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Formal ratification of subseries for the Pleistocene Series of the Quaternary System

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⁴ Table 1

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The Pleistocene Series/Epoch of the Quaternary System/Period has been divided unofficially into three subseries/subepochs since at least the 1870s. On 30th January, 2020, the Executive Committee of the International Union of Geological Sciences ratified two proposals approved by the International Commission on Stratigraphy formalizing: 1) the Lower Pleistocene Subseries, comprising the Gelasian Stage and the superjacent Calabrian Stage, with a base defined by the GSSP for the Gelasian Stage, the Pleistocene Series, and the Quaternary System, and currently dated at 2.58 Ma; and 2) the term Upper Pleistocene, at the rank of subseries, with a base currently undefined but provisionally dated at ~129 ka. Defining the Upper Pleistocene Subseries and its corresponding stage with a GSSP is in progress. The Middle Pleistocene Subseries is defined by the recently ratified GSSP for the Chibanian Stage currently dated at 0.774 Ma. These ratifications complete the official division of the Pleistocene into three subseries/subepochs, in uniformity with the similarly subdivided Holocene Series/Epoch.

Introduction

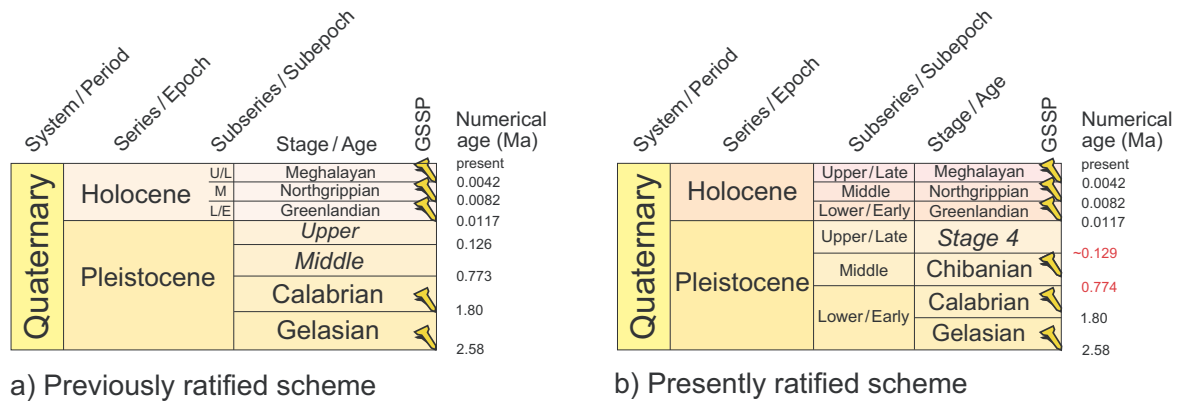
The Pleistocene was first introduced by Charles Lyell as a substitute for his Newer Pliocene (Lyell, 1839, p. 621) although he did not embrace the term formally until 1873 (Lyell, 1873, p. 3–5; Head and Gibbard, 2015a). Only in 1985 was the Pleistocene formally defined as a series/epoch by a Global boundary Stratotype Section and Point (GSSP) at Vrica, Calabria, Italy (Aguirre and Pasini, 1985). Its base was subsequently lowered in 2009 to coincide with that of the Gelasian Stage/Age and Quaternary System/Period, defined by a GSSP at Monte San Nicola in Sicily, Italy, currently dated at 2.58 Ma (Gibbard and Head, 2010).

The Pleistocene meanwhile has been subdivided informally into

three parts since at least the 1870s (Head, 2020). The terms Lower, Middle, and Upper Pleistocene were used at the Second International Conference of l'Association pour l'Étude du Quaternaire européen (a forerunner of the International Union for Quaternary Research [INQUA] and its congresses) held in Leningrad, now Saint Petersburg, Russia in 1932 (Woldstedt, 1953). These positional terms were later used more formally in English by Zeuner (1935, 1945) and Hopwood (1935), as noted by Pillans and Gibbard (2012). Beginning effectively with the Leningrad Conference, the former USSR and Russia established a somewhat different scheme, with the Eopleistocene equivalent to the Gelasian and Calabrian, and the Neopleistocene equivalent to the Middle and Upper Pleistocene. The Neopleistocene itself has lower, middle and upper subdivisions, and the Upper Neopleistocene is exactly equivalent to the Upper Pleistocene (e.g., Tesakov et al., 2015; Head and Gibbard, 2015a and references therein). Nonetheless, the terms Lower, Middle and Upper have a long history of use in chronostratigraphically subdividing the Pleistocene in the former USSR and Russia (Gromov, 1939; Nikiforova, 1987; Gaudenyi et al., 2014).

Although these positional terms have been used regularly for more than a century in the Quaternary literature, where they are treated as chronostratigraphic/geochronologic subdivisions, the formal rank of subseries/subepoch was approved by the International Union of Geological Sciences (IUGS) only in June 2018, specifically with respect to the subdivision of the Holocene. The Holocene is now officially subdivided into Greenlandian, Northgrippian, and Meghalayan stages/ages and their corresponding Lower/Early, Middle, and Upper/Late Holocene subseries/subepochs (Walker et al., 2018, 2019; Fig. 1).

Aubry (2016) and Head et al. (2017) presented a multifaceted case for adopting the subseries/subepoch as a formal rank within the Cenozoic. However, the primary reasoning for Holocene subseries derives from the universal use of geochronology in Holocene stratigraphy, facilitated by an array of geochronometric methods that are considerably more reliable and precise than classical approaches to stratigraphic correlation. Holocene stratigraphic records are accordingly plotted routinely against time rather than depth, and the positional terms Early, Middle and Late are therefore natural in this context (Head et al., 2017;



a) Previously ratified scheme

b) Presently ratified scheme

Figure 1. Quaternary interval of the ICS International Chronostratigraphic Chart showing: a) the scheme as of May, 2019, and b) the now ratified scheme. The previous age for the base of the Middle Pleistocene (0.773 Ma) is based on that of the Matuyama–Brunhes boundary whereas its current age (0.774 Ma) is that of the Chiba GSSP which occurs 1.1 m below this boundary. The current provisional age for the base of the Upper Pleistocene (~0.129 Ma) reflects a sharp rise in temperatures just before peak warming during the Last Interglacial (Head, 2019). See Table 2 and text for colour coding.

Head, 2019; Walker et al., 2018, 2019).

Pleistocene subdivision lends itself to similar justification, such as where continuously deposited marine deposits containing proxies for environmental change are calibrated to an insolation curve that is orbitally derived and hence numerically calculated. Such tuned records are accordingly displayed in years, or thousands of years, before present. They are critical to the numerical calibration of the Global boundary Stratotype Sections and Points (GSSPs) for the Gelasian, Calabrian, and Chibanian stages/ages of the Pleistocene.

Therefore, in order to formalize terms already in long use within the Quaternary community, and to bring Pleistocene subseries/subepoch terminology in line with that of the Holocene, a set of proposals was brought forward to the International Commission on Stratigraphy's (ICS) Subcommittee on Quaternary Stratigraphy (SQS) and then to the voting membership of the International Commission on Stratigraphy.

Proposals and results of SQS and ICS voting

The proposals are given below. Voting within SQS, comprising 22 voting members (one member did not return their ballot form), concluded on November 5, 2018 (Table 1). Voting within ICS, comprising 19 voting members (all returning their ballot forms), concluded on 27th November, 2019.

Proposal 1: to formalize the **Lower/Early Pleistocene Subseries/Subepoch**, comprising the Gelasian Stage/Age and the superjacent Calabrian Stage/Age, with a GSSP corresponding to that of the Gelasian Stage, the Pleistocene Series, and the Quaternary System. Age: 2.58 Ma. SQS vote: 20 in favour, 1 against, 95% supermajority. ICS vote: 17 in favour, 2 against, 89.5% supermajority. There were no abstentions in either vote. The proposal was carried by supermajority.

Proposal 2: to formalize the terms **Upper/Late Pleistocene** with a base currently undefined but provisionally dated at ~129 ka. SQS vote: 19 in favour, 2 against, 90% supermajority. ICS vote: 17 in favour, 2 against, 89.5% supermajority. There were no abstentions in either vote. The proposal was carried by supermajority.

A third proposal, to formalize (but not define) the term **Middle Pleisto-**

cene, had been included in SQS voting and received 20 votes in favour, 1 against, with no abstentions, and hence carried with a 95% supermajority. However, SQS delayed submitting to ICS its set of subseries proposals so that a separate proposal on the Chibanian Stage and Middle Pleistocene Subseries (Suganuma et al., this issue) could be considered simultaneously by ICS. This rendered the third (Middle Pleistocene) proposal redundant, and it was not submitted to ICS for voting.

Ratification of Proposals

On 30th January, 2020, the Executive Committee of the International Union of Geological Societies ratified both **Lower and Upper Pleistocene subseries/subepoch** proposals. The separate proposal to define the **Chibanian Stage and Middle Pleistocene Subseries/Subepoch** (Suganuma et al., this issue) had meanwhile been ratified on 17th January, 2020. These ratifications together completed formal subdivision of the Pleistocene into the desired Lower/Early, Middle, and Upper/Late subseries/subepochs.

Subdivision of the Pleistocene Series/Epoch

Ratification formalizes subseries/subepoch terms already used widely for the Pleistocene. The new definitions of these terms, and the history behind them, are discussed below.

Lower/Early Pleistocene Subseries/Subepoch

The Lower/Early Pleistocene Subseries/Subepoch is defined by the GSSP for the Gelasian Stage/Age, the Pleistocene Series/Epoch, and the Quaternary System/Period, at Monte San Nicola, Sicily, Italy (37°8'45.64"N, 14°12'15.22"E; Figs. 1 and 2), with a currently accepted age of 2.58 Ma (Gibbard and Head, 2009, 2010; Gibbard et al., 2010). It comprises the Gelasian Stage/Age (Rio et al., 1994, 1998) and the Calabrian Stage/Age (Cita et al., 2012).

When an SQS/ICS proposal to define the Upper/Late Pleistocene

Table 1. Voting membership of the ICS Subcommittee on Quaternary Stratigraphy in November, 2018

Brent Alloway	School of Environment, The University of Auckland, Private Bag 92019, New Zealand
Alan G. Beu	Paleontology Department, Institute of Geological & Nuclear Sciences, P. O. Box 30368, Lower Hutt, New Zealand 5040
Kim M. Cohen	Department of Physical Geography, Faculty of Geosciences, Utrecht University, P.O. BOX 80.115, 3508 TC Utrecht, The Netherlands
Philip L. Gibbard	Scott Polar Research Institute, University of Cambridge, Lensfield Road, Cambridge CB2 1ER, United Kingdom
Martin J. Head (Chair)	Department of Earth Sciences, Brock University, 1812 Sir Isaac Brock Way, St. Catharines, Ontario L2S 3A1, Canada
Karen Luise Knudsen	Department of Earth Sciences, University of Aarhus, C.F. Mollers Alle 120, DK-8000 Aarhus C, Denmark
Thijs van Kolfschoten	Faculty of Archaeology, Leiden University, Reuvenplaats 4, 2300 RA, Leiden, The Netherlands
Fabrizio Lirer	Istituto Ambiente Marino Costiero (IAMC)-CNR, Calata Porta di Massa, interno Porto di Napoli 80133, Napoli, Italy
Thomas Litt	Institute of Paleontology, University of Bonn, Nussallee 8, D-53115 Bonn, Germany
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Leszek Marks	Polish Geological Institute, Rakowiecka 4, PL 00-975 Warsaw, Poland
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Brad Pillans (Vice-Chair)	Research School of Earth Sciences, The Australian National University, Acton, ACT, 2601, Australia
Jan A. Piotrowski	Department of Earth Sciences, University of Aarhus, C.F. Moellers Alle 1120, DK-8000 Aarhus C, Denmark
Matti Räsänen	Department of Geology, University of Turku, FIN-20014 Turun Yliopisto, Finland
Sune Olander Rasmussen	Centre for Ice and Climate, Niels Bohr Institute, University of Copenhagen, Juliane Maries Vej 30, 2100 Copenhagen, Denmark
Yoshiki Saito	Estuary Research Center (EsReC), Shimane University 1060, Nishikawatsu-cho, Matsue, 690-8504, Japan
Alexey Tesakov	Geological Institute, Russian Academy of Sciences, Pyzhevsky, 7, 119017 Moscow, Russia
Charles Turner	Department of Earth Sciences, The Open University, Milton Keynes MK7 6AA, United Kingdom
Mike Walker	Department of Archaeology and Anthropology, University of Wales, Lampeter, Ceredigion, SA48 7ED, Wales, United Kingdom
Jan A. Zalasiewicz (Secretary)	School of Geography, Geology and the Environment, University of Leicester, University Road, Leicester LE1 7RH, UK
Caridad Zazo Cardeña	Departamento de Geología, Museo Nacional de Ciencias Naturales (CSIC), Jose Gutierrez Abascal 28006-Madrid, Spain

(Gibbard, 2003; Head and Gibbard, 2015a) was denied ratification by the IUGS EC in 2008 partly on grounds that the rank of subseries/subepoch was not sanctioned for use on the International Chronostratigraphic Chart (Riccardi, 2008), it became clear to SQS that this would seriously hamper formal classification for the entire Quaternary (Head et al., 2017). Accordingly, when the Calabrian Stage was ratified in 2012, following the Gelasian as the second lowest stage of the Pleistocene, it had not been possible to propose simultaneously a Lower/Early Pleistocene Subseries/Subepoch. Cita et al. (2012) nonetheless stated that “these two stages [Gelasian and Calabrian] together will comprise the Lower Pleistocene Subseries (Early Pleistocene Subepoch).” (Cita et al., 2012, p. 388). With the formal subdivision of the Holocene in 2018 (Walker et al., 2018), the rank of subseries/subepoch finally became available for use at least within the Quaternary System/Period. Ratification has now completed the task of formally uniting the Gelasian and Calabrian stages/ages to comprise the Lower Pleistocene Subseries/Subepoch.

The Gelasian Stage GSSP at Monte San Nicola is placed at the base of the marly layer immediately overlying a prominent sapropel known as the Nicola bed (Fig. 2). The Nicola bed is assigned to Mediterranean Precession-Related Sapropel (MPRS) 250, the midpoint of which has an astrochronological age of 2.588 Ma (Lourens et al., 1996; Rio et al., 1998, p. 85). The GSSP is placed at the top of the Nicola bed, and assuming this sapropel represents a duration of 7–10 kyr and is fully preserved without burn-down at this locality, the age of the GSSP is therefore about 3.5–5.0 kyr younger than the midpoint age, rounding down to 2.58 Ma. That age is currently accepted (Gibbard and Head,

2009, 2010; Gibbard et al., 2010; Head and Gibbard, 2015a; Cohen et al., 2013). A foraminiferal isotope record is not currently available for Monte San Nicola, but the relative abundance pattern of the planktonic foraminifera *Globigerinoides ruber*, used here as a substitute for marine isotope stratigraphy, places the GSSP level within MIS 103 (Rio et al., 1998). The precise position and level of the GSSP cannot be ascertained from the Rio et al. study, but because the GSSP is placed at the top of a sapropel (see above), and given that sapropel midpoints in general are assumed to lag insolation maxima by around three thousand years or so (Rohling et al., 2015), the GSSP should occur within the earlier to middle part of MIS 103. The GSSP is located at the approximate level of the Gauss–Matuyama Chron boundary, the precise position of this reversal being unknown at Monte San Nicola (Head, 2019, contra Rio et al., 1998).

Middle Pleistocene Subseries/Subepoch

The Chibanian Stage/Age and Middle Pleistocene Subseries/Subepoch defined by a GSSP at the Chiba Section (35°17'39.6"N, 140°08'47.6"E) in Japan was ratified by the IUGS EC on 17th January, 2020 (Suganuma et al., this issue; Fig. 3). The GSSP is 1.1 m below the directional midpoint of the Matuyama–Brunhes paleomagnetic reversal (Okada et al., 2017), which is astronomically dated at 772.9 ka (Suganuma et al., 2018), and is placed at the base of a regional lithostratigraphic marker, the Ontake-Byakubi E (Byk-E) tephra bed. The GSSP occurs just below the top of Marine Isotope Substage 19c and has an estimated astronomical age of 774.1 ka (Suganuma et al., this issue) which is consist-

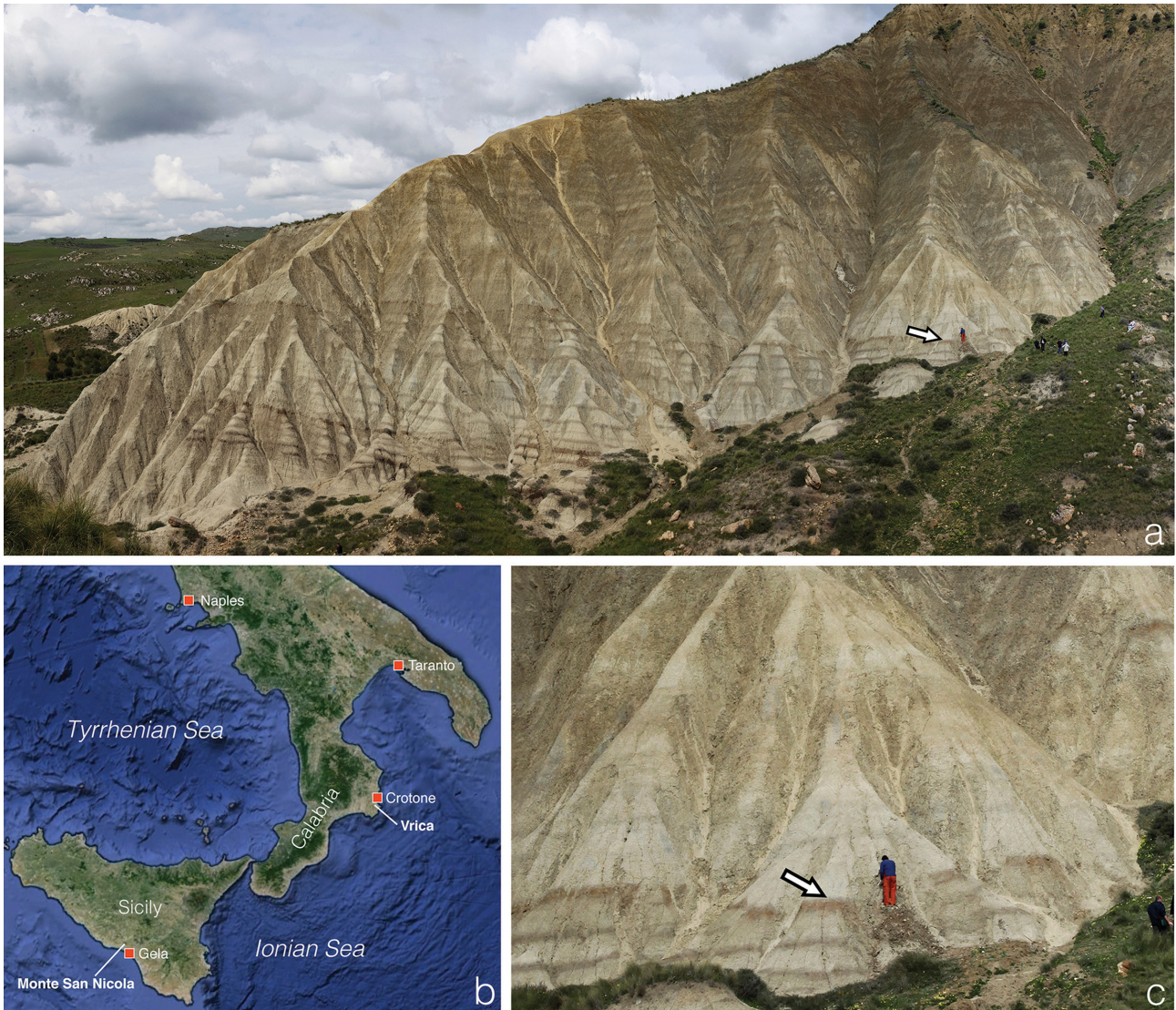


Figure 2. GSSP for the Gelasian Stage, Pleistocene Series, Quaternary System, and the newly ratified Lower Pleistocene Subseries. Panorama (a) and detail (c) of the Monte San Nicola section, showing the level of the GSSP (marked by an arrow) which is placed at the base of a marly layer overlying the prominent, sapropelic Nicola bed. Photographs kindly supplied by John Clague. The location of Monte San Nicola (b) is also given.

ent with a U-Pb zircon age of 772.7 ± 7.2 ka for the eruption/deposition age of the Byk-E tephra (Suganuma et al., 2015).

This placement follows established tradition of using the Matuyama–Brunhes paleomagnetic boundary to define the base of the Middle Pleistocene (Pillans, 2003; Head and Gibbard, 2015a, b), following the recommendations of Butzer and Isaac (1975) and the INQUA Working Group on Major Subdivision of the Pleistocene made at the 12th INQUA Congress in Ottawa in 1987 (Richmond, 1996). In 2004 at the 32nd International Geological Congress in Florence in 2004, the SQS Early–Middle Pleistocene Boundary Working Group adopted this paleomagnetic reversal as the primary guide for the boundary (Head et al., 2008).

Upper/Late Pleistocene Subseries/Subepoch

The terms Upper/Late Pleistocene at the rank of subseries/subep-

och are now ratified in name only, pending definition by a GSSP, but with a provisional age of ~ 129 ka (Fig. 1) relating to significant warming at the beginning of the Last Interglacial (Head, 2019).

During the Leningrad Conference in 1932 it had been decided that the base of the Upper Pleistocene should coincide with the base of the Last Interglacial (the Eemian regional Stage in Europe). At the 12th INQUA Congress in Ottawa in 1987, a proposal was approved to use the base of MIS 5 (Termination II) as the primary guide for the boundary (Anonymous, 1988; Richmond, 1996). The events based on these proposals are now known to be not precisely synchronous, the onset of the Eemian regional Stage off Portugal lagging the inception of MIS 5 by about six thousand years (Shackleton et al., 2003), although it is significant that both proposals reference the Last Interglacial. There are currently two potential candidates for the GSSP, the Fronte section, Taranto, Italy (Negri et al., 2015) and the EPICA Dome C Antarctic ice core (Head and Gibbard, 2015a; Head, 2019).



Figure 3. Chiba section, Japan: site of the GSSP for the now ratified Chibanian Stage and Middle Pleistocene Subseries. The marker bed for the GSSP is the Ontake-Byakubi-E (Byk-E) tephra bed (indicated by an arrow) which is 1.1 m below the directional midpoint of the Matuyama–Brunhes paleomagnetic boundary. This reversal serves as the primary guide to the Lower–Middle Pleistocene boundary, allowing its global recognition. Photograph by MJH taken at the INQUA Post-Congress field trip, August 2015.

Colour Coding of New Units

Each chronostratigraphic unit on the ICS International Chronostratigraphic Chart (Cohen et al., 2013) can be identified by a unique colour following a scheme developed by the Commission for the Geological Map of the World (CGMW). This scheme uses colour codes both in CMYK and RGB, and the International Chronostratigraphic Chart labelled with these codes is available from the CGMW website (www.cgmw.org). CMYK is employed in colour printing, and the CGMW uses this model as the primary reference system in defining its official colours. RGB nonetheless has become increasingly popular owing in part to its compatibility with online publishing. Converting CMYK to RGB is not straightforward and is affected by colour management settings chosen by the user in their computer graphics program. The CGMW converts CMYK to RGB values using the “Emulate Adobe Illustrator 6.0” color function in Adobe® Illustrator®. The present paper (Fig. 1) follows the CGMW scheme which was updated in September, 2020 to provide colours for the recently ratified subdivisions of the Pleistocene and Holocene (B. Vrielynck, written communication to MJH, 14 September, 2020; Table 2). This revision included new colours for the Pleistocene and Holocene series.

Table 2. CMYK and RGB colour codes for the Quaternary and its subdivision (Fig. 1) as adopted by the Commission for the Geological Map of the World (CGMW). New colour codes introduced by the CGMW in September 2020 are in *italics*. Earlier colour codes that have not been superseded are in *roman type*. The CGMW defines its colours by CMYK codes; their RGB equivalents are for information only

	CMYK	RGB
Quaternary System	0/0/50/0	249/249/127
Pleistocene Series	<i>0/5/40/0</i>	<i>255/239/175</i>
Lower Pleistocene Subseries	<i>0/5/35/0</i>	<i>255/240/185</i>
Gelasian Stage	<i>0/5/30/0</i>	<i>255/237/179</i>
Calabrian Stage	<i>0/5/25/0</i>	<i>255/242/186</i>
Middle Pleistocene Subseries	<i>0/5/20/0</i>	<i>255/242/199</i>
Chibanian Stage	<i>0/5/20/0</i>	<i>255/242/199</i>
Upper Pleistocene Subseries	<i>0/5/15/0</i>	<i>255/242/211</i>
Fourth stage	<i>0/5/15/0</i>	<i>255/242/211</i>
Holocene Series	<i>0/10/20/0</i>	<i>254/235/210</i>
Lower Holocene Subseries	<i>0/10/15/0</i>	<i>254/236/219</i>
Greenlandian Stage	<i>0/10/15/0</i>	<i>254/236/219</i>
Middle Holocene Subseries	<i>0/10/10/0</i>	<i>253/236/228</i>
Northgrippian Stage	<i>0/10/10/0</i>	<i>253/236/228</i>
Upper Holocene Subseries	<i>0/10/5/0</i>	<i>253/237/236</i>
Meghalayan Stage	<i>0/10/5/0</i>	<i>253/237/236</i>

Conclusions

The ratified proposals have overwhelming support within the Quaternary community and are strongly endorsed by INQUA (Head et al., 2017; van Kolfschoten, 2020). The terms Lower/Early Pleistocene are now officially available for deposits, events, or transitions that cannot be assigned to a specific (Gelasian or Calabrian) stage. The Chibanian Stage and Middle Pleistocene Subseries/Subepoch result from a simultaneous proposal also recently ratified (Suganuma et al., this issue). The Upper/Late Pleistocene Subseries/Subepoch is ratified in name only, to complete the formal tripartite subdivision of the Pleistocene. Progress on its definition by GSSP, with a corresponding stage, is being made within the Upper Pleistocene Working Group of the SQS.

The Quaternary community uses geochronological terms (Early/Middle/Late) as a natural consequence of displaying geological data against age rather than depth. Such terms are employed widely and with considerable frequency. For example, the term “Late Pleistocene” has been cited in 16,997 publications according to Clarivate’s Web of Science, searched on February 2, 2020, as compared with the term “Silurian” searched at the same time and cited in 8,268 publications. The official recognition of these subseries/subepoch terms, with their long history and wide use, increases their value to the community. Pleistocene subseries/subepoch terminology is now brought in line with that of the Holocene, effecting standardization for the entire Quaternary. This also resolves the editorial quandary of capitalization (Head et al., 2017): an uppercased initial letter is now required unequivocally for subseries/subepoch terms throughout the Quaternary.

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