Chronology of Fluctuating Sea Levels Since the Triassic

BILAL U. HAQ, JAN HARDENBOL, PETER R. VAIL*

Advances in sequence stratigraphy and the development of depositional models have helped explain the origin of genetically related sedimentary packages during sea level cycles. These concepts have provided the basis for the recognition of sea level events in subsurface data and in outcrops of marine sediments around the world. Knowledge of these events has led to a new generation of Mesozoic and Cenozoic global cycle charts that chronicle the history of sea level fluctuations during the past 250 million years in greater detail than was possible from seismic-stratigraphic data alone. An effort has been made to develop a realistic and accurate time scale and widely applicable chronostratigraphy and to integrate depositional sequences documented in public domain outcrop sections from various basins with this chronostratigraphic framework. A description of this approach and an account of the results, illustrated by sea level cycle charts of the Cenozoic, Cretaceous, Jurassic, and Triassic intervals, are presented.

FOR MORE THAN A CENTURY, EARTH scientists have accumulated geologic evidence indicating fluctuations in the mean sea level during Phanerozoic time. In the early 20th century, Suess (*1*) remarked on the apparently synchronous episodes of deposition and nondeposition of marine strata in different parts of the world and suggested that sea level rises and falls may be eustatic (global) in origin. Other researchers have since documented the sea level histories of different parts of the world, and some of them have ascribed the apparent synchroneity of these events to episodes of global tectonics (*2, 3*).

Sea level fluctuations have important implications for organic productivity of the oceans and sediment distribution patterns along the continental margins and in the interior basins. Therefore, the study of these fluctuations is of prime interest to hydrocarbon exploration. Sea level changes are also thought to control hydrographic-climatic patterns and, indirectly, biotic distribution patterns as well. Understanding these changes is of considerable value in deciphering past oceanographic (paleoceanographic) conditions.

Developments in seismic stratigraphy during the 1960s and 1970s led to the recognition that primary seismic reflections parallel stratal surfaces and unconformities (*4*). On this basis, Vail *et al.* (*4*) proposed that sediment packages (depositional sequences) bounded by unconformities and their correlative conformities represented primary units with chronostratigraphic significance. Vail *et al.* used stratal geometries and patterns of onlap, downlap, truncation, and basinward shifts of coastal onlap to interpret sea level histories along various continental margins. The apparent synchroneity of sea level falls in widely separated basins led them to generate a series of charts showing global cycles of relative changes in sea level (*4*).

With the assertion of the method by Vail *et al.* that primary seismic reflections represented time lines, seismic stratigraphy was seen as a breakthrough for regional and global chronostratigraphic correlations. It has been particularly valuable in frontier areas where it aids in the predrill determination of geological exploration parameters from seismic profiles. The original coastal onlap curves (*4*) were largely based on interpretations of seismic sections with paleontological age control from well data. Since publication of the Vail *et al.* method, sea level curves have been a subject of lively debate. The main criticisms of the curves have centered on (i) the lack of adequate corrections for local and regional subsidence and thus the potential error in estimating the magnitude of sea level rises and falls (*5*); (ii) questions about the timing and the global synchroneity of some of the major events and their significance to the events in the deep sea (*5, 6*); (iii) the need for updating the sea level curves in view of the recent refinements of time scales (*6*); and (iv) the nonpublication of supporting evidence (*6, 7*), much of which was considered proprietary. Since the original publication, more up-to-date versions of the global coastal onlap curves for the Jurassic and Cenozoic have been published (*8*), and some of the issues mentioned above have been addressed. However, to reduce the dependence on proprietary seismic and well-log data, the need was seen to develop alternative criteria for identifying sea level fluctuations in easily accessible sections, where lessons learned from seismic interpretation of sea level changes could be applied to public domain outcrop data. The recent advances in sequence stratigraphic concepts (*9*) and the development of depositional models of genetically related sediments during various phases of the sea level cycles (*10, 11*) have helped fulfill this need (see Fig. 1).

The sequence-stratigraphic depositional models, together with detailed paleontological data, enhance the ability to recognize genetically related sediment packages in outcrop sections. They also provide independent avenues by which seismic and diverse subsurface data can be augmented and integrated. Sea level rises and falls are manifested by specific physical surfaces that can be used to identify sequences in land-based and offshore marine sections. In this way, sea level changes can be documented in diverse areas that are within the public domain. [Studies listed in (*11*) cover quantitative models, applications in the field, chronostratigraphic basis, and the documentation of this methodology.] These developments represent a major step forward since the first publication of sea level curves (*4*).

Over the past several years stratigraphers at Exxon Production Research (EPR) have attempted to produce a global stratigraphic framework that integrates state-of-the-art magneto-, chrono-, and biostratigraphies with sequences recognized in the subsurface and outcrop sections in different sedimentary basins. These data have provided a new

The authors are on the scientific research staff of Exxon Production Research Company, Houston, TX 77252.

*Present address: Department of Geology, Rice University, Houston, TX 77251.