Stratigraphy, petrography, and environment of deposition of the Frontier Formation on the western margin of the Crazy Mountains Basin, south central Montana
by John Joseph Tonnsen

A thesis submitted in partial fulfillment of the requirement for the degree of MASTER OF SCIENCE in Earth Sciences (Geology Option)
Montana State University

Abstract:
The Frontier Formation in Montana has been studied only generally until this time. In the Bridget Range in Gallatin County and in the hills northeast of the range there are exposures of the early Upper Cretaceous Frontier Formation on the western margin of the Crazy Mountains Basin. The formation conformably overlies the Mowry Shale Formation and is overlain by the Cody Shale Formation in the study area. Stratigraphic, petrographic, and depositional environment aspects of the formation are studied.

The Frontier Formation is about 520 feet thick in the study area, and three members are observed: A Basal Member about 60 feet thick composed of sandstone, a Middle Member about 380 feet thick containing sandstones, siltstones, and claystones, and an Upper Member about 80 feet thick consisting of sandstone. The Middle Member contains a distinctive zeolite-bearing unit and a black siliceous mudstone unit containing white calcareous bivalve fossils. A chert pebble conglomerate zone in the Upper Member may be associated with a disconformity in the formation. The members and units correlate uniformly throughout the study area.

Thin sections of rock specimens are analyzed for qualitative and quantitative grain, matrix, and cement relationships. Evidence is assembled that explains the provenance of the sediment, the processes by which it was deposited, and the environment it was deposited in.

Proposed sources of the sediment are Precambrian rocks in central Idaho and Paleozoic chert-bearing carbonate and quartzite sedimentary rocks in western Montana. The sediment was deposited by streams discharging into the Cretaceous seaway that extended across central Montana Movement along major Precambrian fault systems displaced basement structures sufficiently to render the basin a favorable location for deposition. Volcanic ejecta was also deposited both from streams and as airborne ash fall from explosive volcanoes presumed to have been associated with emplacement of the Idaho Batholith. A north-trending coastline fluctuated east and west across south central Montana. Fluvial, deltaic, lagoonal and marine sediments were deposited. Steady accumulation and progradation of sediment forced the margin of the sea eastward. The sediment supply diminished near the end of Frontier time and the sea transgressed to western Montana.

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Date September 9, 1975

STRATIGRAPHY, PETROGRAPHY, AND ENVIRONMENT OF DEPOSITION OF THE FRONTIER FORMATION ON THE WESTERN MARGIN OF THE CRAZY MOUNTAINS BASIN, SOUTH CENTRAL MONTANA

by

John Joseph Tonnsen, Jr.

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ABSTRACT

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CHAPTER I. INTRODUCTION

A. Location

The region under study comprises nearly 400 square miles including the east side of the Bridger Range and the hills northeast of the range. This region is in south central Montana and is bounded by the communities of Bozeman, Maudlow, Ringling, and Livingston (Figure 1). The range extends nearly 30 miles in a north to northwest direction from Rocky Canyon on U.S. Interstate 90 about 12 miles east of Bozeman. The mountains are folded Precambrian to Tertiary sedimentary rocks and are faulted normally upwards exposing Precambrian igneous and metamorphic crystalline rocks on the west side. The highest peak is Sacagawea Peak with an elevation of 9665 feet. The mountains mark the eastern end of the Three Forks Valley. The city of Bozeman is in this part of the valley and has an elevation of 4675 feet. The range forms a distinctive skyline visible for many miles in all directions of approach to Bozeman.

Along the crest of the range are palisades that trace the steep eastward dipping to overturned (westward) resistant strata of the Mississippian Madison Limestone Formation. On the east side, the Mesozoic and Cenozoic formations are recumbent folds and tightly compressed and faulted concentric folds that become less strongly folded but dip steeply eastward into the Crazy Mountains Basin. The hilly area northeast of the range contains these sediments in a less intensely folded series of partially eroded anticlines and synclines. Notable structures are the major folds northwest of Wilsall, Montana.

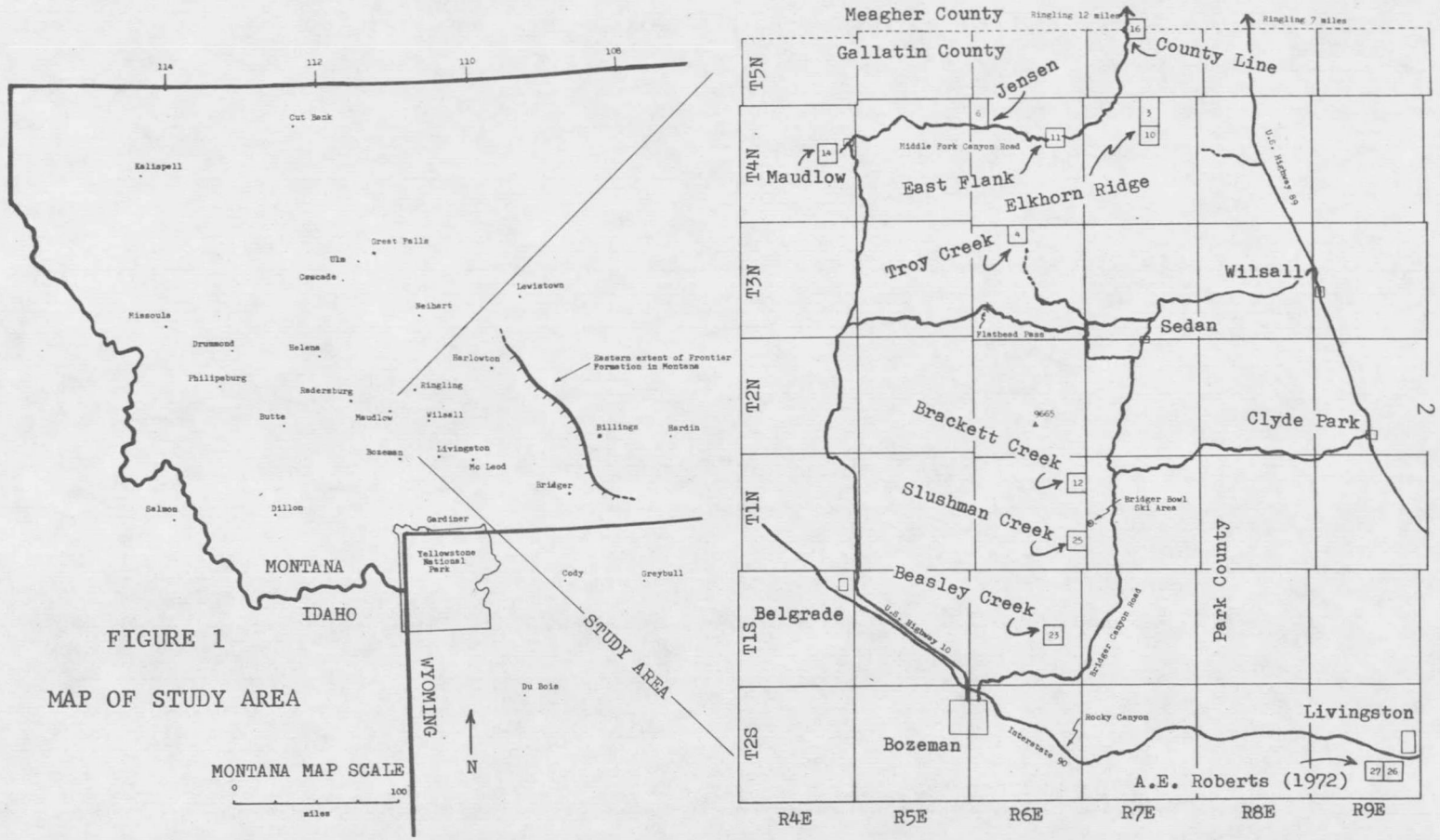

FIGURE 1

MAP OF STUDY AREA

These are, west to east, Elkhorn anticline, Wallrock syncline and Ringling anticline. Prominent anticlinal and synclinal noses form erosional escarpments at Wallrock Basin and Elk Ridge about six miles northwest of Wilsall. The canyon on the Middle Fork of Sixteenmile Creek from Maudlow to Ringling is incised into these sediments, and affords the only west to east access to study through the Bridger Range.

The Crazy Mountains are 25 miles east of the Bridger Range, and in the area between the two mountains, the Paleozoic sediments are estimated to be nearly 17,000 feet deep (Garrett, 1972). The Crazy Mountains are located approximately over the center of the Crazy Mountains Basin. The Bridger Range and the Crazy Mountains Basin are Laramide structures (McMannis, 1955), and the Crazy Mountains are a post-Laramide igneous intrusive that apparently pierced the sedimentary sequence. The sedimentary rocks are observed to dip gently into the basin along U.S. Interstate 90 from Livingston to Billings, Montana, a distance of nearly 130 miles.

B. Purpose of the Study

The initial purpose of this study is to locate exposures of the Frontier Formation in the heavily forested complex structures on the east side of the Bridger Range and along the Middle Fork of Sixteenmile Creek. The formation has been mapped in the course of general geologic mapping of the area, however, the formation has not been studied in detail.

Principal purposes are to measure stratigraphic sections of the formation, to correlate the lithologic relationships, and to study thin sections in order to determine the environment of deposition of the formation on the western margin of the Crazy Mountains Basin.

Other purposes are to propose sources of the sediment, and to compare the formation in the study area with the literature regarding the formation in adjacent areas.

C. Method

During the summer and autumn of 1974, a total of seven weeks was spent in the field measuring stratigraphic sections and collecting specimens.

Aerial photographs were used to judge the terrain for lateral extent and quality of rocky exposures of the Frontier Formation. Stratigraphic sections were measured by traverses with steel tape and Jacob staff.

D. Previous Work

The Frontier Formation is most thoroughly studied in Wyoming. It is named for the town of Frontier, a small coal mining town in Lincoln County two miles north of Kemmerer, Wyoming (Knight, 1902)

In the exposures at the type locality, the formation consists of 2600 feet of interbedded sandstones, siltstones, dark shales, pyroclastic sediments, and coal. A 200-foot thick, fossil mollusk-bearing, muddy sandstone bed 600 feet from the top of the formation forms a

topographic feature known as Oyster Ridge.

Veatch (1907) described the formation as lying stratigraphically between the marine Mowry Shale Formation and the overlying marine Hilliard Shale Member of Colorado Shale Formation.

W.A. Cobban and J.B. Reeside, Jr. assembled considerable information about the formation during the years prior to the Korean War. They published a correlation paper for the Frontier Formation throughout Wyoming and the adjacent areas of Utah, Colorado, Idaho and Montana (Cobban and Reeside, 1952a). This work was accompanied by a contribution correlating all of the Cretaceous formations of the western interior of the United States (Cobban and Reeside, 1952b). These publications still serve as principal references for Cretaceous stratigraphic research in the western states.

In these papers, Cobban and Reeside described the Frontier Formation sediments, and organized the field exposures and oil well drilling data and samples by extensive lithological and paleontological correlations.

The work of Cobban and Reeside was extended by stratigraphers and sedimentologists, who commenced to interpret the lithofacies of the formation and to evaluate the provenance of the sediements and the environment of deposition (Goodell, 1962; Van Houten, 1962). Goodell's work included the Frontier Formation in Wyoming where the main mass of sediment appears to have been deposited. He utilized the terminology

used by petroleum geologists who often describe the Frontier Formation in terms of three major sandstone zones: the First Wall Creek, Second Wall Creek, and Third Wall Creek in the order they are intercepted during drilling. Sometimes these are referred to as formations, but more often they are considered members of the Frontier Formation (Goodell, 1962).

Goodell concludes that the Third Wall Creek Sandstone Member reflects an increase in clastic material from an uplift to the west. The sandstone intertongues with, and, in part, conformably overlies the Mowry Shale Formation.

The Second and then the First Wall Creek Sandstone Members are interpreted to represent subsequent progradations of sediment in response to continued tectonism and uplift. Uplift, batholithic intrusion thrust faults, and volcanism were establishing the Northern Rocky Mountains at this time (Scholten and Ramspott, 1968).

During temporary relaxation of these orogenic events, the Cretaceous Sea transgressed into reentrants along the irregular coastline east of the emerging mountains. The First Wall Creek Sandstone, for example, contains clean, better rounded quartz grains than the lower sandstones and evidences a prominent transgressive phase.

Attempts were made to extend the Wyoming correlations into Montana. The dark line in Figure 1 depicts the easternmost extent of the Frontier Formation in Montana. The formation has been correlated north from the

Big Horn Basin to the area southwest of Billings at Bridger, Montana. Specifically, the Peay Formation and Torchlight Formation have been correlated with the Third Wall Creek Member and First Wall Creek Member, respectively (Knappen and Moulton, 1931; Goodell, 1962).

In the Harlowton area, a 248-foot thick sandstone called the Big Elk Sandstone Fromation was described by Bowen (1918). This sandstone represents the Frontier Formation in that area, and may correlate with the Boulder River Sandstone Member of the Frontier Formation near Livingston (Roberts, 1972). Forty miles west of Harlowton a 232-foot massive sandstone has been suggested to correlate with the Big Elk Sandstone (Tanner, 1949). The sandstone is 15 miles northwest of the study area. In Judith Basin County 50 miles northwest of the study area, the Frontier Formation is not recognized. The Colorado Group there is a 1500-foot thick dark shale with a few thin sandstone units (Zimmerman, 1966).

In a series of lithologic correlations with minor paleontological work, the Frontier Formation has been extended to Mc Leod (Richards, 1957), where the Peay Formation is the Basal Member and is termed the Boulder River Sandstone Member of the Frontier Formation. The Upper Member is considered correlative with the Torchlight Sandstone of Knappen and Moulton (Roberts, 1972). Northwest of the study area, the Frontier Formation is lithologically similar to the sandstone, siltstone and bentonite units of the Vaughn and Bootlegger Members of the

Blackleaf Formation in the Sweetgrass Arch area (Cobban, and others, 1959).

Emmons and Calkins (1913) extended the Frontier Formation lithologically to Philipsburg in western Montana where at least one marine sandstone is even observed. The major part of the Colorado Group, including the Frontier Formation, in western Montana is nonmarine. Klepper (1957) noted a nonmarine "salt and pepper" sandstone and conglomerate of possible Frontier correlation near Radersburg east of the Elkhorn Mountains and about 30 miles west of the study area. At a few localities in western Montana, sandstones, siltstones, dark shales, and conglomerates are part of the Colorado Formation and may correlate with the Frontier Formation. McGill (1959) mapped coarse, conglomeratic sandstone interbedded with dark shales as part of the Colorado Formation in the Flint Creek Range along the western margin of the Deer Lodge Valley not far from Phlipsburg. These may be terrestrial equivalents of the Frontier Formation. Other lithologic correlations have been made to nonmarine volcanic and terrestrial sandstone and shales in the Drummond area (Gwinn, 1961; 1965).

In southwestern Montana the Frontier Formation is apparently missing due either to nondeposition or erosion (McMannis and Chadwick, 1964). The formation may be covered in parts of southern Montana by extensive ash and tuff flows from Yellowstone National Park (Hall, 1961). In a few exposures lithologic equivalents of the Frontier

Formation have been found and some shale units have been correlated with the Mowry Shale Formation (Hall, 1961).

Marine sandstones, shales and clay of Frontier Formation have been measured at Cinnabar Mountain in the Yellowstone Valley (Wilson, 1934; Fraser, 1969). A 45-foot sandstone unit said to be correlative with the Basal Member at Cinnabar Mountain was measured on Mr. Everts in Yellowstone National Park a few miles south of Gardinar, Montana (Ruppel, 1972).

Recently, Roberts (1972) concluded section measurement, geologic mapping, and lithologic correlation of Cretaceous and Tertiary sedimentary rocks in the Livingston area. Skipp and Hepp (1968) mapped the Hatfield Mountain Quadrangle noting the Frontier Formation to be a 500-foot thick sandstone and sandy shale formation with oyster banks and a conglomerate zone. An earlier geologic map of the Maudlow Quadrangle (Skipp and Peterson, 1965) includes 600 to 900 feet of similar lithology as the Middle Member of the Colorado Group with the suggestion that the member correlates with the Frontier Formation. Roberts, Skipp and McGraw, respectively, have many maps that include the study area on Open File with the U.S. Geological Survey and these are all noted in the List of References at the end of this paper.

CHAPTER II. STRATIGRAPHY OF THE FORMATION

A. Stratigraphic and Field Relationships of the Frontier Formation

Field examination of the Frontier Formation indicates that the formation is light gray to greenish-gray, medium- to coarse-grained "salt and pepper" sandstone interbedded with fine-grained sandstone and silty shale. The formation averages 500 feet in thickness. It is positioned stratigraphically between two thick dark shale zones. The underlying shale is the Mowry Shale Formation and the overlying shale is the Cody Shale Formation.

The dark soil in the swales of the covered intervals has a blue or green tint, and is rich in montmorillonite clay. It is possible to auger through the soil and collect chips of gray to black fine-grained sandstone and siltstone. Soil crusts in the grass covered swales form "popcorn" soil clods due to shrinking of the montmorillonite clay. The fine sand and silt texture of these soils drains them better than the soils covering the two dark shale zones.

The chart in Figure 2 shows the formations observed in the study area.

The Mowry and Thermopolis Shale Formations form grass covered swales at all sections measured. They are 940 feet thick in the Livingston area (Roberts, 1972). The formations are thinner and measure only 250 to 300 feet in the study area. It is suggested that the shale is thin due to its incompetence relative to the competent sandstones and carbonate rocks in the folded strata. Numerous small faults