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Hierarchical subdivision of the Cenozoic Era: A venerable solution, and a critique of current proposals

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Abstract

If Tertiary and Quaternary are to be formally defined and ranked, then only one topology and two ranking options for the major subdivisions of the Cenozoic Era are consistent with the principles of hierarchical classification. These are: 1) for the Tertiary and Quaternary to be ranked as Suberas (with the Paleogene and Neogene ranked as Periods of the Tertiary), or 2) for the Tertiary and Quaternary to be ranked as Periods (with the Paleogene and Neogene ranked as Subperiods of the Tertiary). The first option would leave the Period rank empty for Quaternary time, however, so the second option is preferred here. In neither case is an extension of the Neogene to the present permitted. If desired, however, "Early Cenozoic" and "Late Cenozoic" could be defined as formal unranked chrons, with the latter term providing an unambiguous expression for the same concept as the extended Neogene.

Attempts to justify an extended Neogene by reference to a statement arising from the 1948 International Geological Congress fail because they are based on a misinterpretation of that statement. Likewise, an appeal to the alleged original meaning of the Neogene fails because it is factually superficial and would also have unacceptable consequences if applied as a general principle to the rest of the time scale.

Four arguments against a ranked Tertiary and/or Quaternary involve the status of these names as parts of an obsolete classification; the disparity in their durations; an analogy between them and the unranked Precambrian; and their supposed ambiguity. These arguments are readily refuted. Arguments in favor of a ranked Tertiary and Quaternary include the continuing widespread use of these names, their practical relevance for geologic maps, and their role in honoring the pioneers of stratigraphy.

A recent recommendation by the International Commission on Stratigraphy (ICS) would decouple the beginning of the Quaternary from the beginning of the Pleistocene, have the Neogene and Pliocene overlap the Tertiary/Quaternary boundary, and have the Gelasian Age belong to both the Pliocene and the Quaternary. These results violate the existing Guidelines of the ICS. This same proposal would also regard the Quaternary as a Subera within the Neogene Period (the latter being extended to the present). However, this arrangement violates the most fundamental rule of hierarchical classification in that a unit of superior rank would be included entirely within a unit of inferior rank. Given these problems, the International Union of Geological Sciences (IUGS) must reject the ICS recommendation.

An improved version of the ICS proposal (with the Quaternary ranked as a Period and the Paleogene and extended Neogene ranked as Suberas) would still prohibit the Tertiary from being ranked and would either violate "Simpson's rule" or else require a new name for the traditional concept of the Neogene. Because the classification of the Cenozoic advocated here is strictly hierarchical, violates none of the existing Guidelines of the ICS, obeys Simpson's rule, requires no new names, allows the Tertiary, Quaternary, Paleogene, and Neogene to be formally ranked, and has been in general use for more than a century, it is to be preferred.

Only two current options for defining the Quaternary and Pleistocene are valid, namely, to leave the beginnings of these units where they are now (Vrica GSSP at 1.8 Ma), or to move both to the Piacenzian/Gelasian boundary (Monte San Nicola GSSP at

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2.6 Ma). The latter option is not prohibited by Lyell's "types" of the Older Pliocene nor (after 2008) by the existing Guidelines of the ICS, but if enacted could jeopardize the stability of the rest of the standard global time scale.

Keywords: standard global chronostratigraphic hierarchy; Cenozoic; Tertiary; Quaternary; Paleogene; Neogene; Pleistocene

1. Introduction

Following the controversial omission of the Quaternary from the time scales of Gradstein et al. (2004a,b), three significant proposals have been made for the purpose of formalizing the nomenclature of the Cenozoic Era; those of Pillans and Naish (2004), Gibbard et al. (2005), and Aubry et al. (2005). A fourth proposal (Suguio et al., 2005) does not require detailed examination in my view because it is discredited by information presented in Pillans and Naish (2004) and Gibbard et al. (2005).

Contemporaneous with these publications, and as a result of protests from Quaternary scientists about the elimination of their term, a nine-member "Quaternary Task Group" (Gehling et al., 2005) was formed by the International Commission on Stratigraphy (ICS) and the International Union for Quaternary Research (INQUA) for the purpose of recommending a formal definition and rank for the Quaternary (Gradstein and Clague, 2005). Gehling et al. (2005) considered the proposals of Pillans and Naish (2004), Gibbard et al. (2005), and Aubry et al. (2005) and communicated the following recommendations to the ICS (Gibbard, 2006):

1. That the Quaternary is to be recognized as a formal chronostratigraphic/geochronological unit.
2. That the lower boundary of the Quaternary will coincide with the base of the Gelasian Stage and thus be defined by the Gelasian GSSP.
3. That the Quaternary will have the rank of either:
   a. System/Period and will be at the top of the Neogene System/Period, with its lower boundary marking the top of a shortened Neogene [the Gibbard et al., 2005 proposal, in part], or,
   b. Sub-erathem/Sub-era and will be correlative with the upper part of the Neogene System/Period [the Aubry et al., 2005 proposal].

At a meeting of the ICS voting membership in Leuven, Belgium on September 1–5, 2005, Recommendations 1 and 2 were approved unanimously, and Recommendation 3b was approved by 12 "Yes" votes to 5 "No" votes, with one abstention (Gradstein, 2005; Gibbard, 2006). The ICS Recommendation has since been forwarded to the International Union of Geological Sciences (IUGS) for approval (Clague, 2005, 2006a,b).

The purpose of this paper is to show that the proposals of Pillans and Naish (2004), Aubry et al. (2005), and Gradstein (2005) are fundamentally flawed. Given standard principles of hierarchical classification, the Guidelines of the ICS (Remane et al., 1996), and the proven utility of the terms "Tertiary" and "Quaternary" (Salvador, 2006), the only tenable classification of the Cenozoic Era is one in which the Paleogene and Neogene are subdivisions of the Tertiary, the Quaternary is not included in the Neogene, and the beginnings of the Quaternary and Pleistocene are conterminous.

2. Origin of the present controversy

Disagreements about the definition of the Quaternary and Pleistocene have had a long history (e.g., Powell, 1890; Woodward, 1891), but the immediate origin of the present controversy can be traced to two sources. The first of these involves the proposal by several Quaternary workers to have the official Pliocene/Pleistocene boundary moved from the existing GSSP (Global Stratotype Section and Point) at Vrica, Italy (currently dated at about 1.8 Ma; see Aguirre and Pasini, 1985; Pasini and Colalongo, 1997) to a level corresponding to the Gauss/Matuyama polarity–chronologic boundary at about 2.6 Ma (Suc et al., 1997; Morrison and Kukla, 1998; Mauz, 1998). This proposal was defeated by a vote of the Neogene and Quaternary subcommissions of the ICS in December 1998 (Remane and Michelson, 1998), but the desire to lower the Pliocene/Pleistocene boundary persists among many Quaternary workers.

The second source of the controversy has been the continued advocacy by W.A. Berggren and his colleagues of the elimination of the names "Tertiary" and "Quaternary" from the standard global time scale, and for the extension of the Neogene (traditionally considered as "Miocene + Pliocene") to the present (Berggren and Van Couvering, 1974; Berggren et al., 1985, 1995a,b). This advocacy culminated in the influential but incomplete historical analysis of Berggren (1998).

Prior to the events outlined above (with the notable exception of Haug, 1911), the decoupling of the beginning of the Quaternary from the beginning of the

Pleistocene had not been seriously considered for more than a century (e.g, Woodward, 1891; Williams, 1895; Zittel, 1895). Indeed, in a time scale published only two years before Berggren (1998), Gradstein and Ogg (1996) had shown the Neogene and Quaternary to be distinct periods, with the beginnings of the Quaternary and Pleistocene coincident, both being defined by the GSSP at Vrica, Italy (Aguirre and Pasini, 1985). These relationships were retained in several later versions of the ICS time scale (Remane, 2000a; Gradstein, 2000; Remane, 2003). In the latest version of the ICS time scale, however, Gradstein et al. (2004a,b) followed Berggren's (1998) recommendations without significant discussion, apparently accepting his argument that the result would be a more modern classification of the Cenozoic Era (Gradstein et al., 2004c, p. 45).

Clearly, however, the proposed elimination of "Tertiary" and "Quaternary" will not succeed. The terms are far too useful to be abandoned, and their attempted prohibition would be ignored anyway (Pillans and Naish, 2004; Gibbard et al., 2005; Salvador, 2004, 2006). Indeed, the elimination of their term by Gradstein et al. (2004a,b) so upset the Quaternary community (Giles, 2005) that in an equally unwise overreaction, Brad Pillans (Chair of the INQUA Stratigraphy and Geochronology Commission) seized upon this "opportunity" to propose that the beginning of the Quaternary be decoupled from the beginning of the Pleistocene and extended into the late Pliocene, i.e., to the beginning of the Gelasian Standard Global Age (of Rio et al., 1998). Pillans (2004a: 28–29) stated:

> One of the proposed revisions of the GTS is to extend the Neogene System (Period) up to the present, thereby subsuming what is currently the Quaternary System (Period). While some may see this as a threat to the Quaternary, I see it as a wonderful opportunity to redefine the Quaternary in the way that we have wanted for some time, namely to extend the base downwards from 1.81 Ma (Plio/Pleistocene boundary) to 2.6 Ma (base of Pliocene Gelasian Stage). Let me speak plainly when I say that we (INQUA) have little hope of retaining the Quaternary System, above the Neogene System, as it is at present. The weight of support is too great, from within ICS, for extending the Neogene up to the present. Furthermore we have no hope of changing the Plio/Pleistocene boundary; we tried that in 1997–98, resulting in a most acrimonious debate between INQUA and ICS. I believe that our best, and only reasonable course of action, is to grasp the opportunity presented to us, and redefine the Quaternary as a Subsytem within the extended Neogene System, with base at 2.6 Ma….The views expressed are my own, but I sense that they will be widely supported by Quaternary scientists. After all, this is a chance to extend our time domain by 800,000 years! To reiterate, this is a once-in-a-lifetime opportunity — we are unlikely to get another opportunity to define the Quaternary the way we want it.

Pillans is candid in his motivations, and indicates that only the apparently inevitable extension of the Neogene to the present (together with the apparently unmovable Pliocene/Pleistocene boundary GSSP at Vrica) inspired his proposal to detach the beginning of the Quaternary from the beginning of the Pleistocene. This part of Pillans' proposal was subsequently ratified by the ICS (Gradstein, 2005). However, Berggren's (1998) historical claims regarding the extension of the Neogene are refuted by Walsh and Salvador (ms.), and a name-typological obstacle to the possible revision of the Pliocene/Pleistocene boundary will be removed later in this paper (Section 9.2). As such, the two major motivations for decoupling the beginning of the Quaternary from the beginning of the Pleistocene will soon disappear. Accordingly, this paper will demonstrate that recent proposals for the redefinition and/or re-ranking of the Tertiary, Quaternary, Paleogene, and Neogene are unnecessary.

3. Aspects of hierarchical classification relevant to geology

Salvador (2004, 2006) demonstrated that the Tertiary and Quaternary are still widely used in geological work of various kinds, and are definitely "here to stay." As such, it is desirable that the Tertiary and Quaternary be provided with formal ranks and definitions, a view now also shared by Aubry et al. (2005), as well as numerous national stratigraphic commissions and geological surveys (see comments compiled by Clague, 2006c). Given these worthy goals, do the principles of hierarchical normative classification constrain our options for ranking the major subdivisions of the Cenozoic time scale? They do, but in order to explain why this is so it will first be necessary to discuss some general aspects of hierarchical classification that are relevant to geology.

3.1. The purpose of ranked hierarchies

The main purpose of having a hierarchical classification with several ranks is to indicate *relative inclusiveness* of the various named subdivisions (Valentine and May, 1996). For example, if we know that the Hominidae is a subdivision of the Primates (and therefore contains fewer "things" or has less "extension" than the Primates), then the Hominidae must have a rank inferior to that of the Primates. This also works in reverse, of course, and that is where ranks are especially useful. When confronted with two unfamiliar names (for example, "La Jolla" and "Scripps"), one of which is a subdivision of the other, the rank terms attached to the names (La Jolla Group; Scripps Formation) tell us which named unit is the subdivision and which named unit is being divided. These rank terms therefore help us to learn the structure of a given hierarchy much faster than would be possible without them.

Although various terminologies for different kinds of biological hierarchies exist (Valentine and May, 1996, and references therein), in geology it seems necessary only to recognize the two major kinds of hierarchies discussed by Ghiselin (1997, pp. 82; 304); namely, *inclusive* hierarchies, in which classes are included in classes; and *incorporative* or *whole-part* hierarchies, in which an individual at a given level is a part, or component, incorporated in an individual at a higher level.

An example of an inclusive (classes within classes) hierarchy in geology is the unranked classification of igneous rocks of Le Maitre (1989), which consists of a series of subordinated classes (for example: "rock," "igneous rock," "plutonic rock," "granodiorite"). These terms designate universal classes in that any rock formed anywhere in the universe at any time that falls under the definition of any one of these terms is automatically a member of that class. Thus we should not be surprised to find granodiorites on other planets. A similar inclusive hierarchy is provided by the grain-size classification of clastic sediments (Folk, 1974, p. 23).

In contrast, the standard global geological time scale is an example of a whole-part hierarchy, and Ghiselin (1997) used the time scale of Harland et al. (1990) to illustrate this concept.[1] The important point made by Ghiselin (1997, p. 266) is that the geologic time scale "is a straightforward hierarchical classification system, *with smaller taxa falling under larger ones*, and each taxon having a definite categorical rank [italics mine]."

3.2. Semi-hierarchical vs. strict hierarchical classifications

A distinction between two types of whole-part hierarchical classifications must be made for our purposes: 1) **semi**-hierarchical classifications (those in which parts of a unit of a given rank **can** be assigned to two or more units of superior, identical rank) and **strict** hierarchical classifications (those in which parts of a unit of a given rank **cannot** be assigned to two or more units of superior, identical rank).

Examples of semi-hierarchical classification in geology are provided by the application of the ranks of "group," "formation," "member," and "bed" to actual lithostratigraphic units. It is quite possible, for example, that the True Blue Bentonite Bed will occur in more than one formation, such as the Slimy Shale in one area, the Brick Red Sandstone in another, and the Lilac Limestone in yet another. The Lilac Limestone may in turn be assigned to the Purple Haze Group in one area, and considered to be part of the Green Tambourine Group in another. In other words, it is clear that some lithostratigraphic units can be assigned to two or more units of superior, identical rank. Such arrangements are only semi-hierarchical; they are not strictly hierarchical because at least somewhere in the classification there is not a unique subordination of units within units.

The most familiar example of a strict hierarchical classification is that of biological taxonomy, where, for example, it is impermissible for some of the genera assigned to the Family Hominidae to be included in the Order Primates while the remaining genera in the Family Hominidae are assigned to the Order Rodentia. Similarly, in the strict hierarchical subdivision of human history into millenia, centuries, decades, and years, it would be absurd for some of the years of the 1990s to be included in the 20th Century while other years of the 1990s are included in the 21st Century.

Likewise, in order to maximize the stability and heuristic value of our standard global geochronologic units[2], we can and do demand that, for example, the Tithonian Standard Global Age cannot partly belong to both the Jurassic Period and the Cretaceous Period at the same time, the Permian Period cannot partly belong to both the Paleozoic Era and Mesozoic Era at the same time, and the Pliocene Epoch cannot partly belong to both the Tertiary Subera and Quaternary Subera at the same time (contra Aubry et al., 2005; Gradstein, 2005; see also Gibbard, 2004). This prohibition against the

[1] I agree with Ghiselin (1997, p. 266) that, for example, the Permian Period can be treated as an individual, but continue to maintain that the Permian *System* is a spatiotemporally-restricted class (Walsh, 2001). The distinction does not affect the conclusions reached in this paper.

[2] I generally use geochronologic terms (for example, period) rather than chronostratigraphic terms (for example, system) in this paper, because the former necessarily define the content of the latter (Walsh, 2001, 2003). In doing so, however, I do not mean to imply that chronostratigraphic terms are unnecessary, a view that was mistakenly attributed to me by my valued colleagues Gradstein et al. (2004c, p. 21). See Walsh, (2001, p. 712; 2004b).

overlap of our standard global geochronologic units is expressed in the current ICS Guidelines of Remane et al. (1996, p. 78):

> The Global Chronostratigraphic Scale **must**, however, comprise **strictly contiguous units**, **without overlaps** and with no gaps between them [emphasis mine].

This statement of Remane et al. (1996, p. 78) was admittedly made in the context of a discussion of boundary stratotypes vs. unit stratotypes. As such, it may have been intended to mean only that two standard global geochronologic units of the *same* rank must not overlap (for example, the Jurassic Period must not overlap the Cretaceous Period). Nevertheless, the kind of semi-hierarchical classification advocated by Aubry et al. (2005) and Gradstein (2005) would result in situations topologically similar to those which Remane et al. (1996) were trying to avoid (in this case, the fact that the Gelasian Age would belong to both the Quaternary Subera and the Pliocene Epoch). The most reasonable interpretation of Remane et al. (1996) would seem to be that if such overlapping time units are used in the standard global time scale, they cannot be *ranked*, and must instead be regarded as unranked chrons (Salvador, 1994, p. 83).

3.3. Simpson's rule

Another important aspect of many ranked hierarchical classifications is that if an entity is divided, it is generally best that it be *completely* divided, and each of these subdivisions should then be given the same rank. As stated by Simpson (1961, p. 18) in the context of biological taxonomy:

> There is, however, one restriction on freedom of action in this respect: if a subsidiary level is used within any one group it should, as far as possible, be used for all the organisms in that group. For example, if a subfamily is used within a family, then the whole family should be divided into subfamilies…

In our context, "Simpson's rule" is equivalent to the stipulation of Remane et al. (1996, p. 78) that there must be "no gaps" between adjacent standard global geochronologic units, if that statement is interpreted to mean that there will be no *unnamed subdivisions* of any given unit in the time scale at any given rank in the hierarchy (at least down to the level of age/stage in the Phanerozoic; the application of Simpson's rule may become problematical if standard global substages and chronozones are eventually defined). As such, Simpson's rule in this context is simply a practical device to insure clear communication. Suppose, for example, that in the Eocene classification of Luterbacher et al. (2004, pp. 399–400) we were to recognize the Ypresian, Lutetian, and Priabonian Ages, but were to leave a gap between the Lutetian and the Priabonian. We would have to awkwardly refer to this span of time as "the unnamed interval between the Lutetian and the Priabonian." It is much simpler to give this span of time a name (Bartonian) and a rank identical to that of the Lutetian and Priabonian (Age) so that we can refer to it more easily.

As discussed below, the uniform application of Simpson's rule will sometimes lead to redundant ranks (Buck and Hull, 1966). This convention has therefore been questioned for those highly flexible classifications intended to reflect our evolving understanding of natural phenomena, where our knowledge may be very incomplete. For example, Simpson's rule is incompatible with the cladistic classification of organisms, as it would require the recognition of paraphyletic taxa (Wiley, 1981). For similar reasons, in the context of lithostratigraphy, Simpson's rule is not mandated by the North American Commission on Stratigraphic Nomenclature (1983) nor by the International Stratigraphic Guide. Thus, Salvador (1994, p. 34) stated:

> Some formations may be completely divided into members; others may have only certain parts designated as members; still others may have no members. A member may extend from one formation to another.

Simpson's rule cannot be enforced in lithostratigraphy for two reasons. First, our goal in this field is to find a natural classification consistent with the lithological distinctiveness and mappability of our units. It is quite possible, for example, that the Obtuse Conglomerate will be best regarded as a prominent member of the Isosceles Formation in one area, as a thin tongue of the otherwise undivided Equilateral Sandstone elsewhere, and be ranked as its own very thick formation in yet another area. In other words, the complex three-dimensional relationships of lithostratigraphy do not always lend themselves to a complete subdivision and strict hierarchy of units, where each named unit in the classification has a definite sub- or super-ordinated relationship to the other named units. Second, the lithostratigraphic classification of a given area may change with additional information, and the ranks and scopes of the units will often have to be adjusted accordingly.

In the context of the geologic time scale, however, we are in fact defining a strict hierarchy of contiguous time units. As such, the above situations that are common in lithostratigraphy are exactly what *cannot* happen in standard global chronostratigraphy. It would be absurd, for example, to suggest that in some places the Tithonian Standard Global Stage could cross the Jurassic/Cretaceous boundary and then pinch out within the Berriasian Standard Global Stage, or that the Silurian could be ranked as a Period in Europe, as a Subera in Asia, and as an Epoch in North America.

In view of the above, for *normative* classifications, where *stability of the structure* is paramount, the heuristic benefits of Simpson's rule outweigh the occasional existence of redundant ranks. That is, when dealing with a mass of unfamiliar names (for example, from my perspective, the classification of the Permian Period depicted in Wardlaw et al., 2004), the use of Simpson's rule insures a predictable symmetry in our classification that helps us to understand where we are located in the hierarchy. Indeed, Simpson's rule is evident in every major Phanerozoic subdivision of the geologic time scale of Gradstein et al. (2004b) with the exception of parts of the Ordovician and Cambrian, where several standard global ages are not yet recognized (although it is understood that they eventually will be; Cooper and Sadler, 2004; Shergold and Cooper, 2004). To my knowledge, Simpson's rule has been deliberately violated only in the proposal of Pillans and Naish (2004).

3.4. Rules of hierarchical classification minimize instability caused by the whims of respected authorities

Another benefit of having recognized rules of hierarchical classification is that they impose limits on the degree to which the scope and ranks of the units in such a classification can be altered by the personal preferences of influential persons. As stated by Valentine and May (1996, p. 23):

> The heuristic side is most apparent when one is attempting to describe a hierarchy and to specify its ranks. The logic of the hierarchical architecture imposes a rigor on the specifications that often clarifies the interrelation of entities and of their functions.

For example, if there are objective rules requiring that the Grimygulchian be ranked as a Period (given other assumptions), then such rules prevent Professor Grimes (the world's leading authority on the Grimygulchian) from using his influence to argue that "the Grimygulchian really ought to be a Subera, and furthermore, the Grimygulchian really ought to be expanded so as to include the Cruddycreekian." Such changes would potentially cause havoc with the rank and scope of other units of the time scale that were previously inferior and superior in rank and/or that preceded and succeeded the Grimygulchian. By minimizing such moves, hierarchical principles lend stability to these classifications by insulating them from authoritarian influences, as far as that is possible.

4. Hierarchical subdivision of the Cenozoic Era

4.1. Only one basic topology for the subdivision of the Cenozoic is valid

Given the above general considerations, the premise that the Tertiary, Quaternary, Paleogene, and Neogene should be formally ranked (Aubry et al., 2005; Salvador, 2006), and the fact that the extension or non-extension of the Neogene to the present is the main point at issue, is there nevertheless an objective common ground from which all of us can start in our search for a hierarchical subdivision of the Cenozoic? There is, and it consists of the fact that because the Tertiary is of longer duration than the Paleogene, and the latter is included entirely within the former, the Tertiary must have a higher rank than the Paleogene (the fundamental principle of hierarchical classification; Section 3.1).

Now, suppose we wish to rank the Paleogene and Neogene as Periods (Fig. 1A). That would dictate the superior rank of Subera for the Tertiary. Next, because the Tertiary and Quaternary exhaustively subdivide the Cenozoic, they must be given the same rank (Simpson's rule). Therefore, if the Paleogene and Neogene are ranked as Periods, then the Quaternary, like the Tertiary, must have the rank of Subera. But this fact in turn prohibits the extension of the Neogene Period to the present, because the Quaternary *Subera* (of superior rank) would then be contained *entirely within* the much longer Neogene *Period* (of inferior rank), which violates the most fundamental principle of hierarchical classification (Section 3.1).

Because the scheme of Aubry et al. (2005) and the ICS (Gradstein, 2005) violates this principle, it is appropriate to illustrate the nature of the violation by means of familiar analogies. The Quaternary *Subera* (of superior rank) cannot be contained *entirely within* the much longer Neogene *Period* (of inferior rank) for the same reason that the *Order* Primates cannot be contained entirely within the *Family* Hominidae, the Second *Millenium* A.D. cannot be contained entirely within the 19th *Century*, and the La Jolla *Group* cannot be contained entirely within the Scripps *Formation*.

Now, suppose we wish to rank the Quaternary as a Period (Fig. 1B). That would in turn require the Tertiary to be ranked as a Period, and would in turn require the

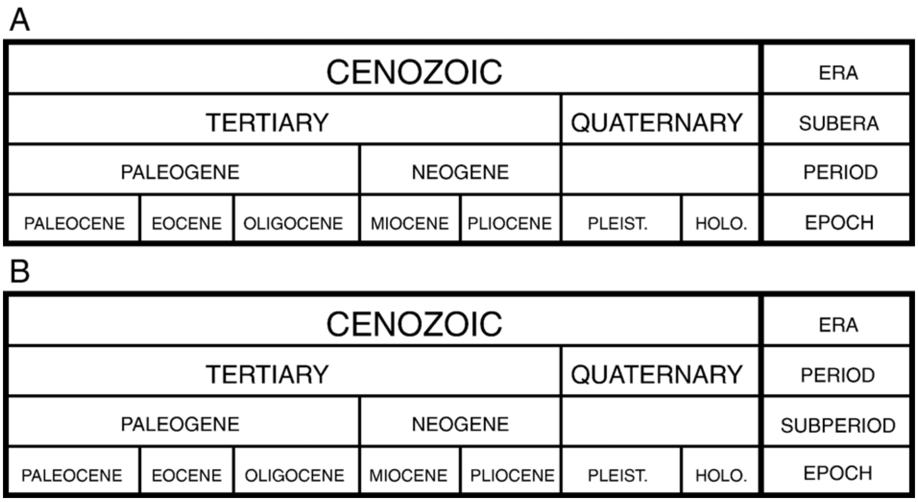

Fig. 1. Mandatory topology of the major subdivisions of the Cenozoic Era given formal ranking of Tertiary and Quaternary and standard principles of hierarchical classification. A. Option with Tertiary and Quaternary ranked as Suberas, and Paleogene and Neogene ranked as Periods of the Tertiary. B. Preferred option with Tertiary and Quaternary ranked as Periods, and Paleogene and Neogene ranked as Subperiods of the Tertiary. Depicted relative durations of the units are not to scale.

Paleogene, and thus the Neogene, to be ranked as Subperiods of the Tertiary. As before, the Neogene could not be extended to the present, because the Quaternary Period (of superior rank) would then be contained entirely within the Neogene Subperiod (of inferior rank), which would again violate the most fundamental principle of ranked hierarchical classification.

4.2. Choosing the best ranking scheme

As a result of the above, if we wish to assign formal ranks to the Tertiary, Quaternary, Paleogene, and Neogene, then only one basic topology of the hierarchical classification of the Cenozoic Era is possible, although we do have the choice of two ranking schemes. In Fig. 1A, the Tertiary and Quaternary are regarded as Suberas, and the Paleogene and Neogene are regarded as Periods of the Tertiary (e.g., Curry et al., 1978, p. 2; Harland et al., 1990, p. 68). Unfortunately, this arrangement initially results in a “ranking gap” between the Quaternary Subera and the Pleistocene and Holocene Epochs (that is, the Period rank is unfilled). However, the Period is essentially a mandatory rank of the standard global time scale, and its absence here would constitute the only such omission for the post-Archean (Gradstein et al., 2004b). Perhaps the “Anthropogene” or “Pleistogene” Period could be added here as a redundant placeholder (Harland et al., 1990, p. 68), but those solutions seem unnecessary.

My preferred arrangement is shown in Fig. 1B, wherein the Tertiary and Quaternary are regarded as Periods, and the Paleogene and Neogene are regarded as Subperiods of the Tertiary. This option would at first glance allow for the formalization of the Early Cenozoic and Late Cenozoic as Suberas, but that would not be possible because the Early Cenozoic Subera would have a higher rank than the Tertiary Period and yet would be contained entirely within the latter. Nevertheless, the more or less unambiguous expression “Late Cenozoic” is widely used for the time interval that W.A. Berggren and his followers have recently called “Neogene,” and might well be formalized. This could be achieved by defining the Early Cenozoic and Late Cenozoic as unranked chrons (Salvador, 1994, p. 83), with the boundary between them equivalent to the Oligocene/Miocene (=Paleogene/Neogene) boundary. The Early Cenozoic would then become isochronous with the Paleogene, but many workers on crystalline rocks and structural geology tend to favor the former expression, so both terms are still useful. The traditional classification depicted in Fig. 1B was widespread both before and after the publication of W.A. Berggren’s paper in 1998 (Salvador, 1985; Cooper et al., 1990; Harland et al., 1990, p. 12; Hansen, 1991; Salvador, 1994; Boggs, 1995; Levin, 1996; Palmer and Geissman, 1999; Boggs, 2001; Levin, 2003).

5. Possible objections

Objections to the above conclusions in Section 4.1 regarding the only permissible hierarchical structure for the major subdivisions of the Cenozoic Era can be raised by attacking the premises assumed in the argument. In particular, if extension of the Neogene to the present is given overriding importance, then the Tertiary must be excluded from the standard global time scale as a ranked unit. This is so because if the Quaternary is included in the Neogene, the Quaternary must have a lower rank than the Neogene, and therefore the *Tertiary* must have a lower rank than the Neogene, and yet the Tertiary *cannot* have a lower rank than the Neogene because the Tertiary *must* have a higher rank than the Paleogene (Section 4.1). Assuming a ranked Paleogene and Neogene, this conflict could only be resolved by eliminating either the Tertiary or the Quaternary as ranked units, and INQUA has already indicated what the outcome of such a contest would be (Clague, 2004). Therefore, two arguments that supposedly require the extension of the Neogene to the present will be addressed here.

5.1. The statement of King and Oakley (1949)

In order to support the extension of the Neogene to the present, several workers have referred to a statement originating from the deliberations of a temporary commission of the 18th International Geologic Congress, appointed to advise on the definition of the Pliocene–Pleistocene boundary. King and Oakley (1949, p. 186) stated:

> The Commission considers that it is necessary to select a type-area where the Pliocene–Pleistocene (Tertiary–Quaternary) boundary can be drawn in accordance with stratigraphic principles... The Commission notes that, according to evidence given, this usage would place the boundary at the horizon of the first indications of climate deterioration **in** the Italian Neogene succession [emphasis added].

Lourens et al. (2004, p. 412), placing great emphasis on the word "in" in the last sentence of this passage, have interpreted it to mean that: "In other words, the Tertiary–Quaternary boundary should fall somewhere within the, apparently at that time, already generally accepted Neogene Period" (see also Hilgen, 2005). Ogg and Van Couvering (2005, p. 12) expressed a similar view:

> The Neogene was never defined as equivalent to Miocene and Pliocene, and its status as a system extending to the present (e.g., implied extent of 'Italian Neogene' in the 1948 resolution) is unchallenged.

However, the interpretations of Lourens et al. (2004), Ogg and Van Couvering (2005), and Hilgen (2005) are unjustified. The statement of King and Oakley (1949) is more reasonably interpreted to mean simply that *somewhere* within the various successions that numerous recent authors had included in the Neogene as of 1949, the Pliocene/Pleistocene boundary would be defined. This interpretation is sound because in none of the 30 papers and abstracts included in Oakley (1950) is there a statement or proposal that the Neogene either is or should be extended to the present. On the contrary, Halicka and Halicki (1950) and Desio (1950) clearly used "Neogene" in the sense of "late Tertiary" (that is, pre-Quaternary), and Russell (1950) explicitly defined the Neogene as "Miocene + Pliocene." It goes without saying that Gignoux (1950, 1955), perhaps the most influential expert on late Cenozoic Mediterranean stratigraphy at the time, used "Neogene" in the sense of "Miocene + Pliocene" (Berggren, 1998, p. 122).

Among British geologists whose work King and Oakley must have been familiar with, Davies (1934, p. 58) had defined the Neogene as "Miocene + Pliocene" in his influential book *Tertiary Faunas*. Zeuner (1945, p. 257) also used the term "Neogene" in the context of a pre-Pleistocene span of time. Likewise, Cooke (1948, p. 42) referred to Haug's (1911) definition of the Neogene/Quaternary boundary and obviously accepted the existence of that boundary.

As far as I can determine, neither W.B.R. King nor K.P. Oakley used the term "Neogene" extensively 1950 (see bibliography of King in Shotton, 1963, and the numerous publications of Oakley cited in Oakley, 1980). In his most detailed discussion of the time scale (Oakley and Muir-Wood, 1949; pp. 57, 62–63; 1959, pp. 57; 62–63; 1967, pp. 58; 63–65), Oakley divided the Cenozoic Era into Tertiary and Quaternary, regarded the Tertiary/Quaternary boundary as equivalent to the Pliocene/Pleistocene boundary, and regarded the Quaternary as being composed of the Pleistocene and Holocene. Clearly, if Oakley had wished to extend the Neogene to the present, he had every opportunity to do so in seven editions of his book between 1949 and 1967. The fact that he did *not* do so suggests that we may confidently reject the premise.

Furthermore, Oakley and Baden-Powell (1963) served as "Recorders" for Volume 1, Part 3aXIII ("England, Wales and Scotland: Neogene and Pleistocene") of the Lexique Stratigraphique International. Although there was no discussion of the Neogene in this publication, it is reasonable to assume that Oakley and the rest of his contributors would have agreed with the definition implied by the title of the publication to which they were contributing: that the Neogene ended with the beginning of the Pleistocene.

In conclusion, the interpretations by Lourens et al. (2004), Ogg and Van Couvering (2005), and Hilgen

(2005) of the ambiguous statement of King and Oakley (1949) are refuted by the contextual evidence. In contrast, as noted by Pillans and Naish (2004, p. 2272), the equation of the Pliocene/Pleistocene boundary with the Tertiary–Quaternary boundary by King and Oakley (1949, p. 186) is entirely *un*ambiguous. That equation recognizes the Tertiary and Quaternary as formal units and therefore logically implies that no matter what rank those units are assigned, the Neogene cannot be extended to the present without violating the principles of hierarchical classification (Section 4.1).

5.2. Berggren's argument for priority of original meaning

Berggren (1998) claimed that Hörnes (1853) originally intended the Neogene to extend to the present, and that we must adhere to this (alleged) original definition today. Indeed, Berggren (1998, pp. 122; 126; 127) clearly implied that any definition of the Neogene in which this unit is *not* extended to the present is *incorrect*. This view was reiterated by Aubry et al. (2005, p. 118) and has played a major role in convincing other stratigraphers that the Quaternary must be included in the Neogene (Lourens et al., 2004; Pillans, 2004b; Ogg and Van Couvering, 2005).

Although Berggren's (1998) paper is of great value overall, Walsh and Salvador (ms.) refute its main historical claim by demonstrating that: 1) Moriz Hörnes' early use of the term "Neogene" was variable; 2) that the definition used by his colleagues was "Miocene + Pliocene, excluding the Diluvium[3] and Alluvium" (Cžjžek, 1854; Stur, 1855; Lipold, 1856; Zollikofer, 1859); 3) that the Austrian Geological Survey formalized the term in this same sense when it published the geologic map of the Austrian Empire (Haidinger, 1865, 1866; von Hauer, 1868, 1869, 1872); 4) that Moriz Hörnes himself implicitly accepted this definition (Hörnes, 1865); and 5) that as a result, the term "Neogene" was defined as "Miocene + Pliocene, excluding the Diluvium and Alluvium" for the rest of the 19th Century by numerous Austrian and German geologists such as Quenstedt (1867), Credner (1872), Zittel (1895), and Moriz Hörnes' own son, Rudolf Hoernes (1884; 1899). These facts refute the claims of Berggren (1998, p. 122) and Aubry et al. (2005, p. 118) that Gignoux (1913) was the "culprit" who adopted an "unjustified" definition of the Neogene. Subsequently, however, during the 20th Century, the end of the Neogene (= end of the Pliocene = end of the Tertiary) became progressively older as the beginnings of the Quaternary and Pleistocene became progressively older (Walsh and Salvador, ms.).

Despite the above, let us assume the truth of Berggren's (1998) historical claim about the original meaning of the Neogene for the sake of illustration. Next, we must note that Berggren (1998) and Aubry et al. (2005) have given us only the conclusion of their argument; namely, that if it is to be defined correctly, the Neogene must be defined in accordance with its original meaning. But, to claim that a given definition of a word is "correct" (Berggren, 1998, p. 122) or "unjustified" (Aubry et al., 2005, p. 118), one must first have an accepted general principle by which to evaluate the correctness of that definition. Therefore, following Engel (2000, pp. 22–28), we must spell out the missing major premise (general principle) and minor premise (specific case) of Berggren's (1998) argument in the form of a syllogism, as follows:

> All standard global geochronologic units must be defined in accordance with their original meaning. The Neogene is a standard global geochronologic unit. Therefore, the Neogene must be defined in accordance with its original meaning.

The conclusion necessarily follows from the premises, but is the major premise true? We can evaluate it by asking what would happen if it were to be consistently applied. The result would be that most of the named units that currently comprise the standard global time scale would have to be either abandoned or redefined, because virtually none of these names reflects the exact concept originally assigned to them by their original authors. For example, the name "Quaternary" would either have to be dropped from the standard global time scale or else be "restored to its original meaning" so as to extend back "well into the modern Miocene," because that was Desnoyers' (1829) original concept of this name (Aubry et al., 2005, p. 118).

What are the implications of "Berggren's principle" for the Lyellian epochs? The Eocene, Miocene, and Pliocene would either have to be excluded from the GSSP-defined time scale, or else be redefined as fuzzy, mollusc-based biochronologic units, as Lyell originally intended them to be and as Lyell actually used them throughout his life (e.g., Lyell, 1874, p. 121). This is the view held by Weaver (1969) and Kleinpell (1979), a view that Berggren has opposed throughout his career (for example, Berggren et al., 1995b).

[3] The "Diluvium" referred to the distinctive deposits of northern Europe that would eventually be recognized as being of glacial origin. As a standard term of the geologic time scale, "Diluvium" (and/or "Diluvial Epoch") was gradually replaced by "Pleistocene" in the late 19th century (Zittel, 1895, p. 6; Berggren, 1998, p. 125).

What are the implications of "Berggren's principle" for the scope of the Cretaceous? The Cretaceous System, "a priori" (Berggren, 1998, p. 120), would have to be re-defined to include the (now early Paleocene) Danian Stage, because the latter was originally included in the Cretaceous (Omalius d' Halloy, 1822; d'Orbigny, 1840-1847; Desor, 1846; Lyell, 1851, pp. 209–211; Muller and Schenck, 1943; Eames, 1968; Davies et al., 1975; Curry et al., 1978, p. 3; Berggren et al., 1985, p. 147; Ogg et al., 2004, p. 345). However, Berggren has opposed the inclusion of the Danian in the Cretaceous throughout his career (Berggren, 1964, 1971; Berggren et al., 1995b).

What are the implications of "Berggren's principle" for the scope of the Carboniferous? The Carboniferous System would have to be re-expanded to include the (mostly Devonian) Old Red Sandstone, because the latter unit was explicitly included in the Carboniferous as originally defined by Conybeare and Phillips (1822, pp. vii; 335; Lyell, 1833, p. 393). Therefore, on Berggren's (1998, p. 127) "first principles," the Devonian must be regarded as a subsystem of the Carboniferous.

Numerous additional examples could be given, but the conclusion is evident. Adoption of the principle of the priority of original meaning in standard global chronostratigraphy would lead to results that, while not actually contradictory in the strict logical sense, are nevertheless clearly unacceptable. Therefore, "Berggren's principle" is refuted (reductio ad ridiculum). Specifically, this principle would lead to a "standard" geologic time scale consisting of a non-hierarchical hodge-podge of overlapping and non-contiguous time units. If, in recognition of this fact, we nevertheless insist on applying the principle in one case (extension of the Neogene to the present) and yet refuse to apply it in any of the other cases (for example, re-inclusion of the Devonian in the Carboniferous), then we engage in special pleading.

6. Critique of two recent proposals

6.1. Pillans and Naish (2004)

Pillans and Naish (2004) reviewed six options for the nomenclature of the major Cenozoic standard global geochronologic units. In none of these is the term "Tertiary" retained, nor would it be easy to incorporate the Tertiary into their Options 1,2,4, and 5. The Tertiary could be added to their Options 3 and 6, but only as an unranked unit together with an unranked Quaternary (Pillans and Naish, 2004, Fig. 1), a solution that few if any Quaternary (or Tertiary) workers would find appealing (Clague, 2004, 2006c; Salvador, 2006). Nevertheless, I reject Options 2,3,5, and 6 because they unnecessarily and unacceptably extend the Neogene to the present.

Pillans and Naish (2004) ultimately recommended their "Option 5" (see Fig. 2A). This option does not recognize the Tertiary and regards the Quaternary as a Subperiod of the Neogene Period, the latter being extended to the present. It also decouples the beginning of the Quaternary from the beginning of the Pleistocene, by leaving the latter at 1.8 Ma (Vrica GSSP of Aguirre and Pasini, 1985), and equating the former with the beginning of the late Pliocene Gelasian Standard Global Age at about 2.6 Ma (Monte San Nicola GSSP of Rio et al., 1998). I further object to this aspect of Option 5 of Pillans and Naish (2004) for the same reasons given by the Italian Commission on Stratigraphy (2002) and Gibbard et al. (2005). Gibbard et al. (2005, p. 4) stated:

> [This] option gives rise to several problems. For example, the separation of the beginning of the Quaternary from the beginning of the Pleistocene is a major departure from historical and current usage, and would cause considerable confusion in the short and medium term. There would be, additionally, a formal problem in that the lower rank boundary between the Pliocene and Pleistocene would not coincide with the higher rank boundary at the base of the Quaternary Sub-period. On these grounds, this option is rejected.

This criticism of Pillans and Naish (2004) by Gibbard et al. (2005) requires amplification because it is of major importance. In support of the alleged tenability of decoupling the beginning of the Quaternary from the beginning of the Pleistocene, Pillans and Naish (2004, p. 2274) quoted the following statement from Harland et al. (1982, p. 7):

> A hierarchy is not essential, and if one is used it matters little whether the distinct ranks in the hierarchy are strictly maintained. Provided each span is properly defined, then usage will consolidate a suitable number of names.

However, it cannot be concluded from this passage that Harland et al. (1982) believed that, for example, we should be allowed to decouple the beginning of the Paleozoic from the beginning of the Cambrian. In fact, Harland et al. (1990, p. 30) later stated just the opposite.

Furthermore, Harland et al. (1990, p. 20) clarified their 1982 statement: "It therefore matters little whether a *rigid* hierarchy be strictly maintained [italics added]." The meaning of this sentence can in turn only be understood with reference to the preceding paragraph in Harland et al. (1990, p. 20), in which it is stated: "The number of ranks is not a matter of principle but of convenience and is an accident of history. There have been attempts to *limit the ranks by standardization*, but sub-eras, sub-periods, etc. have intervened [italics added]." In other words, I believe Harland et al. (1990) meant that it is unnecessary to have a fixed standard global geochronologic hierarchy using just the ranks of era, period, epoch, and age, with no other ranks allowed.

More importantly, the publication of Harland et al. (1982) has no binding authority over the definition of an ICS-sanctioned time scale. The only documents that do have this authority are those of the ICS itself, namely, Cowie et al. (1986) and Remane et al. (1996). Revealingly, neither Pillans and Naish (2004), Aubry et al. (2005), ICS (2005), nor Gradstein (2005) cite either one of these documents as being consistent with their proposals. Remane et al. (1996, p. 78) stated:

> The lower boundaries of chronostratigraphic units of higher rank (series, systems **etc.**) are automatically defined by the base of their lowermost stage. In other words: the lower boundary of a system is **always** also a series and a stage boundary [emphasis added].

Using time terms instead of time–rock terms, and although Remane et al. (1996) did not mention the ranks of subera or subperiod, their use of the words "etc." and "always" indicates that their intention was that the beginning of a standard global geochronologic unit of *any given rank* must correspond to the beginning of its *oldest subdivision of immediately inferior rank*. Therefore, Ogg (2004, p. 126) was incorrect to state that this rule is "not stipulated." Although Remane et al. (1996, p. 78) could have been more explicit, they did stipulate this rule (called the "convention of conterminosity" by Harland et al., 1990, p. 20).

For an example of the convention of conterminosity, in the only other use of the Subperiod rank in Gradstein et al. (2004b; see the large fold-out chart contained therein), the beginning of the Pennsylvanian Subperiod is shown to coincide with the beginning of its oldest subdivision of immediately inferior rank, in this case the Early Pennsylvanian Epoch. The beginning of the Early Pennsylvanian Epoch in turn corresponds to the beginning of its oldest subdivision, the Bashkirian Age/Stage (Davydov et al., 2004).

In the present case, the Remane et al. (1996) Guidelines require that if the Pleistocene is to be the oldest Epoch of the Quaternary Subperiod, then the beginning of

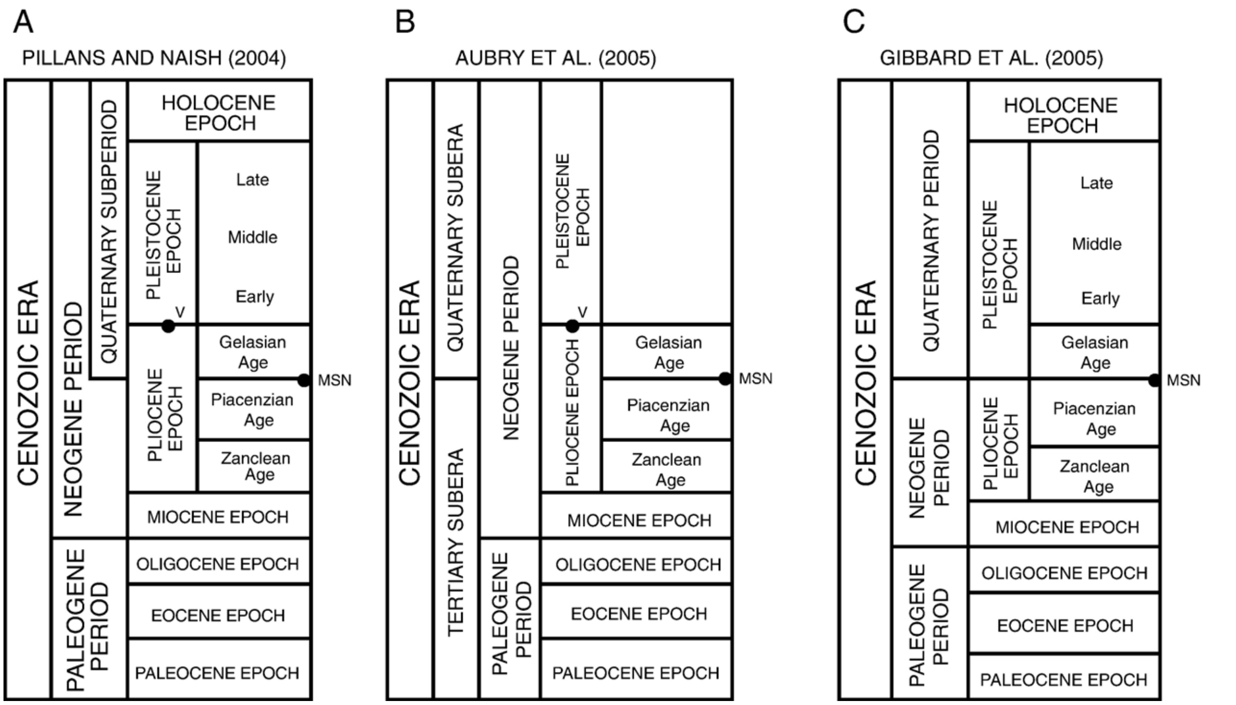

Fig. 2. Three recent proposals for the subdivision of the Cenozoic Era (modified from the original diagrams for ease of mutual comparison). A. Pillans and Naish (2004) (their "Option 5"). B. Aubry et al. (2005). C. Gibbard et al. (2005). V = Pliocene/Pleistocene GSSP of Aguirre and Pasini (1985) at Vrica, Italy. MSN = Piacenzian/Gelasian GSSP of Rio et al. (1998) at Monte San Nicola, Sicily. Depicted relative durations of the units are not to scale.

the Pleistocene must coincide with the beginning of the Quaternary. Therefore, Option 5 of Pillans and Naish (2004) violates the Remane et al. (1996) Guidelines. This option also violates Simpson's rule in that the extended Neogene Period would not be completely divided into Subperiods (Ogg, 2004; Gibbard, 2004).

Furthermore, although much has been made of the fact that Aguirre and Pasini (1985) did not formally equate the Tertiary/Quaternary boundary with the Pliocene/Pleistocene boundary at Vrica (Pillans and Naish, 2004, p. 2272), International Geological Correlation Program Project 41 (which gave birth to the report of Aguirre and Pasini) was explicitly entitled "Neogene/Quaternary Boundary" (Nikiforova, 1997; Nikiforova and Alekseev, 1997). As such, the vast majority of workers would have assumed the equation of the beginning of the Quaternary with the beginning of the Pleistocene, and that equation is reflected in the geologic maps and literature that have been published throughout the world for the past 20 years (Salvador, 2006). Therefore, as stated by Harland et al. (1990, p. 68) in a similar context, the decoupling of the beginning of the Quaternary from the beginning of the Pleistocene "would run counter to history and to an immense literature and would serve no great purpose."

A final problem with Option 5 of Pillans and Naish (2004) is that the Pliocene and Quaternary would then overlap in time, with the Gelasian Age belonging to both of them (Fig. 2A). This problem is also evident in the proposal of Aubry et al. (2005) and the ICS Recommendation of Gradstein, 2005 (Section 6.2; see also the comments of N. Morton in Gibbard, 2006, p. 118). However, this kind of overlap violates the ICS Guidelines of Remane et al. (1996, p. 78) and would only cause needless confusion (Italian Commission on Stratigraphy, 2002, p. 264). By analogy, can the Maastrichtian Age belong to both the Cretaceous Period and the Tertiary Period at the same time?

In practical terms, overlaps of this kind unnecessarily complicate the depiction of our standard global chronostratigraphic units on geologic maps. If, on a given map, Pliocene and Quaternary deposits are colored orange and yellow, respectively, what color should be assigned to the Gelasian strata? Would some authors paint the Gelasian orange? Would others paint the Gelasian yellow? Would still others paint the Gelasian orange, but with yellow dots (or vice versa)? And why should geologists around the world have to deal with these annoying consequences of the questionable aesthetic taste of a handful of marine stratigraphers? In short, the standard global time scale has a strictly hierarchical structure for very good *practical* reasons; such a structure is not merely a "theoretical nicety" as suggested by Pillans (2005, p. 89). Future versions of the ICS Guidelines should make this requirement explicit.

As Options 2–6 of Pillans and Naish (2004) are here rejected, this leaves only their Option 1 available. However, this option still omits the Tertiary and ranks the Paleogene and Neogene as periods, which are unacceptable in my view for reasons discussed in Sections 4.1, 7, and 8) (below), and by Salvador (2006). I therefore reject all six options presented by Pillans and Naish (2004).

6.2. *Aubry et al. (2005) and Gradstein (2005)*

Aubry et al. (2005) proposed that: 1) the Tertiary and Quaternary be regarded as Suberas of the Cenozoic Era; 2) that the beginning of the Quaternary be decoupled from the beginning of the Pleistocene and be redefined to correspond to the beginning of the Late Pliocene Gelasian Age; and 3) that the Neogene be ranked as a Period and extended to the present (Fig. 2B). This proposal has now been approved in its essentials by the ICS (Gradstein, 2005). I applaud Aubry et al. (2005) for advocating that the Tertiary and Quaternary be formally recognized, but reject their proposal on the basis of items 2 and 3, for reasons discussed in Sections 3, 4, 5, and 6.1.

The classification of Aubry et al. (2005) is somewhat unexpected because it contradicts previous statements by J.A. Van Couvering and W.A. Berggren affirming the identity of the beginnings of the Quaternary and Pleistocene (Van Couvering, 1997a, p. xv; Berggren, 1998, pp. 122–123; 125). Berggren's (1998) historical arguments on the Neogene (Section 5.2) have clearly influenced the views of Aubry et al. (2005, p. 119), who stated:

> To *bring* the Quaternary into the time scale also *creates* a second problem — that of its level in the hierarchy. The view of Gibbard et al. (2005) is that Quaternary should properly be a period (system), at the level of Paleogene and Neogene. However, the Neogene extends to the present, and thus its time span covers Quaternary-age strata [italics added].

However, the Quaternary has been a part of most standard geologic time scales for at least 120 years, and has been consistently defined as "Pleistocene+Recent/Holocene" (Prestwich, 1886–1888, vol. I, p. 81; Woodward, 1891, p. B21; Williams, 1895, p. 37; Zittel, 1895, p. 6; Trabuco, 1900, p. 701; Sacco, 1907, p. 423; Grabau, 1924, pp. 22, 1108; Wilmarth, 1925, p. 45; Sacco, 1907, p. 423). Therefore, inclusion of the Quaternary in the time scale has not created and does not create a problem. The additional claim of Aubry et al. (2005, p. 119) that "a consensus has developed to decouple the Quaternary from the Pleistocene, and thus to end an unhappy 150-year old relationship for the good of both parties" may be true for a very small group of marine stratigraphers, but is clearly false for the vast majority of geologists around the world (Salvador, 2006; Clague, 2006c).

Second, Aubry et al. (2005) seem to regard the extension of the Neogene to the present as an irrefutable fact of nature, when it is not (Section 5.2). Their argument against the Gibbard et al. (2005) proposal is just as specious as the analogous argument that because Lyell (1833) originally defined the Eocene and Miocene Epochs to be temporally contiguous, the time span of the Eocene necessarily covers Oligocene-age strata.[4] As such, the Oligocene cannot have the rank of Epoch, but must instead be regarded as a Subepoch of the Eocene Epoch. This is yet another untenable result of the principle of the priority of original meaning. Indeed, if the Neogene/Quaternary boundary is a "dead cat" for the reasons given by Berggren (1998, p. 122), then there can also be no such thing as the Eocene/Oligocene epoch boundary nor the Oligocene/Miocene epoch boundary. Reductio ad ridiculum.

Third, the proposal of Aubry et al. (2005) and Gradstein (2005) violates the ICS Guidelines of Remane et al. (1996, p. 78) in that the beginning of the Quaternary Subera does not correspond to the beginning of any Period or Epoch (convention of conterminosity).

Fourth, the proposal of Aubry et al. (2005) and Gradstein (2005) contains the same anomaly as "Option 5" of Pillans and Naish (2004): the fact that the Gelasian Age would belong to both the Pliocene and the Quaternary. The awkward practical consequences of this "dual citizenship" for geologic maps were discussed in Section 6.1.

Fifth, and most importantly of all, the proposal of Aubry et al. (2005) and Gradstein (2005) violates the most fundamental rule of ranked hierarchical classification, as discussed in Section 3.1. At most, in some cases, the content and/or meaning of a name of one rank might be identical to the content and/or meaning of a name of immediately higher or lower rank. This occurrence of redundant ranks is the occasional result of the uniform application of Simpson's rule, and is exemplified by the identity in meaning of the terms "Early Eocene" (informal subepoch) and "Ypresian Age" (Luterbacher et al. 2004, p. 396). But, it is simply absurd that the scope of a name of *superior* rank (Quaternary Subera) can be included *entirely within* the scope of another name given an *inferior* rank (Neogene Period), as proposed by Aubry et al. (2005). Rephrasing the analogies used in Section 4.1, how can the Family Hominidae contain *more species* than the Order Primates, and how can the 19th Century be of *longer duration* than the Second Millenium?

While the arrangement of Aubry et al. (2005) uses the familiar rank-terms of standard global chronostratigraphy, it is not a genuine hierarchical classification of geochronologic/chronostratigraphic *units* (despite the caption for their table 1). It is best termed "semi-hierarchical" (Section 3.2) because some parts of it are hierarchical while other parts are not. For example, if the Quaternary Subera is contained entirely within the Neogene Period, then the relationship between these two units is not hierarchical, but incoherent.[5] In addition, if the Pliocene Epoch (as well as the Neogene Period) can partly belong to *both* the Tertiary and Quaternary Suberas, then there is no *hierarchical* relationship here because the lower-ranked units are not subordinated to (that is, contained entirely within) either the Tertiary or the Quaternary. These non-hierarchical relationships would again make it difficult or impossible to clearly depict all of these units on the same geologic map.

The proposals of Aubry et al. (2005) and Gradstein (2005) are also inconsistent with the prevailing International Stratigraphic Guide, which states: "A major goal of chronostratigraphic classification is the establishment of a **hierarchy of chronostratigraphic units** of worldwide scope… [Salvador, 1994, p. 85; emphasis added]". As previously noted in Section 3.2, the proposal of Aubry et al. (2005) also ignores the statement of Remane et al. (1996, p. 78) that "The Global Chronostratigraphic Scale **must**, however, **comprise strictly contiguous units**, **without overlaps** and with no gaps between them [emphasis added]."

Aubry et al. (2005, p. 119) correctly noted that if the Tertiary was incorporated into the favored option of Pillans and Naish (2004), then "Tertiary would be in an illogical relationship as a subdivision of both Paleogene and Neogene." However, the same objection applies to

[4] One of Lyell's (1833, pp. 61; 280–281) "syntypes" of the Eocene was the thick section of alternating marine and freshwater strata on the Isle of Wight (UK), the upper part of which is now assigned to the Oligocene (Curry et al., 1978; Hooker, 1992; Daley, 1999; Gibbard and Lewin, 2003). As such, the Isle of Wight section must now be regarded as a loose (rather than strict) nominal stratotype for the Eocene (Walsh, 2005a).

[5] As observed by Buck and Hull (1966, p. 98) in an analogous context, "The statement that Primata [is a member of] Gargantua does not succeed even in saying something false. It is nonsense."

<table>
<tr><td colspan="7">CENOZOIC</td><td>ERA</td></tr>
<tr><td colspan="3">PALEOGENE</td><td colspan="4">NEOGENE</td><td>SUBERA</td></tr>
<tr><td colspan="3"></td><td colspan="2"></td><td colspan="2">QUATERNARY</td><td>PERIOD</td></tr>
<tr><td>PALEOCENE</td><td>EOCENE</td><td>OLIGOCENE</td><td>MIOCENE</td><td>PLIOCENE</td><td>PLEIST.</td><td>HOLO.</td><td>EPOCH</td></tr>
</table>

Fig. 3. Improved version of the Aubry et al. (2005) proposal with the Paleogene and Neogene ranked as Suberas of the Cenozoic, the Quaternary ranked as a Period of the Neogene, the Tertiary unranked, and the beginnings of the Quaternary and Pleistocene restored to equivalence. Incomplete subdivision of the Neogene into Periods would still violate Simpson's rule and the ICS Guidelines of Remane et al. (1996). These flaws could only be corrected by coining a new name for the traditional concept of "Neogene," which would be unnecessary in my view. Depicted relative durations of the units are not to scale.

their own scheme, because the Neogene would be in "an illogical relationship" (that is, a non-hierarchical relationship) as a "subdivision" of both Tertiary and Quaternary (Fig. 2B).

As Valentine and May (1996, p. 23) observed: "The value of the hierarchical structure can be lost when ranks are misspecified." Fortunately, Aubry et al. (2005, p. 119) stated: "If Quaternary is to be accepted as a formal chronostratigraphic unit, it is clear that its preferred definition must not disrupt the existing structure." I agree. The proposal of Aubry et al. (2005) and Gradstein (2005) must therefore be rejected, because its ratification would destroy the hierarchical structure of the Cenozoic time scale.

6.3. Improving the proposal of Aubry et al. (2005)

Can the proposals of Aubry et al. (2005) and Gradstein (2005) be improved? Perhaps, although not without creating other problems. But first, the only way to extend the Neogene to the present without violating the rules of hierarchical classification is for the Neogene to have a higher rank than the Quaternary, and realistically this can only be done by regarding the Neogene and Paleogene as Suberas of the Cenozoic (Fig. 3). Such an elevation in rank would be consistent with the actual durations of these units, and so is reasonable in itself. The Quaternary would then be ranked as a Period of the Neogene Subera. If the original proposals of Aubry et al. (2005) and Gradstein (2005) were further modified such that the beginnings of the Pleistocene and Quaternary were again coincident, then the overall result would be an improvement in my view (Fig. 3).

Given the above scenario, however, the Tertiary could not be ranked as a Period because it would then absurdly contain the Paleogene Subera, of superior rank. Thus, the Tertiary would have to remain unranked, and Simpson's rule would be violated (the Tertiary and Quaternary would still exhaustively divide the Cenozoic but would not have the same rank). As such, the Period rank would be unfilled for Paleogene time. In addition, the expanded Neogene Subera would not be completely divided into Periods, thus violating Simpson's rule for a second time. This result was already criticized by Aubry et al. (2005, p. 119) when they noted that in the preferred option of Pillans and Naish (2004), such an isolated position for the Quaternary "reinforces the image of an irregular, not-quite-real status" for this unit. Furthermore, the scheme shown in Fig. 3 would still violate the convention of conterminosity in that the older boundary of a standard global geochronologic unit (Neogene Subera) would not correspond to the older boundary of its oldest subdivision of immediately inferior rank (Quaternary Period). Both of these problems could be solved by coining a new Period name for the pre-Quaternary part of the expanded Neogene Subera. However, that new name would be identical in meaning to the traditional concept of "Neogene" (Miocene + Pliocene), which would be a pointless exercise in my view.[6]

In conclusion, both the original proposal of Aubry et al. (2005) and the improved scheme discussed here are cumbersome, unprincipled, and unnecessary. Because the classification shown in Fig. 1B is strictly hierarchical, violates none of the existing Guidelines of the ICS, obeys Simpson's rule, requires no new names, allows the Tertiary, Quaternary, Paleogene, and Neogene to be formally ranked and unambiguously depicted on geologic maps, and has also been in general use for more than a century, it is to be preferred. Further arguments along these lines are given in the next two sections.

[6] Suppose that on grounds of "historical correctness," in accordance with Lyell's (1833) original definition, a proposal was made to extend the end of the Eocene Epoch to the beginning of the Miocene; to regard the Oligocene as a subepoch of the Eocene; and then to coin a new subepoch name for the previous concept of "Eocene." Presumably, all would agree that such an exercise would be pointless.

7. Refutation of four arguments against a ranked Tertiary

Given the demonstration in Section 4.1 that if Tertiary and Quaternary are formally ranked then the Neogene cannot be extended to the present, some stratigraphers may propose that the Tertiary and/or Quaternary be abandoned or left unranked yet again. I therefore wish to criticize four recent arguments to this effect.

7.1. Should Tertiary and Quaternary be abandoned because they are part of an obsolete classification system?

Berggren (1998) argued that the Tertiary and Quaternary should be dropped because they belong to an obsolete four-part classification whose other terms (Primary and Secondary) fell into disuse long ago. This argument was repeated by Gradstein et al. (2004c, p. 45) and Luterbacher et al. (2004, p. 38). However, we no longer use the name "Primary" because the so-called "Primary" rocks (granites and gneisses, etc.) were found to be of very different ages (Precambrian to Tertiary), so the term became geologically inappropriate (Lyell, 1833, chapters XXV–XXVI). We no longer use the term "Secondary" because it came to be more or less a synonym of "Carboniferous + Permian + Mesozoic" (Lyell, 1833, pp. 390–393; Rudwick, 1985, p. 55), and such a division was no longer thought to be the best way to classify those rocks. Attempts then persisted to equate the Primary with the Paleozoic and the Secondary with the Mesozoic (e.g., Gignoux, 1955), but this redundant usage was eventually abandoned (Harland et al., 1990, p. 31). The fact that "Primary" and "Secondary" are obsolete is therefore irrelevant to the status of the Tertiary and Quaternary because the latter terms are still highly useful (Prothero and Dott, 2004, p. 71; Salvador, 2006).

Second, Berggren's (1998) argument cannot be accepted because its consistent application to the rest of the time scale would force us to abandon two other major stratigraphic names. In the 1820s and early 1830s, the standard pre-Tertiary stratigraphic scale of northwestern Europe was described in lithologic terms. From youngest to oldest, this scale consisted of the Cretaceous, Oolitic, Lias, New Red Sandstone, Carboniferous (originally including the Old Red Sandstone), Transition, and Grauwacke (De la Beche, 1833; Lyell, 1833). Most of these lithologic terms were gradually excluded from the standard global time scale as the new names Jurassic, Triassic, Permian, Devonian, Silurian, and Cambrian became accepted (Berry, 1987). However, the Cretaceous and Carboniferous were never replaced, even though they are plainly still part of an "antiquated stratigraphic nomenclature." So, if Berggren's (1998, p. 126) argument about the alleged obsolescence of the names Tertiary and Quaternary is taken seriously, then we must abandon the names "Cretaceous" and "Carboniferous" for the same reason. Reductio ad ridiculum.

7.2. Is the asymmetry between the Tertiary and Quaternary unacceptable for a modern subdivision of the Cenozoic?

The ICS (2005, pp. 2–3) significantly modified the proposal of Aubry et al. (2005) when it stated that the Tertiary "is not recommended as a formal division of the geologic time scale, because it is nearly redundant with the entire Cenozoic Era" (see also Gradstein, 2005). However, this claim makes as much sense as the analogous claim that the Pleistocene should not be a formal unit because its duration is nearly the same as that of the Quaternary. Therefore, why not demand that the Pleistocene also be stripped of its rank?

The great disparity in the durations of the Tertiary and Quaternary is not a compelling reason for their exclusion from the standard global time scale (Harland et al., 1990, p. 31). After all, the duration of the Tertiary Period (~63 m.y.) is comparable to the preceding Cretaceous (~80 m.y.), Jurassic (~55 m.y.), and Triassic (~51 m.y.) Periods (Gradstein et al., 2004b). Most Quaternary workers simply view the last ~2 m.y. as the dawning of a new period of Earth history comparable in significance to the preceding four, and the vast majority of geologists have found no reason to contest this view.

7.3. The Precambrian analogy is unconvincing

Ogg (2004) and Pillans and Naish (2004) suggested that one way to deal with the Quaternary would be to define this unit as a "composite epoch." The Quaternary would then be similar to the Precambrian in that both would be formal but unranked units. Because a similar status has now been suggested for the Tertiary (ICS, 2005; Gradstein, 2005), it is important to note that there are significant differences in the cases of it and the Precambrian. First, to my knowledge, the Precambrian has never had a consistent rank. Second, the Precambrian remains unranked because its enormous duration would require a new rank term (Supereon?), in order to allow it to include the Archean and Proterozoic Eons. Third, the application of Simpson's rule would then require a new name with the same rank to redundantly apply to the Phanerozoic Eon. These cumbersome results show why it is unnecessary for the Precambrian to have a formal rank.

With the Tertiary, however, the situation is very different. The Tertiary has traditionally been ranked as a Period, and the application of Simpson's rule would not require us to coin a new name for the youngest part of the Cenozoic because we already have the Quaternary Period. As such, those who wish to leave the Tertiary unranked cannot validly invoke the special circumstances of the Precambrian in support of their views.

7.4. Tertiary and Quaternary are not "ambiguous"

Suguio et al. (2005, p. 199) proposed that Tertiary and Quaternary could be eliminated from the standard global time scale because of their "extreme ambiguity." This claim lacks substance, however, because the only current ambiguity in the scope of these names involves the ongoing controversy over the definition of the Pliocene/Pleistocene boundary.

What Suguio et al. (2005) probably meant, however, is that the name "Quaternary" has several different connotations; for example, as the time of the latest Cenozoic Northern Hemisphere ice ages; as the time of existence of humans or human-like species (or the time of their existence as tool-makers), et cetera. However, the fact that a term has several connotations does not mean that it cannot be well-defined. Therefore, the fact that the initiation of the Northern Hemisphere ice ages and the first appearance of human-like species both predate the beginning of the Quaternary does not invalidate the Tertiary and Quaternary as formal subdivisions of the geologic time scale. By analogy, the Mesozoic Era is commonly known as the Age of Ammonites and as the Age of Reptiles. The fact that ammonites and reptiles both appeared well before the beginning of the Mesozoic does not render this name "ambiguous" because the Mesozoic Era is precisely defined by GSSPs. The same will be true of the Tertiary and Quaternary when a formal definition of their mutual boundary is confirmed.

8. Three arguments in favor of a ranked Tertiary

8.1. Relative frequency of use

Salvador (2006) demonstrated that the term "Tertiary" is still used much more frequently in stratigraphic publications than the terms "Paleogene" and "Neogene." Therefore, if relative frequency of usage by geologists is regarded as a key factor in determining which units should be formally ranked, then there is no question that if Paleogene and Neogene are ranked, Tertiary and Quaternary should also be ranked (see also Pillans and Naish, 2004; Gibbard et al., 2005).

8.2. Tertiary and Quaternary in the context of geologic maps

Those who have advocated eliminating the Tertiary and Quaternary on grounds of the disparity in their durations seem to have overlooked an important point. As noted by Gibbard et al. (2005, p. 3), the areal extent of Quaternary deposits often approaches or even exceeds the areal extent of pre-Quaternary deposits in many regions. As such, the disparity in the absolute durations of the Tertiary and Quaternary has been irrelevant for the majority of geologists who make and use geologic maps. Indeed, what do all geologists want to see when they first look at a geologic map of their field area? They want to see where the potential outcrops of their units are, and for most geologists this is determined by the extent of surficial deposits in that field area. Thus, a geologic map that depicts Quaternary deposits in a distinct color immediately shows Quaternary specialists where their outcrops are, and likewise shows pre-Quaternary specialists where their outcrops are not. Such a differentiation would be more difficult to see on a geologic map if Quaternary deposits were subsumed under and given the same basic color as the Neogene.

An additional practical problem exists with the depiction of Paleogene and Neogene on geologic maps. The abbreviations "T" and "Q" are very distinctive on maps because there are no other major standard global geochronologic units beginning with these letters (with the exception of the Triassic, which is usually abbreviated as "Tr" or "TR"). While the abbreviation "N" is also unambiguous, there are several prominent standard global geochronologic units beginning with the letter "P" (Proterozoic, Paleozoic, Pennsylvanian, Permian, Paleocene, Pliocene, and Pleistocene). Addition of yet another "P" (for Paleogene) on many geologic maps would therefore create an unnecessary obstacle to their ready comprehension.

8.3. Honoring the pioneers of Tertiary stratigraphy

Regarding the ultimate purpose of Berggren's (1998) paper, it is difficult to see how the elimination of the Tertiary Period/System, together with the formalization of the Paleogene and Neogene (terms that Charles Lyell never used), could really "do honour to Lyell" (Berggren, 1998, p. 126). Why not do honour to Adam Sedgwick by eliminating "Cambrian" and replacing it with a term that he never used, such as "Hercynian" (Secord, 1986, pp. 99–101)? Indeed, with "honour" like this, who needs disrespect?

Although Lyell did not coin the name, it was the Tertiary rocks which provided the subject matter for his arguably most important contributions to geology — contributions for which he was awarded the Royal Medal of the Royal Society in 1834 (Rudwick, 1985, p. 108). As stated by none other than Moriz Hörnes (1853, pp. 807–808):

> …we must admire the acumen of this great English geologist because he was the first who brought order into the opinions concerning the age relations of the Tertiary sediments, and in spite of the enormous progress in the science his observations and conclusions have held perfectly true to this day. His classification has been generally accepted because it is based on stratigraphic relations as well as the thorough conchological work of Deshayes.[7]

Lyell has been ranked 28th in a list of the "100 most influential scientists, past and present" (Simmons, 1996), and justifiably so. Important new books on his career continue to appear (Blundell and Scott, 1998; Wilson, 1998), and his formerly battered reputation as a historian of geology has now been partly restored (Şengör, 2002). Clearly, Lyell (as well as Arduino, Cuvier, Brongniart, Brocchi, Deshayes, and Prévost; see Rudwick, 2005) would best be honored by retaining the Tertiary as a formally ranked unit in the standard global time scale.

9. Theoretical aspects of the proposed redefinition of the Pliocene/Pleistocene boundary

9.1. Gibbard et al. (2005)

Gibbard et al. (2005) proposed that the Paleogene, Neogene, and Quaternary be regarded as successive Periods of the Cenozoic Era (Fig. 2C). Topologically speaking, this arrangement represents the "status quo" for many workers (Gradstein and Ogg, 1996; Condie and Sloan, 1998, p. 382; Remane, 2000a; Pillans and Naish, 2004, options 1 and 4). Nevertheless, the fact that the Tertiary is unranked makes this option less desirable than the scheme shown in Fig. 1B for reasons discussed above and by Salvador (2006). Furthermore, the arguments made above demonstrate that if the Quaternary is ranked as a Period and the Tertiary is also to be ranked, then the Paleogene and Neogene must be regarded as Subperiods of the Tertiary.

More importantly, Gibbard et al. (2005) proposed that the beginnings of both the Quaternary and the Pleistocene be lowered so as to correspond to the Monte San Nicola GSSP at 2.6 Ma (that is, to the beginning of the Gelasian Age of Rio et al., 1998). I am skeptical about this proposal, and believe that sound arguments for the retention of the Pliocene/Pleistocene boundary at the Vrica GSSP have been made by Vai (1997), various authors in Van Couvering (1997b), and the Italian Commission on Stratigraphy (2002). Nevertheless, it is important to determine whether the lowering of the Pliocene/Pleistocene boundary (=Tertiary/Quaternary boundary=Neogene/Quaternary boundary) is allowed by nomenclatural principles that are generally accepted in stratigraphy.

9.2. The relevance of Lyell's "types" of the Older Pliocene

Given Lyell's (1833, p. 61) list of several "types" for the Older Pliocene, can or should any of these be regarded as strict name-bearers (see Walsh, 2005a) for the modern Pliocene, which would then forbid the transfer of the Pliocene/Pleistocene boundary from the GSSP at Vrica to the Piacenzian/Gelasian GSSP at Monte San Nicola?

Aubry et al. (1998) stated that one of Lyell's (1833) types for the Older Pliocene was the "Subapennine marls of Asti" (part of the "Subapennine beds" discussed by Lyell, 1833, chapter XII; see also Cita, 1975). Aubry et al. (1998) evidently interpreted these strata to be a strict name-bearer for the modern Pliocene, and concluded that because these strata were (apparently) coeval with the Late Pliocene Gelasian Stage, the Gelasian Stage must by definition remain in the Pliocene. Unfortunately, however, the exact scope of Lyell's (1833, p. 61) Asti locality is unclear. Although some of the Subapennine beds southeast of Asti are indeed of Gelasian age (G.B. Vai, pers. comm., 2006), Selli (1967, p. 79) and Rio et al. (1998) emphasized that the type "Astian" yellow sands of northern Italy are actually of early and/or middle Pliocene age, being a

[7] "…wir müssen dem Scharfsinne des grossen Englischen Geologen unsere volle Bewunderung zollen; denn in der That war er der erste, welcher Ordnung in die Ansichten über die Alters-Verhältnisse der Tertiär-Ablagerungen brachte, und alle seine Beobachtungen und Schlüsse haben sich bis heutigen Tag trotz des riesigen Fortschrittes der Wissenschaft vollkommen bewährt. Seine Eintheilung wurde daher, da sie sich zugleich auf Lagerungs-Verhältnisse und die gründlichen konchyliologischen Arbeiten eines Deshayes basirte, allgemein angenommen."

partly coeval facies of the Piacenzian blue clays (Gignoux, 1955; Sampo et al., 1968; Ferrero, 1971). This point was also made by Berggren (1971, pp. 758, 774). Provisionally, therefore, it would appear that the Pliocene/Pleistocene boundary could be relocated to the Piacenzian/Gelasian GSSP without violating the status of Lyell's (1833) Asti locality as a strict name-bearer for the Pliocene.

Lyell's (1833, p. 61) other Older Pliocene Mediterranean "syntypes" (Perpignan and Nice in France; Parma and Siena in Italy) were also collected from the Piacenzian blue clay facies and the Astian yellow sand facies, and so would still be regarded as early and/or middle Pliocene in age (Lyell, 1833, chapter XII; Gignoux, 1955, pp. 583–584; Wilson, 1972, pp. 213, 224–225; Cigala-Fulgosi, 1988; Mary et al., 1993; Castradori et al., 1998; Fauquette and Bertini, 2003; Manganelli et al., 2004). Therefore, the transfer of the Pliocene/Pleistocene boundary from Vrica to Monte San Nicola would likewise not violate the possible functions of these "syntypes" as strict name-bearers for the Pliocene.

The only other "syntype" of Lyell's Older Pliocene that is problematical in this context is the "English Crag," which was subsequently found to be composed of several units of different ages (e.g., Lyell, 1839, 1851; Wilson, 1972, chapter 14; Berggren, 1998; Gibbard et al., 1998). Curiously, Pillans and Naish (2004, pp. 2278) stated:

> Similarly, shallow water deposits in East Anglia (Red Crag and Norwich Crag Formations), were originally placed in the Quaternary in Britain, following the 1948 IGC (cf. West, 1967), but subsequently had to be included in the Pliocene. In a major review of British Quaternary deposits, Bowen (1999) acknowledged this point, but stated a preference for including them in the Quaternary, in recognition of their historical placement, and in support for a 'long' Quaternary.

However, the Red Crag and Norwich Crag form the upper part of one of the *types* of Lyell's Older Pliocene. Therefore, if, as Aubry et al. (1998) believed, some or all of these types are construed as strict name-bearers for the modern Pliocene, then those name-bearers *must continue to be included in the Pliocene*.

So, how old are the Red Crag and Norwich Crag? According to Hey (1997), Gibbard et al. (1998), Bowen (1999), and Pillans and Naish (2004), these units are of late to latest Pliocene (Gelasian) age given the Pliocene/Pleistocene boundary GSSP at Vrica. Therefore, if the Pliocene/Pleistocene boundary were to be moved to the Piacenzian/Gelasian GSSP at Monte San Nicola, then the status of the "English Crag" as a strict name-bearer for the Pliocene would be violated. However, if the "English Crag" were regarded only as a loose name-bearer for the Pliocene (Walsh, 2005a), then the Pliocene/Pleistocene boundary could be moved from Vrica to Monte San Nicola without difficulty. Indeed, Lyell himself (1851, pp. 148–149) transferred the Norwich Crag from the Older Pliocene to the Newer Pliocene (later to become the Pleistocene) and so did not view this unit as a strict name-bearer for the former. As such, the Pliocene/Pleistocene GSSP could be relocated from Vrica to Monte San Nicola without violating any generally-accepted nomenclatural principles of stratigraphy.

9.3. Should strict nomenclatural constraint be mandatory in standard global chronostratigraphy?

A serious objection to the conclusion reached in Section 9.2 could be made by insisting that only strict nominal stratotypes are valid in the context of standard global chronostratigraphy (see Walsh, 2005a,b,c for discussion). For example, Odin (1997, pp. 5–6) advocated that when possible, the principle of strict nomenclatural constraint should be adopted when defining standard global ages/stages. If this rule was applied to the case of the Pliocene/Pleistocene boundary, then the Pliocene/Pleistocene boundary could never be defined at a horizon that was older than the top of the Norwich Crag. While aesthetically appealing and appropriate in many cases, the requirement that all of our standard global geochronologic units must be defined so as to conform to the principle of strict nomenclatural constraint will frequently be unworkable.

First, as we have seen from the changing Older Pliocene/Newer Pliocene boundary of Lyell (1833, 1839) vs. Lyell (1851), such a principle would often prevent us from adopting a revised concept of a given named unit, even if this revised concept was provided by the same worker who originally proposed the unit. As such, original authors would often be retrospectively forbidden from revising their own work.

Second, exclusive use of the principle of strict nomenclatural constraint would force us to redefine the currently-uncontroversial boundaries of many of our standard global geochronologic units. Examples include the Silurian/Devonian boundary (some of the strata originally included in the "type" of the Devonian System are now assigned to the Silurian System; McLaren, 1977), the Cretaceous/Tertiary boundary (the Danian limestones originally included by Omalius d'Halloy (1822) in the Cretaceous System are now assigned to the Paleocene), and the Eocene/Oligocene boundary (footnote 4).

Third, suppose that the nominal stratotypes of two historical stages overlap one another in time, and yet the names of these historical stages are still chosen to be used for successive divisions of the standard global time scale. In such cases, both names cannot be retained without violating the strict name–typology of at least one of them. For example, Fig. 4 depicts the nominal stratotypes of two hypothetical stages, the Jian and Kian. The spans of time subtended by these two nominal stratotypes overlap one another. How then should we define the formal Jian/Kian standard global geochronologic boundary? A definition using golden spike A would respect the strict name–typology of the Jian, but violate that of the Kian. Golden spike B would violate the strict name–typology of both the Jian and Kian. Golden spike C would respect the strict name–typology of the Kian, but violate that of the Jian. Concrete examples of this situation are provided by the latest Jurassic Tithonian Age/Stage and the earliest Cretaceous Berriasian Age/Stage (Ogg et al., 2004, p. 353), and the late Miocene Tortonian and Messinian Ages/Stages (Colalongo and Pasini, 1997; Rio et al., 1997; Odin et al., 1997, pp. 603–604). So, the distinction between loose and strict nominal stratotypes is quite necessary (Walsh, 2005a), and the exclusive use of the principle of strict nomenclatural constraint cannot be enforced in standard global chronostratigraphy. As such, this principle cannot be used to prevent the transfer of the Pliocene/Pleistocene boundary from the GSSP at Vrica to the GSSP at Monte San Nicola (despite my own skepticism regarding such a transfer).

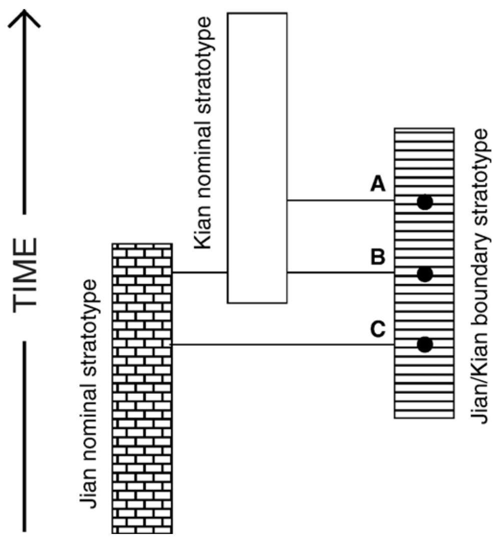

Fig. 4. Diagram showing temporal overlap of the nominal stratotypes of two hypothetical stages, the Jian and Kian, whose names are to be used for successive divisions of the standard global time scale. Golden spike A respects the strict name–typology of the Jian, but violates that of the Kian. Golden spike B violates the strict name–typology of both the Jian and Kian. Golden spike C respects the strict name–typology of the Kian, but violates that of the Jian. See text for discussion.

9.4. Intensional vs. extensional definitions

Many Quaternary workers apparently have not escaped from what I regard as a misconception — the belief that our (or at least *their*) standard global time units must be defined *intensionally* rather than *extensionally* (see Buck and Hull, 1966; Ghiselin, 1997, p. 303; Copi and Cohen, 1998, pp. 137–147). In the context of standard global chronostratigraphy, an intensional definition refers to one or more specific properties and/or geohistorical events that are intended to define a given time/time–rock unit, whereas an extensional definition refers only to an enumerated set of named subdivisions that together are to comprise the unit.

To illustrate, an intensional definition of the Phanerozoic Eon would be the time of Earth history during which "conspicuous animal life" existed, as indicated by the etymology of the name (Chadwick, 1930). Before the discovery of the latest Precambrian Ediacaran fauna, the beginning of the Phanerozoic was equated with the beginning of the Cambrian, and so the extensional definition of the Phanerozoic was "Cambrian to Permian + Mesozoic + Cenozoic." The discovery of the Ediacaran fauna led to the question: Should we extend the beginning of Phanerozoic time to include Ediacaran time, in order to satisfy the intensional meaning of "Phanerozoic"? Or, should we ignore the intensional meaning of "Phanerozoic" and maintain its long-established extensional content, thus restricting this name to Cambrian and younger time? Cloud and Glaessner (1982, p. 783) advocated the former approach:

> By [intensional] definition, the term Phanerozoic must be extended downward to include older discoveries of manifest animal life. In the opinion of one of us (P.C.) this should take the Paleozoic with it, adding a basal extension to previous additions at the younger end of the original Paleozoic Era. Chadwick's definition, geologic consistency, and etymological congruity all equate the base of the Phanerozoic Eon with that of the Paleozoic Era.

Such disputes can occur in geology whenever new discoveries bring about a conflict between the intensional and the traditional extensional meanings of a given name. However, it is probably the rule rather than the exception in stratigraphy for the original intensional meaning of a name to lose its significance. Otherwise, we would have to abandon "Carboniferous" and "Cretaceous," because most Carboniferous rocks are not coal-bearing, and most Cretaceous rocks are not chalky (Lyell, 1867, pp. 112–113; Muller and Schenck, 1943).

Consistent with these realities, the arguments of Cloud and Glaessner (1982) were not accepted by the Precambrian Subcommission of the ICS. As stated by Harland et al. (1990, p. 30):

> All of the above names [e.g., Phanerozoic] carry a descriptive [intensional] meaning related to the evolution of animal life (even when probably there was none), but they have also become conventional [extensionally-defined] names in a stratigraphic hierarchy and this is how they are used here. In other words, initial boundaries are conterminous with successively lower ranks at the defined point. Thus the initial Phanerozoic boundary would be defined at the point that will define the initial Cambrian boundary and not according to successive fossil discoveries or opinions about animal evolution. This opinion was supported by the Precambrian Subcommission of the ICS in 1988.

The proposal by Cloud and Glaessner (1982) to decouple the beginning of the Phanerozoic and/or Paleozoic from the beginning of the Cambrian is analogous to the present attempt by some workers to decouple the beginning of the Quaternary from the beginning of the Pleistocene, or to move the beginnings of both units downwards to a more "natural" climatochronologic level. However, the Quaternary was widely understood to consist of Calabrian and younger strata since the 1948 International Geological Congress (Pomerol, 1982, p. 141), and the Vrica GSSP was defined in accordance with this view (see numerous papers in Van Couvering, 1997b). Nevertheless, many other Quaternary geologists believed that it was more important to define the beginning of this unit by the start of significant Northern Hemisphere glaciations, and if such glaciations occurred before Calabrian time, so be it.

Acknowledging the striking disparity between these views and the intensity with which they are held, it nevertheless has to be understood that whenever a GSSP is ratified, *some* people are going to be unhappy. There are winners and losers in *every* boundary decision. Therefore, arguments by Pillans and Naish (2004) and Gibbard et al. (2005) that, given the Vrica GSSP, certain units in Britain or western Europe or China that were recently included in the Pleistocene had to be transferred to the Pliocene, strike me as irrelevant. Nevertheless, possible improvements to the current ICS procedure for the revision of GSSPs are suggested in Section 10.

Furthermore, if taken too literally, the "intensional" approach to standard global chronostratigraphy is fundamentally at odds with the GSSP concept, because, in the present case, every time evidence of an older glaciation is discovered (Thiede et al., 1998; Ravelo et al., 2004; Carter, 2005), the beginning of the Quaternary and/or Pleistocene would have to be redefined (Vai, 1997; Aubry et al., 1998). There is nothing wrong with the fact that the major late Cenozoic Northern Hemisphere glaciations began during the late Pliocene (Vai, 1997), just as there is nothing wrong with the fact that the evolution of Metazoa occurred during the late Proterozoic.

10. Procedural aspects of the proposed redefinition of the Pliocene/Pleistocene boundary

10.1. Should the ICS rules for GSSP revision be revised?

The Italian Commission on Stratigraphy (2002) pointed out that after the defeat in December 1998 of a previous proposal to move the Pliocene/Pleistocene boundary from 1.8 Ma to 2.6 Ma (Suc et al., 1997; Morrison and Kukla, 1998; Mauz, 1998), no further attempt to achieve such a relocation could be considered for another ten years, according to the Guidelines of the ICS (Remane et al., 1996, p. 80). Thus, the new proposal by Gibbard et al. (2005) is a bit premature, and it seems counterproductive for the ICS Guidelines to allow unceasing attempts to overthrow the same GSSP every few years.[8] Such controversies are exactly what the GSSP concept was intended to minimize (Cowie et al., 1986; Aubry et al., 1998; Walsh, 2001, 2003, 2004a,b; Walsh et al., 2004). While nothing necessarily lasts forever (McLaren, 1977, p. 29), the current ten-year loophole in the ICS Guidelines allows for a continual intrusion of politics into what should be stable, conventional decisions. In my view, therefore, the prolonged existence of the Quaternary debate argues for an increase in the minimum time interval that must elapse before revision of a GSSP can be considered.

How can the ICS Guidelines be modified in such a way that repeated attempts to overthrow a given GSSP every few years are made impractical, while the eventual

[8] I must admit here that a previous discussion of this issue (Walsh, 2004a, section 7.9) was superficial because it did not separate the personal views of the late Jürgen Remane (Remane, 2000b,c) from the more ambivalent (but binding), collective views of Remane et al. (1996). As such, Aubry et al. (1998, 1999) are correct that the ten year loophole in the Remane et al. (1996) Guidelines serves as an open invitation to those on the "losing side" of the original ratification to unnecessarily redefine a GSSP.

redefinition of a truly flawed GSSP is not rendered impossible? I suggest that a staggered time schedule with staggered voting requirements could solve this problem. For example, as first approximations, any revision of a GSSP proposed less than 15 years after its initial ratification would have to be approved by a vote of, say, 80% of the voting members of the ICS body responsible for the boundary and a 70%+1 majority of the voting members of ICS itself (compare with Cowie et al., 1986, p. 6). Revision of a GSSP proposed between 15 and 30 years after its initial ratification would have to be approved by a vote of, say, 70% of the voting members of the ICS body responsible for the boundary and a 60%+1 majority of the voting members of ICS itself. Finally, revision of a GSSP proposed more than 30 years after its initial ratification would have to be approved by a vote of, say, 60% of the voting members of the ICS body responsible for the Boundary and a 50%+1 majority of the voting members of ICS itself. If a given GSSP is in fact revised, then the above time intervals and voting requirements for still further adjustment would be reset to the date of revision.

Such a staggered schedule would effectively terminate efforts to redefine the same GSSP every few years by workers motivated by personal politics or sour grapes, because the voting requirements would be too stringent. However, revision of a truly flawed GSSP would eventually become feasible under this scheme as the voting requirements relaxed over time. Nevertheless, the revision of any GSSP under this proposed system would still be relatively difficult. Once formally ratified, a GSSP should be regarded as the null hypothesis, to be rejected by future workers only at the 95% level of confidence that such a rejection is scientifically appropriate.

10.2. Shouldn't all geologists have a say in this?

Despite the above suggestions, given that a relocation of the Pliocene/Pleistocene boundary will be technically allowable according to current ICS Guidelines starting in December 2008, would such a relocation be a good idea? Holland et al. (2003), Melchin et al. (2004), Zalasiewicz et al. (2004), and Heckert and Lucas (2004) discussed some considerations involved in the possible redefinition of GSSPs. Holland et al. (2003) agreed that GSSPs are not necessarily immutable, but that “to change accepted global definitions, a highly significant ‘head of steam’ in the published literature should be demonstrated to trigger reconsideration by IUGS.”

In the case of the Pliocene/Pleistocene boundary a considerable head of steam has clearly been generated, and many Quaternary workers will argue that the Pliocene/Pleistocene GSSP at Vrica is among those 5% of GSSPs for which the null hypothesis deserves to be rejected. In my view however, even if a majority of Quaternary specialists wished to revise the Pliocene/Pleistocene boundary, that would not in itself be a sufficient reason for revision, because (unlike most standard global geochronologic units), virtually all geologists use “Quaternary” and “Pleistocene.” These geologists require stable definitions of these names for mapping, engineering geology, communication with non-geologists, and other purposes (see comments of J.K. Huber, L. Jackson, and D. Richter in Clague, 2006c). If a majority of *all* geologists (or perhaps, a majority of all national geological surveys) favored the 2.6 Ma boundary, then abandonment of the 1.8 Ma boundary might be well-advised. Perhaps national geological surveys should poll their members and report the results to the ICS. Clearly, the standard global time scale must serve all geologists. Therefore, because the responsibility of the ICS is to standardize the time scale, the ICS is ultimately responsible for serving all geologists, and not just Quaternary specialists.

11. Miscellaneous skeptical remarks on the proposed revision of the Pliocene/Pleistocene boundary

11.1. Chronostratigraphic imperialism

Those in favor of lowering the Pliocene/Pleistocene boundary appear to be correct that the Monte San Nicola GSSP is more correlatable than the Vrica GSSP (Gibbard et al., 2005), and if such a revision is made in accordance with ICS and IUGS procedures, then the revision will have to be respected. Even so, it is difficult to believe that there are no imperialistic motives involved. Consider the counterfactual situation. Suppose that the climatic and magnetic reversal history of the Earth had been different, and the Pliocene/Pleistocene boundary had originally been defined at 2.6 Ma. Suppose further that a horizon much more easily correlated by climatic and polarity–chronologic criteria had subsequently been recognized at 1.8 Ma. Would Quaternary geologists be just as vociferous in demanding that the ICS return 800,000 years of their territory to the Pliocene, in order to establish a more correlatable Pliocene/Pleistocene boundary at 1.8 Ma? If not, then one must admit that a significant element of imperialism does exist in the current proposals to expand the Quaternary and Pleistocene (see also Section 2).

Indeed, it is curious that most of those who oppose the upward extension of the Neogene to the present have no problem with extending the Quaternary and Pleistocene downward so as to include the Gelasian (see numerous comments in Clague, 2006c). But, imperialism is imperialism, whether it originates from above or below.

Interestingly, one reason why Berggren (1998) discussed the work of Moriz Hörnes and Eugène Renevier was to emphasize that Quaternary marine faunas were not very different from late Tertiary marine faunas. As such, the extended, intensionally-defined Neogene would be a more significant or "natural" *marine biochronologic unit* compared to the traditional extensionally-defined Neogene (Miocene + Pliocene). Similarly, however, advocates of the extended Quaternary argue that the resulting interval would be a more significant or "natural" *climatochronologic unit* than the existing Quaternary. Which argument is correct? Both (from the standpoint of the probable facts of each case) and neither (as to the implication that either faunal or climatic criteria can trump all other considerations in the definition of standard global geochronologic units). That is why we have the GSSP process; to reach conventional boundary decisions by debate, compromise, and democratic vote, and that is how the Pliocene/Pleistocene boundary GSSP at Vrica was established (Aguirre and Pasini, 1985; Pasini and Colalongo, 1997; Lourens et al., 2004).

Although their absolute durations are relatively short, the Quaternary and Pleistocene have nevertheless grown in terms of percentage far more than any other unit in the standard global time scale over the past 150 years, at the expense of the Pliocene, Neogene, and Tertiary (Berggren, 1998; Lourens et al., 2004). Indeed, if the current proposal to enlarge the scope of the Pleistocene is approved, then the Pliocene and Pleistocene would have virtually equal durations (2.7 and 2.6 m.y., respectively), and the Pliocene would be further reduced in duration to a mere 13% of the Miocene (2.7 m.y. vs. 20.3 m.y., respectively, given the time scale of Gradstein et al., 2004b). Although these results are not literally incorrect, they are certainly unnecessary in my view.

Furthermore, if the current request to expand the scope of the Quaternary and Pleistocene is approved, what is to stop future Quaternary workers from demanding even more concessions from the Pliocene if their understanding of the onset of the ice ages changes? Quaternary workers may protest that they will have no further territorial ambitions after this "final" request for expansion is granted. However, given that evidence now exists for northern hemisphere glaciations as old as 14 Ma (Thiede et al., 1998; Lourens et al., 2004), future proposals for even further lowerings of the Quaternary are not inconceivable.

11.2. Could the GSSP concept be jeopardized?

Many of our decisions have unintended consequences. If the campaign for the redefinition of the beginning of the Quaternary and Pleistocene is successful, a major psychological threshold would be crossed in that the Vrica GSSP would be the first properly-ratified standard global geochronologic boundary to be revised (and, in percentage terms, to be revised substantially). Similar campaigns against other GSSPs would then likely be initiated (e.g., Holland et al., 2003 vs. Melchin et al., 2004). In particular, it is possible that many hard-won GSSPs would be targeted by those who were on the "losing sides" of a close vote for ratification. Therefore, unless the ICS strengthens its current requirements for GSSP revision (Section 10.1), I again question the need to redefine the *conventional* Pliocene/Pleistocene boundary at Vrica (Italian Commission on Stratigraphy, 2002). The potential for a wider disruption of the time scale is a serious matter, so the burden of proof is on those who favor redefinition.

12. The irony of the present situation and its lessons for standard global chronostratigraphy

Between 1985 and 1995 there seems to have been little interest in redefining the base of either the Quaternary or the Pleistocene, both of which were accepted by most Quaternarists to correspond to the GSSP at Vrica (Aguirre and Pasini, 1985). Today, however, the relocation of the beginnings of both of these units to the Monte San Nicola GSSP seems almost inevitable (see comments in Clague, 2006c), and will likely occur sometime after the expiration of the ten-year ICS moratorium in December 2008. It is instructive to review the causes which have led to this change of opinion.

First, on various grounds (some of which have already been criticized above), several Quaternary workers began to advocate a redefinition of the Pliocene/Pleistocene boundary in the late 1990s (Partridge, 1997; Suc et al., 1997; Morrison and Kukla, 1998; Mauz, 1998). Their formal proposal was defeated (Remane and Michelson, 1998), but a residue of discontent remained.

Second, and at about the same time, Rio et al. (1998) created the late Pliocene Gelasian Standard Global Age/Stage, based on a "unit stratotype-sanctifying philosophy" (criticized by Walsh, 2004a).[9] The creation of this

[9] See Hilgen et al. (2006) for a recent development of this philosophy. Although I agree with Hilgen et al. that unit stratotypes (sensu stricto) can in principle *sometimes* be used in standard global chronostratigraphy, two statements from Walsh (2004a, p. 122) quoted by these authors require clarification (Hilgen et al., 2006, pp. 113–114). In those statements I was (regrettably) using the term "unit stratotype" in the same way that it was (incorrectly) used by Aubry et al. (1999); that is, in the sense of the boundaries of a stage as originally defined in the *historical* stratotype. The distinction between these and other kinds of stratotypes are more fully discussed by Walsh (2005a,b,c).

very short Age/Stage established a GSSP at 2.6 Ma that would be ready-made for the transfer of the Pliocene/Pleistocene boundary when the political circumstances for such a transfer became more favorable. Without the prior existence of this GSSP, the search for a new boundary stratotype section for a revised Pliocene/Pleistocene boundary would have been very difficult to initiate within the ICS.

Third, the repeated arguments of W.A. Berggren and his colleagues for eliminating the Quaternary and extending the Neogene to the present (Berggren et al., 1995a; Berggren, 1998) have irritated many Quaternarists. Nevertheless, these arguments (criticized in Sections 5–8) were accepted by the ICS when the Neogene chapter in the recent time scale volume was co-authored mainly by marine workers (Lourens et al., 2004), without adequate input from the Quaternary community (for example, Gibbard, 2005).

Fourth, the reaction of the Quaternarists to the elimination of the Quaternary has been understandably intense (Giles, 2005; Clague, 2006c), and even resulted in an early overreaction — the proposal by Pillans and Naish (2004) to detach the beginning of the Quaternary from the beginning of the Pleistocene.

Fifth, the publication of the compromise of Aubry et al. (2005) and its acceptance by the ICS (Gradstein, 2005). The result, which was criticized in Section 6.2, illustrates Kleinpell's (1979, p. 11) view that "such symposia can sometimes degenerate into legalistic arbitrations and "back room" caucus sessions that are more in the field of geo-politics than stratigraphic paleontology."

Finally, the justifiable rejection of the ICS Recommendation by INQUA members has led to a new-found feeling of confidence among Quaternarists (see comments in Clague, 2006c; Stratigraphy Commission of the Geological Society of London, in press). It appears that in return for suffering the above indignities at the hands of Neogene-expanders and Quaternaryphobes for several years, many Quaternarists now believe that they are entitled to get exactly what they want — namely, the redefinition of the beginnings of both the Quaternary and the Pleistocene at 2.6 Ma.

So, the irony of the present situation is that by advocating the extension of the Neogene to the present and/or the elimination of the Quaternary, Berggren et al. (1995a,b), Van Couvering (1997a), Berggren (1998), and Aubry et al. (2005) have indirectly contributed to the probable eventual redefinition of the one boundary that they have most forcefully argued should *not* be changed — the Pliocene/Pleistocene boundary at Vrica (Aubry et al., 1998, 2005).

Some lessons to be learned from these developments are as follows. First, the arguments of accomplished scientists may nevertheless be invalid, and such arguments should not be accepted by the ICS merely on the authority of the arguers, especially when those authorities are advocating major changes to the hierarchical structure of the geological time scale. Second, review papers in future ICS publications should be co-authored by workers having a variety of viewpoints, so that controversial views can be subjected to serious internal criticism before publication. Third, as noted in Section 6.1, the revised Guidelines of the ICS should explicitly state that the structure of the ranked standard global time scale *must be strictly hierarchical.* This requirement alone would have prevented many of the controversies of the last three years. Finally, chronostratigraphic imperialism can have unintended consequences. This observation applies to those who wish to extend the Neogene to the present, as well as to those who wish to extend the beginning of the Quaternary and/or Pleistocene to 2.6 Ma.

13. Summary

Owing mainly to the lobbying efforts of W.A. Berggren and his colleagues over the past several years, the Tertiary and Quaternary were excluded from the geologic time scale of Gradstein et al. (2004a,b), and the Neogene was extended to the present. However, the Tertiary and Quaternary are still widely used and so deserve to be formalized (Salvador, 2004, 2006). Although there have been several recent proposals for the subdivision of the Cenozoic, some of these have failed to take into account standard principles of hierarchical classification. These principles serve to restrict our options in determining the ranks and structure of a given classification, and therefore help to minimize the political influence of powerful individuals in their design.

Contrary to Berggren (1998), there is nothing in the traditional hierarchical subdivision of the Cenozoic Era that needs reforming. If Tertiary and Quaternary are to be ranked subdivisions of the Cenozoic, then the only arrangements consistent with the principles of hierarchical classification are for the Tertiary and Quaternary to be ranked as Suberas (with the Paleogene and Neogene ranked as Periods of the Tertiary), or for the Tertiary and Quaternary to be ranked as Periods (with the Paleogene and Neogene ranked as Subperiods of the Tertiary). However, the first option leaves the period rank unfilled for Quaternary time (at least initially), and so the second option is preferred here. In neither case is an extension of the Neogene to the present permitted, because the

Quaternary (of superior rank) would then be contained entirely within the Neogene (of inferior rank), which violates the most fundamental principle of hierarchical classification.

Attempts by some authors to support the extension of the Neogene by appealing to an ambiguous statement of King and Oakley (1949) fail because they are based on a demonstrable misinterpretation of that statement. Likewise, Berggren's (1998) appeal to a principle of the priority of original meaning of the Neogene fails because it is factually superficial and would also result in unacceptable consequences for the rest of the time scale.

"Late Cenozoic" is a very useful expression for the concept that many workers have recently called "Neogene." Although the Early Cenozoic and Late Cenozoic would normally be assigned the rank of Subera, that arrangement is impermissible if the Tertiary and Quaternary are ranked as Periods. If desired, however, the Early Cenozoic and Late Cenozoic could be formally defined as unranked chrons (Salvador, 1994), with their mutual boundary equated with the Oligocene/Miocene boundary.

Recent proposals for the subdivision of the Cenozoic made by Pillans and Naish (2004), Aubry et al. (2005), and Gradstein (2005) are fundamentally flawed. The preferred arrangement of Pillans and Naish (2004), in decoupling the beginning of the Quaternary from the beginning of the Pleistocene, violates the conterminosity convention in the ICS Guidelines of Remane et al. (1996) in that the beginning of a unit of superior rank (Quaternary Subperiod) would not correspond with the beginning of its oldest subdivision of immediately inferior rank (Pleistocene Epoch). In addition, the Gelasian Stage would simultaneously belong to both the Quaternary and the Pliocene, unnecessarily complicating the depiction of this Stage on geologic maps. The favored option of Pillans and Naish (2004) also violates Simpson's rule in that the extended Neogene Period would not be completely divided into Subperiods.

The proposal of Aubry et al. (2005) and Gradstein (2005) violates the ICS Guidelines of Remane et al. (1996) in that the beginning of the Quaternary Subera does not correspond to the beginning of any Period or Epoch (convention of conterminosity), in the fact that the Gelasian Stage would simultaneously belong to both the Quaternary and the Pliocene, and in the fact that the Pliocene Epoch and Neogene Period would belong in part to both the Tertiary and the Quaternary (principle of non-overlap). It also violates the basic rules of hierarchical classification in that the contents of a name of superior rank (Quaternary Subera) would be included entirely within the content of another name given an inferior rank (Neogene Period).

The proposals of Aubry et al. (2005) and Gradstein (2005) could be improved somewhat if the Paleogene and extended Neogene were ranked as Suberas, the Quaternary was ranked as a Period, and the beginnings of the Quaternary and Pleistocene were restored to equivalence. However, this arrangement would leave the Tertiary unranked and would fail to completely divide the Neogene Subera into periods, thus violating Simpson's rule twice. It would also violate the convention of conterminosity. These problems could be minimized by coining a new period name for the pre-Quaternary part of the extended Neogene, but that new name would be identical in meaning to the traditional concept of the Neogene, thus revealing the extension of the latter to be quite unnecessary.

At least four arguments against a ranked Tertiary and/or Quaternary have been made, but can be readily refuted. First, contra Berggren (1998), the fact that these names are parts of an obsolete classification whose other names (Primary and Secondary) were abandoned long ago is irrelevant to the status of Tertiary and Quaternary, because these terms are still highly useful (Salvador, 2006). Indeed, if this argument was consistently applied to the rest of the time scale, we would have to abandon the names "Carboniferous" and "Cretaceous" because they are parts of an obsolete, lithology-based classification whose other names were abandoned even longer ago.

Second, contra Gradstein (2005), the disparity in the durations of the Tertiary and Quaternary is not a compelling reason for their exclusion from the standard global time scale, just as the disparity in the durations of the Pleistocene and Holocene is not a compelling reason to abandon these names.

Third, it has been suggested by Ogg (2004) and Pillans and Naish (2004) that the Tertiary and/or Quaternary could be left as unranked units, just as the Precambrian is still a widely used but unranked unit. However, the Precambrian has never had a consistent rank applied to it. Second, its enormous duration would require us to coin a new rank term (Supereon?) in order for it to include the Archean and Proterozoic Eons. Application of Simpson's rule would then require us to coin a new name with the same rank to redundantly apply to the Phanerozoic Eon. In contrast, the Tertiary has been consistently ranked as a period, and the application of Simpson's rule would not require us to coin a new name for the remaining part of the Cenozoic Era because we already have the Quaternary Period. The "Precambrian analogy" is therefore unconvincing.

Fourth, contra Suguio et al. (2005), the fact that the name "Quaternary" has several connotations does not mean that it cannot be well-defined, nor that it should be removed from the standard global time scale. For example, the name "Mesozoic" has several connotations (Age of Ammonites; Age of Reptiles), but this Era is now precisely defined by GSSPs. The same will be true of the Tertiary and Quaternary when a formal definition of their mutual boundary is reached.

At least three arguments can be made in favor of a ranked Tertiary. First, this name is still very widely used in stratigraphic publications (Salvador, 2006). Second, the disparity in the durations of the Tertiary and Quaternary is irrelevant in the context of geologic maps, because in many regions the areal extent of Quaternary deposits approaches or even exceeds that of the pre-Quaternary deposits (Gibbard et al., 2005). As such, a formal division of the Cenozoic into Tertiary and Quaternary is often more practical in this context. Third, retention of the Tertiary as a ranked unit would honor and call attention to the careers of Lyell, Cuvier, Brongniart, Brocchi, Deshayes, and Prévost, all of whom laid crucial parts of the foundation of our understanding of this part of Earth history.

Despite the best efforts of a persistent group of chronostratigraphic aestheticians to kill them off, the Tertiary and Quaternary are here to stay (Salvador, 2006). As such, there are no compelling reasons to accept any of the changes to the Cenozoic time scale that have been proposed by Pillans and Naish (2004), Aubry et al. (2005), and the ICS (Gradstein, 2005). In particular, the shortsighted extension of the Neogene to the present creates distortions in the hierarchical structure of the time scale. These distortions hamper clear communication among geologists and are therefore self-defeating. In contrast, because the classification shown in Fig. 1B violates none of the existing Guidelines of the ICS, obeys Simpson's rule, requires no new names, is strictly hierarchical, allows the Tertiary, Quaternary, Paleogene, and Neogene to be formally ranked and unambiguously depicted on geologic maps, and has also been in general use for more than a century, it is to be preferred.

The proposal of Gibbard et al. (2005) has the merit of retaining the identity of the beginnings of the Quaternary and Pleistocene, but would relocate this mutual boundary from the Vrica GSSP at 1.8 Ma to the Monte San Nicola GSSP at 2.6 Ma, which is problematical.

In opposing the transfer of the Pliocene/Pleistocene boundary from 1.8 Ma to 2.6 Ma, Aubry et al. (1998) believed the "Subapennine marls of Asti" to be of latest Pliocene (Gelasian) age, and regarded them as a strict name-bearer for the modern Pliocene. However, Selli (1967) and Rio et al. (1998) pointed out that the Astian yellow sands of Northern Italy are actually of early and/or middle Pliocene age. As such, it would appear that the Pliocene/Pleistocene boundary could be relocated from 1.8 Ma to 2.6 Ma without violating the status of Lyell's (1833) Asti locality as a strict name-bearer for the modern Pliocene. In contrast, if this relocation were to occur, then the status of the "English Crag" as a strict name-bearer for the modern Pliocene *would* be violated, because its youngest components (Red Crag and Norwich Crag) would have to be transferred to the Pleistocene. This point is moot, however, because Lyell (1851) himself transferred the Norwich Crag from the Older Pliocene to the Newer Pliocene (later to become the Pleistocene), and therefore did not view the "English Crag" as a strict name-bearing type for the Older Pliocene.

In opposition to the above conclusion, an argument could be made that only strict nominal stratotypes are appropriate in standard global chronostratigraphy, in which case the Pliocene/Pleistocene boundary could never be defined at a horizon that was older than the top of the Norwich Crag. However, the enforcement of this principle would be impractical for three reasons. First, such a principle would often prevent us from adopting a revised concept of a given named unit, even if this revised concept was provided by the same worker who originally proposed the unit. As such, in many cases, original authors would be retrospectively forbidden from revising their own work. Second, exclusive use of the principle of strict nomenclatural constraint would force us to redefine the boundaries of many of our standard global geochronologic units, including the Silurian/Devonian, Cretaceous/Tertiary, and Eocene/Oligocene boundaries. Third, when the nominal stratotypes of two historical stages overlap one another in time, and the names of these historical stages are still chosen to be used for successive divisions of the standard global time scale, both names could not be retained without violating the strict name–typology of at least one of them. The Tithonian/ Berriasian and Tortonian/Messinian standard global ages/stages exemplify this situation.

The continued existence of the Quaternary debate argues for a revision of the ICS Guidelines, which currently allow a ratified GSSP to be revised after only ten years with minimal voting requirements (Remane et al., 1996). A staggered time schedule with staggered (but generally more strict) voting requirements could make politically-motivated attempts to overthrow a given GSSP every few years impractical, but would not render unfeasible the eventual redefinition of a truly flawed GSSP.

Although revision of the Pliocene/Pleistocene boundary will become possible according to the current ICS

Guidelines after 2008, I see no compelling need for such a revision, because there is nothing wrong with having the major late Cenozoic Northern Hemisphere glaciations begin during the Pliocene (Vai, 1997). The Quaternary and Pleistocene have already grown enormously in relative duration from their original extent over the past 150 years, at the expense of the Tertiary, Neogene, and Pliocene. More importantly, if a redefinition of the beginning of the Quaternary and/or Pleistocene is approved, a major psychological threshold would be crossed in that the Vrica GSSP would be the first properly-ratified standard global geochronologic boundary to be revised. Similar campaigns against other GSSPs would then likely be initiated. It is in view of this potential for a wider disruption of the time scale that I question redefinition of the *conventional* Pliocene/Pleistocene boundary at Vrica (Italian Commission on Stratigraphy, 2002).

Despite the above, because the Quaternary and Pleistocene are of unique importance in geology, if a majority of *all* geologists (and not just Quaternary specialists) are in favor of a Pliocene/Pleistocene boundary at 2.6 Ma, then such a redefinition could hardly be criticized. It is therefore suggested that all national geological surveys and stratigraphic commissions be formally polled by the ICS in order to determine the preference of the entire geological community.

An examination of the causes of the current controversy shows that four main lessons should be learned. First, arguments regarding the structure of a particular part of the time scale should not be accepted by the ICS merely on the basis of the authority of the arguer. Second, review chapters in future ICS publications should be co-authored by workers having a variety of viewpoints, so that controversial views can be subjected to serious internal criticism before publication. Third, future Guidelines of the ICS should explicitly state that the structure of the ranked standard global time scale must be strictly hierarchical. Finally, chronostratigraphic imperialism can have unintended consequences. This observation applies both to those who wish to extend the Neogene to the present, and to those who wish to extend the beginning of the Quaternary and/or Pleistocene to 2.6 Ma.

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