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Rapid Communication

Formal ratification of the Quaternary System/Period and the Pleistocene Series/Epoch with a base at 2.58 Ma

PHILIP L. GIBBARD,[1]* MARTIN J. HEAD,[2] MICHAEL J. C. WALKER[3,4] and THE SUBCOMMISSION ON QUATERNARY STRATIGRAPHY[†]
[1] Cambridge Quaternary, Department of Geography, University of Cambridge, Cambridge, UK
[2] Department of Earth Sciences, Brock University, St Catharines, Ontario, Canada
[3] Department of Archaeology and Anthropology, University of Wales, Lampeter, UK
[4] Institute of Geography and Earth Sciences, Aberystwyth University, Aberystwyth, UK

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ABSTRACT: In June 2009, the Executive Committee of the International Union of Geological Sciences (IUGS) formally ratified a proposal by the International Commission on Stratigraphy to lower the base of the Quaternary System/Period to the Global Stratotype Section and Point (GSSP) of the Gelasian Stage/Age at Monte San Nicola, Sicily, Italy. The Gelasian until then had been the uppermost stage of the Pliocene Series/Epoch. The base of the Gelasian corresponds to Marine Isotope Stage 103, and has an astronomically tuned age of 2.58 Ma. A proposal that the base of the Pleistocene Series/Epoch be lowered to coincide with that of the Quaternary (the Gelasian GSSP) was also accepted by the IUGS Executive Committee. The GSSP at Vrica, Calabria, Italy, which had hitherto defined the basal boundary of both the Quaternary and the Pleistocene, remains available as the base of the Calabrian Stage/Age (now the second stage of the revised Pleistocene). In ratifying these proposals, the IUGS has acknowledged the distinctive qualities of the Quaternary by reaffirming it as a full system/period, correctly complied with the hierarchical requirements of the geological timescale by lowering the base of the Pleistocene to that of the Quaternary, and fully respected the historical and widespread current usage of both the terms 'Quaternary' and 'Pleistocene'. Copyright © 2009 John Wiley & Sons, Ltd.

KEYWORDS: Quaternary; Pleistocene; Gelasian; Global Stratotype Section and Point (GSSP); Quaternary/Pleistocene lower boundary.

Introduction

The terms 'Quaternary' and 'Pleistocene' have been used by Earth scientists for more than 150 years, but there has been protracted and, at times, acrimonious debate over their position and status in the geological timescale, and over the intervals of time they represent (e.g. Berggren *et al.*, 1995; Partridge, 1997; Gradstein and Ogg, 2002; Pillans, 2004, 2007; Gibbard and van Kolfschoten, 2005; Aubry *et al.*, 2005, 2009). During the past four years, however, at the instigation of the International Commission on Stratigraphy's (ICS's) Subcommission on Quaternary Stratigraphy (SQS: Table 1) and in combination with the International Union for Quaternary Research (INQUA), a concerted attempt has been made to secure the position of the Quaternary as a formal system/period within the geological timescale and to define the Quaternary with reference to an accepted stratigraphic boundary that may serve as a global marker (Gibbard *et al.*, 2005; Bowen and Gibbard, 2007; Head *et al.*, 2008a; Ogg and Pillans, 2008). These efforts culminated in the submission of a formal 'Quaternary proposal' to the ICS. This was subsequently approved and forwarded to the International Union of Geological Sciences (IUGS) Executive Committee for ratification (Gibbard and

* Correspondence to: P. L. Gibbard, Department of Geography, University of Cambridge, Downing Place, Cambridge CB2 3EN, UK.
E-mail: plg1@cam.ac.uk
[†]Members of Subcommission on Quaternary Stratigraphy (2009): B. Alloway, A. G. Beu, M. Coltorti, P. L. Gibbard (Chair), V. M. Hall, M. J. Head, Liu Jiaqi, K. L. Knudsen, T. van Kolfschoten (Secretary), T. Litt, L. Marks, J. McManus (Vice-Chair), T. C. Partridge, J. A. Piotrowski, B. Pillans, D.-D. Rousseau, J.-P. Suc, A. S. Tesakov, C. Turner, M. J. C. Walker, C. Zazo.

Table 1 Subcommission on Quaternary Stratigraphy (2009)

B. Alloway	School of Geography and Earth Sciences, Victoria University of Wellington, PO Box 600, Wellington, New Zealand
A. G. Beu	School of Geography and Earth Sciences, Victoria University of Wellington, PO Box 600, Wellington, New Zealand
M. Coltorti	Dipartimento di Scienze della Terra, University of Siena, Italy
P. L. Gibbard (Chair)	Department of Geography, University of Cambridge, UK
V. M. Hall	School of Archaeology and Palaeoecology, Queen's University, Belfast, UK
M. J. Head	Department of Earth Sciences, Brock University, Canada
Liu Jiaqi	Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, China
K. L. Knudsen	Department of Earth Sciences, University of Aarhus, Denmark
T. van Kolfschoten (Secretary)	Faculty of Archaeology, Leiden University, The Netherlands
T. Litt	Institute of Paleontology, University of Bonn, Germany
L. Marks	Polish Geological Institute, Warsaw, Poland
J. McManus (Vice-Chair)	Lamont-Doherty Earth Observatory, Columbia University, New York, USA
T. C. Partridge	Climatology Research Group, University of the Witwatersrand, South Africa
J. A. Piotrowski	Department of Earth Sciences, University of Aarhus, Denmark; and Department of Geography, University of Sheffield, UK
B. Pillans	Research School of Earth Sciences, The Australian National University, Canberra, Australia
D.-D. Rousseau	Ecole Normale Supérieure, Laboratoire de Météorologie Dynamique and CERES-ERTI, Paris, France
J.-P. Suc	Laboratoire PaléoEnvironnements et PaléobioSphère, Université Claude Bernard – Lyon 1, France
A. S. Tesakov	Geological Institute, Russian Academy of Sciences, Moscow, Russia
C. Turner	Department of Geography, University of Cambridge, UK
M. J. C. Walker	Department of Archaeology and Anthropology, University of Wales, Lampeter, Wales, UK; and Institute of Geography and Earth Sciences, Aberystwyth University, UK
C. Zazo	Departamento de Geología, Museo Nacional de Ciencias Naturales (CSIC), Madrid, Spain

Head, 2009). Here we report on the decision by the IUGS Executive Committee to accept the proposal that the lower boundaries of the Quaternary System/Period, Pleistocene Series/Epoch and Gelasian Stage/Age be henceforth treated as coterminous, with a currently calibrated age of 2.58 Ma. This ratification officially reaffirms the Quaternary as a chronostratigraphic unit of system/period rank, while lowering its base and that of the Pleistocene by ca. 780 ka.

Roles of IUGS, ICS and SQS

The organisation charged with responsibility for the formal division of geological time, and therefore the internationally sanctioned geological timescale (GTS), is the International Commission on Stratigraphy. The ICS is a constituent group of the International Union of Geological Sciences, which oversees all aspects of global geoscience and which is supported by funding from UNESCO. The principal role of the ICS is the subdivision, classification and enumeration of geological time, i.e. chronostratigraphy and geochronology. The ICS operates through subcommissions, each associated with a particular time period, the Subcommission on Quaternary Stratigraphy, for example, being responsible for the Quaternary. The subcommissions formulate proposals for the formal definition and subdivision of their respective periods that aim to improve the resolution of global correlation. Each division and subdivision represents a key time–stratigraphic unit. Following careful examination of the evidence, the basal boundary of this unit is defined by an appropriate point of reference in a designated sedimentary sequence (Global Stratotype Section and Point, GSSP), and its upper boundary is defined by the base of the succeeding unit. Proposals for such units to be formally recognised are submitted to the ICS for approval. A ballot then follows in which each of the ICS officers (18 in all) has one vote, and a proposal that achieves the appropriate majority (60% of the votes cast) is forwarded by the ICS to the IUGS Executive Committee for ratification. If the Executive Committee is satisfied that the proposal is in order, it is ratified, and the details are published (with at least a summary appearing in the journal *Episodes*). Any changes that arise from the proposal are incorporated into the GTS (www.stratigraphy.org). Once a GSSP has been ratified by the IUGS, a 10-year moratorium on any change then applies (Remane *et al.*, 1996).

Status of the Quaternary in the geological timescale

The geological timescale is based on a hierarchical system of classification in which time–rock sequences (chronostratigraphy) and their corresponding intervals of time (geochronology) are represented by units of progressively lower rank. Both tradition and widespread current usage have accorded the Quaternary the status of *system* (a chronostratigraphic unit of high rank) and *period* (the equivalent geochronological unit) within the Cenozoic Erathem/Era (Salvador, 2006a,b). The Pleistocene is traditionally placed within the Quaternary at the next-lower rank of *series* (chronostratigraphy) or *epoch* (geochronology), as also is the Holocene (Bowen and Gibbard, 2007; Walker *et al.*, 2009). The base of the Quaternary traditionally defines the upper boundary of the Tertiary, the preceding system/period that extends back to the end of the Cretaceous (Hedberg, 1976; Salvador, 1994, 2006a,b).

There has, nonetheless, been opposition to this conventional usage. In 1968, the Stratigraphy Committee of the Geological Society of London recommended that the Cenozoic be divided 'informally' into Tertiary and Quaternary sub-eras, with the Tertiary further divided into Paleogene and Neogene systems/periods, a proposal that was followed in the 1982 and 1989 GTSs (Harland *et al.*, 1982, 1990; Fig. 1(a)). This subdivision was not, however, universally accepted; for example, the timescale adopted by the United States Geological Survey and the Geological Society of America returned the Quaternary and Tertiary to full system/period status (Palmer, 1983; Salvador, 1994; Fig. 1(b)). Nonetheless, in

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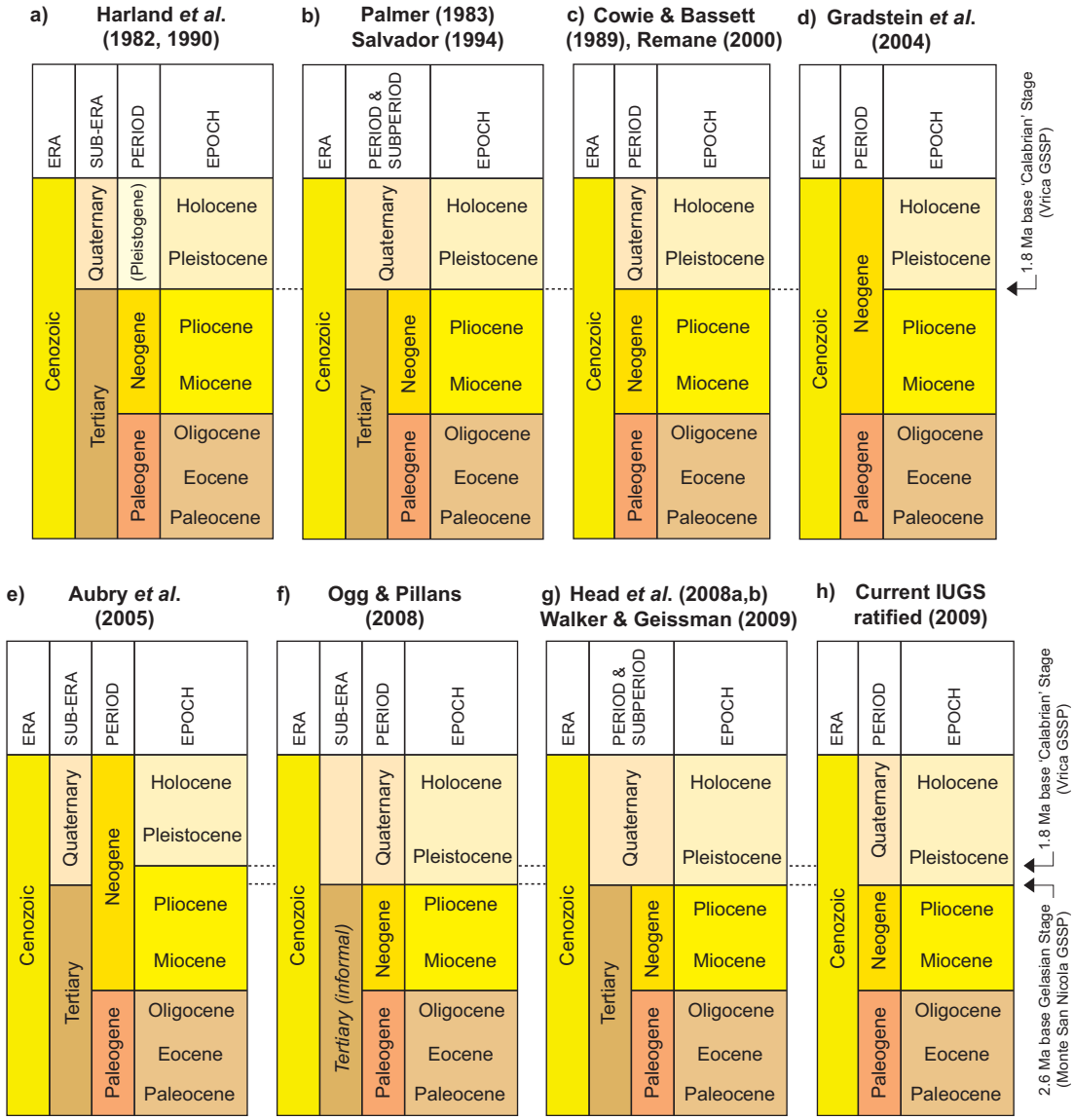

Figure 1 Comparison of Cenozoic timescales. The Palmer/Salvador timescale (b) is the most widely adopted Cenozoic timescale in current use, while the Cowie and Bassett/Remane timescale (c) was, until now, the most recent Cenozoic timescale endorsed by the IUGS. The current timescale, newly ratified by the IUGS (h), follows the Cowie and Bassett/Remane timescale, but with the base of the Quaternary and Pleistocene lowered to 2.6 Ma. The Tertiary (a, b, e–g), while not included in the newly ratified timescale (h), is under consideration for future reinstatement (Head *et al.*, 2008b), and features in the latest Geological Society of America timescale (Walker and Geissman, 2009). The stratigraphical intervals are not scaled to geological time

the subsequent IUGS-approved timescales of Cowie and Bassett (1989) and Remane (2000), the Tertiary was absent (Fig. 1(c)), having been left undefined by the IUGS following the acceptance of GSSPs for the Paleogene in 1991 (Molina *et al.*, 2006) and Neogene in 1996 (Steininger *et al.*, 1997). However, the term 'Tertiary' has never been explicitly eliminated by the IUGS (Head *et al.*, 2008b).

Compounding this difficulty, the 2004 version of the GTS (Gradstein *et al.*, 2004) omitted not only the Tertiary but also Quaternary (Fig. 1(d)). The Miocene, Pliocene, Pleistocene and Holocene series/epochs were instead incorporated within a Neogene Period that extended to the present day (Gradstein *et al.*, 2004, 2005). Although the timescales of Gradstein *et al.* were not sanctioned by either the ICS or IUGS, they reinvigorated debate on the nature, duration and chronostratigraphic position of both the Quaternary and Tertiary, and also of the Neogene (for reviews, see Pillans and Naish, 2004; Aubry *et al.*, 2005; Gibbard *et al.*, 2005; Walsh, 2006, 2008; Lourens, 2008). Intensive discussions between the SQS and INQUA ultimately led to a firm restatement that the Quaternary should remain as a chronostratigraphic/geochronological unit of full system/period status, and that any compromise position (e.g. Fig. 1(e)) should be rejected. In May 2007, the ICS voted in favour of the resulting proposal, and the IUGS ratified the Quaternary as a formal system/period later that month by unanimous vote. This decision officially established the Quaternary at its current stratigraphical rank of system/period (Fig. 1(h)). Ironically, the Quaternary now holds the same rank as it did 25 years ago (Fig. 1(b)), except that its duration has been extended by ca. 780 ka, and it is to this matter that we now turn our attention.

Base of the Quaternary and of the Pleistocene

The need to standardise a basal boundary for the Quaternary (and hence for the Pleistocene) was first recognised as long ago as 1948. At the 18th International Geological Congress held in London that year, it was decided that an objective reference stratotype was required and, following formal stratigraphical

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convention, it was accepted that the Tertiary/Neogene–Quaternary (i.e. Pliocene–Pleistocene) boundary stratotype should be defined in marine strata. But it was not until 1982 at the 11th INQUA Congress in Moscow that the Vrica section in Calabria, southern Italy, was formally proposed as the boundary stratotype for the Pleistocene Epoch. The boundary was defined on lithostratigraphical criteria, the marker point being at the base of the claystone conformably overlying the sapropelic marker bed 'e', which lies within the Olduvai normal polarity subchron (Aguirre and Pasini, 1985; Cita *et al.*, 2008). The boundary was initially dated at 1.64 Ma, but this was subsequently revised by astronomical calibration to 1.806 Ma (Lourens *et al.*, 2005). The Vrica GSSP was formally ratified by the IUGS in 1984 (Bassett, 1985).

This was a controversial decision, however, because even at that time there was widespread feeling, within INQUA and in the wider Quaternary community, that the boundary should be located earlier in the geological record at a time of much greater change in the Earth–climate system. It has long been known that global cooling began in the late Tertiary/Neogene, with multiple major cooling phases between 2.8 and 2.4 Ma (Marine Isotope Stage (MIS) G10 to MIS 96), the expression of which varies according to region (North Atlantic ice-rafted debris at 2.72 Ma; loess–palaeosol accumulation in China at 2.6 Ma; severe cooling in northwestern Europe at 2.52 Ma; arrival of sub-Antarctic molluscs in New Zealand at 2.4 Ma; Head *et al.*, 2008a). Although no single global event emerges as a trigger for these changes, closure of the Panama Isthmus appears to have been the most likely catalyst (Sarnthein *et al.*, 2009). Moreover, with respect to the Vrica section, some of the so-called 'northern guests', cold-tolerant migrants into the Mediterranean that had been used as indicators of cooling at the boundary (Aguirre and Pasini, 1985), have since been found to have arrived in the Mediterranean earlier than 1.8 Ma (e.g. Aiello *et al.*, 1996). Indeed, it is now apparent that major cooling events in the Mediterranean region occurred between 2.8 and 2.5 Ma (e.g. Versteegh, 1997; Monegatti and Raffi, 2001; Roveri and Taviani, 2003), which coincide with the more widely agreed onset of the Quaternary outlined above. In addition, although the GSSP at Vrica is indeed located within the Olduvai subchron, it is 10 m below the top of the subchron and about the same distance from its base (Cita *et al.*, 2008).

Despite growing dissatisfaction in many parts of the Quaternary community with the Vrica stratotype, however, no further formal move was made to propose an alternative GSSP. In 1996, however, the IUGS ratified a new Pliocene stage, the Gelasian, between the underlying Piacenzian Stage and the overlying Pleistocene Series, the lower boundary of the latter being represented by the Vrica GSSP (Fig. 2). The base of the Gelasian was defined by a GSSP at Monte San Nicola in southern Sicily (Figs. 3 and 4) and dated by astronomical tuning to 2.588 Ma (corresponding to MIS 103). The GSSP lies just 1 m above the Gauss–Matuyama palaeomagnetic reversal (Rio *et al.*, 1998; Lourens, 2008). We consider a rounded age of 2.58 Ma to be appropriate for the boundary. This development prompted the ICS to establish a joint Quaternary–Neogene task group to look again at the position of the Pliocene–Pleistocene boundary, but the resulting proposal ultimately failed to reach a supermajority (60%) recommendation (Remane and Michelsen, 1998). As a consequence, the IUGS reaffirmed the Vrica GSSP as defining the base of the Pleistocene and, moreover, implemented a 10-year moratorium that precluded further consideration of the definition of the Quaternary and the relocation of its lower boundary and that of the Pleistocene.

Neither INQUA nor the SQS were prepared to let matters rest, however. Following the largest survey of opinion of its

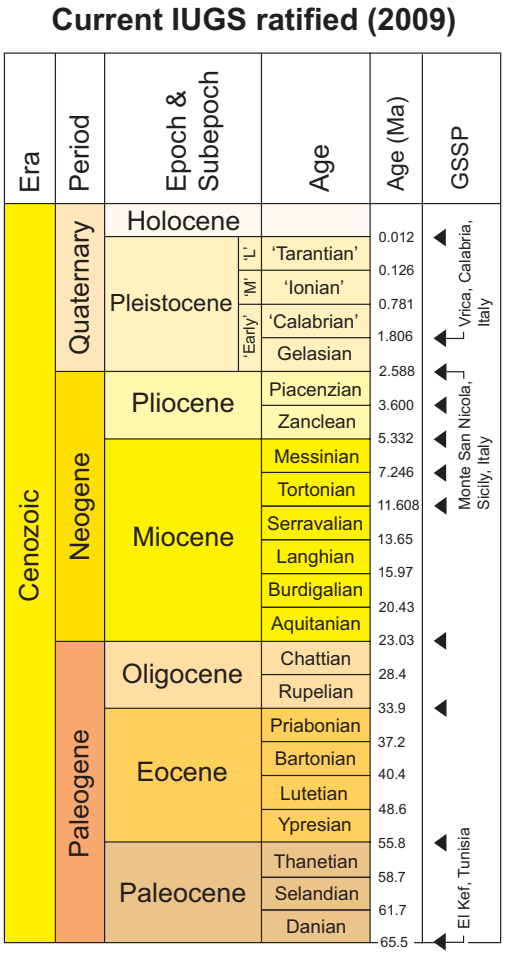

Figure 2 The current IUGS-sanctioned (2009) timescale for the Cenozoic, in which the Quaternary and Pleistocene are coterminous with the base of the Gelasian Stage at 2.6 Ma. Stage names and boundary ages are from the ICS website (January 2008), with the Calabrian and Ionian stages following Cita *et al.* (2006, 2008) and the provisional Tarantian Stage following Cita (2008 and references therein). Currently defined GSSPs are indicated by black arrows. The stratigraphical intervals are not scaled to geological time (modified from Head *et al.*, 2008b)

constituent members ever undertaken, INQUA, jointly with the SQS, in March 2006 requested that the ICS accept the proposition that the Quaternary be officially established at the rank of system/period with its base at the GSSP of the Gelasian Stage (2.6 Ma), and that the base of the Pleistocene also be lowered from 1.8 Ma to coincide with that of the Quaternary. In May 2007, the ICS voted in favour of the SQS/INQUA proposal, but the IUGS Executive Committee, while approving the ICS's request to accept the Quaternary as a formal system/period, declared that the base of the Pleistocene could not be moved until the 10-year moratorium had expired (in January 2009). The Quaternary position was further strengthened following an open forum for discussions at the 33rd International Geological Congress in Oslo in August 2008, which revealed overwhelming support for the Quaternary to be recognised as a full system/period extending from 2.6 Ma to the present day, and for the base of the Pleistocene to be lowered to that of the Quaternary in order to maintain stratigraphic hierarchy (Ogg and Pillans, 2008; Head *et al.*, 2008a). However, there remained a strong voice from the Neogene community reiterating the view that the Neogene Period should extend to the present day, with the Quaternary overlapping the Neogene at the lower or higher ranks of subsystem/subperiod or suberathem/subera respectively (Aubry *et al.*, 2009).

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Figure 3 Panoramic view of the Monte San Nicola section in southern Sicily. The view is to the north and shows a sequence of uplifted Mediterranean precession-related sapropels (MPRS) spanning the Piacenzian and Gelasian stages. Obliquity-controlled glacial cycles are also evident as dark layers in this section. The arrow indicates the position of the sapropelic (dark) Nicola bed, which is the correlative of MPRS-250 (Rio *et al.*, 1998). The Gelasian–Pleistocene–Quaternary GSSP is at the base of the marly (light) layer immediately overlying the Nicola bed, and lies within the Monte Narbone Formation. Photograph courtesy of E. Di Stefano/S. Bonomo

Formal proposals

Following the public discussions at the Oslo congress, the ICS asked the two competing proponents – the Subcommission on Quaternary Stratigraphy (SQS) and the Subcommission on Neogene Stratigraphy (SNS) – to submit formal proposals on which the ICS voting membership could comment and ultimately vote. In summary, the respective cases were as follows:

Quaternary/SQS proposal:

1. The base of the Quaternary System/Period should be lowered to the GSSP of the Gelasian Stage (currently the uppermost stage of the Pliocene Series) within MIS 103, which has a calibrated age of 2.58 Ma.
2. The base of the Pleistocene Series/Epoch should 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) should be retained as the base of the Calabrian Stage, the second stage of the revised Pleistocene Series (Fig. 2).
4. The Quaternary, as already recognised by the IUGS, should retain its system/period status and succeed the Neogene in the GTS.

Figure 4 Close-up view of the Monte San Nicola section showing rhythmic bedding at precession- and obliquity-related, and sub-Milankovitch scales (Hilgen, 2004). The Gelasian–Pleistocene–Quaternary GSSP, dated at 2.58 Ma, is at the base of the marly (light) layer immediately overlying the sapropelic (dark) Nicola bed. The Nicola bed is indicated by an arrow. Photograph courtesy of E. Di Stefano/S. Bonomo

Neogene/SNS proposal:

1. The Cenozoic Era should comprise the Paleogene and Neogene, each as a system/period, and the Quaternary should be a subsystem/subperiod spanning the past 2.6 Ma.
2. The Neogene System/Period should extend to the present day.
3. The Pliocene/Pleistocene boundary should remain at 1.8 Ma as currently defined but the Pliocene Series/Epoch should be split into an Early Pliocene and a Late Pliocene. This would effectively decouple the Quaternary and the Pleistocene in the GTS.
4. The Quaternary Subsystem/Subperiod should contain the Pleistocene and Late Pliocene Series/Epochs.

Full details of the respective cases and of the voting can be found in Gibbard and Head (2009) and on the ICS (www.stratigraphy.org) and SQS (www.quaternary.stratigraphy.org.uk) websites.

Voting was based on the premise that if neither proposal gained a 60% majority the *status quo* would be maintained, namely that the Quaternary would remain as a system/period but with its base still undefined (although not at the Gelasian GSSP), and that the lower boundary of the Pleistocene would continue to be defined by the Vrica GSSP at 1.8 Ma.

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Outcome

The results of the voting were overwhelmingly in favour of the SQS recommendations. In the final ballot, 89% of the ICS voting membership supported the Quaternary case. In May 2009, the ICS forwarded the results to the IUGS Executive Committee, and on 29 June 2009 that body formally ratified the SQS proposal. This brings closure to a debate that has run for more than six decades and, from a Quaternary perspective at least, the outcome is entirely satisfactory. In addition, with the imposition of the 10-year moratorium, this matter cannot be revisited until 2019 at the earliest.

In the scheme that has been accepted by IUGS, the Quaternary System/Period, Pleistocene Series/Epoch and Gelasian Stage/Age share the same GSSP at the base of the Gelasian, which is located at Monte San Nicola, Sicily, and dated at 2.58 Ma. The Holocene, which is now defined with reference to the NGRIP Greenland ice core GSSP (Walker *et al.*, 2009), remains as a series/epoch distinct from the Pleistocene, in recognition of the fundamental impact of humans on an otherwise unremarkable interglacial. Consequently, the terms Quaternary and Pleistocene are both essential. While it has been necessary to lower the base of the Pleistocene, the Vrica GSSP remains available to define the base of the Calabrian Stage (Cita *et al.*, 2008; Fig. 2). The name 'Calabrian' for the second stage of the Pleistocene will be submitted for formal ratification in the near future. This reclassification of the later Cenozoic Era meets all of INQUA's requirements, obeys the principles of a hierarchical GTS, and respects the historical precedents and established usage for the term Quaternary.

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