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.

SHUSTER, MARK W., and JAMES R. STEIDTMANN, Univ. Wyoming, Laramie, WY

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.

SONDEREGGER, J. L., and MAREK ZALUSKI, Montana Bur. Mines and Geology, Butte, MT

Ennis Geothermal System Fracture Porosity: an Overthrust Effect?

The Ennis geothermal area is believed to be an elliptical field, roughly ½ mi long in a north-south orientation and ¼ mi wide, located 1½ 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 2.5×10^{-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?

SOUTHWELL, ELIZABETH H., and JAMES R. STEIDTMANN, Univ. Wyoming, Laramie, WY, and LARRY MIDDLETON, Northern Arizona Univ., Flagstaff, AZ

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.

SPENCER, CHARLES W., U.S. Geol. Survey, Denver, CO

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 reservoir pressure gradients are about 0.42 to 0.46 psi/ft (9.5-10.4 kPa/m). Reservoir pressure gradients in excess of 0.5 psi/ft (> 11.3 kPa/m) are considered overpressured. However, most overpressured reservoirs have pressure gradients greater than 0.6 psi/ft (> 13.6 kPa/m). Although a variety of conditions can cause overpressuring, most high pressures in the region are interpreted to be caused by the "active" generation of oil and gas in sequences that still contain organic matter capable of yielding thermally generated hydrocarbons. Several authors have proposed that hydrocarbon generation can cause overpressuring. It is important to note that significantly overpressured water reservoirs are rare in the Rocky Mountain region and, where present, are usually in pressure continuity with overpressured oil and gas reservoirs. Some slightly overpressured water reservoirs can be explained by local conditions, such as a pressure measurement at a location significantly lower than a topographically high-elevation water recharge area (artesian conditions).

Rocks with above normal pressure in Rocky Mountain basins range in age from Late Devonian to Tertiary and are commonly associated with low-permeability (tight) reservoirs. Most overpressured reservoirs occur in Cretaceous and Tertiary sandstone sequences. Overpressuring is not common in rocks older than Cretaceous except in very organic-rich sequences, probably because lean source beds that have been heated over a long period of time are no longer capable of yielding enough hydrocarbons to maintain abnormal pressure.

Statistically, nearly all overpressured reservoirs and source rocks have temperatures of about 200°F (93°C) or higher. In many basins, the onset of overpressuring occurs rather abruptly at this temperature in organic-rich sequences. In addition, available data indicate that hydrocarbon-related overpressuring does not usually occur if vitrinite reflectance values are < $R_o = 0.5\%$ in oil-prone sequences or < $R_o = 0.7\%$ in gas-prone sequences. These reflectance values are the lower limit for onset of significant generation of oil and gas, respectively.

Hydrocarbons expelled into widespread, high-permeability reservoirs probably migrate owing to hydrodynamic flow and buoyancy. These reservoirs usually have normal pressures. In contrast, low-permeability (tight) reservoirs retain the overpressuring and have maximum pressures about equal to the natural fracture gradient for rocks in a given area. In a 1978 study, F. F. Meissner proposed that pore pressures in excess of the natural fracture gradient initiate formation fracturing, and the hydrocarbons are expelled laterally and vertically until the pore pressure is reduced and the fractures close. These fracture-initiation pressure gradients range from ≈ 0.7 psi/ft (15.8 kPa/m) to > 0.85 psi/ft (> 19.2 kPa/m). The highest reservoir pressure observed to date in the Rocky Mountains is in the Merna area (T36N, R112W), Sublette County, Wyoming, where reservoir pressure gradients in Upper Cretaceous sandstones exceed 0.9 psi/ft (> 20.4 kPa/m). Artificial hydraulic-fracturing pressure data indicate that in this area regional fracture gradients also are higher than normal.

Regional pressure analyses indicate overpressured hydrocarbon-bearing reservoirs occur in the following Rocky Mountain basins: Williston, Powder River, Bighorn, Wind River, Hanna, Green River, Washakie, Great Divide, Sand Wash, Piceance, Uinta, and Paradox.

SPENCER, MARY ALICE S., Bur. Land Management, Billings, MT

Inexpensive Remote Sensing Techniques

Professional aerial photographic missions are expensive, but periodic updates can be obtained for considerably less money using a hand-held camera in a small plane.

Environmentally related problems such as strip-mine reclamation can be monitored by periodic photography, both color and false-color infrared, obtained in this manner. Problem areas such as uneven settling of leveled spoils can be identified for further work.

Photography and imagery available from government agencies can also be used to supplement data from a baseline aerial photographic mission. Landsat imagery acquired during periods of snow cover may accent subtle structural features concealed by vegetation.

Examples of such techniques, and supporting data, will be on display at the poster session.

STEARNS, DAVID W., Univ. Oklahoma, Norman, OK

Considerations of Vertical Tectonics for Big Horn Basin

Referring to the tectonic style of the Big Horn basin as either "horizontal" or "vertical" is an oversimplification. However, these terms have come into vogue and I support vertical tectonics. This term implies that on most structures the vertical component of displacement is larger than the horizontal component of displacement. It does not imply that all faults are absolutely vertical, nor does it preclude crustal shortening. If high-angle reverse faults (dips steeper than 45°) dominate in a basin, a net shortening will result even in a vertical tectonic domain. Furthermore, when applied to the Big Horn basin, the expression "vertical tectonic style" only characterizes behavior 10 to 15 km (6 to 9 mi) into the basement. It implies nothing concerning causative conditions in the lower crust or upper mantle. A given mantle stress condition can produce several different displacement fields in the upper crust depending upon the behavior of the crust.

In accepting either horizontal or vertical as the tectonic style of a region, all of the structures produced during the deformation episode should be considered together as opposed to examining one feature at a time. It is also important to separate second and third order features from primary features. Finally, if there is a governing style, it should be consistent with three-dimensional movements, not just individual cross sections.

STEIDTMANN, JAMES, R., and LINDA C. MCGEE, Univ. Wyoming, Laramie, WY, and LARRY MIDDLETON, Northern Arizona Univ., Flagstaff, AZ

Laramide Sedimentation, Folding, and Faulting in Southern Wind River Range, Wyoming

Surface observations along the southern margin of the Wind River Range in Fremont County, Wyoming, indicate that early motion along the Wind River and Continental faults controlled depositional patterns and lithologic characteristics of the local syntectonic sediments, and that the latest motion on a segment of the Wind River fault between Oregon and Pacific buttes folded some of these same sediments into a monocline. The stratigraphic sequence exposed in the monocline consists (in ascending order) of a lower distal fan or alluvial plain unit (main body of the Wasatch Formation), a lake margin unit (Tipton Tongue of the Green River Formation), a fluvial and deltaic sandbody (Tipton Sandstone), and an alluvial fan unit (Cathedral Bluffs Tongue of the Wasatch Formation). Current direction, clast composition, and clast-size data indicate that a granitic and mafic distal source to the east and a proximal granitic source to the north supplied sediment. Subsequent movement on the Wind River fault warped this sequence into a monocline 2 mi long. This structure dies out in both a northwest and southeast direction along the inferred trace of the Wind River fault and is overlain by undeformed middle Eocene sediments.

Other syntectonic units (e.g., Fort Union, Ice Point, White River, Arikaree, and South Pass conglomerates) occur in patches along the Wind River and Continental faults in this area. Each deposit is of local extent, exhibits rapid thickness and petrofacies changes, and probably represents proximal alluvial fan deposition. These characteristics are typical of syntectonic sediments in transcurrent-faulted terrains, and we are investigating the possibility of such faulting in this area.

Tectonic implications of these interpretations are: (1) early motion on the Wind River fault controlled the margin of Eocene Lake Gosiute and generated a distal sediment source to the east; (2) late early Eocene uplift of the north side of the Continental fault provided a proximal source for pegmatitic and granitic boulders to the north; (3) last motion on the Wind River fault was latest early Eocene or earliest middle Eocene between Oregon and Pacific buttes; (4) the Wind River fault consists of several segments which moved separately rather than as one, long continuous zone of concurrent faulting; (5) while the Wind River Range was being thrust to the southwest it may have been uncoupled from the basins to the south by a zone of transcurrent faulting; (6) Pliocene or younger recurrent motion along the Continental fault was opposite to that in the Eocene.

SUNDELL, KENT A., Univ. California, Santa Barbara, CA, and Ram Oil Co., Inc., Casper, WY

Volcanic Stratigraphy, Timing, and Petroleum Exploration in Southeastern Absaroka Range, Big Horn Basin, Wyoming