CONSULTANT'S REPORT

MARKET STUDY OF BENTONITE PRODUCTS

Prepared by:

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EXECUTIVE SUMMARY

Bentonite production in British Columbia has been limited to local exploitation of native bentonitic soils for civil engineering applications and mining of bentonite-diatomite mixtures for the production of absorbents such as cat litter. Provincial requirements for bentonite products include a number of value-added products that have relatively small markets of high unit value, and larger volume applications in drilling and civil engineering applications and paper making.

At present, the predominant form of bentonite found in British Columbia deposits is the variety in which Ca^{++} rather than Na+ is the main exchangeable cation. This type of bentonite can be activated to enhance its performance, and in its natural state, it can be used as a groundwater fluid barrier. Relatively recent research has indicated that calcium bentonite is degraded less rapidly in service in some common environments than the more chemically active sodium bentonite (Wyoming bentonite).

It appears that a too simple approach has been taken for specifying bentonite types in engineering applications. A more site specific approach, which might include the layering of different clays, should be used for long term performance security.

Civil engineers appear to specify Wyoming bentonite or its equivalent on a basis of tradition more than consideration of cost or performance in service of the bentonitic product. It is possible that greater use of calcium bentonite could be obtained in the Province and subsequently in other market areas, if regulatory agencies responsible for permitting civil engineering applications could be satisfied of its suitability for those applications.

The current market for calcium bentonite in British Columbia, based on official import statistics, is very small, estimated at 260 tonnes with a delivered value of between $50,000 and $100,000. An alternate estimate (that considers imports of drilling mud from Alberta that may not be included in this first estimate) is made of 1,600 tonnes with a delivered value of between $300,000 and $600,000. This estimate includes sodium bentonite market share that could potentially be taken over by calcium bentonite.

A third estimate is based on national consumption data and prorated according to the population of the Province. This approach, taking into consideration the lack of local markets for clay in the production of iron ore pellets, indicated a possible calcium bentonite consumption of 1,225 tonnes.

There is potential for growth in civil engineering applications and in the higher priced but smaller markets of value-added calcium bentonite products. Such products are used in the refining and bleaching of oils, pharmaceuticals, cosmetics and as low cost dessicants.

The overall market size in the Pacific Rim countries, including West Coast of the United States, for calcium bentonite is estimated very tentatively at 238,000 tonnes. An estimate of value is extremely tentative at between $15 million and $22 million f.o.b. West Coast Ports. Considerable potential for overlap exists between calcium bentonite and sodium bentonite uses, because through cation exchange and acid activation, it is possible to attain some similar properties for the two types of clay: Calcium bentonite can be processed to achieve properties that may permit it to obtain market share in some traditional sodium bentonite applications.

Research to modify process technology for bentonite should be focussed on the development of montmorillonite with uniform grade and particle size from bentonitic sediments. Product testing to obtain engineering approvals of calcium bentonite as a permeability barrier of choice also should have a high priority.

INTRODUCTION:.

BACKGROUND & OBJECTIVES:

Devitrification and alteration of certain varieties of volcanic ash and glass, under specific conditions produces a type of clay deposit called *bentonite.* It was first produced in Canada in 1926 from a deposit near Princeton, British Columbia. At present, British Columbia is neither a major producer nor a major user of bentonite, although existing and potential reserves of bentonite have been delineated by industry and by British Columbia Energy, Mines & Petroleum Resources. The province imported only 1,567 tonnes of bentonite in 1990, however certain bentonite products, for example geotechnical composite liners (GCL), may not be recorded in published statistics.

Bentonite is common in the Cretaceous and Palaeocene sediments underlying much of the Alberta Plains and Foothills (Scafe, 1975). However, the known locations of bentonite deposits of acceptable grades and minable widths are limited in Alberta. There is no record of recent bentonite production in Washington State, but bentonite is produced in Idaho for the paper industry and geotechnical usage

Mainstream markets in Canada are in the iron ore pelletising, foundry sand, oil well drilling, agricultural-chemical usage, and geotechnical (barriers). These markets have been recently supplemented by high value-added, low tonnage products. Requirements for all of these products are currently met mostly by imports from the United States and Greece.

This study has been commissioned under, and all funding provided under the Canada-British Columbia Mineral Development Agreement through Natural Resources Canada. The terms of reference for the study require the authors to evaluate the present sources, production and uses of bentonite in an economic context. The data presented have been taken from references that are indicated at the end of the text. Also, extensive use was made of telephone canvassing of consumers and distributors, and civil engineering companies that use bentonite as a membrane to control the migration of fluids. This was done to try to obtain some indication of future market potential for the calcium bentonites that are predominant in the Province, which potential is provisionally described.

The objective of this study of bentonite is to determine if there is sufficient usage of bentonite in British Columbia, and/or potential for market development of bentonite products for domestic use or export to the U.S.A. and Pacific Rim countries. Evaluation of the known deposits and exploration and evaluation of new deposits is recommended as a future work programme. The report describes the characteristics of bentonite and correlates them to the grades and specifications in *major* areas of bentonite applications. It also deals with the industry setting, and briefly describes the geology of known. deposits in the Province, before dealing in some detail with the economic factors. The outlook and strategic considerations summarize the conclusions and recommendations of the report, including the 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 hosted by the **Benton** Shale of Wyoming, U.S.A., named after Fort **Benton,** Montana which is approximately 650 kilometres north of the first bentonite mine.

Subsequently a number of definitions have been used for bentonite based on *mineralogy* and/or *origin* and/or *end usage.* This has caused a lot of confusion particularly if mode of origin and end usage are used in the definition. With respect to 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 **decolourize** and purify oil to commercial grade is also composed of smectite cl&y minerals, but the dominant mineral is calcium montmorillonite and its proper nomenclature is **Fullers' Earth.**

These "overlaps" in nomenclature are still fairly common in the literature, and Table 1 summarises the terms and the regional nomenclature:

TABLE 1: BENTONITE NOMENCLATURE (from Industrial Minerals, Oct.19821

SMECTITE GROUP:		
Dominant Mineral	*Synonymous Terms*	*Regional Terms*
Sodium Montmorillonite	Sodium Bentonite Swelling Bentonite Sodium Activated Bentonite	Wyoming Bentonite (U.S.A.) Western Bentonite (U.S.A.) Bentonite (U.K.)
Calcium Montmorillonite	Calcium Bentonite Sub-bentonite Non-swelling Bentonite	Southern Bentonite (U.S.A.) Texas Bentonite (U.S.A.1 Fullers'Earth (U.K.)
HORMITE* GROUP :		
Dominant Mineral	*'Synonymous Terms*	*Regional Terms*
Attapulgite,	Palygorskite, Mountain Wool, Leather	Fullers' Earth (U.S.A.)
Sepiolite	Mountain Wool, Leather, 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 acidulated to enhance sorptive properties.

***Organophilic** Bentonite or Organoclay:* usually high sodium-activated 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 material composed of illite-smectite mixed layer clay minerals, altered volcanic ash with later potassium addition.

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

SECTION 1: BENTONITE -- INDUSTRIAL MINERAL:

PHYSICAL CHARACTERISTICS OF BENTONITE:

There are three main characteristics of bentonite that make it commercially useful. They include **thixotropy**, welling, and **adsorption**. Thixotropy is the property by which bentonite-water slurries under certain temperature, and ionic concentrations become very viscous - gel like, but lose some of the viscosity under shear stress. Swelling to several times their original volume in water can be caused by hydration of the clay lattice, and when the water is removed the clay lattice assumes its original spacing. The adsorption of exchangeable metallic ions in the clay lattice determines 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 hydroxyl group. 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 tetrahedron structure made up of silica-oxygen (A in Figure 1). The silicon atom is equidistant from four oxygens or hydroxyls arranged in a tetrahedron with the silicon atom at the centre. The tetrahedrons are grouped to form a hexagonal network that is repeated indefinitely to form sheets with the composition $Si_4O_6(OH)_4$ as in Figure 2.

In the "Al" or "Gibbsite Layer" the aluminum-hydroxyl is a layer of octahedron structure (B in Figure 1). The aluminum is embedded at the centre of an octahedron of six oxygens or hydroxyls. The network of octahedrons is repeated to form a sheet between the silica layers, and sharing the oxygen-hydroxyl atoms as shown in Figure 3. The composition of the gibbsite layer is $Al_2(OH)_6$. 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.

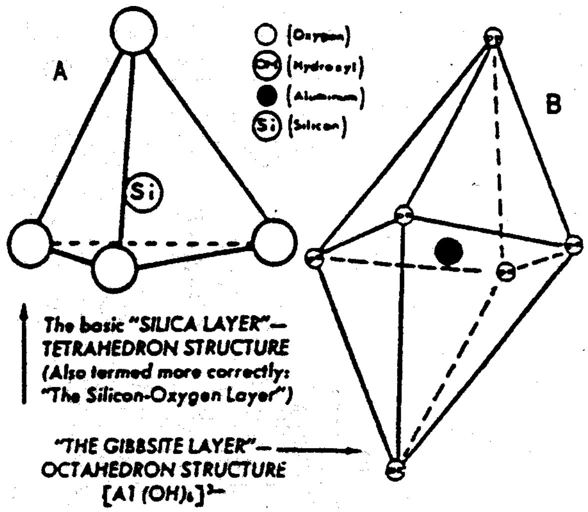
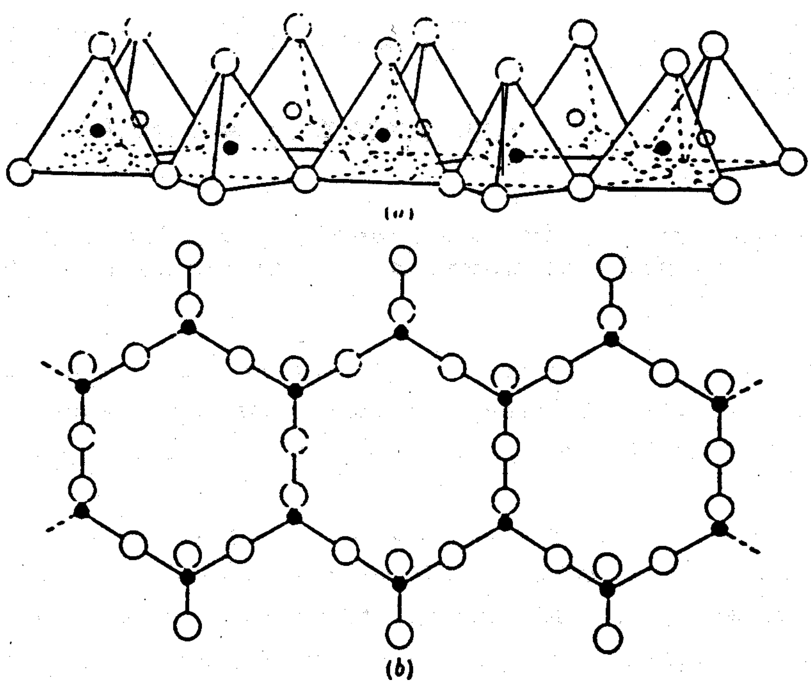
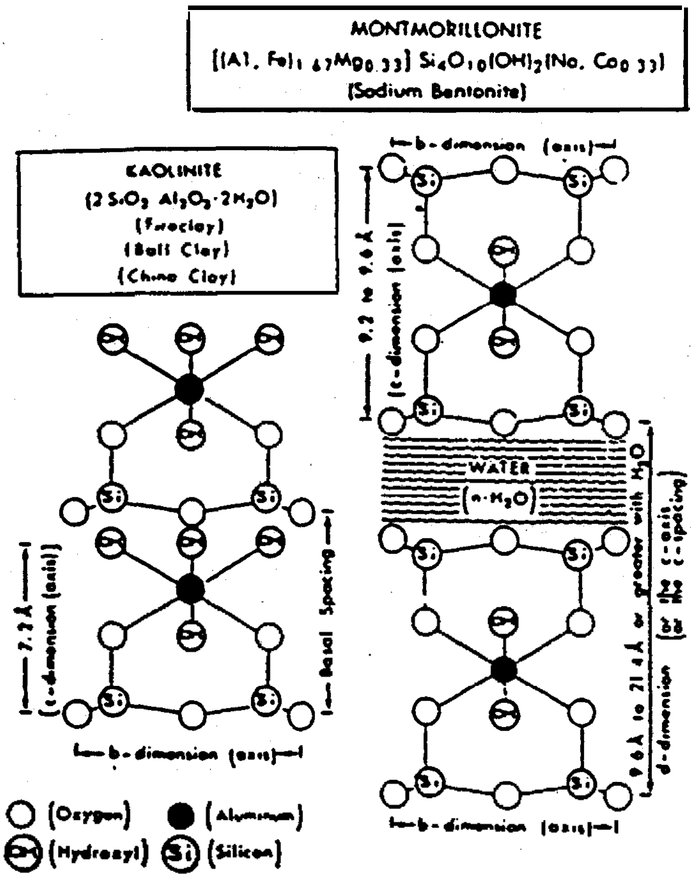


Figure 1: Tetrahedrons(A) and octahedrons(B) are the fundamental components of the silica and gibbsite layers respectively.



Double chains of silica tetrahedra.

Figure 2: Sheet forming **hexagonal** *network* of tetrahedrons.



THE SIMPLIFIED DIMENSIONAL CLAY STRUCTURES

Figure 3: The simplified dimensional clay structures -- the domain structure in montmorillonite.

Part of the aluminum in the central "Al" layer of montmorillonite is usually substituted by magnesium and/or iron. The generally accepted unit (ionic) formula of sodium montmorillonite is $[(Al,Fe)_{1.67}Mg_{0.33}]Si_4O_{10}(OH)_2(Na,Ca_{0.33})$.

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 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 can also 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 cations are relatively easily exchangeable 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 and forcing the sheets apart, and allowing a layer of water to be chemically bonded by electromotive forces. A "domain" structure is a packet of these superimposed flakes with this layer of water molecules between the flakes even when air dried.

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

The relatively high ratio of width to thickness of flake units of montmorillonite provide tremendously greater surface area than in other 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 USAGES OF BENTONITE:

MOLECULAR STRUCTURE	*CHARACTERISTICS*	*EXAMPLES OF USAGES*
Large surface area	Thixotropy Colloidal Dispersion	Suspending Agent Thickener 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: Process and Waste Water Organic Liquids

BENTONITE IDENTIFICATION TECHNIQUES:

For precise identification techniques'like X-ray analysis, differential thermal analysis, and chemical analysis are useful. These tests are not usually employed on a routine basis. Tests for material characterization and product testing and process research include those that directly determine the property or properties employed in the usage of bentonite. These usually include one or more listed in Table 3 below from **Andrews** (1992).

TABLE 3: LABORATORY[1] METHODS FOR IDENTIFICATION & EVALUATION OF BENTONITE:

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		
11.	Colloidal Content	22.	Iron Ore Pellet Strength Tests
12.	Rate of Stabilization	23.	Decolourization
13.	Apparent Viscosity	24.	Cation Exchange Capacity

[1] Other methods of testing are field methods, e.g. macro-permeability for civil engineering applications.

APPLICATIONS OF BENTONITE:

The matrix in Table 4 correlates the four main types of crude bentonite with the mainstream 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: MATRIX CORRELATING CRUDE BENTONITE TYPES AND RANGE OF BENTONITE APPLICATIONS (from Industrial Clays, 1989):

Source: Süd-Chemie

Crude bentonite

	Activated with acid (activated bleaching earth)	Naturally active (Na/Ca-bentonite)	Alkaline (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		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	Bindings agents for synthetic moulding sands, core sands	Binding agents for anhydrous casting sands/for thickening blackwashes

GRADES AND SPECIFICATIONS:

TESTS FOR EVALUATION:

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

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

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

Cation Exchange Capacity: is determined by using ASTM standard test method #C 837 - 81 for Methylene Blue Index of Clay. In some cases, the exchangeable metallic bases are determined by leaching with ammonium acetate.

Percentage Moisture: is the moisture determined at point of manufacture using method specified 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 Practise, Standard Procedure for Field Testing Drill Fluids, Section 5. However, for most usages the weight percent over 200 mesh size is reported.

Percentage *Fines:* are generally 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 microns. Other sizes can be specified as needed.

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

Thermal Durability: is used for evaluating bentonite for foundry usage, and involves heating to 540°C and remeasuring the cation exchange capacity. The percentage of clay activity retained is the thermal durability.

Macro Permeability: is used to test the performance of bentonite liner systems under actual field conditions. One apparatus is a sealed double ring infiltrometer (SDRI), which measures infiltration from a 1.5 metre diameter inner ring within a 3.6 metre diameter outer ring. Establishment of steady state conditions for testing are required.

GRADE OR MATERIAL CHARACTERIZATION:

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

Material Characterization of Naturally Active Sodium Bentonite from *Wyoming* (American Colloid Company):

Chemical Analysis:

	Varies between % by weight:
SiO_2	58.0 to 64.0
Al_2O_3	18.0 to 21.0
Fe_2O_3	2.5 to 2.8
MgO	2.5 to 3.2
CaO	0.1 to 1.0
Na_2O	1.5 to 2.7
K_2O	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 micron

93 to 94% < 5 micron

8'7 to 89% < 0.5 micron

60 to 65% < 0.1 micron

Specific Gravity = 2.7, pH of water suspensions = 8.S to 10

Exchangeable Metallic Bases:

	meq/100 q
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 a volume 12 to 15 times when dry. On drying shrinks to original volume.

In suspension the expanded sheets allow adsorption (and perhaps absorption1 of 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:

With 7 to 10 parts water a gel is formed with the bentonite. 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 kg/m'

Material Characterization of Naturally Active Calcium Bentonite from Manitoba (Pembina Mountain Clays Limited):

The following specifications are identified as #1 from a composite sample of non-swelling bentonite beds from the Pembina Mountain Clays Limited, near Mowbray, Manitoba. #2 is from an activated bleaching clay produced by Filtrol Corporation in California, and #3 is a clay from Panther Creek, Mississippi produced by American Colloid Company and used mainly 'in foundries. The sample collection and analysis are reported by Bannatyne (1963).

Chemical Analysis:

	weight % #1	#2	#3
SiO_2	63.72	66.05	66.05
Al_2O_3	19.86	13.06	13.13
Total Fe	1.42	1.52	5.45
MgO	4.67	3.79	1.57
CaO	0.16	2.88	0.58
Na_2O	0.77	0.10	0.09
K_2O	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
LO1 110°C to 925°C	8.09	11.55	8.73
H_2O below 110°C	10.75	12.87	3.74
H_2O 110°C to 925°C	6.91	9.55	7.62

Screen Analyses: % Retained on Mesh Sires:

	+100	-100+150	-150+200	-200
#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 D#1sity:

#2 0.59 0.45 gm/cm^3 gm/cm^3

#3 0.43 gm/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% sulfuric acid. Also, iron as Fe_2O_3 before and after activation is determined. Filtering rate is another important criteria for evaluation. Transmittance of light through stock motor lubricating oil before and after decolourizing was determined with a Bausch & Lomb Spectronic 20 colorimeter.

	Filtering time	Transmittance	Light reflectivity	Total % Fe
#1			84%	1.42
#1, 1 hour	2.0 min.	92%	83.5%	0.96

Material Characterization of Alkaline (Sodium) Activated Bentonite from Saskatchewan (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 Avonlea's.

The quarried materials at Avonlea were treated with soda ash (0.5 to 0.7%) during drying. Drying was done on pads. Up to a month's aging was required prior to further processing. This partial alkaline activation increased the sodium to calcium ratio. The data on the differences before and after activation are not available.

Chemical Analysis:

	% by weight
SiO_2	65.9
Al_2O_3	17.6
Fe_2O_3	4.1
MgO	2.4
CaO	1.3
Na_2O	2.3
K_2O	0.3
FeO	0.2
TiO_2	0.2
Loss on Ignition	5.1

Moisture:
7 to 9%

Particle Size:
Dispersed in water
80 to 90% - 200 mesh.

Swelling:
650 to 850 in units calculated to 100g from 2.5g/100ml.

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/m^3

Material Characterization of Organically Activated Bentonite from India (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 into development of *organoclays* that are effective gellants for organic liquids. The exchange sites on the basal planal surfaces in bentonite are neutralised 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 as an antisettling 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
Colour	Creamy white
Particle Size	95% < 200 mesh (BSS)
Odour	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

Smectone gels have wide range of thermal stability, are resistant to the action of acids and alkalis between pH 4 to 10.

Smectone gels are non-hygroscopic, safe to handle, chemically inert, and allow long storage.

SPECIFICATIONS:

The term specifications refers to physical and chemical properties of the raw material(s) required by producers of a range of bentonite products, and also refers to the product standards of these industries designed to meet user specifications and standards or just user satisfaction. The types of industries and end users are listed in first left hand column of the matrix in Table 4.

There is a general absence of universally accepted procedures and specifications for bentonite. Part of the reason is for the widely varying properties of the clays. The main reason is that there are many different specifications outlined by purchasers for many uses, but wherever organisations with the help of industry have established useful procedures having wide applications, then these are indicated in the following sections.

Specifications for the Drilling Industry:

The specifications for bentonite usage in the oil well drilling fluids is in American Petroleum Institute (API) Specification 13A (Spec.13A), Twelfth Edition, October 1988, Section 4. More detailed specifications, and methods for performance evaluation are in the Specification No. DFCP-4, October 1973 of the Oil Companies Materials Association (OCMA).

Yield is the most important criteria not only for evaluating bentonite for drilling fluids, but also for various other usages where fluid rheology is important. It is defined by API as the number of barrels of mud with 15 centipoise viscosity obtainable from one ton of clay. The API specifications for drilling mud require a minimum yield of 91 barrels. OCMA specifies that yield of a bentonite/distilled water slurry,, aged for 24 hours with an apparant viscosity of 15 centipoise shall not be less than 16.0m^3/tonne.

Other API specifications for drilling fluids are:

Particle size	>98% -75 microns
Moisture	<10% @90°C
Sand content	maximum 2.5% +75 microns by wet screening
Apparent viscosity	15 centipoise for 6.5g clay/100ml fluid
Plastic 'viscosity	8 centipoise for 10g clay/350ml water
Gel strength (Stormer)	>5g initial, >40g after 10 minutes
pH	>6, >12 in some fluids
Wall building	<15ml fiitrate, 30 minutes at 650kPa

OCMA (European) specifications for drilling fluids include:

Particle size	>98% -100 mesh (150 microns)
Moisture	<15% by weight
Residue	<2.5% by weight on U.S. Standard Sieve 200 Mesh

Specifications for the Foundry Industry:

The Steel Founders' Society of America (SFSA) have "Specification for Western Bentonite 13T-86" for bentonite used in the foundry industry as binding agent.

The main requirements include:

Water content	between 6 and 12% (maintains efficient high-strength bond @ 1600°C in metal casting.
pH	equal to or greater than 8.2.
CaO	< 0.70% (thermal durability)

Liquid limit	(ability to hold-water without flowing and expansion) between 600 and 850.
Particle size	90-95%, <75 microns

In addition, the bentonite grades used in this industry should be able to produce sand/bentonite moulds with the following properties:

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	6 5 6 kPa

Specifications for Iron Ore Pelletising:

Specifications vary from *one* plant to another. Moisture absorption is done by the ASTM Standard Test Method for Water Absorption of Bentonite Porous Plate Method (E946 - 83, Reapproved 1987) designed to determine the weight gain in . bentonite due to absorption of water. The sintered aluminum oxide plate is manufactured by Norton Industrial Ceramics Division. Plants may have moisture control problems with their filter cakes. Higher bentonite concentrations are necessary with increasing moisture in the pelletising circuit to avoid formation of oversized pellets.

The second pelletising test is a non-standard procedure used to evaluate the binding effectiveness of a given bentonite with respect to specific'ore concentrate. Test values are compared to a bentonite of known quality. A procedure developed by Inland Cement is probably the most sophisticated one in use.

The following are *some* of the specifications for bentonite for iron ore pelletizing:

Particle size	80%, <75 microns
Moisture	6 to 8%
Yield	88 to 132 bbl/t
pH	minimum 8.0

The pellets produced should have the user specificationa as follows:

Size	9.5 to 25 mm diameter
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

Specifications for Herbicide/Pesticide, Chemical Carriers:

Particle size is. a critical specification. >90% of the material falls between 20 to 60 mesh or 40 to 80 mesh. Standard sieve shaking techniques are used. *Moisture* is generally specified at <3%.

The most important test parameters are the ability of the bentonite to take *on* organic chemicals by adsorption and absorption. The *sorptive capacity* is tested by determining the amount of trichloroethylene required to saturate the clay using standard procedures. The *liquid holding capacity* (L.H.C.) is reported as %L.H.C. = gm solvent to saturation / gm solvent to saturation + 100 g-m of clay X by 100.

Thirdly, the *hardness* of the bentonite is important. This is measured as loss due to attrition by shaking 100gm for 15 minutes over 100 mesh screen. Attrition loss % = weight passing 100M/ 100g X 100

Hardness, sorptive properties, and liquid holding capacity are user *specified.*

Specifications for Geotechnical Usage:

In civil engineering applications the *lubricity, plastering or sealing ability, thickening and gelling properties* of bentonite are utilised (Industrial Clays, 1989). Five properties of bentonite slurry are tested to measure effectiveness and indication of deterioration - *flow properties and gel strength, water or filter loss,* density, *solids or sand content,* and *hydrogen ion concentration.* For the testing generally < 1% solids content slurry is used to obtain a non-viscous and non-gelling suspension with a large adsorptive surface area.

The usages include preventive and remedial measures. The main usages are in *SOIL STABILISATION, SOIL SEALANT, DRILL HOLE "CEMENT"* FILLER, GROUTING and *DIAPHRAGM WALL CONSTRUCTION.* Sodium bentonites of relatively high grade are generally preferred in the formulations for diaphragm wall construction, grouting, caisson sinking, pile boring, muddying-in, ground impermeabilisation, cement and concrete workability additive, effluent water treatment, tunnel shield lubrication and electrical earthing.

In Canada, the Saskatchewan bentonites that are reported to meet most of these criteria contain 70 to 80% < 200 mesh for lower grades, to 95% < 200 mesh for higher grades. Their moisture content is reported at 6 to 9%, and cation exchange capacity (CEC) by methylene blue from 75 to 90 meq/100g. Recent studies (Dixon et al) on the use of bentonite as barrier material in the Canadian Nuclear Fuel Waste Management Program has indicated potential usage for swelling bentonites similar to the Late Cretaceous deposits of Alberta. Most of the bentonite deposits in British Columbia are of the non-swelling variety.

Wyoming bentonite suppliers produce treated bentonite that will not lose its swelling and adsorptive properties in contact with saline and contaminated water. Cationic exchange polymers are typical additives used and the formula is based on viscosity tests at variable bentonite concentrations, slurry temperature, sand mixtures, and salt, inorganic cation concentrations. It may be possible to formulate suitable bentonite products for geotechnical usage using additives and the non-swelling bentonites from British Columbia

SOIL SEALANT:

One of the fastest growing market for bentonite is in the reduction of seepage and absorption/adsorption of contaminants from ponds, settling basins, dams, and other hydraulic reservoirs (Andrews, 1992). Field trials using different application rates and soil-bentonite proportions are common in sealing and impermeabilisation of soil for waste dump construction.

Five common methods of treatment are employed. The first three methods require hydration of the liner to produce swelling of the bentonite to impart seaming and healing characteristics of the liners:

"Geotextile clay liners" are pre-constructed laminates of sodium bentonite clay laminated between two geotextiles. These liners require site preparation, greater care and protection during installation, and final backfilling, but consume less clay, require less -technical input and pre-testing, are more self sealing and self-seaming.

"Blanket" method requires removal of about 100mm of soil and smoothing *of* the site, followed by layering of about 8.5mm of bentonite. The soil is then replaced and the bed rolled.

"Mixed-Blanket" method about the same amount of bentonite as in the blanket method is spread on the drained floor of the basin. The bentonite is mixed into the top 100mm of soil and packed.

"Granular" method is usually employed in a filled reservoir, and involves the sprinkling of bentonite over the water.

"Sedimentation" method allows the dispersion of bentonite by flowing water.

***SOIL STABILISATION*:**

Bentonite clays calcined between 540° and 1,000°C, are weakly to strongly pozzolanic. When added to soil with lime they convert the soil to a friable and easily workable mix due to cation exchange. Compaction is followed by pozzolanic action between the lime and clay, and the excess lime ***forms*** carbonates. The stable mantle thus formed resists water penetration and also exhibits low to moderate strength. The non-swelling Ca- bentonites of British Columbia would find a market for this usage provided other economic factors are favourable.

DRILLING CONCRETE & GROUTING APPLICATIONS:

In oil-well and civil engineering test wells up to 12% swelling bentonite (80-94% minus 44 microns) may be added to decrease slurry density and allow thixotropic action, increase plasticity and retard water loss. In drilling concrete addition of up to 5% swelling bentonite improves the concrete's workability, aggregate dispersion and impermeability without decreasing its strength.

In underground developments, e.g. potash mines in Saskatchewan, swelling bentonite is applied in relatively large proportions. Its swelling, water impedance properties and minute gel particle size allows it to swell in fissures and open spaces and fill these spaces. The seals will retain their impermeability if the slurry is properly applied, the pressures are not excessive, and calcium ions are not available in sufficient amounts to convert the clay to a non-swelling type (Andrews, 1992). In deeper workings excessive pressures may require formulations with cement and chemicals.

DIAPHRAGM WALL CONSTRUCTION:

According to Andrews (1992) "this application is basically a method of constructing a reinforced concrete wall in the ground to great depths without a casing. A bentonite slurry, in suspensions of 3 to 10%, is used to hold open the excavation and to stabilize its earth walls until, and during, the introduction of concrete. The bentonite slurry exerts a certain lateral pressure on the whole inner surface of the excavation, penetrates the pores of the soil to form a stabilising gel, and deposits an impermeable membrane or cake on the sides."

This technology has most common applications in cut-off trenches under dams and embankments, temporary works in place of sheet piling,'or bored piling, permanent works for retaining walls, load bearing structures, shafts, deep basements, underpasses, tunnels, river and dock walls, shaped piles, etc.

Specifications for Pet Litter and Animal/Poultry Feed:

Most of the specifications in these categories are user specified or the producers have standards designed to meet user satisfaction.

Relatively lower grade sodium montmorillonite and calcium montmorillonite are used for pet litter. Bentonite exhibits special absorbency characteristics which tend to make bentonite granules clump together when wetted, thus facilitating easier separation and disposal of soiled litter (Industrial Clays, 1989). Bentonite's relatively high density also restricts spreading when compared to other lightweight pet litters.

Specifications for pet litter include high liquid and odour absorbency, freeness from dust, uniformity of size, ability not to break down when wet, and absence of harmful forms of silica, e.g. cristobalite.

Bentonite is used as a binder for animal feed. It holds the pellet together, slows the passage of feed through the digestive system -- increasing uptake of nutrients. Bentonite has an affinity for some of the active elements of toxin products formed by bacteria in the digestive tract, and its application in feed allows more rapid weight again of livestock. In poultry bentonite helps increase egg size and shell hardness. No clear guidelines are formulated by the Food & Drug Administration, but no additives are permitted, and close monitoring of trace elements is required. Also, producers of animal feed prefer low grit content to avoid wear on the extruder in the processing plant.

Specifications for Absorbent Granules -- Floor Adsorbents:

Most absorbent granules marketed are made to meet specifications in U.S. Federal Specification P-A-1056A, Absorbent Material, Oil and Water, and/or ASTM Standard Methods for Sampling and Evaluation of Sorptive Methods for Sampling and Evaluation of Sorptive Mineral products Used as Floor Adsorbents (C 431-65).

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 tests specifics, and require comparison with an official natural bleaching earth approved by AOCS. Most userpurchase specifications are based on these tests and comparisons.

Specifications for Drinking, Process Water & for Waste Water Treatment:

Bentonite in these applications is used as a flocculating agent. There are no industry established procedures for specifications of the bentonite, except for lack of additives in drinking and process water usage. 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 the stabilisation 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 (bentonite) 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 acidulation 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, 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 usage depends on-not only the/refining process, but also on the source of the materials, e.g Brazilian soya bean requires bentonite with different specifications to that used for U.S. soya bean. Therefore, universally accepted specifications and procedures are not possible.

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

Modified bentonites (from sodium bentonite) products are used wherever viscosity and flow control properties need enhancement to allow modification and formulation improvement to give easier production, better storage stability and improved performance during application and service.

The products are supplied in the dry state in the form of agglomerated platelet stacks. For usage dispersion and delamination are necessary. Physical energy is supplied by milling equipment, and the 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.

Specifications for Low Cost Dessicant:

United Dessicants produces in its Belen, New Mexico plant a low cost, efficient, packaged clay dessicant (DESI PAK[R]). United Dessicants products include silica gel, activated carbon and DESI PAK, and are used by manafacturers in electronics, pharmaceutical., food and aerospace industries.

United Catalysts gets its clay from a deposit of Ca bentonite near Chambers, Arizona. For dessicants high grade calcium bentonite with low dust content are acid activated. The dessicant has to be packaged in textile bags made of high density polyethylene fibers and spun bonded olefin, and the dessicant has to be resistant to ageing unless exposed to moisture.

Specifications for Paper-Making Applications:

When used as a filler in paper, swelling bentonite improves its opacity, smoothness, printing, softness and absorption characteristics. Its buff colour prevents the use of appreciable quantities unlike other mineral fillers such as kaolin or calcium carbonate.

On the other hand, bentonite has found increasing function as paper pigment and processing aid. A special grade of bentonite combined with polyacrylamide immediately ahead of the paper-machine headbox produces a micro-lattice structure that holds together fibre and pigment components of the paper furnish and encourages easy and rapid water drainage. This results in substantial improvements in pigment retention, uniformity of pigment and fibre distribution in the paper, and also in rapid water drainage from the forming paper sheet in the wire section and presses of the paper machine.

SECTION 2: RESOURCES OF BENTONITE:

INDUSTRY SETTING

THE BENTONITE INDUSTRY

In Table 5 the major world producers of bentonite to 1987 are listed. The U.S. is by far the largest producer of bentonite. However, in 1991 the U.S. accounted for 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.

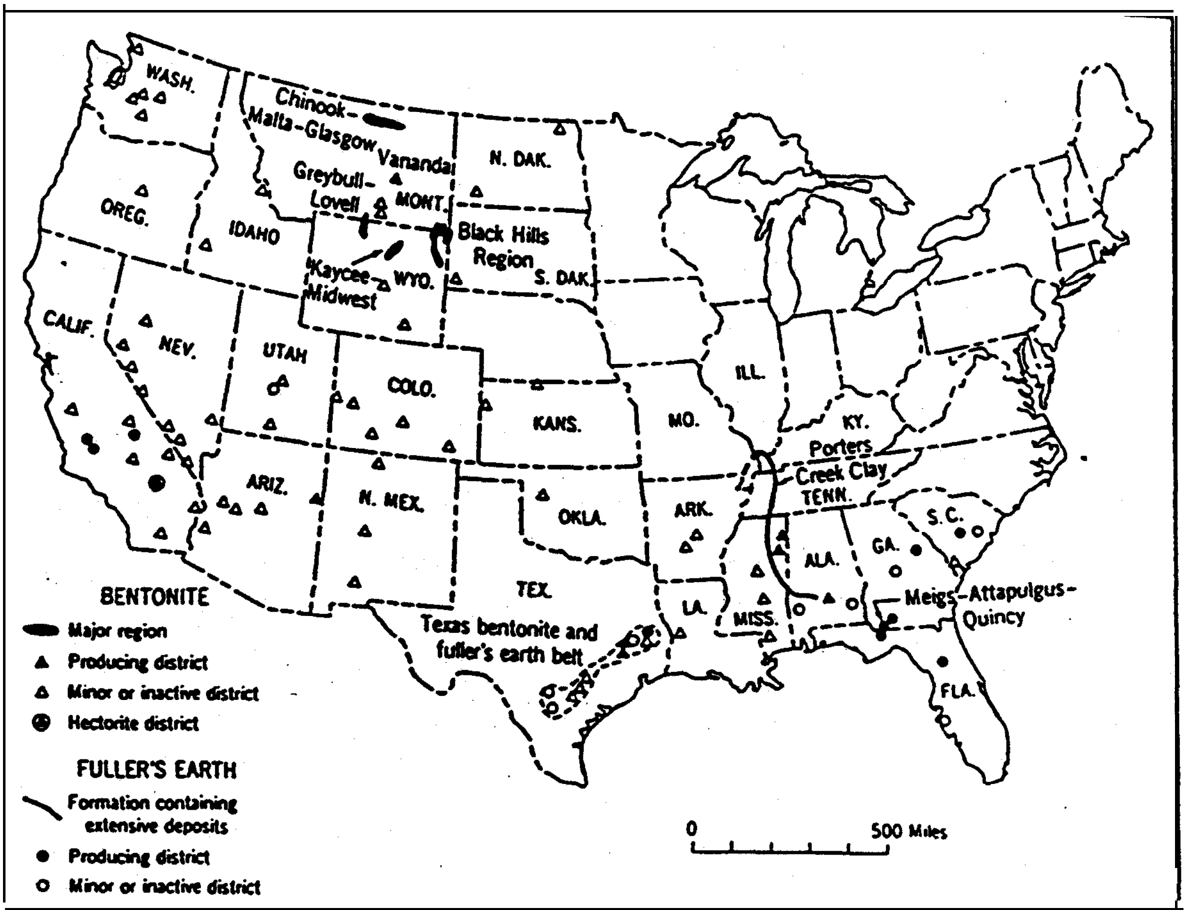


Figure 4: Bentonite and Fuller's Earth districts in the U.S.A.

TABLE 5: MAJOR WORLD PRODUCERS OF BENTONITE AND FULLERS' EARTH:

Major world producers of bentonite and fullers' earth (*tonnes*)

Country	*1985*	*1986*	*1987*
USA			
Bentonite (a)	2,898,710	2,551,950	2,367,000e
Fullers' earth (a,b)	1,868,149	1,732,703	1,774,000e
Greece			
Bentonite	1,054,234	1,317,825	1,250,000e
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	202,000e
Romania (e)			
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

The Statistics for bentonite production in the U.S.A. from 1987 to 1991 indicate an increase in mine production as shown in Table 6. All types of bentonites in most applications constitute a small part cf the final product. For example, it constitutes about 5% of the weight in well drilling fluids, up to 10% in foundry moulding and about 0.5 to 0.8% in iron-ore pelletizing.

TABLE 6: U.S.A. BENTONITE STATISTICS (USBM Mineral Commodity Summaries, 1992):

Mine Production	1987	1988	1989	1990	1991
Bentonite (000 tonnes)	2,309	2,604	2,823	3,151	3,192

Analysis of the U.S. bentonite industry and marketplace, therefore, from 1974 to 1989 by Wright (Industrial Minerals, July 1992) for sodium bentonite provides a good review of the industry.

Figure 5 shows that 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.

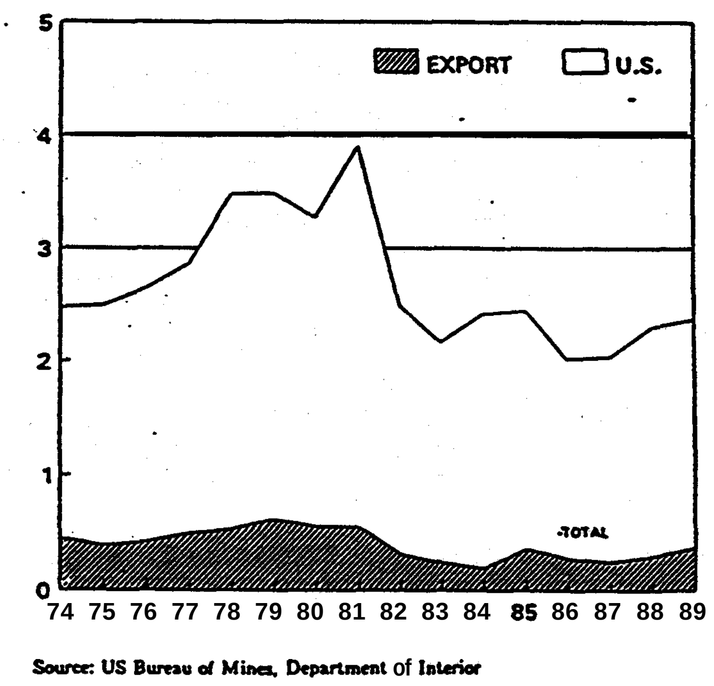
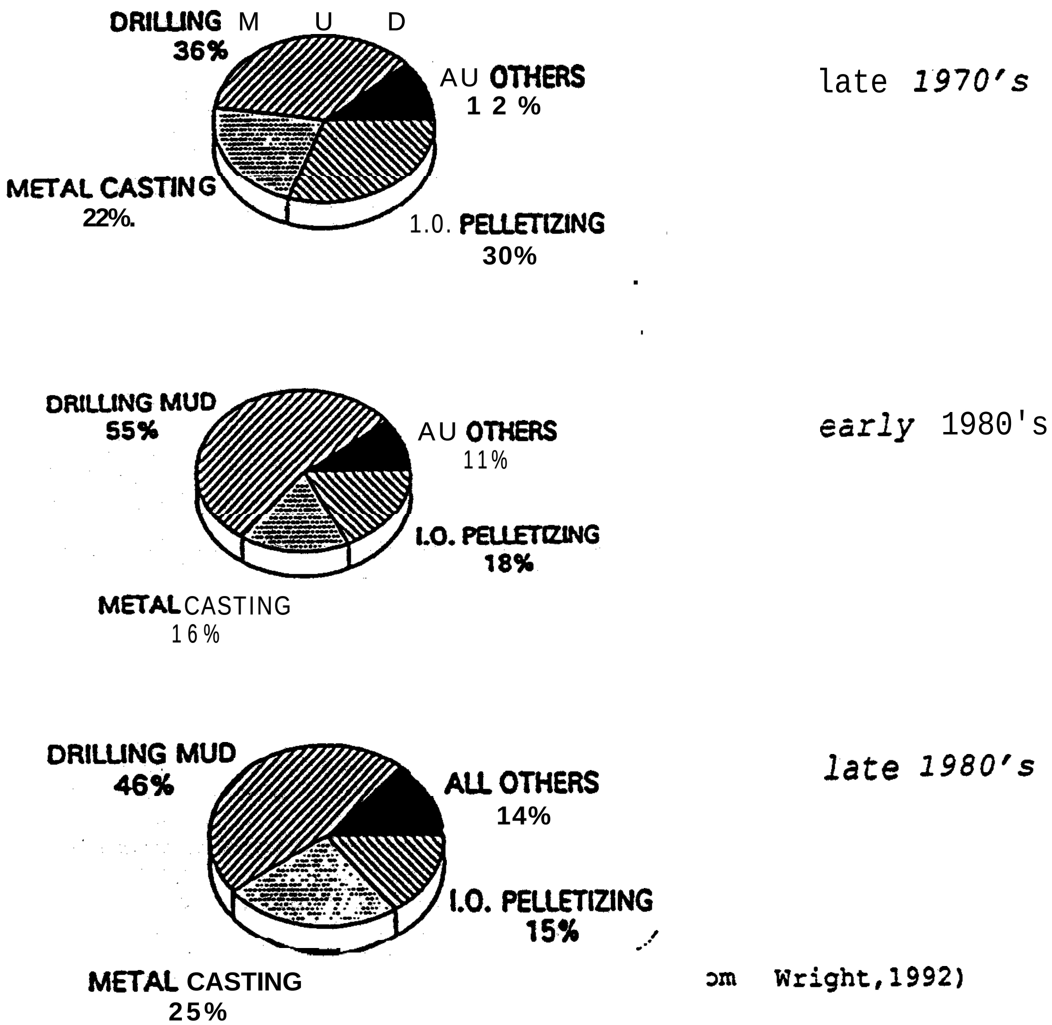


Figure 5: U.S. and export bentonite consumption 1974-89 (Wright, 1992).

Swelling and partly swelling sodium bentonite's widest application continues to be in three mainstream usages that include well drilling fluids, foundry metal casting, and pelletizing for stock and iron ore. In Figure 6 the division of consumption by usage is shown, top to bottom, for the late 1970s, early 1980s and late 1980s.



Other — environmental, animal feed, absorbents, paints, adhesives, pharmaceuticals, cosmetics

Figure 6: Bentonite consumption by use (Wright, 1992).

Historically, drilling fluids have been the largest market for bentonite, with the maximum at 55% in 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 required will not require pelletizing (Kalmakoff, 19911, and bentonite is being replaced by other binders. Metal casting consumption increased back to 25% in the late 1980s, mainly due to the increased ferrous metal casting in the automobile and construction sector. The 'trend towards 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 include geotechnical applications, agriculture-chemical applications, and custom design applications, including environmental, animal feed, paints pharmaceuticals and adsorbents represented 11 to 14% of total market consumption between 1974 -1989.

Since the U.S.A. is a very large market with potential for future Canadian producers to export to, the following Table 7 summarises the tonnage of bentonite sold or used by producers by use in the United States.

TABLE 7: BENTONITE SOLD OR USED BY PRODUCERS'IN THE UNITED STATES IN 1991 BY USE (Minerals Yearbook, USBM, 1991)

USE	THOUSAND TONNES
Adsorbents:	
Oil and grease	81
Pet waste adsorbents	217
Other'	W
Ceramics and glass:	
Catalysts (oil-refining)	W
Glazes,glass and enamels	W
Mineral wool and insulation fibreglass	W
Pottery	W
Other'	32
Civil engineering and sealing	177
Drilling mud	693
Fillers,extenders and binders:	
Adhesives	11
Animal feed	100
Fertilizers	W
Ink	W
Medical,pharmaceuticals, cosmetics	W
Paint	15
Paper coating	W
Pesticides and related products	W
Plastics	W
Rubber	W

TABLE 7: Continued

USE	THOUSAND TONNES
Fillers, extenders and binders:	
Other'	15
Filtering, clarifying, decolourizing:	
Animal **oils, mineral oils,** greases and vegetable oils	5
Desiccants	W
Floor and wall tile:	
Ceramic	([2])
Heavy clay products:	
Brick, extruded	W
Portland and other cements	W
Roofing tile	W
Other'	5
Lightweight aggregates:	
Other[1]	W
Pelletizing iron ore	717
Refractories:	
Firebrick, blocks, shapes	W
Foundry sand	585
Kiln furniture	W
Other'	243
Other[3]	96
Exports	438
TOTAL'.	3,432

W Withheld to avoid disclosing company proprietary data; included in **"Total"** and/or "Other".

1 Includes uses indicated by symbol W

2 Less than half unit

3 Uses not specified

4 Data may not add to totals shown because of independent rounding

Export markets have **historically averaged** 15% of the U.S.A. total consumption. Figure 7 shows that in the early 1980s the drilling mud consumption also increased dramatically as in the U.S.A. The metal casting industry was the primary export market **for** U.S.A. bentonite between 1974 and 1989, and the **"all** other" category in Figure 7 is predominantly for iron ore **pelletizing.**

The United States bentonite market is further analyzed in Table 8 by the tonnages of bentonite sold or used by producers by State. In the U.S. northwest white bentonite was produced by Applied Industrial minerals Corporation at the Ben-Jel bentonite pit near Oreana, Owyhee County, Idaho. **E.J.Wilson &** Sons produced bentonite from the Morning Glory property, also in Idaho, for the sealing of fish ponds, basements, water hazards and golf courses. In Washington no bentonite production was reported **(USBM,** 19911, and in Montana 362,635 tons valued at **$ 11,332,000** were produced in Carter County (swelling type) and in Carbon County (non-swelling type). The bentonite was used in animal food supplement, drilling mud, foundry sand and waterproof sealant.

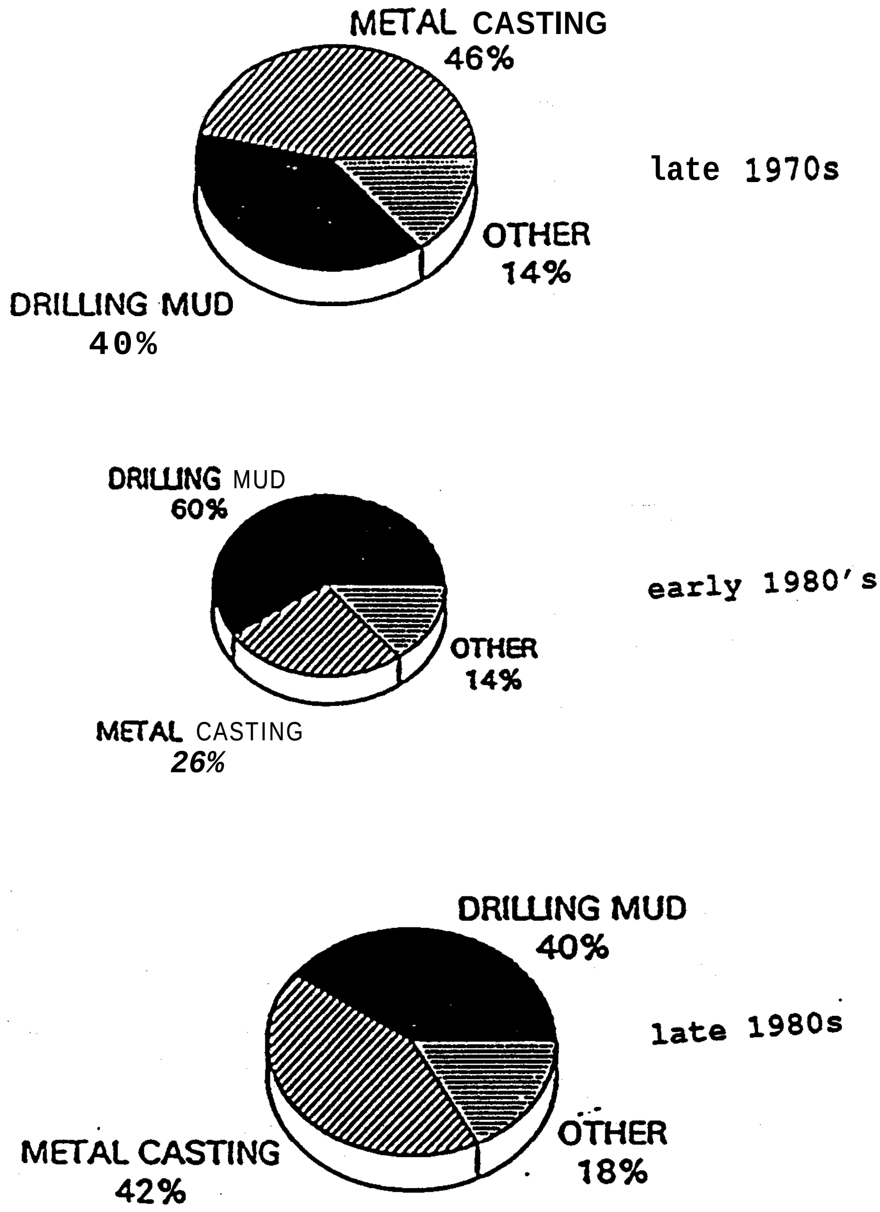


Figure 7: U.S. Export Consumption by use (from **Wright,1992**).

TABLE 8: BENTONITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1991 BY STATE (Minerals Yearbook, USBM, 1991):

STATE	NONSWELLING (000) TONNES	U.S.$	SWELLING (000) TONNES	U.S.$	TOTAL (000) TONNES	$
1990						
Alabama	411	17,217	---	---	411	17,217
and Mississippi		W		W		
Arizona	38	11,403	(1)	1,618	38	W
California	136		17		153	13,021
Colorado	---	---	(1)	4	(1)	4
Nevada	W	W	W	W	35	4,098
Oregon	---	---	25	1,063	25	1,063
Utah	W	W	W	W	W	W
Wyoming	---	em-	2,524	76,083	2,524	76,083
Other[2]	47	2,954	276	12,648	288	11,505
Total'	632	31,575	2,842	91,417	3,474	122,99
1991						
Alabama and Mississippi	281	, 37	W	W	281	, 37
Arizona	17	1,378	W	W	17	1,378
California	129	11,176	W	W	129	11,176
Colorado	W	7	---	---	W	7
Nevada	W	W	W	w	16	3,204
Oregon	W	w	W	W	19	786
Utah	W	40	W	1,104	W	1,144
Wyoming	---	v-m	2,496	81,573	2,496	81,573'
Other[2]	47	1,031	461	19,744	473	16,784
Total[3]	475	22,969	2,957	102,420	3,432	125,38

W Withheld to avoid disclosing company proprietary data, but included in Other

1 Less than 1/2 unit

2 Includes Montana and Texas

3 Data may not add to totals shown because of independent rounding.

CANADIAN PRODUCTION AND CONSUMPTION

Exact figures on Canadian bentonite production are confidential, but Table 9 lists Canadian production between 1984 to September 1987. In 1993 the only producer of bentonite in Canada was Canadian Clay Products Limited from its plant in Wilcox, Saskatchewan. Kalmakoff (1991) indicates productive capacity at Wilcox at 60,000 tonnes per year, and also much of the bentonite processed at this plant comes from M.I. Fluids of Alberta and Pembina Mountain Clays of Manitoba. The considerable gap between bentonite production and consumption is made up by imports into Canada, mainly from the U.S.A.

Tabie 10 lists the Canadian trade statistics for bentonite and Fuller's earth between 1990 and 1992. In Table 11 the history of bentonite and Fuller's earth consumption in Canada between 1980 and 1992 are reported.

TABLE 9: CANADIAN BENTONITE PRODUCTION 1984 - 1987 (Canadian Minerals Yearbook, 1987):

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

TABLE 10: CANADA, BENTONITE & FULLER'S EARTH TRADE, 1990-92 (Canadian Minerals Yearbook, 1992):

	1990		1991		1992p	
	TONNES	$000	TONNES	$000	TONNES	$000
IMPORTS[1]:						
Bentonite:						
United States	226,229'	10,923	220,147	9,274	119,205	7,191
Greece	26,015	1,202	48,430	2,423	63,156	2,919
Germany	2	1	4	3	19	18
Italy	1		5	5	1	1
Other countries	147	130	23	5	--	--
Total	252,395r	12,259r	268,609	11,712	182,381	10,130
Fuller's Earth and Decolourizing Earths:						
United States	6,643	806	6,138	880	5,808	849
Total	6,643	806	6,138	880	,80	
EXPORTS:						
Bentonite:						
United States	1,165	662	1,037	443	1,020	365
Chile	--	--	--	--	326	301
France	3	5	5	11	11	16
Belize	--	--	--	--	5	'2
Other countries	2	2	93	41	--	--
Total	1,170	671	1,136	497	1,362	685
Fuller's Earth and Decolourizing Earths:						
United States	45	10	26	11	106	17
Total	45	10	26	11	106	17

[1] Imports from Other countries may include re-imports from Canada
[p] Preliminary
[r] Revised

Kalmakoff (1991) confirms that Canadian bentonite exports were very marginal at 1,170 tonnes worth $671,000 in 1990, and approximately 1,000 tonnes worth $ 540,000 in 1991.

TABLE 11: CANADIAN BENTONITE IMPORTS AND CONSUMPTION', 1980-92 (Canadian Minerals Yearbook, 1992)

	Imports		Consumption[2]
	Tonnes	$ (000)	Tonnes
1980	469 [illegible],292	18,011	248,585
1981	311,464	13,292	286,359
1982	238,031	12,311	182,266
1983	187,228	9,545	197,429
1984	337,054	15,307	265,289
1985	346,018	18,109	275,725
1986	326,298	15,455	240,408
1987	318,074	14,715	235,488
1988	294,269	15,058	264,032
1989	294,280	15,069	259,468
1990	252,395[r]	12,259[r]	202,335
1991	268,609	11,712	178,245
1992[a]	182,381	10,130	([b])

[1] As reported by consumers
[2] Does not include activated clays and earths or Fuller's earth. See Table 10 for 1990-92 record.
[r] Revised
[a] First nine months of 1992 only.
[b] Not available.

Canada's swelling bentonite consumption has remained stable in the 200,000 to 300,000 tonnes range, and the higher amounts reported for imports in Table 11, may be attributed in part to bentonite that is imported for packaging and reexported from Canada. It is interesting to note that between non-swelling bentonite imports into Canada between 1990 and 1992 in Table 10 are in excess of 6,000 tonnes. Several Ca- bentonite deposits from British Columbia may be evaluated for development to replace some of these imports.

Other sources give a slightly different picture of the Canadian bentonite market. According to Kalmakoff (1991), the 1990 total consumption was near 300,000 tonnes, and in 1991 the civil engineering market for bentonite was expected to exceed 200,000 tonnes in Canada. In addition, 6% or more growth rates in bentonite consumption for absorbent and pet litter markets is anticipated through the year 2000. Usage of non-swelling bentonite in refining food oils is growing in Canada. All sources of data do agree that the considerable gap between bentonite production and consumption is made up by imports, mainly from the U.S.A.

Table 12 lists the Customs tariff, effective January 1993 from Revenue Canada, Customs and Excise, and Harmonized Tariff Schedule of the United States, 1992. Activated clays are one portion of the value added product market that future Canadian producers may be able to exploit.

TABLE 12: TARIFFS (Canadian Minerals Yearbook, 1992)

Item No.	Description	Canada			United States
		MFN	GPT	USA	Canada
2507.00	Kaolin/other kaolinitic clays whether or not calcined	Free	Free	Free	Free
2508.10	Bentonite	Free	Free	Free	Free
2508.20	Decolourizing earths and Fuller's earth	Free	Free	Free	Free
2508.30	Fire clay	Free	Free	Free	Free
2508.40	Other clays (excluding expanded clays)	'Free	Free	Free	Free
3802.90.10	Activated clay	12.5%	8.0%	Free	0.5%

A further analysis of the Canadian bentonite market is done by studying the reported consumption of bentonite in Canada by industry, followed by the distribution of imports of bentonite by Province. Table 13 lists Canadian bentonite consumption based on usage from the statistics in the 1987 Canadian Minerals Yearbook, followed by statistics from the 1992 Yearbook in Table 14.

TABLE 13: CANADIAN BENTONITE CONSUMPTION' 1982 - 1987 (Canadian Minerals Yearbook, 1987):

I	1982	1983	1984	1985	1986
	tonnes	tonnes	tonnes	tonnes	tonnes
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 Drillina	21,060	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'	2,913	2,879	3,275	3,614	2,681
Total	182,266	197,429	248,653	275,725	237,890

[1] Refractory brick mixes, cements, heavy clay products, rubber products, chemicals, paper products and other miscellaneous minor uses.
[2] Does not include activated clays and earths or Fuller's Earth

The patterns of consumption have not changed between 1988 and 1991 and the following Table 14 shows that the principal consuming industry in this period was iron ore pelletizing, followed by foundry mold binding and oil-well drilling fluids.

TABLE 14: CANADA, REPORTED CONSUMPTION'OF BENTONITE BY INDUSTRY, 1988-91
(Canadian Minerals Yearbook, 1992)

Usage	1988 Tonnes	1989[b] Tonnes	1990 Tonnes	1991[P] Tonnes
Iron ore pelletizing	163,446	171,373	([a])	([a])
Foundries	59,720	55,006	187,155'	158,831"
Well drilling	34,053	10,566	7,323	12,266
Refractory brick, mixes	1,173	1,494	1,310	1,007
Other products'	5,640	21,029	6,547	6,141
Total	264,032	259,468	202,335	178,245

*Preliminary
[a] Due to confidentiality, data for iron ore pelletizing are included in Foundries.
[b] Increase in number of companies being surveyed.
[1] Reported from Energy,Mines and Resources Canada survey on consumption of nonmetallic minerals by Canadian manufacturing plants.
[2] Includes animal feeds, structural clay products, pulp and paper products, paint and varnish and other miscellaneous minor uses.

TABLE 15: DISTRIBUTION OF CANADIAN IMPORTS OF BENTONITE (from Andrews, personal communication):

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

[1]For 1991 [2]For 1992

BRITISH COLUMBIA PRODUCTION AND CONSUMPTION

The only production of bentonite in British Columbia at present is from a deposit containing a mixture with other clays and diatomite. This has been successfully used for production of animal litter and absorbents. Civil engineering applications have been supplied either with native bentonitic or clay soils located on site or with Wyoming bentonite. Contractors on civil engineering projects have such a strong tradition of specifying and using Wyoming bentonite that it has been difficult to promote the use of Ca-bentonite. The lower swelling properties of the Ca-bentonite may be offset by simply using larger applications of the material in the mixture (Khera,1992). Also, the alteration of the mineralogical and colloidal chemical properties of Ca-bentonite is slower than Na-bentonite (Brandl,1992), making it more suitable for long term permeability barriers in some applications.

The statistics show that the outlook for conventional *uses* of bentonite is heavily dependent on the oil and iron ore industry. In Western Canada, an increase in oil prices and the continued growth of the natural gas demand will mean continuing strength in exploration, if not growth. This will translate into a higher demand for drilling mud. Increase demand for iron ore, however, according to Kalmakoff(1991) need not increase demand for bentonite because as much of the iron required will not need to be pelletized.

Bentonite demand in the foundry industry is expected to increase because the clay is used in the solidification of materials contained in foundry wastes, reducing their leachibility (Kalmakoff,1991).

Since British Columbia does not have a large oil or iron industry, it is neither a major producer nor a major *user* of bentonite. Drilling muds for oil and gas exploration appear to be repositioned from distributors in Alberta so the consumption figures for this sector may be inaccurate. The province does have a relatively large mining industry whose process waters and leachetes require impoundment. Also, diamand drilling projects for the mining industry require sealing of formational waters after completion, and are estimated to have significant consumption potential 'for bentonite. Although the swelling properties of Ca-bentonites are generally less than the Na bentonite (Wyoming type), the Ca-bentonites of the province may be used if other economic factors, e.g. transportation, are more favourable than those for imported bentonite.

The predominantly Ca-bentonite varieties of the province have potential because of their *adsorptive properties* and for *specialty applications.* The non-swelling type is normally used for adsorptive purposes, because they generally exhibit more pronounced adsorptive characteristics then the swelling bentonites. Bentonite employed for its adsorptive properties finds use in clarifying mineral, vegetable and animal oils and waxes.

Activated bentonite is produced by leaching of high-calcium bentonites with inorganic mineral acids, which dissolves impurities such as calcite, replaces exchangeable divalent calcium ions with monovalent hydrogen ions, and leaches ferric, ferrous, aluminum and magnesium ions. The changes to the crystal structure results in increased specific surface area and porosity giving activated clays far superior adsorptive properties (Andrews,1992).

Animal and vegetable oils (linseed, cottonseed, rapeseed, coconut, corn, palm, sesame, poppyseed, peanut, olive, sunflower, castor), seal, whale, cod and other fish may be clarified by activated Ca-bentonite. Tallow, lard, turpentine, cleaning fluids, vinegar, wine, beer, syrups and other beverages may also be purified. Swelling bentonite is usually used for wine, beer, syrups and other beverages.

"An increasing market for specialty bentonite in Canada is the salad oil market" Kalmakoff(1991). Between 1981 and 1987, Canadian consumption of salad oils increased by 74%. Consumer food trends in Canada and United States point to continued growth in the market for non-swelling bentonite, and should provide new marketing opportunities for bentonite, especially Ca bentonite of British Columbia. Generally the bentonite product has to be tailored for each specific use in close cooperation with the consumer (Andrews,1992).

Specialty applications for bentonite exhibit the strongest growth potential (Kalmakoff,1991), and are becoming especially attractive to producers of added-value bentonite products (Andrews, 1992). Producers in these new markets need to modify or add value to their existing products to satisfy the consumers in the cosmetics, pharmaceuticals, medicines, detergents and catalytic carriers. Civil engineering applications exhibit one of the fastest growth rates for specialty bentonite applications (Kalmakoff,1991).

For pet litter production, bentonite (and Fuller's earth) is preferred over rival clays such as attapulgite and sepiolite. Requirements include high liquid and odour absorbency, absence of dust, uniformity of size and cohesion ability when wet. A number of Ca-bentonite deposits of British Columbia can probably meet most of these specifications. The Red Lake, British Columbia production of Western Industrial Clays Limited is classified as a Fuller's earth by the 1992 Canadian Minerals Yearbook.

ALBERTA BENTONITE PRODUCTION AND CONSUMPTION

The bentonite plants at Rosalind and Onoway are no longer in operation, and Alberta now imports all its bentonite consumption. The principal applications of bentonite from producers in the Rosalind and Onoway areas was in the well drilling, foundry industries, with additional products marketed for the fire retardant and seismic testing industries. The Rosalind operation annual production was estimated at 10,000 t (Andrews, 1992). Kalmakoff (1991) reports that good reserves of bentonite still exist in the Rosalind and Onoway areas.

In 1990 Alberta imported 51,023 tonnes of bentonite with usage in oil well drilling accounting for the largest share of this tonnage (Kalmakoff, 1991). Decline in drilling activity was mainly responsible for reduction in imports to 36,159 tonnes in 1991.

As in other parts of Canada, the fastest growth rate for bentonite consumption is expected in geotechnical usage due to increased concern and regulatory requirements for the environment.

The existence of substantial reserves of swelling and partly swelling bentonite, with two plants available for resumed production, and large reserves of bentonitic sediments in Alberta provide this province with a unique opportunity to market its bentonite products for specialty usage in Canada to replace imports. Increased drilling activity in Alberta and increased environmental remedial and preventive legislation will open up new demand for bentonite products in Alberta and the rest of Canada.

Since alternative sources are in Wyoming and the Dakotas, transportation costs for Alberta bentonites to British Columbia and Central Canada may be competitive.

GEOLOGY AND RESOURCES

BENTONITE MODE OF OCCURRENCE AND ORIGIN:

The mode of origin of 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 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 in length 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 (Israel) to shales (Wyoming) to calcareous fossiliferous sands and marls (England). Non-marine beds are less common, and include fresh water limestones (Brazil, Canada) and carbonaceous shale and coal beds (British Columbia). In Cyprus radiolarian chert is associated with bentonites, and diatomite is found with bentonites in Algeria and Peru.

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

DISTRIBUTION OF DEPOSITS IN CANADA:

In Canada bentonite occurs in beds of Cretac'eous and Tertiary age in many parts of western Canada: In Figure 8 the major producing (and past producing) districts are outlined. They include Onoway (Baroid Canada Ltd.) and Rosalind (Dresser Industries Inc.) in Alberta, Wilcox (Canadian Clay Product Industries) in Saskatchewan, and Pembina district (Pembina Mountain Clays Ltd.) in Manitoba.

Bentonite has also been mined near Princeton, B.C. and deposits have been delineated in the Princeton and Tulameen basins (Read, 1987). Read (1988) also describes seven bentonite occurrences having potential economic significance in the Fraser river valley between Lytton and Gang Ranch. Other areas of bentonite potential in the province are in the Merritt Basin (Read, 1988), and widespread distribution of bentonite is known in the Hat Creek Valley (Read, 1990). References to bentonite in the province include the Mount Klappan area of northwestern British Columbia (Thompson, 1986), and bentonite in the Lower Cretaceous of-northeastern British Columbia is also reported (Kilby, 1985 and Spears, 1984).

A deposit of "unusual thickness" (Andrews, 1992) has been located in rocks of Cretaceous age in the Northwest Territories, with properties similar to the Rosalind deposit in Alberta. A location near Inuvik, N.W.T. has been mentioned in Industrial Minerals and Rocks, 1983.

To evaluate market potential for bentonitic products from raw materials produced in British Columbia reference should be made to the section of this report dealing with the United States market. In addition, the following description on Alberta precedes the section on the bentonite geology and resources of British Columbia.

BENTONITE IN ALBERTA:

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

In the Upper Cretaceous formations of Alberta and Saskatchewan the bentonite content varies from mixtures in shale and fine sandstone to concentrations high enough to be recognisable as distinct beds.

For economic evaluation and testing Scafe (1975) only considered deposits thicker than 30 cm with overburden to bentonite ratio less than 8:1. Based on the thickness and overburden ratio criteria nine bentonite deposits were evaluated.

Determining 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 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.

The specifications for other mainstream high volume bentonite usage 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.

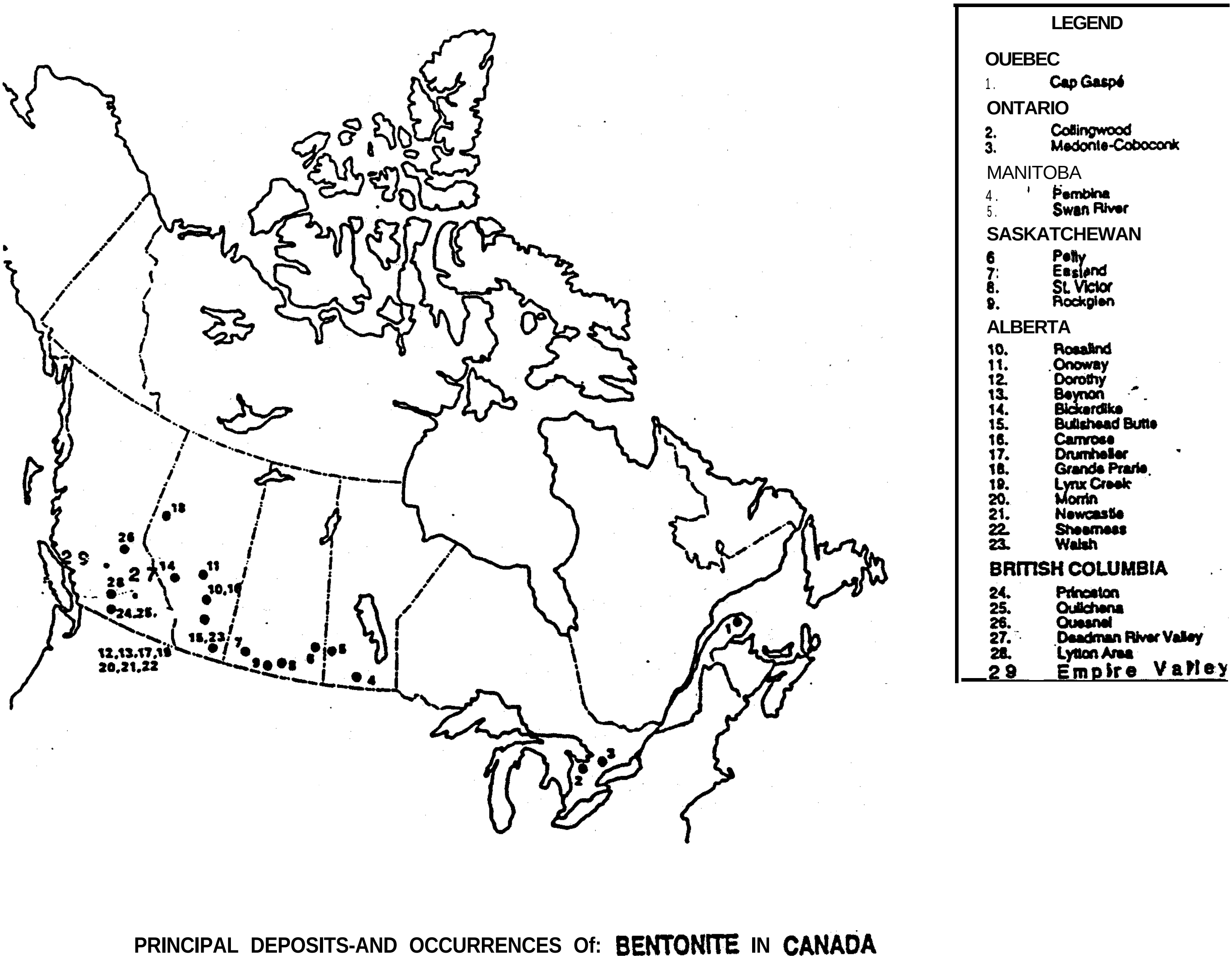


Figure 8: Principal deposits and occurences of bentonite in Canada.

BENTONITE IN BRITISH COLUMBIA:

The British Columbia mining industry, BC Hydro and B.C. Geological Survey (BCEMPR) research projects have identified large potential resources of bentonitic materials.

Princeton Area (Read,1987):

Bentonite is widespread throughout the north half of the Princeton Basin. It occurs in the Allison Formation of the Middle Eocene age Princeton Group, usually in the shale and coal-rich sections. The locations of known bentonite showings and deposits are in Table 16, and are localised in the Vermilion Bluffs Shale, Summers Creek Sandstone, Power Plant Shale, and Ashnola Shale. Grade varies from bentonitic sediments to up to 2 meters of bedded bentonite. Exchangeable cations are generally Ca and Mg; and Na-rich bentonitic materials are also reported. All of the above occurrences are within 8 km of the Canadian Pacific Railway.

In the adjacent Tulameen Basin, within 6 km of the Canadian Pacific Railway, bentonite layers up to a metre thickness are reported. Spot analysis indicates Ca and Mg as the main exchangeable cations.

TABLE 16: LOCATION OF BENTONITE IN PRINCETON AND TULAMEEN BASINS (Read,1987):

Property	Status	Location Easting	Location Northing	Minfile Number
Hamilton Hill	Showing	FK0661610	FK5485900	092HNE187
Blakeburn	Showing	FK0663340	FK5483760	092HSE157
Princeton Coll.	Showing	FK0681500	FK5480930	092HSE158
Gem	Showing	FK0680000	FK5480180	092HSE159
L987	Showing	FK0676370	FK5479280	092HSE160
Princeton Prop.	Past Prod.	FK0680520	FK5479250	092HSE151
Princeton Prop.	Showing	FK0681020	FK5479220	092HSE151
Copper Mtn. RR.	Showing	FK0679080	FK5475650	092HSE161
L3959	Showing	FK0678570	FK5474260	092HSE162
Ashnola	Showina	FK0678570	FK5472330	092HSE163

HAT CREEK (Read,1990):

Over 50000 metres of drilling, 173 test pits and detailed magnetometer and gravity surveys have been completed by B.C. Hydro and Golder Associates to test the coal-bearing Tertiary strata. In the partings of the Claystone and Hat Creek Members of the Kamloops Group (Upper Eocene- Lower Oligocene age), "appreciable bentonite" (Read,1990) has been located. Not much information is in the public domain, but 2 of the 112 samples of the claystone contained more than 98% bentonite (with respect to clay fraction), and also were more than 5 metres in thickness. The exchangeable cation is mainly Ca^{++}. A good swelling bentonite will expand to more than 15 times its original dry volume (Andrews, 1992), and the swelling tests reported by Read (1990) all have expansion less than 15, indicating that Ca" rather than Na^{+} is the predominent exchangeable cation.

Pacific Bentonite is investigating (Read,1990) bentonite resources in a area with thin overburden on the west side of the deposit. The deposit is at UTM Easting EM0597630, Northing EM5625140, MINFILE Number 092INW084. The company estimates a potential reserve of 30 million (Skermer,1994), and bench scale tests show that it can be soda activated.

FRASER RIVER -- LYTTON TO GANG RANCH (Read,1988):

Bentonite is found in this area in the Eocene section, and is absent in the Cretaceous column. Seven occurrences listed by Read (1988) are in Table 17. No exchangeable cation data is available, but the bentonite has been described as "lenticular and impure".

Numerous bentonite applications do not require the drilling fluid grade swelling bentonites imported from Wyoming, but are used because no other local or regional deposits have been developed. The deposits in the banks of the Fraser River near Lytton are relatively accessible to major urban centres and their swelling and cation exchange properties, when known, could be appropriate for several applications at more competitive prices.

TABLE 17: LOCATION OF BENTONITE IN THE FRASER RIVER--LYTTON TO GANG RANCH (Read, 1988):

Property	*Status*	*Location*		*Minfile*
		Easting	*Northing*	*Number*
Crows Bar	Showing	EM0556300	EM5683650	092OSE098
French Bar	Showing	EM0560700	EM5674000	092OSE099
N.Ward Creek	Showing	EM0562500	EM5664900	092OSE102
S.Ward Creek	Showing	EM0564400	EM5662100	092OSE102
W.Blue Ridge	Showing	EM0578100	EM5638350	092INW092
E.Blue Ridge	Showing	EM0579400	EM5638100	092INW093
Glen Fraser	Showing	EM0580100	EM5631100	092INW094

MERRITT BASIN (Read,1988):

"Bentonite-rich" zones up to 8 metres in thickness occur near coal seams in Quilchena and Guichon valleys" (Read,1988). The locations of these showings are in Table 18. Read (1988) also reports on the cation exchange analyses, and concludes that they are mainly divalent. From swelling and water absorption tests it is reported that the Quilchena deposits are "inferior to that from Wyoming*'.

TABLE 18: LOCATION OF BENTONITE IN THE MERRITT BASIN (Read,1988):

Property	status	Location		Minfile
		Easting	Northing	Number
GUICHON CREEK:				
Coutlee	Showing	FL0653150	FL5562300	092ISE203
Coutlee	Showing	FL0653900	FL5562300	092ISE203
QUILCHENA CREEK:				
Quilchena Creek	Showing	FL0679250	FL5556725	092ISE138
Quilchena Creek	Showing	FL0679100	FL5556540	092ISE138

REFERENCES TO OTHER BENTONITE DEPOSITS:

According to Andrews (1992), bentonite was reported by Keele (1913) at Seventeen Mile House and in the Deadman River valley. These are probably in the Tertiary sequence and similar to the bentonites described by Read in southern British Columbia. Andrews also reports that montmorillonite occurs in the Quesnel area. Green (1989) reported bentonite from Eocene strata north of the Empire Valley Ranch.

Lower Cretaceous bentonites have been reported to occur intermittently for 400 km in Glacier National Park (Andrews, 1992), and bentonite occurrences are reported in the Lower Cretaceous Peace River coalfield (Spears,1984, Kilby, 1985), and in the Mount Klappen area of northwestern British Columbia.

Butrenchuk et al. (1988), indicate bentonite in the Cretaceous-Tertiary sequence of Queen Charlotte Islands.

MINERAL TECHNOLOGY:

EXPLORATION, DEVELOPMENT & RESEARCH:

Although several deposits of bentonite have been located in British Columbia, their evaluation requires completion of systematic material characterization, by determining key physical and chemical characteristics. In this report, bentonite identification techniques, grades and specifications used for a variety of applications are described in some detail. It may not be necessary to complete all the tests. The choice of the test parameters will depend on indication of market requirements and initial tests using one or more key characteristics, e.g. cation exchange capability, can be very useful for evaluation.

Comparisons to Wyoming bentonite sometimes lead to underestimation of bentonite deposit potential. Each deposit should be evaluated with respect to product specifications whose potential for replacing imports or new products has been determined by initial market surveys. Invariably higher priced imports are used because they are the only materials available, and their relative higher grade is not necessary for the product or usage.

In Alberta, where there has been a history of bentonite production, many of the potential sources of recognisable bentonite beds (the Late Cretaceous formations) have been identified by mapping and determination of basic characteristics.

In prospecting and initial location, the unique weathering characteristics of bentonitic sediments are useful, 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. These factors should especially be kept in mind when reviewing past work, because the evaluation may not have included the specific properties required for the usage currently planned.

The exploration for and evaluation of non-swelling calcium bentonites and partly swelling bentonites in British Columbia requires the measurement of the bleadhing and clarification characteristics on a routine basis, and since many of the requirements are user specific, the testing methods require modifications based on potential product and user specifications.

Evaluation of bentonite deposits should include bentonitic sediments, and not be confined to beds of "pure bentonite" . For example, 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. Production from the Late Cretaceous sediments in Saskatchewan has shown that it is, however, possible to produce *some* of the mainstream bentonite products, and even some of the low volume, high value added products from 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 limited activation (for example with polymer extenders and soda ash in case of sodium bentonite).

Ideally, production from bentonite seams can be supported 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, process and product research to produce a wide variety of product specifications from economically minable widths and grades of raw materials. In future material characterization programs in the province, tested and untested sites need to be sampled using mining widths as sampling parameters. Widths of 1.5 metres in areas of overburden strip ratios up to 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 usage and for the agro-chemical industry is **recommended.**

Research is needed to produce mono-minerallic products of sodium and calcium *montmorillonite rather than bentonite* from the 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 and other specialty'products. One avenue for research is the wet processing of bentonitic sediments.

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 a 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.

Strict supervision is required to ensure quality control (Andrews, 1992). After the 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, grade determination by measuring specific physical and chemical properties. In some cases geophysical methods (gamma ray bore hole logging) have been found to be very effective grade determination methods in combination with the other criteria.

Most mining operations include preliminary air drying.and partial activation, for example 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 is also 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. In British Columbia, poorly drained deposits may require mining in cold weather.

BENEFICIATION:

For mainstream products the processing of bentonite requires the removal or reduction of moisture content and other volatile matter, and particle sizing through several stages. Figure 9 *is* a flow sheet from a 5 *tons* per hour French bentonite operation (Industrial Minerals, November 1981).

The high-swelling bentonite types contain usually 30% moisture when delivered to the plant, while the Ca-bentonites have about 25% free water. Moisture in processed bentonite is usually reduced to 7 to 8%. Some non-swelling bentonites (Fuller's earth) can also contain as much as 50% volatile matter and 10% impurities (Andrews,1992).

In Western Canadian bentonite operations, material is first fed 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. In the drier a temperature gradient is maintained with temperatures at 800°C at the inlet, from 400°C to 500°C in the main drying zone, and 100°C to 200°C at the outlet, but the temperature of the bentonite itself is less than 150°C (150°C to 650°C for Fuller's earth). The lower part of the temperature range is for colloidal grades and the higher part for absorbent granules.

Drier product is fed into a system of screens whose mesh size is selected according to product specification. Most bentonite and much of the Fuller's earth used is ground to approximately 90%, <75 microns. Specialty market's

Fuller's earth can be 95% <10 microns. Oversize, generally larger than 3/8 inch is recycled to the drying circuit because of agglomeration due to incomplete removal of moisture. The finer fractions and the mids are either marketed directly, or as granular products or further treated by grinding through a Raymond roller mill and/or activation (e.g. polymer extenders) to enhance properties for specific end usages. 'Additives are generally mixed in paddle-type mixers, using cable feeders for low additive rates, 'and screw feeders for higher additive rates (e.g. 2000g/min).

Particle sizes of the finished products may be controlled by combination of forced air flow and a classification devices known as "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 and sized product is air conveyedcarried 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.

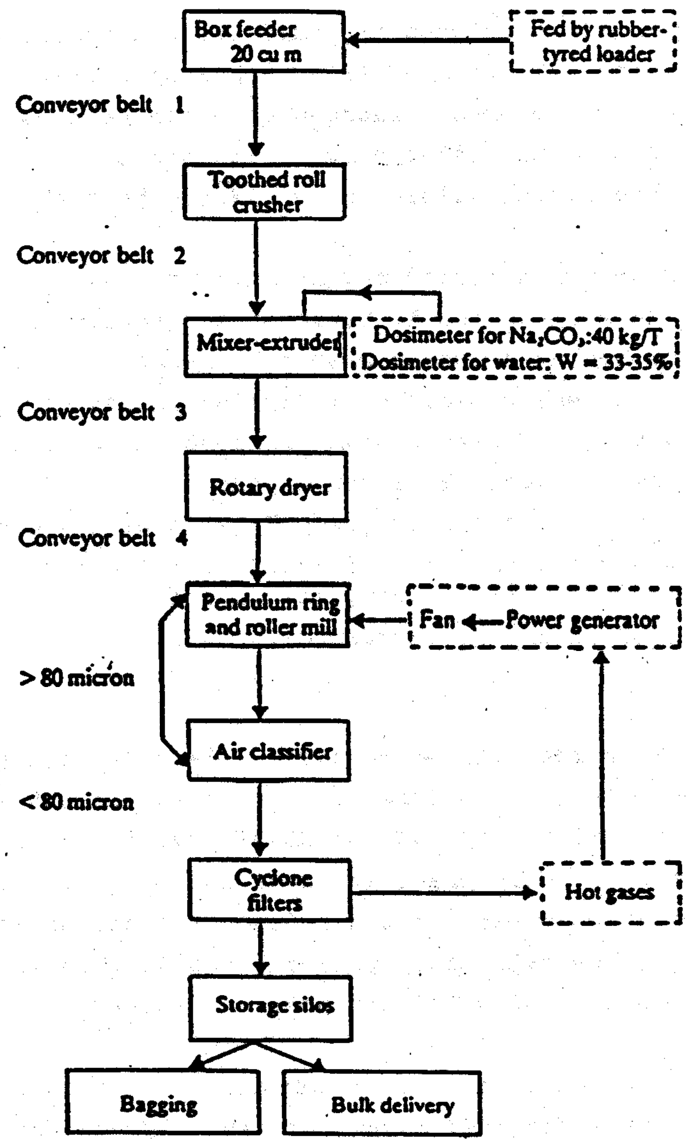


Figure 9: Typical flow sheet for a 4.54 tonnes/hour bentonite processing plant (Industrial Minerals, November 1981).

RESEARCH NEEDS:

In British Columbia and in Alberta there are significant exposures of bentonitic sediments relatively close to developed infrastructure. When the material characterization programs are completed, it is possible that comparisons to Wyoming bentonite will be made. The grades may be determined to be inadequate, because not many bentonite beds of high bentonite to clay, silt and sand ratio will be identified with sufficient width and continuity to provide high grade feed stocks for naturally active bentonite grades.

The replacement of imports from United States and growth of new applications for the local markets may be achieved if one or more of the following suggestions are implemented. Process research is recommended 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 particles, including montmorillonite, and the prevention of agglomeration. Experimentation and process optimisation of process variables, including type and amount of dispersants, and percentage solids will be necessary.

Wet processing will also allow further beneficiation, including reducing organics 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.is already in use for clay beneficiation, e.g kaolin, and a bentonite plant in Nevada is using some of this technology.

Another suggestion for British Columbia bentonites is the processing of high value-added products like acid activated bentonites and organoclays. A plant in British Columbia may be strategically located to handle feed stocks for these products from Alberta and the United States. Montmorillonite product from the newer wet processing technology will be specially 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 environmental remediation remedial action have immense potential for bentonites of geotechnical grades. These grades can be produced from relatively low grade bentonite with minimal activation. Research into development of barriers for specific geotechnical projects requires on site testing and monitoring. In Western Canada there is a significant pool of talent for this research and development.

Research is also necessary for finding commercial methods of blending some of the Province's bentonite grades 'with-natural zeolitic materials to'develop products for a variety of uses. The zeolites find'increasing usage in radioactive waste disposal, sewage-effluent treatment (ammonium ion removal), agriculture'waate water treatment, heavy metals removal from process waste waters; animal nutrition, aquaculture, clarification 'of food materials. Many of these not only overlap traditional benionite usages, but also bentonite would provide the binding power to hold the materials together during application and'subsequent exposure-

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[illegible]

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SECTION 3: ECONOMIC FACTORS:

PRICES AND COSTS

Bentonite is sold to end users in bulk form, by the tonne, or in bagged form. Distribution of product is through industry wholesalers (e.g. Canamera-United, Wyoben, Van Waters & Rogers), retailers and direct sales approach to consumers and 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 fertiliser companies which make pellets from clay. These include Co-operative Fertilisers and Sherritt Gordon. Long term supply contracts requiring competitive pricing and product adaptation are required 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, for example 10 t bagged lots, foundry grade Wyoming bentonite (85% < 200 mesh) delivered U.K is $225 per tonne (Industrial Minerals, December 1992). The price in rail hopper cars or bagged in rail cars FOB plant for Wyoming bentonite ranges from a low of US$ 38.50 per tonne for ceramics, drilling fluids and civil engineering grades, to US$ 55 per tonne for filtering and paint grades, to US$ 95 per tonne for absorbents and desiccants, to US$ 110 per tonne for fertilizer and pesticide use (Kalmakoff,1991). According to the Chemical Marketing Reporter of February 25, 1994 the spot quotations for bentonite range from U.S.$28.60/t to U.S.$30.50/t for bags and carloads F.O.B. works. The cost for bentonite delivered to Smithers in 50lb bags, truckload lots is CDN $400/tonne (Thomas,1993).

Figure 10 from Wright (July 1992), shows the relationship between the dramatic rise and decline in bentonite consumption between 1974 and 1984 and the price of bentonite. As consumption 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.

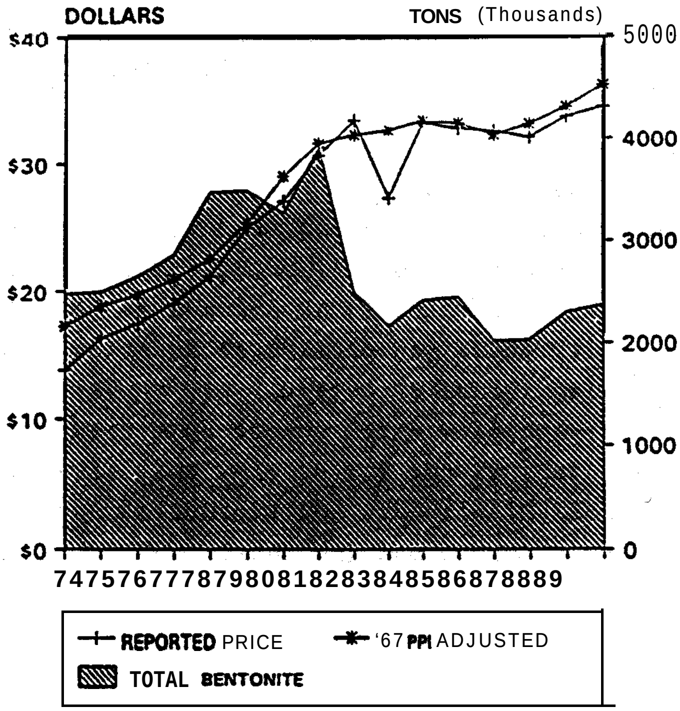

Figure 10: U.S.A. and export pricing. Reported price compared to Producer Price Index price **(Wright,1992).**

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

Mineral Royalty	Can	$00.40
Surface Rights Compensation		00.50
Mining(Stripping,stockpiling,transport)		07.00
Reclamation		00.10
Processing		17.00
Storage & Bagging		11.00
Total Production Cost per tonne		36.00

As stated earlier in this report one of the potential uses for British Columbia bentonite production is the geotechnical applications. A number of engineering consulting firms, bentonite wholesale suppliers, environmental service companies and university staff were surveyed.'These include HBT Agra, Cominco Engineering, Golder Associates, Armtec Construction Products, ID Engineering, Dr. Moir Haug (Department of Civil Engineering, University of Saskatchewan), Van Waters & Rogers, Canamera-United, Russelsteel, Volker Stevin, Hazco Environmental Services Ltd, Elgin Exploration.

For soil sealant and for sealing water wells and civil engineering test wells bentonite is picked up from local suppliers in bags. Na-bentonite from Wyoming is used, partly because of its reputation, but mainly because it is the only bentonite available. One supplier in southern Alberta reported sales of 30 to 40 tons for this use at a price'of $9/50lb bag (CDN$ 396/tonne). Another supplier quoted a price of $5.90/40kg bag (CDN$ 147.50/tonne), for pick up in Edmonton, or $7.75/40 kg bag (CDN$193.75/tonne) delivered to Fort St. John in British Columbia. Most engineering firms were unaware of price and availability, because they rely on the sub-contractors to supply the bentonite. Most sub-contractors for projects in Alberta and northeast British Columbia use drilling mud companies, and order up to two truck loads at a time.

Increasing demand for geosynthetic clay liners was reported. A commonly used type is the Armtec's Claymax bentonite clay liners of Armtec Construction Products which is imported from Georgia, U.S.A.. Price of the liners is $9-$10/m². A sewage system upgrade in Lake Louise, Alberta required 900m² of the liners and a tank farm in Yellowknife, N.W.T. consumed 2,790m². Another project was a sewage treatment pond for the Williams Lake Indian Band that used 9,000m². The data on the annual consumption of Claymax and the actual amounts of. clay used in the liners was not disclosed.

Although sodium bentonite is used in Claymax and for other soil sealant projects in Alberta and British Columbia, it is technically possible to substitute partly swelling bentonites from British Columbia deposits for these end uses. If the Ca-bentonites can be hydrated with fresh water and their swelling is sufficient to impart sufficient self-seaming and self healing properties, they can be marketed to replace the Na-bentonite imports. As a marketing strategy the relative greater stability of the Ca-bentonites under certain conditions, and their cheaper price from local sources can be used. Manufacturers like Armtec may open liner manufacturing plants in the province to reduce shipping costs-- each roll of Claymax is 1700 to 1850 lbs and covers about 130m² -- and to reduce their costs because of the rising value of the U.S.$.

TRANSPORTATION

Transportation costs limit the effective market range of bentonite as it does with other industrial minerals. Table 19 is an example of transportation costs of bentonite products from Hat Creek, British Columbia, which illustrates the relatively high unit transportation costs.

TABLE 19: TRANSPORTATION COSTS FOR BENTONITE FROM HAT CREEK, B.C. (Kalmakoff, 1991) :

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

The most common types of bentonite packaging are bulk shipments in rail cars, bulk ore carriers, and multi-walled 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, therefore, be a major item in the cost of the product.

The method of transportation depends on usage and location of markets. Most of North American bentonite is shipped by rail in bulk hopper cars, some shipments are made by bulk trucks, and for some markets rail boxcars are used. Bagged bentonite is usually pelletized for shipment by rail or truck. Unit trains are used for large shipments to distant points and for.overseas consignments. Partly dried semi-crude bentonite is used for shipments on ore carrier-ships for the Great Lakes and overseas shipments. This allows loading and unloading of bentonite by bulk-handling equipment without bagging, but further drying and grinding is usually necessary at or near the place of usage.

OUTLOOK

According to Kalmakoff (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 sharply by greater than 6%, in the U.S.A. and Canada - the fastest growing market for specialty bentonite. 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, 1991). Bentonite is used as a decolourizing 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.

However, according to Wright (July 1992), historically the drilling fluids, metal casting and iron ore pelletizing (I.O.P.) markets 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 main stream markets will make up the lion share of the bentonite markets.

Wright (July 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 development 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".

Although the above statement is directed to current bentonite producers, the following recommendations by Wright (July, 1992) apply also to potential producers in British Columbia:

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 current 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 users by providing innovative products for existing and new applications.

The costs of production of recent Alberta producers has been reported at $36/tonne in a previous section. Until more data is available this is assumed as a probable cost for a British Columbia producer in south-central area of the province. The cost of transportation from the bentonite deposits in the Hat Creek area to Edmonton is reported at about $32/tonne. This translates to a cost of $68/tonne for B.C. bentonite. For comparison, in Edmonton a 40kg bag of Wyoming bentonite is quoted at CDN$147.50/tonne. Wyoming bentonite delivered to sites in 50lb bags for geotechnical usage by drilling mud suppliers in Alberta is quoted at $12/50lb (CDN$529/tonne). However, a user can get bentonite of civil engineering grade from Wyoming in rail hopper cars or bagged in rail cars FOB plant for U.S.' $30/ton (CDN$45/tonne). The Canadian producer could now compete with imported bentonite on a price basis.

Since the potential producers of bentonite in B.C. will be producing mostly Ca-bentonite they will not be competing with Wyoming bentonite for mainstream usage, e.g. drilling fluids, but will attempt to replace and supplement the imports wherever swelling requirements are not so stringent or important, or in usages where the properties (e.g. adsorption) of Ca-bentonite are preferred over the Na-bentonite types from Wyoming.

Initial development of B.C. bintonite deposits will require convincing current users of imported bentonite that for certain usages locally produced bentonite can be just as effective. For example, potential producers may be required to conduct trials on geotechnical projects with bulk samples from their deposit.

In a systematic program of material characterization of the delineated bentonite reserves the choice of physical and chemical properties for measurement should allow maximum examination of potential for a wide spectrum of existing and new applications (e.g. adsorptive properties). Sampling techniques should emphasize minable widths rather than geological boundaries.

If a large tonnage deposit(s) is outlined after material characterization using minable widths as sampling parameters, then it may be more economic to mine 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.

Other industrial mineral developers in the province may be interested in bentonite if material is readily accessible at economic prices for blending with their product(s), such as zeolites, to enhance their mutual properties.

ESTIMATION *OF* MARKETS *FOR* BRITISH COLUMBIA:

The estimation of markets for calcium bentonite that might be produced in British Columbia is tentatively made with several indirect approaches. The calcium bentonite component of U.S. bentonite consumption appears to be about 17% of the total. It is possible that some substitution by activated calcium bentonite could take place in traditional sodium bentonite markets. Since British Columbia has no consumption of bentonite for the purpose of iron ore pelletizing (typically 15% of the U.S. total), the calcium bentonite consumption could be 20% of the remaining total of uses in the Province.

In the Canada Minerals Yearbook (1992) it is reported that 1991 imports of bentonite to British Columbia amounted to 1,332 tonnes. Using the indicated percentage this would indicate a provincial market for calcium bentonite in the order of 266 tonnes. The delivered cost for the product would be expected to be between $200 and $400 per tonne.

An alternate estimate of bentonite consumption in the Province can be made by assuming that the per capita consumption is approximately uniform across the country, with the exception of the provinces that have iron ore pellet production. Canadian bentonite imports in 1991 amounted to 220,148 reported tonnes. Of this, 158,831 tonnes are estimated to have been used in the iron ore pellet market, leaving 61,317 tonnes for other uses. British Columbia, with about 10 per cent of the national population could have a consumption in the order of 6,130 tonnes of the remaining clay. Of this, if we assume a 20% calcium bentonite component (higher because of the lack of iron ore pellet market in British Columbia), the Provincial market is calculated to be 1,226 tonnes.

There is a probability that this much larger total bentonite tonnage is reflecting drilling mud that is imported from distributors in Alberta by contractors and not formally recorded as imported material. Since drilling mud is typically Wyoming sodium bentonite, it is probable that the 1,226 tonne estimate for calcium bentonite is too high but it may reflect a potential that could be achieved substituting lower cost calcium bentonite in larger volumes.

An estimate of the Pacific Rim calcium bentonite market can be made by applying the assumed proportion of 17% of total bentonite consumption. We can estimate that, from a total bentonite business in the region of, perhaps, 1.4 million tonnes, the calcium bentonite markets could be in the order of 238,000 tonne's. By obtaining 10% of this market British Columbia production units would have a 23,800 tonne business with a value in the order Of $1.5 million on a delivered basis at the Fort of Vancouver.

There is a great risk of under-estimating the market potentials by using this estimating methodology. This risk is underlined by examination of the bentonite production in Montana. Located at a considerable distance from markets, production in 1991 was reported (USBM, 1991) as 362,635 tons valued at $11,332,000 (US $31/s.ton). If the calcium bentonite markets for this production amounted to 17% of the total, we would have a 1991 total value of U.S. $1.9 million for that sector. The impact of energetic market making in a business that is well supplied by existing producers is very difficult'to predict. Any estimates of market size become somewhat academic for a start-up producer who must displace other suppliers.

Market development will also determine the consumption of calcium bentonite as binder in the agro-chemical industry, and its potential usage with other industrial minerals, such as zeolites in the same industries. Increased population growth in the Lower Mainland area will see increasing local food processing and packaging, with greater demand for acid activated calcium bentonite for refining edible oils, fats, soaps, cosmetics, and pharmaceuticals. As more consumer products are processed and packaged in British Columbia, there will be a greater potential for calcium bentonite market development in refining applications including the paint and industrial oil sectors.

An attempt has been made to estimate the potential markets for calcium bentonite in civil engineering applications as this may be a growth market for this clay. The 1991 estimate of this use for the United States was 160,000 tonnes. If we take the population of British Columbia and therefore the industrial activity in the Province to be approximately 0.01% of the United States, we could estimate probable use in the Province for this purpose alone at about 1,600 tonnes.

Engineering companies were canvassed to obtain an estimate for probable consumption and potential markets for this end use. The results were inconclusive, in large part because there was a stated preference for Wyoming bentonite use over a cheaper, local product.

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