Stage boundaries, global stratigraphy, and the time scale: towards a simplification

Gilles Serge Odin, Silvia Gardin, Francis Robaszynski, Jacques Thierry

Stage boundaries, global stratigraphy, and the time scale: towards a simplification

Gilles Serge ODIN[1]

Silvia GARDIN[2]

Francis ROBASZYNSKI[3]

Jacques THIERRY[4]

Abstract: This paper examines four facets of stratigraphic terminology and usage considered faulty and proposes corrective measures. The four perfectible areas are:
(1) The system of dual nomenclature requiring discrete terminologies for the superpositional and temporal aspects of rock units.
(2) The premise that a GSSP establishes the base of a stage as being coincident with the top of the preceding stage rather than simply defining it as the boundary between stages.
(3) The rejection of supplementary (auxiliary) sections that would broaden the knowledge of a GSSP and enlarge the area in which it is easily usable.
(4) The current dual system of nomenclature for Precambrian and Phanerozoic strata is accepted, but a third system is proposed for strata formed in the last 3 to 5 Ma.
In addition, the paper advocates a broader use of a limited number of conventions but warns against their proliferation; units shortened thereby would be more difficult to recognize. It points out the clear distinction between these conventions - a matter of administration and general compliance - and knowledge - a domain where free expression of opinion is indispensable -.

Key Words: Terminology; Chronostratigraphy; Stages; GSSP; Precambrian; Phanerozoic; Plio-Quaternary; Precambrian-Cambrian boundary; Campanian-Maastrichtian boundary; Cretaceous-Palaeogene boundary

Citation: ODIN G.S., GARDIN S., ROBASZYNSKI F., THIERRY J. (2004).- Stage boundaries, global stratigraphy, and the time scale: towards a simplification.- Carnets de Géologie / Notebooks on Geology, Brest, Article 2004/02 (**CG2004_A02**)

Résumé : ***Définition des unités chronostratigraphiques mondiales et échelle des temps : pour des conventions simples et limitées favorisant la mise en oeuvre des connaissances disponibles.-*** Ce travail discute quatre aspects de la terminologie stratigraphique considérés comme inappropriés et propose des améliorations concernant :
(1) le système de double terminologie avec des termes propres pour chacun des aspects temporel et géométrique des corps de roche ;
(2) l'assertion selon laquelle le Point Stratotypique Mondial (PSM) définit la base d'un étage qui coïncide avec le sommet de l'étage précédent au lieu de tout simplement : la limite d'étage ;
(3) la répugnance devant la désignation de sections additionnelles (auxiliaires) qui accroîtraient la connaissance d'un PSM et pourraient ainsi élargir le domaine de corrélation immédiate ;
(4) le système actuel de subdivision différent pour le Précambrien (limites définies par des âges) et pour le Phanérozoïque (limites définies par des PSM) est accepté mais un troisième système (des limites propres à chaque outil de corrélation) est proposé pour les dépôts âgés de 3 à 5 Ma.
Par ailleurs, si le travail encourage l'utilisation universelle d'un nombre restreint de conventions, il met en garde contre une prolifération de celles-ci pour des unités qui, en devenant plus courtes, deviennent plus malaisées à reconnaître. On souligne enfin que la distinction doit rester très claire entre ces conventions qui sont une affaire d'administration et de consensus et la connaissance, un domaine où la libre expression des opinions est indispensable.

Mots-Clefs : Terminologie ; chronostratigraphie ; étages ; Précambrien ; Phanérozoïque ; Plio-Quaternaire ; limite Précambrien-Cambrien ; limite Campanien-Maastrichtien ; limite Crétacé-Paléogène

Version française abrégée

Ce travail est dédié à la mémoire de Jürgen REMANE qui dirigea la Commission de Stratigraphie avec amabilité, diplomatie et intégrité scientifique.

Cette contribution de stratigraphes franco-phones tend à l'amélioration de la terminologie des unités de l'histoire de la Terre rendue possible grâce, notamment, au concept de Point Stratotypique Mondial. Une application de ce concept adaptée aux connaissances disponibles pour reconstituer l'histoire terrestre à partir des

[1] *Université Pierre & Marie Curie, Unité de Géochronologie et Sédimentologie Océanique, Case 119, 4 Place Jussieu, F-75252, Paris Cedex 05, France.*
gilodin@ccr.jussieu.fr
[2] *Université Pierre & Marie Curie, UMR 5143 CNRS/Muséum Paléobiodiversité et Paléoenvironnement, Case 117, 4 Place Jussieu, F-75252, Paris Cedex 05, France.*
gardin@ccr.jussieu.fr
[3] *Faculté Polytechnique, Mines-Géologie, 9 Rue de Houdain; B-7000 Mons, Belgium.*
francis.robaszynski@fpms.ac.be
[4] *Université de Bourgogne, Centre des Sciences de la Terre & UMR-CNRS "Biogéosciences-Dijon", 6 Bd Gabriel, F-21000, Dijon, France.*
jthierry@u-bourgogne.fr

informations enregistrées dans les roches facilitera une simplification qui doit conduire à restreindre à l'essentiel les contraintes de ces conventions.

La terminologie à la mode (dans quelques pays anglophones surtout) recommandait une double hiérarchie des unités stratigraphiques : des unités fondées sur des ensembles de roches (Érathem, Système, Série, Étage) et des unités exprimant le temps (Ère, Période, Époque, Âge) avec des sous-unités formelles inférieur/ moyen/supérieur (Fig. 1). De plus, dans la terminologie francophone, il n'y a pas l'équivalent de l'anglais "Early/Late"; les mots correspondants "précoce" et "tardif", ne sont pas des termes formels pour la plupart des stratigraphes francophones.

En 2004, l'expérience a montré que l'instauration de la dualité adoptée par nos collègues américains surtout, ne facilitait pas la communication, ni avec les géologues non-stratigraphes, ni dans le cadre de l'enseignement et qu'elle n'était pas utilisée avec succès par la majorité des stratigraphes.

Une récente proposition de la Commission de Stratigraphie de la Société Géologique de Londres est favorable à une simplification de cette terminologie, en particulier parce que cette simplification est en accord avec la définition des unités stratigraphiques à l'aide de Sections et Points stratotypiques Mondiaux (GSSP en anglais, nous proposons ici PSM en français).

Nos collègues britanniques plaident pour une hiérarchie Ère, Période, Époque, Âge (ou Étage) et pour les subdivisions "précoce/tardif" (Fig. 2). L'usage francophone favorise les termes Ère, Système, Étage (Fig. 3) avec les subdivisions inférieur/supérieur, voire avec des sous-unités là où le besoin s'en fait sentir (sous-systèmes dans le Cénozoïque). Les équivalents de ces termes sont l'usage dans de nombreuses langues incluant l'allemand, l'espagnol, le grec, l'italien, *etc.* … dès les débuts du développement de la stratigraphie. La raison majeure pour favoriser cette hiérarchie n'est pas seulement due à un usage traditionnel dans telle ou telle langue ; un tel usage 1- n'a jamais généré de problème majeur de compréhension (en fait beaucoup moins qu'une double terminologie) ; 2- recommande l'emploi de termes dont le sens ne peut pas être confondu avec d'autres termes du langage courant ; 3- respecte l'expression naturelle du temps géologique, à savoir que l'histoire de la terre se décrit de bas en haut dans la succession des corps de roches ; ainsi, un temps plus ancien est aisément conçu comme inférieur (Fig. 4).

Nous admettons que la continuité requise dans les successions de corps de roches pour définir un PSM (à la précision de notre connaissance actuelle, Fig. 5), permet au dit PSM de définir une limite (par exemple la limite Campanien-Maastrichtien) ; ce terme simple de limite doit remplacer avantageusement l'expression consacrée par un ancien usage à savoir, "la base d'une unité qui devient automatiquement le sommet de l'unité inférieur" généralement simplifié en base de l'unité (par exemple la base du Maastrichtien).

Les stratigraphes francophones rappellent que la définition d'un Étage nécessite celle de ses deux limites et le choix d'un nom pour le désigner (Fig. 6). Ce nom est généralement dérivé d'un Étage historique défini par son contenu. Il est recommandé de conserver toute leur signification à ces définitions historiques en maintenant l'ensemble des dépôts anciennement désignés dans le stratotype historique à l'intérieur d'un même Étage. Pourtant un léger aménagement reste acceptable si la nouvelle position de la limite est utile à une corrélation plus pratique et plus large. En outre, il n'est pas inutile que la définition d'un PSM (Fig. 7) soit accompagnée de l'étude de sections auxiliaires prises dans des environnements de dépôts différents (Fig. 8-10).

Tout en reconnaissant l'intérêt et, aussi souvent que possible, la nécessité impérative de ne pas limiter la caractérisation d'un PSM à celle d'un groupe fossile comme la pratique n'en est pas rare, on note encore que la biostratigraphie est l'outil cardinal de corrélation entre 540 et 5 Ma. En règle générale, la définition des limites (par les PSM) ne saurait se faire efficacement sans contrôle biostratigraphique car historiquement et pratiquement, les Étages sont d'abord une expression de l'évolution biologique telle qu'elle fut perçue par les pionniers de la stratigraphie.

Le concept de PSM n'est pas nécessaire pour la définition de l'ensemble des unités du calendrier géologique. Pour le Précambrien (Protérozoïque et Archéen), des âges numériques conventionnels remplacent les PSM, en accord avec les recommandations de la Commission Internationale de Stratigraphie et par le simple fait que la géochronologie devient l'outil univoque cardinal pour tout ce qui précède l'apparition des animaux à squelette. La rareté des informations biostratigraphiques précambriennes mais aussi, à notre connaissance, l'imprécision de leur localisation dans le temps ne paraissent pas compatible avec une définition de limite efficace au moyen du concept de PSM. Quant à l'adoption récente d'une unité édiacarienne dont la base est définie par un PSM dont la biostratigraphie est illustrée mais dont l'âge numérique est mal établi par rapport à la convention admise pour l'ancien Protérozoïque III, l'avenir jugera si cette nouvelle convention est utile dans la pratique.

Pour les 3 à 5 derniers Ma, des Étages conventionnels ne paraissent pas nécessaires non plus que l'usage de PSM ; les unités obtenues auraient une autre signification que les Étages du Phanérozoïque quant à leur durée. Selon nous, chaque outil stratigraphique permet de subdiviser l'histoire récente de la terre en unités distinctes et chaque spécialité, chaque succession stratigraphique sera mieux décrite au moyen de l'échelle qui lui est la mieux adaptée (Fig. 11). Un langage commun sera mis en place par le fait que toutes ces catégories d'unité (géochimiques, biostratigraphiques, lithologiques, climatiques, magnétostratigraphiques, industrie humaine, *etc.* ...) peuvent être *in fine* corrélées entre elles par des âges numériques mesurés ou estimés. Nous admettons, parmi ces unités mais non exclusivement, les subdivisions traditionnelles largement utilisés et, donc, utiles de Pliocène ou de Quaternaire.

En conséquence, il ne nous paraît pas nécessaire d'appliquer la lourde démarche de création des "Points Stratotypiques Mondiaux" ailleurs que dans l'intervalle 540-5 Ma ce qui simplifie les conventions nécessaires pour établir l'échelle des temps.

Il est rappelé enfin que les notions conventionnelles discutées ici ne doivent pas être confondues avec les informations relevant de la connaissance que constituent, par exemple, la définition et l'usage des biozones ou les âges numériques des limites entre unités phanérozoïques. Ces derniers ne sauraient être "recommandés" de manière administrative et singulièrement par une structure internationale sans tendre à l'établissement d'une pensée unique contraire aux usages scientifiques jusqu'à ce jour.

Terminology of French-speaking geologists

The state of the art

Under the aegis of the Comité Français de Stratigraphie, SIGAL & TINTANT (1962) were the first to codify the traditional French terminology. Later, LAFFITE *et alii* (1972) attempted to obtain international agreement. A recent and complete review of French terminology is given in REY (1997).

G.S. and C. ODIN (1990) presented a review (in French) of the so-called international terminology of stratigraphic units. This paper explained the dual terminology recommended by HEDBERG (1976, 1979) and accepted later by SALVADOR (1994). Its provisions are: for rock-units (all rock-bodies formed during a given time-interval), the hierarchy is Erathem, System, Series, Stage; for the corresponding time (the interval of time during which these rock-bodies formed), the hierarchy is Era, Period, Epoch, Age (Fig. 1). Two designations: "Chronostratigraphy" and "Geochronology" (altered sense: SALVADOR, 1994) are assigned the corresponding disciplines. In consequence, a dual terminology is recommended for subdivision into Lower/Middle/Upper for chronostratigraphic and into Early/Middle/Late for "geochronological" (altered sense) subunits respectively. This dual approach, favoured by HEDBERG (1976) differs from the French one (*e.g.* SIGAL & TINTANT, 1962). What is the present situation?

Application

The coexistence of the two concepts is obvious. The use of discrete terminologies for these two elements of stratigraphy is quite another problem. SALVADOR notes (1994, glossary) "Chronostratigraphic units are bodies of rocks, layered or unlayered, that formed during a specific interval of time. The units of geologic time during which chronostratigraphic units were formed are called geochronologic units". In French literature, these disciplines have not been and are not separated.

Units	Rock Units	Time Units	Examples
Discipline	CHRONOSTRATIGRAPHY	GEOCHRONOLOGY	
Main Hierarchy	Erathem	Era	Mesozoic
	System	Period	Jurassic
	Series	Epoch	Liassic
	Stage	Age	Hettangian
sub Hierarchy	Lower - Middle - Upper	Early - Middle - Late	

Figure 1: The dual terminology. Note that 2 disciplines with discrete vocabularies are involved for a single subject: the history of the Earth as read in the strata; there is a single name for both kinds of units (right hand column); in one sub hierarchy, the same adjective is used for both units showing that a distinction is not absolutely necessary.

For the subdivision of the history of the Earth, French practice is essentially to use three terms: Era, System, and Stage, together with two sub-units, Subsystem (for the Cenozoic) and Substage (sometimes used regionally). The fundamental unit of this hierarchy is the Stage. The present proposal restricts the terminology to a minimum. These three terms are very specific and well defined. There is no possibility of confusion with more "vernacular" terms such as series, period, epoch which are commonly used more informally.

In the Glossary of Geology (Second Edition, 1980) "Series" is defined: "*A chronostratigraphic unit generally classed next in rank below system and above stage, properly based on a clearly designated stratigraphic interval in a type area (although many series have been adopted quite generally without explicit indication of their limits); the rocks formed during an epoch of geologic time*". The remark in parentheses supports our contention. The same holds for period. After the formal definition is a remark: "*A term used informally to designate a length of geologic time*". A similar remark exists after the formal description of epoch.

Experience has shown that the introduction of the dual terminology chronostratigraphy versus "geochronology" (altered sense) and of the associated terms System-Period, Series-Epoch, Stage-Age, is but poorly understood by and of little help to non-stratigraphers and students. Even among stratigraphers it has not been widely accepted.

As discussed by REY *et alii* (1997) there are several reasons for this: too many formal terms, the subtlety of the difference between them, the difficulty of a hierarchy using terms of the general vocabulary with a formal meaning, and very probably too the absence of a necessity for a dual terminology.

The use of the term "Geochronology" (altered sense)

The use of "geochronology" (altered sense), has been questioned by the community of geochronologists (ODIN, 1995a). Geochronology has a well recognised historical usage. It denotes the science of numerical dating derived from direct measurements. Holmes published several papers with this term in the title (see "Géochronologie africaine ..." or "African geochronology" by HOLMES and CAHEN, 1955, 1957); geochronology is used with this meaning by HARLAND (1964). All geochronologists still use geochronology as the name of their discipline.

Traditionally, a Subcommission on Geochronology, and not on "geochronometry" has been part of the International Commission on Stratigraphy (ICS) though this situation apparently no longer obtains (Subcommission dissolved in 2003). The term geochronometry, suggested in the guide of 1994, reduces the work of geochronologists to an analytical technique. Geochronologists reject this erroneous definition of their discipline.

About the proposal by ZALASIEWICZ *et alii* (2004)

Is a dual terminology necessary?

The stratigraphic Committee of the Geological Society of London (ZALASIEWICZ *et alii*, 2004) proposes to eliminate a dual stratigraphic terminology because the concept of a Global Stratotype Section and Point (GSSP) allows the succession of time to be defined in its entirety using a succession of stages (Fig. 2). This proposal would simplify and insure uniformity in the use of stratigraphic terminology in the several languages, thus making chronostratigraphic standardisation a certainty, with emphasis on the significance of stages (GRADSTEIN *et alii*, 2003). The choice of the term "chronostratigraphy" to designate the unified discipline would be consistent with the recommendations of the Comité Français de Stratigraphie (REY *et alii*, 1997). Their proposal that the term geochronology be restricted to its original and proper use is also relevant.

Units / Discipline	Rock and Time Units / CHRONOSTRATIGRAPHY	Examples
Main Hierarchy	Era	Mesozoic
	Period	Cretaceous
	Epoch	Upper Cretaceous
	Age	Campanian
sub Hierarchy	Lower - Middle - Upper	Upper Campanian

Figure 2: The simplified terminology proposed by ZALASIEWICZ *et alii* (2004).

Adoption of this proposal would result in a single "time-significant" hierarchy of English/American terms for the units of geological time. This is the practice in several other languages (see below). For example, the choice of Eon and Era for the largest units would be consistent with current French usage. Period and Epoch now employed to designate subunits is a source of confusion because both words have a common meaning too and are often used with reference to an informal interval of geological time. Finally, ZALASIEWICZ *et alii* (2004) indicate that the term Stage is preferred for the fundamental and smallest global chronostratigraphic unit of the Phanerozoic. If the term Stage (referring to a body of rocks), instead of Age (referring to an interval of time) were to be accepted as a time unit, there is no reason to reject the term System (instead of Period) which appears more specific to geology and for which the meaning is well established (Fig. 3).

Units / Discipline	Rock and Time Units / CHRONOSTRATIGRAPHY	Examples
Main Hierarchy	Era (**Ère**)	Mesozoic Cenozoic
	System (**Système**)	Jurassic Neogene
	Stage (**Étage**)	Hettangian Messinian
Main Hierarchy	Subsystem	Lower Jurassic (or Liassic) Miocene
	Super- or Sub- stage (regional)	Senonian; Gargasian
	Lower - Middle - Upper (**Inférieur, Moyen, Supérieur**)	Upper Campanian

Figure 3: Terminology used in French publications. Note that the terms used are particular to geology and cannot be confused with vernacular terms; this favors an appropriate use and easy comprehension. Ère, Système, and Étage are in common use in France, Étage much more commonly than Ère and Système.

Lower-Early/Upper-Late

The use of the dual terminology Lower-Early/Upper-Late is difficult for the many geologists who are not native English speakers and in particular for the many communities of geologists that have always used a single terminology corresponding to a geometrical stratal relationship (Lower/Upper in English).

In the American dual terminology, Middle is commonly used for rock and time units; this double usage of the same term demonstrates that a dual terminology is not necessary for understanding the two concepts. We acknowledge that the term Medial is used sometimes for the time relationship, however. In French, only the geometrical terms (inférieur/moyen/supérieur) are used to subdivide a unit. The context connotes whether the time or the rocks are concerned (Fig. 4).

In German, unter/mittel/ober (= lower, middle, upper) is often indiscriminately used for both time and rock units; Early Cretaceous becomes "Unterkreide", and Early Jurassic becomes "Unterer Jura" in the German/English dictionary for geology. However, the terms "früh, mittel, spät" (early, middle, late) are increasingly used for time units in recent literature (after H.-P. LUTERBACHER).

In Greek, as in French, "geometrical" (stratal) terms are used for subdivisions referring to time, for context including a specific term like age, during, *etc.* (*e.g.* Upper Cretaceous age or during the Upper Cretaceous) make it clear that the reference is to time (after T. DANELIAN).

In Italian, the words inferiore/medio/superiore (= lower, middle, upper) are traditionally used for both time and rock-units for the context explains their meaning. The terms "precoce" and "tardo" are tentative translations of "early" and "late" but they are rarely applied.

Polish geologists use a guide of stratigraphy suggesting a dual terminology : Dolny, Srodkowy, Górny (Lower, Middle, Upper) and Wczesnego, Srodkowego, Póznego (Early, Middle, Late; according to one of us, J. T., confirmed by I. WALASZCZYK). However, one of us (F. R.) reports that the recently proposed time subdivisions are as uncommon in the Polish literature as they are in German publications.

In Russian there are two words "rannij" and "pozdnij" for early and late and two others "nizhnij" and "verkhnij" for lower and upper respectively (after A. DHONDT confirmed by A. M. NIKISHIN).

In Spanish, the traditional terms are "Inferior/Medio/Superior" (Lower, Middle, Upper) for both time and rock-units; the recently introduced terms temprano/tardío (early, late) are not in general use (after J.-J. ALVARO).

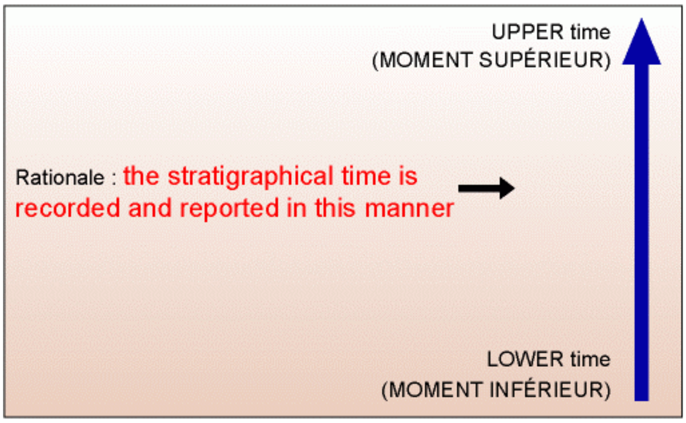

Figure 4: The choice of geometrical terms (recommended here) arises from the procedure used by stratigrapher-geologists to report relationships in time. A stratigrapher easily comprehends a moment as lower or upper; in fact, he understands immediately: the moment (which is represented-recorded in a) lower or upper deposit. The geologist thinks YOUNGER when he hears, says or reads UPPER.

As to the remark that one does not speak of a "Lower January snow accumulation" (GRADSTEIN, 1999, *in* ZALASIEWICZ *et alii*, 2004), the comparison is inappropriate. The use of a term depends on the context (the discipline, the persons, the environment). Another well established usage is to say, in French for example, "Crétacé inférieur" (= Lower Cretaceous) to indicate the older part of a System/Period and this practice obtains in several other languages (Cretacico inferior, Unterkreide ...).

Stratigraphy is *a history which is read from the strata*: strata are geometrically arranged and most are one above another, in superposition. Geological time is thus unique in the sense that it is recorded and defined in and by the strata older below and younger above. Keeping this is mind, it is justifiable to designate an older level as "lower" and a young one as "upper".

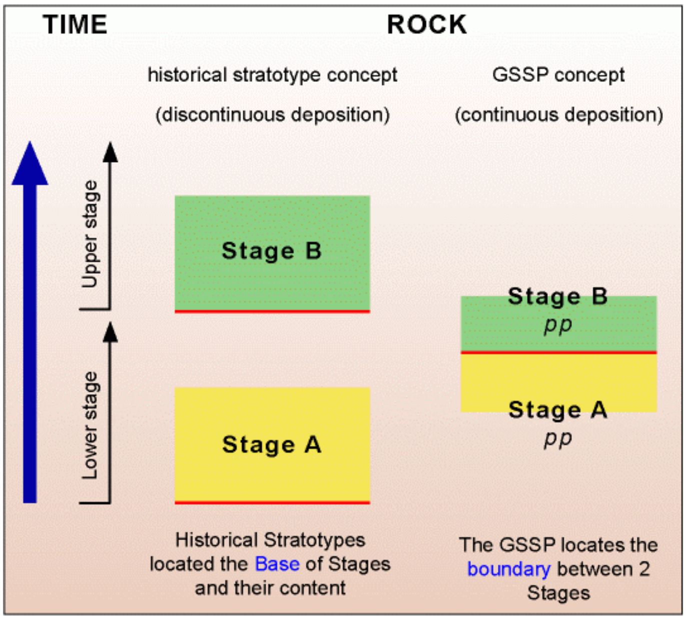

Figure 5: Revision of the boundary concept. Most historical stratotypes were defined in proximal platform facies so deposition was commonly discontinuous between the named stages. In contrast, the boundary concept (GSSP) requires that the boundary of a stage be defined in an uninterrupted sequence of strata. Successive historical stratotypes may leave some undefined intervals of time between them; the rule was that the unrepresented time (depositional gap) below the documented stratotype rocks pertained to the most nearly adjacent previously accepted stage. The GSSP defines a boundary between two stages where the succession is continuous.

GSSP: a boundary or the base of the unit above?

The recommended ICS terminology (REMANE *et alii*, 1996) considers a GSSP (Global standard Stratotype Section and Point) as "*the base of the unit above which automatically coincides with the top of the unit below*". At least in French literature, such a formal designation (base of a unit...) has not been popular among stratigraphers. Our own contributions to the ICS definitions of boundaries are always formally designated for example the "Campanian-Maastrichtian boundary" (ODIN, 2001b), not the base of the Maastrichtian, or the "Eocene-Oligocene boundary" (ODIN & MONTANARI, 1988), not the base of the Oligocene. This terminology is clearly more simple and precise where the record at the boundary is continuous - a requirement for establishing a GSSP (Fig. 5) -.

If a GSSP formally defines the *boundary* between stages, it provides a more satisfying approach to the geological calendar from several points of view. For example, some GSSP's (such as the base of the Ordovician Darriwillian stage), have been defined without any stage formally named below the boundary. The GSSP at the base of the Darriwillian was ratified by I.U.G.S. and the corresponding boundary appears to be between "nothing" unnamed below, and "something": the stage identified above. This is not satisfying. The formal naming of both the older and the younger units should require the collaboration and agreement of experts on the two before the GSSP is proposed for ratification.

The complete definition of a Stage

French practice demands that for its definition, a stage requires that three components be defined (Fig. 6); on one hand, the two boundaries (GSSP's) which fix its limits precisely, and on the other hand, the *historical stratotype* which documents the general content of the unit (MONTANARI *et alii*, 1997; REY *et alii*, 1997). The historical stratotype is the type section which gave its name to the stage. There must be consistency between the content of the historical stratotype as it was defined (*i.e.* d'ORBIGNY, 1849-1852) and the sites of the two GSSP's that define its modern limits (Fig. 7). It is agreed that "*practical considerations will incite us to limit changes to the necessary minimum*" (REMANE *et alii*, 1996). Justification of these changes lies in the obvious desirability of selecting the localities and levels where the best potential for worldwide correlation exists. The requirement of these three components for the definition of a stage would do away with proposals for units without corresponding stage names. For example, following the definition of the Precambrian-Cambrian boundary by LANDING (1994) the first stage of the Cambrian remained unnamed and therefore without a recognised content. Several proposals were made to rectify this lapse such as Nemakyt-Daldynian or Placentian (ODIN, 1993), or an informal term such as "Palaeocambrian" (ODIN, 1994). In 1995 the new term *Terranovian* was proposed to the ICS for this initial stage of the Phanerozoic, not only because it is derived from Terra Nova the French term for Newfoundland where the Precambrian-Cambrian GSSP is defined, but also because the translation, New Earth, is consistent with a new prospect: an earth for the first time inhabited by a biota with hard frameworks (ODIN, 1995a, p. 49).

The unique character of a GSSP is its guarantee that the boundary it defines is conclusive. Thus problems related to the former use of successive historical stratotypes (potentially inconsistent because of a hiatus or an overlap) do not exist. Consequently, the ICS suggests that no parastratotype or any auxiliary section be formally recommended to supplement the GSSP.

However, a single section only rarely documents completely the geological history involved in traversing the boundary of a unit. It is the opinion of many French-speaking stratigraphers that auxiliary sections (not points) could better document the sequence of events bracketing, and the moment in time corresponding to, a GSSP. For example, during the preliminary study for the definition of the GSSP at El Kef, Tunisia (ODIN, 1990), it was suggested that the formal definition of the Maastrichtian-Danian boundary (and in consequence the Cretaceous-Palaeogene boundary) be supplemented by an auxiliary succession in the continental domain. A nearly perfect correlation is possible using the iridium anomaly level found at El Kef and in North America (Fig. 8). The proposal was rejected because of the rule that a GSSP must be unique. The addition of the North-American section at Scollard Cañon would have (indirectly but most certainly) complemented the Tunisian boundary with a contemporaneous continental record of fossils (vertebrate and pollen), and with geochronological and magnetostratigraphic information unavailable in the Tunisian GSSP.

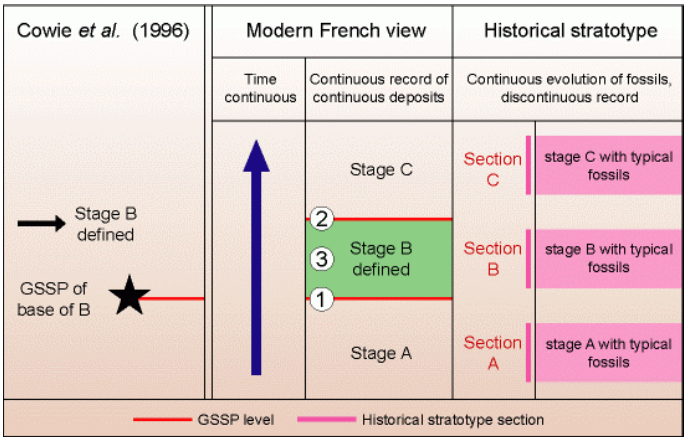

Figure 6: The definition of stratigraphic units. A Stage requires 3 pieces of data for full definition: 1- a GSSP defining its lower boundary, 2- a GSSP defining its upper boundary and 3- its main lithological and faunal characteristics based on the historical stratotype from which its name was derived.

Other working groups have accepted the principle of auxiliary sections; for example, the Aalenian-Bajocian GSSP (PAVIA & ENAY, 1997) is defined at Cabo Mondego in Portugal (ROCHA *et alii*, 1990) and is supplemented by a section in Scotland, at Bearreraig, Isle of Skye (MORTON, 1990).

More recently, the study of the Campanian-Maastrichtian GSSP at Tercis (France) has been supplemented with a review and new information on the Campanian-Maastrichtian successions of other areas (ODIN, 2001a) in particular from the Italian Apennines (GARDIN *et alii*, 2001); this has provided useful additional physico-chemical (magnetostratigraphy) and biostratigraphic (planktonic foraminifera) information that without difficulty can be related to the ratified GSSP (Fig. 9).

Thus, *auxiliary sections* are useful as a supplement for and a complement to the information available in the GSSP, both to provide a more reliable general correlation, and to favour the use of global stratigraphic subdivisions over a greater area. In some cases, a perfect correlation with the GSSP level is possible and an *Auxiliary Section and Point* may be proposed (see Cretaceous/Palaeogene boundary, Fig. 8). In other cases, the auxiliary section can be correlated at several discrete points with the GSSP section; for example, the section of the Bottaccione Gorge in the Apennines can be correlated with 4 or 5 points of the Tercis section (Fig. 9). A comparison can be achieved for deposits accumulated for more than 5 Ma.

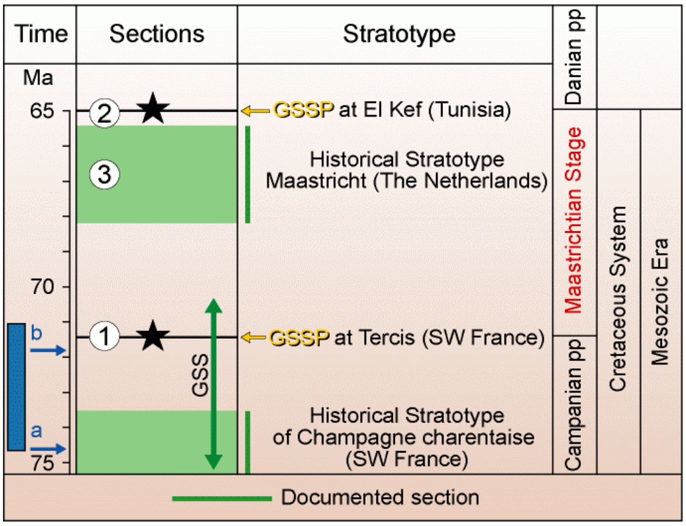

Figure 7: Example of a modern definition, the Maastrichtian Stage. Note that the historical stratotype from Limburg (3) documents only a portion of the modern Maastrichtian; an important interval of time was not represented in the stratotype but its rock equivalents are known from many sections. This has led to differing definitions regionally depending on what portion of these deposits was assigned the Campanian or the Maastrichtian.
Blue box to the left: locations of the different boundaries used in Europe and North America; a: top of the *Radotruncana calcarata* total range zone (foraminifera, Tethyan Domain); b: base of the *Belemnella lanceolata* zone (belemnite, Boreal Domain); 1: location of the Campanian-Maastrichtian boundary stratotype at Tercis (France); 2: location of the Maastrichtian-Danian (and Cretaceous-Palaeogene) boundary stratotype at El Kef (Tunisia).

Auxiliary references may also lead to conflicts (LANE *et alii*, 1999) between a GSSP and the formally suggested auxiliary section and point; this suggests that an auxiliary point should not have a formal status (Fig. 10). However, conflicts in the records eventually lead to a better knowledge of geological history.

The diversified nature of stratigraphy

ZALASIEWICZ *et alii* (2004, p. 3) suggest that "subdivision on the basis of GSSP's is possible for most of the geological record". Being possible is one thing, but efficiency is something else again. GSSP's are applicable to sequences of strata containing common, widely recognised and disseminated criteria for correlation. These facilitate exportation of the definition of the stratotype section elsewhere; in ascertaining the history of the earth the availability of elements that serve for correlation must be taken into account. They include relative abundance, ease of detection and broad distribution in rocks dispersed globally.

Following the appearance of fossils with hard parts, they become the most widely available tool for correlation, for they are unequivocal (we use here unequivocal as opposed to equivocal in the sense discussed by G.S. and C. ODIN, 1990: "*Geochronology and biostratigraphy are unequivocal tools: the same characteristic is unique in time; lithostratigraphy, magnetostratigraphy, chemostratigraphy are equivocal tools: the same characteristic is repeated in time*"). So fossils play a major role in the definition of Phanerozoic stratigraphic units. Consequently, biostratigraphy is the key indispensable tool for correlation between 530 and 5 Ma of earth history. "Key" is used here in its sense of important, essential (in French: cardinal). *Historically and practically, stages are the expression of biological evolution as perceived by pioneer stratigraphers*. This implies that a GSSP established without biostratigraphic control is not a realistic approach to defining a point in time. This does not mean that a GSSP could not be selected as coincident with another (physico-chemical) signal locally considered a more reliable indicator of time-pertinent information; it demands only that time-significant fossils be present.

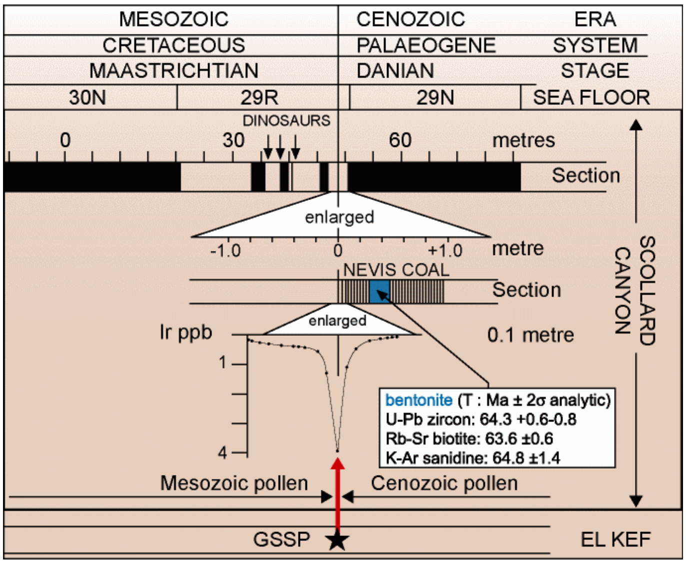

Figure 8: The potential continental Auxiliary Section (and level) for the Cretaceous-Palaeogene boundary, at Scollard Canyon, Red Deer Valley, Alberta, Canada; an exceptional case where, once accepted as an auxiliary section, the continental fossil record might be considered for a boundary definition. The GSSP at El Kef (bottom) can be unequivocally correlated with a contemporaneous level precisely located in the Canadian section by the iridium anomaly signal. The auxiliary reference would then be used to record the magnetostratigraphy of these terrestrial strata (although the quality of the local record has been questioned) and radiometric age data not present in Tunisia (data from LERBEKMO *et alii*, 1987; BAADSGAARD *et alii*, 1988).

This is not possible in most Precambrian rocks and we do not think that the GSSP concept could be used efficiently to establish the chronostratigraphy of Proterozoic and older rocks. In contrast to Phanerozoic deposits where the unequivocal tool is biostratigraphy, correlation of Precambrian rocks is done mainly by geochronology, the most commonly employed unequivocal tool for this part of Earth history. Geochronology can rarely be applied continuously in a section because datable components (geochronometers) are uncommon in many strata.

A second characteristic of these ancient rocks is that there are comparatively few that shed light on the history of Precambrian times and a third is that the preservation of these rocks is poor and the precision of the environmental information initially present is reduced considerably.

So it is not possible to detect and define small Precambrian units of stage dimensions and GSSP's have little applicability. There is thus a specific application of chronostratigraphy to be used below the sharply defined level when faunas with hard parts appear. This method was employed when Global Standard Stratigraphic Ages (GSSA, REMANE *et alii*, 1996) were accepted. This decision simplified the task of the Precambrian Subcommission which was thus relieved of the arduous tasks of selecting type sections and defining GSSP's. The use of these numbers for delimiting intervals of Precambrian time does not obviate the necessity for the selection of regional names in each cratonic area; it simply invites the authors to correlate their regional rankings to a common global scale.

The recently accepted definition of an Ediacarian unit (Ediacaran officially) was based on GSSP procedures. This GSSP uses biostratigraphy as the main tool and the numerical age assigned is poorly constrained compared to those of other Precambrian units including that of the former Proterozoic III; the future will judge the practical usefulness of this convention.

The biosphere is a major interest of Phanerozoic history. Pioneer stratigraphers were able to distinguish successive fossil faunas and thus to create stages they could identify in discrete areas. So evolution is the basis for the recognition of Phanerozoic stages. A review of the pioneers' intuitively established Phanerozoic stages shows that the pace of evolution has been almost unchanging: the mean duration of stages is constant (ODIN G.S. & C., 1990) at about 5 Ma (with a range of variation between half and twice that figure). This demonstrates that pioneer stratigraphers were able to distinguish the successive faunas with a remarkable precision in the interval from 530 Ma to about 5 Ma ago. Fossiliferous rocks are exposed over large areas; correlation is easy between marine deposits and the currently recommended stages are essentially marine.

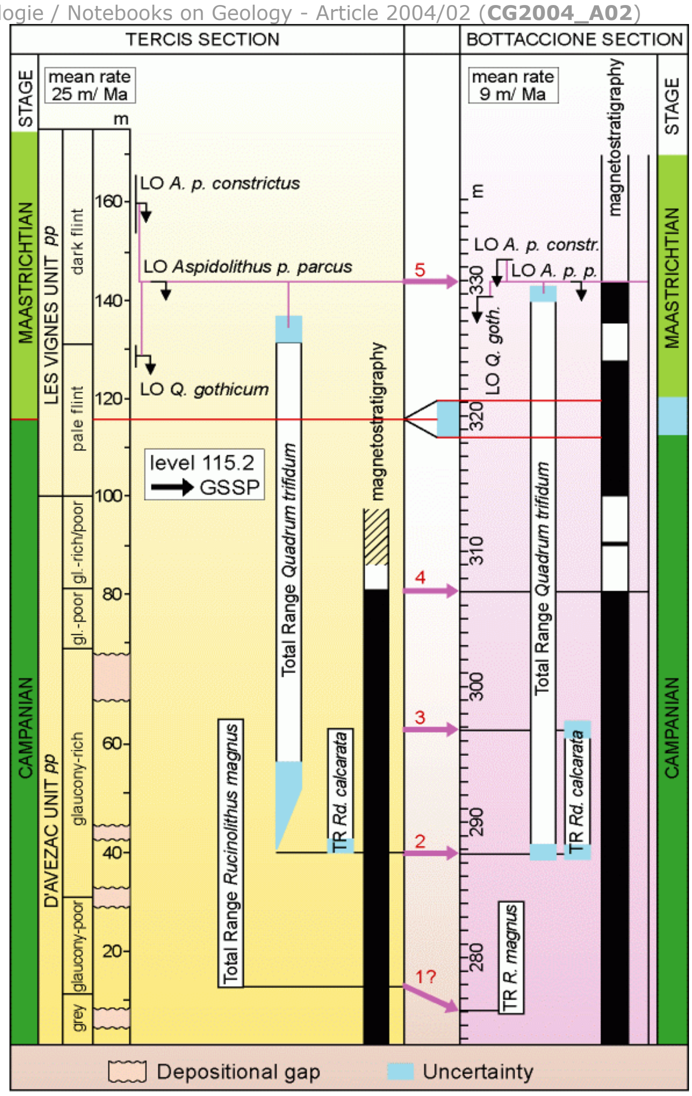

Figure 9: Example of correlation between a GSSP and a potential auxiliary section; the Campanian-Maastrichtian boundary stratotype at Tercis and the Bottaccione section in the Italian Apennines.
Explanation: the GSSPoint is unique but rarely includes all stratigraphic tools; auxiliary sections amplify the documentation of the boundary using other tools in more diverse environments. Note that precise correlation using different tools at 5 discrete levels allows correlation of the Tercis and the Bottaccione sections. Thus the Tercis section is provided indirectly with additional magnetostratigraphic and biostratigraphic information. Note also that the correlation is proposed with an uncertainty. Some correlation lines (nº 3 or 4) are based on a single event (last occurrence -LO- of *Radotruncana calcarata* or top of a normal magnetozone; normal polarity is black, reverse is white, no record is hatched), another correlation line (nº 2) is based on 2 events: the first occurrence –FO- of *Radotruncana calcarata* and the FO of *Quadrum trifidum* (taxa selected because comparatively easy to recognise). Correlation line 5 is a composite one with the LO of *Aspidolithus parcus parcus* as the central level bracketed by the LO of *Quadrum trifidum* and that of *Quadrum gothicum* below, and the LO of *A. parcus constrictus* above. Using this approach, and taking into account the similarity in the succession of events, and the documented continuous and uniform rate of accumulation in the 2 sections, the GSSP at Tercis may be correlated to level 320 in Italy with an uncertainty of about ±1 m in the latter section (adapted from ODIN, 2001b). Uncertainties are shown.

Boundary	GSSP	Additional reference	Comment
Aalenian/Bajocian boundary	Murtinheira Cabo Mondego (Portugal)	Auxiliary Section & Point Bearrering Bay (Scotland)	-> correlation to GSSP level adds some biostratigraphical data: ammonites, bivalves
Cretaceous/Palaeogene boundary	El Kef (Tunisia)	**Potential** Auxiliary Section & Point Scollard Canyon (Canada)	-> perfect correlation to GSSP level adds magnetostratigraphy + direct geochronological data + continental-marine correlation
Campanian/Maastrichtian boundary	Tercis (France)	Auxiliary **section** Bottaccione (Italy)	-> section to section correlation at several points more magnetostratigraphy more planktonic forams
Mid-Carboniferous boundary	Arrow Canyon Reed Deer Valley Nevada (USA)	Auxiliary Section & Point Stonehead Beck Yorkshire (UK)	-> a biostratigraphical conflict resulted due either to diachronism of fauna or to gap of deposition

Figure 10: Selected examples of the application of the concept of auxiliary section. Some of them have been formally voted as an Auxiliary Section and Points (ASP for the Aalenian-Bajocian and Mid Carboniferous boundaries); another has not been voted (Cretaceous-Palaeogene) and is labelled here as a potential ASP (point or level). Two informal auxiliary sections were presented for the Campanian-Maastrichtian boundary but we refrained from suggesting particular levels or points because correlation is commonly a matter of interpretation of the records and may be subject to disagreement (see Mid-Carboniferous boundary).

More diversified tools are available for the investigation of younger strata because more lines of evidence are to hand and preservation is better.

The last 3 to 5 Ma of earth history is a different matter. Stratigraphic tools are abundant, widely available, and sections are uninterrupted in a great number of outcrops. Information is well preserved and accessible for both marine and continental environments because terrestrial deposits are much more widespread than those in older strata. The climate was less stable than that inferred from the aspect of older strata. Finally, the emergence of a human lineage is a biological event that generates special attention to that short segment of time.

For this relatively short period, each tool yields a sure and reproducible approach to the definition and recognition of any one succession. In order to refine interpretation, the use of several independent tools is advisable. Mutual correlation is feasible and desirable when successions are investigated by two or more tools and a common language can be established. This approach facilitates attainment of more nearly complete knowledge of the diversified and relatively unaltered characteristics intrinsic in these successions (Fig. 11). The employment of a single succession of chronostratigraphic units implicit in defining a stage in older rocks would unduly favour a particular tool at the boundaries of these younger units where diversified and significant events merit detailed investigation.

Older portions of this last segment of earth history can be described with great precision locally. However it would be imprudent to suggest that such continuous, accurately recorded knowledge derived from several tools can be extended to deposits much older than 5 Ma.

Each tool produces its own scale. That scale may have reference to biostratigraphic data (such as palynological climatic changes), geochemical data (such as the precisely numbered ^{18}O "stages"), numerical ages (either measured or deduced from Milankovich cycles or ^{18}O curves, with a general precision better than 10 ka), magnetostratigraphic units (which in this time interval have "proper" names, and are not just numbers as in Meso- and Cenozoic times), some lithostratigraphic units (such as glacial deposits which are named variously depending on the area). There is no "principal" tool for recording Plio-Quaternary history; all scales are integrated to precise numerical ages so reference section and GSSP's are not needed. This simplifies the establishment of pertinent conventions, for they are replaced by detailed knowledge about most scales. Among possible units, we admit the traditional and often used subdivisions: Pliocene and Quaternary. However, these must not be used to the exclusion of other means of subdivision which, however, must not exclude the use of traditional units and terminology.

The three domains of geologic time require measuring devices adapted to the correlation tools specific to the domain involved. Previously these domains were known as the "3 stratigraphies" (Odin, 1994). This appellation may be too broad, for there is but one stratigraphy. However, our knowledge of earth history is compartmented as a function of time. Three discrete scales are involved and their general acceptance is urged: 10 to 100 ka for young rocks, about 5 Ma for the Phanerozoic interval and more than 50 to 100 Ma for older rocks. These scales are applicable globally. This does not imply that very precise knowledge cannot be attained locally in the Phanerozoic or "below" but global application of the locally precise bio- magneto- chemo- or lithostratigraphical information is not realistic.

It may appear inconsistent to advocate simplification in terminology and at the same time to recommend the use of several widely disparate measures of chronostratigraphy. However, a simple terminology does not imply a rigid chronostratigraphy. We have diversified sources to improve our knowledge of the history of the earth and consequently must adapt our rules to make full use of those sources.

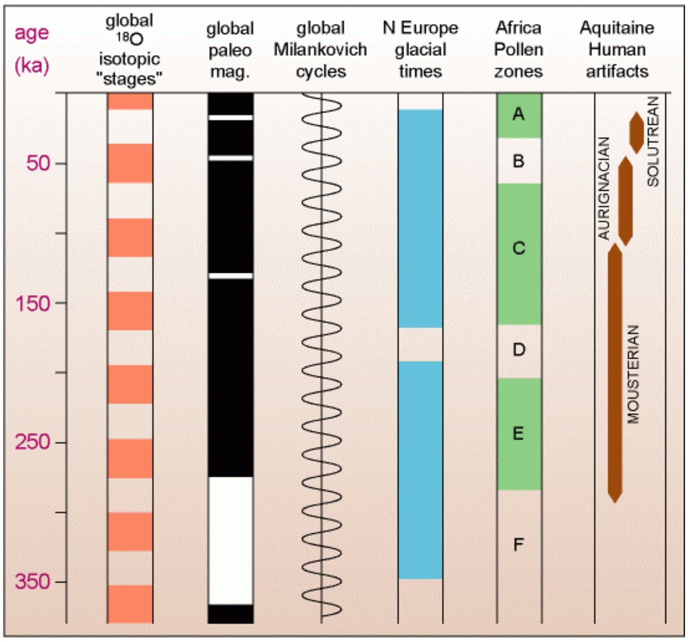

Figure 11: Stratigraphy of young deposits. Where and when several equally useful tools can be used and are correlatable, the GSSP concept is not necessary. The "last stage stratigraphy" may present the results obtained from the use of several types of chronostratigraphic tools in successive parallel columns; they are all precisely related to a numerical scale. A single column would not favour the use the variety of tools available in these deposits. The resulting multiple stratigraphy negates the necessity for the long and arduous procedures required to define reference points. The stratigraphic column is based on the information available and may be useful for regional or global correlation.

Conventions and knowledge

The coordination of information from many sources regarding the deposits in any number of discrete areas demands the adoption of a universally accepted system of reporting that information. The existing framework of that system and the changes necessary to bring it into line with current advances in scientific knowledge have been the main thrust of the arguments presented above. Conventions (common and traditional rules) allow us to reach such a consensus; however, the more numerous these conventions, the less applicable they become globally for they lack the temporal precision provided by the establishment of GSSP's. In this respect, the question of the optimum length of a stage has been addressed above. If stages are too short (too many global conventions), they will become difficult to apply globally; systematic subdivisions of a stage are equally vulnerable: they should remain a regional convention.

When a synthetic time scale is established, the framework discussed here must be clearly separated from the information used to establish its relationship to the relevant data. The boundaries defined by GSSP are points in a section; they should not be equated to any particular body of data. For example: biozonal subdivisions, are made in accordance with the state of knowledge of the fossil group concerned and each author must remain free to have his own opinion on the appropriate placement of the limits of biozonal subdivisions. This question is not a matter of global convention.

Similarly, sequence subdivision, palaeomagnetic units and the numerical ages of chronostratigraphic boundaries established at GSSP's are knowledge. Their relative ages could not be reported jointly without some tendency to "unique thinking" in sharp contradiction to desirable scientific usage.

Conclusion

A simplification of stratigraphic terminology is needed, for some of its subtle recommendations are unnecessary as shown by the disregard for them evinced by many practitioners. In fact, it should be kept in mind that the use of a dual terminology is simply a personal choice; no formal vote on its content has been made in the ISSC or in the ICS (REMANE, 1994; ODIN, 1995b).

In modern stratigraphy, the boundaries of globally recognised time-units and rock-units are coincident thanks to the GSSP ratified by I.U.G.S. Therefore, the same terms can be used in a unified stratigraphy. Time-units and rock-units are discrete concepts, the latter for all the rocks deposited or formed during a defined interval of time, the former for the interval of time itself. In a unified stratigraphy, it is justifiable to recommend a single set of terms to indicate subdivisions of these units and to abandon the distinction between early/late and lower/upper.

For the same reason, the previously recommended formal definition of a GSSP as the "base of the unit above which automatically coincides with the top of the unit below" should be changed to the "boundary between two units".

The GSSP concept which facilitates the definition of stages is useful for most of Phanerozoic time in which the biostratigraphical tool is widely applicable, thus making global correlation easy. Units of older rocks are best defined by numerical ages because measurements of physical age using rates of isotope decay and their interpretation constitute the most commonly applicable unequivocal tool for correlation. For the Plio-Quaternary, an adapted chronostratigraphy is suggested. Many factors point in this sense: its duration similar to that of a stage of the Phanerozoic, the general completeness of the record with good preservation of fossils and of original sedimentary characteristics, the need to consider both marine and continental deposits, *etc.* All of the tools available to subdivide this latest unit of time are capable of generating a calendar applicable world-wide. These calendars, although produced by disparate means, are easily correlated; there is no need for unified boundary conventions.

Acknowledgements

This discussion was prepared at the request of M.B. CITA, chairwoman of the International Subcommission on Stratigraphic Classification; it was presented at the ISSC Workshop "Post-Hedberg developments in Stratigraphic classification" (M.B. CITA & A. RICCARDI convenors) during the International Geological Congress at Firenze (Aug. 27, 2004). Previous versions have been circulated among colleagues of the "Comité Français de Stratigraphie" and those of several neighbouring countries. Comments and informations from J.-J. ALVARO, A.C. BARTOLINI, J.-P. BELLIER, T. DANELIAN, A. DHONT, J. JAGT, M.A. LAMAURELLE, B. LEFEBVRE, H.-P. LUTERBACHER and E. MOLINA are appreciated. We acknowledge the extensive review of our work by H.-P. LUTERBACHER and many points under discussion have been clarified; however, our conclusions do not necessarily reflect his views. P. COURVILLE, secretary of the Comité Français de Stratigraphie, was kind enough to improve this work with his own welcome comments, both during and at the completion of the manuscript. We thank B. GRANIER (figures 1 to 3 and 10) and A. LETHIERS (figures 4 to 9 and 11) who redrew our figures in a mysterious software consistent with electronic distribution. The final version of this paper in English was redacted by the editors of the journal. We are most grateful to N. SANDER for his insuring the accurate explication of our views in English.

This paper is dedicated to Jürgen REMANE, deceased on November 15th 2004. All of us benefited from his open-mindedness, impartiality and kind diplomacy when he was the Chair of the former Commission of Stratigraphy.

Author's affiliations

All authors are (or were) members or the chairman (J. T.) of the Comité Français de Stratigraphie.

GSO: past chairman of the ICS Subcommission on Geochronology; member of the Subcommission on Stratigraphic classification; past member of the International Commission on Stratigraphy and of the Subcommission on Cretaceous Stratigraphy; corresponding member of the Subcommissions on Carboniferous Syratigraphy, Triassic Stratigraphy, Palaeogene Stratigraphy.

SG: secretary of the ICS Subcommission on Cretaceous Stratigraphy.

FR: past member of the ICS Subcommission on Cretaceous Stratigraphy; member of the Belgian National Committee of Geological Sciences.

JT: ICS corresponding member of the Subcommissions on Stratigraphic Classification and on Jurassic Stratigraphy.

Abbreviations used in this paper

ASP: Auxiliary Section and Points
GSSP: Global standard Stratotype Section and Point
ICS: International Commission on Stratigraphy (a body of IUGS)
ISSC: International Subcommission on Stratigraphic Classification (a body of ICS)
IUGS: International Union of Geological Sciences

References

BAADSGAARD H., LERBEKMO J.F. & MC DOUGALL I. (1988).- A radiometric age for the Cretaceous-Tertiary boundary based upon K-Ar, Rb-Sr, and U-Pb ages of bentonites from Alberta, Saskatchewan, and Montana.- *Canadian Journal of Earth Sciences*, Ottawa, Vol. 25, p. 1088-1097.

BATES R.L. & JACKSON J.A. (1980).- Glossary of Geology (2nd edition).- American Geological Institute, 749 pp.

GARDIN S., DEL PLANTA F., MONECHI S. & POZZI M. (2001).- A tethyan reference record for the Campanian and Maastrichtian stages: the Bottaccione section (Central Italy); review of data and new calcareous nannofossil results.- *In*: ODIN G.S. (ed.), Characterisation and correlation from Tercis-les-Bains (Landes, SW France) to Europe and other continents.- IUGS Special Publication (Monograph) Series 36; *Developments in Palaeontology and Stratigraphy*, 19, Elsevier, p. 745-757.

GRADSTEIN F.M., FINNEY S.C., LANE R. & OGG J.G. (2003).- ICS on stage.- *Lethaia*, Oslo, 36, p. 371-378.

HARLAND W.B. (1964).- Preface.- *In*: HARLAND W.B., GILBERT SMITH A., WILCOCK B. (eds.),The Phanerozoic time scale.- A supplement to *The Quarterly Geological Society of London*, Vol. 120 s, , p. vii.

HEDBERG H.D. (1976).- International stratigraphic guide. A guide to stratigraphic classification, terminology and procedure.- John Wiley & Sons, New York, 233 pp.

HEDBERG H.D., ed. (1979).- Guide stratigraphique international. Classification, terminologie et règles de procédure.– Doin Éditeurs, Paris, 233 pp (translated from English).

HOLMES A. & CAHEN L. (1955).- African geochronology - results available to 1 September 1954.- Colonial Geology and mineralogical Resources, London, Vol. 5, p. 3-39.

HOLMES A. & CAHEN L. (1957).- Géochronologie africaine 1956. Résultats acquis au 1er Juillet 1956.- *Mémoires de l'Académie Royale de Belgique*, Bruxelles, (Sciences), t. 5, 169 pp.

LAFFITE R., HARLAND W.B., ERBEN H.K., BLOW W.H., HAAS W., HUGHES N.F., RAMSBOTTOM W.H.C., RAT P., TINTANT H. & ZIEGLER W. (1972).- Essai d'accord international sur les problèmes essentiels de la stratigraphie.- *Comptes rendus sommaires de la Société géologique de France*, Paris, 1972-13, p. 36-45.

LANDING E. (1994).- Precambrian-Cambrian boundary global stratotype ratified and new perspective of Cambrian time.- *Geology*, Boulder, Vol. 22, p. 179-182.

LANE H.R., BRENCKLE P.L., BAESEMAN J.F. & RICHARDS B. (1999).- The IUGS boundary in the middle of the Carboniferous: Arrow Canyon, Nevada, USA.- *Episodes*, Ottawa, Vol. 22, Nº 4, p. 272-283.

LERBEKMO J.F., SWEET A.R. & ST LOUIS R.M. (1987).- The relationship between the iridium anomaly and palynological floral events at three Cretaceous-Tertiary boundary localities in western Canada.- *Geological Society of America*, *Bulletin*, Boulder, Vol. 99, p. 325-330.

MONTANARI A., ODIN G.S. & COCCIONI R., eds. (1997).- Miocene stratigraphy; an integrated approach.- Developments in Stratigraphy, 15, Elsevier, 694 + XVII pp.

MORTON N. (1990).- Bearreraig (Isle of Skye, NW Scotland) as boundary stratotype for the base of the Bajocian stage.- *Memorie descrittive della Carta geologica d'Italia*, Roma, XL, p. 23-47.

ODIN G.S. (1990).- The Cretaceous-Palaeogene boundary definition and age.- *In*: ODIN G.S. (ed.), Échelle numérique du Phanérozoïque.- *Bulletin of Liaison and Information of PICG 196 & IUSG Subcommission on Geochronology*, Paris, 8, p. 14-22 (offset).

ODIN G.S. (1993).- About the recent definition of the Cambrian System resulting from the new conventional Precambrian-Cambrian boundary. Phanerozoic Time scale.- *Bulletin of Liaison and Information of the IUGS Subcommission on Geochronology*, Phanerozoic Time Scale, Paris, 11, p. 9-10 (offset).

ODIN G.S. (1994).- Geological time scale, 1994.- *Comptes Rendus de l'Académie des Sciences*, Paris, Sciences de la Terre, (II), t. 318, p. 59-71.

ODIN G.S. (1995a).- Géochronologie stratigraphique: de l'analyse isotopique à l'âge et à l'échelle numérique. *In*: ODIN G.S. (ed.), *Bulletin of Liaison and Information of the IUGS Subcommission on Geochronology*, Phanerozoic Time Scale, Paris, 13, p. 28-51 (offset).

ODIN G.S. (1995b).- Book reviews, Stratigraphy.- *Earth-Science Reviews*, Amsterdam, Vol. 39, Nº 2, p. 123-127.

ODIN G.S., ed. (2001a).- Characterisation and correlation from Tercis-les-Bains (Landes, SW France) to Europe and other continents.- IUGS Special Publication (Monograph) Series 36; Developments in Palaeontology and Stratigraphy, 19, Elsevier, xxviii + 881 pp.

ODIN G.S. (2001b).- Numerical age calibration of the Campanian-Maastrichtian succession at Tercis-les-Bains (Landes, France) and in the Bottaccione Gorge (Italy).- *In*: ODIN G.S. (ed.), Characterisation and correlation from Tercis-les-Bains (Landes, SW France) to Europe and other continents.- IUGS Special Publication (Monograph) Series 36; Developments in Palaeontology and Stratigraphy, 19, Elsevier, p. 775-782.

ODIN G.S. & MONTANARI A. (1988).- The Eocene-Oligocene boundary at Massignano (Ancona, Italy); a potential boundary stratotype.- *In*: I.U.G.S. Subcommission on Paleogene Stratigraphy, Special Publication, The Eocene-Oligocene boundary in the Marche-Umbria Basin, Italy.- Fratelli Aniballi, Ancona, p. 253-263.

ODIN G.S. & C. (1990).- Échelle numérique des temps géologiques, mise à jour.- *Géochronique*, Paris, Nº 35, p. 12-21.

ORBIGNY A. d' (1849-1852).- Cours élémentaire de paléontologie et de géologie stratigraphiques.- Masson, Paris, 847 pp.

PAVIA G. & ENAY R. (1997).- Definition of the Aalenian-Bajocian Stage boundary.- *Episodes*, Ottawa, Vol. 20, Nº 1, p. 16-22.

REMANE J. (1994).- Foreword. *In*: SALVADOR A. (ed.), International Stratigraphic Guide.- I.U.G.S. & Geological Society of America, p. xi.

REMANE J., BASSETT M.G., COWIE J.W., GORHBRANDT K.H., LANE H.R., MILCHELSON O. & WANG N. (1996).- Revised guidelines for the establishment of global chronostratigraphic standards by the International Commission of Stratigraphy (ICS).- *Episodes*, Ottawa, Vol. 19, p. 77-81.

REY J., ed. (1997).- Stratigraphie, Terminologie Française.- *Bulletin des Centres de Recherches Exploration-Production elf-aquitaine*, Pau, Mémoire 19, 164 pp.

REY J., COUREL L., THIERRY J. & RAYNAUD J.-F. (1997).- Les unités et corrélations chronostratigraphiques. *In*: REY J. (ed.), Stratigraphie, Terminologie Française.- *Bulletin des Centres de Recherches Exploration-Production elf-aquitaine*, Pau, Mémoire 19, p. 115-124.

ROCHA R.B., HENRIQUEZ M.H., SOARES A.F., MOUTERDE R., CALOO B., RUGET C. & FERNANDEZ-LOPEZ S. (1990).- The Cabo Mondego section as a possible Bajocian boundary stratotype.- *Memorie descrittive della Carta geologica d'Italia*, Roma, XL, p. 49-62.

SALVADOR A., ed. (1994).- International Stratigraphic Guide.- I.U.G.S. & Geological Society of America, 214 pp.

SIGAL J. & TINTANT H. (1962).- Principes de classification et de nomenclature stratigraphiques.- Comité Français de Stratigraphie, Paris, 15 pp. (printed booklet).

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*, Boulder, Vol. 32, Nº 1, p. 1-4.