

Gardiner fault. The local thermal features lie on or between the intersections of these faults with the Gardiner fault zone. More than 10,000 ft (3,050 m) of Paleozoic and Mesozoic sedimentary rock is preserved within the graben in the footwall of the Gardiner fault. From a structural high within Yellowstone Park, the sedimentary units dip gently into the Gardiner fault zone, where they are dragged up and overturned locally to form an asymmetric syncline striking northwest. These structural relations suggest that ground waters flow down permeable sedimentary units within the graben from the Yellowstone upland to great depth under the Gardiner fault zone. Waters are heated at this depth and ascend through fractures to the surface. The cavernous Mississippian Madison Limestone, lying near a depth of 10,000 ft (3,050 m) under the Gardiner fault zone, may be the principal aquifer and produce the high calcium content of the active hot springs. A normal thermal gradient could cause significant heating at this depth.

SURDAM, RONALD C., and LESLIE L. LUNDELL, Univ. Wyoming, Laramie, Wyo.

Depositional Environments of Oil Shale

Oil shale in the Green River Formation of Wyoming and Colorado is associated with domal stromatolites, cross-bedded ooliths and pisoliths, ostracodal lag deposits, flat pebble conglomerates, bedded saline minerals, and barren marlstones with flute casts. In addition, some oil shale units contain mudcracks, breccias, and saline mineral nodules. Obviously neither the depth of water, nor the presence of bottom currents in the depositional environment, is a limiting factor relative to oil shale deposition.

On the other hand, the influx of detrital sediments is a serious constraint on oil shale deposition. Kerogen content of oil shale drops drastically near clastic deltas and prograding clastic shorelines. Much of the oil shale in the Green River Formation was deposited in an environment characterized by shallow water, periodic desiccation, high organic productivity, and a very low sediment influx. These conditions are well satisfied by a playa-lake complex, or in other words, a shallow-water lake surrounded and protected by a broad playa fringe.

Kerogen-rich laminae of the oil shale are the result of a relatively continuous deposition of algal mats and oozes, whereas the carbonate-rich laminae are derived from at least two sources: (1) clastic transport and (2) chemical precipitation. Seasonal flooding of the playa lake with fresher water contributes not only detrital carbonates washed into the lacustrine environment from the playa fringer, but also contributes carbonate as a chemical precipitate.

SWETLAND, PAUL J., and JERRY L. CLAYTON, U.S. Geol. Survey, Denver, Colo.

Source Beds of Petroleum in Denver Basin

Crude oil and shale samples from the Denver basin were analyzed by organic geochemical techniques to determine oil-source-bed relations. Infrared spectrophotometry, gas chromatography of the $C_{15}+$ saturates, mass spectrometry, and carbon- and sulfur-isotopic ratios were used to characterize both the crude oils and the extractable organic matter in shales. The oils were characterized further by gas chromatography of the C_4-C_7 fraction and optical rotation measurements.

In general, oils in Cretaceous rocks are compositionally similar, and they can be distinguished from oils in the Permian Lyons Sandstone. The Cretaceous oils were compared with extractable organic matter in Cretaceous shales to determine the regional and stratigraphic occurrence of petroleum source beds. The results show that most Cretaceous shales are thermally immature over a large part of the basin. In areas where the Cretaceous section has had a thermal history sufficient to cause generation of petroleum like hydrocarbons within the shales, many potential source beds exist. The geographically limited occurrence of source beds and the occurrence of oil in thermally immature areas suggest that extensive vertical and lateral migration has occurred.

TAYLOR, H. C. JIM, U.S. Geol. Survey, Billings, Mont.

Corwin Springs Known Geothermal Resources Area, Park County, Montana

The Corwin Springs Known Geothermal Resources Area is contiguous to Yellowstone National Park along a part of the northern boundary of the park near Gardiner, Park County, Montana. The area contains two known sites of hot springs activity—LaDuke Spring, 2.8 km southeast of the small resort community of Corwin Springs, and Bear Creek Spring, 2.6 km east of Gardiner. LaDuke Spring issues from brecciated quartzite and has a flow rate of 380 l/min, a surface water temperature of 65°C, a silica-geothermometer temperature of 66.9°C, and a Na-K-Ca geothermometer temperature of 77°C. Bear Creek Spring issues from limestone and has a flow rate of 4 l/min, a surface water temperature of 32°C, a silica temperature of 44.8°C, and a Na-K-Ca temperature of 87.3°C. The springs, which are actively depositing travertine, are on or near the trace of the Gardiner fault, a high-angle reverse fault which forms the southwestern boundary of the Beartooth uplift.

Interesting features of this potentially significant geothermal area include: (1) the proximity of the Corwin Springs area to the intense geothermal activity and significant Pliocene and Pleistocene volcanism in Yellowstone National Park; (2) the Sepulcher graben, a potential geothermal reservoir and major geologic structure extending from the Corwin Springs area into Yellowstone National Park; (3) the Gardiner fault and its role in localizing thermal activity in the Corwin Springs area; (4) the negative gravity anomaly centered over the northern terminus of the Sepulcher graben; (5) the negative magnetic anomaly in the area; (6) the location of the area within the Intermountain seismic belt; (7) the existence of recent tectonism within the area, as demonstrated by Pleistocene and Holocene faulting; and (8) the observed surface and estimated geochemical temperatures of the two known hot springs—features which do not indicate high subsurface temperatures.

VANINETTI, JERRY, Consulting Geologist, Salt Lake City, Utah

Sedimentation and Multiple Coal-Seam Correlations in Upper Cretaceous Swamp Complex, John Henry

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