A Synopsis of Numerical Time Scales 1917-1986

by Manfred Menning

This review accompanies a multicoloured synoptic chart (inserted loose in this issue) comparing some 30 complete and partial geochronological time scales for the Phanerozoic and published over a 70 year period to 1986. Provided for Episodes readers by the Central Institute for Physics of the Earth in Potsdam, East Germany, the chart illustrates the evolution of the geological time scale since the advent of radiometric dating. It is a salutary experience to see how close the most recent scales are to Barrell's 1917 estimates, and to gauge the extent of "fine-tuning" that has taken place since Arthur Holmes' 1959 scale. This chart provides a convenient companion to the 1989 IUGS Global Stratigraphic Chart, which will be circulated in a forthcoming issue of Episodes. (Ed.)

Introduction

Underlying many geological models and theories is the concept of time. Calculations of the rates of sedimentation and subsidence (Bubnoff, 1948; Menning, 1989), the periodicity of orogenesis (Stille, 1924), changes of global sea level (Vail and Mitchum, 1977) and climate, the velocity of radiation, evolution and extinction of animals, the mass-age distribution of Phanerozoic sediments (Gregor, 1985), and the evolution of isotope ratios (Burke et al., 1982) all depend on one geochronological time scale or another (see Benkő, 1985, for a recent review of geological, geophysical and cosmogenic cycles). The present review and the accompanying synoptic chart (also being published in *Zeitschrift für Geologische Wissenschaften*, vol. 17, 1989) facilitate ready comparisons between these various time scales, and analysis of the trends in variation from one to another.

The New Chart

The synoptic chart presents the data as close as possible to the original versions (for Precambrian time see Cloud, 1987). However, the data are not directly comparable in all cases, in part because different workers derived them by different methods. Values judged by the original author as less reliable are given in the chart with a question mark or in smaller numbers, and the names on the chart reflect the original spelling. Most stratigraphic units are biostratigraphically defined, and some are of lithostratigraphic nature. Consequently, rather than using the term "chronostratigraphic" unit proposed by Hedberg (1976), they are referred to in the legend below the chart as "biostratigraphic" units, a term accepted by many European scientists.

Goodchild (1897, in Barrell, 1917) constructed an astonishingly suitable time scale, in which the base of the Cambrian, for example, was placed at 704 Ma. Following the discovery of the radioactive decay law by Rutherford and Soddy (1902-1903, in Kaemmel, 1986), Barrell (1917, p. 884-885) published the pioneer radiometric time scale. This was based on five isotope age determinations, their fixed place in the geological column, and interpolation of outstanding quality using relative thicknesses of strata. The ages given in column 1 of the synoptic chart are arithmetical means of Barrell's confidence limits for each system boundary. Barrell's scale was improved only in 1959 by Holmes whose earlier time scales (1937, 1947) were influenced by the dating of younger parts of polyphase mineralizations (e.g. at Joachimsthal, Czechoslovakia).

The first estimate of the duration of stages for the Devonian to Cretaceous periods was made by Harland and others (1964). For Mesozoic time they assumed comparable durations for each stage in a separate system. Armstrong (1978) recalculated the ages of the Palaeozoic and Mesozoic stages using the new IUGS decay constants (Steiger and Jäger, 1977). He favoured older dates because of the characteristic daughter product loss in many isotopic systems. Consequently, the age of the most pre-Cretaceous boundaries increased substantially. Armstrong did not publish digital data, so that the ages have to be derived from his Figure 2, which results in some inaccuracies. Likewise, the numerical numbers of Van Eysinga (1975) were taken from a wall chart. Columns 13 and 20 include data from several publications, which considered only part of Phanerozoic time and which are sometimes in disagreement.

The most widely used scales now are those from IGCP Project 196 (Odin, 1982a, b) and from Harland and others (1982), which differ significantly. The Geological Society of America time scale for DNAG (the Decade of North American Geology; Palmer, 1983), the interim time-scale of Snelling (1985b), which was not available for this synopsis, and the present author's own synthetic scale (Figs. 1, 2) are in most parts compromises based on both Harland and colleagues and on Odin. Odin preferred glauconies for Mesozoic and Cenozoic times, and most of his boundaries were clearly younger than the tuff ages favoured by Harland and colleagues. Odin, for example, assumed a longer Lower (40 Ma) and a shorter Upper Carboniferous (30 Ma), relative to Harland's estimates of 27 Ma for the former and 47 Ma for the latter. The duration of the Silurian (18 Ma) was also underestimated by Odin (1982a, b). As to the base of the Phanerozoic, there is no agreement that the Cambrian starts with the Tommotian (530 Ma) as argued by Odin and, in any case, Harland and others (1982) dated the lower boundary of the Cambrian at 590 Ma.

Palmer's (1983) numerical ages were prepared by the Time Scale Advisory Committee of DNAG, in which "all numerical ages except those for the upper and lower boundaries of the Palaeozoic are derived from Harland and others (1982)." The DNAG scale is more useful than the recent COSUNA ("Correlation of Stratigraphic Units of North America") scale (Salvador, 1985), in which pre-Cretaceous ages are rounded off to 5 Ma. However, biological evolution certainly does not follow such a regular pattern. Furthermore, Salvador's scale overestimates the duration of some stages, such as the Rhaetian, which contains only one or two ammonoid zones, in comparison with the Scythian, which contains eight to ten such zones. There is also no geological reason for the big difference on this scale between the Frasnian (5 Ma) and the Famennian (15 Ma).

Carr and co-workers (1984) used a stepwise linear regression model. They calculated system boundaries only, because of insufficient biostratigraphic control on most series and stages. The synoptic chart gives the values from Carr's Table 3, column A, in which stages within each system are assigned equal durations. Their preference for 3 ± 5 Ma as the age of the base of the Quaternary is unrealistic, their

Figure 1: A new preliminary synoptic time scale for use in central Europe. See text for explanation.

Permian is longer (56 Ma) than in any other previous time scale, and the confidence limits for the lower boundary of the Cambrian (± 7 Ma) seem clearly too small.

The time scales of Snelling (1985a, b), Haq and Van Eysinga (1987), Afanasyev (1987) and Bayer (1987) will be added to a second version of the synoptic chart, which will be available later, also from the Central Institute for Physics of the Earth. Snelling (1985a) includes many useful papers by specialists and numerous comments by Odin. Haq and Van Eysinga have reasonably rounded off the pre-Cenozoic system boundaries at 10 Ma. Their scale is founded on the data included in columns 12, 15, 16, 17, 19 of the synoptic chart and on Snelling (1985a). The ages of Afanasyev are based on a mixture of mean values and unpublished data, without sufficient weighting. In Bayer's scale, the ages depend on whether they are computed for stages, series or systems. In some cases the ages are not equal for the lower boundaries of a system and its (included) lowermost stage. Furthermore, the duration of some stages seems unrealistic, for example that of 0.4 Ma for the Emsian plus the Eifelian.

Confidence limits are underestimated by several workers. Thus, the Jurassic-Cretaceous boundary is dated by Odin (1982b) at 130 ± 3 Ma but by Harland and others (1982) at 144 ± 5 Ma. From a mathematical point of view this is not the same boundary because the confidence limits do not overlap. Because of these disadvantages, the time scales of Carr and others (1984), Salvador (1985), Bayer (1987) and Afanasyev (1987) cannot be recommended. The most recent scale is not necessarily the best.

A New Time Scale for Central Europe

For practical purposes in Central Europe, a new preliminary synthetic time scale has been derived (Fig. 1) in cooperation with the biostratigraphers and lithostratigraphers listed in the Acknowledgements. For this we have used the synoptic chart, primary data, and various geological criteria. The most substantial revision concerns the Upper Carboniferous to Middle Triassic interval, based on a combination of intercontinental biostratigraphic (Dunbar and others, 1960; Kozur, 1980; Anderson, 1981) and magnetostratigraphic correlations (Menning, 1986), thicknesses (Likharev, 1966), and radiometric data (Forster and Warrington, 1985; Hellmann and Lippolt, 1981; Hess and Lippolt, 1986; Lippolt, Hess and Burger, 1984; Webb, 1981). An updated and revised version of this approach will be published in *Schriftenreihe Geologische Wissenschaften* (Akademie-Verlag Berlin).

What is needed is a time scale compiled under the auspices of the IUGS Commission on Stratigraphy through interdisciplinary cooperation of specialists in biostratigraphy, lithostratigraphy, isotope-geochronometry, magnetostratigraphy and others with regard to typical thicknesses on platforms, stratigraphic completeness and condensation, number of bio-units, weighted radiometric data, well-founded intercontinental correlations by different methods, and the dating of new minerals (e.g. sylvinite - Pilot and Rösler, 1967). To do this, agreed stratotypes (Cowie et al., 1986) as well as a stable nomenclature (Jaeger, 1980) will have to be established. The application of an improved mathematical algorithm alone (Carr et al., 1984; Bayer 1987) will not solve the calibration problems.

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