found in a porous limestone unit in the middle of the Lower member. Due to limited control, no precise areas for stratigraphic traps are delineated; but all closed anticlines, especially in the southeastern Powder River Basin, should be tested through the limestone and the basal sandstone units.

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Stratigraphy and Conditions Governing Petroleum Occurrence in Lower Cretaceous Rocks, Rocky Mountain Region

Lower Cretaceous stratigraphy of the Rocky Mountain region is complicated by problems of nomenclature, lateral extent, correlation, and age variation of the Dakota group. Lower members of the Dakota group have three different relationships to the underlying Morrison formation: (1) in some areas the basal units were deposited in channels and are unconformable on the Morrison; (2) in many areas the basal units have an intertonguing facies relationship with the upper Morrison, and, (3) a regional unconformity at the base of the Dakota group is developed only in the Great Plains region.

Regional time lines are necessary for an understanding of facies relations. Marine Jurassic formations define an approximate time line at the base of the Morrison in the northern part of the Rocky Mountain region. The Todilto limestone forms an approximate time line in the San Juan basin, but it can not be related precisely to the marine formations farther north. In the northern part of the region the boundary between the Upper Cretaceous and the Lower Cretaceous is placed at the top of the Mowry shale which is marked by the Clay Spur bentonite bed, an excellent time horizon. The marker bentonite of the Denver basin ("X" bentonite), 100–300 feet above the Mowry shale, can be traced throughout the Powder River basin of Wyoming where it marks the base of the Greenhorn faunal zone (Upper Cretaceous). The "X" bentonite bed, and in its absence, the base of the Greenhorn limestone form an excellent time line.

Sediments of the Dakota group were deposited in a sea that advanced from the north and thus these basal sediments become younger in easterly, southerly, and westerly directions. Marine shales of the Thermopolis and overlying Mowry and Graneros formations of Wyoming and Montana were deposited contemporaneously with sandstones of the Dakota group farther south. The lower part of the Dakota group of Wyoming and Montana was deposited contemporaneously with upper Morrison sediments on the south. Over most of the Rocky Mountain region the Dakota group is Lower Cretaceous, but in deposits just south of the San Juan basin the upper part is as young as the Greenhorn limestone, a relation similar to that found in eastern Nebraska, at the type locality, where the Dakota sandstone is largely, if not entirely, Upper Cretaceous.

In Wyoming and Montana, sandstones of the lower Dakota group (Lakota, Fall River, Dakota, Cloverly, Cat Creek, and upper Morrison) produce oil in areas where distinctive, linear, thick sandstones are developed and are notably unproductive in areas of patchy, heterogeneous sand development. In eastern Colorado, the lower part of the Dakota group (Dakota, Lytle, "M", "O", "R", and "T" sandstones) is essentially non-productive. Significant oil production in the Dakota sandstone of western Colorado and the San Juan basin is found in areas characterized by linear sandstone development.

"D" and "J" sandstones of the Denver basin produce petroleum from stratigraphic traps and the southeast limit of significant production coincides with the zero isopach of the Mowry shale. Oil production in the Muddy and Newcastle sandstones of Wyoming (equivalents of lower "J") is stratigraphically trapped in or near linear sandstone trends. Structural entrapments are present where linear trends cross structural highs.

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Geometry of Oil and Gas Accumulations Associated with Edmonton Reef Chain, Central Alberta

The absence of large-scale tectonic disturbances along the eastern flank of the Alberta syncline has made the search for structurally entrapped oil and gas deposits rather minor in comparison with the stratigraphically entrapped deposits. Closed structures occur, but the controlling factors for the closed anomalies lie in draping. Draping is over reef buildups, residual topography on surfaces of unconformity, and structural noses along ancient tectonic trends.

Oil and gas fields along the Edmonton reef chain provide examples of many complex stratigraphic relations which in turn control the entrapment of hydrocarbons. The principal trap along the trend is the carbonate buildup of the Devonian reef entirely enclosed by shale. The geometry of the oil and gas accumulations in the reefs simulates the normal fluid segregations found in simple anticlinal traps. Differential compaction of overlying sediments above the reef massifs causes draping in the overlying sediments and supratenuous anticlines are formed somewhat symmetrically with the reef body. Such features enable seismic exploration to delineate the reef trends, even though seismic records give poor reflections from the reef massifs themselves. Subreef structural relations are unknown at present because of lack of deeper drilling.

The structural closures in the sediments above the reefs account for another type of trap for oil and gas. The Devonian Nisku and Wabamun carbonates, the Cretaceous Basal Quartz and Viking sandstones, and in several places the Cretaceous Cardium sandstone contain oil and gas accumulations with geometry of fluid segregations similar to that found in anticlinal closures. It must be pointed out, however, that in many places, porosity-permeability conditions in these reservoirs modify the geometry of the fluid accumulations to a great degree.

A third type of trap results from erratic porosity development related to the effect of buried highs on subsequent sedimentation. In several places improved porosity conditions in the Devonian Nisku formation account for the extension of oil accumulation some distance beyond the structural closures above the reef massifs. The development of thicker, more porous sands can be found in the Cretaceous Basal Quartz above the inter-reef channels. Some old topographic depressions in the unconformity surface between the Paleozoics and Cretaceous are filled with porous sand lenses in the Basal Quartz sequence.

A fourth type of trap is found in the truncated edge of several Mississippian units. Accumulations of oil and gas are found in porous Rundle carbonates as their regional updip termination crosses the Edmonton reef chain.

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Application of Nuclear Explosives in Exploitation of Underground Resources

The Rainier detonation of 1957 and the underground detonations of October, 1958, produced phenomena of heat, fracturing, and melting which have possible application to mineral and petroleum production. Such effects may be particularly applicable to oil sands and oil shales.

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Overthrust Faulting and Paleozoic Gas Prospects in Montana's Disturbed Belt

The Disturbed belt of Montana lies on the hinge-line between the Central Stable platform on the east and the Rocky Mountain geosyncline on the west. It lies west of the Sweetgrass arch and includes the Rocky Mountain front ranges of western Montana. The Disturbed belt is characterized by a zone of overthrust faulting and folding extending from the Missouri River northward into Canada. Some of the largest gas and distillate reserves in North America have been found in one or more thrust sheets of Mississippian rocks in Canada at Pincher Creek and Waterton Lake and a recent gas discovery was completed in the Devonian formation at Castle River. Northern Natural Gas Company's recent Mississippian gas discovery in Sec. 13, T. 26 N., R. 8 W., may be the first evidence that such accumulations are also present in Montana's Disturbed belt.

Unconformities between the Cambrian and Devonian and between the Mississippian and Jurassic are evidence that the area was tectonically active during Paleozoic time and isopachs of the Jurassic and Cretaceous formations indicate that this activity continued intermittently throughout Mesozoic time. The characteristic overthrust faulting from the west is the result of the Laramide orogeny of early Tertiary time.

The structure of Montana's Disturbed belt is divisible into three layers each younger in age: (1) a regional layer of relatively undeformed rocks comprising the west flank of the Sweetgrass arch over which the high-angle thrust layer has ridden; (2) a high-angle thrust layer of complex faulting and drag folds typical of the Disturbed belt structures; and (3) a low-angle thrust layer, commonly known as the Lewis overthrust, which overrode the high-angle thrust layer. Subsequent high-angle block faulting has added further complexity to the structures.

Three types of traps similar to those of the Canadian Disturbed belt are present: (1) fault traps on the wedge-edge of the Paleozoic thrust sheets; (2) drag folds formed as the result of thrusting; and (3) folds occurring west of the zone of drag folding as typified at Savannah Creek in Alberta. The Northern Natural Gas Company's Mississippian discovery at Blackleaf Creek is of the wedge-edge type.

Structural interpretation of this area is difficult and drilling costs are high. Therefore, much money will have to be spent before the economic possibilities of the hydrocarbons in Montana's Disturbed belt have been adequately evaluated.

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Fractures in Sedimentary Rocks

The most abundant kind of deformation of rocks is by fracturing. There are three principal classes of fractures—(1) joints, (2) faults, and (3) small, irregular breaks (including shatter and breccia zones). In general, joints may be defined as more or less regular groups of relatively long fractures that are paralleled by little or no displacement or orientation of rock components.

Joints occur in sets that may be parallel, radiate, or concentric. Sets occur singly or severally and with no universality of systems. The angular relations of intersecting sets range from sharply acute