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STATE OF SOUTH DAKOTA
Sigurd Anderson, Governor

STATE GEOLOGICAL SURVEY
E. P. Rothrock, State Geologist

Report of Investigations

No. 36

BENTONITE IN SOUTHWESTERN SOUTH DAKOTA

by

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University of South Dakota
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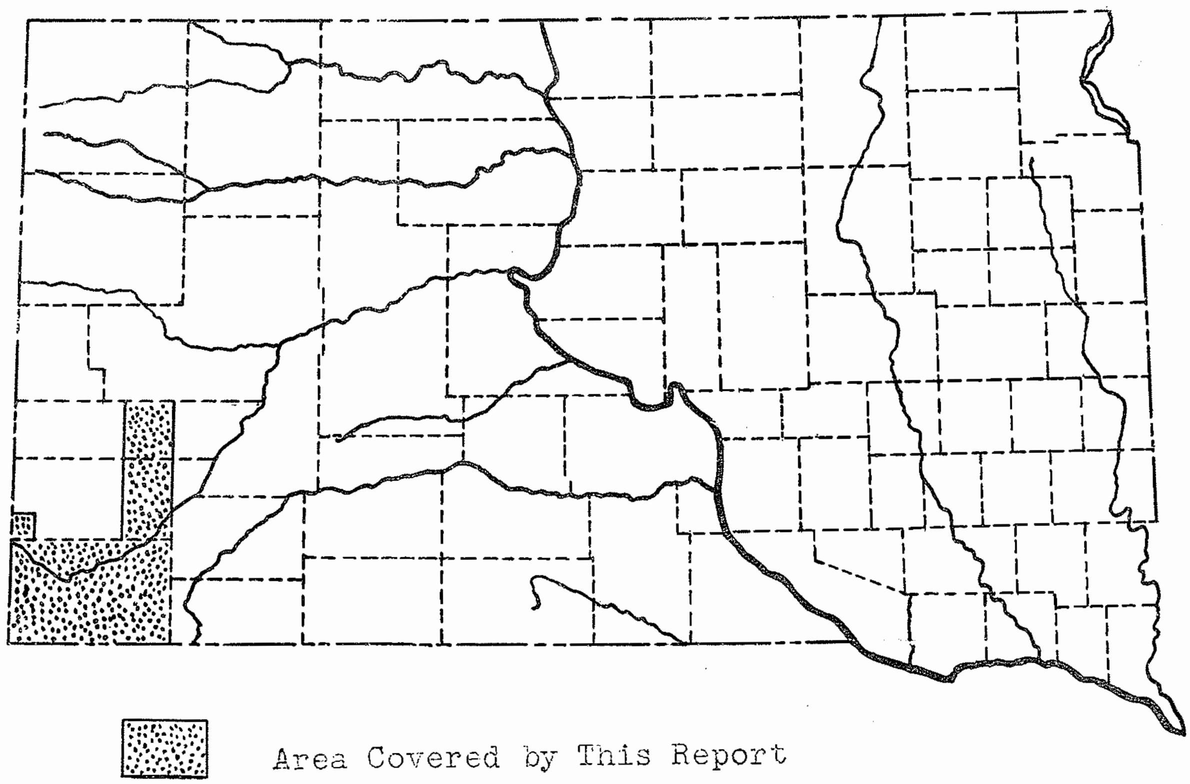

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INTRODUCTION

Bentonite is a clay material formed by the weathering of volcanic ash and composed of particles of colloidal or near colloidal size. It is not itself a distinct mineral, but is composed of a mixture of minerals the most important of which are montmorillonite and beidellite. The physical properties of bentonites from various localities and stratigraphic horizons are quite variable and this variation is to some extent due to varying proportions of the different clay minerals present. The physical properties of bentonite determine its value for different industrial uses, and the most important property is the varying abilities of different bentonites to absorb water and thus increase in volume.

At the present time the most important uses for bentonite are in oil refining, rotary oil well drilling, foundry work and cement manufacturing. Minor uses are for cosmetics, soaps, paints, water softeners; suspending agent in polishes, dyes and pastes; sealing earth dams and ditches; clarifying dry-cleaner's fluids; de-inking newsprint; compounding aqueous emulsions of oils, bitumens, etc.; suspending agent in insecticides and animal dips; etc. New uses for bentonite are steadily appearing, and this has led to increased interest in bentonite deposits during recent years.

Bentonite has been produced commercially from the southwestern South Dakota area since 1915.[1] All of this has been quarried from the Pierre formation at two localities, Buffalo Gap and Ardmore. At the present time the only commercial production of bentonite in the area is at Ardmore, where the Refinite Company processes it for use as a water softener.

The present investigation was undertaken for the purpose of mapping the bentonite deposits in the region south and southeast of the Black Hills, and for acquiring as much information about this bentonite and the formations in which it occurs as might be possible in the limited time available.

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1. Connolly, J. P., and O'Harra, C. C., Mineral Wealth of the Black Hills, S. D. State School of Mines, Bull. 16, p.326, 1929.

The field work was carried on during July and August, 1939. Most of the detailed work was done in Fall River County where the formations containing the bentonite are fairly well exposed. In Custer and Pennington counties most of the area underlain by bentonite-bearing formations is covered by Tertiary or Pleistocene gravel deposits, and the bentonite is exposed only where the gravels have been removed by stream erosion. Because of this, two maps have been prepared. (Plates 8 and 9) One map shows the distribution of bentonite deposits in Fall River County, while the other shows localities where the field party was able to locate exposed bentonite beds in Custer and Pennington counties.

The field work was financed by the State Geological Survey, and Dr. E. P. Rothrock, State Geologist, maintained general supervision of the investigation. The writer wishes to express his appreciation to Dr. Rothrock for his many courtesies and countless valuable suggestions. The writer also acknowledges his indebtedness to his field assistants, Mr. Harold W. Buus and Mr. Merle Crew, without whose cooperation this report would not have been possible. Numerous others have helped in various ways, and the following deserve special mention: Dr. Ralph E. Grim of the State Geological Survey of Illinois for information on base exchange measurements, Dr. Paul F. Kerr of Columbia University for x-ray identification of clay minerals in some of the bentonite samples, and residents of Fall River, Custer, and Pennington counties too numerous to list whose help is sincerely appreciated.

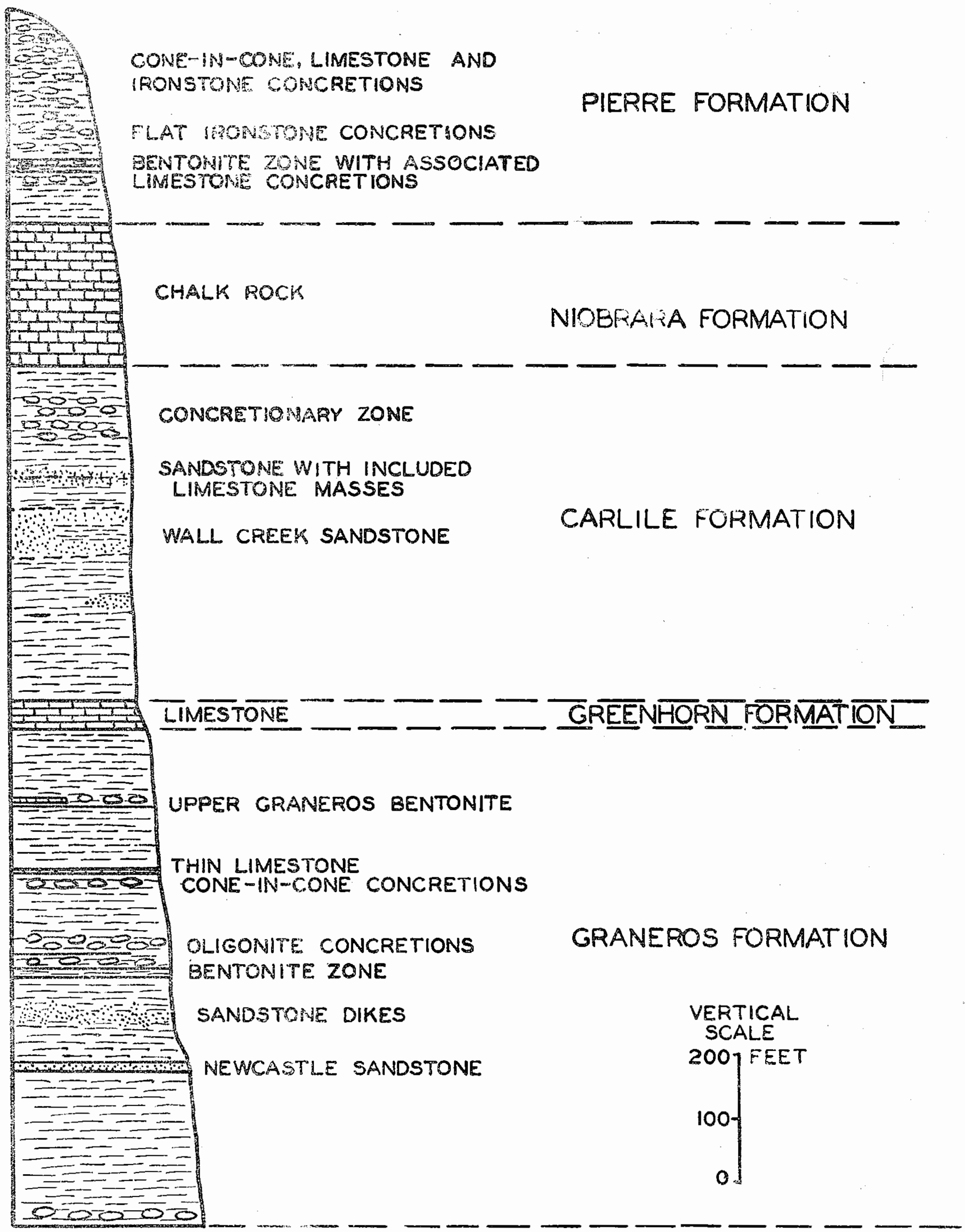

PLATE I GENERALIZED SECTION OF FORMATIONS

FORMATIONS EXPOSED IN THE AREA

The general nature and the thickness of the formations in which bentonite occurs in the southwestern South Dakota area are shown on Plate 1. Description of the important characteristics of each on these formations is given on the following pages.

Pierre Formation

In the plains area south and east of the Black Hills the Pierre shale attains a thickness of 1200 feet or more[1] but in the area investigated only the lower 100 to 200 feet of the formation were studied in detail. These lower beds of the Pierre consist of shale interbedded with several layers of bentonite and contain numerous concretions at more or less constant horizons.

The shale of the lower Pierre is dark gray in color but may be brownish gray to silvery gray when weathered. It is thinly laminated and frequently the thin sheets are separated by thin layers of small selenite crystals which are often stained brown by iron oxide. Although usually the shale is hard and brittle, it forms a sticky gumbo when weathered. Fish scales and vertebra are quite common in the shales of the lower Pierre, and reptile remains occur in some places.

The bentonite beds are mostly confined to a 15 to 20 foot zone beginning some 60 or 70 feet above the bottom of the formation. In Fall River County the bentonite zone has 8 to 12 beds separated by shale. The lowest bed of the zone is about 8 inches thick on the average and is almost invariably brown in color. The next overlying bentonite bed averages a little over 3 feet in thickness and since this bed is the one quarried on a commercial scale at Ardmore, it is designated the Ardmore bed in this report. Overlying the Ardmore bed are alternating layers of bentonite and shale, the bentonites varying from 1 inch to 20 inches in thickness. North of Buffalo Gap the various beds in the bentonite zone cannot be correlated with certainty with the individual beds in Fall River County.

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1. Darton, N.H., and Paige, Sidney, U.S.G.S. Geologic Atlas of the United States, Central Black Hills Folio 219, p. 14, 1925.

Associated with the bentonite zone there are almost invariably from one to three layers of shale containing gray limestone concretions. These concretions average 2 or 3 feet in diameter and typically they are broken into small pieces by an intricate system of irregular cracks, these cracks often being partially filled by coarse crystalline calcite. Upon exposure the concretions commonly break up into small irregular blocks which become scattered over the surface of the outcrop.

In the shales overlying the bentonite beds there are other types of concretions. About 40 feet above the zone there are flat, dark reddish brown ferruginous concretions that often extend several feet laterally. Some 20 feet higher these are usually associated with yellow cone-in-cone rosettes, and still higher there are beds containing cone-in-cone, ferruginous and gray limestone concretions all in close association.

The concretionary beds above the bentonite zone are more resistant to erosion than higher and lower beds so that erosion of the southerly and easterly dipping Pierre formation in this area has produced a nearly continuous escarpment facing the Black Hills. The bentonite zone occurs a little above the base of this escarpment throughout most of the area.

The individual beds of the lower Pierre, especially in the bentonite zone, were studied at numerous localities. A few measured sections which are representative of this part of the formation are given on Plate 4.

Section of Lower Pierre Formation
SW. $\frac{1}{4}$ Sec. 15, T. 11 S., R. 1 E.

Feet	Inches	
10		shale, with a few scattered limestone concretions.
	5	gypsum, in small crystals, partly cemented by iron oxide
	6	shale, gray, with abundant selenite crystals
	8	bentonite
	2	shale
	7	bentonite

	2	shale
	2	bentonite
	1	shale
1		bentonite
	1	shale
4	11	bentonite, Ardmore
	7	shale
	6	bentonite
9	5	shale, with gray limestone concretions 7 feet from bottom
	$\frac{1}{4}$	bentonite
3	2	shale, with gray limestone concretions $2\frac{1}{2}$ feet above bottom
	$\frac{1}{2}$	bentonite
3		shale
	$\frac{1}{4}$	bentonite
7	9	shale
	2	bentonite
	11	shale
	8	bentonite
	2	shale
	2	bentonite
1	3	shale
	1	bentonite
	3	shale
	1	bentonite
	3	shale
	$\frac{1}{4}$	bentonite
1	3	shale
	2	bentonite
4		shale
	7	bentonite
1	5	shale
	3	bentonite
1	8	shale
	2	bentonite
2	1	shale
	2	bentonite
4	9	shale
	6	bentonite
2	9	shale
	$\frac{1}{4}$	bentonite
3		shale
5		chalk, Niobrara, bottom not exposed.
76	5	Total section

Section of lower Pierre
in east central part
Sec. 30, T.10 S., R.2 E.

Feet	Inches	
67		shale, with ferruginous concretions, some of which have a layer of cone-in-cone around them.
7	6	shale, with few ferruginous concretions
	9	bentonite
8		shale, with abundant flat ferruginous concretions
7		shale
	1	bentonite
2	3	shale
	1	bentonite
6	8	shale
	3	bentonite
	7	shale
	7	bentonite
1	2	shale
	1	bentonite
	7	shale
	5	bentonite
	5	shale
	6	bentonite
2	5	shale, with gray limestone concretions
3	3	bentonite, Ardmore
1	5	shale, with gray limestone concretions; bentonite streak near middle
	7	shale
	8	bentonite
5		shale
	1	bentonite
19		shale
	1	bentonite
	9	shale
	7	bentonite
	1	shale
	2	bentonite
1	5	shale
	1	bentonite
	4	shale
	1	bentonite
	4	shale
	1	bentonite
1	3	shale
	2	bentonite
4	9	shale

Feet	Inches	
	5	bentonite
2		shale
	2	bentonite
3		shale
	2	bentonite
7		shale
	5	bentonite
3		shale
5		chalk, Niobrara, bottom not exposed
167	8	Total section

Section of lower Pierre in
NW $\frac{1}{4}$ Sec. 8, T.12 S., R. 4. E.

Feet	Inches	
		soil
28		shale, with a layer of gray limestone concretions 5 feet above the base and another layer 20 feet from the bottom.
	7	bentonite
1	7	shale
	11	bentonite
2	11	shale
	8	bentonite
	8	shale
1	2	bentonite
	7	shale
	6	bentonite
	6	shale
	6	bentonite
1		shale
	1	bentonite
	4	shale
	4	bentonite
	3	shale
	5	bentonite
2		shale
3	2	bentonite, Ardmore
1		shale, containing numerous gray limestone concretions
	8	bentonite
9		shale
1		shale, with few scattered limestone concretions
15		shale

	1/4	bentonite
6	6	shale
	1	bentonite
	5	shale
	6	bentonite
	1	shale
	1	bentonite
	11	shale
	1	bentonite
	3	shale
	1	bentonite
	11	shale
	2	bentonite
2	8	shale
	5	bentonite
	10	shale
	1	bentonite
1		shale
	1	bentonite
1	1	shale
	3	bentonite
	8	shale
30		chalk, Niobrara, bottom not exposed.
120	3	Total section

Section through bentonite zone and overlying concretionary beds in Sec. 34, T.11 S., R.4 E.

Feet	Inches	
300		shale, poorly exposed on grassy slope, with numerous cone-in-cone, gray limestone, and dark ferruginous concretions. Concretions of these different types occur throughout but are most numerous at rather regularly spaced intervals of about 20 feet. These layers containing concretions are more resistant to erosion than the intervening shales and stand up as ridges on the otherwise uniform slope.
26		shale, with a layer of cone-in-cone rosettes at the top and another at the base. Flat ferruginous concretions occur at irregularly spaced intervals through the zone.

Feet	Inches	
18		shale, with numerous ferruginous concretions which are usually confined to definite layers and are often so closely spaced laterally as to form a pavement when exposed by erosion.
12		shale, with few or no concretions.
20		shale, with large (3 x 4 feet) gray limestone concretions. These are often broken up by intricate networks of cracks which are partially filled by calcite.
	3	bentonite
2		shale, with numerous gray limestone concretions.
6		shale
	6	bentonite
1	7	shale
1		bentonite
2	6	shale
	9	bentonite
	8	shale
1	2	bentonite
	6	shale
	6	bentonite
	5	shale
	5	bentonite
1	1	shale
	5	bentonite
	2	shale
	6	bentonite
1	6	shale
3	2	bentonite, Ardmore
	7	shale
	7	bentonite
2		shale
1		shale, with gray limestone concretions.
50		shale, bottom not exposed.
455	3	Total section

Section of lower Pierre in
SW¼, Sec. 32, T.9 S., R.5 E.

Feet	Inches	
40		shale, with yellow cone-in-cone rosettes and ferruginous concretions.
37		shale, with ferruginous concretions

	2	bentonite
14		shale, with numerous gray limestone concretions and a 2 inch thick pavement of dark ferruginous concretions at top.
	1	bentonite
3	6	shale
	3	bentonite, with concretions composed of gray limestone at center surrounded by gypsum crystals which are cemented by iron oxide.
7		shale, with several thin bentonite streaks and a few gray limestone concretions.
	2	bentonite
6		shale, with gray limestone concretions some of which have iron oxide cemented gypsum crystals around the outside.
	7	bentonite
	2	shale
	½	bentonite
2	6	shale, with gray limestone concretions
1		bentonite
3	2	shale, with gray limestone concretions
	1	bentonite
	10	shale
	1	bentonite
2		shale, with gray limestone concretions
	8	bentonite
1		shale
1	5	bentonite
	9	shale
	6	bentonite
	8	shale
	6	bentonite
1	8	shale, with numerous gray limestone concretions
	1	bentonite
	3	shale
	1	bentonite
	2	shale
	4	bentonite
	4	shale
	6	bentonite
2	4	shale
3	10	bentonite, Ardmore
1	4	shale
	8	bentonite
3		shale
	1	bentonite

2	2	shale
	1	bentonite
44		shale
	1	bentonite
1		shale
	8	bentonite
	2	shale
	2	bentonite
2	4	shale
	1	bentonite
	6	shale
	1	bentonite
	6	shale
	1	bentonite
2	3	shale
	2	bentonite
3		shale, bottom not exposed but is probably about 20 feet below
237	11	Total section

A study of the above sections and the columnar sections on Plate 4 shows that the gray limestone concretions in the bentonite zone do not maintain the same relationship to the bentonite beds throughout the area. At some places a layer of concretions is immediately below the Ardmore bentonite, elsewhere there is such a layer above, while at still other places there is no layer closely associated with this bentonite.

Correlation of some of the individual bentonite beds from section to section can be accomplished with reasonable certainty. There seems little doubt that the Ardmore bed can be recognized in all well exposed sections in Fall River County, and some of the associated beds are almost as easily traced. On the other hand, some of the bentonites are lenticular and can be traced only for short distances. North of Buffalo Gap the exposures are much farther apart than in Fall River County, and it is very difficult to recognize individual beds from one exposure to the next. Sections of the bentonite zone in Custer and Pennington counties are given later in this report.

Niobrara Formation

The Niobrara formation consists of soft and non-resistant chalk rock which weathers out into gentle slopes. In the area investigated the formation normally occurs at the base of the Pierre escarpment. When the Niobrara beds are weathered they are white or light yellow in color and are quite conspicuous. In the upper portions; in places where little weathering has occurred, these beds are dark gray or bluish gray in color and often are difficult to distinguish from the overlying Pierre. In some cases it is necessary to test with acid for the presence of calcite in order to find where the calcareous Niobrara beds end and the Pierre non-calcareous beds begin.

Rothrock[1] has measured the Niobrara in the SE$\frac{1}{4}$, Sec. 33, T.9 S., R.5 E. where it was 217 feet thick.

Although this formation contains at least 10 or 12 bentonite beds, occurring at random intervals throughout the formation, none of these were found to be more than 6 inches thick and most were only about 3 inches in thickness.

Carlile Formation

This formation is usually well exposed because it contains sandstone and concretionary beds which, because of their resistance to erosion, generally stand out in low cliffs. The Carlile consists mainly of dark, thinly laminated shale, but 2 or 3 sandstone horizons, as well as a concretionary zone, are usually recognizable.

The lowest sandstone layer, about 160 feet above the base of the formation, is only a few inches thick and is exposed in relatively few places. It probably occurs only in the area of the Cascade anticline.[2]

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1. Rothrock, E.P., The Chilson Anticline, S.Dak. State Geol. Survey R.I. No. 9, p. 8, 1938.
2. Rothrock, E.P., The Cascade Anticline, S.Dak. State Geol. Survey R.I. No. 8, p. 7, 1931.

The second sandstone zone, a little over 200 feet above the base of the formation, consists of 2 or 3 layers in the central part of Fall River County, but toward the west these layers thicken and merge into a thick sandstone bed which is probably a correlative of the Wall Creek sand of Wyoming.

The upper sandstone is about 50 feet above the Wall Creek. It is usually thin bedded and splits into thin sheets which have a smooth surface. In most places it is very fossiliferous, with the fossils often being most abundant in limestone masses found embedded in the sand.

In the upper part of the formation 3 or 4 layers of large calcareous concretions occur. These concretions are usually light brown in color but are sometimes gray. The average diameter is about 3 feet but some are as large as 6 feet. All of the concretions seen in this zone were broken by an intricate network of cracks and these cracks were often filled or partially filled by brown coarsely crystalline calcite.

In one locality (Sec. 21, T.9 S., R.6 E.) a thin bentonite bed was found in the shale zone between the Wall Creek and the upper sandstone layer. No other bentonite beds were seen in the Carlile.

Greenhorn Formation

The Greenhorn is a prominent formation throughout this area because at least the upper part is composed of hard resistant limestone which produces hogbacks and cuestas when erosion has removed adjacent softer rocks. Usually there is present a north or northwest facing escarpment which is quite conspicuous.

The lower part of the formation consists of alternating shale and limestone with occasional beds of bentonite. The limestones of the formation are usually gray, thin-bedded, hard, and contain abundant fossils, the most numerous of which are *Inoceramus labiatus*.

The following sections and the columnar sections on Plate 2 show the characteristics and composition of the Greenhorn formation.

Section of Greenhorn formation in
SW $\frac{1}{4}$, Sec.13, T.9 S., R.2 E.

Feet	Inches	
20		limestone
	6	limestone, soft, with interbedded bentonite
3		limestone
	7	bentonite
1	10	shale
	7	limestone
	4	shale
	6	limestone
	2	shale
	4	limestone
96		shale, Graneros
123	10	Total section

Section of Greenhorn formation in
SE $\frac{1}{4}$, Sec. 2, T.10 S., R.4 E.

Feet	Inches	
18		limestone, gray to bluish gray, hard, mostly thin-bedded but with occasional beds 5 or 6 inches thick. Inoceramus present in great numbers.
	5	bentonite, impure, mixed with gray to grayish tan chalky shale.
3	6	limestone, gray to bluish gray; hard; thin-bedded; with abundant Inoceramus.
	10	shale, gray, calcareous
1	5	bentonite
	2	shale
	6	limestone, gray, with few poorly preserved fish (?) remains.
2		shale, Graneros
26	10	Total section

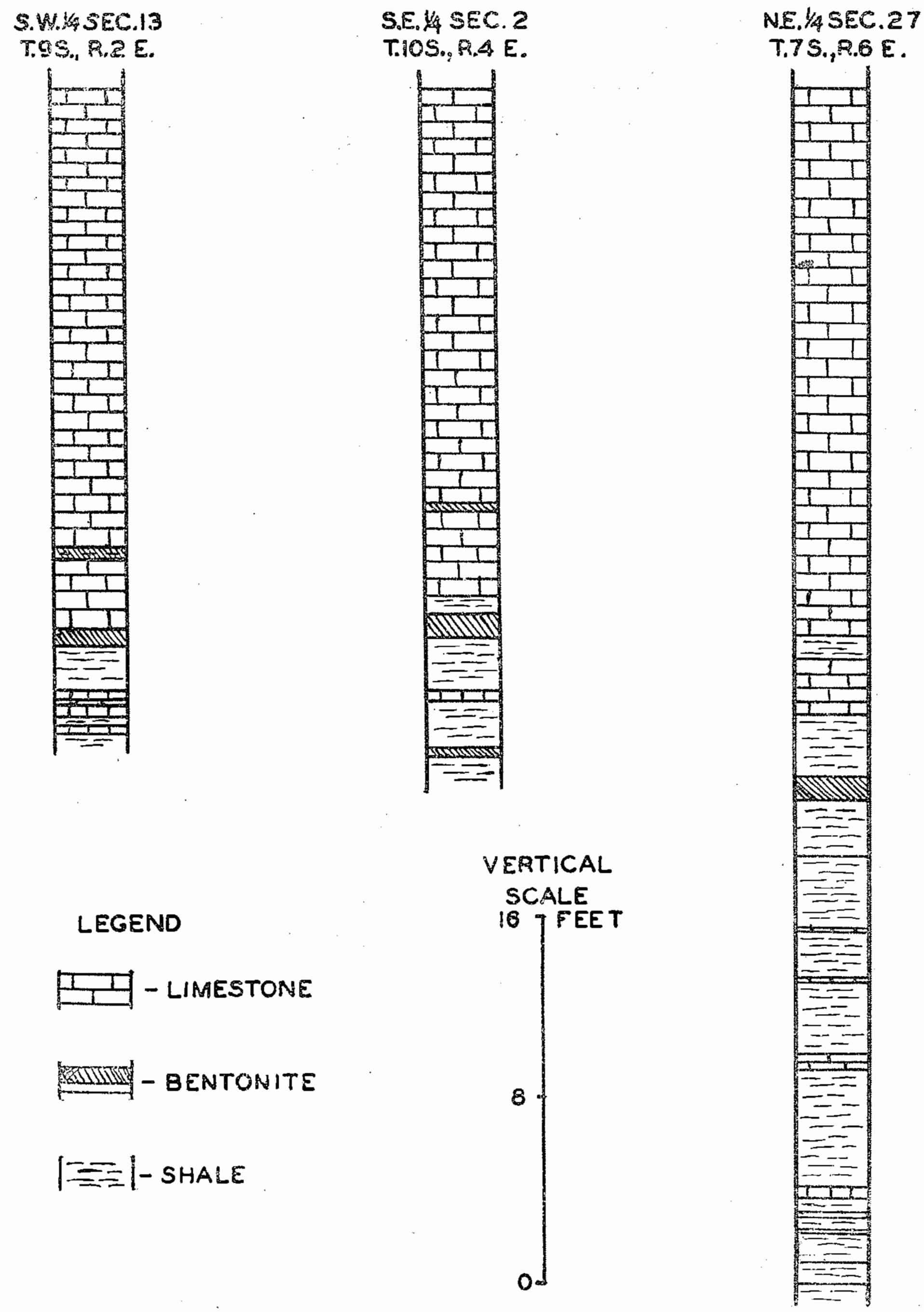


PLATE 2. SECTIONS OF GREENHORN LIMESTONE

Section of the Greenhorn formation
at NE¼, Sec.27, T.7 S.,R.6 E.

Feet	Inches	
24		limestone, gray to bluish and yellowish gray, mostly thin-bedded, but with occasional beds 4 or 5 inches thick; two thin bentonite beds near middle
1		shale, gray with tan streaks
2	6	limestone, bluish gray, poorly bedded, breaks into small irregular blocks.
2	10	shale (or chalk), grayish brown, calcareous, indistinctly laminated.
1		bentonite
2	6	shale, grayish tan, with numerous gray limestone concretions at top.
	2	bentonite
3		shale, gray with tan mottle; indistinctly laminated; sub-conchoidal fracture.
	4	limestone, brown, soft, impure
2		shale, gray with tan mottle
	2	limestone, gray, weathering buff; hard; finely crystalline; petroliferous odor.
3		shale, gray
	7	limestone, gray, weathering buff.
5		shale, grayish tan
	7	limestone, gray, weathering buff; hard; finely crystalline; petroliferous odor.
	7	shale
	1	limestone
	6	shale
	2	limestone, gray, weathering buff; phosphatic material common.
1	5	shale, probably Graneros.
51	5	Total section

Graneros formation

The Graneros is another thick Cretaceous formation which, like the Pierre and Carlile, is composed mostly of dark colored shale. Rothrock[1] in his studies of the structure and stratigraphy of part of Fall River County recognized three members of the Graneros. During the present investigation these members were found to

1. Rothrock, E. P., The Chilson Anticline, S. Dak. Geol. Survey, R.I.# 9, pp. 13-16, Revised 1938.

be easily recognizable, and proved very useful for dividing this thick formation into units convenient for study.

The upper member extends from the Greenhorn limestone down to the bottom of a zone of large dark colored concretions. This member consists primarily of shale which is usually dark gray in color but is frequently lighter gray or tan in the upper part. In the lower part, the shale contains oligonite concretions composed of dark colored iron carbonate with manganese. These concretions vary in diameter from about one foot up to 20 or more feet. Usually they are flattened in the direction of the bedding planes of the shale and sometimes they form pavements 5 or 6 inches thick over an area of several hundred square feet. Upon exposure the oligonite concretions readily break up into small irregular blocks which become scattered over the surface of the exposure. The thickness of the oligonite zone is apparently quite variable. In some localities only about 20 feet of concretion bearing shale was found, while at other places this zone was 70 or 80 feet thick. About 60 or 80 feet above the oligonite zone a shale layer containing cone-in-cone rosettes could be identified in most sections. Some 30 feet above the cone-in-cone a thin but persistent limestone layer was found. From this limestone to the top of the formation the rocks are largely shale with a few thin limestone layers and a few beds of bentonite. The total thickness of the upper member is a little over 400 feet. The general nature of the upper part of this member is shown on Plate 4, Fig. 2.

The middle member of the Graneros of this area can be correlated with the Mowry shale member of Wyoming and Montana.

The Mowry is composed of dark gray siliceous shales which on exposure usually assume a silvery gray color. These shales are hard and brittle and do not become muddy in wet weather. Fish scales, spines and vertebrae occur, although not as abundantly as in some other areas. Near the middle part of the Mowry is a light gray to brown sandstone which appears to have been forced into cracks and along bedding planes so that now it occurs mostly in the form of dikes and sills. In many places the dikes and sills are uniform

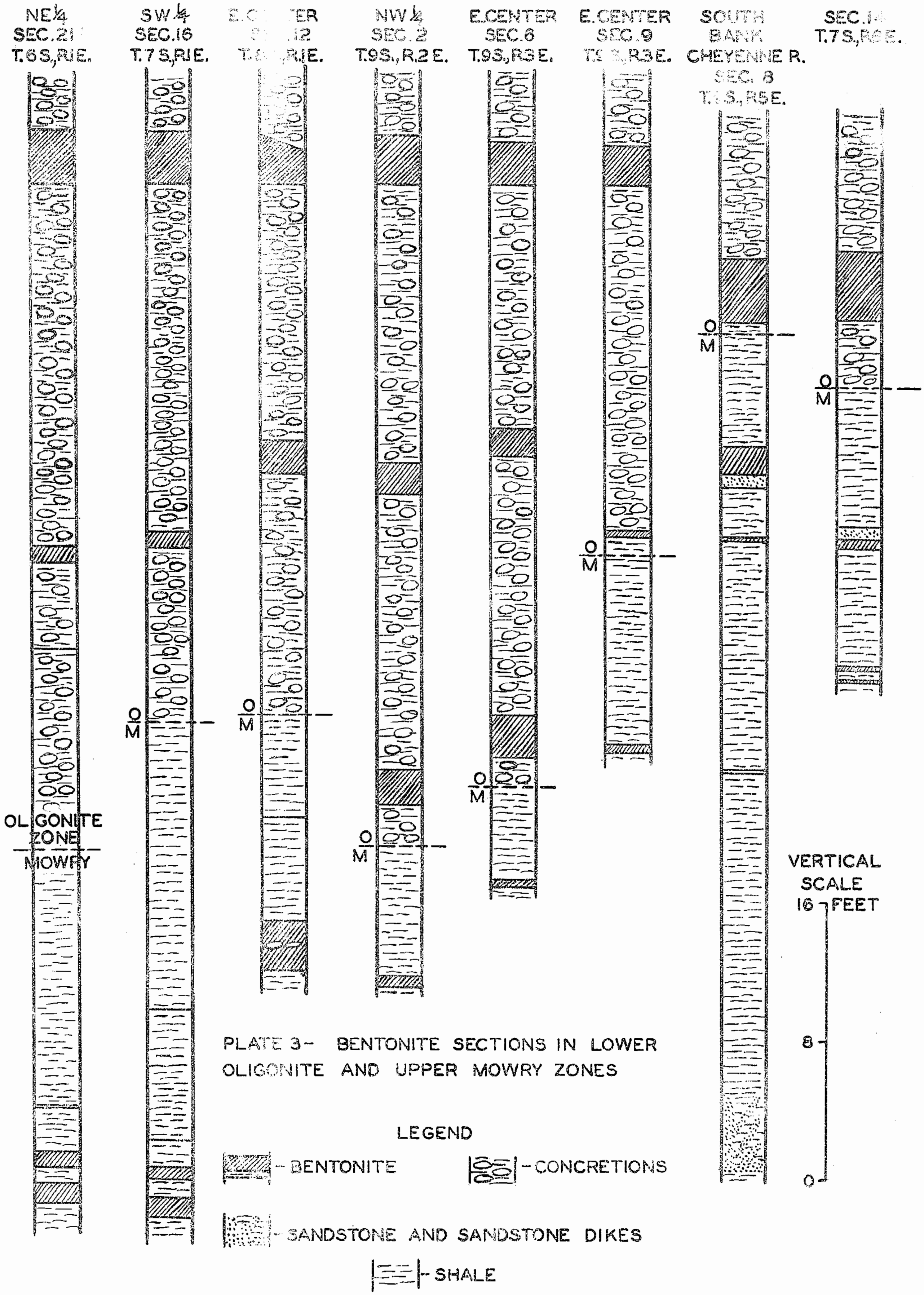


PLATE 3 – BENTONITE SECTIONS IN LOWER OLIGONITE AND UPPER MOWRY ZONES

in thickness and a system of joints and cracks has broken the rock into even-sized blocks so that they resemble man-made walls and pavements. This zone of sandstone dikes is variable in thickness and apparently does not always mark precisely the same horizons in the Mowry. The thickness of the Mowry member in this area is about 150 feet.

The top of the lower member is marked by a ten-foot sandstone which is usually correlated with the Newcastle sandstone of Wyoming. Below this sandstone the member is composed of about 240 feet of dark gray shale with scattered cone-in-cone concretions and near the bottom a layer of limonite or oligonite concretions.

The total thickness of the Graneros is about 800 feet.

Bentonite occurs in the Graneros at several horizons. There are 3 to 5 thin beds in the upper part and at about 130 feet below the top of the formation a 3 or 4 foot bed is usually present. In the oligonite zone, at least one bentonite is present at all outcrops where the lower part of the zone is exposed. In a few exposures as many as four bentonites ranging in thickness up to 3 feet can be seen.

One or two bentonite beds can be found at most exposures of the upper Mowry, although usually the thickness is only a few inches. In the lower part of the Mowry member, a few inches above the Newcastle sandstone, two thin bentonites occur and at some exposures a thin bentonite bed was found in the sandstone dike zone.

Two bentonite beds are exposed in road cuts along a north-south road passing between sections 20 and 21 and between 28 and 29, T.10 S., R.4 E. The lower of these beds is 25 to 36 inches thick, the upper 6 to 30 inches thick, and they are separated by about 3 feet of shale. The stratigraphic position of these beds is somewhat uncertain but they appear to be near the upper part of the sandstone dike zone. Although comparatively thick, these beds could not be traced more than a few feet away from the road, and no bentonite beds were found in any other area which could be definitely correlated with them. Considerable variation in thickness of these beds can be seen where they are exposed and it is probable that they disappear entirely or thin out laterally to such an extent that they are difficult to locate elsewhere.

The following sections show the characteristics of the upper and part of the middle (Mowry) member.

Section of part of the upper Graneros
in Sec. 18, T.9 S., R. 5 E.

Feet	Inches	
	8	limestone, gray to grayish tan; fossiliferous; probably Greenhorn.
17		shale, gray
	5	bentonite
	1	limestone
1	8	shale
	5	bentonite
	1	limestone
17		shale
	1	bentonite
44		shale, medium gray, bluish gray on dry surfaces.
	8	limestone, gray, thinly bedded; with shale partings; contains sharks teeth and other fossils; strong petroliferous odor when struck with hammer.
1	5	shale
	9	bentonite
9		shale, medium gray, with few fish scales.
	2	bentonite
5		shale
	1	bentonite
2	9	shale
	8	bentonite, with abundant small dark grains of mica and other minerals.
9		shale
	9	bentonite
9		shale, bluish gray, dark gray when moist; with thin lenses of limestone.
	7	bentonite
	3	shale
	1	limestone, medium gray; very fossiliferous.

1	8	shale, dark gray
3	6	bentonite, yellow to orange at top, medium gray in middle part and bluish gray below
20		shale, dark gray, thinly laminated; irregularly spaced limestone concretions extend laterally for 3 or 4 feet as thin fossiliferous limestone lenses.
	3	bentonite
7		shale, dark gray; moderately thin laminae; with numerous selenite crystals.
	3	bentonite
6		shale, dark gray, bottom not exposed
160	3	Total section

Section of upper Graneros on banks of Cheyenne River, SE.$\frac{1}{4}$ Sec.4, T.9 S. R.6 E.

Feet	Inches	
		limestone, Greenhorn
72		shale
	3	bentonite, associated with thin limestone lenses
15		shale
	3	bentonite
8		shale
	7	bentonite
12		shale
	8	bentonite
2		shale
	6	limestone, gray, weathering brown
4		shale, with numerous small gray limestone concretions near bottom
2	8	bentonite
20		shale
	4	bentonite
30		shale
	4	bentonite
		shale, bottom not exposed
168	7	Total section

Section of upper part of Graneros
NW ¼ Sec. 13, T. 9 S., R. 2 E.

Feet	Inches	
		limestone, Greenhorn
96		shale, brownish gray
	4	limestone, brown
1		shale
	8	bentonite
17		shale
	4	bentonite
9		shale
1		bentonite
30		shale, with fossiliferous limestone concretions
	6	bentonite
14		shale
	3	bentonite
11		shale
	3	limestone, grayish brown, with sharks teeth and other fossils
2	8	shale, with few cone-in-cone concretions
	3	limestone, as above
	1	bentonite
23		shale, medium gray, with several streaks of bentonite, and thin layers of small selenite crystals
	6	limestone, grayish brown, weathering dark brown
	2	bentonite
2	6	shale
	2	bentonite
5	8	shale
	1	bentonite
28		shale
	6	bentonite
22		shale, dark gray, thinly laminated; often stained brown or yellow by iron oxide; a few calcareous cone-in-cone concretions present.
266	11	Total section

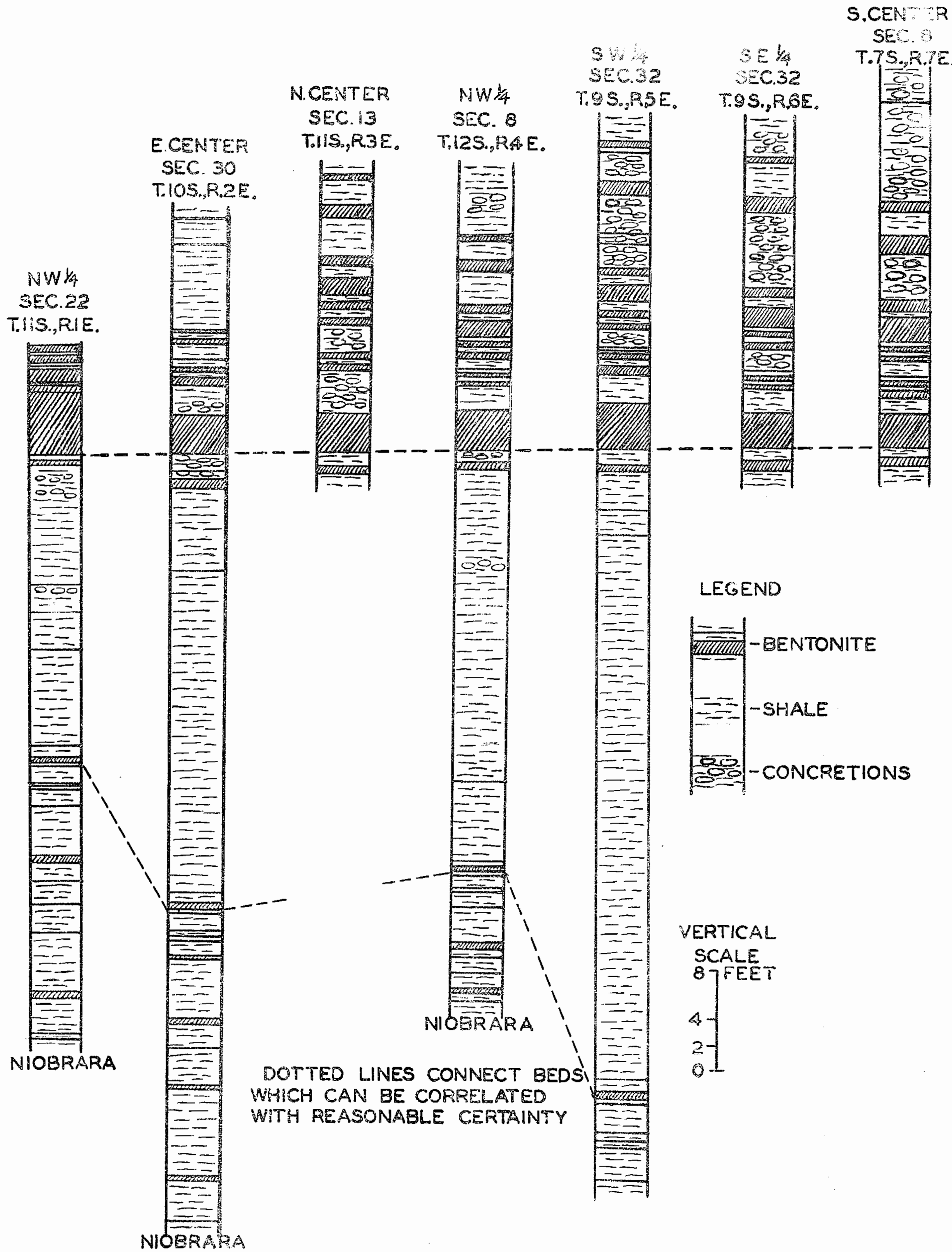


PLATE 4, FIGURE 1 - SECTIONS OF THE LOWER PIERRE FORMATION

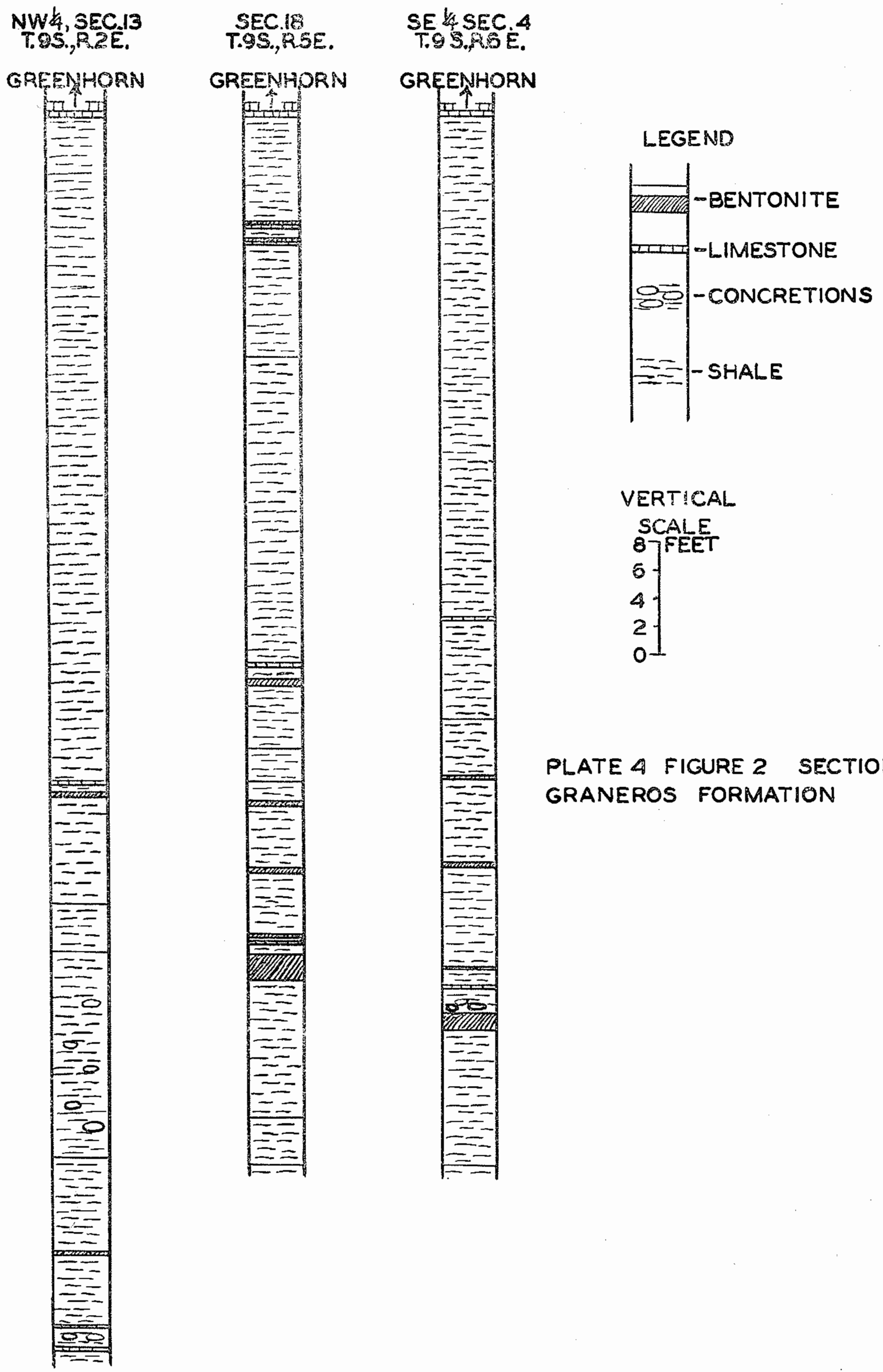


PLATE 4 FIGURE 2 SECTIONS OF UPPER GRANEROS FORMATION

Section of part of Mowry and upper Graneros
on south banks of Cheyenne River
Sec. 8, T.9 S., R.5 E.

Feet	Inches	
	10	limestone, medium gray, weathering brown; thinly and evenly bedded, fossiliferous.
90		shale, medium gray, weathers bluish gray; thinly but unevenly laminated; with abundant fish remains. A zone of cone-in-cone concretions associated with two thin bentonite beds occurs 30 feet from the top.
72		shale, dark gray; oligonite concretions occur throughout the interval, but near the top is a double row of nearly continuous concretions.
3	6	bentonite, greenish gray, with numerous selenite crystals.
7		shale,dark gray, probably Mowry
1	5	bentonite
	8	sandstone, brown, with iron oxide cement.
3		shale,dark gray, brittle, thinly laminated;
	3	bentonite
13		shale, silvery gray, with moderately thin laminae; fish scales common, especially near top.
	3	bentonite
18		shale, silvery gray, brittle; with moderately thin laminae; few fish scales.
27		sandstone, gray to yellow or brown, very irregularly bedded with numerous lenses and small nodules of gray shale included. Laterally the sandstone is replaced by an intricate network of sandstone dikes and sills occurring in gray shale.
236	11	Total section

BENTONITE EXPOSURES

Brief descriptions of each main exposure along the outcrops of the Pierre, upper Graneros, and lower oligonite-upper Mowry beds are given below. Attempts were made to include enough data to permit determination of the possibilities for commercial production of bentonite from each exposure. At the present time most stripping operations are confined to bentonite deposits which have a thickness of 3 feet or more and an overburden of less than 20 feet. For this reason, the width of the area underlain by less than 20 feet of cover has been determined for most of the main exposures. This was computed by measuring the angle between the surface slope at the outcrop and the dip of the bentonite beds and then finding the width of the possible producing area by solving for the sides of a triangle. Measurements of surface slope and dip were made with a hand clinometer, and are accurate only within the limits of such an instrument. It should be noted, also, that many of the exposures are cut by gullies and are quite irregular so that only approximate surface slopes could be determined. In studying shale formations it is important to remember, too, that in many cases slumping has taken place to such an extent that it is impossible to determine the true dip of the exposed beds. This fact was considered when measurements of the dip were made, and at places where there was doubt about the true dip, the steepest dip measured was the one recorded. For this reason determinations of the width of the area having less than 20 feet of overburden are believed to be conservative and to represent minimum values. Length of the exposures and thickness of the bentonite beds are also included so that the approximate amount of bentonite available at each exposure can be computed. (Note: If tonnage available at exposures is desired, allow 75 pounds per cubic foot of bentonite.)

Locations of the exposures were made with a plane table and open sight alidade, and locations given are believed to be accurate to the nearest quarter-section. In some areas, as in T.11 S., R.1 E., where there are few roads, section-line fences, or section corners to use as a check, the accuracy may be somewhat less.

Pierre bentonite exposures

NE$\frac{1}{4}$ Sec.7, T.9 S., R.1 E. The Ardmore bed is about 45 inches thick and is separated by thin shale seams from other thick bentonite beds above. Exact measurements are difficult to obtain because of slumping, but the section seems to be very similar to the one in Sec. 15, T.11 S., R.1 E. (described on page 4). Near the end of the hill on which these exposures occur a bench 100 feet wide by 300 feet long occurs, and this is underlain by bentonite with little cover. For the most part, however, the surface slope is about 15 degrees and the bentonite has a thick cover within a few feet of the outcrop.

N.$\frac{1}{2}$ Sec. 18, T.9 S., R.1 E. The surface slopes are too steep for stripping operations except for one small area, 400 feet long, where the bentonite underlies a dip slope.

W.$\frac{1}{2}$ Sec. 19, T.9 S., R.1 E. The exposure is about 800 feet long, the dip 6 degrees toward the southwest, and the surface slope about 6 degrees. A strip about 90 feet wide has a cover less than 20 feet thick. The following measurements of the exposed beds were taken:

Feet	Inches	
50		shale
	4	bentonite
1		shale, with gray limestone concretions
	1	bentonite
2	2	shale
	1	bentonite
	4	shale
	9	bentonite
1		shale
1	1	bentonite, with abundant selenite crystals
	9	shale
	3	bentonite
	4	shale
1		bentonite
	1	shale
	7	bentonite
	2	shale
3	4	bentonite
	10	shale
	2	bentonite

1	2	shale
	10	bentonite
	1	shale
	2	bentonite
1	1	shale
	1	bentonite
	6	shale
	1	bentonite
2	9	shale
	3	bentonite
		shale, bottom not exposed

Secs. 30, 31, T.9 S., R.1 E. The surface slopes are too steep for stripping operations.

N. central Sec. 34, T.10 S., R.1 E. Exposures are poor, and the bentonite seems to have been partially reworked.

In sections west of here outcrops of limestone concretions mark the approximate position of the Ardmore bentonite, but no thick bentonites could be located. This might be explained by 1) thinning of the bentonite beds to less than 8 inches, or 2) the Ardmore bed being separated from the concretions by thicker shale beds than usual so that it is either covered by gravel on the top of the escarpment or by alluvium at the foot of the escarpment.

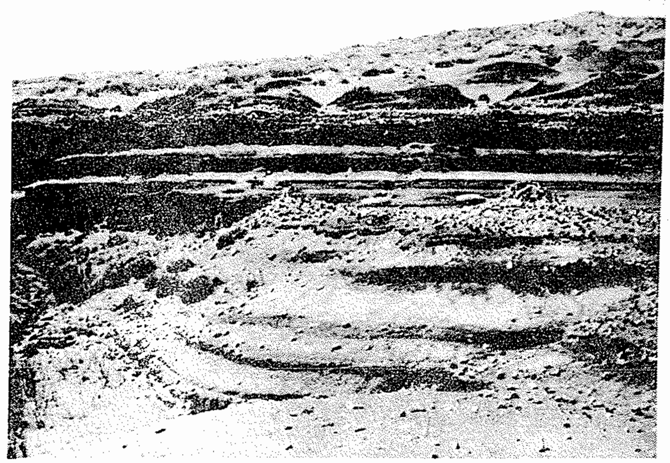
SW ¼, Sec. 15, T.11 S., R.1 E. Detailed measurements of the lower Pierre of this area are given on page 4. The exposure here is over a mile long, the surface slopes up gently (3 degrees) from the bentonite, and the dip is not steep. Bentonite could be produced from an area about 200 feet wide, and this would be an excellent exposure for stripping operations except for the fact that there are no roads within 6 or 7 miles of the area.

Similar exposures also occur to the southwest in sections 27 and 28, but there the surface slopes are steeper.

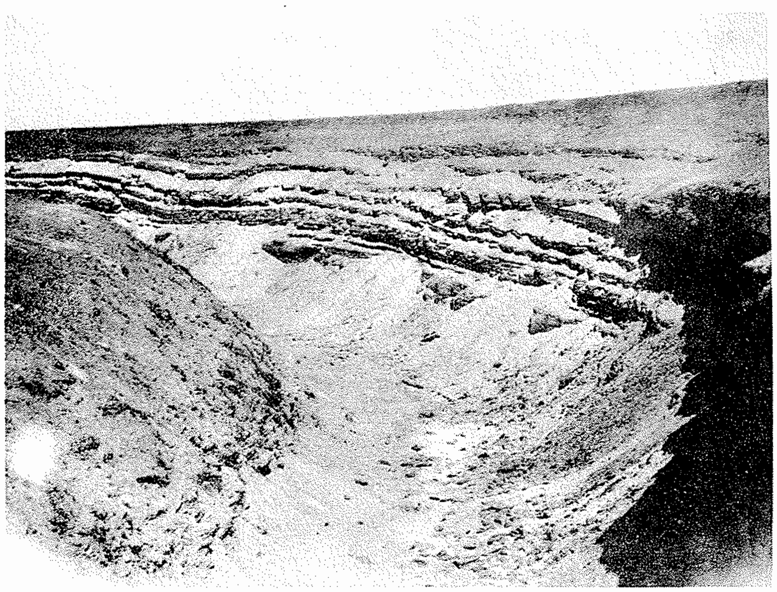
NW ¼, Sec. 1 and adjacent part of Sec.2, T.11 S., R.1 E. The Ardmore bentonite here has a thickness of about 43 inches, but contains 5 to 10 per cent of calcium carbonate

OUTCROPS OF BENTONITE ZONE

at the BASE OF THE PIERRE FORMATION



Upper Part of Zone near Buffalo Gap
Sec. 8, T. 7 S., R. 7 E.
Bentonite beds (light) separated by shale (dark).
Pieces of partially disintegrated limestone concretions are strewn over the outcrop.



Ardmore Bentonite Pits
SE$\frac{1}{4}$ Sec. 32, T. 9 S., R. 6 E.
Fall River County

in irregular beds. The dip of the strata is about 8 degrees and the slope of the surface above the Ardmore bed is about 2 degrees. It would be possible to strip an area 115 or 120 feet wide by 1000 feet long, and it is quite possible that the length of the producing area could be extended a considerable distance to the northeast and southwest by a few test holes.

Sec. 30, T.10 S., R.2 E. The Ardmore bentonite bed has a thickness of 38 to 41 inches in this section. The dip is 4 or 5 degrees, but the surface slope above the Ardmore bentonite averages 10 or 12 degrees. It would be possible to strip an area about 75 feet wide on the average, but locally stripping could be carried down dip for possibly 100 feet. A complete measured section from this area is given on page 6 and 7.

NE corner Sec. 29, T.10 S., R.2 E. This is a long exposure with similar characteristics throughout. The dip of the beds is toward the south except at the western end of the exposure where the dip swings around toward the southeast. The amount of dip varies from 6 to 9 degrees but averages about 7. The surface slope above the Ardmore bentonite is about 5 degrees. It would probably be possible to produce bentonite from an area about 100 feet wide and over a mile long. The Ardmore bed is 38 inches thick.

Sec. 35, T.10 S., R.2 E. Exposures of the bentonite zone are too small to be of any importance. Here, as at most places where the zone is covered, it might be possible to dig test holes and outline fairly large areas where production from the thicker beds of bentonite would be possible.

SW $\frac{1}{4}$, Sec. 25, T.10 S., R.2 E. The Ardmore bed is exposed in a gully where it is about 35 inches thick and occurs, with the overlying beds, over an area of about 400 by 100 feet with a cover of 4 to 12 feet in thickness.

Secs. 19, 20, 21, 30, T.10 S., R.3 E. The dips here are comparatively gentle, about 4 to 6 degrees, toward the southwest. The exposures are mostly on the side of an escarpment that is too steep to permit commercial production of bentonite. The thickness of the Ardmore bed is 36 inches.

<u>Sec. 35, T.10 S., R.3 E.</u> In the southeastern part of the section an exposure about 300 feet long has a surface slope of 10 degrees immediately above the outcrop but within a few feet this flattens out to about 4 degrees. The dip is about 6 degrees, so it would be possible to produce bentonite from an area about 100 feet wide.

At about the middle of the section an exposure occurs with a length of about 600 feet, but with a considerable area toward the northwest which probably has the bentonite zone a short distance below the surface. The dip is 3 or 4 degrees, and the surface slope averages 3 degrees. It would probably be possible to strip an area from 150 to 200 feet wide, depending on local variations in the slope of the surface.

Throughout most of this area the Ardmore bentonite bed has a thickness of 36 inches, but in one gully in the northwest quarter of the section the bed is 50 inches thick.

<u>NW $\frac{1}{4}$, Sec.1, T.11 S., R.3 E.</u> The dip here is 7 or 8 degrees, S.85 degrees W., and the surface slope is about 12 degrees. Because of this steep surface slope, bentonite could be produced only from an area 55 or 60 feet wide; the length of the exposure is a little over one-fourth mile. A map and cross section of this exposure are given on Plate 5.

<u>NE $\frac{1}{4}$, Sec. 13, T.11 S., R.3 E.</u> The dip here, as at most Pierre outcrops, is variable but averages about 8 degrees. The surface slope is only 1 or 2 degrees and it should be possible to strip an area 120 feet wide by 600 feet long. For an additional 600 feet to the south of the actual exposure the bentonite zone appears to lie near the surface, and a few test holes might extend the workable length to 1200 feet or more. A measured section of the bentonite zone is as follows:

Feet	Inches	
20		shale, with gray limestone concretions
	7	bentonite
2	1	shale
1	1	bentonite
3		shale, with numerous limestone concretions
	8	bentonite
1		shale
1	4	bentonite
8		shale
	6	bentonite
	8	shale
	6	bentonite
2	4	shale
	4	bentonite
	5	shale
	6	bentonite
3	4	shale
3		bentonite
1	4	shale
	6	bentonite
51	2	Total section

Sec. 17, 18, 20, 29, 32, T. 11 S., R. 4 E. The bentonite zone is covered by terrace gravels and alluvium across these sections, but the beds can be followed and mapped by assuming them to maintain a constant interval below the cone-in-cone rosettes which are exposed.

SE$\frac{1}{4}$, Sec. 32, T. 11 S., R. 4 E. Two small exposures occur here with too much cover to be of commercial importance.

SW$\frac{1}{4}$, Sec. 5, T. 12 S., R. 4 E. The thicknesses of the bentonite beds here are essentially like those in the Refinite Company pit a short distance to the south. The surface slope averages about 5 degrees and the dip is about 7 degrees. Thus, an area about 100 feet wide has less than 20 feet of overburden. This exposure is only about 300 feet long, but to the north the bentonite is covered by alluvium and a few test holes would reveal whether the cover is thick or whether the bentonite occurs near the surface. For about 200 yards to the south the Ardmore bed is exposed on the west bank of Hat Creek, but the cover is too thick for stripping.

NW $\frac{1}{4}$, Sec. 8, T.1[illegible] S., R.4 E. On the north side of the road running west from Ardmore is located the strip pit now being operated by the Refinite Company. An old pit south of the road has apparently been abandoned.

The dip is about 7 degrees, and the slope of the surface 10 degrees, so that the bentonite can be stripped for about 65 to 70 feet before a cover of 20 feet is reached. The total length of the exposure is about 850 feet.

A measured section of the lower Pierre, including the main bentonite-bearing part of the formation is given on page 7.

NE $\frac{1}{4}$, Sec.9, T.12 S., R.4 E. The Ardmore bentonite has a thick cover because it is exposed at the base of an escarpment. From section 9 northeastward through the eastern part of section 4 and northwest part of section 3 the Ardmore bed is covered by soil. Some of the overlying bentonite beds are exposed, however, and they indicate that the thicker Ardmore bed is not far below the surface.

E.$\frac{1}{2}$, Sec.34 and SE $\frac{1}{4}$, Sec.27, T.11 S., R.4 E. The dip here is about 12 degrees toward the east. For the most part the surface slope is 5 or 6 degrees but near the east central part of Sec. 34 the surface slope is only 2 degrees. Thus it would be possible to strip an area from 60 to 80 feet wide before encountering an overburden of 20 feet.

A complete section through the bentonite-bearing zone is given on page 8.

NE $\frac{1}{4}$, Sec.14, T.11 S., R.4 E. The dip here is toward the southeast and averages about 11 degrees. The surface slope is only about 2 degrees at the outcrop of the Ardmore bed, but increases to 4 or 5 degrees about 75 feet from the outcrop. It would be possible to produce bentonite from an area 80 or 90 feet wide by about 600 feet long. The thickness of the Ardmore bed is 36 to 40 inches.

An exposure similar to this one occurs in the south central part of section 23, and between these two exposures are several smaller exposures--mostly in gullies.

<u>W.½,Sec. 1, T.11 S., R.4 E.</u> This is a long exposure in which the beds have rather gentle dips toward the east. The surface is irregular and cut by several gullies, but in general the slope above the Ardmore bed is not more than 6 or 7 degrees. Thus it should be possible to produce bentonite from an area nearly a mile long and about 100 feet wide. The Ardmore bentonite is 3 feet thick.

<u>E.½, Secs. 25, 24, T.10 S., R.4 E.; W.½, Sec. 30, 19, 18, SE¼, Sec.7, and SW¼ Sec. 8, T.10 S., R.5 E.</u> This exposure is over 3 miles long. The average dip is about 6 degrees and toward the east. The surface slope varies from 1 to 6 degrees and averages about 4 degrees. An area 3 miles long by 100 to 160 feet wide has an overburden less than 20 feet thick.

A section measured at the northwest corner of section 30, T.10 S., R.5 E. is as follows:

Feet	Inches	
100		shale, with numerous limestone, cone-in-cone, and dark ferruginous concretions.
	7	bentonite
2	3	shale
1		bentonite
4	4	shale
	10	bentonite
1		shale
1	4	bentonite
	8	shale
	6	bentonite
	7	shale
	6	bentonite
1	9	shale
	5	bentonite
	4	shale
	6	bentonite
2	2	shale
3	4	bentonite, Ardmore
	11	shale
	6	bentonite
40		shale, bottom not exposed
163	6	Total section

SW$\frac{1}{4}$, Sec. 32, T. 9 S., R. 5 E. The Ardmore bentonite is 46 inches thick at this exposure. The dip is about 6 degrees and toward the southeast. The surface slope averages about 7 degrees and it would be possible to produce bentonite from an area 90 to 100 feet wide by 1$\frac{1}{2}$ miles long. There are numerous gullies cutting across the exposure and the surface is irregular so the width of the possible producing area would vary from place to place.

A section measured at this locality is described on page 9.

Sec. 4, southeastward to Sec. 26, T. 10 S., R. 5 E. The Ardmore bentonite is 25 to 30 inches thick and dips steeply toward the west. In Sec. 4 the dip is about 40 degrees and to the south it gradually decreases to about 15 degrees in Sec. 26. In this area the bentonite has a cover of more than 20 feet within 30 to 50 feet of the outcrop.

Sec. 25, T. 10 S., R. 5 E., northeastward to Sec. 4, T. 10 S., R. 6 E. This is a long and almost continuous exposure, being interrupted only where gullies cut through the escarpment along which the bentonite crops out.

In the southwestern part of the exposure the dip is 12 degrees toward the southeast. To the north the dip decreases to 8 degrees in Sec. 17 and to 7 degrees in Sec. 4, T. 10 S., R. 6 E. The surface slope above the bentonite beds varies from 4 to 8 degrees, but averages about 5 degrees. The width of the area with less than 20 feet of cover would thus vary from 70 to about 100 feet.

Measurements made on the beds in Sec. 25, T. 10 S., R. 5 E. are typical of the entire exposure.

Feet	Inches	
50		shale, with numerous thin streaks of bentonite, and with dark ferruginous and cone-in-cone concretions in the upper part.
	6	bentonite

3		shale, with gray limestone concretions
1		bentonite
4	2	shale, with gray limestone concretions
	1	bentonite
2	3	shale, with gray limestone concretions
	8	bentonite
	9	shale
1	5	bentonite
	8	shale
	5	bentonite
	6	shale
	6	bentonite
1	4	shale
	1	bentonite
	3	shale
	4	bentonite
	3	shale
	5	bentonite
1	6	shale
3	4	bentonite, Ardmore
	10	shale
	8	bentonite
2	9	shale, with gray limestone concretions
77	8	Total section

<u>SE$\frac{1}{4}$, Sec. 32, T.9 S., R.6 E.</u> A map and cross section of this exposure are given on Plate 5. This is one of the most favorable localities found for producing the Pierre bentonite because the Ardmore bed underlies a dip slope and has a minimum of cover over a fairly large area. A section of the bentonite zone was measured as follows:

Feet	Inches	
90		shale, with ferruginous and calcareous concretions
	6	bentonite
2	8	shale
1	1	bentonite
6		shale, with numerous gray limestone concretions
	8	bentonite
	10	shale
1	6	bentonite
	6	shale
	6	bentonite
	6	shale
	7	bentonite

1	6	shale, with gray limestone concretions
	1	bentonite
	4	shale
	5	bentonite
	3	shale
	6	bentonite
1	11	shale
3		bentonite
1		shale
	8	bentonite
115		Total section

Secs. 27, 28, T.9 S., R.6 E. The dip is 20 to 25 degrees, and the surface slope is 6 degrees. The overburden is too thick to permit commercial production of bentonite.

Sec. 26, T.9 S., R.6 E. The exposure is about one-fourth mile long, the Ardmore bed is 3 feet thick, the dip is 12 degrees and the surface slope is 3 degrees. It would be possible to produce bentonite from an area about 75 feet wide.

Secs. 14, 11, T.9 S., R.6 E. Several small exposures, usually not more than 300 feet long, have a dip of 9 degrees toward the southeast and surface slopes of 5 to 8 degrees. Thus, at each exposure an area about 80 feet wide would have a cover of less than 20 feet. A small exposure in the north central part of Sec. 11 is partially covered by a hard iron-cemented sandstone.

NW corner Sec. 2, T.9 S., R.6 E. across E.½, Sec. 34, T.8 S., R.6 E. This exposure is over a mile long and the Ardmore bed is 40 inches thick. The dip is 8 degrees toward the east, and the surface slope is 1 to 3 degrees. An area 100 to 130 feet wide would have a cover less than 20 feet thick.

Secs. 31, 32, T.7 S., R.7 E. This exposure is on the banks of the Cheyenne River, and the overburden is too thick to allow commercial quarrying of the bentonite. The Ardmore bed is 2 feet 8 inches thick.

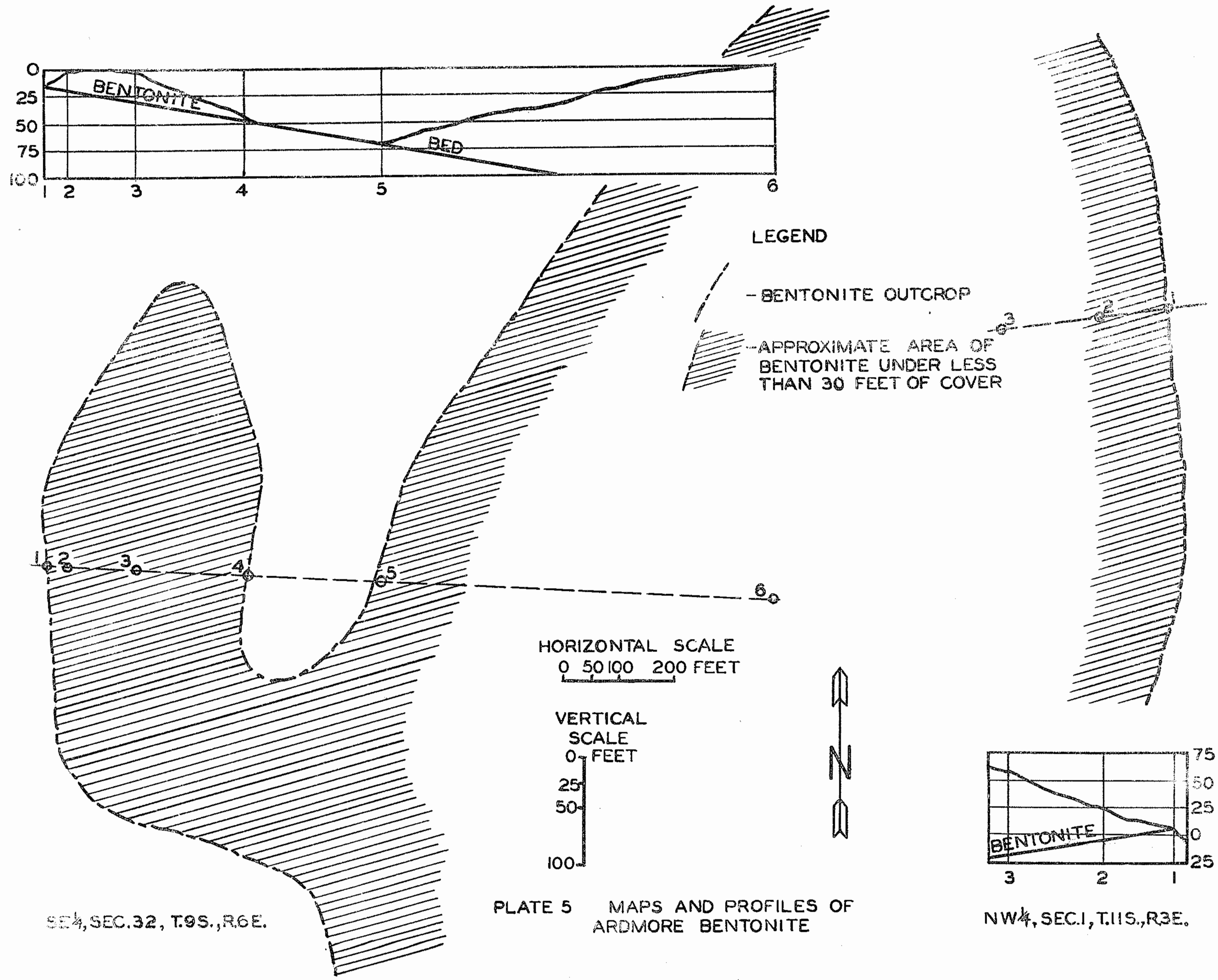


PLATE 5 MAPS AND PROFILES OF ARDMORE BENTONITE

SW$\frac{1}{4}$, Sec. 29, T. 7 S., R. 7 E. The Ardmore bentonite is under a dip slope of 5 degrees and has an average overburden of less than 7 feet throughout the area 250 feet wide and 700 feet long. The thickness of the Ardmore is considerably less than usual, being only 30 to 32 inches, and except for this fact the locality would be a good one for commercial production of bentonite.

Secs. 20, 17, 8, T. 7 S., R. 7 E. In the north central part of Sec. 20 the dip is 10 degrees toward the east. The surface slope is about 8 degrees, and this means an area 60 to 65 feet wide would have less than 20 feet of cover over the bentonite. In the southern part of Sec. 17 the dip remains the same, but the surface slope is about 4 degrees. In the northern part of Sec. 17 the surface slope has decreased to an average of 3 degrees, although it is rather irregular due to gullies which cut through the shale. The Ardmore bed here is 40 inches thick. Slightly south of the center of Sec. 8 the dip is still 10 degrees and the average surface slope is 3 degrees, which would allow bentonite to be produced from an area about 90 feet wide. The thicknesses of the bentonite zone strata were measured as follows:

Feet	Inches	
50		shale, with gray limestone, dark ferruginous, and yellow cone-in-cone concretions
	9	bentonite
1	8	shale
1	5	bentonite, with abundant selenite crystals
3	6	shale, with numerous gray limestone concretions
	10	bentonite, with abundant selenite crystals, often in large aggregates.
	8	shale
1	9	bentonite
	5	shale
	5	bentonite
	5	shale
	6	bentonite
1	2	shale
	1	bentonite
	4	shale
	5	bentonite
	3	shale
	6	bentonite
1	4	shale

3		bentonite, Ardmore
	9	shale
	7	bentonite
70	9	Total section

<u>SE$\frac{1}{4}$, Sec. 16, T.6 S., R.7 E.</u> The dip of the beds is about 10 degrees and the surface is irregular but essentially horizontal. Thus, above any of the bentonite beds present there would be a cover 20 feet thick about 100 to 115 feet from the outcrop. The exposure extends for 1 mile to the northeast and there are intermittent exposures for another 1$\frac{1}{2}$ miles. The strata exposed were measured as follows:

Feet	Inches	
100		shale, with concretions
1	2	bentonite
1		shale, with cone-in-cone concretions
3		shale
	9	bentonite
1	3	shale
1		bentonite
2		shale, with gray limestone concretions
	1	bentonite
	10	shale
	8	bentonite
	6	shale
1	9	bentonite
	4	shale
	5	bentonite
	4	shale
	6	bentonite
1		shale
	4	bentonite
	2	shale
	7	bentonite
1	2	shale
2	6	bentonite
2		shale, with gray limestone concretions
	3	bentonite
50		shale, bottom not exposed; with gray limestone concretions 30 feet from top.
173	7	Total section

<u>Secs. 31, 29, 20, T.5 S., R.8 E.</u> The Pierre bentonite zone outcrops along a discontinuous belt extending from

the southwestern part of Sec. 31 to the southwestern part of Sec. 20. A bentonite bed about 36 inches thick is probably the Ardmore bentonite.

E. center Sec. 33, T.4 S., R.8 E. Part of the Pierre bentonite zone is exposed for about 100 feet in a gully that has been cut through the gravels which cover most of this area.

Sec. 23, T.3 S., R.8 E. Pierre bentonite is exposed in the southeastern and north central parts of this section, but it is doubtful if the bentonite is sufficiently thick to justify any attempts to quarry it. The thicknesses of the exposed beds are as follows:

Feet	Inches	
20		shale, containing gray limestone concretions near bottom
	9	bentonite
	3	shale
1		bentonite
	3	shale
	7	bentonite
	2	shale
1	5	bentonite, with very large proportion of calcite in small crystals
	2	shale
	5	bentonite
	4	shale
	3	bentonite
	1	shale
	8	bentonite
	3	shale
1	10	bentonite, with shale streak near top.
		shale, bottom not exposed
28	5	Total section

SW¼, Sec. 6, T.3 S., R.9 E. This is a small exposure of the Pierre bentonite zone on the north valley wall of Battle Creek. Except for this small area the bentonite is covered by gravel.

NW¼, Sec. 7, T.2 S., R.9 E. The surface slope is rather steep, but an area about 700 feet long by 40 feet wide would have less than 20 feet of overburden covering the bentonite. The individual beds are not very thick, as shown by the following measured section:

Feet	Inches	
50		shale, with gray limestone concretions 18 feet above bottom
1		bentonite
	2	shale
	10	bentonite
	1	shale
	6	bentonite
	3	shale
2	1	bentonite, with numerous dikes and irregular masses of calcite and gypsum crystals that are partially cemented by iron oxide.
	1	shale
	3	bentonite
	1	shale
	5	bentonite
	2	shale
	1	bentonite
	1	shale
	9	bentonite
	2	shale
2		bentonite
	1	shale
	5	bentonite
7		shale
	1	bentonite
1		shale
1	2	bentonite
	8	shale
	1	bentonite
	6	shale
	2	bentonite
5		shale
75	2	Total Section

<u>NE. part of Sec. 13 southwestward across NW$\frac{1}{4}$, Sec. 24, T. 1 S., R. 8 E.</u> For the most part the exposure is on the side of a steep slope of 15 to 20 degrees, but in the northwest quarter of Sec. 24 there are two benches, each about 400 feet long, where the slope is 5 or 6 degrees. Because the slopes are relatively steep and individual bentonite beds are rather thin, it does not seem probable that bentonite could be produced commercially from this

exposure. A section of the bentonite zone was measured as follows:

Feet	Inches	
		shale, with concretions
1		bentonite
	5	shale
	9	bentonite
	3	shale
	3	bentonite
	2	shale
1	2	bentonite, with large proportion of calcite and gypsum crystals
	2	shale
	3	bentonite
	1	shale
	5	bentonite
	3	shale
	4	bentonite
	2	shale
	3	bentonite
	4	calcite, unconsolidated; small, even-sized crystals
	1	shale
2	1	bentonite
	2	shale
	5	bentonite
3		shale
1	1	bentonite
	1	shale
	1	bentonite
	5	shale
	1	bentonite
	4	shale
	3	bentonite
14	4	Total section

<u>N.$\frac{1}{2}$, Sec. 34, T.2 N., R.8 E.</u> The Pierre bentonite zone is exposed for about 400 feet. No measurements of the beds were taken because the strata are poorly exposed on a grassy slope.

Exposures of upper Graneros Bentonite

Secs. 6 and 7, T. 7 S., R. 1 E. The bentonite about 130 feet below the Greenhorn limestone has a thickness of 22 inches. It is exposed on the edge of a bench so that the surface slope is only about 2 degrees above it, and probably an area from 200 to 300 feet wide has less than 20 feet of cover. Commercial production would probably not be possible, however, because of the thinness of the bed.

From this exposure southeastward to Section 22, T. 9 S., R. 3 E. this bentonite bed could not be identified, although several exposures of the upper Graneros were studied. It is probable that this bed is thin throughout this area, and it is likely that one of the bentonite beds found in Sec. 18, T. 9 S., R. 2 E., is its equivalent. (See page 20 and Plate 4, Fig. 2.)

SE¼, Sec. 22, T. 9 S., R. 3 E. Details of this exposure are given in Plate 6. The length is nearly 2000 feet, the dip is 4 degrees, and the surface slope is 5 to 7 degrees. The bentonite bed is 38 to 40 inches thick, and it would be impossible to produce bentonite from an area about 125 feet wide.

NW¼, Sec. 13, T. 10 S., R. 3 E. The Upper Graneros bentonite is exposed near the bottom of a gully cutting through the Greenhorn hogback. Although the bentonite is 38 inches thick it is not of much commercial importance because of the thick cover of shale and limestone overlying it.

SW¼, Sec. 4 and SE¼, Sec. 5, T. 11 S., R. 4 E. The upper Graneros bentonite is exposed on the west bank of Hat Creek, and although 54 inches thick here, it is covered by too much shale and soil to allow mining at present day prices. To the west, however, the bed is exposed in road cuts and on the surface in the southeastern part of section 5. It seems probable that a few test holes would reveal a large area where this bentonite might be produced commercially. If so, this would be a favorable location since it is only three miles to Rumford and seven miles to Ardmore over comparatively good roads.

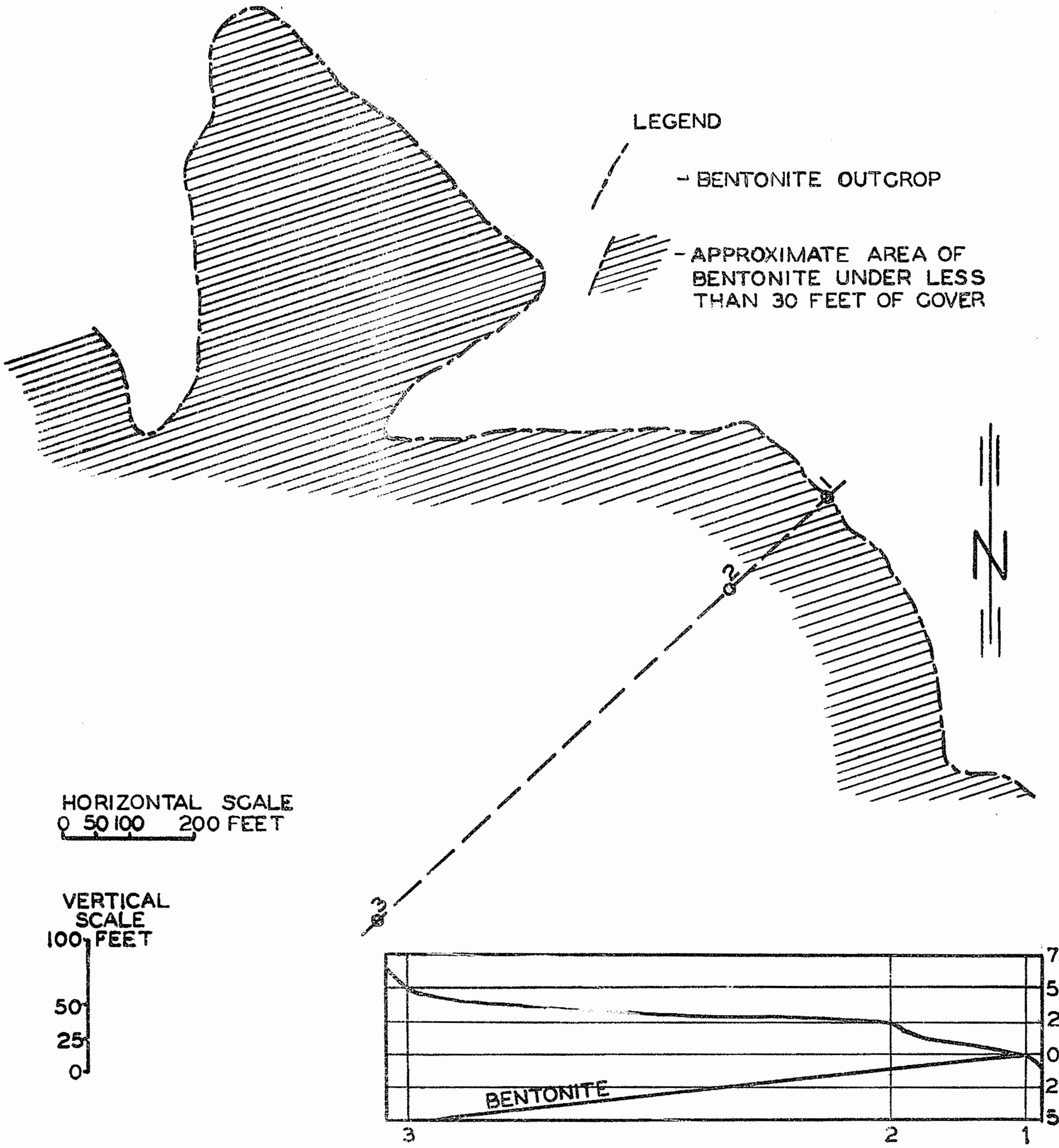


PLATE 6 MAP AND PROFILE OF UPPER BENTONITE OF THE GRANEROS SHALE IN THE SE¼, SEC. 22 T. 9 S., R. 3 E.

NW $\frac{1}{4}$, Sec.32, T.10 S., R.4 E. Upper Graneros bentonite is exposed on grassy slopes below the Greenhorn escarpment.

The dip of the beds is about 16 degrees and the surface slope is 5 degrees so that an overburden of 20 feet would be encountered about 50 feet from the outcrop.

Sec. 30, T.9 S., R.5 E. southeastward to Sec. 15, T.10 S. R.4 E. Upper Graneros bentonite exposed only along banks of Hat Creek, always with from 15 to 20 feet of alluvium overlying it.

SE $\frac{1}{4}$, Sec. 18, T.9 S., R.5 E. A 45 inch bed of bentonite about 130 feet below the Greenhorn limestone is well exposed in a gully. The bed can be traced for about 1 mile to the south and two miles to the northeast, although it is poorly exposed in most places. On the divides between gullies which radiate out from the Greenhorn escarpment the bentonite bed underlies a few inches of soil. For the most part the dip is less than 6 degrees and the surface slopes up from the bentonite at about 3 or 4 degrees. It would probably be possible to produce bentonite from an area 115 to 125 feet wide and, with a few breaks where there are deep gullies, 3 miles long. Since the exposures are poor in most places, it would be necessary to dig a few test holes to confirm surface evidence before attempting to develop this exposure. A measured section is described on page 22.

Secs. 3, 10, T.10 S., R.5 E. In the southeast quarter of Sec. 3 a nearly flat bench 600 feet long and 300 feet wide has the upper Graneros bentonite just a little below the surface. Another good exposure is along a divide in the north central part of Sec. 10. The area underlain by bentonite with less than 20 feet of overburden is about 600 feet long by 200 feet wide. The bentonite in this area is about 40 inches thick. The principal disadvantage here is that there are no roads closer than three or four miles.

E.$\frac{1}{2}$, Sec. 35, N.$\frac{1}{2}$, Sec. 36, Sec. 25, T.9 S., R.5 E. In these sections a few bentonite exposures can be found in gullies but cannot be traced across the grassy slopes of the divides. A few test holes would probably outline deposits from 400 to 800 feet long which would have an overburden less than 20 feet thick in areas 100 to 150 feet wide.

SE$\frac{1}{4}$, Sec. 4, T. 9 S., R. 6 E. The upper Graneros bentonite is exposed on the banks of the Cheyenne River. The thickness is 32 inches.

Secs. 33, 28, T. 8 S., R. 6 E. The upper Graneros bentonite with a thickness of 33 inches, is exposed on a series of small benches below the Greenhorn escarpment. The dip is 12 degrees and the surface slope 4 to 6 degrees, so that an area about 60 feet wide would have an overburden of less than 20 feet.

Sec. 3, T. 8 S., R. 6 E. The upper Graneros bentonite is exposed on high banks of the Cheyenne River where it is 40 inches thick.

Eastern parts of Sec. 34, 27 western part of Sec. 22, T. 7 S., R. 6 E. The upper Graneros bentonite is about 40 inches thick in this area, the dip is 6 or 7 degrees, and the surface slope 4 or 5 degrees. Throughout much of the area the bentonite cannot actually be seen, but its position across the grassy slopes below the Greenhorn escarpment can be traced by means of a row of gray limestone concretions which occur above it. An area 90 to 115 feet wide has an overburden less than 20 feet thick.

Sec. 12, 13, T. 7 S., R. 6 E. In the northern half of Sec. 13 and the southeastern quarter of Sec. 12 two bentonite beds can be seen. Each bed is 36 to 40 inches thick and they are separated by 4 or 5 feet of shale. The dip is 7 degrees and the surface slope about 3 degrees, so that an area about 115 feet wide has an overburden of less than 20 feet. Although the outcrop of these bentonites is on a grassy slope, the position of the beds can easily be determined because of layers of gray limestone concretions above each bed.

Center Sec. 18 and north across SE$\frac{1}{4}$ Sec. 7, T. 6 S. R. 7 E. Concretions above the upper Graneros bentonite mark the position of that bed, although the bentonite itself is poorly exposed. No exposures were found where accurate measurements could be made, but the bed appeared to be about 3 feet thick.

SW.$\frac{1}{4}$, Sec. 30, T.4 S., R.8 E. Bentonite in the upper Graneros formation is exposed for a short distance in a small gully. Neither the bentonite nor the overlying concretions can be traced for more than a hundred feet or so, but the bentonite evidently underlies a rather large area and a few test holes might reveal deposits of commercial importance. The minimum thickness at the exposure is 3 feet.

Upper Mowry-lower Oligonite zone Bentonite Exposures

NE. corner Sec. 17, across S.$\frac{1}{2}$ Sec. 16 and E.$\frac{1}{2}$ Sec. 21, T.6 S., R.1 E. A section showing the thickness of the various bentonites exposed here is given on Plate 3. In section 21 the upper bentonite in the exposure occurs just below the top of small spurs with areas too slight to be of any importance. The lower bentonites are on the sides of steep slopes. In section 17 the Mowry bentonites are mostly covered by alluvium, but in the SE.$\frac{1}{4}$ of this section the two lower bentonites of the Mowry have thicknesses of 25 and 20 inches respectively, separated by 1 foot of shale. The surface is nearly horizontal and the dip about 4 degrees. Although the actual exposure of these beds is only about 75 feet long, it seems likely that test holes might reveal a large area where they might be quarried on a commercial scale. In this same area the upper (40 inch) bentonite is exposed for a distance of about half a mile. The dip is 4 degrees and surface slope about 4 degrees, so an area about 150 feet wide would have a cover less than 20 feet thick over the bentonite. There are many small outliers of this bentonite, also, which have a cover of from 1 to 3 or 4 feet, although on many of these part of the bentonite has been eroded away. The upper bentonite of this area contains 12 to 15 per cent of grit consisting of hematite and feldspar with minor amounts of chlorite and zircon.

NE.$\frac{1}{4}$, Sec. 33, T. 6 S., R. 1 E. The upper bentonite of the oligonite zone is about 3 feet thick and the rest of the beds exposed are similar to those described in section 21. The exposure here is partly covered by deposits of coarse gravel.

Secs. 4, 9, T. 7 S., R. 1 E. The upper bentonites of the oligonite zone are exposed with thicknesses comparable to those in section 21 in the township to the north. The exposures are small because they are found only in railway and highway cuts.

SW$\frac{1}{4}$, Sec. 16, T. 7 S., R. 1 E. A section measured on the west bank of Beaver Creek is as follows:

Feet	Inches	
3		bentonite
20		shale
1		bentonite
10		shale, with oligonite concretions
17		shale, Mowry
	3	bentonite
7	6	shale, Mowry
	3	bentonite
1	6	shale, Mowry
	8	bentonite
1		shale
	10	bentonite
8		shale, Mowry, bottom not exposed
71		Total section

The top bentonite has very little cover over an area 400 by 100 feet, but the lower bentonites are exposed on the valley walls and have a thick cover, as do all the bentonite beds in a continuation of the exposure to the northwest.

E. center Sec. 12, T. 8 S., R. 1 E. This is part of an unusually long exposure of the oligonite zone-Mowry bentonite, since it extends about 1 mile to the southeast and an equal distance to the northwest. Measurements of the bentonite and shale beds are as follows:

Feet	Inches	
		Tertiary gravels
25		shale, with oligonite concretions
2		bentonite
15		shale, with oligonite concretions
2		bentonite (this bed varies in thickness up to 3 feet in some parts of the exposure)
14		shale, with oligonite concretions
6		shale, silvery gray. Mowry
	3	bentonite
6		shale, Mowry
2	9	bentonite, with small masses of dark gray shale included near the middle.
20		shale, Mowry, bottom not exposed.
93		Total section

The surface slope is 2 to 4 degrees above the upper bentonite in the section, but is about 8 degrees above the lower beds. The dip is 4 degrees. Thus an area 140 feet wide would have less than 20 feet of cover over the top bentonite, but the area would be only 80 or 90 feet wide in which the lower bentonites would have less than this amount of overburden.

<u>SE.$\frac{1}{4}$, Sec. 18, to SE.$\frac{1}{4}$ Sec. 34, T.8 S., R.2 E.</u> The bentonite bearing parts of the oligonite zone and the Mowry shale are covered by alluvium in the Cheyenne River valley.

<u>NW.$\frac{1}{4}$, Sec. 2, T.9 S., R.2 E.</u> The bentonite beds here are irregular both in thickness and in dip. Considerable amounts of bentonite have been forced on to the surface while in a plastic condition, but measurements of the beds were made by digging through the bentonite and the overlying shale a few feet from the outcrop.

Feet	Inches	
20		shale, with oligonite concretions
2	8	bentonite
16		shale, with oligonite concretions
1	8	bentonite
16		shale, with oligonite concretions

1	7	bentonite
10		shale, with oligonite concretions in the upper part
	8	bentonite
10		shale, Mowry
78	7	Total section

A map and cross section of this exposure are given on Plate 7. A columnar section is given on Plate 3.

NW$\frac{1}{4}$, Sec. 7, T. 9 S., R. 3 E. In the north central part of this section a 15 inch bentonite bed occurs near the base of the oligonite zone, and this is separated by 23 feet of shale from a 20 inch bentonite above. A few hundred feet to the southwest the lower bed directly overlies an irregular layer of concretions and varies from 21 to 28 inches in thickness within a few feet laterally. In local areas the bentonite beds have little cover, but because of the variable thickness it would be necessary to dig test holes to outline the deposits before attempting to exploit them.

E. central part Sec. 6, T. 9 S., R. 3 E. The bentonite bearing beds of this area occur on the side of a hill with steep slopes. A columnar section on Plate 3 shows the thickness of the beds.

West center Sec. 9, T. 9 S., R. 3 E. The beds exposed here are shown in a columnar section on Plate 3. There are long exposures of bentonite in this area but the beds are too thin and generally occur under slopes too steep to permit commercial production.

Sec. 26, T. 9 S., R. 3 E. A 25 inch bentonite bed occurs in the lower part of the oligonite zone.

E. center Sec. 35, T. 9 S., R. 3 E. A 26 inch bentonite bed occurs in the upper part of the Mowry shale. The exposure is small, and the bentonite cannot be traced far from the banks of Plum Creek where the exposure is located.

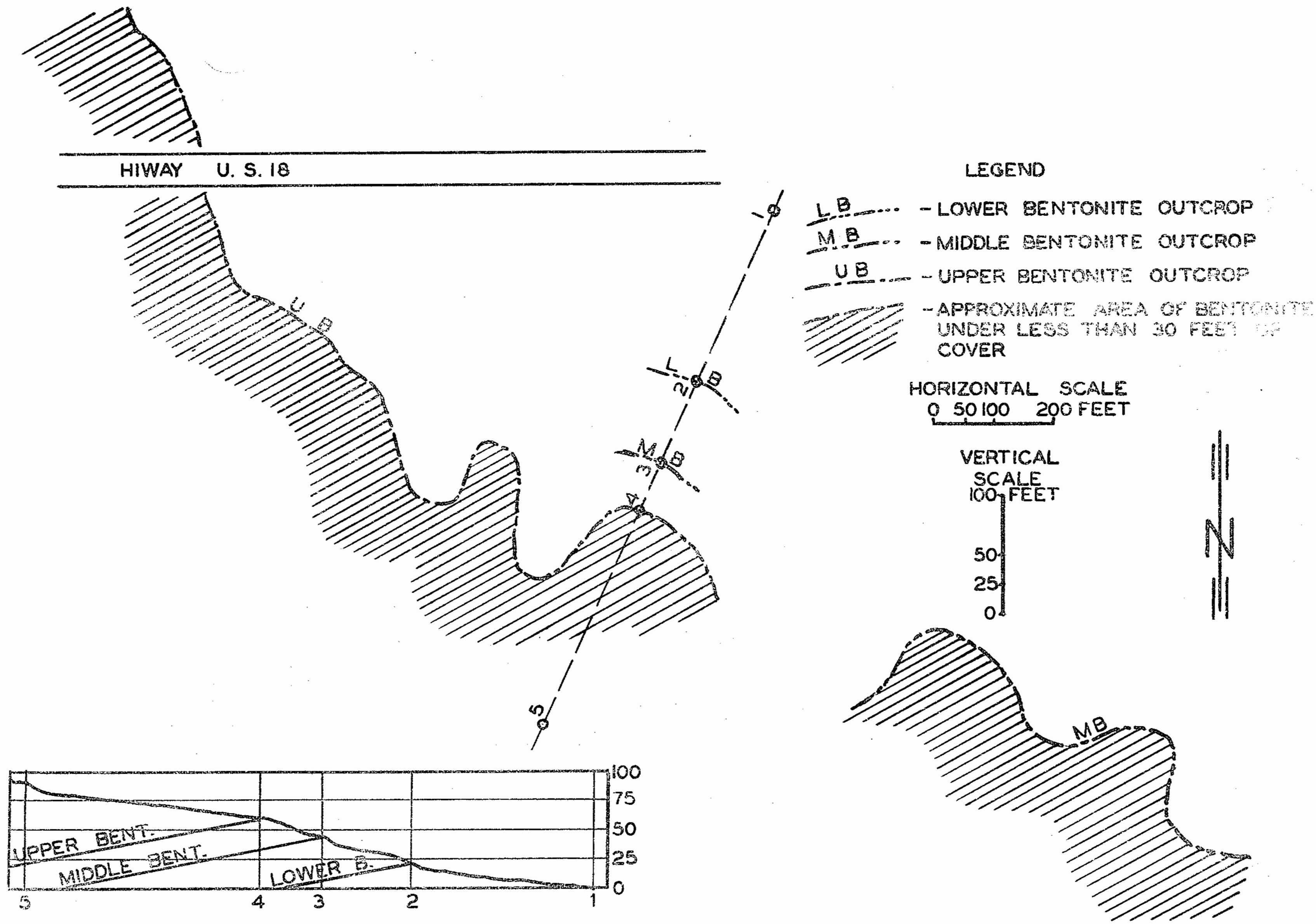


PLATE 7 MAP AND PROFILE OF BENTONITE IN THE OLIGONITE ZONE EXPOSED ABOUT ONE MILE WEST OF EDGEMONT
SEC. 35, T.8S., R.2E., SEC. 2, T.9S., R.2 E..

Secs. 20, 21, T. 1[illegible], R. 4 E. Two thin bentonite beds occur in the upper Mowry shale, and a 23 inch bed occurs in the lower part of the oligonite zone.

Western part Sec. 16, T. 9 S., R. 5 E. In the upper Mowry a 24 inch bentonite occurs 12 to 15 feet above the sandstone dike zone. The dip is 35 degrees.

Sec. 34, T. 9 S., R. 5 E. The lower oligonite zone has two bentonites, the lower 7 inches thick and the other, 5 feet above it, 23 inches thick.

Sec. 23, 24, 26, T. 9 S., R. 5 E. Two bentonite beds, separated by 4 feet of shale, occur near the bottom of the oligonite zone. The lower bed is 20 to 28 inches thick and the upper 8 to 10 inches thick. The oligonite zone and the Mowry shale are heavily timbered with western yellow pine and exposures are poor. The dip was determined as approximately 6 degrees.

Sec. 19, T. 9 S., R. 6 E. No bentonite could be found in the upper Mowry in spite of the fact that the Mowry is exposed from the sandstone dike zone to the bottom of the oligonite zone.

In the oligonite zone a 22 inch bentonite bed occurs about 5 feet above the base and this is separated by 16 inches of shale from an overlying 28 inch bed. The dip is difficult to determine but is approximately 5 degrees and the surface slope averages about 3 degrees. An area about 140 feet wide would have less than 20 feet of overburden. This exposure is not covered by timber as are most of the exposures in areas west of here. This exposure is about three-fourths of a mile long.

NW¼, Sec. 28, T. 8 S., R. 6 E. A 44 inch bentonite bed at the bottom of the oligonite zone is exposed for a distance of about 200 yards. The exposure is in a wooded area and the slopes are too steep for stripping.

Sec. 34, T. 7 S., R. 6 E. The upper Mowry does not contain thick bentonites so far as could be seen. There is a 6 inch bed in the lower part of the oligonite zone and a 28 inch bed 5 feet above it.

W. central part Sec. 27, T. 7 S., R. 6 E. The bottom of the oligonite zone has an 8 inch bentonite bed and 9 feet above it another bed that is 9 inches thick. At this locality the sandstone dikes of the Mowry come up to within 15 feet of the top of the member, and the upper Mowry contains a few bentonites, all less than 6 inches in thickness.

SE$\frac{1}{4}$, Sec. 15, T. 7 S., R. 6 E. A 37 inch bentonite occurs in the lower part of the oligonite zone, about 4 feet above the lowest concretions visible. A 10 inch bentonite occurs in the Mowry, but is poorly exposed so that its exact position is not determinable although it appears to be about 20 feet below the lowermost concretions of the oligonite zone. The dip is about 8 degrees toward the east, the surface is rough but essentially horizontal, and the region is timbered.

S. central Sec. 14, T. 7 S., R. 6 E. The following beds were measured in a road cut:

Feet	Inches	
5		shale, with oligonite concretions
12		shale, Mowry
	8	sandstone
	7	bentonite
7		shale
	4	bentonite
	3	shale
	4	bentonite
26	2	Total section

A few hundred feet to the southeast a 49 inch bentonite in the lower oligonite zone is exposed in a gully.

NW$\frac{1}{4}$, Sec. 13, T. 7 S., R. 6 E. A small exposure has 35 to 40 inches of bentonite in the lower part of the oligonite zone.

Sec. 20, T. 5 S., R. 7 E. Bentonite in the lower oligonite zone is exposed in a few very small areas but is mostly covered by alluvium and gravel. Only one bed is well enough exposed to be measured without considerable digging and it has a minimum thickness of 25 inches.

Sec. 30, T. 2 S., R. 8 E. The Mowry and part of the oligonite zone are well exposed one half mile west of Hermosa, but no bentonite could be located. The Mowry contains large dark colored concretions as well as sandstone dikes and sills.

N. center Sec. 17, T. 1 S., R. 8 E. A section through the upper Mowry was measured as follows:

Feet	Inches	
		shale, with oligonite concretions the lowest of which vary from 5 to 10 feet above the underlying bentonite.
1		bentonite
	3	shale
	2	bentonite
10		shale
	4	bentonite
1		shale
	3	bentonite
15		shale
		shale with thin sandstone dikes
28		Total section

S. center Sec. 31, T. 1 N., R. 8 E. A one foot bentonite occurs in the upper part of the Mowry, and a 39 inch bed occurs about 2 feet above the bottom of the oligonite zone. The bentonite is poorly exposed except for one good exposure on the banks of a creek.

TRANSPORTATION FACILITIES

The map showing the location of bentonite deposits in Fall River County (Plate 8) shows also the location of railroads and some of the main travelled highways. Although not shown on the map, there are roads near all of the bentonite exposures south of Buffalo Gap in T. 7 S., R. 6 and 7 E.

The principal deposits with no roads nearby are those located in T. 11 S., R. 1 E.; T. 10 S., R. 2 E.; T. 10 S., R. 5 E.; and T. 10 S., R. 6 E. All of these areas may be reached over trails which cars can travel except in wet weather.

MINERAL AND CHEMICAL COMPOSITION OF BENTONITE

Bentonite has been defined by Ross and Shannon[1] as "a rock composed essentially of a clay-like mineral formed by devitrification and the accompanying alteration of a glassy igneous material, usually a tuff or volcanic ash; and it often contains variable proportions of accessory crystal grains that were originally phenocrysts in the volcanic glass....The characteristic clay-like mineral has a micaceous habit and facile cleavage, high birefringence, and usually a texture inherited from volcanic tuff or ash, and it is usually the mineral montmorillonite, but less often beidellite."

The essential constituent of all the bentonites studied in southwestern South Dakota was found to be the clay mineral montmorillonite, though beidellite also appears to be present in some of the Graneros beds. Optical, chemical, and x-ray methods were used in the identification of the mineral. Numerous samples from the outcrops of the Pierre, Upper Graneros, and Mowry-oligonite zone of the Graneros were studied under a petrographic microscope and the birefringence was determined as approximately 0.03. The indices of refraction of the various samples were determined by the use of immersion liquids, and the samples were prepared for study by allowing the clay to settle on glass slides suspended in water into which a small amount of bentonite had been vigorously stirred. The individual crystals of montmorillonite are too small for ordinary petrographic study but because of the micaceous type of cleavage possessed by the clay, the thin plate-like crystals assume a more or less uniform orientation on the slide. When dry the aggregates of crystals can be studied like ordinary mineral grains. In this way the indices of refraction of all the aggregates of clay on the slide are of about the same value except for a few that are lower or higher than the average because the aggregate has been rotated so that it has a different orientation from the others. Since in montmorillonite the axis of greatest ease of vibration of light rays is nearly perpendicular to the base of the crystals or cleavage fragments, the index of refraction of the

1. Ross, C.S., and Shannon, E.V., The minerals of bentonite and related clays and their physical properties, Jour. Am. Ceramic Soc., Vol.9,p.79, 1926.

average aggregate is essentially the least index of refraction. The index of refraction of most of the aggregates in every sample of Pierre and Upper Graneros bentonites studied was within the range of 1.500 to 1.510. From this minimum value the indices of a few aggregates varied up to 1.525. The clays from bentonite of the Mowry-oligonite zone show an average index of refraction of 1.520 to 1.535, while some aggregates range up to 1.550. It seems probable that these clays in which the index of refraction is especially high contain beidellite in addition to montmorillonite. This is by no means proved, however, since there is a possibility that some of the exchangeable bases of the clay have been effected by the immersion liquids used. Regardless of this, the index of refraction of clay from all the Pierre and Upper Graneros bentonites and most of the Mowry-oligonite zone bentonites are within the limits for montmorillonite reported by Grim.[1] Additional evidence that the clay mineral present in the bentonite is montmorillonite comes from x-ray studies made by Kerr on bentonite samples from Fall River County, South Dakota. The samples studied came from the Pierre formation (SE.$\frac{1}{4}$ Sec.18, T.9 S., R.5 E.) and oligonite zone of Graneros formation (NW.$\frac{1}{4}$ Sec. 2, T.9 S., R.2 E.). Kerr reports[2] that the x-ray diffraction patterns agree within reasonable limits with x-ray diffraction patterns of montmorillonite on file.

Chemical analyses of six bentonite sample from the Pierre and Graneros formations are given in Table I. Because of the possible presence of two or more different clay minerals or of mineral impurities in the bentonite, it would not be safe to attempt an identification of the clay mineral based on chemical analysis alone. However, used as confirming evidence to support other data, the chemical analyses presented in Table I are quite significant in that they agree within reasonably close limits with analyses of montmorillonite-bearing bentonites from other localities. It can be seen from the analyses that the chemical composition as presented satisfied the formula for montmorillonite given by Grim.[3]

The two different colors of bentonite from the Pierre which occur at many exposures have been explained

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1. Grim, Ralph E., Properties of Clay in Recent Marine Sediments, A Symposium, edited by Parker D. Trask, published by American Assoc.Petroleum Geologists, pp. 466-495, 1939.
2. Kerr, Paul F., personal communication, Oct.30,1939.
3. Grim, Ralph E., <u>op.cit.</u>, pp.466-495.

as being due to different conditions of the iron oxide content.[1] Presumably the unweathered bluish gray material contains ferrous iron while the yellow color of parts of the bed is due to weathering and the consequent oxidation of iron to the ferric condition.

Clay minerals have the ability to carry bases (cations) which can be exchanged for other bases. Thus, if a sample of clay containing sodium as an exchangeable base is mixed with water containing a strong calcium salt, the calcium will go into the clay and the sodium will come out into the solution. It is this property of the clay mineral in bentonite which permits the exploitation of the Ardmore bentonite for use as a water softener.

Different clay minerals vary considerably in their capacity to carry exchangeable bases. Grim[2] reports that montmorillonite has a base-exchange capacity of 60 to 100 millequivalents per 100 grams and that the capacity of kaolinite is only 3 to 15. Kelley[3] states that bentonites of the Wyoming types have a base-exchange power of about 90 millequivalents per 100 grams, while certain bentonites from California and Nevada have a capacity of 100 to 110 millequivalents per 100 grams.

The base-exchange capacities of eleven samples of bentonite from southwestern South Dakota are shown in Table II. It will be seen from this table that the capacities of bentonites from each of the main bentonite zones of the area equal and in many cases exceed the base-exchange values reported for montmorillonite and montmorillonite-bearing bentonites from other areas. Although the base-exchange values of the samples given in Table II show considerable variation, the Pierre bentonite shows the highest average capacity and the Mowry-oligonite zone bentonite has the lowest average capacity. It is doubtful, however, if enough measure-

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1. Connolly, J.P., and O'Harra, C.C., The Mineral Wealth of the Black Hills, S. Dak. School of Mines, Bull. 16, p. 327, 1929.
2. Grim, Ralph E., <u>Ibid</u>., p. 472.
3. Kelley, W. P., Base Exchange in Relation to Sediments, in Recent Marine Sediments, A Symposium, edited by Parker D. Trask, published by American Association Petroleum Geologist, pp.454-465 (456), 1939.

TABLE I

ANALYSES OF BENTONITE

	1	2	3	4	5	6
SiO_2	54.01	54.75	56.42	55.18	55.52	53.77
Al_2O_3	19.20	20.74	23.62	21.28	21.95	22.70
Fe_2O_3	3.57	2.70	1.64	2.36	1.91	4.05
FeO			0.18	0.62		
Mn_3O_4			0.04	0.06		
CaO	1.91	1.00	0.62	2.16	0.55	1.23
MgO	4.41	4.20	4.24	4.26	3.43	3.25
K_2O			0.01	0.14		
Na_2O	1.38	0.76	0.07	2.38	3.32	2.46
SO_3			Tr.	Tr.		
Moisture at 110° C			6.13	6.03		
Loss on Ignition	16.91	16.48	7.18	5.90	13.28	12.17

1. Bluish gray bentonite from Ardmore bed of Pierre formation about 14 miles south of Hot Springs, Fall River County, S. Dak., SE¼, Sec.32, T.9 S., R.6 E. (Analysis made at S.Dak. State Chemical Laboratory, Guy G. Frary, State Chemist, 1939.)
2. Light yellow colored bentonite from Ardmore bed, same location as above. (Analysis at S. Dak. State Chemical Laboratory, Guy G. Frary, State Chemist, 1939.)
3. Light colored sample from property of the Refinite Company, Ardmore, S. Dak. (Analysis by Charles Bentley in Connolly and O'Harra, S.Dak.School of Mines Bulletin No.16, page 331, 1929.)
4. Dark colored (bluish gray) sample, locality and analyst as No. 3.
5. Bentonite from upper part Graneros formation, about 14 miles south of Hot Springs, S.Dak., SE¼, Sec.18, T.9 S., R.5 E. (Analysis at S.Dak. State Chemical Laboratory.)
6. Bentonite from oligonite zone of Graneros formation, one mile west of Edgemont, S.Dak. (Analysis at S.Dak. State Chemical Laboratory.)

TABLE II

Base-Exchange Capacity and pH. of Bentonite from Southwestern South Dakota[1]

Base exchange value expressed in millequivalents per 100 grams

Stratigraphic position and location	Base Exchange Value	pH
Dark, bluish-gray bentonite from Ardmore bed, Pierre formation, SE $\frac{1}{4}$, Sec. 32, T.9 S., R.6 E.	119	8.1
Light yellow bentonite from Ardmore bed, Pierre formation, SE $\frac{1}{4}$, Sec. 32, T.9 S., R.6 E.	132	4.2
Light yellow bentonite from Ardmore bed, Pierre formation, SW $\frac{1}{4}$, Sec. 15, T.11 S., R.1 E.	119	3.0
Dark, bluish-gray bentonite from Ardmore bed, Pierre formation, north pit of Refinite Co., Ardmore, S.D.	92	6.9
Mixture of bluish-gray and yellow bentonite, Ardmore bed, Pierre formation, SW.$\frac{1}{4}$,Sec.29, T.7 S., R.7 E.	110	
Upper Graneros bentonite, NW.$\frac{1}{4}$, Sec.32, T.10 S., R.4 E.	92	5.9
Upper Graneros bentonite, SE.$\frac{1}{4}$, Sec.18, T.9 S., R.5 E.	126	4.3
Upper part of Mowry member, Graneros formation, SW.$\frac{1}{4}$, Sec.16, T.7 S.,R.1 E.	112	
Upper Graneros bentonite, SE.$\frac{1}{4}$,Sec.12, T.7 S., R.6 E.	87	
Oligonite zone, Graneros formation NW.$\frac{1}{4}$, Sec.19, T.9 S., R.6 E.	99	
Oligonite zone, Graneros formation, NW$\frac{1}{4}$, Sec.2, T.9 S., R.2 E.	86	9.3

1. Base exchange and pH determinations made at S. Dak. State Chemical Laboratory, Guy G. Frary, State Chemist, using the method described by Bray in <u>Soil Science</u>, Vol.45, page 487, 1938.

ments of the capacity were made to justify a statement that these averages are characteristic of the bentonites of these zones.

Other minerals in addition to the clays occur in the bentonite samples studied. The presence of calcite and gypsum crystals at many of the bentonite exposures has already been noted, and sometimes one or both of these make up a considerable portion of the exposed beds. The gypsum crystals are usually large, and for commercial production of bentonite would probably offer no serious difficulty since they could be easily separated mechanically from the bentonite. The calcite, however, sometimes occurs in small crystals disseminated through the matrix of the Ardmore bed, and this undoubtedly will decrease the value of bentonite from certain localities for some purposes. Fine grained calcite of this type apparently is confined to parts of the bluish gray bentonite of the exposed beds, and was found to be present in the Ardmore bed at Ardmore and at exposures in Sec. 13, T.11 S., R.3 E., and Sec. 32, T.9 S., R.6 E. Since all bentonite samples were collected near the surface of the exposures of the various beds, it is not possible for the writer to make any statement regarding the amount of calcite in covered portions of the beds.

In addition to minerals already mentioned bentonite of the area contains small quantities of minerals which are typically igneous or formed by alteration of igneous minerals. They were originally crystal grains which occurred as phenocrysts in the volcanic glass. Presence of these minerals in large quantities is objectionable for many commercial uses of bentonite.

Tests were made to determine the amount of such gritty material in the various bentonite samples by suspending a weighed sample in water, allowing the grit to settle, decanting the suspension and then weighing the grit left behind. By this method the Pierre bentonites were found to be nearly free from grit (1 to 6%). The upper Graneros bentonite contains a larger percentage but still not enough to be harmful (6-10%). Some of the Mowry-oligonite zone bentonites, however, do contain an objectionable amount of grit. Samples collected in Sec. 33, T.9 S., R.4 E. and Sec. 19, T.9 S., R.6 E. contain 65% and 40% respectively, but on the average bentonites from this zone do not contain more than 12% grit and this amount probably is not objectionable for most purposes. At both of the locations given above where the percentage of grit in the bentonite is very high, the most abundant mineral in the grit is hematite (Fe_2O_3). This mineral occurs in small grains with perfect crystal forms, and at these places is so abundant that it seems likely at least some of the iron was introduced after deposition of the volcanic ash.

The mineral grains making up the gritty material in the Pierre, Upper Graneros and most of the Mowry-oligonite zone bentonite are as follows:

Mineral	Average per cent of the grit
Feldspar	
Plagioclase (An 10-50)	45
Orthoclase	35
Biotite	10
Chlorite, Zircon, Apatite, Quartz	10

Even though the clay mineral montmorillonite makes up the major portion of nearly all the bentonites of the area, the physical properties of the bentonites show considerable variation. The Pierre bentonite, for example, absorbs water very rapidly but absorbs a relatively small total quantity and does not increase in volume more than 3 to 5 times the original dry volume. Also, this bentonite flocculates very quickly and when suspended in water will settle out of the suspension within an hour. Some of the Graneros bentonites, however, absorb water slowly but take up large quantities of water and consequently swell to many times the original dry volume. These bentonites with the ability to swell markedly in water also remain in suspension indefinitely. One gram of this bentonite when mixed with 10 cc. of water makes a thick gel which is so viscous that it will hold its form for several minutes (that is, holes punched in the surface remain open). There is considerable variation in the ability of the various Graneros bentonites to absorb water and to remain in a suspension. This variation occurs from bed to bed, and also from place to place in the same bentonite bed.

Some of the physical properties of bentonite depend upon the type of clay mineral present and the amount and kind of impurities. Since the bentonites of this area are all composed essentially of the same clay mineral and the impurities usually vary within a narrow range, other factors which influence the properties of bentonite must be considered.

Probably the main cause of variations in physical properties of montmorillonite-bearing bentonite is related to the nature of the exchangeable bases which are held by the clay.[1] If the cation is held loosely by the flakes of clay, water can form a thick film around the flake. This film of water serves to separate the individual flakes and reduce their attraction for each other, and also it acts as a lubricant between the flakes. This thick film of water, then, causes the flakes of clay to behave as individuals and because the flakes are of colloidal size they do not settle out of a suspension. A cation that is held to the flake in this manner is sodium. Bentonite produced commercially at Belle Fourche, South Dakota, and in Wyoming is composed of a sodium montmorillonite and this supports the idea presented above in that this bentonite does absorb large quantities of water and it does remain in suspension indefinitely.

If the exchangeable base is held firmly and closely to the clay flake, water does not form a film around the flake, the attraction the flakes have for each other is not appreciably reduced in the suspension, and aggregates are formed which settle out of suspension. A cation which effects the clay in this manner is hydrogen. The bentonites from the Pierre formation have the properties described above and it seems quite probable that hydrogen is the replaceable base present, though Table II shows that there is no evident correlation between the concentration of free hydrogen ions and the stratigraphic occurrence of the bentonite.

Kelley[2] lists various cations in the order of their power to replace other bases as follows: H, Ca, Mg, K,

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1. Grim, Ralph E., Ibid., pp. 466-495 (478).
2. Kelley, W. P., Base Exchange in Relation to Sediments, in Recent Marine Sediments, edited by Parker D. Trask, published by American Assoc. Petroleum Geologists, pp. 454-465 (455), 1939.

Na. Thus the replacing ability of hydrogen is greater than calcium, which in turn is greater than magnesium, etc. In explaining the variations in the physical properties of bentonite, it seems probable that some of the cations with replacing power intermediate between Na and K may be present in those Graneros bentonites which absorb more water than do the Pierre bentonites but not as much as some of the other Graneros bentonites. The Graneros bentonites with the greatest ability to absorb water and remain in suspensions which were studied were found in the southeast $\frac{1}{4}$ of Sec. 18, T.9 S., R.5 E. (Upper Graneros) and in the northwest $\frac{1}{4}$ of Sec. 2, T.9 S., R.2 E. (oligonite zone). Of these the sample from the oligonite zone resembles very closely the Wyoming type of bentonite and like it has a pH of about 9.3. Apparently the clay mineral present in this bentonite is a sodium-montmorillonite. The Upper Graneros sample, although forming just as strong a gel as the other, shows a high concentration of hydrogen ions (pH 4.3, see Table II) when suspended in distilled water. Thus there is no apparent correlation between the pH and the physical properties of the bentonites studied. Kelley and Jenny[1] have shown that the base-exchange capacity of kaolinite is influenced by the size of the particle. Possibly crystal size also influences the ability of the montmorillonite flakes to hold cations and in some cases even hydrogen may be held loosely enough to permit significant hydration.

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1. Kelley, W.P., and Jenny, Hans, The Relation of Crystal Structure to Base Exchange and Its Bearing on Base Exchange in Soils, <u>Soil Science</u>, Vol. 41, pp. 367-382, 1936.