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Stratigraphic Cross Sections of the Mowry Shale and Associated Strata in the Wind River Basin, Wyoming

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)

Stratigraphic Cross Sections of the Mowry Shale and Associated Strata in the Wind River Basin, Wyoming

By Thomas M. Finn

Introduction

The Wind River Basin is a large northwest-trending structural and sedimentary basin that formed in the Rocky Mountain foreland during the Laramide orogeny in latest Cretaceous through early Eocene. The basin encompasses about 7,400 square miles (mi^2) in central Wyoming and is bounded by the Washakie, Owl Creek, and Bighorn uplifts on the north, the Casper arch on the east, the Granite Mountains uplift on the south, and the Wind River uplift on the west (fig. 1).

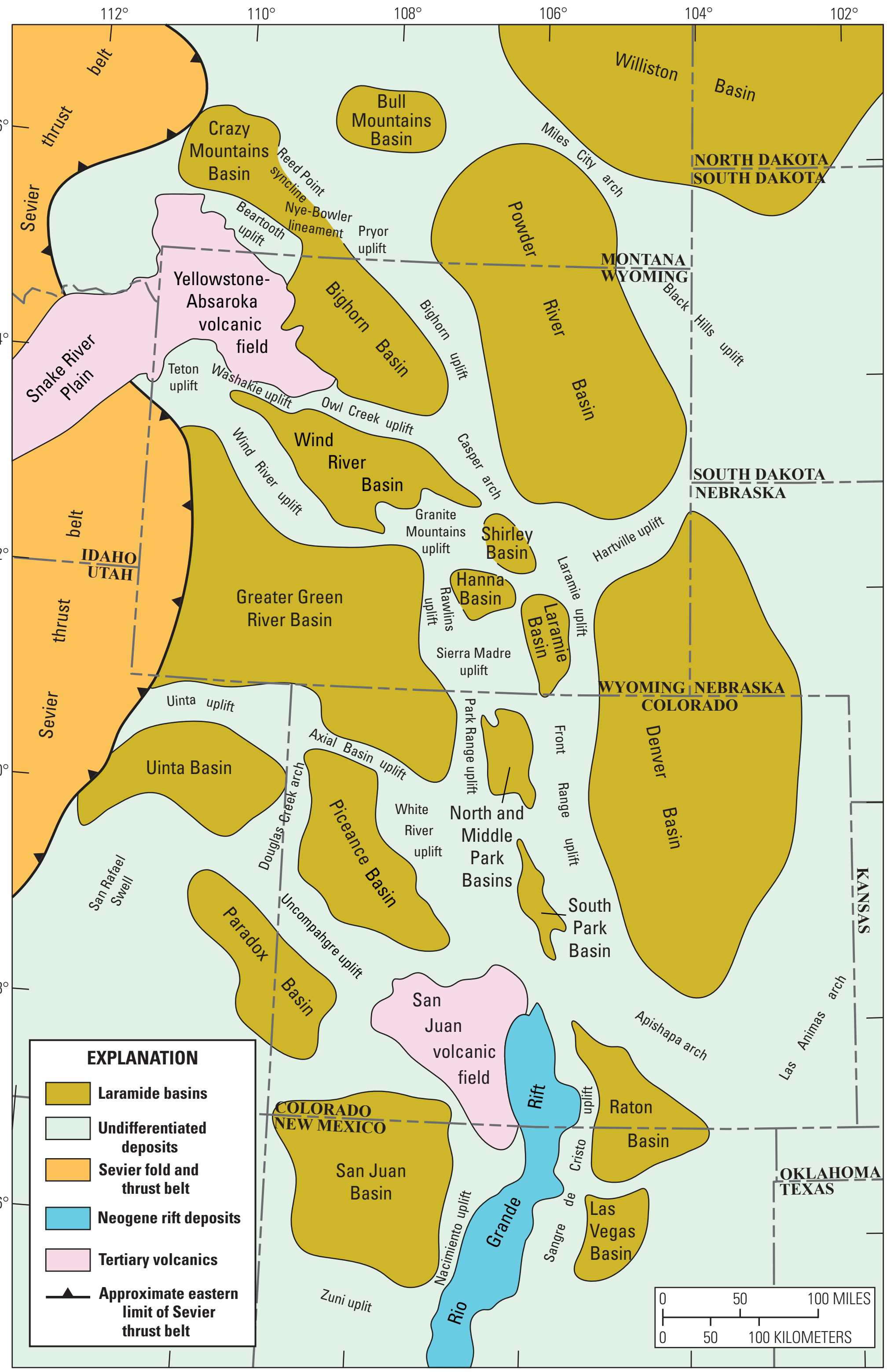
The first commercial oil well completed in the Wind River Basin was drilled near an oil seep in 1884 at Dallas Dome about 8 miles (mi) southeast of the present-day town of Lander (fig. 2) (Biggs and Espach, 1960). Since then, many important conventional and unconventional oil and gas resources have been discovered and produced from reservoirs ranging in age from Mississippian through Tertiary (fig. 2) (Keefer, 1969; Fox and Dolton, 1989, 1996; De Bruin, 1993; Johnson and others, 1996, 2007). It has been suggested that the Mowry Shale is an important source rock for many of these accumulations (Geis, 1923; Schrayer and Zarrella, 1963, 1966, 1968; Nixon, 1973; Burtner and Warner, 1984; Meissner and others, 1984; Davis and others, 1989; Surdam and others, 2010). With recent technological advances and success in horizontal drilling and multistage fracture stimulation, the Mowry Shale is considered an important continuous (unconventional) shale oil and shale gas objective in other Rocky Mountain basins (Sterling and others, 2009; Surdam and others, 2010; Sterling, 2013; Sterling and Grau, 2014; Finley, 2017).

The stratigraphic cross sections presented in this report were constructed as part of a project carried out by the U.S. Geological Survey (USGS) to characterize and evaluate the undiscovered continuous (unconventional) oil and gas resources of the Mowry Shale in the Wind River Basin. The purpose of the cross sections is to show the stratigraphic relationship of the Mowry Shale and associated Lower and lowermost Upper Cretaceous strata.

Two cross sections were constructed using (1) borehole geophysical logs from 41 wells drilled for oil and gas exploration and production and (2) one research well that was cored and logged by the USGS in the southeastern part of the basin (Kirschbaum and others, 2019). Both lines originate at Sheldon Dome in the northwestern part of the basin and end near Bates Creek in the extreme southeastern part of the basin (fig. 2, and map sheet). The northern line extends from Sheldon Dome east along the northern margin of the basin to Madden anticline, then southeast to Tepee Flats and Hells Half Acre, then along the southwest margin of the Casper arch to Bates Creek (fig. 2 and map sheet). The southern line extends from Sheldon Dome southeast to Riverton Dome and along the southern margin of the basin, then southeast along the northeast margin of the Rattlesnake Hills to Bates Creek (fig. 2 and map sheet). The stratigraphic interval extends from the uppermost part of the Upper Jurassic Morrison Formation to the basal part of the Upper Cretaceous Frontier Formation (fig. 3). The datum is the Clay Spur Bentonite Bed, a distinctive bed at the top of the Upper Cretaceous Mowry Shale. This datum was selected because it is easily identified on most well logs and is present throughout the basin (fig. 4 and map sheet) (Finn, 2021).

Depositional Setting

During the Late Jurassic and Cretaceous, the part of Wyoming that is now the Wind River Basin was located in the Western Interior Basin, an elongate north-south foreland basin, that developed to the east of the tectonically active Cordilleran highlands of western North America (DeCelles, 2004). From the Albian to Maastrichtian (latest Early Cretaceous to Late Cretaceous), the foreland basin was periodically flooded by the Western Interior Seaway (WIS), a broad epicontinental sea that developed in response to foreland basin subsidence and eustatic sea-level fluctuations (Steidtmann, 1993). At its maximum extent, the WIS extended for more than 3,000 mi from the Arctic Ocean to the Gulf of Mexico (Kauffman, 1977). Kauffman and Caldwell (1993) identified nine second-order transgressive-regressive marine cycles for the Cretaceous. The most widespread cycle was the Greenhorn Cycle during the Cenomanian and Turonian. The Mowry Shale was deposited during the initial stages of the Greenhorn transgression



Base from U.S. Geological Survey, 1:5,000,000, 1985
Albers equal area conic projection

Figure 1. Map of the Rocky Mountain region showing locations of Laramide basins.

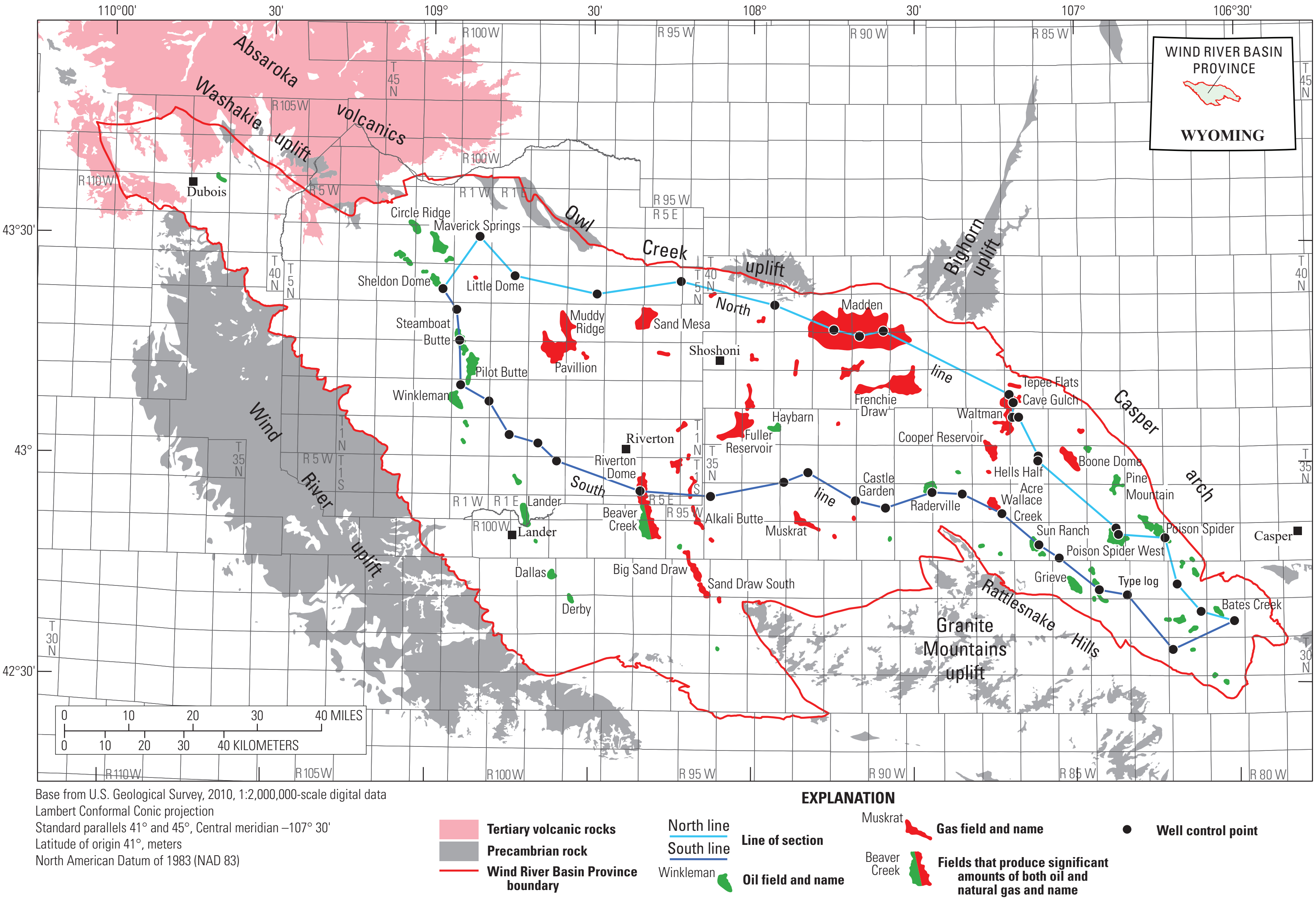


Figure 2. Index map of the Wind River Basin showing major structural elements, principal oil and gas producing fields, and cross section lines shown on map sheet.

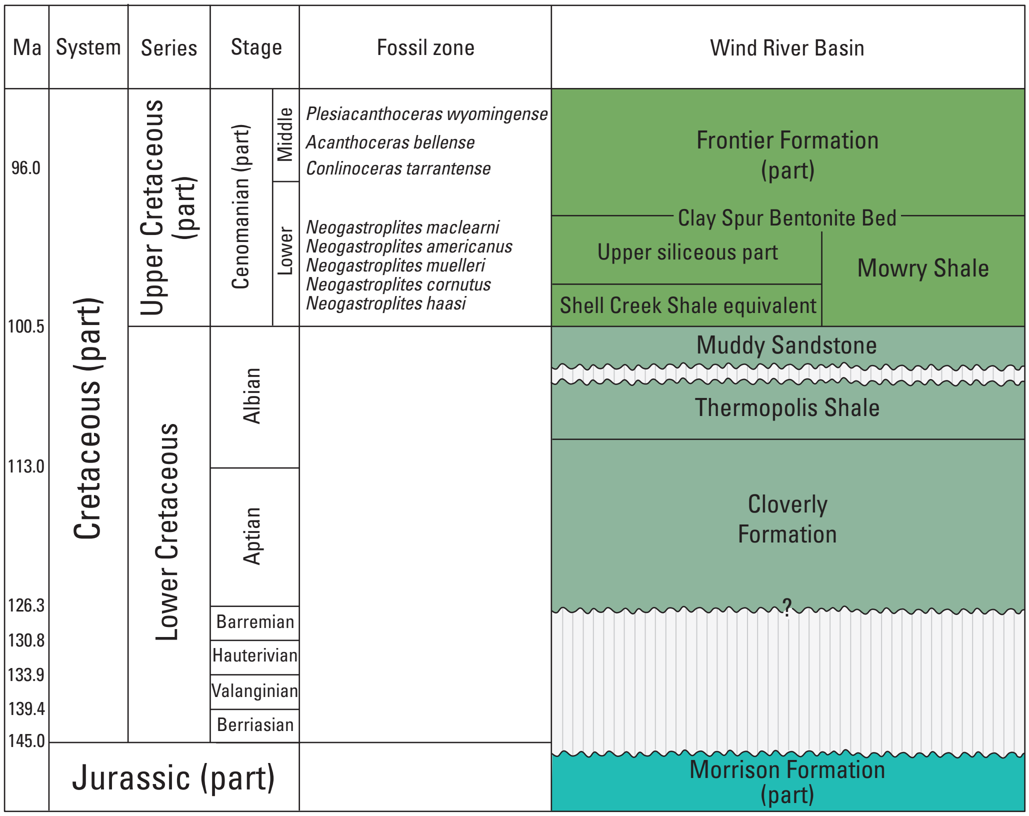


Figure 3. Correlation chart of Lower and lowermost Upper Cretaceous rocks in the Wind River Basin. Compiled from Keefer (1972), Merewether and others (1997), Cobban and others (2006), Gradstein and others (2012), Merewether and McKinney (2015), Walaszczyk and Cobban (2016), and Lynds and Slattery (2017).

in early Cenomanian when the northern arm of the WIS (often referred to as the Mowry Sea) flooded southward to the Transcontinental arch, which acted as a barrier separating the Mowry Sea from the proto-Gulf of Mexico to the south (fig. 5) (Kauffman and Caldwell, 1993; Steidtmann, 1993). Erosion of the Cordilleran highlands supplied coarser grained siliciclastic sediment to the margins of the basin by eastward-flowing streams, while finer grained marine mudrocks and shale accumulated in the offshore areas (Molenaar and Rice, 1988; Roberts and Kirschbaum, 1995). Continued sea level rise of the Mowry Sea breached the Transcontinental arch connecting it with the proto-Gulf of Mexico to form the Greenhorn Sea, which reached the highest eustatic sea level of the Cretaceous by early Turonian (Kauffman and Caldwell, 1993; Roberts and Kirschbaum, 1995; Blakey, 2014).

Stratigraphy

Cloverly Formation

The basal Cretaceous rocks in the Wind River Basin are represented by the Cloverly Formation, which consist of 60–225 feet (ft) of interbedded sandstone, variegated shale, and conglomerate that unconformably overlie the Upper Jurassic Morrison Formation. The sandstones and conglomerates were deposited in fluvial systems that flowed east-northeast from the fold belt across the basin, and the shales accumulated as overbank and lacustrine deposits (May, 1992; Steidtmann, 1993; May and others, 1995). According to May (1992), the Cloverly is Aptian in age; however, Merewether and others (1997) suggest that it is in part Albian.

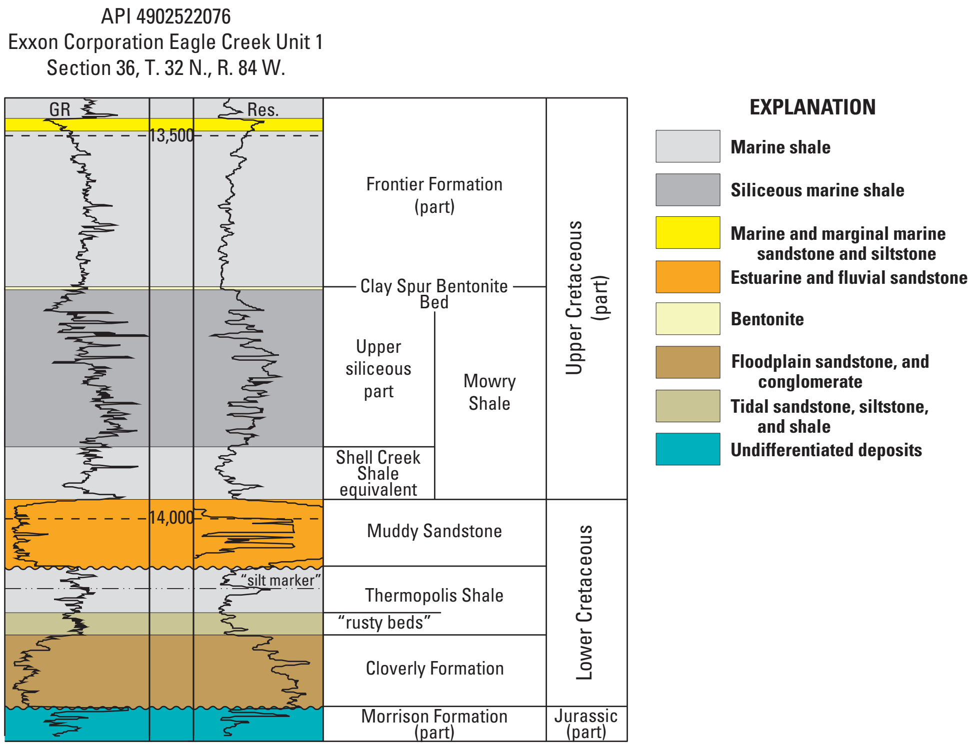


Figure 4. Type log of Lower and lowermost Upper Cretaceous rocks in the southeastern part of the Wind River Basin, GR, gamma ray log; Res., resistivity log. Location shown on figure 2.

Thermopolis Shale

The Lower Cretaceous Thermopolis Shale consists of gray to very dark gray shale, very fine grained sandstone, and siltstone (Burtner and Warner, 1984; Kirschbaum and others, 2019). It was named by Lupton (1916) for exposures near the town of Thermopolis in the southern part of the Bighorn Basin where he recognized a lower shale unit, a middle "muddy sandstone unit" and an upper shale unit. In the Wind River Basin, Love (1948) renamed Lupton's (1916) lower shale the Thermopolis Shale, the middle "muddy sandstone unit" the Muddy Sandstone and included the upper shale unit with the overlying Mowry Shale. This report uses Love's (1948) nomenclature. A distinctive high-resistivity zone or peak near the middle of the Thermopolis Shale is informally referred to as the "Dakota silt" or "silt marker" by Mitchell (1978), Keefer (1997), and Keefer and Johnson (1997) (fig. 4 and map sheet). The basal part of the Thermopolis Shale, informally referred to as the "rusty beds" by Washburne (1908) and Eicher (1962), consists of interbedded shale, bioturbated siltstones, and very fine grained sandstones (May, 1992; Kirschbaum and others, 2019). These units accumulated in tidal flats and represent the initial transgression of the Cretaceous sea during the Albian (May, 1992). While most authors consider the "rusty beds" the basal part of the Thermopolis Shale (Washburne, 1908; Burk, 1956; Eicher, 1960, 1962; Mirsky, 1962; May 1992; May and others 1995), Love (1948) and Keefer and Troyer (1964) included the "rusty beds" with the underlying Cloverly Formation. The Thermopolis Shale, including the "rusty beds," ranges in thickness from 90 to about 220 ft.

Muddy Sandstone

The name Muddy was first used informally by drillers for “muddy sandstones” in the lower part of the Benton Shale as described in Hintze (1915) and was referred to as the Muddy Sandstone in the Wind River Basin by Love (1948). The Lower Cretaceous Muddy Sandstone is composed of fine- to coarse-grained sandstone with interbedded shales deposited in fluvial, marginal marine, and estuarine environments (Dresser, 1974; Curry, 1985; Kirschbaum and others, 2019). The Muddy Sandstone ranges in thickness from near zero (Love, 1948) to about 100 ft, with the thickest accumulations associated with incised valley systems that developed on the exposed surface of the Thermopolis Shale during sea level lowstand (Van Wagoner and others, 1990; Dolson and others, 1991). The age of the Muddy Sandstone is Early Cretaceous, based on the presence of Albian foraminifera and ammonites in adjacent units (Eicher, 1962).

Mowry Shale

The Upper Cretaceous Mowry Shale was named by Darton (1904) for exposures of ridge-forming fossiliferous strata in the northwestern part of the Powder River Basin, and the upper contact was defined as the top of the Clay Spur Bentonite Bed (Ruby, 1930; Nixon, 1973). In the Wind River Basin, the Mowry Shale extends from the top of the Clay Spur Bentonite Bed down to the top of the Muddy Sandstone (figs. 3, 4, and map sheet). The Mowry Shale consists of a lower soft clay-rich shale (originally the upper Thermopolis shale unit of Lupton, 1916) and an upper hard siliceous unit (Keefer and Troyer, 1964; Keefer, 1997). The combined thickness of the lower and upper units ranges from less than 250 ft in the southeastern part of the basin to greater than 625 ft in the northwestern part (fig. 6). This east to west increase in thickness reflects an increase in sediment supply from the tectonically active Cordilleran highlands to the west (Burtner and Warner, 1984). Both units contain abundant fish scales, bone, and *Inoceramus* fragments. Numerous bentonite beds in both the upper siliceous unit and lower shaley unit were derived from volcanic source areas to the west and can be traced in the subsurface throughout the basin (map sheet). The bentonite beds range in thickness from a fraction of an inch to several feet (Byers and Larson, 1979; Kirschbaum and others, 2019).

Eicher (1960, 1962) named the lower part of the Mowry Shale the Shell Creek Shale for exposures in the Bighorn Basin and traced it into several localities in the Wind River Basin. The Shell Creek Shale equivalent strata in the Wind River Basin consists of medium- to dark-gray mudrock, siltstone, very fine grained sandstone, and bentonite (Love, 1948; Keefer, 1997; Kirschbaum and others, 2019) and ranges in thickness from less than 50 ft in the southeastern part of the basin to about 180 ft in the northwestern part (fig. 7).

The upper siliceous part of the Mowry Shale consists of 189 to 460 ft of gray to brown organic-rich, hard brittle siliceous mudrock, siltstone, very fine grained sandstone, and bentonite (fig. 8) (Byers and Larson, 1979; Burtner and Warner, 1984; Kirschbaum and others, 2019). To the west, the upper part of the Mowry Shale grades laterally into sandstones that have been traditionally included with the overlying Frontier Formation (Love, 1948; Keefer, 1972). These sandstones, however, occur below the Clay Spur Bentonite Bed and are included here with the upper part of the Mowry Shale (map sheet).

$^{40}Ar/^{39}Ar$ dates of 98.19 and 99.25 Ma determined on sanidine from bentonite beds in the Shell Creek equivalent strata near Maverick Springs in the northwestern part of the basin and a date of 97.17 Ma for the Clay Spur Bentonite Bed near Casper, along with the presence of ammonites from the genus *Neogastroplites,* indicate an early Cenomanian age for the Mowry Shale (fig. 3) (Reeside and Cobban, 1960; Obradovich, 1993; Weimer and others, 1997; Walaszczyk and Cobban, 2016).

Frontier Formation

The Upper Cretaceous Frontier Formation was named by Knight (1902) for exposures near the town of Frontier in western Wyoming, and the formation name was first used in the Wind River Basin by Hares (1916). In the Wind River Basin, the Frontier Formation consists of alternating sandstone, siltstone, shale, and bentonite that accumulated in marine and marginal marine environments (Merewether and Cobban, 2007). Sandstones are generally present in the upper part of the formation, whereas the lower part is composed of shale, except in the western part of the basin where several sandstone beds are present in the lower part. According to Merewether and Cobban (2007), the Frontier Formation is Cenomanian to Coniacian and ranges in thickness from 650 to 1,000 ft. The Frontier consists of three members, in ascending order: (1) Belle Fourche Shale Member, (2) Emigrant Gap Member, and (3) Wall Creek Sandstone Member. Only the basal part of the Frontier is shown on the cross sections where it conformably overlies the Mowry Shale (map sheet).

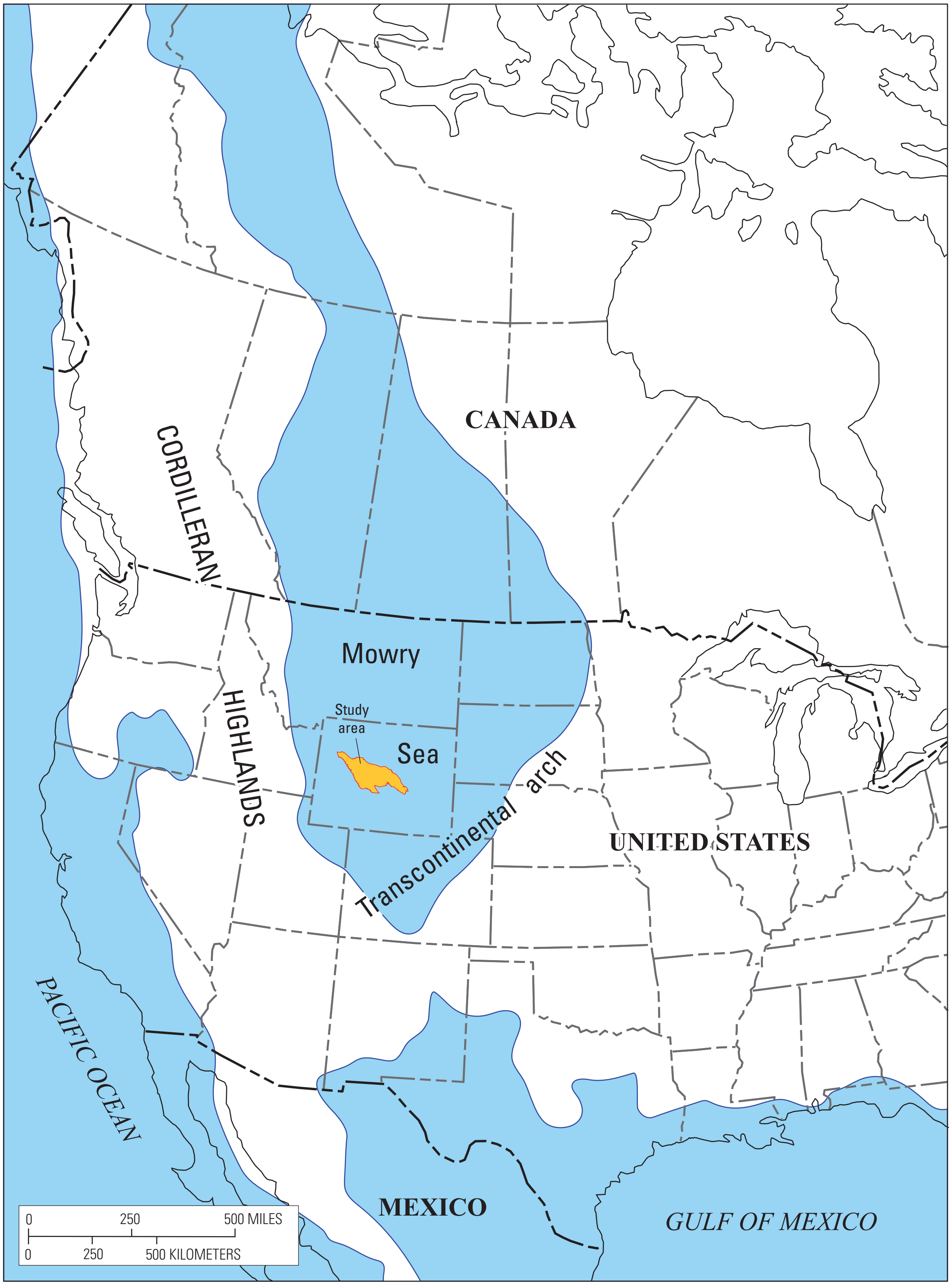


Figure 5. Map showing approximate extent of the Mowry Sea (Western Interior Seaway) in North America during early Cenomanian. Modified from Kauffman and Caldwell (1993) and Blakey (2014).

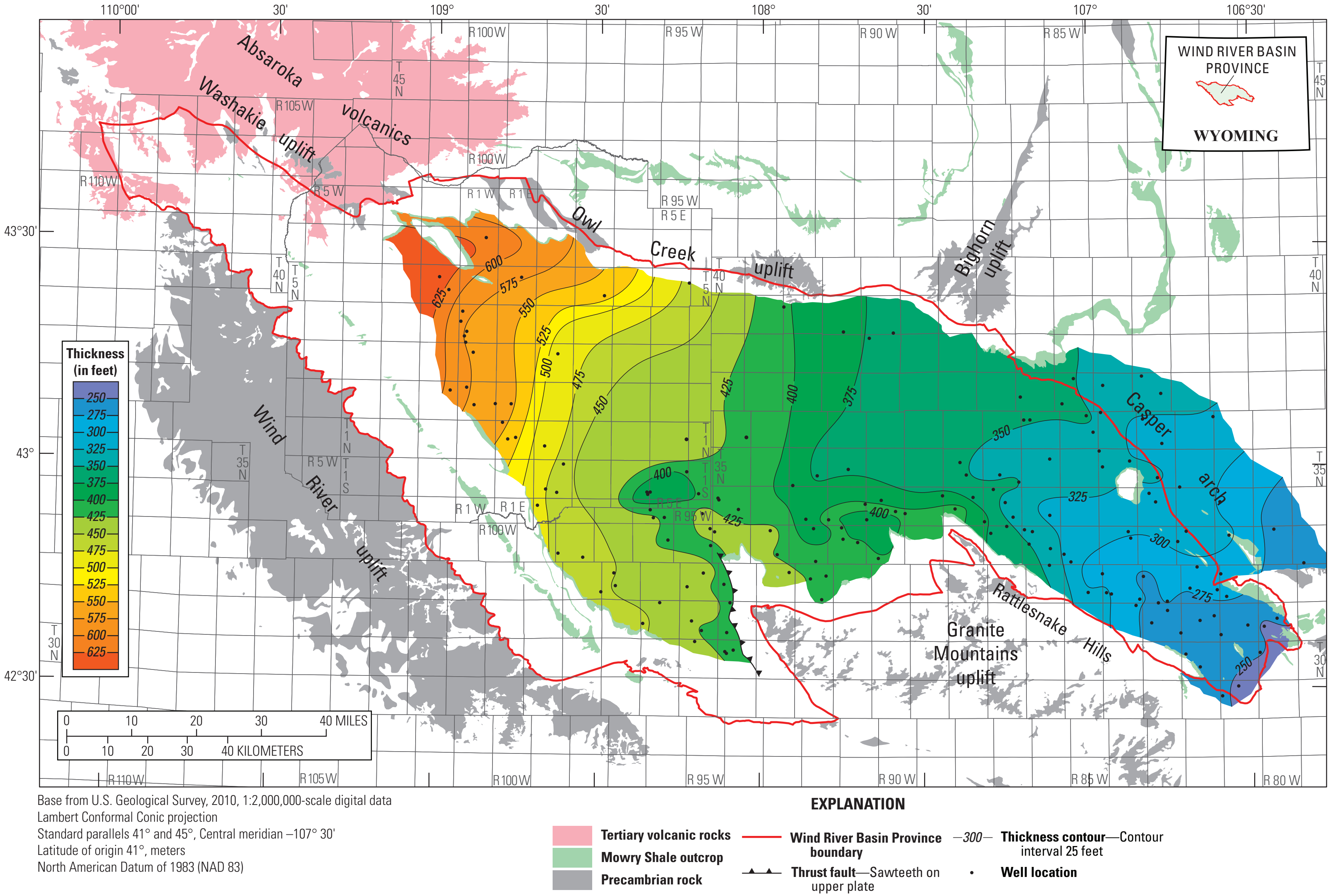
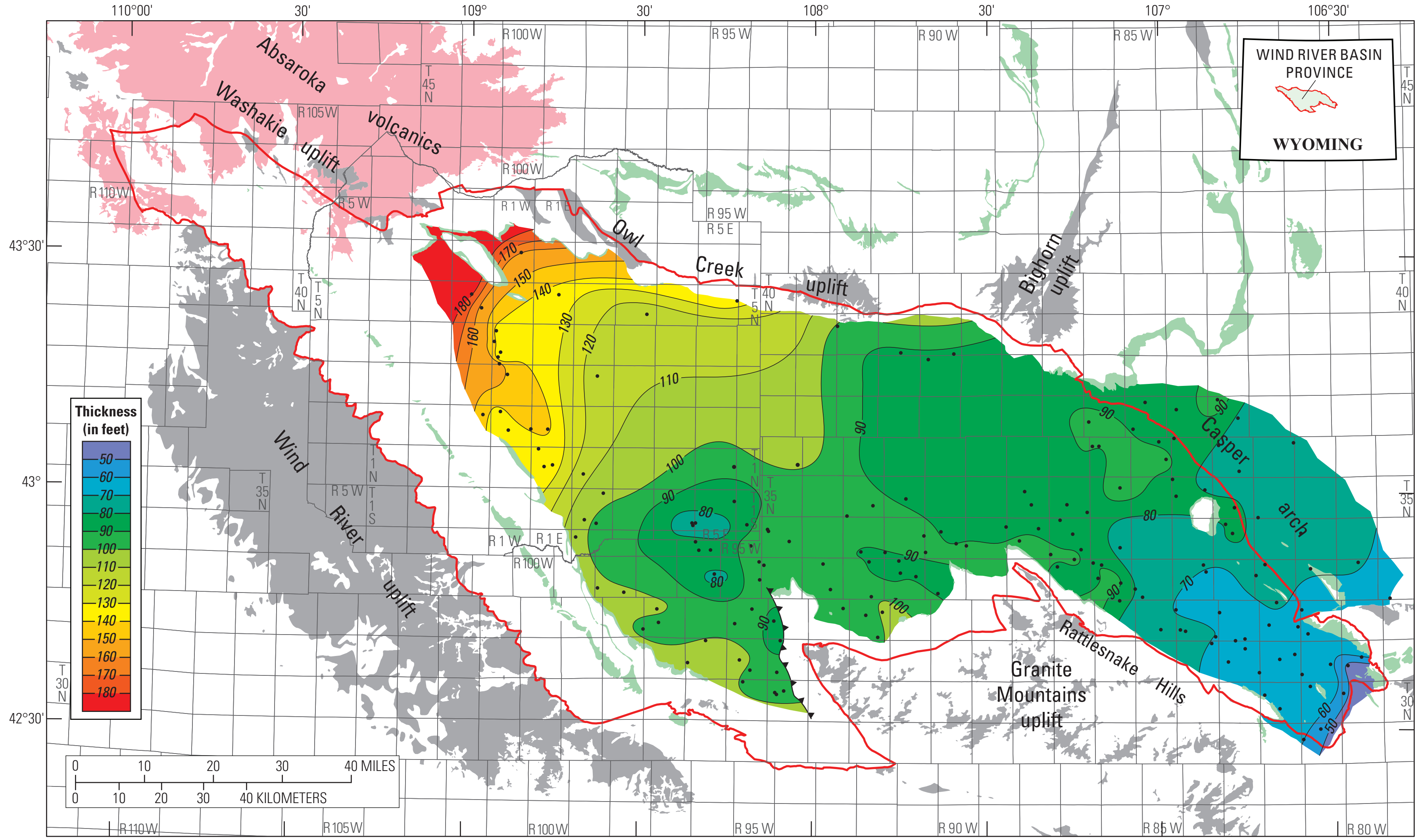


Figure 6. Isopach map of the Mowry Shale in the Wind River Basin. This map includes the interval from the top of the Clay Spur Bentonite Bed to the top of the Muddy Sandstone. Thickness interval 25 feet.



Base from U.S. Geological Survey, 2010, 1:2,000,000-scale digital data
Lambert Conformal Conic projection
Standard parallels 41° and 45°, Central meridian –107° 30'
Latitude of origin 41°, meters
North American Datum of 1983 (NAD 83)

EXPLANATION

- **Tertiary volcanic rocks**
- **Mowry Shale outcrop**
- **Precambrian rock**
- **Wind River Basin Province boundary**
- **Thrust fault**—Sawteeth on upper plate
- —300— **Thickness contour**—Contour interval 10 feet
- **Well location**

Figure 7. Isopach map of the Shell Creek Shale equivalent strata. This map includes the interval from base of the upper siliceous part of the Mowry Shale to the top of the Muddy Sandstone. Thickness interval 10 feet.

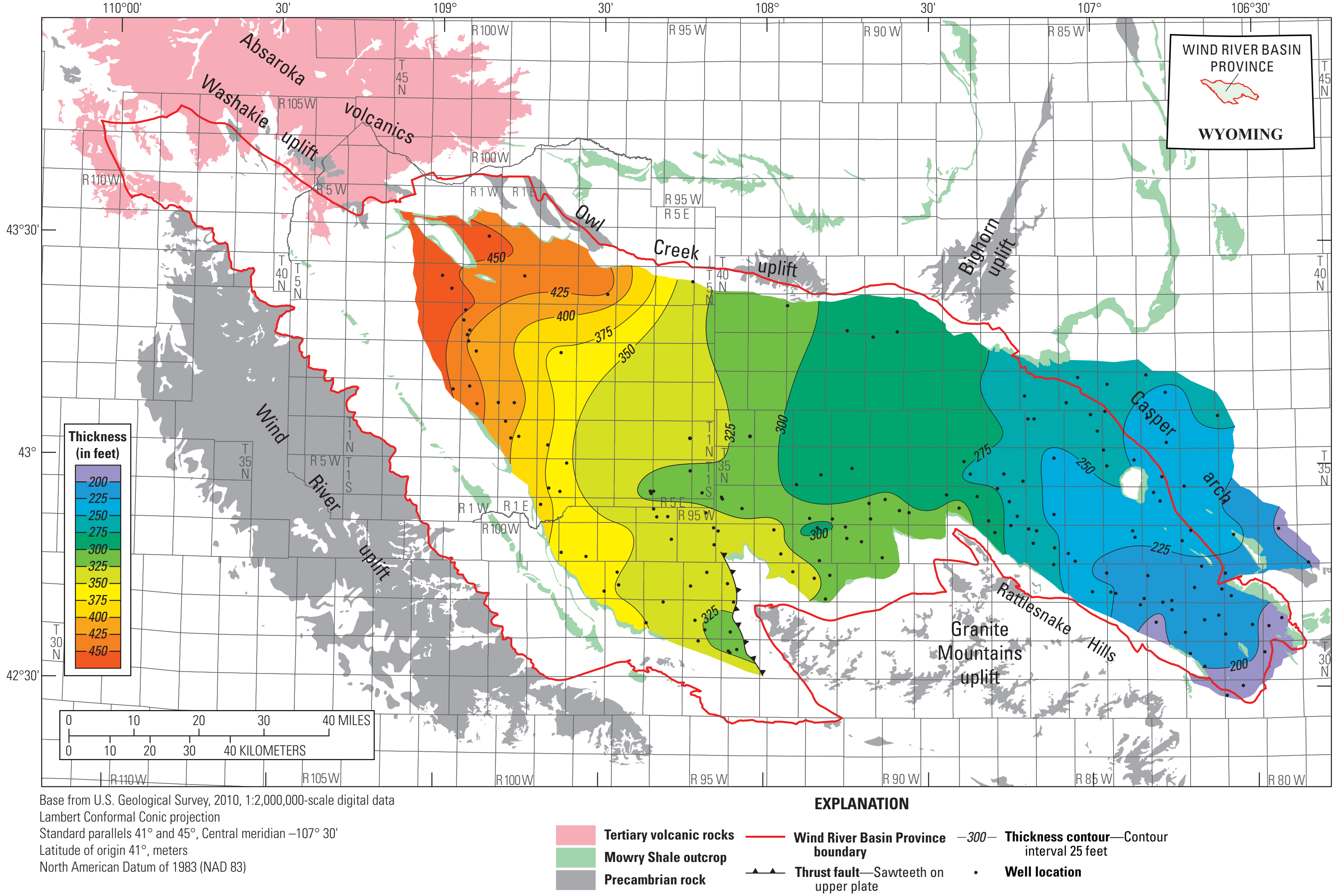


Figure 8. Isopach map of the upper siliceous part of the Mowry Shale. This map includes the interval from top of the Clay Spur Bentonite Bed to the top of the Shell Creek Shale equivalent strata. Thickness interval 25 feet.

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