are those ions that trap excitation energy, but whose outer electron transitions do not result in luminescence. Main quenchers in carbonates are Ni and Fe.

As opposed to visual determination, only a spectral analysis of the emitted radiation paired with a chemical analysis can detect which of all these elements participate in the luminescence of a particular carbonate crystal. A visual observation, such as "bright-orange luminescence," is merely a mixture of wavelengths, and this color can result from different spectral compositions due to correspondingly different trace element contents.

Activators, sensitizors, and quenchers have to be present in certain minimum and below certain maximum concentrations in order to be effective. The minimum concentration for the most important activator in non-hydrothermal carbonates, Mn^{2+}, is well below 100 ppm, and it is even lower if the crystal contains any sensitizors in effective concentrations. Pb^{2+} and Ce^{2+} sensitize Mn-activated luminescence at concentrations as low as perhaps 30 ppm. The most effective quencher is Ni^{2+}, which kills Mn-activated luminescence at concentrations as low as possibly 35 ppm. Fe^{2+} seems to effect initial quenching at about 30 to 60 ppm. Up to about 10,000 ppm, the luminescence behavior of calcite and dolomite depends on the Mn^{2+}/Fe^{2+} ratio. No luminescence occurs above this level, whatever the Mn^{2+} concentration.

Mn^{2+} is the most important activator in carbonates because it leads to the most obvious luminescence; it is relatively abundant. Fe^{2+} is probably the most important, although not most effective, quencher due to its very high and variable abundance. If one attempts to interpret the luminescence behavior of carbonates in terms of the geochemical environment, however, the other activators, sensitizors, and quenchers have to be considered too. In particular, those elements associated with organic matter could be enriched in organic-rich (or even bituminous) carbonates, and elements primarily associated with clay minerals can be expected in impure, argillaceous limestones and dolostones, and their diagenetic carbonate phases.

The luminescence of carbonate cements, thought to result from Mn^{2+} and Fe^{2+} alone, has often been taken as an indicator of the redox-potential of diagenetic fluids. This is only permissible if it can be shown that the other elements are not involved to any significant degree.

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Submarine Cements—The Peloidal Question

The peloidal texture common to submarine substrates lithified by magnesium calcite appears to be the result of the same processes responsible for the deposition of the cement. These peloids do not, as reported earlier, represent the deposition of internal sediment of fecal or unknown origin. Rather, they are the physicochemical product of the precipitation of calcite from seawater, as indicated by: (1) the widespread occurrence of peloidal calcites in a variety of marine environments; (2) the generally limited size range of the peloids; (3) the well-developed zonation of peloidal textures in many cement crusts; (4) the presence of peloids in restricted microcavities; and (5) the chemical similarity of peloids and associated magnesium calcite dentate rim cements.

Although these magnesium calcite peloids resemble aragonite peloids formed by rapid repeated nucleation in experimental precipitation of aragonite from supersaturated seawater, their rates of formation must differ because pore waters are incapable of spontaneously providing the calcium carbonate required for the extensive deposition of magnesium calcite found in restricted submarine settings. Observations of magnesium calcite precipitating on experimental substrates placed on the ceiling of a submarine cave suggest that clotting or nucleation of magnesium calcites may be a very slow process, perhaps commonly involving the nucleation within an initial submicrocrystalline calcite "dust" precipitate. The final stage consists of the precipitation of dentate microcrystalline rim cements around the peloid centers.

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Diagenesis and Mass Transfer in Sandstone-Shale Sequences

An analysis of diagenesis and mass transfer is made drawing on the literature and our work from the Brazilian shelf and Barbados. It is shown (although not unanticipated) that the initial sedimentary mineral composition is a major control of diagenetic products. For example, dioctahedral clay minerals, chlorite, and quartz characterize arkoses, whereas trioctahedral clays and zeolites are most commonly found in lithic sandstone. Dioctahedral smectite-rich shales exhibit the classical smectite/illite to illite burial pattern. However, mafic, trioctahedral clay-rich shales show a burial sequence of saponite to chlorite/saponite mixed layer, a progressive increase of chlorite-rich phases with increasing burial depth. Other compositionally dependent reaction paths are also discussed.

To assess mass transfer between shale and sandstone during burial, all major diagenetic pathways must be known for both rock types. A model for the Brazilian shelf sandstone-shale sequence is used as an example of quantification of mass transfer. Both sands and shales act as nearly isochemical systems; sandstones lose less than 2% K^+ to shales, and gain less than 3% H_2O, H^+, and CO_2 during burial diagenesis.

It is shown using data from Barbados and the literature that burial diagenetic reactions are essentially irreversible, at least until the stage of weathering. Thus, these reactions can be used to assess the amount of overburden removed. Comparison of the diagenetically produced trend of illite/smectite compositions with depth in Barbados to trends produced in areas which have undergone only subsidence (e.g., Gulf Coast) suggests that about 3,300 to 9,800 ft (1,000 to 3,000 m) of overburden has been removed in Barbados.

The irreversible and nearly isochemical nature of burial diagenetic reactions places constraints on the role of diagenesis in the sedimentary rock cycle. An attempt is made to quantify the global importance of these reactions in the rock cycle.

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Mississippian Carter and Lewis Sandstone Petroleum Geology of Black Warrior Basin of Alabama

The Black Warrior basin of northwestern Alabama is an excellent locality to prospect for combination petroleum traps; to date over 1,000 wells have been drilled in the region and 62 petroleum fields and pools have been discovered. Mississippian sandstone reservoirs presently have the greatest hydrocarbon potential, the Carter and Lewis sandstones being the most economic of these reservoirs. Cumulative production for the Carter includes more than 700,000 bbl of oil and 12 bcf of gas. The Lewis has produced over 5,000 bbl of oil and 12 bcf of gas. The Carter was deposited as part of a high-constructive, elongate to lobate delta which prograded from northwest to southeast into the basin. The Lewis accumulated as a series of elongate, northwest to southeast-trending sand bodies on a shallow marine shelf. Carter distribu-

tary mouth bar and distal bar lithofacies and Lewis marine central bar lithofacies constitute the primary Mississippian reservoirs in the basin. Primary interparticulate porosity has been reduced through the development of quartz overgrowths and/or calcite cementation. Secondary porosity involves leaching of carbonate allochems, calcite cement, and/or matrix. The Carter prodelta and interdistributary bay shales and Lewis marine shales make excellent petroleum source rocks. These shales contain amorphous and herbaceous kerogen. The state of alteration of the kerogen indicates that the thermal history of the basin has been favorable for the generation and preservation of hydrocarbons, principally gas. The petroleum-trapping capabilities of these strata have been enhanced because of their association with normal faults.

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Bellerophontaceans from Hancock, Maryland—Gastropod (Torted) or Monoplacophoran (Untorted)?

Mollusk specimens from the Briery Gap Sandstone Member of the Foreknobs Formation in Hancock, Maryland, were previously assigned to the gastropod genus *Bellerophon*. In recent years, the controversy of whether *Bellerophon* belongs to the molluscan class of torted gastropod or that of untorted monoplacophoran has resurfaced. Because of the need for better understanding of molluscan evolutionary history, resolving this controversy is very important for an interpretation of fossil phylogenies as a whole, thus increasing the effectiveness of fossils as biostratigraphic tools.

In determining whether or not these animals were torted or untorted, past emphasis on muscle scar patterns has been proven inadequate due to the lack of specimens exhibiting suitable scars. The emphasis is presently being directed toward other aspects of shell morphology, such as apertural slits and secondary shell layers known as "inductura." The position of the inductura relative to the slit is significant and implies that the animal is oriented in a particular fashion within its shell. This position, in turn, helps to determine whether the animal was torted or not and hence whether it is a gastropod or a monoplacophoran.

Because original shell material was absent, recreating the shell was necessary in evaluating the morphology. This was achieved by replicating the shell using liquid latex. The pouring, hardening, and extraction of latex from external molds yielded replicas exhibiting detailed shell features. Observed was the location of the lateral inductural deposits opposite the apertural slit, implying that the animal's coiled shell was carried over its extended foot as a result of torsion, and therefore the animal belongs to the class Gastropoda.

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Thermal Maturity of Carboniferous Strata, Ouachita Thrust Fault Belt

The Ouachita thrust fault belt, a large, relatively untested hydrocarbon province, contains more than 30,000 ft (9,100 m) of Carboniferous flysch rich in potential source and reservoir rocks. To estimate the thermal maturity of these strata, vitrinite reflectance (in oil) was measured from more than 90 bulk samples of the Carboniferous-age Stanley, Jackfork, Johns Valley, and Atoka Formations. Inasmuch as no subsurface samples were available, the freshest possible outcrop samples were used for the analysis, despite the possible deleterious effects of oxidation on the accuracy of measured reflectance values.

Iso-reflectance contours generally trend parallel to structural grain in the western two-thirds of the Ouachitas. The "core" areas where pre-Carboniferous strata are exposed, as well as areas immediately adjacent to the core, are well defined by reflectance values greater than 2.0%. Outward from the core areas toward the north and south, reflectance values tend to decrease, although some minor variations owing to complex structure are present. In Arkansas, samples from the thrust-fault belts both north and south of the Benton uplift yield reflectance values between 1.0 and 2.0%. In Oklahoma, samples from the area north of the Broken Bow uplift yield reflectance values between 0.5 and 1.0%.

In the eastern third of the Ouachitas, iso-reflectance contours obliquely cut structural grain, and reflectance values are significantly higher. Samples from the Benton uplift give reflectance values higher than 3.0%, and measured values approach 5.0% from samples in and near the core. Although there is a general decrease outward from the core area to both the north and south, reflectance values greater than 2.0% characterize the entire width of the Ouachitas in this eastern area.

Reflectance values obtained from samples collected from both sides of major thrust faults in the western Ouachitas reveal that older, upthrown strata are more thermally mature than younger, downthrown strata. In contrast, samples collected from analogous structural positions in the eastern Ouachitas display identical thermal maturities on both upthrown and downthrown sides of thrust faults.

In the western two-thirds of the Ouachitas, stratigraphic depth of burial appears to have been the primary factor that controlled thermal maturity. The Carboniferous strata at the surface in this area are well within the window of oil and gas generation and preservation. The anomalously high thermal maturity of Carboniferous strata in the eastern third of the Ouachitas is probably the result of heat dissipated from Mesozoic rifting and intrusive events. This thermal overprint places the maturity of these strata beyond the limits of oil preservation and locally beyond the limits of wet gas preservation.

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Eustatic Control of Synchronous Stratigraphic Development: A Case for Facies Prediction in Basin Modeling

Field studies document an apparent eustatic control on facies patterns in isolated basins along a tectonically active margin. In the San Diego embayment and along northern Baja California, progradational-retrogradational shoreline sequences characterize Late Cretaceous and Eocene fore-arc basin-margin stratigraphy. Extensive paleontologic control helps establish the age and distribution of facies changes along these depositionally compact, steep-gradient margins. The observed depositional sequences may be stratigraphically arranged into three scales and patterns of sedimentary cycles. Timing of the two largest cycles provides relative sea level curves that correlate exceptionally well with worldwide sea level curves of Vail and others.

The major depositional cycle is asymmetric—a "hemicycle" hundreds of meters thick, characterized by a thin, basal retrogradational sequence overlain by a thick progradational sequence—and corresponds to eustatic supercycles. Depositional hemicycles are composed of smaller scale rhythmic successions controlled by sea level cycles and paracycles. Depositional pulses produced by local conditions, in turn, overprint these two larger scales of sedi-