FORUM

Generic types of stratigraphic cycles controlled by eustasy: Comment and Reply

COMMENT

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Soreghan and Dickinson (1994) pointed out that cyclic repetition of component lithofacies in shallow-water sequences must largely reflect recurrent changes in water depth, and that periodic changes in water depth must reflect variation in rates of accommodation-space generation via subsidence and sea-level rise and rates of accommodation-space destruction via sediment deposition and sea-level fall. Owing to the potential importance of orbital forcing and periodic sea-level change in the development of cyclicity in stratigraphic sequences, several aspects of tectonic, eustatic, and sedimentologic variation suggested by Soreghan and Dickinson (1994) merit additional discussion and clarification.

Soreghan and Dickinson (1994) suggested that several categories of "end-member" eustatic cyclicity can be distinguished, differentiation of cycle "type" being dependent on if and where the sediment surface intersects sea level relative to some eustatic highstand maxima. However, because this cycle classification relies on knowledge of positions of the sea and sediment surfaces, and because both continually change in response to tectonic, eustatic, and/or sedimentologic processes, these designated categories are not end members at all, but parts of a continuum of sedimentologic response to greater or lesser rates of accommodation-space generation and sediment deposition. Of more importance, the actual stratigraphic record of each cycle "type" is generally indefinite in lithologic character and decidedly indeterminate in cyclic sequences. Except for those repetitive but presumably monolithic "keep-up" sequences, where rate of sedimentation always exceeds rate of flooding and depth is invariant throughout sediment accumulation, all cycle "types" exhibit similar patterns of stratigraphic transgressive flooding and regressive shallowing, and they differ only in the thickness and symmetry of constituent lithofacies and inferred magnitudes of water-depth change (Fig. 1). Net sediment accumulation in any aqueous depositional setting can proceed as water depth increases, remains constant, or decreases. Therefore, particularly in the absence of specific data on secular variation in rate of subsidence, sea-level change, or sedimentation, it is not possible to determine at any single locality if depth changes occur and/or if accommodation space is ultimately filled as sea level rises, at sea-level highstand, as sea level falls, or, for that matter, if sea level changes at all. As a result, the eustatic cycle terminology proposed by Soreghan and Dickinson (1994), while of interest from a purely hypothetical perspective, is generally inapplicable to real-world cyclic sequences.

Soreghan and Dickinson (1994) stated that some "cycles are located sufficiently high up on the shelf that they record only part of the full eustatic range in accommodation because they are exposed at lowstand." This statement also implies that mean position of changing sea level and mean position of the rising-falling sediment surface are independent parameters, and that other cycles, not located "high on the shelf," might somehow record the full range of

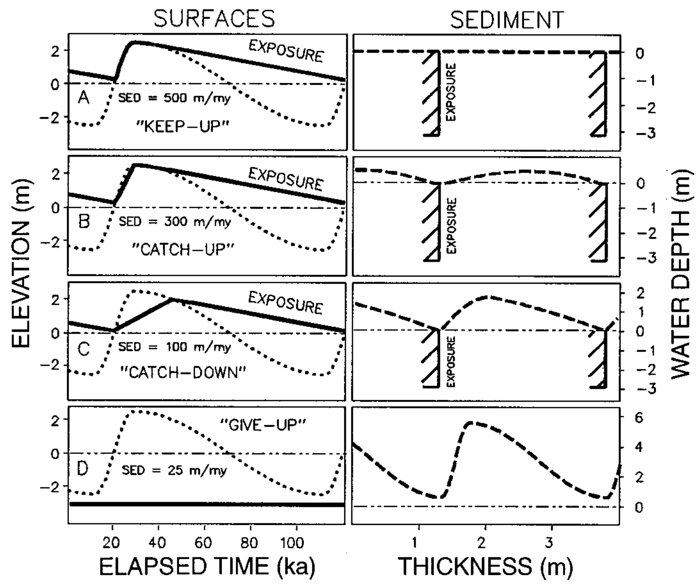

Figure 1. Left: Sediment surfaces (solid lines) and sea surfaces (dotted lines) during cyclic sediment accumulation. All scenarios assume asymmetric sinusoidal sea-level change (amplitude = 5 m, period = 100 ka, rise/fall 0.2), invariant subsidence (25 m/m.y.), and potential accumulation to sea level. Decreasing sedimentation rate (500 m/m.y. in A to 25 m/m.y. in D) yields four "types" of eustatic cyclicity in the parlance of Soreghan and Dickinson (1994). Right: Stratigraphic variation in water depth (dashed lines) and position/elevation of exposure surfaces (hachured lines) for each scenario to the left. All cycles are 2.5 m thick, the product of subsidence rate (25 m/m.y.) and eustatic period (100 ka).

accommodation space generated during changing sea level and subsidence. However, the very existence of spatially recurrent lithofacies associations in shallow cratonic settings requires temporal recurrence of similar (albeit variable) water depths and necessitates short-term rates of deposition in excess of long-term rates of subsidence (e.g., Sadler, 1994). In other words, genuinely periodic recurrence of depth-dependent lithofacies is not achievable during progressive platform flooding as would be the case during the accumulation of "give-up" cycles when net sediment accumulation is less than net subsidence.

Moreover, during truly cyclic accumulation, mean position of the sea surface relative to that of the sediment surface depends only on rates of subsidence and sedimentation. When deposition is only slightly in excess of subsidence, the sediment surface "lowers" toward the bottom of the eustatic curve, thereby minimizing durations of subaerial exposure and maximizing the time interval of sediment deposition (Fig. 2A). Conversely, if deposition greatly exceeds subsidence, the equilibrium sediment surface moves to the top of the sea-level "wave," thereby minimizing intervals of deposition and maximizing hiatal duration (Fig. 2B). As a result, and regardless of whether minimum depths attained during eustatic lowstand are subtidal (e.g., Osleger, 1991) or subaerial (Fig. 2), virtually all cratonic eustatic cycles incorporate at least some interval of hiatal time,

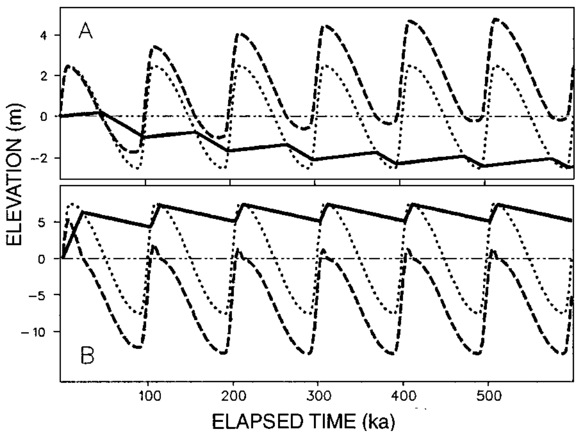

Figure 2. Equilibrium relations between sediment surface elevation (solid lines), sea level (dotted lines), and water depth (dashed lines) for two scenarios of glacioeustatic cycle accumulation. As in Figure 1, for both scenarios, assumptions are: asymmetric sinusoidal sea-level change with period of 100 ka, rise/fall ratio of 0.2, subsidence at 25 m/m.y., and potential accumulation to sea level; sediment and sea-surface elevations are coincident at t_0. In A, sea-level amplitude is 5 m and sedimentation rate is 30 m/m.y.; in B, sea level amplitude is 15 m and sedimentation rate is 300 m/m.y. In both, steady-state cycle thickness (2.5 m) is unrelated to accommodation space.

and cycle accumulation therefore almost never occurs over the full range of eustatic variation. As a result, all truly recurrent lithofacies associations fall within the definition of "base-cutout" cycles; as suggested by Soreghan and Dickinson (1994), this category therefore constitutes an all-inclusive subdivision of cyclic associations.

Finally, Soreghan and Dickinson (1994) stated that cycles exhibit varying degrees of thickness "completeness" relative to amounts of accommodation space generated by subsidence and sea-level rise, and they then discussed the utility of cycle thicknesses to constrain estimates of eustatic amplitude. Decompacted thickness of a cycle in which lithofacies composition is primarily related to water depth depends only on the product of periodicity of accommodation change (be it eustatic or tectonic) and mean rate of basin subsidence. As implied, but not particularly emphasized, by Soreghan and Dickinson (1994), cycle thickness and eustatic magnitude are unrelated parameters.

REFERENCES CITED

Osleger, D., 1991, Subtidal carbonate cycles—Implications for allocyclic vs. autocyclic controls: Geology, v. 19, p. 917–920.

Sadler, P. M., 1994, The expected duration of upward-shallowing carbonate cycles and their terminal hiatus: Geological Society of America Bulletin, v. 106, p. 791–802.

Soreghan, G. S., and Dickinson, W. R., 1994, Generic types of stratigraphic cycles controlled by eustasy: Geology, v. 22, p. 759–761.

REPLY

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We are sorry that Wilkinson et al. appear to dislike our terminology for cycle types, but we have little substantive disagreement with their remarks. Our reaction to specific points they make is as follows:

1. Our reference to different cycle types as "end members" was evidently misleading, for we also presume that each represents a generic variant within a continuum of varied cycle types. It is worth noting, however, that Wilkinson et al. (Comment above) construct their figures and draw their resultant conclusions with the assumption that sea-level change is "asymmetric sinusoidal," with only momentary highstands and lowstands. The relations depicted would be somewhat different if sea-level change instead followed a box-shaped function, with alternations between quasi-stable highstands and lowstands and thus with truncated peaks and troughs. This is the model we envision as particularly applicable to glacioeustasy, and our generic cycle types would be relatively distinct in that case. Further, our proposed classification is explicitly generic, meant to stimulate thoughts on possible relations between processes (rates of sedimentation and accommodation creation) and stratal response (thickness and facies attributes). It is not intended as a descriptive guide for field observations, although we hope that our classification may contribute ultimately toward designing such an application.

2. We agree that most cratonic eustatic cycles incorporate hiatal time; however, our "base-cutout" designation refers to those cycles marked by a basal hiatal surface created specifically by lowstand subaerial exposure. Depending upon shelf position, the cycle may incorporate only a fraction of the eustatic accommodation potential owing to such lowstand exposure. Although most eustatic cycles may well be "base-cutout," in our usage, we think it is important to take this likelihood explicitly into account and to understand that only cycles developed in fortuitous locales may not be base-cutout.

3. Our discussion of generic cycle types not only implies but declares that eustatic magnitude and cycle thickness, even as adjusted to recover effects of compaction, are not equivalent, except under circumstances we detailed (Soreghan and Dickinson, 1994, Fig. 3). We stated that "cycle thickness can never be equated directly with the absolute magnitude of eustatic change" and that "attempts to gauge magnitudes of glacioeustatic fluctuation directly from cycle thickness will thus fail" (Soreghan and Dickinson, 1994, p. 761). We feel that this is a critical, yet commonly neglected point; thus, we thank Wilkinson et al. for amplifying it.

REFERENCE CITED

Soreghan, G. S., and Dickinson, W. R., 1994, Generic types of stratigraphic cycles controlled by eustasy: Geology, v. 22, p. 759–761.

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