for the taxon in the lineage whose range or partial range it represents.

Lineage Biozone
(based on successive species in a segment of an evolutionary lineage)

Taxa: (r, S, t, X, y, Z)



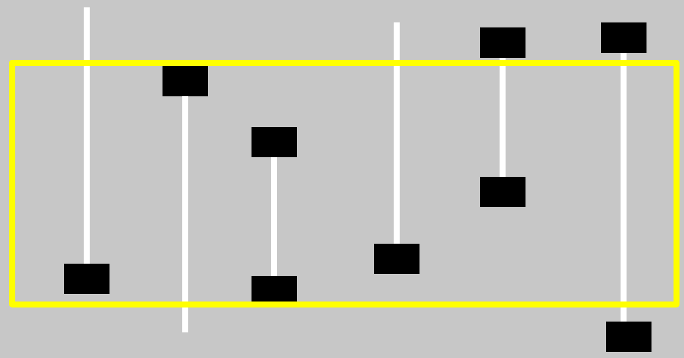


Lineage range biozone example:

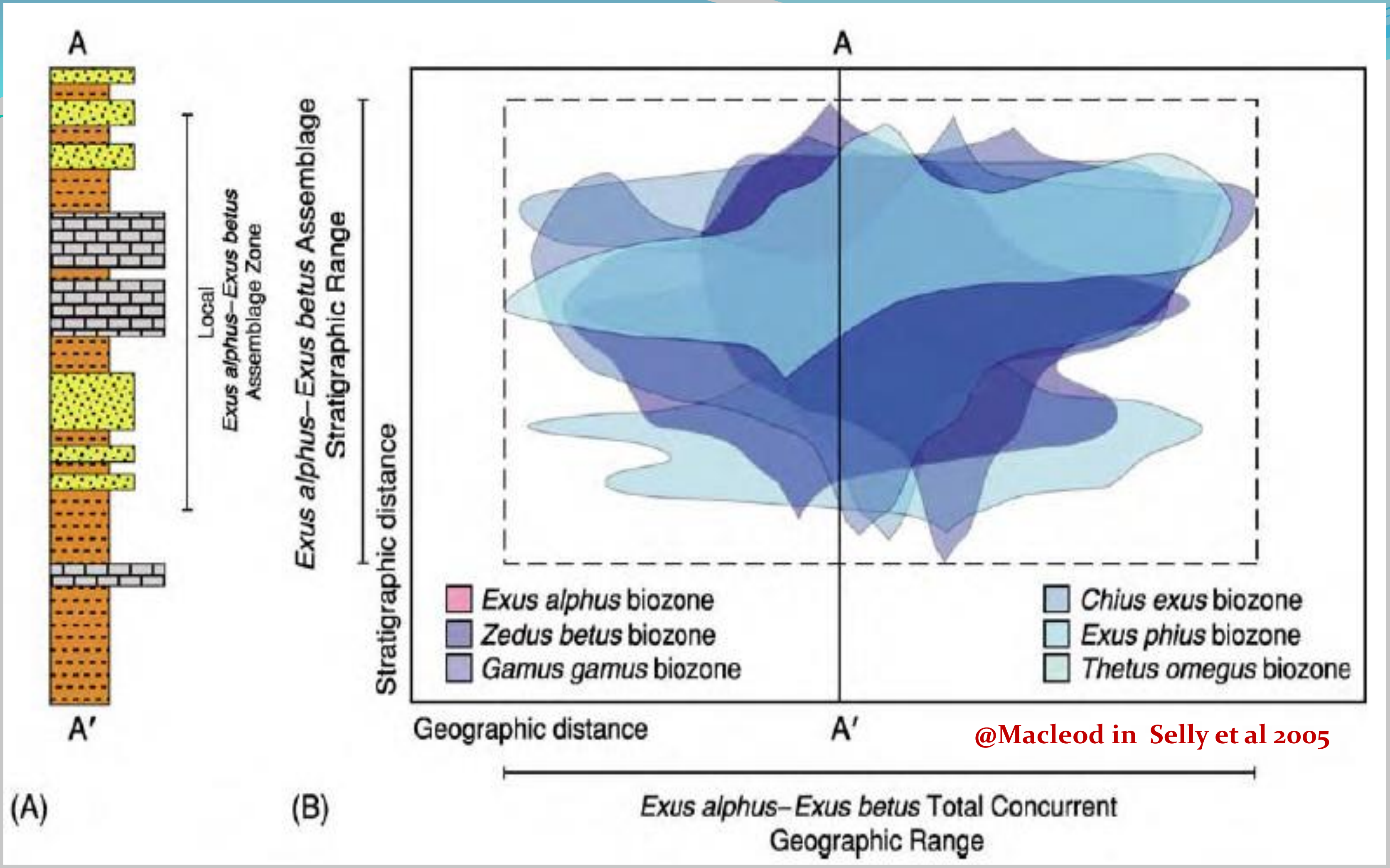
The zone begins at the speciation event of the species Exus alphus (representing the oldest species of the lineage) and encompasses all strata containing fossils assignable to the lineage. In this example, the stacked taxon range biozones for a three species lineage define the overall lineage biozone. Note the strong diachrony of the biozone boundaries.

4. Assemblage Zone

Assemblage Zone (also referred to as a cenozone, ecozone, ecological zone, faunizone, biofacies zone, and association zone) is the body of strata characterized by an assemblage of three or more fossil taxa that, taken together, distinguishes it in biostratigraphic character from adjacent strata. The boundaries of an assemblage zone are drawn at biohorizons marking the limits of occurrence of the specified assemblage that is characteristic of the unit. The total range of any of its constituents may extend beyond the boundaries of the zone. The name of an assemblage zone is derived from the name of one of the prominent and diagnostic constituents of the fossil assemblage.



Assemblage Biozone
(based on overlapping ranges of an assemblage co-occuring taxa)

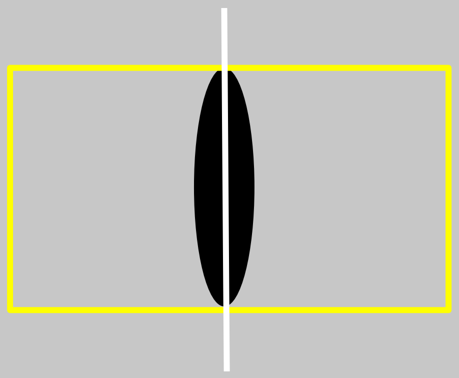


Assemblage range biozone example:

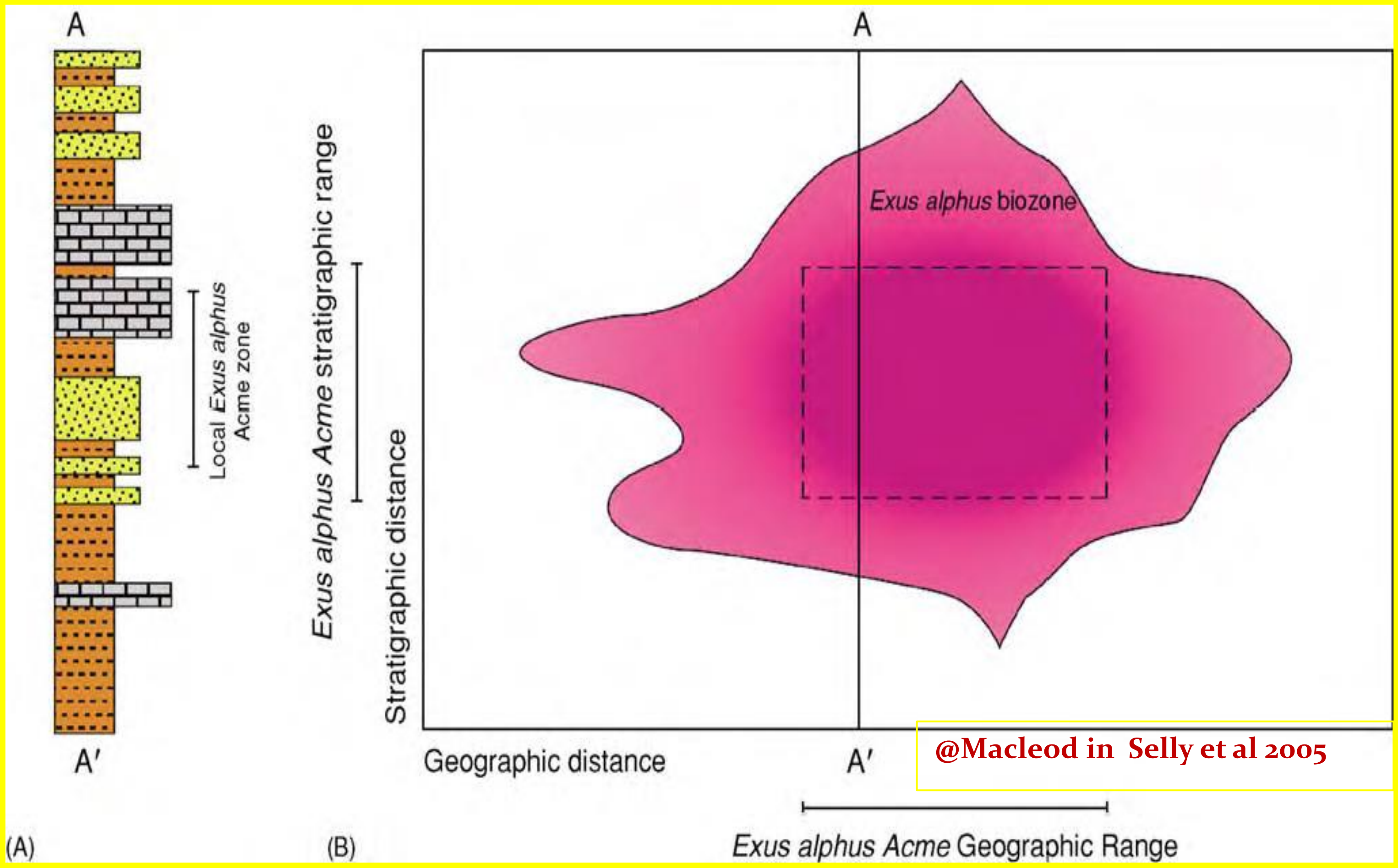
The zone (*Exus alphus* representingthe oldest species in an assemblage of six fossil species usually found together in the same environment) encompasses all strata containing fossils assignable. The boundary definitions are chosen so as to base the zone on a series of ecologically related taxa. Note the strong diachrony of the biozone boundaries.

5. Abundance or Acme Zone

The body of strata in which the abundance of a particular taxon or specified group of taxa is significantly greater than is usual in the adjacent parts of the section. An abundance zone must be identified and traced laterally. The boundaries of an abundance zone are defined by the biohorizons across which there is notable change in the abundance of the specified taxon or taxa that characterize the zone. The abundance zone takes its name from the taxon or taxa whose significantly greater abundance it represents.



Abundance Biozone
(thickned line denotes range of increased abundance of the taxon)



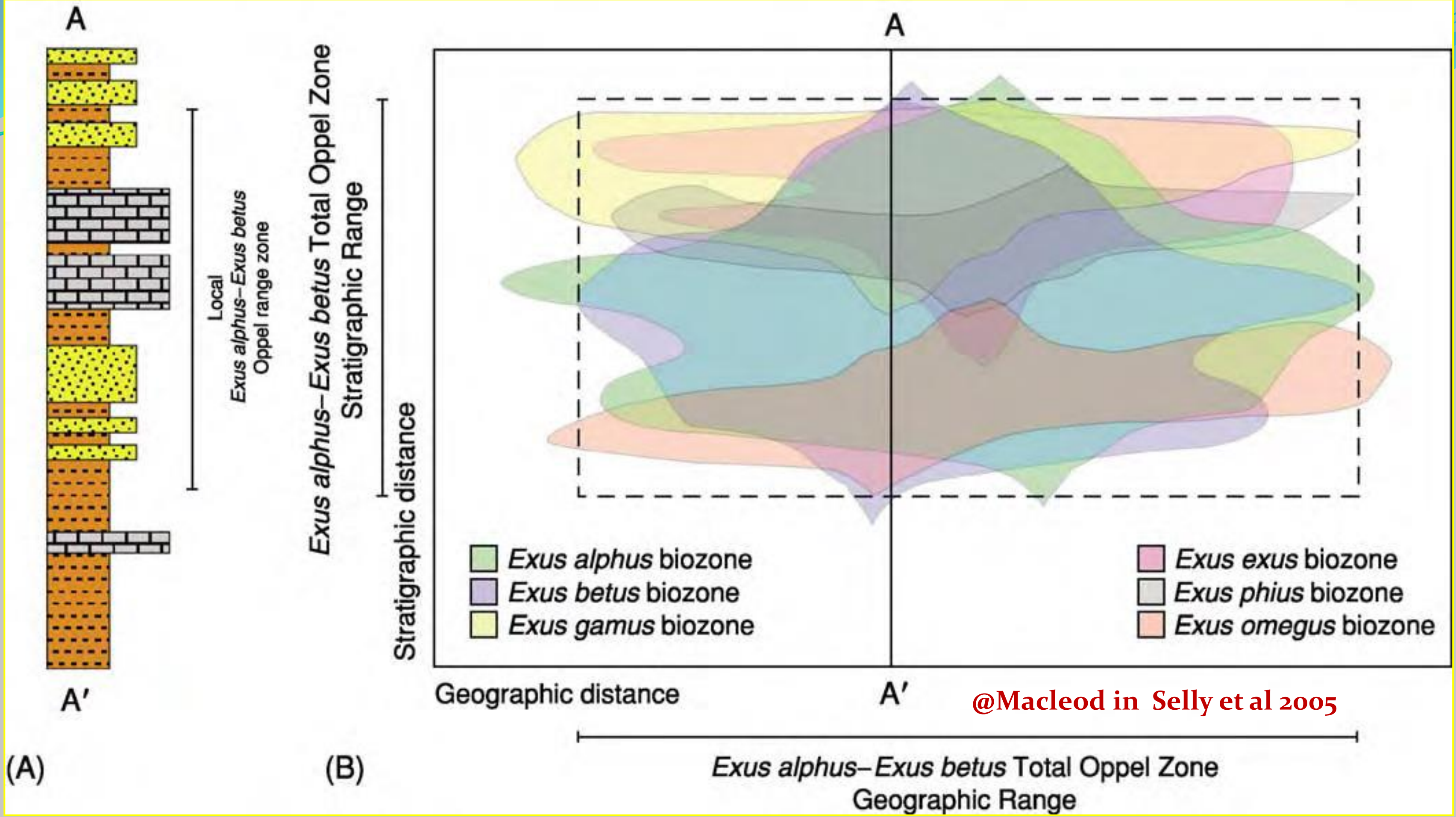
Acme biozone example:

The zone encompasses all strata in which the species is regarded as abundant and substantial increase in the relative abundance of the species (symbolized by dark shading of the hypothetical species *Exus alphus* (dashed box). Note the strong diachrony of the biozone boundaries. Many other definitions of acme are also possible (e.g., increased size, increased ornamentation).

Oppel range (special) biozone

Oppel zone is a body of strata delineated by the ranges and range-limits of a group of fossil taxa selected in such a way as to minimize zonal boundary diachrony and maximize the geographic scope of the interval so defined.

Unlike concurrent range zones, Oppel zones do not rely on the necessary presence of all defining taxa to be recognised. Oppel zones are named for the dominant taxon used to recognise the zone's presence (e.g., *Subcolumbites-Prohungarites* Oppel Zone, *Globigerina selli–Pseudohastigerina barbadoensis* Oppel Zone).



Oppel range biozone (Special and historical biozone):

The zone begins at the speciation event of the species Exus omegus (representing the lowest interval of a concurrent range based on Exus alphus, Exus betus, and Exus omegus), and encompasses all strata containing fossils assignable to the upper limit of the *Exus alphus Exus beta Exus gamus* concurrent range zone. In Oppel type biozones, the boundary definitions are chosen so as to enhance the ability of this zone to approximate biochronozone. Note the relatively modest diachrony of the biozone boundaries.

Establishing and Naming of Biostratigraphic Units

1- Establishing the Units:

- **Assigning reference sections are for the recognized of a biostratigraphic unit.**
- **Biostratigraphic units are extended away from the areas where they were defined or from their reference sections by biostratigraphic correlation, which is not necessarily time-correlation.**

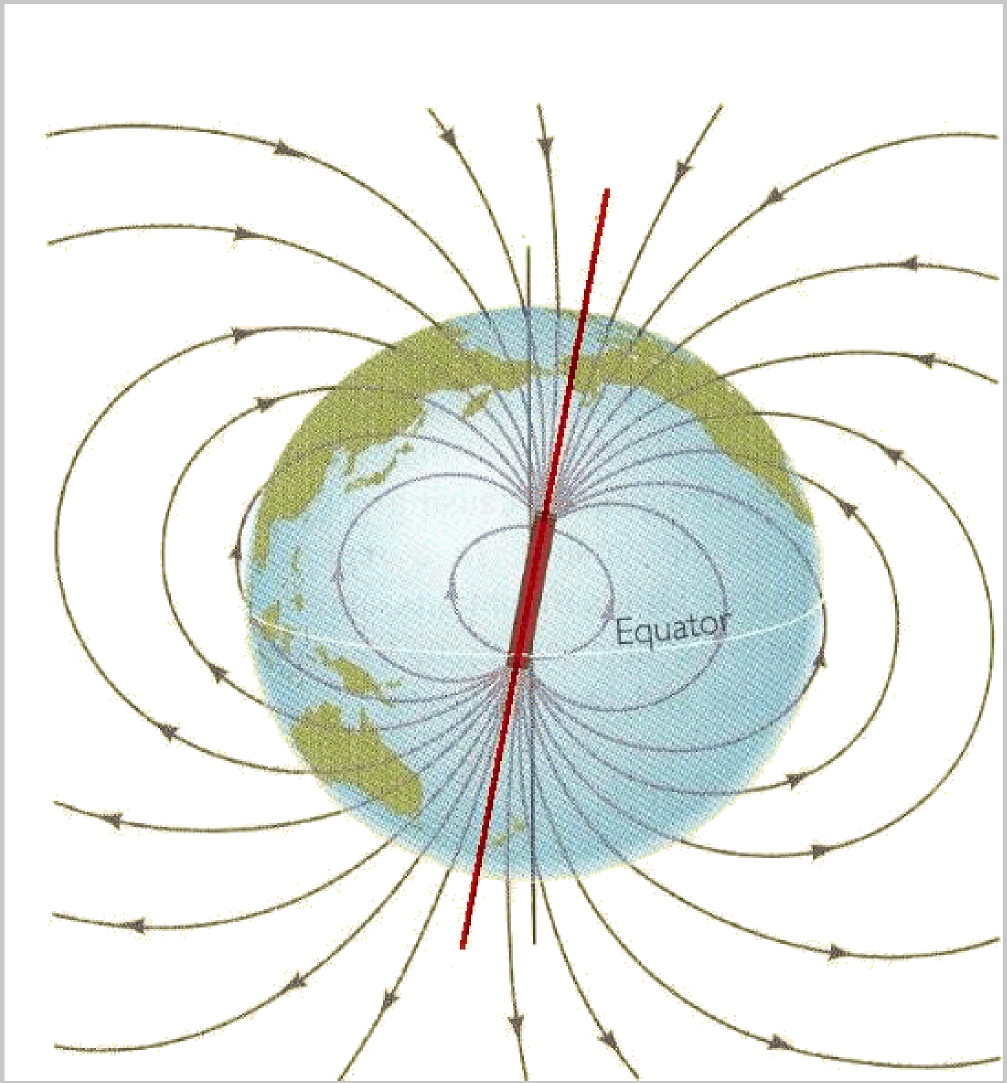
2- The formal name of a biostratigraphic unit:

- **The names of one, or no more than two, appropriate fossils + Appropriate term for unit**
- **The initial letter of the unit-term (Biozone, Zone, Assemblage Zone) should be capitalized as well as that of the generic names; the initial letter of the specific epithets should be in lowercase; taxonomic names of genera and species should be in italics**
- **For example: *Exus albus* Range Zone.**

3- Revision of Biostratigraphic Units:

- The first biostratigraphic zonation to be described is not necessarily the most useful. However, revision or changes in nomenclature of biostratigraphic units may be needed.
- Named biostratigraphic units will automatically change scope to accord with changes in the scope of taxa defining or characterizing them. A fossil name once used for a biozone is not available for use in a different zonal sense by a later author.
- If it is desirable to continue the use of a taxonomic term that is no longer valid, the term should be placed in quotation marks, e.g. "*Rotalia*" *beccari* Zone.

Magnetostratigraphy



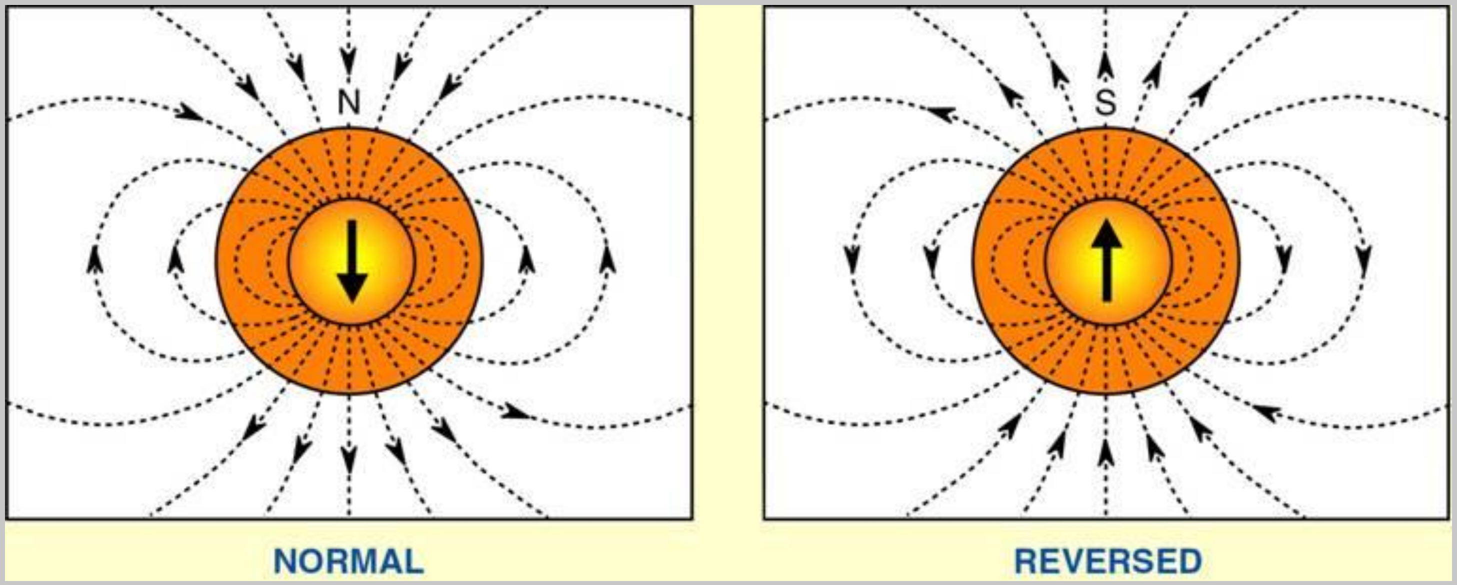
Magnetostratigraphy

- **Magnetostratigraphy** **is the element of stratigraphy that deals with the magnetic characteristics of rock bodies.**

- **Magnetostratigraphic polarity classification** **is the organization of rock bodies into units based on changes in the polarity of their remnant magnetization related to reversals in the polarity of the Earth's magnetic field.**

Magnetostratigraphy
a dipole reversing at irregular times

- In late 19th century, it was discovered that some rock-forming minerals are magnetized in the south magnetic pole rather than the north. The first estimate of the timing of magnetic reversals was made in the 1920s by Matuyama in Japan rocks. Thus, it was suggested that the polarity of the Earth's magnetic field had changed through time.



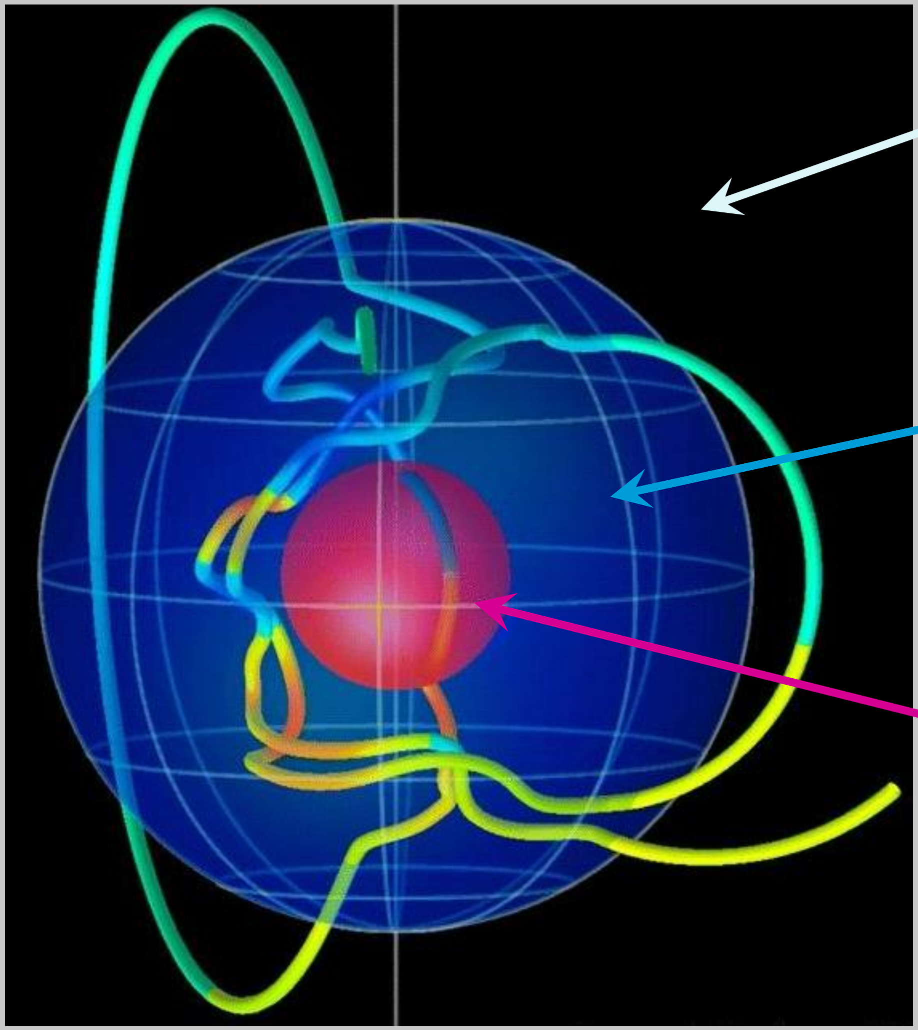
Causes of magnetic reversals

Geomagnetic reversals are the result of internal to the system that generates the Earth's magnetic field and or external events.

I- Internal events aspect:

- **The aspect of dynamo theory is used to interpret the generation of geomagnetic field. In simulations, magnetic field lines can sometimes become tangled and disorganized through the chaotic motions of liquid metal in the Earth's core. During these periods, the direction and magnitude of the magnetic field observed at any point on the surface fluctuate, and net field strength is reduced by dipole-dipole interactions. In some simulations, this leads to an instability in which the magnetic field spontaneously flips over into the opposite orientation.**

- **This scenario is supported by observations of the solar magnetic field, which undergoes spontaneous reversals every 9–12 years.**



Kuang & Bloxham, 1997

Mantle

Convection time scale ~100 Myr

Reversal frequency, superchrons

Liquid outer core

Convection time scale 300-500 yr

Geodynamo action*: Secular variation, excursions, reversals*

Solid inner core

Diffusion time scale 3-5 kyr

Stabilises geodynamo process

II- External events aspect:

- **Geomagnetic reversals are not spontaneous processes but rather are triggered by external events, which directly disrupt the flow in the Earth's core (e.g., Muller, 2002). Such processes may include: the arrival of continental slabs carried down into the mantle by the action of plate tectonics at subduction zones, the initiation of new mantle plumes from the core-mantle boundary, and possibly mantle-core shear forces resulting from very large impact events.**

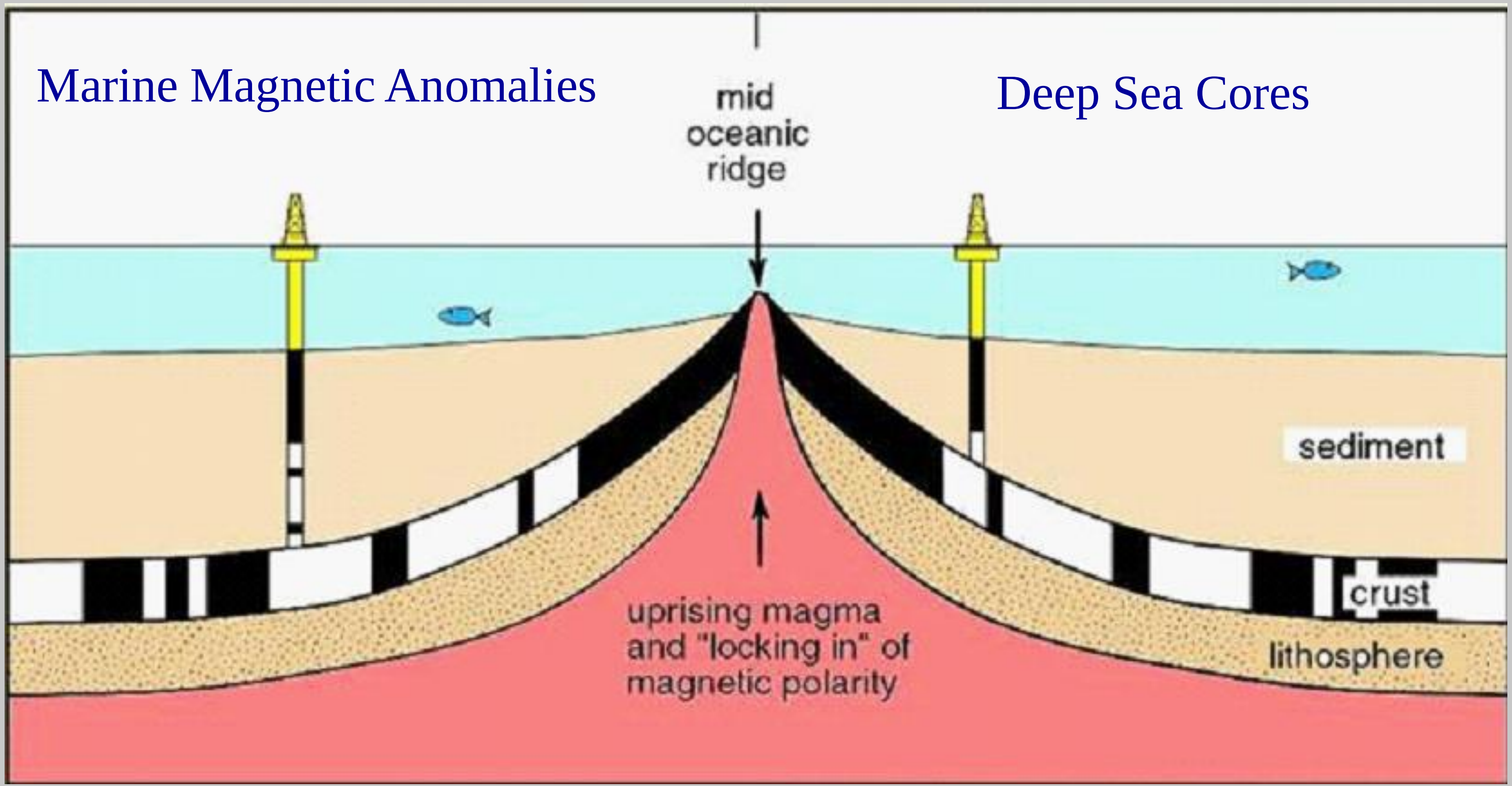
- **Supporters of this theory hold that any of these events could lead to a large scale disruption of the dynamo, effectively turning off the geomagnetic field.**

Methods of measuring paleomagnetic polarity

- **Development of plate-tectonic theory revealed that the sea floor spreading along the mid oceanic crust act as a tape recorder of the change in polarity of the Earth's magnetic field. Lava flows cools through a particular temperature called its Curie point , where it becomes magnetized. High magnetic field strength shows normal polarity, whereas low magnetic field strength shows reverse of today (reversed polarity).**

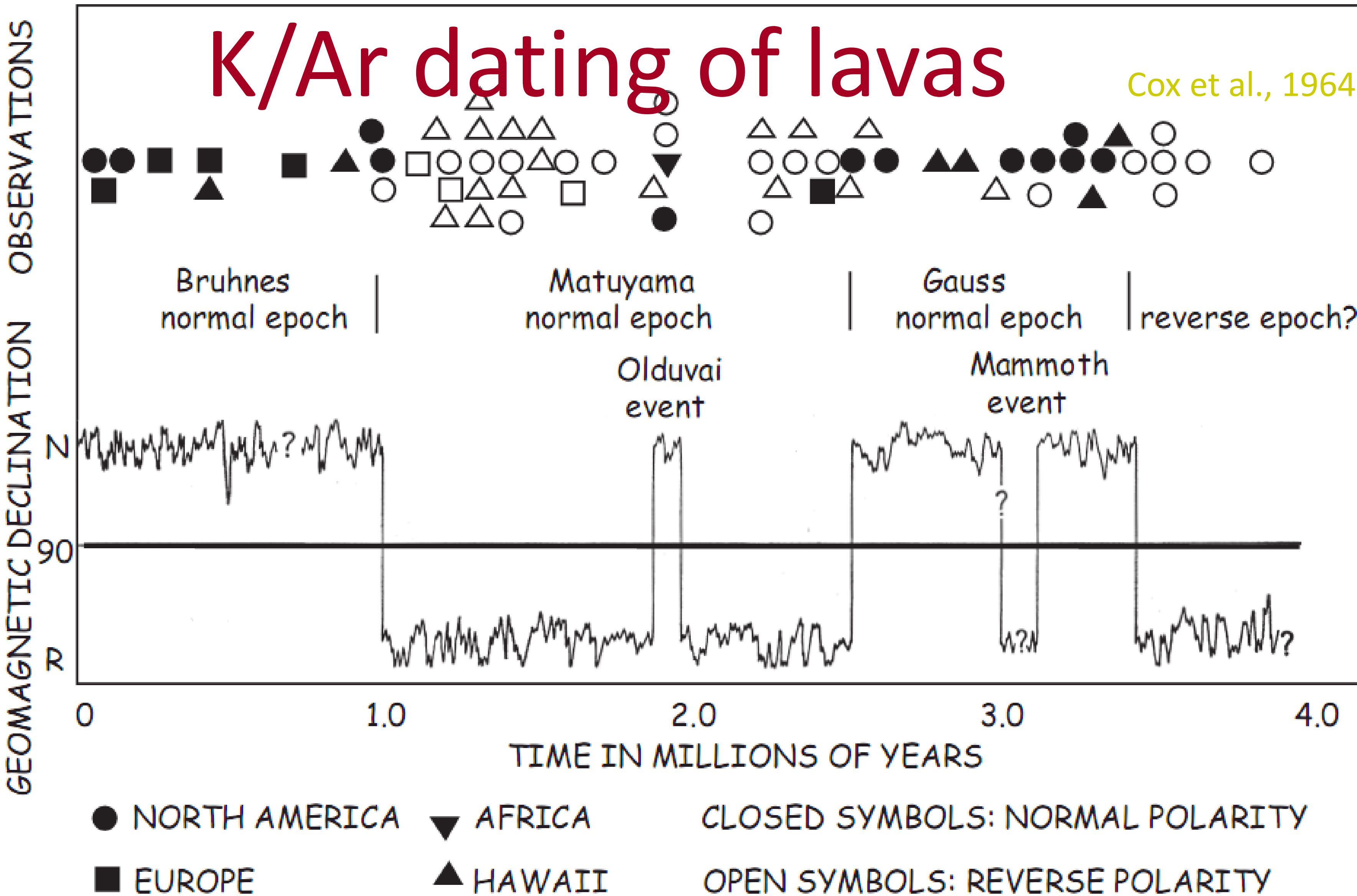
- **Magnetic minerals (iron oxides & clay minerals) in cemented and compacted sediments (neither metamorphosed nor heated above their Curie point) align themselves to reversed or normal polarity.**

- The polarity pattern from both the seafloor basalts and exposed or drilled sedimentary deposits can be correlated within a framework of other dating techniques completed on the same rocks, e.g. biostratigraphy and radiometric dates, enabling a polarity time-scale to be constructed.



K/Ar dating of lavas

Cox et al., 1964



Geomagnetic Polarity Time Scale (GPTS)

Geomagnetic secular variation exhibits periodicities between 1 yr. and 105 yr. Geomagnetic polarity intervals have a range of durations from 104 to 108 yr.

Geomagnetic behavior

Pulsations or short term fluctuations	minutes
Daily magnetic variations	hours
magnetic storms	hours to days
Secular variation	10^2 - 10^3 yr
Magnetic excursions	10^3 - 10^4 yr
Reversal transitions	10^3 - 10^4 yr
Subchrons	10^5 - 10^6 yr
Chrons	10^6 - 10^7 yr
Superchrons	10^7 - 10^8 yr

Development of the Geomagnetic Polarity Time Scale (GPTS)

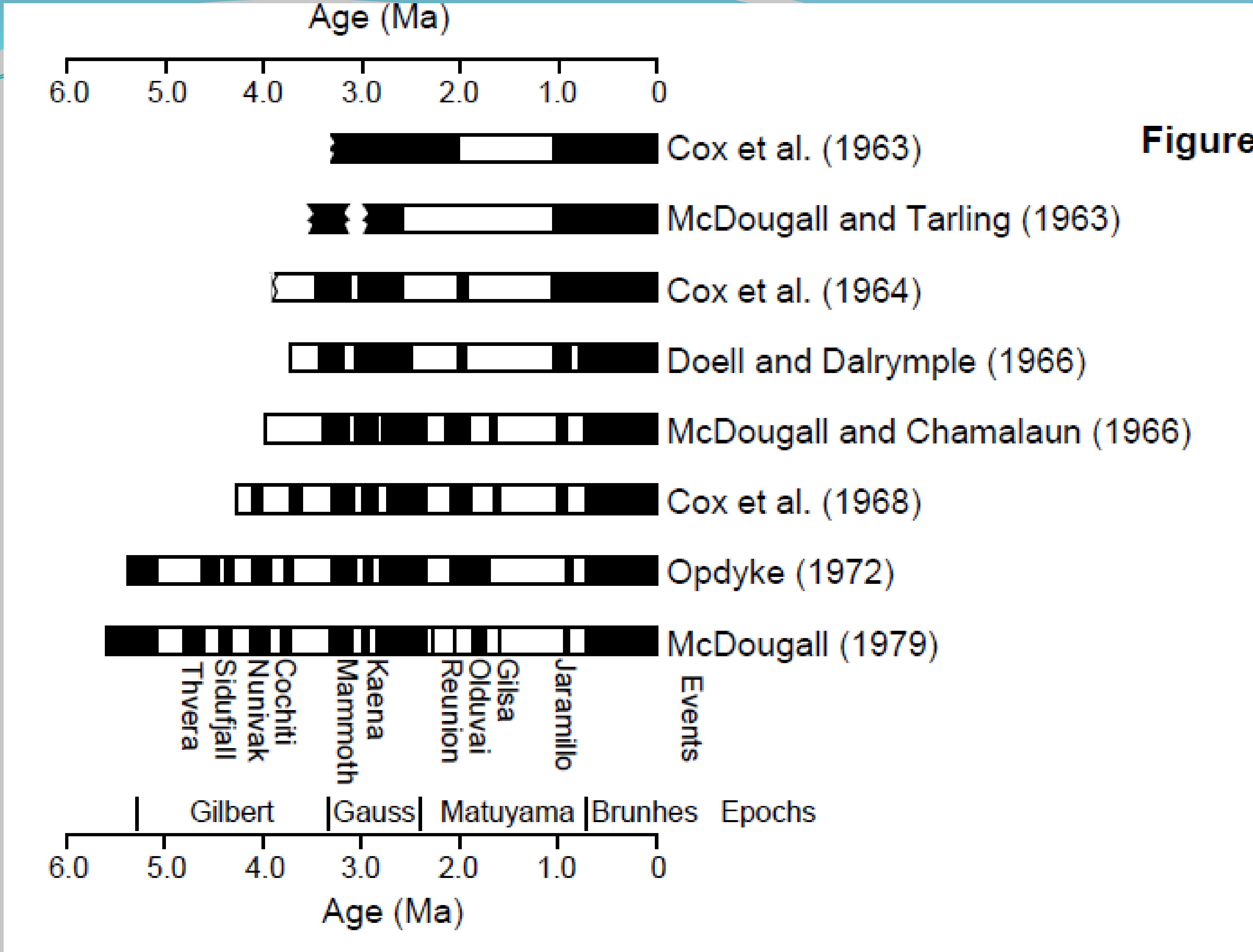
1- The Pliocene–Pleistocene:

Modern development of GPTS was initiated in the 1960s following accurate Potassium-Argon (K-Ar) dating of Pliocene–Pleistocene igneous rocks. Age and magnetic polarity were compiled and led to the development of the first GPTS in the 0- to 5-Ma time interval.

Polarity Epochs (chron): **These polarity intervals were called polarity epochs. These epochs were named for the first time after prominent figures in the history of geomagnetism: Brunhes, Matuyama, Gauss and Gilbert. Polarity intervals (durations of about 1 m.y.)**

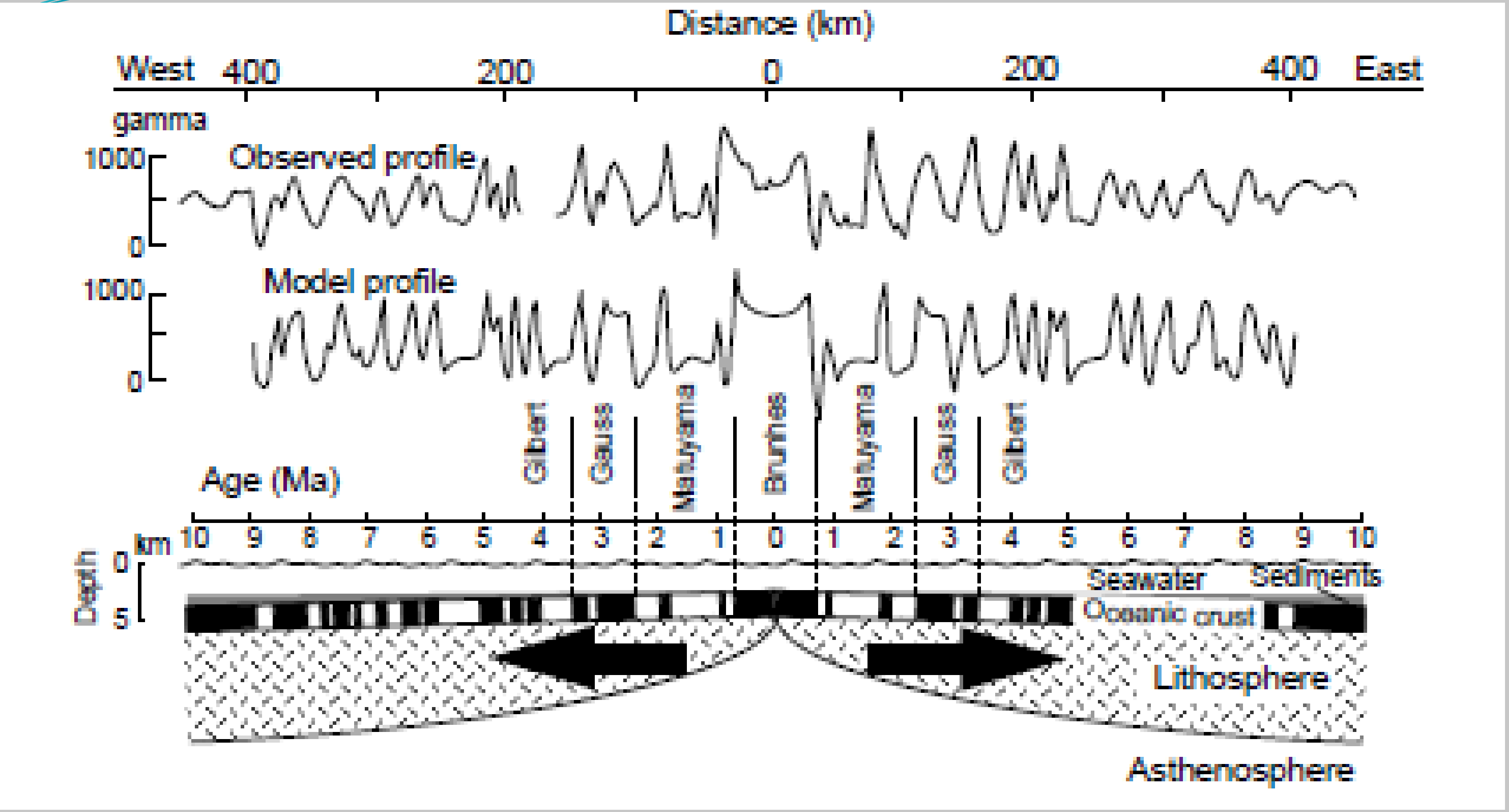
Polarity Events: **Later, shorter intervals of opposite polarity occurred within the polarity epochs. These shorter intervals were called polarity events and were named after the locality at which they were first sampled.**

The polarity epoch and event nomenclature is basically an accident of history but is retained as a matter of convenience for this portion of the time scale.



Evolution of the Pliocene–Pleistocene geomagnetic polarity time scale between 1963 and 1979.

2- Marine magnetic anomalies



Formation of marine magnetic anomalies at an oceanic ridge undergoing seafloor spreading. The black (white) blocks of oceanic crust represent the normal (reversed) magnetic polarity during original cooling of the oceanic crust. Adapted from Pitman and Heirtzler (1966).

- **When marine magnetic anomaly profiles were used to develop geomagnetic polarity time scales, a system of geomagnetic polarity chrons was developed.**

- **A chron is a ime intervals of geomagnetic polarity that is tied to the marine magnetic anomaly numbering system. The normal-polarity time interval (e.g., chron 25) is followed by reversed-polarity time intervals by using a suffix “r” (chron 25r).**

- **Paleontological dating of DSDP sediment cores provided also have provided detailed biostratigraphic calibrations. These polarity zones are labeled by using an alphabetical system. This is now common (and well-advised) practice in magnetostratigraphy.**

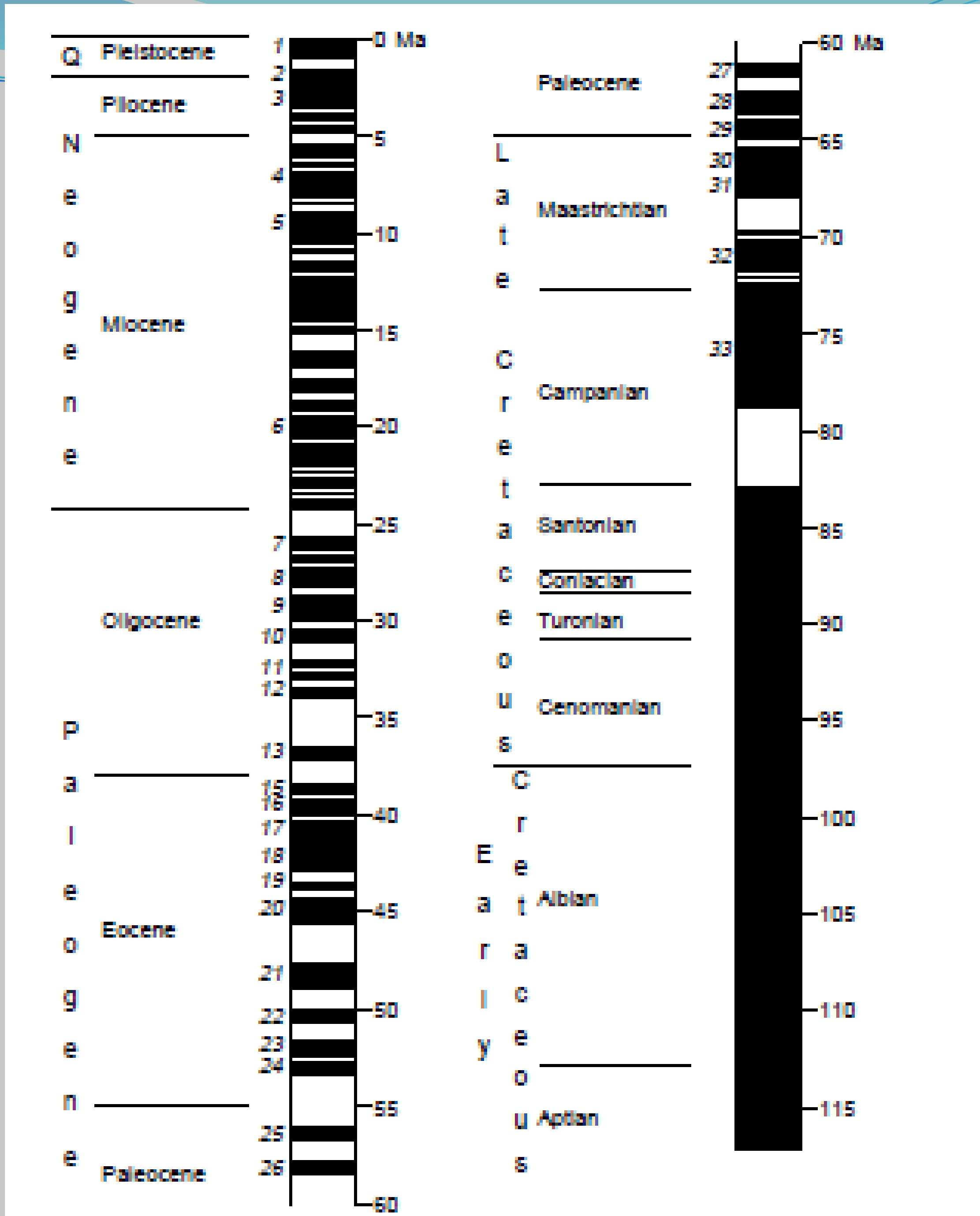
3- Late Cretaceous–Cenozoic GPTS

- The results from DSDP cores and magnetostratigraphic investigations can allow biostratigraphic calibration of the geomagnetic polarity time scale. But what about absolute age calibration? Development of geologic time scales involves association of isotopically dated horizons with the biostratigraphic zones.
- A Late Cretaceous-Cenozoic GPTS developed as part of a larger geological time scale project (and influenced by an effort to minimize changes in seafloor spreading rates) is given in the Figure below by Cox (1982).
- At least for the Cenozoic, we can conclude that absolute ages of magnetic polarity chrons are known to a precision of ~ 2 m.y.
- A major feature of the geomagnetic polarity time scale in the Cretaceous is the Cretaceous normal polarity superchron, during which the geomagnetic field was of constant normal polarity. On the Cox (1982) time scale, this interval has absolute age limits of 118 and 83 Ma; the geomagnetic field did not reverse polarity for ~35 m.y.!

Cretaceous Long Normal Superchron:

A long period of time during which there were no magnetic pole reversals, the Cretaceous Long Normal (also called the Cretaceous Superchron or C34) lasted for almost 40 million years, from about 120 to 83 million years ago (Aptian through the Santonian).

Geomagnetic polarity time scale of Cox (1982) from 0 to 118 Ma. Geologic time to the left of the polarity column; polarity chron numbers are shown in italics at the left of the polarity column; age (in Ma) is shown by the scale to the right of the polarity column.

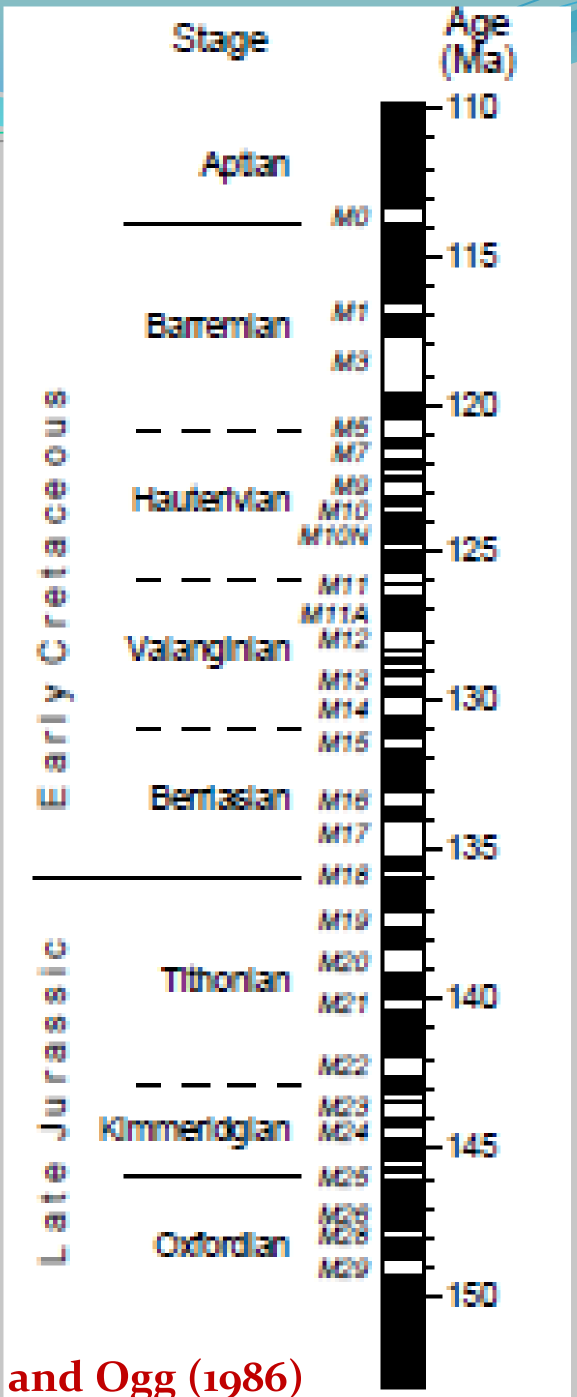


4- The Late Mesozoic

- Marine magnetic anomalies have also been mapped above Late Jurassic and Early Cretaceous oceanic crust. These are the "M anomalies," in which "M" stands for Mesozoic. Again, prominent positive magnetic anomalies have been numbered.

- A recent GPTS for the Late Jurassic and Early Cretaceous is shown in (see Figure). Data from primarily deep ocean cores, deep cores and stratotype sections.

- It is worth to mention that both biostratigraphic calibration and absolute age calibration of the Late Jurassic and Early Cretaceous polarity time scale is uncertain (the absolute age of polarity chrons in this geologic time interval are known to only about 5 m.y). "M anomaly" designations of reversed polarity chrons are given in italics at the left of the polarity column.



After Lowrie and Ogg (1986)

5- Early Mesozoic, Paleozoic, and Precambrian

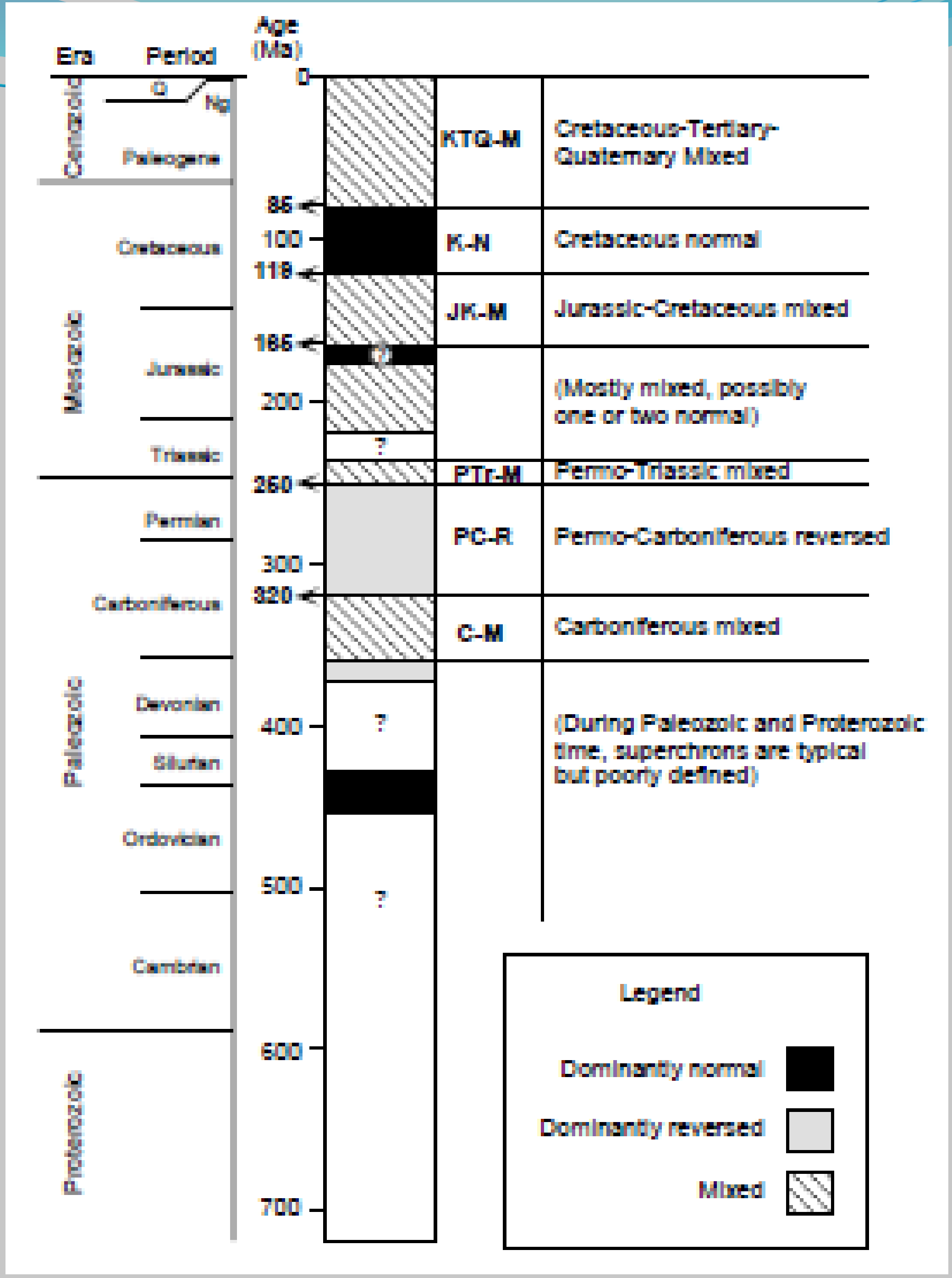
- **The oldest substantial portions of oceanic crust remaining in ocean basins are Late Jurassic in age. So the determination of the GPTS for older intervals must be done by paleomagnetic studies of exposed stratigraphic sections on land. Accordingly, our knowledge of the polarity time scale for Early Mesozoic and older times is much less refined than for the Late Mesozoic and Cenozoic.**

- **Kiaman Long Reversed Superchron: This long period without geomagnetic reversals lasted from late Carboniferous to late Permian (> 50 m.y.) from around 312 to 262 m.y. ago. The magnetic field was reversed polarity. The name "Kiaman" derives from the Australian village of Kiama.**

- **Moyero Reversed Superchron: This period in the Ordovician (>20 m.y.) (485 to 463 m.y. ago). Moyero river section is located at Siberia.**

- **Generally, the pattern of polarity reversals in the Early Paleozoic and Proterozoic is poorly known.**

Polarity bias superchrons during the Proterozoic and Phanerozoic. Absolute age is shown to the left of the polarity bias column with age limits of polarity superchrons shown in bold type; names of polarity bias superchrons are given to the right of the column.

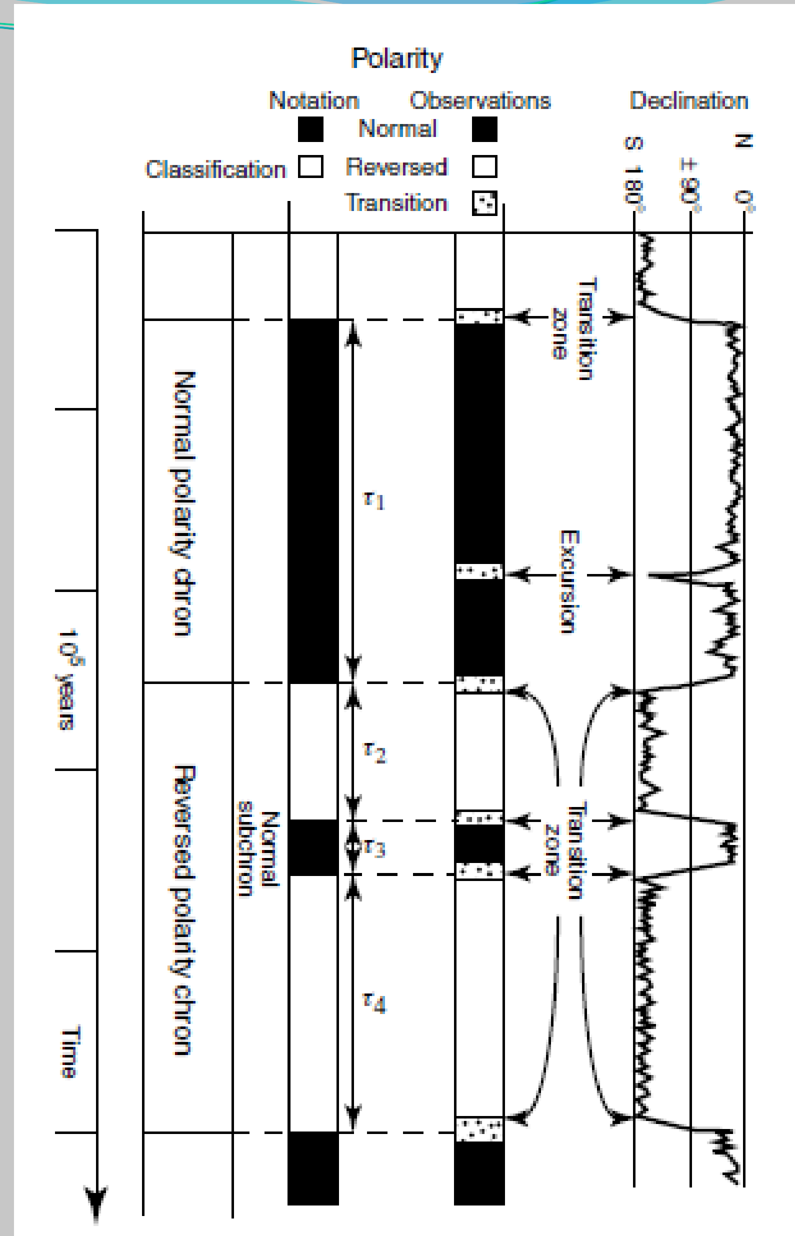


Magnetostratigraphic polarity unit

- **Magnetostratigraphic polarity unit is a body of rocks characterized by its magnetic polarity that allows it to be differentiated from adjacent rock bodies.**

- **Magnetostratigraphic polarity-reversal horizons are surfaces or thin transition intervals across which the magnetic polarity reverses. Where the polarity change takes place through a substantial interval of strata, of the order of 1 m in thickness, the term "magnetostratigraphic polarity transition-zone" should be used.**

- **Magnetostratigraphic polarity-reversal horizons and polarity-transition zones provide the boundaries for magnetostratigraphic polarity units.**



Polarity chrons, polarity subchrons, transition zones, and excursions (from Harland *et al.*, 1982)

Magnetostratigraphic resolution

hierarchy in magnetostratigraphic units and polarity chron (time) units

Magnetostratigraphic polarity units	Geochronologic (time) equivalent	Chronostratigraphic equivalent	Approximate duration (yr)
Polarity megazone	Megachron	Megachronozone	10^8-10^9
Polarity superzone	Superchron	Superchronozone	10^7-10^8
Polarity zone	Chron	Chronozone	10^6-10^7
Polarity subzone	Subchron	Subchronozone	10^5-10^6
Polarity microzone	Microchron	Microchronozone	$< 10^5$
Polarity cryptochron	Cryptochron	Cryptochronozone	Uncertain existence

Modified after Laj & Channell (2007)

- **The basic formal unit in magnetostratigraphic polarity classification is the magnetostratigraphic polarity zone, or simply polarity zone. Polarity zones may be subdivided into polarity subzones and grouped into polarity superzones.**

- **Magnetostratigraphic polarity zones may consist of bodies of strata unified by: a single polarity of magnetization; an intricate alternation of normal and reversed polarity of magnetization; and having dominantly either normal or reversed polarity, but with minor intervals of the opposite polarity.**

Establishment of Magnetostratigraphic polarity units:

(1) Combining the determination of the orientation of the remanent magnetization of sedimentary or volcanic rocks from outcrops or cored sections with their age determined by isotopic or biostratigraphic methods.

(2) Through the use of shipboard magnetometer profiles from ocean surveys to identify and correlate linear magnetic anomalies that are interpreted as reflecting reversals of the Earth's magnetic field, recorded in the lava of the sea floor during the sea-floor-spreading process.

(3) It has been shown that the two kinds of investigation are correlative and record the same causative process. Marine magnetic anomalies are, thus, not true conventional stratigraphic units.

Stratotype of Magnetostratigraphic polarity units

- The standard of reference for the definition and recognition of a magnetostratigraphic polarity unit for land-based units is a designated stratotype in a continuous sequence of strata.

- This sequence of strata shows its polarity pattern throughout and clearly defines its upper and lower limits by means of boundary stratotypes. These are marked with artificial permanent markers to facilitate restudy.

- The standard of reference of marine-based units is a designated profile along a designated traverse with all instrumental and guidance conditions specified. This pattern of polarity reversals from the ocean floor should be dated by extrapolation and interpolation from isotopic and paleontologic information.

- Magnetostratigraphic polarity unit and its boundaries may be extended away from its type locality or stratotype only as far as the magnetic properties and stratigraphic position of the unit can be identified.

Nomenclature of Magnetostratigraphic polarity units

- The formal name of a magnetostratigraphic polarity unit is formed from: the name of an appropriate geographic feature combined with a term indicating its rank and direction of polarity.
  (e.g. Jaramillo Normal Polarity Zone)

- The currently well-established names derived from the names of distinguished contributors to the science of geomagnetism (for example, Brunhes, Gauss, Matuyama) should not be replaced.

- Numbered or lettered units may be used informally, but this is not recommended as a general practice.

- Regarding the magnetic anomalies of the ocean floor, the time interval represented by a magnetostratigraphic polarity unit is called a chron (superchron or subchron if necessary).

- Chronozone is the term used to refer to the rocks formed anywhere during a particular magnetostratigraphic polarity chron.