

BENTONITE
ALBERTA MINERAL COMMODITY PROFILE

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FOREWORD

Alberta Mineral Commodity Profiles is a series of resource analysis synopses on non-hydrocarbon mineral commodities found in Alberta. Each profile presents a review and evaluation of an individual mineral, in a standardized capsule format, addressing the broad headings of *Industry Setting, Geology and Resources, Mining/Mineral Technology, Economic Factors, Industry Operating Factors, Strategic Considerations, and Outlook*. It serves as a technical sourcebook for the mineral, and as a guide in the formulation of research and exploration programs.

This second report in the series profiles the commodity bentonite, a mineral with a history of past production in Alberta and potential importance for future production.

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INTRODUCTION

BACKGROUND

Bentonite is a type of clay deposit formed by the devitrification and alteration of volcanic ash and glass, and is common in the Cretaceous and Paleocene sediments underlying much of the Alberta Plains and Foothills (Scafe, 1975). However, the known locations of bentonite deposits of acceptable grades and mineable volumes are limited in Alberta.

Primary uses in Canada, including Alberta, are for iron ore pelletizing, bonding foundry sand, oil well drilling, agricultural/chemical carriers, and geotechnical barriers. These markets have been supplemented recently by high added value, low tonnage products. Requirements for all of these products are met mostly by imports, mainly from the United States (U.S.A.).

This report examines the possibilities of resuming and expanding production from past producers, of identifying opportunities to replace imports for the primary markets, and of determining potential for production of value-added products that would attract industries to the Province.

DEFINITION OF TERMS

The term *bentonite* was first used to describe clay material present in the Benton Formation of Cretaceous age which is named after Fort Benton, Montana, located approximately 650 km north of the first bentonite mine.

Subsequently, a number of definitions have been used for bentonite based on mineralogy, origin, or end use. For industrial minerals the following definition is useful:

A clay consisting essentially of minerals of the smectite clay mineral group (mainly

sodium montmorillonite), whose physical properties are dictated by the dominant mineral, regardless of mode of origin and occurrence.

Clay material with a capacity to decolorize and purify oil to commercial grade is also composed of smectite clay minerals, but the dominant mineral is *calcium montmorillonite* and its proper nomenclature is Fullers' Earth.

Table 1 summarizes the terms and the regional nomenclature.

Table 1. Bentonite nomenclature (Industrial Minerals, October, 1982)

Dominant Mineral	Synonymous Terms	Regional Terms
SMECTITE GROUP:		
Sodium Montmorillonite	Sodium bentonite	Wyoming bentonite (U.S.A.)
	Swelling bentonite	Western bentonite (U.S.A.)
	Sodium-activated bentonite	Bentonite (U.K.)
Calcium Montmorillonite	Calcium bentonite	Southern bentonite (U.S.A.)
	Sub-bentonite	Texas bentonite (U.S.A.)
	Non-swelling bentonite	Fullers' earth (U.K.)
HORMITE* GROUP:		
Attapulgite	Palygorskite Mountain wool, leather, etc.	Fullers' earth (U.S.A.)
Sepiolite	Mountain wool, leather, etc. Meerschaum	Fullers' earth (U.S.A.)

* fibrous or chain structure rather than layered structure of smectite

Other bentonite terms and types not included in the above table include:

Acid-activated Bentonite: usually high calcium bentonite that has been reacted with acid to enhance sorptive properties.

Organophilic Bentonite or Organoclay: usually high sodium bentonite treated with cationic organic materials to create special properties.

White Bentonite: a high brightness and white calcium bentonite.

Sub-bentonite: a term used inconsistently for low or moderate swelling varieties of bentonite.

Metabentonite: a term used to describe altered material composed of volcanic ash, with later potassium addition, that changed the clay minerals to illite-smectite mixed layer clay minerals.

Volcanic Clay, Soap Clay, Mineral Soap, Bleaching and Absorbent Clays/Earths are loosely used, synonymous terms for bentonite.

PHYSICAL CHARACTERISTICS OF BENTONITE

The three main characteristics of bentonite that make it commercially useful are thixotropy, swelling, and adsorption. Thixotropy is the property of a bentonite-water slurry that allows it to act as a liquid under shear stress but which sets it into a gel upon removal of the stress. The smectite minerals of bentonite swell to several times their original volume in water by hydration of the clay lattice. When the water is removed, the clay lattice assumes its original spacing. The adsorption of exchangeable metallic ions by the clay lattice alters some of the properties of the clay.

Montmorillonite, like other clay minerals, is a hydrous aluminum silicate. The primary elements of its composition are silicon, aluminum, oxygen or hydroxyls. The molecular structure of montmorillonite consists of a unit cell described as a "Si-Al-Si" structure.

The "Si" or "silica layer" is a layer of tetrahedrons made up of silica-oxygen (A in

Figure 1). The silicon atom, at the centre of a tetrahedron, is equidistant from four oxygens or hydroxyls. The tetrahedrons form a hexagonal network that is repeated indefinitely to form sheets with the composition $\text{Si}_4\text{O}_6(\text{OH})_4$ as shown in Figure 2. In the "Al" or "gibbsite layer" the aluminum-hydroxyls form a layer of octahedral structure (B in Figure 1). The aluminum is embedded at the centre of an octahedron formed by six oxygens or hydroxyls. The repeated octahedra form a sheet between the silica layers, sharing the oxygen-hydroxyl atoms as shown in Figure 3. The composition of the gibbsite layer is $\text{Al}_2(\text{OH})_6$.

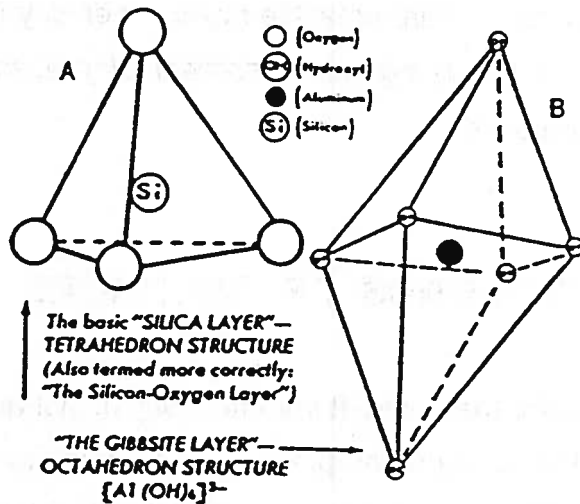
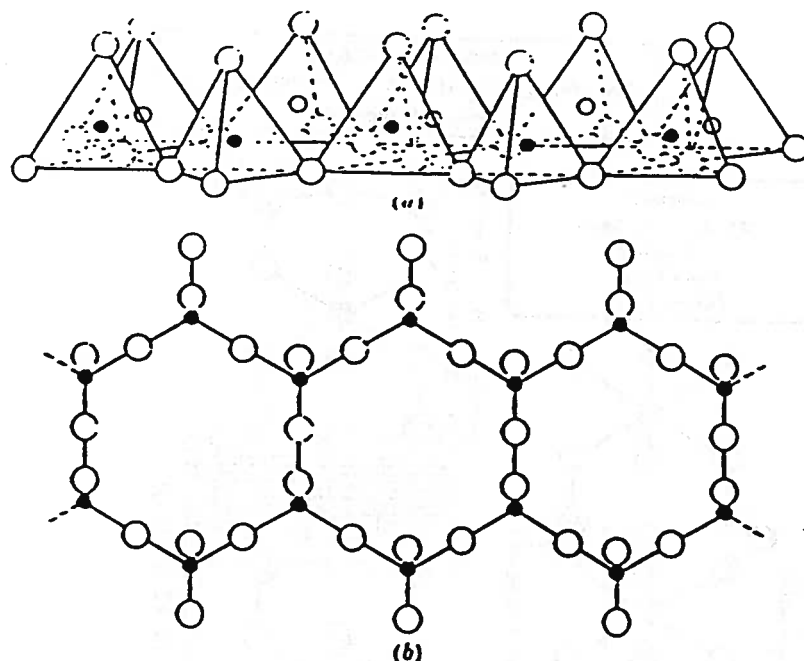


Figure 1. Tetrahedrons (A) and octahedrons (B) are the fundamental components of the silica and gibbsite layers respectively.

The changes in the geometry of these layers create ion exchange properties in the montmorillonites, which contribute towards their fundamental physical properties and are responsible for the three characteristics of bentonite.

Part of the aluminum in the central "Al" layer of montmorillonite is commonly substituted by magnesium and/or iron. The generally accepted unit (ionic) formula of sodium montmorillonite is: $[(\text{Al},\text{Fe})_{1.67}\text{Mg}_{0.33}]\text{Si}_4\text{O}_{10}(\text{OH})_2(\text{Na},\text{Ca}_{0.33})$.

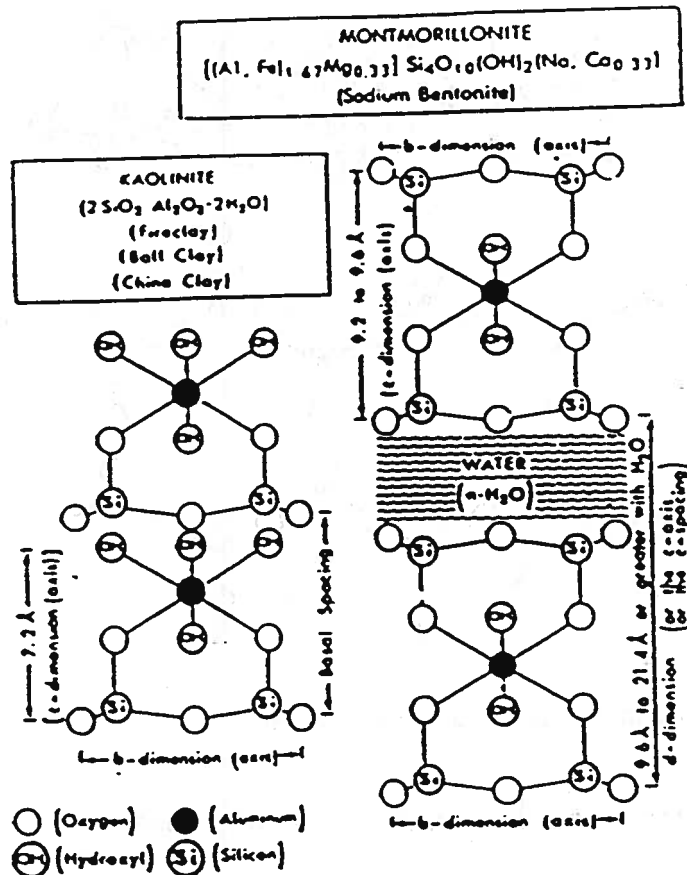


Double chains of silica tetrahedra.

Figure 2. Sheet forming hexagonal network of tetrahedrons.

To balance the anionic charge of the $O_{10}(OH)_2$ the total of the actual positive charges in the unit formula should be 22. The imbalance of the positive charge can be due to the replacement of some of the trivalent aluminum by divalent magnesium and/or iron. One out of every six aluminum-hydroxyl units in the "Al" sheet of commercial bentonite is replaced by magnesium-hydroxyl. The imbalance of positive charge also can be partly due to the replacement of tetravalent silicon by trivalent aluminum in the "Si" sheet of montmorillonite. The electrical neutrality is maintained by other cations external to the lattice, these relatively easily exchangeable cations giving the characteristic high cation exchange capacity when dispersed in water.

A particle of montmorillonite is made up of parallel layers of "Si-Al-Si" units like a deck of playing cards. In Figure 3, the negative charges of silicon-oxygen sheets of adjoining "Si-Al-Si" layers cause a repulsion that forces the sheets apart and allows a layer of water to be chemically bonded by electromotive forces. A "domain" structure is



THE SIMPLIFIED DIMENSIONAL CLAY STRUCTURES

Figure 3. Aluminum in the gibbsite layer shares oxygens with the silica of the silica layer.

a packet of these superimposed flakes, with this layer of water molecules present between the flakes even when the material is air dried.

Swelling of bentonite is caused by water molecules crowding between the flakes and forcing the flakes apart. In addition, this water binds the layers together with increasing force. When the water is removed the mass contracts, due to flakes resuming their original spacing, like an accordion. Organic matter also can be absorbed in mono-molecular layers between adjacent silicon-oxygen sheets.

The relatively high ratio of width to thickness of flake units of montmorillonite provides tremendously greater surface area than in clays like kaolinite. This large surface area relative to mass is responsible for the increased colloidal activity of montmorillonite.

Table 2. Molecular structure, main characteristics and uses of bentonite

Molecular Structure	Characteristics	Examples of Uses
Large surface area	Thixotropy	Suspending agent Thickener
	Colloidal dispersion	Binder - Carrier Lubricating agent Bonding clay
Hydration of lattice	Swelling	Sealant Binder Bonding clay Plasticizer
Substitution of ions	Adsorption Cation exchange capacity	Clarification, purification of: Organic liquids Process waste water

BENTONITE IDENTIFICATION TECHNIQUES

For precise identification, techniques like X-ray analysis, differential thermal analysis, and chemical analysis are used. These are not usually performed on a routine basis. Tests for material characterizations, product testing and process research include those that directly determine the property or properties employed in the use of bentonite, and commonly include one or more of the techniques listed in Table 3.

Table 3. Laboratory methods for identification and evaluation of bentonite (from Andrews, 1992).

Technique or Method	
1. Mineralogical	14. Plastic Viscosity
2. X-ray Methods	15. Yield
3. Chemical Analysis	16. Yield Value
4. Drying	17. Gel Strength
5. Moisture	18. Wall Building
6. Differential Thermal Analysis	19. Hydrogen Ion Concentration
7. Particle Size Distribution	20. Liquid Limit
8. Sand Content	21. Compressive, Shear and Tensile Strength, and Deformation (Foundry)
9. Surface Area	
10. Swelling	22. Iron Ore Pellet Strength Tests
11. Colloidal Content	23. Decolorization
12. Rate of Stabilization	24. Cation Exchange Capacity
13. Apparent Viscosity	

APPLICATIONS OF BENTONITE

Table 4 lists the main applications and the high value-added, low tonnage applications of bentonite. In addition to the naturally active sodium and calcium bentonites of Table 1, several other types of processed and value-added bentonites are included.

Table 4. Major areas of application for bentonites (from Industrial Clays, 1989):

		Crude bentonite			
		Activated with acid (activated bleaching earth)	Naturally active (Na/Ca-bentonite)	Alkaline activated (Na-exchanged bentonite)	Organically activated (organophilic bentonite)
Foodstuffs industry	Refining, decolorising, purifying and stabilising of vegetable and animal oils and fats				
Sulphur production	Refining, decolorising, bitumen extraction				
Forest and water conservation	Powder fire-extinguishing agents/binding agents for oil on water				
Mineral-oil industry	Refining, decolorising and purifying of mineral oils, fats, waxes, paraffin/catalysts for oil cracking				Grease thickening
Beverages and sugar industry	Fining of wine, must and juices/beer stabilisation/purifying of saccharine juice and syrup				
Chemical industry	Catalysts/catalyst carriers, insecticides and fungicides/fillers, dehydrating agents/water and waste-water purification/adsorbents for radioactive materials				
Paper industry	Pigment and colour developer for carbonless copying paper/adsorption of impurities in white water system				
Cleaning and detergents	Regeneration or organic fluids for dry cleaning	Polishes and dressings/additives for washing and cleaning agents and for soap production			
Pharmaceutical industry	Starting material for healing earths and medicaments/bases for creams and cosmetics				
Ore production	Binding agents for ore pelletising				
Building industry	Supporting suspensions for cut-off diaphragm wall constructions and shield tunnelling/subsoil sealing (eg dumps)/anti-friction agents for pipejacking and shaft sinking/additive for soil concrete, concrete and mortar				
Ceramics industry	Plasticising of ceramic compounds/improvement of strength/fluxing agents				
Horticulture, agriculture, animal husbandry	Soil improvement/composting/animal-feed pelletising/liquid-manure treatment/cat litter				
Drilling industry	Borehole scavenging for saltwater	Thixotropic suspensions for borehole scavenging			
Tar exploitation	Emulsification and thixotroping of tar-water emulsions, tar and asphalt coatings				
Paint and varnish industry	Thickening, thixotroping, stabilising and anti-setting agents for paints, varnishes, coating materials, sealing cements, waxes, adhesives				
Foundries	Building agents for special moulding sands	Binding agents for synthetic moulding sands, core sands	Binding agents for anhydrous casting sands/for thickening blackwashes		

GRADES AND SPECIFICATIONS

Most bentonites are evaluated on the basis of the following tests:

Yield: is the number of tons of mud produced per ton of bentonite as specified by American Petroleum Institute (API) Specification 13A, section 4, Table 4.1.

Swelling: is the percentage volume increment exhibited by 2.5 g of bentonite in 100 ml of water calculated to 100 g.

Cation Exchange Capacity: is determined by using ASTM standard test method #C837 - 81 for Methylene Blue Index of Clay. In some uses, the exchangeable metallic bases are determined by leaching with ammonium acetate.

Percentage Moisture: is the moisture determined at point of manufacture using method in API Specification 13A, sections 4.8, 4.9.

Percentage Grit: for drilling muds and high grade products that use drilling mud specifications, is defined and the method of measurement described in API Recommended Practice, Standard Procedure for Field Testing Drill Fluids, Section 5. However, for most uses the weight percent over 200 mesh size is reported.

Percentage Fines: generally are reported by dry sieve analysis as percentage through 200 mesh size. However, in some applications a wet sieve analysis report includes percent finer than 200 mesh, and finer than 20 and 0.5 μm . Other sizes can be specified as needed.

pH and Bulk Density: are measured by standard laboratory procedures.

Thermal Durability: is evaluated for foundry use and involves heating to 540°C and remeasuring the cation exchange capacity. The percentage of clay activity retained is the thermal durability.

Sorptive Capacity: is the ability to take on organic chemicals by absorption and adsorption, and is measured by determining the amount of trichloroethylene required to saturate the clay using standard procedure.

Liquid Holding Capacity: is reported as %L.H.C. = grams solvent to saturation / grams solvent to saturation + 100g of clay x 100.

Hardness: is measured by shaking 100g for 15 minutes over 100 mesh screen, and reported as Attrition loss % = weight passing 100mesh / 100g x 100.

BENTONITE GRADES

The term *grade* here does not necessarily refer to the run of mine grade, but to the physical-chemical characteristics of the product(s) from the main types of bentonite designated in Table 4.

Grades for Naturally Active Sodium Bentonite from Wyoming (from American Colloid Company):

Chemical Analysis:

	<u>% by Weight</u>
SiO ₂	58.0 to 64.0
Al ₂ O ₃	18.0 to 21.0
Fe ₂ O ₃	2.5 to 2.8
MgO	2.5 to 3.2
CaO	0.1 to 1.0

Na ₂ O	1.5 to 2.7
K ₂ O	0.2 to 0.4
FeO	0.2 to 0.4
TiO ₂	0.1 to 0.2
Minor constituents	0.5 to 0.8
Chemically held water	5.64
Mechanically held water	0.00

Particle Size:

Dispersed in water

96 to 97% < 44 μm

93 to 94% < 5 μm

87 to 89% < 0.5 μm

60 to 65% < 0.1 μm

Specific Gravity:

2.7, pH of water suspensions 8.5 to 10

Exchangeable Metallic Bases:

	<u>meq/100 g</u>
Sodium	60 to 65
Calcium	15 to 20
Magnesium	5 to 10
Potassium	1 to 5
Total after correction for sulphates (non-exchangeable ions)	85 to 90

Swelling and Sorption:

Depends on particle size. Faster when bentonite is poured into water. Absorbs nearly 5 times its weight in water and, at full saturation, occupies 12 to 15 times its dry

volume. On drying, it shrinks to the original volume.

In suspension, the expanded sheets allow adsorption (and perhaps absorption) of a number of inorganic and organic materials.

Between 204°C and 660°C the chemically held water is lost. Loss of chemically held water reduces the swelling properties.

Viscosity:

Addition of 7 to 10 parts water forms a gel; with 15 to 20 parts water it forms milky, flowable sols. Viscosity is 8 to 25 centipoise with 15 parts water, and 3 to 8 centipoise with 19 parts water. With 6% or more clay, the viscosity of a slurry is increased with addition of electrolytes.

Bond Strength:

When moistened with 50% by weight of water the clay has maximum adherent powers with other minerals.

Mechanically Held Water:

The clay gains or loses moisture to the atmosphere depending on the humidity. To dry to a moisture free condition requires 2 hours of heating at 105°C to 110°C.

Bulk Density:

865 k/m³

Grades for Naturally Active Calcium Bentonite: the following specifications are from (#1) a composite sample of non-swelling bentonite beds from the Pembina Mountain Clays Limited deposit, near Mowbray, Manitoba; (#2) an activated bleaching clay produced by Filtrol Corporation in California; and (#3) a clay from Panther Creek, Mississippi, produced by American Colloid Company and used mainly in foundries. The sample collection and analyses are reported by Bannatyne (1963).

Chemical Analysis:

	<u>Weight %</u>		
	<u>#1</u>	<u>#2</u>	<u>#3</u>
SiO ₂	63.72	66.05	66.05
Al ₂ O ₃	19.86	13.06	13.13
Total Fe	1.42	1.55	5.45
MgO	4.6	3.79	1.57
CaO	0.16	2.88	0.58
Na ₂ O	0.77	0.10	0.09
K ₂ O	0.26	0.20	1.40
TiO ₂	0.52	0.23	0.70
MnO	0.12		
S as SO ₃	0.62	3.54	0.17
LOI 110°C to 925°C	8.09	11.55	8.73
H ₂ O below 110°C	10.75	12.87	3.74
H ₂ O 110°C to 925°C	6.91	9.55	7.62

Screen Analyses:

	<u>% retained</u>			
	<u>+100 mesh</u>	<u>100 + 150 mesh</u>	<u>150 + 200 mesh</u>	<u>200 mesh</u>
#1	0.1	1.1	5.0	93.8
#2	0.7	2.5	3.3	93.5
#3	8.1	12.7	13.7	65.5

Bulk Density:

#1	0.59 g/cm ³
#2	0.45 g/cm ³
#3	0.43 g/cm ³

pH:

#1	4.3
#3	5.4

Light Reflectivity for use as a Filler:

Standard magnesium carbonate	100.0%
#1	84.0%
#3	53.5%
Volclay (Na bentonite, Wyoming)	69.0%

Bleaching Property:

Bleaching action is compared by measuring light reflectivity before and after acid activation with 10% sulphuric acid. Also, iron as Fe₂O₃ before and after activation is determined. Filtering rate is another important criterion for evaluation. Transmittance of light through stock motor lubricating oil before and after decolorizing is determined with a Bausch & Lomb Spectronic 20 colorimeter.

	<u>Filtering time</u>	<u>Transmittance</u>	<u>Light reflectivity</u>	<u>Total % Fe</u>
#1 (before)	-	-	84%	1.42
#1 (after)	1 hour, 2.0 min.	92%	83.5%	0.96

Grades for Alkaline (Sodium) Activated Bentonite from Saskatchewan (from Avonlea Mineral Industries): these specifications are from Avonlea Mineral Industries Ltd. which operated in Wilcox, Saskatchewan until 1990. Currently the plant is operated by Canadian Clay Products. It is not known if the current processing and product specifications are the same as reported here.

The quarried materials at Avonlea were treated with soda ash (0.5 to 0.7%) during drying on pads. Up to one month of aging was required prior to further processing. This partial alkaline activation increases the sodium to calcium ratio.

Chemical Analysis:

	<u>% by weight</u>
SiO ₂	65.9
Al ₂ O ₃	17.6
Fe ₂ O ₃	4.1
MgO	2.4
CaO	1.3
Na ₂ O	2.3
K ₂ O	0.3
FeO	0.2
TiO ₂	0.2
Loss on ignition	5.7

Moisture:

7 to 9%

Particle Size:

Dispersed in water

80 to 90% <200 mesh.

Swelling:

650 to 850 units (calculated to 100 g from 2.5 g/100 ml)

Grit:

0.2 to 0.4 > 200 mesh

Cation Exchange Capacity:

by Methylene Blue Titration: 80 to 90 meq/100g

pH:

8.0 to 9.0

Specific Gravity:

2.5

Bulk Density:

800 kg/m³

Grades for Organically Activated Bentonite from India (from Cutch Oil & Allied Industries (1949) Pvt. Ltd.): bentonite is an effective gellant for water systems, but is not effective in gelling organic liquids. In 1941 the Baroid Division of NL Industries Inc. began research and development of *organoclays* that are effective gellants for organic liquids. The exchange sites on the basal planar surfaces in bentonite are neutralized with inorganic cations (e.g. sodium). These cations are then exchanged for organic cations (e.g. long chained quaternary ammonium compounds) to produce an organophilic compound.

Cutch Oil produces an organoclay called SMECTONE using highly purified montmorillonite from its Indian production. It is used as a gel thickener and antissettling agent for the grease, paint and oil-well drilling industries, and has applications in printing ink and cosmetics. Quite small quantities are required in these applications.

Typical Properties of SMECTONE:

Form	Finely divided powder
Color	Creamy white
Particle size	95% < 200 mesh (BSS)

Odor	Slight to none
Moisture content	3.5% maximum
Specific gravity	1.7 g/ml
Bulk density	425 kg/m ³
Loss on ignition	41%
Arsenic content	8 ppm
Lead content	8 ppm

Wide range of thermal stability.

Resistant to the action of acids and alkalis between pH 4 to 10.

Non-hygroscopic, safe to handle, chemically inert, long storage life.

BENTONITE SPECIFICATIONS

The term *specifications* refers to the properties specified by the users of the products listed in the first (left hand side) column of Table 4.

There is a general absence of universally accepted procedures and specifications for bentonite. This is partly because of the widely varying properties of the clays, but the main reason is that purchasers have outlined many different specifications for many uses. For the principal uses, however, organizations with the help of industry have established specifications that have wide applications, and these are summarized in Table 5.

Table 5. Summary of common bentonite specifications.

Drilling fluids (American Petroleum Institute Specification 13A, October, 1988):

Yield	> 91 bbl/tonne
Yield point	6 : 1
C.E.C.	N/A
Particle size	>98% -75 µm

Moisture	<10% @ 90°C
Sand content	max. 2.5% +75 µm by wet screening
Apparent viscosity	15 centipoise for 6.5g clay in 100 ml fluid
Plastic viscosity	8 centipoise for 10 g bentonite in 350 ml of water
Gel strength (Stormer)	>5 g initial, >40g after 10 min.
pH	>6, and in some >12
Wall building	<15 ml filtrate, 30 min at 650 kPa

Foundry sand (Steel Founders' Society of America Spec. 13&T-86):

Moisture	6 to 12%
(maintains efficient high-strength bond at 1600°C metal casting)	
pH	>8.2
CaO (thermal durability)	< 0.70%
Liquid limit	600 to 850 (ability to hold water without flowing and expansion)
Particle size	90-95%, <75 µm
Produce sand/bentonite molds with:	
Green compressive strength	58.7 kPa
Green deformation	2.5%
Green shear strength	17.3 kPa
Green tensile strength	10.3 kPa
Dry compressive strength	656 kPa

Iron ore pelletizing:

Particle size	80%, <75 µm
Moisture	6 to 8%
Yield	88 to 132 bbl/t
pH	minimum 8.0
Produce pellets of user specs.:	
Size	9.5 to 25 mm diam.
Proportion	0.6% bentonite, 10% moisture
Green drop number	5.00
Green compressive strength	82.8 kPa
Dry compressive strength	207 kPa
Fired compressive strength	1035 kPa
"Good" tumble index	85

Herbicide/pesticide, chemical carrier:

Particle size	>90%, 20 to 60 mesh 40 to 80 mesh
Moisture	< 3%
Sorptive capacity	user specified
Liquid holding capacity	user specified
Hardness	user specified

Pet Litter:

Liquid absorbency	high, user specified
Odor absorbency	high odor, users have specified test methods
Dust free	producer standards for % fines to meet user satisfaction
Particle size	user specified range uniformity required
Resistance to breakdown when wet	producer standards established to meet user requirements
Free from harmful forms of silica	user standards or legislation

Animal/Poultry Feed Binder:

Additives	nil
Trace elements	user specified, and legislation

Other specifications, mainly for specialty applications, are outlined below.

Specifications for Absorbent Granules – Floor Absorbents: most absorbent granules marketed are made to meet specifications in U.S. Federal Specification P-A-1056A, Absorbent Material, Oil and Water. These specifications require uniformity of mineral type, the granules to be clean, and free of lumps and foreign matter, and no more than 10% <80 mesh in the attrition resistance test.

Specifications for Bleaching Oils: test methods for evaluating bentonite (calcium bentonite) for bleaching soybean and cotton-seed oils are outlined in the American Oil

Chemists Society (AOCS) Official Method Cc8b-52, revised April 1952, and AOCS Official Method Cc8a-52, corrected 1958. These specifications include instructions on bench test specifics and require comparison with an official natural bleaching earth approved by AOCS. Most user purchase specifications are based on these tests and comparisons.

Specifications for Drinking Water, Process Water, and Waste Water Treatment: bentonite in these applications is used as a flocculating agent. Except for lack of additives in drinking and process water use, there are no industry established procedures for specifications of the bentonite. The bentonite grade and particle size must allow maximum colloidal suspension when added to the water/effluent streams. Some users have specific requirements, e.g., in stabilization of floc in water clarifiers.

Specifications for Refining Applications--Edible Oils, Fats, Industrial Oils, Soaps, Cosmetics, Pharmaceuticals, Catalysts, Paints: these applications are for the acid activated montmorillonite derived mainly from calcium bentonite. Acid activation enhances the properties of bentonite by manipulating its physical and chemical attributes without destroying the mineral's layered crystal structure. Variation in the type and degree of acid treatment yields different products with varying bleaching properties (Industrial Minerals, September, 1985). Also, the character of the original bentonite determines the product properties. Another variable is the particle size; in general, the finer the particle size the better the bleaching properties, except that fine particle size adversely affects filtration times and oil retention on filter cake.

Specifications for each use depend on not only the refining process, but also on the source of the materials, e.g., Brazilian soya beans require different specifications to achieve results similar to U.S. soya beans. Therefore, universally accepted specifications and procedures are not possible.

Specifications for Rheological Applications--Paint, Printing Ink, Grease Thickening,

Cosmetics: these modified sodium bentonites are used if viscosity and flow control properties need enhancement to give easier production, better storage stability, and improved performance during application and service. The products are supplied in the dry state as agglomerated platelet stacks. For use, dispersion and delamination are necessary. Physical energy is supplied by milling equipment, and chemical energy by additions of small amounts of alcohols (polar additives). These processes are expensive in time, energy and labour.

Not only does each industry, but each user system has its own specifications. For example, air drying paints require rheological properties which are different from those of industrial paints, high solid coatings or nail lacquers. Universally accepted specifications and procedures are not available.

INDUSTRY SETTING

In Table 6 the major world producers of bentonite in 1987 are listed. The United States of America is by far the largest producer. However, in 1991 the U.S.A. accounted for only 32% of the world's bentonite production (Mining Engineering, June 1992), compared to 60% in 1980 (Industrial Minerals, October 1982). Canada is not on the major producer list. Figure 4 shows the large number of bentonite and Fullers' earth districts in the U.S.A.

The statistics for bentonite production in the U.S.A. from 1987 to 1991 show an increase in mine production as indicated in Table 7. Bentonites in most applications constitute a small fraction of the final product. For example, it constitutes about 5% of the weight in well drilling fluids, up to 10% in foundry moulding sands, and about 0.5 to 0.8% in iron-ore pelletizing.

Analysis of the U.S. bentonite industry and marketplace from 1974 to 1989 by Wright (1992) for sodium bentonite provides a good review of the industry. Figure 5 shows that

Table 6. Major world producers of bentonite and Fullers' earth (from Industrial Clays, 1989)

<i>Country</i>	<i>1985</i>	<i>1986</i>	<i>1987</i>
USA			
Bentonite (a)	2,898,710	2,551,950	2,367,000 ^e
Fullers' earth (a,b)	1,868,149	1,732,703	1,774,000 ^e
Greece			
Bentonite	1,054,234	1,317,825	1,250,000 ^e
West Germany			
Bentonite	169,000	179,000	167,000
Fullers' earth	701,000	680,000	677,000
Spain			
Bentonite	90,239	114,972	na
Japan			
Bentonite	461,530	408,864	415,806
Italy			
Bentonite	299,272	305,622	313,094
Fullers' earth	30,400	30,960	30,660
India			
Bentonite	161,000	105,000	na
Fullers' earth	23,000	85,000	na
Brazil			
Bentonite	236,368	206,021	na
United Kingdom			
Fullers' earth (c)	216,000	202,000	202,000 ^e
Romania (c)			
Bentonite	180,000	185,000	185,000
Yugoslavia			
Bentonite	148,252	141,726	154,288
Hungary			
Bentonite	59,853	79,888	98,331
Poland			
Bentonite	85,200	94,200	88,600
Turkey			
Bentonite	42,040	62,367	85,548
Cyprus			
Bentonite	52,000	55,000	79,600
South Africa			
Bentonite	43,472	48,265	48,953
Morocco			
Bentonite	2,876	3,834	2,948
Fullers' earth (d)	24,425	35,100	46,271
World total			
Bentonite	6,620,000	6,270,000	6,110,000
World total			
Fullers' earth (f)	3,500,000	3,380,000	3,460,000

(a) Sold or used by producers; (b) Mostly attapulgite; (c) BGS estimates of saleable production based on data from producing companies; (d) Smectite; (e) Estimate; (f) Includes attapulgite and sepiolite; (na) Not available

Source: British Geological Survey

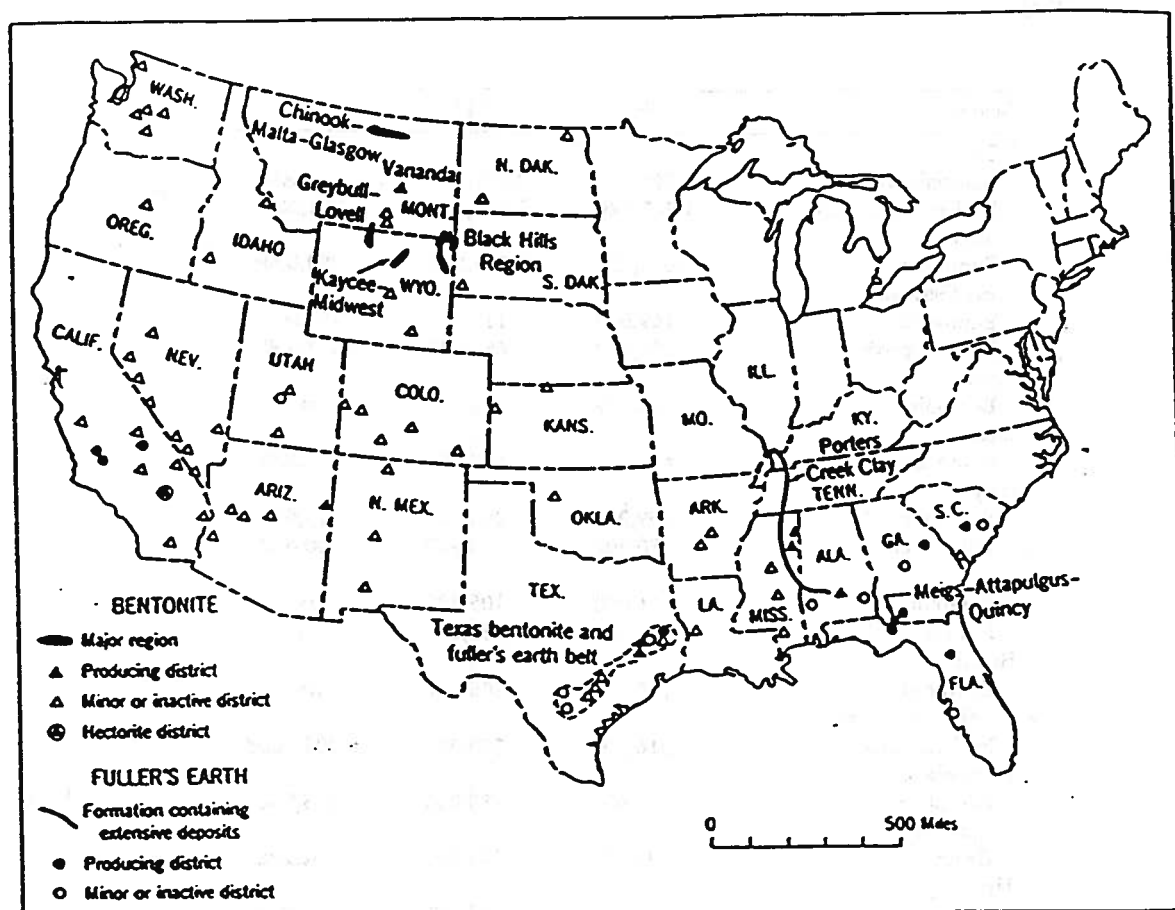


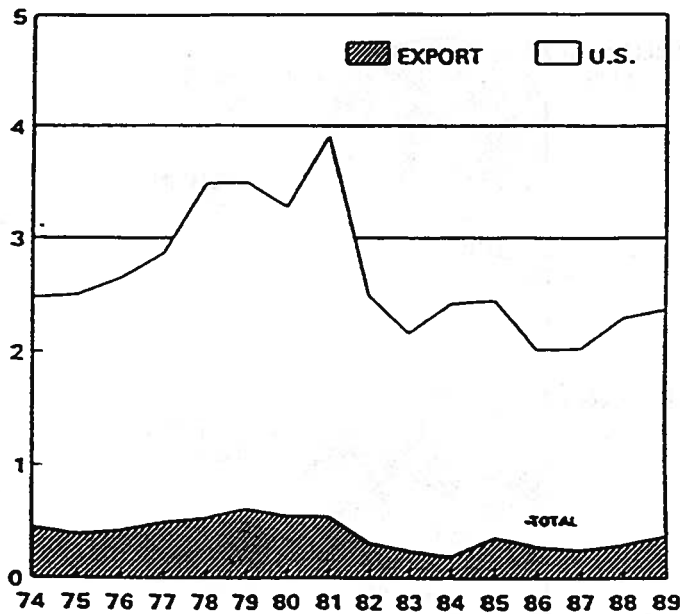
Figure 4. Bentonite and Fullers' earth districts in the United States.

total bentonite consumption ranged from a low of approximately 2 million tonnes in 1986 to a high of 3.8 million tonnes in 1981. During the late 1970s there was dramatic growth in bentonite consumption followed by a period of dramatic decline during the early 1980s, with relative market stability in the late 1980s.

The widest application of swelling and partly swelling sodium bentonite continues to be for three uses that include well drilling fluids, foundry metal casting, and pelletizing

Table 7. U.S. bentonite statistics (U.S.B.M. Mineral Commodity Summaries, 1992):

Mine Production	1987	1988	1989	1990	1991
Bentonite (000 tons)	2,546	2,871	3,112	3,474	3,519



Source: US Bureau of Mines, Department of Interior

Figure 5. U.S. and export bentonite consumption 1974-89 (from Wright, 1992)

animal feed and iron ore. In Figure 6 the division of consumption by use is shown in descending order for the late 1970s, early 1980s and late 1980s.

Historically, drilling fluids have been the largest market for bentonite, with the maximum at 55% in the early 1980s. The iron ore pelletizing industry's bentonite consumption decreased from 30% in the late 1970s to 15% in the late 1980s. Although world demand for iron ore is expected to increase by nearly 30% by the year 2000, much of the iron will not require pelletizing (Kalmakoff et al., 1991), and bentonite is being replaced by other binders. Metal casting consumption increased back to 25% in the late 1980s, mainly

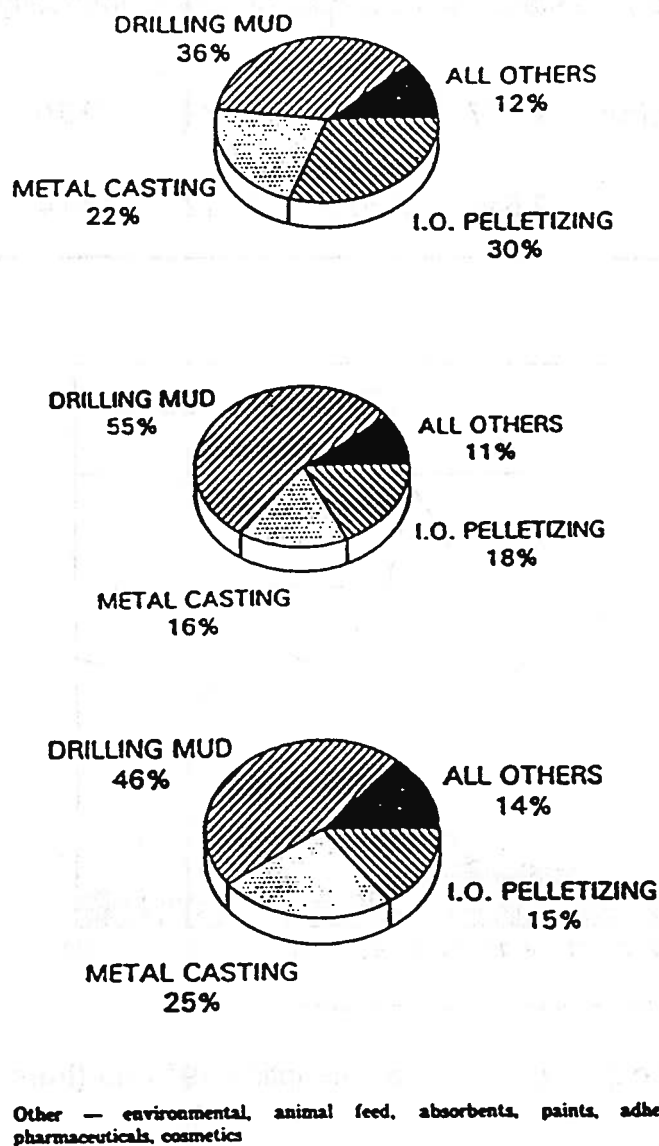


Figure 6. Bentonite, consumption by use (from Wright, 1992). *Top*, late 1970s; *middle*, early 1980s; *bottom*, late 1980s.

due to the increased ferrous metal casting in the automobile and construction sector. The trend toward replacement of ferrous metal by plastics and lighter metals will be compensated by the expected increase in bentonite demand in the foundry industry for use in the solidification of foundry wastes.

Three other market segments - which include geotechnical applications, agriculture-chemical applications and custom design applications, including environmental, animal feed, paints, pharmaceuticals and absorbents - represented 11 to 14% of total market consumption between 1974 and 1989.

Historically, export markets have averaged 15% of the U.S. total consumption. Figure 7 shows that in the early 1980s (middle) the drilling mud consumption also increased dramatically as in the U.S.A., compared to the late 1970s (top) and late 1980s (bottom). The metal casting industry was the primary export market for U.S. bentonite between 1974 and 1989, and the "all other" category in Figure 7 is predominantly for iron ore pelletizing.

CANADIAN PRODUCTION AND CONSUMPTION

Exact figures on Canadian bentonite production are confidential. Statistics available for 1984 to 1987 (Table 8) indicate an increase in production over the period, and according to Kalmakoff et al. (1991) production in 1990 was estimated at 90,000 tonnes. In 1993, however, the only producer of bentonite in Canada was Canadian Clay Products Limited from its plant in Wilcox, Saskatchewan, and Canadian production possibly has decreased considerably. Kalmakoff et al. (1991) indicate production capacity at Wilcox of 60,000 tpa. Currently, much of the bentonite processed at this plant comes from M.I. Fluids of Alberta and Pembina Mountain Clays of Manitoba.

In 1991 and 1992 the principal consumption, in order of importance in Canada, was still pelletizing, foundry metal casting, and oilwell drilling (Andrews, personal communication). According to Kalmakoff et al. (1991), the 1990 total consumption was near 300,000 t, and in 1991 the civil engineering market for bentonite was expected to exceed 200,000 t in Canada. In addition, 6% or more growth rates in bentonite consumption for absorbent and pet litter markets is anticipated through the year 2000. Use of non-swelling bentonite in refining food oils is growing in Canada.

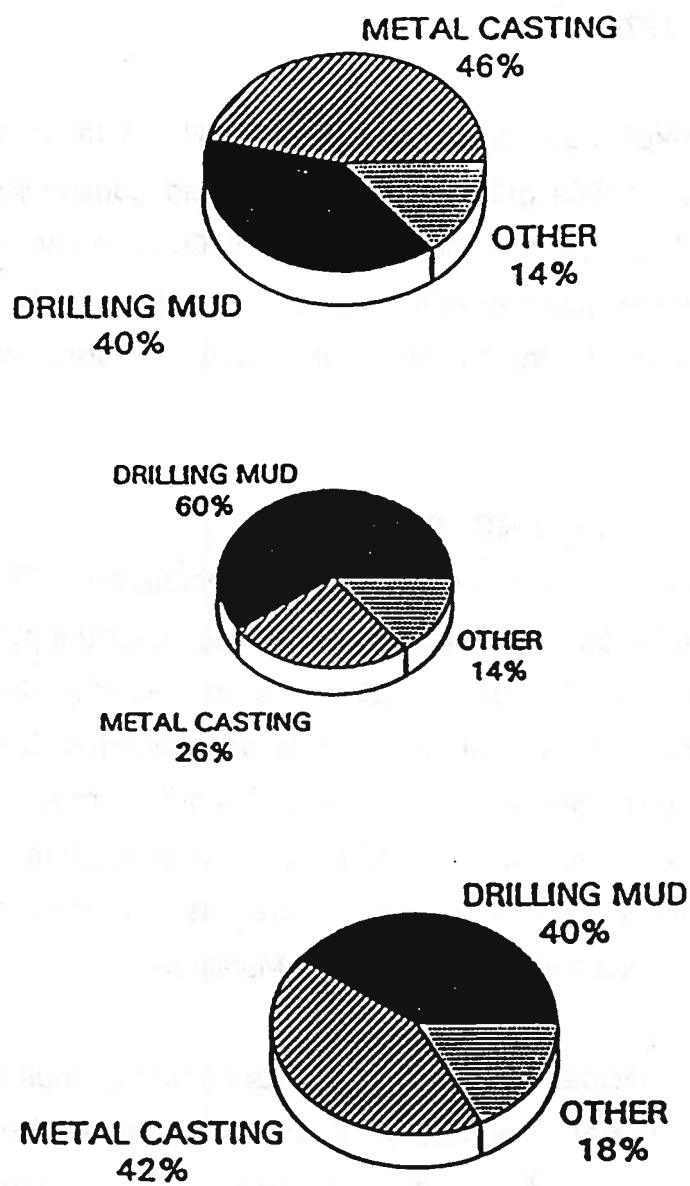


Figure 7. Export consumption by use (from Wright, 1992). *Top*, late 1970s; *middle*, early 1980s; *bottom*, late 1980s.

Table 8. Canadian bentonite production 1984-1987 (from Canadian Minerals Yearbook, 1987)

	1984	1985	1986	1987 Jan-Sept
Production (t)	66,639	65,129	72,026	88,347
(\$ 000)	-----	-----	709	1,151

Table 9 lists Canadian bentonite consumption based on use from the latest available statistics.

Table 9. Canadian bentonite consumption¹ 1982 - 1987 (from Canadian Minerals Yearbook, 1987)

	1982 (t)	1983 (t)	1984 (t)	1985 (t)	1986 (t)
Iron ore pelletizing	127,737	112,181	138,328	149,970	144,477
Foundries	29,042	46,173	57,073	54,756	53,717
Well Drilling	21,860	34,917	46,472	63,918	33,638
Fertilizer stock					
Poultry Feed	158	221	2,420	2,657	2,498
Refractory	556	1,058	1,085	870	879
Other Products ²	2,913	2,879	3,275	3,614	2,681
Total	182,266	197,429	248,653	275,725	237,890

1 Does not include activated clays and earths or Fullers' earth

2 Refractory brick mixes, cements, heavy clay products, rubber products, chemicals, paper products and other miscellaneous minor uses.

The considerable gap between bentonite production and consumption was made up by imports, mainly from the U.S.A. Canadian bentonite imports are listed in Table 10. The distribution of the imports in 1991 and part of 1992 was as indicated in Table 11.

Table 10. Bentonite imports into Canada 1984-1987, 1990-1991 (Canadian Minerals Yearbook, 1987; and Andrews, 1991)

	1984	1985	1986	1987 Jan-Sept	1990	1991
U.S.A.: (t)	243,746	280,868	228,365	154,483	226,297	220,150
(\$000)	10,050	14,304	10,153	6,752	10,910	9,267
Other ¹ : (t)	93,308	65,150	97,933	49,293	26,165	48,462
(\$000)	5,257	3,805	5,302	2,485	1,336	2,435
Total:(t)	337,054	346,018	326,298	203,776	252,462	268,612
(\$000)	15,307	18,109	15,455	9,237	12,246	11,702

¹ mostly Greece.

Canadian bentonite exports, on the other hand, were very marginal at 1,170 t worth \$671,000 in 1990, and approximately 1,000 t worth \$ 540,000 in 1991 (Kalmakoff et al., 1991).

ALBERTA PRODUCTION AND CONSUMPTION

The bentonite plants that operated until recently in Alberta, at Rosalind and Onoway, are no longer in operation. Alberta currently imports all of its bentonite consumption. The uses of bentonite in Alberta are shown by the products produced from the two former plants, as listed in Tables 12 and 13 (Andrews, 1992). The Rosalind operation had annual production estimated at 10,000 t (Andrews, 1992). Kalmakoff et al. (1991) report that good reserves of bentonite still exist in the Rosalind and Onoway areas.

Table 11. Distribution of Canadian imports of bentonite (from Andrews, personal communication)

	Germany	U.S.A.	Greece	Italy	South Africa	TOTAL
	1991	1991	1991	1991	1991	1991
	Jan-Jun	Jan-Jun	Jan-Jun	Jan-Jun	Jan-Jun	Jan-Jun
	1992	1992	1992	1992	1992	1992
	(t)	(t)	(t)	(t)	(t)	(t)
Nova Scotia		494				494
		2				2
New Bruns.		329				329
		237				237
Quebec		126,508	48,430			174,938
		52,202	49,800			102,002
Ontario	4	54,240		5		54,250
	13	27,801		1		27,815
Manitoba		453				453
		360				360
Sask.		633				633
		203				203
Alberta		36,159			22	36,181
		10,350				10,350
B.C.		1,332				1,332
		536				536
Grand Total	4	220,148	48,430	5	22	268,610
	13	91,691	49,800	1		141,505

(t) tonnes

In 1990 Alberta imported 51,023 t of bentonite, with the largest share of this tonnage used in oil well drilling (Kalmakoff et al., 1991). Reduction in imports to 36,181 t in 1991 was due mainly to a decline in drilling activity. The fastest growth rate expected for bentonite consumption in Alberta, as in other parts of Canada, is for geotechnical use, due to increased concern and regulatory requirements for the environment.

Table 12. Bentonite products from the Rosalind area

Product	Principal Application
Arrowhead A	Stock feed pelletizing
Arrowhead B	Stock feed pelletizing
Arrowhead M	Well drilling
Auto Bond	Foundry
Beaver Bond	Foundry
Flameout	Fire retardant
Kwik Thik	Seismic testing
Magcogel	Well drilling
Magcogel #5	Well drilling

Table 13. Bentonite products from the Onoway area

Product	Principal Application
Alberta bond	Foundry
Aquagel	Well drilling
Can Gel	Well drilling

The existence of substantial reserves of swelling and partly swelling bentonite, along with two existing plants available for resumed production and large resources of bentonitic sediments, provide Alberta with a unique opportunity to market its bentonite products for specialty use in Canada to replace current imports. Increased drilling activity and increased environmental remedial and preventive legislation will open up new demand for bentonite products in Alberta and Canada. Because of the locations of alternative sources (in Wyoming and the Dakotas) transportation costs for Alberta bentonites to British Columbia and Central Canada should be competitive.

GEOLOGY AND RESOURCES

BENTONITE MODE OF OCCURRENCE AND ORIGIN

The mode of origin of most bentonites is by the alteration of volcanic ash (Industrial Clays, 1989). The parent ash (volcanic glass) of most bentonites was deposited under marine conditions, and a few deposits accumulated in alkaline lakes. The most common parent materials range from andesite to rhyolite in composition. Certain other bentonites exhibit strong evidence of origin by hydrothermal alteration of igneous rocks.

Beds and lenticular bodies extending between a few hundred metres to more than 300 km are common modes of occurrence of bentonite rocks. In most cases the basal contacts are relatively sharp, and gradational contacts with overlying beds are predominant. Most associated lithologies are of marine origin, ranging from glauconitic sands in Mississippi to limestone in Israel, shales in Wyoming, and calcareous fossiliferous sands and marls in England. Nonmarine beds are less common, and include fresh water limestones (Brazil, Canada) and carbonaceous shale and coal beds (Australia). In Cyprus, radiolarian chert is associated with bentonites. Diatomite is found with bentonites in Algeria and Peru.

Most economic bentonite deposits are of Cretaceous age or younger, although bentonite has been found in formations ranging in age from Upper Palaeozoic to Pleistocene.

DISTRIBUTION OF DEPOSITS IN CANADA

Bentonite occurs in beds of Cretaceous and Tertiary age in many areas of western Canada. The major producing and past producing districts are outlined in Figure 8. They include Onoway (Baroid Canada Ltd.) and Rosalind (Dresser Industries Inc.) in Alberta, Wilcox (Canadian Clay Product Industries) in Saskatchewan, and the Pembina district (Pembina Mountain Clays Ltd.) in Manitoba. Bentonite also has been

mined near Princeton, B.C., and is mined at Hat Creek. Deposits near Inuvik, N.W.T. have been investigated (Industrial Minerals and Rocks, 1983).

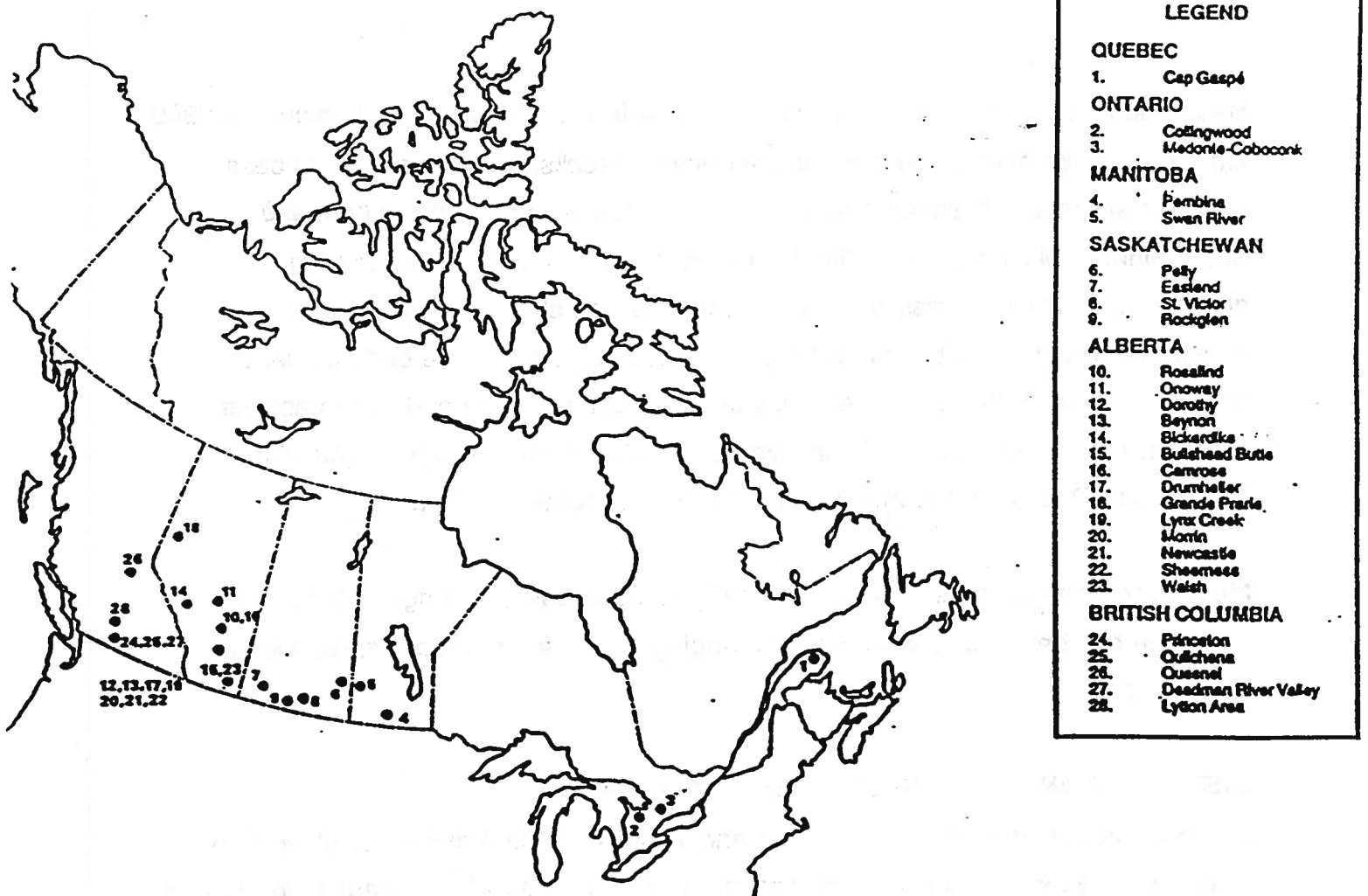


Figure 8. Principal deposits and occurrences of bentonite in Canada.

BENTONITE IN ALBERTA

Distribution of Deposits

Thin beds of bentonite are fairly common throughout the Cretaceous section of Alberta, and also are present in Tertiary rocks (Byrne, 1955). Thick accumulations are present only in the Bearpaw and Horseshoe Canyon Formations and the Wapiti Group of Upper Cretaceous age.

Bearpaw Formation lithologies include dark grey, blocky silty shale, greenish glauconitic or grey clayey siltstone, grey and green mudstone, and concretionary iron beds (Scafe, 1975). In the Bearpaw Formation, bentonite is persistent over large areas. At only two places, south of Irvine and at Dorothy (Figure 9), does the bentonite exceed Scafe's (1975) economic evaluation criteria for a potentially commercial deposit.

Horseshoe Canyon Formation lithologies include grey, feldspathic, clayey sandstone, grey montmorillonitic mudstone and calcareous shale, concretionary ironstone beds, coal and minor limestone beds. Two recent bentonite producers worked deposits from this formation, but the bentonite units are less persistent than those of the Bearpaw Formation. They commonly grade laterally over short distances into montmorillonitic sandstones or shales (Scafe, 1975).

In the Wapiti Group in northwestern Alberta, bentonite beds are persistent only over short distances in the grey, feldspathic, clayey sandstones, grey montmorillonitic mudstones, and scattered coal beds.

Economic Evaluation

For economic evaluation and testing, Scafe (1975) considered only deposits thicker than 30 cm with overburden to bentonite ratio less than 8:1. Based on these criteria, nine bentonite deposits were evaluated. These areas are shown in Figure 9.

Proportion of clay fraction to silt and sand is an important grade criteria. Other grade criteria used by Scafe include yield, cation exchange capacity and iron content. The

results are summarized in Table 14.

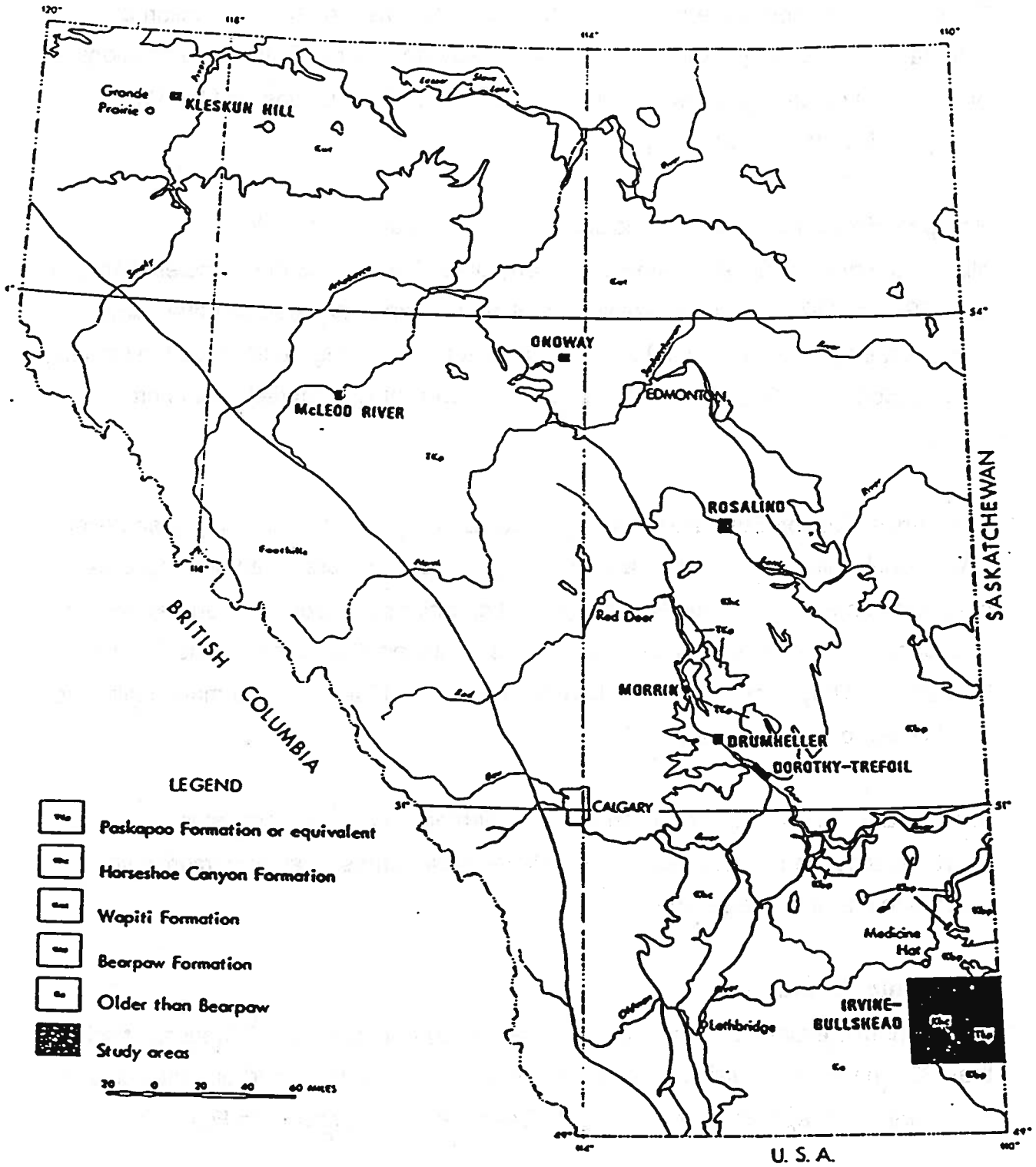


Figure 9. Alberta bentonite locations (from Scafe, 1975).

Table 14. Properties of Alberta bentonites (from Scafe, 1975)

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 ₂ O ₃	Yield (bbl/T)
	Sand	Silt	Clay	<0.2 μ m	Ca	Mg	Na	K			FeO	Fe ₂ O 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

The cation exchange capacity of most of the Alberta bentonites tested is equivalent to or better than the Wyoming bentonite (the best grades of swelling sodium bentonite), but the iron content is substantially higher. Although the yield values are lower than the 91 barrels minimum specification for drilling mud, a number of the deposits may have higher yield with some sodium activation and/or polymer extenders.

Specifications for other high volume bentonite uses do not require high yields and cation exchange capacity. For example, low grade bentonite (low clay : silt and sand) could, with limited sodium activation, supply animal feed, pet bedding, and numerous geotechnical grades. Polymer extenders can upgrade bentonitic sediments to various grades described above.

Description of Some Alberta Deposits

The following descriptions are from Andrews (1992) and Scafe (1975). Unless mentioned, no reserve estimates are available:

Rosalind: Several zones of bentonite occur along and near the Battle River valley about 15 km south of Rosalind. These were recognized in 1958 to be major deposits by Magcobar Mining Company Limited. The host rocks are flat-lying shale and sandstone of the Horseshoe Canyon Formation, and the 150-m wide main zone has been outlined for more than 1,000 m along the valley. In 1964 the reserves were estimated at 1 Mt. The bentonite is 2.6 to 3.2 m thick and is overlain by up to 7.5 m of overburden. Individual seams are up to 0.3 m thick and, when undried are greenish grey, greenish black, and brownish grey. The deposit is underlain by black, carbonaceous shale. Substantial reserves of swelling bentonite exist in the immediate area.

The deposit was mined and processed until October, 1992 by MI Fluids (formerly Dresser Minerals), when processing of stockpiled bentonite ceased and the quarry operations were offered for sale. Plant capacity was 10 tph and annual production was estimated at 10,000 t. Most of the product was used in well drilling. Andrews (1992) reports that there is enough stockpiled material to sustain 4 to 5 years of production.

Onoway: A group of bentonite zones occur in upper Horseshoe Canyon Formation strata about 19 km northwest of Onoway. Overburden varies from 0.6 to 15 m, averaging 1.8 to 2.1 m over the main zone. The bentonite occurs in irregular, discontinuous lenses with sharp contacts, and incomplete estimates indicate a reserve of 300,000 t of swelling bentonite. Until the early 1990s Baroid of Canada operated a well-equipped processing plant at Onoway. The bulk of its production was for drilling fluids, and some products for foundry use and foundry and feed pelletizing were marketed.

Dorothy: Tremendous tonnages of bentonite outcrop for several kilometres along both sides of the Red Deer River valley in the vicinity of Dorothy. The deposit is in the Bearpaw Formation, and ranges from 6 to 9 m thick, with some sandstone and several narrow seams of volcanic ash. Large portions of this deposit have little or no overburden with distinctive outcrops on the valley sides. However, the main deposit extends into the valley sides under deep overburden.

McLeod River: A 2.1 m thick bed of off-white bentonite occurs in the upper part of the Paleocene Paskapoo Formation, which outcrops along the McLeod River near Biskardike. About 1930, small quantities of bentonite were mined and used by an Edmonton firm in cosmetics manufacture.

Irvine-Bullshead: North and west of the Cypress Hills a bentonite and volcanic ash bed 0.3 to 1.5 m thick is present over a wide area beneath 3 to 4.5 m of overburden. The buffish-grey bentonite occurs in the Bearpaw Formation with sharp upper and lower contacts.

Drumheller: Several bentonite beds in the Horseshoe Canyon Formation outcrop near Drumheller. The main bed is 0.75 to 0.9 m thick and outcrops for a few kilometres along the Red Deer River. It has been mined intermittently.

Grand Prairie (Kleskun Hill): Bentonite occurs in a number of lenses up to 1.2 m thick, 19 km northeast of Grand Prairie. It is in the middle part of the Wapiti Group.

EXPLORATION, DEVELOPMENT AND RESEARCH

Many of the bentonite beds in Alberta have been identified by mapping and determination of basic characteristics of the bedrock formations. The Late Cretaceous formations offer the best exploration prospects.

Weathering characteristics of bentonitic sediments are unique, and are useful in locating sources of bentonite, but identification of distinct bentonite horizons and/or

grades of bentonite requires measurement of physical and chemical properties. The choice of sampling methods, and properties for grading depend on the type of bentonite, and the potential end product specifications.

Some of the Alberta bentonites have been developed as producers of sodium and sodium activated bentonite products. However, exploration for and evaluation of non-swelling calcium bentonites and partly swelling bentonites in Alberta has not been very extensive. Measuring the physical and chemical properties for bleaching and clarification characteristics are required on a routine basis, and testing methods require modifications based on potential product and user specifications.

In Alberta it has been difficult to locate bentonite beds of sufficient width and continuity to provide high grade feed stocks for naturally active bentonite grades. However, production experience in Saskatchewan has shown that it is possible to produce some of the common bentonite products, and even some of the low volume, high value-added products from impure bentonitic sediments. Production from sediments with clay, silt and sand mixed with bentonite is possible, provided that the processing is modified by drying, specific grain size separation, and by limited activation (for example, with polymer extenders and soda ash in the case of sodium bentonite).

Ideally, production from thin bentonite seams can be accomplished by mining the surrounding bentonitic sediments, when mine dilution cannot be avoided. Higher grade material can then be blended with production from lower grade beds to produce the specifications required, e.g., bonding characteristics.

Objectives in exploration and development should include material characterization, and process and product research, to produce a wide variety of product specifications from economically minable widths and grades of raw materials. Previously tested and untested sites in Alberta need to be resampled using mining widths as sampling parameters. Widths of 1.5 m in areas of overburden strip ratios of 3:1 are recommended. Grade parameters should be established after process and product research indicates methods necessary to upgrade to a realistic range of user

specifications. Concentration on products for geotechnical use and for the agricultural-chemical industry is recommended.

Research is needed to produce mono-mineralic products of sodium and calcium *montmorillonite*, rather than *bentonite*, from the Alberta bentonitic sediments. These uniform products can then be used to meet a large number of product specifications with minimum adjustments. Also, feed materials of different grades can be used with little or no modifications of the processing. The cut-off grades of the bentonitic sediments will be based on the economics of the beneficiation process. The uniformity of the montmorillonite product will allow development of more applications, and easier production of value-added products such as organoclays. One avenue for research is the wet processing of bentonitic sediments.

MINERAL TECHNOLOGY

MINING

Mining of bentonite raw materials is generally by conventional quarrying methods or by larger scale open pit. Surface mining equipment and methods depend on the nature of the deposit, that is, whether selective mining of a relatively well defined bentonite seam with minimum mine dilution is necessary, or a more conventional wider open pit bench can be excavated for bentonitic sediments. Equipment includes front end loaders, backhoes, scraper loaders, to power shovels and draglines in larger operations.

After removal of the overburden, the previously mapped target horizon is relogged using a quality control system and is quality contoured (Monea, 1984). The quality control system is a combination of geologic logging of cuttings, and grade determination by measuring specific physical and chemical properties. In some cases geophysical methods such as gamma ray borehole logging are very effective grade determination methods in combination with the other criteria.

Most mining operations include preliminary air drying and partial activation (e.g., with soda ash) by stockpiling and harrowing at or near the mine site. In many cases the

overburden is stockpiled for backfill during reclamation, but if the overburden also is bentonitic, the swelling properties of the clays may require careful management of the overburden stockpiles, including drainage at or near the stockpiles and open pits. Generally the overburden is not removed too far in advance of the mining operations. Several open pits and/or shelves may be opened up and mined at a given time to allow blending of plant feed, and management of stripping and reclamation.

PROCESSING

For common products, processing of bentonite requires essentially the reduction of moisture content and particle size separation through several stages. Figure 10 is a flow sheet of a typical operation.

Generally in Western Canadian bentonite operations, material is fed first into a clay feeder (chopper) which discharges into a rotary drier. In Western Canada gas fired driers are preferred. Operating temperatures in the drier are carefully controlled to prevent damage to the product. A temperature gradient is maintained, with drying temperatures from 400°C to a discharge temperature below 100°C.

Drier product is fed into a system of screens whose mesh size is selected according to product specification. Particles larger than 9.5 mm are recycled to the drying circuit because of agglomeration due to incomplete removal of moisture. The finer and middle size fractions either are marketed directly as granular products, or further treated by grinding in a Raymond roller mill and activated with additives such as polymer extenders to enhance properties for specific end uses. Additives generally are mixed in paddle-type mixers, using cable feeders for low additive rates, and screw feeders for higher additive rates (e.g. 2kg/min).

Particle sizes of the finished products may be controlled by combination of forced air flow and a classification device known as a "whizzer" fitted with approximately 60 evenly spaced blades. By adjusting the speed of the blades the particle size is controlled, because the fine particles in the forced air stream can escape by passing between the blades, while the coarser particles are more likely to hit a blade and be

deflected back.

Very fine particles are discharged into a dust collector, and the finished sized product is carried into a storage silo. Depending on the specifications and market, the product from the silos is either loaded into bulk rail cars, trucks or into bagging machines for packaged shipments.

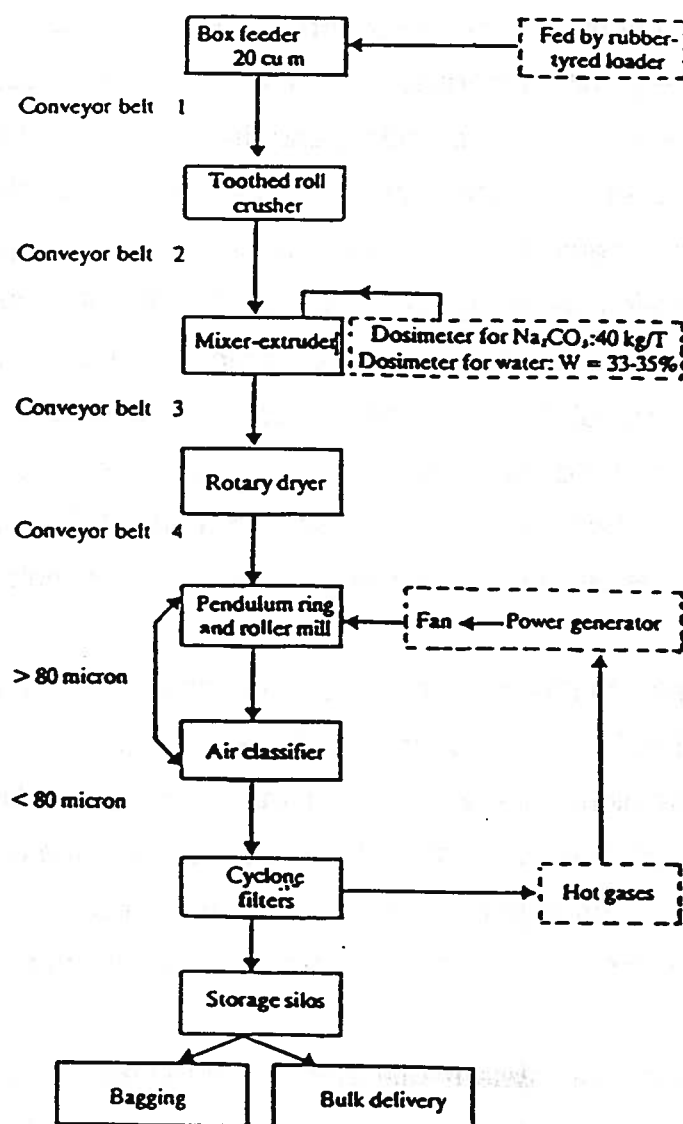


Figure 10. Typical flow diagram for a bentonite processing plant (Industrial Minerals, November 1981).

RESEARCH NEEDS

In Alberta there are significant exposures of bentonitic sediments relatively close to developed infrastructure. However, not many bentonite beds of high clay to silt and sand ratio have been identified with sufficient width and continuity to provide high grade feed stocks for naturally active bentonite grades.

Process research is needed to develop technology for separating relatively uniform grade montmorillonite from bentonitic sediments. A potential method uses blunging and dispersion of feed slurry of bentonitic sediments in water, followed by wet screening to produce a very uniform particle size. The key to the process is proper dispersion of clay size montmorillonite particles, and the prevention of agglomeration. Experimentation and process optimization of process variables, including type and amount of dispersants, and percentage solids will be necessary. Wet processing also will allow further beneficiation, including reducing organic content by oxidation bleaching (e.g., with ozone), and reducing iron contamination by reductive bleaching. Dewatering of the slurry without damaging the montmorillonite structure and without excessive agglomeration will require bench scale and pilot plant scale process research. The technology already is in use for kaolin clay beneficiation, and a bentonite plant in Nevada is believed to be using some of this technology.

Another avenue of research in Alberta bentonites is the processing of high value-added products like acid activated bentonites and organoclays. The feed stocks for these products can be the higher grade products similar to those produced by the Onoway and Rosalind producers. Montmorillonite obtained from the newer wet processing technology mentioned above will be especially suited for developing these low volume, higher priced products that require stringent quality control of feed stocks.

The rapid growth in demand for waste management and remedial action have immense potential for bentonites of geotechnical grades. These grades can be produced from relatively lower grade bentonite with minimal activation. Research into development of barriers for specific geotechnical projects requires on site testing and monitoring. In Alberta there is a significant pool of talent for this research and

development.

Research also is necessary to investigate potential for blending Alberta bentonites with natural zeolitic materials, to develop products for a variety of uses. Natural zeolites are used often in radioactive waste disposal, sewage effluent treatment (ammonium ion removal), agriculture waste water treatment, heavy metals removal from process waste waters, animal nutrition, aquaculture, and clarification of food materials. Many of these overlap traditional bentonite uses, and bentonite would provide the power to bind the materials together during application and subsequent exposure to weather.

ECONOMIC FACTORS

PRICES AND COSTS

Bentonite is sold in bulk or in bags. Distribution of product is through industry wholesalers (e.g. Canamera-United, Wyoben, Van Waters & Rogers), retailers, and the direct sales approach to consumers and end users. Major mud companies, such as Technifluids, Milchem Canada, National, International Drilling Fluids, Reef Mud, Haliburton, and Economy Mud Products sell their product to the oil companies and most drilling companies.

Long term supply contracts are negotiated by bentonite producers with major fertilizer companies that make pellets from clay. These include Co-operative Fertilizers and Sherritt Gordon. Long term supply contracts requiring competitive pricing, and product adaptation usually are necessary for feed stock industry users like Surgain, Feedrite Feeds, Unifeed, Eastmen Feeds and Federated Co-operatives. Direct sales can be negotiated with geotechnical contractors who are tendering construction projects, with iron ore pelletizing and foundry industries, and to waste absorbent manufacturers.

The price of large lots, e.g., 10 t bagged lots of foundry grade Wyoming bentonite (85% <200 mesh) delivered to the United Kingdom is US\$225/t (Industrial Minerals, December 1992). The price in rail hopper cars or bagged in rail cars FOB plant for

Wyoming bentonite ranges from US\$38.50/t for ceramics, drilling fluids and civil engineering grades, US\$55/t for filtering and paint grades, US\$95/t for absorbents and desiccants, and US\$110/t for fertilizer and pesticide use (Kalmakoff et al., 1991).

Figure 11 shows the relationship between the dramatic rise and decline in bentonite consumption between 1974 and 1984 and the price of bentonite. As consumption

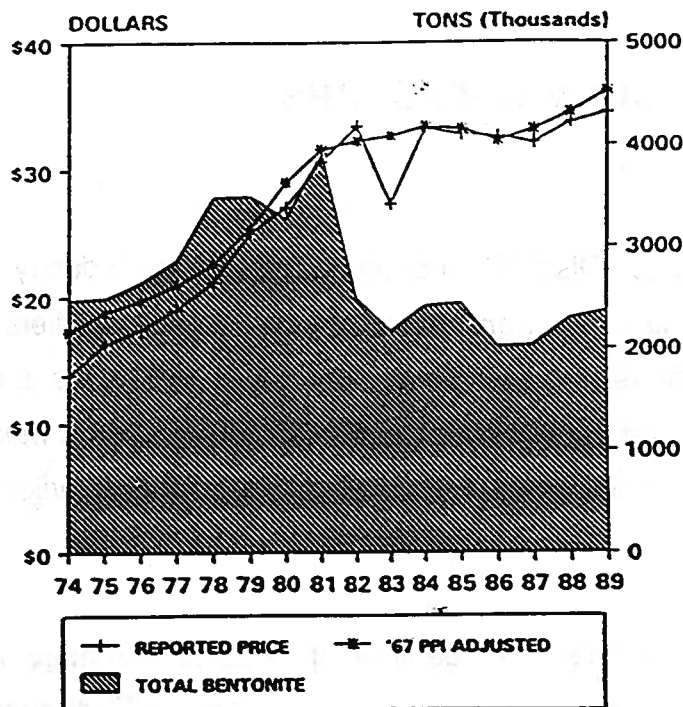


Figure 11. U.S. and export pricing. Reported price compared to Producer Price Index 1967 price (from Wright, 1992).

dramatically increased between 1974-1981, the average price increased as well. The relatively stable prices after 1981 reflect the effects of significantly lower bentonite production. The average price of bentonite after 1981 has followed the producer price index, indicating that bentonite has followed the pricing trend for all commodity products.

Actual production costs are not available from past or current producers, but the following is an estimate of bentonite production costs in southern and central Alberta:

Mineral royalty	\$.40
Surface rights compensation50
Mining (stripping, stockpiling, transport)	7.00
Reclamation10
Processing	17.00
Storage & bagging	<u>11.00</u>
Total production cost per tonne	\$ 36.00

TRANSPORTATION

Transportation costs limit the effective market range of bentonite as it does with other industrial minerals. Table 15 is an example of transportation costs of bentonite products from Hat Creek, British Columbia, illustrating the relatively high unit transportation costs.

The most common types of bentonite packaging are bulk shipments in rail cars, bulk ore carriers, and multiwalled paper bags with plastic liners. Fibre drums are used for specialty products sold in small quantities, and 45 kg metal drums are required to protect absorbent granules and/or where lengthy periods of storage or repeated handling are necessary. Packaging and handling can be a major item in the cost of the product.

The method of transport depends on use and location of markets. Most of the bentonite is shipped by rail in bulk hopper cars, some by bulk trucks, and some by rail boxcars. Bagged bentonite usually is palletized for shipment by rail or truck. Large unit trains are used for large shipments to distant points and for overseas consignments. Partly dried, semi-crude bentonite is transported on ore carrier ships for the Great Lakes and overseas shipments. This allows loading and unloading of

Table 15. Transportation costs for bentonite from Hat Creek, B.C. (from Kalmakoff et al., 1992).

Method	Destination	Equipment	Payload (t)	Cost \$	Cost \$/t
50 - 100 kg bags	Vancouver	Flat/Van	44.9	704	15.68
50 - 100 kg bags	Calgary	Flat/Van	44.9	1,124	25.03
50 - 100 kg bags	Edmonton	Flat/Van	44.9	1,461	32.54

bentonite by bulk-handling equipment without bagging, but further drying and grinding is usually necessary at or near the place of use.

OUTLOOK AND STRATEGIC CONSIDERATIONS

According to Kalmakoff et al. (1991), civil engineering applications, absorbents and desiccants exhibit the fastest growth rates for specialty bentonite applications. By the year 2000, demand for bentonite in absorbent uses is expected to rise by greater than 6% in the U.S.A. and Canada. Increasing pet populations will be responsible for a forecast growth rate of 5 to 7% for bentonite in pet litters.

An increasing market for specialty non-swelling bentonite in Canada is the salad oil market (Kalmakoff et al., 1991). Bentonite is used as a decolorizing agent for vegetable and other salad oils, and between 1981 and 1987 Canadian consumption of salad oils increased by 74%, and food trends indicate continued growth.

According to Wright (1992), the drilling fluids, metal casting and iron ore pelletizing markets historically have driven the bentonite industry and have represented 85 to

95% of total bentonite consumption. Although the specialty markets represent significant growth opportunities, for the near term the three traditional markets will dominate bentonite markets.

Wright (1992) terms the 1990s as "a decade of opportunity" for the bentonite industry, and recommends that "the producers must become more involved in their future. They must become leaders in product and technology department that promote the use of their products." He goes on to state that "this relatively inexpensive natural resource is indeed a buried treasure of the future".

Three areas are recommended by Wright (1992) for the bentonite industry to focus its energy and resources.

1. The producers (and potential producers) must develop advanced methods and technology, that can provide a better understanding of product behaviour and predict product behaviour in new and existing applications.
2. Develop new partnerships between producers, potential producers and the users of their products. This will promote development and transfer of leading edge technology.
3. Contribute to the competitiveness of the product by providing innovative products for existing and new applications.

Alberta has extensive deposits of bentonitic sediments, and is a major consumer of bentonite for drilling mud. Although it suffers some transportation disadvantages to major North American industrial centres and overseas shipment points, the application of the three recommendations would promote the growth of high value-added products industry in the province. The following areas of research and development are recommended for Alberta:

1. A systematic program of material characterization of bentonitic sediments should resume. The choice of physical and chemical properties for measurement should allow examination of potential for a wide spectrum of

existing and new applications, such as pharmaceutical (Anderson and Plein, 1962). Sampling techniques should apply to minable widths rather than geological boundaries.

2. Processing methods employed in Alberta must be sensitive to the clay to silt and sand ratio. The clays will require considerable handling, i.e., stockpiling and partial activation with soda ash, and fixed parameters for drying. Bentonitic sediments in Alberta would be minable on a large scale if a wet processing method was developed to separate relatively pure montmorillonite clay mineral from the sediments, e.g., by fractionation and recovery of solids from colloidal suspensions. Research is required to optimize recovery of a uniform product.
3. Users in the geotechnical and environmental markets may be persuaded by joint product research to utilize lower grade bentonite, e.g. with a lower clay to silt/ sand ratio than the higher priced special packaged products imported from the U.S.A.
4. Concentrate on environmental, food processing, and specific areas of geotechnical uses (e.g., barriers in underground nuclear waste vaults). Develop products in sufficient volume so that they can be test marketed. This program also should include blending bentonite with other mineral products, such as zeolites, to enhance their mutual properties.

Markets for bentonite in specialty applications are expected to rise sharply in the U.S.A. and Canada. Alberta may not be able to take advantage of these markets unless potential bentonite producers, or entrepreneurs and government initiate a program of material characterizations, product and process research in the province. Wright (1992), from the perspective of an interested bentonite producer (and investor), suggests it is more appropriate to ask "what does the bentonite industry hold for the future?" rather than "what does the future hold for the bentonite industry?".

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