The terrestrial rock record

Stratigraphy, vertebrate biostratigraphy and phylogenetics

The Cretaceous-Paleogene boundary at Hell Creek, Montana. Hell Creek Fm. lower, Tullock Fm. upper. (P. David Polly, 1989)
The value of paleontological data

1. Provides unique information about organisms and morphologies that no longer exist and which would not be expected based on living organisms.

   Example: Mosasaurs, gigantic marine lepidosaurs, related to living lizards and snakes but completely unlike them in size and habitat.

2. Provides primary data about the history of Earth and the history of life. These data aid our understanding about the processes that control biological diversity; the interactions between biota and Earth systems such as atmosphere, water, and geochemical cycling; the response of ecosystems to major and minor perturbations; and processes of evolution.

   Example: the interaction between plant communities, atmosphere, and animal diversification in the late Carboniferous.

3. Provides primary data about time. These data provide dates that allow us to calculate rates of evolution, rates of ecological response, rates of continental movements, and the timing of major events, including the origin of our own species. This lecture is about time.
Global Geological time scale
Global chronostratigraphic Scale (GCSS) + Global chronometric scale (GCMS)
Geological time scales

A geological time scale (geochronologic, chronostratigraphic scale) is composed of:

1. stratigraphic divisions (named time periods) based on rock sequences (real sections of rock found somewhere in the world) [chronostratigraphic scale]
2. calibrated in years (based on radiometric dates, etc.) [chronometric scale]

Global geological time scale aims to represent all of geological time with precisely defined and dated stratigraphic divisions that can be applied anywhere in the world.

The global geological time scale is an international convention agreed by the International Commission on Stratigraphy (ICS), part of the International Union of Geological Sciences (IUGS) and international non-governmental scientific organization with 121 nations as members (http://www.stratigraphy.org/)

Regional and local geological times scales are stratigraphic divisions, often calibrated in years, based on regional and local rock sequences.
Regional time scale

This example shows the sequence of rocks in Indiana, each assigned to a North American epoch (regional time scale) and an international period (global time scale).

Note that not all parts of the global geological time scale are represented (because no local rocks are preserved for those ages) and that wavy lines indicate missing time (unconformities).
Correlation

Correlation is the process of determining the time equivalence between rocks in different areas.
Correlated regional scale

Indiana stratigraphic column correlated into the Global geological time scale

Note that vertical scale corresponds to time instead of rock thickness and that missing sections correspond to periods from which no rocks are preserved in the state.
Global biostratigraphic correlation

Biostratigraphic correlation is based on biotic events:

- origination of species or higher taxa
- extinction of species or higher taxa
- migration of species or higher taxa into new regions

Quickly evolving, easily recognized, widespread species are best for correlation

Most biostratigraphic zonation is based on pelagic or planktic marine organisms that are found nearly worldwide

Marine organisms from Mesozoic and Cenozoic are correlated to radioisotopic and magnetostratigraphic data from ocean floors related to spreading ridges
Challenges for terrestrial correlation

Global geological time scale is based primarily on marine rocks, which are comparatively widespread and which contain widespread fossil taxa.

Terrestrial rocks are typically found in isolated pockets and rarely contain fossils that can be directly correlated with marine fossils.

Terrestrial time scales (often called vertebrate zonations) are commonly used in the study of terrestrial vertebrate paleontology.

Correlation between terrestrial and global time scales is made where marine and terrestrial sediments “interfinger” (usually delta deposits) and with the use of radiometric and magnetostratigraphic dates.
Biogeographic barriers to dispersal

Leads to regional biostratigraphic schemes on different continents because of different endemic faunas
**Biostratigraphic terms**

**Stratigraphic Range of a Fossil Taxon**

**LAD (last appearance datum)**

**FAD (first appearance datum)**

**FAD - first appearance datum.** The earliest appearance of a taxon in the fossil record. On a global scale, the FAD is the same or younger than the speciation event that produced the taxon. Locally, the exact date of the FAD varies according to migration of the taxon from its place of origin.

**LAD - last appearance datum.** The last occurrence of a taxon in the fossil record. On a global scale the LAD is the same or older than the extinction of the taxon, on a local scale it may be earlier due to local extinction (extirpation).

**Range (biostratigraphic).** The interval of time between the first and last appearances.

**Fauna.** The assemblage of animal species found at a particular time or place. Depending on scale and preservation completeness, a fauna may be the same thing as a community. Faunas are often used to characterize periods of time (e.g., the Late Cretaceous fauna). **Flora** is used for assemblages of plant species.

**Local fauna.** The fauna found at one or more fossil sites, usually close together in space and time.

**Biozones or chronozones.** Periods of time defined by biotic events, such as FADs, LADs, or ranges.

**Faunal units or assemblage zones.** Periods of time characterized by faunas. The time boundaries of faunal units are less precise than biozones.
Major vertebrate biostratigraphic events

**Extinction of dinosaurs.** The dinosaur LAD has often been used as the practical marker for the end of the Cretaceous (and the Mesozoic) in terrestrial rocks.

**Early Eocene origin of mammalian orders.** In the early Eocene several orders of mammals, including artiodactyls and perissodactyls, appeared for the first time in Europe, Asia, and North America. Their FAD in North America has been used to define the beginning of the Wasatchian Land Mammal Age.

**“Hipparion” datum.** The FAD of the three-toed horse, *“Hipparion”*, which evolved in the late Miocene and spread quickly across Europe and Asia, has been used as a biostratigraphic marker. Name is in quotation marks because the animal is now properly known as *Hippotherium*. 

*Hippotherium* on the move, perhaps to Asia. (Heinrich Harder)
North American Land Mammal Ages (NALMAs)

Regional terrestrial biozonation system for the Cenozoic and late Mesozoic of North America

Originally based on faunal assemblages, now based on FADs and LADs of mammal species

Correlated with the global geological timescale primarily by magnetostratigraphy and radiometric dates

Each Land Mammal Age is named after its type fauna (e.g., Barstovian is named after the mammal species recovered at sites near Barstow, California)

(Tedford et al., 2004. Mammalian biochronology of the Arikareean through Hemphillian interval.)
European Mein Zones

A mammalian faunal assemblage zone system for Europe originally devised by Pierre Mein

Mein zones are designated by an abbreviation and number: MP is for the Paleogene and MN is for the Neogene, with zones numbered starting with the oldest (e.g., zone MN 1 is the first zone of the Neogene)

Correlated with the global geological timescale primarily by magnetostratigraphy and radiometric dates

Correlation of European Mein zones to the global geological timescale (from Steininger et al., 1996. Chronological Correlations of European Mammal Units).
Phylogeny and biostratigraphy

Phylogeny is a necessary tool for biostratigraphic interpretation

Phylogeny can reveal “ghost lineages”, instances where a species or higher taxon is not known from the fossil record but must logically have existed

May affect our confidence in the FAD as a biostratigraphic marker

May illuminate our understanding of directions of migration
Time, ancestors, and phylogenetic analysis

Parsimony and most other methods for phylogeny construction are based on living taxa.

Most principles transfer to fossil data, except that the methods presume that ancestors are not included in the analysis.

Synapomorphies alone cannot distinguish between relation by common ancestry and relation by descent.

Temporal information is required to distinguish between the two.

Cladograms showing recency of common ancestry are therefore distinguished from true phylogenetic trees that also show ancestor and descendant relationships.

For three taxa there are four possible cladograms compared to 18 possible phylogenies.
Paleontological phylogenetic reconstruction methods

Special methods make use of temporal data to not only reconstruct closeness of relationship (recency of common ancestry) but also ancestor-descendant relationships

**Stratophenetics.** Uses quantitative analysis to links samples from adjacent stratigraphic intervals to create phylogeny. Most useful when taxa are very closely related and the fossil record is numerous and “dense”. (Gingerich, 1976).

**Stratocladistics.** Uses parsimony of two forms, character steps and stratigraphic steps, to find the tree that best balances synapomorphies and stratigraphic preservation. (Fisher, 1994)

**Stratolikelihood.** Uses probabilistic model to find the best tree using both character and stratigraphic data.
Scientific papers for further reading


