| Ciências da Terra (UNL) | Lisboa | Nº 18 | pp. 57-60 | 2013 |
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# Palaeozoic stratigraphy: past, recent advances and future challenges

**Elise Nardin[1], Thijs R. A. Vandenbroucke[2], Bradley D. Cramer[3] & Markus Aretz[1]**

[1] Géosciences Environnement Toulouse, CNRS, Observatoire Midi-Pyrénées, Université Paul Sabatier, Toulouse, France; nardin@get.obs-mip.fr; markus.aretz@get.obs-mip.fr

[2] Géosystèmes, CNRS, Université Lille 1, Villeneuve d'Asq, France; thijs.vandenbroucke@univ-lille1.fr

[3] Department of Geoscience, University of Iowa, Iowa City, Iowa, USA

**Summary**

The Palaeozoic Era ranged from 541.0 ±1.0 Ma to 252.17 ±0.006 Ma based on the latest International Chronostratigraphic Chart. Of the 48 stages, 12 have no defined and/or ratified GSSPs (mostly in Cambrian, Carboniferous and Permian) and at least six boundaries are in the process of being revised. For some better-resolved series and stages, international subcommissions are now working on refining the time scale and on the definition of substages or formal stage slices based primarily on biostratigraphic or bio-chemostratigraphic subdivisions. Future challenges in stratigraphy will focus on integrating different lines of stratigraphic evidence when defining a GSSP and on the refinement of the numerical calibration of the geologic time scale.

***Keywords***: Palaeozoic, Stratigraphy

## Introduction

The Palaeozoic Era ranged from 541.0 ±1.0 Ma to 252.17 ±0.06 Ma based on the latest International Chronostratigraphic Chart (Cohen *et al.*, 2013). It comprises six systems subdivided in 48 stages. The establishment of systems within a standardized global chronostratigraphic scheme was mostly based on their characteristic fossil assemblages, which were recognized in the same order of superposition in different countries (e.g., Permian fauna similar in Germany and Russia; Murchison & Verneuil, 1845). Most of the currently used Palaeozoic systems were defined in the 20 years following the pioneering studies of Coneybeare & Phillips *in* 1822 (e.g., Cambrian and Silurian first used by Sedgwick & Murchison, 1836; Devonian by Murchison & Sedgwick, 1839; Carboniferous, by Coneybeare & Phillips, 1822; Permian, by Murchison, 1841). Initially part of either an extended Cambrian (Sedgwick, 1852) or Silurian (Murchison & Sedgwick, 1839) system, the Ordovician system was the last to have been defined (Lapworth, 1879). The international agreement on the validity of the systems was gradually obtained between the 1970's and the 1990's (e.g., Devonian, McLaren 1977; Carboniferous, Paproth *et al*. 1991; Ordovician, Norford, 1991).

The term 'stage' was first used to delimit a succession of rocks with similar faunal composition (Hancock, 1977; McKerrow, 1993). The original series were subdivided into numerous stages, defined by relation to stratotypes since the 1930's (Bancroft, 1933) and now to GSSPs (McLaren, 1977; Cowie, 1986; Remane *et al.,* 1996). International and regional correlations based on indigenous faunas (first) and on the presence of events and/or a compilation of different stratigraphic methods (nowadays) are becoming increasingly precise.

## Report and recent advances

The International Subcommissions on Ordovician (ISOS), Silurian (ISSS) and Devonian (SDS) systems have completed the naming of the stages and the ratification of the GSSPs. The Cambrian period is subdivided in four series and ten stages, of which two series and five stages (Fortunian, Drumian, Guzhangian, Paibian, Jianshanian) are now named and defined by a ratified GSSP (Peng & Babcock, 2011; Gradstein *et al.*, 2012; Cohen *et al*., 2013). Four (out of seven) and three (out of nine) named stages do not yet have a ratified GSSP in the Carboniferous and the Permian, respectively (Gradstein *et al.*, 2012). The priority of the International Commission on Stratigraphy (ICS) is to complete the task of defining GSSPs for these series and stages, especially for the Carboniferous and Cambrian systems (ICS report 2012 in need of revision in light of improved global chronostratigraphic information produced after their formal ratification (often more than three decades ago). The GSSPs for the base of the Carboniferous System, the base of the Emsian Stage, and base of the Aeronian Stage are three examples of 'golden spikes' that are currently undergoing revision and/or reconsideration by their respective subcommissions (e.g. Kaiser & Corradini, 2008; SDS Report, 2012; ISSS Report, 2013; SCCS Report, 2013; Davies *et al.*, 2013). The over-reliance upon single-taxon biostratigraphic zonations as often the only tool for global chronostratigraphic correlation of Palaeozoic GSSPs is at the heart of current revisions/re-evaluations of many Palaeozoic global boundary stratotype sections and points. As high-resolution chronostratigraphic correlation proliferates among the Palaeozoic research community, we are now facing the limits imposed upon correlation by this over-reliance; in particular, in the chronostratigraphic uncertainties introduced by palaeobiogeographic diachroneity, faunal endemism, and inconsistent species concepts among global workers (e.g. Kaiser & Corradini, 2008; Cramer *et al.*, 2011). The growth of chemostratigraphy over the past two decades, as a non-biostratigraphic chronostratigraphic tool, against which various biostratigraphic groups can be calibrated and correlated, has further demonstrated inconsistencies with correlations developed solely from single-taxon biostratigraphic studies and also demonstrated a need for re-evaluation of certain Palaeozoic GSSPs. Finally, some GSSPs must be revisited by their subcommissions due to the wholly practical matter of degradation or destruction of the stratotype section through natural and/or anthropogenic activities (e.g. Base Lopingian Series, Base Wuchiapingian Stage of the Permian System, ICS Report 2012). International Subcommissions of some systems are now focusing on the refinement of the time scale (ISOS Report 2013, and SDS and ICS reports 2012), and a reappraisal of regional stratigraphies (ISOS Report, 2013). Solutions for higher resolution are being introduced in some systems such as the suggestions of stage slices in the Ordovician (Bergström *et al*., 2009) and Silurian systems (Cramer *et al*., 2011) and progress being made at the subcommission level on substages for the Devonian System (Emsian, Givetian, and Frasnian; SDS report 2012).

## Future challenges

Despite the low percentage of formal members from a range of developing countries, regional groups of the International Subcommissions and national stratigraphic committees have an important role to play in the establishment of regional stratigraphic charts and their correlation to the International Stratigraphic Chart, and in the selection of regional key successions. Auxiliary (or regional) boundary stratotypes around the world can help to extend the knowledge gained from GSSPs to the local stratigraphic context, but also provide important complementary information to the GSSP itself (ICS Report 2012).

Biostratigraphic criteria hitherto prevailed when defining Palaeozoic GSSPs (Cowie, 1986; Remane *et al*., 1996). However, the utility of these criteria is potentially subject to varying degrees of inaccuracy at wide geographic and environmental scales due to the nature of the fossil record. The supremacy of biostratigraphy to

correlate GSSPs is progressively supplemented by other stratigraphic techniques. Indeed, it is the consideration of bio-, litho-, chemo-, sequence stratigraphic information at various regional and global scales (e.g., multiple and event stratigraphy) that will help to integrate biologic and non-biologic means of correlation and ultimately improve the Geologic Time Scale. Special emphasis should be placed on the characterization of (bio-, chemo-) stratigraphic events and their correlation with other stratigraphic patterns, which could serve as a global maker, relatively independent of facies changes (e.g., discussion on the Hangenberg Event/Excursion as potential marker for the correlation of the base of the Carboniferous System; SCCS Report 2013). Integrated stratigraphy is essential to establish and accurately frame GSSPs but also to propose high-resolution global chronostratigraphic correlations.

Future research needs to also focus on the acquisition of more robust, chronostratigraphically well-controlled radiometric data to better calibrate the rates of biological and geological processes in each system. Geochronological progress has begun to highlight strong discrepancies in stages durations: the Viséan age lasts ~16myr, the Famennian age ~13myr, the Givetian and the Sandbian ages, ~5myrs, and the Asselian, Dapingian, Paibian and Pragian ages, ~3myrs (see Cohen *et al*., 2013). Differences in stage durations may affect calculation of diversity and also, and not in the least, human perception of past biological and geological events (by the general and specialist audience).

Finally as most geologists are not stratigraphers, the establishment of databases containing major information and their sources on each system should lead to a better understanding of the global Palaeozoic stratigraphic record.

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