THE GEOLOGICAL SURVEY OF WYOMING

HORACE D. THOMAS, State Geologist

PRELIMINARY REPORT NO. 4

Bentonite Deposits of the Clay Spur District, Crook and Weston Counties, Wyoming

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UNIVERSITY OF WYOMING
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INTRODUCTION

Bentonite is a rock formed from the alteration of volcanic ash and is composed chiefly of clay minerals. Most bentonite is found in sedimentary sequences incorporated as thin persistent beds within marine or nonmarine rocks. These beds apparently are the remains of ancient ash falls. The clay mineral present in bentonite usually is a variety of smectite*, most commonly montmorillonite, or mixed layer minerals such as potassium-bentonite. These minerals expand to several times their original volume when placed in water, giving bentonite many valuable physical properties.

Bentonites from the western interior of the United States, and particularly those from Wyoming and the Black Hills region, are used in foundry clay and drilling mud. These clays have extreme dilatancy and form a strong gel with water. Their bonding properties when mixed with foundry sand make them valuable in the manufacture of casting molds. Large quantities are used in "pelletizing" taconite iron ores. They also have uses in cosmetics, medicines, fire-fighting slurries, and as sealers. Bentonite deposits in Cretaceous rocks of northern Wyoming have been exploited for more than sixty years. Deposits in what is termed in this report the Clay Spur district have supplied a large percentage of the bentonite produced in the United States and are a valuable resource of the state of Wyoming. This report is the result of field and laboratory investigations of the geology and economic potential of this district.

Early Investigations

Engelmann (1858, p. 511) first described bentonite as a "yellow unctuous material" found in Carbon Co., Wyoming. Knight (1898, p. 491) named the material bentonite, after deposits found in the Benton formation of Wyoming.

In 1926, Ross and Shannon (p. 76) defined bentonite as "...a rock composed essentially of a crystalline clay-like mineral formed by the devitrification and the accompanying chemical alteration of a glassy igneous material, usually a tuff or volcanic ash."

Until about 1930, few deposits of bentonite were known outside Wyoming and adjacent states. Since then deposits have been found in almost every portion of the globe, although Wyoming is still the single most productive source of commercial bentonite. Darton (1904, p. 9) reported that production of bentonite in the Clay Spur district began before 1903. For many years, the Clay Spur district was the premier source of bentonite, a position eventually usurped by the Northern Black Hills district and newer districts in western Wyoming.

Location

Bentonite deposits of the Clay Spur district occur in the southcentral part of Crook County and northcentral part of Weston County. The district extends from Keyhole Reservoir on the Belle Fourche River south

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*"Smectite" is a term proposed by the Nomenclature Subcommittee of the Clay Minerals Group (British) for the group of minerals commonly referred to as "montmorillonite-type minerals." It is used in the classification scheme devised by Warshaw and Roy (1961) which is used throughout this report.

**Department of Geology, University of Wyoming, Laramie, Wyoming.

to the town of Osage, Wyoming. The mined area is a narrow, sinuous belt mostly confined to the outcrop area of the Belle Fourche shale and is five miles across at its widest north of Upton, Wyoming. It is approximately thirty miles long and includes almost 100 square miles. Outcropping Cretaceous formations dip gently southwestward at 2° to 3° throughout the district. At the northern and southern ends of the district, the dip abruptly increases to 20° or more, which makes mining unfeasible.

Relief in the area is moderate with altitudes ranging from 4,100 feet to 4,700 feet. Topography is controlled by outcropping Cretaceous rocks and consists of northwestward-trending cuestas separated by broad, flat valleys. Some larger streams, such as Belle Fourche River and Wildcat Creek, cut across the regional trend in superposed valleys. Most minor tributaries occupy strike valleys.

Practically all bentonite production in the district comes from the Clay Spur bed of the Mowry shale. Another bentonite bed in the lower part of the Belle Fourche has produced a small quantity of bentonite. A very minor amount of bentonite also has been mined from the Newcastle formation, but none of the operations were commercially successful.

Mining and Milling

Bentonite can be produced economically only where the regional dip is no more than 5°. Throughout the most productive part of the Clay Spur district the average dip is 2° or 3°. Under such conditions, wide areas of bentonite are exposed and a minimum of overburden must be removed from the beds.

Two types of open-pit mines are operated in the district today. One type consists of shallow pits dug through the overburden to uncover bentonite beds preserved in small grabens or tilted fault blocks. The other consists of successive cuts made along bentonite outcrops around margins of hills. The first type requires hauling and piling of overburden and is more expensive than a hillside cut. Consequently, pits are usually less than twenty feet deep, though overburden up to thirty feet thick or more may be removed from a hillside.

Overburden in the district is either shale or unconsolidated alluvium and can be easily removed by bulldozer-drawn scrapers and drag-lines. When a bentonite bed has been cleaned of all overburden, it is ripped up and piled. Some companies allow bentonite to partially dry in the pits, but others haul it directly to storage piles at their processing plants.

At the mill, raw bentonite is blended and passed through a slicer which cuts it into two to three inch diameter pieces. These are fed into large oil-fired rotary driers which lower the moisture content from 30% to 10% or less. The dried bentonite is ground in roller mills to approximately 200 mesh, then stored in large bins. The product is either sacked in 100 pound bags or loaded directly into hopper-bottomed railroad cars. Bentonite is shipped from the plants by truck or railroad. All bentonite produced in the district is transported by truck from mine to mill.

Prior to mining, extensive auger-drilling is done to determine the quality of the bentonite. Clays of different qualities are kept separated at the storage piles and are blended during milling. By judicious mixing of higher and lower grade bentonites, a uniform product is produced with minimum waste of lower grade material.

District Production

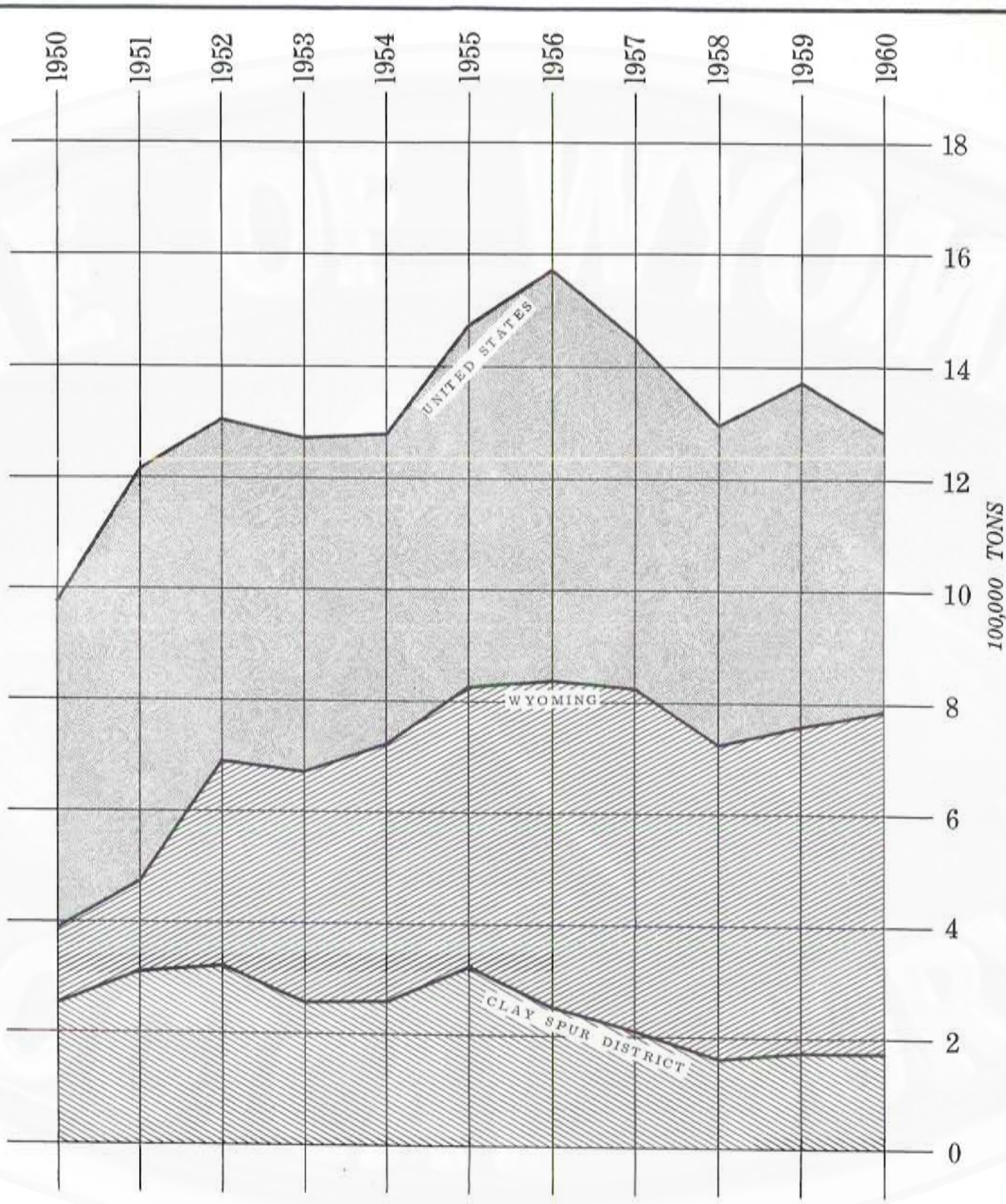
In 1950, 41% of the bentonite utilized in the United States was produced in Wyoming. By 1960, this increased to 62%. However, in the same period the percentage of bentonite contributed by the Clay Spur district to the national total declined from 25% to 14%. In 1950, the Clay Spur district produced 62% of all bentonite mined in Wyoming. By 1960, production had declined to 23% of the state's total. Actual production in the district declined from 247,215 tons in 1950 to 179,920 tons in 1960. Production in the state during the same period increased from 394,939 tons to 782,168 tons (Fig. 1).

The decline in relative productivity of the Clay Spur district is caused by several factors, the largest being increased competition from newer districts in central and western Wyoming and the tri-state area of Wyoming, Montana, and South Dakota. The absolute decline in production is chiefly the result of rapid depletion of reserves in the Clay Spur district. This has necessitated mining from deeper beds and exploiting smaller and less accessible deposits. In addition, reserves are much lower in quality than in the past, the result of high-grading of deposits in the early days of the district.

Figure 1

DOMESTIC BENTONITE PRODUCTION, 1950 - 1960

Showing bentonite production in the United States, Wyoming, and the Clay Spur District, in 100,000 tons, for the period 1950 to 1960. Figures compiled from data supplied by the Division of Mineral Resources, United States Bureau of Mines, and from Minerals Yearbook, 1950 through 1960.



Producers in the district agree that there are only enough reserves left to sustain operations at their present rate for ten years or less. All of the producers are operating plants in other districts or have large holdings in other areas and are planning to transfer operations. Reserves for the entire Clay Spur district are estimated at two million tons or less of commercial bentonite. This estimate assumes that the minimum quality requirements for the various grades of commercial bentonite will not be lowered during this time. If quality requirements are lowered, or a significant new demand develops for moderate or low swelling bentonite, the projected life of the district may be extended.

STRATIGRAPHY

All Cretaceous rocks in the district are considered marine with the exception of the Newcastle sandstone which contains beach and marsh deposits. The formations that occur in this district and their correlatives in other areas are listed in Table 1, which shows the stratigraphic location of major bentonite beds in this and other districts. Plate 1 is a geologic map of the district.

Newcastle Sandstone

The Newcastle sandstone is a highly variable unit approximately fifty feet thick in the Clay Spur district. It consists of complexly interbedded sandstones, siltstones, shales, lignites, and bentonites. Sandstone beds are characteristically cross bedded and ripple marked and contain local unconformities of varying magnitude.

Plant fossils are common in the Newcastle sandstone, particularly in parts of the section which contain lignite. Crowley (1951, p. 85) reported a marine microfauna of twelve genera recovered from oil wells drilled into the Newcastle formation near Osage, Wyoming. Intermixing of terrestrial and marine fossils is indicative of near-shore, lagoon, and beach deposits. Collier, in 1922 (p. 81-82), first advanced the idea that the Newcastle sandstone was the product of such an environmental complex. He suggested that the sands and lignites represented beach and shallow lagoon deposits, and shales resulted from deposition in deeper marine water.

A bentonite bed that has been extensively tested occurs in the Newcastle formation. Some bentonite has been mined from this bed, but operations were not economical and work in recent years has been restricted to sporadic drilling. In sec. 7, T48N, R64W, Weston Co., the following interval was measured (in feet):

NM..................Shale, soft, fissile, medium grey.
2.1..................Bentonite, silty, pale greenish yellow.
10.0 ....Shale, lignitic, thin-bedded to papery, greyish brown.
0.3.................Bentonite, silty, greyish orange.
2.0.................Shale, lignitic, thin-bedded to papery, greyish brown.
0.2.................Siltstone, greyish orange.
4.0.................Shale, fissile, silty, yellowish orange.
1.2.................Sandstone, very fine-grained, light brown.

Bentonite from this location tested considerably below drilling mud standards. Mining companies in the district report that the Newcastle bentonite bed is highly variable in gel strength and that its gelling properties are unpredictable. The bed varies in thickness from 0 to 3.5 feet. Mining is difficult because the floor rock will not support heavy equipment. If a layer of bentonite is not left as a floor, the underlying shale may be ripped up during stripping operations and will contaminate the clay product.

Mowry Shale

The Mowry shale overlies the Newcastle sandstone and consists almost entirely of black, siliceous shale. It is regarded by various geologists as uppermost Lower Cretaceous or as lowermost Upper Cretaceous. Because of its unique lithology, the Mowry shale was the subject of a series of early studies by W. W. Rubey (1929, 1931). The petrology and genesis of the Mowry shale in the Clay Spur district has been discussed in an earlier report (Davis, 1963, p. 135-146).

The formation is 220 feet thick on the north side of Thornton Dome (sec. 7, T48N, R65W) and 190 feet thick in shallow oil wells near Osage, Wyoming (sec. 16, T46N, R63W). Typically the basal twenty feet consist of soft greyish-black fissile shale. In the past, the Mowry was classified as a member of the Graneros shale and this basal part was set apart as the Nefsy shale member (Collier, 1922, p. 82). Since the work of Reeside (1944), the Mowry shale has been elevated to the rank of formation, and the "Nefsy shale"

Table 1

CORRELATION CHART

Showing the stratigraphic nomenclature used in this report of the Clay Spur District in relation to that of the Northern Black Hills District and other areas in Wyoming.

EPOCH	PROVINCIAL AGE	CLAY SPUR DISTRICT	NORTHERN BLACK HILLS DISTRICT (Knechtel & Patterson, 1962)	LARAMIE BASIN, WYOMING	SOUTHWESTERN WYOMING
Upper Cretaceous	COLORADO	CARLILE SHALE	CARLILE SHALE	FRONTIER FM.	FRONTIER FM.
		GREENHORN LS.	GREENHORN LS.		
	BELLE FOURCHE		Bed G		
		"Greenhorn bed"	Bed F		
		BELLE FOURCHE	BELLE FOURCHE		
		"Brown bed"	Bed E		
			Bed D		
Lower Cretaceous	MOWRY	Clay Spur bed	Clay Spur bed	MOWRY SHALE	ASPEN SHALE
		Lower Mowry bed	Bed B		
		MOWRY SHALE	MOWRY SHALE		
	NEWCASTLE	Newcastle bed	Bed A	MUDDY SS.	BEAR RIVER FM.
		NEWCASTLE SS.	NEWCASTLE SS.		
	SKULL CREEK	SKULL CREEK SH.	SKULL CREEK SH.	THERMOPOLIS SH.	

has been dropped as a separate unit.

Overlying this basal part is typical Mowry shale which is greyish black to medium grey in color, highly siliceous, and moderately resistant to weathering. It commonly forms ridges which are covered with dense stands of pine trees. The Mowry fractures subconchoidally, forming a slope of chips which weather silver grey. Interbedded in the shale are bentonite beds ranging in thickness from a featheredge to three feet. Pieces of the shale commonly are coated with a yellow powder identified as jarosite, a hydrous potassium iron sulfate. Gypsum veinlets are common near bentonite beds.

No megascopic marine invertebrate fossils were found in the Mowry shale in this area. The most common fossils are remains of fish, including gill covers, scales, small carbonized bones, and occasional vertebrae. Elongate concentrations of carbonaceous material and grit probably are fecal pellets from fish.

The top of the Mowry shale is marked by the Clay Spur bentonite bed. This bed has supplied most of the bentonite produced in this district. It was named by Rubey (1931, p. 4) for exposures at Clay Spur, Wyoming, a siding on the Chicago Burlington and Quincy Railroad and site of the Baroid Company bentonite mill. The Clay Spur varies from 2.5 feet to 4 feet thick, except in areas where it has been exposed for long periods of time.

The Clay Spur bentonite rests on a hardened floor of silicified shale which extends to a depth of about .8 foot and is brittle and blocky. The bedding plane surface beneath the Clay Spur is coated with fine quartz, feldspar, and biotite sand grains which are embedded in the shale forming a surface resembling sandpaper. The lowermost one-tenth foot of the bentonite bed is very sandy, containing quartz, feldspar, gypsum, and biotite grains. It is orangish to yellowish grey. Overlying this is a zone usually 2 to 3.5 feet thick of moderate greenish-yellow to greenish-grey bentonite which typically is massive, sectile or plastic, and only slightly silty. It grades upward into a zone of shaley bentonite that usually is about one foot thick, consisting of yellowish-grey bentonite. This zone changes upward into a thin-bedded to papery dark grey shale separated by films or laminae of waxy, yellowish-grey bentonite. This zone changes upward into a thin-bedded to papery dark grey shale.

Lower Belle Fourche Shale

The Belle Fourche shale overlies the Mowry shale and is named for exposures along the Belle Fourche River in the area now covered by Keyhole Reservoir. In the type section at the north end of the Clay Spur district, the formation measures about 560 feet thick (Collier, 1922, p. 83). In most areas the Belle Fourche is divided into two unnamed shale members which are separated by a persistent bentonite bed (Knechtel and Patterson, 1962, p. 914) which local producers refer to as the "Greenhorn" bed. In the northern part of the Clay Spur district, this bentonite bed occurs about fifty feet beneath a zone of large calcareous nodules or concretions that are commonly included in the basal part of the Greenhorn formation. South of Upton, Wyoming, this same bentonite is overlain by approximately 200 feet of poorly exposed shale containing occasional thin cone-in-cone limestone beds. The uppermost limits of the Belle Fourche shale, therefore, cannot be strictly defined in this area.

The lower part of the Belle Fourche shale is very distinctive. It consists of a sequence of soft dark grey fissile shales which contain bentonite beds and large concretions. These concretions are composed of siderite and have an oxidized hematite shell. They are dense and heavy and vary in color from dark reddish brown to metallic black. The concretions have a flattened oval or amoeboid shape ranging in diameter from one foot to five feet or more.

In the northern part of the Clay Spur district, there are two sets of thin persistent bentonite beds in the lower Belle Fourche which are called the "Chalk lines." One set is about five feet above the top of the Clay Spur and the other is about twelve feet above the Clay Spur. Generally each of the "Chalk lines" consists of two bentonite beds about .2 foot thick, separated by about .2 foot of soft, dark grey shale. In the southern part of the district the lower "Chalk line" persists as a single bed, but the upper "Chalk line" disappears. At most sections, small fractures and partings filled with a mixture of jarosite, natrojarosite, and quartz are associated with the lower "Chalk lines."

Overlying the horizon of the upper "Chalk line" is an interval of 25 to 30 feet of dark grey shale in which large siderite concretions are especially numerous. Occasionally these concretions are so concentrated in a zone that they coalesce and form a distinct layer or bed. In most sections such a bed occurs at the top of this concretionary interval and is immediately overlain by a sandy bentonite bed about two feet thick. This bentonite is usually pale greenish yellow to olive in color but develops a reddish-brown iron-stained surface when exposed. Locally it has a sandstone or sandy layer at the base or within the bed near the base. In the

Clay Spur district this bed is known as the Brown bed, and will be referred to by this name in this report. It is believed to be correlative with Bed E of Knechtel and Patterson (1956d, sheet 1; 1962, p. 980-982; also Patterson, 1955, p. 97-99) in the northern Black Hills bentonite district.

Overlying the Brown bed is a sequence of dark brownish-grey fissile shale which contains scattered siderite concretions. However, the concretions are not as numerous as they are in the interval below the Brown bed, and decrease in number upward in the section. This unit continues upward to the top of the lower member of the Belle Fourche shale. Sections were not studied above the Brown bed, which marks the top of the productive bentonite zone in this district.

Tertiary (?) Deposits

Deposits of possible Tertiary age are present in the Clay Spur district. Generally, these deposits consist of unconsolidated greyish-orange to dark yellowish-brown medium-grained sand. Deposits vary in thickness up to fifteen feet. In most cases, they lie unconformably on lower Belle Fourche or upper Mowry shale. Cretaceous shales below the unconformity invariably are brecciated and oxidized to a moderate red color. These sands cap low hills approximately eighty feet above the present drainage level in the north end of the district and are topographically about forty feet below the crests of the highest hills in that area. The sands contain a few siderite pebbles and cobbles of local derivation, and some quartz pebbles that may have been derived from the Black Hills. No fossils were found, so the deposits could not be accurately dated. In some areas near Keyhole Reservoir, Tertiary (?) sands unconformably overlie the Clay Spur bentonite bed.

Quaternary Deposits

Deposits of Recent or Pleistocene age also are present in the district. The material in these is a dusky yellowish-brown mud or dirt containing chips of dark grey shale and broken fragments of siderite concretions. Also found are quartz cobbles up to a foot in diameter, smaller rounded cobbles of limestone, sandstone, and rhyolite, and large fragments of petrified wood. Deposits of this material are especially common in the central part of the district east of Thornton Dome and are an important control of the distribution of the Clay Spur bentonite. Erosion of the Clay Spur bentonite and contemporaneous deposition of this Quaternary debris has produced an erratic distribution of commercial bentonite in this area. The lateral disappearance of bentonite in such areas has led some producers to erroneously believe that the bentonite was originally deposited in small lakes or other restricted bodies.

Depositional Environment

A sequence of events can be reconstructed for the Clay Spur district that explains the changes in lithology of the bentonite-bearing formation. This sequence adequately explains the pecularities of deposition in the area west of the Black Hills but may not be applicable in distant areas. Part of the following reconstruction is based on the work of Eicher (1960) on the Thermopolis (Skull Creek) shale.

The Newcastle sandstone was deposited in a variety of brackish, shallow water environments ranging from paludal to neritic. During this time, volcanic eruptions occurred in the west and the Newcastle bentonite and other thin bentonites were deposited. These units are not laterally persistent because they have been removed in areas of penecontemporaneous erosion.

The lower Mowry shale has a gradational contact with the underlying Newcastle sandstone. These units was deposited more or less continuously in deepening water. Salinity of the sea gradually increased until it was near normal at the beginning of deposition of the siliceous phase of the Mowry shale. Volcanic eruptions continued in the west, and radiolarian appeared in this sea for the first time shortly before the end of "Nefsy" deposition. Fish, marine reptiles, and ammonites are known to have lived in this sea. Small planktonic organisms, principally Radiolaria, also flourished. The absence of a bottom fauna suggests that the sea floor was stagnant.

Sediment may have entered this sea from two sources. A tremendous quantity of siliceous volcanic ash may have slowly settled into the basin, as proposed by Rubey (1929, 1931). This ash was subsequently altered to saponite and quartz, with interlayered bentonites. Another possibility is that sediment was supplied from the weathering of adjacent slightly arid landmasses which produced quantities of clay and detrital quartz. Periodic volcanic eruptions to the west caused dense ash falls in this sea. As the volcanic ash settled to the sea floor, silica was dissolved from it, enriching the sea water and promoting the growth of siliceous organisms which in turn added their tests to the accumulating sediment. Volcanic material that reached the sea floor was further altered and eventually changed to bentonite.

Near the end of the time of deposition of the Mowry shale, a volcanic eruption of unusual intensity occurred. Ash from this eruption settled in a thick blanket and eventually formed the Clay Spur bentonite bed. Shortly after this ash-fall, conditions of circulation in the sea changed, possibly caused by shallowing. The differences between the Belle Fourche and Mowry shales may be attributible to such a change.

Large concretions of siderite were formed in the Belle Fourche shale from upward-moving solutions squeezed out of the sediments by compaction. Periodic ash falls were as common in this time as during the period of deposition of the Mowry shale. Like previous ash falls, these altered into bentonite. Bottom conditions became less stagnant following an intense ash fall which altered into the Brown bed bentonite. Eventually the marine environment became highly oxidizing and alkaline, causing the precipitation of thin limestones in the upper Belle Fourche shale and the formation of the Greenhorn limestone. During this stage, a normal marine bottom fauna was established.

BENTONITE BEDS

Clay-sized Fractions

Mineralogy. The clay-sized fractions of the bentonite beds were examined using the scheme devised by Warshaw and Roy (1961). This classification technique involves the successive application of three criteria: (1) thickness of the fundamental layer; (2) gross composition and ionic content of layers; and (3) stacking sequence of layers and degree of orderliness of the clay mineral. The only equipment necessary when utilizing this technique is a diffraction x-ray and a laboratory furnace. All determinations were made using a General Electric XRD-5 unit with copper radiation and a nickel filter (CuK_α = 1.5418 Å).

All of the clays examined were montmorillonite, although they vary widely in their physical properties. These variances, such as dilatancy and green strength, must therefore be dependent upon the nature of the interlayer cations and/or minor variations in the basic montmorillonite structure. Ideally, the formula for montmorillonite may be expressed as $Al_4Si_8O_{20}(OH)_4 \cdot nH_2O$, with a theoretical composition of SiO_2, 66.7%; Al_2O_3, 28.3%; and H_2Om 5% (Grim, 1953, p. 58). However, the actual composition always differs from this as a result of substitution of aluminum for silicon in the tetrahedral layer and the substitution of magnesium, iron, and other ions for aluminum in the octahedral layer (Hendricks, 1942, p. 285-287). Weaver (1959, p. 162) has stated that the degree of expansion of the lattice is a function of the amount of charge produced by these substitutions in the basic lattice. His view may be at least partially correct, because producer's attempts to upgrade bentonite by artificially replacing interlayer Ca^{++} with Na^+ have not been successful.

Another, perhaps more widely held, view is that different interlayer cations are the cause of variations in dilatancy because they will produce different intitial interlayer spacings and bind the lattice together with different amounts of force. The sodium ion, being univalent, acts as a weak bridge between the sheets and allows water to penetrate and force the layers apart. Doubly-ionized calcium will maintain a larger interlayer spacing due to its greater diameter, but binds the sheets together more tightly because of its higher charge. Facilities were not available for determining the exchangeable ions in bentonites from the Clay Spur district. Information given by Knechtel and Patterson (1962, p. 948-949) for bentonites believed to be stratigraphically equivalent to those in this district show that the more sodic bentonites have higher swelling properties.

Chemical analyses were made of those bentonites in the district which were thick enough to be minable. These analyses, listed in Table 4, were made in the Chemical and Bacteriological Laboratory of the Wyoming Department of Agriculture. The samples analyzed include some non-clay material as well as montmorillonite and its adsorbed cations.

Laminations within bentonites. There is a distinct layering within the thicker bentonites of the district. The bottom 50 to 75 percent of a bed usually is lighter in color and relatively uniform. Near the top, the bentonite becomes darker and is finely laminated. The alternating light and dark laminae range in thickness up to one-quarter inch and become more pronounced near the top of the bed where they merge into a sequence of thin alternating layers of bentonite and shale. Many of these laminae show small primary structures similar to those in the Mowry, and indicate that the bottom ooze formed by the ash fall was somewhat soft and unstable. Preservation of these fine layers indicates that the bottom was relatively undisturbed during the time of deposition of the bentonites.

Patterson (1955, p. 75) has suggested that these laminations represent seasonal varves deposited during

Table 2. Chemical analyses of bentonite beds over two feet thick in the Clay Spur district, Wyoming.

	(A)	(B)[2]	(C)[2]	(D)[2]	(E)
SiO_2	62.01	67.41	63.91	53.73	58.33
TiO_2	.14	.10	.12	.23	.09
Al_2O_3[1]	23.76	21.20	22.69	24.33	20.83
Fe_2O_3	3.09	2.94	3.97	6.64	2.57
FeO	.99	.60	.35	2.37	.59
MnO	.01	NA	NA	NA	.002
MgO	2.05	2.15	2.03	2.54	3.13
CaO	1.37	.89	1.06	2.32	.62
Na_2O	2.47	2.34	2.47	2.38	2.41
K_2O	.33	.26	.28	.29	.36
H_2O-	8.84[3]	4.28	4.81	6.47	7.79
H_2O+	3.45				5.26
CO_2					.39
P_2O_5	.19	NA	NA	NA	.06
Total	99.86	102.17	101.69	101.30	102.43

(A) Lower Mowry bentonite bed (B in Figure 3).

(B) Dark olive grey phase of the Clay Spur bentonite bed.

(C) Yellow grey phase of the Clay Spur bentonite bed.

(D) Brown bed of the lower Belle Fourche shale.

(E) "Greenhorn" bed of the upper Belle Fourche shale.

[1]Found by difference.

[2]Used by permission of the Black Hills Bentonite Company.

[3]Uncombined water not included in total.

Analyses by George LeCompte, Wyoming Department of Agriculture.

the waning stages of a volcanic eruption. During the early stages of a heavy ash fall, volcanic material would entirely mask normal sedimentation, but as the amount of ash in the air and water decreased normal sedimentation would become more noticeable. If shaley material were supplied to the basin in a seasonal manner, perhaps caused by annual variations in rainfall on the source area, alternations of shale and bentonite might be produced. However, this would require that ash from a single volcanic event be deposited on the sea floor over a period of time perhaps hundreds of years long. It seems more likely that the laminations are not varves but represent changes in sedimentation of shorter duration. Periodic storms could effect the settling rates of ash particles or the supply of detrital sediments to the basin and might be one of the agents responsible for the laminations.

"Blue egg" structure. "Blue egg" structure may be found in the Clay Spur bentonite in areas of heavy overburden. The "blue egg," a term coined by the pit operators, consist of roughly oval nuclei of dark olive-grey bentonite (Pl. 2, fig. 1). This structure most commonly develops near the top of the bentonite bed, and is used as an indicator of the depth of commercial bentonite.

"Blue egg" structure has been described by Knechtel and Patterson (1962, p. 957-958) from the Clay Spur bentonite of the Northern Black Hills district. They attribute the formation of "blue eggs" to partial oxidation of ferrous non-clay material present in dark grey bentonite. Oxidation has occurred in the subsurface along joint systems which divide the bentonite into small blocks. Yellowish discoloration of the bentonite has proceeded inward toward the center of each block, often leaving an altered core of grey bentonite (Pl. 2, fig. 2). Bentonite near the surface usually is completely discolored to yellow grey, deeply buried bentonite is unaltered dark olive grey, and bentonite at intermediate depths (10 to 25 feet) is characterized by "blue egg" structure.

Surface texture. Bentonite in the Clay Spur district occurs in beds ranging in thickness from a featheredge to about four feet. Where these beds crop out they form a characteristic pattern on the ground. Successive periods of swelling and shrinkage caused by alternate absorption and loss of water produce an "alligator hide" or "popcorn" surface crust on the bentonite. Alligator hide texture, characterized by polygonal shrinkage cracks, develops on weathered surfaces on low dilatancy bentonite (Kerr and Kulp, 1949, p. 58, Pl. 2, fig. 3). High-swelling bentonite develops an outcrop texture composed of irregularly rounded lumps that resembles a mound of popped corn (Pl. 2, fig. 4). The relationship between surface texture and dilatancy has been examined by Knechtel and Patterson (1956b, p. 44-45).

Most freshly exposed bentonite has a sectile, waxy texture. A few beds containing a high percentage of non-clay constituents has a granular to earthy texture. This is well shown in the sandy zone at the basal few inches of the Clay Spur bed. A somewhat similar texture develops in bentonite a few inches beneath its surface crust at outcrops. This texture is especially common in outcrops of the Brown bed. Augering indicates that it gives way to waxy texture a few feet in from the exposed surface.

Bentonite quality. Bentonite quality is judged in terms of the properties of clay-water mixtures, such as dilatancy, viscosity, gel strength, and bonding strength. Viscosity and gel strength are especially important in drilling muds while bonding strength is of prime importance in foundry work and taconite pelletizing. Bentonites are tested by the producers with a variety of instruments, the Marsh funnel being the one most commonly used. This device measures viscosity by the length of time required for a standard mixture of bentonite and water to flow through an orifice in the funnel. The result is usually expressed in barrels per ton yield, or the number of 55 gallon barrels of slurry with a viscosity of fifteen centipoises that can be prepared from a short ton of bentonite. Commercial drilling mud usually must have a yield of 90 barrels per ton or better.

The swelling quality of bentonite is determined by the number and nature of atomic substitutions within the crystal lattice of the mineral and by the nature of the interlayer cations. Ross and Hendricks (1945, p. 65) have noted that bentonites containing sodium ions as exchangeable interlayer cations have high swelling properties, while those with calcium in the interlayer positions have poor swelling properties. Other factors also are important. A clay mineral that has been completely collapsed by compaction is very difficult to expand and has poor gel-forming properties. Some Paleozoic "meta-bentonites" may be clays of this type (Flowers, 1952, p. 2037).

Many investigators have noted a relationship between the quality of bentonites and the thickness of overburden. Williams and others (1954, p. 141-151) have documented a case where gel strength and yield of a bentonite decrease with increasing overburden. There is a corresponding decrease in excess salts and exchangeable sodium and an increase in base-exchange capacity. The quality of bentonite is also usually enhanced by weathering. Weathering usually causes a change in color and may leach exchangeable ions from the clay. Protracted partial hydration of the clay near the surface may also effect the quality.

Figure 1 (above).

Figure 2 (below).

Figure 3 (above).

Figure 4 (below).

NON-CLAY MATERIAL IN BENTONITES

Bentonite beds in the Clay Spur district contain small amounts of non-clay material, mostly in the silt and fine sand sizes. The non-clay part usually constitutes less than 5% of the total weight of a bentonite, although the amount varies from bed to bed. Material of secondary origin in the bentonite consists mostly of small selenite crystals, calcite, natrojarosite, and some iron oxides. Calcite usually is present as fibrous veins and as linings in tiny vugs. Selenite occurs as disseminated crystals of various sizes up to five inches in length, and as efflorescences and crumbly veins accompanied by natrojarosite and other soluble sulfates. Iron oxides occur as stains and "limonite" fillings in small fractures.

Most non-clay material in bentonite consists of fragments of crystals that were incorporated in the volcanic ash from which the bentonite altered. Varying amounts of larger rounded grains of possible detrital origin also are present, but the relative amounts of volcanic and clastic material in the smaller size ranges cannot be determined.

All bentonites in the Clay Spur district contain angular quartz grains, potassium feldspar, plagioclase, biotite, and opaque minerals. Most beds also contain zircon, apatite, and glass shards.

A generalized list of the non-clay fractions of the various bentonites in the Clay Spur district is given in Table 3. Beds are listed in stratigraphic order, from A (lowest) to J (highest). Numbers on the table indicate the estimated order of abundance of the minerals. Largest grains present in the samples were 0.2 mm or less in diameter.

Efflorescences Related to Bentonites

Efflorescences of epsomite and other hydrous sulfates often occur on bentonite outcrops and on old dumps and pit walls. Selenite crystals up to four or five inches long also commonly are found where bentonite has been weathered for protracted periods of time. Dengo (1946, p. 23) suggested that these grew in size in response to weathering, but this has been disputed by Knechtel and Patterson (1962, p. 951). Iron stains are the only other surface feature consistently associated with bentonite outcrops. They are well developed below beds that contain a large proportion of non-clay material, such as the Brown bed and "Greenhorn" bed.

STRUCTURAL CONTROL OF BENTONITE

The bentonite deposits of the Clay Spur district, with the exception of the Newcastle bentonite beds, were deposited in a marine environment. Originally, they apparently had great lateral continuity and extended over the entire district as sheet-like deposits. The Clay Spur bed is known to continue into the Northern Black Hills district, and a thick bentonite within the Mowry shale is tentatively correlated with Bed B of Knechtel and Patterson (1962, p. 969-971) in that district. The "Greenhorn" bed and Brown bed of this district are believed correlative with Bed F and Bed E in the Northern Black Hills district. These same beds also may be present in the Kaycee district on the west side of the Powder River basin.

The erratic distribution of clay beds in the Clay Spur district, particularly in the central part, cannot be due to vagaries of deposition. Rather, it seems due to erosion and preferential preservation of segments protected in favorable structures. In areas of spotty distribution, bentonite beds commonly thin or terminate abruptly against poorly sorted Quaternary debris composed chiefly of shale wash. In some pits, vague trends in the distribution of bentonite and shale debris suggest channeling by streams. However, the localization of commercial deposits of clay is primarily controlled by small structures.

Between Thornton Dome and Pine Ridge the topography reflects the dip of the underlying rocks forming what is essentially a dip slope on the Mowry. Some of the largest remaining reserves in the district lie at shallow depths beneath this dip surface where they are preserved in small downdropped or tilted fault blocks.

In the district, there are two indefinite fault trends. One roughly parallels the northwest strike of the outcropping beds while the other trends at approximately right angles to the strike, or southeast. All of the faults are very small and die out in a few hundred feet or less. The throw varies from a few inches to ten feet or more, but displacements of a few feet are most common. Monoclinal and anticlinal flexures with a relief of five feet or less also are common.

Most of the faults are steeply dipping to vertical normal faults, although a few minor reverse faults occur. They are best observed in the upper Mowry in pits where the overlying bentonite has been removed. The

Table 4. NON-CLAY CONSTITUENTS IN THE BENTONITES OF THE CLAY SPUR DISTRICT.	QUARTZ	K-FELDSPAR	PLAGIOCLASE	GLASS	GREY OPAQUES	APATITE	HEMATITE (?)	ZIRCON Blue	ZIRCON Pink	BIOTITE Brown	BIOTITE Green	LEUCOXENE (?)
A Newcastle bentonite bed	1	2	3		6		4	5				
B Lower Mowry bentonite bed	1	2	4		6			5		3		
C Lower Mowry bentonite bed	2		4	1			3	5				
D Lower Mowry bentonite bed	1	2	3 An_{45}		5	6					4	7
E Thin bentonite in upper Mowry	1	3	2			6	4	8	7	9		5
F Basal Clay Spur bentonite	1	2	3 An_{42}	5		7	9	6			4	8
G Lower "Chalk Line" bentonite	1	3	2			6	4	8	7	9		5
H Upper "Chalk Line" bentonite	1	2	3			5		7			4	6
I Brown Bed bentonite	2	3	4	5			1	7			6	
J "Greenhorn" bentonite bed	3	4	6	1			2	7		5		

Mowry shale near these fractures is highly brecciated and locally marked by slickensides.

East of Thornton Dome, bentonite is preserved in small grabens bounded on the northeast and southwest by inward-dipping normal faults. These faults decrease in throw and die out to the northwest and southeast, forming a small synclinal pocket. Commonly the westernmost fault has the greatest throw, giving the down-dropped block a westward tilt.

Other structural features developed in this area, and on a larger scale south of Upton, are tilted fault blocks. A downdropped segment of the Clay Spur bentonite may be bounded on the northeast by a strong monoclinal flexure and on the southwest by a steeply dipping normal fault (Fig. 2A). Often a series of such tilted fault blocks will repeatedly preserve the Clay Spur bed. These tilted blocks are usually terminated by gradual dying of the fault, or by a series of step-like transverse normal faults (Fig. 2B). In the area south of Upton, the tilted block often has a dip of 15° or more, and the fault has a throw of 20 or more feet.

A variation of this structural pattern is sometimes found, consisting of a tilted block bounded on the northeast and northwest by gentle monoclinal flexures, on the southwest by a steeply dipping normal fault, and on the southeast by a combination of monoclinal flexures and small normal faults. Such a pattern is illustrated in Figure 2C.

Within these larger structures are smaller ones, usually seen as gentle undulations in the floor of the Clay Spur bed. The siliceous Mowry shale is invariably highly fractured by joints following the trend of these minor features. These small undulations may determine the distribution of bentonite where it is extremely close to the surface.

SUGGESTIONS FOR EXPLORATION

The following exploration suggestions are offered merely as guide lines and indicate typical avenues of investigation. They are by no means exhaustive nor are they known to represent positively commercial areas. However, if they encourage sound geological exploration they will have achieved their purpose.

1. The most obvious areas for examination are around the margins of old pits. The cut-off quality of bentonite was much higher in the early days of the district and former sub-marginal deposits may now be profitable. Many small deposits of high-grade bentonite also were left because of their size. These may be mined at a profit with modern machinery.

2. North of Thornton Dome (Shale Hill) presently unexploited bentonite deposits should be present on the dip slope of the Mowry shale. These deposits have been brought close to the surface by a reversal of regional dip associated with folding of Thornton Dome.

3. West of Thornton Dome, bentonite deposits should occur near the Chicago, Baltimore and Quincy railroad tracks.

4. Minable bentonite may be present at the extreme ends of the district, south of Osage and north of Keyhole Reservoir. The steep dip of the beds has prevented earlier exploitation, but long, narrow pits now may be commercially possible.

5. Extensive, unmined deposits may be present west of Pine Ridge in the northern end of the district in T50N, R66W. Pits in this area are not continuous, but deposits should continue between mined areas.

6. The previous suggestions are aimed at exploitation of the Clay Spur bentonite. The Brown bed bentonite is practically untouched and should have very good commercial possibilities throughout its outcrop length.

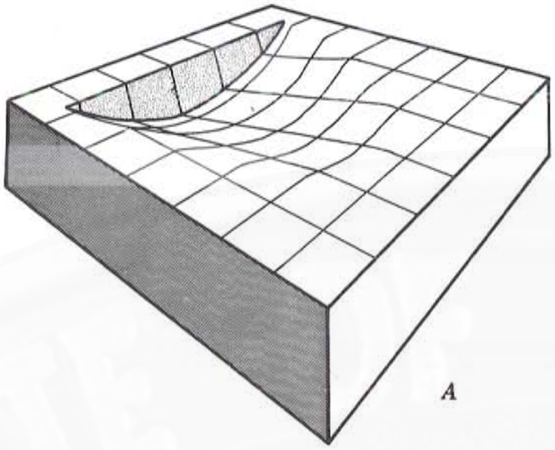
7. The Newcastle bentonite and the "Greenhorn" bentonite are practically unexplored. Commercial possibilities in these beds should not be overlooked.

It is obvious that no new discoveries comparable to those of the early days will be made in the district. However, by investigating the possibilities mentioned above, along with others which will be suggested by extensive geological exploration, the profitable life of the district can be extended beyond the ten years postulated by present reserve figures.

Figure 2

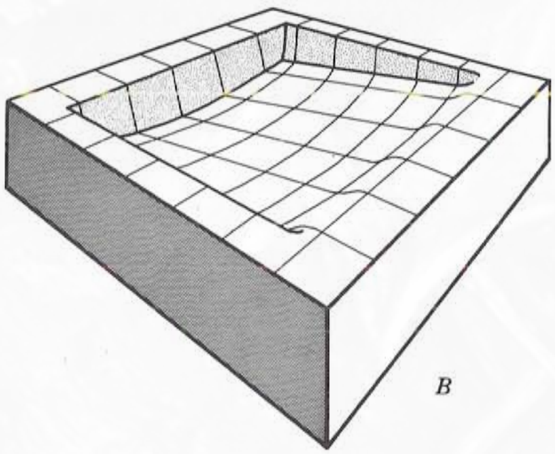
STYLES OF BLOCK FAULTING

A schematic representation of block faulting in the Clay Spur District. These fault structures are best seen in the brittle siliceous phase of the upper Mowry shale. The upper surfaces of the illustrated blocks represent the bedding plane or floor below the Clay Spur bentonite bed. These structures range in size from a few tens of feet to a few hundreds of feet across. Bentonite often is preserved in these structures in the central part of the district.



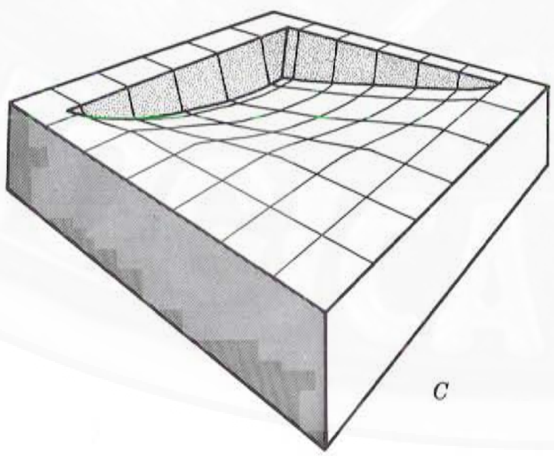
A

(A) Synclinal pocket bounded on the southwest by a steep normal fault. Looking west.



B

(B) Tilted fault block bounded by three steep faults and a monoclinal flexure on the northeast. Looking west.



C

(C) Tilted fault block bounded on the southeast and southwest by normal faults and on the northeast and northwest by monoclines. Looking south.

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