BENTONITE IN OREGON:
OCCURRENCES, ANALYSES, AND
ECONOMIC POTENTIAL

1989

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
DONALD A. HULL, STATE GEOLOGIST

SPECIAL PAPER 20

BENTONITE IN OREGON: OCCURRENCES, ANALYSES, AND ECONOMIC POTENTIAL

By Jerry J. Gray, Ronald P. Geitgey, and Gary L. Baxter,
Oregon Department of Geology and Mineral Industries

1989

Conducted in conformance with ORS 516.030

CONTENTS

ILLUSTRATIONS

COVER PHOTO
    View is looking westerly from a bluff near the Mascall Ranch, Grant County, at outcrops of the Miocene-age Mascall
Formation, which contains bentonite beds. Samples 34-39 were taken from this general area.

BENTONITE IN OREGON: OCCURRENCES, ANALYSES, AND ECONOMIC POTENTIAL

SUMMARY

Analysis of the 152 samples collected for this study from various geological basins ranging in age from approximately 4 to 40 million years shows that exploration opportunities for commercial bentonite deposits exist in Oregon. Preliminary laboratory analyses show that Oregon bentonites have a wide variety of physical properties including degrees of swell, water loss, and grit content that could serve a wide spectrum of industrial uses. The potential for large-size deposits exists in the state. Some samples, for example, were taken from outcrops that had thicknesses of tens of feet. Because of its location, Oregon bentonite could offer transportation advantages to markets on the West Coast and in Pacific Rim countries.

Laboratory research conducted for this study identified some sources of error in testing bentonite. Sample preparation was shown to affect physical properties such as water loss and presumably other properties such as viscosity. Previous studies (Wolfbauer, 1977; Auer and Thayer, 1978) mentioned the possibility that sample preparation could affect physical properties but did not describe it in detail.

National and state production and marketing data on bentonite were used in this study to determine the potential size of markets for bentonite from Oregon. Each year, 150,000 to 200,000 tons of bentonite produced in Wyoming and Montana are exported from Pacific Northwest ports. Between 1958 and 1986, two Oregon bentonite manufacturers also produced a total of about 185,000 tons that they sold to a wide range of markets. This study indicates that there are West Coast and Pacific Rim bentonite markets that Oregon could supply.

INTRODUCTION

BENTONITE, THE ROCK, DEFINED

Bentonite is a rock name for a claystone that consists mainly of the mineral species montmorillonite with varying ratios of sodium (Na) to calcium (Ca) to other exchangeable ions of the mineral group smectite. Bentonites are divided into two general classes: those that swell extensively and form a gel (Na-montmorillonite) when mixed with water, and those that do not swell appreciably (Ca-montmorillonite) or form a gel when wetted.

BENTONITE, THE COMMODITY, DEFINED

The terms "sodium bentonite" (Na-bentonite) and "calcium bentonite" (Ca-bentonite) are used as names for the swelling and nonswelling forms, respectively, of the industry commodity bentonite. The mineral terms "smectite" and "montmorillonite" are seldom used by the bentonite industry. For some segments of the clay industry, the term "fuller's earth" is used interchangeably with the term "Ca-bentonite." According to Patterson and Murray (1983), most but not all fuller's earth deposits are actually bentonite. The term "fuller's earth" comes from its first use, which was cleaning or "fulling" wool (removing the lanolin and dirt) by fullers. In the United States, the term "fuller's earth" is applied to clay or other fine-grained earthy material suitable for such uses as bleaching, absorbing, decolorizing and purifying oils, and petroleum processing. In European commerce, the term "fuller's earth" is used only for Ca-montmorillonite.

PURPOSE

The purpose of this study was to conduct a statewide reconnaissance survey of Oregon bentonite that could serve as a guide for additional exploration by industry and realistic planning by government entities. This bentonite study is one of a series of industrial commodity studies that have been or currently are being conducted by the Oregon Department of Geology and Mineral Industries (DOGAMI).

Mineral-resource development offers substantial opportunity for diversification of the state's economy, especially in the rural portions of Oregon that historically have been dependent on surface resources such as timber and agriculture. The export of minerals also can provide additional economic stimulus to Oregon's port cities. The extent to which this mineral development may be achieved depends in part on the availability of high-quality geologic information that can be used to define areas favorable for the occurrence of a variety of valuable nonmetallic mineral deposits.

The nonrenewable nature of most mineral resources means that a variety of mineral resources should be identified in advance of need so that access for extraction can be provided by land-use planning processes. Commodity profiles such as this suggest opportunities for developing new resources, expanding existing operations, adding value to commodities by processing them in the state, and increasing the volume of resources exported to offshore markets.

SCOPE

This study was on a reconnaissance level because of the size of the state, limited time and money, and the large areal extent of tuffaceous units that could contain bentonite. Samples were taken primarily from roadside outcrops. Because of the reconnaissance nature of this report, only general conclusions should be drawn from it. More detailed sampling, including a properly structured drilling and testing program, is necessary before a specific deposit be characterized as having commercial possibilities.

ACKNOWLEDGMENTS

NATIONAL INDUSTRY STRUCTURE

INTRODUCTION

The U.S. Bureau of Mines collects and publishes mineral production and usage data and classifies clay into six groups: ball clay, bentonite, common clay and shale, fire clay, fuller's earth, and kaolin. The classifications are based on industrial usage and may reflect rock name, end use, or a physical property of the clay. Most fuller's earth is composed of Ca-bentonite; therefore, mineral statistics for both bentonite and fuller's earth were used in this study.

BENTONITE

According to Patterson and Murray (1983), the first shipment of bentonite for commercial purposes was made in 1888 from Rock Creek, Wyoming, by William Taylor. During 1986, according to the U.S. Bureau of Mines, bentonite was produced in 13 states. The 1986 output was 2.8 million tons, worth about $91.4 million in value. Wyoming, Alabama and Mississippi, California, and Montana accounted for 56, 17, 9, and 6 percent, respectively, of the national total. Figure 1 shows the total domestic production of bentonite by end use for the period from 1963 to 1986. Production rose from 1.6 million tons in 1963 to 5 million tons in 1981 and declined to 2.8 million tons in 1986. Two trends have combined to lower the demand for bentonite. The first is the falling production of iron pellets in Michigan and Minnesota, and the second is a precipitous decline in oil and gas drilling. Bentonite, however, is being used in increasing amounts in civil engineering applications, including sealing sanitary land fills, sewage lagoons, and cyanide leach pads for heap leaching of gold ore.
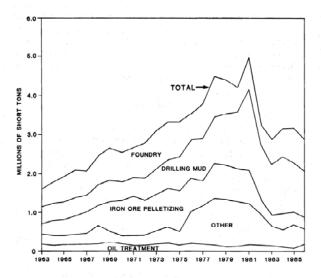
Figure 1. *Bentonite sold or used by domestic producers for specified uses from 1963 to 1986. Data from U.S. Bureau of Mines Minerals Yearbooks, Volume I, 1963 to 1986.*
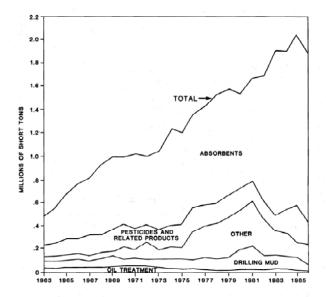
Figure 2. *Fuller's earth sold or used by domestic producers for specified uses from 1963 to 1986. Data from U.S. Bureau of Mines Minerals Yearbooks, Volume I, 1963 to 1986.*

FULLER'S EARTH

According to Patterson and Murray (1983), there is some confusion about when and where the first commercial output of fuller's earth occurred. Small-scale mining of a clay, which was tested for use in refining of cottonseed oil, was reported in 1891 near Alexander, Arkansas. In 1893, a clay deposit containing the amphibolelike clay mineral attapulgite was recognized as fuller's earth near Quincy, Florida, and was developed two years later into a source of fuller's earth for the processing of mineral oil.

U.S. Bureau of Mines statistics show that during 1986 six states reported production of 1.9 million tons valued at $125.5 million. Two states (Florida and Georgia) accounted for 52 percent of the total. Figure 2 shows twenty-three years (1963 to 1986) of production by end use. During these years, output climbed steadily from 0.5 million tons in 1963 to 1.9 million tons in 1986.

COMBINED STATISTICS

To provide a clearer picture of the total U.S. market for bentonite, the U.S. Bureau of Mines production statistics of Ca-bentonite produced as montmorillonite and sold as fuller's earth and the Ca-bentonite produced and sold as nonswelling bentonite were added together in this study to give the total Ca-bentonite production statistics in Table 1 (Plate 1). Total U.S. output of bentonite grew from 3.7 million short tons in 1975 to 5.7 million short tons in 1981 and decreased to 3.8 million short tons in 1986 (Figure 3). Ca-bentonite production averaged 25.6 percent of the total U.S.

*Figure 3. Bentonite, including Ca-bentonite/fuller's earth sold or used by domestic producers for specified uses. Data from U.S. Bureau of Mines Minerals Yearbooks, Volume I, 1963 to 1986.*

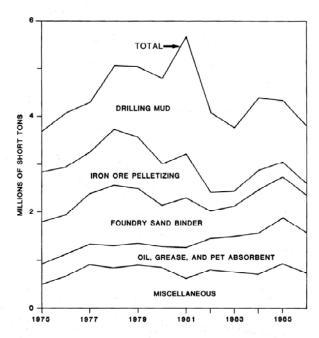bentonite output for the period 1975 to 1981. As the output of Na-bentonite fell from 1982 to 1986, the production of Ca-bentonite rose to 34.4 percent.

USAGE

Drilling mud

For the last 12 years, drilling mud has been and should continue to be a major market for bentonite (Figure 1; Table 1, Plate 1). In the rotary drilling of oil and gas wells, bentonite is used in drilling mud to lubricate the bit, remove cuttings from the bit, and carry them to the surface. It also seals the wall of the hole, prevents drilling-fluid loss, and stops ingress of water from the rock being drilled. The gelling (thixotropic) property of high-swelling Na-bentonite stops cuttings from settling to the bottom of the hole and packing around the drill pipe and bit when the drill stem stops turning. If cuttings were allowed to pack the drill pipe and bit, the drill stem might be stuck to the point where it could not be turned or pulled out. Bentonite used in drilling muds must meet rigid standards set by the industry.

Iron-ore pelletizing

Taconite is cherty or jaspery iron ore that must be finely ground so that the iron-bearing minerals can be extracted. Because the fine dust cannot be used in a blast furnace, the iron-ore concentrate is pelletized by adding a small amount of bentonite to the taconite concentrate in a revolving drum or disk. In addition to its binding action, the bentonite absorbs water from the concentrate, thereby helping to dry it out.

In the past, the mining of taconite iron ore in Michigan and Minnesota provided a large steady market for bentonite. In recent years, however, the market for pelletized taconite

has been declining. According to Kuck (1988), "Consumption of ore and agglomerates at U.S. iron and steel plants dropped to 55 million tons and was only slightly higher than that of 1982, making 1986 the second-worst year for U.S. ore producers since 1939." The mining of iron ore has been moving and will continue to move overseas. An organic binder (Carbinder Polymer 498), which has been developed by Union Carbide Corporation (Rosen, 1988), may be cheaper to use than bentonite and has a lower silica content.

Foundry sand binder

The foundry industry uses bentonite as a binder to hold the refractory sand particles together in a mold that then is filled with metal. The bentonite must be a mixture of non-swelling and swelling bentonite. The Ca-bentonite (nonswelling) gives high "green strength" (the mold holds together until water added to bentonite-sand mixture has evaporated), and Na-bentonite (swelling) gives high "dry strength" (the mold does not break when hot metal is poured into the mold).

The foundry industry seems to exhibit a more steady demand than the oil and gas industry. Specifications are high for this industry, but different users have slightly different specifications, and a producer must be able to meet those individual specifications to be successful in the marketplace.

Oil and grease absorbent and pet litter

The market for absorbent is growing. Major reasons may be the continuing urbanization of the nation and direct advertising to the nation's auto garages and pet owners. There are no formal specifications for this use; however, general characteristics must include high liquid and odor absorbency, no-dust quality, uniform granule size, and wet strength. The market is concentrated in population centers, and the product is often sold in 10-lb sacks. Lower grade bentonite can be used for this market, but by the time transportation and bagging are added, the product commands a high per-ton value.

Miscellaneous

The category labeled "Miscellaneous" in Figure 3 and Table 1 includes a wide variety of markets. There appears to be a relatively steady demand for these "miscellaneous" uses over time, although the individual markets included in the category change over time and are replaced by others.

A current growth market is for "environmental bentonite," used in civil engineering projects to seal sewage lagoons, sanitary land fills, and gold-ore leach pads. Bentonite is also used in sealing irrigation ditches, earthworks, and dams. Bentonite granules can be used to fill diamond-drill holes, seismic shot holes, and the interface between water-well casing and the ground to prevent pollution from moving into an aquifer. An additional civil engineering technique, called "slurry trench or slurry wall construction," is used in digging trenches or walls (Gordon, 1983), which can be very costly and dangerous in unconsolidated earth. In this application, thick bentonite slurry is pumped into the trench as it is being dug. The bentonite keeps the walls of trenches from collapsing. Concrete is then poured into the bottom of the trench; as it fills the trench, the bentonite is drawn off. Alternatively, if a sewage pipe is laid at the bottom of the trench, the bentonite is recovered as the trench is backfilled.

Bentonite is also used as a carrier in horticultural sprays and insecticides, as a suspending agent, and as paste-former and an emulsifying agent for asphalts. It is used for clearing turbid water and for sewage purification. It is also added to concrete to improve workability and to aid in its placement.

EXPORTS

U.S. exports

Between 1982 and 1986, bentonite (not including fuller's earth) was shipped to 92 countries. The export value of the bentonite ranged from $42.5 million to $54.7 million (see Table 2). Exports to Canada and Japan accounted for an average of 29 and 18 percent, respectively, for this entire period. Table 1 shows tonnages and end use of the exports from 1975 to 1986. O'Driscoll (1988) summarized the worldwide status of bentonite in his July 1988 *Industrial Minerals* article, "Bentonite, Overcapacity In Need Of Markets."

Table 2. *U.S. bentonite exports, by country and year (in thousands of dollars).**

Export country	1982	1983	1984	1985	1986
Algeria	$ 65	$ 0	$ 0	$ 0	$ 0
Angola	199	11	124	49	52
Argentina	140	64	37	46	84
Australia	2,666	899	2,738	1,179	1,277
Austria	3	0	0	0	30
Bahrain	77	18	27	0	0
Bangladesh	134	4	8	2	14
Barbados	31	16	13	18	15
Belgium/Luxembourg	33	28	79	43	81
Belize	0	0	28	11	0
Bermuda	0	0	0	5	10
Bolivia	0	71	0	4	2
Brazil	2,551	1,606	1,744	2,071	2,092
Cameroon	34	0	5	0	0
Canada	12,543	11,739	14,507	16,280	12,459
Chile	730	1,184	641	182	526
China	4	2	38	27	121
Colombia	966	609	519	774	201
Congo	57	0	0	0	0
Costa Rica	12	2	38	37	17
Cyprus	0	1	0	0	0
Czechoslovakia	2	0	0	0	0
Dominican Republic	0	10	10	11	24
Ecuador	247	217	230	136	143
Egypt	185	310	197	813	190
El Salvador	37	8	31	8	0
Ethiopia	0	13	0	0	0
Finland	14	0	172	0	0
France	262	545	204	111	124
French Pac. Islands	0	0	3	0	9
Gabon	8	15	256	158	0
Germany West	900	1,832	679	873	127
Greece	5	3	0	2	4
Guatemala	457	31	134	205	14
Guayana	0	0	1	1	0
Haiti	9	5	11	10	1
Honduras	24	55	7	6	7
Hong Kong	234	340	189	210	118
India	33	46	27	38	37
Indonesia	24	898	5	705	9
Iraq	15	0	0	18	0
Ireland	0	2	1	0	1
Israel	167	115	34	0	31
Italy	136	35	4	70	42
Ivory Coast	35	0	0	0	0
Jamaica	88	32	21	20	15
Japan	8,539	7,583	6,990	8,826	9,629
Jordan	0	74	1	0	1
Kenya	0	0	1	3	4
Korea South	952	840	1,256	991	1,456
Kuwait	1,578	647	0	27	278
Lebanon	0	6	3	2	0
Lee/Windward Isles	0	1	0	0	11
Liberia	0	0	67	116	0
Libya	15	0	0	0	0
Madagascar	0	0	0	170	0
Malaysia	136	101	70	483	4,314
Mexico	797	180	525	311	521
Neth. Antilles	16	1	0	0	0
Netherlands	2,303	1,275	2,467	1,645	2,219
New Zealand	50	34	89	94	87
Nigeria	38	2	12	4	0
Norway	275	2	464	118	197
Pakistan	93	90	370	218	9
Panama	37	19	14	27	24
Papua New Guinea	0	52	5	7	0
Paraguay	0	1	2	0	0
Peru	256	169	423	159	88
Philippines	1,192	984	605	439	593
Poland	2	0	0	0	6
Portugal	27	25	12	67	19
Qatar	0	0	14	0	0
Rep. of S. Africa	336	246	253	65	133
Saudi Arabia	4,772	961	705	507	0
Senegal	0	0	0	0	8
Singapore	2,414	2,890	1,725	1,683	1,267
Spain	377	160	214	135	138
Suriname	0	16	13	11	12
Sweden	5	5	5	7	0
Switzerland	21	17	5	3	220
Syria	0	0	0	25	51
Taiwan	897	1,410	1,784	1,788	2,007
Thailand	385	451	625	550	320
Trinidad & Tobago	145	153	210	204	132
Tunisia	64	8	0	0	0
Turkey	8	5	14	7	10
United Arab Emirates	758	780	206	258	20
United Kingdom	2,344	1,128	1,866	1,129	1,499
Uruguay	33	0	15	13	6
Venezuela	2,718	1,536	1,554	886	1,363
Yemen (Sana)	0	0	0	0	77
Yugoslavia	0	0	0	0	0
Total	$54,712	$42,580	$45,375	$44,973	$44,607

*Data provided by International Trade Institute, Portland, Oregon, compiled from U.S. Department of Commerce statistics.

Pacific Northwest exports

Between 1983 and 1986, bentonite was shipped from the ports of Portland, Oregon, and Seattle, Washington (Table 3) to 24 of the 92 countries listed in Table 2. These two ports accounted for 73 percent of the nation's total of 0.3 million tons exported in 1983 but only 39 percent of the national total of 0.4 million tons exported in 1986. Table 3 shows that from three to eight times more bentonite was exported from Portland than from Seattle; however, the Seattle-exported material had a per-ton value twice as high as that being exported from Oregon.

In June 1988, when the pound sterling was floating at around $1.70-1.90 = £1.00, bentonite prices were as follows (Industrial Minerals, 1988):

Wyoming, foundry grade, 85 percent
<200 mesh, bagged, 10-ton lots
del. UK £120-130
FOB plants, Wyoming, rail hopper cars,
bulk, short ton $28.60-30.50
FOB plants, Wyoming, bagged rail cars,
short ton $38.50-39.25
Fuller's earth, soda-ash-treated del.,
UK foundry grade, bagged £70-75
Civil engineering grade, bulk £65-70
Oil Companies Materials Assoc.,
bulk, del. UK £60-65
API, FOB plant, Wyoming, rail cars,
bagged, short ton $44.00-45.50

The above prices suggest that, at that time, foundry-grade bentonite was shipped from Seattle, while lower cost grades were shipped from Portland.

Table 3. *Pacific Northwest exports of bentonite.[1] Values in short tons unless otherwise noted. Numbers do not in all cases add up to totals because of rounding and exports to unlisted countries.*

Year	1983			1984			1985			1986			1987		
Port district	Portland	Seattle	Total	Portland	Seattle	Total	Portland	Seattle	Total	Portland	Seattle	Total	Portland	Seattle	Total
Export country															
Australia	18,229	147	18,376	26,560	190	26,750	19,768	158	19,926	23,666	577	24,243	6,818	1,203	8,021
Brazil	0	0	0	0	0	0	0	0	0	0	0	0	5,614	0	5,614
Canada	0	7,948	7,948	0	7,108	7,108		2,776	2,776	0	2,259	2,259	0	3,683	3,683
China	0	0	0	362	0	362	312	0	312	0	895	895	0	588	588
France	12,478	0	12,478	0	0	0	0	0	0	0	0	0	0	0	0
Hong Kong	4	2,411	2,415	0	521	521	210	100	310	0	139	139	0	418	418
India	0	0	0	0	0	0		0	0	0	0	0	0	66	66
Indonesia	20,647	19	20,666	0	0	0	14,081	0	14,081	0	0	0	0	311	311
Japan	70,585	357	70,942	61,650	694	62,344	91,811	243	92,054	78,736	298	79,034	103,894	7,046	110,940
Korea South	0	2,052	2,052	168	2,669	2,837	0	3,640	3,640	0	2,731	2,731	0	2,784	2,784
Kuwait	13,459	0	13,459	0	0	0	7	0	7	8,871	0	8,871	0	0	0
Malaysia	0	439	439	0	241	241	0	375	375	0	5	5	0	575	575
Netherlands	6,891	0	6,891	0	0	0	0	0	0	0	0	0	0	168	168
New Zealand	0	12	12	0	10	10	0	102	102	0	84	84	0	119	119
Norway	0	0	0	3,182	0	3,182	0	0	0	0	0	0	0	0	0
Other Pacific isles not otherwise listed	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
Peru	0	0	0	0	5	5	77	0	77	0	0	0	0	0	0
Philippines	0	3,240	3,240	0	2,647	2,647	0	2,449	2,449	0	565	565	0	2,310	2,310
Saudi Arabia	10,997	0	10,997	12,696	0	12,696	6,759	0	6,759	0	0	0	0	0	0
Singapore	49,730	500	50,230	27,311	894	28,205	25,199	305	25,504	16,300	967	17,267	10,970	1,800	12,770
Taiwan	1,266	8,173	9,439	59	13,230	13,289	1,699	12,168	13,867	260	16,580	16,840	0	18,782	18,782
Thailand	0	2,167	2,167	0	0	0	57	4,564	4,621	0	1,885	1,885	0	3,182	3,182
United Kingdom	1,796	0	1,796	2,074	4,859	6,933	0	0	0	0	0	0	0	0	0
Venezuela	5,536	0	5,536	8,800	0	8,800	5,762	0	5,762	0	0	0	6,387	0	6,387
Pacific Northwest total	211,618	27,465	239,083	142,862	33,068	175,930	165,742	26,880	192,622	127,833	26,985	154,818	133,683	43,037	176,720
U.S. total			327,319[2]			395,208[2]			463,819[2]			394,164[2]			NA
Pac. NW total % of U.S. total			73%			45%			42%			39%			NA
Total value of Pacific NW exports in thousands of dollars (f.a.s.)	$10,123	$3,256	$13,379	$7,672	$4,576	$12,248	$9,492	$3,027	$12,519	$7,955	$3,030	$10,985	$8,300	$5,231	$13,531
Average value per short ton of bentonite exported	$48	$119	$56	$54	$138	$70	$57	$113	$65	$62	$112	$71	$62	$122	$77

[1] Data provided by International Trade Institute, Portland, Oregon, U.S. Department of Commerce statistics.

[2] See Table 1.

NA = Not available

f.a.s. = free alongside ship

OREGON INDUSTRY STRUCTURE

Oregon has two producers who mine and mill bentonite: Central Oregon Bentonite Company, Roberts Route, Box 500, Prineville, OR 97754; and Teague Mineral Products, Route 2, Box 35C, Adrian, OR 97901 (Figure 4). From 1958, when Oregon bentonite production started, until 1986, about 185,000 short tons were produced in the state and sold.
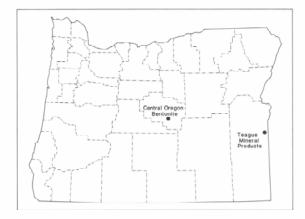

Figure 4. *Oregon bentonite producers.*

CENTRAL OREGON BENTONITE

During 1958, Lewis O. Weaver and other members of his family started producing bentonite under the name Central Oregon Bentonite Company from his ranch and nearby Bureau of Land Management (BLM) land that had been staked with mining claims. An 8- to 10-ton per hour mill and bagging plant was built in 1959. Central Oregon Bentonite Company has marketed its bentonite for cat litter, binder in making stock-feed pellets, ditch and pond sealant, pitch control in paper mills, fire retardant, oil-well drilling mud, and filler in insecticides and fungicides. The mill is located 70 road mi from the nearest railhead and 230 road mi from the Port of Portland.

The bentonite bed is mined from a 3- to 4-ft thick bed in the John Day Formation with a stripping ratio of less than 1:1. An unpublished report by Mason (1981) places mineable reserves at about 3 million tons.

TEAGUE MINERAL PRODUCTS

Teague Mineral Products (Figure 5) started producing bentonite in 1974. The office, milling-bagging plant, and bentonite-zeolite operation is located 1 mi south of Adrian next to a railroad and 1 mi from a siding. The mill, which processes 3 to 7 tons per hour, is 395 road mi from the Port of Portland. The bentonite deposits are located 20 mi south and east on Succor Creek (sample 111, Table 4, Plate 3; Plate 2).
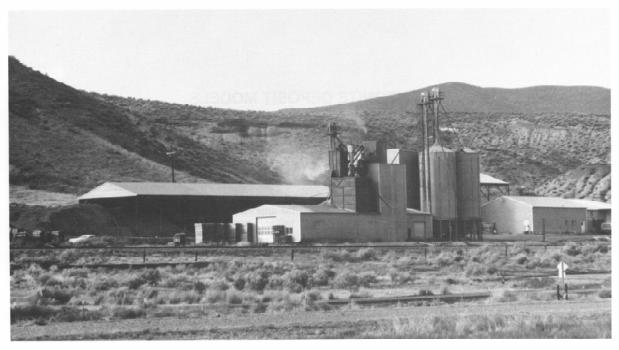

Figure 5. *Teague Mineral Products mill on banks of the Snake River at Adrian, Oregon. The mill is used for storing, grinding, sizing, and bagging bentonite and zeolite mined in several areas of southeastern Oregon. Photo shows stored raw bentonite in open shed on left, silos for storage of finished product at right center. Product from this plant is shipped bagged or in bulk, by rail or truck.*

According to the firm's unpublished data, two different beds have been or are being mined. One bed, the "Main Bed," occurs in an older sequence of beds (Sucker Creek Formation of Miocene age), which strike generally north-south and dip approximately 18° to the west. Vertical faulting subparallel to the strike brings this bed to or near the surface at several locations across the basin and in adjacent basins to the east. Total mineable strike length on the "Main Bed" exceeds 8 mi in the Succor Creek Basin, as determined by outcrop exposures and drill-hole discoveries. The "Main Bed" averages approximately 20 ft thick. Presently, drilled reserves with a 1:1 or less stripping ratio are approximately 1.5 million tons.

The second bed is named "GB Bed" for the graben block zone in which the bentonite occurs. The GB bentonite occurs in a younger sequence of beds (Sucker Creek Formation) that unconformably overlies the older tilted sequence of the "Main Bed." It has a low dip angle, approximately 6° to the southwest. The bed is generally about 30 ft thick. Present drilled reserves with a stripping ratio of about 1:1 are approximately 1 million tons.

Bentonite from this operation has been marketed mainly for use as sealants for sewage lagoons, hazardous-waste sites, gold-ore cyanide leach pads, and drill holes. Other uses are cattle food supplement, water-well drilling mud, and slurry type of trench excavation. The success of the Teague operation is due in part to its laboratory, which provides for qual-ity control of products, and to its applied research for new applications.

MINING AND MILLING OF BENTONITE

Oregon bentonite is produced by open-pit methods. Over-burden is removed and stockpiled for later use in reclama-tion. A bentonite bed is mined in 3- to 4-in. lifts. A disk is used to shave and windrow the top few inches off the ben-tonite bed. The loosened bentonite is air dried for a day or two and may be windrowed again to allow more air drying.

After air drying, the bentonite is removed and loaded into trucks with a front-end loader or with a wheeled elevator and taken to the mill, where it is stored under cover. At the mill, it is fed into a primary crusher, slicer, or breaker unit. At this stage, it may be further dried in a rotary kiln and sent over a screen to produce granules for cat litter. The material may go from the dryer to a pulverizer (Raymond roller mill), where cyclone dust collectors extract the minus-200-mesh pul-verized product.

From the screens and/or cyclone, the material is moved to storage silos. Small amounts of soda ash are added to the bentonite at the mine or at the mill to improve the swelling property of the bentonite. The product is marketed either in bulk form or in bags of sizes ranging from 2,000-lb super-sacks to 10-lb cat-litter bags.

BENTONITE DEPOSIT MODELS

Bentonite deposits form in three different ways (Patterson and Murray, 1983). The first type of deposit—and most important from the commercial standpoint—forms from bedded air-fall volcanic ash or tuff that was deposited into a marine or alkaline-lake environment and subsequently altered to bentonite. Such lakes may or may not have been heated by hot springs. The most common parent volcanic material was andesitic to rhyolitic in composition.

The second type of deposit is a bedded sedimentary deposit in which the bentonite was not altered in place but rather eroded from a preexisting deposit, transported, and deposited into a lake.

A third way bentonite deposits form is by hydrothermal alteration. These bentonite deposits typically are not bedded but occur in irregularly shaped bodies and grade into the host rock through partially altered zones. Fault zones, joints, and other areas of porosity that provide access for heated water control the shape of these bentonite deposits. Kaolinite and jasperoid may be associated with these bentonites.

Plate 2 shows the locations of several large basins ranging in age from 4 to 40 million years in eastern Oregon. During the time each of these basins was receiving sediments, major volcanic activity was occurring, giving rise to air-fall tuffs whose deposition, in turn, disrupted drainages and produced alkaline lakes. The basins trapped transported bentonite, and the volcanic centers produced heat and hydrothermal fluids that caused hydrothermal alteration.

SURVEYING OF OREGON BENTONITES

EXISTING DATA

A search of DOGAMI's Mined Land Reclamation program database for names of past and current bentonite producers revealed that Oregon has two. GeoRef and DOGAMI bibliographies and unpublished commodity and county files were checked for bentonite references. The BLM, the USDA Forest Service (USFS), and county geologists and road engineers were contacted personally by the authors for information on bentonitic areas.

The previously discussed bentonite deposit model of the volcanic ash fall into a basin was used as a guide for this study. Map explanations for the 1:500,000 U.S. Geological Survey (USGS) maps for the east half (Walker, 1977) and west half (Wells and Peck, 1961) of Oregon were used to select tuffaceous sedimentary rock units containing volcanic ash that could have been altered to bentonite clay. The outlines of these rock units were transferred onto a same-scale (1:500,000) base map (Plate 2) and were interpreted to represent basins mostly of Miocene age.

FIELD SURVEYING

The reconnaissance-level field survey included sampling of bentonite beds, mine stockpiles, and finished products of bentonite producers. In addition, roads crossing the identified sedimentary basins were driven for an estimated total of 25,000 mi. Roadcuts, excavations, and outcrops visible from the roads were examined for signs of swelling bentonite such as popcorn weathering (Figure 6; site 40, Plate 2), alligator-hide weathering (Figure 7; site 65, Plate 2), and unvegetated hillsides (Figure 8; sites 40-44, Plate 2). When a likely outcrop was found, a shallow trench was dug to below the popcorn or alligator hide, and a sample was taken (Figure 9; site 12, Plate 2). The sample site was marked on the 1:500,000-scale map and on a 1:24,000-scale map. A small amount of hand augering was done on a couple of outcrops (sites 42-44 and 135-140, Plate 2).
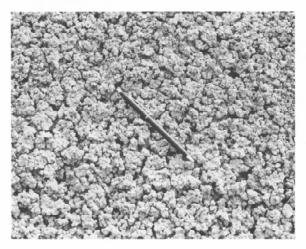
The area covered by this study was extremely large, and a decision was made to sample from locations with expandable soil characteristics. Expandable bentonite, therefore, was the main focus of the study.

All samples were collected by DOGAMI staff except for seven processed samples that were provided by the production firms. Included are two mill samples from Central Oregon Bentonite (samples 86 and 87), one mill sample from a zeolite producer (sample 89), two mill samples from Teague Mineral Products (samples 96 and 97), and one sample each from two Wyoming producers (samples 153 and 154).

OBSERVATIONS MADE DURING FIELD SURVEY AND LABORATORY WORK

During the study, the following observations were made: (1) The surface expression of a bentonite outcrop may appear different, depending on whether it is on the north side of a hill or on the south side of a hill. On the south side, the popcorn weathering seems to be thicker. (2) A siltstone with very little bentonite can produce a good popcorn surface. (3) On an outcrop, a 6-in. layer of bentonite can produce what appears to be a 4- to 5-ft bed of bentonite when the popcorn soil drapes down over an underlying unit. (4) Although field observations indicated no evidence of hydrothermal activity, laboratory analyses of samples 130 and 152 showed anomalous amounts of water-soluble lithium cations, indicating some hydrothermal activity. (5) Sample preparation methods and temperature and length of drying time affected water-loss analyses profoundly (Appendix 8).

COMPILATION GEOLOGIC MAP SHOWING SAMPLE LOCATIONS AND BASIN OUTLINES (PLATE 2)

Plate 2 shows the basin-defined tuffaceous units that were sampled for bentonite, sample locations, and the two producer mines and mills. All but seven samples are considered

Figure 6. Bentonite outcrop at site 40 showing popcorn weathering (see Figure 8).

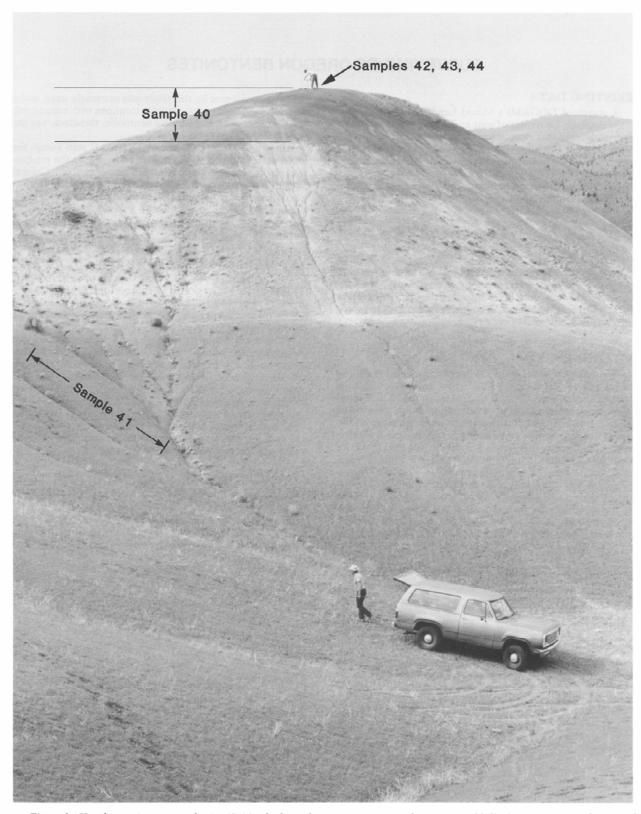Figure 7. Bentonite outcrop at site 65 showing alligator hide weathering.

Figure 8. Hand augering at sample site 40-44, which is a bentonite outcrop with unvegetated hillside. Figure 6 is a close-up of site 40.

Figure 9. Shallow sample trenching of bentonite outcrop at site 12.

to represent ash altered to bentonite in an alkaline lake environment.

Samples 133 through 140 appear to be hydrothermal in origin because of lack of bedding. Sample 46 may be transported material. Samples 5, 6, and 7 appear to be marine sediments with a shallow weathered zone of bentonitic clay.

The reconnaissance nature of this study determines the types of conclusions that can be made from it. For example, it is not known which geological basins or tuff units are most likely to contain commercial bentonite deposits. However, it is clear that a relationship exists between sampling density and geological basins. The sample density is more a function of visible bentonite occurrences than a lack of road coverage. An absence of sample sites does not mean that the area or basin does not contain bentonite. All it means is that in the course of this study the authors did not find any bentonite cropping out along the road in that particular area. Future detailed geologic mapping at a scale of 1:24,000 may show correlations between bentonite beds and specific tuff units that were not detectable at this reconnaissance level.

LABORATORY TESTING

SAMPLES

Of the 154 samples submitted to the laboratory, 147 were collected in the field, and five were mill-run samples from two Oregon Na-bentonite producers and one zeolite producer. Two additional mill-run samples of "Wyoming" bentonite obtained for comparison from two Wyoming producers (American Colloid Company [sample 153] and Federal Bentonite [sample 154]) were also analyzed.

TESTING RATIONALE

Sampling for this study was done to identify deposits of swelling bentonite (Na-bentonite). As field testing for swell was not done, the only sampling control in some cases was the lack of graininess typical of any clay, and it was inevitable that a number of nonswelling materials would be collected. Therefore, a preliminary laboratory test for swell was used to differentiate the swelling (Na-bentonite) and nonswelling (Ca-bentonite) samples. Swell tests with added soda ash were performed to determine which nonswelling samples could be "activated" (made to swell) and which low-swell samples would show improved swell.

Regis (1978) discusses the problems associated with the testing of bentonite, stating, "Testing of bentonite for its specific physical properties and use is hampered by the fact that there are no universally accepted specifications for the major uses. Specific tests for evaluating bentonite for a wide application of uses do not exist." Regis did suggest a testing procedure designed to identify high-grade bentonite, which he characterizes as "one which possesses unique properties which can be mined, processed and marketed for all of the major uses."

Samples were tested for only selected properties in this reconnaissance study. The primary purpose of the study was to identify deposits that had some potential use rather than to find "universal use" bentonite. To that end, samples were tested for a few physical properties that are commonly specified in a variety of applications. Strict adherence to the testing procedures specified by the American Petroleum Institute (API) for certain physical properties was not possible because of equipment limitations. Limited cation analysis was performed to better characterize the materials being tested.

The tests employed in this study included bulk X-ray diffraction (XRD), moisture content, swell (with and without soda-ash treatment), grit content, water loss (with and without soda-ash treatment), and water-soluble and exchangeable cation contents. All tests (other than XRD) were performed in the DOGAMI laboratory. American Colloid Company, Federal Bentonite, and Teague Mineral Products laboratories provided some quality-control data. The test methods are described in the Appendixes.

SAMPLE PREPARATION (PITFALLS)

Bentonite properties are extremely sensitive to the specific manners of sample preparation (see Appendix 8, Tables 12 and 13). Correct and documented preparation of bentonitic samples prior to general testing and correct preparation for certain types of tests are of critical importance. In the laboratory, bentonite becomes a fragile material unless knowledgeable care is exercised.

Three interrelated factors that can affect moisture content and/or particle characteristics and thereby affect physical properties of bentonite were identified: (1) exposure to "elevated" temperatures, (2) type of pulverizer employed, and (3) the mechanical action produced by a pulverizer or other equipment.

Drying at some step in sample preparation is a nearly universal practice. It is apparently done to make a sample more amenable to pulverizing and/or to lower the moisture content to some optimum range wherein the optimum physical properties are retained. (In industry, the latter factor coincides with the desire to reduce shipping weight and is a major production and quality-control problem.) As overdrying can adversely affect physical properties (Papke, 1970; Odom, 1986), the advice of several individuals (R. Berg, G. Teague, D. Leppert; personal communications, 1988) was followed, and samples were pulverized and tested in the air-dried condition.

In similar studies (Berg, 1969; Papke, 1970), samples were uniformly pulverized to a desired particle size (e.g., >90 percent <200 mesh). For a sample that is predominantly bentonitic in content, pulverizing to a very fine particle size should not be necessary; disaggregation upon water slurrying prior to testing should produce extremely fine particles. Pulverizing a less bentonitic sample poses a problem: how to reduce the more abundant concomitant minerals with naturally larger particle sizes to some smaller desired size without overheating the sample. As Berg points out, pulverizing with the wrong equipment can generate sufficient heat to adversely affect physical properties. On the advice of several consultants and producers, a Raymond mill was used in this study for sample pulverizing.

The factor labeled "mechanical action," which is (along with heat) a product of the pulverizer employed, is used here to account for the marked differences in physical properties observed with samples prepared in different types of pulverizers. Mechanical action apparently causes a change in particle characteristics, which, in turn, changes physical properties. This action is probably related to that found in extrusion (Odom, 1986) and compaction (Alther, 1983) processes that are used in industry to beneficiate bentonite. Mechanical action and (mechanically created) heat effects were expected to be minimal with the Raymond mill used in this study.

The requirements for a homogeneous sample for testing are evident. Subsamples of the prepared laboratory sample must be representative of that laboratory sample; the laboratory sample must be representative of the field sample; and the field sample should, in turn, be representative of the deposit.

Because of the effects of sample preparation on sample results, the Appendixes in this report must be consulted when using Table 4 (Plate 3), as the data must be used with the qualifications indicated.

QUALITY CONTROL

For this study, quality control consisted entirely of replicate testing for measurement of precision. Statements of the reproducibility of the various tests are given in the Appendixes. No well-characterized bentonite standard was available for measurement of accuracy.

12

RESULTS

OVERVIEW

Oregon produces commercial grades of bentonite. This study, which is a reconnaissance-level survey, is the first and only statewide sampling of bentonite occurrences. A sampling program with 152 samples is a very small survey for a state the size of Oregon. The heart of this study is the geological-basin outline and sample-location map (Plate 2) and the survey-data table (Table 4, Plate 3). Test results of samples collected from Oregon bentonite occurrences show that Oregon bentonite has physical properties similar to those of samples obtained from commercial producers.

SURVEY-DATA TABLE

The first ten columns of the survey-data table (Table 4, Plate 3) give location and field-site data corresponding to the locations plotted on the map (Plate 2). All of the columns except the sample-interval column are self-explanatory. In it, the intervals listed in the table are slope distances. If the sample was a vertical sample, it was taken from top to bottom of the bed. If a sample interval starts from any number but 0, it means that it was the next sample taken downslope from the previous sample. If there is a gap between the two samples, it means that there were two bentonite beds with a nonbentonite bed between them.

The rest of the table is devoted to results of laboratory testing. The testing included physical tests, mineral determination by X-ray diffraction, and chemical tests. After the test data were listed in Table 4 (Plate 3), the authors spent a great deal of time trying to find relationships between what was seen during field surveying and what was found with the physical tests, X-ray diffraction, and chemical tests. No obvious relationship was found. Others have also found these relationships hard to discover, including Rath (1986),

who stated, "Attempts to correlate physical and chemical properties of bentonite with rheologic properties have been mostly unsuccessful."

The market value of a bentonite source is due to its physical properties. The physical testing in this study indicated that the 18 samples treated, according to common industry practice, with soda ash that had 800 percent or higher swell should be considered Na-bentonite ("Wyoming"). The sixteen samples with 400- to 799-percent swell should be considered to be Na-Ca mixed bentonite, the 48 with 100- to 399-percent swell to be Ca/Na-mixed, and the rest with less than 99-percent swell to be Ca-bentonite, one of the other clay minerals, or a zeolite. The 46 samples that were soda-ash treated and had 10-ml water loss or less should be considered as having possible value for sealing purposes (Dirmeyer and Skinner, 1964).

The data in the grit section of Table 4 must be viewed with reservations. Much of the grit that was listed in the "Crushed" column was shown to be bentonite by the reduction in grit after milling. Another reason the grit percentages may be high is that the samples were not milled, as is called for in industry testing. Even with the above reservations, 17 samples out of a total of 44 milled showed less than 4 percent grit.

To characterize and determine the range of minerals in the grit fraction, 13 samples as received and two milled samples of the 13 were tested by X-ray diffraction. Table 5 shows the results of the X-ray diffraction analyses.

These three physical tests (swell, grit, and water loss) show that many of the deposits that were sampled warrant resampling, detailed mapping, and detailed testing for specific markets. The study results indicate that Oregon has bentonite resources that could meet a variety of end-use markets.

Table 5. *X-ray diffraction results for grit.*

Mineral	Site number														
	2	4	27	32	32*	49	57	58	86	89	93	94	94*	117	139
Quartz	tr	tr	tr	--	--	--	m	m	tr	tr	M	--	--	tr	tr
Feldspar	tr	tr	tr	M	m	M	m	tr	M	m	M	--	--	--	M
Calcite	--	--	--	--	--	--	tr	--	--	--	--	--	--	tr	--
Clinoptilolite	--	--	--	m	m	--	--	--	m	m	--	M	M	tr	--
Cristobalite	tr	tr	tr	--	--	--	tr	--	--	--	--	--	--	--	--
Montmorillonite	tr	tr	--	--	--	m	--	--	--	--	--	--	--	--	--
Kaolinite	--	--	--	--	--	--	--	--	--	--	--	--	--	--	m

```
*  = Sample milled
M  = Major
m  = minor
tr = trace
```

FUTURE STUDIES

This study was designed to be reconnaissance, not definitive. Different approaches, assumptions, laboratory techniques, and laboratory tests would have produced a more nearly complete study. As identification of deposits of swelling bentonite was the first priority of this study, there were biases against collecting fuller's earth/Ca-bentonites and against testing them (where collected) for the properties needed in the fuller's earth market.

This study can be considered, instead, as a large pilot study. Future field studies should include the following: (1) detailed sampling and mapping of sample sites that showed high swell (Na-bentonite), with the sample taken over a long interval (such as was done at sites 15 [0-30 ft], 50 [0-7 ft], 57 [0-10 ft], 62 [0-5 ft], and 121 [0-10 ft]); (2) a rerun of the Ca-bentonites with swell less than 99 percent, as received and acidified for fuller's earth properties; (3) detailed sampling and mapping of those Ca-bentonites; (4) implementation of a much more detailed sampling program in areas with existing detailed geologic mapping to see if correlations can be found between rock units and deposits, thereby making it possible to build a geological model for predicting the occurrence of bentonite resources; and (5) outcrop sampling to relate grade to depth.

Future laboratory studies should include the following: (1) testing for fuller's earth properties; (2) grit testing the rest of the milled samples; (3) running foundry sand binder tests for the Na/Ca-bentonites and Ca/Na-bentonites; (4) viscosity testing; (5) tests for colloid content; (6) pH; (7) gel strength; (8) cation exchange capacity; (9) water loss at reduced pressure (to emulate sealant use); and (10) more detailed mineralogy through XRD analysis.

14

REFERENCES

Alther, G.R., 1983, Low-grade bentonites improved by chemical activation and compaction: Mining Engineering, v. 35, no. 9, p. 1312-1314.

American Petroleum Institute, 1985a, API recommended practice. Standard procedure for field-testing drilling fluids, 11th ed.: Washington, D.C., American Petroleum Institute, API RP 13B, 20 p.

———1985b, API specification for oil-well drilling-fluid materials, 11th ed.: Washington, D.C., American Petroleum Institute, API Spec 13A, 28 p.

Ampiam, S.G., 1985, Clays, *in* Mineral facts and problems: U.S. Bureau of Mines Bulletin 675, p. 157-169.

Auer, D.L., and Thayer, R.L., 1978, Bentonite—update: Production, reserves, quality control, and testing: Salt Lake City, Utah, Society of Mining Engineers of AIME Preprint 78-B-59, 8 p.

Baldwin, E.M., 1964, Geology of Oregon (2nd ed.): Eugene, Oreg., University of Oregon Cooperative Book Store, 165 p.

Berg, R.B., 1969, Bentonite in Montana: Montana Bureau of Mines and Geology Bulletin 74, 34 p.

Brown, C.E., and Thayer, T.P., 1966, Geologic map of the Canyon City quadrangle, northeastern Oregon: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-447, scale 1:250,000.

Corcoran, R.E., Doak, R.A., Porter, P.W., Pritchett, F.I., and Privrasky, N.C., 1962, Geology of the Mitchell Butte quadrangle, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-2, scale 1:125,000.

Dirmeyer, R.D., Jr., and Skinner, M.M., 1964, Evaluation of Colorado clays for sealing purposes: Fort Collins, Colo., Colorado State University Experiment Station, Civil Engineering Section, Technical Bulletin 83, 36 p.

Evernden, J.F., and James, G.T., 1964, Potassium-argon dates and the Tertiary floras of North America: American Journal of Science, v. 262, no. 8, p. 945-974.

Evernden, J.F., Savage, D.E., Curtis, G.H., and James, G.T., 1964, Potassium-argon dates and the Cenozoic mammalian chronology of North America: American Journal of Science, v. 262, no. 2, p. 145-198.

Fleshman, H.G., 1987, Western sodium bentonite industry, 1980's and 1990's: Salt Lake City, Utah, Society of Mining Engineers of AIME Preprint 87-77, 4 p.

Gordon, C., 1983, The slurry wall comes to Seattle: Pacific Builder and Engineer, v. 89, no. 15 (August 8), p. 21-24.

Hampton, E.R., 1964, Geologic factors that control the occurrence and availability of ground water in the Fort Rock Basin, Lake County, Oregon: U.S. Geological Survey Professional Paper 383-B, 29 p.

Hodge, E.T., 1932, Geological map of north-central Oregon: University of Oregon Publication, Geology Series, v. 1, no. 5, 7 p., scale 1:250,000.

Industrial Minerals, 1988, Prices: Industrial Minerals, no. 249 (June 1988), p. 82-83.

Kittleman, L.R., Green, A.R., Haddock, G.H., Hagood, A.R., Johnson, A.M., McMurray, J.M., Russell, R.G., and Weeden, D.A., 1967, Geologic map of the Owyhee region, Malheur County, Oregon: Eugene, Oreg., University of Oregon Museum of Natural History Bulletin 8, scale 1:125,000.

Kittleman, L.R., Green, A.R., Hagood, A.R., Johnson, A.M., McMurray, J.M., Russell, R.G., and Weeden, D.A., 1965, Cenozoic stratigraphy of the Owyhee region, southeastern Oregon: Eugene, Oreg., University of Oregon Museum of Natural History Bulletin 1, 45 p.

Klinefelter, T.A., and Hamlin, H.P., 1957, Syllabus of clay testing: U.S. Bureau of Mines Bulletin 565, 67 p.

Kuck, P.H., 1988, Iron ore: U.S. Bureau of Mines Minerals Yearbook 1986, v. I, p. 495-528.

Leppert, D., 1985, Zeolites and bentonites: The entrepreneurial approach: Adrian, Oreg., Teague Mineral Products, paper presented at 91st annual convention, Northwest Mining Association, Spokane, Wash., 7 p.

Malde, H.E., and Powers, H.A., 1962, Upper Cenozoic stratigraphy of western Snake River Plain, Idaho: Geological Society of America Bulletin, v. 73, no. 10, p. 1197-1219.

Mason, R.S., 1981, Tonnage calculations, Central Oregon Bentonite Company claims, Crook County, Oregon: Unpublished report to Central Oregon Bentonite Co., on file at Oregon Department of Geology and Mineral Industries, 8 p.

Merriam, J.C., 1901, A contribution to the geology of the John Day Basin, Oregon: University of California, Department of Geological Sciences Bulletin, v. 2, no. 9, p. 269-314.

———1910, Tertiary mammal beds of Virgin Valley and Thousand Creek in northwestern Nevada. Pt. 1, geologic history: University of California, Department of Geological Sciences Bulletin, v. 6, no. 2, p. 21-53.

Miles, W.J., and Blair, R.E., 1983, Industrial minerals uses in the drilling industry: Mining Engineering, v. 83, no. 10, p. 1397-1400.

Moll, W.F., 1986, Absorbent clays: Salt Lake City, Utah, Society of Mining Engineers of AIME Preprint 86-334, 9 p.

Newcomb, R.C., 1958, Yonna Formation of the Klamath River basin, Oregon: Northwest Science, v. 32, no. 2, p. 41-48.

———1966, Lithology and eastward extension of the Dalles Formation, Oregon and Washington, *in* Geological Survey research 1966: U.S. Geological Survey Professional Paper 550-D, p. D59-D63.

———1969, Effect of tectonic structure on the occurrence of ground water in the basalt of the Columbia River Group of The Dalles area, Oregon and Washington: U.S. Geological Survey Professional Paper 383-C, 33 p.

Odom, I.E., 1986, Na/Ca montmorillonite: Properties and uses: Salt Lake City, Utah, Society of Mining Engineers of AIME Preprint 86-369, 13 p.

O'Driscoll, M., 1988, Bentonite. Overcapacity in need of markets: Industrial Minerals, no. 250 (July, 1988), p. 43-67.

Palmer, A.R., 1983, The Decade of North American Geology 1983 geologic time scale: Geology, v. 11, no. 9, p. 503-504.

Papke, K.G., 1970, Montmorillonite, bentonite, and Fuller's earth deposits in Nevada: Nevada Bureau of Mines Bulletin 76, 47 p.

Patterson, S.H., and Murray, H.H., 1983, Clays, *in* Lefond, S.J., and others, eds., Industrial Minerals and Rocks (nonmetallics other than fuels), 5th ed.: Salt Lake City, Utah, Society of Mining Engineers of AIME, v. 1, p. 585-651.

Piper, A.M., Robinson, T.W., Jr., and Park, C.F., Jr., 1939, Geology and ground-water resources of the Harney Basin, Oregon: U.S. Geological Survey Water-Supply Paper 841, 189 p.

Prostka, H.J., 1962, Geology of the Sparta quadrangle, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-1, scale 1:62,500.

———1967, Preliminary geologic map of the Durkee quadrangle, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-3, scale 1:62,500.

Rath, D.L., 1986, Origin and characteristics of Wyoming bentonite deposits, *in* Roberts, S., ed., Metallic and nonmetallic deposits of Wyoming and adjacent areas, 1983 conference proceedings: Geological Survey of Wyoming Public Information Circular 25, p. 80-90.

Regis, A.J., 1978, Correlation between physical properties and exchangeable chemistry of bentonites from the western United States: U.S. Bureau of Land Management Technical Note 313, 56 p.

Rosen, M.R., 1988, CARBINDER Polymer 498: A new organic binder for taconite ore: Salt Lake City, Utah, Society of Mining Engineers of AIME Preprint 88-47, 20 p.

Shotwell, J.A., 1956, Hemphillian mammalian assemblage from northeastern Oregon: Geological Society of America Bulletin, v. 67, no. 6, p. 717-738.

Shotwell, J.A., with contributions by Bowen, R.G., Gray, W.L., Gregory, D.C., Russell, D.E., and Taylor, D.W., 1963, The Juntura Basin--Studies in earth history and paleoecology: American Philosophical Society Transactions, v. 53, pt. 1, 77 p.

Smith, W.D., 1926, The southeastern lake province (Physical and economic geography of Oregon, chap. XI): University of Oregon Commonwealth Review, v. 8, nos. 2-3, p. 199-253.

Swanson, D.A., 1969, Reconnaissance geologic map of the east half of the Bend quadrangle, Crook, Wheeler, Jefferson, Wasco, and Deschutes Counties, Oregon: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-568, scale 1:250,000.

Swanson, D.A., and Robinson, P.T., 1968, Base of the John Day Formation in and near the Horse Heaven mining district, north-central Oregon, *in* Geological Survey research 1968: U.S. Geological Survey Professional Paper 600-D, p. D154-D161.

U.S. Bureau of Mines, 1963-1986, Minerals Yearbooks: Washington, D.C., U.S. Government Printing Office.

Walker, G.W., 1977, Geologic map of Oregon east of the 121st meridian: U.S. Geological Survey Miscellaneous Investigations Series Map I-902, scale 1:500,000.

Wells, F.G., and Peck, D.L., 1961, Geologic map of Oregon west of the 121st meridian: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-325, scale 1:500,000.

Wolfbauer, C.A., 1977, Exchangeable cations in Cretaceous bentonites from Wyoming and Montana: U.S. Geological Survey Open-File Report 77-158, 48 p.

Worrall, W.E., 1975, Clays and ceramic raw materials: New York, John Wiley and Sons, 203 p.

APPENDIXES

APPENDIX 1. SAMPLE PREPARATION

Because of recommendations from bentonite producers, a pulverizer was selected that would pulverize but not unduly heat an air-dried but "damp" sample without altering the moisture content. The Raymond mill, a hammer/screen mill equipped with a screen with 0.024-in.-diameter holes, was used to produce a powder of 100-percent <610 micron size. Three producer laboratories used the same or similar pulverizers.

Field samples were air dried in porous olefin bags under room conditions for a period of time ranging from several months to just under two years. Judging by the moisture-content determinations, it appears that the samples retained sufficient moisture so that the tested-for properties were not adversely affected.

Each field sample was crushed in its entirety to minus ¼-in. mesh. The first 97 samples were further reduced by passing them through a BICO pulverizer with plates set with a ⅛-in. gap. Each crushed sample was split on a Jones-type splitter to obtain a raw laboratory sample with a volume of about ½ to ⅔ pint.

Each raw laboratory sample was then pulverized in the Raymond mill to produce the powdered laboratory sample. Sample-to-sample contamination was reduced by compressed-air cleaning of the hopper between samples. As the amount of a sample left within the mill was inconsequential in comparison to the 100 to 200 g of the subsequent sample, and as a small portion of this next sample was then milled and discarded, carryover contamination was considered to be negligible.

The powdered laboratory sample was homogenized by rolling on a rolling cloth. This procedure was difficult because of the bulk of the sample but appeared to be effective, as judged by the close correlation of replicate analyses for water-soluble cations. The action of the mill itself apparently did much of the homogenizing. Each powdered laboratory sample was stored in a waxed-paper pint container to await testing.

APPENDIX 2. X-RAY DIFFRACTION PROCEDURES AND INTERPRETATION

For identification of the major clay and nonclay minerals, about 10 g were split from each crushed sample for bulk X-ray diffraction (XRD) analysis. Each split was hand ground to approximately minus 100 mesh and placed in a side-loaded powder pack mount. The samples were scanned from 2° to 65° 2 theta at a rate of 2° 2 theta per minute on a General Electric diffractometer with nickel-filtered copper radiation. The bulk samples were run by W.S. Titus under the supervision of M.L. Cummings, Department of Geology, Portland State University. Because of the large number of samples collected and the initial lack of in-house facilities for separation and X-ray diffraction, only bulk samples were run. No attempt was made to more fully characterize the clay by expansion, heat treating, or preparing oriented samples. Table 4 (Plate 3) contains the bulk-sample XRD data.

The grit fraction (wet sieved, plus 230 mesh) of selected samples was analyzed in the Oregon Department of Geology and Mineral Industries (DOGAMI) laboratory on a Philips diffractometer with nickel-filtered copper radiation. The samples were scanned from 2° to 55° 2 theta at 2° 2 theta per minute.

Peaks were used to identify minerals, and peak heights were used to estimate their relative concentrations. Because some of the samples contained large components of non-crystalline volcanic ash or poorly crystallized clay minerals, reported minerals may constitute only minor or trace amounts of the total sample. More exact determination of the amount of each mineral phase was precluded by the variable degree of crystallinity, the high potential for preferred orientation of the mounted samples, and the inherent difficulties in any X-ray diffraction method of obtaining quantitative measurements in samples with several mineral phases.

17

APPENDIX 3. MOISTURE CONTENT

Moisture content was determined to provide information on the degree of hydration of all samples prior to testing and to allow calculation of equivalent weights (as per API Specification 13A) (American Petroleum Institute, 1985b) of sub-samples to be tested for water loss.

A 5-g portion of an air-dried, Raymond-milled sample was weighed and placed in a tared aluminum dish, dried at 105 °C to constant weight, and cooled to room temperature in a desiccator. The dish + dried sample were then reweighed, and the moisture was calculated as in API Specification 13A (American Petroleum Institute, 1985b). A trial test of 12 samples showed that 4 hours' time at temperature of 105 °C was sufficient to reach constant weight. This time was used for subsequent samples.

APPENDIX 4. SWELL (PERCENT EXPANSION)

Swell is a somewhat crude field test that has been "upgraded" to a laboratory test. As Auer and Thayer (1978) point out, "This test procedure is very sensitive to operator technique." They list the most critical variables as the following:

1. Rate of addition. (Longer addition time tends to produce higher swell values.)

2. Size of addition. (High swelling clays can form "gel bridges" in the graduate, greatly increasing settling time.) The additions must be very small and isolated from the walls of the graduate.

3. Operator judgment when reading the final sediment volume. (It was noted that in their report they spent two hours to sprinkle a 2-g sample.)

Test trials in this study with a much shorter time interval showed that the use of test samples measured by volume gave results that could not be consistently reproduced. Replicate tests using samples measured by weight, if run back-to-back, gave excellent reproducibility. But weight-measured samples tested over several weeks gave results that varied from poor to good in reproducibility.

For this study, the change in volume was ratioed to the test sample weight.

Calculation

$$\text{Percent expansion} = \frac{100 \text{ (final volume - initial volume)}}{5 \text{ g}}$$

Correction for moisture content was not made. The initial volume was set at 8 ml and was determined by measuring and averaging the volume of three "typical" samples.

Method for determining swell without soda ash addition

1. Add weighed (nominal) 5.000-g sample (air-dried, Raymond-milled) slowly to a 100-ml graduate containing 100 ml of distilled water. Let each small addition of sample become wetted and sink before adding more sample.

2. Age 24 hours and then read volume of sample to nearest milliliter.

Method for determining swell with soda ash addition

After swell test in distilled water:

1. Pour off most of the water, retaining as much of sample as is possible in the graduate.

2. With a stream of the soda ash solution (0.25 percent wt./vol. in water, anhydrous sodium carbonate, reagent grade) in a plastic wash bottle, stir up the sample in the bottom of the graduate. Stir the slurry with a stainless-steel spatula.

3. Fill to 50-ml mark with the soda ash solution.

4. Let set overnight and read volume of sample to nearest milliliter. The soda ash solution provided, with respect to the 5-g sample, the equivalent of approximately 19 meq of sodium cation per 100 g of sample. The maximum swell that could be measured under these conditions was 840 percent, which proved to be inadequate for many samples.

Quality-control replicates

Two or more replicate swell tests were performed on 34 samples without and 25 samples with added soda ash solution. The reproducibility ranged from poor to good.

Comments

While swell testing will distinguish between swelling and nonswelling bentonites, the data herein should not be used for absolute statements of swell capability. The vagaries of the test method dictate caution. The less rigorous swell tests with added soda ash require greater caution. As soda ash addition is an industry practice, these data do provide a rough measure of the potential of the Oregon bentonites.

APPENDIX 5. GRIT

A preliminary wet-screen test for grit content of all the samples was performed on the air-dried, as-crushed splits. Selected samples were subsequently wet-screen tested for grit on dried (at 105 °C) Raymond-milled splits. The method for the milled samples follows that of Berg (1969, p. 10) rather than the more stringent method in API Specification 13A (American Petroleum Institute, 1985b). Both sets of data are reported in Table 4 (Plate 3).

Method for grit on as-crushed samples

1. Place an approximately 5-g sample in a stainless steel mixer cup and add about 0.02 g of $Na_3PO_4 \cdot 12H_2O$.

2. Add about 200 ml of hot tap water and stir for about 5 minutes on the Hamilton Beach mixer.

3. Swirl the slurry and pour onto a 230-mesh (63-micron) stainless steel sieve.

4. Wash screen with copious amounts of hot water.

5. Estimate the amount of the grit retained on the screen.

If the grit was approximately 10 percent or less (by weight) of the original sample, a subsequent test of the sample in the milled form was performed. Where the sample slurry would not wash well because of gel formation and where the grit content appeared to be low (by feel), a test on the sample in milled form was performed. Otherwise, all samples with a water loss of 20 ml or less (in distilled water) were tested in the milled form for grit.

Method for grit on milled samples

1. Dry a nominal 20-g sample overnight or at least 8 hours at 105 °C.

2. Weigh the dried sample to three places after the decimal and transfer to a stainless steel mixer cup; add about 200 ml of hot tap water and 0.02 g of $Na_3PO_4 \cdot 12H_2O$ to the cup.

3. Mix for about 30 minutes. Watch for temperature buildup on mixer motors.

4. Let set for a minimum of 12 hours to age.

5. After aging, remix for 5 minutes and then pour slurry onto 230-mesh stainless steel sieve.

6. If any material remains in the bottom of the cup, add some water, mix, and add to material on the screen.

7. Wash thoroughly with the Gilson triple-head, conical-pattern sprayer to remove all of the undersize material.

8. Transfer the oversize to an aluminum dish, dry, and weigh.

Calculation

$$\text{Percent grit} = \frac{(\text{weight} > 230\text{-mesh fraction})}{\text{dry sample weight}}$$

Quality-control replicates

The reproducibility for grit was adequate; ten samples were tested in replicate (Table 6).

Comments

Grit is a specification applicable to a commercially produced bentonite: a milled product that is largely minus 200 mesh (dry screen). Wet screening of a minus ¼-in. mesh product, as was done for all samples in this study, is effective for measuring grit only in samples that disaggregate readily. Wet screening of selected Raymond-milled samples employed US 230-mesh (63-micron) sieves instead of the US 200-mesh (74-micron) sieves specified by API Specification 13A (American Petroleum Institute, 1985b).

Because of the emphasis on swelling bentonites in this study, it is likely that a number of nonswelling bentonites with low grit and of potential use were overlooked because one criterion (water loss) limited the number of the milled samples to be tested.

Table 6. *Replicate grit analyses.*

Map sample no.	Grit - as crushed (%)	Grit - milled (%)
37	1.80, 1.72	--------
61	8.49, 6.69	3.15, 3.21
72	2.96, 2.85	--------
73	1.73, 0.97	--------
94	5.92, 6.02	--------
111	0.52, 0.45	--------
117	0.96, 1.77	--------
127	<0.01, 0.09	--------
130	21.44, 22.60	--------
153	--------	3.18, 3.22

19

APPENDIX 6. WATER LOSS

A modified form of the API Specification 13A (American Petroleum Institute, 1985b) method for water loss, or "filtrate of suspension" (API designation), was used. The major differences were the mixer employed (13,000 rpm vs. 11,000 rpm, as specified), the mixer impeller, and the mixing times that were limited in this study because of motor overheating). These factors had a major consequence on the accuracy of the data developed (see "Comments" below). Two Baroid filter presses were used.

The samples were tested in distilled water, both with and without added soda ash (anhydrous sodium carbonate, reagent grade). The soda ash provided, with respect to the 22.5-g test sample, the equivalent of 70 meq of sodium cation per 100 g of sample.

Method for water loss

1. For each sample, weigh duplicate 22.5 ± 0.01-g samples (or the weight equivalent to 22.5 g at 10 percent moisture for samples with >10 percent moisture). Place each in a 1-quart canning jar. About 10 samples in duplicate can be prepared at one time for testing on the next day.

Calculation of equivalent weight

$$\text{Equivalent weight of sample} = \frac{20.25 \text{ g}}{(100\% - \%H_2O) \times 0.01}$$

NOTE: If the moisture content of the clay (as received) exceeds 10 percent by weight, use a weight of clay that is equivalent to 22.5 g with 10 percent moisture (American Petroleum Institute, 1985b, p. 14). A 22.5-g sample with 10 percent moisture contains 2.25 g water and 20.25 g bentonite.

2. Place a jar with sample on the top-loading electronic balance, zero, and add 350.00 ± 0.25 g of distilled water (or soda ash solution).

3. Cap the jar with the canning lid and shake by hand until the sample is thoroughly wetted.

4. Let age for a minimum of 16 hours. Trial tests indicate longer aging is not detrimental.

5. After aging, mix the duplicates of a sample for 5 minutes using Hamilton Beach Mixer immediately prior to testing.

6. Pour each slurry into a separate clean and dry test cell with new filter installed and cap. Make sure the cells are not leaking. Make sure the relief valves are closed and a dry graduate is in place.

7. For the first test sample, simultaneously start the stopwatch and open the valve to admit the compressed air. Check to make sure the pressure is at 100 psi. After an interval, start the second test sample in the same manner.

8. After 7.5 minutes, quickly remove the graduate, collecting any liquid adhering to the collection tube, and replace with a dry graduate. Continue to collect the filtrate. Read the 7.5-minute volume to the nearest 0.5 ml and record.

9. At the end of 30 minutes, quickly remove the graduate, collecting any liquid adhering to the collection tube. Close the compressed air valve and open the relief valve. The second test sample is carried through the same series of steps.

10. Read the 7.5- to 30-minute filtrate volume to the nearest 0.5 ml and record. The filtrate volume collected during the 23.5-minute period is the volume reported in Table 4 (Plate 3). The API term for this volume is "filtrate-related 30 minutes."

Quality control

The reproducibility for water loss was generally good. Replicate data are given in Table 7. Table 8 provides a comparison of DOGAMI's data with that of other laboratories.

Comments

A comparison of the water-loss data from four laboratories—apparently obtained in strict adherence to the API method—with DOGAMI data indicates that the latter are significantly lower. DOGAMI data for water loss should be multiplied by 1.9 to obtain results that are comparable to API results (see Table 9).

The apparent cause is the 2,000 greater revolutions per minute (rpm) (versus that of the specified mixer) of the DOGAMI mixer and/or mixer impeller used in this study. The greater mechanical action caused an apparent beneficiation as far as water loss is concerned. However, as DOGAMI tested all of the samples and established that the precision of these results was good, the data are included in Table 4 (Plate 3).

Table 7. *Replicate water-loss analyses.* *

Map sample no.	Untreated water loss (ml) A	B	C	Treated water loss (ml) A	B	C
10	33.0	32.0	--	--	--	--
15	11.5	12.0	--	8.5	9.0	--
16	12.5	15.0	12.5	8.5	10.5	9.5
21	10.0	16.0	--	--	--	--
32	20.5	26.0	--	--	--	--
37	73.5	87.0	--	--	--	--
50	12.0	11.5	--	--	--	--
56	40.0	39.0	--	--	--	--
61	10.0	9.5	--	--	--	--
65	33.0	40.0	--	--	--	--
72	75.0	75.0	--	--	--	--
73	57.0	82.0	--	--	--	--
94	33.0	35.0	--	--	--	--
102	43.0	39.0	--	13.0	13.5	--
103	22.5	26.5	--	11.5	13.0	--
104	35.0(?)	25.0	--	10.5	10.0	--
107	17.5	19.0	--	--	--	--
111	8.5	8.0	--	--	--	--
117	17.5	19.0	--	--	--	--
127	12.0	12.5	--	--	--	--
130	9.5	12.0	12.5	--	--	--
145	TE	TE	--	TE	13.5	--
151	9.5	9.0	--	--	--	--

*Additional replicates given in Table 12.
TE = Totally expelled: >350 ml

20

Table 8. *Interlaboratory comparisons of water loss.**

Map sample no.	AC	FB	T	A-1	A-2	DOGAMI	Map sample no.	AC	FB	T	A-1	A-2	DOGAMI
10	--	--	--	77	60	33	81	--	--	--	96	147	29
11	--	--	--	112	85	57.5	86	23	21	--	--	20	11
12	47	--	44	113	35	20	90	--	--	--	93	64	42
13	--	--	--	50	42	22.5	91	--	--	--	43.5	90	39
14	--	--	--	78	--	32,33,30.5	92	--	--	--	55	28	17.5
15	--	23	--	71	22	12	93	--	--	--	103	--	22.5
16	25	--	--	32	24	12.5,15	94	--	--	--	84	78	33
17	--	--	56	130	--	31	99	--	--	--	80	--	33.5
19	--	--	--	98	--	31	101	--	--	72	137	--	34.5
20	--	32	34	34	26	13	102	--	--	--	65	66	41
21	--	--	--	40	32	17	103	--	--	--	48	46	24.5
22	--	--	--	55	35	18	104	51	--	56	50	39	30
23	--	--	--	31	23	12.5	105	--	--	--	71	--	77
26	--	--	92	200	--	88	108	--	--	--	65	--	75
28	--	--	--	86	--	59	109	--	--	90.5	72	--	79
29	--	--	--	39	--	16.5	112	--	--	--	88	16	7
30	--	--	--	88	--	40	113	--	--	--	77	70	35
31	--	--	--	38	--	10	114	--	--	134	75	104	52
32	--	--	--	53	46	20.5	116	--	--	--	155	26	14.5
34	--	--	50	89	--	82	117	--	40	42	75	33	17.5,19
36	--	--	--	98	--	88	118	--	--	--	93	20	11
37	--	--	124	99	--	73.5	120	--	--	--	49	34	18
38	--	--	--	--	72,75	47	121	47	--	50	38	42	20
39	--	--	--	--	06,112	88	122	--	--	--	22	--	14.5
40	80	--	--	126	--	49	123	--	--	--	100	21	12.5
41	--	--	--	138	--	53	124	--	--	--	25	--	10
42	--	--	--	--	102	49	125	31	--	--	25	30	14.5
43	--	--	--	--	50	36	126	--	--	--	29	30	15.5
44	--	--	--	--	57,60	41	127	--	--	--	72	23	12
45	--	63	46	75	39	27	128	--	--	--	69	25	10
47	--	--	--	75	--	47	129	--	--	--	86	--	9
49	--	--	--	43	--	23	130	--	30	--	160	22	12.5
50	27	--	--	24	44	12,11.5	132	--	86	--	32	73	49
54	--	--	188	38	--	95	141	--	--	--	65	--	44
55	--	--	--	60	--	15	142	--	--	71	114	--	82.5
56	--	--	--	33	--	40	145	--	--	142	200	292	>200
57	--	--	--	--	32,30	20	147	--	--	--	31	24	10
58	--	--	--	--	23,21	14.5	148	--	--	240	250	--	TE
60	--	--	--	80	--	10	150	--	135	--	130	--	62
61	--	--	--	--	16,18	10	151	--	--	--	39	21	9.5
62	--	--	--	--	38,38	24.5							
65	--	--	67	135	--	33							
73	--	--	--	--	114	57							
74	--	--	250	160	--	118							
76	--	--	--	164	--	134							

*Laboratory and its sample preparation prior to water-loss testing:

[1] AC = American Colloid. Tested air-dried, minus 1/8-inch mesh samples as prepared in DOGAMI lab.

[2] FB = Federal Bentonite. Same as above.

[3] T = Teague Mineral Products. Air-dried, Raymond-milled sample, 100 percent <610 microns.

[4] A-1 = Lab A (Preparation method #1). Dried sample at 66 °C for 16 hrs and then pulverized in a BICO disc pulverizer.

[5] A-2 = Lab A (Preparation method #2). Tested air-dried, Raymond-milled sample, 100 percent <610 microns.

TE = Totally expelled.

Table 9. *Summary of ratios of individual laboratory results with respect to the corresponding DOGAMI results.*

Laboratory[1]	Ratio average[2]	No. of samples	Ratio range
AC	2.04	8	1.70- 2.35
FB	2.15	8	1.76- 2.46
T	1.83	18	0.61- 2.62
Lab A-1[3]	3.26	75	0.40-12.80
Lab A-2	1.89	57	1.20- 5.07

[1] See footnote to Table 8 for identification of laboratories.

[2] Average of ratio averages (AC, FB, T, and A-2) = 1.9.

[3] The Laboratory A-1 results were considered to be unreliable. Two factors in Laboratory A's sample preparation method, drying and pulverizer employed, apparently altered the water-loss properties of most of the samples tested. This same laboratory, when testing samples prepared by the DOGAMI laboratory, produced results (A-2) that closely corresponded to the other results (AC, FB, and T). Berg's (1969) warning on the use of a disc-type pulverizer was not heeded by Laboratory A.

Limited trial testing indicated that water loss of some bentonites may be adversely affected by extended drying at the relatively low temperature of 66 °C. While not confirmed, the effect appeared to be limited to some, but not all, samples with Ca or Ca + Mg as the predominant cation(s).

APPENDIX 7. CATION ANALYSIS

The cation extraction methods of Wolfbauer (1977) were modified for use in this study. The process consists of "washing" the samples to remove the water-soluble cations (WSC) and then extracting the exchangeable cations (EC) from the washed samples. The water-soluble cations and the exchangeable cations—of Na, Ca, Mg, K, and Li in both cases—were determined. The SO_4 ion, suspected by Wolfbauer to be the water-soluble constituent contributed by gypsum (common in many bentonites), was not determined. The cation exchange capacity (CEC) of the samples was not determined. However, the sum of the individual exchangeable cations (Regis, 1978) can be used as an approximate measure of cation exchange capacity; this summation is included in Table 4 (Plate 3). Determination of the cation contents was accomplished as indicated below.

ATOMIC ABSORPTION (AA) AND EMISSION ANALYSES

General information

Two sets of artificial standards and a reagent blank, one set for WSC and one for EC, were prepared for analysis of the samples. Aliquots of the 1,000-ppm cation solutions (99.999 percent purity) were made by weight to 0.0001 g on an electronic balance. The concentrations of the cations were calculated in terms of milliequivalents of cation per 100 g of sample (with respect to sample weight [0.5 g] in final analytical sample volumes) for instrument calibration. The standards and blanks contained La for WSC and La + acids + $BaCl_2$ for EC in order to match the matrix solutions of the samples.

Prior to analysis, the absorption or emission readings of the standards were obtained. For each cation, a reading vs. concentration curve was plotted to determine linearity and off-curve standards. Choice of the "high" standard (falling on the linear portion of a curve) was made, and this standard was used for blank/single-standard curve calibration. The reagent blank was used to zero the instrument. Corrections for contamination arising in the extraction, drying, and other steps were obtained from the "reagent + process" blanks and were applied to the data where warranted.

As these cations have few analytical lines, burner size (5 cm or 10 cm) and burner orientation with respect to optical path were the only parameters available for bringing sample absorbence/emission readings within the linear range. Dilutions of sample solutions were made where necessary. For each cation, three sequential, 2-second integrations were made. The Perkin-Elmer Model 4000 spectrometer used in this study provided automatic calculations of the average and coefficient of variation. A printer provided a permanent record of the data.

The instrument parameters used for both water soluble and exchangeable cation analysis are listed below. The flame used in all cases was air-acetylene.

Atomic absorption analyses

Na	Ca	Mg	K
589.0 nm	422.7 nm	285.2 nm	766.5 nm
Na HCL	Ca/Mg HCL	Ca/Mg HCL	Na/K HCL
0.7-nm slit	0.7-nm slit	0.7-nm slit	0.7-nm slit

HCL = Hollow cathode lamp

Emission analyses

Li
670.8 nm
0.2-nm slit

Method for water-soluble cations (0.5 g / 50 ml)—extraction and preparation for analysis

1. Weigh 0.5000 ± 0.0001 g of air-dried, Raymond-milled sample and transfer to a 50-ml "Falcon"-type plastic centrifuge tube.
2. Add via dispenser 25 ml of distilled water, cap the tube, and vortex until sample is thoroughly wetted.
3. Shake for 10 minutes (tubes in vertical position, shaking in horizontal direction.)
4. Centrifuge for 10 minutes at maximum rpm (3,400 rpm = 2,430 relative centrifugal force [RCF]).
5. Uncap the tube and very carefully decant the liquid onto a #42 Whatman filter/funnel assembly. Catch filtrate in a 100-ml plastic Tri-pour beaker.
6. Repeat steps 2 through 5 TWO more times. (Reserve filter paper and sample in the centrifuge tube.)
7. Reduce the filtrate volume to 30-40 ml (do not take to dryness) by heating at 105 °C in the horizontal air flow oven. Remove and cool to room temperature.
8. Transfer the reduced volume filtrate to a clean 50-ml "Falcon" centrifuge tube. Rinse beaker once with distilled water and add washings to tube.
9. Add via dispenser 5 ml of 10,000 ppm La solution (99.999 percent purity, in 0.3M HCl) for ionization suppression. Final concentration in sample is 1,000 ppm).
10. Carefully make to 50-ml volume with distilled water. Cap and store for analysis. Centrifuge those samples that have carry-over colloids.

A distilled water blank (one for every 20 samples) was carried through all of these steps; this blank was called the "reagent + process" blank.

Method for exchangeable cations (0.5 g / 100 ml)—extraction and preparation for analysis

1. Add 25 ml of the $BaCl_2$/alcohol extractant to the residue remaining from the water washing (for water soluble cations). Cap and vortex to disperse the residue.
2. Shake for 10 minutes.
3. Centrifuge for 10 minutes at maximum rpm.
4. Carefully decant the liquid onto the same filter (in a funnel) used for the water soluble cation filtration. Catch the liquid in a 100-ml Tri-pour plastic beaker.
5. Repeat steps 2 through 4 TWO more times.
6. In the moving air stream of a fume hood, reduce the alcoholic content of the liquid to a barely perceptible level (to reduce the flammability).
7. Take the barely alcoholic liquid to dryness at 105 °C in the oven. Remove the beaker and cool to room temperature.
8. Place the beaker with its dried residue on the top-loading electronic balance, zero, and add 100 ± 0.20 g of the acid extractant.
9. Cover the beaker and let set overnight to dissolve the residue.

10. Transfer 50 ml of the resultant solution to a clean 50-ml "Falcon" tube, cap, and store for analysis. The excess solution is discarded.

A BaCl$_2$/alcohol blank called the "reagent + process" blank (one for every 20 samples) was carried through all of these steps:

BaCl$_2$/alcohol extractant — 0.1N BaCl$_2$ in 68 percent alcohol: Dissolve 12.214 g of reagent grade BaCl$_2$ · 2H$_2$O in about 200 ml of distilled water in a one-liter volumetric flask. Add 680 ml of ethyl alcohol and then make to volume with distilled water.

Acid extractant: Add 50 ml HCl + 25 ml HNO$_3$ + 50 ml La solution (1 percent La in 0.3M HNO$_3$) to a one-liter volumetric flask. Add distilled water to make to volume. (Reagent-grade chemicals used; final La concentration is 500 ppm).

Quality-control replicates

Duplicates of one in ten samples were extracted and analyzed for water-soluble and exchangeable cations. The data showed good reproducibility for the former and fair to good for the latter (see Tables 10 and 11).

Comments

The available centrifuge could not produce the 4,500-7,500 RCF used in the study cited. In decanting the water from some samples, small amounts of still-suspended colloids were carried over through the filter into the solutions for water-soluble cations. The approximately 0.03M HCl from the La solution is likely to have "digested" some of the exchangeable cations in the carried-over colloids. The result

would be slightly higher than actual values reported for water-soluble cations in some samples. For the same reason, there would be less material remaining for extraction by BaCl$_2$/alcohol, and the results for exchangeable cations are likely to be somewhat lower than actual for some samples. Although the magnitudes of the errors in both cases are not known, they are believed to be small for all but a few samples, and the data reported are considered to be usable.

In the analysis for exchangeable Li, Li was <0.10 meq/100 g for all samples and was not included in Table 10. As indicated above, corrections to cation data for contamination arising from "reagent + process" blanks were made, and the corrected values were reported in Table 10. The corrections are given below. The minus sign indicated the direction of the correction.

Corrections for "reagent + process" blanks

1. Water-soluble cation analyses:
Na   -0.08 meq/100 g (<6 meq/100 g)
Na   -0.22 meq/100 g (>6 meq/100 g, dilutions)
Ca   None
Mg   None
K   None
Li   None

2. Exchangeable cation analyses:
Na   -0.16 meq/100 g
Ca   -0.15 meq/100 g
Mg   -0.04 meq/100 g
K   -0.03 meq/100 g

Table 10. *Replicate cation analyses.**

Map sample no.	Water-soluble cations (milliequivalents/100 grams)								Exchangeable cations (milliequivalents/100 grams)							
	Na		Ca		Mg		K		Na		Ca		Mg		K	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
11	4.08	4.05	2.94	2.7	1.35	1.25	0.61	0.54	0.90	0.60	27.67	22.14	11.04	9.22	0.40	0.28
13	5.40	5.44	2.29	1.31	0.91	0.81	0.59	0.51	--	--	--	--	--	--	--	--
17	9.5	10.2	4.5	4.5	1.39	1.54	0.41	0.41	7.95	9.09	12.61	15.75	1.38	1.54	0.16	0.28
65	1.08	1.00	0.82	0.83	0.38	0.38	0.09	0.08	0.10	0.11	8.90	9.76	3.64	4.01	0.11	0.05
67	8.8	9.4	6.7	7.5	2.22	2.43	1.04	1.12	2.74	2.68	31.32	29.13	7.70	7.48	0.91	0.84
69	0.2	0.2	0.24	0.22	0.07	0.07	0.34	0.32	0.13	0.06	4.28	3.65	0.99	0.82	0.62	0.44
86	27.9	27.5	7.7	7.5	1.25	1.98	0.20	0.18	53.34	53.79	6.45	5.47	0.40	0.50	0.31	0.35
93	19.2	17.9	7.7	7.2	2.62	2.55	0.43	0.40	7.87	7.75	17.39	17.54	5.06	5.19	0.26	0.26
108	3.66	3.66	10.2	9.9	4.27	4.25	0.21	0.20	0.11	0.19	4.42	5.69	1.70	2.26	0.21	0.31
113	38.0	37.0	74.6	81.2	2.46	2.50	1.43	1.45	1.62	1.86	31.12	36.90	0.87	1.08	0.15	0.20
115	1.85	1.79	0.16	0.16	0.29	0.27	0.16	0.13	5.36	5.06	16.07	14.78	8.42	7.84	1.60	1.40
126	21.8	21.5	4.9	5.3	1.58	1.96	1.59	1.64	10.53	10.09	13.53	12.64	3.72	3.53	1.33	1.15
136	1.08	0.99	0.49	0.47	0.20	0.19	0.12	0.13	0.47	0.57	10.06	9.56	3.62	3.42	0.91	0.36
152	5.18	5.19	10.6	10.2	3.03	2.91	0.59	0.54	0.76	0.69	13.37	13.76	3.40	3.47	0.91	0.85
154	13.7	14.5	3.10	2.90	1.99	1.89	0.20	0.20	38.06	35.20	15.69	13.06	7.57	6.53	0.93	0.86

*A and B values are separate analyses on separate subsamples. Replicate analyses for Li, in both water-soluble and exchangeable forms, were all within the range of <0.01 to 0.01 meq/100 g and are therefore not included in this table.

Table 11. *Cation analysis comparison.**

Map sample no.	Total cation content (WSC + EC) (millequivalents/100 grams)							
	DOGAMI				American Colloid			
	Na	Ca	Mg	Total	Na	Ca	Mg	Total
12	0.7	22.3	13.6	36.6	1	42	28	71
16	30.8	34.7	9.4	74.9	28	26	6	60
40	14.5	14.3	12.3	41.1	13	21	16	50
50	11.1	35.1	12.8	59.2	9	46	16	71
86	81.1	15.1	2.1	98.3	68	<1	<1	68
104	4.9	42.2	12.5	59.6	5	46	12	63
121	57.2	36.5	5.2	98.9	57	35	4	96
125	43.5	28.2	1.5	73.2	42	33	1	76
153	54.6	15.8	8.1	78.5	73	16	1	90

*These results may not be directly comparable. DOGAMI used milled and homogenized samples. American Colloid used subsamples of as-crushed (minus 1/4-in.-mesh) samples that were not homogenized. Sample 153 was a milled sample provided by American Colloid. American Colloid's method extracts both water-soluble cations and exchangeable cations. Five grams of sample are treated with 50 ml of a 3.6-percent solution of benzyl trimethyl ammonium chloride in water. The Na, Ca, and Mg cations are exchanged with ammonium cations.

APPENDIX 8. TRIAL TESTS

Table 12. *Effect of sample-preparation method and drying on water loss.**

	Preparation method	Drying	Water loss (ml)					Water loss, Na treated (ml)			As-tested moisture content (%)
A	Air-dried, Raymond-milled, 100% <610 microns	None	32.0	33.0	30.5	--	--	8.5	9.0	9.0	10.81
B	Air-dried, Raymond-milled, 100% <610 microns	16 hours @ 66 °C	36.0	38.0	35.0	--	--	--	--	--	2.7
C	Air-dried, Angstrom mill, dry-milled to 100% <75 microns	None	55.5	52.0	52.5	53.5	54.0	25.0	24.5	24.2	9.54
D	Air-dried, Angstrom mill, dry but particle size not determined	25 hours @ 105 °C	75.0	75.0	--	--	--	--	--	--	0
E	Air-dried, Angstrom mill, slurry milled with distilled water, dried and hand ground to 100% <840 microns	After milling; air-dried 136 hours; 3 hours; @ 60 °C; 3 hours; @ 80 °C	19.0	18.0	--	--	--	9.0	8.5	--	10.52

*Map sample 14 was used for these tests. It was determined by XRD to contain a major amount of montmorillonite and minor amounts of quartz, clinoptilolite, and feldspar. The total cation contents (WSC + EC) were, in meq/100 g: 1.7 Na, 33.3 Ca, 15.3 Mg, and 0.9 K. Except for D, the as-tested moisture content of a sample was determined by drying a separate subsample at 105 °C for 4 hours minimum. By definition, if not in reality, the moisture content is 0 percent after drying in this manner. Thus, where the test sample itself was so dried, the as-tested moisture was 0 percent (i.e., in D).

Table 13. *Effect of aging time on water loss.**

Age-time (hours)	Water loss (ml)	Preparation method (see Table 12 above)
19.6	33.0	A (distilled water)
20.2	30.5	" "
43.7	32.0	" "
20.8	9.0	" (soda ash tested)
21.5	9.0	" "
44.4	8.5	" "
19.5	55.5	C (distilled water)
20.0	52.0	" "
20.9	52.5	" "
67.7	54.0	" "
70.1	53.5	" "
22.9	25.0	" (soda ash tested)
23.4	24.5	" "
70.0	24.2	" "

*Map sample 14 was used for these tests.

26

APPENDIX 9. SAMPLE-NUMBER CORRELATIONS

Table 14. *Sample-number correlation chart, listed by map number.*

Map	Sample numbers Laboratory	Field	Map	Sample numbers Laboratory	Field	Map	Sample numbers Laboratory	Field	Map	Sample numbers Laboratory	Field
1	1	860610-1	46	95	860926-21	91	69	860911-7	136	136	870709-22
2	2	860610-2	47	51	860829-1	92	71	860911-9	137	137	870709-23
3	3	860610-3	48	52	860829-2	93	55	860909-2	138	138	870709-24
4	4	860610-4	49	53	860829-3	94	54	860909-1	139	139	870709-25
5	11B	860702-2	50	83	860914-1	95	154	880715-1	140	140	870709-26
6	11A	860702-1	51	88	860923-24	96	142	870907-2	141	34	860812-1
7	12	860702-3	52	87	860923-23	97	143	870907-2	142	32	860811-1
8	96	861006-1	53	85	860923-21	98	26	860731-4	143	33	860811-2
9	44	860827-3	54	86	860923-22	99	25	860731-3	144	10	860620-2
10	45	860827-4	55	89	860924-21	100	153	880629-2	145	13	860709-1
11	46	860827-5	56	90	860924-22	101	56	860909-3	146	30	860807-1
12	112	861009-23	57	133	870611-23	102	23	860731-1	147	29	860806-1
13	37	860826-1	58	134	870611-25	103	24	860731-2	148	7	860618-4
14	43	860827-2	59	92	860924-24	104	27	860731-5	149	8	860618-5
15	39	860826-3	60	93	860924-25	105	66	860911-4	150	9	860618-6
16	38	860826-2	61	132	870610-25	106	67	860911-5	151	31	860810-1
17	118	861015-22	62	131	870610-24	107	68	860911-6	152	28	860805-1
18	117	861015-21	63	129	870610-21	108	64	860911-2	153	144	--
19	111	861009-22	64	130	870610-22	109	63	860911-1	154	152	--
20	42	860827-1	65	109	861008-24	110	65	860911-3			
21	40	860826-4	66	94	860925-21	111	141	870907-2			
22	49	860828-3	67	91	860924-23	112	74	860912-3			
23	50	860828-4	68	102	861007-24	113	73	860912-2			
24	119	861015-23	69	100	861007-22	114	72	860912-1			
25	110	861009-21	70	101	861007-23	115	19	860718-1			
26	5	860612-1	71	103	861007-25	116	62	860910-9			
27	6	860612-2	72	104	861007-26	117	61	860910-7			
28	105	861008-1	73	123	870603-21	118	59	860910-5			
29	41	860826-5	74	106	861008-21	119	60	860910-6 ·			
30	47	860828-1	75	107	861008-22	120	75	860912-4			
31	48	860828-2	76	108	861008-23	121	78	860913-1			
32	97	861006-21	77	18	860717-2	122	79	860913-2			
33	122	861017-23	78	147	870814-22	123	58	860910-4			
34	113	861014-21	79	150	870814-25	124	80	860913-3			
35	114	861014-22	80	151	870814-26	125	81	860913-4			
36	115	861014-23	81	99	861007-21	126	82	860913-5			
37	116	861014-24	82	17	860717-1	127	57	860910-1			
38	127	870604-23	83	14	860716-1	128	76	860912-5			
39	128	870604-24	84	15	860716-2	129	77	860912-6			
40	120	861017-21	85	16	860716-3	130	20	860718-2			
41	121	861017-22	86	145	870814-27	131	21	860718-3			
42	124	870604-20	87	148	870814-23	132	22	860718-4			
43	125	870604-21	88	146	870811-21	133	35	860812-2			
44	126	870604-22	89	149	870814-24	134	36	860812-3			
45	98	861007-1	90	70	860911-8	135	135	870709-2			

Table 15. *Sample-number correlation chart, listed by laboratory number.*

Laboratory	Sample numbers Map	Field	Laboratory	Sample numbers Map	Field	Laboratory	Sample numbers Map	Field	Laboratory	Sample numbers Map	Field
1	1	860610-1	45	10	860827-4	91	67	860924-2	136	136	870709-22
2	2	860610-2	46	11	860827-5	92	59	860924-2	137	137	870709-23
3	3	860610-3	47	30	860828-1	93	60	860924-2	138	138	870709-24
4	4	860610-4	48	31	860828-2	94	66	860925-2	139	139	870709-25
5	26	860612-1	49	22	860828-3	95	46	860926-2	140	140	870709-26
6	27	860612-2	50	23	860828-4	96	8	861006-1	141	111	870907-21
7	148	860618-4	51	47	860829-1	97	32	861006-2	142	96	870907-22
8	149	860618-5	52	48	860829-2	98	45	861007-1	143	97	870907-23
9	150	860618-6	53	49	860829-3	99	81	861007-2	144	153	--
10	144	860620-2	54	94	860909-1	100	69	861007-2	145	86	870814-27
11A	6	860702-1	55	93	860909-2	101	70	861007-2	146	88	870811-21
11B	5	860702-2	56	101	860909-3	102	68	861007-2	147	78	870814-22
12	7	860702-3	57	127	860910-1	103	71	861007-2	148	87	870814-23
13	145	860709-1	58	123	860910-4	104	72	861007-2	149	89	870814-24
14	83	860716-1	59	118	860910-5	105	28	861008-1	150	79	870814-25
15	84	860716-2	60	119	860910-6	106	74	861008-2	151	80	870814-26
16	85	860716-3	61	117	860910-7	107	75	861008-2	152	154	--
17	82	860717-1	62	116	860910-9	108	76	861008-2	153	100	880629-2
18	77	860717-2	63	109	860911-1	109	65	861008-2	154	95	880715-1
19	115	860718-1	64	108	860911-2	110	25	861009-2			
20	130	860718-2	65	110	860911-3	111	19	861009-2			
21	131	860718-3	66	105	860911-4	112	12	861009-2			
22	132	860718-4	67	106	860911-5	113	34	861014-2			
23	102	860731-1	68	107	860911-6	114	35	861014-2			
24	103	860731-2	69	91	860911-7	115	36	861014-2			
25	99	860731-3	70	90	860911-8	116	37	861014-2			
26	98	860731-4	71	92	860911-9	117	18	861015-2			
27	104	860731-5	72	114	860912-1	118	17	861015-2			
28	152	860805-1	73	113	860912-2	119	24	861015-2			
29	147	860806-1	74	112	860912-3	120	40	861017-2			
30	146	860807-1	75	120	860912-4	121	41	861017-2			
31	151	860810-1	76	128	860912-5	122	33	861017-2			
32	142	860811-1	77	129	860912-6	123	73	870603-2			
33	143	860811-2	78	121	860913-1	124	42	870604-2			
34	141	860812-1	79	122	860913-2	125	43	870604-2			
35	133	860812-2	80	124	860913-3	126	44	870604-2			
36	134	860812-3	81	125	860913-4	127	38	870604-2			
37	13	860826-1	82	126	860913-5	128	39	870604-2			
38	16	860826-2	83	50	860914-1	129	63	870610-2			
39	15	860826-3	85	53	860923-21	130	64	870610-2			
40	21	860826-4	86	54	860923-22	131	62	870610-2			
41	29	860826-5	87	52	860923-23	132	61	870610-2			
42	20	860827-1	88	51	860923-24	133	57	870611-2			
43	14	860827-2	89	55	860924-21	134	58	870611-2			
44	9	860827-3	90	56	860924-22	135	135	870709-2			

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
DONALD A. HULL, STATE GEOLOGIST

Special Paper 20

Bentonite in Oregon:
Occurrences, Analyses, and Economic Potential
By Jerry J. Gray, Ron P. Geitgey, and Gary L. Baxter

Plate 1

Table 1. Bentonite (Na- and Ca-Bentonite) and fuller's earth (Ca-bentonite) sold or used by domestic producers, by kind and by use (short tons, U.S. Bureau of Mines data).

1975 / 1976 / 1977

Type of bentonite	1975 Fuller's earth	Ca-bentonite Nonswelling	Ca-bentonite Total	Na-bentonite (swelling)	Grand total	1976 Fuller's earth	Ca-bentonite Nonswelling	Ca-bentonite Total	Na-bentonite (swelling)	Grand total	1977 Fuller's earth	Ca-bentonite Nonswelling	Ca-bentonite Total	Na-bentonite (swelling)	Grand total
Use															
Domestic:															
Adhesives	--	--	0	3	3	--	W	W	W	W	--	W	W	4,922	4,922
Animal feed	--	49,774	49,774	126,284	176,058	--	--	0	156,652	156,652	--	84,704	84,704	110,222	194,926
Building brick	--	--	0	1,135	1,135	--	--	0	--	0	--	W	W	W	W
Catalysts (oil refining)	--	7,418	7,418	42	7,460	--	2,208	2,208	9	2,217	--	12,133	12,133	--	12,133
Cement, portland	W	--	W	336	336	W	--	W	250	250	--	W	W	450	450
Drilling mud	--	25,809	25,809	710,446	736,255	5,478	23,451	28,929	950,099	979,028	--	22,205	22,205	1,037,962	1,060,167
Fertilizers	12,065	8,406	20,471	--	20,471	9,309	9,160	18,469	--	18,469	10,857	2,380	13,237	30	13,267
Filtering, etc.[1]	--	112,699	112,699	5,687	118,386	2,113	190,972	193,085	3,969	197,054	--	137,313	137,313	33,037	170,350
Foundry sand binder	--	242,133	242,133	465,800	707,933	--	288,769	288,769	357,704	646,473	--	289,559	289,559	577,746	867,305
Glazes, glass, enamels	--	--	0	141	141	--	--	0	--	0	--	--	0	120	120
Gypsum products	--	--	0	383	383	--	--	0	470	470	--	--	0	303	303
Medical, pharmaceutical, cosmetic	--	58	58	2,019	2,077	--	--	0	1,533	1,533	--	--	0	4,498	4,498
Oil and grease absorbents	148,141	--	148,141	--	148,141	120,954	--	120,954	--	120,954	168,362	--	168,362	--	168,362
Paint	--	--	0	4,102	4,102	--	W	W	W	W	--	--	0	16,516	16,516
Paper coating/filling	--	--	0	878,022	878,022	--	--	0	868,947	868,947	--	--	0	629,353	629,353
Pelletizing (iron ore)	49,250	2,462	51,712	517	52,229	50,839	3,556	54,395	50	54,445	57,295	1,740	59,035	3,260	62,295
Pesticides and related products	222,864	--	222,864	30,134	252,998	294,722	--	294,722	35,416	330,138	196,066	5	196,071	25,496	221,567
Pet absorbent	--	8,054	8,054	--	8,054	--	46,999	46,999	1,925	48,924	--	91	91	--	91
Tile	--	1,820	1,820	33,629	35,449	--	2,402	2,402	63,389	65,791	--	18,589	18,589	59,752	78,341
Waterproofing and sealing															
Miscellaneous[2]	19,051	3,052	22,103	61,984	84,087	44,978	187	45,165	13,766	58,931	62,468	5,510	67,978	103,795	171,773
Total	451,371	461,685	913,056	2,320,664	3,233,720	528,393	567,704	1,096,097	2,454,179	3,550,276	495,048	574,229	1,069,277	2,607,462	3,676,739
Exports:															
Drilling mud	--	--	0	128,848	128,848	--	--	0	184,572	184,572	--	--	0	--	0
Fertilizers	W	--	W	--	0	--	--	0	--	0	--	200	200	150,771	150,971
Foundry sand binder	--	12,821	12,821	154,391	167,212	--	16,331	16,331	153,749	170,080	--	16,538	16,538	168,683	185,221
Oil and grease absorbents	4,544	--	4,544	--	4,544	141	--	141	--	141	39,669	--	39,669	--	39,669
Pelletizing (iron ore)	--	--	0	142,839	142,839	--	--	0	129,596	129,596	--	--	0	203,501	203,501
Pesticides and related products	--	--	0	--	0	--	--	0	--	0	--	--	0	--	0
Pet absorbent	5,734	--	5,734	--	5,734	22,830	--	22,830	--	22,830	33,739	--	33,739	--	33,739
Miscellaneous	7,981	--	7,981	8,019	16,000	7,997	13,068	21,065	1,182	22,247	1,418	384	1,802	24,919	26,521
Total	18,259	12,821	31,080	434,097	465,177	30,968	29,399	60,367	469,099	529,466	74,826	16,922	91,748	547,874	639,622
Grand total	469,630	474,506	944,136	2,754,761	3,698,897	559,361	597,103	1,156,464	2,923,278	4,079,742	569,874	591,151	1,161,025	3,155,336	4,316,361

1978 / 1979 / 1980

Type of bentonite	1978 Fuller's earth	Ca-bentonite Nonswelling	Ca-bentonite Total	Na-bentonite (swelling)	Grand total	1979 Fuller's earth	Ca-bentonite Nonswelling	Ca-bentonite Total	Na-bentonite (swelling)	Grand total	1980 Fuller's earth	Ca-bentonite Nonswelling	Ca-bentonite Total	Na-bentonite (swelling)	Grand total
Use															
Domestic:															
Adhesives	--	W	W	2,747	2,747	--	W	W	1,219	1,219	--	W	W	W	W
Animal feed	--	63,109	63,109	148,161	211,270	--	70,234	70,234	113,813	184,047	20	64,057	64,077	106,379	170,456
Building brick	--	W	W	W	W	--	W	W	W	W	--	W	W	W	W
Catalysts (oil refining)	--	16,843	16,843	--	16,843	--	4,511	4,511	--	4,511	--	8,722	8,722	--	8,722
Cement, portland	--	W	W	W	W	--	W	W	W	W	--	W	W	W	W
Drilling mud	26,189	412	26,601	1,143,635	1,170,236	23,578	14,658	38,236	1,261,477	1,299,713	1,453	59,061	60,514	1,374,150	1,434,664
Fertilizers	15,774	2,420	18,194	17	18,211	19,796	4,764	24,560	--	24,560	24,532	--	24,532	4,658	29,190
Filtering, etc.[1]	--	146,933	146,933	9,379	156,312	--	109,552	109,552	6,784	116,336	--	109,172	109,172	2,787	111,959
Foundry sand binder	--	337,889	337,889	697,939	1,035,828	--	300,576	300,576	595,697	896,273	--	228,550	228,550	403,530	632,080
Glazes, glass, enamels	--	W	W	W	W	--	W	W	W	W	--	--	0	W	W
Gypsum products	--	--	0	W	W	--	--	0	W	W	--	--	0	2,451	2,451
Medical, pharmaceutical, cosmetic	--	50	50	1,232	1,282	--	--	0	3,295	3,295	--	--	0	2,451	2,451
Oil and grease absorbents	191,596	--	191,596	--	191,596	165,174	--	165,174	--	165,174	158,796	--	158,796	--	158,796
Paint	--	213	213	26,767	26,980	--	--	0	13,905	13,905	--	--	0	14,111	14,111
Paper coating/filling	3,245	--	3,245	--	3,245	1,773	--	1,773	--	1,773	--	--	0	--	0
Pelletizing (iron ore)	--	183	183	939,274	939,457	--	13,504	13,504	888,204	901,708	--	849	849	861,538	862,387
Pesticides and related products	56,294	1,496	57,790	3,259	61,049	67,847	1,403	69,250	2,787	72,037	72,351	3,251	75,602	2,694	78,296
Pet absorbent	260,249	--	260,249	W	260,249	250,177	--	250,177	W	250,177	253,875	W	253,875	--	253,875
Tile	--	--	0	--	0	--	--	0	--	0	--	--	0	W	W
Waterproofing and sealing	--	2,952	2,952	71,447	74,399	--	34,372	34,372	41,321	75,693	--	2,160	2,160	89,494	91,654
Miscellaneous[2]	37,365	42,040	79,405	202,364	281,769	49,398	423	49,821	233,481	283,302	54,994	86,043	141,037	126,941	267,978
Total	590,712	614,540	1,205,252	3,246,221	4,451,473	577,743	553,997	1,131,740	3,161,983	4,293,723	566,021	561,865	1,127,886	2,988,733	4,116,619
Exports:															
Drilling mud	--	--	0	171,388	171,388	--	--	0	180,067	180,067	--	1,782	1,782	331,302	333,084
Fertilizers	--	--	0	--	0	--	--	0	--	0	--	--	0	--	0
Foundry sand binder	--	16,998	16,998	222,202	239,200	--	16,964	16,964	250,066	267,030	--	12,646	12,646	222,681	235,327
Oil and grease absorbents	11,940	--	11,940	--	11,940	20,457	--	20,457	--	20,457	24,732	--	24,732	--	24,732
Pelletizing (iron ore)	--	--	0	164,086	164,086	--	--	0	172,515	172,515	--	--	0	--	0
Pesticides and related products	--	--	0	--	0	--	--	0	--	0	--	--	0	--	0
Pet absorbent	5,665	--	5,665	--	5,665	9,100	--	9,100	--	9,100	10,741	--	10,741	--	10,741
Miscellaneous	1,459	1,662	3,121	30,508	33,629	1,650	4,531	6,181	81,952	88,133	6,315	5,320	11,635	60,290	71,925
Total	19,064	18,660	37,724	588,184	625,908	31,207	21,495	52,702	684,600	737,302	41,788	19,748	61,536	614,273	675,809
Grand total	609,776	633,200	1,242,976	3,834,405	5,077,381	608,950	575,492	1,184,442	3,846,583	5,031,025	607,809	581,613	1,189,422	3,603,006	4,792,428

1981 / 1982 / 1983

Type of bentonite	1981 Fuller's earth	Ca-bentonite Nonswelling	Ca-bentonite Total	Na-bentonite (swelling)	Grand total	1982 Fuller's earth	Ca-bentonite Nonswelling	Ca-bentonite Total	Na-bentonite (swelling)	Grand total	1983 Fuller's earth	Ca-bentonite Nonswelling	Ca-bentonite Total	Na-bentonite (swelling)	Grand total
Use															
Domestic:															
Adhesives	--	W	0	W	W	--	--	0	179	179	--	--	0	6,688	6,688
Animal feed	--	57,855	57,855	99,258	157,113	--	66,334	66,334	74,148	140,482	--	38,737	38,737	98,220	136,957
Building brick	--	--	0	W	0	--	--	0	--	0	--	--	0	--	0
Catalysts (oil refining)	--	7,749	7,749	5	7,754	--	4,311	4,311	4	4,315	--	10,329	10,329	178	10,507
Cement, portland	--	--	0	W	W	--	--	0	W	W	--	--	0	W	W
Drilling mud	2,027	60,554	62,581	2,004,088	2,066,669	--	15,275	15,275	1,409,072	1,424,347	--	580	580	1,155,189	1,155,769
Fertilizers	22,841	--	22,841	4,054	26,895	19,285	--	19,285	2,749	22,034	1,576	103,031	104,607	8,463	113,070
Filtering, etc.[1]	--	158,364	158,364	2,610	160,974	--	147,255	147,255	1,936	149,191	--	207,224	207,224	372,726	579,950
Foundry sand binder	--	270,289	270,289	521,430	791,719	--	186,243	186,243	328,028	514,271	--	--	0	W	W
Glazes, glass, enamels	--	--	0	W	W	--	--	0	W	W	--	--	0	W	W
Gypsum products	--	--	0	--	0	--	--	0	8,050	8,050	2	--	2	4,437	4,439
Medical, pharmaceutical, cosmetic	--	--	0	2,818	2,818	--	--	0	8,050	8,050					
Oil and grease absorbents	246,821	--	246,821	--	246,821	232,833	--	232,833	--	232,833	193,946	--	193,946	--	193,946
Paint	--	--	0	14,412	14,412	--	--	0	12,998	12,998	--	--	0	9,223	9,223
Paper coating/filling	--	--	0	--	0	--	--	0	--	0	--	--	0	--	0
Pelletizing (iron ore)	--	--	0	884,976	884,976	--	--	0	396,506	396,506	--	--	0	301,357	301,357
Pesticides and related products	66,669	506	67,175	2,872	70,047	75,210	366	75,576	4,731	80,307	83,858	506	84,364	7,282	91,646
Pet absorbent	304,080	W	304,080	--	304,080	359,958	W	359,958	--	359,958	485,844	W	485,844	--	485,844
Tile	--	--	0	W	W	--	--	0	W	W	--	--	0	W	W
Waterproofing and sealing	--	1,897	1,897	88,882	90,779	--	17,939	17,939	87,527	105,466	--	20,079	20,079	73,534	93,613
Miscellaneous	36,378	63,944	100,322	71,168	171,490	81,557	60,155	141,712	65,817	207,529	51,005	120,488	171,493	74,116	245,609
Total	678,816	621,158	1,299,974	3,696,573	4,996,547	768,843	497,878	1,266,721	2,391,745	3,658,466	829,562	500,974	1,330,536	2,111,413	3,441,949
Exports:															
Drilling mud	--	--	0	364,342	364,342	--	--	0	227,409	227,409	--	--	0	178,037	178,037
Fertilizers	--	--	0	--	0	--	--	0	--	0	--	--	0	--	0
Foundry sand binder	--	13,956	13,956	203,928	217,884	--	109	109	53,441	53,550	--	126	126	34,943	35,069
Oil and grease absorbents	33,112	--	33,112	--	33,112	29,783	--	29,783	--	29,783	36,469	--	36,469	--	36,469
Pelletizing (iron ore)	--	--	0	37,771	37,771	--	--	0	--	0	458	--	458	--	458
Pesticides and related products	--	--	0	--	0	--	--	0	--	0					
Pet absorbent	27,283	--	27,283	--	27,283	27,513	--	27,513	--	27,513	12,898	--	12,898	--	12,898
Miscellaneous[2]	334	2,319	2,653	7,111	9,764	343	2,248	2,591	71,970	74,561	3,011	2,310	5,321	59,067	64,388
Total	60,729	16,275	77,004	613,152	690,156	57,639	2,357	59,996	352,820	412,816	52,836	2,436	55,272	272,047	327,319
Grand total	739,545	637,433	1,376,978	4,309,725	5,686,703	826,482	500,235	1,326,717	2,744,565	4,071,282	882,398	503,410	1,385,808	2,383,460	3,769,268
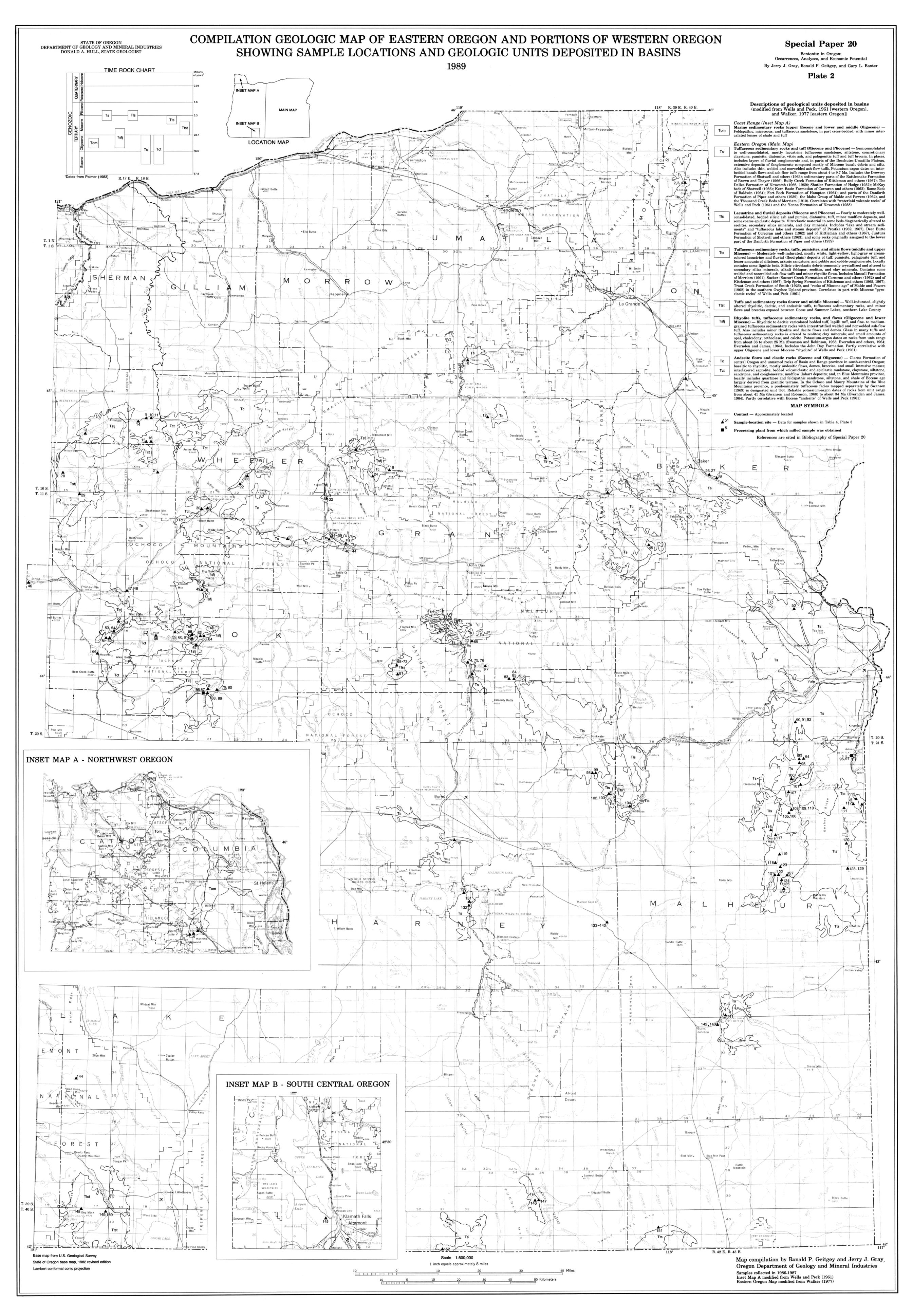
1984 / 1985 / 1986

Type of bentonite	1984 Fuller's earth	Ca-bentonite Nonswelling	Ca-bentonite Total	Na-bentonite (swelling)	Grand total	1985 Fuller's earth	Ca-bentonite Nonswelling	Ca-bentonite Total	Na-bentonite (swelling)	Grand total	1986 Fuller's earth	Ca-bentonite Nonswelling	Ca-bentonite Total	Na-bentonite (swelling)	Grand total
Use															
Domestic:															
Adhesives	--	--	0	6,757	6,757	--	2,000	2,000	6,938	8,938	--	--	0	11,302	11,302
Animal feed	--	49,811	49,811	136,321	186,132	--	38,265	38,265	92,219	130,484	--	43,262	43,262	69,164	112,426
Building brick	--	--	0	--	0	--	--	0	--	0	--	--	0	--	0
Catalysts (oil refining)	--	8,763	8,763	--	8,763	--	5,748	5,748	2,470	8,218	--	5,232	5,232	147	5,379
Cement, portland	--	--	0	W	W	--	--	0	W	W	--	--	0	W	W
Drilling mud	--	14,878	14,878	1,346,191	1,361,069	--	17,913	17,913	1,168,728	1,186,641	--	5,193	5,193	1,031,555	1,036,748
Fertilizers	10,576	--	10,576	--	10,576	10,482	--	10,482	--	10,482	7,379	--	7,379	--	7,379
Filtering, etc.[1]	784	1,074	1,858	5,119	6,977	--	36,500	36,500	3,071	39,571	--	165,679	165,679	2,110	167,789
Foundry sand binder	--	227,886	227,886	520,177	748,063	--	206,388	206,388	522,199	728,587	--	215,004	215,004	401,786	616,788
Glazes, glass, enamels	--	--	0	W	W	--	--	0	W	W	--	--	0	W	W
Gypsum products	--	--	0	--	0	--	--	0	--	0	--	--	0	--	0
Medical, pharmaceutical, cosmetic	--	--	0	5,081	5,081	--	--	0	3,968	3,968	--	--	0	7,321	7,321
Oil and grease absorbents	220,878	100,951	321,829	45	321,874	309,015	34,448	343,463	45	343,508	200,694	8,557	209,251	--	209,251
Paint	--	--	0	10,852	10,852	--	--	0	7,161	7,161	--	--	0	8,446	8,446
Paper coating/filling	--	--	0	--	0	--	--	0	--	0	--	--	0	--	0
Pelletizing (iron ore)	--	--	0	404,493	404,493	--	--	0	290,567	290,567	--	--	0	262,419	262,419
Pesticides and related products	120,223	425	120,648	10,268	130,916	164,546	897	165,443	235	165,678	92,675	1,163	93,838	4,214	98,052
Pet absorbent	506,279	--	506,279	--	506,279	566,869	--	566,869	--	566,869	610,457	W	610,457	--	610,457
Tile	--	--	0	--	0	--	--	0	--	0	--	--	0	--	0
Waterproofing and sealing	--	1,597	1,597	72,795	74,392	--	3,432	3,432	119,876	123,308	--	4,424	4,424	935	5,359
Miscellaneous[2]	50,752	103,016	153,768	67,524	221,292	50,494	126,302	176,796	79,334	256,130	61,462	77,042	138,504	110,465	248,969
Total	909,492	508,401	1,417,893	2,585,623	4,003,516	1,101,406	471,893	1,573,299	2,296,811	3,870,110	972,667	525,556	1,498,223	1,909,862	3,408,085
Exports:															
Drilling mud	--	--	0	153,188	153,188	--	--	0	117,130	117,130	--	--	0	183,934	183,934
Fertilizers	--	--	0	--	0	--	--	0	--	0	--	--	0	--	0
Foundry sand binder	--	1,310	1,310	161,038	162,348	--	24,978	24,978	142,420	167,398	--	52,760	52,760	104,972	157,732
Oil and grease absorbents	38,138	--	38,138	--	38,138	18,701	--	18,701	--	18,701	3,031	--	3,031	--	3,031
Pelletizing (iron ore)	--	--	0	--	0	--	--	0	--	0	--	--	0	--	0
Pesticides and related products	373	--	373	--	373	971	--	971	--	971	2,589	--	2,589	--	2,589
Pet absorbent	12,295	--	12,295	--	12,295	11,434	--	11,434	--	11,434	9,571	--	9,571	--	9,571
Miscellaneous	486	1,638	2,124	26,742	28,866	1,137	1,078	7,215	140,970	148,185	1,348	1,602	2,950	34,357	37,307
Total	51,292	2,948	54,240	340,968	395,208	37,243	26,056	63,299	400,520	463,819	16,539	62,005	78,544	315,620	394,164
Grand total	960,784	511,349	1,472,133	2,926,591	4,398,724	1,138,649	497,949	1,636,598	2,697,331	4,333,929	989,206	587,561	1,576,767	2,225,482	3,802,249

W = Withheld to avoid disclosing company proprietary data; included with "Miscellaneous"

[1] Clarifying and decolorizing mineral, animal, and vegetable greases and desiccants

[2] May include bentonite used for animal feed, chemical manufacturing; paint; fiberglass; firebricks, blocks, and shapes; gypsum products; mineral wool and insulation; paper coating and filling; pet waste absorbents; plastics; rubber; ink; waterproofing and sealing, uses not specified; and data indicated by symbol "W".

COMPILATION GEOLOGIC MAP OF EASTERN OREGON AND PORTIONS OF WESTERN OREGON SHOWING SAMPLE LOCATIONS AND GEOLOGIC UNITS DEPOSITED IN BASINS
1989

TIME ROCK CHART

LOCATION MAP

INSET MAP A
INSET MAP B
MAIN MAP

Descriptions of geological units deposited in basins
(modified from Wells and Peck, 1961 [western Oregon], and Walker, 1977 [eastern Oregon])

Coast Range (Inset Map A)

Marine sedimentary rocks (upper Eocene and lower and middle Oligocene) — Feldspathic, micaceous, and tuffaceous sandstone, in part cross-bedded, with minor intercalated lenses of shale and tuff

Eastern Oregon (Main Map)

Tuffaceous sedimentary rocks and tuff (Miocene and Pliocene) — Semiconsolidated to well-consolidated, mostly lacustrine tuffaceous sandstone, siltstone, concretionary claystone, pumicite, diatomite, vitric ash, and palagonitic tuff and tuff breccia. In places, includes layers of fluvial conglomerate and, in parts of the Deschutes-Umatilla Plateau, extensive deposits of fanglomerate composed mostly of Miocene basalt debris and silts. Also includes thin, welded and nonwelded ash-flow tuffs. Potassium-argon dates on interbedded basalt flows and ash-flow tuffs range from about 4 to 9.7 Ma. Includes the Drewsey Formation of Shotwell and others (1963); sedimentary parts of the Rattlesnake Formation of Brown and Thayer (1966); Bully Creek Formation of Kittleman and others (1967); The Dalles Formation of Newcomb (1966, 1969); Shutler Formation of Hodge (1932); McKay beds of Shotwell (1956); Kern Basin Formation of Corcoran and others (1962); Rome Beds of Baldwin (1964); Fort Rock Formation of Hampton (1964); and parts of the Danforth Formation of Piper and others (1939), the Idaho Group of Malde and Powers (1962), and the Thousand Creek Beds of Merriam (1910). Correlates with "waterlaid volcanic rocks" of Wells and Peck (1961) and the Yonna Formation of Newcomb (1958)

Lacustrine and fluvial deposits (Miocene and Pliocene) — Poorly to moderately well-consolidated, bedded silicic ash and pumice, diatomite, tuff, minor mudflow deposits, and some coarse epiclastic deposits. Vitroclastic material in some beds diagenetically altered to zeolites, secondary silica minerals, and clay minerals. Includes "lake and stream sediments" and "tuffaceous lake and stream deposits" of Piper and others (1939); the Juntura Formation of Corcoran and others (1962) and of Kittleman and others (1967), Juntura Formation of Shotwell and others (1963), and some rocks originally assigned to the Danforth Formation of Piper and others (1939)

Tuffaceous sedimentary rocks, tuffs, pumicites, and silicic flows (middle and upper Miocene) — Moderately well-indurated, mostly white, light-yellow, light-gray or cream-colored lacustrine and fluvial (flood-plain) deposits of tuff, pumicite, palagonite tuff, and lesser amounts of siltstone, arkosic sandstone, and pebble and cobble conglomerate. Locally contains some lignitic beds. Silicic vitroclastic debris commonly crystallized and altered to secondary silica minerals, alkali feldspar, zeolites, and clay minerals. Contains some welded and nonwelded ash-flow tuffs and minor rhyolite flows. Includes Mascall Formation of Merriam (1901), Sucker (Succor) Creek Formation of Corcoran and others (1962) and of Kittleman and others (1967), Drip Spring Formation of Kittleman and others (1965, 1967), Trout Creek Formation of Smith (1926), and "rocks of Miocene age" of Malde and Powers (1962) in the southern Owyhee Upland province. Correlates in part with Miocene "pyroclastic rocks" of Wells and Peck (1961)

Tuffs and sedimentary rocks (lower and middle Miocene) — Well-indurated, slightly altered rhyolitic, dacitic, and andesitic tuffs, tuffaceous sedimentary rocks, and minor flows and breccias exposed between Goose and Summer Lakes, southern Lake County

Rhyolite tuffs, tuffaceous sedimentary rocks, and flows (Oligocene and lower Miocene) — Rhyolitic to dacitic varicolored bedded tuff, lapilli tuff, and fine- to medium-grained tuffaceous sedimentary rocks with interstratified welded and nonwelded ash-flow tuff. Also includes minor rhyolite and dacite flows and domes. Glass in many tuffs and tuffaceous sedimentary rocks is altered to zeolites; clay minerals; and small amounts of opal, chalcedony, orthoclase, and calcite. Potassium-argon dates on rocks from unit range from about 36 to about 25 Ma (Swanson and Robinson, 1968; Evernden and others, 1964; Evernden and James, 1964). Includes the John Day Formation. Partly correlative with upper Oligocene and lower Miocene "rhyolite" of Wells and Peck (1961)

Andesite flows and clastic rocks (Eocene and Oligocene) — Clarno Formation of central Oregon and unnamed rocks of Basin and Range province in south-central Oregon; basaltic to rhyolitic, mostly andesitic flows, domes, breccias, and small intrusive masses; interlayered saprolite; bedded volcaniclastic and epiclastic mudstone, claystone, siltstone, sandstone, and conglomerate; mudflow (lahar) deposits; and, in Blue Mountains province, locally includes quartzose and feldspathic sandstone, siltstone, and shale of Eocene age largely derived from granitic terrane. In the Ochoco and Maury Mountains of the Blue Mountains province, a predominately tuffaceous facies mapped separately by Swanson (1969) is designated unit Tct. Reliable potassium-argon dates of rocks from unit range from about 41 Ma (Swanson and Robinson, 1968) to about 34 Ma (Evernden and James, 1964). Partly correlative with Eocene "andesite" of Wells and Peck (1961)

MAP SYMBOLS

— — — Contact — Approximately located

▲151 Sample-location site — Data for samples shown in Table 4, Plate 3

■5 Processing plant from which milled sample was obtained

References are cited in Bibliography of Special Paper 20

INSET MAP A - NORTHWEST OREGON

INSET MAP B - SOUTH CENTRAL OREGON

Scale 1:500,000
1 inch equals approximately 8 miles

Special Paper 20

Bentonite in Oregon:
Occurrences, Analyses, and Economic Potential

By Jerry J. Gray, Ron P. Geitgey, and Gary L. Baxter

Plate 3

Table 4. *Survey data, Oregon bentonite study.*

(Large multi-column data table, 154 numbered sample rows. Column groups: Location description (County, Quadrangle, Area, Subsection, Sec., T., R., Site), Sample-site description (Type, Sample interval (ft) H-horizontal V-vertical), Physical tests (Moisture (%) after air drying; Swell [% expansion over 24 hr]: As received, Treated [soda ash]; Grit (%): Crushed, Milled; Water loss [not API test; see text]: As received, Treated [soda ash]), X-ray diffraction mineralogy (Clay: Montmorillonite, Kaolinite, Illite; Non-clay: Quartz, Cristobalite, Clinoptilolite, Feldspar, Calcite, Gypsum, Other), Chemical Tests (Water-soluble cations [milliequivalents/100 grams]: Na, Ca, Mg, K, Li, Total; Exchangeable cations [milliequivalents/100 grams]: Na, Ca, Mg, K, Total; Water-soluble cation + exchangeable cations [milliequivalents/100 grams]: Na, Ca, Mg, K, Total), with Map sample no. on both ends.)

Footnotes:

* Because of technical considerations, the percentage of expansion was determined by measuring the change in volume (total volume less 8 ml) divided by 5 grams times 100. The 5 grams was assumed to have a volume of 8 ml.

TE = Total expelled; >350 ml
M = Major portion of sample
m = minor portion of sample
tr = trace