Panel 3: Phanerozoic (541 Ma to now)

This panel begins 541 million years ago, currently the best age for the beginning of the Phanerozoic (visible life) Eon, the Paleozoic Era, and the Cambrian Period. At that point in Earth history there was a sudden appearance of abundant fossils. Once thought to mark the sudden origin of life, it is now realized that life is very much older, and this was instead the rapid appearance of hard parts, like shells, that can be preserved as fossils. Shells may have arisen as protection against increasingly effective predation. The 2012 Geological Time Scale **(A)** divides the Phanerozoic into the Paleozoic (old life), Mesozoic (middle life), and Cenozoic (recent life) Eras, which in turn are divided into 11 periods.[1]

For life history, we follow the branches of the tree of life **(B)** that lead to humans, remembering that every other modern organism has a similarly complicated evolutionary history. In this anthropocentric view, the tree of life based on DNA from living organisms first focuses on fish and then land animals. Humans and our close relatives are confined to near invisibility at the recent end of the Phanerozoic. This DNA-based time-tree of life, from Hedges and Kumar,[2] is used because it is the most detailed and comprehensive study available, but it is important to remember that the dates of the nodes where lineages split are based on the dubious assumption that genetic change accumulates at a constant rate. A further problem is that DNA cannot be recovered from extinct lineages (except for extremely recent lines like the Neanderthals). The DNA-based evolutionary relationships shown, however, are apparently more reliable than those inferred from fossils.

In the 1990s Jack Sepkoski compiled stratigraphic ranges from the literature for hundreds of families and thousands of genera **(C)** of fossil marine animals.[3] His plots provided the first quantitative portrayal of fossil biodiversity through the Phanerozoic and showed five sudden drops in biodiversity which he identified as mass extinctions (the drops are much more dramatic in the original plots, with an expanded vertical axis). These extinction events occurred at the Ordovician-Silurian, Frasnian-Fammenian (FF, late Devonian), Permian-Triassic, Triassic-Jurassic and Cretaceous-Paleogene (KPg, formerly called Cretaceous-Tertiary = KT) boundaries. Since then, the PT event, the greatest of the mass extinctions, has been recognized as a double extinction, with the PT extinction preceded, just 7.6 Myr earlier, by the Capitanian-Wuchiapingian extinction (CW). The correspondence between four mass extinctions and period boundaries is not a coincidence, for the early geologists placed the period boundaries at sudden changes in the fossil fauna. (The placement of mass extinctions on Sepkoski's diagram may not exactly match the period boundaries, because of slight adjustments of the boundary ages in the meantime.) Sepkoski's plot also shows the remarkable increase in genera now called the Great Ordovician Biodiversification Event.[4]

In addition to the six mass extinctions and the Great Ordovician Biodiversification Event, critical Big-History bio-events **(D)** include the population of the land surface. This probably began with single-celled organisms well before the Phanerozoic, although no fossil record has been found. The oldest fossils of land plants occur in the Silurian. There is now a detailed fossil record of the evolution, during the late Devonian, from lobe-finned fishes to tetrapods – land animals with legs.[5] By the Carboniferous Period there were great swampy forests which have turned into coal — hence the name of the period. The Triassic was largely a time of recovery from the double whammy of the CW and PT extinctions. The Jurassic and Cretaceous were the time of dinosaurs, ending with the KPg mass extinction, succeeded by the Cenozoic blossoming of mammals.

The cause of the great extinctions remains a challenging problem. The most recent extinction (KT) coincided precisely with the extraterrestrial impact that produced the huge Chicxulub crater, on Mexico's Yucatán Peninsula[6] **(E)**, but there is no evidence for large-body impact at the times of any of the other five extinctions. However, the four most recent extinctions, and possibly the FF as well, occurred during times when massive outpourings of basaltic lava were taking place — the LIPs, or Large Igneous Provinces **(F)**.[7] The effects of the Chicxulub impact were certainly capable of producing a mass extinction, but there is no obvious global killing mechanism that would result from a LIP. Perhaps there is some combination that would explain why the KPg extinction coincided with both an impact and a LIP.[8]

The ratio of the oxygen isotopes, ^{16}O and ^{18}O, in marine fossils reflects the temperature of the ocean water, giving a rough record of temperature through the Phanerozoic **(G)**. Although not calibrated in degrees, this shows an irregular fluctuation between hot and cold climates, the latter in approximate agreement with times of known glacial episodes.[9]

The various events of the Phanerozoic took place on an evolving global stage that saw the assembly of ancient continents (including the long-lasting southern supercontinent of Gondwana) to form the global supercontinent of Pangea, the persistence of Pangea for about 100 Myr, and its progressive breakup, beginning in the Jurassic and still continuing **(H)**. Examining Ronald Blakey's map reconstructions, beginning with the earliest (540 Ma), we first see unfamiliar continents — Laurentia, Siberia, Baltica, and massive Gondwana — in a pattern that did not change much until 300 Ma, when the northern continents collided with Gondwana to produce the enormous Appalachian mountain chain, which originally continued into modern Europe as the Variscan Mountains. The resulting supercontinent, Pangea, endured until about 200 Ma, surrounded by the even-larger global ocean of Panthalassa, although there were complicated motions of continental fragments within the wedge-shaped Tethyan Ocean that indented Pangea on the east. Pangea began to break up at about 200 Ma, and in later maps the continents of today are recognizable, with their jostlings and collisions producing the Mediterranean Sea and mountain chains of the Himalayas, the Zagros, and the Alps.