regression, and late Turonian and Coniacian transgression was modified in several areas by episodes of slight uplift and attendant erosion. The most evident tectonism was in western Montana during the middle to late Cenomanian (93-94 Ma), in western Wyoming and adjoining areas during the early Turonian to earliest middle Turonian (90-91 Ma), in north-central Colorado, eastern Wyoming, and northwestern Wyoming in the early late Turonian (89.8 Ma), and in northeastern Colorado, Wyoming, and southwestern Montana in the late late Turonian (89.3 Ma). Crestlines of most of the swells trend generally either northwest or northeast. The tectonism of the mid-Cretaceous foreland corresponds in age to displacements of thrusts in the Sevier orogenic belt of southwestern Wyoming and southeastern Idaho. Furthermore, much of the foreland deformation probably reflects episodes of eastward thrusting in the thrust belt.

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Thermal Maturity of Bowie Coals in Southern Portion of Piceance Basin, Colorado

Although the thermal maturity of coals is determined primarily by age and depth of burial, shallow Cretaceous coals in the Piceance basin of Colorado display anomalously high thermal maturities, indicating that age and present depth of burial are not adequate to explain their high thermal maturities. The objective of this study was to investigate the physical factors that may have contributed to the high thermal maturity of the Piceance basin coals. Vitrinite reflectance (R_0), which increases with coal rank and provides a quantitative index of thermal maturity, was used to measure the thermal maturity of the coals.

An examination of published R_0 data and R_0 analyses of coal samples from mines, outcrops, and well cuttings indicated that most of the thermal maturity of these coals is due to the thickness of overburden that covered the coals in Pliocene time. A plot of vitrinite reflectance versus reconstructed depth of burial during Pliocene time shows a reasonably good fit, however, some R_0 values are too high to be explained solely by depth of burial. A map of R_0 "residuals" was constructed using data obtained by subtracting predicted R_0 values from actual values. When compared with a geothermal gradient map, most of the positive R_0 residuals correlated with "hot spots" that were related to known igneous intrusives. Some anomalous hot spots may be related to unknown buried intrusives. A residual R_0 map, modified on the basis of the geothermal gradient map, was combined with the preliminary R_0 map (based on reconstructed Pliocene depth of burial) to show that the resultant R_0 is due to depth of burial and geothermal hot spots.

A final thermal maturity map was used to select areas in the Piceance basin that are most likely to contain thermally mature coals. The same procedure can be used to predict the thermal maturity of coals in other basins.

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Wall-Rock Alteration and Uranium Mineralization in Parts of Thomas Range Mining District, San Juan County, Utah, and Its Significance in Mineral Exploration

Several important uranium deposits associated with fluorspar and beryllium are located in parts of Thomas Range area. The mineralization is found in dolomites and dolomitic limestones of Paleozoic age and sandstones, tuffs, and rhyolites belonging to the Tertiary Spor Mountain and Topaz Mountain Formations.

The pipes, veins, and nodules of fluorspar are replaced by uranium. Veins and disseminations of radioactive fluorspar and opal and overgrowths of secondary minerals are found in rhyolites, tuffs, carbonate rocks, and breccias. The radioactivity in sandstones and conglomerates emanates from weeksite, beta-uranophane, zircon, gummite, etc. Uraninite occurs as rare inclusions in fluorite, gummite, and zircon. It also occurs as highly oxidized rare aphanitic grains disseminated in a few ore deposits. The results of the present investigations may influence the initiation of future exploration programs in the Thomas Range mining district.

Hydrothermal fluids of deep-seated magmatic origin rich in U, V, Th, Be, and F reacted with the country rocks. The nature and sequence of wall-rock alteration and its paragenetic relationship with the ores have been determined. The mineralization is confined to the altered zones. The ore bodies in the sedimentary rocks and the breccias are located in the fault zones. More than 1,000 faults are present in the area, greatly complicating mineral prospecting. The wall-rock alteration is very conspicuous and can be used as a valuable tool in mineral exploration.

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Permian Tectonism in Rocky Mountain Foreland and Its Importance in Exploration for Minnelusa and Lyons Sandstones

Permian sandstones are important producers of oil in the Powder River and Denver basins of the Rocky Mountain foreland region. In the Powder River basin, Wolfcampian Minnelusa Sandstone produces oil from structural and stratigraphic traps on both sides of the basin axis, whereas in the Denver basin, the Leonardian Lyons Sandstone produces oil mainly from structural traps on the west flank of the basin. Two fields, North Fork–Cellars Ranch in the Powder River basin, and Black Hollow in the Denver basin, are examples of Permian growth of structural features.

At North Fork–Cellars Ranch, a period of Permian structural growth and resultant differential sedimentation is documented by structure and isopach maps of the Minnelusa and overlying Goose Egg Formation. Structural growth began at the end of Minnelusa deposition and resulted in deposition of a much thicker Goose Egg section on the west flank of the field. At Black Hollow, mapping indicates structural growth was initiated before deposition of the Lyons Sandstone and continued throughout Leonardian time. In both fields growth abruptly ceased in the Late Permian.

Both North Fork–Cellars Ranch and Black Hollow are located on structural highs, or arches, which trend east-west across the Powder River and Denver basins. These arches were present during the pre-Laramide migration of Paleozoic-sourced hydrocarbons into the basins and acted as pathways for migration. Exploration for Permian reservoirs in the two basins should be concentrated on the arches, as the early formed traps were present when migration began.

MORIARTY, BRUCE, and ROBERT GRUNDY, Redstone Energy Corp., Denver, CO

Seismic Exploration for Pennsylvanian Algal Mounds, Paradox Basin

During the past 2 years, several new field discoveries were drilled in Pennsylvanian algal mounds of the Paradox basin. Most of these discoveries were based, at least partially, on state-of-the-art seismic data. New field production comes from either the Ismay or Desert Creek zones of the Paradox Formation. The algal mounds correlate laterally with either marine shelf or penesaline facies. Detection of the Ismay and Desert Creek buildups is difficult because of their limited thickness. Therefore, the acquisition of good signal-to-noise high-frequency data and stratigraphic processing for frequency enhancement are both critical for successful seismic exploration in the Paradox basin. Bug, Patterson, Ismay, Cache, and Rockwell Springs fields are characteristic of Desert Creek and Ismay stratigraphic trapping.

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Depositional Systems of Fountain Formation and Its Basinal Equivalents, Northwestern Denver Basin, Colorado

The objective of this study is to provide a better understanding of the depositional systems of the Pennsylvanian Fountain Formation in north-central Colorado. The study area is bounded by T4N, T11N, R66W, and R70W, encompassing portions of the foothills outcrop belt and the Denver basin.

The sedimentary sequence observed in surface exposures displays little vertical variation. It is composed of vertically stacked, fining-upward, gravel to siltstone and mudstone cycles containing trough and planar cross-beds, horizontal beds, root structures, and nodular limestone. This succession represents deposition in Donjek-type braided streams and abandoned channel-fill sequences, and the development of soil horizons on a subaerial alluvial fan or alluvial plain.

In the subsurface, the vertical succession begins with a basal coarse-grained 140-ft (43-m) thick interval that is identical on the rocks found in 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