della crenulata Zone. Only rare, fragmentary conodonts have been found in the middle member. Conodont evidence from the middle of the lower shale suggests a late Devonian (Famennian) age (Upper *Polygnathus styriacus* Zone) for this member.

Conodont color has been established as a geothermometer in carbonate rocks. Color alteration indices of conodonts from the Bakken range from 1.5 to approximately 2.5 and indicate a pattern of increasing temperature with depth. These results suggest possible hydrocarbon generation from shallower depths than has been reported previously for the Bakken. The lack of agreement in interpreted hydrocarbon generation depths may be due to, among other things, the clastic nature of the Bakken Formation.

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Geothermal Resources of Wyoming Sedimentary Basins

Geothermal resources of Wyoming sedimentary basins have been defined through analysis of over 14,000 oil well bottom-hole temperatures, thermal logging of 380 wells, measurement of rock thermal conductivities, calculation of 60 heat-flow values, drilling of 9 geothermal exploratory wells, conductive thermal modeling, and the study of existing geologic, hydrologic, and thermal spring data. All data have been integrated into interpretations of the thermal structure of the Big Horn, Wind River, Washakie, Great Divide, Green River, Laramie, Hanna, and Shirley basins of Wyoming.

Controlling factors for the formation of geothermal resources in these basins are regional heat flow, rock thermal conductivity values, depths to regional aquifers, and hydrologic flow directions. Regional basin heat-flow values range from about 40 to 80 milliwatts/m^2; measured thermal conductivities are in the general range of 1.5 to 4.0 watts/m°K; and depths to aquifers are up to 11,000 m (36,000 ft). This results in regional geothermal gradients for Wyoming basins in the range of 15° to 40°C/km (44° to 116°F/mi) with predicted maximum aquifer temperatures near 300°C (570°F).

Anomalous geothermal areas within the basins contain measured thermal gradients as high as 400°C/km (1,160°F/mi) over shallow depth intervals. These anomalous areas are the combined result of local geologic structures and hydrologic flow. A simplified model for such areas requires water movement through a syncline with subsequent heating due to regional heat flow and thermal conductivities of overlying rock units. Consequent flow of the heated water up over an anticline produces a localized area of anomalous geothermal gradients.

Access to Wyoming basin geothermal resources is primarily through producing oil wells. Fifty two oil fields which account for over 90% of Wyoming's oil field water production, produce 575 million L (152 million gal) of thermal water per day. The temperature of this water ranges from 30° to 110°C (86° to 230°F) with 88% warmer than 38°C (100°F) and 60% warmer than 50°C (122°F). Over 50% of this water is disposed of, generally by discharge to the surface.

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Distribution and Age of Clinker in Northern Powder River Basin, Montana

Clinker, rock that has been baked or fused by the burning of underlying coal beds, is abundant in the Tongue River Member of the Paleocene Fort Union Formation in the northern Powder River basin. Being more resistant than unbaked rocks above and below, the clinker commonly caps ridges and plateaus, and forms topographic benches and escarpments. This clinker is primarily red and orange baked sandstone and shale, but it includes gray sintered siltstones (porcellanite) and bodies of black, fused and welded breccia. Detrital zircons in the sandstones are annealed during baking and yield fission-track ages that show the time of cooling.

An inventory of clinker areas has been completed for the Montana part of the northern Powder River basin east of the Crow Indian Reservation. The study area lies within the Powder River resource area of the U.S. Bureau of Land Management. Data were compiled from existing literature, color infrared aerial photographs, and unpublished mapping provided by R. B. Colton, W. C. Culbertson, and S. J. Luft of the U.S. Geological Survey. Clinker covers approximately 2,700 km^2 (1,050 mi^2) or 20% of the Tongue River exposures in the study area. Assuming a 15 to 25 m (50 to 80 ft) average thickness, the volume of clinker would be 40 to 70 km^3 (10 to 17 mi^3).

The most extensive clinker layers locally exceed 60 m (200 ft) in thickness. They are produced by the thickest coal beds, some of which exceed 15 m (50 ft). Two major clinker layers form extensive topographic surfaces and escarpments. (1) Near Decker, Montana, the clinker produced by the Anderson-Dietz coal zone forms benches adjacent to the Tongue River. Because of the gentle southerly regional dip of the beds, this clinker zone rises to the north, where it caps large plateaus dividing the valley of the Tongue River from the valleys of Otter Creek and Rosebud Creek. These clinker plateaus stand up to 400 m (1,300 ft) above the Tongue River. (2) Near Ashland, Montana, the clinker produced by the Knobloch-Nance coal zone, which lies about 300 m (980 ft) stratigraphically below the Anderson-Dietz zone, forms broad benches bordering the Tongue River.

The distribution of fission-track ages shows that coal has burned to form clinker in the region at least since the late Pliocene. A clinker boulder from the base of a gravel deposit 365 m (1,200 ft) above the level of the Yellowstone River west of Forsyth has been dated at 4.0 ± 0.7 m.y. This age establishes a maximum age for the gravel. The oldest in-place clinker sample dated thus far comes from the summit of the Little Wolf Mountains west of Colstrip and is dated at 2.8 ± 0.6 m.y. Clinker from the Anderson-Dietz plateau that rims the Tongue River Valley west and south of Ashland ranges in age from 1.4 ± 0.4 m.y. to 0.7 ± 0.3 m.y. Ages from clinker of the Knobloch-Nance coal zone range from 0.5 ± 0.3 m.y. to < 0.06 m.y. The older ages are from topographically higher clinker layers. Inasmuch as a coal bed cannot start burning until it is exposed by erosion, these ages indicate the Tongue River cut its present valley primarily during the Pleistocene.

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Fault Leakage Characterization by Integrative Gas Geochemistry/Mass Spectrometry/Pattern Recognition Procedures

The application of integrative gas geochemistry combined with mass spectrometry and the use of pattern recognition procedures, has enabled rapid characterization of microseepages of gases along faults and fractures. This has been accomplished by incorporating the activated carbon/Curie point wire collector in gas geochemical surveys of faulted and fractured structures which serve as conduits to the subsurface. Studies conducted in the Denver-Julesburg basin of Colorado, Green River basin of Wyoming, the hingeline of Utah, and the Las Animas arch of Colorado all produced fault-related samples where higher ($<C_7$) molecular weight components were encountered. The results of these fault-associated anomalies have been related to differing organic sources of various samples and may be correlated to areal distribution of the source leakage.

When using the analytical technique in relatively unfractured and unfaulted sedimentary rocks, the mass spectra generated typically indicates the presence of compounds containing up to seven carbon atoms. In dealing with fault samples affiliated with producing areas of petroleum, components with masses up to 150 have been analyzed. The Denver-Julesburg basin, Green River basin, and the Las Animas arch studies were all performed in relation to producing oil and gas fields. Although the results from the first three studies were not insignificant, those associated with the hingeline study have a much greater impact toward the potential of exploration application. Through this study, it was discovered that fault leakage not only changed with differing sources of the organic gases and vapors, but also appears to change with lateral proximity between the sample and the zone overlying the organic source. From these interpretations, an exploration model which utilizes fault leakage as a parameter will be discussed.

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Introduction to Stratigraphy, Structure, and Geologic Problems in Big Horn Basin, Wyoming and Montana