deposition of shelf clastics and dolomitic carbonates was interrupted by several long erosional hiatuses. Major recognizable tectonism first appeared in the Devonian with at least one depositional basin formed west of the Defiance-Zuni uplift. Thin Early Mississippian shelf carbonates and evaporites covered nearly the entire region.

The most significant tectonic activities started in the late Chesterian and extended with increasing magnitude until the end of Wolfcampian time. Local basins and uplifts date from this interval and occurred in two belts. One belt was about 80 mi (130 km) wide along the western sides of the Hueco and Pedernal uplifts and along both sides of the Uncompahgre uplift. Another belt extended northwest from the Pedregosa basin into southeastern Arizona. Major tectonic events initiated the Morrowan, Atokan, and Missourian Epochs and occurred twice within the Wolfcampian Epoch. Leonardian, Guadalupian, and Ochoan Epochs were times of tectonic stability. During the Leonardian, sediments from the Uncompaghre uplift gradually covered all the other uplifts.

The timing of these Paleozoic tectonic events suggests a cause-effect relationship with plate-tectonic histories that brought North American and northern Europe together in the Late Devonian (Acadian orogeny) and Euramerica and northwestern Gondwana together in the Late Mississippian through Early Permian (Appalachian orogeny).

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Lemhi Arch, a Late Proterozoic and Early Paleozoic Landmass, Central Idaho

The northwest-trending Lemhi arch of central Idaho first formed in late middle Proterozoic time, and as much as 4,500 m (14,760 ft) of middle Proterozoic clastic rocks were eroded in later Proterozoic time. The west flank of the arch was partly covered in late Proterozoic(?) and Early Cambrian time by the Wilbert Formation. On the east flank, westward-thinning marine sedimentation began with deposition of the Middle Cambrian Flathead Formation, and continued through the Late Cambrian. During Ordovician and Silurian times, the east flank of the arch was dry. The west flank was submerged in the Ordovician, and the Summerhouse Formation, Kinnikinnic Quartzite, and Saturday Mountain Formation were deposited. The west flank of the arch was briefly exposed after deposition of the Saturday Mountain Formation, but was partly submerged later in the Silurian, when the Laketown Dolomite was deposited. During the Middle and Late Devonian, deposition was renewed on the west flank of the arch, where the Jefferson Formation indicates eastward transgression. The east flank was exposed until the Late Devonian, when a thin sequence of the Jefferson and Three Forks Formations was deposited across the top of the arch, and marine sedimentation was continuous from the miogeocline far onto the craton.

The Lemhi arch continued to influence marine deposition even after it was submerged, separating shelf deposits in southwest Montana and east-central Idaho from miogeoclinal deposits in central Idaho. The arch was overridden by the Medicine Lodge thrust in late Early and Late Cretaceous times.

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Stratigraphy and Depositional History of Coyote Creek-Miller Creek Trend, Lower Cretaceous Fall River Formation, Powder River Basin, Wyoming

The Coyote Creek-Miller Creek trend produces high-gravity, low-sulfur oil from a series of Fall River fields in an area generally characterized by west-southwestward monoclinal dip. The trend includes, from south to north, the Coyote Creek South, Coyote Creek, Donkey Creek, Kummerfeld, and Miller Creek fields. The Wood and West Moorcroft fields produce oil from very similar Fall River traps located several miles east and northeast, respectively, of Miller Creek. Only Donkey Creek includes structural closure; all of the other fields produce from purely stratigraphic traps. The reservoir sandstones are characterized by upward-fining sequences. These sequences locally replace and are generally easily distinguishable from two regionally correlative upward-coarsening sequences. Analyses of cores and nearby outcrops indicate that the upward-fining sequences accumulated on point bars of a meandering river; the upward-coarsening sequences were deposited on the fronts of northwestward-prograding deltas. Detailed mapping of the fluvial and delta-front facies demonstrates that the Coyote Creek-Miller Creek trend, together with the Wood and West Moorcroft fields, represents a meander-belt system that was contemporaneous with the younger of the two delta-front units. Each of the stratigraphic-type fields occurs at a convexity along the eastern edge of the irregularly shaped meander belt; each consists of numerous point bars. Clay plugs, which resulted from infilling of abandoned meander loops, were preferentially preserved along the margins of the meander belt, where they now serve as updip permeability barriers between the oil-bearing fluvial and water-wet delta-front sandstones.

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Stratigraphy, Depositional History, and Petroleum Geology of Lower Cretaceous Fall River Formation, Powder River Basin, Wyoming

The middle Albian Fall River Formation, better known to petroleum geologists as the "Dakota Sandstone," constitutes a northwestward-thinning wedge of predominantly sandy strata under and overlain by marine shale. Two major episodes of deltaic progradation can be recognized in the formation, permitting mapping of lower and upper deltaic members. Study of outcrops, cores, and subsurface relationships indicates that the Fall River consists predominantly of fluvial strata in the southeastern part of the Powder River basin; delta-front and delta-plain facies, which are cut out and replaced locally by northwest-trending meander belts, predominate in an area that trends northeastward across the central part of the basin; the delta-front facies pinches out into offshore marine shale in the northwestern part of the basin. The large majority of Fall River stratigraphic trap-type fields produce oil and gas from sandy meander-belt deposits. The largest accumulations of hydrocarbons in traps of this type, as exemplified by the Powell-Mexican Springs trend (lower member) and the Coyote Creek-Miller Creek trend (upper member), occur in the more seaward parts of the deltaic members, near the seaward termini of meander-belt systems. Mapping of meander belts and of the surrounding deltaic deposits constitutes a necessary first step in exploration for stratigraphic traps within the Fall River Formation.

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Upper Cretaceous Vernal Delta of Utah—Depositional or Paleotectonic Feature?

A conspicuous seaward bulge of the middle to late Turonian shoreline of the Cretaceous seaway in northeastern Utah and southwestern Wyoming has been identified by previous authors as the Vernal delta. Strata of the Frontier Formation and the Ferron Sandstone Member of the Mancos Shale that form the Vernal delta consist largely of fluviodeltaic facies. The delta, however, is not recognizable as a locus of Turonian sedimentation; there is no isopach thick associated with it.

The Vernal delta is a large feature, encompassing an area of at least 6,250 mi^2 (16,187 km^2). A comparison between the depositional setting and paleogeography of northeastern Utah during the Late Cretaceous and a present-day area on the east flank of the Andes in Colombia indicates strong similarities. Further comparison suggests that a feature the size of the Vernal delta could not have been produced by a single river.

The Vernal delta overlies the ancestral Uinta Mountain uplift, an area where Cenomanian marine shales were entirely removed by what appears to have been submarine erosion during early Turonian time. When the shoreline prograded eastward across this area during middle Turonian time, the sediment load caused the area to subside, but at a rate slower than rates of subsidence to the north and south. This differential subsidence is the cause of the shoreline bulge. Although it includes deltaic facies, the Vernal delta is not a delta per se, but a feature produced as the result of interaction between sedimentation and gentle tectonic movement of the ancestral Uinta Mountain uplift.

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Models for Hydrocarbon Accumulation and Maturation in Deep Dysaerobic Basins

The Mississippian Delle Phosphatic Member forms the basal member of seven different formations from southeastern Nevada, through Utah, to southeastern Idaho. The Delle is comprised of mainly dark organic-rich phosphatic mudstone containing large micritic limestone concretions, and bedded radiolarian chert, peloidal phosphorite, and cherty micrite. It was deposited in Osagean to Meramecian time within the eastern half of the Antler foreland trough in dysaerobic settings of the Deseret starved basin and adjacent lower foreslope of a carbonate platform. The Delle Phosphatic Member lacks conspicuous shelly megafaunas but contains a rich microfauna, consisting most importantly of conodonts, radiolarians, and agglutinate foraminiferans. Also present are fewer large planktonic, epiplanktonic, nektonic, and benthic animals, and floating marine and transported land plants. Knowledge of this diverse biota, recovered mostly from the large micritic limestone concretions, is important to an understanding of the source of hydrocarbons in the organic-rich sequence. Organic carbon values are inversely related to conodont alteration index (CAI) values, and comparison of maps of these two sets of values suggests areas where hydrocarbons are either overmature or at optimum maturation for petroleum generation. Models for hydrocarbon accumulation and maturation in the Delle are applicable worldwide to other dysaerobic deep-basinal dark rocks containing similar concretions—for example, the Devonian and Mississippian Bakken-Exshaw-Sappington-Leatham depositional complex and Permian Phosphoria Formation of the western United States, the Devonian Huron Shale Member of the Ohio Shale in Ohio, and the Upper Devonian sequence of western New York.

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New Biostratigraphic and Paleotectonic Interpretation of Devonian and Mississippian Rocks in Southwestern Montana Thrust Belt

The structurally complex area of previously undifferentiated Mississippian rocks below the Meramecian Kibbey Sandstone in the southwestern Montana thrust belt of the northern Tendoy Range actually comprises an unusual combination of Devonian and Mississippian basinal, slope, platform, and nearshore deposits. The lower part of this sequence comprised two widespread western Montana formations: the Devonian part of the Three Forks Formation over 65 m (213 ft) thick, containing all three members, and the basinal Kinderhookian and Osagean Paine Limestone, 228 m (748 ft) thick. However, the Paine is succeeded by an eastern tongue of the older, Osagean part of the lower-slope Middle Canyon Formation, 266 m (872 ft) thick. This tongue consists of clinoform cherty micrite and bedded chert, with some encrinite debris flows that increase upward in number and thickness. The overlying Osagean and Meramecian Mission Canyon Limestone comprises 102 m (335 ft) of an upper-slope encrinite lower member and 74 m (243 ft) of a mainly shelf-margin wackestone and encrinite upper member. Thus, the Mission Canyon here represents the distal part of a broad carbonate platform. Succeeding the Mission Canyon is 140 m (459 ft) of the newly named Meramecian McKenzie Canyon Limestone, which comprises a sabkha, back-mound, and lagoonal sequence of evaporite-solution breccia, micrite, dismicrite, and pelmicrite, with interbeds of crinoidal wackestone, encrinite, and bio-oopelsparite. This formation represents beds absent at an unconformity elsewhere in western Montana and western Wyoming. Thus, the sequence from the Paine through the McKenzie Canyon, constituting the newly named Tendoy Group is 810 m (2,657 ft) thick and represents one of the most complete records of Kinderhookian to Meramecian carbonate deposition in the northwestern United States, displayed in the predominantly upward-shallowing part of a eustatic megacycle. The reconstructed detailed biostratigraphy aids new structural interpretations and provides several new plays for petroleum exploration in the Montana thrust belt.

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Rediscovering an Abandoned Reservoir: Lakota Formation at Lost Soldier Field, Fremont County, Wyoming

Lost Soldier field (T26N, R90W) is one of several fields that parallel the Granite Mountains uplift. The subsurface structure at the Lakota level is a northwest-trending, doubly plunging anticline. The Lakota Formation at Lost Soldier field is a complex, fluvial-sand sequence, representing braided- and meandering-stream environments. Lakota channels have both podlike and sheetlike geometries, and grade laterally into crevasse splay and floodplain deposits.

The Lakota reservoir was discovered in 1922. Between 1922 and the early 1950s, the reservoir produced about 5 million bbl of oil. The early Lakota wells were drilled mainly on the top of the structure and along lease lines. These early wells were all shut-in by the early 1950s when the Lakota reservoir, thought to be depleted, was abandoned.

During the late 1970s, following Amoco's purchase of Lost Soldier field, Amoco geologists noticed high-resistivity anomalies in the Lakota Formation. In 1979 a well was recompleted in the Lakota with an IP of 65 BOPD and 22 BWPD. The successful recompletion proved that the early Lakota producers had not completely drained the reservoir.

Since 1979 Amoco has completed or recompleted 22 Lakota producers. These wells have been drilled to define the oil-water contact for the Lakota, to develop a thick net-sandstone trend on the southern end of the structure, and to test the Lakota production potential in other parts of the field. It is estimated that the recent Lakota wells will produce about 1 million bbl of oil. The average IP for the wells is 67 BOPD and 104 BWPD.

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Erosional History and Possible Passive Uplift of Paris-Willard Thrust Allochthon, Wyoming-Idaho-Utah Thrust Belt

Stratigraphic distribution of clast lithologies in Sevier foreland basin synorogenic conglomerates in the southwestern Wyoming–southeastern Idaho–northeastern Utah thrust belt provides evidence of the erosional history of the Paris-Willard thrust allochthon. Conglomerates of the Upper Jurassic-Lower Cretaceous Gannett Group were deposited in response to initial movement along the Paris-Willard thrust system and are comprised of cobbles and pebbles of Ordovician through Jurassic strata, with upper Paleozoic and lower Mesozoic clasts most common. Thus, by conclusion of initial Paris-Willard thrust movement, the allochthon had been affected by widespread erosion of lower Paleozoic through lower Mesozoic strata.

Evidence for subsequent erosion to deeper stratigraphic levels is contained in the basal Hams Fork Conglomerate Member of the Upper Cretaceous–Paleocene Evanston Formation. This unit contains abundant Precambrian quartzite cobbles, which must have been derived from the Paris-Willard allochthon, the only thrust sheet that contains Precambrian quartzite units. Genesis of the Hams Fork Conglomerate has been related to latest Cretaceous major movement along the Absaroka thrust. Thus, either the Paris-Willard thrust was fortuitously reactivated at the same time as major Absaroka thrust movement or uplift associated with movement along the Absaroka thrust resulted in coeval uplift of the Paris-Willard allochthon.

One mechanism that could elevate the older Paris-Willard allochthon and allow for erosion to deep stratigraphic levels during major displacement along the Absaroka thrust would involve antiformal arching of the Paris-Willard allochthon as it was carried passively over a major footwall ramp of the Absaroka thrust. Folding and uplift of older "passive" thrusts carried piggyback by younger "active" thrusts might be an important mechanism in formation of source terranes for synorogenic foreland basin clastics.

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Integrating Geology and Geophysics in an Interactive Environment

Seismic data may be used to enhance well data in a prospect area. The method involves the generation of depth, time, and velocity surfaces, and manipulation of these surfaces to generate an integrated depth, structure, or isopach map.

The usual sequence is: (1) use well data to generate a depth surface, (2) use seismic data to generate a time surface, (3) divide the above two to obtain a velocity surface, (4) interpolate velocities for seismic data using the velocity surface, (5) calculate depth for seismic data, (6) merge depths from seismic data with those from well data, and (7) use combined depths to generate the enhanced depth surface.

There can be many variations to this procedure, yielding better results in some situations. Special handling is required when there are mis-ties or