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Chronostratigraphic correlations: their importance for the definition of geochronologic units

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Abstract

The present article resumes the philosophy underlying the (re)definition of chronostratigraphic/geochronologic units through their boundaries by working groups of the International Commission on Stratigraphy (ICS), following the ICS Guidelines. With respect to the historical approach, this philosophy implies a change in the way how stages are defined. Stages, originally defined by their contents, are now defined by their lower boundary only: the concept of the Global Stratotype Standard-section and Point (GSSP). As before, stages may be *characterized* by their contents, but precise *definitions* of stages and their scope can only be attained via boundary definitions. The following subjects are dealt with in detail: (1) The choice of the level of a chronostratigraphic/geochronologic boundary which is to be defined by a GSSP; this is determined by practical considerations concerning the correlation of the envisaged stratigraphic level. (2) If traditional names are to be preserved, some kind of compromise is always necessary because none of them is clearly and unequivocally defined. This goal can be attained by a democratic vote. (3) Because of gaps and condensation, even the more favorable historical stratotypes are unsuitable for the redefinition of classical stages by their lower boundaries.

Keywords: International Commission on Stratigraphy (ICS); International Stratigraphic Chart; chronostratigraphy; biostratigraphy; biochronology; stage concept; unit-stratotypes; boundary-stratotypes (GSSP); historical stratotypes; chronostratigraphic markers

1. Introduction

On the occasion of the 31st International Geological Congress at Rio de Janeiro, the second edition of the International Stratigraphic Chart of the International Commission on Stratigraphy (ICS; Remane, compiler, 2000b) was distributed to all participants. This chart, compiled by the author with the helpful collaboration of all Subcommissions of ICS, informs about the geochronologic units in current use on an international scale, highlighting those geochronologic boundaries which are now formally defined by an international agreement (voted by ICS and ratified by the IUGS). The chart is built upon the traditional units of relative ages.

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But why do we still use the traditional scale of relative ages, more than 150 years old, 90 years after the advent of radiometric dating? The answer is simple: in most Phanerozoic sedimentary successions, numerical ages do not allow to correlate with the same precision as the classical scale based on organic evolution. Indeed, already in the middle of the 19th century, Oppel (1856–1858) subdivided the Jurassic Period into 30 zones. This corresponds to an average resolution of 2 m.y., whereas for modern radiometric datings, a margin of 3 m.y. would rather be an optimistic estimate for the Jurassic Period. Modern correlations by fossils are of course much more accurate than at the time of Oppel.

There can thus be no doubt that the old scale of relative ages, mainly based on biostratigraphy and biochronology, offers still the best standard for the subdivision of most of the Phanerozoic systems/periods. This includes also the preservation of the classical hierarchy of stages/ages, series/epochs, systems/periods and so on, with the stage/age as basic unit, as recommended by the International Stratigraphic Guide (Hedberg, 1976; Salvador, 1994; Murphy and Salvador, 1999). But several problems remain, causing difficulties when trying to arrive at modern definitions of units of the traditional hierarchy:

(1) Since its introduction in the first half of the 19th century, there has been a shift from unit-stratotypes to boundary-stratotypes (Global Stratotype Standard-section and Point, abbreviated GSSP) in defining geochronologic units, and, consequently, the new challenge is to find the best way of defining geochronologic boundaries. This is more than a simple technical problem.

(2) As shown by the International Stratigraphic Chart, there is a strong tendency to continue the use of traditional names. This raises the additional problem of how to adapt the scope of classical stages to new definitions.

2. A short look at stratigraphic terminology

Here I would like to draw the reader's attention to some problems of currrent stratigraphic terminology:

(1) The distinction between material *chronostratigraphic* units and immaterial *geochronologic* units as inherited from the late-19th century has always been problematic in a number of cases, especially concerning the strict application of the concept of material chronostratigraphic units bounded by isochronous surfaces (Walsh, 2001). Moreover, with the abandonment of chronostratigraphic unit-stratotypes as motivated below, the stage as a whole loses its material support. But in order to avoid confusion, I continue here to use 'stage' in its currently accepted sense.

(2) Of course, *biostratigraphy* is not the same as *chronostratigraphy*. But if the entire lifetime of a species is in the order of 1 m.y., the possible diachrony of biostratigraphic boundaries is below that of many other methods of long range correlation. The important fact is that *all* chronocorrelations are only approximate. This should constantly be borne in our minds because it is easily forgotten: margins of error in relative ages are not so obvious, because they cannot be calculated in million years or in percents (as in the case of radiometric ages).

(3) Due to the irreversibility of organic evolution, fossil species are unique, biostratigraphic data are thus geochronologically significant. They allow dating rocks with respect to a scheme of reference. This scheme of reference is established by combining biostratigraphic data from different localities, thus proceeding from biostratigraphy to *biochronology*, the *distribution of fossil species in time* (Remane, 1991). The comparison of local biostratigraphic successions with the biochronological standard (e.g. a zonation) allows not only to assign relative ages to rocks, but also to estimate the extent of stratigraphic gaps (Fig. 1).

The distinction between biostratigraphy and biochronology is important in the sense that this is the distinction between the raw data (biostratigraphy) and their regional or interregional geochronological synthesis (biochronology). Dating rocks by fossils is then the interpretation of (biostratigraphic) raw data in the light of this synthesis.

(4) Finally, the reliability and accuracy of all methods of chronocorrelation can be considerably

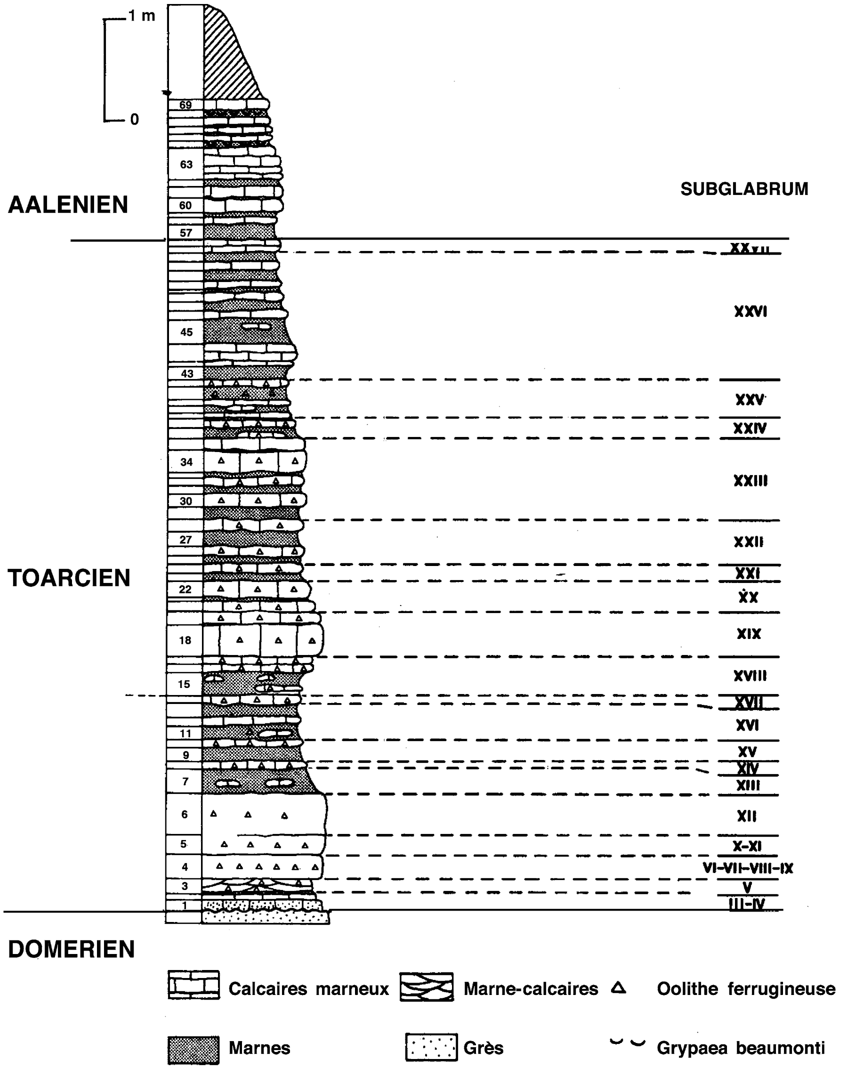

Fig. 1. Succession of strata in the historical stratotype of the Toarcian Stage (Jurassic) at Thouars (France); after Gabilly (1976). Roman numbers to the right indicate ammonite horizons, i.e. regional biochronologic units, subdivisions of subzones.

improved by different methods of quantitative stratigraphy (e.g. Shaw, 1964; Gradstein et al., 1985; Guex, 1987, 1991; Mann et al., 1995).

3. The GSSP concept

3.1. The traditional stage concept

In the spirit of the catastrophist philosophy of the 19th century, stages were defined by their faunal contents, exemplified by unit-stratotypes. Stages were considered as natural units, corresponding to natural epochs of Earth history separated by catastrophic events. Stages had only to be discovered, leaving no choice to the stratigrapher as to their delimitation. The claim that the units of the modern time scale should also be 'natural units' (whatever this may mean in the present context of ideas) still survives. This has created a number of psychological problems in addition to the technical ones, and has often unnecessarily delayed redefinitions of geochronologic units.

In the spirit of the catastrophist philosophy, most stage boundaries were unconsciously placed at stratigraphic gaps or in condensed intervals; apparent faunal turnovers were thus taken for real and explained by catastrophes, instead of suspecting a lack of documentation. This is clearly shown by the historical type-section of the Toarcian (Fig. 1), which is, however, a most favorable example of a historical stratotype, as the succession is rich in ammonites. Thanks to the very detailed regional biochronologic subdivision, which is now available and which allows to further subdivide ammonite subzones into horizons (roman numbers to the right of the lithological column), it can be shown that the two lowermost ammonite horizons of the Toarcian are missing at Thouars (France), whereas others are more or less condensed. Continuous sedimentation starts only with ammonite horizon XII. It appears that according to the current concept of the Toarcian, its lowermost ammonite zone (the Tenuicostatum Zone = horizons I+II) is completely missing. The rest of the early Toarcian and an important part of the middle Toarcian including the Bifrons Zone are imperfectly documented. In other words, if traditional stage names are still to be used, a precise redefinition cannot be accomplished by simply returning to the historical type-locality. The redefinition has to be based on a new stratotype, suitable for a precise boundary definition.

In defining stages by their fossil contents, the importance of faunal differences due to paleoecological or paleobiogeographical factors without chronostratigraphic significance was often underestimated. This has led to overlaps of stages and to chaos in stage nomenclature. According to Arkell (1956, p. 8), nearly 130 stage names have been proposed for the Jurassic System, and, as Arkell says, 'their very numbers proclaim futility'. The current subdivision of the Jurassic System does with 11 stages!

Psychologically, the idea that a stage is best defined by a specific succession of sedimentary strata, seems nevertheless to be very appealing – at least there would be one place in the world where we know what that stage *really is* – and which can serve as a standard for interregional correlations. The notion of the chronostratigraphic unit-stratotype has therefore survived to some degree even in the second edition of the International Stratigraphic Guide (Salvador, 1994; Murphy and Salvador, 1999). However, already the first edition Hedberg (1976, fig. 13) demonstrates the impracticability of unit-stratotypes: *a time scale constituted of strictly contiguous units* – i.e. with neither gaps nor overlaps – can only be realized by means of boundary-stratotypes. The notion of chronostratigraphic unit-stratotypes should therefore have been abandoned altogether already in the first edition of the International Stratigraphic Guide. But this means that there is no longer any stratotype materializing the duration of a stage, no locality were we can confidently say this *is* the Toarcian or any other stage. It should, however, be recalled that a clear distinction has to be made between characterization and definition of a choronostratigraphic unit. The characteristic contents (fauna) will allow to recognize a given unit even if the boundaries are not visible in outcrop, but its scope can only be accurately defined with the help of boundary-stratotypes, i.e. GSSPs.

3.2. Defining geochronologic units by their boundaries

In the work of ICS the emphasis has therefore always been placed on the precise *definition of geochronologic boundaries*. The practical implication is that we do not look any longer for the unit-stratotype providing the standard of the stage under question, but for the succession offering the most detailed and complete documentation of the transition from one stage to the next one. Following this concept, geochronologic units are *defined by their lower boundary* only (Mc Laren, 1977). The upper boundary of the same unit is defined by the lower boundary of the succeeding unit and will mostly be situated in another, more or less distant, locality.

This philosophy was put into practice for the first time with the redefinition of the Silurian/Devonian boundary in 1972 (Mc Laren, 1977). It was then formulated in the Guidelines of ICS

(Cowie et al., 1986), where the concept of the *Global Standard Stratotype-section and Point – the GSSP* was introduced. Eight to nine years later, the Guidelines were extensively rediscussed within ICS. Following a proposal of the Precambrian Subcommission, the boundaries of the Precambrian geochronologic units were defined in terms of absolute ages (they are absolute in the sense that we deal here with theoretical values, independent from any technique of numerical dating), but otherwise the GSSP concept remained unchanged. These Revised Guidelines (Remane et al., 1996) were accepted by ICS in a formal vote with only one opposing ballot.

With the adoption of the GSSP concept, the contents of a stage is no longer an element of its definition. It has therefore been objected that in following this approach stages lose their identity. As stated above, this argumentation confuses characteristics and definition of chronostratigraphic/geochronologic units. The 'identity' of a stage/age corresponds necessarily to a complex combination of various characters. These are very useful for its recognition, but an *exact delimitation* of successive stages in a continuous time scale is only possible on the basis of a precise boundary definition. A discipline working with units of measure which are not rigorously defined cannot claim to be scientific.

It has to be remembered also that the characteristic fauna of a stage is inevitably limited, not only in time but also in space, due to paleoecological and paleobiogeographical constraints, whereas the units of a geochronologic standard scale are global units, delimiting the same time interval worldwide. Even if it has to be admitted that boundaries are not always recognizable worldwide, they can be correlated over greater distances than stages/ages defined (more or less precisely) by their contents.

According to the GSSP concept, lower and upper boundaries of a stage will very often be defined at distant localities. Even if it happens that both boundary-stratotypes lie in the same section, this does not imply that the stratigraphic interval in between offers a good account of the contents of the stage and can be considered as a unit-stratotype (Remane et al., 1996). The situation resulting from the new concept is perfectly illustrated by the GSSPs of the Devonian stage boundaries (Fig. 2): in extreme cases like the Pragian, Emsian, Eifelian, and Givetian, the GSSPs of the lower and the upper boundary of the same stage are situated on different continents! In other words, the notion of a chronostratigraphic unit-stratotype has become completely obsolete.

Devonian GSSPs

	======================		*La Serre, Mgne. Noire,* ***France***
	FAMENNIAN		
Late	-------------------------		*Coumiac, Mgne. Noire,* ***France***
	FRASNIAN		
	-------------------------------------		*Puech de la Suque, Mgne. Noire,* ***France***
	GIVETIAN	!	
Middle	-------------------------		*Jebel Mech Irdane,* ***Morocco***
	EIFELIAN	!	
	-------------------------------------		*Wetteldorf, Eifel,* ***Germany***
	EMSIAN	!	
	-------------------------		*Zinzilban Gorge,* ***Uzbekistan***
Early	PRAGIAN	!	
	------------------------		*Prague,* ***Czech Republic***
	LOCHKOVIAN		
	======================		*Klonk,* ***Czech Republic***

Fig. 2. Overview of the subdivision of the Devonian System/Period into stages/ages, indicating the geographic locations of the respective GSSPs. Note that the lateral distance between GSSPs for successive stage boundaries is at least in the order of tens of kilometers but may attain several thousands of kilometers!

4. The choice of an appropriate boundary level

4.1. How to make the good choice

In trying to find out which would be the best boundary level to define the base of a stage, we are again confronted with an old problem: the claim that the boundary should be the most 'natural' one which is possible. I think this attitude has been perfectly characterized by Ager (1993,

p. 106): 'Yet many paleontologists and stratigraphers still talk of defining boundaries at 'faunal breaks' as though there was a new creation at every stratigraphical boundary and the fossils above the boundary had no ancestors. This is all part of the attitude in stratigraphy that I may call 'the quest for the *golden horizon*'... which says in effect that if one looks (and argues) long enough and hammers hard enough, then eventually one glorious day one will come upon the *golden horizon* that *really is the Silurian/Devonian boundary... the magic moment that was the beginning of the Devonian... ordained by God or Marx* long before Man started his investigations.' (my emphasis).

According to the practice of ICS, the choice of the boundary level is to the contrary entirely guided by practical considerations (unless the introduction of historical aspects creates additional constraints). But this is only the case, if historical chronostratigraphic names are to be preserved.

According to the GSSP concept, a geochronologic boundary is *defined by a point in the rock*, the so-called 'golden spike'. But the boundary will only be recognizable outside the type-section, if the definition is tied to some kind of event in Earth history which is documented in the sediments, in the type-section and elsewhere. Only this will allow to correlate the boundary over an appreciable distance. Therefore, the choice of an appropriate boundary level is of paramount importance. In other words, before formally defining a geochronologic boundary by a GSSP, its practical value – i.e. its correlation potential – has to be thoroughly tested. In this sense, *correlation precedes definition* (Remane et al., 1996; Remane, 2000a).

4.2. 'Primary' and 'secondary' markers

If we look at the procedures followed by different working groups of ICS, it appears that various tactics have been followed. In most cases the boundary definition was, however, tied to one specific event, informally called the 'primary marker'. Several kinds of primary markers have been used: fossil species in the great majority of cases, but also geochemical signals (as the famous Ir spike at the Cretaceous/Paleogene boundary), or magnetic reversals (at the Paleogene/Neogene boundary, Steininger et al., 1997).

The problem is that the ideal marker, specific *and* isochronous at a global scale, does not exist. *Magnetic reversals* are global and practically isochronous, but they are *repetitive*. This is also the drawback of *geochemical signals*, although, unlike fossils, they are less dependent on regional limitations. As a matter of fact, *fossils alone provide distinctive time marks* but their geographical distribution is limited by paleoecological and paleobiogeographical constraints. Nevertheless, under favorable circumstances, fossils may allow very far-reaching correlations as shown by the Early/Mid-Devonian boundary, where the characteristic conodont subspecies has been found in Europe, Siberia, South China, Australia, USA (Nevada), and Morocco (Ziegler and Klapper, 1985). Nevertheless the problem subsists that the *local first occurrence* of a species will often not correspond to its phylogenetic first appearance. This error margin can be minimized by using species where the gradual transition from the ancestral to the descendant species is well documented. This principle was followed in the definition of GSSPs for most of the Devonian stage boundaries, which were based on conodont morphoclines. The reliability of the biostratigraphic signal is thus greatly enhanced, but the exact separation of two successive species within a morphocline remains to a certain degree subjective. Thanks to the golden spike, the chronostratigraphic boundary can, however, be placed exactly within a continuous morphocline, independent from the taxonomic problem where to place the limit between two successive species or subspecies.

The correlation potential of a boundary level is also greatly enhanced if other, nearby stratigraphic events are available. These 'secondary markers' may allow to approximate the boundary where the primary marker is absent, and they will also allow to test the reliability of local occurrences of the primary marker with respect to the phylogenetic event which had guided the boundary definition.

Taking it all together, we may say that 'correlation precedes definition' means that the critical interval around the anticipated boundary has to be studied in great detail in distant regions. The comparison of particularly favorable sections in different continents will allow to clarify the temporal succession of a number of nearby stratigraphic (mostly biostratigraphic) events. The most suitable section will then be chosen as the type-section housing the GSSP. The GSSP might even be placed arbitrarily within such a bundle of events – since it is the point in the rock which defines the boundary! But thus far this has happened only with the base of the Maastrichtian (Odin, 2000). In all other cases, the most suitable among the available stratigraphic events served as guidance for the boundary definition. However, once a geochronologic boundary is formally defined by a GSSP, the sole function of the primary marker in correlations away from the type-section is that of a proxy for the position of the boundary.

4.3. Preliminary conclusion

I think the above-mentioned examples demonstrate clearly that if the boundary levels are carefully selected according to their correlation potential, there are no serious problems in establishing an optimal geochronologic scale of relative ages. Nothing is perfect of course, but optimal means that the geochronologic scale will represent the best possible solution within the limits of the currently available methods.

Additional problems do, however, appear if we want to preserve, together with the traditional hierarchy of units, also traditional names. The choice of the boundary level is then no longer subject to technical constraints alone, historical arguments have also to be taken into account.

5. Problems of nomenclature and priority

5.1. The unsuitable historical stratotypes

To begin with, I want to return to the historical stratotype of the Toarcian (Fig. 1). This is certainly one of the most favorable examples of a historical unit-stratotype as it is rich in ammonites and can be dated throughout. But the lower boundary, and hence the scope of the stage, cannot be unambiguously defined in this succession.

With many other traditional stages, which are in current use, the situation is even more difficult, as stage names have often been used with different meanings by different workers and in different regions, due to uncertain or erroneous interregional correlations or to the use of different fossil groups in 'defining' the boundary. It is not surprising that different fossil groups will lead to different 'natural' boundaries for the same unit (which has often led to endless discussions about what would be the 'most natural' boundary). This situation is illustrated by the Carboniferous/Permian boundary, which was placed at different levels by ammonite, fusulinid and conodont workers until the problem was solved through the agreement on a GSSP (Davydov et al., 1998), where a conodont species was used as 'primary' marker because it offered the best possibilities for interregional correlations (Fig. 3).

We may thus retain that it is *impossible to use historical stage names in their 'original meaning'* because such an original meaning does not exist. Moreover, in the *absence of any formal priority regulation* for chronostratigraphic nomenclature, there is no automatic solution at hand either. Under these circumstances, only two ways are open:

(1) the traditional nomenclature is abandoned altogether, *new names are introduced with the new definitions* through GSSPs; or

(2) the *scope of classical stages is modified*, i.e. adapted to the best possible boundary definition; this would have the advantage of stabilizing a traditional nomenclature which is still in general use.

The first way has thus far only be followed once, with the introduction of the *Gelasian* for the late Pliocene (Rio et al., 1998). The second way was thus more or less strictly followed in all other cases – sometimes by taking stages from different regional schemes – with all the resulting psychological problems which made that many boundary decisions have taken more time than necessary.

5.2. The Ordovician case history

The group which has found the most elegant

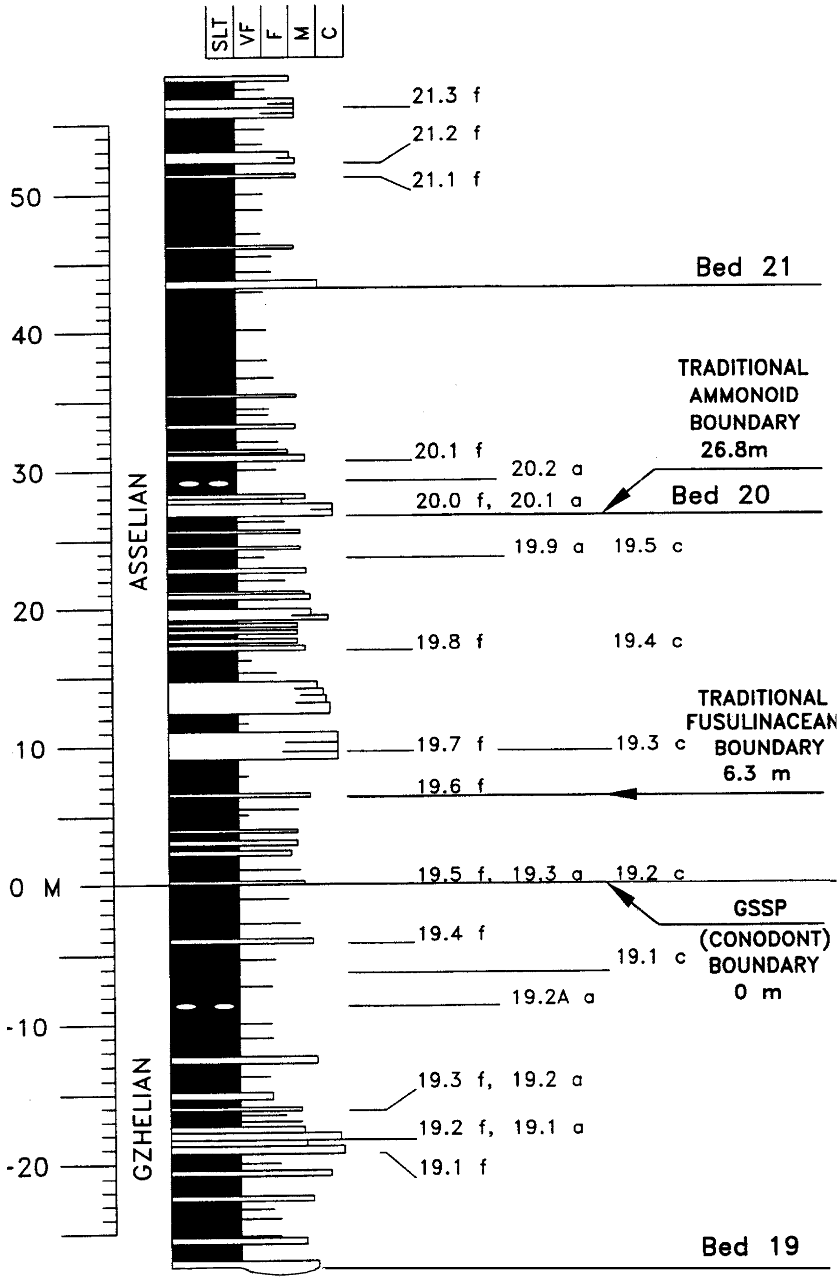

Fig. 3. Biostratigraphy of the type-section housing the GSSP for the base of the Permian, showing the different boundary levels used by workers on different fossil groups. With the formal acceptation of the GSSP the boundary is definitely fixed at the level of the conodont boundary in the type-section; after Davydov et al. (1998).

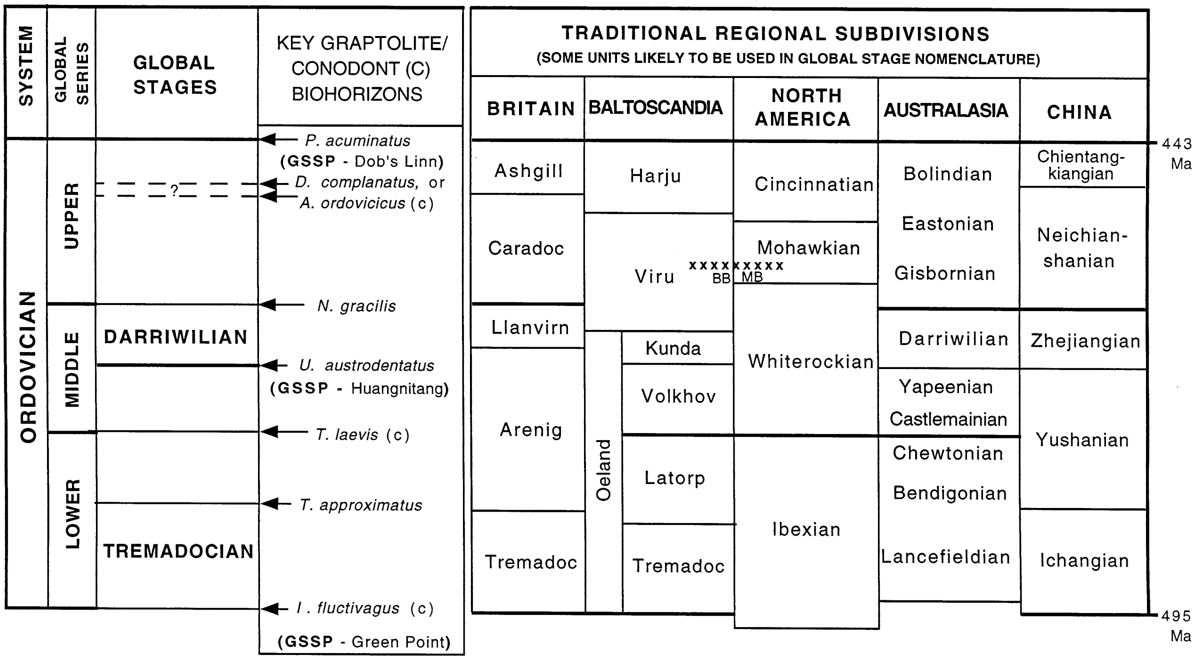

Fig. 4. Ordovician chronostratigraphy after a document kindly provided by B. Webby for the explanatory note of the second edition of the International Stratigraphic Chart, updated to include the GSSP for the base of the Ordovician.

way out of this dilemma in using the second approach, is the ICS Subcommission on Ordovician Stratigraphy. Due to the Ordovician glaciation paleobiogeographic provincialism is particularly pronounced during this period, where only the classical biostratigraphic methods are available for precise interregional correlations. Following the principle 'correlation precedes definition', the Ordovician Subcommission started with working out an agreement about the best biostratigraphic markers for interregional correlation (Fig. 4). Two of these levels are now codified by a GSSP:

(1) The base of the upper of the two Middle Ordovician stages with a GSSP in China; the name Darriwilian was, however, derived from an Australian regional stage, the upper boundary of which fits best with the level envisaged for the Middle/Late Ordovician boundary (Mitchell et al., 1997).

(2) The base of the Ordovician with a GSSP in Newfoundland. It is interesting to note that in this case the vote of the Subcommission was conducted in two steps. The agreement on the GSSP for the base of the Ordovician was voted leaving open the problem of the name of the corresponding stage/age. The classical name Tremadocian was only reintroduced later in an independent vote.

The Ordovician case thus perfectly illustrates that the use of traditional stage names and of *stage nomenclature in general is a matter of pure convention* which can easily be decided by a majority vote.

6. Conclusion

I hope that this brief review has shown in a convincing manner that the establishment of a geochronologic scale with unambiguously defined and reproducible boundaries and units as practised by ICS is only a matter of practical considerations and of common sense. Due to psychological barriers, progress was unfortunately not as rapid as desired: up to the present only about one third of all Phanerozoic stage boundaries have their GSSP. On the other hand, progress has accelerated during the past few years so that

ICS was able to realize a second edition of the International Stratigraphic Chart, thanks also to a very efficient collaboration with the Commission on the Geological Map of the World.

Acknowledgements

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Appendix

List of ratified GSSPs, indicating the reference of the official publication of the decision in Episodes (as appearing on the website of ICS)

Quaternary

1 base of the *Quaternary* System and of the *Pleistocene* Series at Vrica, Italy (*Episodes*, vol. 8/2 (1985): 116–120). *The position of this boundary was contested in the 1990s, but the original GSSP at Vrica was eventually reconfirmed in a formal vote in 1998, and this decision was ratified by IUGS in January 1999.

Neogene

2 base of the *Gelasian* Stage at Gela, Italy (*Episodes*, vol. 21/2 (1998): 82–87). *The new stage name Gelasian was introduced together with the definition of its lower boundary.

3 base of the *Piacenzian* Stage at Punta Piccola, Italy (*Episodes*, vol. 21/2 (1998): 88–93).

4 base of the *Pliocene* Series and of the *Zanclean* Stage at Eraclea Minoa, Italy (*Episodes*, vol. 23/3 (2000): 179–187).

5 base of the *Messinian* Stage at Oued Akrech (Morocco) (*Episodes*, vol. 23/3 (2000): 172–178).

6 base of the *Neogene* System and of the *Aquitanian* Stage, Lemme–Carrosio section, Italy (*Episodes*, vol. 20/1 (1997): 23–28).

Paleogene

7 base of the *Oligocene* Series and of the *Rupelian* Stage at Massignano, Italy (*Episodes*, vol. 16/3 (1993): 379–382).

8 base of the *Paleogene* System, of the *Paleocene* Series, and of the *Danian* Stage at El Kef, Tunisia (ratified in January 1991).

Cretaceous

9 base of the *Maastrichtian*Stage at Tercis-les-Bains, France (ratified in 2001).

10 base of the *Cenomanian* Stage.

Jurassic

11 base of the *Bajocian* Stage at Cabo Mondego, Portugal (*Episodes*, vol. 20/1 (1997): 16–22). *Together with the Cabo Mondego GSSP, an Auxiliary Stratotype section and Point (ASP) at Bearreraig, Scotland, UK, was adopted by ICS.

12 base of the *Middle Jurassic* Series and of the *Aalenian* Stage at Fuentalsaz, Spain (ratified in January 2000).

13 base of the *Sinemurian* Stage at East Quantoxhead, England, UK (ratified in 2000).

Triassic

14 base of the *Mesozoic* Erathem, of the *Triassic* System and of the *Induan* Stage at Meishan, China (ratified in 2001).

Permian

15 base of the *Capitanian* Stage, at Stratotype Canyon, Guadalupe Mts., TX, USA (ratified in 2001).

16 base of the *Wordian* Stage at Stratotype Canyon, Guadalupe Mts., TX, USA (ratified in 2001).

17 base of the *Guadalupian* Series and of the *Rodian* Stage, at Stratotype Canyon, Guadalupe Mts., Texas USA (ratified in 2001).

18 base of the *Permian* System, of the *Cisuralian* Series and of the *Asselian* Stage, in the Aidaralash Creek, Kazakhstan (*Episodes*, vol. 21/1 (1998): 11–18).

Carboniferous

19 base of the *Pennsylvanian* Subsystem, 'Mid-Carboniferous boundary' at Arrow Canyon, NV, USA (*Episodes*, vol. 22/4 (1999): 272–283).

20 base of the *Carboniferous* System, of the *Mississippian* Subsystem, and of the *Tournaisian* Stage, at La Serre, Montagne Noire, France (*Episodes*, vol. 14/4 (1991): 331–336).

Devonian

21 base of the *Famennian* Stage at Coumiac, Montagne Noire, France (*Episodes*, vol. 16/4 (1993): 433–441).

22 base of the *Upper Devonian* Series and of the *Frasnian* Stage at Col du Puech de la Suque, Montagne Noire, France (*Episodes*, vol. 10/2 (1991): 97–101).

23	base of the *Givetian* Stage at Jebel Mech Irdane, Morocco (*Episodes*, vol. 18/3 (1995): 107–115).
24	base of the *Middle Devonian* Series and of the *Eifelian* Stage at Wetteldorf, Germany (*Episodes*, vol. 8/2 (1985)).
25	base of the *Emsian* Stage in the Zinzilban Gorge, Uzbekistan (*Episodes*, vol. 20/4 (1997): 235–240).
26	base of the *Pragian* Stage, at Velka Chuchle, Prague, Czech Republic (*Episodes*, vol. 12/2 (1989): 109–113). *The stage name Pragian was formally introduced with the definition of its lower boundary, thus replacing the traditional Siegenian Stage.
27	base of the *Devonian* System and the *Lochkovian* Stage at Klonk, Czech Republic (A. Martinsson, ed. (1977): The Silurian–Devonian boundary, IUGS Ser. A, No. 5). *The stage name Lochkovian was formally introduced with the definition of its lower boundary, thus replacing the traditional Gedinnian Stage.
Silurian	
28	base of the *Pridolian* Series in the Pozary section, Czech Republic (*Episodes*, vol. 8/2 (1985): 101–103). *In 1996 the Silurian Subcommission of ICS abandoned the project to divide the Pridolian Series into stages.
29	base of the *Ludfordian* Stage in the Sunnyhill Quarry, Wales, UK (*Episodes*, vol. 8/2 (1985): 101–103).
30	base of the *Ludlowian* Series and of the *Gorstian* Stage at Pitch Coppice, Wales, UK (*Episodes*, vol. 8/2 (1985): 101–103).
31	base of the *Homerian* Stage at Whitwell Coppice, Wales, UK (*Episodes*, vol. 8/2 (1985): 101–103).
32	base of the *Wenlockian* Series and of the *Sheinwoodian* Stage at Hughley Brook, Wales, UK (*Episodes*, vol. 8/2 (1985): 101–103).
33	base of the *Telychian* Stage in the Cefn Cerig section, Wales, UK (*Episodes*, vol. 8/2 (1985): 101–103).
34	base of the *Aeronian* Stage at the Cefn Coed–Aeron Farm, Wales, UK (*Episodes*, vol. 8/2 (1985): 101–103).
35	base of the *Silurian* System, of the *Llandoverian* Series and of the *Rhuddanian* Stage at Dob's Linn, Scotland, UK (*Episodes*, vol. 8/2 (1985): 101–103).
Ordovician	
36	base of the *Darriwilian* Stage at Huangnitang, People's Republic of China (*Episodes*, vol. 20/3 (1997): 158–166). *First unit of a revised subdivision of the Ordovician System which has been formally defined.
37	base of the *Ordovician* System and of the *Tremadocian* Stage at Green Point, Newfoundland, Canada (ratified in January 2000).
Cambrian	
38	base of the Cambrian System at Fortune Head, Newfoundland, Canada (*Episodes*, vol. 17/1 and 2 (1994): 3–8).

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