most extensively exposed plate of Oquirrh strata (Pennsylvanian and Permian) with Manning Canyon Shale (Mississippian and Pennsylvanian) at its base lies discordantly on middle Paleozoic units and extends from the Albion Range 100 km east to the Bannock Range. (2) A middle plate of mainly Ordovician to Middle Cambrian strata lies on upper Precambrian quartzite and argillite of the Brigham Group in the Bannock Range between Pocatello and Utah. Ordovician strata in the Raft River and Albion Ranges lie on schist and quartzite of unknown age. (3) A lower plate of mainly upper Precambrian (Mutual and Camelback Mountain) quartzite in the Bannock Range overlies Precambrian rocks of the Scout Mountain Member of the Pocatello Formation, 3 km lower in the stratigraphic sequence. The middle plate locally overlaps the lower, placing Ordovician limestone directly on Scout Mountain strata. Scout Mountain rocks are more intensely sheared, mylonitized, and metamorphosed (greenschist) than any east of the Raft River Range, which poses the problem of whether they are autochthonous.

Prolific Mesozoic hydrocarbon reservoirs of the foreland belt are thus unlikely to be encountered by drilling farther west. Moreover, these thrust plates are cut by younger basin-and-range faults that have enormous apparent stratigraphic throws, further complicating local structure and hydrodynamic history. Reported moderate to high paleotemperatures reflect a complex thermal history with undefined implications for maturation. Nevertheless, regional stratigraphic relations suggest the presence of Paleozoic hydrocarbon source beds and reservoirs, although exploration will be difficult.

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Sedimentary and Tectonic Controls of Uranium Mineralization in Morrison Formation (Upper Jurassic) of South-Central Utah

Sedimentologic studies in the Henry basin of south-central Utah indicate that uranium deposits in sandstones of the Morrison Formation are related to the depositional environment in which the host sandstone bed and nearby mudstones were deposited and to the tectonic setting at the time of deposition. Thus, an understanding of environments of deposition and contemporaneous tectonism may be helpful exploration guides for uranium deposits in sandstones.

Discontinuous tabular uranium orebodies are present in fluvial and marginal lacustrine sandstone beds that lie just above, below, or a short lateral distance from offshore lacustrine gray mudstone beds. The mudstones are present only in the distal part of the lowermost alluvial-plain sequence of the Morrison where fluvial energy regimes and rates of sedimentation were low, allowing lakes to form while the Henry basin was slowly subsiding. The lakes were restricted to the east side of the basin where the least amount of clastic sedimentation by streams occurred. Palynomorphs, carbonized plant debris, and scarce pyrite in the mudstones indicate that the lakes were sufficiently persistent and deep during most of their lifetimes for reducing conditions to persist in the offshore muds. They also indicate that the mudstones were originally gray and are not bleached red mudstones. The gray mudstones are not present in other alluvial-plain sequences of the Morrison because little or no basin subsidence occurred after deposition of the lowermost sequence.

Plant debris and palynomorphs in the gray lacustrine mudstones suggest deposition in humus-producing lakes in which humic and fulvic acids (degradation products of plant tissues) were generated in the lake sediments. The close spatial association of the ore-bearing sandstones and the gray mudstones suggests that pore fluids containing these organic acids were expelled by compaction or seepage from the mudstones into nearby sandstones where they were fixed as tabular humate deposits. Subsequently, uranium in groundwater passing through the sandstone was concentrated by the humate to form the ore deposits.

Gray mudstones which cannot be used as exploration guides are bleached red mudstones and primary gray mudstones containing the alga *Botryococcus*. Sandstone beds adjacent to these gray mudstones are barren of uranium because (1) the gray color in bleached red mudstones is an alteration feature and does not indicate primary reducing conditions, and (2) *Botryococcus* thrives in humus-free lakes whereas humus-producing lakes are considered necessary to form ore deposits.

Thus, the requisites for mineralization appear to have been active crustal downwarping to cause ponding of fluvial sediments, and formation of humus-producing lakes on the alluvial plain, in the most sediment-starved part of the area undergoing basinal downwarping.

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Stratigraphy of Lacustrine Deposits

The major stratigraphic aspects of lacustrine rock units are geometry (thickness and lateral extent), facies patterns, and vertical sequence. Sizes and shapes of modern lakes show wide ranges, but many large ones are subcircular to elongate. In cross section most thick lacustrine units are broadly lenticular with maximum thickness near the center of the basin where subsidence is greatest.

Bottom sediments of modern lakes encompass a wide variety of lithofacies. If clastic sediments dominate, there may be concentric belts of gravel, sand, sandy marly mud, and mud, which are controlled by wave base and overall energy gradients. Facies patterns in chemical and organic sediments are not so easily predicted. However, two carbonate models are recognized, one with increasing carbonate content toward the center of the lake and the other with higher carbonate concentrations near the margins. The former results from nearshore dilution by terrigenous sediment and the latter from greater carbonate productivity in shallower water. Similarly, two organic facies patterns predominate. Offshore increase in organic matter results from deposition and preferred preservation below wave base. In contrast, nearshore concentrations of organic matter are mostly caused by in-place accumulations of organic remains.

Few ancient lacustrine sequences are either sufficiently well preserved or studied in sufficient detail for construction of even general facies maps. One obvious exception is the Green River Formation of Paleocene(?) to Eocene age, the most extensively studied lacustrine rock unit in the world. In the Green River Formation, the general facies pattern in northeast Utah and northwest Colorado is one of marginal coarse clastics and centralized organic-rich mudstone; a general basinward increase in carbonate rock is also notable.

Most lakes pass through more than one cycle of expansion and retreat. The resulting vertical sequence is a composite of many complete and incomplete cycles.

Lacustrine rocks display a variety of allocyclic sequences: glacial and nonglacial varves, transgressive-regressive cycles, and various composite groupings represented by bundles of varves or other cyclic deposits.

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## Evidence for Two Major Cycles of Petroleum Generation in Mississippian Chainman Shale of East-Central Nevada

Marine Chainman Shale from drill cores in Railroad Valley and from outcrops in several mountain ranges of east-central Nevada contains a mixture of marine-sapropel and detrital terrestrial-plant organic matter. The organic matter ranges from immature to supermature in thermochemical evolution as indicated by organic geochemical data on kerogen and on hydrocarbon extracts and oil, by vitrinite reflectance, and by alteration colors of palynomorphs and conodonts. Hydrocarbon contents ($<30$ to 2,000 ppm) and organic-carbon contents ($<0.1$ to 7 weight %) vary widely. A discontinuity in thermochemical maturity has been identified between Paleozoic and Paleogene rocks in uplifted terranes, whereas a more continuous kerogen-maturation profile exists across the Paleozoic and Paleogene boundary where deeply buried beneath Neogene rocks. A two-cycle model of petroleum generation is proposed to account for these variations.

The first cycle of petroleum generation began probably in early Mesozoic time when the Chainman was buried beneath upper Paleozoic and lower Mesozoic rocks. Depth of burial and hence the degree of thermochemical maturation varied with late Paleozoic and Mesozoic folding, faulting, and erosion.

Organic matter in the Chainman is supermature in many localities where higher paleotemperatures were related to subcrustal hotspots or deeper burial. Analyses of surface and subsurface data indicate that although Chainman rocks were subjected to thermochemical degradation and generated some hydrocarbons in Mesozoic time—as evidenced by oil of varying viscosities trapped in fractures, voids, and invertebrate-fossil cavities in dense limestone concretions and beds—organic matter was not completely transformed into petroleum where buried at moderate depths. Uplift of buried Chainman Shale prior to the late Mesozoic arrested the first cycle of petroleum generation in thermochemically immature and mature rocks.

Many organically immature and mature Chainman rocks in this region are now undergoing a second cycle of thermochemical degradation and renewed oil generation in Neogene basins where adequate fill and temperature increase have occurred. Rocks of the Chainman Shale probably are a major source of petroleum in Railroad Valley where oil has accumulated in fractured, welded ash-flow tuffs of Oligocene age. Oil accumulations are inferred to occur in other valleys in eastern Nevada where similar geologic conditions exist.

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## Laramie-Hanna-Shirley Basins—Future Petroleum Potential

The Laramie-Hanna-Shirley basins are three contiguous intermontane basins between the Laramie (Front Range) Mountains and the Sierra Madre and Rawlins uplifts. All of the current major production was discovered prior to 1960. In the last 4 years only 20 wildcats have been drilled in the area, which includes approximately 5,000 sq mi (13,000 sq km).

Hydrocarbon production in these basins is primarily from the Muddy, Cloverly, Sundance, and Tensleep. Lesser amounts of production have been indicated from the Lewis, Mesa Verde, Steele, and Frontier. All of the production in the area, with the exception of one field, is associated with surface and subsurface anomalies. In areas where the Cretaceous and Jurassic are productive, stratigraphic traps are usually associated with these anomalies.

Subsurface and outcrop data indicate that the Laramie-Hanna-Shirley basins have potential for purely stratigraphic entrapment in Cretaceous and Jurassic units. Delineation of facies for these units has indicated areas of best potential for stratigraphic entrapment. In addition, potential exists in the Laramie-Hanna-Shirley basins for entrapment on structural anomalies which have not been tested to deeper objectives.

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## Bowdoin Dome Area, North-Central Montana—Example of Shallow Biogenic Gas Production from Low-Permeability Reservoirs

Natural gas is currently being produced from shallow, low-permeability, low-pressure reservoirs in the Bowdoin dome area, Phillips and Valley Counties, Montana. Most of the gas is stratigraphically entrapped in thin, discontinuous siltstones and sandstones that are enclosed in a thick sequence of shales of Late Cretaceous age. There is some structural influence on the accumulations in more porous zones. The reservoirs and the associated shales were deposited on a shallow marine shelf and thus present different mapping and recovery problems from most low-permeability reservoirs which are of nonmarine origin. The shales enclosing the reservoirs were the source of the early generated biogenic gas.

Natural gas was first discovered at Bowdoin in 1913