Formal Subdivision of the Holocene Series/Epoch

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Abstract This proposal, by a Working Group of Integration of ice-core, marine, and terrestrial records (INTIMATE) and the Subcommission on Quaternary Stratigraphy (SQS) of the International Commission on Stratigraphy (ICS), is for a formal subdivision of the Holocene Series/Epoch. Although previous attempts to subdivide the Holocene have proved inconclusive, recent developments in Quaternary stratigraphy, notably the definition of the Pleistocene–Holocene boundary and the emergence of formal subdivisions of the Pleistocene Series/Epoch, mean that it may be timely to revisit this matter. The Quaternary literature reveals a widespread but variable informal usage of a tripartite division of the Holocene ("early", "middle" or "mid-", and "late"), and we propose that this de facto subdivision should now be formalised to ensure consistency in stratigraphic terminology. We advocate a formal Early–Middle Holocene boundary at 8200 a BP

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R. Rocha et al. (eds.), *STRATI 2013*, Springer Geology,
DOI: 10.1007/978-3-319-04364-7_186,

and a formal Middle–Late Holocene boundary at 4200 a BP, each of which is linked to a Global Stratotype Section and Point (GSSP).

Keywords Holocene · Stratigraphic subdivision · 8.2 ka and 4.2 ka events · NGRIP ice core · Mawmluh Cave stalagmite

Introduction and Context

The Holocene is the most recent stratigraphic unit within the geological record and covers the time interval from 11.7 ka BP to the present day. Along with the preceding Pleistocene, it is now formally defined as a Series/Epoch within the Quaternary System/Period. Holocene stratigraphic records provide evidence, inter alia, of climate and sea-level change, geomorphological and hydrological processes, vegetational developments, and faunal migrations. In addition, the records contain a unique range and wealth of archaeological data that attest to the evolving relationships between people and the environment under near-modern boundary conditions. Holocene sequences are often extremely well preserved, continuous, and able to be examined at a high temporal resolution. It is somewhat surprising, therefore, that relatively little attention has hitherto been paid to a formal subdivision of the Holocene Series/Epoch, particularly in the light of recent developments in Quaternary stratigraphic subdivision and nomenclature (Gibbard et al. 2010; Cita et al. 2012).

In 2010, the Subcommission on Quaternary Stratigraphy (SQS) of the International Commission on Stratigraphy (ICS) invited INTIMATE (Integration of ice-core, marine and terrestrial records, an INQUA International Focus Group) to establish a Joint Working Group to consider a formal subdivision of the Holocene. This is the second Joint INTIMATE/SQS Working Group, the first having proposed a formal definition of the base of the Holocene, which was accepted and

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ratified by the International Union of Geological Sciences (IUGS) in 2008 (Walker et al. 2008, 2009).

This issue of a formal subdivision of the Holocene was last considered over 30 years ago by members of a Working Group of the International Union for Quaternary Research (INQUA). Their conclusions were that neither stratotypes nor inferred climatic change were useful as bases for Holocene subdivision, and although they accepted that radiocarbon dating could be used, they made no proposals for a formal overall chronostratigraphic subdivision of the Holocene Series/Epoch. Over the past 30 years, however, there have been important developments in Quaternary science, which suggests that the time may now be right to revisit this matter. A much wider range of Holocene depositional archives, from both land and sea, and resolved at decadal scale or less, is now available, while advances in geochronology mean that a more secure foundation for chronostratigraphic subdivision and correlation can now be provided. In addition, the Pleistocene–Holocene boundary has recently been formally defined using conventional stratigraphic procedures, suggesting that these approaches might now also be applied to the Holocene Series/Epoch. Finally, it has been proposed that the Pleistocene Series/Epoch be subdivided into four stages (or ages), each linked to a defined Global Stratotype Section and Point (GSSP). Once the Pleistocene has been divided in this way, the Holocene will remain the only unit of Series/Epoch status within the Geological Timescale without formal subdivision.

Examination of the Quaternary literature shows that a de facto subdivision of the Holocene is already being widely employed, with the terms "early", "middle" ("mid-"), and "late" Holocene being routinely but informally applied. Yet the precise temporal limits of each of these subdivisions have never been formally agreed upon, nor have they been defined chronostratigraphically with reference to a stratotype. Here we propose to formalise what is current custom and practice and to employ clearly defined marker horizons to underpin the subdivision. The Working Group is therefore advocating a formal Early–Middle Holocene Boundary at 8.2 ka BP and a formal Middle–Late Holocene Boundary at 4.2 ka BP, each linked to a GSSP (Walker et al. 2012).

The Early–Middle Holocene Subseries/Subepoch Boundary

The boundary between the Early and Middle Holocene subseries/subepochs is based on the 8.2 ka BP event. This was a marked, short-lived cooling event triggered by glacial meltwater outflow into the North Atlantic, and has been recorded in proxy records from many parts of the world, including the Middle East, central and eastern Asia, tropical Africa, the NW Pacific, the South Atlantic, and maybe also Antarctica and New Zealand. It is also reflected in archaeological records from regions where increased aridification associated with cooler North Atlantic surface waters appears to have impacted both settled and hunter–gatherer communities. The event broadly coincides with the Mesolithic–Neolithic

transition and, in parts of southeastern Europe, the Mediterranean, and the Near East, may have triggered the spread of early farmers. The climatic event at *c.* 8.2 ka BP is therefore near global in nature and hence constitutes an ideal time-stratigraphic marker for defining the Early–Middle Holocene boundary.

The 8.2 ka event is most clearly recorded as a marked shift to low $^{18}O/^{16}O$ and D/H values (reflecting abrupt cooling) in oxygen isotope records from the Greenland Ice Sheet. Within the $\delta^{18}O$ minimum there is also a strong volcanic signal marked by a double acidity peak in ECM and by a high fluoride content. This layer, at 1228.67 m depth in the NGRIP1 core, is a key reference point in the Greenland GICC05 timescale, and is dated to 8236 a b2 k (before AD 2000), with a maximum counting error of 47 yr. This is equivalent to an age of 8186 a BP on the calibrated radiocarbon timescale. This clearly defined and well-dated horizon in the NGRP1 ice core is proposed as the GSSP for the Early–Middle Holocene boundary.

The Middle–Late Holocene Subseries/Subepoch Boundary

The boundary between the Middle–Late Holocene Subseries/Subepochs is placed at 4.2 ka BP and is defined by a mid- and low-latitude aridification event. This was a panglobal climatic phenomenon that may have been related to a southward migration of the Inter-Tropical Convergence Zone (ITCZ) and the onset of the modern ENSO (El Niño Southern Oscillation) regime, which inhibited and weakened the Asian monsoon, leading to widespread drought conditions. Aridification at this time is reflected in proxy records from many mid- and low-latitude regions, including mid-continental North America, the Middle East, tropical and subtropical regions of Africa and South America, southern Asia, Australia, and the South Pacific. A contemporaneous climatic shift to wetter conditions is recorded in many mid- and high-latitude regions of the Northern Hemisphere, including northern Canada, western and northern Europe, and northern Russia. In addition, the 4.2 ka event appears to have profoundly impacted human communities, being associated with cultural upheaval in northern Africa, the Middle East, and parts of southern and western Asia. Again, therefore, this is an event of global significance, and constitutes an ideal marker horizon for the boundary between the Middle and Late Holocene.

As the 4.2 ka event was predominantly a mid- and low-latitude phenomenon, the GSSP should be located within these latitudes, and a potential stratotype is the speleothem KM-A from Mawmluh Cave in Cherrapunji, Meghalaya, northeast India. The $\delta^{18}O$ record from this speleothem, which is based on 1128 isotopic measurements, extends from *c.* 3.5–12.0 ka BP at a resolution of $\sim$5 yr per sample. The age–depth relationship is constrained by 12 U/Th dates. An age model for the sequence obtained using the StalAge algorithm of Scholtz and Hoffman (2011) provides an age uncertainty of <30 yr at around the time of the 4.2 ka event. The event itself comprises a two-step sequence, with an initial enrichment at

~4.3 ka and a more pronounced shift (within less than a decade) to more positive values at 4.1 ka. An age of 4.2 ka effectively splits the difference between these two events. Accordingly, we propose a date for the Middle–Late Holocene boundary of 4200 a BP, and suggest that the isotopic signal in the Mawmluh Cave stalagmite should constitute the GSSP for this boundary.

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