stitial clay, and generally lower oil saturations than the thinly interbedded sand and shale. The cross-bedded sands contain the highest oil saturations and form the largest and most continuous reservoir. Oil saturations are commonly lower in the marine sands of the Bluesky Formation where glauconite, clastic carbonate, and local carbonate cement combine to reduce porosity and permeability.

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Paleocene (Midway) Continental Shelf Deposits, Rio Grande Embayment, Texas

The Midway Group has been considered a monotonous section of marine shale which was deposited on the continental shelf during the initial Cenozoic transgression. However, recent studies show the Midway to be a complex group of sediments deposited in environments ranging from deltaic to bathyal.

Sedimentary rocks of the Midway Group crop out along the northern and western edges of the Rio Grand embayment. Siltstones deposited as a beach occur in the northwest corner of the Rio Grande embayment in Uvalde County, Texas. To the east and south, richly fossiliferous carbonate rocks indicate a nearshore shallow-marine environment. Basinward, the Midway Group grades into shale deposited on the shallow continental shelf. Sandstones, up to 10 ft (3 m) thick, occur intermittently throughout the shale. These shallow-marine sands are most likely derived by longshore currents paralleling the coast.

Sandstone in the Midway is increasingly abundant toward the shelf edge near Laredo, Texas. The sand was probably deposited as barrier islands and shallow-marine shelf sands. The source of the sand was probably to the east. Significant quantities of gas have been discovered in these sandstones near Laredo in both the United States and Mexico.

Recent gas discoveries have been made in the Midway rocks of eastern Texas which were deposited in deltaic to bathyal environments. It appears that a delta prograded over the shallow continental shelf, and sediments were deposited on the shelf edge and upper slope. Sands from the delta complex were probably carried by longshore currents to the south and deposited near the shelf edge in the vicinity of Laredo.

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Two Controls of Sand-Wave Size: Dynamic Equilibrium Processes and Kinematic Depositional-Erosional Processes

Studies in flumes and estuaries have shown that the average size of dunes or sand waves in equilibrium with the flow that generated them is controlled primarily by flow velocity, depth, and sediment size. Equilibrium sand-wave height and wavelength increases with flow velocity, for a constant depth and sediment size, until flows become transitional with the upper flat-bed phase.

Additional non-equilibrium processes operate at a site of deposition. Sand is deposited on lee slopes of sand waves more rapidly than it is eroded from stoss slopes. The balance of the sand, that part deposited at the base of lee slopes but not subsequently eroded at the upstream stoss slopes, is left behind. Bed forms decrease in size as sand is thus removed from circulation unless either (1) sediment transported in suspension from outside the depositional area is trapped by sand waves as rapidly as sediment is removed, or (2) sand waves merge to form larger ones.

Sand waves in nonequilibrium flows, where neither of these two processes operates, should show a change in cross-sectional area proportional to the change in the sediment-transport rate. Sand-wave cross-sectional area is observed to be proportional to the sediment-transport rate raised to a power of 0.5 to 2 in equilibrium flows that are not transitional with upper flat beds, and where depth and sediment size are constant. Consequently, where depth is constant, both equilibrium and nonequilibrium processes tend to keep sand-wave cross-sectional area approximately proportional to sediment-transport rates. Where depth changes downcurrent, the two processes may conflict, and the response of the bed will have to be determined experimentally.

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Mechanisms Controlling Porosity in Red River (Upper Ordovician) Carbonate Reservoir, Cabin Creek Field, Montana

Cabin Creek field, on the Cedar Creek anticline in southeastern Montana, produces oil from Mississippian, Silurian, and Ordovician carbonate rocks. The major producing reservoir is the Upper Ordovician Red River Formation.

The Red River of Cabin Creek field is a 500-ft (152 m) thick limestone-dolomite sequence; the upper Red River consists of several cycles of uniformly thick peritidal shelf carbonate rocks. Favorable porosity is restricted to the dolomites; the limestones are nonporous and serve as cap rocks. Porosity and permeability are controlled both by dolomitization and by silica and anhydrite cements. Lateral and vertical variations of dolomitization are mainly responsible for variations in reservoir properties and effective pay thickness. Average porosity is 13%, with a maximum of 25%. Production is from porosity zones in the upper 150 ft (45 m) of the Red River.

Upper Red River limestones consist of biomicrite-wackestones which contain diverse faunal assemblages, and are interpreted as shallow, open-marine shelf deposits. The limestones are pelletal in part, poorly bedded, burrowed, stylolitic, with widespread dolomitic mottling. Producing dolomite zones consist of two distinct facies. The lower facies, interpreted as subtidal, consists of biomicrite-wackestone and skeletal dolomite with moldic porosity. The upper facies, interpreted as intertidal, consists of wavy-laminated, unfossiliferous, microcrystalline dolomite with intercrystalline porosity. The upper facies is abruptly truncated by overlying pelletal limestone and (locally) thin black shale. Conglomerates commonly top the upper facies. In general, producing-zone porosity increases upward from subtidal to intertidal.

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Seismic Models of 15 Stratigraphically Controlled Oil and Gas Fields Containing Sandstone Reservoirs in Rocky Mountain Basins

Two-dimensional, normal-incidence, ray-theory seismic models were generated for 15 stratigraphic traps which have accumulated oil and gas in the Rocky Mountain province. The investigation is a feasibility study to determine the seismic character of moderate-sized (6-30 m thick), lenticular sandstone reservoirs in Rocky Mountain basins. The models are noise free and do not include all the complexities of the seismic phenomenon, but they do provide a reasonable indication of the anomaly to be expected for a specific problem and the quality of seismic data required to solve it. The fields chosen for the model studies represent different kinds of stratigraphic traps, and the reservoirs range in age from Late Pennsylvanian to Late Cretaceous. The fields include nine from the Powder River basin, three from the Denver basin, two from the Green River basin, and one from the San Juan basin.

Each seismic model was constructed from a detailed geologic cross section and typically consists of 30 layers and several hundred velocity and density values. Effects of inelastic attenuation, interbed multiples and diffractions, are not incorporated in these seismic models. Hydrocarbon effects should be partly represented through the response of acoustic and density logs from which the models were derived. Final synthetic seismic sections are displayed with symmetrical Ricker wavelets at three different frequencies.

Many of the 15 fields investigated appear to be detectable on conventional seismic sections, although several of the anomalies are very subtle. The seismic expression of the objectives modeled are manifested by amplitude changes due to acoustic contrasts at stratigraphic boundaries, or to constructive interference of waveforms.

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Middle Member of Minnelusa Formation (Middle and Upper Pennsylvanian)—Implications for Stratigraphic-Trap Oil Accumulations in Powder River Basin, Wyoming

The middle member of the Minnelusa Formation (Middle to Upper Pennsylvanian) thins northward across the Powder River basin from about 150 m thick in the Hartville uplift to less than 50 m near the Wyoming-Montana border. Much of the thinning occurs beneath a regional, pre-Permian unconformity, which is identified in the south half of the basin by a mudstone commonly identified as the red shale marker.

Cyclically arranged units up to 10 m thick, composed in ascending order of black organic-rich shale, mud-supported dolomite, anhydrite, and quartzose sandstone, characterize most of the middle Minnelusa. The majority of the sandstone units (informally designated in the subsurface as the Leo sandstones) are less than 3 m thick, tabular shaped, and commonly cemented with anhydrite and dolomite. Locally, however, the sandstones, particularly in the first Leo interval, are lenticular and linear, very porous, and attain thicknesses of more than 15 m. Several of these 10 to 15-m thick, linear first Leo sandstone bodies trend northwest across the southern Powder River basin. They probably represent wadi-type channels that have cut across sabkha and associated peritidal deposits during low stands of sea level. The source of the Leo sandstones is presently uncertain, but at least the lowermost ones appear to be distal equivalents of the Tensleep Sandstone (Desmoinesian) to the northwest.

Where the thicker sandstone units of the first Leo cross anticlinal noses such as at Red Bird, Pine Lodge, and Little Buck Creek, they commonly contain stratigraphically trapped oil. The oil in these fields was probably locally derived from the thin (0.5 to 2 m), widespread, black organic-rich shale units in the middle member. The lenticularity, proposed northwest trend, thickness, porosity, and associated probable source rocks make these sandstone units prime targets for oil and gas exploration in the sparsely tested, deep, southern Powder River basin.

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Physical Evidence for Cretaceous Tides, Western Interior Basin, North America

Shallow-marine and marginal-marine sandstone bodies constitute important reservoirs for oil and gas in the Western Interior. The geometries and physical characteristics of these bodies reflect the hydrographic regimes of their paleoenvironmental settings.

Tidal range is a primary determinant of hydrographic regime and is, therefore, an important factor in paleoenvironmental reconstruction and in delineation of exploration targets. Two opposed models exist for tidal patterns in epeiric seas: (1) tidal ranges were small, with the amplitude of the tidal wave generally decreasing away from apertures with the oceans; and (2) tidal ranges were large, the tidal wave being amplified with increasing distance from the apertures and attaining maximum amplitudes in the interior parts of the seas. A variety of evidence indicates that the second model is more applicable to the interior Cretaceous seaway. In the Western Interior Cretaceous, features that indicate tides include tidal inlets, tidally influenced reaches of river systems, tidal flats, linear sand bars, and thick foreshore sequences. These paleoenvironments are characterized by suites of physical and biogenic structures. The distribution of these features indicates that tides were present throughout the interior Cretaceous seaway. Microtidal conditions prevailed in the area of its connection with the proto-Caribbean. Tidal range increased northward along the western shoreline, attaining mesotidal amplitudes in Wyoming, in Montana, and probably in southern Alberta. Tidal patterns farther to the north cannot be discerned on the basis of physical evidence. The east-