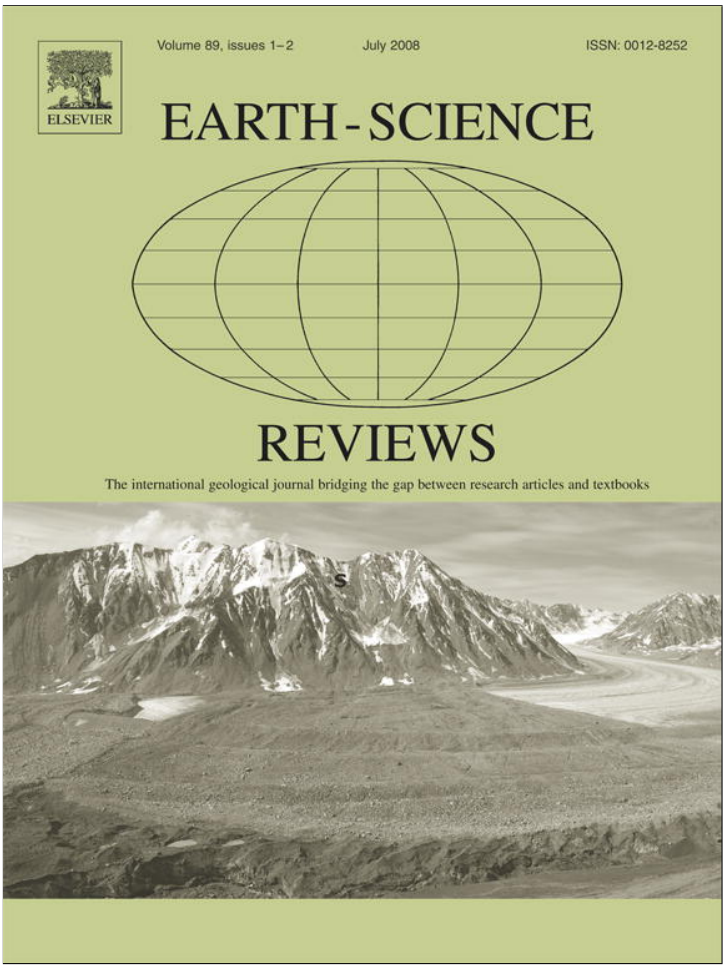

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The Neogene: Origin, adoption, evolution, and controversy

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Abstract

Some stratigraphers have recently insisted that for historical reasons, the Neogene (Miocene+Pliocene) should be extended to the present. However, despite some ambiguity in its application by Moriz Hörnes in the 1850s, the "Neogene" was widely adopted by European geologists to refer to the Miocene and Pliocene of Lyell, but excluding the "Diluvium" (later to become the Pleistocene) and "Alluvium" (later to become the Holocene).

During the late 19th and early 20th centuries, the ends of the Neogene, Tertiary and Pliocene evolved in response to the progressive lowering of the beginnings of the Quaternary and Pleistocene. This evolution was a logical result of the widespread views that the most recent "ice ages" were worthy of recognition as a formal unit of the standard geologic time scale, and that the structure of this time scale must be strictly hierarchical.

Motivations for the extension of the Neogene to the present include the desire to establish a monopoly for marine biochronology in the definition of standard global chronostratigraphic boundaries. This agenda would also eliminate the Tertiary, Quaternary, and Holocene. These changes are unnecessary. There is every reason to retain the traditional hierarchical structure of the Cenozoic time scale.

Keywords: Neogene; Tertiary; Quaternary; Pleistocene; Holocene

1. Introduction

In the late 19th Century and for the first two-thirds of the 20th Century, the term "Neogene" was almost universally used to refer to the later part of the Tertiary Period, consisting of the Miocene and Pliocene epochs, and excluding the succeeding Quaternary Period (itself consisting of the Pleistocene and Holocene epochs; see Fig. 1). Since the 1950s, however, several authors have advocated that the Neogene be extended to the present. Among them are Neaverson (1955), Denizot (1957), Banner and Blow (1965), Dott and Batten (1971), Berggren and Van Couvering (1974), Jenkins et al. (1985), Berggren et al. (1985, 1995a,b), Steininger (2002), and Prothero and Dott (2004). In particular, the review paper of Berggren (1998) seems to have played a major role in convincing the International Commission on Stratigraphy (ICS) to extend the Neogene to the present and to eliminate the Tertiary and Quaternary as ranked units (Gradstein et al., 2004a,b; Lourens et al., 2004). However, this restructuring of the Cenozoic time scale was greeted with a storm of protest (Salvador, 2004; Giles, 2005), and several new proposals for the subdivision of the Cenozoic were subsequently made (Pillans and Naish, 2004; Gibbard et al., 2005; Aubry et al., 2005; Suguio et al., 2005; Gradstein, 2005).

In response to this controversy, Salvador (2006a,b) demonstrated that "Tertiary" is still used more frequently than either Paleogene or Neogene in stratigraphic publications, and that "Quaternary" is probably used more than any other standard global geochronologic unit. Gibbard et al. (2005) and Zalasiewicz et al. (2006) presented additional arguments for the retention of the Tertiary and Quaternary. Walsh (2006) also showed that if Tertiary and Quaternary are to be formally ranked, then the only subdivision consistent with the principles of hierarchical classification is one in

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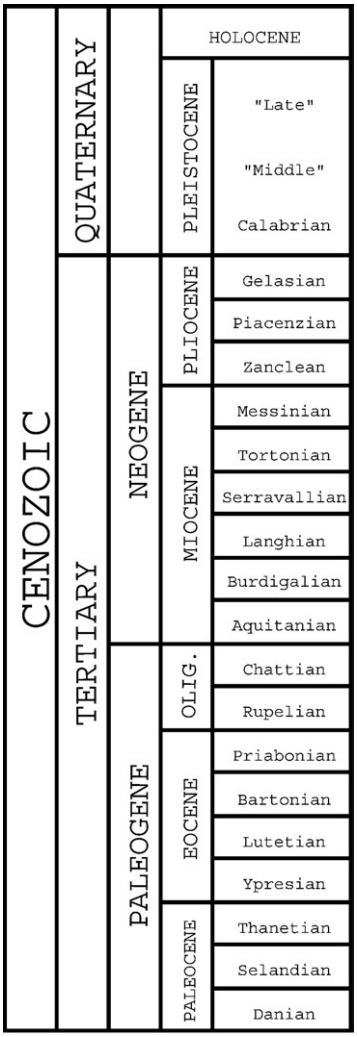

Fig. 1. Traditional structure of the Cenozoic standard global time scale (e.g., Salvador, 1994). Currently accepted stage names from Luterbacher et al. (2004) and Lourens et al. (2004).

which the Cenozoic is composed of the Tertiary and Quaternary, the Tertiary is composed of the Paleogene and Neogene, and the Quaternary is composed of the Pleistocene and Holocene.

Because previous analyses of the "Neogene" have been highly influential and yet incomplete in my view, the main purpose of this paper is to more fully document the origin and evolution of this term. Although detailed discussions of the history of a geochronologic term as presented in Berggren (1998), Steininger (2002), and this paper may seem unimportant, they are worthwhile if they can clarify the nature of more fundamental disagreements. In the case of the Neogene and Quaternary, these disagreements involve the roles of climatic, mammalian biochronologic, and marine biochronologic criteria in the definition and ranking of some of our most important Cenozoic standard global geochronologic units. In presenting a more comprehensive history of usage of the Neogene, I wish to better illuminate this debate.

2. Origin of the term "Neogene"

2.1. Moriz Hörnes and the fossil molluscs of the Vienna Basin

In the middle of the 19th century, Wilhelm von Haidinger[2], Director of the Foundation of the kaiserlich-königlichen geologischen Reichsanstalt in Vienna, asked Moriz Hörnes[3] (Fig. 2) to undertake a study of the Tertiary molluscs of the Vienna Basin, in collaboration with Paul Partsch (von Haidinger, 1851). Early reports on the planning and progress of their work were given by Hörnes (1850a,b, 1851a), and this work would be published in numerous successive articles in the *Abhandlungen der kaiserlich-königlichen geologischen Reichsanstalt* between 1851 and 1870 (a complete citation for the original series of articles comprising Band I is given by Snyder, 1999). These articles were later published together in book form in two volumes. Band I, "Univalvia" (Gastropoda) was published in 1856 (Hörnes and Partsch, 1856; see Jones, 1857 for a review), and Band II, "Bivalvea" was published two years after Hörnes' death, being completed by August Reuss (Hörnes and Reuss, 1870; see Vávra, 2001).

Denizot (1957), Steininger (1981), and many others have maintained that the term Neogene was first coined by Hörnes in a letter to H.G. Bronn dated 3 October 1853 (Hörnes, 1853a). However, Hörnes had previously used the terms "Neogen-Epoche" and "Neogenablagerungen" (Neogene deposits) in a short report on a collection of fossil molluscs from Ottnang, Austria. This report was presented at the 11 March 1853 meeting of the k.-k. geologischen Reichsanstalt (Hörnes, 1853b). Still earlier, however, the first published use of "Neogene" appears to have been by Hörnes (1851b) in the first separate of his treatise (see early reviews by von Hauer (1852) and Anonymous (1852), both of which noted Hörnes' use of the term "Neogene"). Although I have been unable to obtain a copy of this paper as it originally appeared, Hörnes' Vorerinnerung (Preface) in Hörnes and Partsch (1856) is dated 1 July 1851, and seems to have been reproduced directly from the original publication (see the page citations in Anonymous, 1852, p. 113, which match those of Hörnes and Partsch, 1856). Accordingly, the term "Neogene" was introduced by Hörnes (1851b, p. 9), who stated:

> "For now I only want to point out that the calculations of percentages, which form the basis for the subdivisions of Tertiary formations, according to Lyell, into Eocene, Miocene and Pliocene, have created an unnatural division, inasmuch as the great similarity of the so-called Pliocene and

[2] Wilhelm von Haidinger 1795–1871. See Riedl-Dorn (1998) and Leutner (1999) for additional information. Biographical information for most of the 19th and early 20th century geologists discussed here can be found in Poggendorff (1863), Feddersen and von Oettingen (1898), von Oettingen (1904), and Sargeant (1980).

[3] Moriz Hörnes, 1815–1868. At the time, Hörnes was Assistant Curator at the Imperial-Royal Court Mineralogical Museum, and Partsch was the Curator (Hörnes, 1850b). Hörnes would become Curator and Director after Partsch's death in 1856. See Hébert (1869), Riedl-Dorn (1998), and the website of the Hoernes family [http://www.hoernes.net/index.php?id=56].

Fig. 2. Undated portrait of Moriz Hörnes, but ca. 1860s.

> Miocene deposits makes it inevitable that these two should be combined. The striking difference of the Eocene forms, on the other hand, makes their separation appear as one really based in nature. Therefore one will probably come to the conclusion that there are only two formations: an "old-tertiary," *Eocene* one, and a "recent-tertiary" one, or *Neogene*. Further discussion of the hypothesis stated here will be given at the end of this work and will be explained through a summary of all Tertiary fossils."[Italics in original][4]

Unfortunately, the publication of Hörnes' mature views on the stratigraphy and nomenclature of the Vienna Basin and the geologic time scale were prevented by his untimely death in 1868 (Hörnes and Reuss, 1870, p. 466–467).

2.2. Beyrich's criticism

Soon after its introduction by Hörnes (1851b), the term "Neogene" was mentioned by Beyrich (1853)[5]. After first noting the excellent ongoing work of Hörnes in the Vienna Basin and its importance to his own study of the Tertiary molluscs of northern Germany (pp. 274–275), Beyrich (1853, pp. 282–283) nevertheless questioned the need for his colleague's new term:

> "Since Lower Miocene [i.e., Oligocene] formations are intermediate both in their paleontological characteristics and in their stratigraphic position between Eocene and typical Miocene formations, they eliminate the clear distinction which exists in those regions where they do not occur between the Eocene and Miocene Tertiary terranes. In Belgium this is so pronounced that Dumont thought one could generally combine the Eocene and Miocene in the Tertiary terranes as an older formation, from which the Pliocene is distinctly separated as a younger formation. His view in this matter is just as shortsighted, and only appropriate for a local situation, as the opinion which originated elsewhere, that Pliocene and Miocene should be separated from the Eocene as more closely related formations under the name Neogene. The terms Eocene, Miocene, and Pliocene represent time periods whose middle sections are well-known to us, but whose beginnings and endings flow into each other, as is increasingly the case with all geologic time periods the more we learn about them. If we cannot find any sharp boundaries in the faunas, this is no reason to drop the distinction between periods."[6]

[4] "Vorläufig will ich hier nur bemerken, dass die Procentenberechnungen, worauf sich die Unterscheidung der Tertiärformationen nach Lyell in Eocen, Miocen und Pliocen basiren, eine widernatürliche Trennung veranlasst haben; indem bei der grossen Aehnlichkeit der sogenannten pliocenen und miocenen Ablagerungen eine Vereinigung derselben unausweichlich ist. Dieser Erscheinung entgegengesetzt ist die auffallende Verschiedenheit der eocenen Formen, so dass sich diese Trennung als eine wirklich in der Natur begründete darstellt. Es wird sich daher in der Folge wahrscheinlich herausstellen, dass es nur eine alttertiäre oder *eocene* und eine jungtertiäre oder *neogene* Formation gebe. Die weitere Auseinandersetzung des hier aufgestellten Satzes wird am Schlusse des Werkes gegeben und durch eine Zusammenstellung sämmtlicher tertiären Fossilen erläutert werden [italics in original]."

[5] August Heinrich Ernst Beyrich (1815–1896). See Feddersen and von Oettingen (1898) and Sargeant (1980). Later, in his important paper on the Oligocene, Beyrich (1859, p. 58–59) would tacitly approve the use of the term "Neogene" for the concept of "late Tertiary" if the Eocene and Oligocene were understood as early and middle Tertiary, respectively. Interestingly, Helms (1997, p. 299) indicated that an extensive correspondence between Beyrich and Moriz Hörnes is preserved in the Paläontologisches Institut des Museums für Naturkunde in Berlin. An examination of this correspondence would doubtlessly be fascinating, but is beyond the scope of this paper.

[6] "Indem sich die untermiocänen Formationen in ihrem paläontologischen Charakter ebenso wie in ihrer Lagerung zwischenschieben zwischen die eocänen und die typisch miocänen, heben sie die scharfe Scheidung auf, welche in denjenigen Gegenden, wo sie nicht entwickelt sind, das eocäne vom miocänen Tertiär-gebirge entfernt. Dies ist in Belgien in dem Grade der Fall, dass Dumont glaubte, man könne allgemeiner im Tertiärgebirge das Eocän und das Miocän als eine ältere Reihe verbinden, von welcher das Pliocän als eine jüngere Reihe mit bestimmterem Absatz sich scheide. Seine Ansicht ist darin eben so kurzsichtig und nur für lokale Verhältnisse passend, wie die auf anderem Boden entstandene Meinung, man solle Pliocän und Miocän als enger verknüpfte Bildungen unter der gemeinsamen Benennung Neogen von dem Eocän sondern. Die namen Eocän, Miocän und Pliocän repräsentiren Zeitabschnitte, deren Mitten uns wohl bekannt sind, deren Anfang und Ende aber eben so ineinander verlaufen, wie dies bei allen geologischen zeitlichen Unterscheidungen, je mehr sich unsere Kenntniss erweitert, immer mehr und mehr der Fall wird. Wenn wir in den Faunen keine scharfen Grenzen wahrnehmen, so ist dies kein Grund deshalb die zeitliche Unterscheidung fallen zu lassen."

Beyrich's cogent criticisms partly motivated Hörnes' (1853a) letter to H.G. Bronn, co-editor of the *Neues Jahrbuch für Mineralogie, Geologie, Geognosie und Petrefaktenkunde*. Hörnes (1853a, p. 807–808) stated:

> "At this occasion I can't help developing the reasons which led me to suggest the merging of the so-called Miocene and Pliocene deposits under the common designation Neogene, particularly because my esteemed friend Prof. Beyrich (1853), in his excellent work "*die Konchylien des norddeutschen Tertiär-Gebirges,*" spoke out against this suggestion…
>
> It cannot be denied that for some time several paleontologists recognized the close relationship of Miocene and Pliocene deposits, in particular you yourself pointed this out repeatedly in 1838 in the first printing of your *Lethaea* [*Lethaea Geognostica*; Bronn 1838], but there were too few reasons then for deviating from the generally accepted subdivisions. During continuing studies of fossils from individual Tertiary basins, specifically the work of Philippi, Sismonda, etc., and also the new studies in the Vienna Basin, the boundaries between Miocene and Pliocene deposits faded away so that in the end the boundary could no longer be determined. The more this boundary becomes indistinct the clearer becomes the contrast between the Eocene and Miocene faunas."[7]

Once again, Hörnes (1853a) was concerned mainly with emphasizing the similarities between Miocene and Pliocene molluscan faunas and the contrast between this collective assemblage and that of the Eocene, rather than with providing exact definitions of the boundaries of the Neogene. Although the question of the end of the Neogene will be the main focus of this paper, Hörnes' concept of the beginning of the Neogene has to my knowledge not been discussed in much detail. It will therefore be briefly addressed here in order to encourage a more comprehensive historiographical study.

3. Hörnes' concept of the beginning of the Neogene

Hörnes' (1851b, 1853a) biochronological definition of the beginning of the Neogene was a bit imprecise, simply because the definition of the beginning of the Miocene was inherently imprecise at that time. In addition, Hörnes (1853a, 1854a) emphasized that the Neogene strata of central Europe were always found to overlie the Eocene strata with an angular unconformity, a relationship later illustrated by von Hauer (1858, p. 108) and R. Hoernes (1903, p. 925). Thus, as noted by Steininger (1981), Moriz Hörnes' original concept of the Neogene included aspects of what we would now call biochronologic *and* unconformity-bounded units. However, the tectonic component of Hörnes' concept of the beginning of the Neogene would soon become dispensible. First, numerous essentially flat-lying Oligocene strata would be recognized in Germany (Beyrich, 1853; Sandberger, 1853; Beyrich, 1854; Hamilton, 1854; Beyrich, 1859), and second, some of the highly tilted Alpine "Molasse" formations would be recognized as Miocene in age (Studer, 1851–1853).

Despite these minor ambiguities, Van Couvering's (1997, p. xii) suggestion that Hörnes included in the Neogene most or all of what is now the Oligocene can be readily refuted. Hörnes (1853a, p. 808) stated:

> "As discussed by Beyrich (1853), Dumont, on the basis of mineralogical characters of the deposits, suggested a combination of the Eocene and Miocene strata in Belgium. However, we must explicitly note here that Dumont did not base this opinion on the zoological character of the faunas, an error which Lyell (1852a) soon corrected in his excellent paper bringing order to the Tertiary strata of Belgium. With his usual acute perception he recognized the Eocene nature of Dumont's Tongrian and Rupelian systems and established them as upper members of the Eocene Formation, while the Bolderberg Sand is definitely Miocene. The boundary of the Eocene and Miocene is thus as sharply marked in the faunas of Belgium as elsewhere, e.g. in the basin of the Gironde, where the deposits of Gaaz and Lesbarritz were likewise recognized as definitely Eocene."[8]

Hörnes (1853a, p. 808) then went on to disagree with Beyrich's (1853) view that the Tongrian and Rupelian should be assigned to the lower Miocene. Interestingly, some time

[7] "Bei dieser Gelegenheit kann ich nicht umhin, die Gründe zu entwickeln, die mich veranlasst haben, die Vereinigung der sogenannten Meiocän und Pleiocän-Ablagerungen unter eine gemeinsame Bezeichnung "Neogene" zu beantragen. Besonders desshalb, weil mein verehrter Freund, Hr. Prof. Beyrich, in seinem trefflichen Werke "die Konchylien des norddeutschen Tertiär-Gebirges" sich entschieden gegen diese Annahme ausspricht… Es ist zwar nicht zu läugnen, dass schon lange mehren Paläontologen die grosse Verwandtschaft der meiocänen und pleiocänen Ablagerungen aufgefallen ist, namentlich haben Sie selbst schon im Jahre 1838 bei der Herausgabe der ersten Auflage Ihrer "Lethaea" auf diese Verhältnisse wiederholt hingewiesen; allein es lagen damals noch zu wenig Gründe vor, um von dieser einmal allgemein angenommenen Eintheilung abzugehen. Bei den fortgesetzten genaueren Studien über die Fossilien der einzelnen Tertiär-Becken, namentlich durch die Arbeiten von Philippi, Sismonda u.s.w., ferner durch die neuren Studien im Wiener Becken schwanden immer mehr die Grenzen zwischen den meiocänen und pleiocänen Ablagerungen, so dass man am Ende dieselben nicht mehr zu bestimmen im Stande ist. Je mehr nun diese Grenzen sich vermischen, desto schärfer tritt der Gegensatz zwischen der eocänen und meiocänen Fauna hervor."

[8] "Allerdings hat Dumont, auf mineralogische Charaktere der Ablagerungen gestützt, in Belgien eine Vereinigung der Eocän-und Meiocän-Schichten vorgeschlagen, wie Beyrich erwähnt; allein wir müssen hier ausdrücklich bemerken, dass Dumont diese Ansicht nicht auf den zoologischen Charakter der Fauna basirte, ein Fehler, den Lyell bald wieder gut machte, indem er in seiner trefflichen Abhandlung Ordnung in die Tertiär-Schichten von Belgien brachte. Mit gewohntem Scharfblicke hatte er den eocänen Typus des Tongrischen und Rüpelmonder Systems Dumont's erkannt und als ein oberes Glied der Eocän-Formation aufgestellt, während der Sand des Bolderberges entschieden meiocän ist. Die Grenze des Eocän und Meiocän ist also in Belgien in der Fauna eben so scharf markirt wie anderwärts, wie z. B. im Becken der Gironde, wo die Ablagerungen von Gaas und Lesbarritz alsogleich als entschieden eocän erkannt wurden."

between 1858 and 1861, Hörnes had accepted Beyrich's term "Oligocene," but apparently still regarded the Oligocene as a subdivision of the Eocene. Thus, Jokély (1861, p. 380) stated:

> "The term "Neogene" is here of course understood in a much broader geological sense; for recently Dr. Hoernes has sharply separated the Oligocene, which is also represented in the Vienna Basin, from the "Neogene" (Upper Miocene and Pliocene), and at present assigns it to the upper Eocene Formation." ["Der Begriff des "Neogen" ist hier freilich in einem viel weiteren geologischen Sinne aufgefasst; denn Herr Dr. Hornes scheidet in neurer Zeit das Oligocen, welches auch im Wiener Becken vertreten, vom "Neogen" (Ober-Miocene und Pliocen) scharf ab und rechnet es derzeit zur oberen Eocenformation."]

I have been unable to locate a specific paper by Hörnes to which Jokély (1861) may have been referring. However, this verbal redefinition of the beginning of the Neogene was apparently necessary in Hörnes' view because Lyell (1857a) had referred Beyrich's Oligocene strata to the Lower Miocene rather than to the Upper Eocene (see Berggren, 1998, p. 118). Also, Jokély (1858, 1861) had included the Oligocene in the Neogene, and Hörnes was evidently opposed to this expansion of the meaning of his term to include strata that he still regarded as Upper Eocene (Hörnes, 1853a, p. 808; 1854a; Hörnes and Partsch, 1856, p. 405). Whatever the case may be, Hörnes (1864) eventually regarded the Eocene, Oligocene, and Neogene as mutually exclusive time intervals.

A more relevant question for Cenozoic chronostratigraphy, given the recent formal definition of the Oligocene/Miocene boundary (Steininger et al., 1997), would be whether Moriz Hörnes included undoubted Aquitanian (earliest Miocene) strata in the Neogene. Unfortunately, to my knowledge, Hörnes never provided a detailed discussion of Mayer's (1858) stages. Our understanding of this problem is further complicated by the fact that there are numerous ambiguities involved in the early use of the name "Aquitanian" (Berggren, 1963; Drooger, 1964; Berggren, 1971). One ambiguity results from Mayer's (1858, p. 171) simultaneous assignment of the Aquitanian to both the Oligocene *and* the Neogene, while another results from Beyrich's (1859, p. 69) conclusion that the upper boundary of his Oligocene series occurred in the *middle* of Mayer's Aquitanian Stage.

In the only passage I have found in Hörnes and Reuss (1870, p. 123–124) specifically mentioning the Aquitanian Stage, Hörnes regarded the Aquitanian as pertaining to the lowest part of the upper Miocene (sensu Lyell), but cited "Aquitanian" localities that were considered by Denizot (1957, p. 107, 122, 176) to be both Aquitanian (Faluns de Mérignac) and Burdigalian (Saucats, Léognan). According to Drooger (1964, p. 371), however, some of these place names have strata of different ages, so it would be presumptuous to infer Hörnes' intentions on the basis of this evidence alone.

Interestingly, no Aquitanian strata are recorded by Piller et al. (2004) from the Viennese and Styrian basins. Not surprisingly perhaps, as noted by Denizot (1957, p. 141), several Austrian workers of the late 19th century defined the Neogene so as to begin with the "first Mediterranean stage" (Burdigalien Stage of Depéret, 1892a), rather than with the Aquitanian Stage (Hoernes, 1903, p. 919; see also Kuehn, 1962, p. 287). Nevertheless, if additional historiographical work should reveal that Hörnes' concept of the beginning of the Neogene was somewhat different from the beginning of the Neogene as formally defined by Steininger et al. (1997), that would not render the latter definition invalid, for reasons discussed by Walsh (2006) and below.

4. Hörnes' concept of the end of the Neogene

4.1. The evolving definitions of "Tertiary" and "Pliocene" in the 1840s

Given Hörnes' (1851b, 1853a) definition of the Neogene as "young Tertiary" and as a "merging of Miocene and Pliocene deposits," it is necessary to understand contemporary definitions of "Tertiary," "Pliocene," and related terms in order to appreciate his meaning (Fig. 3). Lyell's (1833, p. 53) original definition of the Pliocene (consisting of the Older Pliocene and Newer Pliocene) specifically excluded the "Recent" interval, the latter being defined as "[the time] which has elapsed since the earth has been tenanted by man" (Lyell, 1833, p. 32). Lyell (1833) clearly believed this Recent interval to be only a few thousand years in duration, roughly corresponding to the modern Holocene Epoch. However, some ambiguity is evident in Lyell's (1833) original concept of the Newer Pliocene/Recent boundary, for he also stated (p. 54):

> "The newer Pliocene formations, before alluded to, pass insensibly into those of the Recent epoch, and contain an immense preponderance of recent species. It will be seen that of two hundred and twenty-six species, found in the Sicilian beds, only ten are extinct or unknown species, although the antiquity of these tertiary deposits, as contrasted with our most remote historical eras, is immensely great."

Accordingly, in the second edition of *Elements of Geology*, Lyell (1841, vol. 1, pp. 210–212; 214–215) envisioned the ends of the Pliocene and Tertiary to occur much earlier than the presumed first appearance of humans when he defined the term "Post-Pliocene":

> "I have adopted the term Post-Pliocene for those strata, which are sometimes called modern, *and which are characterized by having all the imbedded fossil shells identical with species now living*, whereas even the Newer Pliocene or newest of the tertiary deposits contain always some small proportion of shells of extinct species... That portion of the Post-Pliocene group which belongs to the human epoch, and which is sometimes called Recent, forms a very insignificant feature in the geological structure of the earth's crust [italics added]."

This definition of the end of Tertiary time was also used by Lyell (1840, v. 1, p. 285) in the 6th edition of *Principles*

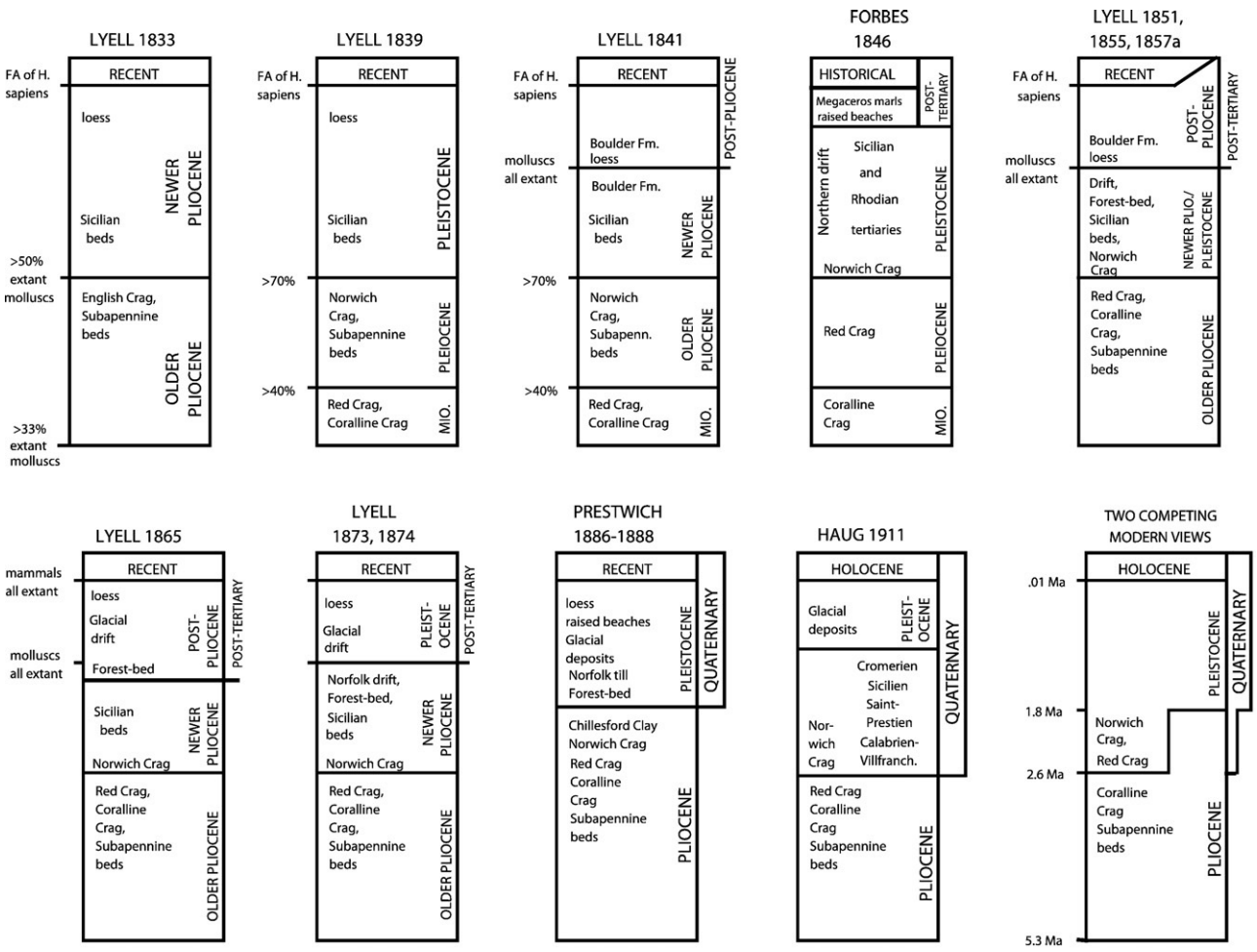

Fig. 3. Evolution of Charles Lyell's usage of "Pliocene" and related terms, along with the classifications of Forbes (1846), Prestwich (1886–1888), Haug (1911), and the two competing modern schemes. 1833: The "English Crag" and the Subapennine beds of Italy are listed by Lyell as types of the Older Pliocene, and the "loess of the Rhine" is assigned to the Newer Pliocene. 1839: Lyell, 1939a suggests "Pleistocene" as a replacement for "Newer Pliocene," and changes his statistical definitions of the Miocene/ Pliocene and Pliocene/Pleistocene boundaries. He also recognizes three distinct units within the original "English Crag," and assigns the Red Crag and Coralline Crag to the Miocene. 1841: Lyell does not mention the term "Pleistocene" and coins the term "post-Pliocene" for those strata with mollusc assemblages containing 99–100% extant species, including the "Recent" interval. He also assigns the loess of the Rhine to the Post-Pliocene and recognizes some parts of the "Boulder formation" as Newer Pliocene, and other parts as post-Pliocene. 1846: Forbes assigns the Red Crag to the Pleiocene, but assigns the Norwich Crag, glacial deposits, and Sicilian and Rhodian tertiaries to the Pleistocene. 1851–1857: Closely following Forbes' usage, Lyell again regards "Pleistocene" as an optional synonym of "Newer Pliocene." He reassigns the Red Crag and Coralline Crag to the Older Pliocene, and assigns the Norwich Crag and Cromer Forest-bed to the Newer Pliocene=Pleistocene. The older part of the "Boulder Formation" is now called "Glacial drift," and is assigned to the Newer Pliocene. Confusingly, Lyell uses "post-Pliocene" for post-Tertiary time, as well as for post-Tertiary time prior to the Recent. 1865: Lyell explicitly defines the "post-Pliocene" as post-Tertiary time excluding the Recent. He discourages use of the term "Pleistocene" and assigns the Cromer Forest-bed and all glacial deposits to the post-Pliocene. Owing to the discovery of archaeological remains in the post-Pliocene strata, Lyell redefines the beginning of the Recent interval as the time when mammalian faunas begin to consist entirely of extant species. 1873–1874: Lyell replaces the term "post-Pliocene" with "Pleistocene," and reassigns the Norfolk drift and Cromer Forest-bed to the Newer Pliocene. 1886–1888: Prestwich abandons the term "Newer Pliocene," defines the Pleistocene so as to consist of the Pleistocene plus most of the Newer Pliocene of Lyell (1873, 1874), and defines the Quaternary to consist of the Pleistocene+Recent. 1911: Haug restricts the Pleistocene to the post-Cromerian, pre-Holocene glacial deposits, and extends the Quaternary downward to include the Norwich Crag and the Calabrian Stage. 1985-present: Aguirre and Pasini (1985) formally define the Pliocene/Pleistocene boundary (and by implication the Tertiary/Quaternary boundary) by means of a GSSP at Vrica, Italy, currently dated at about 1.8 Ma. This definition results in the Norwich Crag being assigned to the Pliocene. Other Quaternarists, however, would prefer a Plio–Pleistocene boundary at 2.6 Ma, which would make both the Red Crag and Norwich Crag early Pleistocene. This arrangement was previously discussed by Prestwich (1888, p. 441) and was commonly accepted by British stratigraphers in the 20th century (e.g., Baden-Powell, 1950; Oakley and Baden-Powell, 1963, p. 133; Gibbard et al., 1998; Bowen, 1999). Depicted relative durations of the units are not to scale.

of Geology. This edition was quickly translated into German (Lyell, 1841–1842; Vaccari, 1998, p. 42), so it is reasonable to assume that a decade later, Moriz Hörnes would have been aware of Lyell's (1840, 1841) revised biochronological concept of the end of the Tertiary. Given Lyell's definition of the end of Pliocene time as the fuzzy transition interval between mollusc faunas that contained at least some extinct species and those that contained all extant species, such "Post-Pliocene" strata could be as old as the last interglacial (ca. 125 Ka) or older, because deposits of this age around the

Herrschaft der Säugethiere.	8. B. Alluvium und A. Diluvium	Gebilde der jetzigen Weltepoche. Herrschaft des Menschen.	Jüngster Meeres-Kalkstein und Sand, Thon, Lehm, Schlamm, Kalktuff, Torf, Infusorienlager u. s. w. Lös; Kies, Sand und Lehm mit Knochen; südeuropäische Knochenbreccie, Knochenhöhlen, Bohnerzgruben, Eis mit Mammuthen u. s. w.	
	7. Molassen- oder Tertiärgebirge. (Tertiary-System; Terrains tertiaires.)	C. **Oberes** M. oder pliocene Periode.	Süfswasserquarz von Paris und Falkenau in Böhmen u. s. w. Süfswasserkalk mit Schieferthon und Polirschiefer von Bilin und Eger in Böhmen. Süfswasserkalk von Steinheim in Würtemberg, von Nördlingen in Baiern und des Mainzer und Wiener Beckens. Oeninger Kalkschiefer. Obere Braunkohlen.? Radoboj in Croatien.	Subapenninenformation. Crag und Bagshot-Sand im südlichen England. Molasse der Schweiz z. Th.
		B. **Mittleres** M. oder miocene Periode.	Oberer Meeres-Sand und Sandstein des Pariser Beckens. Tegel des Wiener und Mainzer Beckens. Molasse der Schweiz z. Th. Faluns der Touraine etc.	
		A. **Unteres** M. oder eocene Periode.	d) Grobkalkformation des Pariser Beckens, mit dem Gypse des Montmartre. Plastischer Thon von London (*London-Thon*). Molasse der Schweiz z. Th. c) Untere Braunkohlenformation, mit Schieferthon, Braunkohlenthon und Braunkohlensandstein von Paris, Böhmen, Sachsen, Altenburg u. s. w. b) Nummuliten- und Pisolithenkalke. a) Fischreicher Schiefer des Monte Bolca und Libanon.	

Fig. 4. Cenozoic classification of Geinitz (1846; fold-out chart following p. viii), showing exclusion of the Diluvium and Alluvium from the "Molassen-oder Tertiärgebirge."

world commonly contain mollusc assemblages with no extinct species.[9]

In addition, many European geologists at this time did not hesitate to use the term "Quaternary" and to distinguish these rocks from the Tertiary (e.g., Geinitz, 1846; d'Archiac, 1848, 1849). As such, and although there were obviously still some exceptions (see Bronn, 1854, p. 45, discussing Sandberger, 1847), European geologists generally excluded the "Diluvium" and related deposits from the Tertiary. For example, Geinitz (1846) departed from the classification of Bronn (1838) by excluding the "Alluvium und Diluvium" from the "Molassen-oder Tertiärgebirge" (Fig. 4). Similarly, C.F. Naumann, in his treatise *Lehrbuch der Geognosie*, divided the Känozoische into the tertiäre und quartäre Formationen, and assigned the Diluvialbildungen to the latter, thus clearly excluding it from the Tertiary and from the Pliocene (Naumann, 1851, p. 50; 54–55). Moriz Hörnes was familiar with these works, as both are listed in the references in Hörnes and Partsch (1856).

The separation of the "Diluvium" and associated deposits from the Tertiary and Pliocene was also accepted by Austrian geologists in the late 1840s and early 1850s. Thus, for the geological context of the Vienna Basin, Hörnes (1851a, p. 100) would refer to a report by von Haidinger (1848) on an early geologic map of the Austrian Empire, a map to which Hörnes contributed (Partsch and Haidinger, 1848), and a map which explicitly excluded the "Diluvium" from the Tertiary (von Haidinger, 1848, p. 232). Similarly, Hörnes' friend and colleague Franz von Hauer (1850, p. 53–56), in discussing the content of the Obere Tertiarformation, noted that it consisted of a lower or Miocene Group and an upper or Pliocene Group, and excluded the Diluvium and Alluvium. Even more significantly, Hörnes (1848, 1850b,c) himself had separated the loess and diluvial beds from the Tertiary beds in a summary of fossil mammal discoveries in the Vienna Basin. This separation was consistent with Lyell's (1840, v. 1, p. 286; 1841, p. 269) previous exclusion of the loess of the Rhine from the Pliocene and Tertiary.[10] Finally, Hörnes (1853a, p. 809)

[9] This biochronological definition of the Tertiary/post-Tertiary boundary would be used by Lyell for the rest of his life (e.g., Lyell, 1873, p. 47), long after most other contemporary workers had accepted a significantly older concept of this boundary. To illustrate with examples from California, of the 273 species of molluscs documented from the middle Pleistocene Santa Barbara Formation by Powell et al. (2002), only 11 are extinct. Powell et al. estimate the numerical age of this unit to be between 490 and 790 Ka. In contrast, Californian marine terraces assigned to the oxygen isotope stage 5e interglacial (ca. 125 Ka) typically contain one or no extinct molluscan species, and terraces correlated with the 80 Ka interglacial contain no extinct species (Kern 1971, 1977). As such, these late interglacial deposits would fall very close to the Tertiary/post-Tertiary boundary as biochronologically-defined by Lyell (1840, 1841).

[10] Contra Berggren (1998, p. 120) and Steininger (2002, p. 42), Lyell never regarded the European loess as being of marine origin. This is an important point because Lyell's evolving views on the loess provide another example of the self-censorship that resulted from the hostile reaction of certain influential persons to Lyell's and Buckland's early adoption of the glacial theory of Louis Agassiz (Boylan, 1998).

Citing the absence of marine fossils and the presence of terrestrial molluscs and mammal bones, Lyell (1833, p. 153) initially regarded the loess as the deposit of a single, muddy, freshwater flood. Later, Lyell (1834, p. 414) proposed that a regional subsidence had occurred, causing the Rhine Valley and other loess-containing European valleys to become filled up with fluviatile silt, after which a re-elevation and erosion of the region must have occurred. Still later, Lyell (1841, p. 266–267) criticized his 1834 hypothesis because it required a major, geologically recent subsidence and re-elevation of much of Europe, "changes which… are not as yet confirmed, in this case, by independent evidence." Therefore, and at the moment being an enthusiastic supporter of Agassiz' glacial theory, Lyell (1841, p. 261; 266–267) favored an origin of the loess in terms of the gradual accumulation of annual deposits of mud derived from the moraines of retreating glaciers. However, after the hostile reaction to his adoption of the glacial theory, Lyell (1851, p. 119) resurrected his 1834 hypothesis, deleted his 1841 objections to it, and deleted all mention of his and Agassiz' alternative explanation.

Modern, aeolian explanations for the origin of the loess date from von Richthofen's (1877) report on China (Zittel, 1901, p. 199–200; Grabau, 1924, p. 565–568; Bowen, 1978, p. 184–188).

had cited a letter to H.G. Bronn from Eugenio Sismonda (1853) that expressed views on the unification of the Miocene and Pliocene very similar to those proposed by Hörnes (1851b) two years earlier. In this letter, Sismonda (1853, p. 335) clearly separated the "Ober-tertiär Gebirge" from the "Alluvio-glacial Gebirge".

4.2. Did Hörnes extend the Neogene to the present?

As documented above, the general exclusion of the loess, Diluvium, and associated deposits from the Tertiary by Hörnes and his Austrian, German, French, and Italian colleagues by the late 1840s has important implications for Hörnes' concept of the Neogene. Berggren (1998, p. 119–120), elaborating on the previous discussion of Steininger (1981), analyzed H.G. Bronn's (1838) "Molasse Gebirge," his subdivisions of this grouping, and their relevance to Moriz Hörnes' work. Berggren (1998, p. 120) stated:

> "In creating the term Neogene for these upper, younger faunas, Hörnes (1853a,b, 1864) referred specifically to the biostratigraphic subdivision of the Tertiary and Quaternary made by his friend Bronn in 1838... Hörnes included in his term Neogene the strata in the Vienna Basin up to and including those in glacial loess and diluvial deposits, as well as correlative Mediterranean faunas in Sicily, Rhodes and Cyprus which would now be included in the Pleistocene. It will be recalled that Lyell coined the term 'Pliocene' in 1833 and subsequently (1839b, 1857a,b) subdivided it into an Older Pliocene and Younger Pliocene (the latter equivalent to the Pleistocene).

First, it should be noted that Lyell's subdivision of the Pliocene into Older Pliocene and Newer Pliocene was introduced in volume 3 of the first edition of *Principles of Geology* (Lyell, 1833, pp. 61–154; 155–201). More importantly, I have been unable to find any discussion in Hörnes (1850a,b, 1851a,b, 1853a,b, 1854a,b, 1856a,b,c, 1855, 1857, 1864), Hörnes and Partsch (1856), or Hörnes and Reuss (1870) of Bronn's (1838) classification of the Molasse Gebirge nor of his biostratigraphic subdivision of the Tertiary and Quaternary.

Third, Berggren (1998, p. 120) correctly noted that Bronn (1838) had assigned the Diluvial Bildungen of Europe to the Pliocene (as did Lyell, 1833), and seems to have inferred from this that Hörnes would have included the Diluvium in the Neogene. This argument was repeated by Steininger (2002, p. 420) and Lourens et al. (2004, pp. 409–410). Again, however, the key inference here is unwarranted. First, as noted above, Bronn's (1838) definition of the Molasse Gebirge (and Pliocene) so as to include the Diluvium was by no means universally accepted in the 1840s (Geinitz, 1846; see Fig. 4). More importantly, as documented above, Hörnes (1848; 1850b, c), as well as many of his Austrian colleagues, had already excluded the loess and Diluvium from the Tertiary. Not surprisingly, therefore, in the third edition of *Lethaea Geognostica*, even HG Bronn (1854, pp. 70–71) would separate the "Pleistocän or Post-pliocän (Diluvial)" deposits from the "Pliocän (Ober-tertiär)" deposits.[11] Evidently then, Bronn's (1838, pp. 787; 790) earlier retention of the Diluvium in the Pliocene and Tertiary in the obsolete second edition of *Lethaea Geognostica* was not relevant to Moriz Hörnes' concept of the Neogene.

Fourth, I have been unable to corroborate the claims of Van Couvering (1997, p. xii), Berggren (1998, p. 120), and Steininger (2002, p. 42) that Hörnes "explicitly" included the loess and Diluvium of the Vienna Basin in the Neogene. On the contrary, in a discussion of the land snail family Colimacea, Hörnes and Partsch (1856, p. 610) stated:

> "In the Tertiary deposits of the Vienna Basin only the genus *Helix* has been found up to now... while in the younger deposits, particularly in the loess, *Helix* and the rest of this family of related genera are abundantly represented." ["In den tertiären Ablagerungen des Wienerbeckens ist bis jetzt nur das Geschlecht *Helix* aufgefunden worden... während in den jüngeren Ablagerungen, namentlich im Löss, *Helix* und die übrigen dieser Familie angehörigen Geschlecter zahlreich vertreten sind."]

This passage again logically implies that Hörnes excluded the loess from the Neogene, because consistent with the original definition of Hörnes (1851b), Hörnes and Partsch (1856, pp. 155, 157, 165, 167, 171, 181, etc.) repeatedly defined the Neogene as "Miocene+Pliocene," or "young Tertiary." As the loess and coarse glacial deposits were generally classified together by most workers of the time as "Diluvium" (Geinitz, 1846; von Hauer, 1850; Naumann, 1851), it would have been unusual for Hörnes to have included the coarser glacial deposits in the Neogene while at the same time excluding the loess.

4.3. Did Hörnes extend the Neogene to the beginning of the Holocene?

Despite the evidence discussed above, some of Hörnes writings can be reasonably interpreted to suggest that he intended the Neogene to extend approximately to what is now the beginning of the Holocene. This was the position of Lourens et al. (2004, p. 412). Specifically, Hörnes (1855, 1857) and Hörnes and Partsch (1856), in discussing the temporal distribution of various gastropod taxa, would frequently refer to the number of Neogene species of a given genus in contrast to the number of living species. The terms that Hörnes most often used to denote this time of the living species were "Jetzwelt" (modern world) and "Jetztzeit" (present time). For example, Hörnes (1855, p. 179–180) stated:

> "According to the newest lists about 80 recent and 60 fossil species [of *Cancellaria*] are currently known...The fossil

[11] Bronn (1854, p. 70), in apparently regarding "Pleistocene" and "post-Pliocene" as synonyms, seems to have misinterpreted Lyell's (1852a, p. 279) simplified correlation chart. At the time, Lyell (1852b, 1851, 1855, 1857a) was using the term "Pleistocene" as an optional synonym of "Newer Pliocene" (which of course he still regarded as Tertiary), and was using the term "post-Pliocene" mainly for the post-Tertiary, pre-Recent interval.

species occur only in the Tertiary deposits, specifically 17 from the Eocene and 43 from the Neogene strata. The small number of species in Eocene time can be explained by the fact that this genus arose for the first time in this period; in the later Neogene time they are more developed, *and finally in the modern world they achieved their many forms*… [italics added]."[12]

Hörnes and Partsch (1856, pp. 201, 386, 497) would use the terms "Jetztwelt," "Jetztzeit," and "der jetzigen Epoche" in several other places in their treatise, in contrast to the Neogene. Bronn (1854, pp. 17–18) noted that the terms "Jetztwelt" and "Jetztzeit" were inexact, but roughly synonymous with the post-Diluvial, "alluvial" time (cf. "Recent" of Lyell). So, did Hörnes use these terms approximately in the sense of the modern Holocene? It is entirely possible that he did. On the other hand, as noted above, Lyell (1841) pointed out that the term "modern" was sometimes used for his concept of the post-Tertiary, i.e., the time interval that commenced when marine faunas began to consist entirely of extant or modern taxa. If Hörnes was using the terms Jetztwelt and Jetztzeit in that sense, then those passages would be more consistent with his explicit definition of the Neogene as "Miocene+Pliocene" and "young Tertiary." I tend toward the latter view, because it seems doubtful that Hörnes believed that the 80 extant species of *Cancellaria* actually originated during the Holocene.

4.4. Additional ambiguities

Other writings of Hörnes raise still more questions. Of particular interest is Hörnes' (1856a,b,c) discussion of some "subfossil" molluscan remains from the Isthmus of Corinth (Greece), collected from 30–36 ft (9–11 m) above sea level (presumably from one of the well-known late interglacial terraces in the Gulf of Corinth; e.g., Armijo et al., 1996; McNeil and Collier, 2004). Hörnes (1856a,b,c) noted that all of the species in this Corinth collection were still living in the adjacent sea. Therefore, according to Lyell's (1840, 1841) definition of the Tertiary/post-Tertiary boundary, the fossiliferous deposit at Corinth would be of post-Tertiary age. Entirely consistent with expectations, in the English translation of Hörnes' report, A.F. Marschall[13] provided the title: "On *post-Tertiary* shells from the coast of Greece" (Hörnes, 1856b; italics added). Therefore, if Hörnes' concept of the end of the Neogene was the same as Lyell's (1841) concept of the end of the Tertiary and Pliocene, then he should have excluded this collection of subfossils from the Neogene. So, did he? Alas, Hörnes was unclear on this crucial point. Hörnes (1856a, p. 173) noted that "Under completely identical circumstances, similar deposits of fossil remains have been found on almost all coasts of the Mediterrranean Sea" ["Unter ganz gleichen Verhältnissen sind ähnliche Ablagerungen fossiler Reste fast an allen Küsten des mittelländischen Meeres gefunden worden"], and gave as examples several localities that he did include in the Neogene (e.g., Rhodes, Cypress, Sicily). Unfortunately, Hörnes (1856a,b,c) did not explicitly state that the collection of subfossils from Corinth was of Neogene *or* post-Neogene age.

4.5. Discussion

What are the most important facts concerning Moriz Hörnes' early writings on the Neogene? First, those writings are frustratingly ambiguous, allowing the reasonable interpretations that Hörnes either intended the Neogene to extend to the beginning of the "Diluvial-epoche," or to the end of the Tertiary sensu Lyell (1841), or to the approximate beginning of the Holocene of modern usage. Although Hörnes apparently never *explicitly* defined the Neogene so as to exclude the Diluvium and Alluvium, this definition was logically implied by him several times, when he defined the Neogene as a subdivision of the Tertiary (Miocene+Pliocene), together with the fact that he had previously excluded the loess and Diluvium from the Tertiary (Hörnes 1848, 1850c, 1851b, 1853a, 1854b, 1855; Hörnes and Partsch, 1856, p. 610). In addition, I have found no passages in Hörnes' writings that either explicitly state or logically imply that the Neogene extended to the present.

Despite the above, it is still possible that Hörnes' reluctance to provide an explicit definition of the end of the Neogene reflects a genuine tension in his thinking between an open-ended biochronological concept and a closed concept dictated by the prevailing exclusion of the loess and diluvium from the Tertiary (Geinitz, 1846; von Haidinger, 1848; Hörnes, 1848, 1850c; Naumann, 1851), and the growing recognition of a geologically recent "ice age" (Agassiz, 1841; Forbes, 1846; d'Archiac, 1848; Morlot, 1854; de Serres, 1855; Zittel, 1901, p. 221–232). Perhaps more likely, Hörnes may have felt that an explicit definition of the end of the Neogene was simply unnecessary at that time, given the rapidly expanding knowledge of European stratigraphy. Nevertheless, my interpretation, which should certainly be tested by additional historiographical work, is that we cannot reject the null hypothesis established by Hörnes' prior separation of the loess and Diluvium from the Tertiary (Hörnes, 1848, 1850b,c; Hörnes and Partsch, 1856, p. 610), and his explicit definition of the Neogene as "young Tertiary" and "Miocene+Pliocene" (Hörnes, 1851b, 1853a; Hörnes and Partsch, 1856). As such, it is reasonable to assume that Hörnes equated the end of the Neogene with the beginning of the Diluvial epoch, and/or with

[12] "Man kennt gegenwärtig nach den neuesten Listen über 80 recente und 60 fossile Arten… Die fossilen kommen nur in den Tertiärablagerungen, und zwar 17 in den Eocen-und 43 in den Neogenschichten vor. Die geringe Anzahl der Arten in der Eocenzeit erklärt sich dadurch, dass dieses Geschlect zu jener Zeit zum ersten Male auftrat, in der späteren Neogenzeit sich mehr entwickelte und endlich in der Jetztwelt ihren vollen Formenreichthum erlangte…"

[13] Aka "Count M" (Hörnes, 1856b, 1865a, 1868). August Friedrich Marschall (1805–1887) was a former archivist of the k.-k. geologischen Reichsanstalt in Vienna who translated scientific papers for Moriz Hörnes (Hörnes, 1867, p. 588). He also contributed many English summaries of German language treatises to the Quarterly Journal of the Geological Society of London (Jones, 1887; Woodward, 1907, p. 158). See Sargeant (1980).

the end of the Tertiary as defined biochronologically by Lyell (1840, 1841).[14]

To conclude this section, it is worth calling attention to the Erläuterung (Explanation) of Hörnes and Partsch's (1856, p. 712) map entitled "Die wichtigsten Fundorte von Versteinerungen im Tertiärbecken von Wien" (The most important fossil localities in the Tertiary Basin of Vienna"). True to form, this map and its explanation do not mention the Neogene, so it is again impossible to deduce from them Hörnes' exact concept of this term. Nevertheless, the final sentence of the Erläuterung states:

> "A detailed portrayal of the geological relationships of the Vienna Basin on a geologic map of the same area and with a more mature consideration of the rest of the Tertiary deposits of Europe will be given at the end of the second volume." ["Eine ausführliche Darstellung der geologischen Verhältnisse des Wienerbeckens mit einer geologischen Karte desselben, und mit steter Hinsicht auf die übrigen Tertiärablagerungen Europas wird am Schlusse des zweiten Bandes gegeben werden."]

Doubtlessly, all ambiguities would have been removed had Hörnes lived to complete this work.

4.6. Relevance to the modern geologic time scale

Even granting my interpretation of Moriz Hörnes' original, predominant concept of the end of the Neogene, it is clear that he included in this unit various "Newer Pliocene" deposits that are now considered to be early, middle, and possibly even late Pleistocene in age. This was the main point correctly emphasized by Berggren (1998) and Steininger (2002). Nevertheless, the meanings of almost all standard global geochronologic names have evolved since they were first used, and whatever Moriz Hörnes' original meaning of the Neogene was, this original meaning is fundamentally irrelevant to the modern classification of the Cenozoic. No particular interpretation of the original meaning of the Neogene can be deemed "correct" modern usage, any more than Lyell's original or subsequent definitions of "Eocene," "Pliocene," or "Pleistocene" can be deemed "correct" modern usage (Fig. 3). As shown by countless examples from the history of stratigraphy, we must expect that a given term would be used in different ways by early workers, including by the very scientist who first coined the term. Ultimately, therefore, the essential questions we must ask do not include: "What was Moriz Hörnes' original meaning of the Neogene?" Rather, they must be: 1. How was the term "Neogene" used by most geologists after it was first introduced? 2. How and why did this term evolve in meaning over time? and 3. Given the fact that in a hierarchical classification, changes in the scope of one name can greatly affect the scope and rank of several other names, what definition of the Neogene should we use *today*, in order to best achieve the goal of clear communication among geologists *now*?

5. Adoption of "Neogene" in the German language literature of the second half of the 19th century

Starting in the mid-1850s, the term "Neogene" was frequently used by Austrian, German, Hungarian, Yugoslav, and Czech geologists, and it almost always excluded the "Diluvium" and "Alluvium" (e.g., Czjzek, 1854; Stur, 1855; Lipold, 1856; Peters, 1856; Lipold, 1857; Peters, 1857; Rolle, 1857; Stache, 1858; von Zollikofer, 1859; Jokély, 1861; Stur, 1864). Lipold (1856) and von Zollikofer (1859) are especially notable in that on their geologic maps and cross-sections, they clearly separated the "Tertiär-Neogen" from the "Alluvium and Diluvium" (Lipold, 1856, Tafel 1), or separated the "Neogenformation" from the "Quaternäre Bildungen," the latter consisting of the "Diluvium" and "Alluvium" (von Zollikofer, 1859, Tafel V). Such usage establishes an independent circumstantial case for Moriz Hörnes' concept of the end of the Neogene, because these men were close colleagues of one another. The geologists of the k-k geologischen Reichsanstalt often cited Hörnes' work (e.g., Czjzek, 1854, p. 527; Stur, 1855, p. 4; Peters, 1857, p. 320; Rolle, 1857, p. 451) and Hörnes frequently cited the geologists' publications, even naming new species of molluscs after von Hauer, Peters, and Rolle (Hörnes and Reuss, 1870, p. 198, 199, 380, 400). Because Hörnes never contradicted the usage of "Neogene" by these geologists, it is again reasonable to assume that he also excluded the Diluvium and Alluvium from this unit.

The only exception to the above general usage of the Neogene that I have found in the German language literature of the 1850s is that of H.G. Bronn (1854, p. 22; 64; 67; 373), who defined this interval as consisting of the Faluns, Subapennine, and Diluvial deposits (his units u^2, v, w, and x). Nevertheless, Bronn still excluded from the Neogene the "lebend" or Jetztzeit (Bronn, 1854, p. 17, 18, 384, 405, 408, 510, 546). However, this inclusion of the Diluvium in the Neogene was inconsistent with Bronn's (1854, pp. 70–71) own correlation chart, which showed the Diluvium as separated from the Pliocene and Tertiary. Variable usage of "Neogene" is again seen in a later work by Bronn (1858, p. 187; 190), where in the first case he implied that the term means Miocene+Pliocene, whereas in the second case he included the "Diluvium" in the Neogene.

Given the otherwise consistent usage of "Neogene" in the numerous papers cited above, the term was soon incorporated into standard textbooks. Thus, Gustav Leonhard, in his textbook *Grundzüge der Geognosie und Geologie*, defined the Neogene

[14] Interestingly, Lyell visited Austria in 1856 and met Theobald Zollikofer, Dionys Stur, and other associates of the k.-k. geologischen Reichsanstalt and the Imperial Museum in Vienna (Wilson, 1970, p. 357; Lyell, 1881, p. 227–228; 247). In the forthcoming third and final volume of his biography of Lyell, Leonard Wilson (electronic comm., 2006) documents an 1856 meeting between Lyell and Moriz Hörnes (recorded in Lyell's Notebook 215), in which Hörnes displayed his collections of Miocene molluscs from the Vienna Basin. Both before and after this meeting, Lyell (1855, p. 180, 1865, p. 242) referred to Hörnes' "excellent work," but did not mention the term "Neogene." Unfortunately, no correspondence between Lyell and Hörnes exists in the Lyell collections at the University of Edinburgh (Alison Cutt, electronic comm., 2005), nor in the archives of the Vienna Museum of Natural History (Crista Riedl-Dorn, electronic comm., 2006). We are therefore ignorant of the content of the fascinating discussions that must have taken place between these two men on the status of the Neogene.

Allu-vium.		1.	Alluvium. — Silt.
		2.	Kalktuff.
		3.	Torf.
Dilu-vium.		4.	Löss.
		5.	Schotter. — Gerölle, Terrassen-Diluvium u. s. w.
Neogen.	Süss-wasser-stufe.	6.	Süsswasserkalk.
		7.	Congerienschichten. — Congerien-Tegel, Lignit.
		8.	Basalttuff. — Wacke im Braunkohlensandstein.
	Bracki-sche Stufe.	9.	Cerithien-Schichten. — Cerithien-Sandstein.
		10.	Hernalser Tegel. — Schwefel von Swoszowice.
		11.	Trachyttuff.
	Marine Stufe.	12.	Leithakalk. — Nulliporenkalk, Loretto-Geschiebe, Leithasandstein, Bryozoensandstein.
		13.	Mariner Tegel und Sand. — Steinsalz von Bochnia und Wieliczka. Süsswasser-Schichten mit Pechglanzkohle von Eibiswald in Steiermark.

Fig. 5. Cenozoic stratigraphic column for the Austrian Empire, from von Haidinger (1866). Note that the "Diluvium" and "Alluvium" are excluded from the Neogene.

as upper Tertiary, comprising the Miocene and Pliocene. Leonhard excluded the "Quartär-Formationen" from the "Tertiär-Formationen," and combined both of these into the "Känolithische Formationen" (Leonhard, 1863, p. 300–301).

In 1864, Moriz Hörnes further discussed his term in a paper summarizing his work on the Tertiary bivalves of the Vienna Basin (Hörnes, 1864; see Hörnes, 1865a for an English summary). Hörnes (1864, p. 510) stated:

> "My intention in creating the term Neogene was not to dismiss the differentiation between Miocene and Pliocene altogether, but merely to define more clearly the relationship of the faunas of the different stages. For in the Eocene we see mainly tropical forms, which disappear after the Oligocene period. Similarly, in the lower Neogene strata subtropical (Senegal-) forms appear, which mingle gradually in an upward direction with Mediterranean forms, until finally, in the uppermost strata, they assume the complete character of the Mediterranean fauna. Just as the Eocene is the cradle of the tropical fauna, the Neogene is the cradle of the subtropical fauna, which was gradually transformed-without sharp boundaries-into the Mediterranean fauna."[15]

Although this passage is subject to interpretation, Hörnes again implies that Neogene time ends when the modern Mediterranean fauna is fully established, emphasizing that this biochronological boundary is gradational. This acceptance of a gradational boundary does not constitute an inconsistency in Hörnes' mature philosophy, because by this time he had accepted the validity of the Miocene and Pliocene along with the fuzzy boundary between them (Hörnes and Reuss, 1870, p. 233). If I have interpreted the above passage correctly, then Hörnes' (1864) concept of the end of the Neogene was again similar to Lyell's (1840, 1841) concept of the end of the Pliocene, with the time of existence of the modern Mediterranean fauna (composed entirely of extant species) corresponding to Lyell's "Post-Tertiary" time.

Consistent with the above interpretation, Hörnes (1865b, 1866), in discussing the 20 geologic units depicted on a geologic map of the Krakau area, noted without disapproval that unit 19 was "Neogen", and unit 20 was "das Diluvium," thereby implicitly agreeing that the Diluvium was excluded from the Neogene (see Hohenegger, 1867). Likewise, von Haidinger (1865, p. 260–261, 1866), in discussing the forthcoming edition of the geologic map of the Austrian Empire, excluded the "Diluvium" and "Alluvium" from the Neogene (Fig. 5), and noted that Hörnes was among those who contributed to the content of the map.

After 1865, the term Neogene was widely used in German language geology journals and textbooks for the rest of the 19th century, and always with a consistent meaning. For example, Friedrich August Quenstedt, in his textbook *Handbuch der Petrefaktenkunde*, defined the Neogene as Miocene plus Pliocene, excluded from it the "Diluvium," and regarded the terms "Drift," "Pleistocen," and "Post-pliocen" as synonyms of "Diluvium" (Quenstedt, 1867, p. 14).

von Hauer (1868, 1869, 1872, 1873), in the explanation of several different sheets of the geologic map of the Austrian Empire, continued to define the Neogene as consisting of the Miocene and Pliocene, and excluding the Diluvium and Alluvium.

Hermann Credner, in his textbook *Elemente der Geologie*, defined the Neogene as Miocene plus Pliocene, and excluded from it the "Diluvium" and "Alluvium" (Credner, 1872, p. 266; 464). Consistent with this definition, Credner (1872, p. 482) implicitly excluded the loess and Diluvium of the Vienna Basin from the Neogene.

[15] "Es handelt sich hier nicht darum die Unterscheidung von Mio-und Pliocen ganz aufzugeben, sondern es war bei Aufstellung des Neogens meine Absicht, lediglich die Zusammengehörigkeit der Faunen der einzelnen Etagen besser zu präcisiren. Wir sehen nämlich im Eocenen vor Allem tropische Formen auftreten, welche nach der Oligocenperiode verschwinden.-Eben so treten in den unteren Schichten des Neogenen subtropische (Senegal-) Formen auf, die nach und nach gegen oben hin sich mit Mediterranformen mengen, bis sie endlich in den obersten Schichten ganz den Charakter der Mediterranfauna annehmen. Wie das Eocene die Wiege der tropischen Fauna ist, so ist das Neogene die Wiege der subtropische Fauna, die stätig, ohne scharfe Grenzen, zur Mediterranfauna umgewandelt wurde."

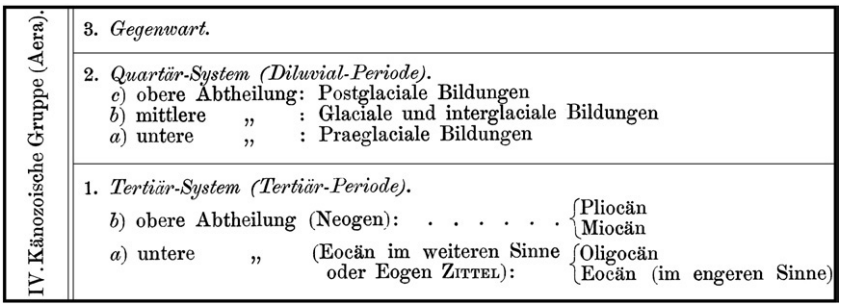

Fig. 6. Cenozoic time scale of Rudolf Hoernes (1884, p. 13). Note that the Neogene is defined as "Miocän+Pliocän" and excludes the "Quartär System (Diluvial Periode)" and "Gegenwart."

Friedrich Pfaff, in his textbook *Grundriss der Geologie*, defined the Neogene as Miocene plus Pliocene, and excluded from it the "Quaternäre Bildungen" (Pfaff, 1876, p. 358; 362; 371).

Following the death of Moriz Hörnes in 1868, his son Rudolf Hoernes[16] became a professor of geology at the University of Graz (Hubmann, 1999). In 1872, Hoernes began to publish a remarkable number of geological and paleontological papers (Heritsch, 1906), many of which would use the term Neogene (e.g., Hoernes, 1875a,b,c, 1876; Hoernes and Auinger, 1879–1891). Hoernes (1875a) pointed out that there was no marine Pliocene in Austria, a fact that may have contributed to his father's skepticism about the existence of a recognizable boundary between the Miocene and Pliocene. Conspicuous by their absence from the Neogene classification of Hoernes (1875a) were the deposits of the "Diluvial-epoche." These deposits were only mentioned at the end of his paper (p. 645), where it was suggested that the distinctive mammalian fauna from the Pliocene of Italy, if found in Austria, would help to identify the local stratigraphic boundaries between the Miocene, Pliocene, and Diluvial sediments.

In his textbooks *Elemente der Palaeontologie* and *Paläontologie*, Rudolf Hoernes again defined the Neogene as late Tertiary (Miocene plus Pliocene), separated the Tertiary from the Quaternary, and combined both (along with the Gegenwart, or Recent) into the Cenozoic Era (Hoernes, 1884, p. 13; 1899, p. 33). The Cenozoic time scale from Hoernes (1884) is reproduced here in Fig. 6, and is noteworthy in that it includes postglacial, glacial, and interglacial, as well as pre-glacial sediments in the Quaternary. The "pre-glacial" sediments referred in part to the Cromer Forest-bed of England, a unit variably assigned by Lyell (1851, 1855, 1865, 1874) to either the Newer Pliocene or the post-Pliocene (Fig. 3), and by modern workers to the early and middle Pleistocene (Gibbard et al., 1998). The French edition of Hoernes' textbook shows the same scheme (Hoernes, 1886, p. 16), and identical or virtually identical concepts of the Neogene would be used in the textbooks and journal articles of Fuchs (1877, 1885), Tietze (1884, 1887), Steinmann and Döderlein (1890), Kayser (1893, 1902, Zittel (1895), Zittel and Broili (1910), Hoernes (1903, 1910), Kittl (1904), and Neumayr (1905). The geologic time scale of Zittel (1895), reproduced here in Fig. 7, is notable in that it may be one of the earliest essentially modern and strictly hierarchical classifications of the Cenozoic Era, disregarding the absence of the Paleocene and the apparently accidental mislabeling of the stages as "Epoche" (see Zittel and Broili, 1921 for a corrected version).

6. Adoption of "Neogene" beyond Austria and Germany

As documented above, the term "Neogene" was commonly used in German language geological journals and textbooks starting in the 1850s, but this usage generally spread to other countries two or three decades later. In any given country, the adoption of a given geochronologic term was probably determined by several factors, including the usage of such terms on national geologic maps, in standard textbooks, and in the articles and treatises of prominent workers in that country. An evaluation of these influences on the acceptance of "Neogene" in every European country is far beyond the scope of this paper. However, I wish to indicate the broad outlines of the usage of this term in several countries particularly important in the development of Cenozoic chronostratigraphic nomenclature, in order to encourage further historiographical work. I focus here on works published before 1913, the year that Maurice Gignoux is alleged to have promulgated an "unjustified" definition of the Neogene (Berggren, 1998, p. 122; Aubry et al., 2005).

6.1. Switzerland

Four Swiss stratigraphers played a prominent role in the early acceptance and evolution of the Neogene. In 1858, Karl Mayer[17] published an important paper and accompanying correlation chart discussing twelve new Tertiary stages. Although the "Neogene" was not depicted on his chart, Mayer (1858, p. 171–172) stated that this interval encompassed his Aquitanian through Astien stages. Along with several undoubted Pliocene deposits such as the Norwich Crag and the

[16] Rudolf Hoernes, 1850–1912. See von Oettingen (1904), Spengler (1912), Sargeant (1980), Hubmann (1999), and Strehlau and Hubmann (2003).

[17] Karl Mayer (aka Karl Mayer-Eymar, 1826–1907) was a French stratigrapher and paleontologist who lived and taught in Zurich, and is best known today for his invention of numerous European stage names. See von Oettingen (1904), Sacco (1907b), and Sargeant (1980). Mayer was also Curator of Paleontology at the Zurich Museum and provided access to this "immense, rich collection" for Moriz Hörnes' studies (Hörnes, 1867, p. 588).

Weltalter (Ära)	Periode			Epoche	
Känozoische Gruppe	Quartär-System	Alluvium		Moderne Ablagerungen	
		Diluvium (Pleistocän)		Postglacial-Stufe Glacial- » Präglacial- »	
	Tertiär-System	Neogen	Pliocän	Sicilische Stufe Asti- »	(Sicilien) (Astien)
			Miocän	Pontische Stufe Sarmatische » Tortonische » Helvetische » Langhische »	(Pontien) (Sarmatien) (Tortonien) (Helvetien) (Langhien)
		Paläogen	Oligocän	Aquitanische Stufe Tongrische »	(Aquitanien) (Tongrien)
			Eocän	Ligurische Stufe Barton » Pariser » Soissonische » Libysche od Thanet-Stufe	(Ligurien) (Bartonien) (Lutetien) (Suessonien) (Thanetien)

Fig. 7. Cenozoic time scale of Zittel (1895, p. 6), one of the earliest essentially modern and strictly hierarchical subdivisions of the Cenozoic Era.

yellow sands of Perpignan, Mayer (1858) included in the Astien some deposits that would now be considered Pleistocene (e.g., "Mergel, vulkanische Tuffe oder Kalk von Messina"), although there is no indication that Mayer (1858) included diluvial deposits or modern alluvium in the Astien Stage. In the third edition of his correlation table, however, Mayer-Eymar (1865) restricted the scope of the Astien Stage and proposed the "Saharien Stage" to include the Norwich Crag as well as much younger glacial and loess deposits of various European basins. Although "Neogene" and the Lyellian epochs do not appear on Mayer-Eymar's (1865) table, Naumann (1872, p. 11) included most of the Saharien in the Pliocene, and thus presumably in the Neogene (Berggren, 1998, p. 124).

Carl Vogt, in the third edition of his *Lehrbuch der Geologie und Petrefactenkunde*, defined the "Neocän" as Miocene+Pliocene, although his correlation chart ironically attributed this term to Beyrich (Vogt, 1868, p. 648–653). Vogt (p. 728) assigned the Norwich Crag and the famous mammal locality from St. Prest, France (currently dated at about 1 Ma; Guerin et al., 2003) to the youngest part of the Pliocene and emphasized that the Pliocene deposits graded into those of the Quaternary or Diluvial epoch. This general concept of the Neogene was also held by another prominent Swiss geologist of time, Bernhard Studer (1872, p. 170).

Eugène Renevier (1874) published a time scale in which the "Période Néogène" or "Molassique" was equivalent to the Late Tertiary. This Période Néogène was composed of the "Aquitanien," "Falunien," and "Subapennin." Consistent with the prevailing usage of Austrian workers, Renevier's (1874) Période Néogène excluded the "Période Moderne" or "Anthropique" (which consisted of the "Epoque Quaternaire"/"Système Diluvien" and the "Epoque Actuelle"/"Système Contemporain"). In part following Heilprin (1891), however, Renevier (1897a,b) revised his earlier classification by abandoning the Quaternary and including in the Période Néogénique the Miocène, Prépliocène, Pliocène, Plistocène (his and Heilprin's spelling), and Holocène epochs (see Berggren, 1998 for discussion). Renevier's (1897a,b) proposals seem to have fallen on deaf ears in his own country, however. A search of volumes of the Swiss geological journal *Eclogae Geologicae Helvetiae* published between 1897 and 1927 revealed no other articles adopting the extended Neogene, and several articles which continued to use "Tertiary" and/or "Quaternary" (Renevier and Schardt, 1900; Aeberhardt, 1909; Antenen, 1909).

6.2. France

The earliest substantive uses of the term "Neogene" in the *Bulletin de la Société Géologique de France* are those of Dollfus (1875), Pilide (1877), and Fontannes (1878). All of these authors appear to have excluded the Quaternary from the Neogene. After an apparent suspension in usage of several years in this journal, Depéret (1892b) and Munier-Chalmas and de Lapparent (1893) defined the Neogene as Miocene+Pliocene, with the Sicilian Stage of Doderlein (1872) being the youngest stage of the Pliocene. de Lapparent (1895) would repeat this definition, and would also depict the Quaternaire as consisting of the Pléistocène+Récente (Fig. 8). Depéret (1895, 1898), Bernard (1895), and Ficheur (1896) would use similar definitions of the Neogene, with Depéret (1895, p. xxxvi) assigning the mammal locality of St. Prest to the youngest part of the Sicilian Stage.

Interestingly, Renevier's (1897a,b) advocacy of the extended Neogene at the 6th International Geological Congress was not accepted by the French geologists Raulin (1901) and Dollfus (1901) at the 8th International Geological Congress. de Lapparent (1900) also ignored Renevier's (1897a,b) proposal. He continued to accept the Quaternary and defined the Neogene in the same way as Munier-Chalmas and de Lapparent (1893).

In an influential work, Haug (1911, p. 1599; 1606) defined the Neogene as Miocene+Pliocene, excluding the Quaternary. He also proposed that the Quaternary be expanded downward to include not only the Sicilian Stage (as suggested by Renevier, 1897a,b, for the Pleistocene), but also to include Gignoux's (1910) newly designated Calabrian Stage, with the Pliocene and Neogene being truncated accordingly. Haug's proposal will be discussed in more detail below.

Given the above, it would appear that French geologists before Gignoux (1913) were virtually unanimous in excluding the gradually-expanding Quaternary from the Neogene. The only exception I have found is that of E. Fallot (in Gaudry et al., 1897), who extended the Neogene to the present but who also retained the Quaternary within it. This arrangement has important consequences for the hierarchical structure of the

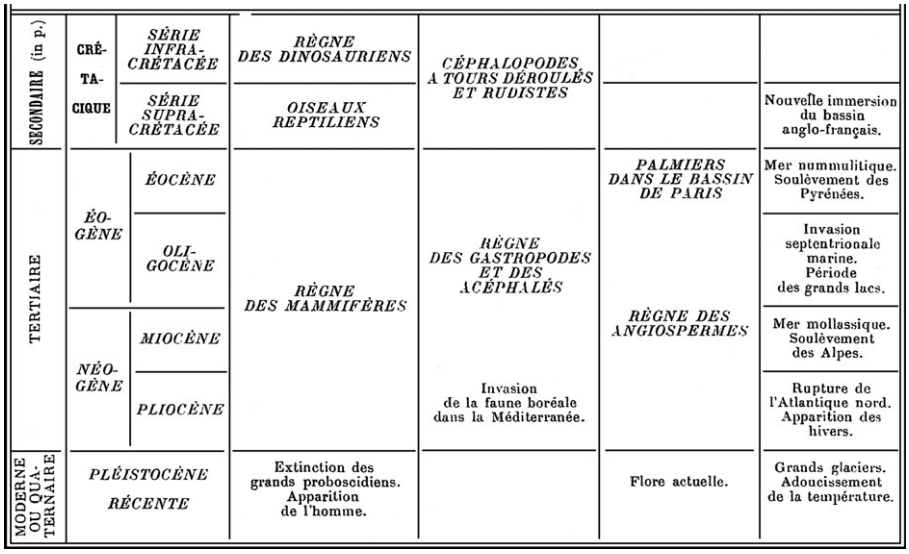

Fig. 8. Cenozoic time scale of de Lapparent (1895, p. 283), showing the Neogene being composed of the Miocene+Pliocene, and the Quaternary being composed of the Pleistocene+Recent.

time scale, however, and will be discussed below in connection with similar proposals made 60 and 108 years later by Denizot (1957) and Aubry et al. (2005), respectively.

6.3. Italy

The manner in which "Neogene" was adopted by Italian geologists is of great interest. Italy is blessed with an abundance of fossiliferous Miocene, Pliocene, and Pleistocene marine strata. However, major lowland glacial deposits ("Diluvium") are less prominent in Italy than in northern Europe. As such, with seemingly less incentive to recognize the "ice age" as a distinct period of Earth history, one might predict that Italian stratigraphers of the late 19th century would be more likely to use a concept of the Neogene in which this unit was extended to the present. A limited search of the Italian literature suggests that this may have been the case in some descriptive paleontological papers, but not the case for more general stratigraphic syntheses in which the Neogene had to be integrated into a more comprehensive hierarchical (chrono)stratigraphic classification.

G.B. Vai (pers. comm, 2006) informs me that the earliest use of "Neogene" in the Italian literature may be that of Omboni (1869, p. 719), who defined the "Neocene" as upper Miocene and Pliocene, excluding the Pleistocene. Professor Vai also reports that the term was seldom used in the 19th century volumes of the *Bollettino della Comitato geologica d'Italia* (established 1870), with one exception being Manzoni (1881, p. 55). However, the term Neogene was used quite frequently in the first few volumes of the *Bollettino della Società Geologica Italiana* (established 1882). For example, Mariani (1886, 1891) used "Neogene" several times, although he did not provide a precise definition. De Stefani (1891, p. 311) also mentioned the term in passing but regarded it as unnecessary. The faunal paper of Ristori (1896) used "Neogene" in the sense of Miocene+Pliocene, whereas the usage of this term is equivocal in the faunal papers of de Angelis d'Ossat and Neviani (1896) and Meli (1899).

Numerous papers and abstracts in the early volumes of *Rivista Italiana di Paleontologia* (established 1895) show that the term Neogene was also being used in several other Italian journals around the turn of the 20th Century, such as *Paleontographia Italica*, the *Atti* and *Memorie della Società Toscana di Scienze naturali*, and the *Atti* and *Memorie della Pontificia accademia romana dei nuovi Lincei*. Although I have been unable to consult these journals directly, the abstracts in *Rivista Italiana di Paleontologia* suggest that usage of the Neogene was about evenly split between those adopting the Miocene+Pliocene definition (e.g., de Regny, 1897, 1899; Oppenheim, 1899) and those apparently adopting the Miocene to Recent definition (Neviani 1901; Seguenza 1904).

Of possible relevance to the evolution of usage of "Neogene" in Italy are the works of Federico Sacco, one of the most important Italian stratigraphers and paleontologists around the turn of the 20th Century. In a paper published in the same Compte Rendu of the 6th International Geological Congress as Renevier (1897a,b), Sacco (1897) presented a time scale in which the Neogene was defined as consisting of the Miocene and Pliocene, with the Pliocene consisting of the Messinian, Plaisancian (Piacenzian), and Astian stages. Sacco (1897) did not define the end of the Neogene explicitly, but appears to have excluded the Sicilian and/or Saharian Stages from it (see Sacco, 1892). Interestingly, Sacco (1891) had objected to Renevier's (1891) earlier proposal to abandon the Quaternary, and along with Trabuco (1900), would soon define this unit as consisting of the Pleistocene+Holocene (Sacco, 1907a).

In the early 1900s, the Neogene became well-established in Italy as consisting only of the Miocene and Pliocene, and excluding the Quaternary (e.g., Parona, 1904, p. 719; Anelli, 1913; Stefanini, 1919; Parona, 1924, pp. 566; 587; see Fig. 9). Variations in the exact content of the Neogene continued to exist owing to the variable inclusion of the Calabrian Stage in the Pliocene or Pleistocene. Nevertheless, the general usage of the Neogene as a pre-Quaternary span of time would prevail among

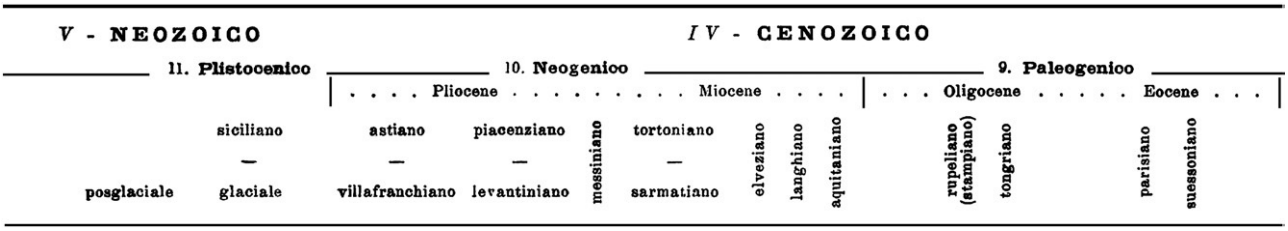

Fig. 9. Cenozoic time scale of Parona (1904, p. 719) showing the exclusion of the Pleistocene from the Neogene and the inclusion of the Sicilian Stage in the Pleistocene.

the vast majority of Italian stratigraphers for the rest of the 20th Century (e.g., Fabiani, 1957; Selli, 1977).

6.4. Britain

British workers would be rather slow to use the term Neogene, perhaps owing to the rarity or absence of Miocene strata in that country (Curry et al., 1978). A check of the indices to the *Quarterly Journal of the Geological Society of London* through 1934 (Belinfante, 1897; Greig, 1937) revealed no uses of "Neogene" by native British geologists. In *The Geological Magazine*, however, Blanford (1884) suggested that a division of the Tertiary into Eocene (including the Oligocene) and Neogene (Miocene and Pliocene) would be "a great improvement," but believed that the adoption of this scheme was unlikely. Blanford (1884) instead proposed that the Oligocene be subsumed within the Miocene and that the Pleistocene be subsumed within the Pliocene. These suggestions apparently had no takers, given that the "Pleistocene" was being widely used as a replacement for "Diluvium," and that a year later (and ten years after Lyell's death), Lyell and Duncan (1885, pp. 102–103) would adopt the name "Oligocene" in essentially its modern sense.

As for British textbooks, the "Neogene" was mentioned only once in Geikie (1882), in the sense of "Miocene+Pliocene." Prestwich (1886–1888, vol. 2, p. 407) briefly mentioned the Neogene being defined as Miocene+Pliocene, although he mistakenly reported that it was introduced by German geologists. Marr (1898) did not mention the term at all. However, Jukes-Browne (1902, p. 23; 506) modified his previous unorthodox scheme (Jukes-Browne, 1885) and defined the Neogene System as extending to the present. Other than the instance of Renevier (1897a,b) discussed above, this is the only other example of the expanded-Neogene usage in a comprehensive time scale that I have seen in the European literature of the time. Anticipating the opinions of certain modern workers, Jukes-Browne (1902, p. 16) found the term "Quaternary" to be "superfluous and misleading," and so extended the Pleistocene, Neogene, and Tertiary to the present. With the exception of Neaverson (1928), his usage was not followed by most British geologists (Geikie, 1905, p. 1584), and was likewise not followed by the vast majority of Continental workers, including Hoernes (1903, 1910), Parona (1904), de Lapparent (1911), and Zittel and Broili (1910). Three decades later, Davies' (1934) book *Tertiary Faunas* would firmly establish the meaning of Neogene as "Miocene+Pliocene" for most British geologists for the rest of the 20th Century.

6.5. United States

American geologists were also slow to use "Neogene" in the late 19th century, but the term was used more frequently after it was incorporated into the official nomenclature of the U.S. Geological Survey (spelled "Neocene"). The term was defined as Miocene+Pliocene, excluding the Pleistocene (Powell, 1890, p. 65). Papers such as those of Dall and Harris (1892) and Ashley (1895) would start to give the term a presence in American stratigraphic literature that would continue into the next century (e.g., Chamberlin and Salisbury, 1909, p. 772). As shown by Wilmarth (1925, plate I), the only American workers to use an extended Neogene concept around this time seem to have been Schuchert (1910) and Ulrich (1911). Schuchert (1910, p. 598; 605) regarded the Neozoic, Cenozoic, and Tertiary as synonyms, eliminated the Quaternary and Holocene without discussion, extended the Pleistocene to the present, and regarded the "Neogenic Period" as being composed of the Miocene, Pliocene, and Pleistocene. Ulrich's (1911) classification of the Cenozoic largely followed Schuchert's (1910). These schemes were not accepted by other American workers, however, and Pirsson and Schuchert (1915, p. 442) later defined the Neogene as "Miocene+Pliocene." Finally, although the Neogene was not endorsed by Wilmarth (1925), the most recent edition of the official USGS nomenclature defines the term as "Miocene+Pliocene" (Hansen, 1991).

6.6. Discussion

The above survey of the history of usage of "Neogene" through the early part of the 20th Century necessarily included only a fraction of the relevant literature, even in the countries specifically addressed. Nevertheless, it is evident that the term was widely used by European stratigraphers in the late 19th century, and that it almost always excluded the Diluvium, Quaternary, and Pleistocene.

Regrettably, owing to linguistic unfamiliarity, I have been unable to consult much of the vast eastern European and Russian stratigraphic literature of this time, but suspect that if the works of Czech, Hungarian, and Yugoslav authors such as Czjzek (1854), Stur (1855, 1864), Peters (1856, 1857), Lipold (1856, 1857), and Koch (1900) are representative, the Diluvium and/or Quaternary would also have been generally excluded from the Neogene by late 19th Century stratigraphers in these regions. Modern Russian stratigraphers, of course, are nearly unanimous in maintaining the independence of the Quaternary (e.g., Zhamoida, 2004).

7. Co-evolution of the Neogene, Quaternary, and Pleistocene

After its adoption by most 19th Century stratigraphers in the sense of Miocene+Pliocene, excluding the Diluvium, Quaternary, and Pleistocene, the term Neogene continued to evolve in meaning. This evolution occurred mostly in the late 19th Century and early 20th Century. Interestingly, the impetus for this evolution can be traced all the way back to Forbes (1846). Five years before Moriz Hörnes coined the term "Neogene," Forbes (1846, p. 403) stated:

> "I have selected the word "glacial," in order to remind the geologists of the ice-charged condition of our seas during that epoch,-conditions which probably did not prevail during its earlier stage, and the gradual disappearance of which marked its conclusion. As, however, it appears almost certain that the "Glacial epoch," and that of the deposition of Sicilian and Rhodian tertiaries were synchronic it would be advisable to adopt some term to express that geological period as a whole, and by which to designate the formations of that period. Mr Lyell's term, "pleistocene," would, perhaps, best serve the purpose, as that of "newer pliocene" is not sufficiently distinctive, and may lead to confusion. In this case, among English tertiaries, the coraline crag would rank as *meiocene*, the red crag as *pleiocene*, the glacial beds as *pleistocene*, and the megaceros freshwater marls and marine raised beaches as two stages of *post-tertiary* [italics in original]."

Forbes (1846, p. 391–393) also assigned the Norwich Crag to the earliest part of the "glacial epoch" (which he then equated with the Pleistocene), and his usage of the latter term was closely followed by Lyell (1851, 1857a; see Fig. 3). Although Lyell (1873, 1855, 1874) would later use the term "Pleistocene" as a replacement for the much more restricted concept of "post-Pliocene," the stage was set for the eventual subsumation of virtually all late Cenozoic continental glacial deposits and their marine temporal equivalents into the Pleistocene.[18,19]

The gradual replacement of the term "Newer Pliocene" with "Pleistocene" occurred mainly because as the latter term acquired a glacial connotation and as older and older glacial deposits continued to be discovered in the Northern Hemisphere, the beginnings of the Pleistocene and Quaternary were extended downward, at the expense of the Pliocene, Neogene, and Tertiary. This co-evolution is best documented in terms of the stage nomenclature that was developed by Mayer (1858) and later workers for various European late Cenozoic deposits in the second half of the 19th Century and early part of the 20th century (Fig. 10; see Migliorini, 1950; Selli, 1967 for helpful reviews).

Before about 1897, the Sicilian Stage (roughly late early Pleistocene and middle Pleistocene of modern usage) was widely regarded as belonging to the Pliocene and Neogene. This can be seen from the time scale of Munier-Chalmas and de Lapparent (1893, tableau no. 3), in which the Pliocene is divided not into Lyell's Older and Newer subdivisions, but rather into the Plaisancien (Piacenzian), Astien, and Sicilien stages (Fig. 10).

Zittel (1895, p. 6) likewise abandoned the Older Pliocene/Newer Pliocene nomenclature of Lyell and regarded the Pleistocene as a synonym of the "Diluvium." Zittel (1895) also regarded the Sicilian Stage as the youngest stage of the Pliocene, but viewed the Pliocene as comprising only the Astien and Sicilien.

Renevier (1897a,b) reiterated his previously-expressed skepticism as to the validity of the Quaternary (Renevier, 1891). He also abandoned the Older Pliocene/Newer Pliocene distinction of Lyell (essentially replacing the Newer Pliocene with the newly-spelled "Plistocène") and regarded the Pliocene as being composed only of the Plaisancien and Astien stages. Unlike Munier-Chalmas and de Lapparent (1893) and Zittel (1895), Renevier regarded the Sicilian as the oldest stage of the Plistocène. Renevier's (1897a,b, p. 559) explanation of the transfer is interesting:

> "The Sicilian is classified by Munier-Chalmers and de Lapparent in the Pliocène and not in the Plistocène, as is generally done. The fact is that it is a stage of transition. What made me associate it with the Plistocène is its almost certain synchronism with an early extension of the glaciers!".[20]

In effect, Renevier (1897a,b) was following the suggestion made by Forbes' (1846) fifty-one years earlier. In addition, Renevier (1897a,b) clearly believed that *non-biochronological* considerations (climate) may be used in determining standard global geochronologic boundaries and the content of units of higher rank (see below).

As noted above, Sacco (1897) also seems to have excluded the Sicilian Stage from the Pliocene. In contrast to Renevier (1891, 1897a,b), however, Sacco (1891, 1897) retained the Quaternary for post-Tertiary time and therefore saw fit to lower the end of the Neogene accordingly. Despite their different views on the scope of the Neogene and value of the Quaternary, the proposals of Renevier (1897a,b) and Sacco (1897) to exclude the Sicilian Stage from the Pliocene would be accepted by many workers in the first decade of the 1900s (e.g., Parona, 1904).

In his slim volume *Paläontologie*, R. Hoernes (1899, p. 33; 1910, p. 26) regarded the Neogene as being composed of the Miocene and Pliocene but did not specify the content of these epochs in terms of stages. However, he regarded the "Quartär

[18] Lyell (1865, p. 107–108) was incorrect to claim that Forbes (1846) had used the term Pleistocene "almost precisely in the sense" as Lyell's (1865) concept of "post-Pliocene." In fact, given Forbes' (1846) inclusion of glacial deposits, the Sicilian marine formations, and the Norwich Crag, his concept of the Pleistocene was virtually identical to Lyell's (1851, 1857a) concept of Pleistocene (=Newer Pliocene), and almost mutually exclusive with Lyell's (1865, 1873, 1874) concept of "post-Pliocene." (Fig. 3).

[19] Berggren (1998, p. 124) was incorrect to claim that "Lyell (1873) later adopted Forbes' usage and incorporated his post-Pliocene into Newer Pliocene or Pleistocene (the latter term he finally accepted and substituted for 'Newer Pliocene')." In fact, Lyell (1873, p. 260; 1874, pp. 109; 171) replaced the term "post-Pliocene" with "Pleistocene," but continued to retain the Newer Pliocene as a distinct time unit immediately preceding the Pleistocene (Fig. 3).

[19] "Le Sicilien est classé par MM. Munier-Chalmers et de Lapparent dans le Pliocène, et non dans le Plistocène, comme on le fait généralement. Le fait est que c'est un étage de transition. Ce qui me l'a fait adjoindre au Plistocène, c'est son synchronisme presque certain avec une ancienne extension des glaciers!"

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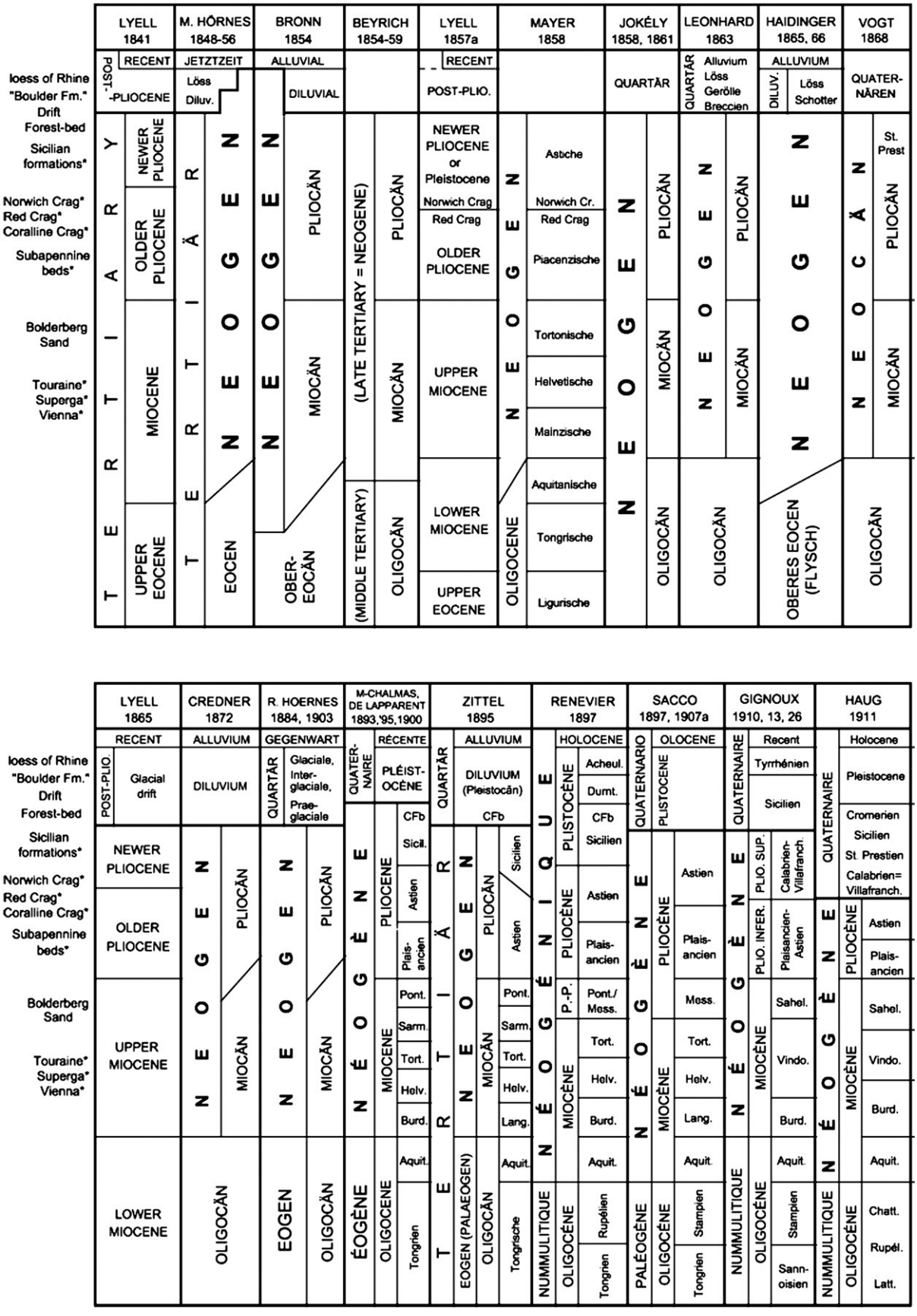

Fig. 10. Evolution of "Neogene" and related terms as used by prominent European geologists from Hörnes (1848–1856) to Haug (1911). Key stratigraphic units arranged on left side of chart, including several of Lyell's (1833) exemplary types (marked with an asterisk). Indicated correlations of units in adjacent columns are only approximate, as different authors often had different concepts of each named unit. Depicted relative durations of the units are not to scale.

Formation," "Diluvium," and "Pleistocän" as synonyms, and included in them the "präglaciale Bildungen" (pre-glacial formations), which included the Cromer Forest-bed of England. Presumably, therefore, Hoernes would have assigned at least part of Sicilian time to the post-Neogene. Indeed, in the third edition of *Grundzüge der Paläontologie (Paläozoologie)*, Zittel and Broili (1910, p. 6) were by now among a minority of stratigraphers who continued to include the Sicilian Stage in the Pliocene and Neogene.

As noted above, Haug's (1911) classification was somewhat radical for its time but partly anticipated future developments. He restricted the Pliocene to the Plaisancien and Astien stages, assigned the Villafranchien, Calabrien, "Saint-Prestien," Sicilien, and "Cromerian" stages to the "ancient Quaternary," and regarded the Pleistocene (glacial deposits *sensu stricto*) as a synonym of his "Middle Quaternary." Haug therefore proposed to extend the beginning of the Quaternary even farther back in time than had been suggested by Renevier (1897a,b) and Sacco (1897). Just as importantly, however, in order to maintain the strictly hierarchical structure of the time scale, Haug continued to tie the ends of the Neogene and Pliocene to the beginning of the Quaternary, and so his extension of the latter necessarily involved a corresponding restriction in the scope of the Neogene and Pliocene. Haug's (1911, p. 1604; 1606) reasons for this change are familiar to modern workers:

> "The delimitation of the Neogene system gives rise to great differences in opinion, which involve the attribution of the Aquitanien stage to either the Oligocene or Miocene, and the incorporation of the Villafranchian (or Calabrian) and Sicilian stages in either the Pliocene or the Quaternary… The Sicilian is considered by a great number of authors to be the highest unit of the Pliocene and consequently of the Neogene. Other geologists assign it to the Post-Pliocene. In this work it is classified, like the Villafranchian, in the lower Quaternary, *because it appears useful to allot to the same geological period all the phases of the diluvial period*. Arguments of a paleontological nature also militate in favour of this classification. The appearance of the genera *Elephas*, *Equus*, and *Bos* throughout Western Europe, in the Villafranchian, distinctly mark the beginning of a new era [emphasis added]."[21]

As such, Haug (1911) took the climatochronologic rationale of Forbes (1846) and Renevier (1897a,b) to its logical conclusion and lowered the ends of the Tertiary, Neogene, and Pliocene accordingly. Interestingly, given his assignment of the Red Crag and Norwich Crag to the Pliocene and Quaternary, respectively, Haug's (1911, p. 1776) concept of the Tertiary/Quaternary boundary was very similar to Lyell's (1851, 1855, 1857a) concept of the Older Pliocene/Newer Pliocene boundary. Moreover, Haug clearly believed that climate and terrestrial mammal biochronology could sometimes outweigh marine biochronology in the placement of standard global geochronologic boundaries. These criteria would play major roles in the decision of the 1948 International Geological Congress to locate the Plio–Pleistocene boundary at the base of the Calabrian Stage, although this decision would later prove to be problematical (Selli, 1967; Hays and Berggren, 1971; Van Couvering, 1997).

Finally, Gignoux (1913, 1914) adopted a concept of the end of the Neogene intermediate between that of Haug (1911) and de Lapparent (1900) when he included his Calabrian Stage in the Pliocene, but assigned the (restricted) Sicilian Stage to the Quaternary (Gignoux, 1908). Gignoux (1913, 1914) did not follow Haug (1911) in assigning the Calabrian to the Quaternary because he believed that the Plaisancian, Astian, and Calabrian all belonged to the same Pliocene cycle of sedimentation (Migliorni, 1950). This concept of the Neogene would also be advocated by Gignoux in his influential textbook (Gignoux, 1926, 1950, chapitre X), and was widely accepted by French workers at the time (Dalloni, 1915, 1954; Depéret, 1926). Ironically, however, Gignoux (1954) himself would eventually adopt Haug's (1911) definition of the Neogene/Quaternary boundary.[22] The evolution of the Plio–Pleistocene (=Neogene–Quaternary) boundary during the 19th and 20th centuries is documented in more detail by Vai (1997, pp. 12–13).

7.1. Discussion

By the time of the publication of the fifth edition of *Grundzüge der Paläontologie (Paläozoologie),* exclusion of the Sicilian Stage from the Pliocene and Neogene was generally accepted by European workers (Zittel and Broili, 1921, p. 8–9). During the next few decades, many would also support Haug's (1911) proposal to include the Calabrian Stage in the Quaternary (Parona, 1924; King and Oakley, 1949; Migliorni, 1950; Società Geologica Italiana, 1954; Gignoux, 1954; Fabiani, 1957). As such, from 1911 until the mid-1950s, the definition of the end of the Pliocene (and Neogene) was established by the great majority of European workers as falling within fairly narrow limits, depending on whether one preferred

[21] "La délimitation du système Neogene a donné lieu à de grandes divergences de vues, qui portent à la fois sur l'attribution de l'ètage Aquitanien soit à l'Oligocene, soit au Miocene et sur l'incorporation, soit au Pliocene, soit au Quaternaire, des étages Villafranchien (ou Calabrien) et Sicilien… Le Sicilien est considéré par un grand nombre d'auteurs comme le terme supérieur du Pliocene et par conséquent du Neogene. D'autres geologues en ont fait le Post-Pliocene. Si, dans le présent ouvrage, cet étage a été classé, de même que le Villafranchien, dans le Quaternaire inferieur, c'est qu'il a paru utile d'attribuer à une même période géologique toutes les phases de l'époque glaciaire. Des arguments d'ordre paléontologique militent également en faveur de cette classification. L'apparition des genres *Elephas, Equus, Bos*, dans toute l'Europe occidentale, au Villafranchien, marquent bien le début d'une ère nouvelle. Nous reviendrons sur cette question, lorsque nous aurons à nous occuper de la délimitation du systéme Quaternaire."

[22] Contrary to the implications of Berggren (1998, p. 122) and Aubry et al. (2005), Gignoux (1913) barely mentioned the term Neogene. As far as I can tell he used it only twice and only in passing (pp. 341, 345), where he did logically imply that the Quaternary (consisting of Sicilian and younger strata) was excluded from the Neogene. The first edition of Gignoux's (1926) textbook *Géologie Stratigraphique* appears to have been much more influential than his 1913 thesis. In this book, however, Gignoux's exclusion of the Quaternary from the Neogene was consistent with the basic earlier usage of other French workers like de Lapparent (1895, 1900), Haug (1911), and his own teacher, Charles Depéret (Gignoux, 1930; Fallot, 1957).

Haug's (1911) or Gignoux's (1913) definition of the beginning of the Quaternary (Migliorni, 1950). With the exception of Neaverson (1928, 1955), I have found no comprehensive Cenozoic time scale published in this interval that followed Renevier (1897a,b) and Jukes-Browne (1902) in abandoning the Quaternary and extending the Neogene to the present. If other such works exist, they clearly form a small fraction of the literature in which a Quaternary separated from the Neogene was established usage.

8. The Neogene divide in Cenozoic chronostratigraphy

8.1. The recommendation of Denizot (1957)

In his brief discussion of the Neogene in the Lexique Stratigraphique International, Denizot (1957, p. 140–141) stated:

> "The stratigraphic grouping instituted by Hoernes is based in paleontology; appearence of new forms over the Oligocene fauna, forms that persist, as they evolve, toward present times. It is essentially the combination of the Miocene and Pliocene systems but with much lack of precision concerning its limits. It is certain that the Neogene fauna has its roots in the Aquitanian, even though Hoernes' contemporaries retained in the Oligocene at least part of the Aquitanian deposits. The upper limit is even more controversial; it is the "Plio–Pleistocene question," currently being debated. It appears that according to the definition of the Neogene itself, it would be convenient to include in it all the Quaternary, whose invertebrate fauna is a simple evolution from that of the older Pliocene."[23]

Echoing the thoughts of Neaverson (1928, 1955), Denizot indicated his desire to use the extended Neogene as a faunally homogeneous, *marine invertebrate biochronologic unit*. Denizot (1968) also seems to have retained the (unranked) Quaternary in the (unranked) Neogene, although other papers published in Milon (1968) did not follow his example (e.g., Durand, 1968; Esteoule Choux, 1968). The most important point here is that given the fact that Denizot (1952, 1957, 1968) retained the Tertiary and the Quaternary, he apparently did not realize that the Neogene could not be extended to the present without violating the strictly hierarchical structure of the ranked standard global time scale (Walsh, 2006).

In general, Quaternary specialists, paleomammalogists, and workers on continental rocks did not accept the extended Neogene as suggested by Neaverson and Denizot (e.g., Oakley and Baden-Powell, 1963). I acknowledge the stratigraphic chart of Krumbein and Sloss (1963, p. 15) and other scattered occurrences cited by Jenkins et al. (1985), but the extended Neogene usage was clearly uncommon at this time. For example, in the published proceedings of the third session of the Committee on Neogene Stratigraphy (Drooger et al., 1966), there is not a single paper advocating an extended Neogene.

8.2. Acceptance by marine micropaleontologists

The late 20th Century trend to extend the Neogene seems to have begun in earnest with Banner and Blow (1965), who, without discussion, defined the Neogene as consisting of the Miocene to Recent. This extension seems to have been made for the convenience of their foraminiferal "N" zone nomenclature, which was widely adopted by other marine micropaleontologists. I assume this to be the case because in their previous papers these authors preferred to use Tertiary, Quaternary, and the standard Cenozoic epochs. They either did not use the term "Neogene" (Blow, 1956, 1959; Eames et al., 1962) or used it only briefly and without definition (Banner and Blow, 1959, p. 2). The decision of Banner and Blow (1965) to extend the Neogene to the present therefore seems to have been made without considering the effect that such usage would have on the hierarchical structure of the time scale. Given the continued use of Tertiary and Quaternary by these authors in subsequent papers (Banner and Eames, 1966; Blow, 1969), Banner and Blow (1965) apparently intended the Neogene to serve as an informal, unranked unit.

Whatever the intentions of Banner and Blow (1965), many marine micropaleontologists adopted the extended Neogene starting in the late 1960s (e.g., Bandy, 1969; Brönnimann and Resig, 1971; Riedel, 1973). Distinguished micropaleontologists who did not follow this trend include Martini (1971), Martini and Müller (1986), and Finger (1990), but the traditional usage of these workers soon became unpopular in their own field, as shown by Kennett and Srinivasan (1983), Ikebe and Tsuchi (1984), and Jenkins et al. (1985).

The accomplished stratigrapher and paleontologist F.F. Steininger (1981) was apparently the first modern worker to analyze Moriz Hörnes' discussions of the Neogene in some detail. Steininger et al. (1997) and Steininger (1999) subsequently advocated the extended Neogene, although Steininger et al. (1996) and Steininger and Piller (1999, p. 19) did not, apparently reflecting the mixed feelings held by European workers on this issue. More recently, however, Steininger (2002) expanded on his 1981 discussions and again proposed that the Neogene be extended to the present. Steininger's (2002, p. 43) view that the use of Tertiary and Quaternary "obstructs the clear, practical, modern version of the terminology of the Cenozoic" is certainly debatable, and I would argue just the opposite (Walsh, 2006).

The latest proponents of the extended Neogene belong to the "astrochronological community" (e.g., Lourens et al., 2004). These are again primarily marine stratigraphers, and so, working with the time scales of Berggren et al. (1985, 1995a, b), use the extended Neogene as a matter of course.

[23] "Le groupement stratigraphique institué par Hornes est fondé sur la Paléontologie; apparition de formes nouvelles audessus de la faune oligocene, et qui se perpétueront, en évoluant, jusque vers les temps actuels. C'est essentiellement la réunion des deux systèmes miocene et pliocene, mais avec beaucoup d'imprécision dans les limites. Il est certain que la faune néogène a ses racines dans l'Aquitanien, bien que les contemporains d'Hornes aient maintenu dans l'Oligocene une partie au moins des gîtes aquitaniens. La limite supérieure est encore plus difficile, c'est la "question plio-pleistocene", actuellement débattue: il apparaît que, par la définition même du Néogêne, il conviendrait d'y mettre tout le Quaternaire dont la faune d'Invertébrés est une simple évolution de celle du Pliocene ancien."

For the last 32 years, the most effective advocate of the extended Neogene has indeed been the prominent stratigrapher and marine micropaleontologist W.A. Berggren, who has published numerous papers and time scales incorporating this extension (Berggren and Van Couvering, 1974; Berggren et al., 1983, 1985, 1995a,b; Berggren, 1998). Although I have found it necessary to criticize several aspects of Berggren's (1998) analysis in the preceding discussions, those criticisms do not detract from the overall value of that paper, which provided the starting point for my own investigation. Nevertheless, by more completely documenting the origin and evolution of the Neogene, I have shown that there is no compelling need to extend this unit to the present on historical grounds. I now wish to discuss what seems to be the primary motivation for this extension.

9. Challenging the monopoly of marine biochronology

How can we resolve the dilemma of the Neogene divide in Cenozoic chronostratigraphy? It appears that we must begin by challenging the central assumption in the arguments of Denizot (1957) and Berggren (1998), which is the view that *marine biochronology should hold a monopoly in the determination of Phanerozoic standard global geochronologic boundaries*. In order to do this, however, we must start in an unlikely place.

9.1. Revenge of the Holocene

At first glance it would seem doubtful that the existence or non-existence of the apparently insignificant Holocene Epoch could determine the structure of the rest of the Cenozoic time scale. But such is in fact the case, and the rationale is as follows. First, all would agree that the Pleistocene is to be ranked as an epoch, consistent with the other Lyellian epochs. Suppose that we also wish to recognize the Holocene as a distinct epoch. Such a recognition automatically justifies the existence of the Quaternary Period, because it is a useful collective term of immediately higher rank for Pleistocene+Holocene. Furthermore, if we recognize the Quaternary Period, then there is every reason to also recognize the Tertiary Period (Van Couvering, 1997, p. xii). As discussed by Walsh (2006), however, if we regard the Tertiary and Quaternary as ranked units, then the Neogene cannot be extended to the present without violating the strictly hierarchical structure of the standard global time scale.

Now, suppose that we do *not* wish to recognize the Holocene Epoch. Then, given Simpson's rule (Walsh, 2006), the Pleistocene would have to be extended to the present, and would therefore become a synonym of the Quaternary. Marine biochronologists would then argue that there is no need for the Quaternary Period, supposedly being based on terrestrial and climatic phenomena (Berggren et al., 1995a). Next, if we drop the Quaternary Period, we can certainly drop the Tertiary Period. And finally, since the period is implicitly understood to be a mandatory rank of the Phanerozoic time scale, we would have no choice but to extend the Neogene Period to the present.

So, the Holocene really does wield "an awful and unsuspected power," as expressed by Twain (1880, p. 602) in another context. It is therefore not surprising that calls to eliminate the Holocene have gone hand in hand with calls to eliminate the Quaternary and to extend the Neogene and Pleistocene to the present, with the latest examples being Aubry et al. (2005) and Suguio et al. (2005). However, arguments for the elimination of the Holocene are easily refuted (Pillans and Naish, 2004; Gibbard et al., 2005). This unit is used not only in stratigraphy, but in engineering geology, neotectonics, archaeology, and other fields, and it is difficult to see why a classification taken for granted by the vast majority of earth scientists should be sacrificed in order to satisfy the narrow vision of a minority of marine biochronologists.

Although the *beginning* of the Pleistocene has been notoriously controversial, the approximate *end* of the Pleistocene has been generally agreed upon by geologists around the world for more than a century (Prestwich, 1886–1888; Woodward, 1891; Zittel, 1895; de Lapparent, 1895; Williams, 1895; Renevier, 1897a,b; Trabuco, 1900; Chamberlin and Salisbury, 1909). As noted by Harland et al. (1990, p. 64, 68), the literature that assumes the existence of a separate Pleistocene and Holocene is immense. Why disrupt this stability? Arguments that the Holocene is merely an interglacial of the Pleistocene (Suguio et al., 2005) only beg the question. It would be correct and uncontroversial to say that the Holocene is an interglacial of the Quaternary. However, the Holocene and Pleistocene are mutually exclusive by definition.

Nevertheless, it is important to understand why some marine biochronologists have been hostile to the existence of the Holocene. The explanation again seems to lie in the fact that *there are no significant marine faunal changes across the Pleistocene/Holocene boundary*. Indeed, in the early 19th century, well before the concept of an "ice age" was proposed, the beginning of the "Recent"/"Actuelle"/"Gegenwart" interval was characterized mainly in terms of *mammalian* biochronologic events, i.e., extinction of the (*Pleistocene!*) large-mammal fauna of Europe, together with the appearance of humans (Lyell, 1833, 1865; Rudwick, 1997, 2005). And, if mammalian biochronology can be used to help recognize or define one standard global geochronologic boundary, then clearly it can also be used to help recognize or define other standard global geochronologic boundaries, such as the Tertiary/Quaternary boundary (as advocated by Haug, 1911, and numerous later workers, but opposed by Van Couvering, 1997 and Berggren, 1998), and the Paleocene/Eocene boundary (as advocated by Gunnell, 1998; Lucas, 1998; Gingerich, 2000, but opposed by Aubry, 2000; Aubry et al., 2000; Aubry and Berggren, 2000).

9.2. The motivation for the expanded Neogene

Consistent with the above, the main motivation for the expanded Neogene was implied by Berggren (1998, p. 125), who stated: "…the boundary of the Quaternary (the base of the Pleistocene) should be based upon changes in marine faunas, as with all other Phanerozoic period/system boundaries…" In discussing the work of Moriz Hörnes and Eugène Renevier, Berggren (1998) wished to emphasize that Quaternary marine faunas were not very different from late Tertiary marine faunas.

As such, there should be *no period/system boundary* at the current Pliocene–Pleistocene epoch boundary. As such, the extended Neogene Period would be a more significant *marine biochronologic unit* compared to the traditional Neogene (Miocene+Pliocene). The implication here is that if there were no major marine faunal changes at a given point in Phanerozoic geohistory, then no major standard global geochronologic boundary should be established at that point.[24] My interpretation is supported by the following statement of Van Couvering (2006, p. 310):

> "Making a place for Quaternary at the expense of Neogene was unlikely to be acceptable [to marine stratigraphers], the more so because it would leave the GTS with its final, concluding series based on climatically controlled continental lithostratigraphy, *in anomalous juxtaposition to the marine biochronological content of all other series in the time scale* [italics added]."

However, as documented above, these arguments ignore the early history of usage of the term Neogene, when it was consciously used by Austrian and German workers as a *pre-Diluvial*, and then later, by the rest of the stratigraphic community, as a *pre-glacial* subdivision of the Tertiary. Indeed, the progressive lowering of the ends of the Neogene, Tertiary, and Pliocene are some of the few examples in the Phanerozoic time scale where marine-biochronological considerations have been of secondary importance in the evolution of standard global geochronologic boundaries.

Apparently unhappy about this challenge to marine biochronology, Berggren (1998, p. 127) suggested that in regards to the definition of the Plio–Pleistocene boundary, alternative criteria such as climatic changes, evidence of glaciation, hominid evolution, and mammalian evolutionary or immigration events are "unscientific." But what if, at a given place in the time scale, these criteria offer better global correlation potential for a boundary in various facies than the available marine biochronology? To paraphrase Hedberg (1965, p. 460), why would it not be much better to leave the way open for *all* kinds of guiding criteria in the placement of standard global geochronologic boundaries, rather than to arbitrarily restrict this field to marine biochronologic evidence? Why not let marine biochronology stand on its own great merit without artificially trying to require it to be the only means?

Fortunately, modern stratigraphy provides numerous potential criteria that may be used to help define and correlate standard global geochronologic boundaries (Salvador, 1994; Remane et al., 1996). For example, the recent formal definition of the Paleocene/Eocene boundary was based on a chemostratigraphic/climatostratigraphic primary guiding criterion, the selection of which was informed by mammalian biochronology as well as by marine biochronology (Ouda and Aubry, 2003). We must conclude, therefore, that given sufficient grounds, it is permissible for a major standard global geochronological boundary (e.g., the Tertiary/Quaternary period boundary) to be defined at a point in geohistory even where no major changes in marine faunas occurred. While our golden spikes should in almost all cases still be placed in essentially conformable marine sections, all available evidence should be used to decide upon the most appropriate level for a given boundary.

10. Miscellaneous points

Even if we agree that marine biochronology should not be granted a monopoly in the definition of Phanerozoic standard global geochronologic boundaries, additional points relevant to the formal definition of the Neogene must be addressed.

Is period/system status for both Tertiary/Quaternary *and* Paleogene/extended Neogene possible?

At first glance, a solution that would grant formal period/system status to both the Tertiary/Quaternary *and* the Paleogene/extended Neogene seems to have merit. This arrangement was implied by Krumbein and Sloss (1963, p. 15), and again by Jenkins et al. (1985, Fig. 1; but see the disclaimer of Bowen and Gibbard, 2007, p. 4).

While freedom of choice is usually a good thing, it is (by definition!) much less relevant to normative classifications. Indeed, the extension of the Neogene to the present under the "four systems" scheme would still conflict with the preference of traditional stratigraphers, so the term "Neogene" would remain ambiguous. This option would also violate the rules of hierarchical classification, because two different units (Quaternary Period and Paleogene Period) would have less extension than, and yet would be contained entirely within, two other units having the same rank (Neogene Period and Tertiary Period, respectively). An analogous scheme in Carboniferous chronostratigraphy would allow the Carboniferous, Mississippian, and and Pennsylvanian to all be regarded as periods/systems. Such arrangements are unacceptable in my view because they would give special pleading a dignity that it does not deserve.

The four systems option is also undesirable in that it would make it difficult or impossible to clearly depict all of these systems on the same regional or national-scale geologic map (given the "one system, one basic color" approach usually used on such maps). Expanding on the discussion of Walsh (2006), it is very useful to depict Quaternary deposits in a distinct color on regional scale geologic maps, because these deposits often reflect the underlying physiography of a given region. Thus, if Quaternary deposits in major river valleys, fluvial and marine

[24] Exactly what might constitute a "major" marine faunal change is debatable, but it is worth noting that significant regional marine faunal changes at the Pliocene/Pleistocene (Tertiary/Quaternary) boundary were documented by Stanley and Campbell (1981), Raffi et al. (1985), and Stanley (1986). Furthermore, the position of the marine biochronological boundary between the Paleogene and Neogene was at least as controversial over the past 150 yr as the Tertiary/Quaternary boundary, precisely because no major marine faunal change occurred at this time (Eames, 1970; Berggren, 1971; Drooger et al., 1976; Jenkins et al., 1985, p. 204). Indeed, Steininger (1981, p. 15) noted that recent proposals for the Paleogene/Neogene boundary ranged in age from the base of Blow's planktonic foraminiferal Zone P19 to the top of his Zone N5. This interval is about 14 m.y. long according to Luterbacher et al. (2004) and Lourens et al. (2004), which is nearly three times as long as the combined Pliocene and Pleistocene. Therefore, if a Tertiary/Quaternary period boundary is invalid from the standpoint of marine biochronology, then a Paleogene/Neogene period boundary is also invalid from the standpoint of marine biochronology.

terraces, lake beds, glaciated areas, etc. are shown in a distinct color, we are better able to orient ourselves on and use these maps (where topographic contour lines are generally absent and cultural features are often obscured by the colored geologic units). To those who would say that such considerations are irrelevant to the definition of the time scale, I would reply that geologists cannot live by marine biochronology alone, and if the units of the time scale are not practical they will be ignored.

10.1. Status of the late Cenozoic marine microfossil "zones"

For some marine micropaleontologists, the traditional definition of the Neogene may be undesirable because it might require the modification of their informal zonal nomenclatures (e.g., the "N-zones" of Banner and Blow, 1965). Such modifications would be trivial, however, because name changes might be advisable only for the very youngest Cenozoic "zones." For example, planktonic foraminiferal Zone N22 (see Lourens et al., 2004, p. 410) might be relabeled as Zone NQ22, or perhaps Zone Q1. European paleomammalogists have already adopted a similar convention by naming their latest Cenozoic mammal unit the "MQ1" unit, which immediately follows the Neogene "MN" units (Agustí et al., 2001).

It is also important to note that these informal biozonal nomenclatures have no binding authority over any other stratigraphic nomenclatures or classifications, let alone the structure of the standard global time scale. Indeed, the *formal* names of the marine microfossil "zones" are really *binomial* (taxonomic) names (Banner and Blow, 1965; Salvador, 1994; Berggren et al., 1995b). As such, the *informal abbreviations* of these names are logically irrelevant to the much more fundamental question of the extension or non-extension of the Neogene to the present.

To illustrate, the oldest three of Banner and Blow's (1965) original N-zones (N1, N2, and N3) were subsequently assigned to the Paleogene, and have been renumbered P20, P21, and P22, respectively (Blow 1969, p. 200-202; Berggren and Van Couvering 1974, Fig. 1; Jenkins et al., 1985, Fig. 4). Somewhat anomalously, therefore, the oldest standard planktonic foraminiferal zone of the Neogene is now called "Zone N4" (Bolli and Saunders 1985, p. 158; Lourens et al., 2004, p. 410). Clearly, because Banner and Blow's (1965) original zonal abbreviations had no power to define the beginning of the Neogene, they also have no power to define the end of the Neogene.

10.2. Rank of the Paleogene and Neogene

A final obstacle to the acceptance by some workers of the traditional classification of the Cenozoic may be that if the Tertiary Period and Quaternary Period are retained, then the Paleogene and Neogene would have to be given the less prestigious rank of subperiod (Walsh, 2006). This may be inconvenient to some stratigraphers who have regarded the Paleogene and Neogene as periods for many years. While that initial attitude may be understandable, it is of no scientific importance. The durations of the Paleogene and Neogene are ~42 and ~21 m.y., respectively. These are quite similar to the durations of the recently-ratified Mississippian and Pennsylvanian subperiods of the Carboniferous Period (~41 and ~19 m.y., respectively; Davydov et al., 2004).[25] So, given that the Mississippian and Pennsylvanian were historically regarded as distinct Periods by American stratigraphers (e.g., Dott and Batten, 1981; Cooper et al., 1990), Paleogene and Neogene workers are in good company.

11. Necessity of the traditional Cenozoic classification

All participants in the current debate are aware that the scope of the Neogene is inextricably tied to the scopes of the Quaternary, Pliocene, and Pleistocene. It is therefore important to note that recent arguments in favor of a monopoly for marine biochronology in the definition and ranking of our standard global time units were implicitly criticized long ago. Joseph Prestwich (1886, p.81; 1888, p.12) was one of the first British stratigraphers to accept the non-Lyellian, Continental term "Quaternary," and to define it explicitly as Pleistocene+Recent. Although his use of rank terms was inconsistent, Prestwich (1888, p. 442) stated:

> "For these reasons I think the term 'Quaternary' useful and fitting. I retain the term 'Pleistocene' also to show its sequence to the Tertiary series. The objection has been raised that being restricted to so small a group of strata, and so short a period of geological time, its value in these respects bears no comparison with the other great primary divisions. But on these grounds alone, neither will the Tertiary compare with the Secondary, nor the latter with the Paleozoic Series… Their value is to be judged of from the importance of their life history, *and of those great physical changes which gave a special stamp to the times* [italics added]."

It is beyond question that the great majority of geologists agree that the Quaternary is worthy of recognition as a ranked subdivision of the geologic time scale (Pillans and Naish, 2004; Gibbard et al., 2005; Bowen and Gibbard, 2007), and this is true whether its beginning is placed at 1.8 *or* 2.6 Ma (both of these "steps" are climatically important; see Van Couvering, 1997). These geologists also find the Quaternary *Period* indispensible as a collective designation for the Pleistocene and Holocene *epochs*. In terms of named subunits, this has been by far the most common definition of the Quaternary since the late 19th century and should remain as such (Salvador, 2006a,b; Clague, 2006; Walsh, 2006; Bowen and Gibbard, 2007).

The great majority of geologists also agree that the Tertiary is a useful geochronologic unit which must be given the same rank as the Quaternary (Salvador, 2006a,b; Clague, 2006; Walsh, 2006). To ignore these facts is to ignore reality, and these facts are all that is necessary to bridge the Neogene divide. Given them, the Neogene cannot be extended to the present without violating fundamental principles of hierarchical classification

[25] Carboniferous workers are by no means unanimous on the merits of the subperiod rank for the Mississippian and Pennsylvanian (Menning et al., 2001). In the case of the Cenozoic, however, if we wish to retain the Tertiary, Quaternary, Paleogene, and Neogene as ranked units, then either suberas or subperiods will have to be used (Walsh, 2006).

that are observed in every other part of the standard global time scale. Such violations would create difficulties in geological communication that would defeat the very purpose of this time scale (Walsh 2006). We therefore have objective grounds for maintaining the traditional hierarchical structure of the Cenozoic time scale, with the Tertiary and Quaternary best ranked as periods, the Pleistocene and Holocene ranked as epochs, and the Paleogene and Neogene ranked as subperiods of the Tertiary.

12. Conclusions

A major argument used in recent debates on the structure of the Cenozoic time scale has involved the original definition of the Neogene. Some have claimed, first, that the Austrian paleontologist Moriz Hörnes defined this term so as to extend to the present; and second, that we must follow this alleged original definition today. Both claims are contested here. Although Hörnes' discussions were somewhat inconsistent, his biochronological concept of the end of the Neogene was for the most part consistent with Lyell's (1840, 1841) definition of the end of the Newer Pliocene; that is, as the transition interval between mollusc faunas that contained at least some extinct species, and those that contained entirely extant species. Furthermore, Hörnes (1848, 1850c) and his Austrian colleagues consistently excluded the "Diluvium" and "Alluvium" from the Tertiary. This fact, together with Hörnes' (1851b, 1853a, 1854b, 1855) repeated and explicit definitions of the Neogene as "Late Tertiary" and "Miocene+Pliocene," indicate that the Neogene was not intended by him to extend to the present. Some ambiguities in Hörnes' early writings on the Neogene do exist, but these have no more relevance to the definition of the modern geological time scale than do Lyell's even more variable usages of "Pliocene," "post-Pliocene," and "Pleistocene."

After its introduction, the term Neogene was quickly adopted by Austrian and German geologists to refer to the Miocene and Older and Newer Pliocene, but excluding the Diluvium and Alluvium. This usage reflected the importance of distinguishing the generally marine "Neogene" and generally non-marine "Diluvium" as mappable rock units in central Europe. This usage was implicitly accepted by Hörnes (1865b, 1866), explicitly adopted by the Austrian Geological Survey (von Haidinger, 1865, 1866), and subsequently used by numerous Austrian and German geologists for the rest of the 19th century. Usage of the term Neogene generally spread to other major European countries in the 1870s and 1880s, and it almost always excluded the Diluvium, Quaternary, and Pleistocene. This usage would overwhelmingly prevail among stratigraphers throughout the world for most of the 20th century.

There is no doubt that in the 1850s and 1860s, the Newer Pliocene of Lyell (and the Neogene of most workers) extended up to approximately the Middle Pleistocene/Late Pleistocene boundary of current usage. However, as the terms "Newer Pliocene" and "Diluvium" were gradually replaced by "Pleistocene," the prevailing concept of the ends of the Tertiary, Neogene, and Pliocene became progressively older, as the beginnings of the Quaternary and Pleistocene became progressively older. This evolution occurred in response to the continuing discovery of older and older glacial deposits and the widespread recognition of the "Ice Age" as a major event in late Cenozoic geohistory. As such, the Neogene lost its early connotations as a marine biochronological unit and as a mappable rock unit and became transformed into the temporal concept of "pre-glacial late Tertiary." Nevertheless, the historical change in meaning of "Neogene" has been trivial compared to that undergone by several other standard global geochronologic names, such as "Cambrian," "Silurian," "Carboniferous," and "Eocene." In virtually every case it would be unnecessary and disruptive to try to return to those original meanings (Walsh, 2006). As such, there are no compelling reasons to extend the Neogene to the present on historical grounds.

Usage of the extended Neogene concept began to grow in the late 20th century as a result of the acceptance by many marine micropaleontologists of the "N-zone" nomenclature of Banner and Blow (1965). This usage was incorporated into the important time scales of Berggren et al. (1985, 1995a,b) and was subsequently accepted by many marine stratigraphers (e.g., Lourens et al., 2004). Unfortunately, this extended usage of the Neogene conflicts with the traditional "Miocene+Pliocene" definition maintained by most terrestrial stratigraphers and Quaternary scientists. As a result, a "Neogene divide" now exists in Cenozoic chronostratigraphy. This divide is obviously counter to the purpose of a standard global time scale, where each named unit must have the same meaning for all geologists.

The primary motivation that marine workers hold in their insistence that the Neogene be extended to the present is the belief that *marine biochronology should hold a monopoly in the definition of Phanerozoic standard global geochronologic boundaries* (Berggren, 1998, p. 125; Van Couvering, 2006, p. 310). This position is outdated, however, because modern stratigraphy supplies many additional criteria for the definition and correlation of such boundaries (Salvador, 1994; Remane et al., 1996).

The vast majority of Cenozoic stratigraphers view the last "Ice Ages" as an important event in geohistory worthy of formalization as the *Quaternary Period*, consisting of the Pleistocene and Holocene *epochs*. Most stratigraphers also accept the existence of the Tertiary Period, as both it and the Quaternary are extremely useful in the context of geologic maps. If these two units are retained, then the Neogene cannot be extended to the present without violating standard rules of hierarchical classification that are universally applied to the rest of the time scale as a matter of course. We therefore have objective grounds for maintaining the traditional hierarchical structure of the Cenozoic time scale, with the Tertiary and Quaternary best ranked as periods, the Paleogene and Neogene ranked as subperiods of the Tertiary, and the Pleistocene and Holocene ranked as epochs of the Quaternary.

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This paper is published posthumously following the untimely death of Stephen L. Walsh on 1 August 2007. The manuscript was originally submitted to and revised by Steve himself for the Journal of Quaternary Science. However following his death it was felt to be more appropriate to a wider geological audience. This publication was made possible through the considerable support of Tony Hallam, Chris Caseldine and the staff of Earth-Sciences Reviews, especially Frans Koning, which we warmly acknowledge.

Steve Walsh received a B.S. degree in Geology in 1987 at San Diego State University, California, USA and worked in various capacities in the Department of Paleontology of the San Diego Natural History Museum from 1988. A brief foray into graduate school proved too stifling to Steve and instead he set out on his own course of study. Initially, his research interests focused on Paleogene stratigraphy and mammal faunas of southern California and the western United States and through his prodigious field and laboratory efforts he built-up a large and comprehensive collection of small fossil mammals from the region. In later years he turned more and more to his new passion for the theoretical foundations of biostratigraphy, biochronology and chronostratigraphy, even teaching himself German so he could read the primary literature in that language. A consummate scholar and philosopher, Steve viewed his science in a fairly strict Popperian sense and challenged others to aspire to a higher level of objectivity. Needless to say he did not suffer fools gladly. It seems clear that Steve was just finding his voice as a mature earth scientist and the strides he was taking were leading him in new directions of discovery. We can only imagine what great things he might yet have accomplished and we hope that this paper serves as an appropriate memorial to our colleague and friend.

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