PRELIMINARY REPORT ON

THE GEOLOGY OF THE NASHUA QUADRANGLE, MONTANA

by

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1951

Prepared as a part of the Department of Interior's program for development of the Missouri River Basin

CONTENTS

ILLUSTRATIONS

GENERAL SETTING

GEOGRAPHY

The Nashua quadrangle covers about 200 square miles in northeastern Montana, mostly in Valley County, partly in McCone County. That part east of Porcupine Creek and the lower course of the Milk River in Valley County is in the Fort Peck Indian Reservation.

Northeastern Montana is in the Missouri Plateau section of the Northern Great Plains physiographic province.

The uplands differ in character in different parts of the quadrangle, being separated by broad alluvial bottom lands of the Milk and Missouri Rivers. The Missouri River flows north into the quadrangle near the southwestern corner, then turns and flows east. South of the river the terrain is rough and irregular, rising about 700 feet to rimrock-capped hills. The Milk River flows southeastward across the central part of the quadrangle and then empties into the Missouri. Between the rivers there is a gently rolling upland bounded by steep hillsides or cliffs 20 to 100 feet high. North of the Milk River, and nearly 200 feet above its flood plain, is an upland of small local relief that rises northward at an increasing rate, reaching about 40 feet per mile at the northern quadrangle boundary. Porcupine Creek, a south-flowing tributary of the Milk River, is entrenched in this upland and has built a flood plain about half a mile wide.

The uplands have integrated drainage except in a number of small areas north of the Milk River and between the Milk and Missouri Rivers.

The Fort Peck Dam impounds the Missouri River in the southwestern part of the quadrangle. The crest of the dam is 250 feet above the flood plain and forms a reservoir holding 19 million acre feet of water that extends 180 miles upstream.

Wheat and cattle ranching is carried on in upland areas, and sugar beets and alfalfa are grown in irrigated bottom lands. Nashua, a town of 1,300 population, is the local marketing center. The area is served by the Great Northern Railway and U. S. Highway No. 2. Fort Peck, a town of similar size, is under the jurisdiction of the Corps of Engineers, U. S. Army.

GEOLOGY

Bedrock.--Three sedimentary formations crop out. 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 that underlies the whole area. The other formations are interbedded gray and brown sandstone, siltstone, and claystone, and are present only in the southeast part of the quadrangle. The formations dip a few feet per mile southeast.

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 nearby parts of the state but test drilling near this quadrangle has been unsuccessful.

Surficial deposits.--Unconsolidated deposits of four kinds mantle most of the surface. The oldest are gravels (Wiota gravels) deposited on gently sloping erosion surfaces cut by streams that flowed at successively lower elevations during the Quaternary period. These gravels discontinuously cover bedrock and underlie younger formations. Unstratified deposits (ground moraine) were subsequently laid down as an uneven blanket over most of the area by an advancing continental glacier of Cary(?) substage. As the glacier melted a third kind of surficial material was locally deposited, stratified drift (consisting of superglacial fluvio-lacustrine deposits, ice-contact meltwater deposits, and outwash terrace deposits). The youngest unconsolidated deposits are alluvium and terrace alluvium in stream valleys, intermittent pond 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.

METHODS AND PROCEDURE

Accurate, detailed geologic mapping is more easily accomplished today than years ago. In addition to natural exposures of geologic units in stream cuts and valley walls there are now a number of road-cuts and borings which afford information that was not available to early workers. A surprisingly large proportion of the area can be traversed by modern vehicles, no mean advantage to present-day geologists over the horseback and horse-and-buggy geologists of former times. Undoubtedly of the most help is coverage by aerial photography, coupled with completed land surveys. Accurate plotting of data becomes no problem, and frequently textural differences in the photos facilitate delimiting geologic units. Though the topographic map of the quadrangle is not comparable to maps made according to modern standards of accuracy, it has been used to advantage. Geologic contacts, drawn on the photographs in the field, have been compiled on a land net taken from the topographic map, using section corners plotted on the air photos for horizontal control. Library and laboratory work, and conferences with interested people, have added much to the understanding of the problems involved.

ACKNOWLEDGMENTS

I wish to take this opportunity to express my gratitude to the personnel of the Corps of Engineers at Fort Peck, in particular Messrs. Carter Johnson and James King of the Field Investigations Office, for making available facilities that have made the work both more pleasant and more profitable.

THE GEOLOGIC FORMATIONS

Subsurface bedrock formations

Beneath the oldest exposed bedrock in the Nashua quadrangle, the middle part of the Bearpaw shale (Upper Cretaceous), are several thousand feet of still older sedimentary strata. A considerable body of information is available as to the nature of these rocks inasmuch as they crop out in many places in the State to the west and southwest, and because they have been penetrated near the quadrangle by oil and gas borings. A study of this information indicates that in the quadrangle there are 7,000 to 7,500 feet of sedimentary strata beneath the Bearpaw shale, resting unconformably on pre-Cambrian crystalline rocks.

The sources of information listed below have been consulted in preparing Figures 1 and 2. In deducing the nature of the strata in this quadrangle liberal use has been made of interpolation and extrapolation from this information, so that the charts should be understood to represent an interpretation. The "References" column of the figures shows numbers that correspond to the numbers in this list.

1. Personal observations made in the vicinity of the Bowdoin dome.

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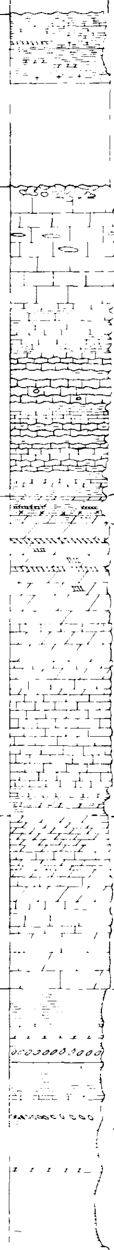
4. Log of Amerada and Gulf No. 1 Molvig wildcat well in sec. 13, T. 29 N., R. 37 E: Petroleum Information, Denver, Colorado, October, 1950; and unpublished communications from C. L. Nieschmidt, U. S. Geol. Survey, Billings, Montana.

5. Log of Texaco No. 1 Government wildcat well in sec. 8, T. 32 N., R. 32 E.: Petroleum Information, Denver, Colorado, April, 1947; and unpublished communications from C. L. Nieschmidt, U. S. Geol. Survey, Billings, Montana.

6. Sullivan, A. M., depths to tops of formations in wildcat well drilled by Carter Oil Co. and Phillips Petroleum Co. in SW sec. 18, T. 29 N., R. 50 E., Roosevelt County, Montana (oral communication).

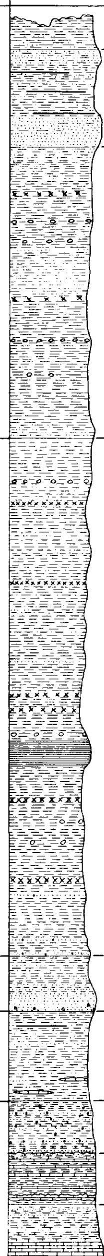
7. Bowen, C. F., Gradations from continental to marine conditions of deposition in central Montana during Eagle and Judith River epochs: U. S. Geol. Survey Prof. Paper 125-B, 1919.

FIGURE 1 PALEOZOIC SUBSURFACE FORMATIONS



SYSTEM	SERIES	GROUP	THICKNESS IN FEET (approx.)	FORMATION	DESCRIPTION	REFERENCES
CARBONIFEROUS	Mississippian	Big Snowy	100	Otter formation	Dark gray, green, and red limey shale and light-colored oolitic limestone. Near base a little anhydrite and gypsum. Upper contact unconformable.	4,5,10, 11,15,16
			100	Kibbey formation	Mostly brick red, in part purple, pink and brown. Lower part sandstone, in part gypsiferous. Upper part shaly, silty, and dolomitic sandstone. Basal part fills cavities and channels in Mission Canyon limestone where Charles formation is absent.	4,5,10, 11,15,16
			?	Charles formation	Questionably present. Light-colored earthy, anhydritic limestone and dolomite, in part oolitic. Thin to thick interbeds of anhydrite, thin interbeds of red and variegated shale	15,1[illegible]
		Madison	340	Mission Canyon limestone	Light cream and white, highly massive, fairly pure limestone, texture granular, petroliferous, some upper beds greenish-gray. Gray-white chert in small to large masses near middle. Uppermost beds porous to cavernous, most openings partially filled with clastics. Upper contact unconformable	2,3,4,5, 11,18,19
			560	Lodgepole limestone	Upper part red and maroon limestone and shale, the shale as thin interbeds. Downward the shale more abundant, the limestone clayey, and thin coatings of yellow chert on wavy limestone bedding surfaces. Lower part gray and brown clayey limestone and shale. A few feet of interbedded yellow-green and black conodont-bearing shale at base.	2,3,4,5, 11,18,19
DEVONIAN	Middle and Upper		80	Threeforks shale	Dolomitic shale, shaly dolomite, minor clayey limestone, bentonitic shale, and evaporite, the last forming some solution breccia. Lower contact transitional.	3,4,5,20
			850	Jefferson dolomite	Upper part light tan to dark brown, massive, saccharoidal dolomite, a few beds of anhydrite and anhydritic dolomite near top. Grades downward to dense dark brown limestone. Red, greenish-gray, and yellowish-gray shale, mudstone, and clayey dolomite at base.	3,4,5,20
ORDOVICIAN	Upper		500	Bighorn dolomite	Upper part dense bedded dolomite, grading downward to massive dolomitic limestone, light gray.	3,20
CAMBRIAN			800 ± 200	Cambrian (undiff.)	Gray and greenish-gray shale, thin interbeds of limestone and dolomite, especially towards top, a few thin beds of intraformational conglomerate. At base about 50 feet of light-colored quartzite, conglomeratic below.	2,3,19
PRE-CAMBRIAN					Crystalline rocks	

FIGURE 2 MESOZOIC SUBSURFACE FORMATIONS

SYSTEM	SERIES	GROUP		THICKNESS IN FEET (approx.)	FORMATION	DESCRIPTION	REFERENCES
CRETACEOUS	Upper Cretaceous	Montana			Bearpaw shale	(See text)	
				300	Judith River formation	Lower and upper parts mostly brown sand, commonly crossbedded and discontinuously cemented as ledges; minor lenticular beds of gray to brown silt and clay and, in places, thin beds of carbonaceous shale and lignite. Middle part mostly clay, silt, and minor sandstone and lignite, all as discontinuous, rather thin beds; light to dark gray and brown. Sandstones yield highly mineralized water under artesian pressure. Upper and lower contacts transitional.	1,2,4,7
				900	Clagett shale	Dark gray clay-shale; marine fossils, concretions, thin bentonite beds, and a few sandy silt beds. Basal part silty shale and sand, representing eastern (seaward) extension of Eagle sandstone. Contacts transitional.	1,2,4,6,7,
		Colorado		1600	Colorado shale	Dark gray or bluish black clay-shale, fissile in part; marine fossils, concretions, and bentonite beds. Discontinuous beds of silty and sandy shale in zone in upper part; about 80 feet of fairly hard siliceous shale, bearing fossil fish scales, below middle; sandstone beds with black chert pebbles in basal part.	2,3,4,8,9
	Lower			170	Kootenai formation	Upper part maroon, green and gray interbedded claystone and siltstone; a few local sandy silt beds. Lower part light gray, medium- to coarse-grained sandstone; a few claystone beds above, some conglomeratic sandstone beds below.	3,4,5,10 11
JURASSIC	Upper			280	Morrison formation	Green, maroon, gray and brown interbedded claystone, siltstone, and medium- to fine-grained sandstone. Locally carbonaceous shale or thin coal beds near top, lenticular fresh-water limestone beds near base. All beds discontinuous; proportions of constituents differ from place to place.	4,5,10,11
		Ellis		160	Swift formation	Glauconitic shale, silty shale, and sandstone; calcareous. Soft, highly glauconitic sandstone at base. Lower contact unconformable.	12,13,14
				160	Rierdon formation	Gray shaly limestone and limey shale, more lime above. At top a few feet of light gray shale and fine-grained sandstone; at base a few feet of greenish-gray shale and nodular limestone.	12,13.14
	Middle			200	Piper formation	Upper part gray, greenish gray, and maroon silty and sandy shale, in part limey, minor siltstone and fine-grained sandstone. Lower part buff to brown thin-bedded limestone, in part oolitic. Red silty sandstone at base. Unconformable lower contact.	12,13,14

8. Reeves, F., Geology of the Cat Creek and Devils Basin oil fields and adjacent areas in Montana: U. S. Geol. Survey Bull. 786-B, 1927.

9. Bartram, J. G., and Erdmann, C. E., Natural gas in Montana: Geology of Natural Gas, pp. 245-276, Amer. Assoc. Petroleum Geologists, 1935.

10. Gardner, L. S., Hendricks, T. A., Hadley, H. D., and Rogers, C. P., Jr., Mesozoic and Paleozoic formations in south-central Montana: U. S. Geol. Survey, Oil and Gas Investigations, Preliminary Chart 18, 1945.

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13. Imlay, R. W., Occurrence of Middle Jurassic rocks in Western Interior of the United States: Amer. Assoc. Petroleum Geologists Bull., vol. 29, no. 7, pp. 1019-1027, 1945.

14. Imlay, R. W., Gardner, L. S., Rogers, C. P., Jr., and Hadley, H. D., Marine Jurassic formations of Montana: U. S. Geol. Survey, Oil and Gas Investigations, Preliminary Chart 32, 1948.

15. Perry, E. S., and Sloss, L. L., Big Snowy Group: Lithology and correlation in Northern Great Plains: Amer. Assoc. Petroleum Geologists Bull., vol. 27, no. 10, pp. 1287-1304, 1943.

16. Rogers, C. P., Jr., Gardner, L. S., and Hadley, H. D., Maps showing thickness and general distribution of Mesozoic and Paleozoic rocks in south-central Montana: U. S. Geol. Survey Oil and Gas Investigations, Preliminary Map 43, 1945.

17. Seager, O. A., Test on Cedar Creek anticline, southeastern Montana: Amer. Assoc. Petroleum Geologists Bull., vol. 26, no. 5, pp. 861-864, 1942.

18. Sloss, L. L., and Hamblin, R. H., Stratigraphy and insoluble residues of the Madison Group (Mississippian) of Montana: Amer. Assoc. Petroleum Geologists Bull., vol. 26, no. 3, pp. 305-335, 1942.

19. Collier, A. J., and Cathcart, S. H., Possibility of finding oil in laccolithic domes south of the Little Rocky Mountains, Montana: U. S. Geol. Survey Bull., 736-E, 1922.

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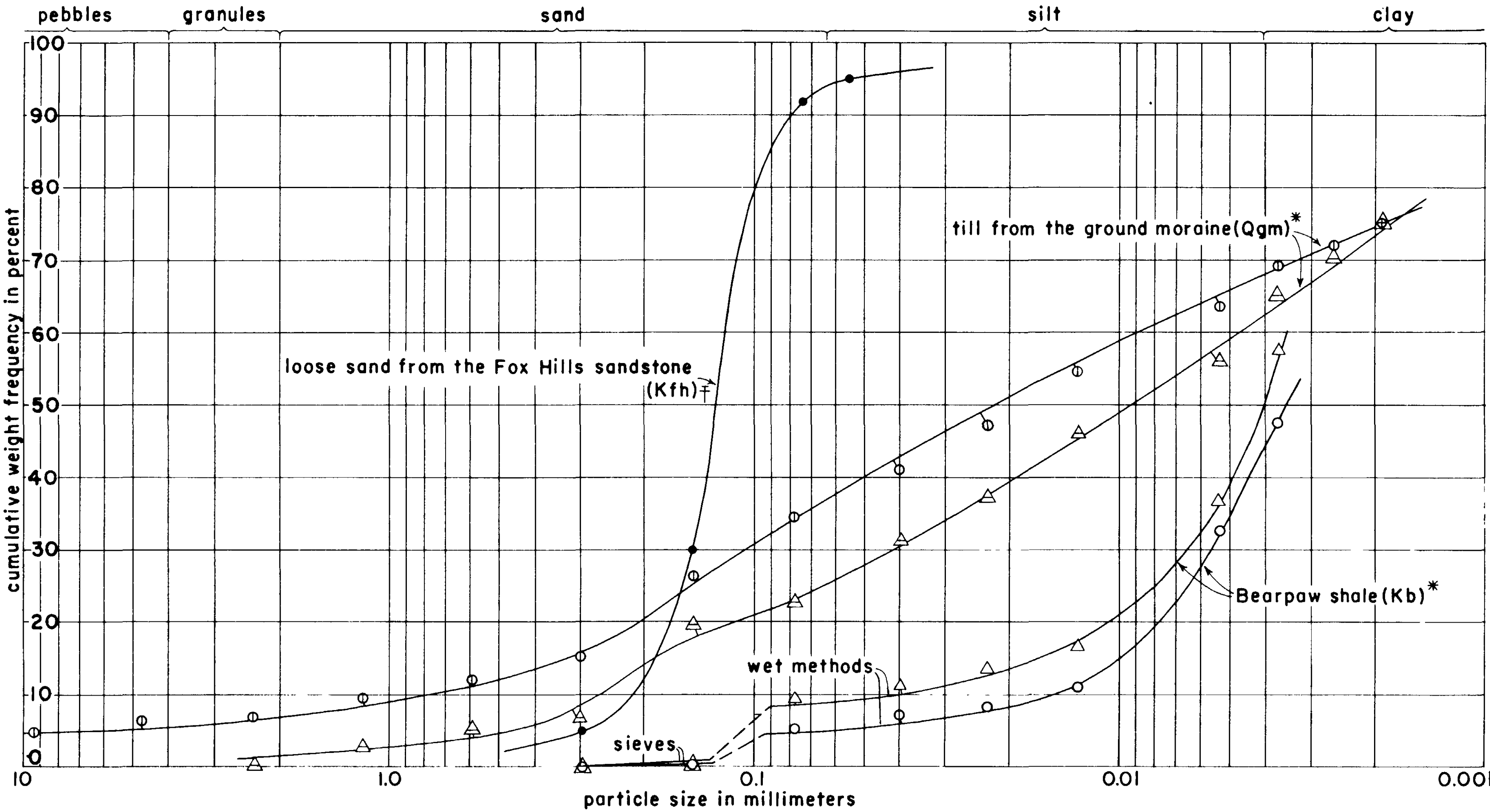
Exposed bedrock formations

Three kinds of information are presented concerning each exposed bedrock formation. The introductory paragraphs deal with general lithologic characteristics and stratigraphic relations. Following these is a paragraph on water-bearing character, and lastly a paragraph or two on engineering considerations. A Geological Survey ground-water study made in 1947 by F. A. Swenson of parts of the area was made available to the author. Further information on ground water is available in a paper by Perry (1934). Additional data concerning engineering properties of the Bearpaw shale and some surficial deposits are contained in the filesof the Fort Peck District of the Corps of Engineers, U. S. Army, at Fort Peck, Montana.

Bearpaw shale (Kb).--The majority of natural exposures are on the sides of stream valleys, where erosion has cut down through overlying materials. Because weathering proceeds together with erosions, fresh shale is not seen at the surface except where erosion is unusually rapid. The only place within the quadrangle where unweathered shale is exposed is at the baffles at the foot of the Fort Peck Reservoir spillway. The shale is dark gray, semi-consolidated clayey shale, slightly fissile. Many beds one-quarter to 1 inch thick of creamy-yellow bentonite characterize the part of the formation exposed here.

Weathering changes the color of the shale to various lighter shades of gray, and softens it considerably, probably through leaching of colloidal matter. Figure 3 shows a mechanical analysis of weathered shale. Salts concentrate in the weathered zone as corroded crystals of selenite ($CaSO_4 2H_2O$).

Thoroughness of weathering is related to rapidity of erosion, so that no general statement can be made on the thickness of the weathered zone. Some parts of the formation contain bentonite dispersed in the other kinds of clay present; the swelling properties of this bentonite help seal exposed surfaces of these parts so that weathering processes are inhibited and depth of weathering is minimized. Shale containing dispersed bentonite is recognized by a porous, cracked surface that feels spongy underfoot. Greatest depth of weathering occurs in non-bentonitic shale that is being slowly eroded, the weathered zone being locally several tens of feet thick. Soft, light-gray shale chips characterize the surface of this kind of shale.



* from data of the U.S. Army Engineers' laboratory at Fort Peck, Montana
† from data of the Montana Highway Department laboratory at Helena, Montana

FIG. 3—MECHANICAL ANALYSES

Abundant fractures separate the shale into small blocks in the weathered zone. These fractures decrease in number downward so that below the weathered zone they are comparatively few. Diastrophic earth movements and slumping caused deeper fractures, a few of which are faults. The shale is nearly impervious except along fractures, though deposition of mineral matter by percolating water has sealed many of these.

Any sizable exposure of Bearpaw shale will show one or more kinds of concretions, though rarely does more than one kind occur at a given horizon. The concretions are hard, ellipsoidal rock masses ranging in longest dimension from less than 6 inches to nearly 6 feet. The commonest kind consists chiefly of iron oxide and clay, the iron oxide imparting a rust-brown color to outer oxidized portions. Other common kinds are mostly gray limestone, some of the larger ones having shrinkage cracks sealed with yellow calcite. The limestone concretions weather light gray or light brown and most contain marine fossils. Some concretions contain a small amount of manganese which forms a blue-black oxide on weathered surfaces.

The Bearpaw shale in this area is between 1,100 and 1,200 feet thick, of which about the upper two-thirds are exposed. It rests conformably on the Judith River formation (Upper Cretaceous) and is conformably overlain by the Fox Hills sandstone (Upper Cretaceous). The formation thins westward and thickens eastward to merge, without marked change in lithology, into the upper part of the Pierre shale. The main body of the shale is nearly homogeneous, though the minor differences allow potential subdivision. The lowest strata exposed within the quadrangle are characterized by abundant shallow water fossils, such as oysters, Ostrea patina, and discoidal ammonites, Placenticeras sp. The next higher beds contain a large number of thin bentonite beds. These beds contain a few baculites, probably assignable to Baculites compressus, which differ from those in higher Bearpaw shale strata by having corrugated venters and inconspicuously ribbed flanks. Overlying are strata containing clay-ironstone concretions and disseminated bentonite. These strata are characterized by a variety of B. compressus having smooth flanks and venters. Unfortunately, these are distinctly uncommon in the "clay-ironstone strata", but become abundant in the overlying strata, where they are enclosed in limestone concretions. The top portion of the formation contains B. grandis and Discoscaphites sp. as characteristic fossils. In general, the oldest strata are exposed in the northwestern part of the quadrangle, the youngest in the southeast.

(A). Water-bearing character: Water wells should not be drilled into the Bearpaw shale unless it is planned to penetrate the underlying Judith River formation, in which case a hole several hundred feet deep will be necessary. The small amount of water along principal fracture planes in the Bearpaw shale contains a large quantity of dissolved solids, principally sodium sulfate and sodium chloride. Fresh shale has a moisture content of about 15%.

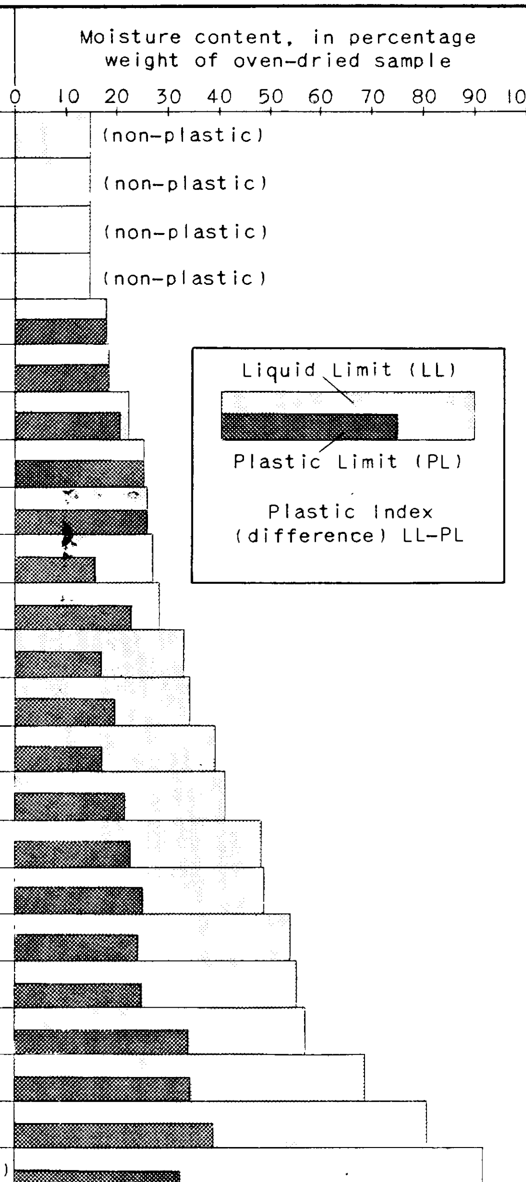
(B). Both weathered and unweathered shale are readily excavated with power tools, though some of the larger concretions may slow progress. Fractures facilitate excavation but necessitate timbering in tunnels or large pits. Water seeps are negligible, except from occasional extensive fractures, because of the very low permeability of the shale. Subsurface drainage is very poor even in highly weathered shale. Foundation sites for heavy structures should be test-drilled to determine presence or absence of bentonite beds, which may cause landsliding. Landsliding is also likely to be a problem if large excavations are made in steep slopes, if heavy structures are built on slopes, or if downhill portions of large landslides are removed. The shale stands well at angles up to about 45° in cuts only a few feet deep, but at such angles deeper cuts may occasion slumping or excessive sloughing from the cut face. Unweathered shale slacks and loses strength very rapidly unless protected from wetting and drying. Unsurfaced roads are impassable in wet weather and surfaced roads require extensive addition of other materials in subbase construction. Figure 3 shows two mechanical analyses of the shale. Soil classification and Atterberg limits are given in Figure 4 for shale containing dispersed bentonite (Sample 25), for nonbentonitic shale (Sample 14), and for bentonite (Sample 13).

Fox Hills sandstone (Kfh).--The rugged hills east of the Fort Peck Reservoir spillway are capped by rust-brown sandstone rimrock that rises in bold relief above grassy slopes below. This rimrock is formed by the upper part of the Fox Hills sandstone and locally by the basal sandstone of the overlying Hell Creek formation as well. In the hillsides facing the Missouri River, where erosion is more rapid than elsewhere, the lower part of the Fox Hills sandstone is locally exposed as a light-gray band between the rust-brown sandstone above and the drab-gray Bearpaw shale below. This picture applies for many miles to the east along the south side of the Missouri River and to the west along the south side of the reservoir.

The lower part of the Fox Hills sandstone is 35 to 40 feet thick and forms a sequence of beds transitional from the underlying Bearpaw shale into the upper part of the formation. The transition sediments are alternating thin beds of silt, clay, and very fine sand, combined in different proportions in the different beds, though the finer-grained sediments predominate nearer the base. The materials are semiconsolidated except for discontinuous lithified ledges up to 8 inches thick in the upper part of the transitional sequence. Bedding is thin and parallel except in these ledges that are cross-bedded on a small scale. Colors are various shades of gray below, replaced upwards by several different yellowish grays and browns.

Fig. 4. Atterberg limits and soils classification of test samples*

†	‡	Map unit
8	A-1-a	Wiota gravels (Qw)
11	A-1-a	Gravel of the Outwash Terrace Deposits (Qot)
23	A-1-a	Sandy gravel from Alluvium (Qal) of Porcupine Creek Valley
31	A-3	Loose sand from the Fox Hills sandstone (Kfh)
12	A-1-a	Gravel of the Outwash Terrace Deposits (Qot)
19	A-1-a	Wiota gravels (Qw)
1	A-4	Loose sand from the upper part of the Wiota gravels (Qw)
30	A-2-4	Alluvium (Qal) of Missouri River valley
4	A-2-4	Sand-silt of the Superglacial Deposits (Qs)
7	A-2-6	Colluvial facies of the Wiota gravels (Qw)
6	A-4	Alluvium (Qal) of Milk River valley
26	A-6	Till from the ground moraine (Qgm)
15	A-6	Till from the ground moraine (Qgm)
28	A-7-6	Till from the ground moraine (Qgm)
22	A-7-6	Till from the ground moraine (Qgm)
2	A-7-6	Till from the ground moraine (Qgm)
24	A-7-6	Clay-silt-sand from upper part of Alluvium (Qal) of Porcupine Ck.
10	A-7-6	Clay from Intermittent Pond Deposits (Qp)
21	A-7-6	Alluvium-Colluvium (Qac)
14	A-7-5	Bearpaw shale (Kb), without disseminated bentonite
3	?	Shaly clay from Superglacial Fluvio-lacustrine deposits (Qs)
25	?	Bearpaw shale (Kb), with disseminated bentonite.
13	A-7-5	Bentonite from Bearpaw shale (Kb)



* Data from results of tests by Montana State Highway Department

† Sample, see accompanying list for locations.

‡ U.S. Bureau of Public Roads Classification of highway subgrade materials.

Locations of test samples, see Figure 4

Sample number	Location
1	SW1/4 of SE1/4 sec. 17, T. 28 N., R. 41 E.
2	NE1/4 of NE1/4 sec. 13, T. 26 N., R. 41 E.
3	C of SW1/4 sec. 19, T. 27 N., R. 42 E.
4	C of SW1/4 sec. 19, T. 27 N., R. 42 E.
6	NE1/4 of NE1/4 sec. 1, T. 27 N., R. 41 E.
7	SE1/4 of NE1/4 sec. 36, T. 28 N., R. 41 E.
8	NE1/4 of NW1/4 sec. 29, T. 28 N., R. 42 E.
10	NW1/4 of NE1/4 sec. 18, T. 27 N., R. 42 E.
11	NE1/4 of SW1/4 sec. 36, T. 28 N., R. 41 E.
12	C of sec. 35, T. 28 N., R. 41 E.
13	C of sec. 35, T. 28 N., R. 41 E.
14	SW1/4 of NE1/4 sec. 11, T. 28 N., R. 41 E.
15	SE1/4 of NE1/4 sec. 20, T. 28 N., R. 42 E.
19	NE1/4 of NE1/4 sec. 29, T. 29 N., R. 41 E.
21	NE1/4 of NW1/4 sec. 28, T. 29 N., R. 41 E.
22	NW1/4 of SW1/4 sec. 36, T. 29 N., R. 41 E.
23	NE1/4 of SE1/4 sec. 23, T. 28 N., R. 41 E.
24	SE1/4 of NW1/4 sec. 31, T. 28 N., R. 42 E.
25	SE1/4 of SE1/4 sec. 6, T. 26 N., R. 42 E.
26	C of sec. 6, T. 26 N., R. 41 E.
28	NE1/4 of NW1/4 sec. 10, T. 27 N., R. 41 E.
30	NE1/4 of SE1/4 sec. 8, T. 26 N., R. 41 E.
31	NW1/4 of NW1/4 sec. 9, T. 26 N., R. 42 E.

(Figure 4 continued)

The transition beds weather light gray, and inasmuch as no fossils have been found in them the weathered color has been used to delimit the base of the formation. Locally glauconite is concentrated at the base as so drawn, but glauconite also occurs at lower horizons, as do silty shale beds, so that these details of lithology are invalid grounds for defining the basal contact.

Locally in eastern Montana the uppermost portion (20 to 50 feet) of the Fox Hills sandstone is a distinctive and unusual type of white sandstone called the Colgate sandstone member. In the area south of the Fort Peck Reservoir, between Snow Creek and the Musselshell River, this sandstone is strikingly conspicuous. Proceeding eastward and northward toward the quadrangle the Colgate sandstone gradually loses its distinctive character to become indistinguishable as a stratigraphic unit. It is definitely not developed in or near the Nashua quadrangle.

The upper part of the formation is mostly very fine sand and sandstone. Discontinuous lenses of thin, evenly bedded silt and clay are present at various horizons, especially toward the top of the formation. Cross-bedding is more common, and generally on a progressively larger scale, upwards. Only locally, however, is the scale or prevalence of cross-bedding comparable to that in the overlying Hell Creek formation.

Much of the sand has been cemented by calcium carbonate to sandstone; some of the sandstone is very hard, some soft and crumbly. The hard sandstone forms discontinuous ledges and spheroidal concretionary masses several feet across. Some of the ledges and concretionary masses show massive structure and are enclosed in compact massive sand. Others show cross-bedding that continues uninterrupted into contiguous uncemented sand. It is the hard sandstone that forms rimrock, the rubbly appearance of which is caused by tumbling of sandstone blocks through erosion.

Concretionary masses of other lithologies and shapes are common. Some of them are pea to golf-ball sized spheres of sandstone cemented by pyrite. Others are dark rusty-brown clay-ironstone concretions of irregular or spheroidal shape.

Weathering imparts the typical rust-brown color to exposures. Unweathered sandstone and sandstone containing little iron are generally gray.

Widely scattered fragments of carbonized plant remains were the only fossils found in the upper part of the formation. Probably the formation represents a gradation, bottom to top, from shallow-water marine to strand-line deposition.

A period of erosion preceded deposition of the overlying Hell Creek formation, resulting in local differences in thickness of the Fox Hills sandstone in at least this part of the State. In the quadrangle the formation is about 120 feet thick, but 15 miles northeast (sec. 15, T. 31 N., R. 43 E.) it is 70 feet thick, and about 70 miles south Bauer (1924, p. 345) reports only 33 feet.

(A). Water-bearing character: Probably very little ground water can be recovered from the Fox Hills sandstone within the quadrangle owing to the small catchment area and the integrated surface drainage. This view is strengthened by the absence of springs at the contact of the relatively pervious sandstone with the nearly impervious shale that is beneath. Because of differences in degree of cementation within the formation, perched water tables are likely. The most promising areas are those where remnants of the formation are largest, or where large areas are also covered by the overlying formation.

(B). Engineering considerations: The semi-consolidated lower part of the formation, and the sand and soft sandstone of the upper part, can be excavated with power tools. However, the discontinuous masses of hard sandstone, so common in the upper portion, require blasting for removal. Cuts, both shallow and deep, 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 may initiate landslides. Some timbering may be necessary in tunnels.

Weathering has no such profound effect on the strength of the material of this formation as it does on Bearpaw shale, though near-surface material has probably been somewhat softened through leaching of cementing constituents. Surface drainage is good. Subsurface drainage differs with degree of cementation but is generally fair to good. Unsurfaced roads are passable in all weather.

The indurated sandstone might be useful as a construction material, but considerable expense would be necessary to obtain any large quantity. Soil classification and Atterberg limits of loose sand from the upper part of the formation are given in Figure 4, sample 31. A mechanical analysis of this sand is shown in Figure 3.

Hell Creek (Khc).--A dirt road winds through the back country in a southeasterly direction from the headgates of the Fort Peck Reservoir spillway. For two or three miles it crosses Bearpaw shale, and then rises across Fox Hills sandstone onto a rolling grassy upland featuring many steep-sided coulees and outcroppings of rusty-brown sandstone ledge-rock. This upland topography, similar to that of the Fox Hills sandstone, is developed on the basal sandstone of the Hell Creek formation. The road crosses country where the larger coulees are cut down into the underlying Fox Hills sandstone and Bearpaw shale, but farther south, beyond the quadrangle, the gentle southerly dip carries these formations further beneath the surface so that only the Hell Creek formation is exposed. Here are the somber clays composing the upper part of the formation, locally eroded to badlands, and to isolated buttes capped by remnants of large lenses of sandstone.

The contact between the Hell Creek formation and the underlying Fox Hills sandstone is sharp, and in many places where exposures of the contact are good the upper surface of the Fox Hills sandstone is seen to be channelled. For the most part these channels are filled with medium-grained sand such as composes the rest of the thick basal sand of the Hell Creek formation. However, channels filled with pebble and cobble conglomerate are not uncommon. Similar conglomeratic lenses are present throughout the lower few feet of the basal sand, but are absent in the Fox Hills sandstone. Large-scale cross-bedding, including a type ascribed by many geologists to wind action, is conspicuous in all sands of the Hell Creek formation in this area. Such cross-bedding is absent from the Fox Hills sandstone in most places. In places, as in the Nashua quadrangle where about 120 feet of Fox Hills sandstone survived pre-Hell Creek erosion, cross-bedding in the uppermost beds is locally comparable to that in the Hell Creek formation. The facts concerning channelling and cross-bedding presented here are at variance with statements made by Thom and Dobbin (1924, p. 486), and by Dobbin and Reeside (1929, p. 25), who hold that channelling and cross-bedding are equally prevalent in the Fox Hills and Hell Creek formations, and that the contact between the two is essentially gradational.

The pebbles and cobbles of the conglomeratic lenses are principally stream-worn pieces of concretionary masses. It is especially noteworthy that some of them are smooth, well-rounded, gray quartzite of a type rarely, if ever, encountered in the Wiota gravels or the similar Flaxville gravel. A small number are porphyry, and a still smaller number are fragments of dinosaur bone. Only cobbles and pebbles undoubtedly in place were considered in establishing these facts because the surface of the ground is littered with quartzite and other kinds of pebbles derived from the Wiota gravels, Flaxville gravel, and glacial drift.

In addition to differences in sand-grain size, bedding structures, and conglomerate content, there are other features useful in distinguishing the two formations. Dark-colored minerals are much more conspicuous in the sand of the Hell Creek formation. Fossilized wood and dinosaur bones are common throughout Hell Creek strata, but are rarely found in the Fox Hills sandstone. There is a difference in color, albeit somewhat subtle because iron-oxide staining is common to both formations: the Fox Hills sandstone is a comparatively bright rusty or yellowish brown, whereas the sand of the Hell Creek formation is a somewhat darker, grayer rusty brown.

The features outlined above that concern the erosional unconformity separating the two formations, and those concerning lithologic, paleontologic, and structural differences between them, have been traced for several tens of miles east and west from the quadrangle and found to be persistent. No evidence was found, however, that sheds light on the magnitude of the time break represented by the unconformity. Bauer's work (1924) on the Freedom Dome indicates the unconformity to be present at least 70 miles to the south. The unconformity may be present over a much larger area than implied by the above, inasmuch as Leonard (1908, p. 44-46 and plate 5) has found an erosional unconformity at this horizon near Marmarth, North Dakota, some 160 miles southeast of the quadrangle.

Cementation by calcium carbonate has produced the same kinds of sandstone ledges and spheroidal masses as in the subjacent Fox Hills sandstone, causing the similarity of topographic expression.

Only the lower 50 to 60 feet of the roughly 300 feet of beds composing the Hell Creek formation are preserved within the Nashua quadrangle.

R. W. Brown, of the U. S. Geological Survey, is now preparing a report on the results of many years' study of the Tertiary-Cretaceous boundary problem. This boundary he places at the contact between the Hell Creek formation and the overlying Fort Union formation. He defines (personal communication) this contact essentially 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 to brighter yellowish-brown colors 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. A few miles south of the Nashua quadrangle this contact is well exposed, and all the characteristics noted above are conspicuous.

(A) Water-bearing character: No springs are present in the area of outcrop of this formation within the quadrangle, nor are there any water wells. It is inferred that only small quantities of ground-water are recoverable because of low recharge rate due to low annual precipitation and integrated surface drainage. As in the Fox Hills sandstone, discontinuous cementation to sandstone ledges probably causes any water available to be perched at different levels. The most promising areas are those where remnants of the formation are largest.

(B) Engineering considerations: Much that has been said concerning the upper part of the Fox Hills sandstone applies equally well to that part of the Hell Creek formation preserved within the quadrangle. The principal differences arise from the coarser grain size of the sand and sandstone of this formation, allowing greater permeability, hence better surface and subsurface drainage. The unconsolidated sand of this formation might be used as fine aggregate in certain small concrete structures south of the Missouri River, inasmuch as more suitable material would have to be brought from north of the river.

Surficial Formations

This part of the report describes unconsolidated and semi-consolidated deposits that rest unconformably on Upper Cretaceous bedrock. In comparison with the thickness of the bedrock formations, these geologic units are thin, both individually and collectively. Most of them average only a few tens of feet, and in no place is their total thickness greater than about 160 feet. Included are all deposits of Quaternary (Pleistocene and Recent) age.

The degree of subdivision used in mapping surficial deposits is more detailed than that adopted for bedrock formations, so that stratigraphic interrelations are much more complex. Included here is a description of the topographic setting and materials of each surficial unit, a paragraph on water-bearing character, and some comments on factors of interest to engineers.

Wiota gravels (Qw).--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 formation lies directly on bedrock, and is overlain by ground moraine except where exposed by erosion. The materials are predominantly of western provenance and discontinuously mantle a 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 farther east altitudes are 2,000 feet or less.

The Flaxville gravel, similar in lithology and mode of deposition, but older, is at altitudes of 2,600 feet or more near the quadrangle, and is generally separated from adjacent Wiota gravels by slopes 100 to 200 feet high.

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.

Most exposures of Wiota gravels here are high on the valley walls of Milk River and Porcupine Creek and their tributaries. Because the Wiota gravels are generally more resistant to erosion than underlying or overlying formations, a small bench locally marks their position. A study of exposures shows the materials composing the formation to have been deposited by both fast and slack water, and by colluvial action on the slopes of former low interstream divides now buried beneath glacial deposits. The formation is absent over many of these old divides, though available information is insufficient to permit showing them on a map.

A typical exposure shows the formation to have much in common with deposits of modern streams of the area, in that the lower part is sandy gravel, moderately well bedded, and having numerous intercalated lenses of medium-grained sand, whereas the upper part is finer sand and silt having intercalated clay lenses. The whole commonly shows some cross-bedding.

The pebbles and cobbles of the Wiota gravels are predominantly quartzite (98%), but include some of amorphous and cryptocrystalline silica ($1\frac{1}{2}$%). The others ($\frac{1}{2}$%) are an unusual kind of green porphyry (tinguaite), and crystalline stones of western (?) provenance. The crystalline stones are very sparsely distributed and are present in a few localities only. The quartzite stones are smooth and well rounded, and the larger pebbles and cobbles have abundant shallow crescentic percussion fractures. Most of the quartzite is medium- to fine-grained. Small amounts are very fine grained or finely conglomeratic. Red, brown, gray, and green pebbles are common, but predominance of the first two imparts a reddish-brown color to exposures.

The coarse fraction ranges in size from granules to 8-inch cobbles, but is mostly $1\frac{1}{2}$ to 3 inches in diameter.

In some places the upper, fine-grained part is absent, the entire thickness being sandy gravel. Elsewhere the formation consists almost wholly of fine-grained sediments, in which places a large proportion falls in the very fine sand, silt, and clay range. In such places any gravel present is at or near the base. Locally a colluvial facies occurs. This ancient colluvium is a compact mixture of fine sand, silt, and clay enclosing more or less abundant pebbles. It strongly resembles till, except that the pebbles show a much more marked alignment of their long axes, and pebbles of northern origin are absent.

The formation is 6 to 20 feet thick where typically developed, that is, where it is sandy gravel. Elsewhere the maximum observed thickness is 30 feet.

In the southwestern part of the quadrangle other material, also overlying Bearpaw shale and underlying glacial deposits, is included with the Wiota gravels on the map. It consists of poorly sorted sandy and clayey, medium- to fine-grained gravel and 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 quartzite or northern crystalline stones. Iron-oxide coatings are prevalent, so that the material is light to dark rust brown. More extensive field investigations will probably result in separating this material as a distinct geologic unit. It is known to be sporadically present to the west and southwest of the quadrangle.

(A) Water-bearing character: The Wiota gravels are an important source of shallow ground water in upland areas. The water is low in dissolved solids, so is excellent for both domestic use and stock. The water percolates to the base of the gravels above the nearly impermeable underlying Bearpaw shale, escaping at the contact as intermittent springs where erosion has dissected the gravels. The quantity of water available differs markedly from place to place, being greatest near the centers of ancient drainage courses and negligible at the sites of drift-buried divides. Wells sunk into the Wiota gravels are from 15 to about 60 feet deep, depending on the thickness of the overlying drift.

(B) Engineering considerations: The formation provides a source of road metal and aggregate. Because it is a fairly widespread formation, haulage distances are limited, though occurrence of the gravel at or near the crests of fairly steep valley walls reduces this advantage in some places. All pebbles are strong, and the percentage of reactive material is small. The stones are smooth and well rounded, so that crushing is necessary when angular material is desired. Detailed prospecting along the line of outcrop is necessary because of lateral facies changes, and because of the differing ratios of thickness of gravel to thickness of overburden. There are more than 1,000,000 cubic yards of economic gravel within the quadrangle. This figure includes those gravels in accessible places that average three yards in thickness and are covered by no more than about two yards of overburden. None of the material mapped as Wiota gravels in the southwestern part of the quadrangle is included in the figure, because this material probably has no value as either road metal or aggregate.

In building water-retaining structures, such as canals and dams, consideration should be given to the high permeability of this formation. Just east of the quadrangle are two stock dams that fail because this factor was not properly analyzed.

The materials composing this formation and the overlying drift are easily worked with power tools. See figure 4, samples 8, 19, 1, and 7 for soil classifications.

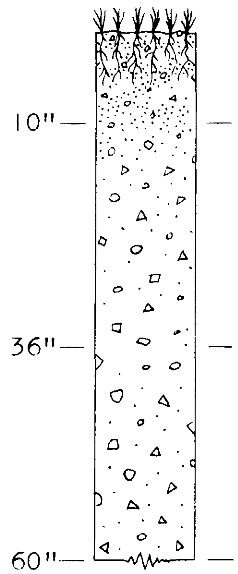
Ground moraine (Qgm).--This formation is at the surface in a large proportion of the quadrangle, and underlies younger deposits in other areas. Where it comprises the surface it forms a treeless, grassy plain of low local relief on which drainage has, for the most part, become integrated.

The material composing the ground moraine is predominantly till, which is the unsorted debris deposited directly by glacier ice. Locally there are intercalated small bodies of sand, silt, or sandy gravel deposited by meltwater from glacier ice.

The till is a very compact, nearly impermeable, and moderately calcareous mixture of clay and lesser quantities of silt, sand, pebbles, cobbles, and boulders. At least locally it is gypsiferous. In mechanical composition it is much the same from place to place. Small crumbs and pieces of black lignite and of rusty-brown limonite are scattered throughout the till, the former being diagnostic in this area. Parting surfaces of the till are commonly coated with thin, discontinuous films of iron and manganese oxides.

Most of the fine-grained material, and a small part of the coarser, including soft sandstone, shale, and lignite, have been derived from local Cretaceous and Tertiary bedrock formations. Pebbles, cobbles, and boulders, derived from the Canadian shield far to the north, are conspicuously present. These glacial erratics are much less smooth and round than the stones from the local, older gravel formation. The glacial erratics are cream-colored limestone and dolomite, various granitoid rocks, and a few schistose and other crystalline rocks. Some of the erratics that contain a large percentage of biotite have a rotted rind, or in the case of the smaller stones, are rotted to the centers. Pebbles and cobbles from the Wiota or older gravels are abundant in the ground moraine, though the percentage differs from place to place. These have not been appreciably altered by glaciation.

Percentages of the different kinds of pebbles in the ground moraine are given in the following list. The figures represent averages taken from several counts.



Humus zone; dark brown; sandy silt, some clay and pebbles.

Caliche zone; lime enriched till, light brown. Lime as irregular pellets and stringers, and dispersed.

Till, containing gypsum grains and nodules, medium brown. Gradational into caliche zone above and unaltered till below. Base indefinite.

Fig. #5

Local Cretaceous and early Tertiary bedrock	3%
Limestone and dolomite	26%
Granitoid, schistose, and other crystalline rocks	15%
Quartzite, amorphous and cryptocrystalline silica	55%

Most pebbles near the ground surface have accumulated a thin coating of lime carbonate on their under surfaces.

Over most of the quadrangle the ground moraine is 7 to 50 feet thick, and has been oxidized to yellowish brown. Near Fort Peck, where it is unusually thick, 100 to 170 feet, weathering processes have not affected that part deeper than about 70 feet, so that the lower portion retains the original gray to bluish-gray color.

Where ground moraine is at the surface, soil-forming processes have altered the upper 5 to 6 feet. It is not known whether or not the zone beneath the caliche zone has been enriched in gypsum. Perhaps the gypsum grains and nodules there present merely indicate recrystallization. Figure 5 shows a typical soil profile.

Small patches of ground moraine are shown on the geologic map in the vicinity of Fort Peck Dam Spillway and thence westward toward the dam itself. Much of this ground moraine is similar to that described above, but a considerable part of it is a heterogeneous assortment of glacio-fluvial deposits, other kinds of water-laid sediments, colluvium, and silty or sandy till. It is probable that the glacier ice 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 meltwater have combined with slumping in both glacial and recent times to produce the varied and nondescript materials present today.

(A) Water-bearing character: Because the ground moraine is so nearly impermeable no appreciable quantities of water can be recovered from it. Even those fortuitous wells that happen to penetrate an intercalated lens of glacio-fluvial sediment cannot be expected to yield more than small quantities of water. Recent alluvium, flooring bottoms of the smaller drainage courses, has not been differentiated from the ground moraine on the geologic map. Some shallow dug wells in this alluvium produce limited quantities of water, the amount varying with the season and weather.

(B) Engineering considerations: From an engineering standpoint the ground moraine is a dense, compact, nearly impermeable clay. Figure 4 (samples 26, 15, 28, 22, and 2) shows the soil classifications and Atterberg limits for till, the predominant component. Figure 3 gives two mechanical analyses of till. The ground moraine is worked easily with power tools, though occasional large boulders may slow progress.

Stability in cuts is proportional to depth and steepness, though cuts less than about 15 feet deep stand well at angles exceeding 45°.

There are a large number of coal mine adits about 6 feet high and 4 feet wide in northwestern North Dakota that are in part excavated in ground moraine. These stand well for a number of years without timbering. As this North Dakota ground moraine is very similar to that of the Nashua quadrangle, tunnels of comparable dimensions dug in the latter would probably stand as well.

Canals and other water-retaining structures dug into ground moraine have negligible seepage losses. Till can be used as an impermeable lining where such structures penetrate pervious materials.

During wet weather unsurfaced roads on ground moraine are slippery and rut badly. During dry weather such roads can be graded to a hard, smooth surface.

Superglacial fluvio-lacustrine deposits (Qs).--The gently rolling upland between the alluvial flats of Milk and Missouri Rivers differs from the ground moraine plain in having greater local relief and smoother, longer hill-swale slopes. Stones are absent from the surface except for a very few widely scattered boulders. Old meanderings of the rivers have cut away parts of this formerly more extensive upland, leaving steep bluffs in many places that expose the superglacial fluvio-lacustrine deposits that form this upland.

As implied by the cumbersome name, this formation had an unusual origin. It was deposited by sluggish streams and ponded waters, and consequently consists predominantly of clay, silt, and very fine sand. Locally there are small quantities of coarser sediments. Broadly speaking, the lower few feet and the upper half are dark-brown clay and silty clay, between is light-brown silt and very fine sand. Lenses of each kind of sediment are intercalated in the other. Locally, such as in the bluffs north of Missouri River in the central part of the quadrangle, the formation is mostly light-brown silt and silty, very fine sand, with dark-brown clay present only at the base. A few miles east and west of the quadrangle the formation is dark-brown clay and silty clay from top to bottom, and may be similar in some parts of this quadrangle. In the quadrangle the clays so commonly present at the base of the formation take the form of soft shale, and the rest of the formation is semi-consolidated, except for the surficial few feet which are softened by weathering. In the few places where bedding structures are visible the sediments are seen to be delicately laminated and cross-bedded, much as are the sediments of the Recent alluvium of Milk and Missouri Rivers. Because a large part of the formation was deposited on top of stagnant glacier ice which later melted, intraformational slumping and folding have produced a complex structural and lithologic pattern.

As preserved today, thicknesses range from a feather edge to more than 70 feet. The formation everywhere rests directly on ground moraine, the contact being sharp and irregularly undulatory, in places dipping as steeply as 60°.

A pattern is used on the map to indicate deposits of poorly understood origin and extent that overlie the superglacial deposits. Some of these deposits are dark-brown, well-sorted, medium-grained sand that, from their topographic form, is clearly Recent dune sand (western part of quadrangle). Others are vaguely bedded, poorly sorted, dark-brown silty and clayey sand that was deposited subsequent to the superglacial deposits and prior to the development of the modern topography. In the central part of the quadrangle they overlie the superglacial deposits, and near the town of Fort Peck they overlie ground moraine.

(A) Water-bearing character: Permeability is low in most parts of the formation. Locally there are pervious materials in which water is available, but because of facies differences and distortion of beds, subsurface circulation is commonly much inhibited. This causes at least some of the water to be highly mineralized and generally unfit for domestic use.

(B) Engineering considerations: Surface drainage is well integrated. Subsurface drainage differs with depth and locality. In many places the near-surface materials are pervious, in part because of the presence of the dark-brown sands noted above, in part because of weathering. Elsewhere, and at greater depths, subsurface drainage is poor. Seepage losses from water-retaining structures will vary from negligible to serious depending on locality and depth.

Under natural conditions the formation erodes to yield nearly vertical slopes, but with increasing depth of erosion landslides become prevalant. This is well demonstrated along the 60- to 100-foot high bluffs at the north side of the Missouri River alluvial plain. Artificial cuts are stable at near-vertical angles if shallow, but should be 45° or less when deep. The materials can be easily handled with power tools.

Unsurfaced roads are passable under all ordinary weather conditions, though when wet only light traffic loads can be carried where the surficial dark-brown sands are absent.

Figure 4 gives the soil classification and Atterberg limits for the clay (Sample 3) and the silty sand (Sample 4) of the formation.

Ice-contact meltwater deposits (Qic).--The ice-contact meltwater deposits accumulated in small channels and basins confined on one or more sides, at the time of deposition, by glacial ice. Subsequent melting of this ice caused collapse of the ice-contact deposits onto the ground-moraine surface.

The resulting topography is so much like that of the neighboring ground moraine as to be useless in delimiting the deposits. Wind and rain have concentrated a few inches of lag gravel on the crests of knolls of ground-moraine and ice-contact deposits alike, so that surface appearance does not aid in mapping. Because exposure of materials is the only usable mapping criterion some areas of these deposits may have been overlooked.

In the northeastern part of the quadrangle, where the deposits have been mapped, the ground-moraine surface is more irregular and rises more rapidly northward than elsewhere, toward remnants of the Flaxville plain. There appears to be a genetic relationship between the occurrence of these ice-contact deposits and the noted ground-moraine characteristics, probably ascribable to mode of ice wastage.

The materials range from poorly sorted sandy gravel to thinly bedded silt and clay. Most pebbles have a thin rind of caliche on their under sides, and some of the erratic pebbles rich in biotite are decomposed. The unit ranges in thickness from a feather edge to an estimated 12 feet.

(A) Water-bearing character: The deposits are of too limited extent to be of significance as a source of water.

(B) Engineering considerations: Local farmers have dug small quantities of sand and gravel from the deposits, but necessity for selective digging prohibits larger-scale exploitation.

Serious seepage from water-retaining structures that encounter such deposits can be expected unless preventive measures are taken.

Outwash terrace deposits (Qot).--Flanking the valleys of Milk River and Porcupine Creek are a few isolated remnants of glacial outwash terraces. The largest of these is but a few feet below upland level, the nearly flat surface being separated from the ground-moraine plain by a low scarp. Other small deposits overlie the superglacial materials previously described, capping the highest land between the Milk and Missouri Rivers. Other remnants form small benches on valley walls. At least two periods of development of terraces are represented, but as erosion has removed so large a proportion of the terraces no differentiation or correlation is made in the map or report. The surfaces of the terrace remnants slope gently to the south or southeast, though this slope has been modified to some extent by slopewash from valley walls.

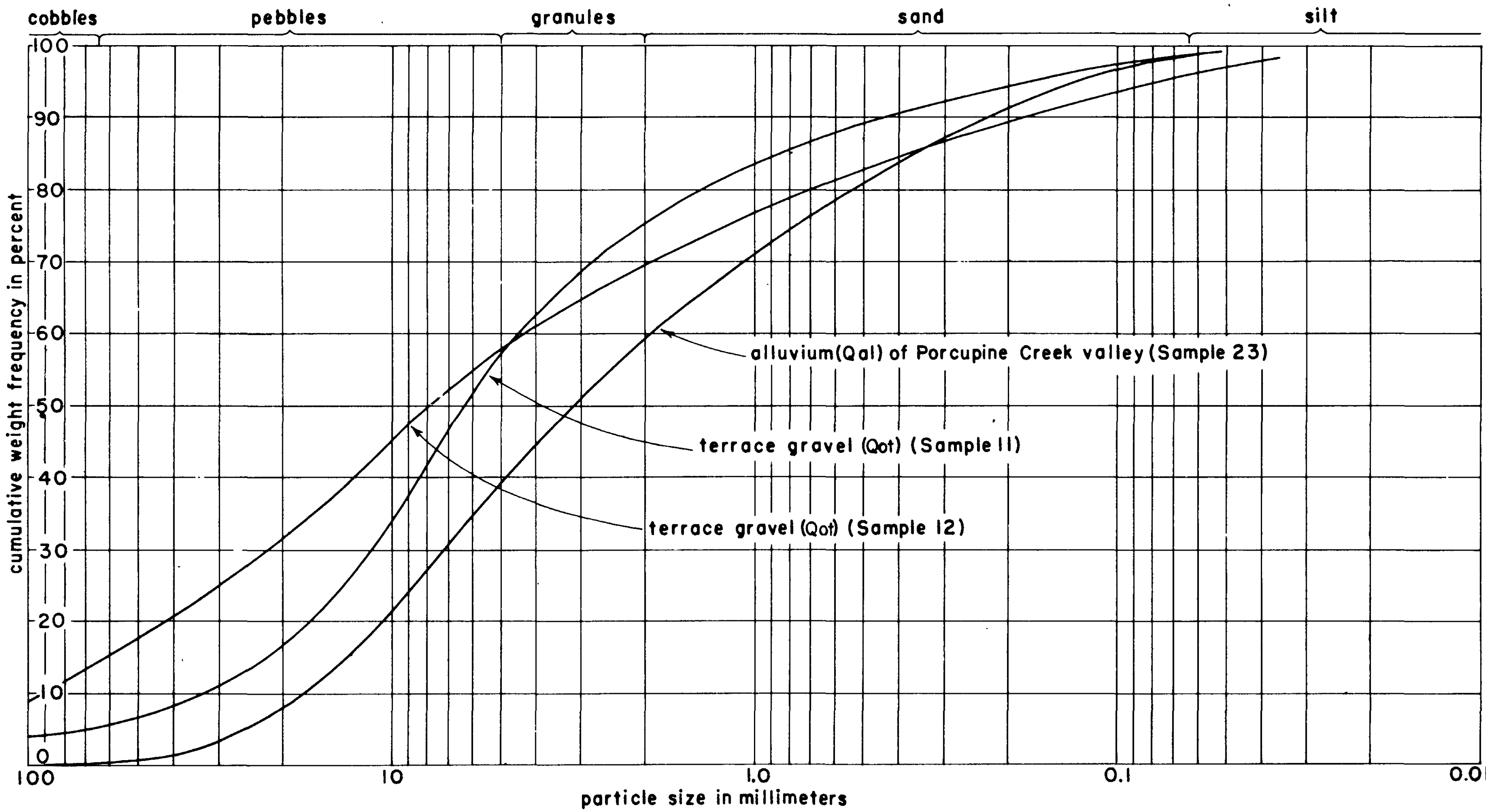


FIG. 6 -MECHANICAL ANALYSES
(adapted from data of the Montana Highway Department)

Most of the material is sandy gravel in lenticular beds a few to several inches thick. Cross-bedding is markedly developed in many places. Intercalated with the sandy gravel are some lenses of sand and lesser amounts of silt and clay. Locally 3 to 5 feet of horizontally and cross-bedded fine sand and silt overlie the sandy gravel. The materials are unconsolidated and the formation as a whole is very pervious.

Pebble types are the same as in the ground moraine; in addition there are a few clay balls. Pebbles are mostly $\frac{1}{2}$ to 3 inches in diameter, though there are a few cobbles and boulders. Caliche coatings are not well developed.

The formation ranges in thickness from 5 to 25 feet, averaging perhaps 12 feet. The larger remnants appear to be the thicker deposits.

(A) Water-bearing character: It is believed that no significant quantities of water are in these deposits, though one intermittent spring does issue from the base of the largest remnant of terrace gravel.

(B) Engineering considerations: The formation is a source of sand and gravel, though poor accessibility and general lack of thick deposits probably limit exploitation to the two terrace remnants just west of Nashua. Detailed prospecting is necessary to determine ratios of thickness of overburden to thickness of usable material. Percentage of chemically reactive components is small, but friable pebbles and clay balls may restrict utility. 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 more than 2 yards thick and beneath less than 2 yards of overburden is estimated at about 4 million cubic yards. Soils classification and Atterberg limits are given in Figure 4, samples 11 and 12. Mechanical analyses of these samples are shown in Figure 6.

Alluvium (Qal and Qalt).--The streams and rivers of the area meander over the alluvial sediments they have deposited. Because these waters differ in volume of flow and in character of load, and because these factors have varied with time, the composition of the alluvium differs horizontally and vertically. In this area the larger streams are in valleys having the deeper alluvial fills.

The alluvial fill in the valleys of Milk and Missouri Rivers has a maximum thickness of about 160 feet. An attempt has been made to limit mapping in minor stream valleys to deposits more than 3 feet thick.

Alluviation in this area has had a complex history, resulting, in the recent past, in deeper fills than are generally present today. Surface remnants of this deeper fill stand 5 to 25 feet above present-day floodplains and are designated terrace alluvium (Qalt), though they are similar to other alluvium in composition. The surface of the alluvium is generally nearly flat, sloping gently downstream.

Discontinuous trenches, reflecting abandoned meanders, are incised in the alluvial bottom lands. These have been partially to wholly filled by slopewash, aeolian, and overbank deposits. Some of the more recent meander scars on the Milk and Missouri floodplains are 10 to 15 feet deep, and contain intermittent ponds and swamps.

The deeper part of the alluvial filling in the valleys of Porcupine Creek and Milk and Missouri Rivers was probably deposited shortly after glacial ice disappeared from the area; this part might be classifiable as glacial outwash.

(A) Alluvium in river valleys: The alluvium in the river valleys is predominantly clay, silt, and fine to medium sand. A small part is coarser sand and gravel, most of which is at, or near, the base of the fills.

All beds are lenticular, though some have a lateral extent of several hundred feet. They commonly range in thickness from less than one inch to 4 feet. A variety of bedding structures are developed, including lamination, thin to thick massive bedding, and cross-bedding ranging in scale from delicate cross-laminae having amplitudes of an inch or less to bold foreset beds 3 to 4 feet in amplitude.

The near-surface alluvium is exposed in river banks and dredge-cut walls which stand 15 to 20 feet above low-water stage. At the surface and in the uppermost few feet are several fairly persistent beds up to one foot thick that are rich in humus. These dark-brown beds are composed principally of poorly sorted mixtures of clay, silt, and fine sand, and alternate with lighter beds to produce conspicuous color banding. The lighter beds are clay, silt, and fine to medium sand, and sorting in individual beds is generally much better. Chiefly because of low permeability some of the clay lenses are unoxidized and retain their original dark bluish-gray color.

With increasing depth there is generally an increase in coarser sediments, so that the basal 10 to 40 feet of the fill is gravel and coarse sand. At any one locality, however, such a simple picture may not apply, inasmuch as test borings by the Corps of Engineers and the Bureau of Reclamation have encountered more or less thick sequences of gravel, sand, silt, and clay at various levels beneath the surface.

(B) Alluvium in creek valleys: The alluvium of Porcupine Creek and the smaller streams is also divisible, in a general way, into an upper fine-grained part and a lower coarse-grained part.

The fine-grained part is only 2 to 15 feet thick. It consists of small interlensing beds of sand, silt, and clay that are gravelly in part and generally poorly sorted. Where these deposits merge with the river floodplains they thicken and are more like the near-surface river alluvium.

The lower coarse-grained part is sandy gravel, in large part cross-bedded and poorly sorted.

Total thickness of the alluvium in Porcupine Creek 3 miles northwest of Nashua is known from a test boring to be about 50 feet. It is probably thinner upstream and must be thicker downstream if, as is supposed, the bedrock floor of this valley is graded to the bedrock floor of Milk River valley. The mapped alluvium flooring other creek valleys is about 3 to probably not more than 15 feet thick.

Where tributaries debouch onto river floodplains, broad and inconspicuous alluvial fans are built in some places. These consist of material intermediate in composition between those of the near-surface parts of river and creek alluvium.

(C) Water-bearing character: Locally gathered data shows alluvium to be an important source of shallow ground water. Much of it is so highly mineralized, however, as to be of limited usefulness. In general the most potable water is in the most pervious beds, which include the gravel and coarser sand beds of both river and creek alluvium. In the finer-grained parts of river alluvium, subsurface circulation of ground water is at a minimum, so that quality is very poor and quantity is limited. It seems probable that wells sunk to near the base of the deepest parts of the alluvial fills will provide best quality and greatest quantities of water. Periods of drought have little effect on water-table level in river alluvium, a somewhat greater effect in Porcupine Creek alluvium, and seriously deplete or eliminate water supplies from the alluvium of lesser creeks.

(D) Engineering considerations: Topographically, alluvial bottomlands are favorable sites for highways, railroads, canals, irrigation projects, and towns. Unusual importance attaches, therefore, to the physical properties of alluvium. As the sediments were deposited under such varying conditions of flow and load these properties differ from place to place and detailed investigations are always advisable. However, certain generalities are applicable.

The materials are all unconsolidated and can be worked easily by hand or with power tools. As the water table is only a few feet beneath the surface, 8 to 20 feet in most places, stability is low beyond such depths. The near-surface materials erode to near-vertical slopes, but are subject to caving and slumping. Permeability of near-surface materials differs with locality, but is generally fairly low. Water-retaining structures may leak badly in places, yet planners of irrigation projects must beware of water logging over much of the alluvial area. Unsurfaced roads are satisfactory when dry, but are impassable in some places when wet.

Locally the alluvium in creek valleys is a source of sand and gravel. Figure 7 shows a mechanical analysis of a sample collected in Porcupine Creek valley. Atterberg limits and soils classification for this sample are shown in Figure 4, sample 23. Soil classifications and Atterberg limits of other samples of alluvium, taken by channelling stream banks, are given in Figure 4, (Samples 30, 6, and 24).

Considerable detailed data concerning Missouri River alluvium are on file at the offices of the Corps of Engineers at Fort Peck and those of the Bureau of Reclamation at Wolf Point, Montana.

Alluvial-colluvial deposits (Qac).--Alluvial-colluvial deposits have accumulated on the lower slopes of hillsides and have spread beyond to mantle the contiguous parts of the flat alluvial valley floors, partially filling the angle between hillside and valley floor and producing a smooth concave-upward curve. In mapping, upslope limits are arbitrarily drawn where these sediments thin to less than about 3 feet. Surface slope of these deposits is approximately normal to that of valley floors, so that the gradational downslope contact with alluvium is along the line of blending of these slopes. Morphologically, these deposits form fanshaped masses, which in many places have coalesced to form aprons.

The distinction between alluvial-colluvial deposits and alluvial-fan deposits is made on both genetic and lithologic grounds. Genetically the former are predominantly talus, creep, slopewash, and rivulet deposits, the later are predominantly deposits of streams much larger than rivulets. A small proportion of each kind of deposit is locally intercalated in the other.

Previously described formations, present upslope, are the source of alluvial-colluvial material. The coarsest of this debris is deposited nearest the source, the finest farthest away. As the sorting powers of the agents of transportation involved are low, a large proportion of all the deposits in this area is silt and clay. These facts, coupled with a knowledge of upslope materials, allow a generalized prediction of lithology of the deposits from place to place.

Bearpaw shale, Wiota gravels, and ground moraine are the principal source materials. The alluvium-colluvium derived from these is a compact, fairly tough mixture of clay, silt, and lesser amounts of sand and pebbles, the last two present locally as small lenses of sandy gravel representing buried channels of former drainage. In cross section the material is much like till, but the arrangement of flat surfaces of pebbles parallel to the colluvial surface gives a more pronounced fabric than that in till. Another point of distinction is color, which is generally a dark grayish brown.

As mapped, the deposits range in thickness from about 3 feet to more than 20 feet.

(A) Water-bearing character: Little or no ground water is contained in these deposits because of low porosity and permeability and well-drained surfaces. Locally wells may be sunk through this formation into underlying alluvium containing water.

(B) Engineering considerations: Sloping surfaces and low permeability combine to provide excellent surface drainage. Drying produces an intricate pattern of polygonal shrinkage cracks extending to a few inches beneath the surface. Surfaces are commonly dissected by shallow, steep-sided gullies. Subsurface drainage is very poor, permitting little seepage loss from water-retaining structures. Alkali salts deposited by evaporating water may make areas underlain by these deposits unfit for irrigation. The material is generally so tough that power tools are necessary for excavation, but this results in cuts being stable at near-vertical angles, providing the cuts are less than about 15 feet deep. 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.

Figure 4, sample 21, gives the soil classification and Atterberg limits of a sample from the most wide-spread type of alluvium-colluvium, that derived from erosion of a slope composed of Bearpaw shale, Wiota gravels, and ground moraine.

Intermittent pond deposits (Qp).--During periods of wet weather, water collects in a number of shallow undrained depressions on the ground-moraine plain and in two similar depressions in the surface of the superglacial fluvio-lacustrine deposits. The resulting ponds are seldom more than a few inches deep and dry up soon after the wet weather passes. Drainage from small areas around these depressions washes clay and silt into them. A lesser amount of clay, silt, and fine sand is brought in by the wind during dry periods. The ponded waters distribute this debris evenly over the bottoms, so that surfaces of the resulting deposits are flat. Filling of these depressions began soon after the glacial ice wasted away, and has continued in most of them to the present. A few have had their walls breached by erosion and no longer accumulate deposits.

Most of the depressions are kettles. The rest originated through fortuitous deposition of glacial debris in such a way as to close off small areas from external drainage. Some small "blowouts" in the dune sand areas, drained only by subsurface percolation, have not yet accumulated mappable deposits. A few of the depressions have abrupt sides 5 to 15 feet high, but most are bounded by very gentle slopes that rise only 3 to 8 feet above the present flat surfaces of the pond deposits. The deposits themselves range in thickness from 6 to probably 12 feet, thinning to feather edges at the borders.

The material composing the deposits is predominantly plastic clay. A small amount of silt and fine sand, either dispersed or as thin laminae, is present in the clay. The uppermost 1 foot is black, clayey, humus-rich soil, less compact than the underlying material which is dark gray, grading downward to light brown 3 to 4 feet beneath the surface. There may be some coarser sand or even gravel at the base of those larger deposits situated on ground moraine.

(A) Water-bearing character: The small amount of recoverable water that may be present at the base of some deposits is stagnant, and consequently so high in dissolved solids as to be unfit for most uses. The deposits are an insignificant source of ground water.

(B) Engineering considerations: Both surface and subsurface drainage is very poor because of the flat surfaces and very low permeability. Stability of all but the shallowest cuts may 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. Testing might show parts of the deposits to be a source of ceramic clay. Figure 5, sample 10, gives the soil classification and Atterberg limits.

SUMMARY OF NATURAL RESOURCES

Non-metallic materials, including water, constitute the only known resources of the quadrangle.

No oil or gas has as yet been discovered, though subsurface formations are present that have yielded both in other parts of the State. Two wildcat wells have been drilled in the vicinity, but both were dry holes. One of these was about 3 miles southwest of Tampico, about 20 miles west of the quadrangle. Started in the lower part of the Bearpaw shale, it was drilled to a depth of 6,110 feet into pre-Devonian strata. The other test was made about 10 miles north of Poplar, about 50 miles east of the quadrangle. It was begun near the top of the Bearpaw shale and stopped at a depth of 5,060 feet, near the base of the Ellis group.

A small quantity of inflammable bituminous matter can be distilled from Bearpaw shale.

There is no coal in the quadrangle.

Sand and gravel.--Wiota gravels and outwash terrace deposits consist in large part of sand and gravel. Fairly large quantities are available. Detailed information is included in the description of these formations in an earlier part of this report.

Riprap.--Minor quantities of cobbles and boulders 6 to 30 inches in diameter have been locally gathered into heaps along section lines on the ground-moraine plain. 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 appear to be those materials mapped as intermittent pond deposits. As 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 of those exposed within the quadrangle are too thin (1/4 to 19 inches) to be at present of economic value. Because the till of the ground moraine is so nearly impermeable it should prove a satisfactory substitute in many cases.

Water.--An abundance of surface water is available at all times in the Milk and Missouri Rivers and the Fort Peck Reservoir. Other streams are intermittent, though isolated pools along the channels of the larger creeks provide sufficient water for stock in all but the driest seasons. Dams across the small upland drainage lines impound water the year around, provided they are judiciously located and properly constructed.

Shallow ground-water supplies differ markedly from place to place. In general, there is an abundance of such ground water in the alluvium of the rivers and larger creeks, and only small quantities in upland areas. Further information on shallow ground water is included in the detailed descriptions of the surficial deposits.

Deep ground water, under artesian pressure, is obtainable from the Judith River formation. The water contains large amounts of dissolved solids but is used domestically by some. Additional information on water from the Judith River formation is contained in the previously cited study by Perry (1934).

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