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The ICS International Chronostratigraphic Chart

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The International Commission on Stratigraphy (ICS) has a long tradition of producing international charts that communicate higher-order divisions of geological time and actual knowledge on the absolute numerical ages of their boundaries. The primary objective of ICS is to define precisely a global standard set of time-correlative units (Systems, Series, and Stages) for stratigraphic successions worldwide. These units are, in turn, the basis for the Periods, Epochs and Ages of the Geological Time Scale. Setting an international global standard is fundamental for expressing geological knowledge. It is also of considerable pragmatic importance as it provides the framework through which regional-scale higher-resolution divisions can be linked, equated and collated. This is a status update on the International Chronostratigraphic Chart and the ICS website www.stratigraphy.org.

Introduction

At the 34th International Geological Congress, in 2012 in Brisbane, over 6000 delegates found the redesigned International Chronostratigraphic Chart of the International Commission on Stratigraphy (ICS) in their conference packages. The ICS Chart is a hierarchy of chronostratigraphic units (e.g. Systems, Series, and Stages) on which geochronological units (e.g. Periods, Epochs, and Ages) are based. With the addition of calibrated numerical ages for unit boundaries it serves as the International Geological Timescale. The ICS Chart caters to a range of users: geologists that are relatively new to a particular time-stratigraphic interval and seek to place named divisions in their correct order and hierarchical structure, professionals who need to look up the latest specific estimates of numerical ages, earth science students at all levels, and the general public interested in the long history of the Earth. For the International Commission on Stratigraphy, the chart is also important for communicating the progress in formalising a single set of global chronostratigraphic units defined by specific boundaries, and for communicating standards of colour coding the divisions for use on geological maps and sections, using the scheme established by the Commission for the Geological Map of the World (CGMW: www.ccgm.org). Furthermore, the Commission on the Management and Application of Geoscience Information (CGI) of the International Union of Geological Sciences (IUGS) uses the units and formally defined boundaries as international standards: they are included in the library of GeoSciML, an application for globally accessing standards-based geoscience data and information. Furthermore, the GSSPs (Global Boundary Stratotype Section and Point) that define the boundaries are recognized as international geostandards, at which ICS encourages the placement of markers, educational exhibits, and even 'golden spikes' in well-attended dedication ceremonies (Schmitz et al., 2011: their Fig. 4; Morton, 2012). Here we present the most recently updated version of the ICS Chart dated January 2013 (Fig. 1).

From earlier editions, we have continued the organisation of the chart in four columns. Three columns present the Phanerozoic, showing four systems in each column. At the lowest level they display 34 + 34 + 32 stages. The stage names are derived from stratotype areas, and the stages are defined primarily on marine faces. The fourth column shows the Precambrian, sub-divided to system level. An innovation to the layout is that the stages of greater temporal duration are shown with thicker intervals in the columns. The numerical ages make clear that the chronostratigraphic units are not of equal temporal duration and that the geological time scale is not a linear one. The three Phanerozoic columns span 145, 214 and 182 Ma respectively, but have equal heights in the chart. Within these columns, each stage is given a fixed proportion of the column height (e.g., 2%). The remaining height (100–(34 x 2) = 32% in the example) is then distributed proportionally to the stages that cover more than the fixed proportion on a linear timescale for that column. With the design we have tried to communicate visually, in improved style, that the division of Phanerozoic geological time is irregular and governed by the stratigraphical successions on which the units were originally defined, to which many subsequent revisions have been made. The chart design is intended to be advantageous in the daily use for both professional geologists and other users alike.

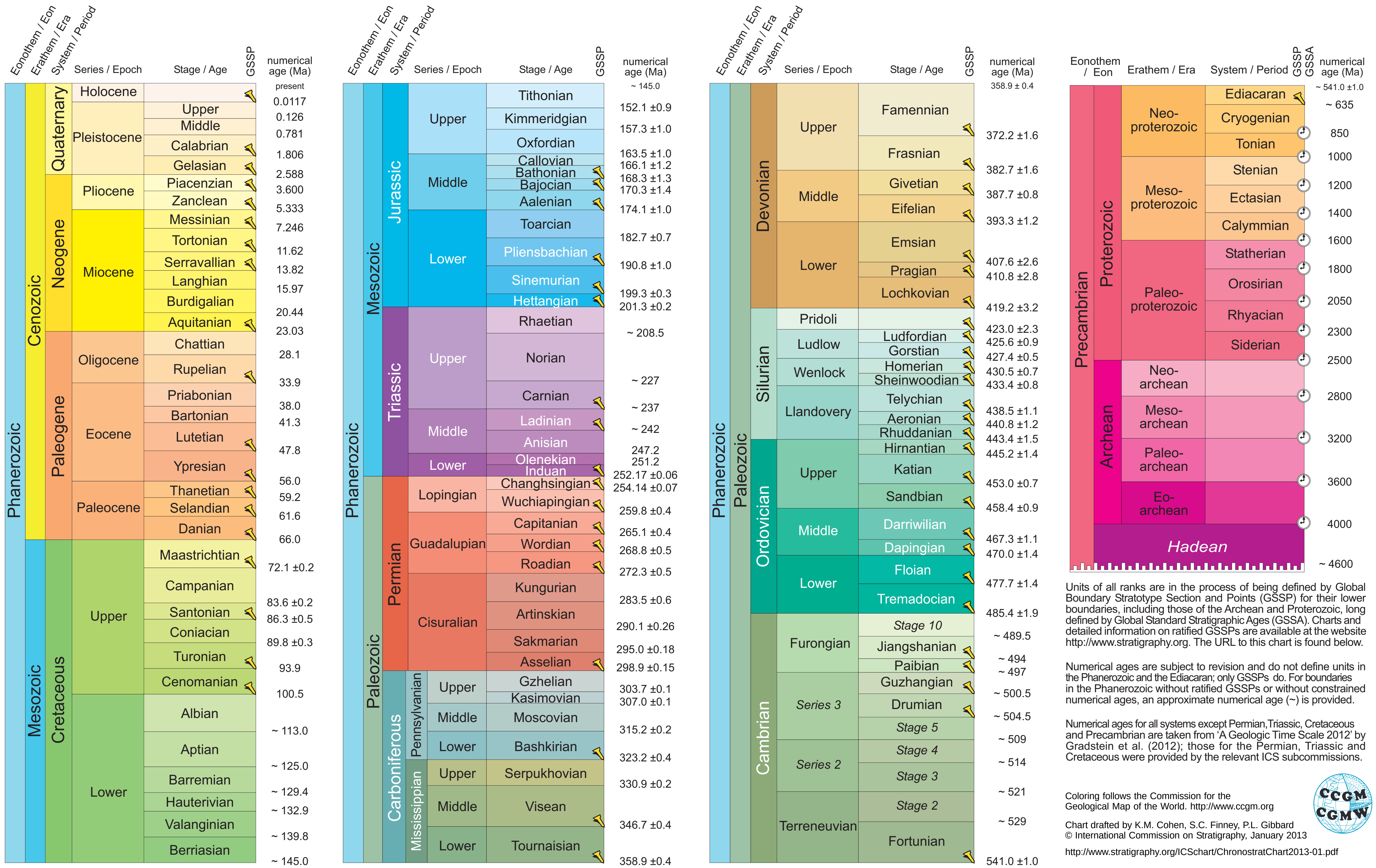
Global divisions and 'Golden Spikes'

Units of all ranks are in the process of being defined by GSSPs for their lower boundaries, including those of the Archean and Proterozoic, the latter long defined by Global Standard Stratigraphic Ages (GSSA). The status of each GSSP is displayed in the chart by small golden-spike icons at the base of the divisions that they define. The status of each GSSA is indicated similarly with clock icons. For boundaries in the Phanerozoic for which no GSSP is currently ratified, or which lack constraining numerical ages, an approximate numerical age (~) is provided. Note that numerical ages do *not* define units in the Phanerozoic and the Ediacaran, they are only defined by GSSPs.

IUGS

INTERNATIONAL CHRONOSTRATIGRAPHIC CHART

www.stratigraphy.org International Commission on Stratigraphy v 2013/01



Units of all ranks are in the process of being defined by Global Boundary Stratotype Section and Points (GSSP) for their lower boundaries, including those of the Archean and Proterozoic, long defined by Global Standard Stratigraphic Ages (GSSA). Charts and detailed information on ratified GSSPs are available at the website http://www.stratigraphy.org. The URL to this chart is found below.

Numerical ages are subject to revision and do not define units in the Phanerozoic and the Ediacaran; only GSSPs do. For boundaries in the Phanerozoic without ratified GSSPs or without constrained numerical ages, an approximate numerical age (~) is provided.

Numerical ages for all systems except Permian, Triassic, Cretaceous and Precambrian are taken from 'A Geologic Time Scale 2012' by Gradstein et al. (2012); those for the Permian, Triassic and Cretaceous were provided by the relevant ICS subcommissions.

Coloring follows the Commission for the Geological Map of the World. http://www.ccgm.org

Chart drafted by K.M. Cohen, S.C. Finney, P.L. Gibbard

http://www.stratigraphy.org/ICSchart/ChronostratChart2013-01.pdf

CCGM CGMW

Cohen, K.M., Finney, S.C., Gibbard, P.L. and Fan, J.-X., 2013, The ICS International Chronostratigraphic Chart, Episodes, v. 36, no. 3, pp. 199-204.

Most of the systems, series and stages were first defined from type-sections in Europe, the historical home of stratigraphy. Subsequent study of stratigraphical successions worldwide has led to a proliferation of regional units. These historical units did allow Phanerozoic strata to be correlated and mapped worldwide. However, as it happened, most successive chronostratigraphic units are located in geographically separated type sections, which have more recently been shown to be separated by significant gaps or to overlap considerably. These problems, and the general lack of defined boundaries for historically established units, became serious hindrances to high-resolution correlation of geographically widespread stratigraphic successions. Equally, these problems hindered the establishment of a common language for international communication at a time when the Geological Sciences have been rapidly evolving, and international study of global Earth-system events was accelerating. Accordingly, the ICS was established by the IUGS, with the primary objective of developing a single hierarchy of global standard chronostratigraphic units with boundaries formally defined by ratified GSSPs. This boundary-stratotype approach results in units with precisely defined boundaries and with no overlaps and no gaps between successive units.

Candidate GSSPs are evaluated by the ICS and its constituent working groups based on a long list of criteria (Hedberg, 1976; Cowie et al., 1986; Salvador, 1994; Remané et al., 1996). The most important of these is that the boundary at the candidate stratotype is defined at the level of 'a single stratigraphic signal within an interval of multiple, varied stratigraphic signals', that should allow for reliable, high-resolution correlation across the greatest possible palaeogeographical range of palaeoenvironmental settings (Finney, 2013). Identification and field investigations of candidate stratotype sections and boundary intervals are carried out by the system-based subcommissions of ICS and often by smaller boundary-working groups. One or more candidate GSSP proposals are considered for approval by the voting members (~20) of a subcommission, and a single proposal that receives a supermajority vote (>60% of the voting membership) is considered approved. One consequence of this approach is that disagreement often arises, because type sections that are favoured for historical reasons may be abandoned, previously established boundary levels may be greatly changed, and in some instances historical units are replaced by different new ones. Once accepted by a subcommission, a proposal is then forwarded to the ICS for consideration. The ICS voting members are the executive officers of ICS and the chairs of the 16 ICS subcommissions (www.stratigraphy.org), each of whom has a single vote. They evaluate and discuss each proposal. If they approve it by a supermajority vote, the proposal is finally forwarded to the IUGS Executive Committee. Once a proposal is approved by a majority of the IUGS Executive Committee members, the proposal is formally ratified and recognised as an international geostandard. The ratified GSSP proposal must then be published, generally in *Episodes*, and a marker should be placed at the GSSP stratotype locality. The international teams of dedicated stratigraphic experts that develop the GSSP proposals, the rigorous criteria on which each GSSP proposal is evaluated, and the several levels at which they must be evaluated and approved provide validity and authority to the GSSPs and ensure the global chronostratigraphic units they define as international geostandards. Of the 100 stage boundaries illustrated on the ICS Chart, several of which coincide with boundaries of higher level units, 62 have ratified GSSPs, although a few have been found to be seriously deficient and are currently the subject of re-examination.

The times they are changing

The chronostratigraphic units of the ICS Chart serve as the fundamental, material basis on which the geochronologic units of the Geological Timescale are based. The numerical ages shown for the boundaries between successive units are determined by using a range of geochronologic techniques, including stable and unstable isotopes, palaeomagnetochronology, and astronomical tuning of sedimentary cycles. Sometimes numerical ages have been determined from specific levels within boundary intervals at stratotype sections, but the majority have been determined from distantly separated stratigraphic sequences. They have been correlated to stratotype sections with varying degrees of confidence and resolution. Many numerical ages for boundaries are interpolated between widely-spaced geological levels for which numerical ages were originally obtained (Gradstein et al., 2012). The ICS Charts published in 2004, 2008, 2009, and 2010 carry numerical ages derived from Gradstein et al. (2004) and Ogg et al. (2008). The charts in these volumes are known as GTS2004/2008/2012. The GTS volumes were closely associated with ICS when the two lead editors served as Chair and Secretary-General, respectively, of ICS (2000-2008). However, because these are commercial books, created independently of ICS and without ICS oversight on content, ICS decided to produce the ICS Chart independently and to disseminate it via the ICS website and *Episodes*. Most of the numerical ages shown in the 2012 and 2013 versions of the ICS Chart follow Gradstein et al. (2012), except those for the Permian, Triassic and Cretaceous, where the respective subcommissions provided different interpretations of age calibrations. In these cases, numerical ages are not available from critical stratigraphic intervals and many units are yet to have boundaries defined by GSSPs. The 2013 chart contains the 2012-revised numerical ages, as provided and approved by the respective subcommission chairs. Today, the development of consistent, high-precision numerical dating techniques and the continued acquisition of new numerical ages continue to increase the refinement of the time scale. The ages of individual boundaries have changed significantly during the evolution of numerical dating technology and techniques, but they today are becoming more firmly established. Nevertheless, it is to be expected that as techniques improve, almost all the ages will be subject to further revisions; some will become highly constrained, whilst others will remain less certain. Thus, in the current ICS Chart, boundaries are defined by GSSPs, not by their calibrated numerical ages.

Updates and source data

The units of the ICS Chart are only occasionally subject to revision. GSSPs are regularly ratified (2-4 each year on average) to define units formally, new units are approved and the hierarchical positions and relationships reconsidered. For reasons of stability, a newly established GSSP cannot be proposed to be changed in the first 10 years after its ratification. By contrast, numerical ages are more frequently subject to revision (e.g., Gradstein et al., 2012: figures 1.5-1.7). These part geological-scientific, part geological-administrative processes require that the ICS Chart and the table of GSSPs be updated annually and on occasions even more often; hence we introduce chart version numbering (year/ month; e.g. 2013/01). Any printed version will also include this version number.

The documents of ICS decisions have long been held in both paper and digital formats by the ICS Chair and Secretary-General. It is the intention of ICS to make its website the primary archive of matters dealt with and the decisions made by the Commission. Thus, both the most recent version of the ICS Chart, earlier versions and the table of GSSPs are posted on the renewed ICS website www.stratigraphy.org, which is designated the permanent archive of the ICS international geostandards. The website and the GSSP Table were recently redesigned and reorganised with this purpose in mind. Henceforth all documentation on present and future ICS decisions (e.g., GSSP proposals and later revisions, summaries of deliberations and discussions, ballots, tabulations of votes and letters of approval) will be posted on the ICS website. With time, the documentation of past ICS decisions will also be included.

In the January 2013 version of the ICS Chart and GSSP Table, one new GSSP was added, that for the Santonian Stage (Cretaceous), which was ratified in late 2012. In addition, numerical ages for some stage boundaries in the Permian and Triassic have also been revised, including that for the Permian-Triassic boundary (base-Induan Stage), which is now calibrated with significantly greater precision (0.06 vs. 0.5 Ma) and is 30 ka younger. For the Permian, numerical ages have been modestly revised for the bases of the stages that comprise the Cisuralian and Lopingian series, with revisions ranging from 60 ka for the base Changhsingian to 4 Ma for the base Kungurian. These revisions result from recently acquired, very high-precision radiometric ages, together with radiometric and biostratigraphical re-calibrations (Henderson et al., 2012a, 2012b; Schmitz and Davydov, 2012; Shen et al., 2011). For the Triassic, numerical ages are substantially revised for the bases of the Carnian and Norian. The new numerical age for the base of the Carnian, changed from 235 Ma to 237 Ma is based largely on the acquisition of a U/Pb age of 237.773 Ma for the uppermost Ladinian Stage at a section close to the stratotype and in the first ammonite subzone below the base of the Carnian Stage (Mietto et al., 2012). In the absence of radiometric ages, two very different durations (12-15 Ma and 22 Ma) have been proposed for the Norian Stage on the basis of magnetostratigraphy and cyclostratigraphy. Newly acquired U/Pb ages from the lower and middle Norian section in British Columbia, Canada, biostratigraphically calibrated with conodonts, are consistent with the long-duration of the Norian Stage (Diakow et al., 2011, 2012) now shown as 18.5 Ma.

A growing number of chart translations

The archived International Chronostratigraphic Chart is published in English for international use. Since 2012, the ICS Chart has been translated into French, Japanese, Chinese, Spanish (Castilian), Catalan, Basque, Portuguese and Norwegian. Translations into American Spanish, Thai and Russian are in progress at the time of writing. These charts are of identical format as the original ICS Chart and carry the logotypes of both the ICS and IUGS; the only change is in the translation of all text, and the addition of information from the national groups that produced the translation, together with their logotypes, as appropriate. The version numbering of a translation copies that of the English version used as the source. These translations provide standardised official spelling for the chronostratigraphic units in the target language.

Reproduction of the ICS chart in unmodified form is allowed, upon receipt of written authorisation from the ICS Chair. Placing the IUGS and ICS logotypes on an altered design is not permitted. If the numerical ages are removed before use, but not the column layout, the original source should still be cited (this paper, and the www.stratigraphy.org specific URL of the latest version).

For textbook authors and conference promotion, the ICS holds alternative chart designs – which include space for sponsor logotypes. These include a two-sided, double-column version that can be laminated to provide a field-reference card, and a three-column version that fits a square-format mouse mat. On occasion, the ICS grants sponsor logotype placement when hard copies of the chart are reproduced for circulations at meetings and other gatherings of geoscientists. The digital version available for download on the web does not include commercial logotypes. The PDF-versions distributed on the web can be privately reproduced at a range of scales. They contain vector graphics only and produce well both as a large poster and as pocket-sized reference cards.

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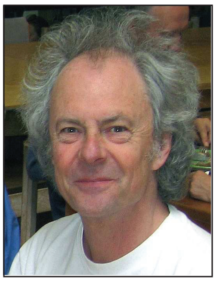

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