The Neogene and Quaternary: chronostratigraphic compromise or non-overlapping magisteria?

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ABSTRACT: The International Commission on Stratigraphy (ICS) together with its subcommissions on Neogene Stratigraphy (SNS) and Quaternary Stratigraphy (SQS) are facing a persistent conundrum regarding the status of the Quaternary, and the implications for the Neogene System/Period and the Pleistocene Series/Epoch. The SQS, in seeking a formal role for the Quaternary in the standard time scale, has put forward reasons not only to truncate and redefine the Neogene in order to accommodate this unit as a third System/Period in the Cenozoic, but furthermore to shift the base of the Pleistocene to c. 2.6 Ma to conform to a new appreciation of when "Quaternary climates" began. The present authors, as members of SNS, support the well-established concept of a Neogene extending to the Recent, as well as the integrity of the Pleistocene according to its classical meaning, and have published arguments for workable options that avoid this conflict. In this paper, we return to the basic principles involved in the conversion of the essentially marine biostratigraphic/ biochronologic units of Lyell and other 19th-century stratigraphers into the modern hierarchical arrangement of chronostratigraphic units, embodied in the Global Standard Stratotype-section and Point (GSSP) formulation for boundary definitions. Seen in this light, an immediate problem arises from the fact that the Quaternary, either in its original sense as a state of consolidation or in the more common sense as a paleoclimatic entity, is conceptually different from a Lyellian unit, and that a Neogene/Quaternary boundary may therefore be a *non sequitur.* Secondly, as to retaining the base of the Pleistocene at 1.8 Ma, the basic hierarchical principles dictate that changing the boundary of any non-fundamental or "higher" chronostratigraphic unit is not possible without moving the boundary of its constituent fundamental unit. Therefore, to move the base of the Pleistocene, which is presently defined by the Calabrian GSSP at 1.8 Ma, to be identified with the Gelasian GSSP at 2.6 Ma, requires action to formally redefine the Gelasian as part of the Pleistocene. Finally, it is important to keep in mind that the subject under discussion is chronostratigraphy, not biostratigraphy. Both systems are based on the fossil record, but biostratigraphic units are created to subdivide and correlate stratigraphic sequences. The higher-level units of chronostratigraphy, however, were initially selected to reflect the history of life through geological time. The persistence of a characteristic biota in the face of environmental pressures during the last 23 my argues strongly for the concept of an undivided Neogene that extends to the present.

Several ways to accommodate the Quaternary in the standard time scale can be envisaged that preserve the original concepts of the Neogene and Pleistocene. The option presently recommended by SNS, and most compatible with the SQS position, is to denominate the Quaternary as a subperiod/subsystem of the Neogene, decoupled from the Pleistocene so that its base can be identified with the Gelasian GSSP at c. 2.6 Ma. A second option is to retain strict hierarchy by restricting a Quaternary subperiod to the limits of the Pleistocene at 1.8 Ma. As a third option, the Quaternary could be a subera/suberathem or a supersystem/ superperiod, decoupled from the Neogene and thus with its base free to coincide with a convenient marker such as the base of the Pleistocene at 1.8 Ma, or to the Gelasian at 2.6 Ma, as opinions about paleoclimatology dictate. If no compromise can be reached within hierarchical chronostratigraphy, however, an alternative might be to consider Quaternary and Neogene as mutually exclusive categories (climatostratigraphic vs. chronostratigraphic) in historical geology. In this case, we would recommend the application of the principle of NOMA, or Non-Overlapping Magisteria, in the sense of the elegant essay by the late Stephen J. Gould (1999) on the mutually exclusive categories of Religion and Science. In this case the Quaternary would have its own independent status as a climatostratigraphic unit with its own subdivisions based on climatic criteria.

INTRODUCTION

The tide of protest that arose after the International Commission on Stratigraphy (ICS) omitted the category "Quaternary" from the latest incarnation of the Chronostratigraphic Scale (Gradstein et al. 2004), forced the Neogene community (principally researchers in marine stratigraphy, but also a significant number of nonmarine workers, who consider the Neogene to extend to the present) to consider the assertion of the Quaternary community (principally workers involved in nonmarine paleoclimatology but also many state and national geological surveys who are accustomed to applying this term to all unconsolidated deposits) that the final 2.6 million years (my) of geological time should be considered as an interval of Earth history so dramatically distinct as to be a separate Quaternary period (e.g., Gibbard et al. 2005; Bowen and Gibbard 2007; Head et al. 2008). This is to return to the same strident, seemingly endless debate about the meaning of the "ice ages" that consumed the profession for more than a century up to the establishment of the Pleistocene GSSP at Vrica (cf. Berggren and Van Couvering 1978; Van Couvering 1997; see Kerr 2008), but now one in which the division of the Cenozoic itself is at stake.

Far from being restricted to two subcommissions of the ICS, the Neogene-Quaternary controversy represents an important debate that concerns the stratigraphic community at large because it brings into question the very fundamental concept of chronostratigraphy and its principles.

Papers about the controversy have either been devoted to justifying the formal use of the term Quaternary (Head et al. 2008; Ogg and Pillans 2008; and citations therein), to defending the original concept of a Neogene Period that extends to the Present (Berggren 1998; Hilgen et al. 2008; Lourens 2008; McGowran et al., in press; and references therein) or to explore solutions to the problem (e.g., Pillans and Naish 2004; Aubry et al. 2005; Walsh 2006, 2008). An essential aspect of Earth history has been neglected in these discussions: namely, the role that biotic history plays in the temporal subdivision of the geological record, and in particular its role in the delineation of the Neogene Period. The objective of this paper is to demonstrate that there was no major break in the evolutionary history of life in the past 23 my, that would justify a three-fold subdivision of the Cenozoic Era at the period level. Prior to this however, it is necessary to clarify an often-misunderstood relationship between chronostratigraphy and means of stratigraphic correlation, and in particular biostratigraphy. For clarity, we first review briefly the content of the Neogene- Quaternary controversy.

THE NEOGENE-QUATERNARY CONTROVERSY: A BRIEF OVERVIEW

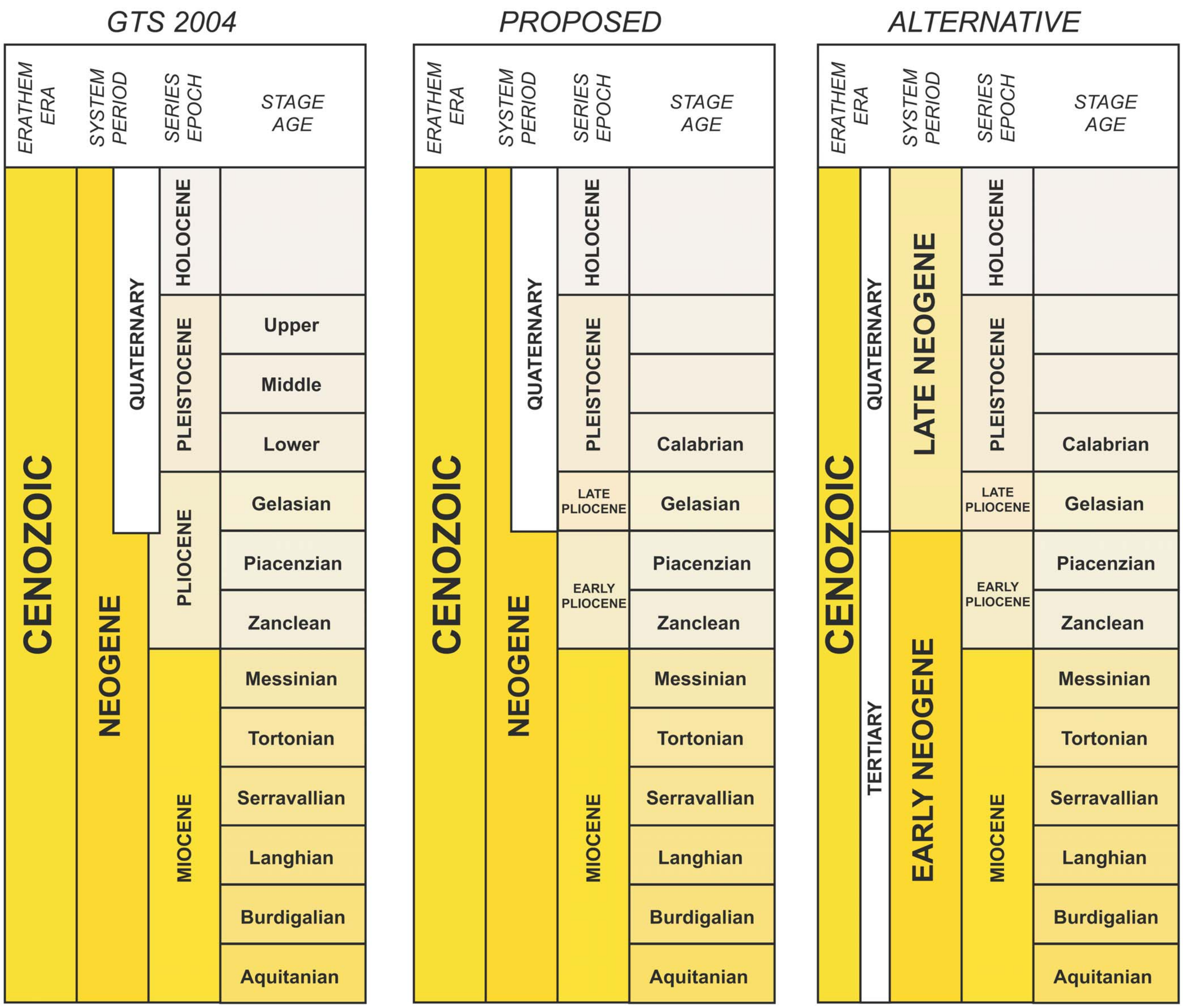
The position of the SQS in the Neogene-Quaternary debate is straightforward, inflexible, and exclusive. The SQS requests the formalization of a *Quaternary Period* in recognition of what it sees to be an unprecedented climatic time in Earth history. Continental sedimentary deposits of the last 2.6 my distinctly reflect an intensification of climate cycles superimposed on the general cooling trend in the Cenozoic, that resulted in the periodic development of continental ice sheets in the Northern Hemisphere. For instance, the earliest deposition of glacially-derived Chinese loess across northern China constitutes a prominent and easily mapped lithostratigraphic record of the beginning of this new phase. The appearance of new elements in the continental fauna, in particular that of the genus *Homo,* has also been linked to this particular shift in climate. As a consequence, in the view of SQS, the base of the Pleistocene Series should be lowered according to a new consensus on the beginning of "Quaternary conditions", using the GSSP of the Gelasian Stage at San Nicola (Rio et al. 1998) to provide the necessary definition for a chronostratigraphic unit. The Cenozoic Erathem would thus be divided in three parts (as has often been accepted in the past, and still is by some, e.g., Cita 2008), but—in an unprecedented move—the Quaternary would include stratigraphic units that have *always* been included in the Neogene System and Pliocene Series.

The position of the SNS is also straightforward, but with the intention of being more flexible and inclusive. For reasons that are historical (original definition of the Neogene by Hörnes 1853), methodological (the use of the astrochronological calibration of the stratigraphic record to refine the numerical time scale) and rational (that the cooling cycle that began at 2.6 Ma, whatever its local impact, was only one of the steps in the irregular progress of global cooling that began in the late Eocene), the SNS holds the view that the Cenozoic Erathem/Era comprises only two systems/periods—Paleogene and Neogene—and the Pleistocene Series must remain tied to the Calabrian Stage (Berggren 1998; Aubry et al. 2005; Hilgen et al. 2008; Lourens 2008; McGowran et al., in press). This position has also been found acceptable to some members of the Quaternary community (Pillans et Naish 2004). In accordance with the rules of chronostratigraphy, in which series are defined by their lowest stage, the base of the Calabrian Stage and the Pleistocene Series were simultaneously formalized by the establishment of the Calabrian GSSP at Vrica (Van Couvering 1997; see review in Aubry et al. 1999). The recent proposal of a unit-stratotype of the Calabrian Stage at Vrica (Cita et al. 2006, 2008) further emphasizes the role of the base of the Calabrian Stage in fixing the base of the Pleistocene Series. Although uncompromising with regard to the upper/younger limit of the Neogene, the SNS has offered several options for resolving the Neogene-Quaternary controversy that are *inclusive solutions*, allowing both communities to conduct their research within a sound, formal chronostratigraphic framework (text-fig. 1).

The concept of an extended Neogene is supported by a majority of earth scientists who work in the marine realm, whether paleontologists, stratigraphers, or paleoceanographers, as well as by a substantial number of terrestrial (predominantly vertebrate) paleontologists. While the concept of a formal Quaternary System is also widely supported (cf. Open Meeting on the Neogene-Quaternary, at the 33 IGC, Oslo, 9 August 2008) there is disagreement within this group as to the appropriate location and status of its base. This may be because the formal definition of the Pleistocene in the GSSP of the Calabrian Stage at Vrica was set forth by IGCP 41. The objective of the latter was to carry out the resolution adopted at the 1948 London IGC to establish a physical reference point for the base of the Pleistocene (1.8 Ma), point which would also mark the beginning of the Quaternary (Van Couvering 1997). Accordingly, a number of the organizations that support formalization of the Quaternary, such as the Austrian Geological Survey and the United States Geological Survey, as well as the national stratigraphic committees of Austria (P. Smolka, personal communication, August 2008), and Russia (Y. Gladenkov, personal communication, August 2008), and the North American Commission on Stratigraphic Nomenclature (NACSN), accept the IGCP 41 determination. The conflicting proposal by SQS is based on the fact that it has become possible to date evidence for an earlier glacial cycle beginning c.2.6 Ma, prior to the more widely recognized cycle that began c. 1.8 Ma (see Hilgen et al. 2008, fig. 2). The basic premise of the SQS is that the most recent period of intensified global cooling deserves special recognition. Some see it as a grand conceptual "Age" compared to the Tertiary "Age of Mammals", the Mesozoic "Age of Reptiles" and the Paleozoic "Age of Fishes", but whether as an "Age of Man" or "Age of Ice" is not agreed. In actual practice, however, the Quaternary is distinct, in the minds of most geologists, not in the time sense but in its medieval sense as the fourth stage of lithification/consolidation, in which deposits are assigned to the Quaternary based on lithology or geomorphology, and designated as "Qt", "Qal", etc., with little concern for their actual age. The question before us, however, is how to reconcile the unique Quaternary concept, however it is expressed, with the standard chronostratigraphic scale.

The role of marine biostratigraphy in global chronostratigraphy

Although Walsh waivered on the status of the Quaternary in chronostratigraphy (compare Walsh 2006 and 2008), his analysis of the concept "Neogene" provided the SQS with documentation that appeared to reinforce the legitimacy of its request. Walsh's argument (2008) revolved around two propositions.

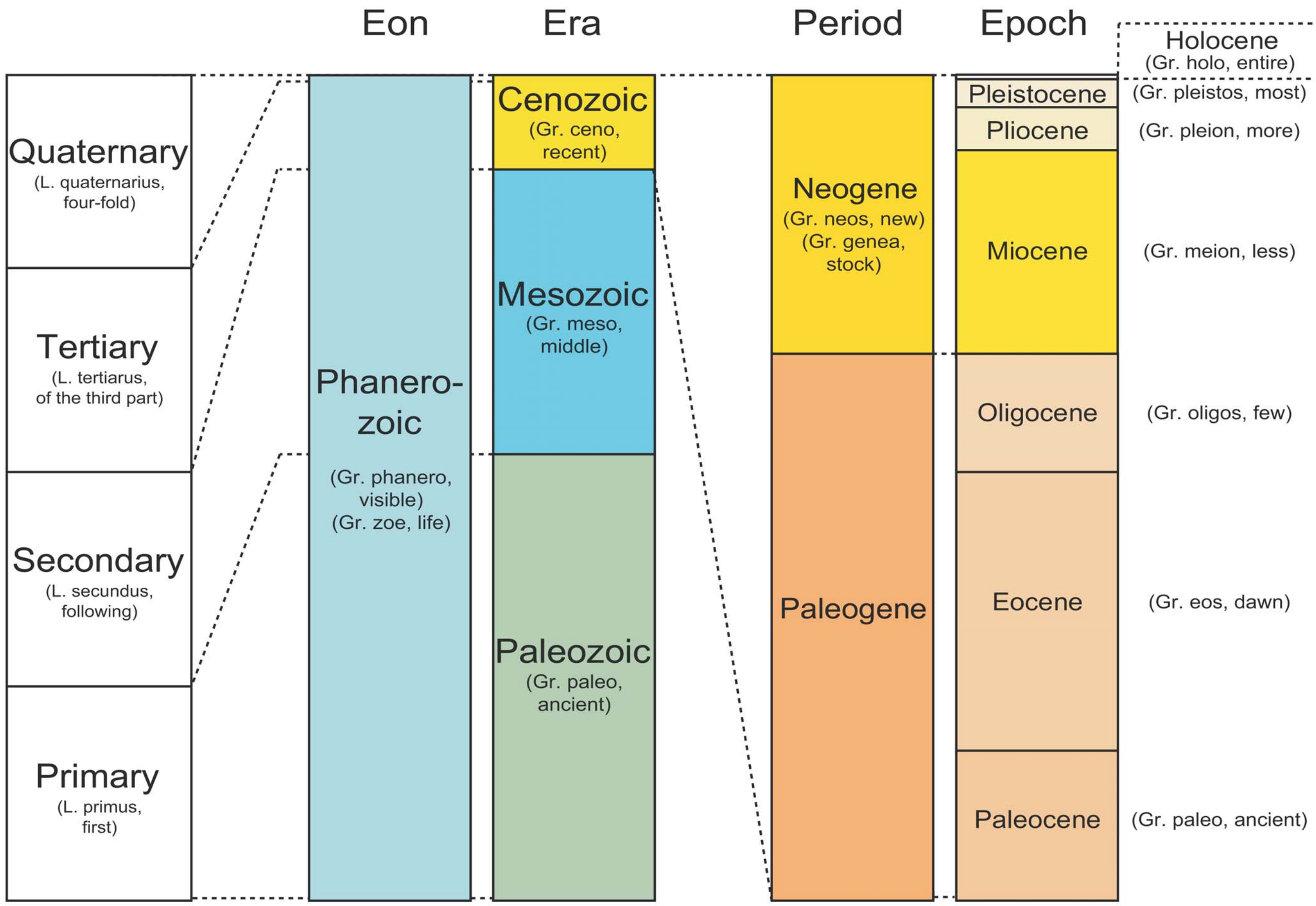


TEXT-FIGURE 1
Solutions proposed by the SNS to resolve the Neogene-Quaternary controversy. One solution ("proposed") is to formalize the Quaternary as a subsystem/subperiod (shown; our preferred solution) or a superseries/superepoch (Lourens 2008). The other solution ("alternative") is to formalize the Quaternary as a subera of the Cenozoic following Aubry et al. (2005). Both solutions are valid whether the base of the Quaternary is defined by the base of the Calabrian Stage at 1.8 Ma (in which case the Quaternary will be equated with the Pleistocene) or by the base of the Gelasian Stage at 2.6 Ma (in which case the Quaternary will encompass the upper Pliocene and the Pleistocene. The ICS and several of its subcommissions will now debate the fate of the Neogene and Quaternary, following submissions by the Subcommissions on Neogene Stratigraphy (SNS) and Quaternary Stratigraphy (SQS) of proposals to the ICS (as requested by ICS Chairman Stan Finney, at the ICS in Oslo, 9 August 2008).

One is that Bronn's intent in introducing the Neogene was ambiguous. The other is that marine biostratigraphy has overextended its "monopoly" in the matter of chronostratigraphy. In Walsh's opinion there is no reason that climatic criteria cannot play a decisive role in the *definition* of chronostratigraphic units. The first proposition is dealt with in McGowran et al. (2008) who reaffirmed the continuity of the Neogene extending to the present, while clarifying a common confusion between the hierarchies in taxonomy and chronostratigraphy. Walsh's far-reaching second proposition requires scrutiny here, even though one might have hoped that extensive discussion on this subject would have already sufficed to clarify the role of paleontology in Earth Sciences.

Principles of an historical geology

The time had to be right for stratigraphy, that quintessentially historical science, to flourish. For many years Nicolaus Steno's 17th-century principles of rock relationships (1669) languished without meaningful application or even discussion. Robert Hooke who (1705) speculated that one might erect a chronology based on the fossils in strata, may have been the first of several in the 18th century who glimpsed this association. Towards the end of the century, the prolific lateral thinker Johann Wolfgang von Goethe wrote (1782) in a letter to his friend Merck: "*Es wird bald die Zeit kommen wo man Versteinerungen nicht mehr durcheinanderwerfen, sondern verhältnismäßig zu den Epochen der Welt rangieren wird* [The time will soon come

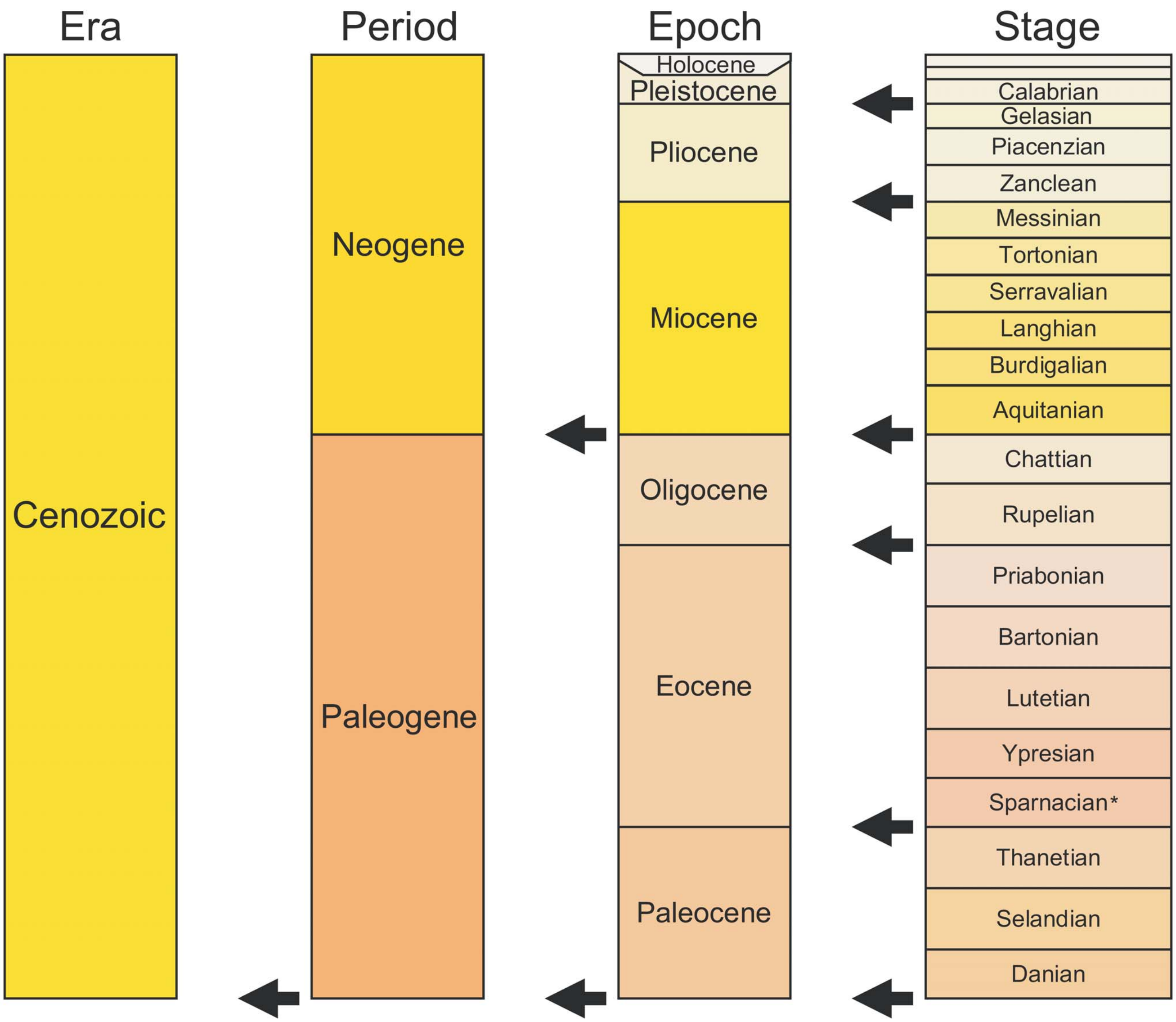


TEXT-FIGURE 2
The periods and epochs of the Cenozoic era. The etymology of their name is indicative of the biostratigraphic/biochronologic concept they originally expressed. This common etymology gives a remarkable integrity to Cenozoic chronostratigraphy. The terms Tertiary and Quaternary are remnants of an antiquated classification of rocks based on an assumed time of formation (Arduino 1760). The terms *Primary* and *Secondary* have been eliminated from the hagiography. The terms *Tertiary* and *Quaternary* are redundant (Berggren 1998, contra Salvador 2006). For full references, the names given to eras were introduced by Philips (1840), those of periods by Hörnes (1856, those of series by Lyell (1830-1833), Hörnes (1853; but see discussion in Walsh 2008), Beyrich (1854) and Schimper (1874).

when one will not mix up fossils, but order them to the Epochs of the world]'. The time, in fact, had already arrived. While many emphasize the significance of the "deep time" theory of James Hutton vis-à-vis the "deep space" theory of William Herschel (Holmes 2008), an appreciation of the duration of geological time was already commonplace among their contemporaries on the continent (Rudwick 2005). Credit is widely given to William Smith for the careful use of fossils to identify stratigraphic units, but Georges Cuvier and Alexandre Brongniart soon went beyond Smith in reconstructing an alternation of marine and freshwater environments from evidence of molluscan assemblages and (thence) a *geohistory* of the Paris region: "They reconstructed a complex story in which the seas had alternated in the deep past with freshwater lakes or lagoons: it was a geohistory as unpredictable and contingent as the turbulent politics they had both lived through in the past two decades" (Rudwick 2005, p. 648).

The study of fossils in sedimentary strata was absolutely central to the developing understanding of earth history (Laudan 1987; McGowran 2005; Rudwick 2005). Fossils could be grouped in specific assemblages, each assemblage characteristic of correlative strata, i.e., strata thus deposited during the same interval of time. Rudwick (2008) describes the emerging realization that successional fossil assemblages of molluscs, first two, then three, and then more, could be distinguished in the various sedimentary basins of the European marine "Tertiary". The agreed departure point was the assemblages from the Paris Basin, painstakingly described in the great malacological school in Paris and especially by Gérard-Paul Deshayes. This systematic paleontology was then exploited by Lyell (1830-1833) to subdivide the "Tertiary" record into series and epochs (text-fig. 2).

The modern Cenozoic chronostratigraphic framework is directly inherited from Lyell's biochronologic framework, expanded to include the Paleocene and Oligocene by Schimper (1873) and Beyrich (1854), respectively, and with a somewhat profound conceptual shift, as explained below. The periods Paleogene and Neogene were also introduced specifically as biochronologic units (Hörnes 1853; Naumann 1866; see Berggren and Van Couvering 1978), and so too were the three eras of the Phanerozoic (Phillips 1840) (text-fig. 2). There is thus no question that biostratigraphy/biochronology was utterly paramount in the establishment of a relative chronology and



TEXT-FIGURE 3
Conversion of biochronologic units into chronostratigraphic units via the definition of stages. See text for explanation (* = not ratified).

time scale of Earth history. Geo-historicism emerged from 18^{th}-century neptunism but the standard lithological succession (Arduino 1760) collapsed. It is also interesting and important that the successional, non-iterative history of life could be used to build the time scale without an acceptable theory of speciation to match the fact of extinction established by Cuvier in the 1790s. Indeed, Philips himself could not accept Darwin's theory of the *Origin of species* (Darwin 1859; Phillips 1861), and even Lyell did not embrace it immediately (Gould 1987).

Establishing chronostratigraphy

Following upon the discussions of the late 19^{th} and early 20^{th}-centuries regarding the reliability of paleontologic groups for correct age assignment, Hedberg (1948) envisioned a new method of relative dating, based on the rock strata themselves, divided into stages. Chronostratigraphy would constitute an independent means of relative chronology. The strata themselves would be grouped in isochronous packages holding the key to relative time (see review in Aubry et al. 1999). It took several decades of engaging discussions for Hedberg's vision to become accepted, but ultimately the concepts of unit- and boundary-stratotypes were born, that anchored boundaries in geological time to physical points in the rock record, and not to historical concepts whose limits had to be arguably reinterpreted for each location (Hedberg ed. 1976; George et al. 1967). The change was radical, and would establish chronostratigraphy as an independent science because the criteria for definition were separate from those for correlation. In other words, the means of correlation would differ from the definition itself. The subsequent replacement of the simple "golden spikes" described by George et al. (1967) with standardized GSSPs with formal procedural rules (Cowie 1986; Cowie et al. 1986; Remane et al. 1996) would further solidify the chronostratigraphic revolution.

The conventional acceptance of boundary stratotypes and the subsequent formal definition of GSSPs for the base of the (global) stages (which differ from regional stages in casting a global isochronous shadow) have led to the full conversion of biochronological units (Lyell's, Beyrich's and Schimper's epochs; Hörnes' period, Philips' era) into chronostratigraphic units (the epochs, periods and eras in the modern time scales, beginning with Berggren [1971, 1972]) (text-fig. 3). The choice of stages and their hierarchical grouping into series/epochs, then systems/periods, and ultimately erathem/era is a matter of convention, as part of the framework category of Harland (1973, 1975; see McGowran and Li 2007) although the strata included in each category would be as respectful as possible of the original definition. In these circumstances, and if the purpose of chronostratigraphy is clearly understood, how could there be a "desire to establish *a monopoly for marine biochronology in the definition* of standard global chronostratigraphic boundaries"? (Walsh 2008, p. 42; emphasis in the original text). This is to confound the formal chronostratigraphy of the time scale with chronostratigraphy in general (e.g., biochronostratigraphy), as if the GSSPs for the high-rank units of the global time scale could be anything other than a choice of physical points that exemplify the original marine biochronological concepts.

The introduction of rules in chronostratigraphy has another significant implication: the resolution of current chronostratigraphic problems should only be dealt with regard to these rules. In the case of the Neogene-Quaternary controversy, reference to the recommendation made at the IGC in London in 1948 (to equate the Pliocene/Pleistocene boundary with the Tertiary/Quaternary boundary but apparently not with the top of the Neogene) has become less than relevant; the ambiguity of the text of this decision and its varied interpretation (see Hilgen et al. 2008) should play no role in the Neogene-Quaternary argument.

Correlation of chronostratigraphic boundaries

Chronostratigraphy relies on various stratigraphic means for the purpose of correlation. Biostratigraphy plays the foremost role, particularly in the Paleozoic and Mesozoic (http://www.stratigraphy.org/ as of 28 November 2008). However, magnetic reversals and isotopic signatures are also successfully used. Several large amplitude, negative or positive, short-term shifts of $d^{13}C$ or $\delta^{18}O$ constitute primary means of chronostratigraphic correlation. Examples are distinctive patterns of ^{13}C variations associated with the base of the Ediacaran System (Knoll et al. 2004); a 3-4‰ $\delta^{13}C$ shift at the base of the Eocene Series (Aubry et al. 2007); and a 1-2‰ $\delta^{18}O$ shift (Mi3b) at the base of the Serravallian Stage (Hilgen et al. 2008). These isotopic signals are used *only* because of their characteristic signature in the stratigraphic record. Their significance as proxies for paleoceanographic/paleoclimatologic history is wholly irrelevant to chronostratigraphy.

Applying these observations to the matter under discussion, the association of the base of the Gelasian Stage with marine isotopic stage 103 should be seen simply as a geochemical feature, regardless of its significance as a marker of intensification of glacial conditions. Its interpretation in the reconstruction of Earth history, however significant, would have no consequence for chronostratigraphic correlations, which are concerned only with global recognition of a specific horizon in marine and terrestrial stratigraphies. The importance of such a horizon is that it marks a specific moment in time, regardless of what happened on Earth other than the deposition of this horizon.

It is important to recognize that even the most conspicuous non-paleontologic markers used in chronostratigraphic correlation require a biostratigraphic context (text-fig. 4). Organic evolution is an ordinal phenomenon that provides a unique signal in stratigraphic correlation. With the exception of radioisotopic and biotic chronology, all other aspects of Earth history are iterative—i.e., not self-datable—including glacial climate cycles (see also McGowran et al., in press). Whereas characterizations such as the "Age of Fishes" for the Paleozoic Era can be somehow justified, there is no such thing as *the Ice Ages*, because ice ages have occurred repeatedly throughout Earth history, including the Proterozoic "snowball Earth" (Kirschvink 1992; Hoffman et al. 1998; Crowell 1999), the brief and severe Late Ordovician-Early Silurian episodes of iciness (Crowell 1999), and the early Oligocene southern hemisphere glaciation which initiated the 'ice-house mode' of the Neogene (Miller et al. 1991; Coxall et al. 2005). Additionally, the beginning and termination of a given "ice age" can be difficult to delineate since the underlying climatic changes are incremental. Evidence for major Northern Hemisphere ice-sheets can be dated at ~3 Ma. Ice-rafted debris in the north Atlantic off Greenland have been dated to 7 Ma. Recent modeling studies have shown that intermittent ice-sheets may have been present in the northern polar regions as far back as 25 Ma (DeConto et al. 2008) whereas middle Eocene (~44 Ma) ice-rafting has recently been depicted off Greenland (Tripati et al. 2008).

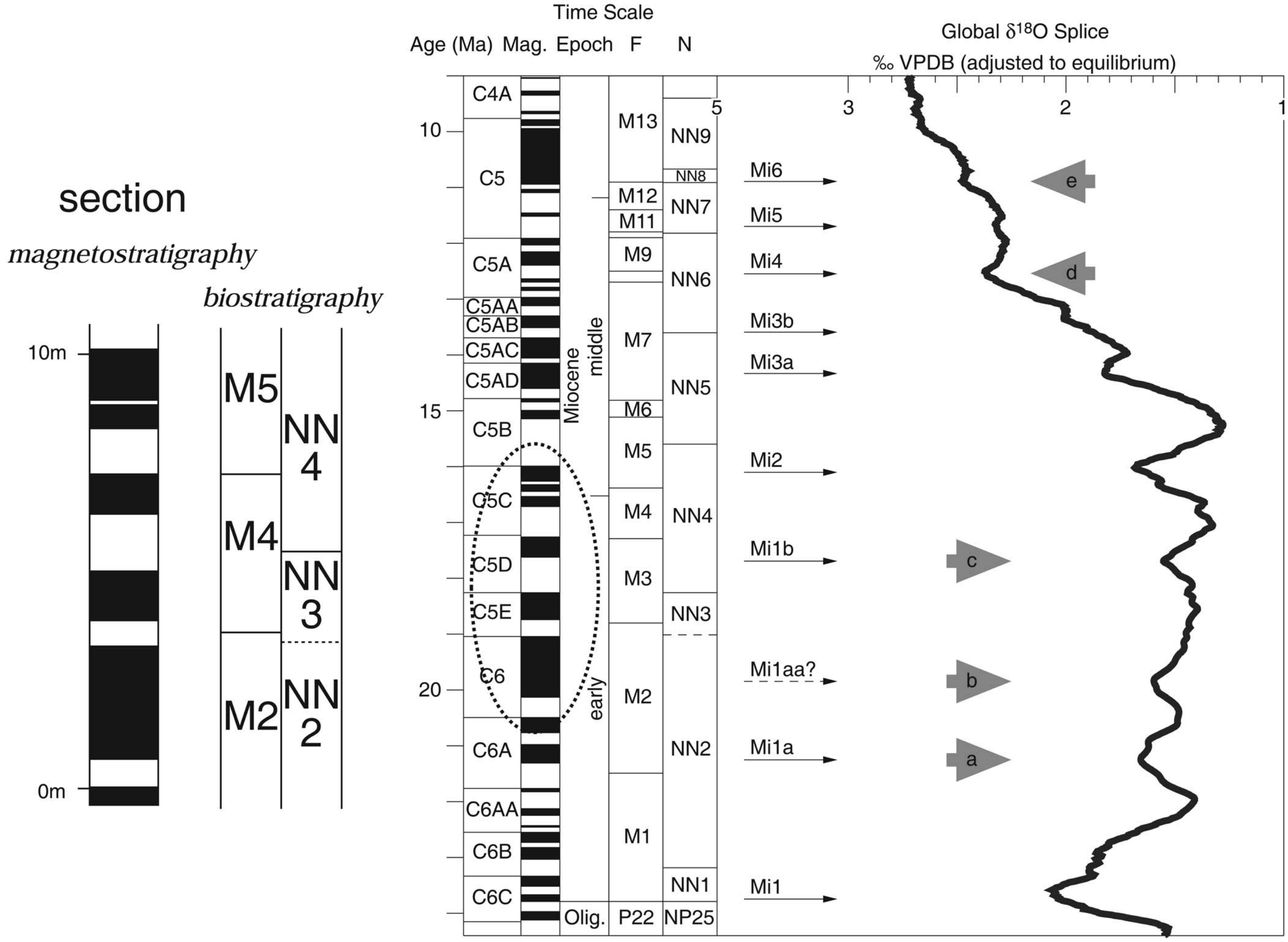
In summary, biochronology has been a major player in the conceptualization of the larger divisions of Earth history. Because of its ordinal character, the evolution of life is the most obvious and accessible means of characterizing large intervals of time. Biochronology, however, does not rule chronostratigraphy. It assists, directly and indirectly, with the correlation of chronostratigraphic horizons and units.

Should Pleistocene and Quaternary be equated with a common base at 2.6 Ma?

Ever since Forbes (1846) equated the Pleistocene with the evidence for continental glaciaton in northern Europe, the Quaternary community has equated Quaternary (introduced conceptually as a climatic unit) with Pleistocene (plus Holocene) (introduced conceptually as a biochronologic unit). Accordingly, the SQS has requested that the base of the Pleistocene Series be lowered to accommodate recalibrating the base of the Quaternary to encompass as much as possible of the time when glacial conditions can be recognized in the continental stratigraphic record of the Northern Hemisphere, specifically including the oldest level of Chinese Loess (see Hilgen et al. 2008, fig. 2).

In the light of the above discussion, there seems to be no way to accommodate such a proposal. The two units, Pleistocene and Quaternary, were originally introduced on different conceptual grounds (text-fig. 2). Through the definition of the Calabrian GSSP (Aguirre and Pasini 1985; Van Couvering 1997; reconfirmed by Cita et al. 2006, 2008), the *base* of the Pleistocene Series became irremediably linked to the *base* of the Calabrian Stage. The ensuing conversion of a biochronologic unit (the Pleistocene of Lyell) into a chronostratigraphic unit was officially ratified by the IUGS, at the International Geological Congress in Moscow 1984.

As a result of this conversion, and in explicit consideration of the historical background of the terms, the stratigraphic units and their fossils that characterized the original Pleistocene and



TEXT-FIGURE 4
The paramount role of biostratigraphy in stratigraphic correlations. A. The chrons (dotted oval) represented by this succession of three magnetozones (left) cannot be confidently identified through straightforward pattern matching. Biozonal correlations is required. B. Isotope signatures are iterative. Without paleontology, it would not be possible to determine which of the glacial events (Mi) are recorded in any section. (Aubry 2004; McGowran 2005). Chronology of Miocene isotopic events from Browning et al., in press.

Pliocene biochronological divisions of Lyell are now unambiguously and soundly placed into the GSSP-defined Pliocene and Pleistocene Series/Epochs. As noted above, the definition of a unit-stratotype for the Calabrian Stage further strengthens the role of this stage in defining the Pleistocene Series. As noted by Cita (2008, p. 9): "The GSSP of the Calabrian Stage in the Vrica section corresponds to the GSSP where the Plio/Pleistocene boundary was defined and ratified (Aguirre and Pasini 1985; Bassett 1985). This point is well constrained in terms of calcareous nannoplankton biostratigraphy, magnetostratigraphy and marine isotope stratigraphy. […] Consequently the base of the Calabrian Stage can be easily detected both in the tuned Mediterranean and extra-Mediterranean record …". Under the procedures accepted by the ICS, it would be acceptable to slightly adjust the point that defines the base of the Calabrian (with corresponding adjustment to the base of the Pleistocene) should an unlikely demand for better correlation arise, but an independent reassignment of the base of the Pleistocene to the base of another stage (in this case the Gelasian Stage) would simply be in flagrant contradiction of the current rules of chronostratigraphy (see also Walsh 2006). To extend the range of the Pleistocene is in fact to extend the age of the Calabrian Stage, in which the base of the Pleistocene is defined. This might have been conceivable prior to the introduction of the *Pliocene* Gelasian Stage (Rio et al. 1998) in the pre-Vrica interval that was not represented in the Piacenzian stratotype, but this is now impossible because the two stages would overlap.

The Pleistocene is a series formally defined by the base of its lower stage, the Calabrian, which is also formally defined. The formalization of two other stages (Ionian and Tarantian Stages) is anticipated for 2009 (http://www.stratigraphy.org/gssp.htm, as of 12 February 2009). The status of the Quaternary is ambiguous (see Cita et al. 2008), and this unit has no subdivisions (http://www.stratigraphy.org/gssp.htm). The Quaternary has long been considered to be equivalent with the Pleistocene, and explicitly so in the resolution of the 1948 London IGC that led to the establishment of the GSSP for the Calabrian and, thus, for the Pleistocene (see above). However, this automatic hierarchical definition for the Quaternary was rejected by INQUA (1995; in Cita et al. 2008). Although Remane (2000) reaffirmed that the base of the marine claystone that overlies sapropel bed "e" at Vrica defined the base of *both* the Pleistocene and the Quaternary, the issue is clouded by the fact that the ICS and INQUA have recently recommended (2007) that the Quaternary be considered "as a formal Period/System of the Cenozoic. It is the interval of oscillating climatic extremes (glacial and interglacial episodes) that was initiated at about 2.6 Ma (set equal to base of Gelasian stage), therefore it encompasses the Holocene and Pleistocene epochs and the late Pliocene" (http://www.stratigraphy.org/gssp.htm).

The situation then is the following. 1) If the Quaternary is formally defined by the Pleistocene (Van Couvering 1997; Remane 2000), its base is fixed in the base of the Calabrian at Vrica and cannot be changed without formal procedure to redefine the Pleistocene. 2) If the Quaternary is not formally defined by the Pleistocene, its introduction into the geological time scale should be made with respect for the existing hierarchical framework. Requiring that the base of the Pleistocene be lowered to fit a conceptual Quaternary boundary, as requested by SQS, would be to disrupt the established organization of the time scale simply to accommodate a changing opinion in paleoclimatology, with a serious destabilizing effect on the literature. In addition, in a Quaternary inherently defined by any version of the Pleistocene, the creation of Quaternary subdivisions that reflected the continental record of climate cycles (see Bowen and Gibbard 2007) would necessarily require that Pleistocene marine stages be invented simply to provide the GSSPs for a superimposed hierarchy, in complete contradiction of standard procedure.

In discussing the problem of the Quaternary and Pleistocene, several authors (including Walsh 2008) have referred to the case of the Paleocene/Eocene boundary. In fact, the two situations are not comparable. In the case of the Quaternary, the issue is changing the concept of a formalized series by abandoning its defining lower stage. In the case of the Eocene, the issue is to identify a stage that accommodates the existing GSSP for the Eocene Series (Aubry et al. 2003). The Ypresian Stage is regionally well defined in northwestern Europe where its base in outcrops is substantially younger than the base of the GSSP-defined Eocene (Aubry and Berggren 2001). Although introduction of the Sparnacian Stage has been recommended, the Eocene is currently defined *without* reference to a formal lower stage (Aubry et al. 2007), as provided in the guidelines for such circumstances (Cowie et al. 1986).

SUBDIVISION OF THE CENOZOIC ERA: TWO OR THREE PERIODS?

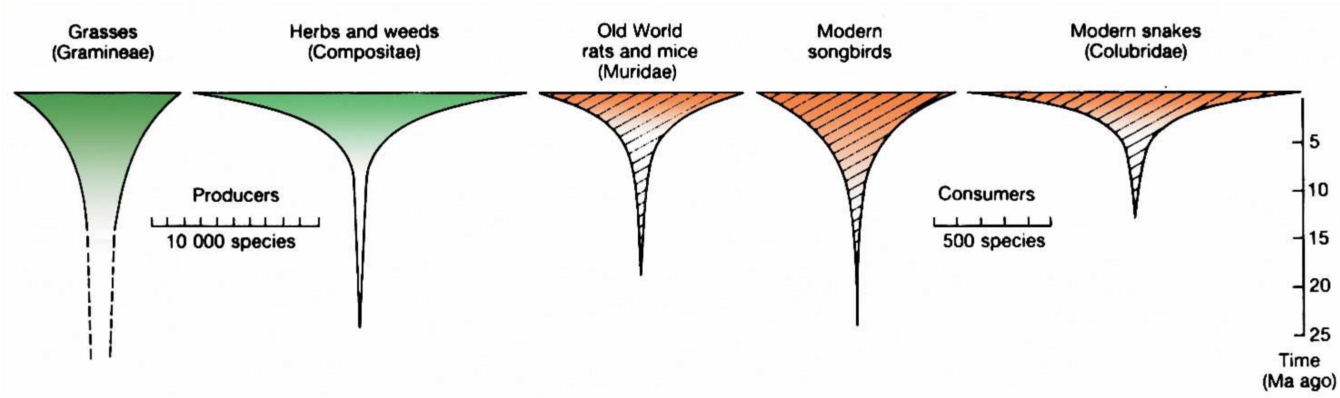
Two subdivisions of the Cenozoic, Paleogene and Neogene, are currently recognized by the ICS (as of 2004) and the SNS, as well as by most earth scientists. The Paleogene includes Paleocene, Eocene and Oligocene Series/Epoch and spans the interval ~66 Ma to 23 Ma. The Neogene comprises the Miocene, Pliocene and Pleistocene (including Holocene), and spans the interval from 23 Ma to 0 Ma. The GSSP for the Miocene has been placed at Level 35m (as measured downward) in the Lemme Section in the Piemont Basin in Italy (Steininger et al. 1997; see discussion on procedures in Aubry et al. 1999 and Berggren 2007) and is denoted by the Chron C6n.2n$_{(o)}$ currently estimated at 23.03 Ma (Lourens et al. 2004). It also coincides with $\delta^{18}O$ shift Mi1 of Wright et al. (1991). While there is no mass extinction associated with the Paleogene/Neogene boundary, there are major turnovers (e.g., in molluscans, vertebrates, and protists) spanning the late Oligocene-early Miocene (Chattian-Burdigalian) interval that mark the first appearances of important modern lineages.

Biochronology is the most readily accessible means of demonstrating and organizing historical progression, and it has originally served, and still serves, to determine the chronostratigraphic units of higher ranks. For historical (pragmatic and logical) reasons, chronostratigraphic units are required to be couched in terms of biochronological data that reflect major events in the fossil record. We thus examine below the fundamental relationship between chronostratigraphy and marine biotic evolution.

Chronostratigraphy and the description of the evolution of life

As Harland (1973, 1975) has pointed out, chronostratigraphy is, in principle, a matter of convention in the framework category of classification, but it must also be recognized that it follows the logic of the 19th-century discovery of Earth history, which was based on fossils (e.g., Lyell, Hörnes, and many others) and on "landscape surfaces" (the unconformities of d'Orbigny 1849, 1851). In sofar as biotic evolution is shaped, at least to some extent, by abiotic forcing, the temporal propinquity/association between short-term evolutionary changes and major disruptions of the Earth system is predictable. These cause-and-effect relationships were inherent in early divisions of the stratigraphic record and thus the apportionment of geological time, and are therefore incorporated in the current chronostratigraphy. For instance, the beginning of the Archean Eon is associated with the appearance of life (Cloud 1987, 1988; see also Robb et al. 2004); the beginning of the Phanerozoic Eon is marked by widespread biomineralization in the Kingdom Animalia (Brazier et al. 1994, 1996) while two of the largest mass extinctions of the last 542 my separate its three eras (Sepkoski 1982; Raup and Sepkoski 1982); the beginning of the Eocene is marked, on land, by the appearance of most modern orders of mammals (e.g., Gingerich 2001) and, in the deep sea, by the extinction of the long-lived Late Cretaceous-Paleocene *Stensioina beccariiformis* benthic foraminiferal assemblage (Tjalsma and Lohman 1983; Thomas 1992); the list goes on. The remarkable advantage of this historical precedent is that the history of life (and, consequently, to a large extent, Earth history) is easily described in chronostratigraphic terms, since the biotic changes (mass extinctions and short-/long-term turnovers) are associated with chronostratigraphic boundaries, evolutionary radiations occurring in the course of epochs and periods.

The propinquity of chronostratigraphic boundaries and biotic events does not imply that the chronostratigraphic hierarchy parallels the taxonomic hierarchy in any fossil group. Conceptually different (McGowran and Li 2007; McGowran et al., in press), taxonomic and chronostratigraphic hierarchies are also structurally independent. Thus, the fifth largest mass extinction (in terms of the number of taxa affected; see McGhee et al. 2004) marks the boundary between the Mesozoic and Cenozoic eras whereas the second largest mass extinction occurred near the Ordovician/Silurian boundary. Likewise, the Paleocene/Eocene epochal boundary was marked by evolutionary events at the rank of orders among Eutherian mammals, whereas the



TEXT-FIGURE 5
Cascading radiation of terrestrial plants and vertebrates during the Neogene (modified after Stanley 1990, fig. 1.4). In the absence of a well preserved fossil record, molecular biology has clarified the time of the origination of these groups, which, for most of them, happened during the Eocene. However, their radiation did not occur until the Neogene. Other radiations include those of the whales, camelids, equids, and the south American Edentates (*Glossotherium*, *Glyptotherium*, *Dasypus*).

boundary between the Paleogene and Neogene periods concerns only their families (e.g., the appearance of Bovidae, Giraffidae, and Hyaenidae in the early Miocene; Carroll 1988).

The Neogene and its biotas

We introduce this discussion with a quote by Steven M. Stanley in his textbook *Earth System History* (2009, p. 456): "Because it leads to the Present, the Neogene Period holds special interest for us. It was during the Neogene that the modern world took shape—that is, when global ecosystems arrived at their present state and prominent topographic features assumed the configurations we observe today. […] The most far-reaching biotic changes were the spread of grasses and weedy plants and the modernization of vertebrate life. Snakes, songbirds, frogs, rats, and mice expanded dramatically, and apes—and then humans— evolved […]. In general, the animals and plants that inhabit Earth today are representative of Neogene life …". Whether we study the progression of life through the fossil record, or the origin of living faunas and floras by tracing their lineages back through time via molecular phylogeny, a remarkable evolutionary continuum from Miocene to present is obvious, with groups that arose during the Miocene still undergoing an adaptive radiation (Stanley 1990; text-fig. 5).

The cascading radiation of plant and animal lineages during the Neogene appears to have been driven directly and indirectly by cooler and drier climates (Stanley 1986, 1990) as a result of intensification of cooling and glaciation, first in the southern hemisphere (following the early Oligocene establishment of a permanent ice-cap on Antarctica), then (~7 Ma) in the Northern Hemisphere (Zachos et al. 2001; Miller et al. 2005). The closure of the Isthmus of Panama at ~3 Ma disrupted ocean circulation and intensified glacial build up around the Arctic margin (de Menocal 1995; Lourens 2008; but see Molnar 2008). The downward steps in global climate led to progressive shifts in continental environments. Habitats changed progressively, with the retreat of dense tropical forest and the expansion of vegetations that were more adapted to strong seasonal variation, such as deciduous forest. Fire-adapted communities spread during the Miocene, and in particular during the late Miocene climatic downstep (Cerling et al. 1993, 1997; Keeler and Rundel 2004), such that open grasslands and shrublands now occupy vast tracts from the (sub)tropical savannah to high latitude steppes, and on all continents except Antarctica. Two groups of plants benefited from this habitat transformation. One group comprises the herbs of the sunflower alliance of families (including the Family Compositaceae [= Asteraceae]) which now consist of >23,000 species divided among >1,500 genera (Bremer 1994). The family originated in the late Eocene, but diversified in the earliest Miocene (Kim et al. 2005) when its pollen became very abundant worldwide (Graham 1996). The other group is the Family Graminaceae, or true grasses, with approximately ~10,000 species in more than 700 genera, which now dominates in a greater area of the world's land surface than any other plant family (Chapman and Peat 1992; Cheplick 1998). Grasses and other C4 plants expanded their geographic distribution between 9 and 6 Ma (Cerling et al. 1993; Retallack 1997; Osborne and Beerling 2006).

This progressive change in vegetation led to a cascade of adaptive radiations as well as extinctions among herbivorous terrestrial animals. Simply put, the sharply increased amount of solar radiation reaching earth surface as the Neogene progressed, and the greater efficiency of C4 plants to store that energy, represented a huge increase in food supply at ground levels for grazers and seed eaters (Cerling et al. 1977). The early Miocene radiation of the horse *Merychippus* (~20-15 Ma) from *Parahippus* (23 Ma), the middle Miocene (15 Ma) Eurasian spread of *Hipparion*, and the evolution of *Equus* (~3.5 Ma) are well known because of an abundant fossil record (Radinski 1984; Carroll 1988; McFadden 1988, McFadden and Hubbert 1988; Prothero and Schoch 1989). Also at the beginning of the Miocene, proboscideans (gomphotheres, mastodons and elephants) and the newly evolved bovids (antelopes, cattle and goats) entered the Northern Hemisphere from Africa, to quickly become the dominant herbivores throughout the world's grasslands outside of Australia (Madden and Van Couvering 1976; Janis 2007). Less known are the Neogene radiations of the Family Passeridae (or song birds) which represent 50% of living birds with more than 5,000 species (Mayr 1946; Barker et al. 2004), and of the rodents, particularly the murids (mice and rats) that are now the most diverse of all mammal groups with more than 1700 species (Carroll 1998), both induced by increased availability of seeds from herbs and grasses. These radiations led, in turn, to the radiation of specialized predators, among which the Family Colubridae, which is the largest family of snakes and the most rapidly evolving group of reptiles, with ~1600 living species (Carroll 1988; Stanley 1990; Shine 1998), and the carnivorous mammals (Carroll 1988). The history of the Felidae (cats) from an ancestor of Asian origin is entirely contained in the last 11 my (Johnson et al. 2006). Encephalisation in crown canids occurred near the Miocene/Pliocene boundary, coincident with rapid diversification and expansion throughout Eurasia (Finarelli 2008). Our own ancestry is a Neogene story, deeply rooted into the Miocene. The remains of the oldest known hominoid, *Kamoyapithecus,* were recovered from strata 26 million years old, just below the Oligocene/Miocene boundary at Lothidok in northern Kenya (Boschetto et al. 2001). *Sahelanthropus* (late Miocene, ~6.5 Ma; Brunet et al. 2002) is the oldest known genus of the subfamily Homininae which also includes *Orrorin, Kenyanthropus, Ardipithicus*, *Australopithecus, Paranthropus* and *Homo*.

Modern groups of marine vertebrates are also rooted in the Neogene. Marine carnivores (seals, sea-lions and walruses) have a fossil record that extends back to the latest Oligocene-earliest Miocene and they diversified during the middle and Late Miocene (Carroll 1988; Hidgen et al. 2007). The divergence and radiation of modern toothed and baleen whales (odontocetes and mysticetes, respectively) during the Neogene was triggered by changes in oceanic circulation and increased ocean productivity (Carroll 1988, Fordyce 1980; Prothero and Schoch 2002).

In addition to these evolutionary radiations, Neogene morphologic trends are pronounced across diverse groups, both terrestrial and marine. The expansion of grasslands is reflected in progressive adaptations to compensate for increased tooth wear due to diet of tough, drought-resistant plants, whether in thickened enamel for tubers (suids, hominins) or hypsodonty to deal with silica (phytoliths) in grasses (bovids, giraffids, camels, rhinoceros, and equids; Carroll 1988; Prothero and Schoch 1989; Prothero and Foss 2007, Prothero 2002). Possibly climatically- or productivity-driven trends towards increasing shell size during the last 23 my have been described in the planktonic foraminifera (Schmidt et al. 2004, 2006), the diatoms (Finkel et al. 2005) and the ostracods (Hunt and Roy 2006), whereas a parallel trend but towards decreasing size has been documented in the coccolithophorids (Aubry 2007; Aubry 2009; Aubry and Bord 2009).

No "Quaternary Period"

As briefly reviewed above, much of today's biodiversity results from evolutionary radiations that occurred during the last 23 my. Indeed, several of the groups involved (e.g., Compositaceae, Graminaceae, Murinae, Passerida) are in the midst of an adaptive radiation. There can be no disputing Stanley's point (2009), quoted above, that the modernization of the world's biota began near the Oligocene-Miocene transition with initial diversification in those groups, as disparate as whales and sunflowers, that predominate today. It was the evidence of this step in modernization in the fossil record of Vienna Basin mollusks, plain to see in one of the first in-depth biochronological studies ever made, that led Hörnes (1856) to coin the term Neogene. And it is in recognition of this biotic unity that faunal assemblages are, and have been for over 30 years, referred collectively and naturally as *Neogene* by marine micropaleontologists among others.

Introducing a "Quaternary period" for the last 2.6 my (or the last 1.8 my) of the Neogene would obviously require a change in denomination, from "Neogene" to "Neogene-Quaternary", to describe this single natural interval. Aside from this awkward construction, however, the truncation of the Neogene system/period to insert the Quaternary, in accord with the SQS proposal, would means an equally awkward imposition of an inappropriate concept into the time scale. The term Neogene applies well to the radiation and establishment of modern faunas and floras. It has also come to be associated with the long-term climatic, paleoceanographic and tectonic history of the Earth for the last 23 my (see overview in Stanley 2009). In this context, the term Quaternary, which derives from continental lithostratigraphy with a subsequent paleoclimatic interpretation, is not a logical equivalent to the Neogene. Even in terms of climate change during the Neogene, a separate identity for the term Quaternary is hard to justify, since this relates only to the most recent of several deterioration steps during the past 23 my (Miller et al. 2005), and it is not the most consequential in any respect except for its impact on high latitude terrestrial environments. More importantly, to insert Quaternary in a series of units originally characterized on biochronology grounds would require a major evolutionary break at a 'Neogene/Quaternary boundary'. There is, however, no faunal or floral change near 2.6 Ma that could be called significant on the scale of Neogene biotic history. For example, reorganization of herbivore communities in Europe around 2.6 Ma was marked by the extinction of seven species of small Pliocene deer and the immigration of *Equus*, which Brugal and Croitor (2007) described as "setting up of a modern Paleoarctic zoogeographical region in northern Eurasia" (op. cit., p. 145). This is, however, hardly remarkable against the background of decreasing diversity among families of herbivorous mammals that began in the late Miocene (Carroll 1988; Brugal and Croitor 2007), and so cannot be considered as a justification for introducing a new period in the time scale. Sequential extinctions among the calcareous plankton (Berggren et al. 1995; Aubry 2007) and mollusks (Stanley and Campbell 1981; Jackson et al. 1993) mark the upper Pliocene Gelasian Stage, but these are rather minor, slightly above background.

Does the appearance of our own genus deserve recognition as a major evolutionary event that would justify setting up a formal period? There can be no question that the appearance of *Homo sapiens* in the latest Pleistocene (c. 125 Ka) has had an extraordinary impact on the global ecosystem, as well as on the terrestrial surface. It is, however, not as well realized that the earlier species assigned to this genus were neither numerous nor environmentally significant. Fossil remains of humans at the "*erectus*" grade preceding *sapiens* (i.e. *H. erectus*, *H. ergaster*, *H. antecessor*, *H. steinheimensis*, *H. neanderthalensis*, and several less well recognized taxa) are among the rarest constituents of mid-Pleistocene mammal faunas. There is no suggestion that "*erectus*" grade humans lived in communities or were cultivators, and it is now widely accepted that their preserved tools—projectiles such as "hand axes" and coarsely flaked choppers and scrapers—are not consistent with hunting large animals, but with driving away the actual predators and scavenging their kills (Stanford and Bunn 2001; Pickering and Bunn 2007). The remains of earliest "*habilis*" grade humans (*H. habilis*, *H. rudolfensis*, *H. georgicus*) are even more spectacularly rare, and the associated crudely flaked "olduwan"-type tools are even less effective for hunting. Thus, early humans must be regarded as inconspicuous skulkers with virtually no effect on the global ecosystem.

In another aspect, recent detailed studies indicate that the linkage of the "first *Homo*" and the "earliest glaciation" may be misplaced. The earliest records that may be dubiously referred to genus *Homo* are associated with the sharp shift in the African ecosystem at c. 2.4 Ma, coincident with the development of Walker circulation in the Indian Ocean (Prat 2007). The impact of this event was distinct from, and much stronger than the local effects of the earlier climate change that brought about the formation of continental ice fields in high latitudes some 200,000 years previously. We can only conclude, from the virtually imperceptible record of *Homo* during most of its history, and also the poor correlation between its first occurrence and the beginning of the Quaternary as proposed by SQS, that our ancestry should not be considered as a guide fossil for this interval.

DISCUSSION AND CONCLUSIONS

We have clarified the role of biochronology in chronostratigraphy, and have shown that, even though the two have always been closely linked, chronostratigraphy is independently regulated. We have reiterated the fundamental role of the stage as the basic unit of chronostratigraphic hierarchy, and explained why, as a consequence, the lowering of the base of the Pleistocene Series without the simultaneous lowering of the base of the Calabrian Stage would violate chronostratigraphic principles and procedures. The logic would apply as well to the Quaternary, if defined by the base of the Calabrian Stage as maintained by some. We have explained that the modern world, and in particular its biodiversity, took shape progressively through the last 23 my of Earth history. We have pointed out that the biologic evidence for a coherent and distinctive Neogene Period extending to the present is consistent in scope, character, and principles of definition of the other high rank chronostratigraphic units in the time scale, and that in this context there is nothing that rises to the level of a separate period in the paleontological record of the last 2.6 my. We would furthermore disagree that climate change attributed to the Quaternary, even if this were a valid criterion for a geological time unit, meets the standard of a major boundary. Taken on its own, polar glaciation began much earlier than 2.6 Ma in the Northern Hemisphere (~7 Ma, and perhaps earlier), and even earlier on Antarctica (~34 Ma or older).

Climate-induced biotic changes, with the development of dominant modern groups in response to increased seasonality clearly began in the Miocene with selection from Eocene and Oligocene stocks, and not from the impact of glacial-interglacial cycles on global ecosystems during the past 2.6 my. As fascinating as it may be for us, the evolution of *Homo* beginning at about the same time (ca 2.4) cannot be seen as more remarkable, or as less banal, than the evolution of any other genus. It was only within the last one hundred thousand years that human evolution took a great leap forward with the acquisition of social strategies that enabled the dispersal of humans around the world (Wells 2002).

We reiterate our firm commitment to the philosophical approach to chronostratigraphy as promulgated by Hedberg, which describes a distinct discipline that is independent in its definitions from any conceptual aspect of Earth history in order to shine an impartial light on the evidence of this history. However, for historical reasons, high-ranked chronostratigraphic boundaries (series/epochs and above) correspond also to natural boundaries, representing transitions in Earth history. Remane et al. (1996, p. 78) recognized the importance of this when they stated: "Placing a boundary within such an interval [critical biotic or climatic transition] will preserve the advantage of having successive units which are distinguished by their content". The interval of time we call *Neogene* precisely follows this principle with regard to the time scale. Well characterized by its biotic, climatic and tectonic content, it has historical integrity, and should be retained as a period incorporating the Miocene-Recent (extending from 23 Ma to today).

The longstanding debate on the connotation and denotation of the stratigraphic terms *Neogene* and *Quaternary* is moving towards a resolution—at least for this generation. The Neogene is firmly ensconced in the conceptual hierarchy of chronostratigraphic classification and is generally considered by the marine and a significant component of the terrestrial (vertebrate) community as the younger of a two-fold system/period subdivision of the Cenozoic Erathem/Era that includes the Miocene-Recent (23-0 Ma) interval. The Quaternary, on the other hand, has a long-standing history as a climatostratigraphic unit, with a historically ill-defined and unsettled conceptual boundary, based on different interpretations of the nature and initiation of Northern Hemisphere glaciation. In this regard the Neogene and Quaternary are inherently different and might usefully be described, in the terms of the late Stephen J. Gould's categorization of Religion and Science, as Non-Overlapping Magisteria or NOMA.

In his eloquent reconciliation of the persistent conflict between religion and science, Gould wrote:

> "Our preferences for synthesis and unification often prevent us from recognizing that many crucial problems in our complex lives find better resolution under the opposite strategy of principled and respectful separation. People of good will wish to see science and religion at peace, working together to enrich our practical and ethical lives….
>
> "I do not see how science and religion could be unified, or even synthesized, under any common scheme or explanation or analysis; but I also do not understand why the two enterprises should experience any conflict. Science tries to document the factual character of the natural world, and to develop theories that coordinate and explain these facts. Religion, on the other hand operates in the equally important, but utterly different, realm of human purposes, meanings and values—subjects that the factual domain of science might illuminate, but can never resolve. Similarly, while scientists must operate with ethical principles, some specific to their practice, the validity of these principles can never be inferred from the factual discoveries of science.
>
> "I propose that we encapsulate this central principle of respectful noninterference—accompanied by intense dialogue between the two distinct subjects, each covering a central facet of human experience—by enunciating the principle of NOMA, or Non-Overlapping Magisteria." (Gould 1999: 4, 5)

Substituting the words Neogene and Quaternary for the terms Science and Religion (or Religion and Science) is illuminating in view of the (almost) wholly different precepts and methodologies followed by the two sides of the discussion. While the concept of NOMA is not fully applicable, in that both sides adhere to scientific principles, we may still find the situation engendered by the Neogene-Quaternary debate to give some useful perspective in resolving the current standoff.

If the Quaternary community insists on the validity of geological time units that embody concepts in paleoclimatology, imposed on the chonostratigraphy of the units of the existing time scale founded on biochronological analysis (Gradstein et al. 2004), the NOMA paradigm may be appropriate. The request of the Quaternary community to formalize the boundary of a Quaternary Period by defining it with the GSSP of the Gelasian Stage at 2.6 Ma, and then to appeal to hierarchical logic to lower the base of the Pleistocene Epoch to fit this paleoclimatic preconception, is a mistake. In this proposal the Quaternary is made to outwardly conform to the appearance of a chronostratigraphic unit in the geological time scale, while in fact it ignores the biochronological analysis upon which the time scale is built. Prima facie evidence that the Quaternary concept belongs in a separate magisterium is the absence of a Period-quality change in the biotic record to distinguish the Quaternary from the Neogene, let alone any attempt by SQS to address the question of the missing boundary event. Without a transition of comparable extent to the turnover and rapid radiation in marine and terrestrial ecotones that separate the Paleogene from the Neogene, a Quaternary unit of equal rank, set in this context, does not exist.

Several solutions have been proposed to satisfy the request of the SQS while simultaneously preserving the integrity of the Neogene System/Epoch. One possibility might be to define a Quaternary time-rock unit at the rank of subsystem or superseries, encompassing Holocene, Pleistocene and upper Pliocene. Another possibility is to recognize it as a suberathem joined with the Tertiary. If it is to be considered a chronostratigraphic unit in the geological time scale, it must be inserted harmoniously in the current hierarchy. Our recommendations therefore are as follows:

1- The status of Neogene as a system/period that extends to the Recent should be confirmed.

2- The Quaternary should be included either as a subsystem/subperiod (Pillans and Naish 2004; our preference), as a superseries/superepoch (Lourens 2008) or as a suberathem/subera (Aubry et al. 2005) of the Cenozoic.

3- The lowering of the Quaternary from 1.8 Ma (where it is currently located in some time-scales) to 2.6 Ma (as requested by the SQS) should not involve the lowering of the Pleistocene Series/Epoch. The identity of Pleistocene as a unit of the Quaternary has never been formally confirmed.

4- The Calabrian Stage, which formally defines the base of the Pleistocene, and the Gelasian Stage, which was introduced specifically as the uppermost stage of the Pliocene, should not be reassigned on paleoclimatic grounds.

If a cogent compromise cannot be found that is satisfactory to both the SNS and the SQS, we suggest recognition that the Neogene and the Quaternary do not belong to the same conceptual category, the former being a chronostratigraphic entity identified according to the biochronological divisions of the Phanerozoic, and the latter being a (potentially) chronostratigraphic entity identified on paleoclimatic evidence. In this case the application of NOMA may be appropriate.

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