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Preliminary report on the Geology of the Frazer Quadrangle, Montana

by

Fred S. Jensen

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GENERAL SETTING

Geography

The Frazer quadrangle covers about 200 square miles in northeastern Montana, mostly in Valley County, partly in McCone County. That part in Valley County is within the Fort Peck Indian Reservation which extends many miles to the east, north, and west. Northeastern Montana is in the Missouri Plateau section of the Northern Great Plains physiographic province.

The Missouri River meanders on a floodplain 2 to 3 miles wide extending from west to east across the southernmost part of the quadrangle. All other drainage is tributary to the Missouri River, the largest being Little Porcupine Creek, in the eastern part of the quadrangle, which flows southward on a floodplain about one-half mile wide.

The river bottom land was formerly covered with groves of cottonwood, willow, green ash and boxelder. Most of this land has now been cleared for farming. A row of trees borders Little Porcupine Creek and some of its more recently abandoned meanders. The only other trees are around Frazer townsite.

Drainage is well integrated except for numerous small areas on the upland.

Most of the surface is a grassy plain sloping gently southward towards the Missouri River. Local relief on this plain generally is only a few feet, but in the northern part of the quadrangle remnants of an old plateau surface stand more than 200 feet above the general level. Little Porcupine Creek has trenched as much as 80 feet into the upland, and steep bluffs at the north edge of the Missouri River floodplain are of similar height.

South of the Missouri River floodplain much dissected remnants of a tableland more than 200 feet above river level rise southward to blend with a still higher upland just beyond the quadrangle.

The town of Frazer, population about 500, is on the main line of the Great Northern Railway and on U. S. Highway 2, both of which cross the southern part of the quadrangle. There are a few unimproved roads, used by local ranchers and wheat farmers, in the northern part, and a network of improved roads in the southern part of the quadrangle. Just to the east of the quadrangle a gravelled highway leads north from U. S. Highway 2. Damming has created an artificial lake for storing irrigation water near Frazer, the water being supplied during spring runoff by a canal from Little Porcupine Creek.

Geology

<u>Bedrock</u>. -- Three sedimentary formations crop out at the surface. From oldest to youngest these are the Bearpaw shale, Fox Hills sandstone and Hell Creek formation, all of Upper Cretaceous age. The

Bearpaw shale is a dark gray clayey shale underlying the whole area. The others are interbedded gray and brown sandstone, siltstone, and claystone, and are present only in small areas in the northeast and southwest parts of the quadrangle. The formations dip a few feet per mile to the east and southeast. Exposures are mostly along stream valleys and on steep hillsides.

An additional 7,500 feet (estimated) of sedimentary strata underlie the Bearpaw shale and overlie pre-Cambrian crystalline rocks. These strata include a great variety of rock types, including sandstone, shale, limestone, conglomerate, gypsum, and anhydrite. Some of them contain oil and gas in other parts of the state but recent test drilling near this area has been unsuccessful.

Surficial deposits. -- Unconsolidated deposits of four kinds mantle most of the surface. The oldest are gravels (Flaxville gravel and Wiota gravel) deposited on gently sloping erosion surfaces cut by streams which flowed at successively lower elevations during the latter part of the Tertiary period and well into Quaternary time. These gravels discontinuously cover bedrock and underlie younger formations. Next came unstratified deposits (ground moraine) laid down as an uneven blanket over most of the area by an advancing continental glacier of Cary (?) sub-age. As the glacier waned a variety of stratified materials (superglacial fluvio-lacustrine deposits, pitted outwash deposits, outwash gravels deposited in channels, and outwash terrace deposits) was deposited. The stratified drift differs locally in thickness and is of discontinuous distribution. It lies upon unstratified drift, pre-Cary (?) gravels, or bedrock according to the depth of erosion concurrent with deposition. The youngest unconsolidated deposits are alluvium and terrace alluvium in stream valleys, intermittent sand deposits in irregularities of the ground moraine surface and alluvium-colluvium on valley-side slopes. These are post-glacial and are associated with the most recent stages of geomorphic development.

BEDROCK FORMATIONS

Upper Cretaceous formations

Bearpaw shale. (Kb)

1. Description.-- Bearpaw shale underlies all of the quadrangle. It is about 1,100 feet thick and is predominantly semi-consolidated dark gray clayey shale, slightly fissile.

Weathering softens the near-surface few feet, probably by leaching of colloidal matter, and lightens the color. Part of the formation consists of bentonite, a clay mineral having marked swelling properties. It occurs both dispersed in the other types of clay present in the shale, and in separate beds. Where bentonite is dispersed in the shale, the shale weathers so as to feel soft and spongy underfoot. Shale containing no dispersed bentonite weathers to a mass of soft, light gray chips up to half an inch across.

Bentonite also occurs in many creamy yellow beds which range in thickness from a fraction of an inch to 8 inches.

In addition to bentonite the formation contains several kinds of hard ellipsoidal concretions, most of which are either rusty brown clay-ironstone or light gray limestone, arranged along bedding planes and more or less widely spaced. Any of the concretions are likely to contain marine fossils, but in the limestone concretions alone are they abundant and well preserved.

Only the upper few hundred feet of the formation are exposed in the quadrangle so the fossils represent but two paleontologic zones. The uppermost zone is characterized by certain ammonites, *Discoscaphites sp.* and *Baculites grandis*. The other zone is characterized by a form of *Baculites compressus*, an ammonite, having smooth flanks and venter. Many other species of fossils, in particular *Inoceramus sp.*, are present in both zones.

2. Water-bearing character. -- The formation is so nearly impervious that no appreciable quantities of ground water can be recovered from it. Unweathered shale has a moisture content of about 15 percent but the water is highly mineralized and any small amounts recovered are unfit for use. Water wells should not be drilled into Bearpaw shale unless it is planned to penetrate the underlying Judith River formation, in which case a hole 700 to 1000 feet deep is necessary.

3. Engineering considerations. -- Both weathered and unweathered shale can be excavated with power tools. Fractures facilitate excavation but necessitate timbering of tunnels and revetting of large cuts having slopes in excess of about 45 degrees. Because of low permeability underground water seepage is negligible and subsurface drainage is poor, even in the weathered material.

Foundation sites for heavy structures should be test-drilled to determine the presence or absence of bentonite beds, which may cause landsliding. Landsliding may also be initiated by large excavations in shale hillsides or near their bases, or by heavy structures on such hillsides. Unweathered shale slacks and loses strength very rapidly on exposure to the atmosphere.

During wet weather unsurfaced roads are impassible.

Fox Hills sandstone (Kfh).

1. Description. -- Fox Hills sandstone has been eroded from the quadrangle except for small areas near the northeast and southwest corners. It is about 120 feet thick and grades upward from the Bearpaw shale through about 35 feet of alternating, thin-bedded, gray brown, and yellow silty claystone, siltstone, and fine grained sandstone, all of which have a light gray weathered surface. The remainder of the formation is yellowish rust brown fine-grained sandstone, discontinuously cemented by calcium carbonate to form ledges and spheroidal concretionary masses. Several other kinds of smaller concretions, of both regular and irregular shapes, are scattered throughout the formation. Materials like those in the lower 35 feet are present as lenses within the upper part. Cross-bedding is more common toward the top of the formation but is nowhere as common or on as large a scale as in the unconformably overlying Hell Creek formation. The only fossils are a few carbonized plant fragments near the top of the formation.

2. Water Bearing character. -- A few intermittent springs issue from hillsides near the base of the formation. Accordingly, wells sunk to this horizon should yield water, though no data are available as to quantity. Quality of water from this formation is reportedly good. (Perry, 1934, p. 6.)

3. Engineering considerations. -- The discontinuous masses of hard sandstone in the upper part require blasting for removal, but the rest of the formation can be excavated with power tools. Cuts should stand well, even at angles steeper than 45 degrees, unless they extend into the underlying Bearpaw shale. In the latter case land-sliding may take place. Subsurface drainage differs with the degree of cementation, and perched water tables can be expected above ledges. Unsurfaced roads are passable during all normal weather conditions. The harder ledge rock may be suitable as a construction material, but quarrying on any but the smallest scale would entail considerable expense.

Hell Creek formation (Khc).

1. Description. -- The Hell Creek formation has only a small area of outcrop, in the northeastern corner of the quadrangle, where all but the basal 50 to 60 feet were eroded away prior to deposition of the overlying Flaxville gravel. That part remaining is grayish rust brown medium-grained sandstone containing conspicuous dark mineral grains. It is discontinuously cemented to form ledges and concretionary sandstone masses of log-like or spheroidal form.

Included in the sandstone are lenses of poorly consolidated conglomerate, many of them at the channeled contact with the underlying Fox Hills sandstone. The conglomerate pebbles are mostly fragments of concretions, but of particular importance is the presence of numerous smooth, well-rounded pebbles and cobbles of light gray quartzite. The coarser grain size of the sand and the conglomerate indicate a marked shift in conditions of deposition following Fox Hills time.

Cross-bedding is widely developed, and on a larger scale than in the underlying formation.

Fragments of dinosaur bone and wood are common, some being incorporated in the conglomerate lenses.

2. Water-bearing character. — No ground water data are available concerning the formation in the quadrangle. The formation yields some water in nearby areas but within the quadrangle the overlying and underlying formations are probably more satisfactory sources.

3. Engineering considerations. — Engineering characteristics of the Hell Creek formation are essentially similar to those of the Fox Hills sandstone. However, the coarser grain size of the sand in the Hell Creek formation probably produces higher permeability, hence better subsurface drainage.

SURFICIAL DEPOSITS

Pre-Cary (?) formations

The subdivision into two formations of the gravels that form this group of deposits is based entirely on age differences. There is no apparent distinction in lithology or method of deposition. Since identifiable fossils are comparatively rare, age differences are deduced from elevation above sea level and from gradients of the erosion surfaces on which the gravels lie. Detailed work in this and surrounding areas shows the dividing line between the formations, based only on elevations and gradients, to be somewhat arbitrary, and more precise formational definition must await further fossil discoveries.

<u>Flaxville gravel</u>. (Tfg)

1. Description. -- The Flaxville gravel is at the surface in small areas in the northern part of the quadrangle, capping remnants of old plateau surfaces. The average thickness is about 20 feet. It may also underlie ground moraine in other small areas in the northwestern part. The plateau surfaces range in elevation from somewhat more than 2,600 feet to about 2,700 feet above sea level and slope to the southeast and south. Fragments of mammal bones found in the gravel north and northeast of the quadrangle are of late Miocene or early Pliocene age. (Collier and Thom, 1918, p. 181.) The pebbles in the gravel are composed predominantly of very fine- to medium-grained quartzite. Average pebble size is $1\frac{1}{2}$ and 3 inches, though the range is from a fraction of an inch to about 7 inches in diameter. The pebbles are smooth and well-rounded, and are various shades of brown,

green, gray, and red-brown. Light gray pebbles such as those at and near the base of the Hell Creek formation are rare if present at all. A small number of pebbles are cryptocrystalline silica, tinguaite porphyry, and soft sandstone or siltstone derived from the local bedrock. The gravel is sandy and includes sand, silt, and clay as thin lenses. In a few places it is discontinuously cemented to conglomerate.

2. Water-bearing character. -- Where Flaxville gravel covers large areas it is a good source of shallow ground water, though quantity may diminish during extended periods of drought.

3. Engineering considerations. -- The formation is a source of sand and gravel, most of it uncemented and easily excavated. Crushing is necessary when angular material is desired. Chemically reactive material probably nowhere exceeds 1 to $1\frac{1}{2}$ percent. Isolated patches of drift and of aeolian (?) silt mantle the formation in places so that detailed prospecting is necessary to assess overburden.

Wiota gravels, (Qw)

1. Description. -- The formation is discontinuously present beneath the drift over many parts of the quadrangle north of Missouri River. It floors buried stream courses and mantles buried erosion surfaces which slope towards the Missouri River or border it on the north.

The lithology is like that of the Flaxville gravel but thickness is generally less, commonly between 8 and 15 feet. However, one difference is that the lowest level (youngest) of the Wiota gravels contain a few glacial erratics, probably representing drift of an ice sheet that did not advance this far south. The gravel is uncemented. The tooth of a mammoth (Mammuthus primigenius) shows that the lowest level gravels are of Wisconsin, probably late Wisconsin age.

2. Water-bearing character. -- The formation is a source of shallow ground water, but the discontinuous development of the formation makes prospecting difficult. The quantity of water available is small and differs markedly from place to place. Prolonged periods of drought would probably reduce and, locally eliminate water supplies.

3. Engineering considerations. -- The overburden of drift limits exploitation of the sand and gravel. The few small pits which have been opened are in the southwestern part of the quadrangle. Probably of most significance is the high permeability of the formation, causing serious seepage losses from unprotected water-retaining structures that intersect it.

Unstratified Glacial deposits

Ground Moraine (Qgm).

1. Description.-- Ground moraine forms the surface over much of the quadrangle and underlies younger deposits in other large

areas. Its thickness is commonly 5 to 15 feet, but where it buries parts of pre-Cary (?) valleys it is locally more than 40 feet thick Scattered thin patches of ground moraine and other drift on the high remnants of Flaxville gravel are not mapped. In the northern part of the quadrangle some small areas have topography reminiscent of end moraine, where the thickness may be several tens of feet.

Almost all of the ground moraine is till, the remainder being widely scattered thin lenses and irregular masses of sand, silt, and gravel intercalated in the till.

Till is a compact, unstratified mixture of clay and lesser quantities of silt, sand, and stones of various sizes ranging from pebbles to boulders. The stones are of several kinds. An average of several pebble counts shows the following breakdown: 55 percent derived from Flaxville and Wiota gravels, 26 percent cream-colored limestone and dolomite from Paleozoic formations of Canada, 15 percent granitic and schistose rocks from the Canadian pre-Cambrian, and 3 percent from local bedrock. There are scattered grains and small lumps of lignite and reddish-brown limonite. The till is light to medium brown with a yellowish cast.

In the central part of the quadrangle is a network of low, rounded ridges that apparently reflect a conjugate system of fractures formed in stagnant glacier ice. The ridges are of till, though erosion by wind and rain have cuased lag concentration of a few inches of gravel on their crests. Lag concentrates also mantle most other positive irregularities of the ground moraine surface.

Soil-forming processes have developed, from the surface downwards, the following: a dark brown humus zone 6 to 10 inches thick. a lime-enriched zone about 2 feet thick, and a zone 2 or more feet thick where gypsum grains have formed singly or in small clusters. Oxidation has changed the color of the ground moraine from the original bluish-gray.

2. Water-bearing character. -- The ground moraine is nearly impervious and yields negligible water, though small amounts are recoverable from wells that fortuitously intersect the intercalated lenses of sand and gravel.

3. Engineering considerations. -- The ground moraine is very compact but is easily worked with power tools. It stands well in cuts as much as 15 feet deep at angles greater than 45 degrees. Because it is nearly impermeable, seepage losses from water-retaining structures are negligible. Till is accordingly useful for lining such structures where built in pervious materials. Seepage at the contact of ground moraine with underlying formations must be guarded against in most places. When wet, unsurfaced roads are slippery and rut badly.

Stratified glacial deposits

<u>Superglacial Fluvio-lacustrine deposits</u> (Qs).

1. Description. -- In the southern part of the quadrangle superglacial fluvio-lacustring deposits form a gently rolling surface. In the east-central part they are covered by younger deposits of

outwash gravel. Thicknesses range from a feather edge to about 70 feet (see map section A-A'). The materials differ in composition from place to place but are mostly dark brown clay and silty-clay. The remainder is a tan silt and very fine sand, generally present in the middle and lower parts. In a few places the entire thickness is silt and sand.

Bedding planes are commonly folded and faulted and the surface of the ground moraine on which the deposits lie is markedly irregular. For the most part the clays have massive structure, but the silts and sands are delicately laminated and current-bedded like those in present-day river alluvium.

2. Water-bearing character. -- Little water can be recovered from these deposits, and that only from the silts and sands. The complex structure results in discontinuity of aquifers, so that subsurface circulation is inhibited. Because of poor circulation the water contains large amounts of dissolved solids.

3. Engineering considerations. -- All but the near-surface materials are compact or semi-consolidated so that power tools are necessary for excavating. Cuts less than 20 to 30 feet deep stand well at 30 degree angles unless considerable silt and fine sand is encountered, in which case slumping may be initiated in the deeper cuts. Shallow cuts stand at near vertical angles. Subsurface drainage is poor. Surface drainage is well integrated except for a few small areas. When wet, unsurfaced roads are slippery and rut badly.

Pitted outwash gravel (Qpo).

1. Description.-- In the east-central part of the quadrangle is an area of glacial gravels having an uneven surface marked by a number of undrained depressions. Local relief is commonly 5 to 12 feet. The surface on which the gravels lie is in many places irregular. The formation is commonly 10 to 15 feet thick, but along the eastern margin of outcrop it thins to a feather edge.

The gravel is sandy, having pebbles that range from one-half to 4 inches in diameter. A large proportion of the pebbles are identical to those in the Flaxville and Wiota gravels. Many others are limestone, dolomite and crystalline glacial erratics, and a small number are from the local bedrock. There are a few clay-balls.

About 2 miles west of Frazer are other small areas of deposits having the same characteristics, though these deposits are only 2 to 3 feet thick.

The pitted outwash gravels were deposited by melt-water that flowed at least in part on stagnant glacial ice.

2. Water-bearing character. -- The gravels are pervious and so provide abundant reservoir space, but inasmuch as the catchment area is limited, only a small amount of water can be expected.

3. Engineering considerations. -- Large reserves of gravel estimated at 5,000,000 cubic yards, and having negligible overburden, are readily available. Clayballs and reactive silica constitute very small percentages, but crushing might be necessary when angular material

is required. Inasmuch as surface and subsurface drainage are generally good, exploitation would not be hindered by excessive ground water.

Outwash gravel (Qo).

1. Description. -- In the northwest and southeast parts of the quadrangle there are deposits of outwash gravel 2 to 5 feet thick flooring flat-bottomed channels that were eroded by glacial meltwaters. Most of the gravel is sandy; some is silty and clayey. Pebbles are identical to those in the pitted outwash gravels described above.

The channels were eroded in ground moraine and locally deeper, into Bearpaw shale. At the time of deposition glacial ice constituted parts of the channel walls. Now that the ice has melted channel sides are locally higher on one side than the other.

2. Water-bearing character. -- Dissection caused by post-depositional erosion has drained the deposits and decimated their catchment areas, so that little or no water is retained in them.

3. Engineering considerations. -- The gravel is either too thin or too poorly sorted to be of economic value. The high permeability of the formation must be considered when building water-retaining structures.

Outwash terrace deposits (Qot)

1. Description. -- A number of terrace remnants mantled with outwash deposits flank the alluvial bottom land of Little Porcupine Creek, and are commonly separated from the bottom land by scarps 5 to 15 feet high. The deposits range in thickness from 3 to 10 feet and rest on either ground moraine or Bearpaw shale. Because the alluvium is also terraced (see below), and because the outwash terrace surfaces slope towards the creek as well as downstream, height of terrace surface depends on points of measurement. In no place are terrace surfaces more than 20 feet above the bottomland. Just north and northwest of Frazer a terrace remnant surface grades imperceptibly into that of the contiguous terrace alluvium.

The deposits are mostly gravel, in part poorly sorted and very sandy. The remainder is silt and sand enclosing thin gravel lenses. Pebble types are the same as in the pitted outwash gravel.

2. Water-bearing character. -- The deposits are similar to outwash gravel in their water-bearing characteristics, except that some water might be available in the larger terrace remnant near Frazer.

3. Engineering considerations. -- Detailed prospecting should show some of the deposits to be an economic source of sand and gravel. Because of surface slope and high permeability, drainage is good. Unsurfaced roads are passible in all weather.

Post-glacial deposits

Alluvium (Qal) and Terrace Alluvium (Qalt).

1. Descritpion. -- Alluvium covers the floors of river and creek valleys and is also spread over some other areas as broad, more or less coalesced fans. Terrace alluvium is locally present bordering the Missouri River floodplain and Little Porcupine Creek valley. It is separated from alluvium on a topographic basis because generally there is no marked difference in composition.

The surfaces slope gently downstream, and are nearly flat except where interrupted by meander scars or low scarps bounding remnants of terrace alluvium. The alluvial fans have very subdued topographic expression and appear nearly flat. They form an irregular outcrop pattern in the south-central part of the quadrangle, mostly between the Great Northern Railway and U. S. Highway 2.

Valley deposits of larger streams are thicker than those of smaller streams. Missouri River alluvium is commonly 100 to 130 feet thick, Little Porcupine Creek alluvium less than half as thick, and the mapped alluvium and alluvial fans of lesser streams 3 to probably 20 feet thick. Alluvium less than 3 feet thick is not mapped.

The alluvium is clay, silt, sand, and gravel, of various brown and gray colors. The near-surface materials are mostly clay, silt, and sand, arranged in horizontal, lenticular beds a few inches to a few feet thick. Cross-bedding is common. Near the surface gravel and coarse sand are present only in creek valleys and alluvial fans, though only as small lentils. At depth coarser grained sediments, sand and sandy gravel, form thin to thick lenses and fairly continuous beds. In the river valley these are generally several tens of feet beneath the surface, but elsewhere are only 3 to 15 feet down.

The terrace alluvium is locally coarser than other alluvium, being medium-grained sand and gravelly sand.

Terrace surfaces are 10 to 15 feet above the alluvium along the Missouri River floodplain. The difference in elevation between the alluvium and terrace alluvium lessens northward along Little Porcupine Creek valley, and the two surfaces blend in the northeastern part of the quadrangle.

2. Water-bearing character. -- There is abundant shallow ground water in the alluvium of Missouri River and Little Porcupine Creek valleys, but because subsurface circulation is low in the finer grained material the water is high in dissolved solids. Potable water is restricted to the gravels and coarser sands.

3. Engineering considerations. -- Alluvium is readily worked with power tools. The water table is generally 8 to 15 feet beneath the surface so that stability is poor at and below such depths, but shallower cuts are stable at near vertical angles. When wet some of the unsurfaced roads are impassable. Degree of both surface and subsurface drainage differs markedly from place to place. Locally the alluvium is a source of sand and gravel.

Alluvial-Colluvial deposits (Qac)

1. Description. -- Rivulet action, slopewash, creep, and slumping have combined to cause accumulations of debris on hillsides and the contiguous parts of valley floors. Surface profiles are smooth, concave-upward curves, progressively steeper upslope.

Upslope limits are drawn where the deposits thin to about 3 feet, downslope limits at the line of blending with valley alluvium. Maximum thicknesses of individual deposits range from 10 to 20 feet.

Most deposits are grayish brown, compact mixtures of silt, clay and scattered thin lentils of sand and gravel, the coarser fraction more abundant upslope. Local differences in source materials have caused variations from this composition, some of the deposits being almost entirely clay.

2. Water-bearing character. — The deposits contain little or no ground water because of low porosity and permeability.

3. Engineering considerations. — The deposits are workable with power tools and stand at near vertical angles in cuts. Subsurface drainage is very poor and though surface drainage is good there are concentrations of alkali salts at and near the surface. Unsurfaced roads corrugate in dry weather and rut badly when wet.

Intermittent Pond deposits (Qp).

1. Description. — Interspersed over the quadrangle are a large number of small undrained areas that contain shallow ponded water during parts of wet years. These depressions have been partially filled with clay and lesser amounts of silt from surrounding slopes, and are bounded by sides 3 to 15 feet high that are abrupt to indistinct. Reworking and deposition by ponded waters have distributed the sediments in such a manner that the depressions are now flat-floored. The deposits are dark gray near the surface,

grading to light brown at depth, and range in thickness from 3 to probably 10 feet.

2. Water-bearing character. -- The deposits contain little or no ground water because of low porosity and permeability.

3. Engineering considerations. -- Unsurfaced roads are impassable when wet.

SUMMARY OF GEOLOGIC HISTORY

Cretaceous period.

A thick sequence of clay and lesser amounts of silt and sand accumulated in a broad shallow sea which occupied this part of the continental interior during much of the Cretaceous period. Concurrently, intermittent outbursts of volcanic activity in adjacent regions spread thin layers of volcanic ash over thousands of square miles in this area. The ash was subsequently altered to bentonite. The name Bearpaw shale is used to designate the last of the formations deposited in this sea. The overlying Fox Hills sandstone resulted from strand line deposition during the withdrawal of this sea to the east. A period of erosion followed, which removed locally differing thicknesses of Fox Hills sandstone and on the resulting uneven surface a sequence of sediments, the Hell Creek formation, was deposited under markedly changed conditions. Continental deposition of these strata is attested by flucial and aeolian cross-bedding, relative coarseness of sediments, and the prevalence of fossil wood and dinosaur bone fragments.

Tertiary period. --

Fresh water sediments (Fort Union formation) continued to accumulate during the Paleocene epoch. Conditions then changed, and thick sequences of sediments accumulated successively farther to the east.

The Fort Union formation has been eroded from the quadrangle, but is present in areas a short distance to the north, east, and south. (Collier, 1918, Collier and Knechtel, 1939, Smith, 1910.)

The later part of the Tertiary was one of alternate planation and downcutting, probably accompanied by intermittent crustal uplift. During this time the general features of the modern terrain began to be developed. The ancestral Missouri River was evidently established during this time for the oldest plateau surface present slopes toward the modern river. This plateau surface is capped by the Miocene or Pliocene Flaxville gravel, its remnants within the quadrangle ranging in elevation from 2,600 to 2,700 feet above sea level.

Quaternary period. -- Intermittent periods of downcutting and planation continued, and a series of erosion surfaces discontinuously mantled with Wiota gravels was developed. Each surface is vertically separated from the preceding by but a few feet, and each covers but a small area as compared with the Miocene-Pliocene plain.

The time boundary between the Tertiary and Quaternary periods has not been located, and the deposition of the oldest of the Wiota gravels may well have occurred in Tertiary time.

These processes continued to operate during much of the Quaternary period, and by the time the first continental glacier arrived, the bedrock floor of Missouri River was at a position now about 2,000 feet above sea level, which is approximately the level of the river today.

There are indications that a glacier advanced into this general area prior to glaciation of the quadrangle itself, because a few pebbles of Canadian provenance are locally present in the Wiota gravels. A fossil mammoth tooth (Mammuthus primigenius) was found in gravels underlying the drift of the glacier that covered the quadrangle. This fossil shows the drift to be of Wisconsin, and probably of late Wisconsin, age. Judging from the amount of post-glacial erosion, this drift is thought to be older than Mankato and is provisionally assigned to the Cary substage.

Colton (1951)has found large areas of the higher portions of the Flaxville Plain, north and northeast of the quadrangle, to be free of drift. This indicates that the Cary (?) glacier advanced as a number of lobes flowing between and around the higher plateau remnants to coalesce southward in the river valley. The ice spread beyond to the south wherever the barrier formed by the south valley wall had been sufficiently reduced by tributary erosion.

Deglaciation proceeded in an unusual manner. Ice had been thin at the sites of the higher hills and plateau remnants so that nunataks formed and enlarged north of stagnant ice occupying the valley. Ice marginal meltwater channels bordered the nunataks, drainage accordingly being normal in many places to the slope of the sub-ice land surface Meltwaters carried little outwash for outwash is surprisingly thin and scattered.

As meltwater volume decreased, or as the peak of sediment load was approached, degradation of valleys ceased and aggradation began. Aggradation in Missouri River valley controlled that in Little Porcupine Creek valley, and proceeded until floodplain level in the river valley was several feet higher than at present. The aggradational effect of this rising fill was propagated up Little Porcupine Creek valley, being most pronounced in the downstream portion. The latter aggraded so as to partially bury the outwash terrace remnant near Frazer.

The most recent event in drainage history was a further period of degradation, leaving as terraces remnants some of the older alluvium.

SUMMARY OF NATURAL RESOURCES

Water

<u>Artesian water</u>.- The Judith River formation (Upper Cretaceous) underlies the Bearpaw shale at a depth of about 700 feet beneath the river bottom, and is proportionately deeper beneath the uplands. Water in this formation is under artesian pressure (Perry, 1934), and flows at the surface from a well near Frazer. It is highly mineralized and not generally potable.

<u>Shallow Ground Water</u>. -- The best quality water is in the Flaxville and Wiota gravels and in the gravel and coarse sand of the alluvium. Large quantities are limited to the alluvium of Missouri River and Little Porcupine Creek valleys, though some of this is highly mineralized. More detailed statements are given in the descriptions of individual formations.

As wasting proceded, yet prior to disappearance of stagnant ice from the major valleys, these valleys again came into use as trunk drainageways. Irregularities in the ice surface, coupled with low volume of flow, evidently resulted in sluggish streams and shifting ponded bodies of water, as indicated by the fact that the earliest superglacial deposits are fine grained fluvial and lacustrine deposits.

The ground moraine surface onto which the superglacial fluvio-lacustrine deposits were finally lowered is marked in places by a network of till ridges, apparently reflecting a conjugate system of fractures formed in stagnant ice. Small volume of meltwater during shrinkage is indicated by an almost complete lack of water-sorted debris in the ridges. The fractures are thought to be due to crustal movement that occurred intermittently throughout the geologically recent past, as witnessed by numerous structural and geomorphic features in this part of the state. Locally the fracture pattern appears to have been influenced by flow lines in the ice.

With further ice shrinkage meltwater drainage became better integrated and water spilled in larger volume down Little Porcupine Creek valley and ancestral East Fork of Charley Creek, in part on stagnant ice, in part trenching ground moraine. Various channel segments, many containing no deposits, record successive stages of ice shrinkage. The last of the meltwater, which flowed after ice had disappeared from the quadrangle, cut the inner valley of Little Porcupine Creek and, incidental to this downcutting, left remnants of outwash terrace deposits along the sides.

Downcutting proceded until Missouri River valley was some 1[illegible]0 feet deeper than at present. Presumably the bedrock floor of Little Porcupine Creek valley is graded to that of Missouri River,

Construction materials

Sand and gravel. — Large scale exploitation of sand and gravel is feasible in areas of pitted outwash gravel. Progressively lesser quantities are available in the Flaxville gravel, outwash terrace deposits, Wiota gravels, outwash gravel, and Little Porcupine Creek valley alluvium. Except for the pitted outwash gravels, all are covered with different thicknesses of overburden, necessitating detailed prospecting. Further information is given in the descriptions of individual formations.

Other. — Till from the ground moraine is suitable for impervious fill or for lining water-retaining structures built in pervious materials. Exploitation of the bentonite in the Bearpaw shale is not economically feasible at present. There are no commercial quantities of riprap within the quadrangle. Parts of the terrace alluvium and outwash terrace deposits are probably suitable for highway sub-base construction.

REFERENCES

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.

Collier, A. J., 1918, Geology of northeastern Montana: U. S. Geol. Survey, Prof. Paper 120-B.

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

Colton, R. B., (in preparation), Geology of the Oswego quadrangle, Montana: U. S. Geol. Survey, Geological Quadrangle Maps of the U.S.

Perry, E. S., 1934, Geology and artesian water resources along Missouri and Milk Rivers in northeastern Montana: Montana Bureau of Mines and Metallurgy, Memoir 11.

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