Bentonite Deposits of the Northern Black Hills District Wyoming, Montana, and South Dakota

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

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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An investigation of the district that has supplied most of the gel-forming sodium-type bentonite produced to date in the United States

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By Maxwell M. Knechtel and Sam H. Patterson

ABSTRACT

The northern Black Hills bentonite mining district includes parts of Crook County, Wyo., Carter County, Mont., and Butte County, S. Dak. Within this district, many beds of bentonite occur interspersed with sedimentary strata of Cretaceous age that have an average total thickness of about 3,000 feet and consist chiefly of marine shale, marl, and argillaceous sandstone. The bentonite beds occur in formations ranging upward from the Newcastle sandstone to the lower part of the Mitten black shale member of the Pierre shale. Tertiary (?) and Quaternary deposits of gravel, sand, and silt are present on extensive terraces, and deposits of such materials also extend along stream courses in all parts of the district.

The overall geologic structure of the district is that of a broad northwestward-plunging anticline, in which the strata dip gently toward the northeast, north, and northwest. The overall structure is interrupted, however, by several subordinate folds which bring the bentonite beds to the surface repeatedly, so that large resources of bentonite are present under light overburden.

The northern Black Hills district is an important source of commercial gel-forming sodium-type bentonite. During the period 1941–56 more than 5 million tons of raw bentonite was mined, most of which came from the Clay Spur bed near the top of the Mowry shale; a few thousand tons was mined from bed A in the Newcastle sandstone. Calcium-type bentonite occurs in bed B in the Mowry shale and in bed I at the base of the Mitten black shale member. Seven other beds are sufficiently thick and continuous to warrant consideration as prospective sources of bentonite for industrial use. Most of the bentonite produced is sold for use (a) as an ingredient of drilling mud; (b) for preparing metallurgical molding sand of superior dry strength; and (c) for the bonding material used in pelletizing taconite iron ore of the Lake Superior region.

The results of drilling-mud and foundry-sand bonding-clay tests of several hundred samples, as well as analyses of selected samples, chiefly by X-ray, differential thermal, base exchange and spectrographic methods, are included in this report.

INTRODUCTION

Extensive deposits of bentonite, a valuable clay derived from alteration of volcanic ash, are present in the Cretaceous sedimentary rocks of the western interior of the United States. As defined by Ross and Shannon (1926, p. 79), "Bentonite is a rock composed essentially of a crystalline claylike mineral formed by the devitrification and the accompanying chemical alteration of a glassy igneous material, usually a tuff or volcanic ash." Field and laboratory investigations of bentonite deposits in several parts of the Missouri River basin within Montana, Wyoming, and South Dakota have been carried on intermittently since 1946 by the U.S. Geological Survey. The deposits investigated occur in the Cretaceous formations that crop out in an irregularly shaped, somewhat arbitrarily delimited, area of about 980 square miles, herein referred to as the northern Black Hills district. This district, which extends about 60 miles along the north side of the Black Hills of Wyoming and South Dakota, and the Hardin bentonite district (Knechtel and Patterson, 1956a) in Montana and Wyoming are shown in figure 74. As shown in figure 74 almost two-thirds of the northern Black Hills district lies in the northern part of Crook County, Wyo.; approximately a quarter is in the western part of Butte County, S. Dak.; and the remainder is in the southern townships of Carter County, Mont.

The only populous communities in the district are the town of Belle Fourche, which is the seat of Butte County, S. Dak., and the village of Alzada in Carter County, Mont. A branch of the Chicago and North Western Railway, along which the bentonite-processing plants of the district are situated, extends northwestward from Belle Fourche to the vicinity of the post office at the abandoned village of Colony in Crook County, Wyo. Highway 212 parallels the railroad from Belle Fourche to Colony and continues northwestward through Alzada to the northern limit of the district; Highway 85 extends from Belle Fourche northward across the part of the district in Butte County. These two highways and many secondary roads and trails give access to the scattered outcrops of bentonite in various parts of the district.

The northern Black Hills district and a somewhat less extensive area to the west of the Black Hills in Crook and Weston Counties, Wyo., have been the source of most of the bentonite produced in the United States. They include the bulk of the Nation's known minable reserve of bentonite suitable for use by the petroleum industry as a high-grade ingredient of drilling mud, by the ferrous metals industries for bonding certain types of molding sand, and for pelletizing the iron oxide concentrates obtained in processing low-grade taconite iron ores (Engineering and Mining Journal, 1956, p. 96) of the Lake Superior region.

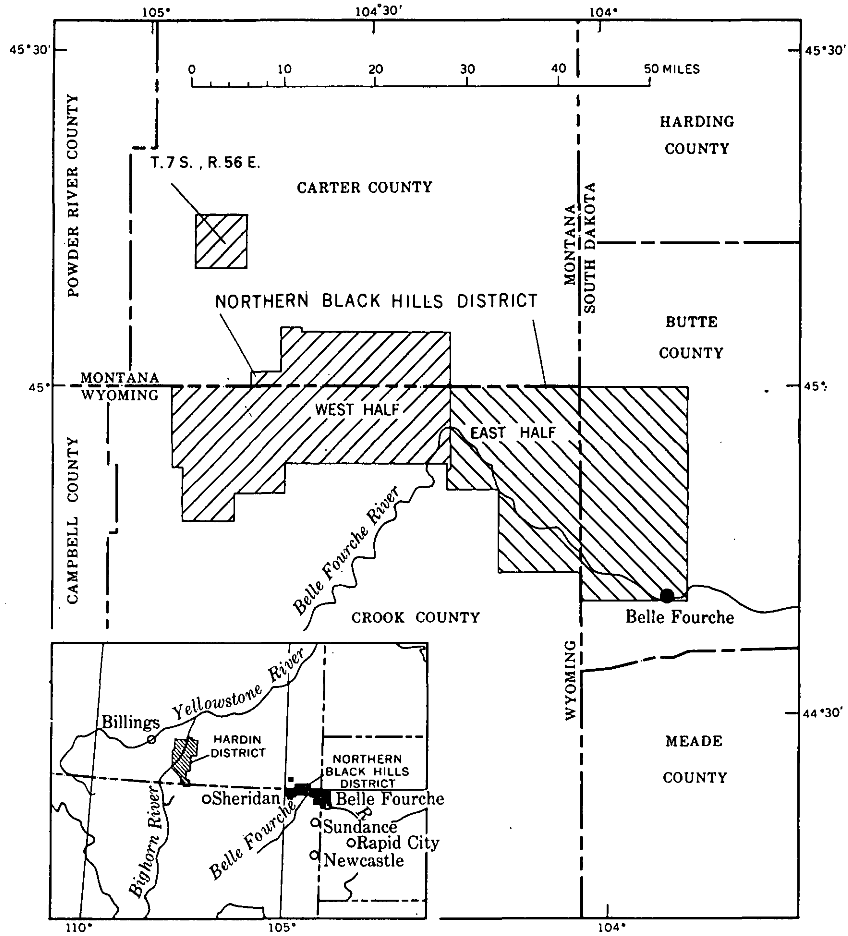


FIGURE 74.—Index map showing location of (a) the northern Black Hills district, Wyoming, Montana, and South Dakota, appearing on the geologic map (pl. 60); (b) T. 7 S., R. 56 E., Carter County, Mont. (fig. 92); and (c) the Hardin district in Montana and Wyoming.

Production of bentonite in Wyoming and South Dakota has increased greatly since 1933 when, as reported by the U.S. Bureau of Mines (1933–55), it amounted to only 21,650 short tons valued at $168,394. In 1953 the production was 876,059 short tons, valued at $12,561,715; and the total production from these two States from 1933 to 1953 was 6,909,801 short tons, valued at $74,505,786. Production in Wyoming for 1954 was 742,453 short tons, valued at $9,339,755; and for 1955 it was 825,810 short tons, valued at $10,721,577. Production for 1954 and 1955 in South Dakota is not reported separately but is included in the total production for several States. Nearly all the material reported from Wyoming and South Dakota was shipped from the northern and western Black Hills districts.

The field study leading to the present report was carried out with the assistance of J. C. Hathaway, R. S. Roth, W. J. Sando, and L. G. Schultz in June, July, and August 1947; June, July, and August 1950; and June and July 1951. The bentonite deposits and associated rocks were examined, measured, and sampled in many natural exposures, mine workings, and shallow holes bored with an earth auger. Geologic field mapping (pl. 60) was performed concurrently on contact prints of aerial photographs, from which it has been transferred to a grid compiled from township plats in the files of the U.S. Bureau of Land Management.

Various laboratory tests were performed primarily to determine the potentialities of the clay sampled for use by the ferrous metals industry as bonding material for synthetic molding sands and by the petroleum industry as ingredients of rotary well drilling mud. In an effort to correlate the differences in physical properties with mineralogical characteristics of the materials tested, differential thermal, X-ray, and cation-exchange analyses of selected samples were made. The fractions of nonclay material in all the samples tested were estimated with the aid of a microscope.

The physical properties of the samples involved in the studies were investigated in the laboratory with the assistance of Dale E. Parro at Urbana, Ill., in 1948 and 1949. Members of the Illinois Geological Survey who contributed much to the value of the laboratory results include M. M. Leighton, chief of the Illinois Geological Survey, who placed the survey's facilities and experience at the authors' disposal; R. E. Grim, petrographer and head of the section of Clay Resources and Clay Technology, who contributed 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. The authors are also indebted to H. G. Fisk and J. A. Brown, of the University of Wyoming Natural Resources Research Institute; and to officials of the American Colloid Co., the Baroid Sales Division of the National Lead Co., the Eastern Clay Products Co., and the Magnet Cove Barium Corp. Laboratory determinations by several of the authors' colleagues of the U.S. Geological Survey are acknowledged at appropriate places in this report.

EARLY INVESTIGATIONS

The clay material now called bentonite was formerly known in the western interior region as soap bog, soap clay, or mineral soap, because of the soapy consistency of the mud it forms and because of its detergent power. In some localities it was known as soda bog, probably reflecting a familiar association of bentonite outcrops with conspicuous white efflorescences of alkaline salts.

Apparently the earliest comments on the geological significance of such clay material as it occurs in this region appear in a description by Engelmann (1858, p. 511; see also Knechtel, 1952) of strata of Cretaceous age cropping out on the north side of the Medicine Bow Range in Carbon County, Wyo. Engelmann (1858) described certain beds in this locality, probably belonging, at least in part, to the Mowry shale (Cretaceous), as consisting of "yellow unctuous matter" which "readily imbibes water" and "seemed to be a product of the decomposition of the igneous rocks."

Probably the first mention of the idea that such material represents altered volcanic ash appears in an account by Condra (1908, p. 13; see also Knechtel, 1952) of observations by Prof. J. E. Todd, relating to a bentonite bed near the middle of the Carlile shale of northeastern Nebraska. The idea was later applied and elaborated by Hewett (1917), with reference to bentonite deposits of Cretaceous age in the Bighorn basin, Wyoming, and by Wherry (1917) in describing other deposits south of the Black Hills, S. Dak. This concept was developed further by Ross and Shannon (1926), who made it an essential part of their definition of bentonite, and by Rubey (1929), who demonstrated that the Mowry shale, which contains the Clay Spur and other beds of bentonite, is derived largely from volcanic ash. Abundant supporting evidence has since been found in studies of bentonite deposits in various parts of the world.

The earliest references to the bentonite deposits in the northern Black Hills district probably were made by Darton and O'Harra (1907, p. 8; 1909, p. 4, 7). More recently, Wing (1940) has described the deposits in a part of the district in Butte County, S. Dak.; and still more recently, Knechtel and Patterson (1956b) have dealt with the bentonite deposits of the entire district.

HISTORY OF PRODUCTION

The earliest production of bentonite in the western interior of the United States was obtained in 1888 from a pit opened by William Taylor on his ranch near the town of Rock River, Albany County, Wyo. (Darton and Siebenthal, 1909, p. 60). In the first description of the clay that was mined, it was called taylorite (Knight, 1897); but that name was later found to be preoccupied. The clay was thereupon renamed bentonite (Knight, 1898), after the Benton formation of Cretaceous age, from which it was mined. Deposits of bentonite have since been reported in over half the States, as well as in many foreign countries. Figure 82 illustrates the growth of the bentonite industry in the United States in the 19-year period from 1937 to 1955; the total value of the domestic tonnage for 1955 was $17,219,015 (U.S. Bureau of Mines, 1937–1955). The tonnage does not include a rather large amount of bentonite produced in the Southern and Southwestern States that has been reported, for technological reasons, as "fuller's earth."

Mining of the extensive deposits of bentonite in Weston County, Wyo., southwest of the Black Hills, began before 1903 (Darton, 1904, p. 9). The commercial possibilities of the deposits in the northern Black Hills district had also attracted attention and by the 1920's were being promoted for development and exploitation. In 1923 the Belle Fourche Bentonite Products Corp., primarily a lease-holding organization, was established; but only a few carload lots of crude bentonite were shipped from the district before 1934. In that year the first mill for processing finished powdered bentonite went into production, followed by others in 1935, 1941, and 1946. Three of these plants, which have been gradually improved and modernized, are still producing powdered and pelleted bentonite. By 1949 the output of the district, which is largely shipped through the railroad town of Belle Fourche, S. Dak., exceeded that of the rest of Wyoming. Annual shipments by rail from Belle Fourche are given below and represent nearly all the bentonite produced in the northern Black Hills district from 1941 to 1953:

Year	Carloads	Approximate weight (short tons)	Year	Carloads	Approximate weight (short tons)
1941	1613	64,520	1949	6342	253,680
1942	2242	89,680	1950	8236	329,440
1943	2809	112,360	1951	9575	383,000
1944	4130	165,200	1952	9170	366,800
1945	4295	171,800	1953	9132	365,280
1946	4363	174,520			
1947	4469	178,760	Total		2,946,480
1948	7286	291,440			

The total tonnage for the 13-year period represents chiefly material that was used in the oil fields of the United States and other countries as an ingredient of rotary drilling muds, and by foundries and steel works for bonding synthetic molding sands. From 1954 through 1956 rail shipments through Belle Fourche amounted to an estimated 30,000 carloads, valued at approximately $4 million. The approximately 4,150,000 short tons shipped by rail during the 16-year period from 1941 to 1956 must have required mining more than 5 million short tons of raw bentonite, inasmuch as the average moisture content of the raw clay is about 30 percent as compared with about 5 to 10 percent for processed bentonite. The tonnage actually mined includes, in addition, some material shipped by truck, for which figures are not available, as well as a large amount of material that has been stockpiled by the several operating companies. As shown on plate 60, all four plant sites are situated not only on the railroad but also near Highway 212.

MINING

Bentonite is mined in the northern Black Hills district by the open-cut or stripmining method exclusively. The bentonite is mined chiefly from late spring to autumn, because during much of each winter the ground at stripping sites is frozen so solid that it is virtually unworkable. Even during the warmer seasons, mining is occasionally interrupted by wet weather, which causes roads leading to most of the workings to become too muddy for hauling. In order that ample supplies may be available to keep the processing plants running throughout the year, mining is carried on intensively during favorable weather, and large stock piles are maintained at the plants.

In selecting sites for stripmining operations, the thickness of both clay and overburden is measured, and the quality of the clay is tested. In general practice, measurements and samples for testing are obtained with machine-driven augers towed by trucks. Some companies, however, use equipment of this kind only to penetrate the overburden; hand augers are then used in boring through the bentonite, in order to ensure accurate measurement of the thickness and to avoid undue contamination of the samples that are taken. Selecting material to be used in drilling mud, and for other purposes requiring highly colloidal clay, generally involves boring more holes and testing more samples than does blocking out material to be used as foundry-sand bonding clay.

In all the pits that have been opened to date (1956), the overburden is shale or soft sandstone, which is readily removed by earth-moving equipment. Notwithstanding the softness of the overburden, the high walls of excavations will ordinarily stand nearly vertically for at least one mining season, which is sufficient time for removal of the bentonite before it is covered by slumping. After the overburden has been removed, the clay is loaded into trucks to be delivered to the processing plants.

PROCESSING

In most of the processing plants, the primary operations involved in preparing the bentonite for the market are cutting, drying, crushing, grinding, and packing. In order that the ultimate product may be fairly uniform in quality, the raw material that is dumped on the stockpile is thoroughly mixed and spread out by a bulldozer. Such mixing is desirable because of the variation in the quality of clay, even from a single small excavation. The clay as taken from the stockpile for further processing is mostly in large chunks and retains most, if not all, of the original moisture, which is about 30 percent by weight, of the raw clay as taken from the mine. Usually, it is first passed through a clay slicer, which cuts the chunks into pieces ranging from 2 to 3 inches in diameter, and then it is hoisted to large rotary oil-fired driers, which remove most of the moisture. In most plants, the dry material is crushed and ground to powder of which 75 to 90 percent passes through a 200-mesh sieve. Some is also produced as fine pellets, which are classified into several size grades, each of which is intended for one or more specific uses. The product is next stored in bins from which it is fed mechanically to packing machines that rapidly fill 4-ply paper bags of 100 pounds capacity for shipment to many parts of the United States and to other countries.

STRATIGRAPHY

Bentonite occurs in many parts of the world in formations ranging in age from early Paleozoic to late Cenozoic; however, according to available data, production has come only from Cretaceous and younger deposits. Figure 75 shows the principle bentonite-producing localities in the United States in relation to the outcrop areas of Cretaceous and Tertiary sedimentary rocks. In Wyoming, South Dakota, and Montana, bentonite occurs at many stratigraphic positions in the succession of Mesozoic and Cenozoic strata; it has been mined, however, only from strata of Cretaceous age. The correlation chart (table 1) shows the classification of the Cretaceous formations of the northern Black Hills district in relation to that of equivalent stratigraphic intervals in areas further west. Older rocks, ranging in age from Cambrian to Jurassic (Leatherock, 1950), have been reached within the district in exploratory drilling for petroleum; partial data on these rocks are given in table 2.

CRETACEOUS SYSTEM

Within the northern Black Hills district, the rocks of Cretaceous age, which contain the bentonite deposits described in this report, are exposed in many localities, but in other localities they are covered by surficial deposits of gravel, sand, and silt that range in age from Oligocene(?) to Recent. Even in areas where such surficial deposits are absent, the bedrock is largely obscured by soil and vegetation.

The Cretaceous formations consist mostly of shale, marl, and argillaceous sandstone. Their total thickness is more than 4,200 feet. Beds of bentonite and other material of pyroclastic origin are interspersed among the sedimentary formations, especially within the Mowry shale. Nearly all the Cretaceous rocks—including most of the bentonitic and other pyroclastic material—were deposited under marine environmental conditions. At least one formation, the Newcastle sandstone, contains shallow-water and beach deposits, and the Fuson member of the Lakota formation and the lower three-fourths of the Fall River formation include some material of nonmarine origin.

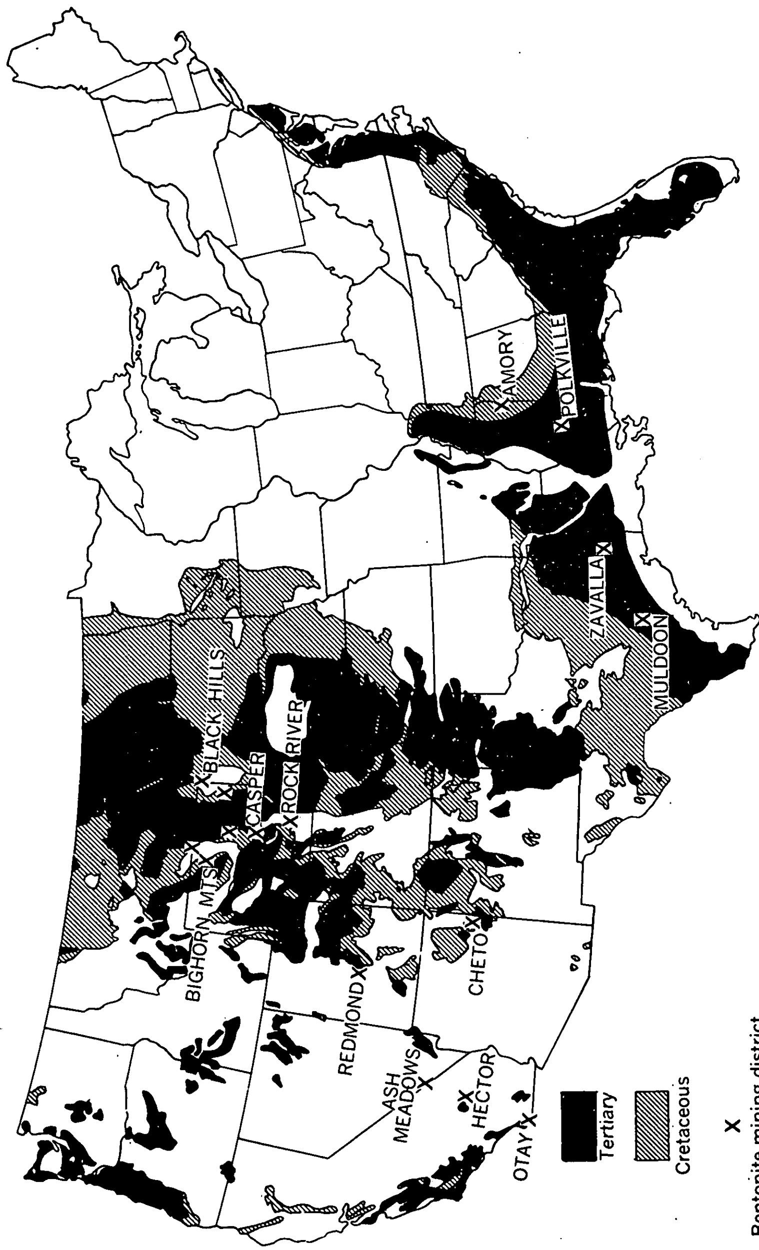


FIGURE 75.—Map showing location of the northern and western Black Hills districts and various other bentonite-mining districts of the United States in relation to outcrops of sedimentary bedrock of Cretaceous and Tertiary age.

TABLE 1.—*Correlation chart showing the stratigraphic nomenclature of the area covered by this report in relation to that of other areas in Wyoming and Montana*

[Wavy line (————) indicates intertonguing]

<table>
<tr><th colspan="3">This report</th><th colspan="4">Hardin district, Montana and Wyoming (Knechtel and Patterson, 1956a)</th><th colspan="2">Central Montana (Reeside, slightly modified)</th><th colspan="2">Salt Creek oil field, Wyoming (Thom and Spieker, 1931)</th><th colspan="2">South of Billings, Montana (Knappen and Moulton, 1930)</th><th>Bighorn Basin, Wyoming (Pierce and Andrews, 1941)</th></tr>
<tr><td rowspan="7">Montana group (part)</td><td rowspan="7">Pierre shale</td><td>Unnamed</td><td rowspan="7">Montana group (part)</td><td colspan="3">Bearpaw shale</td><td rowspan="7">Montana group (part)</td><td>Bearpaw shale</td><td colspan="2">Lewis shale</td><td rowspan="7">Montana group (part)</td><td>Bearpaw shale</td><td>Meteetse formation</td></tr>
<tr><td rowspan="2">Monument Hill bentonitic member</td><td rowspan="3">Judith River formation</td><td rowspan="2">Upper unnamed member</td><td rowspan="2"></td><td rowspan="3">Judith River formation</td><td rowspan="3">Mesaverde formation</td><td>Teapot sandstone member</td><td rowspan="3">Judith River formation</td><td rowspan="3">Mesaverde formation</td></tr>
<tr><td>Unnamed</td></tr>
<tr><td>Unnamed member</td><td>Parkman sandstone member</td><td>Judith River formation</td><td>Parkman sandstone member</td></tr>
<tr><td>Mitten black shale member</td><td rowspan="3"></td><td colspan="2">Claggett shale member</td><td>Claggett shale</td><td rowspan="3">Steele shale</td><td>Unnamed member</td><td>Claggett formation</td><td rowspan="3"></td></tr>
<tr><td rowspan="2">Gammon ferruginous member</td><td colspan="2">Unnamed sandy shale member</td><td>Eagle sandstone</td><td>Shannon sandstone member</td><td>Eagle sandstone</td></tr>
<tr><td colspan="2">Telegraph Creek member</td><td>Telegraph Creek formation</td><td>Unnamed member</td><td>Telegraph Creek formation</td></tr>
</table>

Colorado group: Niobrara formation	Colorado group: Cody shale: Niobrara and Carlile shale members	Colorado group: Warm Creek shale: Upper member	Niobrara shale	Colorado group: Niobrara and Carlile shales	Cody shale
Colorado group: Carlile shale: Sage Breaks shale member			Carlile shale		
Colorado group: Carlile shale: Turner sandy member			Frontier formation		?—?—?
Colorado group: Carlile shale: Pool Creek shale member				?	
Colorado group: Greenhorn formation	Colorado group: Cody shale: Greenhorn calcareous member	Colorado group: Warm Creek shale: Middle unit with Mosby sandstone member at base		Colorado group: Frontier formation	Frontier formation
Colorado group: Belle Fourche shale	Colorado group: Cody shale: Belle Fourche member	Colorado group: Warm Creek shale: Lower member			
Mowry shale	Mowry shale	Mowry shale	Mowry shale	Mowry shale	Mowry shale
Newcastle sandstone and Skull Creek shale	Thermopolis shale	Thermopolis shale	Thermopolis shale	Thermopolis shale	Thermopolis shale
Inyan Kara group	Cloverly formation	Kootenai formation, including 1st Cat Creek sandstone (of drillers) at top	Cloverly formation	Cloverly formation	Cloverly formation

TABLE 2.—*Records of dry holes drilled in Crook County, Wyoming*

Company	Location (pl. 60)			Date of completion	Total depth (feet)	Bedrock formations	Remarks
	Section	Township N.	Range W.				
Roxana Petroleum Co	SE¼NW¼ 17	57	61	1920's	510	Skull Creek shale (Cretaceous) to Morrison formation (Jurassic).	Colony anticline.
Roxana Petroleum Co	SW¼SW¼ 27	57	61	10-26-20	2,290	Skull Creek shale (Cretaceous) to Minnelusa (?) sandstone (Pennsylvanian).	Colony anticline.
Marine Oil Co	SE¼NE¼ 3	57	62	8-13-25	968	Belle Fourche shale (Cretaceous) to Newcastle (?) sandstone (Cretaceous).	Water from 929 to 956 feet.
Union Oil Co	NE¼NW¼ 3	57	62	7-11-40	4,243	Belle Fourche shale (Cretaceous) to Deadwood formation (Cambrian).	Bull Creek anticline.[1]
Vickers Petroleum Co	NW¼SW¼ 28	57	64	1941	2,476	Fuson member of Lakota formation (Cretaceous) to Pahasapa limestone (Mississippian).	Government Canyon anticline.
Montah-Wyco Oil Corp.; Korda Oil and Gas Co.	NW¼NW¼ 15	57	65	11-13-50	2,760	Newcastle sandstone (Cretaceous) to Pahasapa limestone (Mississippian).	
Amerada Petroleum Corp	SW¼SE¼ 6	57	66	6-29-50	1,678	Greenhorn formation (Cretaceous) to Pahasapa limestone (Mississippian).	
Amerada Petroleum Corp	SW¼SW¼ 23	57	67	6-20-50	1,511	Carlile shale (Cretaceous) to Morrison formation (Jurassic).	

[1] For additional data on Paleozoic rocks, see Leatherock (1950).

All the formation and member names used in this report have appeared in earlier publications on the geology of the region except the name Pool Creek shale which is introduced (p. 921) for the heretofore unnamed lower member of the Carlile shale. The classification shown on plates 60 and 61, however, involves additional taxonomic adjustments made so recently that they call for brief comment.

In accordance with a precedent established by Reeside (1944), the formation name "Graneros shale" has been dropped in this area, and the four members once included under that name have been given formational rank. The name Niobrara, formerly applied to a unit that included two members—the Sage Breaks shale member and the overlying Beaver Creek chalky member—now refers only to the strata of the upper of these members. The name Beaver Creek has accordingly been discarded as superfluous, and the Sage Breaks shale is treated as a member of the Carlile shale (Cobban and Reeside, 1952, p. 1031).

Various horizons have been designated in earlier publications as marking the contact between the Lower Cretaceous series and the Upper Cretaceous series of the western interior region. In the vicinity of the Black Hills, this contact was regarded by Darton and O'Harra (1905, 1907, and 1909) as the top of the "Dakota" (herein designated the Fall River formation), and the Lower Cretaceous series was regarded as including definitely only the strata that underlie the "Dakota" beds and overlie the Morrison formation. The Morrison formation was also included provisionally in the Lower Cretaceous by Darton but is now classified by the U.S. Geological Survey as Upper Jurassic. More recently, the Fall River formation and the overlying Skull Creek shale have been generally regarded as Lower Cretaceous, and the still younger Newcastle sandstone and Mowry shale are also regarded as Lower Cretaceous (Cobban, 1951; Cobban and Reeside, 1951, 1952; Knechtel and Patterson, 1956(a); Richards, 1956). The assignment of the Mowry to the Upper Cretaceous series, however, is still favored by some paleontologists (Yen, 1954).

INYAN KARA GROUP

The Inyan Kara group, which includes the oldest rocks mapped on plate 60, comprises two formations: The Lakota formation, including the Fuson member, and the Fall River formation. The lower part of the Lakota sandstone, including some of the basal material of the Fuson member, is present only in the subsurface of the area shown on plate 60. Most of the Fuson member and the entire overlying formation, the Fall River sandstone, are well exposed at several places near the south margin of the district.

LAKOTA FORMATION

The lower part of the Lakota formation, which crops out just beyond the southern margin of the area shown on plate 60, is presumably present in all the subsurface of the area. The lower part of the Lakota is believed to contain little or no bentonitic material and was, therefore, neither mapped nor examined in detail during our investigation. The Lakota, as exposed nearby to the south, is described by Darton and O'Harra (1905, 1907, 1909) as a formation which ranges from 25 to 100 feet in thickness and consists of "gray to buff sandstone, massive to flaggy, mostly hard," in the Belle Fourche quadrangle (Darton and O'Harra 1909, p. 4 and 9).

FUSON MEMBER

The Fuson member of the Lakota formation, the oldest unit exposed in the area, (pl. 60) crops out only in a few valleys and small canyons, none of which have been cut deep enough to expose its contact with the underlying beds of the Lakota. Exposures along Government Canyon, in T. 57 N., R. 64 W., Crook County, Wyo., show 109 feet of Fuson consisting of red, purple, and light-gray variegated shale. The Fuson evidently thins toward the east, inasmuch as its total thickness east of the district, within the Belle Fourche quadrangle, is only 60 to 70 feet (Darton and O'Harra, 1909). There and in small exposures within the eastern part of the district, the Fuson includes a considerable amount of dark-gray shale and sandstone. It contains also some light-gray shale that seems to be somewhat bentonitic, inasmuch as weathering of its exposed surfaces in many places has resulted in soft, puffy ground—a fairly reliable indicator of dilatancy comparable to that of many bentonitic materials.

The following section of the Fuson member was measured in Government Canyon in SE¼ sec. 20, T. 57 N., R. 64 W., Crook County, Wyo.:

Fall River formation.

Fuson shale member of Lakota formation:

	Ft	In
1. Shale, light-gray, silty; contains many root holes or worm borings	1	6
2. Shale, light-gray, soft, fissile	12	0
3. Shale, brownish-red; upper and lower parts are mottled white and purple	17	0
4. Shale, gray, fissile, weathers very light gray	13	0
5. Shale, gray, silty, bentonitic	20	0
6. Shale, light-gray, iron-stained; upper part is hard	7	0
7. Shale, light-greenish-gray, bentonitic	16	6
8. Shale, purplish-red, hard	22	0
9. Covered	--	--
Total measured thickness	109	0

FALL RIVER FORMATION

The Fall River sandstone, which was defined by Russell (1928, p. 136), was considered by Rubey (1930, p. 5) as equivalent to the unit mapped and described by Darton and O'Harra (1905, 1907, 1909) as the "Dakota" sandstone. The Fall River formation was redefined by Waagé (1959) to include all the rocks down to the transgressive disconformity which marks the top of the Fuson member of the Lakota formation. Because the Fall River is relatively more resistant to erosion than the shaly strata of the formations above and below, it commonly forms mesas, hogbacks, and broad cuestas with prominent rocky escarpments along their updip sides. The Fall River, which ranges in thickness from 120 to 140 feet, consists mostly of sandstone, but includes in its lower and middle parts some shale and siltstone interstratified with thin beds of brownish-gray to buff sandstone that is commonly ripple marked and crossbedded. The upper third or more of the formation is largely made up of thin-bedded hard ferruginous standstone containing many small nodular ferruginous concretions, some of which are hollow.

The following section of the Fall River formation was measured in Government Canyon near the southeast corner sec. 20, T. 57 N., R. 64 W., Crook County, Wyo.:

	Ft	In
Skull Creek shale.		
Fall River formation:		
1. Sandstone, buff, fine-grained; small hollow ferruginous concretions; lower part crossbedded; upper part ripple marked	12	0
2. Siltstone, light-brownish-gray; many iron-stained lamina	2	2
3. Siltstone, brownish-gray, hard, ferruginous; weathers to rusty color		1½
4. Shale, gray, silty	8	6
5. Siltstone, light-yellowish-gray, thin-bedded		6
6. Siltstone, brown, silty, hard, ferruginous; weathers to rusty color		5
7. Shale, dark-gray, fissile, soft	12	0
8. Sandstone, grayish-orange to red, medium-grained, crossbedded, friable; many small ferruginous concretions	8	2
9. Sandstone, brownish-gray, medium-grained, crossbedded; a few thin, soft, silty beds	9	0
10. Siltstone, light-gray; argillaceous beds, as much as 5 in. thick, interbedded with brown ferruginous siltstone beds as much as 2 in. thick	4	6
11. Sandstone, brownish-gray; beds, as much as 8 in. thick, interbedded with thinner soft argillaceous beds	16	3
12. Sandstone, light-brownish-gray, fine-grained	1	9
13. Covered	3	9
14. Sandstone, brownish-gray, fine-grained; forms small ledge	2	6
15. Sandstone, light-gray, fine-grained, soft, silty	4	3
16. Sandstone, brownish-gray, medium-grained; a few partings of soft siltstone	3	4

Fall River formation—Continued	*Ft*	*In*
17. Sandstone, soft; poorly exposed	12	0
18. Sandstone, brownish-gray, fine-grained		8
19. Sandstone, light-brownish-gray, platy, fine-grained		4
20. Sandstone, brown, medium-grained, crossbedded	1	7
21. Siltstone, brownish-gray, platy, soft		3
22. Sandstone, brown, fine-grained, crossbedded	1	2
23. Siltstone, brownish-gray, platy, soft		6
24. Siltstone, brown, ferruginous, hard; weathers to rust color		2
25. Shale, gray, silty, soft	8	1
26. Sandstone, brownish-gray, fine-grained	2	6
27. Siltstone, gray; carbonaceous plant remains		3
28. Sandstone, light-brownish-gray, fine-grained; many carbonceous plant remains		9
29. Coal; much sand and silt		10
30. Siltstone, gray; much coaly material in upper part	1	0
Total measured thickness	121	3½

Fuson shale member of Lakota formation.

SKULL CREEK SHALE

The Skull Creek shale is about 250 feet thick at the few exposures where its thickness can be accurately measured. This formation is relatively soft and is covered largely by soil and alluvium. The Skull Creek shale is made up chiefly of soft dark-gray fissile shale; within it are several zones containing rather abundant concretions of ferruginous mudstone. In the basal part of the formation are many thin beds of argillaceous sandstone, others of carbonaceous shale, and some of dark bentonitic shale. Sandstone dikes commonly cut the beds near the top and, to a lesser extent, those near the base. The dikes near the base generally consist of poorly consolidated gray medium-grained sandstone, and their width ranges from that of paper-thin seams to that of slabs about 4 inches thick. Most of them are traceable for only a few feet. Most of the dikes near the top of the formation are much larger but are so poorly exposed that their dimensions can be estimated only roughly. Some of them can be traced for more than 200 feet horizontally but are present only in the uppermost 50 feet of the formation. Apparently the distance between the eroded top and the bottom of even the largest dikes rarely exceeds 20 feet. The dikes near the top of the Skull Creek consist of sandstone similar to that of the coarsest material of the overlying Newcastle sandstone. In some of these dikes the sandstone shows poorly defined bedding, the attitude of which differs from that of the enclosing shale. Differential erosion has formed high hills and ridges along some of the larger dikes, on the walls of which some slickensides have been observed.

The following section of the Skull Creek shale was measured on a steep hillside in the southern part of sec. 36, T. 57 N., R. 63 W., Crook County, Wyo.:

	Ft	In
Newcastle sandstone.		
Skull Creek shale:		
1. Shale, dark-gray, soft, fissile, poorly exposed; a few gray clay ironstone concretions and some calcareous concretions with cone-in-cone structure; both types of concretions are as large as 8 in. by 1½ ft	70	0
2. Shale, dark-gray, soft, fissile; at top, a zone of septariate clay ironstone concretions is veined with white calcite; the concretions, which are as large as 6 by 16 in., weather dark brown	69	6
3. Shale, dark-gray, soft, fissile; at top, a zone of gray clay ironstone concretions, which are weathered very dark brown and as large as 8 in. by 2 ft	88	0
4. Shale, dark-gray, soft; poorly exposed; dark-brown concretions and some sandy zones	28	0
Total measured thickness	255	6
Fall River formation.		

NEWCASTLE SANDSTONE

The Newcastle sandstone differs greatly from place to place in its thickness and lithologic character. It is more than 60 feet thick near the southwest corner of the northern Black Hills district, but generally it thins eastward across Crook County, Wyo. It consists characteristically of sandstone interstratified with siltstone, sandy shale, carbonaceous shale, bentonite, and impure lignite. In many places the sandy strata are conspicuously crossbedded and ripple marked, and many of the beds contain numerous small stemlike objects, which may represent fossil worm trails or borings.

For many miles along its outcrop, the Newcastle is largely made up of massive beds of sandstone of a coarse- to medium-grained texture resembling that of the Fall River sandstone. The general massiveness of the formation is lost farther east, as indicated by exposures in the vicinity of Chicago Creek, a few miles west of the South Dakota boundary, where the Newcastle consists mainly of thin-bedded soft sandstone with only a few intercalated lenses of massive sandstone. Still farther east, in Butte County, S. Dak., only the thin bedded sandy material persists. The Newcastle is therefore, shown on plate 60, as a separate stratigraphic unit only as far southeast as Chicago Creek. Beyond this locality, the equivalent strata which contain many small phosphatic and gypsiferous nodules, are assigned to the Mowry shale, and the Mowry is accordingly represented as resting directly on the Skull Creek shale. The Mowry is also shown in direct contact with the Skull Creek in various exposures not so far east, where the thinning of the Newcastle is interrupted by local irregularities. For example, the Mowry shale in N½ sec. 20, T. 56 N., R. 61 W., includes a thin basal zone of sandy shale containing only one bed of sandstone, which is about 1½ feet thick and is made up of extraordinarily flexible bedding plates. In outcrops about 1½ miles southeast of this outcrop of sandy shale, in a direction involving the overall thinning of the Newcastle, the equivalent stratigraphic position is occupied by cross-bedded sandstone, which forms a prominent unit 21 feet thick and is mapped as the Newcastle sandstone.

Fossil remains of terrestrial plants occur in the Newcastle sandstone of this district; and a marine microfauna, comprising 12 genera, is reported (Crowley, 1951) from the Newcastle of the oil-producing area in Weston County, Wyo., on the southwest side of the Black Hills. The idea that the sediment of the Newcastle was deposited along or close to an old shoreline was first stated by Collier (1922, p. 81–82), who suggested that the sandier parts of the formation accumulated on beaches and in shallow lagoons and that the more shaly beds were deposited in deeper marine water. Collier's interpretation is supported and somewhat amplified by the reported presence of small gold nuggets occurring in a drill core from Weston County, suggesting that at least some of the sedimentary material in the Newcastle sandstone was furnished by Precambrian rocks postulated by Crowley (1951) to have been exposed during Newcastle time in the part of the area that is today occupied by the Black Hills.

The Newcastle sandstone includes bentonite bed A (p. 965) and a few less extensive lenticular bodies of bentonite. So far as is known, none of these bentonite deposits extend as far as the limits within which the Newcastle is readily recognizable and beyond which equivalent beds are mapped as Mowry shale (pl. 60).

The following section of the Newcastle sandstone was measured in a cliff near the northeast corner sec. 25, T. 57 N., R. 63 W., Crook County, Wyo.:

	Ft	In
Mowry shale:		
1. Shale, brownish-gray, siliceous; grades into subjacent shale; 3 ft thick.		
2. Shale (Nefsy shale of former usage), dark-gray, soft, fissile; 12 ft thick.		
Newcastle sandstone:		
3. Siltstone, light-gray, platy, friable; many worm borings	3	6
4. Siltstone, light-gray; many plant remains		10
5. Coal, silty, poorly consolidated		6
6. Sandstone, light-gray, iron-stained, friable; worm borings or root holes in upper part	6	6
7. Shale, gray, silty, soft; weathers light gray	8	0
8. Bentonite (bed A; p. 965), greenish-gray, waxy; forms a moderately well-developed popcornlike crust in weathering	5	0
9. Coal and platy carbonaceous shale with much sand and silt	1	0

	Ft	In
Newcastle sandstone—Continued		
10. Sandstone, light-gray, medium-grained, friable, lenticular	1	6
11. Sandstone, light-gray, medium-grained, poorly consolidated, crossbedded	5	6
12. Sandstone, light-gray, medium-grained, massive, resistant	3	0
13. Sandstone, light-brown, medium-grained, friable,	2	6
14. Sandstone and siltstone, soft; interlaminated with dark-gray shale		9
15. Siltstone, light-yellowish-gray, soft	2	0
16. Shale, light-brownish-gray, silty; weathers very light gray	12	6
17. Sandstone, brownish-gray, medium-grained, soft, friable	3	0
18. Sandstone, light-gray, fine-grained, friable, lenticular; wedges out 200 yd from point of measurement	5	0
19. Sandstone, dark-brownish-gray, friable; many fragmental plant remains	4	6
Total measured thickness	65	7
Skull Creek shale.		

MOWRY SHALE

The Mowry shale is less readily eroded than are the formations above and below. It tends accordingly to stand in relief, forming rounded silver-gray hills and ridges. The Mowry ranges in thickness from 195 to 250 feet and consists chiefly of brownish-gray hard siliceous shale which fractures conchoidally, interbedded with subordinate amounts of brownish silty mudstone and brightly colored bentonite. The basal 10 to 20 feet of the formation consists of dark-gray fissile shale grading upward into siliceous shale. This basal dark shale has the lithologic character and stratigraphic position of the Nefsy shale of former usage (Collier 1922, p. 82) of areas farther southwest, but here it is too thin and poorly exposed to be mapped as a separate unit.

The contact between the Mowry and the overlying Belle Fourche shale is represented on plate 60 as marked by the top of the Clay Spur bentonite bed, whereas actually, in much of the district, a layer of siliceous shale, which is a few feet thick and typical of the Mowry, intervenes between the Clay Spur bed and the unsilicified shale typical of the base of the Belle Fourche shale. (See p. 914.) This siliceous shale layer cannot be satisfactorily delineated at the map scale of plate 60, and is thereon treated as an undifferentiated part of the Belle Fourche shale. The exposed part of the siliceous shale of the Mowry has weathered largely silver gray and generally its hardness has increased slightly. Where freshly exposed and in a moist condition, it emits a sulfurous odor and many joints and bedding surfaces within it exhibit thin coatings of powdery, yellow sulfurous material. Many of the beds contain abundant fossil remains of fishes, including vertebrae, fins, gill covers, and scales.

The following section of the Mowry shale was measured in a cut bank of the Belle Fourche River near the center of sec. 20, T. 57 N., R. 62 W., Crook County, Wyo.:

	Ft	In
Belle Fourche shale.		
Mowry shale:		
1. Shale, gray, siliceous; weathers light-gray; interlaminated with gray bentonitic shale		10
2. Bentonite (Clay Spur bentonite bed; see p. 971), light-yellowish-green, waxy	2	0
3. Shale, dark-brownish-gray, weathered light-silvery gray, siliceous; limonite and sulfurous stains along joints; fish remains in lower part; somewhat less resistant than the siliceous strata below	31	0
4. Bentonite (bed B; see p. 969), light-gray, waxy, limonite-stained		11
5. Shale, gray to brownish-gray, siliceous; limonite and sulfurous stains along joints; uppermost 2 in. very hard	13	6
6. Bentonite, light-gray, waxy		10
7. Shale, brownish-gray, siliceous; limonite and sulfurous stains along joints; abundant fish remains	11	0
8. Bentonite, light-gray, waxy		10
9. Shale, brownish-gray, hard, siliceous; calcareous lenses as much as 4 inches by 3½ feet in dimension, with poorly developed cone-in-cone structure; some lenses overlain by thin deposits of fibrous gypsum	3	2
10. Bentonite, light-gray, waxy		4
11. Shale, dark-brownish-gray, hard, siliceous; abundant fish remains	3	3
12. Bentonite, waxy, light-brownish-gray; dark gray laminae in upper part		1½
13. Shale, hard, dark-brownish-gray; siliceous; limonitic and sulfurous stains along joints		5
14. Bentonite, light-yellowish-gray, waxy		1
15. Shale, dark-brownish-gray, hard, siliceous		8
16. Bentonite, light-yellowish-gray, waxy		7
17. Shale, brownish-gray, hard, siliceous; sulfurous deposits along joints	9	0
18. Shale, dark-gray, somewhat siliceous; much softer than enclosing strata	1	3
19. Shale brownish-gray, hard, siliceous; sulfurous stains and ting gypsum crystals along joints; abundant fish remains	25	0
20. Shale, dark-gray, siliceous; several thin laminae of bentonite		10
21. Shale, dark-brownish-gray, siliceous; limonite and sulfurous stains along joints; fish remains	2	3
22. Shale, dark-gray, siliceous; many thin laminae of bentonite	4	6
23. Shale, dark-brownish-gray, hard, siliceous; many vertical joints, most of which show sulfurous residues and stains	10	2
24. Shale, dark-gray, somewhat siliceous; much softer than enclosing beds; bentonitic near base	1	1
25. Bentonite, brownish-gray, limonite-stained, waxy	0	3

Mowry shale—Continued

	Ft	In
26. Shale, dark-brownish-gray, hard, siliceous; sulfurous residues along joints; abundant fish remains	2	6
27. Shale, dark-gray, soft; bentonitic in lower part		5
28. Bentonite, brownish-gray, waxy		1
29. Shale, dark-brownish-gray, hard, siliceous	1	8
30. Bentonite, light-gray, waxy		½
31. Shale, dark-gray, siliceous, platy	2	8
32. Bentonite, dark-gray and light-gray interlaminated, waxy		1½
33. Shale, dark-gray, silty, siliceous	2	8
34. Bentonite, light-gray and dark-gray interlaminated, waxy		2½
35. Shale, dark-gray, siliceous		1
36. Bentonite, gray, waxy; a few light-gray laminae		6
37. Bentonite, light-gray, waxy, iron-stained		10
38. Shale, dark-brownish-gray, hard, siliceous; uppermost inch exceptionally hard	2	3
39. Bentonite, light-gray, waxy	1	0
40. Shale, dark-brownish-gray, hard, siliceous; sulfurous and limonitic stains along joints; abundant fish remains	4	11
41. Shale, dark-gray, soft, bentonitic		2
42. Bentonite, light-gray, waxy; dark-gray laminae in upper part		3½
43. Shale, dark-brownish-gray, hard, siliceous; sulfurous efflorescence on weathered surfaces	6	2
44. Bentonite, yellowish-gray, waxy		4
45. Gypsum, gray, fibrous, shaly		1½
46. Shale, dark-gray, soft, fissile		1
47. Siltstone, brownish-gray, weathered rusty-brown, soft, lenticular	2	1
48. Shale, dark-brownish-gray, hard, siliceous	1	4
49. Shale, dark-gray, soft, bentonitic		8
50. Bentonite, limonite-stained, waxy; lower half is brownish gray, upper half is light gray		6
51. Shale, dark-brownish-gray, hard, siliceous, sulfurous; limonite stains along joints; abundant fish remains	3	4
52. Shale, dark-gray, soft, platy		2
53. Shale, dark-brownish-gray, hard, siliceous; abundant fish remains	3	6
54. Shale, dark-gray, soft; lower part is bentonitic		8
55. Shale, gray, hard, siliceous; sulfurous and limonitic stains along joints; abundant fish remains	3	3
56. Bentonite, light-gray, iron-stained, waxy; dark-gray laminae in uppermost 3 inches	1	10
57. Shale, cherty, gray, very hard		1
58. Shale, dark-brownish-gray, siliceous; many vertical joints; abundant fish remains	3	2
59. Bentonite, light-gray, waxy, lenticular; dark-gray laminae in upper part		3
60. Shale, dark-brownish-gray, hard, siliceous; some fish remains		11
61. Covered with talus deposits to level of Belle Fourche River (water level marks approximate base of Mowry shale)	24	0
Total measured thickness	196	9

COLORADO GROUP

BELLE FOURCHE SHALE

The Belle Fourche shale, named by Collier (1922, p. 83) after exposures along the Belle Fourche River in the southwestern part of Crook County, consists chiefly of very dark-gray fissile shale with subordinate amounts of sandy shale and many beds of bentonite. The beds range in thickness from less than an inch to more than 6 feet. In the vicinity of the South Fork (T. 56 N., R. 67 W.), near the southwestern corner of the area (pl. 60), this formation comprises two members with an aggregate thickness of about 825 feet. The lower member, of which bentonite bed F is the uppermost stratum, contains more sandy material and includes many more bentonite beds than does the upper member.

At the southwest corner of the district, the only strata typical of the Belle Fourche shale, and accordingly so designated, are those equivalent to the lower member. Near the town of Belle Fourche the equivalent of the lower member is only about 425 feet thick, and the rocks equivalent to the upper member, which are largely of a highly calcareous facies, have been mapped (pl. 60) as an undifferentiated part of the Greenhorn.

LOWER MEMBER

The lower member of the Belle Fourche shale ranges in thickness from about 425 feet near the town of Belle Fourche to about 540 feet in the vicinity of South Fork. It is well exposed along Burrows Creek—a small tributary of Belle Fourche River southwest of Highway 212, in sec. 22, T. 57 N., R. 62 W., Crook County, Wyo.—where the member is a little more than 500 feet thick and is divisible into three lithologic units. These three subdivisions are also recognizable in other parts of the district but are not shown separately on plate 1 because their contacts with one another are concealed by soil and other surficial material so that they cannot be mapped satisfactorily.

The lowermost unit, which rests on the Mowry shale, ranges in thickness from 30 to 45 feet. Although it is not mapped separately, its outcrops are nearly coextensive with areas (pl. 1) in which the Clay Spur bentonite bed lies beneath less than 30 feet of cover. This lowermost unit, which includes bentonite beds D and E (p. 979), consists primarily of dark shale that is harder and less fissile than that of the overlying strata. It contains many oblate spheroidal concretions, commonly corrugated or pit marked, of hard gray finely crystalline slightly manganiferous siderite. The concretions range from about 1 to 5 feet in their major diameter, but rarely more than 1 foot in their lesser diameter. Weathered surfaces of these concretions are purplish-brown or black from the oxidation of iron and manganese, and they lend to the unit as a whole a striking dark coloration that persists far beyond the district. South of Alzada, Mont., the lowermost 25 feet of strata also contains ovoid calcareous concretions, with an average maximum diameter of about 1½ feet, that are yellowish brown on weathered surfaces and that show cone-in-cone structure. Concretions of this kind are increasingly abundant toward the west side of the district.

The unit resembles (a) the "oligonite zone" (Spivey, 1940, p. 16), exposed on the south side of the Black Hills in Fall River and Custer Counties, S. Dak., which comprises 60 to 80 feet of strata above the Mowry shale; (b) strata at various localities north of the Bighorn Mountains, as exemplified by 24 feet of beds at the base of the Belle Fourche shale exposed in Beauvais Creek, T. 4 S., R. 31 E., Big Horn County, Mont. (Knechtel and Patterson, 1956a, p. 74); and (c) the basal beds of the Warm Creek shale as exposed on the east side of the Little Rocky Mountains in north-central Montana (Knechtel, 1959, p. 741).

The middle unit of the lower member is about 215 feet thick as exposed along Burrows Creek. It consists largely of sandy shale intercalated with many beds and lenses of soft gray sandstone, most of which are less than 2 inches thick, and thick layers of dark-gray soft, fissile shale. Beds of bentonite, generally ranging in thickness from less than an inch to 1½ feet, occur at many horizons within this unit. Clay-ironstone concretions occur in a thick layer of dark shale in the middle of the lower half of the unit, and lenticular cone-in-cone aggregates occur in two higher strata. The relative abundance of sandy material in the middle unit no doubt represents deposition related to that of correlative strata of the Frontier formation farther west in the region, as on the west side of the Powder River basin of Wyoming.

The uppermost unit of the lower member contains less sandy material than does the middle unit, but it includes many more bentonite beds than does the upper member of the Belle Fourche shale. The uppermost unit of the lower member at Burrows Creek is approximately 250 feet thick. About 20 miles farther southeast, in the vicinity of Belle Fourche, S. Dak., strata believed to be continuous with the upper part of this unit contain so much calcareous matter that they are regarded as part of the overlying Greenhorn formation and the uppermost unit of the lower member of the Belle Fourche shale as there measured, is only about 200 feet thick. Along Burrows Creek, where the entire uppermost unit is well exposed, most of it consists of soft dark-gray shale which is, in part, fissile and which includes many beds of bentonite and, in its upper part, a few layers that contain highly calcareous material largely in the form of concretions and lenticular cone-in-cone aggregates. A thin bed of sandy shale occurs close to the middle and a zone of shale, 20 feet higher, contains small concretions of brown siltstone. The topmost stratum is bentonite bed F, which is about 4½ feet thick at this locality but pinches out about 22 miles farther southeastward where the base of the Greenhorn lies directly above the beds equivalent to the uppermost unit of the lower member. Among the other beds of bentonite exposed along Burrows Creek, one bed, about 63 feet lower than bed F, is 1⅙ feet thick; another, about 10 feet lower, is 10 inches thick. Many other beds in various parts of the unit generally range in thickness from less than 1 inch to 6 inches. Possibly the 2 relatively thick beds just mentioned represent the same episodes of volcanic-ash deposition as do the 2 even thicker bentonite beds, less than 100 feet below bed F, that are exposed about 35 miles farther southwest, in the vicinity of South Fork, just within the southwest margin of the district.

UPPER MEMBER

The upper member of the Belle Fourche shale is made up almost entirely of soft dark-gray shale, with a few strata containing calcareous concretions, and some bentonite beds, including bed G of the west side of the district (see p. 986). The member rests on bentonite bed F (see p. 982) and is overlain by the Greenhorn formation. The thickness of this member decreases eastward across the Northern Black Hills district. Owing largely to a lateral change of lithologic facies (see p. 919), the Belle Fourche-Greenhorn contact drops to lower positions within the sequence of strata. Thus, in the southwestern part of T. 56 N., R. 67 W., Crook County, Wyo., bed F underlies about 285 feet of strata of the upper member of the Belle Fourche shale, whereas northeast of this locality, that is, northwest of Alzada, Mont., bed F is only about 177 feet below the base of a thin limestone stratum, which marks the bottom of the overlying Greenhorn formation. East of Alzada, where the base of the Greenhorn drops to the level of the base of a thin limestone bed—the Orman Lake limestone of Petsch (1949)—about 45–60 feet below bed G, the upper member of the Belle Fourche includes only 32 feet of dark shale; near the Wyoming-South Dakota boundary, its thickness decreases to 12 feet. It is only 6 feet thick about 4 miles northwest of the town of Belle Fourche in Butte County, S. Dak., where bed F thins out. From the State boundary southeastward, this member is relatively thin and crops out mostly on the steep up-dip scarps of cuestas capped by the basal limestone bed of the Greenhorn formation. The member cannot, therefore, be delineated satisfactorily as a separate unit at the map scale used on plate 60 on which it is mapped as an undifferentiated part of the Greenhorn.

The following section of the Belle Fourche shale was measured in Burrows Creek, sec. 22, T. 57 N., R. 62 W., Crook County, Wyo.:

	Ft	In
Greenhorn formation.		
Belle Fourche shale:		
Upper member:		
1. Shale, dark-gray, soft, fissile	25	0
Lower member:		
Upper unit:		
2. Bentonite (bed F, p. 982); upper half is gray; lower half is reddish brown and waxy	4	6
3. Shale, dark-gray, soft, fissile; a few thin bentonite beds	63	0
4. Bentonite, dark-reddish-brown, granular; many dark mineral particles	1	2
5. Shale, dark-gray, soft	8	0
6. Bentonite, gray, limonite-stained, waxy		10
7. Shale, dark-gray, soft	12	6
8. Shale, dark-gray, soft; at top, a zone of thin lenses of limestone with cone-in-cone structure	26	3
9. Shale, dark-gray, soft; at top, a zone of small brown siltstone concretions	21	0
10. Shale, gray, iron-stained, sandy	1	2
11. Shale, dark-gray, soft; a few septariate limestone concretions, which average 4 by 2½ ft, are veined with white calcite	37	10
12. Bentonite, greenish-gray, waxy		2
13. Shale, dark-gray, soft	1	0
14. Bentonite, gray, waxy		6
15. Shale, dark-gray, soft, fissile	2	0
16. Bentonite, gray, waxy		3
17. Shale, dark-gray, soft, fissile	19	0
18. Bentonite, light-yellowish-gray, waxy		6
19. Shale, dark-gray, soft, fissile	14	0
20. Bentonite, light-gray, waxy		1½
21. Shale, dark-gray, soft, fissile	21	0
22. Bentonite, yellowish-brown		1
23. Shale, dark-gray, soft, fissile	1	0
24. Bentonite, yellow, waxy		3½
25. Shale, dark-gray, soft	1	0
26. Bentonite, yellow, limonite-stained		3
27. Shale, dark-gray, soft	7	6
28. Bentonite, dark-gray, waxy		1
29. Shale, dark-gray, soft	2	6
30. Bentonite, gray, iron-stained, waxy		1½
31. Shale, dark-gray, soft, fissile	5	0
32. Bentonite, light-yellowish-gray, waxy		4
Middle unit:		
33. Shale, dark-gray, sandy, soft	21	6
34. Bentonite, gray, waxy		1
35. Shale, dark-gray, soft, sandy	5	0
36. Bentonite, grayish-yellow, waxy		2
37. Shale, dark-gray, soft; many thin soft gray sandstone lenses	54	0
38. Bentonite, waxy; lower part is brown; upper 5 in. is gray	1	0
39. Shale, dark-gray, soft; 1 in. of bentonite near middle	6	0
40. Bentonite, gray, waxy		3

Belle Fourche shale—Continued
Lower member—Continued

Middle unit—Continued	Ft	In
41. Shale, dark-gray, soft, sandy	20	0
42. Sandstone, gray, soft fine-grained		2
43. Shale, dark-gray, soft, sandy	1	6
44. Sandstone, gray, fine-grained; interbedded with limestone exhibiting cone-in-cone structure		5
45. Shale, dark-gray, sandy, soft	13	0
46. Bentonite, gray, waxy		1
47. Shale, dark-gray, soft; a few laminae of bentonite and some thin sandstone lenses	21	6
48. Shale, dark-gray, sandy; at top, a zone of cone-in-cone lenses, which average 2 in. by 2 ft., overlapping one another in shingle fashion	19	8
49. Bentonite, light-gray, waxy		3
50. Shale, dark-gray, soft; a few clay ironstone concretions, which average 6 in. in diameter	18	0
51. Bentonite, yellow, waxy		2
52. Shale, dark-gray, soft	2	0
53. Bentonite, yellow, waxy		2
54. Shale, dark-gray, soft, fissile; bentonite laminae in lower part	11	0
55. Bentonite, gray, waxy; upper part grades into a thin zone of sandy shale		4
56. Shale, dark-gray, soft, fissile	1	2
57. Bentonite, light-gray, waxy		1
58. Shale, dark-gray, soft fissile	16	0
59. Bentonite, brownish-orange, waxy	1	6
Lower unit:		
60. Shale, dark-gray, soft; many maganiferous siderite concretions, which average 5 in. by 1 ft	14	0
61. Bentonite (bed E, p. 980); upper and lower parts are light gray; middle 8 in. is reddish brown	1	2
62. Shale, dark-gray, soft; many maganiferous siderite concretions, which average 4 in. by 1 ft	24	0
63. Bentonite (bed D, p. 979), waxy; lower half is cream; upper half is gray		10
64. Shale, dark-gray, soft	4	6
Total measured thickness	537	5½

Mowry shale.

GREENHORN FORMATION

The Greenhorn formation consists mainly of brownish-gray calcareous shale and marl containing a few thin beds, lenses, and concretions of limestone. It also contains some noncalcareous dark shale and some bentonite, notably in bed G of the eastern part of the district (see p. 986). This formation is only about 70 feet thick in the vicinity of South Fork, near the southwest corner of this district. About 370 feet of beds are included 40 miles eastward, near the head of Ghost Creek, in sec. 31, T. 57 N., R. 60 W., just west of the Wyoming-

South Dakota boundary. The eastward increase in thickness is due primarily to a change of lithologic facies, already noted in describing the upper member of the Belle Fourche shale (p. 916). Thus, the lime carbonate content of rocks within the stratigraphic interval occupied by the upper member of the Belle Fourche shale of the South Fork locality increases eastward. The Greenhorn-Belle Fourche contact, consequently, migrates 45–60 feet downward from a position above bentonite bed G to the base of a limestone stratum, whereas the contact of the Greenhorn with the overlying beds of the Carlile shale is virtually at the same horizon throughout the district. The entire Greenhorn as mapped in the vicinity of South Fork, accordingly, represents only the uppermost beds of the Greenhorn of the Ghost Creek section; the underlying strata of the Greenhorn at Ghost Creek are continuous with the upper member of the Belle Fourche shale of the South Fork section.

Treatment of the Belle Fourche-Greenhorn contact in this manner conforms to the usage established for the eastern part of this district by Rubey and Bramlette (Moore, 1949, p. 27). It supersedes the treatment given by Darton and O'Harra (1909, p. 4, 9), which is virtually the same as that more recently given by Petsch (1949, p. 7–10). Only the uppermost beds, ranging in thickness from 25 to 35 feet, were regarded by these authors as Greenhorn limestone; the beds below were assigned to the upper part of the Belle Fourche (Graneros) shale, even where they contained a large amount of calcareous material closely resembling that of the uppermost beds. The thickness of the "Greenhorn limestone" as mapped by Darton and O'Harra (1905), however, corresponds only locally to the relatively small thickness of that unit in secs. 15 and 22, T. 9 N., R. 2 E., Butte County, S. Dak., as specified in their descriptions. Elsewhere they mapped much greater thicknesses. In the vicinity of Ghost Creek, for example, approximately 370 feet of strata are included in the Greenhorn (pl. 60; Darton and O'Harra, 1905).

The following section of the Greenhorn formation was measured in the vicinity of Ghost Creek in sec. 31, T. 57 N., R. 60 W., Crook County, Wyo. It is fairly representative of the succession of strata of the Greenhorn formation in the eastern half of the district (pl. 60). Units 1 to 6, with a total thickness of 86 feet, resemble and are tentatively correlated with the entire Greenhorn formation in the vicinity of the South Fork and in most of the western half of the district.

	Ft	*In*
Carlile shale.		
Greenhorn formation:		
1. Marl, gray, weathered very light gray, soft	32	0
2. Marl, gray, weathered light-gray, soft; at top, a zone of limestone concretions, which are weathered light brown and average 8 in. by 1½ ft	4	0

	Ft	In
Greenhorn formation—Continued		
3. Bentonite, gray, granular; upper part is iron stained; many dark mineral particles	2	0
4. Shale, gray, highly calcareous, soft	3	0
5. Shale, gray, weathered light-yellowish-gray, soft; at top, a zone of septariate calcareous concretions, which average 1 by 1½ ft and are veined with white calcite	12	0
6. Shale, gray, weathered light-yellowish-gray, soft; at top, a zone of gray septariate limestone concretions, which average 1½ by 2 ft and are veined with calcite	33	0
7. Bentonite, gray, iron-stained, granular		3
8. Shale, gray, soft; weathers light yellowish gray	3	0
9. Shale, gray, weathered light-gray, soft, calcareous; at top, a zone of septariate white limestone concretions, which average 1½ by 2½ ft and are veined with white calcite	22	0
10. Limestone, brown, platy, fossiliferous	7	0
11. Shale, gray, weathered yellowish-gray, soft; a few small limestone concretions near base	14	0
12. Limestone, light-brown, platy, crystalline		8
13. Shale, gray, weathered light-yellowish-gray, soft, calcareous; near base, a zone of white limestone concretions, which average 1 by 1½ ft	11	3
14. Limestone, brown, platy; phosphatic nodules		8
15. Shale, gray, weathered light-yellowish-gray, calcareous	12	0
16. Limestone, light-brown, platy; many small phosphatic nodules	1	0
17. Shale, gray, weathered yellowish-gray; lower third is poorly exposed	97	6
18. Limestone, light-brownish-gray, platy, fossiliferous	1	6
19. Shale, gray, weathered light-yellowish-gray, soft, calcareous; poorly exposed	61	6
20. Limestone, light-brownish-gray, platy, crystalline; *Inoceramus* fragments and some shark teeth	1	0
21. Shale, brownish-gray, soft, highly calcareous	6	6
22. Bentonite (bed G, p. 986), gray, waxy; powdery on weathered surfaces	2	6
23. Shale, brownish-gray, weathered light-yellowish-gray, highly calcareous	46	9
24. Limestone, light-brownish-gray, platy, crystalline; many fossil shell fragments, fossil teeth, and vertebrae of sharks		6
Belle Fourche shale:		
25. Shale, dark-gray, soft, fissile	----	----
Total measured thickness	369	2

CARLILE SHALE

The Carlile shale, named by Gilbert (1896, p. 565) for exposures west of Pueblo, Colo., averages about 500 feet in thickness in the northern Black Hills district where it "attains its maximum known thickness in the Great Plains region" (Cobban, 1951, p. 2187). The rocks of the Carlile as exposed here consist predominantly of gray shale, containing some sandy beds, rather abundant concretionary nodules of calcareous, ferruginous, and phosphatic materials, and a few very thin beds of bentonite. Fossils of many species (Cobban, 1951, p. 2187–2190) occur at various horizons. Mappable stratigraphic subdivisions of the Carlile of this district (pl. 60) are: (a) the Pool Creek shale member, (b) the Turner sandy member, and (c) the Sage Breaks shale member.

POOL CREEK SHALE MEMBER

The basal member of the Carlile shale, which is herein named the Pool Creek shale member, is approximately 70–150 feet thick as exposed in this district. Exposures at the type locality, near the point at which Highway 85 crosses the head of Pool Creek (pl. 60), 5 miles north of the town of Belle Fourche, are described by Cobban (1951, p. 2187) as follows:

> The basal dark shale member is made up of two distinct lithologic units. North of Belle Fourche the lower unit consists of 13 feet of dark-gray soft papery shale that weathers bluish gray. It contains some thin calcareous shale partings and a few thin lenses of buff-weathering limestone as much as ½ inch thick that are largely made up of minute *Inoceramus* prisms. The top of the basal unit is marked by limestone concretions that are commonly 6–8 inches thick and 3 feet in diamenter. These are dark gray on fresh fracture but readily weather light-bluish gray and finally buff. They are enveloped by a soft mixture of selenite and limonite. Many concretions are septarian, with thin veins of pale yellow to white or colorless calcite; and in some concretions, the selenite-limonite crust extends throughout as septarian veins.
>
> North of Belle Fourche the upper unit of the unnamed member of the Carlile shale consists of 81 feet of black-gray to dark gray shale that contains in the lower part two 6-inch bentonite layers, and in the upper 37 feet numerous clay ironstone concretions. The shale of the lower part is darker, more fissile, and more resistant to weathering than that of the upper part. The ferruginous concretions in the upper part are so abundant that they impart a rusty appearance to the outcrop. They are ordinarily 2–3 inches thick and 6–12 inches in diameter, but those lowest in the unit may be as much as 6 inches thick and 4 feet long. The concretions are dark gray on fresh fracture but weather dark maroon, rust, or orange tan. Small buff- or tan-weathering claystone nodules are present in many of them. Interspersed with the clay ironstone concretions at the top of the member are large wide-spaced yellow-weathering calcareous concretions that contain thin veins of pale yellow calcite. A layer of white-weathering phosphatic claystone nodules occurs 15.5 feet below the top. Many of these nodules are formed about fragments of crustaceans.

Cobban (1951) lists fossil species collected by him from each of the two units described. In some exposures strata equivalent to both units include bentonite beds, though none of these are sufficiently thick to be regarded as potential sources of commercial bentonite.

The following section of the Pool Creek shale member of the Carlile shale was measured on a hillside in NW¼ sec. 30, T. 58 N., R. 61

W., Crook County, Wyo., about 25 miles northwest of the exposures described by Cobban (1951):

	Ft	In
Carlile shale:		
Turner sandy member:		
1. Shale, dark-gray, soft, sandy	----	----
Pool Creek shale member:		
2. Shale, dark-gray, soft, fissile; at top, a zone of fossiliferous ironstone concretions, which average 2 by 8 in. and are weathered rusty brown	7	0
3. Shale, dark-gray, soft, fissile; at top, a zone of subspherical septariate calcareous concretions, which range from 2 to 3 ft in diameter and are veined with yellow calcite	6	0
4. Siltstone, brownish-gray, weathered rusty-brown, platy		4
5. Shale, dark-gray, fissile, soft; at top, a zone of calcareous concretions, which average 1½ by 2½ ft, with poorly developed cone-in-cone structure	16	6
6. Shale, dark-gray, soft, fissile; at top, a zone of calcareous concretions, which are weathered buff and average 1½ by 3 ft, with poorly developed cone-in-cone structure	52	0
7. Bentonite, gray, waxy		2
8. Shale, dark-gray, soft, fissile	12	0
Greenhorn formation:		
9. Shale, calcareous	----	----
Total measured thickness	94	0

TURNER SANDY MEMBER

The Turner sandy member, the middle subdivision of the Carlile shale, is composed of dark shale containing many limestone concretions and lenses of light-gray sandstone and sandy shale. Locally this member also includes lenses containing phosphatic nodules and intraformational shale pebbles. The concretions, some of which are more than 6 feet in diameter, are especially abundant in several zones about halfway between the base and top of the member. Because these concretions are less readily eroded than is the enclosing shale, the several zones containing them commonly crop out on hillsides as parallel ledges rising one above another in steplike fashion.

The Turner sandy member, 6 miles north of Belle Fourche, S. Dak., is about 260 feet thick (Cobban 1951, p. 2188, 2189). About 25 miles farther northwest, in secs. 3 and 4, T. 57 N., R. 61 W., Crook County, Wyo., this member is about 210 feet thick, and on the west side of the district it is only about 150 feet thick. The convergence thus exemplified is due to the westward pinching out of some of the lowermost beds of the characteristic sandy material of this member. Following is a summary (omitting lists of fossils) by Cobban (1951, p. 2188–2189) of his measurements of the Turner strata, 6 miles north of Belle Fourche.

	Thickness (feet)
(Uppermost unit). Shale, gray, finely sandy; weathers light buff-gray; contains tan-and-yellow-weathering calcareous concretions that are commonly septarian, with coarsely crystalline pale yellow to dark-brown calcite veins	89
Shale, dark gray; weathers dark; contains some sandy beds and numerous ferruginous concretions that weather reddish, orange and rusty	82
Shale, dark gray; weathers medium gray; contains large yellow-weathering calcareous concretions and small gray-weathering calcareous concretions. Few fossils in lower part	47
Shale, gray, very sandy; weathers medium gray; contains large yellow-weathering sand, calcareous concretions at top and in middle, chert pebbles and coarse sandstone at base	40
Total	258

The following section of the Turner sandy member was measured in secs. 3 and 4, T. 57 N., R. 61 W., Crook County, Wyo.:

	Ft	In
Sage Breaks shale member:		
1. Shale, gray, soft, fissile	----	----
Turner sandy member:		
2. Shale, gray, weathered yellowish-gray, very sandy	3	0
3. Shale, gray, weathered yellowish-gray, very sandy; at top, a zone of calcareous concretions, which average 1½ by 3 ft and are weathered light brown	11	0
4. Shale, gray, weathered yellowish-gray, very sandy; many large calcareous concretions weathered light orangish brown; supports a low scarp	13	0
5. Shale, dark-gray, soft; many calcareous concretions which average 10 in. by 1 ft and are weathered rusty brown	11	0
6. Shale, dark-gray, soft, fissile; at top, a zone of calcareous concretions, which average 1 by 1½ ft and are weathered light buff	8	0
7. Shale, gray, soft, fissile; at top, a zone of very fossiliferous brown clay ironstone concretions, which average 1½ by 2½ ft	4	0
8. Shale, dark-gray, soft; at top, a zone of fossiliferous calcareous concretions, which average 2 by 3 ft and are weathered light brown	7	0
9. Shale, dark-gray, soft, fissile; at top, a zone of calcareous concretions, which average 8 in. by 1 ft and are weathered rusty brown	4	6
10. Shale, dark-gray, soft, fissile; at top, a zone of calcareous concretions, which average 8 in. by 1 ft and are weathered rusty brown	14	0
11. Shale, dark-gray, soft; lower part is sandy; at top, a zone of gray limestone concretions, which average 4 by 6 ft and are weathered light yellowish brown	31	6
12. Shale, dark-gray, sandy, poorly exposed; at top, a zone of fossiliferous limestone concretions which average 2 by 3 ft and are weathered light buff; thin lenses of calcareous cone-in-cone material occur above most of the concretions	51	0

	Ft	In
Turner sandy member—Continued		
13. Sandstone, gray, medium-grained, crossbedded, calcareous, concretionary; many lenses of calcareous cone-in-cone material in upper part	2	6
14. Shale, dark-gray, soft; interbedded with soft gray calcareous sandstone as much as 1½ in. thick	47	0
Pool Creek shale member:		
15. Shale, dark-gray, soft, fissile	----	----
Total measured thickness	207	6

SAGE BREAKS SHALE MEMBER

The Sage Breaks shale member of the Carlile is made up of dark-gray noncalcareous shale containing many limestone concretions. Six miles north of Belle Fourche, S. Dak., the thickness of this member is 195 feet (Cobban, 1951, p. 289), whereas 20 miles farther northwest, in secs. 34 and 35, T. 58 N., R. 61 W., Crook County, Wyo., the thickness is nearly 300 feet. In the vicinity of the South Fork, near the southwest corner of the district, the thickness is approximately 225 feet. The possibility that different horizons were chosen for the base and top of the member at the three localities at which these measurements were made may account, in part, for the reported differences in thickness.

The Sage Breaks shale member forms prominent, nearly barren outcrops, which are mostly somber gray. However, a zone of shale at the top weathers to light gray shades similar to those characteristic of the calcareous strata in the overlying Niobrara formation. In fact, except for its much smaller content of calcareous matter, this zone could easily be mistaken for a part of the Niobrara. The concretions occur in zones that, owing to their relative firmness, commonly form the crests of prominent ridges and small buttes. Practically all the concretions are septariate. Most of them are subspherical or ovoid and range from 1 to 3 feet in diameter; however, some ovoid concretions have maximum diameters of 8 feet or more and minimum diameters of 4 or 5 feet. The concretions of the upper part of the member are characterized by veins of dark-brown or black calcite, whereas many of the concretions near the middle of the member tend to be veined by calcite of three colors. The color in the core of such a concretion is most commonly brown; in the veins of a surrounding layer it tends to be yellow or orange; and in the outer layer it is generally white. The concretions commonly contain abundant fragments of shells but rarely yield unbroken fossils. According to Cobban (1951, p. 2190), who lists fossil species from the Sage Breaks shale member, the fauna resembles that of the upper part of the Turner sandy member.

The following section of the Sage Breaks shale member was measured in secs. 34 and 35, T. 58 N., R. 61 W., Crook County Wyo.:

	Ft	In
Niobrara formation:		
1. Marl, brownish-gray, weather very light gray	----	----
Carlile shale:		
Sage Breaks shale member:		
2. Shale, gray, soft, fissile; grades into superjacent marl through a zone about 10 in. thick	48	0
3. Shale, gray, soft, fissile; at top, a zone of septariate concretions, which measure 8 by 10 in. and are veined with black calcite	6	0
4. Shale, gray, weathered light-gray, soft	2	0
5. Shale, gray, weathered light-gray, soft; at top, a zone of light-gray septariate limestone concretions, which contain abundant fossil fragments; the concretions average 2 by 4 ft and are veined with brown calcite	10	0
6. Shale, gray; weathers light gray; at top, a zone of light-gray septariate limestone concretions, which average 3 by 4½ ft and are veined with brown and yellow calcite	8	0
7. Shale, gray, soft, fissile; at top, a zone of septariate limestone concretions, which average 1½ by 3½ ft and are veined with brown calcite	31	6
8. Shale, gray, soft, fissile; at top, a zone of septariate limestone concretions, which are weathered very light gray, veined with brown calcite, and range from 8 by 14 in. to 1½ by 5 ft	14	0
9. Shale, gray, soft, fissile; at top, a zone of light gray septariate limestone concretions, which average 1 by 2½ ft and are veined with light-yellow calcite	16	0
10. Shale, gray, soft, fissile; at top, a zone of septariate limestone concretions, which average 10 in. by 1½ ft and are veined with dark-brown calcite	3	0
11. Shale, gray, soft, fissile; at top, a zone of septariate limestone concretions, which average 10 in. by 1 ft and are veined with dark-brown calcite	7	0
12. Shale, gray, soft, fissile; at top, a zone of septariate limestone concretions, which average 2½ by 5½ ft and are veined with white and brown calcite; concretionary zone supports a prominent ridge	54	0
13. Shale, gray, soft, fissile; at top, a zone of light-gray septariate limestone concretions, which average 3 by 8 ft and are veined with white calcite; concretionary zone supports a prominent ridge	26	0
14. Shale, gray, soft, fissile; at top, a zone of septariate limestone concretions, which average 8 in. by 1½ ft and are veined with dark-brown calcite	40	6
15. Shale, gray, fissile, soft; at top, a zone of light-gray septariate limestone concretions, which average 2 by 4 ft and are veined with yellow and brown calcite	22	6
16. Shale, gray, soft, fissile; at top, a zone of gray, septariate limestone concretions, which average 2 by 3 ft and are veined with yellow calcite	10	0
Turner sandy member:		
17. Shale, gray, sandy	--	--
Total measured thickness	298	6

NIOBRARA FORMATION

The thickness of the Niobrara formation is approximately 200 feet throughout most of the district but is only 120 feet thick as exposed in the vicinity of South Fork, in T. 56 N., R. 67 W., Crook County, Wyo., near the southwest corner of the district.

The Niobrara formation is largely made up of grayish-brown marl, which weathers very light gray, partly with a yellowish or faintly orange cast. The uppermost fourth of the formation also contains variable amounts of soft dark-gray shale, some beds of which are locally as much as 15 feet thick. Commonly the strata near the base and top of the formation include a relatively small amount of limestone as concretions and lenses and a few thin beds of limestone consisting chiefly of loosely cemented oyster shells. The concretions, which average about a foot in diameter, are mostly septariate. The upper half of the formation contains many beds of medium- or dark-gray bentonite, commonly iron stained and rarely exceeding 6 inches in thickness. The surficial crusts that have formed from the weathering of this bentonite are of the "alligator-hide" variety, indicating that most of it is clay of low dilatancy. Fossil remains of fishes, including bones, teeth, and scales, are contained in some of the beds of the Niobrara formation but, as reported by Cobban (1951, p. 2192), "the only invertebrate megafossils noted were fragments of *Inoceramus* encrusted with *Ostrea congesta* Conrad."

The following section of the Niobrara formation was measured on the north side of Owl Creek valley in sec. 24, T. 9 S., R. 61 E., Carter County, Mont. (outside the area shown on plate 60):

	Ft	In
Pierre shale:		
Gammon ferruginous member.		
Niobrara formation:		
1. Marl, yellowish-gray, weathered very light orangish gray, soft, fissile, argillaceous; a few platy limestone lenses and many fragments of *Inoceramus* in lower part	38	6
2. Bentonite, gray, waxy limonite-stained		6
3. Marl, yellowish-gray, weathered very light gray, soft, fissile	3	6
4. Bentonite, yellowish-brown, waxy		2
5. Marl, light-brownish-gray, weathered very light gray, soft, fissile	1	6
6. Bentonite, gray, waxy		2
7. Marl, light-brownish-gray, weathered light-yellowish-gray, soft	2	6
8. Shale, dark-gray, soft, fissile, noncalcareous	1	0
9. Bentonite, light-gray, waxy		1
10. Shale, dark-gray, soft, fissile, noncalcareous	3	6
11. Bentonite, light-gray, hard		1½
12. Shale, dark-gray, fissile, soft, noncalcareous	6	6
13. Marl, brownish-gray, weathered light-yellowish-gray, fissile, soft; at top, a zone of septariate limestone concretions, which average 6 in. by 1½ ft and are veined with white calcite	6	0

Niobrara formation—Continued

	Ft	In
14. Marl (approximate base of Niobrara formation), brownish-gray, weathered light gray with a faint orange cast; poorly exposed; at top, a zone of septariate limestone concretions, which average 1 by 1½ ft and are veined with brown calcite	132	0
15. Quaternary alluvium	----	----
Total measured thickness	196	½

MONTANA GROUP

The Montana group as exposed in the vicinity of the Black Hills comprises two formations, the Pierre shale and the Fox Hills sandstone. The beds of the Fox Hills crop out in the area shown on figure 92, but have been entirely eroded from the area shown on plate 60.

PIERRE SHALE

The Pierre shale crops out in areas along the northeast and west edges of the northern Black Hills district. In this district, its total thickness ranges, approximately, from 1,600 to 1,750 feet. Most of the Pierre is made up of dark- to light-gray shale but a small part of the formation consists of sandstone and sandy shale, and beds of bentonite are intercalated at various horizons.

According to Rubey (1930, p. 3–5), the Pierre shale as exposed on the west and north sides of the Black Hills can generally be subdivided into five members. From oldest to youngest, these are the Gammon ferruginous member, which rests on the Niobrara formation; the Mitten black shale member; and three upper members. The middle one of the upper members is the Monument Hill bentonitic member. In some exposures in the part of Carter County, Mont., north of the northern Black Hills district, all five subdivisions are distinctly recognizable; but within the district, they are largely obscured by soil and alluvium so that only three units—the Gammon and Mitten members and an undivided unit equivalent to Rubey's three upper members—have been mapped during our investigation.

GAMMON FERRUGINOUS MEMBER

The Gammon ferruginous member, the lowermost of the three subdivisions of the Pierre shale that have been mapped in this district (pl. 60), is approximately 800 feet thick. This member consists largely of soft medium-gray shale which weathers very light gray to light tan. Many gray calcareous concretions and one bentonite bed (bed H; see p. 989) are contained in the shale of the upper 150 feet of the member, and numerous rusted ferruginous concretions are distributed throughout its entire thickness. The ferruginous concretions lend a faint pinkish coloration to the landscape of many areas in which the shale of the Gammon crops out. Such areas commonly are broad flats with a peculiar hummocky relief characterized by innumerable small, closely spaced hillocks. These features are believed to have formed by differential erosion, which leaves the more resistant clusters of concretions in the Gammon standing in relief as the relatively soft shale that surrounds them is washed away. Such flats are generally almost devoid of vegetative cover. The Groat sandstone bed, in the upper part of the member, ranges from about 50 to 150 feet in aggregate thickness; its upper limit is about 150 feet below the base of the Mitten black shale member. The sandstone of the Groat bed, which is greenish gray and fine grained, is partly glauconitic. It generally weathers grayish brown to brown. In places, some of the sandstone in the middle of the Groat sequence is so resistant to erosion that it forms the crests of low ridges and buttes. The sandstone of the higher and lower beds is more argillaceous and is not much, if any, more resistant than is the overlying and underlying shale into which it grades.

In the following section of the Gammon ferruginous member, units 1 to 5 were measured in sec. 10, T. 11 N., R. 2 E., Butte County, S. Dak.; units 6 to 12 were measured in sections 20 and 30 of the same township.

	Ft	In
Pierre shale:		
Mitten black shale member:		
1. Bentonite (bed I, base of Mitten shale member; see p. 990).		
Gammon ferruginous member, upper part:		
2. Shale, gray, soft; many gray oval ferruginous mudstone concretions, which average 6 in. by 1 ft and weather rusty brown	32	0
3. Shale, gray, weathered; many round septariate calcareous concretions, which average about 1 ft in diameter and are veined with orange and brown calcite	12	6
4. Shale, gray, weathered; many concretions, which average 8 by 14 in.; some concretions are calcareous and fossiliferous, and are weathered brown; other concretions consist of ferruginous mudstone	30	6
5. Bentonite (bed H, p. 989), ivory, hard, silty; basal contact is sharp; grades into superjacent rocks through a thin zone of bentonitic shale	1	6
6. Shale, gray, soft; fossiliferous calcareous concretions, which average 4 in. by 1 ft; abundant ferruginous mudstone concretions in lower part	72	0
7. Shale, very sandy; weathers light yellowish brown; a few fossiliferous calcareous concretions, which average 8 by 10 in.	38	6
Groat sandstone bed:		
8. Sandstone (top of Groat sandstone bed), grayish-brown, fine-grained; weathers rusty brown; many tiny glauconite grains; forms a small ledge	3	0

	Ft	In
Pierre shale—Continued		
Groat sandstone bed—Continued		
9. Sandstone, grayish-brown, fine-grained, soft; lower part is argillaceous	30	6
10. Shale (base of Groat sandstone bed), brownish-gray, very sandy, soft; calcareous concretions average 10 in. in diameter	82	6
Gammon ferruginous member, lower part:		
11. Shale, gray, soft, poorly exposed; many zones of ferruginous mudstone concretions weathered reddish brown	420	0
12. Covered by Quaternary alluvium (base of Gammon ferruginous member)	75–100	
Total thickness, measured and estimated	798–823	

MITTEN BLACK SHALE MEMBER

The Mitten black shale member, which is approximately 150–200 feet thick, consists mainly of dark-gray to black shale, with abundant calcareous septarian concretions; the basal stratum is bentonite bed I (see p. 990). The shale of this member weathers somber brown, and the concretions weather yellow and brown by the oxidation of small contained amounts of iron. As compared with the strata above and below the Mitten, the shale of this member is more cohesive and contains concretions in much greater abundance; in many localities differential erosion of the Mitten member has formed extensive gently sloping, smoothly rounded, grass-covered scarps facing the characteristic nearly barren flats underlain by the Gammon ferruginous member.

UPPER MEMBERS (INCLUDING MONUMENT HILL BENTONITIC MEMBER)

The upper three members of the Pierre shale, which have an aggregate thickness of about 800 feet, are mapped on plate 1 as a single unit.

The lowest of these three members, which lacks a name, is about 450 feet thick. It is composed of dark-gray shale, the lower half of which is nearly everywhere sandy and, at some places in the northeastern part of the district, includes lenses and beds of fine-grained friable sandstone. The upper half of this member contains numerous concretions, some of which are calcareous, others ferruginous.

The middle member of the composite upper unit of the Pierre is the Monument Hill bentonitic member, about 150 feet thick. This member consists primarily of dark-gray shale and bentonitic shale. The bentonitic shale becomes light gray upon weathering. The upper three-fourths of this member includes thick beds of dark-gray bentonitic shale and several beds of light-gray bentonite, none of which exceeds 1½ feet in thickness. Several zones within this member contain large light-gray limestone concretions. In places, the outcrops of bentonite beds are littered with fragments of fibrous calcite; elsewhere they are strewn with subspherical concretions, which average about 1½ inches in diameter and consist of radiating fibrous to wedge-shaped barite crystals that may have formed by replacement of calcite.

The highest member of the Pierre shale, which is an unnamed unit about 200 feet thick, consists largely of dark-gray soft fissile shale containing a few calcareous concretions.

FOX HILLS SANDSTONE

The Fox Hills sandstone, which forms a prominent zone of grass-covered hills extending along the west margin of T. 7 S., R. 56 E., in Carter County (fig. 92), is made up chiefly of brown sandy shale and argillaceous siltstone with a few beds of sandstone. The formation contains marine fossils and many concretions; some of the concretions are highly ferruginous. The contact between the beds of the Fox Hills and the underlying Pierre shale is transitional. The Fox Hills here appears to range in thickness from about 150 to 250 feet, though it has been reported to be about 400 to 450 feet thick farther southwest, in the Devils Tower quadrangle (Darton and O'Harra, 1907, p. 5).

TERTIARY(?) AND QUATERNARY SYSTEMS

The history, composition, and distribution of the surficial material deposited by streams during late Tertiary(?) and Quaternary time are intimately related to the development of the present land surface. The following treatment of these deposits, therefore, involves a discussion of the geomorphology of the district.

The southern edge of the district (pl. 60) lies within the northern foothills of the Black Hills, a fairly rugged group of mountains which lie about 150 miles east of the Rocky Mountains in an unglaciated part of the Missouri Plateau section of the Great Plains province (Fenneman, 1931, pl. 1). The surface of the district is only moderately dissected, with a total relief of about 1,000 feet. In an overall sense, the surface slopes gently downward toward the north, away from the mountainous area of the Black Hills. There are, nevertheless, many steep hillsides and much of the surface actually slopes in southerly directions. The lowest altitude, which is about 3,000 feet above sea level along the Belle Fourche River near the town of Belle Fourche, S. Dak., occurs within 3½ miles of the southernmost section line of the district. A drainage divide extends northeastward approximately across the center of the district. West of this divide the runoff drains into the Little Missouri River and east of it into Belle Fourche River. In the western part of the district (pl. 60), landslide blocks, consisting of material from the Newcastle sandstone and Mowry shale and resting on Skull Creek shale, have been mapped at the following localities: south line of sec. 22, T. 57 N., R. 63 W.; secs. 1 and 2, T. 57 N., R. 64 W.; sec. 33 and north line of sec. 34, T. 58 N., R. 64 W., Crook County, Wyo.

The geomorphic history of the district is known in broad outline. Nearly all the sediments of the exposed Cretaceous bedrock formations were deposited in an epicontinental sea, which disappeared in Late Cretaceous time. After the disappearance of the sea, and continuing into early Tertiary time, additional sedimentary strata of terrestrial origin, deposited mostly by aggradational streams, are believed to have accumulated here to a considerable thickness. These strata are believed to have included formations ranging in age from Hell Creek (Late Cretaceous) to Wasatch (Eocene). All the rocks of this district and adjoining areas, including all such younger strata, were later deformed during the Laramide orogeny. By Oligocene time, however, denudative processes had become dominant and have continued so through most of post-Oligocene time. As a consequence, the only rocks remaining today in this district that are younger than the folded and faulted marine Cretaceous bedrock formations are surficial deposits (pl. 60) of silt, sand, and gravel, that lie on terraces and on the flood plains of the present streams. The base of the terrace deposits is seldom exposed and, therefore, their thickness cannot generally be determined accurately. Few of them appear to be more than 40 feet thick.

The surficial deposits are partly of local and partly of extraneous derivation. Virtually all the gravel of the terraces in the valleys of Owl Creek and North and South Indian Creeks is of local origin. Most pebbles in the deposits on these terraces are angular and less than 2 inches in diameter; they are chiefly fragments of ferruginous and calcareous concretions, which are residual products of the erosion of Upper Cretaceous rocks like those described in this report. Elsewhere in the district, the alluvial material is made up mostly of rock fragments derived from outcrops in the central Black Hills; it was transported and deposited within the area on flood plains that antedated those of the present streams. The pebbles and cobbles in the gravel are most commonly subrounded to subangular, indicating only moderate distances of transportation. They are composed chiefly of limestone, quartz, quartzite, and ferruginous rocks and are commonly intermixed with subordinate amounts of sandstone, chert, and igneous rocks. Most of the material of the coarser gravels is poorly sorted, but in certain layers or lenses the pebbles are nearly uniform in size. In general, the component fragments in the gravel of the lower terraces are smaller, and they include much material that has been washed down from the higher terraces and reworked.

Isolated boulders as much as 1½ feet in thickness occur in all the terraces. Lenses of silt and sand are most abundant in the Stoneville (Qt_3) and younger (Qt_2) and Qt_1) terraces (see plate 60).

The most extensive surficial deposits are those mapped as younger alluvium, which occupy the flood plains along the present streams. The six categories of older surficial deposits, which range from 30 to more than 450 feet in height above the Belle Fourche River are coextensive with remnants of terraces representing, from highest to lowest, six successive stages in the sculpturing of the surface. All these categories of older surficial deposits are present in the part of the district drained by the Belle Fourche River and its tributaries. In that part lying within the watershed of the Little Missouri River, however, only deposits of the three oldest categories (Qt_4, Qt_5, and Tt_6) are represented. Restriction of the three youngest categories of the older surficial deposits (Qt_3, Qt_2, and Qt_1) to the part of the district east of the central divide is a result of a stream capture that occurred at some time during the Pleistocene epoch. As outlined by Darton and O'Harra (1905, p. 1, 2), the circumstances relating to this incident are as follows:

> One of the most notable topographic features in the quadrangle is the Stoneville Flats, (NW cor. T. 57 N., R. 62 W.) a smooth-bottomed valley that extends completely across the low divide between Little Missouri and Belle Fourche rivers. Originally it was occupied by the upper part of the Belle Fourche, which then flowed northward into the Little Missouri. The flat is floored with a deposit of loam and gravel, some of which continues on the high terraces up the Belle Fourche, and to the north it merges into the alluvium lying along the Little Missouri. This change of course of the stream is a clear case of stream robbery, the lower Belle Fourche, with the advantage of steeper declivity, having cut back the head of its valley until in the present big bend it has captured the stream which originally flowed into the Little Missouri through the Stoneville Flats. Since that time the Belle Fourche Valley has been deepened about 100 feet, for there is a high bank of about that height in the bend of the river. In other words, a dam somewhat over 100 feet in height would turn back the waters of the upper Belle Fourche into the Little Missouri, but, on the other hand, a dam of very moderate height would deflect the waters of the Little Missouri across the Stoneville Flats into the Belle Fourche. There is but little erosion in these flats at present, but it is probable that a stream will eventually develop there that will cut across them and deflect the head of Little Missouri River into the Belle Fourche. Such a stream has already begun the excavation of a valley along the eastern side of the flats.

Each of the terraces on which the older surficial deposits lie is assignable to a position on, above, or below a nearly horizontal surface that is considered to represent the approximate former position of the flood plain of the principal stream that flowed in the immediate vicinity at the time of the capture. The alluvial material in the stream valleys within the part of the district drained by Little Missouri River and its tributaries generally lies on such a surface. So do the terrace deposits designated Qt_3 (pl. 60) in the vicinity of the Belle Fourche River and its tributaries. In this report, all such surfaces are collectively termed the "Stoneville surface" because they are all believed to have originated at the same, or nearly the same, time as Stoneville Flats, where the capture occurred. The material on terraces higher than the Stoneville surface (Qt_4, Qt_5, and Tt_6) is accordingly classified as pre-Stoneville, and that at lower levels (Qt_2 and Qt_1) as post-Stoneville.

The highest and oldest pre-Stoneville terrace (Tt_6) averages about 325 feet higher than does the Stoneville surface, and may have been contemporaneous in origin with the Meadow Mountain surface of the Black Hills, believed by Fillman (1929) to have originated in middle Oligocene time. If so, it is posible that they are outliers of the Cypress plain (Alden, 1932), which is believed to have extended over much of the northern Great Plains during Oligocene time. However, their correlation with deposits so far outside this district is questionable and the highest terrace deposits can be assigned only tentatively to the Oligocene series; they may be much younger, as was believed by Darton and O'Harra (1905).

Two stages of stream erosion in the interval between the deposition of the highest surficial material and that on the Stoneville surface (Qt_3) are represented by terraces that are about 210 feet (Qt_5) and 130 feet (Qt_4) higher than the Stoneville surface. Most of the remnants of those two pre-Stoneville surfaces occur southeast of the central drainage divide, but a few are also present in the valley of Little Missouri River.

The most extensive surficial deposits are those closely associated with the Stoneville surface. In most of the area east of the central divide, these deposits (Qt_3) represent material that had already accumulated at the time of the stream capture. In the Stoneville Flats and along the Little Missouri River, Thompson Creek, and their tributaries, the large areas mapped as younger alluvium include material deposited at that time as well as younger material, which is partly equivalent in age to deposits on the post-Stoneville terraces (Qt_2 and Qt_1) of areas east of the divide and partly equivalent to deposits of Recent alluvium occupying the flood plains of Belle Fourche River, Owl Creek, and South Indian Creek. The higher (Qt_2) of the two post-Stoneville terraces is about 40 feet below the Stoneville surface; the lower is about 75 feet below that surface. The alluvium along Belle Fourche River is about 100 feet below the Stoneville surface.

GEOLOGIC STRUCTURE

The sedimentary strata of Wyoming, Montana, and western South Dakota are nearly everywhere tilted, chiefly as a result of major deformational stresses at and near the beginning of Cenozoic time. Since the tracts in which bentonite beds lie under light overburden tend to be broadest where the dip is gentle, attractive strip-mining sites are virtually limited to localities in which the dip is no more than about 5°. The presence of many sites fulfilling this structural requirement is largely responsible for the importance of the northern Black Hills district as a source of commercial bentonite.

The structural geology of the district is illustrated on plate 60. Since the district lies on the north side of the great domal uplift centering in the Black Hills, its overall structure is that of a broad anticlinal nose, the axis of which plunges at a low angle northward across the approximate center of the district. The overall dip on the east side of this nose is gentle and northeastward; on the west side it is gentle and northwestward. Accordingly, the successive geologic formations generally crop out in parallel arcuate belts that are convex toward the north and extend eastward across the district; the oldest rocks are exposed in the south-central part and the youngest, along the northeast and northwest margins. This general pattern is interrupted locally, however, by anticlinal and synclinal flexures, the axes of which tend to parallel the arcuate belts, and by many small normal faults. The displacement on the faults is commonly no more than a few feet, especially in the eastern two-thirds of the district, and small undulations of the surface on which the Clay Spur bentonite bed rests have been revealed in various pits excavated in strip-mining operations. Some of these irregularities may have originated through processes not directly related to folding of the rocks in the region (see p. 979). As explained on page 962, such minor structural features may account, in part, for local variations in the quality of the bentonite.

Anticlinal flexures include the North Fork anticline, in T. 57 N., R. 65 W.; the Government Canyon anticline, in T. 57 N., R. 64 W.; the Bull Creek anticline, an elongated dome with its apex near the north line of T. 57 N., R. 62 W.; the Colony and Shepard anticlines, in T. 57 N., R. 61 W.; and the Chicago Creek and La Flamme anticlines, in T. 56 N., R. 61 W., all of which are located in Crook County, Wyo.; and the Boxelder anticline, in T. 10 N., R. 1 E., in Butte County, S. Dak. The anticlines are separated by nameless synclines. Extending northward along the west side of T. 56 N., R. 67 W., in the vicinity of South Fork and Mud Creeks, is a monocline that is conspicuously expressed in outcrops of the Mowry, Niobrara, and intervening formations and that dips steeply westward (cross section A–A′, pl. 60). The relation between the geologic structure of a deposit and the availability of commercial bentonite is exemplified by the meager strip-mining potential of the narrow belts of steeply dipping bentonite lying close to the surface along this monocline, as contrasted with the extensive resources of the broad area, south and west of Colony post office, that encompasses the Colony, Shepard, Chicago Creek, and La Flamme anticlines, and several flexures near the Belle Fourche River. In this broad area the Clay Spur bentonite bed, largely because of its prevailing gentle dip and broadly undulatory structure (cross section B–B′, pl. 60), lies near the surface and, consequently, can be strip mined in tracts aggregating many square miles.

The structure of the Bull Creek, Colony, Shepard, and Chicago Creek anticlines is virtually that of elongated domes extending northwestward. The cross sections normal to the elongation of these folds are nearly symmetrical. The Government Canyon anticline is subcircular. The possibility that some of these anticlines formed partly by pressure from below is suggested by the subcircular form of the Government Canyon anticline and by the geologic structure of several mountainous areas in the surrounding area. Under this hypothesis, some of the anticlines of this district would be due, in part, to upward pressure of deep-seated bodies of magma and would be analogous, therefore, to several subcircular domes that formed in early Cenozoic time in the northern part of the Black Hills (Darton and Paige, 1925, p. 19–24), in the Little Rocky Mountains (Knechtel, 1944; 1959), and in several other isolated mountainous areas in Montana east of the Rocky Mountain front.

BENTONITE DEPOSITS

SOURCE OF PARENT VOLCANIC ASH

The volcanic ash, from which the bentonite deposits of the northern Black Hills district and other parts of the western interior of the United States were formed, is believed to have been ejected from various centers of volcanic activity that existed in Cretaceous time in the Rocky Mountain region. Isopach maps by Reeside (1944) show that the Cretaceous sedimentary-rock sequence of the western interior is thickest in the western part of the large basin in which it was deposited and thins greatly toward the east side of the basin. This is also true, in general, of the contained bentonite beds. Both the volcanic ash from which the bentonite beds were formed and the other sediments comprising the Cretaceous rocks seem to have come from sources far to the west of the northern Black Hills district. This interpretation is in harmony with much evidence of contemporary volcanic activity on the west side of the basin. For example, tuffaceous material and ash derivitives are abundant in the Aspen shale (Cretaceous) in eastern Idaho, where the thickness of that formation is as much as 2,000 feet; and Rouse and others (1937) and Parsons (1942) describe evidence of Late Cretaceous eruptions, beginning in Judith River time and ending before Hell Creek time, near the Beartooth Mountains in southwestern Montana.

ALTERATION OF THE ASH

The original composition of the pyroclastic material from which the Clay Spur bentonite bed and other bentonite deposits in the marine Cretaceous rocks in the vicinity of the Black Hills were derived is believed to have been closely akin to that of alkalic rhyolites containing, according to Rubey (1929, p. 161), "from 70 to 80 percent of SiO_2 and commonly from 1 to 7 percent each of Na_2O and K_2O." Rubey concluded "that the original ash in the bentonite at Clay Spur and in the Mowry shale was of acidic composition and that during its alteration the alkalies were largely removed by solution." Much silica was also removed, and it has been suggested by Ross and Hendricks (1945, p. 67) that the alkalies were flushed out by "escaping colloidal silica"; they also suggested that "high-silica montmorillonite—the type characterizing bentonites * * * forms only where magnesium is available in the rock or where it can be abstracted from ocean, lake or ground water" and, further, that some varieties of bentonite "contain more essential calcium and magnesium than did the parent glass." As pointed out on page 953, however, much of the bentonite of the Cretaceous formations in the vicinity of the Black Hills and in the surrounding region is of the unusual sodic variety; and inasmuch as sodium is lower in the replacement series than is calcium, the concentration of the sodium ion in the solutions entering some of the deposits may have been greater than that of the calcium ion for at least part of the time since deposition of the ash.

Volcanic glass is soluble in alkaline solutions; and it, therefore, is conceivable that chemical alteration of fine-grained ash accumulating in a marine environment could begin while the ash was settling through the sea water. Glassy particles remaining in suspension for protracted intervals of time before reaching the bottom would seem to be particularly subject to such attack. Assuming that partial alteration did occur during settling, the pyroclastic deposits that accumulated on the sea bottom may have consisted initially of rather plastic mixtures of unaltered ash and montmorillonite. The presence of montmorillonite gel at the time of deposition is suggested by the blurred appearance of the boundaries between the light and dark laminae in the upper part of the Clay Spur bentonite bed of the northern Black Hills district (pl. 64*A*). Whether or not any appreciable alteration had occurred before the burial of the pyroclastic material and subsequent withdrawal of the sea, some alteration did occur later, as, indicated by the chertlike character of the floors of several bentonite beds in the marine Cretaceous sedimentary formations of Montana, Wyoming, and South Dakota, and of other regions. This widespread phenomenon supposedly results from impregnation of the sedimentary material beneath the beds by silica dissolved from the pyroclastic material by water percolating downward through it.

As pointed out by Ross and Hendricks (1945, p. 67), such downward movement could scarcely have occurred beneath standing water. After withdrawal of the sea, however, saline water entrapped in sediments left standing above sea level would tend to seep downward and gradually be replaced by meteoric water. So long as this process continued, silica would be leached from the glassy constituents of the ash-bearing mixture. Precipitation of the silica in the dark shale or other underlying rock may have been due to the neutralizing effect of organic matter contained in such rock.

CONSTITUENT MINERALS

According to Ross and Shannon (1926, p. 79), bentonite "often contains variable proportions of accessory crystal grains that were originally phenocrysts in the volcanic glass. These are feldspar (commonly orthoclase and oligoclase), biotite, quartz, pyroxenes, zircon, and various other minerals typical of volcanic rocks. The characteristic claylike mineral has a micaceous habit of facile cleavage, high birefringence and a texture inherited from volcanic tuff or ash, and it is usually the mineral montmorillonite but less often beidellite."

The rock known as bentonite ordinarily contains appreciable amounts of nonigneous material. This is true of the deposits in the northern Black Hills district, which are made up largely of the clay mineral montmorillonite, intermixed not only with grains of nonclay minerals inherited from volcanic ash but also with nonclay detrital material that became mixed with the ash at the time of its accumulation. The shape of nonclay mineral grains of sand or larger size is a fairly reliable criterion that may be used to determine whether they are of pyroclastic or detrital origin; angular grains are generally regarded as of pyroclastic origin, rounded or frosted grains as water- or wind-transported material. However, no such criterion exists for silt and smaller particles, which are almost all angular. The bentonite also contains both organic and inorganic substances that have been deposited in the clay by circulating aqueous solutions or suspensions. Minerals belonging to this category are selenite, calcite, and limonite. The bentonite of this region also commonly contains small deposits of glauber's salt and possibly other soluble salts.

DETERMINATIVE TECHNIQUES

The mineralogical data presented in this report are based chiefly on differential thermal, X-ray, and cation-exchange analysis. The analytical methods and techniques used in obtaining the data are described only briefly below and on following pages. They have been treated at greater length, and with many more bibliographical references, by Grim (1953).

The differential thermal method is comprehensively described by Mackenzie (1957) and others. Identification and study of minerals by differential thermal analysis depend on thermal reactions that occur intermittently within many crystalline substances as they are heated from room temperature to several hundred degrees centigrade. These reactions are of two kinds: endothermic, in which the sample absorbs heat, and exothermic, in which heat is given off by the sample. The features of such reactions that are useful in identification of minerals are their intensity, duration, and the temperature at which they occur.

In differential thermal analysis, the specimen is heated along with a thermally inert reference material, that is, one in which no thermal reaction occurs as it is heated, and the relation between the temperatures of the two substances is recorded at frequent intervals or continuously. During the period of heating, the temperature of the reference material increases at nearly the same rate as that of the furnace. This is true also of the specimen, so long as there is no thermal reaction. In the absence of such a reaction, the line traced by a recording device tends to follow a horizontal baseline (fig. 76, *AH*) representing virtual equality in the temperature of the two substances. During an endothermic reaction, however, the specimen becomes appreciably cooler than the reference material, and the disparity between their temperatures is recorded as a downward inflection (fig. 76, *BCD*), termed an "endothermic inflection." An upward inflection (fig. 76, *EFG*), termed an "exothermic inflection," indicates

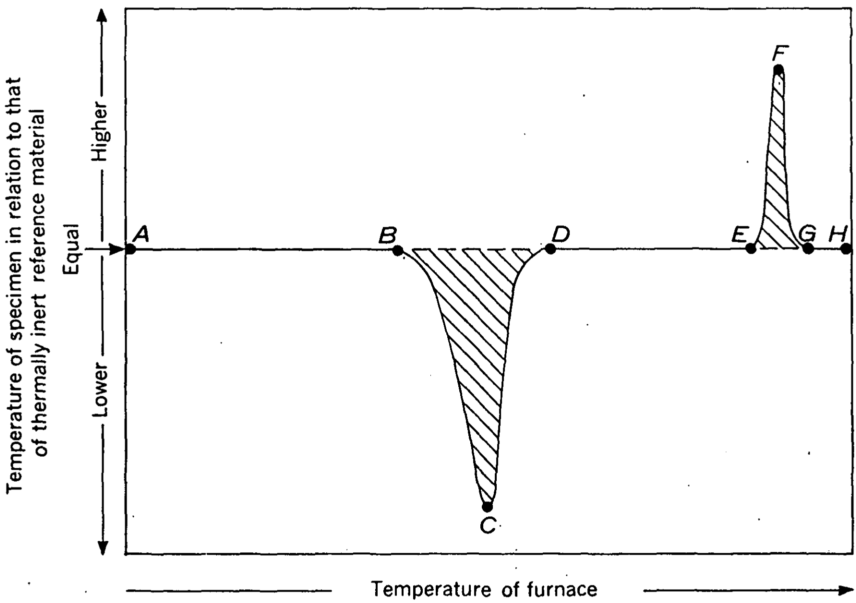


Figure 76.—Idealized differential thermal diagram: *AH*, base line; *BCD*, endothermic inflection; *EFG*, exothermic inflection. Temperature of furnace increases from 0° C at *A* to 1,000° at *H*.

that the specimen was momentarily hotter than the reference material. The dimensions of such inflections indicate the intensity and duration of the reactions in the specimen and can be used as a basis for estimating what proportion of the material participated in the reaction; the positions of the inflections on the diagram indicate the temperatures at which the reactions occur.

Figure 77 shows differential thermal diagrams of three varieties of montmorillonitic bentonite in comparison with diagrams typical of kaolinite and hydrous mica. The five diagrams illustrate the manner in which clay minerals may be distinguished from one another by noting the positions and dimensions of the various inflections.

The causes of the thermal reactions represented by such inflections have been the subject of much investigation. For montmorillonite, it is generally agreed that the prominent endothermic inflection with its bottom corresponding to temperatures between 100°C and 200°C is due mainly to loss of water between the unit sheets of montmorillonite. The inflection with its bottom corresponding to temperatures ranging from 650°C to 750°C is generally believed to represent the loss of the hydroxyl ions that form part of the composition of the unit sheets. Inflections corresponding to higher temperature are believed to represent reactions in which the structural lattice of the clay mineral is destroyed.

The X-ray method of identifying and studying clay minerals has been treated at length by Brindley (1951) and others. X-ray analysis makes use of the geometrical relations between the planar sheets of atoms, molecules, or comparable structural units, of which all crystalline substances are composed. Each face of any given crystal is paralleled by a system of such regularly spaced planar sheets. The distance between the centers of any two adjacent planar sheets is termed "interplanar spacing." This distance, which is usually expressed in angstrom units, is measured by means of the diffraction pattern produced by X-ray beams reflected from a powdered specimen. The interplanar spacing generally helps in identifying crystalline minerals. The X-ray diagrams reproduced in this report (figs. 78 and 80) were obtained through the use of a diffractometer. Such diagrams show sharp upward inflections whose positions indicate those values of the incident angle (θ) in which the X-ray waves do not interfere with one another but rather reinforce one another and are, therefore, reflected by the powdered minerals. From the value of θ corresponding to each inflection and the wavelength (λ) of the X-rays used, the interplanar spacing (d) may be computed, in angstrom units, from the following equation, known as the Bragg equation:

$$d=\frac{n\lambda}{2\sin\theta}$$

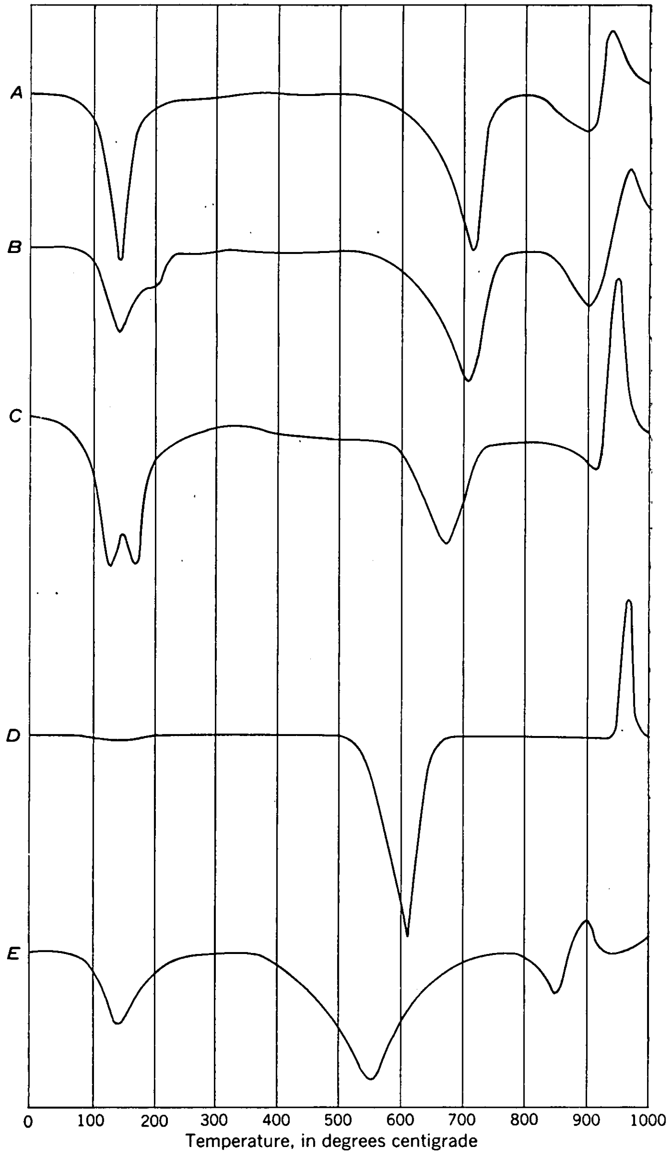


FIGURE 77.—Differential thermal diagram showing inflections typical of (*A*) Na^{+1} bentonite, (*B*) Ca^{+2} bentonite, (*C*) H^{+1} bentonite, (*D*) kaolinite, (*E*) hydrous mica.

The value of n is 1 for reflections of the first order, 2 for those of the second order, and subsequent integers for those of higher orders. For many reflections, however, the value of n cannot be readily determined and X-ray reflections are, therefore, usually described by reporting their value of d/n, in angstrom units, in which substitution of the appropriate integers for n denotes the actual spacing between planar sheets for reflections of the first order, ½ the actual spacing

FIGURE 78.—X-ray diffractometer diagrams showing inflections typical of (*A*) quartz, (*B*) cristobalite, (*C*) orthoclase, (*D*) gypsum, and (*E*) air-dried bentonite (solid line) and same material after treatment with glycerol (broken line).

for those of the second order, ⅓ for those of the third order, and so on. The figures for all such reflections are referred to in this report as spacings, which may be defined as

$$\frac{d}{n}=\frac{\lambda}{2\sin\theta}$$

The wavelength of the X-ray beams used in the studies for this report was 1.548 A and, substituting this figure for λ, the spacing corresponding to any given value of the incident angle θ becomes 0.7709 A/ sin θ.

Reflections from bentonite corresponding to spacings of less than about 9.6 A are emitted partly from the fundamental structural units of the constituent clay mineral or minerals and partly from crystals of the omnipresent nonclay constituents. The actual interplanar spacing of the clay mineral montmorillonite is indicated by the position of the inflections, shown near the right side of the X-ray diffraction diagrams (fig. 78, diagram *E*), corresponding to interplanar spacing larger than 10 A. Virtually all montmorillonite, except that dried at relatively high temperatures, contains water between the planar sheets. The thickness of a single planar sheet is about 9.6 A, but the basal spacing is greater in the presence of water. Because the amount of water between the planar sheets is variable, the basal spacing for 14 samples prepared for X-ray analysis by air-drying ranged from 12.2 to 14.7 A (table 3). The basal spacing of samples prepared under a relative humidity of 50 percent ranged from 11.0 to 15.5 A. The factors that determine the variation in the interplanar spacing are described on page 945.

Where the water molecules between the planar sheets of montmorillonite are replaced by certain organic molecules, specimens containing different exchangeable cations show identical basal spacing. For example, the interplanar spacing was uniformly 17 A in all specimens treated with glycerol. Such a relatively wide spacing, together with the absence of any reflection corresponding approximately to a 10 A spacing, rules out presence of hydrous mica. A smoothed diffraction diagram of a glycerol-treated bentonite specimen from this district is compared with an unmodified diagram of an air-dried sample in figure 78 (diagram *E*).

CLAY FRACTION

Montmorillonite, the only clay mineral that has been identified with certainty, constitutes from 2/3 to 9/10 of the bentonite, by volume, in all but one of the samples studied. A small amount of hydrous mica is present in a sample from bed G. Much of the literature relating to research on the crystalline structure, chemical composition, physical properties, and genesis of montmorillonite is cited and summarized by Ross and Hendricks (1945) and by Grim (1953). The mineral is essentially a hydrous silicate of aluminum and magnesium containing small amounts of alkalies, alkaline earth, and other elements. It is closely comparable in composition and crystalline structure to vermiculite (Grim, 1953, p. 67–77) and to various micas. On some electron photomicrographs, montmorillonite appears to be made up of flakes, some of which are only about 20 A thick, stacked one upon another.

The fundamental structural unit of montmorillonite, as deduced from X-ray diffraction data, is a planar sheet about 9.6 A thick. This sheet according to the interpretation of Hofmann, Endell, and Wilm (1933), Marshall (1935), and Hendricks (1942), is comprised of two ionic layers of Si^{+4}, tetrahedrally coordinated with ions of O^{-2}, and separated by a layer of Al^{+3} ions and their proxies (fig. 79). The Al^{+3} ions and their proxies are coordinated octahedrally with O^{-2} ions, which are shared also by the silica tetrahedra, and with OH ions. A few ions of Al^{+3} may proxy for tetrahedrally coordinated Si^{+4}. Without exception, however, there is some substitution of proxies, such as Mg^{+2}, Fe^{+2}, and Fe^{+3}, for the Al^{+3}. Thus the montmorillonite lattice unit may be visualized as comparable to two contiguous planar layers of cristobalite (SiO_2) and an intervening layer of gibbsite [$Al_2(OH)_6$]. As a result of the partial substitution of divalent positive ions, such as Mg^{+2} and Fe^{+2}, for those of trivalent positive charge, a deficit of positive charge occurs in the lattice. This deficit is so nearly balanced by the positive charges contributed by the ions of the alkali metals, the alkaline earths, and hydrogen, which occupy the positions between the sheets of montmorillonite, that the lattice units carry only weak residual charges. In the presence of certain positively charged ions, notably Na^{+1}, together with a little Ca^{+2}, water is readily adsorbed between the sheets. If the ambient water carries ions of alkali, alkaline earth, or hydrogen in solution, these ions may move in between the sheets and replace all or a part of the cations already present.

The presence of replaceable cations may be ascertained by cation exchange analyses, and some of them, especially Na^{+1}, Ca^{+2} or Mg^{+2}, and H^{+1}, can be detected by differential thermal analysis. Exchangeable Na^{+1} shows a single sharp endothermic inflection on differential thermal diagrams, corresponding to the loss of interplanar water which begins at about 90° C, reaches a maximum near 150° C, and is completed at about 180° C. Loss of interplanar water from montmorillonite containing Ca^{+2} as the dominant exchangeable cation occurs, as first shown by Hendricks, Nelson, and Alexander (1940), through a somewhat higher and broader temperature range, from between 170° C and 200° C to less than 250° C. Furthermore, the diagram for this reaction shows two endothermic inflections, of which the first is much the stronger. The second inflection is generally believed to correspond to the dehydration of Ca^{+2} though montmorillonite saturated with Mg^{+2} gives an identical inflection. Differential thermal diagrams (fig. 86*E*) for bentonite in which H^{+1} is indicated as the dominant exchangeable cation have been shown by Barshad (1950) to be characterized by two inflections, nearly equal in prominence, between 130° C and 180° C. The loss of interplanar water from montmorillonite containing H^{+1} as the dominant exchangeable cation is complete at or below 210° C.

X-ray diffraction diagrams (fig. 80) indicate that montmorillonite is the only clay mineral in the bentonite, and they provide some in-

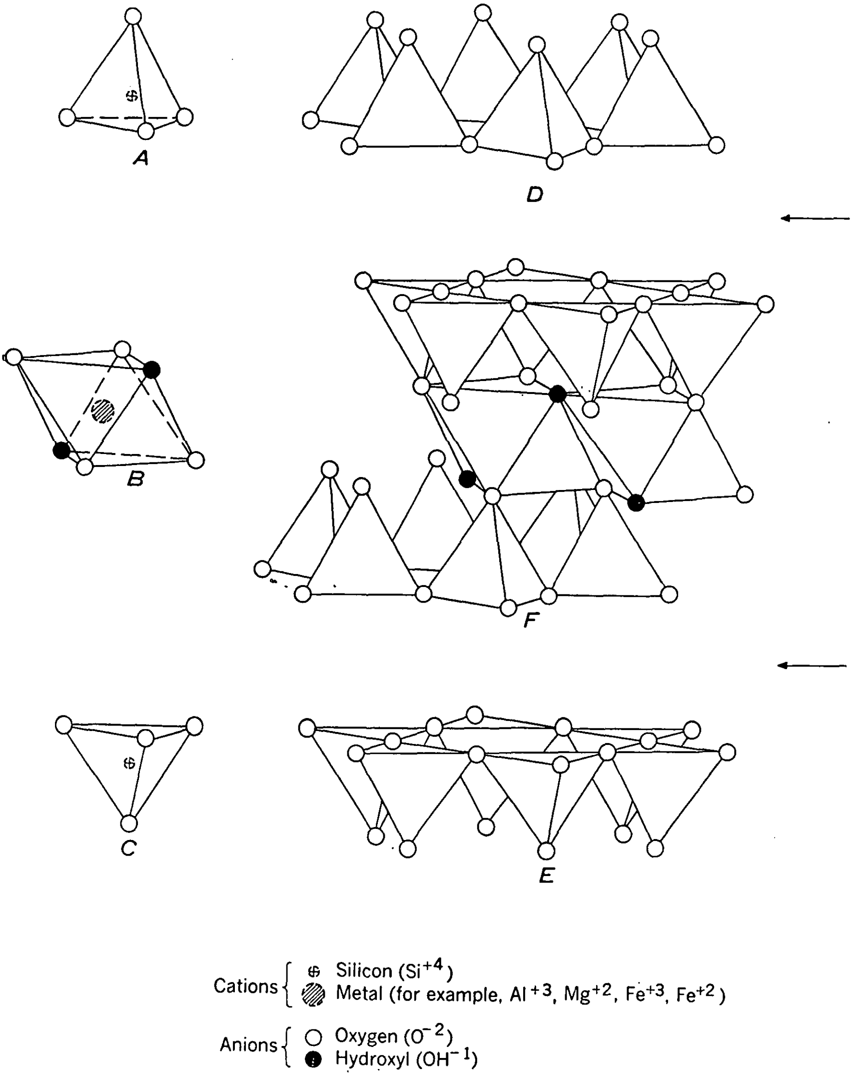


FIGURE 79.—Diagrams illustrating crystalline structure of montmorillonite: (*A*) Cation (Si^{+4}) tetrahedrally coordinated with 4 anions (O^{-2}); (*B*) metallic cation (for example, Al^{+3}, Mg^{+2}, Fe^{+3}, Fe^{+2}) octahedrally coordinated with 6 anions (O^{-2} and OH^{-1}); (*C*) silica tetrahedron, inverted but otherwise like that shown on diagram *A*; (*D*) anions of 6 silica tetrahedrons arranged in a ring; (*E*) inverted ring of 6 silica tetrahedrons; (*F*) anions of montmorillonite lattice sheet, in which a layer of octahedrons, like the one shown on diagram *B*, shares oxygen ions with 2 enclosing layers of silica tetrahedrons, like the ones shown on diagrams *D* and *E*. Arrows indicate intersheet spaces occupied by adsorbed water and by ions, mostly exchangeable, of alkali metals, alkaline earths, and hydrogen.

formation concerning the exchangeable ions present. The interplanar spacing in bentonite samples prepared in a controlled relative humidity of 50 percent is about 14.7 A where Ca^{+2} is the dominant exchangeable ion (table 3), 15.5 A where H^{+1} is dominant, and 11 to 12.2 A where Na^{+1} is dominant. These results are of the same magnitude as those of Mielenz, Schieltz, and King (1955, p. 167) who, using a sample of bentonite of Miocene(?) age from Colorado, found that the basal spacing in synthetically prepared monoionic montmorillonites was 15.3 A for Ca^{+2}, 15.0 A for Mg^{+2}, 15.3 A for H^{+1}, and 12.6 A for Na^{+1} at a relative humidity of 52 percent.

Table 3 gives the results of total ion-exchange determinations by Dorothy Carroll, exchangeable-cation analyses by W. W. Brannock, and X-ray measurements by J. C. Hathaway (fig. 80) and F. A. Hildebrand, relating to many of the samples given in table 4. Differential thermal curves determined by S. H. Patterson for samples from various localities are given in figures 86, 88, 89, and 90.

Some of the samples examined by X-ray methods were air dried (fig. 80); others were packed in standard X-ray diffractometer sample holders and kept at a relative humidity of 50 percent. Diffractometer patterns were obtained through the use of copper *K*-alpha radiation with a nickel filter. Seventeen specimens were then treated with glycerol, and additional patterns were obtained. Samples for which nonclay minerals only are given in table 3 were examined by the powder-camera technique.

The apparatus used for the differential thermal analyses was similar to that described by Grim and Rowland (1944). The samples were first placed in an atmosphere with a relative humidity of 46 percent and left there for several days. In performing the analyses, care was taken to center the thermocouples and to increase the temperature at a constant rate of approximately 100°C every 10 minutes.

The methods used in determining the total cation-exchange capacity and content of exchangeable Na^{+1}, Ca^{+2}, K^{+1}, Mg^{+2}, and H^{+1} for samples examined in the present investigation were similar to those described by Foster (1951). The samples were placed in desiccators for several days and were further dried at 100°C prior to examination. The total cation-exchange capacity was found by using the Kelley and Brown NH_4Cl method (Kelley, 1948). Exchangeable H^{+1} was determined by using the method described by Brown (1943). To determine the total exchange capacity and content of exchangeable Ca^{+2} and Na^{+1}, it was necessary to ascertain the amount of gypsum present so that the calcium dissolved by the NH_4Cl could be subtracted from the milliequivalents of exchangeable Ca^{+2} found. The gypsum content was determined by precipitating the sulfate ion in the original leachate with $BaCl_2$. Gypsum was found in all the samples except two: one from bed B at locality 30, sec. 34, T. 58 N., R. 63 W., and the other from the olive-green bentonite of the Clay Spur bentonite bed at the strip mine in sec. 36, T. 57 N., R. 62 W. The sodium chloride content was determined by precipitation with $AgNO_3$.

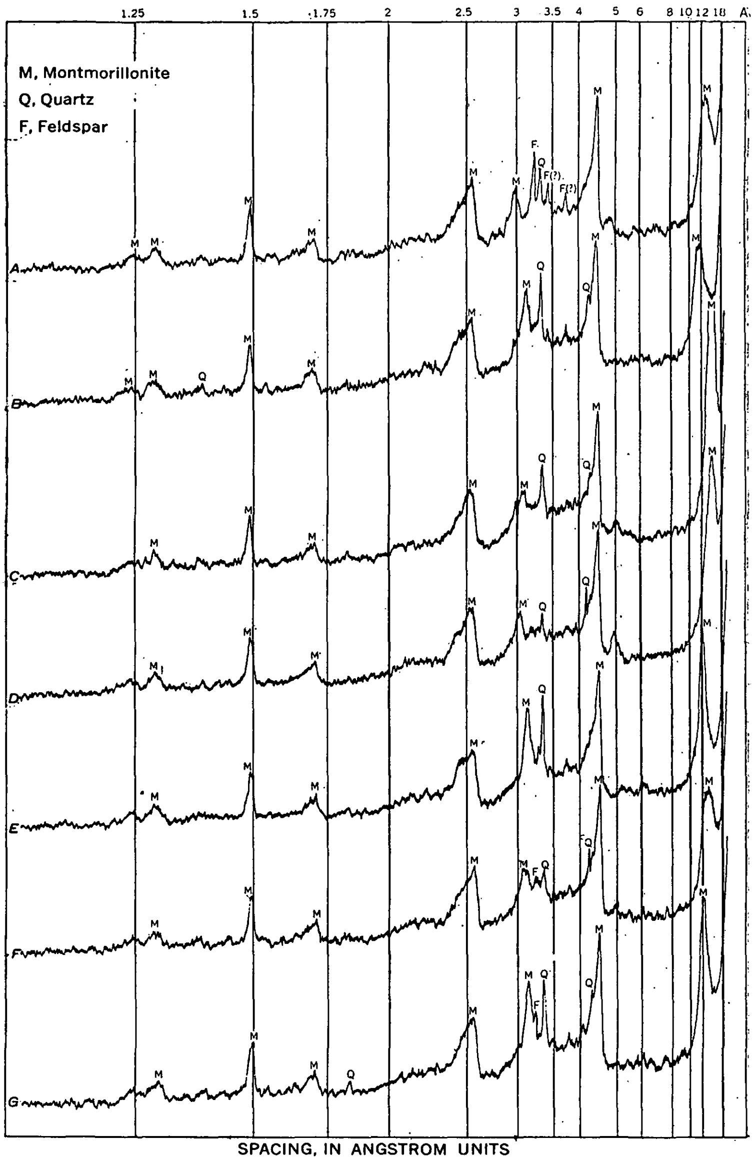
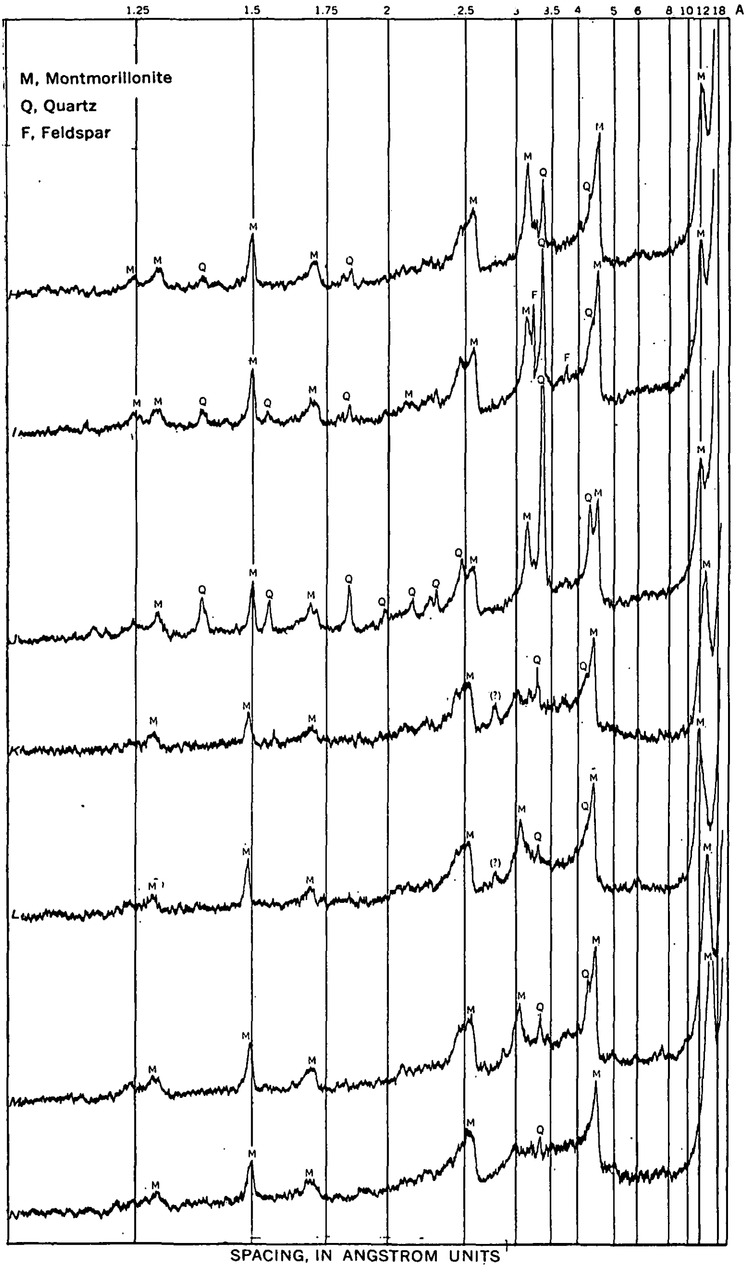


FIGURE 80.—X-ray diffractometer diagrams, by J. C. Hathaway, of air-dried unoriented powdered bentonite, as sampled at numbered localities (pl. 60) (Copper *K*-alpha radiation; nickel filter; wavelength, 1.5418 A): (*A*) Bed A, locality 27, materials 3–4 (p. 1011, fig. 86*B*); (*B*) bed A, locality 58a, materials 3–6 (p. 1000, fig. 86*C*); (*C*) bed B, locality 30, materials 3–4 (p. 1011, fig. 86*E*); (*D*) bed B, locality 46, material 2 (p. 1003, fig. 86*F*); (*E*) Clay Spur bentonite bed, locality 19, material 2 (p. 1020); (*F*) Clay Spur bed, locality 34, materials 3–6 (p. 1008, fig. 88*B*); (*G*) Clay Spur

[FIGURE 80—Continued]



bed, locality 76, materials 2–4 (p. 995, fig. 88*J*); (*H*) Clay Spur bed, oxidized olive green; (*I*) Clay Spur bed, undiscolored blue gray (p. 960, fig. 83*E*); (*J*) Clay Spur bed, partially oxidized "eggs" (materials of *H, I,* and J, are from the strip mine of the Eastern Clay Products Co. in sec. 36, T. 57 N., R. 62 W., Crook County, Wyo.); (*K*) bed F, locality 42, material 4 (p. 1006, fig. 89*G*); (*L*) bed F, locality 54, materials 3–7 (p. 1002, fig. 89*I*); (*M*) bed G, locality 38, materials 2–4 (p. 1005, fig. 90*B*); (*N*) bed I, locality 78, materials 8–11 (p. 1023, fig. 90*D*).

TABLE 3.—*Cation exchange and X-ray data for samples of bentonite from the Northern Black Hills district, Montana, Wyoming, and South Dakota*

[Total ion-exchange determinations by Dorothy Carroll, exchangeable-cation analyses by W. W. Brannock, X-ray determinations by J. C. Hathaway and F. A. Hildebrand]

Bentonite bed	Locality (see geologic map)	No. of material given in measured sections (p. 995–1024)	Cation-exchange capacity (milliequivalents per gram)							X-ray determination (Copper K-alpha radiation; nickel filter; wavelength, 1.5418 A)			
										Interplanar spacing of montmorillonite (angstrom units)			
			Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Hydrogen (H)	Total [1]	Determined	Air-dried samples (see fig. 77)	Sample prepared in relative humidity of 50 percent [2]	Air-dried samples after treatment with glycerol	Nonclay minerals
A	27	3–4	0.53	0.24	0.13	0.02	Trace	0.79	0.77	13.1			Feldspar, quartz.
	58a	3–6	.18	.23	.55	.01		.80	.81	11.9	12.8	17.7	Quartz, feldspar.
B	30	3–4			.01	.01	0.32	[3].54	.69	14.7	15.5	17.7	Quartz.
	46	2	.59	.26	.07	.03		.89	.91	14.7			Quartz.
Clay Spur	19	2	.03	.09	.68	.03		.85	.84	12.2			Quartz, feldspar.
	26	4–6	.12	.28	.36	.01	.02	.79	.83		13.2	17.7	Gypsum(?), quartz.
	28	4–5											Quartz, cristobalite, feldspar.
	33	4–6											Quartz, feldspar.
	34	3–6	.31	.24	.31	.02		.87	.80	13.2	12.8	17.7	Quartz, gypsum(?).
	43	2–3											Quartz, cristobalite (approximately 10 percent), feldspar, gypsum.
	56	4											Quartz, feldspar.
	56	5	.03	.12	.81	.02		.91	.84		11.6	17.7	Quartz, feldspar (trace).
	56	3–6											Quartz, feldspar, gypsum (trace), cristobalite (trace).
	62	3–5	.02	.09	.68	.01		.81	.83		11.9	17.7	Gypsum, quartz, feldspar(?) (trace).
	70	8–9	.26	.21	.35	.01	.02	.85	.89		14.3	17.7	Feldspar, quartz(?).
	76	2–4		.14	.48	.03		.65	.64	12.2			Quartz, feldspar.
	76	5	.16	.19	.49	.02		.85	.82				Quartz, feldspar, gypsum, mica (trace), cristobalite (trace).
	77	3											Quartz, feldspar.
	(4)	(5)	.20	.06	.65	.01		.78	.78	12.2	12.1	17.7	Quartz, feldspar.
	(4)	(6)	.01	.01	.64	.02		.68	.68	12.0	12.1	17.7	Quartz (10 to 20 percent).
	(4)	(7)	.20	.03	.76	.02		1.00	.85	12.2	12.4	17.7	Quartz, feldspar.
	(8)	(5)	.29	.09	.48	.01		.87	.67		11.0	17.7	Cristobalite(?) (trace), quartz(?) (trace), feldspar(?).
	(8)	(9)	.31	.11	.29	.02		.73	.66		11.5	17.7	Cristobalite(?), quartz (trace), feldspar(?).
D	70	3–4											Gypsum, feldspar, quartz (trace), mica (trace), cristobalite (trace).

F	4	4–10	.67	.24	.42	.02		[10] 1.35	.87		14.7	17.7	Quartz, calcite.
	42	4	.34	.41	.20	.02		.78	.85	14.0	14.5	17.7	Quartz, feldpsar.
	54	3–7	.12	.27	.42	.02		.82	.83	12.2	13.2	17.7	Quartz(?).
G	38	2–4	.22	.53	.42	.03		1.00	.93	14.0	14.7	17.7	Quartz, cristobalite(?), hydrous mica.
I	78	8–11	.54	.16	.18	.01	.06	.95	.88	14.7	15.2	17.7	Quartz(?).
	78	17	.64	.44		.02		1.06	.95				Calcite, marcasite(?) (trace).

[1] Corrected for soluble chloride and sulfate where found.
[2] Small variations in interplanar spacing may have been caused by departure from a relative humidity of 50 percent during exposure to X-rays.
[3] Sample had a pH of 3.71 and was not saturated by a base; includes 0.20 meq aluminum per gram.
[4] Three localities in the strip mine of the Eastern Clay Products Co., sec. 36, T. 57 N., R. 62 W.
[5] Unoxidized bluish gray.
[6] Partially oxidized "eggs."
[7] Oxidized olive green.
[8] Strip mine of the American Colloid Co., sec. 15, T. 9 N., R. 11 E.
[9] Artificially oxidized.
[10] High value suggests that a soluble salt other than the chloride or the sulfate is present.

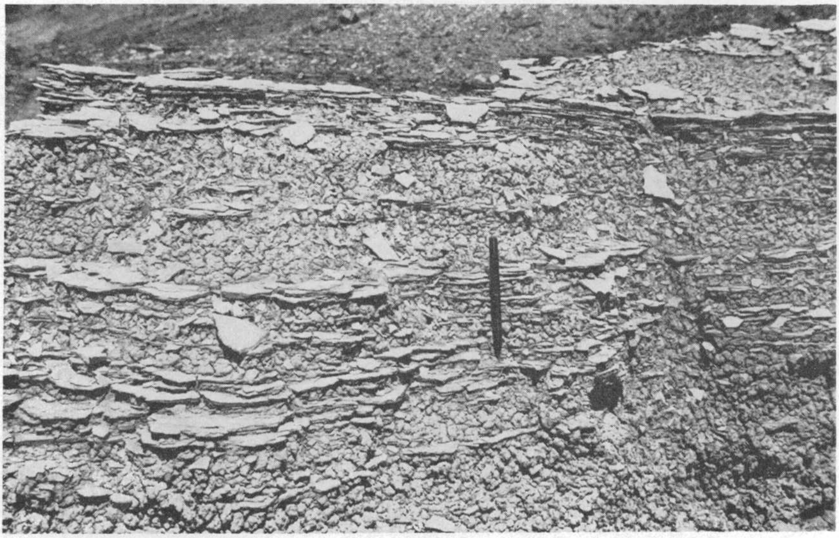
NONCLAY FRACTION

For bentonite samples from the district as a whole, the nonclay fraction, including both pyroclastic and nonpyroclastic constituents, ranges, generally, from less than $\frac{1}{10}$ to more than a $\frac{1}{3}$ of the total volume. For any one bentonite bed, however, the range in the content of such materials is smaller, and it varies not only from bed to bed but also from place to place within each bed. The grains of the nonclay material in nearly all the samples range in size from that of submicroscopic particles to that of sand. The sand and silt-sized grains, collectively termed "grit" (table 4), are too large to pass through a 325-mesh sieve (opening diameter, 44 microns). Some of the grains are angular, indicating a pyroclastic origin; others are more or less rounded, indicating a detrital origin.

Most of the angular grains visible through the microscope consist of quartz and feldspar, with some biotite, small amounts of muscovite, shards of volcanic glass, and traces of other minerals of igneous origin. In some samples, submicroscopic particles of cristobalite, also derived from volcanic ash, have been detected through X-ray diffraction analysis. According to Gruner (1940a, b), as much as 30 percent of the volume of two bentonite samples from Wyoming that were studied by him consists of cristobalite "even in fractions as fine as 1.25 microns." The rounded and subangular grains consist of quartz, feldspar, biotite, and small amounts of other durable minerals. One bed (bed A) contains many rounded grains of hematite but this mineral is not common in the other bentonite beds of this district.

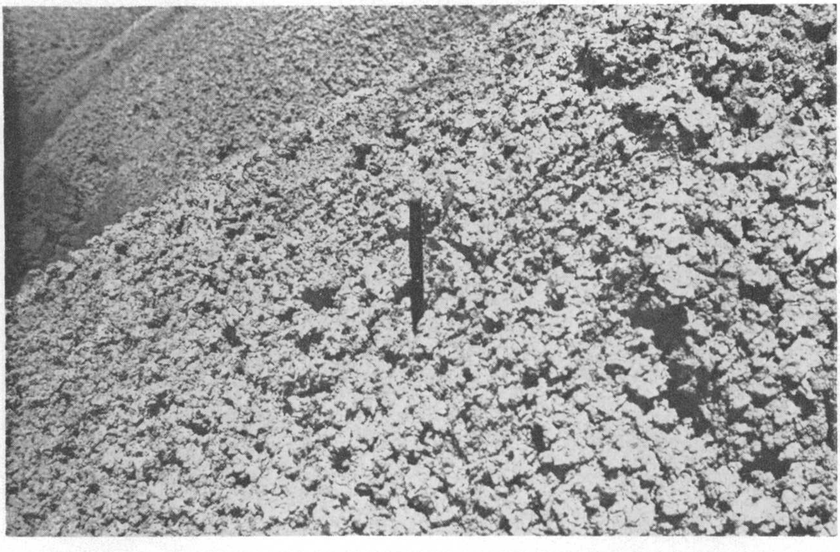
The rounded and subangular grains, which vary greatly in amount, are most numerous in the dark material of the relatively thin transitional zone between the material of the roof and the brightly colored bentonite that makes up the bulk of each deposit and ordinarily contains few such grains. Even the brightly colored material of some beds, however, contains large quantities of nonclay mineral grains. Such bentonite is likely to be deficient in the physical properties characteristic of valuable drilling mud and foundry-sand bonding clay.

Nonclay constituents that are interpreted as having been largely, if not wholly, deposited by circulating underground water since deposition and alteration of the volcanic ash include selenite, iron oxide, carbonates, and organic matter. Probably sodium sulfate, chlorides, and other soluble salts are also present in small amounts. The nonclay constituents occur partly in joint systems and partly disseminated through the clay. Those in the joint systems are chiefly selenite, calcite, and iron oxide. The calcite commonly occurs in the joints as fibrous crystalline veins most of which are less than an inch thick. The selenite occurs as disseminated euhedral crystals,

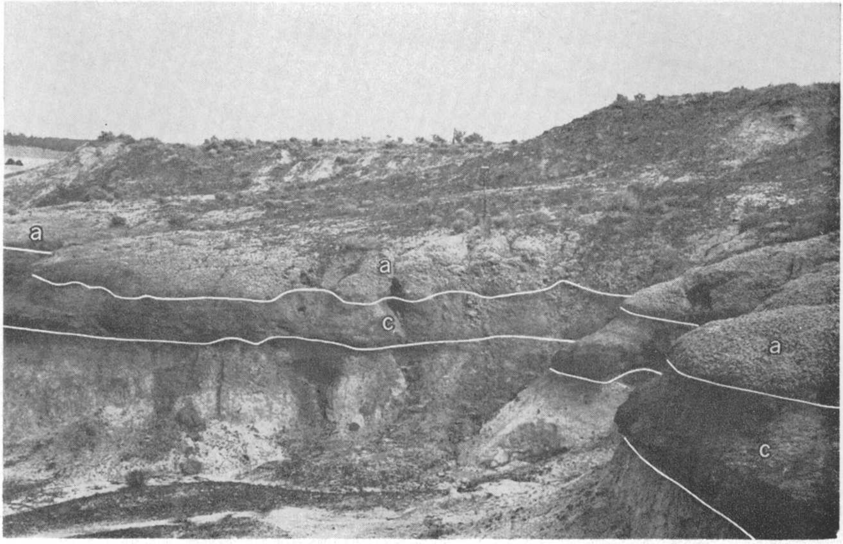


A. ZONE ABOVE THE CLAY SPUR BENTONITE BED IN SE¼ SEC. 7, T. 56 N., R. 61 W., CROOK COUNTY, WYO.

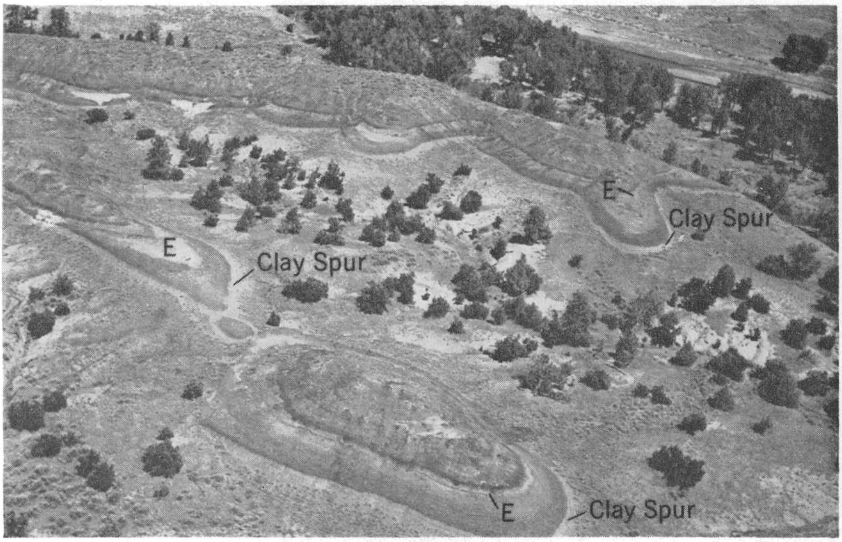
Made up of platy siliceous shale interbedded with gray bentonite and bentonitic shale. Bentonitic materials have weathered surfaces resembling alligator hide.



B. POPCORNLIKE AGGLOMERATION OF CLAY LUMPS AS TYPICALLY PRODUCED IN WEATHERING OF THE CLAY SPUR BENTONITE BED



A. BENTONITE BED A (*a*) AND SUBJACENT CARBONACEOUS STRATUM (*c*) IN NW¼ SEC. 11, T. 57 N., R. 65 W., CROOK COUNTY, WYO.



B. CHARACTERISTIC OUTCROPS OF THE CLAY SPUR BENTONITE BED AND BENTONITE BED E commonly 5 inches or more in their longest dimension. Selenite crystals occurring in parts of the Clay Spur bentonite bed that have been exposed to intensive and long-continued weathering differ little, if any, in size from those of less weathered parts of the bed, as observed in mine excavations within this district. Thus Dengo's (1946) interpretation, that an increase in the size of the selenite crystals is caused by weathering, does not seem to be applicable to the Clay Spur bentonite bed of the northern Black Hills district. The uppermost parts of the bentonite deposits also contain small amounts of organic matter, most of which occurs in the dark transitional zones.

Differential thermal analyses of synthetic mixtures of selenite and a variety of virtually pure sodic bentonite show a characteristic endothermic reaction between 150° and 200°C. The intensity of this reaction increases as the proportion of selenite in the mixture is increased (fig. 81). Endothermic reactions of the same magnitude occur in bentonite known to contain naturally disseminated selenite in approximately the same proportions as these synthetic mixtures.

X-ray diffractometer diagrams (fig. 80) also provide a means of identifying minor amounts of nonclay minerals, particularly where their reflections are not obscured by those of the clay minerals. For

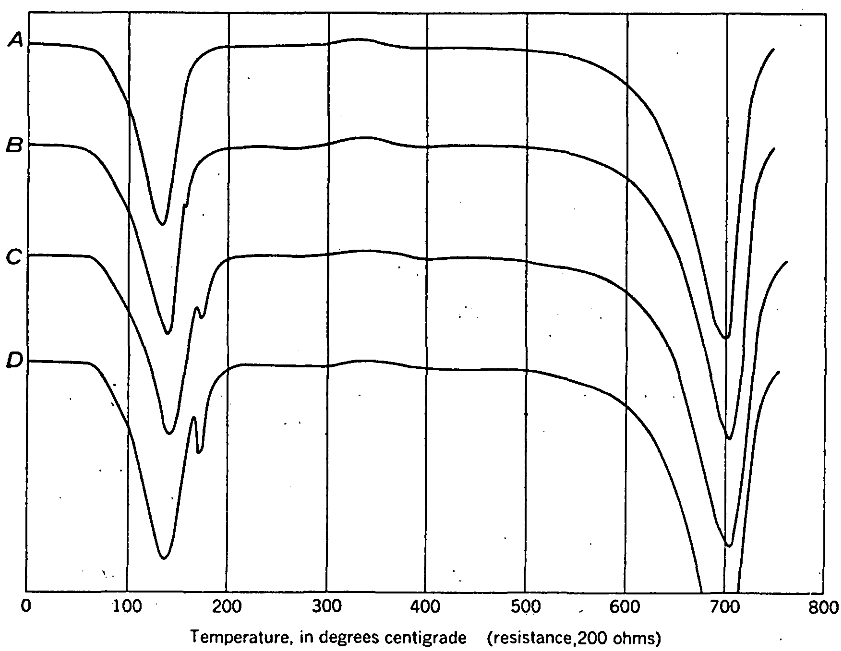


FIGURE 81.—Differential thermal diagrams showing inflections for (*A*) sodic bentonite of high purity, (*B*) same material mixed with 1 percent, by weight, of selenite, (*C*) mixed with 2 percent selenite, and (*D*) with 3 percent selenite.

example, quartz, the most common nonclay mineral, is recognized by reflections corresponding to spacings of 3.34 A, 4.26 A, and 1.82 A and feldspar, by reflections corresponding to spacings of about 3.2 A, 3.46 A, and 3.7 A.

MINOR ELEMENTS

Chemical analyses of the bluish-gray and olive-green bentonite taken from the Clay Spur bentonite bed as exposed in a strip-mining pit northwest of Colony, Wyo., are given on table 5. Following are the results of spectrographic analyses, by K. J. Murata of the U.S. Geological Survey, in which are listed the oxides of the minor elements found in the bluish-gray and olive-green bentonite from the same pit:

	Bentonite			*Bentonite*	
Oxide	*Bluish-gray*	*Green*	*Oxide*	*Bluish-gray*	*Green*
K_2O	0. 3	0. 2	B_2O_3	0. 002	0. 002
Li_2O	0. 01	0. 008	Y_2O_3	0. 006	0. 006
ZrO_2	0. 03	0. 03	Yb_2O_3	0. 0008	0. 0008
TiO_2	0. 05	0. 05	MoO_3	0. 001	0. 0008
MnO	0. 001	0. 001	PbO	0. 003	0. 003
BaO	0. 003	0. 003	BeO	0. 0004	0. 0004

NOTE.—Minor elements looked for but not found were Zn, Cd, Cu, Bi, As, Sb, Sn, Ag, Au, Pt, Pd, Re, Tl, In, Ge, V, Cr, Cb, Ta, W, Ni, and Co. K. J. Murata, analyst.

RADIOACTIVITY

Samples of bentonite from deposits in the marine Cretaceous formations of this district and from the surrounding region are, almost without exception, weakly radioactive. A sample of the radioactive bentonite, which was taken from the stockpile of a processing plant near Colony, Wyo., and which was analyzed by F. J. Flanagan of the U.S. Geological Survey, contained approximately 0.001 percent of uranium in about 0.002 percent of equivalent uranium. Roughly comparable percentages were found in weakly radioactive samples of bentonite from outcrops of marine Cretaceous formations in Bighorn and Rosebud Counties, Mont.

PROPERTIES RELATED TO USE AS FOUNDRY-SAND BONDING CLAY AND IN DRILLING MUD

The potentialities of any given bentonite for use as foundry-sand bonding clay, drilling clay, and many other uses depend primarily on the character of the clay fraction and the proportion of clay to nonclay constituents. In the evaluation of bentonite with a low content of nonclay material, certain physical properties of the clay fraction are critical factors. Commercially significant properties of bentonite-water mixtures, such dilatancy (swelling capacity), viscosity, thixotropy (gel strength), and bonding strength, are widely interpreted as largely the result of the interplay of the electrochemical forces exerted by the lattice units, adsorbed water, and replaceable cations. In a clay fraction consisting of montmorillonite, such properties are believed to be determined largely by the ionic radii of the various component cations, particularly those in exchange positions.

In the clay fraction of many samples of the bentonite occurring in the Cretaceous strata cropping out in the northern Black Hills district and elsewhere in Wyoming, South Dakota, and Montana, Na^{+1} is the predominant exchangeable cation, whereas that which is characteristic of the samples from most other regions is Ca^{+2}. In this connection Ross and Hendricks (1945, p. 65) have commented:

A few types with sodium as the exchangeable base, as illustrated by . . . Wyoming bentonites, form a gel-like mass on absorption of water; but in general, bentonites are characterized by calcium as the replaceable base, and these varieties tend to swell slightly and crumble into a granular mass. The gel-forming types tend to stay in suspension indefinitely, but the more widespread calcium type commonly yields only a small percentage of material that remains in permanent suspension.

The two varieties thus differentiated are designated by various terms, such as "type 1," "Wyoming type," or "Black Hills type" for the sodium-bearing bentonite and "type 2," "southern type," and "subbentonite" for the calcium-bearing bentonite. In this report the two varieties are termed "sodic" and "calcic" respectively.

The distinction between the two types is significant in relation to the uses for which bentonite is marketed. The gel-forming sodic variety includes most of the bentonite used in drilling mud; the calcic variety includes practically all that is used by the petroleum refineries for bleaching, filtering, and catalysis. Foundries and steel works use both varieties as bonding material for molding sands; as such, the sodic bentonite is superior in dry strength, though distinctly inferior in green strength, to the calcic type.

The superior dry strength of the sodic variety makes it suitable also for pelletizing the finely ground concentrate of iron oxide obtained in processing low-grade iron ore, usually referred to as taconite, of the Lake Superior region. In 1956 thousands of tons of bentonite were shipped from the northern Black Hills district for this purpose, for which tonnage requirements are expected to increase as the production of such iron ore increases. It is noteworthy, however, that in making the pellets only 8 or 9 pounds of bentonite are added to each ton of concentrate (Engineering and Mining Journal, 1956, p. 96), whereas 100 to 120 pounds are required in preparing a ton of molding sand.

As shown in figure 82, most of the commerical supply of sodic bentonite in 1950 came from deposits of Cretaceous age in Wyoming, Montana, and South Dakota, whereas most of the calcic variety came from deposits of Cretaceous and Tertiary age in Mississippi,

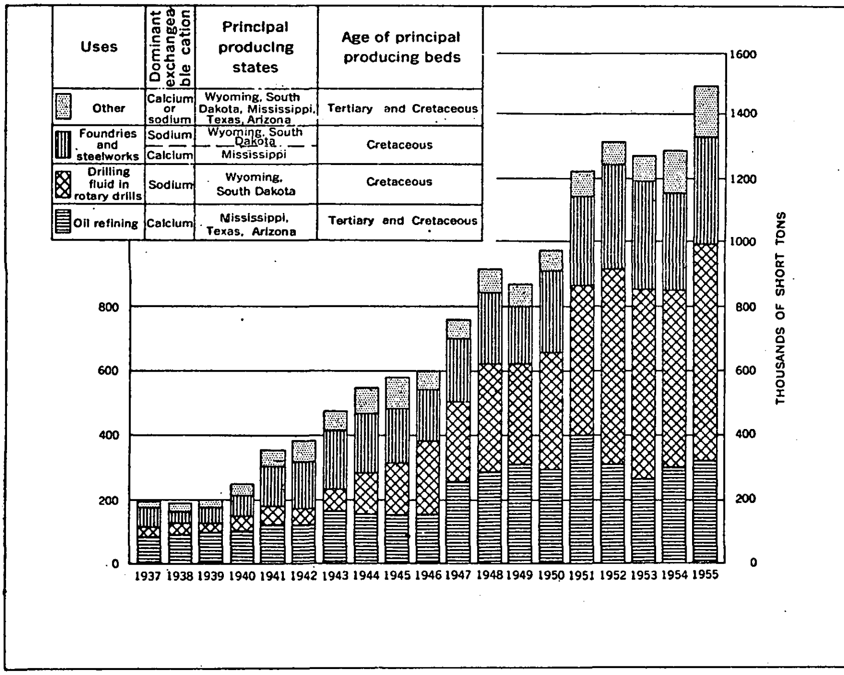


FIGURE 82.—Graph showing bentonite sold or used by domestic producers during the period 1937–1955 in relation to specific uses, dominant exchangeable cations, regional distribution, and geologic system. Tonnages from U.S. Bureau of Mines Minerals Yearbook, 1955.

Texas, and Arizona. In the Nation as a whole, probably no rock formations older than Cretaceous or younger than Tertiary contain appreciable reserves of bentonite that would meet current specifications for use in rotary drilling mud or as foundry-sand bonding clay.

Summarized in table 4 are the results of empirical tests of many bentonite samples from locations indicated by numbered localities on plate 60; such tests (Knechtel and Patterson, 1956a, p. 100–112) are designed to determine the suitability of the clay for use as foundry-sand bonding clay and in rotary oil-well drilling mud. Although the bentonite shipped from this district belongs largely to the highly dilatant gel-forming sodic type, tests of the samples obtained in the present investigation indicate that the properties (table 4) of the bentonite differ considerably from bed to bed and at different places within each bed. According to P. G. Nutting (oral communication, 1948), none of many bentonite samples from this and other areas in Wyoming, Montana, and South Dakota proved upon testing to be usable as oil-bleaching and decolorizing agents. Tempered mixtures of molding sand and clay that have green-compression strengths of 8 or more pounds per square inch and compression strengths of 50 pounds per square inch after drying are commonly regarded as suitable for preparing the molds used by foundries and steel works in manufacturing metal castings. In order to determine if a clay is suitable to be sold for use in rotary well-drilling mud, bentonite producers in the vicinity of the Black Hills commonly use rule-of-thumb specifications in which the computed yield (number of barrels of slurry with a viscosity of 15 centipoises that can be prepared from a short ton of clay) must be at least 90 barrels per ton and in which the volume of the filtrate produced in wall-building tests (see table 4) is 16 or less milliliters in a 30-minute period. A product conforming to these requirements, however, may be prepared by adding bentonite with a "high gel" strength or small amounts of chemical reagents to material that yields much less than 90 barrels. A satisfactory product may even be prepared by mixing together two or more different subgrade clays, if by so doing, proper proportions of Na^{+1}, Ca^{+2}, and other exchangeable cations are attained. Some subgrade material is mined in the northern Black Hills district and is made to conform to specifications by suitable treatment. The significance of the various tests, from which the data in table 4 were obtained, is explained more fully by Knechtel and Patterson (1956a) and by Fisk (1946).

MOISTURE CONTENT

The moisture contained in the bentonite of the northern Black Hills district ranges from about one-tenth to several times the weight of the dry bentonite. It tends to be greatest at poorly drained sites. At most sites, part of the moisture escapes by evaporation during dry periods and is restored during wet periods. The moisture content of the raw clay as it comes from the pits is usually assumed by the operators to average 30 percent. It was determined in the laboratory for five samples, whose moisture content was preserved by coating them with paraffin immediately after they were taken from various points in a pit in sec. 36, T. 57 N., R. 62 W., Crook County, to be 30.35, 30.05, 29.38, 28.68, and 28.39 percent, with an average of 29.37 percent.

TEXTURE

Most of the bentonite of this district has a waxy consistency; a granular texture, like that of cornmeal, is common but as a rule is restricted to layers near the top and base of the brightly colored bentonite. Residual particles of nonclay minerals, many of which are dark, are present in all the beds and are collectively termed "grit" by producers and buyers of bentonite. The content of grit varies greatly from layer to layer, some layers showing conspicuous amounts, others little or none.

Weathered surfaces of bentonite that swells only slightly are characterized by polygonal shrinkage-crack patterns in which the corners of most of the polygons are rounded off. The appearance of such surfaces (pl. 62*A*) has been compared to that of alligator hide (Kerr and Kulp, 1949, p. 58, pl. 15).

Outcrops of bentonite having moderate to high dilatancy tend to have a very different appearance from that of outcrops of bentonite having only a slight dilatancy (Knechtel and Patterson, 1956a, p. 44–45, fig. 10). During cycles of rainy and fair weather, repeated wetting and drying of such material ordinarily produces agglomerations of irregularly rounded, popcornlike lumps, which are a conspicuous feature of many outcrops of sodic bentonite (pl. 62*B*). Similar agglomerations can be produced in the laboratory by alternate wetting and drying of sodic bentonite. Upon becoming saturated with water, typical sodic bentonite that has previously been dried out forms a gel and swells enormously. When this material is again dried out, shrinkage breaks the clay into fragments that are more or less angular. Upon rewetting, the clay of the outer part of each fragment once more begins to gel, but water is adsorbed so slowly that the centers of the fragments remain dry for several days. While wet, the gelled material of the outer part tends to flow, and during repeated brief periods of wetting, followed by periods of drying, the fragments gradually form popcornlike lumps.

Such popcornlike material forms a surficial crust a few inches thick at many places and is separated from the firmly compacted bentonite of the bed beneath by several inches of loose granular bentonite, similar to cornmeal in texture, like that which commonly occurs in the basal few inches of the bentonite beds. This mealy material, a product of weathering, is most commonly associated with beds of bentonite that is heavily stained by iron oxide or contains much nonclay material. Mealy bentonite also commonly occurs under a thin cover of soft, spongy soil. The dilatancy of the mealy material is generally lower than that of the more compact bentonite from which it is derived. Inasmuch as a tendency toward granularity is known to be characteristic of limy soils, the mealy texture may be in some way due to acquisition of Ca^{+2} in cation exchange reactions.

COLOR AS AFFECTED BY WEATHERING

The predominant colors of the unweathered bentonite of this district are shades of medium bluish gray. As freshly exposed in mine excavations and in fresh cuttings from boreholes, nearly all the clay lying under more than a few yards of overburden is bluish gray. Much of the clay at shallow depth has become discolored by weathering and is mostly olive, cream, and drab; accordingly, these are the predominant colors of the bentonite of natural exposures in this district. The discolored moist bentonite of the Clay Spur bentonite bed generally reflects shades of olive, the color of much of it being a close match for the color designated 5Y 6/3 (pale olive) in the Munsell system. Bed F, however, is characterized by conspicuous bright-red specks and bed E has a striking rusty color.

The discoloration that results from weathering has been attributed (Knechtel, 1947; Knechtel and Patterson, 1956a, p. 45) to oxidation of a small amount of iron that is shown by analyses to be present in the bentonite. Oxidation of the iron is evidently caused by exposure to air, as well as by solutions bearing atmospheric oxygen which have seeped from the surface into the joint systems that divide the clay into innumerable small blocks. Such solutions have deposited rusty films on the joint surfaces, from which the discoloration has progressed toward the center of each block. Nearly all the bentonite under less than 10 or 12 feet of overburden has become discolored in this way, but many blocks below that depth contain cores of undiscolored bluish-gray clay. The amount of discolored bentonite decreases with depth and generally none of the bentonite under more than 25 feet of overburden is discolored.

Oxidation of the iron, with the associated discoloration, has been observed in the laboratory. The bluish-gray clay fraction of a block of bentonite was allowed to weather for a period of 11 months; it changed gradually to olive green as oxidation of the iron proceeded (Foster, 1953, p. 1003; 1954, p. 20–21). The following chemical analyses (table 5) show the composition of the montmorillonite fraction of bentonite from two partly weathered joint blocks which were obtained, during our investigation in 1947, from a mine in the Clay Spur bentonite bed near Colony, Wyo.

TABLE 5.—*Chemical analyses of the clay fraction of bluish-gray and olive-green bentonite of the Clay Spur bentonite bed from NW¼SW¼ sec. 36, T. 57 N., R. 62 W., Crook County, Wyo.*

[Analyst: M. D. Foster, U.S. Geological Survey]

Oxide	Block 1		Block 2	
	Bluish-gray bentonite	Olive-green bentonite	Bluish-gray bentonite	Olive-green bentonite
SiO_2	54. 34	54. 62	54. 34	54. 07
Al_2O_3	19. 92	20. 08	20. 12	20. 24
Fe_2O_3	1. 11	2. 36	1. 13	2. 45
FeO	2. 17	1. 03	2. 06	. 74
TiO	. 11	. 11	. 14	. 14
CaO	. 33	. 40	. 53	. 55
MgO	2. 21	2. 15	2. 02	1. 92
Na_2O	2. 65	2. 26	2. 44	2. 35
K_2O	. 45	. 35	. 49	. 40
MnO	. 01	. 01	. 01	. 01
SO_3	. 18	. 16	. 15	. 17
H_2O-	11. 73	11. 78	12. 18	11. 90
H_2O+	4. 50	4. 58	4. 62	4. 89
Total	99. 71	99. 89	100. 23	99. 83

In the following formulas, which were derived from the analyses (table 5) by using the method described by Ross and Hendricks (1945, p. 41–45), the various ions are assigned positions according to the generalized formula, [Cations with octahedral coordination] [Cations with tetrahedral coordination] $[O_{10}(OH)_2x_{0.33}]$, in which x represents the exchangeable cations and the subscript 0.33 is the average quantity of such cations reported by Ross and Hendricks (1945) for many samples of minerals in the montmorillonite group. In the formulas relating to blocks 1 and 2, however, subscripts corresponding to the measured quantity of exchangeable cations are substituted.

Block	Color of bentonite	Formula
1	Bluish gray	$[Al^{+3}_{1.60}Fe^{+3}_{0.06}Fe^{+2}_{0.13}Mg^{+2}_{0.22}]$ $[Si^{+4}_{3.91}Al^{+3}_{0.09}]$ $[O_{10}(OH)_2x_{0.41}]$
	Olive green	$[Al^{+3}_{1.61}Fe^{+3}_{0.13}Fe^{+2}_{0.06}Mg^{+2}_{0.20}]$ $[Si^{+4}_{3.92}Al^{+3}_{0.08}]$ $[O_{10}(OH)_2x_{0.36}]$
2	Bluish gray	$[Al^{+3}_{1.62}Fe^{+3}_{0.06}Fe^{+2}_{0.13}Mg^{+2}_{0.20}]$ $[Si^{+4}_{3.92}Al^{+3}_{0.08}]$ $[O_{10}(OH)_2x_{0.38}]$
	Olive green	$[Al^{+3}_{1.62}Fe^{+3}_{0.13}Fe^{+2}_{0.05}Mg^{+2}_{0.19}]$ $[Si^{+4}_{3.90}Al^{+3}_{0.10}]$ $[O_{10}(OH)_2x_{0.37}]$

The crystalline structure of the clay fractions analyzed may be only approximately that indicated by the formulas because of various uncertainties involved in the derivation of formulas from chemical analyses by methods comparable to the one used in this investigation (Kelley, 1945, 1955). The presence of cristobalite and quartz was established by X-ray examination (Foster, 1953, p. 997) and these nonclay constituents were taken into account in calculating the formulas. It is also probable that part of the iron and oxygen present in the clay fractions occurs in nonclay constituents though, in the calculations, these two elements were treated wholly as integral parts of the crystalline structure of montmorillonite. Assuming that the iron and oxygen indicated in the analyses (table 5) are present partly as nonclay constituents of the bentonite, the color change, from bluish gray to olive green, was probably brought about chiefly, if not entirely, by oxidation of ferruginous nonclay compounds through exposure to atmospheric oxygen during weathering.

Table 6 shows some effects of weathering on the physical properties of bentonite of the Clay Spur bentonite bed.

The results (table 6) of drilling-mud tests of bentonite samples which were obtained from the same mine as the bentonite blocks referred to in table 5, confirm the generalization that progressive weathering, as indicated by the discoloration, affects the yield, viscosity, filtrate volume, and gel strength. The tests of slurries A, B, C, and D show the effect of natural weathering on these properties; those for slurries E and F show that comparable changes occurred in the

TABLE 6.—*Drilling-mud tests of slurries prepared from discolored and undiscolored bentonite of the Clay Spur bentonite bed*

A–D. Slurries containing bentonite from strip mine of American Colloid Co., sec. 15, T. 9 N., R. 1 E., Butte County, S. Dak.: A. undiscolored bentonite; B. undiscolored bentonite from locality several yards closer to discolored material; C, partly discolored bentonite, containing "blue eggs"; D, completely discolored bentonite.
E–F. Slurries containing bentonite from strip mine of Eastern Clay Products Co., sec. 36, T. 57 N., R. 62 W., Crook County, Wyo.: E, undiscolored bentonite; F, part of sample E, discolored after repeated wetting and air-drying in the laboratory over a period of 4 months.

Slurry[1]	Swelling capacity, in milliliters, of 2 g. of bentonite	Yield (bbl per ton)	pH	Viscosity, in centipoises, for slurries containing indicated percentages of clay by weight			Filtrate, in milliliters, for indicated periods, in minutes			Gel strength, in Stormer grams, of 6 percent clay by weight for indicated periods, in minutes	
				6	6½	7	2	15	30	0 (initial)	10
A	--------	85	9.9	12	----	----	4.8	12.8	17.0	3	5
B	--------	88	9.9	14	----	----	4.6	11.2	16.0	3	3
C	--------	97	9.8	18	----	----	4.0	10.2	14.0	5	15
D	--------	117	9.5	32	----	----	3.8	9.8	13.8	10	75
E	34	76	9.2	7	10	14	7.4	18.3	26.0	3	4
F	37	83	8.9	9	14	21	5.5	13.4	17.0	4	8

[1] Prepared with distilled water.

laboratory over a period of 4 months, during which the color of the samples changed from bluish gray to olive green. These results are in harmony with the appreciable increase in dilatancy observed by Foster (1953, p. 1003–1004) for bluish-gray bentonite that was exposed to air in the laboratory over a period of 11 months.

The differential thermal diagram of the bentonite from which slurry E was prepared (fig. 83*E*) shows an endothermic inflection, corresponding to about 450°C, that is believed to have been caused by the presence of a small amount of iron sulfide, whereas that of the bentonite from which slurry F was prepared (fig. 83*F*) does not show such an inflection.

OTHER EFFECTS OF WEATHERING

Weathering generally enhances the commercial value of the bentonite of the Clay Spur bed (Knechtel, 1947; Knechtel and Patterson, 1956a, p. 44–45). Locally, however, weathering may have an adverse effect on its useful properties. Beneficial effects of weathering are illustrated in figure 84, which indicates that the yield, gel strength, and ion-exchange capacity of the samples from a deposit of this clay near Colony, Wyo., tend to increase as the overburden at the localities sampled thins from approximately 12 feet to less than an inch. Thus, the yields for three air-dried samples taken from exposures beneath several feet of overburden were 95, 101, and 105

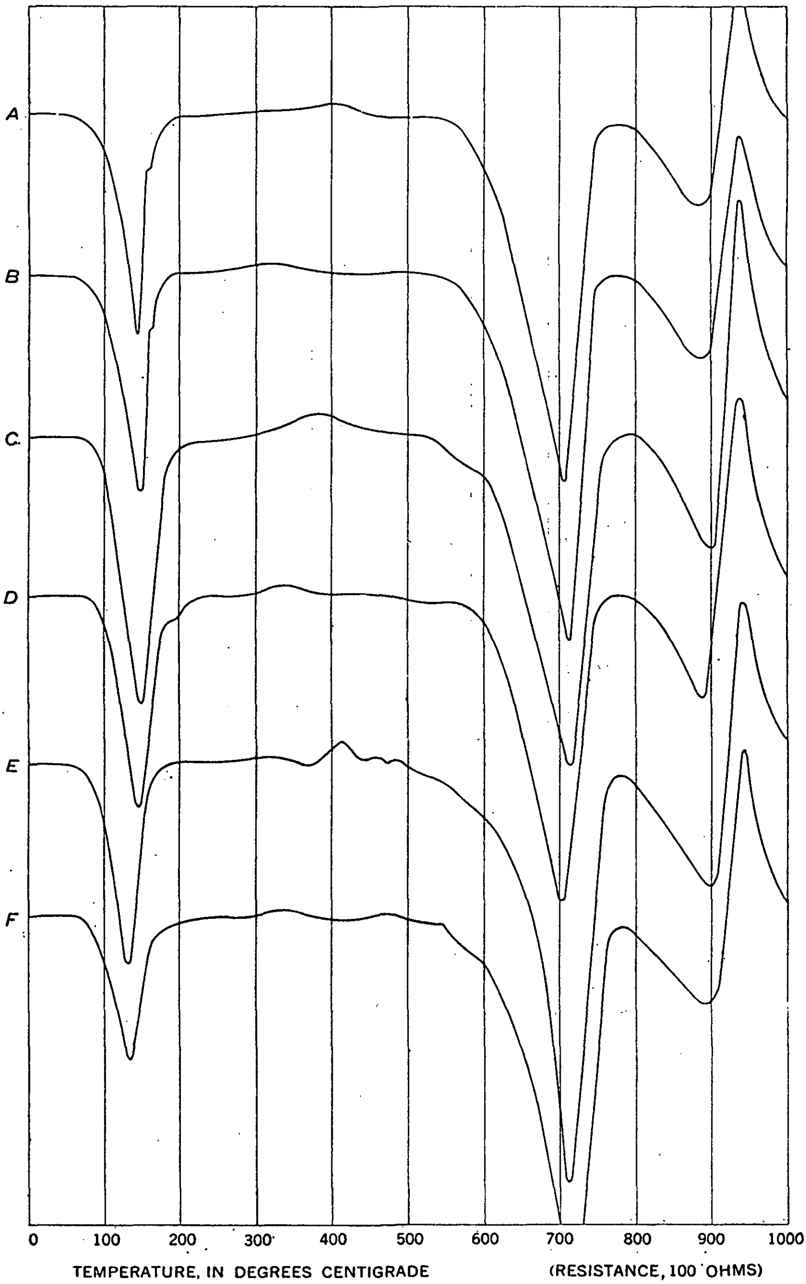


FIGURE 83.—Differential thermal diagrams of undiscolored and discolored bentonite from the Clay Spur bentonite bed: (*A*) Undiscolored bentonite from the strip mine of the American Colloid Co. in sec. 15, T. 9 N., R. 1 E., Butte County, S. Dak.; (*B*) discolored material from same excavation; (*C*) —2 micron fraction of a duplicate specimen represented by curve *A*; (*D*) —2 micron fraction of a duplicate specimen represented by curve *B*; (*E*) undiscolored bentonite from the strip mine of Eastern Clay Products Co. in sec. 36, T. 57 N., R. 62 W., Crook County, Wyo; (*F*) duplicate specimen represented by curve *E*, after artificial weathering for a period of 4 months.

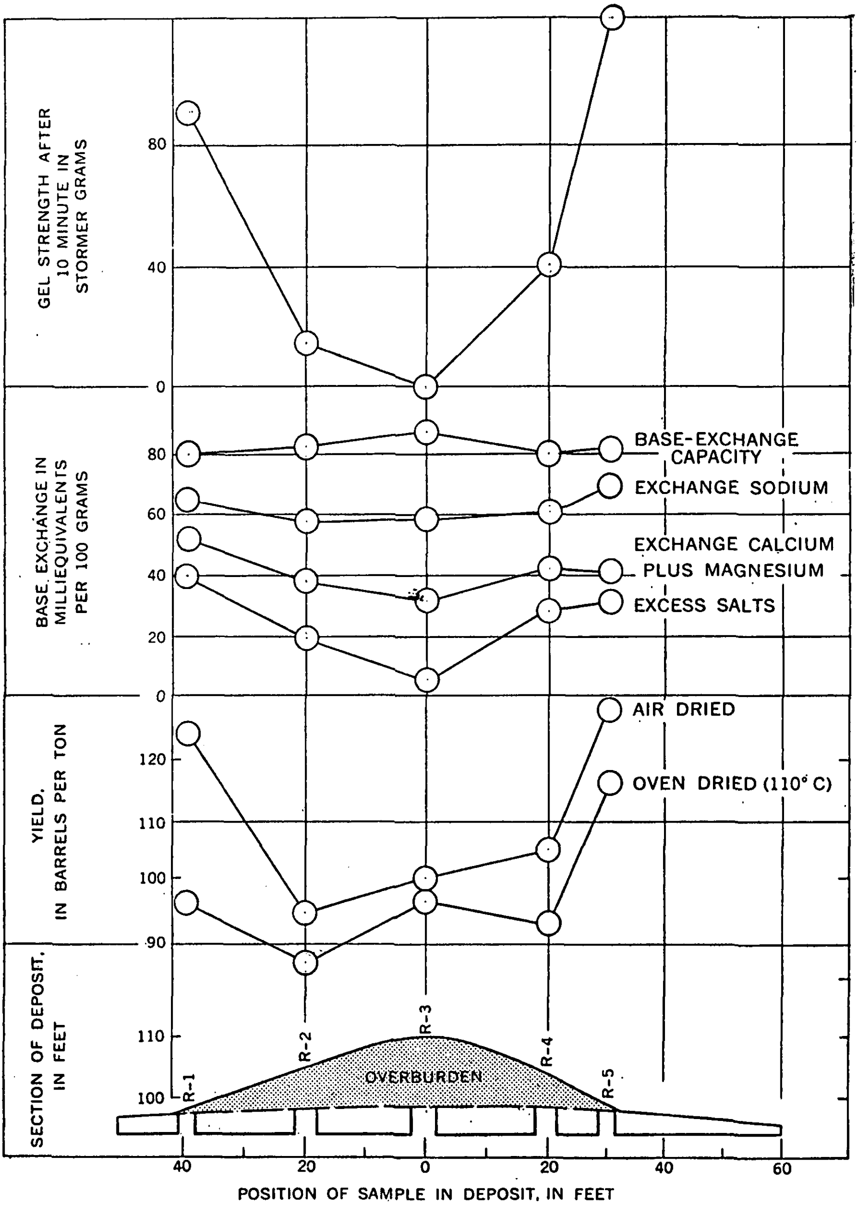


FIGURE 84.—Variation in the properties of bentonite from the Clay Spur bentonite bed near Colony, Wyo., as a function of overburden (Williams, Neznayko and Weintritt, 1953). R-1 to R-5 are drill holes.

barrels per ton, whereas samples taken from nearby outcrops of the same deposit were 125 and 129 barrels.

The dilatancy or swelling capacity of the clay fraction of bentonite is also a controlling factor in determing the yield, as shown by the following data obtained from the two partly weathered joint blocks referred to in table 5.

Block	Color of bentonite	Dilatancy [1] (milliliters)
1	Bluish gray	39. 5
	Olive green	60. 0
2	Bluish gray	40. 0
	Olive green	60. 0

[1] From Foster (1953, p. 1004).

The term "dilatancy" refers to the maximum volume, in milliliters, of the gel that is formed in distilled water by 1 gram of crushed dry clay that has passed through a 20-mesh screen and has been retained on a 40-mesh screen. The dilatancy of the bluish-gray clay of block 1, after having been allowed to weather in the laboratory for 11 months, increased from 39.5 to 60 ml.

The variations in dilatancy that are reflected in the foregoing data, however, can be of only limited significance, inasmuch as the preparation of each clay fraction for testing and analysis involved an induced cation exchange to complete the "conversion to the Na form" (Foster, 1953, p. 997). The behavior of the clay fractions in the tests performed by M. D. Foster would no doubt have been somewhat different if the exchangeable-cation content could have been left undisturbed.

In some places weathering appears to have had an adverse effect on the dilatancy and other useful properties of the bentonite. In many such places, this effect may be largely, if not entirely, due to the union of sulfate and calcium ions to produce gypsiferous material intimately associated with the flakelike particles of the montmorillonite. Experiments by Knechtel suggest that such gypsiferous material may tend to interfere with the dispersion and the capacity of the montmorillonite to expand in the presence of water.

The probability that minor details of the geologic structure, through their influence on ground-water circulation, cause local variations in the quality of the bentonite is suggested by data relating to strip-mining pits excavated in 1957 at localities (pl. 60) 80, 80A, and 80B, in E½, T. 9 N., R. 1 E., in Butte County, S. Dak. The pit at locality 80 occupies a narrow strip extending about half a mile northeastward. The yield of the bentonite at locality 80 (table 4) was found to be high (104 barrels per ton) and the viscosity of virtually all the clay that was mined from the pit, including a large amount of bluish-gray bentonite, is reported to have been high. The Clay Spur bentonite bed here dips gently northeastward and shows neither faulting nor conspicuous minor folds. By contrast, all the bentonite uncovered in a pit of approximately equal dimensions at locality 80A (pl. 60), about 1½ miles southeast of locality 80, was olive green, which is typical of the weathered bentonite, yet it all tested low in viscosity. The Clay Spur dips gently northeastward at both of these localities but the Clay Spur bentonite bed in the pit at locality 80 is crossed by three normal strike faults, each showing upward displacement of less than 3 feet on the northeast (updip) side. These circumstances, together with data on a third pit at locality 80B (pl. 60), suggest that there is a general relation between the viscosity of the bentonite and the local geologic structure. Data on samples taken from scattered drill holes (fig. 85) prior to excavation of this pit indicate that the bentonite high in viscosity is present

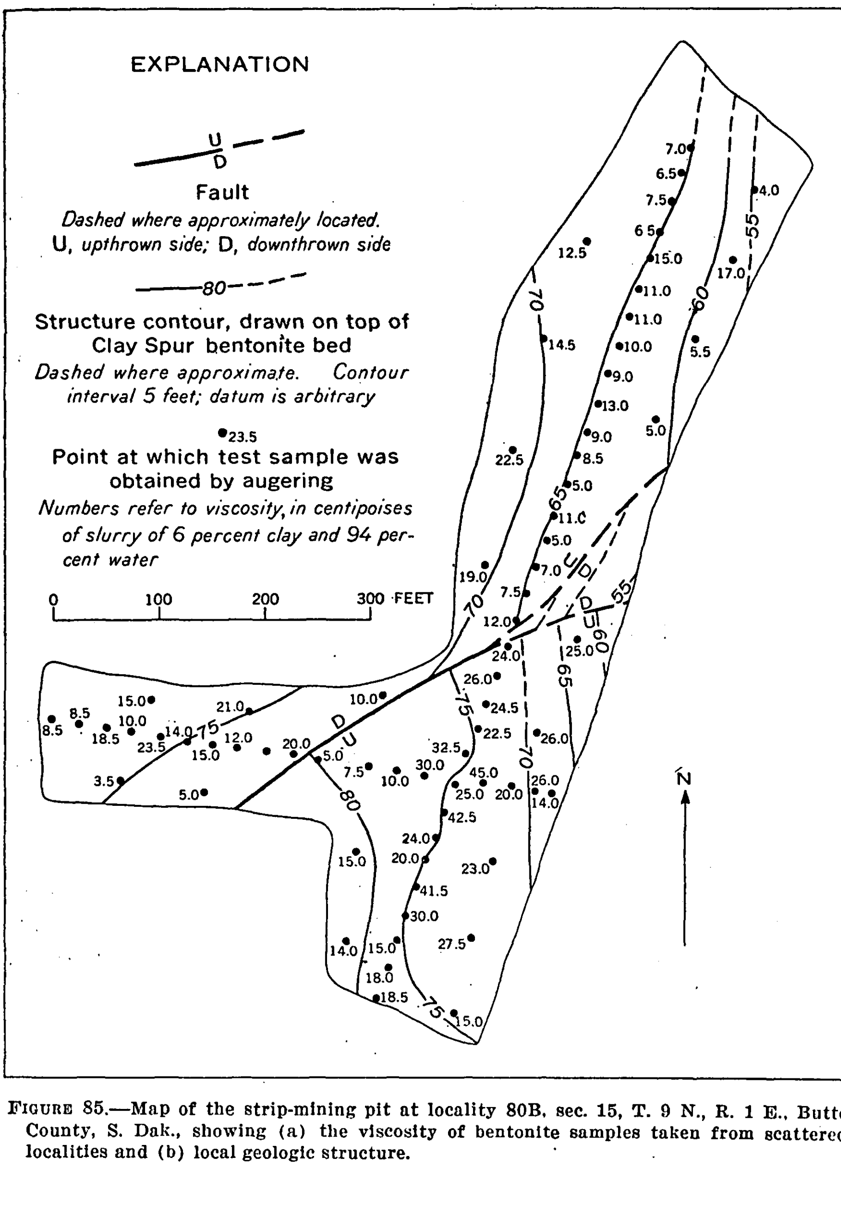


FIGURE 85.—Map of the strip-mining pit at locality 80B, sec. 15, T. 9 N., R. 1 E., Butte County, S. Dak., showing (a) the viscosity of bentonite samples taken from scattered localities and (b) local geologic structure.

mainly south of a fault zone that extends east-northeastward across the pit. The bentonite of all three pits contains rather abundant crystals of selenite, ranging in size from that of coarse sand to that of medium-sized pebbles.

FLOOR AND ROOF OF BEDS

The bentonite deposits of the northern Black Hills district are ordinarily in sharp contact with the floor on which they rest. Commonly the floor (pl. 64*B*) consists of shale, which in many places has become silicified to form a thin hard cherty layer (pl. 65). In general, the roof is less easily defined than is the floor and the bentonite of the upper part of the bed ordinarily grades into the overlying bedrock, which is commonly shale, through a zone of dark bentonitic shale. The local concentration of siliceous material in the floor was undoubtedly caused by silica that was leached from the original volcanic ash during the alteration to bentonite and was redeposited by downward-moving solutions. Such an extremely hard floor tends to be economically advantageous, particularly where the dip is gentle. The hard floor and bentonite bed together form a resistant unit and the overlying strata, if less resistant, as is commonly true, tend to be largely removed by erosion. The overburden on broad areas of bentonite deposits is, therefore, apt to be sufficiently thin to favor mining the bentonite by the strip-mining method. The hard floor also facilitates excavation with mechanical scrapers or shovels, inasmuch as the bentonite resting upon it can be picked up easily without appreciable admixture of the underlying material.

LAYERS WITHIN BEDS

A bentonite bed is ordinarily made up of clay layers which differ from one another in color, texture, or colloidal properties. The lower and middle parts of many beds are composed of light-colored material, which is commonly overlain by a layer consisting mainly of dark-colored bentonite or, less commonly, dark bentonitic shale. In general, the thickness of such a layer is less than one-third that of the underlying light-colored clay, but locally more than one-half the thickness of the bentonite may be dark colored. As a rule, many laminae of light-colored bentonite are intercalated in the lower part of the dark material, but they are less numerous in its upper part. The light-colored clay thus grades upward into the dark material which, in turn, grades into the material of the roof.

DESCRIPTION BY BEDS

Though bedrock containing bentonite deposits is exposed extensively in this district, outcrops of the bentonite are ordinarily somewhat obscured by surficial debris. Trenching or boring with augers is, therefore, generally required for accurate measurement of the thickness of the deposits and for careful observation and sampling of the clay. As shown by table 7, the sampled bentonite varies in thickness, in identity of exchangeable-cations, in nonclay mineral content, and in commercially significant physical properties. Measurements made at many localities are given in the descriptions on pages 995–1024. In general, the bentonite beds range in thickness from about ½ inch to 8 or more feet; but at one locality, in sec. 6, T. 56 N., R. 62 W., a bentonite bed in the Newcastle sandstone is 30 feet thick. Five of the nine beds for which measurements are given—bed A, the Clay Spur bentonite bed, and beds F, G, and I—have average thicknesses of more than 3 feet and are comparable in thickness with the deposits being mined. The other four beds are generally too thin to be of economic value. However, each of the nine beds is separately described. The search for deposits of economic value has been primarily directed toward discovery of mining sites similar to those in operation.

BED A

Bentonite bed A (pl. 63*A*), locally called the Newcastle bentonite bed, is known to crop out only in Crook County, where it is exposed intermittently for more than 30 miles. This bed was once regarded (Heathman, 1939) as forming the base of the Mowry shale, but it is now known to lie within the upper part of the Newcastle sandstone. Bed A has been mapped only as far west as the northeast corner of T. 56 N., R. 66 W. Farther west it is poorly exposed and is unfavorably situated for strip-mining. The bed thins eastward within the northern half of T. 56 N., R. 62 W., and is not present in T. 56 N., R. 61 W. Farther south and east the entire Newcastle sandstone grades into shaly strata that are mapped with the Skull Creek shale, but these strata are not known to include bed A.

TABLE 7.—*Summary of data on bentonite of beds A to I*

Bed	Approx. average thickness (feet)	Dominant exchangeable cations	Percentage of nonclay minerals	Yield	Green strength	Dry strength
I	[1] 1-3	Ca^{+2}, Mg^{+2}	10-20	Very poor	Excellent	Poor.
H	1½		45-65	do	Very poor	Do.
G	2-5	Mg^{+2}, Na^{+1}, Ca^{+2}.	20-35	do	Fair	Very good.
F	2-5	Ca^{+2}, Na^{+1}	15-25	Poor to good	Good	Do.
E	1-1½	Na^{+1}(?)	20-35	do	Fair	Do.
D	½	Na^{+1}	10-20	Very good	do	Do.
Clay Spur	2½	Na^{+1}	10-20	Fair to excellent.	Good	Very good to excellent.
B	1	Ca^{+2}	15-25	Very poor	Very good	Poor.
A	3-5	Na^{+1}, Ca^{+2}	10-40	Poor to excellent.	Good	Very good to excellent.

[1] Thickness is that of lowermost layer of bed I—a composite bed containing several thick partings of shale.

The Newcastle sandstone is varied in thickness, and both the thickness of bed A and its position with reference to the base and top of the formation differ from place to place. In sec. 7, T. 56 N., R. 62 W., bed A is less than 6 feet above the base of the Newcastle; less than 4 miles to the northwest, it is about 30 feet above the base. Still farther west, along the Little Missouri River, the thickness of the Newcastle is less varied and bed A is near the middle of the formation. The bentonite of this bed is generally between 3 and 5 feet thick, but it pinches out in some places and is as much as 8 feet thick in others. An unusually large local thickness of 30 feet was penetrated with a power auger in sec. 6, T. 56 N., R. 62 W., where the bed is associated with lenticular beds of sandstone and apparently occupies a channel scoured out by an ancient stream or tidal current. Nearby exposures of bed A show less than 5 feet of bentonite.

The popcornlike crusts, ordinarily associated with highly dilatant montmorillonitic clay of sodic bentonite (see p. 956), are commonly well developed along weathered outcrops of bed A, but are locally supplanted by the "alligator hide" surfaces characteristic of the exposures of the less dilatant calcic bentonite. The presence of both calcic and sodic bentonite in this bed is confirmed by the results of cation-exchange measurements (table 3) and differential thermal analysis (fig. 86*A–D*) of samples from several localities in which bed A crops out.

For example, a sample of bentonite taken from bed A at locality 58a, sec. 6, T. 56 N., R. 62 W., is shown by the results of ion-exchange measurements (table 3) to contain Na^{+1} as the principal exchangeable cation. The differential thermal diagram for this sample (fig. 86*C*) accordingly shows the single sharp low-temperature endothermic inflection that characterizes montmorillonite in sodic bentonite, whereas the corresponding inflection for a sample of bentonite taken from bed A (fig. 86D), in which exchangeable Ca^{+2} predominates (table 3), is followed by a weaker endothermic reaction, between 175° and 225°C, that is indicative of calcic bentonite. Samples from both the dark upper part and the brightly colored lower part of bed A at locality 27, sec. 32, T. 58 N., R. 63 W., proved also (fig. 86 *A*, *B*) to be composed chiefly of calcic bentonite; the presence of some hydrous mica in the upper part is suggested by an endothermic inflection, corresponding to about 540°C (fig. 86*A*). The results of these ion-exchange and thermal measurements conform, in part, to data obtained in commercial tests of the bentonite sampled (table 4). For example, the sodic bentonite from locality 58a proved to be highly dilatant and gave good results in drilling-mud tests, whereas the calcic bentonite from localities 58 and 27 was shown to be less highly dilatant and less well suited for use in drilling mud. Samples of

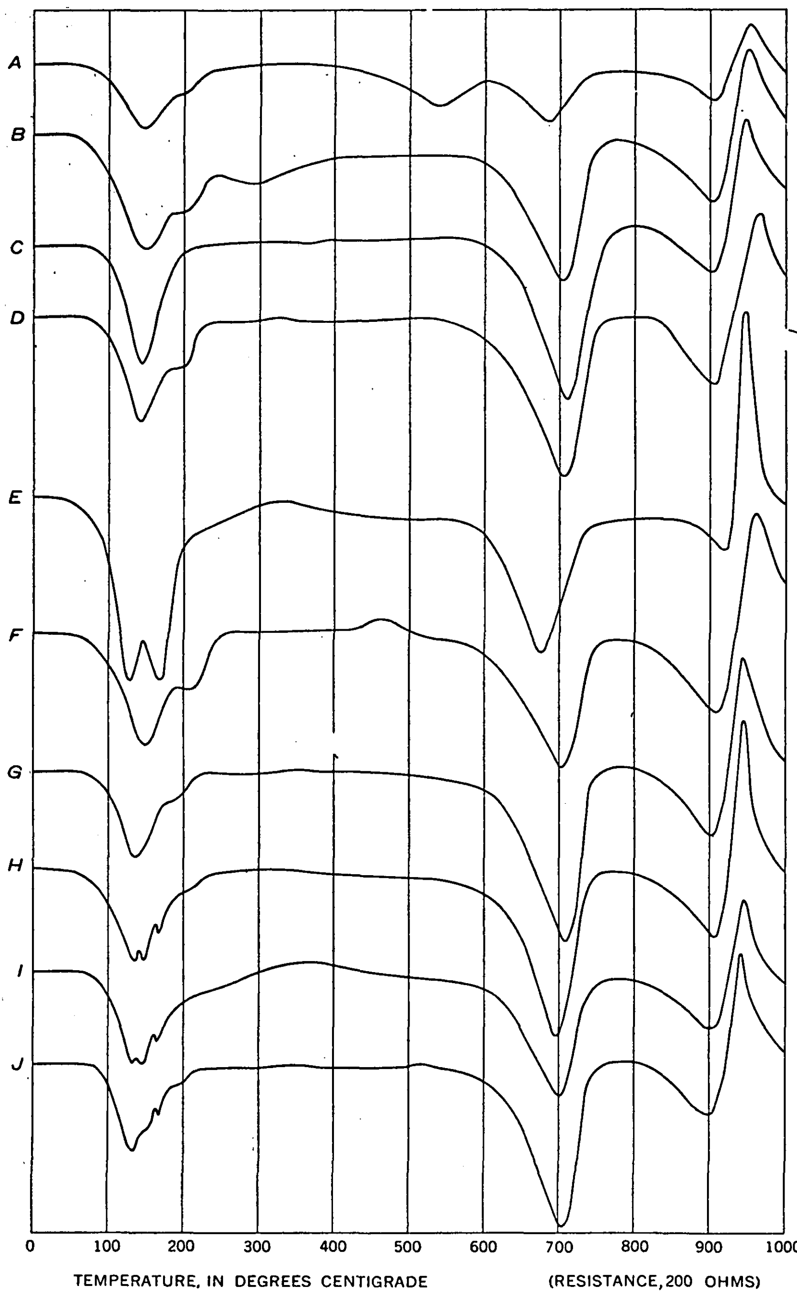


FIGURE 86.—Differential thermal diagrams of bentonite from beds A and B and from the Clay Spur bentonite bed as sampled at numbered localities (pl. 60 and table 4); (*A*) Bed A, locality 27, page 1011, material 2; (*B*) bed A, locality 27, page 1011, materials 3 and 4; (*C*) bed A, locality 58a, page 1000, materials 3–6; (*D*) bed A, locality 58, page 1000, material 5; (*E*) bed B, locality 30, page 1011, materials 3 and 4; (*F*) bed B, locality 46, page 1003, material 2; (*G*) Clay Spur bentonite bed, locality 13, page 1018, materials 4–6; (*H*) Clay Spur bed, locality 26, page 1012, materials 4–6; (*I*) Clay Spur bed, locality 28, page 1011, materials 2 and 3; (*J*) Clay Spur bed, locality 28, page 1011, materials 4 and 5.

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both varieties showed high dry strength and low green strength when tested as foundry-sand bonding clay.

Where bed A lies under deep cover, the bentonite is bluish gray; where it lies at, and close to, the surface, the bentonite ranges from olive green through shades of greenish gray to brownish gray, owing to the oxidation of a small amount of iron that is present. As compared with most other bentonite beds of this district, bed A tends to be discolored to unusually great depth and the areal distribution of the discolored material is less clearly related to the configuration of the land surface. No doubt the freer circulation of ground water in the porous sandy material overlying bed A has resulted in more rapid oxidation of the iron in bed A than has been possible in the other beds, all of which are overlain by considerable thicknesses of comparatively impervious strata. In some places the bentonite adjacent to joints or other fractures within the bed is darker than the rest. The darker bentonite apparently has been stained by traces of organic matter. Except for such staining, the bentonite is commonly rather uniformly light colored, though nonpersistent layers of different shades occur within it.

The bentonite of bed A contains nonclay fragments of various kinds, sizes, and shapes. Crystals of selenite and angular fragments of fibrous calcite are strewn along, and adjacent to, some of the outcrops, and several samples of the bentonite contain from about 10 to 35 percent by volume of disseminated nonclay grains. As much as one-third or more of the nonclay material consists of grains large enough to be described as grit. About four-fifths of the grit consists of clear subangular grains of quartz and the remaining one-fifth consists of small rounded masses of limonite, euhedral and rounded flakes of biotite, small crystals and fragments of selenite, and traces of various other minerals—notably muscovite, garnet, zircon, and magnetite, as well as glass shards and small rounded grains of exceedingly fine-grained schist. Nonclay material that is more finely comminuted than the grit consists chiefly of angular particles of quartz with X-ray reflections (fig. 80 *B*, *C*) corresponding to spacings of 3.34A and 4.26A, and feldspar (fig. 80 *A*, *B*), with reflections corresponding to spacings of 3.24A, 3.46A, and 3.77A; also present but not in sufficient amounts to give pronounced X-ray reflections are biotite, selenite, iron oxide, traces of many other accessory minerals, and a few particles of glass. Much of the nonclay material in the bentonite is no doubt inherited from the parent volcanic ash, but a large part of the quartz, as well as the rounded grains of schist, biotite, and other material, is believed to have been transported and deposited here by streams and near-shore currents that also deposited the sand of the Newcastle sandstone.

The materials comprising both the floor and roof of bed A differ somewhat from place to place. The rock of the floor is everywhere in sharp contact with the bentonite and tends to form small but prominent ledges. In most exposures, the floor consists of platy hard carbonaceous material, which in some places is coal and in others carbonaceous shale; small charcoal-like fragments are common in the lower part of the bentonite bed. Elsewhere, the floor consists of friable rock, mostly siltstone and fine-grained sandstone, which locally has become hardened by silicification to depths ranging from 1 to 5 inches below the bentonite. Presumably the silica was leached from the original volcanic ash of bed A during the alteration to bentonite. In most places the floor is sufficiently firm to support heavy mining equipment and to permit the bentonite to be picked up and loaded mechanically without undue admixture of the underlying rock.

Locally the material of the roof is in sharp contact with the bentonite of bed A, but commonly the clay grades into this overlying material through a zone of impure bentonite, ranging from 1 to 6 inches in thickness. Generally this transitional zone is directly overlain by friable sandstone or siltstone, but locally it is separated from such material by a few inches of gray soft silty shale or, as in a few places, a thin layer of impure coal. The part of the Newcastle sandstone above bed A, which forms the overburden on most parts of this bed that are accessible for strip-mining, ranges in thickness from 20 to 25 feet and consists mostly of sandstone and siltstone intercalated with subordinate amounts of shale. Generally, the overburden is sufficiently resistant to form small ridges, but it can nevertheless be easily removed by bulldozers or power shovels. Because the basal black shale (Nefsy shale of former usage) of the overlying Mowry shale is less resistant than the Newcastle, gently dipping beds of the Newcastle have locally formed rather extensive dip slopes beneath which bed A lies at depths that are shallow enough to allow uncovering of the bentonite in strip-mining, as in the northwestern sections of T. 56 N., R. 62 W., in the southeastern sections of T. 57 N., R. 66 W., and in parts of the broad, shallow anticline in the western half of T. 57 N., R. 65 W., all in Crook County.

BED B

Bentonite bed B lies in the upper part of the Mowry shale and is from 30 to 35 feet below the Clay Spur bentonite bed. It is only 10 to 18 inches thick and is, therefore, not shown on plate 60. This bed is nevertheless persistent and is present in nearly all exposures of the rather hard siliceous shale that makes up the upper part of the Mowry. This upper part crops out chiefly in steep cut banks and in the escarpments of cuestas. The persistence of bed B, its relatively uniform thickness, and the presence of marine fossils in the enclosing shale suggest that the bed was deposited in quiet water on a nearly smooth sea bottom.

Bed B rests on a floor of chertlike material, ranging from ½ to 1 inch in thickness, that is much harder than the underlying siliceous shale and that in its roof. In the subsurface, the bentonite of bed B is predominantly bluish gray of various shades, whereas the bentonite that has been exposed to weathering is discolored to light yellowish gray. In most exposures of bed B, only the bentonite within a few inches of the surface is discolored, whereas the bentonite of other beds is commonly discolored to depths of many feet. The prevalence of undiscolored clay close to the surface may be due to some peculiarity in its composition; it may, however, be partly due to the steepness of the cut banks and hillsides on which this bed most commonly crops out and from which the weathered rock is rapidly washed away, thereby preventing the discoloring effects of weathering from extending inward more than a few inches.

Differential thermal analyses (fig. 86 *E*, *F*) and ion-exchange data (table 3) for samples from localities 46 (sec. 8, T. 57 N., R. 61 W.) and 30 (sec. 34, T. 58 N., R. 63 W.) show that Ca^{+2} and H^{+1}, respectively, are the dominant exchangeable cations in the bentonite of this bed. The Ca^{+2} content of the clay from locality 46 is believed to have caused the inflection shown on the diagram (fig. 86*F*), corresponding to temperatures between 190°C and 225°C. The presence of H^{+1} in considerable quantity in the clay from locality 30 is indicated by a pH of 3.4 and by two inflections (fig. 86*E*) relating to the loss of interplanar water; these inflections represent two endothermic reactions occurring at the same temperatures as those reported by Barshad (1950, p. 228) for hydrogen-saturated montmorillonite. Since the material from locality 30 is a channel sample obtained close to the surface, its acidity is presumably due to replacement of Ca^{+2} by H^{+1} during weathering. The conclusion that exchangeable cations other than Na^{+1} prevail in the bentonite of bed B is further supported by (a) the nature of the weathered material along most outcrops, which consists partly of powdery material and partly of material with the "alligator hide" appearance that is characteristic of bentonite of low dilatancy; (b) the low dilatancy of the samples (table 4) from localities 30 and 46; (c) the high green strength and low dry strength shown by these samples in tests for foundry-sand bonding clay; and (d) the relatively weak tendency of the samples to disperse in water, as compared with that of most bentonite containing Na^{+1} as the principal exchangeable cation. Because of the low dilatancy of the clay and because of the inadequate thickness and the narrowness of the bentonite belts that lie under overburden light enough for removal by strip mining, bed B will probably never be a source of commercial bentonite.

The content of nonclay minerals in samples taken from bed B at localities 30 and 46 is estimated at 15 percent by volume. Diffraction diagrams (fig. 80*C*, *D*) show that quartz, with reflections corresponding to spacings of 3.34 A and 4.26 A, is the only nonclay mineral present in sufficient amount to be identified by X-ray techniques. Optical examination revealed that much of the quartz is present as angular grains, ranging in size from that of silt to that of fine sand, and that small amounts of biotite, feldspar, and gypsum, as well as traces of several other minerals, are also present.

CLAY SPUR BENTONITE BED

The Clay Spur bentonite bed in the uppermost strata of the Mowry shale is named after outcrops at the Clay Spur siding of the Chicago, Burlington and Quincy Railroad, in sec. 30, T. 47 N., R. 63 W., Weston County, Wyo. (Rubey, 1930, p. 4). This bed is known also as the "Upper Mowry bed" (Wing, 1940; Moore, 1949) or, in mining parlance, as the "commercial bed." It has been the source of more than 95 percent of all the bentonite shipped to date from the northern and western Black Hills districts and contains the Nation's largest known reserve of high-grade drilling-mud bentonite. The deposition of the volcanic ash of which the bed originally consisted was nearly, if not precisely, contemporaneous with the accumulation of the ash that gave origin to the bentonite deposits in the uppermost beds of the Mowry in Carbon (Engelmann, 1858, p. 511) and Albany (Knight, 1898) Counties, Wyo. The same episode of ash deposition was probably involved in the origin of a bed cropping out in the Hardin district (Knechtel and Patterson, 1956, p. 10) and at various other localities in the vicinity of the Bighorn Mountains. Although no fossils have been found in the Clay Spur bentonite bed, the Mowry shale, of which the Clay Spur is a part and which is largely made up of altered pyroclastic material (Rubey, 1929), shows abundant paleontologic evidence of having been deposited in a submarine environment.

The Clay Spur bentonite bed (pl. 63*B*) is present at or near the surface where the contact between the Mowry and Belle Fourche shales is exposed as mapped on plate 60. In many localities the Clay Spur bentonite bed is well exposed in open pits and natural outcrops, but in much of the district it is buried deeply or is concealed by Quaternary and Recent deposits of alluvium and soil. It has been removed by erosion from much of the central and southern parts of the district.

The thickness of the Clay Spur bentonite bed within this district is locally as much as 7 feet but it commonly ranges from 2 to 3 feet. Although the thickness of the Clay Spur in a few places is less than 2 inches, this bed is present in all the outcrops of the uppermost strata of the Mowry that have been studied. The thick and thin parts of the Clay Spur are irregular in their areal distribution, and locally the thickness along the outcrop ranges from less than 1 to 3 feet within 50 yards; generally, however, such a range in thickness occurs over a much greater distance.

The consistency of undried raw bentonite of the Clay Spur bentonite bed is generally waxy, but the bentonite that lies within ¼ to ½ inch of the floor is granular, like cornmeal, and it contains abundant large crystals and grains of selenite, small flakes of biotite, and grains of quartz and feldspar. However, the bed as a whole contains smaller amounts of nonclay minerals than do most bentonite deposits in the western interior of the United States. Table 8 shows a comparison of the approximate percentage of clay and nonclay constituents in samples taken from the Clay Spur bentonite bed and from beds which lie above and below the Clay Spur.

Variations in the thickness of the Clay Spur bentonite bed are associated with certain rather consistent differences both in the bed itself and in the strata immediately below and above (fig. 87). Where the Clay Spur bentonite bed is very thin, the floor beneath it commonly consists of soft dark shale that grades upward into the base of the bentonite bed through a zone of dark bentonitic shale, ranging from ½ to 1 inch in thickness. Where the bed is more than a few inches thick, however, it commonly makes a sharp

TABLE 8.—*Approximate percentage of clay and nonclay constituents in samples taken from the Clay Spur bentonite bed and from the overlying and underlying rocks*

Sample	Description	Whole sample				<2-micron fraction			
		Clay minerals		Nonclay minerals		Clay minerals		Nonclay minerals	
		Montmorillonite	Hydrous mica, including mixed layered minerals	Quartz	Miscellaneous, chiefly biotite and feldspar	Montmorillonite	Hydrous mica	Quartz	Miscellaneous
a	Soft dark shale from Belle Fourche shale 12 ft above Clay Spur bentonite bed	40–45	0–5	40–45	10–15	55–65	0–5	35–45	0–5
b	Laminated Mowry shale from zone 1½ ft above Clay Spur bentonite bed	35–40	0–5	45–50	5–10	50–60	0–5	40–50	0–5
c	Bentonite of Clay Spur bentonite bed	85–90	0	5–10	0–5	<100	0	Trace	Trace
d	Chertlike material 0–2 in. below Clay Spur bentonite bed	10–20	0–5	65–75	5–10	40–45	0–5	45–50	Trace
e	Mowry shale 6 in. below Clay Spur bentonite bed	25–30	0–5	60–65	5–10	50–55	0–5	45–50	Trace
f	Mowry shale 20 ft below Clay Spur bentonite bed	25–35	0–5	55–60	5–10	50–55	0–5	45–50	Trace

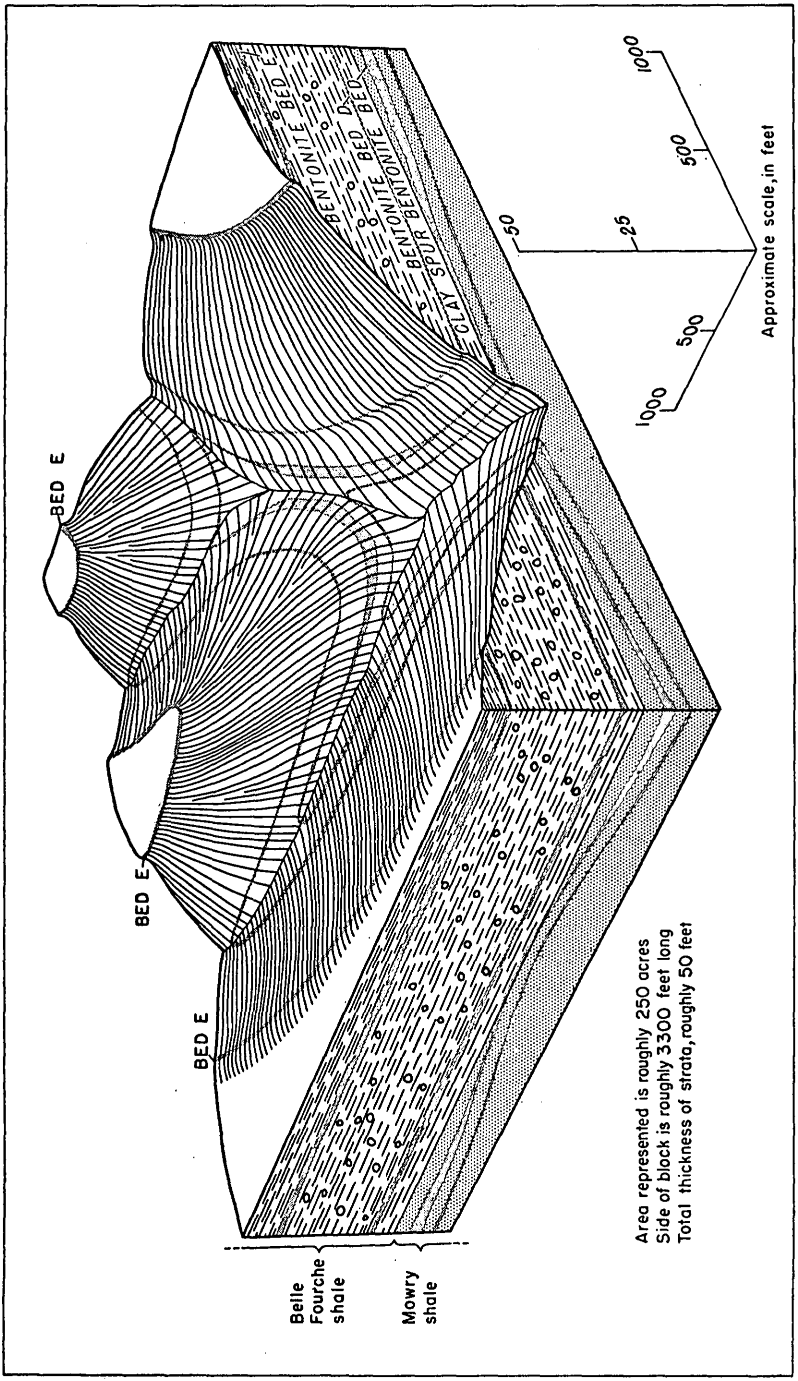


FIGURE 87.—Diagram showing local variation in thickness of the Clay Spur bentonite bed and the associated variation in the overlying zone of the Mowry shale.

contact with the floor of dark-gray cherty material, generally ranging from 2 to 8 inches in thickness, that grades downward into gray siliceous shale (p. 65).

The underlying siliceous shale, although generally softer than the cherty material directly beneath the bentonite bed, locally contains thin seams of harder material along vertical joints that cut across the bedding in various directions; the silicification of the floor appears, therefore, to have been brought about by downward-moving aqueous solutions. Ordinarily, where the bed is as thin as 2 inches, it consists of bright-gray bentonite that tends to be heavily stained by iron rust; where its thickness is more than a few inches, only a little of the material close to its base is rust-stained and the rest of the bed is divisible, on the basis of color, into two persistent strata. The lower of these, which at most places ranges from 2½ to 4 feet in thickness, is made up almost wholly of light-colored waxy clay which, at any one locality, is subdivisible into several distinct, though nonpersistent, thinner layers of various colors, most commonly shades of yellow, olive green, greenish gray, and light gray. The rust-stained layer at the base ranges from ½ to ¼ inch in thickness and has a texture similar to that of cornmeal. As the thickness of the bed as a whole varies, that of the upper dark stratum remains fairly constant in relation to that of the lower brightly colored stratum. In thin parts of the bed, however, the upper dark stratum is supplanted by a thin zone of bentonitic shale.

As shown by X-ray and thermal analysis (table 3; figs. 86 and 88), virtually the only clay mineral present in the bentonite of the Clay Spur bed is montmorillonite. Differences in thermal diagrams are related to the various component exchangeable cations and the amount of nonclay constituents in the different samples. In all the samples analyzed, the dominant exchangeable cation is Na^{+1}, but most of the samples contain also appreciable amounts of Ca^{+2} and H^{+1}, or both. The amount of Ca^{+2} in relation to that of other exchangeable cations ranges from a trace in virtually pure sodic bentonite (fig. 88*E*) to as much as 25 percent in calcic bentonite (fig. 86*G*). The presence of H^{+1} is indicated in two of the samples by two small low-temperature inflections shown in the differential thermal diagrams (fig. 86*H*, *I*) and is confirmed by a pH of only 4.7 in the sample represented in diagram *H*.

The brightly colored bentonite of the Clay Spur bed contains less nonclay material than do most bentonite deposits. Grit rarely makes up as much as 5 percent of the clay and generally the total nonclay content is below 18 percent; it is nevertheless much higher locally. Most of the nonclay matter consists of fine-grained angular quartz, with X-ray reflections corresponding to spacings of 3.34 A and 4.26

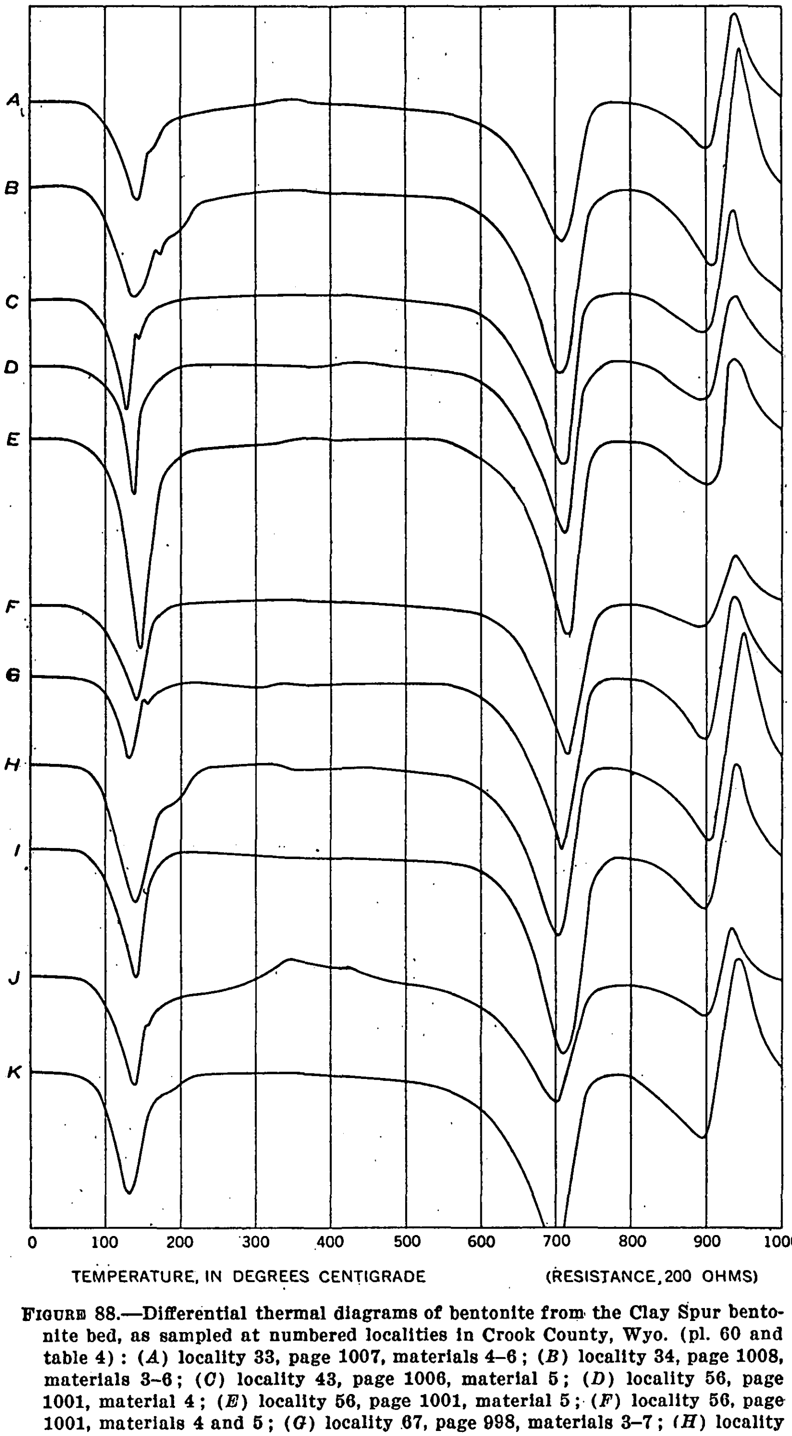


FIGURE 88.—Differential thermal diagrams of bentonite from the Clay Spur bentonite bed, as sampled at numbered localities in Crook County, Wyo. (pl. 60 and table 4) : (*A*) locality 33, page 1007, materials 4–6 ; (*B*) locality 34, page 1008, materials 3–6 ; (*C*) locality 43, page 1006, material 5 ; (*D*) locality 56, page 1001, material 4 ; (*E*) locality 56, page 1001, material 5 ; (*F*) locality 56, page 1001, materials 4 and 5 ; (*G*) locality 67, page 998, materials 3–7 ; (*H*) locality 70, page 999, materials 8 and 9 ; (*I*) locality 76, page 995, material 5 ; (*J*) locality 76, page 995, materials 2–4 ; (*K*) locality 77, page 995, materials 2–3.

A, and feldspars, with reflections corresponding to spacings of about 3.2 A and 3.8 A (fig. 80*E–J*). The sample represented in diagram J is exceptionally high in quartz, as indicated by the very strong reflections corresponding to spacings of 3.34 A and 4.26 A and by lesser reflections corresponding to spacings of 2.46 A, 2.27 A, 2.13 A, 1.97 A, 1.81 A, 1.54 A and 1.37 A. X-ray patterns (not herein reproduced) obtained by the powder-camera technique also show the presence of cristobalite, gypsum, and mica (probably biotite) in some samples. One sample from locality 56 (sample 4) showed approximately 10 percent cristobalite, but the other samples examined by using this technique contain very much less. A small amount of gypsum is suggested in a sample from locality 34 (fig. 80 F) by reflections corresponding to spacings of 7.56, 3.06, and 4.27 A and by the minor endothermic inflection corresponding to a reaction at approximately 170° C (fig. 88B). Gypsum, in the form of selenite, and biotite are common in the lower part of the bed. At a few localities about 5 percent of the clay material is selenite. Optical examination showed that very small amounts of zircon, garnet, pyrite, pyrrhotite, calcite and various other minerals are also scattered through the bed.

The moisture content of the brightly colored clay commonly ranges from 15 to 40 percent and averages about 30 percent, but it reaches several hundred percent in particularly damp places. With a moisture content of less than about 20 percent, the bentonite is almost as hard as the fingernail and fractures with a hackly parting; with about 20 to 40 percent, it tends to fracture subconchoidally. Further wetting causes the clay to become plastic and ultimately to acquire the consistency of a thixotropic gel.

Because the bentonite of the lower brightly colored part of this bed is generally highly dilatant, it weathers almost invariably to a popcornlike crust. When dry, this material is almost white, and outcrops of the Clay Spur bed, as seen from a distance in dry weather, commonly appear as conspicuous light-colored bands; when wet, this material is darker, and the outcrops appear to be greenish or yellowish.

The upper stratum, which is as much as 1 foot thick, is largely made up of dark-gray bentonite, although laminae of light-colored clay are contained in the lower part of the stratum and also, in a few places, in the upper part.

The dark bentonite of the upper part of the Clay Spur bentonite bed is shown by differential thermal analysis (figs. 86*I* and 88*J*) to consits of montmorillonite with various amounts of other matter, very little of which is organic. The dark material is generally less dilatant than that of the underlying bright layer, and it tends to weather to surfaces of the "alligator hide" variety.

Varvelike laminae of bright and dark bentonite, tissue thin to more than 1/4 inch thick, are present in this part of the Clay Spur bed (pl. 64*A*). Even the thinnest of such laminae commonly persist for several yards within the limits of fresh exposures in strip mines; others pinch out within a few inches and still others appear to be truncated by overlying laminae. Generally the thinner laminae are distinctly separate units with a tendency for the bright and dark layers to be about equal in thickness and in sharp contact with one another. In some of the thicker laminae, however, the bright and dark colors are mixed and the boundaries between laminae are blurred.

Examination of thin sections shows that the laminae of bright bentonite in the upper part of the Clay Spur bentonite bed are composed of relatively pure montmorillonite, which is similar in composition to that of the bentonite in the lower part. Nonclay minerals, mostly fine grains of quartz that are predominantly angular but partly subrounded, make up about 15 percent of the bentonite of the light laminae and about 25 to 35 percent of the dark laminae. Most such grains are nearly equidimensional and, consequently, show no marked uniformity in the orientation of their outlines, but platy particles of mica and the few elongate particles of other minerals lie approximately parallel to the laminae. The coloration of the dark laminae is chiefly due to small amounts of dispersed organic matter, most of which is present in the form of blotchy coatings on the nonclay mineral grains; the rest of this organic matter forms small scattered irregular masses that are mostly elongated parallel to the lamination.

The laminae of some uniform and continuous zones which are as much as half an inch thick, appear to be slightly distorted; other zones are almost free of lamination. Small irregular masses of the bright bentonite are enclosed here and there in the dark material, particularly in the thicker, poorly laminated dark zones, but fragments of the dark clay are rarely enclosed in the bright clay.

The thinness and persistence of laminae, which closely resemble varves of glacial origin, indicate that muddy sediments in the upper part of the Clay Spur bentonite bed accumulated in quiet water. However, the contacts between the thinner laminae are much sharper than those between glacial varves; moreover, the coarser material occurs only in the dark clay, whereas coarser material occurs also in the bright clay of some glacial varves. The dark laminae in the upper part of the bentonite bed may have resulted from periodic influx of shale and organic matter derived from nearby areas when the rate of accumulation of the parent volcanic ash had become much slower than that during the deposition of the lower, brightly colored part of the bed.

The ordinary upward gradation from bright to dark material, within the Clay Spur bed and continuing into the overlying strata, indicates that the rate of deposition of the original volcanic ash, which must have been rapid for the bright material, decreased gradually and was eventually surpassed by that of nonpyroclastic material. Submarine flowage on gentle slopes is suggested by the mixing of colors in some laminae, by the slight distortion of some groups of laminae that are enclosed by zones of undistorted laminae, and by the inclusion of tiny blocks of bright clay within the dark material of some laminae. In places, the zones in which such displacement is indicated are very thin. The contacts between the thicker dark laminae and the subjacent light clay are generally sharp, whereas the contacts of these laminae with the superjacent dark clay are generally indistinct. The presence of small blocks of the bright clay within the dark material suggests that this dark material was deposited as exceedingly plastic clay or as partially compacted "clouds" of flocculated clay particles, whereas the original volcanic ash that is represented by the bright clay tended to be more coherent, having probably undergone only slight alteration to clay at the time.

Where the bentonite bed is thinnest, it grades into the superjacent shale through a zone of bentonitic shale 1 to 2 inches thick. This zone marks the contact of the Mowry shale with the soft dark shale of the overlying Belle Fourche. Where the bed is thicker, however, the bentonite of the dark upper stratum, which contains light-colored laminae in its lower part, grades upward into the roof rock through a zone of increasingly numerous dark shaly laminae. In most localities this roof material, which is as much as 6 feet thick, consists of siliceous shale interlaminated with dark bentonite and dark shale. Because it is similar in its lithologic character to the beds underlying the bentonite bed, it is regarded as the uppermost part of the Mowry shale, which separates the Clay Spur bentonite bed from the overlying Belle Fourche shale. The lowermost part of the Belle Fourche is a zone, containing numerous manganiferous siderite concretions, that is more resistant to erosion than is the part of the Belle Fourche immediately above; it, consequently, serves as a protective cover for the Clay Spur bentonite bed. In rather broad belts, from which the shale above this zone has eroded away, the overburden of the bentonite bed is light enough to permit strip mining. Such belts include numerous elongate spurs and small outliers of the lowermost strata of the Belle Fourche shale (fig. 87).

The total thickness of the Clay Spur bentonite bed and the zone of siliceous shale above it ranges from 3 inches to 12 feet, whereas a uniformly dense cloud of air-borne volcanic dust settling upon the surface of an epicontinental sea and sinking to its bottom might be expected to form a pyroclastic sedimentary deposit of uniform thickness. Possibly the submarine floor on which the original ash deposit accumulated was initially an uneven surface comparable to that of the "giant ripples" of Recent origin on the sandy floor of the Bahama Banks (Rich, 1948) and elsewhere (Hantschell, 1948). If so, the variation in the thickness of the bentonite bed might have come about through the action of gentle currents, removing most of the ash falling upon the higher areas and sweeping it into the depressions. Such a process may have continued during the deposition of the overlying siliceous shale, inasmuch as this material is absent above the thinnest parts of the bentonite bed.

The structure contours shown on plate 60 indicate the approximate amount and direction of dip of the Clay Spur bentonite bed. Outcrops of this bed and the strata immediately above and below it dip steeply in T. 56 N., R. 67 W., at the westside of the district, but lie flat, or are tilted only a few degrees, everywhere else in the district. Many exposures of the strata associated with the Clay Spur bed exhibit details of geologic structure too small to be represented by the contours. Such minor details include (a) normal faults (pl. 64*B*) on which the displacement is no more than a few feet, (b) folds of comparable size, and (c) minor, possibly nondeformational, undulations of the floor of the bentonite bed which, as has been suggested, may represent giant ripple marks.

BED D

Bentonite bed D, one of the basal strata of the Belle Fourche shale, is underlain by about 3 to 4 feet of dark-gray shale that rests in some places on laminated siliceous shale, which is typical of the Mowry shale, and elsewhere on bentonite of the Clay Spur bentonite bed. Bed D is in sharp contact with the dark shale of its floor but grades into the material of its roof, which is similar to that of the floor, through a thin zone of interlaminated bentonite and dark shale.

The thickness of bed D is not more than 4 inches in most exposures but is as much as 14 inches at some places in the western part of the northern Black Hills district; it is nowhere known to be of sufficient thickness to warrant mining and is, therefore, not shown on plate 60. This bed is generally thickest where the Clay Spur bed is of more than average thickness, and it is thinnest where the Clay Spur bed is relatively thin; the variation in thickness may be due to processes that became effective before the close of Mowry time and persisted into early Belle Fourche time. Possibilities regarding such processes have already been suggested in the discussion of the depositional history of the Clay Spur bentonite bed.

The bentonite of bed D is generally light gray or cream, but it commonly is darker gray near the top and reddish brown or salmon near the base. At many places along the outcrop of bed D, popcornlike crusts are well developed, indicating highly dilatant clay; table 4 shows that the bentonite of bed D compares favorably, in dilatancy as well as other physical properties, with commercial grades of well-drilling clay. A thermal diagram (fig. 89*A*) shows that the bentonite is of a typical sodic variety containing an appreciable amount of selenite, as indicated by the small but sharp inflection at about 170°C. The nonclay matter makes up only 10 to 12 percent, by volume, of the samples from three localities. Most of such matter consists of angular particles of quartz and feldspar, and crystals of selenite. X-ray patterns show also traces of cristobalite and mica (probably biotite). The bentonite from bed D generally shows high dry strength but low green strength. This bed is nevertheless too thin to have commerical value as a reserve of foundry-sand bonding clay, and the bentonite it contains is cast aside as waste in the mining of the Clay Spur bentonite bed.

BED E

Bentonite bed E, in the lower part of the Belle Fourche shale, is sometimes called the "mud bed" because of its dark color and large content of nonclay material. This bed ranges in thickness from 1 to 3½ feet at many exposures, but in a few places it is only a thin zone of dark bentonitic shale. The bentonite is most commonly dark, medium, and brownish gray, and the bentonite in the lower part of the bed is generally stained brown by iron oxide, imparting a rusty color to the outcrop at most places; a few thin layers of the clay near the middle of the bed are light gray. Nonclay minerals, chiefly quartz and feldspar, make up more than 20 percent, by volume, of the bed and are particularly abundant in the darker parts of the bed. Biotite flakes are abundant along some bedding planes, and nearly all the clay contains some selenite. Two samples of bentonite from bed E were tested as foundry-sand bonding clay and showed adequate dry strength but only moderate-to-low green strength. These samples tested unsatisfactorily as drilling clay, except for one sample taken from a light-colored thin stratum at locality 25, sec. 27, T. 58 N., R. 65 W., which gave excellent results.

The bentonite of bed E grades into the relatively soft shale of the roof and floor through transitional zones of interlaminated shale and bentonite. The weathered crust associated with the thicker parts of the bed generally has a poorly developed popcornlike appearance, whereas surfaces associated with the thinner parts resemble alligator hide. In some places the presence of bed E is indicated by soft puffy soil; in other places the bed is completely concealed by soil or alluvium.

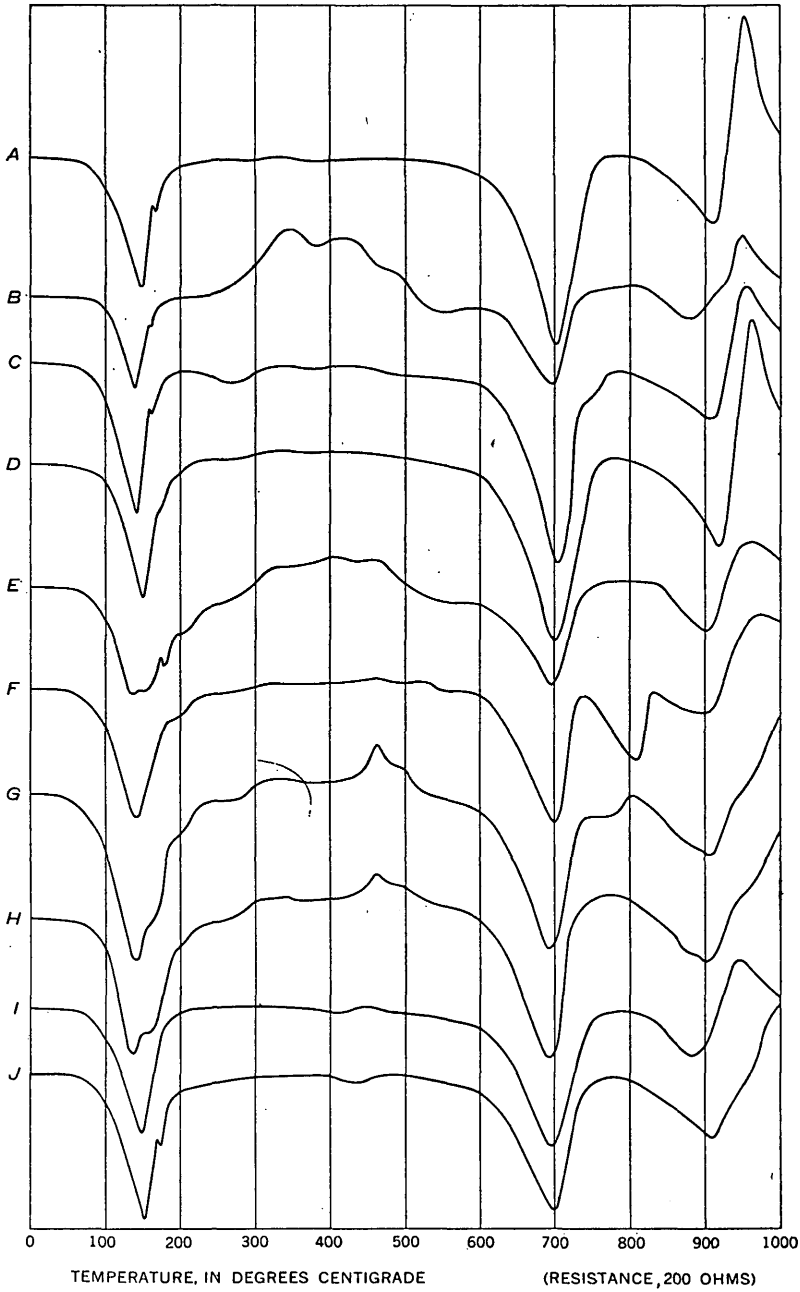


FIGURE 89.—Differential thermal diagrams of bentonite from beds D, E, and F, as sampled at numbered localities (pl. 60 and table 4) : (*A*) Bed D, locality 70, page 999, materials 3 and 4 ; (*B*) bed E, locality 25, page 1012, materials 2 and 3 ; (*C*) bed E, locality 25, page 1012, materials 4 and 5 ; (*D*) bed E, locality 41, page 1006, material 4 ; (*E*) bed F, locality 4, page 1016, materials 2 and 3 ; (*F*) bed F, locality 4, page 1016, materials 4–10 ; (*G*) bed F, locality 42, page 1006, material 4 ; (*H*) bed F, locality 42, page 1006, material 6 ; bed F, locality 54, page 1002, materials 3–7 ; (*J*) bed F, locality 74, page 996, materials 2 and 3.

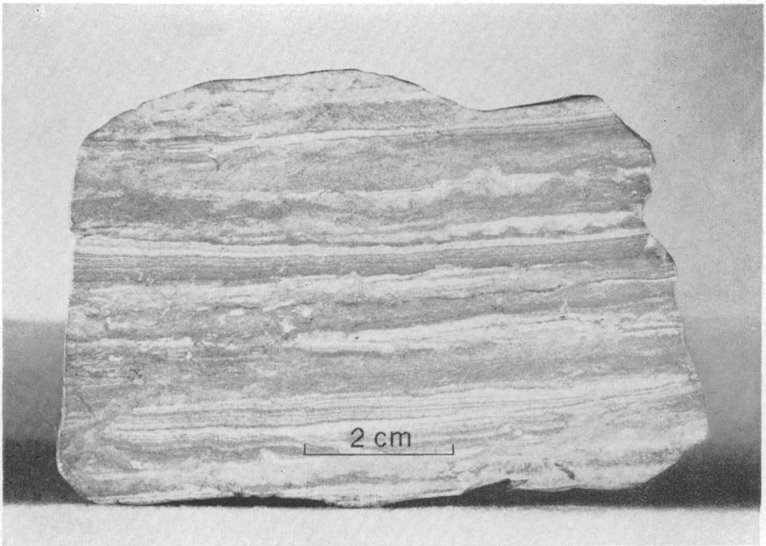
Differential thermal diagrams of three samples (fig. 89 *B*, *C*, *D*) indicate that the bentonite of bed E is madeup of chiefly of sodic monmorillonite, though the diagram for one of the samples, from locality 41 (pl. 60), shows a gentle inflection corresponding to temperatures between 190°C and 215°C, that may be due to exchangeable Ca^{+2}; the presence of a small amount of selenite in all three samples is indicated by slight inflections in the diagrams corresponding to a temperature of approximately 170°C.

A small amount of bentonite at or near the same stratigraphic position as bed E has been mined farther southwest in the western Black Hills district; but because of the impurity and inadequate thickness of the bentonite, this bed appears unpromising as a source of commercial supply and is, therefore, not shown on plate 60. Because of its stratigraphic position in relation to the valuable Clay Spur bentonite bed, however, bed E is useful as a guide in the location of prospective mining sites. In Crook and Carter Counties, where the interval between the Clay Spur bed and bed E is from 27 to 30 feet, the outcrops of bed E (fig. 63*A*) facilitated the drawing of the broken lines and shaded areas employed on the geologic map to indicate localities in which the thickness of overburden on the Clay Spur bentonite bed is 30 feet or less and is therefore regarded as readily removable by strip-mining equipment. In Butte County, where bed E is likewise useful as a guide in the location of favorable mining sites, the stratigraphic interval separating bed E from the Clay Spur bentonite bed thins eastweard from about 27 feet in the vicinity of the Wyoming-South Dakota boundary line to 18 feet near the town of Belle Fourche.

BED F

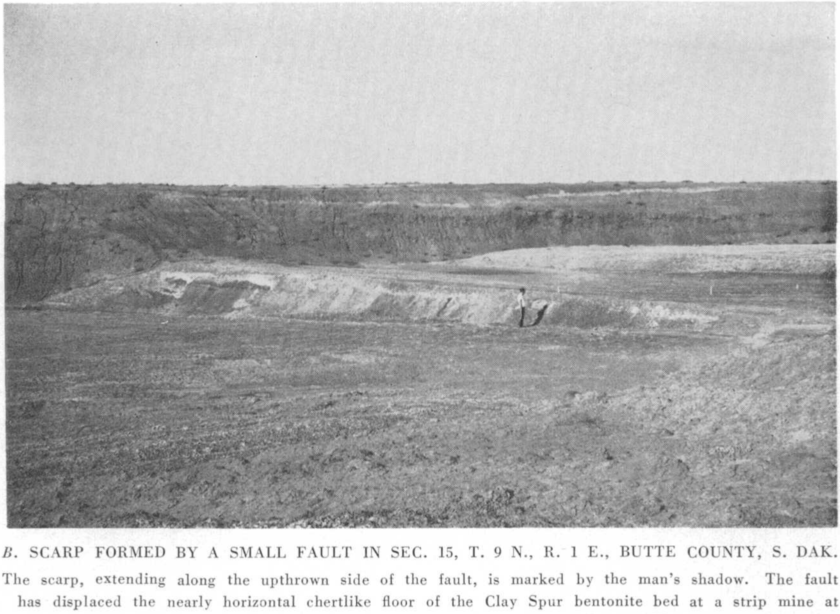
Bed F, in the Belle Fourche shale, was once informally termed the "Gray-Red" bentonite bed (Rubey and Bramlette, 1949), owing to its characteristic coloration in a large part of this district. It is the bentonite bed described by Wing (1940, p. 25) as occurring about 9 feet below his "Middle Creek limestone" in the western part of Butte County, S. Dak. Bed F and the Soap Creek bentonite bed, which occupies a comparable position in the Belle Fourche shale north and east of the Bighorn Mountains (Knechtel and Patterson, 1956a), may represent ash deposits that accumulated during the same episode of volcanic activity.

Bed F, although locally covered by soil and alluvium, is extensively exposed in outcrops of the uppermost strata of the Belle Fourche shale northwest of the Little Missouri River and in belts extending southeastward near Highway 212 as far as an exposure in which bed F pinches out in sec. 20, T. 9 N., R. 2 E., in Butte County, about 4 miles from Belle Fourche. It is not present among the strata of the



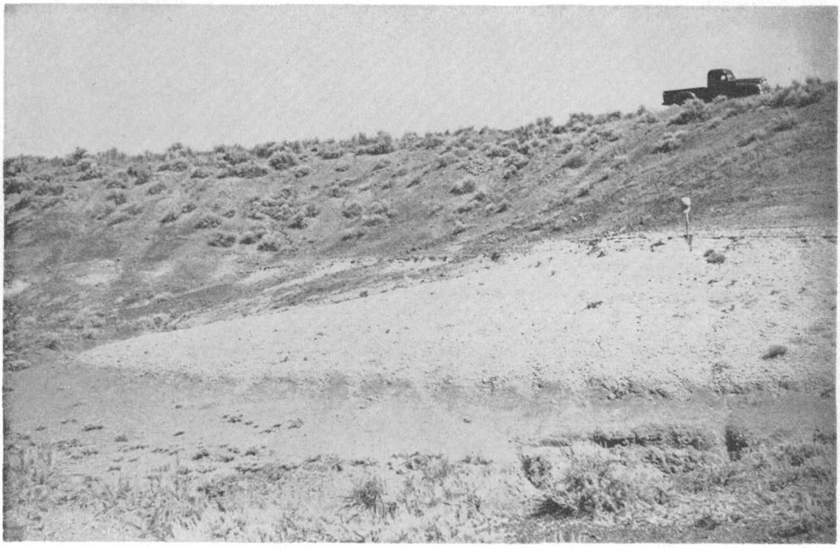
A. VARVELIKE LAMINAE IN BENTONITE FROM THE UPPER PART OF THE CLAY SPUR BENTONITE BED

Shown in natural size.



B. SCARP FORMED BY A SMALL FAULT IN SEC. 15, T. 9 N., R. 1 E., BUTTE COUNTY, S. DAK.

The scarp, extending along the upthrown side of the fault, is marked by the man's shadow. The fault has displaced the nearly horizontal chertlike floor of the Clay Spur bentonite bed at a strip mine at this location. The dark material exposed in the background is the overlying Belle Fourche shale. The white layer near the top of the exposure is bentonite bed E.



THE CLAY SPUR BENTONITE BED IN SE¼ SEC. 7, T. 56 N., R. 61 W., CROOK COUNTY, WYO.

The bed is resting on a chertlike floor and is overlain by a laminated zone of siliceous shale. The thickness of the bentonite is 5½ feet.

Belle Fourche shale exposed in the extreme southeastern townships of the area. In an exposure less than 2 miles northwest of the locality at which it pinches out, bed F is a little more than 2 feet thick. Throughout the western three-fourths of the district, bed F appears to be a continuous stratum, which averages about 4 to 5 feet in thickness and is locally as thick as 7 feet. Bed F lies only about 6 feet below the Greenhorn formation at some localities northwest of Belle Fourche, whereas it lies about 285 feet below that unit in the southwestern part of the district, as explained on page 916.

Most of bed F, at the 16 localities at which it was drilled with a hand-operated earth auger, is made up of waxy bentonite containing small flakes of biotite, grains of feldspar, quartz, sulfates, carbonates, and traces of various other nonclay substances. The clay is largely light gray or buff, but some of the clay lying under cover in the western three-fourths of the district has been stained bright red by small amounts of iron oxide, probably hematite, which gives a brownish cast to the outcrop. Generally, only the lower half of the clay is red; but where the red is especially intense in the lower half, the unweathered clay of the lower part of the upper half of the bed contains a profusion of minute red mineral particles which, in the aggregate, produce shades of purple or, less commonly, red. However, this purple-red coloration of the upper half of the bed is readily changed in weathering and, unlike that in the lower half, has little or no effect on the color of the bentonite in the outcrop. In the eastern part of Crook County, Wyo., the red coloration is less pronounced and in Butte County, S. Dak., it is supplanted by yellow and yellow-brown staining.

Differential thermal and X-ray diagrams (figs. 89*E*–*J* and 80*K*, *L*) and ion exchange measurements (table 3) show that bed F is composed chiefly of monmorillonite in which Ca^{+2}, Na^{+1}, and Mg^{+2} are the predominant exchangeable ions. One thermal diagram (fig. 89*I*) of a sample with the properties of good drilling clay is similar, for temperatures below 900° C, to the diagrams of samples of sodic bentonite of commercial grades from the Clay Spur bentonite bed; however, the inflection on this diagram corresponding to an exothermic reaction between 900° and 1,000° C differs considerably from that on most thermal diagrams pertaining to sodic bentonite. Diagrams of samples which consist of more weakly colloidal clay from bed F show marked variation in the characteristics of the low-temperature reactions caused by release of water adsorbed between the planar layers of montmorillonite. These variations reflect differences in concentration of exchangeable cations. Analyses (table 3) show that a sample of bright bentonite from locality 4 contains Ca^{+2} as the dominant exchangeable cation; rather high proportions of both Na^{+1} and Mg^{+2} are also present. In another sample, from locality 42 (sec. 23, T. 57 N., R. 62 W.), Mg^{+2} is predominant, with only a little less Ca^{+2} but considerably less Na^{+1}. In a third sample, from locality 54 (sec. 9, T. 56 N., R. 67 W.), Na^{+1} leads, with Mg^{+2} and Ca^{+2} following in order of abundance. The ion-exchange measurements of these three samples showed very little K^{+1} and no H^{+1}. In diagram *F* (fig. 89), a strong endothermic inflection corresponding to a reaction between 775° and 850° C indicates the presence of calcium carbonate as an impurity. Notwithstanding the considerable iron content indicated by the strong reddish color of two samples, their diagrams (*G* and *H*) do not indicate the endothermic reaction, between 550° and 600° C, that is characteristic of nontronite, the iron-rich member of the mortmorillonite group of clay minerals. The thermal diagram of a dark sample (fig. 89*E*) shows that this material is also composed chiefly of montmorillonite; the dark color is due to impurities. Dilution of the montmorillonite by considerable nonclay matter is shown by the relatively weak endothermic reactions associated with release of interplanar water and dehydration of the interplanar sheets. Gypsum, organic matter, and a little iron sulfide are also indicated.

Moderately strong X-ray reflections corresponding to spacings of 3.34 A and weak reflections corresponding to spacings of 4.26 A indicate that quartz is the most abundant nonclay mineral in samples of bentonite from bed F at locality 42 (fig. 80*K*). Weak reflections corresponding to spacings of about 3.2 and 3.46 A suggest that some feldspar is also present. On diffractometer diagrams (not shown in this report) of material from locality 56 (sec. 4, T. 56 N., R. 66 W.), the reflections indicating quartz are weak and apparently no other nonclay minerals are present in sufficient amount to give pronounced reflections.

Weathered surfaces of bed F ordinarily exhibit a moderately well-developed popcornlike crust, ranging from 1 to 3 inches in thickness, beneath which there is commonly a zone of loosely compacted granular material. The principal exchangeable cation in the bentonite of bed F, as sampled at several localities, is Na^{+1}. Consequently, several samples tested as drilling material gave rather favorable results. As foundry-sand bonding clay, the samples showed high dry strength and low green strength.

Bed F is overlain and underlain by shale. The bright clay grades upward into the soft dark-gray shale of the roof through a zone, ranging generally from about 8 to 10 inches in thickness, of interlaminated dark shale and bentonite. In most places the bright bentonite rests with a sharp contact on a floor of soft dark-gray shale; but locally the bentonite and shale are separated by about 1 to 4 inches of firmer shale containing siliceous matter believed to have been leached from the overlying bed of volcanic ash in the process of its conversion to bentonite.

The character of a sparse fauna in the enclosing strata indicates accumulation of the bentonite in a marine environment. The nearly uniform thickness of the bentonite bed within areas of many square miles and the uniformly sharp and even contact with the floor of the bed suggest that accumulation began on a smooth surface and that it took place below the depth of vigorous wave action. The absence of dark nonpyroclastic material within the bed, except in the zone of interlaminated shale and bentonite at the top, suggests that most of the ash accumulated rapidly. The thinness of the zone containing pyroclastic material suggests that the time during which deposition finally slackened and ceased was shorter than it was for most bentonite beds of comparable thickness.

Bed F is crisscrossed by innumerable joints that probably were formed during deformation following burial and compaction of the bed under a heavy load of sediment. Many of the joints, particularly those in the western part of the district, contain veins as much as 2 inches thick of light yellowish-gray fibrous calcite with the fibers mostly elongated at right angles to the walls of the veins. As the weathered bentonite of bed F is eroded along many outcrops, fragments of this calcite accumulate at the surface in great profusion. Presumably the lime carbonate of the veins was deposited by aqueous solutions percolating through the joints in the bentonite, as well as through the enclosing rocks. The carbonate content of the original ash must have been too small to account for more than an insignificant amount of the carbonate in the veins, and the evidence for their deposition after burial and deformation of bed F would appear to rule out sea water as a hypothetical immediate source of the carbon. Large amounts of lime carbonate might have been dissolved by ground water percolating downward through bed F from the highly calcareous Greenhorn formation, the base of which is separated from bed F by the noncalcareous uppermost strata of the Belle Fourche shale. The validity of this explanation is nevertheless doubtful, inasmuch as the calcite veins in bed F are much more numerous in the western part of the district than they are in the eastern part, where the Greenhorn formation is thicker and is separated from bed F by a smaller thickness of noncalcareous Belle Fourche shale. The source of the vein material, as well as the geochemical processes by which it was precipitated from solution, are unknown.

The minable reserve of potentially valuable bentonite in bed F within this district is believed to be small, notwithstanding the large aggregate amount of material it contains and the ease with which the soft shale above it could be removed by strip mining equipment.

Circumstances unfavorable to exploitation are the large amounts of calcite and other impurities in the clay and the narrowness of most of the zones in which the clay lies at sufficiently shallow depth to be uncovered by such equipment.

BED G

Bentonite bed G, which lies from 65 to 85 feet above bed F, occurs in the uppermost part of the Belle Fourche shale in the western part of the northern Black Hills district (pl. 60); farther east, in the vicinity of Highway 212, this bed is assigned to the lowermost part of the Greenhorn formation because of an eastward transition of the enclosing strata to a more calcareous facies (see p. 919). Thus bed G as exposed northwest of the Little Missouri River is 47 feet or more below the top of the Belle Fourche shale, whereas in the eastern part of the district it is from 45 to 60 feet above the base of the Greenhorn. Bed G ranges from 3 to 6 feet in thickness.

Rain soaking causes only slight swelling of the clay of bed G, which resists erosion about as effectively as do the rock strata above and below it. Consequently, outcrops typical of bed G differ from those of most other beds in this district in that they show no appreciable ledge-forming tendency and in that they are most commonly marked by a loosely compacted soil that supports only scant vegetation. The position of bed G is further marked locally by efflorescent white alkali, but generally bed G is so poorly exposed that it has been mapped in only two localities. One is west of the Little Missouri River in T. 9 S., Rs. 58 and 59 E., Carter County, Mont., and the other is about 2 miles west of the bridge that crosses Thompson Creek on the road from Alzada to Ridge, Mont.

Differential thermal analyses of a few samples (fig. 90) indicate that the bentonite of bed G consists chiefly of montmorillonite, together with considerable amounts of calcite and other impurities. The one sample from bed G for which ion-exchange measurements were made (table 3) showed a rather high exchange capacity of 0.93 milliequivalents per gram. Mg^{+2} was the dominant replaceable ion, followed in order of abundance by Na^{+1}, Ca^{+2}, and K^{+1}. The ratio of exchangeable Na^{+1} to exchangeable Ca^{+2} and Mg^{+2} varies greatly. The concentration of these divalent ions seems to exceed that of Na^{+1} throughout most of the bed, as is suggested by the low swelling capacity of the contained bentonite; but Na^{+1} appears, nevertheless, to be the dominant exchangeable ion in some strata within the bed. Accordingly, foundry-sand bonding-clay tests of some samples high in exchangeable Ca^{+2} and Mg^{+2} show high green strength and low dry strength, whereas those high in exchangeable Na^{+1} show high dry strength and low green strength. The bentonite of bed G is greatly inferior as drilling mud material to that

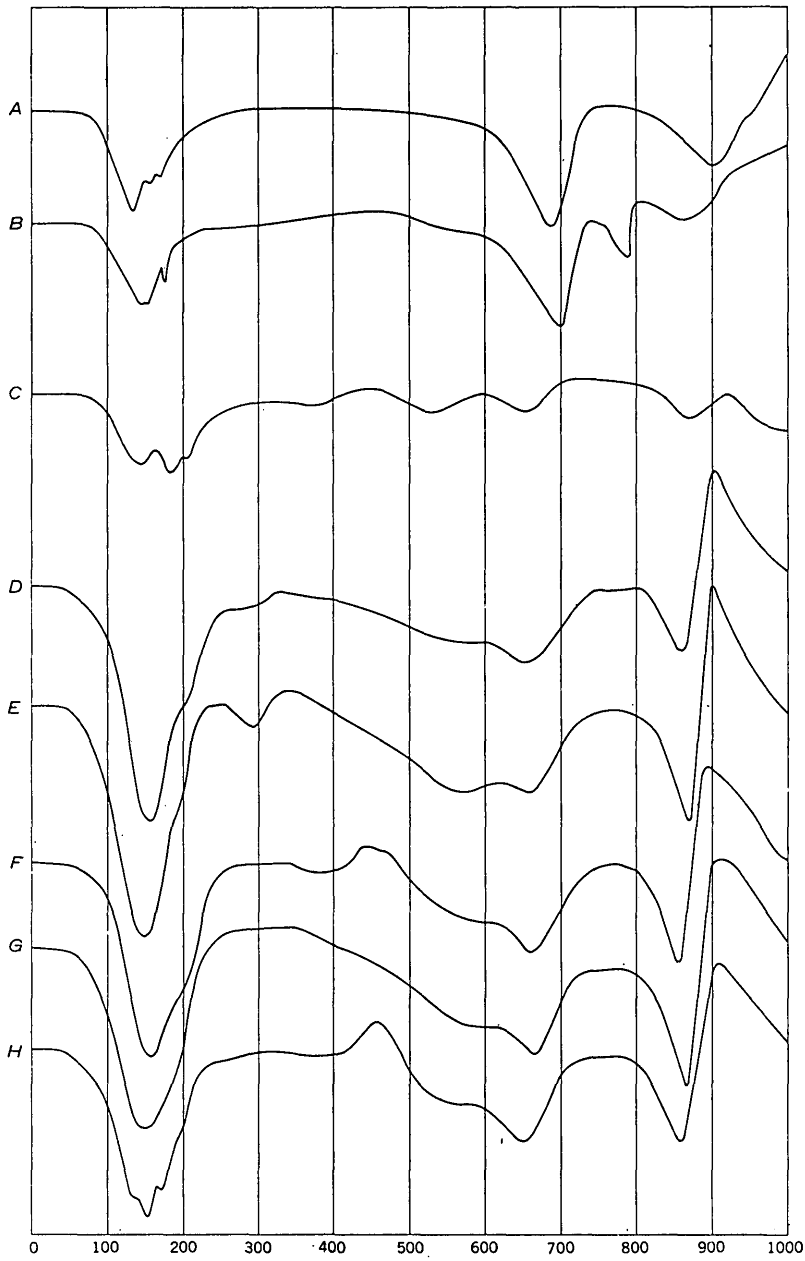


FIGURE 90.—Differential thermal diagrams of bentonite from beds G, H, and I, as sampled at numbered localities (pl. 60 and table 4); (*A*) bed *G*, locality 31 page 1010, materials 2–6; (*B*) bed G, locality 38, page 1005, materials 2–4; (*C*) bed H, sample taken at locality east of area shown on plate 60; (*D*) bed I, locality 78, page 1023, materials 8–11; (*E*) —2 micron fraction of a duplicate specimen represented by curve *D*; (*F*) bed I, locality 78, page 1023, material 17; (*G*) —2 micron fraction of a duplicate specimen represented by curve *F*; (*H*) bed I, locality 79, page 1022, materials 21 and 22.

mined from other bentonite beds in the district. The differential thermal analyses reveal a gypsum content of about 3 to more than 7 percent, as well as the presence of considerable amounts of calcite in parts of the bed. Microscopic examination of the clay reveals that the calcite is present as very irregular grains, most of which have been partly dissolved by ground water. Traces of iron sulfide and organic matter are also present.

The X-ray diffraction diagram (fig. 80*M*) of a sample of bentonite taken from bed G at locality 38 (sec. 9 T. 57 N., R. 62 W.) shows the presence of quartz by reflections corresponding to spacings of 3.34 A and 4.26 A; cristobalite is also suggested by a weak reflection corresponding to spacings of 4.04 A. The X–ray diffraction diagram (not shown in this report) of a part of this same sample which was treated with glycerol indicates a small amount of hydrous mica.

The bentonite of bed G is gray or brown, with the middle and upper parts of the bed commonly stained heavily by iron rust. Most of the bentonite is earthy like many ordinary clays, but some of it has a waxy consistency. Some of it contains as much as 30 percent nonclay material, by volume, of which grit-sized grains locally make up as much as 10 percent. The nonclay material includes unusually large amounts of biotite and calcite, together with minor amounts of fine-grained angular quartz, feldspar, selenite, traces of other minerals, and a little volcanic glass. The biotite along some bedding planes is so abundant that the bentonite appears almost black. The clay probably contains soluble salts in rather large amounts, particularly where the weathered outcrops show efflorescent alkali. Locally the bentonite contains ovoid limestone concretions, the largest of which are about 8 inches in diameter. Near the base of the bed, in some places, are rounded pockets of loosely compacted, powdery calcite which seem to have resulted from partial disintegration of such concretions.

The bentonite of bed G is in sharp contact with the shale of its floor but grades into the superjacent shale through a transition zone ranging from 6 to 12 inches in thickness. West of the Little Missouri River, where the bentonite of bed G is enclosed in dark Belle Fourche shale, it grades upward through a transition zone of progressively wider spacing between the laminae of bentonite. Farther east, however, where the upper part of bed G is similar in color and texture to the overlying calcareous shale of the Greenhorn formation, it grades upward less conspicuously and no laminae seem to be present.

In the western part of the district, where bed G is enclosed in strata of the Belle Fourche shale, macrofossils have not been observed in any of the beds with which it is closely associated. However, in the eastern part of the district, where this bed forms part of the Greenhorn formation, a thin ripple-marked limestone bed, 5 to 6 feet above bed G, contains fossils in great profusion, especially shark teeth and pelecypod fragments. The fauna, as well as the ripple marks, indicate that the limestone bed was formed in a rather shallow marine environment, and this is probably true also of bed G both here and in the western part of the district, where it is enclosed in the Belle Fourche shale. The probability of shallow-water deposition, together with the relatively uniform thickness of bed G and that of the limestone bed and the intervening shale, suggests that bed G was deposited in quiet water.

The limestone bed, like the zone of siliceous shale that overlies the Clay Spur bentonite bed in many localities (p. 978), serves as a protective cover for the bentonite of bed G; consequently, this bentonite lies at shallow depth in areas of considerable extent. However, mining of bed G probably would be uneconomical, owing to the rather large content of nonclay material.

BED H

Bed H, a thin but conspicuous bed of impure bentonite, occurs from 70 to 75 feet below the top of the Gammon ferruginous member of the Pierre shale. Although this bed is only about 1½ feet thick, it is persistent throughout the extreme northeastern part of the district (pl. 60). It is exposed, but not mapped, in a few places at the extreme west margin; presumably it is also exposed at many localities where the Gammon crops out north of this district, in Carter County, Mont. Bed H, which is represented on plate 60 primarily because it is an excellent stratigraphic key bed, consists of light-brownish-gray hard platy argillaceous material that weathers to shades of light gray or ivory. The material contains from 50 to 65 percent nonclay particles of which as much as 25 percent are grains as large as those of silt and fine sand. The nonclay minerals are chiefly quartz and feldspar, which occur as angular grains, with minute quantities of biotite and volcanic glass. Thermal analysis of a sample of bentonite from bed H (fig. 90*C*) indicates a large content of nonclay constituents; the clay swells only a little, indicating that the material of this bed would be unsatisfactory as drilling clay. Tests indicate that the material is also unsatisfactory as foundry-sand bonding clay. Bed H forms "alligator hide" surfaces in weathering, and the ground along its outcrops is commonly littered with small plates of brittle clay. Bed H probably has little or no potential value as a source of commercial bentonite.

BED I

Bentonite bed I, at the base of the Mitten black shale member of the Pierre shale, is a composite bed made up of several strata of bentonite separated by partings of dark fissile shale. Within the northern Black Hills district (pl. 60), bed I is exposed in two areas: (a) In the northwestward-trending belt of the Mitten black shale member in the northwestern part of Butte County, S. Dak., that is drained by North and South Indian Creeks; and (b) in the small area in T. 58 N., R. 67 W., Crook County, Wyo., at the west margin of the district, where the outcrop of the Mitten trends northeastward. The outcrop of the Mitten black shale member in Butte and Crook Counties continues north of the area shown on plate 60, converging in Carter County to form a broad arcuate belt of outcrop that is convex toward the north. The northernmost exposures of bed I in Carter County are several miles northwest of Albion, and bed I is well exposed in T. 7 S., R. 56 E. (fig. 92), on the northwest side of the arcuate belt of the Mitten black shale member.

The westward thinning of bed I, which ranges in thickness from about 3 feet on the west side of the district to more than 12 feet near the east margin of the district, at North Indian Creek, is illustrated in figure 91. Within the area shown on the map (pl. 60), bed I resembles the thick zone of bentonite and shale in alternating layers that is present in the basal part of the Claggett shale exposed at many localities on the Montana plains such as in NE¼ sec. 21, T. 24 N., R. 25 E., Phillips County, in the foothills south of the Little Rocky Mountains (Knechtel, 1944, 1959); and in NW¼NW¼ sec. 7, T. 10 N., R. 37 E., 18 miles north-northwest of Vananda, Rosebud County, Mont., on the southwest flank of the Porcupine dome. The widespread bentonite deposits exposed and reached by drilling in the basal beds of the Mitten and the Claggett probably originated from the alteration of ash deposits that accumulated similtaneously.

At some exposures in Butte County, S. Dak., bed I comprises as many as eight layers of bentonite interstratified with partings of shale. In general, the shale partings do not exceed 9 inches in thickness. A bentonite layer that occurs persistently at or near the base of the bed has an average thickness of 3 feet, but the layers of bentonite in the middle and upper parts of the bed are generally much thinner and less persistent; one that is more than 3 feet thick nevertheless occurs in the upper part of bed I as exposed in a cutbank of North Indian Creek.

In most places bed I, like the other bentonite beds of the northern Black Hills district, is in sharp contact with its floor; this is also true of the component layers of bentonite and their floors. However, the roofs of the bentonite layers are unusual in that they too are commonly marked by sharp contacts. Even where these con-

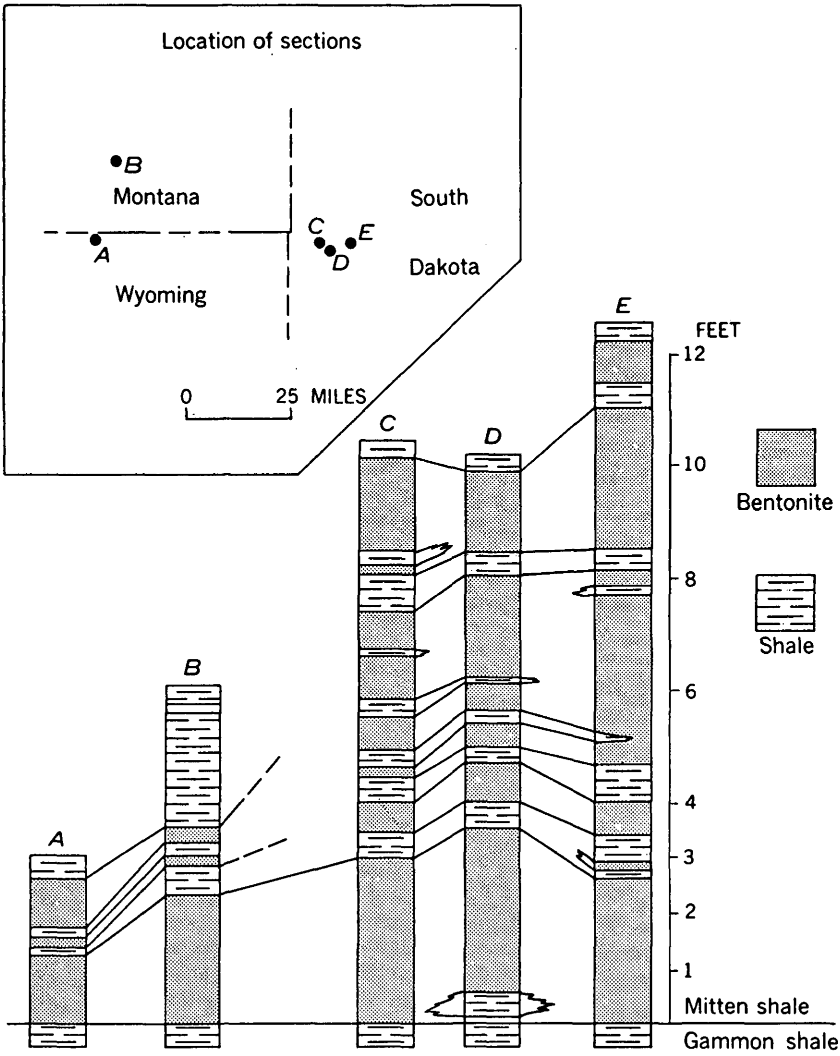


FIGURE 91.—Sections of bentonite bed I at five localities (A–E), showing tentative correlation of component layers based on their thickness, characteristic weathering, and order of superposition: (*A*) Locality A, sec. 30, T. 58 N., R. 67 W., Crook County, Wyo. (pl. 60); (*B*) locality 1, sec. 16, T. 7 S., R. 56 E., Carter County, Wyo. (fig. 92); (*C*) locality E, sec. 30, T. 12 N., R. 2 E., Butte County, S. Dak. (pl. 60); (*D*) locality F, sec. 31, T. 12 N., R. 2 E., Butte County, S. Dak. (pl. 60); (*E*) locality 78, sec. 35, T. 12 N., R. 2 E., Butte County, S. Dak. (pl. 60).

tacts are not sharp, the transitional zones of interlaminated shale and bentonite are generally thinner than are those above other bentonite beds of this district. The individual bentonite layers and partings vary in thickness and even pinch out here and there, so that in places two successive bentonite layers or shale partings coalesce to form a single stratum, either of bentonite or of shale. Owing to such irregularities and discontinuities, the selection of favorable sites for mining bentonite from bed I would involve a great deal of intensive exploration.

Results of differential thermal analyses (fig. 90*D–H*) and commercial tests indicate that bed I consists largely of montmorillonite in which Ca^{+2} is the principal replaceable cation. Samples tested as foundry-sand bonding clay accordingly show high green strength but low dry strength; they do not have the properties of high-grade drilling-mud material. In samples of bentonite from bed I, the content of nonclay material, which consists of about 60 percent "grit" that is made up of grains of fine sand and silt, averages about 25 percent by volume. The remainder of the nonclay material is more finely divided and consists chiefly of angular grains of quartz and feldspar, with some biotite, gypsum, iron oxide, calcite, and other minerals, and very few scattered shards of volcanic glass. The grit, which makes up as much as 15 percent of the bentonite, contains, in addition, a few small grains of pyrite and euhedral crystals of magnetite. Unlike the grit in most of the other bentonite beds of this district, a large part of that in the bentonite of bed I consist of slightly rounded particles, of which a great number are frosted grains of quartz.

Much of the bentonite of bed I contains small crystals of fibrous selenite, particularly along joints, of which there are many. In the eastern part of the district, the upper part of the bed commonly contains irregularly shaped concretions, which range in diameter from about 8 inches to 2 feet. Some of these concretions consist of fibrous calcite; others consist of gypsum, heavily stained by limonite. Marine fossils occur in the concretions embedded in the shale above and below bed I.

The unweathered bentonite of the various layers of bed I is mostly greenish gray; but owing to the oxidation of its small content of iron, the clay weathers to shades of yellow or orange, with rusty films along many of the joint planes. In some localities much of the bentonite exposed is also conspicuously stained rust brown. In the eastern part of the district, the greenish-gray color of the unweathered bentonite of the lowest layer of bed I is darker than that of the higher layers and tends to be less changeable where exposed to weathering. The relative colorfastness of the darker bentonite is presumably due to ferruginous matter that oxidizes less readily than that which is responsible for the discoloration of the higher layers; possibly the iron in the darker bentonite is more intimately associated with the clay minerals.

Bentonite of bed I that contains a large percentage of moisture has a waxy texture but it becomes more granular as it dries. It generally includes small flakes of biotite in most of which the cleavage is approximately parallel to the bedding; many of these flakes are waterworn to rounded shapes.

The inflections appearing on thermal diagrams (fig. 90*D–H*) indicate low-temperature endothermic reactions, which culminate at about 150°C and are generally complete at about 250°C, caused by the release of interplanar water. On most of the diagrams a second endothermic reaction, vaguely discernible at about 200°C, is believed to represent water loss in the presence of hydrated exchangeable Ca^{+2}. This interpretation is confirmed by ion-exchange determinations (table 3), which also show the presence of some Mg^{+2}. The endothermic reaction caused by dehydration of unit layers of montmorillonite begins at about 400°C, a much lower temperature than that at which the loss of interplanar water begins for most varieties of sodic bentonite, and continues somewhat irregularly to a maximum of about 675°C. The broad temperature range through which this reaction occurs suggests that some of the hydroxyl ions in the crystalline structure of the montmorillonite of bed I are bound more tightly than are other kinds of ions and that a large part of the hydroxyl ions are less securely held than are those in the montmorillonite of other beds in the northern Black Hills district.

Pyrite is present in the bentonite of bed I but probably makes up less than 2 percent of the volume. A few small pyrite crystals were observed in grit washed from the undiscolored clay; in the thermal diagram (fig. 90*F*) of an undiscolored sample, pyrite is recognizable by a characteristic double exothermic inflection corresponding to a reaction between 400° and 500°C, similar to that described by Grim and Rowland (1944). The pyrite does not occur as finely divided particles, however, as is indicated by the absence of this reaction in a −2-mu fraction of the same undiscolored sample (fig. 90*G*). Thermal diagrams (fig. 90*D* and *E*) indicate that the reaction is also absent in a discolored sample, in which the presence of limonite, no doubt resulting from oxidation of pyrite as well as the ferrous iron of other compounds, is indicated by an inflection corresponding to a characteristic endothermic reaction at about 300°C; in the whole sample (*D*) this reaction was weak but was moderately intense in the −2-mu fraction (*E*). Apparently the limonite, which is believed to cause the yellowish color of this material, occurs as very fine particles.

The X-ray diffraction diagram (fig. 80*N*) of a sample of bentonite from bed I indicates only very weak reflections for all minerals other than montmorillonite. A small inflection corresponding to spacings of 3.34 A indicates presence of a little quartz. Diagrams (not shown in this report) of a part of this sample indicate presence of small amounts of cristobalite and feldspar. X-ray examination of a sample representing material 17, locality 78 (p. 1023), by the powder-camera technique indicate the presence of calcite and traces of marcasite.

Much of the biotite in the bentonite of bed I seems to have been transported by water currents, and perhaps was thereby concentrated to some extent during accumulation of the original volcanic ash. The ash, from which the bentonite of bed I was formed, probably accumulated in fairly deep water and rather far from shore, as suggested by the dark color, fine-grained texture and widespread areal distribution of the enclosing strata of the Mitten black shale member and its stratigraphic correlatives in other parts of the region. However, bed I was probably not deposited in a deep-ocean or "fondo," environment, as described by Rich (1951, p. 9). It is evident that the parent layers of ash accumulated much more rapidly than did the mud that is represented by the interlayered dark shale, inasmuch as most of the bentonite of bed I is virtually uncontaminated by dark pyroclastic matter. The interstratification of the bentonite and shale probably means that the ash was deposited periodically; the interfingering of the two materials may be due to the action of submarine currents or to mud flowage.

Owing largely to the soft floor and the low dilatancy of the bentonite, bed I in most places is not more resistant to erosion than is the shale above or below it. This bed tends, therefore, to crop out less prominently than do bentonite beds having cherty floors and superior dilatancy. Bed I is nevertheless well exposed at a few localities and elsewhere lies under only slight colluvial cover at the base of low scarps, such as those commonly formed by the relatively resistant Mitten black shale member. Bed I can be located without much difficulty, even on aerial photographs, by the comparative sparseness of vegetation along its outcrop and by the contrast in color between the somber brownish-gray soil that forms from the overlying Mitten black shale member and the paler, rusty-gray soil associated with the underlying Gammon ferruginous member. Where freshly exposed, however, the rocks above and below bed I show no such distinct difference in color.

DESCRIPTION BY COUNTY, TOWNSHIP, AND RANGE

Most of the sections given in the following descriptions were measured by boring with an earth auger, and the numerical order in which the materials are listed in each section corresponds to the downward sequence in which the bentonite and associated rocks were penetrated in boring.

CROOK COUNTY, WYO.

T. 55 N., Rs. 60 AND 61 W.

This area is moderately dissected and has a relief of about 650 feet. The lowest ground is the alluvial plain along the Belle Fourche River, which meanders across the northeastern part. The highest surfaces are those occupied by the old alluvial deposits (pl. 60) in the southwestern part of the area.

A broad anticline, which is probably an extension of the La Flamme anticline and is flanked on the west by a broad, shallow syncline, plunges across the east side of the area. The beds of the Mowry and Belle Fourche shales are exposed extensively in R. 61 W., within the syncline, and in the northeastern part of the area. The Clay Spur bentonite bed, which lies beneath less than 50 feet of cover in the greater part of its areal extent, crops out around the margins of several outliers of the Belle Fourche shale. Results of tests of bentonite samples (table 4) from the Clay Spur bed from two localities southwest of the Belle Fourche River at which the following sections were measured suggest presence of much material suitable for foundry-sand bonding clay and drilling mud. At the time of mapping, however, mining had been carried on only in secs. 5 and 6, T. 55 N., R. 60 W., northeast of the river (pl. 60).

Section measured in T. 55 N., R. 61 W.

Description of materials	Thickness				Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4)		
	All beds		Bentonite only		Green strength ≧8 psi	Dry strength ≧50 psi	Yield ≧90 bbls per ton
	Ft	in	Ft	in			
LOCALITY 76, SECTION 10 [Nos. 2-4 from Clay Spur bentonite bed]							
1. Shale, dark-gray		8	--	--	--------	--------	--------
2. Bentonite, dark-brown, weathered		5	4	8	5	5, 2-4	5
3. Bentonite, dark-gray, waxy; a few light-gray laminae	1	2					
4. Bentonite, light-gray, waxy, gypsiferous; a few dark-gray laminae	1	3					
5. Bentonite, olive-green, waxy, gypsiferous; limonite stained at base	1	10					
6. Shale, dark-gray, siliceous	--	--	--	--	--------	--------	--------
LOCALITY 77, SECTION 23 [Nos. 2 and 3 from Clay Spur bentonite bed]							
1. Shale, dark-gray		5	--	--	--------	--------	--------
2. Bentonite, interlaminated dark-gray and olive-green, waxy	1	8	3	5	2, 3	2, 3	3
3. Bentonite, olive-green, waxy; half an inch at base has cornmeal texture	1	9					
4. Shale, dark-gray, siliceous, hard	--	--	--	--	--------	--------	--------

T. 56 N., R. 60 W.

The southeastern part of the Chicago Creek anticline plunges southeastward across the southern part of this township and is flanked in sec. 31 by a shallow syncline. The Mowry shale crops out in the syncline and on the flanks and nose of the anticline. The Clay Spur bentonite bed, which is exposed along the contact between the Mowry shale and the overlying Belle Fourche shale, is under less than 30 feet of cover in broad areas and has been mined in several localities (pl. 60). Bed F, in the uppermost part of the Belle Fource shale, crops out northeast of Highway 212, in the face of a long escarpment capped by a limestone bed that forms the base of the Greenhorn formation in this vicinity. Tests (table 4) of a sample from bed F in this township indicate the presence of material suitable for use as foundry-sand bonding clay, but the bed lies under light cover in only a narrow belt, which offers no very attractive mining sites.

Sections measured in T. 56 N., R. 60 W.

Description of materials	Thickness: All beds (Ft)	Thickness: All beds (in)	Thickness: Bentonite only (Ft)	Thickness: Bentonite only (in)	Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4): Green strength ≧8 psi	Dry strength ≧50 psi	Yield ≧90 bbls per ton
LOCALITY 74, SECTION 17							
[Nos. 2 and 3 from bed F]							
1. Shale, dark-brown and gray	1	0	--	--	--------	--------	--------
2. Bentonite, light-brownish-gray, waxy		8	2	2	2–3	2–3	--------
3. Bentonite, light-gray, waxy; dark mineral particles	1	6					
4. Shale, dark-gray, soft	--	--	--	--	--------	--------	--------
LOCALITY 75, SECTION 19							
[Nos. 2-11 from Clay Spur bentonite bed]							
1. Shale, dark-gray	1	3	--	--	--------	--------	--------
2. Bentonite, dark-gray		6	1	2	--------	--------	--------
3. Bentonite, brownish-gray		3					
4. Bentonite, cream; cornmeal texture		5					
5. Shale, dark-gray		11	--	--	--------	--------	--------
6. Bentonite, brown, impure		3	2	9	[1] 9–11	[1] 9–11	--------
7. Bentonite, light-brown, waxy		1					
8. Bentonite, brown		6					
9. Bentonite, interlaminated olive-green and light-brown; lightest color in lower part	1	6					
10. Bentonite, light-grayish-green; darker in lower part		3					
11. Bentonite, yellow; cornmeal texture		2					
12. Shale, dark-gray, siliceous	--	--	--	--	--------	--------	--------

[1] Test data for composite sample of materials 6–8 are given in table 4.

T. 56 N., R. 61 W.

The Mowry and Belle Fourche shales crop out extensively northeast of the Belle Fourche River in this township. Several northwestward-trending folds are present, the most prominent of which is the Chicago Creek anticline. The Clay Spur bentonite bed (pl. 65) is under less than 30 feet of cover in broad areas, and tests of samples (table 4) from scattered localities indicate that it contains much material suitable for use as foundry-sand bonding clay and as a drilling mud ingredient. Bentonite has been mined at many places. The Colony bentonite-processing plant of the Baroid Sales Division of the National Lead Co. is in sec. 11, and the site of the projected plant of the Wyodak Chemical Co. is in sec. 3.

Sections measured in T. 56 N., R. 61 W.

Description of materials	*Thickness*				*Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4)*		
	All beds		*Bentonite only*		*Green strength ≧8 psi*	*Dry strength ≧50 psi*	*Yield ≧90 bbls per ton*
	Ft	*in*	*Ft*	*in*			
LOCALITY 59, SECTION 1							
[Nos. 2-6 from Clay Spur bentonite bed]							
1. Shale, dark-gray		9	---	---	---	---	---
2. Bentonite, interlaminated dark-gray and olive-green, waxy		11					
3. Bentonite, olive-green, waxy; a few dark-gray laminae		4					
4. Bentonite, olive-green, waxy	1	4	3	5	2-3, 4-6	2-3, 4-6	4-6
5. Bentonite, greenish-gray, waxy		7					
6. Bentonite, light-gray, flaky; limonite at base		3					
7. Shale, dark-gray, siliceous	---	---	---	---	---	---	---
LOCALITY 60, SECTION 3							
[Nos. 2-6 from Clay Spur bentonite bed]							
1. Shale, dark-gray	1	1	---	---	---	---	---
2. Bentonite, gray, waxy; some olive-green laminae	1	5					
3. Bentonite, light-olive-green, waxy; some gray laminae	1	2					
4. Bentonite, rusty-yellow, gypsiferous		4	4	11	2-6	2-6	---
5. Bentonite, light-olive-green, limonite-stained	1	11½					
6. Bentonite, gray; cornmeal texture		½					
7. Shale, dark-gray, siliceous	---	---	---	---	---	---	---
LOCALITY 61, SECTION 7							
[Nos. 2-7 from Clay Spur bentonite bed]							
1. Shale, dark-gray, soft	1	2	---	---	---	---	---
2. Bentonite, dark-gray, weathered, impure		6					
3. Bentonite, interlaminated dark-gray and very light gray, waxy		3					
4. Bentonite, interlaminated light-gray and cream, waxy		5	2	11	4-7	2-3, 4-7	4-7
5. Bentonite, light-olive-green, waxy		10					
6. Bentonite, grayish-green, waxy		7					
7. Bentonite, olive-green, limonite-stained, waxy; 1 in. at base has cornmeal texture		4					
8. Shale, dark-gray, siliceous, hard	---	---	---	---	---	---	---
LOCALITY 62, SECTION 11							
[Nos. 2-5 from Clay Spur bentonite bed]							
1. Shale, dark-gray, siliceous	1	1	---	---	---	---	---
2. Bentonite, dark-gray, gypsiferous; a few olive-green laminae		4					
3. Bentonite, olive-green, waxy		8	1	10	3-5	3-5	3-5
4. Bentonite, light-olive-green, waxy		9					
5. Bentonite, yellow; cornmeal texture		1					
6. Shale, dark-gray, siliceous	--	--	---	---	---	---	---
LOCALITY 63, SECTION 11							
[Nos. 9-15 from Clay Spur bentonite bed]							
1. Shale, dark-gray	1	1	---	---	---	---	---
2. Bentonite, gray, flaky		9½					
3. Bentonite, yellow; cornmeal texture		3	1	½	---	---	---
4. Shale, dark-gray		10½	---	---	---	---	---
5. Bentonite, gray and brown, limonite-stained		½		½	---	---	---
6. Shale, dark-gray		8½	---	---	---	---	---
7. Bentonite, cream, waxy; brown near top		5		5	---	---	---
8. Shale, dark-gray and brown		8	---	---	---	---	---
9. Bentonite, dark-grayish-brown, gypsiferous		7					
10. Bentonite, olive-green gypsiferous		8					
11. Bentonite, olive-green, limonite-stained		7					
12. Bentonite, yellowish-green, waxy		11	3	1	9-10, 11-15	9-10, 11-15	11-15
13. Bentonite, yellow; cornmeal texture		1					
14. Bentonite, gray, limonite-stained		2					
15. Bentonite, gray, waxy		1					
16. Shale, dark-gray, siliceous	--	---	---	---	---	---	---

Sections measured in T. 56 N., R. 61 W.—Continued

Description of materials	*Thickness*				*Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4)*		
	All beds		*Bentonite only*		*Green strength*	*Dry strength*	*Yield*
	Ft	*in*	*Ft*	*in*	*≧8 psi*	*≧50 psi*	*≧90 bbls per ton*
LOCALITY 64, SECTION 13							
[Nos. 2 and 3 from bed D or Clay Spur bentonite bed]							
1. Shale, dark-gray, weathered	1	6	---	---	--------	--------	--------
2. Bentonite, dark-gray	2	8					
3. Bentonite, gray, waxy; bluish gray near base		10	[1]6	7½	--------	2, 3	3
4. Shale, dark-gray, bentonitic	3	1					
5. Bentonite, gray, waxy		½					
6. Shale, dark-gray, soft	--	---	---	---	--------	--------	--------
LOCALITY 65, SECTION 15							
[Nos. 2–4 from Clay Spur bentonite bed]							
1. Shale, dark-gray, soft	---	---	---	---	--------	--------	--------
2. Bentonite, interlaminated dark-gray and olive-green, waxy	1	6					
3. Bentonite, olive-green, limonite-stained, waxy	1	2	3	10	2, 3–4	2, 3–4	2, 3–4
4. Bentonite, olive-green, waxy; half an inch at base has cornmeal texture	1	2					
5. Shale, dark-gray, siliceous	---	---	---	---	--------	--------	--------
LOCALITY 66, SECTION 16							
[Nos. 2–6 from Clay Spur bentonite bed]							
1. Shale, dark-gray; siliceous in lower part	20	0	---	---	--------	--------	--------
2. Bentonite, dark-gray		4					
3. Bentonite, interlaminated dark-gray and olive-green, waxy		8					
4. Bentonite, olive-green, waxy; a few dark-gray laminae	1	2	4	9	2–3, 4–6	2–3, 4–6	2–3, 4–6
5. Bentonite, olive-green, waxy, gypsiferous	1	6					
6. Bentonite, olive-green, limonite-stained, waxy; half an inch at base has cornmeal texture	1	1					
7. Shale, dark-gray, siliceous	---	---	---	---	--------	--------	--------
LOCALITY 67, SECTION 17							
[Nos. 2–7 from Clay Spur bentonite bed]							
1. Shale, dark-gray, siliceous	1	0	---	---	--------	--------	--------
2. Bentonite, interlaminated dark-gray and olive-green, waxy		4					
3. Bentonite, olive-green, waxy; a few gray laminae		9					
4. Bentonite, olive-green, waxy	1	0	3	0	3–7	3–7	3–7
5. Bentonite, brown, waxy		6					
6. Bentonite, grayish-green, waxy		3					
7. Bentonite, limonite-stained, gypsiferous		2					
8. Shale, dark-gray, siliceous	---	---	---	---	--------	--------	--------
LOCALITY 68, SECTION 18							
[Nos. 2–6 from Clay Spur bentonite bed]							
1. Shale, dark-gray, siliceous	1	2	---	---	--------	--------	--------
2. Bentonite, dark-gray, weathered	1	4					
3. Bentonite, dark-gray and olive-green, waxy	1	2					
4. Bentonite, olive-green, waxy; a few gray laminae		10	5	7	2–3, 4–6	2–3, 4–6	4–6
5. Bentonite, olive-green, waxy, gypsiferous	1	10					
6. Bentonite, brown, limonite-stained, gypsiferous		5					
7. Shale, dark-gray, siliceous	---	---	---	---	--------	--------	--------
LOCALITY 69, SECTION 20							
[Nos. 2–6 from Clay Spur bentonite bed]							
1. Shale, dark-gray		11	---	---	--------	--------	--------
2. Bentonite, interlaminated dark-gray and olive-green, waxy	1	1					
3. Bentonite, olive-green, waxy; a few gray laminae		7					
4. Bentonite, olive-green, waxy	1	1	3	1	2, 3–6	3–6	--------
5. Bentonite, brown, limonite-stained, waxy		3					
6. Bentonite, gray, limonite-stained, gypsiferous		1					
7. Shale, dark-gray, siliceous	---	---	---	---	--------	--------	--------

[1] Material 4 included because it is bentonitic; test data given in table 4.

Sections measured in T. 56 N., R. 61 W.—Continued

Description of materials	*Thickness*				*Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4)*		
	All beds		*Bentonite only*		*Green strength ≧8 psi*	*Dry strength ≧60 psi*	*Yield ≧90 bbls per ton*
	Ft	*in*	*Ft*	*in*			
LOCALITY 70, SECTION 26							
[Nos. 3–4 from bed D; 6–9 from Clay Spur bentonite bed]							
1. Shale, dark-gray	6	0	---	---	--------	--------	--------
2. Shale, dark-gray, bentonitic		6	---	---	--------	--------	--------
3. Bentonite, light-gray, flaky		8	1	1½	3, 3–4	3, 3–4	--------
4. Bentonite, creamy, flaky		5½					
5. Shale, dark-gray; siliceous in lower part	4	8½	---	---	--------	--------	--------
6. Bentonite, dark-gray, waxy; a few olive-green laminae	1	0					
7. Bentonite, interlaminated light-gray and olive-green, waxy		6					
8. Bentonite, olive-green, waxy		11	3	4	6–7, 8–9	6–7, 8–9	8–9
9. Bentonite, grayish-green, waxy; a 2-inch limonite-stained stratum at base		11					
10. Shale, dark-gray, siliceous	---	---	---	---	--------	--------	--------
LOCALITY 71, SECTION 28							
[Nos. 2–9 from Clay Spur bentonite bed]							
1. Shale, dark-gray	1	0	---	---	--------	--------	--------
2. Shale, dark-gray, bentonitic		3					
3. Bentonite, cream		1½					
4. Bentonite, brown, limonite-stained, impure		1½					
5. Bentonite, interlaminated dark-gray and light-gray		7					
6. Bentonite, interlaminated dark-gray and olive-green, waxy		4	[1]3	2	6–9	2–5, 6–9	6–9
7. Bentonite, olive-green, waxy, gypsiferous; some dark mineral particles	1	4					
8. Bentonite, light-grayish-green, waxy		3					
9. Bentonite, greenish-gray; ½-inch limonite-stained stratum at base has cornmeal texture		2					
10. Shale, dark-gray, siliceous, hard	---	---	---	---	--------	--------	--------
LOCALITY 72, SECTION 33							
[Nos. 2–4 from bed D; 8–14 from Clay Spur bentonite bed]							
1. Shale, dark-gray	10	0	---	---	--------	--------	--------
2. Bentonite, gray		½		½	--------	--------	--------
3. Shale, dark-gray, soft		2	---	---	--------	--------	--------
4. Bentonite, cream, waxy; dark-gray laminae in upper part		2		2	--------	--------	--------
5. Shale, dark-gray, bentonitic		½	---	---	--------	--------	--------
6. Shale, dark-gray; interlaminated with gray bentonite		5	---	---	--------	--------	--------
7. Shale, dark-gray; siliceous in lower part	5	6	---	---	--------	--------	--------
8. Bentonite, interlaminated dark-gray and olive-green, waxy	1	2					
9. Bentonite, bluish-gray, limonite-stained, waxy		11					
10. Bentonite, light-bluish-gray, waxy		5					
11. Bentonite, grayish-green, waxy		3	3	7	8, 9–14	8	--------
12. Bentonite, bluish-gray, waxy		4					
13. Bentonite, light-gray, waxy		5					
14. Bentonite, gray, waxy		1					
15. Shale, dark-gray, siliceous	---	---	---	---	--------	--------	--------
LOCALITY 73, SECTION 34							
[Nos. 2–5 from Clay Spur bentonite bed]							
1. Shale, dark-gray, soft	1	4	---	---	--------	--------	--------
2. Bentonite, dark-gray, waxy; a few light-gray laminae	1	1					
3. Bentonite, olive-green, waxy; a few dark-gray laminae		5	3	5	3–5	2, 3–5	3–5
4. Bentonite, grayish-green, limonite-stained, waxy	1	3					
5. Bentonite, light-olive-green, limonite, stained, waxy; granular in lower part		8					
6. Shale, dark-gray, siliceous	---	---	---	---	--------	--------	--------

[1] Material 2 is included because it is part of the composite material tested.

583554—61——8

T. 56 N., R. 62 W.

In the northern half of this township, gently folded strata of the Newcastle, Mowry, and Belle Fourche formations crop out extensively. Bentonite bed A, in the Newcastle sandstone, crops out for about 2 miles in secs. 5, 6, 7, and 8, where it is under less than 30 feet of cover in areas aggregating nearly a square mile. Tests of samples (table 4) taken at 2 localities indicate that this bed contains material suitable for use as foundry-sand bonding clay, and at 1 of the 2 localities the bed appears to contain excellent material for use in drilling mud. The Clay Spur bentonite bed in the Mowry shale crops out around the margins of many outliers of the Belle Fourche shale, and it is under less than 30 feet of overburden for the greater part of the areal extent of that formation. Tests (table 4) of a sample from locality 57 in sec. 1 indicate that the bentonite has the properties of excellent foundry-sand bonding clay and drilling mud material. At the time of our examination, bentonite had been mined from bed A at two sites in sec. 6 and from the Clay Spur bentonite bed at sites in secs. 1 and 2.

Sections measured in T. 56 N., R. 62 W.

Description of materials	*Thickness*				*Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4)*		
	All beds		*Bentonite only*		*Green strength ≥8 psi*	*Dry strength ≥50 psi*	*Yield ≥90 bbls per ton*
	Ft	*in*	*Ft*	*in*			
LOCALITY 57, SECTION 1							
[Nos. 2–4 from bed E, 6 from bed D, 8 from Clay Spur bentonite bed]							
1. Shale, dark-gray, soft	2	0	--	--	--------	--------	--------
2. Bentonite, dark-brownish-red and grayish-brown, waxy	--	2					
3. Bentonite, dark-brown, waxy	--	8	1	0	--------	--------	--------
4. Bentonite, bluish-gray, waxy	--	2					
5. Shale, dark-gray; siliceous near base	24	6	--	--	--------	--------	--------
6. Bentonite, cream, flaky	--	2½	--	2½	--------	--------	--------
7. Shale, dark-gray	--	5½	--	--	--------	--------	--------
8. Bentonite, olive-green, waxy; some gypsum and a little limonite staining; 1 in. at base consists of granular bentonite	2	5	2	5	8	8	8
9. Shale, dark-gray, siliceous	--	--	--	--	--------	--------	--------
LOCALITY 58a, SECTION 6							
[Nos. 3–6 from bed A]							
1. Sandstone, brown, weathered	2	0	---	---	--------	--------	--------
2. Shale, gray, soft, silty	6	0	---	---	--------	--------	--------
3. Bentonite, dark-brownish-gray, waxy; a few light-gray laminae		9					
4. Bentonite, olive-green, waxy; dark mineral particles	1	11					
5. Bentonite, brown, waxy; dark brown along joints		3	4	8	3–6	3–6	3–6
6. Bentonite, light-yellowish-gray, waxy; a few dark mineral particles; small particles of organic matter near base	1	9					
7. Coal, platy; shale and silt	---	---	---	---	--------	--------	--------
LOCALITY 58, SECTION 8							
[Nos. 3–6 from bed A]							
1. Sandstone, flaggy, gray; weathers rusty	2	0	---	---	--------	--------	--------
2. Sandstone, light-gray- soft, very rusty	4	6	---	---	--------	--------	--------
3. Bentonite, light-olive-green; dark laminae near base	1	10					
4. Bentonite, light-olive-green, waxy	1	4					
5. Bentonite, light-olive-green, waxy; blue and gray laminae	1	1	5	11	3–4, 5	3–4, 5	--------
6. Bentonite, light-gray	1	8					
7. Shale, dark-gray, carbonaceous; much admixed coaly material	2	0	---	---	--------	--------	--------
8. Clay, light-gray, brittle	2	0	---	---	--------	--------	--------
9. Clay, gray, rusty-stained, silty to sandy	3	4	---	---	--------	--------	--------
10. Shale, dark-gray, soft, fissile	---	---	---	---	--------	--------	--------

T. 56 N., R. 66 W.

The Newcastle, Mowry, and Belle Fourche formations crop out in the northern and northwestern parts of this township but are largely concealed by alluvial deposits of the flood plain of the Little Missouri River. The overall geologic structure is homoclinal, with the beds dipping gently northwestward. In a few places the beds are cut by faults of small displacement which trend northeastward. Bentonite bed A, in the Newcastle sandstone, crops out in sec. 2, and the Clay Spur bentonite bed is exposed at the margins of a number of outliers of the Belle Fourche shale in secs. 3 to 9. Tests of samples (table 4) of the Clay Spur from locality 56, in sec. 4, indicate presence of excellent material for use as foundry-sand bonding clay and as an ingredient of drilling mud. The bentonite of this bed is less than 30 feet beneath the surface in several areas of sufficient size to warrant consideration as potential strip-mining sites. However, owing to its distance from processing plants, this material had not been mined at the time (1948) of our examination.

Section measured in T. 56 N., R. 66 W.

Description of materials	*Thickness*				*Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4)*		
LOCALITY 56, SECTION 4	*All beds*		*Bentonite only*		*Green strength* ≧*8 psi*	*Dry strength* ≧*50 psi*	*Yield* ≧*90 bbls per ton*
[Nos. 2–6 from Clay Spur bentonite bed]	*Ft*	*in*	*Ft*	*in*			
1. Shale, dark-gray, siliceous	1	0	---	---	--------	--------	---------
2. Bentonite, interlaminated dark-gray and light-gray, waxy		11					
3. Bentonite, light-greenish-gray, waxy; limonite-stained in lower part, with a few dark mineral particles		10	3	8	4, 5, 6, 3–6	2, 3, 4, 5, 6, 3–6	3, 4, 5, 6, 3–6
4. Bentonite, olive-green, waxy		11					
5. Bentonite, olive-green; cornmeal texture		6					
6. Bentonite, greenish-gray, waxy; ½-inch light-colored stratum at base has cornmeal texture		6					
7. Shale, dark-gray, siliceous	---	---	---	---	--------	--------	---------

T. 56 N., R. 67 W.

In a monoclinal belt along the west side of this township, the Mowry shale, the Gammon ferruginous member of the Pierre shale, and the intervening strata dip westward at angles as steep as 29°. Elsewhere in the township the dip is gentle and northward. The strata are cut locally by faults of small displacement. The Mowry and Belle Fourche shales crop out extensively in the central and northern parts of the township. In the southern part of the monoclinal belt, where the Clay Spur bentonite bed and bentonite bed F crop out about a third of a mile apart, both beds are so steeply inclined as to offer no attractive mining sites. Farther north, however, the outcrops of both beds swing eastward, away from the monocline, and continue across the areas of gentle dip in the central and northeastern parts of the township. As a consequence, the Clay Spur bentonite bed lies under less than 30 feet of cover in a belt that is about 6 miles long and averages about a quarter of a mile wide, as well as within several small outliers of the Belle Fourche shale in secs. 12 and 13. Tests of samples (table 4) from locality 55 in sec. 13 indicate that the bed contains good material for use as foundry-sand bonding clay. Though the samples tested did not conform to requirements for use in drilling mud, material suited for such use is probably present elsewhere along the outcrop of this bed.

Sections measured in T. 56 N., R. 67 W.

Description of materials	Thickness: All beds Ft	Thickness: All beds in	Thickness: Bentonite only Ft	Thickness: Bentonite only in	Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4): Green strength ≧8 psi	Dry strength ≧50 psi	Yield ≧90 bbls per ton
LOCALITY 54, SECTION 9 [Nos. 2-7 from bed F]							
1. Shale, dark-gray, soft	1	7	---	---	--------	--------	---------
2. Bentonite, interlaminated brownish-gray and light-gray, waxy		6					
3. Bentonite, gray, limonite-stained, waxy; dark mineral particles	1	1					
4. Bentonite, greenish-gray, waxy, gypsiferous; dark mineral particles	1	3	6	3	2, 3, 4, 5, 7, 3-7	2, 3, 4, 5, 6, 7, 3-7	3, 4, 5, 6, 3-7
5. Bentonite, brownish-gray, waxy; dark mineral particles		8					
6. Bentonite, reddish-brown, waxy	2	2					
7. Bentonite, gray, waxy; dark mineral particles		7					
8. Shale, dark-gray, soft	---	---	---	---	--------	--------	---------
LOCALITY 55, SECTION 13 [Nos. 2-4 from Clay Spur bentonite bed]							
1. Shale, dark-gray, siliceous; weathers light-gray	1	5	---	---	--------	--------	---------
2. Bentonite, interlaminated light-gray and dark-gray, waxy; limonite-stained in lower part		7					
3. Bentonite, olive-green, waxy, gypsiferous	1	5½	2	2	2, 3-4	2, 3-4	---------
4. Bentonite, greenish-gray, waxy; ½-inch light-gray stratum at base has cornmeal texture		1½					
5. Shale, dark-gray, siliceous	---	---	---	---	--------	--------	---------

T. 57 N., RS. 60 AND 61 W.

The overall dip of the strata in this area is northeastward; the structure in the southwestern part is undulatory. The Colony anticline, which is an elongate, domelike feature extending northwestward with the Skull Creek shale exposed at its apex, is the most prominent fold in the area. The Mowry and Belle Fourche shales occupy large areas on both of its flanks. On the southwest side of the Colony anticline is the Shepard anticline, a smaller domelike structure expressed in outcrops of the Mowry and Belle Fourche shales. Bentonite bed B, the Clay Spur bentonite bed, and bentonite bed F crop out in the vicinity of these anticlines. Areas in which the Clay Spur lies under less than 30 feet of overburden are fairly extensive. Bentonite had been mined from pits in secs. 7, 32, and 33, R. 61 W., at the time of our examination. Tests of bentonite samples (table 4) taken from the Clay Spur bed indicate the presence of material suitable for use as foundry-sand bonding clay at 6 localities and as an ingredient of drilling mud at 3 of them. A sample of bentonite taken from bed F at a locality in sec. 23, T. 57 N., R. 61 W., showed green and dry compression strengths adequate for foundry-sand bonding clay, but bed F does not offer any attractive strip-mining sites in this part of the district.

A sample (table 4) of the bentonite from bed B as exposed in sec. 8, T. 57 N., R. 61 W., tested high in green strength and low in dry strength (see p. 970).

Sections measured in T. 57 N., R. 61 W.

Description of materials	Thickness				Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4)		
	All beds		Bentonite only		Green strength ≧8 psi	Dry strength ≧50 psi	Yield ≧90 bbls per ton
	Ft	in	Ft	in			
LOCALITY 46, SECTION 8							
[No. 2 from bed B]							
1. Shale, dark-gray, siliceous, hard	---	---	---	---	--------	--------	---------
2. Bentonite, bluish-gray, waxy	2	11	2	11	2	--------	---------
3. Shale, dark-gray, siliceous	---	---	---	---	--------	--------	---------
LOCALITY 47, SECTION 7							
[Nos. 2-6 from Clay Spur bentonite bed]							
1. Shale, dark-gray, siliceous		6	---	---	--------	--------	---------
2. Bentonite, interlaminated olive-green and dark-gray, waxy, gypsiferous	2	5	4	10	2-4, 5-6	2-4, 5-6	2-4, 5-6
3. Bentonite, olive-green, limonite-stained, gypsiferous		3					
4. Bentonite, interlaminated olive-green and dark-gray-waxy		3					
5. Bentonite, olive-green, waxy	1	8					
6. Bentonite, greenish-gray, waxy		3					
7. Shale, dark-gray, siliceous	---	---	---	---	--------	--------	---------
LOCALITY 48, SECTION 21							
[Nos. 2-8 from Clay Spur bentonite bed]							
1. Shale, dark-gray		11	---	---	--------	--------	---------
2. Shale, dark-gray; bentonitic in lower part		9	[1] 4	8	2-4, 5-8	2-4, 5-8	5-8
3. Bentonite, brownish-gray, waxy, gypsiferous		2					
4. Bentonite, dark-gray and brown, gypsiferous		5					
5. Bentonite, light-olive-green, waxy; gray laminae	1	2					
6. Bentonite, light-olive-green, waxy		7					
7. Bentonite, light-greenish-gray, waxy	1	2					
8. Bentonite, light-gray, limonite-stained, waxy		5					
9. Shale, dark-gray, siliceous	---	---	---	---	--------	--------	---------
LOCALITY 49, SECTION 23							
[Nos. 2-8 from bed F]							
1. Shale, dark-gray, soft	1	8	---	---	--------	--------	---------
2. Bentonite, light-gray, waxy; some limonite stains and dark mineral particles	1	3	4	8	2, 4, 2-8	2, 2-8	--------
3. Bentonite, bluish-gray; waxy		1					
4. Bentonite, light-gray, limonite-stained, waxy; dark mineral particles		9					
5. Bentonite, bluish-gray, waxy		1					
6. Bentonite, light-brownish-gray, limonite-stained, waxy; dark mineral particles		6					
7. Bentonite, bluish-gray, waxy		9					
8. Bentonite, bluish-gray, limonite-stained; dark mineral particles	1	3					
9. Shale, dark-gray, soft	---	---	---	---	--------	--------	---------

[1] Material 2 is included because it is part of composite sample tested.

Sections measured in T. 57 N., R. 61 W.—Continued

Description of materials	*Thickness*				*Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4)*		
	All beds		*Bentonite only*		*Green strength ≧8 psi*	*Dry strength ≧50 psi*	*Yield ≧90 bbls per ton*
	Ft	*in*	*Ft*	*in*			
LOCALITY 50, SECTION 25							
[Nos. 2–6 from bed F]							
1. Shale, dark-gray, soft	1	7	---	---	--------	--------	--------
2. Bentonite, light-gray, limonite-stained, waxy; dark mineral particles	2	7					
3. Bentonite, light-brown, waxy; dark mineral particles; small nodules of bluish-gray bentonite	1	6	[2] 4	6	2–6	2–6	--------
4. Bentonite, light-gray, waxy; granular in lower part		2					
5. Shale, dark-gray, soft		1					
6. Bentonite, light-gray, waxy		2					
7. Shale, dark-gray, soft	---	---	---	---	--------	--------	--------
LOCALITY 51, SECTION 27							
[Nos. 2–6 from Clay Spur bentonite bed]							
1. Shale, dark-gray	1	3	--------		--------	--------	--------
2. Bentonite, dark-gray, impure		7					
3. Bentonite, dark-gray, waxy; a few light-gray laminae		8					
4. Bentonite, olive-green, waxy; a few dark-gray laminae		9	4	2	2–3, 4–6	2–3, 4–6	--------
5. Bentonite, olive-green, waxy; limonite stains along joints	2	0					
6. Bentonite, greenish-gray, waxy		2					
7. Shale, dark-gray, siliceous	---	---	---	---	--------	--------	--------
LOCALITY 52, SECTION 28							
[Nos. 2–5 from Clay Spur bentonite bed]							
1. Shale, dark-gray		11	---	---	--------	--------	--------
2. Bentonite, interlaminated dark-gray and light-gray, waxy	1	1					
3. Bentonite, olive-green, waxy, gypsiferous; a few dark-gray laminae	1	0	3	10	3–5	2, 3–5	--------
4. Bentonite, olive-green, waxy, gypsiferous	1	8					
5. Bentonite, greenish-gray, waxy		1					
6. Shale, dark-gray, siliceous	---	---	---	---	--------	--------	--------
LOCALITY 53. SECTION 29							
[Nos. 2–5 from Clay Spur bentonite bed]							
1. Shale, dark-gray	1	3	---	---	--------	--------	--------
2. Bentonite, dark-gray, waxy, gypsiferous, some olive-green laminae in lower part	1	4					
3. Bentonite, interlaminated olive-green and gray	1	7	5	0	3–5	2, 3–5	3–5
4. Bentonite, light-olive-green, limonite-stained, waxy; gray in lower part	1	11					
5. Bentonite, yellow; cornmeal texture		2					
6. Shale, dark-gray, siliceous	---	---	---	---	--------	--------	--------

[2] Material 5 is included because it is part of composite sample tested.

T. 57 N., R. 62 W.

The strata of this township are gently folded. The Bull Creek anticline and the shallow syncline on its southwest side occupy the area northeast of the Belle Fourche River. Southwest of the river a few smaller folds trend northwestward. Strata cropping out in the area range from the Skull Creek shale to the basal shale member of the Carlile shale. Bentonite beds that have been mapped are bed A, the Clay Spur bentonite bed, and beds F and G. Although bed A extends southward along the west boundary of the township from sec. 19, measurements of its thickness are not available. The aggregate area in which the Clay Spur bed lies beneath less than 30 feet of cover is rather extensive. All samples from the Clay Spur, E, F, and G beds showed green and dry strengths adequate for foundry-sand bonding clay. Tests of samples (table 4) taken from the Clay Spur bed at 4 localities indicated the presence of valuable drilling-mud material at 2 of them (locs. 43 and 45, secs. 33 and 36). At the time (1948) of this examination, the bentonite of the Clay Spur bentonite bed had been mined from several pits near the Belle Fourche River.

Sections measured in T. 57 N., R. 62 W.

Description of materials	*Thickness*				*Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4)*		
	All beds		*Bentonite only*		*Green strength ≧8 psi*	*Dry strength ≧60 psi*	*Yield ≧90 bbls per ton*
	Ft	*in*	*Ft*	*in*			
LOCALITY 36, SECTION 4 [Nos. 2-7 from bed F]							
1. Shale, dark-gray, soft	2	10	---	---	---	---	---
2. Bentonite, brownish-gray, impure, weathered		3					
3. Bentonite, brownish-gray, limonite-stained		11					
4. Bentonite, gray, waxy; dark mineral particles	2	4					
5. Bentonite, gray; red mineral particles		6	4	8	3-7	3-7	---
6. Bentonite, reddish-brown, waxy; dark mineral particles		4					
7. Bentonite, light-brown, limonite-stained, waxy		4					
8. Shale, dark-gray, soft	---	---	---	---	---	---	---
LOCALITY 37, SECTION 9 [Nos. 2-8 from bed F]							
1. Shale, dark-gray, soft	2	1	---	---	---	---	---
2. Bentonite, dark-gray		5					
3. Bentonite, gray and brown		2					
4. Bentonite, rusty-gray, waxy, gypsiferous		6					
5. Bentonite, brownish-gray		1	4	5	[1] 3-8	[1] 3-8	---
6. Bentonite, gray, waxy	2	6					
7. Bentonite, gray; numerous tiny red mineral particles		6					
8. Bentonite, gray, heavily limonite-stained		3					
9. Shale, dark-gray, soft	---	---	---	---	---	---	---
LOCALITY 38, SECTION 9 [Nos. 2-4 from bed G]							
1. Shale, brown, soft	3	2	---	---	---	---	---
2. Bentonite, brownish-gray, waxy; dark mineral particles and some gypsum	1	0					
3. Bentonite, gray, granular		4	2	7	2-4	2-4	---
4. Bentonite, light-bluish-gray; dark mineral particles and limonite stains	1	3					
5. Shale, brown, soft	---	---	---	---	---	---	---
LOCALITY 39, SECTION 15 [Nos. 2-5 from bed F]							
1. Shale, dark-gray, soft		11	---	---	---	---	---
2. Bentonite, dark-brown, limonite-stained, granular		1					
3. Bentonite, light-gray, limonite-stained, waxy	1	7					
4. Bentonite, gray, waxy; thin veins of fibrous calcite	1	1	5	1	3-5	3-5	---
5. Bentonite, light-bluish-gray, waxy; dark mineral particles	2	4					
6. Shale, dark-gray, soft	---	---	---	---	---	---	---
LOCALITY 40, SECTION 16 [Nos. 3 and 4 from Clay Spur bentonite bed]							
1. Shale, dark-gray	10+	--	---		---	---	---
2. Shale, dark-gray, bentonitic		4	---		---	---	---
3. Bentonite, dark-gray, waxy	1	1	1	11	3, 4	3, 4	---
4. Bentonite, gray, waxy, gypsiferous		10					
5. Shale, dark-gray, siliceous	---	---	---	---	---	---	---

[1] Test data for material 2 are given in table 4.

Sections measured in T. 57 N., R. 62 W.—Continued

Description of materials	*Thickness*				*Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4)*		
	All beds		*Bentonite only*		*Green strength ≧8 psi*	*Dry strength ≧50 psi*	*Yield ≧90 bbls per ton*
	Ft	*in*	*Ft*	*in*			
LOCALITY 41, SECTION 21							
[Nos. 3 and 4 from bed E]							
1. Shale, dark-gray, soft	2	5	---	---	--------	--------	---------
2. Shale, dark-brown, bentonitic		3	---	---	--------	--------	---------
3. Bentonite, dark-gray, waxy		6	1	9	3, 4	3, 4	---------
4. Bentonite, gray, waxy; dark mineral particles	1	3					
5. Shale, dark-gray, soft	---	---	---	---	--------	--------	---------
LOCALITY 42, SECTION 23							
[Nos. 2-7 from bed F]							
1. Shale, dark-gray, soft	1	1	---	---	--------	--------	---------
2. Bentonite, light-gray, limonite-stained, waxy	1	0	4	10	2, 3, 4, 6, 7, 2-7	2, 3, 4, 5, 6, 7, 2-7	---------
3. Bentonite, light-gray, waxy, gypsiferous; dark mineral particles	2	6					
4. Bentonite, reddish-brown, waxy; dark mineral particles		6					
5. Bentonite, light-gray, waxy; dark mineral particles		1					
6. Bentonite, reddish-brown, waxy; dark mineral particles		4					
7. Bentonite, brownish-gray, waxy; limonite stained in lower part		5					
8. Shale, dark-gray, soft	---	---	---	---	--------	--------	---------
LOCALITY 43, SECTION 33							
[Nos. 2-6 from Clay Spur bentonite bed]							
1. Shale, dark-gray	1	0	--	----	--------	--------	---------
2. Bentonite, interlaminated brown and gray, waxy, gypsiferous	1	10	7	2	2-3, 5, 4-6	2-3, 5, 6	5, 4-6
3. Bentonite, interlaminated olive-green and grayish-brown, waxy	1	5					
4. Bentonite, olive-green, waxy; a few dark-gray laminae	1	4					
5. Bentonite, olive-green, waxy, gypsiferous; dark mineral particles	2	1					
6. Bentonite, olive-green, limonite-stained, waxy		6					
7. Shale, dark-gray, siliceous, hard	--	----	--	----	--------	--------	---------
LOCALITY 44, SECTION 36							
[Nos. 4-5 from bed D; 7-12 from Clay Spur bentonite bed]							
1. Shale, dark-gray, soft	--	----	--	----	--------	--------	---------
2. Bentonite, cream, waxy		1½		1½	--------	--------	---------
3. Shale, dark-gray, bentonitic		5	--	----	--------	--------	---------
4. Bentonite, light-gray; dark-gray laminae in upper part; dark mineral particles		7		11½	--------	--------	---------
5. Bentonite, olive-green, waxy		4½					
6. Shale, dark-gray; siliceous in lower part	5	7	--	----	--------	--------	---------
7. Bentonite, dark-gray, waxy; a few light-gray laminae	1	8	3	11	7, 8-12	7	---------
8. Bentonite, light-gray, waxy; a few dark-gray laminae		7					
9. Bentonite, bluish-gray, waxy		2					
10. Bentonite, light-bluish-gray, waxy		4					
11. Bentonite, light-gray, waxy		11					
12. Bentonite, light-gray; two thin beds of bluish-gray, waxy bentonite in lower part		3					
13. Shale, dark-gray, siliceous	--	----	--	----	--------	--------	---------
LOCALITY 45, SECTION 36							
[Nos. 2-5 from Clay Spur bentonite bed]							
1. Shale, dark-gray		6	--	----	--------	--------	---------
2. Bentonite, dark-gray, waxy; olive-green laminae in lower part	2	1	4	3	2-3, 4-5	2-3, 4-5	4-5
3. Bentonite, olive-green, waxy; dark-gray laminae		4					
4. Bentonite, olive-green, waxy, limonite-stained, gypsiferous	1	5					
5. Bentonite, grayish-green, waxy		5					
6. Shale, dark-gray	--	----	--	----	--------	--------	---------

T. 57 N., RS. 63 AND 64 W.

The strata cropping out in this area belong to the Fuson member of the Lakota formation, the Belle Fourche shale, and the intervening units. The overall dip is northeastward and gentle. The bentonite-bearing strata of the Newcastle and Mowry formations are extensively exposed in the northeastern part but have been removed by erosion in the rest of the area. The outcrop of bed A, in the Newcastle sandstone, is believed to be continuous for several miles in the southeastern, central, and northwestern parts of T. 57 N., R. 63 W., and occurs in two outliers in secs. 1 and 12, T. 57 N., R. 64 W. The Clay Spur bentonite bed is exposed in outliers northeast of bed A. Bed A and the Clay Spur bed are present beneath less than 30 feet of cover in several areas that are large enough to be regarded as potential strip-mining sites.

T. 57 N., R. 65 W.

The bedrock cropping out in this township includes strata of the Fall River formation, Belle Fourche shale, and the intervening units. The rocks are gently folded with overall northwestward dip. The beds of the Newcastle and Mowry formations, which are extensively exposed in the northwestern part of the township, have been entirely removed by erosion in the southeastern part. Areas in which bentonite bed A and the Clay Spur bentonite bed are present under less than 30 feet of cover are extensive, and some bentonite had been mined from both beds at the time (1948) of our examination. Bentonite samples from the Clay Spur bed taken at three localities showed (table 4) green and dry strengths adequate for foundry-sand bonding clay. One of these samples appears also to fulfill the test requirements for commercial drilling-mud bentonite.

Sections measured in T. 57 N., R. 65 W.

Description of materials	*Thickness*				*Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4)*		
	All beds		*Bentonite only*		*Green strength ≧8 psi*	*Dry strength ≧50 psi*	*Yield ≧90 bbls per ton*
LOCALITY 33, SECTION 5 [Nos. 2–6 from Clay Spur bentonite bed]	*Ft*	*in*	*Ft*	*in*			
1. Shale, dark-gray, siliceous	--	10	---	---	--------	--------	---------
2. Bentonite, dark-gray, impure	--	5					
3. Bentonite, interlaminated light-gray and dark-gray, waxy	--	6					
4. Bentonite, light-gray, waxy, limonite-stained, gypsiferous; a few dark-gray laminae	--	10	3	5	2–3, 4–6	4–6	--------
5. Bentonite, olive-green, waxy; some limonite stains	1	4					
6. Bentonite, greenish-gray, waxy; some dark mineral particles; half an inch at base has cornmeal texture and rather light color	--	4					
7. Shale, dark-gray, siliceous	--	--	---	---	--------	--------	---------

Sections measured in T. 57 N., R. 65 W.—Continued

Description of materials	*Thickness*				*Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4)*		
	All beds		*Bentonite only*		*Green strength ≧8 psi*	*Dry strength ≧50 psi*	*Yield ≧90 bbls per ton*
	Ft	*in*	*Ft*	*in*			
LOCALITY 34, SECTION 7							
[Nos. 2–6 from Clay Spur bentonite bed]							
1. Shale, dark-gray siliceous	--	11	---	---	--------	--------	---------
2. Bentonite, brownish-gray, waxy	--	3					
3. Bentonite, light-gray, waxy	--	3					
4. Bentonite, interlaminated olive-green and dark-gray, waxy	--	5	2	10	3–6	3–6	--------
5. Bentonite, olive-green, waxy, gypsiferous	1	7					
6. Bentonite, gray, waxy, limonite-stained; 1 inch at base has cornmeal texture	--	4					
7. Shale, dark-gray, siliceous	--	--	---	---	--------	--------	---------
LOCALITY 35, SECTION 10							
[Nos. 2–8 from Clay Spur bentonite bed]							
1. Shale, dark-gray, fissile, siliceous	1	1	---	---	--------	--------	---------
2. Bentonite, dark-gray, weathered		4					
3. Bentonite, interlaminated dark-gray and light-gray, waxy, gypsiferous	1	5					
4. Bentonite, light-greenish-gray, waxy, gypsiferous; many dark-gray laminae	1	7					
5. Bentonite, olive-green, waxy; a few dark-gray laminae	1	6	6	11	2–4, 5–7	2–4, 5–7	5–7
6. Bentonite, olive-green, waxy, gypsiferous; some limonite stains	1	8					
7. Bentonite, greenish-gray, waxy; dark mineral particles	--	4½					
8. Bentonite, very light greenish-gray; cornmeal texture	--	½					
9. Shale, dark-gray, siliceous	--	--	---	---	--------	--------	---------
LOCALITY C, SECTION 11							
[No. 4 from bed A]							
1. Siltstone, brown, sandy, thin-bedded, soft	5	0	--------		--------	--------	---------
2. Sandstone, buff, fine-grained; forms resistant ledge; rust-colored ironstone concretions in lower part	1	6	---	---	--------	--------	---------
3. Siltstone, light-yellowish-gray, soft, argillaceous	14	0	---	---	--------	--------	---------
4. Bentonite, olive-green, waxy	2	1	2	1	--------	--------	---------
5. Shale, dark-gray, hard, platy; much coaly material		2	---	---	--------	--------	---------
6. Shale, light-gray and yellow, silty, soft; thin siltstone beds	10	6	---	---	--------	--------	---------
7. Bentonite, olive-green, waxy	1	8	1	8	--------	--------	---------
8. Shale, dark-gray, hard; carbonaceous material in upper part		11	---	---	--------	--------	---------
9. Shale, light-gray and tan, silty. hard	11	0	---	---	--------	--------	---------
10. Covered	---	---	---	---	--------	--------	---------
LOCALITY D, SECTION 20							
[Nos. 7–9 from bed A]							
1. Siltstone, light-gray, soft	5	0	---	---	--------	--------	---------
2. Siltstone, dark-brown, platy; carbonaceous material	2	0	---	---	--------	--------	---------
3. Siltstone, gray, friable	2	6	---	---	--------	--------	---------
4. Sandstone, light-gray, fine-grained		4	---	---	--------	--------	---------
5. Shale, light-gray, silty	3	6	---	---	--------	--------	---------
6. Siltstone, light-gray; lower part is bentonitic	2	0	---	---	--------	--------	---------
7. Bentonite, olive-green, waxy	3	0					
8. Bentonite, brown, waxy; some carbonaceous material in lower part	2	10	6	1	--------	--------	---------
9. Bentonite, light-yellowish-gray, waxy		3					
10. Siltstone, gray, hard		2	---	---	--------	--------	---------
11. Siltstone, gray, soft	---	---	---	---	--------	--------	---------

T. 57 N., R. 66 W.

This township is occupied largely by the alluvial deposits along the flood plains of the Little Missouri River and Thompson Creek. The bedrock that crops out belongs to the Skull Creek and Carlile shales and the intervening units. The dip is mostly gentle and northwestward. Bentonite bed A crops out in the southeastern part of the township and the Clay Spur bentonite bed in the southern and eastern parts. Bed F crops out farther northwest in several of the areas in which the Belle Fourche shale is exposed. Bentonite bed A and the Clay Spur bentonite bed are under less than 30 feet of cover in broad areas and good potential strip-mining sites are believed to be present. However, no bentonite had been mined in this township at the time (1948) of our examination.

Section measured in T. 57 N., R. 66 W.

Description of materials	*Thickness*				*Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4)*		
LOCALITY B, SECTION 25	*All beds*		*Bentonite only*		*Green strength ≧8 psi*	*Dry strength ≧50 psi*	*Yield ≧90 bbls per ton*
[No. 3 from bed A]	*Ft*	*in*	*Ft*	*in*			
1. Siltstone, light-gray	--	--	--	--	-------	-------	-------
2. Shale, dark-brown, carbonaceous, silty, soft	--	3	--	--	-------	-------	-------
3. Bentonite, gray, waxy; thin dark-gray impure bentonite zones at top and at base; veins of fibrous calcite	3	11	3	11	-------	-------	-------
4. Siltstone, dark-gray; carbonaceous material	--	4	--	--	-------	-------	-------
5. Shale, light-gray, silty	2	10	--	--	-------	-------	-------
6. Shale, light-yellowish-brown, bentonitic	3	0	--	--	-------	-------	-------

T. 57 N., R. 67 W.

The bedrock cropping out in this township belongs to the Belle Fourche shale, the Gammon ferruginous member of the Pierre shale, and the intervening units. The dip is gentle and northwestward in most of the township; in the extreme southwestern part it is westward and somewhat steeper. Bed F lies under less than 30 feet of cover in three relatively small areas within 2 miles of the southeast corner of the township.

T. 58 N., RS. 60 AND 61 W.

The west edge of this elongated area along the Montana boundary is crossed by the northward-plunging axis of the Colony anticline. Bentonite bed F, in the uppermost part of the Belle Fourche shale, is under less than 30 feet of cover in a comparatively narrow belt in secs. 31 and 32.

T. 58 N., R. 62 W.

This tract occupies a little more than 12 square miles adjacent to the Montana boundary; it includes a part of the Bull Creek anticline and parts of the synclines that flank this anticline on both sides. Outcropping strata include those of the Belle Fourche shale, the Sage Breaks shale member of the Carlile shale, and the intervening units. Beds F and G are the only bentonite beds of possible economic value. Several areas in which bed F is under less than 30 feet of cover are broad enough to be regarded as prospective strip-mining sites.

Sections measured in T. 58 N., R. 62 W.

Description of materials	Thickness: All beds Ft	Thickness: All beds in	Thickness: Bentonite only Ft	Thickness: Bentonite only in	Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4): Green strength ≧8 psi	Dry strength ≧50 psi	Yield ≧90 bbls per ton
LOCALITY 31, SECTION 29 [Nos. 2–6 from bed G]							
1. Clay, brown, soft	1	1	--	--	--------	--------	--------
2. Bentonite, dark-brownish-gray, gypsiferous; mineral particles	4	3					
3. Bentonite, brown, waxy; numerous tiny mica flakes	--	8					
4. Bentonite, light-gray, waxy, gypsiferous	--	6					
5. Bentonite, light-gray, limonite-stained; many mineral particles	--	10	6	9	3	2, 3, 2–6	--------
6. Bentonite, light-bluish-gray, gypsiferous; limonite-stained in the lower part	--	6					
7. Shale, dark-brownish-gray	--	--	--	--	--------	--------	--------
LOCALITY 32, SECTION 31 [Nos. 2–9 from bed G]							
1. Shale, brown, weathered	--	6	--	--	--------	--------	--------
2. Clay, dark-brown, soft	1	3					
3. Bentonite, brown, impure	--	7					
4. Bentonite, gray and brown, granular	1	6					
5. Bentonite, grayish-brown, waxy	--	10					
6. Bentonite, gray, waxy	--	11	[1] 5	8	--------	2–3, 4–9	--------
7. Bentonite, light-yellow, granular	--	2½					
8. Bentonite, dark-rusty-brown, limonite-stained, waxy	--	3½					
9. Bentonite, reddish-gray, granular	--	1					
10. Shale, dark-brownish-gray, soft	--	--	--	--	--------	--------	--------

[1] Material 2 is included because it is part of the composite material tested.

T. 58 N., RS. 63 AND 64 W.

Most of this elongated tract of about 25 square miles adjacent to the Montana boundary is occupied by alluvial deposits of Quaternary age. The outcropping bedrock belongs to the Skull Creek and Belle Fourche shales and the intervening units. Bentonite bed A and the Clay Spur bentonite bed are under less than 30 feet of cover in several areas large enough to be regarded as prospective strip-mining sites. Bentonite samples (table 4) taken at 1 locality from bed A and at 2 localities from the Clay Spur bed in the eastern half of the tract showed green and dry strengths adequate for foundry-sand bonding clay; one sample from an outcrop of bed B at locality 30 showed high green strength but low dry strength. Bed B, as exposed at locality 30, is described further on page 970. At the time (1948) of our examination, bentonite from bed A had been mined from 1 pit at locality 27 in sec. 32, R. 63 W., and that from the Clay Spur bed, from 3 pits farther east in secs. 33 and 34, T. 58 N., R. 63 W.

Sections measured in T. 58 N., R. 63 W.

Description of materials	Thickness: All beds Ft	Thickness: All beds in	Thickness: Bentonite only Ft	Thickness: Bentonite only in	Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4): Green strength ≧8 psi	Dry strength ≧50 psi	Yield ≧90 bbls per ton
LOCALITY 27, SECTION 32							
[Nos. 2-4 from bed A]							
1. Sandstone, gray, soft, friable; bentonitic at base	--	--	--	--	--------	--------	--------
2. Bentonite, brownish-gray, waxy	2	0					
3. Bentonite, greenish-gray, waxy	3	6	5	9	3-4	2, 3-4	--------
4. Bentonite, light-gray, waxy		3					
5. Sandstone, gray	--	--	--	--	--------	--------	--------
LOCALITY 28, SECTION 33							
[Nos. 2-5 from Clay Spur bentonite bed]							
1. Shale, dark-gray, siliceous; weathers light gray	1		--	--	--------	--------	--------
2. Bentonite, dark-gray, impure		3					
3. Bentonite, interlaminated dark-gray and light-gray, waxy		8					
4. Bentonite, light-gray, waxy; a few dark-gray laminae	1	4	4	0	2-3, 4-5	4-5	--------
5. Bentonite, olive-green, waxy; 1 in. of gypsiferous bentonite at base has cornmeal texture	1	9					
6. Shale, dark-gray, siliceous	--	--	--	--	--------	--------	--------
LOCALITY 29, SECTION 34							
[Nos. 2-5 from Clay Spur bentonite bed]							
1. Shale, dark-gray, weathered		10	--	--	--------	--------	--------
2. Bentonite, dark-gray, weathered; a few light-gray laminae		10					
3. Bentonite, light-greenish-gray, waxy; a few dark-gray laminae		9					
4. Bentonite, olive-green, waxy, gypsiferous; a few dark-gray laminae	1	1	4	8	2-3, 4-5	2-3, 4-5	--------
5. Bentonite, olive-green, waxy, gypsiferous; half an inch of gray bentonite at base	2	0					
6. Shale, dark-gray, siliceous	--	--	--	--	--------	--------	--------
LOCALITY 30, SECTION 34							
[Nos. 3 and 4 from bed B]							
1. Shale, dark-gray, siliceous		11	--	--	--------	--------	--------
2. Shale, dark-brown, bentonitic, soft		5	--	--	--------	--------	--------
3. Bentonite, brown, granular		3		8	3-4	--------	--------
4. Bentonite, very light brown, granular		5					
5. Shale, dark-gray, siliceous	--	--	--	--	--------	--------	--------

T. 58 N., R. 65 W.

The bedrock cropping out in this elongated tract of about 13 square miles includes strata of the Skull Creek, Newcastle, and Belle Fourche formations. The Clay Spur bentonite bed lies under less than 30 feet of overburden in areas that total more than 3 square miles. Samples (table 4) taken from two localities on the outcrop tested as suitable for use as foundry-sand bonding clay and as an ingredient of drilling mud. At the time (1948) of our examination, bentonite had been mined from two pits in secs. 25 and 26.

Sections measured in T. 58 N., R. 65 W.

Description of materials	Thickness: All beds Ft	in	Bentonite only Ft	in	Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4): Green strength ≧8 psi	Dry strength ≧50 psi	Yield ≧90 bbls per ton
LOCALITY 25, SECTION 27							
[Nos. 2–6 from bed E]							
1. Shale, dark-gray, soft		11	---	---	--------	--------	--------
2. Bentonite, dark-gray and brown, weathered, impure, gypsiferous	2	5					
3. Bentonite, dark-gray, waxy		10	3	9	--------	2–3, 4–5	4–5
4. Bentonite, gray, waxy; dark mineral particles		4					
5. Bentonite, dark-brown, limonite-stained, granular		2					
6. Shale, dark-gray, hard	---	---	---	---	--------	--------	--------
LOCALITY 26, SECTION 34							
[Nos. 2–6 from Clay Spur bentonite bed]							
1. Shale, dark-gray, siliceous	2	0	---	---	--------	--------	--------
2. Shale, dark-gray, bentonitic		5					
3. Bentonite, dark-gray; limonite-stained in upper part		6					
4. Bentonite, light-gray, waxy; some limonite stains; a few dark mineral particles		6	[1]2	5	4–6	4–6	--------
5. Bentonite, cream, waxy		6					
6. Bentonite, light-gray, waxy; 1 in. at base has corn-meal texture		6					
7. Shale, dark-gray, siliceous	---	---	---	---	--------	--------	--------

[1] Material 2 is included because it is part of the composite material tested.

T. 58 N., R. 66 W.

The bedrock cropping out in this elongate tract of about 13 square miles belongs to the Belle Fourche, Greenhorn, and Carlile formations. The strata dip very gently northwestward. Outcrops of beds F and G extend generally northeastward across the eastern half of the tract. Tests of samples (table 4) from three localities indicate that bed F contains material that is usable as foundry-sand bonding clay. The bed appears to be sufficiently thick to warrant consideration as a possible source of commercial bentonite. The belt, however, in which the bentonite lies at depths that are within reach of strip-mining equipment, is comparatively narrow.

Sections measured in T. 58 N., R. 66 W.

Description of materials	Thickness: All beds Ft	in	Bentonite only Ft	in	Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4): Green strength ≧8 psi	Dry strength ≧50 psi	Yield ≧90 bbls per ton
LOCALITY 22, SECTION 24							
[Nos. 2–6 from bed F]							
1. Shale, dark-gray, soft	1	3	--------		--------	--------	--------
2. Bentonite, dark-brown, limonite-stained, gypsiferous, weathered		7					
3. Bentonite, light-brownish-gray, gypsiferous; texture is flaky in upper part, grading downward to waxy; half an inch thick vein of light-green fibrous calcite in lower part	3	7	5	0	2	3–6	--------
4. Bentonite, light-gray, waxy; dark mineral particles		2					
5. Bentonite, dark-brownish-red, waxy		7					
6. Bentonite, light-gray		1					
7. Shale, dark-gray, soft	--	----	----	--	--------	--------	--------

Sections measured in T. 58 N., R. 66 W.—Continued

Description of materials	*Thickness*				*Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4)*		
LOCALITY 23, SECTION 35 [Nos. 2-8 from bed F]	*All beds*		*Bentonite only*		*Green strength ≧8 psi*	*Dry strength ≧50 psi*	*Yield ≧90 bbls per ton*
	Ft	*in*	*Ft*	*in*			
1. Shale, dark-gray, soft		10	--	--	--	--	--
2. Bentonite, dark-brownish-gray, weathered		4					
3. Bentonite, light-brown, limonite-stained, waxy		7					
4. Bentonite, gray, waxy; limonite stained in upper part		4					
5. Bentonite, light-gray, waxy, gypsiferous; some limonite stains; dark mineral particles and a few thin fibrous calcite veins	2	9	5	11	3-8	3-8	--
6. Bentonite, light-gray, waxy; dark mineral particles	1	1					
7. Bentonite, dark-reddish-brown, waxy, gypsiferous		8					
8. Bentonite, gray, waxy; dark mineral particles		2					
9. Shale, dark-gray, soft	--	--	--	--	--	--	--
LOCALITY 24, SECTION 36 [Nos. 2-7 from bed F]							
1. Shale, dark-gray, soft		10	--	--	--	--	--
2. Bentonite, brownish-gray, limonite-stained		4		4	--	--	--
3. Shale, dark-gray, soft	1	0	--	--	--	--	--
4. Bentonite, waxy, gypsiferous; limonite stained in upper part	1	3					
5. Bentonite, light-gray, waxy, gypsiferous; dark mineral particles	1	0	3	0	4-7	4-7	--
6. Bentonite, reddish-brown, waxy; dark mineral particles		7½					
7. Bentonite, gray, waxy; granular at base		1½					
8. Shale, dark-gray, soft	--	--	--	--	--	--	--

T. 58 N., R. 67 W.

The exposed bedrock in this elongated tract of about 13 square miles includes strata of the Carlile shale, and the Gammon ferruginous and Mitten black shale members of the Pierre shale. The overall dip is very gentle and northwestward. At the base of the Mitten, which is exposed in the northwest corner of the tract, bed I crops out for about 1½ miles.

Section measured in T. 58 N., R. 67 W.

Description of materials	*Thickness*				*Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4)*		
LOCALITY A, SECTION 30 [Nos. 2-6 from bed I]	*All beds*		*Bentonite only*		*Green strength ≧8 psi*	*Dry strength ≧50 psi*	*Yield ≧90 bbls per ton*
	Ft	*in*	*Ft*	*in*			
1. Shale, dark-brownish-gray, weathered	1	0	--	--	--	--	--
2. Bentonite, yellow, granular; some dark mineral grains		10½		10½	--	--	--
3. Shale, dark-gray, soft		2	--	--	--	--	--
4. Bentonite, yellow, limonite-stained, granular		1½		1½	--	--	--
5. Shale, dark-gray, soft		1½	--	--	--	--	--
6. Bentonite, yellow, granular; dark mineral particles and some gypsum	1	5	1	5	--	--	--
7. Shale, dark-gray, soft	--	--	--	--	--	--	--

CARTER COUNTY, MONT.

T. 7 S., R. 56 E.

This township (figs. 74 and 92) lies north of the area mapped on plate 60. The bedrock cropping out belongs to the Pierre shale, except in a narrow strip along the west margin of the township, where

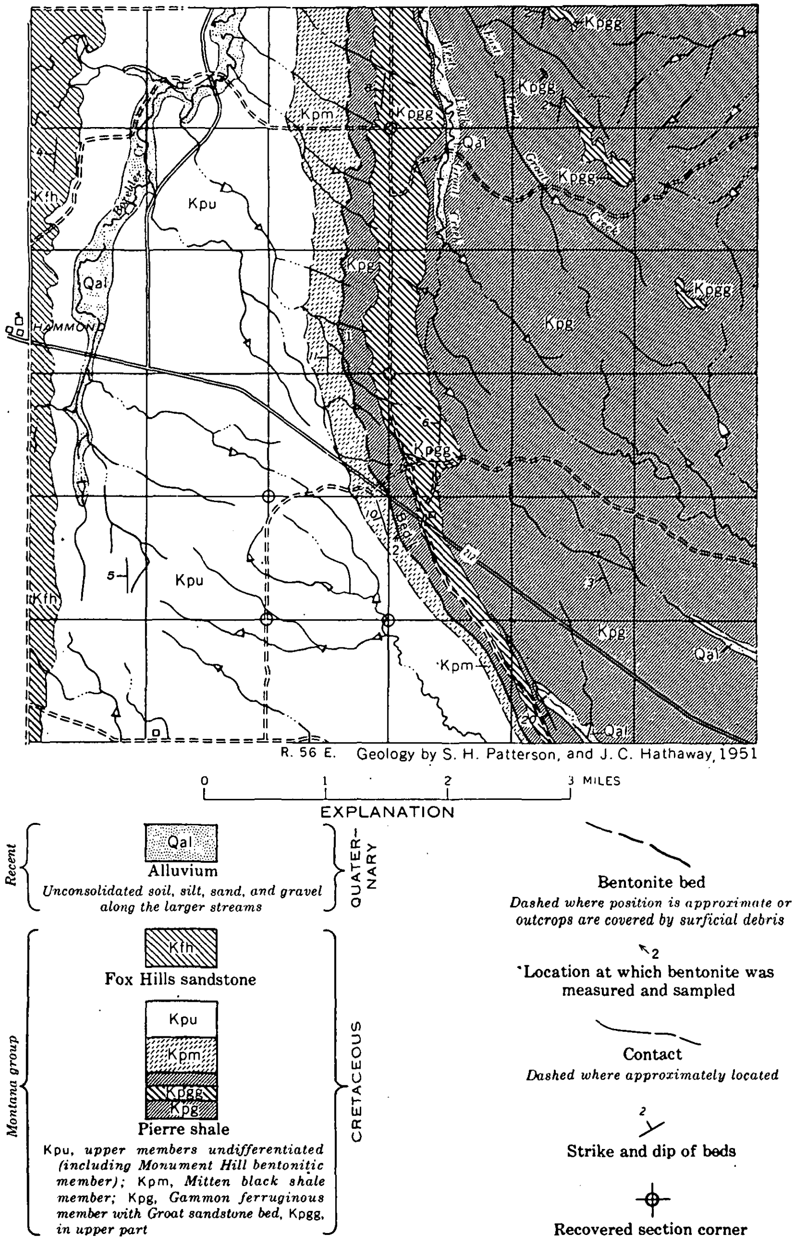


FIGURE 92.—Geologic map of T. 7 S., R. 56 E., Carter County, Mont., showing outcrop of bentonite bed I at the base of the Mitten black shale member of the Pierre shale.

the Fox Hills sandstone is exposed. The dip of the strata is gentle to moderate and westward. The outcrop of bentonite bed I, at the base of the Mitten black shale member, extends northward across the central part of the township, where the presence of material with high green strength, suitable for use as foundry-sand bonding clay, is indicated by tests of samples (table 4) taken from two localities. Farther west, in the part of the Pierre shale between the Mitten and the Fox Hills sandstone, are outcrops of the Monument Hill bentonitic member of the Pierre; the several bentonite beds contained in this member, however, are so thin or impure that they are of little or no interest as prospective sources of commercial bentonite.

Sections measured in T. 7 S., R. 56 E.[1]

Description of materials	Thickness: All beds Ft	Thickness: All beds in	Thickness: Bentonite only Ft	Thickness: Bentonite only in	Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4): Green strength ≧8 psi	Dry strength ≧50 psi	Yield ≧90 bbls per ton
LOCALITY 1, SECTION 16[1] [Nos. 2-13 from bed I]							
1. Shale, dark-brown	3	9	--	--	--------	--------	--------
2. Bentonite, yellowish-gray		1		1	--------	--------	--------
3. Shale, dark-brown, limonite stained	2	1½	--	--	--------	--------	--------
4. Bentonite, brown and yellow, granular		2	}	2½	4-5	--------	--------
5. Bentonite, cream, granular		½	}				
6. Shale, dark-brown		3	--	--	--------	--------	--------
7. Bentonite, yellow, granular		2		2	--------	--------	--------
8. Shale, dark-brown		7½	--	--	--------	--------	--------
9. Bentonite, brown, granular		½	}				
10. Bentonite, brownish-yellow, granular		2	}				
11. Bentonite, brown, granular		2½	2	3½	10-13	--------	--------
12. Bentonite, brown and yellow, granular		1	}				
13. Bentonite, yellow, granular	1	9½	}				
14. Shale, dark-brownish-gray	--	--	--	--	--------	--------	--------
LOCALITY 2, SECTION 27[1] [Nos. 2-10 from bed I]							
1. Shale, brown, weathered	1	11	--	--	--------	--------	--------
2. Bentonite, light-brown, granular, gypsiferous	1	0	}				
3. Bentonite, light-brown, granular, gypsiferous		2	2	1	2-4	--------	--------
4. Bentonite, cream, granular, gypsiferous		11	}				
5. Shale, brown		10½	--	--	--------	--------	--------
6. Shale, light-brown, bentonitic		2½	--	--	--------	--------	--------
7. Shale, dark-gray		7	--	--	--------	--------	--------
8. Bentonite, light-gray, impure		2		2	--------	--------	--------
9. Bentonite, yellowish-gray, granular, gypsiferous		7	}				
10. Bentonite, light-yellowish-gray, granular; limonite-stained at base		6	1	1	9-10	--------	--------
11. Shale, dark-brown	--	--	--	--	--------	--------	--------

[1] See fig. 92.

T. 9 S., R. 57 E.

The bedrock cropping out in the part of this township that is mapped on plate 60 belongs to the Belle Fourche, Greenhorn, and Carlile formations. The overall dip is northwestward and very gentle. Bentonite bed F crops out, with only a few interruptions, from sec. 33 northeastward to sec. 1. Tests of samples (table 4) of the bentonite from two localities on this bed indicate presence of material well suited for use as foundry-sand bonding clay, but the areas in which the bentonite is accessible to strip-mining equipment are rather narrow and the bentonite had not been mined at the time (1948) of our examination. Bed G crops out parallel to bed F as far northeast as a locality in sec. 15, beyond which it could not be traced; it offers no promising strip-mining sites.

Sections measured in T. 9 S., R. 57 E.

Description of materials	*Thickness*				*Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4)*		
	All beds		*Bentonite only*		*Green strength ≥8 psi*	*Dry strength ≥50 psi*	*Yield ≥90 bbls per ton*
	Ft	*in*	*Ft*	*in*			
LOCALITY 3, SECTION 12 [Nos. 2-8 from Bed F]							
1. Shale, dark-gray soft	1	11	---	---	--------	--------	--------
2. Bentonite, dark-gray, waxy, weathered		5					
3. Bentonite, brown, limonite-stained, waxy		4					
4. Bentonite, gray, waxy; dark mineral particles and some red mottling	2	11	5	5	2-3, 4-8	2-3, 4-8	--------
5. Bentonite, gray, limonite-stained, waxy		1					
6. Bentonite, slightly pinkish gray, waxy		7					
7. Bentonite, reddish-gray, waxy	1	0					
8. Bentonite, gray, waxy		1					
9. Shale, dark-gray, soft	---	---	---	---	--------	--------	--------
LOCALITY 4, SECTION 26 [Nos. 2-10 from Bed F]							
1. Shale, dark-gray	2	9	---	---	--------	--------	--------
2. Shale, dark-brown, bentonitic		4					
3. Bentonite, brown, waxy		5					
4. Bentonite, brownish-gray, waxy; dark mineral particles		3					
5. Bentonite, brownish-red, waxy		3					
6. Bentonite, light-gray, waxy; some limonite stains	2	3	[1]5		4-10	2-3, 4-10	--------
7. Bentonite, pinkish-gray, waxy		8					
8. Bentonite, light-gray, waxy		4					
9. Bentonite, pinkish-gray, waxy		5					
10. Bentonite, light-gray, waxy		3					
11. Shale, dark-gray, soft	---	---	---	---	--------	--------	--------

[1] Material 2 is included because it is part of composite material tested.

T. 9 S., R. 58 E.

The bedrock exposed in this township belongs to the Mowry, Belle Fourche, and Greenhorn formations. The overall dip is northward at a low angle, with the strata folded slightly in the southern part of the township, where the Clay Spur bentonite bed lies at shallow depth beneath extensive areas. Samples from eight localities along its outcrop indicate a large content of material suitable for use as foundry-sand bonding clay and as an ingredient of drilling mud. At the time of our examination (1948), bentonite from this bed had been mined in several pits in sec. 25 and 36, and there appeared to be many other attractive strip-mining sites. Samples taken from bentonite bed D, a few feet above the Clay Spur bentonite bed, at two localities gave good results (table 4) when tested as foundry-sand bonding clay. One of the samples from locality 14, sec. 36, showed an unusually high yield when tested for use in drilling mud. Bentonite bed F crops out in many localities within the northern part of the township, where it lies under light cover in several rather narrow areas; tests of samples from two localities indicate that bed F contains material suitable for use as foundry-sand bonding clay. Bentonite bed G crops out in sec. 1, but offers no attractive mining sites.

Sections measured in T. 9 S., R. 58 E.

Description of materials	Thickness: All beds Ft	All beds in	Bentonite only Ft	Bentonite only in	Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4): Green strength ≧8 psi	Dry strength ≧50 psi	Yield ≧90 bbls per ton
LOCALITY 5, SECTION 11							
[Nos. 2–7 from bed F]							
1. Shale, dark-gray, soft		11	---	---	--------	--------	--------
2. Bentonite, dark-brown, weathered		3					
3. Bentonite, light-gray, limonite-stained		9					
4. Bentonite, light-gray, waxy	1	5					
5. Bentonite, yellow, limonite-stained, waxy		6	5	6	2–3, 4–7	4–7	--------
6. Bentonite, gray, waxy		3					
7. Bentonite, light-bluish-gray, waxy	2	4					
8. Shale, dark-gray, soft	---	---	---	---	--------	--------	--------
LOCALITY 6, SECTION 12							
[Nos. 2–6 from Bed F]							
1. Shale, dark-gray, hard	1	10	---	---	--------	--------	--------
2. Bentonite, dark-brown, waxy, weathered		3½					
3. Bentonite, light-gray, limonite-stained, waxy		4½					
4. Bentonite, light-gray, waxy; veins of fibrous calcite as much as half an inch thick	2	4	4	8	2–3, 4–6	2–3	--------
5. Bentonite, light-bluish-gray; a few gray laminae in lower part; dark mineral particles	1	0					
6. Bentonite, rusty-brown, waxy		8					
7. Shale, dark-gray, soft	---	---	---	---	--------	--------	--------
LOCALITY 7, SECTION 25							
[Nos. 2–4 from bed D; 6–9 from Clay Spur bentonite bed]							
1. Shale, dark-gray, soft		6	---	---	--------	--------	--------
2. Bentonite, light-gray		4					
3. Bentonite, cream		1	1	1	--------	--------	--------
4. Bentonite, salmon		8					
5. Shale, dark-gray; siliceous laminae in lower part	4	7	---	---	--------	--------	--------
6. Bentonite, light-greenish-gray		8					
7. Bentonite, olive-green, waxy, gypsiferous; dark-gray laminae	1	8	3	9	6–7, 8–9	6–7, 8, 9, 8–9	8, 9, 8–9
8. Bentonite, yellowish-green, waxy		7					
9. Bentonite, greenish-gray, waxy		10					
10. Shale, dark-gray, siliceous, hard	---	---	---	---	--------	--------	--------
LOCALITY 8, SECTION 25							
[Nos. 1–7 from Clay Spur bentonite bed]							
1. Shale, drak-gray, siliceous	1	7	---	---	--------	--------	--------
2. Bentonite, dark-gray, weathered		8					
3. Bentonite, interlaminated brown and gray, waxy		4					
4. Bentonite, cream, limonite-stained		4					
5. Bentonite, very light greenish-gray, waxy, gypsiferous; some limonite stains		9	3	6	4–7	2–3, 4–7	--------
6. Bentonite, greenish-gray, waxy		5					
7. Bentonite, light-bluish-gray; half an inch limonite-stained stratum at base has cornmeal texture; the rest is waxy.	1	0					
8. Shale, dark-gray, siliceous	---	---	---	---	--------	--------	--------
LOCATION 9, SECTION 26							
[Nos. 2–7 from Clay Spur bentonite bed]							
1. Shale, dark-gray, siliceous	1	4	---	---	--------	--------	--------
2. Bentonite, dark-gray, weathered	1	5					
3. Bentonite, interlaminated dark-gray and very light olive-green, waxy.		9					
4. Bentonite, interlaminated gray and grayish-green, waxy.		8	4	5	4–7	2–3, 4–7	4–7
5. Bentonite, light-olive-green, waxy		5					
6. Bentonite, olive-green, waxy		6					
7. Bentonite, gray, waxy; 1-inch light-gray stratum at base has cornmeal texture.		8					
8. Shale, dark-gray, siliceous, hard	---	---	---	---	--------	--------	--------
LOCALITY 10, SECTION 27							
[Nos. 2–5 from Clay Spur bentonite bed]							
1. Shale, dark-gray, siliceous		11	---	---	--------	--------	--------
2. Bentonite, dark-gray, weathered		4					
3. Bentonite, light-olive-green, waxy; a few light-gray laminae.		10					
4. Bentonite, light-olive-green, waxy		10	3	1	3–5	3–5	3–5
5. Bentonite, greenish-gray, waxy; rather dark in lower part; ½-inch stratum at base has cornmeal texture.	1	1					
6. Shale, dark-gray, siliceous, hard	---	---	---	---	--------	--------	--------

Sections measured in T. 9 S., R. 58 E.—Continued

Description of materials	Thickness: All beds Ft	Thickness: All beds in	Thickness: Bentonite only Ft	Thickness: Bentonite only in	Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4): Green strength ≧8 psi	Dry strength ≧50 psi	Yield ≧90 bbls per ton
LOCALITY 11, SECTION 32							
[Nos. 2–5 from bed D; 7–10 from Clay Spur bentonite bed]							
1. Shale, dark-gray, soft	1	1	--	--	--------	--------	--------
2. Bentonite, cream, waxy		2					
3. Bentonite, dark-gray, waxy		2					
4. Bentonite, light-gray, waxy		9	1	4	2–5	2–5	--------
5. Bentonite, cream; cornmeal texture		3					
6. Shale, dark-gray, soft; hard siliceous laminae in lower part	5	0	--	--	--------	--------	--------
7. Bentonite, interlaminated olive-green and dark-gray, waxy		10					
8. Bentonite, olive-green, waxy	1	2					
9. Bentonite, greenish-gray, waxy		4	2	9	7, 8–10	7, 8–10	8–10
10. Bentonite, gray, waxy, half an inch stratum at base has cornmeal texture		5					
11. Shale, drak-gray, siliceous, hard	--	--	--	--	--------	--------	--------
LOCALITY 12, SECTION 33							
[Nos. 2–7 from Clay Spur bentonite bed]							
1. Shale, dark-gray, siliceous; weathers light gray	1	0	--	--	--------	--------	--------
2. Bentonite, interlaminated dark-gray and olive-green, waxy		6					
3. Bentonite, interlaminated olive-green and gray, waxy	1	10					
4. Bentonite, interlaminated olive-green and light-gray, waxy		7	4	7	2–3, 4–7	2–3, 4–7	2–3, 4–7
5. Bentonite, olive-green, waxy	1	0					
6. Bentonite, greenish-gray, waxy		5					
7. Bentonite, gray, limonite-stained; cornmeal texture		3					
8. Shale, dark-gray, siliceous	--	--	--	--	--------	--------	--------
LOCALITY 13, SECTION 34							
[Nos. 2–6 from Clay Spur bentonite bed]							
1. Shale, dark-gray, siliceous; weathers light gray	1	1	--	--	--------	--------	--------
2. Bentonite, dark-gray, waxy, weathered		11					
3. Bentonite, interlaminated dark-gray and olive-green, waxy	1	5					
4. Bentonite, olive-green, waxy	1	2	4	1	2–3, 4–6	2–3, 4–6	--------
5. Bentonite, greenish-gray, waxy		3					
6. Bentonite, gray, limonite-stained; cornmeal texture		4					
7. Shale, dark-gray, siliceous	--	--	--	--	--------	--------	--------
LOCALITY 14, SECTION 36							
[Nos. 2–4 from bed D; 6–9 from Clay Spur bentonite bed]							
1. Shale, dark-gray, soft	2	1	--	--	--------	--------	--------
2. Bentonite, brownish-gray and cream		2					
3. Bentonite, light-gray		8	1	5	2–4	2–4	2–4
4. Bentonite, cream; cornmeal texture		7					
5. Shale, dark-gray, soft; hard siliceous laminae in lower part	4	2	--	--	--------	--------	--------
6. Bentonite, brownish-gray		7					
7. Bentonite, brownish-gray and yellow		6					
8. Bentonite, yellowish-green, limonite-stained, gypsiferous; rather dark in upper part	2	10	4	5	--------	6–7, 8–9	8–9
9. Bentonite, light-green, waxy		6					
10. Shale, dark-gray, siliceous	--	--	--	--	--------	--------	--------
LOCALITY 15, SECTION 36							
[Nos. 2–5 from Clay Spur bentonite bed]							
1. Shale, dark-gray, siliceous		9	--	--	--------	--------	--------
2. Bentonite, dark-gray, waxy		8					
3. Bentonite, olive-green, waxy	1	11					
4. Bentonite, greenish-gray, waxy; somewhat darker in lower part		5	3	1	2, 3–5	2, 3–5	3–5
5. Bentonite, gray, limonite-stained; cornmeal texture		1					
6. Shale, dark-gray, siliceous, hard	--	--	--	--	--------	--------	--------

T. 9 S., RS. 59 AND 60 E.

This tract of about 54 square miles is largely occupied by alluvial deposits of Quaternary age. The bedrock that crops out belongs to the Mowry, Belle Fourche, and Greenhorn formations. The overall dip is northeastward and very gentle. The central part of T. 9 S., R. 60 E., is occupied by the northwestern end of the Bull Creek anticline and the syncline on its southwest side. In the southern part of T. 9 S., R. 59 E., the Clay Spur bentonite bed lies under a relatively thin cover in extensive areas, and tests of bentonite samples from four localities indicate that it contains material suitable for use as foundry-sand bonding clay and in drilling mud. The Clay Spur, however, had not been mined in this area at the time (1948) of our examination. Bentonite beds F and G crop out in the northern part of T. 9 S., R. 59 E., and in the south-central part of T. 9 S., R. 60 E.; tests of samples from two localities indicate that bed F contains material suitable for use as foundry-sand bonding clay.

Sections measured in T. 9 S., R. 59 E.

Description of materials	*Thickness*				*Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4)*		
	All beds		*Bentonite only*		*Green strength ≧8 psi*	*Dry strength ≧50 psi*	*Yield ≧90 bbls per ton*
	Ft	*in*	*Ft*	*in*			
LOCALITY 16, SECTION 7							
[Nos. 2–6 from bed F]							
1. Shale, dark-gray, hard	1	11	---	---	---	---	---
2. Bentonite, dark-brownish-gray, waxy; limonite-stained in lower part		8					
3. Bentonite, light-brownish-gray, waxy	1	4					
4. Bentonite, light-gray, waxy; dark mineral particles	2	2	5	6	2, 3–6	2, 3–6	---
5. Bentonite, reddish-gray, waxy; dark mineral particles		8					
6. Bentonite, grayish-red; dark mineral particles; 1-inch gray stratum at base has cornmeal texture		8					
7. Shale, dark-gray, soft	---	---	---	---	---	---	---
LOCALITY 17, SECTION 11							
[Nos. 5–9 from bed F]							
1. Shale, dark-gray and brown, soft	3	10	---	---	---	---	---
2. Shale, dark-grayish-brown, bentonitic		4	---	---	---	---	---
3. Bentonite, gray; cornmeal texture; dark mineral particles		5		5	---	---	---
4. Shale, dark-gray, soft	108	0	---	---	---	---	---
5. Bentonite, dark-brown, weathered		3					
6. Bentonite, light-grayish-brown, limonite-stained, waxy		10					
7. Bentonite, gray, limonite-stained, waxy		5	3	7	[1] 5–6, 8	[1] 8	---
8. Bentonite, light-gray, waxy, gypsiferous; dark mineral particles	1	7					
9. Bentonite, dark-reddish-gray, waxy		6					
10. Shale, dark-gray, soft	---	---	---	---	---	---	---
LOCALITY 18, SECTION 28							
[Nos. 2–4 from Clay Spur bentonite bed]							
1. Shale, dark-gray	1	0	---	---	---	---	---
2. Bentonite, dark-gray, waxy		9					
3. Bentonite, olive-green, limonite-stained, waxy		5	2	2	3–4	2, 3–4	3–4
4. Bentonite, light-grayish-green, waxy	1	0					
5. Shale, dark-gray, siliceous, hard	---	---	---	---	---	---	---

[1] Test data for composite material 7–9 are given in table 4.

Sections measured in T. 9 S., R. 59 E.—Continued

Description of materials	Thickness: All beds Ft	Thickness: All beds in	Bentonite only Ft	Bentonite only in	Green strength ≧8 psi	Dry strength ≧50 psi	Yield ≧90 bbls per to
					Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4)		
LOCALITY 19, SECTION 30							
[Nos. 2-6 from Clay Spur bentonite bed]							
1. Shale, dark-gray, soft		10	---	---	--------	--------	--------
2. Bentonite, brownish-gray, waxy		6	2	1	[1] 3-6	[1] 3-6	--------
3. Bentonite, olive-green; gray laminae in upper part		11					
4. Bentonite, light-greenish-gray, waxy		3					
5. Bentonite, gray, waxy		4½					
6. Bentonite, limonite-stained; cornmeal texture		½					
7. Shale, dark-gray, siliceous, hard	---	---	---	---	--------	--------	--------
LOCALITY 20, SECTION 34							
[Nos. 2-7 from Clay Spur bentonite bed]							
1. Shale, dark-gray, soft		11	---	---	--------	--------	--------
2. Bentonite, dark-gray, gypsiferous, weathered	1	3	4	3	2-3, 4-7	2-3, 4-7	4-7
3. Bentonite, interlaminated dark-gray and olive-green, gypsiferous		7					
4. Bentonite, olive-green, waxy, gypsiferous, a few gray laminae in upper part	1	8					
5. Bentonite, grayish-green, waxy		3					
6. Bentonite, gray, waxy		1½					
7. Bentonite, gray, limonite-stained, waxy		4½					
8. Shale, dark-gray, siliceous	---	---	---	---	--------	--------	--------
LOCALITY 21, SECTION 35							
[Nos. 2-6 from Clay Spur bentonite bed]							
1. Shale, dark-gray, soft		9	---	---	--------	--------	--------
2. Bentonite, dark-gray, waxy, weathered	1	0	4	7	2-3, 4-6	2-3	4-6
3. Bentonite, interlaminated dark-gray and olive-green	1	5					
4. Bentonite, olive-green, waxy, gypsiferous		10					
5. Bentonite, light-greenish-gray, waxy, gypsiferous		8					
6. Bentonite, gray, waxy; half an inch at base has cornmeal texture		8					
7. Shale, dark-gray, siliceous	---	---	---	---	--------	--------	--------

[1] Test data for material 2 are given in table 4.

BUTTE COUNTY, S. DAK.

T. 8 N., RS. 1 AND 2 E.

The bedrock cropping out in this elongate tract of about 24 square miles, extending westward from the town of Belle Fourche, belongs to the Fall River formation and the Skull Creek, Mowry, and Belle Fourche shales. The overall dip is northeastward and very gentle. The Clay Spur bentonite bed crops out north and west of the town, where it lies under light overburden in fairly broad areas. In most exposures the thickness of the bed is only 15 inches or less and for that reason there are no attractive mining sites in this tract. At the time (1948) of our examination the bentonite had been mined from pits in secs. 26 and 29, R. 2 E.

T. 9 N., RS. 1 AND 2 E.

The bedrock cropping out in this tract belongs to the Fall River formation and the Skull Creek, Mowry, Belle Fourche and Carlile shales. These two townships are crossed by Highways 212 and 85 and a spur of the Chicago and Northwestern Railroad. The overall dip is very gentle and northeastward. The Clay Spur bentonite bed lies under light overburden in a broad belt, and there are several outliers between the railroad and the Belle Fourche River. A sample (table 4) of the bentonite tested high in the properties essential for use as foundry-sand bonding clay and in drilling-mud; such material has been mined from many pits. Bentonite bed F crops out in a butte at the north line of sec. 5 and along the escarpment northeast of Highway 212 in sec. 142, T. 9 N., R. 1 E., and in sec. 18, T. 9 N., R. 2 E.; farther southeast, this bed is believed to pinch out.

Section measured in T. 9 N., R. 1 E.

Description of materials	*Thickness*				*Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4)*		
LOCALITY 80, SECTION 15	*All beds*		*Bentonite only*		*Green strength*	*Dry strength*	*Yield*
[No. 2 from Clay Spur bentonite bed]	*Ft*	*in*	*Ft*	*in*	$\geq$*8 psi*	$\geq$*50 psi*	$\geq$*90 bbls per ton*
1. Shale, dark-gray	---	---	---	---	--------	--------	--------
2. Bentonite, olive-green, waxy; limonite-stained along joints	2	2	2	2	2	2	2
3. Shale, dark-gray, siliceous, hard	---	---	---	---	--------	--------	--------

T. 10 N., RS. 1 AND 2 E.

The bedrock cropping out in this area belongs to the Mowry, Belle Fourche, Greenhorn, Carlile, Niobrara, and Pierre formations. The overall dip is gentle and northeastward. The Boxelder anticline extends northwestward in the central part of the area and is flanked on the southwest by a shallow syncline. The Clay Spur bentonite bed crops out in the extreme southwest corner of the tract, where it is under light cover in two broad areas. Bentonite bed F crops out northeast of Highway 212 in the face of an escarpment that is capped by the basal limestone bed of the Greenhorn formation; it crops out also at the peripheries of outliers of the Greenhorn formation on both sides of the highway.

T. 11 N., RS. 1 AND 2 E.

The bedrock cropping out in this area belongs to the Carlile shale, the Niobrara formation, and the Gammon ferruginous and Mitten black shale members of the Pierre shale. The axis of a shallow syncline plunges gently northward across the central part of T. 11 N., R. 2 E. The dip is northeastward, west of this axis, and northwestward east of it. On the north side of the area bentonite beds H and I are exposed in the trough of the syncline. Samples (table 4) taken from beds I at locality 79 (sec. 10, T. 11 N., R. 2 E.) tested high in green strength and two of them also tested high in dry strength. Mineralogical data on the bentonite exposed at locality 79 and elsewhere in the district are given on pages 992–994.

Sections measured in T. 11 N., R. 2 E.

Description of materials	Thickness: All beds Ft	Thickness: All beds in	Thickness: Bentonite only Ft	Thickness: Bentonite only in	Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4): Green strength ≧8 psi	Dry strength ≧50 psi	Yield ≧90 bbls per ton
LOCALITY 79, SECTION 10							
[Nos. 2–23 from bed I]							
1. Shale, dark-gray, soft		10	---	---	--------	--------	--------
2. Bentonite, light-gray, limonite-stained, granular		2					
3. Bentonite, cream, granular		8					
4. Shale, gray and brown, bentonitic		6					
5. Bentonite, light brown, granular		1½					
6. Bentonite, cream, granular		6½	[1]3	4½	2–10	--------	--------
7. Bentonite, dark-brown, granular, gypsiferous		1					
8. Bentonite, cream, granular, limonite-stained		5					
9. Bentonte, interlaminated dark-gray and light-gray, gypsiferous; a few laminae of dark-gray shale		7					
10. Bentonite, cream, granular, limonite-stained		3½					
11. Shale, dark-gray, soft		1½	---	---	--------	--------	--------
12. Bentonite, brown, limonite-stained, granular		6					
13. Bentonite, light-brown, granular; dark mineral particles	1	5	2	10	12–15	--------	--------
14. Bentonite, dark-brown, granular, impure		3					
15. Bentonite, light-grayish-brown, granular		8					
16. Shale, dark-gray, soft	2	0	---	---	--------	--------	--------
17. Bentonite, light-brownish-gray, limonite-stained		6		6	17	--------	--------
18. Shale, dark-gray, soft		8	---	---	--------	--------	--------
19. Bentonite, light-brownish-gray, granular		8		8	19	19	--------
20. Shale, dark-gray, soft		8	---	---	--------	--------	--------
21. Bentonite, light-yellowish-brown, granular	1	2					
22. Bentonite, greenish-gray, granular		2	3	3	23, 21–23	23	--------
23. Bentonite, light-bluish-gray, granular, gypsiferous	1	11					
24. Shale, dark-gray, soft	---	---	---	---	--------	--------	--------
LOCALITY G, SECTION 5							
[Nos. 2–8 from bed I]							
1. Shale and soil, dark-brownish-gray, soft, weathered	1	7	---	---	--------	--------	--------
2. Bentonite, dark-brown, granular; much gypsum		8					
3. Bentonite, light-yellowish-brown, granular		6	2	4	--------	--------	--------
4. Bentonite, yellow, granular	1	2					
5. Shale, dark-gray, soft		5	---	---	--------	--------	--------
6. Bentonite, gray, iron-stained, granular		7					
7. Bentonite, yellow, granular, gypsiferous	1	5	2	8	--------	--------	--------
8. Bentonite, yellowish-brown, gypsiferous		8					
9. Shale, dark-gray, soft	---	---	---	---	--------	--------	--------
LOCALITY H, SECTION 9							
[No. 3 from bed H]							
1. Shale, brownish-gray, soft	---	---	--------		--------	--------	--------
2. Shale, brown; interlaminated with light-brown bentonite		2	--------		--------	--------	--------
3. Bentonite, very light brownish-gray, hard; some limonite stains; much silt	1	3	1	3	--------	--------	--------
4. Shale, brown; interlaminated with light-brown bentonite		2	--------		--------	--------	--------
5. Shale, dark-gray, soft	---	---	--------		--------	--------	--------

[1] Material 4 is included because it is part of composite material tested.

T. 12 N., RS. 1 AND 2 E.

The bedrock cropping out in this elongate area of about 38 square miles belongs to the Pierre shale. The dip is gentle and northeastward except in the eastern part of T. 12 N., R. 2 E., where it is northward. Bentonite beds H and I crop out in both townships. Samples (table 4) from bed I, taken at locality 78 (sec. 35, T. 12 N., R. 2 E.), tested unusually high in green strength but low in dry strength (see p. 994).

Sections measured in T. 12 N., R. 2 E.

Description of materials	*Thickness*				*Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4)*		
	All beds		*Bentonite only*		*Green strength ≧8 psi*	*Dry strength ≧50 psi*	*Yield ≧90 bbls per ton*
	Ft	*in*	*Ft*	*in*			
LOCALITY 78, SECTION 35							
[Nos. 2-17 from bed I]							
1. Shale, dark-gray, fissile, soft	30	0	---	---	-------	-------	-------
2. Bentonite, light-tan, waxy		9		9	-------	-------	-------
3. Shale, dark-gray, fissile, soft		6	---	---	-------	-------	-------
4. Bentonite, yellow, granular; veins of gypsum in upper part; at top, irregularly shaped iron-stained concretions of gypsum and fibrous calcite, which are as much as 1 by 1½ ft	2	3	2	3	-------	-------	-------
5. Shale, dark-gray, fissile, soft		4	---	---	-------	-------	-------
6. Bentonite, yellow, granular; many dark mineral particles		4		4	-------	-------	-------
7. Shale, dark-gray, soft		2	---	---	-------	-------	-------
8. Bentonite, yellow, iron-stained, granular; many dark mineral particles	1	7					
9. Bentonite, greenish-gray, waxy		9	3	1	8-11	-------	-------
10. Bentonite, dark-brown; shale impurities		2					
11. Bentonite, yellow, limonite-stained, waxy		7					
12. Shale, dark-gray, soft; thin laminae of bentonite		8	---	---	-------	-------	-------
13. Bentonite, yellow, limonite-stained, granular		8		8	-------	-------	-------
14. Shale, dark-gray, soft		6	---	---	-------	-------	-------
15. Bentonite, yellow, granular		2		2	-------	-------	-------
16. Shale, dark-gray, soft		1	---	---	-------	-------	-------
17. Bentonite, greenish-gray, waxy to granular; weathers yellow; a few dark laminae near base	2	7	2	7	17	-------	-------
18. Shale, dark-gray, soft	---	---	---	---	-------	-------	-------
LOCALITY E, SECTION 30							
[Nos. 2-20 from bed I]							
1. Shale, dark-gray, fissile, soft; small gypsum crystals along joints; a few bentonite beds which are less than 1½ in. thick	48	0	--	--	-------	-------	-------
2. Bentonite, yellowish-orange, granular, gypsiferous; many dark mineral particles	--	11	--	11	-------	-------	-------
3. Shale, dark-gray, soft; a few lenses of bentonite as much as 1 in. thick	9	0	--	--	-------	-------	-------
4. Bentonite, greenish-gray, granular; weathers yellow with iron stains; at top, irregularly shaped concretions of gypsum and fibrous calcite, which are as much as 1 by 1½ ft	1	7	1	7	-------	-------	-------
5. Shale, dark-gray, fissile, soft	--	3	--	--	-------	-------	-------
6. Bentonite, yellowish-orange, granular; many light and dark mineral particles	--	2	--	2	-------	-------	-------
7. Shale, dark-gray, soft	--	9	--	--	-------	-------	-------
8. Bentonite, greenish-gray, granular; weathers yellow with iron stains	--	6½	--	6½	-------	-------	-------
9. Shale, dark-gray, soft	--	1	--	--	-------	-------	-------
10. Bentonite, greenish-gray, granular; weathers yellow with iron stains	--	10	--	10	-------	-------	-------
11. Shale, dark-gray, fissile, soft	--	4	--	--	-------	-------	-------
12. Bentonite, greenish-gray, granular; weathers yellow; many dark mineral particles	--	7	--	7	-------	-------	-------
13. Shale, dark-gray, fissile, soft	--	4	--	--	-------	-------	-------
14. Bentonite, greenish-gray, granular	--	2	--	2	-------	-------	-------
15. Shale, dark-gray, soft; bentonitic in lower part	--	5	--	--	-------	-------	-------
16. Bentonite, greenish-gray, limonite-stained, granular	--	5½	--	5½	-------	-------	-------
17. Shale, dark-gray, soft	--	6	--	--	-------	-------	-------
18. Bentonite, greenish-gray, granular; a few small biotite flakes oriented parallel to bedding planes	2	10					
19. Bentonite, gray, waxy	--	1	3	½	-------	-------	-------
20. Bentonite, light-bluish-gray, waxy	--	1½					
21. Shale, dark-gray, fissile, soft	--	--	--	--	-------	-------	-------

Sections measured in T. 12 N., R. 2 E.—Continued

Description of materials	*Thickness*				*Numbers of sampled materials which show adequate sand-bonding strength and (or) drilling-mud yield (see table 4)*		
LOCALITY F, SECTION 31	*All beds*		*Bentonite only*		*Green strength ≧8 psi*	*Dry strength ≧50 psi*	*Yield ≧90 bbls per ton*
[Nos. 3-17 from Bed I]	*Ft*	*in*	*Ft*	*in*			
1. Soil	---	---	---	---	--------	--------	---------
2. Shale, dark-gray, fissile, soft		6	---	---	--------	--------	---------
3. Bentonite, yellow, granular	1	4	1	4	--------	--------	---------
4. Shale, dark-gray, fissile, soft		6	---	---	--------	--------	---------
5. Bentonite, yellow, granular; much gypsum in upper part	1	10	1	10	--------	--------	---------
6. Shale, dark-gray, fissile, soft		1	---	---	--------	--------	---------
7. Bentonite, greenish-gray, granular; weathers yellow with iron stains		4½		4½	--------	--------	---------
8. Shale, dark-gray, fissile, soft		4	---	---	--------	--------	---------
9. Bentonite, yellow, iron-stained, granular		4½		4½	--------	--------	---------
10. Shale, dark-gray, fissile, soft		3	---	---	--------	--------	---------
11. Bentonite, yellow, iron-stained, granular		9		9	--------	--------	---------
12. Shale, dark-gray, fissile, soft		6	---	---	--------	--------	---------
13. Bentonite, greenish-gray, waxy; small biotite flakes oriented with bedding planes	3	2					
14. Bentonite, dark-gray, waxy		1½	3	5½ (Nos. 13–15)	--------	--------	---------
15. Bentonite, yellow, granular		2					
16. Shale, dark-gray, soft		6	---	---	--------	--------	---------
17. Bentonite, yellow, granular		2		2	--------	--------	---------
18. Shale, dark-gray fissile, soft	---	---	---	---	--------	--------	---------

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