Geology of the Fort Peck Area, Garfield, McCone and Valley Counties Montana

GEOLOGICAL SURVEY PROFESSIONAL PAPER 414-F

Prepared as a part of a program of the Department of the Interior for development of the Missouri River basin

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By FRED S. JENSEN *and* HELEN D. VARNES

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

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SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

GEOLOGY OF THE FORT PECK AREA, GARFIELD, McCONE, AND VALLEY COUNTIES, MONTANA

By Fred S. Jensen and Helen D. Varnes

ABSTRACT

The Fort Peck area, in the central part of northeast Montana, includes a little more than three 15-minute quadrangles and covers an area of about 600 square miles. The area is in the northern part of the Great Plains physiographic province and is predominantly an undulating grassy treeless prairie upland which rises gradually to the north. The Milk and Missouri Rivers have carved their channels into this prairie upland, so that steep scarps as much as 200 feet high border the wide bottom lands. South and southwest of the rivers, the surface rises abruptly and irregularly through a belt of "breaks" to a rolling dissected prairie with badland areas along many of the drainage courses.

The exposed bedrock is Late Cretaceous in age; the oldest formation is the Judith River formation, which is exposed only in the complexly faulted Tiger Butte area. The overlying Bearpaw shale is the surface bedrock except for about 12 square miles in the southern part and in the extreme northeast corner where the Bearpaw shale is overlain by the Fox Hills sandstone. The Hell Creek formation, generally considered to be latest Cretaceous in age, is the youngest bedrock in the Fort Peck area; it disconformably overlies the Fox Hills in an area of about 5 square miles.

The unconsolidated and semiconsolidated materials overlying the Cretaceous bedrock are Miocene or Pliocene or younger and represent later chapters in the long history of intermittent regional uplift that was characteristic of the Great Plains province since early in the Tertiary. The oldest are preglacial sediments deposited on stream-cut plains and terraces. Of these, the Flaxville formation (Miocene or Pliocene) is limited to a few small plateau remnants in the extreme northeast corner of the area. The younger Wiota gravels (Pleistocene) are extensively deposited along the rivers and their major tributaries.

The surficial material over more than half the Fort Peck area is ground moraine of Wisconsin (Pleistocene) age. At one time the ground moraine probably covered the entire area, but postglacial erosion has stripped it from major valleys and from the hilly belt of shale and sandstone in the southern and southwestern parts of the area.

The Kintyre formation, composed of fluviolacustrine silt and fine sand and clay, overlies the ground moraine in some parts of the Milk and Missouri River valleys. The Kintyre formation was deposited on stagnant ice of the wasting Wisconsin glacier. Glacial outwash is limited to widely separated deposits in the rolling prairie upland and to terrace deposits.

Since the disappearance of the glacier ice, erosion has been dominant except in the trenches of the Milk and Missouri Rivers and along their major tributaries, where alluviation has been dominant.

INTRODUCTION

GENERAL LOCATION AND PURPOSE OF THE WORK

The Fort Peck area (fig. 1) includes about 600 square miles in the central part of northeastern Montana in

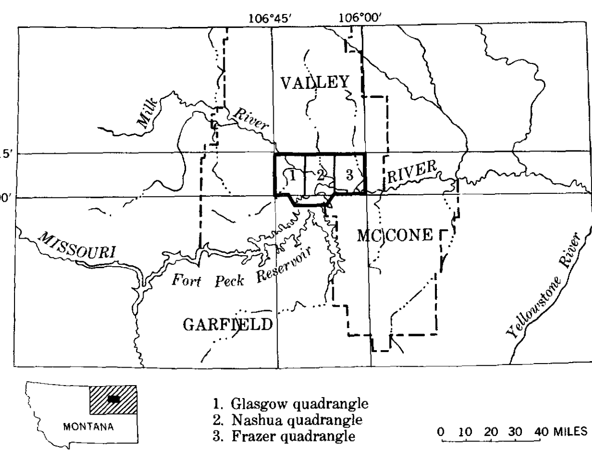


Figure 1.—Index map of the Fort Peck area, Montana.

the northern part of the Great Plains physiographic province. It consists of the Glasgow, Nashua, and Frazer 15-minute quadrangles and a small additional area of about 26 square miles southwest and southeast of the Fort Peck Dam.

The development of the natural resources of the Missouri River basin has been aided since the middle 1930's by several government agencies, which are engaged in a long-term multiple-phase program. This program relates to mineral resources, efficient land use, and the construction of dams and canals for flood control, power, irrigation, and navigation.

Begun in 1933 and officially completed in 1941, the Fort Peck Dam, in the south-central part of the report area, stands 250 feet above the Missouri River. The reservoir extends nearly 180 miles upstream and has a capacity of 20 million acre-feet of water.

The purpose of the present investigation is to supply basic geologic data in support of Missouri River basin development program and to add to the geologic knowledge of an area where only reconnaissance geologic work has been done previously.

GEOGRAPHY AND CLIMATE

The Fort Peck area is typical of much of the northern Great Plains. It is a rolling upland dissected by the Milk and Missouri Rivers and their tributaries. The rivers have broad, flat flood plains. Most of the area is between 2,100 and 2,300 feet in altitude, although the high terrace remnants in the northeast corner locally are more than 2,700 feet above sea level. The gradient along the eastward-flowing Milk and Missouri Rivers averages only slightly more than 1 foot per mile.

The Missouri River crosses the south-central margin of the area and then swings almost due east. The Milk River, which enters the area northwest of Glasgow, flows southeast to join the Missouri near the town of Nashua. Lewis and Clark, as well as the host of traders, trappers, steamboat men, and hunters who followed them, traveled up the Missouri River through the heavily wooded strip of country along the river. A reader of their journals might get an unbalanced picture of the plains of northeastern Montana were he not careful to note that beyond the flat bottom lands of the major rivers and creeks are grassy treeless plains rising slowly to the north in a series of irregular steps that culminate in broad mesalike plateaus. In the Fort Peck area the rivers have cut against these uplands so that abrupt scarps, locally as much as 200 feet high, border the valley floors. Southward from the Missouri River the surface rises both abruptly and irregularly through an area of "river breaks" to rolling prairies dissected into small badland areas along many of the drainage courses.

Strip cultivation and summer fallowing have permitted some successful wheat farming on the upland north of the Milk and Missouri Rivers. Part of this northern upland, however, and all the area south of the Missouri River, are used as grazing land.

During the early 1920's many of the homesteaders were near economic ruin because of dry years and attendant crop failures. The Federal government undertook a relocation program, installed irrigation systems in the Milk River bottom land, and resettled many homesteaders there. The N-bar-N Cattle Co. and other private concerns constructed irrigation systems on bottom lands of the Missouri and Milk Rivers, so that today much of this land has been cleared of cottonwood groves to make way for irrigated fields of sugar beets, alfalfa, and other crops.

There are four towns in the area. Glasgow, the county seat of Valley County, has a population of 6,398 (1960 census). It is situated on the Great Northern Railroad and U.S. Highway 2 and is the principal marketing center of the area. Nashua (population 796) and Frazer (population 378) are along the highway and railroad east of Glasgow. Fort Peck, the second largest town in the area, has a population of 950 (1960 census). It is under the jurisdiction of the U.S. Army Corps of Engineers and is the site of the offices and laboratories of the Fort Peck district.

The following tabulations summarize climatic conditions (U.S. Dept. of Agriculture Yearbook, 1941).

	Temperature (°F)
Average, June to August	65
Average, December to February	10
Summer maximum	110
Winter minimum	−60

		Daylight
Longest day	hr	16
Shortest day	hr and min	8, 25
Sunshine:		
In summer	percent	65
In winter	do	50

Wind averages 10 to 12 miles per hour (in July from northwest; in January from southwest). The growing season averages 90 to 120 days without killing frost. Annual precipitation ranges from 10 to 15 inches, half of which falls in May, June, and July. There are about 40 days between April and September with 0.01 inches or more of rainfall. Annual snowfall averages 30 inches. There is an average of 90 days per year with snow cover; first snowfall in autumn occurs on about October 8.

FIELDWORK AND ACKNOWLEDGMENTS

Fieldwork was done largely in 1948, 1949, and 1950 by Fred S. Jensen assisted by Frederick T. Fisher and James O. Kistler. The geology was mapped on aerial photographs, mostly on a scale of 1:20,000, and then transferred by sketchmaster, at a scale of 1:31,680, to base maps compiled from topographic maps of the Nashua and Frazer quadrangles and from U.S. Bureau of Land Management township plats for the Glasgow quadrangle. Culture was interpreted from the photographs and in most places was field checked. Where topographic maps were not available or were not sufficiently accurate, altitudes were determined by Paulin altimeter and by telescopic alidade.

Geologic data were obtained from auger holes and shallow trenches to supplement information obtained from existing exposures of the rock strata. Information on the rocks at greater depth was obtained from logs of water wells, test holes drilled by oil companies, and from numerous drill holes in the vicinity of the Fort Peck Dam put down by the U.S. Army Corps of Engineers. Other information on the Bearpaw shale and some surficial deposits was made available by the Fort Peck District of the Corps of Engineers at Fort Peck, Mont. The soils classification tests (fig. 6) and mechanical analyses (fig. 5 and 18) were made by the Montana State Highway Department.

In this report, where names of colors of geologic materials are followed by letter-number symbols in parentheses, both name and symbol are taken from the "Rock-Color Chart" of the National Research Council (Goddard, 1948). Where color names are used without the symbol, a more general meaning is implied.

Preliminary reports on the geology of the Nashua and Frazer quadrangles were prepared by Fred S. Jensen and released for open file in 1951. Jensen also prepared a preliminary draft for the chapters on the Cretaceous stratigraphy and structure in the present report. Helen D. Varnes prepared the rest of the report.

CRETACEOUS STRATIGRAPHY

Geographically and geologically the Fort Peck area is an integral part of the northern Great Plains; so, a sketch of the development of geological understanding in the region is included in this report.

The northern Great Plains are underlain by a great succession of nearly flat lying marine and fresh-water strata of Cretaceous and Tertiary age, interrupted in places by small groups of mountains of a more complex structure. The several sequences of fresh-water strata resemble each other in so many respects that this misidentification was an early source of confusion. Efforts to determine the correct interrelations resulted in much discussion as given in a very large body of literature.

MONTANA GROUP

The first published statements on the differences between the lower and upper parts of the Upper Cretaceous rocks of the Great Plains were made by Meek (1886, p. 32–33). He noted the magnitude of the paleontologic break between the two parts (later named the Colorado group and the Montana group, respectively). And stated that "the upper surface of the Niobrara beds [Colorado group] is, at several places on the Missouri, seen to have been eroded into irregularities, or depressions, previous to the deposition of the succeeding [Montana group] * * *." White (1878, p. 21, 22, 30) redefined the Colorado group, as the term is presently used, and Eldridge (1889) proposed the term Montana group in its present connotation.

The sequence and identification of formations in the Montana group were open to question for many years, principally because studies were begun in an area much complicated by folding and faulting. Stebinger (1914, p. 64) gave a concise account of this subject. The commonest error had been in the identification of the Judith River formation, which occupies a medial position in the Montana group, with other continental formations younger than the group. Careful study of this area (around the mouth of the Judith River, about 150 miles west of Fort Peck) by Stanton and Hatcher (1905) established the correct sequence of formations. They found the fresh- and brackish-water clays, lignites, and sandstones of the Judith River formation to be both overlain and underlain by lead-gray shales resembling the "Fort Pierre shale" in physical appearance and fossil content. They gave the name Claggett shale to the shale below the Judith River formation, from old Fort Claggett at the confluence of the Judith and Missouri Rivers. The shale above the Judith River formation they named the Bearpaw shale, from typical exposures north, east, and south of the Bearpaw Mountains. Their report (Stanton and Hatcher, 1905, p. 68) correlated the formations of the Montana group in central Montana with those in South Dakota. The following information is taken from their original chart (Stanton and Hatcher, 1905, p. 62):

Group	South Dakota section	Central Montana section:
Montana	Fox Hills formation	Fox Hills(?) formation
	Pierre shale	Bearpaw shale Judith River formation Claggett shale Eagle sandstone

It remained for Stebinger (1914) to construct a unified picture for the area east of the Rocky Mountains in northwestern Montana by using the data gathered by earlier workers and supplemented by his own fieldwork. His stratigraphic diagram (Stebinger, 1914, p. 67, fig. 9) is reproduced in figure 2 with slight modifications.

The diagram shows that two readvances of the sea took place during Montana time and that the second readvance, represented by the Bearpaw shale, was more extensive than the first, represented by the Claggett shale. Continental sediments, which include the upper part of the Eagle sandstone, the Judith River formation, and the Two Medicine formation, accumulated in areas from which the seas had withdrawn. Sandstones such as those that occur in the Virgelle sandstone member of the Eagle sandstone and the Fox Hills sandstone are strandline deposits.

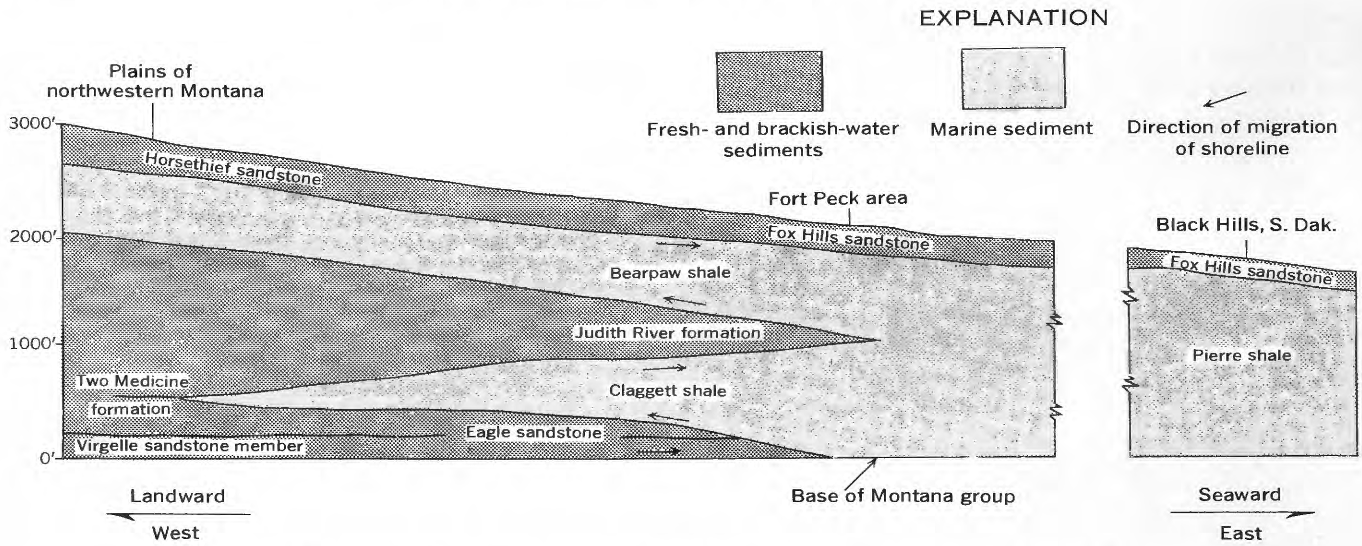


FIGURE 2.—Generalized stratigraphic diagram of the Montana group. (Adapted from Stebinger, 1914.)

C. F. Bowen did mapping in the Judith River area at about the same time that Stebinger was engaged in the work discussed previously. Bowen's (1915) work is important, because he collected and summarized the evidence that clarified the fundamentals of Montana group stratigraphy.

POST-MONTANA GROUP FORMATIONS

The thick fresh-water formations that overlie the Montana group are important because they include enormous tonnages of low-rank coal. The older post-Montana group formations, the Fox Hills and Hell Creek of Cretaceous age, are exposed in the extreme northeast corner and across the southern part of the Fort Peck area. The overlying Fort Union formation of Tertiary age has been stripped entirely from the area.

Some of the earliest and most important contributions to post-Montana group stratigraphy were made by Barnum Brown who spent the summers of 1902 to 1906 in the badlands around Hell Creek, a few miles southwest of the Fort Peck area, where he studied the stratigraphy and collected remains of many kinds of dinosaurs.

Among other salient points, Brown (1907) named and described the dinosaur-bearing "Hell Creek beds" as consisting of a lower sandstone portion, separated from the subjacent Fox Hills sandstone by an erosional unconformity, and an upper portion consisting of clays and sandstones. He stated that no lignite occurs in the lower portion and described none in the upper. He also described lignite-bearing beds above the "Hell Creek beds" as being entirely free of dinosaur remains. These beds have a lignite bed at the base and probably are of Fort Union age. He unconditionally assigned the next higher strata to the Fort Union formation.

Barnum Brown returned to Montana during the summers of 1908 and 1909 to map the Upper Cretaceous rocks just to the south and southeast of Fort Peck. In his report on these studies Brown (1914, p. 357) stated that "marine and brackish-water sandstones [of the Fox Hills sandstone] grade into the massive sandstones above [Hell Creek formation] without any sign of discordance."

In later years, coal-mapping parties working in eastern Montana generally failed to recognize an erosional break at the top of the Fox Hills sandstone and considered the separation of the Fox Hills and Hell Creek formations to be arbitrary. Some geologists considered the names inappropriate, and—for a time—the name Lance formation, which was being used in Wyoming, was applied collectively to the Fox Hills and Hell Creek strata in Montana (Collier, 1918, p. 31–32).

Several more papers subsequently presented evidence bearing on the Fox Hills-Hell Creek contact. Probably one of the more important papers resulted from a study by Bauer (1924) on the Freedom dome, some 65 miles south-southwest of Fort Peck. In his report Bauer described a persistent bed at the base of the Hell Creek member of the Lance (Barnum Brown's Hell Creek beds) that contains numerous quartzite and porphyry pebbles. He noted that the subjacent Fox Hills(?) ranges in thickness from 35 to 66 feet. Since his field investigation covered only a small area, he was not aware of how widespread these phenomena are. The most recent work (Jensen, 1951c, 1952b; Colton, 1955a, b) on the stratigraphy of these beds show conclusively that a time break does exist.

SUBSURFACE BEDROCK FORMATIONS

Except for one outcrop of the Judith River formation at Tiger Butte, the Bearpaw shale is the oldest exposed bedrock in the Fort Peck area. Beneath the Bearpaw are several thousand feet of older sedimentary strata. These rocks are relatively well known, because they crop out in many places to the southwest and west. Where they are not exposed, they have been penetrated by many oil and gas borings. Information from these borings indicates that, beneath the Bearpaw shale in the Fort Peck area, there is 7,000 to 7,500 feet of sedimentary strata that range in age from Late Cretaceous to Cambrian and rest unconformably on Precambrian crystalline rocks.

EXPOSED BEDROCK FORMATIONS

The bedrock formations exposed at the surface in the general vicinity of the Fort Peck area (pl 1) range in age from mid-Late Cretaceous to Tertiary (Paleocene) and include, from oldest to youngest, the Judith River formation, the Bearpaw shale, the Fox Hills sandstone, the Hell Creek formation, and the Fort Union formation (Ross, Andrews, and Witkind, 1955). The first three formations form the middle and upper parts of the Montana group; the Hell Creek is uppermost Cretaceous and the Fort Union formation is Tertiary. All were formerly present throughout the Fort Peck area (fig. 1), but extensive erosion occasioned by uplift of the Bowdoin dome to the northwest has removed the Fort Union entirely and much of the Hell Creek and the Fox Hills formations. These formations, however, remain in large nearby areas to the south, east, and north. The Judith River formation crops out immediately to the northwest, but only one small area of outcrop within the report area is identified with this formation (see p. F25). The bedrock formation at the surface in most of the Fort Peck area is the Bearpaw shale.

JUDITH RIVER FORMATION

The rocks provisionally assigned to the Judith River formation are in a fault-bounded sliver on Tiger Butte about 7 miles southeast of Glasgow (pls. 1 and 3). The material is predominantly soft gray-brown siltstone and sandy and silty shale but includes some layers of very fine grained thin-bedded sandstone. Although the lack of fossils prevented positive identification, indirect evidence, which is discussed more fully on page F25, indicates that this isolated sliver was upthrown from the upper part of the Judith River formation which, elsewhere near this point, lies more than 400 feet beneath the surface.

BEARPAW SHALE

NAME AND DISTRIBUTION

The Bearpaw shale was first named and described by Stanton and Hatcher (1905) for typical exposures north, east, and south of the Bearpaw Mountains of central Montana. The Bearpaw shale is the surface bedrock in the Fort Peck area, except for a total area of about 12 square miles in the extreme northeastern and southeastern parts of the area.

The middle and upper parts of the formation are adequately exposed for study in the mapped area; satisfactory exposures of the lower beds were studied a few miles northwest of the mapped area in T. 29 N., R. 38 E.

TOPOGRAPHY

The Bearpaw shale is more easily eroded than any of the bedrock formations which overlie it. The slopes of the detrital shale commonly form smooth curves. In those few broad areas where the shale is the surface deposit, the Bearpaw forms either badlands (fig. 3) or

FIGURE 3.—The Bearpaw shale on the lower slopes of Milk River Hill in sec. 4, T. 26 N., R. 42 E., erodes to badlands and supports only sparse vegetation. Scars of old landslides illustrate the inherent instability of the Bearpaw even when undisturbed by human agency.

a terrain of small hills having gentle slopes. The badlands formed from the Bearpaw are generally much less rugged than those formed from the Hell Creek and Fox Hills, because Bearpaw strata vary less in their resistance to erosion.

Structure contours on the bedrock surface in the Fort Peck reservoir area are approximately parallel to the long axis of the reservoir, so that the same suite of bedrock strata form the shore throughout the extent of the reservoir. These strata are the upper part of the Bearpaw shale.

THICKNESS

Fieldwork in the mapped area indicates the Bearpaw shale to be about 1,140 feet thick. Electric logs of test wells for oil and gas that were drilled a few miles south and east of the Fort Peck area indicate a somewhat smaller thickness. This difference in thickness may be due to an actual northerly and westerly thickening of the formation, to errors in the surface measurements, or to inconsistencies in the choice of formation limits.

Tests wells near the Fort Peck area in which the entire Bearpaw shale was recorded on electric logs yield the following data:

Well	Location	Bearpaw shale [1] (feet)		
		Top	Bottom	Thickness
Stanolind-Amerada 1 N.P.R.R.	SE¼SE¼ sec. 5, T. 20 N., R. 45 E.	1,283	2,193-2,228	910-945
Socony-Vacuum, Pegasus Div. F-11-20-P. Waller.	NW¼NW¼ sec. 20, T. 21 N., R. 46 E.	1,457	2,193-2,420	935-963
Amerada 1 Rock Creek Unit.	SE¼SE¼SW¼ sec. 10, T. 22 N., R. 44 E.	856-894	1,890-1,908	996-1,052
Shell 22-35 "A" N.P.R.R.	SE¼NW¼ sec. 35, T. 22 N., R. 47 E.	1,450	2,354-2,402	904-952
Marigold Oil, Ltd., 1 Farnham.	SW¼SW¼ sec. 14, T. 25 N., R. 48 E.	861-874	1,805	931-944

[1] The different curves of the electrical survey of some individual wells indicate formation boundaries to be at somewhat different levels; where this ambiguity occurs the indicated range of values is given. Electric log interpretation by F. S. Jensen.

STRATIGRAPHIC POSITION

The Bearpaw shale lies conformably on the Judith River formation; the contact is transitional. It is overlain conformably by the Fox Hills sandstone; this contact also is transitional.

AGE

The Bearpaw shale, which is in the upper part of the Montana group, is of Late Cretaceous age. According to W. A. Cobban (oral communication, 1960), the Bearpaw of the Fort Peck area, referred to the European standard section, is of Maestrichtian and possibly very late Campanian age.

LITHOLOGY

Almost all the formation consists of dark-gray clayey shale. Bentonite occurs either as distinct beds or is disseminated in the shale. Concretions of several kinds, as well as some sandy shale and silty shale, also make up the formation. A composite measured section is presented in plate 2; all the measurements of units constituting the composite section were made in the Fort Peck area except for measurements of the lower two units, which were made northwest of Glasgow in T. 29 N., R. 38 E.

The Bearpaw shale is subdivided into seven units on the basis of lithology and on the nature and distribution of concretions and bentonite beds. Some units have been traced a few tens of miles, others less. It is not known how persistent or useful the units will prove to be for stratigraphic correlation in adjacent areas or whether any of them deserve member rank.

Bentonite, a common constituent, is disseminated in the shale and occurs as distinct beds. Bentonite beds are so abundant in some parts of the formation or are of such distinctive character or sequence that stratigraphic position within the formation is readily determined by them. Most are ¼ inch to 2 inches thick; several are 2 to 10 inches thick, and a few are locally as much as 2 feet thick. Distinctive character depends on thickness, color, and presence or absence of mica. Colors range from pale green, pale yellow, or cream to neutral gray. The mica, probably biotite, where present, is more abundant near the base of individual beds, but in some places the mica is so abundant throughout that it darkens the color of the rock considerably. Lower contacts of the bentonite beds are sharp; upper contacts are gradational.

Distinctive concretions are characteristic of certain parts of the formation; in some places a particular kind of concretion is limited to a single bed, in other places a distinctive kind occurs in zones that are as much as a few hundred feet thick (pl. 2). Cone-in-cone structures, which occur as partial envelopes around concretions, are common in the Bearpaw shale. The concretions are classified as follows:

1. Clay-ironstone concretions (fig. 4), the most abundant, generally range from 6 inches to 2 feet in maximum diameter. The smaller concretions are generally oval both in plan and cross section. The large ones are oval in cross section but nearly circular in plan. They are nonseptarian and contain

FIGURE 4.—Alternate wetting and drying, the result of fluctuating water levels, cause the Bearpaw shale exposed along the shoreline of the Fort Peck Reservoir to slack and disintegrate. Wave action then moves the comminuted shale to deeper water, leaving behind a "lag concentrate" of concretions.

very few fossils. Unweathered cores are light olive gray (5*Y* 6/1), and outer weathered parts are dusky red (10*R* 2/2) and dusky brown (5*YR*

2/2). Clay-ironstone concretions and bentonitic shale are so commonly associated that a genetic relation is suggested.

2. Medium dark-gray ($N4$) fossiliferous limestone concretions are second in abundance and are limited largely to the upper and middle parts of the formation. These are similar in size to the clay-ironstone concretions and are also nonseptarian. They generally weather yellowish gray ($5Y$ 8/1).
3. Ovoid and disk-shaped septarian concretions, some of which are fossiliferous, seem to be limited to a few stratigraphic positions within the formation. They are 3 to 8 feet in diameter, and exhibit, in different strata, all the colors noted for the other types of concretions. Locally, the concretions are enclosed in yellowish-brown "envelopes" several inches thick that are also of concretionary origin. The septaria are generally honey-yellow calcite although, at one horizon near the top of the formation, they are also composed of colorless or smoky barite.
4. "Tepee butte" limestone concretions of the type first described in the Pierre shale of southeastern Colorado by Gilbert and Gulliver (1895) occur in the Fort Peck area in a thin zone about 530 feet below the top of the Bearpaw. They commonly occur in this general stratigraphic position in many western interior States (Darton, 1905, p. 68, 108, 168). In general, the "tepee butte" concretions of the Fort Peck area conform to Gilbert's original description (Darton, 1905, p. 108) which states that the concretions consist of "coarse, gray fossiliferous limestone, irregular or rudely cylindrical in form and standing vertical within the shale mass. Ordinarily they are from 5 to 30 feet in horizontal diameter and their vertical extent is greater." Except at Twin Buttes, 2 miles southwest of the Glasgow quadrangle, the concretions in this area do not form prominent topographic features but occur as irregular masses only partially stripped of the enveloping shale. Most are found in the central part of T. 26 N., R. 39 E., and along the highway in sec. 29, T. 28 N., R. 42 E. Only locally are the concretions of this zone large enough to constitute "tepee butte" limestone masses. The zone is represented laterally by concretions of gradually diminished size; the smaller concretions of this zone are similar in size and shape to the fossiliferous-limestone concretions just described, although they are somewhat lighter in color.

WEATHERING

The shale at the surface is much weathered, and completely unweathered shale is exposed only at the baffles at the foot of the Fort Peck Reservoir spillway (locality inaccessible), where erosion is extremely rapid. The fresh shale is very dark gray and seems fairly well consolidated.

Weathering disaggregates the shale considerably, probably through leaching of colloidal matter. Corroded crystals of selenite form in the weathered zone. The scarcity or absence of these crystals on actively eroding slopes indicates that the crystals are entirely a product of weathering. Figure 5 shows two mechanical analyses of weathered shale, which is generally close to light olive gray ($5Y$ 5/1 to $5Y$ 5/2) though somewhat darker at places where less thoroughly weathered, such as in cutbanks that are being actively eroded.

Depth and thoroughness of weathering depend upon rate of erosion, composition of the beds, and intricacy of jointing. Thus, the thickness of the weathered zone ranges from several feet to several tens of feet. Other factors being equal, the weathered zone is relatively shallow over beds that contain appreciable quantities of bentonite dispersed in the shale or that include laminations of nearly pure bentonite. Initial weathering concentrates the bentonite as a surface rind that swells when wet and forms a seal that inhibits further weathering. When dry, the rind has a cracked and porous spongy surface and is easily distinguished from the soft flaky chips that mantle the nonbentonitic shale. Weathering is deepest in nonbentonitic shale where there is little erosion.

Abundant shallow fractures separate the weathered shale into small blocks. These fractures decrease in number downward and are comparatively rare in fresh shale. The comparatively few deep fractures found locally in the Bearpaw shale were produced by slumping of large blocks and, in a few places, by faulting. Because the shale is nearly impervious, except along fractures, deposition of mineral matter by percolating water has sealed many of the fractures.

FAUNA

A large marine fauna, mostly molluscan, has been collected from the Bearpaw shale of the Fort Peck area. This material was referred to William A. Cobban of the U.S. Geological Survey for identification; his faunal lists are given in the following table. Among his comments (written communications, 1952) on the material are the following:

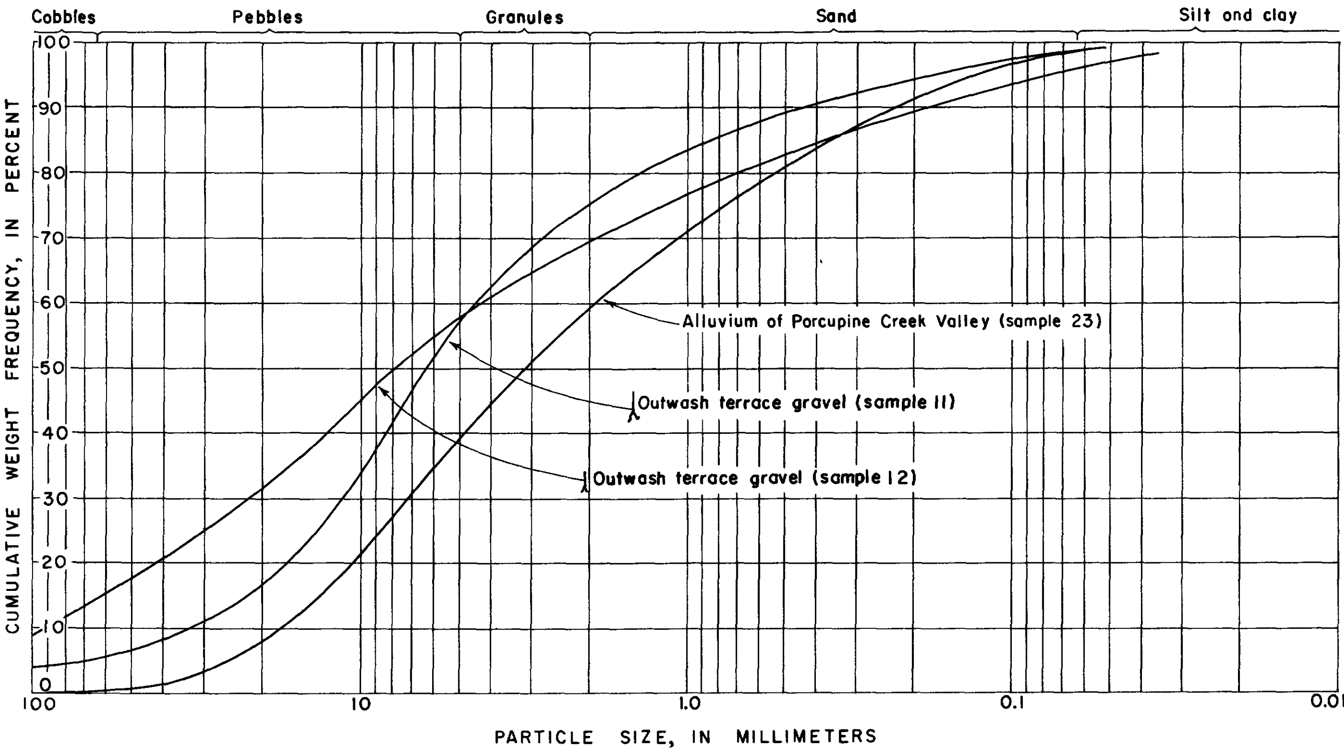


FIGURE 5.—Mechanical analyses of samples of weathered Bearpaw shale, Fox Hills sandstone, and till.

These collections are of * * * interest and value in that they contain excellent specimens of such rare species as Warren's *Pecten saskatchewanensis*, Whitfield's *Hoploparia browni*, and the young stages of Hyatt's *Emperoceras*.

Actinosepia canadensis Whiteaves is the pen of a cuttle-fish, described originally from the "Upper Montana" of Canada. This is the third record of the fossil.

[Collection 23509] containing *Hesperorhynchia superba* Warren, is of exceptional interest in that this brachiopod has never previously been reported from the United States.

The scaphite collections show the presence of two zones. The lower, which extends through most of the [Bearpaw] formation, is characterized by the genus *Acanthoscaphites*. The upper zone has *Discoscaphites* as its guide fossil.

The genus *Baculites* is well represented in the Bearpaw shale, and the several species present have proved to be very useful in zoning. Specimens are of varied abundance stratigraphically but are present throughout.

List of fauna collected from the Bearpaw shale of the Fort Peck area, Montana

[Units within Bearpaw shale: L, lower unit; M, middle unit, U, upper unit; ?, unit uncertain]

	USGS Mesozoic locality	Location	Units within Bearpaw shale (see pl. 2*B;* L, lower; U, upper)													
			1		2		3	4		5			6			
			L	U	L	U		L	U	L	M	U	L	M	U	?
			MOLLUSCA													
			Pelecypoda													
"Astarte" gregaria (Meek and Hayden)	23361	E½ sec 5, T. 26 N., R. 42 E												×		
Pecten nebrascensis Meek and Hayden	23361	do												×		
Cuspidaria ventricosa (Meek and Hayden)	23361	do												×		
Cymella montanensis (Henderson)	23387	S½ sec. 3, T. 33 N., R. 37 E				×										
Dosiniopsis deweyi (Meek and Hayden)	23366	E½ sec. 11 and NE¼ sec. 26, T. 28 N., R. 41 E.					×									
Goniomya americana (Meek and Hayden)	23376	Center sec. 16, T. 29 N., R. 43 E												×		
Inoceramus sp	23360	E½ sec. 5, T. 26 N., R. 42 E												×		
Inoceramus sagensis Owen	22140	NE¼ sec. 12, T. 26 N., R. 41 E											×			
	23359	E½ sec. 5, T. 26 N., R. 42 E											×			
	23361	do												×		
	23369	SE¼ sec. 11, T. 28 N., R. 41 E					×									
	23376	do												×		
	23388	SE¼SW¼ sec. 1, T. 26 N., R. 41 E											×			
	23392	SE¼ sec. 11, T. 28 N., R. 41 E					×									
	23502	do							×							

List of fauna collected from the Bearpaw shale of the Fort Peck area, Montana—Continued

	USGS Mesozoic locality	Location	Units within Bearpaw shale (see pl. 2*B;* L, lower; U, upper)													
			1		2		3	4		5			6			
			L	U	L	U		L	U	L	M	U	L	M	U	?
MOLLUSCA—Continued																
Pelecypoda—Continued																
Inoceramus cf. *I. sagensis* Owen	23362	SE¼ sec. 5, T. 26 N., R. 41 E.														
Inoceramus sublaevis (Hall and Meek)	23387	SE¼ sec. 5, T. 26 N., R. 42 E.			×											
Laternula? sp	23366	do					×									
Leptocardia borealis (Whiteaves)	23361	do												×		
	23371	SE¼SE¼ sec. 11, T. 26 N., R. 41 E.											×			
	23374	W½ sec. 2, T. 27 N., R. 40 E.														×
	23388	do											×			
Leptocardia subquadrata (Evans and Shumard)	23361	do												×		
	23363	do													×	
Limopsis parvula (Meek and Hayden)	23386	Near S½ sec. 3, T. 33 N., R. 37 E.	×													
Lucina occidentalis (Morton)	23366	do					×									
	23370	SE¼NW¼ sec. 29, T. 28 N., R. 42 E.							×							
Lucina subundata (Hall and Meek)	23389	Center sec. 34, T. 29 N., R. 41 E.						×								
Nucula sp	23360	do												×		
Nucula cancellata Meek and Hayden	23363	do													×	
Nucula subplana Meek and Hayden	23361	do												×		
	23376	do												×		
Ostrea sp	23361	do												×		
Ostrea patina Meek and Hayden	23365	NE¼ sec. 26, T. 28 N., R. 41 E.					×									
	23366	do					×									
	23369	do					×									
	23375	NE¼ sec. 36, T. 28 N., R. 41 E.					×									
	23380	SW¼ sec. 13, T. 28 N., R. 41 E.					×									
Pecten saskatchewanensis Warren	23366	do					×									
Pteria linguaeformis (Evans and Shumard)	23376	do												×		
	23381	Near S½ sec. 3, T. 33 N., R. 37 E.	×													
Pteria (*Oxytoma*) *nebrascana* (Evans and Shumard)	23359	do											×			
	23361	do												×		
	23366	do					×									
	23376	do												×		
Volsella meekii (Evans and Shumard)	23376	do												×		
Volsella cf. *V. meekii* (Evans and Shumard)	23509	do											×			
Volsella, n. sp	23361	do												×		
Veniella cf. *V. subtumida* (Meek and Hayden)	23509	do											×			
"*Yoldia*" *evansi* (Meek and Hayden)	23361	Near S½ sec. 3, T. 33 N., R. 42 E.												×		
	23362	SE¼ sec. 5, T. 26 N., R. 42 E.													×	
Gastropoda																
Acteon? sp	23361	E½ sec. 5, T. 26 N., R. 42 E.												×		
Anisomyon alveolus (Meek and Hayden)	23360	do												×		
Anisomyon sexsulcatus (Meek and Hayden)	23373	W½ sec. 2, T. 27 N., R. 40 E.														×
Cylichna cf. *C. secalina* Shumard	23376	do												×		
Drepanochilus evansi Cossman	23361	do												×		
	23363	do													×	
Drepanochilus cf. *D. evansi* Cossman	23360	do												×		
Ellipsoscapha subcylindrica (Meek and Hayden)	23361	do												×		
	23363	do													×	
Fasciolaria galpiniana (Meek and Hayden)	23370	do							×							
Fasciolaria(?) *flexicostata* (Meek and Hayden)	23376	do												×		
Fasciolaria(?) sp	22140	do											×			
Polinices sp	23361	do												×		
	23381	do	×													
Pyrifusus newberryi (Meek and Hayden)		do												×		
Vanikoro ambigua (Meek and Hayden)	23361	do												×		
Scaphopoda																
Dentalium gracile Hall and Meek	23360	W½ sec. 2, T. 27 N., R. 40 E.												×		
Dentalium pauperculum (Meek and Hayden)	23361	do												×		
	23391	SE¼sec. 5, T. 26 N., R. 42 E.													×	
Cephalopoda																
Decapoda: *Actinosepia canadensis* Whiteaves	21381	SE¼ sec. 5, T. 26 N., R. 42 E.												×		
Nautiloidea																
Eutrephoceras montanensis (Meek)	23360	SE¼ sec. 5, T. 26 N., R. 42 E.												×		
	23370	do							×							
	23502	do							×							

List of fauna collected from the Bearpaw shale of the Fort Peck area, Montana—Continued

	USGS Mesozoic locality	Location	Units within Bearpaw shale (see pl. 2*B*; L, lower; U, upper)													
			1		2		3	4		5			6			
			L	U	L	U		L	U	L	M	U	L	M	U	?
MOLLUSCA—Continued																
Ammonoidea																
Acanthoscaphites sp.	22145	E½ sec. 5, T. 26 N., R. 42 E.										×				
Acanthoscaphites brevis (Meek)	22142	SE¼ sec. 5, T. 26 N., R. 42 E.												×		
	22141	SE¼SE¼ sec. 11, T. 26 N., R. 41 E.											×			
	22139	SE¼NW¼ sec. 29, T. 28 N., R. 42 E.							×							
Acanthoscaphites nodosus (Owen)	22140	NE¼ sec. 12, T. 26 N., R. 42 E.											×			
Acanthoscaphites planus (Meek and Hayden)	22142	do.												×		
	22143	SE¼ sec. 5, T. 26 N., R. 42 E.												×		
	22141	do.											×			
	22140	do.											×			
Acanthoscaphites quadrangularis (Meek and Hayden)	22142	do.												×		
Baculites sp.	23381	do.														
	23387	do.														
B. compressus Say	22141	do.														
	23358	do.														
	23364	NW¼ sec. 1, T. 27 N., R. 42 E.									×					
	23370	do.														
	23371	do.														
	23378	NW¼SW¼ sec. 8, T. 27 N., R. 42 E.						×								
	23379	SW¼NE¼ sec. 14, T. 26 N., R. 41 E.											×			
	23382	Near S½ sec. 3, T. 33 N., R. 37 E.				×										
	23384	W½ sec. 2, T. 27 N., R. 40 E.														
	23390	T. 34 N., R. 38 E.									×					
	23393	Opposite mouth of Musselshell River.								×						
B. corrugatus Elias	23373	do.														
	23385	W½ sec. 2, T. 27 N., R. 40 E.														
	23389	do.														
	23368	NE¼ sec. 26, T. 28 N., R. 41 E.					?									
	23360	do.														
	23359	do.														
	23361	do.														
B. grandis Hall and Meek	22144	do.														
	23363	do.														
	23391	do.														
Discoscaphites n. sp.	22146	SE¼ sec. 5, T. 26 N., R. 42 E.													×	
	23391	do.													×	
Discoscaphites n. sp., aff. *D. abyssinus* (Morton)	22144	SE¼ sec. 5, T. 26 N., R. 42 E.													×	
Didymoceras nebrascense (Meek and Hayden)	23373	do.														×
	23381	do.	×													
Didymoceras stevensoni (Whitfield)	23382	do.				×										
	23383	W½ sec. 2, T. 27 N., R. 41 E.														×
	23384	do.														×
Placenticeras intercalare Meek	23377	NE¼ sec. 21, T. 28 N., R. 41 E.					×									
Placenticeras meeki Boehm	23366	do.					×									
	23367	NE¼ sec. 26, T. 28 N., R. 41 E.					×									
	23502	do.							×							
Rhaeboceras albertense (Warren)	23390	NE¼ sec. 26, T. 28 N., R. 41 E.										×				
Solenoceras mortoni (Meek and Hayden)	23388	do.											×			
BRACHIOPODA																
Inarticulata																
Lingula nitida Meek and Hayden	23376	NE¼ sec. 26, T. 28 N., R. 41 E.												×		
Articulata																
Hesperorhynchia superba Warren	23509	NE¼ sec. 26, T. 28 N., R. 41 E.											×			
ARTHROPODA																
Crustacea																
Hoploparia browni Whitfield	23371	NE¼ sec. 26, T. 28 N., R. 41 E.											×			
Hoploparia aff. *H. tennesseenis* Rathbun	21380	W½ sec. 4, or E½ sec. 5, T. 26 N., R. 42 E.										×				

Most fossils are in moderate-to-small-sized limestone concretions. A few are in the large septarian concretions, although they are somewhat less abundant in the concretions containing sufficient iron oxide to make the weathered outer portion dark reddish brown. Fossils are very sparse in clay-ironstone concertions.

ENGINEERING CONSIDERATIONS

Both unweathered and weathered shale are readily excavated with power tools, although some of the larger concretions might slow down progress. The network of small fractures in the weathered part facilitates excavation but necessitates timbering in tunnels and in large pits. Because the shale has a very low permeability, water seepage is negligible except along major fractures. Subsurface drainage is very poor, even in highly weathered shale.

Landslides, including large-scale slumping, are potential hazards wherever the shale is exposed to unusually rapid weathering and wherever construction involves cutting or building on steep slopes.

Unweathered shale slacks and loses strength very rapidly unless protected from wetting and drying. Wet shale reverts rapidly to plastic mud, so that unsurfaced roads on the shale are impassable in wet weather. Large quantities of coarse aggregate must be added to produce a satisfactory subgrade. Figure 5 shows two mechanical analyses of the weathered shale. Soil classification and Atterberg limits are given in figure 6 for shale containing dispersed bentonite (sample 25), for nonbentonitic shale (sample 14), and for bentonite (sample 13).

The characteristics just mentioned are of considerable significance in regard to shoreline erosion, which is unusually active along the borders of the Fort Peck Reservoir (fig. 4). The upper part of the Bearpaw shale, which everywhere forms the shoreline, provides a soft, easily erodible material that is readily removed by wave action, precipitation, and the slumping that results from fluctuations in reservoir level.

The hills that border the reservoir are in many places capped by the Fox Hills and Hell Creek formations. Where these more resistant strata have slumped, the Bearpaw shale slopes are partly but inadequately protected by the resulting debris (fig. 7) against shoreline erosion.

The rate of recession of the shoreline is a function of the ease with which the shale weathers (fig. 4) and of the frequency and magnitude of reservoir-level fluctuations. Weathering causes an intricate system of fractures to develop in the shale. Water enters these fractures and lubricates the fracture surfaces, thereby promoting landsliding. The water introduced into the shale by precipitation and by infiltration below minimum reservoir level plays an important role in these processes, but particularly important are the rises in reservoir level which cause saturation of the contiguous parts of the shale slopes. The stability of the shale is greatly reduced during the ensuing drawdown because of the lubrication of the fracture surfaces and because of the weight of the added water. The net effect is to provide a large amount of slump debris at the shoreline, which is soon triturated by wave action and comminuted by wetting and drying. The resulting fine-grained debris is moved to deeper water by gentle currents over low gradients; hence, the shore profile of equilibrium that is now developing will be a long slope gently concave upward.

FOX HILLS SANDSTONE

The Fox Hills sandstone was first described by Meek (1886) and Hayden (1862) from exposures along the bluffs of Fox Ridge in the area that is now northwestern Armstrong and southwestern Dewey Counties in northwestern South Dakota, about 350 miles southeast of the Fort Peck area.

DISTRIBUTION

The Fox Hills sandstone underlies 12 square miles in the south-central and extreme northeastern parts of the map area; locally, it is overlain by the younger Hell Creek formation or is partly concealed by surficial materials.

Studies of the Fox Hills were extended beyond the mapped area, even though all parts of the formation are well exposed here, in order to determine the persistence and lateral relationships of stratigraphic features within and bounding the formation. These studies were extended southwestward to include the Hell Creek-Devil Creek-Seven Blackfeet Creek drainage areas in Garfield County on the south side of Fort Peck Reservoir and the Larb Hills in Valley County on the north side; traverses were also made eastward into McCone County and northward to the Opheim area in Valley County; the Colgate sandstone member was examined at its type locality in Dawson County.

TOPOGRAPHY

The Fox Hills is well exposed in the badlands (fig. 7) east of the Fort Peck Reservoir but is only poorly exposed on slopes of the hilly upland in the northeast corner of the map area. The number and quality of exposures differ according to the part of the formation involved. The lower beds are soft and largely uncemented, and most beds commonly weather to gentle or moderate slopes (fig. 7). The well-cemented parts of the upper part of the Fox Hills sandstone stand out as rimrock (figs. 7 and 8) because of their superior resistance to erosion.

THICKNESS

The Fox Hills sandstone reaches a thickness of as much as 120 feet in the Fort Peck area. The lower 35 to 40 feet is made up of beds transitional from the underlying Bearpaw shale to the overlying sandstone. The period of erosion in northeastern Montana that intervened between deposition of the Fox Hills and the overlying Hell Creek formation produced considerable local variations in the thickness of the Fox Hills, so that in and adjacent to the Fort Peck area the measured thickness ranges from at least 35 to 146 feet (fig. 9).

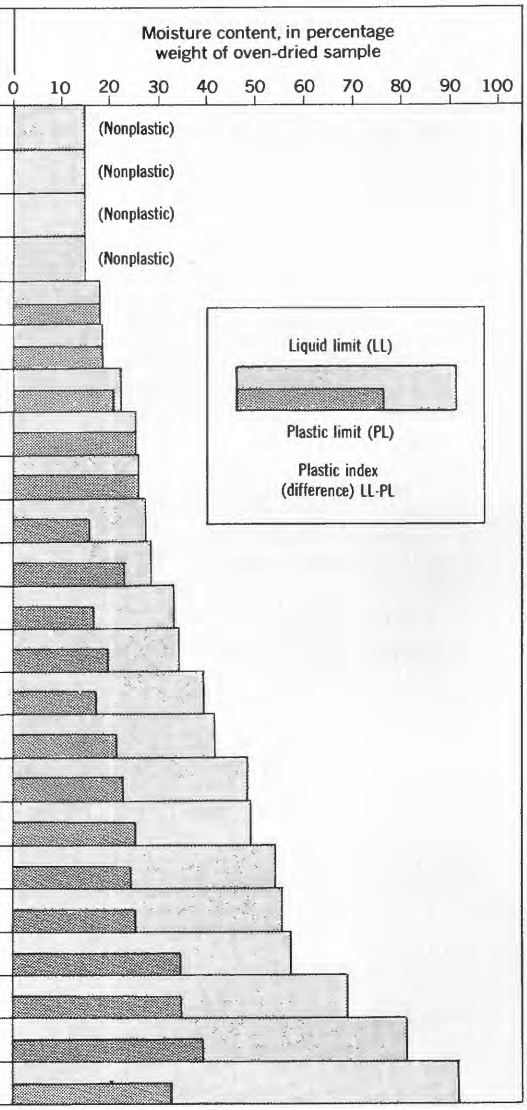
STRATIGRAPHIC POSITION

The Fox Hills sandstone lies conformably on the Bearpaw shale; the contact is transitional (fig. 10). An erosional unconformity separates the Fox Hills from the overlying Hell Creek formation.

AGE

The Fox Hills sandstone, the uppermost formation of the Montana group, is of Late Cretaceous age. The formation is not of the same age throughout its area of occurrence in the northern Great Plains, inasmuch as it is a strandline deposit of an easterly retreating shoreline. W. A. Cobban (oral communication, 1952) said that the fauna near the type locality indicates a younger age than the fauna of the Fox Hills in northeastern Montana.

Sample	Location	Classification[1]	Map unit	Moisture content, in percentage weight of oven-dried sample
8	NE¼NW¼ sec. 29, T. 28 N., R. 42 E.	A-1-a	Wiota gravels (Qw)	(Nonplastic)
11	NE¼SW¼ sec. 36, T. 28 N., R. 41 E.	A-1-a	Gravel of the outwash terrace deposits (Qot)	(Nonplastic)
23	NE¼SE¼ sec. 23, T. 28 N., R. 41 E.	A-1-a	Sandy gravel from alluvium (Qal) of Porcupine Creek valley	(Nonplastic)
31	NW¼NW¼ sec. 9, T. 26 N., R. 42 E.	A-3	Loose sand from the Fox Hills sandstone (Kfh)	(Nonplastic)
12	Center sec. 35, T. 28 N., R. 41 E.	A-1-a	Gravel of the outwash terrace deposits (Qot)	
19	NE¼NE¼ sec. 29, T. 29 N., R. 41 E.	A-1-a	Wiota gravels (Qw)	
1	SW¼SE¼ sec. 17, T. 28 N., R. 41 E.	A-4	Loose sand from the upper part of the Wiota gravels (Qw)	
30	NE¼SE¼ sec. 8, T. 26 N., R. 41 E.	A-2-4	Alluvium (Qal) of Missouri River valley	
4	Center SW¼ sec. 19, T. 27 N., R. 42 E.	A-2-4	Sand-silt of the Kintyre formation (Qk)	
7	SE¼NE¼ sec. 36, T. 28 N., R. 41 E.	A-2-6	Colluvial facies of the Wiota gravels (Qw)	
6	NE¼NE¼ sec. 1, T. 27 N., R. 41 E.	A-4	Alluvium (Qal) of Milk River valley	
26	Center sec. 6, T. 26 N., R. 41 E.	A-6	Till from the ground moraine (Qgm)	
15	SE¼NE¼ sec. 20, T. 28 N., R. 42 E.	A-6	Till from the ground moraine (Qgm)	
28	NE¼NW¼ sec. 10, T. 27 N., R. 41 E.	A-7-6	Till from the ground moraine (Qgm)	
22	NW¼SW¼ sec. 36, T. 29 N., R. 41 E.	A-7-6	Till from the ground moraine (Qgm)	
2	NE¼NE¼ sec. 13, T. 26 N., R. 41 E.	A-7-6	Till from the ground moraine (Qgm)	
24	SE¼NW¼ sec. 31, T. 28 N., R. 42 E.	A-7-6	Clay-silt-sand from upper part of alluvium (Qal) of Porcupine Creek	
10	NW¼NE¼ sec. 18, T. 27 N., R. 42 E.	A-7-6	Clay from intermittent pond deposits (Qp)	
21	NE¼NW¼ sec. 28, T. 29 N., R. 41 E.	A-7-6	Alluvium-colluvium (Qac)	
14	SW¼NE¼ sec. 11, T. 28 N., R. 41 E.	A-7-5	Bearpaw shale (Kb), without disseminated bentonite	
3	Center SW¼ sec. 19, T. 27 N., R. 42 E.	?	Shaly clay from the Kintyre formation (Qk)	
25	SE¼SE¼ sec. 6, T. 26 N., R. 42 E.	?	Bearpaw shale (Kb), with disseminated bentonite	
13	Center sec. 35, T. 28 N., R. 41 E.	A-7-5	Bentonite from Bearpaw shale (Kb)	



[1] U.S. Bureau of Public Roads Classification of highway subgrade materials

FIGURE 6.—Atterberg limits and soils classification of test samples. Data from results of tests by Montana State Highway Department.

FIGURE 7.—On Milk River Hill (sec. 4, T. 26 N., R. 42 E.) the upper part of the Bearpaw shale (foreground) is overlain by light-gray weathered beds composing the lower part of the Fox Hills sandstone. The resistant sandstones of the upper part of the Fox Hills cap the hill. Mass wasting has mantled the Bearpaw shale with debris of the Fox Hills sandstone.

FIGURE 8.—The rimrock formed by the upper beds of the Fox Hills sandstone is characteristically developed here on Milk River Hill in the SE cor. sec. 5, T. 26 N., R. 42 E. Flattened ellipsoidal concretionary masses, harder and darker than the sandstone matrix, form ledges and cap pedestals.

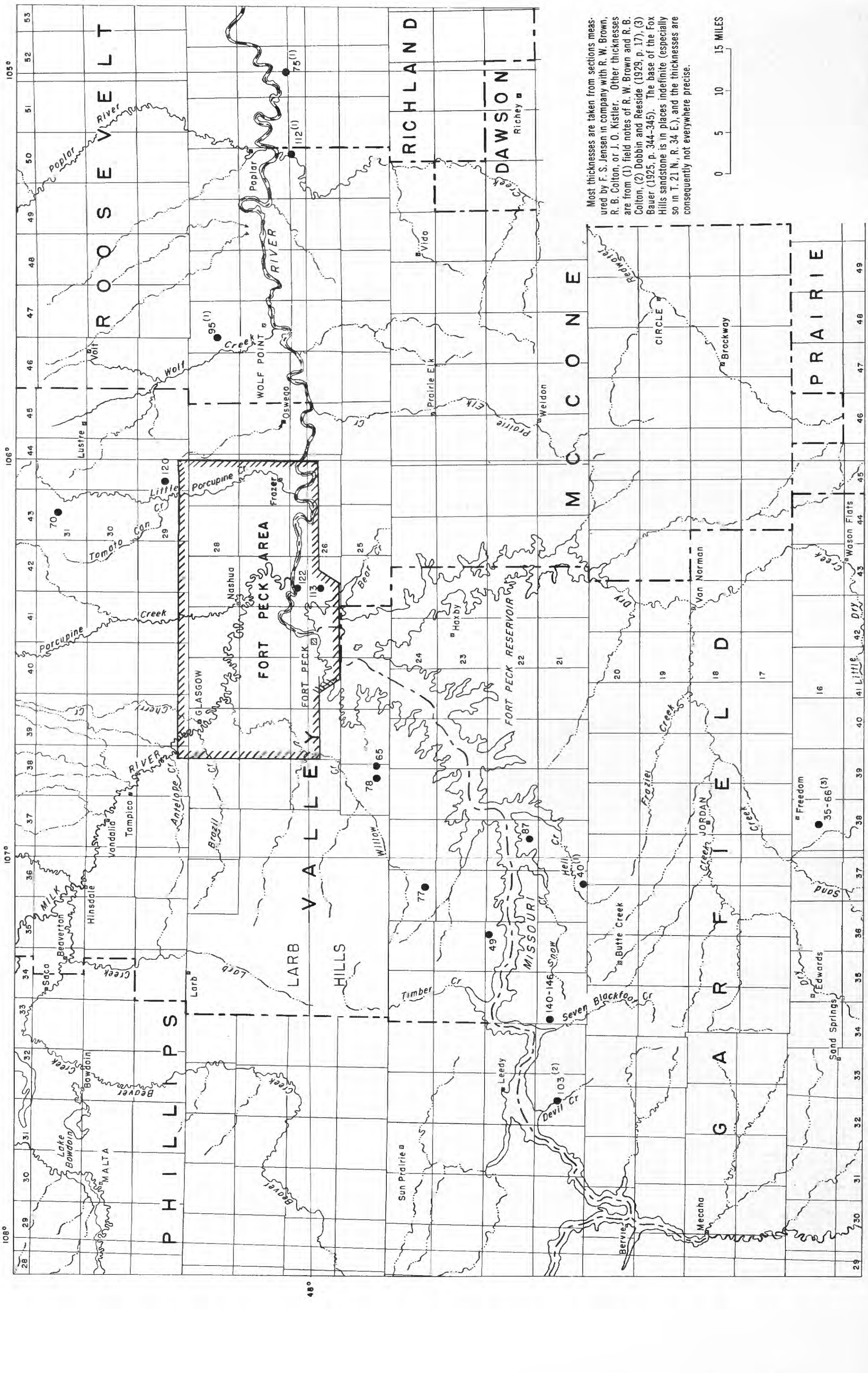


FIGURE 9.—Map of the Fort Peck area and adjoining portions of northeastern Montana showing thickness, in feet, of the Fox Hills sandstone, including the Colgate member where present.

LITHOLOGY

The lower part of the Fox Hills is composed of noncalcareous thin beds of alternating soft claystone, siltstone, and very fine sandstone, the finer grained beds predominating near the base. Near the top of this sequence at most localities there are 1 or 2 discontinuous ledges of sandstone as much as 8 inches thick lithified with calcareous cement. These ledges show small-scale crossbedding, but other bedding in the lower part of the formation is parallel. Unweathered rocks beneath the surface are various shades of yellowish gray (5*Y* 6/1, 5*Y* 6/2, 5*Y* 7/2) below and of light dusky yellow (5*Y* 7/4) and dark yellowish orange (10*YR* 6/6) above. The lower part of the Fox Hills sandstone typically weathers light olive gray (5*Y* 7/1) and light gray (*N*7), colors that are easily distinguished from the underlying drab-gray Bearpaw shale.

The upper part of the Fox Hills is as much as 85 feet thick. Most of it is fairly uniform very fine grained sandstone; the rest is lenticular thin-bedded shale and siltstone. Some of the sandstone is thin bedded; much is massive bedded, and a small part is crossbedded. Some of the crossbedding near the top is on a fairly large scale, approaching that seen in the overlying Hell Creek formation. Most of the weathered material is yellowish brown (10*YR* 6/4) to dark yellowish orange (10*YR* 6/6), but many colors from dark brown to pale gray are represented. Fresh sandstone is close to pale yellowish brown (10*YR* 6/2). The sandstone ranges from very soft to hard owing to differential cementation by calcium carbonate.

At several localities in the vicinity of Fort Peck where tests were made, all the cemented Fox Hills above the transition beds, as well as the cemented sandstones within the Hell Creek formation, are calcareous. The transition beds and the Bearpaw shale are, on the other hand, noncalcareous. The fact that the cementing material is calcium carbonate contrasts with the findings of Thom and Dobbin (1924, p. 492), who hold that the Fox Hills and the underlying strata are relatively free of lime, whereas the Colgate,[1] Hell Creek, and overlying strata are markedly calcareous.

Concretionary masses (fig. 8) are common in the Fox Hills sandstone above the transition beds. Most abundant are thick lens- and log-shaped concretions cemented by calcium carbonate ranging from several feet to several yards in maximum dimension; these form the intricately eroded rimrock that is a conspicuous feature of the Fox Hills sandstone in this area (fig. 8).

Small spherical sandstone concretions cemented by pyrite are also common. They are pea-sized to golf-ball sized and occur alone or joined in pairs or chains. There are clay-ironstone concretions, generally smaller than those in the Bearpaw shale, that range from walnut size to slabs 6 to 8 inches thick and 2 to 3 feet long.

ORIGIN OF THE FOX HILLS

The composition and bedding of the lower part of the formation are consistent with the widely held view that the Fox Hills is predominantly marine, but an unequivocal statement as to the marine brackish- or fresh-water character of the Fox Hills in the Fort Peck area cannot be made on the basis of the present study.

No fossils, other than a few carbonized plant fragments near the top of the formation, were found during the present study; however, marine fossils have been reported from the Fox Hills in several other parts of Montana. Barnum Brown (1907, p. 827) collected 14 species of marine invertebrates from the Fox Hills at a point on Hell Creek about 40 miles southwest of Fort Peck. Bowen (1915, p. 116) obtained a small collection of the marine brachiopod *Lingula* from a sandstone "probably near the top of the transition zone" of the Fox Hills at a point about 90 miles southwest of Fort Peck. Dobbin and Reeside (1929, p. 17) cited a measured section at a point on Devil Creek about 60 miles west-southwest of Fort Peck, in which they list a 2-foot-thick bed of "hard brown sandstone [containing] *Lingula nitida* Meek and Hayden in abundance." This bed is 59 feet above the base of the Fox Hills and is 12 feet below the Colgate member (this member is present locally at the top of the Fox Hills sandstone in eastern Montana and is discussed subsequently). Colton (oral communication, 1952) has found a few specimens of *Halymenites*, a fucoid commonly considered marine, in the lower part of the Fox Hills at a point just south of the Missouri River and about 50 miles east of Fort Peck. Dobbin and Reeside (1929, p. 11) said that in southeastern Montana "the lower member of the [Fox Hills] formation contains a few marine invertebrates." Dobbin and Reeside (1929, p. 15) also reported "abundant remains of *Halymenites major*" from the Colgate member. In South Dakota, Wyoming, and Colorado, marine fossils are so characteristic that Lovering and others (1932, p. 702–703) have defined the top of the formation as the top of predominantly marine beds.

In eastern Montana, however, there is some basis to suggest that the upper part of the Fox Hills is non-

[1] Samples were collected by Jensen from the lower, middle, and upper parts of the Colgate member near its type locality in southeastern Montana, and from the Colgate member on Devil Creek in northwestern Garfield County, Mont. The material is uniformly noncalcareous.

marine. R. W. Brown (1939, p. 239) described a flora from the Colgate member in southeastern Montana and, in noting other plant collections from the Fox Hills, said: "Plant fossils, although relatively scarce, have been reported occasionally from the continental and shore facies of the Fox Hills sandstone." Thom and Dobbin (1924, p. 490) agreed with those specifying a nonmarine character for parts of the formation, for in describing the Colgate member "along the Missouri between Hell Creek and Musselshell River" they said that the member resembles "its type development in lithology, though probably of fresh-water rather than strand accumulation."

In the Fort Peck area the presence of plant fragments and sandstones in the top few feet of the Fox Hills suggests a continental origin for this part of the Fox Hills. Much of the continental material in this general area has probably been removed by pre-Hell Creek erosion, and surviving beds are apparently limited to places where the overall thickness of the Fox Hills sandstone is the greatest.

APPLICABILITY OF THE TERM COLGATE MEMBER IN THE FORT PECK AREA

Collier and Knechtel (1939, p. 9–10, pl. 3) held that the Colgate member of the Fox Hills is present in McCone County. A part of the county is in the Fort Peck area, but no part of the Fox Hills formation cropping out in McCone County corresponds to the following description by Thom and Dobbin (1924, p. 490):

> the conspicuous, white, upper sandstone of the Fox Hills, typically developed between Colgate station and Glendive, Montana, and extensively exposed along Cedar Creek anticline and elsewhere in eastern Montana. In addition to fossil leaves, the Colgate sandstone * * * contains abundant casts of *Halymenites major* in exposure along the Cedar Creek anticline and is gradational into the underlying marine strata on Little Beaver Creek. The Colgate is strikingly developed along the Missouri between Hell Creek and Musselshell River * * *.

In company of R. W. Brown, R. B. Colton, and J. O. Kistler, the senior author visited the area between Hell Creek and the Musselshell and attempted to trace the Colgate member eastward into McCone County and the Fort Peck area. Snowy white in its more westerly exposures, the member gradationally changes its character eastward and is indistiguishable as a lithologic unit before Hell Creek is reached. Though Collier and Knechtel (1939, p. 10) base their opinion on the work of Barnum Brown (1914), nowhere in his paper nor, as a matter of fact, in his earlier paper on this area (Barnum Brown, 1907) is there any mention of a white sandstone. It seems most probable that the upper part of the Fox Hills sandstone in the Fort Peck-McCone County area is the stratigraphic equivalent of the Colgate member, but there is no reason for applying the member name here.

ENGINEERING CONSIDERATIONS

Weathering has not affected the strength of the material of the Fox Hills to the degree that it has affected the Bearpaw shale, though near-surface material has probably been somewhat softened by the leaching of cementing constituents. Surface drainage is good. Subsurface drainage varies with degree of cementation but is generally fair to good.

Probably very little ground water can be recovered from the Fox Hills sandstone within the Fort Peck area. There are no springs at the contact of the relatively pervious sandstone with the nearly impervious Bearpaw shale beneath. Minor perched water tables are likely to be present because of the wide local variations in degree of cementation within the formation.

The semiconsolidated lower part of the formation and the sand and soft sandstone of the upper part can be excavated with power tools. The discontinuous masses of hard sandstone, which are so common in the upper part, require blasting for removal.

Both shallow and deep cuts should stand well even at angles steeper than 45°, though some sloughing from cut surfaces should be expected. Large cuts extending through the formation into the underlying Bearpaw shale might be subject to landsliding. Unsurfaced roads crossing the Fox Hills sandstone are passable in all weather.

The indurated sandstone might be useful as a construction material, but the irregular occurrence of these hard layers and the wide variations in quantity from one outcrop to the next would greatly raise the costs of development.

Soil classification and Atterberg limits of loose sand from the upper part of the formation are given in figure 6 (sample 31). A mechanical analysis of this sand is shown in figure 5.

STRATA OVERLYING THE MONTANA GROUP

One of the most widely discussed questions of the early geologists of the western interior of the United States was the Cretaceous-Tertiary boundary (the subject was often referred to as "the Lance-Laramie Problem"). The strata principally involved in the discussions were the Fox Hills sandstone, the Hell Creek formation, the Fort Union formation, and the lateral time equivalents of these and other formations that were believed to chronologically intervene or to be lateral time equivalents.

At present the position of the Tertiary-Cretaceous boundary itself is no longer actively disputed and is placed at the contact of the Hell Creek formation (or the equivalent Lance) with the overlying Fort Union formation (Dorf, 1942). The nature of the contact between the Fox Hills and the Hell Creek was studied by Thom and Dobbin (1924) and again by Dobbin and Reeside (1929), and they expressed the opinion that there was virtually no break in sedimentation between the Fox Hills and the Hell Creek. Recent studies of the Fox Hills and Hell Creek formations in the general Fort Peck area establish that the two formations in that part of Montana are consistently disconformable (fig. 10), and that a significant break in sedimentation between the two there may be indicated.

HELL CREEK FORMATION

NAME AND DISTRIBUTION

The Hell Creek formation was named and first described by Barnum Brown (1907) for typical exposures along Hell Creek in Garfield County, 30 to 40 miles southwest of the Fort Peck area.

The lower part of the Hell Creek formation is present in about 5 square miles in the northeastern and south-central parts of the area.

The Hell Creek formation was also examined beyond its scanty occurrences in the mapped area; these examinations were made in McCone County south and east of the mapped area, in the Valley County as far north as the Opheim area and as far west as the Larb Hills (fig. 13), and in Garfield County at the type locality along Hell Creek.

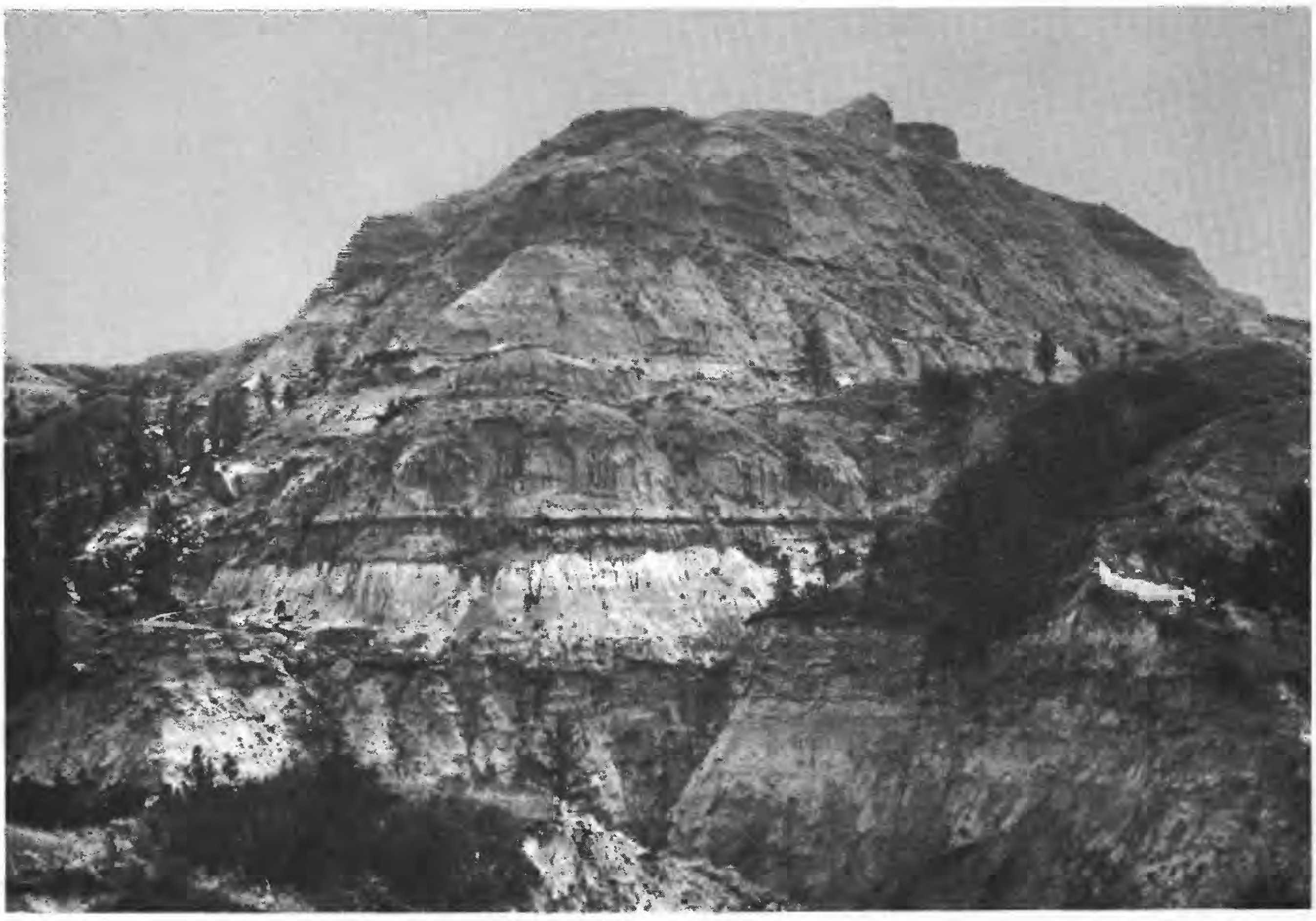


FIGURE 10.—The contact of the white Colgate member of the Fox Hills sandstone with the overlying Hell Creek formation is sharp and scalloped by pre-Hell Creek erosion. Photograph taken in the valley of the Seven Blackfoot Creek (T. 20 N., R. 34 E.). The Bearpaw shale exposed in the lower parts of the narrow canyon is gradational upward into the lower member of the Fox Hills sandstone.

TOPOGRAPHY

The Hell Creek formation underlies the Flaxville formation, which caps the isolated hills and the upland in the northeastern part of the Frazer quadrangle. In the area east of the Fort Peck Dam and south of the Missouri River, the Hell Creek formation and the Fox Hills sandstone form a rolling upland. This terrain is much dissected by steep-sided coulees (fig. 12) and otherwise interrupted by ledges of sandstone (fig. 11), which owe their prominence to their superior resistance to erosion. Growths of green ash and cottonwood trace the coulee bottoms and provide shelter for deer and cattle. Sandstone ledges, remnants of lenses well above the base of the formation, occur in buttes here and there on the upland (fig. 11).

Farther south, where it is more extensive, the Hell Creek formation is eroded into spectacular badlands in many places; the hard concretionary masses and remnants of sandstone ledges cap pedestals, buttes, and various intricate landforms having sides or lower slopes cut, commonly in fluted fashion, in the softer interbeds. Bentonitic beds resist erosion more effectively than otherwise similar beds lacking disseminated bentonite, and many badland domical hills and round-topped ridges, totally devoid of vegetation, owe their prominence to protective caps of bentonitic sand or shale.

THICKNESS

Except at Indian Hill (fig. 11) where about 140 feet of the Hell Creek formation is present, only the lower 50 to 60 feet of the formation is preserved in the Fort Peck area. Barnum Brown (1907) reported 560 feet to be the total thickness of the formation at the type locality, and R. B. Colton (written communication, 1952) reported that the Hell Creek ranges from 220 to 280 feet in total thickness in the bluffs south of the

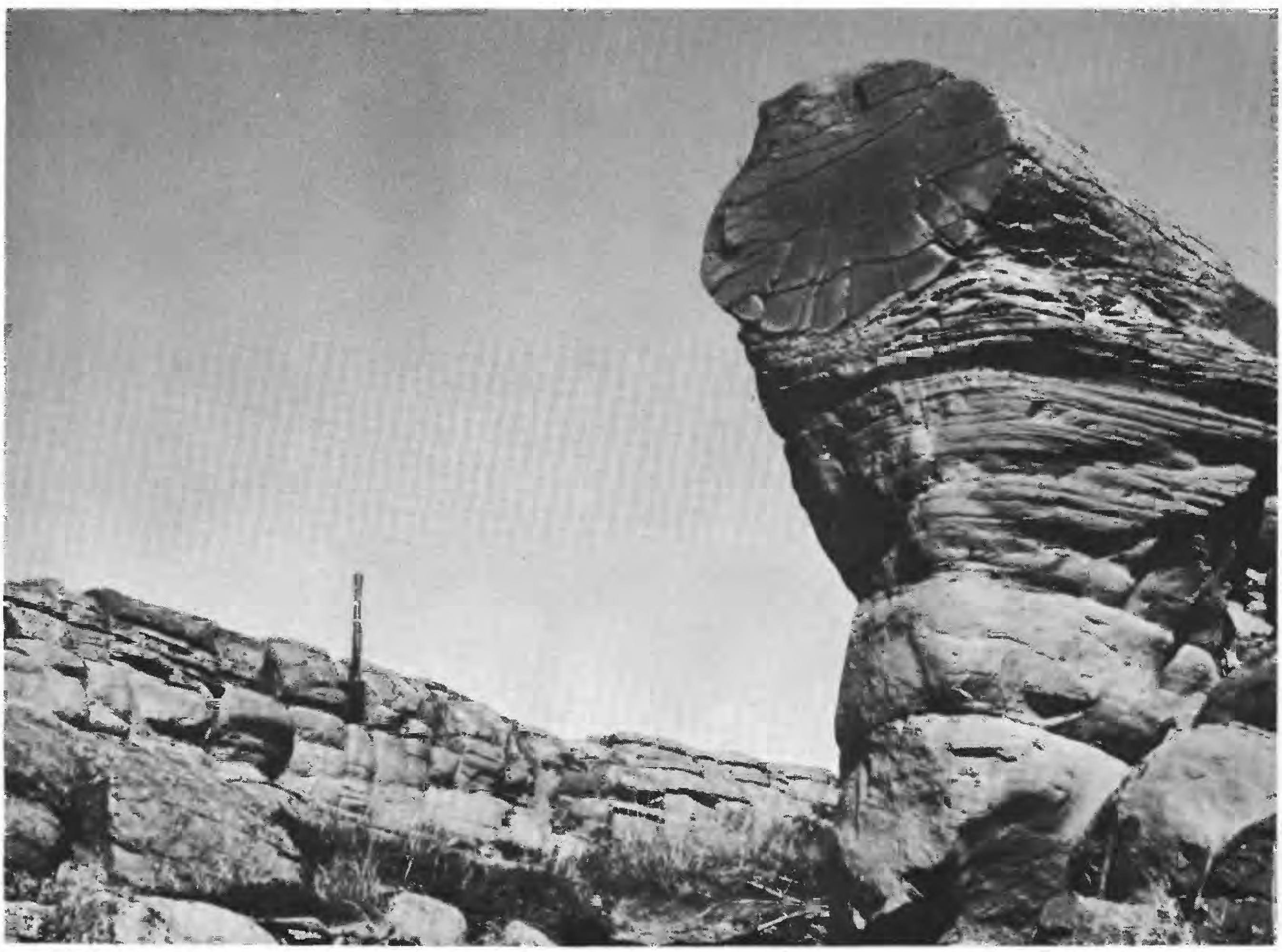


FIGURE 11.—Indian Hill (sec. 28, T. 26 N., R. 42 E.) is typical of the hills and buttes capped by resistant lenses of sandstone in the Hell Creek formation in the southeastern part of the Fort Peck area. Hard, loglike sandstone concretions, such as the one pictured above, are common in these lenses. A small trenching shovel, 27 inches long, provides scale.

Missouri River, about 45 miles east of Frazer between Poplar and Brockton.

AGE

The Hell Creek formation is the youngest Cretaceous formation in the area, and it, as well as its lateral equivalent, the Lance (see p. F17), is further considered to be latest Cretaceous in age. In its type area it carries a classic and abundant dinosaurian fauna, in addition to a sparse invertebrate fauna and substantial flora. Dinosaur bones and fossil plants are common in Hell Creek strata in most exposure in eastern Montana.

LITHOLOGY

The Hell Creek formation is of continental fresh-water origin and consists dominantly of soft claystone and shale (carbonaceous in part), siltstone, and silty fine- to medium-grained sandstone. The colors range through many shades of brown, gray, and violet (fig. 12); the Hell Creek strata are often referred to in the literature as the "somber beds." Some of the beds are bentonitic, and all are lenticular. Beds of soft and hard brown medium-grained sandstone occur at the base and as lenses higher in the formation. The basal sandstone also contains lenses of finer grained sediments which are more common upward, so as to be gradational into overlying beds. Lignite and lignitic beds are present although very sparse and discontinuous in the upper part of the formation.

In the Fort Peck area the basal sandstone is consistently present in the lower several tens of feet of the formation and is, moreover, fairly uniform in lithologic character. The sand is medium grained, fairly well sorted, rusty gray brown, and conspicuously speckled with black minerals (fig. 5). Large-scale crossbedding, including a type ascribed by Collier (1918, pl. 4*B*) to wind action, is conspicuous in this basal sandstone, as well as in most of the beds of well-sorted sandstone higher in the formation (fig. 13). Some of the sand-

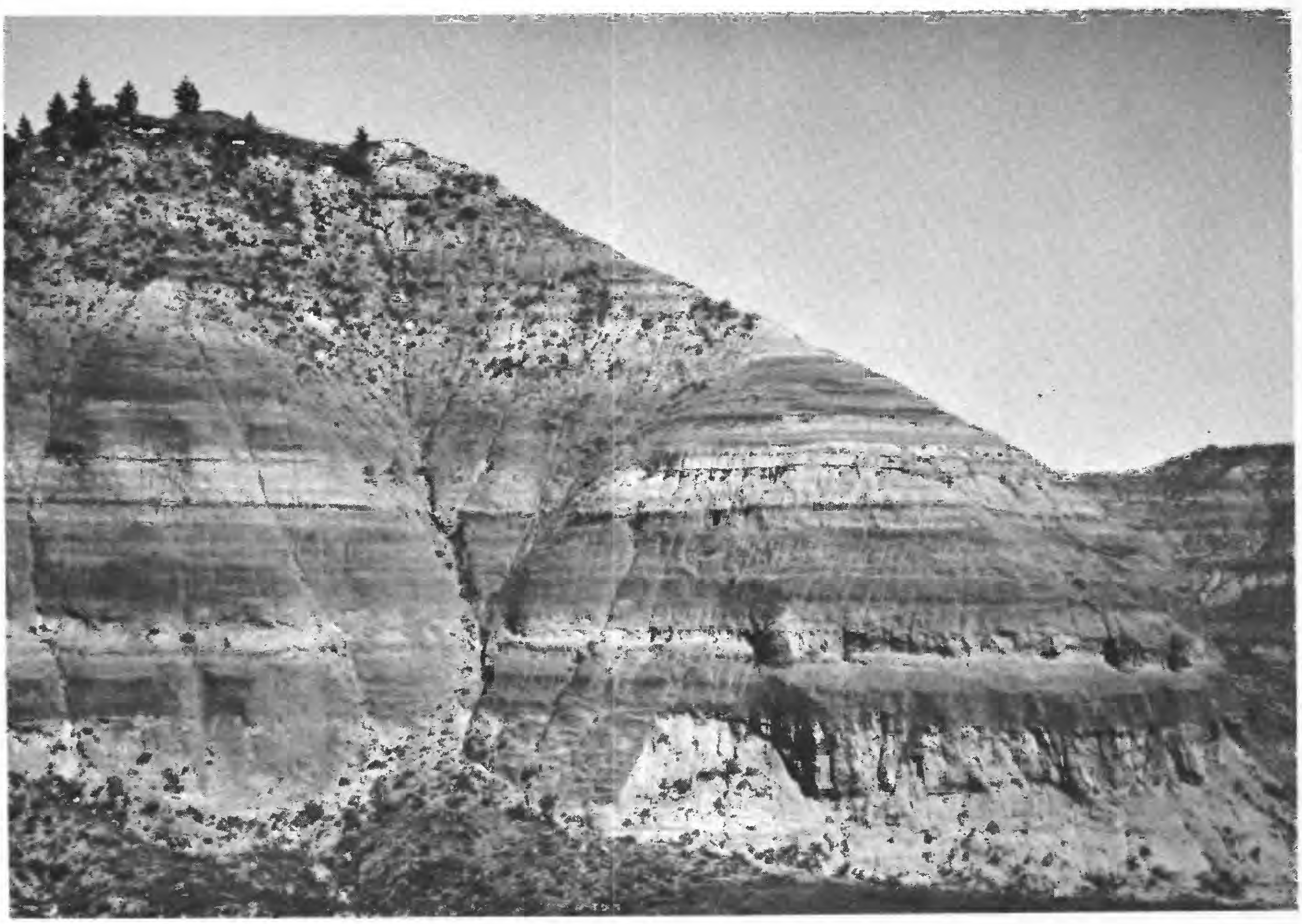


FIGURE 12.—Except for basal sandstone beds and some stratigraphically higher local sandstone layers, the Hell Creek formation is composed of clays, silts, and soft silty sands, in part carbonaceous and in part having disseminated bentonite. Many hills eroded from beds of the Hell Creek are capped by sandstone ledges, such as this one in sec. 7, T. 26 N., R. 43 E.

stone is cemented by calcium carbonate into hard ledge-forming rock. Some of this cementation affects whole sandstone lenses, but more commonly it seems to form concretionary structures around point and linear centers yielding hard ellipsoidal and cylindrical masses (figs. 13 and 11). This differential cementation has limits, which in some places are abrupt and in others gradational.

Locally in the lower few feet of the formation there are lenses of poorly sorted conglomerate. The conglomerate occupies channels eroded, in some places, into the upper surface of the Fox Hills sandstone, and in other places into the lower beds of the Hell Creek formation (fig. 14). The lenses are generally less than 2 feet thick, even where the channels are deeper; in places are mere pebble lines. The conglomerate is poorly sorted, heavily iron stained, and—on the whole—weakly cemented, mostly by oxides of iron. None was found which is sufficiently hard to be topographically prominent. Most of the component fragments are subangular to subrounded and from ½ inch to 4 inches in long dimension; a very few are 6 to 9 inches across. The fact that the chief constituent is fragments of concretions from the local bedrock may be the reason why these conglomerate lenses have gone unnoticed by earlier workers; the lenses are similar in appearance to the "trashy" concretionary layers commonly found higher in the formation. Minor constituents are surrounded pieces of lithified dinosaur bones and fossil wood and smooth well-rounded pebbles and cobbles of quartzite (fig. 16). Almost all the quartzite pebbles are light gray (*N* 5.5 to *N* 8), though some are slightly stained by iron oxide and are yellowish gray.

This quartzite is dissimilar to the pebbles in the Wiota gravels or the Flaxville formation, and its source is not suggested by any evidence available in the Fort Peck area.

R. B. Colton (oral communication, 1958) found these conglomerate lenses, containing the same constituents, at and near the base of the Hell Creek in the area adjoining the Fort Peck area on the east.

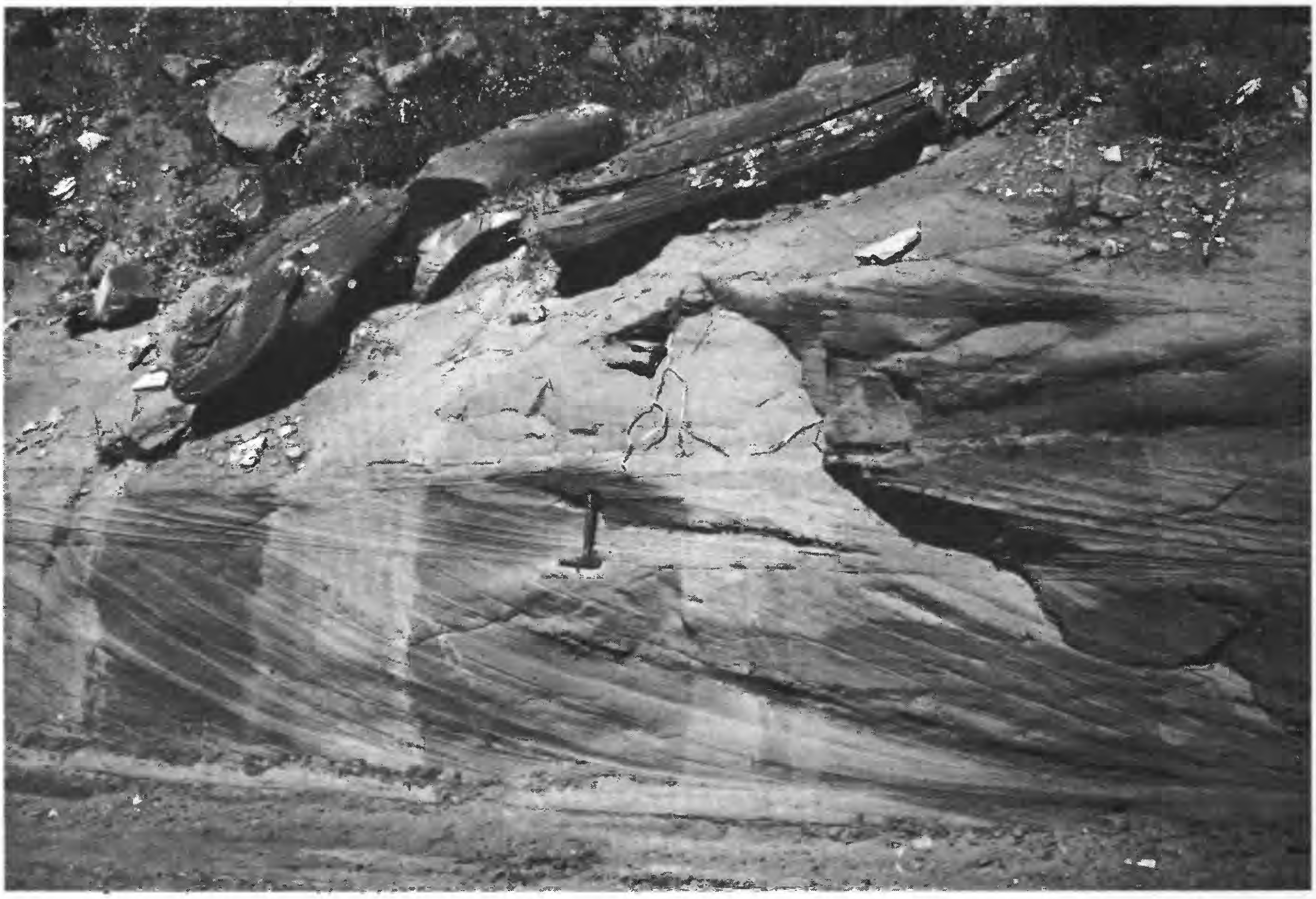


FIGURE 13.—Large-scale crossbedding and hard ovoid sandstone concretions are prominent features of the sandstone beds in the Hell Creek formation in the east-central part of Montana. Photograph taken in the Larb Hills in sec. 30, T. 24 N., R. 36 E. Hammer provides scale.

Quartzite pebbles in this stratigraphic position have previously been reported by Bauer (1924) 65 miles south-southwest of Fort Peck:

one-half to three inches or more in diameter, at the base of the [Hell Creek] formation * * *. The pebbles are imbedded in impure limonite which also contains a small amount of coarse sand * * *. Most of the pebbles are of light-buff quartzite, but several porphyry pebbles were also found * * *. The contact does not seem very irregular at this place, and indications of channeling are rare, though the varying thickness [35 to 66 feet] of the Fox Hills(?) indicates a slightly undulating surface upon which the earliest [Hell Creek] strata were deposited, suggesting a local unconformity at least.

The lower 50 to 60 feet of the Hell Creek formation in the mapped area consists for the most part of sandstone; in addition, there are thin lenses of pebble-and-cobble conglomerate and a variety of concretionary masses of fossil bones and fossil plants, including wood. The ledge weathers to yellowish brown (10*YR* 4.5/3); where unweathered, it is gray.

The beds above the basal sandstone are commonly very thin or absent in the mapped area except at Indian Hill. This hill is a butte standing about 100 feet above the surrounding upland. It is capped by a remnant of a 15-foot-thick hard sandstone lens; below the caprock the slopes of the butte are characteristic somber-colored clays and shales, some of which are carbonaceous.

DISCONFORMABLE CONTACT WITH THE FOX HILLS SANDSTONE

The contact between the Hell Creek formation and the underlying Fox Hills sandstone was examined by the senior author in the area extending from the longitude of Seven Blackfeet Creek (fig. 10), in Garfield County, eastward to the longitude of Prairie Elk Creek, in McCone County, a distance of about 100 miles. Wherever exposed, the contact is sharp (fig. 10), and the upper surface of the Fox Hills is channeled in many places. Individual channels are generally less than 10 feet deep, but R. B. Colton (oral communication, 1958) reported a channel more than 35 feet deep in northwestern Richland County in sec. 26, T. 27 N., R. 52 E.

FIGURE 14.—The Hell Creek formation locally contains conglomeratic lenses in channels at the base or within the lowest few feet of the formation. At the point of the pick is one of the smooth well-rounded gray quartzite cobbles which are a distinctive feature of these channel fills in the Hell Creek. Photograph taken by R. B. Colton in sec. 11, T. 26 N., R. 47 E. The pick handle is 17 inches long.

Most of the channels are filled with medium-grained sandstone of the same composition as the rest of the thick basal sandstone of the Hell Creek; however, channels floored with conglomerate are not uncommon, and fine-grained carbonaceous "trash" fills some of the channels cut into the Colgate in Garfield County. Barnum Brown (1907, p. 827) found in the Hell Creek country that "there is usually a thin layer of ferruginous flat concretions of small size" capping the top of the Fox Hills.

Even where the actual contact cannot be examined, the following differences persist between the basal sandstone of the Hell Creek formation and the sandstone of the Fox Hills and allow ready identification of the contact.

1. The grain size of the basal sandstone of the Hell Creek is medium, distinctly coarser than the fine-grained sandstone of the Fox Hills.
2. The sandstone of the Hell Creek formation has a conspicuous peppered appearance which the sandstone of the Fox Hills does not.
3. There is a difference in color, subtle only to the unpracticed eye; the sandstone of the Fox Hills is comparatively bright rusty yellow brown, whereas the sandstone of the Hell Creek formation is a more somber and darker rusty yellow brown.
4. Conglomerate beds, some containing a few quartzite pebbles and cobbles (fig. 14), are peculiar to the Hell Creek, except for a very few small lenses of edgewise conglomerate in the Fox Hills.
5. Dinosaur remains, fossil wood, and fossil plants are common in Hell Creek strata and are extremely scarce in Fox Hills strata.
6. Crossbedding in sandstone of the Hell Creek formation is on a relatively large scale (fig. 13) and can be measured in feet; crossbedding in the Fox Hills sandstone is, for the most part, on a relatively small scale and measurable in inches. Exceptions to these general conditions occur in the areas where pre-Hell Creek erosion has not too severely reduced the thickness of the Fox Hills. In these places, crossbedding in the upper part of the Fox Hills in similar to that in the Hell Creek.

Where the white Colgate member is present and exposed, the use of the distinguishing features just mentioned is academic in locating the contact between the formations. The observed maximum and minimum thicknesses for the Fox Hills sandstone in this part of Montana (fig. 9) are 146 and 35 feet; some of the difference is probably due to original deposition, but pre-Hell Creek erosion is probably an important factor.

Two types of evidence thus are combined to indicate an erosional unconformity between the Fox Hills sandstone and the Hell Creek formation:

1. The sharp and channeled contact between the two formations (fig. 10) and the substantial local differences in thickness of the Fox Hills.
2. The abrupt and substantial differences across the contact in sedimentary and ecological characteristics.

The significance of the disconformity is difficult to assess; it may be a stratigraphic feature restricted to this part of Montana, and it may, moreover, represent an inconsequential gap in the geologic record. Almost certainly it means that the effects of the Laramide Revolution were being felt this far to the east, and hidden in the gap may be clues to changing ecological conditions that soon were to bring about extinction of the dinosaurs.

Some evidence suggests that the disconformity may be widespread. Bauer (1924, p. 344–346) found evidence of disconformity in Garfield County at Freedom dome, 65 miles south-southwest of Fort Peck, and Leonard (1908, p. 44–46, pl. 5) found an erosional unconformity at this horizon near Marmath, N. Dak., some 160 miles to the southeast.

Barnum Brown (1907, p. 829), in his original description and definition of the Hell Creek formation at its type locality 30 or 40 miles southwest of Fort Peck, said that "[the Hell Creek formation] unconformably overlies the Fox Hills * * *. This unconformity is erosional in character." In a later paper Brown (1914, p. 357) gave additional details:

> On the east fork of Crooked Creek near the old Cook ranch, on the west fork of Crooked Creek near the Gus Colin claim, and on the east fork of Hell Creek near the EE cattle camp these marine beds [Fox Hills sandstone] have been eroded in places, sometimes to a depth of 10 feet, before the succeeding massive sandstones of the fresh-water "Lance" [Hell Creek formation] were deposited. The strata are, however, in all cases parallel to the bedding plane of the succeeding sandstones, and the break is evidently of local erosional character.
>
> It was observation of these local erosional breaks in the vicinity of Hell Creek that led to the statement that the beds did not represent a continuous sedimentation from the marine Fox Hill. In view of later work, this statement must be modified.

Barnum Brown's concluding sentence here is unexplained; prossibly it relates in some way to the Cretaceous-Tertiary transition.

CONTACT WITH THE FORT UNION FORMATION

Although the Fort Union formation and the upper Hell Creek strata are missing in the Fort Peck area, the contact between these formations is well exposed less than 8 miles southeast of the Fort Peck Dam. R. W. Brown places the Tertiary-Cretaceous boundary at the contact between the Hell Creek formation and the overlying Fort Union formation.[2] He defines this contact as follows:

"The base of the Fort Union formation (Paleocene) is marked by a persistent lignitic zone or lignite bed, above which lignite beds are common and below which even discontinuous lignite beds are uncommon. At, or within, about 50 feet above the persistent lignite, the somber colors typical of the Hell Creek formation give way upward to a brighter yellowish-brown color typical of the lower part of the Fort Union formation. Dinosaur remains are abundant in the Hell Creek formation but are totally absent in the Fort Union formation."

ENGINEERING CONSIDERATIONS

Most of the statements made concerning the upper part of the Fox Hills sandstone apply equally well to those parts of the Hell Creek formation preserved in the Fort Peck area. The principal differences arise from the coarser grain size of the sand and the sandstone in the Hell Creek formation, which is more permeable and, hence, allows better surface and subsurface drainage.

There are no springs or wells in the Hell Creek formation within the Fort Peck area. It is inferred that only small quantities of ground water are recoverable because of the low annual precipitation, well integrated surface drainage, and dissection by erosion. As in the Fox Hills sandstone, discontinuous cementation probably causes any available water to be perched at different levels.

The unconsolidated sand of this formation might be used as fine aggregate for small concrete structures south of the Missouri River to avoid the expense of bringing in more suitable material from north of the river.

STRUCTURE

REGIONAL STRUCTURAL SETTING

The major bedrock structures of eastern Montana are broad and open, dipping generally only a few tens of feet per mile. Dobbin and Erdmann's (1955) structure-contour map of the Montana plains shows that the attitudes of the beds in the Fort Peck area are influenced by three of these major structures: the Bowdoin dome, the Blood Creek-Sheep Mountain syncline, and the Williston basin.

The Fort Peck area lies on the southeast flank of the Bowdoin dome, about 50 miles from its structural summit. The Bowdoin dome is a nearly circular uplifted area that has about 600 feet of closure over a diameter of roughly 65 miles. It was originally described by Collier (1917), and its central part was later mapped in greater detail by Erdmann and Schwabrow (1941). The Fort Peck area also includes the north limb of the broad Blood Creek-Sheep Mountain syncline, an east-west trending structure no more abrupt than the Bowdoin dome. The synclinal axis is about 60 miles south of the area and plunges gently eastward toward the largest structure in this part of the Great Plains, the Williston basin. Finally, the Fort Peck area is on the extreme west margin of the Williston basin, whose center is more than 100 miles to the east, in western North Dakota.

Between the crest of the Bowdoin dome and the deepest part of the Williston basin there is about 3,500 feet of structural relief, as measured on the top of the Dakota sandstone. Known minor structures and the indications of others, which are as yet unmapped, show that the dip of the strata is not regular either in rate or direction over the great area encompassed by the three major structures.

STRUCTURAL FEATURES IN THE FORT PECK AREA

The structure-contour map (pl. 2*A*) compiled by the senior author is drawn on the top of the Judith River formation and shows only mild departures from the previous regional structure presented by Dobbin and Erdmann (1955). Gentle southeasterly dips from the crest of the Bowdoin dome and toward the Blood Creek-Sheep Mountain syncline and the Williston basin prevail across the entire mapped area. Other lesser structural features, including faults and—in one small area at Tiger Butte—steeply inclined beds, have been positively identified. The presence of similar features is suspected other places. These lesser structural features are noteworthy because (1) few conspicuous structural features have been reported so far in this part of the plains and (2) the involvement of the Wiota gravels in the faulted structures at Tiger Butte show that some of the structural movements have occurred as recently as late Quaternary, a circumstance heretofore almost unrecognized in the northern Great Plains.

Determination of structure was hindered by the character and discontinuous exposure of the Bearpaw

[2] The information presented here regarding the Hell Creek-Fort Union contact was originally collected and organized by Roland W. Brown of the U.S. Geological Survey, who was long a student of the stratigraphy and paleontology of the rocks near the Tertiary-Cretaceous boundary. The boundary near the Fort Peck area was examained in the field by the senior author, in company with Brown, R. B. Colton, and others.

shale, the only surface bedrock formation in most of the area. The Bearpaw is nearly homogeneous and subject to slumping; key beds had to be established at fairly short intervals, and evaluation of slumping effects was made wherever exposures were adequate.

About 50 control points were established for the structure-contour map by measuring with a Paulin altimeter the elevations of (1) key beds within and at the top and bottom of the Bearpaw shale (the Bearpaw-Judith River contact is exposed just northwest of the mapped area) and (2) the level of water in certain wells. Wells yielding water under artesian pressure penetrate the Judith River formation, and well records,[3] therefore, provide an estimate of the depth to the top of Judith River. The map (pl. 2) shows the contours on the top of the Judith River formation.

The position of the several key beds above the top of the Judith River formation were determined by measurement of the intervals between them wherever useful exposures existed; the composite columnar section (pl. 2) is built from average thicknesses based on 1 to 6 measurements per interval. The thickness of the beds not examined in detail (pl. 2) is inferred, because the propensity of these beds to slump prevented accurate measurement. The total thickness of the Bearpaw shale given here, 1,140 feet, is thus only approximate, and—by the same token—so also are the positions of the key beds.

The effects of faulting were not considered in drawing structure-contour lines. Except at Tiger Butte, the few faults observed have displacements of less than 20 feet and are visible only in the cutbanks of streams; therefore, their strikes are indeterminate. Presumably, undetected faults exist.

DEFORMATION AT TIGER BUTTE

Topographically, Tiger Butte (pl. 3; secs. 2 and 3, T. 27 N., R. 40 E.) is an irregular high area about 1 mile in diameter that bears little or no resemblance to the form generally connoted by the word "butte." Its highest hill is near the center of the area and stands about 300 feet above the Milk River flood plain to the north and about 150 feet above the benchland to the south. Because Tiger Butte is flanked immediately on the north by the Milk River flood plain, it is probable that the northern part has been truncated by the river's activity. No topographic or geological elements of the remaining part suggest that Tiger Butte is a remnant of a once larger feature having radial or bilateral symmetry.

[3] Well records were obtained from the files of the Montana State Board of Health at Helena, Mont.

Structurally, Tiger Butte is an "island" of strongly tilted and faulted strata (pl. 3) that rises abruptly from the broad gentle regional dips characteristic of eastern Montana. Tiger Butte is of especial interest, not only because such acute deformation is distinctly abnormal in this area but also because Pleistocene, as well as Mesozoic, deposits have been involved.

The Bearpaw shale is strongly tilted and faulted. If the gentle southesterly dip prevalent in the surrounding areas had not been severely disturbed, beds belonging to the middle part of the formation would crop out at Tiger Butte. Instead, the shale beds exposed there have the characteristics of the lower part of the Bearpaw shale (pl. 3; unit 2 and the upper two-thirds of unit 1). Fossils are comparatively scarce, but collections include *Emperoceras* and *Nostoceras*, two aberrant ammonite genera which W. A. Cobban (written communication, April 1951) specifies as characteristic of the lower part of the Bearpaw. The fact that many hundreds of feet of shale can be measured perpendicular to strike is attributed to repetition of beds resulting from the presence of overthrust bedding-plane faults, because all the beds of the Bearpaw in Tiger Butte apparently can be identified with the lower few hundred feet of the formation elsewhere.

The Wiota gravels of Pleistocene age (see p. F28) are present at several places in the hills of Tiger Butte; near the summit they are clearly tilted and overlain by Bearpaw shale at an overthrust bedding-plane(?) fault. Elsewhere they seem to be involved in deformation in an equally integral manner, but their uncemented character makes objective observation difficult.

Lithologically the Wiota gravels of Pleistocene age (see p. F28) are identical with the Flaxville formation of late Tertiary age (see p. F27), but the gravel beds at Tiger Butte were assigned to the younger formation because of the following evidence: (1) There is no Flaxville formation present for many miles in any direction from Tiger Butte, but Wiota gravels are common in nearby areas; (2) in company with the senior author, Mr. Clarence Lohman found a mammoth tooth in the gravels a few feet from the highest peak of the hills (pl. 3, fossil loc. 5). Jean Hough (written communication, September 26, 1950) of the U.S. Geological Survey reported, in part, as follows:

> The specimen is a lower molar of *Mammuthus boreus* Hay (*Mammuthus primigenius* Blumenbach—*Parelephas jeffersoni* Osborne).
>
> Since mammoths arrived in North America, as far as present knowledge goes, early in the Pleistocene, the age range can be Nebraskan to Wisconsin [any part of the Pleistocene]. If the tooth is correctly associated with the gravels these cannot be [so old as] Pliocene according to vertebrate evidence.

Though the Wiota gravels were deposited discontinuously during much of the Pleistocene, it seems likely that the gravels involved in the Tiger Butte disturbance were deposited late in the Pleistocene, as indicated by the position of Tiger Butte relative to the old valley of the Missouri River (fig. 19). This valley was floored with the youngest of these gravels and flanked by slightly older terrace gravels, which are also included in the Wiota gravels. Thus, the deformation can be stated to be definitely Pleistocene and probably late Pleistocene.

The third geologic formation in the Tiger Butte hills crops out in only one small area but is of unusual interest because it closely resembles certain beds of the Judith River formation. The top of the Judith River formation is calculated to be more than 400 feet beneath the Milk River flood plain elsewhere in this vicinity (pl. 2*A*). (The strata in question form a steeply dipping lens-shaped body about 15 feet wide and 50 yards long that crops out in a precipitous ravine about 300 yards north of the highest hill of Tiger Butte.)

Most of the lens consists of soft gray-brown siltstone and silty and sandy shale that strongly resemble siltstone and sandy shale the transition beds from the Judith River formation to the Bearpaw shale. Some of the material is light-brown very fine grained sandstone, thin bedded and lithified, that closely resembles the ledge-forming beds of the upper part of the Judith River that are exposed on the northeast side of the Milk River flood plain 8 to 10 miles northwest of Glasgow. Assignment of these beds to the Judith River can be only provisional, because no fossils were found in the lens and because there are similar beds in the Fox Hills sandstone. Identification with the Judith River formation rather than the Fox Hills is preferred because:

1. The siltstone and sandy shale "transition" beds in the lens do not weather to the conspicuous light gray rock that is characteristic in this area of the lower part of the Fox Hills sandstone.
2. In the areas around Tiger Butte, the top of the Judith River formation is between 1,600 and 1,700 feet above sea level (fig. 32*A*), and Fox Hills strata are not found below about 2,800 feet. By the time of deposition of the Flaxville formation (late Miocene or Pliocene), the land surface in this area was eroded to elevations lower than 2,800 feet and was eroded still lower by the time of the Tiger Butte disturbance (Pleistocene?). The Fox Hills sandstone, therefore, likely was not present to form part of the hills of Tiger Butte.
3. The presence of beds probably belonging in the lower part of the Bearpaw shale suggests the Tiger Butte area to be one of uplift rather than of subsidence.

Faults of two ages are present. The older faults are subparallel bedding faults produced by overthrusting from the north. They seem to account for repetition of beds within the Bearpaw shale and for emergence of the Judith River formation at the surface. A set of subparallel younger faults strike west-northwest and offsets both the strata and the older faults. The most prominent fault of this second set passes near the highest hill of Tiger Butte and divides the area of Tiger Butte into two nearly equal parts. On the north side of the trace of the fault, the strata strike about N. 58° E. and dip to the northwest at angles ranging from 70° to nearly vertical. On the south side of the trace, the strata strike about N. 75° E. and dip to the north at much less steep angles. Rotation on the fault surface probably accounts for the differences in dip and strike. Slumping associated with modern geomorphic development results in superficial anomalies.

Although the geologic history leading to the structural pattern observed is not known, the following sequence of events is postulated as consistent with known facts:

1. Thrust faulting from north to south yielded imbricate structure, repetition of beds, and relatively steep dips. During this stage the Judith River formation was brought near the surface. Bedrock overrode the Wiota gravels and caused them, in part, to take on the lenticular character of fault gouge.
2. Thrust pressure dissipated and normal faulting was initiated. The normal faulting was accompanied by some rotation, bringing about the steep dips in those fault blocks in the northern half of the hills.
3. The modern topography evolved. Because Tiger Butte is made of weak material, slumping as well as erosion has played a part in shaping topography; slumping causes some aberrant surficial bedding attitudes.

Deep-seated, rather than surficial, causes are responsible for the deformation at Tiger Butte, as evidenced by:

1. The regularity of bedding attitudes in the incompetent Bearpaw shale. Although tilting and faulting are pronounced, there is a marked absence of contorted beds such as would be expected to occur in incompetent rocks deformed by glacial Hills sandstone therefore likely was not present action. Ice shove is likely to produce radically

different structures, such as those in east-central Alberta described by Slater (1927). In that locality the beds have been contorted into sigmoid curves, drag and attenuated-flow overfolds, and diapir curves, all complicated by thrust faults that produced imbricate structure. Furthermore, Tiger Butte is situated in or near the center of the abandoned valley of the ancestral Missouri River (fig. 19), and, owing to this topographic situation, the site should have been "out of reach" of shoving glacial ice. Slumping as a prime cause of deformation is ruled out by the regularity of dips and strikes over most of the butte area.

2. The regularity in the distribution and attitude of the Wiota gravels of Pleistocene age involved in the deformation.
3. The appearance of beds at the surface probably belonging to the Judith River formation.
4. The presence of Bearpaw shale strata other than those to be expected if there had been no crustal disturbance in the local area.

Within the Fort Peck area there is other evidence that crustal adjustments occurred subsequent to the Tazewell(?) glaciation of the area. In the face of a steep cutbank of Porcupine Creek (SE$\frac{1}{4}$ sec. 11, T. 28 N., R. 41 E.), a well-exposed fault offsets Bearpaw shale strata by about 8 feet. Near the top of the cutbank, the same fault offsets the overlying Pleistocene deposits, but the displacement is less than 2 feet. Thus, the fault was active both before and after the Pleistocene materials were deposited.

Abrupt crustal deformation in this part of the northern Great Plains is apparently not unique at Tiger Butte. Townsend (1950) reported folded and faulted Fort Union (Paleocene) strata in northwestern North Dakota extending over an area about 7 miles long and a mile wide and presents evidence indicating a wider distribution of the deformed strata. In further support of his qualified conclusion that the deformation is due to deep-seated causes, Townsend (1950, p. 1563–1564) wrote:

> The Fort Union is generally an incompetent formation, most portions of which, unless firmly confined, would yield easily to the presumably lateral pressures of ice shove and result in a jumbled mass lacking continuity of bedding. Also, the structure near Lignite is at such an elevation and so related to the probable preglacial topography that the beds could hardly have constituted a prominence more vulnerable to ice deformation than surrounding undeformed beds. Deformation similar to that near Lignite but much smaller in scale and extent is conceivable. If evidence favoring ice shove were more abundant in the area described or in other related areas, more weight could be given this possibility. Lacking this, the weight of evidence favors structural deformation.

POST-CRETACEOUS STRATIGRAPHY

GENERAL STATEMENT

The present configuration of the northern Great Plains of the United States and the adjoining Prairie Provinces of Canada is largely the work of two major forces operative during post-Cretaceous time: (1) Gentle but intermittent uplift that probably began in the late Eocene and may be still continuing into Recent time and (2) successive invasions and retreats of Pleistocene ice sheets. The deposits that resulted from these events are largely unconsolidated and can be compared with blankets of uneven thickness, discontinuous distribution, and varied composition. They may be divided into deposits antedating local glaciation, deposits resulting from local glaciation, and deposits formed after glaciation.

FORMATIONS ANTEDATING GLACIATION

The preglacial surficial materials of the Fort Peck area are part of a widespread group of Tertiary and Quaternary gravelly deposits laid down by streams draining east and northest from the Rocky Mountains. These deposits represent recurrent times of regional stability that alternated with times of gentle regional uplift, so that each succeeding deposit mantles a surface that is topographically lower than its predecessor. Because there is no apparent difference in lithology or method of deposition and because identifiable fossils are comparatively scarce, age differences in many places are deduced largely from elevations above sea level and from gradients of the erosion surfaces on which the gravel deposits lie.

The oldest Tertiary formation of the northern Great Plains area is the Cypress Hills gravel of Oligocene age, which is limited to southern Saskatchewan. Deposits assigned to other, possibly less important, times of planation and deposition which followed the Cypress Hills have also been found in southern Canada. Of these, the Wood Mountain gravel (Russell, 1853) of Miocene age is probably the most important. The oldest surficial formation in the Fort Peck area is the Flaxville formation of Miocene and Pliocene age (see p. F27) which is extensively distributed over large parts of northern Montana and eastern Saskatchewan but is present only in the extreme northeast corner of the Fort Peck area. The Wiota gravels, a younger preglacial fluviatile formation, is exposed along the Milk and Missouri Rivers and their major tributaries in the report area and consists of fluviatile material of Pleistocene age.

TERTIARY DEPOSITS

FLAXVILLE FORMATION

NAME TYPE OF DEPOSIT DISTRIBUTION

The Flaxville formation originally described and named by Collier and Thom (Collier, 1917, p. 194–195; Collier and Thom, 1918, p. 179–184) is a fluviatile deposit that caps generally even-topped plateaus and benches sloping gently eastward from about 3,200 feet at the west margin of Blaine County, Mont., to about 2,600 feet above sea level in the southeastern part of Sheridan County, Mont. Within the Fort Peck area, the exposures of the Flaxville are about 2,700 feet in altitude. Alden (1932, p. 13) estimated that the remnants of the Flaxville erosion surface total about 1,800 square miles. R. B. Colton (oral communication, 1958) mapped about 750 square miles of the Flaxville in the Fort Peck Indian Reservation, which includes parts of the area of this report. Within the area of this report, the Flaxville formation is limited to a few small plateau remnants near the northeast corner.

TOPOGRAPHY AND THICKNESS

The Flaxville formation was deposited in northeastern Montana on a well-developed pediplain cut across the Bearpaw, Fox Hills, Hell Creek (Lance), and Fort Union formations at altitudes ranging from 700 to 1,500 feet below the level of the Cypress Hills plain (Alden, 1932, p. 13). The formation is very porous and has eroded slowly except along its margin where it sloughs off owing to the removal of the underlying soft shales and clayey sandstones. Hence, it forms short steep slopes bordering relatively flat uplands or benches. The average thickness of the Flaxville in the Fort Peck area is about 20 feet.

STRATIGRAPHIC POSITION AND AGE

In the Fort Peck area, the Flaxville formation was deposited unconformably on the Bearpaw, Fox Hills, and Hell Creek formations. The ground moraine, which overlaps the Flaxville as well as the older bedrock, is the only material overlying the Flaxville in this area. Elsewhere in northeastern Montana, the Flaxville is locally covered by alluvial and eolian, as well as glacial, deposits. Numerous fragmentary vertebrate remains indicate that the Flaxville formation is probably lower Pliocene. The first important collections by Collier and Thom (1918, p. 181) were pronounced by J. W. Gidley to be "not older than Miocene or younger than lower Pliocene."

R. B. Colton made fossil collections to the east that contained specimens identified by Jean Hough (written communication, 1950) of the U.S. Geological Survey as probably early Pliocene. Colton (written communication, 1959) also stated that "collections of vertebrate fossils from Flaxville made by R. W. Brown and the author were identified by Louis Gazin of the U.S. National Museum as probably early Pliocene or possibly late Miocene."

LITHOLOGY

Within the Fort Peck area, the Flaxville formation is composed predominantly of smooth well-rounded pebbles averaging 2 inches in maximum diameter. Most are brownish gray very fine to medium-grained quartzite, although pebbles of reddish argillite are common. Light-gray quartzite pebbles, such as those at and near the base of the Hell Creek formation, are scarce. The gravel is sandy and includes sand, silt, and clay in thin lenses. In a few places, it is discontinuously cemented to form conglomerate.

Collier and Thom (1918, p. 181) described the Flaxville as

> composed of yellowish to ash-gray gravel, clay and sand, but in some places it contains beds of white marl and volcanic ash. The gravel consists of well-rounded pebbles from less than an inch to a foot or more in diameter, of quartzite and argillite derived from the Rocky Mountains. Limestone pebbles from the same source may have been dissolved and the lime deposited as cementing material and beds of marl. The materials composing the Flaxville gravel are mostly noncoherent and are excavated easily by well diggers, though beds of hard sandstone and conglomerate cemented with calcite from 1 foot to several feet thick are encountered in most of the wells. In places the formation is very thoroughly cemented with calcite and forms prominently outcropping ledges of sandstone and conglomerate * * *.

Collier and Thom (1918, p. 182) also gave a generalized section of the Flaxville formation, in secs. 19, 20, and 29, T. 35 N., R. 43 E., with approximate thickness of each unit as follows:

	Feet
Marl, containing a few scattered quartzite pebbles	15
Sandstone cemented with calcite	30
Volcanic ash, white to yellow, very pure but mixed with the underlying gravel at the base	15
Gravel, more or less cemented	20
Fort Union formation	80

Thus the Flaxville of the Fort Peck area coincides reasonably well with gravel units discussed by Collier and Thom but lacks the ash, sandstone, and marl units.

ENGINEERING CONSIDERATIONS

The Flaxville formation is a source of sand and gravel. Most of it is uncemented and is easily excavated; however, crushing is necessary if angular material is desired. Chemically reactive material (hydrous silicates) probably is less than 1½ percent. Detailed prospecting is necessary to assess overburden.

QUATERNARY DEPOSITS

WIOTA GRAVELS

NAME, TYPE OF DEPOSIT, AND DISTRIBUTION

Although preglacial gravels that are post-Flaxville in age have long been recognized in eastern Montana, they were not given a definite name until 1951. In his report on the Nashua quadrangle Jensen (1952b, p. 45–50) grouped these deposits under the name of Wiota gravels after the Wiota railroad station on the Great Northern Railroad at the junction of the U.S. Government's spur line leading to Fort Peck. According to Jensen's original definition,

Wiota gravels is the name here applied to gravels and associated sediments deposited by streams and rivers prior to glaciation of the sites of deposition of the gravels. The materials are predominantly of western provenance and discontinuously mantle of plain that forms the upland areas of the quadrangle. Wiota gravels underlying this upland are at altitudes ranging from about 2,100 feet to about 2,400 feet above sea level, but further east altitudes are 2,000 feet or less * * *. The Wiota gravels are typically exposed at several places within a radius of about 10 miles of Wiota railroad junction, which is in the eastern part of the quadrangle.

These gravels were deposited on a number of levels ranging from about 200 feet to more than 500 feet below the gravel plain of the Flaxville formation. It is the consensus of the workers that the gravels on these several benches and terraces in eastern Montana cannot be properly subdivided at the present time and that one formational name should be used to refer to them all.

The Wiota gravels are probably the most widespread of the preglacial fluviatile deposits. Field studies by Colton (1951a, b; 1953, 1954; 1955a, b), Witkind (1949), and Jensen (1951a, 1952b) show that the Wiota gravels are present over large areas in Valley, Roosevelt, and Sheridan Counties. The literature strongly indicates that they are also present over other large areas to the west in Montana and to the north in southern Saskatchewan.

Within the Fort Peck area, the formation is discontinuous but widespread beneath the glacial drift north of the Missouri River. It floors buried stream channels and mantles buried erosion surfaces, which generally slope toward the Missouri River. Extensive exposures border the valleys of the Milk River, Porcupine Creek, Cherry Creek, and Little Porcupine Creek.

TOPOGRAPHY AND THICKNESS

Most outcrops of the Wiota gravels are high on the valley sides. Small benches or topographic noses commonly mark the position of the formation, which is generally more resistant to erosion than the overlying or underlying beds.

In most places the observed thickness is 6 to 20 feet, although the formation reaches a maximum thickness of about 30 feet in the vicinity of Wiota.

STRATIGRAPHIC POSITION AND AGE

The Wiota gravels immediately overlies bedrock. In the Fort Peck area the formation rests entirely on Bearpaw shale. Elsewhere in northeastern Montana, the underlying bedrock includes Cretaceous rocks younger than the Bearpaw, as well as the Fort Union formation of Paleocene age. In the Fort Peck area the Wiota immediately underlies ground moraine; it crops out in only a few small areas other than the narrow bands exposed in hillsides.

Fossils are extremely scarce, but fortunately they are strongly diagnostic of the Pleistocene. Within the Fort Peck area, some horse teeth, resembling those of the modern *Equus*, were collected at the following localities: (1) About 4 miles west of Nashua, Valley County, Mont., in sec. 36, T. 28 N., R. 41 E.; and (2) a gravel pit on the upland about 10 miles south-southeast of Glasgow, Valley County, Mont., in sec. 28, T. 27 N., R. 40 E. C. L. Gazin (J. B. Reeside, written communication, March 11, 1949) of the U.S. National Museum, who made the identifications at the latter locality, reported that both specimens "appear to be well fossilized and are almost surely Pleistocene in age. The species cannot be determined." A mammoth tooth was identified as *Mammuthus primigenius* by Jean Hough written communication, April 12, 1950) who commented as follows:

The tooth in question is a portion of an upper molar of *Mammuthus primigenius*. This is the wooly mammoth which ranged over northern Europe, Asia and North America from Pleistocene to Recent times. However, the species (and genus) became extinct in the United States at about the time of the major retreat of the Wisconsin ice sheet. Your gravel is, therefore, almost certainly Wisconsin in age and probably late Wisconsin.

The early and middle Pleistocene mammoths, *Mammuthus* (*Archidiskodon*) *imperator*, were extremely large with very massive teeth. Your specimen is small, even for *Mammuthus primigenius*, and the tooth plate ridges narrow and closely spaced. Its referral to this species is pretty surely correct and the age determination can be depended upon.

In connection with this comment, however, G. E. Lewis of the U.S. Geological Survey provided the following oral communication:

Evidence in other portions of the Great Plains, however, indicates that *Mammuthus primigenius* is generally associated with pre-Wisconsin deposits. Schultz, Lueninghoener, and Frankforter (1951, table 1) point out that in Nebraska, *Mam-*

muthus primigenius (Blumenbach) has a known occurrence in Yarmouth sediments and only a probable additional Sangamon-Wisconsin range, whereas, *Parelephas columbi* (Falconer) is the known characteristic Wisconsin mammoth.

This tooth was found in a bed of the Wiota gravels exposed in a cutbank of the Missouri River in the SW¼ sec. 5, T. 26 N., R. 44 E., Valley County, Mont. (see p. F30). Its presence demonstrates that the younger members of the Wiota gravels could be as recent as Wisconsin in age; even so, these younger members are virtually nonglacial in the Fort Peck area.

The oldest and topographically highest deposits of the Wiota in the Fort Peck area are presumably only slightly younger than the youngest part of the Flaxville formation, as indicated by the modest difference in altitude (about 200 feet) within the local area of common occurrence of the two formations. No fossils, however, have been reported from either the youngest part of the Flaxville formation or the oldest part of the Wiota gravels, and therefore the age of the time boundary between the two formations remains conjectural. Insofar as the bulk of the deposits is concerned, it seems more than likely that the Flaxville is Pliocene and the Wiota is Pleistocene. It seems likely, however, that Wiota deposits range in age from early to late Pleistocene. The extremely scarce glacial erratics found locally in the younger (lower) part of the Wiota gravels of the Fort Peck area probably represent much attenuated drift from an ice sheet (Illinoian or Iowan?) that did not advance as far south as the Fort Peck area.

Collier and Thom (1918, p. 182) regarded the older part of this formation as being late Pliocene or early Pleistocene. Alden (1932, p. 44–45; 59–60) recognized these gravels in part, using the symbols T_2 and T_3 in referring to them. These symbols have been found to be incompatible with the results of later detailed mapping because of the multiplicity of levels on which the gravels occur, coupled with the difficulty of differentiating and correlating them. He regards the older part of this formation (T_2) as early Pleistocene, and the younger part (T_3) as older than the Wisconsin stage of glaciation.

LITHOLOGY

A typical exposure shows that the Wiota has much in common with modern stream deposits and with the Flaxville formation. Generally, the lower part is moderately well bedded sandy gravel containing numerous lenses of medium sand. The upper part is commonly silt and fine to medium sand with intercalated clay lenses. Consistent with typical patterns of stream deposition, however, the composition of the formation varies from outcrop to outcrop. In places, the upper sand is thin or absent. In others, the entire formation may be composed of sand. Locally, all or part of the formation changes laterally into a very poorly sorted colluvial facies. Most exposures exhibit crossbedding. The following sections are typical of the Wiota gravels in the Fort Peck area.

1. North wall of tributary to Porcupine Creek, NE¼ NE¼ sec. 29, T. 29 N., R. 41 E.

	Feet
Ground moraine (Pleistocene):	
Till	15+
Wiota gravels (Pleistocene):	
Clay and silt; grade from dark brown at the base to light brown at the top	19
Sandy silt; partly thin bedded	5
Sand, medium-fine, clean, light-tan	1
Sandy gravel; pebbles are as much as 7 inches in diameter but are predominantly 1–2½ inches; pebbles are all derived from the Flaxville formation, as there are no glacial erratics present. Some thin discontinuous sand beds are present	5
Total Wiota	30
Bearpaw shale (Cretaceous):	
Shale, dark-gray	30+

NOTE.—Altitude of Bearpaw shale-Wiota gravels contact is about 2,400 ft.

2. Highway cut near upland level, N¼ cor. sec. 29, T. 28 N., R. 42 E.

	Feet
Ground moraine (Pleistocene):	
Till	10–15
Wiota gravels (Pleistocene):	
Sandy gravel; contains numerous lenses, as much as 1 ft thick, of pebbly to clean medium cross bedded sand	22
Bearpaw shale (Cretaceous):	
Shale, dark-gray	15+

NOTE.—The gravel contains no glacial erratics. The altitude of the Bearpaw shale-Wiota gravels contact is about 2,275 ft.

3. Roadcut of road leading from U.S. Highway 2 north to gravel pit, SW¼ sec. 36, T. 28 N., R. 41 E.

	Feet
Outwash terrace gravel (Pleistocene):	
Gravel with abundant glacial erratics	12+
Ground moraine (Pleistocene):	
Till	7
Wiota gravels (Pleistocene):	
Light-brown unit consisting of alternate beds of clean fine-grained sand and thinly bedded clay	8
Gravel, poorly sorted; pebbles are as much as 5 inches in diameter but are mostly 1–3 inches; glacial erratics are extremely scarce. Tooth of *Equus* was found	4
Total Wiota	12
Bearpaw shale (Cretaceous):	
Shale, dark-gray	15+

NOTE.—The altitude of the Bearpaw shale-Wiota gravels contact is about 2,100 ft.

4. Gravel pit, center N½ sec. 10, T. 27 N., R. 41 E.

	Feet
Ground moraine (Pleistocene):	
Till	3–12
Wiota gravels (Pleistocene):	
Sand and sandy silt, medium- to fine-grained, laminated and crossbedded, tan	4–5
Sandy gravel; pebbles are as much as 6 inches in diameter but are mostly 1–3 inches; commonly contains lenses of pebbly to clean sand. Erratics are extremely scarce	11
Total Wiota	15–16
Bearpaw shale (Cretaceous):	
Shale, dark-gray	pit bottom

NOTE.—The altitude of the Bearpaw shale-Wiota gravels contact is about 2,100 ft.

5. Cutbank on north bank of Missouri River, SE¼ sec. 6, T. 26 N. R. 44 E.

	Feet
Kintyre formation (Pleistocene?):	
Fine sands and silts, tan to brown	60+
Ground moraine (Pleistocene):	
Till	7–15
Wiota gravels (Pleistocene):	
Sand and gravel. This unit is present from river level to 22 ft above river level. At the east end of the exposure, the upper three-quarters of this unit consists of sand and silt, varying in grain size with the bed and showing cross-bedding in places. The finer grained material is generally nearer to the top of the section. The lower part of the section consists of sandy gravel containing pebbles as much as 5 inches in diameter, although most are ½ inch to 2 inches; the lower part also contains a few sand lenses. Toward the west end of the exposure, where sand lenses are more abundant, the gravel gradually increases in thickness and eventually constitutes the entire unit. No erratics were found. One horse (*Equus*) tooth and one mammoth (*Mammuthus primigenius*) tooth were found near east end of cutbank in SW¼ sec. 5	22
Bearpaw shale (Cretaceous):	
Shale, dark-gray (exposed during low-stage of river).	

NOTE.—The Wiota railroad junction is centrally located relative to these sections.

The pebbles in the Wiota gravels vary in lithologic character in northeastern Montana according to altitude and locality. In the Fort Peck area, the higher (older) parts consist entirely of reworked Flaxville formation; about 98 percent of the pebbles is smooth, well-rounded percussion-marked argillite and quartzite. These pebbles are as much as 7 inches in length and are various shades of brown, reddish brown, pink, green, and gray (the overall color of the formation is reddish brown). About 1½ percent is polished more or less pitted brown chert pebbles as much as 3 inches long. The other one-half of 1 percent is green tinguaite porphyry pebbles that presumably are all derived from the several isolated intrusions exposed in western Montana. The pebbles are similar in shape and size to the quartzite and argillite pebbles, though less smooth.

At lower (younger) levels in the Fort Peck area the pebbles are identical in origin and lithology, except that in a few places the gravels contain a small fraction of 1 percent of crystalline-rock erratics of apparent northern provenance. None of these erratics have been found west of the outcrop of Wiota gravels about a mile west of the town of Nashua. The gravels in this outcrop are presumed to have been deposited by the preglacial Porcupine Creek. Not all the lower level Wiota gravels east of this outcrop contain erratics.

Cream-colored limestone and dolomite, so common as erratics in the local drift, are absent from the Wiota gravels of the Fort Peck area. This absence is clean cut, as there is no known example of in-place erosion by leaching in the Fort Peck area to suggest that this absence is due to any cause other than nondeposition of these soluble rock types.

R. B. Colton (written communication, 1957) and Witkind (1949) found that east of the Fort Peck area there are gravels similar to the Wiota in stratigraphic position, age, mode or origin, and lithology in which erratics become increasingly abundant. Some low-level gravels in Sheridan County are reported (Colton, written communication, 1957) to contain 30 percent glacial-erratic pebbles. It is the intention here, however, to restrict the name Wiota gravels to deposits mostly nonglacial in origin.

Some scattered deposits of unconsolidated sediments in the southwestern part of the area have been designated on the map as Wiota gravels, although they differ considerably in appearance and lithology. Like the Wiota, these deposits overlie the Bearpaw shale and underlie glacial deposits. They consist primarily of poorly sorted sandy and clayey medium- to fine-grained gravel and include abundant lenses and beds of sand, silt, and clay. All the pebbles are fragments of concretionary masses derived from the local Cretaceous bedrock formations. There are no pebbles of quartzite or of northern crystalline rocks. Iron-oxide coatings are prevalent, so that the material is light to dark rust brown. More extensive field investigations may result in separating this material as a distinct geologic unit.

ENGINEERING CONSIDERATIONS

Except for the poorly sorted low-strength material in the southwestern part of the area, the Wiota gravels are a source of road metal and aggregate. The pebbles are smooth and well rounded, so that crushing is necessary if angular material is desired; reactive material (amorphous and cryptocrystalline silica) composes about 1 percent. Detailed prospecting along the line of outcrop is necesary because of lateral changes in composition and because of the differing ratios in the thickness of gravel to overburden.

The materials composing this formation and the overlying glacial drift are easily worked with power tools. The Wiota is highly permeable, so that canals and small dams in this formation probably would require lining. Figure 6 (samples 1, 7, 8, and 19) gives typical soil classifications for this formation.

The Wiota gravels are a shallow source of ground water in upland areas. The water is low in dissolved solids and is excellent both for domestic use and for stock. The water percolates to the base of the gravels above the nearly impermeable underlying Bearpaw shale, escaping as intermittent springs at the contact where erosion has dissected the gravels. The quantity of water available differs markedly from place to place and is greatest near the centers of ancient drainage courses and negligible at the sites of drift-buried divides. Wells sunk into the Wiota gravels range from 15 to 60 feet depth, which depends on the thickness of the overlying drift.

GLACIAL DEPOSITS

GENERAL DISCUSSION

Deposits of Pleistocene age, probably all related to a single phase of the Wisconsin glaciation, possibly the Tazewell, are the surface material covering a large part of the Fort Peck area. Ground moraine blankets the uplands north of the Milk and Missouri Rivers, and remnants of moraine have also been mapped south and west of the rivers. Next in abundance are the large patches of fluviolacustrine sediments that were laid down on tongues of stagnant ice in the old Missouri River trench during the wasting of the Tazewell(?) glacier. Glacial outwash deposits are comparatively small and widely scattered. Some mark channels carved by early melt water of the glacier but soon abandoned for courses that apparently conformed nearly to present-day drainage lines. The rest of the outwash occurs on discontinuous terrace remnants along the Milk River and some of the main tributaries of the Missouri River.

GROUND MORAINE

DISTRIBUTION

Ground moraine of Wisconsin age mantles more than half of the Fort Peck area. It has been eroded from the inner valleys of the Missouri and Milk Rivers and their principal tributaries, and has been largely stripped from the hilly belt of Bearpaw shale in the south-central and southwestern parts of the mapped area. Beyond the area of more or less continuous cover, there are scattered patches of ground moraine and isolated erratics resting on bedrock; this evidence suggests that the entire area was once glaciated. The ground moraine is predominantly till (the largely unsorted debris having been deposited directly by glacial ice), but it also includes sparse intercalated bodies of rudely stratified silt, sand, and sandy gravel. Recent alluvium that floors the bottoms of the smaller drainage courses has not been differentiated from the ground moraine on the geologic map.

TOPOGRAPHY AND THICKNESS

The ground-moraine surface north of the Milk and Missouri Rivers is a relatively flat plain that slopes gently southward. Although there are some inconspicuous surface irregularities that include undrained depressions, drainage is mostly integrated. The surface is commonly checkered by a characteristic network of vertical desiccation fissures that penetrate the upper few feet of the moraine.

The ground moraine is generally 5 to 20 feet thick except in the preglacial valleys. In the larger preglacial valleys it is as much as 170 feet thick, and in the smaller valleys it is a few tens of feet thick. Generally, however, it is not thick enough to completely obscure the configuration of the ancient valleys. In the northern part of the Frazer quadrangle, some small areas have topography similar to that of the end moraines; the thickness of the ground moraine in these areas reaches several tens of feet.

A network of low rounded till ridges, which apparently reflect a conjugate system of fractures formed in stagnant glacial ice, characterizes the ground-moraine surface east of Wiota. East of Frazer, ridges of this type are more numerous and longer. Colton (1958) traced these till ridges eastward as far as Westby in Sheridan County, a distance of 110 miles. He (Colton, 1958) stated that

> The surface of the [ground moraine] in the valley of the Missouri River below an elevation of 2,400 feet is characterized by hundreds of ridges 50 to 100 feet wide, as much as 20 feet high, and 2½ miles long. The longer ridges are parallel, 650 to 1,200 feet apart and average five per mile. * * * the width of the belt ranges from 5 to 20 miles.

STRATIGRAPHIC POSITION AND AGE

The ground moraine was deposited in part on the Cretaceous bedrock and in part on the preglacial fluviatile materials. It is overlain by scattered outwash deposits, glaciofluvial deposits, probable eolian deposits, alluvium, pond deposits, and alluvium-colluvium deposits. Throughout the area, the ground moraine is remarkably uniform in composition, soil profile, degree of dissection, and integration of drainage; this evidence indicates that the ground moraine is the product of a single ice sheet. However, in the western part of the Glasgow quadrangle south of the Milk River and west of Willow Creek, patches of ground moraine become sparse and thin and give way westward and southwestward to erratics lying free on bedrock. This area may represent simply an attenuated-drift border; on the other hand, this material may be drift of an older ice sheet.

Colton (1958) reported that the drift in the Fort Peck area continues eastward, and that in the vicinity of Medicine Lake in Sheridan County this drift is overlain by a younger moraine that he believed to be Cary in age. The ground moraine in the Fort Peck area overlies the Wiota gravels containing the mammoth tooth remains identified as "almost certainly Wisconsin in age and probably late Wisconsin." (See p. F28.) Presumably, if Colton is correct in his estimate of the age of the drift near Medicine Lake, the drift in the Fort Peck area is approximately Tazewell in age.

LITHOLOGY

The till constituting the ground moraine is a very compact, nearly impermeable moderately calcareous mixture of clay and lesser quantities of silt, sand, pebbles, cobbles, and boulders with traces of lignite. Its mechanical composition is much the same throughout the area. The clay and silt fractions make up 50 to 60 percent of the total volume, the sand fraction constitutes 20 to 30 percent, and the rest is pebble sized and larger.

Sand sized and smaller grains, as well as some granule- and pebble-sized fragments of friable sandstone, shale, and lignite, were derived mostly from local bedrock of Cretaceous and Tertiary formations underlying much of this part of Montana. The silt and clay fractions probably were derived mainly from the Bearpaw shale, and the sand, sandstone, and lignite were derived mainly from the Hell Creek and Fort Union formations. In the coarse fraction, materials derived from the Flaxville and Wiota formations predominate, although the percentages vary from place to place. Pebbles, cobbles, and boulders derived from the Canadian Shield and the Paleozoic belts far to the northeast are also conspicuously present. Almost all boulder-sized material is Canadian in origin. These erratics are much less smooth and rounded than the stones from the Flaxville and Wiota formations. They consist chiefly of cream-colored limestones and dolomites, various granitoid rocks, and a few schistose and other crystalline rocks. Although most of the erratics are largely unaltered by weathering, those containing a large percentage of biotite have a disintegrated rind or, in the case of the smaller stones, are disintegrated to the center.

Percentages of the different kinds of pebbles in the ground moraine are given below. The figures represent averages taken from several pebble counts, in which the lower limit of size was one-half inch.

	Percent
Upper Cretaceous and lower Tertiary bedrock (local origin)	3–4
Limestone and dolomite (northeast Canadian provenance)	26
Granitoid, schistose, and other crystalline rocks (northeast Canadian provenance)	15
Quartzite, amorphous and cryptocrystalline silica (from Wiota and Flaxville formations)	55

Large cobbles and boulders make up only a small percentage of the ground-moraine volume. Even so, boulders as large as 3 feet are not difficult to find. The largest boulder found, in NE¼SW¼ sec. 16, T. 28 N., R. 40 E., was about 20 feet long before it was split by frost action.

WEATHERING

Where the ground moraine is less than 70 feet thick, it has all been oxidized yellowish brown; where it is thicker, the lower parts are gray to bluish gray.

Soil-forming processes have further altered the upper 5 or 6 feet. From the surface downward, a common soil profile (fig. 15) includes a dark-brown humus zone 6 to 10 inches thick, a lime-enriched zone about 2 feet thick, and an underlying zone 2 feet or more thick, in which gypsum crystals have formed singly or in small clusters. It is not known whether the lowest zone has been enriched in gypsum or whether the crystals and nodules merely represent recrystallization of calcium sulfate originally disseminated in the till. Most pebbles within the upper two soil zones are coated with a thin layer of calcium carbonate on their undersurfaces.

The small patches of ground moraine shown on the geologic map in the vicinity of the Fort Peck Dam spillway and thence westward toward the dam itself are composed partly of till, but a considerable part of the material is a heterogeneous assortment of glaciofluvial deposits, other kinds of water-laid sediments, colluvium, and silty or sandy till. It is probable that the glacier involved in deposition of these materials was thin and more or less brittle, so that the effects of both ice shove and minor amounts of melt water have combined with slumping in both glacial and more recent times to produce the varied and nondescript materials present today.

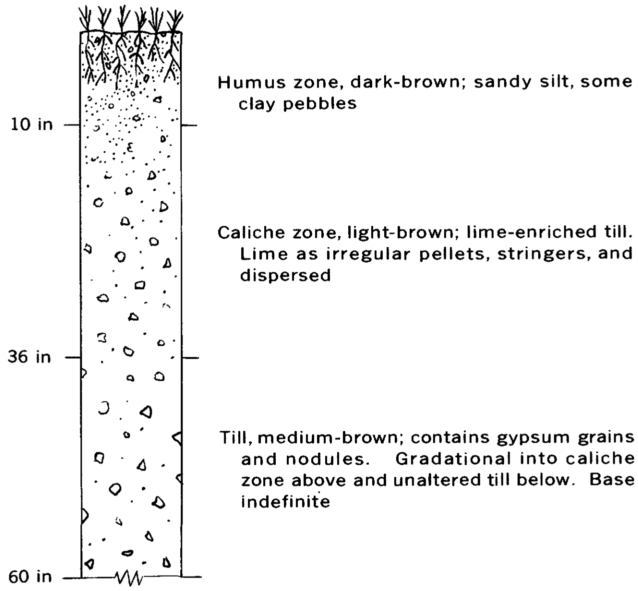


FIGURE 15.—Characteristic soil profile of the ground moraine in the Fort Peck area.

ENGINEERING CONSIDERATIONS

The till of the ground moraine is a dense, compact, nearly impermeable clay that is sticky when wet and hard and tough when dry. Figure 6 (samples 2, 15, 22, 26, and 28) shows the soil classifications and Atterberg limits for the till. Figure 5 shows two mechanical analyses of till.

The ground moraine is worked easily with power tools, though the presence of a few large boulders might slow progress. Stability in cuts is proportional to their depth and steepness; cuts less than about 15 feet deep stand well at angles exceeding 45°. The small slides that are common in open cuts are due more to the penetration of water along the network of vertical fissures (see p. F31) in the till than to the weakness of the material.

In North Dakota northest of the mapped area there is a large number of coal-mine adits, about 6 feet high and 4 feet wide, that are partly excavated in ground moraine. These stand well for a number of years without timbering. Inasmuch as the ground moraines here and in the mapped area are very similar, tunnels of comparable bore dug in till of the mapped area would probably stand as well.

Ground moraine is a stable foundation material, and settlement under heavy loads is negligible. It compacts well under optimum moisture conditions.

Unsurfaced roads on ground moraine are slippery and rut badly during wet weather; however, such roads in dry weather can be graded to a hard smooth surface.

Canals and other water-retaining structures constructed in ground moraine have negligible seepage losses. Till can be used as a nearly impermeable lining where such structures are constructed in pervious materials.

Because the ground moraine is so nearly impermeable, no appreciable quantities of water can be recovered from it. Even for the wells that happen to penetrate an intercalated lens of glaciofluvial sediment, the yield can be expected to be small.

Some shallow dug wells tapping this material produce small quantities of water, the amount varying with the season and weather.

KINTYRE FORMATION

NAME AND DISTRIBUTION

The Kintyre formation, here named for exposures near Kintyre, a siding on the Great Northern Railway about 5 miles west of the town of Frazer, is composed of fluviolacustrine sediments that were in large part deposited on stagnant ice in the old Missouri River trench (fig. 19). Although meanderings of the Milk and Missouri Rivers have cut away large parts, the formation still covers more than 70 square miles in the Fort Peck area and extends a considerable distance beyond both the east and west boundaries.

Large bodies of the Kintyre formation occur on the north side of the Missouri River east of Wiota and in a large triangular area west of the confluence of the Milk and Missouri Rivers and on the west bank of the Milk River southwest of Glasgow. Additional areas underlain by the formation are south of the Missouri River and east of Little Porcupine Creek. There is evidence that the Kinytre is also present in the Milk River valley northwest of the Glasgow quadrangle, and Colton (1958) mapped the formation east of the Fort Peck area.

TOPOGRAPHY AND THICKNESS

The Kintyre formation has an irregular gently rolling surface that differs from the ground-moraine surface chiefly in having greater local relief and smoother, longer hill-swale slopes. The topography is characterized by low gently rounded knobs, closed depressions, and poorly integrated drainage. It is notable also in that there are no erratics on the surface, except for a very few widely scattered glacial boulders.

The upland underlain by the Kintyre rises 75 to 150 feet above the river flood plains. The formation forms nearly vertical cliffs where erosion is rapid, but it slumps to form irregular hummocky slopes where erosion is slow. The best sections were measured in gullies, which are now actively dissecting the cutbanks of the Missouri River near the town of Frazer and also about 6 miles south of the town of Nashua.

The formation ranges in thickness from 0 to more than 70 feet; in most areas of exposure the formation ranges in thickness from 20 to 70 feet. The variation probably reflects to a large degree the irregularities of the underlying ice when the formation was deposited.

STRATIGRAPHIC POSITION AND AGE

The Kintyre is a Pleistocene formation laid down during the wasting of the Tazewell(?) ice sheet, which deposited the ground moraine in the Fort Peck area. The formation now rests directly on ground moraine in most places, but it rests on Bearpaw shale in some places south of the Missouri River. Generally it is the surface formation, although at a few localities it is overlain by outwash terrace gravels, pitted outwash gravels, alluvium, and alluvial-colluvial deposits, or by patches of silt and clay deposited in intermittent ponds. South and west of Nashua the Kintyre formation is locally overlain by postglacial deposits of dark-brown sand that seem to be, at least in part, of eolian origin.

LITHOLOGY

The lithology of the Kintyre formation varies considerably throughout the area. In most places the basal few feet consists of fissile olive-brown clay that is shalelike when dry. The overlying deposits are semiconsolidated interbedded fine-grained sands, sandy silts, clayey silts, and clay and include some small areas and isolated small lenses of unconsolidated medium- to coarse-grained sand. Broadly speaking, the lower half of the beds overlying the basal clay consists predominantly of light-tan silt and very fine sand interbedded with minor amounts of clay and silty clay. The upper half consist predominantly of dark-brown clay and silty clay. Locally, as in the bluffs north of the Missouri River in the central part of the Nashua quadrangle, the formation consists mostly of light-brown silt and silty very fine sand and includes dark-brown clay at the base.

Some sections of the Kintyre, which were measured near the town of Glasgow in the northwestern part of the area and near Frazer in the southeast, are composed only of dark-brown clay and silty clay from top to bottom.

For the most part, clays are massive, but silts and sands are delicately laminated and current bedded (fig. 16) similar to the structures observed in the Recent alluvium of the Milk and Missouri Rivers. Beds within the Kintyre are almost horizontal in many places, but in many others they have been folded, broken, and otherwise contorted (fig. 17) on a scale that precludes frost action and under conditions that rule out modern landsliding action. The amount of folding and bending is probably an indirect reflection of the irregularities in thickness and shape of the ice upon which the beds of the Kintyre were originally deposited. Where the ice was thin or comparatively uniform in thickness, the sediments probably settled down onto the underlying materials with little or no distortion during ice wastage. On the other hand, melting of large blocks or irregular masses of ice probably caused extensive readjustment and distortion as the fluviatile cover settled.

ENGINEERING CONSIDERATIONS

Although all but the near-surface materials are compact or semiconsolidated, the Kintyre formation could be worked with either hand tools or power equipment.

Permeability is low in most parts of the formation, and it will be necessary to insure adequate drainage in any construction area. The average clay content is high, so that most materials found in the Kintyre are plastic when wet. Except where the dark-brown surficial sands are present, unsurfaced roads crossing the formation are nearly impassable in wet weather.

Unsupported shallow cuts are fairly stable at nearly vertical angles; cuts 20–30 feet deep stand well on 30° slopes where the material is predominantly clay. Where appreciable quantities of sand occur, slumping is prevalent.

Small quantities of ground water can be obtained from lenses of pervious materials. Subsurface circulation is limited by lateral facies changes and by distortion of beds; therefore, groundwater is highly mineralized by soluble materials in the Kintyre formation and is generally unfit for domestic use. Seepage losses from small dams and earth tanks vary from negligible to serious, depending on locality and depth.

OUTWASH CHANNEL DEPOSITS

DISTRIBUTION

Several widely separated deposits of glacial outwash have been mapped in the Fort Peck area. They consist predominantly of sandy gravel interbedded with lenses of sand, silt, and clay and are studded with numerous glacial erratics. A few outwash deposits are irregular in shape but most are long and narrow. They range from ¼ mile to more than 3 miles in length and from a few tens of feet to more than a mile in width. Although a few show no apparent relation to modern drainage, most of the deposits in the Fort Peck area roughly parallel present-day valleys.

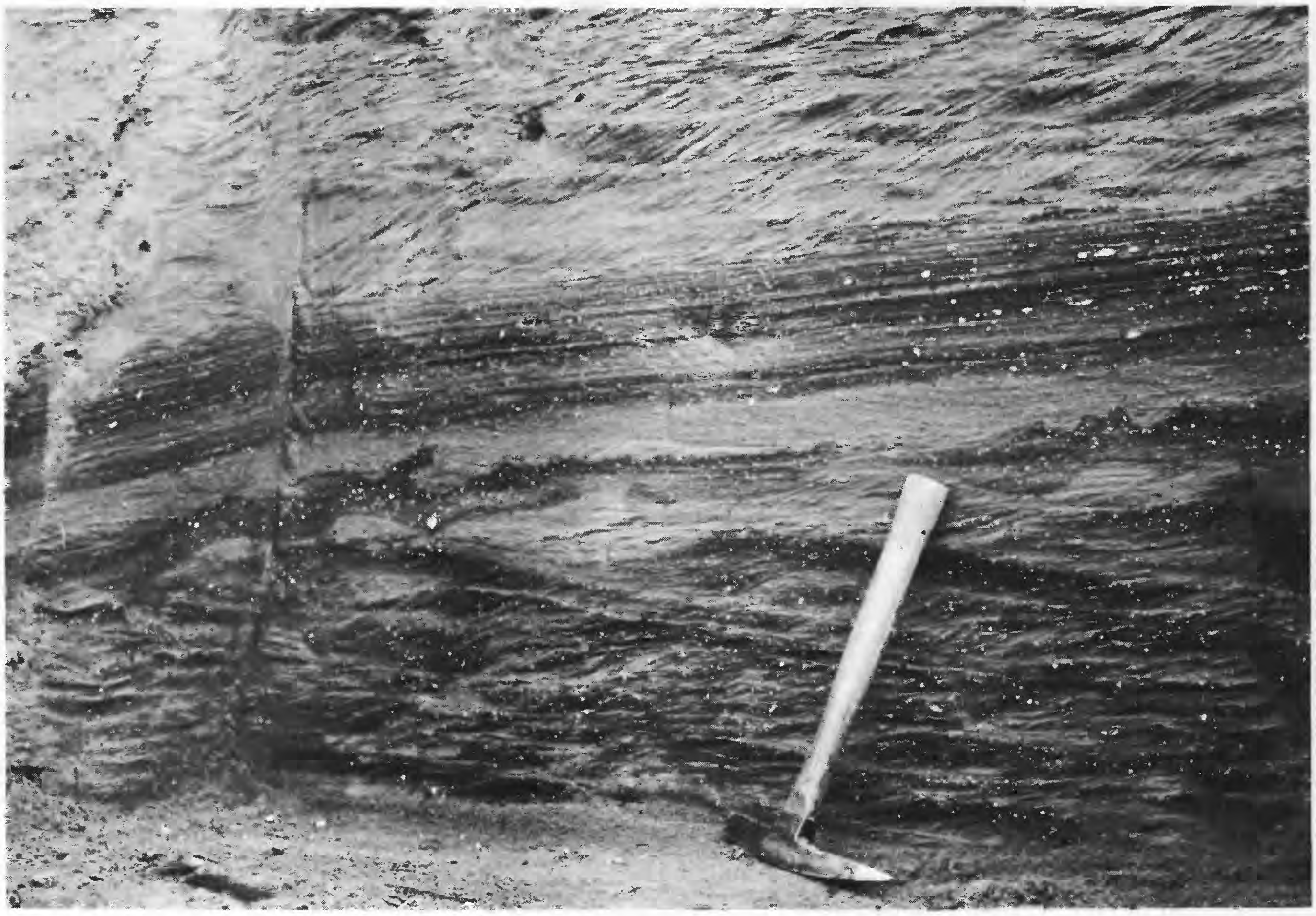


FIGURE 16.—In some places the beds of the Kintyre formation are definitely crosslaminated (photographed in sec. 23, T. 27 N., R. 41 E.). The similarity of this bedding to some in local alluvium of Quaternary age of the Missouri River supports a fluviatile origin for parts of the Kintyre formation. The white spots are calcium sulfate concentrations.

TOPOGRAPHY AND THICKNESS

Topographically, most of the outwash deposits are nearly identical with the surrounding ground-moraine plain. Surface appearance is distinctive only on the east side of Little Porcupine Creek, where the outwash deposits are marked by numerous irregular mounds and hollows that give them a pitted appearance.

Most outwash deposits in the map area are relatively thin and range from a few inches to 12 feet in thickness. The pitted outwash of Little Porcupine Creek, however, generally averages about 12 feet in thickness.

STRATIGRAPHIC POSITION AND AGE

The outwash gravels were deposited by the melt waters of the retreating Tazewell(?) ice. Most were laid down in flat-bottomed channels carved in the moraine. Locally, melt-water erosion cut channels completely through the ground moraine into the underlying Bearpaw shale. North of Frazer along the east fork of Charley Creek there are outwash deposits on Wiota gravels. Wherever present, the outwash deposits are at the surface.

FIGURE 17.—Folds in the Kintyre formation exposed on the south side of the road at the curve in NE¼SE¼ sec. 23, T. 27 N., R. 41 E.

LITHOLOGY

The materials range from poorly sorted sandy gravel to well-sorted thin-bedded silt and clay. The gravel pebbles generally range from ½ to 4 inches in diameter. A large proportion of the pebbles is derived from the Flaxville and Wiota formations. Most of the rest are glacial erratics composed of limestone, dolomite, and crystalline rock; a few are derived from the underlying bedrock formations of Cretaceous age. Most of the erratics are pebbles, but a few are boulders and large cobbles. Most pebbles have a thin rind of caliche on their undersides, and some of the erratic pebbles that are rich in biotite are disintegrated.

ENGINEERING CONSIDERATIONS

The large body of outwash gravel on the east side of Little Porcupine Creek (secs. 16, 17, 20, 21, 28, 34 of T. 28 N., R. 44 E., and sec. 3 of T. 27 N., R. 44 E.) constitutes the largest usable gravel reserve in the area. An estimated 5 million cubic yards is available; overburden is negligible, and excavation generally would be easy. Clay balls and reactive silica (hydrous silicates) are present in minor amounts. Most of the pebbles are rounded, so that crushing may be necessary if angular material is desired. Other outwash deposits are generally too thin or too poorly sorted to be of economic importance.

The outwash gravels are generally very permeable, and serious seepage can be expected to result from small dams and stock ponds that are built in these deposits.

OUTWASH TERRACE DEPOSITS

DISTRIBUTION

Terrace remnants that consist of glacial-outwash deposits discontinuously flank the alluvial bottom lands of Little Porcupine Creek, Porcupine Creek, and Milk River. Outwash terraces that commonly are ⅔ to 1 mile wide and 1 mile to more than 2 miles long are present north of Frazer and west of Nashua. Two long, narrow outwash terraces on the east side of Little Porcupine Creek range in width from a few tens of feet to one-fourth mile and are 4½ and 3 miles long. A few small widely separated remnants are distributed on the west side of Little Porcupine Creek, along Porcupine Creek, and in the area between the Milk and Missouri Rivers. At least two periods of terrace development are represented, but no differentiation or correlation was attempted, because erosion has removed much of the terraces.

TOPOGRAPHY AND THICKNESS

Most of the outwash terraces have relatively even surfaces that slope gently downstream and also toward the streams that they border. Outwash terraces along Little Porcupine Creek are commonly separated from the bottom land by scarps 5 to 20 feet high. The large outwash terrace north of Frazer, however, has no well-formed scarps and grades almost imperceptibly into bordering alluvium.

Scarps bounding the outwash terraces along the valleys of Porcupine Creek and Milk River are generally 40 to 60 feet high, although some are more than 100 feet above the younger alluvial deposits.

The deposits range in thickness from 3 to 25 feet and average perhaps 12 feet. The larger remnants seem to be also the thicker deposits.

STRATIGRAPHIC POSITION

The outwash terrace deposits on the highland between the Milk and Missouri Rivers overlie the Kintyre formation. Elsewhere they rest on the Wiota gravels or the Bearpaw shale.

LITHOLOGY

Most of the material is sandy gravel (fig. 18) in lenticular beds, a few to several inches thick. Crossbedding is prominent in many places. Intercalated with the sandy gravel are some lenses that consist of sand and lesser amounts of silt and clay. Locally, 3 to 5 feet of horizontally bedded and crossbedded fine sand and silt overlie the sandy gravel. The materials are unconsolidated, and the deposits, as a whole, are very pervious.

The rock types are the same as those in the ground moraine, except that hard clay balls are scattered through the outwash terrace deposits. Pebbles, generally ½ to 3 inches in diameter, are the most common size fraction, although there are some cobbles and boulders.

ENGINEERING CONSIDERATIONS

The deposits are a source of sand and gravel, although the general lack of thick deposits probably limits exploitation to the terrace remnants just west of Nashua and north of Frazer. Detailed prospecting is necessary to determine the thickness ratios of overburden to usable material. The percentage of chemically reactive components is small, but friable pebbles and clay balls may limit the utility of the deposits. Because most pebbles are smooth well-rounded quartzite, crushing is necessary if angular material is required. For uses where cobbles and boulders are objectionable, the gravel must be screened. Accessible gravel deposits more than 6 feet thick and beneath less than 6 feet of overburden are estimated at about 6 million cubic yards. Soils classification and Atterberg limits are given in figure 6 (samples 11 and 12). Mechanical analyses of these samples are shown in figure 18.

POSTGLACIAL QUATERNARY AND RECENT DEPOSITS

Erosion has been dominant since deglaciation except for deep alluviation in the trenches of the Milk and Missouri Rivers and along their major tributaries. Some fairly extensive colluvial deposits have accumulated along the lower slopes of these valleys. Pond and dune deposits are present, but only a few are large enough to map.

ALLUVIUM

DISTRIBUTION

Since the retreat of the last ice sheet, the rivers and streams have laid in their valleys extensive unconsolidated deposits of clay, silt, sand, and fine gravel; these deposits are everywhere characterized by both vertical and horizontal variations in composition and bedding. In general, the upper part of the alluvium is finer grained than the lower part.

Most of the mapped deposits are in the valleys of the Missouri and Milk Rivers and their larger tributaries; long, narrow bodies of alluvium floor some of the minor tributaries. Alluvium less than 3 feet thick was not mapped as a separate unit; thus no alluvium is shown on the map in many tributary valleys, in areas where thin alluvial deposits locally overlie glacial outwash, or in undrained depressions in the ground moraine.

TOPOGRAPHY

Most of the alluvial deposits of the Milk and Missouri Rivers valleys are comparatively flat except for shallow discontinuous meander scars. Many abandoned meanders are largely filled by slope-wash, eolian, and overbank deposits. Some of the more recent meander scars are 10 to 15 feet deep and contain intermittent ponds and swamps.

The surface of the alluvial fill of the principal tributaries is nearly level. Broad low alluvial fans have built up at many points where tributaries debouch onto the main flood plain; the fans are very gently convex and merge inconspicuously with the river alluvium.

Alluviation in this area has had a complex history, resulting in a generally greater rate of deposition dur-

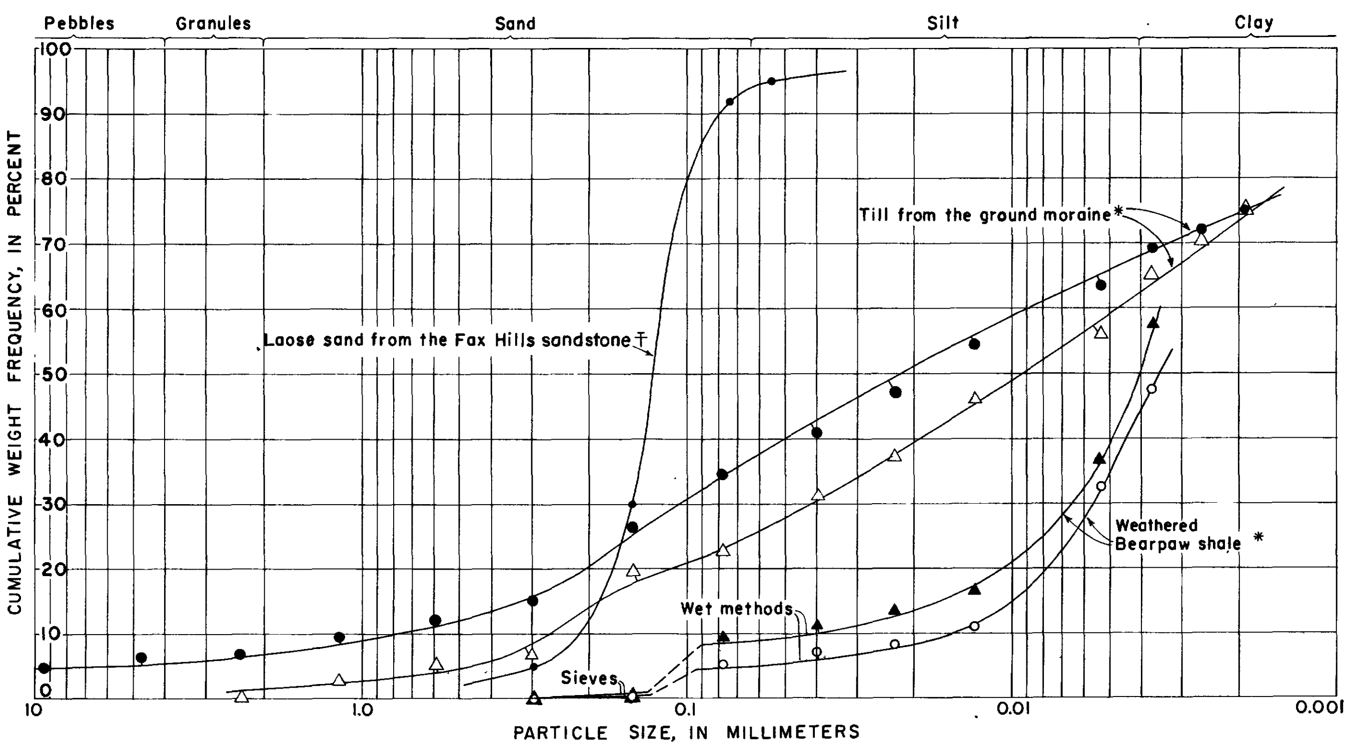


FIGURE 18.—Mechanical analyses of alluvium and outwash terrace gravel samples (adapted from data of the Montana State Highway Department). Sample numbers refer to figure 6.

ing the recent past than at present. The older thicker fill forms terraces 5 to 25 feet above the present-day flood plains and is similar in composition to the younger thinner alluvium.

THICKNESS

Thicknesses of the alluvium in this area are difficult to determine. Exposures are limited to riverbanks and dredge cuts that stand less than 20 feet above the low-water stage. Some information is available from logs of scattered drill holes and wells in the valleys, but, except for the area near the Fort Peck Dam, only a few borings penetrated to bedrock. Drill holes put down by the U.S. Corps of Engineers at and near the site of the dam show that alluvial fill is 122 to 164 feet deep near the center of the valley. A typical test hole by the U.S. Bureau of Reclamation at the center of the boundary between sec. 25, T. 27 N., R. 41 E., and sec. 30, T. 27 N., R. 42 E., showed that the fill is 114 feet thick. A drill hole near the center of sec. 6, T. 26 N., R. 43 E., entered the Bearpaw shale at 138 feet. R. B. Colton (written communication, 1959) stated that wells drilled in the Wolf Point and Poplar quadrangles to the east of the report area indicate that "more than 120 feet of alluvial fill is below the level of the present flood plain." These data support the general estimate that the alluvium along these segments of the Milk and Missouri Rivers ranges from 90 to 130 feet in thickness.

The maximum thickness of the alluvium in Porcupine Creek northwest of Nashua is known from test borings to be about 50 feet. The alluvium is probably thinner upstream than downstream, if, as is supposed, the bedrock floor of this valley is graded to the bedrock floor of Milk River valley. Alluvial deposits of Little Porcupine Creek north of Frazer, Cherry Creek to the north of Glasgow, and Brazil and Willow Creeks south and west of Glasgow are presumed to have comparable thicknesses. The mapped alluvium in the smaller tributaries ranges in thickness from 3 feet to probably not more than 15 feet.

STRATIGRAPHIC POSITION AND AGE

During wasting of glacier ice from the trunk drainage lines of the Missouri and Milk Rivers, headwater regions supplied sufficient water, supplemented by local melt water, to initiate trenching of the main valleys and to the fix main features of the present drainage pattern. Subsequent aggradation began sometime after the Tazewell(?) glaciation. Thus, much of the alluvial fill in the principal valleys is probably Pleistocene in age, and, inasmuch as drill-hole data show that the basal fill is predominantly coarser grained than the upper alluvium, it may be glacial outwash.

Test holes in the valley bottoms and exposures along the walls indicate that the alluvium of the Milk and Missouri Rivers, as well as that which floors most tributaries, was laid directly on the Bearpaw shale. In some of the smaller tributaries, especially near their heads, the alluvium was deposited on the ground moraine and, locally, on the Wiota.

Although the alluvium is generally finer grained than the glacial outwash, the alluvium and outwash are so similar that contacts between them are drawn largely on the basis of topography.

The alluvial-colluvial deposits (p. F40) built out over the margins of the valley alluvium are the only deposits that are, at least in part, younger than the alluvium except for intermittent pond deposits in meander scars and in shallow depressions in ground moraine.

LITHOLOGY

The alluvium is composed of unconsolidated clay, silt, sand, and some gravel (fig. 18, sample 23). In nearly all deposits the upper beds have a higher percentage of fine materials than the lower beds. Lithologically, the alluvium is very similar to the fine-grained fractions of the ground moraine and the Bearpaw shale from which it was derived.

Most of the alluvium is moderately to well sorted. Individual beds range in thickness from 1 inch to 4 feet. All are lenticular, although some have a lateral extent of several hundred feet. Bedding structural features are varied and include lamination, thin to thick massive bedding, and crossbedding which ranges from delicate laminae having amplitudes of an inch or less to bold foreset beds 3 to 4 feet in amplitude.

The upper 15 to 20 feet of alluvium in the Milk and Missouri River valleys commonly has several fairly persistent dark beds a few inches to a foot thick, that are rich in humus. These dark beds are composed chiefly of poorly sorted mixtures of clay, silt, and fine sand and alternate with lighter nonhumic beds to produce conspicuously colored bands. The lighter beds also are composed of clay, silt, and sand but are generally better sorted. Unoxidized clay lenses that retain their original dark-bluish-gray color are common within the light-colored beds. The dark humic beds probably represent immature soil profiles formed when weathering was the dominant process in the cycle of alluviation. Because alternation of deposition and weathering both laterally and vertically would have occurred from the beginning of postglacial deposition, similar weathered zones probably are present to the base of the fills.

Test holes drilled by the U.S. Bureau of Reclamation show that as depth increases the sediments generally increase in coarseness. A typical drill hole in sec. 36, T. 27 N., R. 42 E., shows the following profile:

	Feet below surface
Silt	7
Loose fine sand	15
Plastic clayey silt	8
Sand and gravel (maximum pebble diameter, 1 inch)	14
Total thickness	44

Bedrock (Bearpaw shale).

In the center of sec. 6, T. 26 N., R. 43 E., a test hole drilled 138 feet deep to the underlying Bearpaw shale passed through 10 to 15 feet of sandy clay, 85 feet of clayey silty sand, and 40 feet of sand and gravel. Without specific site investigations, however, it cannot be assumed that the alluvial sequence for any given location is as simple as has been indicated. Several borings by the U.S. Bureau of Reclamation and the U.S. Army Corps of Engineers have logged relatively thick bodies of gravel, sand, silt, or clay at various depths.

ALLUVIUM IN CREEK VALLEYS

The alluvium of Porcupine Creek, Little Porcupine Creek, and other tributaries is also divisible, in a general way, into a lower coarse-grained part and an upper fine-grained part. The lower coarse-grained part is 2 to more than 30 feet thick and is largely sand and gravel. Most of these deposits are poorly sorted, and crossbedding is common. The upper part is generally 2 to 15 feet thick. It consists of small interfingering beds of fine sand, silt, and clay. In most tributaries, these beds are poorly sorted and also contain minor amounts of gravel which occur either as scattered pebbles or as small lenticular beds in addition to the finer material. Upstream, the sand fraction increases, and the clay and silt fractions are commonly very small. Downstream, as the tributaries approach the Missouri River flood plain, the silt and clay content increases, and the deposits are almost identical with the near-surface river alluvium.

ENGINEERING CONSIDERATIONS

The alluvium has considerably greater variation in permeability than most of the other unconsolidated materials. Permeability is low in the fine-grained parts of the river alluvium. As a result ground-water circulation is inhibited and the little water available in these fine-grained beds is unfit for drinking. The beds of both river and tributary alluvium are highly permeable where gravel and coarse sand are present, and they, as well as certain areas of Wiota and glacial gravels, are the best sources of potable water.

Topographically, alluvial bottom lands are favorable sites for highways, railroads, canals, irrigation projects, and towns. The physical properties of alluvium are therefore of unusual importance. These properties differ considerably from place to place, because the sediments composing the alluvium were deposited under such varying conditions of flow and load.

The materials are all unconsolidated and can be worked easily by hand or with power tools. As the water table is only 8 to 20 feet beneath the surface in most places, slopes are not stable below shallow depths. The near-surface materials erode to near-vertical slopes, but, because cohesion is low, cutbanks are subject to caving and slumping. Unsurfaced roads are satisfactory when dry but commonly become impassable when wet unless they are properly drained.

The basal beds of the alluvium along the tributaries are a source of sand and gravel, although the problem of removing the overlying fine-grained deposits limits their usefulness. Figure 18 shows a mechanical analysis of a sample (No. 23) collected in Porcupine Creek valley. Atterberg limits and soils classification for this sample are shown in figure 6 (sample 23). Soil classifications and Atterberg limits of other samples of alluvium, taken by channeling streambanks, are given in figure 6 (samples 6, 24, 30).

INTERMITTENT POND DEPOSITS

NAME AND DISTRIBUTION

There are a large number of small undrained depressions in the area. Most are on the ground moraine, and the rest occur on the Kintyre formation. Most of the depressions in the ground-moraine surface are kettles that formed when buried ice blocks melted; the others originated through the fortuitous deposition of glacial debris in such a way as to block the drainage of small areas. The depressions in the Kintyre are probably due to uneven settling during the wasting of the formerly subjacent glacial ice. Ponds, a few inches deep, form in them during wet weather but dry up soon afterward. Runoff from the ground immediately around the depressions washes silt and clay into them; the wind carries in a lesser amount of clay, silt, and fine sand, especially during drought years.

TOPOGRAPHY AND THICKNESS

Except for a few saucer-shaped "blowouts," which contain no mappable deposits, the depressions have flat floors. A few have steep sides, 5 to 15 feet high, but most are bounded by very gentle slopes that rise only 3 to 8 feet above the flat pond deposits. The deposits themselves range in maximum thickness from 6 to 12 feet and thin to a featheredge at the margins.

STRATIGRAPHIC POSITION AND AGE

The filling of the depressions probably began soon after the glacial ice wasted away and has continued in most of them to the present. A few depressions have had their walls breached by erosion and no longer accumulate deposits.

LITHOLOGY

The pond deposits are predominantly plastic clay. A small amount of silt and fine sand is present either as thin laminae or admixed with the clay. The larger deposits overlying the ground moraine commonly have some coarse sand and fine gravel at the base of the clay. The uppermost foot of the deposits is a black clayey humus-rich soil. As the organic content decreases downward, the underlying material becomes denser and more compact and grades from dark gray below the humic soil zone to light brown 3 to 4 feet below the surface.

ENGINEERING CONSIDERATIONS

Both surface and subsurface drainage is very poor because of the flat surfaces and very low permeability of the deposits. Stability of all but the shallowest cuts would be reduced by periodic inundation unless drainage facilities are provided. The deposits are handled easily by power tools. During wet weather unsurfaced roads are slippery and rut badly because of high plasticity of the deposits. Parts of the deposits may be suitable for ceramic clay. Figure 6 gives the soil classification and Atterberg limits of a sample (No. 10).

ALLUVIAL-COLLUVIAL DEPOSITS

DEFINITION AND DISTRIBUTION

Alluvial-colluvial deposits are deposits that have accumulated on the lower slopes of valley sides and over contiguous parts of the valley floors through creep, slope wash, and deposition by intermittent rivulets. These deposits therefore differ genetically from alluvial fans that accumulate by depositions from intermittent streams. The buoyant force acting on transported particles during alluviation derives from water, whereas in colluviation this force derives from the matrix of transported particles which is merely lubricated by water. Hence, in alluviation the role of water is direct and primary, and the role of gravity is indirect and secondary; in colluviation the reverse is more nearly true.

The term "alluvial-colluvial deposits" as used here connotes two things: a genetically intermediate origin for some of the deposits, and a commingling of the two types in other deposits where the scale of mapping makes it impossible to show them as separate units.

TOPOGRAPHY AND THICKNESS

Morphologically these deposits form broad, low fan-shaped masses that, in many places, have coalesced to form aprons. The surface profiles are smooth concave curves that become progressively steeper upslope. Most are partly dissected by shallow steep-sided gullies. During dry periods the surfaces are checked by an intricate pattern of polygonal shrinkage cracks that commonly extend several inches into the ground.

Individual beds range in maximum thickness from 10 to 20 feet. Near their margins, colluvial deposits diminish to a featheredge; downslope, they commonly grade imperceptibly into the valley alluvium. In general, map limits are arbitrarily drawn where the sediments thin laterally or upslope to less than 3 feet; downslope limits are based on topography.

STRATIGRAPHIC POSITION AND AGE

The colluvial deposits are contemporaneous with the more recent parts of the valley alluvium. No younger materials overlie the colluvium, and all animal remains discovered in them are those of living species.

LITHOLOGY

The composition and color of the colluvial deposits clearly reflect the parent materials. The Bearpaw shale, the Wiota gravels, and the ground moraine are the principal sources in the Fort Peck area. The colluvium derived from these deposits is predominantly a grayish-brown compact fairly tough mixture of clay and silt, but it includes minor amounts of sand and gravel that commonly occur as small scattered lenses in the upslope parts of the deposits.

In cross section, the material resembles till, but the presence of rude bedding and the arrangement of the flat surfaces of pebbles parallel to the colluvial surfaces gives a more pronounced fabric than that in till.

Figure 6 (sample 21) gives the soil classification and Atterberg limits of a colluvial deposit derived from the Bearpaw shale, the Wiota gravels, and the ground moraine.

ENGINEERING CONSIDERATIONS

The sloping surfaces and low permeability of the colluvial deposits combine to provide excellent surface drainage. Subsurface drainage is very poor, permitting little seepage loss from water-retaining structures. Alkali salts deposited by evaporting water make certain areas underlain by these deposits unfit for irrigation. The material is generally so tough that power tools are necessary for excavation. Cuts less than about 15 feet deep are stable at near-vertical angles. Deeper cuts at steep angles will initiate slumping.

Unsurfaced roads on such material are usually rough in dry weather and are slippery and subject to rutting when wet.

GEOLOGIC HISTORY OF THE TERTIARY AND QUATERNARY DEPOSITS

PREGLACIAL HISTORY

Post-Cretaceous deposits older than early Pliocene or possibly late Miocene are not known in the Fort Peck area. To consider the Flaxville and Wiota formations in proper perspective, however, it is desirable to comment on the geologic history in the plains areas of Montana and the Prairie Provinces of Canada as far back as the approximate beginning of the Oligocene.

Three major drainage basins in this area seem to have been in existence continuously since early Oligocene time: the Yellowstone River drainage basin in southern Montana, the Missouri River drainage basin in central and northern Montana and in the southern part of the Prairie Provinces, and a drainage system in central and northern Alberta and Saskatchewan. In each basin prominent fluviatile deposits were laid down and, owing to differences in provenance, there are striking differences in lithology. The Missouri River has brought quartzite and argillite eastward from the Belt series, whereas the Yellowstone River has brought predominantly volcanic rocks.

From the beginning of deposition of the Cypress Hills gravel in southern Saskatchewan in the early Oligocene until continental glaciers invaded northeastern Montana late in the Pleistocene, pediplanation [4] was a geologic process of prime importance in the Montana plains and neighboring parts of Canada's Prairie Provinces. During this time intermittent regional uplift and changes in stream regimen shaped the major features of the modern topography. This topography, broadly speaking, consists of a sequence of pediplains sloping eastward away from the Rocky Mountains, each younger pediplain at a lower elevation than its predecessor. Locally the slopes do not dip eastward, according to the positions and courses of the drainages that governed them. Remnants of old surfaces are present far from the mountains, and younger surfaces extend around and between them. For the most part the older surfaces are today the less extensive ones, but in the Fort Peck area this is not so. Here glaciation halted development of the lowest surface (Wiota age) shortly after its initiation, so that this surface is not much more than the "inner valley" of the preglacial drainage system.

A sedimentary mantle ranging from 0 to more than 100 feet in thickness, but commonly from 5 to 35 feet in thickness, covers these pediplain surfaces. Sandy gravel, in some areas cemented to form conglomerate, is the predominant material of this mantle, which is distinctive lithologically as it corresponds to the provenance of the drainage basin. The youngest of the gravel was deposited prior to the arrival of continental glaciers at the site of deposition; the gravel is entirely nonglacial in character and underlies drift wherever drift is present.

The bench gravels of the ancient Missouri River system are dominated by characteristic pebbles and cobbles of smooth well-rounded chattermarked quartzite. The oldest bench gravel is preserved only atop the Cypress Hills in southwestern Saskatchewan and southeastern Alberta and was described by McConnell (1885). The formation has yielded Oligocene mammal remains. Some of the succeeding pediplains and their associated deposits blend almost imperceptibly into each other, as the difference in profile is so minor and the scarp between them is so inconspicuous. Others are readily separable. The two youngest (?) that are easily recognizable are the Flaxville formation and the Wiota gravels; a number of other units of subformational rank seem potentially recognizable. The Flaxville formation was named by Collier and Thom (1918, p. 179) for typical exposures near the town of Flaxville in northeastern Montana. It covers large areas in this part of the State and contains Miocene or Pliocene fossils. Wiota gravels is the name introduced by Jensen (1951a) for gravel deposits younger than the Flaxville but older than local glacial deposits. They are widely distributed in this part of Montana and are known from fossil evidence to be, in part, as young as Wisconsin, probably late Wisconsin (Pleistocene).

In a few localities in the Nashua and Frazer quadrangles, the topographically lowest (that is, the youngest) parts of the Wiota gravels contain isolated glacial erratics. Jensen (1952b) therefore deduced that an ice

[4] Pediplanation is the process yielding pediplains. King (1953) introduced the term "pediplain" into American literature. An individual pediplain may be defined as a simple or complex surface of regional extent consisting of either a single pediment or of a number of pediments forming an essentially continuous sequence of surfaces including no scarps other than local ones and no pronounced differences in profile form. Because pediplains enlarge by parallel retreat of headward scarps, more than one generation of retreating scarps may be present in an area at the same time. This multiple scarp condition holds in the northern Montana plains vicinity.

sheet, older than the one (Tazewell?) that deposited the ground moraine of the Fort Peck area, advanced southward to within a few tens of miles of the area and that outwash from this ice sheet is responsible for the erratics. Porcupine Creek in pre-Tazewell(?) time apparently carried a small amount of this outwash, so that part of the Wiota gravels eastward (downstream) from Nashua also contains sparse erratics. No glacial erratics were found in the Wiota gravels west of the area near Nashua. The more northeasterly parts of Montana were evidently either closer to the margin of this ice sheet or were the sites of more important outwash drainage channels, for in these areas erratics are a conspicuous element in gravels of apparently equivalent age (Colton, 1951a, b; 1954; 1955a, b).

Jensen (1952b) believed that these gravel deposits associated with the development of the Tertiary and Pleistocene pediplains in central and northern Montana can be included in McConnell's (1885) South Saskatchewan group of Canada.

The term "South Saskatchewan group" was first used in 1885 by McConnell (1885) on a map of the Cypress Hills, Wood Mountain, and adjacent country showing reconnaissance geologic mapping in southern Saskatchewan. In his text McConnell (1885, p. 70c) used the term "South Saskatchewan gravels" for this map unit, the term being applied "as a general name" to deposits which he considered to be "not all contemporaneous." McConnell (1885, p. 45c, 57c, 70c) found these gravel deposits to be lithologically like those capping the Cypress Hills, to be derived from the gravels on the Cypress Hills, and to be widespread. In statements regarding age relations and age assignments, McConnell (1885, p. 33c, 36c, 45c, 57c, 59c, 70c) made it clear that his intent was to include in the two names "Cypress Hills gravel" and "South Saskatchewan gravels" all the preglacial quartzite gravels [5] in his map area, dividing them into two parts on the basis of age alone.

GLACIAL HISTORY

REGIONAL BACKGROUND OUTLINED BY EARLIER STUDIES

Chamberlin (1888) was the first to recognize that northeastern Montana had been invaded by continental glaciers spreading southward from Canada. He drew the southern limit of this invasion a few tens of miles south of the Fort Peck area. A few years later Calhoun (1906, p. 32–45) undertook a study of the glacial geology of central western Montana, where he found evidence that led him to conclude that in preglacial times the Missouri River flowed north around the Bearpaw Mountains and down the course of the present Milk River.

In 1911, Alden undertook a more ambitious study, attempting to determine the later Tertiary and Pleistocene history of some 114,000 square miles in Montana, North Dakota, and Wyoming. He worked at this project intermittently until 1924, doing considerable fieldwork and collecting data gathered by other geologists working in this large area. His published work (Alden, 1932) is of necessity rather generalized.

GLACIAL HISTORY OF THE FORT PECK AREA

The ground moraine in the Fort Peck area is very uniform in composition, in soil-profile development, and in stage of slope dissection and drainage integration. No buried soils have been found within it. All evidence found during this study indicates the exposed ground moraine and associated drift to be the result of a single ice sheet. These characteristics are common to the ground moraine in the contiguous and nearby parts of the Fort Peck Indian Reservation to the east, to which R. B. Colton (written communication, 1959) assigned a Tazewell(?) age.

R. B. Colton (written communication, 1959) has found that large areas of the Flaxville plain north and northeast of the Fort Peck area are driftless areas in the otherwise drift-mantled plains of northeastern Montana. This evidence indicates that the Tazewell(?) ice sheet, in its general southerly or southwesterly advance, was separated into lobes by the Flaxville topographic prominences. Lobes of the glacier moved between and around the plateau remnants; as a result, the Tazewell(?) ice sheet advanced into the Fort Peck area from an easterly rather than a northerly direction and moved directly westward up the Missouri River valley. It is likely that another lobe of this glacier moved westward around the north end of the driftless areas and, having passed this topographic barrier, turned south and southeast down the Milk River valley toward Glasgow. The following evidence, although inconclusive, supports such a hypothesis: (1) Ground moraine capping low mesas on the east flank of the Bowdoin dome northwest of the Fort Peck area has the same characteristics as the ground moraine of the Fort Peck area and the Fort Peck Indian Reservation area to the east; this evidence suggests that the ice which deposited the moraine near Bowdoin dome has much in common with the ice depositing the moraine of the Fort Peck area; (2) ground moraine of the Fort

[5] Calhoun (1906, p. 49–52), who coined the informal term "quartzite gravels" to describe deposits of the South Saskatchewan group in the northwestern plains of Montana, apparently chose not to use the available more formal term "South Saskatchewan," because McConnell (1885) and Dawson and McConnell (1895) had not defined clearly the exact scope of the term.

Peck area becomes attenuated westward from the approximate longitude of Glasgow. This fact indicates that the lobe that advanced westward up the Missouri River valley did not advance much beyond this longitude; (3) the interbedded ground moraine and gravel exposed in a gravel pit 3 miles northwest of Glasgow indicates a complex glacial history possibly attributable to interaction of multiple ice lobes of the same glaciation.

Evidence of the Tazewell(?) glaciation dominates the geologic scene, but other evidence here and in nearby areas shows that the Tazewell(?) ice was not the first glacier to advance over the Fort Peck area.

1. A few miles south and west of the Fort Peck Dam are the Larb Hills (fig. 9), whose flat tops are similar in elevation to many parts of the driftless areas of the Flaxville plain a few miles to the north and northeast of the Fort Peck area. On these hilltops are abundant granite erratics lying on the bedrock surface. The fact that the ice was not thick enough to override the Flaxville plain to the northeast shows clearly that the ice responsible for the drift that was on the Larb Hills could not have advanced from the northeast. The Larb Hills ice must have derived from the north or northwest and may have been the same ice that deposited the southeasterly aligned Snake Butte boulder train (Knechtel, 1942) in north-central Montana.
2. The few erratics in the Wiota gravels indicate the early presence of an ice sheet within at least a few scores of miles of the Fort Peck area.
3. Thickly scattered erratics rest on the bedrock surface of the high hills in the southernmost part of the Nashua quadrangle and in the westernmost parts of the Glasgow quadrangle. These represent either the distal parts of the attenuated Tazewell(?) drift margin or the much eroded remnants of the same drift that once covered the Larb Hills.

DRAINAGE HISTORY

Rivers and streams in the Fort Peck area were temporarily or, in some reaches, permanently displaced from their valleys by glaciation; commonly the axes of the modern valleys are offset to one side of preglacial-valley axes. The glaciation of the Larb Hills presumably affected drainage in the general area as much as did the subsequent Tazewell(?) ice, but data available on the Fort Peck area are too fragmentary to allow analysis of glacial-drainage history related to the earlier glaciation.

Drainage conditions just prior to the advance of the Tazewell(?) ice are evidenced by abundant data. The ground-moraine blanket is thicker in preglacial valleys than in preglacial divide areas but is not thick enough to obscure the positions or, in most places, the margins of these ancient valleys. Figure 19 shows the pre-Tazewell(?) positions of principal streams in the Fort Peck area. Borehole data and natural exposures reveal no Wiota gravels in the Fort Peck area at altitudes of less than 2,030 feet in the western part of the area and of 2,005 feet in the eastern part of the area. It is therefore concluded that preglacial trunk drainage entered the Fort Peck area on the west at approximately 2,030 feet above sea level and departed on the east at approximately 2,005 feet above sea level.

The valley now occupied by the Milk River and the part of the Missouri River valley downstream from the Fort Peck Dam represent the preglacial course of the Missouri River. This course is broader and morphologically more mature than the Missouri River valley upstream from the dam, which was established during the Pleistocene when advancing ice older than the Tazewell(?) ice blocked the old valley and forced the river into a new course. The topography bordering the Fort Peck Reservoir is characterized by dissected and commonly steep-sided ridges and hills; the tributary valleys have narrow V-shaped profiles. The main valley of the Missouri River itself, prior to the filling

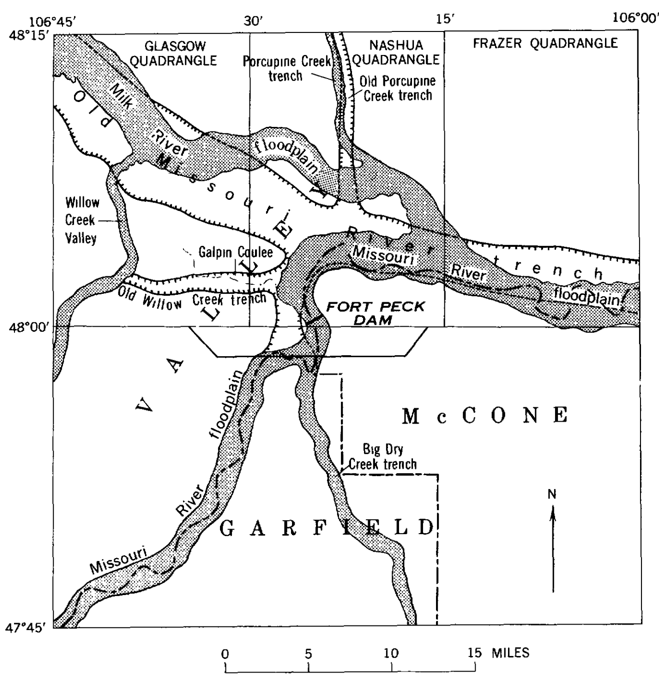


FIGURE 19.—Sketch map showing drainage history in the Fort Peck area and vicinity.

of the reservoir, was considerably narrower and generally lacked the broad flood plain of the valley downstream from the dam. Surface exposures and drill-hole data on the area near Fort Peck Dam show that the river valley near the dam is partly filled by Tazewell(?) moraine and, therefore, antedates the Tazewell(?) glaciation. The fact that the Larb Hills west of Fort Peck was glaciated before Tazewell(?) time also indicates that the Missouri River was moved southward out of the Milk River valley to its present course prior to Tazewell(?) time.

Present principal drainage lines follow, in a general way, their pre-Tazewell(?) courses except for Willow Creek south of Glasgow. The chief difference is that the modern valleys are generally located at an edge of the preglacial valleys. Thus, the modern Missouri River flood plain is displaced to the south edge of the preglacial valley; the Milk River flood plain is generally north of the buried-valley axis; and Porcupine Creek is displaced a short distance to the west (fig. 19). This situation apparently is due to the fact that the thin ground moraine on soft Bearpaw shale at the old valley sides was more easily eroded than the thicker ground moraine in old valley centers.

In local areas the modern streams have abandoned preglacial courses entirely; for example, the lower reaches of Porcupine Creek and the Milk River downstream from Nashua. These changes probably began during meandering of the Milk River over a valley full of stagnant ice, the courses of the streams becoming fixed by the time the obstructing ice wasted from the original valley.

A drainage change of more significance occurred on Willow Creek, which in preglacial time flowed east in a broad valley across the southern part of the Glasgow quadrangle and emptied into the Missouri River. Willow Creek at present turns abruptly north in the southwestern part of the quadrangle, flows through a comparatively steep-sided valley, and empties into the Milk River.

The Tazewell(?) ice lobe that advanced westward into the Glasgow quadrangle might have formed a glacial lake in the Willow Creek valley, but no field evidence was found to support this hypothesis. In the Milk River valley west and southwest of Glasgow are deposits mapped as Kintyre formation; these may represent a lake backed up by the Tazewell(?) ice. The canyon of Willow Creek was almost certainly a spillway channel from the indicated lake west of Glasgow into the postulated lake in the upper Willow Creek valley.

Willow Creek history may have been as follows: Ponding in the Milk River valley west of Glasgow caused a divide at the position of the canyon to be overtopped; ponded water then spilled into the glacial lake in Willow Creek in which the water level may subsequently have risen until it too reached a spill point to the southwest (sec. 34, T. 24 N., R. 39 E.). As the ponding barrier formed by ice in the Milk River valley was reduced by melting and evaporation, the lake west of Glasgow drained away down the Milk River valley and the direction of flow in the Willow Creek spillway was reversed, so that the glacial lake in Willow Creek drained into the Milk River. The flow continuously deepened the spillway in the process, resulting finally in the relatively steep-sided valley seen today.

As the Tazewell(?) ice advanced up the Missouri River valley into the Fort Peck area, the trunk drainage must certainly have been effectively blocked. Resultant ponding presumably backed water up tributaries leading into the river valley from the south and southwest until divides were overtopped. In this way the water gathered by the Missouri River drainage system was allowed to escape to the west. As the ice moved westward, these spillways would be overrun at their junctions with the main valley, and new spillways would be required; generally these would develop at different elevations because of the drainage-system gradient and the elevations of the lowest available spill-point divides. How many times this phenomenon occurred in the vicinity of the Fort Peck area is not known, but numerous spillway-channel remnants are known to exist south of the Missouri River in McCone County and in Valley County in the area between Willow Creek and the Fort Peck Reservoir to the west of the Fort Peck area.

LATE-GLACIAL AND POSTGLACIAL HISTORY OF THE FORT PECK AREA

The wasting of the Tazewell(?) glacier contributed to the formation of many of the present geologic features of the Fort Peck area. During wasting of the ice, the driftless-area nunataks enlarged and others formed in nearby areas; eventually, a stage was reached when much of the area north of the Missouri River valley was ice free, while the valley itself, where ice had been thickest, was still occupied by stagnant ice. As this ice thinned, it became less of a barrier to drainage, and in time the river overtopped this barrier and flowed on the stagnant ice. Irregularities in the ice surface included depressions that became the sites of ponds and lakes whose outlines and positions changed as deposition and melting proceeded. Melting of the stagnant ice was presumably slow, owing to insulation by fluvial and lacustrine deposits and may not have been complete until many years after the disappearance of ice elsewhere in this part of Montana.

The nunatak area to the north of the mapped area enlarged during wasting and eventually included the higher northern parts of the Fort Peck area. Evidence for the ice-free condition of these northern areas during a time when ice still occupied the Missouri River valley to the south is found, among other places, in the northern part of the Frazer quadrangle. Here, melt waters flowed along the margins of the nunataks in channels trenched partly in ice-free ground and partly in ice, as indicated by discontinuous and fragmentary surface markings of the courses. Additional evidence lies in the trend of some of these channels (T. 29 N., R. 43 E.), which is east normal to the southward slope of the ground-moraine plain; the scars of these channels are illuminating as to their origin in that the south sides are lower and less well defined than the north sides; indeed, in some places there is no evidence of a south side at all. Evidently the missing features in the channels were formed by the glacial ice, which has long since melted.

The East Fork of Charley Creek, a south-flowing stream near Frazer, provides additional evidence that much or all the northern part of the Frazer quadrangle was ice free at a time when ice still lay in the broad valley to the south. This creek follows a glacial-outwash channel which, though dissected, is topographically distinct except near its southern limit. Here the outwash deposits have no topographic boundary and are superposed on the irregular surface of the underlying ground moraine. This irregular surface is reflected in the uneven surface of the outwash deposits and is exposed in a highway cut in the SW¼ sec. 20 and NW¼ sec. 29, T. 27 N., R. 44 E. The deduction is that the water in the southern reaches of the channel flowed on stagnant ice lying in the valley of the Missouri River and that the channel deposits were laid down on the moraine as the ice melted away.

Collapse features within the superglacial fluviolacustrine deposits (Kintyre formation) are striking evidence of the persistence of underlying stagnant ice in the Missouri River valley long after the valley was reoccupied by trunk drainage. Folds, as great as 6 feet in amplitude, formed by collapse are common—for example, in the Missouri River bluffs south of Frazer and at a highway cut about 4 miles south of Nashua (fig. 17). In the south bluff of the Missouri River south of Nashua near the common corner of Tps. 26 and 27 N., Rs. 41 and 42 E., blocks of sand and silt as large as 30 feet on a side are locally enclosed in finer-grained sediments. Exposures in the gullies dissecting the bluffs on the other side of the river show that the deposits are a jumbled mass of blocks and irregular stringers. The unconformable relations of the stratified eolian sand south of Nashua to the underlying superglacial deposits indicates that the structure of the superglacial deposits is not the result of slumping initiated by modern erosion of river bluffs. The bedding in this sand is not disturbed; therefore, the sand must have been deposited after deformation of the superglacial deposits. On the other hand, the bedding of the sand is unconformable with the present topography and, therefore, the sand must have been deposited prior to the existence of this topography.

Previous to the spilling of glacial Milk River onto the ice surface, a set of conjugate fractures opened in the stagnant ice in the central part of the Frazer quadrangle. These fractures became filled with till and their pattern consequently has been preserved on the ground moraine plain as a network of low ridges. In a few places these ridges have surface expression, even where covered by the Kintyre formation; this condition is consistent with the hypothesis that the Kintyre is a superglacial deposit that was draped over the ridge deposits as the intervening ice wasted away.

Outwash-gravel deposits, including outwash terrace gravels, and ice-contact gravel deposits are thin and sparse in the Fort Peck area compared with many other glaciated areas. This indicates a dearth of melt water and suggests that ice wasting was either slow or was accomplished less by melting than by evaporation. The fine-grained character of the Kintyre, which was certainly deposited during ice wasting, also supports the hypothesis that a slack-water low-volume drainage regimen existed during waning stages of the Tazewell(?) glaciation.

The hummocky pitted outwash on the east side of Little Porcupine Creek is probably a collapse deposit of stratified drift that was originally laid down by melt water on a thin tongue of stagnant ice.

As the glacial age progressed, downcutting began along drainage courses and continued until the valleys of the Milk and Missouri Rivers were some 160 feet deeper than they are today. A shift in regimen reversed the procedure, and valleys then began to be aggraded. It is not known at which point melt waters ceased to contribute a major portion of stream volume; however, the fact that the coarser material is largely confined to the lower part of the fill suggests that it was well before the end of aggradation. Aggradation in the valleys of the Milk and Missouri Rivers controlled deposition in Porcupine Creek, Little Porcupine Creek, and other large tributaries and continued until the flood-plain level in the main valleys was several feet higher than at present. The effect of aggradation was extended far up the tributaries, although it was most pronounced near the confluence with the main valley.

Within comparatively recent time, the rivers have resumed downcutting, which has lowered flood-plain levels about 25 feet below the highest terrace alluvium of the valleys.

SUMMARY OF NATURAL RESOURCES

Nonmetallic construction materials—suitable mostly for concrete aggregate, fill, highway base course, or highway surfacing—are the major natural resources, other than soil and water, known to be present in the Fort Peck area. There are no known deposits of metallic ore; the coal-bearing Fort Union formation, present in nearby areas, has been removed by erosion from the Fort Peck area. No oil or gas has as yet been discovered, although the subsurface formations include favorable stratigraphic units that have yielded both oil and gas in other parts of the State.

The following discussion summarizes and, in places, supplements the information presented under the heading "Engineering considerations" in the discussion of each geologic unit.

HIGHWAY SUBGRADE MATERIALS

Nearly all materials from the Tertiary and younger formations can be and have been used in the construction of the subgrade of primary highways. The entire road grade of secondary roads is usually constructed from the underlying material. The Bearpaw shale, particularly the bentonitic members, is generally considered unsuitable for road construction. Most of the poorly consolidated parts of the Fox Hills and Hell Creek formations could be used for surfacing and base course but have not been developed because more suitable materials are generally available nearer the highways.

SAND AND GRAVEL

The principal sources of sand and gravel include the Wiota gravels, the Flaxville formation, the outwash-gravel deposits, and some stream alluvium. Varying thickness, lateral extent, and amount of overburden require detailed prospecting of each deposit as a prelude to exploitation. Most of the existing gravel pits are in the Wiota gravels. Poor accessibility has limited development of the Flaxville formation in the Fort Peck area. Except for a large deposit on Little Porcupine Creek, which represents the largest usable gravel reserve in the area, most of the outwash deposits are too thin or too poorly sorted to have any commercial value.

RIPRAP

Cobbles and boulders, 6 to 30 inches in diameter, have been gathered into heaps along some section lines on the ground-moraine plain; these and the harder ledge rock in the Fox Hills sandstone and Hell Creek formation might be of some economic value as riprap.

CERAMIC CLAY

The most promising source of ceramic clay seems to be those materials mapped as intermittent pond deposits. Because the ground moraine and Bearpaw shale consist very largely of clay, these formations might also merit testing.

MATERIAL FOR LINING WATER-RETAINING STRUCTURES

Bentonite is commonly used to prevent seepage loss from water-retaining structures. The Bearpaw shale contains a large number of bentonite beds, but all those exposed within the map area are too thin (¼ inch to 19 inches) to be of economic value at present. The till of the ground moraine is so nearly impermeable that it might prove to be a satisfactory substitute in some uses.

LIGHTWEIGHT AGGREGATE

A major cement company has tested the Pierre shale in northeastern Colorado and has found it generally acceptable for the production of lightweight aggregate. Because the Bearpaw shale is the equivalent of the upper part of the Pierre and is similar in composition in most localities, the Bearpaw shale warrants investigation as a possible source of lightweight aggregate in eastern Montana. The expense of production often limits the use of lightweight aggregate; however, the small quantities of good natural aggregate and the abundance of the Bearpaw shale might justify the construction of a lightweight-aggregate plant in this area.

SELECTED REFERENCES

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

Bartram, J. G., and Erdmann, C. E., 1935, Natural gas in Montana, *in* Lay, G. A., ed., Geology of natural gas: Am. Assoc. Petroleum Geologists, p. 245–276.

Bauer, C. M., 1924, Quartzite pebbles at the base of the Lance formation in Montana: Am. Assoc. Petroleum Geologists Bull., v. 9, no. 2, p. 344–346.

Bowen, C. F., 1915, The stratigraphy of the Montana group, with special reference to the position and age of the Judith River formation in north-central Montana: U.S. Geol. Survey Prof. Paper 90, p. 95–153.

Brown, Barnum, 1907, The Hell Creek beds of the upper Cretaceous of Montana: Am. Mus. Nat. History Bull. 23, p. 823–845.

——— 1914, Cretaceous-Eocene correlation in New Mexico, Wyoming, Montana, Alberta: Geol. Soc. America Bull., v. 25, p. 355–380.

Brown, R. W., 1939, Fossil plants from the Colgate member of the Fox Hills sandstone and adjacent strata: U.S. Geol. Survey Prof. Paper 189–I, p. 239–275, 63 pls.

——— 1952, Tertiary strata in eastern Montana and western North and South Dakota, *in* Sonnenberg, F. P., ed.: Billings Geol. Soc. Guidebook 3d Ann. Field Conf., p. 89–92.

Calhoun, F. H. H., 1906, The Montana lobe of the Keewatin ice sheet: U.S. Geol. Survey Prof. Paper 50, 62 p.

Chamberlin, T. C., 1888, The rock-scorings of the great ice invasions: U.S. Geol. Survey 7th Ann. Rept., p. 147–248.

Collier, A. J., 1917, The Bowdoin dome, Montana, a possible reservoir of oil or gas: U.S. Geol. Survey Bull. 661, p. 193–209.

——— 1918, Geology of northeastern Montana: U.S. Geol. Survey Prof. Paper 120, p. 17–39.

Collier, A. J., and Knechtel, M. M., 1939, The coal resources of McCone County, Montana: U.S. Geol. Survey Bull. 905, 80 p.

Collier, A. J., and Thom, W. T., Jr., 1918, The Flaxville gravel and its relation to other terrace gravels of the northern Great Plains: U.S. Geol. Survey Prof. Paper 108–J, p. 179–184.

Colton, R. B., 1951a, Geology of the Oswego quadrangle, Montana: U.S. Geol. Survey open-file report.

——— 1951b, Preliminary report on the Otter Creek quadrangle, Montana: U.S. Geol. Survey open-file report.

——— 1953, Geologic map of the Fort Peck Indian Reservation and vicinity, Montana: U.S. Geol. Survey open-file report.

——— 1954, Geology of the Chelsea and Poplar quadrangles, Montana: U.S. Geol. Survey open-file report.

——— 1955a, Geology of the Brockton quadrangle, Montana: U.S. Geol. Survey open-file report.

——— 1955b, Geology of the Wolf Point quadrangle, Montana: U.S. Geol. Survey Geol. Quad. Map GQ–67.

——— 1958, Ice-crack moraines in northwestern North Dakota and northeastern Montana: North Dakota Geol. Survey Misc. Ser. no. 10, p. 97.

Colton, R. B., and Jensen, F. S., 1953, Crevasse fillings on the glaciated plains of northeastern Montana [abs.]: Geol. Soc. America Bull., v. 64, no. 12, pt. 2, p. 1542–1543.

Colton, R. B., Lindvall, R. M., and Appledorn, C. R., 1952, Direction of glacial movement in northern Montana [abs.]: Geol. Soc. America Bull., v. 63, no. 12, pt. 2, p. 1360.

Darton, N. H., 1905, Preliminary report on the geology and underground water resources of the central Great Plains: U.S. Geol. Survey Prof. Paper 32, 433 p.

Dawson, G. M., and McConnell, R. G., 1895, Glacial deposits of southwestern Alberta in the vicinity of the Rocky Mountains: Geol. Soc. America Bull., v. 7, p. 31–66 [1896].

Dobbin, C. E., and Erdmann, C. E., 1934, Geologic occurrence of oil and gas in Montana, *in* Problems of petroleum geology (Sidney Powers Memorial volume): Am. Assoc. Petroleum Geologists, p. 695–718.

——— 1955, Structure contour map of the Montana Plains: U.S. Geol. Survey Oil and Gas Inv. Map OM–178–A, revised.

Dobbin, C. E., and Reeside, J. B., Jr., 1929, The contact of the Fox Hills and Lance formations: U.S. Geol. Survey Prof. Paper 158–B, p. 9–25.

Dorf, Erling, 1942, Application of paleobotany to the Cretaceous-Tertiary boundary problem: New York Acad. Sci. Trans., ser. 2, v. 4, no. 3, 73 p.

Eldridge, G. H., 1889, Some suggestions upon the method of grouping the formations of the middle Cretaceous and the employment of an additional term in its nomenclature: Am. Jour. Sci., 3d ser. v. 38, p. 313–321.

Erdmann, C. E., and Schwabrow, J. R., 1941, Border-Red Coulee oil field, Toole County, Montana, and Alberta, Canada, *in* Levorsen, A. I., ed., Stratigraphic-type oil fields, p. 267–326.

Gilbert, G. K. and Gulliver, F. P., 1895, Tepee Buttes [Colorado], Geol. Soc. America Bull. 6, p. 333–342.

Goddard, E. N., chm., and others, 1948, Rock-color chart: Washington, Natl. Research Council; republished by Geol. Soc. America, 1951.

Hayden, F. V., 1862, On the geology and natural history of the upper Missouri: Am. Philos. Soc. Trans., separate, 218 p.

Jensen, F. S., 1951a, Preliminary report on the geology of the Frazer quadrangle, Montana: U.S. Geol. Survey open-file report.

——— 1951b, Bedrock deformation of late Quaternary age at Tiger Butte, northeastern Montana [abs.]: Geol. Soc. America Bull., v. 62, no. 12, pt. 2, p. 1452.

——— 1951c, Disconformity at the contact of the Fox Hills sandstone and Hell Creek formation in northeastern Montana [abs.]: Geol. Soc. America Bull., v. 62, no. 12, pt. 2, p. 1453.

——— 1952a, Structural contour map of part of the Williston basin in the Fort Peck area, Montana: U.S. Geol. Survey open-file report.

——— 1952b, Preliminary report on the geology of the Nashua quadrangle: U.S. Geol. Survey open-file report.

——— 1953a, Preliminary geologic map of the Glasgow quadrangle, Montana: U.S. Geol. Survey open-file report.

——— 1953b, Preliminary geologic map of Tiger Butte, Glasgow quadrangle, Montana: U.S. Geol. Survey open-file report.

King, L. C., 1953, Canons of landscape evolution: Geol. Soc. America Bull., v. 64, no. 7, p. 721–751.

Knechtel, M. M., 1942, Snake Butte boulder train and related glacial phenomena, north-central Montana: Geol. Soc. America Bull., v. 53, no. 6, p. 917–935.

Lemke, R. W., 1960, Geology of the Souris River area, North Dakota: U.S. Geol. Survey Prof. Paper 325, 138 p.

Leonard, A. G., 1908, Geology of southwestern North Dakota, with special reference to the coal: North Dakota Geol. Survey Bienn. Rept. 5, p. 27–114.

Lindvall, R. M., 1954, Preliminary geologic map of the geology of the Boxelder quadrangle, Montana: U.S. Geol. Survey open-file report.

——— 1953, Geology of the Eagleton quadrangle, Montana: U.S. Geol. Survey Geol. Quad. Map GQ–29.

——— 1956, Geology of the Kenilworth quadrangle, Montana: U.S. Geol. Survey Misc. Geol. Inv. Map I–129.

——— 1956, Geology of the Big Sandy quadrangle, Montana: U.S. Geol. Survey Misc. Geol. Inv. Map I–130.

Lovering, T. S., and others, 1932, Fox Hills formation, northeastern Colorado: Am. Assoc. Petroleum Geologists Bull., v. 16, no. 7, p. 702–703.

McConnell, R. G., 1885, Report on the Cypress Hills, Wood Mountain and adjacent country: Canada Geol. Survey Ann. Rept., v. 1, p. 1c–78c.

Meek, F. B., 1886, A report on the invertebrate Cretaceous and Tertiary fossils of the upper Missouri country: U.S. Geol. Survey Terr. (Hayden), v. 9, 629 p.

Perry, E. S., 1934, Geology and artesian-water resources along Missouri and Milk Rivers in northeastern Montana: Montana Bur. Mines and Geology Mem. 11, 34, p.

Ross, C. P., Andrews, D. A., and Witkind, I. J., 1955, Geologic map of the State of Montana: Scale, 1:500,000, U.S. Geol. Survey.

Russell, L. S., 1953, Tertiary stratigraphy of southwestern Saskatchewan, *in* Parker, J. Marchbank, ed.: Billings Geol. Soc. Guidebook 4th Ann. Field Conf, p. 106–113.

Schultz, C. B., Lueninghoener, G. C., and Frankforter, W. D., 1951, A graphic résumé of the Pleistocene of Nebraska (with notes on the fossil mammalian remains), Nebraska Univ., Nebraska State Museum Bull., v. 3, no. 6, 41 p.

Slater, George, 1927, Structure of the Mud Buttes and Tit Hills in Alberta: Geol. Soc. America Bull., v. 38, no. 4, p. 721–730.

Smith, C. D., 1910, The Fort Peck Indian Reservation lignite field, Montana: U.S. Geol. Survey Bull. 381, p. 40–59.

Smith, J. F., Witkind, I. J., Trimble, D. E., and Duckworth, E. G., 1955a, Preliminary geologic map of the Goose Mountain No. 1 quadrangle, Montana: U.S. Geol. Survey open-file report.

——— 1955b, Preliminary geologic map of the Goose Mountain No. 2 quadrangle, Montana: U.S. Geol. Survey open-file report.

——— 1955c, Preliminary geologic map of the Lonesome Lake No. 2 quadrangle, Montana: U.S. Geol. Survey open-file report.

——— 1955d, Preliminary geologic map of the Lothair quadrangle, Montana: U.S. Geol. Survey open-file report.

Stanton, T. W., and Hatcher, J. B., 1905, Geology and paleontology of the Judith River beds: U.S. Geol. Survey Bull. 257, 128 p.

Stebinger, Eugene, 1914, The Montana group of northwestern Montana: U.S. Geol. Survey Prof. Paper 90–G, p. 61–48.

Swenson, F. A., 1955, Geology and ground-water resources of the Missouri River valley in northeastern Montana: U.S. Geol. Survey Water-Supply Paper 1263, 128 p.

Thom, W. T., and Dobbin, C. E., 1924, Stratigraphy of Cretaceous-Eocene transition beds in eastern Montana and the Dakotas: Geol. Soc. America Bull., v. 35, no. 3, p. 481–505.

Townsend, R. C., 1950, Deformation of the Fort Union formation near Lignite, North Dakota: Am. Assoc. Petroleum Geologists Bull., v. 34, no. 7, p. 1552–1564.

U.S. Department of Agriculture, 1941, Climate and Man, *in* Yearbook of Agriculture, 1941: U.S. 77th Cong., 1st sess., House Doc. 27.

Weed, W. H., 1899, Description of the Fort Benton quadrangle [Montana]: U.S. Geol. Survey Geol. Atlas, Folio 55.

White, C. A., 1878, Report on the geology of a portion of northwestern Colorado: U.S. Geol. and Geog. Survey Terr. (Hayden), v. 10, 132 p.

Williams, M. Y., and Dyer, W. S., 1930, Geology of southern Alberta and southern Saskatchewan: Canada Geol. Survey Mem. 163, 160 p.

Witkind, I. J., 1959, Quaternary geology of the Smoke Creek-Medicine Lake-Grenora area, Montana and North Dakota: U.S. Geol. Survey Bull. 1073, 80 p.

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