# Paleocene/Eocene boundary and continental vertebrate faunas of Europe and North America

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The geological time scale has evolved considerably since the eighteenth century. It has changed from a single rudimentary "Primary–Secondary–Tertiary" scale, reflecting fabric as well as superpositional relationships of rocks and sediments – to the present scale, which involves (1) correlation based on the evolution of life and its stratigraphic record, (2) enhancement of precision using binary magnetic, chemical, and sea level events that are global and abiotic (and hence independent of evolution), and (3) numerical calibration of composite sequences using radioactive elements whose decay is independent of both evolution and the binary events used to enhance precision. The "Tertiary" part of the time scale was first subdivided into Eocene (Gr. *eos*, aurora or dawn, and *kainos*, recent), Miocene, and Pliocene epochs by Lyell (1833), and these were soon grouped into the Kainozoic or Cenozoic (*kainos* and *zoon*, animal) by Phillips (see Berggren 1998) – reflecting the central role faunal succession plays in the study of earth history.

The Paleocene epoch was named later by Schimper (1874, p. 680; *Paléocène* from *palaios*, ancient, and *kainos*) for a distinctive terrestrial flora, both Cretaceous and Eocene in aspect, that subsequently came to dominate northern continents. Schimper's Paleocene floras came from the *Sables de Bracheux*, *Travertins de Sézanne*, and *Lignites et Grés du Soissonais* in the Paris Basin. The *Sables de Bracheux* and *Travertins de Sézanne* are considered Thanetian today, while the *Lignites et Grés du Soissonais* are considered both Sparnacian *s.l.* (*Lignites du Soissonais*, similar to but older than the *Argile à Lignites d'Epernay*) and Cuisian (*Grés de Belleu*, equivalent to the *Sables de Cuise*).

At virtually the same time, Gervais (1873) reported a distinctive ensemble of terrestrial vertebrates, again Cretaceous and Eocene in aspect, from the *Conglomérat de Cernay*. These were collected by Lemoine and included a champsosaur vertebra of a type found in the Cretaceous but not the Eocene, and a large avian vertebra of a type found in the Eocene but not the Cretaceous. Later Gervais (1877) described more specimens in the Lemoine collection from the *Conglomérat de Cernay* and the *Calcaires de Rilly*, including a distinctive mammal that he named *Plesiadapis tricuspidens*, and proposed a new faunal interval, the Orthrocene (*Orthrocène* from *orthros*, dawn, and *kainos*), intercalated between the Cretaceous and the Eocene. In North America, Cope discovered a rich and similarly-intermediate Cretaceous–Eocene fauna, which he took to represent a new "Puerco" epoch (reviewed in Cope 1888).

Neither Orthrocene nor Puerco survived as epochs in stratigraphic nomenclature, but Gervais, Lemoine, and Cope demonstrated that Paleocene vertebrate faunas are both distinctive and important. Historically, vertebrates more than any other group are responsible for recognition of the Paleocene as a distinct epoch of Cenozoic time.

*Paleocene/Eocene boundary in Europe.* – Paleocene and early Eocene mammals have been studied intensively in Europe since the time of Gervais and Lemoine, and there is universal agreement that the *Champsosaurus-Plesiadapis* fauna from Cernay and elsewhere is late Paleocene (Russell 1964), while faunas from Dormaal (Smith & Smith 1995), Meudon (Russell et al. 1990), Suffolk Pebble Bed localities at the base of the London Clay (Hooker 1998), and others are generally regarded as early Eocene in age. These Eocene faunas differ in having the modern cosmopolitan orders Perissodactyla, Artiodactyla, Primates, and family Hyaenodontidae that are not found in Paleocene faunas.

The problem with study of Paleocene–Eocene vertebrate faunas in Europe is that most samples come from isolated exposures, there are few long and continuous stratigraphic sections, and deposition near sea level means that substantial hiatuses are common (Pomerol 1989; Dashzeveg 1988; Hooker 1998).

*Paleocene/Eocene boundary in North America.* – The North American record of vertebrate change across the Paleocene/Eocene boundary is more continuous and more complete, particularly in the richly-fossiliferous Clarks Fork and northern Bighorn basins of Wyoming. Paleocene vertebrates were first found here in 1912, and faunal change has been studied intensively since 1975. Results are summarized in Fig. 1. The principal stratigraphic section is some 2300 m long, spanning virtually all of the late Paleocene (Tiffanian and Clarkforkian land-mammal ages) and much of the early Eocene (Wasatchian). Two formations are involved (Fort Union and Willwood), and these have yielded vertebrate fossils, principally mammals, from 145 collecting intervals. Collecting intervals are concentrated in the middle part of the section, where stratigraphic resolution is on the order of ±5 m and temporal resolution is on the order of 20 k.y.

Our University of Michigan project was initiated in 1975 to clarify mammalian evolution across the Paleocene/Eocene boundary. Study of *Plesiadapis* corroborated existence of a distinct Clarkforkian land-mammal age (Gingerich 1976), and we set out to improve documentation of this (Rose 1981). Subsequent studies have concentrated on Wasatchian biostratigraphy and faunal change (Gingerich 1983, 1989, 1991; Clyde & Gingerich 1998). As in Europe, *Champsosaurus* and *Plesiadapis* are present in Paleocene faunas. Rodents, tillodonts, and *Haplomylus* (and *Coryphodon*, not shown) appear at or near the beginning of the Clarkforkian. Perissodactyls, artiodactyls, primates (including *Cantius*), and hyaenodontids appear at the beginning of the Wasatchian (Wa-0). Late Paleocene mammals tend to be endemic on the northern continents, but Wasatchian mammals in North America are part of a cosmopolitan early Eocene assemblage appearing at or near the beginning of the Eocene in Europe (Hooker 1998) and Central Asia (Meng & McKenna 1998), and present early in the Eocene in South Asia (Gingerich et al. in prep.) – making the Paleocene and Eocene sharply distinct on all three northern continents.

The age of the Clarkforkian-Wasatchian faunal turnover is

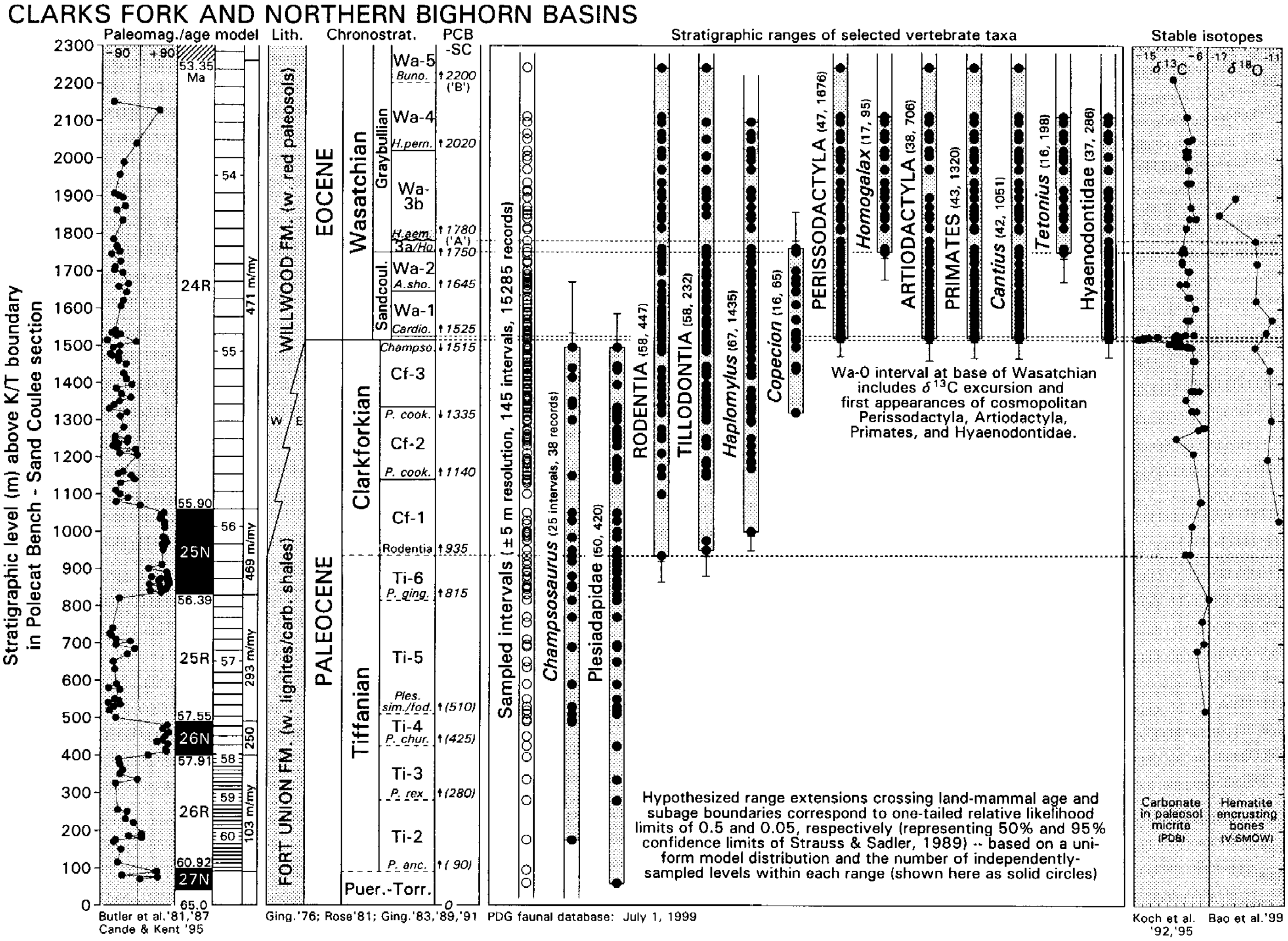


*Fig. 1.* Stratigraphic ranges of selected vertebrate taxa in the Polecat Bench–Sand Coulee section of the Clarks Fork and northern Bighorn basins, Wyoming. Note first appearances of cosmopolitan Perissodactyla, Artiodactyla, Primates, and Hyaenodontidae in the Wa-0 faunal zone coincident with the carbon isotope excursion, and interpolated near or slightly younger than 55.0 Ma.

constrained in two ways. Paleomagnetic stratigraphy has been studied by Butler et al. (1981, 1987) and nearby by Clyde et al. (1994). Wa-0 falls within Chron C24r. Interpolation using the numerical calibration of Cande & Kent (1995) places Wa-0 near or slightly younger than 55.0 Ma. Carbon isotope stratigraphy has been studied by Koch et al. (1992, 1995), and the negative carbon isotope excursion correlative with extinction of deep-sea benthic forams falls within Wa-0. Norris et al. (1999) place the beginning of the carbon isotope excursion at about 55.1 Ma, with the event lasting some 130 k.y.

More needs to be done to trace continental paleotemperatures across the Paleocene/Eocene boundary. Fossil leaves and pollen have not yet been found in association with Wa-0 mammals (Wing et al. 1999). Oxygen isotopes from carbonate have proven highly variable (Koch et al. 1995), and more promising hematite encrustations have not yet been found in Wa-0 (Bao et al. 1999).

*Conclusions.* – The North American record of continental vertebrate evolution across the Paleocene/Eocene boundary is exceptionally complete. It corroborates the sharp distinction of Paleocene and Eocene mammalian faunas first discovered in Europe. In addition, tight paleomagnetic and isotopic control permits the North American record to be widely compared to biotic and environmental changes observed in the sea and elsewhere.

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