Aperiodic accumulation of cyclic peritidal carbonate: Comment and Reply

COMMENT

David Osleger
Department of Earth Sciences, University of California, Riverside, California 92521-0423

Drummond and Wilkinson (1993) contended that exponential thickness-frequency distributions of peritidal carbonate cycles provide evidence for aperiodic deposition, and "probably record stochastic processes of sediment accumulation." I assert that thickness-frequency distribution plots of carbonate cycles are not diagnostic guides to determining the presence or absence of periodic forcing. I also point out a few misinterpretations of the literature. My purpose here is not to beat the drum leading the way for the Milankovitch bandwagon. We are all aware of the inherent dangers of forcing a set of observations into a fashionable model without incontrovertible proof. Rather, my intent is to add balance to what I perceive as a one-sided presentation of a very equivocal data set.

Drummond and Wilkinson (1993) gathered published data of Proterozoic and Cambrian-Ordovician peritidal carbonate cycle thicknesses, plotted their frequency, and concluded from an apparently exponential distribution that these cycles were deposited in response to aperiodic, stochastic processes. They stated that a distinct modal frequency distribution should be evident if successions of carbonate cycles were actually generated in response to a driving periodicity. Thickness-frequency plots of synthetic cycles generated from hundreds of two-dimensional computer models (Read et al., 1991) exhibit a range of distribution patterns *even when the input sea-level driver is composed of Milankovitch periods superimposed upon a longer term signal*. The synthetic cycles generated from the mutually interfering input signals bear a striking resemblance to field-measured cycles (Osleger and Read, 1991), and their thickness-frequency distributions range from unimodal spikes around the thinnest cycles to broad bands spanning a range of thicknesses, depending upon the complex interaction of the input rates of sedimentation, subsidence, and sea level. The reason for the range of distributions is that peritidal carbonate cycles are usually not faithful recorders of any periodic driver because of (1) the 60% to 90% of nondepositional time per cycle represented at cycle contacts (Koerschner and Read, 1989; Wilkinson et al., 1991) and (2) the skipping of individual pulses of sea level when the rate of long-term sea-level fall exceeds the local subsidence rate (i.e., "missed beats"). Apparent exponential distributions of field-measured cycle thickness data appear to reflect this inherent complexity and, in most cases, say very little about periodic or aperiodic forcing.

Drummond and Wilkinson (1993) suggested in their abstract that exponential thickness-frequency distributions may be controlled by aperiodic accumulation or that "periodic forcing manifest during sedimentation has been masked by the vagarious nature of depositional processes." Yet the latter mechanism is totally disregarded as a possibility throughout the rest of their paper. Anyone who has logged sections of cyclic peritidal carbonates recognizes that an autogenic imprint characterizes almost all cyclic successions, reflecting the caprices of natural depositional systems, which may obscure any controlling periodic driver (Osleger, 1991; Osleger and Read, 1991). Aperiodic processes such as variations in sediment production and dispersal, wave and storm activity, changing oceanic currents, and ambient ocean chemistry and temperature, all acting on a laterally variable platform physiography, may conspire to add complexity to the stratigraphic record. Furthermore, complications due to erosion and nondeposition during exposure of the cycle cap also may distort the thickness of individual carbonate cycles. It is certain that bed thicknesses include the effects of these natural autogenic processes, which may produce an exponential distribution. The overriding question is whether these cumulative autogenic effects mask an underlying periodic signal or whether they instead represent the primary controls on deposition.

Drummond and Wilkinson (1993) misinterpreted the literature when they stated in their introduction that cycle thickness data were used by several workers to determine mean cycle frequency and therefore to interpret a Milankovitch orbital control. Although most of the references listed in support of this claim reported the mean cycle duration as an arithmetic average, *none* actually used mean cycle frequency to establish the probable controlling mechanisms. Bond et al. (1991) used a sophisticated quantitative technique, the gamma method, to refine time series and thus argue for Milankovitch astronomical control from the resultant power spectra. Goldhammer et al. (1990) and Osleger and Read (1991) used a set of crosschecking methods, including rhythmic-cycle bundling patterns, autocorrelation, time-series analysis, and one- and two-dimensional computer models, to interpret a Milankovitch influence on cycle deposition. All of these authors have referenced Algeo and Wilkinson's (1988) admonition that the geologic time scale lacks sufficient resolution to use average cycle frequency to infer Milankovitch periodic control.

Finally, Drummond and Wilkinson (1993) used stochastic modeling in an attempt to invalidate the necessity of high-frequency sea-level oscillations in the generation of carbonate cyclicity. Their modeling results predictably show that a succession of cycles with an exponential thickness distribution could be deposited in response to a stochastic process. If they truly believed their modeling results, they should have at least suggested a viable, naturally occurring mechanism to explain the ubiquitous presence of repetitive patterns of sedimentation in the stratigraphic record. Their results leave us not with a clearer understanding of the controlling processes behind the generation of cyclic successions but rather with a more ambiguous view, searching for an alternative mechanism that may fit their overly rigid statistical argument.

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REPLY

Carl N. Drummond, Bruce H. Wilkinson
Department of Geological Sciences, University of Michigan, Ann Arbor, Michigan 48109-1063

Complex In, Complex Out. Osleger contends that computational simulations produce a wide range of size-frequency distributions, some of which exhibit nearly exponential thickness frequencies. This is true, but exponential distributions are characteristic of most cyclic sequences, and appropriate computational models in agreement with these data should (at least) be documented before being cited as affirmation of geologic understanding. Because relations between input parameter (sea level, subsidence, and sedimentation) variations and resultant cycle thickness distributions are as yet undocumented, we cannot comment upon unpublished results. However, our modeling efforts indicate that simple in-phase eustatic oscillators (Osleger and Read, 1991) produce simple modal (nonexponential) thicknesses, whereas more complex oscillators can result in exponential thickness-frequency distributions. In this regard, it is important to note that (1) the proportion of time partitioned between cyclic units and hiatal contacts is irrelevant to discussion of periodicity of sediment accumulation, (2) nondeposition during relative sea-level lowstand (missed beats) results in underrepresentation of thin (not thick) cycles, (3) suitable combinations of periodic input variables yielding exponential thickness frequencies include only a small range of plausible eustatic scenarios, (4) eustatic models that yield exponential thickness frequencies have never been seriously proposed or defended as accurately representing lithologic variation in natural sequences, and (5) those combinations of periodic sea-level parameters sufficiently complex as to yield exponential thickness frequencies also result in the aperiodic accumulation of synthetic peritidal cycles. If regularly recurrent but out-of-phase eustatic signals yield aperiodic durations between episodes of carbonate accumulation, are these cycles reasonably construed as being periodic? We think not.

If It's There, Can We See It? Osleger notes the predominance of autogenic features in many cyclic sequences and ascribes these to the dominantly stochastic nature of sediment production and dispersal in epicratonic settings. We completely agree with such an assessment; control by such processes during partial or complete filling of accommodation space represents nonperiodic accumulation. We also concur that the fundamental query now to be addressed is determining whether random processes mask some underlying periodic signal or whether stochastic sediment production and dispersal are the only important processes in low-latitude settings. In either case, we do not view such processes as composing a conspiracy of nature to mask the importance of underlying chromatic eustasy.

We Said, He Said. Osleger incorrectly contends that we misrepresented the literature by stating that several workers employed cycle thickness data to interpret a Milankovitch control. In fact, these were cited only as studies where a similarity of ranges of supposed Earth-orbital and variously calculated cycle frequencies were taken as evidence of Milankovitch-driven eustatic change. In addition, perhaps most would agree that stratigraphic data on cyclic sequences consist of little more than tabulated thicknesses of contiguous lithofacies and that many workers have relied either directly or indirectly on such measures to infer Milankovitch forcing. In this regard, uses of time (thickness) series analysis (Bond et al., 1991), autocorrelation techniques (Goldhammer et al., 1990), or subjective (nonquantitative) identification of cycle bundling (Osleger and Read, 1991) are only relevant to the discrimination of lower frequency (longer duration) patterns of stratigraphic order and are inconsequential when discussing the nature of single-cycle periodicity.

Deliberate Reiteration. Osleger suggests that we have not clearly identified naturally occurring mechanisms by which to explain the ubiquitous presence of repetitive patterns of carbonate sedimentation in the stratigraphic record. These mechanisms are episodic sediment production and dispersal by waves, storms, and oceanic currents under conditions of changing ambient ocean chemistry and temperature, and the accumulation of this sediment via partial to complete filling of available accommodation space during deposition across platforms with laterally variable physiography during the progradation and/or lateral migration of contiguous peritidal environments. We contend that these autogenic processes are either entirely responsible for the thickness-frequency distribution of peritidal carbonate units or that they have overprinted any periodic origin to such a degree as to render it indiscernible. In either case, the derivation of a high-resolution chronostratigraphic framework from cyclic peritidal carbonate sequences is unattainable.

Faith in Doctrine. Finally, Osleger questions if we truly believe in our modeling results. This is not religion, and it is therefore unimportant what we actually believe about the importance of periodic eustatic change during sediment deposition. What is important is the degree to which data on cycle thicknesses do or do not support hypotheses of periodic vs. stochastic formation. We do contend and it is our fervent conviction (at least for this month) that more agnostic perceptions of stochastic peritidal carbonate accumulation are in complete agreement with observational data, whereas scenarios of periodic sea-level change now held in reverence by the general population are not.

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