The American Association of Petroleum Geologists Bulletin
V. 67, No. 11 (November 1983), P. 2155-2157

Association Round Table

DISTINGUISHED LECTURE TOURS, 1983-84

Abstracts

ARTHUR, MICHAEL A., Univ. Rhode Island, Narragansett, Rhode Island

Notions of Stinking Oceans? Models for Organic Carbon Burial During Cretaceous "Anoxic Events"

In modern marine environments, preservation of organic carbon in sediments is influenced by several variables: (1) primary production; (2) water depth and bottom-water oxygen content; and (3) bulk sedimentation rate—higher sedimentation rates enhance organic carbon accumulation rates. High organic carbon values and accumulation rates are found today under highly productive upwelling zones where intense oxygen-minimum zones ($O_2 < 0.5$ mL/L) impinge on upper continental slopes or outer shelves. However, high organic carbon concentrations are also found in the abyssal sediments of the anoxic Black Sea, where surface productivity is relatively low. Therefore, when examining occurrences of ancient marine "black shales," we must be able to distinguish the relative effects of the variables discussed above. The globally widespread "black shales" of some periods in the geologic past cannot be simply explained by patterns of upwelling alone; other, perhaps unusual, conditions must have contributed to their origin.

The Cretaceous is one period during which, at times, marine "black shales" were much more globally widespread than today. These intervals of time have perhaps unfortunately been termed "oceanic anoxic events," but the basic concept of an "anoxic event" involves a time envelope on the order of 10^6 years, during which organic carbon burial appears to have been more widespread in a variety of marine environments than at other times. However, regional or interbasinal differences in the timing, amounts, and types of organic carbon preserved are apparent during a single "anoxic event," and "anoxic events" of different ages differ in overall character. Therefore, no single model can explain the origin of these widespread episodes of organic carbon deposition. There are common associations between "anoxic events"; they tend to occur during global marine transgressions, and they are marked by warmer, more equable global climates.

Three main "anoxic events" occurred during the Cretaceous. These were of late Barremian-mid-Albian age (peak at Aptian-Albian boundary), mid-Cenomanian-early Turonian age (peak at Cenomanian-Turonian boundary), and late Coniacian-early Campanian age. During portions of the first two "anoxic events," organic carbon burial in pelagic and hemipelagic environments may have exceeded 10 times that of today, as indicated by calculations of accumulation rates and model calculations from secular $\delta^{13}C$ curves. The amount and types of organic carbon preserved in strata of different basins suggest that expansion and intensification of deep-water oxygen deficits were responsible for organic carbon preservation in many settings. This may have been partly due to the decreased solubility of oxygen in warm, saline deep-water masses. The feedback between sea level and development of surface and deep-water masses was an important factor. During the Aptian-Albian episode, overall surface-water productivity appears to have been low, and burial of terrestrial organic carbon in marine environments was significant. Enhanced marine surface productivity may only have been important during the relatively brief Cenomanian-Turonian episode.

It is important that we understand the nature of these "anoxic events" so that predictive models of organic contents and types can be constructed and utilized in frontier areas of hydrocarbon exploration, among other reasons.

BALSLEY, JOHN K., Geological Consultant, Mitchell Energy Corp., Denver, Colorado

Cretaceous Wave-Dominated Delta, Barrier Island, and Submarine Fan Depositional Systems of the Rocky Mountains: Clastic Models for Hydrocarbon Exploration

The distinctive characteristics of the three sand-dominated depositional systems are described with emphasis upon criteria useful in recognizing the systems in outcrop and subsurface settings. Interrelationships between the systems are examined with the aid of a complete sediment dispersal network extending from fluvial coastal plain through wave-dominated delta, strand plain, and barrier island systems to basin floor submarine fans. This network was deposited along the western margin of the Cretaceous interior seaway and was subsequently exposed in the Book Cliffs of Utah and Colorado.

Wave-dominated deltas are commonly cuspate to arcuate in plan, and sheet-like in cross section. Apparent widths range up to 40 mi (64 km). Typical delta front facies tracts consist of laterally extensive shoreface-foreshore sequences locally replaced by distributary mouth-bar deposits. The bar deposits reflect density flow processes and hyperpycnal inflow at the shoreline. Extensive coals and thin transgressive units cap the delta front sequences. The deltas occur in both vertically stacked and imbricate patterns.

The barrier island system is characterized by a sheet sand-body geometry, and by a dip-oriented facies tract consisting of a shoreface-foreshore barrier sequence replaced in a landward direction by tidal inlet and flood tidal delta deposits. Brackish-water lagoonal sediments overlie the entire tract. Characteristics of the system indicate deposition in a microtidal setting.

Submarine fans occur in distal settings beneath the prograding delta and barrier-island systems. Fan deposits are lenticular in cross section and isolated in basinal shale. The deposits range from thickening-upward sandstone-shale sequences reflecting deposition in outer fan environments to thick, sand-dominated, channelized sequences reflecting deposition in more proximal fan environments.

HAMILTON, WARREN, U. S. Geol. Survey, Denver, Colorado

Mode of Extension of Continental Crust

Cordilleran continental crust, from central British Columbia through Sonora, has been doubled in width by middle Eocene through Quaternary extension. Extensional structures seen at comparable levels of erosion are similar throughout the Cordillera and elsewhere in the world, so a model of general application can be deduced. "Core complexes" form beneath normal-fault blocks of basin-range type.

The lower third of the crust (seen in the Cordillera primarily by seismic reflection profiling; typically granulite-facies rocks where exposed elsewhere) is extended by laminar ductile flow. Preexisting rock masses are transposed into subhorizontal sheets.

The middle crust (seen in Cordilleran outcrop in Eocene through Pliocene "core complexes," as well as by reflection profiling) is extended by discontinuous ductile flow. Rocks are transposed, and recrystallized commonly in greenschist facies, in anastomosing ductile shear zones along which lenses of all sizes up to tens of kilometers long slide apart.

The composite top of the lenses is a "detachment fault"; petrologic barometers indicate a preextension depth of 10 to 12 km (6 to 7 mi) to typify this level. Heating by magmatism preceded or accompanied much extension, but "core complex domes" are the tops of structural lenses of middle-crust rocks, and are neither anticlines nor products of thermal highs.

The upper third of the crust adjusts to extension of its substrate by gravitational collapse of rotating brittle fault blocks. No correlation exists between direction of rotation and the local slopes of underlying lenses; blocks within panels up to 100 km (62 mi) across rotate in single directions. Sediments and slide breccias deposited against growing normal faults tend to maintain truncation angles near 50° as the strata are "reverse drag" rotated on listric faults to abut gently undulating detachment faults.

Depth and temperature of all components lessen as extension continues, so effects of successively colder and more brittle styles of deformation are superimposed as rocks rise through pressure-temperature boundaries between ductility regimes.

JONES, DAVID L., U. S. Dept. of Interior, U. S. Geol. Survey, Branch of Paleontology and Stratigraphy, Menlo Park, California

Accretionary Growth of Western North America: Examples from Alaska

It is now recognized that much of the Cordillera of western North America was assembled during Mesozoic time by accretion of allochthonous terranes. These terranes include: oceanic island arcs, scraps of ocean basins with ophiolitic basement, and fragments of continental margins, some with Precambrian basement, as well as composite terranes composed of two or more unlike elements joined together before accretion. Approximately 200 separate terranes have now been recognized in the Cordillera, each of which contains a distinctive stratigraphic record that differs strongly from that of its neighbor. Combined geologic, paleontologic, and physical (paleomagnetic) data substantiate that some of these terranes have been displaced thousands of kilometers northward from low paleolatitudes. As a result of these movements, paleobiogeographic provinces have been disrupted, and nonindigenous faunal elements transported to North America. A similar pattern of accretionary terranes characterizes much of the circum-Pacific margin, including China, eastern Australia, New Zealand, and parts of Antarctica. The great number and diversity of the displaced terranes found throughout this region suggest that the paleogeography of Panthalassa was extremely complex.

KASTNER, MIRIAM, Scripps Institution of Oceanography, La Jolla, California

Origin of Dolomite and Its Spatial and Chronological Distribution—A New Insight

One of the oldest problems in sedimentology is the origin of dolomite. Dolomite, $CaMg(CO_3)2$, is one of the most common sedimentary carbonate minerals. Its density is 2.866, and calcite's density is 2.710. The absolute abundance of dolostones, as well as the dolostone/limestone ratio, increase with geologic age. Changes in seawater magnesium concentration were invoked to explain these observations. During the last 30 years, for both scientific and economic reasons, many attempts were made to explain the scarcity of recent dolomites. Carbonate rocks composed mainly of dolomite generally have high porosities, and are important reservoir rocks for oil.

Dolomite is the thermodynamically stable carbonate phase in seawater. Its relative scarcity in recent marine carbonate sediments, therefore, cannot be explained simply by the thermodynamic properties of dolomite; dolomite formation appears to be inhibited by seawater. Most sedimentologists assumed that the formation of dolomite is mainly controlled by the dissolved magnesium/calcium (Mg^{2+}/Ca^{2+}) ratio in seawater; the molar (Mg^{2+}/Ca^{2+}) ratio in seawater is 5.3. It was therefore assumed that dolomite formation requires a still higher ratio. This explanation, however, had to be abandoned when primarily during the last 2 to 3 years, dolomite was observed as an important constituent of many modern marine organic-rich sediments; for example, in the California borderlands, Gulf of California, the Japan Trench, Cariaco basin off the coast of Venezuela, and the Solar Lake in Israel. In the Guaymas basin, for example, dolomite actively forms from pore fluids with Mg^{2+}/Ca^{2+} ratios of 1 to 2. Similar dolomite formed in the Miocene Monterey Formation, either as penecontemporaneous or early diagenetic nodules or as laminated dolomite. The $\delta^{18}O$ values of these dolomites range from -6 to $+7$ ‰ (PDB), and their $\delta^{13}C$ values range from -30 to $+20$ ‰.

Experiments conducted recently in our laboratory have shown that the important condition of dolomite formation is not high Mg^{2+}/Ca^{2+} ratios, but low dissolved sulfate (SO_4^{4-}) content, which inhibits dolomite formation, seawater contains 28 mM SO_4^{2-}. Dolomitization of calcite is already inhibited at sulfate concentrations of approximately 5 to 7% of seawater value. Aragonite dolomitization, however, though strongly retarded at these low dissolved SO_4^{2-} concentration values, is inhibited at sulfate concentrations of approximately 50% of seawater's value. We have also shown that dolomitization of $CaCO_3$ proceeds through protodolomite, a calcium-rich disordered dolomite which would transform to dolomite if equilibrium were established. Dissolved SO_4^{2-} also retards the rates of protodolomite transformation to dolomite and dedolomitization.

Sulfate ions adsorbed to the surfaces of calcite, dolomite, or aragonite may affect the kinetics of phase transformations in the carbonate system. In a sulfate-depleted environment, sulfate is rapidly desorbed; at 15° to 35°C (59° to 95°F), the process is completed in 1 to 2 days.

Thus, favorable sites for dolomite formation in the marine environment are those where dissolved SO_4^{2-} concentrations are low. The most effective processes of sulfate removal from or its dilution in marine pore fluids are microbial reduction in organic-rich sediments and mixing of seawater with large amounts of fresh water. This happens, for example, in continental margin sediments with high rates of deposition, as in the Gulf of California, or in deeper water sediments associated with black shales. The presence of much dissolved SO_4^{2-} in seawater also explains the almost absence of dolomite in apparently highly favorable environments, for example, in open marine carbonates.

The relative paucity of dolomite-rich carbonate rocks (dolostones) formed during the last 100 to 120 million years, as compared with their abundance in older sediments, in particular in the Precambrian and early Paleozoic, could be explained on the basis of changes in the depositional environments and in the carbonate mineralogy of the primary calcareous sediments. These differences do not necessarily reflect changes in seawater magnesium concentrations.

LOCKRIDGE, JOHN P., Mountain Petroleum Corp., Denver, Colorado

Shallow Gas Fields in High Porosity Chalk: An Independent's Exploration Strategy

The Niobrara gas-producing area on the eastern flank of the Denver basin is an interesting example of the recognition of shallow gas potential and development of production in an area where many unsuccessful wildcats had previously been drilled and abandoned in the futile search for production from deeper prospective formations. Exploration strategies have included the development of bypassed fields as indicated by logs from older deeper wildcats, subsurface mapping, pattern drilling, random drilling, and seismic surveys directed toward structural definition or observance of amplitude anomalies.

Natural gas is produced from the Cretaceous Niobrara Formation at approximately 40 fields in eastern Colorado and nearby counties in northwestern Kansas and southwestern Nebraska. The discovery for the province was in 1919 at the Beecher Island field in Yuma County, Colorado, but commercial development did not commence until 1972.

Biogenic gas is produced from a primary chalk reservoir with high porosity but low permeability at the top of the Smoky Hill Chalk Member of the Cretaceous Niobrara Formation at depths ranging from 900 to 3,200 ft (275 to 975 m). The chalk reservoir is comprised dominantly of coccolith plates, and is 85 to 95% calcite. Accumulations are normally on low-relief anticlinal and faulted anticlinal closures. The wells are stimulated with a foam fracturing treatment and will deliver from 20 to 500 MCFGD. The estimated recovery per well is normally 100 to 500 mmcf and a few exceptionally good wells should recover more than 1,000 mmcf. Cumulative production from the Niobrara wells through 1982 is 28 bcf. Ultimate production is estimated to be 320 bcf. Although Niobrara gas wells are small, the low cost of drilling and completion permits an attractive economic return for a small independent.