

Editorial – Rock, time, and reconsideration

No living stratigrapher can remember a time without controversy over differing perceptions of the terms Tertiary, Quaternary, Pleistocene, Paleogene and Neogene. The International Commission on Stratigraphy is presently engaged in an effort to find enduring compromises that may reconcile the contesting factions. The challenge faced by ICS is exemplified in two recently published papers (Lourens et al. 2005; Gibbard et al. 2005) that reiterate, once again, the reasons why one usage of the terminology should prevail over another. What appears to be absent from the debate is an awareness of the history and variability of the terms in question, that might suggest points of view that are not apparent from the trenches. We have therefore been asked by Felix Gradstein, Chair of ICS, to republish the key parts of a review of the history of Cenozoic chronostratigraphic terminology that was prepared by the editor of this journal, William A. Berggren, for the Lyell Bicentenary at Royal Holloway College, University of London, Egham, on 31 July-1 August 1997. While Dr Berggren's partisan views at the time are clearly evident in the article – after all, there has been no neutral ground in Cenozoic chronostratigraphy for over a century – his scholarly examination of the development of this field allows all sides to examine the inherent meaning(s) of the terms we use (or abuse) today, to understand how the conflicts over their formulation arose, and thus – hopefully – to discover nuances that could help to resolve the present impasse. In other words, it may be that the best way forward is to revisit the past.

John A. Van Couvering, Editor in Chief, *Micropaleontology Press*

[From Berggren W. A., 1998. The Cenozoic Era: Lyellian (chrono)stratigraphy and nomenclatural reform at the millennium. In: Blundell, D. J. and Scott, A. C., Eds., *The Past is the Key to the Present*. Geological Society, London, Special Publications, 143: 111-132.]

ABSTRACT

[...] Lyell's terms Eocene, Miocene, Pliocene (1833) and Pleistocene (1839) were essentially biostratigraphic/biochronologic in nature. Together with the subsequently defined Oligocene (1854) and Paleocene (1874), they have been gradually given a chronostratigraphic connotation over the past 100 years. The term Neogene (Hörnes 1853 1856 1864), when transferred from its original biostratigraphic/biochronologic (Lyellian) to a chronostratigraphic connotation, includes the stratigraphic record of the Miocene, Pliocene, Pleistocene and Recent (subsequently termed Holocene) Epochs (= "periods" of Lyell). Thus a Neogene/Quaternary boundary is wholly inappropriate as a standard chronostratigraphic boundary. The Paleogene (Naumann 1866) now comfortably accommodates the stratigraphic record of the Paleocene, Eocene and Oligocene Epochs. [...]

HISTORICAL BACKGROUND

[...] A fourfold subdivision of mountains and their associated rock types was introduced by Giovanni Arduino (1760, or 1759?) based on field observations in Tuscany and Vicenza Province (the valley of the Agno, northwest of Vicenza): Primary, Secondary, Tertiary, and modern alluvial deposits. Field work during the second half of the 18th century on the Continent and in Britain led to the recognition that these terms were more appropriate as descriptive rock terms than they were applicable to any chronologic succession. As a result, in the course of the first half of the nineteenth century the meanings of the terms were transformed to include groups of units based on an observed succession of rock types and associated fossils. The Tertiary was given its essentially modern connotation by Brongniart during the period 1807-1810 (text-fig. 1 herein) in being applied to the succession of rocks that occur above the Chalk in the Paris Basin (which essentially encompasses the Paleogene in modern terms) and which was the focus of the ma-

ior study by Cuvier and Brongniart (1811) a year later. Its chronologic/stratigraphic extension to include rocks subsequently encompassed by most of the Cenozoic (Phillips 1840) was quickly established. However, the Quaternary (Desnoyers 1829) was carved out of the upper part of the Tertiary (stratigraphically equivalent to the Neogene of Hörnes (1853) and this paper), but its limits were immediately modified, and temporally shortened to include the diluvium deposits in accordance with the biblical deluge (De Serres 1830). It was in its recently modified, truncated form that Lyell inherited the term 'Tertiary' when he set about subdividing it into his 'periods' in Volume 3 of the *Principles* (1833). [...]

THE NEOGENE

A historical review of the Tertiary period/system and of its constituent epochs/series has been presented by Berggren (1971), and of the Quaternary period/system by Hays and Berggren (1971) and Berggren and Van Couvering (1982). At this point I shall consider briefly contemporaneous investigations (1830-1870) on the Continent that had an impact on Lyellian stratigraphic terminology.

Heinrich Georg Bronn (1800-1862), professor of zoology and technology at the University of Heidelberg made extensive trips between 1824 and 1827 in southern France and Italy. In 1831 Bronn published a major study on the fossils in the Italian Tertiary (Bronn 1831) which also included a comprehensive catalogue of the relative and absolute numbers of invertebrates, vertebrates, worms and 'zoophagous' (animal-eating) and 'phytophagous' (plant-eating) forms from the formations of various basins in Europe. He listed the numbers of definitely recognizable species in Italy (770), the Paris Basin (546), Bordeaux Basin (296), Montpellier Basin (529) and Vienna Basin (113) in terms of Lamarckian classification, and remarked on the degree of similarity of the Paris and London Basin faunas.

EPOCH	ARDUINO (1769-1770)	BRONGNIART (1807)	MANTELL (1822) BUCKLAND (1823)	DESNOYERS (1829)	MARCEL DE SERRES (1830)	LYELL		PHILLIPS (1840)	BRÖNN (1838)											
						(1831)	(1833, 1839)		III. Molasse Gruppen	ALLUVIUM										
PLEISTOCENE	TERTIARY	"TERRAINS TERTIAIRES"	ALLUVIUM (Rivers)	QUATERNAIRE (≅ Neogene of Hörnes, 1853, and later authors)	Q (Early Man-Hominids)	CONTEMPORARY	RECENT	KAINOZOIC = CENOZOIC		5th PERIOD: MOLASSEN GEBIRGE (Tertiär und Quartär Formationen)	I. Molasse Gruppen	Untere Abtheilungen	Tegel Formation Faluns, Miocene of Lyell and Deshayes							
PLIOCENE			DILUVIUM (Biblical flood)			LIMINAL? or PENULTIMATE	PLEIOSYNCHRONOUS		PLIOCENE					NEWER	Obre Abtheilungen	Subapennine Fm. Diluvial-Bildung. Pliocene of Lyell-Deshayes; Knochen-Breccien, Marine Strata; Italy- Apennine Coast to their highest level				
MIOCENE														OLDER (Pliocene)						
OLIGOCENE															MEIOSYNCHRONOUS	MIOCENE				
EOCENE															PROELIMINAL?	EOCENE				
PALEOCENE															EOSYNCHRONOUS					
	SECON- DARY	CRAIE				ASYN- CHRO- NOUS						Grobkalk Fm. Pariser Becken, London Clay, Lower Tertiary of No. America								

TEXT-FIGURE 1 [figure 2 in original]

History of terminology applied to Cenozoic chronostratigraphic units. Note that Tertiary nomenclature ascribed to Lyell (1831) represents an informal attempt to derive a suitable classification for what subsequently (1833, 1839) became the standard, classic terms still in use today. In a letter dated 21 January 1831, the informal terms were submitted to William Whewell who replied ten days later suggesting to Lyell some etymologically more appropriate terms which Lyell enthusiastically accepted and published in his first edition.

He recognized a division of the Tertiary into lower and upper parts based on the presence or absence, respectively, of the large foraminiferid *Nummulites* in the Italian, Paris, London and Vienna Basins. Finally, he recognized the need for extensive additional studies on the faunas of European basins before a fundamental subdivision of the Tertiary could be made (Bronn, 1831, p. 174). Lyell made this subdivision two years later based on his extensive investigations with Deshayes on

molluscan faunas of the European Tertiary basins, but there is no evidence that Lyell was aware of Bronn's concurrent studies or that they played any role in his own subdivision of the Tertiary. Indeed, Lyell lamented the fact that many important treatises were in German, in which he possessed 'only perfunctory skills'. He met Bronn finally, and briefly, during his honeymoon visit to Heidelberg in 1832. Bronn appears not to have suffered from the chronic Anglo-Saxon illness of linguaphobia;

descriptions of the most noteworthy of fossil forms from various formations in a set of 47 folio plates (1838).

Bronn divided Earth history in five periods and denominated as his fifth period of geologic history, the *Molasse Gebirge* (text-fig. 1) which included the *Tertiär und Quartär Formationen* and which corresponded essentially to what Lyell, following the historical progression in geologic terminology since Arduino's introduction of the term in 1760, referred to as the 'Tertiary', i.e. all the rocks above the Chalk. The minor difference was that Lyell terminated his 'Tertiary' conceptually, if not actually, within the Pleistocene, in (unhappily for posterity) restricting the term 'Recent' to the 'interval since the earth has been tenanted by man'. The *Molasse Gebirge*, in turn, was subdivided into three groups, termed the *Molasse Gruppen*. The first (lowest) unit was correlated with Lyell's recently defined Eocene 'Period'; the second, or *Molassen Gruppe (sensu stricto)*, included the Miocene and Pliocene 'Periods' *sensu* Lyell and were treated as subunits and referred to as the *untere Abtheilung* (Miocene) and *obere Abtheilung* (Pliocene), respectively. The upper part of this unit was correlated with the Subapennine Formation of Italy, the *Diluvial Bildungen* of Continental, predominantly Austrian and German, authors, the Pliocene of Lyell and Deshayes and the Middle Tertiary of North America (*partim*). The third *Molassen Gruppe* contained the *Alluvial und Quartär-Gebilde zum Theille* (corresponding essentially to what is termed Recent or Holocene at present), the Pleistocene proper *Knochen Breccien, Knochen-Hohlen und der Loss*, the latter of which Bronn interpreted, as did Lyell, as marine deposits that were already incorporated within the upper part of his second *Molassen Gruppe* (text-fig. 1). Bronn noted that he was unable to distinguish the faunas from the Vienna and Hungarian Basins, Poland and the Siebenburg from those of the Subapennine strata of Italy and thus was unable to consider them as older, contrary to the opinion of Deshayes. He also compared the percentage of fossil taxa relative to living forms in a manner similar to Deshayes but does not appear to have applied it rigorously as a biostratigraphic tool.

Twenty-five years later, in the course of preparing a monograph on the molluscan faunas of the Vienna Basin, Moritz Hörnes (1815-1868), Director of the Museum of Natural History in Vienna (1836-1868), noted that the Miocene and Pliocene faunas were more similar to each other than to those of the Eocene. In creating the term Neogene for these upper, younger faunas, (Hörnes 1853, 1864) referred specifically to the biostratigraphic subdivision of the Tertiary and Quaternary made by his friend Bronn in 1838. Indeed, Hörnes drew attention to his observation that so similar were the typical Mio-Pliocene faunas of the Vienna Basin to the 'Pliocene' faunas of Sicily, Rhodes and Cyprus that no clear line of demarcation was possible between the two units; he favoured combining the two into a single unit. He further remarked that rigorous adherence to quantitative methodology was of little worth. Rather he preferred to use the overall character of the fauna and, in particular, the more or less common occurrence of index forms as indicators of relative stratigraphic position in preference to what he saw as the shortcomings of current practice. These included (a) unique occurrences, (b) poorly determined forms and (c) immature individuals, all of which yield unreliable results. The original Neogene concept thus includes *a priori* all post-Eocene molluscan faunas. Hörnes appears to have understood the distinction between typical Eocene, Miocene and the term his friend Beyrich was about to create (1854) and insert between the two, namely the Oligocene see Hörnes (1853, p. 808).

Hörnes included in his term Neogene 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 that would now be included in the Pleistocene. It will be recalled that Lyell coined the term 'Pliocene' in 1833 and subsequently (1839a, 1857a, b) subdivided it into an Older Pliocene and Younger Pliocene (the latter equivalent to the Pleistocene). At the same time it should be remembered that Hörnes' Neogene specifically referred to, and incorporated inclusively, the subdivision of the Tertiary and Quaternary of Bronn (1838) and not that of Lyell (1833).

The Neogene was originally proposed to characterize the faunal (and particularly molluscan) and floral changes that denote the middle part of the Cenozoic (beginning, but not clearly delimited originally, at the present day Oligocene/Miocene boundary) and continue to the present day. While its original connotation was that of a biostratigraphic term (as were Lyell's Tertiary 'periods'), in its modern resurrection as a chronostratigraphic unit it corresponds to the interval since the beginning of the Miocene epoch/series.

The term 'Neogene' and 'Palaeogene' found little favour in British geologic circles until the 1960s. Indeed, there was widespread resistance to the whole concept of 'stages' in British geologic circles until after World War II. In contrast to this, in continental Europe and to a lesser extent North America the term 'Neogene' was widely acknowledged, and generally accepted, in subdivisions of the upper Cenozoic during the latter half of the nineteenth century (cf. Van Couvering 1997, p. xii). Renevier (1897), for example, recognized it as a fundamental unit in the subdivision of the upper part of the Cenozoic era. By way of background a few notes are listed here on Renevier's use of terminology:

(1) In conforming to the rules established at the International Geologic Congress at Bologna in 1881, Renevier adopted a nested hierarchy of four orders of subdivision with decreasing importance in regional extent:

- (i) eras = groups; of global/mondial extent/value;
- (ii) periods = systems; of very general extent/value;
- (iii) epochs = series; primarily of European extent/value;
- (iv) ages = Stages; of only regional extent/value.

A fifth order, substages/beds, is viewed as strictly of local value.

(2) The term *Cénozoaire* (fr.) = 'Cenozoary' (engl. [sic!]) is used to signify the ordinal value of the division. *Néogenique* (fr.) = 'Neogenic' (engl. [sic!]) is used for the second order.

(3) 'Ceno-' is preferred to 'Kaino-' in conformity with the construction of the words 'Pliocene', 'Miocene', 'Eocene', etc. Inasmuch as the roots are identical, if one accepts 'Kainozoaire', one must also accept 'Pliokaine'.

(4) 'Plistocene' is used in preference to 'Pleistocene' which is consistent with 'Pliocene'. Inasmuch as the root of the former (Plistocene) is the superlative of that of the second (Pliocene), they must be interpreted in the same manner. Whereas it may be etymologically more correct to say 'Pleistocene', it would then be necessary to use 'Pleiocene' and 'Meiocene'; "any other usage is illogical!" observed Renevier.

(5) Consistent with earlier editions of his work, Renevier included in the Tertiary Era the Plistocene and Recent (“*actuelle*”) and equated the Tertiary and Cenozoic. By way of justification he referred to his earlier (1874) explanation that there are no important organic changes between the Tertiary (older usage) and the Quaternary. Few types disappeared and few new forms appeared except humans, whose existence during the Pliocene in Italy and Belgium has been indicated by several contemporary authors. Compare the major differences between the Primary, Secondary and Tertiary eras on the other hand, he declared. He observed that his (deceased) teacher F.-J. Pictet had expressed the same views in 1857, and repeated from his earlier publication (Renevier 1874, p. 233) the contemporary quote of Gervais:

L’ époque que l’on continue, on ne sait trop pourquoi à appeler Quaternaire, comme si elle constituait une nouvelle grande série de faunes et de flores... (‘the epoch which we continue to call, for some reason which is not all clear, Quaternary, as if it constituted a new and important series of faunas and floras...’).

(6) Renevier pointed to the diverse usages of the ‘Tertiary’ and ‘Quaternary’. D’Orbigny and Mayer set the Recent epoch apart but combined the Tertiary and Quaternary. Lyell and Gaudry terminated the Tertiary above the Plistocene with *Elephas meridionalis*, i.e., in the middle of the Quaternary of most authors. Finally Naumann subdivided the Cenozoic in Quaternary and Tertiary. Renevier (1897, p. 558) concluded, “Ces divergences confirment ma thèse qu’il n’y a point là de division primordial naturelle.” (These differences confirm my thesis that this is not a natural and fundamental division).

Renevier’s (1897) subdivision of the upper part of the Cenozoic era is shown below in Figure 3 [text-fig. 2 herein]. Renevier’s use of the term ‘Prepliocene’ was unfortunate in hindsight, but fully understandable in light of the knowledge available at the time on the stratigraphic position of the Pontian Beds of eastern Europe. The Pontian stage now rests relatively secure in the bosom of the late Miocene (Steininger et al., 1989, 1996). It will be readily seen that Renevier’s (1897) denotation of the term ‘Neogene’ is essentially identical to that endorsed here a hundred years later.

De Lapparent (1885, 1906) in the second and third editions, respectively, of his monumental third editions of his monumental *Traite de Géologie*, equated the Cenozoic with the *Néozoïque* (fr.) = ‘Neozoic’. He followed Lyell’s threefold subdivision of the Tertiary, included the Miocene and Pliocene in the Neogene and equated the ‘*Ere moderne ou Quaternaire*’ with the ‘*Époque Pliocène*’. The latter was considered to be characterized by the appearance of humans and of glacial climates on Earth; De Lapparent indicated a preference for the term ‘Pleistocene’ (rather than ‘Quaternary’) because of its unequivocal denotation of continuity with the term Pliocene. While admitting that it was still impossible for the science of geology to provide a precise chronometry for the Pleistocene, he believed this interval was relatively short, on the order of several hundreds of thousands of years. It is an irony of history that De Lapparent’s second edition (1906) was published in the same year that the first use of radiometry was made in the service of a geological timescale, following the discovery of radioactivity a decade earlier by Becquerel (1896). In this context it is also important to remember that De Lapparent followed contemporary opinion in including the Sicilian ‘stage’ in the ‘upper Pliocene’ (*contra* Lyell 1833); he equated it with the Norwich Crag, the Forest Bed of Cromer, the Amstelian of Belgium-Holland and the appearance of *Elephas meridionalis* in southern France (Langue-

Néogénique Récent	
<i>Holocène</i>	Actual Palafittien
<i>Plistocène</i>	Acheulien Durnténien Sicilien
<i>Pliocène</i>	Astien Plaisancien
Néogénique Ancien	
<i>Prépliocène</i>	Pontien
<i>Miocène</i>	Tortonien Helvétien Burdigalien Aquitainen

TEXT-FIGURE 2 [fig. 3 in original]
Subdivision of the upper part of the Cenozoic Era, by Renevier (1897).

doc-Roussillon) and considered the base of the Pleistocene essentially contemporaneous with the first appearance of *Elephas antiquus*, *Rhinoceros mercki*, *Hippopotamus major*, *Ursus spelaeus*, *Cervus megaceros* and (in neritic environments) *Mya truncata*. This demonstrates that the base of the Pleistocene (or Quaternary) at the turn of the nineteenth century (in the sense shown here) was located at a level corresponding to what is currently considered close to the early/ middle Pleistocene boundary near the Brunhes/ Matuyama boundary at a little over 0.8 Ma (Jenkins et al., 1985; Berggren et al. 1985; Van Couvering 1997).

In his *Manual of Geology*, Dana (1894) referred to the use by some contemporary authors (e.g. William H. Dall and Gilbert D. Harris), and even by the US Geological Survey map of 1884, of ‘Neocene’ for the combined Miocene and Pliocene. He noted (Dana 1894, p. 880) the curious, if not iconoclastic subdivision by Heilprin in 1887 of the Cenozoic into the Eocene (Eocene plus Oligocene), Metagene (Miocene) and Neogene (Pliocene plus Quaternary). Finally Dana observed that the Tertiary “is a relic of early geological science which retains its place simply because of the convenience of continuing an accepted name” and notes that the term ‘Neozoic’ (originally described by Edward Forbes (1846) to denote the Mesozoic and Cenozoic) is sometimes used in a more restricted sense to denote the Tertiary and, occasionally, as a substitute for the entire Cenozoic.

The culprit behind the current misunderstanding of the correct denotation of the term ‘Neogene’ appears to be Maurice Gignoux (1913), who used the term in his doctoral thesis on the Plio-Pleistocene succession in Italy without providing a discussion of the historical framework of the term. He simply excluded the Pleistocene (or Quaternary) from the Neogene. This

viewpoint was promulgated in his subsequent textbook (Gignoux 1955). The term appears to have served as little more than 'a casual literary convenience', as Van Couvering (1997a, p. xii) so aptly put it. It should be recalled that whereas Hörnes (1853) did not recognize a separation of Pliocene and Pleistocene in his original distinction of the Neogene, Gignoux (1913, 1950, 1955) took for granted such a separation. It may be of interest to note that one of the few instances in which the Neogene has been used correctly in its original sense (incorporating the Miocene through the Holocene) is in a recent text book on historical geology (Cooper et al. 1996, fig. 3.1, p. 66, fig. 3.2, p. 67).

This failure to recognize the original intent for the term 'Neogene' has had unfortunate consequences in attempts to modernize the standard chronostratigraphic subdivision of the Cenozoic. In overlooking the fundamental historical background to the term 'Neogene', the INQUA Subcommittee on the Neogene/Quaternary (N/Q) boundary inherited a 'dead cat' when it, and eventually the International Commission on Stratigraphy (ICS), wrestled with the boundary problems in the late 1970s and early 1980s. The Neogene period/system, in its original sense, was a biochronologic unit (Berggren and Van Couvering, 1974, 1979), overlapping chronologically the Quaternary era/erathem in its modern sense, and quite irrelevant to questions of a lower boundary for the Quaternary. Perhaps most damning to proponents of a distinction between Neogene and Quaternary is the simple fact that no upper limit to the Neogene was specified either by Hörnes (1853) or by Gignoux (1913, 1950, 1955). There is, simply, no post-Neogene! We are still living in the Neogene period!

It is ironic that Gignoux's revised concept of the Neogene has been accepted by those who advocate eliminating the term 'Tertiary' (Harland et al. 1982, 1990), whereas the IUGS (Cowie and Bassett 1989) simply omitted the Tertiary in their 'official' timescale and juxtaposed the Neogene and Quaternary, the latter a rather inappropriate denomination for a third, rather than fourth, subdivision of the Cenozoic, as Van Couvering (1997a, p. xii) has ruefully observed. The original IUGS commission declaration (King and Oakley, 1950) specified that it was the Tertiary/Quaternary boundary that was to be identified with the Pliocene/Pleistocene boundary. This has finally been achieved in a satisfactory manner (Aguirre and Pasini 1985, Pasini and Colalongo 1997). Current attempts in some quarters to lower the boundary of the Pleistocene to a level around 2.6-2.75 Ma, based on climatic criteria, are viewed here as misguided and ill-informed. They will confuse a situation that has only recently seen the agreement of both the Neogene and Quaternary Subcommittees of the IUGS in selecting a Global Stratotype Section and Point (GSSP) for the base of the Pleistocene (and Quaternary).

THE PALAEOGENE

If the Neogene has suffered from neglect and connotational and denotational misinterpretation, the Palaeogene may be said to have suffered a crisis of author identity. The term was attributed to Hörnes by no less than Dana (1894, p. 880), Harland et al. (1990, p. 61), Schoch (1989, p. 25) and seemingly by Papp (1959, p. 5; 1981, p. A499), among others, a classic example of Norman Watkins' famous dictum on the reinforcement syndrome: 'repeat it often enough and it becomes the accepted truth'. Fortunately, authorship was correctly ascribed by Denizot (1962, p.151) in his contribution to the *Lexique Stratigraphique International*.

The term 'Palaeogene' owes its origin to Carl Friedrich Naumann, professor of mineralogy and geology at the University of Leipzig (beginning in 1842). Before this, Naumann had been successor to Werner (who had been professor of crystallography in Freiburg/Saxony) as professor of geognosy. The term 'Palaeogene' was introduced in the third volume of Naumann's monumental *Lehrbuch der Geognosie* (1866, p. 8). In his second volume (1854, pp. 1029-1033) Naumann had reviewed the role played by Deshayes in establishing the quantitative methodology as a biochronologic tool in Tertiary stratigraphy, and Lyell's subsequent application of this to establish formal subdivisions of the Tertiary. He drew attention to his friend Hörnes' warning that caution should be used in applying Deshayes' quantitative methodology in a rigorous manner, owing to the problem of identifying rare species, etc. (an echo of what Hörnes expressed the year before in his 1853 letter to Naumann about the term 'Neogene'; see above). He noted his indebtedness to Hörnes, who had recently (1853) confided to him his observations on various faunas of the Tertiary and his intent and reasons (i.e. the major difference between Eocene and Mio-Pliocene molluscan faunas) for proposing the new term 'Neogene'. He noted that none of this was particularly new, for Bronn had focused attention on these facts in the first edition of his *Lethaea Geognostica* (1838), as well in the third edition of the work, when dividing the Tertiary into a lower and an upper part. He observes that, according to Hörnes, the Tertiary formations can be subdivided in the following manner:

- A. Eocene
 - 1. Older Eocene; Paris Basin, London
 - 2. Younger Eocene; Lesbaritz, Tongrian and Rupelian System in Belgium, Westeregeln near Magdeburg (which was to become part of Beyrich's Oligocene in 1854)
- B. Neogene
 - 3. Older Neogene; Touraine, Bordeaux, Vienna, Turin, Poland
 - 4. Younger Neogene; Asti, Castell' Arquato, Sicily, Rhodes, i.al.

We see that Naumann was not ready to subdivide the lower part of the Tertiary at this stage (1854). At this time he used the terms *Nummuliten und Flysch Formation* for what he subsequently termed 'Palaeogene'. However, in the third volume of his *Lethaea*, published a decade later (1866, p. 8), Naumann states,

Da sich nun Hörnes noch neurdings dahin erklärt hat, dass er durch den Collectiv-Namen neogen nur auf die scharfe Gränze zwischen den eocänen und den neueren Tertiärbildungen hinweisen wolltte, ohne deshalb die Möglichkeit einer weiteren Eintheilung dieser beiden Haupt-Etagen in Abrede zu stellen, so lässt sich die viergliederige Eintheilung er Tertiärformationen auch in folgender Weise darstellung machen: (Inasmuch as Hörnes has recently explained that by means of the collective name of Neogene he is referring only to the sharp boundary between the Eocene and the younger Tertiary strata, without the possibility of any further subdivision of these two main 'stages' [periods/systems in modern parlance], this allows further subdivision of the Tertiary formations in the following manner):

- A. Palaeogene Tertiary
 - 1. Eocene Formations
 - 2. Oligocene Formations
- B. Neogene Tertiary
 - 3. Miocene Formations
 - 4. Pliocene Formations

In other words, it seems that Naumann felt that he was obliged by default to name the Palaeogene since Hörnes had shown no inclination to do so following his introduction of the term 'Neogene' a decade earlier. In an interesting comment, Naumann (1866, p. 9) drew attention to the recent (1857) classification of the Tertiary of Europe by Mayer-Eymar into 'Stufen' (or stages), based on his belief in the superiority of this approach as opposed to the classification of Deshayes and the nomenclature of Lyell. Naumann then listed the six Lower Tertiary and six Upper Tertiary stages of Mayer, and observed that the upper two stages (Astian and Saharan, which included the Norwich Crag, as well as the Sands of the Subapennine Formation and many younger units) would be included under the term Pliocene. This further illuminates the original intent of Hörnes' definition of the term 'Neogene' and contemporary understanding (by Naumann) of this. The stages of Mayer (and those of d'Orbigny 1849-1852) and their role in Cenozoic stage terminology have been discussed in greater detail by Berggren (1971).

The denotation of the Palaeogene has not suffered the same convoluted history as its younger counterpart, the Neogene. With the addition of the term 'Palaeocene' by Schimper (1874), a threefold subdivision of the Cenozoic was generally accepted on the Continent; elsewhere adoption of the term 'Paleocene' was delayed for various reasons (it was not acknowledged in Britain, nor was it formally accepted in the United States until 1939). Acceptance of the term 'Palaeogene', however, has been uneven. For instance, our hero of the Neogene, Renevier (1897) balked at accepting it on rather flimsy grounds (seen from this vantage point), saying it was too similar to 'Palaeocene' or 'Palaeozoic', while acknowledging current usage of 'Eogene' as a synonym. 'Je comprends Néogène (nouvellement formé), mais Eogène (aurora formée) c'est ridicule!' (I understand the term Neogene (recently formed), but Eogene, that is ridiculous!) (Renevier 1897, p. 562). Instead he fell back on the familiar and popular French term *Nummulitique*, which remains popular in French texts to this day but is inappropriate as a chronostratigraphic term on stratigraphic and etymologic grounds (*Nummulites* ranged from the late Palaeocene - Thanetian Age - until the end of the early Oligocene - Rupelian Age - and the term defined in this manner scarcely encompasses the time between the Cretaceous/Palaeogene (Senonian/Paleocene) boundary and the Palaeogene/Neogene (Oligocene/Miocene = Chattian/Aquitainian) boundary.

THE PLEISTOCENE AND THE QUATERNARY

Lyell (1839b) created the term 'Pleistocene' for his Younger or Newer Pliocene (1833), almost as an afterthought, in an appendix to a French translation of his *Elements of Geology* (1838). Its boundary (and that of the Tertiary) with the Recent was said to conform with the appearance of humans, a definition that, in hindsight, was quite unfortunate and led to varying degrees of confusion in determining the limits of upper Cenozoic (chrono)stratigraphic terms. Lyell used the term 'Post-Tertiary' for the formations above/younger than the Tertiary and retained the subdivision into post-Pliocene and Recent through many editions of his *Principles*.

The Pleistocene had been given a 'glacial' connotation by Forbes (1846) in referring to what he thought Lyell (1833) had termed Newer Pliocene (or Pleistocene). But Lyell pointed out that Forbes' use referred to post-Pliocene and Lyell withdrew the term Pleistocene. This inappropriate use of the term resulted from the fact that Lyell retained glacial and associated topics

under the Newer Pliocene through to the fifth edition of the *Manual of Elementary Geology* (1855). Lyell (1857a,b) modified his Tertiary terminology in distinguishing the following units (in descending order): Recent (deposits with human remains, alluvial deposits of the Thames Valley with buried ships); post-Pliocene (in which he grouped deposits with fossil shells of living species in which no human remains have been found and shell-marls of Scottish and Irish lakes); Newer Pliocene, or Pleistocene (with which he equated glacial deposits as well as preglacial deposits of the Thames Valley and the Norwich Crag and the *Terrain quaternaire, diluvium* and *Terrains tertiaires supérieurs* of the Continent). Below these units followed the Older Pliocene, Miocene (subdivided into an upper and lower part, the latter consisting of what had previously been included in his upper Eocene), and an upper and lower Eocene. Above the post-Pliocene was the post-Tertiary. Lyell clearly considered the Tertiary to encompass all but the youngest, superficial deposits of the present day.

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'). Modern usage of the term 'Pleistocene' encompasses Lyell's (1833) Newer Pliocene or Pleistocene and his vaguely defined 'Post-Pliocene'. The term 'Holocene' has generally been used for the present interglacial with a defined base at about 10 ka (radiocarbon), but is little more than an interglacial interval of the Pleistocene (Berggren and Van Couvering 1974, pp. 51, 55).

The base of the Pleistocene has recently been stratotypified at the Vrica section in Calabria (southeastern Italy), at a level near the top of the Olduvai Magnetic Polarity Chronozone (C2n) with an estimated age of 1.81 Ma (Berggren et al. 1995; Pasini and Colalongo 1997; Van Couvering 1997). With the recent addition of a Milankovich-based astronomical timescale, we now have a precise chronology for the events associated with this boundary. We can link the bounding limits of the Olduvai Subchron with isotope stages 64 (younger) and 72 (older), respectively, and can effectuate global correlations via integrated magnetobiochronologic studies. The Pliocene remains strongly anchored to proper Lyellian stratigraphic procedures with a threefold chronostratigraphic subdivision (Zanclean, Piacenzian and the recently proposed Gelasian stage).

The Quaternary (Quaternaire ou Tertiaire récent) was introduced by Jules Desnoyers (1829) as the fourth, and final, subdivision of the then threefold subdivision of the geological record (Primary, Secondary and Tertiary), for the rocks in the Loire-Touraine Basin and Languedoc that were demonstrably younger than those of the Seine-Paris Basin. He subdivided the rock units into three parts (from younger to older): 3) *Recent*; 2) *Diluvium*; 1) *Faluns de Touraine, la Molasse suisse, le Pliocène marin du Languedoc*. In retrospect we see that this original definition essentially corresponded to, and included, what Lyell was to include in his Miocene, Pliocene and Recent (1833, 1839b) and Hörnes (1853) in his Neogene. Marcel de Serres (1783-1862), professor at the University of Montpellier, used the term *Quaternaire* in 1830, in considering it synonymous with the term *Diluvium* (as first used by Mantell in 1822 and Buckland in 1823 for deposits of the biblical deluge), and observed that humans were contemporaneous with these Quaternary deposits, thereby restricting its stratigraphic and chronologic extent closer to its modern denotation (see also De Serres 1824). This apparently led him later (1855) to claim,

with questionable justification, priority for creation of the term 'Quaternary'.

The term 'Quaternary' was given a faunal connotation by Reboul (1833), who distinguished it as containing living species of animals and plants (*Période anthropéenne*) as opposed to the Tertiary, which was believed to contain mostly, if not exclusively, extinct species. This work and the classic treatise of d'Archiac (1849) on the *Terrain Quaternaire* or *diluvien* gave added weight to acceptance of the term 'Quaternary' in geological literature. The Swiss archeologist C. A. Morlot (1854/1856) introduced the word *Quaternaren* into the German language and subsequently (1858) modified it to *Quartären*, a translation of the term *Quartaire* which he had proposed that same year and restricted to the post-Pliocene. The term *Diluvium* was used in earlier German literature as a synonym for the Pleistocene and *Alluvium* for the Recent (in sharp contrast to early English usage following Mantell's (1822) original designation of superficial sediments in two categories: 'Diluvium', sediments formed during, and by, the biblical Flood; and 'Alluvium', post-Flood sediments formed by modern rivers, streams, etc.). The two terms equated, respectively, with glacial and post-glacial time. They have historically been combined to represent the Quaternary period/ system in both German and Anglo-Saxon literature, and also, but with a predominantly mammalian faunal denotation, in French literature. Modern studies have shown that there is no relationship between the initiation of polar glaciation and the base of the Quaternary, and that the placement of 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 (see reviews in Hays and Berggren 1971; Berggren and Van Couvering 1982).

Lyell (1833) introduced the term 'Recent' (see above) for the time 'which has elapsed since the earth has been tenanted by man' at the same time as Reboul (1833) was busy redefining the Quaternary. As such the Recent included both the Pleistocene and Holocene of modern usage (although the term 'Recent' has since been modified to correspond to the Recent, or interglacial, epoch of some geologists). To add further to the confusion, Gaudry, with the tacit approval of Prestwich and De Lapparent, introduced at the International Geological Congress in London (1888) the proposal that humans (represented by their artefacts in particular) were the characteristic element of the Quaternary (*vide* Hays and Berggren 1971, p. 670).

In presenting a review of the terminology of post-Pliocene stratigraphic terminology, Richard Foster Flint (1947, p. 281), patron saint of glaciologists and Quaternary geologists and professor of Geology at Yale University, pointed to the transitional nature of Pliocene-Pleistocene strata in terms of both lithostratigraphy and biostratigraphy and concluded

that to consider such a boundary as separating time units of so major an order as periods, equivalent in rank to the Cretaceous period, is to overemphasize its importance. The Pliocene- Pleistocene boundary cannot justifiably have 'system' value, but only 'series' value. It follows that the ancient concept of a 'Tertiary period' and a 'Quaternary period', though fully adequate for the time it was first used, does not now rest on firm ground and should be abandoned. In other words we should think of the present as a part of the initial period of the Cenozoic era.

He urged recognition of the Pleistocene as a time-stratigraphic unit based on fossils and not climate (although climatic perturbations would be expected to have left a characteristic imprint

upon the stratigraphic record of the Pleistocene) and remained cool about use of 'Holocene' as a formal time-stratigraphic term, suggesting, instead, informal use of the terms 'recent' or 'postglacial' in geographically restricted areas.

Flint (1965, 1971, p. 384) reiterated these views a couple of decades later in updated discussions of the terms 'Pleistocene' and 'Quaternary' and concluded by saying

we dissent from common practice in that we favor the dropping of Tertiary System and Quaternary System from stratigraphic nomenclature. If this were done, the Pleistocene Series would include all post-Pliocene strata, as implied by Lyell in 1839. Further, we believe, in view of the long term span of the succession of late-Cenozoic cold climates that the Pliocene/ Pleistocene boundary should not be based on climatic indications. Finally we think the terms recent and postglacial should be used only informally, and applied only within geographically restricted areas. We have little hope that these changes will come about soon, but we think they are soundly based. (Flint 1971, p. 384)

The recommendations by Schuchert and Dunbar (1941), Dunbar and Rogers (1957) and Flint (1947, 1965), among others, to discard the terms 'Tertiary' and 'Quaternary' have been echoed more recently in the publications of Berggren and Van Couvering (1974), Berggren et al. (1995) and Steininger (1996), and (at least for 'Quaternary') Harland and colleagues (1990). Pomerol (1973, p. 12) expressed the situation well in stating "l'ère quaternaire' ...n'est paléogéographiquement parlant, que la projection du Néogène dans les temps actuels". Unfortunately, after making this observation he proceeded to separate the Neogene from the Quaternary at the Pliocene/Pleistocene boundary thus adding to the proliferation of misconceptions about the denotation of the Neogene period/system.

NOMENCLATURAL REFORM

The discovery of radioactivity by Becquerel in 1896 provided one of the great ironies in history. It squashed once and for all the intellectual conservatism and arrogance of the physicist William Thomson (Lord Kelvin) (Emiliani 1982) who had denied Charles Darwin, the 'deep time' he required to explain his observations on evolution as reflected in the geological record. Kelvin gave the geologists up to 100 Ma but more likely 20 Ma based on his estimates of cooling rates in the Earth's interior. Darwin died in 1882, believing there had been inadequate time for evolution to have occurred as he believed via natural selection. At the same time the discovery vindicated the 'deep time' expounded by James Hutton a century earlier based only on his interpretation of the relatively long time necessary to account for the tectonic upheavals observed in the form of major Palaeozoic unconformities in Scotland.

In the intervening century, geologists had no means of independently calibrating to a standard scale the geological events that they - 'uniformitarians' and 'catastrophists' alike - gradually came to realize were spread out over a considerably longer interval of time than that represented in the 'orthodox' Mosaic chronology of six millennia allotted the Earth by Bishop Ussher. Lyell wrestled with these problems in the course of a long and productive career that spanned about 40 years. He developed an essentially steady-state, non-directional view of history in building upon Hutton's theory of recurring geological cycles. But in contrast to his intellectual mentor, Lyell championed the idea that a long period of time was required to record the Earth's history as manifested in the stratigraphic record, and thus effected a major breakthrough, allowing his contemporaries to come to grip with the concept of 'deep time'. The passage

of time as recorded in the rocks was placed in a conceptual framework by Lyell; this remains one of his major legacies to modern stratigraphy. His stratigraphic terms were subsequently placed in a more rigorously based hierarchical system over the century following his death. We can do no greater honour to Lyell on this bicentenary of his birth than to place his now standard subdivisions of the Cenozoic erathem into a modern chronostratigraphic framework and to eliminate the last vestiges of antiquated stratigraphic nomenclature.

Modern concepts and principles of stratigraphic classification and procedure were formulated by the International Subcommission on Stratigraphic Classification (Hedberg 1976) of the International Geological Union of Geological Sciences (IUGS) International Commission on Stratigraphy (ICS), and recently updated by Salvador (1994). A corollary of this work has been the delineation of guidelines for establishing boundary stratotypes between the stage, series and systems of the Cenozoic erathem (Cowie 1986, recently updated in Remane et al. 1996). Working groups have been established under the aegis of the Palaeogene and Neogene Subcommissions of the ICS and several boundary stratotypes have now been submitted to, and ratified by, the ICS; for example, Cretaceous/Paleogene (= Danian/Maestrichtian); Eocene/Oligocene (= Priabonian/Rupelian); Palaeogene/Neogene (= Oligocene/Miocene = Chattian/Rupelian); Pliocene/Pleistocene (= Gelasian/Calabrian). Working groups are currently involved in studies on boundary stratotypes for the Palaeocene/Eocene and Miocene/Pliocene boundaries, as well as the intra-series stage boundaries with a view to completing most of this work by the next International Geological Congress at the turn of the century.

The proper stratigraphic procedure for defining upper Cenozoic GSSPs was debated at length during the late 1960s, the 1970s and early 1980s at numerous international conferences of the International Geological Correlation Program (IGCP) 41 (Pliocene/Pleistocene Boundary), the Neogene Subcommission and the INQUA Subcommission on the N/Q Boundary (particularly in the former Soviet Union). At these meetings most Soviet and other geologists specializing in Quaternary studies were finally convinced that chronostratigraphic boundaries are typified in marine stratigraphic sections and that the definitions are lithostratigraphic (GSSP), whereas the means of correlation were/are heterogeneous (biostratigraphic, paleomagnetic, radioisotopic, stable isotopic, etc.). More recently, astronomical periodicity in the stratigraphic record has played a major role in chronostratigraphy. INQUA geologists have often resorted to special pleading for definition of boundaries in the Quaternary (Hays and Berggren 1971) in terms of vague and unscientific criteria (such as climatic changes, evidence of glaciation, hominid evolution, mammalian evolutionary or immigration events). [...]

The basic principles of stratigraphy and a terminological hierarchy to accommodate the primary subdivisions of the geological record were established only after Lyell's death, so that to speak of a Lyellian 'chronostratigraphy' is, strictly speaking, incorrect. Nevertheless, in order to recognize the fact that Lyell's fourfold subdivision (into epochs/series, in modern parlance) of the Cenozoic era has withstood the test of time and subsequently been given a chronostratigraphic connotation, I have chosen to place the 'chrono-' component of 'chronostratigraphy' in the title of this paper in parenthesis.

Lyell died in 1875, the same year as his longtime collaborator Paul Gerard Dehayes, his-long time colleague (and antagonist) Adam Sedgwick and the Belgian palaeontologist Jean Baptiste Julien d'Omalius d'Halloy, a year after (1874) Léonce Élie de Beaumont (his French antagonist, with whom he retained cordial relations throughout his life) and a year before (1876) his long-time friend George Pouillet Scrope. It was a 'rapid turnover'.

CONCLUSIONS

[...] This study has shown that:

(1)The Neogene period/system includes - on first principles harking back to Hörnes' (1853) definition based partially on Bronn's (1838) subdivision of the *Molasse Bildungen* of the Vienna Basin, plus his own reference to the younger (i. e. Pleistocene or Newer Pliocene) outcrops of Malta, Sicily and the Italian coast - the time and corresponding rocks from the revised, post-Lyellian base of the Miocene up to and including the Pleistocene and Holocene.

(2)The term 'Tertiary' should be suppressed (as it was most judiciously by Cowie and Bassett (1989) in their IUGS Time Scale) along with the 'Quaternary' as remnants of a now outmoded and inappropriate terminology, as suggested by Flint half a century ago (1947) and reiterated a quarter of a century later (Flint 1971; see also Berggren et al. 1995). [...]

(3)The Palaeogene (Palaeocene, Eocene and Oligocene, together with the Neogene (Miocene, Pliocene, Pleistocene and (reluctantly) Holocene) represent appropriate period/system subdivisions of the Cenozoic era/erathem.

Adoption of the procedures recommended here will finally rid Cenozoic stratigraphy of the last vestiges of terminological conservatism, and diminish, if not eventually eliminate, unnecessary and unscientific rancorous debate and allow our science to flourish with renewed vigor at the turn of the millennium. This will serve as a fitting tribute to Sir Charles Lyell, whose pioneering studies in (bio)stratigraphy established the standard epoch/series units of the modern Cenozoic era/erathem, and whose eclectic approach led to the first great synthesis of geology, which established historical geology as the fundamental basis for a modern natural philosophy of life.

[...]

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