A Quick Look at the Cenozoic World

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The Extent of the Cenozoic
The Cenozoic Era began at the end of the Cretaceous period. The well-known asteroid impact that marked the end of the Cretaceous is dated by the Berkeley Geochronology Center to about 66.043 ± 0.011 million years ago.

The Cenozoic Era is subdivided into three periods (Paleogene, Neogene, and Quaternary) and seven epochs (Palaeocene, Eocene, Oligocene, Miocene, Pliocene, Pleistocene and Holocene). The Paleogene Period (65 million to 23 million years ago), comprises the Palaeocene, Eocene and Oligocene epochs. The Neogene Period (23 million to 2.6 million years ago) comprises the Miocene and Pliocene epochs; while the Quaternary Period (2.6 million years ago to today), includes the Pleistocene and Holocene epochs. Figure 1 gives the time frames of the Cenozoic periods and epochs.

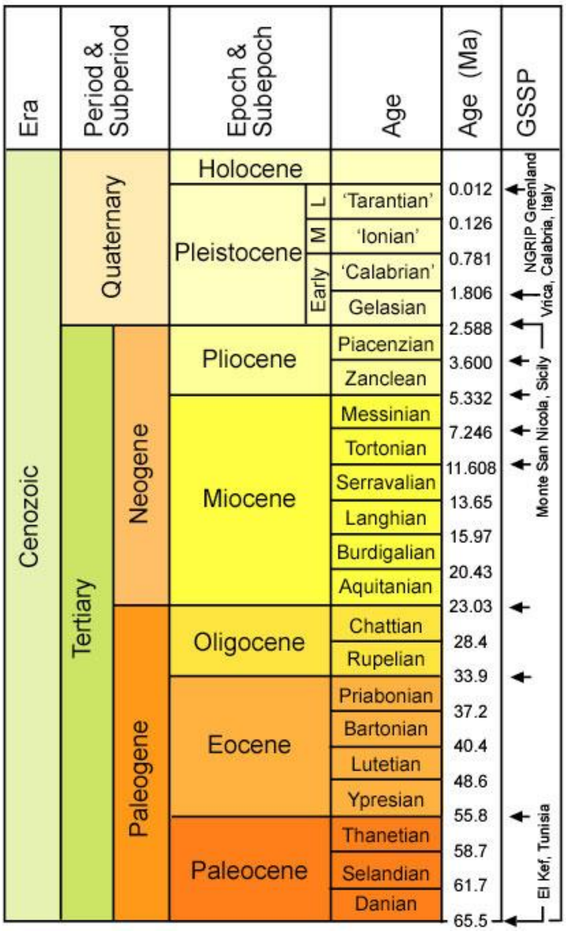

Figure 1: The Cenozoic and its seven epochs

The Cenozoic epochs vary in duration but average about 9.4 million years. The Miocene Epoch had the greatest duration, extending from about 23 million to about 5.3 million years ago, a total duration of about 17.7 million years. The shortest was the Holocene, the current geologic epoch, which commenced approximately 11,650 years ago, following the last glacial period. The Cenozoic is further subdivided in 22 ages of a few million years each (except for the Holocene which is comparatively very short).

The Earth's Continents and Oceans

The Cenozoic global climate was cooler and dryer than that of the Cretaceous, and involved several glaciations. During the Cenozoic the Earth's land masses (continents) drifted apart and eventually assumed their current positions.

Figure 2 shows the configuration of Earth's land and oceans in the late Cenozoic (50.2 million years ago).

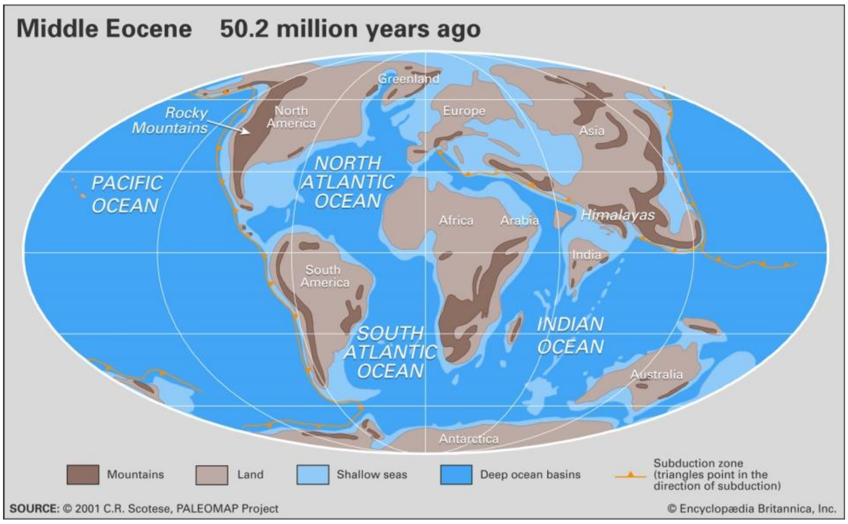

Figure 2: The configuration of Earth's land and oceans in the Mid-Eocene

Africa and South America were now further apart than during the Cretaceous, but much closer than they are now, and Europe and North America were much closer too.
During the Cenozoic the Atlantic Ocean opened, the Tethys Ocean closed, and the Alpine-Himalayan Mountain System was formed. Many mountain ranges were uplifted and continental drift led to new oceanic and atmospheric circulation and therefore new, and generally cooler, climates. Many oil deposits had previously been laid down in the mid-Cretaceous but now almost half of the world's productive oil deposits were formed during the Cenozoic.

Europe and Africa moved closer. Asia and Arabia and India also moved closer, and convergence of land masses and consequent uplift formed the Alpine-Himalayan mountains and the Tibetan Plateau. These mountain chains still exert important influences on the Earth's climate. For example, they have led to monsoons in the Indian Ocean and the creation of the Gobi desert. Continued separation of the continents gave rise to the Antarctic Circumpolar Current. This current flows around Antarctica and isolates Antarctica from warmer waters.

Earth's Magnetism

Magnetic reversals involve flipping of the Earth's magnetic field, such that the north and south poles essentially swap places. Generally, this phenomenon occurs somewhat randomly every few million years. Currently, the magnetic north points roughly towards the geographic north pole – a situation known as 'normal polarity'. Phases of tectonism are more frequent in epochs of frequent geomagnetic reversals. Over the last 24 million years reversals were numerous and tectonic phases came one after another with enhanced frequency. Tectonic phase peaks tended to lag by about one to two million years relative to the magnetic reversals. The observed chronological relationships suggest that phases of tectonism are initiated by geodynamic processes in the lithosphere and the action of energy pulses that occur in the Earth's core and at the boundary of the core with the mantle, where the Earth's magnetic field is generated.

Climate and Life of the Cenozoic Epochs

The Cenozoic is characterised by the emergence of mammals, following the extinction of dinosaurs and other groups. Initially, mammalian and other fauna were typically small. However, both mammals and birds evolved, diversified and radiated all over the Earth, including both land and the oceans. Although not rivalling the largest dinosaurs in size, nevertheless some mammals became much larger than the largest mammals of the present.

Figure 3 shows the difference in estimated mean global surface temperature during the Cenozoic and the mean temperatures of today.

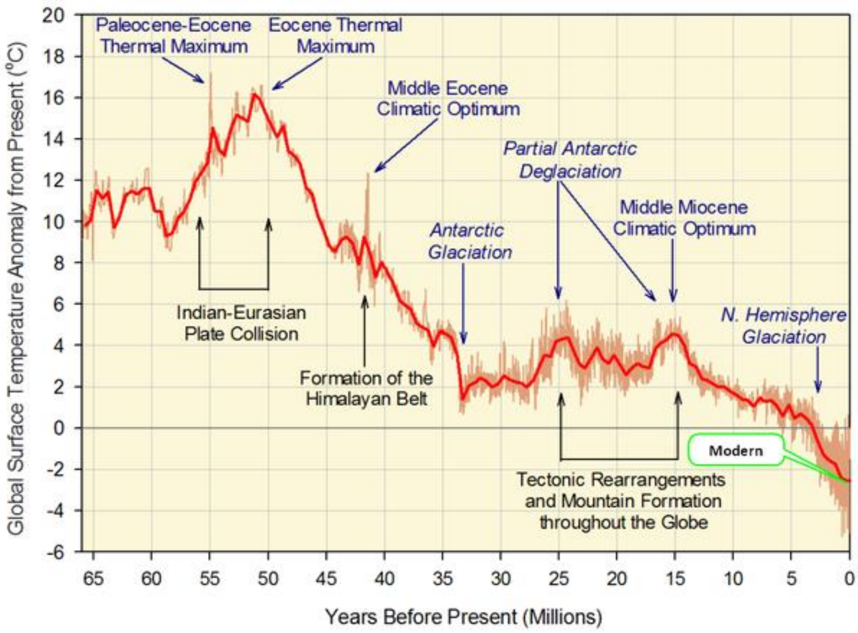

Figure 3: Difference in global mean temperature during the Cenozoic and today

Figure 3 shows that, while the surface temperatures varied greatly during the different epochs, the Cenozoic was generally warmer than today, though not as warm as the

Cretaceous. Surface temperatures reached their maxima during the Palaeocene and Eocene epochs. The Atlantic Ocean continued to widen, which helped to reduce global temperatures. After cooling steadily for some 15 million years, around 35 million years ago the Earth cooled again, leading to successive advances and retreats of glaciation.

Let's summarise the key climate and evolutionary developments of the seven epochs.

1. The Palaeocene Epoch (about 65 million to 55 million years ago) was generally warm and characterised by dense forests. The mean temperature difference between the poles and the Equator was about five degrees Celsius, much less than the 25 degrees Celsius of today. Mammals were usually small. Around 50 to 55 million years ago the earliest primates evolved.

2. The Eocene Epoch (about 55 million to 33 million years ago) was warm initially but became cooler and dryer, and forests became less prominent. Grasses evolved in the late Eocene and began to replace forests. Mammals became the dominant fauna. In Alaska and the Norwegian Arctic fossils of tropical faunas (e.g. molluscs and sharks) and fossils of reptiles and mammals in the Canadian Arctic indicate subtropical conditions there during the early Eocene.

3. The Oligocene Epoch (about 33 million years ago to about 23 million years ago) became even cooler and dryer, and grasses became a more dominant ground cover than earlier. New mammals, such as the first elephants, appeared. New plant species evolved, including evergreen trees. Some mammals became very big, though not as big as the sauropod dinosaurs.

4. The Miocene Epoch (about 23 million years ago to about five million years ago) became even cooler and drier and forests continued to retreat. Grasslands radiated over much of the Earth's land and grazing mammals became more diverse and numerous. Many ape species and new plants evolved, including most modern seed plants.

5. In the Pliocene Epoch (about five million to about 2.6 million years ago) the Earth became even dryer and cooler. Tropical grasslands (savannas) appeared. The Australopithecines evolved in the African savannas and the oceans and continents gradually assumed their current configurations.

6. The Pleisotcene Epoch (about 2.58 million to 11,700 years ago) became even cooler and periods of glaciation occurred. The Sahara and Kalahari deserts emerged. Very large mammals evolved (megafauna), including mammoths, saber-toothed cats and giant beavers. These megafauna became extinct at the end of the epoch. Homo sapiens evolved.

7. The Holocene Epoch (about 12 thousand years ago to today) is the epoch of Homo Sapiens. Many animal species became extinct because of human activity. Over the last century, some of the observed rise in temperature (global warming) has been

due to human industrial activity. In turn, higher sea levels enhance the Earth's reflectance of solar energy, which could bring a new period of glaciation.

Cenozoic Land Animals

During the Cenozoic mammals, flowering plants, insects, birds, corals, plankton, and molluscs and other groups diversified and radiated all over the Earth and in the oceans.

Figure 4 shows a fossil insect *Palaeovespa Florissantia* from the Florissant fossil beds of Colorado, USA.

Figure 4: A fossil insect, *Palaeovespa Florissantia*

This insect is dated to about 35 million years ago, or possibly somewhat younger.

Figure 5 shows fossil insect from Colorado, USA.

Figure 5: A fossil insect from Colorado, USA

This insect is dated to the Eocene epoch.

Figure 6 shows fossil insects from the Aix-en-Provence Formation in southern France.

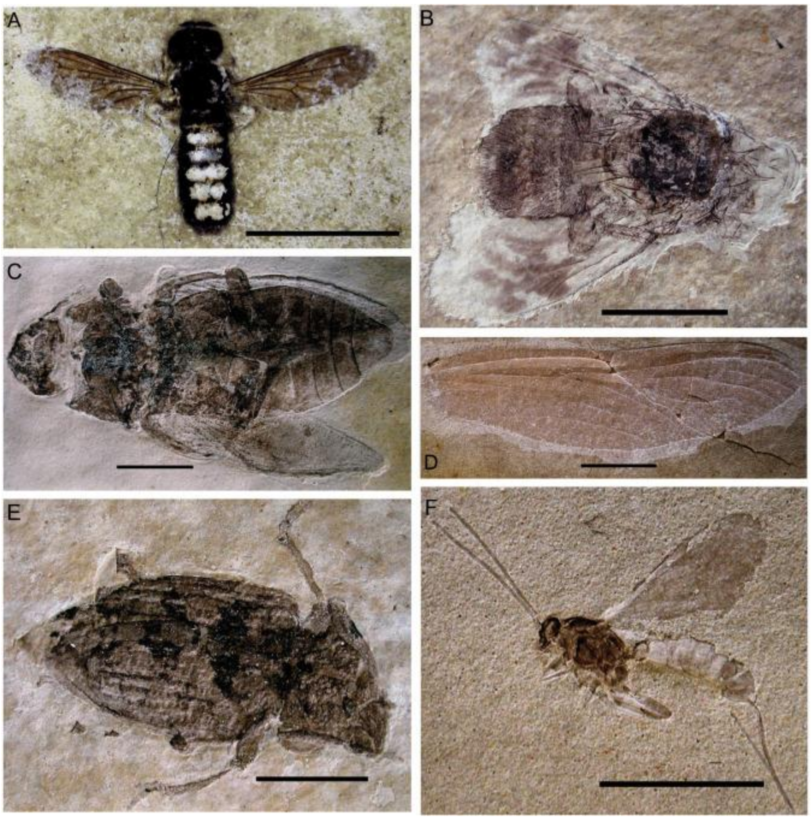

Figure 6: Oligocene fossil insects from Southern France

This formation includes organisms that demonstrate the existence of a subtropical brackish lagoon during the late Oligocene (28 million to about 23 million years ago).

Figure 7 shows a flea, trapped in amber from the Dominican Republic.

Figure 7: Flea trapped in amber about 20 million years old

This preserved flea has been dated to around 20 million years ago. Scientists have identified a plague bacterium within the flea's body, which may be an ancestral form of the plague bacterium (*Yersinia pestis*).

Figure 8 shows a Cenozoic bird, *Septencoracias*; one of an extinct genus of birds related to modern kingfishers and bee-eaters. Also shown is an artist's rendition of how it may have looked in life.

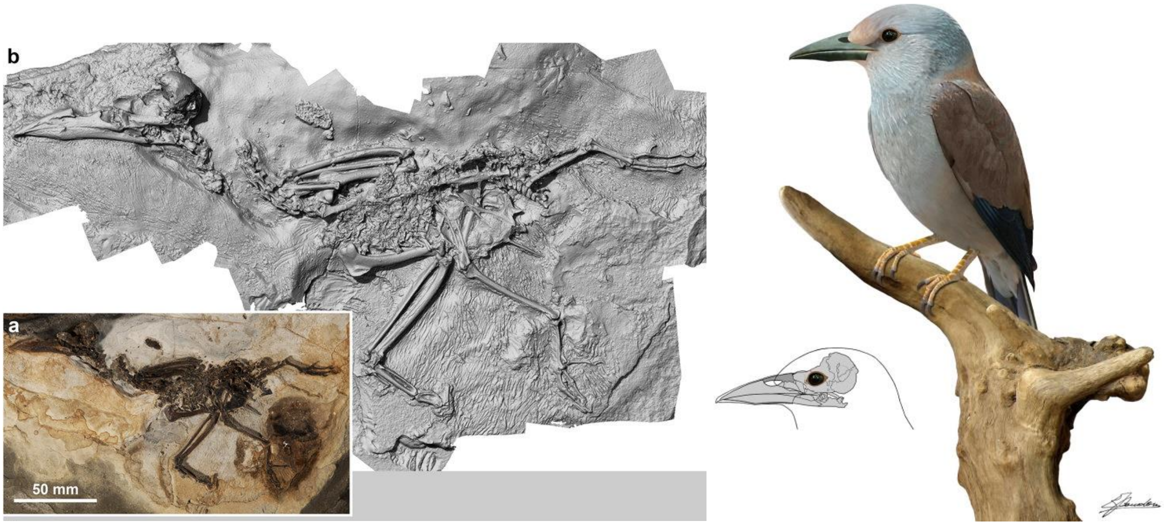

Figure 8: A Cenozoic bird, *Septencoracias*

This fossil was found in the Fur Formation of Denmark, of the Eocene Epoch, and is about 54 million years old.

Figure 9 shows an unidentified fossil bird from the Green River Formation, Wyoming, USA.

Figure 9: Unidentified fossil bird from Green River

The Green River Formation records the sedimentation in a group of lakes along the Green River, which flows through western Colorado, eastern Utah and southwestern Wyoming in the United States. The fossil beds date to between 53.5 million and 48.5 million years ago. Fossils found at Green River indicate that the climate was moist temperate or sub-tropical, and temperatures ranged from 15 to 20 degrees Celsius.

Figure 10 shows a fossil *Leptictidium nasutum*, an extinct genus of small mammal.

Figure 10: *Leptictidium nasutum*, a bipedal mammal

Leptictidium nasutum may have been a fully bipedal mammal. This fossil was found in Messel, Germany and dates to the Eocene Epoch. This animal may have been omnivorous, consuming insects, lizards and small mammals. It appeared first in the Lower Eocene approximately fifty million years ago, becoming extinct about thirty-five million years ago.

Figure 11 shows a fossil bat *Palaeochiropteryx tupaiodon*.

Figure 11: A fossil bat, *Palaeochiropteryx tupaiodon*

This fossil bat is dated to the Eocene, about 47 million years ago. It is from the Messel Pit close to Frankfurt am Main in Germany. In this fossil bat we see wonderful preservation of the soft-tissues. The flight membrane and the outlines of the ears have been preserved through fossilized bacteria. The oldest known fossil bat dates also from the Eocene, about 52.5 million years ago, from the Green River formation in Wyoming, USA. Fossil bats are preserved very rarely because of their fine bones.

The visual appearance and mode of flight of the oldest bats differed from those of the present. Probably they did not flap their wings continuously but instead alternated between flapping and gliding to move between trees. We believe that they spent much of their time walking or hanging from tree branches. Early bats may have used gravity rather than generating ground speed for lift-off and evolved true flight over time.

Cenozoic Fish
Figure 12 shows two Cenozoic fishes from the Aix-en-Provence Formation in southern France.

Figure 12: Cenozoic fishes, *Pharisatichthys aquensis* and *Tarsichthys macrurus.*

These fishes of the Aix-en-Provence Formation are *Pharisatichthys aquensis* and *Tarsichthys macrurus.* They date from the late Oligocene (about 33.9 million to about 23 million years ago).

Figure 13 shows a fossil stingray from the Eocene (about 56 million to about 33.9 million years ago).

Figure 13: A fossil stingray from the Eocene

This stingray was found in the Green River Formation in Wyoming, USA.

Sharks were the dominant marine predators for much of the Cenozoic, though toothed whales such as Basilosaurus (a large predatory whale from the late Eocene, approximately 41.3 million to 33.9 million years ago) were also apex predators. Figure 14 shows two fossilised *Carcharocles angustidens* teeth, from the Oligocene, of Victoria, Australia (approximately 33.9 million to about 23 million years ago).

Figure 14: *Carcharocles angustidens* teeth from the Oligocene, Australia

Carcharocles angustidens and its relatives lived in the Oligocene Epoch, between about 33 and about 22 million years ago. Possibly it was closely related to the more famous *Carcharocles Megalodon*. Not quite as large as Megalodon, nevertheless *Carcharocles angustidens* grew up to nine metres long and was an apex predator, probably killing and consuming pinnipeds and small whales. Its teeth are found in New Zealand sediments.

Figure 15 shows a fossilised tooth from a member of the Megalodon family. It was found off Carolina, USA, and dated to between 6 million and 16 million years old (indeed a very wide range!).

Figure 15: A tooth from a member of the Megalodon family

I bought this tooth about five years ago from a US dealer who came to New Zealand to sell fossils. I was interested to estimate the total length of the living shark and found the following relationship on a web-site:

Total Length = 11.788 X Crown Height + 2.143

where the total length is in centimetres and the crown height, the length from the outer (labial) edge of the tooth to its base, is in mm (Shimada, 2003). This regression relationship was established for the modern great white shark but, in the absence of anything better, I am using it as a proxy for an estimation of the length of the specimen that provided this tooth. Its crown height is 64 mm. Thus, my best guess at the body length of the shark was 7.57 metres, or just under 25 feet – very large by today's standards but not large by comparison with the biggest Megalodon specimens. The tooth is robust, at over a centimetre thick. I imagine that the robustness of this tooth reflects a need to grapple with large, struggling prey and possibly to bite through bone.

Cenozoic Marine Mammals
Ancestral whales first appeared about 50 million years ago. Figure 16 shows a fossilised *Dorudon* at the Senckenberg Museum of Frankfurt. *Dorudon* was an extinct carnivorous whale that lived between about 40.4 million and about 33.9 million years ago during the Eocene.

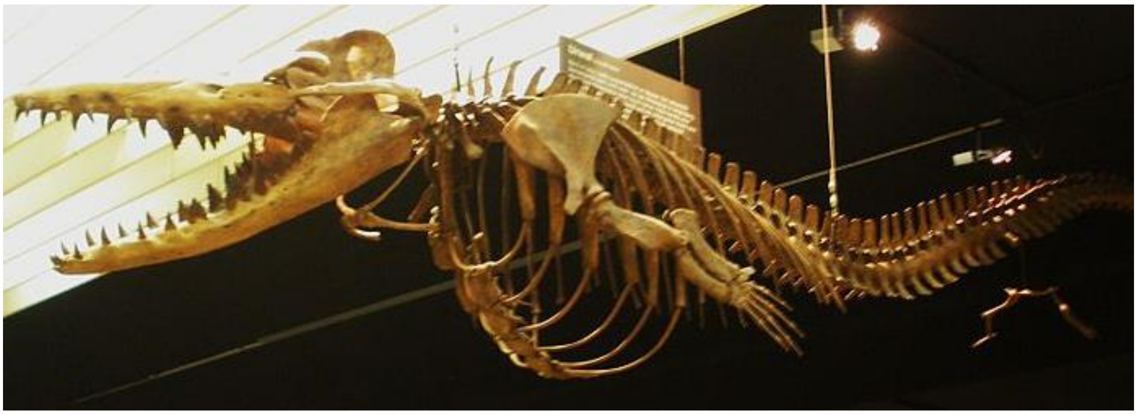

Figure 16: *Dorudon*, an ancient whale

Dorudon was about five metres in length and probably fed on small fish and molluscs. It lived in warm seas along the former shorelines of Egypt and Pakistan, the United States, New Zealand and the Western Sahara.

Today's pinnipeds are a group of 34 species of aquatic mammals comprising sea lions, seals and walruses. Pinnipeds live in rich marine environments and some inland or tropical freshwater environments. The earliest documented records of pinnipeds derive from the late Oligocene, about 27 million to 25 million years ago, though some older fossils (around 29 million years old) may in fact belong to the pinniped family. Figure 17 shows the skeleton of *Allodesmus*, a genus of pinniped from the middle to late Miocene of California and Japan.

Figure 17: *Allodesmus*, an extinct pinniped

The teeth of *Allodesmus* are all alike in shape and adapted for eating fish and it is thought to have been an active swimmer and predator. Scientists believe that *Allodesmus* was itself hunted by *Carcharodon megalodon* and other large sharks.

Molluscs and Small Marine Life-forms

Diatoms (single-celled algae with cell walls made from transparent silica) emerged during the Cretacesous, and radiated into the oceans. However, during the Cenozoic they moved into fresh waters.

Molluscs proliferated in the Cenozoic. Figure 18 shows a fossil *Glycymeris* clam.

Figure 18: A Cenozoic fossil clam from Madagascar

This fossil clam is from the Neogene (about 23.03 million years ago to the beginning of the present Quaternary Period about 2.58 million years ago) of the Southeastern United States. Figure 19 shows another fossil clam, embedded in sandstone from Bordeaux, France.

Figure 19: A fossil clam from the early Miocene

This clam is dated to early Miocene (Burdigalian Stage) and is dated to between about 16 million and about 20 million years old.

Figure 20 shows a fossil crab, *harpactocarcinus quadrilobatus*.

Figure 20: Eocene fossil crab

This crab is from the Eocene, found near Vicenza in northeastern Italy. The species is found in many Eocene localities across Europe, especially Slovakia and Italy. It was a heterochelous species - i.e. characterized by bilateral asymmetry due to morphologically dissimilar chelae (claws). Such asymmetry can result from specialised feeding techniques (in shrimps, lobsters and crabs, and their role as predators on molluscs through geologic time) or mating behaviour, such as in fiddler crabs.

Cenozoic Plants and Flowers
Flowering plants (angiosperms), which have seeds enclosed within an ovary (often a fruit), arose at the start of the Cretaceous and became more abundant as time progressed, especially through the Cenozoic.

Figure 21 shows a fossilised flower, *Florissantia quilchenensis.*

Figure 21: A fossil *Florissantia quilchenensis* flower

Florissantia quilchenensis is an extinct species from western North America, of the Malvaceae Family, which includes the Cocoa (chocolate) and Mallow (marshmallow) plants. They flourished in the Eocene and Oligocene epochs. These flowers are approximately 2.5 - 5 centimetres across.

Figure 22 shows a sycamore leaf, *Platanus wyomingensis.*

Figure 22: An Eocene Sycamore leaf

This leaf was found at Green River and dates from the Eocene between 53.5 million and 48.5 million years ago.

Figure 23 shows fossil *Fagaceae* leaves from the Eskihisar, Tınaz and Salihpasalar lignite mines in Turkey.

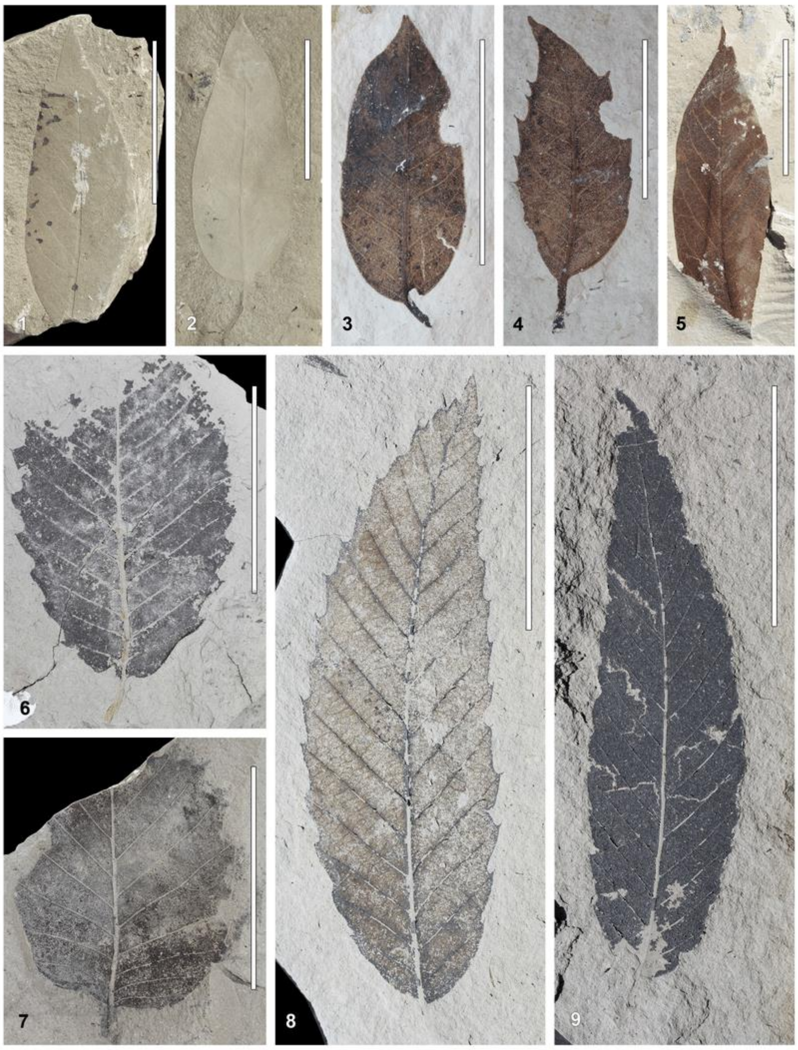

Figure 23: Middle Miocene *Fagaceae* leaves

These fossil leaves date from about 16 million to about 11.6 million years ago.

The Cenozoic culminated in the emergence of man (*Homo Sapiens*), following several million years of relatively rapid evolution from tree-dwelling hominins. Figure 24 shows the skull of the earliest known definite ancestor of modern humans.

Figure 24: Skull of *Australopithecus anamensis* from 3.8 million years ago

Found in Ethiopia and dated to 3.8 million years ago, *Australopithecus anamensis* is regarded as the oldest known species on the human evolutionary tree. It is believed to be the direct ancestor of *Australopithecus afarensis* (Lucy). *Australopithecus anamensis* was in the process of emerging from the trees to walk bipedally, but retained an ape-like protruding face, large jaws and small brain. It is the oldest-known member of the Australopithecines and therefore is considered to be a direct ancestor of man.

Reference to a publication

Shimada, K. (2003). The relationship between the tooth size and total body length in the white shark, Carcharodon carcharias (Lamniformes: Lamnidae). Journal of Fossil Research 35:28-33.

References to Figures

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Figure 2: retrieved from https://www.britannica.com/science/Paleogene-Period

Figure 3: retrieved from http://p2merielw-gts.weebly.com/the-cenozoic-era.html

Figure 4: retrieved from https://truthbook.com/urantia-book/paper-61-the-mammalian-era-on urantia

Figure 5: retrieved from http://centexnaturalist.com/foldermainmenus/sfgeology/folderfossils/eoceneinsects.html

Figure 6: retrieved from: https://www.sciencedirect.com/science/article/pii/S1631068317300799

Figure 7: retrieved from http://www.eartharchives.org/articles/trapped-in-time-the-top-10-amber-fossils/ Image credit: Dr. George Poinar Jr.

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Figure 9: retrieved from https://www.alamy.com/stock-photo-unidentified-fossil-bird-green-river-formation-wyoming-usa-25884809.html

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Figure 11: retrieved from https://www.researchgate.net/figure/Small-bat-Palaeochiropteryx-tupaiodon-Revilliod-1917-This-is-an-especially-beautiful_fig44_329970301

Figure 12: retrieved from https://www.sciencedirect.com/science/article/pii/S1631068317300799

Figure 13: retrieved from https://www.alamy.com/fossil-stingray-eocene-period-green-river-formation-wyoming-usa-image277950060.html

Figure 14: retrieved from https://collections.museumvictoria.com.au/specimens/2269660

Figure 15: Photograph taken at my home

Figure 16: retrieved from https://commons.wikimedia.org/wiki/File:Dorudon_atrox_5.jpg

Figure 17: retrieved from https://commons.wikimedia.org/wiki/File:Allodesmus_sp._NSM-PV_20546_-_National_Museum_of_Nature_and_Science,_Tokyo_-_DSC06931.JPG

Figure 18: retrieved from https://neogeneatlas.net/families/glycymerididae/

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Figure 20: retrieved from https://www.christies.com/lotfinder/Lot/crabe-harpactocarcinus-quadrilobatus-eocene-vicenza-italie-5062273-details.aspx

Figure 21: retrieved from https://stonerosefossil.org/fossils/florissantia-quilchenensis/

Figure 22: retrieved from https://ucmp.berkeley.edu/tertiary/eoc/greenriver.html

Figure 23: retrieved from https://www.researchgate.net/figure/Plate-5-Fossil-Fagaceae-leaves-from-the-E-Eskihisar-T-Tinaz-and-S_fig16_321765889

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