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.

PETERSON, FRED, U.S. Geol. Survey, Denver, CO

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.

PETERSON, JAMES A., U.S. Geol. Survey, Missoula, MT

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.

PETERSON, JAMES A., U.S. Geol. Survey, Univ. of Montana, Missoula, MT, and LAWRENCE M. MACCARY, U.S. Geol. Survey, Spokane, WA

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.

PICHA, FRANK, and RICHARD I. GIBSON, Gulf Oil Exploration and Production Co., Houston, TX

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.

PIERCE, FRANCES WAHL, and CAROL L. MOLNIA, U.S. Geol. Survey, Denver, CO

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, were previously estimated at 113 billion short tons. This deposit is in the Paleocene Tongue River Member of the Fort Union Formation; overburden ranges from 700 to 2,400 ft (213 to 732 m).

The "Big George" bed was initially outlined using geophysical logs from nearly 300 oil and gas drill holes. More logs were studied in the northern portion of "Big George" and as far north as the Montana state line to examine the entire system of coal beds that includes this thick bed. We interpreted geophysical logs primarily for coal and sandstone, digitized lithologic intervals, and generated strip logs of lithologic sequences using a microcomputer. These computer-generated logs were generated in lines of sections, on matching elevations, to reconstruct the stratigraphic framework of subsurface coal in this part of the Powder River basin.

The framework was used to trace the interval containing the Anderson deposit into the Decker, Montana, and Recluse, Wyoming, areas. This interval appears to be confined by the Smith coal bed above; the bottom of the interval is less well defined. Lithologic patterns of the framework suggest that a major fluvial channel system defined part of the northwestern boundary of the "Big George" coal bed. The locations of these channels may have been controlled primarily by Laramide deformation in the Powder River basin.

PILATZKE, R. H., Coastal Oil and Gas, Denver, CO, D. W. FISCHER, North Dakota Geol. Survey, Grand Forks, ND, and C. L. PILATZKE, Southport Exploration, Denver, CO

Stratigraphic Controls on Duperow Production in Williston Basin, Montana and North Dakota

There are presently over 200 wells in Montana and North Dakota that produce from, or have indicated pay, behind pipe in the Duperow Formation. Production is primarily confined to the basin center, decreasing greatly as the shallower rim of the basin is approached. There is no production from the Duperow Formation in the Canadian portion of the Williston basin.

Production in the Duperow Formation is primarily from dolomitized stromatoporoid-assemblage patch reefs that occur in the lower unit of the formation. Published work by others concisely defines the stratigraphy, paleontology, and facies subdivisions within the Duperow Formation. The formation consists of series of distinctive shoaling-upward carbonate sequences, and contains cyclic or repetitious bedding characteristic of the formation.

There appear to be three types of traps in the Duperow Formation reservoirs in the Williston basin. The structural type is most common on the Nesson anticline. The structural-stratigraphic type is the most common trap found in the Billings nose area. The unconformity-stratigraphic type is uncommon and found only at Seven Mile and Ollie fields in Montana.

The growth of stromatoporoid bioherms appears to have been influenced by tectonic activity. Many structurally positive areas, such as the Billings nose and the Nesson anticline in North Dakota and the Poplar dome and Sweetgrass arch in Montana, have stromatoporoid biohermal accumulations. These areas, probably slight topographic expressions during Duperow deposition, apparently offered optimum growth position for framework builders.

A stromatoporoid bioherm is interpreted to be the reservoir at Ridgelawn field, Montana. Eight wells appear to be capable of production from the basal portion of cycle 3. The wells appear to define a patch reef that is oriented northwest-southeast and is perhaps 1-1.5 mi (1.6-2.4 km) in its longest dimension.

PIRKLE, FREDRIC L., E. I. du Pont de Nemours, Starke, FL, and HARRY DEMBICKI, JR., Marathon Oil Co., Littleton, CO

Source-Potential Rating Index—Evaluation of Bakken Formation

The Bakken Formation, an organic-rich, oil-prone unit, is the source of the crude oils found in the middle Bakken and overlying Madison Group. Thickness, organic carbon, and vitrinite reflectance data for the Bakken were gathered from 101 wells within the Williston basin and evaluated in terms of source potential.

An index exists that combines sediment thickness, organic carbon content, and thermal maturity data into a single mappable parameter that indicates areas of potential hydrocarbon generation. Multiplying the average percent organic carbon by the effective source rock thickness of a formation yields a richness factor that is then multiplied by maturity scaling factors to give source potential ratings for oil and/or gas generation. By using burial-history curves and thermal-maturation modeling, the rating index can be used to look at source potential through geologic time. The Bakken Formation has been evaluated with the aid of the rating index.

The source-potential rating index provides objective semiquantitative measures by which the source potential of a single formation can be compared within an area or the source potential of two or more formations can be compared within the same or different basins. The Bakken did not begin to reach high source potential until toward the end of the Late Cretaceous. This contrasts with previous authorities who believed the Bakken was at peak generation and expelling hydrocarbons throughout the Cretaceous.

PITMAN, J. K., D. E. ANDERS, T. D. FOUCH, and D. J. NICHOLS, U.S. Geol. Survey, Denver, CO

Depositional Environments, Diagenesis, and Hydrocarbon Potential of Nonmarine Upper Cretaceous and Lower Tertiary rocks, Eastern Uinta Basin, Utah

Core studies of nonmarine rocks from the Natural Buttes field, Utah, indicate that depositional environment and diagenetic alteration control the geometry and quality of low-permeability gas reservoirs in the eastern part of the Uinta basin. The Tuscher Formation (Upper Cretaceous) is composed of fine to medium-grained, moderately to well-sorted sandstones and less abundant carbonaceous and coaly shale that formed on the lower part of an alluvial braidplain. The Wasatch Formation (Paleocene and Eocene) unconformably overlies Cretaceous rocks and consists of fine-grained lenticular cross-bedded sandstones, argillaceous siltstones, and variegated mudstones, which were deposited in lower deltaplain settings along the margin of Lake Uinta. Cretaceous and Tertiary sandstones have been modified by minor quartz overgrowths, by the precipitation and subsequent dissolution of ferroan and nonferroan calcite, by poikilotopic anhydrite, and by the formation of authigenic illite, mixed-layer illite-smectite, kaolinite, chlorite, and corrensite. Most authigenic carbonate and anhydrite formed during early burial, before significant compaction. During later stages of diagenesis, precipitation of authigenic clay in secondary pores created by carbonate dissolution reduced porosity and permeability. Large amounts of natural gas generated in situ are stratigraphically trapped in these lenticular, diagenetically modified sandstones. Source rocks in the Tuscher Formation have reached the advanced stages of thermogenic gas generation (0.7% R_0) but are only moderately mature with respect to liquid hydrocarbon generation. Interbeds of lacustrine Green River shale are in the early stages of gas generation (0.5% R_0) and are source rocks for gas produced from the Wasatch Formation.

PITMAN, JANET K., U. S. Geol. Survey, Denver, CO, and EVE S. SPRUNT, Mobil Oil, Dallas, TX

Origin and Distribution of Fractures in Tertiary and Cretaceous Rocks, Piceance Basin, Colorado, and Their Relation to Hydrocarbon Occurrence

Gas production in the lower Tertiary Wasatch Formation and Upper Cretaceous Mesaverde Group, Piceance basin, Colorado, is controlled by a network of open and partly mineralized natural fractures. These fractures formed in response to high pore-fluid pressures that developed during hydrocarbon generation, and to widespread tectonic stress associated with periods of uplift and erosion that occurred during the late Tertiary. Sandstone beds commonly contain vertical extension fractures that are cemented with fine to coarsely crystalline calcite and locally with quartz, barite, and dickite. These minerals cut detrital grains, authigenic cements, and secondary pores, indicating that fracture mineralization occurred during later stages of diagenesis. Isotopic compositions for fracture-fill calcite in the Wasatch vary from -5.0 ‰ to -11.6 ‰ for $\delta^{13}C$ and from -9.5 ‰ to -14.9 ‰ for $\delta^{18}O$. In the Mesaverde, calcite ranges from -0.7 ‰ to -10.4 ‰ for $\delta^{13}C$ and from -13.3 ‰ to -17.7 ‰ for $\delta^{18}O$. These isotopic data indicate that fractures were mineralized during burial by fluids of meteoric origin, with temperatures that remained fairly constant, or by fluids that circulated at a rate that