

# Do GSSPs render dual time-rock/time classification and nomenclature redundant?

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**ABSTRACT:** The Geological Society of London Proposal for "...ending the distinction between the dual stratigraphic terminology of time-rock units (of chronostratigraphy) and geologic time units (of geochronology). The long held, but widely misunderstood distinction between these two essentially parallel time scales has been rendered unnecessary by the adoption of the global stratotype sections and points (GSSP-golden spike) principle in defining intervals of geologic time within rock strata." Our review of stratigraphic principles, concepts, models and paradigms through history clearly shows that the GSL Proposal is flawed and if adopted will be of disservice to the stratigraphic community.

We recommend the continued use of the dual stratigraphic terminology of chronostratigraphy and geochronology for the following reasons: (1) time-rock (chronostratigraphic) and geologic time (geochronologic) units are conceptually different; (2) the subtended time-rock's unit space between its "golden spiked-marked" lower and upper boundaries, actually corresponds to the duration of the time-rock unit's defining geologic s.l. events-set; therefore, in no way can physical time (instants or intervals) be directly defined by GSSPs, (3) combining in a single system of "chronostratigraphic units" the time-rock and geologic time units as currently understood, leads to the epistemological error of uniting *evidence* (rock successions) with *inference* (the interpreted duration of chosen defining events); (4) the redundancy of the terms eonothem, erathem, system, series, and stage with eon, era, period, epoch and age lacks support, given that they are conceptually different; in fact, referring to "eon," "era," etc. as terms uniting both time-rock and geochronologic connotations will produce needless nomenclatorial confusion, attaching different meanings to already well known and widely used geologic terms; and (5) the reversion of 'geochronology' to its main stream and original meaning of numerical dating has no foundation, just by considering that the use of geochronology precedes numerical dating, which became practical by the 1960's.

We endorse the following: (1) the GSSP network needs to be improved through the use of reference sections at high latitude sites, and in sedimentary continental rock successions of achievable, dependable positioning in the global standard timetable; and (2) to attend to researchers using astronomically-forced sedimentary systems, the designation of unit stratotypes needs to be reinstated as a valid and as a, complementary means of defining chronostratigraphic units, particularly at the stage and lower chronostratigraphic rank.

## INTRODUCTION

The time dimension in stratigraphy, particularly the record of it as regards dating and duration, as well as the ways to accurately correlate two or more rock bodies has been the subject of intense debate almost since the inception of this science, because there is no ready answer to the host of geologic questions related to time (the "when", and "how long" aspects) of geologic phenomena, as well as to how they are related, if a coherent history of the Earth is to emerge from their scientific study.

Different and even contrasting approaches to solve such questions have been proposed and used, based on different philosophies and principles, stemming from the accumulated empirical geologic knowledge (Miall 2004), duly processed through inductive logic reasoning, and influenced by its interplay with the conceptual paradigms held (explicitly or implicitly) during the different developmental steps of stratigraphy.

For instance, numerous empirical studies undertaken in Western Europe during the late 1700's-early 1800's, whose results were processed inductively, led to accumulating a substantial body of geologic knowledge on the large packages of sedimentary strata that make up that region, as well as on the different biotas they bear. However the same body of knowledge led to

contrasting interpretations linked to different paradigms: Cuvier and Orbnigny explained these packages by the tenets of catastrophism, using deductive reasoning; whereas Hutton and Lyell also using deductive reasoning, interpreted them *via* the Uniformitarian/Gradualistic paradigm premise. Although the sequential order or succession of the packages was not at issue, the length of the time recorded in the packages, as well as their subdivision in chronostratigraphic/geochronologic units (so to speak) were certainly different. (cf. Cuvier and Brongniart 1811; Orbnigny 1849-1852; other view: Hutton 1795; Lyell 1830.1833).

The introduction of the Global Stratotype Section and Point system (hereafter GSSP) approach (Cowie 1986; Remane et al. 1996) to establish unique points in the rock record marking precise instants of geologic time to define the lower boundaries of chronostratigraphic units of worldwide extent, which successively upward "determine" the duration of such units, is believed by some geologists to have made redundant the long-held distinction between chronostratigraphic units and geochronologic units, in turn based on the principle that the rock record is the basis to establish the time inferences and not *vice versa* as the "GSSPs extreme proponents" claim.

These opposing views have fostered a long debate. Rock-stratigraphic (lithostratigraphic), soil-stratigraphic, biostratigraphic, time-stratigraphic (chronostratigraphic), geologic-time (geochronologic), and geologic-climate (restricted to the Quaternary) units became formalized in the Code of Stratigraphic Nomenclature (ACSN 1961), through a sustained effort that lasted nearly 15 years, and involved many stratigraphers having different, and even contrasting conceptions. The path toward conceptualization of the chronostratigraphic units followed the lead of Schenk and Muller (1941), and Hedberg (1948, 1958, 1969a, 1973, 1978), was upheld and further developed in the successive editions of the Code (ACSN 1970; NACSN 1983, 2005), and made its way to the International Stratigraphic Guide (ISG hereafter, Hedberg 1976; Salvador ed. 1994). Through these publications, this concept won a nearly worldwide recognition and acceptance.

However, right from the very beginning, such conceptualization did not go unchallenged, (cf. Schindewolf 1957; Wilson 1959, 1960, 1971; Bell et al. 1961; Harrington 1965), and continued to be opposed by a minority, but very vocal group of dissenters (cf. George et al. 1967, 1969; Harland 1970, 1973, 1978; Holland 1978; Watson 1983; Basset 1985; Harland et al. 1990; Whittaker et al. 1991; etc.). The proponents of such challenges eventually introduced the GSSPs approach, which culminated in the Geological Society of London (GSL here after) proposal (Zalasiewicz et al. 2004) to unify geochronology and chronostratigraphy into a single science, “chronostratigraphy,” on the grounds that conceptually they are indistinguishable, because the introduction of GSSPs made redundant the distinction between geochronologic and chronostratigraphic units, and that practically, it avoids needless nomenclatorial confusion. So. It appears that the latest swing of the pendulum of scientific history is toward the opposite side, or has it?

An intense controversy is still going full swing (cf. Aubry et al. 1995, 1999; 2000; Berggren 1998; Easton et al. 2003; Lee et al. 2003, *partim*; Vai et al. 2004, *partim*; Heckert and Lucas 2004; Gladenkov 2007; Hilgen et al. 2006, 2007; Aubry 2007a-b; and Owen, this volume, *in contra*: Holland 1986; Cowie 1986; Harland 1992; Remane et al. 1996; Odin 1997; Holland 1999; Walsh 2001, 2003, 2004, 2006; Lee et al. 2003, *partim*; Gradstein et al. 2004; Odin et al. 2004; Vai et al. 2004, *partim*; Walsh et al. 2004; Zalasiewicz et al. 2004, 2007; 2008; McGowran 2007; McGowran and Qianyu 2007). What seems to be at the core of this controversy, is the application of two conceptions or contrasting models of chronostratigraphy, labeled long ago by Harland (1978) as the **rock-time model** [championed by Hedberg, leading to chronostratigraphy as expressed in the North American Stratigraphic Code (NACSN 2005), and in the ISG (Salvador 1994)] and the **time-rock model** [championed by Harland, leading to GSSPs and the GSL proposal]; see 4(B.5) below.

We, members of the North American Commission on Stratigraphic Nomenclature, strongly disagree with the GSL proposal, and conclude that although much has been stated (both for and against), the matter is far from settled. Our approach will include presenting a historical perspective on the development of stratigraphic classification (cf. Appendix I), and a review of basic stratigraphic concepts, principles and paradigms, which shall allow us to place the proposal in a broad conceptual context, thus ensuring a fair assessment not only of the tenets themselves, but of the principles and concepts on which they

are based, as well as on the real feasibility of their worldwide application.

We fully realized that, as Harrington (1965) pointed out long ago, there is “*nihil novum sub sole, nec valet quisquam dicere: ecce hoc recens est*”. [Nothing new under the sun, but let no one say (then): Look how fresh it is!], so we claim originality only in the way we treat facts and ideas already widely known and discussed (cf. Appendix II for specific sources and credits), yet feel that our effort could contribute to their clarification.

## DISCUSSION

We address below the Geological Society of London proposal to “... end the distinction between the dual stratigraphic terminology of time-rock units (of chronostratigraphy) and geologic time units (of geochronology) [Zalasiewicz et al. 2004],” and tenets derived from it, as developed therein, and expressed in their Conclusions and Recommendations section. Such proposal is hereafter referred to as LonPro.

### LonPro, Chief Tenet:

“... the practice of chronostratigraphy today defines the time framework of geochronology, because intervals of geologic time are now being precisely defined within rock successions by GSSPs (golden spikes).” [Zalasiewicz et al. 2004, p.4].

### Assessment:

(a) The expression “The practice of chronostratigraphy today defines the time framework of geochronology...” is semantically questionable on two counts: (1) is the practice of chronostratigraphy today restricted to defining geologic time intervals within rock successions by GSSPs (golden spikes)? Obviously not, stratigraphers today as in the past are engaged among other things in chronostratigraphic activities, such as measuring the age of rock bodies as records of past lithogenetic events [i.e., properly positioning them in the standard geologic timetable] by the best suited method(s), establishing their time relationships with other rock bodies, etc. (2) besides the time framework, does geochronology have other frameworks? Certainly not, hence this expression is redundant.

(b) The expression “...intervals of geologic time are now being precisely defined within rock successions by GSSPs (golden spikes).” is also semantically questionable: are geologic time intervals ontologically immaterial or material entities? If **immaterial**, how could the intervals of “geologic time” be defined within material entities, namely the rock successions? If **material**, how would they be defined, if time is not? Time is a dimension or a *continuum* of instants that endlessly succeed each other, the present one being the reference for previous and future instants (see B.1. below); there is no materiality in them.

These questions illustrate the confusion resulting from the different current views on basic stratigraphic concepts, principles, methodologies, models and paradigms, hence a review of them is necessary, to properly assess the LonPro, and duly support our analysis and conclusions. Such review follows:

### Summary review of basic stratigraphic concepts, principles and paradigms

Terminology is of prime importance to assess different views, given that a proper understanding of other persons’ ideas or positions requires that the words used to convey them, particularly the technical terms, have an explicit, commonly acknowledged

meaning, so that unambiguous interpretations emerge from their use. Discussing the various meanings and usages of every pertinent term, however, would distract the reader's attention from the flow of ideas being considered; to avoid it, we have provided an appended glossary of terms (cf. Appendix II), where the several terms' meanings or usages are presented and discussed. For clarity's sake, we present our understanding of the concepts, principles and paradigms under consideration, and furnish the reasons that support our expressed preference. We begin the review with general concepts and then move on to the more specialized ones.

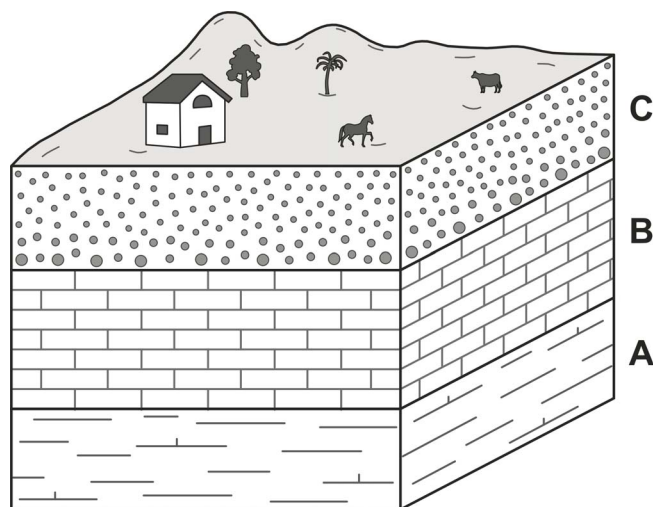
The vastness and complexity of the study of stratigraphy, i.e., Earth's crust (in space and time), account for the numerous definitions proposed (cf. Grabau 1913; Gignoux 1950, 1960; Dunbar and Rodgers 1957; Weller 1960; Krumbein and Sloss 1963; Dunbar and Waage 1968; *Geology Today* 1974; ISG, Hedberg 1976; Salvador 1994; Corrales et al. 1977; Schoch 1989; Vera 1994; Prothero and Schwab 2004; McGowran 2005; *Glossary of Geology-Fifth Edition* 2005; see also Appendix II, this work), each stressing the study of one aspect or another of such complexity; those cited in the Appendix II bracket the conceptual spectrum. An eclectic definition based on them follows: **stratigraphy** is the scientific study of the shape, dimensions, and spatial relations of the rock masses forming the Earth's crust, organizing them on the basis of their inherent characters into mappable geologic units, and detecting the space/time relation of the lithogenetic events which they recorded and represent, for reconstructing the Earth's history.

### Space, Time and Events

The first question we wish to review is whether the **space** and **time frames of reference** in stratigraphy, and in earth sciences as a whole, are unique to it, or are the same ones used in other sciences, and in everyday human activities as well? The answer is no, both frames are as we know them; neither is a material entity of the external world (cf. Appendix II). **Space** is a tri-dimensional extent in which material objects are located and events occur; both have relative positions and direction; space is independent of its occupation by matter (*Webster's Dictionary* 2002). Restricted portions of space occupied by discrete portions of matter or where particular events occur are localities. Geological localities' attributes are *size* and *geographic position*.

**Time** is, paraphrasing Eddington (1929), a uni-dimensional *continuum* of world-wide instants (sort of "world-wide instant-thick time slices") that endlessly succeed each other, the present one being the reference for past and future instants; hence time has an inherent polarity (from past to future), and is independent of matter (cf. Appendix II). In restricted segments of time, i.e., intervals, an event or condition exists or continues; further, it is only through events or happenings that intervals become meaningful. In other words, time intervals acquire reality only by the events occurring in them; therefore "empty," "happenings-free" time intervals are mere abstractions, and have no reality.

Then it is evident, that **geologic time** is not a particular kind of time (cf. Appendix II), different from other kinds, but it is merely a convenient informal term to designate the span of time elapsed since the formation of the Earth as a solid, differentiated planet of the Solar System; it is qualitatively similar to such expressions as medieval time or Roman time. Unique, specific sets of events provide meaning to these time intervals, and



TEXT-FIGURE 1

Block diagram depicting a rock succession consisting of the rock bodies A, B, and C. Space relations are evident: C overlies B, which in turn overlies A. A, B, and C acquire time significance *only* when interpreted as material records of past lithogenetic events, thereby becoming a kind of geologic unit (lithostratigraphic in this instance); then the Law of Superposition applies, indicating that the lithogenetic events recorded as geologic unit A took place *before* those recorded as units B and C. It also follows that the events recorded in A are the earliest, whereas those recorded in C are the latest.

restrict them to a particular (bounded) space; without events such intervals are meaningless. To speak of the *Alpha Centauri* innermost planet's geologic time would be nonsensical, because the unique event of Earth's formation and differentiation did not reach *Alpha Centauri* space. To speak of medieval time outside western Europe, let us say in Eastern Asia, America or Australia would also be pointless, because the historic events that occurred in Western Europe during the Middle Ages did not extend to these other continents.

Given that through events time and space are actually tied (i.e., inextricably associated), it is appropriate to define them (cf. Appendix II). **Event** is a unique combination of matter and energy that takes place in a restricted portion of space (i.e., a locality) and occurs in a restricted segment of time (i.e., a time interval) [Ferrusquía 1978, modified from *Webster's Dictionary*]. By their duration, events including geologic ones are either *extremely short lasting*, "instantaneous" (e.g. seisms, faulting, volcanic eruptions, avalanches, tsunamis and the like) or *long lasting*, which Harrington (1965) appropriately labeled them "flow-events" [e.g., "normal" sedimentation, plutonic emplacement, plate-tectonic displacements, speciation, species endurance (i.e. species range), eustatic sea-level changes, regional uplift, erosion, etc.].

Time involves two concepts: *date* (a particular position in the tempo-frame given by the instant of occurrence of an event), and *duration* (the "length" or total-occurrence time of an event, or the total occurrence time between two events). Since duration is defined by dates, the latter is the primary concept. The unit of duration in physics is the second (which is a specific fraction of the sidereal day), yet it is not a measure of "pure" time, but of



movement and ultimately of space. So, “measuring time” is actually counting “units of duration” between specified date-defining events. Counting and measuring are different operations.

### Geologic Units and Stratigraphic Classification

The second question pertains to **geologic units**: What are they? How are they organized? On which basis? What do they record or represent? Geologic units are not standards of measurement (e.g., meters, Celsius degrees of temperature, etc.), but material entities that are constituents of a whole (cf. Unit in Appendix II), discriminated from the whole on the basis of selected criteria, such as lithic makeup, fossil content, and the like. The (formal) procedure to “create” geologic units is **stratigraphic classification** (cf. Appendix II). Given this, geologic units include **an objective part** (i.e. a material, natural, tri-dimensional object) and **a subjective part** (that is the selection of characters or attributes established as defining criteria to erect the unit by its creator). As the objective part becomes less tangible, the subjective one gains importance. Subjectivity engenders opinion and differences thereof; consequently it is no wonder that units based on “time” (dubbed “time-rock”, “tempo-stratal,” “chronostratic,” or “chronostratigraphic”) have always been controversial.

It should be noted that *stratigraphic classification* actually is an inherited, historic misnomer, because geologic units are generated by a process of discriminating or subdividing parts of a whole, not by placing independent, already discrete elements into groups, which indeed is the basic meaning of classification (cf. *Webster’s Dictionary* 2002, and Appendix II). Unfortunately, the term *stratigraphic classification* is so entrenched in geological literature, that attempts to replace it by a more appropriate one (e.g., stratigraphic organization, or stratigraphic subdivision) would be futile.

As material entities, geologic units occupy discrete portions of space, i.e., localities, whose size and geographic position in the space frame are defined by three dimensions (coordinates), which also allows for establishing their positions relative to other such units. As material objects, however, their space relations carry no temporal significance. “Time” enters with events. Only when geologic units are regarded as records of lithogenetic events, may temporal relationships be detected among them.

Let us consider the rock succession illustrated in text-figure 1. Rock body A, lies below rock body B, which in turn lies below rock body C. Here, spatial relationships (below/above) are apparent, but time relationships are not; in fact, they are meaningless, as are those among the bricks forming a wall. Yet, once rock bodies are defined or created as some kind of geologic unit (lithostratigraphic in this case) resulting from lithogenetic events, then it becomes appropriate to seek the temporal relationships among them. This is done by applying the Law of Superposition, which aptly expresses the correspondence between the relative spatial position of the events’ material (rock), as recorded among them, with the relative temporal occurrence of the events among themselves, whereby the spatial terms below/above or lower/upper correspond to the temporal terms before/after or earlier than/later than. Only then, does it become possible to establish that the lithogenetic events recorded as unit A occurred before those recorded as unit B, which took place before the ones recorded as unit C. Notice that one can only know the temporal relationship before/after for each event set, but one can not establish the “when” (dates are missing), nor the

“how long” (it is not possible to determine duration without dates); the latter also precludes knowing whether units A, B, and C are succeeding (i.e., no time elapsed between A, B and/or C), or subsequent (i.e., intervals of time occurred between A and B, and/or C).

### Dating and Correlation

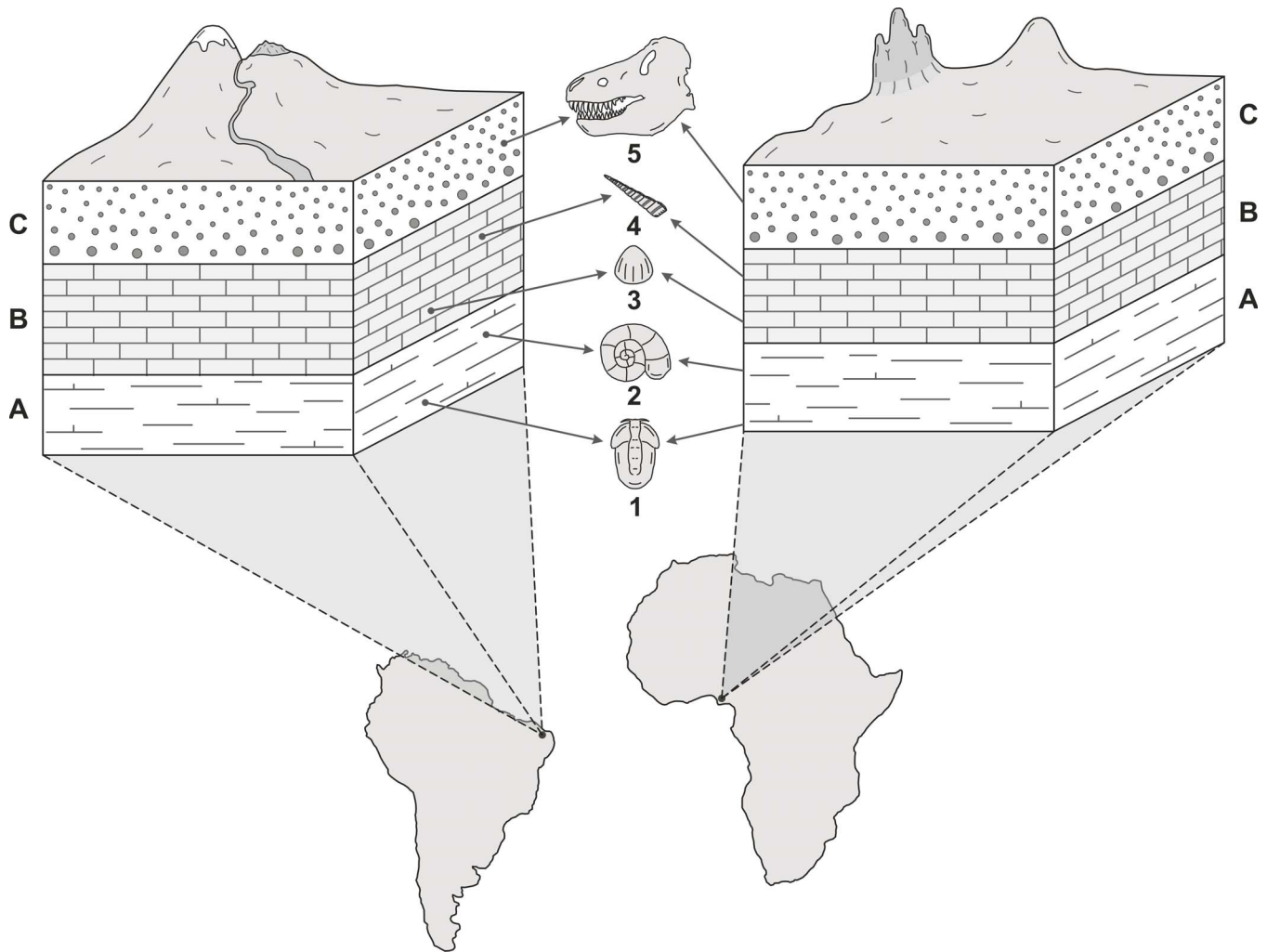
The next question pertains to **dating** and **correlation**. As mentioned above, stratigraphy’s time frame is the same as that of other sciences, and of every day human activities; for them “time” is expressed (i.e. counted) in sidereal units of duration, namely seconds, hours, days, years and multiples/submultiples thereof. This frame’s expression, however, only became partly available in geology in the 1960’s, when radio-isotopic dating emerged as a routine process. Much later, other events/records such as geomagnetic normal/reverse polarity successions, and astronomically-forced cyclic sedimentary systems, duly selected and calibrated, were added, thus contributing to a better punctuation of the “geologic time frame” with dates expressed in sidereal units of duration (i.e., units of the so called “physical time”). However, the number of numerical dates for the whole of geologic time, or even for the Phanerozoic, remains painfully small, and very likely it will remain so, because the appropriate available record is quite limited.

Under such circumstances, fossils, as records of past bio-flow events, coincide with past sedimentary lithogenetic flow-events (i.e., fossils contained in strata) provide most of the practical building blocks to construct a “proxy time frame,” i.e., a geologic timetable [see (B.4) below] for reference to geologic phenomena and their material rock record.

### Dating

The groundwork to build such a frame (i.e., the geologic timetable) occurred largely in western Europe during the 18<sup>th</sup> and 19<sup>th</sup> Centuries and became refined since (cf. Appendix I). Its genesis and development involved these factors: (1) an extensive knowledge of fossil taxa’s identity, and space/time distribution; (2) application of the principles of superposition and lateral extension both to stratal rock bodies and to their fossil content; (3) the acceptance of evolutionary theory as producing a unique, unidirectional, non- repetitive record of life through time; (4) a perception of “geologic time’s” enormous magnitude, quite beyond human experience; (5) an awareness that both recent and fossil taxa have a limited, biogeographic distribution, whose extent is quite variable; and (6) a selection of key-events (biogenetic, lithogenetic, diastrophic, erosional, etc.) to organize (i.e., “classify”) crustal rock masses into discrete, characteristic geologic units. By far most selected key-events were biogenetic.

Such stratigraphic organization or classification, first produced geologic material units of different magnitude, which eventually became hierarchically arranged, whereby higher ranked units included all lower ranked ones (cf. Table 1-2). The time significance of these material units stems from their being records of past lithogenetic events (undated and of unknown duration), amenable to dating only in relation to other material records of other lithogenetic events through the application of the Law of Superposition. Given, however, that lithogenetic events produced similar records without regard for time, whereas biogenetic events produced different fossils through time, successions of rock masses bearing distinctive fossil assemblages soon were preferred to perform stratigraphic organization (i.e. classification); the resulting formal geologic units



TEXT-FIGURE 2

Block diagrams depicting the generalized geologic makeup and fossil content of two sites located at least, 5,200 km apart, one in South America, and the other in west-central Africa. This graphic composition illustrates the principle of chronostratigraphic correlation, i.e., the correspondence in age and chronostratigraphic position between two stratigraphic sections; it follows that they share the same position in the standard geologic timetable. Given that organic evolution generates unique biotic assemblages (= bio-events) through geologic time, the significant fossil assemblages 1-5 correspondence of the sections in both sites could most parsimoniously be interpreted as resulting from co-occurrence of such bio-events in them, which in turn places these bio-events and associated lithogenetic events as having occurred in the same geologic time span. The similarity in the records order of occurrence in the said sections adds a strong support to this interpretation. It should be stressed that only the presence of linking events (in this case the bio-events 1-5) in the different areas or rock successions makes chronostratigraphic correlation possible.

served as the basic components of the geologic timetable, which because of its making, included both a hierarchically arranged set of material units, and a corresponding set of hierarchically arranged temporal units inferred from the former. This stratigraphic concept, based on the dual stratigraphic classification and nomenclature systems, was generally accepted by most geologists in the second half of the 19<sup>th</sup> Century, it was, however, very differently expressed and applied by individual national or regional groups. During the epoch-making IGC 2<sup>nd</sup> Session, Bologna 1881, the standard expression of this concept was proposed and accepted; from it emerged the present-day dual stratigraphic classification systems. In this way, a standard geologic timetable was established and internationally accepted [see Appendix I].

Let us now consider dating. Because a **date** is the particular position of an event in the tempo-frame given by the instant of its occurrence (or of its beginning/ending), **dating a geologic event** (cf. Date in Appendix II) means to place it in the geologic timetable, because such event (i.e. as recorded by a particular material body) is shown to unequivocally correspond to a particular key-event of it (the timetable). Notice that “showing this unequivocal correspondence” implies the recognition of the selected key-event of the geologic timetable [let us say the fossil taxa that make up a given assemblage zone] in any place other than that where it was established as an element of the timetable, and thereby set as a criterion to define a particular interval of it (the timetable).

| P H A N E R O Z O I C |                 | EONOTHEM/EON  |  |
|-----------------------|-----------------|---------------|--|
| M E S O Z O I C       |                 | ERATHEM/ERA   |  |
| JURASSIC              |                 | SYSTEM/PERIOD |  |
|                       | Upper/<br>Late  |               |  |
|                       |                 |               |  |
|                       |                 |               |  |
|                       | Middle          |               |  |
|                       |                 |               |  |
|                       |                 |               |  |
|                       |                 |               |  |
|                       | Lower/<br>Early |               |  |
|                       |                 |               |  |
|                       |                 |               |  |
|                       |                 |               |  |
|                       |                 |               |  |

TEXT-FIGURE 3

The Jurassic segment of the Global Standard Geologic Timetable depicting the full hierarchical range of chronostratigraphic units (from eonothem to stage), and the strict lockstep correspondence with the derived/inferred geochronologic units (from eon to age). Chronostratigraphic terms are **bold-faced**.

As in any hierarchical system, the “vertical” relations between units of different rank, are such that within the stated limits, any unit includes all lower ranked ones, and in turn it is included by all higher ranked ones (Simpson 1961; Ferrusquía 1978). This effect could easily be grasped in analogy to the well known Chinese boxes sets. In vernacular stratigraphic parlance, these relationships are referred to as the “nested hierarchy.”

When applied to chronostratigraphic units, the rigidity of hierarchical relations causes among others, this particular important effect: The lower boundary of the lowest ranked unit, which in turn occupies the lowest position within that particular set of equally ranked units, *ipso facto* becomes the lower boundary of all higher ranked units, e.g. the lower boundary of the Hettangian Stage, is also the lower boundary of the Early Jurassic Series, as well as the lower boundary of the Jurassic System. Given the one-to-one correspondence that exists between chronostratigraphic units and their derived geochronologic units, the Hettangian Stage lower boundary also corresponds to the beginning not only of the Hettangian Age, but concatenately to the beginning of the Early Jurassic Epoch, and of the Jurassic Period as well.

Further, for methodological reasons, the lower boundary of bottom stages in any particular system-stage set, becomes *ipso facto* the formally acknowledged upper limit not only of the underlying stage, but of the underlying series and system as well; this effect extends to the corresponding, geochronologic units, thus such particular stage lower boundary marks the end not only of the previous age, but of the previous epoch and period as well. Given the particular position of some stages, this effect may extend to erathems/eras and eonothem/eons. This is the beauty of chronostratigraphic/geochronologic classification systems, and it also explains the generous amount of attention paid to defining lower stage boundaries, and the still ongoing controversy as to the best way of doing it.

## Correlation

Given that one of stratigraphy’s major purposes is to reconstruct Earth’s history, it follows the need to integrate geologic information from different sites, and thus it becomes essential to place the geologic events or phenomena and their material (rock) record of each site in the standard geologic timetable (i.e., to date them), and to establish their mutual relations, particularly the temporal ones; the procedure to accomplish it is known as **stratigraphic correlation** (cf. Appendix II), or simply as **correlation** (cf. Appendix II). This term has several meanings (cf. Appendix II), however, the one pertinent here is “the establishment of the temporal relations between geologic events s.l. (thus including “fossil-genetic” ones) that occurred in the past, and concomitantly of their material (rock) record.” This particular kind of correlation is diversely known as time-correlation, chrono-correlation or temporal correlation (cf. text-figure 2).

The temporal relations between geologic events are: **simultaneity** (i.e. full co-occurrence, or synchrony; rarely in geology two flow-events have coincidental dates and duration; cf. Appendix II), **partial simultaneity** (i.e. partial co-occurrence, or partial synchrony, or partial “time overlap;” many flow-events in geology belong to this kind); **succession** (i.e. immediate post-occurrence of an event with respect to other event of the same kind; notice that this “immediateness” does not mean without an interval of time between the successive events; the terms *before* and *after* describe the time relations between this kind of events; cf. Appendix II), and **subsequence** (i.e. not immediate post-occurrence, whereby other events of different kind, or “time” occur without altering the occurrence-order between them; subsequent events are simply anterior/posterior with respect to each other; cf. Appendix II).

If one is interested only in the events’ order of occurrences, thus excluding events of other kind(s), or the passage of time, as it frequently occurs dealing with geologic phenomena, it follows that *successive* and *subsequent* events are practically indistinguishable; thereby this is the only class of temporal relation that can commonly be established in geology. Finally, within their localities, some events (and their material record) may not occur everywhere at the same time, so that “sub-localities” (particular segments of the total locality-area) may not be of the same age/duration; such events as well as their material record, are dubbed diachronic or “time transgressive.”

To correlate geologic events that are recorded at different sites (see text-figure 2), it is necessary to know their dates [i.e., their position in the geologic timetable], and through that demonstrate that they are simultaneous or at least partly simultaneous. To do so requires that in each site, the material record of geologic events s.l. [that is, the rock body(ies) succession], no matter how different may it be from that of other sites, must include one or more records of the key-events that make up the geologic timetable, or of other events/records demonstrably associated to them, directly or indirectly. Then, such events/records also function as **linking events/records** between/among sets of events/records placed in different sites, making relative temporal correlation possible locally, regionally or world-wide. No geologic integration and historical reconstruction is possible without correlation. In short, the events/records of different sites (extending locally, regionally or worldwide) are correlated with **the key-events/records that make up the geologic timetable**, not with “physical” time.



## THE GEOLOGIC TIMETABLE

The next set of questions stems from a closer look at the **geologic timetable**. How is it organized? What kind of units is it of? What is their time/space significance? How did it become a standard? How is correlation accomplished: stressing units' content, or stressing units' boundaries?

### Nature and components

The geologic time-frame-building effort (Table 3), as reviewed before (cf. Appendix I) was non-systematic; it involved assembling diverse parts produced by many geologists holding different philosophical positions and using diverse methods, so that eventually, international agreements were needed to establish the standard framework, also known as the “geologic time scale” (cf. Appendix II). It should be stressed that such scale is not a measuring device, nor its units are standards of measurement, hence it is not properly a time scale at all, but a kind of **timetable** (i.e. schedule), i.e., a fixed, sequential set of “times” (i.e. dates/hours/minutes) when or within which a set of events takes place; timetables are usually expressed as matrices with the “times” set in one axis and the events set in the other. The geologic timetable (cf. Appendix II) largely consists of biogenetic events [fossil taxon(a) first/last appearance(s), fossil taxa associations, fossil taxon(a) unique occurrence(s), etc.] selected and set to produce a unidirectional, non-repetitive, relative-positional “chronology” to which geologic and “past-biotic” phenomena could unequivocally be referred to (cf. text-figure 3). This explains why fossils and biostratic units are so inextricably entrenched in geochronology.

It should be noted, that the **geologic timetable** is much *less informative* than an airline or bus timetables. The latter provide a detailed, physical time chronology (expressed in dates/hours/minutes) to which the set of arrival/departure occurrences take place is univocally referred to; from this information, not only the occurrence of events is precisely known (i.e., dated), but also accurate estimates of the time intervals between events could be obtained. In contrast, the geologic timetable provides only the sequence of selected past biogenetic events established as the “chronologic frame,” but without their actual, univocal correspondence to physical time; it follows that without this correspondence, the date and duration of the selected key-events, as well as that of the time intervals between them can not be established (text-figure 3).

The geologic timetable is “printed” in rock successions made up of the material records of the selected key-events constituting it, which lie exposed in selected sites/rock bodies (i.e., localities, type localities, sections, type-sections, stratotypes), whose locality and description (of both content and boundaries) are made available to anyone concerned by a formal publication. *Thus the geologic timetable includes two conceptually different components:* (1) The **material record of the selected key-event(s)**, which are hierarchically arranged in “units” of increasing/decreasing rank, and (2) the **non-material, inferred time-intervals from the corresponding material units**; it follows that the time-intervals or units are also hierarchically arranged in lockstep with the material units. These ideas are illustrated and further elaborated in text-figure 3.

Both classes of units have been variously named: For the first class, the terms *time-rock*, *chronostratigraphic* (cf. Appendix II), *chronostratic* and *chronostratal* have been used; for the second class the terms *time*, *temporal* and *geochronologic* (cf. Appendix II) have been used. Finally, it would be extremely rare

TABLE 1

Summary of chronostratigraphic resolutions about nomenclature adopted at the IGC 2<sup>nd</sup> Session, Bologna 1881 (Capellini 1882, p. 196-197) [Modified from Vai 2007, Tab. 5].

| Hierarchy                              | Time-stratigraphic Divisions <sup>1</sup> |                      | Chronologic Divisions <sup>2</sup> |
|--|---|----------------------|------------------------------------|
| Rank                                   | Terms                                     | Example              | Terms                              |
| Grand division                         | Group <sup>3</sup>                        | Secondary Group      | Era                                |
| Division                               | System                                    | Jurassic System      | Period                             |
| First [Rank subdivision] <sup>4</sup>  | Series                                    | Lower Oolitic Series | Epoch                              |
| Second [Rank subdivision] <sup>4</sup> | Stage                                     | Bajocian Stage       | Age                                |
| Third [Rank subdivision] <sup>4</sup>  | Sub-Stage (Assise) <sup>5</sup>           |                      | [No term provided]                 |
| Nth [Rank subdivision] <sup>4</sup>    | Bed <sup>6</sup>                          |                      | [No term provided]                 |

[Mineral masses of the Earth's crust are called **rocks**<sup>1</sup> as to their nature and **formations**<sup>2</sup> as to their origin and mode of building]<sup>7</sup>.

#### Notes:

<sup>1</sup> In current terminology it would correspond to chronostratigraphic categories

<sup>2</sup> In current terminology it would correspond to geochronologic categories

<sup>3</sup> Later replaced by Erathem (ISG, Hedberg, ed. 1976)

<sup>4</sup> Not mentioned in the text of the resolution

<sup>5</sup> It was discarded, although recently Aubry et al., 1999 have proposed to reestablish it.

<sup>6</sup> It was discarded (ACSN 1961 Code does not include it)

<sup>7</sup> *Verbatim* from the text of the resolution

<sup>a</sup> It corresponds to a rock body *s. l.* [regardless of size and/or composition]

<sup>b</sup> In this sense, “formation” is a genetic/architectural term, comparable to facies; hence it is quite different from the homonym concept/name of the lithostratigraphic category, which is recognized in many current stratigraphic codes (cf. NACSN 1983, 2005; Rawson et al. 2002), and in the ISG (Hedberg, ed. 1976; Salvador, ed. 1994).

that in a single section or outcrop, high-ranked “time-rock” units could be fully exposed, hence in actual practice, the typification of “time-rock” units is restricted to low-ranked ones (i.e., stages and chronozones). In the Historical Perspective (Appendix I) section, an account of the efforts to construct the standard geologic timetable (cf. text-figure 3), as well as the paradigms held by the stratigraphers involved were critically reviewed; they are summarized in Tables 1-3.

### Effect of Stratigraphic Correlation

The geologic work in western Europe during the early-middle 1800's proceeded in a piece-meal fashion, extending from the “first” or already known areas/regions to the unknown or little known ones, so that the latter were compared/contrasted with the former, which “played” the role of “standards.” This “centrifugal” piece-meal work frequently showed significant correspondence between the stratal succession (i.e. sequence) of the “new study” area/region and that of the known “standard” one; such correspondence involved both the makeup of the fossil assemblages born by the stratal bodies (i.e. “units”) composing the rock succession, and the stratigraphic occurrence order (from bottom to top) of fossil assemblages from sequentially overlying stratal bodies. This correspondence was striking, particularly so, if rock bodies of (very) different aspect (i.e. facies) were involved. Such phenomenon was named **stratigraphic correlation** (cf. Appendix II).

Once advanced, correlation triggered a centripetal effort, a striving for regional integration of the disperse geologic information to produce first, a coherent, meaningful geologic history of the whole western European region, later of other regions, and eventually of the whole world (cf. Appendix I). This effort promoted a critical, methodological re-evaluation of correlation procedures and related concepts, including better definitions of pertinent geologic (time-rock) units, both in content and in boundaries, understanding the nature (concordant/discordant) of surfaces bounding geologic units, the meaning of sedimentary facies, the significance of fossils as biogeographic entities (space distribution), and as “time keepers”/indicators (i.e. time distribution) because of their ultimate dependence on organic evolution, the understanding that all fossil taxa are not equally valuable as “time keepers,” environmental (i.e. facies-related) indicators, or have similar geographic distribution, the uniqueness of fossil assemblages within certain bounds, the diachrony of time-rock units, fossil assemblages and “biostratigraphic” units. Particular attention was given to the concepts of **zones** and **stages** as the most important elements or means of correlation.

### Stages and Zones

Stages and zones were previously considered (cf. Appendix I), it was said that Orbigny’s (1849-1852) stages were in fact “... an inextricable combination of lithostratigraphic, biostratigraphic, allostratigraphic (synthem-like) and chronostratigraphic units,” as discussed here. Given the effect of Orbigny’s concept of stage in the later development of stratigraphy, and the diverse ways it has been interpreted, we deem it appropriate to reproduce his definition in the Appendix II (Orbigny 1851, pp. 256-257), and also we thoroughly reviewed his classic, 3-volume “*Cours élémentaire de Paléontologie et de Géologie Stratigraphique*,” to properly assess his conception and usage of stage, and conclude that it is an inextricable combination of lithostratigraphic units (cf. for instance the 4<sup>th</sup>-11<sup>th</sup> features to describe the Cenomanian Stage, Orbigny 1852, pp 232-238; the same applies for the description of his 27 Stages, Orbigny, 1851 and 1852), biostratigraphic units (cf. the title of Paragraph 1610, *Définition d’un étage géologique par rapport aux espèces* = Definition of a geological stage in reference to the species; Orbigny 1851, p. 256; as well as the introductory paragraphs and the 19<sup>th</sup>-23<sup>rd</sup> features to describe the Cenomanian Stage, including *Chronologie historique*, which largely is a relation of taxa as they appear in the record, Orbigny 1852, pp 630, 642-652; the same applies for the other stages), chronostratigraphic units (cf. Orbigny, 1851, Chapter 9E, *Deductions climatologiques et géographiques comparées*, pp 239-248; his tables on pp 247 and 263, and 3<sup>rd</sup> sentence of his definition of stage (op. cit. p.257), and allostratigraphic or synthem-like units (cf. Orbigny 1851, p. 256, paragraph 1609, and 6<sup>th</sup>-7<sup>th</sup> features to describe the Cenomanian Stage, Orbigny 1852, pp 635-636).

On the other hand, Oppel’s (1856-1958) stages were groups of zones, hence they evidently were biostratigraphic units. The acceptance of the Darwin/Wallace Organic Evolution Theory (Darwin, 1859) allowed to interpret the fossil record as that of the unidirectional, irreversible and unique evolutionary process of life, whose particular biogenetic events, recorded by particular fossil(s) set(s) could serve as building blocks (i.e. elements) to construct a dependable (geologic) timetable, to which geologic events/records from sites, dispersed at various levels (local, regional, continental, global) could unequivocally be placed (i.e. dated, or referred to), and confidently correlated among themselves, thus making it possible to construct a coherent

geologic history (i.e., the appropriate integration of information on a given geographic entity, derived from different sites located within the stated boundaries of such entity).

Because of this potential, stages became “abstract,”/utilitarian concepts, useful *means of correlation*, which must be defined as precisely as possible (both in content and boundaries), if they are to effectively serve as global standards. Stages as **correlation concepts** include not only the set of zones originally selected in the type locality where a given stage was named, but also incorporate set(s) of all other zones seen as equivalent to the original set (wholly added key-zone events). In this concept (cf. Appendix II), there is plenty of room for subjectivity and dissent. Stages in this role are actually operational concepts, and to properly serve as global standards, their boundaries **must be postulated as isochronous surfaces worldwide**. This postulation and procedure freed stratigraphers from demonstrating that such boundaries are indeed globally isochronous, which is an impossible task, given that no “physical” surface within the geologic material record could be proven to be the record of a single worldwide event.

The key idea is to consider **stages as operational correlation concepts** that are not 100% objective (i.e., “real”) entities, but hybrid ones, partly material and partly abstract. Hence, their content and boundaries must be established by international agreement, after due allowance to hear and ponder all interested voices, and taking properly into account relevant previous work.

### STRATIGRAPHIC PRACTICE AND THE GSSPS APPROACH

The foregoing discussion shows that in stratigraphy, one does not define intervals of pure physical time nor measure it as such, but rather proceed as follows: (1) Select key events to characterize (“conceptualize”) the unit stratotype and delimit operational chronostratigraphic units (in this instance **stages**); the corresponding inferred (i.e. derived) time unit (i.e. interval) becomes also delimited by this procedure (in this case **ages**). Notice that the chronostratigraphic unit is material, whereas the time unit is not, and does not correspond to an independent (i.e. pure) physical time interval, but to the time span delimited by the material record of the stated geo/bioevents that define (i.e. characterize) the chronostratigraphic unit;. (2) further, for methodological purposes, it is *postulated* that the boundaries of such units are globally isochronous surfaces (i.e. the boundary stratotypes); (3) designate as global reference through international agreement, a site (geographic place) where the unit is properly (partly) displayed, and at least either the lower or the upper boundary are apparent; and (4) finally, to formalize this designation, its description and pertinent historical background, as well as the arguments leading to such selection must be published in an appropriate journal, and a permanent material mark (i.e. “golden spike”) is placed in the lower boundary of the respective chronostratigraphic unit, namely the stage. The combined set of thus defined units constitutes the Global Stratotype Section and Point system, acronymed GSSPs (cf. Appendix II).

It is clear then, that the GSSPs does not erase the conceptual difference between “time- stratigraphic” (i.e., time-rock, or chronostratigraphic units; cf. Appendix II) and “time units,” (i.e., geologic time units, cf. Appendix II), hence, both sets of units (i.e. classification systems) and their respective nomenclatorial systems are needed in stratigraphy; it should be stressed that indeed both actually are operational concept-systems, and



that because of their inherent subjectivity components, could not be purely objectively derived-systems. Therefore they must be treated accordingly, as developed below.

Undue emphasis on overcoming diachronism, led to the contention that chronostratigraphic units *should be defined solely on the basis of boundaries*, thus setting up the practice of designating boundary stratotypes (ISG, Hedberg 1976; 2<sup>nd</sup> Edit., Salvador 1994) as the primary valid means of establishing formal chronostratigraphic units. This practice was taken a step further with implementing the GSSPs as the only valid procedure of establishing such formal units, with the explicit exclusion of the unit's content (unit stratotype) as a defining criterion.

The attempt to maximize the correlation usefulness of defining golden-spiked-boundary stratotypes has actually restricted the choice of sites to those where seemingly continuous marine stratal successions occur, and to formally select a single one, as the bearer of the golden spike, i.e., the standard global reference (lower) boundary of a given chronostratigraphic unit (cf. Cowie 1986; Holland 1986; Remane et al. 1996).

The selection of golden-spike-bearing sites, however, is strongly biased toward continental platform marine successions, placed at low/mid latitudes, thereby excluding high latitude ones, as well as continental sedimentary rock successions. This practice ignores the real difficulty of confidently tracing golden-spiked boundaries from their type localities to high latitude (or equatorial) ones. Further and in the case of continental successions, the difficulty becomes an impossibility. Due to methodological reasons, the Guidelines to establish GSSPs (cf. Cowie 1986 and Remane et al. 1996) formally prevent the designation of reference sections of any kind. This prevention does not allow the designation of supplementary/complementary sections and/or boundaries that may be needed to mitigate/solve these problems.

An excellent example of alternative approaches to the current guidelines comes from the Precambrian Canadian Shield in Ontario, where volcanic-based informal chronostratigraphic units termed "tectonic assemblages" have been in widespread use for the past 20 years (Thurston 1991; Thurston et al. 2008; Easton, this volume). These units are defined in low- to medium- grade metamorphic successions where primary depositional textures are well preserved, and consist of lithostratigraphic units (in some cases, formally defined groups and/or formations), which are grouped into tectonic assemblages on the basis of their depositional setting, geochemical affinity, and formation within a specific time range as determined by a combination of relative-age relationships and high-precision ( $\pm 1$  million years) isotopic ages. Boundaries between tectonic assemblages may be conformable, unconformable, or tectonic, and the basal boundaries of these tectonic assemblages could easily be defined as a form of GSSP, if so desired. Tectonic assemblages have been chrono-correlated over large parts of the Canadian shield (distances of several hundred kilometers). Ironically, the "tectonic assemblage" approach was originally developed to study Phanerozoic sedimentary and volcanic successions within the Canadian Cordillera, to allow chron-correlation between these diverse rock classes (Tipper et al. 1978). Thus, the ability to successfully create a variety of chronostratigraphic units for a variety of rock types other than fossiliferous continental marine successions, is limited by current guidelines with respect to the application of chronostratigraphy, and not by limitations within the scientific method.

TABLE 2

Stratigraphic classification and list of possible names [eras and periods/systems] accepted but not formally adopted in the IGC 8th Session, Paris 1900. [Data source: Vai 2007, p. 91]

| [Hierarchy] <sup>1</sup> | [Chronologic Divisions] <sup>1</sup> | [Time-stratigraphic Divisions] <sup>1</sup> |                                     |
|--------------------------|--------------------------------------|---|-------------------------------------|
| [Rank] <sup>1</sup>      | [Terms] <sup>1</sup>                 | [Terms] <sup>1</sup>                        | [Example] <sup>1</sup>              |
| First-order division     | Era <sup>2</sup>                     | [No term provided]                          |                                     |
| Second-order division    | Period <sup>3</sup>                  | System <sup>3</sup>                         | [Jurassic System] <sup>1</sup>      |
| Third-order division     | Epoch                                | Series                                      | [Lower Oolitic Series] <sup>1</sup> |
| Fourth-order division    | Age                                  | Stage                                       | [Bajocian Stage] <sup>1</sup>       |
| Fifth-order division     | Phase                                | Zone  |                                     |

<sup>1</sup> Words not provided in the in the IGC 8<sup>th</sup> Session publications, but supplied here to facilitate comparison with the resolution of the IGC 2<sup>nd</sup> Session (cf. this paper, Tab. 1).

<sup>2</sup> Accepted concurrent use of traditional and subsequent names: Primary or Paleozoic, Secondary or Mesozoic, Tertiary or Cenozoic.

<sup>3</sup> Possible Period/System names: Cambrian, Silurian, Devonian, Carboniferous, Triassic, Jurassic, Cretaceous; Tertiary, Modern.

Another problem with the GSSPs is posed by the rapid development of astronomically forced sedimentary systems studies, and their potential for unprecedented precise dating for most of the Phanerozoic (cf. among others Hilgen et al. 2005, 2007; Hinnov and Ogg 2007; and Schwarzscher 2007). This kind of research requires studying the rock successions themselves, their boundaries (whether golden-spiked or not) play little role, if any, in retrieving the needed scientific information. This fact demands re-establishing stratotypes as valid (or at least complementary) means for erecting formal chronostratigraphic units.

Finally, for argument's sake, let it be granted that the LonPro becomes formally accepted; what shall be done with the Precambrian? It consists by far of highly complex plutonic and metamorphic rock bodies, whose chronostratigraphic classification is incompatible with GSSPs theory and practice. On what basis could "time planes" be selected as boundary stratotypes? One answer might be the aforementioned "tectonic assemblages." Another might be the bar-coding approach advocated by some using regional dike swarms and the products of large-igneous provinces in conjunction with high-precision isotopic ages for global correlation? Should we instead apply a variety of approaches, including GSSPs where feasible. The current approach to stratigraphic differentiation for the bulk of Precambrian rock has been based largely on isotopic dating with only a limited tie to the geologic rock record. Should we abandon Precambrian chronostratigraphy because of the difficulty in applying GSSP procedures? Should we rather develop a multi-faceted approach?

The limitations and arbitrariness of the GSSP concept become apparent when considering the Precambrian. Although certain parts of the Precambrian record contain both low- to mid-latitude continental marine successions with macro- and trace-fossils suitable for the establishment of standard GSSPs (the newly minted Ediacaran Epoch for example), much of the Precambrian consists of lithodemic units, which although amenable to high-precision isotopic dating, require a different approach than the standard chronostratigraphy applied to the Phanerozoic over the past 150 years. Imagine if you will, what a Phanerozoic timescale might look like, if it was developed primarily on the

TABLE 3

Evolution of the geologic timetable from Lyell 1833 to the present: A concise rendering. Numbers 1-3 in each column refer to decreasing rank of chronostratigraphic/geochronologic category names as follows: 1, **Eonothem**/Eon; 2, **Erathem**/Era; 3, **System**/Period; Chronostratigraphic terms are **bold-faced**. The format is that of Krumbein and Sloss 1963, Tab. 2-1 (slightly modified), from which the first ten columns were taken; their sources correspond to well-known, and widely used geologic works, largely text books. The sources of the remaining columns were chosen with the same criteria. The selection is indicative, not comprehensive.

| LYELL 1833                     |  | PHILLIPS 1838        |  | LYELL 1872            |  | DANA 1880     |  | MILLER 1889             |  | CHAMBERLAIN and SALISBURY 1905 |  | SCHUCHERT 1910  |  | ULRICH 1911                           |  | GRABAU 1913                           |  | MOORE 1949                                  |  |
|--------------------------------|--|----------------------|--|-----------------------|--|---------------|--|-------------------------|--|--------------------------------|--|---|--|---------------------------------------|--|---------------------------------------|--|---|--|
| 2                              |  | 3                    |  | 2                     |  | 3             |  | 2                       |  | 3                              |  | 2   |  | 3                                     |  | 2                                     |  | 3   |  |
| RECENT PERIOD                  |  |                      |  |                       |  |               |  |                         |  |                                |  |   |  |                                       |  |                                       |  |   |  |
| TERTIARY PERIOD                |  |                      |  | TERTIARY STRATA       |  |               |  |                         |  |                                |  | NEOZOIC, TERTIARY OR CENOZOIC                                     |  |                                       |  | CENOZOIC                              |  | CENOZOIC OR QUATERNARY                      |  |
| Newer Pliocene                 |  |                      |  | Post-Tertiary         |  | CENOZOIC      |  | Quaternary              |  | CENOZOIC                       |  | Present Pliocene  |  | Neogenic                              |  | Present Pliocene                      |  | Quaternary                                  |  |
| Older Pliocene                 |  |                      |  | Pliocene              |  |               |  |                         |  | Pliocene                       |  | Pliocene  |  | Neogenic                              |  | Neogenic                              |  | Tertiary                                    |  |
| Miocene                        |  |                      |  | Miocene               |  |               |  | Tertiary                |  | CENOZOIC                       |  | Miocene   |  | Eogenic                               |  | Eogenic                               |  | Tertiary                                    |  |
| Eocene                         |  |                      |  | Eocene                |  |               |  |                         |  | CENOZOIC                       |  | Eocene  |  |                                       |  |                                       |  | Tertiary                                    |  |
| SECONDARY PERIOD               |  |                      |  | SECONDARY OR MESOZOIC |  | MESOZOIC      |  | MESOZOIC                |  | MESOZOIC                       |  | MESOZOIC  |  | MESOZOIC                              |  | MESOZOIC OR SECONDARY                 |  | MESOZOIC                                    |  |
| Cretaceous Wealden             |  | Cretaceous system    |  | Cretaceous            |  | Cretaceous    |  | Cretaceous system       |  | Cretaceous Comanchean          |  | Cretaceous period Comanchic period                                |  | Cretaceous Comanchean                 |  | Cretaceous Comanchic                  |  | Cretaceous                                  |  |
| Oolite or Jura limestone group |  | Oolitic system       |  | Jurassic              |  | Jurassic      |  | Jurassic system         |  | Jurassic                       |  | Jurassic period   |  | Newark or Jurassic-Triassic           |  | Jurassic                              |  | Jurassic                                    |  |
| Lias                           |  |                      |  | Triassic              |  | Triassic      |  | Triassic system         |  | Triassic                       |  | Triassic period   |  |                                       |  | Triassic                              |  | Triassic                                    |  |
| New red sandstone group        |  | Red sandstone system |  | Permian               |  | Carboniferous |  | Carboniferous system    |  | Permian                        |  | Pennsylvanian-Permian period                                      |  | Pennsylvanian                         |  | Permian                               |  | Permian                                     |  |
| Coal measures                  |  | Carboniferous system |  | Carboniferous         |  | Carboniferous |  | Subcarboniferous system |  | Coal measures or Pennsylvanian |  | Tennesseic period Mississippian period                            |  | Tennessian Waverian                   |  | Carbonic                              |  | Pennsylvanian                               |  |
| Mountain limestone             |  |                      |  | Devonian              |  | PALEOZOIC     |  | Devonian system         |  | Devonian                       |  | Devonian period   |  | Devonian                              |  | Devonic                               |  | Devonian                                    |  |
| Old red sandstone              |  |                      |  | Silurian              |  | Silurian      |  | Upper Silurian system   |  | Silurian                       |  | Siluric or Ontaric period   |  | Silurian                              |  | Siluric                               |  | Silurian                                    |  |
| Transition limestone           |  | Silurian system      |  | Cambrian              |  | Cambrian      |  | Lower Silurian system   |  | Cambrian                       |  | Cincinnati period Ordovician period Canadic period Ozarkic period |  | Ordovician Canadian Ozarkian          |  | Ordovician                            |  | Ordovician                                  |  |
| PRIMARY PERIOD                 |  | PRIMARY STRATA       |  | PRIMARY OR PALEOZOIC  |  | ARCHAEOZOIC   |  | AZOIC                   |  | ARCHAEOZOIC                    |  | ARCHAEOZOIC   |  | EUPALEOZOIC                           |  | ARCHAEOZOIC                           |  | PRE-CAMBRIAN                                |  |
|                                |  | Grauwacke system     |  |                       |  |               |  | Eozoic                  |  | Taconic system                 |  | Keweenawan Antimexan Huronian                                     |  | Keweenawic Huronic Keewatic Laurentic |  | Keweenawic Huronic Keewatic Laurentic |  | Keweenawan Huronian Temiskamian Keewatinian |  |
|                                |  | Clay-slate system    |  |                       |  |               |  | Azoid                   |  | Laurentian system              |  | Archean complex   |  |                                       |  |                                       |  |   |  |

basis of lithodemic units (intrusive rocks and the high-grade cores of orogenic belts) with the use of high-precision isotopic dating for worldwide correlation of units? In fact, we should be striving to create a Phanerozoic time scale that incorporates both GSSP-based elements, as well as lithodemic-based chronostratigraphic units, to truly represent the geologic history of the planet.

Summing up the review of chronostratigraphic/geochronologic procedures outlined above, it is evident that centuries of geologic work tended to conceptualize both kinds of units, applying the described methodological/epistemological postulations (whether explicitly or implicitly), that led to the generation of the geologic timetable, which eventually became agreed upon (IGC 2nd Sess., Bologna 1881); it is largely based on bioevents, and hierarchically organized, yet it was produced establishing the higher ranked units before lower ones.

On the basis of this geologic timetable through its various versions, dating and correlation of spatially “dispersed” geologic phenomena, that is, of geologic s.l. events/records from different geographic localities throughout the world, as well as cognitive integration, allowed the creation of a coherent, ever-clearer

and more-complete geologic history at local, regional, continental or global levels. This demonstrates the utmost importance and attention that creating the geologic timetable has always required. Further, given the inherent subjective component of the content and boundaries of chronostratigraphic units, shown above, the major role that international agreement has played in establishing “acceptable” (i.e. working) decisions becomes quite apparent, as Laffite (1972) pointed out, and Vai (2007) more fully elaborated on, the need to maintain stability must reflect agreements of national codes and/or guides (Vai 2002).

The extensive application of radio-isotopic dating since the 1960s made chronologic calibration possible, thereby allowing incorporation of some physical time data in the geologic timetable. The actual distribution of the rare radio-isotopically datable material, however, renders dates few and far apart. Recent Geomagnetic studies together with radio-isotopic calibration of the normal-reverse polarity sequence, permitted correlation of marine and continental rock bodies from mid-Mesozoic onward with; confidence increasing inversely with age. Research on astronomically forced sedimentary systems potentially allow unprecedented precision dating ("oligo-thousand-years" range) for most of the Phanerozoic; their methods requires analysis of

TABLE 3  
*continued.*

| DUNBAR AND ROGERS 1957 |               | DUMBAR AND WAAGE 1969 |               |           | GEOLOGY TODAY 1974 |           |               | HEDBERG, ED. 1976 |                         |           | HARLAND ET AL. 1990       |           | SALVADOR, ED. 1994      |           |               | GRADSTEIN ET AL. 2004 |               |           | U.S.G.S. 2006 |           |                         | MURCK ET AL. 2008 |               |           |                                 |               |                         |               |                         |               |                         |               |                         |               |            |            |
|------------------------|---------------|-----------------------|---------------|-----------|--------------------|-----------|---------------|-------------------|-------------------------|-----------|---------------------------|-----------|-------------------------|-----------|---------------|-----------------------|---------------|-----------|---------------|-----------|-------------------------|-------------------|---------------|-----------|---------------------------------|---------------|-------------------------|---------------|-------------------------|---------------|-------------------------|---------------|-------------------------|---------------|------------|------------|
| 2                      | 3             | 1                     | 2             | 3         | 1                  | 2         | 3             | 1                 | 2                       | 3         | 2                         | 3         | 1                       | 2         | 3             | 1                     | 2             | 3         | 1             | 2         | 3                       | 1                 | 2             | 3         |                                 |               |                         |               |                         |               |                         |               |                         |               |            |            |
| CENOZOIC               | Quaternary    | CENOZOIC              | Quaternary    | CENOZOIC  | Quaternary         | CENOZOIC  | Quaternary    | CENOZOIC          | Quaternary              | CENOZOIC  | Quaternary or Pleistogene | CENOZOIC  | Quaternary              | CENOZOIC  | Neogene       | CENOZOIC              | Quaternary    | CENOZOIC  | Quaternary    | CENOZOIC  | Quaternary              | CENOZOIC          | Quaternary    | CENOZOIC  | Quaternary                      |               |                         |               |                         |               |                         |               |                         |               |            |            |
|                        | Tertiary      |                       | Tertiary      |           | Tertiary           |           | Tertiary      |                   | Tertiary                |           | Tertiary                  |           | Tertiary                |           | Tertiary      |                       | Tertiary      |           | Tertiary      |           | Tertiary                |                   | Tertiary      |           |                                 |               |                         |               |                         |               |                         |               |                         |               |            |            |
| MESOZOIC               | Cretaceous    | MESOZOIC              | Cretaceous    | MESOZOIC  | Cretaceous         | MESOZOIC  | Cretaceous    | MESOZOIC          | Cretaceous              | MESOZOIC  | Cretaceous                | MESOZOIC  | Cretaceous              | MESOZOIC  | Cretaceous    | MESOZOIC              | Cretaceous    | MESOZOIC  | Cretaceous    | MESOZOIC  | Cretaceous              | MESOZOIC          | Cretaceous    | MESOZOIC  | Cretaceous                      |               |                         |               |                         |               |                         |               |                         |               |            |            |
|                        | Jurassic      |                       | Jurassic      |           | Jurassic           |           | Jurassic      |                   | Jurassic                |           | Jurassic                  |           | Jurassic                |           | Jurassic      |                       | Jurassic      |           | Jurassic      |           | Jurassic                |                   | Jurassic      |           |                                 |               |                         |               |                         |               |                         |               |                         |               |            |            |
|                        | Triassic      |                       | Triassic      |           | Triassic           |           | Triassic      |                   | Triassic                |           | Triassic                  |           | Triassic                |           | Triassic      |                       | Triassic      |           | Triassic      |           | Triassic                |                   | Triassic      |           | Triassic                        |               |                         |               |                         |               |                         |               |                         |               |            |            |
| PALEOZOIC              | Permian       | PALEOZOIC             | Permian       | PALEOZOIC | Permian            | PALEOZOIC | Permian       | PALEOZOIC         | Permian                 | PALEOZOIC | Permian                   | PALEOZOIC | Permian                 | PALEOZOIC | Permian       | PALEOZOIC             | Permian       | PALEOZOIC | Permian       | PALEOZOIC | Permian                 | PALEOZOIC         | Permian       | PALEOZOIC | Permian                         |               |                         |               |                         |               |                         |               |                         |               |            |            |
|                        | Pennsylvanian |                       | Carboniferous |           | Carboniferous      |           | Pennsylvanian |                   | Carboniferous           |           | Carboniferous             |           | Pennsylvanian           |           | Carboniferous |                       | Carboniferous |           | Pennsylvanian |           | Carboniferous           |                   | Carboniferous |           | Pennsylvanian                   | Carboniferous | Carboniferous           | Pennsylvanian | Carboniferous           | Carboniferous | Pennsylvanian           |               |                         |               |            |            |
|                        | Mississippian |                       |               |           |                    |           | Mississippian |                   |                         |           |                           |           | Mississippian           |           |               |                       |               |           | Mississippian |           |                         |                   |               |           | Mississippian                   |               |                         | Mississippian |                         |               | Mississippian           | Mississippian | Mississippian           | Mississippian |            |            |
|                        | Devonian      |                       | Devonian      |           | Devonian           |           | Devonian      |                   | Devonian                |           | Devonian                  |           | Devonian                |           | Devonian      |                       | Devonian      |           | Devonian      |           | Devonian                |                   | Devonian      |           | Devonian                        | Devonian      | Devonian                | Devonian      | Devonian                | Devonian      | Devonian                | Devonian      | Devonian                | Devonian      | Devonian   |            |
|                        | Silurian      |                       | Silurian      |           | Silurian           |           | Silurian      |                   | Silurian                |           | Silurian                  |           | Silurian                |           | Silurian      |                       | Silurian      |           | Silurian      |           | Silurian                |                   | Silurian      |           | Silurian                        | Silurian      | Silurian                | Silurian      | Silurian                | Silurian      | Silurian                | Silurian      | Silurian                | Silurian      | Silurian   |            |
|                        | Ordovician    |                       | Ordovician    |           | Ordovician         |           | Ordovician    |                   | Ordovician              |           | Ordovician                |           | Ordovician              |           | Ordovician    |                       | Ordovician    |           | Ordovician    |           | Ordovician              |                   | Ordovician    |           | Ordovician                      | Ordovician    | Ordovician              | Ordovician    | Ordovician              | Ordovician    | Ordovician              | Ordovician    | Ordovician              | Ordovician    | Ordovician | Ordovician |
|                        | Cambrian      |                       | Cambrian      |           | Cambrian           |           | Cambrian      |                   | Cambrian                |           | Cambrian                  |           | Cambrian                |           | Cambrian      |                       | Cambrian      |           | Cambrian      |           | Cambrian                |                   | Cambrian      |           | Cambrian                        | Cambrian      | Cambrian                | Cambrian      | Cambrian                | Cambrian      | Cambrian                | Cambrian      | Cambrian                | Cambrian      | Cambrian   | Cambrian   |
|                        |               |                       |               |           |                    |           |               |                   | PRECAMBRIAN PROTEROZOIC |           | Upper                     |           | PRECAMBRIAN PROTEROZOIC |           |               |                       | SINIAN        |           | Vendian       |           | PRECAMBRIAN PROTEROZOIC |                   |               |           | PPROTEROZOIC<br>NEO-PROTEROZOIC | Ediacaran     | PRECAMBRIAN PROTEROZOIC | Ediacaran     | PRECAMBRIAN PROTEROZOIC | Ediacaran     | PRECAMBRIAN PROTEROZOIC |               | PRECAMBRIAN PROTEROZOIC |               |            |            |

stratal successions (unit stratotypes), boundaries being of no significance. Studies of this kind are just starting. These methodologies add precision to the geologic timetable, but do not conceptually change it into a physical-time scale, nor could geologic events/records be placed there or have any historical-geologic meaning in the absence of their previous positioning in the geologic timetable.

## THEORETICAL MODELS IN STRATIGRAPHY

Considering that the application of contrasting models of chronostratigraphy, labeled long ago by Harland (1978) as the **rock-time model** [championed by Hedberg, leading to chronostratigraphy as expressed in the North American Stratigraphic Code (NACSN 2005) and the ISG (Hedberg 1976; 2<sup>nd</sup> Edit., Salvador 1994)] and the **time-rock model** [championed by Harland, leading to the GSL Proposal (Zalasiewicz et al. 2004)] underlie the current controversy on this subject, it is necessary to discuss them.

### Rock-Time Model and Time-Rock Model Definitions

Neander (2007) has stressed the relevance of mental representation on scientific research, and how it sways not only results, but the very way one perceives reality. It follows that building/using models influences not only the answers sought, but

the research approach itself that one chooses. A survey of definitions pertaining to *model*, *rock-time model* and *time-rock model* are presented in the Appendix II. The definition of model most adequate for this case is reproduced here: **model** is a working hypothesis or precise simulation, by means of description, statistical data, or analogy, of a phenomenon or process that cannot be observed directly or that is difficult to observe directly (Glossary, 2005). The key concepts **rock-time** and **time-rock models** were not formally defined by Harland (1978, p. 23-24 and Fig. 4), his proponent, who instead presented an interpretative comparison of both, thus making it difficult to objectively assess them; to do so we relied on these interpretations:

The **rock-time model** (Aubry 2007b) is the conceptual relationships whereby stratigraphic horizons define the boundaries of specific stratigraphic units (the stratomeres) representative of specific temporal units (the chronomeres). In this paper, the **rock-time model** is an expression of the relationship between a chronostratigraphic unit (stratomere) and a geochronologic unit (chonomere), whereby the latter (time unit) is the derivative concept, because its limits (beginning and end) are determined by the physical boundaries of the rock body, which is then the primary concept.



The same applies to the other model (Aubry 2007b). The **time-rock model** is the conceptual relationship whereby *points* are selected in the rock as representative of pre-selected events (i.e., pre-selected instants); in this paper: the **time-rock model** is an expression of the relationship between a chronostratigraphic unit and a geochronologic unit, whereby the former (rock body unit or stratomere) is the derivative concept, because its boundaries are defined by specifying two points in the rock section that are interpreted as two instants in time that define the geochronologic unit.

### Assessment

It follows that the time-rock model definition is not objective, but rather quite subjective on two grounds: (1) the action of “specifying two points in the rock section” has no temporal significance by itself, but acquires meaning through the subjective action of interpreting such points as recording two geologic (i.e. lithogenetic) events of instantaneous duration and worldwide extent, assuming them to correspond to the beginning and end of a particular time span, thus so “defining” the geochronologic unit; and then (2) the ultimate basis of conceptualizing a chronostratigraphic unit, actually is researcher’s (no matter how well qualified) **preconceptions**. These facts leave no support for the contentions that the “time-rock model” is better than the “rock-time model” (Harland 1978), and that intervals of geologic time are now being precisely defined within rock successions by the GSSPs, i.e., the golden spikes. (Zalasiewicz et al. 2004)

As shown in the Historical Perspective (Appendix I), such intervals were conceptualized long before GSSPs practice, which only defines the precise chronostratigraphic unit boundaries, and by correspondence, those of their derivative geochronologic counterparts. That is, GSSPs are spatial elements set on a 3-dimensional material body of rock, and carry no time connotation by themselves. The time meaning appears only when such points are interpreted as the accepted boundaries of an already recognized chronostratigraphic unit, which also serves as the defining basis of the corresponding geochronologic unit; the boundaries of the former function too as “boundaries” of the latter. In short, the material record of events used (i.e., the chronostratigraphic unit or stratomere) give meaning to the corresponding time interval of geologic history (i.e., the geochronologic unit or chronomere).

### Concluding Remarks

In conclusion, neither the rock-time model nor the time-rock models fit the definitions of model presented above, hence neither is *sensu stricto* a model; they appear to be paradigms or philosophic postulates, i.e., unproven and improvable statements used as the basis to construct a system of ideas or concepts. Hence, they should be treated as such.

The “rock-time model” is logically consistent, however, with the actual (current and historic) stratigraphic (i.e. scientific) methodology, and as a theoretical basis to construct the geological timetable, allows one to proceed from facts or observations to interpretation and inference, and not *vice versa*. This is why the “time-rock model” is rejected, and must not be used as a theoretical basis to construct the geologic timetable.

### Paradigms

We consider it necessary to discuss the concept of paradigm because the generation of scientific knowledge largely depends on the underlying adopted (explicitly or implicitly) form of reason-

ing, as well as the assumptions methodologically related to it; i.e., the **paradigms** (cf. Appendix II). For instance, in geological sciences, the replacement of the Wernerian/geognostic- for the Uniformitarian/gradualistic-paradigm, or that of the geosyncline/fixist- for the plate tectonics paradigm-provided a very different approach to studying and interpreting geologic phenomena. Zalasiewicz et al. (2004) basically propose unifying chronostratigraphy and geochronology into a single discipline, “chronostratigraphy.” Thus the need of abandoning the current dual stratigraphic classification terminology follows, which they (implicitly) regard as an obsolete paradigm. Further, they anticipate (Zalasiewicz et al. 2004, p.4) that the replacement would not be an easy, swift process, a common problem with paradigms. Is unifying chronostratigraphy and geochronology into a single discipline (“Chronostratigraphy”) a paradigm? Let us examine this question.

The paradigm entry in the Encyclopedia-Britannica Online [Encyclopedia-Britannica 2008] provides its current definitions (included in Appendix II), as well as an explanatory excerpt from a leading philosopher and historian of science. On this basis, it could be established that paradigm is a set of practices that define a scientific discipline during a particular period of time, which are regarded as exemplary. Prevailing paradigms represent specific ways of viewing reality, thus setting limitations on observing, researching and/or interpreting them beyond the more general scientific method. Paradigms are epistemologically unique and self-supported, hence, a “new” paradigm that replaces an “old” is not necessarily better, because the criteria of judgement depend on each paradigm. In a way, paradigms are cognitively similar to postulates, but of a more general scope.

It follows that unifying chronostratigraphy and geochronology is not a paradigm, but an unsupported assertion as shown below [cf. (C) Critical assessment of the LonPro tenets], and that the permanency of the dual stratigraphic terminology stems from the need for keeping evidence separate from inference, and not from the conservatism of the scientific community, usually non-amenable to new paradigms.

## CRITICAL ASSESSMENT OF THE LONPRO TENETS (AS EXPRESSED IN ZALASIEWICZ ET AL. 2004, P. 4)

### Tenet 1

The practice of chronostratigraphy today defines the time framework of geochronology, because intervals of geologic time are now being precisely defined within rock successions by GSSPs golden spikes.

#### Considerations:

(a) The semantic questions presented in the assessment above (cf. p.11) are sustained.

(b) In the foregoing discussion (cf. Points B.1, B.2 and B.4) it was shown that intervals of geologic time become meaningful through the events selected to define them, that such geologic events are recorded in rock successions, i.e., chronostratigraphic units, whose boundaries are postulated isochronous surfaces worldwide; these units also become the basis to infer in precise lockstep fashion the corresponding time intervals, that is the so determined geochronologic units.

(c) Given the mixed nature of chronostratigraphic units [cf. Consideration (g)], and the fact that most events historically selected to define this kind of unit (largely bio- and lithogenetic

ones) proved to be *diachronous*, subjectivity is unavoidable, whence precisely defining chronostratigraphic units' content and/or boundaries have been an endless source of controversies.

(d) Such controversies are objectively unsolvable, therefore international agreement became an appropriate way to pragmatically resolve them. This has required following a fairly elaborated procedure, whereby a group of experts vested with formal authority to know and resolve controversies of this kind, after duly pondering the views of interested parties, as well as the public response they elicited, they make a decision, which is binding and internationally accepted.

(e) Historically, the International Commission on Stratigraphy (ICS) created in Bologna 1881, discussed the issues, took decisions during the IGC sessions, and published results in the corresponding IGC proceedings (cf. Appendix I). However, in the IGC 22<sup>nd</sup> Session, New Delhi 1964, the management of all IGC commissions (including the ICS) was transferred to the International Union of Geological Sciences (IUGS, created in Rome 1963), whereby IUGS publications and not IGC proceedings have been, the media to disseminate decisions on stratigraphic matters since.

As discussed earlier, during the IGC 18<sup>th</sup> Session, London 1948 emphasis on the definition of chronostratigraphic units shifted from the content (unit stratotype) to the boundaries (boundary stratotype). This change eventually led to the establishment of the GSSPs. During the IGC 23<sup>rd</sup> Session, Montreal 1972, setting of the first GSSP was approved, and became implemented later (McLaren 1977); it refers to the Lochkovian Stage lower boundary, which because of the hierarchical arrangement of chronostratigraphic units, also defines the base of the Devonian System, as well as the Silurian/Devonian Systems boundary. Guidelines for boundary stratotypes, though were published somewhat later than the Montreal 1972 approval (Hedberg 1976; Cowie 1986; Salvador 1994; Remane et al. 1996).

(f) Is GSSPs practice qualitatively and conceptually different from pre-GSSPs practice? Certainly not, it only adds precision and international acceptance to the boundaries of chronostratigraphic units *already established*. Does GSSPs practice define the time framework of geochronology, because intervals of geologic time are now precisely defined within rock successions by golden spikes? Again, the answer is *no*, because the time framework of geochronology was established almost since the inception of Stratigraphy and Geology as sciences (cf. Appendix I), becoming formally defined during the IGC 2<sup>nd</sup> Session, Bologne, 1881, as the dual time-rock/time classification systems.

(g) Finally, does the GSSPs practice erase the conceptual difference between chronostratigraphic and geochronologic units? Once more the answer is *no*, as shown below:

*Chronostratigraphic units* (cf. Appendix II) are mixed entities with (1) a **material component**, in which the rock succession is a record of the past bio- and lithogenetic events-set chosen to define the unit, postulating that its boundaries (lower and upper) extend worldwide as isochronous surfaces, and (2) a **non-material component**, which is the duration of the chosen events-set, with a beginning and end that respectively coincide with the lower and upper boundaries (mentioned above). Further, these boundaries are postulated to correspond to specific points ("instants") in the geologic timetable.

*Geochronologic units* (cf. Appendix II) are the time intervals corresponding and/or defined by chronostratigraphic units. By their very nature, geochronologic units are conceptual and inferential; they are not independent segments of geologic time or of physical time, but become meaningful by the geologic s.l. events recorded in the rock succession that is designated as a specific or particular chronostratigraphic unit.

A geochronologic unit's beginning and end are recorded by the corresponding lower and upper boundaries of the defining chronostratigraphic unit, which are postulated to be isochronous surfaces worldwide, and now GSSPs practice to highlight stages by "golden spikes;" such boundaries most frequently correspond to flow-events. By the same token, the rock succession's space subtended between the lower and upper golden spiked-marked boundaries (i.e., the chronostratigraphic units), actually correspond to the duration of the chronostratigraphic unit's defining geologic s.l. events-set. It follows that in no way physical time [instants or intervals] is directly defined by GSSPs, as Zalasiewicz et al. (2004) maintain. Events-free time intervals are mere abstractions and have no reality. In short, chronostratigraphic and geochronologic units although related, *are conceptually different*. Golden spikes are not fixed on any rock succession, but precisely in successions that are already recognized as chronostratigraphic units; thus fixing them otherwise would generate *geologically meaningless time intervals*.

It should be noted that the GSSPs methodology faces the real danger of using *ad hoc* marker events/records to precisely define boundary stratotypes most useful for correlation; unit stratotypes by themselves have little significance. The process of selecting sections and boundaries, however, may be arrived at by deductive reasoning, the premise being the hypothesized global extent and geological superiority of certain events/records, for defining the "best" boundaries of already **preconceived** chronostratigraphic units and/or geologic time intervals; therefore such events are chosen for this purpose. The chief criterion to select events/records to define GSSPs is their global correlation potential. The pertinent historically accumulated knowledge on the subject remains subservient to this purpose.

(h) Considerations (a) to (g) leads to rejection of Tenet 1.

## Tenet 2

The effect of Tenet 1 is that chronostratigraphy and geochronology (in the senses of time-rock stratigraphy and geologic time stratigraphy, respectively) should become one and the same discipline, as Harland et al. (1990) realized. For this discipline, we propose to keep the name "chronostratigraphy," which in the sense of this paper is the definition and application of a hierarchy of eons, eras, periods, epochs and ages. (N.B. Harland et al. [1990, p. 21] prefer retaining the term "stage" instead of "age," to liberate the word "age" for general use; this solution might ultimately prove optimal). However, capitalization of the formal geochronologic unit, Age, preserves the distinction of the informal term, age, for general usage.

## Considerations

(a) The Considerations (a) to (g) that led us to reject Tenet 1 equally apply to Tenet 2, however we elaborate further as follows:

(b) The definitions of chronostratigraphy ("in the sense of time-rock stratigraphy," or "the defining of use of time-rock units, e.g. Cretaceous System,"), and geochronology ("in the

sense of geologic time stratigraphy,” or “the defining of use of units of stratigraphic time, e.g. Cretaceous System”) provided by Zalasiewicz et al. (2004, p. 1) are cognitively incomplete, whence for assessing this tenet, we have resorted to follow the most frequent definitions of stratigraphy, chronostratigraphy and geochronology (cf. Appendix II), as shown below:

*Stratigraphy* is the scientific study of the shape, dimensions, and spatial relations of the rock masses forming the Earth’s crust, organizing them on the basis of their inherent characters into mappable geologic units, and detecting the space/time relation of the lithogenetic events which they recorded and represent, for reconstructing the Earth’s history.

*Chronostratigraphy* is the element of Stratigraphy that deals with the relative time relations and ages of rock bodies (ISG, Salvador 1994, p. 113).

*Geochronology* is the science of dating and determining the time sequence of events in the history of the Earth (ISG, Hedberg 1976, p. 15; 2<sup>nd</sup> Edit., Salvador 1994, p.16); it includes *Geochronometry* as its branch dealing with the quantitative (numerical) measurements of geologic time in thousands or millions of years (*Glossary of Geology* 4<sup>th</sup> Ed., 1997).

This comparison demonstrates that chronostratigraphy and geochronology *are conceptually different*, and consequently, can not become one and the same discipline; their distinction may be regarded as subtle, but real, and as different as algebra and arithmetic, or the operations thereof.

Additional support comes from the persistence of the dual geologic time/time-rock classification systems, which confirms the need to keep separate the interpreted inference (i.e, time intervals, dating, duration, correlation, etc.) from the evidence (i.e, the geologic rock successions regarded as geologic s.l. events-sets that define time-rock units, both in the global standard section or locality and elsewhere), which must remain fixed, whereas the interpretation can always be improved with the advancement of science. If the persistence of both systems has occurred because they “... are effective ways of looking at Earth’s history with a time interval in one hand, and in the other, geologic succession laid down during that time interval” as claimed by Zalasiewicz et al. (2004, p. 4), the reality of this need is further supported, but see Discussion, B.1 and B.4 above.

(c) Should Tenets 1 and 2 be well founded and accepted, the term “chronostratigraphy” acquires a meaning quite different from the one commonly understood in geology s.l.; its use as such would cause needless conceptual and nomenclatorial problems, which would foster confusion within and outside geological sciences. The same would occur with the terms eons, eras, periods, epochs and ages.

(d) The possible replacement of stage for age (Harland et al. 1990, p. 21) is unacceptable, because it would add another meaning to the already complicated conceptual and nomenclatorial history of stages (cf. Discussion, Point B.4c), and again it would promote confusion.

(e) Given the above, Tenet 2 is left with no support, and should be discarded.

### Tenet 3

The terms eonothem, erathem, system, series and stage (see above) thus become formally redundant, although they may continued to be used informally.

#### Considerations:

(a) The demonstrated lack of support of Tenets 1 and 2 removes all foundations to this tenet.

(b) Using these terms with a different connotation from that already well known in the geological sciences leads to confusion, because of the needless conceptual and nomenclatorial problems involved; such confusion may extend beyond the geological sciences, thus making difficult communication across disciplines now that is most needed.

(c) Considerations (a) and (b) suffice to discard Tenet 3.

### Tenet 4

The time units defined by chronostratigraphy may be qualified by “early,” “middle,” (“mid-“ in UK terminology) and “late,” but not “lower” and “upper.” As an example, one would not speak of e.g. a lower January snow accumulation. The qualifiers “lower,” “middle,” and “upper” continue to be applicable to the rock bodies of lithostratigraphy.

#### Considerations:

(a) The first sentence is a truism, because time units independently of how are they defined, must be qualified by temporal adjectives (e.g. early or late), not by spatial ones (e.g. lower or upper); the adjective middle has both connotations (temporal and spatial), unfortunately.

(b) This sentence also leaves a legitimate semantic doubt: either the term chronostratigraphy in Tenet 3 is used in a different sense than that employed in Tenet 2, or such difference does not matter.

(c) Following Tenets 1 and 2, time units are defined by GSSPs within rock successions, their lower, middle and upper parts logically correspond to the early, middle and late portions of such units, however the adjectives lower and upper could not be applied to them. If indeed chronostratigraphic and geochronologic units were conceptually the same, as the first sentence of Tenet 1 logically demands, this no-application is incongruent.

(d) It is said that “The qualifiers lower, middle. and upper continue to be applicable to the rock bodies of lithostratigraphy.” This statement *de facto* restricts the application of such qualifiers to the rock bodies of lithostratigraphy. What about other materially-based rock bodies, e.g. biostratigraphic, allostratigraphic and magnetostratigraphic units? Further, one could well apply these spatial qualifiers to chronostratigraphic units, e.g., Upper Phanerozoic Erathem, Lower Cambrian System, Middle Jurassic Series, Upper Albian Stage.

(e) Finally, the wording of this tenet implies a recognition that the time-rock (i.e. chronostratigraphic) units are *different* from geologic time units, and therefore that chronostratigraphy and geochronology are not one and the same discipline; given their purported conceptual identity, both sets of qualifiers would be interchangeable. The fact that they are not demonstrates their intrinsic difference, as expressed in the example proposed by Zalasiewicz et al. (2004).

(f) Considerations (a) to (e) lead to disregard Tenet 4.



**Tenet 5.** The time units defined by chronostratigraphy are founded within strata, but encompass all rock on Earth.

### Considerations

(a) Taken at its face value, this is a declarative statement, to accept it requires prove of its reality (i.e. truth). Nowhere in the Zalasiewicz et al. (2004) paper is this concept discussed, so it stands as an unsupported affirmation. Epistemologically this statement is a kind of *postulate*, i.e., a methodological assertion that serves as a basis to construct a system of ideas or concepts, like the postulates of Euclidean Geometry. The veracity of postulates is out of question. Postulates remain valid or useful as long as logical deductions/conclusions based on them do not lead to contradiction.

To avoid this conceptual pitfall, we explicated [cf. (Discussion, B.4.c-4.d) and Tenet 1, Consideration (g)] that the boundaries of chronostratigraphic units are postulated to be isochronous surfaces worldwide; it logically follows that although they were originally defined in stratal rock successions, they also include all coeval rock bodies on Earth, regardless of their lithic makeup. It also follows that time units (i.e. geochronologic) “defined by chronostratigraphy” or properly stated: The time units defined by chronostratigraphic units, include all demonstrably coetaneous rock bodies on Earth, regardless of their lithic composition.

(b) The second part of the sentence (“...but encompass all rock on Earth:”) is semantically questionable, given that chronostratigraphy deals with bodies of rock not rocks by themselves, and that both concepts refer to objects that have different levels of organization, as well as different attributes, which are unique to each level and can not be transferred across level boundaries.

(c) Both the North American Stratigraphic Code (NACSN 1983, 2005), including its predecessors (ACSN 1961, 1970), and the International Stratigraphic Guide (Hedberg 1976; Salvador 1994) formally recognize that chronostratigraphic and geochronologic units apply to all rock bodies on Earth, regardless of their lithic composition. So the provision made by Zalasiewicz et al. (2004) has been standard practice in North America and elsewhere for many years, thus it needs no reiteration.

(d) Tenet 2, Consideration (b) applies here too.

(e) Considerations (a) to (d) support disregarding Tenet 5.

### Tenet 6

The term “geochronology” reverts to its vernacular usage of referring to dating and ordering geologic events, particularly by obtaining numerical estimates of time, through, among others, radiometric dating and the counting of Milankovitch cycles.

### Considerations

(a) Discussing Tenets 1 and 2 shows that chronostratigraphy and geochronology are related, but conceptually different disciplines, and that therefore, they could not be merged into single discipline (“chronostratigraphy”).

(b) As shown in Tenet (2), Consideration (b), Geochronology as currently understood is the science of dating and determining the time sequence of events in the history of the Earth (ISG, Hedberg 1976, p. 15; and 2<sup>nd</sup> Edit., Salvador 1994, p.16); it in-

cludes *Geochronometry* as its branch dealing with the quantitative (numerical) measurements of geologic time in thousands or millions of years. (*Glossary of Geology* 4<sup>th</sup> Ed. 1997). Thus geochronology as currently understood and used needs no reversion to a purported “vernacular” usage of “referring to dating and ordering geologic events, particularly by obtaining numerical estimates of time, through, among others, radiometric dating and the counting of Milankovitch cycles.”

(c) Considerations (a) and (b) lead to discard Tenet 6.

### Further Assessments, Part A

Throughout the paper, Zalasiewicz et al. (2004) made other assertions supporting their tenets. We feel it necessary to addressed those not directly discussed before. Particularly, they hold (Zalasiewicz et al. 2004, p.2) that the distinction between geochronologic and chronostratigraphic classification, as well as their (further combined) distinction from “numerical” time classification, causes these undesirable results: (á) [It] “... blurs the essential simplicity of stratigraphic classification, ...” (â) [It] “... is a significant barrier to understanding, not least as regards extending the messages within stratigraphy (biotic evolution or environmental change) to the lay people.” (ã) [It contradicts the fact that] “It is important to preserve this fundamental simplicity today, when the oft-quoted “holy trinity” of rock, time, and fossils has been joined by a host of other types of stratigraphy, such as those employing paleomagnetic reversals, or the sedimentary signature of Milankovitch climatic cycles.” (ä) “The term “geochronology” as applied to periods, epochs and so on does not reflect its mainstream vernacular use (e.g. Bates and Jackson, 1987).” “Isotope geologists ... consider themselves to be geochronologists (not geochronometricists) working on geochronologic problems of geochronology; they do not use the term geochronometry (and neither do mainstream geologists) in their every day work.” Below we separately address these claims.

### Assertion

It blurs the essential simplicity of stratigraphic classification.

*Assessment:* Given that Stratigraphy is the scientific study of the shape, dimensions, and spatial relations of the rock masses forming the Earth’s crust, organizing them on the basis of their inherent characters into mappable geologic units, and detecting the space/time relation of the lithogenetic events which they recorded and represent, for reconstructing the Earth’s history; the complexity of this discipline’s study object becomes evident. It follows that describing such many-fold objects can not be accomplished using a simple classification system, and that Stratigraphy’s *praxis* could not be inherently simple. In other disciplines, however, the same occurs, e.g. Cladistic Phylogenetic Systematics. Cladistic tenets seem simple and straight forward, but their application is far from simple, yet this science is widely practiced today. So, the “essential simplicity of stratigraphic classification,” remains to be proven.

### Assertion

It is a significant barrier to understanding and to communication, not only within stratigraphy [biotic evolution, environmental changes, etc.], but also for the layman.

*Assessment:* This distinction has not hampered communication within the geologic community s.l., particularly among different specialists, as evidenced by the host of works on organic evolution or environmental change through time that use either

or both classification systems to best meet the particular needs. Although more communication is desirable, it is up to the specialists to decide and make the effort to cross discipline barriers. The dual chronostratigraphic/geochronologic classification system *per se*, plays no part in this decision-making. Further, this distinction has not hampered communication and understanding between the scientists and the laymen either. It is up to the former to make themselves understood by the latter. The large assortment of popular books on Geology and related sciences reflects its high demand, thus witnessing the success of such communication.

### Assertion

It undermines the fundamental simplicity of stratigraphic classification, now that other types of stratigraphy, e.g. Magnetostratigraphy and Cyclostratigraphy require to use it.

*Assessment:* First, as shown above, the fundamental simplicity of stratigraphic classification remains to be proven. Second, the manifold stratigraphy's object, i.e. the material record of past geologic s.l. events could be approached from different aspects, whereby particular kinds of event-signals could be organized (i.e. stratigraphically classified) into particular kinds of stratigraphic units, which in turn could ultimately be assigned to standard chronostratigraphic/geochronologic units. This process requires of course, the presence and recognition of the appropriate link-events/records that would confidently allow dating and correlating such units with the standard ones.

It follows that the work of specialists such as magnetostratigraphers, geophysicists, and "cyclostratigraphers" has actually been facilitated by keeping separate the geochronologic and chronostratigraphic classification concepts and/or units. The material record of the geologic s.l. events they are concerned with is referred to and compared with chronostratigraphic units (i.e., the record of geologic s.l. events-set established as standard global reference). Only through this process such events become geochronologically/geologically meaningful. The work of these specialists has greatly improved our understanding of Earth's history, not *vice versa*, as it would have occurred should this claim be true. Also, the stratigraphic units used by many of these specialists parallel the dual geochronologic-chronostratigraphic classification: for example, the Polarity-Chronologic and Polarity-Chronostratigraphic Units of magnetostratigraphy (NACSN, 2005; Salvador, 1994).

### Assertion

The term "geochronology" as applied to periods, epochs and so on does not reflect its mainstream vernacular usage." Radioisotope geologists regard themselves as geochronologists working on geochronologic problems; they do not use the term geochronometry in their every day work:

*Assessment:* First, the conceptual restriction of "geochronology" to the application of time divisions, e.g. Periods, Epochs, etc. is not supported, given that as shown above (cf. Tenet 2), Geochronology is the science of dating and determining the time sequence of events in the history of the Earth, and that it also includes *Geochronometry* as its branch dealing with the quantitative (numerical) measurements of geologic time in thousands or millions of years. Therefore, the radioisotope geologists rightly regard their work as geochronologic, taking Geochronology in the sense defined above.

Second, for argument's sake, let it be granted that: "The term 'geochronology' as applied to periods, epochs and so on does not reflect its mainstream vernacular use (e.g. Bates and Jackson 1987)." According to the *Webster's Dictionary*, "vernacular" is a qualifier for referring to common, non-technical, or non-standard names, concepts, things, etc. Zalasiewicz et al. (2004, p. 2) furnish a single evidence to support their claim, the *Glossary of Geology*, 3<sup>rd</sup> Ed., a technical reference, which includes "geochronology" in the sense of these authors, as one of this discipline's several definitions; thus this reference does not afford sufficient support to their contention. Further, one would have expected citations of numerous popular books on Geology and/or related sciences, rather than a single reference to a technical book. In addition, later editions of the *Glossary* define geochronology in the sense applied in the previous paragraph. Summing up then, this contention lacks objective support.

### Further Assessments, Part B

Zalasiewicz et al. (2004) fully express their position on the chronostratigraphic/geochronologic terminology issue in this statement: "Two main purposes are generally adduced for time-rock classification. First it provides a convenient shorthand to refer to strata..." Second, it provides a time-based classification of strata (physical realities) separate from deductions (elapsed time intervals)." "...the dual terminology may be said to separate the evidence (the rocks) from the inferences (the time). However we do not find this argument compelling. It is a truism that our knowledge of Earth's history comes from the rock record, and also that a our grasp of any time plane is derived from the plexus of preserved events in the rock record above and below any GSSP. However, our inferred geologic time intervals cannot be said to be separated from the physical reality of the strata: these intervals, and their boundaries, are now created and modified (and may be abolished) in precise lockstep with our observation-led decisions on the rock record. Whatever the constraints on our ability to date and correlate a GSSP, there is no doubt that, at a chosen location, it marks the passage of a unique instant of elapsed time. It is this unique time plane that we attempt to correlate, however imperfectly, by whatever means possible." (Zalasiewicz et al. 2004, p. 3). This statement includes two major assertions, one of which involves six different claims; we shall separately address them all below.

### Assertion 1

One of chronostratigraphy's main purpose is to provide a convenient shorthand to refer to strata.

As discussed elsewhere [Discussion, Tenet 2, Consideration (g) and Tenet 5, Consideration (a)] chronostratigraphy and geochronology are conceptually different, as are the units of their respective classification systems; hence they could not be unified into a single discipline. However, for argument's sake let us suppose that they are. Could it be true that chronostratigraphy's and geochronology's descriptive functions seem duplicated? The statements below convey this impression: "... monograptid graptolites are characteristic of the Silurian System." "... the monograptid graptolites are characteristic of strata laid down during the Silurian Period." (Zalasiewicz et al. 2004, p. 3).

The impression is erroneous. The Silurian strata bear monograptid graptolites, given that among other lithogenetic events and bioevents, these graptolites were chosen to define the time-rock unit Silurian System; from it, postulating that this unit's lower and upper boundaries are isochronous worldwide,

and that they correspond to the beginning and end of the defining time-rock unit's geologic s.l. events-set, then and only then, the time elapsed between the beginning and end of such events becomes a particular geologic time unit, in this instance, the Silurian Period.

This reasoning evidences that the “descriptive functions” of chronostratigraphy and geochronology are not duplicated. The shorthand expression “...monograptid graptolites... are common in the Silurian” is just a convenient, informal way of referring to strata. However the making of such kind of conveniences, *is not one of chronostratigraphy's main purposes.*

## Assertion 2

The contention that “the dual terminology does not separate the evidence (the rocks) from the inferences (time),” is supported in the quoted statement by six arguments; we discuss each of them separately below:

*Claim 2a.* “It is a truism that our knowledge of Earth's history comes from the rock record, ...”

*Consideration (a)* It indeed would be one, if such knowledge would result from our mere, effortless observation of the rock record, but it does not, as shown below:

The expression rock record implies that the material rock body or rock mass *is interpreted* as the record of the past lithogenetic events that generated it. Without this mental operation, rocks, rock bodies or rock masses are merely three-dimensional bodies that occupy a specific or limited portion of space, and *have no time or historic significance* whatsoever.

Current Earth's history knowledge is the result of a complex integration of very diverse information and/or data on the material record of geologic s.l. events from many parts of the planet, which have properly been interpreted, dated, correlated and placed in the “standard” geologic timetable. To make a truism of this highly complex operation is objectively wrong.

*Claim 2b.* “... and also ...” [it is a truism] ... “that our grasp of any time plane is derived from the plexus of preserved events in the rock record above and below any GSSP.”

*Consideration (a)* As discussed earlier (cf. B.1 above), the time frame of stratigraphy is the same as that the one used in other sciences and in everyday life, it is physical time, i.e., a uni-dimensional *continuum* of world-wide instants [i.e. “world-wide instant-thick time slices”] that endlessly succeed each other, the present one being the reference for past and future instants; hence time has an inherent polarity (from past to future), and is independent of matter. In restricted segments of time (i.e., in time intervals) an event or condition exists or continues. Further, it is only through events (i.e. happenings) that intervals become meaningful, that is acquire reality; “empty,” “happenings-free” time intervals are mere abstractions, and have no reality. In consequence, there is no such a thing as “time plane,” given that planes or surfaces are spatial attributes or properties of material entities, not of temporal ones.

*Consideration (b)* It was also discussed [cf. Discussion, B.4.c-4.d and Tenet 5, Consideration (a)] that for methodological reasons, the boundaries of chronostratigraphic units [i.e., the three-dimensional-material rock record-bodies used to infer time, as well as to meaningfully integrate information to pro-

duce (a coherent) geologic history], *are postulated isochronous surfaces worldwide.* Only then one can say that “time planes” could be “grasped” from the material record of events *defining* the chronostratigraphic units above and below GSSPs. These mental operations and procedures are not truisms, on the contrary they must be kept in mind to do objective (i.e. valid) stratigraphic work, not merely stating one's preferences or pre-conceived ideas or opinions.

*Claim 2c.* “However,” [given the above “facts,” it follows that] “our inferred geologic time interval cannot be said to be separated from the physical reality of the strata: ...”

*Consideration (a)* This contention is erroneous. It has been shown [cf. Tenet 1, Consideration (g)] that chronostratigraphic and geochronologic units are conceptually different. **Chronostratigraphic units** are mixed entities, *partly material* (the rock successions as records of the geologic s.l. events-set selected to define one such unit, whose lower and upper boundaries are postulated isochronous units worldwide; they include all demonstrably coeval rock bodies on Earth, regardless of their lithic makeup), and *partly nonmaterial* (the duration or time span of the above mentioned events-set).

On the other hand, **geochronologic units** are nonmaterial entities, the portions of geologic time strictly inferred from the corresponding chronostratigraphic unit; their beginning and end are postulated to coincide with the lower and upper boundaries of the given chronostratigraphic unit. Geochronologic units, “chronomeres” or specific portions of (geologic) time only become meaningful through the chronostratigraphic unit's defining geologic s.l. events-set. It follows that specific geologic time intervals (i.e., geochronologic units) could only be recognized through (the identification of) the rock record of the geologic s.l. events-set chosen to define the chronostratigraphic unit.

*Consideration (b)* Summing up then, the dual chronostratigraphic/geochronologic classification effectively keeps separate evidence (chronostratigraphic units) from inference (geochronologic units)

*Claim 2d.* [Further, it could be said that] “...these intervals and their boundaries, are now created and modified (and may be abolished) in precise lockstep with our observation-led decisions on the rock record.”

*Consideration (a)* Geochronologic units (“these time intervals”) **not only now** but throughout the history and practice of Stratigraphy (cf. Appendix I) always have been “created and modified (and might have been abolished) in precise lockstep with” “observation-led decisions on the rock record” made by scientists who formally proposed them.

*Consideration (b)* As shown above, the reason for such practice is that time units have been conceived (implicitly first, and explicitly since the early 1800's) as inferred “time concepts” from specific portions of the geologic s.l. events-rock record, which constitute specific chronostratigraphic units.

*Consideration (c)* The arguments above leave this contention without support.

*Claim 2e.* [In conclusion] “Whatever the constraints on our ability to date and correlate a GSSP, there is no doubt that, at a cho-



sen location, it [i.e. the GSSP] marks the passage of a unique instant of elapsed time.”

*Consideration (a)* As discussed previously, GSSPs mark the lower/upper boundary(ies) of a chronostratigraphic unit, which have been already established and recognized as such, whose boundaries are postulated isochronous surfaces throughout its extent as well as worldwide, and further, are postulated to coincide with the beginning and/or end of the defining geologic s.l. events-set of the chronostratigraphic unit being considered (i.e. of the given time-rock unit). Only through this conceptualization (i.e. mental process) “time” enters into the picture.

*Consideration (b)* Therefore, the GSSPs only mark the time-rock’s lower boundary postulated to correspond to the beginning of a geologic s.l. event, which most frequently is a flow-event, given that the known record of demonstrably truly instantaneous geologic events of continental extent, let alone worldwide, is quite meager. Therefore, GSSPs do actually mark beginnings/ends of geologic s.l. events, rather than as claimed, *events-free instants of elapsed time*

*Consideration (c)* The arguments presented above leave this contention without support.

*Claim 2f.* [A derivation from the conclusion] “Its is this unique time plane that we attempt to correlate, however imperfectly, by whatever means possible”.

*Consideration (a)* As discussed before (cf. 1 above) conceptually “time planes” do not exist, because applying spatial attributes to time is not logical.

*Consideration (b)* Accepting for the sake of argument the “reality” of time planes, it is questionable whether in stratigraphy we are solely concerned with correlating time planes “however imperfectly, by whatever means possible.” Just as important is the attempt to date and correlate seemingly coeval geological s.l. events/records from different parts of the world with the rock succession established as global standard (i.e., the chronostratigraphic unit stratotype). Such objective becomes crucial in working terrestrial and non-sedimentary rock bodies, where physical tracing of the chronostratigraphic units’ boundaries is equivocal or altogether impossible, given that chronostratigraphic units have (largely) been established in sedimentary marine rock successions (before and after GSSPs). Furthermore, the application of astronomically forced sedimentary systems methodology, which potentially allows unprecedented precision dating for most of the Phanerozoic, particularly demands the use of rock successions, given that boundaries do not furnish relevant information for these kinds of studies.

*Consideration (c)* Again, considerations (a)-(b) leave this contention without support.

## CONCLUSIONS AND RECOMMENDATIONS

Two underlying opposing views in chronostratigraphic/geochronologic stratigraphic classification/nomenclature have fostered a long debate and led to seemingly irreconcilable systems, one of them sees time-rock units as primary concepts, from which derive the concept of geologic time units; the other sees geologic time units as primary concepts and time-rock units as derived concepts. The first is expressed in the International Stratigraphic Guide and the North American Stratigraphic Code; the second is expressed in the Geological Society of London proposal to end “...the distinction between the dual

stratigraphic terminology of time-rock units (of chronostratigraphy) and geologic time units (of geochronology). The long held, but widely misunderstood distinction between these two essentially parallel time scales has been rendered unnecessary by the adoption of the global stratotype sections and points (GSSP-golden spike) principle in defining intervals of geologic time within rock strata.” The second proposal has the merit of eliciting a wide response, both for and against. Throughout the foregoing presentation and discussion, we have fairly analyzed it, and thus conclude as follows:

Chronostratigraphic and geochronologic units are conceptually different. *Chronostratigraphic units* are mixed entities, having a **material component**, the rock succession as record of the past geologic s.l. events-set chosen to define a particular such unit, postulating that its boundaries (lower and upper) extend worldwide as isochronous surfaces, and a **nonmaterial component**, which is the time duration of the chosen events-set, whose beginning and end coincide respectively with the lower and upper boundaries (mentioned above). *Geochronologic units* are the time intervals corresponding and/or defined by the chronostratigraphic units. By their very nature, geochronologic units are conceptual and inferential; they are not independent segments of geologic time, or of physical time. Geochronologic unit’s beginning and end are recorded by the corresponding lower and upper boundaries of the defining chronostratigraphic unit, (which are postulated to be isochronous surfaces worldwide), and now due to GSSPs practice, those of stages are highlighted by “golden spikes;” such boundaries most frequently correspond to flow-events. Given the above, to claim that “The time units defined by chronostratigraphy are founded within strata, but encompass all rock on Earth.” is a needless reiteration; further, its application has been standard practice for much of the history of geologic studies (cf. ACSN 1961; ISG, Hedberg 1976).

It also follows that the rock succession’s space subtended between the lower and upper golden spiked-marked boundaries (i.e., the time-rock unit), actually corresponds to the duration of the time-rock unit’s defining geologic s.l. events-set. Therefore, in no way is physical time (instants or intervals) directly defined by GSSPs. Events-free time intervals are mere abstractions and have no reality. In short, chronostratigraphic and geochronologic units although related, *are conceptually different*. Golden spikes are not fixed on just any rock succession, but precisely in successions that are already recognized as chronostratigraphic units; thus fixing them otherwise would generate *geologically meaningless time intervals*.

Combining in a single system of “chronostratigraphic units” (*sensu* Zalasiewicz et al. 2004) the chronostratigraphic and geochronologic units as currently understood, leads to the epistemological error of uniting *evidence* (rock successions as particular time-rock units) with *inference* (the interpreted duration of particular time-rock units’ defining geologic s.l. events-sets). Scientific methodology demands this separation, so that the evidence remaining fixed, is always available to all concerned, whereas the interpreted inference will change and be improved with the advancement of science. The geologic community realized this demand before the formal establishment of the dual time-rock and geologic time classification/nomenclature systems (IGC 2nd Sess., Bologna, 1881); in fact, satisfying this scientific methodological demand, was one of the driving forces that made this congress possible; it also accounts for the

permanency up to the present, of the dual stratigraphic classification/nomenclature systems.

The redundancy of the terms eonothem, erathem, system, series, and stage with the corresponding terms eon, era, period, epoch and age is not supported, because they are conceptually different, as argued above. Both the time-rock unit concept/term set and the geochronologic unit concept/term set address different aspects of Stratigraphy and must be maintained separate. Further, to combine the meaning of eonothem/eon, erathem/era, system/period, series/epoch, and stage/age into single concepts, now respectively designated “eon”, “era”, “period”, “epoch” and “age,” shall cause two deleterious effects: (a) It will produce needless nomenclatorial confusion, giving a different meaning to already well known and widely used geologic terms; and (b) it will induce the error of using spatial qualifiers (such as lower/upper) to time terms (e.g. era or age), rather than the appropriate temporal qualifiers (e.g. early/late).

“The claimed reversion of ‘geochronology’ to its mainstream and original meaning of numerical age dating,” made possible by adopting the above mentioned proposal, is untenable because, as currently understood, geochronology is the science of dating and determining the time sequence of events in the history of Earth; it also includes *Geochronometry* as its branch dealing with the quantitative (numerical) measurements of geologic time. Such measurements became feasible only since the 1960’s, before geochronology relied mostly on biostratigraphic methods to date and determine the time sequence of events in the history of the Earth; thus geochronology originally meant performing dating and determining the time sequence of events in Earth’s history. It follows that numerical age dating is not geochronology’s original meaning. Further, as shown above, geochronology and geochronometry are conceptually different; the restriction of geochronology to numerical age dating is a gratuitous assertion; as it is to claim that such conception of geochronology is the mainstream one.

Given that designating GSSPs for all Phanerozoic stages is nearing completion, and that all chosen sections by definition are/respond to sedimentary marine rock successions, it seems most appropriate to recommend complementing the GSSPs network with reference sections at high latitude sites constituted by sedimentary marine sequences, as well as in sedimentary continental rock successions, where other means of dating and correlation (e.g., geomagnetic polarity normal/reverse signatures, or demonstrably reliable mammal taxa) would ensure their dependable positioning in the global standard timetable. Finally, considering that the increasing study of astronomically-forced sedimentary systems, which potentially allows unprecedented precision dating, it is necessary to re-establish the designation of unit stratotypes as valid, complementary means to define chronostratigraphic units, particularly of stage and lower rank ones.

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## APPENDIX I

### HISTORICAL PERSPECTIVE OF STRATIGRAPHIC CLASSIFICATION AND NOMENCLATURE

#### Introductory statement

Basic treatment of Stratigraphic classification and nomenclature have been presented in many stratigraphy textbooks (cf. Grabau 1913; Gignoux 1950, 1960; Dunbar and Rodgers 1957; Weller 1960; Krumbein and Sloss 1963; Corrales et al. 1977; Schoch 1989; Vera 1994; Prothero and Schwab 2004; etc.), and at greater depth in monographic works dealing with geologic principles and history of Geology (cf. Zittel 1901; Geikie 1905; Albritton 1963; Conkin and Conkin 1984; Hallam 1992; etc.), and discussed and reviewed in papers devoted to it (cf. Harland 1970; Wiedman 1970; Vai 2007); regardless of it, we feel it appropriate to furnish a historical perspective on the development of stratigraphic classification and terminology (emphasis on chronostratigraphic/geochronologic aspects, cf. Tables 1-3), where not only the ideas and concepts are presented, but also the scientific/philosophical paradigms that underlined their development, as well as the intellectual atmosphere prevailing at the time they were made. This approach will allow the reader to objectively follow the “conceptual path” that led to the current situation, and it could help to find a way out.

#### Early work

Although much descriptive knowledge on minerals, rocks, and geomorphic features existed up to the Early Modern Age (middle 1600's), geology as a scientific endeavor owes very little, if any to Classical Antiquity. No theory of the Earth existed to guide mining, civil engineering works, or to explain the properties and origin of such natural objects and features as minerals, rocks, volcanoes, mountain ranges, seas, rivers, valleys, etc. It was through looking at nature with the fresh and direct approach brought about by the Renaissance, the exploration of *terra incognita*, driven by the prospect of finding new riches, the increment of international trade, and a general socio-economic improvement in Western Europe, that the stage was set for the Enlightening Era, which made it possible to pose key questions about the structure and origin of land features, and of the Earth as a whole. The answers were sought both inductively *via* empiric work on particular observations and problems (cf. Miall 2004), and deductively, proposing theoretical generalizations (on the basis of little objective evidence), models so to speak, which served as guides for further observations and confirmations.

It was in this atmosphere that Steno (1669), studying a territory in northern Italy described the stratigraphic principles of super-

position and horizontal continuity, hence according to some people, giving birth to stratigraphy; he recognized two fundamental, superposed rock units, thus producing the first “stratigraphic classification”. This is contested though, because: (a) There seems to be evidence that L. da Vinci (~1500) anticipated him (Vai 1995), and (b) Steno’s work remained nearly unknown, until it was translated to French in 1832 by de Beaumont (Zittel 1901, p. 26), more than 160 years later. Lister (1671), Hooke (1705) and Woodward (1728, 1728-1729) discussed on the importance of fossils for discriminating strata; the latter stressed the order and positioning of fossils within strata. However, Steno actually used his principles in the field to reconstruct geologic history, whereas Lister, Hooke, and Woodward presented them in a more abstract sense.

Economics of the Industrial Revolution demanded a greater amount of mineral resources (mainly iron and coal) and speedier transport and distribution of goods, which required extensive mining as well as the building of more and better roads (including rail-roads), thus promoting a close look at the territories where the resources lie, the roads that would be traversed, or dams and irrigation channels that would have to be built, and particularly about the makeup and physical properties of these minerals. As a result, much geologic (i.e., stratigraphic and paleontologic) groundwork was done in Western Europe (largely France, Germany, northern Italy and England) during the remaining 1700’s. Lehman (1756) in Germany and Arduino (1759) in northern Italy described stratal piles, and arranged the strata in three successive larger “groups”, thus establishing the first stratigraphic classification; the latter named such divisions *Primary*, *Secondary* and *Tertiary*, and added another, the Fourth Order Division (i.e. *Quaternary*) for the recent, unconsolidated material. Michell (1760) highlighted fossils as means of stratal discrimination and correlation. Guettard (1765) proposed an early version of uniformitarianism, by comparing fossil and recent sea shells, using the latter to understand the former.

Unfortunately, along with basic geologic work, it became fashionable in the academic world, to “over-interpret” the meager data-base then available, to support hypotheses (some quite fanciful) on the origin of the Earth, or of Earth’s major features (mountain chains, continents, oceans, etc., cf. Zittel 1901). One such hypothesis was Werner’s (1786) universal ocean theory, designed to explain the orderly successions of strata, as the result of sedimentation from a global ocean; interruptions of this process, caused by forceful (might even be catastrophic) Earth movements, which produced the boundaries of the major divisions. Earth’s geologic history could readily be discerned from the stratal record. Time was not a major concern. Earth was considered to be less than 6000 years old by European scientists at this time.

Werner improved on Lehman’s and Arduino’s work, and seemingly used Bergman’s (1766) ideas on physics (cf. Hedberg 1969b), to increase the number of stratigraphic divisions to five, culminating in the stratigraphic classification effort started by Steno’s (and da Vinci’s) bipartite scheme, followed by Lehman’s tripartite arrangement, and Arduino’s tetrapartite system. Werner’s pentapartite scheme is the most coherent one. In this “proto-stratigraphic” timetable or scale, the time component is derived from the principles of superposition; the divisions are rock bodies; and a repetitious or “cyclic” nature of the stratigraphic record is also implied. Werner’s model, arrived at by empirical inductive work, became a paradigm for his follow-

ers, who spreading out from Freiburg, attempted to describe and explain local geologic features anywhere, deductively applying this paradigm.

In Britain, another paradigm, uniformitarianism, was soon developed (Whitehurst 1786; Hutton 1795; both men understood the significance of angular unconformities); as the previous one, this paradigm was generated also by empirical/inductive work; both sought to explain geologic features involving the interplay of natural causes or factors still discernible and operating today; changes occurred gradually, thus implying the necessity long spans of time. The application of this paradigm required more empirical/inductive work. To make any sense out of so much local information, and to produce a coherent general geologic history, it was mandatory to establish the rock bodies’ order of succession in the local sections, somehow dating them, and then correlating them, i.e., establishing their time relations [simultaneity (full or partial) or succession/antecession), using the means then available: *Order of succession* (based on the principles of superposition and lateral extension), and *fossils* (based on the principle of faunal succession).

By the turn of the 18<sup>th</sup> Century, due to increased knowledge and economic demands, geologic work became more sophisticated: Better descriptions of rock bodies, including their spatial extent, and characterization among other descriptors became standard practice. Cuvier and Brongniart (1811, in France) and Smith (1815, in England) produced the first geologic maps; all of them systematically used fossil assemblages to discriminate and characterize the stratal rock bodies, stressing their order of superposition. Cuvier and Brongniart (1811) used for the first time the term **stage**, applying it to stratal rock bodies, and recognized sedimentary facies long before Gressly (1838) and Prevost (1845) named them. It should be noted though, that Marsili (1728) produced a geologic map, a column and cross sections of the southern Apeninnes, much earlier than Cuvier and Brongniart, or Smith. Marsili’s work, however remained nearly unknown (Ellenberger 1988; Vai 2006).

This trend away from theorizing resulted in the production of much detailed stratigraphic and paleontologic work, applying the “uniformitarian” approach. The characterization of stratal bodies included their “mineral” (i.e., lithic) makeup, thickness, geographic extent, stratigraphic position, and fossil content; the latter being important to trace the stratal bodies away from the initial study areas. A few examples of such works are: Cuvier and Brongniart 1811; Parkinson 1811; Richardson 1811; Schlotheim 1813; Brocchi 1814; Halloy 1822; Phillips 1829; Sedwick 1829; Murchison 1835; Orbigny 1849-1852.

The terms **stratum** (Greenough 1819), **formation** (Conybeare and Phillips 1822) and **system** (Murchison 1835) came into use then, but their meanings varied; all include, however some time-component derived from the principle of superposition, as well as a genetic connotation. Fossils were regarded as time indicators due to the principle of faunal succession, and as prime means of correlation, because their presence and orderly succession could be recognized regionally, even in stratal bodies with different aspects (facies) from those where they were initially studied (cf. Sedwick 1829; Lyell 1830-1833; Murchison 1835; Hunton 1836). Phillips (1829) and Hunton (1836) pioneered in using fossil taxa’s stratigraphic ranges (i.e., **zones**) in characterizing stratal bodies, the latter only used for subdivision of strata and, species whose distributions were well known.; Oppel

(1856-1858) used this concept most extensively and consistently.

Significant for the development of stratigraphic classification were the recognition of discordant stratigraphic relations (Whitehurst 1786, Hutton 1795; Cuvier and Brongniart 1811; Lyell 1830-1833, 1838), and of facies (Gressly 1838; Prevost 1845), because they have a bearing in assessing the time component of stratal bodies, and on establishing their correlation. Lyell's (1833, 1838) classification of Tertiary formations in chronological order formalized a quite different methodological approach, whereby Phillips' (1829) three criteria to date any given stratal set, *superposition*, *mineral character* (i.e. lithic composition), and *organic remains* were accepted, but the latter was used in a very peculiar way: The age of a stratal set is given by the percentage of living mollusks species contained as organic remains; he proposed a tri-partite classification of the Tertiary, coining the terms Pliocene, Miocene and Eocene for them; these terms could be regarded as a combination of chronostratigraphic, biostratigraphic and geo-biochronologic concepts, although others considered them as purely biostratigraphic (Berggren 1998). Lyell followed the precedent of Deshayes (1829, 1830), and in part that of Bronn (1831).

The term **stage** was introduced by Cuvier and Brongniart (1811), but Orbigny (1849-1852) and Oppel (1856-1858) extensively developed and used this concept. Orbigny's stages were stratal bodies ("formations") characterized by: (a) the composition of a fauna [it follows that in a succession of stages, a whole fauna that characterized a given stage, became annihilated and replaced by another, which is present in the succeeding stage], and (b) the extinction of genera or families (i.e., last appearance of fossil taxa); they were bound by unconformities, as witnesses of catastrophic events. Further, Orbigny regarded stages as worldwide in extent, and also having time significance (i.e., a particular duration and a unique temporal position in Earth's history); he named stages from geographic sites, -as Murchison (1835) did for geologic units-, and zones after a given species or group of species; throughout his work, however, zones and stages are used as interchangeable concepts.

So, in modern terms, Orbigny's stages are an inextricable combination of lithostratigraphic, biostratigraphic, allostratigraphic (synthem-like) and chronostratigraphic units (cf. Discussion, Point B.4.c); hence the convoluted development and use of this concept in later years, should not be surprising. Oppel (1856-1858), Quenstedt (1858), Arkell (1956) and others criticized the methodological diversity of definition, and the boundary-precision of some of Orbigny's stages, as well as his appeal to catastrophism, which seemed less "natural" than gradualism/uniformitarianism.

A review of Oppel's monumental work (1856-1858) shows that he repeatedly used the expression *Etagen oder Zonengruppen*, thus indicating that he conceived stages as groups of (very precisely defined) zones, and systematically used them in this sense throughout his work. It follows that Oppel's stages represent the recorded life range of the whole set of organisms present in the successive zones that make up a given stage. This is why a stage (usually a part of it) is easier to recognize region-wide than a zone is, and again, this is why they become very useful stratigraphic correlation concepts. In short Oppel stages are biostratigraphic units.

It was through the acceptance of the Darwin/Wallace evolutionary theory (Darwin 1859), and of its implication on the unidirectionality, irreversibility and uniqueness of life's evolution, that the fossil record was seen as a dependable time-keeper, which together with the principles of superposition and faunal succession, make it possible to construct a scientifically sound (beyond empiricism) and precise Earth's chronology or timetable, on the basis of the record of life' evolution, i.e., the fossil record scientifically studied and interpreted in consonance with this theory. Thus stages and zones acquired a temporal and or chronostratal significance, and became major components of the global geologic timetable (i.e., scale). Stages and zones have thus become essentially concepts similar to those in practical modern usage (cf. among others Spath 1923, 1931; Arkell 1933, 1956; Teichert 1958; Hancock 1977; Johnson 1979).

Under this new guise, however stages also became somewhat abstract, utilitarian concepts, which combine the roles of *time indicators* [i.e., "temporal-datum tellers" (both of position in the geologic timetable, and of duration of discrete sets of evolutionary events, and by extension, of the acknowledged coeval geological events "associated" to such sets), and of *means of correlation*, whose effectiveness to fulfill this role requires that stages be defined as precisely as possible (both in content and in the boundaries). This aspect is amenable to subjectivity, and we believe it has fostered endless disagreement, still going on at present, whose settlement has required international agreement.

#### **Emergence and maturation of the dual Chronostratigraphic/Geochronologic Classification and Nomenclature**

The basic conceptual groundwork of stratigraphy was completed by the early-middle 1800's: The principles of superposition, lateral continuity, faunal superposition were the key-tools to describe and characterize rock bodies; geologic work (stratigraphic and paleontologic) was conducted empirically/inductively; results were largely interpreted through the uniformitarian/gradualistic paradigm; an insight on the real magnitude of time was acquired; evolutionary theory allowed the perception of the fossil record as that of the unique, unidirectional, non-repetitive evolution of life, thus making it possible to be the basis of a sound Earth chronology, i.e., concisely expressed as a dependable geologic timetable; in fact, existing timetables based on other paradigms, were modified to adjust to current geologic knowledge and prevailing concepts, so that Paleozoic, Mesozoic and Cenozoic gradually replaced Primary, Secondary and Tertiary as major divisions of the stratigraphic record, and of Earth's history. Fossils were also regarded as appropriate means of correlation; actually long range correlation (i.e. inter-regional or intercontinental) although still in its infancy, was then already a fact. The significance of discordant stratigraphic relationships, facies and diachronism of both, rock bodies and fossil assemblages (cf. Huxley 1862), were fully realized. Tables 1-2 concisely express the chronostratigraphic/geochronologic classification and nomenclature proposals, from which the current systems ultimately stem; Table 3 is a selected *resumP* of formal chronostratigraphic/geochronologic classification and nomenclature systems through time up to the present, starting with Lyell's system (1830-1833) introduced in his influential *Principles of Geology*; the table intends to reflect the most important changes in conceptions, as well as in the prevailing underlying paradigms.

Western Europe politics also played a role in the development of stratigraphy, and of science in general at this time: historic



and economic rivalries of major nations led to a fierce competition for markets and commodities, thus exacerbating nationalism; whereas increasing commercial trade established strong and complex international ties, promoting a kind of “proto-globalization”. This contradiction permeated the academic world: nations conducted geologic work independently of each other, and with little coordination within each nation; this practice fostered significant differences among national groups, not only in the methodology, terminology and presentation of results, but also in the way they were integrated and communicated to others in and out of each country.

Such common terms as *formation* and *group*, were used both as “lithostratigraphic” and “chronostratigraphic” entities; *zones* and *stages* were differently characterized and defined; many local and provincial schemes were constructed, but it was hard to correlate them beyond the provinces or regions where they were proposed. At the same time, the realization that geologic phenomena transcended national boundaries, and that a coherent description of the Earth and of its history, beneficial to all concerned, could only be worked out through the meaningful integration of geologic information from all countries, it was essential to ease and promote communication, to do away with the barriers of local terminology, methodology, usage, and interpretation, and to establish a common understanding, meaningful to all concerned. This effort, although outwardly predicated by all, in practice seems an unfinished, endless task (cf. Vai 2001).

Under these circumstances, some stratigraphers saw international agreement as the most appropriate solution; Capellini (cf. Vai 2002a) was one of the driving forces to establish the International Geologic Congress (IGC hereafter). Vai (2007) ably reviewed the important role that international agreement has played in stratigraphy, particularly so on stratigraphic classification and terminology, and how such agreement has been reached in the IGC sessions. At the IGC Second Session, Bologna 1881 (Vai 2004), the dual chronostratigraphic and geochronologic hierarchical classification and nomenclature systems were established (see Table 1): grand division is the highest ranked category in both systems, *group* is the time-stratigraphic term, and *era* is the chronologic term. Division, first rank subdivision, second rank subdivision and third rank subdivision are succeeding down-ranked categories, the corresponding time-stratigraphic terms are *system*, *series*, *stage* and *substage* (i.e. *assise*); the chronologic terms *period*, *epoch* and *age* cover down to the second rank subdivision. The term *bed* is that of the lowest ranked category (i.e., the *n*<sup>th</sup> rank subdivision) of the time-stratigraphic classification.

In spite of the formal agreement, however, much dissension remained after the Bologna IGC Session: The chronostratigraphic unit stage was flatly ignored by North American stratigraphers, who instead used the term *group*, but down-ranked it much; a major departure from the agreed hierarchy; stages and zones were still very differently conceived. Many local to regional chronostratigraphic schemes, based on local to regional zones and stages were kept in use, and some new ones were added (cf. Zittel 1901; Geikie 1905; Conkin and Conkin 1984; Hallam 1992; McGowran 2005; Vai 2007; etc.). Summing up, although the chief purpose of the Congress was formally achieved, it produced very little change toward a common geologic “trans-national” understanding.

Decisions addressing particular stratigraphic items were adopted in the succeeding IGC Sessions. In the 8<sup>th</sup> Session, Paris 1900, the dual stratigraphic classification and nomenclature systems were slightly modified (CICS 1901; this work, Table 2); it is briefly expressed below by this word combination: the hierarchical rank is stated and coloned: followed by a binomial usually consisting of the chronologic term/time-stratigraphic term: first-order division: era/(no tempo-stratigraphic name provided), second-order division: period/system, third-order division: epoch/series, fourth-order division: age/stage; fifth-order division: phase/zone; however these concepts and terms were not formally adopted. No decisions on stratigraphic classification and nomenclature (structure or principles) were passed in the succeeding IGC Sessions.

Besides the IGCs, other factors influenced stratigraphic thinking during this period. Paramount in this is a revival of the Wernerian paradigm, in the guise of global diastrophic events becoming the ultimate basis of long range (global) stratigraphic correlation (Chamberlain 1898), and on the recurrent or cyclical nature of major stratigraphic events (Ulrich 1911, and Grabau 1936). Another important factor was the publication of the “Ashley Code” (1933, Classification and nomenclature of rock units), which was the first codification of stratigraphic procedures based on the 8<sup>th</sup> IGC decisions that were put in practice by a major country, and as such it became quite influential. The following chronostratigraphic (not so named) units, *system*, *series* and *group* are recognized (Art. 2); the corresponding chronologic divisions *era* (no chronostratigraphic equivalent unit name provided), *period* (system) and *epoch* (series) are presented (Art. 23); *formation* is regarded as the fundamental unit in local classification, and is defined on the basis of lithic characters, and also it is conceived as a genetic entity (Art. 6). Correlation by fossils is advocated. The “Ashley Code” does not explicitly deal with chronostratigraphic nor with geochronologic units. The relationships between these two kinds of units were developed by Schenk and Muller (1941), they distinguished and characterized three categories of units: *rock units*, *time-rock units* and *time units*, thus paving the way for the formal recognition of chronostratigraphic units; *zones* were considered as the lowest rank unit of the time-rock category.

### Refinement and Precision: The GSSPs and Beyond

This period spans from the second half of the 20<sup>th</sup> Century to the present, during it major changes in geology took place: The advent of the plate tectonics paradigm replaced the geosyncline as one of the appropriate theoretical bases of interpreting Earth’s makeup, dynamics and evolution. Ocean-floor studies allowed retrieval of orderly successions of geomagnetic signals that recorded ocean crust generation and permitted building a relative timetable of world-wide application. Radio-isotopic dating became extensively available, affording means to date and independently calibrate geologic events. Deep-sea drilling made it possible to study deep marine, seemingly uninterrupted successions, thus providing a reference for comparison with the much studied platform and marginal-oceanic successions. Extensive seismic studies, conducted in the search for oil and gas deposits, disclosed the presence of thick sedimentary packages of strata bound by unconformities, which appear to define regional (basin-wide) patterns, possibly recognizable world-wide; their systematic study produced sequence stratigraphy. Finally, the influence of astronomic motions on the Earth’s climate and through it on sedimentation, produced repeated patterns that were becoming understood, its acceptance and systematic study leading to the emergence of cyclostratigraphy, and opening the

way to a precise, global, high-resolution event stratigraphic correlation in the range of a few thousands of years. It is worth noting, as Vai (2007) remarked, that in spite of such major conceptual and paradigmatic changes, basic stratigraphic classification and nomenclature systems (as well as the theoretical/methodological basis on which they were created), being always regarded as essential elements of communication, have been actively preserved (Vai 2002b), and, thus, allowed for expression of the results of new research, with only minor adjustments needed (cf. Table 3).

Clearly then, the stage is set for an extensive integrating and synthesizing effort, whereby stratigraphy remains at the center of it; stratigraphy should provide a much needed common ground for communication, namely a carefully built **geologic timetable**, whose component units could be unequivocally and holistically recognized and/or identified world-wide, i.e., the recognition must occur not only through unit boundaries, but also through the unit contents. Again this effort coincides with the globalization trend that currently permeates all aspects of human endeavor, although it is glaringly obvious in economic trade, electronic communication, science, arts and technological transfer. In the remainder of the paper, we shall see how the stratigraphic community is meeting this challenge.

In the IGC 18<sup>th</sup> Session, London 1948, a shift in the definition of chronostratigraphic/geochronologic units occurred, whereby the emphasis of definition no longer relied on the unit's content (i.e., the stratotype), but on the unit's boundary (i.e., the boundary stratotype). The key feature of this procedure (we refuse to call it a new paradigm) was/is to select and permanently mark by international agreement, a bedding plane within a fossiliferous marine stratal section and locality, which will serve as the acknowledged global standard boundary between succeeding overlain chronostratigraphic units, and by strict inferential correspondence, it would also separate succeeding geochronologic units. This procedure actually reduces the bedding plane to a particular point in a specific stratal section, whence the name Global Stratotype Sections and Points system, acronymed GSSPs; other terms used to refer to this procedure are: boundary stratotype-, bench mark-, golden spike- and auri-methodology or chronostratigraphy. At any rate, such procedure basically is a delayed reaction to overcome diachronism, a problem detected long ago. The procedure is accomplished by appealing to internationally agreed, conventional decisions, which once approved, become binding [see (C) below].

The IGC 21<sup>st</sup> Session, Copenhagen 1960 included the publication of the "*Statement of principles of stratigraphic classification and terminology*," whereby the **litho-, bio-, and chrono-stratigraphic triad** became disseminated world-wide. The Code of Stratigraphic Nomenclature (ACSN 1961), resulting from a ~15 year effort of many North American stratigraphers, expressed similar views; hence, it is clear that such efforts antedated the IGC publication, and actually largely inspired it. From the next IGC Session, New Delhi 1964 onward, all IGC commissions including the long-standing International Commission on Stratigraphy, ICS, were turned over and administered by the then recently formed (Rome, 1963) International Union of Geological Sciences, IUGS; thus, matters concerning formal stratigraphic terminology were taken up by IUGS, hence its publications are since then the media to discuss and publish on such matters (Vai 2007).

In the IGC 23<sup>rd</sup> Session, Prague 1968 (unfinished), the International Geological Correlation Program (IGCP) was approved; it provided an enormous impetus to develop better means of accurate dating and trust-worthy long-range correlation. Within four years, the formal procedure and respective designation of the *ad hoc* committee to establish the first GSSP (to define the base of the Devonian System) were approved (IGC 23<sup>rd</sup> Session, Montreal 1972); it became officially implemented later (McLaren 1977). Subsequently, the International Subcommission on Stratigraphic Classification (ISSC), a part of the IUGS, published the ISG (Hedberg, ed. 1976), where the concept of boundary stratotype is formally presented; in the ISG second edition (Salvador, ed., 1994), unconformity-bounded units are introduced.

Within the next decade efforts made on both sides of the Atlantic, guided by different conceptions or paradigms, produced two significant but contrasting documents: the North American Stratigraphic Code (acronymed NASC, NACSN 1983; revised edition 2005), and the "Guidelines for Boundary Stratotypes" (Cowie 1986; revised in 1996, Remane et al.). The first is of much wider scope, including besides the well known triad (litho-, bio-, and chronostratigraphic units), categories demanded by specific sectors of the geologic community (such as allostratigraphic, lithodemic, magnetostratigraphic and pedostratigraphic), thus meeting the need of current geologic practice. In regard to chronostratigraphic/geochronologic units; NACSN (2005) carries concepts and principles established in earlier Codes (ACSN 1961, 1970); the NASC also largely coincides with the ISG (Hedberg, ed. 1976). Specific items shall be treated in the next section.

On the other hand, the "Guidelines for Boundary Stratotypes" (Cowie 1986; Remane et al. 1996) deals only with chronostratigraphic/geochronologic units, it sets forth the principles or concepts on which GSSPs are based, as well as the procedures to establish them. It should be noted that much of the material offered in Cowie (1986), and in Remane et al. (1996) is already presented in the ISG (Hedberg, ed. 1976; and Salvador, ed. 1994). As for the Code above, specific items of the Guidelines shall be dealt with in the next section.

The Stratigraphic Commission of the Geological Society of London made a proposal (Zalasiewicz et al. 2004) to discard the dual chronostratigraphic/geochronologic classification and terminology, on the grounds that the GSSPs render it redundant, and also because it produces needless nomenclatorial confusion. This Commission invited comments about it from the international community. This move occurred in the midst of a heated controversy in progress (among others cf. Odin 1997; Odin et al. 2004; Walsh 2001, 2003, 2004; Walsh et al. 2004; Gradstein et al. 2004; Zalasiewicz et al. 2004; for the opposite view, see among others Aubry et al. 1995, 1999, 2000; Berggren 1998; Easton et al. 2003; Heckert and Lucas 2004; Hilgen et al. 2006), which gained momentum, so that a Penrose Conference on this subject ["Beyond the GSSP: New developments in Chronostratigraphy"] was held in Schloss Seggau, Lebnitz Austria, June 2006, and the results published in *Stratigraphy* (Vol. 4, Nos. 2/3, 2007). Diverse views were presented, yet as anticipated, no agreement stemmed from the Conference. We benefited from such presentations, and with some, we hold similar views, however, we take full responsibility for the concepts and ideas expressed in this paper.

Finally, as a parenthetic note just to conclude this historic perspective, it should be added that sequence stratigraphy has flourished since the 1980's, and with it, the need to formally deal with "stratigraphic sequences" as *de facto*, a new kind of stratigraphic unit. This on its own started a still ongoing debate (cf. Mancini, ed. 2001; Vai et al. Conveners 2004; Christie-Blick et al. 2007). One side of the argument is expressed in the ISG 2<sup>nd</sup> Edition (Salvador, ed. 1994), with the introduction of unconformity-bounded units. The NASC (NACSN 1983; revised edition 2005) has already addressed this issue, formalizing the category of allostratigraphic units. In some ways the debate about chronostratigraphic and geochronologic units parallels the debate between the two schools of sequence stratigraphy. The original Exxon school continues to use a mixture of time-based and material-based sequence-stratigraphic surfaces (Catuneanu 2006; Catuneanu et al. in press), while others use only material-based sequence-stratigraphic surfaces (Embry 2002; 2008a, 2008b, 2008c; 2009a, 2009b, 2009c).

## APPENDIX II: GLOSSARY

**BOUNDARY STRATOTYPE 1.** A specific point in a specific sequence of rock strata that serves as the standard for definition and recognition of a stratigraphic boundary (ISG, Hedberg 1976, p. 24).

2. A specified sequence of rock strata in which a specific point is selected that serves as the standard for definition and recognition of a stratigraphic boundary (ISG, Salvador 1994, p. 26).

**CHRONOSTRATIGRAPHY 1.** The element of stratigraphy that deals with the age of strata and their time relations (ISG, Hedberg 1976, p. 66).

2. The element of stratigraphy that deals with the relative time relations and ages of rock bodies (ISG, Salvador 1994, p. 113).

3. The branch of stratigraphy that deals with the age of strata and their time relations (ISG, Hedberg 1976, p.66). Syn: *time-stratigraphy* (*Glossary of Geology-Fifth Edition* 2005).

**CHRONOSTRATIGRAPHIC CLASSIFICATION** The organization of rock strata into units on the basis of their age or time of origin (ISG, Hedberg 1976, p. 66), (*Glossary of Geology-Fifth Edition* 2005).

**CHRONOSTRATIGRAPHIC CORRELATION (CHRONOCORRELATION, TIME CORRELATION).** Correspondence in age and chronostratigraphic position between two stratigraphic sections (ISG, 2<sup>nd</sup> Edit., Salvador 1994, p. 113).

**1. CHRONOSTRATIGRAPHIC UNIT 1.** It is a subdivision of the rocks considered solely as the record of a specific interval of geologic time (Code..., Art. 26, ACSN 1961, 1970).

2. A body of rock strata that is unified by being the rocks formed during a specific interval of geologic time. Such a unit represents all rocks formed during a certain time span of Earth history (...). Chronostratigraphic units are bounded by isochronous surfaces (ISG, Hedberg 1976, p. 67).

3. A body of rocks established to serve as the material reference for all rocks formed during the same span of time. Each of its boundaries is synchronous. The body also serves as the basis for defining the specific interval of time, or *geochronologic unit*, represented by the referent (NACSN 1983, Art. 66), (*Glossary of Geology-Fifth Edition* 2005).

**General comment:** Chronostratigraphic units are mixed entities with a **material component**, the rock succession as record of the past bio- and lithogenetic events-set chosen to define the unit, postulating that its boundaries (lower and upper) extend worldwide as isochronous surfaces, and a **nonmaterial component**, which is the duration of the chosen events- set, whose beginning and end coincide respectively with the lower and upper boundaries (mentioned above). Further, these boundaries are postulated to correspond to specific points ("instants") in the geologic timetable.

**CLASSIFICATION** A systematic arrangement of entities in groups or categories according to established criteria (*Webster's Dictionary* 2002).

**Comment:** The key action is to group already individualized entities. Hence, **Stratigraphic classification**, i.e., the systematic organization of the Earth's rock bodies, into units based on any of the properties or attributes that rocks may possess, **is not classification at all**, but the subdivision of a whole into **geologic units** (on the basis of previously selected criteria). The key action here is dividing not grouping.

**CORRELATION** The condition, state or fact of being correlated. Reciprocal relation in the occurrence of different structures, characteristics, or processes (*Webster's Dictionary* 2002).

**DATE (TO)** "To date" in geology, means, to correlate an event with one or more events in the succession of key-events making up our "geological timetable". We can determine the relative "when" of an event in relation to the succession of "key events", but we can not determine its absolute "when" in the frame of physical time. (Harrington 1965)

**EVENT 1.** Something that happens. Occurrence. Happening. The fundamental entity of observed physical reality represented by a point designated by three coordinates of place and one of time in the space-time continuum (*Webster's Dictionary* 2002).

2 Happenings in the external world (...) perceived as signals or motions, as changes in the existing condition, which occur in a restricted portion of space, and time (Harrington, 1965 p. 1611).

3. A unique combination of matter and energy taking place in a particular segment of tri-dimensional space, occurring in a given portion of time. There are two kinds: Instantaneous and "longer than instantaneous", usually designated flow-events. (Ferrusquía et al. this paper).

**GEOCHRONOLOGIC UNIT 1.** A subdivision of geologic time (ISG, Hedberg 1976, p. 15), (ISG, 2<sup>nd</sup> Edit., Salvador 1994, p.16).

2. A division of time traditionally distinguished on the basis of the rock record as expressed by chronostratigraphic unit (NACSN 1983, Art. 80).

3. A division of time traditionally distinguished on the basis of the rock record as expressed by a chronostratigraphic unit. It is not a material unit but corresponds to the time span of an established chronostratigraphic unit (NACSN 1983, Art. 80). Geochronologic units in order of decreasing rank are eon, era, period, epoch, and age. Names of periods and units of lower rank are the same as those of the corresponding chronostratigraphic units; the names of some eras and eons are independently formed. (*Glossary of Geology-Fifth Edition* 2005).



**GEOCHRONOLOGY 1.** The science of dating and determining the time sequence of events in the history of the Earth (ISG, Hedberg 1976, p. 15), (ISG, 2<sup>nd</sup> Edit., Salvador 1994, p.16).

2. The science of dating and determining the time sequence of events in the history of the Earth (ISG, Hedberg 1976, p. 15; 2<sup>nd</sup> Edit., Salvador 1994, p.16); it includes *Geochronometry* as its branch dealing with the quantitative (numerical) measurements of geologic time in thousands or millions of years (*Glossary of Geology-Fifth Edition* 2005).

3. The science of numerical dating derived from direct measurements (Odin et al. 2004).

*Comment:* This definition actually correspond to Geochronometry.

**GEOCHRONOMETRY.** The branch of geochronology that deals with the quantitative (numerical) measurement of geologic time in thousands or millions of years (ISG, Hedberg 1976, p. 15), (ISG, 2<sup>nd</sup> Edit., Salvador 1994, p.16), (*Glossary of Geology-Fifth Edition* 2005).

**GEOLOGIC CORRELATION 1.** Demonstration of correspondence in character and in stratigraphic position between geographically separated stratigraphic sections or rock bodies (ISSC 1994, p.15). "There are different kinds of correlation depending on the feature to be emphasized. Lithologic correlation demonstrates correspondence in lithologic character and lithostratigraphic position; a correlation of two fossil-bearing beds demonstrates correspondence in their fossil content and in their biostratigraphic position; and chronostratigraphic demonstrates correspondence in age and in chronostratigraphic position" (ISG, Hedberg 1976, p.14).

2. The condition or fact of being correlated, such as the correspondence between two or more geologic phenomena, features, or events (*Glossary of Geology-Fifth Edition* 2005).

3. A proposition (geologic correlation by any character or criteria, not only time correlation) (Harland 1978).

**GEOLOGIC TIME** The period of time... extending from the end of the formative period of the Earth as a separate planetary body to the beginning of written history. The term implies extremely long duration or remoteness in the past, although no precise limits can be set (*Glossary of Geology-Fifth Edition* 2005).

*Comment* It is an informal term.

**GEOLOGIC TIME SCALE** An arbitrary chronological arrangement or sequence of geologic events, used as a measure of the relative or absolute duration or age of any part of geologic time, and usually presented in the form of a chart showing the names of the various rock-stratigraphic, time-stratigraphic, or geologic-time units, as currently understood; e.g. the geologic time scales published by Harland et al. (1982), Odin (1982), Palmer (1983), and Salvador (1985) [*Glossary of Geology-Fifth Edition* 2005].

*Comment;* The geologic time scale must by definition be a particular kind of a scale; however, the definition above does not fit that of scale (see below); it rather resembles that of the geologic timetable (see below). In fact, one can not measure geologic time with this scale, but only place geologic events/records in this scale; further, geochronologic units are not units of measurement, but disaggregate parts of a whole.

**GEOLOGIC TIMETABLE** A concisely expressed successional, hierarchically arrangement of geologic s.l. key events that occurred in the past, which have been selected as means to refer to other geologic events/records; through this reference, the relative age and/or duration of the latter can be ascertained. Sharing the same position in the geologic timetable makes geologic s.l. events/records from two or more different site or localities chronostratigraphic/geochronologic correlatives (Extensively modified from Harrington 1965).

*Comment:* The geologic timetable is usually presented as a chart showing the names of the chronostratigraphic/geochronologic unit terms, as currently understood. Most selected key-events that make up the geologic timetable are flow bioevents. The geologic timetable is akin to an airline or bus schedule, but the latter are more informative, because in addition to the order of arrivals/departures, precise dates of physical time are provided, from them the intervals between arrivals/departures can accurately be established. By comparison, the geologic timetable providing only the geologic events/records- order of succession, is much less informative.

**GLOBAL BOUNDARY STRATOTYPE SECTION AND POINT (GSSP)** It is designated stratigraphic boundary, identified in published form and marked in a particular place in a specific sequence of a rock strata. It constitutes the standard for the defining and recognizing the boundary between two named global standard stratigraphic (chronostratigraphic) units. A GSSP is unique signal for the world geological stratigraphic time scale (Cowie 1986, p. 78).

*Comment.* In the selected stratigraphic rock succession that bears the designated lower boundary stratotype, a permanent mark, the "golden spike" is placed. In practice, golden spikes are placed only in stage-rank chronostratigraphic units, because it would be most unlikely that higher ranked units, such as Series or Systems could be fully exposed in a single section. The line subtended between two successive GSSPs represents to the duration of the chronostratigraphic unit, and according to the time-rock model followers, it actually defines the corresponding chronostratigraphic unit.

**HIERARCHY** A polar series set of elements arranged into inclusive/exclusive subsets, whereby the higher ranked subsets include all the lower ones, and equal ranked subsets are mutually exclusive (Simpson 1961), (Ferrusquía 1978). Syn. Nested hierarchy.

**LOCALITY.** A portion of the Earth where a given geologic event has occurred. Geological localities have two main attributes: geographical position and size (Modified from Harrington 1965).

**MODEL 1.** A miniature representation of something (*Webster's Dictionary* 2002).

2. A description or analogy used to have visualize something (*Webster's Dictionary* 2002).

3. A system of postulates, data, and inferences presented as mathematical description of an entity or state of affairs (*Webster's Dictionary* 2002).

4. A working hypothesis or precise simulation, by means of description, statistical data, or analogy, of a phenomenon or pro-

cess that cannot be observed directly or that is difficult to observe directly (*Glossary of Geology-Fifth Edition* 2005).

**PARADIGM** 1. An example or pattern (*Webster's Dictionary*, 2002), (*The Oxford Thesaurus*).

2. Set of practices that define a scientific discipline during a particular period of time (interpreted from Kuhn, cited by Encyclopedia Britannica on line).

3. Set of exemplary experiments that are likely to be copied or emulated, thus defining a scientific discipline during a particular period (interpreted from Kuhn, cited by Encyclopedia Britannica on line).

4. Paradigm is the conceptual frame or "box" that conducts reasoning within "accepted" normal science. Thinking outside the "box" is usually unsuccessful, when rarely becomes successful, it leads to new paradigms, and through them to major changes in the scientific world view (interpreted from Kuhn, cited by Encyclopedia Britannica on line).

**ROCK TIME MODEL** 1. A conceptual model as explained here (Harland 1978).

*Comment:* This definition is cognitively incomplete.

2. An expression of the relationship between a chronostratigraphic unit and a geochronologic unit, whereby the latter (time unit) is the derivative concept, because its limits (beginning and end) are determined by the physical boundaries of the rock body, which is then the primary concept (As interpreted from Harland (1978, p. 29), since he did not define the model).

*Comment:* This is our interpretation of Harland's idea.

3. Conceptual relationship whereby stratigraphic horizons define the boundaries of specific stratigraphic units (the stratomeres) representative of specific temporal units (the chronomeres) (Modified from Aubry 2007, p. 127).

**SCALE** 1. A ladder, or a flight of stairs (*Webster's Dictionary* 2002).

2. A series of spaces marked by lines and used to measure distances or to register something (*Webster's Dictionary* 2002).

3. Something graduated esp. when used as a measure or rule: as a: a series of spaces marked by lines and used to measure distances or to register something (as the height of the mercury in a thermometer) b: a divided line on a map or chart indicating the length used to represent a larger unit of measure (as an inch to a mile) e: an instrument consisting of a strip (as of wood, plastic, or metal) with one or more sets of spaces graduated and numbered on its surface for measuring or laying off distances or dimensions (*Webster's Dictionary* 2002).

4. A graduated series or scheme of rank or order (*Webster's Dictionary* 2002).

5. A proportion between two sets of dimensions (as between those of a drawing and its original) (*Webster's Dictionary* 2002).

6. A graded series of tests or of performances used in rating individual intelligence or achievement - scale (*Webster's Dictionary* 2002).

**SIMULTANEITY** The quality, condition, state or fact of occurring at the same time (*Webster's Dictionary* 2002).

*Comment:* In Geology, this concept expresses the temporal relationships among events whose record demonstrably coincides, whereby are interpreted as having occurred at the same time.

**SPACE** A boundless three-dimensional extent in which objects and events occur and have relative position and direction. Syn. Physical space (*Webster's Dictionary* 2002).

*Comment.* Space is a kind of three-dimensional frame where material things are located in the external world; it is independent of its occupation by matter.

**STAGE** 1. One of a series of positions or stations one above the other. Step. Station (*Webster's Dictionary* 2002).

2. "Un étage, pour nous, est une époque en tout identique à l'époque actuelle. C'est un état de repos de la nature passée, pendant lequel il existait, comme dans la nature actuelle, des continents et des mers, des plantes et des animaux terrestres, des plantes et des animaux marins; et, dans les mers, des animaux pélagiens et des animaux côtiers à toutes les zones. de profondeur. Pour qu'un étage soit complet, il doit montrer un ensemble d'êtres terrestres ou marins, qui puisse représenter une époque tout entière, analogue au développement que nous voyons actuellement sur la terre. Lorsqu'on ne connaît que quelques parties de cet ensemble qui devrait exister à la fois, c'est que les autres ont été anéanties lors des perturbations géologiques, ou qu'elles nous sont encore inconnues. Ainsi donc, nous ne pourrions admettre, comme étage, des couches mères discordantes, quelle que soit leur puissance, si elles ne contiennent pas leurs faunes caractéristiques. Nous regardons, par ce motif, comme tout à fait fausse l'idée que chaque étage doit avoir peu d'espèces spéciales; car il est évident que si (ce que nous démontrerons) chaque étage est une époque semblable à l'époque actuelle, il doit renfermer une faune proportionnée; et que si nous n'y connaissons que peu d'espèces, c'est que la trace de la plus grande partie des espèces de la faune qu'il renfermait a été entièrement anéantie ou nous est inconnue. Nous pensons encore que le nombre aujourd'hui découvert des espèces propres à chaque étage doit considérablement s'augmenter par les recherches qui nous restent à faire pour connaître les divers âges du monde, sur tous les points du globe; et nous ne serions pas étonnés si ce nombre, par la suite, devait se tripler.

Il est, relativement aux limites de l'étage, un écueil qu'il faut soigneusement éviter: c'est celui d'attacher trop d'importance à la distribution locale des fossiles par couches, avant de s'être assuré si ces détails sont les mêmes sur tous les points du monde. Le plus souvent, en effet, quand, dans un bassin géologique, on trouve que telles couches renferment telles séries d'espèces, on est naturellement porté à regarder cette disposition comme un fait important de stratigraphie, comme une époque spéciale, distincte, quand ce n'est, le plus souvent, ainsi que nous nous en sommes aperçu par la comparaison, qu'une disposition purement locale, qui ne permet sa généralisation nulle part et qui tient seulement aux compositions des sédiments ou aux oscillations locales du sol, ce que nous chercherons à démontrer aux étages en particulier" (Orbigny 1851, p. 256-257).

(An stage is for us, an epoch in all identical to the present one. It is an state of rest of past (= ancient) nature, during which existed

as nowadays continents and seas, terrestrial plants and animals, as well as marine plants and animals, and in the seas pelagic and shore animals at all depths. For a stage to be complete, it must show an assemblage of terrestrial and marine beings that could represent a whole epoch, analogous in development to what we see on Earth today. When we know only some parts of the assemblage that should have existed at that time, it is that the other parts were annihilated during the geologic perturbations, or we do not know them yet. Thus we can not accept as a stage the same beds regardless of their thickness, if they do not contain their characteristic faunas. For this motive we regard as false the idea that each stage ought to have a few particular species; because it is evident (and we shall demonstrate it) that if each stage is an epoch similar to the present one, it must contain a fauna proportional to it; and that if we know only a few species, it is that the vestiges of most of the fauna's species were entirely annihilated or we know not of them. We still think that the number of known species for each stage shall considerably increase for the research that lacks to be done to know the diverse ages of the world on all points of the globe; and it would not surprise much if such number were tripled.

It is in relation to stage boundaries that we should carefully avoid the pitfall of attributing much importance to the local distribution of fossils in the beds, before being sure that the details (of such distribution) are the same in all parts of the world. It is frequent that when in a geologic basin such and such beds contain such and such set of species, naturally one tends to regard this ordering as an important fact of stratigraphy, as a special and distinct epoch, when actually we perceive it by comparative studies to be a local ordering that does not allow a generalization from any part, and that it pertains only to the sediments' composition or to local soil oscillations, which we in particular attempt to demonstrate for the stages (Orbigny 1851, p. 256-257)).

*Comment:* This is the full citation of Orbigny's *Définition d'un étage géologique par rapport aux espèces*.

3. It is a succession of strata or a stratigraphic interval with characterizing fossil aggregate delineated in "a continuous fossiliferous section exposing also fossiliferous sections of both subjacent and superjacent Stages" (Kleinpell 1938, p. 103; as interpreted by Walsh 2004).

*Comment:* Kleinpell's stages are biostratigraphic rather than chronostratigraphic units.

4. It is a time-stratigraphic unit next in rank below series (Code ..., Art. 31, ACSN, 1961), (Code ..., Art. 31, ACSN 1970).

5. It is a chronostratigraphic unit of relatively minor rank in the conventional hierarchy of formal chronostratigraphic terms, representing a relatively minor interval in geologic time. Its geochronologic equivalent is known as an age and carries the same proper name as the corresponding stage (ISG, Hedberg 1976, p. 70-71)

6. A unit of the conventional hierarchy of formal chronostratigraphic terms ranking next below a series; considered the basic working unit of chronostratigraphic classification (ISG, 2<sup>nd</sup> Edit., Salvador 1994, p. 137).

7. A chronostratigraphic unit of smaller scope and rank than a series. It is most commonly of greatest use in intra-continental classification and correlation, although it has the potential for

worldwide recognition. The geochronologic equivalent of a stage is an age (NACSN 1983, Art. 74).

8. It is a stratigraphic unit that "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." (Odin et al. 2004, p. 6).

9. A chronostratigraphic unit of smaller scope and rank than a series. It is most commonly of greatest use in intra-continental classification and correlation, although it has the potential for worldwide recognition. (NACSN 1983, Art. 74). The temporal equivalent of stage is age. A stage may be, but need not be, divided into substages. Most stage names are based on lithostratigraphic units, although preferably a stage should have a geographic name not previously used in stratigraphic nomenclature; the adjectival ending for the geographic name is most commonly "-an" or "-ian", although it is permissible to use the geographic name without any special ending, such as "Clairborne Stage" (*Glossary of Geology-Fifth Edition* 2005).

10. An informal term used to indicate "any sort" of chronostratigraphic unit of approximate stage rank "which is not a part of the standard hierarchy" of named chronostratigraphic units (ISG, Hedberg 1976, p.24-25) (*Glossary of Geology-Fifth Edition* 2005).

11. A *paratime-rock* unit consisting of two or more zones (Wheeler et al. 1950, p.2364). (d) A term used in England for a rock-stratigraphic unit (*Glossary of Geology-Fifth Edition* 2005).

*General Comment.* The assortment of stage definitions presented above, not exhaustive at all shows the wide range of meanings and connotations accorded to it, including a paleogeographic one (cf. Gignoux 1960), therefore it has engendered confusion. Walsh (2004) has pointed out that stage is used for three different stratigraphic concepts: unit stratotype, synthem, and the set of all existing material strata in a given geographic area (usually the whole world) that were deposited during a given, golden spike-defined age. The latter is an unsupported restriction of Walsh, because stages as chronostratigraphic unit stratotypes include all the world's rock bodies generated in the same time span, regardless of their lithic makeup.

**STRATIGRAPHIC CLASSIFICATION 1.** It is the systematic organization of the Earth's rock strata, as they are found in their original sequence, into units with reference to any of the characters, properties or attributes that rocks may possess. Many different properties and attributes of rock strata may serve usefully as the bases for stratigraphic classification, and so there are many different categories of stratigraphic classification (ISG, Hedberg 1976, p.13).

2. The systematic organization of the Earth's rock bodies, as they are found in their original relationships, into units based on any of the properties or attributes that rocks may possess (ISG, 2<sup>nd</sup> Edit., Salvador 1994, p. 137).

3. The arbitrary but systematic arrangement, zonation, or partitioning of the sequence of rock strata of the Earth's crust into units with reference to any or all of the many different characters, properties, or attributes which the strata may possess



(Hedberg 1958, p.1881-1882) (*Glossary of Geology-Fifth Edition* 2005).

**STRATIGRAPHIC CORRELATION** 1. Correspondence in character and/or in stratigraphic position (ISG, Hedberg 1976, p.14), (ISG, 2<sup>nd</sup> Edit., Salvador 1994, p. 15).

2. The process by which stratigraphic units in two or more separated areas are demonstrated or determined to be laterally similar in character or mutually correspondent in stratigraphic position, as based on geologic age (time of formation), lithologic characteristics, fossil content, or any other property; *correlation (geol)* in the usual or narrowest sense. See also: *lithostratigraphic correlation*. (*Glossary of Geology-Fifth Edition* 2005).

Comment: The first sentence (...are demonstrated or determined to be laterally similar in character) actually refers to identifying the same rock body in different areas.

**STRATIGRAPHIC UNIT** 1. It is a stratum or assemblage of adjacent strata recognized as a unit (distinct entity) in the classification of the Earth's rock sequence, with respect to any of the many characters, properties, or attributes that rock possess (ISG, Hedberg 1976, p.13).

*Conceptual complement:* Stratigraphic units based on one character will not necessarily coincide with those based on another; it is therefore essential that different terms be used for each so that their named units can be distinguished from each other. Clear definition of a stratigraphic unit is of paramount importance (ISG, Hedberg 1976, p.13).

2. It is a body of rock recognized as a unit (distinct entity) in the classification of the Earth's rocks, based on any of the many properties and attributes that rocks possess. Stratigraphic units based of one property will not necessarily coincide with those based on another (ISG, 2<sup>nd</sup> Edit., Salvador 1994, p. 137).

3. A stratum or body of rock recognized as a unit in the classification of the Earth's rocks with respect to any of the many characters, properties, or attributes that rocks may possess (ISG 1994, p.14), for any purpose such as description, mapping, and correlation. Rocks may be classified stratigraphically on the basis of lithology (lithostratigraphic units), fossil content (biostratigraphic units), magnetic polarity (magnetostratigraphic polarity units), being bounded by unconformities (unconformity-bounded units), age (chronostratigraphic units), or properties (such as mineral content, radioactivity, seismic velocity, electric-log character, chemical composition) in categories for which formal nomenclature is lacking. Stratigraphic units based on one property will not necessarily coincide with those based on another. It is, therefore, essential that different terms be used for each so that their named units can be distinguished from each other. Clear definition of a stratigraphic unit is of paramount importance. A geologic-time unit is not a stratigraphic unit. Syn: *stratic unit* [*Glossary of Geology-Fifth Edition* 2005].

**STRATIGRAPHY** 1. The inorganic side of historical geologic, or the development through the successive geologic ages of the earth's rocky framework or lithosphere (Grabau 1913).

Comment. This "definitions reflects original concepts of stratigraphy as the branch of geologic sciences concerned with the de-

scription, organization, and classification of stratified rocks" (Krumbein and Sloss 1963).

2. It properly "deals with the overall relations of the stratified rocks, areal and temporal, and with the history they record" (Dunbar y Rodgers 1957).

3. It is the branch of geology that deals with the study and interpretation of stratified an sedimentary rocks and with the identifications, description, sequence, both vertical and horizontal, mapping, and correlations of stratigraphic rocks unit (Weller 1960).

4. The study of the shape, dimensions, and spatial relations of the rock bodies, and of the space-time relation of the lithogenetic events which they recorded and represent (modified from Harrington 1965).

5. The study of rocks and their distribution in space and time with the object of reconstructing the history of the earth (Laffitte et al. 1972).

6. The science of rock strata (ISG, Hedberg 1976, p.12).

*Conceptual complement:* Stratigraphy "is concerned not only with the original succession and age relations of rock strata but also with their form, distribution, lithologic composition, fossil content, geophysical and geochemical properties indeed, with all characters, properties and attributes of rocks as strata, and their interpretation in terms of environment or mode of origin, and geologic history. All classes of rocks igneous and metamorphic as well sedimentary, consolidated or unconsolidated fall within the general scope of stratigraphy and stratigraphic classification. Some nonstratiform rock bodies are considered under stratigraphy because of their association with or close relation to rock strata (ISG, Hedberg 1976, p.12).

7. The science dealing with the description of all rock bodies forming the Earth's crust-sedimentary, igneous, and metamorphic and their organization into distinctive, useful, mappable units based on their inherent properties or attributes. Stratigraphic procedures include the description, classification, naming, and correlation of these units for the purpose of establishing their relationship in space and their succession in time (ISG, 2<sup>nd</sup> Edit., Salvador 1994, p. 137).

8. The science of rock strata. It is concerned not only with the original succession and age relations of rock strata but also with their form, distribution, lithologic composition, fossil content, geophysical and geochemical properties indeed, with all characters and attributes of rocks as strata; and their interpretation in terms of environment or mode of origin, and geologic history. All classes of rocks, consolidated or unconsolidated, fall within the general scope of stratigraphy. Some nonstratiform rock bodies are considered because of their association with or close relation to rock strata (ISG, Hedberg 1976, p.12). Syn: *stratigraphic geology* (*Glossary of Geology-Fifth Edition* 2005).

Comment. There are minor differences with the original source.

9. The science dealing with the description of all rock bodies forming the Earth's crust sedimentary, igneous, and metamorphic and their organization into distinctive, useful, mappable units based on their inherent properties or attributes. Stratigraphic procedures include the description, classification, naming, and correlation of these units for the purpose of establishing

their relationship in space and their succession in time (ISG 2<sup>nd</sup> Edit., 1994 p.13) (*Glossary of Geology-Fifth Edition* 2005).

*Comment.* There are minor differences with the original source.

10. The arrangement of strata, esp. as to geographic position and chronologic order of sequence (*Glossary of Geology-Fifth Edition* 2005).

11. The sum of the characteristics studied in stratigraphy; the part of the geology of an area or district pertaining to the character of its stratified rocks (*Glossary of Geology-Fifth Edition* 2005).

12. It is the scientific study of the shape, and spatial relations of the Earth's crust rock bodies, organizing them on the basis of their inherent characters into mappable geologic units, and detecting the space/time relation of the lithogenetic events which they *recorded* and *represent*, for reconstructing Earth's history (This paper).

*General comment:* Stratigraphy's definitions presented above reflect its wide conceptual spectrum, given the complexity and extent of this science object of study, which could be approached from very different aspects; the last definition is an eclectic, conceptual synthesis of them all.

**SUBSEQUENCY** Quality or condition of being subsequent, i.e., following in time order or place to other (*Webster's Dictionary* 2002).

*Comment:* In geologic sense, it is a time relationship whereby events/records making up a seemingly continuous sequence of a particular kind, may actually include events/records of different kind, or "time" without altering the occurrence-order among them. Subsequent events/records are simply anterior/posterior with respect to each other. Frequently this is the only time relationship that can be ascertained in routine geologic work.

**SUCCESSION** Quality or condition of being successive, i.e., following next in time order or place to other (*Webster's Dictionary* 2002).

*Comment:* In geologic sense, it is a time relationship whereby events/records making up a seemingly continuous sequence of a particular kind, do not include among themselves events/records of different kind, or "time." The condition of immediate-following among events/records requires demonstration, and demands having a really complete record of events that affords dependable geochronologic data or information. For this reason, to establish succession is beyond routine geologic work.

**SYNTHEM 1.** A body of rocks bounded above and below by specifically designated, significant and demonstrable discontinuities of regional or interregional extent in given stratigraphic succession [Slightly modified from Chang 1975, p.1546].

2. A body of rocks bounded above and below by specifically designated, significant and demonstrable discontinuities of regional or interregional magnitude in the stratigraphic succession; the basic unconformity-bounded unit (ISG, 2<sup>nd</sup> Edit., Salvador 1994, p. 139).

**TIME 1.** The measured or measurable period during which an action, process, or condition exists or continues (*Webster's Dictionary* 2002).

2. The period when something occurs. Occasion (*Webster's Dictionary* 2002).

3. It is a uni-dimensional *continuum* of world-wide instants (sort of "world-wide instant-thick time slices") that endlessly succeed each other, being the present one the reference for anterior (past) and future instants; hence time has an inherent polarity (from past to future), and is independent of matter (Slightly modified from Eddington 1929).

*Conceptual complement 1:* In restricted segments of time, i.e., intervals, an event or condition exists or continues; further, it is only through events or happenings that intervals become meaningful. In other words, time intervals acquire reality only by the events occurring in them; therefore "empty," "happenings-free" time intervals are mere abstractions, and have no reality.

*Conceptual complement 2:* Physical time actually refers to two related but different things or meanings: *date* and *duration*. The first is the moment or instant at which an event begins/ends, e.g. the beginning of an Earth's magnetic field reverse polarity event. The second is the elapsed time interval delimited by the beginning and end of a particular event, or the interval of time elapsed between two or more events. Duration of physical time is measured in seconds (i.e., specific fractions of the sidereal day); hence "measuring time" is actually *counting* the number of units of duration in which an event occurs.

4. Measured or measurable duration; nonmaterial dimension of the universe, representing a period or interval during which an action, process or condition exists or continues (*Glossary of Geology-Fifth Edition* 2005).

5. A reference point from which duration is measured; e.g., the instant at which a seismic event occurs relative to a chosen reference time such as a shot instant (*Glossary of Geology-Fifth Edition* 2005).

6. A reckoning of time, or a system of reckoning duration (*Glossary of Geology-Fifth Edition*, 2005).

7. An informal term proposed by the ISST (1961, p.13, 25) for the geologic-time unit next in order of magnitude below *age* (*geochron*) (a), during which the rocks of a substage (or of any time-stratigraphic unit of lesser rank than a stage) were formed. It is a syn. of *subage*; *episode* (b); *phase* (*geochron*) (a). (e) Any division of geologic chronology, such as "Paleozoic time" or "Miocene time" (*Glossary of Geology-Fifth Edition* 2005).

**TIME PLANE** A stratigraphic horizon identifying an *instant* in geologic time (*Glossary of Geology-Fifth Edition* 2005).

*Comment:* Given that horizon and plane are spatial attributes, is epistemologically erroneous to apply them to time. Even granting that, it remains to be proven that the selected stratigraphic horizon actually records an instant of geologic time. It appears that this concept actually involves some kind of postulate.

**TIME ROCK MODEL 1.** A conceptual model as explained here (Harland 1978).

*Comment:* This definition is cognitively incomplete.

2. An expression of the relationship between a chronostratigraphic unit and a geochronologic unit, whereby the former (rock body unit) is the derivate concept, because its boundaries are defined by specifying two points in the rock section that are

interpreted as two instants in time that define the geochronologic unit. (As interpreted from Harland (1978, p. 29), since he did not define the model).

*Comment:* This definition is quite subjective, because the action of “specifying two points in the rock section” has no temporal significance by itself; it acquires meaning through the subjective action of interpreting such points as two instants in time, which “define” the geochronologic unit:

3. Conceptual relationship whereby *points* are selected in the rock as representative of pre-selected events (i.e., preselected instants) (Modified from Aubry 2007, p. 127).

*General comment:* Given the definitions of model above, neither satisfy them; both models seem to correspond to paradigms or to “philosophic postulates,” that is, they are unproven and unprovable statements used as the basis to construct a system of ideas or concepts.

**TIME-ROCK UNIT** See chronostratigraphic unit

**UNIT 1.** A determinate quantity (as of length. time. heat. value, or housing) adopted as a standard of measurement (*Webster's Dictionary* 2002).

2. A distinct part or member analyzable in an aggregate or whole; A single thing, person or group that is a constituent of a whole (*Webster's Dictionary* 2002).

*Comment:* All geologic units belong to the second category.

**UNIT-STRATOTYPE 1.** The type section of strata serving as the standard for the definition and recognition of a stratigraphic unit (ISG, Hedberg 1976, p.24).

2. The type section of a layered unit that serves as the standard of reference for the definition and characterization of a unit. In the case of a complete and well-exposed layered unit, the upper and lower limits of a unit stratotype are the boundary stratotypes (ISG, 2<sup>nd</sup> Edit., Salvador 1994, p.26).

3. The type section of a layered stratigraphic unit that serves as the standard of reference for the definition and characterization of a unit. The upper and lower limits of a unit stratotype are its boundary stratotypes (*Glossary of Geology-Fifth Edition* 2005).