CHENOWETH, WILLIAM L., Consultant, Grand Junction, CO

Uranium Exploration in 1970s and 1980s, Lessons for the Future

During the period 1974-83, the uranium industry spent $1.8 billion on domestic exploration, including 264 million ft of surface drilling. Exploration activities reached a high level in 1978-79, and have declined each year since. This effort was largely concentrated in the Colorado Plateau, Wyoming basins, and the south Texas coastal plain where ore deposits were located in the vicinity of producing mines. Significant new deposits also were found adjacent to producing areas, in inactive districts, and in frontier areas. Discoveries in nonsandstone environments in Canada, Australia, and Mexico gave impetus to exploration for similar deposits in the United States. The rapid decline in the uranium market caused many well-planned exploration programs to be cancelled just as they were getting under way. However, this past cycle of exploration has shown that (1) world class deposits exist in the Appalachians and in the Great Plains, (2) concepts of "mineral belts" are often oversimplified, (3) deposits in collapsed pipe structures are more widespread than originally thought, (4) large deposits can be found in old, inactive districts, and (5) nonsandstone environments throughout the United States appear to be attractive exploration targets. The large amount of geologic information now available from the Department of Energy's National Uranium Resource Evaluation Program, and from the other sources should aid in the development of geologic models before the next increased demand for uranium.

CLAYTON, JERRY L., and J. DAVID KING, U.S. Geol. Survey, Denver, CO

Three Oil Types in Paleozoic Rocks of Northern Denver Basin—Implications for Exploration

Analysis of 22 oil samples produced from Pennsylvanian and Permian rocks across the northern Denver basin revealed three genetically distinct oil types. One type is produced from the Permian Lyons Sandstone from fields located near the structural axis and along the west flank of the basin. This oil type is characterized by pristane-phytane ratios of less than 1.0 (average 0.8), $\delta^{13}C$ values of -28.5 to -29.1 ppt for saturated hydrocarbons, low relative amounts of n-alkanes, and absence of hopanoid biomarker compounds. The second oil type is produced from rocks of Virgilian and Wolfcampian ages in northeastern Colorado and southwestern Nebraska. This oil has a pristane-phytane ratio of about 1.5, n-alkanes dominant in the saturated hydrocarbon fraction, abundant hopanoid biomarker compounds, and $C_{15}+$ saturated hydrocarbon fractions depleted in carbon-13 compared to the Lyons oil type ($\delta^{13}C$ values -28.8 to -30.4 ppt). Oil produced east of the Denver basin from rocks of the Lansing Group ("F" zone) and Ordovician rocks at Boveau Canyon and Sleepy Hollow fields, respectively, is geochemically similar to this second oil type. The third oil type is produced from rocks of Desmoinesian age. This oil has a pristane-phytane ratio near 1.0, contains intermediate amounts of n-alkanes relative to isoprenoids compared to the other oil types, and contains the isotopically heaviest saturated hydrocarbons of the three oil types ($\delta^{13}C$ values -27.7 to -27.8 ppt). These three oil types have probably been generated from three different source rocks. The geographic distribution of the Virgilian-Wolfcampian and the Desmoinesian oil types suggest at least two broad areas for possible future exploration: for the Desmoinesian type, along a trend subparallel to the eastern limit of Desmoinesian rocks in the subsurface from the Nebraska panhandle to east-central Colorado; and for the Virgilian-Wolfcampian type, along a generally east-west trend in northern Colorado, southwestern Nebraska, and northwestern Kansas.

CLEMENT, JAMES H., Shell Oil Co., Houston, TX

Cedar Creek—Significant Paleotectonic Feature of Williston Basin

More than 327 million bbl of oil have been produced from Paleozoic carbonate reservoirs in 15 fields along the Cedar Creek anticline. This pronounced fold developed through a geologic history of recurrent tectonic movements along a northwest-southeast-striking fault zone. Four major periods of tectonism from early Paleozoic through mid-Tertiary are documentable in the Cedar Creek area.

Post-Silurian to pre-Middle Devonian.—Uplift and fault movement accompanied north and east tilting of the main Cedar Creek block. Several hundreds of feet of Silurian strata were eroded and a karst plain developed on the Silurian surface. Middle and Upper Devonian sediments onlapped and infilled the uplifted, northwest-plunging element.

Late Devonian to pre-Mississippian.—During latest Late Devonian and possibly earliest Mississippian, the Cedar Creek block was uplifted and tilted north and east. Extensive erosion resulted in the near peneplanation of the structure and significant truncation of Upper Devonian strata.

Late Mississippian (Chester) through Triassic.—During the Late Mississippian (Chester) and Early Pennsylvanian, the central and northern portion of the Cedar Creek area underwent gentle downwarping and periods of subsidence occurred with relative down-to-the-east fault movement along most of the ancestral master and subsidiary faults. Similar fault movement(s) and subsidence continued during the Permian and Triassic Periods. Relative tectonic stability was attained by the Middle Jurassic and essentially maintained until post-Paleocene time.

Post-Paleocene.—The Cedar Creek block underwent its greatest magnitude of uplift during post-Paleocene tectonism resulting in an extensive, linear belt of symmetric drape-folding generally aligned with the ancestral fault zones, and deep fault adjustment. During epeirogenic phases of the mid-Tertiary in the northern Rocky Mountain region, 1,500 ft (457 m) of Paleocene and Upper Cretaceous strata were eroded along the axis of the present structure.

COALSON, EDWARD B., Bass Enterprises Production Co., Denver, CO, DAN J. HARTMANN, Independent Geologist, Fredricksburg, TX, and JOHN B. THOMAS, Reservoirs, Inc., Denver, CO

Rock Types, Pore Types, and Hydrocarbon Exploration

A proposed exploration-oriented method of classifying porosity in sedimentary rocks is based on microscopic examination of cores or cuttings. Factors include geometry, size, abundance, and connectivity of the pores. The porosity classification is predictive of key petrophysical characteristics: porosity-permeability relationships, capillary pressures, and (less certainly) relative permeabilities. For instance, intercrystalline macroporosity typically is associated with high permeability for a given porosity, low capillarity, and favorable relative permeabilities. This is found to be true whether this porosity type occurs in a sucrosic dolomite or in a sandstone with pervasive quartz overgrowths.

This predictive method was applied in three Rocky Mountain oil plays. Subtle "pore throat" traps could be recognized in the "J" sandstone (Cretaceous) in the Denver basin of Colorado by means of porosity-permeability plotting. Variations in hydrocarbon productivity from a Teapot Formation (Cretaceous) field in the Powder River basin of Wyoming were related to porosity types and microfacies; the relationships were applied to exploration. Rock and porosity typing in the Red River Formation (Ordovician) reconciled apparent inconsistencies between drill-stem test, log, and mud-log data from a Williston basin wildcat. The well was reevaluated and completed successfully, resulting in a new field discovery. In each of these three examples, petrophysics was fundamental for proper evaluation of wildcat wells and exploration plays.

CROSS, TIMOTHY A., Colorado School of Mines, Golden, CO, and REX H. PILGER, JR., Louisiana State Univ., Baton Rouge, LA

Variations in Plate Kinematics and Subduction Geometries: Unifying Explanation of Mesozoic and Cenozoic Deformation in Rocky Mountains Region

The variety of late Mesozoic through early Cenozoic tectonic elements and events in the Rocky Mountains region shows temporal and spatial correspondence with inferred variations in kinematics of plate interactions and geometries of subducted oceanic lithosphere. From this space and time correspondence and current understanding of subduction processes and responses, we suggest a unified explanation for the occurrence and genesis of these features. The following tectonic elements and events are regarded as genetic expressions of variations in subduction modes and geometries: (1) the history of igneous activity in the western United States, (2) the contrasting styles and loci of deformation along the foreland fold and thrust belt (Sevier style) and the basement-cored uplifts (Laramide style) bordering the northern and eastern margins of the Colorado Plateau, (3) the development and maintenance of the Colorado Plateau as a relatively rigid tectonic block, (4) the timing and geometry of subsidence in the foreland basin, (5) the disjunct history of subsidence and subsequent uplift of the Colorado-Wyoming-Utah (CWU) region beyond the foreland basin, and (6) the initial stability and subsequent subsidence of the High Plains region.

During normal subduction, thin-skinned crustal deformation was continuous opposite the convergent margin. During the ensuing period of low-angle subduction, the Colorado Plateau region was underpinned by subducted lithosphere, anomalous subsidence occurred in the CWU locus, and deformation was transferred to the position of greatest contrast in mechanical properties of the crust (the eastern and northern boundaries of the plateau). Decoupling of subducted lithosphere from overlying lithosphere caused uplift and erosional stripping of the CWU region, crustal flexure to the east, and sediment accumulation on the High Plains.

DECKER, DAVID, Resource Enterprises, Inc., Grand Junction, CO

Appropriate Stratigraphic Nomenclature for Coal Reservoirs in Piceance Basin, Colorado

Coal-bearing intervals occurring within the Upper Cretaceous Mesaverde Group in the Piceance basin have been described by various authors. The most current and widely accepted work has the Sego, Corcoran, Cozzette, and Rollins Sandstone Members comprising the Iles Formation. The overlying Williams Fork Formation is divided into the basal Bowie Shale Member and Paonia Shale Member, with the upper remaining section undifferentiated.

Coal seams associated with the Iles Formation belong to the Black Diamond coal group. The Fairfield coal group and the South Canon coal group are part of the Bowie Shale Member. These two coal groups, continuous throughout the basin, are also called the Sommerset coals in the Sommerset coal field and the Cameo coal measures in the Grand Mesa coal field. Although priority of nomenclature dictates otherwise, established usage of the "Cameo coals" for coal seams in the Bowie Shale Member should be continued as the most appropriate nomenclature.

The basal coal seam of the proposed Cameo coal group is laterally continuous throughout the Piceance basin. A second coal seam 40-120 ft (12-37 m) above the basal coal also has large areal extent. Both coal seams, as existing and potential future pay zones, are of significant economic importance and should, in ascending order, be classified as the Cameo coal A and D seams.

The coal seams in the Paonia Shale Member, extremely variable in thickness, continuity, and quality, have been established as the Coal Ridge coal group.

DEJARNETT, JEFF, Champlin Petroleum Co., Englewood, CO

Paleogeographic and Sedimentologic Significance of Mississippian Sequence at Mt. Darby, Wyoming

Mississippian strata at Mt. Darby comprise the Madison Group and the overlying Humbug Formation. This sequence, although initially transgressive, exhibits an overall regressive character produced by progradation of platform carbonates in response to sea level fluctuations related to Antler orogenic events.

The Paine Member of the Lodgepole Limestone, the basal formation of the Madison Group, consists of relatively deep-water carbonates including a possible Waulsortian-type carbonate bank that accumulated on a Kinderhookian foreslope. At least five shoaling-upward grainstone cycles are recognizable in the Woodhurst Member of the Lodgepole Limestone. These cycles record Osagean deposition in shallow agitated environments that developed high on a clinoform ramp. Shelf-margin and platform carbonates dominate the Mission Canyon Limestone, the upper formation of the Madison Group. This unit consists of two asymmetric depositional cycles, each with a thick regressive phase, capped by an evaporite solution breccia and an overlying thin transgressive phase.

The Humbug Formation, a sequence of fine-grained carbonates and sandstones, represents part of a deltaic complex that developed offshore from the Meramecian karst plain. Humbug sediments were transported northward to the Mt. Darby area from the area of the present Uinta Mountains, or another deltaic system formed there. Deposition in the study area was apparently continuous upward from the Madison carbonates into the Humbug. The middle Meramecian shoreline trended northwest between the present locations of Mt. Darby and Haystack Peak.

DESMOND, ROBERT J., Maze Exploration, Inc., Englewood, CO, JAMES R. STEIDTMANN, Univ. Wyoming, Laramie, WY, and DONALD F. CARDINAL, Consultant, Casper, WY

Stratigraphy and Depositional Environments of Middle Member of Minnelusa Formation, Central Powder River Basin, Wyoming

Regional correlations, from the southern to northern Black Hills and across the central Powder River basin to the Bighorn Mountains, serve as the frame work for a depositional model of middle Minnelusa sediments. In the eastern part of the study area, deposition took place in a carbonate sabkha environment. During transgressive periods, most of this region was covered by a restricted shallow sea. In the northern Black Hills, close to the limit of the transgression, deposition occurred in a coastal dune setting. During regressions, the sabkha prograded westward toward the Lusk embayment. Coastal dune fields to the north and isolated dune complexes to the south migrated southwestward across this prograding sabkha. West of the Lusk embayment, deposition occurred in a sand-dominated tidal-flat environment during transgressions and along the coastal edge of an eolian sand sea during regression.

DICKINSON, WARREN W., and B. E. LAW, U.S. Geol. Survey, Denver, CO

Burial History of Upper Cretaceous and Tertiary Rocks Interpreted from Vitrinite Reflectance, Northern Green River Basin, Wyoming

The burial history of Upper Cretaceous and Tertiary rocks in the northern Green River basin is difficult to reconstruct for three reasons: (1) most of these rocks do not crop out, (2) there are few stratigraphic markers in the subsurface, and (3) regional uplift beginning during the Pliocene caused erosion that removed most upper Tertiary rocks. To understand better the burial and thermal history of the basin, published vitrinite reflectance (R_0) data from three wells were compared to TTI (time-temperature index) maturation units calculated from Lopatin reconstructions. For each well, burial reconstructions were made as follows. Maximum depth of burial was first estimated by stratigraphic and structural evidence and by extrapolation to a paleosurface intercept of $R_0 = 0.2\%$. This burial was completed by early Oligocene (35 Ma), after which there was no net deposition. The present geothermal gradient in each well was used because there is no geologic evidence for elevated paleotemperature gradients.

Using these reconstructions, calculated TTI units agreed with measured R_0 values when minor adjustments were made to the estimated burial depths. Reconstructed maximum burials were deeper than present by 2,500-3,000 ft (762-914 m) in the Pacific Creek area, by 4,000-4,500 ft (1,219-1,372 m) in the Pinedale area, and by 0-1,000 ft (0-305 m) in the Merna area. However, at Pinedale, geologic evidence can only account for about 3,000 ft (914 m) of additional burial. This discrepancy is explained by isoreflectance lines, which parallel the Pinedale anticline and indicate that approximately 2,000 ft (610 m) of structural relief occurred after maximum burial. In other parts of the basin, isoreflectance lines also reveal significant structural deformation after maximum burial during early Oligocene to early Pliocene time.

DIMITRAKOPOULOS, R., W. GRIFFIN,* and G. D. WILLIAMS, Univ. Alberta, Edmonton, Alberta, Canada

Conditional Simulation: Geostatistical Tool Applied to Athabasca Oil-Sands Deposit

Geostatistical modeling of reservoir variability in the Athabasca oil-sands deposit prior to either surface or in-situ mining can provide valuable information to guide the extraction process. Geologic and engineering characteristics (variables), such as elevations of bitumen-saturated and waste (barren) zones, and percentage bitumen saturation, porosity, and permeability, have a controlling effect on recovery methods.

Each geologic variable is considered to be a particular realization of a random function defined within a geologic domain. This function can be inferred from available data (boreholes) under the hypothesis of stationarity. Other realizations (models) of the same random function can then be generated using the technique of conditional simulation, which is