

(13,716 m) thick. It is believed that these sediments range from Pennsylvanian through middle Cretaceous. We project these Sonora trough marine sedimentary rocks to the northwest under the thrust plates exposed in southwestern Arizona.

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Depositional Setting of Middle Dolomite Unit in Metaline Formation, Metaline District, Washington

The middle dolomite unit of the Cambrian Metaline Formation in the Metaline district, Washington, was deposited in a low-energy, shallow-water environment. Deposition occurred as a complex mosaic of subtidal, intertidal, and supratidal environments in a restricted lagoonal and broad tidal-flat setting.

Where primary depositional features have not been masked by intense diagenesis, the middle dolomite unit is characterized by seven distinctive lithofacies. The vertical succession of these lithofacies differs from locality to locality and is laterally discontinuous. The seven lithofacies and interpreted depositional environments are: (1) black, birdseye dolomite, deposited in the supratidal zone; (2) cryptogalaminate dolobindstone, deposited in the upper intertidal and supratidal zones; (3) laminated, intraclastic dolofloatstone, deposited in the outer intertidal zone; (4) gray massive to mottled dolomite, deposited in the intertidal and subtidal zone; (5) intraclastic-oncolitic dolofloatstone, deposited as lag deposits in tidal-flat channels; (6) oncolitic dolofloatstone, deposited in shoal areas in the upper subtidal zone; and (7) lenticular-bedded dolomite, deposited in the subtidal zone.

Changes in lithofacies over narrow vertical ranges were due more to changing hydrographic and sediment-supply conditions than to numerous minor eustatic sea level changes. Through time, however, there was a gradual rise in sea level, and subtidal sediments became dominant in the upper middle dolomite unit.

The low-energy nature of the middle dolomite unit was the result of either a very long wave fetch, which extended across many kilometers of shallow water, or a remote barrier, which effectively reduced the hydrokinetic energy below that expected in open-marine conditions.

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Wamsutter Arch Tight Gas Play, Southern Wyoming—New Look at Old Area

Efficiently exploiting the natural gas from the Upper Cretaceous Mesaverde Formation in the Wamsutter area of southern Wyoming has depended on new applications of existing technology. An understanding of trapping conditions and reservoir performance has required determination of reservoir rock types based on depositional environments and regional stratigraphy.

Two types of traps were discovered: (1) updip shalows of sandstones in the upper Almond and Ericson Formations, and (2) increased gas and water interfacial tension in the lower Almond Formation on the cooler updip flanks of the area.

Reservoir performance is strongly influenced by rock types and reservoir geometries. These are controlled by depositional environments which were determined early in the play by examination of slabbed cores. Productive sandstones were observed from the following environments: nearshore marine (upper Almond), high-energy fluvial (Ericson), and low-energy fluvial (lower Almond). Upper Almond sandstones have the best production because of generally good pore geometry and great lateral continuity. Ericson sandstones produce at high rates in a few areas, but tend to produce water because of their great lateral extent. In contrast, lower Almond sandstones rarely produce water, but only flow gas at low rates due to their poor pore geometry and very limited extent.

Drilling plans, completion procedures, and formation evaluation methods all were influenced by the understanding gained from this integrated geologic and petrophysical study.

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Brae Field Area, North Sea

Several hydrocarbon accumulations were discovered between 1975 and 1977 in Block 16/7 in United Kingdom waters along the western edge of the Viking graben. By 1978, 13 exploratory wells were completed, and development planning focused on the southern part of the area.

The southern part of the Brae area is unique compared with other documented North Sea fields. An oil column of about 1,500 ft (457 m) is contained in Upper Jurassic conglomerate and sandstone shed off the Fladen Ground Spur as it was uplifted by faulting and as the Viking graben subsided. This major fault zone places Upper Jurassic against Devonian rocks and is the important seal along the west flank of the field. The cap rock and likely oil source are provided by the Upper Jurassic Kimmeridge Clay, which drapes a low anticline and dips eastward into the basin.

Stratigraphic changes within the reservoir interval are abrupt. The depositional setting is interpreted as coalescing fan deltas spilled into the basin from adjacent uplands. Conglomerate and sandstone were deposited mainly subaerially on fan-delta surfaces, whereas laterally adjacent siltstone was laid down as fringing marine foresets. Complex diagenetic events have overprinted these facies.

Other hydrocarbon accumulations similar in setting to the Brae field undoubtedly await discovery.

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Conodonts—Models of Pragmatic Paleontology

The composition, size, diversity, and distribution of conodonts make them unique and invaluable geologic tools. These marine apatitic microfossils that evolved and spread rapidly throughout the Paleozoic and Triassic undergo visible color changes from 50 to 500°C as a

result of organo-mineral metamorphism. Consequently, they are useful thermal indices, especially for carbonate rocks and cherts in which other organic and mineral indices are virtually absent. Because of their mineral composition, conodonts can be concentrated from a variety of sedimentary rocks (particularly limestone, dolomite, shale, and chert) and persist into low-grade metamorphic rocks (marble and metacarbonate interbedded with chlorite-, biotite-, and garnet-bearing pelitic rocks).

Relatively new applications for conodonts include: (1) dating of siliceous facies; (2) dating of low to medium-grade metamorphic rocks; (3) timing of thermal events; (4) assessment of hydrocarbon and mineral-resource potential; and (5) tectonic interpretation. New techniques for thermal assessment and age determination, such as autofluorescence and stable-isotope analysis, are being actively investigated by several workers. Conodonts are versatile tools that provide chronologic and thermal clues for interpretation of the geologic history and evaluation of the resource potential of Paleozoic and Triassic sedimentary and metasedimentary terranes throughout the world.

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Conodont-Based Assessment of Thermal Maturity in Paleozoic and Triassic Rocks, Central Great Basin

Conodonts (marine apatitic microfossils) are of organic origin and have biostratigraphic value. They are used as mineral thermal indices that undergo visible color changes between 50 and 500°C. Using these changes, color alteration index (CAI) maps were compiled for Ordovician through Triassic Systems in Nevada and adjacent parts of Idaho, Utah, and California using more than 5,000 samples. The maps show three thermal intervals which generally correspond to: (a) the thermal window for oil generation (CAI 1 to 2); (b) the upper thermal interval for gas generation (CAI 2 to 4.5); and (c) the thermal cutoff for most hydrocarbon generation (CAI >4.5).

The Great Basin is one of the most difficult areas in which to interpret thermal metamorphism in Paleozoic and Triassic rocks. Original burial metamorphic patterns are disrupted by thrust and normal faulting, masked by post-Triassic sedimentary and igneous rocks, and "overprinted" by post-Triassic thermal events. Nevertheless, maps show broad regional thermal patterns for Paleozoic and Triassic Systems which help delineate prospective areas for continued hydrocarbon and mineral exploration.

In general, Ordovician through Triassic rocks west of 117°30'W longitude and most Ordovician through Pennsylvanian rocks north of 41°30'N latitude and west of 113°W longitude and in the Oquirrh basin have CAI values >4.5 and appear to be unfavorable targets for hydrocarbon exploration.

Ordovician through Triassic rocks in central Nevada and Millard County, Utah, have regional moderate to low CAI values. This area, which includes the only two producing oil fields in Nevada, should provide a variety

of hydrocarbon exploration targets. The Paleozoic and Triassic rocks of the Overthrust belt of southeast Idaho and Utah predictably have low to moderate CAI values.

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Cretaceous Sea Level and Stratigraphy, Eastern Arabian Peninsula

The stratigraphy of the eastern Arabian Peninsula should accurately record Cretaceous sea level changes owing to long-term regional tectonic quiescence and carbonate platform deposition. The setting is thus not dependent on coastal or shelf-edge processes. We have constructed from well studies and numerous published sources a regional sea level curve for the Cretaceous using paleobathymetric relations within precisely dated stratigraphic sequences adjusted for isostatic response to sea level motion. The isostatic response for any section encountered in a well can be calibrated by constructing a depth/burial curve which is corrected for compaction, sediment loading, thermal cooling, and tectonic subsidence.

The Cretaceous of the eastern Arabian Peninsula is comprised of three lithic sequences bounded by four regional unconformities. The lithic sequences are: the Lower Cretaceous Thammama Group, shallow-water carbonate rocks; the middle Cretaceous Wasia Group, shallow-water carbonate rocks; and the Upper Cretaceous Aruma Group, deep-water shales changing laterally into shallow-water limestones. The unconformities, agreeing closely with eustatic sea level lows, occur during: the latest Jurassic/earliest Cretaceous, the middle Aptian, the late Cenomanian-Turonian, and the latest Cretaceous/earliest Paleocene. The Turonian exposure was reinforced by regional tectonic upwarp. Low stands of less magnitude occur during the Barremian, late middle Albian, and middle Cenomanian. A Valanginian unconformity, recognized in the stratigraphic sequence of eastern Saudi Arabia, does not appear to be regional in extent. In the Upper Cretaceous (Coniacian-late Campanian), the effect of regional tectonic subsidence on the sedimentary facies overshadows the general eustatic high stand.

Our examination of carbonate provinces elsewhere indicate that the major unconformities are not localized and therefore probably represent global eustatic sea level lows.

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Freshwater Cementation of Holocene and Jurassic Grainstones

Freshwater cementation of Holocene sands in the Bahamas provides a modern analog to enhance our understanding of some cements in Jurassic grainstones of southern Arkansas. The Joulter's Cays, three late Holocene islands on Great Bahama Bank, formed when ooid sands were subaerially exposed and lithified by freshwater cements. Cement fabric above the standing water table (vadose zone) and below (phreatic zone) is strikingly different. Vadose cements, characterized by