Essay Review

Stratigraphical Procedure, edited by P. F. Rawson, with P. M. Allen, P. K. Brenchley, J. C. W. Cope, A. S. Gale, J. A. Evans, P. L. Gibbard, F. J. Gregory, E. A. Hailwood, S. F. Hesselbo, R. W. O'B. Knox, J. E. A. Marshall, M. Oates, N. J. Riley, A. G. Smith, N. Trewin and J. A. Zalasiewicz, 2002, Professional Handbook series, Geological Society, London, vi+57pp. ISBN 1-86239-094-0 (PB), £16 (Geological Society members £8).

This is the latest edition of a series going back to 1967 of guides to stratigraphy published by the Geological Society. The need for such guides becomes ever greater as the time devoted in our institutions of higher education both to the theory of the subject and to its practice in the field becomes ever more compressed; and, it has to be added, as stratigraphy becomes ever more diverse – and bewildering? – in the range of its applications through the introduction of new experimental techniques. 'This Handbook ... is designed to explain the different stratigraphic methods, show how they can be applied by the practising geologist ... [and tries to] encourage a common approach ... by offering clear guidelines on usage' (p. 1) – so the Introduction. 'This handbook will be an essential tool for all Earth Scientists: professional, academic, student and amateur, particularly those with an interest in the British Isles' – so the publisher's blurb on the back cover. As in previous versions, a laudable mission statement and a reassuringly authoritative endorsement of its reliability and usefulness. Has it succeeded in fulfilling its objectives and promises?

Up to a point. The layout of the text is vastly improved compared with that of previous versions and so now is its destrangulated use of the English language. The subject (abbreviated to 'SP' in what follows) is presented in seven chapters: 1: Introduction; 2: Establishing the rock succession; 3: Calibrating and correlating successions; 4: Establishing a relative time-scale: chronostratigraphy; 5: Determining a numerical time-scale: geochronometry; 6: Combining the approaches: holostratigraphy; 7: Databases. Most chapters are then subdivided into sections and subsections under a hierarchy of headings. It seems a clear, comprehensive and logical plan of exposition and individual topics are easily located under their headings in the Contents. Nevertheless, the treatment of some of the topics continues to give me problems, particularly in what is still the dominant core of the subject: lithostratigraphy (SP2), biostratigraphy (SP3) and chronostratigraphy (SP4).

The crux lies in the need to follow the basic principles underlying all of the physical sciences, of the clear distinctions to be made between **definition, observation, interpretation** and **application** – in that order, with particular emphasis on the precision of definitions. Failure to do this leads to confusion. The authors refer to 'the development of new approaches and methods of correlation that have revitalized stratigraphy' (p. 2). But friends – professional stratigraphers – tell me that what had caused much of the stratigraphic devitalization from which we are allegedly recovering was widespread confusion arising from just such imprecision in so many of the innumerable *Stratigraphic Codes* and *Guides* (*International* or not) that have assailed us in the last quarter century. Stratigraphy is diverse but simple – provided its concepts are clearly defined and separated. I have always found it to be a subject particularly well suited to analysis guided by what I used to propose to students as the Physical Scientist's Catechism:

Cm (1): *What is it*? – definitions of concepts (e.g. stratigraphy), terms, quantities.
Cm (2): *How do you measure it*? – methods (e.g. in recording sections).
Cm (3): *How big is it*? – results (e.g. stratigraphic logs, ranges, maps)
Cm (4) *What does it mean*? – interpretation (e.g. correlations, ages, genesis)
Cm (5) *What use is it*? – applications (e.g. historical geology, palaeobiology, tectonics, basin analysis)

Let us examine the chapters in turn.

SP1: Introduction

We start with some generalities. Quite properly, one of the leading points to be made at the outset is to tell us what stratigraphy is *for* [Cm(5)]: '... *the* [my italics] essential purpose of stratigraphy as a whole remains simple. It is to create an ordered history of Earth .... Thus it is of primary importance to understand the relative ages of rocks ..., that is to have reliable correlations' (p. 1). But one wonders already here whether oil explorers, hydrogeologists or civil engineers would necessarily agree with the emphasis on geochronology contained in the first sentence; and whether the term 'correlate' has the restricted meaning – of **time**-correlation – implied in the second. There is then a brief summary of what the diverse areas of stratigraphy are essentially concerned with [Cm(2), (4)]. But as to what stratigraphy actually *is*, a precise definition, not a word. The unspoken assumption is presumably that everybody already knows what stratigraphy is, hence no need to dwell on it. And this is where some of the problems start.

I would have welcomed a firm basis in first principles for what follows, with asubsection 1.1 entitled 'Some basic definitions' [Cm(1)]:

Stratigraphy is the study, description and classification of layered rocks.

The important word here is **classification**, for this implies **criteria**, which themselves fall broadly into three categories: **genesis** – mode of formation; **constitution** – mineral composition, structure, fossil contents; and **age** – relative (stratigraphic), absolute (radiometric).

The next requirement is a **metric** [Cm(2)]. As all layered rocks are discontinuous on one scale or another in one or more of the basic categories, their descriptions are made in terms of systems of building blocks, or **stratigraphical units**:

Stratigraphical units are bodies of strata delimited by boundaries that separate them.

Then we are away. There are many criteria and attributes of rocks that can be applied to their descriptions, each of which can then be made the basis of an independent stratigraphy, each with its own system of units. Leading among them are the Sacre dTrinity:

lithostratigraphy:	by lithology	(no mention of time or fossils)
biostratigraphy:	by fossil content	(no mention of lithology or time)
chronostratigraphy:	by age	(no mention of lithology or fossils)

Other criteria include remanent magnetism (magnetostratigraphy, SP3.9), radioactivity (radiostratigraphy, SP3.3), the widespread effects of geological events (eustatic event stratigraphy, bentonite stratigraphy, asteroid impact stratigraphy, SP3.8), stable elemental isotope-ratios (isotope stratigraphy, SP3.10), elastic reflectivity and refractivity (seismic stratigraphy, SP3.4), porosity and permeability (hydrostratigraphy), periodic fluctuations in solar insolation governing climate (cyclostratigraphy, SP3.6,7), genetic model-dependent patterns of sedimentary facies (sequence stratigraphy, SP3.4) and so on. ('Holostratigraphy': that is another matter).

SP2: Establishing the rock succession

SP2.1. Lithostratigraphical units.
'Lithostratigraphical units are sedimentary or igneous units that conform to the Law of Superposition.' (p. 3). No definition of lithostratigraphy itself, but as we have helpfully indicated one above, no need to repeat it. But what is this Law of Superposition? We are not told. If it is Steno's (1669), its purpose is to couple the **interpretation** of layering [Cm(4)], in terms of time, to the **observation** of layering [Cm(2)]: the higher the younger. But what does time have to do with lithostratigraphy? William Smith never mentioned time, either in his *Prospectus* of 1801, or in his *Map* of 1815, or in his *Strata Identified* of 1816, in which he founded lithostratigraphical units still in use today. (His Kelloway's Stone of Wiltshire and the Kelloway Rock of Yorkshire do not even overlap in age.) And a famous exposure at the Schwandenerloch in Canton Glarus, Switzerland (1 km east of my sister-in-law's former home) shows a fine and apparently conformable section through three sharply bounded lithostratigraphical units, each clearly defined over a century ago, clearly recognizable and mapped over distances up to 20 km: Verrucano [Formation] on Lochseitenkalk [Formation] on North-Helvetic Flysch [Formation]. Only subsequently was it established that the ages were Permian on Late Jurassic on Early Tertiary (note capital initials). Steno's Law turned out not to apply: does this mean these Formations are not valid lithostratigraphical units?

SP2.2. Definitions of lithostratigraphical units.
Two points. First, it is useful to distinguish systematically between **formal** and **informal** units (analogous to, but not in the precise sense of **standard** units in chronostratigraphy, of which more below), and to indicate this orthographically by writing the names of such units with capital initials. This is done here in part but not consistently ('The basic unit is the formation' (p. 3) – *recte* Formation). Second, hierarchy: 'Units are defined within a hierarchical framework: Supergroup ... Formation ...'. (p. 3). This hierarchy encompasses a particular kind of **set of sets** of different **ranks**: each member at one level is made up of a set of members of next lower rank. As a consequence, the set at any one level is complete: a Group consists of the Formations in it (which could be but a single one); no Formation belongs to more than one Group; and no Group includes beds that are not included in a Formation. In this way, the classification of any rock in a stratum is unique. The classification can be changed by subdivision, promotion or demotion as stratigraphers see fit, but changes must preserve the hierarchical structure; and it is useful to restrict the term 'formal' to units that are members of the hierarchy. It should also be mentioned that the taxonomy (*sic*) of lithostratigraphic units is a highly subjective matter. Fixed rules for assigning rank – Group, Formation, Member – are unlikely to attract general agreement, even less observance. It is reassuring, however, to see the retention of one traditional British criterion, that of mappability.

The lowest rank in the hierarchy is here taken unchanged from the previous edition (Whittaker *et al.*, 1991) to be that of Bed. This surprises me, for in North America – the cradle of formal lithostratigraphy – it has always been that of Member. Named beds have been a traditionally British favourite precisely because they are **not** members of the formal hierarchy: their function is to act as **informal** markers **within** Members or Formations. That does not mean that they need not be subject to the same strict requirements governing their definitions as are the formal units. Where would we be in Dorset without our Lower Skulls, Specketty, Gumption or Grey Ledge in the Blue Lias Member of the Lower Lias Formation of the Lias Group? Or the Snuff-boxes, the Astarte Bed, Truellei Bed, Sponge Bed, Zigzag Bed, the Scroff, in the Inferior Oolite Formation? Or the Flats, Washing Ledge, Maple Ledge, Cattle Ledge Stone Bands, the Blackstone, in the Kimmeridge Clay Formation? To judge by recent map-sheet Memoirs, our Geological Survey (BGS) also still draws the formal line above Bed, which it retains in the old sense – as does *Stratigraphical Procedure* itself, in Figure 2.1, which marks out 14 such named beds in a part of the Flamborough Chalk alone.

SP3: Calibrating and correlating successions

SP3.1. Biostratigraphy.
The confusion now really deepens. 'Biostratigraphy is the use of fossils in stratigraphy.' (p. 15). Really? There is then hardly a sentence in what follows that would survive intact scrutiny under the catechism.

> It relies on [is in part?] the study of fossil distributions to allow recognition of stratigraphically restricted … taxa …, which enables subdivision [?] and correlation of lithostratigraphical successions. Such taxa may be selected as index fossils and used as the basis of biostratigraphical correlation – one of the most powerful tools for correlating Phanerozoic sequences (p. 15).

Again, the implication here that there is only one kind of correlation, **time**-correlation. In fact, what both biostratigraphical and lithostratigraphical correlations provide may in the first instance be no more than bio- or litho**facies** correlations. To convert these into time correlations involves extra steps of interpretation (now enter Steno) that are the subject of **chrono**-stratigraphy (*q.v.*). And these steps are not trivial and have to be justified (enter T. H. Huxley and homotaxis). Using fossils as geological clocks works well with some but not with others: how do you know? How do you 'select' the good ones – called **guide**-fossils by v. Buch (1839, Jurassic), not to be confused with **index**-fossils as introduced by Oppel, (1856, more Jurassic) for an entirely different purpose? Easy: good guide-fossils are those that are found widely distributed in narrowly isochronous strata. And how do you know the strata are narrowly isochronous? Easy: by means of their guide-fossils. Indeed; and how we regret the time spent correcting papers by authors who got it wrong.

Then:

> The basic unit of biostratigraphy is the biozone, which is formally [*sic*] described in terms of its fossil indices [*sic*] and contents. Biozones are then ordered in stratigraphical position [?] ultimately to allow correlation of lithostratigraphical units [more time-correlation] …. Most Phanerozoic successions with fossil remains … have been subdivided [?] biostratigraphically. … Biozones may be further subdivided. Sub-biozones [bio-subzones?] are defined by taxa that may be of only local importance [?] within the more regionally extensive hierarchy [*sic*] of biozones (p. 15).

But Figure 3.1, 'Types of biozone' (p. 17) then illustrates graphically what appears to be a different kind of biozone, in conventional form in terms of vertical ranges between 'first (evolutionary) appearances (FO)' and 'last (evolutionary) occurrences (LO)' (§3.1.4, p. 19) of up to ten separate single taxa in parallel! No hierarchy, no order in stratigraphical position. But whose taxa? And hence, evolutionary changes identified by whom? Where? According to the state of knowledge at what date? The ranges are plotted relative to two parallel horizontal lines but we are not told what these represent: whether time-planes (interpretation) or lithostratigraphical boundaries in a real section (observation). And so on: few things can be more subjective and ephemeral than the time-ranges of named, i.e. identified, palaeobiological taxa. Ranges are being constantly extended, taxa reclassified.

Then, back to biozones of the first kind: 'Biozones should normally be named after their most characteristic fossils [decided by whom?], using standard Linnéan binomial notation … with biozone capitalized, e.g. *Hyperlioceras discites* Biozone' (p. 16). The example chosen (again Jurassic) now at least leaves no doubt as to what meaning is intended. It cannot be the *H. discites* biozone in the sense of Figure 3.1 and in the sense understood by all Jurassic biostratigraphers, for that biozone is unknown: *Amm. discites* Waagen, 1867, is currently uninterpretable because the type specimen is lost (revision in progress) and the species as represented by its former type, known from a photograph, has never been found in Britain. The Discites Zone (standard chronozone) is, however, in excellent shape, quite clearly defined in terms both of its contents (Callomon & Chandler, 1990, *op. cit.* in *Stratigraphical Procedure*, biohorizons (*sic*) Bj-1, 2, 3, clearly defined and having nothing whatever to do with maximum flooding surfaces, p.15) and, exceptionally, typologically by its base, which is hierarchically and automatically also the base of the Bajocian Stage (defined as a 'GSSP' [Global Stratigraphic Section and Point] on p. 35, a concept discussed in more detail below) at Cap Mondego in Portugal. It is, however, certain that the *discites*biozone lies at least mostly, if not exclusively, in the Discites Zone. 'Biozones' of SP and biozones are clearly not the same thing. More widely, none of the Jurassic ammonite 'biozones' to which the reader is referred in Cope *et al.* (1980a, b) – the Geological Society's own correlation charts – are biozones or Biozones either: they too are standard chronozones. I am afraid the authors of *Stratigraphical Procedure* do not seem to understand the basic difference between biostratigraphy and chronostratigraphy.

SP4. Establishing a relative time-scale: chronostratigraphy

So what is this elusive chronostratigraphy?

> Chronostratigraphy is the classification of layered rocks according to their ages.
>
> And chronostratigraphic units?
>
> A chronostratigraphic unit consists of all the rocks lying between two time-planes.

This somewhat paraphrased definition goes back to Hedberg (1954), who coined the term in a refreshingly simple distillation from what sounds to have been another turgid succession of reports by a Stratigraphic Commission, the American one on Stratigraphic Nomenclature (consisting, however, of only 15 members). While precise, this definition by itself is not very helpful. Every point picked out in a stratified section defines a time-plane. (A stratigraphical time-plane has its simplest meaning in the context of the ideal model of continuous sedimentation to which (Steno's) Law of Superposition applies most precisely and in which the limit of zero thickness implies an instant of zero duration. Recognizing time-planes [Cm(2)] at any one place may therefore be difficult or impossible. Nevertheless, the Earth has a sharply defined surface at any one instant, which may be used to define a time-plane, and all such time-planes are therefore global.) Every biozone, for instance, defined by the points of first and last appearance of its eponymous taxon in a section thereby automatically defines a conjugate chronostratigraphic unit, a chronozone. One suspects this may be the intended meaning of the vertical spaces between those selected pairs of parallel horizontal lines in Figure 3.1. Conversely, the number of chronozones thus defined by a faunal assemblage, many of them overlapping, is unlimited and constantly changing. If we wish to express the ages of rocks by assigning them **uniquely** to chronostratigraphic units – as apparently we have done since the times of Brongniart, Murchison, Lyell, Phillips, d'Orbigny, Oppel and so on, and still do – we have to select chronostratigraphic units in temporal successions having **no gaps and no overlaps**: a given piece of rock is either Silurian or Devonian and there are none that fall in between. Such units are called **standard** chronostratigraphic units and form **standard scales**. In a way analogous to that in formal lithostratigraphy, the names of standard chronostratigraphical units are written with capital initials (in the most important table in the book, on p. 35, they are not).

These definitions, as *Stratigraphical Procedure* quite correctly notes, generate a rock–time duality: the rocks are the tangible record of geological events during a time interval, and the time interval is that of the formation of the rocks. The standard succession of rock units makes up what used to be called the 'standard geological column' and the conjugate succession of standard time units was what Buckman (1898) so aptly called the '[standard] geological **calendar**', a term for it that deserves to be revived. But is it in fact necessary to retain a duality of nomenclature, that of standard chronostratigraphy for the rocks and that of standard geochronology for the conjugate time? *Stratigraphical Procedure* is not sure (p. 35) and already warns us that the Stratigraphy Commission is currently reviewing the matter – be afraid. To a physicist, the answer is emphatically yes, for the usual reasons: the rocks are what you see [Cm(2)], the time is what you infer [Cm(4)]. The duality is moreover not symmetric: the record of time in the rocks is generally incomplete, whereas time is not. At Faringdon, Oxfordshire, the Lower Greensand (Formation) of Early Cretaceous, Aptian age rests directly on the Coral Rag (Member) of the Osmington Oolite (Formation) of Late Jurassic, Oxfordian age: the Portlandian Stage is missing (cut out by erosion, we have extraneous reasons to believe). Would we say that at Faringdon, the Portlandian Age had been absent? (This point was first expressed more colourfully by Buckman (1902) in the parable of the Dorset labourer whose lunch-packet – the tangible manifestation of lunch-time – had been eaten by a dog: would we have said 'my dinner is gone, one o'clock must have been absent'? There is much more in the same vein, a gem of invective, but all making the same point. Geologists then were having the same problems with rock–time duality as we still see today. But that was a century ago!) Elsewhere, the **observation** is that the Fuller's Earth Bentonite Bed of Bath is in the Hodsoni Zone of the Upper Bathonian, but that the **event** that brought it there must have been a volcanic eruption in the Hodsoni Chron of the Late Bathonian.

In attempts to construct scales of standard chronostratigraphical units, the selection of such units is driven by practical needs and the tools available [Cm(2)] which, in time-measurement, are chronometers or **clocks**. And, as we all know, by far the most versatile, widely distributed and easily recognizable geological clocks in the Phanerozoic have been its guide-fossils. Thus it is that our familiar primary chronostratigraphical classification of the Phanerozoic is based almost entirely on time-diagnostic biozones. As in lithostratigraphy, it is convenient to use units of widely differing relative magnitudes according to the **precision** of the age of a rock or the date of an event to be described and so, again, our scales are cast in a hierarchy of ranks – Mesozoic Erathem/Era>Jurassic System/Period>Oxfordian Stage/Age and so on. *Stratigraphical Procedure* takes as its lowest rank the Chronozone/Chron, but in the Jurassic, at least, the lowest level in the hierarchy is the Subzone/Subchron (see Cope et al. (1980a, b), in which the whole of the British Jurassic is classified down to this level – 70 Zones, 141 Subzones, not counting the non-marine Purbeckian at the top). The hierarchy has a similar set structure as that of formal lithostratigraphy and, even more appropriately, as that of Linnéan biological taxonomy, in which each unit of higher rank is defined in terms of the units of the rank below it that it contains. This has important consequences when it comes to typological definitions, on which more below.

A further important point that would have been useful in *Stratigraphical Procedure* is to take account of the fact that even in rocks of the same age-range, there is usually more than one kind of clock that can and may have to be used. An obvious example is the use of microfossils in drill-cuttings in which macrofossils, such as ammonites, trilobites, goniatites or graptolites are not available. And, as we all know, the biostratigraphy of microfossils (including conodonts) has been made the basis of many alternative chronostratigraphical zonations, each conforming to the requirements of a standard (for a review, see Cox, 1990). Such alternative standard zonations are of equal validity but they may of course differ in temporal resolving power, regional extent, facies-dependence or whatever. Such 'second-best' standards are called **secondary** standards. (We are accustomed to weather reports that give temperatures in degrees Celsius as well as degrees Fahrenheit. Both of these are secondary standard scales of temperature, the primary scale being that of Kelvin.) They may need mutual calibration and calibration against the primary standard. They may have restricted ranges. But all of them are global.

Infra-standard units: those biohorizons. They are biozones representing unknown but usually short durations of time, separated by also unknown but possibly longer intervals of time, more often than not represented by disconformal partings in the rocks. They lie within standard chrono-units and fulfil there the same function as 'Beds' do in lithostratigraphy, acting as markers.

Lastly, the typological definitions of chrono-units: the 'Golden Spikes' driven into type-sections at the levels of the time-planes that define the units, the GSSPs. *Stratigraphical Procedure* still emphasizes this as the major preoccupation of chronostratigraphy: 'Many of our chronostratigraphical units were originally defined rather loosely. Hence modern work focuses on the rigorous definition of each component of the time-scale' (p. 35) and refers us to the International Commission of Stratigraphy's (ICS) pronouncements in this field. That is at least an advance on Whittaker *et al.* (1991), in which this activity was the sole purpose of chronostratigraphy: 'Chronostratigraphy is the definition of internationally agreed boundaries for systems, series and stages.' (Whittaker *et al.*, 1991, p. 816).

The confusion in the ICS's *Guidelines* (Cowie *et al.*, 1986; Remane *et al.*, 1996) is, if anything, perhaps even greater than in *Stratigraphical Procedure* but cannot be gone into here in detail. In brief, first, the chronostratigraphical hierarchy is taken down only as far as Stage, even in Systems (such as the Jurassic) in which it goes two steps of rank further down. The hierarchical principle is abandoned at Stage level, so that the Bajocian Stage in the Middle Jurassic, one of the only three of the 11 in that System so far ratified by a majority vote of the ICS, has its GSSP at Cap Mondego in Portugal, whereas the lowest of the four biohorizons of *Hyperlioceras* that is used to locate the base of the Discites Zone, the basal Zone of the Bajocian, is best characterized in Dorset. It is, therefore, hard to see why anyone interested in close time-correlations around the base of the Bajocian would want to go to Cap Mondego rather than to Dorset – or other localities at which correlation has shown the *H. politum* biohorizon to be comparably well developed (which does not include Cap Mondego). Second, the reason for this emphasis on Stages is that the ICS thinks this is the lowest level at which standard chronostratigraphical units can be 'applied' globally: hence the special value of the defining time-planes of a Global Stratotype Section and Point (GSSP). But as we have seen above, all times-planes are global. The Commission confuses 'Global' with 'Primary Standard', and PSSP would be a more appropriate term.

This goes to the heart of the matter. Whereas we formally **define** standard chronostratigraphical units in terms of their bounding time-planes, we **recognize** them in a section – correlate them with the standard – not by locating those time-planes themselves but by means of what lies between them: for instance, our guide-fossils (or magnetic polarity, or the strontium isotope-ratio in its calcitic fossils, or whatever). That is the whole point of using stratigraphic **units** as the metric of time-correlations (back to Square One). And the **precision** of correlation is expressed in terms of the rank of the units used. The Astarte Bed of the Inferior Oolite on the Dorset coast (0.2 m thick) includes the *Parkinsonia rarecostata* biohorizon Bj-26b of the Acris Subzone of the Parkinsoni Zone of the Upper Bajocian of the Middle Jurassic (for which the Bajocian GSSP is irrelevant). The non-marine Scalby Formation of Yorkshire (50 m) is mostly Bathonian, Middle Jurassic – that is as far as one can go (for which, *a fortiori*, the definition of the Bathonian GSSP is irrelevant). The standard chronostratigraphy of the British Jurassic encompasses 11 Stages subdivided (*sic*) into some 75 Zones and up to 150 Subzones. The Stages can be recognized more or less all over the world but their boundaries only to perhaps Zonal level. The Zones can be recognized widely in Europe but become increasingly tenuous further afield, as for instance in the Andes. The Subzones are even more geographically restricted in their recognizability. Yet the standard chronostratigraphy of the Jurassic of Chile and Argentina is almost as refined as that of Britain. It has its own standard zonation, a geographical **secondary** standard. And all this without GSSPs.

In other Systems, such as the Devonian, the interest lies in the construction and correlation of secondary standards based on different fossil groups, such as the ammonoids and conodonts, and their correlation with the primary standard based on graptolites (at least, one hopes this is the case: the much-trumpeted GSSP of the

Devonian System graced by a spectacular monument at Klonk in Bohemia marks the base of the biohorizon of *Monograptus uniformis uniformis* with *M. uniformis angustidens,* taken to be the biozone by which the base of the Devonian can be recognized and correlated). And it is the working out and correlation of such standards using all available clocks that engages 'modern' chronostratigraphers, *pace Stratigraphical Procedure*, not 'the rigorous definition of each component of the time-scale [in terms of a GSSP]' (p. 35). This distinction between definition [Cm(1)] and recognition [Cm(2)] is crucial. If you cannot measure it, little point in defining it, the physicist would say. (There are some who would maintain that this distinction marks also the difference between science and theology.)

Space for only one brief final comment.

SP6: Combining the approaches: holostratigraphy

'Holostratigraphy is a holistic approach to stratigraphy – it brings together every possible method to produce an integrated correlation that may have much higher resolution than any one method' (p. 43). Yes, integrating parallel primary and secondary chronostratigraphic classifications can be a good thing, which is why we have been doing it since forever. But the whole cannot be more than the sum of the parts (unlike, perhaps, holistic medicine, which carries a strong spiritual element). A fruit salad is a mixture of apples, oranges and pineapples. It does not consist of sliced holofruit bred by crossing apples, oranges and pineapples. And, as the subsequent discussion itself points out, one of the clocks available in any given situation is usually so much better than the others, that it will win the day. In the marine Jurassic, ammonites have it hands down. 'It's a fine day, let's go out and do some holostratigraphy': what do you actually **do**? Do you need a hammer? Do you have Professors of Holostratigraphy to guide you? Or do you need just a computer back home to juggle your databases, to integrate them? Is holostratigraphy any more than a buzz-word to try on potential research-grant donors?

Conclusion

Stratigraphical Procedure leaves me disappointed. Every point touched on above has been debated in the literature for many years and the problems arisen resolved, even if at the time not always in the precise terms we use today. The concepts of hierarchical standard chronostratigraphy down to zonal level go back to d'Orbigny and Oppel in the years 1850–1858, even if the 'standard' was not explicitly introduced until 1941 by Muller, elaborated into a Code of Stratigraphical Nomenclature by Arkell in 1946; and the term 'chronostratigraphy' goes back to Hedberg in 1954. The call for typological definitions of chronostratigraphical units by their bases arose at the Luxembourg Colloquium on the Jurassic in 1962 (Ager, 1963), the need for this to be done at the lowest level in the hierarchy, by analogy with zoological taxonomy, in 1965 (Callomon, 1965). The concepts and consequences of rock-time duality were fully understood and laid out by Buckman at the end of the nineteenth century (Buckman, 1893, 1898) – remembered largely for his dreaded 'hemerae', which were in fact little more than the time-equivalents of the biohorizons so powerfully resurrected in Jurassic stratigraphy the world over today. He stressed particularly the highly incomplete record of time in the rocks as revealed by fossils at the hemeral level of time-resolution: the paradox that the more complete the biostratigraphical record becomes, the less complete the chronostratigraphical record turns out to be. All this was cast in modern terms in a critical review in 1995 in one of the Geological Society's rare publications priced at a level ordinary folk can afford (Callomon, 1995), in which is also laid to rest once and for all the spectre of the 'Oppel-zone' that caused so much confusion in the *International Stratigraphical Guide* of 1976 (Hedberg, 1976), together with an explanation of the difference between v. Buch's guide-fossils and Oppel's index-fossils. The basic physical ideas behind the use of fossils as clocks to construct calendars and then to date rocks are explored by analogy with familiar historical calendars and time-scales in another of the Geological Society's publications (Callomon, 2001). All these principles are now being followed the world over by the Jurassic community, at least. They are also increasingly being followed by the BGS itself, to judge by recent Memoirs covering map-sheets incorporating Jurassic rocks. Yet there is nothing in these principles that restricts them to the Jurassic.

Of all this, *Stratigraphical Procedure* shows little sign. What we get strikes me as a rather tired mixture of what some of us do at the BGS or the Natural History Museum, what our predecessors wrote in 1991 and what it says in various *Codes* and *Guides* put out by other Commissions on Stratigraphy. That 17 authors should combine and publish under their joint names their views on stratigraphy is fine and their business: we may agree with them or not, with no further consequences. That they should individually agree with all the propositions in the present publication would, however, strike me as improbable. That a soviet of 17 authors should, however, publish the present document under the aegis without disclaimer of the Geological Society as a Stratigraphy Commission of that Society is another matter. The implication is that it carries the authority of the Society as a distillate of its collective wisdom, as something greater than the authorities of the individual authors. And, as a member of that Society, that makes it my business: I object. So, finally, what advice to give to all those Earth Scientists for whom the Society assures us this Handbook will be an essential tool? The professional will decide for him- or herself whether it is essential. Academics should be able to look after themselves, for it used to be the function of academics to be able to relate the understanding of their subject back to its first principles. Students and amateurs: all I can offer is the old saw – don't believe everything you read in books.

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