Yet another possibility is that the width of the fault is not the appropriate measure of the dimension of an earthquake. Models of the spatial distribution of earthquake slip are quite heterogeneous. The picture that emerges from modeling strong-motion data is that earthquakes typically comprise multiple areas of high slip. In this case, the rise time may be controlled by the dimensions of high-slip regions. Quasi-dynamic models of recent earthquakes that account for observed slip variations and use a simple velocity-independent sliding friction support this possibility.

Whatever the physical mechanism behind short rise times, the simple observation that they are short has important effects on earthquake strong ground motion, which in turn has important consequences for earthquake engineering. Since the same amount of slip across a fault occurs during a short rise time, the ground velocity close to an earthquake fault can be high. These high velocities may not be accounted for in current seismic-design criteria for engineered structures. The vulnerability of such structures to earthquakes, particularly earthquakes that occur on faults in urbanized areas, may be higher than previously thought.

A better understanding of the factors controlling hazardous, strong ground motion during earthquakes will lead to a better understanding of the physics of earthquake rupture and an increased ability to anticipate and design for strong shaking in future earthquakes.

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Sequence Stratigraphy

Sequence stratigraphy concepts have stimulated an explosion of ideas and controversy. Key topics include the validity of the "Exxon" cycle chart, which details the sea-level curve throughout the Mesozoic and Cenozoic; conceptual sequence models, which elaborate on systems tract ideas and quantitative aspects of basin accommodation; and methods for developing a high-resolution sequence stratigraphic framework using outcrop, core, and well data. Stratigraphic studies have been numerous, and conventional lithostratigraphy has faced serious challenges with shortcomings in old methods of correlation, development of facies models, and nomenclature recognized. As much effort has gone into dispelling the notion that sequences exist as the proponents have put into demonstrating the existence of these unconformity-bounded packages of rock. Sequence stratigraphy may or may not have revolutionized stratigraphy, but it has made a number of scientists reconsider old ideas and change interpretations.

To test the "Exxon" cycle chart, researchers documented patterns of sea-level change through the Mesozoic and Cenozoic in various basins of northern Europe, focusing on sequences related to third-order-cycle changes in sea level or changes at frequencies of about one million years. This research has identified problems in the "Exxon" cycle chart and has highlighted previously unrecognized local stratigraphic complexity of various European type sections. Many researchers recognize that more sequences exist in the rock record than are recorded in the "Exxon" cycle chart. Third, fourth, and fifth order cycles of sea level are interpreted locally, and the rocks deposited during those cycles display the attributes of sequences. The abundance of high-frequency sequences makes it difficult to resolve surfaces on an interregional basis and use the "Exxon" cycle chart as a predictive tool.

Sequence frequencies as high as 100,000 years are usually not resolvable with conventional biostratigraphy or radiometric techniques, particularly in rocks older than the Neogene. The task of identifying the same surface in disparate basins is a challenge but, as dating techniques become more refined, resolving global patterns of sea-level change and the sequence development will improve.

Sequence stratigraphy research formerly was focused on the internal architecture of shallow-marine strata. Beds within these strata were observed to stack in predictable patterns and to form a stratigraphic unit called a parasequence, which was bounded by a parasequence boundary or flooding surface. Part of the debate over the significance of parasequences and parasequence boundaries has centered around the origin and resolution of ravinement surfaces, transgressive surfaces, parasequence boundaries, and sequence boundaries. New work will resolve issues regarding the origin of parasequences as well as focus on developing facies models within a high-resolution stratigraphic framework. These facies models should offer greater sophistication and provide for greater predictability of bed continuity and shape than in the past.

Developing sequence models for non-marine strata is controversial because of the difficulties in tracing surfaces across a depositional shelf from the marine to the continental setting. Relating sequence patterns in lacustrine basins to marine settings is a challenge; relating surfaces in eolian facies to coeval marine basins is even more of a problem. The efforts with fluvial strata have begun to provide a new stratigraphic framework for many basins. Work on the fill in Quaternary incised valleys in the Gulf Coast by John Anderson at Rice University and Michael Blum from Southern Illinois University offers new insight into the timing of valley formation and the architecture of the marginal marine to non-marine valley fill. Refinements are likely; the potential here is to revise not only the stratigraphy of many basins that are dominated by non-marine rocks, but also to enhance the facies models of non-marine systems.

The general problem of the interaction between basin tectonics, sediment supply, and eustacy remains an area for extensive research. Sequence-stratigraphy models were originally developed for passive margins and sag basins. The importance of tectonics was not underestimated, but it was not documented for the variety of basin types that exist in nature. Arguments exist regarding the general applicability of sequence concepts in active tectonic settings. Questions center around the cause of various unconformities and their extent. Regions of active tectonism typically exhibit great structural deformation, which makes continuity of outcrop and stratigraphic surfaces limited; however, the potential for very high-resolution stratigraphy makes it feasible to time structural events and to develop a detailed tectonic history for different basins.

Many of the breakthroughs in sequence stratigraphy will come from groups of geoscientists working together to integrate large datasets. Stratigraphers and sedimentary petrologists will provide new ideas for predicting cement distribution and the stratigraphic controls on cements in clastic and carbonate rocks. Similarly, stratigraphers, working with geophysicists, structural geologists, and petrologists will develop stratigraphic models in complex tectonic terranes which will further our understanding of how these complex terranes evolve. As more and more basins are examined, the geometry of sequences and their components will be refined, and the debate will continue.

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Low Temperature Isotope Geochemistry

Natural variations in the isotopic composition of a number of elements have been increasingly applied to studies of sedimentology, climatology, oceanography, and hydrogeology. Recent results give insight into the interplay between changes in paleoclimate, sea level, weathering processes, fluid-rock interaction, and surface-water and ground-water migration.

Uranium-series

Technical advances in measuring isotopes that occur in very low concentrations provide an improved dating tool, the ^{238}U-^{234}U-^{230}Th geochronometer. New questions regarding Pleistocene climate change, sedimentation, and diagenesis can be addressed using the improved precision and small sample size capability of this technique. No matter how precise the age determinations may be, the applicability of this geochronometer to corals as precise indicators of the timing of past high sea levels requires detailed understanding of effects of diagenesis on the accuracy of coral ages. C. Gallup and others (University of Minnesota, Minneapolis) used high-precision ^{234}U-^{230}Th measurements on a series of coral reef terraces on Barbados, West Indies, to model the timing and nature of diagenetic addition of these isotopes to coral skeletons. Such detailed, high-precision coral studies will be required, along with studies of other marine and continental records, for the continued evaluation of models for climate change.

Boron

The partitioning of the isotopes of boron between sea water and marine minerals is pH-dependent, as shown by G. Hemming and others (SUNY, Stony Brook). This advance offers the intriguing prospect of reconstructing temporal changes in the pH of the oceans through measurements on well preserved marine fossils. Such measurements may provide an independent record of changes in atmospheric CO_2 contents.

Oxygen and carbon

The carbon isotopic composition of seawater from modern marine platforms of the Bahama Banks and Florida is different from open ocean water as a result of several processes, including evaporation, $CaCO_3$ production, and freshwater discharge (W. Patterson and L. Walter, University of Michigan, Ann Arbor). These results call for caution in interpreting $^{13}C/^{12}C$ values in ancient platform carbonate rocks, which are commonly analyzed for studies of secular changes in ocean chemistry. Carbon isotope variations in modern planktonic foraminifera are used to determine anthropogenic input of CO_2 to the surface ocean (N. Beveridge and N. Shackleton, University of Cambridge, United Kingdom). Covariations of carbon and oxygen isotopes have been a standard tool in interpreting the composition and temperature of paleo-ground-waters in ancient limestone aquifers. These covariations have recently been used as key evidence for paleo-ground-waters as agents of aragonite and dolomite cement precipitation in coastal marine-freshwater mixing zones (T. Kimbell and J. Humphrey, Colorado School of Mines, Golden, and H. Cander, Amoco, Houston).

Lead

Studies of ancient limestones have lacked geochronologic tools for timing processes of deposition and diagenesis, thereby limiting rigorous tests of models for sequence stratigraphy and paleohydrology. The application of the U-Pb isotope system, well-established in igneous and metamorphic studies, to sedimentary systems provides a means to date Phanerozoic sediments and unconformities (P.E. Smith and others, University of Toronto, and J. Hoff and others, SUNY, Stony Brook).

Strontium

Whereas the oceans are well mixed at a given time with respect to strontium isotopes, marine strontium isotope values have changed over geologic time and reflect variations of controls on the hydrologic cycle of strontium. A number of linked processes in Earth history, including orogenesis, climate change, weathering, surface-water flux, and diagenesis can affect the marine Sr isotope record. Advances in our knowledge of Neogene to Pleistocene (by S. Clemens and others, Brown University) and Phanerozoic marine records have come from enhanced analytical and temporal resolution, as well as from careful scrutiny of the preservation of ancient samples. Understanding the effects of diagenesis in ancient sequences will be improved through investigations of the geochemical behavior of Sr in modern aquifers, estuaries, and deep sedimentary basins (T. Bullen and others, USGS, Menlo Park; J. Banner and others; L. Land and others, University of Texas, Austin; G. Wasserburg and others, Caltech). This work will improve chemostratigraphic resolution and models for modern and ancient hydrologic cycling of Sr.

J. Blum and others (Dartmouth College, Hanover, N.H.) find that streams draining the more recently glaciated parts of the Sierra Nevada have the highest $^{87}Sr/^{86}Sr$ values, indicating relatively rapid weathering rates of minerals such as biotite in recently glaciated bedrock. These results are consistent with correlated changes in the Pleistocene marine $^{18}O/^{16}O$ record, which reflect glacial-interglacial ice volume changes, and the Pleistocene marine $^{87}Sr/^{86}Sr$ record, which may reflect glacial-interglacial weathering-rate changes. Such studies underscore the role of the hydrologic cycle in linking changes in climate with weathering rates and ocean chemistry.

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