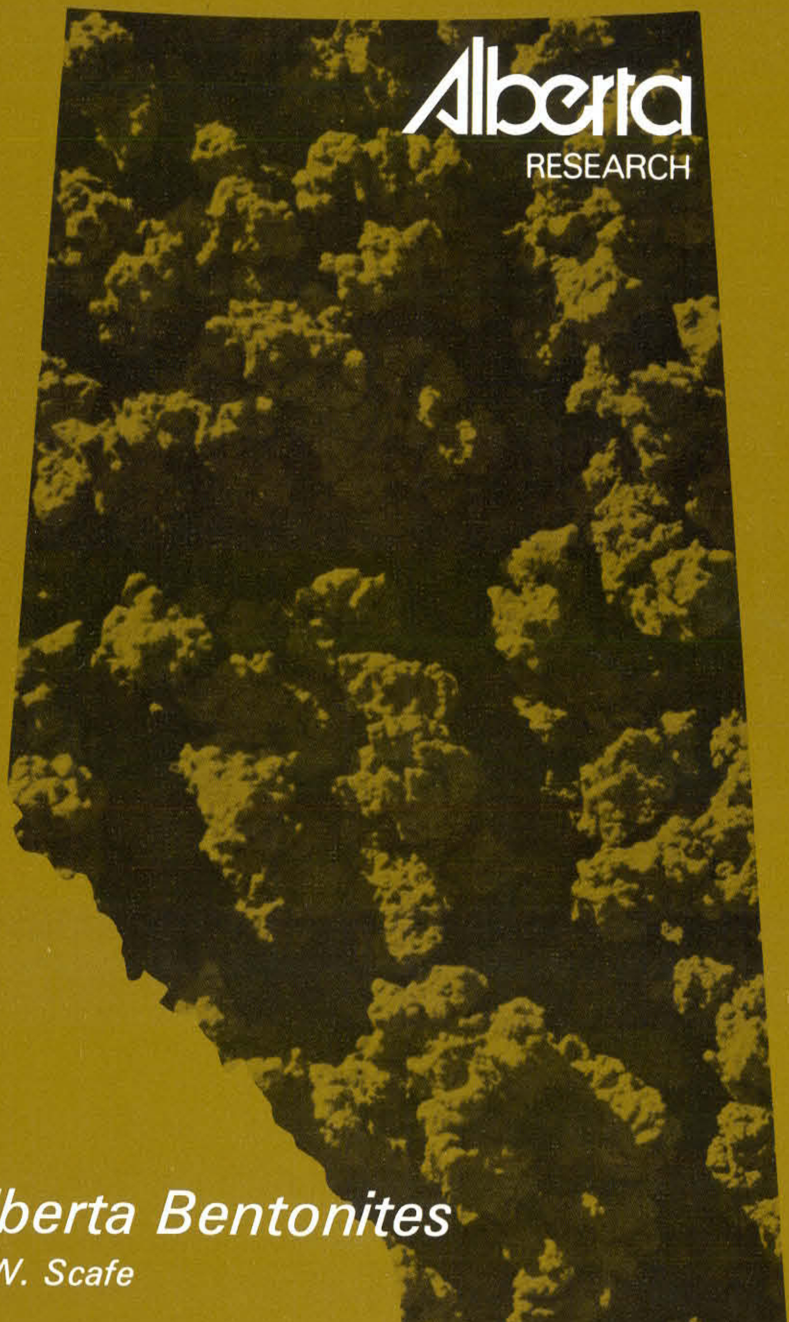

Alberta Bentonites

D. W. Scafe

Alberta Bentonites

ABSTRACT

Suspension properties of bentonites from the nine areas in Alberta where deposits are thicker than 1 foot indicate that production of high-swelling bentonite probably will remain limited to deposits presently being mined. Low yields, high grit content, or thick overburden reduce the desirability of other deposits.

The paucity of glass shards and the mineralogy of the sand and silt fractions suggest rhyodacite as the composition of the parent volcanic ash for each deposit. Absence of allogenic material indicates that differences in the amount of clastic constituents within and between deposits are the result of differences of original mineralogy and diagenetic alteration. Clay content can be related to the amount of sand- and silt-sized volcanic glass altering to montmorillonite. Evidence suggests no preference for diagenesis or adsorption from groundwater to explain the origin and distribution of Na, Ca + Mg, and Fe.

Multiple regression analysis of seven compositional properties shows that 81 percent of the variation in yield (bbl/T) of 15-centipoise mud can be attributed to their concomitant variation; however, 72 percent of the variation in yield can be attributed to one property (clay content). The remaining variables ($<0.2\,\mu m$ clay, exchangeable Na, exchangeable Ca + Mg, Fe^{+2} and Fe^{+3} contents and CEC) contribute little additional precision to the regression analysis when clay content is included in the equation.

by
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ALBERTA BENTONITES

INTRODUCTION

Bentonite, composed essentially of the clay mineral montmorillonite that has formed by alteration of volcanic glass, is common in the Cretaceous and Paleocene sediments underlying much of the Alberta Plains and Foothills. The rock has a variety of industrial uses: as a binder for foundry sands, iron ore pellets, livestock feed pellets, bricks made from fly ash, and so on; as a major component of drilling muds; as grouting clay; as a filler in roofing products; and as a component of many other products. Currently, Alberta bentonite is commercially exploited at two locations in the province: Dresser Minerals mines bentonite from deposits along the Battle River south of Rosalind (Fig. 1), and at Onoway, Baroid of Canada Ltd. processes material that was stockpiled in 1968.

This report presents the results of a detailed study of the known deposits of Alberta bentonites which are thicker than 1 foot. An economic evaluation is made for each deposit based on suspension properties, thickness of overburden, extent of deposit, amount of grit, and so on. These data, plus mineralogy, cation exchange, and iron content, subsequently are used to suggest why different bentonites possess diverse properties.

Acknowledgments

Assistance and courtesies received from Messrs. B. Sturek, L. Boulter, and J. S. Carter of Dresser Minerals, and T. Vaughn of Baroid of Canada Ltd. is gratefully acknowledged. The comments of J. H. Wall, R. Green, and W. N. Hamilton helped to smooth and clarify the presentation.

SAMPLING

Trenches were dug into outcrops, pit faces, or stockpiles far enough to expose moist bentonite. Samples were taken at each color change or at 6-inch vertical intervals if the color was uniform. Each sample was described, color coded using the Rock-Color Chart (Rock-Color Chart Committee, 1963), and then sealed in a double-walled plastic bag to preserve moisture and color.

ANALYTICAL PROCEDURES

Certain properties of each sample were measured. Yield is the number of barrels of mud with 15-centipoise viscosity obtainable from 1 ton of clay, and it is the information most often desired by drilling companies, foundries, and pelletizing companies. Percentage of sand, silt and clay, cations exchangeable by ammonium acetate, and percentages of ferrous (Fe^{+2}) and ferric (Fe^{+3}) iron were determined in order to attempt to explain why some bentonites produce higher yields than others.

Yield was determined for suspensions of 10 percent by weight using procedures for testing oilwell drilling fluid materials (American Petroleum Institute, 1969a, b).

Sand-sized (>63 μm) material was obtained by wet sieving a hydrated suspended sample through a Canadian Standard 230-mesh sieve. The weight of the sand-sized material was determined, heavy minerals (sg >2.96) were separated using tetrabromoethane (sg 2.96 at 20°C), and an X-ray powder pattern was obtained of the heavy and light (sg.< 2.96) fractions. Heavy minerals were mounted in Aroclor (n = 1.66) and light minerals in Lakeside 70 (n = 1.54) for optical examination with a petrographic microscope.

The <230-mesh material was separated into 63-2 μm and <2 μm fractions. The <2 μm material was separated further into 2-0.2 μm and <0.2 μm fractions using procedures only slightly modified from those of Tanner and Jackson (1948) and Jackson *et al,* (1950). X-ray powder patterns for the 63-2 μm material were obtained for mineral identification.

The sedimentation method was used to prepare glass slide mounts of the 2-0.2 μm and <0.2 μm material for X-ray identification of minerals. Slides were equilibrated at 50 and 80 percent relative humidity (RH) for 24 hours, and RH was maintained during X-radiation by utilizing a modified goniometer radiation shield (Gillery, 1959). X-ray diffractograms were obtained from Cu Kα radiation produced by a Philips X-ray generator set at 40kV and 20mA and recorder settings appropriate to keep major peaks on scale. Each <2 μm fraction was freeze-dried prior to determination of exchangeable Ca and Mg by atomic absorption and Na and K by flame photometry procedures. Iron content as Fe^{+2} and Fe^{+3} was determined for <2 μm material.

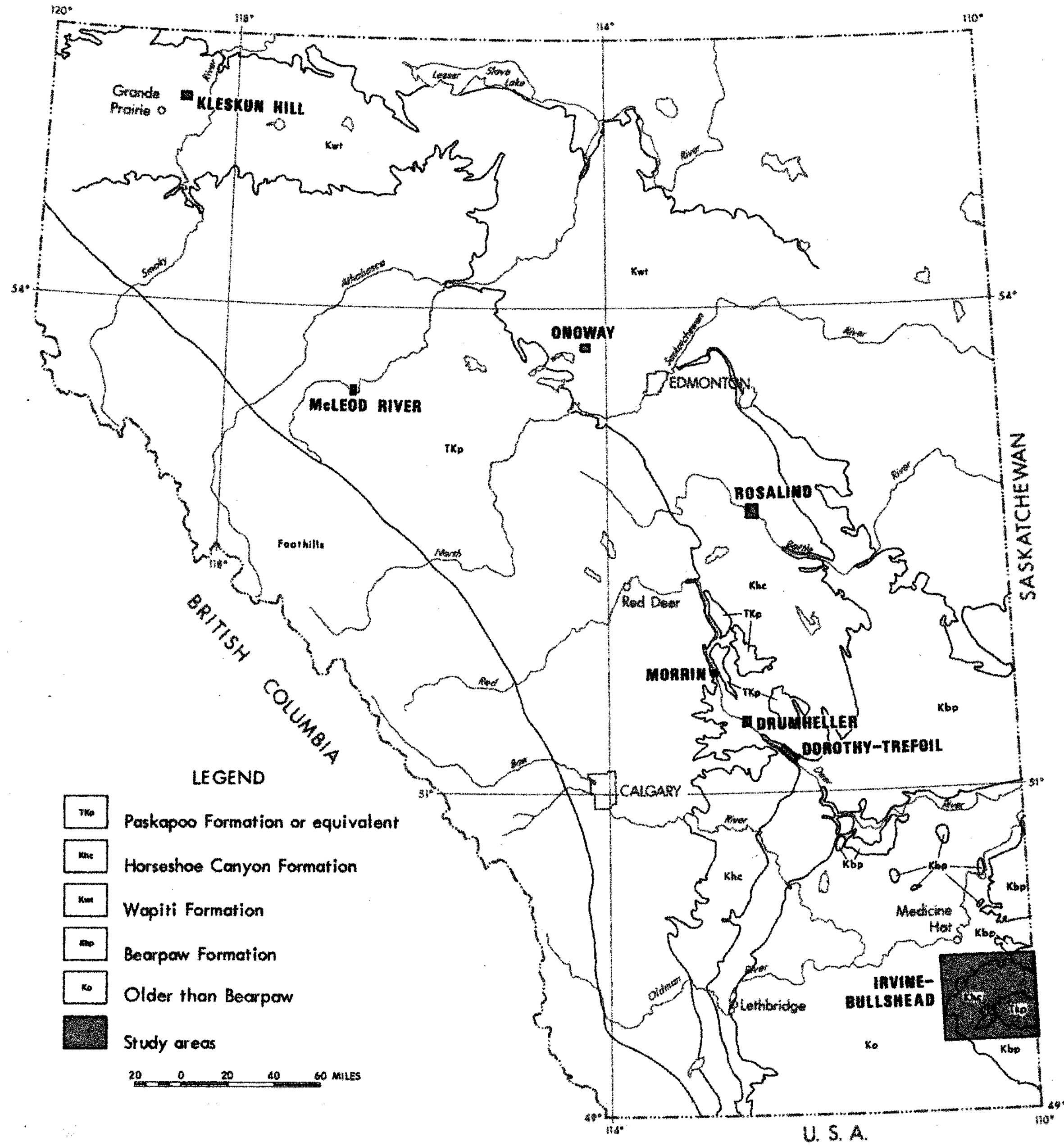

FIGURE 1. Location of study areas.

PART 1: DESCRIPTION AND ECONOMIC EVALUATION OF ALBERTA BENTONITES

DESCRIPTION OF DEPOSITS

Four rock units (Table 1, Fig. 1) contain the bentonites investigated in this study. The Bearpaw Formation is composed of dark grey blocky shale and silty shale, greenish glauconitic or grey clayey siltstone, grey and green mudstone, and concretionary ironstone beds. Bentonite deposits generally are less than 1 foot thick, but are persistent over wide areas. Only at two locations – south of Irvine and at Dorothy (Fig. 1) – are beds thick enough to consider for exploitation.

The Horseshoe Canyon Formation consists of grey, feldspathic, clayey sandstone, grey montmorillonitic mudstone and calcareous shale, concretionary ironstone beds, coal, and minor limestone beds. Present bentonite production in Alberta is from beds of this formation. Bentonite beds in this rock unit generally are less persistent than those of the Bearpaw Formation, commonly grading laterally into montmorillonitic sandstones or shales over short distances.

The Wapiti Formation in northwestern Alberta is equivalent to the Horseshoe Canyon Formation and older beds, and consists of grey, feldspathic, clayey, sandstone, grey montmorillonitic mudstone, and scattered coal beds. Bentonite beds are persistent only for short distances.

Table 1. General Stratigraphic Terminology in the Study Area

	Northwestern Alberta	Central and Southeastern Alberta
Age	Formation	
Tertiary	Paskapoo	
Late Cretaceous	Wapiti	Horseshoe Canyon
		Bearpaw
		Belly River

Rocks of the Paskapoo Formation vary in age from Late Cretaceous to Tertiary and consist of grey to greenish grey, thick-bedded, calcareous, cherty sandstone, grey and green siltstone and mudstone, thin limestone, coal, and tuff beds. Locally, some tuff beds have altered to bentonite.

Irvine-Bullshead

In southeastern Alberta, north and west of the Cypress Hills (Fig. 2), a bentonite and volcanic ash bed 1 to 5 feet thick is present over a wide area beneath 10 to 15 feet of overburden. The bentonite bed, in the Bearpaw Formation about 100 feet above the base, consists of pale olive to greyish olive, blocky, massive to slightly bedded bentonite resting on dark brown to black massive shale. Iron stain is present along fractures in both the bentonite and the shale, and gypsum crystals commonly litter the bentonite outcrop. The bentonite is overlain by light to dark grey banded shale. Upper and lower contacts are sharp.

Two localities (Fig. 2) were sampled and tested from those reported in the area (Babet, 1966). Sand-sized material varies from 1 to 30 percent of the total size fraction and averages 9 percent (Table 2). Plagioclase, quartz, and biotite are the most prominent primary minerals present in the sand fraction. Secondary minerals include gypsum, cristobalite, barite, calcite, and witherite. Gypsum is the most abundant sand-sized mineral in samples taken at the surface of an outcrop. Silt-sized material varies from 13 to 67 percent of the total size fraction, and plagioclase, quartz, biotite, and cristobalite are the minerals present. Plagioclase composition is always near the oligoclase-andesine boundary, in both silt and sand fractions. Clay-sized material varies from 28 to 77 percent and averages 50 percent of the total size fraction. In the clay fraction, montmorillonite is the only mineral present. Of the suspension properties, yield varies from 29 to 88 bbl/T and averages 50 bbl/T (Table 2).

Dorothy-Trefoil

Traceable for 10 miles along the Red Deer River (Fig. 3) and best exposed at Dorothy, is the thickest and most extensive bentonite outcrop in Alberta. The bed, 110 feet below the Horseshoe Canyon-Bearpaw contact (Given and Wall, 1971), is 33 feet thick at Dorothy. Moist bentonite varies from yellowish grey through olive grey, but the outcrop weathers to light olive grey. The massive, blocky bentonite (with dark reddish brown stain along fractures)

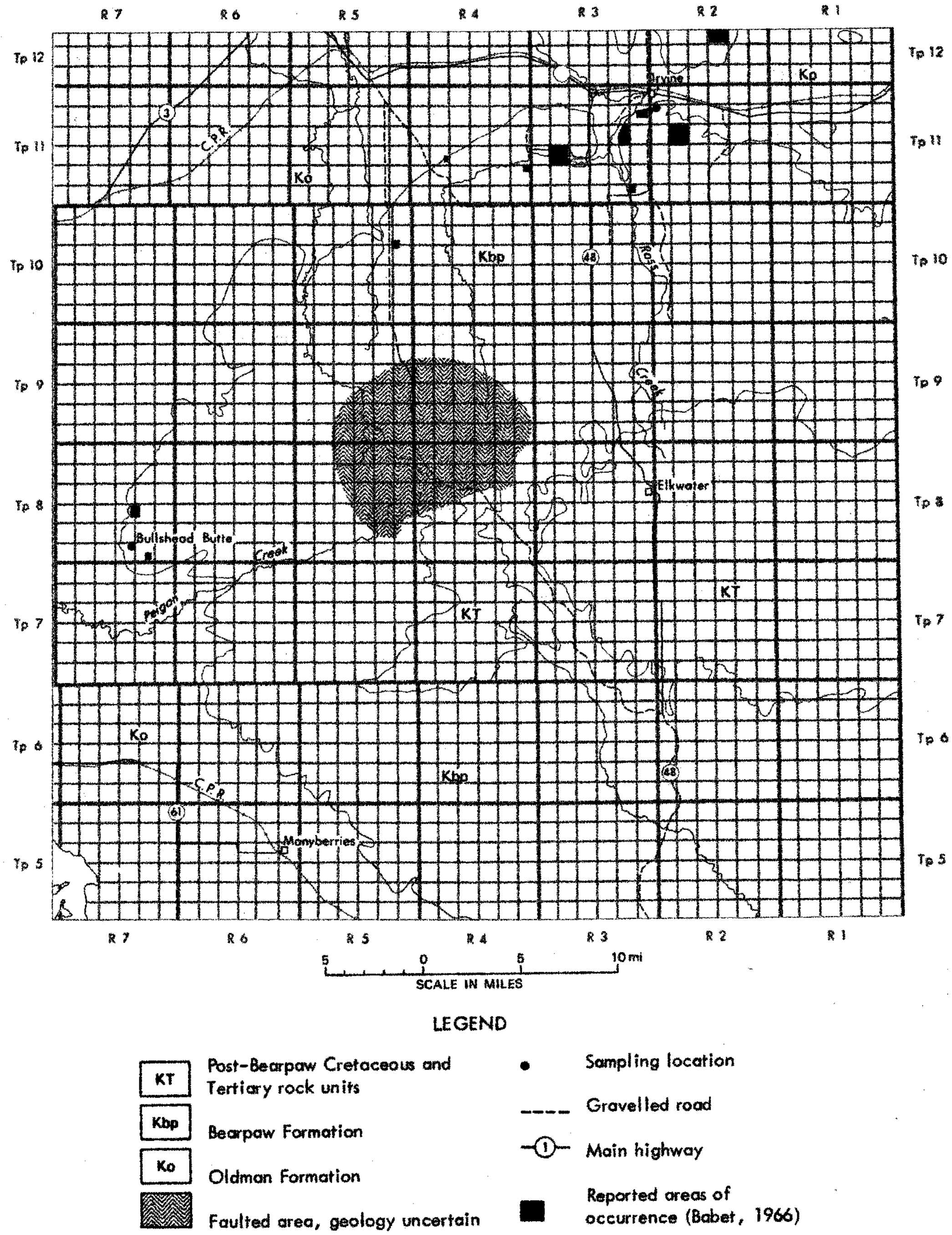

FIGURE 2. Sampling locations and reported bentonite occurrences, Irvine-Bullshead area.

Table 2. Properties of Alberta Bentonites

Locality	Particle Size Distribution (weight percent)				Average Cation Exchange (meq/100 gm)				Cation Exchange Capacity (meq/100 gm)	Ca+Mg: CEC	Average Iron		FeO: Fe_2O_3	Yield (bbl/T)
	Sand	Silt	Clay	<0.2 μm	Ca	Mg	Na	K			FeO	Fe_2O_3		
Rosalind														
Bottom Bed	1	11	88	64	22	3	64	10	99	25	0.56	2.32	0.24	105
Green	1	15	84	61	-	-	-	-	-	-	-	-	-	80
Arrowhead	1	19	80	59	17	3	52	12	84	24	0.46	2.37	0.20	76
Grey	1	22	76	30	14	3	75	2	94	18	0.27	2.71	0.10	67
Section 19	1	23	76	49	20	6	79	2	107	24	0.32	6.26	0.05	81
Irvine	4	46	47	21	23	27	46	2	98	20	0.10	4.25	0.03	44
Bullshead	11	35	54	20	20	6	78	3	107	24	0.10	3.88	0.04	56
Dorothy 10	2	47	51	30	11	4	82	2	99	15	0.35	4.21	0.05	38
Dorothy 16	1	48	51	27	13	2	73	2	90	17	0.40	4.81	0.04	39
Dorothy 19	2	45	53	27	14	1	86	1	102	15	0.16	4.47	0.04	37
Trefoil	7	44	49	19	12	9	58	2	81	26	0.50	4.63	0.01	36
Drumheller 13	7	27	66	46	15	2	51	1	69	25	0.11	3.12	0.04	77
Drumheller 14	12	30	58	36	15	2	50	2	69	25	0.15	2.95	0.05	67
Morrin	5	38	57	32	19	3	64	1	87	25	0.48	5.30	0.05	41
Sheerness	22	63	17	6	30	6	42	2	80	45	1.30	2.49	0.03	28
Onoway 21	2	43	54	20	21	5	37	1	64	41	0.82	4.23	0.05	48
Onoway 22	7	49	44	17	26	4	49	1	80	37	0.31	5.33	0.06	36
Onoway 23	10	40	50	24	31	4	45	1	81	43	0.16	5.62	0.03	42
McLeod River	3	77	20	8	-	-	-	-	-	-	-	-	-	30
Kleskun Hill	7	51	42	-	-	-	-	-	-	-	-	-	-	40

has a sharp contact with the underlying dark grey, silty shale, but the upper contact is gradational into brownish grey, silty shale through a distance of about one foot. Overburden, absent or thin along the outcrop parallel to the river, quickly increases to prohibitive thickness away from the river in the vicinity of Dorothy. Downriver toward Trefoil both the bentonite and overburden thin and southeast of Trefoil the bentonite is absent.

Four localities were sampled and tested along the outcrop (Fig. 3). In these samples, sand-sized material varies from 0.1 to 17 percent of the total size fraction, but usually is less than 3 percent. In this sand material, shards of volcanic glass are common, the primary minerals include quartz, plagioclase, biotite, zircon, and apatite. Secondary minerals consist of cristobalite (forming from volcanic glass), calcite, barite, gypsum, siderite, heulandite, and hematite (trace or very rare). Silt-sized material varies from 24 to 62 percent but averages about 45 percent of the total size fraction; quartz is the dominant mineral, especially in localities at either end of the outcrop area. Plagioclase and cristobalite are present in lesser amounts and in nearly equal concentrations, the plagioclase composition falling near the oligoclase-andesine boundary (with oligoclase being slightly more prominent). Clay-sized material varies from 24 to 76 percent of the total size fraction; the $<0.2\,\mu m$ material varies from 19 to 45 percent but averages 30 percent of the total size fraction. Montmorillonite is the only mineral present in the clay fraction.

Yield varies from 29 to 59 bbl/T but averages 37 bbl/T.

Drumheller

Excellent exposures of the Horseshoe Canyon Formation exist along both sides of the Red Deer River at Drumheller, where the typical popcorn weathering of swelling bentonite is observable at many places. However, many of the bentonite beds grade laterally into montmorillonitic shales or sandstone and are less than 1 foot thick, or are beneath thick overburden. One bentonite zone, approximately 15 feet thick, was sampled at two localities for this report (Fig. 4): Drumheller 13, approximately 300 yards north of the area mined for many years by the late G. L. Kidd, and Drumheller 14 which is from the equivalent bentonite bed on the south side of the river. This bentonite zone rests with a sharp contact on dusky yellowish brown to dusky brown silty, slightly laminated shale and grades upward into a dusky yellowish brown carbonaceous shale. The bentonite is light olive grey through olive grey to dusky brown in color, massive, waxy, slightly silty, and breaks into pieces

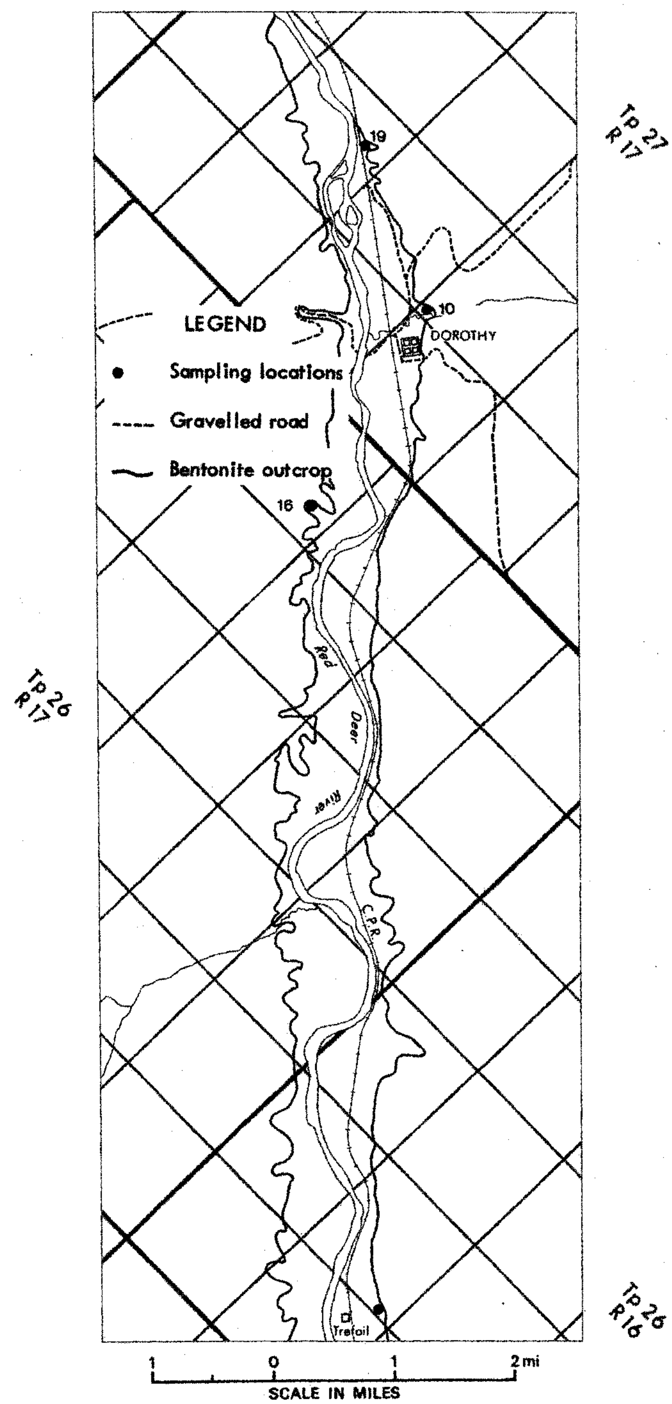

FIGURE 3. Sampling locations and extent of bentonite outcrop, Dorothy-Trefoil area.

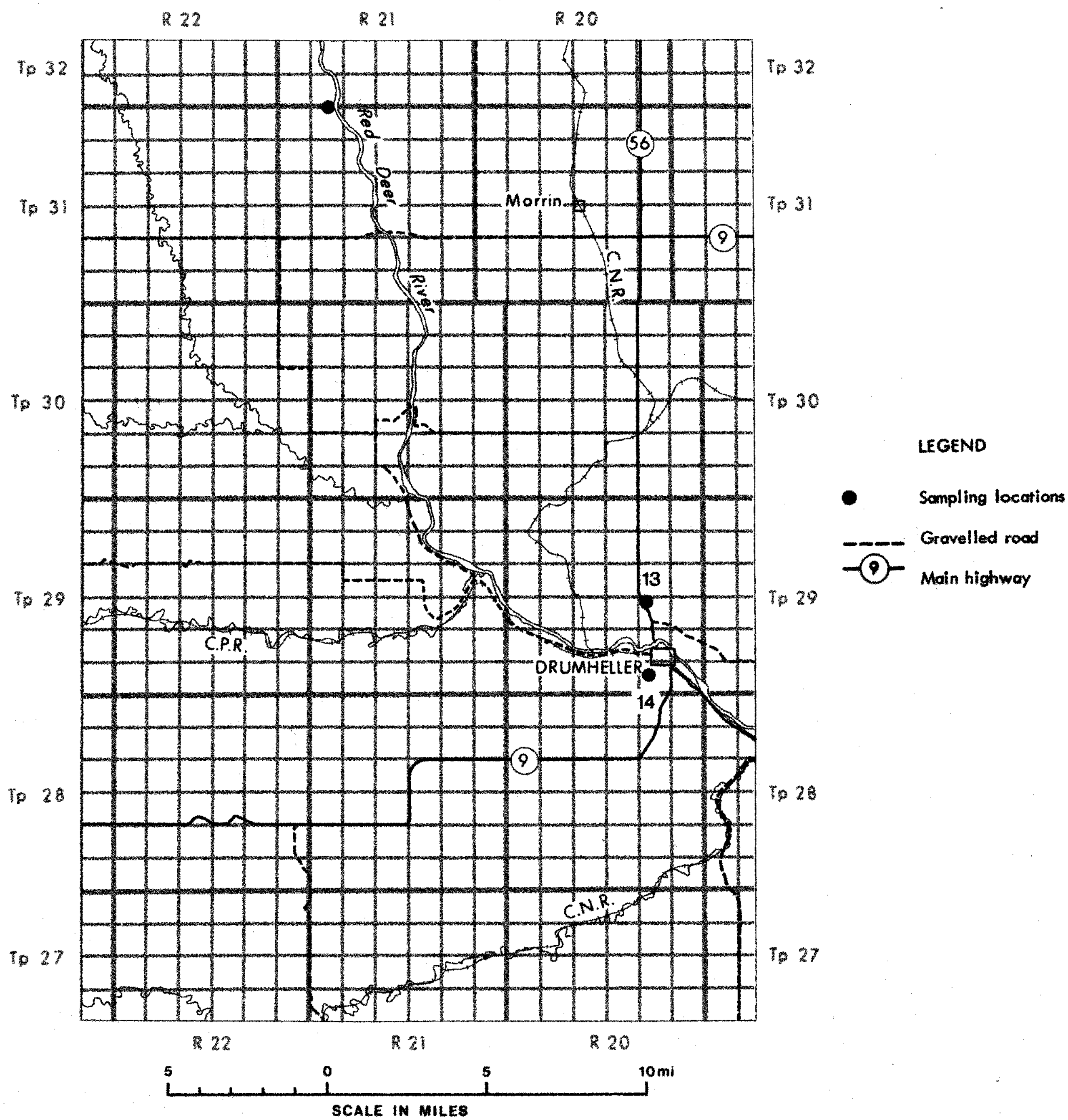

FIGURE 4. Sampling locations, Drumheller and Morrin areas.

<1 inch square. Overburden probably is too thick for mining at the Drumheller 13 locality, but commonly is less than 10 feet thick on buttes in the area of Drumheller 14.

Sand-sized material varies from 0.5 to 38 percent, averaging 5 percent of the total size fraction. The high sand values are from five 3- to 4-inch bands approximately 3 feet apart that have higher concentrations of quartz, plagioclase, and cristobalite than surrounding material. Silt varies from 7 to 46 percent and averages 23 percent of the total size fraction. Montmorillonite is the only mineral present except for cristobalite, which is present in clay-sized material of the sandy bands.

Average yield is 72 bbl/T and varies from 37 to 115 bbl/T.

Morrin

Four miles north of the so-called "Morrin bridge" across the Red Deer River (Fig. 4) is a 3- to 5-foot thick bed of bentonite in the Horseshoe Canyon Formation. The bentonite, light olive grey to olive grey in color and massive, rests with sharp contact on a 4-inch to 1-foot bed of medium light grey tuff, and is overlain by very thick overburden. The bentonite grades laterally into montmorillonitic sandstone or siltstone.

Sand content in the bentonite varies from <1 to 5 percent and silt varies from 27 to 56 percent of the total size fraction. Quartz, plagioclase, cristobalite, biotite, apatite, zircon, and barite are the minerals present in these size fractions. Montmorillonite is the only mineral present in the clay fraction. Clay material varies from 43 to 64 percent of the total size fraction.

Yield varies from 30 to 48 bbl/T and averages 41 bbl/T.

Sheerness

Directly above the thick coal seam mined from the Horseshoe Canyon Formation at Sheerness by Battle River Coal Co. Ltd., is a 4.5-foot zone of bentonite. The lower 2 feet of this bentonite is olive grey, gritty, and laminated, with carbonaceous films along laminae. The upper 2.5 feet is olive black, massive, less gritty, and grades rapidly into a 1- to 2-foot weathered coal zone above.

The lower 2-foot section of the bentonite contains an average of 40 percent sand and the upper 2.5-foot section an average of only 4 percent sand, but the lower section averages 80 percent silt compared with 45 percent silt in the upper. The usual suite of quartz, plagioclase, and cristobalite is present in the light minerals. Only a few grains of heavy minerals are present, consisting of hematite, zircon, and apatite. Biotite is absent. Clay material averages only 15 percent of the total size fraction and montmorillonite is the only mineral detected in this fraction.

Maximum yield is 30 bbl/T and 28 bbl/T is the average.

Rosalind

The only area in Alberta where bentonite is actively being mined is 9 miles south of Rosalind, both north and south of the Battle River, on property leased to Dresser Minerals. Bentonite mined from these leases is hauled to Rosalind for processing. Active mining is from two areas (Fig. 5), although mineable bentonite is present in four areas and from four stratigraphic horizons in the Horseshoe Canyon Formation. The beds, which have a regional dip to the southwest of approximately 14 feet per mile, are exposed beneath glacial till in incipient badland topography.

A 5- to 8-foot bed of bentonite underlies much of the southwest quarter of section 5 (Fig. 5) and is highest stratigraphically in the area. This bentonite has been used as a flame retardant for fighting forest fires and as a mud for diamond drilling, but at present the pit is closed until new markets develop.

Bentonite of the main mine in section 31 (Fig. 5) is 10 feet stratigraphically below that of section 5. Within an 8- to 10-foot interval bentonite of four distinct qualities (based on suspension properties) can be mined. Dependent upon their specific characteristics these bentonites have been used for feed pelletizing, binding foundry sands for steel or grey iron casting, oilwell drilling, dam sealing, and iron ore pelletizing.

Eighty feet stratigraphically below the bentonite of the main mine, in sections 7 and 8 (Fig. 5), is a 6- to 8-foot bed of bentonite that is white when processed. Although bentonite from this deposit was tested extensively by the company in the past, no development has taken place.

The lowest bentonite is present in section 19 (Fig. 5) and is 80 feet stratigraphically below the bentonite of sections 7 and 8. Bentonite from this 4- to 6-foot bed is used for binding foundry sands and in oilwell drilling.

The bentonite in section 31 rests with sharp contact on black carbonaceous shale and is overlain by glacial till that

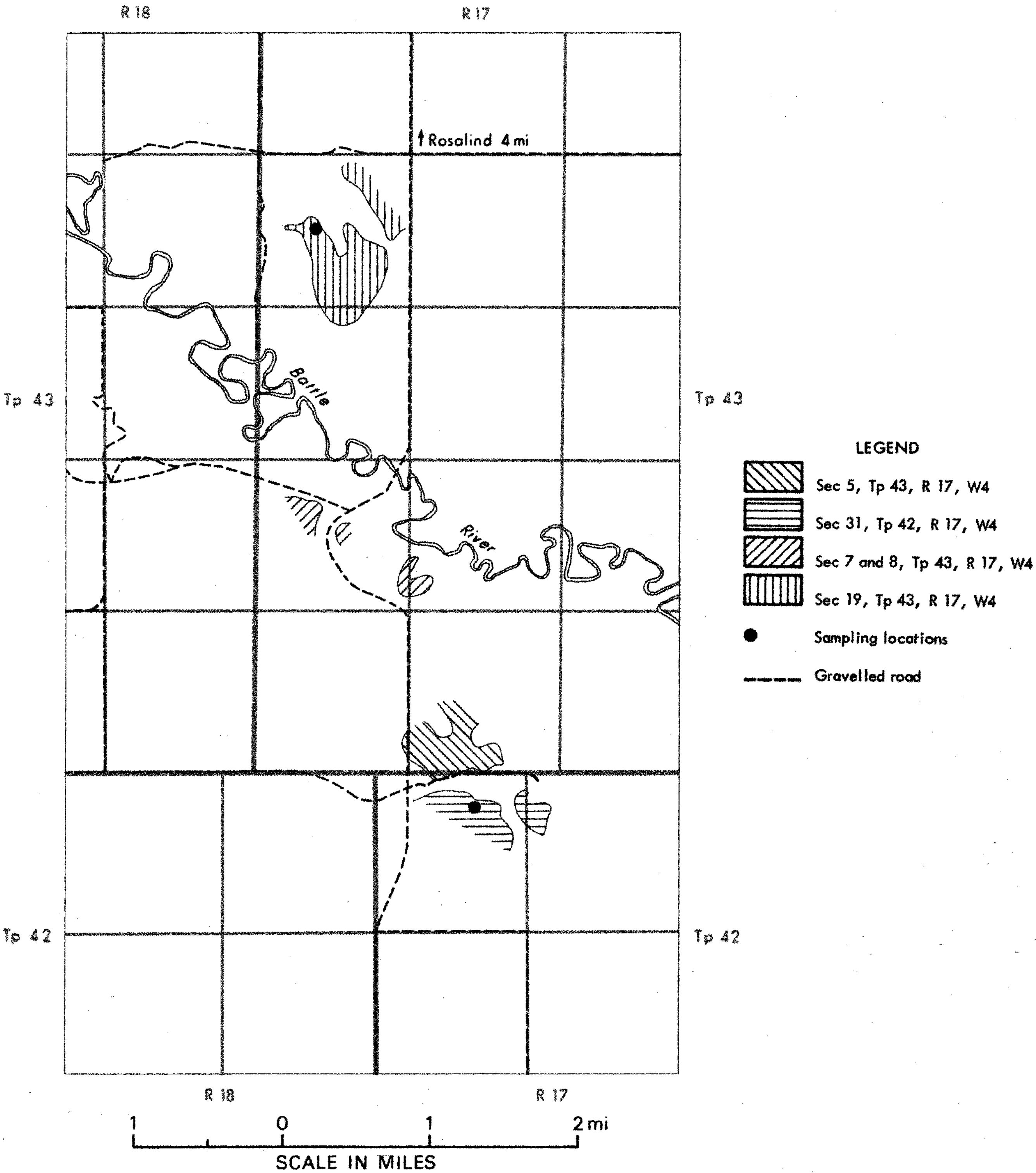

FIGURE 5. Sampling locations and outlined bentonite deposits, Rosalind area.

attains thicknesses of as much as 25 feet. Bentonite at this locality can be divided into four units based on suspension properties:

(1) The lowermost unit, the "Bottom Bed," is light olive grey to greyish olive, massive, and blocky fracturing.

(2) "Green" clay is bentonite above the Bottom Bed and nearest to the outcrop face. It is dusky yellow green to greyish olive green, laminated, and blocky fracturing.

(3) "Arrowhead" clay, found above the Bottom Bed behind the Green clay, varies in color from dusky yellow green to dusky yellowish brown, and is discolored along fractures, laminae surfaces, and entire laminae by the reds and browns of oxidized iron. This material generally breaks into 1/2-inch blocks.

(4) "Grey" bentonite, varying between light olive grey and olive grey, is farthest from the outcrop face and under the deepest overburden. Laminae can be traced from Grey clay into Arrowhead and Green clays across the color boundaries.

In the four units, sand content varies from 0.1 to 12 percent but averages 1 percent of the total size fraction. Quartz, plagioclase (andesine-oligoclase), cristobalite, and a few K-feldspar grains are the light minerals usually present in sand fractions. Calcite is often the major mineral in those samples containing more than 2 percent sand. Fresh volcanic glass is observed only in a few sand samples, but partially devitrified glass is found in many samples; under polarized light it is observed to be mainly aggregates of very fine cristobalite and montmorillonite. Biotite is the dominant heavy mineral, and zircon, apatite, marcasite, barite, and siderite are common in trace amounts.

Silt varies from 6 to 39 percent, and averages in the four units increase from Bottom Bed through Green and Arrowhead to Grey clay (Table 2). Mineralogy of silt material is similar to that of the sand fraction.

Averages for clay-sized material decrease from Bottom Bed through Green and Arrowhead to Grey clay (Table 2). Clay mineralogy of the units is similar, with montmorillonite being the clay mineral.

Bentonite from section 19 rests on black, laminated, silty shale and is overlain by green "salt-and-pepper" sandstone. The clay is massive and most breaks into 1- to 1.5-inch blocks. It is medium dark grey to greyish olive green and weathers to olive grey. Along the weathering color contact, "eggs" of grey clay surrounded by olive are common. The olive color also extends along fractures.

Sand varies from 0.2 to 4 percent, with an average of 1.6 percent, and its mineralogy is similar to that of section 31 bentonite. Silt and clay concentrations vary within narrow limits around their averages of 23 and 75 percent, respectively, and their mineralogy also parallels that of section 31 bentonite.

From section 31, Bottom Bed material gives yield values averaging 105 bbl/T, which is consistently higher than bentonite from any other unit. Averages for Green, Arrowhead, and Grey clays are 80, 76, and 67 bbl/T, respectively. Section 19 clay averages 81 bbl/T.

In-situ samples from section 5 or sections 7 and 8 were not available for this study; the company reports yield values of 75 bbl/T for the bentonite from section 5 and 68 to 70 bbl/T for material from sections 7 and 8.

Onoway

Baroid of Canada Ltd. maintains the other benonite operation in Alberta by processing material from leases 11 miles northwest of Onoway (Fig. 6). Production is low.

The bentonite, from the Horseshoe Canyon Formation, does not outcrop but is found in irregular lenses up to 5 feet thick, below 6 to 7 feet of glacial overburden. Lensing, partly due to irregularities inherent in bentonite formation and partly due to glacial loading, causes problems during exploration and development. The light olive grey material usually weathers to dusky yellow but the reds and browns of oxidized iron are present on laminae and fractures.

Sand varies from 0.5 to 13 percent and averages 6 to 7 percent. Quartz, plagioclase, and cristobalite are the common light minerals, and hematite, biotite, barite, zircon, and apatite are the heavy minerals, with hematite fairly abundant in some samples. Silt averages 44 percent of the total size fraction and its mineralogy is similar to that of the sand fraction. Clay averages 48 percent of the total size fraction and the clay mineral is montmorillonite.

Yield varies from 28 to 68 bbl/T and averages 42 bbl/T.

McLeod River

A 7-foot bed of bentonite is found on the south bank of the McLeod River upstream from the CNR Coal Branch bridge, and many years ago a small quantity of bentonite was mined from this deposit for use as a filler in cosmetics.

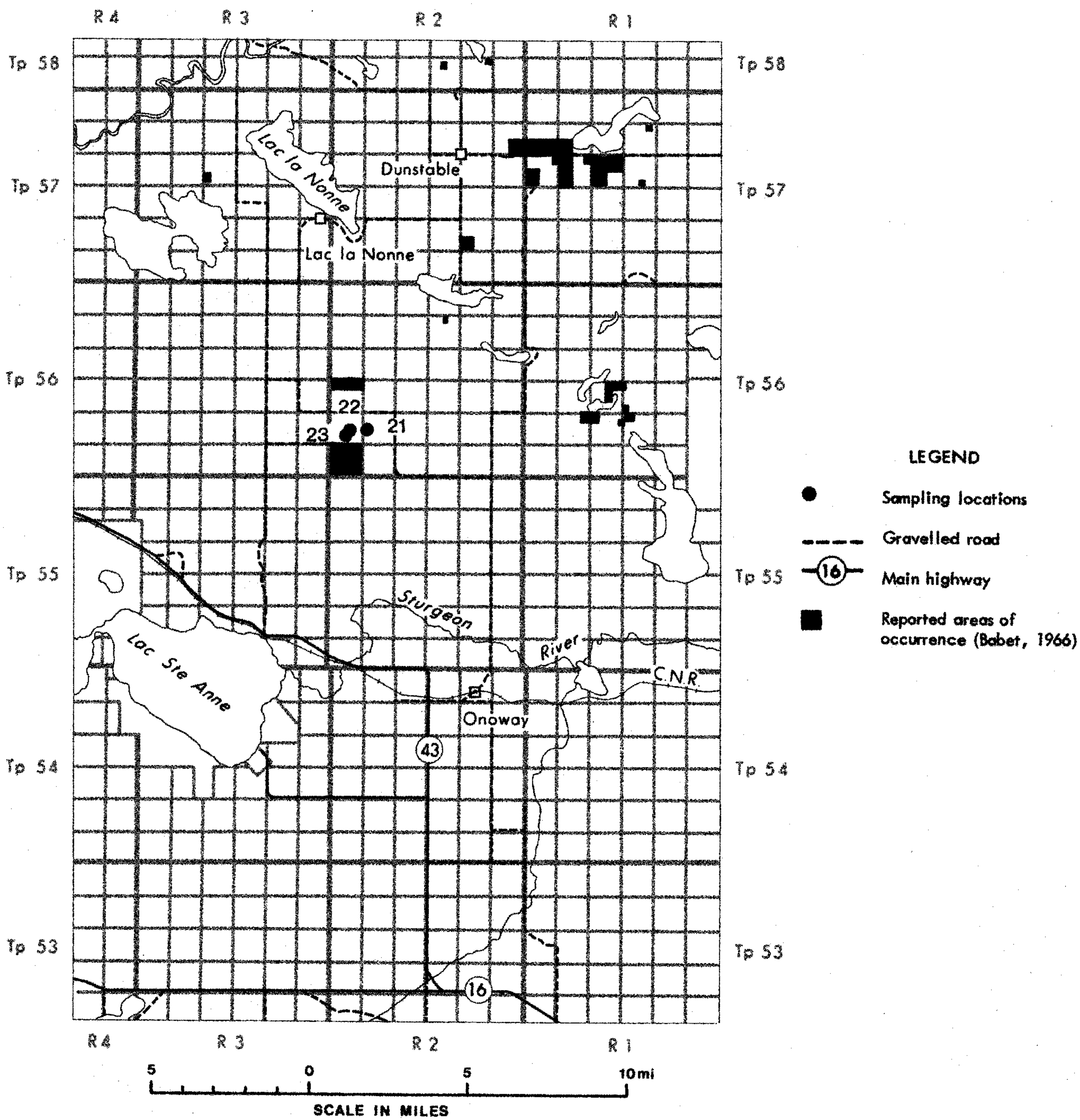

FIGURE 6. Sampling locations and reported bentonite occurrences, Onoway area.

The abandoned workings in this so-called Bickerdike deposit can still be seen during periods of low water. Approximately 25 feet of shale and sandstone of the Paleocene Paskapoo Formation overlies the 100 foot outcrop of pale olive bentonite that dries to yellowish grey.

Sand varies from 1 to 5 percent, but is usually <3 percent. Cristobalite, quartz, plagioclase, and the zeolite mordenite are the usual light minerals. Volcanic glass shards, now partly devitrified to cristobalite and montmorillonite, are dominant. Biotite is the most abundant heavy mineral, but barite is prominent in samples near the top of the deposit. The percentage of silt present varies only slightly from its average of 77 percent, and mineralogy of the silt is similar to that of the sand fraction with the exception that mordenite is absent. Clay percentage varies only slightly from its average of 20 percent of the total size fraction. Montmorillonite is the clay mineral.

Maximum yield is 33 bbl/T and average yield is 30 bbl/T.

Kleskun Hill

On the flanks of Kleskun Hill northeast of Grande Prairie, there is a bentonite-volcanic ash bed that varies from 18 inches to 4 feet in thickness beneath approximately 2 feet of overburden. Light olive-grey bentonite lenses pinch out into the hard, medium grey montmorillonitic sandstones and siltstones of the enclosing Wapiti Formation of Cretaceous age.

These bentonite lenses can have sand concentrations as low as 1 percent, but 7 percent is more common. Silt varies from 30 to 60 percent and averages 51 percent. Mineralogy is the usual quartz, plagioclase (oligoclase-andesine), feldspar, cristobalite, biotite, zircon, apatite assemblage. Clay averages 42 percent of the total size fraction, and montmorillonite is the clay mineral present.

Yields can be as high as 76 bbl/T, but the usual yield is <40 bbl/T.

ECONOMIC EVALUATION

The economic outlook for any product depends on many factors. For bentonite, the first consideration is the quality of the product as defined by accepted standards, and the second is the ratio of bentonite to overburden. A number of bentonite occurrences in Alberta reported in previous publications can be discounted because they are thin or lensy deposits of poor quality or are covered by prohibitive thicknesses of overburden. For this report, only deposits thicker than 1 foot, with the ratio of overburden to bentonite less than 8:1, are considered. Although facilities were not available to the author to perform all the tests required for bentonite sold to foundries and iron ore pelletizing plants, these users include yield data as a primary requirement in the specifications; therefore, economic evaluation of Alberta deposits can be applied to these uses even though the tests are for drilling mud suitability. Data for suspension properties are based on tests of many samples from each deposit.

Data in table 2 illustrate that the high yields usually requested by users can be supplied only by material from the Rosalind or Drumheller deposit, but the high sand content of the Drumheller deposits limits its suitability. Similarly, the high sand and silt content plus the low yield values from the other deposits decrease their desirability.

Irvine-Bullshead

This deposit was described either as a bentonite or as a volcanic ash deposit by geologists in the past, and similar ambivalence applies today. Lenses of high yield, low-grit material grade laterally into low yield, high-grit material. Thin overburden is a positive aspect, but the rapid lateral variations in quality suggest that quality control would be extremely difficult to maintain.

Dorothy-Trefoil

This thick bentonite deposit has excited investigators for many years, but should be deleted from the list by those who are looking for high-yield bentonite. Low yield, overburden that thickens quickly, and variable grit content are undesirable characteristics that outweigh the large tonnages available.

Drumheller

Samples tested from the same bed north and south of the Red Deer River give yields comparable with material presently being produced in Alberta, but north of the river the overburden is extremely thick and grit content is high. South of the river, overburden thickness is acceptable but grit content is particularly high in five 3- to 4-inch bands which would be difficult to eliminate during mining.

Morrin

Unremarkable yields and prohibitive overburden thickness should eliminate this deposit from consideration.

Sheerness

Although mining conditions are more favorable than for any other deposit presently known in the province, grit content is too high and yield values are too low to consider this deposit valuable.

Rosalind

Good to excellent yields, low grit content, and thin overburden combine in these deposits along the Battle River to give them the best commercial potential of any yet discovered in the province. Production has continued since 1959, and reserves are sufficient for many years to come.

Onoway

Fair yields, moderate grit content, and discontinuity of beds combine to give only marginal potential to this deposit that is produced intermittently. Yields can be raised by beneficiation.

McLeod River

The limited known extent of the deposit, relatively thick overburden, exposure at river level, and low yields suggest a dim future for this deposit. The high silt and low clay content also suggests that it was an abrasive filler in the cosmetics for which it was mined in the 1930's.

Kleskun Hill

Thin overburden is a favorable aspect associated with this bentonite, but high grit content and low yields outweigh this advantage.

OUTLOOK

Optimistic projections often are easy to make when few facts are available, but as data accumulate the projections become tenuous. Results obtained for this report indicate that enthusiasm on the future of high swelling bentonite production in Alberta is warranted only for the deposits presently mined.

PART 2: CHARACTERISTICS OF ALBERTA BENTONITES

PROPERTIES OF ALBERTA BENTONITES

Mineralogy

Angular quartz usually is the dominant mineral in sand-sized material. Plagioclase feldspar, usually with composition centering around the oligoclase-andesine boundary, is the next most dominant mineral. Minor quantities of K-feldspar also are present in a few samples. Fresh volcanic shards are not common, but partly devitrified glass is found in most samples and under polarized light this is observed to be mainly aggregates of very fine-grained cristobalite and montmorillonite. Authigenic gypsum or calcite is present in some samples, and either of these minerals is the dominant mineral in a few samples. An unusual occurrence of the zeolite mordenite is present in samples from the McLeod River deposit. Biotite is the dominant accessory heavy mineral, and other heavy minerals common in trace amounts include zircon, apatite, and marcasite or hematite. Barite, siderite, and witherite are found also in a few samples.

Quartz, plagioclase, biotite, cristobalite, and in a few cases K-feldspar or the zeolite heulandite are the minerals identified in the silt fraction. The method of Goodyear and Duffin (1954) was used to determine oligoclase-andesine as the most common plagioclase feldspar in this fraction.

Except for a trace of kaolinite in a few samples, montmorillonite is the only clay mineral present in <2μm material. Cristobalite is more common than quartz in the 2-0.2μm fraction and biotite is unusual. The <0.2μm fraction consists of montmorillonite exclusively. Expansion of montmorillonite, in association with particle size distribution, aids in determining how valuable the material will be as a swelling bentonite. Montmorillonite from most deposits expands to 15-15.5A upon equilibration at 80 percent RH (Fig. 7). Exceptions are material from Dorothy 16 and Trefoil that expand only to 12.63A, and from Onoway and Kleskun Hill that expand to <15A. Expansion as high as 17A at 80 percent RH can be obtained in Bottom Bed samples from Rosalind. This material usually expands slightly further and is better crystallized than that from the Green, Arrowhead, and Grey clay units.

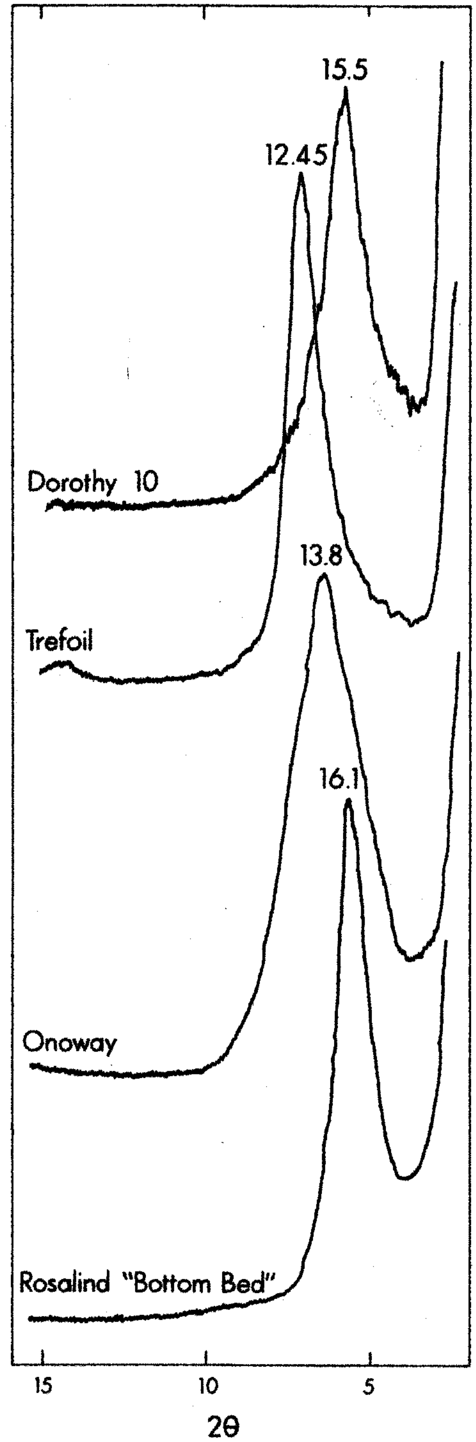

FIGURE 7. X-ray diffractograms of <0.2μm material at 80 percent RH, showing variation of expansion within a deposit and between deposits.

Particle Size Distribution

Sand exceeds the recommended maximum of 2.5 percent for oil well drilling fluids (American Petroleum Institute, 1969a) in over half of the sample groups tested (Table 2). Silt is the most abundant size in samples from Sheerness, McLeod River, Kleskun Hill, and one group of samples from Onoway. Clay usually is the most abundant size, and <0.2 μm material also forms a significant portion of the total size fraction.

Previous work by Scafe (1973) suggests that the content of <0.2 μm material is more effective than six other properties in determining yield, and further results support this suggestion for yields as low as 60 bbl/T. However, as yield decreases below 60 bbl/T the amount of <2 μm material becomes the most significant variable affecting yield (Fig. 8).

Exchangeable Cations

Clay minerals are surrounded by loosely held cations that neutralize unsatisfied electrical charges associated with the clay particle. These cations are exchangeable for other cations. It is possible to determine the amount of sodium (Na), calcium (Ca), magnesium (Mg), potassium (K), and so on, exchanged by a cation such as ammonium. The total of all the exchanged cations is known as the cation exchange capacity (CEC).

Sodium is the most abundant exchangeable cation at all localities. The concentrations of exchangeable Mg and K are low at all localities with the exception of high Mg at Irvine. Only three of the ratios of Ca + Mg to CEC in table 2 fall within the 40 to 60 percent range, in which small changes in the amount of Ca or Na are reported to induce large changes in yield (Williams ***et al***, 1953a); however, no obvious relationship exists between this ratio and yield for the samples examined for this report.

Iron Content

Foster (1953, 1955) and Davidtz and Low (1970) suggest that iron oxidation (among other variables) might be significant in increasing swelling properties of a bentonite. With increased swelling, yield would increase. Observations on most bentonites from Alberta suggest that the hypothesis has some merit because the reddish brown stain of oxidized iron appears in samples from all localities studied for this report. The percentage FeO present in a sample varies from a low of 0.03 in one sample from Irvine-Bullshead to a high of 2.61 in a sample from Sheerness. More abundant Fe_2O_3 varies from a low of 1.82 percent in one sample to a high of 6.77 percent in another sample from Rosalind. The FeO: Fe_2O_3 ratio varies from 0.01 to 0.33 in individual samples.

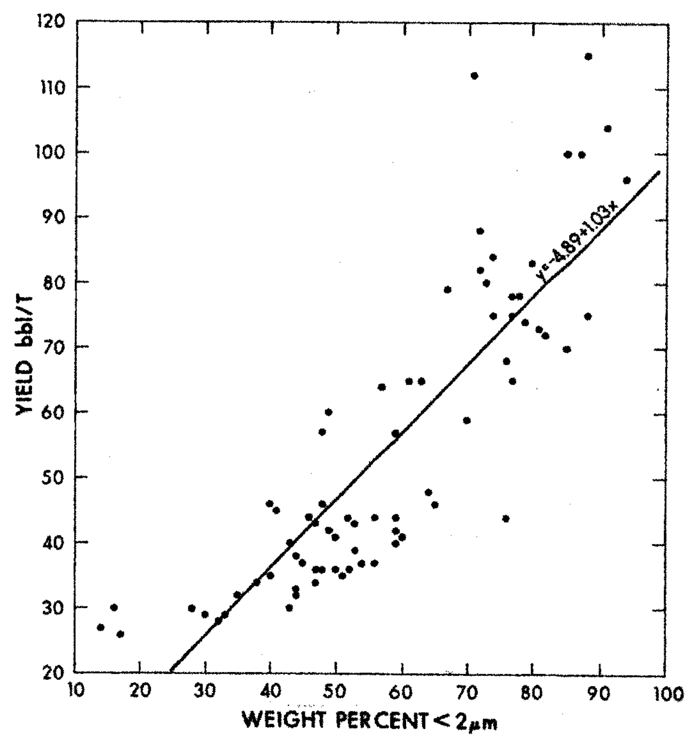

FIGURE 8. Relationship between yield and <2 μm fraction.

At Rosalind, ratios are smallest in samples from section 19 clays and increase in section 31 clays from Grey through Arrowhead clay to Bottom Bed. Averages for each deposit are listed in table 2 and it is obvious that deposits with similar ratios have widely divergent yields. Iron content does not seem to be closely related to yield.

Suspension Properties

Yield is the property of a bentonite that is common to specifications from such diverse industries as oil well drilling and iron ore pelletizing. Yield values show the number of barrels of mud with viscosity of 15 centipoise that can be produced from 1 ton of clay, and high yields usually are specified because less material is needed to attain the results desired.

Yields range from 26 to 115 bbl/T. Rosalind bentonites exhibit consistently higher yield values than those from other deposits. The relationship between yield and other properties of the samples is analyzed further in the following section.

MULTIPLE REGRESSION ANALYSIS OF PROPERTIES ASSOCIATED WITH BENTONITE YIELD

Suspension properties of Alberta bentonites vary markedly from one deposit to the next and among individual samples within deposits. Variations in yield can be related in part to variations in other properties (e.g.,$<2\,\mu$m clay content) but in some cases (e.g., CEC) there is no obvious correlation with yield values. Since there does not appear to be a simple set of interrelationships among yield and other properties a multivariate statistical technique — multiple regression — is used to evaluate relative importance of these properties on yield values.

In multiple regression, an equation of the form shown below is calculated:

$$y = a + b_1x_1 + b_2x_2 \ldots\ldots b_nx_n$$

where
y = dependent variable
x_n = independent variable
b_n = partial regression coefficients.

Yield is designated the dependent variable (y), and total clay content, $<0.2\,\mu$m clay content, ferrous and ferric iron contents, exchangeable Na and Ca + Mg contents, and CEC are independent variables.

Values for these properties are from 77 samples representing the localities listed in table 2 and the corresponding multiple regression equation is calculated to be:

$$y = 17.1576 + 0.6780x_1 + 0.3919x_2 - 2.1901x_3 - 3.7719x_4 - 0.0678x_5 + 0.2495x_6 - 0.0130x_7$$

where
x_1 = percent clay content
x_2 = percent $<0.2\,\mu$m clay content
x_3 = percent Fe^{+2}
x_4 = percent Fe^{+3}
x_5 = exchangeable Na (meq/100 gm)
x_6 = exchangeable Ca+Mg (meq/100 gm)
x_7 = CEC (meq/100 gm).

Partial regression coefficients indicate the average increase or decrease (depending on the sign) in the dependent variable (y) per unit increase in the corresponding variable x, independent of other variables in the equation. However, because different units of measurement are associated with the independent variables, partial regression coefficients cannot be compared directly to determine the relative contribution of each variable to variation in yield values. Furthermore, the independent variables themselves are interrelated, and values of the partial regression coefficients will change if variables are dropped from or added to the equation.

Table 3. Multiple Regression Analysis of Properties Associated with Bentonite Yield

Variable	Standard Partial Regression Coefficients (b')			
	First Trial	Second Trial	Sixth Trial	Seventh Trial
x_1 (Clay content)	0.5603	0.5604	0.5693	0.8476
x_2 ($<0.2\,\mu$m clay content)	0.2860	0.2849	0.3173	-
x_3 (Fe^{+2})	-0.0343	-0.0343	-	-
x_4 (Fe^{+3})	-0.2051	-0.2042	-	-
x_5 (Na)	-0.0557	-0.0662	-	-
x_6 (Ca + Mg)	0.2070	0.1962	-	-
x_7 (CEC)	-0.0130	-	-	-
R^2	0.8086	0.8086	0.7416	0.7184

N = 77

To assess the relative importance of the independent variables in predicting yield values, standard partial regression coefficients (b′) (Snedecor, 1956) were calculated. The b′ values in table 3 indicate the relative contribution or importance of each independent variable to observed fluctuations in yield values; that is, the extent to which yield values will change in response to changes in the respective independent variables. From this it is seen that when all samples are included (N = 77)x_1 (total clay content) is the most important contributor to variation in yield values and x_7 (CEC) the least important. The value for R^2 (square of the multiple correlation coefficient) represents the fraction of total variation in the dependent variable (y) attributable to the regression. For the first trial in table 3, R^2 is 0.8086; that is, 81 percent of the total variation in yield values can be attributed to or "explained" by concomitant variation in the seven independent variables. The remaining 19 percent of the variation in yield values is "unexplained" or "random" variation.

If the least important variable (CEC) is omitted and the multiple regression equation and b′ values are recalculated for the six remaining variables (second trial, Table 3), x_1 is still the most important contributor to variation in yield values (b′ = 0.5604), and R^2 does not change. The six independent variables together still explain 81 percent of the total variation in yield values.

By omitting the least important variable, recalculating new regression equations, b′ and R^2 values, only variables x_1 and x_2 remain by trial six and these account for 74.2 percent of the total variation in yield. If <0.2 μm clay is omitted the R^2 value only drops to 71.8 percent (seventh trial, Table 3). The loss of <10 percent efficiency of the regression analysis by eliminating six of the seven independent variables suggests that total clay content is the only variable among the seven properties considered which has a significant relationship with yield of Alberta bentonites.

Multiple regression analysis on 20 samples from the Rosalind deposit suggested to Scafe (1973) that the content of <0.2 μm material is the most effective variable affecting yield. Multiple regression analysis for this study (not shown) indicate that <0.2 μm material remains the most effective variable until minimum yield of 60 bbl/T is reached, but analyses that include yields below 60 bbl/T show that <2 μm total clay content assumes the role of most effective variable (Fig. 8, Table 3). A plot of yield ***versus*** <0.2 μm material (Fig. 9) shows the same general trend as in figure 8 but data points are more widely scattered.

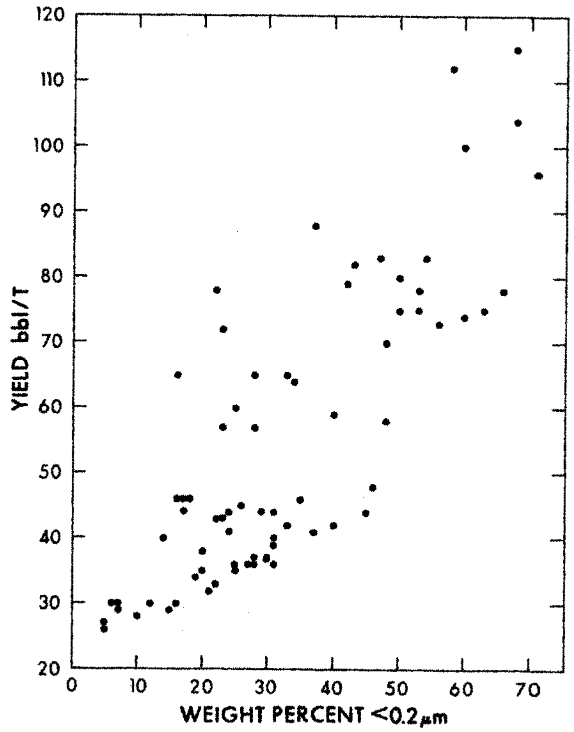

FIGURE 9. Relationship between yield and <0.2 μm fraction.

DISCUSSION OF RESULTS

Composition and Origin

Bentonite composition is a function of the parent volcanic ash composition, diagenesis, and the effects of weathering. Oligoclase-andesine plagioclase, K-feldspar, and quartz contents suggest rhyodacite as the parent material for bentonites in this study. Compositions between rhyolite and dacite with a preponderance of rhyodacites also were suggested by Lerbekmo (1968) for Upper Cretaceous and Paleocene bentonites from the Alberta Foothills.

Although gross composition of the parent ash seems to have been a rhyodacite, mechanical analyses and microscopic observations suggest that mineralogy and diagenetic alteration probably varied significantly between and within deposits. The bentonites are free of allogenic material and few shards of fresh volcanic glass are present. Unaltered quartz, plagioclase, and biotite are the dominant primary minerals and their content in the bentonite should reflect their concentrations in the original ash. Cristobalite, usually authigenic in bentonites (Henderson *et al*, 1971), is observed to be forming from volcanic glass in sand fractions of

Alberta bentonites; however, this cristobalite also is intermixed intimately with montmorillonite and the combination probably is an intermediate product between volcanic glass and montmorillonite. Another example of this diagenetic alteration is present in the Section 31 Rosalind deposit where the low silt, high clay relationship in Bottom Bed clays changes progressively through Green and Arrowhead clays to the high silt, low clay relationhip of Grey clay. This suggests that clay content is increasing by diagenetic processes which alter sand- and silt-sized volcanic glass to montmorillonite. The combination of small changes in the amount of quartz and plagioclase crystallized from an igneous melt, and subsequent small changes in diagenetic alteration of the volcanic glass could be sufficient to cause the differences obtained in mechanical analyses of the different deposits.

The origin and distribution of Na, Ca + Mg and Fe are difficult to explain because diagenesis of volcanic glass or adsorption from groundwater at a later stage could provide these cations to the clays, and there is little evidence to show a preference for either mechanism in any bentonite deposit in Alberta. Williams ***et al,*** (1953b) suggest that iron starts as exchangeable Fe^{+2}, oxidizes to Fe^{+3}, then hydrolyzes to hydrous ferric oxide which is irreversibly removed near the outcrop as overburden thickness decreases. Exchange sites left vacant by iron removal can be filled by Na and Ca, but Ca also can be removed as gypsum or calcite which would then leave Na as the most abundant exchangeable cation, as in fact it is in most Alberta bentonites.

Suspension Properties

Swelling of montmorillonite was shown to be unrelated to CEC (Foster, 1953, 1955). Also, swelling was shown to decrease with increasing octahedral substitution, but to increase markedly with oxidation of Fe in the octahedral position. Davidtz and Low (1970) agreed that ion substitution is important, but also believe that oxidation of Fe decreases the b-dimension of the crystal lattice and, as the silica tetrahedra rotate and adjust to the altered dimensions of the octahedral layer, the water structure attached to the tetrahedra also changes. With the net loss in free energy resulting from the adjustments, the montmorillonite absorbs water and swells.

Exchangeable cations also can affect the configuration of the montmorillonite lattice and swelling capacity (Ravina and Low, 1972). Montmorillonites with Ca as the exchangeable cation give lower yield values than those of equal particle size with Na as the exchangeable cation (Mungan and Jessen, 1963).

Multiple regression analysis in this study shows that total clay content is the only independent variable of seven variables considered that has a significant relationship with yield, the dependent variable. When considered simultaneously with total clay content, the six other independent variables account for <10 percent of the total variation in yield. Total clay content as the most effective variable appears contrary to the results of Scafe (1973) who found that the $<0.2\,\mu m$ clay fraction is the most important independent variable in the Rosalind deposit, where Bottom Bed clay has the greatest amount of $<0.2\,\mu m$ material and the greatest yield, and Grey clay has the least amount of $<0.2\,\mu m$ material and the lowest yield. Arrowhead and section 19 clays have intermediate contents of $<0.2\,\mu m$ material and intermediate yields.

When the factors determining yield are considered it is possible for $<0.2\,\mu m$ material to be replaced by total clay content as the most important variable when yields <60 bbl/T are included in the multiple regression. Yield is calculated from a measured property, apparent viscosity, which results from mechanical friction between solid particles in the mud, friction between solids and liquid, attractive and repulsive forces among clay particles, and shearing of the liquid itself. As total clay content decreases, yield decreases (Fig. 8) and, as $<0.2\,\mu m$ content decreases, yield decreases (Fig. 9); but $<0.2\,\mu m$ content probably becomes less effective when its concentration is reduced because factors such as exchangeable cations and iron oxidation have sufficient influence on this smaller clay size to change the interaction of clay particles among themselves and with the liquid, and thus cause the scatter of points in figure 9.

CONCLUSIONS

Production of high-swelling bentonite in Alberta probably will remain limited to deposits presently being mined because thick overburden, high clastic content, or low yields debase the quality of other deposits. Mineralogy of sand and silt fractions suggests rhyodacite as the parent volcanic ash for Alberta bentonites, but mechanical analyses and microscopic observations suggest that mineralogy and diagenetic alteration varied considerably within and between deposits. Clay content appears to be related to the amount of sand- and silt-sized volcanic glass which is altering to montmorillonite. Multiple regression analysis shows that clay content is the only variable of the seven independent variables considered that has a significant relationship with the dependent variable yield.

REFERENCES CITED

AMERICAN PETROLEUM INSTITUTE (1969a): API specifications for oil-well drilling-fluid materials; API Std 13A. Am. Petroleum Inst., Div. Production, Dallas, 12 pages.

________ (1969b): Standard procedure for testing drilling fluids; API RP 13B. Am. Petroleum Inst., Div. Production, Dallas, 19 pages.

BABET, P. H. (1966): Some characteristics of bentonite in Alberta; Res. Coun. Alberta Rept. 66-2, 25 pages.

DAVIDTZ, J. C. and P. F. LOW (1970): Relation between crystal lattice configuration and swelling of montmorillonites; Clays and Clay Minerals, Vol. 18, p. 325-332.

FOSTER, M. D. (1953): Geochemical studies of clay minerals – II. Relations between ionic substitution and swelling in montmorillonite; Am. Mineralogist, Vol. 38, p. 994-1006.

________ (1955): The relation between composition and swelling in clays; Clays and Clay Minerals, Vol. 3, p. 205-220. (Nat. Acad. Sci. – Nat. Res. Coun. Pub. 395)

GILLERY, F. H. (1959): Adsorption-desorption characteristics of synthetic montmorillonoids in humid atmospheres; Am. Mineralogist, Vol. 44, p. 806-818.

GIVEN, M. M. and J. H. WALL (1971): Microfauna from the Upper Cretaceous Bearpaw Formation of south-central Alberta; Bull. Can. Petroleum Geol., Vol. 19, p. 504-546.

GOODYEAR, J. and W. J. DUFFIN (1954): The identification and determination of plagioclase feldspars by the X-ray powder method; Min. Mag., Vol. 30, p. 306-326.

HENDERSON, J. H., M. L. JACKSON, J. K. SYERS, R. N. CLAYTON and R. W. REX (1971): Cristobalite authigenic origin in relation to montmorillonite and quartz origin in bentonite; Clays and Clay Minerals, Vol. 19, p. 229-238.

JACKSON, M. L., L. D. WHITTIG and R. P. PENNINGTON (1950): Segregation procedure for the mineralogical analysis of soils; Soil Sci. Soc. Am. Proc., Vol. 14, p. 77-81.

LERBEKMO, J. F. (1968): Chemical and modal analyses of some Upper Cretaceous and Paleocene bentonites from western Alberta; Can. Jour. Earth Sci., Vol. 5, p. 1505-1511.

MUNGAN, N. and F. W. JESSEN (1963): Studies in fractionated montmorillonite suspensions; Clays and Clay Minerals, Vol. 11, p. 283-294 (Pergamon Press, New York).

RAVINA, I. and P. F. LOW (1972): Relation between swelling water properties and b-dimension in montmorillonite-water systems; Clays and Clay Minerals, Vol. 20, p. 109-123.

ROCK-COLOR CHART COMMITTEE (1963): Rock-Color Chart; Geol. Soc. Am., New York.

SCAFE, D. W. (1973): Bentonite characteristics from deposits near Rosalind, Alberta; Clays and Clay Minerals, Vol. 21, p. 437-450.

SNEDECOR, G. W. (1956): Statistical Methods; Iowa State College Press, Ames, 593 pages.

TANNER, C. B. and M. L. JACKSON (1948): Nomographs of sedimentation times for soil particles under gravity or centrifugal acceleration; Soil Sci. Soc. Am. Proc., Vol. 12, p. 60-65.

WILLIAMS, F. J., M. NEZNAYKO and D. J. WEINTRITT (1953a): The effect of exchangeable bases on the colloidal properties of bentonite; Jour. Phys. Chem., Vol. 57, p. 6-10.

WILLIAMS, F. J., B. C. ELSLEY and D. J. WEINTRITT (1953b): The variations of Wyoming bentonite beds as a function of the overburden; Clays and Clay Minerals, Vol. 7, p. 141-151 (Pergamon Press, New York).