

## Stratigraphy and Time

Zalasiewicz et al. (2004) have proposed fundamental changes in the definition and application of stratigraphic terminology involving time-rock and geologic-time units that fly in the face of widely accepted principles that have been tried and tested in establishing an international unified stratigraphic hierarchy and nomenclature. Their adoption would create major disruption to established procedures.

The principal problem with the paper is that the authors appear to be confused about how time is related to stratigraphy; this misunderstanding starts with the title, it permeates the whole paper, and confuses arguments. Major dictionaries (e.g., Oxford, Webster's, Chambers) define stratigraphy as the study of strata and their succession and relative position; there is no mention of time there. Time itself cannot have a stratigraphy as implied in their title, which is why we do not use it in our comments and we cannot agree with their use of simplifying in this context.

The authors' failure to grasp the essential difference between time and rock is demonstrated by their Table 1, where the features labeled Chronostratigraphy are in fact units of standard chronostratigraphy, that is classification of rocks by age measured on a standard time scale (i.e., the geological column comprising units of system, series, stage rank, etc.), commonly referred to as time-rock units. The hierarchy of units applied here is defined ultimately by the bases of the units set by marker points (golden spikes) in rock within type-sections in a global stratotype section and point (GSSP); the defined base of each unit of a higher rank corresponds automatically with the base of the lowest unit at the next lower rank of the hierarchy. Thus the marker point coinciding with the lowest occurrence of *Monograptus uniformis* in the type-section at Klonk, Czech Republic, marks the base of the Lochkovian Stage, and also the bases of the Lower Devonian Series, the Devonian System, and the Upper Paleozoic Suberathem. The important point about all these units is that they apply to rocks, can be examined in the field, and one can hammer a golden spike into them.

The items under the heading Geochronology in Table 1 are geologic-time units; these are arranged in a chronologic order and have a hierarchy of units (in the same way as year, day, hour, minute, etc.). Geochronology, on the other hand, is an arrangement of events by age that has nothing to do with time itself nor with a hierarchy of units. Geologic-time units include the familiar periods, epochs, etc., but they do not have an exactly corresponding stratigraphy. How stratigraphy at any point relates to time is a matter of interpretation. Each unit in every part of the geologic-time unit hierarchy is bounded by time instants (i.e., points on a linear time scale) and comprises a total record of time without gaps or overlaps. These units can neither be seen in the field nor can you hammer a golden spike into them. The only point at which there is known correspondence with time-rock boundaries is at the golden spikes. Thus these geologic-time units differ in principle from time-rock units and their distinction is necessary for the purposes of language and communication.

Having thus defined units, it is possible to appreciate why a dual terminology is needed. It is to maintain clarity of thought. The Zalasiewicz et al. (2004) proposal that a GSSP should define both the base and the top of a unit clearly reveals why it is important to maintain a difference between chronostratigraphy and time units. A GSSP is a point in rock coinciding with a point in time that defines the base of a unit at one locality and provides a standard with which other sections can be correlated and calibrated. A GSSP is thus defined at a point at which some event occurred, believed to be time diagnostic; this may be based on such factors as a biostratigraphic criterion (e.g., the appearance of a time-significant fossil), or on time-significant lithostratigraphic criteria (e.g., an iridium-enriched clay band signifying an impact event). In selecting a point for a GSSP, the event should be chosen preferably to allow the possibility of correlation as closely as possible with other sections across the same time interval.

Even if the rock successions at GSSPs are believed to be "in continually [continuously] deposited sections," it would be remarkable if this were so; time is inevitably unrepresented by sediments at some part

of any section, whether on land, in an Ocean Drilling Program core, or wherever. Bedding planes themselves may represent a break in sedimentation, so that time is likely to be unrecorded there. Such appreciation led to the decision to fix GSSPs by their bases only. In fact, long before the concept of a GSSP was introduced for the base of the Devonian System (McLaren, 1977), the same method had been used in Jurassic stratigraphy for a great number of years (Callomon, 1995). GSSPs cannot thus define tops as well as bases of time units, but they may correlate with the tops of chronostratigraphic units. It should also be pointed out that they need not be used to define the tops of standard chronostratigraphic units because these coincide automatically with the bases of the succeeding standard chronostratigraphic units.

The authors refer to Hedberg's (1976) stratigraphic guide, and the principles of distinction between rocks and time have also been enunciated clearly by other authors (e.g., Callomon, 1995). The rock-time duality has been seen to be essential for over 150 years; its evolution has led to a stratigraphic classification that has been both practical and broadly accepted internationally. To abandon that duality now would be a retrograde step that will simply confuse stratigraphic thought. Zalasiewicz et al. (2004) may well be correct in saying that the distinction between the duality of time and rock is "not clear to the greater part of the professional (or student) geological community," but this is no reason to abandon it! What is needed is clearer understanding of the principles, and not an abandonment of methodologies and definitions that now do so much in promoting global correlation of geological events.

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## REPLY

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We thank Gong et al., Heckert et al., and Bassett et al. for their comments on our discussion paper. Their varied responses are typical of the range of responses we have received informally and that have been published elsewhere (e.g., Ogg, cf. Edwards in Pratt, 2004), from enthusiastic support to outright disagreement. This represents, within the geological community, a surprising divergence concerning the relationship between two such fundamental phenomena as rock and time.

In response to Heckert et al. and Bassett et al., we agree that rock and time are separate phenomena, but then we reach different conclusions than them. Thus, we assume and safely believe that our sense of the passage of time and of the succession of processes that have created Earth as it is now derive directly from the rock record. This assumption holds whether we use the evidence of fossils, paleomagnetic properties, contained isotopes (stable or radiogenic), or even astronomically produced characters (for it is the orbital variations of a solid, spinning Earth that are captured by accumulating sediment).

Thus, stratigraphic geology is essentially a forensic science, and we use the evidence contained in the rocks to interpret how Earth has changed through time and to devise a time scale within which past events from different parts of Earth can be placed and interpreted. Geologists have found it most convenient, and most precise, to set up such a relative time scale using the wealth of evidence of elapsed events—biological, paleomagnetic, and so forth—in stratal successions: hence, the origin of the term stratigraphy, a term which now, though, encompasses all rock on Earth (Salvador, 1994; Rawson et al., 2002) and, as study of our nearest planetary neighbors continues, beyond. Further, the practical development of the global stratotype section and point (GSSP) principle is allowing the creation of a time scale with no gaps and no overlaps throughout the Phanerozoic and potentially embracing much of the Precambrian (Gradstein et al., 2004; see also Nisbet, 1982).

GSSPs, as noted by Heckert et al., are not immutable, nor is their position always determined by the purest academic motives. Nevertheless, whether regarded as spikes of gold, silver, or (to emphasize their potential for obsolescence) rusty iron, they serve as effective temporal reference points, the precision of correlation being the same for time as for time-rock units. If the position of a GSSP is moved, by due process of agreement, (or even if, say, a magnetic chron ceases to be recognized) then this does not mean that an interval of elapsed geological time somehow disappears. It simply represents a change in the way in which the geological community chooses to subdivide the passage of elapsed time. And if we agree that the Silurian and Devonian periods are contiguous, it follows that the GSSP for the beginning of the Devonian effectively represents also the end of Silurian time; the extent to which this should be formally recognized is, of course, a matter for discussion.

Given this, we see no necessity taking this stratal succession and making a separate time-rock scale of it as well as inferring a time scale from it. One can classify the rocks themselves in many ways: by their overall lithological characters (in lithostratigraphy); by fossil content (biostratigraphy); by relative position within an astronomical bar-code pattern; and so on (and we agree with Gong et al. that this last approach offers real potential of providing shorter-term units). Any of these classifications may be subject to modification as our knowledge of the rock record is refined. We continue, therefore, to see no fundamental necessity, no imperative of logic to retain the dual time scale and do not agree that its abandonment would provide a fatal chink in our philosophical armor that creationists, for instance, could exploit.

We do, though, recognize that a case can be made for retaining a capacity to define strata by the relative time of their deposition, which is effectively what the chronostratigraphy branch of the dual terminology does. This is particularly the case for the biostratigraphical community, which is used to the dual terminology and finds it provides them with an effective shorthand means of communication. Thus, it is easier, certainly, to say the Arenig Series rather than strata deposited during the Arenig Epoch.

However, for geologists dealing with complex orogenic collages of igneous, metamorphic, and sedimentary rocks, as noted by Gong et al., the dual terminology is at best an irrelevance, and what is necessary here is to fit a diverse succession of geological events into a temporal and spatial framework to say what happened when and where. In such circumstances, a single, numerically calibrated scale of relative geological time is appropriate. Thus we disagree with Heckert et al.'s assertion that igneous plutons (still less, high-grade tectonometamorphic complexes) can easily comprise part of systems, stages, and so on. Similarly, a unified time scale would, we consider, facilitate interdisciplinary use of stratigraphic data by biologists, climate scientists, and others not familiar with the long history of stratigraphic nomenclature. Given the current urgency of providing effective past analogues for future environmental change, this seems no longer a minor consideration.

Thus, the perceived need for, and utility of, a dual versus a unified time scale seems to correlate with a geologist's perspective and context. We maintain that the most fundamental need is a single scale of geological time, abstracted from the rock record, and applicable to all rocks, whether stratified or not, and across all the sciences. It follows that the time-time-rock duality, as currently employed, is not symmetrical: time-rock functions essentially as a means of classifying stratified rocks by the relative time of their deposition and is most useful to those geologists working mainly on such successions. Producing an effective time scale and reconciling the working needs of different groups of scientists is the challenge that we face.

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