Lewis and Clark and the Geology of the Great Plains

by
R. F. Diffendal, Jr.
and
Anne P. Diffendal

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Editing: Charles A. Flowerday

Design and Layout: Reynold Peterson

Cartography: Ann M. Mack

Photography: R. F. Diffendal, Jr., unless otherwise noted.

R. F. Diffendal, Jr., Ph.D., is Professor and Research Geologist, Emeritus, in the Conservation and Survey Division, School of Natural Resources, University of Nebraska-Lincoln. He has prepared geologic maps of many areas of Nebraska and written articles, reports and guidebooks on the geology of Nebraska and adjacent parts of the plains.

Anne P. Diffendal, Ph.D., is a historian who spent much of her career as an archivist. For the past several years she has been a consultant on a wide variety of archival and historical projects throughout the United States.

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General Introduction

Meriwether Lewis and William Clark undertook their journey with the Corps of Discovery in 1804-1806 in order to explore the area that the United States had purchased from France in 1803. Then known as Louisiana, this region included almost everything west of the Mississippi to the continental divide (fig. 1).

In order to find the best route across the continent, President Thomas Jefferson charged Lewis with following the Missouri River to its headwaters and then locating rivers flowing down the west side of the Rocky Mountains to the Columbia River and into the Pacific Ocean. Jefferson's written instructions further specified that the members of the expedition collect and describe plants and animals new to science; enter the latitude and longitude of the rivers, mountains, and other features; and note the land's potential for farming, as well as the climate, timber, and wildlife. They were also to record the occurrences of volcanic features and minerals of all kinds, but especially metals, limestone, coal, and saline and mineral waters. [37]

Meriwether Lewis by Charles Willson Peale, from life, 1807; William Clark by Charles Willson Peale, from life, 1807-1808; courtesy of Independence National Historical Park, National Park Service

Jefferson, an avid fossil collector, had contributed to scientific knowledge about fossil mammals. He joined many naturalists of the time in the hope that

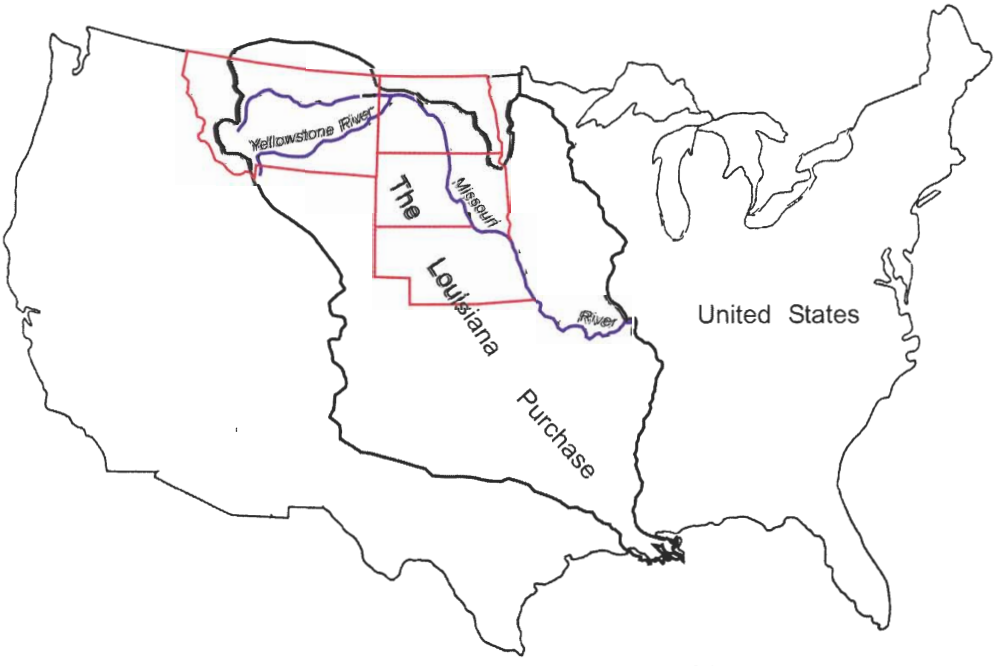


Fig. 1. The Louisiana Purchase of 1803 doubled the area of the United States.

"The Face of the Countrey....

The Countrey bordering on the Missourie....from the Plate to the Fort Mandan the Countrey is Generally open Plains, intersperced with Groves of Timber, which is to be found on the Rivers & Smaller Streams Generally–

Ores Minirals Salts & Salt Salines

I know of no Body of ore.... The Bluffs of the Missouri above R. Jacque abounds in minerals of various Kinds, Such as Cobalt, Piritus, Alum, Coperas, & a variety of other mineral Salt is Collected in various parts of the Missourie Country...."

winter, 1804-1805

[summary report sent to President Thomas Jefferson from the winter camp at Fort Mandan, North Dakota]

living examples of animals, known only by their petrified remains, might yet be found in unexplored regions of the Earth. [51]

Their journals, notebooks, and maps indicate that Lewis and Clark took their charge seriously and gathered a great deal of information on these topics. The explorers were astute observers of the land through which they traveled. In most cases, however, they did not know what had caused its appearance. At that time, few, if anyone, would have because the discipline of geology was in its infancy.

Because of the great interest in the Lewis and Clark expedition, large numbers of people have visited or will visit its sites, tracing some or all of its route. A large part of this route follows the Missouri and the Yellowstone rivers through the Great Plains, a region with a rich geologic history. This publication introduces the general reader to an explanation of the geology of the Great Plains as it is understood today. Quotations from the journals of Lewis and Clark describe geologic features of the landscape seen by the explorers and largely still visible to the traveler today.

This educational circular is divided into two sections. The first describes the general geology of the Great Plains. The second directs the modern traveler to some of the places where Lewis and Clark recorded geologic observations as they made their way across the Great Plains. It follows the expedition up the Missouri River in 1804-1805 and Clark's return down the Yellowstone River in 1806. Appendixes include suggestions for further reading and a list of U.S. Geological Survey topographic maps that trace the Missouri and Yellowstone rivers across the Great Plains.

The Words of Lewis and Clark

Because spelling, punctuation, and capitalization had not yet been standardized, the writings of Lewis and Clark contain many different forms and abbreviations of the same word. An unfamiliar term can often be recognized by reading it aloud.

When traveling on rivers, the explorers used the nautical terms larboard *and* starboard *to indicate direction. Facing in the direction of travel, larboard (now called* port*) or larboard side (l.s. or L.S.) means left; starboard or starboard side (s.s. or S.S.) means right.*

Quotations are used by permission of the University of Nebraska Press from: Moulton, Gary E. (ed.), 1983-2000, **The Journals of the** Lewis **and Clark Expedition:** *University of Nebraska Press, Lincoln, Nebraska, and London, 13 volumes.*

I. The Geology

INTRODUCTION

When Lewis and Clark undertook their journey in 1804-1806, the science of geology was near its beginning. Although James Hutton, the father of modern geology, had published his *Theory of the Earth with Proofs and Illustrations* in 1795, few people were aware of the work nine years later. [45] The concepts of geologic time and of absolute dating were only beginning to be developed in Europe. The first geologic map by William Smith in England was not published until 1815. [58] The ideas of continental glaciation and of the widespread floodings of continents by oceans had not yet been proposed.

In 1669 Nicholas Steno of Denmark outlined some general principles used in geology, including those applied to the study of layered sediments and layered sedimentary rocks. [18] Among Steno's principles are, first, in an undeformed sequence of sediments or sedimentary rocks, the deposits were usually laid down nearly horizontally. Second, the oldest layer of sediment or sedimentary rock is at the bottom of the sequence, and the layers above are progressively younger upward. James Hutton, elaborating on another of Steno's ideas, proposed the concept now known as the *Principle of Cross-cutting Relationships.*

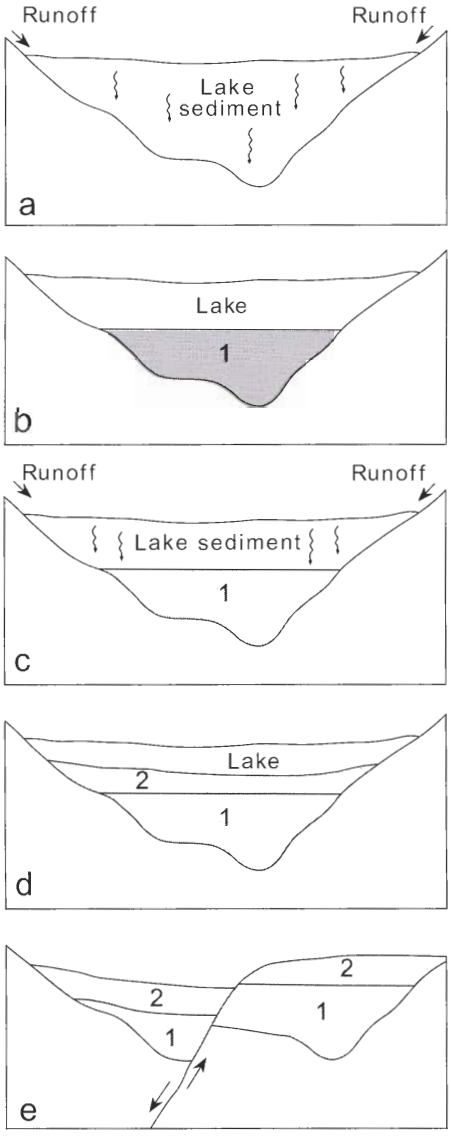


Fig. 2. Cross sections showing Steno's principles and Hutton's Principle of Cross-cutting Relationships: a) stream runoff carries sediment into a lake, where it begins to sink to the lake floor; b) sediment accumulates as layer 1 on the floor of the lake – Steno's Principle of Lateral Continuity (note bottom of layer 1 fits irregular lake floor, but top of layer 1 is nearly horizontal); c) second period of stream runoff carries new sediment into waters of lake; d) new sediment accumulates on top of layer 1 and forms layer 2 – Steno's principles of Superposition, Original Horizontality, and Lateral Continuity; e) movement along earthquake fault cuts rocks beneath lake and layers 1 and 2, offsetting them from one another across the fault (arrows indicate relative movement on either side of fault) – Hutton's Principle of Cross-cutting Relationships. From Diffendal. [18]

"...proceeded on pass the Bluffs Compsd. of a Yellowish red, & brownish White Clay which is a hard as Chalk"
September 1, 1804
[bedrock of Cretaceous age; Knox County, Nebraska, and Bon Homme County, South Dakota]

"...I walked on Shore with a view to find an old Vulcanio, Said to be in this neighborhood.... I walked on Shore the whole day without Seeing any appearance of the Villcanoe...."
September 14, 1804
[search for a volcano; Lyman County, South Dakota]

"all the hills have more or Less indefferent Coal in Stratias at different hites from the waters edge to 80 feet. those Stratias from 1 inch to 5 feet thick."
April 9, 1805
[strata of coal; McLean and Mercer counties, North Dakota]

That is, any geologic feature which cuts across another must be the younger of the two features. For example, if layers of sediment or sedimentary rocks are faulted or folded, this faulting or folding occurred after the deposition of the layers (fig. 2).

The bedrock exposed across most of the Great Plains along the Missouri River and its tributaries in Nebraska, Iowa, South Dakota, North Dakota, and Montana is mostly sedimentary, composed primarily of claystones and shales interbedded with coals, sandstones, siltstones, and limestones or chalks. These rocks were deposited as sediments in the period approximately from 104 to 55 million years ago, and they were subsequently changed into rock by the natural processes of compaction and cementation. This time span extends from near the end of what geologists have sometimes called the *Age of Dinosaurs* (Mesozoic Era-Cretaceous Period) to the beginning of what some have termed the *Age of Mammals* (Cenozoic Era-Tertiary Period-Paleocene Epoch). [6]

In some places across the Great Plains, older rocks are exposed in the centers of regional upfolding, such as the Black Hills in South Dakota and Wyoming and the Bears Paw Mountains and other local uplifts in Montana. The uplifts in Montana occurred during the early parts of the Tertiary Period. [2, 12a]

In 1822, a French geologist defined the rock formations belonging collectively to the Cretaceous System of rocks in France and later reported that this system extended into other countries in western Europe. [6] The name *Cretaceous* is derived from the Latin word for chalk, a rock formation that typified a major part of the Cretaceous System in western France and in Great Britain (the Chalk Cliffs of Dover are part of the Cretaceous).

Geologists from around the world began to see the same systems with the same general fossil successions in the rock sequences in their countries. In the United States, the first report of Cretaceous rocks and fossils was published in 1824 by an Englishman who had visited the eastern part of the country. The first report of Cretaceous fossils from the area drained by the Missouri River was published in 1841-1842 by Samuel Morton. [56] In 1845, Charles Lyell, a prominent English geologist, showed Cretaceous rocks on his geologic map of the United States in the area where northeastern Nebraska is now located. [42] The overall distribution and interpretation of the origins of the Cretaceous strata in North America were shown on a geologic map and in reports in the late 19th century. [56, 57]

Geological observations began to make more sense after 1859 when Charles Darwin outlined his theory of organic evolution in *On the Origin of Species by Means of Natural Selection.* [17] After this, the changing sequence of fossils through sedimentary rock sequences came to be recognized as evidence of evolution. A fourth dimension, time, was introduced more forcefully into geological thinking with this discovery.

It is unlikely that either Lewis or Clark knew about formations, geologic ages, or the principles outlined above. The formations that they saw were named years after their expedition, and the distribution of these formations across the Great Plains and other parts of North America was mapped even later (fig. 3).

However, some people did know, in a general way, something about geology. They knew how to identify some minerals and rocks; they recognized certain fossils. They were also aware of natural hazards such as landslides, floods, and volcanic activity. From the notations in their journals, it is clear that both Lewis and Clark understood some of these aspects of geology. Among the books that they took with them was Richard Kirwan's *Elements of Mineralogy*, first

"our peroge and the Canoes passed over to the Lard. side in order to avoid a bank which was rappidly falling in on the Stard."

April 12, 1805
[landslide; McLean and Mercer counties, North Dakota]

"the broken hills of the Missouri about this place exhibit large irregular and broken masses of rocks and stones; some of which tho' 200 feet above the level of the water seem at some former period to have felt it's influence, for they appear smooth as if woarn by the agetation of the water."

April 22, 1805
[rock worn smooth by water; Williams and McKenzie counties, North Dakota]

"The Country on either hand is high broken and rockey; the rock is either soft brown sand stone covered with a thin strata of limestone, or a hard black rugged grannite, both usually in horizontal stratas and the Sandy rock overlaying the other."

May 25, 1805
[layers of different kinds of rock; Fergus County, Montana]

published in London in 1784, with a second expanded edition in 1794-1796. [40]

Although Lewis and Clark frequently described geologic features, they seldom speculated on the processes that might have produced them. The exceptions concern the effects of flowing water. They noted landslides and banks being undercut, as well as shifting sand bars and old river channels and cut-offs. They also commented on water's role in rounding pebbles and in shaping rock.

Subsequent study of the Earth, including the regions of North America, has expanded the body of knowledge about geologic causes and effects. The concepts of the Great Plains Physiographic Province, the Cretaceous Western Interior Seaway, ancient rivers, deformation and uplift of rock strata, the Ice Ages, fluvial processes, and geologic natural resources can help to explain the origins of features noted by Lewis and Clark.

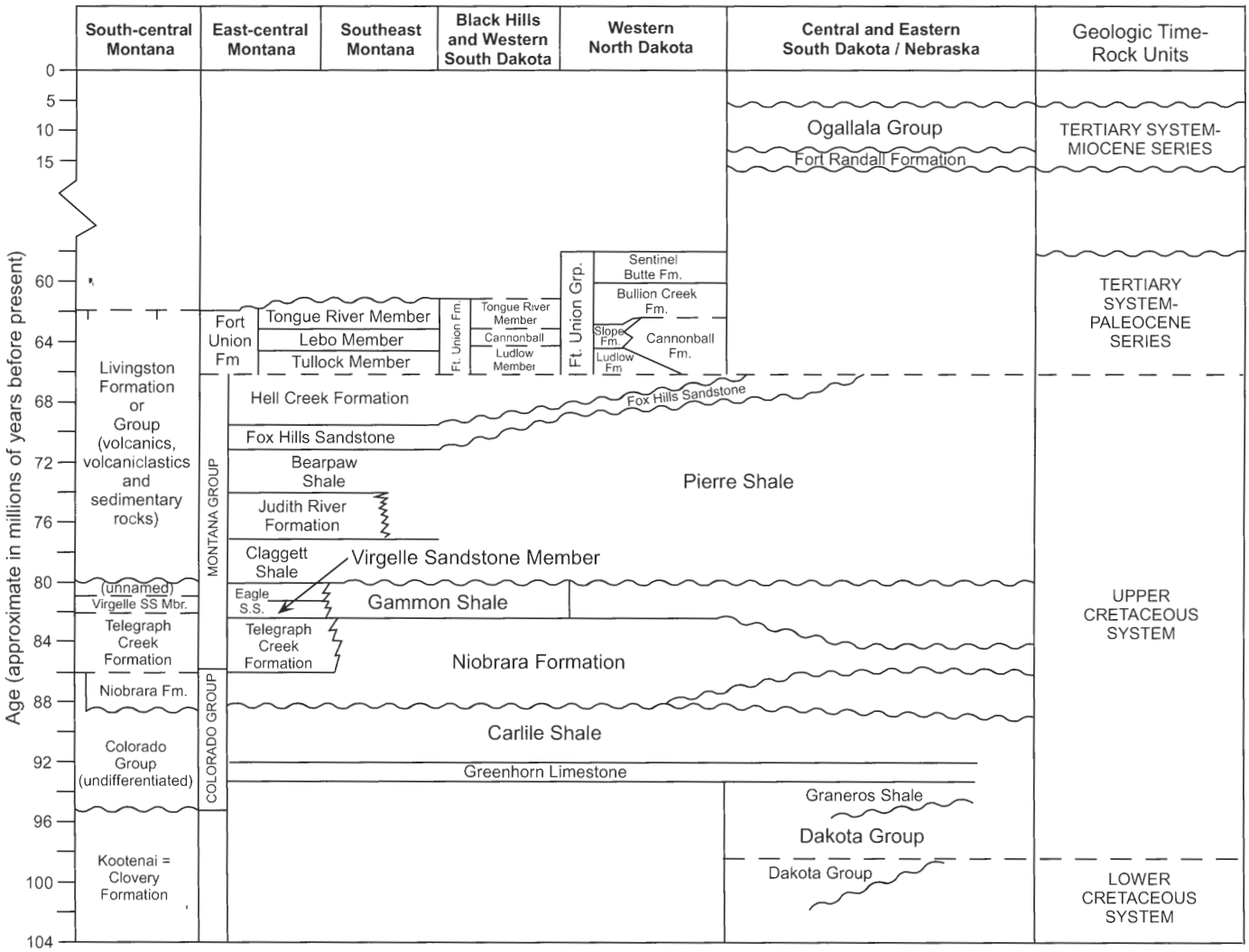


Fig. 3. This correlation chart shows the general relationships of sedimentary rock formations of the same geologic age across the Great Plains region, as well as the relationships of the older and younger formations. The names are usually those of the geographic places where the layers of rock were first described by geologists. The Hell Creek Formation, for example, is a group of rock layers first studied along Hell Creek in east-central Montana. Occasionally, the names for the same rock layer(s) change from state to state because of differences, sometimes minor, in the opinions of researchers studying the rocks in different areas. Only rocks noted by Lewis and Clark are named here. The chart is blank where a formation does not appear on the surface along the expedition's route because Lewis and Clark would not have observed those rocks. Modified from Balster, [4] Mallory, [44] Witzke, [59] Witzke, [60] Hartman, [31] Diffendal, [20] Rice, [48] Cherven, [13] Daly. [15]

THE GREAT PLAINS

The lands of the world can be divided into physiographic provinces based on differences in landforms such as mountains, plateaus, and plains (for example, the Rocky Mountains or the Colorado Plateau), which reflect differences in rock structures such as folds, faults and regional uplifts. The physiographic provinces can be subdivided into sections on the basis of the presence of smaller-scale features such as the dunes of the Nebraska Sand Hills.

The Great Plains is a major physiographic province of North America, extending from the Texas-Mexico border to northwestern Canada (fig. 4).[55] The western boundary is easy to identify because, for much of the way, it follows the front of the Rocky Mountains, large folded and faulted mountains. The only exceptions are in eastern New Mexico and western Texas, where it is bounded by parts of the Basin and Range Province; and in Wyoming, where it is bounded by the part of the Wyoming Basin, which is separated from the Great Plains by the Oil Mountain Anticline, an upfold of rocks between the Laramie Range and the Big Horn Mountains.

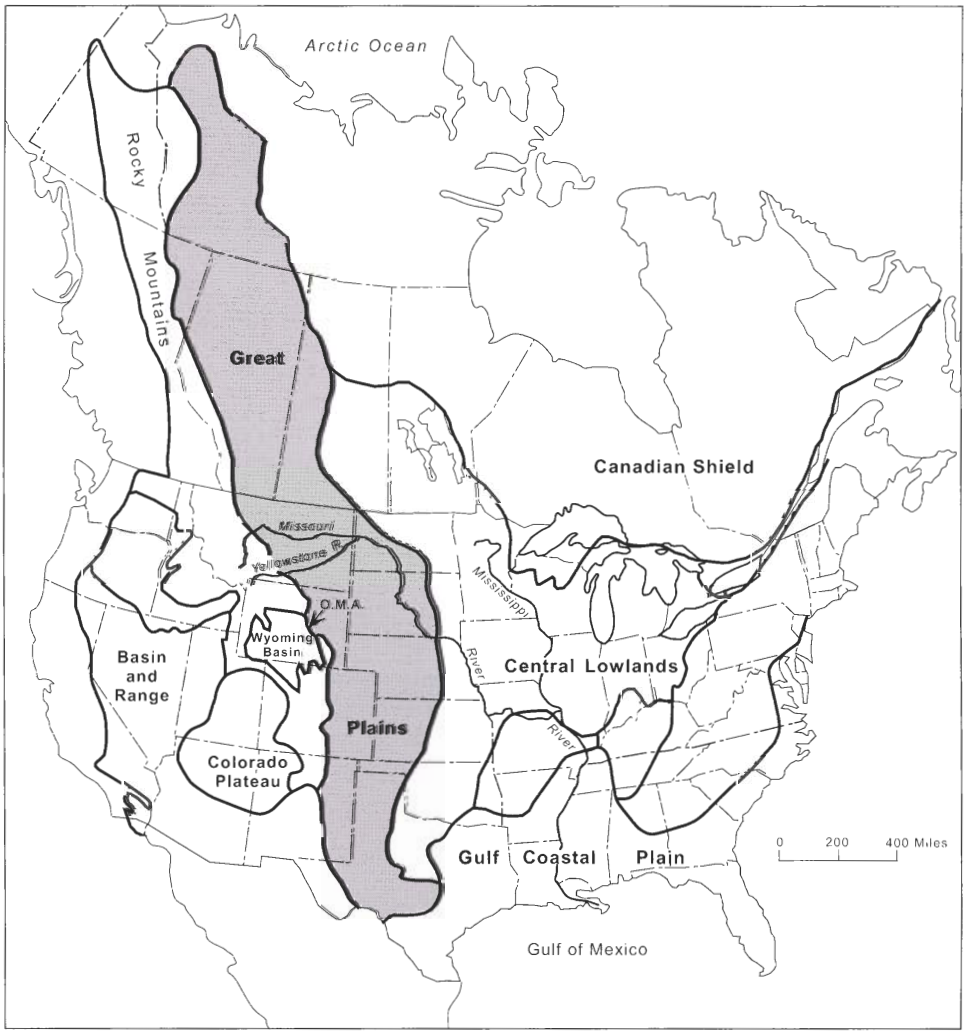


Fig. 4. Some physiographic provinces of North America. O.M.A. - Oil Mountain Anticline. Modified from Douglas,[21] Gerlach.[28]

"The High Land approaches near the river on the L.S. and well timbered next to the river, back of those hills the Plains Commence."
July 10, 1804
[treeless plains; Richardson County, Nebraska]

"I steered my course through the wide and level plains which have somewhat the appearance of an ocean, not a tree nor a shrub to be seen."
July 17, 1806;
[treeless plains; Chouteau County, Montana]

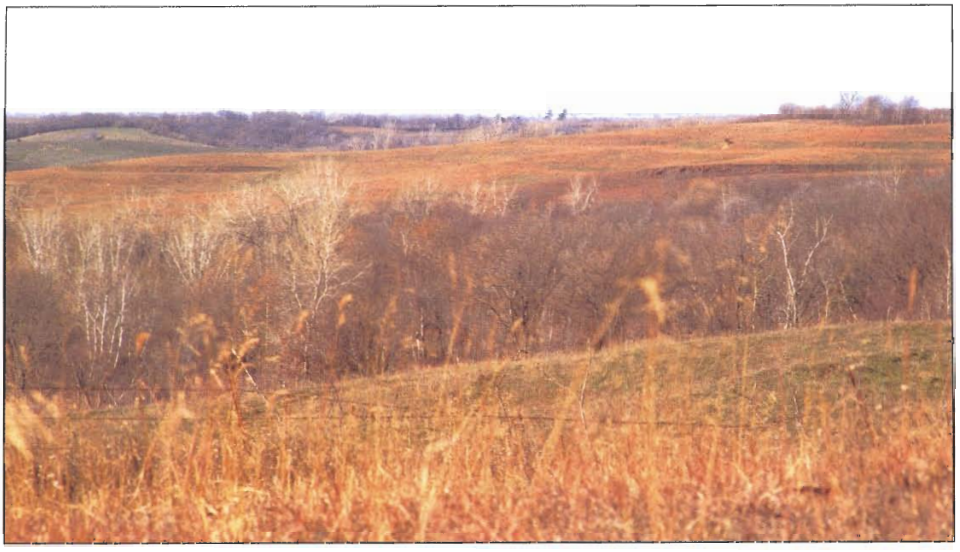


Fig. 5. For several days after entering what is now southeastern Nebraska, Clark commented on the absence of trees on the flat uplands away from rivers and creeks. Although east of where most geographers today would locate the Great Plains Province, the explorers recognized a change in the landscape here. View to the northwest from St. Deroin Cemetery in Indian Cave State Park, Nemaha County, Nebraska. [39]

The eastern boundary of the Great Plains is not structurally separate from the province to the east, the Central Lowlands, which includes much of the central United States. Because of the lack of a structural difference between these two provinces, the boundary has been drawn in slightly different places by different physiographers, using the presence or absence of one or more features. [3, 22, 52, 34] Some of the characteristics used to define this boundary are the 1,500- or the 2,000-foot contour, marking height above sea level; the change from tallgrass (2-6 feet) prairie to shortgrass (less than 2 feet) prairie vegetation; the change from tree-covered to treeless plains; the change from acid soils to alkaline soils with accumulations of calcium carbonate in the latter; either the 98th or the 100th meridian, west longitude; the eastern limit of Tertiary Age deposits (65-1.6 million years old); and the 20-inch line (called an *isohyet*) of annual precipitation. Many of the foregoing features change position with changing climate. Others shift more slowly due to such things as regional tilting of the Earth's surface and erosion of the land. We will use the western margin of the glaciated region in Nebraska and the Missouri Coteau Escarpment in South and North Dakota to denote the boundary between the Great Plains and the Central Lowland provinces (this escarpment is the east-facing side of a plateau forming the eastern border of the Great Plains in southern Canada and the Dakotas).

For Lewis and Clark, the appearance of treeless plains in the area that today is southeastern Nebraska marked a significant change in the landscape as they journeyed from the east (fig. 5). They anticipated present-day geographers in recognizing the Rocky Mountains as a sign of dramatic change farther west.

"greater appearance than usual of the saline incrustations of the banks and river hills. we passed two creeks the one on Stard. side, and the other just below our camp on the Lard. side; each of these creeks afford a small quantity of runing water, of a brackish tast. the great number of large beds of streams perfectly dry which we daily pass indicate a country but badly watered, which I fear is the case with the country through which we have been passing for the last fifteen or twenty days."

May 17, 1805
[salts, little rainfall; Phelps and Garfield counties, Montana]

"where the land is level, it is uniformly fertile consisting of a dark loam intermixed with a proportion of fine sand. it is generally covered with a short grass resembling very much the blue grass."

April 14, 1805
[shortgrass prairie vegetation; Montrail and Dunn counties, North Dakota]

ANCIENT SEAS – THE CRETACEOUS WESTERN INTERIOR SEAWAY

Today we know that rocks from the Cretaceous System extend from the Gulf of Mexico to the Arctic Ocean across the central part of North America following the Great Plains and adjacent physiographic provinces. We also know that these strata were deposited as sediments in a sea and by rivers on adjacent coastal plains (fig. 6).

At times during the Cretaceous, sea level rose (a transgression) with respect to land and flooded parts of the continents. At other times, sea level fell (a regression), increasing the land areas of continents and islands and exposing to erosion the emergent deposits lain down in the former sea areas. Not all of these deposits were eroded away, and so across the Great Plains today we have a good geological record of the sea's change. Overall, five major Cretaceous cycles of the rise followed by the fall of sea level are represented by the rocks seen by Lewis and Clark (fig. 7).[38] The cycles were caused by worldwide climate change resulting in the waxing and wan-

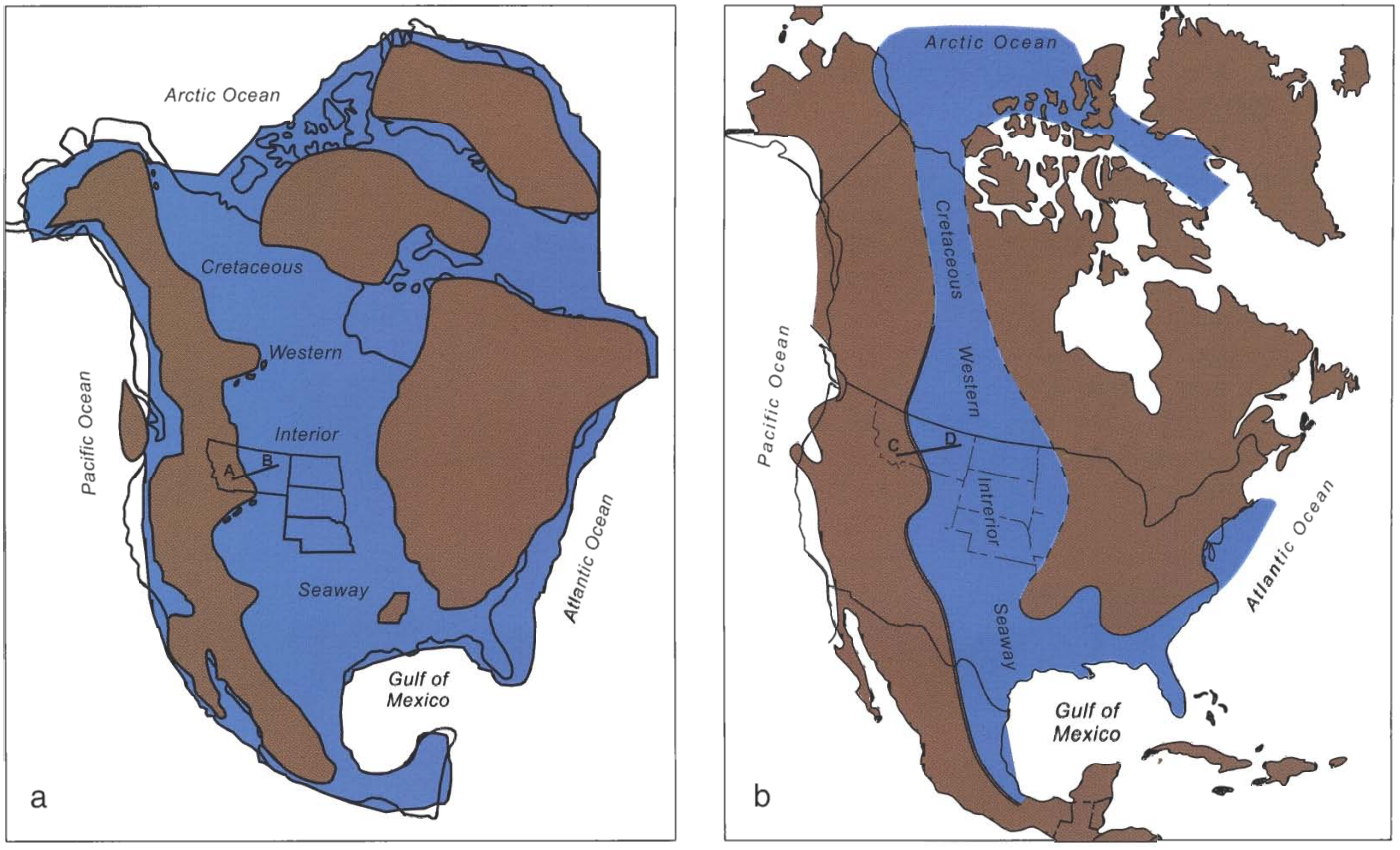


Fig. 6. During the Cretaceous Period, from about 110 million to about 65 million years ago, the Cretaceous Western Interior Seaway covered much of the interior of North America. Sea levels rose and fell several times, inundating more or less land area: a) the maximum transgression of the seaway during the deposition of the rocks of the Niobrara Formation about 86 million years ago. See the corresponding A-B line on figure 7; b) the maximum transgression of the seaway during the deposition of the Pierre Shale and equivalent rocks, such as the Bearpaw Shale, about 72 million years ago. See the corresponding C-D line on figure 7. Note the differences in the extent of the seaway during the two transgressions. Modified from Gill,[29] Diffendal.[19]

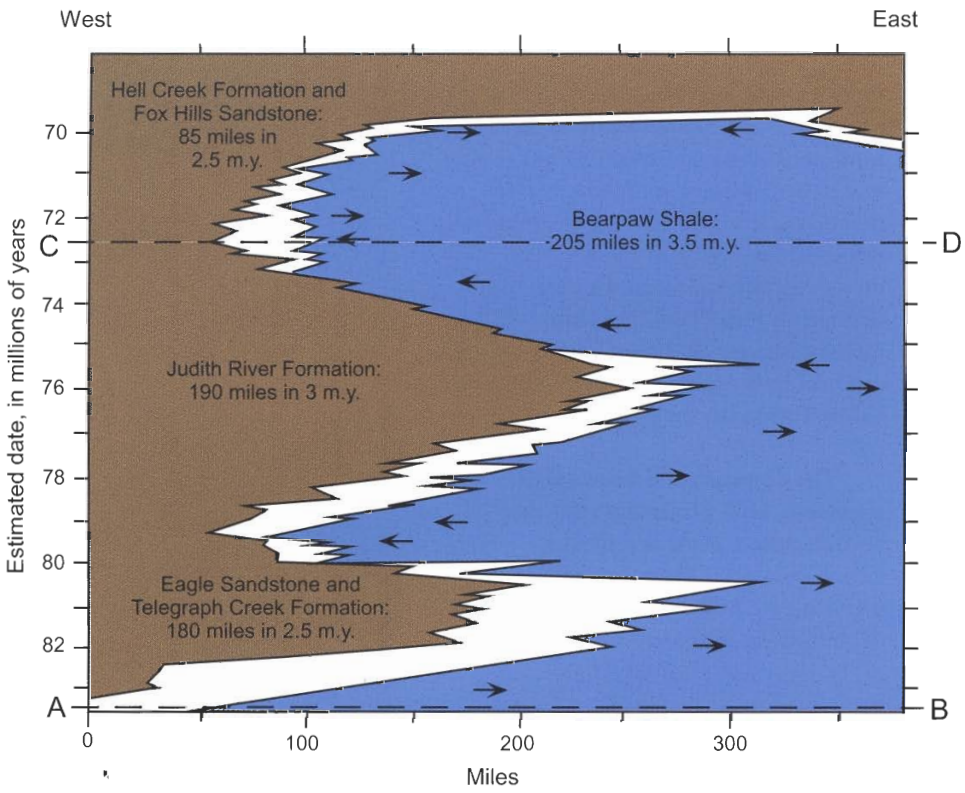


Fig. 7. Three of the five Cretaceous cycles of sea level rise and fall are represented by rocks exposed on the surface across parts of Montana. Beds deposited on the coastal plain and in deltas are shown in brown. Beach and shallow water deposits are in white. Marine shale deposits are in blue. Arrows indicate the direction of shoreline movement. Lines A-B and C-D represent slices of time during the maximum transgressions shown in figure 6. Compare the dates of these cycles with the dates for the deposition of the rock formations shown on figure 3, the correlation chart. Modified from Gill. [29]

ing of glaciers, and also by structural changes in the geometries of ocean basins and land masses. The Western Interior Seaway became narrower in Late Cretaceous and Paleocene times. [26] By the end of the fifth cycle, the western margin of the seaway was located in central North Dakota and remained there during parts of the Paleocene Epoch. [29]

Although Lewis and Clark did not know about the Cretaceous System, they observed the formations that had been deposited during this geological period. They described some rocks made up of cemented shells and others containing bones of what they took to be fossil fish (later found to be fossil bones of ocean-going reptiles and land-dwelling dinosaurs). They also noted minor beds of coal (now known to have been formed from plant debris deposited in swamps) interbedded with some non-marine sandstones and shales.

"...on the top of a ridge we found a back bone with the most of the entire laying Connected for 45 feet those bones are petrified, some teeth & ribs also Connected."

September 10, 1804

[plesiosaur, an ocean-going reptile, Pierre Shale, Upper Cretaceous System; Gregory County, South Dakota]

"passed a Bluff...Several mile in extent of white Clay Marl or Chalk...."

August 27, 1804

[marine deposits, Niobrara Formation, Upper Cretaceous System; Cedar County, Nebraska]

"the shores are abbrupt and bould and composed of a black and yellow clay...."

May 21, 1805

[marine deposits, Bearpaw Shale, Upper Cretaceous System; Phillips County, Montana]

"a high Clift of yellowish Gritty Stone on the stard Side."

July 24, 1806

[beach deposits, Virgelle Sandstone Member of the Eagle Sandstone, Upper Cretaceous System; Yellowstone River, Yellowstone County, Montana]

ANCIENT RIVERS

Above the Cretaceous rocks are sandstones, siltstones, claystones and coals of the rock formations of the Paleocene, the earliest part of the Tertiary Period. By the end of the Cretaceous Period, the Western Interior Sea had largely withdrawn from Montana and the western Dakotas. Only large river systems and swamplands remained there as sites for large-scale sediment deposition on a vast coastal plain (figs. 6, 7).

The sandstones were initially deposited as sands in river and delta channels and on adjacent floodplains (fig. 8), the siltstones and claystones as silts and clays on floodplains, and the lignite coals as accumulating plant debris on the floors of vast swamps near the rivers and the delta channels. All were later hardened into rock either by precipitation of natural cements from water moving through sediment pore spaces, by compaction of sediment due to the increased weight of overlying sediment, or by a combination of the two. Although minor coal beds occur in the Late Cretaceous Hell Creek Formation, thicker, more widespread and more numerous lignite coal beds appear in the Paleocene Fort Union Formation (or Group) (fig. 3). [31, 13, 15, 48]

The dinosaurs and many smaller organisms, both plants and animals, became extinct at the end of the Cretaceous. [14, 46] Others, including the mammals on land, became dominant at the beginning of the Paleocene.

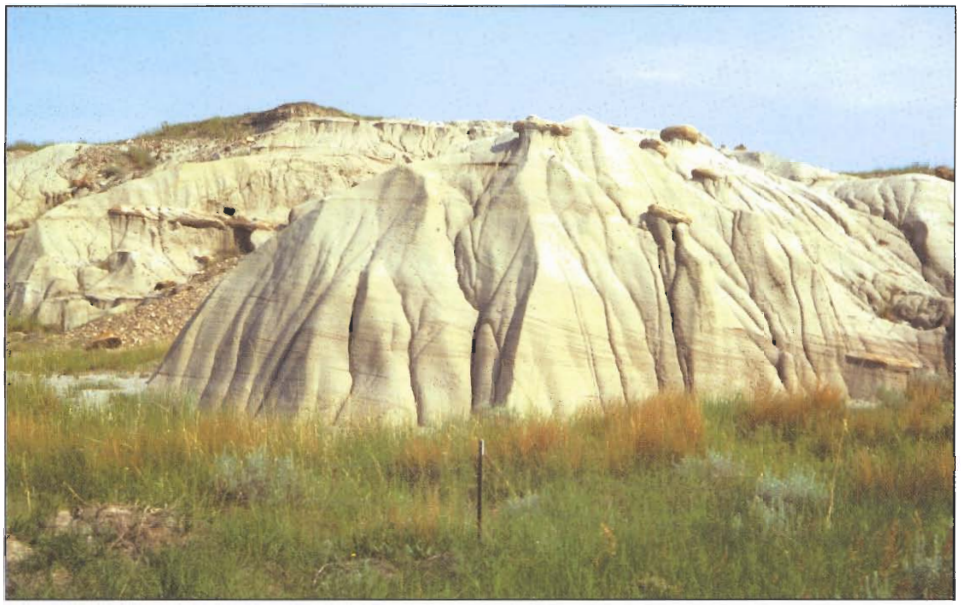


Fig. 8. River deposits of the Paleocene Fort Union Formation; on a tribal road south of U.S. Highway 2 between Brockton and Fort Kipp, Roosevelt County, Montana, on the Fort Peck Indian Reservation.

"to a Coal point of the Lard Bluff in which there is 5 Stratias of Coal at different hights all Horozontal."

July 28, 1806

[swamp and coastal plain deposits, Tullock Member of the Fort Union Formation, Tertiary System-Paleocene Series; Yellowstone River, Rosebud County, Montana]

"the Bluffs of the river which we passed today were upwards of a hundred feet high, formed of a mixture of yellow clay and sand many horizontal stratas of carbonated wood, having every appearance of pitcoal at a distance; were seen in the face of these bluffs. these stratas are of unequal thickness from 1 to 5 feet, and appear at different elivations above the water some of them as much as eighty feet."

April 9, 1805

[delta, floodplain and swamp deposits, Sentinel Butte Formation, Tertiary System-Paleocene Series; McLean County, North Dakota]

UPLIFT AND DEFORMATION OF ROCK STRATA

James Hutton discussed uplift and deformation of rock strata in his *Theory of the Earth with Proofs and Illustrations* (1795). Earlier, Richard Kirwan had also briefly considered these topics in his *Elements of Mineralogy* (1784, 1794-1796). Certainly both Lewis and Clark could have observed deformation of rocks with folding, and perhaps even faulting, in the Appalachian Mountains of the eastern United States before they went west. In 1804, however, detailed descriptions of rock structures and the causes of their deformation and uplift were years away from publication. The broad theory and modern paradigm of deformation, now called *plate tectonics*, was first proposed in 1931 by the British geologist Arthur Holmes, and then largely forgotten until its rediscovery in the 1960s. [33] Today we understand that the Earth's crust is broken into a series of large fragments called *tectonic plates* that move generally horizontally with respect to each other. Where the plates collide, mountains and adjacent deep ocean troughs are formed that are sites of earthquakes, volcanic and other igneous activity, and folding and faulting of rock strata (fig. 9). [10]

The movement and associated igneous activity that produced the Northern Rocky Mountains occurred mainly in the Late Cretaceous Period in the area that is now Montana and Idaho. This deformation was caused by

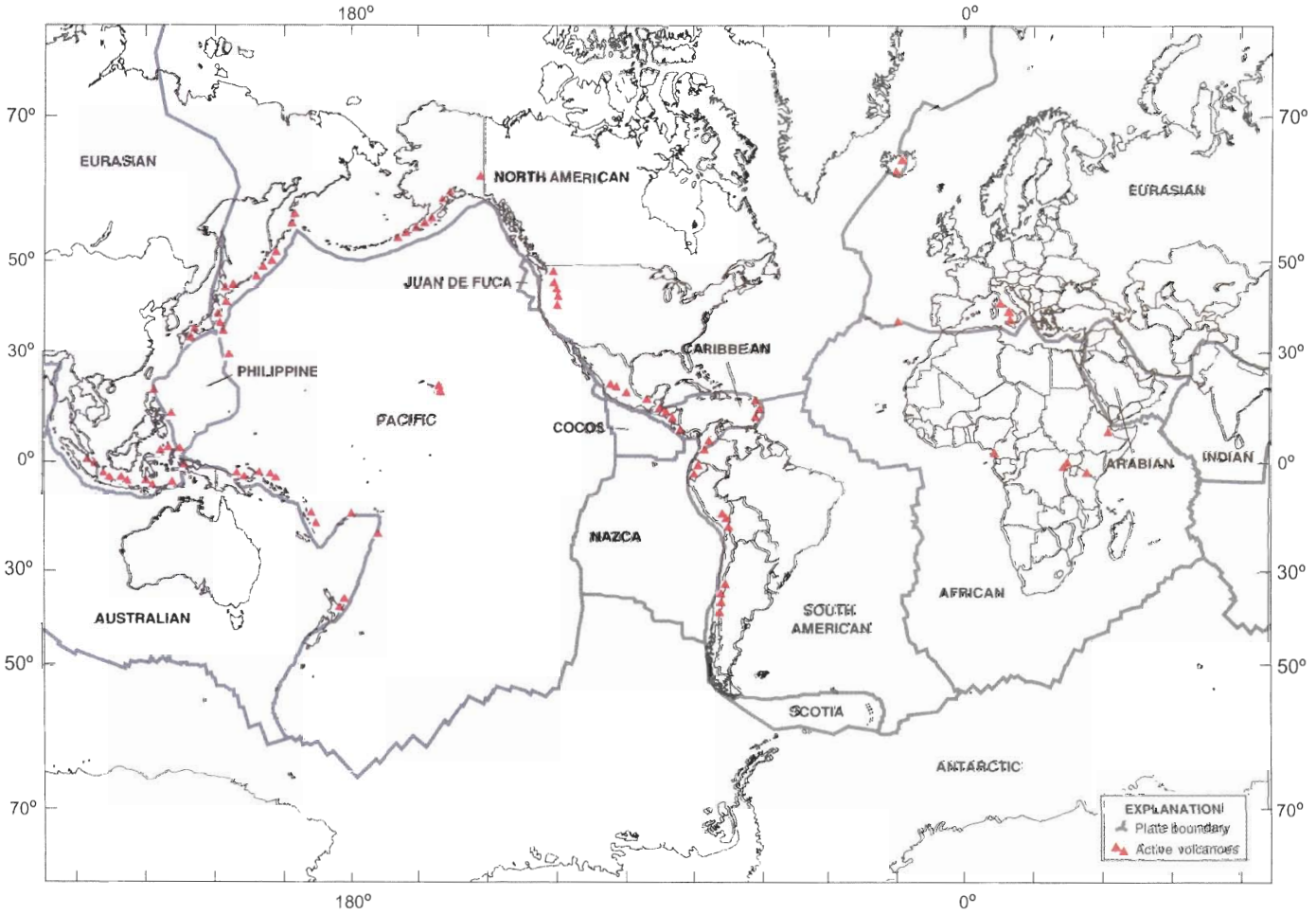


Fig. 9. The major tectonic plates of the Earth and their names. [10]

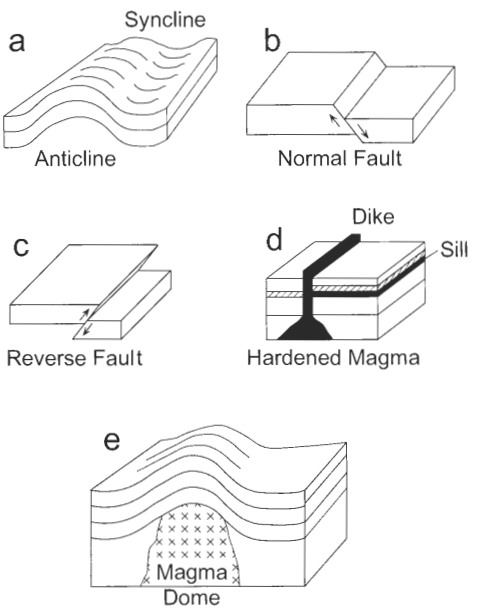


Fig. 10. Rock structures and igneous processes.

compressive forces resulting from the collision of the Pacific Plate with the North American and other smaller plates. After the Northern Rocky Mountains had been formed, molten magma was forced upward from great depths beneath the Earth's surface. Injected into and through the overlying rock strata, this magma uplifted and deformed them. In places, magmas were injected along fractures, cutting across sedimentary rock layers to form igneous dikes. Other magmas, forced between weak layers of sedimentary rocks, cooled and hardened to form sills (figs. 10-13). Yet other magmas came to the Earth's surface and flowed onto the land as lavas.

In the Great Plains area of Montana, many features resulted from these processes. Heat and pressure from the magmas sometimes shaped the overlying rock layers into upfolded domes or more elongated arches. Today, these anticlines are a series of small, isolated mountains. [34] Older rock, pushed up from below, is exposed at or around the centers of some of them; in the centers of others are Tertiary-age igneous intrusives (formed when molten rock was injected through older Earth materials beneath the Earth's surface). Examples of these mountains include the Bears Paws, the Highwoods, the Little Rockies, and the Judiths. Elsewhere, older rock is found in uplifts with smaller relief, such as Poplar Dome in northeastern Montana, where Late Cretaceous rocks are exposed with younger Paleocene strata of the Fort Union Formation surrounding them (fig. 14). [2]

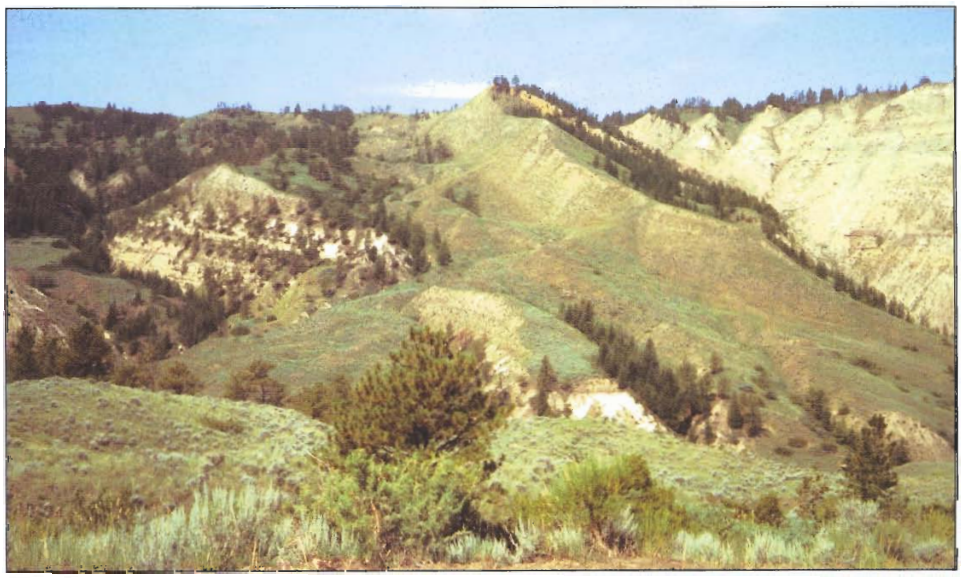


Fig. 11. Cretaceous strata tilted along a fault; 1 mile upstream from Stafford Ferry, north of Winifred, Fergus County, Montana.

"The stone of which these walls are formed is black, dence and dureable.... These walls pass the river in several places, rising from the water's edge much above the sandstone bluffs, which they seem to penetrate; thence continuing their course on a streight line on either side of the river through the gradually ascending plains, over which they tower to the hight of from ten to seventy feet untill they reach the hills, which they finally enter and conceal themselves. these walls sometimes run parallel to each other, with several ranges near each other, and at other times interscecting each other at right angles...."

May 31, 1805

[dikes in the Virgelle Sandstone Member of the Eagle Sandstone; White Cliffs area, Chouteau County, Montana]

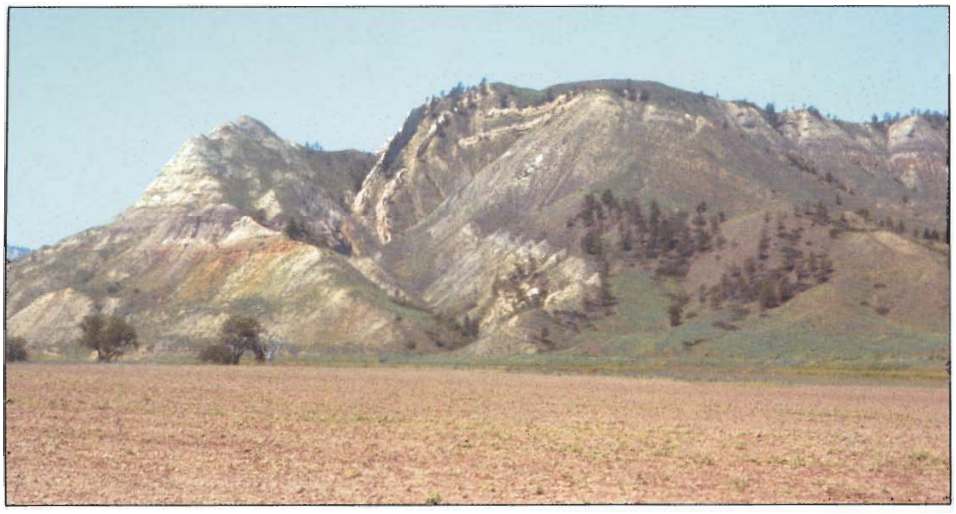


Fig. 12. Folded Cretaceous strata; along the road to Stafford Ferry, 13.6 miles north of Winifred, Fergus County, Montana.

Fig. 13. An Eocene dike; Big Sag Road, 0.7 miles northeast of the intersection with Shankin Road in the Highwood Mountains, Judith and Chouteau counties, Montana.

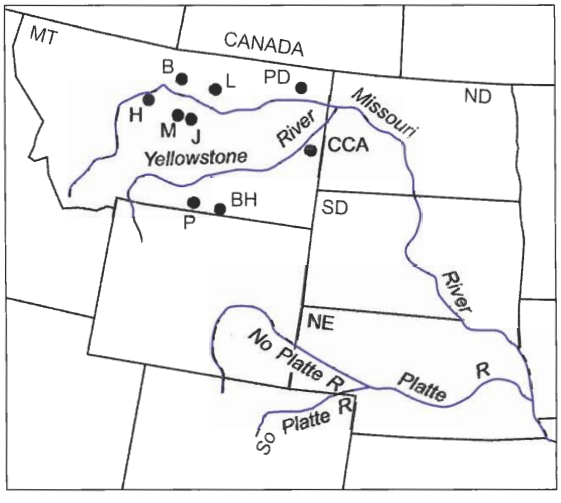


Fig. 14. Some early Tertiary uplifts in Montana: B - Bears Paw Mountains; BH - Big Horn Mountains; CCA - Cedar Creek Anticline; H - Highwood Mountains; J - Judith Mountains; L - Little Rocky Mountains; M - Moccasin Mountains; P - Pryor Mountains; PD - Poplar Dome. [50]

"since the hills have become lower the appearance of the stratas of coal burnt hills and pumice stone have in great measure ceased: I saw none today."

May 3, 1805

[older strata without coal exposed in the center of an uplift, Poplar Dome; Roosevelt County, Montana]

"In my walk of this day I saw mountts. on either side of the river at no great distance, those mountains appeared to be detached, and not ranges...."

May 25, 1805

[anticlines; Little Rocky, Bears Paw, and Judith Mountains; seen from Fergus County, Montana]

THE ICE AGES

From the quotations to the right, a geologist today would recognize features produced by the ice sheets that advanced from Canada during the several Ice Ages over the last 2.5 million years (fig. 15). The boulders Lewis and Clark speak of, called *erratics*, were carried by the ice sheets into the area and left behind on the land surface, or buried in finer grained deposits when the ice melted away. The rolling, wave-like land is underlain by glacial deposits left behind by the melting ice (figs. 16, 17, 18).

At the time of the expedition, little was known about glaciation. In 1795 James Hutton had reported his observations and those of other European geologists about glaciers and their movement in the Alps. However, recognition that these Alpine glaciers, as well as continental ice sheets, had covered the plains of western Europe did not occur until

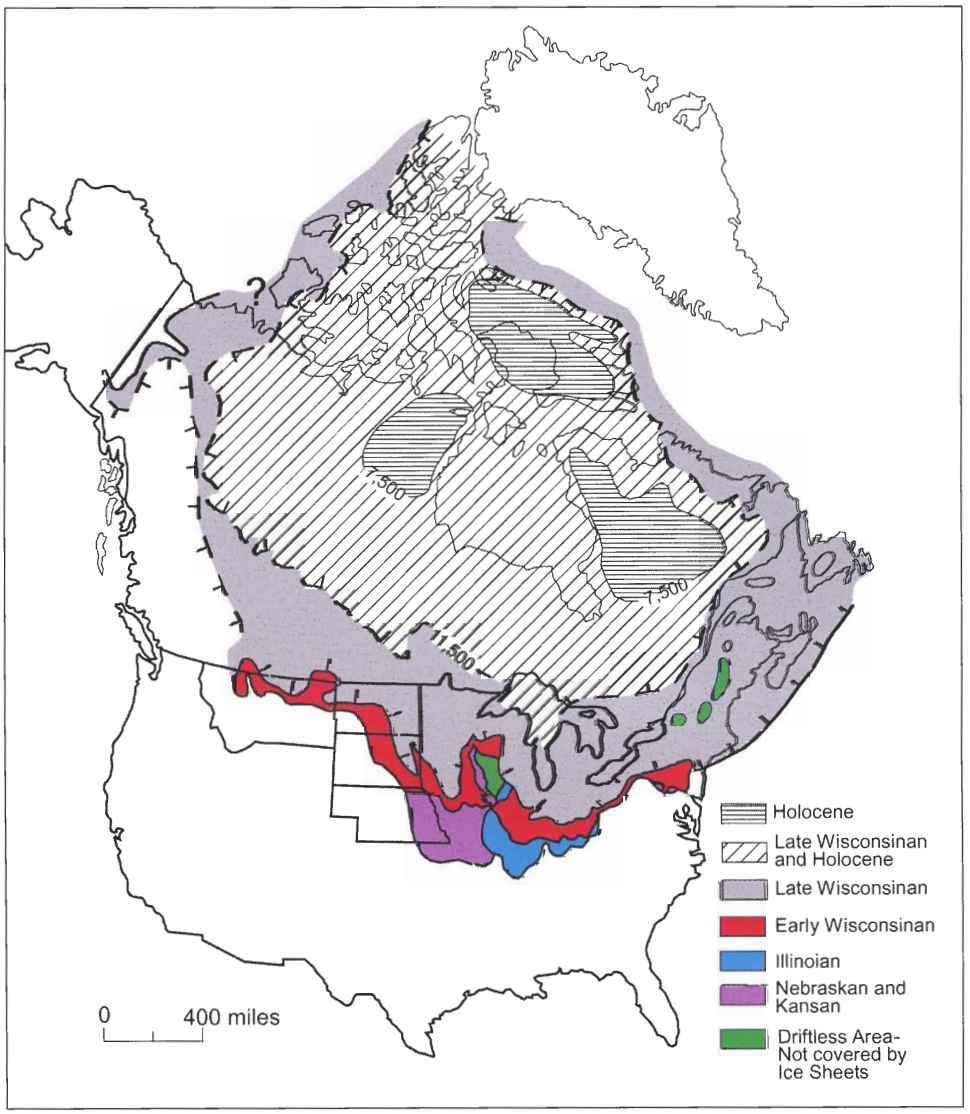


Fig. 15. Ice Age glaciations of North America. Colors and patterns indicate the maximum extent of the several Pleistocene glaciations from the oldest, the Nebraskan and Kansan, to the youngest, the Holocene. Younger deposits may cover older ones. The numbers indicate the approximate margins of the ice sheet 7,500 and 11,500 years ago. [21, 28]

"...passed a no: of large round Stones, Som distance in the river as also in the Sides of the hills,..."

September 22, 1804
[glacial erratics; Lyman and Hughes counties, South Dakota]

"Great numbers of verry large Stone on the Sides of the hills...."

October 17, 1804
[glacial erratics; Sioux County, North Dakota]

"The country in most parts very level and in others swelling with gentle rises and decents, or in other wirds what I have heretofore designated a wavy country destitute of timber except along the water-courses."

July 14, 1805
[glacial till plain; Cascade County, Montana]

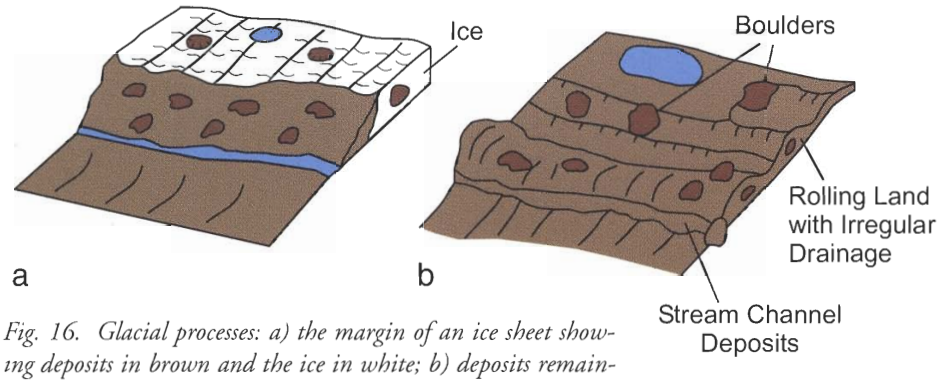


Fig. 16. Glacial processes: a) the margin of an ice sheet showing deposits in brown and the ice in white; b) deposits remaining after an ice sheet has melted.

Fig. 17. Glacial erratics in a pasture; at the entrance to the Platte Creek State Recreation Area, south of Platte, Charles Mix County, South Dakota.

Fig. 18. Irrigated hay fields on rolling glacial terrain. In the background are bluffs on the west side of the Missouri River; South Dakota Highway 1804, east of the Platte Creek State Recreation Area, Charles Mix County, South Dakota.

"the broken hills of the Missouri about this place exhibit large irregular and broken masses of rocks and stones;.... this collection consists of white & grey gannite, a brittle black rock, flint, limestone, freestone, some small specimens of an excellent pebble...."

April 22, 1805
[glacial erratics; Williams and McKenzie counties, North Dakota]

"the country is not so broken as yesterday tho' still high and roling or wavy...."

May 22, 1805
[glacial till plain; Phillips County, Montana]

...the Soil composed of black mole & a Small perportion of Sand containing great quantity of Small peable Some limestone, black flint, & Sand Stone."

April 12, 1805
[glacial till; McLean and Mercer counties, North Dakota]

1832; and general acceptance of this idea only came 25 years later. Support for the concept of continental glaciation began in the United States in 1839, but not until after 1860 did the areal extent of the North American glaciations begin to be understood. Today we know that the development of the Missouri River valley was controlled in large part by the erosion of the land along the margins of these former Ice Age ice sheets. [36, 25, 53, 41]

The Missouri River had a markedly different path before the start of continental glaciation in North America than it has today. In some places in Montana, the Dakotas, and the adjacent Canadian provinces, sediments deposited in the valleys of the ancestral Missouri and its tributaries have been preserved in part beneath the younger glacial deposits in the area that was later covered by ice sheets. In the parts of Montana, the Dakotas, Nebraska, and adjacent states to the west, where ice sheets were not present, remnant valley fills of river sediment mark the positions of these ancient, pre-Ice Age rivers. About 2.5 million years ago, parts of the ancestral Missouri, its tributaries the Yellowstone and the Platte, and other rivers probably flowed to the north into south-central Canada and entered the Arctic Ocean via the Hudson Bay Lowland (fig. 19). [1, 8, 9, 12, 24, 19]

The present Missouri Valley developed in three segments in the late Ice Age or Late Pleistocene time. [52] The southernmost part of the present Missouri is geologically the oldest. It probably formed along the margin of the ice sheet of an older glaciation during an early part of the Ice Ages. The part of the valley extending from near Kansas City, Missouri, to eastern South Dakota was eroded by runoff waters from the outflow of the ancient glacial Lake Agassiz, located in what is now eastern North Dakota, western Minnesota, and adjacent southern Manitoba, Canada. [8] The valley from the eastern edge of the Great Plains in Nebraska to the mountain front in Montana was eroded during the maximum extent of the last ice sheets in the Wisconsinan glacial epoch (fig. 15).

Thick deposits of wind-eroded and -transported silt, called loess (pronounced *luhss*), mantle the valley sides of the Missouri in Nebraska and Iowa. [49] These are generally thought to have been carried by the Missouri in its waters as the river was developing thousands of years ago in the later stages of the Ice Ages. The silts were deposited on the developing river floodplain and were picked up later by winds and redeposited along the valley sides and adjacent parts of the plains. Smaller remnants of loess are found along the Missouri in parts of the Dakotas as well. [27]

"...the earth above that for 30 or 40 feet is a brownish yellow, a number of bars of course gravel and Stones of different Shape & Size &c."

June 12, 1805

[bluff of glacial till; Chouteau County, Montana]

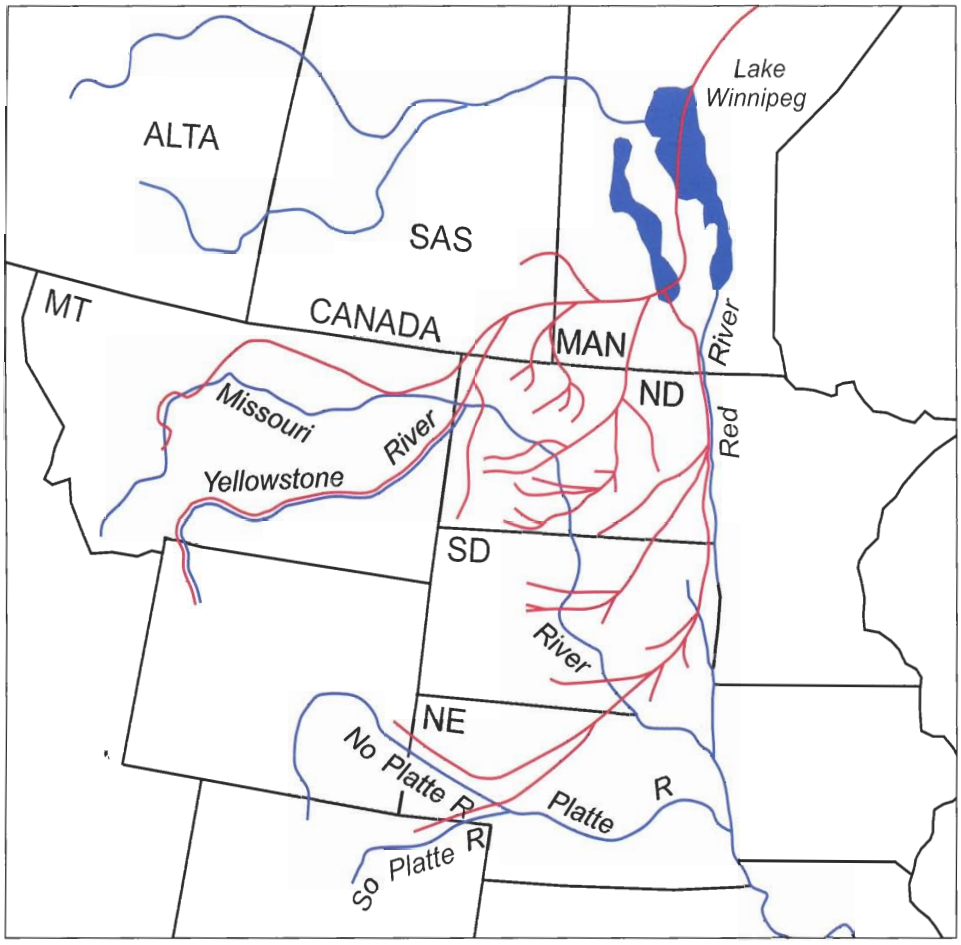


Fig. 19. Probable drainage pattern before the earliest Ice Age, about 2.5 million years ago. Ancient rivers are indicated in red, modern rivers in blue. Modified from Alden, [1] *Bluemle,* [8] *Bluemle,* [9] *Calhoun,* [12] *Flint.* [24]

"The plains are high and rich Some of them are Sandy Containing Small pebble, and on Some of the hill Sides large Stones are to be Seen...."

April 11, 1805

[glacial till and erratics; McLean and Mercer counties, North Dakota]

FLUVIAL PROCESSES – RIVERS AND THEIR WORK

Rivers erode rock, sediment, and soil, transport the debris, and deposit it in their channels and on their floodplains.

The Missouri is a meandering river in some places, a braided river in others, and elsewhere a combination of the two (fig. 20a-c). The different forms are related to changes in the gradient or slope of the river, differences in the amounts and kinds of sediment supplied to the river, and variations in regional climate and in vegetative cover.

Charged with mapping the Missouri River and marking the mouths of its tributaries, Lewis and Clark made extensive notes on what they saw and experienced while traveling on this and other

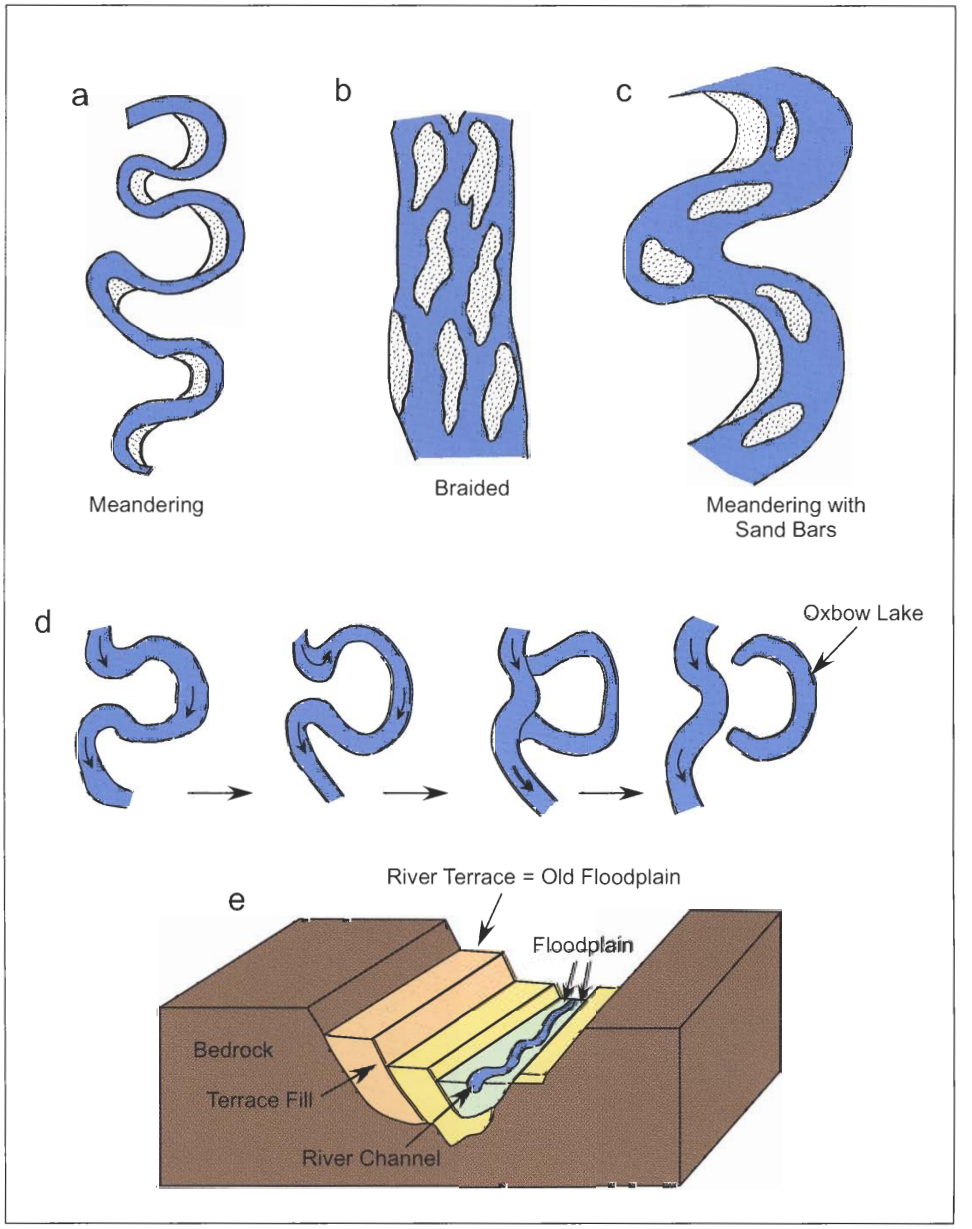


Fig. 20. Fluvial (stream-deposition and -erosion) processes.

"we made Severl. attempts to find the main Channel between the Sand bars, and was obliged at length to Drag the boat over to Save a league which we must return to get into the deepest Channel, we have been obgd to hunt a Chanl. for Some time past the river being devided in many places in a great number of Chanels,...." *October 6, 1804*
[braided river; Walworth and Dewey counties, South Dakota]

"...traces of the ancient beds of the river are visible in many places through the whole extent of this valley."
May 3, 1805
[old river channels; Roosevelt and Richland counties, Montana]

rivers (fig. 21). Change was a theme common to most of these observations. The explorers saw evidence of change in abandoned segments of former channels and several oxbow lakes (fig. 20d). They suffered the effects of wind-blown sand from bars bare of vegetation. On more than one occasion, expedition members were awakened when the river rose and began to wash sand away from the bar beneath their camp site. At the mouths of rivers carrying a great load of sand, such as the Niobrara, the number and size of the bars made navigation difficult. At places where the river cut into the bedrock and soils along its banks, landslides developed, sometimes extending for more than a mile.

Lewis and Clark made frequent observations on the sediments carried by the Missouri and its tributaries. The rivers mostly transported sand and silt. The Platte was much sandier than most. The Niobrara had more and larger gravel. Tributaries entering the Missouri trench in the Dakotas and Montana frequently carried large boulders of granite and other rocks from non-local sources, originally brought to the area by ice sheets. The rivers sometimes carried locally eroded concretions of many shapes, including ones resembling cannonballs. In reaches of the upper Missouri, rocks washed down from the valley sides above and collected in the river forming shallow areas and rapids. Often, gravels in the tributaries would be composed of different kinds of rocks than those carried by the Missouri upstream of their mouths.

The explorers understood that erosion explained the origin of some valley features that they observed. At the Great Falls of the Missouri, Lewis noted that "the river appears here to have woarn a channel in the process of time through a solid rock." (June 13, 1805)

Across the Great Plains today, human intervention has tamed the Missouri River. It is dammed in many places, channelized in others, and controlled by structures such as groins (similar to a jetty) and levees. Previously, the river flooded more commonly; it frequently shifted its channel by forming cut-off necks and oxbow lakes. Floods

Fig. 21. Sand bars and shoals in the Yellowstone River; looking southwest from the frontage road on the south side of the river, 1 mile south of the Powder River, near Terry, Prairie County, Montana.

"on the banks of the river there are many large banks of sand much elivated above the plains on which they ly and appear as if they had been collected in the course of time from the river by the almost incessant S. W. winds; they always appear on the sides of the river opposite to those winds."

July 15, 1805
[banks of wind-driven sand; Cascade County, Montana]

"...this morng at a half past one oClock the Sand bar on which we Camped began to give way, which allarmed the Serjt on guard & the noise waked me, I got up and by the light of the moon observed that the Sand was giving away both above & beloy and would Swallow our Perogues in a few minits, ordered all hands on board and pushed off we had not got to the opposit Shore before pt. of our Camp fel into the river."

September 21, 1804
[river-eroded sand bar; Lyman and Buffalo counties, South Dakota]

could fill the entire valley floor, causing major changes in the positions of the channel and the floodplain. The scouring effects of the water, together with periodic uncontrolled burning, reduced the number of trees and the amount of other vegetation in the valley. As a result, during dry periods, sand from bars was more easily eroded by water and transported by strong winds. Since the construction of six large dams in the 1940s and 1950s, the Missouri River no longer undergoes large-scale abrupt change of the kind recorded by Lewis and Clark.

During their return, near the present border between North and South Dakota, Clark described changes typical of the Missouri before the mid-20th century: "I observe a great alteration in the Corrent course and appearance of this pt. of the Missouri. in places where there was Sand bars in the fall 1804 at this time the main Current passes, and where the current then passed is now a Sand bar – Sand bars which were then naked are now covered with willow Several feet high. the enteranc of Some of the Rivers & Creeks Changed owing to the mud thrown into them, and a layer of mud over Some of the bottoms of 8 inches thick." (August 20, 1806)

"...the banks are falling in very fast; I sometimes wonder that some of our canoes or perogues are not swallowed up by means of these immence masses of earth which are eternally precipitating themselves into the river; we have had many hair breadth escapes from them but providence seems so to have ordered it that we have as yet sustained no loss in consequence of them."

May 11, 1805

[landslide; Valley and Garfield counties, Montana]

"...at the entrances of the little gullies from the hills, those rivulets having brought down considerable quantities of stone and deposited it at their entrances forming partial barriers to the water of the river to the distance of 40 or 50 feet from the shore, arround these the water run with great violence...." *May 25, 1805*

[rocks washed down into river from valley sides; Fergus County, Montana]

GEOLOGIC NATURAL RESOURCES

Thomas Jefferson had instructed the expedition's leaders to observe the land's farming potential, as well as its water and mineral resources. Accordingly, Lewis and Clark commented on the topography and soil. They noted flat, well-drained areas, in addition to steeper sloped lands and others with poor drainage. They observed fertile soils that supported vegetation, as well as saline soils and rocky soils that did not. They found "gumbo" soils with high clay content, slippery when wet, but quick to crack when dry.

As they traveled into and across arid land, they tasted the water from springs and sometimes suffered ill effects. Generally the water tasted salty, now understood to be due to salts that are leached out by the water as it flows through surrounding rock formations. Occasionally they discovered freshwater springs, such as Giant Springs near the present city of Great Falls, Montana. Such water flows out of the Northern Rocky Mountains down inclined

Fig. 22. Fresh spring water flowing from joints in the Lower Cretaceous Kootenai Formation; Giant Springs, Great Falls, Montana.

"I walked on Shore the fore part of this day over some broken Country which Continus about 3 miles back & then is leavel & rich all Plains"
September 11, 1804
[character of the land and soils; Charles Mix and Gregory counties, South Dakota]

"the country on both sides consists of beautifull level and elivated plains; asscending as they recede from the Missouri...." *April 13, 1805*
[character of the land; McLean and Mercer counties, North Dakota]

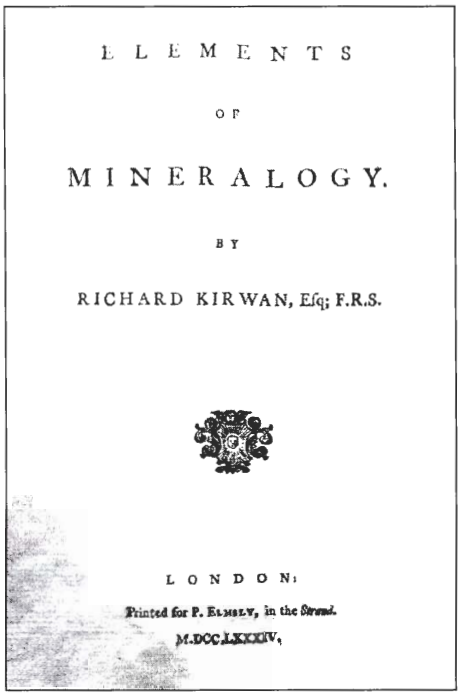
"The country high and broken... the soil poor and sterile, sandy near the tops of the hills, the whole producing but little grass...." *May 24, 1805*
[character of the land and soils; Fergus County, Montana]

"...it is a light coloured soil...,when dry it cracks and appears thursty and is very hard, in it's wet state, it is as soft and slipry as so much soft soap."
July 17, 1806; Lewis
["gumbo" clay soil; Chouteau County, Montana]

cavernous limestone strata and then up along cracks in the overlying rocks to the plains above (fig. 22). [23]

To assist in identifying minerals, Lewis had purchased a copy of *Elements of Mineralogy* by Richard Kirwan, the major English-speaking mineralogist of his day (fig. 23). [40] From some of their descriptive terms, it appears that Lewis and Clark made use of Kirwan. Unfortunately, the book relies heavily on laboratory analysis to describe substances, and so it is not a very helpful guide to identification in the field.

Among the mineral resources reported by the explorers were numerous examples of coal beds in rock formations along the rivers (fig. 24). They also noted rocks suitable for grindstones. Often they were incorrect in their identifications, but in this they tended to be consistent. They were accurate, however, in their locations; and so it is possible today to find what they noted and correct it. For example, the substance that they called *quarts* (quartz) is most likely the sulfate mineral selenite, a common crystal form of gypsum in the Cretaceous marine shales that often crop out along the upper Missouri. The beds of lightweight, gritty, red-colored stone that they named *pumice* is coal and shale that has been altered by the heat from burning lignite coal. This material is known locally in North Dakota and Montana as *clinker* or *scoria*. [9]


ELEMENTS

OF

MINERALOGY.

BY

RICHARD KIRWAN, Esq; F.R.S.

LONDON:

Printed for P. Elmsly, in the Strand.

M.DCC.LXXXIV.

Fig. 23. The title page of Richard Kirwan's Elements of Mineralogy, *1784.* [39]

Fig. 24. A present-day lignite coal mine; near Underwood, McLean County, North Dakota.

"...Seveal Mineral Springs broke out of the water of which had a taste like Salts,"

***September** 5, 1804*

[salt springs; Knox County, Nebraska]

***"...we discovered** Large Stone resembling lime incrusted with a Substanc like Glass which I take to be Cabolt, also ore...."*

***August** 27, 1804*

[minerals; Cedar County, Nebraska]

"the mineral appearances of salts, coal and sulpher, together with birnt hills & pumicestone still continue"

***April** 14, 1805*

[minerals and coal; McLean and Mercer counties, North Dakota]

"...the hills are high and ruged Containing Coal in great quantities."

***July** 29, 1806*

[coal; Yellowstone River, Custer County, Montana]

II. The Geological Observations of Lewis and Clark

INTRODUCTION

Many of the geological features noted by Lewis and Clark are accessible to today's traveler. Others are not, for a variety of reasons: river channels have shifted, making identification problematic; increased vegetation obscures river banks; reservoirs on the Missouri have flooded large stretches of the valley; dam-building and other kinds of construction have altered the landscape; and much of the land along the rivers is now privately owned. Nevertheless, many sites can still be seen.

The features described in this section were chosen from among the many observed by the explorers for three reasons: 1) they clearly illustrate the various geologic processes that formed the Great Plains; 2) they are located at or near the places where Lewis and Clark made their observations; and 3) they are visible from public lands such as parks, recreation areas, and scenic overlooks or along roadsides.

The order follows the route of the expedition up the Missouri River from northeastern Nebraska, where rocks from the ancient Cretaceous Western Interior Seaway first appear, to the mountain front in Montana. Upon its return across the Rockies in 1806, the party split. Clark recorded features on the Yellowstone River as he proceeded downstream to rejoin Lewis near its confluence with the Missouri.

The name of the relevant U.S. Geological Survey topographic map is given in brackets for each feature, for example: [Atkinson]. Appendix B lists all of the maps in this series that show the Missouri and Yellowstone rivers across the Great Plains. Travelers visiting the geologic sites will find useful details on these maps, such as the locations of unpaved roads.

CAUTIONS

- **Do not go onto private land without permission.**
- **Do not collect anything from federal, state, or reservation land.**
- **Collecting along road cuts is usually permitted but check with each state to make sure.**
- **Watch for and avoid cactus, poisonous plants, ticks, and rattlesnakes.**
- **Keep up to date about weather conditions.**
- **Carry plenty of food and water.**
- **Keep your vehicle in good repair.**
- **Do not rely solely on a cell phone. Service is not available in many remote areas.**
- **Do not walk or drive over hazardous areas where, for example, landslides have occurred.**
- **Heed signs indicating that unpaved roads are impassable when wet. Do not attempt to travel on them if they are wet or if weather forecasts indicate that they may become wet while you are using them.**

The Words of Lewis and Clark

Because spelling, punctuation, and capitalization had not yet been standardized, the writings of Lewis and Clark contain many different forms and abbreviations of the same word. An unfamiliar term can often be recognized by reading it aloud.

When traveling on rivers, the explorers used the nautical terms **larboard** *and* starboard *to indicate direction. Facing in the direction of travel, larboard (now called* port*) or larboard side (l.s. or L.S.) means left; starboard or starboard side (s.s. or S.S.) means right.*

Quotations are used by permission of the University of Nebraska Press from: Moulton, Gary E. (ed.), 1983-2000, The Journals of the Lewis and Clark Expedition: *University of Nebraska Press, Lincoln, Nebraska, and London, 13 volumes.*

MISSOURI RIVER – NEBRASKA-IOWA-SOUTH DAKOTA

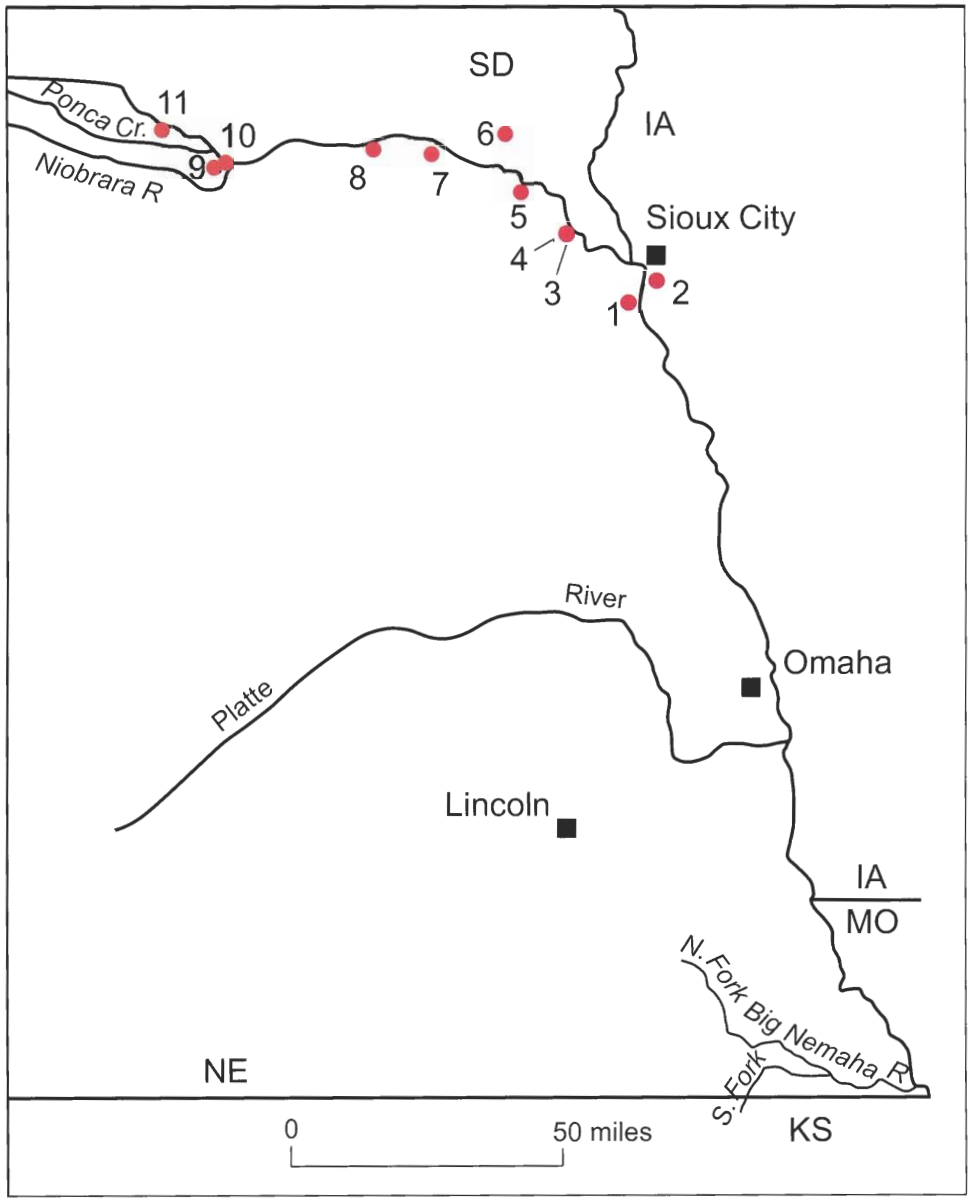


Fig. 25. Nebraska-Iowa-South Dakota sites.

Dakota Group, Cretaceous System; bluff (fig. 26)

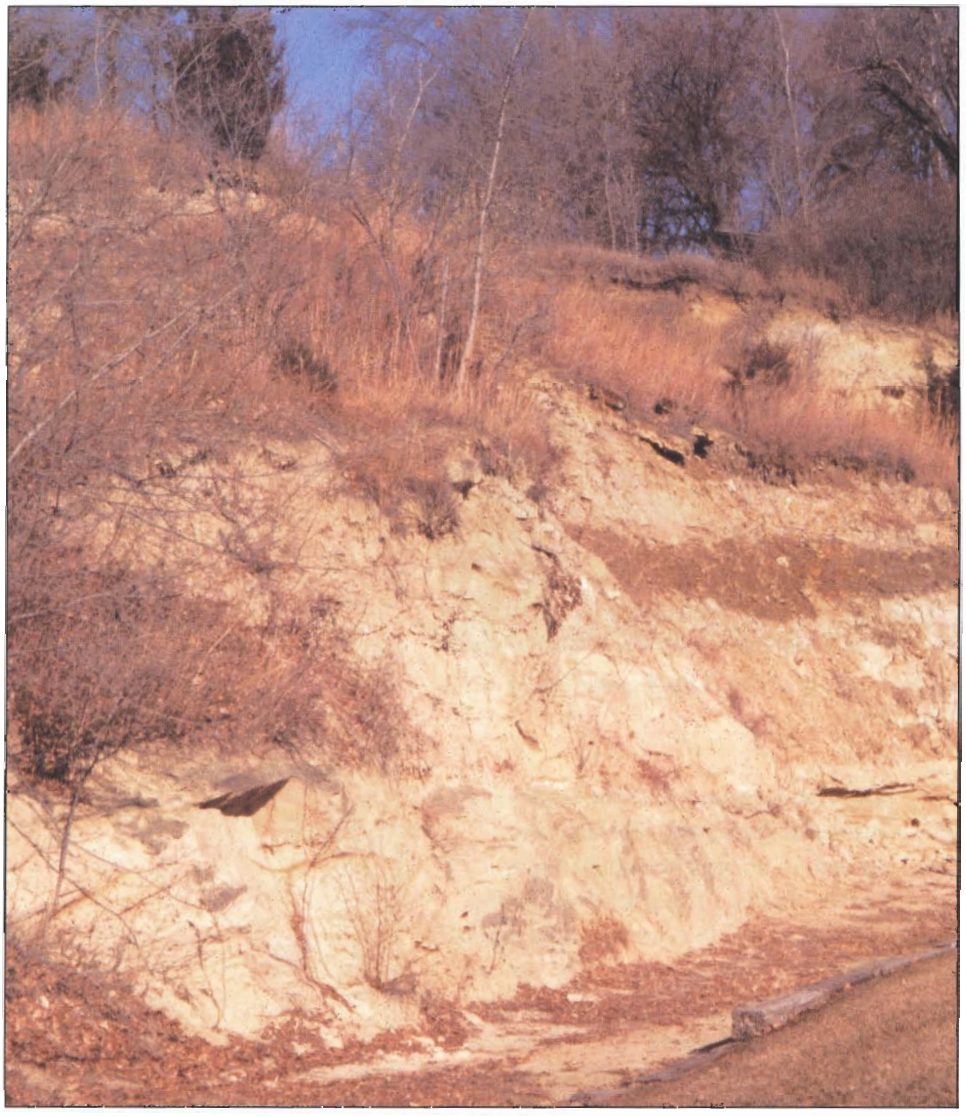


Fig. 26. Sandstone in the Dakota Group; just west of the high school football field, Homer, Dakota County, Nebraska.

The Dakota consists of sandstones and some chert pebble conglomerates deposited in river channels, and siltstones and claystones deposited in channels and adjacent floodplains. The colors of exposed rocks are reds, yellows, and browns, reflecting the presence of iron oxide (rust) in the rocks. Sandstone beds are frequently cross-bedded, typical of the bedding in sand bars. Fossils include pollen, impressions of tree stems and leaves, and some clams. Because bluffs in this area are often heavily wooded, good rock exposures are rarely natural. The Dakota Group was deposited at the start of the second major cycle of transgression and regression of the Cretaceous Western Interior Seaway, the Greenhorn Cycle.[38, 59, 60] [Sioux City South]

Site 1.

"...the Commencement of a Bluff which is about 4 miles extending on the river, of yellow and brown Clay in Some parts in it near the river a Soft Sand Stone is inbeded on the top (which is from 20 to 150 feet above the water....)"

August 12, 1804

Peoria Loess, Upper Pleistocene Series; bluff (fig. 27)

Fig. 27. The view of the Missouri River valley from the top of Floyd's Bluff, underlain by Peoria Loess; the Sergeant Floyd Monument, Sioux City, Iowa.

Near here, Sergeant Charles Floyd, the only member of the expedition to die during the journey, succumbed to what was probably appendicitis. Underlying the bluff where Floyd was buried is Peoria Loess. This is a widespread deposit composed of silt and very fine sand that blankets river terraces, valley sides, and uplands along the Missouri River in Nebraska, northernmost Missouri, Iowa, and southeastern South Dakota. Approximately 20,500 to 10,000 years ago, the loess (pronounced *luhss*) was lifted from river valleys by winds and deposited on the land when the winds slackened. This unit was named for an area first studied near Peoria, Illinois. The thickest deposits, more than 180 feet, are found in central Nebraska. Peoria Loess is light tan to yellow in color and has small calcium-carbonate concretions. Loess frequently has vertical or nearly vertical joints. Layering or stratification is usually not obvious. Loess is thicker along the Missouri River and thins away from the valley in all directions.[27, 49] [Sioux City South]

Site 2.

"we Buried him [Sgt. Charles Floyd] *to the top of a high round hill over looking the river & Countrey for a great distance"*

August 20, 1804

Greenhorn Limestone underlain by Graneros Shale, Upper Cretaceous System; bluff (figs. 28, 29, 30)

Site 3.

"...a Clift of Allom Stone of a Dark Brown Colr..."
August 22, 1804

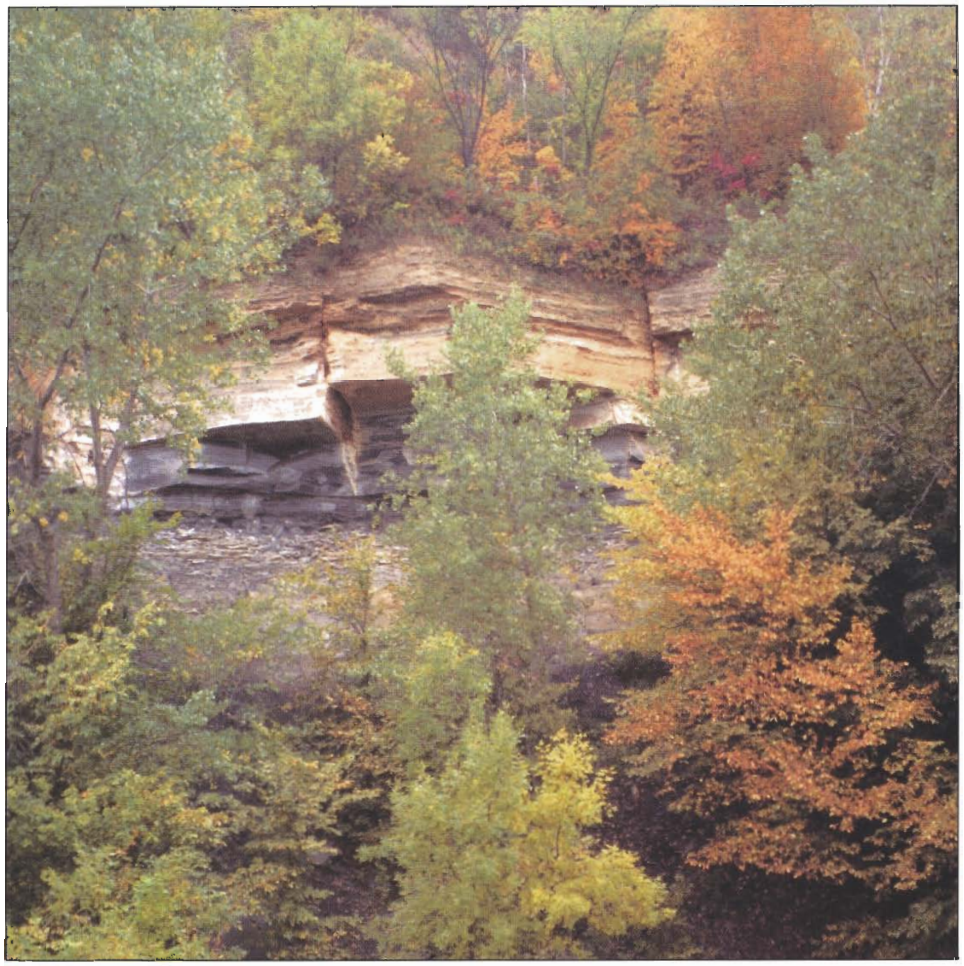


Fig. 28. Prominent ledges in the Greenhorn Limestone underlain by the Graneros Shale. Below the Graneros, rocks of the upper Dakota Group are hidden by trees; at the boat ramp in Ponca State Park, north of Ponca, Dixon County, Nebraska.

These limestones and shales weather brown to yellowish brown with red iron oxide formed from the decomposition of iron sulfide minerals such as pyrite and marcasite. Unweathered rocks are gray to very light gray in color. The limestone beds, which are harder than the shales, form ledges that protrude from bluff slopes. Fossils include skeletal plates from coccoliths, shells of foraminifera, shells of clams, scales and bones from fish, teeth of sharks, and bones of marine reptiles called *plesiosaurs.* In some places in the Greenhorn Limestone, the rock is composed of fossil clam shells held together by a fine grained matrix of cemented lime mud.[43, 45] The Graneros and the Greenhorn were deposited during the second major cycle of the Cretaceous Western Interior Seaway, the Greenhorn Cycle.[38] [Sioux City North]

Fig. 29. Reddish iron oxide in the thin-bedded Greenhorn Limestone; at the boat ramp in Ponca State Park, north of Ponca, Dixon County, Nebraska.

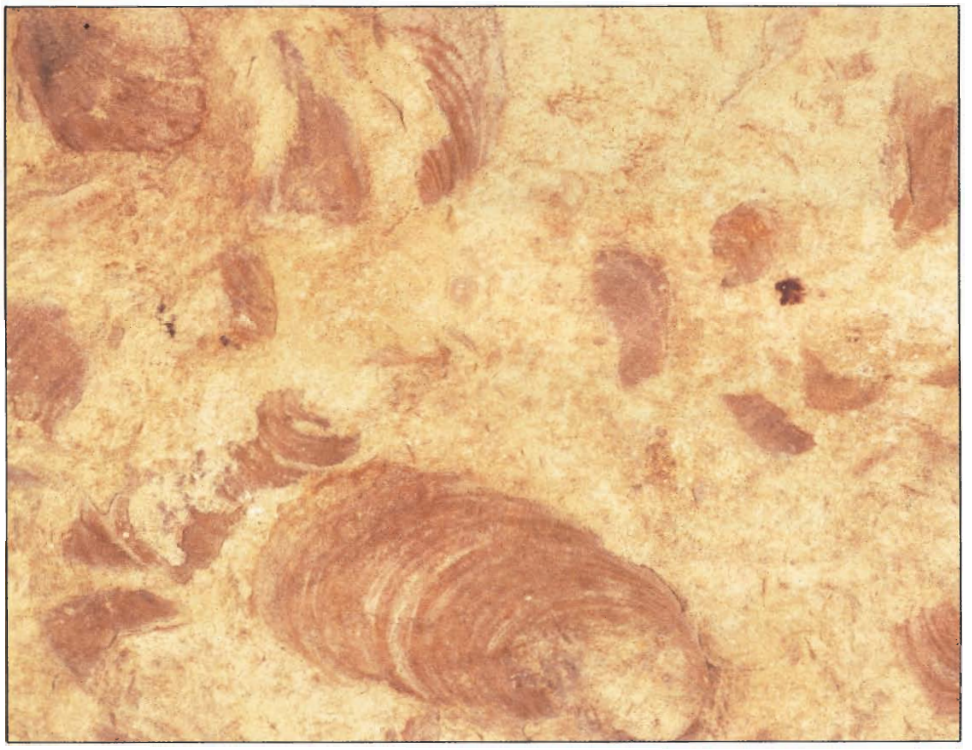


Fig. 30. Fossil clam shells on a bedding surface in the Greenhorn Limestone.

Site 3.

"Containing also in crusted in the Crevices & Shelves of the rock great qts. of Cabalt, Semented Shels & a red earth."
August 22, 1804

Sand blowing from bars (fig. 31)

Fig. 31. Wind-deposited sand that has been reworked from sand bars; at the tent camping area in Ponca State Park, north of Ponca, Dixon County, Nebraska.

During floods, the Missouri River transports and deposits a considerable amount of sand on bars in and along the river channel and on its floodplain. Recently deposited sand may be picked up and transported by winds if vegetation has not yet covered it, or if the vegetative cover has died off in a dry period. Beds of redeposited silt or very fine sand are called loess. [Sioux City North]

Site 4.

"The Wind blew hard West and raised the Sands off the bar in Such Clouds that we Could Scercely See this Sand being fine and verry light Stuck to every thing it touched, and in the Plain for a half a mile the distance I was out every Spire of Grass was covered with the Sand or Dust"

August 23, 1804

Carlile Shale, Upper Cretaceous System; bluffs (fig. 32)

Fig. 32. The Carlile Shale at the Ionia Volcano. *The dark-colored bed in the center is probably lignite. Today the Missouri's channel, seen in the upper right of the photograph, is far from this bluff. The overlook is located on private land that has generally been open to visitors; north from Nebraska Highway 12 at a Nebraska State Historical Society marker in Newcastle, Dixon County, Nebraska.*

The *Ionia Volcano*, as it has come to be called since Lewis and Clark visited the site, is a bluff and landslide area in the Carlile Shale.[11] According to Clark's map, in 1804 the Missouri River flowed against this bluff, thereby eroding it. Thin lignite coal beds occur here in the Carlile Shale; as does marcasite, the iron-sulfide mineral that is unstable when exposed to air, and selenite, the crystalline form of gypsum. Decomposition of marcasite yields heat and a sulfur smell; lignites may spontaneously combust also, producing heat. Either or both of these processes could have caused the heat that Clark reported. The "Cabalt" was probably selenite. The Carlile Shale is the upper part of the second major cycle of the Cretaceous Western Interior Seaway, the Greenhorn Cycle.[38] [Sioux City North]

Site 5.

"those bluffs has been lately on fire and is yet verry Hott, Great appearance of Coal, & imence quantities of Cabalt in Side of that part of the Bluff which Sliped in,...."

August 24, 1804

Erosional remnant; hill (fig. 33)

Fig. 33. The Niobrara Formation at Spirit Mound with glacial erratics exposed in the field in the foreground (arrow); South Dakota Highway 19, 6 miles north of Vermillion, Clay County, South Dakota.

During the Ice Ages, continental ice sheets moved into southeastern South Dakota, eroding the bedrock in places. At this hill, now known as *Spirit Mound*, the ice did not wear the rock down to a flat surface, but instead left behind an erosional remnant of chalk from the Niobrara Formation. The hill is surrounded on all sides by lower and flatter land covered by glacial deposits, including some erratic boulders.[16, 24, 53, 54] [Sioux City North]

Site 6.

"Capt Lewis and my Self Concluded to visit a High Hill Situated in an emence Plain three Leagues N. 20° W. from the mouth of White Stone [now Vermillion] *river, this hill appear to be of a Conic form and by all the different Nations in this quater is Supposed to be a place of Deavels..."*

August 24, 1804

"this hill is about 70 foot high in an emince Prarie or leavel plain from the top I could not observe any woods except in the Missourie Points...."

August 25, 1804

Niobrara Formation over Carlile Shale, Upper Cretaceous System; bluffs (fig. 34)

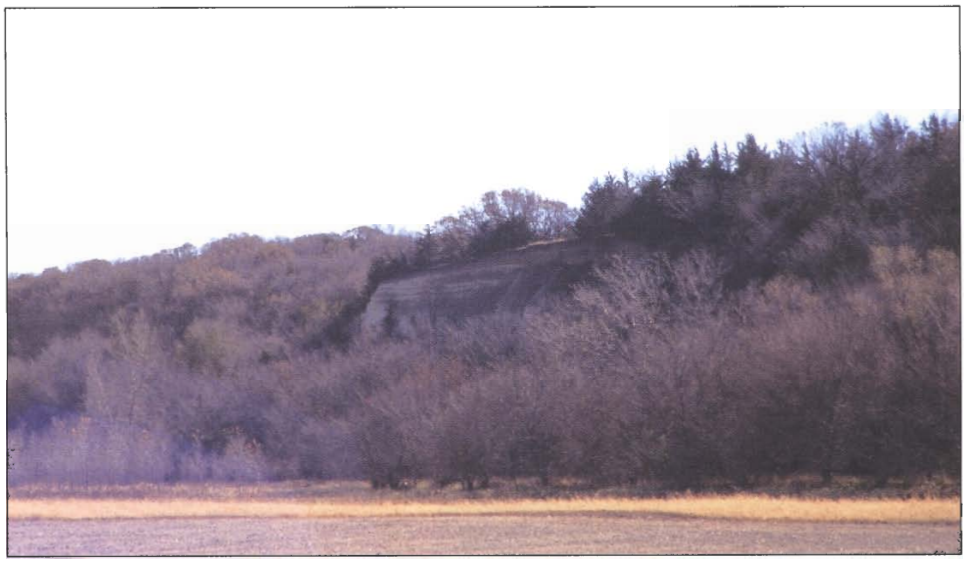


Fig. 34. The Niobrara Formation over the Carlile Shale in bluffs along the valley; near St. Helena, Cedar County, Nebraska.

The Niobrara chalks are white to cream and light yellow colored. The Carlile is dark gray or bluish gray in this area.[11] [Yankton]

Site 7.

"passed a Clift of White & Blue or Dark earth of 2 miles in extent on the L.S....."
August 26, 1804

Niobrara Formation, Upper Cretaceous System; bluffs (fig. 35)

Fig. 35. The Niobrara Formation at the southern end of Gavins Point Dam at Calumet Bluff; west of Yankton, South Dakota.

The Niobrara Formation is widely exposed both downstream and upstream of Gavins Point Dam.[11] When weathered, this chalk is light gray to white or yellowish-cream colored. Some surface exposures have a red color due to the presence of iron-oxide minerals in the rocks. The chalk is darker gray in unweathered exposures. Fossils make up most of the rock. Most are microscopic coccolith debris and foraminiferal shells. Larger fossils include shells of clams and oysters, and bones, scales and teeth of fishes. The best exposures of the chalk are on the Nebraska side of the Missouri River valley in the vicinity of the former site of the Calumet Bluff, where Lewis and Clark met with the Yankton Sioux. Much of the bluff was removed during dam construction. The Niobrara is the lower formation in the third major cycle of the Cretaceous Western Interior Seaway, the Niobrara Cycle.[38] [Yankton]

Site 8.

"...passed a Bluff containing Some white earth on the L.S..... we proceeded on about 3 Miles higher and Camped below the Calumet Bluff in a Plain on the L.S....."

August 28, 1804

Lower part of Pierre Shale, Upper Cretaceous System; bluff (fig. 36)

Fig. 36. The Pierre Shale in a roadcut; north side of Nebraska Highway 12, just west of the entrance to Niobrara State Park, Knox County, Nebraska.

Bluffs of "blue clay" were noted by Lewis and Clark at several places along the Missouri Valley.[20, 26] The lower Pierre Shale is predominantly a dark gray to black shale with a bluish undertone in parts. The Pierre is a marine deposit that contains fossil clams, ammonites, and other invertebrates; shark teeth and the bones of fishes and of the swimming reptiles, mosasaurs (sea-going lizards) and plesiosaurs. The formation also contains iron sulfide and often yields a sulfur smell at exposures. The Pierre is unstable on hill sides and often develops landslides where it is at or near the land surface. The lower Pierre Shale is in the third major cycle of the Cretaceous Western Interior Seaway, the Niobrara Cycle.[38] [Yankton]

Site 9.

"...the high land jut the river forming a Bluff of Bluish Clay."

September 4, 1804

Sand bars at the mouth of the Niobrara River (figs. 37, 38, 39)

Fig. 37. Sandbars near the mouth of the Niobrara River; from the former railroad bridge in Niobrara State Park, Knox County, Nebraska.

Clark compared the Niobrara River to the Platte. Both have many bars, but, as he noted, the Niobrara's sands are coarser. This difference is due to the Niobrara's eroding the coarser gravels and sands of the ancestral Platte River that once flowed across this area; it then moved to the south before the Niobrara Valley began to form (fig. 19). From time to time, the Niobrara floods and changes the position of its main channel. Today the river is building a delta into the headwaters of Lewis and Clark Lake, the reservoir behind Gavins Point Dam. The large load of sand carried by the Niobrara is also contributing to the growth of the many large sand bars in the reservoir downstream of its confluence with the Missouri.[26] [Atkinson]

Site 10.

"...passed the mouth of the River Que Courre (rapid R) [now Niobrara] *on the L.S. ...this River is 152 yards wide at the mouth & 4 feet Deep Throwing out Sands like the Platt (only Corser) forming bars in its mouth....this river widens above its mouth and is devided by Sand and Islands, the Current verry rapid, not navagable for even Canoos without Great dificulty owing to its Sands; the color like that of the Plat is light"*

September 4, 1804

Fig. 38. Satellite image of the mouth of the Niobrara River, 1988 (image courtesy of CALMIT, University of Nebraska-Lincoln).

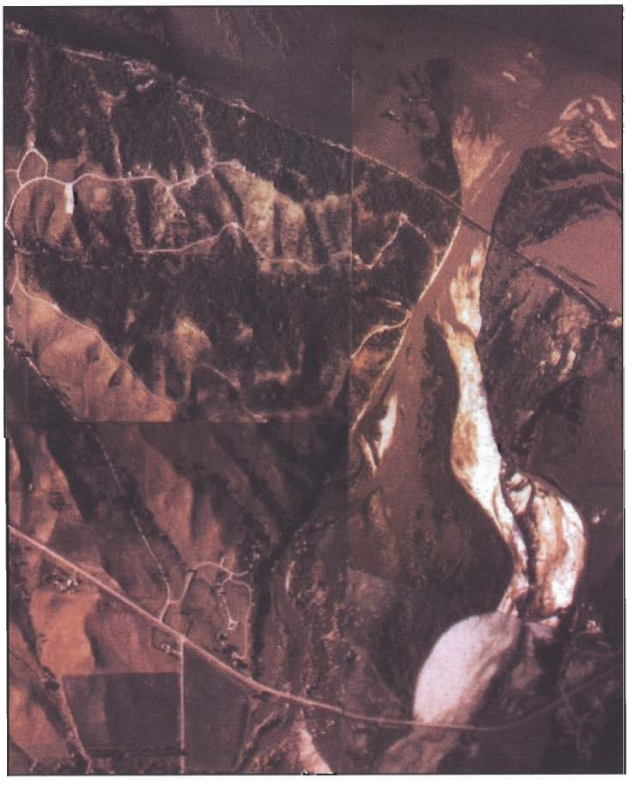


Fig. 39. Aerial photograph mosaic of the mouth of the Niobrara River, 1995. The white sand along the right side marks the former position of the main channel as seen in the 1988 image (fig. 38). In the upper right corner is the delta that is building out into the reservoir (photo courtesy of U.S. Natural Resources Conservation Service).

Site 10.

[on the return journey]
"at 9 A. M we passed the enterance of River Quiequur which had the Same appearance it had when we passed up water rapid and of a milky white Colour"

September 1, 1806

Erosional remnant; hill (fig. 40)

Fig. 40. Chalk beds in the Pierre Shale at Old Baldy (upper center-left); eastern Boyd County, Nebraska, west side of a county road from Nebraska Highway 12 to the Missouri River valley, just before the Missouri turns north and fully enters South Dakota.

The dome-shaped hill that has been known as *Old Baldy* or *The Tower* draws attention for its unusual light color. Chalks in the Upper Cretaceous Pierre Shale weather light yellow to white when exposed to the air, as do those in the Niobrara and Greenhorn formations. Vegetation does not grow readily on this Pierre Chalk member. This hill is an erosional remnant that has not yet been leveled by streams.[20] [Atkinson]

Site 11.

"we landed...near the foot of a round mounting which I saw yesterday resembling a dome. Capt Lewis & my Self walked up, to the top which forms a Cone and is about 70 feet higher than the high lands around it, the Bass is about 300 foot in descending this Cupola, discovered a Village of Small animals that burrow in the grown [prairie dogs]...."

September 7, 1804

MISSOURI RIVER – SOUTH DAKOTA

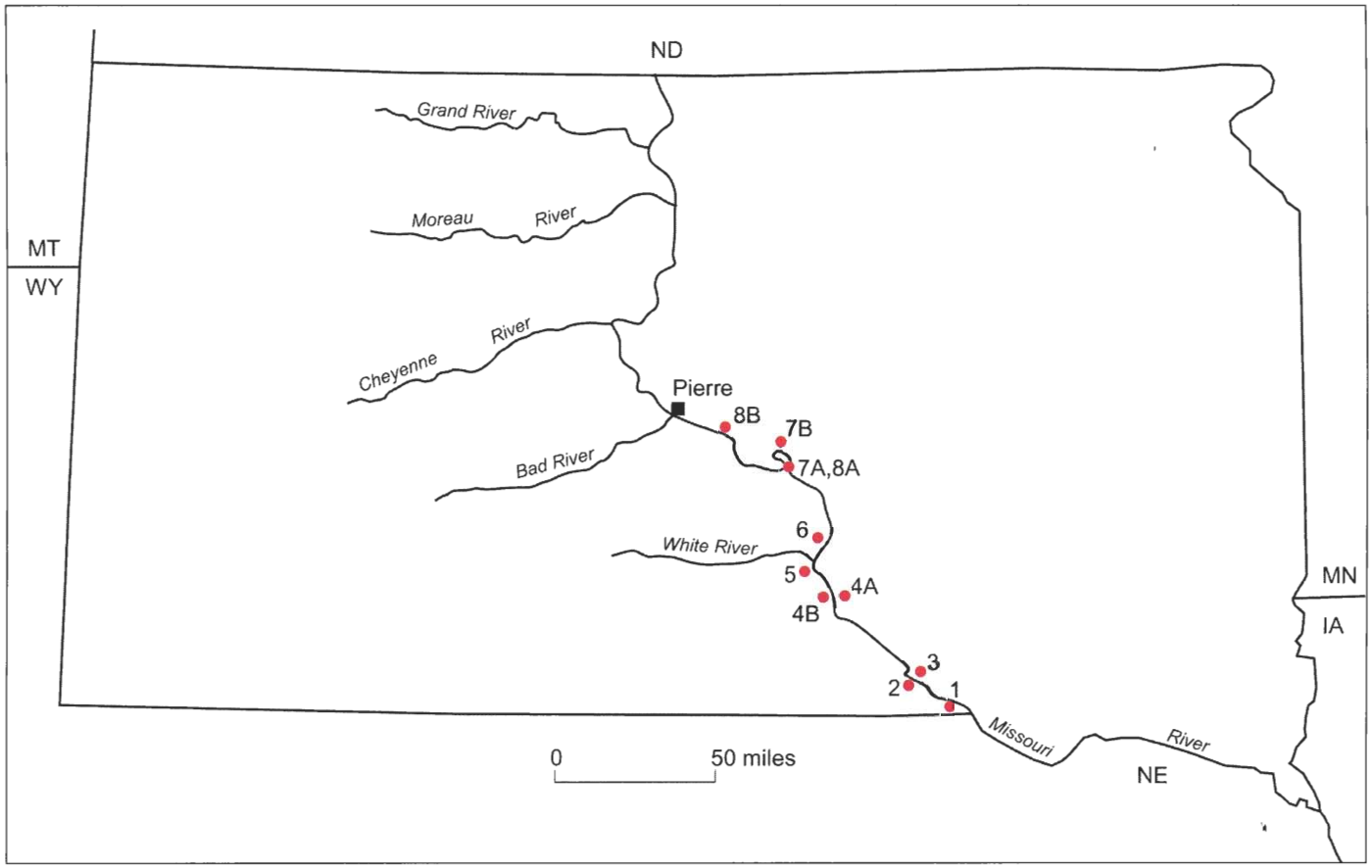


Fig. 41. South Dakota sites.

Grass fires
(fig. 42)

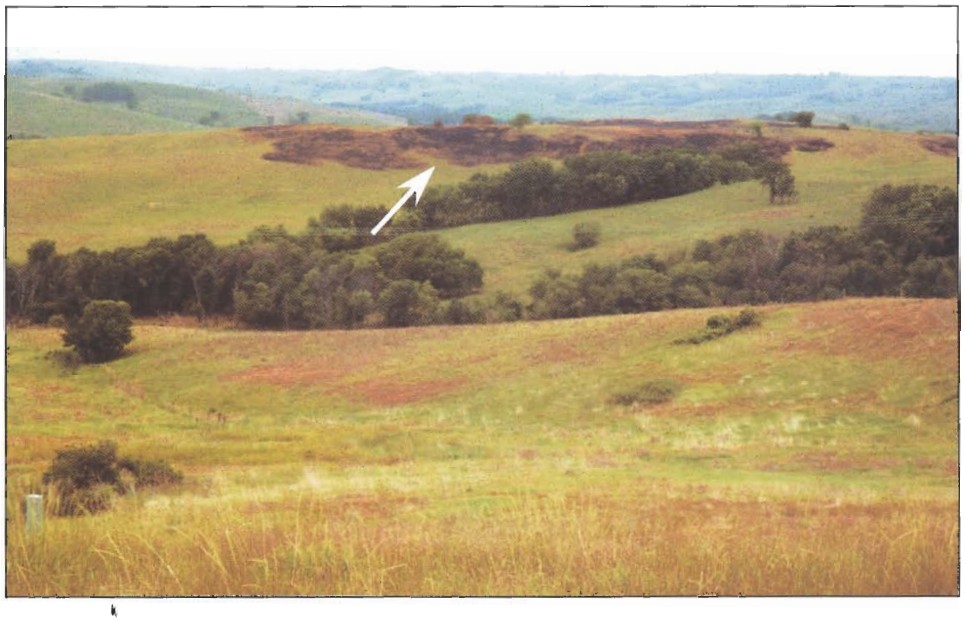


Fig. 42. A fire-blackened area of pasture in the center background; U.S. Highway 281/18, just west of Fort Randall Dam, Gregory County, South Dakota.

When the expedition crossed the semi-arid Great Plains, grass fires were common. Many were intentionally or accidentally set by humans, while others were ignited by lightning strikes. Farther north, where lignite coal beds come to the land surface, these coals may have spontaneously combusted and set prairie vegetation on fire. [Lake Andes]

Site 1.

"on the S.S. much higher hills than usial appear to the North distant 8 miles recently burnt...."

September 8, 1804

Fossil in the Pierre Shale, Upper Cretaceous System (fig. 43)

Fig. 43. In the center background is the approximate location where Lewis and Clark found the fossil of a Cretaceous marine reptile in the Pierre Shale. This site is on private land. The general area may be viewed from an access road on the west side of the Missouri River at Mulehead Point, north of Whetstone Bay in Gregory County, South Dakota, or seen with binoculars from the east side of Lake Francis Case, about 11 miles south of Platte, Charles Mix County, South Dakota.

Plesiosaurs were ancient marine reptiles that swam in the seas during the Cretaceous and earlier geologic periods in the Mesozoic Era. They occur as fossils in the dark-colored shales, like the Pierre in this case. The complete animal had a long snake-like neck and a squat turtle-like body with a short tail. Its limbs were modified into paddle-like flippers. The overall length of some plesiosaurs reached about 50 feet, close to that of the fossil reported by Clark, who thought that he had found a fish. The true nature of plesiosaurs was not determined by paleontologists until after the time of the Lewis and Clark expedition. [Lake Andes]

Site 2.

"...on the top of a ridge we found a back bone with the most of the entire laying Connected for 45 feet those bones are petrified, Some teeth & ribs also Connected."

September 10, 1804

Landslides in Pleistocene glacial till over the Pierre Shale, Upper Cretaceous System (fig. 44)

Fig. 44. The stair-stepped areas are landslides in glacial till and in the Pierre Shale; east side of Lake Francis Case, about 11 miles south of Platte, Charles Mix County, South Dakota.

Landslides are common in glacial tills and in the Pierre Shale, particularly where slopes are steep and water is abundant. Neither tills nor shale absorb water readily. Their weathered surface deposits rapidly turn to mud when saturated with water and flow or slide downslope. At this particular site, both materials are present and both are involved in landslides. The stair steps in the surface deposits are landslide masses that have moved downslope. [Lake Andes]

Site 3.

"in My ramble I observed, that all those parts of the hills which was Clear of Grass easily disolved and washed into the river and bottoms, and those hils under which the river run, Sliped into it and disolves and mixes with the water and mud frome the hills about three Inches deep...."

September 14, 1804

Erosional remnants; buttes (figs. 45, 46)

Fig. 45. Part of the Bijou Hills; east of the Missouri River, Brule County, South Dakota.

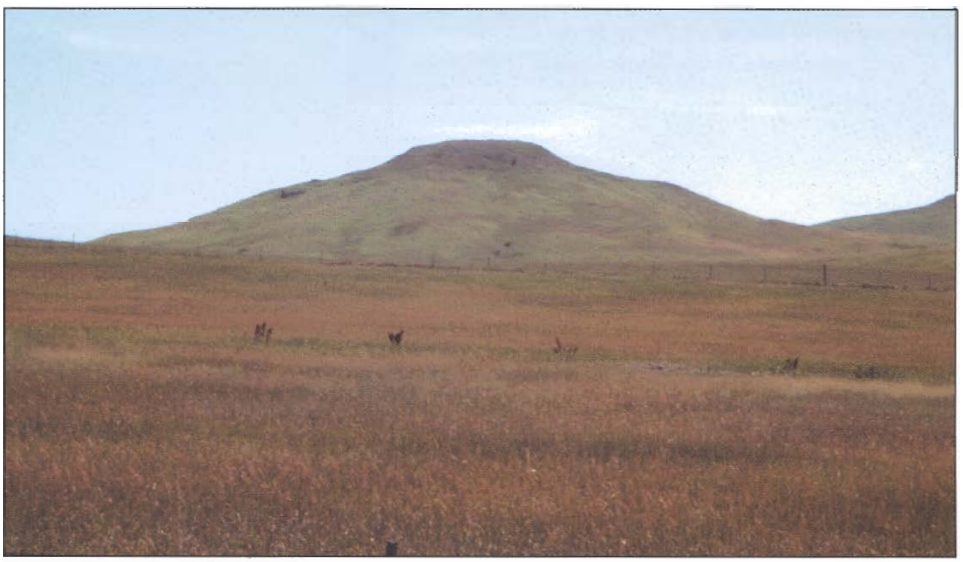


Fig. 46. Part of the Iona Hills; west of the Missouri River, Lyman County, South Dakota.

A line of isolated buttes, oriented generally east to west on either side of the Missouri River, are underlain by Tertiary-age continental deposits of the Miocene Ogallala Group and the Fort Randall Formation, laid down by rivers and wind (fig. 3). Some of those to the east of the river are known as the Bijou Hills, others to the west, the Iona Hills. The buttes are remnants of the High Plains that have not yet been worn away by water, most likely because they are capped by harder silica-cemented sandstone that resisted erosion.[20] [Chamberlain]

Site 4.

"I walked out in the morn:g and....observed..., Some verry high hills on each Side of the river."

September 12, 1804

Pierre Shale, Upper Cretaceous System; bluffs (fig. 47)

Fig. 47. The Pierre Shale with black manganese dioxide nodules; in a roadcut on the west side of South Dakota Highway 47, just north of Bull Creek, Lyman County, South Dakota. [Chamberlain]

The Pierre Shale crops out along the Missouri River valley across all of South Dakota.[5, 16] This dark gray to black shale formation includes some thinner limestone members. The Pierre is a marine deposit that contains fossil clams, ammonites, and other invertebrates, shark teeth and the bones of fishes and of the swimming reptiles, mosasaurs (sea-going lizards) and plesiosaurs. The formation also contains iron sulfide and often yields a sulfur smell at exposures. One prominent part includes manganese dioxide nodules in such numbers that the land appears to have been recently burned where vegetation is thin.[30] The shale weathers to soft clays at the surface, but is rather hard in fresh exposures. The Pierre is unstable on hill sides and often develops landslides where it is at or near the land surface. It was deposited from the latter part of the third major cycle through the fifth major cycle of the Cretaceous Western Interior Seaway, the Niobrara, Clagett and Bearpaw cycles.[38] [Lake Andes; Chamberlain]

Site 5.

"...undr. a bluff of hard black earth,..."
September 10, 1804

"...on the L. Side to the Commencement of the black Bluffs"
September 13, 1804

Treeless plains
(fig. 48)

Fig. 48. Treeless plains along American Crow Creek; west of Oacoama, Lyman County, South Dakota.

Along the Missouri River in South Dakota, the plains on the uplands adjacent to the river valley are generally treeless today, as they were in the early 1800s. Trees are found naturally only in tributary valleys and other moist places. [Chamberlain]

Site 6.

"Sergt.' Gass and Reubin Fields whom we had sent out yesterday to expore the White river returnd at four oclock this day and reported that they had foll meanders of that stream about 12 miles r[iver]'s general course West,.... the country broken on the border of the river about a mile, when the level planes commence and extend as far as the eye can reach on either side; as usual no timber appeared except such as from the steep declivities of hills, or their moist situations, were sheltered from the effects of the fire. these extensive planes had been lately birnt and the grass had sprung up and was about three inches high. vast herds of Buffaloe deer Elk and Antilopes were seen feeding in every direction as far as the eye of the observer could reach.

September 16, 1804

Meander; Big Bend of the Missouri River (figs. 49, 50, 51)

Fig. 49. Looking south at the neck of the Big Bend of the Missouri River; Narrows Area Overlook, Lyman County, South Dakota, on the Lower Brule Indian Reservation.

Fig. 50. The north curve of the Big Bend of the Missouri River; looking south on the road to the North Bend Recreational Area, Hughes County, South Dakota, on the Lower Brule Indian Reservation.

This huge meander is incised into the Pierre Shale. The overall length is about 30 miles, but, at its narrowest, the neck between one side of the meander and the other is only about 2,200 feet wide. Geologists disagree about the origin of incised meanders. Some think that they formed when the meandering river downcut its valley rapidly after some kind of uplift, while others do not believe that uplift is necessary for such a feature to develop.

A good view of both sides of the river across the neck is located about 4 miles north of Lower Brule, Lyman County, South Dakota, on an unpaved road. There is a paved parking area and an access trail to the Narrows Area Overlook. For a view of the entire Big Bend, take the unpaved road south from South Dakota Highway 34 toward the North Bend Recreational Area, Hughes County, South Dakota, for about 4 miles. Access to both of the sites is on tribal land; visitors should remain on roads and marked trails [Big Bend Dam].

Site 7.

"...at Daylight proceeded on to the Gouge of this Great bend and Brackfast, we Sent a man to measure step off the Distance across the gouge, he made it 2000 yds. The distance arround is 30 mes. The hills extend thro: the gouge and is about 200 foot above the water–in the bend as also the opposite Sides both abov and below the bend is a butifull inclined Plain...."

September 21, 1804

Fig. 51. The Big Bend area on a U.S. Geological Survey 30-minute x 60-minute metric topographic map. [Big Bend Dam]

Glacial outwash; concretions (fig. 52)

Fig. 52. A glacial erratic on the neck of the Big Bend; Narrows Area Overlook, Lyman County, South Dakota, on the Lower Brule Indian Reservation. [Big Bend Dam]

Rocks of cobble and boulder sizes were carried into the area by glaciers and washed out of glacial tills by the Missouri River. In places, the boulders and cobbles have been redeposited on river terraces, and in other places they have been washed down tributaries into the river where they may make the bed rough and the channel shallow. Large concretions that occur in parts of the Pierre Shale are left behind when the softer shale has been eroded away by the river and its tributary streams. These concretions, where abundant, could also cause shallowing of the river where they are concentrated.

The results of a large volume of water flowing from a melting glacier are visible from a scenic overlook on South Dakota Highway 34, at Medicine Knoll Creek, about 15 miles southeast of Pierre, Hughes County, South Dakota. North from the overlook, where the land becomes lower, is the site of a former glacial sluiceway. Water from the melting Wisconsinan ice sheet to the east flowed west though this sluiceway to the developing Missouri River. Abundant glacial sand and gravel is evidence that this low spot was a site of major runoff from the melting ice sheet.[24] [Pierre]

Site 8.

"The Shore on each Side is lined with hard rough Gulley Stones of different Sises, which has roled from the hills & out of Small brooks,...."

September 21, 1804

"The large Stones which lay on the Sides of the banks in Several places lay Some distance in the river, under the water and is dangerous &."

September 22, 1804

MISSOURI RIVER – NORTH DAKOTA

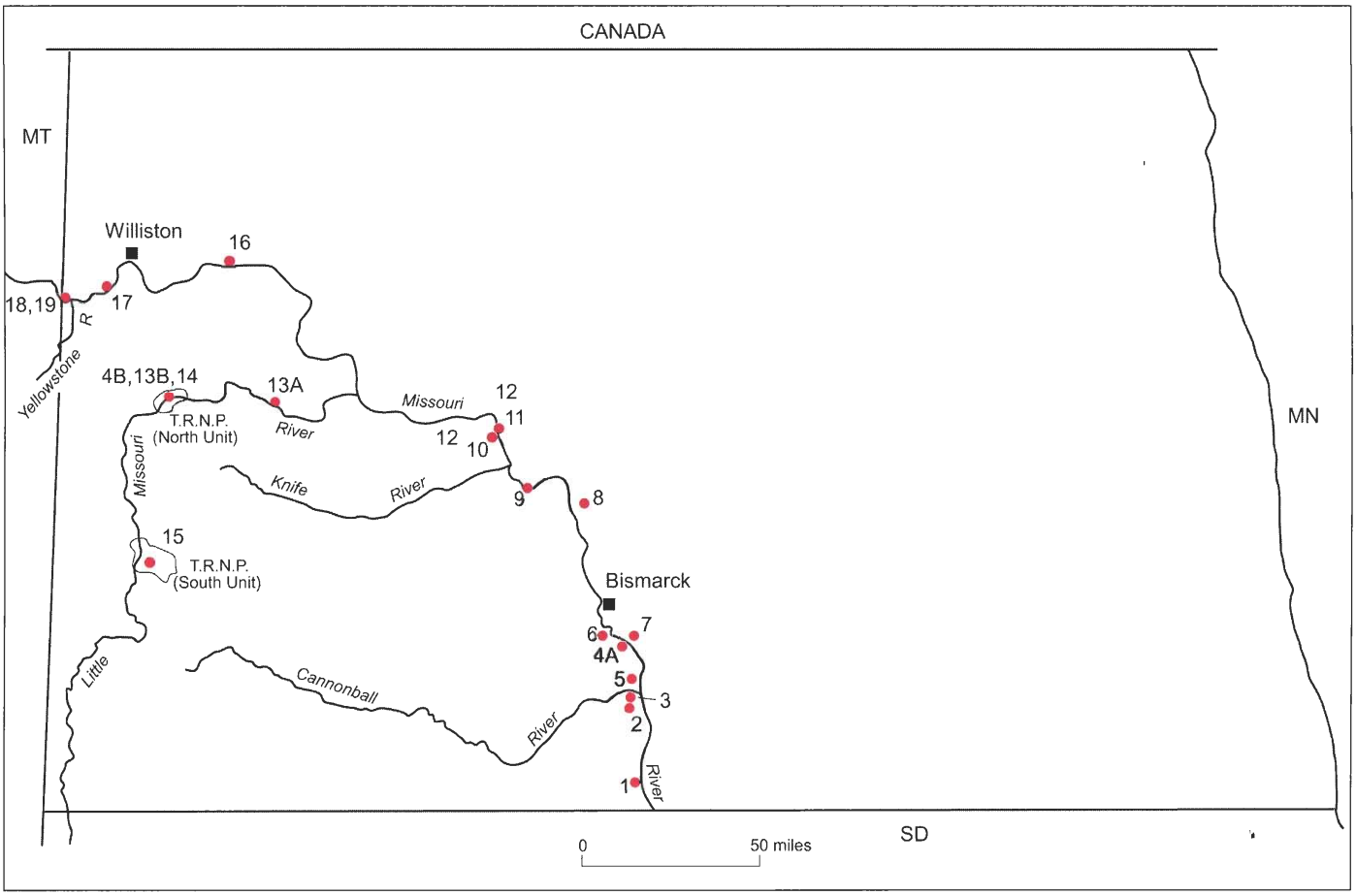


Fig. 53. North Dakota sites; T.R.N.P. – Theodore Roosevelt National Park.

Erosional remnants (fig. 54)

Fig. 54. Proposal Hill, an erosional remnant; Fort Yates, Sioux County, North Dakota, on the Standing Rock Indian Reservation.

At many places along the Missouri Valley and its tributaries in North Dakota, there are remnant hills that have not yet been eroded away by running water. Many of these have the shapes of human-made features. If the top is flat, it may be composed of harder rock that is resistant to erosion. Peaked tops are of softer, less resistant rock. [Linton]

Site 1.

"Saw many Curious hills, high and much the resemblance of a house with a hiped roof,...."

October 15, 1804

Glacial erratics (fig. 55)

Fig. 55. Glacial erratics in a burned pasture; looking southwest from the intersection of North Dakota Highway 24 and North Dakota Highway 1806, southwest of Cannonball, Sioux County, North Dakota, on the Standing Rock Indian Reservation.

Cobbles and boulders of rock from distant sources have been left behind when the ice sheets melted away across this part of North Dakota. The finer grained parts of glacial tills have often been washed away, leaving behind only the larger rocks. High grasses and other tall vegetation may make viewing these erratics difficult, but they can be seen where the grasses have been cut down or burned. Where fields have been cleared for production agriculture, the erratics may have been moved to the edge of the field or removed entirely. [Linton]

Site 2.

"Great numbers of verry large Stone on the Sides of the hills...."

October 17, 1804

Fox Hills Sandstone, Upper Cretaceous System; butte (fig. 56)

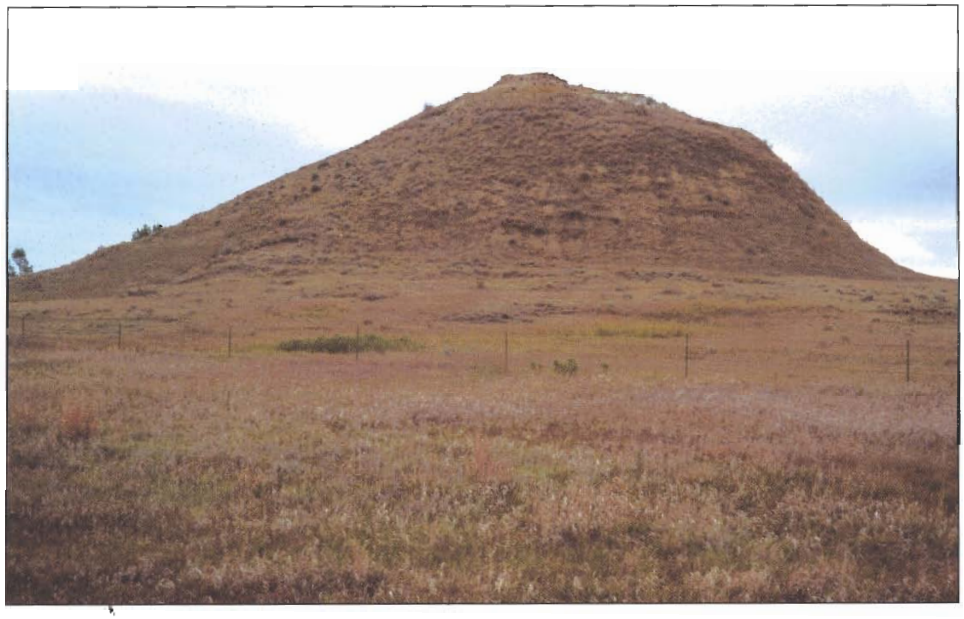


Fig. 56. The Fox Hills Sandstone in an erosional remnant on the south side of the Cannonball River; looking south from North Dakota Highway 1806, Sioux County, North Dakota, on the Standing Rock Indian Reservation.

The Fox Hills Sandstone is composed mostly of brown-colored sandstone that weathers to brown sand and silt, as well as some finer grained beds.[9, 32] The sandstone contains fossils of land plants and invertebrates. It was deposited on a coastal plain and in deltas during the fifth major cycle of the Cretaceous Western Interior Seaway, the Bearpaw Cycle.[38] [Linton]

Site 3.

"...Some rock of a brownish Colour in the Ld. Bend...."
October 17, 1804

Concretions; water-rounded sandstones (figs. 57, 58)

Fig. 57. Cannonball concretions along a driveway; North Dakota Highway 1806, Huff, Morton County, North Dakota. [Bismarck] The concretions may have been obtained from exposures of the Fox Hills Sandstone on the Missouri River near the mouth of the Cannonball River.

Spherical or nearly spherical concretions up to several feet in diameter have weathered out of some of the Cretaceous (Fox Hills Sandstone) and Paleocene (Cannonball, Bullion Creek, and Sentinel Butte) formations.[32] Because of the shape and size, the name *Cannonball* has been given to one type of these concretions. Cobble- and boulder-sized pieces eroded from other well-cemented sandstone beds have subsequently been rounded into cannonball and shell-shaped pieces during water transport. The concretions are generally concentrically cemented, while the rounded sandstone pieces are not. The Upper Cretaceous Fox Hills Sandstone through the Paleocene Fort Union Group were deposited by rivers on coastal plains, coal swamps and deltas after the final transgression of the Cretaceous Western Interior Seaway, the Bearpaw Cycle.[38] [Linton]

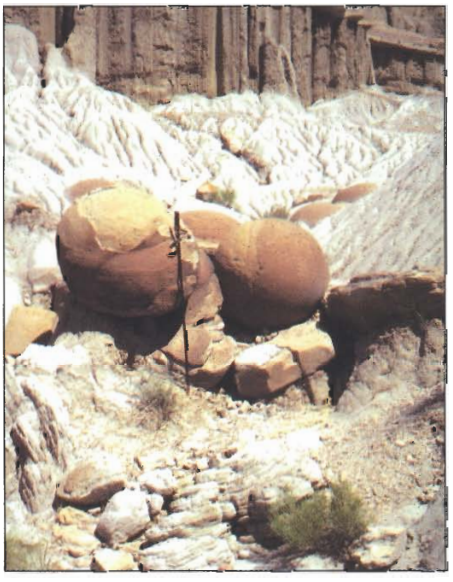


Fig. 58. Cannonball concretions in the Sentinel Butte Formation; Cannonball Concretion Pull Out in the Theodore Roosevelt National Park-North Unit, McKenzie County, North Dakota. [Watford City] Although not directly on the route taken by Lewis and Clark, the park is an excellent place to see examples of the geology of the general area through which they travelled.

Site 4.

"above the mouth of this [Cannonball] *River, in and at the foot of the Bluff, and in the water is a number of round Stones, resembling Shells and Cannon balls of Different Sises, and of excellent grit for Grindstons–"*

October 18, 1804

Salts
(fig. 59)

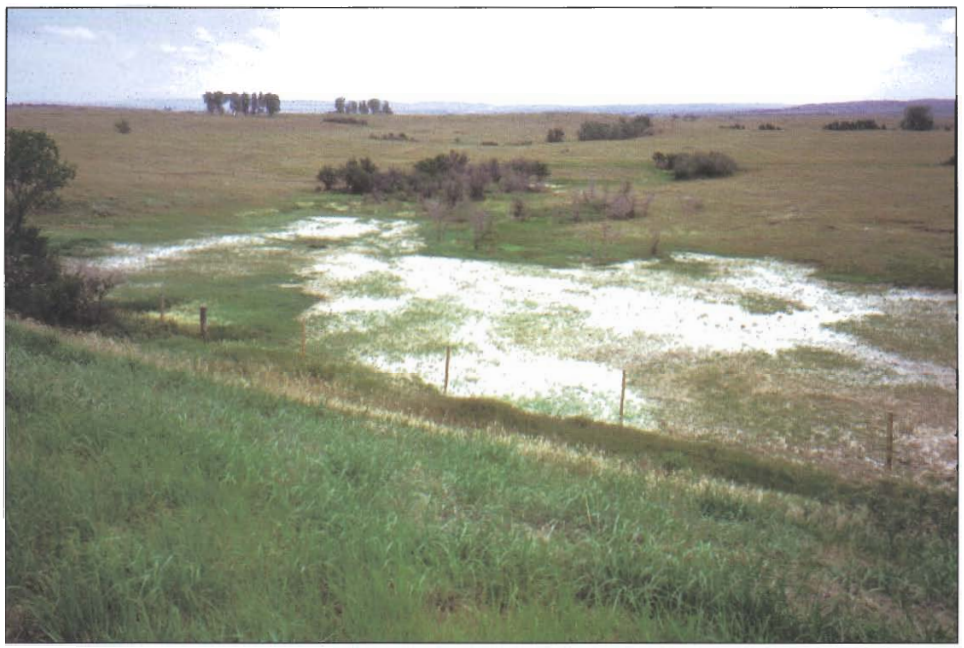


Fig. 59. Salt crusts; east side of North Dakota Highway 1806, 2 miles north of the mouth of the Cannonball River, Morton County, North Dakota.

Mineral salts are leached from the Cretaceous and Tertiary bedrock and form crusts after the water that dissolved them has evaporated. These white crusts are common along many intermittent streams and evaporated ponds and lakes in North Dakota. One of President Jefferson's charges to Lewis and Clark was to locate sources of mineral salts and saline waters. [Linton; Bismarck]

Site 5.

"all the runs which come from the high hills which is Generally about one or 2 miles from the water is brackish and near the Hills (the Salts are) and the Sides of the Hills & edges of the Streams, the mineral salts appear"

October 19, 1804

Erosional remnants (fig. 60)

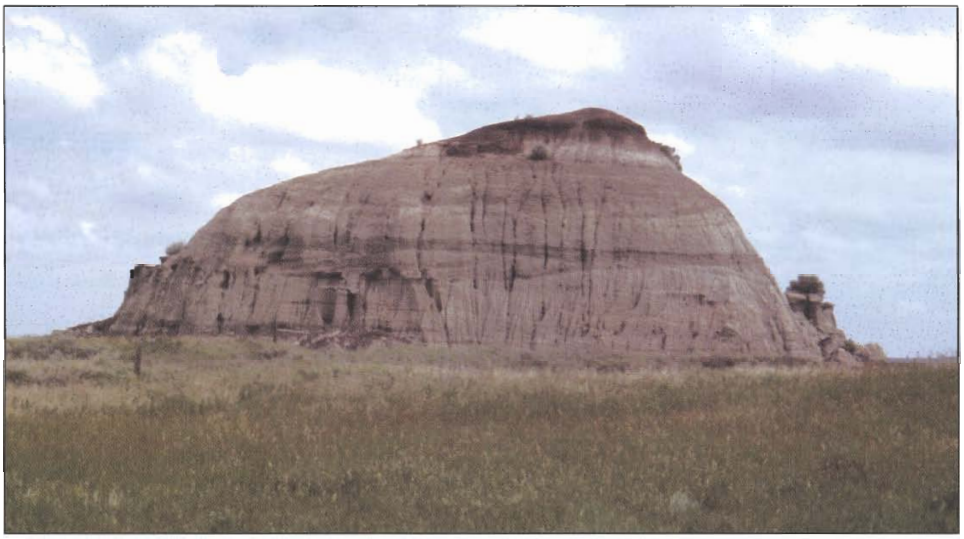


Fig. 60. Erosional remnants in the Fox Hills Sandstone; North Dakota Highway 1806, 1-2 miles north of County Road 80, near Sugarloaf Butte, north of Huff, Morton County, North Dakota.

Where a remnant is not capped by hard rock resistant to erosion, the remnant hill may have an inverted cone shape. Hills of this shape are very common along the Missouri and its tributaries in North Dakota. During rains and snow melts, water may move more easily down vertical fractures in the rock than through the unfractured parts. The rock along the fractures may be differentially eroded to form pipe-like conduits that are taken up as homes by birds and other animals. [Bismarck]

Site 6.

"I saw Som remarkable round hills forming a Cone at top one about 90 foot one 60 & Several others Smaller, the Indian Chief Say that the Callemet bird live in the holes of those hills, the holes form by the water washing thro Some parts in its passage Down from the top...."

October 19, 1804

Sand blowing from bars

The Corps of Discovery frequently camped on sand bars in and along the river. Bare of vegetation, the sand in these bars was easily picked up and blown about by winds. Today, the river is controlled by dams, and sand bars are difficult to find in many places. Some ancient sand bar deposits and dunes are preserved along the Missouri Valley. These can be distinguished by their characteristic bar or dune shape even when covered with vegetation. Grass-covered sand bars and sand dunes can be seen southeast of Bismarck, in southwestern Burleigh County, North Dakota. [9, 32] [Bismarck]

Site 7.

"...this morning the wind rose and blew with great Violence untill 4 P. M. and as our camp was on a Sand bar we were very much distressed with the blows of Sand."

October 19, 1806

Meander cut-off, oxbow lake (fig. 61)

Fig. 61. An oxbow, Painted Woods Lake; east side of the Missouri River, west of U.S. Highway 83, south of Washburn, McLean County, North Dakota.

Where the Missouri Valley widens in North Dakota, an oxbow that was noted by Clark in 1804 is known today as *Painted Woods Lake.* As an oxbow forms, the two cut banks on either side of the meander neck are eroded by the river; eventually the neck is breached, and the channel is shortened. Deposits clog the two ends of the abandoned channel segment, and an oxbow lake is formed (fig. 20d). Sediment washes and is blown into the lake over time. Plants grow in and along the shallow water at the edge of the lake. As they die, they accumulate as debris on the lake floor. Eventually the lake fills in with sediment and organic debris. [McClusky]

Site 8.

"passed a Island on the S.S. made by the river Cutting through a point, by which the river is Shortened Several miles"

October 24, 1804

Sand bars; shoals (fig. 62)

Fig. 62. Sand bars in the river; from North Dakota Highway 200A, 4 miles east of Fort Clark, Oliver and McLean counties, North Dakota.

Sand bars continued to be a problem for the explorers (fig. 20b, c). Glacial cobbles and boulders, fragments of bedrock, and concretions that accumulated in the channel made navigation difficult at times. [Hazen]

Site 9.

"river full of Sand bars & we are at a great loss to find the Channel of the river, frequently run on the Sand bars which Detain us much passed a verry bad riffle of rocks in the evining by takeing the L.S. of a Sand bar...."

October 25, 1804

Sentinel Butte Formation, Tertiary System-Paleocene Series; bluffs; coal (fig. 63)

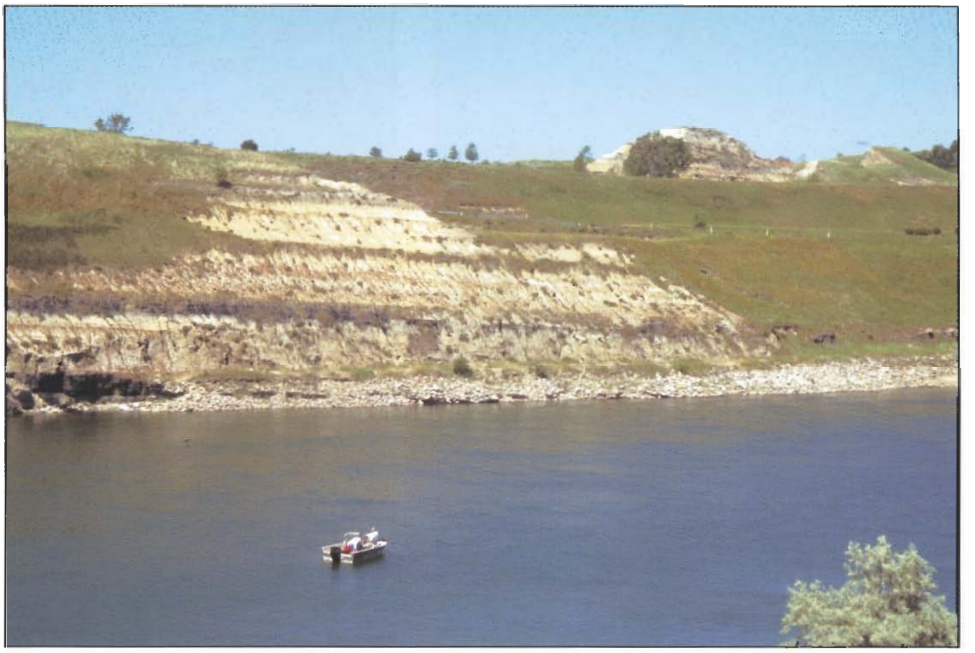


Fig. 63. The Sentinel Butte Formation; from below Garrison Dam, looking to bluffs on the west side of the Missouri River, Mercer and McLean counties, North Dakota.

The Paleocene Sentinel Butte Formation of the Fort Union Group is a complex of coastal plain, lake, coal swamp, and delta deposits. The formation is generally gray in color, but yellow, red, and brown are also present. Lignite coal beds are common throughout the formation. After the final retreat of the Cretaceous Western Interior Seaway from this area, ancient rivers brought sediments eroded from mountains located in what is now western Montana. They deposited these sediments on a vast coastal plain bordered on the east by deltas.[32] [Hazen]

Site 10.

"the Bluffs of the river which we passed today were upwards of a hundred feet high, formed of a mixture of yellow clay and sand – many horizontal stratas of carbonated wood, having every appearance of pitcoal at a distance; were seen in the face of these bluffs. these stratas are of unequal thicknesses from 1 to 5 feet, and appear at different elivations above the water some of them as much as eighty feet."

April 9, 1805

Coal
(fig. 64)

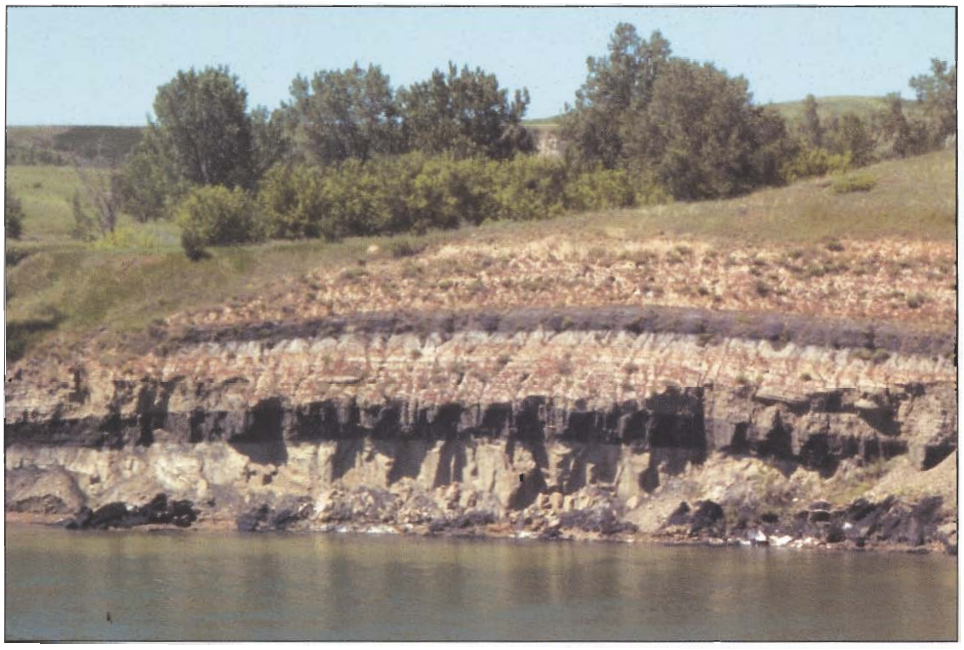


Fig. 64. Lignite coal in the Sentinel Butte Formation; from below Garrison Dam, looking to bluffs on the west side of the Missouri River, Mercer and McLean counties, North Dakota.

Instructed by Jefferson to look for usable mineral deposits, including coal, the explorers made notes on every reach of the Missouri where coal occurred. The notes were detailed enough that, had they been tied to Clark's maps of the river, a general geologic map of the distribution of coal-bearing formations could have been drawn, but this never was done.

Some of these coal beds are being mined today for use in running local electrical generating plants. In this case, the coal beds are in the Sentinel Butte Formation.[9, 32] [Hazen]

Site 11.

"many horizontal stratas of carbonated wood, having every apperance of pitcoal at a distance; were seen in the face of these bluffs...."

April 9, 1805

Treeless plains

The surface of the Great Plains along the Missouri Valley has been smoothed out by glacial erosion during the last Ice Age of Pleistocene times (Wisconsinan) (fig. 15). The area today is semiarid, and normal vegetation on the prairie is short grass and other low-growing drought-tolerant plants. Unless tended by humans, trees grow naturally only in sheltered spots with more abundant water. Great Plains topography can be seen in upland areas away from valleys and farms in Mercer and McLean counties, North Dakota. [Hazen, Garrison, Parshall]

Site 12.

"The country on both sides of the missouri from the tops of the river hills, is one continued level fertile plain as far as the eye can reach, in which there is not even a solitary tree or shrub to be seen except such as from their moist situations or the steep declivities of hills are sheltered from the ravages of the fire."

April 10, 1805

Valley of the Little Missouri River (fig. 65)

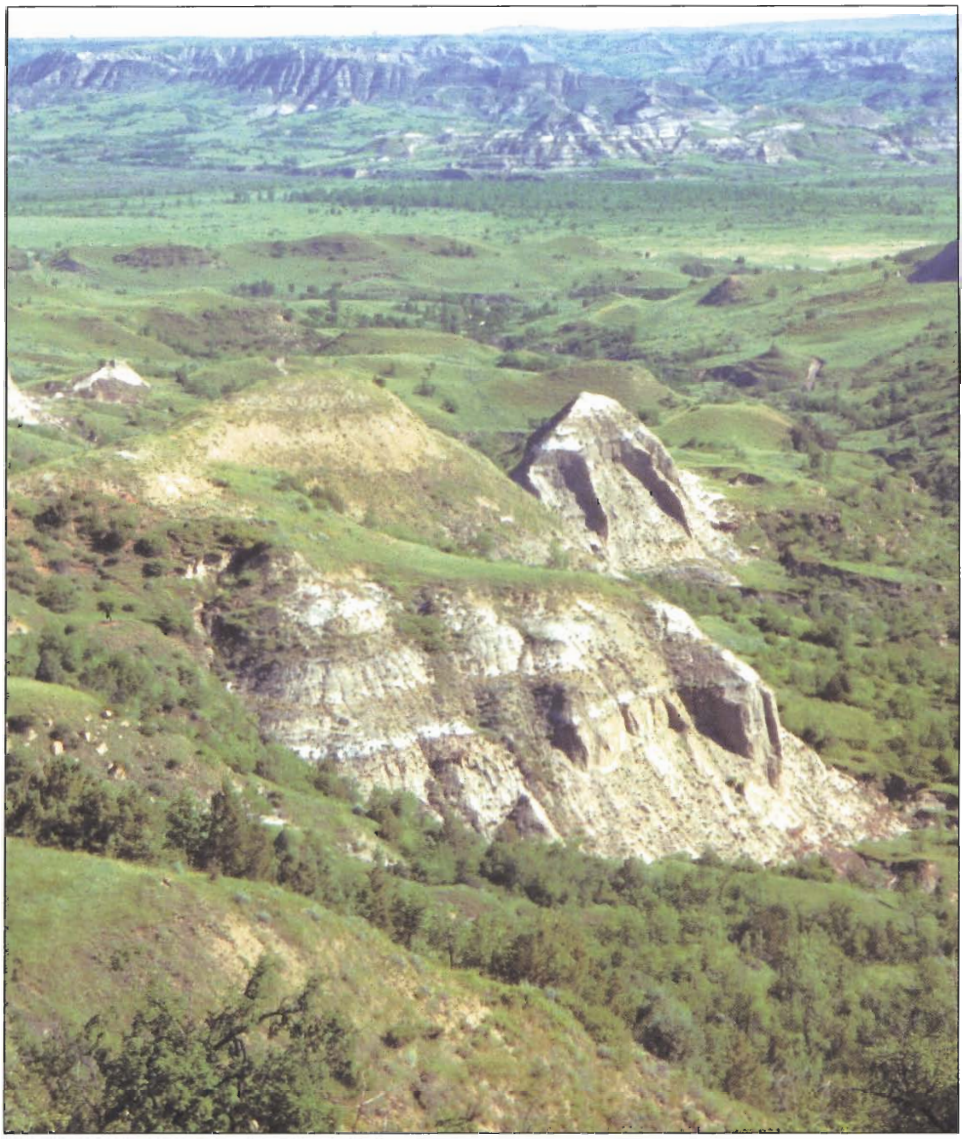


Fig. 65. Bluffs of the Sentinel Butte Formation along the valley of the Little Missouri River; at North Dakota Highway 22, Dunn County, North Dakota.

The Little Missouri has eroded its valley into rocks of the Sentinel Butte Formation, just as the (big) Missouri has. The rocks along both valleys in this area are essentially of the same rock types and erode in a similar manner. [Parshall]

The Theodore Roosevelt National Park-South Unit in Billings County, North Dakota; and the North Unit in McKenzie County, North Dakota, are excellent places to learn about the geology of the area, providing interpretive signs, maps, and publications. Although Lewis and Clark did not venture so far up the Little Missouri, examples of many of the geologic features that they noted on the Missouri are more easily seen today in the park because of changes brought by dams and reservoirs.[7] [Belfield, Grassy Butte, Watford City]

Site 13.

"...it's [Little Missouri River] *appearance in every respect resembles the Missouri; I am therefore induced to believe that the texture of the soil of the country in which it takes it's rise, and that through which it passes, is similar to the country through which the Missouri passes after leaving the woody country, or such as we are now in."*

April 12, 1805

Landslide in the Sentinal Butte Formation, Tertiary System-Paleocene Series (fig. 66)

Fig. 66. An example of a landslide (left center) in the Sentinel Butte Formation; Theodore Roosevelt National Park-North Unit, McKenzie County, North Dakota.

The Paleocene formations exposed along valley sides in North Dakota are prone to landslides just as the Cretaceous formations are. [Parshall, Watford City]

Site 14.

"the lard.shore on which I walked was very broken, and the hills in many places had the appearance of having slipped down in masses of several acres of land in surface."

April 14, 1805

Petrified wood
(fig. 67)

Fig. 67. An example of a petrified stump; Theodore Roosevelt National Park-South Unit, Billings County, North Dakota. [Belfield, Grassy Butte]

Petrified wood is found in the various formations of the Fort Union Group of North Dakota. Under favorable environmental conditions, dissolved minerals are precipitated from the groundwater into the wood cells, thus producing a solid or nearly solid fossil, frequently with the cellulose cell walls preserved. The wood is usually found in sediments or sedimentary rocks deposited on the Paleocene coastal plain during the last cycles of the Western Interior Seaway.[7 32] [Williston]

Site 15.

"I met with several stones today that had the appearance of wood first carbonated and then petrefyed by the water of the river,...."

April 16, 1805

Coal; clinker or scoria (fig. 68)

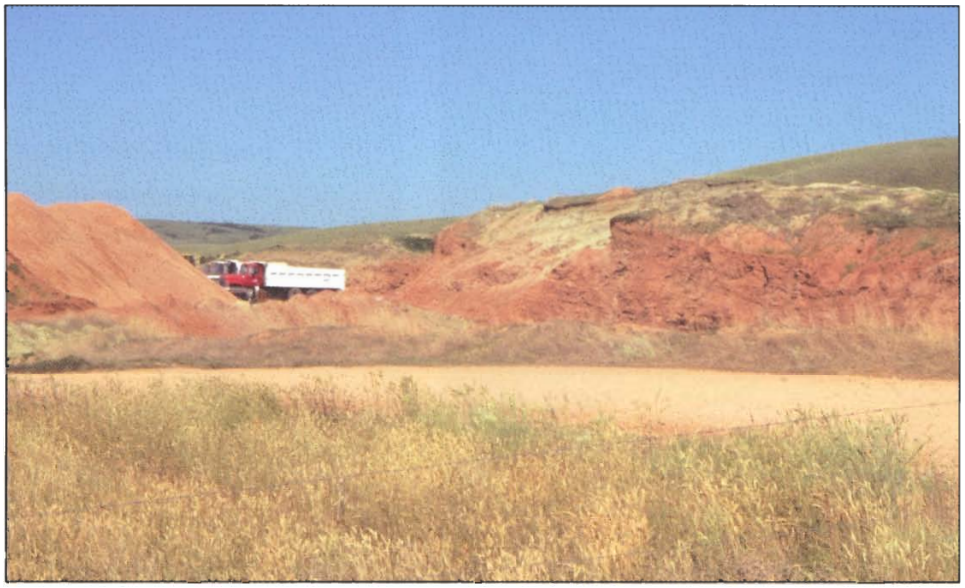


Fig. 68. A scoria pit in the Fort Union Group; north side of North Dakota Highway 1804, 12.5 miles east of the turn-off to Lewis and Clark State Park, Williams County, North Dakota.

Lignite coal beds are common in the Paleocene Fort Union Group of North Dakota. At many sites, some of these beds have undergone combustion, altering the coal and the surrounding fine-grained sedimentary rock to produce a red rock that appears to have had an igneous origin. Some of it is light in weight with many holes. If the rock contains enough air-filled openings, it may float in water. Known locally as *clinker* or *scoria*, Lewis and Clark mistakenly called this rock *pumice* and *lava*, both with volcanic, that is igneous, origins.[9] [Williston]

Site 16.

"...the mineral appearances continue with greater appearances of Coal, much greater appearance of the hills having been burnt, more Pumice Stone & Lava washed down to the bottoms and some Pumice Stone floating in the river,...."

April 17, 1805

Sand blowing from bars (fig. 69)

Fig. 69. Sand dunes on an island in Lake Trenton; North Dakota Highway 1804 on the east side of Trenton, Williams County, North Dakota.

Sand bars provided places for the expedition to camp for the night all along the Missouri River. Where the bars lacked vegetative cover, winds eroded and carried away the sands or deposited them as dunes on the bars and floodplain of the river. [Williston]

Site 17.

"...the immence quantities of sand which is driven by the wind from the sandbars of the river in such clouds that you are unable to discover the opposite bank of the river in many instances. the particles of this sand are so fine and light that they are easily supported by the air, and are carried by the wind for many miles, and at a distance exhibiting every appearance of a collumn of thick smoke."

April 24, 1805

River terrace (fig. 70)

Fig. 70. A terrace on the north side of the Missouri River valley at its confluence with the Yellowstone; at the picnic area in Confluence Park at Fort Buford State Historic Site, Williams County, North Dakota.

When rivers cut deeper channels, remainders of former floodplains line the valley sides above the surface of the new floodplain, particularly where the river valley is wide. These older floodplains, called terraces, have flat or nearly flat surfaces and are underlain by river sediments (fig. 20e). Many terraces along the Missouri are covered by reservoirs and thus are no longer visible. Because the Yellowstone has not been dammed, terraces can still be seen along some of its reaches where farming development has not modified them. [Watford City, Culbertson]

Site 18.

"about 1 mile from the point at which place the 2 rivers [the Missouri and the Yellowstone] *are near each other a butifull low leavel plain Commences, and extends up the Missourie & back,...this low plain is not Subject to over flow, appear to be a few inches above high water mark and affords a butifull commanding Situation for a fort...."*

April 26, 1805

Glacial erratics (fig. 71)

Fig. 71. A limestone erratic; adjacent to the parking area at Fort Union Trading Post National Historic Site, Williams County, North Dakota.

From Fort Union Trading Post National Historic Site westward along the Missouri and lower Yellowstone valleys, the glacial deposits contain cobbles and boulders of light gray, hard, and durable limestone. Some of the limestone has been reworked by the rivers and redeposited on river terraces. The rock was brought to this area by ice sheets from Canada, not derived from bedrock at or near the surface in western North Dakota or eastern Montana. If found in sufficient quantities, this rock would make good building stone.[9] [Watford City, Culbertson]

Site 19.

"a suficient quantity of limestone may be readily procured for building near the junction of the Missouri and yellowstone rivers. I could observe no regular stratas of it, tho' it lies on the sides of the river hills in large irregular masses, in considerable quantities;...."

April 26, 1805

MISSOURI RIVER – MONTANA

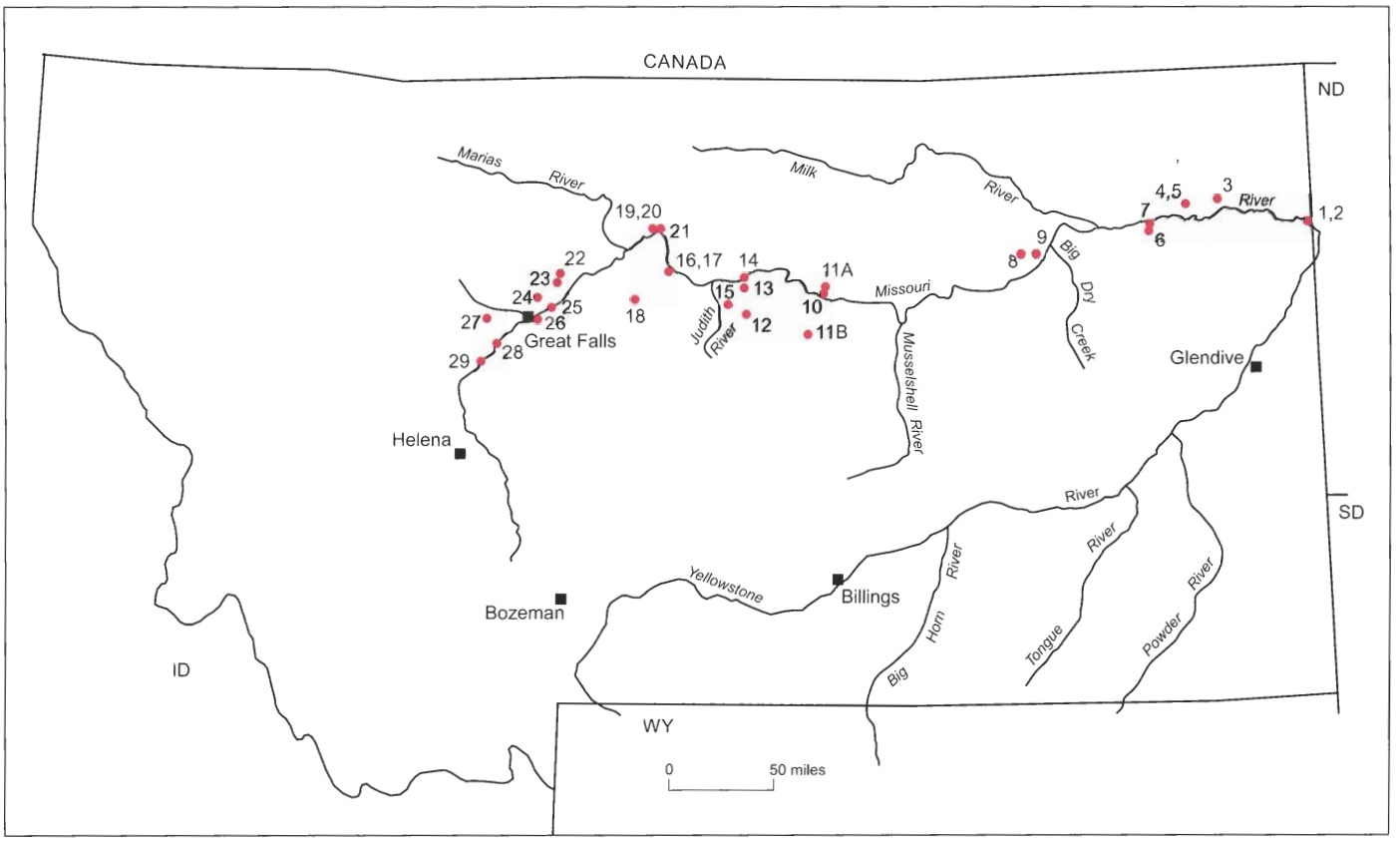


Fig. 72. Montana – Missouri River sites.

Fort Union Formation, Tertiary System-Paleocene Series; bluffs; coal (fig. 73)

Fig. 73. Lignite coal beds (dark seams) in the Fort Union Formation; along the north side of Montana Highway 327, about 4 miles west of Fort Union Trading Post National Historic Site, Richland County, Montana.

The Fort Union Formation crops out extensively along the Missouri River between its confluences with the Yellowstone and the Big Muddy rivers. [47, 50] This formation contains yellow- and brown-colored sandstones, siltstones and claystones, and prominent lignite beds. The Fort Union was deposited in swamps and deltas on the Paleocene coastal plain during the last cycles of the Western Interior Seaway. [13, 15] [Culbertson]

Site 1.

"...the hills & Bluffs Shew the Straturs of Coal,..., in and about them I could find no appearance of Pumice Stone,....the Bluffs in this part as also below Shew... Coloured earth, such as dark brown, yellow a lightish brown, & a dark red &c."

April 28, 1805

Salts
(fig. 74)

Fig. 74. Saline seeps and salts (note white crusts along foot of exposure); along the north side of Montana Highway 327, about 4 miles west of Fort Union Trading Post National Historic Site, Richland County, Montana.

Groundwater from the Fort Union and other formations comes to the surface in springs and seeps, and evaporates, leaving behind white incrustations of mineral salts. These deposits are common across the Great Plains in Montana and pose a significant problem for farmers in the state as soils become increasingly saline. [Culbertson]

Site 2.

"...the salts still increase in quantity; the banks of the river and sandbars are incrusted with it in many places and appear perfectly white as if covered with snow or frost."

April 28, 1805

Treeless plains (fig. 75)

Fig. 75. Treeless plains; near Brockton, Roosevelt and Richland counties, Montana.

The land on the uplands along the Missouri River is covered by glacial till deposits that potentially make good agricultural land. [Culbertson]

Site 3.

"the high country on either side of the river is one vast plain, intirely destitute of timber, but is apparently fertile, consisting of a dark rich mellow looking lome."

May 1, 1805

Bearpaw Shale, Upper Cretaceous System, exposed in an anticline (fig. 76)

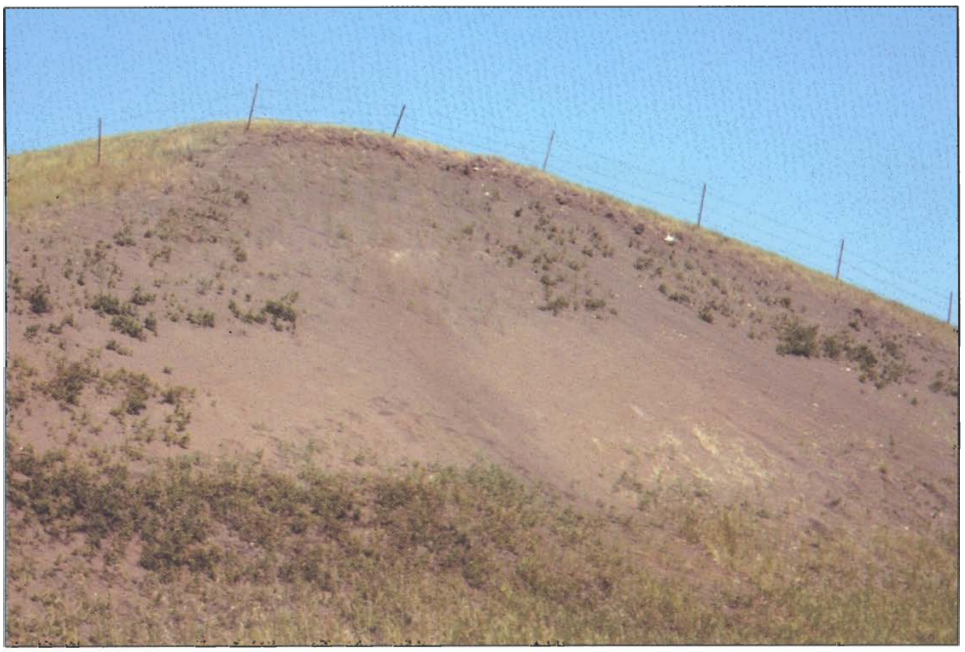


Fig. 76. The Bearpaw Shale in an uplift; about 2 miles north of Poplar, Roosevelt County, Montana, on the Fort Peck Indian Reservation.

A gentle anticlinal fold, called Poplar Dome, brings older Cretaceous dark gray to black shales of the Bearpaw Shale to the surface near Poplar, Montana.[50] These marine shales were deposited in the Cretaceous Western Interior Seaway and contain no coal or other land deposits. Upon exposure, the shales weather into blue or black clays. The upfold has resulted in the younger Paleocene Fort Union Formation being eroded from the top of the anticline and exposing the older rocks down to the Bearpaw (figs. 10, 14). [Wolf Point]

Site 4.

"since the hills have become lower the appearance of the stratas of coal burnt hills and pumice stone have in a great measure ceased; I saw none today....banks and bottoms are formed of a stiff blue and black clay;"

May 3, 1805

Glacial erratics (fig. 77)

Fig. 77. A glacial erratic of limestone with scratches (white lines) caused by contact with other rocks as they were moved along by the ice; north of Poplar, Roosevelt County, Montana, on the Fort Peck Indian Reservation.

Just as in northwestern North Dakota, cobbles and boulders of limestone from Canada occur in glacial tills, outwash deposits, and in river terrace deposits in northeastern Montana.[2] The light gray color and the durable nature of the rock make it easy to discern in pastures and other exposures. [Wolf Point]

Site 5.

"I Saw on the high land limestone & pebble–"
May 3, 1805

River gravels (fig. 78)

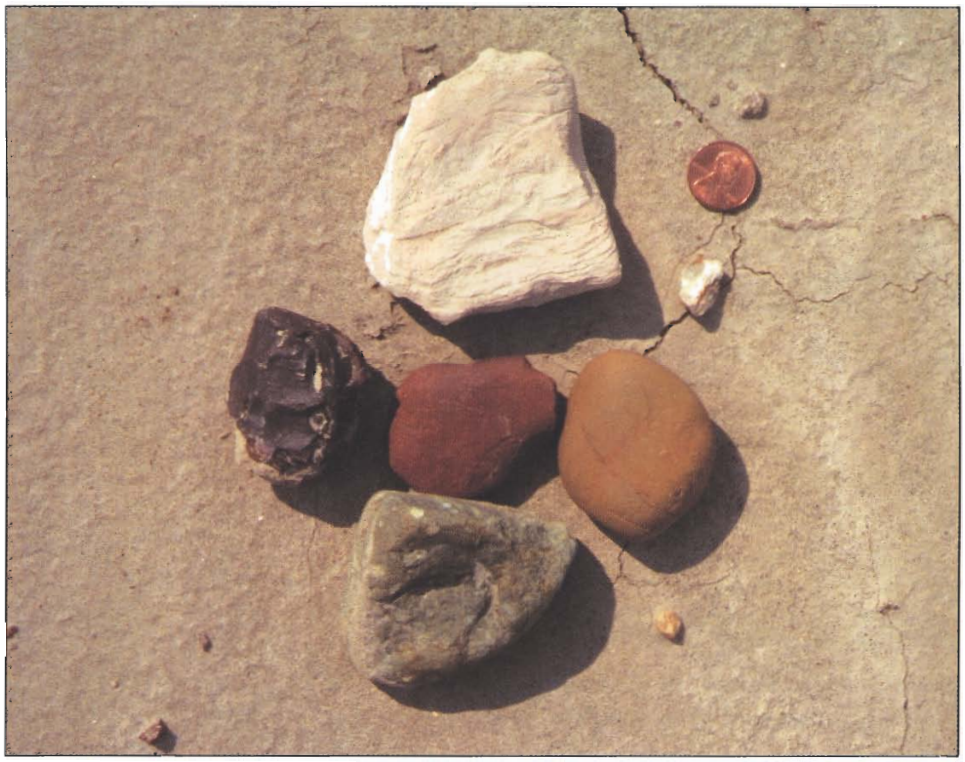


Fig. 78. River gravels of several colors; along Montana Highway 528 south of Wolf Point, McCone County, Montana.

Along the channels of intermittent streams and on the exposed bedrock surfaces on valley sides and uplands, brown to gray sandstones of the Upper Cretaceous Fox Hills Sandstone crop out along the south side of the Missouri River.[50] Pebbles of several different colors, probably washed from the glacial till and from the sandstone, occur on the surface of the sandstones in natural exposures and along road cuts. [Wolf Point]

Site 6.

"...their beds are almost entirely formed of a fine brown sand intermixed with a small proportion of little pebbles, which were either transparent, white, green, red, yellow or brown."

May 6, 1805

Dry creeks; semi-arid plains (fig. 79)

Fig. 79. A dry creek and semi-arid plains, along Montana 528 south of Wolf Point, McCone County, Montana.

There are many intermittent stream tributaries on the south side of the Missouri River in northeastern Montana. The channels of these steams are cut down into bedrock of the Fort Union, Hell Creek, and Fox Hills Sandstone formations. Water flows in most of these stream channels only after heavy rains or snow melts. [Wolf Point]

Site 7.

"...passed two Creeks & a River to day on the Lard. Side, neither of them discharged any water into the Missouri, they were wide and Continued their width for Some distance, the little water of those Creeks & the little river must wash in the low Country on bottoms, I believe those Streams to be the Conveyance of the water of the heavy rains & melting Snows in the Countrey back &c. &c."

May 6, 1805

Glacial erratics (fig. 80)

Fig. 80. Glacial erratics resting on the Bearpaw Shale (center and upper right background); north side of Fort Peck Lake, about 10 miles from end of the road to The Pines Recreation Area, Valley County, Montana.

The Bearpaw Shale is widely exposed between the Missouri and Milk rivers west of their confluence.[50] Cobble- and boulder-size glacial erratics of granite, left on the surface of the shale, are often all that remain of glacial deposits that once covered this area. The finer grained parts of the deposits have been either washed away by water runoff or blown away by winds, leaving only the larger rocks from these deposits behind. [Fort Peck Lake East]

Site 8.

"The country on the Lard. side of the river is generally high broken hills, with much broken, grey black and brown grannite scattered on the surface of the earth in a confused manner."

May 8, 1805

Salts; selenite (fig. 81)

Fig 81. Selenite (light brown crystals on top of soil) in mud-cracked shale; north side of Fort Peck Lake, about 4 miles from end of the road to The Pines Recreation Area, Valley County, Montana.

Crystals of the gypsum variety called *selenite* are common in the Bearpaw and other marine formations that are composed mostly of shale. The crystals were precipitated after deposition and consolidation of the sediments into shale. Water wetting the weathered surface of the shale dissolves some of the selenite and other salts and then reprecipitates these salts at the surface as white crusts. In some pastures, the exposed shale surface is mostly white in color from the presence of these salts. The weathered shales at and near the surface are composed of clay minerals that form slippery "gumbo" soil when wet, and shrink and crack when they dry out. These cracks are conduits along which water moves after rains or snow melts. The water from these events dissolves the salts. [Fort Peck Lake East]

Site 9.

"great appearance of quarts and mineral salts, the latter appears both on the hills and bottoms, in the bottoms of the gullies which make down from the hills it lies incrusting the earth to the debth of 2 or 3 inches, and may with a fether be swept up and collected in large quantities,.... the quarts appears most commonly in the faces of the bluffs. no coal, burnt hills, or pumice stone."

May 11, 1805

Bearpaw Shale over Judith River Formation, Upper Cretaceous System; bluffs (fig. 82)

Fig. 82. The Bearpaw Shale over the Judith River Formation; north side of the Missouri River, just upstream of the U.S. Highway 191 bridge, Fergus County, Montana.

The dark gray-to-black marine Bearpaw Shale overlies the terrestrial sandstones and shales of the Judith River Formation along this reach of the Missouri River.[50] The rocks of the Judith River Formation were deposited on a coastal plain during the latter part of the fourth major cycle of the Cretaceous Western Interior Seaway, the Claggett Cycle, and the beginning of the fifth cycle. The clay-rich shales of the Bearpaw were deposited offshore in the Cretaceous Western Interior Seaway as sea level rose. The Bearpaw Cycle is the fifth major cycle of the Seaway.[38] [Zortman]

Site 10.

"The country high and broken, a considerable portion of black rock and brown sandy rock appear in the faces of the hills; the tops of the hills covered with scattering pine spruce and dwarf cedar; the soil poor and sterile, sandy near the tops of the hills, the whole producing but little grass...."

May 24, 1805

Uplift; Little Rocky, Bears Paw and Judith Mountains (fig. 83)

Fig. 83. An uplift, part of the Judith Mountains (in the background); looking southwest from Montana Highway 19, 5.5 miles south of U.S. Highway 191, Fergus County, Montana. [Winnett, Lewistown]

Both Lewis and Clark frequently walked up out of the Missouri Valley to observe the land. On this day, Clark recognized that the mountains he saw to the north, northwest and south were not the main part of the Rocky Mountains because they were isolated peaks and not continuous (figs. 10e, 14). In fact, these mountains are anticlinal uplifts raised up during the early Tertiary Period by igneous magmas forcing their way toward the surface from deep inside the Earth.[2, 12a] [Zortman]

Site 11.

"In my walk of this day I saw mountts. on either side of the river at no great distance, those mountains appeared to be detached, and not ranges...."

May 25, 1805

Dry creeks; semi-arid plains; salts (fig. 84)

Fig. 84. Salt crusts edging a pond; along Montana Highway 236, about 3 miles south of Winifred, Fergus County, Montana.

Away from the Missouri River, intermittent streams become more or less perennial. The water in these streams is highly mineralized with salts, which accumulate on the surface adjacent to ponds formed behind small dams. [Winifred]

Site 12.

"...it affords no water at its mouth but has runing water at some small distance above, this I beleive to be the case with many of those creekes which we have passed since we entered this hilley country, the water is absorbed by the earth near the river and of course appear dry; they afford but little water at any rate, and that is so strongly impregnated with these salts that it is unfit for uce...."

May 23, 1805

Judith River Formation over Claggett Shale, Upper Cretaceous System (figs. 85, 86)

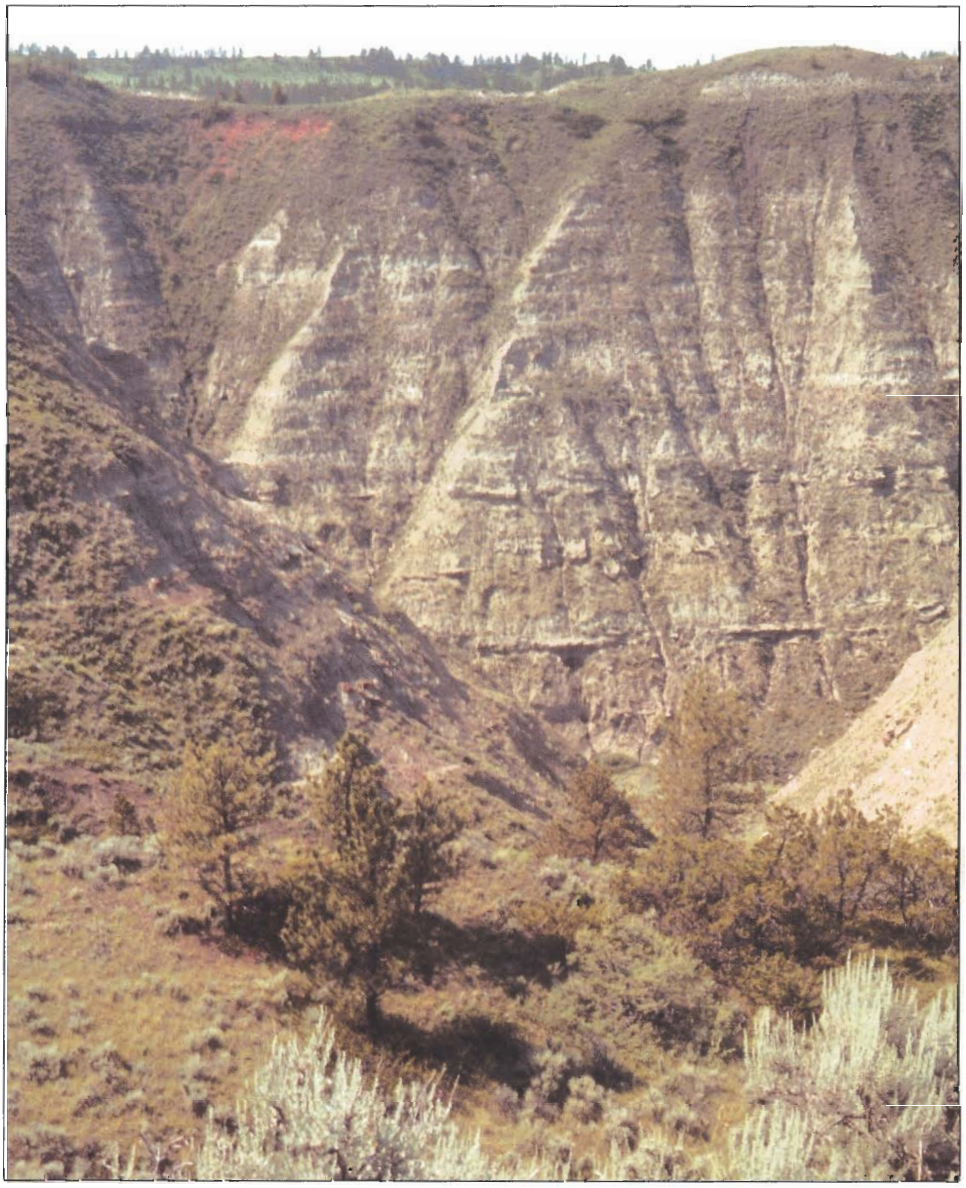


Fig. 85. The Judith River Formation with red scoria near the top (upper left); along the road to Stafford Ferry, about 13 miles north of Winifred, Fergus County, Montana. This road can be dangerous. The grades are very steep; it becomes slippery when only slightly wet.

The Judith River Formation is exposed above the Claggett Shale in the upper parts of the valley sides on the east side of the Judith River and its tributaries and along the Missouri River.[50] The Judith River Formation was deposited on a coastal plain and in deltas marginal to the Cretaceous Western Interior Seaway.[29] From time to time, sea level rose, flooding the area and leaving behind concentrated accumulations of shells of bivalves that were preserved as fossils cemented into rock. Most of the Judith River Formation is brown to

Site 13.

"The country which borders the river is high broken and rocky, generally imbeded with a Soft Sand Stone higher up the hill the Stone is of a brownish yellow hard and gritty those Stones wash down from the hills into the river and cause the Shore to be rocky &c. which we find troublesom to assend there is Scerce any bottom between the Hills & river and but a fiew trees to be Seen on either Side except Scattering pine on the Sides of the emence hills...."

May 26, 1805

Fig. 86. Fossil clam shells from the Judith River Formation.

yellow sandstone and shale. It also includes lignite coal beds and the red clinker or scoria, which the explorers called *pumice stone*, but which formed when coal burns. Spherically shaped, iron-oxide-cemented concretions occur in parts of the formation. The underlying Claggett Shale is a dark gray-to-black marine deposit. White layers of altered volcanic ash called *bentonite* occur in the Claggett in this area. The Claggett and the Judith River were deposited during the Claggett and Bearpaw cycles, the fourth and fifth major cycles of sea-level rise and fall of the Cretaceous Western Interior Seaway. [38] [Winifred]

Site 13.

"the black rock has given place to a very soft sandstone which appears to be washed away fast by the river, above this and towards the summits of the hills a hard freestone of a brownish yellow colour shews itself in several stratas of unequal thicknesses frequently overlain or incrusted by a very thin strata of limestone which appears to be formed of concreted shells.... The appearances of coal in the face of the bluffs, also of birnt hills, pumice stone salt and quarts continue as of yesterday."

May 26, 1805

Shoals and rapids; alluvial fans (fig. 87)

Fig. 87. Shoals, rapids, and an alluvial fan (at the right center of the photograph); at Dauphine Rapids, about 0.5 miles downstream of Stafford Ferry; north of Winifred, Fergus County, Montana. The ferry crosses the river in the center background. The road to this area can be dangerous. The grades are very steep; it becomes slippery when only slightly wet.

Sandstone bedrock comes to the surface at the base of some parts of the Missouri River channel in this area. Runoff water from tributaries to the Missouri also carries sediments, including cobbles and boulders of sandstone, down the valley sides and deposits them in the river from time to time after heavy rains or large melts of snow. This rock debris forms fans at the mouths of the tributaries that project out into the Missouri. Rocks reworked from these fans are carried out into the main river channel and deposited on its floor, producing shoals and rapids. [Winifred]

Site 14.

"The river is verry Shoaley and the bad places are verry numerous, i e at the mouth of every Drean the rocks which is a hard gritey Stone is thrown out Some distance in the river which Cause a Considerable riffle on that Side...."

May 27, 1805

The Missouri Breaks (fig. 88)

Fig. 88. Looking north across the plains into the Missouri Breaks; Montana Highway 236 about 10 miles south of the bridge at the mouth of the Judith River, north of Winifred, Fergus County, Montana.

The valley sides of the Missouri are increasingly high and eroded with many steeply sloping tributaries cutting back irregularly into the adjacent plains. This area is called the Missouri Breaks. [Winifred]

Site 15.

"the countrey more broken and barren than yesterday, if possible."

May 27, 1805

Virgelle Sandstone Member of the Eagle Sandstone; Upper Cretaceous System; bluffs (fig. 89)

Fig. 89. The Virgelle Sandstone Member of the Eagle Sandstone; White Cliffs area, Chouteau County, Montana.

The White Cliffs area begins in the Missouri Breaks west of the Judith River and continues along the Missouri River upstream to the vicinity of Virgelle, Montana. Prominent in this area is the Virgelle Sandstone Member of the Eagle Sandstone.[29] This formation is spectacular because it appears very white in full sunshine. The white color comes from the cement holding the sand grains together. After the miles of dark-colored rock that they had encountered across Montana, it is easy to see why the white sandstone caught the eyes of the explorers. Lewis and Clark observed how runoff from rains wore away the soft sandstone and shaped it into remnants that looked like towers and statuary decorating the walls of ancient buildings. This formation is a coastal deposit laid down during the third major cycle of the Cretaceous Western Interior Seaway, the Niobrara Cycle.[38] [Fort Benton]

The White Cliffs area is located about 29 miles east of Fort Benton, Montana. The route by land is on private property, accessible only by permission of the property owners or by escorted land tour, if one is available. The route by water is part of the Upper Missouri National Wild and Scenic River. Professional outfitters offer services ranging from fully guided river trips to equipment rental and vehicle shuttling.

An outcrop of the Virgelle Sandstone can be seen on the north side of Montana State Highway 80, about 2.3 miles southeast of Square Butte, Chouteau County, Montana. [Belt]

Site 16.

"The bluffs of the river rise to the hight of from 2 to 300 feet and in most places nearly perpendicular; they are formed of remarkable white sandstone which is sufficiently soft to give way readily to the impression of water; two or thre thin horizontal stratas of white free-stone, on which the rains or water make no impression, lie embeded in these clifts of soft stone near the upper part of them.... The water in the course of time in decending from those hills and plains on either side of the river has trickled down the soft sand clifts and woarn it into a thousand grotesque figures...."

May 31, 1805

Igneous dikes and sills (fig. 90)

Fig. 90. Black igneous intrusions; White Cliffs area, Chouteau County, Montana. Dikes are the linear vertical structures in the center foreground and background; sills are the dark horizontal layers in the bluff on the far side of the river that resemble beds of sedimentary rock.

In the White Cliffs area, dikes and sills of black crystalline igneous rock of Eocene age intrude into older Cretaceous rocks.[2] When Clark described these layers as walls of rock that continue their course into the "Sand Clifts," he was giving an example of the Principle of Cross-cutting Relationships (figs. 2, 10). The igneous rock cuts across the older sedimentary rocks and is younger than those it cuts across. The igneous rock is harder and more durable than the sedimentary rocks and is left behind as high rock walls after weathering and erosion have affected the area. [Fort Benton]

The White Cliffs area is located about 29 miles east of Fort Benton, Montana. The route by land is on private property, accessible only by permission of the property owners or by escorted land tour, if one is available. The route by water is part of the Upper Missouri National Wild and Scenic River. Professional outfitters offer services ranging from fully guided river trips to equipment rental and vehicle shuttling.

Dikes can be seen to the southwest from Montana State Highway 80, 3 miles south of Geraldine, Chouteau County, Montana; and in the nearby Highwood Mountains, Chouteau and Judith counties, Montana. [Fort Benton]

Site 17.

"in maney places of this days march we observe on either Side of the river extraodanary walls of black Semented Stone which appear to be regularly placed one Stone on the other, Some of those walls run to the hite of 100 feet, they are from about 1 foot to 12 feet thick and are perpendicular, those walls Commence at the waters edge & in Some places meet at right angles–those walls appear to continue their Course into the Sand Clifts...."

May 31, 1805

Salts
(fig. 91)

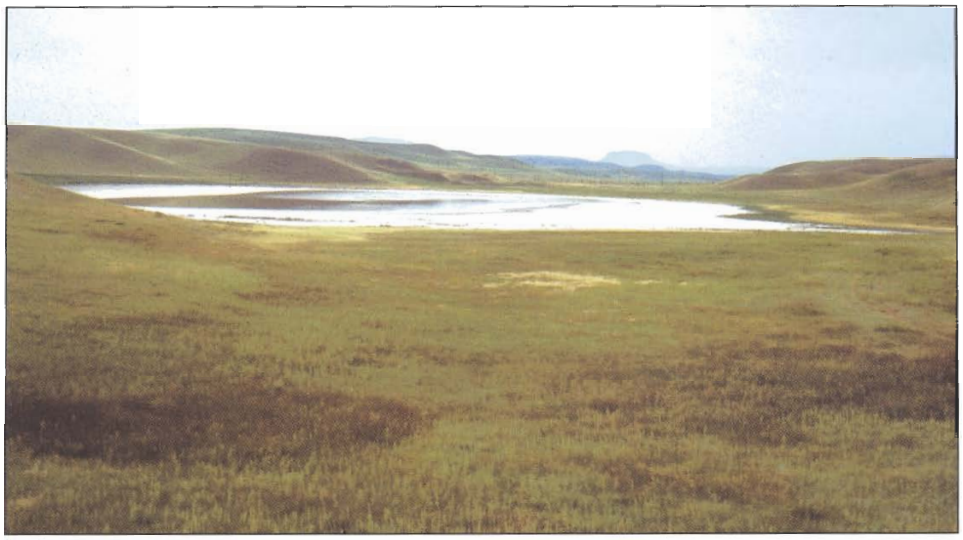


Fig. 91. Salts on the shore of a saline lake; southwestern side of Montana Highway 80, about 16.5 miles southeast of Fort Benton, Chouteau County, Montana.

Numerous intermittent lakes dot the Great Plains in this part of Montana adjacent to the Missouri Valley. When their waters evaporate, salts are left behind in the form of white lake bed sediments. [Fort Benton]

Site 18.

"the mineral salts have in some measure abated...."

May 31, 1805

Mud-cracked clay; slippery clay soils (fig. 92)

Fig. 92. Mud cracks in weathered clay; Coal Banks Landing State Recreation Area, near Virgelle, Chouteau County, Montana.

Glacial tills and the fine-grained Cretaceous and Paleocene deposits across the Great Plains in Montana contain high proportions of clay minerals that swell when wet, and shrink and crack when water evaporates from them. When rain falls on them or snow melts, the water does not readily pass through the clays and often wets only a few inches to a foot at the top of the deposit. This wet clay, called *gumbo*, is very slippery and adheres to boots, vehicle tires, and other objects passing across it. [Lonesome Lake]

Site 19.

"...added to this the banks and bluffs along which they are obliged to pass are so slippery and the mud so tenacious that they are unable to wear their mockersons...."

May 31, 1805

Coal
(fig. 93)

Fig. 93. Thin beds of coal (darker beds near middle of exposure) in the Telegraph Creek Formation; Coal Banks Landing State Recreation Area, near Virgelle, Chouteau County, Montana.

Above the Colorado Group, the Late Cretaceous Telegraph Creek Formation contains some thin coal beds.[50] These coals were deposited as plant debris in swamps on coastal plains during the third major cycle of the Cretaceous Western Interior Seaway, the Niobrara Cycle.[38] [Lonesome Lake]

Site 20.

"some coal appear in the bluffs."

June 1, 1805

River gravel
(fig. 94)

Fig. 94. River gravel in a field; about 1 mile east of Coal Banks Landing State Recreation Area, near Virgelle, Chouteau County, Montana.

Gravel from the river, its tributaries, and that reworked from glacial deposits is often well rounded. It was rolled by running water during at least part of its history and rounded by abrasion during contact with other pieces of gravel. [Lonesome Lake]

Site 21.

"...the surface of the earth is very generally covered with small smothe pebbles which have the appearance of having been woarn by the agitation of the waters in which they were no doubt once immerced."

June 1, 1805

Ponds on a till plain (fig. 95)

Fig. 95. Ponds on a till plain; along Carter Road W, 6 miles west of U.S. Highway 87, west of Fort Benton and northwest of Floweree, Chouteau County, Montana.

When ice sheets melt back more or less continuously, they leave behind land covered with a layer of glacial till of varying thickness. Initially, the till lacks a well-established drainage network, and so the low spots hold water in the form of lakes and ponds. Lewis noticed these ponds on the return journey, while he was travelling overland north from the Great Falls to seek the headwaters of the Marias River. [Great Falls North]

Site 22.

"...the little ponds which are distributed over the face of these plains...."

July 17, 1806

Treeless plains
(fig. 96)

Fig. 96. Treeless plains; along Antelope Lake Road, just north of U.S. Highway 87; southwest of Fort Benton and west of Floweree, Chouteau County, Montana.

As the ice sheets of the Wisconsinan glaciation melted back, they left behind a till plain with a rolling, undulating surface. On this part of the Great Plains in 1806, the land would have been treeless and covered mostly by grasses, just as the uncultivated areas are today. Lewis made this observation upon his return to the plains from the mountains, while he was travelling overland north from the Great Falls to seek the headwaters of the Marias River. [Great Falls North]

Site 23.

"I steered my course through the wide and level plains which have somewhat the appearance of an ocean, not a tree nor a shrub to be seen."

July 17, 1806

Erosional remnants; buttes (fig. 97)

Fig. 97. Buttes south of Black Horse Lake (far background); on the east side of U.S. Highway 87, north of Great Falls, Cascade County, Montana.

Erosional remnants of Cretaceous rock form buttes south of Black Horse Lake. They were not eroded away by the ice sheets during the Ice Ages. [Great Falls North]

Site 24.

"...two curious mountains presented themselves of square figures, the sides rising perpendicularly to the hight of 250 feet and appeared to be formed of yellow clay; their tops appeared to be level plains...."

June 13, 1805

Falls
(figs. 98, 99)

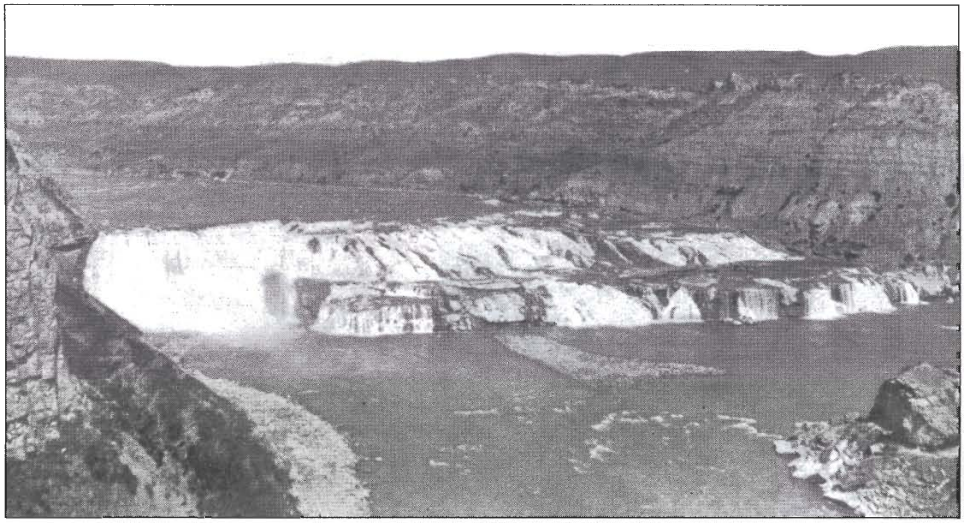


Fig. 98. The Great Falls in 1906. From Calhoun.[12]

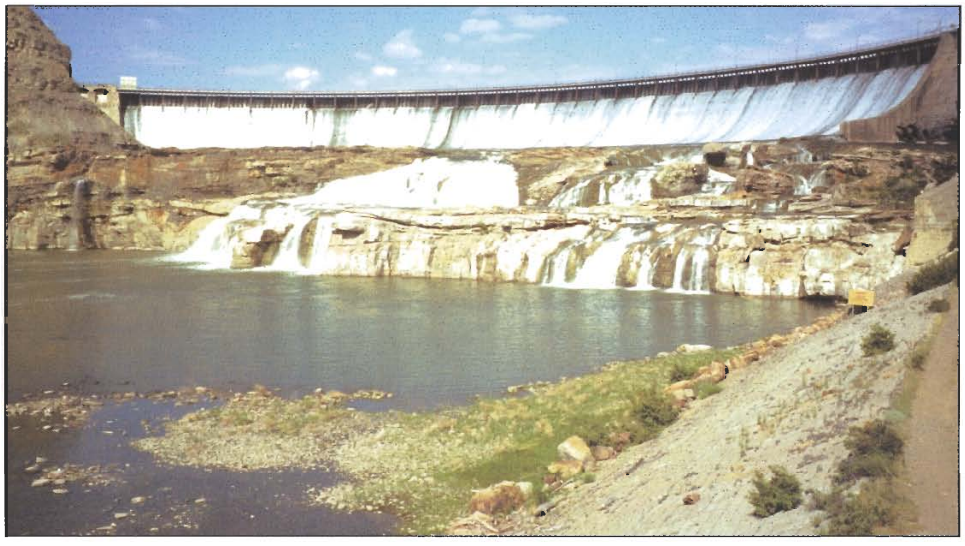


Fig. 99. The Great Falls and Ryan Dam in 2002; northeast of Great Falls, Cascade County, Montana.

The first of five falls encountered by Lewis, known as the Great Falls, was about 75 feet high. All of the falls are now the sites of hydroelectric dams, their former beauty subdued by this construction. Their steep and rocky walls are in the Lower Cretaceous Kootenai Formation, deposited on a coastal plain during the second major cycle of the Cretaceous Western Interior Seaway, the Greenhorn Cycle.[38] Here, the Missouri is geologically a very young river that has eroded back and deepened its valley until it encountered the harder sandstone rocks of the Kootenai. The strata of this formation are not uniformly hard, and so there are falls at each of the more durable exposures of rock.[23] [Great Falls North]

Site 25.

"...the grandest sight I ever beheld,...projecting rocks below receives the water in it's passage down and brakes it into a perfect white foam which assumes a thousand forms in a moment.....the river was one continued sene of rappids and cascades...and the Clifts still retained their perpendicular structure and were from 150 to 200 feet high; in short the river appears here to have woarn a channel in the process of time through a solid rock."

June 13, 1805

Freshwater spring (fig. 100)

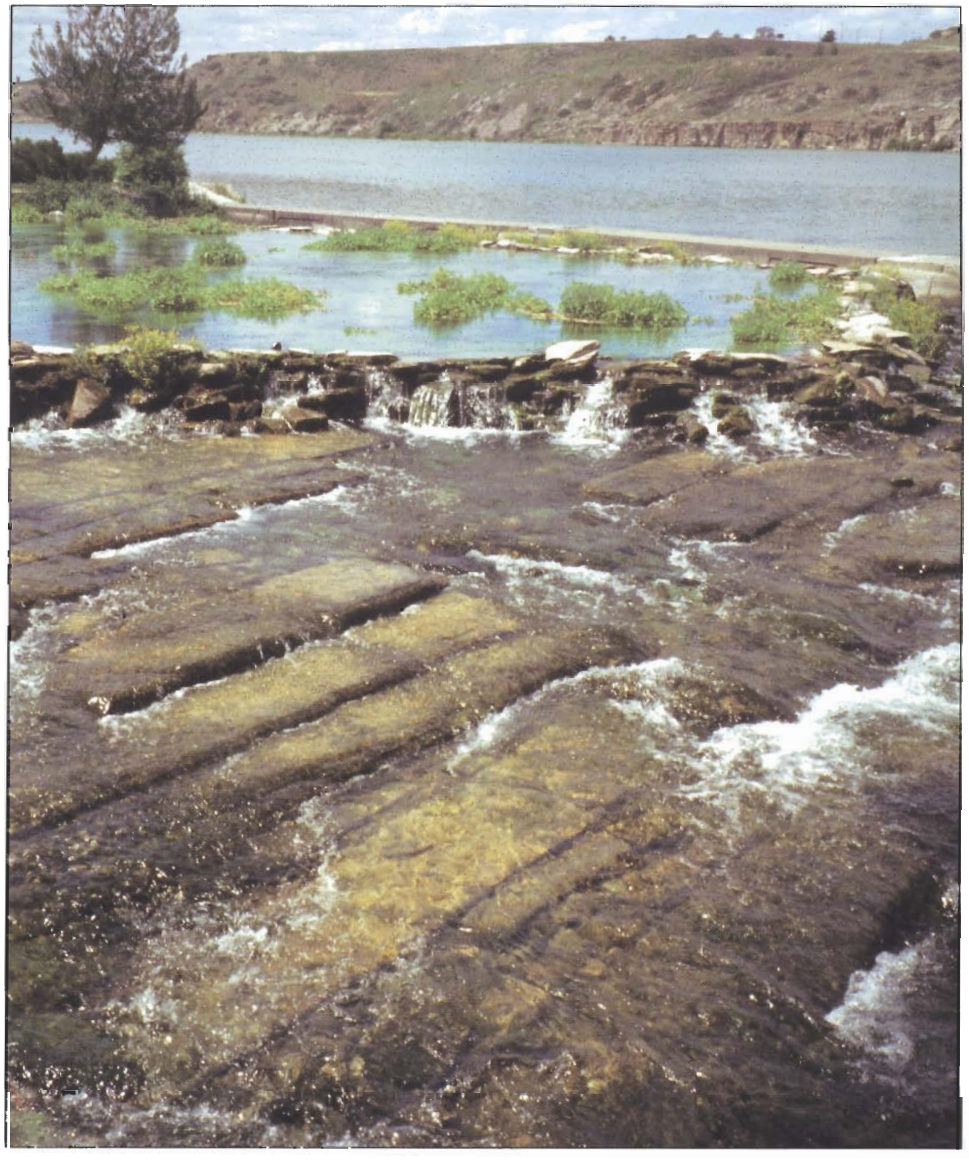


Fig. 100. The Giant Springs; Giant Springs Park, Great Falls, Cascade County, Montana.

Giant Springs is on the south side of the Missouri River at the eastern end of the present city of Great Falls, Montana. At the spring, water surfaces along fractures in the sandstone of the Lower Cretaceous Kootenai Formation. Geologists believe that the water is actually moving through underground cavern systems in the geologically much older Madison Limestone of Mississippian age, from sites in the Rocky Mountains to the Great Falls area. The water, under hydraulic head at Great Falls, is forced to the surface along the joints in the Kootenai and older rocks above the Madison. Giant Springs is the largest freshwater spring along the Missouri and one of the largest in the United States. [Great Falls North]

Site 26.

"...the largest fountain or Spring I ever Saw, and doubt if it is not the largest in America Known, this water boils up from under th rocks near the edge of the river and falls imediately into the river 8 feet and keeps its Colour for 1/2 a mile which is emencely Clear and of a bluish Cast...."

June 18, 1805

Erosional remnant; butte (fig. 101)

Fig. 101. Square Butte; north side of the Missouri River, south of Fort Shaw, Cascade County, Montana.

Square Butte, called *Fort Mountain* by Lewis, is capped with igneous rock.[2] The igneous rock resists erosion and has helped to retard the destruction of the butte by the effects of exposure to weather. [Great Falls South]

Site 27.

"we have now passed Fort Mountain on our right....it is situated in a level plain, it's sides stand nearly at right angles with each other and are each about a mile in extent. these are formed of a yellow clay...and rise perpendicularly to the hight of 300 feet. the top appears to be a level plain and...covered with a similar cost of grass with the plain on which it stands....from it's figure we gave it the name of forrt mountain. those mounds before mentioned [site 24] *near the falls have much the same appearance but are none of them as large as this one."*

July 15, 1805

Meanders, cut-offs, ox-bow lakes (fig. 102)

Fig. 102. A meander with Square Butte in the background; Montana Highway 330 about 10 miles south of Ulm, Cascade County, Montana.

Southwest of the city of Great Falls, Montana, the Missouri Valley is wide and not very deep. The river has short and frequent meanders with cutoffs and oxbow lakes on its floodplain. Although not as large a river here, in this area the Missouri resembles its undammed part along the Nebraska border more than it does most of the remainder of its course from Nebraska to Great Falls across the Great Plains. Roads on either side of the river offer good views. [Great Falls South]

Site 28.

"we find it inconvenient to take all the short meanders of the river which has now become cooked and much narrower than below...."

July 15, 1805

Boundary between the Great Plains and the mountains; erosional remnant; abandoned channel (fig. 103)

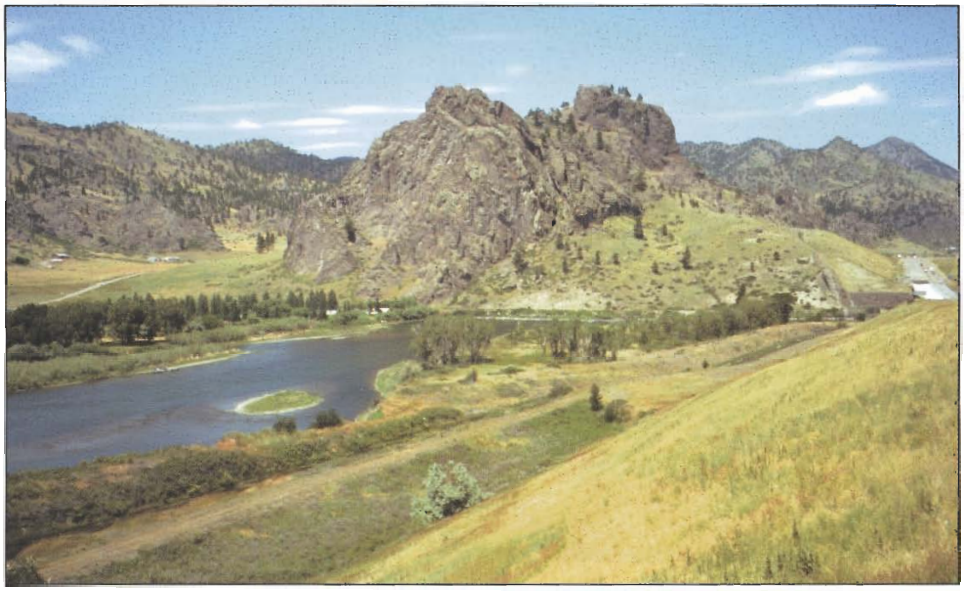


Fig. 103. Where the Missouri River exits the mountains; looking downstream from U.S. Interstate Highway 15, just southwest of Hardy, Cascade County, Montana. The Missouri River in the foreground passes the "tower" rock at the far right of the photograph, flowing toward the Great Plains that are not in view. Part of the "handsome little plain," the abandoned channel, is visible to the left of the rock.

The Adel Mountains are a volcanic area near Hardy, Montana. Although they abut the Northern Rocky Mountains, the Adels are younger and not truly a part of these older mountain chains beyond.[2] Unaware of the ages of these rocks, nevertheless, Lewis recognized that he was no longer on the plains.

An erosional remnant of the Adel volcanics is located in the Missouri Valley at Hardy. Lewis estimated its height at 400 feet, a figure that is confirmed by the U.S. Geological Survey topographic map of the area. The Missouri River flows against this rock on its southwestern side. The "handsome little plain which surrounds its base on 3 sides" is the location of the former channel of the Missouri that has since been abandoned for the present one. [Great Falls South]

Site 29.

"...we pursued our rout through a high roling plain to a rappid immediately at the foot of the mountain where the Missouri first enters them....these mountains appear to be only about 800 feet above the river.... at this place there is a large rock of 400 feet high wich stands immediately in the gap which the missouri makes on it's passage from the mountains; it is insulated from the neighbouring mountains by a handsome little plain which surrounds it base on 3 sides and the Missouri washes it's base on the other, leaving it on the Lard. as it decends. this rock I called the tower. it may be ascended with some difficulty nearly to it's summit, and from it there is a most pleasing view of the country we are now about to leave. from it I saw this eveing immence herds of buffaloe on the plains below."

July 16, 1805

YELLOWSTONE RIVER – MONTANA-NORTH DAKOTA

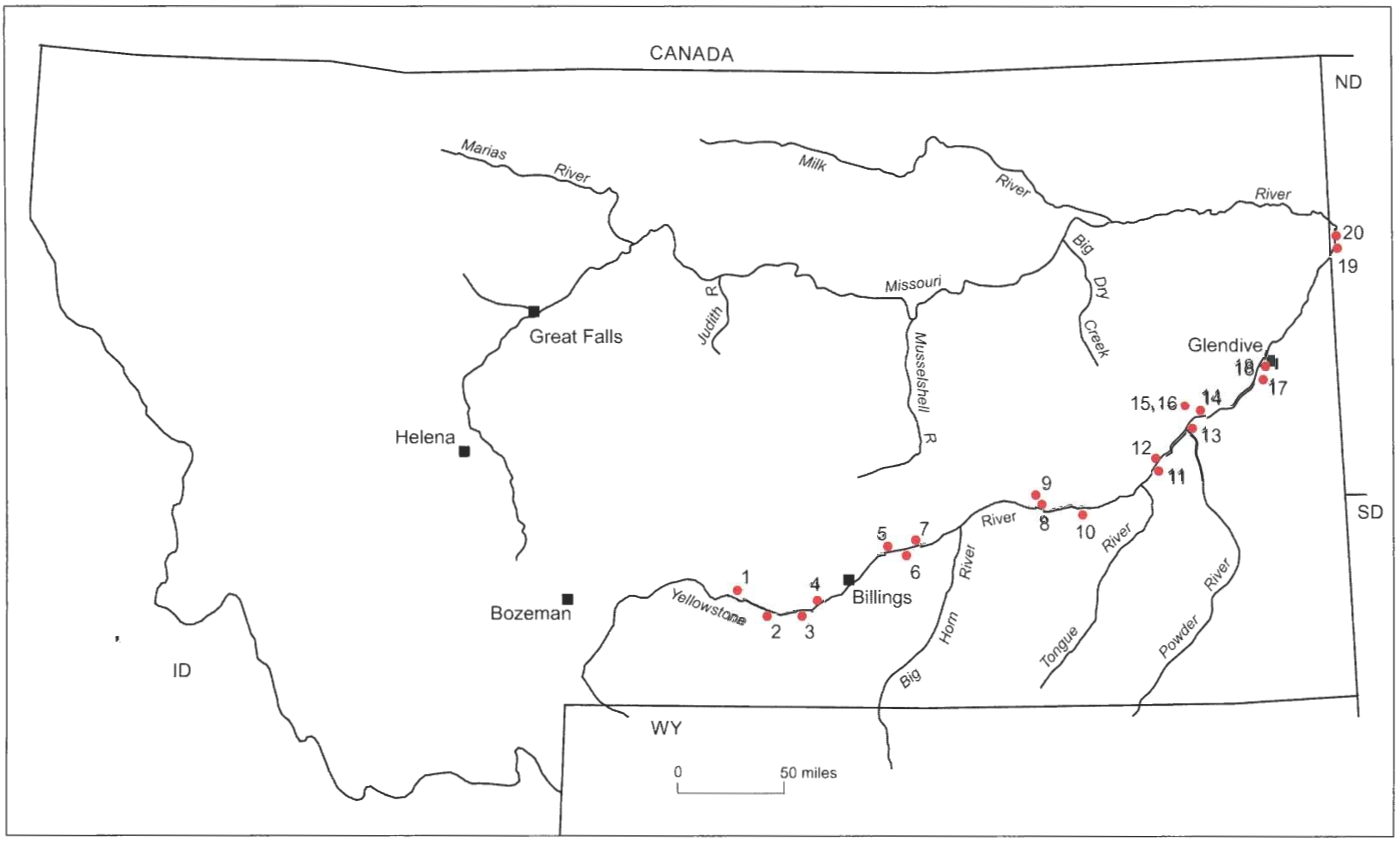


Fig. 104. Montana and North Dakota – Yellowstone River sites.

River terrace and gravel bars; Hell Creek Formation, Upper Cretaceous System; bluffs (figs. 105, 106)

Fig. 105. A river terrace and gravel bars on the north side of the Yellowstone River; Indian Fort River Access, 0.5 miles west of Reed Point, Stillwater County, Montana.

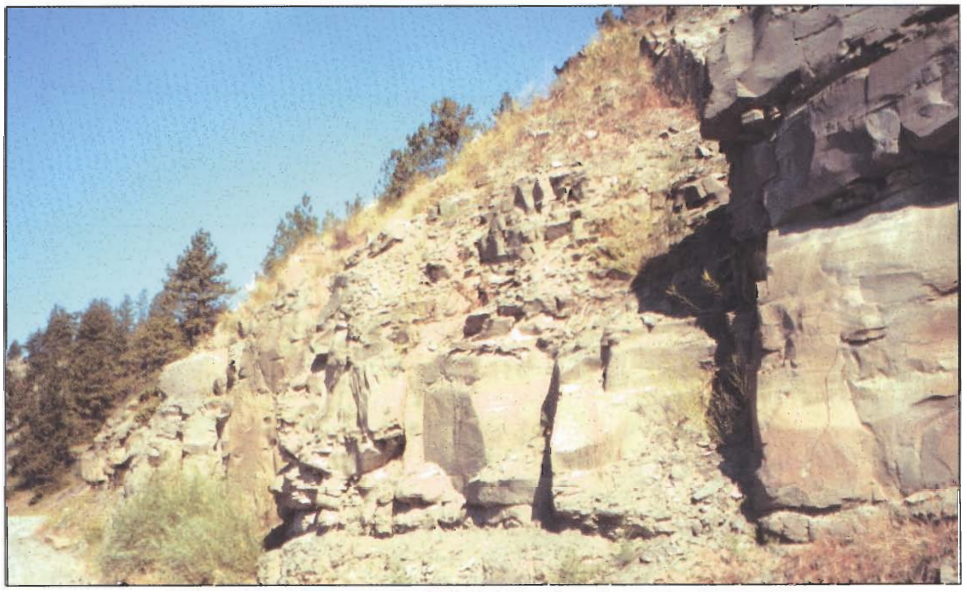


Fig. 106. Sandstone in the Hell Creek Formation on the north side of the Yellowstone River; Indian Fort River Access, 0.5 miles west of Reed Point, Stillwater County, Montana.

River terraces marking the positions of former floodplains are commonly preserved along the Yellowstone River (fig. 20e). The composition of the sand and gravel on these terraces is similar to that of the sediment carried in the river. Cobbles and even some boulders are present in the gravel. Almost all are well rounded. The present floodplain is underlain by the same kinds of river sands and gravel. The bedrock exposed here along the valley side is brown sandstone of the Upper Cretaceous Hell Creek Formation. This formation was deposited on a broad coastal plain during the fifth and last regressive cycle of the Cretaceous Western Interior Seaway, the Bearpaw Cycle.[38] [Big Timber]

Site 1.

"The river here...rapid as usial and the water gliding over corse gravel and round Stones of various sizes of an excellent grite for whet-stones....the hills...are generally rocky and composed of rocks of the same texture of a dark Colour of Grit.... The high bottoms is composed of gravel and Stone like those in the Chanel of the river...."

July 18, 1806

Virgelle Sandstone Member of the Eagle Sandstone, Upper Cretaceous System; bluffs (fig. 107)

Fig. 107. The Virgelle Sandstone Member of the Eagle Sandstone on the south side of the Yellowstone River; Montana Highway 421, 8-10 miles southeast of Columbus, Stillwater County, Montana.

The Cretaceous sandstone beds in this area along the Yellowstone weather into soils with a dark yellow color.[50] To the general observer, this sandstone looks much like almost every other sandstone formation exposed along the Yellowstone River. Only careful field work has allowed geologists to separate these formations from one another. The Virgelle Sandstone was deposited on a coastal plain during the third major cycle of the Cretaceous Western Interior Seaway, the Niobrara Cycle.[38] [Big Timber]

Site 2.

"The high lands...of the Stard Side form Bluffs of a darkish yellow earth;"
July 17, 1806

Colorado Group, Upper Cretaceous System, exposed in an uplift (fig. 108)

Fig. 108. Black shale in the upper part of the Colorado Group in an uplift on the south side of the Yellowstone River; 2.5 miles southeast of Park City, Stillwater and Carbon counties, Montana.

Some deformation in the area has brought older dark gray to black marine shales of the Upper Cretaceous Colorado Group to the surface (fig. 10). They are exposed in cut banks along the river for a short distance.[50] Sandstones of the younger Telegraph Creek Formation crop out higher on the valley side above the shale. As is true of the sandstones, many of the black shale formations look alike. Only by careful observation, by following the exposed formations across the land surface, and by accurately mapping their areas of exposure have geologists been able to separate these formations one from another. The upper part of the Colorado Group was deposited during the third major cycle of the Cretaceous Western Interior Seaway, the Niobrara Cycle.[38] [Billings]

Outcrops of the shale can be seen along U.S. Interstate Highway 94 on the south side of the Yellowstone River from about 1 mile west of Park City, Montana, for about 2 miles; and also at Billings, Interstate 94, exit 450.

Site 3.

"one Chanel of the river passes under a high black bluff.....to the enterance of a brook on the Stard. Side. passing at the foot of a high black bluff bank on the Stard. Side"
July 24, 1806

River terraces (fig. 109)

Fig. 109. Terrace gravels on the north side of the Yellowstone River; about 2 miles northeast of Laurel, Stillwater County, Montana.

In this area are river terraces with many rounded pebbles and cobbles of river gravel at the surface (fig. 20e). [Billings]

Site 4.

"the plains are butifull and leavel but the Soil is but thin Stoney."

July 21, 1806

Bearpaw Shale, Upper Cretaceous System; bluff (fig. 110)

Fig. 110. The Bearpaw Shale on the north bank of the Yellowstone River; Gritty Stone Fishing Access, north of Worden, Yellowstone County, Montana.

The dark gray to black Bearpaw Shale is exposed along the banks of the river.[50] The Bearpaw is the marine shale that was deposited in the fifth major cycle of the Cretaceous Western Interior Seaway, the Bearpaw Cycle.[38] [Billings]

Site 5.

"to a low black bluff on the Lard. Side...."

July 25, 1806

Erosional remnant; butte (fig. 111)

Fig. 111. Pompey's Pillar on the south side of the Yellowstone River; about 28 miles northeast of Billings, Montana, near the village of Pompeys Pillar, Yellowstone County, Montana.

Clark called this butte *Pompy's Tower*, after his nickname for Sacagawea's little son. Clark also carved his name and the date on the side of the butte, an inscription that has been preserved and can be seen today. Although the floodplain of the Yellowstone is mostly to the south of this feature, the present river channel is located between the butte and low sandstone bluffs to the north. Known today as *Pompey's Pillar*, it continues to erode and will ultimately be worn away by the actions of water, wind, and animals. The butte is composed of sandstone that is part of the Upper Cretaceous Hell Creek Formation.[50] The Hell Creek was deposited on a coastal plain during the fifth and last regressive cycle of the Cretaceous Western Interior Seaway, the Bearpaw Cycle.[38] [Billings]

Site 6.

"...a remarkable rock Situated in an extensive bottom on the Stard. Side of the river.... This rock which I shall call Pompy's Tower is 200 feet high and 400 paces in secumphrance and only axcessable on one Side which is from the N. E the other parts of it being a perpendicular Clift of lightish Coloured gritty rock on the top there is a tolerable Soil of about 5 or 6 feet thick Covered with Short grass."

July 25, 1806

Fossil in the Hell Creek Formation, Upper Cretaceous System (fig. 112)

Fig. 112. The approximate location where Clark found a vertebrate fossil in the Hell Creek Formation, on the north side of the Yellowstone River; view from Montana Highway 312, near the mouth of Cow Gulch, about 3.5 miles northeast of the village of Pompeys Pillar, Yellowstone County, Montana.

Clark found "pieces of the rib of a fish" in the rock in this area. He collected no specimens. From their size and the formation in which he found them, however, the fossil remains were more likely those of a dinosaur than of a fish. The Hell Creek Formation, laid down on a coastal plain, is noted for its dinosaur fossils. [Hysham]

Makoshika State Park, southeast of Glendive, Dawson County, Montana, is an excellent place to see dinosaurs and other fossils from the Cretaceous Hell Creek Formation, as well as fossils from the younger Paleocene Fort Union Formation.

Site 7.

"...I employed my Self in getting pieces of the rib of a fish which was Semented within the face of the rock this rib...is 3 feet in length tho a part of the end appears to have been broken off I have Several peces of this rib the bone is neither decayed nor petrified but very rotten. the part which I could not get out may be Seen...in the face of the Lard. Clift about 20 feet above the water."

July 25, 1806

Point bars and meanders (fig. 113)

Fig. 113. The meander in the center middle ground (across the river) has been cut off by the present river. A point bar (left arrow) is just to the left of the light-colored sand. Point bars and meander cut-offs (right arrow) can be seen along the frontage road between Montana Highway 39 and Forsyth, Rosebud County, Montana.

The Yellowstone, like the Missouri, meanders, leaving behind in places point bars on the inside of meander curves and cut banks on the outside where the water currents are faster (fig. 20d). [Forsyth]

Site 8.

"it's [Bighorn River] *Current is regularly Swift, like the Missouri, it washes away its banks on one Side while it forms extensive Sand bars on the other."*

July 26, 1806

Erosional remnant; butte (fig. 114)

Fig. 114. Buttes on the north side of the Yellowstone River; from U.S. Highway 12, about 5.5 miles northwest of Forsyth, Rosebud County, Montana. They can also seen from the frontage road between Montana Highway 39 and Forsyth.

The Upper Cretaceous Hell Creek Formation has many beds of harder sandstone sandwiched between softer beds of siltstone and claystone.[31] When the harder rock caps buttes, they may be eroded into shapes resembling houses when seen from a distance. In this case, a smaller remnant-capping sandstone layer over softer rock is preserved as a feature resembling a chimney on top of the house-shaped sandstone butte. The rocks below the house-shaped butte are generally soft and have the shape of a cone with its inverted base truncated. [Forsyth]

Site 9.

"to a Stard. point opposit a Conic Mound on the top of which is a rock resembling a house & Chimney."

July 27, 1806

Fort Union Formation, Tertiary System-Paleocene Series; coal beds (fig. 115)

Fig. 115. Coal (thin, dark middle band) in the Fort Union Formation on the south side of the Yellowstone River; on the frontage road 1 mile east of the town of Rosebud, Rosebud County, Montana.

East of the town of Rosebud, Montana, the Yellowstone River passes through country underlain by the Fort Union Formation.[50] This formation contains yellow and brown colored sandstones, siltstones and claystones; and prominent lignite beds. The Fort Union was deposited in swamps and deltas on the Paleocene coastal plain during the last cycles of the Western Interior Seaway.[13, 15] Clark recorded the occurrence of layers of lignite coal in this formation along the banks of the river. He probably judged it inferior because of his familiarity with the harder coal found in the Appalachian Mountains of the eastern United States. [Forsyth]

Site 10.

"..I passd. Straters of Coal in the banks on either Side those on the Stard. Bluffs was about 30 feet above the water and in 2 vanes from 4 to 8 feet thick, in a horozontal position. the Coal Contained in the Lard Bluffs is in Several vaines of different hights and thickness. this Coal or Carbonated wood is like that of the Missouri of an inferior quallity."

July 28, 1806

Shoals and rapids (fig. 116)

Figs. 116. Shoals and rapids downstream from Kinsey Bridge; off Montana Highway 489, south of Kinsey, Custer County, Montana.

Gravel reworked from the river, as well as gravel eroded from adjacent terraces and washed into the river, forms shoals and rapids. Harder sandstone bedrock, exposed in places on the channel floor, may also cause rapids to form, particularly at low water. [Terry]

Site 11.

"...the Commencement of Shoals.... passed a Succession of those Shoals for 6 miles the lower of which was quit across the river and appeared to have a decent of about 3 feet....the worst of those Shoals, which I call the Buffalow Sholes"

July 30, 1806

Fort Union Formation, Tertiary System-Paleocene Series; bluff (fig. 117)

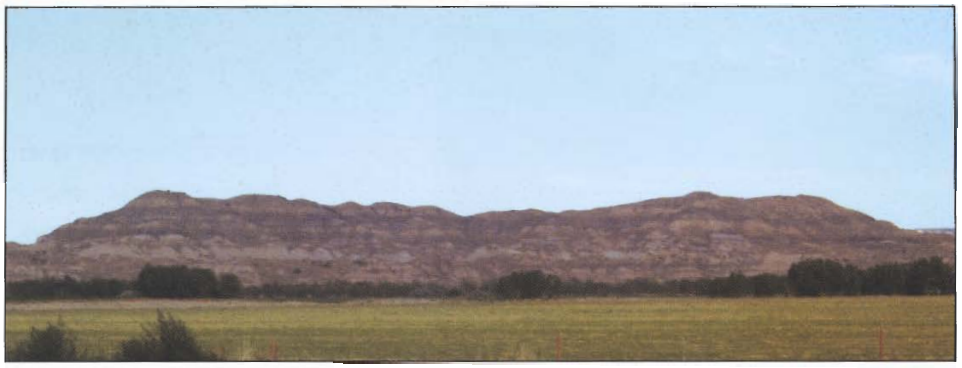


Fig. 117. The Fort Union Formation on the south side of the Yellowstone River; about 0.5 miles south of Kinsey Bridge, off Montana Highway 489, south of Kinsey, Custer County, Montana.

At the some of the shoals, harder brown sandstone of the Paleocene Fort Union Formation is exposed along the banks of the river.[50] [Terry]

Site 12.

"the rock which passes the river at those Sholes appear hard and gritty of a dark brown Colour "

July 30, 1806

River gravels (fig. 118)

Fig. 118. Clinker (or scoria) gravel on bars near the mouth of the Powder River on the south side of the Yellowstone River; Powder River Depot Fishing Access, off the access road to U.S. Interstate Highway 94, southwest of Terry, Prairie County, Montana.

The Powder River, at and upstream from its confluence with the Yellowstone, has gravel bars with many pebbles of red-colored clinker or scoria eroded from parts of the Fort Union Formation upstream from this area. [Terry]

Site 13.

"passed the enterance of a river [Powder River].... *this river is Shallow and the water very muddy and of the Colour of the banks a darkish brown. I observe great quantities of red Stone thrown out of this river...."*

July 30, 1806

Dry creeks; semi-arid plains (fig. 119)

Fig. 119. A dry creek and semi-arid plains on the north side of the Yellowstone River; Montana Highway 253 to Scenic View Road, north of Terry, Prairie County, Montana.

Many tributaries of the Yellowstone on both sides of the river are intermittent streams that carry water at some times and are dry at others. Clark's observations about their huge discharges from time to time were correct. [Terry]

Site 14.

"I landed at the enterance of a dry Creek on the Lard side below the Shoals.... Those Dry Rivers, Creeks, &c are like those of the Missouri which take their rise in and are the Conveyance of the water from those plains. they have the appearanc of dischargeing emence torrents of water. the late rains which has fallen in the plains raised Sudenly those Brooks which receive the water of those plains on which those Suden & heavy Showers of rain must have fallen...."

July 30, 1806

Fort Union Formation, Tertiary System-Paleocene Series; bluffs; coal (fig. 120)

Fig. 120. Coal near the top of the Fort Union Formation (near walking stick) on the north side of the Yellowstone River; Montana Highway 253 to Scenic View Road, northwest of Terry, Prairie County, Montana.

Parts of the Fort Union Formation are made up mostly of soft sedimentary rocks that do not erode into ledges, including yellow and brown colored sandstones, siltstones and claystones, as well as lignite coal beds. The Fort Union was deposited in swamps and deltas on the Paleocene coastal plain during the last cycles of the Western Interior Seaway. [13, 15] [Terry]

Site 15.

"those hills appear to be composed of various Coloured earth and Coal without much rock"

July 31, 1806

Erosional remnants; buttes (fig. 121)

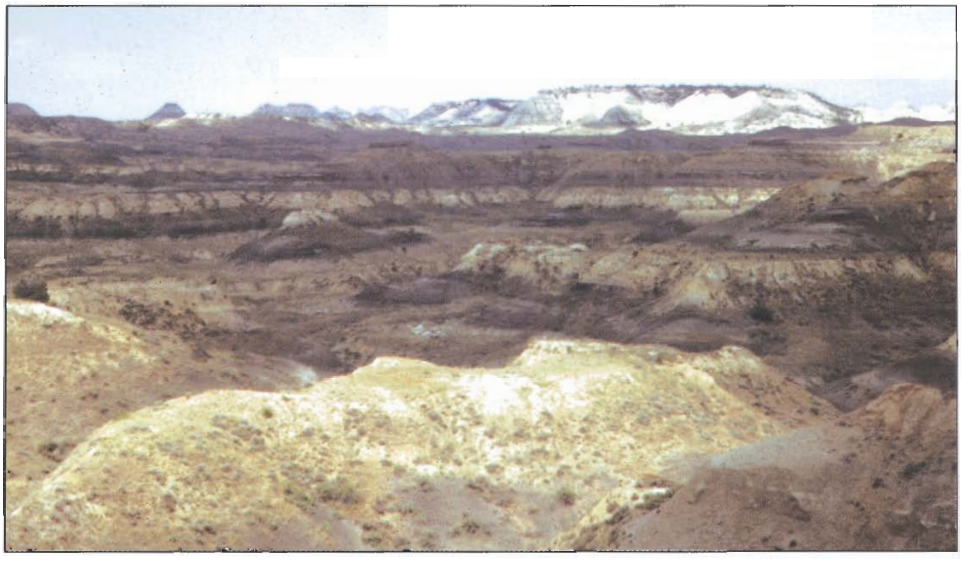


Fig. 121. Buttes on the north side of the Yellowstone River; Montana Highway 253 to Scenic View Road, northwest of Terry, Prairie County, Montana.

The valley sides and adjacent uplands have many buttes of various sizes and shapes left as remnants from the partial erosion of the Paleocene Fort Union Formation. [Terry]

Site 16.

"I observe Several Conical pounds [mounds] *which appear to have been burnt. this high Country is washed into Curious formed mounds & hills and is cut much with reveens."*

July 31, 1806

Pierre Shale, Upper Cretaceous System, exposed along anticline axis (fig. 122)

Site 17.

"Some high black looking Bluffs...."

July 31, 1806

Fig. 122. The Pierre Shale exposed in the center of the Cedar Creek Anticline; Montana Highway 335 at Cedar Creek, approximately 13 miles south-southwest of Glendive, Dawson County, Montana.

For several days, the rocks that Clark encountered along the Yellowstone were quite similar–sandstone, coal beds, rocks of shades of brown, tan and yellow. And then just upstream from the present town of Glendive, Montana, he noted "black looking Bluffs." The black shale here is the Upper Cretaceous Pierre Shale brought to the surface by erosion along the crest or axis of the Cedar Creek Anticline southwest of Glendive (figs. 10a, 14).[2, 50] The Pierre is a marine shale deposited from the latter part of the third major cycle through the fifth cycle of the Cretaceous Western Interior Seaway, the Niobrara, Claggett and Bearpaw cycles.[38] [Wibeux]

Sand bars; islands (fig. 123)

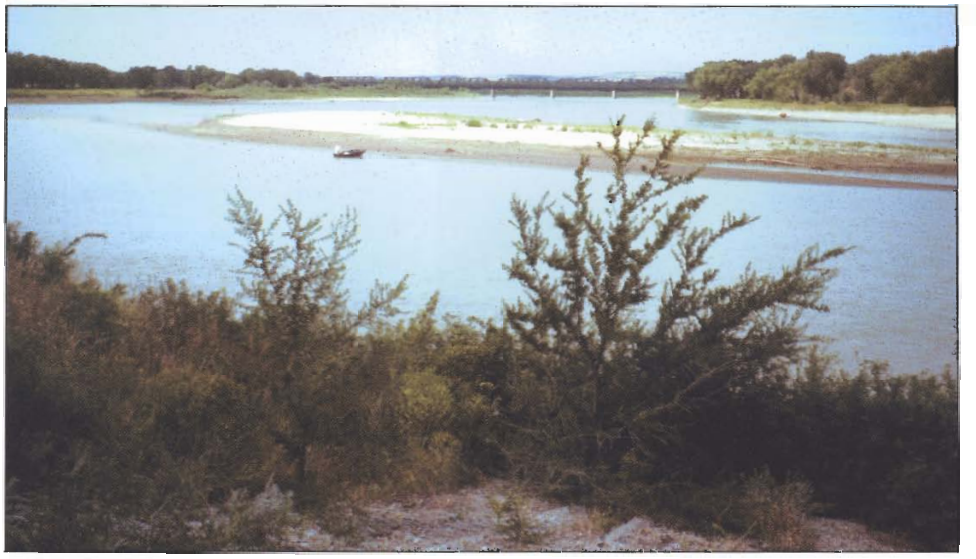


Fig. 123. The Yellowstone, a braided river; from Montana Highway 335 at the southern edge of Glendive, Dawson County, Montana.

In this reach, the Yellowstone is a braided river with many sand bars and islands (fig. 20b). [Glendive]

Site 18.

"river wide and very much divided by islands and Sand and Mud bars."

August 2, 1806

Fort Union Group (Formation), Tertiary System-Paleocene Series; bluffs (fig. 124)

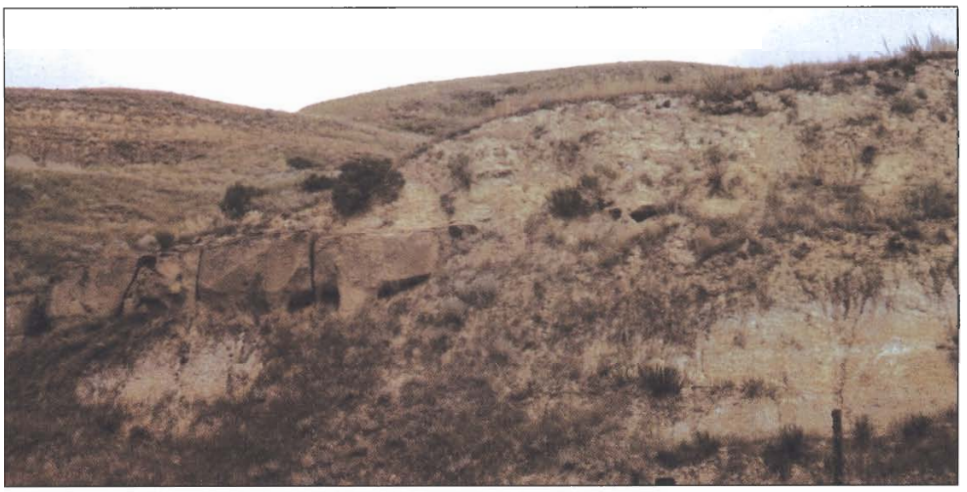


Fig. 124. Sandstone bluffs in the Fort Union Group; southwest of Fairview, Montana, at the mouth of Horse Creek, McKenzie County, North Dakota.

Yellow sandstone of the Fort Union Group (*Formation* in Montana) crops out on the east bank of the Yellowstone River at this site. The Fort Union was deposited in coastal plain, coal swamp and delta environments during the last cycles of the Western Interior Seaway.[9, 13, 15] [Watford City, North Dakota]

Site 19.

"to a Bluff Point of the Stard. bend Some yellow rock just above the water"

August 2, 1806

Landslides in the Fort Union Group (Formation), Tertiary System-Paleocene Series (fig. 125)

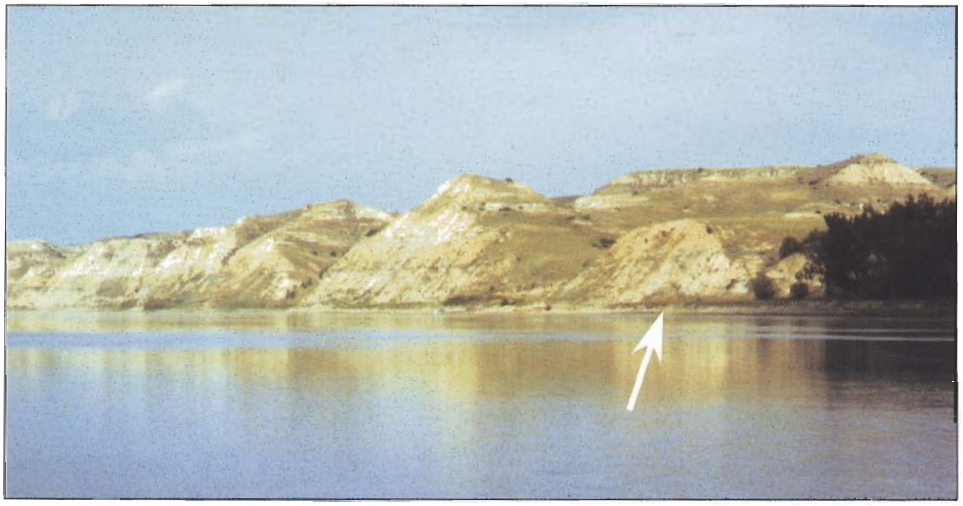


Fig. 125. Landslides at the base of bluffs on the east bank of the Yellowstone River; seen from the west side of the river at Sundheim Park, North Dakota Highway 200, McKenzie County, North Dakota.

The east side of the Yellowstone is a cut bank into the Fort Union Group (*Formation* in Montana). As the river undercuts the rocks of the formations, landslides occur. [Watford City, North Dakota]

Site 20.

"...passed the enterance of Jo. Field's [now Charbonneau] *Creek 35 yards wide immediately above a high bluff which is falling into the river very fast."*

August 3, 1806

REFERENCES CITED

1. Alden, W.C., 1932, Physiography and glacial geology of eastern Montana and adjacent areas: U.S. Geological Survey Professional Paper 174, 133 p.

2. Alt, D., and Hyndman, D.W., 1986, Roadside Geology of Montana: Mountain Press Publishing Co., Missoula, Montana, 427 p.

3. Atwood, W.W., 1940, The Physiographic Provinces of North America: Ginn and Co., Boston, 536 p.

4. Balster, C.A., compiler, 1980, Stratigraphic nomenclature chart for Montana and adjacent areas: Montana Bureau of Mines and Geology Geologic Map 8, one sheet.

5. Bennison, A.P., and Chenoweth, P.A., compilers, 1984, Geologic highway map of the northern Great Plains region: American Association of Petroleum Geologists Geologic Highway Map No. 12, one sheet.

6. Berry, W.B.N., 1968, Growth of a Prehistoric Time Scale Based on Organic Evolution: W.H. Freeman and Co., San Francisco, 158 p.

7. Biek, R.F., and Gonzalez, M.A., 2001, The geology of the Theodore Roosevelt National Park, Billings and McKenzie counties, North Dakota: North Dakota Geological Survey Miscellaneous Series No. 86, 74 p.

8. Bluemle, J.P., 1988, North Dakota geologic highway map: North Dakota Geological Survey Miscellaneous Map 29, one sheet, scale approx. 1:1,013,760.

9. Bluemle, J.P., 1991, The face of North Dakota: North Dakota Geological Survey Educational Series 21, 177 p.

10. Brantley, S.R., 1995, Volcanoes of the United States: U.S. Geological Survey, 44 p.

11. Burchett, R.R., Dreeszen, V.H., Souders, V.L., and Prichard, G.E., 1988, Bedrock geologic map showing configuration of the bedrock surface in the Nebraska part of the Sioux City 1° x 2° quadrangle: U.S. Geological Survey Miscellaneous Investigations Map I-1879, one sheet, scale 1:250,000.

12. Calhoun, F.H.H., 1906, The Montana Lobe of the Keewatin ice sheet: U.S. Geological Survey Professional Paper 50, 62 p.

12a. Chadwick, R.A, 1985, Overview of Cenozoic volcanism in the west-central United States, in Flores, R.M. and Kaplan, S.S. (eds.), Cenozoic paleogeography of the west-central United States: SEPM Rocky Mountain Section Paleogeography Symposium 3, p. 359-382.

13. Cherven, V.B., and Jacob, A.F., 1985, Evolution of Paleogene depositional systems, Williston Basin, in response to global sea level changes, in Flores, R.M. and Kaplan, S.S. (eds.), Cenozoic paleogeography of the west-central United States: SEPM Rocky Mountain Section Paleogeography Symposium 3, p. 127-170.

14. Colbert, E.H., 1968, Men and Dinosaurs: E.P. Dutton and Co., Inc., New York, 283 p.

15. Daly, D.J., Groenewold, G.H., and Schmit, C.R., 1985, Paleoenvironments of the Paleocene Sentinel Butte Formation, Knife River area, west-central North Dakota, in Flores, R.M. and S.S. Kaplan (eds.), Cenozoic paleogeography of the west-central United States: SEPM Rocky Mountain Section Paleogeography Symposium 3, p. 171-185.

16. Darton, N.H., compiler, 1951, Geologic map of South Dakota: U.S. Geological Survey map, scale 1:500,000.

17. Darwin, C., 1963 [1859], The Origin of Species: Washington Square Press, Inc., New York, 506 p.

18. Diffendal, R.F., Jr., 1999, Earth in four dimensions: Development of the ideas of geologic time and history: Nebraska History, v. 80, no. 3, p. 95-104.

19. Diffendal, R.F., Jr., chair, and Flowerday, C. F., (ed.), 1995, Geologic field trips in Nebraska and adjacent parts of Kansas and South Dakota: University of Nebraska-Lincoln Conservation and Survey Division Guidebook 10, 135 p.

20. Diffendal, R.F., Jr., and Voorhies, M.R., 1994, Geologic framework of the Niobrara River drainage basin and adjacent areas in South Dakota generally east of the 100th meridian west longitude and west of the Missouri River: University of Nebraska-Lincoln Conservation and Survey Division Geological Survey Report of Investigations 9, 13 p.

21. Douglas, R.J.W. (ed.), 1968, Geology and economic minerals of Canada: Geological Survey of Canada, Economic Geology Report 1, 5th ed., 838 p.

22. Fenneman, N.M., 1931, Physiography of the Western United States: McGraw Hill, New York, 534 p.

23. Fisher, C.A., 1909, Geology and water resources of the Great Falls region, Montana: U.S. Geological Survey Water-Supply Paper 221, 89 p.

24. Flint, R.F., 1955, Pleistocene geology of eastern South Dakota: U.S. Geological Survey Professional Paper 262, 173 p.

25. Flint, R.F., 1971, Glacial and Quaternary Geology: John Wiley and Sons, Inc., New York, 892 p.

26. Flowerday, C.F., and Diffendal, R.F., Jr. (eds.), 1997, Geology of Niobrara State Park, Knox County, Nebraska and adjacent areas—With a brief history of the park, Gavins Point Dam, and Lewis and Clark Lake: University of Nebraska-Lincoln Conservation and Survey Division Educational Circular 13, 28 p.

27. Fullerton, D.S., 1995, Quaternary geologic map of the Dakotas 4° x 6° quadrangle, United States: U.S. Geological Survey Miscellaneous Investigations map I-1420, one sheet, scale 1:1,000,000.

28. Gerlach, A.C., ed., 1970, The National Atlas of the United States of America: U.S. Geological Survey, 417 p.

29. Gill, J.R., and Cobban, W.A., 1973, Stratigraphy and geologic history of the Montana Group and equivalent rocks, Montana, Wyoming, North and South Dakota: U.S. Geological Survey Professional Paper 776, 37 p.

30. Gries, J.P., 1996, Roadside Geology of South Dakota: Mountain Press Publishing Co., Missoula, Montana, 358 p.

31. Hartman, J.H., Johnson, K.R., and Nichols, D.J. (eds.), 2002, The Hell Creek Formation and the Cretaceous-Tertiary boundary in the northern Great Plains: An integrated continental record of the end of the Cretaceous: Geological Society of America Special Paper 361, 520 p.

32. Hoganson, J.W. and Murphy, E.C., 2003, Geology of the Lewis and Clark Trail in North Dakota: Mountain Press Publishing Co., Missoula, Montana, 264 p.

33. Holmes, A., 1931, Radioactivity and Earth movements: Transactions of the Royal Society of Glasgow for 1928-29, v. 18, no. 3, p. 559-606.

34. Hunt, C.B., 1974, Physiography of the United States: W.H. Freeman and Co., San Francisco, 725 p.

35. Hutton J., 1795, Theory of the Earth with proofs and illustrations: Strauss and Cramer, GmbH., Germany, 1972 reprint of original, v. II, 567 p.

36. Imbrie, J., and Imbrie, K.P., 1979, Ice Ages – Solving the Mystery: Enslow Publishers, Short Hills, New Jersey, 224 p.

37. Jackson, D.D., 1981, Thomas Jefferson and the Stony Mountains: Exploring the West From Monticello: University of Illinois Press, Urbana, 339 p.

38. Kauffman, E.G., 1977, Geological and biological overview: Western Interior Cretaceous Basin: Mountain Geologist, v. 14, p. 75-99.

39. Kaul, R.B., 1975, Vegetation of Nebraska (Circa 1850): University of Nebraska-Lincoln Conservation and Survey Division General Information Map 8, one sheet, scale 1:1,000,000.

40. Kirwan, R., 1784; 1794 & 96, Elements of Mineralogy: London, P. Elmsly, 1st ed., 412 + xviii p.; 2nd ed., v. I, 510 + xxxi p., v. II, 529 + xvi p.

41. Lennox, D.H., Maathuis, H., and Pederson, D., 1988, Region 13, Western glaciated plains, in Geology of North America: Geological Society of America, v. O-2 Hydrogeology, p. 115-128.

42. Lyell, C., 1845, Travels in North America in the Years 1841-2: Wiley and Putnam, New York, v. I, 251 p.

43. Maher, H.D., Jr., Englemann, G.F. and Shuster, R.D., 2003, Roadside Geology of Nebraska: Mountain Press Publishing Co., Missoula, Montana, 264 p.

44. Mallory, W.W. (ed.), 1972, Geologic Atlas of the Rocky Mountain Region: Rocky Mountain Association of Geologists, Denver, Colorado, 331 p.

45. Pabian, R.K., and Lawton, D.R., 1984, Geology of Ponca State Park, Nebraska: University of Nebraska Conservation and Survey Division Educational Circular No. 6, 33 p.

46. Powell, J.L., 1998, Night Comes to the Cretaceous: W.H. Freeman and Co., New York, 250 p.

47. Renfro, H.B., and Feray, D.E., compilers, 1997, Geologic highway map Northern Rocky Mountains region: American Association of Petroleum

Geologists Geologic Highway Map No. 5, one sheet.

48. Rice, D.R., and Shurr, G.W., 1983, Patterns of sedimentation and paleogeography across the Western Interior Seaway during time of deposition of Upper Cretaceous Eagle Sandstone and equivalent rocks, northern Great Plains, in Reynolds, M.W., and Dolly, E.D. (eds.), Mesozoic paleogeography of west-central United States: SEPM Rocky Mountain Section Paleogeography Symposium 2, p. 337-358.

49. Richmond, G.M., 1994, Quaternary geologic map of the Platte River 4° x 6° quadrangle, United States: U.S. Geological Survey Miscellaneous Investigations Map I-1420 (NK-14), one sheet, scale 1:1,000,000.

50. Ross, C.P., Andrews, D.A., and Witkind, I.J., 1955, Geologic map of Montana: U.S. Geological Survey Map R-4111, two sheets, scale 1:633,600.

51. Schultz, C.B., 1943, Thomas Jefferson, pioneer paleontologist: The Compass, v. 23, no. 4, p. 264-267.

52. Thornbury, W.D., 1965, Regional Geomorphology of the United States: John Wiley and Sons, Inc., New York, 609 p.

53. Todd, J.E., 1898, The moraines of southeastern South Dakota and their attendant deposits: U.S. Geological Survey Bulletin 158, 171 p.

54. Todd, J.E., 1908, Description of the Elk Point quadrangle, SD, NE, IA: U.S. Geological Survey Folio 156, 8 p.

55. Trimble, D.E., 1981, The geologic story of the Great Plains: U.S. Geological Survey Bulletin 1493, 55 p.

56. White, C.A., 1891, Correlation papers Cretaceous: U.S. Geological Survey Bulletin 82, 273 p.

57. Whiteaves, J.F., 1893, The Cretaceous System in Canada: Royal Society of Canada Proceedings and Transactions, v. XI, sec. IV, p. 3-19.

58. Winchester, S., 2001, The Map That Changed the World: HarperCollins Publishers, New York, 329 p.

59. Witzke, B.J., and Ludvigson, G.A., 1994, The Dakota Formation in Iowa and the type area, in Shurr, G.W., Ludvigson, G.A., and Hammond, R.H. (eds.), Perspectives on the eastern margin of the Cretaceous Western Interior Basin: Geological Society of America Special Paper 287, p. 43-78.

60. Witzke, B.J., Ludvigson, G.A., Poppe, J.R., and Ravn, R.L., 1983, Cretaceous paleogeography along the eastern margin of the Western Interior Seaway, Iowa, southern Minnesota, and eastern Nebraska and South Dakota, in Reynolds, M.W., and Dolly, E.D. (eds.), Mesozoic paleogeography of the west-central United States: SEPM Rocky Mountain Section Paleogeography Symposium 2, p. 225-252.

APPENDIX A

FOR FURTHER READING

LEWIS AND CLARK

Moulton, Gary E. (ed.), 1983-2000, *The Journals of the Lewis and Clark Expedition*: University of Nebraska Press, Lincoln, Nebraska, and London, hard cover, 13 volumes.
[The following volumes cover the Great Plains.]
Vol. 1: *Atlas of the Lewis and Clark Expedition.*
Vol. 2: *August 30, 1803-August 24, 1804.*
Vol. 3: *August 25, 1804-April 6, 1805.*
Vol. 4: *April 7-July 27, 1805.*
Vol. 8: *June 10-September 26, 1806.*

Moulton, Gary E. (ed.), 2002, *The Definitive Journals of Lewis and Clark*: University of Nebraska Press, Lincoln, Nebraska, and London, paper cover, 7 volumes, Bison Books reprint.
[Comparable to volumes 2, 3, 4, and 8 above.]
From the Ohio to the Vermillion
Up the Missouri to Fort Mandan
From Fort Mandan to Three Forks
Over the Rockies to St. Louis

Ambrose, Stephen E., 1996, *Undaunted Courage: Meriwether Lewis, Thomas Jefferson, and the Opening of the American West*: Simon and Schuster, New York.

Fifer, Barbara, and Soderberg, Vicky, 2001, *Along the Trail with Lewis and Clark* (2nd ed.): Montana Magazine and Farcountry Press, Helena, Montana.

GEOLOGY

General

Trimble, Donald E., 1990 [1983], The Geologic Story of the Great Plains: U.S. Geological Survey Bulletin 1493, reprinted with minor revisions by Theodore Roosevelt Nature and History Association.

Bennison, A.P, Chenowith, P.A., compilers, 1984, Geological Highway Map of the Northern Great Plains Region: North Dakota, Minnesota, South Dakota, Iowa, Nebraska: American Association of Petroleum Geologists, Tulsa, Oklahoma.

Renfro, H.B., Feray, D.E., compilers, 1997, Geological Highway Map of the Northern Rocky Mountain Region (rev.): Idaho, Montana, Wyoming: American Association of Petroleum Geologists, Tulsa, Oklahoma.

Nebraska/Iowa/South Dakota

Flowerday, Charles A., and Diffendal, R. F., Jr. (eds.), 1997, Geology of Niobrara State Park, Knox County, Nebraska and adjacent areas – with a brief history of the park, Gavins Point Dam, and Lewis and Clark Lake: University of Nebraska-Lincoln, Conservation and Survey Division, Lincoln, Nebraska, Educational Circular 13.

Maher, Harmon D., Jr., Engelmann, George F., and Shuster, Robert D., 2003, *Roadside Geology of Nebraska*: Mountain Press Publishing Co., Missoula, Montana.

Pabian, Roger K., and Lawton, Dennis R., 1984, Geology of Ponca State Park, Nebraska: University of Nebraska-Lincoln, Conservation and Survey Division, Lincoln, Nebraska, Educational Circular 6.

South Dakota

Gries, John Paul, 1996, *Roadside Geology of South Dakota*: Mountain Press Publishing Co., Missoula, Montana.

North Dakota

Hoganson, John W., and Murphy, Edward C., 2003, *Geology of the Lewis and Clark Trail in North Dakota*: Mountain Press Publishing Co., Missoula, Montana.

Bluemle, John P., 1991, The Face of North Dakota: Revised Edition: North Dakota Geological Survey, Bismarck, North Dakota, Educational Series 21.

Biek, Robert F., and Gonzalez, Mark A., 2001, The Geology of Theodore Roosevelt National Park: Billings and McKenzie Counties, North Dakota: North Dakota Geological Survey, Bismarck, North Dakota, Miscellaneous Series No. 86.

Montana

Alt, David, and Hyndman, Donald W., 1986, *Roadside Geology of Montana*: Mountain Press Publishing Co., Missoula, Montana.

Feldman, Robert, 1996, *Rockhounding Montana*: Falcon Publishing Inc., Helena, Montana.

Monahan, Glen, and Biggs, Chandler, 2001, *Montana's Wild and Scenic Upper Missouri River* (2nd ed.): Northern Rocky Mountain Books, Anaconda, Montana.

APPENDIX B

U.S. GEOLOGICAL SURVEY TOPOGRAPHIC MAPS

30-minute x 60-minute series;
1:100,000 scale; metric

Order from:
USGS Map Sales
Box 25286
Denver, CO 80225
1-888-275-8747

Maps are listed following the Missouri River upstream and the Yellowstone River downstream.

MISSOURI RIVER
Nebraska-Iowa-South Dakota

Sioux City South (IA-NE-SD)
42096-A1-TM-100
Sioux City North (IA-SD-NE)
42096-E1-TM-100
Yankton (SD-NE)
42097-E1-TM-100
Atkinson (NE-SD)
42098-E1-TM-100

MISSOURI RIVER
South Dakota

Lake Andes (SD)
43098-A1-TM-100
Winner (SD)
43099-A1-TM-100
Chamberlain (SD)
43099-E1-TM-100
Big Bend Dam (SD)
44099-A1-TM-100
Pierre (SD)
44100-A1-TM-100
Onida (SD)
44100-E1-TM-100
LaPlant (SD)
45100-A1-TM-100
Mobridge (SD-ND)
45100-E1-TM-100

MISSOURI RIVER
North Dakota

Linton (ND)
46100-A1-TM-100
Bismarck (ND)
46100-E1-TM-100
McClusky (ND)
47100-A1-TM-100
Hazen (ND)
47101-A1-TM-100
Garrison (ND)
47101-E1-TM-100
Killdeer (ND)
47102-A1-TM-100
Parshall (ND)
47102-E1-TM-100
Stanley (ND)
48102-A1-TM-100
Williston (ND)
48103-A1-TM-100
Watford City (ND)
47103-E1-TM-100

LITTLE MISSOURI RIVER
North Dakota

Theodore Roosevelt National Park South Unit
Belfield (ND)
46103-E1-TM-100
Grassy Butte (ND)
47103-A1-TM-100
Theodore Roosevelt National Park North Unit
Watford City (ND)
47103-E1-TM-100

MISSOURI RIVER
Montana

Sidney (MT-ND)
47104-E1-TM-100
Culbertson (MT-ND)
48104-A1-TM-100
Wolf Point (MT)
48105-A1-TM-100
Glasgow (MT)
48106-A1-TM-100
Fort Peck Lake East (MT)
47106-E1-TM-100
Fort Peck Lake West (MT)
47107-E1-TM-100
Sand Springs (MT)
47107-A1-TM-100
Zortman (MT)
47108-E1-TM-100
Winifred (MT)
47109-E1-TM-100
Fort Benton (MT)
47110-E1-TM-100
Lonesome Lake (MT)
48100-A1-TM-100
Great Falls North (MT)
47111-E1-TM-100
Great Falls South (MT)
47111-A1-TM-100

In parts of Montana, roads do not closely follow the Missouri River. The following maps do not show the river, but indicate roads which lead to river access or other points of interest.

Jordan (MT)
47106-A1-TM-100
(south of Fort Peck Lake East)
Winnett (MT)
47108-A1-TM-100
(south of Zortman)
Lewistown (MT)
47109-A1-TM-100
(south of Winifred)
Belt (MT)
47110-A1-TM-100
(south of Fort Benton)

YELLOWSTONE RIVER
Montana-North Dakota

Big Timber (MT)
45109-E1-TM-100
Billings (MT)
45108-E1-TM-100
Roundup (MT)
46108-A1-TM-100
Hardin (MT)
45107-E1-TM-100
Hysham (MT)
46107-A1-TM-100
Forsyth (MT)
46106-A1-TM-100
Miles City (MT)
46105-A1-TM-100
Terry (MT)
46105-E1-TM-100
Wibaux (MT)
46104-E1-TM-100
Glendive (MT)
47104-A1-TM-100
Sidney (MT)
47104-E1-TM-100
Watford City (ND)
47103-E1-TM-100

GLOSSARY

absolute dating - the calculation of absolute age in years before present, usually but not always on the basis of radioactive isotopes.

alluvial fan - a low, outspread, relatively flat to gently sloping mass of loose rock material, shaped like an open fan or segment of a flattish cone, deposited by a stream at a place where it issues from a narrow valley onto a plain.

ammonite - an extinct shell-bearing cephalod mollusk related to the octopus, squid and chambered nautilus.

anticline - a fold in rock, generally convex upward.

bluff - a high bank with a broad, steep cliff face overlooking a plain or a body of water.

boulder - a detached rock mass having a diameter greater than 10 inches, being somewhat rounded or otherwise distinctly shaped by abrasion during transport.

braided - branching and rejoining repeatedly to form an intricate pattern or network of small interlacing stream channels.

butte - a conspicuous, usually isolated, generally flat-topped hill with relatively steep slopes often capped by a resistant layer of rock.

clay - a plastic material consisting mainly of particles less than 0.074 mm (0.0029 inch) in diameter.

clinker - a local term used for remains of coal that have burned and the surrounding rock that has been transformed during the burning of the coal.

cobble - a rock fragment from 2.5 to 10 inches in diameter, somewhat rounded by abrasion during transport.

coccolith - microscopic external skeletal debris secreted by cells of marine, floating algae of the class Chrysophyceae.

concretion - a hard, compact mass or aggregate of mineral matter, nearly spherical; formed by precipitation from water around a center such as a leaf, shell, etc.

Cretaceous - about 142 to 65 million years ago, the youngest time period of the Mesozoic Era. Also the rocks formed during this time. The name is derived from the Latin word for *chalk*.

cutoff - the new and relatively short channel formed when a stream cuts through a narrow strip of land called a *neck*, and thereby shortens the length of its channel.

deformation - a general term for folding and faulting of rocks as a result of various Earth forces.

dike - a tabular (book-shaped) igneous intrusion that cuts across the bedding of older rock.

Eocene - 55 to about 35 million years ago, an epoch of the Tertiary Period. Also the rocks formed during this time.

erratic - a rock fragment carried by glacial ice, deposited at some distance from the rock outcrop from which it was derived, and generally but not necessarily resting on bedrock or sediment of different composition.

fault - a discrete surface or zone of surfaces separating two rock masses across which one rock mass has slid past the other.

fold - curved or bent rock strata.

foraminifera - protozoa (single-celled animals) that secrete a shell of one or more chambers.

formation - a body of rock that is usually tabular and has certain unifying characteristics that can be used to separate it from other formations. It is mappable at the Earth's surface or traceable in the subsurface.

glacial sluiceway - an overflow channel; a channel formed by an ice-marginal, englacial (within the glacier), or subglacial stream.

gravel - an unconsolidated, natural accumulation of typically rounded rock fragments greater than 1/12th inch in diameter.

groin - a long, narrow, man-made jetty, usually extending roughly perpendicular to the shoreline to protect the bank or shore from erosion.

gumbo - a local term for a clay soil that becomes sticky, impervious, and plastic when wet.

hydraulic head - water-level elevation in a well, or elevation to which the water of a flowing artesian well will rise in a pipe extended high enough to stop the flow.

igneous - said of a rock or mineral that solidified from molten or partly molten material (that is, from magma or lava).

igneous intrusives - formed from molten rock and cross-cutting other Earth materials beneath the Earth's surface.

lignite - a brownish-black coal intermediate between peat and subbituminous in the transformation of plant debris into coal.

loess - a widespread, homogeneous, usually not layered, clay, silt and very fine sand deposit that blankets the land. Loess readily breaks into its constituent particles and often contains calcium carbonate. It is generally light yellow or yellowish brown. Loess is

generally thought to be wind-blown dust. Pronounced *luhss.*

magma - naturally occurring molten or partially molten rock material, generated within the Earth.

meander - one of a series of freely developing sinuous curves in a stream.

Mesozoic - about 245 to 65 million years ago. Also the rocks formed during this time.

Missouri Coteau Escarpment - the eastward-facing side of a plateau forming the eastern border of the Great Plains in southern Canada and the Dakotas.

mosasaur - an ocean-dwelling lizard, up to 30 feet long, that lived during the Cretaceous Period.

oxbow - the abandoned bow- or horseshoe-shaped channel of a former meander left after the meander has been cut off.

Paleocene - 65 to about 55 million years ago, the oldest epoch of the Tertiary Period. Also the rocks formed during this time.

Pleistocene - from about 1.6 million to 11,500 years ago, an epoch of time between the Pliocene and the Holocene epochs during the Quaternary Period. Also the rocks and sediments formed during this time.

plesiosaur - a marine reptile of the Mesozoic Era having a very long neck, small head, and limbs shaped like paddles for swimming.

point bar - one of a series of low, arc-shaped ridges of sand and gravel developed on the inside of a growing meander by slow accretion of sediment accompanying migration of the channel toward the outer bank.

pumice - a volcanic glass, very light in weight.

regression - the retreat of the sea from land areas.

sand - rock or mineral fragments having a diameter between 1/16th and 2 mm (0.0025 and 0.08 inch).

scoria - see *clinker.*

sedimentary - pertaining to solid material that originates from weathering of rocks and minerals, accumulation of organic debris, precipitation of solids from solutions, or combinations of these.

selenite - the clear, colorless variety of gypsum (calcium sulfate) occurring in transparent crystals.

shale - a laminated (layered) rock composed of more than 2/3 clay-sized particles.

shoal - a shallow place in a stream.

sill - a tabular (book shaped) igneous intrusion that parallels bedding (layering) of sedimentary or other layered rocks.

silt - sedimentary particles having a diameter in the range of 1/256th to 1/16th mm (0.00016 to 0.0025 inch).

stratum - a tabular or sheet-like body of sedimentary rock visually separable from layers above and below it. A bed of rock. Plural: *strata.*

syncline - a concave upward fold of rock. Generally u-shaped in side view.

terrace - a former floodplain. Any long, narrow, gently inclined surface bounded along one edge by a steeper descending slope and along the other by a steeper ascending slope.

Tertiary - 65 to 1.6 million years, the older of two periods of time of the Cenozoic Era. Also rocks formed during this time.

till - glacial deposits, predominantly unsorted and unlayered.

transgression - the rise of the sea over land areas.

uplift - a structurally high area in the Earth's crust, produced by positive movements that raise or upthrust the rocks (as opposed to a depression).

weather - to undergo change such as discoloration, softening, crumbling, or pitting of rock or mineral surfaces, brought about by exposure to the atmosphere and its agents.