Vail's Sea-Level Curves Aren't Going Away

Academic researchers are beginning to gather support for Exxon's new stratigraphic organizing scheme as its interpretation becomes more sophisticated

In 1975 Exxon announced to the scientific community that it had a new way to read the geologic record preserved in marine sediments. The key markers of geologic time can be the gaps that punctuate the record, Exxon researchers said, rather than any guide preserved in the sediments. And a key tool in sorting out the successive processes that caused the gaps and laid down the sediments between them is the remote-sensing technique of seismic reflection profiling, which can help locate and date gaps relatively cheaply. Given this new technique of seismic stratigraphy, Exxon claimed, gaps of the same age can be found around the world, like universal bookmarks in the geologic record.

After years of half-believing the Exxon researchers, if only because their mass of secret data so overwhelms any publicly available, some researchers outside the oil industry are developing their most convincing evidence yet that Exxon may be right, that erosion sliced away the same sections of accumulated sediments at the same time at widely separated sites from Australia to the North Sea. A raging controversy still surrounds the ultimate cause of the missing sediments. The Exxon group, headed by Peter Vail of Exxon Production and Research, Houston, has heeded the criticism of academics. It now considers a combination of processes to be responsible, but the group's continuing claim that rapid, global sea-level changes throughout the past 500 million years have exposed continental margins to erosion has yet to find many supporters.

Although Exxon's evidence comes from 60 regions around the world and its derived curves of changing sea level have been associated with everything from coal formation in Utah to volcanic activity in the central Pacific, the only concerted, nonproprietary evaluations of the Exxon hypothesis focus on the margins of the North Atlantic. *Geologic Evolution of the United States Atlantic Margin*, a nine-paper volume, looks at the sediments of the coastal plain, the continental shelf, and the outlying slope and rise. In his preface to the book, editor Wylie Poag of the U.S. Geological Survey (USGS) in Woods Hole, Massachusetts, notes that a common theme in most of the papers is the way similar groupings of sediment are separated by gaps of missing sediment—surfaces called unconformities—of similar age. Detectable by analysis of core samples and often by the seismic waves reflected from them, the same unconformities seem to separate the same groupings of sediment strata from place to place across a region like the Baltimore Canyon trough and even along the entire U.S. Atlantic margin.

In a paper in *Interregional Unconformities and Petroleum Accumulation* published last month, Poag and John Schlee of the USGS in Woods Hole drew on some of these same U.S. Atlantic margin observations to conclude that "our data fit the Vail model well enough to justify its cautious use as a predictive tool in deciphering the geologic history of other parts of the U.S. margin, such as the Carolina trough, where drill-hole data are not yet available." They traced seven unconformities in offshore sediment-filled basins from Florida into Canadian waters. At least six of these unconformities coincide in age with Vail's major unconformities, Poag and Schlee say.

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Perhaps the most striking bit of support for the Vail hypothesis in the public domain comes from holes drilled on either side of the Atlantic by the Deep-Sea Drilling Project. In each of three drill holes on the slope just off the Irish shelf, four unconformities dating from 10 million to 60 million years ago coincide with one of the six major unconformities identified by the Exxon group, according to Poag. On the New Jersey slope, five of seven unconformities in the same period coincide with Vail unconformities.

Other researchers have suggested that sea-level change and its resulting unconformities are useful elsewhere than in broad-scale studies of the presently submerged margins. Susan Kidwell of the University of Arizona found that unconformities divide sediments exposed along cliffs of Chesapeake Bay into units deposited during a single cycle of encroaching and then retreating seas. Although apparent at the pick-and-shovel level of outcrop geology rather than through the larger scale of seismic profiling, three of these unconformities seem to match minor rapid sea-level changes of the Vail curves dated as being 16.5, 15.5, and 13 million years old.

At the other extreme from coastal sediment outcrops, John Barron and Gerta Keller of the USGS in Menlo Park, California, have reported an apparent relation between Vail's record of sea-level change and the deposition of sediment in the deep sea, far from any erosion caused by rain or river. Barron and Keller searched Pacific deep-sea sediment cores for hiatuses in deposition caused by eroding currents, dissolution by corrosive bottom water, or a cutoff of sediment supplies. Of their six hiatuses between 5 and 16 million years ago, four match one of the five sea-level falls on the Vail curve. How a sea-level fall of some tens of meters could be related to sedimentation thousands of meters down is not immediately clear. The connection could be indirect. Barron and Keller suggest that one connection may be through a surge in bottom currents that accompanies cooling and increased glaciation, an increase in ice being the accepted cause of lowered sea level during the past few tens of millions of years.

Although the relative trickle of new public data tends to confirm the repeated, synchronous erosion of continental margins around the world, the biggest step toward acceptance of that hypothesis has come from Exxon itself. Vail and his group have conceded that they erred in interpreting the basic observations. In their initial 1977 paper they assumed that the rising sea laid down sediment layers higher and higher on the continental margin, as seemed clear in seismic reflection profiles across the continental shelf. When the sea withdrew, it laid down a series of retreating sediment layers as it went. Exposure of the shelf to the elements then led to erosion and an unconformity. On the basis of this view of the seismic profiles, the sea seemed to have risen gradually and then dropped almost instantaneously, giving Vail's curves of sea-level change an odd saw-toothed character (*Science*, 25 July 1980, p. 483).

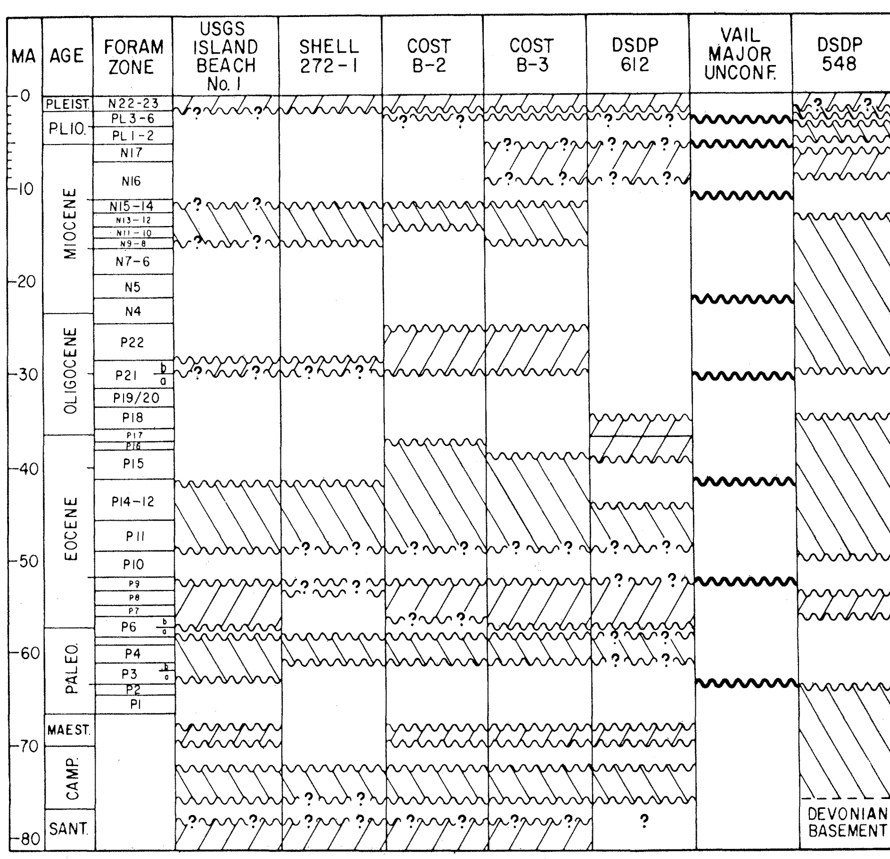
But as Walter Pitman of Lamont-Doherty Geological Observatory and others quickly pointed out, sea level was not the only thing moving around. The continental margin is sinking at a rate of 1 to 2 centimeters per thousand years as it cools after the opening of the Atlantic basin. If global sea level remains unchanged, the sea will still creep up the shelf as it sinks. Even if global sea level drops fast enough to overtake subsidence and cause the sea's edge to retreat down the margin, sediments washing off the continent can stop short of the sea and fill in space created by subsidence above the waterline. Unable to distinguish between these subaerial sediments and true submarine sediments, the seismic stratigraphy technique would show sea level still rising while it was actually falling, argued Pitman. The inferred sea level falls would be too brief and thus too rapid.

Vail and the Exxon group now agree that appearances on the margins can be deceiving. Not only sea-level change is involved. The subtle interplay of sea level and subsidence plus the amount of sediment that reaches a site determines the configuration of sediment layers. The Exxon group now recognizes two types of unconformities: one is presumed to be caused by a rapid global sea-level fall that overtakes subsidence and leads to complete exposure of the shelf to erosion, and another would be caused by a slower fall that can expose only the inner, more slowly subsiding shelf. A sufficiently rapid global sea-level rise, on the other hand, would trap sediment closer to land and starve outlying areas, creating there a condensed section of slowly accumulating sediment that can be mistaken for an unconformity.

Exxon's acceptance of the central role of the *rate* of sea-level change in controlling sedimentation has done much to calm the heated reception given its announcement. But Exxon continues to fan the flames of controversy by claiming that global unconformities are caused by global sea-level change, due in all likelihood to the waxing and waning of great ice sheets. Virtually everyone has problems with the ice sheet part—Vail shows sea-level changes 100 million years ago when Earth was enjoying a warm spell that most experts presume left no spot cold enough for a major ice sheet.

Most researchers would prefer to explain many of Vail's unconformities by other mechanisms. Anthony Watts of Lamont has argued that the expected variations in the rate of subsidence as a margin cools more slowly is likely to dominate the interaction of land and sea much of the time. An appearance of global synchroneity might have been imposed by the nearly simultaneous opening of many ocean basins around the world during the breakup of Pangaea, he notes. Other possible mechanisms merit further attention as well, he says, such as changes in sediment supply and the ability of bottom water to erode sediments through chemical dissolution.

Vail sees no obvious alternative to rapid, global sea-level changes. Exxon's secret data show that the unconformities are global, he says, a fact that tends to be supported by public and reportedly by private data but is not likely to be independently confirmed for years. The same unconformities are found on such widely dispersed, tectonically unrelated margins, he argues, that only a global sea-level change could link them. His curves of sea-level change derived through seismic stratigraphy are no longer jagged and saw-toothed; both rises and falls are gentle and subdued. The rate of change, however, is still relatively high—greater than 3 to 4 centimeters per 1000 years, according to Vail. No one has thought of a way to account for a sea-level change of more than about 1 centimeter per 1000 years except by the accumulation and melting of a lot of ice. Therefore, he concludes, ice is the best present explanation of global unconformities whether there are indications to the contrary or not.—**Richard A. Kerr**



W. Poag

Tying together the jumbled marine sediment record

The open spaces in these diagrams of Atlantic sediment cores represent unconformities, missing sections of sediment laid down during that time period and later eroded away. The bold squiggles in the "Vail Major Unconformity" column mark the ages of unconformities found around the world by Exxon researchers. In this summary of cores from the New Jersey continental margin (left) and the Ireland margin (right) prepared by Wylie Poag, the regional unconformities found in publicly available data tend to line up with the global Vail unconformities, which are based on proprietary data.

Additional Reading

1. J. A. Barron and G. Keller, *Geology* **10**, 577 (1982).
2. C. W. Poag, Ed., *Geologic Evolution of the United States Atlantic Margin* (Van Nostrand Reinhold, New York, in press).
3. J. Thorne and A. B. Watts, *Nature (London)* **311**, 365 (1984).
4. J. S. Schlee, Ed., *Interregional Unconformities and Hydrocarbon Accumulation* (Memoir 36, American Association of Petroleum Geologists, Tulsa, 1984); P. R. Vail, J. Hardenbol, R. G. Todd, in *ibid.*, pp. 129–144; C. W. Poag and J. S. Schlee, in *ibid.*, pp. 165–182; S. M. Kidwell, in *ibid.*, pp. 37–58.
5. A. B. Watts, *Nature (London)* **297**, 469 (1982).