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Sea Level History

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The article "Chronology of fluctuating sea levels since the Triassic" (*1*) provides a new version of the Exxon-based sea level and sedimentary cycles chart, calibrated to a new geological time scale. It is not clear to us (i) how and why this time scale differs from other recently published scales (*2–5*); (ii) what the criteria are that are used to correlate the first-, second-, and third-order sedimentary onlap events; and (iii) where the type sections are for the sedimentary sequences.

Our commentary is directed to the following points: (i) the time scale appears to be constructed from mixtures of low- and high-temperature ages, which arbitrarily lengthens or shortens its segments; (ii) some correlations are not well documented and, where sufficient documentation exists, in several cases the correlations can be shown to be erroneous; and (iii) the chronostratigraphic framework is insufficient to test the existence and age of third-order cycle boundaries.

The authors (*1*) criticize the preferential use of one set of isotopic ages over another (referring to high- versus low-temperature ages) and indicate that adoption of one technique over another introduces a "distinct bias" and "ignores a large body of potentially valuable analytical and empirical data. . . ." They base their time scale on both high-temperature and low-temperature (glauconite) isotopic ages. Other time scales have been based primarily on either high-temperature (*2, 3, 5*) or low-temperature (*6*) ages. Although some of the glauconite ages used by the Exxon group are concordant with the high-temperature ages used (Fig. 1), many are discordant. In general, glauconite ages are younger than correlative high-temperature ages (Fig. 1). In this regard it should be noted that the author of most of the glauconite ages (*7*) adds qualifications such as that for sample NDS 2: "39.6 ± 1.8 Ma [million years ago] is a minimum age . . . bearing in mind the long time necessary for the evolution of the dated glaucony. One should therefore add 1.5 to 2 my (about 1 biozone + duration of genesis) to give a number representative of the limit. . . ." It appears to us that this qualification should be applied to any and all suitable glauconites. In the absence of independent criteria, it appears prudent not to mix high- and low-temperature ages if at all possible (*8*).

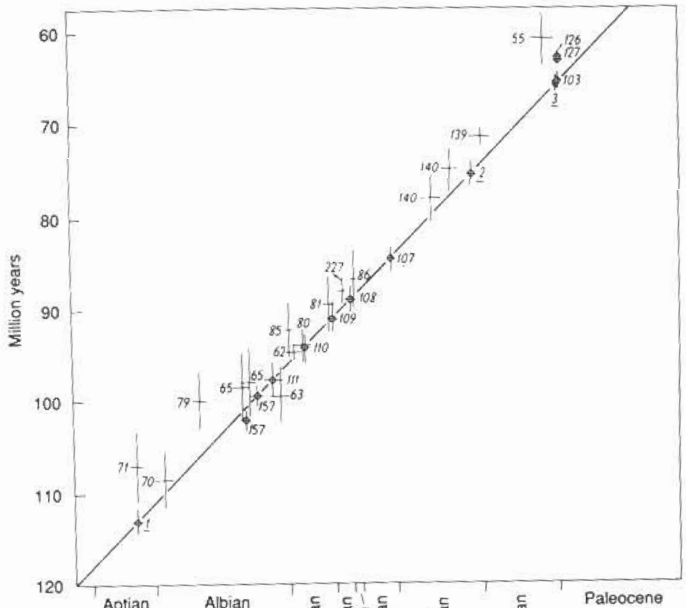

Fig. 1. Plot of radiometric ages based on high-temperature (ϕ), and low-temperature (+ = glaucony) dates, that shows the systematic trend in the glaucony dates toward younger values. Numbers identify specific dates as reported [after Aubry *et al.* (*22*)].

Because the low- and high-temperature dates are mixed, the Exxon time scale shows the Jurassic to be 13 my longer than in other scales (*3–5*). This is because it relies on published high-temperature ages for the base of the Jurassic, the average being around 208 to 210 Ma, and low-temperature ages for the Oxfordian-Kimmeridgian of 138 to 148 Ma, as well as several low-temperature (glauconite) ages for the Tithonian (*2, 3, 7–9*). Nevertheless, high-temperature ages for the Oxfordian-Kimmeridgian boundary are greater than 150 Ma (*10, 11*). Similarly, their young Aptian-Albian age of 108 Ma is in disagreement with a series of excellent high-temperature ages of 113 ± 1.4 Ma and 112 ± 2 Ma (*10, 12*) dated with ^{40}Ar–^{39}Ar on bentonites from the *Parahoplites nutfieldensis* zone of the latest Aptian age in England and northwestern Germany.

In the Tertiary, high-temperature ages for the early-middle Eocene boundary are at 52 Ma (*13*, p. 162; *14*), while glauconite ages from this interval are 45 Ma (*6*). The Exxon authors (*1*) average these divergent high- and low-temperature ages and place this boundary at 49 Ma. In our view such biased averaging does not increase the reliability or stability of a time scale (*1*, p. 1158).

Every time scale requires some interpolation between directly dated stratigraphic levels. Magnetochronology, biochronology, and statistical techniques have been used by investigators to infer the numerical ages of stratigraphic boundaries including stages (*2, 3, 5, 8, 11, 15, 16*). In our view, the equal duration of standard ammonite zones (*3, 4*) or subzones (*17*) between selected tie points and checkpoints based on clusters of high-temperature dates for the time being is a reasonable approach for the Jurassic. Stages were scaled in time according to the number of standard zones or subzones. The simple postulate of constant mean duration of Jurassic ammonite zones or subzones, although not required by evolutionary theory, is preferred (*17*) over a loose framework constructed with poorly known and biased isotopic age mixtures. The latter makes the Exxon estimates for the (subboreal) ammonite zones in the Hettangian and Aalenian a factor of 4 or more longer than in intermediate stages, which is unlikely.

For the Late Jurassic to Early Cretaceous and from the Late Cretaceous to Recent our interpolation scheme (*3–5, 13*) was based on construction of a standard magnetochronology from the examination and comparison of sea-floor marine magnetic anomaly spacing in different ocean basins (*18*). The Exxon authors (*1*) criticize a tiepoint approach with geological interpolations in between and instead propose a "best-fit" approach with the use of all "analytically sound and stratigraphically constrained radiometric dates." They do not, however, specify criteria for selection or do they refer to the specific dates used, but they imply that their methodology in assigning ages is more objective than previous attempts.

We also question the correlation of various microfossil groups with the magnetic polarity record and with the numerical time scale. The criteria for such correlations are unspecified other than with general references to the literature. We can cite several examples where the correlations provided are either speculative or are based on older literature, and are incorrect.

1) It is premature to extend the M-series of anomalies back to PM29 (*1*), because the pre-M25 biomagnetostratigraphy in the sedimentary record is tentative at best and not correlated with the Pacific or Atlantic ocean anomalies.

2) The Exxon authors define the Jurassic-Cretaceous boundary in a subboreal sense, between the Portlandian and the Ryazanian; but it is not clear how this ties to the magnetochronology at M15–16. Also it is not clear why the *Calpionella* Zone B is placed with polarity chron 17 and in the Berriasian, rather than, as we have shown, with chrons 19n-17 (*19*) at the Tithonian-Berriasian boundary.

3) A few years ago, Epoch 9 was correlated with Anomaly 5 (*16*), and this correlation was used by the Exxon authors (*1*). We have since then shown that Anomaly 5 can be correlated with Epoch 11 (*20*), which requires recalibration of foraminiferal and nannofossil zones near the boundary of the middle and late Miocene. The Exxon authors (*1*) adopted ages for nannofossil zones that are similar to ours and placed the base of the upper Miocene at 10.2 Ma. Yet, both of the correlations are valid only if Epoch 11 correlates with Anomaly 5.

The ability to differentiate interregional sea-level fluctuations and thus test the Exxon cycle chart is a function of stratigraphic uncertainties. In order to establish the validity of the cycles as eustatic events, they must be proved to be synchronous in different locations. Recent studies have determined that it is possible to establish good interregional correlations of the second-order sequence boundaries (*21*), strengthening the case that these were, in fact, caused by eustatic falls. We believe it is premature to correlate consistently and interregionally higher-order sea-level cycles. For example, the mean duration of the third-order Cenozoic cycles is about 1.5 my, while biostratigraphic resolution in this interval is typically 1 to 2 my. Until it is documented in detail that (i) minor cycles can be recognized both regionally and globally and (ii) these minor cycles are synchronous in a global sense, we believe such minor sequences cannot be used for global geochronology.

Nevertheless, we admire the attempt to unify such a large body of data.

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8. One of us (F.P.A.) has applied maximum likelihood estimation [F. P. Agterberg, in *Computers and Geology 6*, D. F. Merriam, Ed. (Pergamon, New York, in press)] to the 19 low-temperature and high-temperature isotopic ages for the time interval from 116 to 148 Ma, previously used by Harland *et al.* (*2*, figures 3 and 4b) in their chronogram for the Tithonian-Berriasian (Jurassic-Cretaceous) boundary. The log-likelihood function for all the isotopic ages of Berriasian or younger age and Tithonian or older age is a parabola with its peak at 136.3 Ma and a corresponding standard deviation of 1.8 my. Glauconite ages separately give 133.2 ± 4.6 Ma, which is close to Haq *et al.*'s estimate (*1*) of 131 Ma. The high-temperature estimate gives 147.3 ± 10.7 Ma. Statistically, it is 99% certain that the glauconite-based maximum likelihood age is different and younger than that based on the high-temperature isotope ages, in agreement with Fig. 1. According to studies by one of us (J.G.O.), it is likely that several of the Jurassic chronostratigraphic assignments for the glauconite isotopic ages are too old, which also casts doubt on the young age for the Jurassic-Cretaceous boundary.
9. Ages between 150 and 157 Ma from U-Pb analysis in zircons from igneous rocks in northern California and Oregon bracket the *Buchia concentrica* zone, mid-Middle Oxfordian to mid-Upper Kimmeridgian [J. B. Saleeby, J. D. Harper, A. W. Snoke, W. D. Sharp, *J. Geophys. Res.* **86**, 3831 (1982); J. B. Saleeby, *Geol. Soc. Am. Ann. Mtg. Alaska* **16**, 5, 331 (1984) (abstract)].
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