Eocene Paleotectonics and Sedimentation in the Rocky Mountain-Colorado Plateau Region

The Laramide orogeny (c. 80 to 40 m.y.B.P.), which culminated during early Eocene time, resulted in the development of numerous uplifts and basins in the foreland of the western United States. Uplifts are assignable to three general classes: (1) Cordilleran thrust belt uplifts, (2) basement-cored, fault-bounded uplifts of the classic Laramide Rocky Mountains, and (3) monocline-bounded uplifts of the Colorado Plateau. Basins were also of three types: (1) Green River type—large equidimensional to elliptical basins bounded on three or more sides by uplifts and commonly containing lake deposits, (2) Denver type—asymmetrical, synclinal downwarps with a related uplift along one side, and (3) Echo Park type—narrow, highly elongate basins with through drainage and of strike-slip origin. Green River-type basins exhibit quasiconcentric zonation of facies, in contrast to the unidirectional, proximal-to-distal facies tract of Denver-type basins. Facies distribution in Echo Park-type basins is complex and often difficult to reconstruct due to faulting, erosional truncation, and cover.

The prevalence of en echelon structures in the deformed zone east of the Colorado Plateau, and evidence for significant crustal shortening north of the plateau, suggest that the major structural features of the Laramide foreland were produced by large-scale, north-northeastward translation of the relatively rigid Colorado Plateau block. The magnitude of this motion, as indicated by dextral offset of lineaments which cross the eastern margin of the plateau and by the amount of crustal shortening in the Wyoming province, may be as great as 65 to 120 km (40 to 75 mi). This translation probably resulted from the interaction of relatively competent Colorado Plateau lithosphere with the underlying, gently dipping Farallon plate, which was being overridden by the western United States in Laramide time.

Evidence for increased strain rates in early Eocene time includes: (1) markedly higher rates of deposition and sand/shale ratios in the Gulf Coast geosyncline (Wilcox Group), (2) formation of several new basins in the southern Rocky Mountains in which Eocene deposits rest unconformably on pre-Cenozoic rocks, and (3) the generally coarser and more arkosic nature of Eocene sediments, as compared to older Laramide deposits, in many areas throughout the foreland. The early Eocene culmination of Laramide tectonism appears to result from two factors. First, the subducted Farallon plate achieved its shallowest dip at about 55 m.y.B.P., resulting in increased viscous coupling with the overriding continental lithosphere. Second, changing spreading-center geometries in the Labrador Sea, Norwegian Sea, and Arctic Ocean caused the maximum horizontal stress direction to shift to a northeasterly orientation, causing the Colorado Plateau block to increasingly decouple from the craton along north-trending wrench faults in the southern Rocky Mountains. Translation of the Colorado Plateau to the north-northeast during Laramide time resulted in a series of transpressive uplifts and basins along its eastern margin and large-scale crustal shortening in the Wyoming province to the north.

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Relation of Lithofacies and Diagenesis to Porosity Development, Mississippian Mission Canyon Formation, Eastern Montana and Western North Dakota

The ability to map lithofacies trends suitable for hydrocarbon reservoirs is critical for a successful exploration program. In exploring basins with carbonate reservoirs, diagenetic alterations must also be understood in relation to porosity development. The Mississippian Mission Canyon formation of the Williston basin provides an excellent example of the need to understand the lithofacies/diagenesis relation.

During the Mississippian the Williston basin was the site of subtidal to supratidal carbonate deposition. In general, depositional environments became more restricted from Montana eastward into North Dakota. Subsurface mapping suggests a strong relationship between the degree of marine restriction and diagenesis and porosity development in carbonate sediments. Two fields that produce from the Mission Canyon interval illustrate this relationship.

MonDak field, situated on the Montana-North Dakota border, lies west of the limit of massive Mission Canyon anhydrite in a sequence of normal marine sediments. Reservoir porosity is due to fracturing of tight, fine-grained limestones. Low matrix porosity and sparse, erratic fracturing are responsible for low daily production rates.

The Billings Nose-Little Knife trend (Billings, Dunn, and McKenzie Counties, North Dakota) is well within the limit of massive anhydrite. Reservoir porosity consists of a thick sequence of intertidal-supratidal sucrosic dolomites which are sealed by 20 to 25 m (65 to 82 ft) of massive anhydrite. Reflux of magnesium-rich brines is believed to be the process leading to dolomitization.

Good matrix porosity and permeability allow for higher daily production rates. Regional mapping indicates that the presence or absence of anhydrite correlates directly with the development of good matrix porosity.

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Cedar Creek—A Significant Paleotectonic Feature of Williston Basin

Cedar Creek is the major anticlinal structure demarcating the southwest flank of the Williston basin. This pronounced fold developed through a geologic history of recurrent tectonic movements along a northwest-southeast striking fault zone. The four major periods of tectonism documentable in the Cedar Creek area from early Paleozoic through mid-Tertiary affected the local and regional distribution, erosion, and/or preservation, and, though moderately, the depositional facies of sedimentary strata since Ordovician time.

Post-Silurian-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 prior to Middle Devonian time, and a karst plain developed on the Silurian surface. Middle and Upper Devonian sediments progressively onlapped and infilled the uplifted, northwest plunging element.

Late Devonian-Pre-Mississippian.—During latest Upper Devonian—possibly earliest Mississippian—pronounced fault movement occurred along the major fault zone. The Cedar Creek block was uplifted and tilted north and east; maximum displacement along the zone appears to have occurred in the vicinity of the Pine-Gas City-Glendive oil fields. Extensive erosion resulted in the near peneplanation of the structure and significant truncation of Upper Devonian strata. Continued paleostructural influence during Mississippian time is indicated by the distribution and facies of early and middle Mississippian rocks.

Late Mississippian (Chester) through Triassic.—In late Mississippian (Chester) and early Pennsylvanian time, 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 parts of the ancestral master and subsidiary faults. Similar fault movement(s) and subsidence which continued to occur during the Permian and Triassic periods significantly influenced the deposition and preservation of these evaporite rich, red-bed sequences. 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 the post-Paleocene; younger Tertiary beds are not present in the area. This uplifting was accompanied by major flexuring, the extensive linear belt of asymmetric drape-folding generally aligned with the ancestral fault zones, and deep fault adjustment. Northwest plunge along the crestal portion was significantly increased. The entire area was subsequently uplifted during epeirogenic phases of the mid-Tertiary in the northern Rocky Mountain region and about 1,500 ft (460 m) of Paleocene and Upper Cretaceous strata eroded along the axis of the present structure.

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Depositional Environment and Diagenesis of Teapot Sandstone (Upper Cretaceous), Converse and Natrona Counties, Wyoming

The Teapot Sandstone forms the upper member of the Upper Cretaceous Mesa Verde Formation in the Powder River basin. Previous interpretations of the Teapot based on outcrop or subsurface data range from nearshore marine to fluvial. Integration of outcrop data with subsurface data from cores provides a more complete interpretation of depositional environment because of the rapid facies changes in the Teapot. The Teapot Sandstone has a complex diagenetic history and diagenetic patterns are facies controlled.

Lithofacies of the Teapot Sandstone are analogous to the modern Nile delta. The Teapot Sandstone is interpreted as a regressive, wave/fluvial-dominated deltaic sequence which prograded eastward into the Cretaceous seaway. Marine lithofacies coarsen upward from bioturbated offshore siltstone to nearshore sandstone with large, pellet-lined ophiomorpha and overlying well-sorted, horizontally laminated foreshore sandstone exhibiting ridge and runnel topography. Marine foreshore sandstone is overlain by complexly interbedded sandstone and carbonaceous shale in stacked fining-upward sequences of the delta plain. Rootlets and contorted beds are common. Fining-upward units are interpreted as abandoned channels, whereas coarsening-upward sequences are interpreted as interdistributary bay or lagoonal deposits. Capping the sequence is a thick, cross-bedded fluvial section consisting of levee, point bar, and channel sand deposits. Slumped beds, intraformational basal conglomerates, and minor eolian ripple laminations are present in fluvial sandstone.

The Teapot Sandstone has a complex diagenetic history. Siderite and framboidal pyrite formed early in the diagenetic sequence at shallow depths of burial under anaerobic conditions. Pore-filling kaolinite, chlorite, and quartz overgrowths formed coevally following dissolution of relatively unstable framework grains. Poikilotopic calcite cement is locally abundant and extensively replaces framework grains. Depositional facies exert strong control on diagenetic patterns. Kaolinite occurs predominantly in fluvial sandstone. Chlorite is restricted to marine facies, and calcite is further restricted to well-sorted foreshore marine sandstone. Quartz overgrowths occur only in relatively well-sorted sandstone, whereas pyrite and siderite are common in shaly sandstone and siltstone.

Nearshore marine and fluvial sandstone are potentially hydrocarbon reservoirs, although authigenic clays have significantly reduced permeability. Reservoir potential of well-sorted foreshore marine sandstone was destroyed by pore-filling calcite cement. However, tightly cemented sandstone forms a potential diagenetic trapping mechanism.

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Tectonic Significance of Ross Pass Fault Zone, Central Bridger Range, Montana

The Ross Pass fault zone (RPFZ) in the central Bridger Range marks the boundary between Proterozoic Belt Supergroup rocks to the north and Archean metamorphic rocks to the south, and may represent the overlap of two Laramide styles of deformation: thin-skinned fold and thrust deformation to the north and basement-involved foreland deformation to the south.

The fault zone consists of three northwest-trending, northeast-dipping, oblique-slip thrust faults with varying amounts of displacement. The middle thrust, the Pass fault, is the most extensive within the zone; to the west, the Proterozoic LaHood Formation is faulted against Archean quartzo-feldspathic gneisses and amphibolites and overlying Middle and Upper Cambrian strata. Displacement decreases eastward as the fault offsets the lower Paleozoic section and dies out within the upper Paleozoic strata. This variation in displacement is caused by folding within the hanging wall strata along the fault plane during thrusting. The folded strata are again offset by another smaller thrust to the northeast, the Peak fault, which may have originated as an out-of-the-syncline thrust. The Dry Fork fault, southwest of the Pass fault, is largely an intraformational thrust within the Middle Cambrian Meagher Limestone which formed in response to buttressing against the Archean foreland block to the south.

South of the RPFZ, both the Archean and the overlying Phanerozoic strata have been deformed into a large asymmetric, steeply dipping, eastward verging fold typical of basement-involved foreland structures.

The structural relationships along the RPFZ developed as the southeast margin of the Montana salient of the Cordilleran fold and thrust belt impinged on the northern margin of the Laramide foreland province. The relatively small displacement within the thrusts indicates that the RPFZ is within or near the leading edge of the Montana salient. The RPFZ may be an extension of the inferred ancestral Willow Creek fault zone to the west, which was the southern margin of the Proterozoic Belt basin. Laramide compressional stresses exploited this long active zone of weakness and resulted in the impingement of fold and thrust structures upon a foreland uplift.

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Paleotectonics of Frontier Formation in Wyoming

The most intense and widespread pre-Laramide structural deformation of Cretaceous sedimentary rocks in Wyoming is associated with the Wall Creek sandstone of the Frontier Formation. Most of the evidence of structural deformation is found immediately below the regional unconformity at the base of this sandstone.

Regionally, an isopach map from the top of the Frontier Formation to the top of the Mowry Formation shows strong and persistent thinning onto a north-trending arch in western Wyoming and thickening into a northwest trending basin in eastern Wyoming.

Part of the thinning onto the western arch is caused by progressively deeper erosion of a regional unconformity at the base of the Wall Creek sandstone, and regional onlap of the Wall Creek sandstone above the unconformity. There is also some westward thinning of the lower Frontier interval, however, which is not related to the Wall Creek unconformity.

Of the more specific paleostructures discussed, the north-trending anticlines in the vicinity of the Moxa arch in southwestern Wyoming are particularly well developed. An east-west anticline in the Bison basin area appears to have been faulted on the south flank, and a broad arch on the west side of the Powder River basin may have influenced paleocurrents and sandstone depositional trends of the productive "First Frontier Sandstone" of that area.

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Vitrinite Reflectance of Coals from the Heath Formation, Central Montana

The Heath Formation (Mississippian) in central Montana is a black calcareous shale containing low to moderate amounts of oil (Fischer assay) and is considered a petroleum source rock for the overlying Tyler Sandstone.

Seven core holes were drilled in the summer of 1982 by the Montana Bureau of Mines and Geology in cooperation with the Mineral Management Service. Thin coal seams from the core samples were studied using vitrinite reflectance analysis. Since vitrinite reflectance is a method of determining thermal maturation of organic material in sediments (in this case, a thin coal seam near the base of the Heath Formation), it was possible to construct an iso-reflectance map of the Heath Shale in this area, and estimate the minimum temperature of heating undergone by the organic constituents.

Reflectance values show a regional trend caused by burial and the geothermal gradient. Little variation is present in these reflectance values (0.49% to 0.55%). The lowest reflectance values are in the central portion of the study area, and increase to the east and west. However, substantially higher vitrinite reflectances were recorded in the far eastern portion of the area. These high reflectances probably are the result of heating by an igneous intrusion, which was cored during drilling.

The sediments heated by the normal geothermal gradient have immature vitrinite which is below the limits of the petroleum generation window. In the small area where the intrusive was discovered, the vitrinite is mature and there is a good possibility of oil generation.

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Influence of Transcontinental Arch on Cretaceous Listric-Normal Faulting, West Flank, Denver Basin

Seismic studies along the west flank of the Denver basin near Boulder and Greeley, Colorado illustrate the interrelationship between shallow listric-normal faulting in the Cretaceous and deeper basement-controlled faulting. Deeper fault systems, primarily associated with the Transcontinental arch, control the styles and causative mechanisms of listric-normal faulting that developed in the Cretaceous. Three major stratigraphic lev-