by Davide Castradori

A complete standard chronostratigraphic scale: How to turn a dream into reality?

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The way toward a complete standard chronostratigraphic scale is paved with endless discussions on the principles lying behind the definition of chronostratigraphic units. I will briefly review the two most important and diverging approaches to the problem, with the aim at illustrating how in practice they can both contribute toward our common final goal, that of giving the next generations of geologists an invaluable tool for their every-day job.

Introduction

"...Aquitanian, Burdigalian, Langhian..." we recited trustfully while preparing the first exams at the University. I distinctly remember how at ease I felt with that list of names looking at me from those coloured pigeonholes in the book of introductory geology. They seemed to me the proud pillars of an universal law, like the immutable string of natural numbers. I was about as sure that the Langhian "mathematically" followed the Burdigalian as that the 3 followed the 2.

I also remember exactly when the first doubts crept into my mind. "Portlandian" I read on a time scale on the internal side of the door to a professor's room, precisely where I was sure I should have read "Tithonian". Once the first breach was opened, the magic was suddenly gone, but it was not until the years of the Ph. D. when I fully realised that a perfect mess was often concealed below that sacred list of names.

The first test for a then disenchanted mind was the Pleistocene. I wanted to write an introductory chapter to my thesis to briefly sketch the standard chronostratigraphy of the Pleistocene and I ended up with several pages of text and a synoptic table that left me more confused than ever and irremediably sceptic.

However, in exploring the subject, I became aware that there was a community of people, namely the International Commission on Stratigraphy with its Subcommissions, that was trying to unravel and clarify all this complicated matter by defining a standard chronostratigraphic scale*. At about the same period, I also became aware that Maria Bianca Cita, a few doors down the corridor from me, was fighting as she only can to make Italian stratigraphers agree on some sort of reference chronostratigraphic scheme for the Pleistocene, on one side, and to revitalise a somewhat dormant Subcommission on Neogene Stratigraphy, on the other. I was lucky enough to get a place beside her in this adventure: at that moment the final spell was cast and, from that time on, I have never ceased to work and push, push and work, to make this story come full circle and to end up with a *true* magic list of names for the future generations of geologists.

Some work has been done in this direction in the Pleistocene and the Neogene (Steininger et al., 1997, Rio et al., 1998a, Castradori et al., 1998; Van Couvering et al., 2000, Hilgen et al., 2000, to cite only the final paper on each different chronostratigraphic unit), but what remains still constitutes a formidable task for all of us. And this is even more true for other parts of the time scale.

However, the way is paved with endless discussions on the principles that lay behind the construction of a standard chronostratigraphic scale. This debate is most important and interesting, even in itself (I did enjoy taking part in it in the last years!), but we should not permit it to take us even one step farther from our common final goal of establishing a standard chronostratigraphic scale once and for all.

It is far beyond the scope of the present paper to present the details of the ongoing discussions and of the different positions. You can get a flavour of it by reading the recent reviews by Aubry et al. (2000) and Remane (2000).

What I want to attempt is to briefly summarise the two main approaches commonly applied to the definition of chronostratigraphic standards, then continue by arguing how some of the past resolved controversies can show us a possible way out of the problems ahead and finally conclude with an appeal.

Different approaches to the same problem

I will take the liberty of informally nick-naming the two different basic approaches to the problem as the *Historical and Conceptual approach* (championed by M.-P. Aubry, B. Berggren, J. Van Couvering among others) and the *Hyper-pragmatic approach* (championed by J. Remane and the recent executive committees of the International Commission on Stratigraphy).

The *Historical and Conceptual approach* advocates the key role of historically recognized stages, the importance of unit-stratotypes as permanent archive of stratigraphic information as well as boundary-stratotypes** as correlatable definitions in the rock, the supremacy of the Stage in the construction of the standard scale, and the need to keep chronostratigraphic units well separated intellectually from the time span they represent.

All of this can be summarised in the well-known motto "definition precedes correlation". One must first study the stratigraphic architecture of the historical Stage, then point out the events useful to correlate the entire unit and particularly its base, then, if necessary, move away from the historical type-locality in order to find a suitable section to house the boundary-stratotype. Once the lower boundary of a Stage is established, definition of Series and higher units will follow accordingly.

* I will refrain from using acronyms for the standard chronostratigraphic scale (like SGCS or GSS) as it seems that they can generate some confusion and discussion in themselves.

** I will also refrain from using the acronym GSSP, since it is regarded by some not simply as a nick-name for boundary-stratotype, but as implying a certain way of selecting boundary stratotypes.

The champions of this philosophy reject forcefully the practice of establishing first the boundary-stratotype of a higher-rank unit (e.g. a Series) to correspond with some clear and widely recognisable event and only then to make the boundary of the lowest Stage coincide with it by definition. This would be exemplified, according to them, by the ongoing attempt to fix the base of the Eocene equivalent to a clear $\delta^{13}\text{C}$ excursion and then to adjust the base of the historical Ypresian Stage downward by a million years to fit that definition.

The *Hyper-pragmatic* approach advocates the key-role of boundary-stratotype and rejects altogether unit-stratotypes, emphasises the importance of fixing boundaries at (or near to) the most correlatable event within the interval of interest (which is not limited to the historical base of the relevant Stage, which constitutes simply a reference and not a mandatory choice), and accepts the definition of the base of a Series *ab initio*. In this view, by giving the geohistorical events themselves the key-role in the establishment of chronostratigraphic units, the distinction between the latter and the geochronologic units becomes insubstantial.

All of this can be summarised in the well-known motto "correlation precedes definition". One must first establish which is/are the best event(s) in the time-span of interest (should it be the base of a Stage or of a Series), then demonstrate their world-wide correlability, and finally find a suitable section to house the boundary-stratotype (which still remains a point in the rock). This approach is exemplified by the proposed choice for the base of the Eocene without regard for the historical base of the Ypresian (see above) or by the already selected and ratified base of the Miocene, where definition of the base of the Aquitanian Stage (admittedly a difficult concept in the past) followed *a posteriori* (Steininger et al., 1997).

What past case histories can teach us for the solution of future problems

The two approaches briefly discussed above can be justly said to be almost irreconcilable in theory, but I want to demonstrate that they are very seldom so in practice. My position as an officer of the Sub-commission on Neogene Stratigraphy and, at the same time, as a geologist in an oil company permits me, I believe, to be a little bit informal and utilitarian in undertaking this task.

As a start, let me say that a timely completion of the standard chronostratigraphic scale (by 2008, according to the request of IUGS and ICS) is a necessary and noble task that, once achieved, will improve the every-day life of all geologists of future generations. I firmly believe that to have a complete standard chronostratigraphic scale referred to by everybody in the world, even if it should contain some rather summarily defined units or some coarseness or impropriety both of style and of merit, would be better than to have no scale at all.

However, since (lamentably) we do not have a complete standard chronostratigraphic scale yet, we have the opportunity to complete it in the best way, provided that this does not cause the whole procedure to take forever.

Let's analyse a few examples from the past (i.e. questions already settled) and see what lessons they can teach us in view of the solution of the problems ahead. You will note, I hope, how each situation is different from all the others and how there can be room for both the above-mentioned approaches to contribute, in different way in each different situation, to the final goal of completing the standard chronostratigraphic scale.

In the selection of case histories, I will restrict myself to the youngest part of the time scale, the interval I am most familiar with, but I think that the general rules are exactly the same for older periods.

1) The Pliocene-Pleistocene boundary was defined in the early Eighties and ratified by IUGS in 1985 (Aguirre and Pasini, 1985, Bassett, 1985). An endless debate, probably the longest and

hottest in the entire field of stratigraphy for over a century, preceded and followed this choice. To go to the end of this very long story (for the details see Rio et al., 1998b), the final controversy was to decide whether or not the base of the Pleistocene was to be lowered from its formally approved boundary stratotype (in the Vrica section, Italy, at about 1.8 Ma) to the base of the underlying Upper Pliocene (at about 2.6 Ma; see also example 2). The rationale behind the request for lowering the boundary followed the "hyper-pragmatic" principle that the earlier boundary was apparently "stronger" in that it could have been more easily correlated in different domains, and it coincides with a more evident threshold in the extended development of the climate system towards the "ice ages". The proposal was finally rejected (by formal vote) on three different grounds. Firstly (and most importantly), on the grounds that the proposed change would have disrupted the historical framework of the Neogene and Pleistocene in its type area, causing the inclusion in the Pleistocene of sedimentary succession that had always been attributed to the Pliocene. Secondly, and chiefly to try to counter the opposing party on its preferred ground, by demonstrating that the correlation potential of the two boundaries were perfectly comparable. Thirdly (and less importantly), by advocating that changing for the first time a ratified boundary stratotype could possibly open the way to endless changes and adjustments, hence to confusion. *What can we learn from this example?*: When a boundary respects the historical concepts and, at the same time, presents a more than acceptable correlation potential, the request for choosing a historically unjustified boundary only for its supposed higher correlation potential and its more "natural" character must be rejected.

2) The Gelasian Stage was introduced by Rio et al. (1994) to cover a stratigraphic interval comprised between the top of the historical Piacenzian Stage and the base of the Pleistocene. The authors openly acknowledged that the mere demonstration of such a gap did not automatically call for the erection of a new Stage; however, the interval of time represented by this Stage was believed to have both sufficient length and homogeneous character to justify this proposal (Rio et al., 1998a). In fact, this Gelasian Stage is such a well-defined interval that it seemed logical to some people to make it the lowest part of the Pleistocene (see above). *What can we learn from this example?*: Should the necessity arise, we must not be afraid of creating new stratigraphic units, provided that we define them appropriately at their very first appearance (see, on the contrary, example 5). Obviously, the widely acknowledged rule that "base defines boundary" implies that the discovery of a gap between two successive units, the higher having a base defined by a boundary stratotype, will most of the times be resolved by attributing the time-rock interval corresponding to the discovered gap to the lower unit.

3) The boundary stratotype of the Piacenzian Stage (Middle Pliocene) was published by Castradori et al. (1998), after a very smooth and simple process of approval by SNS, ICS and IUGS. It was proposed to house the boundary stratotype in what is probably the best section in the world for the bio-, magneto-, and cyclostratigraphy of this time interval, the Punta Piccola segment of the Rossello Composite Section, Sicily. Once the approximate position in time of the base of the historical Piacenzian in northern Italy was determined (Rio et al., 1988 and Raffi et al., 1989), it was easy to form a large consensus around the possibility of moving away from the type area to find a more suitable reference section for the boundary. *What can we learn from this example?*: From a procedural point of view, this was really a piece of cake! It shows that it can be desirable and feasible to respect the historical stage and the stratigraphic level of its classical base, even when we move hundred of kilometers away from the type area to find a more suitable boundary-stratotype section.

4) The base of the Zanclean Stage and of the Pliocene Series was proposed in the Capo Rossello section some thirty years ago by Cita (see Cita, 1975). It corresponded to the base of the Trubi Marls that mark the rather abrupt flooding following the so-called

Messinian Salinity Crisis. This informal boundary remained since in wide-spread use, although challenged by an important group of stratigraphers headed by R. L. Benson, who advocated the moving of the type section outside the Mediterranean area to meet with continuous marine sedimentation (Bou Regreg section, Atlantic side of Morocco). The "extra-Mediterranean group" also sought to lower the boundary level defining the base of the Miocene down to the base of the Gilbert magnetic Epoch, as a "hyper-pragmatic" alternative to the base of the historical Zanclean Stage. After the results of an informal questionnaire circulated within SNS in 1997, the decision was taken to proceed with the approval and ratification of the Capo Rossello boundary, although in a slightly better nearby section (the Eraclea Minoa segment of the Rossello Composite Section), as base of the Zanclean Stage and of the Pliocene Series. The decision was obviously a difficult one, since it was the first time a boundary stratotype was proposed in a section where continuous marine sedimentation was present only above (and not below) the boundary. What in the end convinced the majority of the scientists involved was, I believe, the consideration that cyclostratigraphy, when coupled with magneto- and biostratigraphy, allowed for the very precise correlation of the boundary in extra-Mediterranean sections, where the marine record below the boundary level could be freely studied. Therefore, the shortcomings of having such a peculiar stratotype-section, with non-marine sedimentation below the boundary, were compensated in practice by the recent advancement of new stratigraphic techniques, thus rendering the stylistic flaw more digestible. *What can we learn from this example?* I believe this to be the most outstanding example of flexibility applied so far to normative stratigraphy. By accepting the evidence that the knowledge of the stratigraphic signature across the boundary was very good even if the type section itself recorded only half of the story, and by accepting a small "pragmatic" bending of the guidelines, we succeeded in ratifying a boundary that both perfectly respects the historical use and also constitutes a reasonably correlatable level with respect to other possible solutions. The fact that all proposed boundaries are subsequently ratified by three or four different bodies (working group, related Subcommittee, ICS, and IUGS) will always guarantee that such exercises of flexibility will not lead to total deregulation (cfr. Remane et al., 1996).

- 5) The last example I will briefly present is different from all the others in that it does not deal with the successful definition of a boundary stratotype, but with the informal proposal of a chronostratigraphic scheme. After several years of discussion, chiefly among the Italian stratigraphers, and a couple of workshops and field-trips, Cita and Castradori (1995) proposed a new chronostratigraphic scheme for the entire Pleistocene. Old and new Stages were included and the criteria for the selection of boundary-stratotypes were proposed. The Subcommittee on Quaternary Stratigraphy, however, was apparently interested only in trying to change the Pliocene-Pleistocene boundary, so the proposed scheme was never used as a base for subsequent action. It took root, however, in the literature: a reference scheme, albeit informal, is very useful and saves time and space for those that do not want to enter into much discussion in their papers. *What can we learn from this example?* To introduce a new scheme, containing even a new Stage, without being 100% sure to be able to formalise it rapidly through the approval of the related boundary stratotypes was, I believe, a mistake. An informal scheme, if reasonable, can make us feel so much at ease as to forget that it is not officially accepted, that it was not evaluated in comparison with other proposals, and that it was not presented for approval to different groups of scientists.

How can we summarise the picture coming out of these examples? I think that the overall idea is that we must try as much as possible to save the historical archives upon which stratigraphy was born and grew up. As much as possible means, in my opinion, up to the point of bending the guidelines a little bit, as in the case of the base of the Zanclean Stage. But we must also be accessible and

open-minded towards rather unusual solutions, like the erection of a new Stage (e.g. the Gelasian) or the rescue of a poorly characterised, but widely known, Stage by redefining *ex-novo* its base in a position only broadly respective of its historical stage.

I believe the latter to be the case of the Burdigalian Stage. Due to the unfavourable facies of the historic stratotype (see Berggren, 1971), the position in time of the base of the Burdigalian is rather poorly constrained. The questionnaire circulated within SNS in 1997 (see also above) clearly demonstrated that most stratigraphers dealing with this time period do want to use this Stage in their job, but also showed that their preferred primary events to recognise its base were distributed over an ample stratigraphic interval.

I would, and I will, suggest to tackle this situation vigorously by deciding to save the Burdigalian and to redefine it in a good marine section at a level, reasonably respectful of the historic concepts, with the best correlation potential.

In a nutshell, where there is no much history and information to respect, but only names to preserve, let's go straight for the best level and save time.

The same, I believe, would have applied to the Aquitanian Stage, whose base is also poorly constrained in time as that of the Burdigalian. Therefore, the selection of the boundary stratotype for the Miocene Series (Steininger et al., 1997), without even mentioning the Aquitanian Stage (that was subsequently fitted to it as an afterthought), was certainly a mistake, but did not cause, in practice, any big inconvenience or conceptual conflict.

Apparently (but I am no expert here), one cannot say the same for what concerns the base of the Oligocene Series and the base of the Eocene Series. In both cases, one already approved and ratified (Premoli Silva and Jenkins, 1993) and the other the subject of the ongoing harsh discussion (see Aubry et al., 2000 and Remane, 2000), the position in time of the historical stages on both sides of the boundaries are rather well constrained and should be, or should have been, taken in higher consideration.

To conclude, an appeal

To conclude, I hope to have illustrated how the occurrence of such different historical and objective situations offers plenty of opportunities for the champions of both approaches to contribute to their solutions, provided that a degree of flexibility is accepted by both. In the end, what we will get would be a standard chronostratigraphic scale in which everybody will recognise his/her pupils and will turn up his/her nose to other units, but, as long as it will be useful and universally used, it will nevertheless be a great success.

So let me launch here an appeal for a truce. Let's bury the hatchet and try always to remember that the most important thing is to complete the standard chronostratigraphic scale in a few years and in an acceptable (not always the best) way. I believe that this would be the most noble and valuable gift to the generations of geologists to come.

"...Aquitanian, Burdigalian, Langhian..." they will recite trustfully. Let's see to it that they will not be disappointed.

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References

- Aguirre, E., and Pasini, G., 1985, The Pliocene-Pleistocene Boundary. *Episodes*, v. 8, no. 2, pp. 116–120.
- Aubry, M.-P., Van Couvering J., Berggren W.A., and Steininger, F., 2000, Should the Golden Spike glitter? *Episodes*, v. 23 no. 3, pp. 203–210.
- Bassett, M., 1985, Towards a "Common language" in stratigraphy. *Episodes*, v. 8: pp. 87–92.
- Berggren, W A, 1971, Tertiary boundaries and correlations, in Funnell R.M.S. and Riedel W.R. eds, *The Micropaleontology of Oceans*: Cambridge Univ. Press, pp. 693–809.
- Castradori, D., Rio, D., Hilgen, F. J., and Lourens, L. J., 1998, The Global Standard Stratotype-section and Point (GSSP) of the Piacenzian Stage (Middle Pliocene). *Episodes*, v. 21, no. 2, pp. 88–93.
- Cita, M. B., 1975, The Miocene/Pliocene boundary: History and definition. In: Saito, T. and Burckle, L. H., *Late Neogene Epoch Boundaries*: New York, Micropaleontology Press, Spec. Publ. 1: pp. 1–30.
- Cita, M.B., and Castradori, D., 1995a, Rapporto sul workshop "Marine sections from the Gulf of Taranto (southern Italy) usable as potential stratotypes for the GSSP of the lower, middle and upper Pleistocene" (29 settembre - 4 ottobre 1994). *Boll. Soc. Geol. It.*, 114, pp. 319–336.
- Cita, M.B., and Castradori, D., 1995b, Workshop on marine sections from the Gulf of Taranto (southern Italy) usable as potential stratotypes for the GSSP of the lower, middle and upper Pleistocene (Bari, Italy, Sept. 29–Oct. 4, 1994). *Il Quaternario*, v. 7, no. 2, pp. 677–692.
- Hilgen, F. J., Iaccarino, S., Krijgsman, W., Villa, G., Langereis, C. G., and Zachariasse, W. J., 2000, The Global Boundary Stratotype Section and Point (GSSP) of the Messinian Stage (uppermost Miocene). *Episodes*, v. 23, no. 3, pp. 172–178.
- Premoli Silva, I., and Jenkins, D. G., 1993, Decision on the Eocene-Oligocene boundary stratotype. *Episodes*, vol. 16, no. 3, pp. 379–382.
- Raffi, S., Rio, D., Sprovieri, R., Valleri, G., Monegatti, P., Raffi, I., and Barrier, P., 1989, New stratigraphic data on the Piacenzian stratotype: *Boll. Soc. Geol. It.*, v. 108, pp. 183–196.
- Remane, J., Bassett, M. G., Cowie, J. W., Gohrbandt, K. H., Lane, H. R., Michelsen, O., and Naiwen, W., 1996, Revised guidelines for the establishment of global chronostratigraphic standards by the International Commission on Stratigraphy (ICS). *Episodes*, v. 19, no. 3, pp. 77–81.
- Remane, J., 2000, Comments on the paper of "Should the Golden Spike glitter" by M.-P. Aubry et al. *Episodes*, v. 23, no. 3, pp. 211–213.
- Rio, D., Sprovieri, Raffi, I., and Valleri, G., 1988, Biostratigrafia e paleoecologia della sezione stratotipica del Piacenziano. *Bull. Soc. Paleont. It.*, v. 27, no. 2, pp. 213–238.
- Rio, D., Sprovieri, R., and Di Stefano, E., 1994, The Gelasian Stage: a proposal of a new chronostratigraphic unit of the Pliocene Series. *Riv. It. Paleont. Strat.*, v. 100, no. 1, pp. 103–124.
- Rio, D., Sprovieri, R., Castradori, D., and Di Stefano, E., 1998a, The Gelasian Stage (Upper Pliocene): a new Unit of the Global Standard Chronostratigraphic Scale. *Episodes*, v. 21, no. 2, pp. 82–87.
- Rio, D., Castradori, D., and Van Couvering, J. A., 1998b, Against the lowering of the Pliocene-Pleistocene boundary. *Neog. Newsl.*, 5, pp. 78–103.
- Steininger, F. F., Aubry, M. P., Berggren, W. A., biozzi, M., Borsetti, A. M., Cartlidge, J. E., Cati, F., Corfield, R., Gelati, R., Iaccarino, S., Napoleone, C., Ottner, F., Rogl, F., Roetzel, R., Spezzaferri, S., Tateo, F., Villa, G., and Zevenboom, D., 1997, The Global Stratotype Section and Point (GSSP) for the base of the Neogene. *Episodes*, v. 20, no. 1, pp. 23–28.
- Van Couvering, J. A., Castradori, D., Cita, M. B., Hilgen, F. J., and Rio, D., 2000, The base of the Zanclean Stage and of the Pliocene Series. *Episodes*, v. 23, no. 3, pp. 179–187.

Comment

The website of ICS <http://stratigraphy.org> provide detailed guidelines in connection with the erection of Global Boundary Stratotypes and Points (GSSP's). Formal characterization and recognition of the 90+ stratigraphic units in the Phanerozoic is beyond daydreams and well on its way to completion, targeted for 2008. This process in the great majority of cases is going smoothly and involves intelligent geological choices. ICS is fortunate to harbour many stratigraphic experts. If 'correlation would precede definition', or 'definition would precede correlation', stratigraphy would be on the rocks.

ICS Executive Committee

A Clarification

The last issue of *Episodes* (March, 2002; p. 44) carried my report summarizing the 2002 IUGS Executive Committee (EC) meeting. Included in the report was notice that the EC had ratified three new Global Stratotype Sections and Points (GSSPs) approved by the IUGS International Commission on Stratigraphy (ICS). The characterization of the new GSSPs in the *Episodes* report was brief, confusing, and contained an obvious error, which I regret. In order to alleviate any possible confusion, following are revised and expanded descriptions of the three new GSSPs approved by the ICS and ratified by the EC.

Base of the Second Stage of the Lower Ordovician

The Global boundary Stratotype Section and Point for the base of the Second Stage of the Lower Ordovician is defined just above the E bed in the lower Toyen Shale, about 2 m above the top of the Cambrian, in the inactive Diabasbrottet quarry at base of the the north-east slope of the Hunneberg Mountain, Province of Västergötland, southern Sweden. This level coincides with the first appearance of the graptolite *Tetragraptus approximatus* and associated fauna.

Base of the Upper Ordovician Series (and base of the Fifth Stage)

The Global boundary Stratotype Section and Point for the base of the Upper Ordovician Series is defined 1.4 m below a phosphorite marker bed in the E14a outcrop along the south bank of the Sularp Brook at Fågelsång, 8 km east of the center of the City of Lund, Scane, southern Sweden. This level coincides with the first appearance of the graptolite *Nemagraptus gracilis*.

Base of the Cenomanian Stage (Late Cretaceous)

The Global boundary Stratotype Section and Point for the base of the Cenomanian Stage is defined at 36 meters below the top of the Marnes Blues Formation on the south side of Mont Risou, east of Rosans, Haute-Alpes, France. This level coincides with the first appearance of the planktonic foraminiferan *Rotalipora globotruncanoides* Sigal, 1948, and can be placed in the context of a series of secondary marker levels based on nannofossil, planktonic foraminifera, ammonites and an ornate ^{13}C curve.

Full details of these newly approved and ratified GSSPs will be published in a future issue of *Episodes*.

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