PROVINCE OF ALBERTA

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Bentonite in Alberta

by

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Bentonite in Alberta

INTRODUCTION

This report is intended to serve as a summary of present knowledge on the bentonite resources of Alberta. In the course of preparing the report, deposits reported in the literature were visited and several new deposits were investigated. All deposits were sampled and preliminary tests for drilling fluid characteristics and decolorizing ability were run.

In general, the report has been written for those interested in the practical application of Alberta's bentonite resources. Details about the fundamental nature of bentonite are discussed in the Appendix.

Previous Work

Four deposits of Alberta bentonite were described by Spence in 1924. Since that time several geological reports have included descriptions of bentonite beds (Russell and Landes, 1940; Allan and Sanderson, 1945), but no results of systematic surveys have been published. Recently, work was carried out on a number of deposits by Matthews (1952) for the Mines Branch, Ottawa, but the results of this work have not been published.

Scope of the Survey

The present survey was concentrated upon the Edmonton and Bearpaw formations, since previous geological work indicated that they contain the thickest deposits of bentonite. Fairly complete sections of the Bearpaw formation were examined near Lethbridge, in the Cypress Hills area and along the Red Deer river. Scattered outcrops near the U.S. border southeast of Lethbridge were also visited. A complete section of the Edmonton formation was examined in the Drumheller region, and scattered outcrops in the vicinity of Castor, Nevis, Donalda, Camrose and Edmonton were visited. A few outcrops of the Lethbridge member of the Oldman formation in the Cypress Hills area and one outcrop near Lethbridge were examined. Attention was given to several outcrops of the Saunders formation along the Edson-Cadomin road and to several outcrops of the upper Wapiti formation in the Peace River area.

While, on the basis of our present knowledge, the foregoing areas are among the most promising for the occurrence of bentonite, it is clear that the survey cannot pretend to give a complete coverage of the province.

Acknowledgments

The writer extends his thanks to J. G. Matthews, C.P.R. Department of Industrial Development, Calgary; L. G. Schultz, formerly of the University of Illinois; J. Visman, Department of Mines and Technical Surveys, Calgary; P. deBruin, Calgary; Don Lang, Oilfield Technical Service Limited, Edmonton; officials of the Alberta Mud Company, Aetna Coal Mine and Red Deer Valley Coal Co.; as well as other individuals and firms who gave assistance in this bentonite survey.

Some of the mineralogical work discussed in the Appendix was carried out at the University of Illinois under the supervision of R. E. Grim, whose assistance was most valuable.

Thanks are also extended to the following members of the Research Council: L. G. Bartlett, who capably assisted in carrying out laboratory tests, and S. J. Groot, who did all the drafting.

THE NATURE OF BENTONITE

Bentonite was defined in 1926 as "a rock composed essentially of a crystalline claylike mineral formed by the devitrification and accompanying chemical alteration of a glassy igneous material, usually a tuff or volcanic ash" (Ross and Shannon, 1926). The "claylike mineral" in the definition has been shown to be montmorillonite. Since this definition was proposed, the term bentonite has been widely used for any soapy, highly plastic clay which swells appreciably in water. These properties are typical of the mineral montmorillonite. Hence bentonite could be defined simply as "a clay composed essentially of montmorillonite", and it is in this sense that the term bentonite is used in this report. It has already been established that many bentonites have actually been derived from the decomposition of volcanic ash, and it is likely that most of them —if not all—have had such an origin.

The soapy nature and swelling properties of bentonite are distinctive enough to permit ready identification. The color is usually greenish yellow, but may be various shades of green, blue, grey or brown. Naturally occurring bentonite has a moderately high water content, but outcrop surfaces are usually dry and very light in color. In outcrop, bentonite beds are characterized by a badly cracked surface, which resemble popcorn when most strongly developed.

The extent to which bentonite will swell in water varies considerably. Bentonites are often divided into two classes, referred to as swelling bentonite and non-swelling bentonite. However, it is questionable whether a sharp division exists between these two classes, hence this classification will not be used in this report.

Specific properties of bentonite which make it of economic value are discussed in the next section.

USES OF BENTONITE

Bentonite is used as a component of oil well drilling fluids, as a bonding agent for foundry sand and other materials, as a decolorizing agent for oils, as a catalyst in oil refining, and as a filler in a number of products.

The chief market for bentonite in Alberta is as a component of oil well drilling fluids, and it is with the potentialities of local bentonites for such a use that this report is chiefly concerned. The functions of bentonite in drilling fluid are to add viscosity and thixotropy* to the fluid and to build up a thin, impervious "filter cake" on the walls of the hole. Bentonites vary considerably in their suitability for use in drilling fluids. Evaluation of any bentonite requires testing of the viscosity, thixotropy and wall-building characteristics of water suspensions of the bentonite. These tests are discussed very briefly in the next section.

The use of bentonites as a decolorizing agent or catalyst in oil refining is assuming less importance in recent years due to the development of synthetic substitutes. Preliminary tests for decolorizing ability were carried out on samples, but tests for catalytic action were not run in view of the limited market for catalytic bentonites.

Considerable tonnages of bentonites are used annually as a bonding agent in foundry sands. A variety of bentonites are used for this purpose, hence it is considered likely that at least some of the Alberta bentonite could be used as a bonding agent. However, tests for bonding characteristics were not carried out on any Alberta bentonites due to lack of the facilities required for such tests.

The chief requirement of bentonites used as fillers is that they have a low silt content. The silt content of all samples was determined in the course of this investigation.

TESTING OF BENTONITE

Standard tests for various uses of bentonite do not require full discussion here as they are described in a number of references (American Petroleum Institute, 1942; Baroid Sales Division, 1938; Fisk, 1946; Nutting, 1943; Foundry Sand Testing Handbook, 1944). The general nature of the tests which were carried out on Alberta bentonites will be discussed briefly so that the significance of the test results may be fully appreciated.

Testing of bentonites for drilling fluid characteristics involves testing for viscosity, thixotropy and wall-building characteristics. The viscosity of a bentonite is usually expressed in terms of the **yield**, which is defined as the number of barrels of 15-centipoise-viscosity mud which can be prepared from one ton of the bentonite.

*Thixotropy is defined as "the property, shown by certain gels, of liquefying on being shaken and of re-forming on standing" (Chambers's Technical Dictionary, 1943).

The yield is determined by measuring viscosities of a number of bentonite suspensions of differing concentrations, graphing the results, determining the concentration which gives a 15-centipoise viscosity and expressing the results in terms of barrels of mud per ton of bentonite. Commercial bentonites have a yield of 100 barrels per ton. Since the majority of Alberta bentonites proved to have low yields, further testing for drilling fluid characteristics was not carried out on them.

The silt content was determined by suspending ten grams of the bentonite in water, passing the suspension through a 200-mesh sieve, and drying and weighing the residue.

Accurate measurement of the decolorizing ability of a bentonite requires a fairly elaborate procedure. However, a fairly accurate estimate can be obtained by passing a crude oil diluted with 50% white gasoline through a tube containing about three inches of the bentonite wetted with white gasoline to prevent "channelling". The resulting product is white initially, and then passes through a series of progressively darker colors until the oil passes through without being decolorized. In the present investigation, crude oil from the Redwater oil field, Alberta, was used. Commercial floridin bleaching clay was used as a standard. In the case of several samples, acid treatment was tried in an effort to improve the decolorizing ability. This involved adding five ml. of concentrated hydrochloric acid of a 10% suspension containing ten grams of clay, refluxing for two hours, washing out the excess acid, and then drying at 100°C. Results for each sample were expressed as a percentage of the decolorizing ability of the standard sample.

GEOLOGY OF ALBERTA BENTONITES

Thin beds of bentonite are fairly common throughout the Cretaceous section of Alberta, and are also present in the Tertiary. However, thick accumulations have been reported only from the Upper Cretaceous.

Generalized stratigraphic sections of the Upper Cretaceous of Alberta are given below:

	Southern and central Alberta	West-central Alberta	Peace River area
Upper Cretaceous	Edmonton formation Bearpaw formation Oldman formation Foremost formation Pakowki formation Milk River formation	Saunders formation	Wapiti formation
	Alberta group	Alberta group	Smoky group

The greatest concentration of bentonite occurs in the upper portion of the Upper Cretaceous. The Oldman formation contains a large amount of bentonitic sandstone and bentonitic shale, particularly in the upper portion. However, to date, only one bed of pure bentonite has been found in the Oldman formation, and it occurs near the top of the formation in the vicinity of Walsh in southeastern Alberta. A section covering the same stratigraphic interval as this bed was examined eight miles to the west, but no pure bentonite was present. Presumably, the bentonite near Walsh grades laterally into bentonitic sandstone or shale.

In general, the bentonite beds of the Bearpaw formation are only a few inches in thickness. However, in southeastern Alberta and southwestern Saskatchewan, a persistent bed of mixed bentonite and volcanic ash, varying from three to ten feet in thickness, occurs 100 feet from the base of the Bearpaw formation. Elsewhere in Alberta the same bed is not found, or is represented by only a few inches of bentonite. Another thick bed of bentonite occurs near the top of the Red Deer formation along the Red Deer valley. This bed, which attains a thickness of about twenty feet, can be traced for several miles, but it is not present in outcrops north or south of the Red Deer river.

The thinner beds of the Bearpaw formation also are persistent for several miles and make excellent marker horizons for local structural surveys. However, correlation of bentonite beds of one area with those of another area thirty or forty miles away is impossible (Russell and Landes, 1940).

The bentonite beds of the Edmonton formation are, in general, similar to those of the Oldman formation. The bentonite usually occurs mixed with shale or fine-grained sandstone. Beds or lenses of pure bentonite varying in thickness from a fraction of an inch to several feet are fairly common. The bentonite beds of the Edmonton formation usually have less lateral persistence than those of the Bearpaw formation. Beds of pure bentonite frequently grade laterally into bentonitic clays, shales or sandstones which are indistinguishable from similar sediments which make up a large part of the formation.

In the introduction to this report, it was stated that most—and possibly all—bentonites are derived from the alteration of volcanic ash. The manner in which bentonites of Alberta, particularly those in the Edmonton formation, grade laterally into "normal" sediments would seem to indicate that they did not have such an origin. On the other hand, the association of volcanic ash with the bentonite in the Bearpaw formation and the occurrence of distinct beds of essentially monomineralic material in a sequence of multimineralic rocks can only be explained by assuming the bentonite to be an alteration product of volcanic ash. In an effort to test this theory, silt fractions of bentonites from the Bearpaw and Edmonton formations were examined under binocular and petrographic microscopes. Biotite and quartz were found to be the dominant minerals in most samples. A small percentage of volcanic glass was also present, in addition to some light-brown cellular material which showed irregular extinction and probably represents partially devitrified glass.

Further evidence for the volcanic origin of Alberta bentonites is provided by the occurrence of cristobalite, the high-temperature form of silica, in nearly all of them. Gruner (1940) discussed the occurrence of cristobalite in bentonites and noted that other clays do not contain cristobalite. He concluded that the occurrence of cristobalite is connected with the volcanic origin of bentonite.

DESCRIPTION OF INDIVIDUAL DEPOSITS

Introduction

The following discussion is confined to major deposits, i.e., those containing bentonite of high purity in beds over two feet thick. Test results for those deposits are given briefly and are tabulated in a more convenient form in Table I. The distribution of the deposits is shown in Figure 1.

A word of caution should be given regarding the interpretation of the test results. The experience of operators in the bentonite deposits of Wyoming, South Dakota and Montana has shown that an individual bed frequently shows wide variation within a very short distance, particularly with respect to drilling fluid characteristics. The test results shown in Table I are based on single samples, hence they can give only a general idea of the quality of the deposit in question. Deposits for which yields of about 60 barrels per ton are reported might contain substantial reserves of bentonite having a yield of 90 barrels per ton. It should be noted that the yield data shown in Table I are for samples in their natural state, and that beneficiation might result in a considerable improvement in the quality of any bentonite. Some of the factors involved in beneficiation are discussed in the Appendix.

1. Drumheller

Several beds of pure bentonite occur in the Drumheller area. The apparent prevalence of bentonite in this particular region is due to the fact that bentonite is very common in the lower and middle members of the Edmonton formation as defined by Allan and Sanderson (1945). The Drumheller area has the best outcrops in the province of this particular stratigraphic horizon.

The best known bentonite deposit in the Drumheller area is a three-foot bed occuring on a ridge 1½ miles north of Drumheller in the NW ¼ section 14, township 29, range 20, west of the 4th meridian. This has been mined intermittently for a number of years. Test results on the bentonite show it to have a yield of 56 barrels per ton and a silt content of 2.3%. It is claimed that the deposit is fairly constant in quality (Kidd, 1954).

TABLE I

SUMMARY OF TEST RESULTS ON BENTONITE FROM DEPOSITS DISCUSSED IN THIS REPORT

No.	Area	Location	Stratigraphic horizon	Yield, barrels per ton	Silt content (over 200-mesh), %	Decolorizing ability, as % of standard	
						Untreated	Acid treated
1	Drumheller	NW 14-29-29 W4	Edmonton	56	2.3	60	35
2	Rosedale	SE 22-28-19 W4	Edmonton	90	0.4	Nil	Nil
3	Newcastle	SE 9-29-20 W4	Edmonton	42 to 66	3.9 to 11.6	Nil	15
4	Morrin Ferry	NE 32-31-21 W4	Edmonton	42	1.1	.....	.....
5	Beynon	SE 32-27-20 W4	Edmonton	51	0.2	.....	.....
6	Dorothy	NE 3-27-17 W4	Bearpaw	30	0.2	10	.....
7	Sheerness	W½ 13-29-13 W4	Edmonton	58	0.5	.....	.....
8	Camrose	SE 21-46-20 W4	Edmonton	51	3.0	35	35
9	Walsh	SW 28-11-1 W4	Upper Oldman	28	8.8	Nil	Nil
10	Irvine	NW 30-11-2 W4	Bearpaw	38	4.9	10	10
11	Bullshead Butte	NE 2-8-7 W4	Bearpaw	58	6.7	.....	.....
12	Bickerdike	NE 6-52-18 W5	Saunders	27	0.1	20	5
13	Busby	36-57-1 W5	Edmonton	.....	.....	.....	.....
14	Grande Prairie	SE 27-72-4 W6	Upper Wapiti	60	0.6	5	10

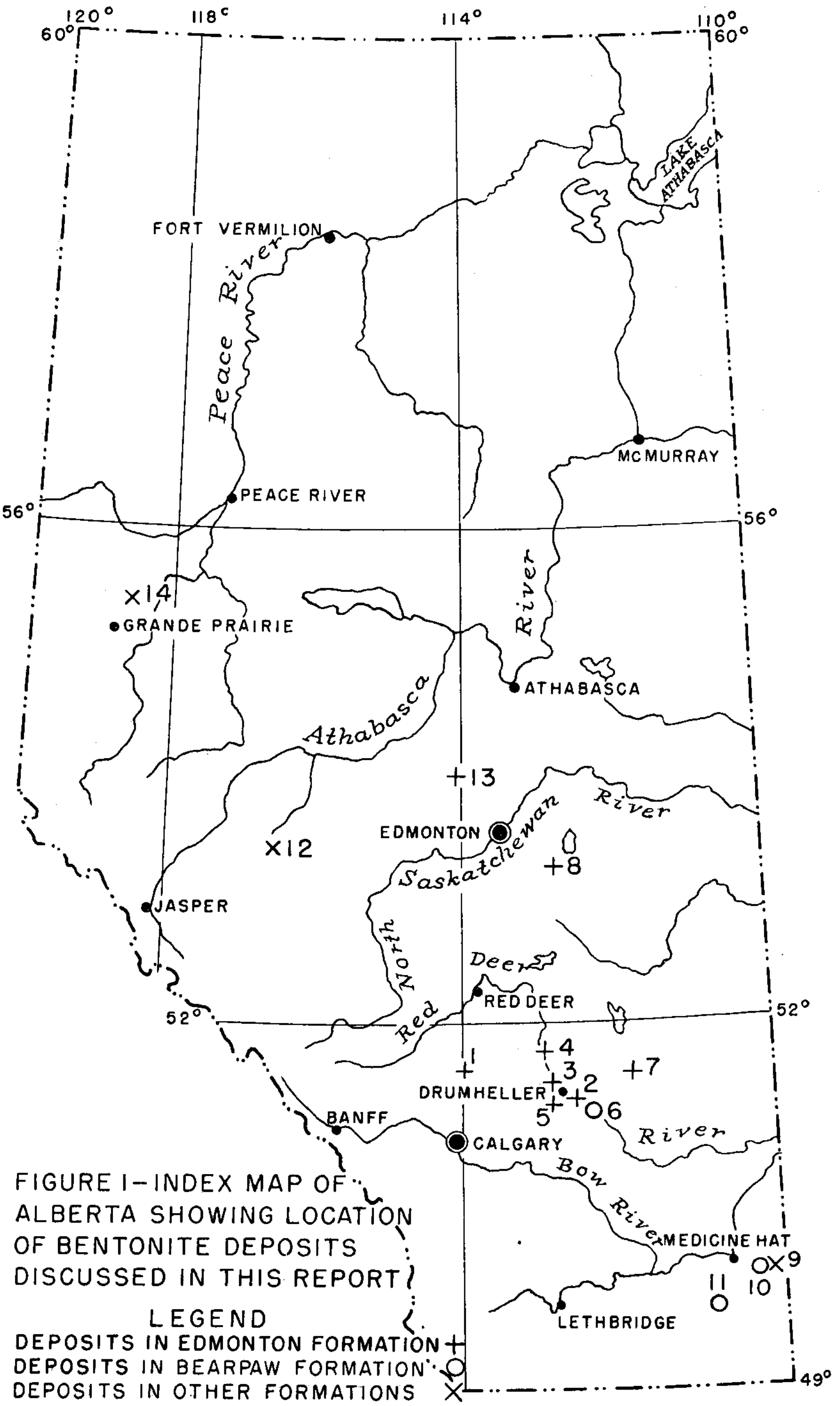

FIGURE 1—INDEX MAP OF ALBERTA SHOWING LOCATION OF BENTONITE DEPOSITS DISCUSSED IN THIS REPORT

The bentonite horizon described above can be traced both upstream and downstream from this deposit. Downstream, the deposit passes under heavy overburden and gradually grades into white bentonitic sandstone within about half a mile. Upstream, the bed can be traced for about two miles. Detailed examination at two localities showed that the bed was too silty for commercial use. The same horizon was picked up on the other side of the river in the NE ¼ section 34, township 28, range 20, west of the 4th meridian, where about one foot of pure-looking bentonite is present. This bed appears to become siltier both upstream and downstream.

The above discussion illustrates the considerable variability of bentonite beds within the Edmonton formation. Other bentonite deposits in the Drumheller area are discussed in the following sections.

2. **Rosedale**

A thin parting of bentonite occurs throughout the Drumheller region in the No. 1 coal seam of the Edmonton formation (Allan and Sanderson, 1945). The parting is well developed at the Aetna coal mine at Rosedale, where it attains a thickness of six to eight inches. A representative sample of the bentonite gave a yield of 90 barrels per ton. The silt content is negligible, while the thixotropy is quite low.

This bentonite might be obtained while mining the coal, but the thinness of the bed would make control of quality very difficult. Furthermore, the variability in the thickness of the bed would lead to uncertainty concerning the amount mined in any given period.

3. **Newcastle**

A variable bed of bentonite is present in the Edmonton formation under light overburden over a fairly large area of the SE ¼ section 9, township 29, range 20, west of the 4th meridian. The bentonite, which varies from five to ten feet in thickness, is fairly silty and contains local lenses of fine-grained sandstone. Three samples taken from the bed gave yields varying from 42 to 66 barrels per ton; the silt contents varied from 3.9 to 11.6%. Since lenses of sandstone were avoided when sampling, the bed would appear to be too silty to warrant exploitation.

4. **Morrin Ferry**

A five-foot bed of bentonite is present in the middle member of the Edmonton formation in the NE ¼ section 32, township 31, range 21, west of the 4th meridian, 19 miles northwest of Drumheller along the Red Deer river. The bed is underlain by a four-inch bed of bluish-grey tuff. This bed occurs at a stratigraphic horizon below the Kneehills tuff, which is the only tuff bed in the Edmonton formation hitherto reported in the literature. The bentonite grades laterally into silty bentonite, and is present under prohibitive overburden at this locality. Bentonite from this deposit gave a yield of 42 barrels per ton and had a silt content of 1.1%.

5. **Beynon**

A lens of bentonite 3½ feet in thickness outcrops under low overburden, along the Rosebud river in the SE ¼ section 32, township 27, range 20, west of the 4th meridian. The bed occurs in the Edmonton formation below a 2½-foot coal seam. The relationship of the bentonite to surrounding sediments is illustrated in Figure 2. Whether the observed relationships are depositional or erosional is not known.

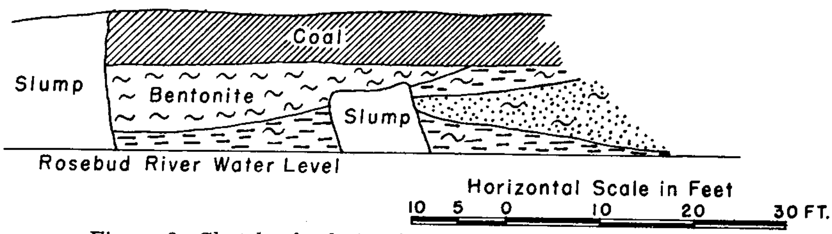

Figure 2—Sketch of relationship of bentonite near Beynon to surrounding sediments.

From the outcrop observed, the total amount of bentonite available cannot be estimated. Drilling would be necessary to determine the amount present. This bentonite has a yield of 51 barrels per ton and a silt content of 0.2%.

6. **Dorothy**

A twenty-foot bed of bentonite, occurring in the upper part of the Bearpaw formation, is exposed for several miles along the banks of the Red Deer river in the vicinity of Dorothy approximately 20 miles downstream from Drumheller. A substantial tonnage of bentonite, which appears quite pure, is available under low overburden, but the quality of the bentonite is very inferior. Two samples were taken and both gave yields of about 30 barrels per ton. A railway runs through the valley adjacent to the deposit. Large tonnages are also available across the river from the railway.

7. **Sheerness**

A bed of bentonite occurs in the overburden above the coal seam being strip mined at the property of Western Dominion Coal Mines, Sheerness, Alberta. The author has not had the opportunity of visiting this deposit, but J. G. Matthews of the C.P.R. Department of Industrial Development at Calgary has sampled the deposit and kindly provided the following field information (Matthews, 1954): The bentonite bed which occurs in the Edmonton formation appears to vary from one to five feet in thickness. Its lateral extent will not be known until further stripping has been done at the mine. The bed is olive green in color and is overlain by brown bentonite of slightly lower quality.

The olive-green bentonite has a yield of 58 barrels and a silt content of 0.5%, while the overlying brown material has a yield of 43 barrels and a silt content of 1.7%.

8. **Camrose**

Poor outcrops of the Edmonton formation are present along a creek running south from Camrose into the Battle river. One outcrop, about three miles south of Camrose on the east side of the creek, exposes three feet of bentonite overlain by dark bentonitic clay under heavy overburden. The bentonite has a yield of 51 barrels per ton.

9. **Walsh**

A four-foot bed of bentonite with a silty parting near the top occurs just south of the Trans-Canada highway in the SW ¼ section 28, township 11, range 1, west of the 4th meridian. Due to the lack of outcrops in the vicinity, the stratigraphic position of this bed is not certain. If normal dips prevail in the area, the bentonite bed occurs in the upper part of the Oldman formation. The same stratigraphic horizon was examined in the Irvine area, about eight miles west of the Walsh deposit, and was found to consist mainly of bentonitic sandstone and bentonitic shale. No beds of pure bentonite were present.

The Walsh deposit is under overburden less than ten feet in thickness over a sizeable area, but the quality of the bentonite is poor. It has a yield of less than 30 barrels per ton and a silt content of 8.2%.

10. **Irvine**

A bed of mixed bentonite and volcanic ash totalling five to ten feet in thickness occurs about 100 feet from the base of the Bearpaw formation in an area surrounding the Cypress hills. The bed has its best development north and west of the hills. The most accessible deposit in this bed occurs one mile south of Irvine, which is a town about 20 miles east of Medicine Hat on the C.P.R. main line. This bentonite, which is located in the NW ¼ section 30, township 11, range 2, west of the 4th meridian, varies from one to five feet in thickness and has a yield of 38 barrels per ton. The overburden is of the order of five to ten feet. The bentonite is associated with volcanic ash and ashy bentonite, with the bentonite having an irregular and patchy distribution. The same bed was noted at a number of localities east of this deposit, and the same general relationships were found to hold. At most other localities, there was a slightly higher ratio of volcanic ash to bentonite.

11. **Bullshead Butte**

The bentonite bed discussed in the previous section was sampled in the NE ¼ section 2, township 8, range 7, west of the 4th meridian, at the top of an area of badlands in the southwest side of a hill known as Bullshead Butte. This deposit is located 25 miles south and five miles east of Medicine Hat, so it is rather unattractive from the point of view of distance from transportation. The bentonite bed is two feet in thickness and occurs under about ten to fifteen feet of overburden. The tonnage available at the deposit is small, but might be increased by further prospecting. Samples taken at the deposit gave a yield of 58 barrels per ton.

Another sample taken from the NW ¼ section 14, township 8, range 7, west of the 4th meridian, about 1½ miles to the north, where the same bed is present under greater overburden, gave a yield of 32 barrels per ton.

12. **Bickerdike**

A bentonite deposit in the Saunders formation of Paleocene and/or late Upper Cretaceous age is located along the McLeod river in section 6, township 52, range 18, west of the 5th meridian, about 15 miles southwest of Edson. A six- to eight-foot bed of almost pure white bentonite outcrops under heavy overburden, near river level, about 200 yards upstream from the C.N.R. bridge. The same bed could probably be located under lighter overburden in the same general area. However, the commercial possibilities of this material are very limited due to its poor drilling fluid characteristics and bleaching ability. Limited quantities have been mined in the past for use in the manufacture of cosmetics.

13. **Busby**

Substantial reserves of bentonite occurring in section 36, township 57, range 1, west of the 5th meridian, and also in the surrounding general area have been explored by various individuals and companies. The bentonite does not outcrop in this area. General information suggests that there are three beds present, of which the lower two are of rather poor quality. The upper bed is about five feet thick and occurs under light overburden.

14. **Grande Prairie**

Rutherford (1930) pointed out that the upper portion of the Wapiti formation, which is exposed in the Kleskun hills about 12 miles northeast of Grande Prairie, consists of sediments lithologically similar to the Edmonton formation. Included in these Edmonton-type sediments is a four-foot bed of bentonite which is exposed in a road cut in the SE ¼ section 27, township 72, range 4, west of the 6th meridian, on the north flank of the

Kleskun hills. The bentonite is overlain and underlain by silty bentonites and bentonitic sands. The lateral persistence of the bed is uncertain, but it would occur over a fairly large area under light overburden if it is persistent. The sample taken from this bed gave a yield of 60 barrels per ton. It would appear that this deposit merits further investigation.

SUMMARY AND CONCLUSIONS

Bentonite is a common constituent of Upper Cretaceous sediments in Alberta, the most promising deposits found to date occurring in the Bearpaw and Edmonton formations. All deposits tested to date, except for a thin bed occurring as a parting in a coal seam, were found deficient in drilling fluid characteristics. In the course of the survey, the Bearpaw formation was examined in more detail than the Edmonton formation due to a shortage of outcrops of the latter.

In general, the bentonites occurring in the Edmonton formation appear to be of higher quality than those in the Bearpaw formation. It would seem that future prospecting should be concentrated in the Edmonton formation.

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APPENDIX

THE MINERALOGY OF BENTONITE

The chief component of bentonite is the clay mineral montmorillonite. Variations in the properties of bentonites may usually be ascribed to variations in the physical, chemical and mineralogical properties of the montmorillonite which they contain. Hence, any attempt to explain inadequacies in drilling fluid properties of Alberta bentonites must be prefaced by a discussion of the possible variations which might be expected in montmorillonites.

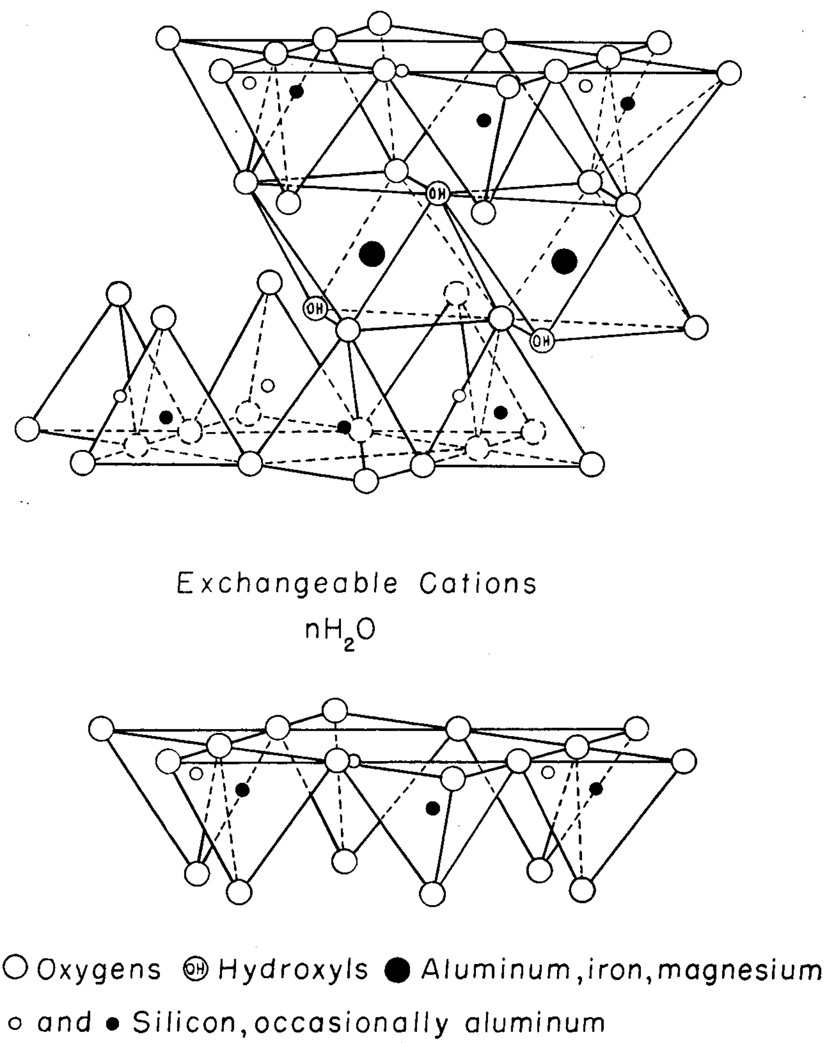

Figure 3—Diagrammatic sketch of the structure of montmorillonite.

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Like most other clay minerals, montmorillonite is a layer-type silicate which occurs as very small crystallites of the order of one micron in size. The general structural scheme of the mineral is shown schematically in Figure 3 which indicates that the structure consists of two outer layers of silica tetrahedra tied together at three corners to form an outer hexagonal net of oxygen ions. The inward-pointing apical oxygens of the tetrahedra, together with coplanar hydroxyl ions, surround an inner layer of octahedrally co-ordinated aluminum ions. Montmorillonite always has isomorphous substitutions, usually of magnesium or iron for aluminum in the octahedral layer, or of aluminum for silicon in the tetrahedral layer, thereby creating a net negative charge which is satisfied by exchangeable cations held largely on the basal oxygen surface of the tetrahedral layer (Grim, 1953). The commonest cations held by montmorillonite are calcium and sodium, while magnesium and hydrogen are encountered less frequently. Under suitable conditions, one of the cations may be replaced by another. This phenomenon is known as base exchange, or more accurately, cation exchange. One or more molecular layers of water may enter between each of the unit sheets of montmorillonite as described above. The amount of water which can be adsorbed is dependent upon the amount of water available, the nature of the exchangeable cations held by the montmorillonite and possibly upon other unknown factors.

Montmorillonite differs from well crystallized layer silicates in the manner in which unit sheets are stacked upon one another. In well crystallized layer silicates this stacking is regular so that each unit sheet is a mirror image of its neighbor, whereas in montmorillonite the stacking is more irregular.

Hitherto, it has been believed that the drilling fluid properties of a bentonite were due entirely—or very largely—to the nature of the exchangeable cations held by the montmorillonite. Bentonites consisting largely of sodium-bearing montmorillonite were considered to have high viscosity and thixotropy, while those consisting largely of calcium-bearing montmorillonite were considered to be deficient in these properties. Since montmorillonite will hold calcium in preference to sodium, most naturally-occurring bentonites contain calcium montmorillonite. In all cases, the calcium montmorillonite is deficient in drilling fluid properties. The small number of naturally-occurring bentonites containing sodium montmorillonite that have been studied have shown good drilling fluid properties.

In the course of this investigation about twenty Alberta bentonites, including bentonites from eleven of the deposits discussed in this report, were subjected to x-ray diffraction analysis. This showed that all the bentonites were predominantly sodium-bearing. This finding was confirmed for bentonites from deposits 2, 5 and 6 by the chemical analyses shown in Table II. Since all these bentonites are to a variable extent deficient in drilling fluid properties, the nature of the exchangeable cations is not the only factor controlling these properties.

TABLE II

CHEMICAL ANALYSES OF ALBERTA BENTONITES*

Sample No.	No. 2 (Rosedale)	No. 5 (Beynon)	No. 6 (Dorothy)
SiO_2	57.18	63.61	65.74
Al_2O_3	20.25	17.37	13.89
TiO_2	0.11	0.24	0.33
Fe_2O_3	2.08	3.18	3.32
FeO	0.51	0.60	0.09
MnO	0.00	0.01	0.01
MgO	2.72	1.86	1.75
CaO	1.09	1.19	1.10
Na_2O	2.21	2.18	2.40
K_2O	0.30	0.63	0.69
H_2O^-	8.44	4.16	6.00
H_2O^+	4.79	3.99	3.89
Loss on ignition	0.67	1.11	0.93
	100.35	100.13	100.14

*These analyses were performed by the Rock Analysis Laboratory, University of Minnesota, Minneapolis, Minn.

Another factor which is commonly believed to affect the properties of a bentonite is the impurities—i.e., minerals other than montmorillonite which it contains. These impurities may be in the form of silt, cristobalite, soluble salts, gypsum, or clay minerals other than montmorillonite. Silt present in a sample will affect the properties only by dilution, hence it is not a serious problem except for its undesirable abrasive qualities. The only effect of cristobalite on the properties of a bentonite should be one of dilution. The other types of impurities—soluble salts, gypsum, etc.—may have a major effect through cation exchange taking place in a water suspension. However, most Alberta bentonites do not appear to contain more of these impurities than do other bentonites with good drilling fluid characteristics.

The cause for the deficiency in the drilling fluid characteristics of Alberta bentonites must be looked for within the montmorillonite. Variables which may be responsible include variations in the amount and kind of isomorphous substitution, variations in the geometrical arrangement of substitutions, strains and distortions in the crystal lattice, and variations in the degree of randomness of stacking of unit sheets. In an attempt to arrive at some conclusions as to the extent to which these variables did influence properties, a comparative study of a number of bentonites was undertaken by the author for his Ph.D. thesis. It was found that every naturally-occurring montmorillonite contains several components mixed on the unit cell scale (Byrne, 1953). With this intimacy in mixing, evaluation of the variations between different components of any montmorillonite, or between montmorillonites, becomes impossible with present knowledge and techniques.

Other factors which must be considered are the size and shape of individual montmorillonite particles. Due to the crystal structure of montmorillonite, individual particles are flake-shaped. Basal surfaces and edge surfaces on these flakes may be expected to show considerable differences due to differences in the arrangement of surface ions and differences in charge distribution. These factors are, in turn, affected by the factors previously discussed. In addition, the size of the particle and its relative dimensions—the ratio of length to breadth to thickness—will affect the colloidal properties, and these variables are difficult to evaluate. Size measurements of montmorillonites using Stokes' Law are of little value, since individual particles are far from the spherical shape postulated in that law. Electron microscopy is of limited value due to the tendency of montmorillonite particles to agglomerate upon drying. Some indirect evidence of the effect of grain size is provided by recent experiments carried out by Tomkins (1954), who showed that the addition of sodium to a calcium bentonite produces a more beneficial effect if the mixture is ground. This effect is believed by Tomkins to be due to breaking of Ca—O bonds with the result that cation exchange takes place more readily. It is possible that alteration of grain-size distribution is also a contributing factor.

It is clear from the foregoing discussion that beneficiation of Alberta bentonites will be difficult to achieve until more is known of the factors responsible for their deficiencies in drilling fluid properties.