style of thin-skinned overthrust deformation, which occurred north of the lineament, to the foreland basement-involved thrust deformation, which occurred to the south. The differential motion of the basement was absorbed by small amounts of left-lateral transform motion.

This lineament may also have created a weak zone in the crust into which the Boulder batholith intruded during the early stages of the Laramide. The voluminous volcanic material associated with the batholith created a supracrustal load which downwarped the adjacent lithosphere. If the batholith itself slid eastward, as advocated by Hyndman in 1979, the load was enhanced. Decoupling of the lithosphere along the southernmost elements of the Lewis and Clark lineament localized and accentuated the load-induced subsidence, creating the Crazy Mountains basin and localizing the accumulation of the thick volcaniclastic sediments of the Livingston Group.

LOWELL, JAMES D., Colexcon, Inc., Denver, CO

Foreland Detached Deformation

In an area having perhaps more relief on the top of the Precambrian surface than any other structural province in the world, attention understandably has been focused on the basement-cored structures of the Rocky Mountain foreland. Deep-seated compression interpreted as responsible for the shortened basement features has also created detached structures in the overlying sedimentary cover. These latter structures have never been the object of systematic study, yet they provide important additional evidence of a compressional origin for the Rocky Mountain foreland and other forelands, and are also prospective for oil and gas.

Detached structures can be attributed to at least two types and stages of deformation. First, compression operating early in the development but prior to the differentiation of the foreland created small-scale fold and thrust structures. Probable examples of early compressional structures include those formed on what are now the gentle tilted flanks of the Owl Creek Range in Wyoming and the Cara Cura Range in Argentina. Second, after differentiation of the foreland into blocks, the flexural slip mode of folding in competent sedimentary layers dictates that space problems in both anticlines and synclines be accommodated by the creation of decollement surfaces and associated detachment structures. Examples have been documented from virtually every Rocky Mountain foreland basin. Specifically cited are the North Park basin in Colorado, Elk Mountain area, northwestern Wind River basin, and Big Horn basin in Wyoming, and the Cara Cura mountains in Argentina. Prominent detachment horizons in the Rocky Mountain foreland are shales of Cambrian, Triassic (Chugwater), and Cretaceous (Mowry, Cody, and equivalent) age.

Oil and gas have been produced from detached folds. A negative aspect is that otherwise prospective beds beneath a completely detached structure do not have closure unless they are affected by deeper faults. More optimistically, closures related to local detachment are prospective.

MAUGHAN, EDWIN K., and WILLIAM J. PERRY, JR., U.S. Geol. Survey, Denver, CO

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 near the cardinal points of the compass, approximately N5°-15°E and N75°-85°W;the other set is oriented diagonally, about N50°-60°E and N30°-40°W.

At small scales, the crosscutting lineaments of either set suggest 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. Throughout 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.

MCBANE, J. DUNCAN, and ROBERT P. SWINEHART, Milestone Petroleum Inc., Billings, MT

Depositional Environment of Leo Sands, Middle Minnelusa Formation, Niobrara County, Wyoming

The Upper Pennsylvanian middle Minnelusa Formation "Leo Sands" in the north half of Niobrara County, Wyoming, and southwestern South Dakota, may have been deposited in a nearshore eolian sabkha environment. Cores reveal sedimentary features which support this hypothesis, such as deflation lags, avalanche-produced strata, probable interdune deposits, and nodular anhydrites.

The "Leo Sands" have proven to be excellent reservoir rocks. Associated anhydrites provide the seal for hydrocarbons which may have been generated from organic-rich interdunal shales.

MIKESH, DAVID L., Mallon Oil Co., Denver, CO, and RANDAL F. LAFOLLETTE, Reservoirs Inc., Denver, CO

Sedimentary Facies and Reservoir Characteristics of Cretaceous "J" Sandstone at Torrington Field (North), Goshen County, Wyoming—Exploration and Development Implications

Torrington field (North) is productive from the Lower Cretaceous "J" sandstone in the Wyoming portion of the Denver basin. The trapping mechanism is stratigraphic, with reservoir sandstones enveloped laterally and updip by shale-dominated lithofacies. The field has produced 13,000 bbl of oil from two wells since its discovery in late 1981. However, production can be increased by development based on recognition of features comprising the "J" sandstone depositional system.

Three major sedimentary environments and their associated facies, characteristic of a meandered fluvial system, occur within the "J" interval in the area: abandoned channel, point bar(s), and interfluvial plain. Production at both Torrington (North) and Torrington is from reservoir development within point bar deposits. Cores of the "J" point bar at Torrington (North) show that it is comprised primarily of very fine to fine-grained quartzarenites and sublitharenites. Dominant framework grains are quartz and lithic fragments which are cemented by quartz overgrowths and authigenic clays (primarily kaolinite). Sedimentary structures observed in the cores include burrowing and bioturbation, high-angle plane-parallel cross-bedding, discontinuous wavy shale laminae, climbing ripples, and truncated laminae. Although excellent hydrocarbon shows occur from the base to the top of the point bar, production appears to be confined to thin intervals of medium-grained quartzarenite found near the middle of the vertical sequence. This may be due to flow regime size sorting which affected differential clay diagenesis within the point bar.

Petrophysical reservoir characteristics of the "J" sandstone were established through examination of X-ray diffraction, scanning electron microscopy, thin-section petrography, and conventional core analysis data. Microporosity development and geometry also affect production.

Field extension locations and an exploratory drill site have been established as a result of this study.

MOORE, C. E., and R. J. ARCHER, ARCO Exploration Co., Denver, CO

Pennsylvanian Tyler Stratigraphic Seismic Concepts

Recent drilling in the Rattler Butte area of central Montana has renewed interest in the Pennsylvanian Tyler Formation as a drilling objective. New production in this area, coupled with the surrounding well density, provides an ideal situation for further development of Tyler stratigraphic-seismic exploration concepts and methods.

Both geologic and geophysical Tyler thickness maps have proven to be useful tools in delineating eroded Heath and subsequent lower Tyler deposition. Seismic modeling has revealed a series of possible Tyler-Heath erosional edge characteristics, providing another tool for Tyler-Heath boundary definition. In modeling specific seismic sand signatures, it was found that seismic character and amplitude are dependent upon both formation thickness and lithology.

Detailed mapping of the study area also revealed a new environmental interpretation of the Tyler. Unlike the fluvial system to the north, the Tyler regime in the Rattler Butte area appears to have fluctuated among fluvial, deltaic, and marine systems.

Two hydrocarbon occurrence patterns have been noted within the Tyler: (1) although reservoir quality sands are present throughout the Tyler, those within the lower Tyler are more likely to contain hydrocarbons, and (2) close proximity to the Tyler-Heath erosional edge increases the chances of discovering oil-filled Tyler sands.

Combined use of these exploration tools should greatly enhance the chances for successful lower Tyler exploration.

MOORE, W. RICHARD, Independent Geologist, Denver, CO

Fault Control of Channel Sandstones in Dakota Formation, Southwest Powder River Basin, Wyoming

The Dakota Formation is an important oil reservoir in the southwestern Powder River basin and adjoining Casper arch. Two fields, Burke Ranch and South Cole Creek, are used as examples to show the depositional environments of the Dakota and to indicate the influence of tectonic control on the distribution of the environments.

Burke Ranch field is a stratigraphic trap which produces oil from the upper bench of the Dakota. The environment of deposition of the reservoir, determined by subsurface analysis, is a channel sandstone. South Cole Creek field is a structural-stratigraphic trap which produces from the lower bench of the Dakota. Two distinct facies, a channel and channel margin sandstone, exist at South Cole Creek.

At both Burke Ranch and South Cole Creek it can be shown that the Dakota channels were deposited on the downthrown side of faults, which were present during Dakota time and which now are reflected on the surface by drainage patterns. An understanding of the environments of deposition of the Dakota and control of the environments by paleotectonics is necessary for exploration for these prolific reservoirs.

NICHOLS, K. M., U.S. Geol. Survey, Denver, CO

Facies in Upper Part of Madison Group, Sawtooth Range, Northwestern Montana

Portions of the Mississippian Madison Group are gas reservoirs in the plains adjacent to the Sawtooth Range, northwestern Montana, and are equivalent to Mississippian carbonates that are major gas producers in the Canadian Foothills. In the Sawtooth Range, three facies are recognized in the upper 125 m (410 ft) of the Madison Group; they comprise a carbonate shelf sequence that is several hundred meters thick, shoals upward, and is unconformably overlain by Jurassic strata. Economically significant porosity may occur in the upper part of the Madison Group, controlled by the eogenetic secondary dolomitization of a conspicuous crinoidal grainstone unit within it.

This dolomitized crinoidal grainstone unit (termed facies C) is the lowest of three facies in the upper part of the Madison Group, and it abruptly overlies lagoonal limestone that forms the major part of the group. Facies C is massively bedded and exhibits large-scale planar cross-stratification suggestive of its origin as a subaqueous dune field. Measured porosity in surface samples of the dolomitized grainstone of facies C is a maximum of 18% and consists of vuggy, intergranular, and intercrystalline pores. The upward transition from limestone to secondary dolomite commonly occurs in the lower part of facies C. The thickness of facies C ranges from 35 to 75 m (115 to 250 ft) and is inversely proportional to the thickness of the intertonguing and overlying facies B.

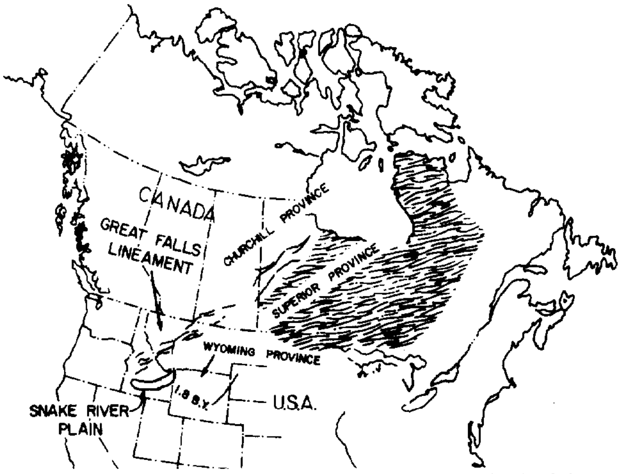
The uppermost two facies, termed B and A, reflect the upward transition from and open platform to a restricted platform environment. Facies B ranges in thickness from 25 to 75 m (80 to 250 ft) and is a nonporous, dolomitized mudstone and wackestone sequence generally containing some 1 m (3 ft) interbeds of porous dolomitized grainstone. This sequence is capped by < 10 m (30 ft) of intertidal rocks of facies A, which are thin-bedded, partly algally laminated, dense dolomites.

Locally, facies A and parts of B have been removed as a result of pre-Jurassic folding and erosion in the Sawtooth Range. However, all lateral thickness changes in facies C reflect its intertonguing with B. Although original facies patterns are greatly telescoped by thrusting, the porous grainstones of facies C are best developed in the vicinity of Blackleaf Canyon, Montana, the site of a recently developed commercial gas field in dolomite of the Madison Group.

O'NEILL, J. MICHAEL, U.S. Geol. Survey, Denver, CO, and DAVID A. LOPEZ, North American Resources Co., Inc., Billings, MT

Great Falls Lineament, Idaho and Montana

The name "Great Falls lineament" is given to a northeast-trending zone of diverse geologic features that can be traced northeastward from the Idaho batholith in the Cordilleran miogeocline of the United States, across thrust belt structures and basement rocks of west-central and southwestern Montana, through the cratonic rocks of central Montana, and into southwesternmost Saskatchewan, Canada. The zone is well represented in east-central Idaho and west-central Montana where geologic mapping has outlined northeast-trending, high-angle faults and shear zones that: (1) extend more than 150 km (93 mi) from near Salmon, Idaho, northeastward toward Anaconda, Montana; (2) define a nearly continuous zone of faulting that shows recurrent movement from middle Proterozoic to Holocene time; (3) controlled the intrusion and orientation of some Late Cretaceous to early Tertiary batholithic rocks and early Tertiary dike swarms; and (4) controlled the uplift and orientation of the Anaconda-Pintlar Range. Recurrent movement along these faults and their strong structural control over igneous intrusions in this region suggest that northeast-trending faults represent a fundamental tectonic feature of the region.



Geologic features that are similar to those mapped in the Salmon-Anaconda region are present to the southwest and the northeast. In central Idaho, these structures include numerous northeast-trending faults and pronounced topographic lineaments that cut across the southern part of the Idaho batholith, and a northeast alignment of Tertiary igneous rocks that cut the Idaho batholith and adjacent rocks. East and southeast of the Anaconda-Pintlar Range, subparallel, high-angle faults and topographic lineaments are present in the Highland, Pioneer, Ruby, and Tobacco Root Mountains. High-angle faults may have in part controlled the orientation of the northeast-elongate Boulder batholith. Northeast-trending structures are not easily traced across the thrust belt of western Montana or across the Lewis and Clark line. In the central Montana plains, northeast of the disturbed belt, however, a broad zone of colinear, northeast-trending structures is present, and includes: parallel, buried basement highs that in part controlled depositional patterns of some Paleozoic and Mesozoic sedimentary rocks; major physiographic features, such as the remarkably straight, 175-km (109-mi) long segment of the Missouri River, and equally long, buried river channels in southwestern Saskatchewan; a northeasterly alignment of highly differentiated igneous rocks and a belt of ultrabasic intrusions and related diatremes;