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The newly-ratified definition of the Quaternary System/Period and redefinition of the Pleistocene Series/Epoch, and comparison of proposals advanced prior to formal ratification

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The base of the Quaternary System is defined by the Global Stratotype Section and Point (GSSP) of the Gelasian Stage at Monte San Nicola in Sicily, Italy, currently dated at 2.58 Ma. The base of the Pleistocene Series is redefined by the same GSSP, having previously been defined by the GSSP at Vrica, Calabria, Italy, which is dated at 1.806 Ma. These important changes to the geological time scale were formulated through extensive consultation with the Quaternary community through the International Union for Quaternary Research (INQUA), proposed by the International Commission on Stratigraphy's (ICS) Subcommittee on Quaternary Stratigraphy, endorsed by the voting membership of the ICS, and ratified in June 2009 by the Executive Committee of the International Union of Geological Sciences. Two competing proposals had been advanced: a 'Neogene' proposal advocated by the ICS Subcommittee on Neogene Stratigraphy, and a 'Quaternary' proposal championed by the ICS Subcommittee on Quaternary Stratigraphy. The status quo position would have persisted had neither proposal received a majority of votes. These proposals are compared and evaluated, the 'Quaternary' proposal is presented in detail, and future directions are discussed.

Introduction

In June 2009, the Executive Committee of the International Union of Geological Sciences (IUGS) ratified a proposal submitted by the International Commission on Stratigraphy (ICS) to define the base of the Quaternary System by the Global Stratotype Section and Point (GSSP) of the Gelasian Stage at Monte San Nicola in Sicily, Italy, currently dated at 2.58 Ma (Gibbard et al., 2010; Figure 1). The base

of the Pleistocene Series was simultaneously redefined (lowered) so as to be coterminous with that of the Quaternary. The top of the Neogene System is accordingly defined by the base of the Quaternary System, and the top of the Pliocene Series by the base of the Pleistocene (Gibbard and Head, 2009a, b; Gibbard et al., 2010; Finney, 2010). The Pleistocene had previously been defined by the GSSP at Vrica, Calabria, Italy, which is dated at 1.806 Ma (Lourens et al., 2005; Figure 1). The IUGS Executive Committee had already given its unanimous approval on 28 May 2007 that the Quaternary be recognized as a formal system/period (Bobrowski, 2007). The present paper highlights the newly ratified scheme, and provides the underlying justification for the ICS proposal. A companion paper by Finney (2010) describes the procedure leading to ratification.

This formalization has brought official closure, for the next ten years at least, to a protracted debate within and far beyond the ICS. In arriving at this juncture, the ICS and its Quaternary and Neogene subcommittees (SQS and SNS, respectively) had spent considerable time and energy over the proposed revision of the base of the Pleistocene Series and the first formal, explicit definition of the base of the Quaternary System. Developments leading up to 2008 are described by Pillans and Naish (2004), Bowen and Gibbard (2007), Pillans (2007), Ogg and Pillans (2008), Gibbard and Head (2009b), and Cita and Pillans (2010).

A process of open discussion by meetings, e-mail exchanges, webpages, and journal articles was initiated at the 33rd International Geological Congress (IGC) in Oslo, August 2008. At the IGC, an open forum focused specifically on the status and duration of the Neogene and Quaternary systems, and the possible redefinition of the Pleistocene Series, and was attended by a wide range of stakeholders. Presentations allowed all opinions to be aired, and they were followed by questions and discussion. Following this public meeting, proponents of the various positions were asked to submit formal proposals to the ICS.

Proposals submitted

Two proposals were submitted. The 'Neogene' proposal advocated extending the Neogene to the present, revising the rank of the Quaternary to subsystem with its base at the base of the Gelasian

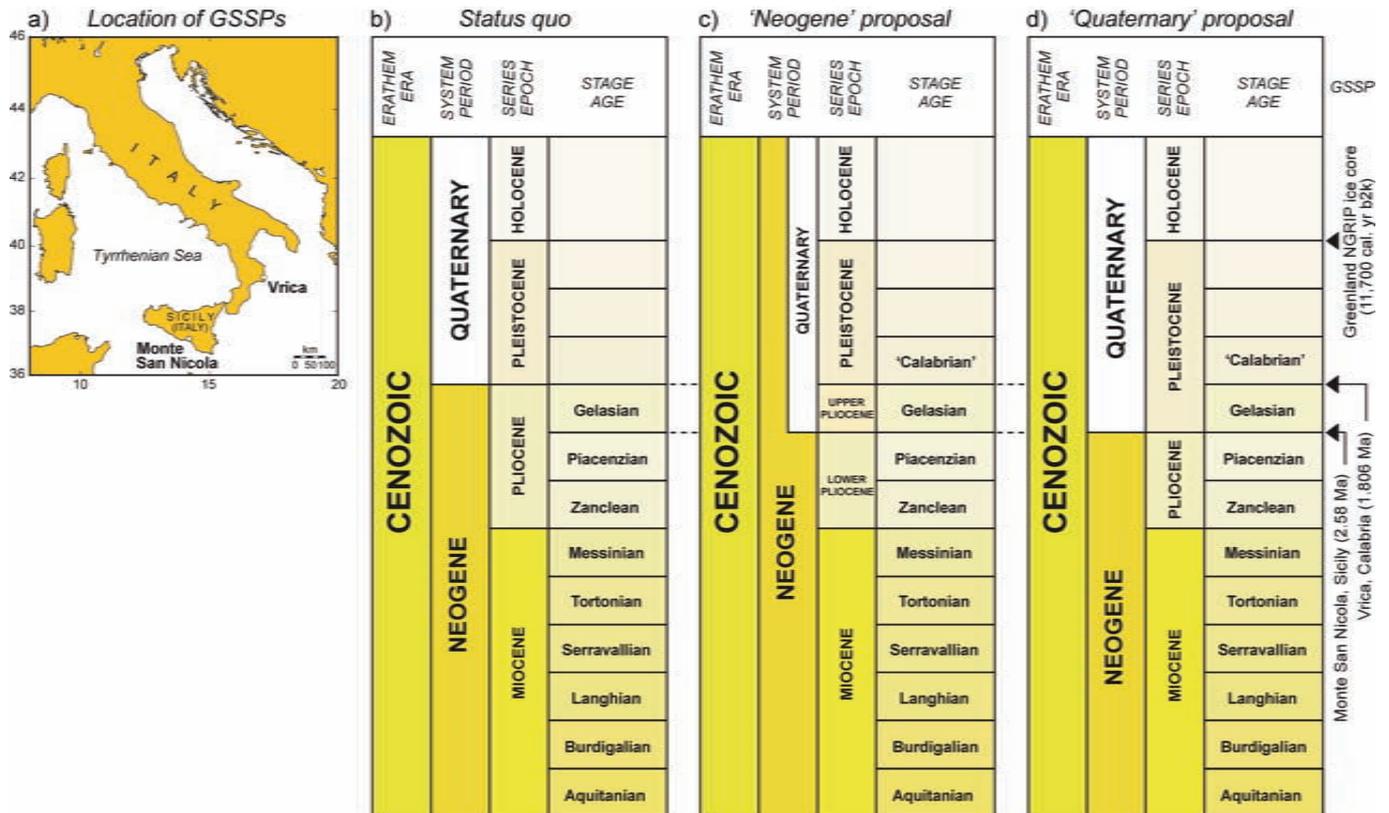


Figure 1. (a) Location of the two Global Stratotype Sections and Points (GSSPs) discussed in the text: the Monte San Nicola GSSP now defining the base of the Gelasian Stage, Pleistocene Series and Quaternary System, and the Vrica GSSP having previously defined the base of the Pleistocene Series and still available to define the base of the 'Calabrian' Stage. (b) The status quo scheme represents the most recent previous IUGS-sanctioned time scale (Remane, 2000) as a fall-back position had neither the 'Quaternary' nor 'Neogene' proposal been successful. (c) The defeated 'Neogene' proposal has the Quaternary depicted as a subsystem, and the Pliocene Series is split into two separate series, a Lower Pliocene and an Upper Pliocene. (d) The 'Quaternary' proposal represents the now official scheme in the IUGS-sanctioned geological time scale. Although no stratigraphic units below the Quaternary were mentioned in this proposal, they are included here to illustrate the current IUGS-sanctioned time scale for the Cenozoic. The position of the GSSP defining the base of the Holocene Series (Walker et al., 2009), dated at 11,700 calendar years before AD 2000, is also shown.

Stage, maintaining the Pleistocene Series as defined by the GSSP at Vrica in Italy, and replacing the Pliocene Series by a Lower Pliocene Series (restricted to the Neogene) and an Upper Pliocene Series (Neogene and Quaternary) (Figure 1c). The 'Quaternary' proposal recommended extending the Pleistocene Series downwards to incorporate the Gelasian Stage and formally defining the base of the Quaternary System at this same level (Figure 1d).

Neither proposal involved the establishment or redefinition of GSSPs since the GSSPs proposed were in use at that time.

Procedures

The ICS Neogene and Quaternary subcommissions were directed to consider both proposals, to discuss them extensively and then to vote on them. The 'Quaternary' proposal was accepted by the Quaternary Subcommission and rejected by the Neogene Subcommission. The 'Neogene' proposal was accepted by the Neogene Subcommission and rejected by the Quaternary Subcommission. From a procedural viewpoint with regard to competences, the ICS was fit to decide because the proposals of both subcommissions agreed on lowering the base of the Quaternary to include the Gelasian, and the

redefinition of the base of the Pleistocene was then a matter exclusively under the competence of the Quaternary Subcommission.

Accordingly, both proposals were received by the ICS for discussion, deliberation and voting. At this stage, the ICS opened a 35-day period of e-mail discussion that allowed comments on both proposals to be posted from members of both subcommissions, together with all voting members of the ICS and all other interested persons inside or outside the ICS who wished to contribute (Finney, this issue).

A review of the nature of the issues with respect to the 'Neogene' and 'Quaternary' proposals was presented by the ICS Chair, and this and all circulated comments, manuscripts and points of discussion were posted on the ICS and SQS websites: <http://www.stratigraphy.org> and <http://www.quaternary.stratigraphy.org.uk>. This period of discussion was brought to a close, and the ICS voting membership was asked to vote according to a procedure that required two rounds. The first ballot asked for 'Yes', 'No' or 'Abstain' responses for each of the 'Quaternary', 'Neogene' and *status quo* proposals, and a majority of 'Yes' votes was required to move the proposal forward to the next ballot. The *status quo* position (Figure 1b) represented the alternative should neither the 'Quaternary' nor 'Neogene' proposal receive a majority of votes in favour. In such a situation, the

Pleistocene Series would remain defined by the GSSP at Vrica, and the Quaternary System would be formally defined by the same GSSP. It should be emphasized that while the 'Quaternary' and 'Neogene' proposals were substantially different, both agreed on lowering the base of the Quaternary to that of the Gelasian, which disagreed with the *status quo* position.

Voting Results

In the first round, only the 'Quaternary' proposal received a majority of 'Yes' votes (72%), which resulted in the 'Neogene' proposal being excluded from the second voting round. A second ballot included only the 'Quaternary' proposal, and members were asked to vote 'Yes', 'No' or 'Abstain', with a 60% majority required to move the proposal forward. In this round the 'Quaternary' proposal was formally accepted by the ICS ballot with a majority of 89% 'Yes' votes received (Gibbard and Head, 2009b). Accordingly, on 2 June 2009 the 'Quaternary' proposal was forwarded to the IUGS Executive Committee for ratification.

Proposal approved by the IUGS Executive Committee

The following recommendations were submitted by the ICS to the Executive Committee of the IUGS, that:

- 1) the base of the Pleistocene Series/Epoch be lowered such that the Pleistocene includes the Gelasian Stage/Age and its base is defined by the Monte San Nicola GSSP, which also defines the base of the Gelasian;
- 2) the base of the Quaternary System/Period, and thus the Neogene-Quaternary boundary, be formally defined by the Monte San Nicola GSSP and thus be coincident with the bases of the Pleistocene and Gelasian, and
- 3) with these definitions, the Gelasian Stage/Age be transferred from the Pliocene Series/Epoch to the Pleistocene.

These recommendations were approved by majority vote of the IUGS Executive Committee on 29 June 2009 (letter of 30 June 2009 to P.R. Bown, Secretary-General, ICS from A.C. Riccardi, President, IUGS).

Specific details of the approved proposal

The following letter, representing the 'Quaternary' proposal, had been submitted to S. Finney, Chair of the ICS, on 1 September, 2008. Literature references were not provided in this letter, but selected references are included here together with brief annotations.

Formal request to ICS that the base of the Quaternary System/Period be lowered to the Gelasian Stage GSSP (at 2.588 Ma), and that the base of the Pleistocene Series be lowered to the same position.

Following the public forum discussion meeting held at the 33rd IGC in Oslo, the International Subcommittee on Quaternary Stratigraphy formally requests to the incoming ICS that the base of

the Quaternary System/Period be lowered to the Gelasian Stage GSSP (at 2.588 Ma [now revised to 2.58 Ma; Gibbard and Head, 2009a]) and that the base of the Pleistocene Series be lowered to the same position. The Quaternary is already recognised by the IUGS as having System/Period status and succeeding the Neogene, but with its base currently defined by the Pleistocene System GSSP at Vrica (at 1.806 Ma). The specific details of this request are that:

1. The base of the Quaternary System be lowered to the GSSP of the Gelasian Stage (currently the uppermost stage of the Pliocene Series) at the base of Marine Isotope Stage 103 [now considered not at the base of MIS 103, but within MIS 103; Gibbard and Head, 2009a], which has a calibrated age of 2.588 Ma [now 2.58 Ma].
2. The base of the Pleistocene Series be lowered to coincide with that of the Quaternary System boundary (the Gelasian GSSP).
3. The Vrica GSSP (the present Quaternary and Pleistocene basal boundary) be retained as the base of the Calabrian Stage, the second stage of the revised Pleistocene Series.

This request follows a previous ICS proposal, dated 13 May 2007, which was supported by a separate request directly to IUGS by the INQUA [International Union for Quaternary Research] Executive Committee. It was subsequently supported by a unanimous vote of the INQUA General Assembly at the INQUA Congress held in Cairns, in Australia in August 2007.

Supporting case

Thank you for this opportunity to present our final case for the Quaternary as a period/system with its base defined by the base-Gelasian GSSP at Monte San Nicola, Sicily, which has an astronomical age of 2.588 Ma [2.58 Ma; Gibbard and Head, 2009a]. On hierarchical as well as scientific grounds, this definition requires that the base of the Pleistocene Epoch/Series be lowered from its present GSSP at Vrica, Calabria, Italy (dated astronomically at 1.806 Ma) to the GSSP at Monte San Nicola. The Vrica GSSP would, however, remain to define the base of the 'Calabrian' Age/Stage. This proposal moreover reflects widespread current and historical usage of the term Quaternary, and is supported by INQUA, the SQS, and the outgoing ICS for 2004–08. This position has been summarised recently by Head, Gibbard and Salvador (2008[a]) and Ogg and Pillans (2008) (attached) and is highlighted below. We welcome this opportunity also to address opposing views by Lourens (2008) and Hilgen et al. (2008) including their desire to extend the Neogene to the present day.

1. The Quaternary was first proposed as a concept by Arduino in 1759 [Arduino, 1760] and was used formally by Desnoyers in 1829, predating both the terms Pleistocene (Lyell in 1839) and Neogene (Hörnes in 1853).
2. The traditional and current view (and that of the IUGS) is that the Neogene represents the Miocene and Pliocene, and that the Quaternary represents the Pleistocene and Holocene, as any wide perusal of the current literature will show. Maps displayed in the exhibitors' booths at the 33rd IGC in Oslo offered a snapshot of absolutely current usage. Of 29 maps inspected,

- representing geological surveys and NGOs [non-governmental organizations] from around the world, just three depicted the Neogene extending to the present day – the overwhelming majority illustrating a Neogene below the Quaternary.
3. Claims that the Neogene should be extended to the present day are based on flawed historical interpretation. Hörnes [1853] was vague about where his Neogene should end but it is clear that he did not intend it to extend to the present day or indeed include parts of the Pleistocene (Walsh, 2008).
 4. Assertions that the Holocene should be treated as a subdivision of the Pleistocene, rendering the Quaternary superfluous, deny the unique qualities of the Holocene and its pervasive use in the literature. Furthermore, the argument is now moot – the Holocene having been ratified as an epoch/series within the Quaternary Period/System by the IUGS earlier this year [Walker et al. 2009; Figure 1].
 5. Ratified in 1985 [31 May 1985; Bassett, 1985], the base-Pleistocene is defined by the Vrica GSSP [Aguirre and Pasini, 1985] at a position now dated astrochronologically at 1.806 Ma. This position was incorrectly thought to represent the first climatic deterioration in the Italian Plio–Pleistocene. For example, the ostracod *Cytheropteron testudo*, a ‘northern guest’ singled out as having special significance for recognising the Vrica GSSP, has since been recorded at 2.4 Ma within the Monte San Nicola section in Italy (Aiello et al., 1996). Consequently, the Vrica GSSP has poor potential for correlation and, in retrospect, provides an arbitrary rather than descriptive means to subdivide geological time. This boundary is inappropriate and unworkable for defining the base of an epoch, let alone a period.
 6. The first significant cluster of cooling events within the Italian Plio–Pleistocene and elsewhere extends from 2.7 to 2.4 Ma. Earlier cooling events, such as the Mammoth cooling event (3.3 Ma), are best viewed as precursor occurrences. Fundamental changes to the Earth’s climate system and associated biotic response make this episode the logical start of the Quaternary. The Monte San Nicola GSSP dated at 2.588 Ma [now 2.58 Ma] occurs conveniently at the approximate mid-point of this cooling interval, and within 1 m of the Gauss–Matuyama Chron boundary. The fact that this GSSP occurs in a warm stage (MIS 103) has little overall consequence for the widely agreed concept of the Quaternary, namely the onset of major glaciation in the Plio–Pleistocene. The wide support for this boundary recognises that the Quaternary must be defined by scientifically meaningful as well as practical criteria.
 7. Although it coincides with a period of significant global cooling, the Gelasian GSSP, which will serve to define the base-Quaternary and base-Pleistocene boundary, was selected and approved as a globally correlative chronostratigraphical horizon by marine geochronologists of the Neogene Subcommittee (Rio et al., 1998 [ratified in 1996]). Thus, the Quaternary and Pleistocene, if redefined at this boundary, will not be climatostratigraphical units as some have suggested but biochronologically defined divisions.
 8. INQUA and common usage both assert the need for the Quaternary to remain at its present IUGS-sanctioned rank of period/system; a status confirmed twice by formal ICS votes in 2005 and 2007. For reasons of hierarchy and common sense, the base of the Pleistocene should therefore be lowered to that of the Quaternary. Although the Vrica GSSP was re-ratified in 1999 (by minority vote), there has been unremitting dissatisfaction with this boundary from a substantial community since its inception in 1985 and indeed before. As has been demonstrated by the voting of the INQUA members, most recently and unanimously at the 2007 INQUA Congress in Cairns, an overwhelming majority of Quaternary / Pleistocene workers wants the units changed. Moreover, because INQUA now has adopted the definition proposed here, which currently differs from that accepted by ICS and IUGS, the present situation generates great confusion.
 9. The vague term ‘Plio–Pleistocene’ has become the legacy of the existing Vrica boundary which has little meaning beyond the local Mediterranean area. Lowering the base-Pleistocene to the Monte San Nicola GSSP will align it with the base-Gelasian and base-Quaternary. This also brings the lowered Pleistocene into better accord with the 1948 IGC decision that the Pleistocene should include the Villafranchian regional mammal stage, the base of which is now known to extend beyond 1.806 Ma.
 9. A base-Quaternary boundary at 2.6 Ma will strengthen recognition within terrestrial as well as marine sections owing to major global changes in the terrestrial biota, including humans, and in sedimentation particularly with respect to loess deposition across northern Eurasia. Such major global changes are lacking around 1.8 Ma.
 10. Although the SQS and SNS are equal members under the ICS, and IUGS and INQUA equal members under the International Council for Science (ICSU), the user-base for the geological time scale should also be considered carefully. The current INQUA–SQS position has the overwhelming support of users – the large global population of Quaternary scientists that has resulted in INQUA being the only geological period to have its own union under the ICSU.
 11. The suggestion by Lourens (2008) to lower the base-Quaternary and base-Gelasian to 2.72 Ma (rather than our 2.6 Ma) would weaken its potential for correlation owing to a significantly increased distance from the Gauss–Matuyama Chron boundary. Furthermore, relegating the Quaternary Period to be a subperiod of an extended Neogene Period runs counter to an enormous literature and the weight of current opinion, and would be unnecessarily disruptive. Moreover, termination of the Neogene at 2.6 Ma is logical given the fundamental changes to Earth’s climate system at around this time [e.g. Sarnthein et al., 2009].
 12. Sanctioning two independent geological time scales, one for the Quaternary and another showing an extended Neogene, as suggested by Hilgen et al. (2008, p. 30), would be confusing, divisive and only defer a decision that should be made now. It would be the worst of all possible compromises. INQUA, SQS and the 2000–2004 ICS have accepted an existing GSSP (the Monte San Nicola GSSP) to define the base-Quaternary as a compromise in the interests of expediency and stability.
 13. The proposed changes will affect both the Quaternary and Neogene communities. However, since Quaternary workers have long favoured the 2.6 Ma boundary, and many indeed have applied this boundary for decades already, the impact for them will be slight. For Neogene workers the effect will be greater because of the reattribution the Gelasian Stage to the Quaternary,

but this stage was ratified only 10 years ago by the Neogene community in acknowledgement of important changes occurring at *ca.* 2.6 Ma. Hence, we consider any confusion regarding the reallocation of the Gelasian to be short lived.

We hope these points will be useful to the ICS in making its recommendation to the IUGS, and we look forward to ending finally a debate that began exactly 60 years ago (the London IGC in 1948) [King and Oakley, 1949, 1950] to resolve the status and duration of the Quaternary.

Submitted by Philip Gibbard and Martin J. Head, for the Subcommittee on Quaternary Stratigraphy (1 September 2008). [A copy of Head et al. (2008a) and Ogg and Pillans (2008) was included in the submission.]

Following the formal voting and ratification of the 'Quaternary' proposal, the details of the proposal and the outcome were published by Gibbard and Head (2009a, b) and Gibbard et al. (2010).

Monte San Nicola versus Vrica GSSPs

To understand the reasoning behind the 'Quaternary' proposal, it is necessary to touch upon the historical precedents that led to the two GSSPs in question. The Vrica proposal and its approval occurred within the International Geological Correlation Program (IGCP), Project 41 – Neogene–Quaternary boundary (Nikiforova and Alekseev, 1997); the final report (Van Couvering, 1997) being published after long delay. The selection of Vrica as the base of the Pleistocene in the late 1970s (Selli et al., 1977) was in direct response to a formal resolution of the 18th International Geological Congress (IGC) in London in 1948 that the base of the Pleistocene (and Quaternary) should be defined in Italy within marine deposits of Calabrian age and at the first indications of climatic deterioration (King and Oakley, 1949, 1950). This climatic deterioration was linked to the first appearances of cold-water Atlantic immigrants, most notably *Arctica islandica* (a bivalve, and historically the index for the beginning of the Calabrian), *Hyalinea baltica* (a foraminiferan), and *Cytheropteron testudo* (an ostracod) (Aguirre and Pasini, 1985; Nikiforova and Alekseev, 1997). It has since been discovered that some immigrants ('northern guests') had actually arrived in the Mediterranean earlier than previously believed, as noted in the 'Quaternary' proposal above (see also Arias et al., 1980, for a *ca.* 2.0 Ma record of *Arctica islandica* in Italy). At the time of the 18th ICS in 1948, it had been thought that the bases of the Praetiglian pollen stage of Northwestern Europe, the Villafranchian mammal stage of Europe, and the Calabrian deposits of Italy, were all coincident (King and Oakley, 1949). It is now known that the Villafranchian began during the Piacenzian (Rook and Martínez-Navarro, 2010); a marked large-mammal turnover (the Early–Middle Villafranchian transition) in fact occurred in Italy, as elsewhere, between 2.8 and 2.5 Ma (Bonadonna and Alberdi, 1987; Rook and Martínez-Navarro, 2010; Bertini et al., 2010); and the Praetiglian pollen stage belongs to the early Gelasian (Head et al., 2008a). In fact, there had been dissatisfaction with the Vrica GSSP since its first approval at the 11th INQUA Congress in Moscow in 1982 (Cita and Pillans, 2010).

The Vrica proposal was a product of its historical constraints,

and based on the observational data and correlation tools available at that time. Moreover, by the time the proposal had finally been formulated, it addressed only the basal boundary of the Pleistocene, without reference either to the Calabrian Stage or the Quaternary System (Aguirre and Pasini, 1985). This was a curious development, given the established convention that the lower boundaries of the Quaternary and Pleistocene are coincident (e.g., King and Oakley, 1949), and that the base of a series is defined by that of its lowest stage (in this case the Calabrian), which should therefore also be defined. The consequence was that the Quaternary and Calabrian Stage remained unratified.

While the Vrica GSSP quickly proved unsatisfactory for defining the base of the Quaternary, the Gelasian GSSP at Monte San Nicola in contrast was conveniently placed. Already by 1977 (during a meeting of the governing board of the IGCP in Paris, March 1977) the interval of significant climate change corresponding to the Early–Middle Villafranchian transition and close to the Gauss–Matuyama Chron boundary was being considered for the lower boundary of the Quaternary, although no suitable marine Italian section was then available (Nikiforova and Alekseev, 1997). Eventually, such a section was identified, and it became the type section for the Gelasian Stage. As noted by Rio et al. (1998, p. 82), the Gelasian was proposed largely in response to observations that the top of the subjacent Piacenzian stratotype 'falls in a critical point of the evolution of Earth climatic system (i.e. close to the final build-up of the Northern Hemisphere Glaciation)', thus making it undesirable to extend the Piacenzian Stage upwards to the Vrica GSSP. The official Gelasian proposal was preceded by an informal presentation to an international Pliocene symposium held in Baton Rouge, Louisiana, in 1993 which made the point that 'The base of the Gelasian is close to a major climatic event detectable not only in marine successions, but also in the continental record. Initiation of loess sedimentation in China (Kukla and Han, 1989), the palynological pre-Tiglian/Tiglian boundary in Europe (Zagwijn, 1974), major migrational events in mammalian fauna (e.g., the mid-Villafranchian elephant–*Equus* migrational event in the Eurasian region, Masini and Torre, 1990) all occur close to the Gauss–Matuyama boundary, and hence close to the base of the Gelasian.' (Cita et al., 1999, p. 59). These justifications for the Gelasian Stage, which incidentally was supported by a large majority of the Subcommittee on Neogene Stratigraphy (Rio et al., 1998), explain why the Gelasian GSSP has now been chosen also to define the base of the Quaternary System/Period and Pleistocene Series/Epoch.

Work in progress

The 'Quaternary' proposal requested, *inter alia*, that the Calabrian Stage be officially recognized with its base defined by the Vrica GSSP. Although this request was included in the ballot voted on and accepted by the SQS, it failed to appear on the ballot sent to the ICS voting membership due to an oversight. Hence, while all scientific and technical requirements for acceptance of the Calabrian Stage have otherwise been met (Cita et al., 2008), it must be approved by the ICS and then ratified by the IUGS. The ICS intends to move this process forward.

Pleistocene global 'standard' stages above the 'Calabrian', and all subseries of the Pleistocene (Lower, Middle and Upper), have yet to be defined formally, although working groups of the SQS, together

with Italian colleagues, are making progress in this regard (e.g., Cita et al., 2006; Cita, 2008; Head et al., 2008c; Litt and Gibbard, 2008).

The Executive Committee of the IUGS noted that the Quaternary should be defined with ‘due consideration and respect for the issue of the Tertiary’ (IUGS correspondence to ICS, May 2007; Head et al., 2008b). However, for practical purposes, the ‘Quaternary’ proposal (above) mentioned neither the Tertiary nor any other unit below the Quaternary, and the IUGS ratification of the ‘Quaternary’ proposal leaves the Neogene defined as a full system immediately beneath the Quaternary (the *status quo* topology). The issue of the Tertiary should nonetheless continue to deserve consideration because there is a long and still strong tradition of treating it as full system immediately beneath the Quaternary, with the Neogene and Paleogene as subsystems of the Tertiary (Head et al., 2008b; Walker and Geissman, 2009; Knox et al., 2010; Menning, 2010; U.S. Geological Survey Geologic Names Committee, 2010).

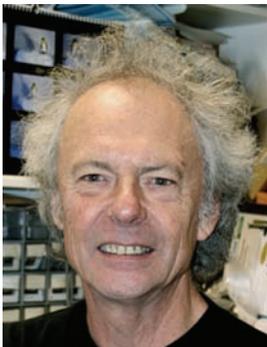
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