Bear River marine shales grade upward into marine shales of the Aspen Formation, deposited when the Mowry sea transgressed across the thrust belt region. Lack of significant tectonic activity during this time is suggested by the paucity of sand in the Aspen Formation.

Aspen strata pass upward through marginal marine strata into a thick sequence of meandering stream deposits of the Frontier Formation that were derived from erosion of subdued Paris-Willard highlands. Subsequent transgression of the Greenhorn sea westward covered the entire region, producing extensive Frontier marginal marine sandstones and marine shales. Renewed intensive uplift in the source area caused rapid eastward progradation of the Greenhorn sea shoreline and concurrently deposited cobble conglomerates in northeastern Utah. Coarse detritus was deposited in eastward-flowing braided streams near the source area (northeastern Utah) and in meandering stream channels farther eastward (western Wyoming). The Niobrara sea subsequently covered much of the region, and synorogenic sedimentation related to the Paris-Willard thrust system was thus completed.

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Trace Fossils as Environment Indicators in the Rocky Mountains

Ichnology is the study of the traces ancient organisms have left in or on the substrate. These traces, or lebensspuren, are in the form of tracks, burrows, trails, or borings, and are important clues in determining ancient rock environments.

Throughout time, organisms have left various types of traces while engaged in different activities. The two major types of lebensspuren were made by suspension feeders found in turbulent water where organic matter is held in suspension, and by deposit feeders whose habitat is found in quiet, deeper waters where large quantities of organic matter settle from suspension.

The different activities which occur in these two environments are the cause of the traces found in sediments. These include escape structures resulting from degradation or aggradation of sediments, feeding structures, dwelling structures, grazing traces, crawling traces, and resting traces.

The use of trace fossils in hydrocarbon exploration is especially helpful in the Cretaceous sandstones of the Rocky Mountains because of the relative abundance of outcrops and the scarcity of body fossils. By combining the interpretation of physical processes with the biological traces, one more tool is made available in the determination of rock environments as an aid in hydrocarbon exploration.

Materials exhibited include 8 × 10 color prints of different Cretaceous lebensspuren, hand-drawn "cartoons" of the six different trace activities, and a regional cross section of the Eagle sandstone illustrated by photographs of different traces near each location, as well as a variety of rock samples.

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Color Infrared Imagery as an Aid to Regional Geological Mapping

Frontier areas, particularly, lend themselves to initial phase study via remote sensing imagery. The many types of satellite imagery have the advantage that large areas of the earth's surface may be studied quickly, cheaply, and thoroughly enough to lead directly into more detailed photogeology and/or surface mapping. Imagery can be acquired in various spectra, the most useful of which are normal color, normal black and white, color infrared, black and white infrared, and side-looking radar. Perhaps the best single imagery for most geological mapping is the band 7 "False Color" infrared, at the scale of 1:250,000. Each photo measures approximately 29 in.$^2$ (187 cm$^2$) and covers 115 mi (185 km) on a side; the cost in 1982 was $80 per photo.

Using the 1:250,000 band 7 color infrared images, good sharpness and color contrast are retained, yet enough magnification is present to allow visual recognition of roads, small towns, smaller lakes and streams, railroads, and agricultural features. Recognition of such physical features is necessary for satisfactory ground control.

Geologic and geomorphic features such as tonal, color, and drainage anomalies, linears, and more direct features such as actual geologic structures, faults, and regional structural dip directions often may be recognized. In areas of sparse well control and/or limited geophysical data, recognition of such features and geological data is of extreme importance and is a good beginning step in studying remote areas.

I have selected two 1:250,000 band 7 color infrared images from central and north-central Montana to display the variety of geologic, geomorphologic, and physical features that may be determined. Easily denoted features include regional dip; domal and anticlinal structures; tonal, drainage, and color anomalies; regional lineations; fault traces, and igneous activity. Subtle features are shown such as noses, subtle anticlines, and radial and concentric fracture patterns associated with the Bearpaw and Little Rockies uplifts. Follow-up work was performed using 1:20,000 stereo pairs, and several examples are available for inspection. In many situations, the leads from color infrared imagery subsequently proved to be bonafide geologic features.

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Landsat Linear Features in Montana Plains

Multispectral scanner images obtained from satellites provide a unique regional perspective of geologic features on the earth's surface. Linear features observed on Landsat images are particularly conspicuous and can be mapped easily. In Montana, east of long. 110°W and in adjoining parts of Canada, the Dakotas, and Wyoming, linear features have been mapped on 14 images. Black and white film products in bands 5 and 7 at a scale of 1:1,000,000 were employed. Specific linear features observed on both bands were compiled on a mosaic covering more than 90,000 mi$^2$ (233,000 km$^2$). Trends to the northwest and northeast are most common, but north-south and east-west linear features are also observed.

Four separate tectonic regions of the Montana plains seem to be characterized by different populations of linear features. In an area 100 mi (160 km) wide along the Canadian border, linear features trending northwest are common, and only a few local structures, such as Poplar and Bowdoin domes, are present. In the vicinity of the Central Montana uplift, east-west linear features are associated with features trending northwest and northeast. An area 80 mi (129 km) wide along the Wyoming border has linear features which trend dominantly north-south and east-west, although northeast and northwest trends are also present. This part of southern Montana includes the northern flanks of the Big Horn uplift, Powder River basin, and Black Hills uplift. In eastern Montana the western margin of the Williston basin has linear features which trend mainly northeast and northwest; north-south and east-west trends are rare.

Published syntheses of geophysical, structural, and stratigraphic data can be used to establish the geologic significance of specific linear features. Magnetic, gravity, and seismic data suggest that linear features may reflect basement structural elements such as fault-bounded blocks. Some specific geologic structures shown on structure contour maps are marked by linear features. Examples include Bowdoin dome, portions of Cat Creek, Lake basin, and Nye-Bowler fault zones, Cedar Creek anticline, and the Brockton-Froid fault zone. Paleotectonic features interpreted from stratigraphic maps have surface expression on Landsat that have not been recognized previously. For example, the southern margin of the Alberta shelf (Mississippian) appears to correspond with a zone of concentrated east-west linear features in north-central Montana.

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Late Cretaceous marine deposition in the western interior of the United States occurred in an epicontinental seaway elongate in a north-south direction. In central Montana, the western side of the seaway was characterized by a broad, tectonically active shelf. In eastern Montana and the western Dakotas, an actively subsiding basin was located in the central part of the seaway. In western and central South Dakota, the eastern side of the seaway was a more stable west-sloping ramp. Distinctive facies belts in the Eagle Sandstone and equivalent rocks are found in each of these tectonic settings, and some specific tectonic features have expression in the facies patterns. However, paleotectonism was even more important than suggested by these regional patterns. Selected study areas show that subtle tectonic features have influenced deposition within each of the regional facies belts.

On the western shelf, coastal sandstones of the Eagle Sandstone near the Bearpaw Mountains show facies and isopach variations which are controlled by linear features visible on satellite images; the linear features generally trend north-south and east-west. Inner shelf sandstones of the Eagle thin and pass laterally northeastward into marine siltstones and shales across the Cat Creek fault zone near Winnett, Montana. Sandstone lenses in the lower Eagle, which are interpreted to be sand ridges, prograde south and west at approximately right angles to the fault zone. Farther east on the outer margin of the western shelf, areas of sand ridge fields in the Shannon Sandstone Member of the Gammon Shale are delimited by northeast and northwest linear features observed on satellite images near the northern Black Hills. Within the basin, thick areas of Gammon Shale are delimited by northeast and northwest lineaments interpreted from Landsat linear features. On the eastern ramp, noncalcareous shales of the Gammon Member of the Pierre Shale thin and intertongue eastward with chalks in the upper part of the Niobrara Formation. This facies change occurs across linear features visible on Landsat images in western South Dakota. To the east at the inner margin of the ramp, the degree of erosion on the unconformity between the Niobrara Formation and the overlying Pierre Shale changes systematically across northeast-trending Landsat linear features observed near the Missouri River in central South Dakota.

Based on these studies, we interpret the stratigraphic variations to be the expression of paleotectonism on discrete basement blocks bounded by fault zones which are observed on Landsat images as linear features. On the western shelf, elevated blocks controlled the sites of the winnowing and deposition of sandstones. Within the basins, subsiding basement blocks were filled by deposition of shales. These basin blocks acted as sediment sinks which inhibited the eastward dispersal of terrigenous materials from the west. On the eastern ramp, chalks were deposited and locally eroded on slightly elevated blocks which were relatively free of terrigenous material. Paleotectonism, therefore, influenced deposition not only on the active western shelf and in the basin, but also on the more stable eastern ramp.

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## Origin and Development of Northern Green River Basin: A Stratigraphic and Flexural Study

Two-dimensional profiling of the northern Green River basin using topographic, stratigraphic, and structural information shows that the basin can be modeled effectively as a flexural depression resulting from extrabasinal and intrabasinal loading on an elastically behaving lithosphere. Two distinct approaches were used: present basin geometry profiling and sediment thickness profiling. Present basin geometry profiling involves analysis of predicted present-day basin configuration compared with the observed configuration. Sediment thickness profiling, a procedure based on isostatic compensation for flexural responses to loading, relates stratigraphic thicknesses of basinal rocks to coeval tectonic loading. Results of both methods suggest that lower Tertiary and perhaps some uppermost Cretaceous sediments accumulated as a result of flexure due to loading by the Darby and Prospect thrusts to the west and the Wind River foreland thrust to the east. Moreover, results of the sediment thickness profiling are of predictive value, resolving stratigraphic problems and timing structural events. Tentative results imply: (1) the northern Green River basin was full by the end of the early Eocene, and subsequent erosion has been negligible; and (2) the first movement on the Wind River thrust in latest Cretaceous was significant in controlling basin configuration.

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## Ennis Geothermal System Fracture Porosity: an Overthrust Effect?

The Ennis geothermal area is believed to be an elliptical field, roughly 1/2 mi long in a north-south orientation and 1/4 mi wide, located 1 1/2 mi north of Ennis, Montana. The valley is bounded by Precambrian (X) rocks to the west, and by Paleozoic and Mesozoic rocks to the east. Geophysical data indicate a major north-south valley-bounding fault, and the presence of minor east-west cross-valley faults with minor displacement. The geothermal fluids occur with the quartzofeldspathic gneiss and hornblende gneiss which is overlain by a thin (465 to 650 ft, 140 to 200 m) layer of Tertiary and Quaternary sediments along the major axis of the field. Production is from a highly fractured zone within bedrock. Fluids produced average 189°F (87°C), with a total dissolved solids content of 1,000 mg/L.

Two wells penetrate the fracture zone, and a third well is completed in the Precambrian gneiss but is not believed to intersect the major fracture zone. The southern deep well, TX-12, intercepted the top of the fracture zone at a depth of 492 ft (150 m), 25 ft (8 m) below bedrock contact; it penetrated the bottom of this zone at a maximum depth of 615 ft (187 m), 148 ft (45 m) below top of bedrock. The northern well, MAC-1, intersected the fracture zone between the depths of 1,100 to 1,200 ft (335 to 365 m). The nonflowing temperature log on TX-12 shows a maximum of 198°F (92°C) at a depth of 500 ft (150 m), whereas the shut-in log on MAC-1 is reported to indicate a maximum temperature of 206°F (97°C) at about 1,100 ft (335 m).

Hydraulic connection between the two deep wells was established during a pump test on MAC-1, with transmissivity and storativity values of 4,000 $ft^2$/day (370 $m^2$/day) and $2.5 \times 10^{-4}$, respectively. The two deep wells are 1,010 ft (308 m) apart along a north-south line, and the third well is 260 ft (80 m) south-southwest from the pumped well. The rate of drawdown during pumping was greater in the distant well, which fully penetrates the fractured zone, than in the third well; this indicates the hydraulic conductivity of the Precambrian gneiss is considerably smaller outside of the fracture or shear zone.

With only two wells, a three-point problem solution to the orientation of the fracture zone cannot be solved. However, we have established a north-dipping fracture zone (minimum dip 30°) which does not fit either into Precambrian or Tertiary tectonic domains. Could the structural control on this geothermal system be related to the Overthrust belt?

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## Depositional Environments of Fort Union Formation, Bison Basin, Wyoming

The Paleocene Fort Union Formation crops out in the vicinity of the Bison basin, approximately equidistant from the southeast terminus of the Wind River Range and the southwestern edge of the Granite Mountains uplift in central Wyoming. Early Laramide tectonic activity produced a series of uplifts north of the area forming a platform separating the Wind River and Great Divide basins. During middle to late Paleocene, aggrading fluvial systems flowing southward, rapidly deposited a sequence of thin, lenticular conglomerates and medium to coarse-grained planar-bedded sandstones in braided and anastomosing stream channels and carbonaceous overbank silt and claystones. Subaerially exposed interchannel areas developed cyclic pedogenic horizons. Early diagenetic cementation preserved tubular burrows and rhizoliths as well as impressions of fruits, nuts, leaves, and wood. Anomalous silicic cementation of mudstone, sandstone, and conglomerates probably are silcrete soil horizons developed in a warm temperate to subtropical humid climate.

The sandstones are multicyclic containing fragments of preexisting siliceous sedimentary rocks (e.g., Tensleep Sandstone, Mowry Shale, and cherts from the Madison, Morrison, and Phosphoria Formations). Reworked glauconite is locally abundant in some Fort Union sandstones, reflecting the proximity of Paleozoic sources. Altered and embayed feldspars are present in trace amounts throughout most of the section, but significant accumulations of fresh feldspar are present near the top, indicating unroofing of Precambrian source before the Eocene.

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## Overpressured Reservoirs in Rocky Mountain Region

Overpressured oil and gas reservoirs in the Rocky Mountain region are more widespread than generally recognized. "Normal" Rocky Mountain