zone that bows up the upper plate of the Keystone thrust. The Red Springs thrust is interpreted as the Keystone thrust, which was broken and differentially rotated during Neogene oroclinal bending associated with the Las Vegas shear zone. The structural relationships in the Spring Mountains do not require any Mesozoic or Cenozoic deformational episodes other than the well-known Sevier and basin-range events.

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Carboniferous Tectonics, Stratigraphy, and Mississippian-Pennsylvanian Boundary, Western Interior United States

Current proposals for the mid-Carboniferous boundary at the first occurrence of *Declinognathodus noduliferus* place this boundary within rocks previously considered Morrowan by many workers in the Western Interior. This placement is higher than that of the Mississippian-Pennsylvanian systemic boundary between the Big Snowy and Amsden Groups in Montana by E. K. Maughan and A. E. Roberts, which is approximately coincident with the transition from Foraminifera Zone 18 to 19 and the first occurrence of *Adetognathus unicornis* and *Rhachistognathus muricatur*, based on paleontologic identifications by B. R. Wardlaw. An episode of differential regional uplift in the west, which seems to have been coincident with a major mid-Carboniferous event during the Allegheny orogeny and continent-wide epeirogeny, interrupted the deposition of Mississippian dominantly carbonate sediments. It created a regional erosional unconformity, and it initiated the deposition of Pennsylvanian dominantly siliciclastic sediments. Uppermost Big Snowy strata indicate regression of the sea from the western continental shelf and weathering and erosion of rocks exposed there, coincident with the approximately 320 Ma global sea level decrease shown by P. R. Vail. Lowermost Amsden strata record alluviation in valleys on the subaerially exposed continental shelf, and subsequent transgression of the sea. Valleys in the shelf margin were inundated first, and the sea then transgressed onto the adjacent platforms and shelves. This lithostratigraphic placement of the boundary corresponds to the criteria originally indicated by T. C. Chamberlin and R. D. Salisbury in 1906 for dividing the Carboniferous in North America; this is the Mississippian-Pennsylvanian boundary indicated by M. G. Cheney in 1945 to correspond to the Namurian A-B boundary in western Europe. Also, this boundary is about coincident with the base of the Pennsylvanian System stratotype in Virginia and West Virginia proposed by K. J. Englund in 1979.

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Lineaments and Their Tectonic Implications in Rocky Mountains and Adjacent Plains Region

Two orthogonal sets of lineaments in Phanerozoic rocks of the Rocky Mountains and adjacent plains region probably reflect recurrent structural movement along corresponding fractures in the underlying igneous and metamorphic rocks. The lineaments seem to have been primarily paleotopographic features that affected the depositional and erosional margins, thicknesses, and the distribution of lithofacies of Phanerozoic strata. One set is oriented approximately N5-15°E and N75-85°W; the other set is oriented about N50-60°E and N30-40°W.

At small scales, the crosscutting lineaments of either set indicate primarily vertical movements of rectangular blocks along through-going rectilinear fractures in the basement rocks. At larger scales, the differential movement of these blocks apparently was propagated upward through the strata and formed a variety of structures, many of which are en echelon. Blocks in the region moved at different times, and they commonly rotated about horizontal axes, as indicated by lateral differences in rates of associated sedimentation and by structural features along the lineaments. Through most of the Phanerozoic, the movements seem to have been mainly along the diagonal set (northeast, northwest) of lineaments, but the cardinal set (north-south, east-west) also influenced the development of Laramide structures and the present landscape in the Rocky Mountain region. The structural stresses, which were released along the two sets of lineaments, may reflect plate movements, and they probably are related to orogenies caused either by plate collisions or by rifting and continental fragmentation.

MEISSNER, FRED F., Bird Oil Corp., Denver, CO

Pressure Cycles Related to Gas Generation in Coals and Their Relation to Deep Basin Gas Accumulations

Bedded humic coals generate, store, and expel large amounts of gas when they achieve ranks greater than those approximating a high-volatile A bituminous containing 37.8% volatile matter. Gas volumes generated in excess of temperature- and pressure-dependent storage capacity are expelled into nearby sandstone reservoirs. High-volume rates of generation and/or expulsion lead to associated high formation fluid pressures both in the coals and associated sandstones. Lowering of temperature may decrease the generation rate and increase the coal storage capacity resulting in reabsorption of previously generated gas from adjacent sandstones. Cooling-related reabsorption processes may contribute to the formation of fluid under-pressures. The generation-expulsion and cooling-reabsorption processes may cause pressure cycles within a basin that create and control both overpressured and underpressured "basin bottom" gas accumulations in complex and interrelated coal-bed and sandstone reservoirs. Examples of the phenomena are present in the Mesaverde Group of the Green River and San Juan basins, Wyoming and New Mexico.

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Regional Hydrocarbon Generation, Migration, and Accumulation Pattern of Cretaceous Strata, Powder River Basin

A "cell" of abnormally high fluid pressure in the deep part of the Powder River basin is centered in an area where oil-generation-prone source rocks in the Skull Creek (oldest), Mowry, and Niobrara (youngest) formations are presently at their maximum hydrocarbon-volume generation rate. The overpressures are believed to be caused by the high conversion rate of solid kerogen in the source rocks to an increased volume of potentially expellable fluid hydrocarbons. In this area, hydrocarbons appear to be the principal mobile fluid species present in reservoirs within or proximal to the actively generating source rocks.

Maximum generation pressures within the source rocks have caused vertical expulsion through a pressure-induced microfracture system and have charged the first available underlying and/or overlying sandstone carrier-reservoir bed. Hydrocarbons generated in the Skull Creek have been expelled downward into the Dakota Sandstone and upward into the Muddy Sandstone. Hydrocarbons generated in the Mowry have been expelled downward into the Muddy or upward into lower Frontier sandstones. Hydrocarbons generated in the Niobrara have been expelled downward into upper Frontier sandstones or upward into the first available overlying sandstone in the Upper Cretaceous. The first chargeable sandstone overlying the Niobrara, in ascending order, may be the (1) Shannon, (2) Sussex, (3) Parkman, (4) Teapot, or (5) Tekla, depending on the east limit of each sandstone with respect to vertical fracture migration through the Cody Shale from the underlying area of mature overpressured Niobrara source rocks.

Vertical charge into each of the various carrier-reservoir sandstone units from their related source rock has been followed by a process of dominantly lateral updip migration within the carrier-reservoir bed toward sites of entrapment. Purely updip migration paths have been modified by both stratigraphic complexity and ground-water hydrodynamic flow. Stratigraphic-type traps terminating migration paths predominate on the north flank of the basin. Anticlinal traps predominate on the western and southern flanks.

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Biostratigraphic Units and Tectonism in Mid-Cretaceous Foreland of Wyoming, Colorado, and Adjoining Areas

Chronolithologic units and unconformities in mid-Cretaceous formations of the central Rocky Mountains region indicate widespread marine transgressions and regressions as well as recurrent deformation of the foreland in the Western Interior during Cenomanian, Turonian, and Coniacian times (88-96 Ma). The stratigraphic record of the widely recognized Cenomanian and early Turonian transgression, middle Turonian 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.

MOORE, W. RICHARD, Independent, Denver, CO

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