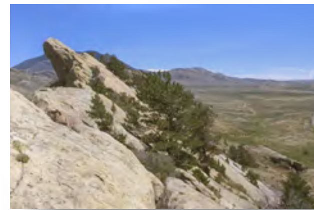
Chapter 16

Geothermal Gradient Map of the Southwestern Wyoming Province, Southwestern Wyoming, Northwestern Colorado, and Northeastern Utah



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By Thomas M. Finn

Chapter 16 of
Petroleum Systems and Geologic Assessment of Oil and Gas in the Southwestern Wyoming Province, Wyoming, Colorado, and Utah
By USGS Southwestern Wyoming Province Assessment Team

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Geothermal Gradient Map of the Southwestern Wyoming Province, Southwestern Wyoming, Northwestern Colorado, and Northeastern Utah

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Introduction

The geothermal gradient map (pl. 1) was constructed as part of a project conducted by the U.S. Geological Survey to characterize and evaluate the undiscovered oil and gas resources of the Southwestern Wyoming Province (SWWP), which essentially coincides with the Greater Green River Basin, one of the many structural and sedimentary basins that formed in the Rocky Mountain region during the Laramide orogeny (Late Cretaceous through Eocene) (fig. 1). The SWWP encompasses about 25,000 mi^2 in southwestern Wyoming, northwestern Colorado, and northeastern Utah (fig. 2). It is bounded on the west by the Wyoming thrust belt, on the north by the Wind River Mountains and Granite Mountains, on the east by the Rawlins, Sierra Madre, and Park Range uplifts, and on the south by the Uinta Mountains and Axial Basin uplifts. Several major intrabasin uplifts are present, including the La Barge platform, Moxa arch, Sandy Bend arch, Rock Springs uplift, Cherokee ridge, and the Wamsutter arch (fig. 2). Several of these uplifts subdivide the province into smaller subbasins including the Washakie, Great Divide, Hoback, Sand Wash, and Green River Basins (fig. 2).

Important conventional oil and gas resources have been discovered and produced in the SWWP from reservoirs ranging in age from Cambrian through Tertiary (Law, 1996). In addition, an extensive unconventional (continuous) basin-centered gas accumulation (BCGA) has also been identified in Cretaceous and Tertiary reservoirs by numerous researchers, including Law and others (1980), McPeek (1981), Davis (1984), Law (1984a,b), Spencer (1987), Law and others (1989), Tyler and others (1995), Law (1996), Surdam (1997), and Surdam and others (1997). This BCGA is overpressured throughout large areas of the province, and Spencer (1987) believed that the overpressuring is the result of present-day or recently active generation of large volumes of thermogenic gas. The overpressuring occurs in low-permeability rocks that are associated with organic-rich source rocks that are still capable of hydrocarbon generation (Spencer, 1987). Law and others (1989) and Spencer (1987) observed that, in many areas of the SWWP, the position of the top of the overpressured zone generally coincides with a vitrinite reflectance value higher than about 0.8 percent and an uncorrected present-day temperature of about 180°F or greater (corrected to about 190° to 200°F). The purpose of this geothermal gradient map (pl. 1) is to show variations in gradient values across the SWWP and to provide data for the generation of temperature maps showing areas that are potentially overpressured based on measurement of present-day temperature.

Methods of Study

The geothermal gradient map was constructed using about 4,300 bottom-hole temperature (BHT) measurements collected from about 3,300 geophysical-log headers from oil and gas exploration and production wells. All temperature measurements were corrected using the “AAPG correction” (Kehle, 1972) to compensate for thermal disturbances in the well bore caused by drilling fluids. According to Kehle (1972), the correction “factor” adds a temperature increment to the BHT reported on the log header to make it more representative of the true undisturbed equilibrium BHT. In all cases, if a suite of logs was run, the highest temperature recorded for a particular depth was used.

Control points shown on plate 1 represent geothermal gradients derived by three different methods according to the amount of well data available in a given area. The first method was used in areas where isolated single wells recorded a temperature measurement only for a single depth, in which case the gradient was calculated using a formula from Meissner (1978):

$$\text{gradient in }^{o}\text{F/100 ft} = \frac{\text{log header BHT }(^{o}\text{F}) + \text{AAPG correction }(^{o}\text{F}) - \text{MAAT }(^{o}\text{F})}{\text{depth (100's of feet)}}$$

where the MAAT is the mean annual air temperature. Lowers (1960) reported the mean annual air temperature (MAAT) for different locations in the Green River/Bear River drainages in southwestern Wyoming to be between 38^{o} and 44^{o}F, with an annual mean of about 40^{o}F. According to Heasler and Hinckley (1985), the MAAT is assumed to approximate the mean annual ground temperature, and in this study a MAAT of 40^{o}F was used to calculate the gradients for the entire Southwestern Wyoming Province.

The second method was used in areas where isolated single wells reported temperature measurements from logging runs recorded at different depths. In this case, the temperature measurements were corrected and plotted on a depth vs. temperature graph. Using a MAAT of 40^{o}F, a visual best-fit line was drawn through the data points to determine the

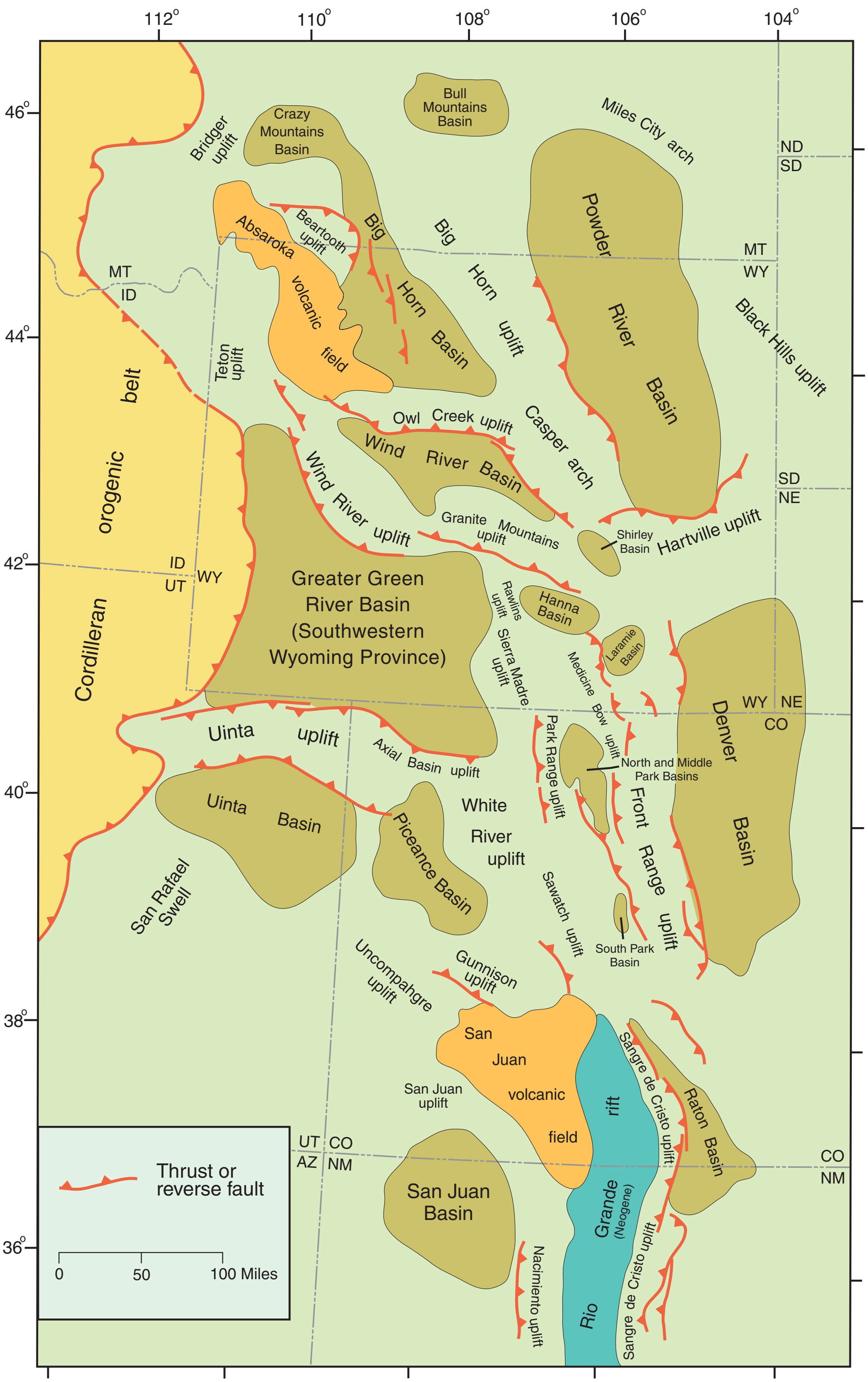


Figure 1. Rocky Mountain region showing the location of Laramide sedimentary and structural basins and intervening uplifts. Modified from Dickinson and others (1988).

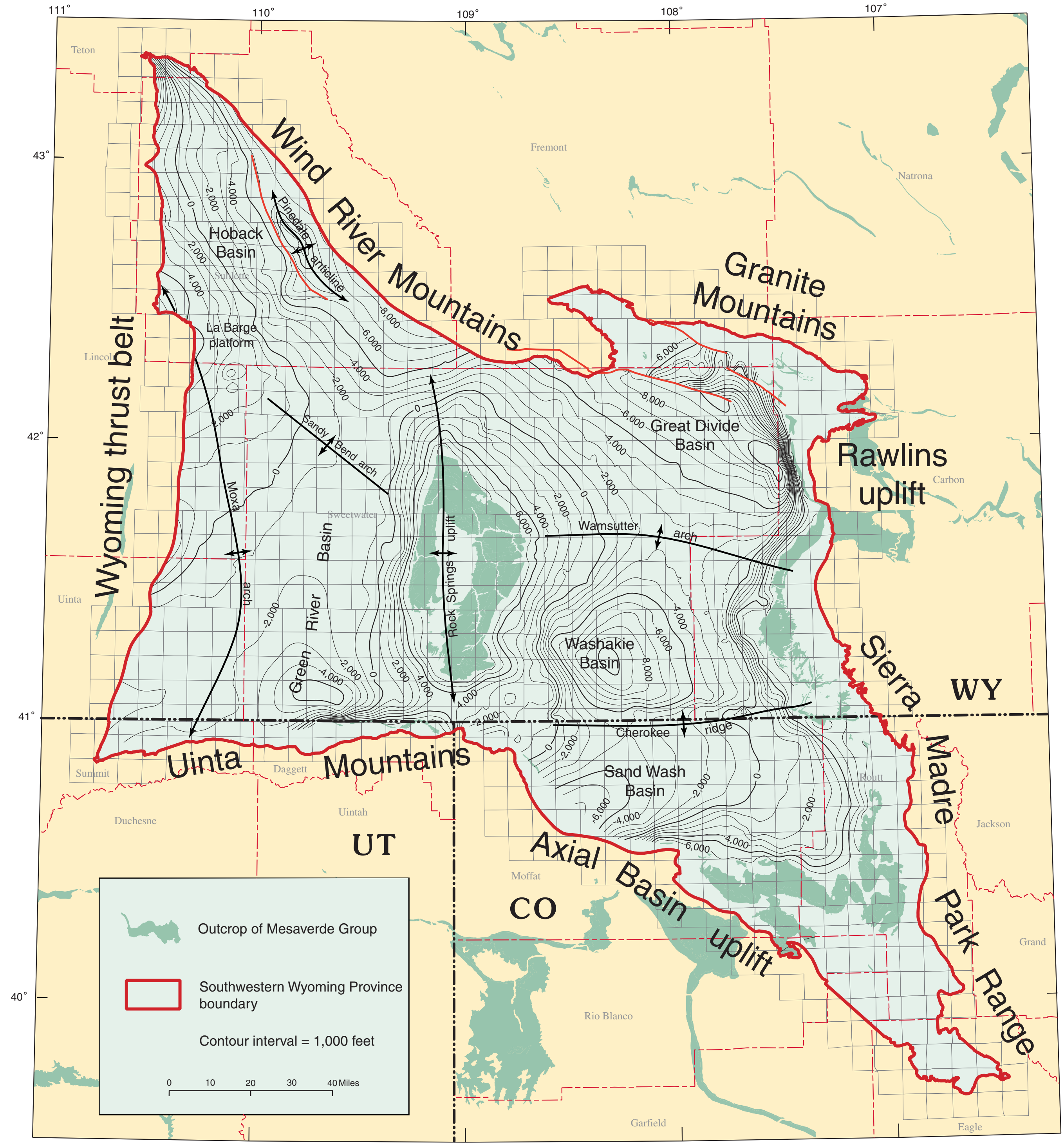


Figure 2. Index map of southwestern Wyoming, northeastern Utah, and northwestern Colorado showing the major structural elements of the Southwestern Wyoming Province. Structure contours drawn on top of the Upper Cretaceous Mesaverde Group. Contour interval, 1,000 feet.

geothermal gradient for that location. Data points that appeared to be anomalously high or low with respect to the main trend of the data were disregarded.

The third method was used in areas of high drilling density, such as oil and gas fields. In this case, temperature measurements from as many depths as possible were collected from numerous wells within the cluster, then were corrected and plotted on a composite depth vs. temperature graph. As in the second method, a MAAT of 40ºF was used and a visual best-fit line was drawn through the data points to determine a gradient. In most cases the well that was closest to the geographic center of the cluster of wells used for the composite was selected as the location for the control point on plate 1, and that gradient value represents all of the wells within the cluster. As in the second method, data points that appeared to be anomalously high or low with respect to the main trend of the data were disregarded. The gradient values were plotted on a 1:500,000-scale base map and contoured by hand using a 0.2ºF/100-ft contour interval.

Discussion

Plate 1 shows that geothermal gradients are highly variable across the SWWP and range from less than 1.2ºF/100 ft to more than 2.2ºF/100 ft. Gradient values are generally highest east of the Rock Springs uplift. The lowest gradient values are in the southern part of the Green River Basin adjacent to the Uinta Mountain uplift. Law and Clayton (1987) believed that this lower gradient was the result of cold meteoric water moving down faults on the north flank of the uplift. A similar relation was observed in the Uinta Basin to the south by Chapman and others (1984), who showed that heat flow decreases in a northward direction from the central part of that basin toward the Uinta Mountain uplift. They (Chapman and others, 1984) believed that one explanation for the northward decrease in heat flow was ground-water recharge in the steeply dipping sedimentary rocks along the south flank of the Uinta Mountains uplift. The highest geothermal gradient values in the SWWP are around the southern and eastern parts of the Sand Wash Basin (pl. 1) and are possibly related to the numerous hot springs that have been described by Barrett and Pearl (1978) and Cappa and Hemborg (1995).

Maps (figs. 3–6, at back of report) showing areas where the present-day temperature is greater than 200ºF for key stratigraphic horizons were constructed using the geothermal gradient map in combination with available well data and overburden maps (see Finn and others, Chapter 10, and Kirschbaum and Roberts, Chapter 5, this CD–ROM). The mapped horizons range from Late Cretaceous to Paleocene in age and include the top of the Frontier Formation, the top of the Mesaverde Group, the base of the Rock Springs Formation and equivalent rocks, and the base of the Fort Union Formation (fig. 7). These units are important natural gas producers and are closely associated with important hydrocarbon source rocks (Law and others, 1989). The purpose of these maps (figs. 3–6) is to show the approximate areal distribution of an unconventional (continuous) overpressured basin-centered gas accumulation in the SWWP. The 200-ºF isotherm was chosen on the basis of studies by Spencer (1987) and Law and others (1989) which indicate that the generation of large volumes of thermogenic gas causing overpressuring occurs at present-day temperatures of 190º to 200ºF. In the SWWP, the top of the overpressured interval is generally believed to coincide with the top of the gas-saturated interval that forms the large regional BCGA (Spencer, 1987). Law and Smith (1983) and Law and others (1989), agree that present-day temperature can be used to predict overpressuring. However, they stress that, due to variations in thermal and burial history, structural setting, and source rock type and richness from one place to another, this criterion should be used in conjunction with other available data such as drill-stem tests, mud weights, and gas analysis from mud logs.

References

Barrett, J.K., and Pearl, H.P., 1978, An appraisal of Colorado's geothermal resources: Colorado Geological Survey Bulletin 39, 224 p.

Cappa, J.A., and Hemborg, H.T., 1995, 1992–1993 low-temperature geothermal assessment program, Colorado: Colorado Geological Survey Open-File Report 95–1, 19 p.

Chapman, D.S., Keho, T.H., Bauer, M.S., and Picard, M.D., 1984, Heat flow in the Uinta Basin determined from bottom hole temperature (BHT) data: Geophysics, v. 49, no. 4, p. 453–466.

Davis, T.B., 1984, Subsurface pressure profiles in gas-saturated basins, *in* Masters, J.A., ed., Elmworth—Case study of a deep basin gas field: American Association of Petroleum Geologists Memior 38, p. 189–203.

Dickinson, W.R., Klute, M.A., Hayes, M.J., Janecke, S.U., Lundin, E.R., McKittrick, M.A., and Olivares, M.D., 1988, Paleogeographic and paleotectonic setting of Laramide sedimentary basins in the central Rocky Mountain region: Geological Society of America Bulletin, v. 100, p. 1023–1039.

Heasler, H.P., and Hinckley, B.S., 1985, Geothermal resources of the Bighorn basin, Wyoming: Geological Survey of Wyoming Report of Investigations no. 29, 28 p.

Kehle, R.O., 1972, Geothermal survey of North America, 1971 annual progress report: Austin, University of Texas, 31 p.

Law, B.E., 1984a, Geological characterization of low-permeability Upper Cretaceous and lower Tertiary rocks in the Pinedale anticline area, Sublette County, Wyoming: U.S. Geological Survey Open-File Report 84–753, 107 p.

Law, B.E., 1984b, Relationships of source-rock, thermal maturity, and overpressuring to gas generation and occurrence in low-permeability Upper Cretaceous and Lower Tertiary rocks, Greater Green River Basin, Wyoming, Colorado, and Utah, *in* Woodward, J., Meissner, F.F., and Clayton, J.L., eds., Hydrocarbon source rocks of the greater Rocky Mountain region: Rocky Mountain Association of Geologists Guidebook, p. 469–490.

Law, B.E., 1996, Southwestern Wyoming Province, *in* Gautier, D.L., Dolton, G.L., Takahashi, K.I., and Varnes, K.L., eds., 1995 National assessment of United States oil and gas resources—Results, methodology, and supporting data: U.S. Geological Survey Digital Data Series DDS–30, release 2.

Law, B.E., and Clayton, J.L., 1987, A burial, thermal and hydrocarbon source rock evaluation of Lower Cretaceous rocks in the southern Moxa arch area, Utah and Wyoming, *in* Miller, W.R., ed., The Thrust Belt revisited: Wyoming Geological Association 38th Annual Field Conference Guidebook, p. 357.

Law, B.E., and Smith, C.R., 1983, Subsurface temperature map showing depth to 180^0 Fahrenheit in the Greater Green River Basin of Wyoming, Colorado, and Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF–1504.

Law, B.E., Spencer, C.W., and Bostick, N.H., 1980, Evaluation of organic matter, subsurface temperature and pressure with regard to gas generation in low-permeability Upper Cretaceous and lower Tertiary sandstones in the Pacific Creek area, Sublette and Sweetwater Counties, Wyoming: The Mountain Geologist, v. 17, no. 2, p. 23–35.

Law, B.E., Spencer, C.W., Charpentier, R.R., Crovelli, R.A., Mast, R.F., Dolton, G.L., and Wandrey, C.J., 1989, Estimates of gas resources in overpressured low-permeability Cretaceous and Tertiary sandstone reservoirs, Greater Green River Basin, Wyoming, Colorado, and Utah, *in* Eisert, J.L., ed., Gas resources of Wyoming: Wyoming Geological Association Fortieth Field Conference Guidebook, p. 39–61.

Lowers, A.R., 1960, Climates of the States—Wyoming: U.S. Deptartment of Commerce, Weather Bureau, Climatology of the United States no. 60–48, p. 1–15.

McPeek, L.A., 1981, Eastern Green River Basin— A developing giant gas supply from deep, overpressured Upper Cretaceous sandstones: American Association of Petroleum Geologists Bulletin, v. 65, no. 6, p. 1078–1098.

Meissner, F.F., 1978, Patterns of source-rock maturity in non-marine source rocks of some typical western interior basins—Non-marine Tertiary and Upper Cretaceous source rocks and the occurrence of oil and gas in the west-central U.S.: Rocky Mountain Association of Geologists Continuing Education Lecture Series.

Ryder, R.T., 1988, Greater Green River Basin, *in* Sloss, L.L., ed., Sedimentary cover—North American craton: The Geological Society of America, Decade of North American Geology, p. 154–165.

Spencer, C.W., 1987, Hydrocarbon generation as a mechanism for overpressuring in the Rocky Mountain region: American Association of Petroleum Geologists Bulletin, v. 71, no. 4, p. 368–388.

Surdam, R.C., 1997, A new paradigm for gas exploration in anomalously pressured "tight gas sands" in the Rocky Mountain Laramide Basins, *in* Surdam, R.C., ed., Seals, traps, and the petroleum system: American Association of Petroleum Geologists Memoir 67, p. 283–298.

Surdam, R.C., Jiao, Z.S., and Heasler, H.P., 1997, Anomalously pressured gas compartments in Cretaceous rocks of the Laramide basins of Wyoming —A new class of hydrocarbon accumulation, *in* Surdam, R.C., ed., Seals, traps, and the petroleum system: American Association of Petroleum Geologists Memoir 67, p. 199–222.

Tyler, R., Kaiser, W.R., Scott, A.R., Hamilton, D.S., and Ambrose, W.A., 1995, Geologic and hydrologic assessment of natural gas from coal—Greater Green River, Piceance, Powder River, and Raton basins, western United States: Gas Research Institute Report of Investigations no. 228, 219 p.

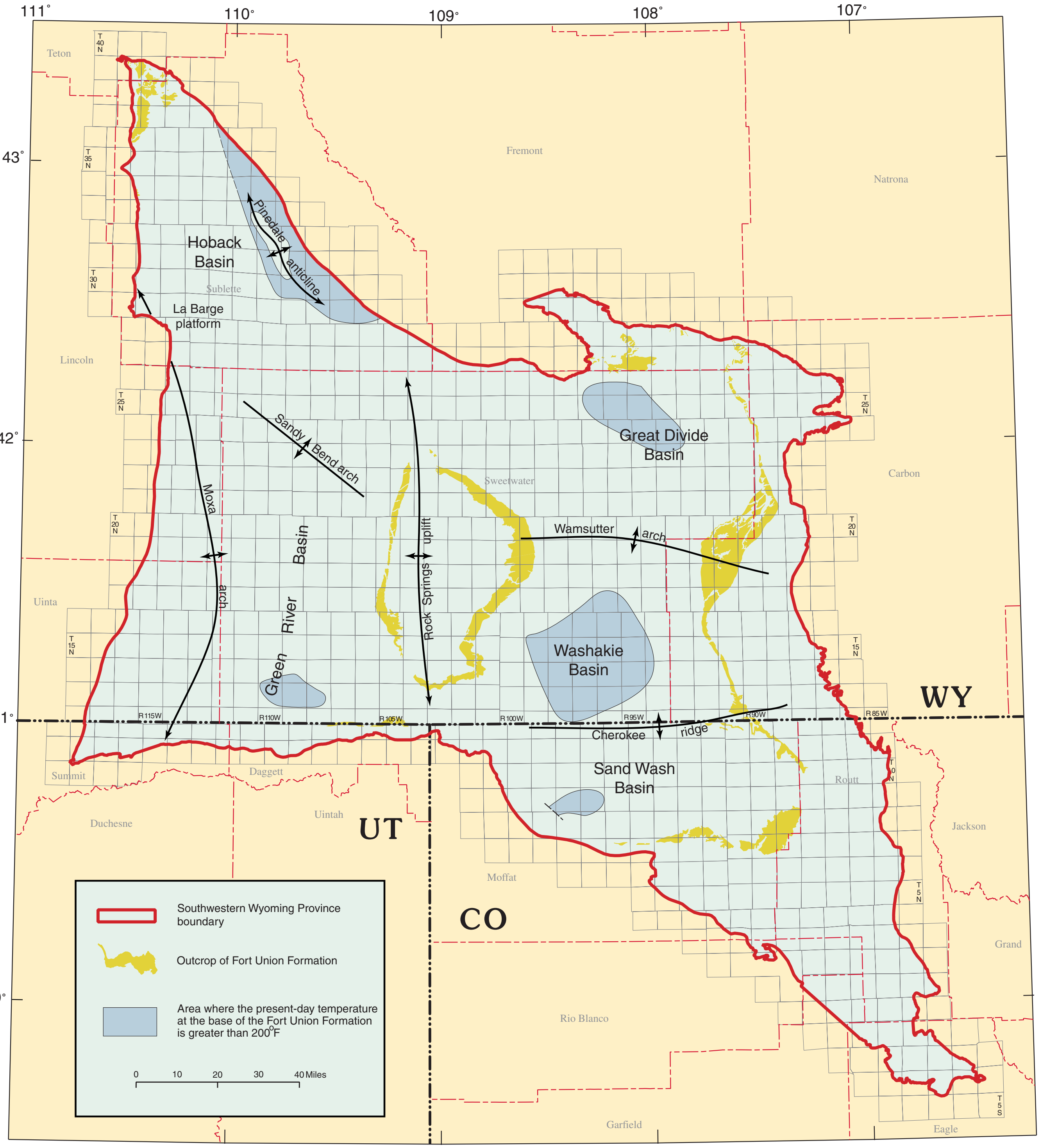


Figure 3. Map showing areas where the present-day temperature is greater than 200° Fahrenheit at the base of the Fort Union Formation.

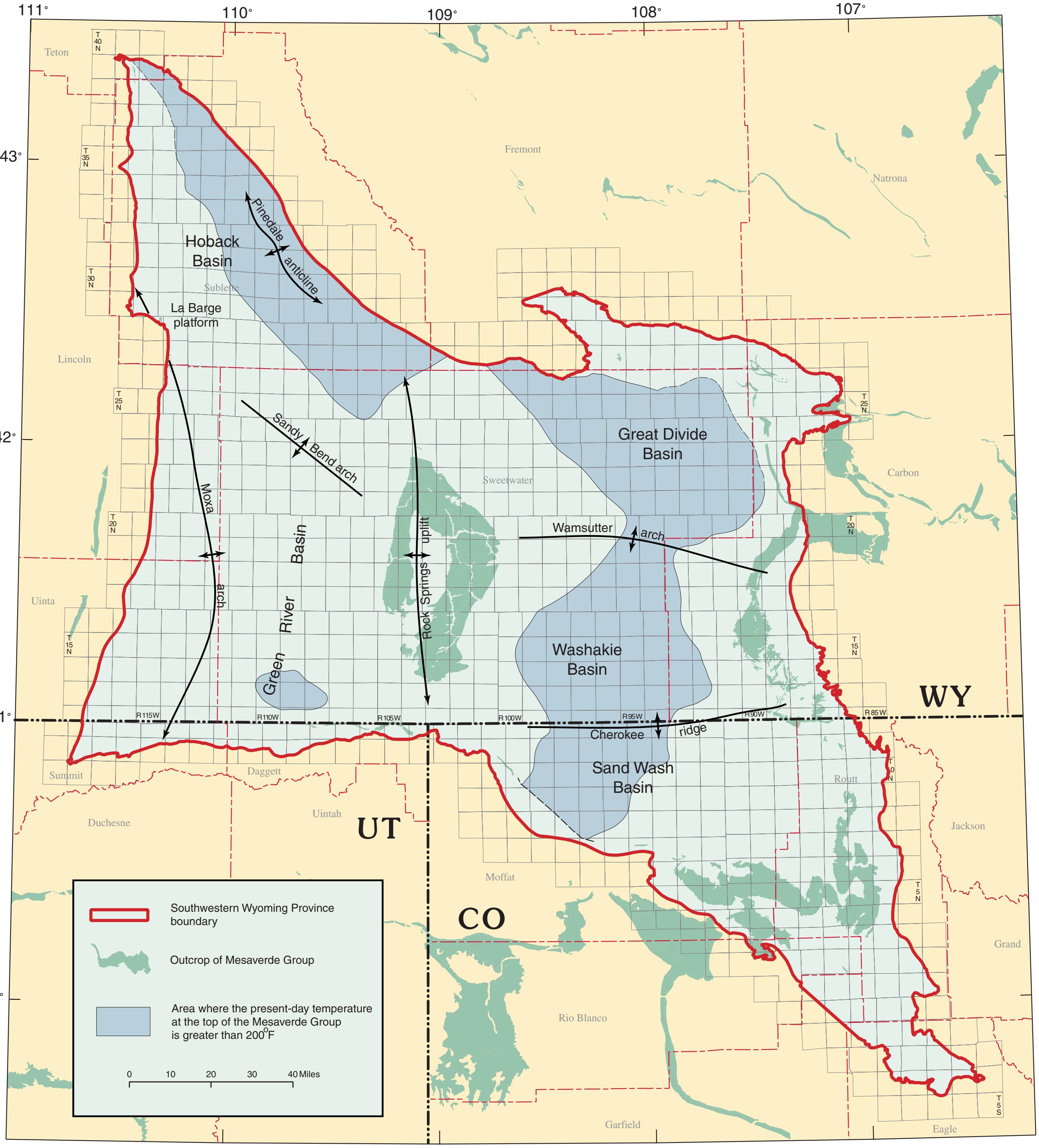


Figure 4. Areas where the present-day temperature is greater than 200° Fahrenheit at the top of the Mesaverde Group.

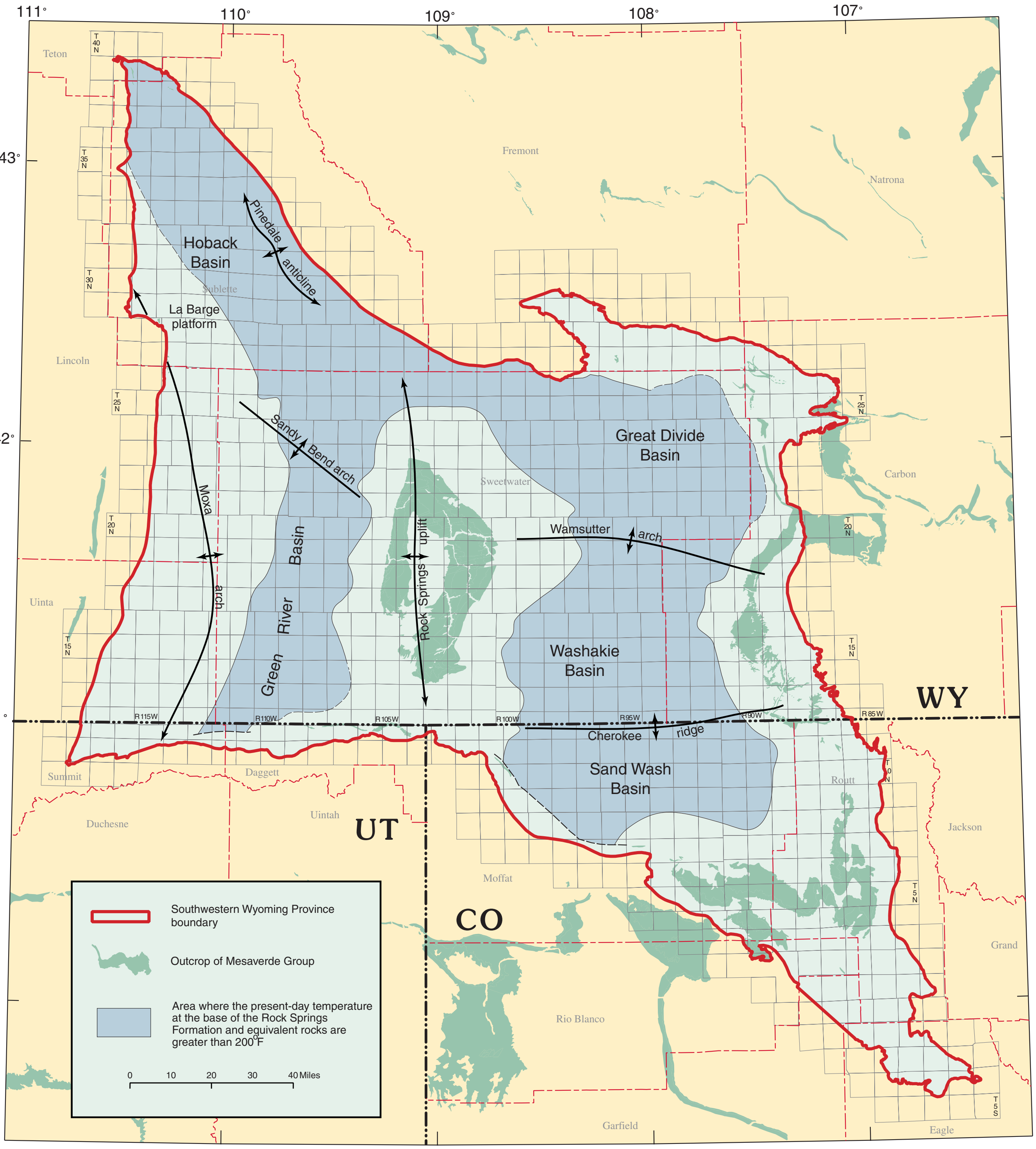


Figure 5. Areas where the present-day temperature is greater than 200° Fahrenheit at the base of the Rock Springs Formation and equivalent rocks.

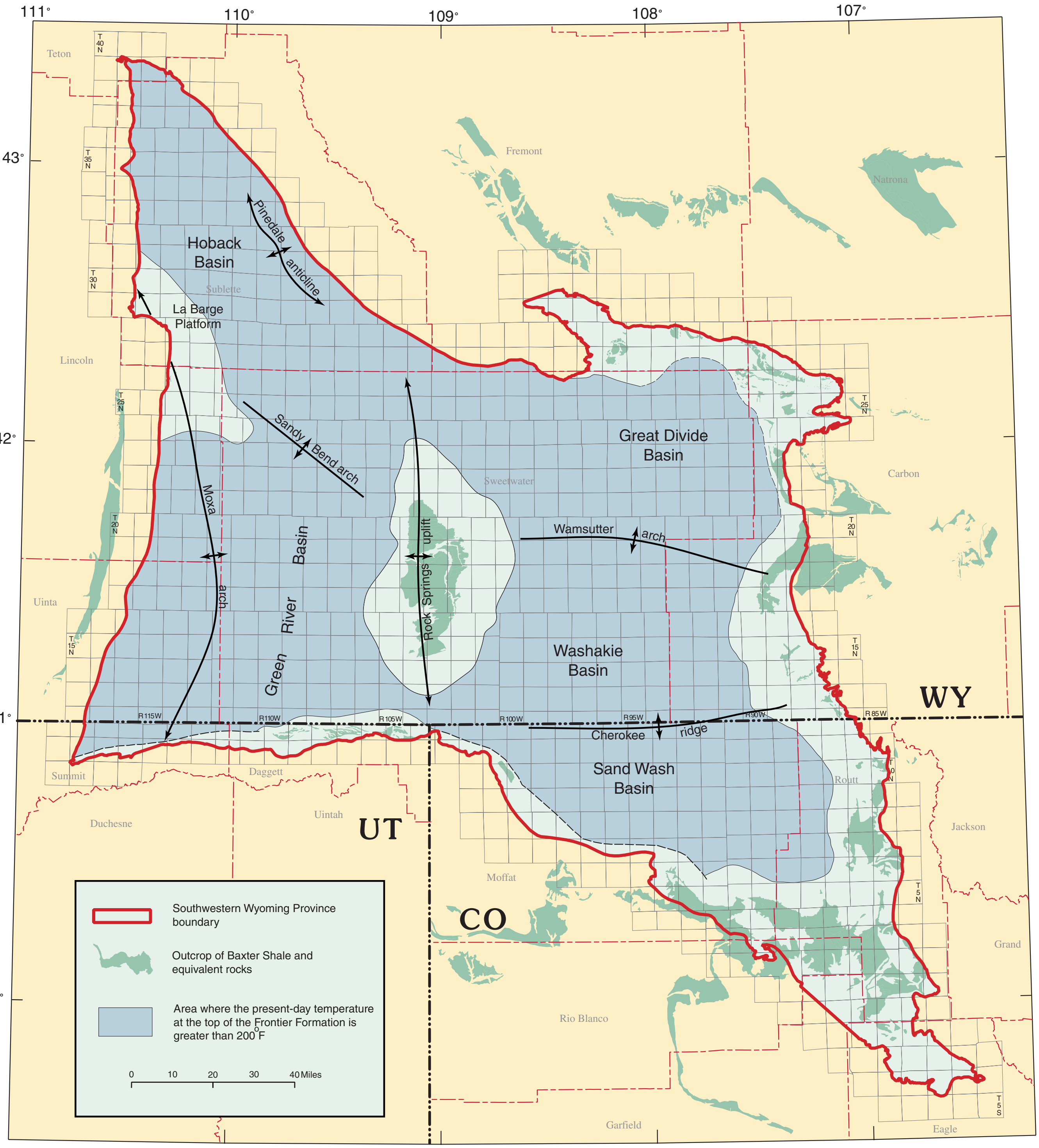


Figure 6. Areas where the present-day temperature is greater than 200° Fahrenheit at the top of the Frontier Formation.

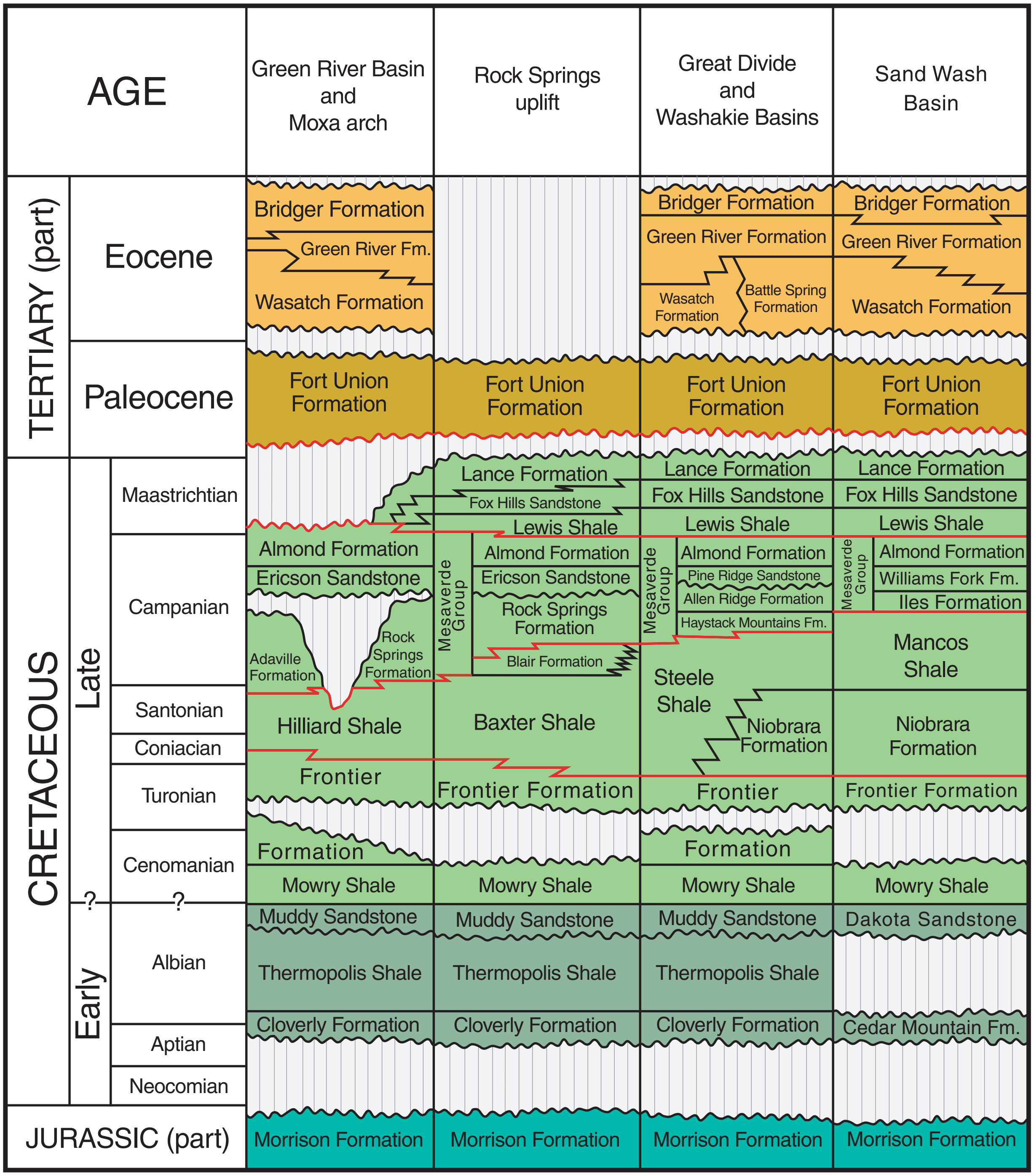


Figure 7. Generalized correlation chart of Cretaceous and lower Tertiary rocks in the Southwestern Wyoming Province. Red lines indicate the mapped horizons shown in figures 3–6. Modified from Ryder (1988).

Click on image below to bring up high-resolution image of plate 1.

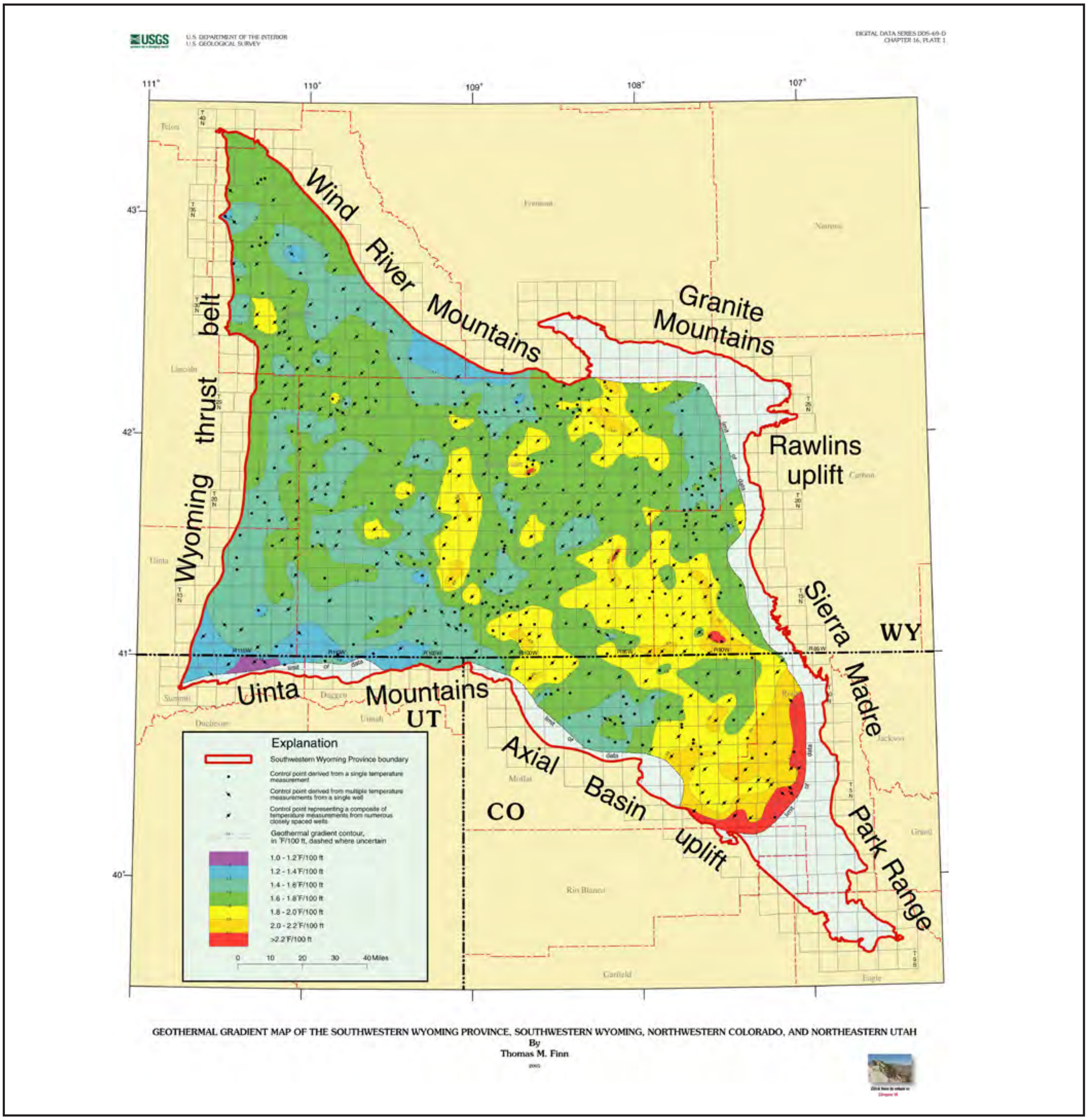
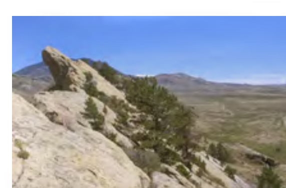


Plate 1. Geothermal gradient map of the Southwestern Wyoming Province, southwestern Wyoming, northwestern Colorado, and northeastern Utah.



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