Clinker Distribution and Age in the Powder River Structural Basin

By
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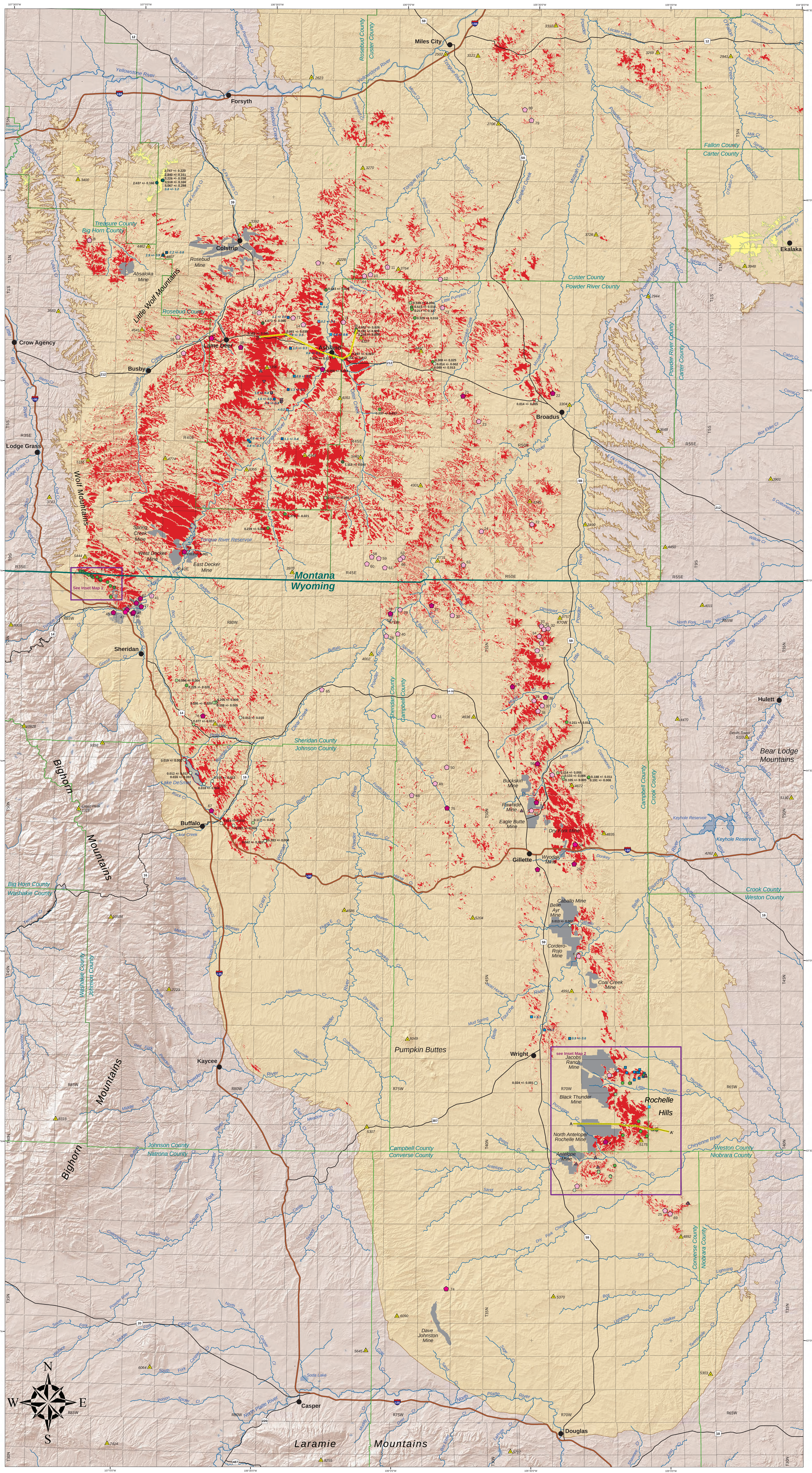


Base map created in ArcMap for a poster presentation at AAPG Rocky Mountain Section Meeting, Cheyenne, Wyoming June 2011.

10 0 10 20 30 40 miles

10 0 10 20 30 40 50 kilometers

Transverse Mercator Projection
UTM Zone 13N, NAD 1983

Land and Resource Data

- Cities and towns
- State boundary
- County boundary
- 4301 Summit elevations in feet above mean sea level
- Area underlain by Tertiary sediments
- Early Quaternary / Late Tertiary gravel terraces (only those in Montana shown)
- Major paved highways
- Interstate highways
- Rivers and streams

Coalbed Fires

Active and historical coal fires, identification number indicated. Refer to coal-fire spreadsheet for details, available on the Montana Bureau of Mines and Geology website at http://www.mbmg.mtech.edu/.

- 42 Mine fires
- 47 Spoil fires
- 41 Outcrop fires

The Powder River Basin, with its dry climate, low-rank coalbeds rich in volatile matter, and commonly occurring range fires, provides ideal conditions for coalbed fires. Near-surface and exposed coalbeds above the water table have ignited due to causes as diverse as lightning strikes, wildfires burning trees and bushes rooted in coalbeds, and spontaneous combustion in coal mines and outcrops. The 81 coal fires shown were compiled by the lead author from personal contacts and observations, published maps and articles, U.S. Bureau of Mines fire control project reports, and U.S. Office of Surface Mining, Wyoming Abandoned Mine Land Division, and U.S. Bureau of Land Management records. The recent vast range fires in the northern Powder River Basin during the summer of 2012 may have ignited additional coalbed fires.

Coal Mines

- Mined areas through 2010

The 16 active coal mines in the Powder River Basin—12 in Wyoming and 4 in Montana—include the largest coal mines in North America. These mines produced 462.6 million short tons, 42.2% of total U.S. production, in 2011 (U.S. Energy Information Administration). Of this total, 426.1 million short tons came from Wyoming and 36.5 million came from Montana. The approximate areas where coal has been mined are shown in dark gray on the map. These areas are based on mine plans and annual reports of coal mine permits on public file with State mine regulatory agencies. Total areas mined through the year 2010 cover about 164 sq. mi. (425 sq. km.). Each mine has a program to quickly extinguish coal fires in mining pits, highwalls, and spoil piles.

Clinker

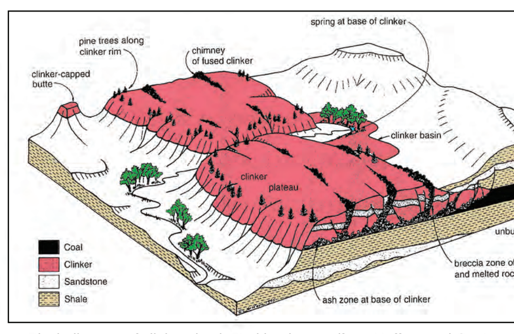
- Clinker outcrops

Clinker is rock that has been baked, sintered, or melted by burning of underlying coalbeds. Clinker forms reddish layers that cap hills and escarpments in the landscape. In the southeast corner of this map (and Inset Map 2), the Rochelle Hills form an east-facing escarpment capped by clinker of the Wyodak coal zone. The coal is being mined just west of its outcrop/burn line. Nearly all of the coal in the map area occurs in formations of Tertiary age. The clinker in the map area results from natural burning in prehistoric times of coalbeds in the Paleocene Fort Union and Eocene Wasatch Formations. Additional clinker may be present in the subsurface beneath younger alluvium, but not exposed at the surface. Clinker is also common in landslides and talus deposits downslope from clinker-capped ridges.

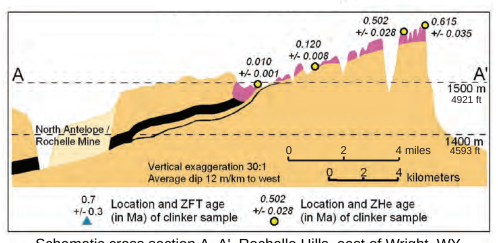
Clinker outcrops shown on this map of the Powder River Basin cover a total of 1,472 sq. mi. (3,812 sq. km.). Of this total, 1,094 sq. mi. (2,833 sq. km.) of clinker are in Montana and 378 sq. mi. (979 sq. km.) are in Wyoming. These clinker outcrops represent the natural burning of tens of billions of tons of coal. Much additional clinker, perhaps an order of magnitude more, has been eroded away and carried downstream into the tributaries of the Missouri River. The record of this eroded clinker is present as clinker cobbles in Quaternary and late Tertiary gravel terraces. Natural coal fires have been a significant source of greenhouse gas emissions in prehistoric times, although the rate of natural burning is much less than the current rate of coal mining.

The clinker outcrops shown were mapped by E.L. Heffern, the lead author, from the following public sources: published geologic maps and digital data files from the U.S. Geological Survey, Montana Bureau of Mines and Geology, and Wyoming State Geological Survey; data interpreted by the author from color and color infrared aerial photography and National Agriculture Imagery Program color and color infrared orthophotos; and data from coal mine permit maps on public file with the State of Wyoming Land Quality Division. The full reference list is available on the Montana Bureau of Mines and Geology website at http://www.mbmg.mtech.edu/.

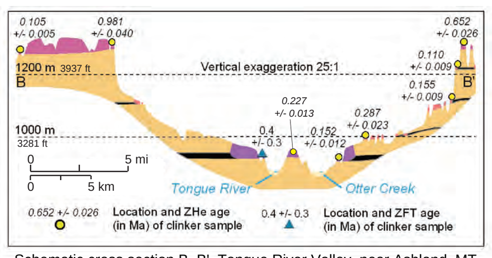
The Tertiary bedrock of the Fort Union and Wasatch Formations is mostly poorly to moderately consolidated sandstone, siltstone, and shale interfingered with coalbeds. When a subaerially exposed coalbed catches fire, the fire front burns back beneath the sandstone, siltstone, and shale overburden of these sediments. It 'fires' the overlying rock in a manner similar to 'firing' bricks. The result is the hardened, fractured rock called clinker. Most clinker is red, but some contains shades of yellow, orange, and black. In general, baked sandstone retains its original grain structure. The grains of fine-grained sediments are sintered—heated and welded together to form a coherent mass without melting—resulting in a rock similar to porcelain. A small amount of rock—primarily in fissures that served as chimneys— has been melted to hard black paralava. Virtually all of this clinker is harder than the parent rock. At the base of the clinker lies a thin layer of light tan ash mixed with greenish glass. In addition, clinker is highly fractured and allows much water to drain through rather than run off. The greater hardness, combined with fracture permeability, makes the clinker more resistant to erosion than the unfired bedrock strata above and below. Consequently, regional downwasting leaves the clinker forming the tops of scarps and ridges. See block diagram and cross sections.



Block diagram of clinker-dominated landscape (from Heffern and Coates, 1997)



Schematic cross section A–A', Rochelle Hills, east of Wright, WY



Schematic cross section B–B', Tongue River Valley, near Ashland, MT

- Cross section
- Ma = millions of years
- clinker of Knobloch coal zone
- clinker of Anderson coal zone
- clinker of other coal beds

(Cross sections from Heffern and others, 2007)

Age of Clinker

How long ago did coal at a given location burn to form clinker? Clinker can be dated by several means, including uranium-thorium / helium ratios and fission-track counts in zircon grains from within baked sandstone, as well as paleomagnetic dating of magnetite, hematite, and goethite in paralava. These dates, in turn, help us to better understand how the landscape evolved over geologic time as major river systems cut down into the sediment of the Powder River Basin, and the rate at which coalbeds were exposed, burned, and released combustion gases into the atmosphere.

Uranium-Thorium/Helium (ZHe) ages of clinker, in millions of years (Ma)

- 0–0.049
- 0.050–0.149
- 0.150–0.249
- 0.250–0.499
- 0.500–0.999
- 1.000–1.999
- 2.000 and older

All ZHe analyses are from Reiners and others (2011), Riihimaki and others (2009), and Heffern and others (2007).

Zircon fission-track (ZFT) ages of clinker, in millions of years (Ma)

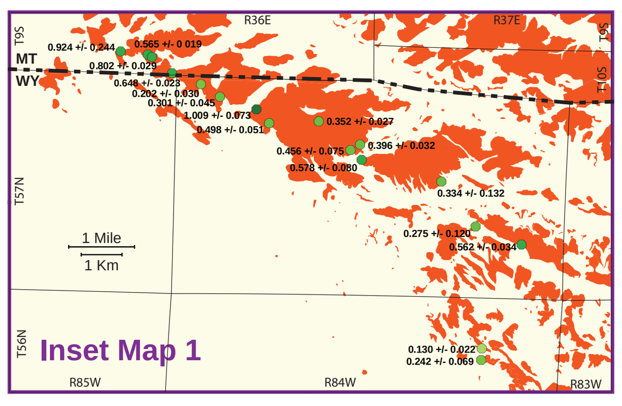
- 0–0.149
- 0.150–0.249
- 0.250–0.499
- 0.500–0.999
- 1.000–1.999
- 2.000 and older

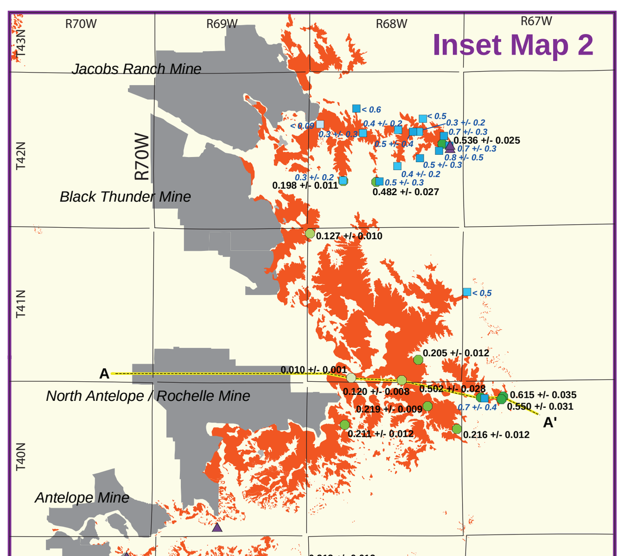
All ZFt analyses are from Heffern and others (2007) and Coates and Naeser (1984).

Paleomagnetic samples of clinker

- Normal polarity
- Reversed polarity

All paleomagnetic analyses are from Jones and others (1984).
Normal polarity indicates the coal burned more recently than the Matuyama-Brunhes magnetic reversal at about 0.78 Ma.





This map prepared in cooperation with the U.S. Bureau of Land Management.

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MBMG

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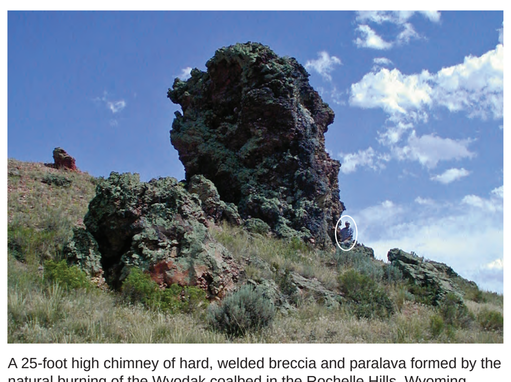
Ed Heffern below the base of the clinker formed by the burning of the Knobloch coalbed in the Tongue River valley north of Ashland, Montana. Collapsed blocks of reddish baked sandstone overlie the basal ash zone that marks the original base of the coalbed, underneath which is unburned sandstone.



A 25-foot high chimney of hard, welded breccia and paralava formed by the natural burning of the Wyodak coalbed in the Rochelle Hills, Wyoming. Note the person (white oval) standing on the right side of the chimney.

The Rochelle Hills escarpment capped by the clinker formed by the burning of the Wyodak coalbed, at Keyton Canyon east of Wright, Wyoming.

Mark Engle of the U.S. Geological Survey sampling gases coming off a coalbed fire along the banks of the Tongue River north of Sheridan, Wyoming.

View of collapse along burn front of the same active coalbed fire shown in picture to left, north of Sheridan, Wyoming. The reddish color in parts of the collapsed area marks areas where clinker has formed.