Bentonite Deposits in Marine Cretaceous Formations, Hardin District, Montana and Wyoming

GEOLOGICAL SURVEY BULLETIN 1023

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By MAXWELL M. KNECHTEL *and* SAM H. PATTERSON

With a section on

LABORATORY PROCEDURES USED FOR TESTING THE BENTONITES

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BENTONITE DEPOSITS IN MARINE CRETACEOUS FORMATIONS OF THE HARDIN DISTRICT, MONTANA AND WYOMING

By Maxwell M. Knechtel and Sam H. Patterson

ABSTRACT

The bentonite deposits described in this report, which are roughly and tentatively estimated to include a minable reserve of 110 million short tons of montmorillonitic clay, are shown on a geologic map covering approximately 1,280 square miles, mostly in the Crow Indian Reservation, Big Horn County, Mont., but extending a short distance southward into Sheridan County, Wyo. Bentonite has been mined in recent years from two small workings in Sheridan County, one of which is north of Gay Creek and the other near West Pass Creek; the clay has been processed within the district in a plant at Aberdeen Siding, Mont., a shipping point on the Chicago, Burlington and Quincy Railroad.

The bentonite beds of minable thickness are interspersed among strata belonging to Cretaceous formations ranging from the Thermopolis shale to the Bearpaw shale. Two beds in the Cody shale and two other beds in the Bearpaw shale are extremely thick locally; these, and a number of other beds, are favorably situated for mining along some parts of their outcrops.

Primarily, the beds are described with reference to their location, stratigraphic positions, thicknesses, geologic structural relations, accessibility and content of material that might be suitable for industrial use. Also outlined are the laboratory procedures employed in testing samples of the bentonite as molding-sand bonding materials for use by foundries and as ingredients of rotary oil well drilling muds.

INTRODUCTION

LOCATION AND FIELD WORK

Extensive deposits of bentonite, a valuable rock material consisting essentially of clay derived from alteration of volcanic ash, are present in the Cretaceous sedimentary rocks of the western interior of the United States. A field and laboratory investigation of such bentonite deposits in several parts of the Missouri basin lying in Montana, Wyoming and South Dakota, has been carried on intermittently since 1946 by the U. S. Geological Survey. Results of part of the work accomplished are embodied in the present report. The senior author has supervised the geologic field and office work since its inception, and the junior author has taken an active part in all phases of the work since 1947. Participation by other workers, including members of the U. S. Geological Survey, the Illinois Geological Survey and the University of Wyoming Natural Resources Research Institute, is acknowledged at appropriate places in the report.

Unusually thick beds of bentonite crop out in the plains that skirt the northeast flank of the Big Horn Mountains in Montana and Wyoming. A segment of the belt of exposed Cretaceous rocks, in which these beds occur, is referred to in this report as the "Hardin district." It includes a large part of the tract of land described by Richards and Rogers (1951) as the "Hardin area." The segment thus designated parallels the base of the mountain range and lies mostly in the Crow Indian Reservation, in Big Horn County, Mont., but it extends for a short distance into the adjacent part of Wyoming (fig. 1).

Large deposits of bentonite are present in the Hardin district at many sites where mining may be feasible; some of these deposits contain clay that appears to be suitable for industrial uses. Because the bentonite deposits are of interest to the clay industry, to the Bureau of Reclamation, and to the Bureau of Indian Affairs, the deposits within the somewhat arbitrarily limited tract mapped on plate 1 have been the subject of a study by the Geological Survey as a part of the program of the Department of the Interior for development of the natural resources of the Missouri River basin. This tract comprises about 1,280 square miles in Big Horn County, Mont., and about 8 square miles in Sheridan County, Wyo.

The Hardin district is crossed by the Chicago, Burlington & Quincy Railroad and by U. S. Highway 87, and most of the bentonite outcrops may be reached by motor vehicles over secondary roads and trails. Hardin, the seat of Big Horn County, is the largest town and the principal railroad shipping point in the area studied and its immediate vicinity; smaller centers of population farther south along the railroad are Crow Agency, Lodge Grass, and Wyola; St. Xavier, another such center, can be reached by a hard-surfaced road that leads south from Hardin.

In studying the bentonite deposits of the Hardin district, where in recent years a small tonnage has been mined by stripping, attention has been given primarily to their stratigraphic positions, thicknesses, geologic structural relations, accessibility, and content of material suitable for industrial uses. Most of the samples and detailed measurements of the beds referred to in this report were obtained by hand-boring with a 2-inch earth auger; some were obtained by trenching.

ACKNOWLEDGMENTS

Field mapping of the bentonite deposits in relation to the geology, stream patterns, and cultural features was performed directly on aerial photographs. The work was then transferred to a map pre-

pared from township plats of the U. S. Bureau of Land Management, supplemented by planetable work by the Geological Survey and by land-survey data obtained from the Hardin, Mont., offices of the Agricultural Conservation Association, the County Engineer of Big

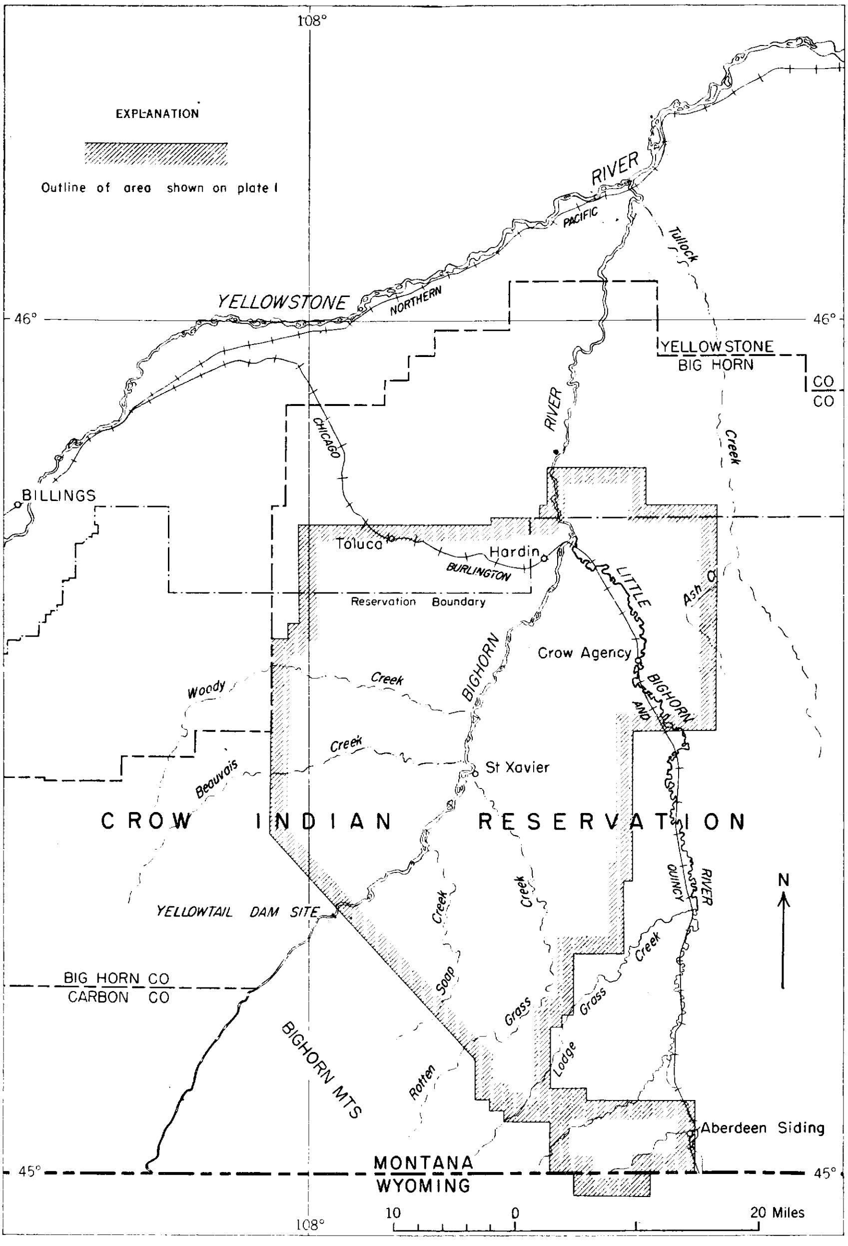

FIGURE 1.—Index map showing location of area mapped in the Hardin district, Montana and Wyoming.

Horn County, and the State Water Resources Survey Office in Billings, Mont.

A preliminary field study of this district was made in 1946 in the course of a regional reconnaissance of bentonite deposits by M. M. Knechtel, who was assisted by I. G. Sohn. S. H. Patterson measured and sampled the bentonite beds in the late summer and autumn of 1947 and mapped the southern and northeastern extremities of the district in the summer of 1948 and autumn of 1951. W. A. Cobban studied the stratigraphy of the distict in relation to the bentonite beds during the latter part of the summer of 1947; detailed sections measured by Cobban at that time, together with his paleontologic determinations, are presented in this report in the chapters dealing with the stratigraphy of the bentonite-bearing formations. A geologic map (Richards and Rogers, 1951), prepared by a party of the Geological Survey that was assigned concurrently to study the oil and gas possibilities of the Hardin district, has been utilized in the preparation of plate 1.

The physical properties, whereby the usefulness of bentonites is judged, were investigated in the laboratory by Mr. Patterson at Urbana, Ill., in 1948 and 1949. The results relating to samples from the Hardin district are given in table 1 and are discussed at appropriate places in this report; the testing procedures employed are described by him in the final section. The authors are indebted for generous cooperation in this phase of the work to several members of the Illinois Geological Survey, including M. M. Leighton, chief of that organization, who placed its facilities and experience at our disposal; R. E. Grim, petrographer and head of the section of Clay Resources and Clay Technology, who contributed much invaluable guidance, counsel, and advice relative to testing procedures and interpretation of results; and W. A. White, geologist, who gave helpful counsel on clay-study techniques.

GEOLOGY

SURFICIAL FEATURES

The Hardin district is situated in moderately dissected plains that slope gently downward in a northeasterly direction from the foot of the Big Horn Mountains. The bedrock that underlies the district is largely concealed: (1) by deposits of alluvium, of late Tertiary(?) and Quaternary origin, on steplike terraces that represent a number of successive stages in the sculpturing of the land surface of the district; and (2) by rather extensive Quaternary and Recent alluvial deposits on the flood plains of Bighorn River and its larger tributaries. The classification of the various terraces, whose upper surfaces (pl. 1) are coextensive with the deposits of Tertiary(?) and Quaternary age, is explained by Richards and Rogers (1951) as follows:

> Six main levels of stream terraces, ranging in height from 10 to 650 feet above the Bighorn River, occur in the plains area. The terraces along the Bighorn River are designated on the map by numbers from 1 to 6 according to their height above the river, and terraces along the tributary streams are correlated with them. Each terrace has been mapped as a surface, and its boundary line on the map represents the approximate outline of the top of the terrace.
>
> The terrace designated Qt 1, which is the lowest and youngest level, forms most of the valley floors in the area. The top of its streamward edge is commonly about 10 feet above the flood plain in the valley of the Bighorn River, but locally the Qt 1 terrace merges into the alluvial flood plain (Qal). Although Qt 1 is mapped as a separate surface in the Bighorn Valley, it is included in the Quaternary alluvium (Qal) in all other valleys. This lowest terrace is a composite surface consisting of many small terrace surfaces left by the stream as it swung laterally at the time it was in the process of forming the terrace. The surface of the terrace has a pronounced riverward slope that is accentuated by alluvial-fan material deposited on it by intermittent tributary streams.
>
> Terrace Qt 2, which forms the top of the 125-foot bluffs along the Bighorn River, and terrace Tt 5, which forms the highest benches southwest of Hardin, are the most extensive erosion surfaces above the valley floor surface. Terraces Qt 3 and Qt 4 are well preserved west of the Bighorn River west of St. Xavier but are represented only by small remnants elsewhere. The Tt 6 terrace occurs only in the area north of the mouth of the Bighorn Canyon, although a few high terraces along the Bighorn-Little Bighorn River divide may represent the same level. Some local surfaces which do not correspond in elevation to any of the main levels have been mapped separately and, depending on whether they are higher or lower than the nearest principal terrace level, are designated by a minus or plus sign.

BENTONITE-BEARING FORMATIONS

The rocks associated with the beds of bentonite that are exposed in this district are stratified sedimentary deposits belonging to formations that range in age from Early Cretaceous to Late Cretaceous (fig. 2). They tend to be exposed chiefly along the marginal escarpments of terraces and in the valleys of minor streams. A generalized composite columnar section of these formations, giving the stratigraphic positions of the principal bentonite beds, is shown on plate 2; more complete descriptions appear below and on following pages.

The bentonite-bearing formations, with an aggregate thickness of about 4,400 feet, are made up almost entirely of fine-grained sedimentary material; about one-half is shale, about two-fifths is sandy shale, and the remainder is sandstone and calcareous shale in about equal amounts. The rock materials associated with the bentonite deposits are thus predominantly argillaceous, but they grade westward and southward into stratigraphically equivalent strata of a more sandy facies. The various stratigraphic units to which the exposed rocks are assigned crop out in relatively narrow belts (pl. 1), each of which

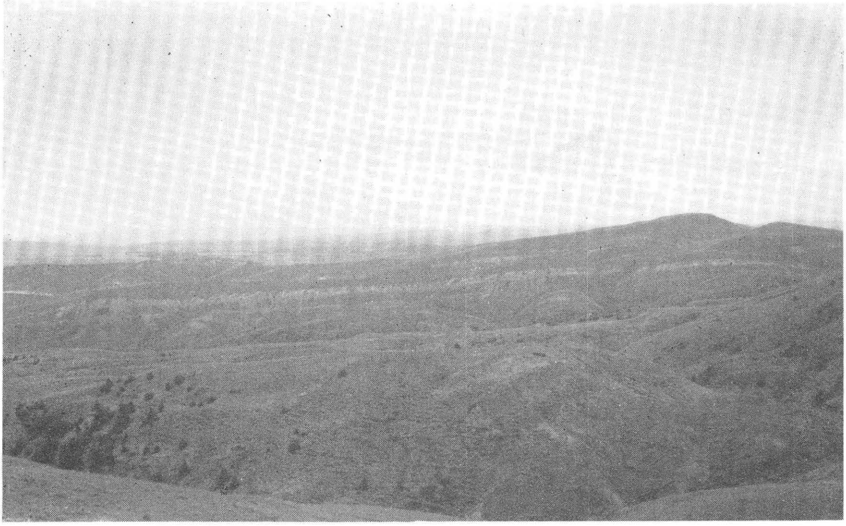

FIGURE 2.—View northeastward from point in sec. 23, T. 9 S., R. 34 E., southeast of Little Bighorn River. Low, rounded hill in foreground consists of Mowry shale; escarpment beyond has Clay Spur bentonite bed at base and shows several higher bentonite beds, most prominent of which (long, white band) is Soap Creek bentonite bed.

trends, in any given neighborhood, approximately in the direction of strike, as indicated by structure contours.

Within the Missouri River Basin, the bentonite contained in the Thermopolis shale and the Mowry shale is, in general, superior in quality to that contained in the younger Cretaceous formations. This is true with respect particularly to viscosity, thixotropy, and dilatancy (swelling capacity)—three of the properties of bentonites that are of value in the preparation of rotary well-drilling fluids. That this generalization holds true for the Hardin district is indicated by the data in table 1 (in pocket) relating to bentonite beds in the Thermopolis shale and the Mowry shale as compared with the data on beds in the Cody shale and the Bearpaw shale.

LOWER CRETACEOUS SERIES

The Lower Cretaceous series within this district comprises three formations. From oldest to youngest these are the Cloverly formation, Thermopolis shale, and Mowry shale. The Lower Cretaceous series thus includes younger strata than were assigned to it on earlier maps of this district, including a map by W. T. Thom and others (1935), which showed only the Cloverly as Lower Cretaceous, and a map by Richards and Rogers (1951), on which only the Cloverly and Thermopolis were so designated. Paleontologic data recently adduced by Cobban and Reeside (1951) indicate that the Mowry shale is likewise Lower Cretaceous. However, the Early Cretaceous age assignment of the Mowry is questioned by Yen (1954).

The Lower Cretaceous strata of the Hardin district include many beds of bentonite, and some of the material of these beds is believed to be comparable in its physical properties to much of the high-grade drilling clay that is mined from the Mowry shale in the Black Hills district. Because of its unfavorable structural and topographic relations, however, the bentonite in the Thermopolis and Mowry strata of the Hardin district would be difficult to mine.

CLOVERLY FORMATION

The Cloverly formation is the lowermost Cretaceous stratigraphic unit present in the Hardin district. The following generalized description of this formation is given by Richards and Rogers (1951):

> Generalized section: In Limekiln Gulch and Grapevine Creek areas, north and south respectively of the mouth of the Big Horn River Canyon, the Cloverly formation consists of a lowermost 125 to 150 feet of conglomeratic sandstone and sandstone (Pryor conglomerate member) overlain by about 50 feet of mostly concealed variegated beds and an upper 40 feet of interbedded shale, siltstone, and sandstone beds which include 'rusty beds'; topmost thin calcareous sandstone bed forms low ridges in covered areas . . . A few miles farther south, near head of Soap Creek, the Pryor conglomerate is missing . . . At Soap Creek dome the basal Cloverly sandstone is only 20 to 30 feet thick and is underlain by black and red shales of the Morrison formation.

Richards and Rogers also note that:

> A thick lenticular zone of bentonite and bentonitic shale in the undifferentiated Cloverly and Morrison formations is exposed north of Rotten Grass Creek in the central part of sec. 1, T. 8 S., R. 32 E.

The Cloverly dips steeply at most of its exposures in the Hardin district and is not advantageously situated for strip mining; consequently, its lithologic features have not been examined as closely as those of overlying formations during the study of the bentonite deposits of this district.

THERMOPOLIS SHALE

The Thermopolis shale, which rests on the Cloverly formation, consists chiefly of dark-gray shale with abundant ferruginous concretions. At Soap Creek dome, where the thickness of the Thermopolis is 468 feet, the shale of the lowermost 110 feet, below a sandstone that is correlated with the Birdhead sandstone, is almost wholly dark-gray and fissile; the shale higher in the formation, which is lighter in color and which tends to weather to dark-gray gumbo, contains many beds of bentonite; four of these have thicknesses of 2 feet or more. A few small sandstone dikes are present just below the middle of the formation. Fossils are scarce, though the upper part of the Thermopolis contains a small undescribed invertebrate fauna. The Thermopolis shale was formerly regarded as Late Cretaceous in age, but it is now considered to be Early Cretaceous.

The laboratory test results shown in table 1 indicate that some of the bentonite of beds *A*, *B*, *C*, and *D* in the Thermopolis shale might be suitable for industrial use. However, these beds offer no sites favorable for strip mining anywhere in the Hardin district. The Thermopolis shows the following sequence of strata where it was measured and sampled in the escarpment carved from steeply upturned beds on the east flank of the Soap Creek dome, in the southeastern part of T. 6 S., R. 32 E. Units are numbered in descending sequence.

Rock Material	*Feet*	*Inches*
1. Shale, dark-gray, soft, fissile; contains a few hard, thin, ripple-marked siltstone layers	16	0
Ammonite		
2. Shale, dark-gray, soft, fissile; contains ferruginous concretions that weather purplish black to maroon	16	6
Inoceramus sp.		
Ammonites		
3. Shale, dark-gray, soft, fissile; contains near top a 1-in. hard, fossiliferous ferruginous layer consisting largely of tiny calcite prisms derived from *Inoceramus*	37	0
Cardium? sp.		
Entolium? sp.		
Inoceramus sp.		
Ostrea sp.		
Pteria, n. sp. aff. *P. nebrascensis* (Evans and Shumard)		
Gastropod		
Fragments of ammonites		
Fish scales		
4. Shale, dark-gray; contains three bentonite beds, 1 to 9 in. thick	3	8
5. Shale, dark-gray; contains a few hard, shaly siltstone beds	9	0
6. Bentonite, olive-yellow; weathers to gray ledge (bed *D*)	3	8
7. Shale, dark-gray, fissile, soft; upper part contains selenite crystals	4	6
8. Shale, dark-gray; some parts bentonitic; contains ferruginous concretions that weather purplish and dark brown and contain fish teeth and bones	32	0
Carcharias macrota (Agassiz),		
Lamna appendiculata Agassiz,		
Lepidotus sp.		
9. Bentonite, grayish-green, upper half is bentonitic shale (bed *C*)	3	0
10. Shale, dark-gray; some parts bentonitic; contains silty and sandy streaks and a few ferruginous concretions	30	0
Inoceramus sp.		
11. Bentonite, olive-yellow	1	2
12. Shale, dark-gray; contains silty and sandy streaks and, in lower third, ferruginous concretions	41	6
13. Shale, dark-gray, bentonitic; contains silty partings and at top a bed containing prominent dark ironstone concretions	13	0

Rock Material	*Feet*	*Inches*
14. Bentonite, olive-green; weathers to bare, light-gray gumbo ledge (bed *B*)	4	2
15. Shale, dark-gray, bentonitic; contains numerous ferruginous concretions and light-gray-weathering claystone nodules	31	0
16. Bentonite, olive-yellow to olive-green; weathers to prominent, bare, light-gray gumbo ledge (bed *A*)	3	10
17. Shale, dark-gray, soft and fissile to chunky and bentonitic; contains light-gray-weathering claystone nodules and at least six beds containing prominent dark ironstone concretions. Unit is cut by sandstone dikes	80	0
18. Bentonite, creamy-gray	1	0
19. Shale, dark-gray	2	0
20. Bentonite, gray; weathers to conspicuous, bare, light-gray gumbo ledge	1	9
21. Shale, dark-gray, bentonitic; contains small ironstone concretions near top; weathers brownish	7	6
Turtle bones undetermined		
Reptile teeth and bones		
Hybodus cf. *clarkensis*		
22. Sandstone, gray and tan, very fine grained, soft and argillaceous (Birdhead?)	1	6
23. Bentonite and bentonitic shale, olive-green to gray and brownish	3	6
24. Shale, dark-gray, bentonitic; weathers brownish gray; in middle contains ferruginous concretions and light-gray claystone nodules	15	6
25. Shale, dark-gray, fissile; contains ironstone concretions that weather purplish black	50	0
26. Shale, dark-gray; contains distantly-spaced ferruginous concretions, some of which contain teeth and bones of fish and black-coated phosphatic pebbles	--	6
27. Shale, dark-gray, fissile	8	3
28. Bentonite: cream		5
29. Shale, dark-gray, fissile; contains two brown ferruginous layers	13	4
30. Shale, dark-gray, fissile; contains lenses composed of gypsum, sandstone, limonite, fish teeth, and tiny black phosphatic pebbles	--	5
31. Shale, dark-gray, fissile; contains a few ferruginous layers, ironstone concretions, sandy partings and, rarely, fish scales; (base of formation)	37	6
Total measured thickness	473	2

MOWRY SHALE

The Mowry shale, a formation of widespread occurrence in Montana, Wyoming, and the western part of the Dakotas, crops out at several localities in the Hardin district. At Soap Creek dome, where the Mowry is approximately 400 feet thick and forms a prominent hogback, it consists of hard gray sandy shale, dark-gray, hard siliceous shale, and many beds of bentonite; in many localities the middle and upper parts of the formation contain thin-bedded, fine-grained gray sandstone. Scales and bones of fish, which occur at various horizons, are the only abundant fossils. Until recently the Mowry was regarded as belonging to the Upper Cretaceous series.

Bentonite beds *E*, *F*, *G*, and a bed believed to be the Clay Spur bentonite bed, crop out at a number of localities in the Hardin district and were measured at exposures among steeply upturned Mowry beds on the east side of the Soap Creek dome. The bed believed to be the Clay Spur bed occurs just below the top of the Mowry shale at, or near, a stratigraphic position correlative with that of the Clay Spur bed at its type locality in the Black Hills district, where it is extensively mined. In the Hardin district this bed, and the rocks immediately above and below it, closely resemble the Clay Spur and associated beds of many outcrops on the north side of the Black Hills. Some of the laboratory tests indicate that much of the bentonite of exposures of the Clay Spur bed in the Hardin district is suitable for industrial use; this is true also of beds *E*, *F*, and *G*. However, the bentonite beds of the Mowry are not known to crop out here under conditions favorable for strip mining. The following detailed section of the Mowry was measured on the east side of the Soap Creek dome, in the southeastern part of T. 6 S., R. 32 E. Units are numbered in descending sequence.

Rock Material	*Feet*	*Inches*
1. Sandstone and shale, interbedded: shale is gray and hard (top of formation)	3	6
2. Bentonite, lower 5 ft cream yellow; remainder is gray; weathers to very light gray bare gumbo (Clay Spur bentonite bed)	9	10
3. Shale, dark-gray, hard; contains thin, hard, laminated sandstone	8	9
4. Shale, dark-gray, hard, somewhat hackly; forms dark-bluish-gray bare outcrop	25	0
5. Sandstone and shale; shale is gray, very fine grained, and hard and is interlaminated and interbedded with thin-bedded ripple-marked sandstone; shale contains fish scales	42	0
6. Bentonite, greenish-yellow grading up into gray (bed *G*)	2	8
7. Shale, dark-gray, hard; softer than underlying beds and forms back slope of hogback	32	0
8. Shale, weathers light gray, hard; forms crest of Mowry hogback	21	0
9. Bentonite, light-gray; contains a siltstone parting in lower part (bed *F*)	9	9
10. Shale; weathers light gray, hard; in lower part contains a 4-in. and a 6-in. bentonite bed	30	0
11. Bentonite, light-green	2	0
12. Siltstone and shale interbedded and interlaminated; weathers light gray, hard. Several thin bentonite beds in lower 50 ft. Some interbedded fine-grained sandstone in upper 45 ft	110	0
13. Bentonite, yellow	2	0
14. Shale, dark-gray, silty; contains two thin bentonite beds	6	0

Rock Material	*Feet*	*Inches*
15. Bentonite, creamy-yellow and light-green	1	0
16. Shale, dark-gray, silty. Five thin bentonite beds in upper part	29	0
17. Bentonite, chiefly greenish	2	8
18. Shale, dark-gray, silty; interlaminated with lighter gray, hard siltstone and very fine-grained sandstone	13	0
19. Bentonite, creamy-gray	1	0
20. Shale, dark-gray, hard; contains fish scales; weathers to dark, bare, steep slope	38	0
21. Bentonite, gray	--	4
22. Shale, dark-gray, hard, fissile; contains fish scales; weathers to silvery-gray bare ledge	5	6
23. Bentonite, gray to greenish-gray (bed *E*)	4	8
24. Shale, dark-gray, hard, fissile; contains fish scales (base of formation)	--	8
Total measured thickness	400	4

UPPER CRETACEOUS SERIES

All the bedrock strata younger than the Mowry shale that crop out within the area studied are assigned to four formations of the Upper Cretaceous series. These formations—from oldest to youngest—are the Cody shale, Judith River formation, Bearpaw shale, and Hell Creek formation; all of these, except the Hell Creek formation, are included in the Colorado and Montana groups. In other parts of the western interior of the United States (fig. 3) and on previously published maps of this area (Thom and others, 1935; Richards and Rogers, 1951), the Colorado and Montana groups are separated, in accordance with established usage, by the contact between beds equivalent to the Niobrara formation and those of the next-younger stratigraphic unit. The separation in the area studied is accordingly made at the contact of the Niobrara shale member of the Cody shale with the overlying Telegraph Creek member. The definitions of the formations and lesser subdivisions of the Colorado and Montana groups of this district have, however, been modified considerably, in part on the basis of information gathered in studying the bentonite deposits of this and other areas in Montana, Wyoming, and South Dakota.

On the whole, the changes that have been effected are believed to represent steps toward a satisfactory adjustment of the local terminology to that of equivalent rocks of other parts of the western interior of the United States. Concerning the general character and interrelations of the Upper Cretaceous sedimentary rocks of that region, Reeside (1944) has commented:

In general, the Upper Cretaceous sediments in this region comprise an alternation of coarser- and finer-grained rocks, all marine in the east but including progressively more nonmarine rocks and more coarse material westward.

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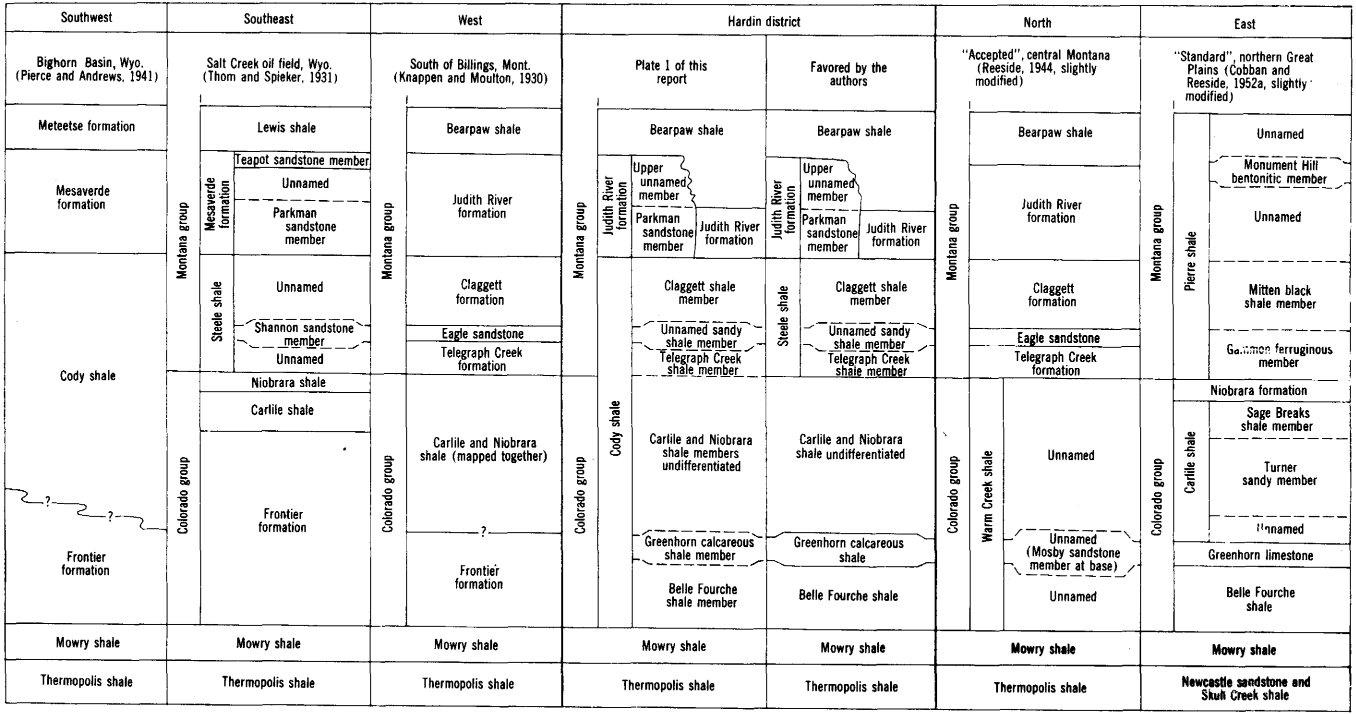

FIGURE 3.—Stratigraphic nomenclature employed on plate 1 and nomenclature favored by the authors; shown in relation to that of other parts of the western interior region of the United States.

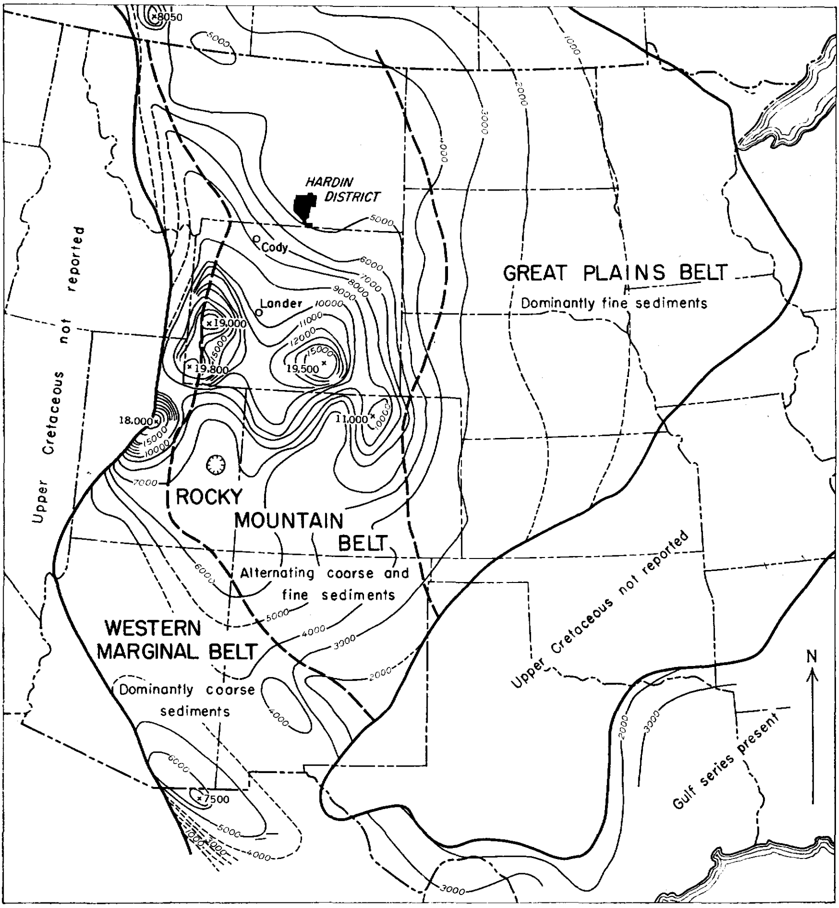

FIGURE 4.—Belts and thicknesses of Upper Cretaceous deposits of the western interior region of the United States.

In figure 4, which is adapted from one of Reeside's maps, the large basin in which sedimentation took place in the western interior of the United States during much of Late Cretaceous time is shown as divisible, somewhat arbitrarily, into three great belts: (1) the Great Plains belt, which is characterized by "dominantly fine sediments," (2) the Rocky Mountain belt, where "alternating coarse and fine sediments" predominate, and (3) the western marginal belt, where the sedimentary rocks are "dominantly coarse."

However, the transition from the lithologic facies characteristic of the Great Plains belt to that of the western marginal belt takes place

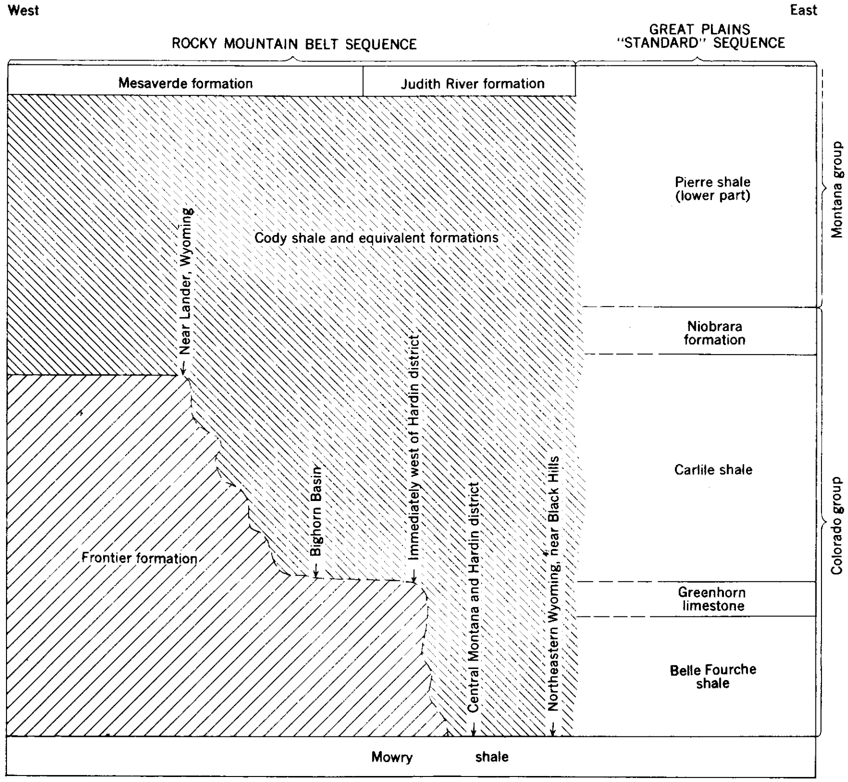

FIGURE 5.—Schematic diagram showing position of facies at top of Frontier formation in different parts of Rocky Mountain belt in relation to "standard" sequence of Great Plains belt.

in an irregular manner, and the sequences of stratigraphic units recognizable within the Upper Cretaceous series of the western interior differ from one another markedly, not only from one belt to another but also from place to place within each belt. In the Hardin district, which lies in the central part of the Rocky Mountain belt (fig. 4), the newly recognized sequence of subdivisions of the Colorado and Montana groups (fig. 3, col. 4) bears far more resemblance to the "standard" sequence cited by Reeside for the Great Plains belt (fig. 3, col. 7) than to the sequence he cited as representative of the equivalent stratigraphic interval in west-central Utah, within the western marginal belt (Reeside, 1944). Within surrounding parts of the Rocky Mountain belt, the corresponding sequences in areas to the southeast (fig. 3, col. 2) and north (fig. 3, col. 6) have more in common with the sequence in the Hardin district than does that of the Bighorn basin (fig. 3, col. 1), the northeast margin of which lies only 60 miles southwest.

Among the significant circumstances leading to the changes in local nomenclature is the predominance (fig. 3, cols. 4 and 5) of shaly materials in beds equivalent to the typical, prominent, readily mappable, cliff-forming sandstone strata of the Frontier and Eagle formations that are present only a few miles farther west (fig. 3, col. 3). As a consequence, the names "Frontier" and "Eagle," which appear on the maps published by Thom and others (1935), Richards and Rogers (1951), and Knechtel and Patterson (1952), have been eliminated from the nomenclature adopted for use in the present report, and the strata that were designated Frontier formation are assigned to the Belle Fourche member of the Cody shale. The Cody is now set up in this district as a formation that includes all of the units between the Mowry shale and the Judith River formation. Two other innovations are the recognition of the Greenhorn calcareous member as a mappable unit within this district and the introduction of the name "Judith River formation" to include, as members, the Parkman sandstone member and an unnamed overlying unit.

Elimination of the name "Frontier" in the Hardin district, as well as in central Montana and near the Black Hills, is consistent with the practice whereby the top of the interval to which this name refers is mapped at different stratigraphic horizons in different parts of the western interior region. Near Lander, Wyo., for example (fig. 5), the uppermost strata of the Frontier formation include sandstone beds containing fossils of lower Niobrara age (Sharkey, 1946), whereas, farther east, in the Wind River Basin (Hares, 1946) and in the Salt Creek oil field, the top of the Frontier forms the top of sandstone strata equivalent to beds within the Carlile member of the Cody formation. In the area immediately west of the Hardin district (Knappen and Moulton, 1930) the top of the Frontier is placed approximately at the top of sandstone beds that are correlated with the upper part of the Greenhorn calcareous member (fig. 3, cols. 3 and 4). In effect, elimination of the name "Frontier" as applied to the Hardin district may be regarded as placing the top of the formation at the lowest possible position, making it coincide with the top of the Mowry shale and thus reducing the thickness of the Frontier formation to zero.

The reasons for eliminating the name "Eagle sandstone" for strata in the upper part of the Cody formation and for introducing the name "Judith River" for younger beds are fundamentally the same reasons as those justifying elimination of the name "Frontier" and introduction of the name "Greenhorn calcareous member". All of these changes in the local nomenclature have to do with lateral variations in lithologic facies within the Cretaceous rocks of this region.

Thus, the local rocks that were formerly called Eagle sandstone (now assigned to an unnamed sandy shale member of the upper part of the Cody) represent a shaly facies of strata that elsewhere in central Montana include the thick, massive sandstone beds that are typical of the Eagle sandstone. In a similar manner the sandy beds in the southern part of the district, which heretofore have been mapped as part of the Bearpaw shale (Thom and others, 1935) and which are now assigned to the upper member of the Judith River formation, are equivalent to the dark shales in the lower and middle parts of the Bearpaw of the neighborhood of the Custer battlefield and localities farther north.

Following are three other changes in the local nomenclature that have not been adopted by the Geological Survey, although they are favored by the authors: (1) Elimination of the name "Cody shale"; (2) introduction of the name "Steele shale" to designate a formation containing the three members of the Cody (Telegraph Creek member, "unnamed member," and Claggett member) that fall within the Montana group; and (3) promotion to formation rank of each of the three members of the Cody (Belle Fourche member, Greenhorn member, and Carlile-Niobrara member) that are included in the Colorado group.

Elimination of the name "Cody shale" from the local terminology would, in the authors' opinion, be consistent with the contrast in lithologic facies that exists between the Frontier-and-Cody sequence of the Bighorn Basin of Wyoming and the corresponding six units—Belle Fourche, Greenhorn, Carlile–Niobrara, Telegraph Creek, unnamed, and Claggett—that are mapped as Cody shale on plate 1. This change, and the other changes that are favored, would serve to eliminate a feature of the nomenclature employed in this report whereby a group—the Colorado group—is represented as containing only part of a single formation—the Cody shale; the nomenclature would then clearly and unquestionably conform to the rule by which a group "contains two or more formations (Ashley and others, 1933, p. 429)."

The marine Cretaceous strata of the Hardin district contain many beds of bentonite (pl. 2). Locally, these beds are exceedingly thick, contain much bentonite that appears to be suitable for use as sand-bonding clay by foundries and steel works, and are so situated in relation to geologic structure and topographic features that they offer excellent strip-mining sites. The results of many laboratory tests indicate, however, that little, or none, of the material at such sites is as well suited for use in rotary well-drilling muds as is the bentonite mined for that purpose from the Mowry shale of the Black Hills district.

COLORADO GROUP

The base of the Colorado group was mapped by Thom and others (1935) at the contact between the Cloverly formation and the Thermopolis shale. As already pointed out, however, the Thermopolis and Mowry beds have come to be regarded in recent years as Lower Cretaceous, whereas the Colorado group is still generally understood to include only Upper Cretaceous rocks. Therefore, the Geological Survey's classification has recently been modified to exclude the Thermopolis and Mowry beds from the Colorado group.

The Colorado group, as mapped on plate 1, comprises the lowermost three of the six members of the Cody shale that are recognized in the Hardin district. As shown in figure 3, the sequence of three of these members—Belle Fourche, Greenhorn, and Carlile-Niobrara—is essentially equivalent to the sequence of strata between the Mowry shale and the Pierre shale in the vicinity of the Black Hills (fig. 3, col. 7), to the Frontier and Carlile-Niobrara sequence of the Salt Creek oil field (fig. 3, col. 2), to the Frontier formation plus the lower part of the Cody shale of the Bighorn Basin (fig. 3, col. 1), and to the Warm Creek shale of central Montana (fig. 3, col 6).

LOWER PART OF THE CODY SHALE

Belle Fourche shale member.—The strata that are mapped on plate 1 as Belle Fourche member of the Cody formation occupy essentially the same stratigraphic position as the Belle Fourche shale of the east side of the Powder River Basin and as the part of the Warm Creek shale that underlies the Mosby sandstone of north-central Montana. In their stratigraphic position the Belle Fourche strata are equivalent also to rocks, consisting in part of conspicuous cliff-forming sandstone beds, that are included in the Frontier formation of areas not far west (fig. 3, col. 3) and southeast (fig. 3, col. 2) of the Hardin district; in fact, heretofore the rocks of this interval have, in part, been designated Frontier formation in publications dealing with this district (Thom and others, 1935; Richards and Rogers, 1951; Knechtel and Patterson, 1952). Unlike the typical Frontier strata, however, they consist almost wholly of shale, although a few obscure beds and lenses of sandy material are discernible upon close examination of some outcrops in the southeastern part of the district. Consequently, the entire interval between the Mowry formation and the Greenhorn member is shown on plate 1 as the Belle Fourche member. As already pointed out, the thickness of the Frontier is thereby, in effect, reduced to zero for this district, as well as for central Montana and northeastern Wyoming (fig. 5).

At the Soap Creek dome, the Belle Fourche member consists of three subdivisions, but the differences between these subdivisions are somewhat vaguely defined. The lowermost subdivision, which is 82 feet thick, consists of dark-gray shale, some of which is sandy with ferruginous concretions. The intermediate subdivision, the top of which is arbitrarily placed at the top of a thick bentonite layer (referred to in this report as the Soap Creek bentonite bed), is approximately 200 feet thick and consists of dark-gray shale, some of which is sandy, with several intercalated beds of bentonite. The uppermost subdivision, which is approximately 190 feet thick, consists of dark-gray shale, the basal 60 feet of which includes sandy beds; the top is marked by the base of bentonite bed *M*. In the equivalent part of the Belle Fourche member in the southern part of the Hardin district, sandy beds are also readily discernible, though these are much less prominent than Cobban and Reeside (1952b, p. 1960) seem to imply in characterizing 25 feet of strata, including such beds, collectively as a "massive bed of sandstone." The aggregate amount of sandy material in the shaly strata of the lower part of the upper subdivision is here much greater than the sand content in any comparable thick sequence of Belle Fourche strata exposed elsewhere within this district; but, even here, these shaly strata, together with those of the underlying subdivisions, which also contain a small amount of sandy material, bear only a remote resemblance to the massive, cliff-forming sandstone beds of the typical facies of the Frontier formation. In the field studies leading to the present report, mapping of the top of these sand-bearing shale strata has proved impracticable, and, as they are no more sandy than some of the typical beds of the Belle Fourche member in the vicinity of the Black Hills, they are mapped (pl. 1) as part of the Belle Fourche member of the Cody shale.

Such sandy beds are not present at Woody Creek dome, 20 miles north of Soap Creek, where the uppermost subdivision of the Belle Fourche consists of dark-gray, fissile shale containing several layers of bentonite with many beds of gray- and brown-weathering calcareous concretions. According to Cobban and Reeside (1952b, p. 1960), the uppermost member of the Belle Fourche of this district contains, in its lower part, the large acanthoceratid ammonite that is found in the Torchlight sandstone member of the Frontier in areas farther west and southwest, and it contains, in its middle part, the ammonites *Dunveganoceras pondi* Haas and *Mantelliceras canitaurinum* Haas. The uppermost subdivision of the Belle Fourche was included by Thom and others (1935, p. 49–51) in the basal part of the Carlile shale, notwithstanding the presence in the overlying deposits of fossils equivalent in age to those of the Greenhorn.

Bentonite bed *I* is in the lower subdivision of the Belle Fourche member, between 12 and 25 feet stratigraphically above the Clay Spur bentonite bed. Weathered outcrops of bed *I* are characteristically rusty in color, apparently from oxidation of a small amount of iron contained in the bentonite. Bed *J*, higher in that subdivision, ranges

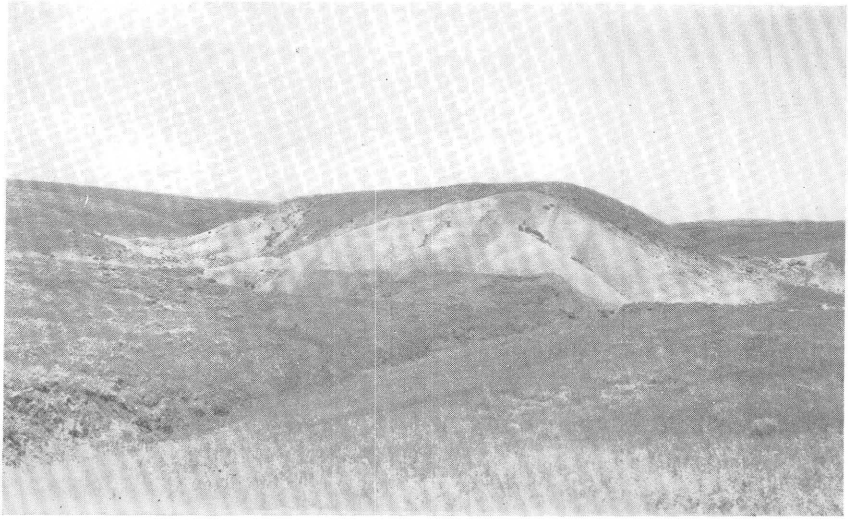

FIGURE 6.—Soap Creek bentonite bed locally thickened by flowage, in NW¼ sec. 31, T. 7 S., R. 33 E.

from about 3 to 7 feet in thickness and forms a narrow outcrop that can be traced for considerable distances, as shown on plate 1. Beds *I* and *J* are known to be present under thin overburden in only a few small areas.

The thick Soap Creek bentonite bed contains a large part of the bentonite reserve of the district and is the only bed that has been mined here to date. This bed marks the top of the medial subdivision of the Belle Fourche. Buff calcareous concretions, 3 to 10 feet in diameter, are commonly strewn along weathered surfaces of this bed and are particularly abundant in the southern part of the area shown on plate 1. Parts of the Soap Creek bentonite deposit consist of material that is suitable for use in preparing drilling muds, and nearly all of it is believed to have the properties of good foundry sand bonding clay. The Soap Creek bed ranges from 12 to more than 30 feet in thickness in much of the area it occupies, and large tonnages are accessible to strip mining. Forty-five feet of bentonite was measured at point 37, sec. 31, T. 7 S., R. 33 E., but the thickness of the bed there has been augmented by flowage of bentonite into a small dome (fig. 6), which is associated with a minor fault; another measurement of the Soap Creek bed, obtained less than a mile away, shows 16 feet of bentonite, which is believed to represent approximately the average thickness in the neighborhood of the dome. It is possible that several such unusually thick sections reflect subsurface flowage or swelling of the bentonite at the outcrop.

Bentonite bed *L*, in the uppermost subdivision of the Belle Fourche, is relatively thick, contains a large amount of bentonite under light overburden, and has utilizable properties; in general, however, it is not as accessible as other beds and appears to be of secondary importance.

The following section of the Belle Fourche member was measured in the southeastern part of T. 6 S., R. 32 E., on the east side of the Soap Creek dome. Units are numbered in descending sequence.

Rock Material	*Feet*	*Inches*
1. Bentonite, gray, impure (bed *M* in base of Greenhorn calcareous member)	7	9
2. Shale, dark-gray (top of Belle Fourche member)	19	0
3. Shale, dark-gray; contains three beds of light-gray and buff-weathering calcareous concretions, septariate with dark-brown calcite	20	0
4. Shale, dark-gray	37	0
5. Shale, dark-gray; with concretions, light-gray-weathering, calcareous, septariate, distantly-spaced	1	0
6. Shale, dark-gray	28	0
7. Shale, gray, bentonitic	18	0
8. Bentonite, gray; contains brown-weathering fibrous aragonite 21 in. above base; weathers to gray, bare, gumbo ledge (bed *L*)	7	0
9. Shale, dark-gray; contains very fine-grained sandy streaks	19	6
10. Shale, dark-gray, with concretions commonly measuring 1½ by 3 ft; brown-weathering, calcareous, septariate with white to pale-yellow calcite veins	1	6
11. Shale, dark-gray; contains fine-grained sandy streaks and, rarely, thin sandstone beds and black chert pebbles. Locally at base a thin friable coarse-grained sandstone is present	40	0
Acanthoceras? sp.		
12. Bentonite, greenish-yellow to gray; weathers to prominent, bare, light-gray gumbo ledge. (Soap Creek bentonite bed)	12	0
13. Shale, dark-gray, sandy, bentonitic; contains gray-weathering calcareous concretions and fewer, but much larger (as large as 4 by 8 ft), brown-weathering calcareous concretions	10	6
Acanthoceras? amphibolum Morrow		
14. Shale, dark-gray; contains sandy streaks and a few thin beds of shaly sandstone, particularly 15 to 20 ft above base	73	0
Inoceramus sp.		
15. Bentonite, gray	1	0
16. Shale, dark-gray; contains some sandy streaks and a few beds of bentonite less than 5 in. thick	67	0
17. Bentonite, light-gray to green; weathers to prominent, bare, light-gray gumbo ledge (bed *J*)	6	11
18. Shale, dark-gray; contains some sandy streaks and a 6-in. bentonite bed	31	0
19. Shale, dark-gray; contains some silty streaks and five or six beds containing ironstone concretions that are commonly 6 by 24 in., weathering dark brown to dark maroon	64	0
20. Bentonite, green to gray with limonitic streaks staining lower 18 in. to rusty color (bed *I*)	5	0

Rock Material	Feet	Inches
21. Shale, dark-gray, bentonitic; contains three bentonite beds, none thicker than 8 in. Two beds contain ferruginous concretions	7	6
22. Bentonite, gray; contains much brown-weathering aragonite	1	6
23. Shale, dark-gray; lower half sandy	2	0
24. Bentonite, grayish-green; contains brown-weathering aragonite	2	0
Total measured thickness	482	2

Greenhorn calcareous member.—Rocks that are equivalent to the Greenhorn formation of the east side of the Rocky Mountain belt form a mappable unit in the Hardin district. This unit, which was treated by Thom and others (1935) as an undifferentiated part of the Carlile shale, has been mapped on plate 1 as the Greenhorn calcareous member of the Cody formation.

The Greenhorn in this area generally is readily distinguishable from the overlying and underlying strata by its larger lime content. However, it is much less calcareous than correlatives of the Greenhorn east of the Powder River Basin, where the Greenhorn formation contains beds of limestone and marl. The Greenhorn of the Hardin district is similar in lithology to beds of equivalent age forming the part of the Warm Creek shale immediately above the Mosby sandstone of areas farther north in Montana. A few miles west of this district, the material of the Greenhorn unit passes laterally into strata, including conspicuous sandstone units, that are mapped by Knappen and Moulton (1930, pl. 1) as the upper beds of the Frontier formation.

The Greenhorn of the Hardin district consists of dark-gray calcareous shale that weathers whitish. At Soap Creek, light-gray limestone concretions are numerous in the Greenhorn, and these concretions contain an invertebrate fauna that is characterized by the ammonite *Vascoceras*. Although a thick zone of bentonitic shale is present in the base, only a few thin layers of pure bentonite are present in the Greenhorn member of that vicinity. About 1 mile farther south, the basal zone is represented by a thick bed of bentonite; near Rotten Grass Creek, this bentonite bed is more than 20 feet thick, and at Black Gulch dome it is about 25 feet thick. The Greenhorn calcareous member is approximately 60 feet thick on Black Gulch dome, and it is 115 feet thick at Soap Creek. A bentonite bed, designated as bed *M*, crops out locally at the base of the Greenhorn. At some localities its thickness is as great as 33 feet, and large amounts of the bentonite it contains are accessible to strip mining. However, in much of the area of outcrop of the Greenhorn, bed *M* is absent or is represented only by bentonitic shale. The bentonitic material of bed *M* varies greatly in quality, but some of it possibly could be used as molding-sand bonding clay in foundries and steel works.

The following section of the Greenhorn calcareous member was measured on the east side of Soap Creek dome in the southeastern part of T. 6 S., R. 32 E. Units are numbered in descending sequence.

Rock Material	*Feet*	*Inches*
1. Shale, dark-gray, weathering bluish and then white, calcareous; contains a few limestone concretions 5 ft above base	28	0
2. Shale, dark-gray, with concretions; medium-gray, weathering light gray to buff, calcareous	1	0
3. Shale, dark-gray, weathering bluish and then white, calcareous	28	0
4. Shale, dark-gray; with medium-gray concretions, weathering light gray to buff, calcareous, commonly 9 by 12 in.; some are somewhat geodal with calcite crystal-lined cavities	1	0
Inoceramus labiatus Schlotheim		
sp.		
Ostrea n. sp.		
Plicatula? sp.		
Gastropod undet.		
Allocriceras		
Psuedoaspidoceras? sp.		
Pseudotissotia (*Choffaticeras*) sp.?		
Scaphites delicatulus Warren var.		
Vascoceras moultoni Reeside		
stantoni Reeside		
thomi Reeside		
Watinoceras reesidei Warren		
Schloenbachia? sp.		
Fish bones		
5. Shale: dark-gray, weathering bluish and then white, calcareous	38	0
6. Bentonite: gray, limonitic	1	0
7. Shale, dark-gray	10	0
8. Bentonite, gray, impure (bed *M*)	7	9
Total measured thickness	114	9

Carlile-Niobrara shale member.—The strata in the Hardin district that belong to the Carlile-Niobrara member of the Cody shale are, as a rule, readily distinguishable from older and younger rocks. Locally, the Carlile and Niobrara portions of the member are separable from each other in mapping, but the contact between them cannot everywhere be mapped satisfactorily. Following a precedent set by Thom and others (1935, pl. 1), they are shown on plate 1 as a single unit, which is referred to as "Carlile and Niobrara shale members, undifferentiated." In the present report, the composite subdivision is defined as resting on the Greenhorn member, whereas the undifferentiated Carlile and Niobrara, as mapped by those authors, included all of the Greenhorn beds and the uppermost beds of the Belle Fourche member.

The Carlile shale member in the Hardin district comprises four lithologic units with a total thickness of approximately 280 feet. The lowest unit consists of about 95 feet of dark-gray sandy shale with two beds of bentonite, each 2 to 3 feet thick, in the upper part. This sandy shale is overlain by about 25 feet of dark-gray shale containing numerous flat clay-ironstone concretions that weather rusty to dark maroon-brown. About 30 feet of gray sandy shale makes up the third unit. The top unit consists of approximately 130 feet of dark-gray shale containing many beds of gray-weathering calcerous concretions that are septariate with thick veins of dark-brown calcite.

Fossils are rare in the lower two units and none that have been found are diagnostic. The 30-foot gray sandy shale unit contains *Prionocyclus wyomingensis* Meek and *Inoceramus perplexus* Whitfield. The top unit is poorly fossiliferous, but contains fragments of *Prionocyclus* and other fossils of Carlile age.

Bentonite beds *N* and *O* are in the lower part of the Carlile member. These beds are known only at the locality at which the stratigraphic measurements given below were recorded and are believed to be of little importance.

The following section of the Carlile shale member was measured on the east side of Soap Creek dome in the southeastern part of T. 6 S., R. 32 E. Units are numbered in descending sequence.

Rock Material	*Feet*	*Inches*
1. Shale, dark-gray; readily breaks down into soft, light-gray soil; contains two beds of light-gray-weathering calcareous concretions, septariate with yellow and dark-brown calcite veins	13	6
2. Shale, dark-gray; contains fragments of large thin-shelled *Inoceramus* encrusted with *Ostrea congesta* Conrad	3	6
3. Shale, dark-gray; readily breaks down into soft, light-gray soil; contains calcareous septariate concretions that weather light gray to yellowish tan	3	6
Inoceramus sp.		
4. Shale, dark-gray, weathering light gray	15	0
Inoceramus sp.		
Ostrea congesta Conrad		
5. Septarian zone: Large calcareous concretions weathering light gray or buff, and septariate with thin yellow calcite veins; embedded in dark shale	5	0
Inoceramus sp.		
6. Shale, dark-gray; forms a dark, bare outcrop, with local alkali patches and selenite crystals; contains thin sandy streaks, particularly in the middle, and a few calcareous septariate concretions	33	6
Inoceramus sp.		
"*Martesia*" sp.		
Ostrea sp.		
Veniella sp.		
7. Shale, dark-gray; at base and top contains light-gray-weathering calcareous concretions septariate with thick, dark-brown and yellow calcite	7	0
Inoceramus sp.		
Nucula sp.		
Prionocyclus sp.		

Rock material	*Feet*	*Inches*
7. Shale—Continued		
Septariate concretions, 16 ft above yellowish-tan-weathering concretions of unit 8 at Soap Creek, yielded the following fauna:		
"*Corbula*" n. sp.		
Inoceramus n. sp.		
Nucula sp.		
Yoldia sp.		
Turritella aff. T. *whitei* Stanton		
Dentalium sp.		
Baculites n. sp.		
Scaphites n. sp.		
Reeside identified the following additional fossils collected by Thom's party, probably from this bed as well as from the yellowish-tan concretions below:		
Anomia sp.		
Barbatia, sp.		
Callista tenuis Hall and Meek		
Nemodon n. sp.		
Gyrodes cf G. conradi Meek		
aff. *G. petrosa* (Morton)		
Turritella n. sp.		
8. Shale, dark-gray; some beds weather light gray. In middle part it contains closely spaced calcareous septariate concretions that weather light gray to yellowish tan	14	3
"*Martesia*" sp.		
Veniella cf V. goniophora Meek		
Placenticeras stantoni Hyatt		
Driftwood		
9. Shale, dark-gray, with large, yellowish-tan-weathering calcareous concretions, commonly 1½ by 3 ft to 3 by 6 ft, septariate with thick, dark-brown and yellow calcite veins. Fossiliferous. (Base of Niobrara member—Thom and others, 1935)	4	6
"*Corbula*" n. sp.		
Crassatellites cf. *C. reesidei* Sidwell		
Inoceramus altus Meek and Hayden?		
Veniella cf. *V. goniophora* Meek		
Tritonium? cf. *T. kanabense* Stanton		
Gastropods indt.		
Baculites n. sp.		
Placenticeras stantoni Hyatt		
Scaphites n. spp.		
10. Shale, dark-gray; contains light-gray-weathering calcareous concretions, septariate with dark-brown calcite veins. In middle part it contains a bed with larger septarian concretions that weather yellowish tan	28	6
Membraniporina sp.		
Inoceramus flaccidus White		
n. spp.		
Nucula sp.		
Ostrea sp.		
Baculites n. sp.		
Prionocyclus wyomingensis Meek		
Scaphites n. sp.		

Rock material	*Feet*	*Inches*
11. Shale, dark-gray with thin gray sandy streaks; readily weathers to soft, gray soil	30	0
12. Conglomerate, composed of light-gray-weathering pebbles of clayey siltstone, commonly ½ in., but some as much as 3 in. long, that either lie in dark shale or form pebble bands of yellowish-tan-weathering calcareous concretions	--	4
13. Shale, dark-gray; contains some thin sandy streaks and 10 layers or more of very hard gray ironstone concretions that weather bright rusty orange and dark maroon brown. The concretions average from 12 in. to 15 in. and 2 in. to 3 in. in their longest and shortest dimensions, respectively, and are abundant. Some layers contain bright-tan-weathering clayey nodules	25	0
Inoceramus sp.		
Scaphites sp.		
14. Shale, dark-gray; contains sandy streaks	6	5
15. Bentonite, gray	--	6
16. Shale, dark-gray; contains sandy streaks	25	6
17. Bentonite, gray, olive at base (bed *O*)	3	2
18. Sandstone and shale, in thin beds	3	9
19. Bentonite, chiefly greenish gray (bed *N*)	3	1
20. Shale, dark-gray; contains very fine-grained sandy streaks	55	0
Inoceramus sp.		
Prionocyclus sp.		
Total measured thickness	281	0

The Niobrara shale member of the Cody shale of this district consists of approximately 410 feet of dark-gray shale with many beds containing gray-weathering calcareous concretions and numerous thin layers of bentonite. A 9-foot bed of calcareous shale is present 75 feet above the base of the formation.

Fossils are common in some of the concretions. The lower 75 feet of the formation contains *Inoceramus deformis* Meek. The overlying 335 feet contains *Baculites codyensis* Reeside and *Scaphites vermiformis* Meek and Hayden.

Bentonite beds *P* and *Q* crop out in the northwestern part of the area mapped on plate 1.

The following section of the Niobrara member was measured along the bluffs on the east bank of Bighorn River, starting 5 miles south of Hardin in the E½NE¼SE½ sec. 15, T. 2 S., R. 33 E., and extending northeastward to the center of the north line of the NE¼ sec. 1, and thence northward to the NE¼NE¼ sec. 25, T. 1 S., R. 34 E., 1 mile southeast of Hardin. Units are numebered in descending sequence.

Rock material	Feet	Inches
1. Shale, dark-gray; contains very fine grained sandy streaks and gray-weathering calcareous concretions. Few fossils	32	0
Inoceramus n. sp.		
Ostrea sp.		
Pteria aff. P. *nebrascana* (Evans and Shumard)		
Baculites codyensis Reeside		
Scaphites vermiformis Meek		
2. Shale, dark; contains small gray-weathering calcareous concretions and four thin bentonite beds	18	0
3. Bentonite, gray with efflorescent alkali	--	4
4. Shale, dark-gray	2	0
5. Shale, dark-gray; contains small, rusty ironstone concretions	1	0
6. Shale, dark-gray	10	7
7. Shale, dark-gray; contains three 1½-in. bentonite beds and a bed of calcareous concretions	7	9
8. Shale, dark-gray; contains about 12 very thin bentonite beds, commonly with aragonite	31	8
9. Bentonite, gray, streaked with yellow	--	4
10. Shale, dark-gray; contains two very thin bentonite beds	13	6
11. Shale, dark-gray; contains some crushed fossils	18	6
12. Shale, dark-gray; contains four bentonite beds 1 to 3 in. thick	20	7
13. Shale, dark-gray; contains a few crushed fossils	9	6
Inoceramus spp.		
Baculites codyensis Reeside		
Scaphites vermiformis Meek		
14. Bentonite and aragonite, gray	--	4
15. Shale, dark-gray; contains a few ripple-marked, sandy layers in lower part	19	0
16. Bentonite, gray; contains distantly spaced lenticular calcareous concretions commonly measuring 4 by 36 in	--	1
17. Shale, dark-gray	6	9
18. Shale; contains concretions, gray-weathering, calcareous, distantly spaced, commonly measuring 6 by 18 in	--	6
19. Shale, dark-gray	7	9
20. Bentonite, gray	--	9
21. Shale, dark-gray	23	3
22. Bentonite, gray, finely micaceous	2	0
23. Shale, dark-gray	8	5
24. Bentonite, gray	--	6
25. Shale, dark	1	1
26. Bentonite, gray and orange	--	4
27. Shale, dark	3	8
28. Bentonite, gray, finely micaceous	1	6
29. Shale, dark	1	0
30. Bentonite, gray, finely micaceous	1	0
31. Shale, dark-gray; contains six bentonite beds, 1 to 6 in. thick	21	2
Inoceramus sp.		
32. Shale, dark-gray; with concretions, light-gray-weathering, calcareous, commonly 8 by 18 in	--	8
Anomia n. sp.		
Inoceramus sp.		
Ostrea sp.		
Baculites n. sp.		

Rock material	*Feet*	*Inches*
33. Shale, dark-gray, faintly calcareous; contains crushed fossils	9	0
Inoceramus spp.		
Ostrea n. sp.		
Baculites codyensis Reeside		
n. sp.		
Pelecypods indt.		
34. Shale, gray; contains concretions, light-gray-weathering, calcareous, commonly 1 by 2 ft, distantly-spaced	1	0
35. Bentonite, gray, finely micaceous	1	0
36. Shale, dark-gray, slightly calcareous	10	6
Inoceramus sp.		
37. Shale, dark gray; contains concretions, light-gray-weathering, calcareous, septariate, closely-spaced	--	6
38. Shale, dark-gray; lower part slightly calcareous; contains crushed fossils	29	0
Inoceramus sp.		
Ostrea congesta Conrad		
Baculites n. sp.		
Fish scales		
39. Bentonite, gray, micaceous	--	6
40. Shale, dark-gray, calcareous; contains crushed fossils; forms conspicuous yellowish-cream soil that supports greasewood on east side of Bighorn River from locality near Hardin southward to at least as far as Rotten Grass Creek	9	2
Inoceramus sp.		
Ostrea congesta Conrad		
Veniella? sp.		
Baculites n. sp.		
Scaphites sp.		
Fish scales		
41. Shale, dark-gray, slightly calcareous; contains two 1-in. bentonite beds	7	8
42. Shale, dark-gray; shows yellow surfaces	4	0
43. Bentonite, gray with rusty spots	--	5
44. Shale, dark	1	3
45. Bentonite, greenish	--	6
46. Shale, dark	1	7
47. Bentonite, gray	--	6
48. Shale, dark-gray; contains two thin bentonite beds	13	0
49. Shale, gray, bentonitic; contains distantly-spaced, large, buff-weathering calcareous concretions	--	5
50. Bentonite, light-gray	--	5
51. Shale, dark	4	6
52. Bentonite, gray	--	3
53. Shale, dark	1	6
54. Bentonite, gray	--	6
55. Shale, dark-gray; contains scattered biotite flakes	11	0
Inoceramus sp.		
Ostrea congesta Conrad		
56. Bentonite, gray to greenish-gray, finely micaceous; contains large, elongated, light-gray limestone concretions that weather buff	1	6
Inoceramus sp.		

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Rock material	Feet	Inches
57. Shale, dark-gray, faintly calcareous	2	6
58. Bentonite, greenish-gray	--	1
59. Shale, dark-gray; contains biotite	--	6
60. Bentonite, greenish-gray; weathers very light gray; with efflorescent alkali	1	0
61. Shale, dark-gray; 1-ft. layer in middle is calcareous; contains a few sandy streaks in lower part and four thin bentonite beds in upper 3 ft	7	4
Inoceramus sp.		
Ostrea congesta Conrad		
62. Concretions, calcareous, weather light gray, as large as 1½ by 2 ft., embedded in shale. Concretions contain large *Inoceramus*	1	6
Inoceramus deformis Meek		
Ostrea n. sp.		
Baculites n. sp.		
n. sp. aff. *B. codyensis* Reeside		
Scaphites sp.		
Nautiloid		
Gastropod		
63. Shale, dark-gray; contains sandy streaks in middle	10	0
Inoceramus deformis Meek		
n. sp.		
Baculites n. sp.		
Echinoid spines		
64. Shale, dark-gray; contains very fine grained sandy streaks	8	9
65. Bentonite, gray, shaly, micaceous; with concretions, light gray, weathering buff, calcareous	1	3
Inoceramus deformis Meek		
Baculites n. sp.		
Scaphites n. sp.		
Gastropods indt.		
Total measured thickness	408	1

MONTANA GROUP

UPPER PART OF THE CODY SHALE

The Montana group, as mapped on plate 1, comprises the uppermost three members of the Cody shale and two overlying formations, the Judith River formation and the Bearpaw shale. The Montana group, as thus constituted, appears to occupy very nearly the same stratigraphic interval as the Pierre shale; it is possible, however, that the uppermost part of the Bearpaw, as here mapped, may in part be stratigraphically equivalent to the Fox Hills sandstone, which overlies the Pierre in the vicinity of the Black Hills.

In the lower part of the Montana group, between the Niobrara and Judith River units, are strata composed predominantly of shale, which are divisible, in some parts of the Hardin district, into three lithologic units. From the Montana-Wyoming boundary northward as far as the mouth of the Little Bighorn River (pl. 1), these strata are mapped as a single unit of member rank that forms the uppermost part of the Cody shale; in the area east of Hardin, these three lithologic units are shown separately as (1) the Telegraph Creek member of the Cody; (2) an overlying unnamed shale member equivalent to the Eagle sandstone; and (3) the Claggett shale member, forming the top of the Cody.

The strata in the interval between the Niobrara shale member and the Judith River formation, as mapped on plate 1, occupy the same stratigraphic position as the Steele shale of areas farther southeast along the margin of the Powder River Basin (Wegemann, 1918, p. 13; Thom and Spieker, 1931, table 4). On the east side of that basin, near the Black Hills (fig. 3, col. 7), the beds of the lower part of the same interval are known as the Gammon ferruginous member and those of the upper part are known as the Mitten black shale member of the Pierre shale. A few miles west of the Hardin district the rocks of this interval pass laterally into strata among which are the prominent cliff-forming beds of the Eagle sandstone.

Telegraph Creek member.—This member, which is largely buff-weathering sandy shale, measures 867 feet in thickness where it is exposed along the Little Bighorn River near Hardin; Telegraph Creek, the intermittent stream from which the member derives its name, crosses U. S. Highway 87 about 15 miles west of Hardin. Fossils, which are scarce, are marine forms of early Montana age. The only deposit of bentonite known to occur in the Telegraph Creek beds of this district is about 3 feet thick and crops out a few hundred yards in a northerly direction from the southeast corner of T. 1 N., R. 33 E. This bentonite contains a good deal of sand and shaly material. It is not represented on plate 1.

Unnamed sandy shale member.—An unnamed member, with a thickness of about 375 feet (east of Hardin), is approximately equivalent to the Eagle sandstone of areas farther west and northwest, to the Groat sandstone bed of northeastern Wyoming and, in part, to the Shannon sandstone member of the Steele shale of central Wyoming. This member, which consists largely of buff-weathering sandy shale, is much like the underlying Telegraph Creek member; however, it can be identified by the presence of numerous beds of rusty-weathering ferruginous concretions, which are lacking in the Telegraph Creek member. In the northeastern part of the area shown in plate 1, the rocks of this unit are less sandy than those of the Telegraph Creek member, but farther south, in T. 9 S., R. 35 E., the unit contains a thin, but conspicuous, layer of sandstone. The rock materials numbered 21, 22, and 23 in the measured section below form a prominent ledge. Marine invertebrate fossils, which are abundant in some beds, include *Scaphites hippocrepis* (De Kay), *Scaphites aquilaensis*

Reeside, *Hamites novimexicanus* Reeside, and *Baculites aquilaensis* Reeside, all of which are common in the Eagle member.

A conspicuous group of bentonite beds is present in the upper part of the unnamed sandy shale member. Bentonite bed *R* is in the lower part of the upper third. At point 1, sec. 13, T. 1 S., R. 34 E., where this bed was measured and sampled, it is composed of three bentonite beds that are separated by thin shale strata.

Because of the prevailing steep dip of the strata in the area occupied by the outcrop of bed *R* (amounting to 12° or more at most outcrops), this bed lies under heavy overburden, except in very narrow belts along its outcrop.

Claggett shale member.—Approximately 400 feet of strata forming the uppermost part of the Cody shale comprise the following units, in ascending order, which are believed to represent the Claggett shale of central Montana: (1) About 100 feet of gray-weathering bentonitic shale, containing several beds of yellow bentonite and several beds with gray- and brown-weathering calcareous septarian concretions; (2) about 200 feet of gray-weathering shale, many beds of which contain brown- and gray-weathering, calcareous septarian concretions; and (3) about 100 feet of dark-gray, soft fissile shale forming dark outcrops and containing calcareous septarian concretions that weather yellow-tan to dark-brown. Marine fossils typical of the Claggett shale of central Montana are fairly common in the uppermost dark shale unit.

Bentonite beds *S*, *T*, and *U* are in the lower part of the Claggett shale member. Bed *S* has been used as a horizon marker for the base of that unit, and its location is indicated on the map by the lower boundary of the Claggett member. Each of these three beds was measured at only one locality, and they are believed to have little economic value.

The following section of the upper Cody beds was measured 6 to 7 miles east of Hardin, along a line more or less parallel to, and within half a mile of, the Hardin-Sarpy road. The measured section of the lowermost 615 feet of the Telegraph Creek member extends from the base of a steep east-facing hill in the SE¼SE¼ sec. 11, T. 1 S., R. 34 E., due east to a prominent cut bank on the south side of Dry Creek near the center of the S½SW¼ sec. 12. The uppermost part of the Telegraph Creek, the entire Eagle equivalent, and the Claggett shale member were measured along the local drainage divide extending eastward across the northern part of sec. 13, T. 1 S., R. 34 E., to the base of the hills on which the Judith River formation crops out on the same divide in the NE¼SW¼NW¼ sec. 18, T. 1 S., R. 35 E. Units are numbered in descending sequence.

Rock material	*Feet*	*Inches*
Claggett shale member:		
1. Shale, dark-gray; crops out as dark, soft, flaky shale, contrasting strongly with light-colored overlying sandy unit. Contains brown-weathering calcareous concretions, septariate with yellow calcite and white barite; contains same fauna as underlying fossiliferous concretion bed	16	0
2. Shale, dark-gray; with concretions, yellow-tan to brown-weathering, calcareous, quite fossiliferous, closely-spaced; septariate with thin, pale-yellow calcite veins; commonly 10 by 18 in. to 15 by 30 in., but as much as 2 by 6 ft	1	6
Caprinella coraloidea Hall and Meek		
Inoceramus barabini var. *inflatiformis* Douglas		
barabini var. *magniumbonatus* Douglas?		
cf. *I. sagensis* Owen		
saskatchewanensis Warren		
vanuxemi Meek and Hayden		
Pteria cf. *P. notukeuensis* Warren		
"*Yoldia*" sp.		
Acanthoscaphites aff. A. brevis Meek		
Baculites n. sp. aff. *B. thomi* Reeside		
3. Shale, dark-gray; contains a bed of calcareous septariate concretions 28 ft. below top	42	0
4. Shale, dark-gray; with concretions that weather rusty-brown, tan and reddish, calcareous, very closely spaced, septariate with thin, pale-yellow calcite veins	1	0
5. Shale, dark-gray; contains a few brown-weathering calcareous concretions, septariate with yellow calcite. Crops out as dark, soft, flaky shale contrasting with underlying gray-weathering shale	40	6
Baculites cf. *B. aquilaensis* Reeside		
6. Shale, dark-gray; with concretions, brown-weathering, calcareous, very closely spaced, septariate with brown or white calcite veins	1	0
Baculites haresi Reeside		
7. Shale, dark-gray; weathers to gray, soft, grass-covered soil; contains at least eight beds of brown-weathering calcareous concretions, septariate with yellow or brown calcite veins	156	0
Baculites sp.		
8. Shale, dark-gray; weathers to bare, gray gumbo soil; contains a few small gray calcareous concretions	40	0
Baculites aquilaensis var. *separatus* Reeside		
haresi Reeside		
9. Shale, concretion-bearing, and bentonite; two beds of shale, containing gray calcareous concretions that weather light gray and brown, are separated by about 3 ft of gray bentonite and bentonitic shale. Concretions are very closely spaced and somewhat septariate, with veins of pale-yellow to brown calcite and, rarely, bluish chalcedony	4	6
10. Shale, dark-gray with bentonitic beds; weathers lighter gray with gumbo bands	30	0
11. Bentonite, yellow (bed *U*)	2	9

Rock material	*Feet*	*Inches*
Claggett shale member—Continued		
12. Shale, dark-gray, bentonitic; weathers lighter gray	31	6
13. Bentonite, yellow; forms bare, gray gumbo (bed *T*)	1	11
14. Shale, dark-gray; contains gray-weathering calcareous concretions at base	25	0
15. Bentonite, yellow (bed *S* at base of *Claggett* shale member)	2	10
Total measured thickness	396	6
Unnamed sandy shale member equivalent to Eagle sandstone:		
16. Shale, dark-gray; weathers brownish; contains brown- and gray-weathering calcareous concretions, some of which are septariate with thin, white calcite veins	27	6
Inoceramus cf. *I. barabini* Morton		
spp.		
Baculites aquilaensis Reeside		
var. *separatus* Reeside		
haresi Reeside		
minerensis Landes		
Placenticeras sp.		
17. Shale, dark-gray, weathering to brownish soil; contains calcareous ironstone concretions that weather rusty brown and reddish	15	0
Baculites sp.		
18. Shale, dark-gray, weathering brownish gray; contains some brown-weathering calcareous concretions, septariate with yellow calcite veins	46	0
Goniochasma crockfordi Warren		
Inoceramus barabini Morton		
saskatchewanensis Warren		
subdepressus Meek and Hayden		
n. sp.		
Pholadomya aff. *P. subventricosa* Meek and Hayden		
Baculites sp.		
Placenticeras planum Hyatt		
19. Bentonite, yellowish-gray, grading upward into brownish gray. Contains much white aragonite (top of bed *R*)	2	9
20. Shale, dark-bluish-gray, silicified	1	6
21. Bentonite, creamy-yellow grading upward into brownish gray	7	0
22. Shale, dark-bluish-gray, silicified	1	0
23. Shale, gray, bentonitic	5	0
24. Bentonite, yellowish-cream, grading upward into gray; forms rather bare gray gumbo (base of bed *R*)	6	0
25. Shale, dark-gray, weathering to light-gray soil with bluish bands. Middle part contains numerous small calcareous concretions thta weather bluish gray to buff	45	0
Baculites aquilaensis var. *separatus* Reeside		
haresi Reeside		
Reptilian bones		
26. Shale, dark-gray, weathering lighter gray; contains very fine grained sandy partings and about 25 beds of closely-spaced ironstone concretions that weather rusty to dark maroon, embedded in shale	50	0
Baculites haresi Reeside		

Rock material	*Feet*	*Inches*
Unnamed sandy shale member equivalent to Eagle sandstone—Con.		
27. Shale, gray; with concretions, gray, weathering tan, rusty, and dark maroon, ferruginous, calcareous and silty, very closely spaced. Forms a more or less continuous ledge	1	0
Baculites haresi Reeside		
28. Shale, gray, sandy; contains a few gray silty calcareous concretions and, locally, crossbedded sandstone concretions that weather buff gray	5	0
29. Shale, gray; with concretions, gray-weathering, calcareous, fairly closely spaced, usually somewhat septariate with thin white calcite veins. Some are fossiliferous carrying a prolific fauna typical of the *Eagle*	1	0

Anomia sp.
"*Callista*" cf. *C. pellucida* (Meek and Hayden)
sp.
Cardium (*Ethmocardium*) *whitei* Dall
Corbulamella cf. *C. gregaria* (Meek and Hayden)
Crenella cf. *elegantula* Meek and Hayden
Cymbophora? sp.
Cymella montanensis (Henderson)
Inoceramus barabini Morton
Leptosolen cf. *L. conradi* Meek
Lima n. sp.
Lithophaga n. sp.
Pinna cf. *P. dolosoniensis* McLearn
Syncyclonema halli (Gabb)
Spironema aff. *S. tenuilineata* Meek and Hayden
Volsella n. sp. aff. *V. meeki* (Evans and Shumard)
Capulus? aff. *C.? microstriatus* Stephenson
Drepanochilus aff. *D. evansi* Cossman
Spironema aff. *S. tenuilneata* Meek and Hayden
Other gastropods undetermined
Baculites aquilaensis Reeside
var. *separatus* Reeside
haresi Reeside
var. (corrugated venter)
thomi Reeside
Hamites novimexicanus Reeside
Helicoceras rubeyi Reeside
Placenticeras meeki Boehm
Scaphites aquilaensis Reeside
var. *costatus* Reeside
var. *nanus* Reeside
hippocrepis (DeKay)
var. *crassus* Reeside
var. *pusillus* Reeside
var. *tenuis* Reeside
stantoni Reeside
n. sp.
Ammonite, possibly new genus
Crustacean remains
Fish scale

Rock material	*Feet*	*Inches*
Unnamed sandy shale member equivalent to Eagle sandstone—Con.		
30. Shale, dark-gray, weathering buff gray, silty; contains ferruginous, tan-weathering, calcareous concretions, so widely separate that they are rarely seen in exposures	42	0
31. Shale, dark-gray, weathering light-gray, silty; contains a few brown-weathering calcareous ironstone concretions as much as 4 ft in length	72	0
Baculites sp.		
32. Bentonite, gray and yellow	1	6
33. Shale, dark-gray; contains ironstone concretions	17	0
34. Bentonite, yellowish-cream; contains much aragonite	1	0
35. Shale, dark-gray, somewhat silty; contains numerous layers of ironstone concretions that weather rusty brown and dark maroon	29	0
Total measured thickness	376	3
Telegraph Creek sandy shale member:		
36. Shale, gray, sandy; contains gray-weathering calcareous concretions, especially in lower 5 ft where they are septariate with orange calcite veins	65	0
Inoceramus sp.		
Baculites haresi Reeside		
Scaphites sp.		
37. Sandstone and shale, gray, weathering light-tan-gray; contains small gray calcareous concretions and large (1 by 2 ft to 3 ft by 5 ft) yellowish-tan-weathering, silty, lenticular, calcareous concretions	17	0
Baculites aquilaensis Reeside		
haresi Reeside		
38. Bentonite, cream-colored, contains white aragonite	--	6
39. Sandstone and shale: shale is gray, weathering light tan-gray, very fine grained, soft; sandstone is in thin layers commonly less than 1 in. thick, more or less ripple-marked, and separated by thin layers and laminae of dark-gray shale. Upper 50 ft contains a few calcareous concretions that weather gray or yellowish tan. Lower 100 ft contains ledge-forming, brown-weathering sandstone lenses that are commonly ripple-marked and crossbedded	170	0
Ostrea sp.		
Baculites haresi Reeside		
Scaphites sp.		
40. Sand and shale, as above	614	6
Total measured thickness	867	0

JUDITH RIVER FORMATION

The Judith River formation (pl. 1), which rests with apparent conformity upon the Claggett shale member of the Cody, consists largely of light-colored sandy strata. As shown in figure 3 (cols. 2 and 4), it is approximately equivalent to the Mesaverde formation of the Salt

Creek oil field, Wyoming, which lies farther southeast in the Powder River basin, and (fig. 3, col. 6) to the Judith River of central Montana. The Judith River, as mapped near the Montana-Wyoming boundary (pl. 1), comprises two members—an unnamed member and the Parkman sandstone member. Farther north within the Hardin district, however, the upper member loses its identity through a northward interfingering transition into dark, marine shale beds of the lower and middle parts of the Bearpaw shale; north of T. 3 S., R. 35 E., therefore, the Judith River formation is mapped as a single unit that is equivalent only to the lower member, the Parkman sandstone.

The Judith River formation is about 255 feet thick as exposed east of Hardin, where, as has just been explained, it is equivalent to the Parkman sandstone of localities farther south. The lowermost beds near Hardin are buff-weathering sandy shale, which diminishes gradually upward for about 110 feet as it becomes intercalated with increasing amounts of sandstone similar to that of the overlying 145 feet of beds. These overlying beds consist of massive, soft, buff, brownish and olive-green sandstone containing harder, brown-weathering sandstone concretions and rusty, limonitic nodules. No fossils have been observed in the Judith River at this locality.

The following section of the Judith River formation (the equivalent of Parkman sandstone member) was measured 7 miles east of Hardin in the high hills north of the Sarpy road in the E½NE¼SE¼ sec. 7 and S½NW¼SW¼ sec. 8, T. 1 S., R. 35 E. Units are numbered in descending sequence.

Rock material	*Feet*	*Inches*
1. Sandstone, buff, brownish and olive-green; commonly very soft with harder, brownish-weathering, concretionary sandstone and rusty limonitic nodules. Forms west-facing sandy hills	145	0
2. Shale, buff-weathering; transitional upward from silty shale to very sandy shale. Contains four or five beds of silty calcareous concretions that weather gray, yellowish tan, or brown	109	0
Total measured thickness	254	0

Parkman sandstone member.—Near the Montana-Wyoming boundary, where the Judith River formation comprises two members, the lower (Parkman sandstone) member is made up of strata about 350 feet thick, which are lithologically similar to the rocks described in the foregoing section of the Judith River as measured near Hardin.

Upper member—The upper member of the Judith River formation consists of about 700 feet of rather massive brown and gray sandstone, interbedded with green and light-brownish-gray sandy shale and dark-gray shale and, in the lower part, a few beds of coal and clinker. Only the lower part of this member is mapped on plate 1. Farther north, as has already been stated, the beds of this member interfinger with the dark marine shale beds of the Bearpaw shale; in T. 3 S., R. 35 E., they are represented only by a few thin sandy beds, and such material seems to be absent in the equivalent strata of the next township to the north. Thick beds of bentonite that occur in the part of the Bearpaw shale that is involved in this transition do not extend southward into the upper member of the Judith River; within this district the Judith River contains little or no bentonite.

BEARPAW SHALE

The Bearpaw shale, where it is exposed east of Hardin, is about 865 feet thick. It consists largely of dark-gray shale, containing numerous brown-weathering calcareous concretions and much bentonite in its middle part. The formation is divisible into three units on the basis of relative amounts of contained bentonite: a basal unit about 315 feet thick, with only a few thin bentonite beds; a medial unit about 240 feet thick, with many beds of bentonite, one of which has a maximum thickness of 22 feet; and an upper unit about 310 feet thick, which, like the basal unit, contains little bentonite.

The medial unit is believed to be stratigraphically equivalent to the Monument Hill bentonitic member of the Pierre shale of the Black Hills region and to a highly bentonitic part of the Bearpaw shale that is extensively exposed in Rosebud and Treasure Counties, Montana.

Fossils are abundant in the Bearpaw shale, the most characteristic forms being *Baculites compressus* Say, "*Acanthoscaphites nodosus*" (Owen), *Placenticeras meeki* Boehm, and several species of *Inoceramus*.

Bentonite beds *V*, *W*, and *X* occur in the medial part of the Bearpaw shale. These beds are of particular interest because they include large deposits of bentonite that crop out in areas close to the railroad.

A thickness of 21½ feet was measured for bed *V* at point 11, sec. 8, T. 2 S., R. 35 E., and this bed is believed to be similarly thick in the southern half of T. 1 S., R. 35 E., and in the northern half of T. 2 S., R. 35 E. The bed contains enormous tonnages of bentonite under less than 30 feet of overburden in the areas indicated on plate 1. Some of the bentonite of bed *V* has valuable foundry-sand bonding properties, but most of it probably does not have the properties desirable in clay that is to be used for preparation of drilling mud. Calcareous concretions, which weather light-brown and which are 8 to 12 feet in diameter, are abundant on the exposed surfaces of this bed (figs. 7 and 8).

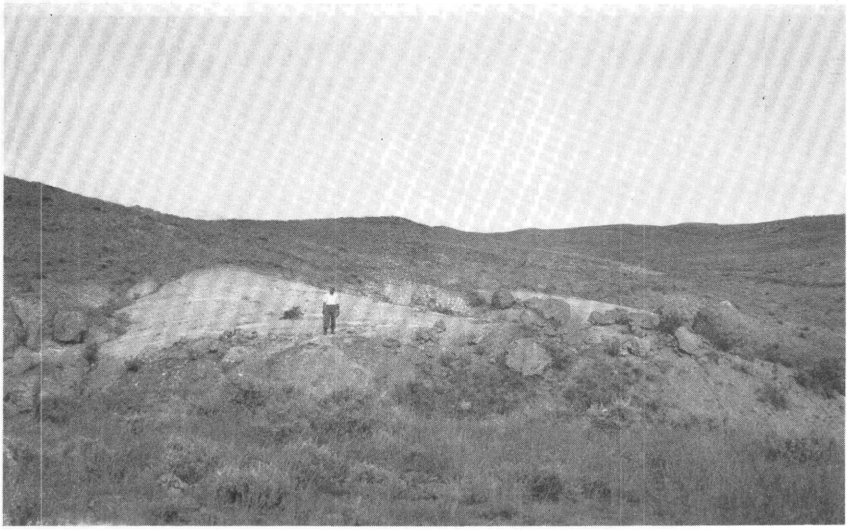

FIGURE 7.—View southward along outcrop of bentonite bed V in NW¼ sec. 17, T. 2 S., R. 35 E.; note large limestone concretions.

FIGURE 8.—Closeup of large limestone concretions along outcrop of bentonite bed V in NW¼ sec. 17, T. 2 S., R. 35 E. (location same as shown in fig. 7).

FIGURE 9.—View southward along outcrop of bentonite bed W from point in SE¼ sec. 17, T. 2 S., R. 35 E. Bed appears as white material in foreground and as long, white band in background.

The most conspicuous outcrops of bentonite bed *W* are in T. 2 S., R. 35 E. (fig. 9). At most of its outcrops in this township, bed *W* consists of 3 to 8 feet of light-colored bentonite, overlain by a thick bed of dark-gray bentonitic shale. Parts of the light-colored material are believed to be suitable for use in drilling muds, and most of the bed, including some of the dark bentonitic shale, appears to contain good bonding material for synthetic molding sands.

Bentonite bed *X* is 6 feet 10 inches thick at point 2, T. 1 S., R. 35 E., but it is much thinner 2 miles farther south. The bentonite of bed *X* is believed to be suitable for sand bonding.

The following section of the Bearpaw shale was measured from the center of the SW¼ sec. 8 eastward through S½ secs. 8 and 9 to the base of a sandstone (believed to be in the Hell Creek formation) that is exposed at the Sarpy road in W½NW¼SW¼ sec. 10, T. 1 S., R. 35 E.

Rock material	*Feet*	*Inches*
Upper unit:		
1. Shale, gray, sandy; interlaminated with very fine grained soft sandstone	10	0
2. Shale, dark-gray	25	0
3. Shale, dark-gray; with concretions, dark-brown-weathering, calcareous	1	0
Nucula planimarginata Meek and Hayden		

Rock material	*Feet*	*Inches*
Upper unit—Continued		
4. Shale, dark-gray	8	0
5. Shale, dark-gray; with concretions, dark-brown-weathering calcareous	1	0
Protocardia subquadrata (Evans and Shumard)		
"*Yoldia*" *evansi* Meek and Hayden		
Baculites grandis Hall and Meek		
6. Shale, dark-gray	21	0
7. Bentonite, greenish-gray; with concretions, dark-brown-weathering, calcareous	--	8
8. Shale, dark-gray	25	0
9. Shale, dark-gray; largely concealed. Exposed along Bighorn River bluffs near old Nine Mile bridge	150	0
Lucinid pelecypod, possibly new genus		
"*Acanthoscaphites*" *nodosus* (Owen)		
Baculites compressus var. *corrugatus* Elias		
Placenticeras meeki Boehm		
planum Hyatt n. var.		
10. Shale, dark-gray with small gray-weathering, hard, nodular, calcareous concretions and large, odd-shaped, cavernous masses of limestone containing abundant *Lucina occidentalis* (Morton)	5	0
Chlamys nebrascensis (Meek and Hayden)		
Inoceramus barabini var. *inflatiformis* Douglas		
Lucina occidentalis (Morton)		
subundata Hall and Meek		
Ostrea sp.		
Pteria linguaeformis (Evans and Shumard)		
Polinices aff. *P. concinna* (Hall and Meek)		
Baculites compressus var. *corrugatus* Elias		
Discoscaphites aff. *D. nicolleti* (Morton)		
11. Shale, dark-gray; contains a few calcareous concretions	15	0
12. Shale, dark-gray; contains calcareous concretions that are more or less ferruginous	35	0
Baculites compressus corrugatus Elias		
13. Shale dark-gray; contains calcareous concretions	18	0
Cymbophora cf. *C. gracilis* (Meek and Hayden)		
Inoceramus altus Meek		
Baculites compressus Say		
Placenticeras meeki Boehm		
Total measured thickness	314	8
Bentonitic unit:		
14. Shale, dark-gray, poorly exposed; contains a few thin olive-green bentonite beds and calcareous concretions	28	0
15. Bentonite, olive-green	1	0
16. Shale, dark-gray	6	6
17. Bentonite, greenish-gray	1	0
18. Shale, dark-gray; contains a few calcareous concretions	2	6
19. Shale, dark-gray; with concretions, weathering brown or gray, calcareous, variable in size; some are fossiliferous	1	0

Rock material	*Feet*	*Inches*
Bentonitic unit—Continued		
20. Shale, dark-gray; contains two thin bentonite beds	4	6
21. Shale, dark-gray; with concretions, weathering bright brown, calcareous, distantly-spaced. Smaller grayish-brown-weathering calcareous concretions are highly fossiliferous	1	0
Cuspidaria aff. *C. moreauensis* (Meek and Hayden)		
ventricosa (Meek and Hayden)		
Cymbophora gracilis (Meek and Hayden)		
Cymella meeki (Whitfield)		
Gervillia recta Meek and Hayden		
Inoceramus tenuilineatus Hall and Meek		
sp.		
Lucina subundata Hall and Meek		
Ostrea cf. *O. subalata* Meek		
Pteria cf. *P. parkensis* (White)		
Syncyclonema halli (Gabb)		
"*Yoldia*" *evansi* Meek and Hayden		
aff. *Y. ventricosa* Hall and Meek		
sp.		
Acmaea occidentalis (Hall and Meek)		
Drepanochilus evansi Cossman		
nebrascensis (Evans and Shumard)		
Fasciolaria aff. *F. gracilenta* Meek		
Haminea? occidentalis (Meek and Hayden)		
subcylindrica (Meek and Hayden)		
Polinices aff. *P. concinna* (Hall and Meek)		
Dentalium pauperculum Meek and Hayden		
"*Acanthoscaphites*" *brevis* (Meek)		
nodosus (Owen)		
quadrangularis (Meek and Hayden)		
compressed variety		
Aptychi		
Baculites compressus Say		
Placenticeras intercalare Meek		
two varieties		
meeki Boehm		
22. Bentonite, cream-colored	1	0
22A. Shale, dark-gray	10	0
22B. Bentonite, olive-yellow to gray	1	6
23. Shale, dark	2	6
24. Bentonite, olive-green to grayish-green	1	6
25. Shale, contains concretions: weathering brown and gray, calcareous, closely-spaced	1	0
Inoceramus vanuxemi Meek and Hayden		
"*Acanthoscaphites nodosus*" (Owen)		
Baculites compressus Say, var.		
26. Shale, dark-gray; contains calcareous concretions in middle	10	9
27. Bentonite, olive-green	--	6
28. Shale, dark-gray	3	0
29. Bentonite, olive-green	1	6

Rock material	*Feet*	*Inches*
Bentonitic unit—Continued		
30. Shale, dark-gray; contains calcareous concretions near middle	12	6
Cymbophora gracilis (Meek and Hayden)		
31. Bed *X:*		
Bentonite, yellow, grading upward into gray	1	6
Shale, dark-gray, somewhat sandy	2	6
Bentonite, yellow to yellowish green	1	0
Shale, dark-gray, partly sandy and bentonitic	2	0
Bentonite, green, grading upward into gray; locally contains large, gray, calcareous concretions. Forms prominent, light-gray bare gumbo	5	0
Shale, dark-gray, contains gray, sandy, calcareous concretions with silicified pelecypods	--	6
Cymbophora gracilis (Meek and Hayden)		
Inoceramus sp.		
Bentonite, light-green grading upward into dark-green	2	0
32. Shale, dark-gray, bentonitic; lower 9 ft. sandy	22	0
33. Shale, dark-gray; with concretions, weathering dark-brown and purplish, calcareous, sandy, ferruginous, closely-spaced	1	0
Cymbophora gracilis (Meek and Hayden)		
Inoceramus sp.		
Baculites compressus Say		
Placenticeras sp.		
34. Shale, dark-gray, soft, somewhat sandy; contains calcareous concretions 8 ft above base	20	0
Lucinid pelecypod, probably new genus		
"*Acanthoscaphites*" sp.		
Baculites compressus Say		
Placenticeras sp.		
35. Shale, gray, bentonitic; contains a few gray calcareous concretions	35	0
36. Shale, gray, very bentonitic, weathering to gray, bare gumbo (bed *W*)	13	0
37. Shale, alternate units of gray bentonitic shale and darker, soft, fissile shale; poorly exposed	42	0
38. Bentonite, olive-green (bed *V*) at base of middle unit	3	0
Total measured thickness	241	9
Lower unit:		
39. Shale, dark-gray; contains brown- and gray-weathering septariate calcareous concretions 8 ft and 22 ft below the top	53	0
40. Shale, dark-gray; contains several beds of calcareous, brown-weathering, ferruginous concretions	20	0
41. Shale, dark-grey; contains a few calcareous concretions	45	0
Inoceramus sp.		
Placenticeras meeki Boehm		

Rock material	*Feet*	*Inches*
Lower unit—Continued		
42. Shale, dark-gray; with concretions, brown-weathering, calcareous, septariate with yellow calcite veins. Commonly 1.5 by 3 ft, but as large as 2 by 10 ft	1	6
43. Shale, dark-gray; contains a few brown-weathering calcareous concretions	63	0
44. Shale, dark-gray; contains numerous brown-weathering calcareous concretions more or less septariate with yellow calcite veins	37	0
Inoceramus cf. *I. palliseri* Douglas		
sagensis Owen?		
saskatchewanensis Warren		
tenuilineatus Hall and Meek		
Ostrea sp.		
"*Yoldia*" sp.		
Baculites compressus Say		
45. Shale, dark-gray; contains a few small gray calcareous concretions	20	0
Inoceramus sp.		
Lucina sp.		
46. Shale, dark-gray; contains some bentonitic beds and, rarely, calcareous concretions	54	0
47. Shale, dark-gray: with concretions weathering buff and brown, calcareous, closely spaced	--	6
Inoceramus barabini var. *inflatiformis* Douglas		
Helicoceras simplicostatum Whitfield		
48. Shale, dark-gray	15	0
Total measured thickness	309	0

HELL CREEK FORMATION

The Hell Creek formation, the uppermost Cretaceous stratigraphic unit exposed in the Hardin district, consists largely of massive, scarp-forming sandstone beds and greenish-gray sandy clay. Some of the clay in the Hell Creek may be altered volcanic material, but this formation is not known to contain bentonite beds of commercial value.

Thom and others (1935, p. 61) report that the Hell Creek of this locality, which is largely of fluviatile origin, contains "fresh-water invertebrate fossils, fragments of turtle shells, and fossil bones identified as belonging to the dinosaurian genus *Trachodon*."

GEOLOGIC STRUCTURE

The geologic structure of the Hardin district is illustrated (pl. 1) by means of contours drawn on the Clay Spur bentonite bed. The structure of the district is broadly homoclinal with the prevailing strike in a northwesterly direction and the overall dip northeastward, or away from the great uplift centering in the Big Horn Mountains. Therefore, the oldest rocks crop out along the southwestern side of the district, and the youngest crop out along the northeastern side. The strata dip steeply in a belt along the southwestern margin of the district, adjacent to the mountains, but they are less steeply inclined almost everywhere else. The homoclinal structure is interrupted locally by synclinal and anticlinal flexures, mostly with northwesterly-trending axes. There are also a few normal faults, most of which trend in northeasterly directions, approximately normal to the prevailing strike of the rocks.

The anticlinal flexures include the Black Gulch dome, with its apex in the eastern part of T. 9 S., R. 34 E.; the Rotten Grass dome, in the southern part of T. 7 S., R. 33 E.; the Soap Creek dome, with its apex in the southern part of T. 6 S., R. 32 E.; the Woody Creek dome, with its apex in the southern part of T. 3 S., R. 31 E.; and the Dunmore dome, with its apex in T. 1 S., R. 34 E. Synclinal areas lie southwest of each of these anticlinal folds. Further information on the structural features is given in the closing chapter of the present report, where the geology is described, by township and range, in relation to the bentonite deposits.

BENTONITE DEPOSITS

The data presented below and on following pages, dealing primarily with the Hardin district, are, in part, contingent upon general information on bentonites (relating to their origin, manner of occurrence, composition, physical and chemical properties, and industrial testing procedures) that is contained in other reports, now in preparation, on bentonite deposits in the marine Cretaceous formations of various parts of the Missouri River basin. The bentonite deposits of this basin are similar to one another in so many respects that much of the information to be presented in these other reports is applicable to the deposits in the Hardin district.

A bentonite bed ordinarily consists of a number of layers of clay that differ from one another in one or more characteristics, such as color, texture, or collodial properties. As a rule, the bentonite of all these layers is light in color, with the exception of a top layer, which is dark-colored. The miners in the Black Hills district usually cast aside this top layer as waste material, though some of it is known to be suitable for use as foundry-sand bonding clay and as drilling-mud material. Most of the bentonite has a waxy consistency, and granular or other nonwaxy textures are commonly restricted to layers near the top and near the base of the light-colored material.

The floor of most of the bentonite beds is marked by their sharp contact with the subjacent shale, which is locally silicified just below the bentonite to form a thin, hard, chertlike layer. In general, the roof is less definite, and the bentonite of the upper part of the bed ordinarily grades upward through an indistinct zone of dark bentonite and bentonitic shale into the overlying bedrock, which is most commonly dark-gray shale.

MINERAL CONTENT

The bentonites of the Hardin district belong in general to the gel-forming types, although they differ considerably, from bed to bed and from place to place, in their behavior when immersed in water after drying. Results of differential thermal analyses, performed with a portable apparatus by Elizabeth A. Fischer, of the U. S. Geological Survey (informal communication, 1947), on several samples collected during the present investigation, indicate that the bentonite deposits of the Hardin district consist predominantly of the clay mineral montmorillonite. They also commonly contain mica, feldspar, quartz, gypsum, soluble salts, and unaltered volcanic glass. Tiny, but plainly visible, residual particles of such non-clay constituents, many of them dark in color, are present in all the beds and are referred to collectively as "grit" by producers and buyers of bentonite. The grit content varies greatly from layer to layer, some layers showing conspicuous amounts and other layers showing little or none.

CHARACTERISTICS OF OUTCROPS

Freshly exposed bentonite ranges in texture from essentially homogenous, firm, waxy clay to loosely compacted granular material, some of which resembles corn meal. When freshly exposed in mine excavations and prospect openings, much of the bentonite quickly crumbles into grains, flakes and lumps of various sizes and shapes. The ground in the vicinity of the bentonite exposures is commonly littered with residual fragments of selenite, calcite, or aragonite, and, in a few places, with conspicuous large limestone concretions (figs. 7 and 8) that have formed within the bentonite beds. During rainy periods, bentonite of moderate to high dilatancy soaks up many times its own volume of water, swells, and becomes a slippery thixotropic gel. On drying, the swollen clay contracts to nearly its original volume, and, in so doing, it cracks and forms a peculiar popcorn-like clay bloom (fig. 10). In general, the bentonite beds resist weathering to a slightly greater degree than the enclosing Cretaceous shales, and accordingly they tend to form conspicuous hillside ledges and buttresses.

EFFECTS OF WEATHERING ON COLOR AND COLLOIDAL PROPERTIES

The prevailing hues reflected by most outcrops of the light-colored material of the bentonite beds are olive green, cream, and drab, representing discoloration of the bentonite upon exposure. Where the

FIGURE 10.—Popcornlike clay bloom as shown on outcrop of Soap Creek bentonite bed in SE¼ sec. 15, T. 7 S., R. 32 E.

beds pass under more than a few yards of cover, such colors are ordinarily supplanted by the shades of bluish-gray or white that prevail in subsurface sections of the light-colored material. The discoloration is an effect of weathering. Any concomitant discoloration of the darker clay that forms the uppermost parts of most beds is so indistinct as to have escaped observation.

In the Black Hills district, weathering of the bentonite is associated with an apparent enrichment of its valuable colloidal properties. Bentonite that is under more than 30 or 40 feet of overburden, and accordingly has the bluish-gray color of unweathered material, is considered, as a rule, to be less highly colloidal than the more shallow material, which is largely discolored. The data at hand do not reveal the extent to which this rule may be applicable within the Hardin district.

Experiments performed by Margaret D. Foster, of the U. S. Geological Survey (informal communication, 1948), on samples from the Black Hills district that were collected for the present study, confirm the popular view that the discoloration of the weathered bentonite is due chiefly to oxidation, from the ferrous to the ferric condition, of small amounts of iron in the clay. Undiscolored bentonite that was weathered experimentally under laboratory conditions over a period of 11 months became distinctly discolored as the iron rapidly oxidized. Weathering during the 11-month period also resulted in an appreciable increase in the dilatancy of the bentonite.

MINING

A small bentonite-processing plant (the only one in Montana) has been operated by the Wyotana Mining Co. intermittently since 1946 at Aberdeen siding, 6 miles south of Wyola. The fuel used at this plant is crude oil. The clay, after passing through a rotary drier, is mechanically pulverized and packed in 100-pound paper sacks. The clay is supplied from the company's two small strip mines in Wyoming, one on the north side of Gay Creek and the other on the west side of West Pass Creek; both mines are close to the Montana State line.

If plans materialize for the construction of a large dam across the canyon of the Bighorn River, 35 miles south of Hardin, Mont., electric power may become available for operation of processing plants.

Although bedrock containing thick bentonite deposits crops out extensively in this district, the deposits are obscured in many places by surficial debris. Trenching or hand-boring is generally required for accurate measurement of their thickness and for sampling the clay.

The beds of minable thickness, as already stated, are interspersed among strata that belong to Cretaceous formations ranging from the Thermopolis shale upward to the Bearpaw shale. Nearly all the bentonite that has been mined in the principal producing districts of Wyoming and South Dakota has been taken from the Clay Spur bentonite bed, just below the top of the Mowry shale. This bed is believed to have been recognized in the Hardin district, but it is not present here in situations where mining would be profitable; consequently, the possibility of producing bentonite in this district must depend almost entirely on the potentialities of other beds. Two beds of the Cody shale are especially thick and favorably situated for mining along parts of their outcrops—one of these beds is in the Belle Fourche shale member, and the other is in the Greenhorn calcareous member. All the bentonite mined by the Wyotana Mining Co. has been taken from the Soap Creek bed of the Belle Fourche member.

The bedrock above and below almost all the bentonite beds is shale. The bedrock immediately above the beds can in general be removed by stripping with bulldozers or other types of excavating equipment. The hard, chertlike, silicified shale of the floor below some beds should facilitate loading the bentonite with drag-lines or power shovels without admixture of the underlying material. Presumably, the large calcareous concretions (figs. 7 and 8) occurring in some beds would not give serious trouble.

A few of the beds are persistent and can be traced for considerable distances, but the thickness of any given bentonite bed is by no means uniform from place to place, as shown by the sections recorded elsewhere in this report, which give detailed descriptions of the bentonite deposits by township and range. Some of the beds are lens-shaped deposits, which crop out locally with great thickness but which pinch out completely within a few miles. In some outcrops the typical, light-colored bentonite passes laterally into dark bentonitic shale, which grades, in turn, into shale similar to that of the enclosing bedrock.

Outcrops of bentonite beds comparable in thickness with deposits mined in the Black Hills district are mapped on plate 1 in relation to their geologic structure. For several of these beds, the approximate areal extent of bentonite deposits under thin overburden also is indicated. For these beds, much of the bentonite lying between the line of outcrop and a roughly-sketched subsurface line, along which the overburden upon the deposits is estimated to be 30 feet deep, is considered to be suitably situated for strip-mining. The shallow deposits, thus outlined on plate 1, underlie belts of land that tend to be elongated approximately in the directions of strike of the beds. These belts vary in width because of changes in the dip of the bentonite beds and because of irregularities of the land surface. Accordingly, the belts underlain by shallow deposits tend to be widest, and tend to offer the most promising strip-mining sites, where the beds are horizontal, or nearly horizontal, and where the slope of the land is gentle.

The dip of the strata is prevailingly gentle in several wide tracts along the axial portions of folds. Within some of these tracts, thick bentonite beds crop out in areas of many acres in which the land slopes gently, as, for example, in some parts of the syncline extending across T. 7 S., R. 32 E. Here, they are under a light cover of the superjacent bedrock, which consists generally of soft shale that could easily be removed; in such areas large amounts of bentonite could be mined by stripping. However, in some belts on the flanks of folds, the bentonite beds are steeply inclined, as, for example, near the base of the Big Horn Mountains in T. 5 S., R. 30 E. Here, beds could be strip-mined only in narrow zones along their outcrops and would yield relatively little bentonite.

Bentonite beds of this region range in thickness from a few inches to more than 15 feet. Locally, one bed in the Hardin district (fig. 6) attains a thickness of 45 feet because of flowage, and unusual thicknesses in a few other localities may also be a result of flowage or swelling. In the present work, emphasis has been placed on beds comparable in thickness and quality to the Clay Spur bentonite bed in the Black Hills district of Wyoming and South Dakota, where the thickness of this bed ranges from 1½ to 5 feet. As a rule, beds averaging less than 3 feet in thickness cannot be mined profitably, and attention has been restricted largely to beds with thicknesses averaging 3 feet or more, among which are those mapped on plate 1.

Thinner beds have been measured and sampled at some places, but these beds are not included in the following tonnage estimates.

Within the area studied, beds of minable thickness lying in belts more than 50 feet wide under less than 30 feet of overburden are estimated to contain about 110 million short tons of bentonite. In computing this figure, the bulk density of crude bentonite, with its large moisture content, was assumed to be 100 pounds per cubic foot. The estimated total tonnage is distributed among the townships (pl. 1) as follows:

Township	*Short tons (thousands)*
T. 1 S., R. 35 E	7, 600
T. 2 S., R. 35 E	9, 750
T. 3 S., R. 31 E	9, 600
T. 3 S., R. 32 E	1, 800
T. 3 S., R. 35 E	1, 400
T. 5 S., Rs. 33 and 34 E	15, 000
T. 6 S., R. 32 E	2, 750
T. 6 S., R. 34 E	300
T. 7 S., R. 32 E	9, 400
T. 7 S., R. 33 E	15, 700
T. 8 S., R. 33 E	17, 850
T. 9 S., R. 34 E	12, 850
T. 9 S., R. 35 E	4, 000
T. 58 N., R. 88 W. (Wyoming)	2, 000
Total	110, 000

How much of the bentonite reserve covered by the foregoing estimates conforms to present specifications for foundry clay and drilling-mud material can be determined only in a general way from data based on the small number of samples tested. Results of empirical tests of various physical properties of 94 samples (table 1) nevertheless indicate that much material of potential value is included. Apparently, all the beds contain some bentonite that is suitable for use as foundry clay and the reserve tonnage of such material is believed to be large. Some of the bentonite of this district also could be used as an ingredient of drilling mud, but most of it is not comparable in quality to the best grades of drilling clay mined in the Black Hills district. Part of the relatively small tonnage of white-ground bentonite produced to date by the Wyotana Mining Co. has been sold for use as filler for paper. Much of the bentonite of the various deposits described in this report would also be suitable for sealing reservoirs, irrigation canals and dams against leakage of water, and no doubt much of it could be adapted to a great variety of useful purposes, including the removal of impurities from public water supplies. It is improbable, however, that any of it would be suitable for use as a catalyst in petroleum refining or as a filtering and decolorizing medium for mineral and vegetable oils; supplies for these purposes are rarely, if ever, found in deposits of bentonite of the gel-forming types.

The outlook for utilization of bentonite from the Hardin district is thus thought to depend primarily upon the practicability of mining large tonnages of this material for use as sand-bonding clay, or for other uses that do not involve all of the essential properties of high-grade drilling clay. It is perhaps worthy of comment that exploitation of the deposits of this district in competition with those of the bentonite-producing districts in the Black Hills and in southern Wyoming would be hampered somewhat by the greater cost of transporting the clay 200 to 300 miles farther to the foundries and steel works of the middle-western and eastern States; this disadvantage is likely, moreover, to continue for many years to come, inasmuch as the reserves of foundry clay of the Black Hills and other bentonite-producing districts of the western interior region will probably last much longer than their reserves of drilling-mud bentonite. Much of the bentonite of the Hardin district may nevertheless eventually be developed for use as foundry clay.

As compared with its sand-bonding possibilities, the outlook for use of bentonite from the Hardin district as drilling-mud material appears unpromising. Although the reserves are large the quality of nearly all of it, with reference to this use, is medium or low, and while much of it could no doubt be beneficiated to meet commercial specifications, the cost of production and refinement would make competition with other districts difficult. Nevertheless, the prospect for development of drilling-mud supplies will undoubtedly improve as the reserves of "commercial bentonite" in other districts become depleted, and, unless unforeseen changes in drilling technology weaken the demand, it appears probable that some deposits, in addition to those mined by the Wyotana Mining Co., will eventually be developed for use in drilling fluids.

The Soap Creek bed contains the largest accessible reserve of bentonite of this district that is suitable for use as foundry-sand bonding clay; other deposits that may eventually be mined for this use are present in beds *M*, *R*, *U?*, *V*, and *W*. The bentonite that appears best suited for use in drilling muds occurs in the Clay Spur and Soap Creek beds and in bed *W*. Drilling-mud bentonite of good quality is also present in several other beds—chiefly in the Thermopolis and Mowry shales; however, in this district, beds of such material crop out chiefly in zones of steeply dipping strata and where the topographic configuration is comparatively rugged. Because most of the beds are therefore covered by thick overburden, they cannot be considered as potential sources of commercial supply. On following pages, further comments are offered concerning the potentialities of some of the principal bentonite beds for production of material to be used as foundry-sand bonding clay, as rotary drilling-mud material, and for a few other purposes.

UTILIZATION

FOUNDRY-SAND BONDING CLAY

Tempered mixtures of molding sand and clay that possess green compression strengths of at least 8 pounds per square inch (psi), and compression strengths of 50 psi. after drying, are commonly regarded as suitable for preparing most types of molds used by foundries and steel works in manufacturing metal castings. Measurements of the green and dry strength of many such mixtures in which the clay fraction was bentonite from the Hardin district (table 1) compare favorably with figures obtained in testing bentonites from the northern Black Hills district for use as bonding clay. In this connection, figures relating to a sample of commercial bonding bentonite from the latter district are included in table 1 for comparison. However, "commercial" bonding clay is not susceptible of hard-and-fast definition, and the commercial clay cited in table 1 does not represent a standard. Accordingly, samples whose test figures differ widely from those given for the clay cited may nevertheless represent valuable bonding-clay deposits.

Perhaps a more satisfactory basis for comparison is provided by a summary of significant bonding-test figures relating to the Hardin district (fig. 11–*B*) in comparison with those obtained in testing 49 samples from the Clay Spur bentonite bed of the Black Hills district (fig. 11–*A*), which is the chief source of a large tonnage of bentonite sold yearly as foundry-sand bonding clay. The figures for these 49 samples involve a fairly broad representation of the various bond-strength characteristics of bentonites mined in the Missouri River basin for use by foundries and steel works. Significant circumstances brought out by this tabular summary are: (1) a wider range of figures relating to the bond-strength characteristics of samples from the beds in the Hardin district as compared with the corresponding figures for the Clay Spur bed in the Black Hills district, and (2) the proportion of samples from the Hardin district having green strengths of 11 psi or more, and dry strengths of 50 psi or more; this is much higher than the proportion for the Black Hills district. Several of the samples having low dry strength proved to have exceptionally high green strength, and several of those having unusually high dry strength possessed only low green strength. The presence of both types of bentonite in the Hardin district may enhance the economic potentialities of both, inasmuch as blending can be considered. Also,

Green compression strength (psi), computed on basis of 1.4 percent tempering water	Dry compression strength (psi) computed on basis of 2 percent tempering water						
	>64	60–64	55–59	50–54	45–49	40–44	<40
11.0–11.9			1				
10.0–10.9	4	1	3	1	1		
9.0–9.9	6	6	6	6	4	4	1
8.0–8.9	1		1			1	1
7.0–7.9				1			

Summary of data on 49 mixtures containing bentonite from northern Black Hills district. Average strength (psi): green, 9.5; dry, 56.7

A

Green compression strength (psi), computed on basis of 1.4 percent tempering water	Dry compression strength (psi) computed on basis of 2 percent tempering water						
	>64	60–64	55–59	50–54	45–49	40–44	<40
14.0–14.9							1
13.0–13.9						2	1
12.0–12.9		1	1				1
11.0–11.9	2	3	3		1		
10.0–10.9	3	3	3			1	2
9.0–9.9	8	4	2	3	5	2	1
8.0–8.9	6	1	3	3	2	1	1
7.0–7.9	4	2	1			1	1
6.0–6.9	4				1		
5.0–5.9	2		1				
4.0–4.9	1	1			1		
Unknown			1	1	1		1

Summary of data on 94 mixtures containing bentonite from the Hardin district

B

EXPLANATION

- Both green and dry strength greater than usual minimum requirements for foundry sand bonding clays mined in Missouri River basin
- Green strength adequate but dry strength less than generally required
- Dry strength adequate but green strength less than generally required
- Both green and dry strength less than generally required

FIGURE 11.—Test data on tempered mixtures of molding sand from Illinois, with bentonite of (*A*) 49 samples from Clay Spur bentonite bed in northern Black Hills district and (*B*) of 94 samples from various beds in Hardin district.

both the green and dry strength of many samples would be much greater if 6 percent by weight of clay were used instead of only 4 percent, which was the proportion used in all of the bonding tests performed in this investigation.

ROTARY DRILLING-MUD MATERIAL

In preparation of rotary well-drilling fluids, which has become a specialized field of engineering, various types of clay are mixed with other materials. Bentonite of the Missouri River basin that has high dilatancy and conforms to certain specifications relating to viscosity, yield, gel strength (thixotropy), wall-building characteristics, and "grit"— or particles of nonclay minerals, many of which are dark—is much in demand for use as one of the ingredients. Tests for all of these properties (table 1) indicate that some of the bentonite of the Hardin district is suitable for use in the preparation of drilling mud.

Approximately 900,000 short tons of bentonite—about two-thirds of which was sold as drilling-mud material—was mined in 1952 from the Clay Spur bentonite bed in the Northern Black Hills district. Of 49 samples of bentonite from that district, secured during the present investigation and tested at Urbana, Ill., all but two samples swelled at least to 20 milliliters (ml) when 2 grams were added slowly to distilled water; these two samples were further tested for use in drilling muds. For these samples the computed yield (number of barrels of slurry with a viscosity of 15 centipoises that can be prepared from 1 short ton of clay) ranged from 55 to 125 bbl, with an average of 92.8 bbl. In the wall-building tests, the least, and therefore the most favorable, water-loss volume (measured in milliliters of filtrate during a 30-minute period from a 6 percent suspension of clay in distilled water under a pressure of 100 psi) was 13.4 ml; the greatest water-loss volume, and therefore the least favorable, was 35.5 ml.

Producers of clay that is to be shipped from points in the Missouri River basin for use as drilling-mud material commonly employ rule-of-thumb specifications, whereby the computed yield must be at least 90 bbl and the filtrate must be no more than 16 ml. However, a product conforming to these requirements is often prepared by adding "high-gel" bentonite, or small amounts of chemical reagents, to material that yields much less than 90 bbl; some of the material mined in the Black Hills district is given such treatment. The feasibility of beneficiating the bentonite of some of the deposits in the Hardin district might be worthy of investigation.

CLAY SPUR BENTONITE BED

Five samples of bentonite showing marked dilatancy that were obtained from the light-colored portion of the Clay Spur bentonite bed have been tested for use in drilling fluids (table 1). The computed yield for these samples ranged from 95 to 67 bbl per ton, and the 30-minute wall-building filtrate volume ranged from 14.2 to 17.8 ml. A sample from sec. 26, T. 6 S., R. 32 E., with a yield of 92 bbl and a water-loss of 14.2 ml, is judged to be one of the best drilling-mud materials among the samples from this district listed in table 1. Some of the bentonite of the Clay Spur bed of this district also conforms to specifications for foundry-sand bonding clay that are employed elsewhere in the Missouri River basin. However, this bed lies mostly in positions unfavorable for strip-mining, and it contains a minable reserve of only a few hundred thousand short tons.

SOAP CREEK BENTONITE BED

The Soap Creek bentonite bed contains a much larger minable reserve than any other bed in the district. Tests of the foundry-sand bonding efficiency of the bentonite of 23 samples from this bed showed green compression strength ranging from 7.7 to 12.6 psi when 1.4 percent of tempering water is present in the core mixture and showed a dry compression strength ranging from 35 to 78 psi with 2.0 percent of tempering water before drying. This bed is believed to contain a very large tonnage of bentonite that is suitable for use as foundry clay.

All of the bentonite that has been mined by the Wyotana Mining Co. in Sheridan County, Wyo., close to the Montana State line (pl. 1), has come from this bed, and part of this material has been sold for use in drilling muds. Of 15 samples from the lower, light-colored part of the bed, 14 exhibit marked dilatancy and have been tested for use as mud materials (table 1). The yield of these samples ranges from 80 to 45 bbl per ton, with an average of 60 bbl; the wall-building filtrate volume ranges from 17.2 to 35 ml, with an average of 22.2 ml. Judged as drilling-mud material, the average quality of the bentonite in the Soap Creek bed probably is inferior to that of the Clay Spur bed of the northern Black Hills district. However, inasmuch as bentonite from this bed has actually been mined in the Hardin district and sold as drilling clay, it is possible that detailed testing will reveal some better drilling clay in the Soap Creek bed than is indicated by the 14 tests listed in table 1.

Much of the lower, light-colored portion of the Soap Creek bed is nearly white when it is finely ground. Presumably, much of this material would be suitable for use in pharmaceutical preparations and in other products requiring white clay for their manufacture—such as certain types of paper filler, for which part of the Wyotana Mining Company's production has been sold.

BED M

The bentonite of bed *M*, which contains large minable tonnages in the southern half of the district, is chiefly clay of low or moderate dilatancy that typically contains relatively abundant grit and is discolored by impurities consisting largely of shale and organic matter. Consequently, this bed appears to contain very little, if any, material that conforms to the regional specifications for commercial drilling-mud bentonite. While much of the material of bed *M* appears to be suitable for use as foundry-sand bonding clay, it is considered to be generally inferior for this purpose to the bentonite of the Soap Creek bed (table 1).

BED R

A sample of bentonite having low dilatancy and representing a considerable tonnage contained in a bed (tentatively correlated with bed *R*) that crops out in the area west of the Little Bighorn River shows exceptionally high green compression strength (table 1). The material of this deposit, which lies only 9 miles from the Chicago, Burlington and Quincy Railroad, possibly could be mixed with clay that is deficient in green bonding strength to produce marketable foundry clay at low cost.

BED U

Several hundred thousand tons of accessible bentonite are contained in a bed, tentatively correlated with bed *U*, that crops out in T. 9 S., R. 35 E. High to moderate dry compression strength is shown (table 1) by a single sample, which is bentonite of low to moderate dilatancy. This bed is advantageously situated for mining because of its nearness to the processing plant of the Wyotana Mining Company and to the Chicago, Burlington and Quincy Railroad.

BED V

The bentonite of bed *V* conforms, in part, to present requirements for foundry-sand bonding clay, but most of it is unsuitable for commercial drilling-mud material. The bed contains large tonnages of bentonite in the area southeast of Hardin. The deposits are close to the railroad and are otherwise advantageously situated for mining. Presumably, stripping and loading would not be seriously hampered by the many large calcareous concretions they contain (figs. 7 and 8).

BED W

Part of the large deposit of bentonite in bed *W* has adequate green and dry compression strength; however, it also contains material that is deficient in green strength and high in dry strength, as well as some that is high in green strength and deficient in dry strength (table 1). Careful control in mining would be necessary to maintain a uniform product. The bed crops out (fig. 9) close to the Chicago, Burlington and Quincy Railroad, and some of the bentonite it contains could probably be mined at low cost and sold as foundry-sand bonding clay. Of five samples obtained from this bed, three were sufficiently dilatant to warrant testing for use in drilling fluids. The yield of these samples ranges from 86 to 78.7 bbl per ton, and the wall-building filtrate volume ranges from 17.5 to 23.6 ml. For use as drilling-clay, the bentonite of these three samples compares favorably with that of the Soap Creek bentonite bed, but is of mediocre quality in comparison with most of the clay shipped from the northern Black Hills district and other localities in the Missouri River basin.

DESCRIPTION BY TOWNSHIP AND RANGE

Most of the measured sections set forth in the following descriptions were obtained by boring with an auger, and the numerical order in which the bentonite and associated rock materials are listed in each section corresponds to the downward sequence in which they were penetrated in boring. Asterisks (*) indicate sampled materials for which test data are given in table 1.

T. 1 N., RS. 33 AND 34 E.

About 27 square miles have been mapped (pl. 1) in the southern parts of these two townships. Unimproved roads lead southward to the County road between Hardin and Sarpy.

The land surface within this tract is moderately dissected as a result of long-continued erosive action by watercourses draining to Bighorn River, which flows along the west side of the tract; the largest of these are Nine Mile Coulee, which extends in a northwesterly direction across the central part, and Dry Creek, which cuts across the southwestern corner. Flood plains, underlain by Recent alluvium, occupy about 1½ square miles along the river and along Dry Creek; older alluvial deposits underlie terraces, occupying a total of about 2 square miles, close to the river and near the divide between Nine Mile and Dry Creeks.

The tract is situated on a broad northeasterly-plunging anticlinal nose. The bedrock strata dip in a northerly direction nearly everywhere on the northwest side of the axis of this fold, and the dip is prevailingly east-southeastward on its southeast side. The oldest strata exposed are those of the Telegraph Creek member of the Cody shale, which crops out in the south-central part of the tract; the youngest, in the lower part of the Hell Creek formation, crop out in the northeastern corner. Four intervening stratigraphic units—the uppermost two members of the Cody shale, the Judith River formation, and the Bearpaw shale—crop out in a broad, roughly arcuate belt that is convex toward the northeast; this belt extends from the western side of the tract to its southeastern corner and crosses the anticlinal axis in section 28. At a number of places on both sides of the plunging anticlinal axis, this belt is offset by normal tear faults, downthrown on the side toward the axis. Thus, the plunging nose is essentially a great arch that is broken into a series of down-faulted, wedge-shaped blocks or grabens, one within another.

Beds of bentonite occur in this tract in the uppermost part of the Cody shale and in the Bearpaw shale. Two beds in the Cody—bed *R*, in the unnamed sandy member that is equivalent to the Eagle sandstone, and bed *S*, at the base of the Claggett shale member—are comparable in thickness to the same two beds where they were measured farther south, in T. 1 S., R. 34 E. (q.v.). As exposed within this tract, however, the bentonite contained in both beds appears to have poor colloid-forming properties and is probably of little value. Both beds, moreover, are cut by numerous faults, and, because they crop out in a belt wherein the strata dip rather steeply, their content of bentonite under overburden sufficiently light to favor strip-mining is restricted to narrow zones adjacent to their outcrops.

While bed *W*, in the Bearpaw shale, has not been recognized within this tract, it is probably present as material that swells little and consequently does not crop out conspicuously; it may consist of bentonitic shale—as in T. 1 S., R. 35 E., immediately to the southeast—or it may be represented only by shale containing little or no bentonite.

Bed *X*, in the Bearpaw shale, crops out locally in secs. 26, 27, and 35, R. 34 E., but elsewhere in the tract this bed and the enclosing strata are concealed by soil. Small tonnages could be mined in section 26, where the bed contains 4 or 5 feet of light-colored bentonite overlain by a thick zone of bentonitic shale. North of the fault that crosses the southeast corner of section 27, however, the bed and the enclosing strata dip steeply and crop out only on steep hillsides; consequently, within a few feet of the surface the overburden is so thick that strip-mining would be impracticable.

T. 1 S., RS. 30, 31, 32, AND 33 E.

A tract of about 86 square miles lying within these townships (pl. 1) extends eastward from the center of T. 1 S., R. 30 E., to the east side of T. 1 S., R. 33 E.; the town of Hardin lies within the eastern end of this tract. The Chicago, Burlington and Quincy Railroad and U. S. Highway 87 pass eastward across the northern part; a paved highway leads south from Hardin, and unimproved roads and trails give access to various other parts.

Bighorn River flows northward within the eastern margin of the tract. A divide extends in a northerly direction across the western half; beyond this divide the surface run-off drains westward into Fly Creek, a northward-flowing tributary of Yellowstone River, and nearly all of the land on the near side of the divide drains eastward to Bighorn River through Williams Coulee, Paritsa Creek, and their numerous branches. A small area extending along the south boundary of the tract lies within the basin drained by Two Leggin Creek, another minor affluent of the Bighorn.

Recent alluvium underlies the broad flood plain along Bighorn River and the narrower plains along Fly Creek, Williams Coulee and Paritsa Creek. Older alluvial deposits occupy several areas of benchland within the eastern third of the tract; together, these older deposits represent a flood plain upon which Bighorn River flowed at some time during the Pleistocene epoch. Deposits that originated still earlier in the Pleistocene are present in a small area about 500 feet higher, in SE¼ sec. 28, T. 1 S., R. 31 E.

All of the bedrock exposed within this tract belongs to the Carlile–Niobrara member of the Cody shale, except in small areas on the east side of Bighorn River, where undivided upper Cody beds crop out, and along the northern margin, where scattered areas aggregating about 6 square miles are occupied by outcrops of the Telegraph Creek member.

The tract lies on the northern side of Two Leggin uplift, a broad, anticlinal nose, whose axis plunges at a low angle northward across the eastern half of T. 1. S., R. 31 E. Three small normal faults have been mapped, two of which are in the southern part of that township; the third is in sec. 9, T. 1 S., R. 32 E.

Bentonite beds *P* and *Q*, in the upper part of the Carlile–Niobrara member of the Cody shale, crop out in the southeastern part of T. 1 S., R. 32 E. These bentonite beds are well exposed where the gently-dipping strata enclosing them are dissected by local drainage. The thickness of each of the two beds averages more than 2 feet, and their dip is everywhere less than 2°; because of the large shale content, however, the swelling capacity of the bentonite is so low that it probably is unsuitable for the uses for which most of the bentonite produced in the Missouri River basin is marketed. Also, because beds *P* and *Q* crop out mostly on rather steep hillsides, relatively little of the material they contain lies under overburden sufficiently thin to favor strip mining.

Outcrops of the bentonite beds can be reached over trails leading southward from U. S. Highway 87, at a point located a quarter of a mile southwest of the overhead bridge near Toluca, and from the railroad at Rowley siding.

T. 1 S., RS. 34 AND 35 E.

The rectangular tract comprising these two contiguous townships (pl. 1) centers about 7 miles east of the town of Hardin. Bighorn River, which meanders northward along the west margin of the tract, is joined near Hardin by Little Bighorn River and, farther north, by Dry Creek. U. S. Highway 87, and the Chicago, Burlington and Quincy Railroad, cross the Bighorn on bridges about 1 mile east of Hardin and continue southeastward up the valley of the Little Bighorn. A graveled county road, branching off at a point near the highway bridge, extends across the northern part of the tract; unimproved roads and trails give access to various other localities.

Extending northward across the eastern end of the tract is the drainage divide between Bighorn River and Tullock Creek—a minor tributary of Yellowstone River that flows northward across the next township to the east. West of this divide the run-off from the moderately dissected land surface is carried to Bighorn River by means of Dry Creek and its numerous branches.

Surficial materials deposited in Pleistocene and Recent time on the flood plains of Bighorn and Little Bighorn Rivers occupy a total of about 11 square miles in the southwestern part of T. 1 S., R. 34 E.; Recent alluvium also underlies areas along Dry Creek and several of its branches.

A subcircular dome with a closure of less than 100 feet is centered in the south-central part of T. 1 S., R. 34 E. The strata throughout the tract generally dip outward from the apex of this dome. The angle of dip is less than 2° except in the middle of the tract, where, in a northward-trending belt of rather steeply tilted strata, the dip is as much as 22°.

The Hell Creek formation, which is the youngest and highest bedrock unit exposed, crops out along, and east of, the drainage divide that crosses the eastern end of the tract. The oldest unit—the Carlile-Niobrara member of the Cody shale—crops out in the bluffs along the southwestern side of the flood plain of Little Bighorn River, and it probably directly underlies the Recent alluvial deposits northeast of the bluffs. The Telegraph Creek member of the Cody is exposed in the vicinity of the Little Bighorn and as far east as the central belt of steeply inclined rocks. Cropping out within that belt are the higher members of the Cody shale and the Judith River formation; the Bearpaw shale is at the surface in the broad area between the top of the Judith River and the base of the Hell Creek formation, which lies about 3 miles farther east.

Detailed stratigraphic sections, appearing in this report under the heading "Upper part of the Cody shale" were measured near the middle of this tract, half a mile south of the Hardin-Sarpy road. The section given for the Judith River formation was measured in sections 7 and 8, north of the road; the section for the Bearpaw was measured farther east, also close to the road.

The principal bentonite beds exposed in this tract belong to the upper members of the Cody shale and to the Bearpaw shale. The principal bentonite beds in the Cody include bed *R*, in the unnamed shale member equivalent to the Eagle sandstone, and in beds *S*, *T*, and *U*, in the Claggett shale member. Tests of samples from point 1, in sec. 18, T. 1 S., R. 34 E., indicate that beds *R*, *S*, *T*, and *U* contain some good foundry clay and that some of the material of bed *R* might be usable as drilling clay. However, no attractive mining sites occur along their outcrops because the beds are largely covered by surficial detritus and dip to the east as much as 22°. The following section of beds *R*, *S*, *T*, and *U* and the associated bedrock at point 1 is partly a repetition of data given in the stratigraphic section of the upper members of the Cody shale, appearing elsewhere in this report.

Section measured at point 1, NE¼ sec. 18, T. 1 S., R. 34 E.

Bed	Material	Thickness, All beds, Feet	Thickness, All beds, Inches	Thickness, Bentonite only, Feet	Thickness, Bentonite only, Inches
	1. Shale, bentonitic, brown	0	6		
Bed *U*	2. *Bentonite, gray, impure, sticky when wet	1	10	2	9
	3. *Bentonite, cream-colored, granular, with much aragonite	---	11		
	4. Shale, dark-gray, bentonitic in part	31	0		
Bed *T*	5. *Bentonite, yellowish-gray, granular	---	6	1	11
	6. *Bentonite, yellow, granular	1	5		
	7. Shale, gray, bentonitic in part	25	0		
Bed *S*	8. *Bentonite, yellow, granular: (base of Claggett member)	2	10	2	10
	9. Shale, dark-gray	88	6		
Bed *R*	10. *Bentonite, gray, granular	---	4	2	9
	11. *Bentonite, grayish-cream-colored, granular, with some aragonite	2	5		
	12. Shale, gray, hard	1	6		
	13. *Bentonite, brownish-gray, granular	3	0	6	4+
	14. *Bentonite, cream-colored	3	4		
	15. Bentonite (not penetrated in boring)	?	---		
	16. Shale, silicified, dark-bluish-gray	1	0		
	17. Shale, gray, bentonitic	5	0		
	18. Bentonite, yellowish-cream-colored, grading upward into gray	6	0	6	0
	19. Shale, dark-gray.				

The Bearpaw shale contains numerous bentonite beds, but only the middle unit, which is considered to be approximately equivalent to the Monument Hill bentonitic member of the Pierre shale of the Black Hills region, contains deposits thick enough to represent a possible source of supply. This middle unit, in which beds *V*, *W*, and *X* are the thickest and most prominent bentonite beds, crops out along a west-facing escarpment that extends southward from sec. 5 to sec 31, T. 1 S., R. 35 E., crossing the Hardin-Sarpy road in the SE¼ sec. 8. These three bentonite beds dip about 3° to 5° eastward, except in sec. 31, where the dip is much steeper. Soft sandy shale forms the overburden upon all of the bentonite beds.

Bed *V* averages nearly 20 feet in thickness in sections 17, 20, 29, 30, and 31, and it forms striking outcrops that are littered with large calcareous concretions derived from the bed. In section 8, bed *V* thins considerably and seems to disappear farther north in section 5, where its horizon is marked only by the characteristic large concretions. Within this tract, the reserve of minable bentonite from bed *V* is estimated at 7,550,000 short tons; it is believed that the large concretions would not seriously interfere with mining operations. When tested for use by foundries as sand-bonding clay, a composite sample of materials 2 to 4 of bed *V*, obtained at point 2 (pl. 1), showed high dry compression strength; a composite of materials 1 and 2 from point 6 tested high in both green and dry strength. The sampled material from point 6 might also be adaptable for use as well-drilling clay, even though its quality seems inferior to that of the best grades of such clay mined in the Black Hills district.

In this tract, bed *W* is represented only by a bed of dark bentonitic shale, whereas farther south, in T. 2 S., R. 35 E., it is composed of light-colored waxy bentonite overlain by bentonitic shale. Notwithstanding the shaly character of bed *W* within this tract, the material it contains may be of some value because the one sample tested as foundry clay—material 2 from point 4—showed high dry compression strength.

Bed *X* is composed of several layers of bentonite separated by thin beds of soft shale. The most prominent of these layers ranges from 6 to 7 feet in thickness in sections 9 and 15. In the southern part of the tract, bed *X* is much thinner and is largely covered by surficial detritus. A composite sample obtained at point 5, representing materials 5 to 7 of bed *X*, tested high in both green and dry strength.

Following are measured sections of the bentonite and associated rock materials cropping out at five numbered points in T. 1 S., R. 35 E.

Sections measured in T. 1 S., R. 35 E.

	Material	All beds: Feet	All beds: Inches	Bentonite only: Feet	Bentonite only: Inches
Point 2. SE¼SE¼ sec. 8:					
	1. Shale, dark-brown, soft	0	5	---	----
Bed *V*	2. *Bentonite, dark-brownish-gray, granular, gypsiferous, with dark mineral particles; somewhat lighter colored in lower part	3	6	4	3
Bed *V*	3. *Bentonite, gray, cornmeal texture, with dark mineral particles	---	3		
Bed *V*	4. *Bentonite, yellow, cornmeal texture, gypsiferous, with dark mineral particles	---	6		
	5. Shale, dark-gray, soft.				
Point 3. NW¼SW¼ sec. 9:					
	1. Shale and sandy shale	4	6+	---	----
Bed *X*	2. Bentonite, cream-colored, waxy, gypsiferous	1	3	1	3
Bed *X*	3. Shale parting	2	9	---	----
Bed *X*	4. Bentonite, dark-tan, waxy	---	6	7	4
Bed *X*	5. Bentonite, light-gray, waxy, with a few dark mineral particles and some gypsum	5	0		
Bed *X*	6. Bentonite, gray, basal 2 in. limonite-stained	---	7		
Bed *X*	7. Bentonite, light-green, waxy, with dark mineral particles	1	3		
	8. Shale, brown.				

Sections measured in T. 1 S., R. 35 E.—Continued

		Material	Thickness: All beds, Feet	All beds, Inches	Bentonite only, Feet	Bentonite only, Inches
Point 4, SW¼SW¼ sec. 9:						
		1. Shale, brownish-gray, soft	0	3	---	----
Bed W		2. *Shale, bentonitic, brownish-gray	6	5	6	5+
		3. Shale, bentonitic, (not penetrated in drilling)	---	---		
Point 5, NE¼NW¼ sec. 16:						
		1. Shale, gray, soft	---	8+	---	----
Bed X		2. Bentonite, brown, waxy to granular	1	0	1	4
		3. Bentonite, brownish-yellow, granular, waxy in part	---	4		
		4. Shale, brown, soft, sandy	4	8	---	----
		5. *Bentonite, light-brownish-gray, granular, waxy in part, with dark mineral particles	3	6	6	10
		6. *Bentonite, light-brownish-gray, waxy	1	10		
		7. *Bentonite, brownish-yellow, cornmeal texture	1	6		
		8. Shale, brown, hard	3	0	---	----
		9. Bentonite, brown, granular	---	4	1	2
		10. Bentonite, light-brownish-gray, waxy to granular, gypsiferous	---	10		
		11. Shale, brownish-gray, gypsiferous.				
Point 6, SE¼SE¼ sec. 30:						
(Top not exposed)						
Bed V		1. *Bentonite, gray, waxy, gypsiferous	13	2	17	2+
		2. *Bentonite, light-gray, waxy	4	---		
		3. Bentonite (not penetrated in boring)	?	?		
		4. Shale, dark-gray, hard, siliceous, chert-like.				

T. 2 S., RS. 30, 31, AND 32 E.

All of T. 2 S., Rs. 31 and 32 E., together with 25 square miles mapped within T. 2 S., R. 30 E. (pl. 1), are here described as a single tract, elongated from west to east, having a width of 6 miles and a maximum length of 18 miles. Unimproved roads and trails, giving access to various parts of this tract, branch southward from U. S. Highway 87 and westward from the St. Xavier-Hardin highway.

A divide extends in a northerly direction across the tract, within its western boundary. West of this divide, the surface runoff drains to Fly Creek, a northward-flowing affluent of Yellowstone River; the east side of the divide lies within the watershed of Bighorn River, into which most of the runoff is carried by Two Leggin Creek and its many branches.

Recent alluvium underlies the flood plains along Fly Creek and along the lower part of Two Leggin Creek. Older alluvial deposits occupy areas of several square miles along the eastern margin of the tract; these represent a flood plain on which Bighorn River flowed at some time during the Pleistocene epoch. Some hundreds of feet higher, in scattered small areas of benchland elsewhere in the tract, are deposits that originated still earlier in the Pleistocene.

All of the bedrock cropping out in this tract belongs to the Carlile-Niobrara member of the Cody shale, except for the outcrops in about ½ square mile at the northwest corner, which are assigned to the lower part of the overlying Telegraph Creek member of the Cody.

This tract lies on the north side of the Two Leggin uplift—a broad anticlinal nose whose axis plunges at a low angle northward across the middle of the tract. Accordingly, the strata cropping out in the western half of the tract dip mostly in northwesterly directions, and those in the eastern half dip in northeasterly directions; the dip does not exceed 3° within this tract.

Bentonite beds *P* and *Q* of the Niobrara shale crop out at the southwestern extremity of the tract, and within its northern part they crop out as far east as sec. 1, T. 2 S., R. 32 E. As a rule, neither of these beds exceeds 2 feet in thickness. Both beds are composed of granular, gray bentonite, whose natural exposures show a moderately well-developed popcornlike clay-bloom. Both beds, however, are largely concealed by soil and other surficial material.

Following are measured sections of bentonite beds *P* and *Q* and the associated rock materials cropping out at two numbered points:

Section measured in T. 2 S., Rs. 30, 31, and 32 E.

Material	Thickness: All beds, Feet	All beds, Inches	Bentonite only, Feet	Bentonite only, Inches
Point 7, sec. 18:				
1. Shale, soft, fissile, dark gray	1	1	---	----
Bed *P* 2. Bentonite, granular, gypsiferous, gray	1	10	1	10
3. Shale, soft, dark-gray	---	¼+	---	----
Point 8, sec. 18:				
1. Shale, weathered, soft, dark-gray	1	10	---	----
Bed *Q* 2. Bentonite, granular, gray, with many dark mineral particles	2	1	2 (items 2–3)	2 (items 2–3)
Bed *Q* 3. Bentonite, granular, gray, heavily stained by brown iron oxide	---	1		
4. Shale, moderately hard, dark-gray	---	¼+	---	----

T. 2 S., RS. 33 AND 34 E.

The rectangular tract of 72 square miles that comprises these two townships lies south of the neighborhood of Hardin (pl. 1).

This tract has low topographic relief; Bighorn River flows northeastward across its western half, and Little Bighorn River flows northwestward across its eastern half. U. S. Highway 87, and the Chicago, Burlington and Quincy Railroad extend along the valley of Little Bighorn River. The paved highway between Hardin and

St. Xavier extends along the flood plain of Bighorn River and crosses the river on a bridge near the mouth of Two Leggin Creek.

The bedrock of extensive areas within this tract is concealed under deposits of surficial materials, including Recent deposits occupying the wide flood plains along Bighorn and Little Bighorn Rivers and older deposits on broad areas of higher ground flanking those plains.

The northern part of T. 2 S., R. 34 E. includes the southern flank of the shallow subcircular dome that centers in T. 1 S., R. 34 E. (q. v.) and is separated by a shallow structural sag from a gently northeastward-dipping homocline that occupies the entire western half of the tract. In most of the remainder of the tract—that is, along its eastern margin and in most of the southern part of T. 2 S., R. 34 E.—the strata dip in east-southeasterly directions. In a monoclinal belt that here extends across the tract in a northeasterly direction, the strata dip at comparatively steep angles of as much as 20°; everywhere else in the tract they dip less than 2°.

The youngest exposed bedrock is that of the Judith River formation, which crops out along the monoclinal belt at the extreme eastern margin of the tract. The bedrock of all other exposures belongs to the Carlile-Niobrara and younger members of the Cody shale. These younger members—the Telegraph Creek, unnamed Eagle equivalent and Claggett—are mapped separately only in an area of about 2 square miles east of Little Bighorn River; farther west, they are mapped as one unit.

Bentonite bed *R*, in the unnamed member that is equivalent to the Eagle sandstone, is exposed for a distance of about 1 mile in sections 6 and 7. The nearest exposure that has been measured and sampled in the course of the present investigation is at point 1, in sec. 18, T. 1 S., R. 34 E.

T. 2 S., R. 35 E.

The southwestern corner of this township is less than 1 mile northeast of Crow Agency station of the Chicago, Burlington and Quincy Railroad, where an unimproved road leads to the southeastern part of the township; access from the north is provided by an unimproved road branching southward from the Hardin-Sarpy road.

Little Bighorn River enters the township close to its southwestern corner and flows for a distance of 2½ miles within its west boundary. Ash Creek, a branch of Tullock Creek which is a minor tributary of Yellowstone River, enters the township ½ mile north of the southeast corner, bends northeastward in its central part, and leaves the township ½ mile south of the northeast corner. Extending across the township a short distance west of Ash Creek is the drainage divide between Tullock Creek and Little Bighorn River. Between this divide and the river, a westward-facing escarpment extends diagonally across the western half of the township. In general, the land surface rises gently eastward from the top of this escarpment to the drainage divide and descends gently westward from the base of the escarpment to the river.

Alluvial deposits occupy belts along Ash Creek and along Little Bighorn River and two of its small tributaries in the southwestern part of the township. The bedrock dips toward the east. The unnamed members that are equivalent to the Eagle sandstone and the Claggett shale member crop out at the northwestern margin of the township. The Judith River formation, which crops out east of the Claggett shale member extends southward as a narrow belt along the eastern side of the flood plain of Little Bighorn River. East of the Judith River is a broad belt of Bearpaw shale, and, still farther east, the Hell Creek formation crops out in large areas along, and east of, the drainage divide.

The principal bentonite beds exposed in this township belong to the uppermost members of the Cody formation and the Bearpaw shale. Those in the Cody include beds *R* and *S*, but these beds, as in T. 1 S., R. 34 E., dip steeply and are therefore believed to be of little value. For that reason, and because they were examined in detail at point 1, about 4 miles to the north, they were neither measured nor sampled in this township.

The Bearpaw shale contains numerous bentonite beds, but only the middle unit, which is regarded as approximately equivalent to the Monument Hill bentonitic member of the Pierre shale of the Black Hills region, contains deposits sufficiently thick to be of interest as possible sources of industrial supplies. The west-facing escarpment, already described, is a result of the greater degree of resistance to erosion that is offered by this middle bentonitic unit, as compared with that of the less bentonitic parts of the Bearpaw shale, both above and below.

The most prominent and most resistant of the bentonite beds are beds *V* and *W*. Bed *V* ranges from 16 to 22 feet in thickness in sections 6, 7, and 8, where its outcrop is conspicuously marked by large limestone concretions (figs. 7 and 8). Southward, bed *V* thins to less than 10 feet in the southern part of section 17; from section 20 southward, both the bentonite and the characteristic large concretions are apparently absent. Tests of samples of bed *V*, taken at point 9 in section 6 and at point 11 in section 8, suggest the presence of foundry clay of fairly good quality; within this township, the bed is estimated to contain approximately 4,200,000 short tons of bentonite under less than 30 feet of overburden.

The outcrop of bed *W* (fig. 9) extends in a southerly direction across the township. Along most of its outcrop, this bed consists of relatively pure, light-colored bentonite, with a maximum thickness of 8 feet, which is overlain by a layer of bentonitic shale; in the northern part of section 6, the bed appears to contain only bentonitic shale. Tests of samples from point 10 in section 8, and from point 12 in section 20, indicate that the bed contains good foundry clay and some low-grade well-drilling clay. Within this township, bed *W* is estimated to contain about 5,550,000 short tons of bentonite under less than 30 feet of overburden. Attractive mining sites occur on the numerous spurs and outliers in sections 20, 21, 28, and 29.

Following are measured sections of the bentonite beds and associated rock materials at four points in T. 2 S., R. 35 E.

Sections measured in T. 2 S., R. 35 E.

	Material	Thickness: All beds, Feet	All beds, Inches	Bentonite only, Feet	Bentonite only, Inches
Point 9. SE¼SE¼ sec. 6:					
	(Roof not exposed)				
Bed *V*	1. *Bentonite, gray, gypsiferous, with some dark mineral particles	12	8	12	8+
	2. Bentonite (not penetrated in boring)	?	?		
	3. Shale, dark-gray, hard, siliceous, chert-like.		0		
Point 10. NW¼SE¼ sec. 8:					
	1. Shale, brown, soft	---	2	---	----
Bed *W*	2. Bentonite, brown, impure, granular	1	4	5	1
	3. *Bentonite, light-olive-green and gray interlaminated, waxy	1	7		
	4. *Bentonite, olive-green, waxy	---	8		
	5. *Bentonite, gray, waxy	1	2		
	6. *Bentonite, olive-green, waxy	---	4		
	7. Shale, bentonitic, brown, hard.				
Point 11. SE¼SW¼ sec. 8:					
	1. Sandstone, gray, coarse-grained, containing plant remains and pelecypods	2	0	---	----
Bed *V*	2. *Bentonite, greenish-gray, waxy, gypsiferous, with dark mineral particles	3	6	21	6
	3. *Bentonite, gray, cornmeal texture	6	6		
	4. *Bentonite, light-gray, granular hard	11	6		
	5. Shale, dark-brown, sandy, siliceous, containing plant remains	---	6	---	----
	6. Shale, brown, sandy, soft.				
Point 12. SW¼NE¼ sec. 20:					
	1. Shale, bentonitic, brown	1	8	---	----
Bed *W*	2. *Bentonite, brownish-gray, granular, gypsiferous	1	9	7	4
	3. *Bentonite, greenish-gray, waxy, gypsiferous	---	3		
	4. *Bentonite, gray, waxy	2	0		
	5. *Bentonite, light-gray, waxy	1	0		
	6. *Bentonite, gray, waxy	1	9		
	7. *Bentonite, light-gray, waxy	---	7		
	8. Shale, bentonitic, dark-brown.				

T. 3 S., R. 30 E.

The surface of the eastern half of this township, including 15 square miles shown in plate 1, is comparatively rough. This part of the township is crossed by the North and South forks of Woody Creek, both of which are flanked by flood plains underlain by Recent alluvium; the alluvium also extends along the lower parts of the largest tributaries of these streams.

In a small area west of a synclinal axis that extends northward across section 34, the bedrock dips gently eastward; in the remainder of the area it dips gently westward from the Woody Creek dome, which has its apex in the next township to the east. The rocks exposed in this area include the uppermost part of the Belle Fourche shale, which crops out in about 3 square miles within the eastern boundary, and strata of the Greenhorn and Carlile-Niobrara members, which crop out farther west. The exposed rocks are not known to contain bentonite deposits of value.

T. 3 S., R. 31 E.

This township, whose northeast corner is about 12 miles southeast of Hardin, can be reached by truck over unimproved roads and trails branching westward from a graveled road that crosses the next township to the east.

The township has moderate topographic relief. Woody Creek, whose flood plain is underlain by Recent alluvium, meanders across its central part. There are older alluvial deposits on stream terraces, the largest and highest of which are at the southern and northeastern margins of the township.

The geologic structure is that of a broad dome of small closure, known as Woody Creek dome, with its apex in the south-central part of the township. A normal fault, upthrown on its southeastern side with a vertical displacement of more than 100 feet, cuts northeastward across the apical part of this dome; a few normal faults with small displacements are present in the north-central part of the township.

The oldest strata exposed are those of the Mowry shale, which form two inliers on opposite sides of the fault that crosses the apex of the dome. The youngest rocks are those of the Carlile-Niobrara unit, which crop out in a broad belt along the northern margin and in about ½ square mile inside the southwestern corner of the township. The Greenhorn calcareous member crops out conspicuously in narrow belts bordering these two areas; the Belle Fourche member forms the bedrock in broad areas intervening between the outcrops of Mowry and Greenhorn. Bentonite beds are present in the Mowry, Belle Fourche, and Greenhorn units.

The Clay Spur bentonite bed, in the topmost strata of the Mowry shale, is nearly horizontal as exposed in the two inliers in the central part of the Woody Creek dome. According to laboratory tests of a sample from point 16, this bed contains good foundry and drilling clay; it is only 1 foot, 7 inches thick at that point, however, and the topographic configuration there, and elsewhere along its outcrops, indicates that the bentonite lies under light overburden only in narrow zones; consequently, the reserve of minable clay in the Clay Spur bed, as exposed in this township, is probably negligible.

Within the township, on the north, west, and south flanks of the Woody Creek dome, the Soap Creek bentonite bed crops out extensively with low dip. Thicknesses of 12 feet, 5 inches, measured at point 14, and 10 feet, measured at point 13, are believed to be fairly representative of the thickness of this bed in the township as a whole; a sample taken at the latter point gave good results when tested as foundry clay. North of Woody Creek, in sections 24 and 13 and in the eastern half of section 14, the bed crops out in the basal part of a rather steep escarpment, and consequently it is present under light overburden in only a narrow zone. Elsewhere along its outcrop, the bed occurs at many sites that offer large tonnages under overburden thin enough to be removed easily. The total reserve available for mining is estimated at about 9,600,000 short tons.

Bentonite bed *L*, in the Belle Fourche, 40 to 60 feet stratigraphically higher than the Soap Creek bed, also crops out extensively with low dip, but its outcrop in this township is largely concealed by surficial detritus. At point 15, the bed is 5 feet, 6 inches thick, and, according to tests of a single sample, it contains material that could be used satisfactorily as foundry clay. Although the bed may offer a few fairly good mining sites along its outcrop, its reserves of minable material are small as compared with those in the Soap Creek bed.

A bentonite bed, believed to be bed *M*, is present in the escarpment north of Woody Creek, but it has not been found elsewhere in the township and has not been measured or sampled.

Following are measured sections of the bentonite beds and associated rock materials cropping out at four points in T. 3 S., R. 31 E.

Sections measured in T. 3 S., R. 31. E.

	Material	Thickness: All beds, Feet	All beds, Inches	Bentonite only, Feet	Bentonite only, Inches
Point 13.	SE ¼ SE ¼ sec. 8:				
	1. Shale, dark	--	11	---	----
Soap Creek bed	2. Bentonite, brownish-gray	1	3	10	8
	3. Bentonite, light-olive-green	9	5		
	4. Shale, dark-gray, hard siliceous, chert-like.				

Sections measured in T. 3 S., R. 31 E.—Continued

		Material	All beds Feet	All beds Inches	Bentonite only Feet	Bentonite only Inches
Point 14.		SW ¼ SE ¼ sec. 13:				
Soap Creek bed		1. *Bentonite, gray, granular	2	6	12	5
		2. *Bentonite, grayish-green, granular, with dark mineral particles	7	11		
		3. *Bentonite, light-gray, waxy, with many dark mineral particles	2	0	---	----
		4. Shale, dark-gray, hard, siliceous, chertlike.				
Point 15.		SW ¼ SE ¼ sec. 13:				
		1. Shale, dark-gray.				
Bed *L*		2. *Bentonite, greenish-yellow, with corn-meal texture; much selenite present	2	6	4	6
		3. *Bentonite, greenish-yellow, waxy, some iron stains in lower part; much selenite present	2	0		
		4. Shale, dark-gray.				
Point 16.		SW ¼ SW ¼ sec. 21:				
		1. Shale, dark-gray	---	11	---	----
Clay Spur bed		2. Bentonite, dark-gray and olive-green interlaminated, waxy	---	4	1	7
		3. *Bentonite, olive-green, waxy	1	3		
		4. Shale, dark-gray, hard, siliceous, chertlike.				

T. 3 S., R. 32 E.

The northeastern corner of this township is about 10 miles south-southwest of Hardin and lies about 4 miles beyond the bridge over which the hard-surfaced Hardin-St. Xavier road crosses the Bighorn River near the mouth of Two Leggin Creek. The township can be reached over a gravel road that extends southwestward from a point near the bridge; it can be entered also over unimproved roads and trails approaching from other directions.

The eastern half of the township lies almost wholly in a broad area of lowlands bordering Bighorn River, which enters from the south and flows for a distance of about 4 miles within the eastern boundary of the township. Here, the bedrock is almost completely concealed by alluvial deposits underlying the flood plain of the river and capping broad, low terraces. In the western half of the township, which is hilly, alluvial deposits are restricted to the flood plain along Woody Creek and to several terraces in the southwestern and northwestern parts of the township; here, bedrock strata, dipping gently northeastward on the flank of Woody Creek dome, are extensively exposed. The strata are displaced downward about 50 feet on the eastern side of a normal fault that trends south-southwestward in sections 18 and 19.

The oldest rocks exposed in the township are strata in the vicinity of Woody Creek that belong to the part of the Belle Fourche member that is below the Soap Creek bentonite bed. The Greenhorn and Carlile-Niobrara units crop out in much of the northwestern part of the township.

The Soap Creek bentonite bed, which crops out in the southwestern part, offers attractive mining sites in sections 19, 20, and 31; it is estimated to contain a minable reserve of 1,800,000 short tons within this township. At point 18, in section 19, on the east side of the above-mentioned fault, this bed is 13 feet, 9 inches thick and dips about 2 degrees north; at point 19, in section 28, it is 10 feet, 3 inches thick. Tests of a sample obtained at point 19 suggest that some of the bentonite would be marketable as foundry clay.

At point 18, in section 19, bed *L* is present in the Belle Fourche about 40 feet higher, stratigraphically, than the Soap Creek bed, and in sections 19 and 20 a bed of bentonite about 4 feet thick occupies a position about midway between the Soap Creek bed and the base of the Greenhorn calcareous member. Neither of these beds is present at sites where mining would be feasible, and they have been neither measured nor sampled.

At point 17, in section 19, the thickness of bed *M*, in the base of the Greenhorn calcareous member, is 7 feet, 9 inches, including 3 feet, 11 inches of bentonitic shale in its upper part. The material of the bed as a whole, as represented by two samples taken at point 17, is evidently suitable for use as sand-bonding clay, because it tested high in green compression strength and the bentonitic shale showed exceptionally high dry strength. However, bed *M* crops out in this township only on steep hillsides, where the cost of mining would probably be prohibitive.

Following are measured sections of bed M and the Soap Creek bentonite bed at three points in this township.

Sections measured in T. 3 S., R. 32 E.

		Thickness			
		All beds		Bentonite only	
	Material	*Feet*	*Inches*	*Feet*	*Inches*
Point 17. NE¼NE¼ sec. 19:					
	1. Shale, brown (light-gray when dry), calcareous	--	6	---	----
Bed *M*	2. *Shale, bentonitic, brown, limonite-stained, gypsiferous	3	11	7	9
	3. *Bentonite, gray, granular, gypsiferous, with mica flakes	2	6		
	4. *Bentonite, light-brown	---	3		
	5. *Bentonite, brownish-yellow, granular	---	1		
	6. *Bentonite, light-gray, granular, limonite-stained	1	0		
	7. Shale, dark-gray, soft.				

Sections measured in T. 3 S., R. 32 E.—Continued

	Material	Thickness: All beds, Feet	All beds, Inches	Bentonite only, Feet	Bentonite only, Inches
Point 18. NW¼SE¼ sec. 19:					
	1. Shale, brownish-gray, soft	---	5	---	----
Soap Creek bed	2. *Bentonite, brownish-gray, flaky	1	7	13	9
	3. *Bentonite, light-gray, flaky, gypsiferous	1	0		
	4. *Bentonite, greenish-gray, lighter-colored in lower part, flaky, granular in part, gypsiferous	10	8		
	5. *Bentonite, gray, waxy, with dark mineral particles	---	6		
	6. Shale, brownish-gray, hard, siliceous, chert-like	---	6	---	----
Point 19. NW¼NE¼ sec. 28:					
	1. Gravel	20	0	---	----
	2. Shale, dark	6	0	---	----
Soap Creek bed	3. Bentonite, dark-gray, waxy	---	10	10	1
	4. Bentonite, light-gray-green, hard, chunky	9	3		
	5. Shale, dark-gray.				

T. 3 S., RS. 33 AND 34 E.

The rectangular tract encompassing these two contiguous townships includes the town of Crow Agency, which lies within its northeast corner on Little Bighorn River, and segments of U. S. Highway 87, and the Chicago, Burlington and Quincy Railroad. Bighorn River flows in a northeasterly direction within the northwestern corner of the tract. From a drainage divide that extends northward across the central part of the tract, the land slopes generally eastward to the Little Bighorn and westward to the Bighorn. In much of the northeastern and extreme western parts of the tract, surficial deposits conceal the bedrock; the strata in all parts of the tract dip in westerly directions, and they include rocks belonging to the Judith River formation, the Carlile-Niobrara, and undivided upper members of the Cody shale. None of the rocks exposed here are known to contain valuable bentonite deposits.

T. 3 S., R. 35 E.

The Chicago, Burlington and Quincy railroad crosses this township in a northerly direction. The northwestern corner of the township is less than 1 mile northeast of Crow Agency station. Garryowen siding is in section 32. U. S. Highway 87 parallels the railroad and is joined about 1½ miles south of Crow Agency by State Highway 8, which extends eastward across the central part of the township. Near the junction of the highways, a hard-surfaced road branches southeastward from Highway 8, passes through the Custer Battlefield National Cemetery, and continues to the Reno Battlefield in section 34. An unimproved road leads from Crow Agency to the north-central part of the township.

Little Bighorn River flows in a northwesterly direction midway between the Battlefield road and Highway 87 and crosses the west township line at a point near the Cemetery, where it turns northward. Beyond Crow Agency, it re-enters the township and cuts across the northwestern corner of section 6.

The surface of the township slopes downward from its eastern boundary to the flood plain of Little Bighorn River. Recent alluvial deposits underlie the flood plain and extend for several miles along two tributaries that enter the river from the east; older alluvium is present on low terraces bordering the flood plain.

The exposed bedrock dips gently eastward; it belongs to the Bearpaw shale everywhere except in an area underlain by the Hell Creek beds in the northeastern part of section 1, and in a belt of Judith River formation extending northward from the Cemetery, close to the river. The middle bentonitic unit of the Bearpaw shale crops out in an area within the Reno Battlefield and continuing northward across the central part of the township; this unit crosses Highway 8 in section 16 and leaves the township at the north line of section 4.

The Bearpaw shale contains numerous bentonite beds, but only bed *W*, in the middle bentonitic unit of the formation, is thick enough to be considered minable within this township. Its thickness in section 4 is nearly 10 feet, but it is considerably thinner in the southern half of the township. Tests of a sample obtained at point 20 suggest the presence of material that might be used as rotary well-drilling clay, and a sample from point 22 showed exceptionally high green strength when tested as foundry clay. Bed *W* is estimated to contain approximately 1,350,000 short tons of crude bentonite, under less than 30 feet of overburden, within T. 3 S., R. 35 E. The best mining sites are in section 4.

Following are sections of bed *W* and associated bedrock at three points along its outcrop.

Sections measured in T. 3 S., R. 35 E.

	Material	Thickness: All beds, Feet	All beds, Inches	Bentonite only, Feet	Bentonite only, Inches
Point 20. NE¼NE¼ sec. 4:					
	1. Shale, gray, soft	2	1	---	----
Bed *W*	2. *Bentonite, gray, waxy	---	7		
Bed *W*	3. *Bentonite, light-gray, waxy, gypsiferous	3	1		
Bed *W*	4. *Bentonite, cream-colored, granular, gypsiferous	---	5		
Bed *W*	5. *Bentonite, light-gray, waxy, gypsiferous	3	5	9	11
Bed *W*	6. *Bentonite, dark-gray, granular	1	6		
Bed *W*	7. *Bentonite, cream-colored, waxy, gypsiferous	---	9		
Bed *W*	8. Bentonite, yellowish-gray, waxy	---	2		
	9. Shale, dark-gray.				

Sections measured in T. 3 S., R. 35 E.—Continued

		Material	Thickness: All beds, Feet	All beds, Inches	Bentonite only, Feet	Bentonite only, Inches
Point 21. SE¼SW¼ sec. 16:						
		1. Soil and clay, light-brown	3	5	---	---
Bed *W*		2. Bentonite, cream-colored, waxy	2	---	5	2
		3. Clay, light-brown	1	7		
		4. Bentonite, yellowish-gray, waxy	---	9		
		5. Bentonite, cream-colored, waxy	---	10		
		6. Shale, light-brown.				
Point 22. NE¼NE¼ sec. 33:						
		1. Shale, brownish-gray, somewhat sandy.				
Bed *W*		2. *Bentonite, gray, waxy	3	0	3	0
		3. Shale, brownish-gray, somewhat sandy.				

T. 4 S., R. 30 E.

This township has a comparatively rough surface. The three largest streams—Beauvais Creek, Muddy Creek, and an affluent of Muddy Creek—are bordered by narrow flood plains underlain by Recent alluvium. Older alluvial deposits lie on several terrace remnants in the east-central part of the township.

In an arcuate monoclinal belt extending southeastward from the northwestern corner of the township, the strata dip rather steeply in northeasterly to easterly directions; throughout the rest of the township, on both sides of this belt, the dip is more gentle. A shallow syncline parallels the monoclinal belt on its east side; the area on the west side of the belt has a rather uniformly gentle, but irregular, dip, as indicated by the structure contours on plate 1. The bedrock exposed within the syncline belongs to the Carlile-Niobrara sequence; the bedrock of the remainder of the township includes strata of the Thermopolis and Mowry formations, as well as the Belle Fourche and Greenhorn members. Bentonite beds are present in this township but there are no known deposits that could be mined economically.

T. 4 S., R. 31 E.

The surface of this township is comparatively rough. Beauvais Creek flows eastward across the northern half, and Hay Creek flows for about 5 miles within the southern margin. The bedrock of the township is partly concealed by Recent aluvium underlying narrow flood plains that border these two streams and by older alluvial deposits lying on widely scattered terraces. The geologic structure of the township is that of an anticline, the axis of which extends in a northerly direction across its eastern half. The bedrock strata dip gently on both limbs of this anticline. The Mowry shale crops out within the east boundary of the township, where the anticlinal axis crosses Beauvais Creek, and the Belle Fourche member is extensively exposed in the eastern and northern parts of the township. The Greenhorn and Carlile-Niobrara members are exposed in its southwestern part and along its western margin.

Bentonite beds in the Mowry shale and in the Belle Fourche member are conspicuously exposed in a steep southward-facing slope on the north side of Beauvais Creek. Tests of a sample of the Clay Spur bentonite bed, obtained at point 24, where it is 3 feet, 3 inches thick and dips gently eastward, indicate the presence of foundry clay having good dry compression strength. However, this bed and several others, including bed *J* and the Soap Creek bentonite bed, crop out only in hillside sites where only negligible amounts of clay occur under light overburden. Attractive mining sites have not been found in this township.

Following are sections of the bentonite beds and enclosing bedrock, as measured at points 23 and 24.

Sections measured in T. 4 S., R. 31 E.

	Thickness			
	All beds		Bentonite only	
Material	*Feet*	*Inches*	*Feet*	*Inches*
Point 23. E½ sec. 11:				
1. Covered interval to top of gravel terrace	28	5	---	----
2. Bentonite, yellowish-green	3	7	3	7
3. Shale, dark-gray, fissile, with a few thin beds of sandstone	57	0	---	----
4. Bentonite, cream-colored, waxy	1	0	1	----
5. Shale, dark, fissile	19	0	---	----
6. Sandstone, thin beds and plates; intercalated shale, dark-gray	3	0	---	----
7. Sandstone, brown, soft, shaly	2	0	---	----
8. Shale, dark; some layers consist of thin beds and laminae of bentonite and shale	14	0	---	----
9. Shale and bentonite, in alternating thin beds and laminae	5	0	---	----
Bed *J*----10. Bentonite, green; contains bluish-gray clay nodules	2	5	2	5
11. Shale, dark-gray, and siltstone, light-gray, in alternating plates and laminae	25	0	---	----
12. Bentonite	---	1½	---	1½
13. Shale, dark-gray	15	0	---	----
14. Sandstone, dark-gray, fine-grained, ferruginous	---	6	---	----
15. Shale, gray, sandy	14	6	---	----
16. Shale, reddish-brown, fissile	2	9	---	----
17. Shale, dark-gray, bentonitic	---	7	---	----
18. Bentonite, dark-greenish-gray	2	4	3 (18–19)	2 (18–19)
19. Bentonite, greenish-gray	---	10		
20. Shale, dark, fissile; sandy in upper part	21	0	---	----
21. Bentonite, olive-green, waxy, with dark mineral particles	2	2	2	2

Sections measured in T. 4 S., R. 31 E.—Continued

		Material	Thickness: All beds, Feet	All beds, Inches	Bentonite only, Feet	Bentonite only, Inches
Point 23. E½ sec. 11—Continued						
	22.	Shale, dark-gray	3	6	---	----
	23.	Bentonite, greenish-yellow, flaky	---	4	---	4
	24.	Shale, dark-gray	3	9	---	----
	25.	Bentonite, dark-greenish-gray	---	4½	---	4½
	26.	Shale, dark-gray; makes conspicuous dark band on weathered surfaces	23	0	---	----
	27.	Bentonite, dark-grayish-green, flaky (base of Frontier)	---	8	---	8
	28.	Shale, gray, fissile, siliceous	5	8	---	----
Clay Spur bed	29.	Bentonite, light-green, flaky	3	3	3	3
	30.	Shale, gray, fissile, with a few partings of fine-grained platy sandstone	14	0	---	----
	31.	Shale, gray, with a few thin beds of sandstone in the upper part	25	0	---	----
	32.	Shale, olive-green	2	0	---	----
	33.	Bentonite, bright-yellowish-green, waxy, with dark mineral particles	---	9	} 1	} 2½
	34.	Bentonite, variegated orange, red and yellow	---	5½		
	35.	Sandstone, fine-grained, thin-bedded	6	0	---	----
	36.	Shale, brownish-gray, bentonitic	5	0	---	----
	37.	Sandstone, fine-grained, thin-bedded, with thin, fissile, gray shale partings	7	0	---	----
	38.	Shale, dark-gray, fissile	6	0	---	----
	39.	Bentonite, light-greenish gray, waxy	1	6	} 3	} ----
	40.	Bentonite, green, with ½-inch of yellow at base	1	6		
	41.	Shale, dark-gray; silicified in upper 3 ft; weathers light-bluish-gray	14	0	---	----
Point 24. SE¼NE¼ sec. 11:						
	1.	Shale, light-gray, siliceous, fissile	---	1	---	----
Clay Spur bed	2.	*Bentonite, olive-green and gray interlaminated, waxy	1	4	} 2	} 11
	3.	*Bentonite, olive-green, waxy	1	7		
	4.	Shale, dark-gray, hard, siliceous, chert-like.				

T. 4 S., R. 32 E.

The central and eastern parts of this township lie in the wide area of lowlands bordering Bighorn River, which flows in a northerly direction across the central part; the western half of the township includes a broad tract of the adjacent upland. Rotten Grass Creek, a tributary entering from the southeast, joins Bighorn River near St. Xavier, a small settlement in the southeastern part of the township; Beauvais and Hay Creeks flow eastward to Bighorn River in the central and southern parts.

The bedrock is largely concealed by Recent alluvium beneath the flood plains of the river and the three above-mentioned tributaries, and the bedrock is concealed also by older alluvial deposits on terraces that are widely distributed over the township. Nevertheless, the geologic structure is known to be essentially homoclinal, with a low dip toward the east. The Mowry shale crops out for a distance of 2½ miles along Beauvais Creek, and the Belle Fourche member crops out extensively between the river and the west township line, in belts lying between areas occupied by older alluvial deposits.

At a point a little more than 1 mile west of this township—point 24, in T. 4 S., R. 31 E.—the Clay Spur bentonite bed, which is 3 feet, 3 inches thick, contains good foundry clay. In T. 4 S., R. 32 E., the Clay Spur bed is well exposed north of Beauvais Creek. The Soap Creek bentonite bed crops out on the west side of section 7, but it is concealed farther east, partly by old alluvial deposits and partly by surficial detritus of Recent origin. Although both of these beds dip gently, they are exposed only on hillsides where the amount of bentonite under light overburden is small.

T. 4 S., R. 33 E. AND PART OF R. 34 E.

A rectangular tract of approximately 63 square miles that has been mapped within these two townships (pl. 1) includes the eastern margin of the broad area of lowland bordering Bighorn River in the vicinity of St. Xavier. The remainder of the tract is moderately rugged, and the drainage divide between Bighorn River and Little Bighorn River extends in a northerly direction across the central part.

The bedrock is concealed by Recent alluvium in the lowland near St. Xavier. On the adjacent higher ground to the east, it is concealed locally by older alluvial deposits on several small remnants of terraces, and a still older alluvial deposit occurs several hundred feet higher, in the SW¼ sec. 35. Outcrops of the Belle Fourche, Greenhorn and Carlile-Niobrara members, and undivided upper Cody strata occur in the hilly country between the western marginal lowland and the east end of the tract. No bentonite deposits of commercial value are known to be exposed within this tract.

T. 5 S., R. 30 E.

The surface of this township, which has an overall slope downward and toward the northeast, is rather rugged in the southwestern part and in and adjacent to the Big Horn Mountains, but it is less rugged farther to the northeast. The bedrock in the northern part is partly concealed by Recent alluvium underlying the narrow flood plain of Muddy Creek; in areas aggregating several square miles in the eastern part, it is concealed by older alluvial deposits.

The geologic structure is essentially homoclinal with a northeasterly dip. Pre-Cretaceous rocks are exposed in the southwestern uplands, and Carlile-Niobrara beds crop out in an area of about 7 square miles in the eastern part of the township. The intervening Cretaceous rock strata, comprising the Cloverly, Thermopolis, and Mowry formations and the Belle Fourche and Greenhorn members, crop out in a belt extending diagonally southeastward across the township. The Cretaceous rocks include many bentonite beds, some of which are of minable thickness, but their dip is so steep that only small amounts of clay are present under light overburden; this township therefore contains no attractive mining sites.

T. 5 S., R. 31 E.

In the north-central part of section 9 of this township, a good road leads northeastward toward Hardin from the Williams ranch office.

Bighorn River flows in a northeasterly direction within the southeast margin of the township, and Muddy Creek flows within the northwest margin. Recent alluvium underlies flood plains along these streams, and alluvial deposits also conceal the bedrock within extensive areas occupied by remnants of ancient terraces.

The geologic structure is somewhat obscured by the widespread alluvial deposits, but available evidence suggests that most of the township is occupied by a broad, shallow synclinal basin, the axis of which trends in a northwesterly direction across the western half of the township. However, the structure of areas north and south of the township suggests that an anticlinal axis extends northward within its eastern margin.

The oldest bedrock strata exposed in the township belong to the Mowry shale, which crops out on the northwest side of Bighorn River, and the youngest strata belong to the Carlile-Niobrara sequence, which crops out along the marginal escarpment of a large terrace that occupies most of the land in the western half of the township. The Greenhorn calcareous member is poorly exposed in a narrow belt along this escarpment, and the Belle Fourche member crops out in a rather broad belt, largely covered by alluvial deposits, between the escarpment and the Bighorn River.

Strata of the Mowry, Belle Fourche, and Greenhorn include many bentonite beds, some of which are of minable thickness. These beds have not been studied in detail because of the extensive cover of surficial material and vegetation; nevertheless, it is considered possible that, from section 27 northward, the Belle Fourche member may contain large quantities of bentonite under light overburden.

T. 5 S., R. 32 E.

This township can be reached from St. Xavier, which lies 2 miles from its north boundary, over a graded road that extends along the southeastern side of the valley of Bighorn River. A road that branches off near the auxiliary airfield in section 29 leads to the Soap Creek oil field, in the next township to the south.

The part of the township shown in plate 1 lies largely in a broad area of lowland plains bordering the river, which flows for a distance of about 5 miles within the west margin of the township. Recent alluvium underlies these plains and a narrow belt along Soap Creek, a tributary entering the river from the south; this material and the older alluvial deposits on extensive terraces conceal the bedrock for many square miles on both sides of the river.

The geologic structure of the southwestern quarter of the township is that of a broad anticlinal nose plunging in a northerly direction. The structure of the rest of the township is largely concealed by the extensive alluvial deposits, but there is evidence that all the strata dip gently eastward.

The Thermopolis shales is exposed in a small area in section 32, within the anticlinal nose, where it is in contact on its eastern side with the Mowry shale, which crops out in an area largely covered by older alluvial deposits on the western side of the Soap Creek dome. The Mowry is exposed also in a small area on the western side of the Bighorn River in section 19. The Belle Fourche member is exposed farther north along the river and in a broad belt within the northwestern margin of the township. The valley of Bighorn River is bordered on the east, as far north as section 1, by an outcrop of the Belle Fourche member extending along the lower slopes of the eastern hilly belt. The higher parts of this belt are underlain by beds of the Greenhorn member and the Carlile–Niobrara member.

The exposed bedrock formations include bentonite beds, but, because of the extensive alluvial cover, no deposits are present in this township at sites where mining would be feasible.

T. 5 S., RS. 33 AND 34 E.

A rectangular tract of approximately 63 square miles has been mapped within these two townships (pl. 1). The western half of this tract is crossed by a graveled road that extends along Rotten Grass Creek; trails branching northward near the center of T. 6 S., R. 34 E. give access to the eastern half.

The lowest land within the tract lies along Rotten Grass Creek; the highest ground lies along the crest of a prominent cuesta that extends in a north-northwesterly direction across the central part, forming the drainage divide between Rotten Grass Creek and Little Bighorn River.

Alluvial deposits of Recent age underlie the flood plain along Rotten Grass Creek; many remnants of older alluvial deposits lie at higher altitudes west of that stream, and still older aluvium occupies a few small areas east of the drainage divide.

Throughout the tract, the bedrock dips in easterly directions at low angles; several small tear faults cross the central cuesta. The Greenhorn calcareous member crops out in a small area at the northwestern corner of the tract, but almost everywhere else in the western third of the tract the bedrock belongs to the Carlile-Niobrara member of the Cody shale. The bedrock belongs to the undivided upper Cody everywhere east of a crooked line about half-way between Rotten Grass Creek and the boundary between the two townships.

Strata of the part of the undivided upper member of the Cody shale that is thought to be stratigraphically equivalent to the Eagle sandstone crop out in a belt along the central cuesta. A bentonite bed that is tentatively correlated with bed *R* crops out prominently in the westward-facing escarpment of the cuesta; this bed also crops out in two areas in sections 29, 32, and 33, where the eastern, dip-slope, side of the cuesta has been incised by minor streams to form inliers of the strata beneath the bed. Here the bentonite bed is underlain by a thin bed of coarse sand and shale with abundant fragments of silicified wood and rounded, water-worn fossil cephalopods.

The bentonite contained in the bed is not of uniform thickness; however, a thickness of 9 feet, present at the locality in which the following section was measured, probably represents the approximate average thickness of the bed. The part of the bed at a depth of less than 30 feet below the land surface is estimated to contain a reserve of about 15 million short tons of bentonite, most of which occurs in areas broad enough to favor strip-mining. Although the bed has not been sampled here, test data on bed *R*, with which it is tentatively correlated, are given in table 1 for samples from T. 1 S., R. 34 E.

Section measured in T. 5 S., Rs. 33 and 34 E.

	Material	Thickness: All beds, Feet	All beds, Inches	Bentonite only, Feet	Bentonite only, Inches
Point 26A, sec. 19:					
	1. Soil and shale, bentonitic, grayish-brown, weathered	---	6	---	----
Bed *R?*	2. Bentonite, light-yellowish gray, granular, with traces of selenite	8	0	9	----
Bed *R?*	3. Bentonite, light-yellow, granular	---	4		
Bed *R?*	4. Bentonite, light-yellowish gray, granular	---	8		
	5. Sand, dark-gray, shaly, containing cherty pebbles, water-rounded fragments of silicified wood and fossil cephalopods	---	3	---	----
	6. Shale, soft, dark-gray.				

T. 6 S., R. 31 E.

The area within this township that is shown on plate 1 lies at the base of the Big Horn Mountains and includes in its northern part a segment of the Bighorn River immediately below the Yellowtail dam site. Steeply sloping land extends along the southwestern margin of this area, and a belt of upland lies along its eastern margin. The intervening land slopes northeastward to War Man Creek. Farther north, a broad belt of lowland extends along the river. Most of this lowland belt is occupied by Recent alluvium, which also extends along War Man Creek; it also includes large areas underlain by older alluvial deposits.

The geologic structure of the township is essentially homoclinal, with the over-all dip northeastward. Cloverly, and older, rocks crop out along the southwestern margin, and in a small area north of Bighorn River they are overlain by strata of the Thermopolis and Mowry formations and the Belle Fourche member that dip rather steeply northward. Southeast of the river, a broad outcrop of Thermopolis shale lies between the Cloverly and strata of the Mowry that crop out with gentle dip on the upland at the eastern margin of the township.

The Thermopolis, Mowry, and Belle Fourche strata include bentonite beds, but unfavorable geologic structure and topographic features probably rule out any possibilities for profitable mining in this township.

T. 6 S., R. 32 E.

This township is remote from rail transportation, but it is conveniently accessible over a graveled road that enters from the north and extends to the Soap Creek oil field, which is situated within the south boundary. Soap Creek, a perennial stream, enters from the south and flows northward across the central part of the township along a flood plain bordered by low, stream-carved terraces; a large tributary, West Soap Creek, also enters from the south and joins the main stream near the center of the township.

The part of the township lying west of Soap Creek and its large tributary is mostly upland, although Beaver Creek makes a long, deep incision extending northward from the southern boundary, and low terraces associated with Bighorn River occupy a small area at the northwestern margin of the township. The land on the eastern side of Soap Creek valley rises, in an escarpment of moderate steepness facing westward, to another belt of high land that extends along the entire eastern margin of the township. In the vicinity of the Soap Creek oil field, however, a conspicuous hogback extends in a north-northwesterly direction between the creek and the main escarpment.

The Soap Creek dome, an elongated, asymmetrical fold having its steeper limb on the eastern side and its apex in the northern part of section 34, extends across the township in a north-northwesterly direction. On its western side, this dome is paralleled by a shallow synclinal belt that occupies most of the western half of the township.

The oldest strata exposed are those of the Morrison formation, which forms a small inlier at the apex of the Soap Creek dome; the youngest strata belong to the Carlile–Niobrara unit, which is exposed in the upland at the east margin of the township. Outcrops of all the intervening rock units are present between this upland and the inlier beds of the Morrison formation; the detailed stratigraphic sections of the Thermopolis, Mowry, Belle Fourche, and Greenhorn units, appearing in a preceding chapter of this report, were measured in this vicinity (in sections 35 and 36). Within this township, the bedrock exposed on the west limb of the Soap Creek dome belongs chiefly to the Thermopolis shale. It is succeeded farther west, in the adjacent broad synclinal belt, by the Mowry shale, which is the most extensively exposed bedrock formation in the uplands of the western part of the township.

At least 15 bentonite beds with thicknesses of more than 18 inches crop out in this township, and several of these beds contain good foundry and well-drilling clay.

Results of tests of a sample from the Clay Spur bentonite bed (in the topmost strata of the Mowry shale) at point 27 suggest that the material of that bed is probably the best drilling clay exposed in the township, though other test data indicate that beds *A* and *B* in the Thermopolis shale and bed *L* in the Belle Fourche shale member also contain clay suitable for drilling. Good sand-bonding clay is present in nearly all of the bentonite beds. Samples of the Soap Creek bed, obtained at point 29 where the bed is 12 feet thick, showed exceptionally high green strength and good dry strength. The Soap Creek bed is estimated to contain approximately 2,520,000 short tons of accessible clay in a sinuous belt, about 3½ miles long and averaging about 200 feet wide, that extends from section 15 to section 36. Nearby, bed *M* (at the base of the Greenhorn calcareous member) contains a minable reserve of clay estimated at 230,000 short tons; a sample of this material from section 36 consists of bentonitic shale that tested high in dry strength and showed moderate green strength. The structural and topographic features associated with the remainder of the bentonite beds exposed in this township indicate that the amount of clay under light overburden is present in extremely narrow belts and is too small for economical mining.

Measured sections of the bentonite beds and associated rock materials cropping out at five numbered points in T. 6 S., R. 32 E. are given in the following table. The sections for points 27, 28, and 29 consist partly of data that are given also in stratigraphic sections appearing elsewhere in this report.

Sections measured in T. 6 S., R. 32 E.

	Material	Thickness: All beds, Feet	Thickness: All beds, Inches	Thickness: Bentonite only, Feet	Thickness: Bentonite only, Inches
Point 25. SW¼ sec. 4:					
	1. Shale, alternating light-and dark-gray layers, containing a few thin bentonite beds and a few ferruginous concretions	20	0	---	----
	2. Shale and bentonite, alternating thin beds	15	0	---	----
	3. Shale, like No. 1 (above)	27	0	---	----
	4. Bentonite	2	0	---	----
	5. Shale, like No. 1 (above)	35	0	---	----
Bed *B*	6. Bentonite, impure	---	8		
Bed *B*	7. Bentonite, light-olive-green, waxy	---	8		
Bed *B*	8. Bentonite, reddish-brown and olive-green, mottled, waxy	---	4	2	8
Bed *B*	9. Bentonite, greenish-yellow, waxy	1	0		
	10. Shale, like No. 1 (above)	40	0	---	----
Bed *A*	11. Bentonite, light-greenish-yellow, darker in upper part, flaky	2	8	2	8
	12. Shale, like No. 1 (above)	80	0	---	----
	13. Bentonite, dark, impure	---	8		
	14. Bentonite, dark-gray, olive-green in lower 3½ in., waxy	---	8½	1	4½
	15. Shale, dark-gray	2	6	---	----
	16. Bentonite, dark-olive-green, lighter-colored near base, waxy	1	5½	1	5½
	17. Shale, dark, with thin plates of yellowish-green bentonite	2	6	---	----
	18. Shale, gray, hard, siliceous, chertlike	---	3	---	----
	19. Shale, gray	20	0	---	----
Point 26. NW¼NW¼ sec. 22:					
Bed *C* or Bed *D*	1. Shale	---	0	---	----
Bed *C* or Bed *D*	2. Bentonite, yellowish-green	2	0	2	0
Bed *C* or Bed *D*	3. Shale.				
Point 27. NW¼SW¼ sec. 26:					
	1. Shale, dark-gray, soft	---	6	---	----
Bed *I*	2. Bentonite, dark-gray, waxy	---	6		
Bed *I*	3. *Bentonite, olive-green, granular, with dark mineral particles	3	2		
Bed *I*	4. *Bentonite, brownish-yellow, cornmeal texture, rusty-colored near middle	1	1	5	9
Bed *I*	5. *Bentonite, greenish-gray, waxy, with dark mineral particles	---	9		
Bed *I*	6. *Bentonite, rusty-colored, cornmeal texture	---	3		

Sections measured in T. 6 S., R. 32 E.—Continued

	Material	Thickness: All beds, Feet	Thickness: All beds, Inches	Thickness: Bentonite only, Feet	Thickness: Bentonite only, Inches
Point 27. NW¼SW¼ sec. 26—Continued					
	7. Shale, dark-gray, bentonitic, containing three very thin bentonite beds and some ferruginous concretions	7	6	---	----
	8. Bentonite, gray, containing much brown aragonite	1	6	1	6
	9. Shale, dark-gray, lower part sandy	2	0	---	----
	10. Bentonite, grayish-green, containing some brown aragonite (base of Frontier formation)	2	0	2	0
	11. Sandstone interbedded with shale, gray, hard	3	6	---	----
Clay Spur bed	12. *Bentonite, dark-gray and brown, impure, granular	4	6		
Clay Spur bed	13. *Bentonite, greenish-gray, waxy	---	8		
Clay Spur bed	14. *Bentonite, light-olive-green, waxy, gypsiferous	2	4	9	10
Clay Spur bed	15. *Bentonite, greenish-gray, waxy, gypsiferous, with dark mineral particles	2	4		
Clay Spur bed	16. *Bentonite, limonite-stained	---	½		
	17. Shale, dark-gray, hard, siliceous, chert-like.				
Point 28. NW¼, sec 35:					
	1. Shale, bentonitic, dark-brown, granular	1	6	---	----
Bed *G*	2. *Bentonite, gray, waxy, with dark mineral particles	---	4		
Bed *G*	3. *Bentonite, olive-green, waxy, gypsiferous, with dark mineral particles	1	11	2	8
Bed *G*	4. *Bentonite, greenish-gray, waxy, with dark mineral particles	---	3		
Bed *G*	5. *Bentonite, light-gray, waxy	---	2		
	6. Shale, dark-gray, hard, siliceous, chert-like	32	0	---	----
	7. Shale, weathers light-gray, hard; forms crest of Mowry hogback	21	0	---	----
Bed *F*	8. *Bentonite, brownish-gray, granular, impure	1	4		
Bed *F*	9. *Bentonite, olive-green and dark-gray, interlaminated, waxy	---	8	4	7
Bed *F*	10. *Bentonite, greenish-gray, waxy with dark mineral particles	2	4		
Bed *F*	11. *Bentonite, greenish-gray, waxy	---	3		
Bed *F*	12. Shale, weathers light-gray, siliceous	---	11	---	----
Bed *F*	13. *Bentonite, light-gray, granular	2	9		
Bed *F*	14. *Bentonite, light-gray (darker than above), waxy, with some dark mineral particles	---	8	4	3
Bed *F*	15. *Bentonite, olive-green, waxy	---	10		

Sections measured in T. 6 S., R. 32 E.—Continued

Material	Thickness: All beds, Feet	All beds, Inches	Bentonite only, Feet	Bentonite only, Inches
Point 28. NW¼, sec. 35—Continued				
16. Shale, dark-grayish-brown, hard, siliceous, chert-like	---	6	---	----
17. Shale, weathers light-gray, with a 4-in. and a 6-in. bentonite bed in the lower part	29	6	---	----
18. Bentonite, light-green	2	0	2	0
19. Siltstone and shale, weathering light-gray, hard; interbedded and interlaminated. Several thin bentonite beds in lower 50 ft. Some interbedded fine-grained sandstone in upper 45 ft	110	0	---	----
20. Bentonite, yellow	2	0	2	0
21. Shale, dark-gray, silty, with two thin bentonite beds	6	0	---	----
22. Bentonite, yellow and light-green	1	0	1	0
23. Shale, dark-gray, silty, with few thin bentonite beds in the upper part	29	0	---	----
24. Bentonite, green	2	8	2	8
25. Shale, dark-gray, silty; interlaminated with lighter-gray hard siltstone and very fine grained sandstone	13	0	---	----
26. Bentonite, light-gray	1	0	1	0
27. Shale, dark-gray, hard, containing fish scales; weathers to dark, bare, steep slope	38	0	---	----
28. Bentonite, gray	---	4	---	4
29. Shale, dark-gray, hard, fissile, containing fish scales, weathers to silvery-gray	5	6	---	----
Bed *E*: 30. Bentonite, dark-brown, impure, granular	---	8	4 (beds 30–32)	8 (beds 30–32)
Bed *E*: 31. *Bentonite, gray, waxy, limonite-stained, gypsiferous, with dark mineral particles	3	0		
Bed *E*: 32. *Bentonite, reddish-brown, waxy, gypsiferous, with dark mineral particles	1	0		
33. Shale, dark-gray, hard, fissile, containing fish scales (base of Mowry shale)	---	8	---	----
34. Shale, siltstone and three thin bentonite beds	79	2	---	----
Bed *D*: 35. Bentonite, dark-gray, granular	1	9	3 (beds 35–36)	8 (beds 35–36)
Bed *D*: 36. *Bentonite, olive-green, limonite-stained in lower part, waxy, with dark mineral particles	1	11		
37. Shale, dark-gray, bentonitic in part	36	6	---	----

Sections measured in T. 6 S., R. 32 E.—Continued

Bed	Material	All beds Feet	All beds Inches	Bentonite only Feet	Bentonite only Inches
	Point 28. NW¼, sec. 35—Continued				
	38. Shale, bentonitic, dark-gray	1	5		
Bed *C*	39. Bentonite, greenish-gray, granular, gypsiferous, appears waxy when moist	1	3	1	7
Bed *C*	40. *Bentonite, light-olive-green, waxy, gypsiferous	---	4		
Bed *C*	41. Shale with silty and sandy streaks; bentonitic in basal 13 ft; a 14-in. bentonite bed 30 ft. from top	85	8	---	----
Bed *B*	42. *Bentonite, light-gray, waxy, limonite-stained at base	1	1	1	1
Bed *B*	43. Shale, dark-brownish-gray, soft	1	0	---	----
Bed *B*	44. *Bentonite, greenish-gray, waxy, with dark mineral particles	2	0	2	0
	45. Shale, dark-gray, bentonitic, with numerous ferruginous concretions and light-gray-weathering claystone nodules	31	0	---	----
Bed *A*	46. *Bentonite, light-gray, limonite-stained, waxy, gypsiferous, with some dark mineral particles	1	7	2	10
Bed *A*	47. *Bentonite, greenish-gray, waxy, with dark mineral particles	1	3		
Bed *A*	48. Shale, bentonitic, dark-brown, granular	---	10	---	----
Bed *A*	49. Bentonite, light-gray, waxy	---	2	2	0
	50. Shale, bentonitic, brown	---	3	---	----
	51. Shale, dark-gray.				
	Point 29. Secs. 35 and 36:				
	1. Shale, dark-gray	1	10	---	----
Bed *O*	2. *Bentonite, brown, granular; with thin beds of gray, waxy, gypsiferous bentonite in lower part	2	8	3	2
Bed *O*	3. *Bentonite, greenish-gray, granular, gypsiferous	---	6		
	4. Sandstone	---	11	---	----
	5. Shale, dark-gray, soft	---	9	---	----
Bed *N*	6. *Bentonite, dark-greenish-gray, waxy, with dark mineral particles	---	5	3	1
Bed *N*	7. *Bentonite, dark-gray, waxy	---	3		
Bed *N*	8. *Bentonite, dark-greenish-gray, waxy, with dark mineral particles	2	2		
Bed *N*	9. *Bentonite, light-gray, granular, limonite-stained, with dark mineral particles	---	3		
	10. Shale, dark-gray, with fine sandy streaks (base of Carlile shale member)	35	0	---	----

Sections measured in T. 6 S., R. 32 E.—Continued

	Material	All beds Feet	All beds Inches	Bentonite only Feet	Bentonite only Inches
Point 29. Secs. 35 and 36—Continued					
	11. Shale, calcareous, dark-gray, weathering bluish and white, containing calcareous concretions	96	0	---	----
	12. Bentonite, gray, limonite-stained	1	0	1	0
	13. Shale, dark-gray	10	0	---	----
Bed *M*	14. *Shale, bentonitic, brown (base of Greenhorn calcareous member)	7	9	---	----
	15. Shale, dark-gray	105	0	---	----
	16. Shale, gray, bentonitic	18	0	---	----
Bed *L*	17. *Bentonite, brown and light-brown, granular	2	8	7	0
	18. *Bentonite, light-brownish-gray, with dark mineral particles	4	4		
	19. Shale, with sandy streaks; in a few places contains thin sandstones and black chert pebbles; locally at base a thin, friable, coarse sandstone	61	0	---	----
Soap Creek bed	20. *Bentonite, brown, granular, impure	---	11	12	0
	21. *Bentonite, brownish-gray, granular to waxy	---	4		
	22. *Bentonite, greenish-gray, granular, limonite stained in lower part	8	8		
	23. *Bentonite, olive-green, waxy, gypsiferous, with dark mineral particles	1	8		
	24. *Bentonite, light-greenish-gray, waxy, with dark mineral particles	---	5		
	25. Shale, dark-gray, sandy, bentonitic; contains gray-weathering calcareous concretions and a few large brown-weathering calcareous concretions	10	6	---	----
	26. Shale, gray; contains sandy streaks and a few thin beds of shaly sandstone	73	0	---	----
	27. Bentonite, gray	1	0	1	0
	28. Shale, dark-gray; contains some sandy streaks and a few beds of bentonite less than 5 in. thick	67	0	---	----
	29. *Shale, bentonitic, dark-brownish-gray	1	9	---	----
Bed *J*	30. Bentonite, dark-brown, waxy to granular, gypsiferous	1	6	5	2
	31. *Bentonite, gray, granular to waxy	---	1		
	32. *Bentonite, brownish-gray, waxy, gypsiferous	---	6		
	33. *Bentonite, olive-green, waxy, gypsiferous with dark mineral particles	3	1		
	34. Shale, dark-gray, hard, siliceous, chert-like.				

T. 6 S., RS. 33 AND 34 E.

The rectangular tract comprising these two townships (pl. 1) is crossed by the graveled road that leads from St. Xavier to Lodge Grass; from this principal route, other parts of the tract may be reached over unimproved branch roads and trails.

Lodge Grass Creek, which flows northward across the central part of the tract, divides it into two moderately dissected upland areas. Recent aluvium underlies the flood plain of Lodge Grass Creek; remnants of older alluvial deposits occur on higher ground west of that stream and elsewhere in the tract.

The bedrock strata, which everywhere dip in easterly directions at low angles, belong to the Cody shale—except for an outlier of Judith River formation southeast of Good Luck Creek, in sec. 25, T. 6 S., R. 34 E. A bentonite bed that crops out in the northern half of sec. 4, T. 6 S., R. 34 E. is tentatively correlated with bed *R* of the sandy shale unit equivalent to the Eagle sandstone. The exact thickness of this bentonite bed has not been determined, but 3 miles farther north, at point 24A, it is 9 feet thick. This bed is estimated to contain approximately 300,000 short tons of accessible clay.

T. 7 S., R. 32 E.

The southwestern part of this township, which lies within the Big Horn Mountains, is not shown on plate 1. The part that is shown on plate 1 can be reached conveniently by automobile over roads and trails branching from an unimproved road leading southward from the Soap Creek oil field, which lies less than 1 mile north of the township.

The land surface has an overall northeasterly slope and lies almost entirely within the drainage area of Soap Creek, which flows in a north-northeasterly direction across the central part of the township. In the southern half of the township, a belt of rather rugged upland extends along the margin of the Big Horn Mountains; the relief is more moderate farther north.

Recent alluvial deposits underlie the flood plains of Soap Creek, West Soap Creek, and their tributaries, and older alluvium lies on terraces at a number of places in the northern third of the township.

The principal geologic structures are: (1) an anticlinal nose plunging southeastward into the northeastern part of the township from the Soap Creek dome, the apex of which lies just outside the northern boundary, and (2) a broad shallow syncline extending in a northwesterly direction and having its greatest structural depression near the southeast corner of section 8. From that locality, the axis of the syncline rises to a point near the north line of section 23; beyond this point, it plunges southeastward into a more shallow structural concavity in the next township to the east. The syncline is asymmetrical, with the rocks southwest of its axis more steeply inclined than those on its northeast side.

Pre-Cretaceous rocks are at the surface on the southwest limb of the syncline, and the youngest rocks within the syncline belong to the Belle Fourche member, which is extensively exposed on both sides of the synclinal axis. Southeast of the part of Soap Creek that is above the mouth of Dry Soap Creek, the shale of the interval between the Mowry formation and the Greenhorn member contains, in general, more sand than does the shale of the same interval northwest of that locality. This is true particularly of the part of the interval below bed *L*. The Thermopolis and Mowry extend in narrow belts along the southwest limb of the syncline, where they dip steeply northeastward. The Mowry is also exposed in an area lying within the anticlinal nose and extending westward along the northern margin of the syncline. The Belle Fourche shale member crops out on the eastern side of the nose, and the Greenhorn and Carlile-Niobrara units are exposed in the northeastern quarter of section 1.

Bentonite beds are present in the Thermopolis, Mowry, Belle Fourche, and Greenhorn units. Those in the Thermopolis, as exposed on the southwest flank of the syncline, dip steeply and are of little or no interest as possible sources of supply; they have, therefore, not been studied in detail.

The Clay Spur bentonite bed crops out at many places along the margins of the syncline; tests of a sample of this bed from point 32 in section 10, where it is 6 feet, 5 inches thick, indicate that it contains good foundry clay. However, the topographic and structural conditions along its outcrop are such that only small amounts of the clay lie under light overburden.

Bed *I*, in the basal part of the Belle Fourche interval, is about 12½ feet higher than the Clay Spur bed and is 4 feet, 8 inches thick at point 32, where the outcrop of the bed encircles a large outlier of the Belle Fourche member. Tests of a sample of this bed obtained here indicate that it contains excellent foundry clay and good drilling-mud material, but, like the Clay Spur bed, it does not offer attractive mining sites.

The Soap Creek bentonite bed is extensively exposed in this township, where its thickness averages about 16 feet. Tests of samples obtained at points 30, 33, and 34 indicate that it contains excellent foundry clay. The bed lies under light overburden in rather broad belts at many places along its outcrops within the syncline and on the eastern side of the Soap Creek anticlinal nose. It is estimated that 9,240,000 short tons of crude bentonite are present under less than 30 feet of overburden in these belts, which include some of the most attractive mining sites in the Hardin district.

Bed *L*, in the Belle Fourche member, dips gently in sections 9, 15, and 16 and is more than 8 feet thick at point 31 in section 9. However, this bed appears at the surface only on steep, grass-covered hillsides, where only small amounts of the contained bentonite are under light overburden. Tests of a sample from point 31 suggest, moreover, that this material would not be well adapted for use as drilling clay nor as foundry clay.

Bed *M*, at the base of the Greenhorn calcareous member, crops out for a distance of ½ mile in section 1, where it is estimated to contain about 110,000 short tons of bentonitic shale under less than 30 feet of overburden. Its thickness is more than 7 feet a few hundred feet north of the township, and a sample obtained there showed high dry compression strength when tested as foundry clay; more complete data on this deposit are given in the preceding description of the bentonite deposits in T. 6 S., R. 32 E.

Following are sections of the bentonite beds and enclosing bedrock at five points in T. 7 S., R. 32 E.

Sections measured in T. 7 S., R. 32 E.

	Material	Thickness: All beds, Feet	All beds, Inches	Bentonite only, Feet	Bentonite only, Inches
Point 30, SW¼SW¼ sec. 5:					
	1. Soil, bentonitic, brownish-gray, soft	1	0	---	----
Soap Creek bed (lower part only)	2. Bentonite, gray, waxy, gypsiferous	---	10	6 (items 2–3)	2 (items 2–3)
	3. *Bentonite, light-greenish-gray, with dark mineral particles	5	4		
	4. Shale, dark-brownish-gray, hard, siliceous, chert-like.				
Point 31, SE¼SW¼ sec. 9:					
	1. Soil, brown, bentonitic	1	0	---	----
Bed *L*	2. *Bentonite, brownish-gray, waxy	8	3	8	3
	3. Shale, brown, hard, siliceous, chert-like.				
Point 32, NW¼NE¼ sec. 10:					
	1. Shale, dark-gray, hard	---	3	---	----
Bed *I*	2. Bentonite, dark-gray and olive-green interlaminated	---	6	4 (items 2–4)	8 (items 2–4)
	3. *Bentonite, olive-green, waxy, limonite-stained	1	9		
	4. *Bentonite, olive-green, darker in lower part, waxy	2	5		
	5. Shale, gray, soft	1	0	---	----
	6. Shale, bentonitic, gray, soft	---	8	---	----
	7. Shale, bentonitic, gray, hard	---	8	---	----
	8. Shale, gray, soft (base of Frontier)	7	4	---	----
	9. Shale, gray, sandy, hard	3	0	---	----

Sections measured in T. 7 S., R. 32 E.—Continued

Bed	Material	All beds: Feet	All beds: Inches	Bentonite only: Feet	Bentonite only: Inches
	Point 32, NW¼NE¼ sec. 10—Continued				
Clay Spur bed	10. *Bentonite, dark-gray, with a few olive-green laminae in lower part	1	11	6	5
	11. *Bentonite, light-olive-green, waxy	2	8		
	12. *Bentonite, dark-greenish-gray, waxy	1	10		
	13. Shale, dark-gray, hard, siliceous, chert-like.				
	Point 33, SW¼SE¼ sec. 15:				
	1. Shale, dark-gray, soft	---	5	---	----
Soap Creek bed	2. *Bentonite, gray and greenish-gray interlaminated, flaky, lighter-colored in lower part	4	3	16	8
	3. *Bentonite, light-greenish-gray, with dark mineral particles; lower 6 in. darker in color and with many more mineral particles	12	5		
	4. Shale, dark-brownish-gray.				
	Point 34, NW¼NE¼ sec. 17:				
	1. Shale, dark-gray, soft	---	6	---	----
Soap Creek bed	2. Bentonite, brownish-gray, granular, impure	---	4	18	2
	3. *Bentonite, light-greenish-gray, waxy	4	5		
	4. *Bentonite, light-greenish-gray, waxy, with dark mineral particles	10	2		
	5. *Bentonite, bluish-gray, waxy, with dark mineral particles	3	3		
	6. Shale, dark-gray, hard, siliceous, chert-like.				

T. 7 S., R. 33 E.

This township may be reached by driving 12 miles southwestward over a graded road from Lodge Grass, a small town on the Chicago, Burlington and Quincy Railroad; unimproved roads and trails give access to several parts of the township.

The surface of the township is comparatively rugged. Rotten Grass Creek cuts northeastward across its southeastern part, and a tributary of Soap Creek flows northward along the western margin. Between these streams, the land surface rises to a high divide that extends from section 34 in a northerly direction across the township.

Recent alluvial deposits underlie the flood plains of Rotten Grass Creek and a tributary of Soap Creek at the west margin, and older gravel deposits are present on remnants of dissected terraces at a number of localities in the intervening area. The overall dip of the bedrock strat is northwestward; therefore, the youngest strata, belonging to the upper members of the Cody shale, are exposed in the northeastern part of the township; the oldest strata are in the southwestern part. In the southwestern part, however, the structural uniformity is interrupted by two flexures: (1) a small northwestward-trending anticline, known as the Rotten Grass dome, the apex of which is in the southern part of section 29; and (2) farther southwest, a small elongated structural basin, trending parallel with the anticline and forming part of a long syncline that extends northwestward into the adjacent township to the west.

The oldest rocks exposed, which belong to the upper part of the Mowry shale, crop out at the axis of the Soap Creek dome in section 29 as a small inlier within an area of about 7 square miles that is occupied by beds of the Belle Fourche. The interval is bordered on the east by a relatively narrow outcrop of the Greenhorn calcareous member. The Carlile-Niobrara strata crop out in a broad area lying between the Greenhorn and the area of upper Cody strata in the northeastern part of the township.

Bentonitic material is present in all the formations exposed, but the only beds believed to be of interest as possible sources of bentonite supplies belong to the Belle Fourche and Greenhorn members.

Bed *J*, in the Belle Fourche, ranges from 3½ to 6½ feet in thickness in exposures northwest and southeast of this township, and bed *L* is at least 9 feet, 11 inches thick at a locality in the next township to the south. However, beds *J* and *L* are poorly exposed in this township and have not been studied in detail.

The Soap Creek bentonite bed is here extensively exposed and is 16 feet thick at point 38. In section 31, the bentonite of this bed is locally 45 feet thick in a nearly circular dome (fig. 10) almost 125 yards in diameter, which has been formed by lateral flowage of the bentonite (p. 19). Sand-bonding tests of samples of bentonite taken at points 37, 38, and 39 indicate that the bed contains material with high green compression strength and satisfactory dry strength. Some of it might also be usable as drilling clay, although the yield, viscosity and gel strength of samples that have been tested are somewhat lower than is desirable. It is estimated that 14,000,000 short tons of crude bentonite of this bed lie beneath less than 30 feet of overburden within this township. Along the outcrop of the Soap Creek bed are several good prospective mining sites; the most attractive are in sections 30 and 31.

Bed *M*, at the base of the Greenhorn, is 6 feet, 1 inch thick at point 36, where it is overlain by at least 1 foot, 2 inches of bentonitic shale. Bentonitic shale obtained from this bed, less than 1 mile from the northwest corner of the township, in section 36, T. 6 S., R. 32 E., showed high dry strength when tested for use as foundry clay. Within the township, 1,650,000 short tons of crude bentonite of bed *M* are estimated to be present under less than 30 feet of overburden, but this bed offers no attractive mining sites.

Sections measured in T. 7 S., R. 33 E.

	Material	Thickness: All beds, Feet	Thickness: All beds, Inches	Thickness: Bentonite only, Feet	Thickness: Bentonite only, Inches
Point 35, SW¼NE¼ sec. 18:					
	1. Soil	1	0	---	----
Soap Creek bed	2. Bentonite, dark-olive-green, gypsiferous	---	7		
	3. Bentonite, green, waxy, with dark mineral particles; blue-gray streak 30 in. above base	6	9	7	4+
	4. Shale.				
Point 36, NW¼SE¼ sec. 20:					
	1. Shale, brown, bentonitic	1	2	---	----
Bed *M*	2. Bentonite, greenish-gray	2	0		
	3. Bentonite, yellow	2	6		
	4. Bentonite: upper half nearly white; lower half yellowish with orange mottling	1	7	6	1
	5. Shale, brownish-gray.				
Point 37, NW¼NW¼, sec. 31:					
Soap Creek bed.	1. *Bentonite, in small dome into which it has flowed; olive-green and dark-gray bentonite interlaminated and in irregular masses	45	---	45	----
	2. Shale, dark-gray, hard, siliceous, chert-like.				
Point 38, NE¼NW¼ sec. 31:					
	1. Shale, dark-gray, soft.				
Soap Creek bed	2. *Bentonite, dark-gray and olive-green, interlaminated, waxy	12	0		
	3. *Bentonite, olive-green, grayish in upper and lower parts, waxy, with dark mineral particles	4	0	16	
	4. Shale, dark-gray, siliceous	---	4	---	----
	5. Shale, dark-gray, soft.				
Point 39, NW¼NE¼ sec. 32:					
	1. Shale, brown, soft.				
Soap Creek bed	2. Bentonite, dark-gray and olive-green interlaminated, waxy	8	0		
	3. *Bentonite, olive-green, darker colored in upper part, waxy	6	5	14	5
	4. Shale, dark-gray, hard, siliceous, chert-like.				

T. 8 S., R. 33 E.

The northeastern corner of this township is about 14 miles southwest of Lodge Grass, a small town on the Chicago, Burlington and Quincy Railroad. A graded road leads from Lodge Grass to a point 1 mile north of the township, and unimproved roads give access to its northern and eastern parts.

A belt of rather rugged upland extends along the west margin, within, and close to, the Bighorn Mountains, but the topographic re-

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lief is somewhat less pronounced in most other localities. The land surface is drained by Rotten Grass Creek and Lodge Grass Creek, which are northeasterly-flowing perennial streams with broad flood plains flanked by gravel-capped alluvial terraces, and by numerous tributaries of these streams.

The northeastward dip of the bedrock is steep in a belt close to the mountains, but it is more gentle farther east in the township. Rocks of pre-Cretaceous age are exposed in the upland belt at the western margin of the township, and Cretaceous rock formations crop out in northwesterly-trending belts farther east. The youngest bedrock strata are those of the Carlile–Niobrara sequence, which form an outcrop about 10 square miles in area in the northeastern part of the township.

Bentonite beds of minable thickness are present in the Mowry, Belle Fourche, and Greenhorn units. The Clay Spur bed in sections 17 and 21, and bed *J* in sections 6, 7, and 8, contain small tonnages of bentonite under light overburden. Bed *L* is at least 9 feet, 11 inches thick at point 41, but elsewhere it is largely covered by vegetation and has not been examined.

It is estimated that 11,250,000 short tons of accessible clay are contained in the Soap Creek bed. This bed, which is marked here by many large, brown calcareous concretions, averages about 25 feet in thickness. Particularly favorable mining sites occur on several spurs, which jut westward from an escarpment that crosses sections 9 and 15, and in two outliers in section 27. At point 42, bed *M* at the base of the Greenhorn member is more than 20 feet thick, and it retains this thickness throughout the township. In the southern part, however, bed *M* contains a larger proportion of green waxy clay than is present at point 42. Probably about 6,600,000 short tons of clay could be mined from bed *M* within this township.

When tested as foundry clay, most of the samples taken from the Soap Creek bed and beds *L* and *M* showed high green strength, and a few samples showed high dry strength; a sample taken from the Soap Creek bed at point 45 gave fairly encouraging results as drilling clay, but four other samples were inferior in quality.

Sections measured in T. 8 S., R. 33 E.

		Thickness			
		All beds		Bentonite only	
	Material	Feet	Inches	Feet	Inches
Point 40, SE¼NW¼ sec. 6:					
	1. Shale, brown, soft.				
Soap Creek bed	2. *Bentonite, dark-gray and olive-green interlaminated, waxy	10	0	19	6
	3. *Bentonite, olive-green, waxy	9	6		
	4. Shale, brown, hard, siliceous, chert-like.				

Sections measured in T. 8 S., R. 33 E.—Continued

	Material	Thickness: All beds, Feet	All beds, Inches	Bentonite only, Feet	Bentonite only, Inches
Point 41, NW¼SE¼ sec. 6:					
	1. Shale, bentonitic, brown	---	11	---	----
Bed *L*	2. *Bentonite, brownish-gray, waxy	9	6	9	11
Bed *L*	3. *Bentonite, light-yellowish-green, iron-stained	---	5		
	4. Shale, dark-gray.				
Point 42, SW¼NE¼ sec. 6					
Bed *M*	1. *Bentonite, dark-gray, waxy (lower 9½ ft. not penetrated in drilling)	14	6	20	9+
Bed *M*	2. *Bentonite, greenish-gray, waxy, with dark mineral particles	2	1		
Bed *M*	3. *Bentonite, olive-green, waxy	---	5		
Bed *M*	4. *Bentonite, olive-green, waxy, with many dark mineral particles	3	1		
Bed *M*	5. *Bentonite, light-gray, with some orange-red laminae, waxy, many dark mineral particles present	---	8		
	6. *Shale, brown, soft.				
Point 43, NE¼NW¼ sec. 16:					
Soap Creek bed	1. *Bentonite, dark-gray and olive-green interlaminated, waxy, gypsiferous	15	10	30	5
Soap Creek bed	2. *Bentonite, light-olive-green, waxy, with dark mineral particles	10	8		
Soap Creek bed	3. *Bentonite, olive-green (darker than above), waxy	3	11		
	4. Shale, dark-gray, hard, siliceous, chert-like.				
Point 44, NW¼NE¼ sec. 16:					
	1. Shale, brown, soft	1	3	---	----
Bed *M*	2. *Bentonite, brownish-gray, granular, gypsiferous	10	6	10	6+
Bed *M*	3. Bentonite (not penetrated in drilling)	---	---		
Point 45, SW¼NE¼ sec. 27:					
	1. Shale, brown, soft.				
Soap Creek bed	2. *Bentonite, dark-gray and olive-green interlaminated, waxy	22	0	29	10
Soap Creek bed	3. *Bentonite, grayish-green, waxy	2	0		
Soap Creek bed	4. *Bentonite, olive-green, waxy	5	10		
	5. Covered.				

T. 9 S., R. 34 E.

The northeastern corner of this township is about 5 miles southwest of Wyola, a small town on the Chicago, Burlington and Quincy Railroad. Most of the township is accessible by gravel roads extending southwestward along the flood plain of Little Bighorn River and by unimproved roads and trails. The topography, both north and south of Little Bighorn River, is moderately rugged.

Terrace gravel is present on high ridges in sections 6 and 25, and gravel-capped terraces occur at lower levels north of Little Bighorn River. The bedrock beneath lands aggregating several square miles in area is concealed by gravels capping the terraces and by alluvial deposits underlying the flood plains of Little Bighorn River, several of its tributaries, and Gay Creek, in section 36.

The principal structural features of this township are a large anticline that extends eastward across the central part and a syncline in the southeastern part. The anticline is essentially a broad structural nose that plunges eastward, but it bulges locally at the eastern margin of the township to form the Black Gulch dome. A nearly vertical westerly-trending fault, downthrown on the southern side and having a maximum displacement of more than 1,000 feet, cuts the northwestern side of the Black Gulch dome, crosses the structural sag west of it, and continues westward for several miles on the southern flank of the large plunging anticline. The oldest rocks appearing at the surface in this arched structure are pre-Cretaceous strata that crop out in the southwestern and west-central parts of the township; farther east, along its crest and on its flanks, beds of Cretaceous age (the youngest being those of the Carlile–Niobrara member) crop out in the synclinal area to the south and in two areas along the eastern and northern margins of the township.

Bentonite beds are present in the Thermopolis, Mowry, Belle Fourche, and Greenhorn units. Some of these beds are so thick that large tonnages of bentonite are available for mining, notwithstanding unfavorable topographic relations along their outcrops (fig. 2), whereby deposits under light overburden occuring mostly in narrow belts.

The Clay Spur bentonite bed, as measured at point 48 in section 14, is 4 feet, 9 inches thick. Tests of a sample taken here indicate that this bed contains drilling and foundry clay that is comparable in quality to much of the bentonite that is mined in the Black Hills district. The bed crops out in several places within the township but offers no attractive mining sites.

Bed *I*, as measured at point 50 in section 14, is 7 feet thick and contains good foundry clay. This clay might be used as drilling-mud material, but, like the Clay Spur bed, bed *I* here contains only negligible reserves.

Bed *J*, as measured at point 49 in section 14, is 6½ feet thick, and at point 51 in section 34, it is 3½ feet thick. At both points this bed contains good foundry clay. Although the bed crops out extensively in this township, it is not present at sites that could be mined economically.

The Soap Creek bentonite bed, as measured at point 47 in section 13, is 22 feet thick and is overlain by approximately an equal amount of bentonitic shale. Brown calcareous concretions, as much as 8 feet in diameter, are abundantly scattered along the weathered outcrop, especially in sections 13, 14, and 15. The bed contains good foundry clay. A reserve of about 7,900,000 short tons of accessible bentonite is estimated to be available within this township.

Bed *M*, as measured at point 46 in section 13, is 33 feet thick. This bed dips about 10 degrees northeast and its weathered outcrops are strewn with light-gray calcareous concretions, many of which are about 3 feet in diameter. At point 46, the bed contains foundry clay having good green strength; in sections 13 and 24, it is estimated that the minable reserve amounts to about 4,950,000 short tons of bentonite.

Following are measured sections of the bentonite beds and associated rock materials at seven numbered points in T. 9 S., R. 34 E.

Sections measured in T. 9 S., R. 34 E.

		Thickness			
		All beds		Bentonite only	
	Material	Feet	Inches	Feet	Inches
Point 46, NE¼SW¼ sec. 13:					
	1. Shale, brown, soft.				
Bed *M*	2. *Bentonite, gray, granular (lower 10 ft not penetrated in drilling)	16	6	33	0
	3. *Bentonite, light-green, waxy (lower 6½ ft not penetrated in drilling)	11	0		
	4. *Bentonite, yellowish-green, waxy	5	6		
	5. Shale.				
Point 47, SW¼SW¼ sec. 13:					
	1. Shale, bentonitic, brownish-gray, soft.				
Soap Creek bed	2. *Bentonite, olive-green and dark-gray interlaminated, waxy	14	0	22	0
	3. *Bentonite, olive-green, waxy, with dark mineral particles	8	0		
	4. Shale, dark-gray, hard, siliceous, chert-like.				
Point 48, NE¼SW¼ sec. 14:					
Clay Spur bed	1. *Bentonite, gray, waxy	---	4	4	9
	2. *Bentonite, light-green, somewhat darker in lower part, waxy	4	5		
	3. Shale, gray, hard, siliceous, chert-like.				
Point 49, NE¼SE¼ sec. 14:					
	1. Shale, dark-gray, soft.				
Bed *J*	2. *Bentonite, light-green	---	6	6	6
	3. *Bentonite, dark-green, waxy	2	6		
	4. *Bentonite, gray, waxy	3	6		
	5. Shale, dark-brownish-gray				

Sections measured in T. 9 S., R. 34 E.—Continued

Material		Thickness: All beds Feet	All beds Inches	Bentonite only Feet	Bentonite only Inches
Point 50, SE¼SE¼ sec. 14:					
Bed *I*	1. *Bentonite, dark-gray and olive-green interlaminated, waxy	1	6	7	----
	2. *Bentonite, greenish-gray, waxy	2	0		
	3. *Bentonite, olive-green, waxy	2	0		
	4. *Bentonite, greenish-gray, waxy	1	6		
Point 51, NW¼NW¼ sec. 34:					
	1. Shale, brownish-gray, sandy.				
Bed *J*	2. *Bentonite, dark-greenish-gray, waxy	3	6	3	6
	3. Shale, brownish-gray, sandy.				

T. 9 S., R. 35 E.

U. S. Highway 87 and the Chicago, Burlington and Quincy Railroad extend northward across the eastern part of this township, the southern boundary of which lies along the Montana-Wyoming State line; the northeast corner is about 3 miles southeast of the railroad station at the small town of Wyola. The bentonite processing plant of the Wyotana Mining Co. is at the Aberdeen siding of the railroad, in sec. 13, and a graded road that enters the township near its southwest corner has been used for hauling bentonite to this plant from the small mines in T. 58 N., R. 88 W., Sheridan County, Wyo. A graveled road, leading southwestward and up the valley of Little Bighorn River from Wyola, crosses the northwest corner of the township.

The surface configuration of this township is comparatively rugged, with a total relief of approximately 1,150 feet. The highest land lies along a divide that extends northeastward between the valley of Little Bighorn River and the valley in the central part of the township that is drained by Pass Creek and its tributary West Pass Creek.

Beneath the flood plains of Little Bighorn River, Pass Creek, and their tributaries, the bedrock is concealed by Recent alluvial deposits. In the southern and eastern parts of the township, a few small tracts on stream terraces at higher levels are occupied by older alluvial deposits.

The overall dip of the bedrock strata is eastward. The oldest strata exposed, belonging to the Mowry shale, occupy the central part of Black Gulch dome, the apex of which is at the western side of the township; the youngest strata belong to the Judith River formation, which extends northward through the easternmost tier of sections. The geologic structure of a tract that extends from Black Gulch dome eastward across the central part of the township is essentially that of a broad, eastward-plunging anticlinal nose; the axis of this anticlinal nose lies about midway between two broad, shallow synclines, with axes also plunging eastward, which occupy large parts of the northern and southern halves of the township, respectively. A normal fault, with a northeasterly trend, crosses the anticlinal axis diagonally near the center of the township, displacing the rocks on its southeastern side downward about 400 feet and thereby offsetting the southerly-trending belts of outcrop of the upper members of the Cody formation more than 1 mile to the southwest. The displacement on this fault decreases progressively, in opposite directions along its trace, from its intersection with the anticlinal axis and is believed to die out within the east and west limits of the township.

At point 48, about 1½ miles west of the township, the Clay Spur bentonite bed is 4 feet, 9 inches thick and contains clay of good quality. This bed is also exposed for a short distance in the southwest quarter of section 19, T. 9 S., R. 35 E., but, because of its steep dip, it contains only a small amount of minable clay.

The Soap Creek bed and bed *M* crop out in section 19 on the steeply dipping eastern and northern flanks of Black Gulch dome. One mile west of this township, at point 47, the Soap Creek bed is 22 feet thick, and at point 46, in the same neighborhood, bed *M* is 33 feet thick. The beds at both of these points contain good foundry clay. Assuming that comparable thicknesses occur in section 19, T. 9 S., R. 35 E., it is estimated that the Soap Creek bed here contains about 150,000 and that bed *M* contains about 1,850,000 short tons of crude bentonite under less than 30 feet of overburden.

A bentonite bed that crops out intermittently in the north-central part of the township is nearly equivalent, stratigraphically, to bed *R*. The bentonite of this bed, as observed at its few exposures, is dark in color, and inasmuch as it supports a growth of grass along most of its outcrop, it probably has a high content of shaly impurities with correspondingly low colloidality. This bed seems to have little potential value. Because the bed was estimated to be only 1½ to 2½ feet thick, it was neither measured nor sampled within this township; however, its outcrop is mapped on plate 1.

A bentonite bed at approximately the stratigraphic position of bed *U* crops out conspicuously in sections 2, 9, 10, and 15. The bentonite of the lower two-thirds of this bed weathers very light gray; its total thickness at point 51A is 13 feet. Assuming that 13 feet is the average thickness for the township, the bed here contains a reserve of about 2,000,000 tons of bentonite under less than 30 feet of overburden. Test results indicate that the colloidality of this material is relatively low, but that it has potentialities for use by foundries as sand-bonding material. The best prospective mining sites along outcrops of this bed lie within 4 miles of the bentonite processing plant of the Wyotana Mining Co. Following is a section that was measured at one of these sites:

Section measured in T. 9 S., R. 35 E.

	Material	Thickness: All beds, Feet	All beds, Inches	Bentonite only, Feet	Bentonite only, Inches
Point 51A, SW¼ sec. 10:					
	1. Bentonite, gray with laminae of dark-gray shale (not drilled or sampled)	3	0	---	----
Bed *U?*	2. Bentonite, light-yellowish-gray, granular	10	6	13	0
Bed *U?*	3. Bentonite, very light yellowish gray, granular	2	0		
Bed *U?*	4. Bentonite, very light yellowish gray, granular, with particles of biotite and other dark minerals	---	6		
	5. Shale, soft, dark-gray.				

Clinker was quarried years ago for road metal from a small working in section 36, and a small amount of coal formerly was mined in sections 26 and 36. A large amount of gravel has been hauled recently from terrace deposits in section 13 for use on U. S. Highway 87.

T. 58 N., R. 88 W., SHERIDAN COUNTY, WYO.

This township, which is bounded on the north by the Montana State line, lies directly south of T. 9 S., Rs. 34 and 35 E. It can be reached over a road leading southwestward from Aberdeen, Montana, a siding of the Chicago, Burlington and Quincy Railroad 3 miles north of the State line. The part of the township shown on plate 1 is a strip of land about 1⅓ miles wide, extending about 5 miles eastward from the west township line.

The topographic configuration of this strip is moderately rugged. Gay Creek, which flows northeastward across its western part, and West Pass Creek, which crosses the central part, have narrow flood plains flanked by tracts of hilly country. Recent alluvial deposits underlie the flood plains; older gravel caps a high terrace remnant in section 20.

In the west-central part of the strip, the bedrock dips locally in a northerly direction toward the axis of an eastward-trending syncline that lies within the adjacent part of Montana. Everywhere else within the strip the dip is toward the northeast. The oldest exposed rocks belong to the Cloverly formation, which crops out in the southwest corner of the strip; the youngest bedrock is the unnamed Eagle equivalent, which was identified in the northeast corner of the strip. In the intervening land, strata of the Thermopolis and Mowry formations, as well as the Belle Fourche, Greenhorn, and Carlile-Niobrara members of the Cody formation, crop out in belts trending northwestward. Bentonitic material is present in all these units, but the only beds considered to be possible sources of commercial bentonite are the Clay Spur bed, at the top of Mowry, and two beds—bed *J* and the Soap Creek bed—in the Belle Fourche member.

At point 53, the Clay Spur bentonite bed crops out with a thickness of 5 feet, 1 inch. Tests of two samples obtained at this point indicate that the bed contains material well adapted for use as foundry clay, and one sample, taken from the lower 3½ feet, showed possibilities as drilling clay. However, only small amounts of the bentonite of the Clay Spur bed lie under less than 30 feet of overburden, and there are no attractive mining sites within the area under discussion. This is also true of bed *J*, which is 3½ to 6½ feet thick in the adjacent part of Montana. Bed *J* has not been measured nor sampled in this township.

As measured at point 52, the Soap Creek bentonite bed is 20½ feet thick, including 7 feet of dark, impure bentonitic material at the top of the bed. Two samples of bentonite from this point indicate the presence of good foundry clay and also material that can be used as drilling clay. The bed has been strip-mined at a small working of the Wyotana Bentonite Mining Co. in sections 17 and 18, where it crops out on a steep south-facing hillside overlooking the valley of Gay Creek and in a small mine in section 21 on the west side of West Pass Creek. Owing to steepness of both the dip and the land surface at these sites, mining is limited to belts only a few yards wide along the outcrops. At both sites, mining has proceeded from east to west along the outcrops, and the crude bentonite has been hauled 10 to 12 miles by truck to a small processing plant at Aberdeen siding. So far as known, all of the small commercial production of bentonite from the Hardin district has come from these two mines. Comparable sites for mining of the Soap Creek bed lie in sections 20 and 22, and it is estimated that this bed contains 2,000,000 short tons of clay under less than 30 feet of overburden in the strip of land under discussion.

Following are sections of the Soap Creek bentonite bed measured at point 52 and of the Clay Spur bed measured at point 53:

Sections measured in T. 58 N., R. 88 W.

Material		Thickness: All beds, Feet	Thickness: All beds, Inches	Thickness: Bentonite only, Feet	Thickness: Bentonite only, Inches
Point 52, SW¼SW¼ sec. 17:					
Soap Creek bed	1. Bentonite, dark-gray, with a few laminae of green waxy bentonite	7	3	20	5
	2. *Bentonite, greenish-gray, waxy, gypsiferous	4	5		
	3. *Bentonite, light-greenish-gray, waxy, gypsiferous, with dark mineral particles	8	6		
	4. *Bentonite, olive-green, waxy, with dark mineral particles	---	3		
	5. Shale, dark-gray, hard, siliceous, chert-like.				
Point 53, NW¼NW¼ sec. 20:					
	1. Shale, brownish-gray	---	6	---	----
Clay Spur bed	2. *Bentonite, dark-brown, waxy	1	6	5	1
	3. *Bentonite, light-yellowish-gray and brown interlaminated, waxy	1	6		
	4. *Bentonite, light-yellowish-gray, waxy	1	3		
	5. *Bentonite, light-bluish-gray, waxy	---	6		
	6. Bentonite, light-gray, waxy, limonite-stained	---	4		
	7. Shale, dark-gray, hard, siliceous, chert-like.				

LABORATORY PROCEDURES USED FOR TESTING THE BENTONITES

By Sam H. Patterson

The purpose of this chapter is to outline several laboratory testing procedures which have been employed in evaluating bentonite for use by the foundry industry as molding-sand bonding clay, and by the petroleum industry as rotary well-drilling clay. The resulting test data, together with geologic descriptions of the various bentonite deposits studied, are presented in other sections and in table 1 of this publication, and in other publications of the Geological Survey (Knechtel and Patterson, 1952, 1955).

Modern research procedures that are employed in studying the identity, character, and mode of origin of clays include differential thermal analysis, X-ray diffraction, and electron-microscope studies as well as optical examination, ion-exchange measurement, and chemical analysis. By such diverse means, a large amount of information has been gathered concerning the composition, geochemistry, and petrology of bentonite and related clay materials; much of this information has been summarized by Ross and Hendricks (1945, p. 1–79) and by Grim (1953). Resulting concepts of the composition and crystalline structure of clays aid in explaining some of the distinctive properties that determine the commercial value of bentonites. For example, such concepts are, in large part, the basis for conclusions reached by Grim and Cuthbert (1945, p. 1–55 and 1946, p. 1–36) regarding the factors affecting the bonding properties of clays used in preparing synthetic molding sands.

While mineralogical and chemical information is important in any effort to explain such properties, commercial evaluation and selection of bentonite deposits to be mined are more largely based on descriptions of certain physical properties of the contained material as revealed by various laboratory tests. Thus, bentonite used by the foundry industry as sand-bonding clay must possess the required green or dry bonding strength (or both), and bentonite used for drilling-mud must show adequate viscosity, yield, gel strength, and other colloidal properties. Whether or not the bentonite of any deposit possesses such properties in sufficient degree to be mined and sold at a profit is generally determined by means of tests of the type herein described as well as by its actual use in industrial operations.

These tests are performed primarily for the purpose of evaluating bentonite for use in foundry-sand bonding materials and in rotary-well drilling muds; however, the test results are also helpful in evaluating the bentonite for other uses. Drilling-mud tests, because they are related to dilatancy and viscosity, are thus helpful in evaluating bentonite for suspending agents, for water impedance, and for other uses. Color is a primary requirement for bentonite used in various products. The bentonite in pharmaceutical preparations, paper filling, and for other purposes must be nearly white. Color of the bentonite was determined by comparing small amounts of ground bentonite with the "Rock-color chart" (Goddard, 1948).

The samples of raw bentonite to be tested were air dried at room temperature, crushed in a small laboratory crusher to one-fourth of an inch or finer, and ground fine enough in a disc-type grinder to permit approximately 90 percent of the pulverized material to pass through a 200-mesh sieve. Some of the samples required drying with the aid of an electric fan, for periods ranging from 2 to 10 days before they could be ground. The pulverized samples were reduced to comparable moisture content by additional drying in an oven at 105° C. for 4 hours, and then were placed in desiccators and cooled to room temperature.

USE AS FOUNDRY SAND-BONDING CLAY

Tests having to do with use of the sampled materials in bonding foundry sands, as described in this report and in studies of the Northern Black Hills district (Knechtel and Patterson, 1955) were made according to the procedure set forth by the American Foundryman's Society (Anon., 1952, p. 17–28, 82–85).

In naturally bonded molding sands which were formerly used by all foundries in the manufacture of metal castings, constituents such as clay and organic matter serve as the bonding material. Most of the sand now used in preparing molds for such use is synthetically bonded, and much of the bentonite that is produced in the Missouri River basin is marketed as sand-bonding clay. Synthetically bonded sand is prepared by a thorough mechanical mixing of clean sand with proper amounts of one or more carefully selected bonding agents such as underclay, bentonite, or certain substances present in cereals. The resulting mixture, when made ready for casting, must be sufficiently strong to withstand the erosive or cutting action of liquid metal as it flows into a mold, but it must not be so strong that it interferes with free contraction of the metal in contact with it during cooling and solidification; such interference might cause difficulty in removing the mold from the hardened casting.

The quality of bentonites in relation to their suitability for use as bonding clays cannot be determined satisfactorily by any known field tests and therefore must be judged largely by the results of time-consuming laboratory tests of samples, whereby their bonding strength may be compared with that of clays actually used in foundries. However, other significant properties of bonding clays are not revealed in the laboratory tests, and the need for final test runs in foundries has been emphasized by Grim (1950, p. 1) as follows:

> In order finally to prove the worth of a clay for foundry use, it must be tried in actual foundry practice by individual foundries, because each foundry has its own peculiar practices and because certain attributes of molding sand-clay mixtures show up only when metal is actually cast in them. On the basis of determinations of green and dry compression strength, it may be determined whether or not a clay has any potential use as a foundry bonding agent. If a clay shows strength value at least equal to those of clays currently used in foundries, obviously it has potentialities for this use and is worth actual foundry trial.

In production of castings, the two molding processes employed are known as "green-sand molding" and "dry-sand molding." In green-sand molding, which is the process employed in making most iron castings, the metal is poured into moist sand molds, whereas in dry-sand casting, which is employed commonly in the manufacture of large castings, the mold is dried thoroughly before the metal is poured.

According to a publication of the American Foundrymen's Society (Anon., 1944, p. 73–74):

> In many cases, the use of green sand has been found essential to the commercially satisfactory manufacture of steel castings of intricate designs. The

resistance of dry sand molds and cores to the solid contraction of steel frequently prohibits their economical application where light and intricate castings must be produced. Good green sand does not exert as much resistance to the normal contraction of the casting as does dry sand, and, consequently, severe strains which might result in hot tears or cracks often are avoided.

In the bonding tests conducted during the investigations of the bentonite deposits described in the present bulletin and in studies of the Northern Black Hills district (Knechtel and Patterson, 1955), the procedure outlined in detail in the Foundry Sand Handbook (Anon., 1952, p. 17–28, 82–85) was followed closely except for the type of sand used. The handbook (p. 28) defines standard testing sand in terms of U. S. Standard Series Sieve Nos. as follows:

The standard sand shall consist of washed and dried, rounded-grain, silica sand. All grains shall pass through a No. 40 sieve, 95 percent passing the No. 50 sieve and remaining on the No. 70 sieve. Any grains passing the No. 70 sieve shall remain on the No. 100 sieve. This sand shall have an A. F. S. fineness number of 50 plus or minus 1.

However, the cost of preparation of standard sand makes its use prohibitive for testing of numerous samples. A sand produced in Illinois, which approximates the foregoing rigid specifications, was therefore substituted. The table below gives the results of a sieve analysis of this Illinois sand as compared with the grain-size requirements for standard sand.

Percentages of standard and substituted sand retained on five United States standard sieves

United States standard sieve No.	Percent, by weight, retained	
	Substituted sand	A. F. S. standard sand
30	0. 10	0
40	16. 63	0
50	56. 41	0–5
70	17. 40	95–100
100	7. 98	0–5
Pan	1. 46	0
Total	99. 98	100

The substituted sand, as shown by the table, differs rather widely from the standard sand in the percentages passing through and retained on the different sieves. The results of bonding tests in which the substituted sand is used nevertheless correspond closely to those obtained with the standard sand; the slightly excessive percentage of fines tends to give greater compression strength to sand-clay mixtures containing the substituted sand, but this tendency is nearly counterbalanced by the weakening effect of the excessive percentage of coarse grains.

Progress toward an understanding of the bonding action of clays in foundry sands has resulted from the work of Grim and Cuthbert (1945, p. 1–55; 1946, p. 1–36) in the United States and from the work of Davies (1946, p. 6–46) in England. These authors have demonstrated that the green-compression strength of sand-clay mixtures differs from the dry-compression strength of the same mixtures in its manner of responding to variation in the amount of tempering water used in their preparation. Whereas the green-compression strength of a given mixture of sand and bentonite is reduced when water is added slightly in excess of an optimum amount (fig. 12*A*), maximum dry-compression strength is attained when much larger amounts of water have been used in preparation of the mixture for drying (fig. 12*B*). More than 95 percent of the several hundred mixtures tested during the investigations in the Hardin and Northern Black Hills districts reached their optimum green-compression strength when only 1.3 to 1.5 percent of tempering water was present. Nearly all the mixtures tested required the presence of more than 2.2 percent of tempering water to reach their maximum dry-compression strength. Mixtures of sand and clay that maintain high green-compression strength throughout a considerable range of tempering-water content and have high dry-compression strength when low proportions of tempering water are used in their preparation are especially desirable.

Because high dry-compression strength occurs only when considerably more tempering water is used than is necessary to attain maximum green strength, adequate evaluation of both green and dry strength requires preparation and testing of several mixtures of each bentonite sample that differ only in their moisture content. In an effort to determine approximately the optimum attainable green strength for each sample tested, quadruplicate 2-kilogram mixtures were prepared containing 4 percent clay by weight, or 80 grams of the bentonite of each sample to 1,920 grams of sand. Occasionally a fifth mixture was added, as represented in figure 12*A*, in order to complete the curve. Accordingly each of the 2-kilogram mixtures was mulled for 2 minutes in a mechanical mixer. The required range of tempering water was then introduced by adding 35, 40, 50, and 60 milliliters of water, respectively, to the four mixtures and each mixture was again mulled for 5 minutes. Immediately after mulling, each mixture was riddled through a screen of one-quarter-inch mesh and kept in an airtight glass jar for at least 2 hours. Standard test specimens were formed from each mixture by weighing out the necessary amount, placing it in a core mold, and ramming it three times with an A. F. S. standard ramming apparatus. The cores were then stripped from the mold and immediately tested for green compression strength in an apparatus of the dead-weight type. Because of appreciable variations in the figures obtained in testing different cores prepared from the same mixture, the average for four to eight cores of each mixture was calculated and recorded as its green-compression strength.

During the testing procedure, duplicate portions of each of the four mixtures were placed in weighing vials for use in determining the percentage of tempering water. To obtain the data for calculating this figure, each duplicate portion was weighed, dried overnight at 105°C, brought to room temperature in a desiccator, and reweighed. The percentage of tempering water and the green compression strength for each of the four mixtures were then plotted, as illustrated in figure 12*A*, and a curve was drawn from which the strength for any given percentage of water could be estimated.

For most of the samples tested, a sufficient increase in the percentage of tempering water would produce a dry-compression strength exceeding 100 psi, which is the maximum stress that could be applied with the core-breaking apparatus employed. Inasmuch as 100 psi exceeds nearly all specifications for clay used by foundries in dry-sand molds, determination of maximum dry-compression strength has not been attempted.

The dry-compression tests for each sample of bentonite were made only on dried cores of the two wettest mixtures prepared for the green strength tests. Six cores, which were prepared from each of the two mixtures containing 50 to 60 milliliters of water, respectively, were dried in an oven at 105°C for 2 hours, were reduced to room temperature in desiccators, and were then tested for dry-compression strength in the same apparatus that was used in determining green strength. As a rule, three or four out of the six test readings for each mixture were in close agreement, whereupon the average for this group was calculated and recorded as the dry-compression strength. When the figures failed to fall into such a group, the average of all six readings was recorded. The dry-compression strength of the two mixtures was plotted against corresponding percentages of tempering water (same data as calculated for green strength) and curves were drawn which permitted estimation of dry-strength values for amounts of tempering water ranging from 1.6 to 2.2 percent. The manner in which a dry-strength curve is prepared is illustrated by

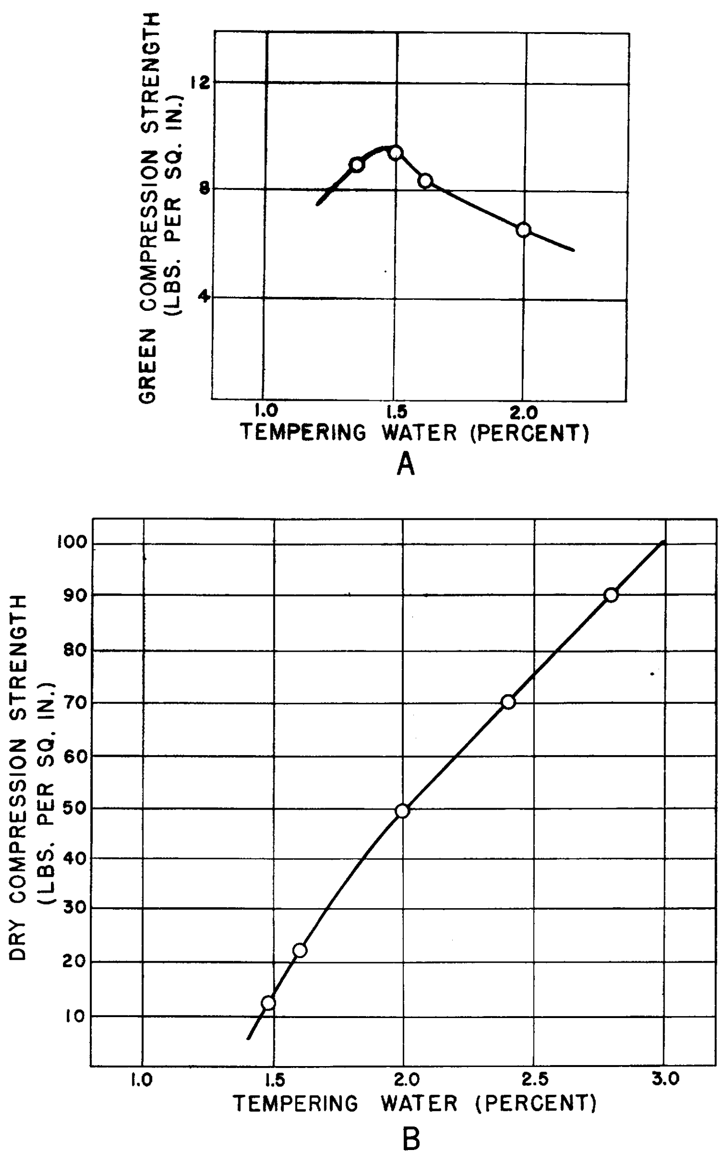

FIGURE 12.—Curves for a sample of bentonite from the Soap Creek bed. *A*, Variation of green bonding strength according to percentage of tempering water in sand-clay mixture at time of test; *B*, variation of dry bonding strength according to percentage of tempering water in sand-clay mixture when cores were made.

the curve shown in figure 12*B*. This curve represents a wider range of moisture content than was used in any of the other dry-compression tests performed during the present investigation and illustrates the manner in which the dry strength increases with increasing percentages of tempering water.

USE AS A CONSTITUENT OF ROTARY WELL-DRILLING MUD

Most of the tests relating to properties of significance in evaluating the samples as drilling-mud materials were made according to procedures employed by companies producing bentonite in the vicinity of the Black Hills. Most of these procedures have been outlined by Fisk (1946, p. 1–39). The apparatus used has been described by the American Petroleum Institute (Anon., 1942, p. 1–14), and by Stern (1941, p. 29–42).

Many types of clay and other substances, including artificially prepared mixtures, are used in rotary well-drilling fluids; the preparation of these fluids has become a specialized field. Bentonite with a high dilatancy, in addition to various other colloidal properties, is much in demand for use as one of the ingredients because of its efficiency in performance of several useful functions. Its role as a drilling-fluid constituent is briefly summarized by Fisk (1946, p. 7) as follows:

In the rotary drilling of wells, a "mud" is pumped down a drill pipe carrying the bit to wash away cuttings and to raise them to the surface through the annular space between the drill pipe and the walls of the hole. The mud also functions to seal the walls of the hole and prevent water loss, as well as ingress of water from the formations penetrated. Bentonite added to the drilling mud enhances its lubricating and wall-sealing properties and also, due to its thixotropic properties, assists in keeping cuttings from settling in the hole in the event of a shutdown of the drilling equipment. Where weighting additions to the mud such as barite are necessary to hold gas pressures, bentonite aids in maintaining the weighting material in suspension.

Although opinions differ regarding the value of certain tests for determining the suitability of clays for use in preparing drilling mud, nearly all investigators agree that some tests give useful results. In the wall-building tests, which are designed to determine the ability of a mud to form a thin, impervious cake under pressure, conditions in the testing apparatus differ somewhat from those encountered in the drilling of wells, but the results of these tests, as well as those relating to the characteristic known as "yield" are unquestionably valuable. The data on yield provide a basis for estimating the amount of any given clay that would be required for preparation of a drilling mud of any desired viscosity and volume. They also afford a rough idea of the gel strength of the mud, which tends to be greatest for clays that test high in yield; such clays moreover, generally contain the smallest percentages of grit.

DILATANCY (SWELLING CAPACITY)

All the bentonites from the Missouri River basin that are regarded as high-grade drilling-mud material possess a marked propensity to absorb water and thereupon to swell. However, some bentonites having ample dilatancy lack some of the other essential properties of good drilling-mud material. Therefore, swelling tests were made on all of the samples under investigation and the samples that showed moderate-to-high dilatancy were tested further to determine whether or not they represent material that would be suitable for use as drilling-mud material.

The procedure outlined by the American Colloid Co. (Anon., 1945, p. 1, 2) was followed in making the swelling tests. Two grams of ground bentonite were added slowly to 100 milliliters of distilled water in a graduate, by sprinkling very small amounts on the surface and allowing them to settle before adding more material. One hour after the last grains had been added, the volume of the resulting gel in milliliters (cubic centimeters) was recorded as the "swelling capacity" of the bentonite.

A dilatancy of 20 milliliters was arbitrarily chosen as the minimum requirement in selecting clays to be tested further for use in drilling mud; only a few samples having lower dilatancy were tested for viscosity, yield, gel strength, and wall-building efficiency. Few, if any, of the samples that swell to less than 20 ml represent drilling-mud material of the high quality demanded by present markets, and the time consumed by extensive tests of such samples would therefore not be commensurate with the value of the results. However, some of these materials might be satisfactory under special conditions such as might exist if wells were being drilled close to the bentonite deposits, where the disadvantage of using large amounts of bentonite of an inferior grade might be offset by elimination of transportation costs.

VISCOSITY

Viscosity, which is an important property of drillings muds, is defined as a measure of a fluid's internal resistance to flow; it is usually expressed in centipoises. The standard apparatus for measuring the viscosity of drilling fluids is the Stormer viscometer (Anon., 1942, p. 3–6). The viscosity of an aqueous suspension of a clay depends on the proportions of clay and water used in its preparation; consequently, viscosity test data relating to different samples are readily comparable only for suspensions containing the same proportions of clay and water. For each of the samples to be tested for viscosity, a 6-percent-by-weight suspension of clay was prepared, as well as two or more suspensions containing other percentages of clay. These additional suspensions were tested primarily to obtain viscosity data for computing yield by the method to be described below, but the results of the three or more viscosity measurements also show the extent to which the viscosity of suspensions of each sampled clay varies in consequence of known variations in their clay content.

In preparing the suspensions, the clay and distilled water were carefully weighed at room temperature; however, the water could have been measured volumetrically without serious loss of accuracy. Then, they were mixed in an electric blender for 3 minutes, with one brief interruption for scraping down the lumps from the sides of the cup with a spatula; immediately after mixing, the viscosity of a portion of the suspension was determined by means of a Stormer viscometer.

YIELD

Mainly in consequence of differences in the dilatancy of bentonites, equally viscous suspensions prepared from equal weights of these clays contain variable amounts of water and may accordingly differ greatly in volume. The volume, in 42-gallon barrels, of an aqueous suspension with a viscosity of 15 centipoises that can be prepared from 1 short ton of clay is known as its yield (Williams and others, 1953, p. 7; Knechtel and Patterson, 1952, p. 5). In general, clays showing satisfactory yield possess most of the properties that are considered desirable for preparation of drilling mud.

The laboratory investigation of the bentonites from the Hardin district, described in this report, and from the northern Black Hills district (Knechtel and Patterson, 1955) has been greatly facilitated through use of a diagram showing "Representative yield curves," which was furnished by the Baroid Sales Division of the National Lead Co. The curves show the relation between viscosity and the proportions of clay and water used in preparing various drilling muds. Use of these curves permits a rough estimate of the percentage of the clay of each sample that will produce a suspension having any desired viscosity, after the viscosity of a suspension containing a known percentage of the clay has been determined.

The viscosity figure that was obtained for each 6 percent-by-weight suspension described above was accordingly compared with this diagram and the percentage of clay of each sample that would be contained in a suspension with a viscosity of 15 centipoises was estimated. At least one additional suspension containing a little more, and at least one containing a little less, than this estimated percentage were now prepared and tested in an effort to produce at least one suspension with a somewhat higher, and another suspension with a slightly lower, viscosity than 15 centipoises. Then the three or more viscosity figures for each clay, including the figure relating to the 6-percent suspension, were plotted on the "Representative yield curves" diagram against the corresponding clay percentages, and the yield of the clay, expressed in barrels per ton of a 15-centipoise suspension, was obtained from the diagram by interpolation.

GEL STRENGTH (THIXOTROPY)

Bentonite of high dilatancy when mixed with water, characteristically forms a fluid that becomes a jellylike mass if left undisturbed for a short period but again becomes a fluid when agitated. A reversible transformation of this kind, involving no change in temperature, is referred to as thixotropy or gelling. As indicated by Stern (1941, p. 371), the ability of bentonites to form strong gels is not considered as important now as it once was, though it is still a much-desired property. The function of thixotropy in drilling is primarily to prevent the cuttings and weighting material, such as barite, from settling in the hole when the drill pipe and mud-circulating system are not in motion. Most of the bentonitic clays from the Missouri River basin that are shown by the tests to have the yield, viscosity, and wall-building properties of good drilling-mud material also show satisfactory gel strength.

The gel strength of a suspension of clay, as measured with a Stormer viscometer, is expressed as the weight in grams that must be placed on the scale of that instrument to start its rotor revolving against the resistance of the suspension after it has been allowed to gel. Two determinations of gel strength have been made for each of the 6-percent-by-weight suspensions that were prepared for the viscosity and yield tests. Determinations for each of the two or more suspensions containing larger percentages of clay were also made in order to ascertain roughly the relation between gel strength and the amount of clay in suspension. For each suspension, gel strength was measured immediately following thorough agitation and once again after the suspension had remained undisturbed for a period of 10 minutes.

WALL-BUILDING EFFICIENCY

Some of the bentonites with high dilatancy are among the most effective of all known drilling-mud materials for forming a thin, impervious layer, or wall, on the sides of holes bored with rotary well-drilling equipment. This wall tends to reduce loss of water from the mud, thus permitting greater control over its viscosity, and prevents caving of the sides of the well, which sometimes occurs when soft rock materials absorb moisture from drilling fluids.

The wall-building propensities of samples of bentonite that swelled to more than 20 milliliters were tested with the aid of a filter press in accordance with the procedure outlined by the American Petroleum Institute (Anon., 1952, p. 3, 11). In this procedure, a suspension of bentonite is filtered under a pressure of 100 pounds per square inch to form a filter cake comparable to the wall that would form on the sides of a drill hole. The degree of imperviousness of the cake is indicated by the volume of filtrate that accumulates, the smaller volumes indicating the more impervious, and accordingly the better, wall-building material.

Admittedly, the conditions under which this test is performed differ slightly from those in a drill hole, because a suspension in a filter press is not in motion, whereas the mud in a drill hole circulates continuously while the drill is rotating. Because a suspension in the test apparatus is essentially motionless, some of the grit and smaller nonclay particles settle out whereas they would not do so if the suspension were in circulation. The rate of settling, which varies inversely with the viscosity and gel strength of the suspension, is most rapid at the beginning of the test period and slackens progressively as gelling sets in. The proportion of grit and smaller nonclay particles is nevertheless highest in the early accumulations of the filter cake, and these particles tend to reduce its imperviousness by interfering with the orientation and tight compaction of the clay particles. The actual wall-building efficiency of a clay-water suspension is therefore thought to be greater than the efficiency indicated by the test results. The results are nevertheless useful because they serve as a basis for comparing the wall-building characteristics of different clays.

For the wall-building tests, a moistened Watman no. 52 filter paper was placed in the bottom of the cylinder of the testing apparatus. About 300 milliliters of a 6-percent-by-weight suspension of the clay to be tested was introduced into the cylinder, and the apparatus was assembled. A pressure of 100 psi was then applied to the suspension and the volume of filtrate, representing the water-loss, was recorded in milliliters at periods of 2, 15, and 30 minutes after the pressure was first applied. Immediately following the 30-minute period, the pressure was released, the apparatus was taken apart, and the surplus suspension was removed from the cylinder. The filter cake was gently flushed with water, and its thickness was measured and recorded in thirty-seconds of an inch.

CONTENT OF NONCLAY MATERIAL (INCLUDING GRIT)

The nonclay material present in bentonites is composed of grit, as well as smaller particles. The term grit refers only to those nonclay particles, consisting of mica, quartz, gypsum, calcite, feldspar, and various other minerals present in pulverized bentonite, that are too large to pass through a 325-mesh sieve. The finer constituents include particles of the same minerals as the grit, as well as softer nonclay particles, consisting partly of soluble salts and partly of insoluble matter. Because of the adverse effects of nonclay matter on the properties that give value to bentonites, the amount of such matter in samples is of interest in connection with efforts to explain differences in quality of the sampled clays. The total amounts of nonclay matter and the amount of grit were therefore estimated for the samples from the Hardin and Black Hills districts.

In estimating the total content of nonclay material, each of the pulverized samples was examined microscopically, employing the liquid immersion method. Because of the great variety of nonclay minerals present and the impracticability of separating all of them from the clay, the estimated total percentages were based on their volume, rather than their weight; the procedure followed was similar to that described by Barrell (1901, p. 513) as follows:

> The field of view of the microscope is divided into quadrants by the cross hairs, and these are mentally divided into sectors which are thirds, fifths, or smaller fraction. By taking such a power of objective that the component to be estimated is represented in the field of view by a fair number of crystals, the latter can be mentally collected together and packed into one quadrant, and the fraction which it fills estimated.

Rectangular subdivisions were used instead of the sectors described by Barrell. Estimates were based on the fractions of subdivisions filled by clay and by nonclay material. Several random fields on each slide were carefully studied before estimates were made, and at least two estimates were made for each sample. If the second of these estimates approximated the first, the average of the two estimates was assumed to be the correct figure. When they differed by more than a few percent, repeated estimates on additional slides were made until consistent results were obtained. Estimates for samples containing less than 25 percent of nonclay material are believed to be no more than 5 percent in error. The limit of error is somewhat greater for samples having higher percentages of nonclay constituents.

To determine the approximate amount of grit, 25 grams of ground bentonite was dispersed in water, and the resulting suspension was washed through a 325-mesh sieve. The grit, consisting of mineral particles remaining on the sieve, was washed into a watch glass and was dried and weighed; the weight of the grit was then computed and recorded as a percentage of the original 25 grams of bentonite.

Most of the samples tested in the present investigation yielded less than 5 percent of grit; however, some of the samples showed much larger amounts. In general, samples containing more than 5 percent of grit proved to be deficient in the physical properties that give value to bentonites. It is possible to improve the quality of bentonite by removing grit, but the processes involved are costly.

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