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RECENT ADVANCES IN PHANEROZOIC TIME-SCALE CALIBRATION

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Abstract

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The recent review and synthesis of the numerical calibration of the Phanerozoic time scale, undertaken in 1980—1982, has revived interest in the subject. As a result, an I.G.C.P. Project was created in 1983 in an attempt to resolve some of the remaining uncertainties. This special issue has been organized to publish some of the results obtained since the previous synthesis. The most spectacular achievement of the recent years has been the increase of data available for the Paleozoic time. These new ages allow us to propose more reliable estimates for the Caradocian, Silurian and Carboniferous times. Presently, the most urgent need for improvement of the Phanerozoic time scale is the finding of adequate samples of Jurassic age.

Résumé

À la suite de la proposition publiée en 1964, une nouvelle synthèse sur la calibration de l'échelle numérique des temps phanérozoïques avait été réalisée dans les années 1980—1982. Cette nouvelle proposition a renouvelé l'intérêt des géochronologistes pour ce sujet d'étude. Un projet du P.I.C.G. a été organisé et accepté en 1983 dans le but de tenter d'améliorer certaines des incertitudes encore existantes. La publication d'un numéro spécial a été entreprise pour rassembler et publier un certain nombre de résultats nouveaux. La plus spectaculaire réalisation des dernières années a été l'accroissement des données disponibles pour calibrer le Paléozoïque. Les âges nouveaux permettent de proposer des estimations plus assurées pour le Caradoc (base à plus de 450 Ma), le Silurien (base à plus de 430 Ma) et le Carbonifère (compris entre 405 et 300 Ma). Dès lors, le besoin le plus urgent pour améliorer la présente échelle du Phanérozoïque est de trouver de bons échantillons datables d'âge jurassique.

1. Introduction

In 1981, more than fifteen years had elapsed since the joint meeting of the Geological Society of London and Glasgow produced the book *The Phanerozoic Time Scale* (Harland et al., 1964) which was widely accepted as the authoritative reference for age estimates of the stratigraphical boundaries. Considering the progress in the knowledge of decay constants (Steiger and Jäger, 1977), the availability of new data slowly accumulated during that time, and the better understanding of the isotopic geochemistry of the used chronometers, a new synthesis was undertaken (Odin, 1982a). In the course of that work, it became clear that a crucial point consisted in the fact that a careful examination of the different uncertainties, specific to that exercise, was required before reaching conclusions. This is more and more true today due to the considerable progress in the radiometric measurement techniques. The analytical precision is such now that analytical uncertainty has become nearly negligible compared to the other possible sources of error for time-scale calibration. Four types of sources of error were identified (Odin, 1982b); the *stratigraphical* uncertainties, i.e. the stratigraphic correlation between the chronometer used and the definition of the stratigraphic sequence; the *genetic* uncertainties, i.e. the problems of the initial isotopic ratio and precise time of closure of the chronometer compared to the time of introduction in the stratigraphic sequence; the *historical* uncertainties, i.e. the possible modifications of the chronometer from the time of formation until the time of collection; and finally the *analytical* uncertainties, i.e. the problem of representativity of the analytical data in regard to the sampled formation, the analytical precision itself being usually comparatively the least important question. Due to the complexity of estimating these uncertainties, the proposal of a new time-scale reference point becomes more an exercise of analysis of this question than a real problem of isotopic analysis.

A second aim of the synthesis published in 1982 was the compilation of the new data to make them available in a single reference. Obviously, this compilation needed to select the reference data. This was only possible when sufficient details were published to permit an estimation to be made of the uncertainties described above. For this reason, many numbers published in the literature cannot be assessed and remain of little use.

One of the results of the 1982 synthesis was the opportunity to emphasize the problems associated with time-scale calibration. Three types of situations were identified. The first one was the definition of intervals of time within which the considered stratigraphical boundaries lie. From this more or less restricted interval, it was possible to estimate the need for more precision. The second situation was the incompatibility between different sets of data. Some cases existed within the Early Paleozoic time. The third situation was the absence of really acceptable data able to calibrate a particular boundary in regard to those above and below; the Jurassic, Silurian and Cambrian systems were good examples. Finally, it may be noted that in no case was a single number proposed as an age for characterizing a boundary. This is the corollary of the systematic presence of the uncertainties mentioned above. Recommendations can only be given with the necessary estimate of the precision with which it is defined; then the geochronological results only permit us to define *intervals of time* within which a boundary probably lies.

In an attempt to resolve some of the problems defined during this synthesis, a new I.G.C.P. Project "Calibration of the Phanerozoic Time Scale" was proposed in 1982 by the present author and accepted in 1983; N.H. Gale, the second project leader, was replaced by A.J. Hurford during the 1986 annual meeting. The aim of this project is to encourage research able: to accumulate data for undocumented systems; to reduce the interval of time for some imprecisely located boundaries; and to encourage a better interlaboratory link especially for the question of calibration of the analytical methods.

The present special issue gathers some recent results and consolidates the activity of the project. Although still in a preliminary form, several of these papers already improve some of the situations discussed above.

2. Reconsideration of the time scale

2.1. Early Paleozoic time

Two main questions have been subjected to new research under the aegis of the project: the age of the Precambrian—Cambrian boundary and the documentation of Silurian time. Following the considerations gathered in Odin (1982a), an age of 520—540 Ma was suggested (Odin et al., 1983) in contrast to the previous estimates of ~600 Ma: an age still preferred by many authors. Complementary results have been obtained since that time. On one hand, a major question has been raised by the results obtained from Chinese sediments. Following Zhang et al. (1982), a number of papers have considered isotopic ages which would suggest an age of ~610 Ma for the Precambrian—Cambrian boundary. These results were obtained on clays, a chronometer for which a detailed discussion on the meaning of the apparent ages and a study of different size fractions is needed. One still has to wait for this detailed publication. Another point has weakened the confidence in the 520—540-Ma estimate and concerns the data from the Wrekin area, U.K. (Patchett et al., 1980). New field observations (Beckinsale et al., 1984) showed that the dated granophyre (533 ± 12 Ma) instead of being covered by is intrusive into at least the base of the Early Cambrian overlying sediments.

On the other hand, recent research in the Massif Armoricain, Brittany, France, has made much progress especially on the paleontological point of view (Doré, 1984). The new data seem to confirm that the older side of the 520—540-Ma estimate could be reasonable as the age of the earliest Cambrian of that area.

The uncertainty over the age of the Ordovician—Silurian boundary came from the fact that few results were available in 1981 and that, moreover, there was incompatibility between them. This was discussed by Gale (1982) who chose to reject the date from Alaska, North America (Lanphere et al., 1977) and suggested the interval of time of 408–423 Ma in contrast to ~435 Ma preferred by Lanphere et al. New results have been published from Australia (Wyborn et al., 1982) and Great Britain [two K—Ar biotite ages by Ross et al. (1982)]. These results are concordant and show that the Late Silurian basal Ludlow series has an age of ~420 Ma, which leads Gale (1984) to propose an age of 425 Ma for the boundary, the interval of time 420—435 Ma seeming appropriate to locate it (Odin, 1984a).

New results obtained from bentonites are presented in this volume. They are summarized in the Table I, together with previous ages considered reliable. One has to accept today that the Ordovician—Silurian boundary is most probably older than 430 Ma which solves one of the controversies still present a few years ago.

Maximum ages for the Ordovician—Silurian boundary have been obtained on several occasions from acceptedly Caradocian rocks: bentonites from the U.S.A. (Kunk and Sutter, 1984) or from Sweden (Williams et al., 1982). The recent results proposed by Rundle (1986 in this special issue) agree with these previous studies. All these data are of ~450 Ma. According to them, the Caradoc—Llandeilo boundary must be older than 450 Ma (Fig. 1). This is older than suggested previously (Gale, 1982) according to the less precise age data available at that time.

The age of the upper boundary of the Silurian system is also discussed in this special issue (Peucat et al., 1986). The new results are coherent with the estimate of 395—410 Ma proposed by Odin and Gale (1982). This is also coherent with the results of R.J. Pankhurst on the Lorne lavas, U.K. (Clayburn et al., 1983).

2.2. Late Paleozoic time

In 1981, some data were available in the upper part of the Carboniferous system (de Souza, 1982). However, more data were

TABLE I

Comparison of new data with previous ones for the Silurian system

Some previous data		New data (this special issue)	
		Late	(417.0 ± 9.6)
	Ludlow	Middle	(422.5 ± 9.0)
419 ± 7 (*1*); 423.7 ± 1.7 (*2*); 421 ± 2 (*3*) (same horizon)		Early	424.0 ± 8.0
		Late	425.8 ± 6.0
	Wenlock	Middle	(427.4 ± 6.0)
		Early	
			430.5 ± 6.0
431.0 ± 6.6 (*4*)			
	Llandovery		
408–423 (*5*); ~435 (*4*)	SILURIAN		
420–435 (*6*); 433–445 (*2*)	Ashgill	ORDOVICIAN	

Consequences on the Ordovician–Silurian boundary age are estimated. Data in brackets are less reliable. *References*: *1* = J.D. Obradovich in Ross et al. (1982); *2* = Kunk et al. (1985); *3* = Wyborn et al. (1982); *4* = Lanphere (1982); *5* = Gale (1982); *6* = Odin (1984).

needed to precisely calibrate that portion of the time scale. The team at Heidelberg has undertaken a very complete study on European tonsteins of that age. A review of this research is presented in this special issue by Hess and Lippolt (1986). As a result, a good calibration of the continental European stratigraphical sequence is now available; this is a possible reference to compare with other successions in other parts of the world. New data on the Visean from France have also been gathered by Montigny et al. (1984). These data suggest that the Devonian–Carboniferous boundary must be older than 350 Ma (Fig. 1).

2.3. Mesozoic time

Although the other parts of the Triassic system are not badly documented, the question of the Carnian–Norian–Rhetian sequence previously raised (Odin and Létolle, 1982) remains open. New research on the Jurassic system will be especially encouraged in the future because we still have very few good data. The main problem is in obtaining favourable chronometers that are precisely enough correlated with the stratigraphic sequence. Bellon et al. (1986 in this special issue) have tried to document the Bajocian–Bathonian boundary in France but the stratigraphical uncertainties remain significant in the studied outcrop.

If the Lower Cretaceous subsystem is difficult to calibrate due to the comparatively low number of good results available, the Upper Cretaceous is more easy to subdivide. Shibata (1986, in this special issue) gives new information on the upper part of the system which generally agree with the previous age estimates for the Campanian–Maastrichtian time.

2.4. Paleogene time

One of the problems concerning the current Paleogene numerical time scale is the use of very precise (too precise) interpolated scales based on the constant sea-floor spreading-rate principle postulated for a "standard" section of the paleomagnetic record obtained from the South Atlantic Ocean. This scale continues to be used although the many geochronological data available show that the re-

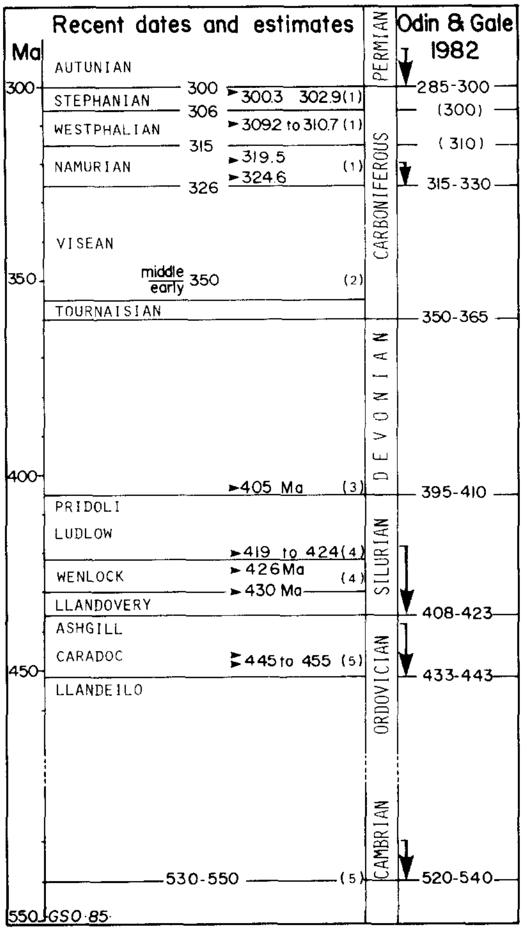

Fig. 1. Recent improvements for the dating of the Paleozoic stratigraphical sequence compared to the intervals of time suggested according to the data available before 1981. [*1* = according to the review by Hess and Lippolt (1985, 1986 in this special issue); *2* = according to Montigny (1984); *3* = according to Peucat et al. (1986 in this special issue); *4* = according to the results gathered in Table I; *5* = according to the discussion in Section 2]. Error bars on the measured age (*arrows*) are ±1—2% of the age.

lated interpolated age estimates are locally very discordant with the direct age measurements. Moreover, comparison of the sea-floor spreading-rate measured in different oceans and in different portions in a single ocean shows that the relative interbasinal spreading rates are not constant. Because it is not known how to judge where the rate could be expected to be the most constant, the principle of the interpolation is basically biased (Odin and Curry, 1985). Interpolation can be useful, however, if some prerequisites are considered: only short interval of time (of the order of 5—10 Ma) can be confidently submitted to the exercise; comparison of several paleomagnetic tracks have to be considered to estimate an error bar; acceptable geochronologically-based reference points have to be taken at the two extremes of the interpolated succession; uncertainties on both of the two references points and the interpolation system have to be combined and explicitly quoted for the estimates obtained and, finally, the interpolated numbers must be compatible with the geochronological data available, if any, between the reference points. Long-term interpolations without estimated uncertainties will most probably give a false impression of the actual duration of the geological phenomena, and especially the variation of the sea-floor spreading-rate: a fundamental question for the understanding of the Earth's history.

New research has been undertaken to calibrate or improve the precision of some more reference points in the Paleogene. Especially the work by MacIntyre and Hamilton (1984) on the Paleocene—Eocene boundary, and that by Montanari et al. (1985) on the Eocene—Oligocene boundary in Italy. This last question will be developed in papers in press and in further collaboration within I.G.C.P. Project *196* (Odin, 1985). The present special issue includes new data on the Eocene—Oligocene boundary (Glass et al., 1986 in this special issue) and the Eocene from the southern Alps (Odin et al., 1986 in this special issue).

2.5. *Quaternary time*

The geochronology of Quaternary time is dominated by the analytical precision problem. The problem is a technological one: in determining accurately the very small amounts of radiogenic daughter products produced in this relatively short time. About 10 years ago, there was a break in the time range 0.2—0.5 Ma between techniques suitable for rocks older than that and those suitable for younger ones; but recently improved and new techniques have been developed which span this gap. In this special issue, Gillot and Cornette (1986) (see also Cassignol and Gillot, 1982) and Lippolt et al. (1986) give nice examples of the results which may be obtained using sophisticated geochronological analyses. These two contributions link the geochronologically obtained ages with the *paleoclimatic curve* recorded from oceanic carbonates: a very efficient tool for relative stratigraphy in this domain of the sedimentary deposits.

3. Analytical problems

In spite of, as well as due to, the high *precision* of the presently available systems of measurement, the question of interlaboratory comparisons has raised practical analytical problems. This is crucial for the most recently developed techniques of measurement like fission-track and $^{39}Ar/^{40}Ar$ analyses. Especially, there is a need for reliable (i.e. very reproducible and known) reference minerals. Although the question is not discussed in detail in this special issue, it may be remembered that fission-track analysis is now progressing toward more confidence than was accepted previously. Detailed proposals have especially been published recently by Hurford and Green (1983) and discussed under the aegis of the project (Hurford, 1984). The introduction of fully acceptable reference materials for analysis is also needed for $^{39}Ar/^{40}Ar$ analysis and for very young rocks (Odin, 1984b). The recent study of a low-K Quaternary K—Ar possible reference material by Jäger et al. (1985) is a good example of the difficult research undertaken in this domain. This need is a constant problem for the necessary interlaboratory compatibility required for time-scale calibration, a point already emphasized in the synthesis of 1982 (Odin et al., 1982).

4. Conclusion

Following the publication of a new synthesis on the Phanerozoic time scale in 1982, new interest has been shown by geochronologists for the question of the direct measurement of the numerical age of the boundaries defined in the relative stratigraphic column. New research has been undertaken which has sometimes rejected the proposals made in 1982, sometimes confirmed or refined the proposal where they were hazardous, and sometimes established ages for boundaries previously undocumented. The I.G.C.P. Project *196*, in liaison with the Subcommission of Geochronology of the International Union of Geological Science (I.U.G.S. — leader, N.J. Snelling; secretary, A.J. Hurford), tries to organize and encourage studies related to the calibration of the Phanerozoic time scale. The aim of this work is to obtain a better tool for use in estimating the duration or speed of geological phenomena. Data are accumulating. However, much more is needed in several areas: (1) information on the Jurassic, Cambrian and Ordovician; (2) the improvement of interlaboratory calibration by preparation and study of new reference materials for isotopic analysis; (3) the reinforcement of the credibility of the geochronological data vs. the large-scale interpolation system using the constant sea-floor spreading-rate hypothesis in order to be able to fruitfully combine these two possibilities at a time when they are opposed due to the incorrect application of the interpolation process.

The present special issue gathers contributions able to improve the still insufficient knowledge of the Phanerozoic time scale.

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