v. 295, p. 1077; and Godderis and Francois, *Chemical Geology*, v. 126, p. 169).

Attempts to model the dynamics of metamorphism became increasingly sophisticated, particularly in the extent to which the modeling is based on direct field observation. For example, recent modeling of fluid pressure and fracture evolution (Dutrow and Norton, *Journal of Metamorphic Geology*, v. 13, p. 677), fluid production (Hanson, *Geological Society of America Bulletin*, v. 107, p. 595), and fluid transport (Dipple, *Geophysical Research Letters*, v. 22, p. 3127) during metamorphism led to interesting hypotheses testable through detailed field study. Field-based studies of metamorphic rocks provided extremely complementary information regarding permeability evolution and magnitudes of fluid flux in the crust.

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Carbonates

Carbonate research during 1995 focused on revitalization of stratigraphic studies within a sequence stratigraphic framework. Diagenetic studies also reflect this emphasis on stratigraphic analysis, with the development of integrated geochemical studies designed to augment stratigraphic correlations and refine geochronology.

Carbonate stratigraphy

Icehouse-greenhouse models: One avenue of carbonate research that showed significant potential this year is a trend toward categorization of carbonate platforms, not by external geometry (for example, ramp, rimmed shelf), but instead by whether the platform developed under global icehouse or greenhouse climatic conditions. F. Read of Virginia Polytechnic Institute began successfully to integrate both observational data and forward stratigraphic simulations of icehouse, greenhouse, and transitional icehouse-greenhouse platforms (*SEPM Short Course Notes No. 35*) into a simplified framework. This approach links carbonate platform types to differing Milankovitch-band glacioeustatic signals and thus to cycle-scale stacking patterns and facies architecture, reservoir heterogeneity, and characteristic icehouse/greenhouse carbonate mineralogies and attendant diagenetic pathways.

Carbonate geochemisty and geochronology: A second area that heated up in 1995 and that promises increased activity in 1996 is the area of Sr isotope analysis of sedimentary rocks. Researchers at the University of California, Riverside and the University of Texas (I. Montanez and others), the University of Texas Bureau of Economic Geology (S. Ruppel and E. James), and Cambridge University (D. Cummins and H. Elderfield) have now begun to integrate $^{87}Sr/^{86}Sr$ trends in specific textural components, such as conodonts and brachiopods, to provide a higher-resolution correlation tool. The more detailed studies illustrate a high-resolution geochemical cycle that could provide resolution for dating at the scale of third-order sequences. These integrated stratigraphic/geochemical approaches are becoming increasingly important as modern high-resolution sequence stratigraphic analysis consistently operates at a level that cannot be effectively supported by conventional biostratigraphic techniques.

Other researchers making a splash in geochronology of sedimentary rocks this year include J. Grotzinger and S. Bowring of the Massachusetts Institute of Technology. Their work on improving our understanding of rates of early metazoan evolution was featured in *TIME* magazine. Bowring has made significant strides in geochronology by extending zircon-based U-Pb dating to younger age strata. There is no question that the improved temporal resolution provided by these techniques will allow stratigraphers and sedimentologists to test numerous hypotheses that require definitive age determinations, such as the viability of the terminology of stratigraphic cycles (2nd, 3rd, 4th, and 5th order cycles) that has crept into the literature.

High-resolution sequence and cyclic stratigraphy: Another significant contribution to high-resolution carbonate stratigraphy is the recently published work of C. Kerans and W. Fitchen of the University of Texas Bureau of Economic Geology on the stratigraphic hierarchy and facies architecture of Permian ramp systems, which are spectacularly exposed in the Guadalupe Mountains of west Texas. This detailed work provides superb data on the lateral variations of facies architecture within carbonate ramps and demonstrates that ramp facies models are dynamic both in space and time. This study transcends knowledge derived from vertical stacking pattern analyses and provides a ground truth foundation for stratigraphic modeling.

Carbonate diagenesis

Our understanding of the processes of chemical and textural alteration that affect carbonate sediments and rocks has been advanced through an application of new analytical techniques as well as creative new petrographic-stratigraphic observations. Since ancient marine limestones are our best storehouses for clues to the chemistry of ancient oceans and the development of aquifers and petroleum reservoirs, there is a clear need for more rigor in understanding the effects of diagenesis in altering original fabrics and compositions. Such rigor is essential for furthering our pursuit of secular variations in ocean chemistry and the associated paleoclimatic/paleotectonic implications, as underscored by L. Land (University of Texas).

Stratigraphic patterns of diagenesis: One of the most significant publications dealing with carbonate diagenesis in 1995 is AAPG Memoir 63 (D. Budd, A. Saller, and P. Harris, eds.), which examines unconformities and porosity in carbonate strata. This publication, which contains papers presented at a 1994 Hedberg conference, dispels the myth that porosity enhancement is consistently associated with unconformity-related exposure.

Technological advances: Diagenetic studies continue to benefit from new techniques for enhanced spatial resolution for textural analysis and geochemical sampling. These techniques include microscopic drilling, laser ablation, secondary ion mass spectrometry, transmission electron microscopy, and computed X-ray tomography. They have been applied to high-resolution studies of stable isotope, chemical, mineralogical, and porosity variations within carbonate cements and skeletal components. Previously unrecognized inter- and intra-growth-zone variations portray the complexities of crystal growth, mineral-solution reactions, and porosity development in marine through freshwater carbonate diagenetic systems (K. Lohmann and others, and L. Walters and others, University of Michigan; J. Dickson and others, Cambridge University; M. Kwong and others and B. Kirkland and others, University of Texas; M. Savard and others, Geological Survey of Canada/University of Ottawa; and J. Paquette and R. Reeder, the State University of New York, Stony Brook). The application of geochronologic techniques to diagenetic phases holds promise for assessing the time scales of (and relationship between) fluid-rock interaction, subaerial exposure, and sea level and climatic fluctuations. Uranium-series isotopes will see increasing application to timing Pleistocene-Holocene diagenetic processes preserved in pore-filling cements and speleothems (R. Edwards and others, University of Minnesota, University of Texas).

Microbial diagenesis: The important association of microbes with diagenetic processes has become increasingly recognized (R. Folk, University of Texas; B. Jones, University of Alberta). We can expect significant advances in understanding the exact role of these "nannogeochemists" in producing and destroying calcium carbonate, and the links between biological and mineralogical worlds.

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Clastic Sedimentology

As a science matures, artificial boundaries that define its subdisciplines tend to converge, reflecting an increased understanding of their interrelationships. Such is the case in clastic sedimentology, where over the last few years there has been a growing synergy between sedimentology and stratigraphy. The increased predictive capabilities achieved from this union provide multiple sedimentologic and stratigraphic criteria for establishing a common theoretical depiction of phenomena. Merging scales of observation further abrogate the division of these subdisciplines in outcrop studies that facilitate such scalar integration.

Perhaps the greatest traditional difference between these allied endeavors is their scale of investigation. Advances in clastic sedimentology continue to emphasize process-response models to explain the genesis of smaller scale sedimentary structures and surficial processes responsible for their origin. Advances in stratigraphy have recently focused on expanding the catalog of groups, formations, and members to include chronostratigraphic units and criteria for their recognition and correlation.

An increased measure of prediction within clastic sedimentology can be achieved through multiscale investigations that show how small-scale sedimentologic changes occur within the context of larger stratigraphic systems. The challenge for clastic sedimentology, therefore, is the replacement of "static" facies models with dynamic ones that examine process-response sedimentology within a stratigraphic context. Similarly, stratigraphy must integrate a sedimentological hierarchy to incorporate complex feedback responses governing depositional regimes.

To illustrate both the problems and promise of such a holistic sedimentary geology, the following discussion briefly highlights recent advances that augur well for convergence among these subdisciplines. These are examined from the context of geographic position along a depositional profile of continental, shallow-marine and deep-marine environments. It is precisely the linkage among these environments that facilitates an understanding of their interrelationships, incorporates fundamental principles of conservation of mass and energy, and will ideally dictate the conduct of future research in clastic depositional systems.

Continental environments

The relatively poor continuity and facies organization of non-marine deposits have led many colleagues to conclude that correlation of these deposits is a matter of faith rather than a demonstrated methodology. Yet paradoxically, the work of fluvial sedimentologists best illustrates the utility of a dynamic sedimentology that facilitates stratigraphic correlation. Multiscale geomorphic bodies can be related to quasi-equilibrium flow conditions in fluvial regimes. A hierarchy of sedimentary structures that scale to the boundary layer, turbulent streamflow, and channel morphology directly relates to efficiency of sediment transport because these structures record a balance between erosion and deposition. Consideration of the balance between erosion and deposition places us squarely in the domain of stratigraphy. Surficial processes that erode, transport, and deposit sediment reflect changes in the accommodation/sediment supply ratio. Hence, an essential measure of stratigraphic and sedimentologic scale is achieved by placing facies arrangements within a stratigraphic context. Integrating architectural element analysis with hierarchical sequence stratigraphy further bridges the "scalar" or spatial gap between sedimentology and stratigraphy because multiscale stratal units can be objectively defined using the same geometric criteria of discordance and stratal termination. This approach resolves the smallest scale "genetic" (for example, accommodation/sediment supply governed) stratal units that can be linked to common depositional and *preservational* processes.

The utility of "indicator facies" such as organic-rich, evaporite, and/or tidal deposits for non-marine correlation, and distinguishing valley fills from channel fills remain areas that will benefit from integrated sedimentologic and stratigraphic research. Incorporating principles of mass-balanced sediment volumes, or sediment budgeting within and between temporally and spatially linked environments shows promise in helping resolve correlations of non-marine strata. For example, sediment volumes excavated during valley incision and accounted for elsewhere may help distinguish a valley from a channel fill.

Shallow-marine environments

Shallow-marine deposits are among the most thoroughly studied and arguably the best understood siliciclastic strata. Despite this heritage, advances are needed in our understanding of dynamic shoreline responses to sediment budgeting across *linked* marine and non-marine environments. If these facies models are to be useful in predicting stratal architecture, a new generation of revised facies models must incorporate a dynamic sedimentology responsive to stratigraphic position. For example, shorezone facies models commonly regard different delta morphologies as products of differing sediment supply, subsidence, and oceanic current and wave regimes. Thus, end-member "wave-dominated," "fluvial-dominated," and "tide-dominated" deltas are commonly regarded as distinct entities reflecting different sedimentologic, geomorphic, and tectonic regimes. Recent work documents different delta morphologies with accompanying changes in facies composition and stratal architecture in constant tectonic and geomorphologic settings. The only variable that appears to control observed differences is variations in sediment flux to the delta front, which is due to sediment-volume partitioning within linked environments rather than variations in other external variables.

Although recent research has produced better descriptions of shelf deposits, transport processes responsible for their emplacement remain poorly understood. The distinction between shelf sandstones and beheaded shoreface deposits encased in mudstone remains unresolved and represents an area for future research in both modern and ancient shelf systems. Although ill-defined, the concept of "forced regression" may help stimulate interest in this research topic.

Deep-marine environments

Advances in deep-water sedimentology require "getting below the surface of the problem." For many years, the study of deep-water deposits focused on the morphology and shallow seismic of modern fans, providing little information on their stratigraphy. Attendant outcrop studies focused on deep-water sedimentology, but the scales of these two study types differ substantially. This led to the misapplication of fluvial models to interpret deep-water channels. These attempts at analog sedimentology reflect a lack of understanding of deep-water transport and depositional processes. The next generation of sedimentological research must focus on unifying the rheology, geometry, continuity, kinematics, and mode of emplacement of sediment gravity flow deposits of contrasting density and concentration.