Technical Comments

Sea Level History

Bilal U. Haq and his co-workers have completed an important update of the chronology of coastal onlap and eustatic fluctuations in Mesozoic and Cenozoic time (*1*). Seismic stratigraphic results are augmented in the new charts by outcrop and well-log studies to document an impressive total of 119 sea level cycles since the beginning of the Triassic. In addition, the Cretaceous results have been published officially for the first time. However, apart from distinguishing between relative changes of coastal onlap and eustasy, the methodology and assumptions are much the same as those used to construct the first version of the "sea level curve" in 1977. In a recent evaluation of the seismic stratigraphic record of sea level change (*2*), we drew attention to two problems in particular.

1) All of the observed depositional cycles are assumed by Haq *et al.* to be eustatic. Nearly 50% of the sequence boundaries cannot be identified in seismic data. For many of these minor boundaries it is difficult to demonstrate a downward shift in coastal onlap and to eliminate the possibility that a given boundary might be due to autocyclicity or to fluctuations in sediment supply rather than to a lowering of depositional base level. In spite of considerable recent efforts to calibrate sequence boundaries, it is not possible to determine the ages of many of the minor ones (that is, third-order cycles) sufficiently well to permit objective correlation between basins because the spacing of the boundaries is close to or finer than biostratigraphic resolution. Matching patterns of sequences are valid only insofar as a global sea level signal is known to be present. We agree with Haq *et al.* that of the 61 seismically resolvable sequence boundaries, many may prove to be of eustatic origin, but questions remain about the calibration even of these boundaries to the geological time scale.

2) The global onlap chart, which forms the basis for the smoothed eustatic curve, has little physical meaning. Coastal aggradation (the vertical component of coastal onlap) is primarily a result of basin subsidence. It is not even a good approximation of relative sea level rise because the datum changes according to whether the onlapping strata are truly coastal or accumulated in an alluvial environment. In addition, the amount of aggradation measured in a given sequence varies from one seismic section to another, and where differential subsidence is pronounced, it is critically dependent on the path taken across any particular section. Because coastal aggradation is measured incrementally, corrections for subsidence are difficult to apply. Downward shifts in onlap are a response not to a sea level fall, but to an increase in the rate of sea level fall. Thus even if a downward shift is somehow corrected for the effects of subsidence and for datum errors, the shift in onlap still provides little information about the magnitude of sea level change. Similarities in the patterns of coastal onlap for different basins for the most part indicate similar overall subsidence history. Combining onlap charts for different basins is equivalent to estimating the average subsidence history of basins. Although Haq *et al.* title their article "Chronology of fluctuating sea levels since the Triassic" and portray the inferred amplitudes of eustatic oscillations only as a best estimate, we do not think that smoothing a global onlap chart is a valid method for making such an estimate.

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REFERENCES

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2. N. Christie-Blick, G. S. Mountain, K. G. Miller, in *Sea-Level Change*, R. Revelle, Ed. (National Academy of Sciences, Washington, DC, 1988).

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Response: We are sympathetic to the arguments presented in the critique by Nicholas Christie-Blick *et al.* (*1*). They state that the new version of the sea level curves is based on much the same methodology as the 1977 version. As we pointed out, the new version is based on the recognition of depositional sequences in outcrops and well logs, in addition to seismic data. Sequences are subdivided into genetically related sedimentary units (systems tracts) that are interpreted as the sedimentary response to various phases of the sea level cycle. Sequence analysis of outcrops can be undertaken independent of seismic data and therefore represents a new methodology that augments the approach used in preparing earlier versions of sea level curves. Those were based entirely on coastal onlap patterns in seismic profiles, dated by biostratigraphy from well data.

We disagree with the critique that all observed depositional cycles are assumed to be eustatic. The succession of sea level events interpreted from depositional sequences and systems tracts and corrected for subsidence in any region are correlated with similar successions of events from other, often widely separated, regions. Rigorous pattern-matching of not only the sequences but also the systems tracts within the sequences, together with litho- and biofacies information, help weed out local events and ensure the retention of consistent and widely distributed events.

Admittedly, minor events are more readily identified in outcrops and well logs. However, it is not strictly correct to say that minor sequences can not be identified on seismic profiles. The characteristic geometric response of minor sea level falls may be subtle, but the development of these geometric patterns is a function of sediment supply, and minor sequences are easily resolvable in thick sections. Moreover, when seismic data is augmented with well data, even in relatively thin sections minor sequence boundaries become easily detectable. A good example of this is provided by the third-, fourth-, or even fifth-order sequences of the Quaternary that are obvious on seismic profiles and well logs in the Gulf of Mexico (*2*). Downward shifts of coastal onlap are more difficult to demonstrate for minor boundaries. However, minor sequence boundaries are identified by a number of criteria, not just downward shifts of coastal onlap. A sequence boundary is marked and identified on well logs and in outcrops by (i) truncation below the boundary, (ii) onlap onto the boundary, and (iii) a basinward shift in facies associated with the boundary (a basinward shift in facies is characterized by shallow-marine or nonmarine rocks above the boundary resting sharply on deeper marine rocks, such as shelf mudstones, below the boundary with no intervening rocks deposited in intermediate depositional environments). These three criteria must be identified regionally before the surface that they define as a sequence boundary can be interpreted. When observed in well-log cross sections and outcrops, these three characteristics indicate that sequence boundaries are the result of a relative fall in sea level and are not the product of autocyclicity. Distributary channel erosion, associated with rapidly prograding shifting delta lobes, can locally produce erosion and an apparent basinward shift in facies. However, where they erode into prodelta mudstones, distributary channel sandstones are laterally encased in stream-mouth bar and delta-front rocks. This lateral facies relation exists because the distributary channel cannot build seaward unless it moves over subaqueous delta platform, even if the deltaic progradation is extremely rapid. The resulting vertical succession of facies, with local exceptions produced by rapid progra-