Geological Society, London, Memoirs

An interim time-scale

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Geological Society, London, Memoirs 1985, v.10; p261-265.
doi: 10.1144/GSL.MEM.1985.10.01.19

Notes

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SUMMARY: The time-scale presented here endeavours to take cognisance of the views expressed in the Symposium, those expressed in other recent publications, notably the reviews and collations of Odin (1982) and Harland *et al.* (1982; based on Armstrong 1978), and the suggestions of the Subcommission on Precambrian Stratigraphy (Sims 1980). The conclusions of the contributors to these various works are not always compatible and this scale involves elements of both compromise and personal judgement. No plus or minus figures have been assigned to the boundaries although estimates of the uncertainty to be attached to the boundaries are commonly to be found in the more recent literature. It should be emphasized that these uncertainties are generally expressions of the limits within which a particular boundary probably lies *according to the author concerned*, they are thus apt to be somewhat subjective.

The Precambrian

Cowie & Johnson (this volume) discuss the late Proterozoic time-scale and compare the chronometric scale proposed by the Subcommission on Precambrian Stratigraphy in 1979 (Simms, op. cit.) with the chronostratigraphic scale proposed by Harland *et al.* (op. cit.) 'designed to satisfy the aspirations of the Australian, Chinese, Russian and Scandanavian communities ...'. The former is virtually the same as the proposed for the USA and Mexico (Harrison & Peterman 1980), it is essentially lithostratigraphic in that the boundaries were selected so as to 'split as few major rock sequences as possible'. Other lithostratigraphic scales can be drawn up for the other continents with significantly different boundaries but which are equally relevant and functional for the regions concerned — compare for example the scales for the Canadian Shield, Africa, and the USA and Mexico (Snelling, this volume); thus, despite the advocacy of the Subcommission on Precambrian Stratigraphy there would seem to be no reasons for adopting their proposed chronometric scale in preference to any of the others.

The latter chronostratigraphic scale is a clear reflection of the world-wide effort that has been put into the application of the principles used to define Phanerozoic chronostratigraphic divisions to the supracrustal rocks of the Precambrian; including the vigourous persual of stromatolite and microphytolite biostratigraphy, and the correlation potential of glaciogenic deposits, palaeomagnetism, and the conventional methods of geochronology (Trompette 1982). The proposal to use the name Sinian for the youngest era or sub-era of the Precambrian, however, could introduce a considerable degree of confusion. As used by Chen Jinbiao *et al.* (1981) the 'Sinian Suberatherm' extends from *c.*1950 Ma to the lower boundary of the Palaeozoic, while the 'Sinian System' is the youngest chronostratigraphic unit in the Sinian Suberatherm. Even if this problem of nomenclature can be resolved a restructuring of the late Precambrian chronostratigraphy would be called for, specifically 'a radical restriction of R_3' — the Karatavian (Harland *et al.* 1982). Despite some confusion in the classification of the late Riphean, the 'Riphean' is clearly regarded by Soviet geologists as an entity as emphasized by their two-fold division of the Proterozoic into Lower (unnamed) and Upper (Riphean) units only. The proposal of the Comité français de Stratigraphie (1980) to assign the Upper Riphean (R_3 and R_4) and the Vendian to the Upper Proterozoic, with the Middle and Lower Riphean (R_1 and R_2) constituting the Middle Proterozoic, would allow such a restructuring of the late Proterozoic chronostratigraphy, although it might not initially find favour with Soviet specialists. These are taxing but not insoluble problems, but their resolution can only be achieved through international co-operation and co-ordination.

The Lower Proterozoic represents a long period of time, the subdivision of which is only briefly touched upon by Harland *et al.* (1982). An important division can clearly be made at *c.*2000 Ma which is marked by the appearance of the oldest fossils known to display a clear differentiation into two or more types of cells (the Gunflint microbiota; Cloud 1983), the near limitation of the banded iron formations to rocks older than about 2000 Ma (98%; Goodwin 1982) and the appearance of the oldest conspicuous 'red beds' at about this time. Irrespective of arguements concerning the relation between these phenomena and the actual oxygen level in the atmosphere, these observations seem sufficient to justify a division at about 2000 Ma. The period of time from *c.*2000 Ma to *c.*1650 Ma could then constitute an era or sub-era for which I would suggest the name 'Guianian' reflecting the spectacular development of the Roraima 'red beds' Supergroup in the Guiana Highlands of South America, deposited in this time interval.

The foregoing discussion leads again to consideration of the rejection of the etymologically unsatisfactory Proterozoic and the substitution of Proterophytic and Palaeophytic, both of eon status, the former extending from the 'conventional' end of the Archaean at 2500 Ma to *c.*2000 Ma, and the latter from 2000 Ma to the Precambrian: Cambrian boundary. It would seem not impossible to define the Proterophytic: Palaeophytic boundary following chronostratigraphic principles. The Palaeophytic Eon would thus consist of three Eras, viz: the Guianian from *c.*2000 Ma to *c.*1650 Ma; the Riphean from 1650 Ma to ?*c.*680 Ma; and the Vendian (± the Kudashian, R_4) to the Precambrian-Cambrian boundary. Restructuring of the late Palaeophytic could be expected with advances in stromatolite biostratigraphy (Bertrand-Sarfati & Walter 1981) and further research on Ediacaran faunas.

Consideration of the recent literature suggests that there is still considerable scope for the International Commission on Stratigraphy to co-ordinate and rationalize work on the Precambrian time-scale and the prospect that a functional chronostratigraphic scale will be developed seems to be very real. Precambrian chronstratigraphy is developing rapidly particularly under the auspices of the IGCP Projects 99 and 118 (see Precambrian Research, **15**, 1981 and **18**, 1982; Cowie & Johnson, this volume) suggesting that the international adoption of the chronometric scale proposed by the Subcommission of Precambrian Stratigraphy in 1979 might be premature.

The Precambrian: Cambrian boundary and the Palaeozoic and Mesozoic time-scale

The continuing resolution of biostratigraphic problems within the Cambrian System, including a significant measure of agreement on the definition of the base of the Cambrian System at the Precambrian–Cambrian boundary has not been accompanied by comparable improvements in our understanding of the chronology of the Cambrian Period. Indeed Gale (1982) considered it necessary to reject much of the earlier geochromometric data and from consideration of a few (in his view reliable) age determinations suggested an age for the base of the Cambrian (the Precambrian–Cambrian boundary) of 530 ± 10 Ma, an interpretation which was further amplified by Odin *et al.* 1983. This view has been slightly modified following the demonstration that the critical Caer Caradoc granophyre intrudes 'lower' Cambrian sediments, although its relationship to the lowest fossiliferous Cambrian sediments is not so certain. In their review of the current situation Odin *et al.* (this volume) suggests an age for the Precambrian–Cambrian boundary not much older than 540 Ma. Cowie & Johnson (this volume) would regard much of the data considered by Odin *et al.* (this volume) as ambiguous or unreliable and tend to stress Chinese data, particularly a uranium-lead isochron determination on Atdabanian black shales which indicates an age of *c.*570 Ma. So far, however, the Chinese data have received inadequate documentation and remain difficult to assess; Cowie & Johnson are unable to come to any firm conclusion regarding the age of the Precambrian–Cambrian boundary but leave open the possibility that it may be appreciable older (+ 570 Ma) than the younger age favoured by Odin *et al.*

The writer's view of the Cambrian time-scale is conditioned by a willingness to accept: (1) that the Vire-Carolles granite appears to be pre Atdabanian (relation to Tommotian is less certain) and that the most reliable age that can be extracted from the plethora of discordant data from this intrusion is 540 ± 10 Ma (Pasteels & Doré 1982); (2) that the Caer Caradoc granophyre — 533 Ma — possibly intrudes trilobite bearing Atdabanian sediments (Cowie & Johnson, this volume). None of the other data discussed by Cowie & Johnson, and Odin *et al.* seem to be sufficiently unambiguous to throw any more helpful light on the problem. This estimate for the age range of the Atdabanian is of course at variance with the age of *c.*570 Ma determined on uraniferous sediments from China of Atdabanian age (this seems to be the least ambiguous of the considerable body of Chinese data). As far as the Precambrian–Cambrian boundary itself is concerned a reviewer can do little more than follow Lambert (1971) and accept the late Precambrian Holyrood granite as being 'significant'. Gale (1982) has recalculated the age of this intrusion to 585 ± 15 Ma. McCartney *et al.* (1966) suggested that an arbitrary 15 Ma may have elapsed between the emplacement of this granite and the deposition of overlying Early Cambrian (possible pre-Atdabanian) sediments. Tommotian-type (s.l.) fossil assemblages are present in Newfoundland, and one would not seem to be doing too much violence to the generally unsatisfactory evidence to retain as an interim figure an age of 570 Ma for the

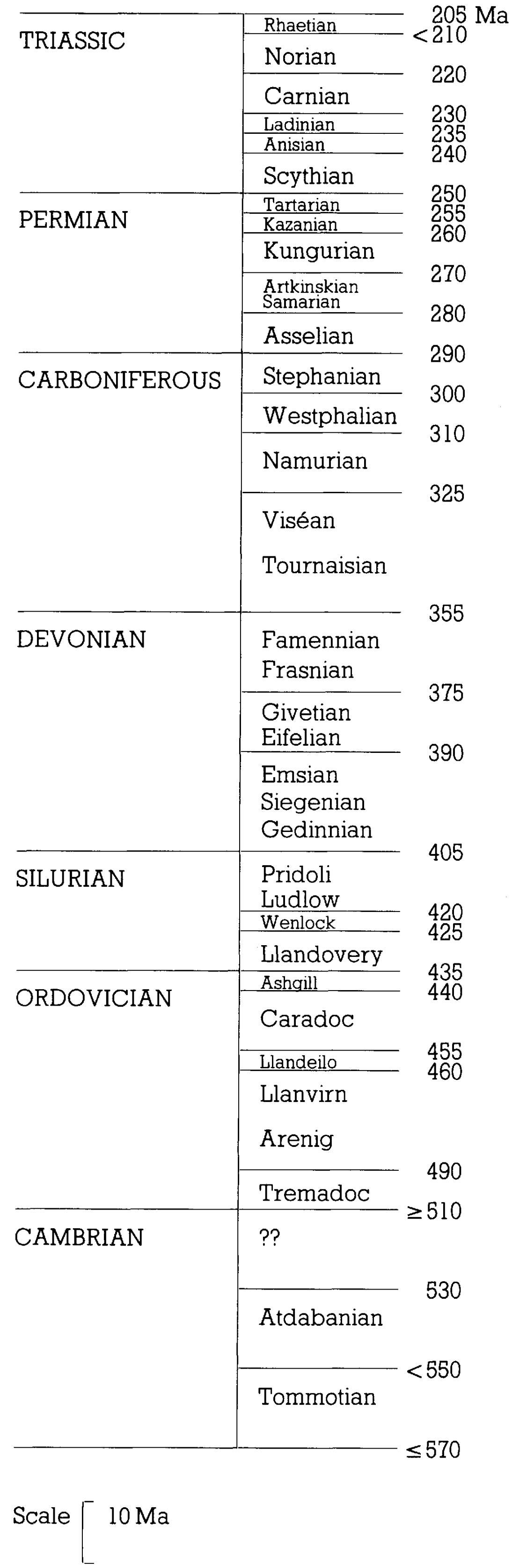

FIG. 1. The Phanerozoic time-scale: Cambrian to Triassic.

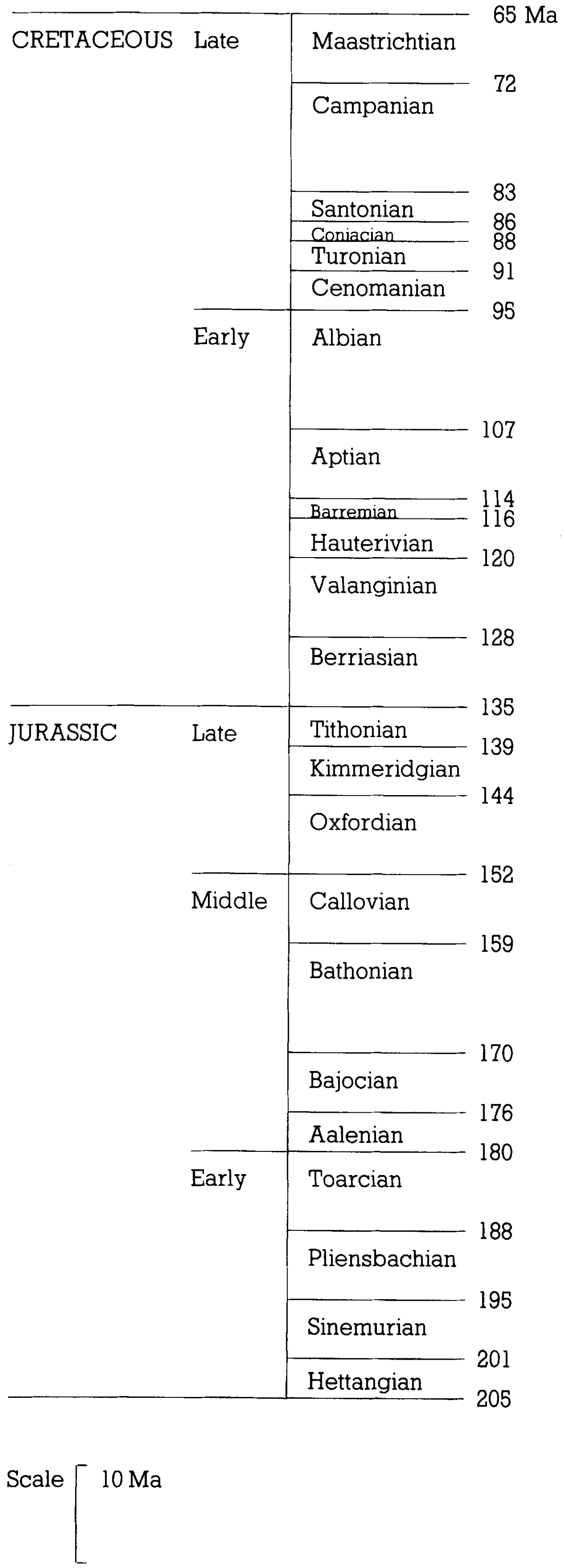

FIG. 2. The Phanerozoic time-scale: Jurassic and Cretaceous.

Precambrian–Cambrian boundary.

There are no data relevant to the younger limit to the Cambrian. A figure 510 Ma is adopted here based on the extrapolations to the base of the Tremadoc by McKerrow *et al.* and Gale (this volume). The remainder of the Palaeozoic time-scale (Fig. 1) generally follows the views expressed by the various contributors to this volume; the ages having been rounded off to the nearest five million years. This rounding-off seems justifiable in view of the debatable methods of extrapolation used by McKerrow *et al.* and Gale. It is only in the late Silurian and early Devonian that there are significant differences among the various contributors which are largely due to inclusion by Gale of the Stockdale Rhyolite data. The data presented in this volume on the Esquibel Island hornblende and Hopedale biotite (see Kunk *et al.*, this volume), and the results of Wyborn *et al.* (1982) on the Laidlaw Volcanics all suggest that the Stockdale Rhyolite age is anomalous; it is here excluded from consideration. An age of 405 Ma has been adopted for the Silurian: Devonian boundary as a compromise between the ages determined by McKerrow *et al.* (this volume, 412 ± 5 Ma) by Gale, 1982 ($400 \pm ^{10}_{5}$ Ma), and by Harland *et al.* 1982 (408 Ma).

The Upper Palaeozoic and Triassic time-scales of Foster & Warrington, and Odin (this volume), shown an encouraging convergence and the scale by Forster & Warrington, slightly modified in accordance with some of Odin's comments is adopted here (Fig. 1). The Jurassic and Cretaceous time-scale of Hallam *et al.* (this volume) is largely based on that by Kennedy & Odin (1982). The most significant divergence in scales is at the geochronologically poorly defined Jurassic–Cretaceous boundary for which Hallam *et al.* prefer an age of 135 Ma in contrast to 130 Ma adopted by Kennedy & Odin (op. cit.) and 144 Ma adopted by Harland *et al.* (1982). One new datum on sanidine from an Upper Aptain fuller's earth (Jeans *et al.* 1982) has prompted Hallam *et al.* to adopt an age of 114 Ma for the base of this stage. Kennedy & Odin (op. cit.) had suggested that the Barremian-Aptian boundary lay in the interval 110–114 Ma with the higher figure most likely. The prefered scale in Fig. 2 attempts a compromise between the aforementioned alternatives. However, greater weight has been given in most cases to the Kennedy & Odin scale for which the assessment of the time-scale utility of the analysed samples is exhaustively documented.

The Cenozoic

Although there would now seem to be a reasonable convergence of opinion concerning most of the Palaeozoic and Mesozoic time-scale there is a strong divergence of opinion for the Paleogene where no compromise would seem at present to be acceptable. The problems of Paleogene correlations have been effectively summarized by Hardenbol & Berggren (1978) and Harland *et al.* (1982). The various proposed stratotypes are scattered among many small outcrops in basins all over Western Europe where the intercalation of marine, marginal marine and non-marine sediments together with lateral facies changes 'all combine to render inter-basin correlation difficult, and the possibility of world-wide correlation even more remote'. (Harland *et al.* 1982, p. 34). However, the development of biostratigraphic zonations based on planktonic foraminifera, calcareous nannoplankton, and radiolaria is generating a biostratigraphic framework into which the European Paleogene stratotypes may be placed.

The time-scale presented by Berggren *et al.* (this volume) is a comprehensive integration of the aforementioned biostratigraphic zonations with ocean floor spreading (paced by ocean crust magnetic lineations), the rate of which is calibrated by age determinations on terrestial volcanics. The rationale here is that terrestial volcanics will give more reliable ages compared with glauconies which unless carefully selected can yield K:Ar ages which may be too low or too high. In generating the time-scale, however, assumptions must be made about the rate of sea-floor spreading — it is assumed to be more or less constant, but does it vary significantly with time? (see Curry, this volume); foraminifera, nannoplankton and radiolaria zones must be correlated with terrestrial faunas associated with the dated volcanics; and the polarity signature of the dated volcanics must be related to the ocean floor magnetic lineaments.

The alternative approach is to undertake age determinations on glauconies which are common in the Paleogene basin sediments of western Europe, to supplement this data where possible by dating intercalated volcanics, and to integrate such data with the stratigraphy in the conventional way. The principle difficulties of this approach lie in the problems of inter-basin and worldwide correlation, and the heavy, thought not exclusive, reliance on glauconies as the dated mineral (the suitability of this mineral for dating must be assessed with great care). Such a time-scale for the Paleogene has been established by Curry & Odin (1982).

The Paleogene time-scale derived by Berggren *et al.* (this volume) is summarized in Fig. 3 and the Paleogene scale determined by Curry & Odin (1982; the scale is fully documented in this reference) is given for comparison. That such different scales have emerged is a clear indication of the difficulty of the task and of the need for further research. The discrepancy may in part reflect significant variations in the rate of sea-floor spreading as emphasized by Curry (this volume), and both approaches may be subject to uncertainties in stratigraphic correlations, and distortions due to the vagaries of the dated rocks and minerals. An interim scale cannot yet be drawn up for the Paleogene, and it must be left to interested individuals to make their own assessments of the voluminous documentation which back up both scales. For the Neogene the scale proposed by Berggren and his co-workers in Jenkins (this volume) is here adopted, viz: base of Miocene 23.7 Ma, base of Pliocene 5.3 Ma, and the Pliocene–Pleistocene boundary at 1.6 Ma. It should be noted, however, that Curry & Odin (1982) would date the base of the Miocene at 23 Ma and that the definition and hence the age of the base of the Pleistocene remains the subject of debate (Bowen, *In*: Jenkins, this volume).

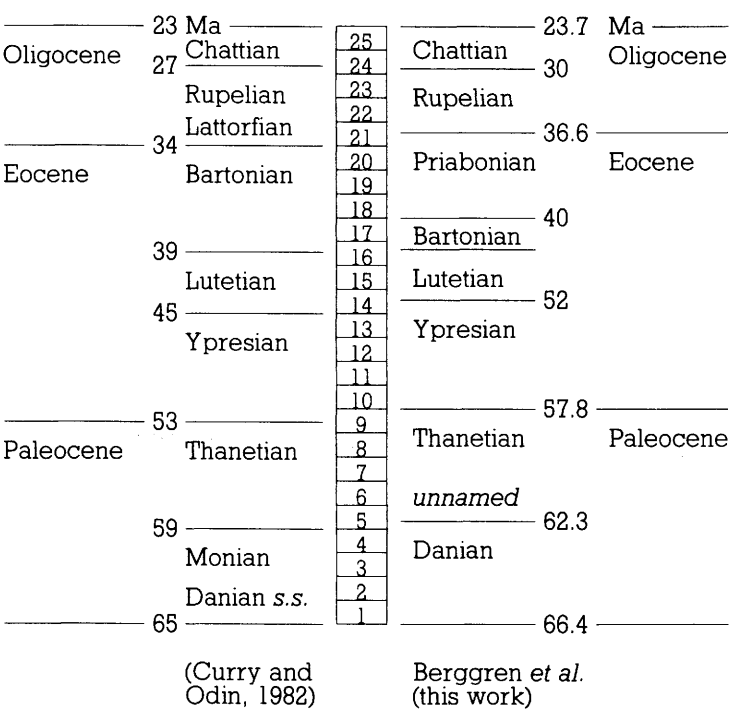

FIG. 3. Paleogene time-scales related to calcareous nannoplankton.

Concluding comments

The Phanerozoic time-scale suggested here differs remarkably little from that proposed following the Phanerozic Time-Scale Symposium of 1964. However, the 1964 scale gave time boundaries which were often dependent on a general agreement of individually unreliable sets of figures. Many of the 1964 data have now been discarded and much of the time-scale suggested here is based on relatively new and more reliable analytical data, though often the stratigraphic constraints are still poor. Except for the Cambrian where there is a dearth of universally acceptable data, there is an encouraging measure of agreement among the various contributors about the Palaeozoic time-scale, an agreement which also extends upwards through the Triassic. Indeed the time-scale for the Permian and Triassic presented here is a major improvement on any previous scale. The Mesozoic time-scale is similarly much improved mainly because of our better understanding of glaucony as a geochronometer, and the thorough assessment of analysed samples from both the geochemical and stratigraphic points of view by Odin and his collaborators (Odin 1982). However, the resolution of stages within the Jurassic and Cretaceous remains very poor and the lingering element of subjectivity in the assessment of glaucony ages inevitably weakens confidence in the accuracy of the Mesozoic scale. Improvements in resolution can still be hoped for, at least down to the limits imposed by the typical experimental errors of *c.* ± 3% of the age. The more pressing need, however, is for assurances concerning the accuracy of the scale (see for example the discussion by Hallam 1984, concerning the problems of mass extinctions); this can best be bought about — given the slight subjectivity of glaucony ages and the 'element of vagueness associated' with dated plutons (Lambert 1981, p.17) — by the search for and successful dating of stratigraphically constrained volcanic horizons.

Although an impressive potential for resolution has been demonstrated for the Cenozoic the question of accuracy is here particularly acute. That the scales of Berggren *et al.* (this volume) and Kennedy & Odin (1982) can be more or less concordant at the beginning and the end of the Paleogene but differ by as much as 10% in the Eocene, speaks of systemmatic error(s) in one or both scales which have yet to be recognized.

The definitive time-scale still remains elusive, however, the resolution of the problem of the half-life of rubidium-87 has resulted in the wider application of the Rb-Sr method on whole rock systems, as appealed for by Lambert (1971), with significant improvements in the Palaeozoic and early

Mesozoic parts of the time-scale. Our better understanding of the glaucony geochronometer has equally led to improvements in the Mesozoic and Cenozoic time-scales. While there still remains room for improvements in analytical methods, particularly perhaps in the dating of accessory minerals such as zircons from younger intrusives and volcanics by the U:Pb method, and the wider applications of the Sm:Nd method, it remains appropriate to echo Lambert's view that 'the present situation regarding the development of the scale is clear enough: there is a shortage of raw material suitable for its further refinement ____' It is encouraging that exploration, development and reassessment in the earth sciences continues to produce such raw materials, and that the hope 'that this co-operative enterprise will continue' as expressed by Harland in the Preface to the *Geological Society 1964 Phanerozoic Time-scale*, continues to be fulfilled.

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Received March 1984