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PRELIMINARY REPORT ON GEOLOGY

OF PART OF THE

CHAMBERLAIN QUADRANGLE, SOUTH DAKOTA

by

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Introduction

This map and report were prepared as part of the Geological Survey's mapping and mineral resource investigations that are being made as part of the Department of the Interior's program for the development of the Missouri River Basin.

The Chamberlain quadrangle lies somewhat southeast of the center of South Dakota, and includes a segment of the Missouri River trench together with upland areas on either side. This report describes the geology of an irregularly shaped area constituting about two-thirds of the southern half of the quadrangle.

The primary purposes of mapping are to determine the geologic history of the Chamberlain area and to provide basic geologic data regarding the distribution, structure, and physical properties of materials that underlie and crop out in the area.

The report is based on less than five months field work in the Chamberlain area during the summers of 1948 and 1949. Part of this time was spent in studying adjacent areas that contain evidence critical to the determination of relations within the quadrangle.

Geologic mapping was done principally on vertical aerial photographs, scale approximately 1:20,000, but some was done on Corps of Engineers maps (War Dept., 1947, sheets nos. 45 and 46, scale 1:24,000) that cover part of the area. Geologic contacts were transferred to the topographic map of the Chamberlain quadrangle, enlarged from the published scale of 1:62,500 to approximately 1:31,680. The topographic base was eliminated in the final copy, as the lines were so numerous as to be illegible in a black-line print showing both the topography and the geologic contacts.

The senior author was assisted in the field in 1948 by E. A. Goodrich and in 1949 by R. R. McDonald. Many of the concepts set forth were developed as the result of discussions with R. F. Flint. Especial acknowledgment is due to Mr. E. J. Bergner, who donated the fossils that provided the key to the entire Pleistocene chronology. The section on mass-wasting movements under Economic Geology was written by Dwight R. Crandell of the Geological Survey. Mr. Crandell spent about 7 days in the Chamberlain quadrangle in 1951.

General geology

Almost no well-consolidated bedrock occurs within several hundred feet of the surface at any point in the Chamberlain quadrangle. The entire area is directly underlain by poorly consolidated sediments of late Cretaceous and Pleistocene age. The Cretaceous formations are flat-lying marine bentonitic shales and claystones with some impure chalky beds; strata of these types exceed 1,000 feet in thickness, reaching from the highest point on the quadrangle at 1,918 feet to hundreds of feet below the lowest (the Upper Cretaceous Dakota sandstone was encountered at 867 feet above sea level in a well 1-1/2 miles south of the quadrangle. C. L. Baker, personal communication). These beds formerly extended unbroken and with very little lateral variation in lithology over the entire quadrangle and for many miles beyond its borders. The Pleistocene deposits, by contrast, are highly variable, and local in their distribution; they include glacial, stream, and eolian accumulations.

Cretaceous sedimentary rocks

The Cretaceous beds that underlie the entire Chamberlain quadrangle were laid down far out at sea, and are therefore essentially uniform over the area. These strata are characterized by an extremely weak, bentonitic character, which allows them to slide so readily that few if any exposures exist that have not been moved from their original positions; because the amount of movement that has occurred varies greatly from place to place, the original stratigraphic relations are commonly obscured.

Niobrara formation (Kn).--The oldest rock exposed in the Chamberlain quadrangle is the Upper Cretaceous Niobrara formation. The Niobrara consists largely of impure chalk, though thin beds of bentonite and seams of gypsum are present. The chalk is soft and friable, but its resistance to erosion is enough greater than that of the overlying shale and claystone so that it commonly stands in vertical cliffs, forming a bench-like feature along the walls of the Missouri River trench. It is dark gray on fresh exposures, but readily weathers to a yellowish-brown color. Although the formation is locally slumped, it is by far the most stable bedrock in the Chamberlain area. The formation reaches an altitude of about 1,420 feet in the vicinity of Chamberlain, the thickness above river level being, therefore, nearly 100 feet.

Pierre shale.--The Pierre (pronounced pier) shale includes all the Cretaceous beds in the quadrangle above the Niobrara formation. Very little of it in this area can properly be called shale, as it is largely claystone and mudstone. Thin bentonite beds occur at many places in the Pierre, and much of the claystone and mudstone is bentonitic. The formation is lithologically subdivided into 8 members (Crandell, 1950). Four units are differentiated on the accompanying map.

Sharon Springs member (Kps).--The Sharon Springs is a bituminous shale that has a sufficiently high petroleum content so that in places the beds have actually burned. The burned shale is brick-red, but in most places the Sharon Springs weathers to silvery gray chips. The moist rock is black, drying to a dark gray. The lower part is streaked with thin white beds of bentonite, and the upper part contains many impressions of fish scales on bedding surfaces.

The thickness of the Sharon Springs member is in some doubt. On the weathered outcrop the petroleum content is reduced by weathering, and the thickness is inferred from the distribution of the silvery chips into which the member weathers. On this basis, a maximum thickness of 55 feet was inferred in sec. 17, T. 104 N., R. 71 W. For 1-1/2 miles northeast from this locality, however, the shale appears to be only 10 to 20 feet thick. The cause of this apparent variation is not clear. It may be in part real, due to differences in the original thickness of deposition or to an erosional unconformity between the Sharon Springs and the overlying Gregory member. However, the area of apparent thinness may be the result of a massive landslide or series of slides that have cut out the Sharon Springs beds to nearly the same degree throughout the 1-1/2 mile distance. A third possibility is that the 55-foot thickness is too great: although the silvery chips develop on the Sharon Springs, there may be places where similar chips weather from the lower part of the Gregory. No outcrop of the Sharon Springs member fresh enough to expose actual bituminous shale more than about 15 feet thick has been found, and the Sharon Springs may be only 10 to 30 feet thick over the whole area.

Gregory member (Kpg).--The Gregory member, overlying the Sharon Springs, is a gray bentonitic claystone that weathers to a brown or lighter gray color. In places a marl occurs at or near its base. Pelecypods and coiled and straight-shelled ammonites have been collected from these beds, and rare reptilian remains occur.

The total thickness of the Gregory plus the Sharon Springs is about 100 feet near Chamberlain. This stratigraphic interval appears to increase to 150 and perhaps 180 feet farther to the west, but the apparent thickening may be in part the result of landslides that have lowered the Pierre/Niobrara contact and obscured the true thickness.

Crow Creek and DeGrey members (Kpd).--As seen from almost any point in the Missouri River trench or the lower parts of its tributaries, the Pierre shale walls are marked by a prominent dark-colored band with a thin, buff-bolored unit at its base. The dark band is formed by the DeGrey member of the Pierre shale, and the buff-colored unit is the Crow Creek member. The Crow Creek is too thin to be mapped separately on the scale here used, and on this map is combined with the DeGrey member.

The Crow Creek member is the most distinctive member of the Pierre formation in this area. It is composed largely of marl. Near its base is a layer of highly calcareous siltstone that weathers into very thin slabby sheets. The origin of this siltstone is not yet understood; though apparently nowhere more than 2 feet and rarely more than 1 foot thick, it extends almost continuously for scores of miles and is known at points 120 miles apart. The marl of the Crow Creek, and especially the siltstone at its base, is more resistant to erosion than the rest of the Pierre shale. The member rarely exceeds 10 feet in total thickness.

The DeGrey member (Crandell, 1950) includes the "Agency zone" and the "Oacoma zone" (pronounced oh-CO-muh); of the South Dakota Geological Survey (Wing and Gries, 1941, and references there cited). In this area the DeGrey member includes the beds forming the conspicuous black band along the outcrop area, together with a few feet of gray clay between these and the Crow Creek calcareous beds. It consists largely of bentonitic claystone and mudstone with numerous thin seams of bentonite; the black color characteristic of the outcrop is due to the presence of abundant nodules of iron-manganese carbonate (subsequently described more fully under Economic Geology) that weather to a rich purplish-black color. These nodules remain hard even after weathering, and accumulate as a lag concentrate on the surface as the enclosing material is washed away by the beating rains; they are so numerous that in many places they protect the surface from erosion. The upper limit of the DeGrey is somewhat indefinite and variable, depending on the highest manganiferous nodules present in any given section, but the unit has a thickness of about 50 feet, of which all but a few feet at the base (perhaps 10 feet at the most) contains manganese-bearing concretions. The DeGrey member is extremely susceptible to landsliding and does not, therefore, form a suitable stable base for highways or other structures.

Most of the fossils collected in the course of this study were obtained from the DeGrey member. Parts of several mosasaurs, a type of marine reptile, were discovered. Another vertebrate fossil is a fish identified by Dr. D. H. Dunkle of the U. S. National Museum as *Syllaemus latifrons* Cope. This fish is preserved without flattening or distortion as a rounded mold in a manganese nodule, an occurrence which suggests that the manganiferous carbonate nodules were formed as a soft precipitate, probably a colloidal gel, on the sea floor prior to burial and are not epigenetic concretions formed by ground water. A considerable number of invertebrates occur in the DeGrey member, commonly preserved in the nodules. Pelecypods, especially *Inoceramus*, are common, and several baculite specimens were collected.

Verendrye and overlying members (Kpv).--The Pierre shale members above the DeGrey are not subdivided on the accompanying map. They include, in ascending order, the Verendrye (pronounced Ver-EN-dree), Virgin Creek, and Mobridge members, but in most places in this quadrangle the exposures of these beds are not good enough to permit tracing of their contacts. The Mobridge is a calcareous shale with many foraminiferal shells flattened along bedding surfaces; the other members are bentonitic claystones and mudstones distinguished by minor lithologic differences only recognizable in fresh exposures.

Structure.--The Cretaceous strata are so nearly horizontal that any departure from that attitude measurable with a brunton compass may fairly safely be taken as evidence that the exposure showing it is part of a landslide. Nevertheless, there probably is a slight amount of genuine variation in the altitudes of the contacts. The base of the Crow Creek member stands at about 1,520 feet near Chamberlain, is apparently at about 1,530 feet in the bluff west of the Missouri at the south edge of the map, and rises to a crest of about 1,560 feet within two miles to the west. It is not known whether this variation is the result of differences present at the time of initial deposition, of differences in subsequent compaction of the beds, or of slight structural deformation.

Pleistocene deposits

The Pleistocene deposits of the Chamberlain quadrangle are of continental origin, and are therefore much more highly varied and less continuous than the marine Cretaceous beds. They include stream deposits of material brought from the west by the White River and one of its former tributaries; till and related meltwater deposits containing stones brought by ice from areas to the northeast; materials derived from these and from the Cretaceous beds and redeposited by local streams; non-glacial and glacial deposits of the Missouri River; and eolian deposits chiefly blown up from the latter. These deposits are described in order from older to younger in the sections that follow; the evidence on which these age relations are assigned is presented in a separate section on geologic history that follows the descriptions of the deposits themselves.

Yarmouth [/] gravel deposits (Qyg).--The oldest Cenozoic deposit

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/ The standard Pleistocene sequence, used in this paper, is as follows:

Epoch	Stage	Substage
		Mankato
		Cary
	Wisconsin Glacial	Tazewell
		Iowan
	Sangamon Interglacial	
Pleistocene	Illinoian Glacial	
	Yarmouth Interglacial	
	Kansan Glacial	
	Aftonian Interglacial	
	Nebraskan Glacial	

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identified in the Chamberlain quadrangle is stream-deposited pebble gravel that thinly mantles uplands at altitudes above 1,700 feet in the northwestern part of the area mapped. Deposits of this age are generally only a foot or two thick, and in many places shown on the map by the symbol (Qyg) there is only a scattering of stones, which may be almost completely obscured by eolian deposits that overlie them. Aside from a variable content of locally derived stones such as Pierre nodules, the gravel consists of hard pebbles, chiefly chalcedony, quartz, sandstone, and perthitic feldspar. This lithology indicates that the gravel was derived from the west: the glacial deposits brought to this area from the northeast include many granitic and calcareous stones. A few such erratic stones are scattered on the surface of the Yarmouth gravel under the covering eolian deposits.

A gravel-capped terrace of somewhat younger Yarmouth age occurs at a lower altitude in secs. 3 and 4, T. 103 N., R. 72 W. Three other Yarmouth gravel bodies shown on the map were originally veneers on similar terraces, but have subsequently been buried under later deposits, so that they are exposed only where the later cover is stripped off. These are a mile north of Oacoma, a mile northeast of Chamerlain, and at the south edge of the map in secs. 5 and 6, T. 103 N., R. 71 W. The deposits consist of sand and pebble gravel and reach a maximum thickness of about 12 feet. The material in these deposits is lithologically similar to the earlier Yarmouth gravel on the upland.

Illinoian (?) gravel deposit (Qig).--A deposit of sand and gravel in secs. 4, 5, and 9, T. 103 N., R. 72 W., may be Illinoian in age. The lower part of this deposit is interbedded coarse sand and pebble gravel; the upper part is bedded sand with some clayey silt. The stones in the gravel beds are chalcedony, quartz, and feldspar, like those in other gravels derived from the west. The total thickness is more than 17 feet. The deposit is buried under till, believed to be Iowan or Tazewell, and is exposed only where the till has been removed by erosion.

Illinoian till (Qit).--The oldest glacial drift in the Chamberlain quadrangle is a very clayey till, containing few boulders. It is hard and compact, has a blocky jointing, and is deeply stained by weathering to a purplish or chocolate color. It was formerly considered to be Kansan in date (Flint, 1949), but it has been shown by the present study to be Illinoian (Warren, 1949, 1953). It is at least 25 feet thick in a single exposure at Chamberlain, and south of the quadrangle it reaches a maximum thickness probably greater than 120 feet. The Illinoian till is deeply stained throughout this thickness by weathering, but the original upper surface appears to have been removed by erosion, and no gumbotil has been recognized in the area. The till is exposed only where erosion has removed a cover of late Wisconsin till and loess deposits under which it was buried. Soil-test data concerning the Illinoian till are given in the Appendix.

Iowan (and Tazewell?) deposits.--The Iowan ice sheet probably covered the whole of the Chamberlain quadrangle (Flint, 1949, p. 70 and fig. 1). As yet no Tazewell drift has been definitely identified in the area, but some of the deposits in and east of the Missouri River trench may be of this date. The early Wisconsin_/ glacial drift in the

_/The term "early Wisconsin" is used in this paper to include the Iowan and Tazewell substages.

quadrangle includes till, meltwater deposits, and eolian material. The latter deposit, blown up by the winds from the surface of an outwash fill in the Missouri River trench, forms the main mass of the eolian mantle that covers most of the upland areas.

East of the Missouri River, the early Wisconsin eolian deposit is loess, generally less than 10 feet thick. Where uneroded, its upper part is a rich, black, humified soil 1 to 3 feet thick. Beneath this it normally grades down through yellow into yellow mottled with bluish gray. Its lower part commonly retains rounded hollow tubules of yellow iron oxide that were possibly deposited around rootlets. The corresponding deposit west of the Missouri is coarser grained, generally fine sand rather than silt, and is apparently thinner.

Though the eolian deposits are widespread on the upland areas, and are of great economic importance because of their value as agricultural soils, they are not shown on the accompanying map, the materials inferred to underlie them being shown instead. In general, all areas of flat upland underlain by Iowan or older units may be expected to carry from 2 to 12 feet of early Wisconsin eolian material.

Iowan (and Tazewell?) till (Qwit).--Till of Iowan age occurs on the uplands west of the Missouri River. No exposures of this till more than 2 feet thick were observed above 1,600 feet altitude, and the upland till is discontinuous and patchy; exposures are not good enough to permit delimiting those areas where it is represented only by a scattering of stones from those where it is an actual body of till under the obscuring loess cover, but it should not be assumed to occur as a continuous body of till in all places shown on the map by the (Qwit) symbol.

Till mapped as early Wisconsin at the south edge of the map west of the Missouri River is probably 10 feet thick, and possibly several times that amount. East of the Missouri River the early Wisconsin till reaches a maximum thickness of more than 12 feet. These thicker tills may be (partly?) Tazewell. On the average, they are somewhat less hard and jointed than the Illinoian till. They are commonly somewhat silty and sandy, with more stones and less clay than the older till, and they are generally yellow or chocolate in color. The early Wisconsin till varies greatly in appearance, however, and cannot be definitely distinguished from other tills by its lithologic characteristics. Soil-test data concerning the Iowan (and Tazewell?) till are given in the Appendix.

Nearly all flat areas of early Wisconsin till are covered with 5 to 15 feet of loess.

Ice-contact(?) deposit (Qwii).--Extending south-southeast from a point opposite Oacoma, and then south-southwest to rejoin the Missouri River trench at the south edge of the quadrangle, are remnants, now partly isolated by erosion, of a body of early Wisconsin sand and gravel. This deposit, now about 40 feet thick and perhaps originally thicker in the central part of the channel, may be part of the early Wisconsin outwash fill described in the next section, but more probably it was deposited while Iowan or Tazewell ice blocked the main valley of the Missouri. Most of the deposit is medium to coarse sand, but it contains many gravel beds, especially in its lower part. The stones in the gravel beds include western pebbles and nodules derived from the Pierre shale and many glacial erratics, some of them of boulder size. Part of the deposit in this channel, a glacial gravel in the NE$\frac{1}{4}$SW$\frac{1}{4}$, sec. 6, T. 103 N., R. 71 W., is firmly cemented with calcium carbonate to form a hard conglomerate. The channel fill deposits are partly buried under alluvium washed from higher land on either side, under two separate loess deposits, and under Cary gravel.

Outwash deposits (Qwio).--After ice of the Iowan substage retreated from its maximum westerly extent, outwash accumulated in the Missouri River trench to a depth of at least 150 and perhaps nearly 300 feet; the profile of the Missouri River was raised by the aggradation to an altitude of at least 1,530 feet near the south edge of the quadrangle. The lower part of this fill is largely gravel, and includes erratic boulders as much as 2-1/2 feet in diameter; near the northeast corner of the Chamberlain quadrangle 4-foot boulders occur in what is probably part of the same deposit. The upper parts of the outwash fill include some gravel, but generally consist largely of sand and even include laminated silt.

In places the stones in the gravel consist almost wholly of local materials, chiefly nodules derived from the Pierre shale, but in most places they include many glacial erratics, and stones of the types brought from the west by such streams as the White River.

Though the original thickness and volume of this deposit were considerable, it has been extensively eroded. Such remnants as are preserved in the trench are generally thin, with surfaces sloping toward the axis of the trench more or less parallel with the surface of the underlying Cretaceous beds. Probably few of the remnants shown on the map with the symbol (Qwio) are more than 20 feet thick. Their surfaces are locally veneered with a foot or two of fine eolian sand.

Post-Iowan gravel deposits (Qwg).--After the Iowan substage, the Missouri River cut down again, removing nearly all of the outwash it had deposited. The White River likewise cut down and planed laterally in the process. Two terraces in secs. 5, T. 103 N., and 32, T. 104 N., in R. 72 W. appear to have been cut by meanders of the White River at this time. Both are veneered with a foot or two of pebble gravel of western lithology like that of the Yarmouth gravel described above. The higher and more northerly terrace bears scattered erratics that show it was covered by ice, doubtless the thin Cary ice; it has been partly buried by a large landslide.

Cary deposits.--The Cary ice sheet, the last glacier that reached the Chamberlain area, appears to have covered all the area east of the Missouri River shown on the accompanying map and to have largely filled the trench. It also crossed the relatively low divide in the southern part of the quadrangle and reached the meander loop of the White River, but apparently it did not otherwise get up on the uplands west of the trench. This ice was apparently very thin, so little able to erode that in many places it left the soil on the underlying Iowan loess quite intact. Nevertheless, the Cary glacier left deposits of till, and its meltwaters appear to have left ice-contact deposits and to have formed an outwash fill in the trench. These deposits are described in the sections that follow.

Probably contemporaneous with the outwash fill in the valley is a deposit of loess that accumulated on the uplands, doubtless blown up from the aggrading surface of the Cary fill. This loess, not shown on the accompanying map, is 1 to 3 feet thick on nearly all upland flat areas in the quadrangle. On the uplands it generally rests on the black soil marking the upper surface of the early Wisconsin eolian deposits. It is generally browner in color than the older yellowish loess. It lacks the extensive humification of the older soil, but a moderately well-developed soil profile, the present soil of the area, is generally present on it.

Cary(?) till and till-equivalent (Qwct).--In many exposures on the uplands east of the Missouri River the thin brownish Cary loess rests on the black, humified soil marking the upper surface of the early Wisconsin loess. Where an extensive exposure is available, a careful search along the contact between the two loesses generally reveals a few scattered pebbles. In many places, these pebbles are all that remain to record the former presence of Cary ice. Although this deposit is a definite till-equivalent, it can scarecely be called till. A similar scattering of erractic stones was left by Cary ice on the areas between the meander loop of the White River and the Missouri River in the southwestern part of the quadrangle.

The only areas of Cary(?) till that are shown on the map are areas in the Missouri River trench adjacent to the high Cary(?) terraces described in the following section. The till reaches a thickness of 16 feet in road cuts north of Oacoma, and may be thicker in places. It is a gray, clayey till, not highly consolidated or deeply stained.

Cary(?) ice-contact sand and gravel deposits (Qwci).--Two bodies of glacial sand and gravel that form prominent terraces about 350 feet above the Missouri River in secs. 8 T. 104 N., R. 71 W., and 13, T. 104 N., R. 72 W., are believed to have been deposited by meltwater streams that flowed for most of their courses through the upper part of ice that nearly filled the Missouri River trench in Cary time. The deposits range in thickness from a mere scattering of stones to probably 20 and possibly as much as 60 feet (Pesonen, Tullis, and Zinner, 1949A, p. 21 and sec. D-10). Most of the material ranges in grain size from coarse sand to pebble gravel, though some fine sand and a few cobbles are present. The pebbles are largely granitic and carbonate rocks; few if any western stones are present, and even nodules from the Pierre shale are rare. Many of the stones are coated with calcium carbonate.

Two small patches of high-level gravel a foot or two thick in sec. 36, 2 miles south of Oacoma, may also belong to this episode of deposition.

Cary(?) outwash deposits (Qwco).--The lower part of the city of Chamberlain is built on a terrace that is underlain largely by stratified sand which includes beds ranging in grain size from silt or clay up to pebbles and cobbles; a few small boulders are present that may have been carried by floating ice. The deposit forms bluffs about 70 feet high at Chamberlain, and its original thickness, including the portion below the present river surface, may have been nearly twice as great. The terrace was dissected by gullies, eolian sand was deposited and a humified zone was developed on it before the accumulation of a second eolian sand about 2 feet thick.

A second portion of this same fill may be preserved in remnants east of the Missouri River near the south edge of the map. The more northerly of these, largely in sec. 36, T. 104 N., R. 72 W., shows eolian sand resting on a humified zone comparable to that at Chamberlain. These southern remnants, however, are only about 50 feet above the river. They may have been formed by cutting during the removal of the Cary(?) fill in the Cary-Mankato interval, or their lower altitude may be the result of a steeper gradient of the Missouri River in Cary time required to carry the heavy loads of sediment contributed to the river by the melting ice.

Soil-test data on samples of the Cary(?) outwash deposit at Chamberlain are given in the Appendix.

<u>Mankato(?) outwash deposits (Qwm)</u>.--Terraces in the Missouri River trench that are slightly lower than the Cary(?) terraces lack the humified zone buried beneath eolian sand that appears to be characteristic of the higher ones. The Mankato(?) terrace deposits consist of local alluvium together with sand and silt comparable in grain size to the material forming bars in the Missouri River today. This material reaches a maximum thickness of perhaps 60 feet above the river level; the original thickness, including portions below present river level, may have been twice as great. It seems likely that these terraces record the deposition of Mankato outwash. This outwash probably provided the source of the eolian sands resting on the Cary(?) terraces.

Aggradation in the Missouri River trench was naturally accompanied by deposition in the tributary valleys. In the larger valleys, terraces believed to correlate with one or more of the late Wisconsin fills in the Missouri are sufficiently prominent to be shown on the accompanying map. They consist of clayey alluvium with some stony layers, resembling the material being carried by the same streams today.

Recent deposits

Landslide deposits (Qlq, Qlp, Qlpg, Qln, Ql).--An outstanding characteristic of the bentonitic strata of the Pierre shale is their instability. Landsliding is so general that it is doubtful whether there is a single Pierre shale exposure anywhere in the quadrangle that has not been displaced to some degree from its original position. Blocks ranging in size from a few to many thousands of cubic yards have been tilted at various angles. Masses have also broken loose and moved downslope. In this type of sliding, the various stratigraphic units commonly become mingled together. In places siltstone from the base of the Crow Creek member rests on the Niobrara formation, and elsewhere the Verendrye member has slumped down onto the Gregory member so that the Crow Creek and DeGrey members appear to be missing. In secs. 31 and 32, T. 104 N., R. 72 W., nearly a quarter of a square mile of a terrace cut by the White River has been covered by one great slide of Pierre shale debris.

Sliding is especially characteristic of the Pierre shale, being most common in the DeGrey member, but it also occurs in other materials. Some of the exposures of the Niobrara formation have obviously been tilted or otherwise displaced, although this formation is far less susceptible to landsliding than is the Pierre shale. Many slides initiated in the Pierre shale also involve overlying Pleistocene deposits. Finally, some slides appear to occur within the clayey tills. East of the Missouri River, and east of Oacoma on the west side of the river, no attempt was made in the field to map these various landslide materials separately, but west of Oacoma symbols are used to distinguish the various types of materials.

Landsliding has occurred at many different times in this area. Many slides are active today or have occurred within recent years, but others occurred before the deposition of the early Wisconsin gravel fill in the Missouri River trench. As is to be expected under these circumstances, many slides can be inferred from stratigraphic evidence for which no topographic evidence is preserved.

The great prevalence of landsliding in this area presents a problem in mapping methods. In places the Pierre shale units can be identified within the landslide blocks and mapped as slid DeGrey member, etc., but in many places the scale of the slides is too small to permit delineating the units, and in general it seems to require more time than the practical value of the results could justify. Therefore only those parts of the Pierre shale contacts that appear to be most nearly in place have been mapped; it should be realized, however, that probably none of the contacts are actually in their initial positions. In general, in those areas where the contacts between Pierre shale members show evidence of having been lowered or tilted, the head of a slide can be recognized farther up the hill. The areas below such scars are in most places mapped as slide. Little attempt was made, however, to map slides that occur wholly within a single map unit. The contrast between the relatively large proportion of Verendrye and higher units mapped as being in place, and the small amount of DeGrey and lower members so mapped, is perhaps in part real, both because the DeGrey is probably more susceptible to sliding than the other Pierre units, and because the lower slopes are commonly steeper and therefore more conducive to sliding, but it is for the most part the result of the mapping method used.

Alluvium and colluvium (Qa).--As in most areas, slopewash and creep materials are abundant on most of the slopes in the Chamberlain area. This material is generally clayey, but nodules from the Pierre shale and commonly stones from the Pleistocene deposits are included in it. It is not shown on the map except in areas where it is so prevalent as to obscure the character of the underlying materials. The same map symbol is used to designate areas of bars built by the Missouri River. These consist of stratified silt and sand. Some such bars, like American and Bice Islands, support stands of mature cottonwood trees, indicating stability over a period of decades, but others form and shift each year.

Geologic history

The geologic history that may be inferred from a study of the sediments exposed in the Chamberlain quadrangle begins with the area lying below the shallow waters of an extensive inland sea in late Cretaceous time. Deposition of the chalky beds of the Niobrara formation was followed by a time of muddier seas. Much of the mud consisted of dust blown to the area from explosive eruptions of volcanoes, and many definite beds of volcanic ash, now altered to bentonite, were deposited. By the end of Cretaceous time such muds, together with a few interbedded calcareous layers, had accumulated to a thickness of nearly 500 feet.

The Cenozoic history of the area prior to the Pleistocene is recorded within the quadrangle only by the erosional unconformity separating the Cretaceous sediments from the Pleistocene ones, but Ogallala(?) sandstones and orthoquartzites capping Medicine Butte to the northwest and the Iona and Bijou Hills to the south indicate that in Miocene and probably in Pliocene time the land surface was several hundred feet above the highest Cretaceous beds now present in the mapped portion of the quadrangle.

The number of separate sedimentary units of Pleistocene age distinguished on the map may suggest that the Pleistocene history of the area can be inferred in considerable detail, but in spite of the complexity of the known history, the detailed record does not begin before the Yarmouth Interglacial stage.

Yarmouth erosion.--As is shown by their lithology, the thin gravels on the uplands in the northwestern part of the accompanying map were deposited by a stream from the west. They evidently represent a veneer left by the ancestral White River when it wandered across the area by lateral planation, removing part of the Cretaceous marine deposits. No diagnostic fossils have been found in the gravels to indicate the time of this extensive erosion, but its Yarmouth date is indicated by the vertical relations of the planation surfaces to deposits occurring on the Iona quadrangle to the south.

Seven miles south of the Chamberlain quadrangle, in sec. 10, T. 102 N., R. 71 W., is a high summit at 1,857 feet, capped by a body of gravel deposited by the ancestral White River. This gravel is at least 27 and perhaps as much as 50 feet thick, much thicker than the gravel veneers left on normal planation surfaces by the ancestral White, and it must record an episode of aggradation by that stream at a time when the general surface at this longitude was at least 1,850 feet above present sea level. Vertebrate fossils found in this thick gravel deposit / show it to be Kansan or younger in date (for details, see Warren,

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/ Generously donated by Mr. E. J. Bergner, who collected them from his gravel pit, and kindly identified and dated by Professor C. Bertrand Schultz, Director of the University of Nebraska State Museum, and by Mr. Weldon D. Frankforter, of the same institution.

1953). Thus at some time during or after the Kansan glaciation the area of the present planation surfaces on the Chamberlain quadrangle stood above 1,850 feet. Because the planation surfaces that exist today are well below that altitude, the ancestral White River must have had time for considerable post-Kansan erosion of Cretaceous materials before it deposited the gravels that mantle them. The gravels are therefore post-Kansan. On the other hand, by the time the Illinoian ice reached the area, the ancestral White River had cut down to 1,433 feet, and quite surely it never thereafter flowed on a profile that was as high as 1,600 feet at this longitude. The post-Kansan White River gravels above 1,700 feet on the upland flats must therefore be pre-Illinoian, and are thus of Yarmouth date.

The Missouri River did not exist in Yarmouth time, and the ancestral White River drained eastward to the James Valley lowland (Flint, 1949, and references there cited; Warren, 1949, 1953). In later Yarmouth time, downcutting by the White was more rapid in comparison with lateral planation, and the stream became confined in a valley 5 or 6 miles wide (Warren, 1953, fig. 2). A tributary stream cut a smaller valley approximately along the courses of the present American Crow

Creek and American Creek, and joined the White River at a point beneath Pukwana, 7 miles east of Chamberlain (Flint, 1949, fig. 1). Within these valleys were formed gravel-veneered terraces that record later stages of the Yarmouth downcutting. Two of these terraces, lying east of the Missouri, are buried under Illinoian till in a manner that appears to prove their Yarmouth age.

Illinoian glaciation: Creation of Missouri River.--When Illinoian ice advanced westward from the James Valley lowland, it blocked the lower courses of the ancestral White River and other east-flowing streams and diverted them southward around its margin, creating the Missouri River. The mechanism of this diversion has been described by Flint (1949), and its Illinoian date has been shown by the present investigation (Warren, 1949, 1952).

Before the Illinoian ice reached the Chamberlain area, it obstructed the lower course of the White River, forcing the stream to aggrade. The resulting deposit reaches a thickness of 70 feet of gravel and sand in an exposure in the SW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 19, T. 103 N., R. 71 W., 3 miles south of the Chamberlain quadrangle. This deposit, probably correlating with the Crete formation of Nebraska geologists, has not been certainly identified west of the Missouri, but a possible correlative has been described above (Qig).

The Illinoian ice appears to have advanced up the valley of the White River to the vicinity of Chamberlain. Its till is now exposed in two areas along the east wall of the Missouri River trench. One of these, at the south edge of the quadrangle, lies at the north edge of the pre-Illinoian valley of the White. The basal contact of the northern body of Illinoian till, resting on the Pierre shale walls of the valley cut by the tributary of the ancestral White River, is now exposed at considerably varying altitudes in T. 104 N. This variation in altitude is believed to result from the fact that the present valley of the Missouri southwest from Chamberlain is partly re-excavated from the till that was deposited in the old valley, so that the altitude of the contact depends on the accidental intersection of the present irregular erosion surface with the irregular pre-till erosion surface. Because the Missouri River trench was created marginal to the Illinoian ice, no Illinoian till is to be expected west of the Missouri River.

No Loveland loess has been identified on the Chamberlain quadrangle. The apparent absence of this loess may be due to the fact that none was deposited, it may be due to erosion that has destroyed also the weathered upper surface of the Illinoian till, or it may be due to other causes.

Sangamon erosion.--During the Sangamon Interglacial stage, the newly formed Missouri River cut down to a profile that was probably near its present one, and was certainly less than 50 feet higher. The walls of the resulting trench were widened out by mass-wasting to nearly their present form. The White River and the smaller tributary streams cut down accordantly with their local baselevel. Erosion was probably active throughout the interglacial interval, and no deposits of Sangamon age are recognized in the Chamberlain quadrangle.

Early Wisconsin glaciation.

Till.--The Missouri River trench across South Dakota must have been in existence before any ice crossed its site (cf. Flint, 1949, pp. 70-71). Any drift now found west of the Missouri must therefore be Wisconsin. Because the Iowan is everywhere the most extensive of the Wisconsin ice advances, the glacier ice that left the erractics and thin till on uplands west of the Missouri River is believed to be Iowan (cf. Flint, 1949, p. 70 and fig. 1). The greater thickness of the early Wisconsin till east of the Missouri River may be the result of its including Tazewell in addition to Iowan deposits, but it may equally well be the normal thickness for Iowan till, the thinness west of the trench being the result of deposition from the relatively clean upper ice of the glacier, the heavily loaded basal ice having been trapped in the trench so that the upper ice sheared across it to cover the uplands west of the valley.

Ice-contact(?) deposit.--The sand and gravel deposit occupying the trench extending southeast and then southwest from Oacoma might be part of the early Wisconsin outwash, as it is similar in lithology and reaches only slightly higher altitudes. However, a hill of this material that lies at an altitude of 1,584 feet, 1-1/2 miles southeast of Oacoma, carries thick loess that includes a buried soil profile 13 feet below the hill crest. If the gravel making up most of the hill is early Wisconsin outwash, the two loesses on it would have to be of Cary and Mankato age, here abnormally thick because of proximity to the source in the Missouri; the soil separating them, however, is thick and strongly humified, much blacker and better developed than any seen elsewhere on Cary loess, and resembles that found on the early Wisconsin loess on the upland. The lower loess is therefore probably of early Wisconsin age. If so, this area must have stood above the early Wisconsin outwash while the loess was accumulating, and thus must be somewhat older than the early Wisconsin outwash. It is probably Wisconsin rather than Illinoian; if so, and if it is covered by early Wisconsin loess, it is probably an ice-contact deposit laid down by meltwater while Iowan or Tazewell ice blocked the main valley of the Missouri.

Outwash.--After the Iowan ice had melted back sufficiently to free the Missouri River trench of ice, outwash accumulated in the trench. That the outwash is Wisconsin is evident because it was deposited after the trench had reached nearly its present depth and width. The walls of the trench have been widened out and lowered by a few tens of feet since the gravel was deposited between them, but the major part of the work of cutting the trench antedates the fill. Because the Missouri River was not established in its present course before Illinoian time (Warren, 1949, 1952), the trench must have been greatly broadened and deepened during the Sangamon interval, and the outwash fill within it cannot relate to any ice older than Wisconsin. Remnants of the fill can be traced down to altitudes well below 1,433 feet, the depth to which the White River, then the master drainage of the area, had cut by Illinoian time. On the other hand, a thin veneer of stones was deposited by Cary ice on the sloping surfaces of remnants of the fill in such a manner as to show that before Cary ice invaded the trench, the fill had been almost entirely removed by erosion and the surfaces of its remnants had been lowered by mass-wasting to essentially their present gently graded slopes almost parallel with the Pierre shale walls of the trench. The outwash fill is therefore early Wisconsin, and the long time interval indicated by the completeness of its erosion suggests that the Iowan-Tazewell interval may have been involved, in addition to the longer Tazewell-Cary hiatus; if so, the outwash is Iowan rather than Tazewell in date. In this case, probably no Tazewell glacial drift is present in the area.

Eolian deposits.--The early Wisconsin eolian deposits that mantle the uplands east and west of the Missouri River are believed to be contemporary with and derived from the Iowan (and/or Tazewell?) outwash that was accumulated in the valley below. They rest on early Wisconsin till and were weathered to a strong soil profile before the Cary glacier overrode the area east of the Missouri. Their derivation from the outwash fill in the trench is indicated by the facts that they are somewhat thicker and coarser near the trench than farther away, that they differ in character on the two sides of the trench, and that they are thickest, in spite of being finer in average grain size, on the east side of the valley, in the downwind direction of the prevailing winds of the area. The deposit is believed to have been formed by dust deflated by the wind from the outwash fill in the valley below. The surface of the fill must have been kept bare of vegetation by the periglacial cold climate, by the rapidity of aggradation, or by both factors.

Intra-Wisconsin erosion.--After depositing the early Wisconsin outwash, the Missouri River cut down again, removing nearly all of the fill it had just dropped. Inconclusive evidence suggests that prior to the arrival of the Cary ice, the profile of the Missouri may have been even lower than it is today. The Cretaceous strata forming the floor of the Missouri River trench lie approximately 90 feet below the present normal water level at Chamberlain _/, and although this depth may possibly be reached by scour during rare floods under the present regimen of the river, it probably represents a former lower stream profile. Many of the local tributaries are today incised below a late Wisconsin fill terrace, but appear to be still well above the bedrock floors of their valleys; these relations suggest that prior to the late Wisconsin the profile of the Missouri River was lower than it is today.

_/ Data courtesy of U. S. Army, Corps of Engineers.

It is believed that it was during this time of downcutting that the White River, cut the two terraces shown on the map as being veneered with probably post-Iowan gravel.

Late Wisconsin substages.--The presence of a late-Wisconsin till-equivalent consisting of pebbles scattered on the black soil formed by the weathering of the early Wisconsin loess has been described. No Mankato ice came within 20 miles of the Chamberlain quadrangle (R. F. Flint, manuscript in preparation), so that the late Wisconsin ice that reached the Chamberlain area cannot be other than Cary. The scanty character of the deposits left by it suggests that this Cary ice was thin and carried few stones.

The probable Cary age of the high terraces north and northeast of Oacoma is inferred because their surfaces are nearly flat, showing little evidence of mass-wasting comparable to that which has modified the remnants of the early Wisconsin outwash fill in the trench below, and because they lack any thick loess cover such as occurs on the flat upland areas known to be as old as early Wisconsin. The eroded remnants of the early Wisconsin outwash in the valley show no evidence of recent deep burial, and it cannot be supposed that the high terraces record an accumulation that filled the valley to their level. The presence of till on the riverward flanks of these terraces confirms the conclusion that they are ice-contact deposits formed by a stream that flowed for most of its course over or through ice.

After the Cary ice had melted, the thin brownish loess accumulated on the Cary till-equivalent. This loess has been traced eastward by Flint, who found (personal communication) that it is normally present on the Cary till, and that it passes beneath Mankato drift deposits farther east. It is therefore a late Cary deposit. Its presence argues that Cary outwash was deposited in the Missouri River trench, and supports the inference of a Cary date for one or another of the late fills in the Missouri. The terrace at Chamberlain shown by the symbol (Qwco) appears to be the required Cary outwash: the presence of cobbles and small boulders suggests an outwash origin, but its material is different from the early Wisconsin terrace and its surface is relatively flat and topographically fresh-looking, and appears to rest with angular discordance against the eroded slope of the older and higher fill. Though younger than the early Wisconsin, it was eroded by gullies, eolian sand was accumulated on it, and a humified zone was developed before the deposition of a second eolian sand about 2 feet thick. One of the two eolian sand deposits is probably Mankato, so that the terrace on which they rest is probably Cary.

The probable Mankato terraces in the trench have been described. Although Mankato ice did not reach the Missouri valley at Chamberlain, meltwaters from that ice discharged into that valley at points above Chamberlain, and the river may have been obstructed by ice at points downstream. Both of these causes might lead to the aggradation of a fill at Chamberlain. It is possible that the terraces mapped with the symbol (Qwm) record one or more episodes of filling resulting from climatic fluctuations other than glacial ones, or some of them may be part of the Cary(?) fill, and others may be post-Mankato. Whatever the date (or dates) of the post-Cary aggradation in the trench, the eolian fine sand mantling the gullied surface of the Cary(?) terraces was doubtless blown up during the accumulation of the post-Cary fill.

Since the maximum of the Mankato substage, much of the Mankato(?) outwash fill has been removed from the Missouri River trench, but the tributaries have in general not had time to widen out their valleys after cutting down in response to the downcutting of the master stream.

Economic Geology

The term economic geology as here used is intended to include all the economic applications of geology: not only the study of metallic and nonmetallic mineral deposits of economic value, but also the applications of geology to engineering.

Metallic minerals--manganese

The large total tonnage of manganese contained in the nodules of the DeGrey member of the Pierre shale in the vicinity of Chamberlain has attracted attention to the area as a possible domestic source of this strategic metal for many years (for bibliography, see Pesonen, Tullis, and Zinner, 1949, pp. 88-90). The data in the following description are based on reports (Pesonen, Tullis, and Zinner, 1949, 1949A) of a recent study of these deposits made by the U. S. Bureau of Mines.

Several million tons of metallic manganese are contained in the carbonate nodules, one-half inch to several inches in diameter, within the Chamberlain quadrangle. Much of this material is buried under 100 to perhaps 400 feet of overburden, but perhaps 300,000-500,000 tons could be obtained from outcrops and landslides in dissected areas where the member is exposed, and perhaps three times that amount is present if manganiferous shale under a stripping ratio of about 1/2:1 is included.

Probably 2,000,000-3,000,000 tons are present if manganese disseminated in the shale is included with that contained in the nodules. The possible ore is in general 40 to 50 feet thick, from the top of the DeGrey member as mapped to within a few feet of the top of the calcareous beds of the Crow Creek member. Similar deposits occur for scores of miles up and down the Missouri River, although some of the best deposits appear to be within the Chamberlain quadrangle.

Although the total tonnage of the manganese is large, the grade of these deposits is low. In areas within the Chamberlain quadrangle sampled by the Bureau of Mines, the shale is calculated (Pesonen, Tullis, and Zinner, 1949, pp. 75-77) to contain 4.01 to 5.94 percent of concretions on a dry weight basis. These concretions average 15.10 to 17.43 percent manganese, so that the average tenor is 0.7 to 0.9 percent manganese in the dry shale. The actual tenor of the concretions in the shale as mined will be lowered by the high moisture content of the bentonitic shale. Elsewhere the authors state (1949A, p. 2) that "while the shale contains approximately 1 percent manganese in the form of concretions, much of it contains an equal amount in addition to this that is disseminated throughout the shale". Manganese disseminated in the shale is probably not economically recoverable by methods available at present. In any case, the grade is far below the minimum for economic exploitation under present conditions. Any attempts at production from the exposures and by stripping moderate amounts of overburden would prove expensive: the DeGrey is the most unstable member of the Pierre shale, and cuts would be in constant danger of slides. Furthermore, transportation costs would be high: graveling the miles of access roads that would be required for large-scale exploitation of the far-flung outcrops would be expensive.

The only other metal known to occur in the area in concentrations that might be of economic significance is selenium. This element is sufficiently abundant to affect the growth of plants, and to cause "alkali disease" (selenium poisoning) in animals that eat such plant species as are able to survive in the seleniferous soils. The results of a study of the stratigraphic distribution of selenium in this region have been published by Moxon, Olson, and Searight (1939).

Nonmetallic materials

Nonmetallic materials of economic importance present in the Chamberlain quadrangle include bituminous shale, clay, bentonite, gypsum, limestone, glacial boulders, water, and gravel. Of these, the resources of greatest importance appear to be water and gravel. In addition to the materials mentioned above, almost any of the materials present in the quadrangle are so little consolidated that they can be bulldozed or shoveled up for use as fill without the necessity for blasting. Pierre shale is considered to be poor material for use in fills because of its bentonitic nature and tendency to slide. Till and loess generally provide suitable fill material.

Bituminous shale.--The Sharon Springs member of the Pierre shale contains enough organic matter so that certain outcrops of it have burned; However, it is thin (see p. 5, above), and nearly everywhere its outcrop belt is narrow, the member quickly disappearing under a thick cover. Mining and transportation costs in exploitation of the shale would probably be even higher than in mining the DeGrey member for manganese.

Clay, bentonite, gypsum, limestone, boulders.--Clay develops rapidly from even brief weathering of the poorly consolidated Pierre shale beds above the Sharon Springs member. Bentonitic clays such as these, however, are believed to be of little value for ceramic purposes.

Thin bentonite beds occur at many places throughout the DeGrey member and are common in the other members of the Pierre and in the Niobrara. A 16-inch and a 10-inch bed were seen in one Sharon Springs exposure on the Iona quadrangle, to the south, but no others more than 6 inches thick were observed. These beds appear to be too thin and too distant from markets to be of commercial importance at the present time.

Gypsum is present in beds as much as 2 inches thick in the Niobrara, and as scattered crystals on Pierre shale outcrops. It does not appear to be present in economic quantities.

The Niobrara is a calcareous formation that would produce an impure lime on burning, and was formerly used in the manufacture of Portland cement near Yankton, South Dakota. Marl layers occur in the Gregory member, and the Crow Creek member is calcareous. None of these is sufficiently consolidated to be of use for structural purposes.

Erratic boulders of granite, granite gneiss, limestone, dolomite, and other rock types occur scattered over the mapped area. Many are several feet in diameter and some reach sizes as large as 8 by 9 feet. Because of the inaccessibly great depth of all hard bedrock within hundreds of miles of the area, these boulders may be of some local importance for construction purposes. However, in most places they are so scattered that any attempt to exploit them would probably prove expensive.

Water supplies.--The impermeable character of most of the formations in the Chamberlain area and the low rainfall make water supplies difficult to obtain. Although small amounts are obtained in some places from shallow wells penetrating near-surface formations, and larger amounts of water for stock are obtained by impounding the runoff in small valleys, the principal supplies are obtained from two sources: the Missouri River, and artesian wells penetrating the Dakota sandstone. The Chamberlain water supply, taken from the Missouri, is the softest water for many miles around; because of this the city is the local bottling point for carbonated beverages and is a watering point on the railroad. The artesian water in the Dakota sandstone is very hard, and much of it contains enough iron to form limonite on exposure to the air. The pressure is high enough to provide water for a fire hydrant in Oacoma, and many flowing wells exist in the lower parts of the Missouri River trench; most farms and communities on the upland pump water from the Dakota.

A possible source of water that has been indicated by the present study is the gravel bodies lying in the ancestral White River drainage system. Gravel deposits in the old valley of the White River (Warren, 1953) supply perennial seepage springs over hundreds of linear feet of the outcrop in sec. 19, T. 103 N., R. 71 W. Suitably located wells undoubtedly could tap this source in the area eastward from sec. 19 to Red Lake and possibly northeastward from Red Lake to Pukwana or beyond. Similar water-bearing gravels may possibly be present under American Creek.

Gravel

Gravel suitable for road construction is available at various places within the quadrangle, but there is little or none that would pass rigid specifications for use in concrete aggregate. Three types of deposits occur:

Gravel of the White River.--Gravel brought from the west by the White River in Yarmouth, Illinoian(?), and post-Iowan time are shown on the map. A small quantity of this gravel has been scraped up in sec. 3, T. 103 N., R. 72 W., but these gravels are generally thin, in many places less than a foot thick, and buried under loess; they are of little economic value.

Thicker bodies of White River gravel occur in the Iona quadrangle, south of and adjoining the Chamberlain quadrangle. One, the high gravel at 1,857 feet, in the SW¼ sec. 10, T. 102 N., R. 71 W., has produced many tons of gravel and still contains several thousand cubic yards. A second deposit, of Illinoian age, in the SW¼NW¼ sec. 19, T. 103 N., R. 71 W., reaches a total thickness of about 70 feet of sand and gravel (Warren, 1952, fig. 2), the lower half of which is believed to be largely gravel, though the upper part is almost entirely sand. This deposit contains tens, and probably several hundreds, of thousands of yards of gravel and a comparable amount of sand that is fairly readily accessible to truck transportation, and will be conveniently accessible to barge transportation on the lake that will be formed in the Missouri River trench when the Fort Randall dam is completed. The deposit may extend eastward for several miles under a cover of 120 to 150 feet of Illinoian till and younger deposits.

The pebbles in the White River gravel are hard, largely quartz, sandstone, chert, and perthitic feldspar. The feldspars, and probably also the chert, appear to make the gravel unsuitable for concrete aggregate for large construction projects, but it is excellent for road construction and ballast uses.

Iowan and/or Tazewell gravel.--Four general areas of Iowan and/or Tazewell gravel are mapped: the ice-contact(?) channel filling south of Oacoma, and remnants of the outwash fill at and north of Chamberlain, at and near Oacoma, and 1-1/2 to 3 miles south of Oacoma. In each area, the gravel occurs in patches isolated by local gullies.

These deposits vary considerably in lithology. In a pit northeast of Chamberlain the stones are almost entirely nodules from the Pierre shale, but in most places they are mixtures of such local materials with glacial and some western stones. Some of these deposits are described by Rothrock (1944).

Cary(?) high terrace gravel.--The two ice-contact terraces of probable Cary age constitute the third type of gravel deposit in the area. They consist largely of glacial erratic stones, chiefly granitic and carbonate types, heavily coated with calcium carbonate. A considerable quantity of gravel has been taken from the terrace north of Oacoma, described by Rothrock (1944, p. 100). The similar deposit to the northeast is less accessible and has not been exploited.

Possible reservoir leakage through channel deposits of the ancestral White River

The White River gravel, which reaches a thickness of 70 feet in sec. 19, T. 103 N., R. 71 W. (p. 35, above), occupies the valley in which the White River was flowing at the time the Illinoian ice advanced up it and caused the diversion that created the Missouri. The existence of such a valley has long been known (cf. Flint, 1949), but information gained during the present study has shown that it is much deeper than had been supposed. Though this valley lies south of the Chamberlain quadrangle, a tributary valley extends eastward from Chamberlain, probably joining the main valley in the vicinity of Pukwana.

The greatest depth to which the old channel is known to have been cut is approximately 1,433 feet above sea level (Warren, 1953, fig. 2). The actual bottom of the valley may be a few feet deeper but probably does not go below 1,400 feet. It thus appears to be safely above the presently projected maximum water level (1,375 feet) of the reservoir behind the Fort Randall dam, now under construction. If any higher dam is projected in the future in this area, however, the danger of leakage through this channel should be considered, as the gravel is highly permeable. Such leakage would not necessarily occur, for the eastern end of the channel in northern Aurora County (Flint, 1949, fig. 1) or some other part of it may be sealed off by till, but the possibility exists and should be kept in mind.

Mass-wasting movements

The abundance of landslides in the Chamberlain quadrangle causes difficulties in assuring stable foundations for highways, bridges, railroads, and buildings, and requires special consideration in planning all types of construction. Because of the prevalence of landslides, it seems desirable to make some general comments concerning the factors that govern mass-wasting movements.

Mass movements are caused by one or more changes that affect slope stability. These changes are an increased load, a decrease in strength of soil or bedrock, a decrease in friction, and a less favorable stress distribution. The change in stress distribution might result from steepening a slope, from excavation at the toe of a slope, or from removal of some external support of part of the load. Lateral erosion by running water probably is the most common cause of natural excavation at toes of slopes. This sets up an unequal stress distribution that ultimately is balanced by downslope movement of material.

Many slope failures occur during or shortly after a rainfall. The movement can be attributed chiefly to an increase in pore-water pressure, which decreases the shearing resistance of the material. The added water also increases the weight of a unit mass and thereby might destroy its equilibrium. Under certain conditions, and in some materials, the added moisture might act as a lubricant.

It is essentially impossible to locate a road or highway that crosses the Missouri River trench which does not cross a wide belt of landslide material. In general, it seems advisable to cross such a belt at its narrowest point, if this can be done without appreciably lengthening the highway. It is evident that if a highway is greatly lengthened in order to bypass a landslide area, the increased cost might be far greater than the cost of maintaining the highway through the unstable area.

Where a wide belt of landslide material is crossed, excavations should be kept to a minimum in order to avoid reactuation of dormant landslides. It generally is advisable to build on fill on lower slopes as much as possible rather than to make extensive excavations; cuts generally are safer near the tops of slopes than at the toes. Adequate drainage should be provided for cuts and fills alike so as to prevent undue amount of precipitation from soaking into the soil. Any deep cuts made in the Pierre shale for highway or railroad grades should be opened out to wide angles to prevent possible landsliding onto the grade.

Landslides in the Pierre shale are chiefly of the slump variety in which movement generally occurs as a backward rotation of the block on a more or less horizontal axis parallel to the slope from which the slump block is derived. The surface of movement is typically spoon-shaped, and the mass initially moves as a unit-block with little or no internal deformation. Where a slump in shale is started or reactuated by excavation at its toe, the slump might be stabilized by a replacement of the excavated toe, plus a safety factor of perhaps 10 to 20 percent of the original volume excavated. Along with this remedy, open cracks should be filled and sodded over to prevent infiltration of water along the zone or surface of movement. This remedy involves nothing more than an attempt to re-establish conditions that existed prior to movement. The sooner such a remedy is applied after initial slump movement, the better will be the chance of permanent stabilization.

At some places it might be necessary to stabilize a slump by removing material from the landslide itself so as not to disturb the alignment of a highway. If this treatment is used, it is important to understand that material removed from the toe of a slide serves only to speed the rate of movement and decreases overall stability; excavation of the upper part of the slump, on the other hand, will slow the rate of movement and probably will effectively stabilize the slump if sufficient material is removed. This remedy has a serious drawback: removal of toe support from material behind the slump might cause upslope recession of the scarp. For this reason, head excavation generally should be accompanied by grading the slope behind the slump scarp to a ratio known to be stable for the material involved.

Mass-wasting movements in glacial drift generally take the form of debris-slides, in which the mass becomes internally disturbed as it moves downward. Remedies for this type of failure include retaining walls, if the mass involved is not large and if a suitable stable foundation can be obtained for the wall, and excavation of the debris-slide material.

Where the soil and subsoil become saturated with an undue amount of water, slope failure may occur as flowage. This type of failure is fairly common in till and occurs locally in the Pierre shale where the shale is overlain by a weathered mantle of cracked and granular gumbo. When a large amount of water is added to this gumbo, a viscous mass is formed that will flow downslope if in a suitable topographic situation. The only practical remedy for this type of slope failure is to excavate the resulting deposit.

A rise in the water table may cause a decrease in slope stability in some materials. The rise of the water table will be accompanied by an increase in pore-water pressure to the point at which existing slopes may be thrown out of equilibrium. Likewise, a sudden drop of the water table, such as might occur by appreciably lowering the level of a reservoir over a short period, decreases slope stability by leaving saturated masses of material standing on slopes no longer partly supported by the water.

In this regard, it seems advisable to point out the possibility of landsliding of the west edge of the terrace on which Chamberlain is situated. This terrace is underlain by fine to medium sand, silt, and clay, in which there are lenses of coarse sand and pebble gravel. In anticipation of the closure of the Fort Randall dam, the edge of this terrace has been cut back to slopes ranging from about 1 on 2 to 1 on 2.5, and covered with a blanket of riprap to retard wave erosion. The rise of the water table that will accompany creation of the reservoir, and the occasional drawdowns that probably will occur after the reservoir has been filled, conceivably could cause sliding of large masses of the terrace deposit into the reservoir. A somewhat similar situation exists along the reservoir walls of Lake Franklin D. Roosevelt behind Grand Coulee Dam in the State of Washington. At many places along the shoreline there have been large-scale landslides since creation of the lake.

Before the probability, or even the possibility, of landsliding at Chamberlain can be accurately predicted, exhaustive tests should be made of the natural properties of the materials in the terrace deposit.

Measurements of existing stable slope angles in undisturbed Pierre shale in the Chamberlain quadrangle indicates that angles as high as 40 degrees in the Gregory member and as high as 50 degrees in the Verendrye member are stable. Because of its susceptibility to sliding, slopes on artificial cuts in the DeGrey member probably should not exceed 25 degrees. Except for some minor slumping, natural slope angles on the Niobrara formation as high as 90 degrees are stable. Slopes approaching the vertical in till appear to be stable except for sloughing off of small masses of several cubic yards or less. The angle of cuts in gravel deposits are determined by the angle of repose of the material, which generally ranges from 25 to 35 degrees. Deposits of sand and silt, such as that on which the town of Chamberlain is situated, stand at what appear to be stable slopes as high as 90 degrees where undercut by the Missouri River. Doubtless if the river were not continually trimming the base of such slopes, they would soon flatten out to a much lower angle because of an accumulation of slopewash at the toe.

Although not specifically related to mass-wasting movements, the presence of wet zones at contacts between some of the map units should be noted. Springs and seeps locally occur at the contact of the Sharon Springs member and the Niobrara formation, and also at the contact of outwash sand and gravel deposits and the Pierre shale. Where a highway or railroad grade is located at or near one of these contacts, special care should be taken to allow free drainage away from the grade. Where possible, such locations should be avoided so as to prevent possible costly maintenance operations.

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APPENDIX

Map designation of unit tested	Iowan (and Tazewell?) till		Illinoian till	
Location	NE$\frac{1}{4}$ sec. 22, T. 104 N., R. 71 W.	NW$\frac{1}{4}$ sec. 11, T. 104 N., R. 71 W.	NE$\frac{1}{4}$ sec. 22, T. 104 N., R. 71 W.	NW$\frac{1}{4}$ sec. 11, T. 104 N., R. 71 W.
Classification (Allen) HRB	A-7-6(15)	A-6(10)	A-7-6(13)	A-7-6(14)
% Pass. 3/8 Sieve	100	100	100	100
% Pass. No. 4 Sieve	98.3	97.3	99.0	100
% Pass. No. 10 Sieve	96.7	95.0	97.0	97.3
% Pass. No. 40 Sieve	90.7	88.5	89.0	89.3
% Pass. No. 200 Sieve	73.9	70.1	69.6	62.5
Sand Content	30.1	35.4	36.1	36.2
Silt Content	28.2	32.4	26.4	26.5
Clay Content	38.4	27.2	34.5	34.6
Lower Liquid Limit	46.9	36.4	44.5	46.0
Plasticity Index	25.4	16.3	23.7	26.3
Field Moisture Equivalent	22.8	21.0	21.9	21.9
Centrifuge Moisture	60.4	21.9	59.1	53.9
Shrinkage Limit	16.5	18.1	16.3	17.5
Shrinkage Ratio	1.88	1.86	1.88	1.85
Volume Change	11.7	5.39	10.6	8.1
Specific Gravity	2.73	2.80	2.72	2.74
Lb./Cu. Ft. Dry Loose	74.1	71.1	75.6	75.9

These data were determined by the Soils Laboratory of the South Dakota State Highway Commission from samples submitted by the junior author. The test analyses were run according to A.S.T.M. Standard Specifications.

APPENDIX

Map designation of unit tested Location	Cary(?) outwash deposits $SE\frac{1}{4}NE\frac{1}{4}$ sec. 16, T. 104 N., R. 71 W.*					
Depth, Ft.	1,347-1,350	1,350-1,353	1,353-1,356	1,356-1,359	1,359-1,362	1,362-1,365
Textural Classification	Clay	Clay	Clay	Clay	Clay	Clay foam
Classification (Allen) HRB	A-7-6-(19)	A-7-6-(19)	A-7-6(13)	A-7-6(15)	A-7-6(20)	A-6(7)
% Pass. 3/8 Sieve	100	100	100	100	100	99.0
% Pass. No. 4 Sieve	100	100	99.7	100	100	98.7
% Pass. No. 10 Sieve	100	100	98.3	99.0	100	96.7
% Pass. No. 40 Sieve	98.0	98.0	95.5	87.1	96.8	89.5
% Pass. No. 200 Sieve	91.8	94.8	80.4	78.2	87.0	62.6
Sand Content	19.6	13.6	29.1	25.4	29.6	38.3
Silt Content	37.6	41.6	33.0	39.2	33.6	36.4
Clay Content	42.8	44.8	36.2	34.4	36.8	22.0
Lower Liquid Limit	52.7	56.9	42.8	46.1	58.6	33.5
Plasticity Index	31.7	33.5	23.6	25.0	37.1	14.8
Field Moisture Equivalent	23.6	27.6	23.1	24.2	26.4	21.6
Centrifuge Moisture	49.2	59.0	25.4	33.3	40.1	17.0
Shrinkage Limit	15.7	14.8	16.0	17.1	15.8	17.9
Shrinkage Ratio	1.89	1.94	1.88	1.89	1.92	1.82
Volume Change	14.8	24.8	13.4	13.5	20.4	6.7
Specific Gravity	2.69	2.73	2.70	2.79	2.76	2.70
Lb./Cu. Ft. Dry Loose	72.0	77.7	75.0	72.9	70.8	77.7

*Samples were taken from west edge of terrace, about 200 yards downstream from the highway bridge across the Missouri River. Samples were collected from 3 foot vertical channels from 1,347 to 1,365 above sea level.