surface outcrops to the west. This interval is overlain by 410 ft (125 m) of red shale, siltstone, sandstone, and fossiliferous limestone that grades eastward into black organic shale and limestone. Capping the sequence is a 500-ft (152 m) interval of red shale, siltstone, sandstone, gypsum- and anhydrite-bearing dolomites and fossiliferous limestones that interfinger with typical Fountain coarse-grained terrigenous clastics.

This vertical succession of Fountain rocks in the subsurface suggests the following sequence of depositional systems from base to top: alluvial fan and braided alluvial plain, fan deltas, and small interfan embayments that grade eastward into a normal-salinity marine shoreface and an offshore hypersaline carbonate shelf. Normal salinity marine conditions were probably maintained in the parallic zone by the influx of ancestral Front Range runoff.

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Regional Significance of Mississippian Rocks at Pentagon Mountain, Lewis and Clark Range, Northwestern Montana

Pentagon Mountain exposes one of the best of the few sections of Mississippian rocks in the Lewis and Clark Range of northwestern Montana. This section consists of 225 m (738 ft) of marine carbonate rocks from which conodonts, ranging in age from earliest Osagean to early Meramecian, have been identified. Its stratigraphic base is well exposed, but the top has been eroded. Five units are recognized in this sequence, in ascending order: (1) phosphatized coarsely crinoidal and spiculitic wackestone, (2) dolomitic lime mudstone or wackestone, thinly interbedded with spiculitic biogenic chert, (3) partly dolomitized lime bioclastic wackestone showing much pressure-solution compaction, (4) partly dolomitized lime bioclastic packstone or wackestone, also showing much pressure-solution compaction, and (5) dolomitic mudstone.

The Mississippian sequence at Pentagon Mountain can be readily correlated lithologically, across the Lewis thrust system with Mississippian rocks that crop out to the east in the Sawtooth Range. This implies either that Mississippian units were originally widespread or that the magnitude of thrusting between the Mississippian rocks in the Lewis and Clark Range and those in the Sawtooth Range was insignificant. However, Mississippian rocks at Pentagon Mountain exhibit extreme pressure-solution compaction, which suggests greater stratigraphic or structural burial of these rocks than their Mississippian counterparts in the Sawtooth Range.

Secondary dolomite is pervasive in the lower part of the Mississippian section in the Lewis and Clark Range, and spectacular solution breccias locally disrupt the base of the section. These breccias and the adjacent dolomite are probably related, as both are thought to result from the passage of fluids through these rocks during Laramide uplift and/or post-Laramide erosion and extension.

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Morrow Fluvial and Deltaic Sandstones of Anadarko Basin in Southeastern and East-Central Colorado

Paleozoic sediments in southeastern and east-central Colorado were deposited in the northwest portion of the Anadarko basin. The primary hydrocarbon reservoirs are fluvial and/or deltaic sandstones that represent late regressive cycles of Morrowan sedimentation in the Anadarko basin. The associated transgressive cycles resulted in deposition of marine shales above and below the sandstones. These shales are the source rock in which oil was generated. Morrowan point bars, bar fingers, and the Keyes Formation are productive in the study area along with 11 other formations, both younger and older. Deeper objectives, such as the Arbuckle Limestone and Misner Sandstone, have had limited penetrations and were mostly off-structure tests.

The primary objectives of earlier wells in the area were the Mississippian reservoirs. Many of these wells were located on seismic highs or randomly drilled along the Las Animas arch. One reason that better oil production from Morrowan point bars was not found in earlier tests was a lack of understanding of the depositional history of the region.

The primary objectives of current wells being drilled in the area are the numerous Morrowan point bars, which are located by stratigraphic seismic methods along with a thorough understanding of the geologic framework in the study area. The point bars have excellent reservoir qualities, with porosities ranging from 18 to 22% and permeabilities as high as 5,500 md being reported. Point bars have been defined that cover over 3,000 ac and can be penetrated above 6,500 ft (1,981 m).

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Seam Profiling of Three Coals from Upper Cretaceous Menefee Formation near Durango, Colorado

Column samples of three separate coal seams from the Upper Cretaceous Menefee Formation near Durango were examined with reflected light and oil immersion to characterize the vertical variation in the coal petrography. In order to interpret the paleoenvironments of the coal, the macerals (microlithotypes) that make up the coal were identified and their association (whether they are in microbands or dispersed throughout), their physical condition (if they show signs of weathering or transportation), and their modal composition were observed.

The observed petrography indicates two main environments of deposition. Most of the microlithotypes are rich in vitrinite. This and the association and physical condition of the macerals indicate a terrestrial forest containing mainly woody plants and trees with a slightly fluctuating ground-water level. Less commonly, the microlithotypes have less vitrinite and more mineral matter, suggesting deposition in an open moor or deep water usually inhabited mainly by herbaceous plants. Macerals from both environments are weathered, suggesting infrequent dry periods or periods of lower water-table levels where the peat was exposed to subaerial oxidation.

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Cedar Hills Field, San Juan County, New Mexico: a Multi-Well Coal Degasification Project, San Juan Basin, New Mexico—a Case Study

Amoco Production Company is operating a multi-well coal degasification site, Cedar Hills field, in San Jaun County, New Mexico. Data presented here have been made available by Amoco at public hearings before the New Mexico Oil and Gas Commission.

The Cedar Hills field produces from the lowermost coal bed in the Cretaceous, Fruitland Formation, stratigraphically positioned above the Pictured Cliffs Sandstone. The coal bed reservoir is 18-20 ft (5-6 m) thick at a depth of 2,800 ft (853 m). The first well in this field was the Amoco 1 Cahn, completed in 1977 with an initial production of 200-300 MCFGD and 200-300 BWPD. These rates increased to 1.5 MMCFGD and 80 BWPD by January 1984. This well's production history exhibits a "negative" decline (incline) curve.

Gas analyses, water analyses, and reservoir pressure data strongly indicate that the 1 Cahn well is producing from the Fruitland coal bed rather than the Fruitland sandstones or underlying Pictured Cliffs Sandstone.

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Structural Geometry of Newly Defined Blacktail Salient of Montana Thrust Belt

Complexly imbricated Upper Devonian and Mississippian rocks in the northeastern Tendoy Mountains, Montana, form the previously unrecognized McKenzie thrust system, which is south of and structurally above the south-plunging Armstead anticline and north of the Tendoy thrust sheet. The northern margin of the McKenzie system, east of Garfield Canyon, displays a minimum of 4 mi (6 km) of eastward displacement. The southeastern margin is south of Kelmbeck Creek, near McKnight Canyon. The eastern edge of the system is buried under Quaternary to Late Cretaceous cover at or east of Red Rock Valley. East of the McKenzie system, the front of the Montana thrust belt extends north-northeast from Dell, Montana, to the eastern Blacktail Range, on the basis of unpublished mapping by J. C. Haley and W. C. Pecora, Jr. The convex eastward curvature of the thrust belt in this area, including the McKenzie thrust system, is herein designated the Blacktail salient.

Imbricates of the McKenzie thrust system comprise two duplex fault zones between Bell and McKenzie Canyons. The lower duplex involves a unique suite of platform to basinal Kinderhookian to lower Meramecian (Mississippian) carbonate rocks as well as Upper Devonian rocks. The floor thrust of this imbricate stack appears to lie within the Upper Devonian Three Forks Formation; the roof thrust lies within the middle Meramecian Kibbey Sandstone. The upper duplex involves Upper Mississippian rocks above the Kibbey Sandstone. Its roof thrust closely follows bedding near the top of the Mississippian sequence. The geometry of imbricate stacks within the McKenzie plate demands shortening of greater than 100%, resulting in at least 2 mi (3 km) additional eastward displacement of its trailing edge.

Recognition of the Blacktail salient with its complex structural patterns and unusual platform to basinal carbonate sequence provides new exploration targets in the southwestern part of the Montana thrust belt.

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Jurassic Crustal Deformation in West-Central Part of Colorado Plateau

Although the Jurassic Period is commonly thought of as a time of tectonic quiescence, updated isopach maps and new sedimentologic information indicate that it was a time of notable crustal deformation on the Colorado Plateau. A significant change in structural style occurred in Middle Jurassic time, especially during the erosion interval that produced the J-3 unconformity.

Prior to late Middle Jurassic time, the region had been tilted westward and structural troughs formed in the area of the present-day Circle Cliffs uplift and in the vicinity of the the Circle Cliffs and Black Mesa regions were uplifted and the nearby Henry and Kaiparowits regions began to be downwarped as troughs or basins. It cannot be determined if or how the present-day monoclines flexed during the Jurassic. However, the direction of structural tilt across these areas changed from west side down to east side down during the late Middle and early Late Jurassic. The Monument region, the largest and most persistent structural element in the region, changed from a structural bench to a positive structure in the early Late Jurassic.

In most cases the positive structures subsided more slowly than adjacent downwarps. Two exceptions during the Late Jurassic are the Black Mesa and Emery uplifts. These are the only uplifts that actually rose above the level of sediment accumulation.

Jurassic rocks are not known to contain significant hydrocarbon resources in this region, but their tectonic history may offer clues to the structural history of underlying Paleozoic strata, which are the primary hydrocarbon exploration targets.

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Subsurface Stratigraphy and Depositional History of Madison Limestone (Mississippian), Williston Basin

Cyclic carbonate-evaporite deposits of the Madison Limestone (Mississippian) in the Williston basin are made up of four main facies. From basin to shelf, the normal facies transition is from offshore deeper water (Lodgepole) facies to crinoidal-bioclastic banks at the basin to shelf transition, to oolite-algal banks and back-bank fine carbonate, evaporite, and minor terrigenous clastic beds on the shallow shelf. Five major depositional cycles are correlated and mapped on the basis of shaly marker beds identified on gamma-ray-neutron or gamma-ray-sonic logs. The marker beds are interpreted as reworked and redistributed silt and clay-size sediments originally deposited, possibly by eolian processes, on the emergent shelf during low sea level phases of cycle development. From oldest to youngest, the first two cycles are characterized by increasing amounts of crinoidal-bioclastic and oolite-algal carbonates, culminating in the Mission Canyon facies of the middle cycle. The upper two cycles are characterized by increasing amounts of evaporite deposits, culminating in the Charles salt facies of the youngest cycle.

Much of the Madison section on the south and east flanks of the basin consists of dolomite. Dolomite content decreased toward the basin center, where a major share of Madison petroleum production is located. Reservoir beds in the oil fields are primarily partially dolomitized oolite-algal or crinoidal-bioclastic bank carbonates. Most of the productive petroleum reservoirs are located in the middle cycles of the Madison.

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Regional Stratigraphy and General Petroleum Geology, Williston Basin

Paleozoic sedimentary rocks in the Northern Great Plains and northern Rocky Mountain region include a sequence of dominantly shallow-water marine carbonate, clastic, and evaporite deposits of Middle Cambrian through Early Permian age. The lower part of the Paleozoic section is a sequence of marine sandstone, shale, and minor limestone, ranging in age from Middle Cambrian through Middle Ordovician. Some porous sandstone beds occur in this section, mainly in the eastern and southern bordering areas of the Williston basin and Central Montana trough. Upper Ordovician through middle Upper Mississippian rocks are primarily carbonate beds, which contain numerous widespread cyclic interbeds of evaporite and fine-grained clastic deposits. Carbonate mounds or banks were deposited through most of this time in the shallow-water areas of the Williston basin and northern Rocky Mountains. Porous units, mainly dolomite or dolomitic limestone, are common but discontinuous in most of this sequence, and are more widespread in the eastern and southern margins of the Williston basin.

The upper Paleozoic beds are dominated by clastic rocks, beginning with the green and gray marine shales, marine carbonates, red beds, and some evaporites of the Upper Mississippian Big Snowy Group, and terminating with relatively thick marine and eolian sandstones and widespread red bed and evaporite facies of Pennsylvanian and Permian age. The Big Snowy Group is present only in the Central Montana trough and the central part of the Williston basin. Pennsylvanian and Permian beds, where present, unconformably overlie the Big Snowy Group, and overlie Mississippian or Devonian rocks in most of the remainder of the Northern Great Plains and northern Rocky Mountains, pinching out the Upper Pennsylvanian and Lower Permian section in Wyoming, southeastern Montana, northwestern South Dakota, and southwestern North Dakota.

Cumulative petroleum production (January 1982) in the United States part of the Williston basin was about 1.1 billion bbl of oil and 1.6 tcf gas. Estimated remaining recoverable reserves are about 400 million bbl of oil and 0.8 tcf gas. U.S. Geological Survey 1980 estimates of undiscovered recoverable oil and gas resources are about 900 million bbl of oil and 3.5 tcf gas.

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Influence of Preexisting Tectonic Trends on Geometries of Sevier Orogenic Belt and Its Foreland in Utah

The tectonic style of the late Mesozoic Sevier orogenic belt in Utah was greatly affected by preexisting structural trends that date from the late Precambrian rifting and fragmentation of the North American continent.

The late Precambrian cratonic margin (Cordilleran hinge line) was marked by a system of prominent faults including the north-south-trending ancestral Wasatch and ancient Ephraim faults and the southwest-northeast-trending Leamington, Scipio, Cove Fort, and Paragonah faults.

During the Paleozoic and Mesozoic, renewed activity on these faults affected the geometries of the late Paleozoic Paradox and Oquirrh basins, the boundaries of the Jurassic Arapien Formation, and the sedimentary pattern of the Cretaceous foreland basin.

Many of these fault zones were reactivated as tectonic ramps (e.g., the ancient Ephraim fault) and tear faults (e.g., the Leamington fault) during the compressional Sevier tectonism. The Fillmore arch and some other structural highs situated along the edge of the late Precambrian craton caused ramping of the inner Keystone-Pavant-Canyon thrust sheets and telescoping of the frontal thrust sheets.

Post-thrust uplift of basement highs led to tectonic denudation and to the development of low-angle, extensional faults, such as the Sevier detachment. Northeast-trending lineaments, such as the Cove Fort and Paragonah lineaments, were reactivated as right-lateral strike-slip faults. They also affected the extent of the Marysvale volcanic field.

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Computer-Assisted Reconstruction of Stratigraphic Framework of an Anderson Coal Deposit, Powder River Basin, Wyoming

The "Big George" coal bed, 30 mi (48 km) west of Gillette, Wyoming, is the thickest part of a large Anderson coal deposit. The coal resources of this central core, essentially a single bed of coal up to 202 ft (62 m) thick,