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Seismic Profile Across Leading Edge of Fold and Thrust Belt of Southwestern Montana

The fold and thrust belt of southwestern Montana and east-central Idaho is the northern continuation of the thrust belt of Utah, Wyoming, and southern Idaho. The frontal fold and thrust zone, which the seismic profile transects, is in the same structural position and exhibits similar geologic relationships as the disturbed belt farther north in Montana and the part of the Utah-Wyoming thrust belt east of the Paris-Willard thrust. The seismic profile illustrates: (1) rocks of the Archean basement complex dip gently westward beneath the thrust belt, (2) the Phanerozoic section is thickened dramatically in the western part of the profile by thrusting and folding, (3) the principal decollement horizon is probably at the top of the Mississippian section, (4) at least one thrust involves basement rocks, (5) the basement surface is also cut by steep reverse faults, (6) Tertiary basins contain numerous steep normal faults which cut basement rocks, several of which can be projected to connect with steep northwest-trending reverse faults in the Ruby Range, and (7) Tertiary rocks in the Beaverhead Valley immediately overlie either a thin Paleozoic section or Archean basement indicating that most of the stratigraphic section was removed prior to mid-Tertiary normal faulting.

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Tectonostratigraphic Analysis of Powder River Basin, Wyoming

The Powder River basin of northeastern Wyoming is a basin of the broken foreland between the stable interior of the craton and the Cordilleran orogenic belt. The formation of the basin reflects the complex depositional history of both regions. The rock strata within the basin may be divided into tectonostratigraphic units that allow interpretation of basin evolution within a plate-tectonic context.

During Precambrian to Late Devonian time, the area occupied by the present-day basin was transitional between the craton and the rifted margin of the continental shelf to the west. The basin area occupied a complex setting peripheral to foreland basins and the stable continental interior during the Antler orogeny (Devonian-Mississippian), Humboldt orogeny (Pennsylvanian-Permian), Sonoman orogeny (Permian-Triassic), and Nevadan stage of the Cordilleran orogeny (middle Late Jurassic). After the beginning of the Sevier orogeny in the Late Jurassic, the area was within the Cretaceous retroarc foreland basin. The first indication of subsidence within the basin is late in Laramide time (Paleocene); subsidence continued through at least early Eocene time. Stream drainages in Paleocene to early Eocene time were dominated by rising highlands, which produced a north-flowing trunk stream. During much of the Paleogene, this drainage was connected to the Wind River basin on the southwest.

A-type subduction of the cratonic margin beneath the rising magmatic arc in the western batholithic belt, following collision of exotic terranes during a period of increased movement of the craton relative to the Pacific plate, was the most probable cause for events of the Cordilleran orogeny. Laramide-style basement-block uplifts express the extension of the thin-skinned tectonics in the western orogenic belt eastward into the thicker lithosphere of the foreland along the craton margin, possibly during overriding of an aseismic ridge on the Pacific plate by western North America. Uplift and erosion of the basin since early Eocene time may be due to thermotectonic uplift around the apices of the Snake River plain and the Rio Grande rift.

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Early Campanian Coastal Progradational Systems and Their Coal-Forming Environments, Wyoming to New Mexico

Ammonite zones (*Baculites obtusus-Scaphites hippocrepis*) in the marine facies associated with the Mesaverde Formation in the Bighorn basin, Wyoming, Star Point Sandstone and Blackhawk Formation in the Wasatch Plateau, Utah, and the Point Lookout Sandstone, Menefee Formation, and Crevasse Canyon Formation in the Gallup coalfield, New Mexico, indicate that these formations were deposited during early Campanian time (80-84 Ma).

The coal-forming environments of these early Campanian formations were located landward of wave-reworked coastal sand complexes of progradational systems along the western margin of the Cretaceous seaway from Wyoming to New Mexico. The Mesaverde coals accumulated in swamps of the lower delta plain and coeval interdeltaic strandplain environments. The Star Point-Blackhawk coals accumulated in swamps of the lower delta plains of laterally shifting, prograding deltas and associated barrier ridge plains. The Point Lookout, Menefee, and Crevasse Canyon coals formed in swamps of the lower delta plain and infilled lagoons behind barrier islands.

Although the common coal-forming environments of these progradational systems are back barrier and delta plain, the former setting was the more conducive for accumulation of thick, laterally extensive coals. Economic coal deposits formed in swamps built on abandoned back-barrier platforms that were free of detrital influx and marine influence. Delta-plain coals tend to be lenticular and laterally discontinuous and thus uneconomic.

The early Campanian coal-forming coastal-plain environments are analogous to modern peat-forming environments along the coast of Belize, Central America. Deltaic sediments deposited along the Belize coast by short-headed streams are reworked by waves into coastal barrier systems.

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Estimating Coal Quality from Borehole Logs

Evaluation of coal quality is traditionally done on borehole cores in the laboratory; it is expensive and time consuming. Now, using a microcomputer-based geologic work station, geologists can obtain inexpensively reliable coal-quality estimates in minimal time. Typical coal borehole logs (gamma, density, and resistivity) are calibrated with a few core analyses from a specific area by correlating dry BTU content (measured in the laboratory) with measured log values for each zone analyzed. Multiple regression techniques describe the relationship between logs and BTU content. The regression surface of BTU on gamma and density, or the regression hypersurface of BTU on gamma, density, and resistivity is used to estimate the BTU for user-specified depth zones in boreholes that have not been cored. Confidence surfaces nested around the regression surfaces and hypersurfaces bracket the estimated BTU values within preselected confidence intervals.

The estimated BTU content of a coal seam is expressed as an expected value per depth increment. Each is easily qualified with user-specified confidence limits. Expected values can be averaged over any zone of interest, either an entire coal seam or a zone within the seam. Expected coal-quality values for numerous boreholes can be contoured to produce a coal quality isograd map. The volume of coal within any isograd can then be estimated. With a stand-alone geologic work station, geologists can make estimates and relevant maps on site; they no longer need to wait for core analyses as results are immediate.

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Reinterpretation of Relationships Among Keystone Thrust, Red Springs Thrust, Contact Thrust, and Cottonwood Fault, Clark County, Nevada

The basin-range and Sevier tectonic events are well-documented in Clark County, Nevada. Other tectonic events have been interpreted from structural relationships in the Spring Mountains. These include an early thrust-faulting event and a high-angle faulting event that occurred between emplacement of the early thrust and emplacement of the Keystone thrust. The results of this study indicate that there was not an early thrust event nor was there high-angle faulting prior to the Sevier deformational event.

The Cottonwood fault and the Contact thrust in the Spring Mountains are interpreted here as a lateral ramp and floor thrust beneath a duplex fault zone. The Keystone thrust forms the roof thrust for the duplex fault 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.

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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