Ciências da Terra (UNL)	Lisboa	Nº 18	pp. 35-40	2013

Global Stratotype Sections and Points (GSSP) and Stratotypes

Markus Aretz[1] & Stephen Hesselbo[2]

[1] Université de Toulouse (UPS), GET (OMP), 31400 Toulouse; France, markus.aretz@get.obs-mip.fr,
[2] Department of Earth Sciences, University of Oxford, Oxford OX1 3AN, United Kingdom; stephess@earth.ox.ac.uk

Summary

The formalisation and standardisation of stratigraphic scales based mainly on fossil content has been a process ongoing since geology emerged as a distinctive science. Latterly, new techniques (e.g. chemostratigraphy) and refinements in established techniques (e.g. U-Pb dating) have allowed global correlations at resolutions equivalent to or even surpassing those based on biostratigraphy. As a result the range of complementary correlation tools needed to establish stable and useful Global Stratotype Sections and Points (GSSPs) has also widened significantly in recent years. This combination and integration of techniques has in part been driven by renewed research efforts to understand whole Earth evolution spanning all disciplines of geosciences across a broad range of geological ages. Further methodological developments will in the future affect the practice of GSSP definition, particularly the incorporation of astronochronology, necessitating a combination of robust boundary definitions and full characterisation of the intervals between the boundaries.

Keywords: Chronostratigraphy, stratigraphic scales, GSSP, stratotype

Introduction

Any study that attempts to understand the history of our planet, and the geological processes that are related to it, relies on a solid temporal framework. This frame is generally called stratigraphy, and the superposition of strata implying an age relation (e.g. Steno, 1669) and its application (e.g. Smith, 1815), is common to our science since the very early days of modern geology. Stratigraphic scales have been developed since these early days, and by the middle of the 19th century most of the major units had been introduced. These time units were mostly identified and separated by distinctive faunas; often associated with major changes or breaks in the lithological succession (e.g. Permian: Murchinson, 1841; Kimmeridgian: Thurmann, 1832). Many regional stratigraphic scales and stratigraphic units have been developed more or less in parallel in the 19th century often combining local and regional information and names with more generally accepted time units. Many historical stratotypes are rooted in this period.

The formalisation and standardisation of the competing scales and time units to achieve a global stratigraphic scale has been an important task, but also a problem for the geological community, which already dates back at least to the 1st International Geological Congress (Anonymous, 1882). For long the progress was slow, although spasmodically globally defined boundaries were established. The base of the Carboniferous as defined at the Second Heerlen Congress in 1935 (Jongmans & Gothan, 1937) is one of these examples, and retrospectively parts of the procedure look not too different from the today's GSSP concept. In the last five decades the International Commission on Stratigraphy (ISC) and its subcommissions have made tremendous efforts and progress to establish a global chronostratigraphic scale (e.g. Hedberg, 1976; Cowie *et al*., 1986; Gradstein *et al*., 2004). Today the chronostratigraphic scale of the Phanerozoic (Fig. 1) is composed of a chronological order of 98 stages and 2 series. These time units represent a mixture of modernised "historical" units already defined in the 19th century (e.g. Cretaceous stages) or newly established units (e.g. Cambrian stages).

The concept of GSSPs

The backbone of this global chronostratigraphic scale was and is the establishment of Global Stratotype Sections and Points (GSSPs). A GSSP does not define the entire content of a time unit (stage), only its base, which is placed at a single point in a single section. This point in a stratigraphic succession, representing a single point in time is thus the global standard for correlation. A so-called "Golden Spike" often symbolizes this point.

The first GSSP was defined in 1977 for the base of the Lochkovian Stage (base of the Devonian Period) in the Klonk Section in the Czech Republic (McLaren, 1977). Today 64 global chronostragraphic units (63 stages + 1 series) are defined by a GSSP ratified by ICS (Fig. 1). The procedure for the GSSP definition follows specific rules and recommendations, which have been slightly modified with time. Remane *et al.* (1996) listed requirements and desirable characteristics for establishing global chronostratigraphic units, thus also for GSSPs. The list is long and one may ask if all these characteristics can exist in a single outcrop (see Table 2.1 in Gradstein *et al*., 2012).

However, there are requirements, which every GSSP should fulfil.

- The GSSP defines the lower boundary of a stage in a continuous, marine, fossiliferous section without lithofacies changes in the boundary interval.
- The section should expose a significant rock record below and above the boundary in a tectonically stable and tranquil setting. It should be accessible without logistical or administrative problems.
- The fossil content should be diverse and abundant, if possible comprise fauna and flora, and contain a large number of geographically widely distributed taxa.
- The geological and palaeontological characteristics of the section should be well studied and published.
- Selection of a GSSP should take into account traditional boundaries.
- A GSSP should contain many specific markers to enable long-distance correlation in sedimentary successions representing a wide range of depositional environments.

This list could be continued or some points more detailed, but already a look on the defined GSSPs shows that every GSSP is the individual best compromise between the geological and palaeontological nature of the boundary and the requirements defined by ICS.

Discussions and trends

Currently several GSSPs are under revision, because since their definition severe problems or new data have become available (such as the primary marker being found lower in the section). Examples are several Silurian GSSPs (ISSS, 2013) or the base of the Carboniferous (Kaiser, 2009). These revisions are to some extent a violation of the GSSP idea, because it should guarantee stratigraphic stability, especially since more than one primary marker should have established global correlations and additional stratigraphic tools should be available. Thus the failure of one element should not raise fundamental questions for the GSSP. The base of the Devonian is such an example where the primary marker was found below the GSSP boundary (Clupac, 1993), but the original definition remains valid since the stratigraphic community has adopted other tools for the definition. Hence practicability governs the decisions and stratigraphic practice.

Biostratigraphy has been for a long time the dominating tool for stratigraphers, and thus it is not surprising that many GSSPs have been defined by a biostratigraphic marker. The postulate that without lithological changes the changes in the fossil assemblages reflect evolutionary processes, and thus an ideal first appearance datum (FAD) in an evolutionary lineage exists, has been and is still an important idea guiding many discussions on the ideal GSSP level. It certainly influences the above-mentioned necessity to revise a GSSP. Despite the dominance of biostratigraphic markers in many time units, the use of other stratigraphic markers is starting to become common stratigraphic practice, especially in the Cainozoic and Mesozoic, where isotopic peaks or magnetic reversals are used to define the lower boundaries of stages.

Remane (2003) highlighted the practical value of a GSSP. Extensively tested and applied global correlation is the key element for a stable and successful GSSP. Biostratigraphic tools, often the primary marker, have been the chief element in these correlations. However, discussion is often centred on the appearance or presence of a single species in different sections around the globe. A common shortcoming in these discussions is that chronozone and biozone are not conceptually separated or rigorously defined, which results in contradicting interpretations of similar datasets. However, as stated in the GSSP requirements, correlation should be based on several markers. Especially nowadays, when very different and often complementary stratigraphic tools are available, the reliance put upon one primary marker should decrease. The technical and scientific progress enables today more high precision dates and information and the disciplinary spectrum is much larger than some decades ago.

High-resolution data becoming available from tools such as isotope stratigraphy and geochronology, orbital-tuned cyclostratigraphy (astrochronology), and sequence and event stratigraphy are continuously changing and challenging the traditional ideas on stratigraphic subdivisions and time units (e.g. Zalasiewicz *et al*., 2007, and other contributions *in* McGowran, 2007). The Geological Time Scale 2012 (Gradstein *et al*., 2012) is a typical case in which these new methods are strongly emphasised and put forward. Additionally, as increasingly sophisticated astronomical models of solar system evolution are developed so the *continuous* stratigraphic record of orbital forcing will become more important both to provide a metronome of geological time between the fixed points in the chronostratigraphic hierarchy, and as the basis for refined understanding of solar system orbital history (e.g. Hinnov & Ogg, 2007). - Development and application of cyclostratigraphy is bound to lead to more emphasis in the future being placed on the identification of continuous sedimentary records that represent the complete history of the units defined by GSSPs leading us back to an informal variant of the ‘unit stratotype’ concept that is complementary to the scale defined by GSSPs. – On the other hand, methods such as cyclostratigraphy do not replace well-known tools like biostratigraphy. All disciplines are useful elements of a whole package of tools, which enables us to perform high-resolution, multi-proxy analysis to define time units and stratigraphic scales.

GSSPs are a powerful concept, but all stratigraphers should have in mind that they work for the geoscience community. – Boundaries and their identification should be logical and understandable for the non-specialists. A GSSP, which is only meaningful to stratigraphers, is a lost one. This brings us to events, which are often easy to recognize in the field and which correspond to major changes and reorganisations in the sedimentological and palaeontological records. These event horizons are rarely in agreement with GSSP requirements, but they can be time lines and easily identifiable. The integration of these time lines into the chronostratigraphic scales will be one of the many challenging discussions in stratigraphy and at least partly challenge our understanding of the relevance and positions of GSSPs. – Good recent examples of events close to but not precisely coincident with the adopted GSSP definitions are the end-Permian and end-Triassic mass extinctions (Yin *et al.*, 2001; Hillebrandt & Krystyn, 2009); in both of these cases the GSSP ‘rules’ favoured definition based on post-event recovery faunas rather than associated with the more profound changes linked to the preceding mass extinctions.

The search for robust GSSP definitions has periodically had unsought for scientific benefits. The detailed interdisciplinary study, and whole-Earth perspective, required for boundary definition has often provided new insights into the nature of global change that occurred at the time. One example is the proposed base of the Toarcian (Early Jurassic) at Ponta do Trovão, Peniche, Portugal. In this case, palaeontological sampling and high-resolution carbon-isotope stratigraphy has revealed a large perturbation in the carbon cycle associated with mass extinction that was previously unknown (e.g. Hesselbo *et al*., 2007).

Not all stratigraphic boundaries are natural boundaries. Some of the stratigraphic boundaries for which GSSPs have proven most difficult to agree coincide with minimal global palaeoenvironmental change coinciding with high degrees of faunal and floral endemism; despite years of painstaking work, the base-Berriasian (i.e. base-Cretaceous) boundary is not yet defined (e.g. Rogov *et al.,* 2010).

Conclusions

The geoscientific 'landscape' in which stratigraphers work is constantly changing, requiring a similarly constant re-assessment of the best practices for construction of a formal stratigraphic framework. Increasingly, a concern with the history of the planet across all depositional environments, marine and non-marine, and a requirement for full understanding of sedimentary, igneous and metamorphic process, has led to an integration of accurate and precise radioisotope geochronology, magnetostratigraphy, and astrochronology into everyday stratigraphic practice. - In consequence definition of GSSPs singularly by marine macrofossils or microfossils in sedimentary outcrops without wider context is no longer tenable. As work continues towards definition of the remaining so-far undefined GSSPs it is becoming ever more clear that some earlier GSSP definitions will have to be revisited to make them both stable and more useful. As cyclostratigraphy matures as a discipline so to the requirement for continuous sedimentary records of GSSP-defined units will come progressively to the fore.

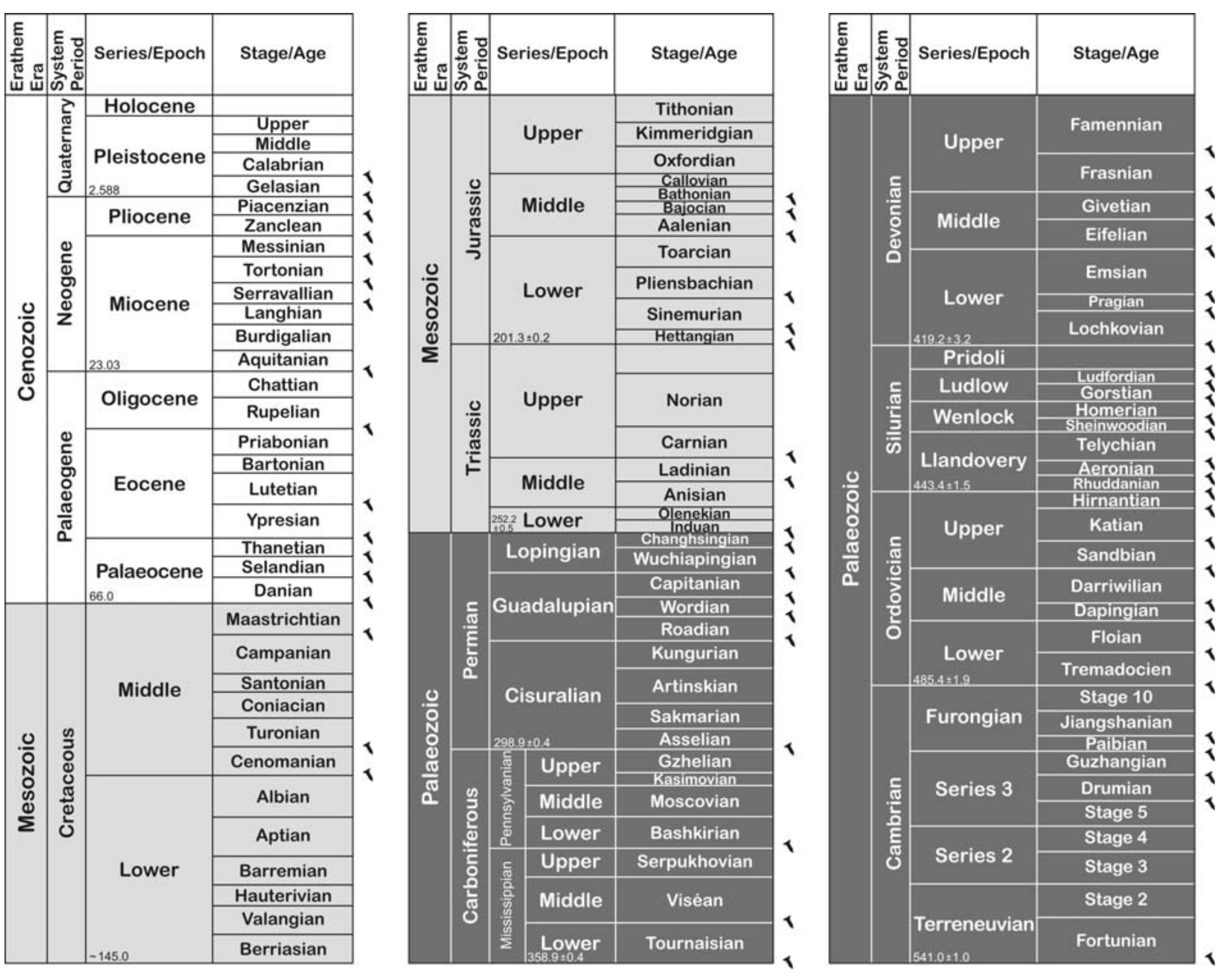

Fig. 1 – International chronstratigraphic scale for the Phanerozoic. Ratified Global Stratotype Sections and Points (GSSP) are indicated by small spike to the right of the stage boundary. Modified from GTS 2012.

References

ANONYMOUS (1882) – *Congrès international de Géologie. Comptes Rendus de la 2eme Session, Bologne 1881*. Fava & Garagni, Bologna, 85-87.

CLUPAC I. (1993) – *Geology of the Barrandian. A field trip guide.* Senckenberg Buch, Frankfurt/Main, 163.

COWIE J. W., ZIEGLER W., BOUCOT A. J., BASSETT M. G. & REMANE J. (1986) – Guidelines for Boundary Stratotypes. *Episodes* 9, 649–677.

GRADSTEIN F. M., OGG J. G., SCHMITZ M. D. & OGG G. M. (2012) – *The Geologic Time Scale 2012*. Elsevier, Amsterdam, 1st edition, 1176 p.

HEDBERG, H. (Ed) (1976) – *International stratigraphic guide: a guide to stratigraphic classification, terminology and procedure*. Wiley, New York, 200 p.

HESSELBO S. P., JENKYNS H. C., DUARTE L. V. & OLIVEIRA L. C. V. (2007) – Carbon-isotope record of the Early Jurassic (Toarcian) Oceanic Anoxic Event from fossil wood and marine carbonate (Lusitanian Basin, Portugal). *Earth and Planetary Science Letters* 253, 455–470.

HILLEBRANDT A. V. & KRYSTYN L. (2009) – On the oldest Jurassic ammonites of Europe (Northern Calcareous Alps, Austria) and their global significance. *Neues Jahrbuch Geologie und Paläontologie Abh*. 253, 163-195.

ISSS (2013) – Annual Report (2012) of the Subcommission on Silurian Stratigraphy. *In* VERNIERS J. (Ed), *Silurian Times* 20, 6-12.

HINNOV L. A. & OGG J. G. (2007) – Cyclostratigraphy and the Astronomical Time Scale. *In* MCGOWRAN B. (Ed.), Beyond the GSSP: New Developments in Chronostratigraphy. *Stratigraphy* 4, 239-252.

JONGMANS W. J. & GOTHAN W. (1937) – Betrachtungen über die Ergebnisse des zweiten Kongresses für Karbonstratigraphie. *In* Jongmans W. J., Deuxième Congrès pour l'avancement des études de stratigraphie carbonifère, Heerlen, Septembre 1935. *Compte Rendu* I, 1-40.

KAISER S. I. (2009) – The Devonian/Carboniferous stratotype section La Serre (Montagne Noire) revisited. *Newsl. Stratigr*. 43 (2), 195-205.

MCGOWRAN B. (2007) – Beyond The GSSP: New Developments in Chronostratigraphy. *Stratigraphy* 4.

MCLAREN D. J. (1977) – The Silurian-Devonian Boundary Committee; a final report. *In* MARTINSSON A. (Ed.), *The Silurian-Devonian boundary*. IUGS Series A 5. Schweizerbartsche Verlagsbuchhandlung, 1-34.

MURCHISON R. I. (1841) – First sketch of some of the principal results of a second geological survey of Russia, in a letter to M. Fischer. *Philosophical Magazine and Journal of Science* Series 3, 19, 417-422.

REMANE J. (2003) – Chronostratigraphic correlations: their importance for the definition of geochronological units. *Palaeogeo., Palaeoclim., Palaeoeco.* 196, 7–18.

REMANE J., BASSETT M. G., COWIE J. W., GOHRBANDT K. H., LANE H. R., MICHELSEN O. & NAIWEN W. (1996) – Guidelines for the establishment of global chronostratigraphic standards by the International Commission on Stratigraphy (ICS). *Episodes* 19, 77–81.

ROGOV M. A., ZAKHAROV V. A. & NIKITENKO B. L. (2010) – The Jurassic-Cretaceous boundary problem and the myth on J/K boundary extinction. *Earth Science Frontiers* 17, 13-14.

SMITH W. (1815) – *A delineation of the strata of England and Wales with part of Scotland; exhibiting the collieries and mines, the marshes and fen lands originally overflowed by the sea, and the varieties of soil according to the variations in the substrata, illustrated by the most descriptive names* [ca. 1:313 800]. J. Cary, London.

STENO N. (1669) – *De solido intra solidum naturaliter contento dissertationis prodromus*.

THURMANN J. (1832) – Sur les soulèvemens jurassiques du Porrentruy. Description géognostique de la Série Jurassique et théorie orographique du soulèvement. *Mém Soc. Hist. Nat. Strasbourg* 1, 1–84.

YIN H., ZHANG K., TONG J., YANG Z. & WU S. (2001) – The Global Stratotype Section and Point (GSSP) of the Permian-Triassic boundary. *Episodes* 24, 102-114.

ZALASIEWICZ J., SMITH A., HOUNSLOW M., WILLIAMS M., GALE A., POWELL J., WATERS C., BARRY T. L., BOWN P. R., BRENCHLEY P., CANTRILL D., GIBBARD P., GREGORY F. J., KNOX R., MARSHALL J., OATES M., RAWSON P., STONE P. & TREWIN, N (2007) – The scale-dependence of strata-time relations: implications for stratigraphic classification. *In* MCGOWRAN B. (Ed.), Beyond The GSSP: New Developments in Chronostratigraphy. *Stratigraphy* 4, 139-144.