Simplifying the stratigraphy of time

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ABSTRACT

We propose 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 in stratigraphy has been rendered unnecessary by the widespread adoption of the global stratotype sections and points (GSSP—golden spike) principle in defining intervals of geologic time within rock strata. We consider that the most appropriate name for this stratigraphic discipline is "chronostratigraphy," which would allow "geochronology" to revert to its mainstream and original meaning of numerical age dating. This in turn makes the little-used formal term "geochronometry" redundant. The terms "eonothem," "erathem," "system," "series," and "stage" would become redundant, in favor of "eon," "era," "period," "epoch" and (disputably) "age." Our favored geologic time units may be qualified by "early" and "late," but not by "lower" and "upper." These suggested changes should simplify stratigraphic practice, encompass both stratified and nonstratified rocks, and help geologic understanding, while retaining precision of meaning.

Keywords: stratigraphy, chronostratigraphy, geochronology.

INTRODUCTION

In geology, there has been a long-held distinction between chronostratigraphy (the defining and use of time-rock units, e.g., the Cretaceous System) and geochronology (the defining and use of units of stratigraphic time, e.g., the Cretaceous Period). These hierarchies of time divisions have exactly parallel units that have been at the heart of stratigraphic geology virtually since its beginnings.

We (members of the Stratigraphy Commission of the Geological Society of London) have considered the distinction between chronostratigraphy and geochronology in the course of preparing the latest guide to stratigraphic procedure of the Geological Society (London) (Rawson et al., 2002). We consider that there are now both practical and theoretical objections to their continued distinction. Thus we propose—modifying and extending an argument made in Harland et al. (1990)—that they may be unified.

Because this change would require significant changes to long-established stratigraphic practice and internationally agreed terminology, we present our views here to stimulate discussion and feedback from the wider geologic community, prior to considering any formal recommendations.

TIME IN STRATIGRAPHY

Stratigraphy, originally restricted to the study of stratified rocks (e.g., Dunbar and Rodgers, 1957), now has come to encompass all rocks on Earth (e.g., Salvador 1994; Rawson et al., 2002) and the principles are applied to mapping the surface of the Moon and the solid planets. One of its aims is to discover the history of rock strata and other rock bodies by ordering them into a chronological succession, assigning relative or numerical ages to that succession and correlating it with successions elsewhere. Three forms of chronology are currently used in the definition of Phanerozoic time scales (Hedberg, 1976; Whittaker et al., 1991; Salvador, 1994; Rawson et al., 2002), as detailed in Table 1.

Chronostratigraphy and geochronology (exemplified by systems and periods, respectively) together make up parallel branches of the standard global stratigraphic scale of the International Stratigraphic Guide (Hedberg, 1976), while the radiometric time scale was named the global chronometric scale by Harland et al. (1990). The divisions of the first two are relative, and defined by their positions in stratigraphic successions; their values on the global chronometric scale are the best estimates of their ages in years. The difference between chronostratigraphy and geochronology was likened by Hedberg (1976; repeated in Salvador, 1994) to an hourglass through which sand is flowing: the sand that flows through the hourglass in a given interval of time represents chronostratigraphy (e.g., the Cambrian System), while the time interval represents geochronology (e.g., the Cambrian Period).

Formal time-rock units are those qualified by "Lower,"

TABLE 1. FORMS OF CHRONOLOGY CURRENTLY USED IN DEFINITION OF PHANEROZOIC TIME SCALES

Chronostratigraphy	Time-rock units or time-stratigraphic units represent stratified rock successions (e.g., system, series) assigned to geologic time units
Geochronology	Units of geologic time (e.g., period, epoch), with a parallel and exactly corresponding stratigraphy
Geochronometry	The measurement of absolute time in years as numerical ages (e.g., 345 Ma), principally by means of radiometric dating, but increasingly, in Phanerozoic rocks, by the numerical dating of Milankovitch cycles (e.g., Gale et al., 1999)

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‘‘Middle,’’ and ‘‘Upper’’ (e.g., Lower Jurassic), while formal time units are qualified by ‘‘Early,’’ ‘‘Middle,’’ (‘‘Mid-’’ in UK terminology), and ‘‘Late’’ (e.g., Early Jurassic). Informal units are written in lowercase (e.g., middle Cretaceous).

HISTORICAL BACKGROUND TO THE DUAL TIME/TIME-ROCK CLASSIFICATION

The dual geologic time/time-rock classification goes back almost to the mid-eighteenth century (Dunbar and Rodgers, 1957, p. 289–307; Aubry et al., 1999). For example, the German geologist Georg Fuchsel established rock series and exactly parallel time units in Thüringia in 1761; such early geologists defined their rock units by mapping, and units of stratigraphic time were then conceived as being the time equivalent of the rock units that had already been defined. The next hundred years, however, saw debate between geologists such as Abraham Gottlob Werner, who equated rock units with time, and paleontologists, who argued that successive assemblages of fossils better expressed the (relative) age of rocks.

This debate over whether rock strata or fossils represented the better proxies for time persisted through the late nineteenth and early twentieth centuries, and helps explain why units of pure time were kept separate from the rock- or fossil-based stratigraphic column. For example, in the first internationally accepted classification set up by the second International Geological Congress (IGC) in Bologna in 1881, the time units ‘‘era,’’ ‘‘period,’’ ‘‘epoch,’’ and ‘‘age’’ were set against the ‘‘stratigraphic’’ terms ‘‘group,’’ ‘‘system,’’ ‘‘series,’’ ‘‘stage,’’ ‘‘assise’’ (bed), and ‘‘stratum’’ (Anonymous, 1882). Thus the earliest ancestor of our current chronostratigraphical hierarchy was essentially lithostratigraphical in nature. By the Eighth IGC in Paris in 1900 (Commission Internationale de Classification Stratigraphique, 1901), the paleontologists had the upper hand, and below system, series, and stage there was now ‘‘zone,’’ in its sense of a fossil zone, here used as a time-rock unit. In the stratigraphic code of 1933 (Committee of Stratigraphic Nomenclature, 1933), the balance had shifted again, so that time (period, epoch, and age) was faced by a scheme much closer to our current lithostratigraphical hierarchy (system, series, group, formation, member, and bed). This approach was controversial, flying in the face of the growing recognition that many rock units were diachronous.

Modern stratigraphic terminology is largely descended from the influential response to the 1933 scheme, published by Schenck and Muller (1941), wherein the lithostratigraphic hierarchy was clearly separated from ‘‘geologic time’’ units (e.g., era, period) and ‘‘time-stratigraphic’’ units (system through zone). This tactic separated rocks, fossils, and time clearly, but it is significant that in this 1941 scheme, fossils persisted (as ‘‘zones’’) as the basis of the ‘‘time-stratigraphic’’ units that evolved into what we now understand as chronostratigraphy.

This equating of fossil zones with time units persisted for some years (see Hancock, 1977). As stratigraphic ideas evolved, the problem of diachronism, as regards both rocks and fossils, was dealt with by defining ‘‘boundary stratotypes’’ or type sections; this was to lay the foundations of modern chronostratigraphic practice, and widespread dissemination of these concepts took place after the publication of Hedberg’s (1976) influential *International Stratigraphic Guide.* The first major period (and therefore system) boundary, marking the base of the Devonian, was fixed a year later (McLaren, 1977).

The duality of geologic time and time-rock classifications persisted for so long because stratigraphers considered it a rigorous and effective way of looking at Earth’s stratigraphic history, with, on the one hand, a time interval and, on the other, the geologic succession laid down over that time interval. This succession was variously interpreted as the effective equivalent of either lithostratigraphy or biostratigraphy, as is clear from the units that made up the lower hierarchical levels of the various schemes proposed. However, with the widespread use of boundary stratotypes, we consider that the raison d’être of separately distinguishable geologic time and time-rock units has now largely disappeared. We set out our reasons in the following.

CURRENT DRAWBACKS OF THE DUAL CLASSIFICATION

By definition, a chronostratigraphic unit consists of all strata formed during the time span of a fundamental geochronological unit. For example, the Carboniferous System is made up of all deposits formed during the Carboniferous Period. Similarly, the Tournaisian Series (chronostratigraphic unit) is made up of all strata formed during the Tournaisian Epoch (the equivalent geochronological unit).

Our experience, however, suggests that making practical distinctions between chronostratigraphy and geochronology is often problematic, for the following reasons:

1. The distinction between the two parallel hierarchies of chronostratigraphy (time-rock) and geochronology (geologic time) is subtle, and, we believe, not clear to the greater part of the professional (or student) geological community. The distinction is normally only encountered when correct terminology (e.g., period versus system, lower versus early) needs to be used in writing or editing scientific papers. Terms such as Early Jurassic and Lower Jurassic are often used interchangeably.

2. Chronostratigraphic units currently refer to stratified rocks only. Thus, the Tournaisian Series, for example, comprises strata, but not granites or high-grade metamorphic complexes. However, one can say that discrete magmatic crystallization or metamorphic events took place during the Tournaisian Epoch (see following discussion). Thus, geologic time is of wider applicability than the time-rock classification, and of more use in the kind of cross-disciplinary studies that now increasingly characterize geology.

3. The distinction between geologic time and time-rock classifications, and their distinction from numerical time, blurs the essential simplicity of stratigraphic classification, and is a significant barrier to understanding, not least as regards extending the messages within stratigraphy (biotic evolution; environmental and climatic change) to the lay public. It is important to preserve this fundamental simplicity today, when the 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.

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

Subtlety, complexity, and formal versus vernacular terminological conflicts are not in themselves reasons for change. We consider, though, that there is no longer a strong conceptual justification for the dual terminology, because of what boundary stratotypes represent.

SIGNIFICANCE OF GLOBAL STRATOTYPE SECTIONS AND POINTS (GSSPs)

The divisions of the stratigraphic time scale (of both chronostratigraphy and geochronology) are in the process of being precisely demarcated (by GSSPs) and increasingly well but still imperfectly dated (mainly by radiometric means). The base of a system and its equivalent period is defined uniquely in a suitable section by a GSSP (the golden spike). The top of this unit is defined by a second GSSP representing the base of the succeeding system (period). The second GSSP can be geographically distant from the first. For example, the base of the Silurian has been defined in Scotland, and the top of the Silurian is defined by the base of the Devonian in the Czech Republic. The same GSSP may serve as the initial boundary of several ranks in the geochronological hierarchy (Harland et al., 1990, p. 3).

The association of the GSSP with the base of the overlying unit, rather than the top of the underlying one, reflects historical practice, when stratotypes of time units could include a basal unconformity: the time represented by missing strata was by convention assigned to an earlier unit. GSSPs today are placed in continually deposited sections, and so in practice should represent both (top and base, respectively) of the two time units either side of the boundary. It may become useful to acknowledge more formally that a GSSP defines a boundary between two units and not just the base of one.

Subdivision on the basis of GSSPs is possible for most of recorded geologic time, because stratified deposits approaching 4 b.y. old are known. In practice, it is still largely confined to the Phanerozoic, because of the effectiveness of fossils as correlative tools. In the Precambrian, the major time divisions are numerical ones (e.g., the Archaean-Proterozoic boundary is set at 2500 Ma), although the subdivision of the Precambrian by GSSPs has been recommended (Holland, 1986; Harland et al., 1990).

A GSSP is intended to be immovable and so provide stability, no matter what is subsequently learned about the enclosing rock. For example, the base of the Devonian at Klonk in the Czech Republic has been fixed at the point where *Monograptus uniformis* has been observed to appear. The golden spike will not be moved even if later work were to discover this taxon appearing lower down in the section (as is possible: see Signor and Lipps, 1982). This inflexibility is intended to stabilize stratigraphic classification. Clearly, though, increased knowledge is likely to show that some GSSPs would have been better placed elsewhere in the succession or in entirely different successions. There is for this reason an escape clause: golden spikes may, exceptionally, be relocated, though not normally until 10 years after ratification (Remane et al., 1996).

Supplementary reference points cannot in principle be used as ‘‘doubles’’ for a GSSP, for it is certain that the same time instant cannot be pinned in two places in the world by two golden spikes (although reference points defined by a geomagnetic boundary are unlikely to differ globally by more than a few thousand years). In practice, parallel schemes have often been established, different in detail and each serving a particular region (e.g., the parallel Ordovician series [epoch]) schemes in the United States and Britain). The relative merits of the competing schemes are discussed and one is eventually adopted as a global standard. GSSPs are then defined as necessary. Schemes that are not adopted may continue to be valuable for local or regional correlation as secondary standards (Cope, 1996).

NATURE OF THE TIME FIXED AT GSSPs

We consider the time fixed between successive golden spikes need not be regarded as parallel courses of time-rock units and geologic time, but simply as time in which sediment has been laid down and eroded, biota have evolved, volcanoes have erupted, granites have crystallized, and so on. Thus the rock between two golden spikes (e.g., the Silurian System) is only a time-rock unit in that two points in time are defined at sedimentary horizons. Hedberg’s (1976) ingenious hourglass analogy is thus not altogether apt, for the stratigraphic record reflects not so much the sand pouring through an hourglass, as the capture of successive instants of time as sand grains hit the base of the hourglass.

What does the Silurian System comprise? Again, Hedberg’s (1976) hourglass analogy is a simplification of geologic reality. The sedimentary grains were forged much earlier, while isotope ratios (e.g., neodymium) in these grains might have been inherited from yet more ancient times. And in these ‘‘Silurian’’ rocks, much mineral matter might be the result of Devonian authigenesis, Carboniferous metamorphism, Permian mineralization, and Quaternary weathering. The term ‘‘Silurian’’ when applied to these rocks simply refers to the deposition of the sediment grains and associated fossils on the seafloor, an important part of the geologic history, but only a part. This equation of the rock record with the depositional record is the convention in stratigraphy. However, it downplays the significance of rock as a multicomponent archive of time and process.

The GSSPs that constrain the Silurian System (Period) therefore explicitly indicate Silurian time. There was Silurian sedimentation, Silurian diagenesis (not necessarily in strata deposited in Silurian time), Silurian magmatism, and a Silurian biota. There may now be said to be (with the caveats just expressed) Silurian sedimentary rocks, Silurian igneous bodies, and Silurian fossils. The rocks only act, at the boundary in the type section, as a point of reference to the passage of time. It follows, therefore, that chronostratigraphic practice is in effect establishing the geochronological time framework, as Harland et al. (1990, p. 20) realized.

FUNCTION OF TIME-ROCK CLASSIFICATION TODAY

What use is there today for time-rock classification, and what consequences would there be if it were abandoned? Two main purposes are generally adduced for time-rock classification. First, it provides a convenient shorthand to refer to strata; thus, one can say that monograptid graptolites are characteristic of the Silurian System. Second, it provides a time-based classification of strata (physical realities) separate from the deductions (elapsed time intervals).

The first descriptive function seems easily duplicated if chronostratigraphy were unified with geochronology. One could thus say that the monograptid graptolites are characteristic of strata laid down during the Silurian Period. This form of words is slightly longer, but has not lost any precision. If, more briefly, one wrote that monograptid graptolites are characteristic of Silurian strata, or, simply, are common in the Silurian, then, regardless of the use of the term Silurian as adjective or noun, the meaning would be clear from the context.

The second point is apparently more of a stumbling block, in that 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 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 separate 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 the 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.

DUAL TERMINOLOGY IN RELATION TO STRATIFIED AND NONSTRATIFIED ROCKS

The definition of a chronostratigraphic unit such as the Silurian System appears to exclude nonstratified rocks (see Hedberg, 1976, p. 67). There seems to be good reason for this: e.g., a pluton that was being emplaced in Late Silurian time may have begun to crystallize zircons during emplacement, while subsequent crystallization of biotites and feldspars may have taken place over a long time interval spanning the Silurian-Devonian boundary. Thus the pluton cannot sensibly form part of either system. Similar arguments can be applied to metamorphic complexes.

Moreover, if stratified rocks form part of systems and series, while nonstratified rocks do not, it follows that there is an intervening ‘‘gray’’ area where stratified successions grade into migmatitic complexes. To what level of metamorphic or tectonic complexity does time-rock classification persist?

However, events within the evolution of igneous and metamorphic complexes may be dated and correlated to particular intervals within the Silurian and Devonian Periods, as defined within strata. It is possible to have time-rock units restricted to stratified rocks, and then to extend the parallel time arm of the dual time scale into nonstratified rocks: this is our current practice. However, it is simpler to have one relative time scale that deals directly with both stratified and nonstratified rocks. Formally defined time planes are anchored in strata simply because we can catalogue and correlate time-linked events most precisely within strata, at least within the Phanerozoic.

DEALING WITH COMMON USAGE

Abandoning chronostratigraphical terms, even if agreed at international committee level, would neither be easy nor swift, because the terminology is familiar and commonly, if unevenly, used. Systems, series, and stages are part of the geologic lingua franca, eonothems and erathems less so. Popular terms will not be abandoned simply at the behest of stratigraphic committees, especially if they are convenient in some circumstances. A reasonable interim path may be to regard their use as informal or descriptive, to denote the strata deposited within a certain (formal) time interval. We emphasize here the unwinding of time in geology as one phenomenon, albeit of almost unimaginable duration: that unity of time should be reflected in a unity of time units. If this concept becomes widely accepted, time-rock terms may eventually decline and be abandoned.

CONCLUSIONS AND RECOMMENDATIONS

1. We consider that 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).

2. The effect of this 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] preferred retaining the term ''stage'' instead of ''age,'' to liberate the word ''age'' for general use; this solution might ultimately prove optimal).

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

4. The time units defined by chronostratigraphy may be qualified by ''early,'' ''middle,'' (''mid-'' in UK terminology) and ''late,'' but not by ''lower'' and ''upper.'' As an example, one would not speak of, e.g., ''a Lower January snow accumulation'' (F. Gradstein, 1999, personal commun.). The qualifiers ''lower,'' ''middle,'' and ''upper'' continue to be applicable to the rock bodies of lithostratigraphy.

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

6. The term ''geochronology'' reverts to its vernacular use of referring to dating and ordering geological events, particularly by obtaining numerical estimates of time, through, among others, radiometric dating and the counting of Milankovitch cycles.

These are our suggestions. We invite comment and discussion.

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