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THE STATUS OF STRATIGRAPHY IN THE 21ST CENTURY

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Abstract

The 21st century geological time scale (GTS) will comprise an internationally agreed chronologic hierarchy. Correlation of events into the GTS will be undertaken using a wide variety of methods, including numeric dating, fossil occurrence, physical and chemical properties, tephrochronology and astrochronologic retrodictions. Chronostratigraphic subdivision of the sedimentary rock record should proceed in a bottom up hierarchical manner with lower units defining the boundaries of stratigraphically higher units. A moderate amount of work is required to improve the basis of the hierarchical subdivision of some Cenozoic series boundary subdivisions and to bring them in line with recommendations by the Stratigraphic Guide and recommendations by the International Committee of Stratigraphy (ICS).

Key words: *stratigraphic classification, chronostratigraphy, geochronology.*

1. Introduction

Stratigraphy provides the time frame and descriptive background against which all geology is undertaken, including particularly the description of fossil organisms, the deciphering evolutionary patterns and the reconstruction of geological paleo- environments. The advanced stratigraphic techniques underpin the discovery and exploitation of sedimentary mineral and energy resources. In addition stratigraphy has a part to play in the understanding of dangerous natural hazards and climate change.

During the Italian renaissance, stratigraphy was marked especially by Leonardo's recognition that marine fossil shells represented the remains of animals that formerly lived on ancient seabeds, and Steno's elucidation of the time significance of stratification. Afterwards, the scene shifted to post-Enlightenment western Europe. There, in late 18th century Scotland, James Hutton generalized Leonardo's earlier insights by applying them to igneous rocks and geological observation in general. Then, in early 19th century England, William Smith laid the foundations of geological mapping and biostratigraphy, work that led to the recognition and naming of the Periods of the geological time scale by stratigraphic pioneers such as Sedgwick, Lapworth and Murchison. Meanwhile, Charles Lyell wove the gold thread of uniformitarian interpretation into geological study in his book Principles of Geology, thereby allowing the previous 400 years of insight to be summarized by the pithy aphorism - "the present is the key to the past", (Lyell, 1833). The development of the geological time scale and all preceding geological studies, largely had their basis in observational field evidence. By the late 19th century with the increasing specialization of different branches of geology and the widespread adoption of the petrographic microscope, the need arose for a more systematic approach to the naming and classification of different types of strata, which led into the codex age of stratigraphy. The demand for more organized codifications of sedimentary rocks was reflected in the distinction drawn at the 2nd International Geological Conference at Bologna (1881) between those terms to be used for past geological time periods (Era, Period. Epoch and Age) and the distinct hierarchy of-terms that were then concerned with the naming of rock bodies (Group, System. Series, Stage).

2. Post Hedberg stratigraphic classification: order or chaos?

Since the First International Geological Congress (IGC, 1878) one of the main issues for global geology was to achieve some order in Stratigraphic Classification and Terminology. Only in 1952 (19th International Geological Conference) the International Subcommission on Stratigraphy was created, under the leadership of H. Hedberg, to produce an International Stratigraphic Guide (ISG). The Guide, published in 1976 (Hedberg, 1976), was the result of an international consensus on a set of principles embodied in a simple and readily usable classification and was soon to become a model for most National and Regional Stratigraphic Codes. After one hundred years of work it seemed that the original goal had been achieved. However, already in 1977 oil geologists introduced "sequence stratigraphy", and the 1983 North American Stratigraphic Code included several new categories. Meanwhile, a number of other stratigraphic methodologies began to be applied, e.g. astronomical calibration in sedimentary cycles. In spite of all that, the ISG second edition was still restricted to the classical categories accepted in 1976, although with the addition of Magnetostratigraphic and Unconformity-Bounded Units (UBUs). The so called "Lithodemic Units" prompted the use of different terminology for non sedimentary rock bodies. "Allostratigraphic units" resulted in a still unsettled discussion on their relationship to UBUs and Sequence Stratigraphy. Chronostratigraphic, Chronometric and Geochronologic units were used in the Geologic Time Scale. These developments were paralleled by the work done by the International Commission on Stratigraphy aimed to achieve a world-wide "chronostratigraphic standardisation" based on "Global Stratotype Sections and Points" (GSSP) for which priority as well as permanence is considered as irrelevant. This resulted in a series of GSSPs defining a scale where the classical time-rock concept becomes redundant and its application represents a practical problem to be solved.

Geologic Time Sca1e 2004 (Gradstein et al., 2004) integrated all the available stratigraphic and geochronology information. The construction of Geological Time Scale 2004 (GTS2004) incorporated different techniques depending on the data available within each interval. Construction involved a large number of specialists, including contribution by past and presents subcommissions officers of the International Commission on Stratigraphy (ICS), geochemists working with radiogenic and stable isotopes, stratigraphes using diverse tools from traditional fossils to astronomical cycles to data base programming, and geomathematicians.

3. Simplifying the Stratigraphy of Time: Implications and practical consequences

Stratigraphy, originally restricted to the study of stratified rocks (e.g., Dunbar and Rodgers, 1957), now has come to encompass all rocks on Earth (e.g., Salvador 1994; Rawson et al., 2002). Three forms of chronology are currently used in the definition of Phanerozoic time scales (Hedberg, 1976; Whittaker et aI., 1991; Salvador, 1994; Rawson et aI., 2002).

The present international nomenclature in English/American recommends a dual hierarchy for the stratigraphical units: rock-units (Erathem, System, Series, Stage) and time units (Era, Period, Epoch, Age) with formal subdivisions into Lower/Upper and Early/Late subunits respectively; the corresponding disciplines are respectively called chronostratigraphy and "geochronology".

By definition, a chronostratigraphic unit consists of all strata formed during the time span of a fundamental geochronological unit. However, making practical distinctions between chronostratigraphy and geochronology is often problematic. In particular the distinction between the two parallel hierarchies of chronostratigraphy (time-rock) and geochronology (geologic time) is subtle, and, not clear to the greater part of the geological community. The distinction is normally only encountered when correct terminology (e.g., period versus system, lower versus early) needs to be used in writing or editing scientific papers. Terms such as e.g. Early Jurassic and Lower Jurassic are often used interchangeably.

Chronostratigraphic units currently refer to stratified rocks only. However, geologic time is of wider applicability than the time-rock classification, and of more use in the kind of cross-disciplinary studies that now increasingly characterize geology.

The distinction between geologic time and time-rock classifications, and their distinction from numerical time, blurs the essential simplicity of stratigraphic classification, and is a significant barrier to understanding, not least as regards extending the messages within stratigraphy (biotic evolution; environmental and climatic change) to the lay public. It is important to preserve this fundamental simplicity today, when the main stratigraphic features of rock, time, and fossils have been joined by numerous other types of stratigraphy, such as those employing paleomagnetic reversals, or the sedimentary signature of Milankovitch climatic cycles.

The term "geochronology" as applied to periods, epochs, and so on does not reflect its mainstream vernacular use (e.g., Bates and Jackson, 1987). Isotope geologists working with radiometric dating generally consider themselves to be geochronologists (not geochronometricists) working on problems of geochronology; they do not use the term geochronometry (and neither do mainstream geologists) in everyday work.

In a discussion paper of the Stratigraphy Commission of the Geological Society of London (Zalasiewicz et al., 2004; elaborating an earlier concept of Harland et al., 1990), the following proposals were made:

- ending the distinction between the dual stratigraphic terminology of time-rock, units (of chronostratigraphy) and geologic time units (of geochronology), on the basis that the long-held, but widely misunderstood distinction between these two essentially parallel time-scales in stratigraphy has been rendered unnecessary by the widespread adoption of the GSSP (=golden spike) principle, in defining intervals of geologic time within rock strata.
- using the name "chronostratigraphy" for the definition and application of a hierarchy of eons, eras, periods, epochs and ages. The time units defined by chronostratigraphy in this sense may be qualified by "early" and "late", but not by "lower" and "upper". Although found within strata, they encompass all rock on Earth.
- making the terms eonothem, erathem, system, series and stage formally redundant.
- allowing the term "geochronology" to revert to its mainstream vernacular use of referring to dating and ordering geological events, particularly by obtaining numerical estimates of time, through radiometric dating, the counting of Milankovitch cycles etc.

It was argued that these suggested changes should simplify stratigraphic practice, encompass both stratified and non-stratified rocks, and help geologic understanding, while retaining precision of meaning. What would be the practical consequences of implementing such changes? In the short term, there would certainly be reluctance by many working stratigraphers, possessing long familiarity with the dual terminology, to abandon terms such as "systems" and "series", which are convenient shorthand for referring to the depositional ages of strata. Longer-term, and, more widely, there may be considerable advantages in operating a unified geological time-scale: this would facilitate the correlation of diverse geological phenomena in the construction of increasingly sophisticated (and societally relevant) models of earth history, and aid research between geologist and scientists of other disciplines.

4. Status of the hierarchical subdivision of higher order marine Cenozoic chronostratigraphic units

Chronostratigraphy remains at the center of the science of Stratigraphy. It provides the conceptual framework in which a hierarchical subdivision of the passage of time is recorded in the rock record. International committees have consistently recommended that this subdivision should proceed in a bottom-up succession, beginning with the stage as the fundamental unit in global chronostratigraphy except where this procedure is not possible owing to inadequately documented lower rank (stage) units.

The following represent the recent developments in the status of the hierarchical subdivision of Cenozoic chronostratigraphic units (Berggren, 2007):

- The base of the Pleistocene has been redefined as Gelasian Stage. The placement of the base Pleistocene equivalent to the base Calabrian at Vrica is a convoluted matter as explained in Van Couvering (1997) and Aubry et al. (1999).The GSSP for the Pliocene/Pleistocene boundary was placed at the base of the Pleistocene Series at Vrica (Calabria, Italy) by the joint Working Group of IGCP-4l and the INQUA Subcommission on the Neogene/Quaternary boundary, submitted to, and approved by, the International Commission on Stratigraphy (ICS) in 1983. The proposal was published by Aguirre and Pasini (1985), and accepted by the International Union of Geological Sciences (lUGS) at the 27th International Geological Congress (IGC) in Moscow (Bassett 1985). The GSSP lies at the base of uniform marls just above sapropel bed “e”, within the uppermost part of the Olduvai Magnetozone (C2n) (Zijderveld et al. 1991) with a currently estimated astronomical age of 1.806 Ma (Lourens et al. 2004). However, Quaternary geologists have refused the ICS proposal in 2005, to decouple the Pleistocene (base 1.8Ma) and Quaternary (base 2.6 Ma), and to reinstate the Quaternary at the Suberathern/Subera level in the chronostratigraphic hierarchy. In June 2009, the Executive Committee of the International Union of Geological Sciences (IUGS) formally ratified a proposal by the International Commission on Stratigraphy to lower the base of the Quaternary System/Period to the Global Stratotype Section and Point (GSSP) of the Gelasian Stage/Age at Monte San Nicola, Sicily, Italy. The Gelasian until then had been the uppermost stage of the Pliocene Series/Epoch. The base of the Gelasian corresponds to Marine Isotope Stage 103, and has an astronomically tuned age of 2.58 Ma. A proposal that the base of the Pleistocene Series/Epoch be lowered to coincide with that of the Quaternary (the Gelasian GSSP) was also accepted by the IUGS Executive Committee. The GSSP at Vrica, Calabria, Italy, which had hitherto defined the basal boundary of both the Quaternary and the Pleistocene, remains available as the base of the Calabrian Stage/Age (now the second stage of the revised Pleistocene). In ratifying these proposals, the IUGS has acknowledged the distinctive qualities of the Quaternary by reaffirming it as a full system/period, correctly complied with the hierarchical requirements of the geological timescale by lowering the base of the Pleistocene to that of the Quaternary, and fully respected the historical and widespread current usage of both the terms ‘Quaternary’ and ‘Pleistocene’ (Gibbard et al., 2009).
- The base Oligocene was defined with no mention of the constituent stages concerned (Priabonian and Rupelian); the base Oligocene has since been found to lie at a level stratigraphically within the upper third of the Priabonian Stage, effectively decapitating the upper part of the Priabonian Stage and at a level - 0.4 my younger than the currently recognized GSSP for the base of the Eocene.
- The base/GGSP of the Eocene was placed at a stratigraphic level nearly 1 my older than the accepted base of the Ypresian Stage s.s.; the Ypresian Stage was simply lowered by this amount, effectively decapitating a significant part of the underlying Thanetian Stage which has been considered of Paleocene age for over a century, and transferring rocks belonging to the upper/late

Thanetian to the lower/early Eocene; the insertion of the "Sparnacian Stage"-which has been shown to span the chronostratigraphic/geochronologic interval from base Eocene to base Ypresian s.s as the basal stage of the lower Eocene –has been suggested.

- The base Pliocene Series was correctly based on a GSSP for the base of its lowest component, the Zanclean Stage, in the Eraclea Minoa section of the composite Rossello section, in south coast of Sicily. The Subcommision on Neogene Stratigraphy (SNS) recommended that the base (GSSP) of the Zanclean Stage (and base Pliocene Series) be placed at the base of the carbonate bed of small-scale cycle 1 in the Trubi Marl Formation in the Eraclea Minoa section (itself a component sub-section of the Capo Rossello Composite Section), southern coast of Sicily, corresponding to insolation cycle 510 from the present with an estimated astrochronologic age of 5.33 Ma (Van Couvering et al. 2000). In a recent study of the stratigraphically continuous Miocene-Pliocene Loulja marine section of Atlantic facies (Bou Regreg area, NW Morocco) Van Der Laan et al. (2006) have shown that the Miocene/Pliocene boundary may not coincide with isotope stage TG5 but rather with an "extra (weak) obliquity-controlled cycle between TG 7 and TG5. If true, the authors point out that the boundary would not coincide with a major deglaciation event and associated glacio-eustatic sea-level rise as generally believed; tectonics, rather, are thought to have played a significant role. Earlier, Krijgsman et al. (2001) have shown that the initiation of the Messinian Salinity Crisis at - 6 Ma was not related to a glacio-eustatic event either.

5. Conclusions

After 200 years of discussion, two editions of the International Stratigraphic Guide and with the forthcoming completion of definition of GSSP at all Period boundaries, the stratigraphic community is well prepared to contribute to dealing with mankind's needs and problems. During the 21st century, stratigraphers will continue to provide both the time skeleton and the environmental flesh for imaginative reconstructions of the history of planet earth. Stratigraphers will also remain deeply involved in the search for earth resources, especially sedimentary-based energy resources such as coal, petroleum and uranium, and will help to provide high resolution histories of the occurrence of earthquakes, tsunami, volcanic eruptions and floods.

However 21st century Stratigraphy must conform to criteria of usefulness -both scientific and politicaI. At the same time, the discipline will need to remain true to its historic scientific roots, of which the most important is the application of a strong principle of priority of nomenclature to preserve the value of order observations and literature.

Impediments which today remain to ready and consistent communication of stratigraphic information include differences in approach, and sometimes nomenclature, between different national or regional geological communities; and a number of minor inconsistencies in stratigraphic usage that need to be tidied up. Stratigraphy should add value by providing concise and clear nomenclatural schemes, not subtract value by interminable arguments, or by introducing unnecessary complexity of classification.

6. References

Aguirre, E., Pasini, G., 1985. The Pliocene-Pleistocene boundary. *Episodes*, 8, 116-120.

Aubry, M.-P., Berggren, WA., Van Couvering, JA., and Steininger, E, 1999. Problems in chronostratigraphy: Stages, series unit and boundary stratotypes, global stratotype section and point and tarnished golden spikes. *Earth-Science Reviews*, 46, 99-148.

Bassett, M. G., 1985. Towards a "common language" in stratigraphy. *Episodes*, 8, 87-92.

Bates, R.L., Jackson, lA, 1987. *Glossary of geology*. (third edition), Alexandria, Virginia, American Geological

Institute, 788 p.

Berggren, W.A., 2007. Status ofthe hierarchical subdivision of higher order marine Cenozoic chronostratigraphic units. *Stratigraphy*, 4, 99-108.

Dunbar,C.O., Rodgers, L, 1957. *Principles of stratigraphy*. New York, John, Wiley, 356 p.

Gibbard, PL., Head, M.J., Walker, M.J.C. & the Subcommission on Quaternary Stratigraphy, 2009. Formal ratification of the Quaternary System/Period and the Pleistocene Series/Epoch with a base at 2.58 Ma. *Journal of Quaternary Science*. (in press).

Gradstein, F.M., Ogg, J.G., Smith, A.G., Agterberg, F.P., Bleeker, W., Cooper, R.A., Davydov, V., Gibbard, P., Hinnov, L., House, M.R., Lourens, L. Luterbacher, H-P., McArthur, J., Melchin, M.J., Robb, L.J., Shergold, J., Villeneuve, M., Wardlaw, B.R., Ali, J., Brinkhuis, H., Hilgen, F.J., Hooker, J., Howarth, R.J., Knoll, A.H., Laskar, J., Monechi, S., Powell, J.,

Plumb, K.A., Raffi, I., Röhl, U., Sanfilippo, A., Schmitz, B., Shackleton, N.J., Shields, G.A., Strauss,H., Van Dam, J., Veizer, J., van Kolfschoten, Th., Wilson, D., 2004. *A Geologic Time Scale 2004*. Cambridge University Press, ~500 p.

Harland, W.B., Armstrong, R.L., Cox, A.V., Craig, L.A., Smith, AG., Smith, D.G., 1990. *A geologic time scale 1989*. Cambridge, Cambridge University Press, 263 p.

Hedberg, RD., 1976. *International stratigraphic guide*. New York, John Wiley, 200 p.

Krijgsman, W., Fortuin, A.R., Hilgen, F.J., Sierro, F.J., 2001. Astrochronology for the Messinian Sorbas basin (SE Spain) and orbital (precessional) forcing for evaporite cyclicity, *Sedimentary Geology*, 140, 43–60.

Lourens, L., Hilgen, F., Shackleton, N. J., Laskar, J., Wilson, J., 2004. The Neogene period. In F. M. Gradstein et al. (eds), *A Geologic Time Scale 2004*, p. 409-440, Cambridge University Press.

Lyell, C., 1833. *Principles of Geology, Being an Attempt to Explain the Former Changes of the Earth's Surface by Reference to Causes Now in Operation*, vol. III, John Murray, London p. 398.

Rawson, P.E, Allen, P.M., Bevins, R.E., Brench1ey, P.J., Cope, J.C.W., Evans, JA., Gale, AS., Gibbard, P.L., Gregory, E.J., Hesse1bo, S.P., Marshall, J.E.A, Knox, R.W.O.B., Oates, M.J., Riley, N.J., Rushton, A.W.A, Smith, A.G., Trewin, N.H., Zalasiewicz, J.A, 2002. *Stratigraphical procedure*. Geological Society of London Professional Handbook, 57 p.

Salvador, A., 1994. *The International Stratigraphic Guide: A guide to stratigraphic classificationterminology,and procedure*. New York, John Wiley, 214 p.

Van Couvering, J., 1997. Preface, the new Pleistocene. In: van Couvering, J. (ed.) *The Pleistocene boundary and the beginning of the Quaternary*. University Press: Cambridge. ii-xvii.

Van Couvering, J.A., Castradori, D., Cita, M.B., Hilgen, F.J., Rio, D., 2000. The base of the Zanclean Stage and of the Pliocene Series. *Episodes*, 23, 179–187.

Van Der Laan, E., Snel, E., De Kaenel, E., Hilgen, F.J., Krijgsman, W., 2006. No major deglaciation across the Miocene-Pliocene boundary: Integrated stratigraphy and astronomical tuning of the Loulja sections (Bou Regreg area, NW Morocco). *Paleoceanography*, 21 (3), art. no. PA3011.

Whittaker, A., Cope, J.C.W., Cowie, J.W., Gibbons, W., Hailwood, E.A., House, M.R., Jenkins, D.G., Rawson, A.W.A., Rushton, A.W.A., Smith, D.G., Thomas, A.T., Wimbledon, W.A., 1991. A guide to stratigraphical procedure. *Journal of the Geological Society*, *London* 148, 813–824.

Zalasiewicz, J., Smith, A., Brenchley, P., Evans, J., Knox, R., Riley, N., Gale, A., Gregory, F.J., Rushton, A., Gibbard, P., Hesselbo, S., Marshall, J., Oates, M., Rawson, P., Trewin, N., 2004. Simplifying the stratigraphy of time. *Geology*, 32, 1-4.

Zijderveld, J.D.A., Hilgen, F.J., Langereis, C.G., Verhallen, P.J.J.M., Zachariasse, W.J., 1991. Integrated magnetostratigraphy and biostratigraphy of the upper Pliocene-lower Pleistocene from the Monte Singa and Crotone areas in Calabria, Italy. *Earth and Planetary Science Letters*, 107 (3-4), 697-714.