and a well-defined pattern of northeast-trending gravity and aeromagnetic anomalies underlying this part of central Montana and southwesternmost Saskatchewan.

Taken together, all these geologic features define a broad, northeast-trending zone at least 150 to 200 km (93 to 125 mi) wide and more than 1,000 km (620 mi) long. The zone is approximately colinear but not demonstrably continuous with the well-exposed boundary in eastern Saskatchewan and Manitoba between the Archean Superior and the Proterozoic Churchill provinces of the Canadian Shield. This boundary is also characterized by: high-angle faults, shear zones, and topographic lineaments; pronounced linear gravity and magnetic anomalies; igneous intrusions; and fault controlled depositional patterns and mineralization. That the Great Falls lineament is controlled by a similar Precambrian boundary between the Archean Wyoming province of southwestern Montana and early Proterozoic terrane to the north is speculative; however, the geologic features found along the Great Falls lineament share many common characteristics with features present along the Archean-Proterozoic boundary in Canada.

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Erosional History of Big Horn Basin: Mackin Revisited

The classic study of the erosional history of Big Horn basin is by Mackin in 1937. In it he studied the terrace levels which ranged in age from Late Tertiary to late Pleistocene. He postulated that the terraces were the product of stream captures or intervals of interglacial stability alternating with glacial incision. More recent studies have revised Mackin's classically simple model.

Detailed studies have increased the number of terrace levels, changed the timing of their stability episode, and estimated their ages. The number of terrace levels has been increased to nine along the Greybull and Bighorn Rivers and to six along the Shoshoni River. Because some of the different levels occur along each river, the number of unique levels within the basin is 12. The occurrence of a 600,000 and a 100,000 year old ash on two terrace levels allows the ages of the terraces to be estimated. The estimated ages range from 3 m.y. for the Tatman to 49,000 years for the Himes, which is the lowest level along the Bighorn River. Both ashes were deposited during river stability intervals and indicate that the Bighorn River and its eastern tributaries were stable late in the interglacial episodes. In contrast, the glaciofluvial gravels along the Shoshoni River at Cody indicate a late glacial stability episode for the western tributaries. The terrace cycles along the Bighorn River and its western tributaries are therefore out-of-phase. This relationship fostered the numerous stream captures recognized by Mackin, as well as some unusual terrace geometries. Comparison of the estimated terrace ages to termination in the marine isotopic record indicates that not all of the Pleistocene climatic cycles are preserved in the Big Horn basin terrace chronology. The present chronology is currently more complete than that of Mackin's pioneering work of the 1930s, but it has not changed his basic story.

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Seismic Data Acquisition Parameters, Northwest Montana

The Montana Overthrust area and adjacent Disturbed Belt are characterized by extremely complex geology and rugged topography. To date, several hundred miles of high quality seismic data have been acquired in this area. The first step in obtaining this data quality was to understand the physical characteristics of the rock properties for seismic signal and noise, then to apply this information in designing our data acquisition parameters.

At the commencement of each seismic specification program, a complete suite of experimental tests were run over carefully selected areas. These tests generally included noise and reflection analysis, geophone patterns, energy input patterns, offsets, expanding spreads, and specific problems (i.e., traffic, freezing, thawing). From these tests, appropriate field parameters were selected for various surface and subsurface geologic environments.

It is the scope of this paper to discuss the results of these tests and the subsequent fine tuning of both acquisition and processing parameters of this data.

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Late Jurassic Tectonism on West Side of Colorado Plateau, Utah and Arizona

Detailed sedimentologic studies in south-central Utah and north-central Arizona indicate that several major basins and uplifts as well as many smaller folds within them were actively growing during deposition of the Salt Wash Member of the Morrison Formation. The region lies outside that part of the Colorado Plateau underlain by thick Pennsylvanian halite deposits so the structures are not related to salt deformation. Tectonic activity in the region is inferred from several types of sedimentologic features which include thickness variations, facies distribution, cross-bedding parameters, and bedding ratios. Distribution of the various features studied indicates the Emery, Circle Cliffs, Echo Cliffs-Kaibab, Cow Springs, and Monument uplifts, as well as the Henry and Kaiparowits basins, were active during the Late Jurassic. In addition, several anticlines and synclines that were active at the same time can be delineated in or near the Henry and Kaiparowits basins.

The apparent absence of local angular unconformities in the Salt Wash near the positive structures suggests that most of the tectonic movements were the result of differential subsidence rather than uplift of the positive structures. It could not be determined if the San Rafael swell near the Emery uplift was active during Late Jurassic time. Also, the relationships are not entirely conclusive but suggest that the Cow Springs uplift may have extended southeast across Black Mesa and that downwarping may not have occurred there in the Late Jurassic.

Late Jurassic folds have essentially the same northwest to north-northwest trend as many of the Laramide and possibly younger folds in the region although the older folds tend to be less sinuous. Vertical repetition of lacustrine strata, deposited under conditions especially sensitive to slight tectonic movements, suggest that the movements were episodic. Comparison of the present amount of structural relief with the Late Jurassic structural relief indicates that approximately 3 to 7% of the present-day relief between several of the major basins and uplifts can be attributed to tectonic movements during deposition of the Salt Wash. Thus, it is erroneous to assume that all of the structural deformation in the region occurred during or after the Laramide orogeny.

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Mesozoic and Early Tertiary Paleostructure and Sedimentology of Central Wasatch Mountains, Uinta Mountains, and Uinta Basin

During latest Cretaceous-Eocene time, 5,000 m (16,000 ft) of beds were deposited in central and northeast Utah. In the Late Cretaceous, sediment derived from the Sevier-Laramide thrust belt was transported to the east and southeast. Southerly paleocurrent directions in the base of the Currant Creek Formation (Maestrichtian) raise the possibility that uplift of the Uintas may have begun by then. The thrust belt continued as a major highland during the early Paleocene, and major uplift of the Uintas occurred. By the middle Paleocene there was an extensive lake which regressed during the late Paleocene as uplift of the Uintas continued. Lake Uinta reached its maximum size during the middle Eocene. During the late Eocene, Lake Uinta regressed and, near the end of the epoch, the lake expired. Major sediment influx was from the east and southeast. Lower (early Duchesnean) and upper (Late Duchesnean) conglomeratic intervals record major episodes of uplift in the Uintas during latest Eocene.

Structurally, the Wasatch Mountains are part of a marginal foreland fold and thrust belt. In the northern Wasatch Mountains, pre-Late Cretaceous thrust fault plates were folded in part of a large, ramp-anticline that is cored by allochthonous, crystalline basement. Foreland thrust belt structures in the central Wasatch Mountains were folded about the east-trending Uinta axis as the Uinta Mountains formed. Eastward movement on the Hogsback thrust during the Paleocene was transferred onto the adjacent Uinta axis and Uinta Mountains structure, causing about 20 km (12 mi) of sinistral slip in the western Uinta Mountains. Deformation in the Uinta Mountains continued following cessation of movement on the Hogsback thrust system. A south-dipping fault ramp was located beneath the Uinta Mountains and extended to depths of 15 to 20 km (9 to 12 mi).

Oblique-slip on this ramp probably resulted in about 20 km (12 mi) of crustal shortening perpendicular to the trend of the mountains.

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Dissolution of Permian Salt and Mesozoic Depositional Trends, Powder River Basin, Wyoming

Salt deposits in the Powder River basin of Wyoming occur in the Late Permian Ervay Member of the Goose Egg Formation which was deposited in a redbed-evaporite trend extending from the Williston basin of North Dakota to the Alliance basin of Nebraska and Wyoming. However, only remnants of the once extensive Ervay salt remain in the Powder River basin, with major salt dissolution events occurring during Late Jurassic and Early Cretaceous. Subsidence and deposition at the surface were contemporaneous with subsurface salt dissolution except in areas where uplift and erosion were occurring. The presence or absence of Ervay salt and the relationship to overlying syndepositional strata can be seen readily and mapped using borehole logs or seismic data.

Earliest dissolution of the Ervay salt occurred in the Jurassic, during regional uplift and erosion of the overlying Triassic Chugwater Formation in the present Hartville uplift and southeastern Powder River basin areas. Thickness variations of the Canyon Springs and Stockade Beaver members of the early Late Jurassic Sundance Formation, which unconformably overlie the deeply eroded Chugwater Formation, may be related in part to dissolution of the Ervay salt. Extensive salt dissolution, synsubsidence, and syndeposition occurred throughout most of the Powder River basin during latest Jurassic and Early Cretaceous. Evidence of this is seen in thick trends of the Morrison, Lakota, Dakota, or Muddy formations overlying areas of Ervay salt collapse. One area escaping extensive dissolution in the Early Cretaceous was the eastern Belle Fourche arch, which trends northeast across the middle of the Power River basin. Here the Lakota, Dakota, and Muddy formations are thin over areas with underlying Ervay salt, but thicken rapidly in areas of salt collapse.

Many producing fields from the Mowry, Muddy, and Dakota formations exhibit either rapid stratigraphic changes syndepositional to salt collapse or fracture-enhanced reservoir quality due to postdepositional salt collapse. Major Muddy accumulations occurring in areas of local Ervay salt collapse include Kitty, Hilight, Fiddler Creek, and Clareton which have produced jointly over 172 million bbl of oil. The relationship of Ervay salt dissolution to Lower Cretaceous deposition can be exploited as an effective exploration tool.

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Structural and Depositional History, Jefferson and Madison Basins, Southwestern Montana

Recent seismic and gravity data from the Cenozoic Jefferson and Madison basins provide new information concerning their structural and depositional histories. Both basins are north-south elongated structural basins formed as a result of horizontal extension after Laramide horizontal thrusting. Each basin is bounded on the east side by a sinuous faulted steep mountain front, and large west-sloping alluvial fans extend almost completely across both basins.

Gravity data show that each basin in the subsurface is asymmetric with a large steep west-dipping fault on the east flank, and one or more east-dipping fault(s) of smaller magnitude on the west flank. The deep axis of each basin runs parallel to the east mountain front and lies east of the surface geographic central axis. Jefferson basin has two deep, closed, structural lows (one east of Silver Star and one east of Twin Bridges), which are separated by a structural arch. Sediment depth on the arch exceeds 3,000 m (10,000 ft). Madison basin is shallow on its north end (approximately 2,100 m, 7,100 ft) where it is terminated by the prominent northwest-southeast Spanish Peaks structural trend, and progressively becomes deeper (4,500 m, 5,000 ft or more) south of Ennis, Montana.

Seismic data confirm or support the gravity data. Seismic also shows the folded and thrusted rocks of the east mountain footwall block dipping steeply westward to where they gradually disappear beneath the thick Tertiary sediments. Tertiary strata lying directly against the large west-dipping basin fault show dip reversal caused by drag-folding during basin subsidence. Downthrown "rollover" type anticlines are thus present on the east side of the basins. Numerous small faults, many antithetic, cut the deeper strata and diminish in throw upward.

Strata seen in the seismic sections can be subdivided into a lower set which forms the bulk of the basin fill (possibly equivalent to the Renova Formation, late Eocene to early Miocene); a thinner middle set unconformably overlying the lower set (equivalent to the Sixmile Creek Formation, Miocene and Pliocene); and an upper set composed of west-dipping Quaternary alluvial fan deposits. Each set thickens toward the east basin-bounding fault. In the lower "Renova" set, lacustrine intervals are indicated by their consistent lateral seismic character, whereas fluvial intervals appear to terminate abruptly.

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Example of Inner-Shelf Sand Ridges from Upper Cretaceous Eagle Sandstone, Central Montana Uplift

The Upper Cretaceous Eagle Sandstone of central Montana was deposited during a general eastward progradation of the western shoreline of the narrow, north-south-trending Western Interior epicontinental seaway. Cordilleran highlands to the west were episodically uplifted, and provided the main source for sediments deposited in the seaway.

On the Central Montana uplift, the lower member of the Eagle consists predominantly of very fine-grained sandstone, which is exposed as a thick (average 100 ft, 30 m), continuous topographic rim. This sandstone gradationally overlies shales of the Telegraph Creek Formation. Within the rim, resistant beds and concretions of calcite-cemented sandstone define several smaller units, which can be traced laterally over distances of several miles. These units maintain fairly uniform thicknesses from north to south. However, in an east-west direction, the units thin, are imbricated, and become younger to the west. Excellent exposures of these imbricated lenses occur along a rim that extends 12 mi (19 km) southwest from the town of Winnett.

Although the sandstone of the lower member is very fine-grained throughout the rim, systematic changes occur within a single lens. These changes include: (1) thinning and grading into shale and siltstone to the southwest: (2) bioturbation decreasing upward and to the northeast; (3) oblique *Asterosoma* burrows predominating in the lower part of each lens and to the southwest, with horizontal *Ophiomorpha* burrows being more common in the middle part of each lens and to the northeast; (4) parallel bedding and hummocky cross-stratification successively occurring in the upper part of each lens and to the northeast; and (5) relatively straight-crested symmetrical ripples generally capping each lens. The sedimentary structures within each lens indicate increasing energy and shoaling upward, but do not indicate subaerial exposure.

The lenses in the lower member are interpreted as landward-prograding (westward) sand ridges that were deposited on the inner shelf at distances of tens of miles from the shoreline. Laterally equivalent coastal sandstones of the Virgelle Sandstone Member prograded seaward (eastward) at this same time. The lenses are elongated in a north-south direction, generally parallel to the coast. However, the exact geometry of individual ridges is unknown. After bypassing the shoreface zone, the sand probably was transported parallel to the shoreline by geostrophic currents driven by wind-forcing. Storm waves reworked the upper, seaward-facing slopes of the ridges, whereas landward-facing parts of the ridges were more protected and subjected to bioturbation.

Ridges that occur on the Central Montana uplift are comparable in many aspects to sand ridges on the modern Atlantic inner shelf. However, the modern sand ridges differ from those of the Eagle in two ways: (1) they occur at angles oblique to the shoreline, and (2) they resulted from "shoreface detachment" during the Holocene transgression.

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Haybarn Field, Fremont County, Wyoming, an Upper Fort Union (Paleocene) Stratigraphic Trap