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MARKET AND ECONOMIC CONSIDERATIONS OF KAOLIN CLAY

Minnesota Department of Natural Resources
Division of Minerals

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MARKET AND ECONOMIC CONSIDERATIONS OF KAOLIN CLAY

PREPARED FOR THE LEGISLATIVE COMMISSION ON MINNESOTA RESOURCES' KAOLIN CLAY PROJECT UNDER CONTRACT WITH THE MINERALS RESOURCES RESEARCH CENTER, UNIVERSITY OF MINNESOTA

by

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INTRODUCTION

The Legislative Commission on Minnesota Resources (LCMR) in 1987 provided a total of $392,000 to four state agencies in order to assess the potential for commercial development of the kaolin clay deposits near Redwood Falls, Minnesota, for use in the paper and other industries. Under contract with the Minnesota Resources Research Council ,Univerity of Minnesota, the Department of Natural Resources' Division of Minerals was assigned to carry out studies of the pertinent market conditions and relative environmental issues. The objective of this report is to document the findings of the marketing research; the environmental issues are discussed in a separate report.

The results of the market review are based on extensive research of the existing literature and on numerous contacts with appropriate individuals from the mining industry, academic institutions, paper companies, research organizations, transportation companies, manufacturing/chemical industries, government agencies, and consulting experts, both locally and from other parts of the nation. Additionally, site visits of kaolin mining companies, kaolin processing plants, and kaolin consuming industries proved beneficial and provided a better understanding of the various economic and technical factors inherent in a marketing analysis.

This report is divided into six sections. The first section is an overview of the kaolin industry, in which the main uses, sources, and terminology of the industry are discussed. In the second section the various types of kaolin and the processes used to produce these types are outlined. The third section is devoted to U.S. and world kaolin production. The fourth section is an analysis of current kaolin consumption, prices, and end-use/property relationships. In the fifth section the current Minnesota and upper Midwest markets are analyzed, along with transportation considerations. The sixth section is devoted to a discussion of possible future market developments. Finally, conclusions and recommendations are offered, followed by a list of the references utilized in this project.

AN OVERVIEW OF THE KAOLIN INDUSTRY

Kaolin, commonly known as china clay, is a fine-grained white clay whose physical properties make it ideal for an assortment of industrial applications.

Individual grains of kaolin usually occur in a plate-like form, or stacks of such plates. These plates are very small, often being less than two microns in diameter. The basic component of kaolin is kaolinite, a clay mineral having a chemical formula of $Al_2O_3*2SiO_2*2H_2O$.

Kaolin deposits can be classified into two types, residual and sedimentary. Residual deposits, which include most Minnesota kaolins, have formed in place due to weathering of feldspar-rich rocks. Residual kaolins are usually less pure, but normally have a higher brightness than sedimentary deposits.

Sedimentary deposits, such as those of Georgia and South Carolina, represent residual kaolins which have been transported and redeposited. Sedimentary deposits are known for their high kaolin content and their purity.

The basic properties which distinguish kaolin from other clays are its softness, whiteness, and ease of dispersion in liquids. These properties , along with its platy structure, inertness to most chemicals, and reasonably low price compared to other commodities, combine to give kaolin a variety of properties which are desirable in a number of different industrial applications.*

The quality of a particular kaolin is measured by a number of parameters. An important measure of the value of a kaolin for many industrial application is its "brightness," or reflectivity, which is usually expressed as a percentage. One hundred percent (100%) brightness would mean that the material was equal in brightness to titanium dioxide, which is taken as a standard.

Another important statistic is the percentage of particles smaller than standard mesh sizes, particularly 2 microns. Many properties of kaolin, including brightness and dispersibility in liquids, depend in large part on the average size and uniformity of the kaolin particles.

Kaolin is used extensively in a number of industries including paper, plastics, adhesives, rubber, paint, refractories, cement, bricks and ceramics. The most important of these uses is in the paper industry, which accounts for over 60% of the total U.S. kaolin usage and even a greater portion of kaolin usage by Minnesota companies. Kaolin is used in the paper industry as both a filler due to its lower price than pulp, and as a coater due to the increasing demand for color printing which requires coated papers. It is valued for its smoothness and whiteness, as well as its receptiveness to printing inks. In addition to being the highest volume usage of kaolin, paper coating grade kaolins command a relatively high price compared to kaolin destined for other end-uses. In most other industries, such as paint, rubber, and plastics, kaolin is used as a filler. In this application the most important property of kaolin is its unit price.

The world kaolin market is unusual in that it is dominated by two large free market economy countries: the United States and the United Kingdom. About one-third of the yearly world kaolin supply is derived from extensive deposits in Georgia and South Carolina. Practically all kaolin used by Minnesota paper companies currently comes from Georgia. The second largest producer is the United Kingdom, which accounted for over three million tons or about 13% of world production in 1987. Besides these two major producers, other sources included Brazil, Germany, Australia, and the Eastern Block.

MINING AND PROCESSING OF KAOLIN

Kaolin is mined almost exclusively using open pit mining methods. There are many reasons for this, the most important being that kaolin is simply not a valuable enough mineral to mine using expensive underground mining techniques.

In Georgia, the overburden is typically very thin, although occassionally may reach about 100 feet. The stripping ratio is usually 2:1 to 7:1, with open pits reaching depths of 150 feet or deeper, using strip mining methods. In such relatively pure deposits where the percentage of kaolin in the source rock can reach 75% or greater, simple dragline mining methods are used. Small draglines feed the excavated clay into blungers where the clay is suspended in water, degritted, and pumped to a central processing plant.

In less pure deposits, such as those in the United Kingdom where kaolin percentages average only 10 to 40%, kaolin is mined hydraulically by using high-pressure water jets to selectively mine the most kaolin-rich deposits. The kaolin slurry formed by this process is then segregated by particle size and the finer grained material is pumped to a processing plant.

The kaolin is further processed using one of two primary processing methods, air-floating and water-washing. In general, most filler grade clays are processed using the air floating method. The clay is dried, then pulverized and classified by particle size. In this way kaolin concentrations can reach about 80%. Because air-floatation is not delicate or sophisticated enough to remove great amounts of impurities, typically it involves kaolin deposits of lesser volume and of higher purity, e.g., maximum grit of about 5%. Air-floating is inexpensive compared to water-washing, but it does produce just as pure of a clay. Brightness levels obtained by air-floating vary from deposit to deposit, but can reach a maximum of about 84%.

All paper coating-grade clays and most filler clays are processed using the water-washing method that typically involves deposits of lesser quality such as those containing chemical contaminants and high grit percent (maximum 30% to 40%). Water-washing is by far a more complex and costlier method than air-floatation. In this method, the kaolin begins in slurry form, which is mixed with water and dispersant, is screened to remove the largest particles, and then is further segregated by a floatation process. Floatation allows many of the impurities to be scraped off the surface of the water, and allows easy segregation of large and small kaolin grains. The kaolin which passes through both screens is considered of primary quality, while the reject solution contains waste and kaolin of secondary quality.

Other processing techniques which crude kaolin may undergo include chemical bleaching, high intensity magnetic separation, calcining, delamination, and surface modification.

Chemical bleaching is a process used to improve the brightness of a kaolin by adding chemicals to the slurry. The chemicals can vary substantially from deposit to deposit, but sodium and zinc hydrosulfate in combination with sulfuric acid are perhaps the most common. These chemicals bleach color-altering impurities such as iron and titanium.

If chemical bleaching does not raise the brightness to sufficiently high levels, high intensity magnetic separation can be used. By passing kaolin slurries through high intensity magnets, iron and titanium impurities which tend to depress brightness levels can be removed. Depending on the amount of iron and titanium involved, this process can increase the brightness of a kaolin by over ten percent.

Calcination is a process that results in driving the water out of the crystal structure of the kaolin, by heating it above 1000 degrees Fahrenheit, and then heating the kaolin further until the particles fuse together. Calcination increases many desirable properties of kaolin, such as brightness and oil absorption, but increases the abrasiveness. Calcination is also energy intensive, which causes calcined kaolins to have a very high unit price.

Delamination of kaolin clays involves applying shear stress on the larger stacks of kaolin so that they separate and thus reduce the average particle size. Delaminated clays are valued in some types of paper, such as lightweight coated paper, because of the thinness of the coating needed to provide a glossy finish. Delaminated clays are also fairly expensive due to the high processing costs.

A final processing technique is surface modification. This is a process by which the chemically active sites on the surface of the kaolin are modified in order to improve the bonding of kaolin to the matrix material in filler applications.

Minnesota's kaolin deposits can also be classified as both residual (primary) and sedimentary (secondary). The residual kaolinitic clays were developed from weathering of Precambrian crystalline rocks such as granite and gneiss. The associated kaolinitic shales, directly overlying the residuum, were formed by the Cretaceous seas. Subsequent sedimentation, including by glaciation, has covered these kaolinitic clays with a thick mantle that reaches a thickness of about 400 feet in northwestern Minnesota. These clays occupy approximately the western 2/3 of the state, and are either exposed, or near the surface along the major valleys, such as those of the Minnesota and Mississippi River in the southwestern and central parts of the state, respectively. The implication of these facts on the mining methodology and costs for such a physical environment are beyond the scope of this study.

There is an inherent relationship between kaolin deposit characteristics, production volumes, and processing methodology. From preliminary data from the other three state agencies participating in this project, it appears that the kaolin deposits in the Minnesota River Valley are, in general, non-uniform and with elevated silica content. Therefore, it would appear that for small production volumes - tending to favor the cheaper air floatation - only localized, higher grade kaolin deposits could be utilized that would require minimum blending. Conversely, in order to apply the more expensive water-washing process, large production volumes would be required, thus rendering the utilization of the poorer-grade, non-uniform Minnesota kaolin deposits acceptable.

KAOLIN PRODUCTION

Kaolin is one of the most abundant minerals at the earth's surface. Although some kaolin production occurs in most of the nations of the world, it is rare that deposits are large enough and concentrated enough to support a large kaolin mining operation. When such deposits are present, however, they can be very profitable to mine.

World production is dominated by the United States, the United Kingdom, and the Soviet Union. It reached a new peak of 26.5 million short tons in 1987, once again confirming its well-known relationship to the free world's trade and business cycle, as evidenced by comparison with sales prior to and following the recession of 1982. The production cycle is less evident when the tonnages of the Communist Block countries are considered, primarily due to their fairly stable production levels (less than 2% per year kaolin production increase in the last 5 years). In North America, the deposits in the southeastern U.S. have been by far the most prominent source of good quality kaolin. In the U.S. kaolin production levels have experienced a yearly growth of about 5% in the last 5 years of record.

United States

The U. S. Bureau of Mines' figures show that in 1987, the last year for which published figures are available, total U.S. kaolin production stood at 8,827,210 short tons. Of this amount, 7,423,820 tons, or 84.1% of the total, were mined in Georgia. The second largest producer by state was South Carolina with 809,460 tons, or 9.2% of the total, followed by Arkansas with 202,209 tons, or 2.3% of the total. No other state had production levels above 100,000 tons. The Georgia-South Carolina kaolin belt thus dominates U.S. production, accounting for about 93% of total production. (See Table on page 8).

The belt is also a major world source of kaolin. In 1987, world production of kaolin amounted to 26,491 thousand tons. Total U.S. production in this same year amounted to about 33.3% of total world production. In this same year, Georgia and South Carolina together accounted for 31.3% of total world production.

-CLAYS SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1987, BY STATE1/
(SHORT TONS UNLESS OTHERWISE SPECIFIED)

STATE	BALL CLAY	BEN-TONITE	COMMON CLAY AND SHALE	FIRE CLAY	FULLER'S EARTH	KAOLIN	TOTAL	TOTAL VALUE
ALABAMA-------------	--	W	2,071,690	126,840	--	40,441	2/2,238,971	2/$16,216,547
ARIZONA-------------	--	28,530	189,621	--	--	--	218,151	1,905,317
ARKANSAS------------	--	--	706,185	--	--	202,209	908,394	8,651,462
CALIFORNIA----------	--	116,293	2,092,234	--	--	87,805	2,296,332	33,045,543
COLORADO------------	--	100	289,002	--	--	2,948	292,050	1,763,455
CONNECTICUT---------	--	--	W	--	--	--	W	W
FLORIDA-------------	--	--	127,518	--	431,147	38,522	597,187	39,496,244
GEORGIA-------------	--	--	2,439,686	--	591,234	7,423,820	10,454,740	756,093,514
IDAHO---------------	--	W	W	--	--	8,944	21,781	229,835
ILLINOIS------------	--	--	232,949	--	W	--	3/232,949	3/977,048
INDIANA-------------	--	--	1,036,669	W	--	--	4/1,036,669	4/4,055,534
IOWA----------------	--	--	472,788	--	--	--	472,788	1,494,770
KANSAS--------------	--	W	603,680	--	--	--	2/603,680	2/2,575,572
KENTUCKY------------	W	--	883,267	W	--	--	1,030,518	8,820,874
LOUISIANA-----------	--	--	356,904	--	--	--	356,904	9,191,774
MAINE---------------	--	--	W	--	--	--	W	W
MARYLAND------------	--	--	383,054	--	--	--	383,054	1,939,968
MASSACHUSETTS-------	--	--	W	--	--	--	W	W
MICHIGAN-----------	--	--	1,333,498	--	--	--	1,333,498	5,338,433
MINNESOTA-----------	--	--	W	--	--	W	W	W
MISSISSIPPI---------	W	278,871	559,955	--	W	--	1,123,325	26,932,947
MISSOURI------------	--	--	1,139,749	336,088	W	--	3/1,475,837	3/10,414,581
MONTANA-------------	--	--	28,879	W	--	--	4/28,879	4/98,270
NEBRASKA------------	--	--	223,728	--	--	--	223,728	721,059
NEVADA--------------	--	11,799	--	--	W	W	65,424	2,468,190
NEW HAMPSHIRE-------	--	--	W	--	--	--	W	W
NEW JERSEY----------	--	--	W	5,985	--	--	5/5,985	5/139,768
NEW MEXICO----------	--	--	50,350	898	--	--	51,248	141,110
NEW YORK------------	--	--	672,635	--	--	--	672,635	3,562,468
NORTH CAROLINA------	500	--	3,173,037	--	--	55,516	3,229,053	15,282,025
NORTH DAKOTA--------	--	--	50,101	--	--	--	50,101	99,701
OHIO----------------	--	--	2,895,970	291,300	--	--	3,187,270	12,713,992
OKLAHOMA------------	--	--	797,301	--	--	--	797,301	1,782,741
OREGON--------------	--	18,147	249,677	--	--	--	267,824	985,880
PENNSYLVANIA--------	--	--	1,182,748	23,373	--	W	6/1,206,121	6/4,750,713
PUERTO RICO---------	--	--	148,029	--	--	--	148,029	317,751
SOUTH CAROLINA------	--	--	1,244,886	--	139,194	809,460	2,193,540	3/38,243,426
SOUTH DAKOTA--------	--	--	W	--	--	--	W	W
TENNESSEE-----------	691,570	--	569,303	--	W	--	3/1,260,873	3/25,480,282
TEXAS---------------	W	27,547	3,283,652	4,225	W	W	3,474,976	25,959,476
UTAH----------------	--	29,000	286,154	--	--	--	315,154	1,958,941
VIRGINIA------------	--	--	1,171,442	--	W	--	3/1,171,442	3/6,291,100
WASHINGTON----------	--	--	412,031	3,562	--	--	415,593	2,355,954
WEST VIRGINIA-------	--	--	266,037	--	--	--	266,037	564,574
WYOMING-------------	--	2,127,645	W	--	--	--	5/2,127,645	5/62,031,122
UNDISTRIBUTED-------	291,735	168,301	703,316	11,280	895,216	157,545	7/1,569,629	7/67,509,912
TOTAL-------------	983,805	2,806,233	32,327,725	803,551	2,056,791	8,827,210	47,805,315	1,202,601,873

W WITHHELD TO AVOID DISCLOSING COMPANY PROPRIETARY DATA; INCLUDED WITH "UNDISTRIBUTED."
1/INCLUDES PUERTO RICO.
2/EXCLUDES BENTONITE.
3/EXCLUDES FULLER'S EARTH.
4/EXCLUDES FIRE CLAY.
5/EXCLUDES COMMON CLAY.
6/EXCLUDES KAOLIN.
7/INCOMPLETE TOTAL; DIFFERENCE INCLUDED WITH INDIVIDUAL STATE TOTALS.

The Georgia-South Carolina kaolin belt extends though a strip of land about 25 miles wide and 150 miles long from Aiken, South Carolina to Andersonville, Georgia. The strip follows the Tuscaloosa fall line, which represents both the present boundary between the Piedmont and the coastal plain, and an ancient seashore. The deposits of the belt are both extremely pure and extremely large, their average kaolinite content is 90%, and contain only small quantities of quartz and mica as impurities. Ultimate kaolin reserves in the belt are very large, and only the most attractive deposits are being currently mined.

Mining in Georgia is dominated by three large corporations, all with total mining capacities of over 1 million tons of kaolin per year, each. Georgia Kaolin Company Inc., a subsidiary of Combustion Engineering Inc., has a total annual production of about 1.6 million tons of delaminated, calcined, and water-washed kaolins. The Engelhard Corporation, which in 1985 purchased fellow kaolin producer, the Freeport McMoRan company, has a annual capacity of about 1.5 million tons. Engelhard is the premier supplier of calcined pigment clays, in addition to clays for use in catalysts. JM Huber Corporation has an annual capacity of 1.3 million tons, and was a pioneer in magnetic separation. In 1986 it announced the installation of a superconducting magnetic separator at its Wrens, Georgia plant, which was reportedly the first industrial application of a superconductor. In addition to these three, other major Georgia producers include Thiele Kaolin Company, ECC America Inc., Nord Kaolin Company, Hecla, which recently bought the Cyprus Industrial Minerals kaolin operations, Albion Kaolin Company, and the Evans Clay Company.

Non-Georgia kaolin operations are on whole much smaller than the Georgia companies and usually produce specialized kaolin products. The American Cyanamid Company runs a mine at Benton, Arkansas producing less than 100,000 tons annually of bauxitic kaolin for use in refractories. The Feldspar Corporation produces 50,000 tons a year of ceramic-grade kaolin from a kaolinitic sand deposit at Edgar, Florida. The North American Refractories Company has a plant at Ione, California which specializes in calcined clay, and also produces two varieties of filler clays, with total production of about 60,000 tons annually. C-E Minerals is the largest supplier of calcined kaolin, producing about 360,000 tons annually with plants in Georgia and Alabama. Finally, a number of minor producers specializing in fillers for plastics and refractory grade kaolin are spread throughout the country.

Though these smaller non-Georgia producers are important in particular usages of kaolin, the Georgia-South Carolina belt dominates the U.S. market. For instance, although the California sources of kaolin are much closer to the paper mills of the Pacific Northwest than the Georgia sources, the California mines do not produce high quality water-washed kaolin, and the mills are thus forced to purchase it from Georgia. The opening of a new source in Minnesota would probably save these Pacific Northwest companies substantial amounts of transportation expenses.

The 1987 kaolin sales by U.S. producers, along with their gross monetary value by type of clay, are tabulated below.

Type of Clay	Tons(million)	$
Air-float	1.6	74M
Calcined	1.2	202M
Delaminated	1.1	104M
Unprocessed	0.7	15M
Water-washed	4.3	380M

Current production and utilization of Minnesota kaolin clays is addressed on pages 25 and 36.

Other Sources

The main world source of kaolin, other than the U.S., is the United Kingdom. In 1987, sales of kaolin by companies from the U.K. amounted to 3,500,000 tons, or 13.2% of world production. The deposits of the U.K. occur in Cornwall and Devon. They are residual deposits which are not particularly concentrated, containing only 10-40% kaolin. They do, however, have a very high brightness.

The main English producer is ECC International Ltd., which in 1985 had kaolin production of 2.6 million tons, making it the world's largest corporate kaolin producer. Approximately 80% of production is slated for the paper industry, while another ten percent finds usage in the ceramics industry.

Canada, although it currently produces no high-grade kaolin, has two potential sources. The Wood Mountain area of southern Saskatchewan is the site of a much studied kaolinitic sand deposit, and mining of this deposit is now in review. The Wood Mountain deposit, if developed, would have many of the same geographic advantages as a Minnesota kaolin deposit and would probably become a competing source. Current plans for this source call for an annual production of 150,000 tons of filler grade clay.

In addition to the Wood Mountain source, a sedimentary kaolin deposit in the Moose River Basin of northeastern Ontario is also being studied. No production plans for this deposit have been presented as of yet, and it is unlikely that this source will produce paper coating grade clays.

The third largest producer of kaolin world-wide is the Soviet Union whose production was estimated at 3,300,000 tons in 1987. Production is concentrated mainly in the central Asiatic provinces, however, little of this kaolin enters world trade.

A growing producer is Brazil. Brazilian production in 1987 was only 710,000 tons, but this was almost entirely composed of high quality paper grade clays. The deposit currently being mined is extremely high grade, containing an average of 98% kaolinite and is large enough to last 500 years at the current rate of extraction. The development of this deposit is one of the main reasons for the current growth of the Brazilian paper industry.

A potential large scale producer of high quality coating clays is Australia. Although current Australian kaolin production is only about 200,000 tons a year, deposits are high grade and expansion seems likely.

Other significant world producers include West Germany, France, South Korea, India and Czechoslovakia from the eastern block.

CONSUMPTION, END-USES, AND PRICES

Kaolin is an extremely useful mineral. Its properties of white color, softness, small particle size, and chemical inertness make it suitable for a number of different industrial applications. The desired properties of the kaolin used varies greatly between these different applications, however. What might be a good clay for paper coating might not be an acceptable clay for use as a filler in rubber. In this section the various usages for kaolin are discussed, including both yearly rates of consumption and product-property relationships.

The tabulation on page 13 contains 1987 U.S. Bureau of Mines figures on kaolin volume sold or used by U.S. producers, in various end-uses, both in the domestic and in the international markets, for 1986 and 1987. It is apparent there that the highest proportion of the yearly kaolin volume (about 60%) is consumed by the paper industry. This domination is expected to continue in the near future.

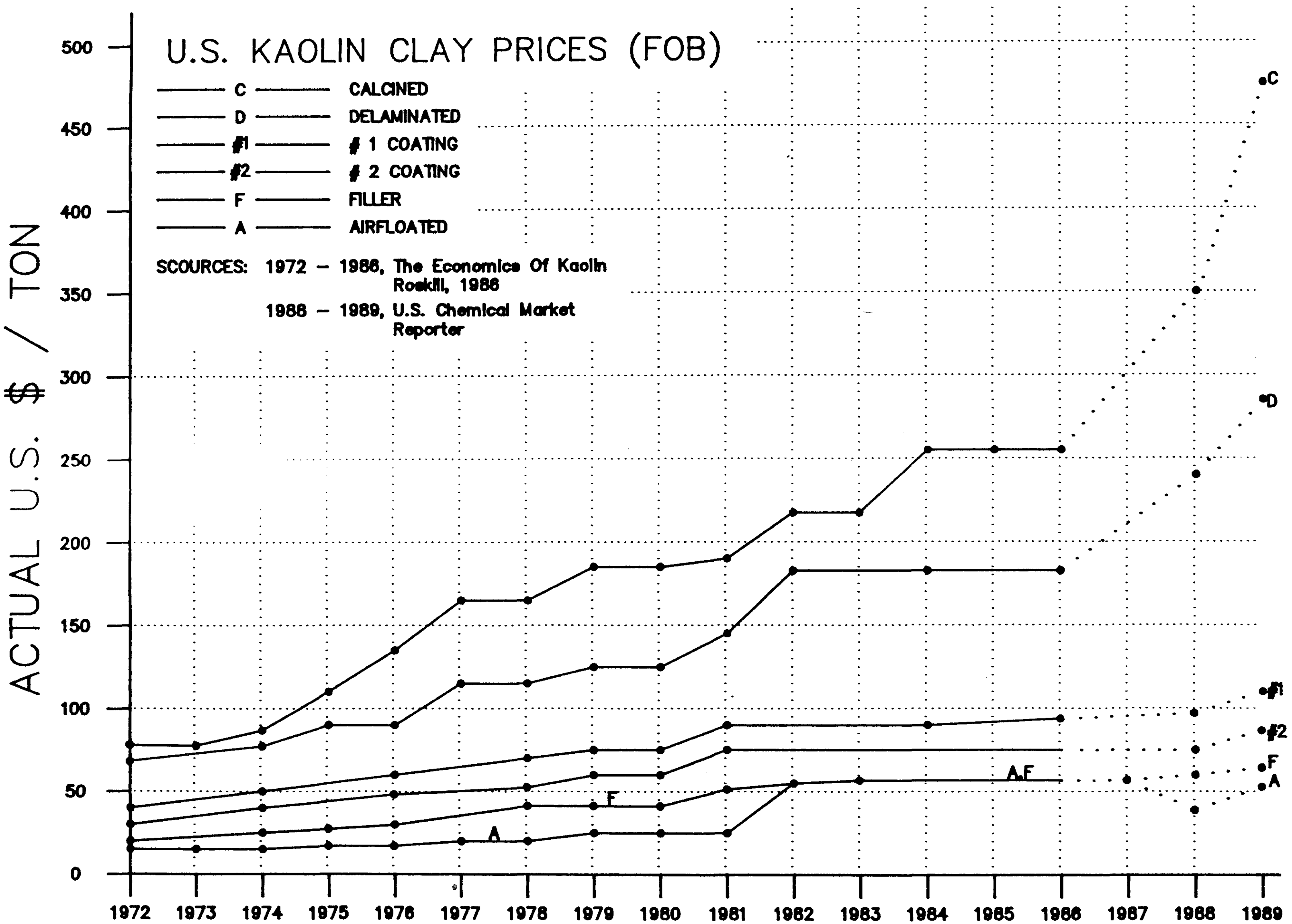
The unit price in terms of actual, i.e., non-constant dollars for various kaolin products and grades has seen a steady growth over the last 17 years, though it is somewhat limited by the strong competition in the market following the capacity expansion of 1979 - 1981 that was geared towards value-added paper grades. Yet, certain products such as calcined clay, has increased in value at a much faster pace. The unit price growth rates are of course slower, even flat for certain products, if one considers a constant (inflation adjusted) dollar value. The chart on page 14 portrays the recent historical record of the U.S. kaolin prices in actual U.S. dollars.

The relationships between kaolin deposit properties and end-uses are extremely important in that they potentially define the processing/beneficiation needs and the range of utilization of the resource. The vast variety in testing procedures and testing equipment; the differences in standards and specifications from one industry to another type of industry; the inevitable variance of requirements within one industry (or even between the purchasing and the production divisions in <u>one</u> plant) regarding raw material quality; and the inherent proprietary knowledge in this highly competitive market;

--KAOLIN SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE
(SHORT TONS)

USE	1986 AIR-FLOAT	1986 UNPROC-ESSED1/	1986 WATER-WASHED2/	1986 TOTAL	1987 AIR-FLOAT	1987 UNPROC-ESSED1/	1987 WATER-WASHED2/	1987 TOTAL
DOMESTIC:								
ADHESIVES	43,921	--	25,978	69,899	45,020	--	22,967	67,987
ALUMINUM SULFATE AND OTHER CHEMICALS	--	155,352	--	155,352	--	210,609	--	210,609
ANIMAL FEED	33,615	--	3,259	36,874	37,409	--	4,000	41,409
BRICK, EXTRUDED AND OTHER	6,655	645,289	236	652,180	--	353,239	2	353,241
CATALYSTS (OIL AND GAS REFINING)	107,528	--	17,153	124,681	64,261	--	47,911	112,172
CEMENT, PORTLAND	--	204,339	--	204,339	--	81,288	--	81,288
CHINA AND DINNERWARE	20,209	1,377	3,000	24,586	21,827	--	--	21,827
CROCKERY AND OTHER EARTHENWARE	W	W	--	W	9,164	--	--	9,164
ELECTRICAL PORCELAIN	16,773	--	4,043	20,816	6,460	--	2,393	8,853
FERTILIZERS 3/	--	--	4,846	4,846	23	--	2,863	2,886
FIBERGLASS, MINERAL WOOL AND OTHER INSULATION	268,387	--	98,990	367,377	358,276	--	100,253	458,529
FIREBRICK, BLOCKS AND SHAPES	66,031	2,723	95	68,849	84,743	33,846	--	118,589
FLOOR AND WALL TILE, CERAMIC; GLAZES, GLASS, ENAMELS	20,331	5,194	5,719	31,244	12,597	2,723	3,646	18,966
FLUE LININGS, HIGH-ALUMINA BRICK AND SPECIALTIES	661	87,903	400	88,964	694	68,800	--	69,494
FOUNDRY SAND	412	--	--	412	--	--	--	--
GROGS AND CALCINES, REFRACTORY	2,794	388,562	464	391,820	22,786	574,956	469	598,211
GYPSUM PRODUCTS AND WALLBOARD	14,983	3,257	806	19,046	7,746	2,026	4,000	13,772
INK	--	--	W	W	85	--	2,243	2,328
KILN FURNITURE; REFRACTORY MORTAR AND CEMENT	20,903	35,936	1,389	58,228	2,619	--	1,368	3,987
LINOLEUM AND ASPHALT TILE	13,512	--	4,043	17,555	16,133	--	5,089	21,222
MEDICAL, PHARMACEUTICAL, COSMETIC	1,629	--	1,291	2,920	2,178	--	1,063	3,241
PAINT	13,367	3,789	233,373	250,529	15,904	3,573	267,768	287,245
PAPER COATING	--	--	2,315,664	2,315,664	--	--	2,487,279	2,487,279
PAPER FILLING	187,564	--	1,153,431	1,340,995	231,091	--	1,114,071	1,345,162
PESTICIDES AND RELATED PRODUCTS	7,004	11,509	2,265	20,778	20,622	17,882	2,300	40,804
PLASTICS	13,181	--	37,397	50,578	9,567	--	47,742	57,309
POTTERY	35,041	689	465	36,195	65,238	--	--	65,238
ROOFING GRANULES	26,868	--	1,000	27,868	7,313	--	22	7,335
ROOFING AND STRUCTURAL TILE	348	--	--	348	392	--	--	392
RUBBER	266,153	--	21,794	287,947	222,345	--	32,320	254,665
SANITARY WARE	130,689	11,705	6,601	148,995	58,437	--	1,000	59,437
WATERPROOFING AND SEALING	--	--	W	W	--	4,950	3,724	8,674
MISCELLANEOUS	53,017	12,481	191,833	257,331	120,275	7,334	195,971	323,580
TOTAL	1,371,576	1,570,105	4,135,535	7,077,216	1,443,205	1,361,226	4,350,464	7,154,895
EXPORTS:								
CERAMICS	13,337	--	5,804	19,141	9,760	--	--	9,760
FOUNDRY SAND, GROGS AND CALCINES; OTHER REFRACTORIES	1,700	212,000	--	213,700	1,849	--	--	1,849
PAINT	124	--	118,087	118,211	127	--	35,985	36,112
PAPER COATING	27,386	--	776,962	804,348	28,492	--	1,154,774	1,183,266
PAPER FILLING	5,120	--	222,479	227,599	22,441	--	284,347	306,788
PLASTICS	40	--	--	40	41	--	--	41
RUBBER	31,403	--	19,863	51,266	55,359	--	23,663	79,022
MISCELLANEOUS	3,989	1,782	32,190	37,961	10,468	1,667	43,342	55,477
TOTAL	83,099	213,782	1,175,385	1,472,266	128,537	1,667	1,542,111	1,672,315
GRAND TOTAL	1,454,675	1,783,887	5,310,920	8,549,482	1,571,742	1,362,893	5,892,575	8,827,210

W WITHHELD TO AVOID DISCLOSING COMPANY PROPRIETARY DATA; INCLUDED WITH "MISCELLANEOUS".
1/INCLUDES HIGH-TEMPERATURE CALCINED.
2/INCLUDES LOW-TEMPERATURE CALCINED AND DELAMINATED.
3/INCLUDES SOIL CONDITIONERS AND MULCHES.


U.S. KAOLIN CLAY PRICES (FOB)
C — CALCINED
D — DELAMINATED
#1 — # 1 COATING
#2 — # 2 COATING
F — FILLER
A — AIRFLOATED
SCOURCES: 1972 – 1986, The Economics Of Kaolin Roskill, 1986
1988 – 1989, U.S. Chemical Market Reporter
ACTUAL U.S. $ / TON
0
50
100
150
200
250
300
350
400
450
500
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
A,F
F
A
C
D
#1
#2
F
A

they all make the identification of the physical properties of a kaolin deposit that are required for a particular end-use a very difficult and delicate task to complete. Therefore, only the most basic properties of kaolin, by end-use, have been reviewed in this study. A detailed discussion of the above follows.

Paper

The paper industry is by far the largest single user of kaolin clay. The paper industry accounted for 5,322,495, or 60.3%, of the 8,827,210 tons of kaolin sold or used by U.S. producers in 1987. Kaolin is used in paper to add a bright, glossy sheen as in magazines, to improve the ink receptiveness and the smoothness of fibrous papers, and as a substitute for pulp. There are two basic types of clays used in paper; filler clays and coating clays.

Kaolin used as a paper filler has to meet less rigorous standards than coating clays. Use of mineral fillers is advantageous to papermakers because the fiber which makes up the matrix of the paper has an irregular and sometimes transparent surface, and is relatively expensive. The use of mineral fillers, such as kaolin, increases the brightness and opacity of the paper while also making it more receptive to printing inks. Paper producers have increasingly adopted the use of kaolin as fillers because they are usually less expensive than the pulp matrix.

Filler clays can either be water-washed or air-floated. Air-floated filler kaolin has an average brightness of between 78 and 81% and an average of 70-80% particles smaller than 2 microns. Water-washed filler clay has a greater particle size, averaging between 50 and 70 percent below two microns, but a greater brightness of 83 to 85 percent.

Sales of kaolin by U.S. companies for paper filling totalled 1.6 million tons in 1987, or 19% of total sales, out of which 1.3 million tons were used domestically. The production of filler clays is dominated by Georgia. In 1987, 99% of paper filling clay produced in the U.S. was mined in Georgia, and it is noted that 86% of that clay was produced using the water-washing method. The current price for filler clays is about $64 a ton.

Paper coating is the most desirable end-use for kaolin producers, because it is both the highest volume use of kaolin and also commands one of the highest unit prices. Paper is coated with a kaolin clay slurry which increases its brightness, glossiness, and ink receptiveness. Glossy papers such as those used in magazines can be as much as 40% kaolin by weight. Normal printing and writing papers average about 30% kaolin.

Production of paper coating clays in the United States is dominated by Georgia producers. In 1987, total production of paper coating grade kaolin in the United States totalled 3 million tons, out of which 99% came from Georgia sources. Total kaolin usage by U.S. companies in 1987 ammounted to 2.5 million tons, of which 99% came from Georgia sources. Kaolin destined for paper coating end-uses amounted in 1987 to 41.3% of the total U.S. kaolin production.

Prices for coating grade kaolins range from about $85 for low grade No.3 coating clays to about $110 for high grade No. 1 clays. Price is mainly based on the brightness of the clays, which is controlled by the average particle size and the amount of impurities within the clay. A No. 1 clay has on average 95-100% particles under 20 microns, and an average brightness of 86-87% for regular and 90-92% for high brightness grades.

From these figures it is clear that production of paper-coating grade kaolin would be extremely profitable if a good source were found. Production in the U.S., however, is totally dominated by one state, Georgia, whose clays show ideal characteristics for coating-grade kaolins. The critical characteristics of a high quality coating grade kaolin are a high brightness of at least 85%, a small average particle size with a high percentage of particles less than 2 microns of 70 to 80%, low abrasiveness, and good high and low shear viscosity at high percentage solids.

High brightness is an essential characteristic of a coating grade kaolin because paper-producers normally attempt to add brightness to paper by coating it. Small average particle size is important because it increases both the brightness and the ink-receptiveness of the kaolin. Low abrasiveness is essential to paper-manufacturers who wish to minimize wear on their machines. Low shear viscosity is important because the kaolin is applied in slurry form at about 70% solids, which flow well so that the kaolin can be easily applied and so that the coat be even.

Almost all kaolin used for paper coating is water-washed. Some calcined kaolin is now being used, but this has the disavantage of having a much higher abrasiveness than normal water-washed kaolin. In addition, some delaminated kaolin is used in lightweight paper products where the thickness of the coating can be very important.

In the mid-seventies it was feared that consumption of paper products was about to fall precipitously, due to the development of widespread computer use. These fears proved not to be valid, however, as computers actually seemed to help the paper industry due to a more widespread reliance by business on the transfer of information in general. Consumption of paper products tend to rise and fall with general economic conditions, and it seems that this trend will continue. If economic conditions stay generally healthy, production of paper and use of kaolin by the paper industry should continue to increase.

Ceramics and Refractories

Although the major use of kaolin clay in the United States is in the paper industry, there are many other uses and there are several successful mining companies which specialize in producing kaolin destined for non-paper industry end-uses. While paper coating and filling is the most profitable end-use for high quality kaolins, due to both high volumes and rather high unit prices, other end-uses are worth looking at both as supplements to a paper-grade operation and as alternatives if the Minnesota kaolins do not reach paper industry standards.

One of the highest volume non-paper end-uses for kaolin is in the ceramics and refractory industries. Clay is an essential raw material in ceramic products, composing 25-100% of the ceramic body. Kaolin, however, is one of a number of clays used in this industry. Kaolin makes up an average of 25% of earthenware, 60% of porcelain, 20-30% of vitrous-china sanitary ware, and 20% of electrical porcelain and wall tiles. Ceramic and refractory end-uses amounted to almost 950,000 tons of kaolin in 1987, or 11% of total usage. Refractory uses include linings of open-hearth and blast furnaces in the steel industry, and in cement and ceramic kilns. Refractory grogs and calcines accounted for 598,211 tons of this total, and fire-brick for 118,389 tons. These figures make this catagory the largest volume end-use of kaolin outside of the paper industry.

Consumption of kaolin in the ceramics industry reached a peak of 270,000 tons in 1977 but fell to a low of 161,000 in 1983. 1987 consumption was about 180,000 tons. Consumption by the refractories industry peaked at 998,000 tons in 1980, but fell to 385,000 tons in 1982, and has rebounded to about 770,000 tons in 1987. Further growth is considered unlikely due to changes in the use of refractories in heavy industry.

Kaolin used for ceramic and refractory end uses is much less refined and has a much lower unit value than kaolin used in the paper industry. Of the 598,211 tons used for refractory grogs and calcines, for instance, 574,956 tons were unprocessed. Unprocessed kaolin grades average only about $35 a ton.

The uses of kaolin in the ceramics and refractory industries can be separated into two groups based on the importance of a white firing color to the end-use. White-firing colors are most important in the production of porcelains and wall and floor tiles, which are rather low volume industries in the U.S. White color is much less important in the production of refractories. Important properties for the use of kaolin in ceramics and refractories are green strength, dry strength, drying and firing shrinkage, refractory grade, and fired color.

Green strength and dry strength refer to the wet and dry strength of the clay in question. Kaolin has high green and dry strengths but is not very plastic when wet, which creates some problems when molding. Shrinkage is important to the ceramics manufacturer who usually wants a clay with low shrinkage. Examples of some raw material properties are tabulated on pages 19 and 20.

Refractory clays, such as fire clays and flint clays are those in which fusion does not occur until past 1500°C. They generally have a high alumina content and they may be classified in terms of the temperature of softening or on the basis of the standard pyrometric cone equivalent. Melting point

Compositions and properties of kaolins used in ceramics

	Wt % 1	2	3	4	5
SiO_2	48	48	48	48	48.8
Al_2O_3	37	37	37	36.3	36.1
Fe_2O_3	0.65	0.70	0.85	1.0	0.62
CaO	0.07	0.06	0.07	0.1	0.12
MgO	0.3	0.3	0.3	0.3	0.35
Na_2O	0.1	0.1	0.1	0.1	0.14
K_2O	1.6	1.85	1.75	1.8	2.60
TiO_2	0.02	0.02	0.05	0.1	0.07
Loss on ignition	12.5	12.5	12.1	12.3	11.20
% < 2μm	70	57	40	50	48
% > 10μm	4	10	18	4	14
% > 53μm	0.03	0.05	0.10	0.06	0.15
Modulus of rupture at 110°C (Kgf/cm^2)	31.7	25.7	10.9	7-11	25
Brightness at 1,180°C	91(a)	86(a)	86(a)	85(b)	83(c)
Brightness at 1,280°C	88(a)	86(a)	87(a)	—	—
Brightness at 1,410°C	77(a)	75(a)	—	—	—

(a) at an effective wavelength of 457 nm;
(b) at 464 nm; (c) at 495 nm.

Source:

1. 'Standard Porcelain' ECLP. High quality tableware, porcelain and bone china.
2. 'Grolleg' ECLP. Earthenware tableware.
3. 'Remblend' ECLP. Sanitaryware.
4. 'CC 31' Watts Blake Bearne & Co PLC. Sanitaryware and general purpose ceramic clay.
5. 'Diamond Ceramic' The Goonvean Rostowrack China Clay Co Ltd. Ceramic clay including bone china.

Some Properties of Fireclays from various Localities

Chemical Analysis (%)	South Midlands		Yorkshire		Northumberland and Durham		Scotland		Staffordshire and Shropshire	
	Mean	*Range*	*Mean*	*Range*	*Mean*	*Range*	*Mean*	*Range*	*Mean*	*Range*
SiO_2	56.5	45.9—67.3	60.1	53.4—76.5	59.5	48.6—81.6	57.4	44.5—79.6	60.9	44.5—71.1
Al_2O_3	26.6	19.4—33.2	25.7	15.5—30.0	26.0	12.2—32.5	26.4	11.9—37.8	23.7	16.7—33.8
Fe_2O_3	2.4	1.3— 5.6	1.7	0.8— 2.8	1.6	0.6— 3.4	1.9	0.7— 4.2	2.2	1.1— 4.4
TiO_2	1.5	1.3— 2.1	1.2	1.0— 1.6	1.2	1.0— 1.6	1.2	0.7— 1.9	1.3	1.1— 1.5
CaO	0.3	0.1— 0.8	0.4	0.2— 0.5	0.4	0.1— 0.8	0.3	0.1— 0.6	0.3	0.0— 1.6
MgO	0.5	0.2— 0.7	0.5	0.2— 0.8	0.5	0.2— 0.8	0.5	0.2— 1.0	0.6	0.0— 1.7
Na_2O	0.2	0.1— 0.5	0.15	0.1— 0.3	0.1	0.0— 0.3	0.1	0.0— 0.4	0.2	0.0— 0.4
K_2O	1.4	0.4— 2.6	1.3	0.7— 2.7	1.7	0.9— 2.6	1.2	0.2— 1.7	1.8	0.8— 3.5
Ignition loss	10.6	6.8—17.1	9.3	5.3—12.6	9.0	3.9—13.1	10.9	4.4—14.8	8.9	5.6—19.6
SO_3	0.4	0.1— 1.0	0.5	0.2— 1.1	0.2	0.1— 0.4	0.3	0.1— 0.4	0.3	0.1— 1.8
Carbon	1.6	0.1— 5.7	0.9	0.3— 2.1	0.9	0.3— 2.2	1.7	0.3— 4.8	1.2	0.2— 5.6
Kaolinite	53.3	35.6—75.6	52.6	28.7—68.4	50.4	23.5—67.8	55.5	23.4—93.3	42.9	26.9—67.6
Mica	14.8	6.5—25.8	12.6	6.5—27.8	15.7	7.6—24.0	12.1	2.2—28.9	17.7	5.8—30.6
Quartz	25.4	9.0—44.6	30.0	19.0—58.0	29.3	10.4—67.0	26.2	0.1—65.6	33.1	4.7—50.8
Carbonaceous matter	2.2	0.2— 7.7	1.3	0.0— 3.3	1.2	0.0— 3.0	2.6	0.5— 6.1	2.0	0.3— 9.9
Particle size (%)										
μ										
<0.1	9	4 —12	4	3 —6	3	2 — 7	3	2.5— 7	—	—
0.1— 2.0	38	9 —47	24	17 —30	22	9 —30	29	13 —53	49.8	33.0—83.5
2.0— 5.0	19	10 —26	13	8 —20	13	8 —18	14	3 —23	22	8 —35
5.0—10.0	9	1 —15	10	6 —28	11	5 —18	9	0 —19	12	2 —21
10.0—25.0	10	5 —17	12	8 —17	14	4 —20	10	1 —16	10	0 —31
Critical moisture content (%)	11.0	9.0—15.1	10.1	9.1—11.5	9.6	8.5—11.4	10.0	8.5—12.1	11.5	9.1—15.3
Modulus of rupture (unfired) (lb/in²)	314	155— 540	304	170— 480	266	190— 500	318	180— 950	430	220— 840
Refractoriness (°C.)	1647	1530—1710	1630	1460—1680	1662	1595—1700	1660	1490—>1770	1595	1410—1720
Linear firing-shrinkage (%)	4.6	2.0— 6.0	2.8	0.0— 4.0	2.8	0.0— 5.0	3.2	0.5— 5.0	4.2	0.9— 8.5

is the most important characteristic of kaolin in the refractory industries. An ideal kaolin loses its water at about 1000 Fahrenheit, but does not undergo strength loss until about 1700 Fahrenheit. A kaolin must come close to these figures for use in refractories. The presence of impurities can greatly depress the above temperature figures.

Kaolin used for white-firing end-uses must be extremely pure. The maximum permissible iron content is about 1%, the maximum permissible titanium 0.5%, and the maximum manganese content is .1%. The copper content must not be higher than .01%.

Since the ceramics industry uses precise formulas of different raw materials, it is very important that clay destined for usage in the ceramics industry have extremely uniform properties.

Finally, a growing use of kaolin in the refractory industry is in the production of sythetic mullite, or aluminum oxide, which is an important refractory material that can be produced by removing the silica in kaolin. Kaolin is not the main source for such use, but as other sources become fewer and more expensive, a growing use of kaolin in this industry could be expected.

Plastics, Adhesives, and Fiberglass

In both the ceramics and the paper industries, the main reason for the use of kaolin is its particular properties, such as high brightness, low abrasiveness, and small particle size. The relatively low cost of kaolin, while being an important factor, was not nearly as important as the physical characteristics of the mineral. In the three applications discussed in this section and also in the sections on rubber and paint which follow, the low cost of kaolin is of primary importance and the physical properties, while they can be beneficial, play a secondary role. Most processed grades of kaolin can be used for these various products. In plastics kaolin is used both as a diluent filler, and as a reinforcing filler in epoxy resins, polyesters and vinyls.

The use of kaolin in the plastics, adhesives, and fiberglass industries is as a filler, a substitute for some of the resin, which is one of the most expensive materials in the manufacture of these products. The use of kaolin in these products can be separated into uses in which kaolin is important only in lowering raw material costs, and those in which the use of kaolin also gives secondary benefits based on its physical properties. The perfect filler for these industries would have a number of characteristics including low cost, good availability, low oil absorption, small and uniform particle size, good dispersion, low density, good chemical resistance, light color, and low free moisture levels. Kaolin, while not having all of these properties, does have perhaps the best selection of properties of any filler available.

Specific advantages of kaolin over other mineral fillers include its fine particle size and relatively uniform particle size distribution; its large surface area which allows for good bonding with the matrix material; its nonabrasive character; low chemical reactivity; and high-temperature thermal characteristics. These qualities manifest themselves in plastics where the kaolin provides protection against cracking and in glass reinforced polyesters where good flow properties and resistance to chemical attack are important. Disadvantages of kaolin include its poor packing fraction, which refers to its relatively low density when packed tightly, and its poor dispersion in melted polymers.

To increase the value of kaolin in filler applications, it is usually surface modified, or surfied. This increases the number of active bonding sites on the surface of the kaolin grains, which in turn increases the high and low stress viscosity of the kaolin and improves its dispersion characteristics.

The use of kaolin in fiberglass is furthered by an unusual chemical characteristic of kaolin. Kaolin remains chemically stable when heated to about 1000 Fahrenheit, at which point it begins to dehydroxylate by losing its water. This process is usually not damaging to the product involved. At 1700 Fahrenheit, the dehydroxylation is complete, and the fiberglass melts and reacts with the kaolin to form a much higher melting glass. The simultaneous release of water and the fiberglass-kaolin fusion allow the product to retain its shape, making this combination of kaolin and fiberglass one of the ultimate materials for fire resistance. Coarse quartz particles are a serious impurity in fiberglass manufacture and must be less than 9 particles per pound of clay.

Most filler kaolin used in these industries is of the air-floated variety, although calcined, surface modified, delaminated, and water-washed kaolins can be also used. These kaolins tend to be in a medium price range, although surface modified and calcined kaolins are much more expensive. Consumption of kaolin by the fiberglass and insulation industries in 1987 was 458,529 tons. Consumption by the adhesives industry was 67,987 tons, and consumption by the plastics industry was 65,238 tons. These figures are likely to increase in future years given the faster rate of price increase of resin compared to that of kaolin in the last 15 years, and the increasing interest of the kaolin industry in these end-uses.

Rubber

Use of kaolin in the rubber industry is very similar to the use in the fiberglass, plastics, and adhesives industries. The primary beneficial quality of kaolin for rubber is its low cost, since it is much cheaper than either natural rubber or man made elastomers. Kaolin stiffens the compound and reinforces it when cured. It is also used as a low-cost pigment.

The primary filler used in the rubber industry is carbon black, which adds more strength to rubber than kaolin and is also inexpensive. Kaolin is normally used in non-black rubber goods such as toys and floor mats, although there are exceptions, such as in dark-colored automotive products and parts subjected to low mechanical stress.

Kaolins used in the rubber industry can be divided into hard and soft clays. Hard clays are used in applications such as floor mats where resistance to abrasion is important, while soft clays are used in applications such as toys where abrasion resistance is not important. Soft clays are used only to reduce the raw material cost of the rubber, while hard clays additionally have a functional application.

Most kaolins used in the rubber industry have poorer color than the average industrial kaolin, they are mainly air-floated and are mined primarily in South Carolina. South Carolina kaolins tend to be finer-grained but more consolidated and harder than Georgia kaolins. Of the 333,687 tons of kaolin mined in the U.S. in 1987 for the rubber industry, 194,283 tons, or 59%, were mined in South Carolina. This is, thus, one of the few end-uses for kaolin where Georgia does not lead in production.

Kaolin used in the rubber industry must have a constant specific gravity, so that it can be formulated with the other ingredients of the rubber compound, low amounts of coarse materials, very fine grain size, low amounts of impurities, and a pH value of 4.5-5.5.

Paints

Kaolin is complementary as well as competitive with other pigments in the production of paints. Kaolin is used in the manufacture of paint as an extender white pigment. It increases the whiteness of a paint, but on its own will not add to the covering (hiding) power of a paint as will higher quality pigments such as titanium dioxide. When used with other pigments kaolin will increase their covering power because of its flat shape in which particles arrange themselves in an overlapping pattern. For this reason, kaolin is classified as an extender pigment. Kaolin is also valued for its hydrophillic characteristics, which make it a premier extender in latex paint. Because of its high oil absoption characteristics, however, kaolin reduces the gloss in gloss paints and thus its use is limited to no more than 10% by weight in this application.

Production of kaolin for paints in 1987 was 323,597 tons, and of this amount, 285,452 tons were produced in Georgia. Most of this clay was of the water-washed, high brightness variety. The consumption of kaolin by the paint industry has varied considerably in the last 10 years, falling to about 70,000 tons in 1981, yet showing a remarkable recovery over the last 5 years. The F.O.B. quoted unit price for paint grade, water-washed calcined kaolin has increased from about $260/ton in 1988 to about $323/ton in June 1989.

The paint industry has very specific requirements for kaolin, and these specifications can vary greatly between paint formulations. The most important property for the use of a kaolin as a white pigment is its whiteness, but the amounts and types of impurities (salts) are also important, as well as the shape and size of the kaolin grains (70-80% smaller than 2 microns is required).

Bricks and Cement

The majority of clay deposits are composed of a mixture of more than one clay mineral together with non-clay minerals. Such clays are generally not sold in the raw state, but are commonly used in the manufacture of cement and structural or face bricks. The bulk of the Minnesota kaolin production is consumed in these two uses.

Portland cement is manufactured by cintering a mixture of raw materials that include large tonnages of clay or other argillaceous deposits, e.g., shale. They provide a source of alumina, silica, and iron oxides which, together with a calcareous raw material (such as limestone), form the calcium silicates and aluminates present in the cement clinker. The composition of the raw mix has to be adjusted within narrow limits with respect to content of oxides of calcium, silicon, aluminum and iron. The amount present of other constituents, such as magnesium and alkalies, has to be maintained below a specified level. Iron in particular is a deleterious component which can be avoided by using kaolin, an alumino-silicate with a very low iron content. Lime, alumina, and silica make up over 90% of the composition of commercial portland cement. Kaolin typically constitutes less than 10% of the cement raw mix. In the last 15 years, the proportion of the total U.S. kaolin consumption by the cement industry is below 1%, firmly indicating that kaolin is not an essential constituent in cement production and that it can readily be substituted with other alumino-silicate raw materials. Production of cement in the U.S. has fluctuated between 58-78 million tons per year in the last 20 years and is projected to stay fairly steady in the foreseeable future.

Whereas the requirements for a whiteware or refractory clay are fairly stringent, those for a brick-clay are much less so. A wide range of compositions can therefore be tolerated in brick-making clays and shales, as evidenced by the tabulation below that shows the analyses and important physical properties of some brick clays. In general, the brick clay should be sufficiently plastic for satisfactory shaping, and should not shrink excessively on drying. The fired color of brick clays is chiefly due to iron oxides, such as ferric oxide that produces various shades of red and yellow, or ferrous oxides that result in bluish or black colors.

After mining, processing of clay for brick manufacture includes, in general, crushing of the raw material, pulverizing, screening, forming and shaping. This is followed by a glazing procedure, drying and kiln burning. Kaolin

Analyses of Bricks made from Clays of Various Geological Deposits (%)
(From *Clay Building Bricks of the United Kingdom*, by Bonnell and Butterworth, HMSO, 1950)

	Alluvial	*London stock*	*Glacial*	*Oligocene*	*London clay*	*Gault*	*Weald*	*Oxford clay (Fletton)*	*Middle Lias*	*Keuper Marl (Upper)*	*Keuper Marl (Middle)*	*Keuper Marl (Lower)*	*Permian*	*Etruria Marl*	*Coal measure*	*Coal measure*	*Coal measure*	*Devonian*
SiO_2	64·7	68·7	62·5	77·8	64·4	47·2	68·4	56·2	57·8	58·3	46·2	66·0	60·1	62·7	54·9	61·7	61·9	59·6
Al_2O_3	12·7	11·0	18·6	15·8	15·8	19·4	17·2	20·9	23·2	15·3	13·7	13·9	16·7	23·1	34·9	21·6	24·0	19·9
Fe_2O_3	8·3	7·0	6·6	0·8	7·9	6·1	6·3	6·0	9·3	6·0	6·0	6·8	5·8	8·4	3·4	8·0	8·7	11·4
TiO_2	1·6	0·7	0·9	2·2	1·6	0·8	1·3	0·5	1·2	0·7	0·8	0·6	0·5	1·2	0·6	1·2	1·1	1·2
CaO	7·9	8·1	4·1	0·3	1·1	19·2	1·9	8·1	1·0	6·2	11·4	3·5	6·5	0·9	2·1	0·6	0·6	0·2
MgO	1·9	0·8	3·4	0·4	2·4	1·9	1·2	1·7	2·5	7·3	12·8	2·9	4·2	1·2	0·7	1·0	1·1	1·2
Na_2O	0·4	0·8	0·5	0·5	0·5	0·6	0·5	0·5	0·9	0·7	0·3	0·6	1·2	0·4	0·1	1·2	0·2	1·0
K_2O	1·5	2·0	2·9	1·8	3·2	3·1	2·2	3·6	2·9	4·7	3·3	4·1	3·3	2·6	2·6	3·1	1·6	4·2
SO_3	1·4	0·6	0·4	0·5	2·3	1·4	0·7	1·9	0·3	0·5	5·6	1·0	0·9	0·7	0·1	1·5	—	0·1
Loss	0·3	nil	0·3	0·3	1·1	0·4	0·3	0·6	1·0	0·4	0·5	0·2	0·3	nil	0·6	0·1	0·5	0·5

Physical Properties of some Brick Clays

	Particle size (% smaller than 2 μm diameter)		*Working moisture content (% dry basis).*		*Linear firing shrinkage (%)*		*Fired colour for different temperatures*	
Clay	*Range*	*Average*	*Range*	*Average*	*Temperature (°C)*	*Range*	*Temperature (°C)*	*Colour obtained*
Coal Measure shale (outcrop)	16–78	34	15·1–31·2	19·5	1050°	0·2–7·7	1050°	Light salmon, red pink light cream
					1180°	2·0–9·7	1180°	Green-grey, dark brown, chocolate brown, greenish yellow
Coal Measure shale (from coal seams)	14–43	26	15·0–25·1	17·8	1000°	0·4–5·1	1000°	Salmon pink, pale pink, buff, white
					1180°	0·7–7·7	1180°	Green-grey, light grey, cream
Etruria Marls	24–74	47	15·2–30·2	23·6	1180°	0·6–12·1	1000°	Light buff, pink buff, light red, light brown, light chocolate brown, pink, cream
							1180°	Dull brown, red brown, purple brown, medium red, stone, greyish buff
Weald clay	15–85	47	23·8–42·2	30·9	900°	0–3·4	850°	Salmon pink, light red-brown, buff
					1100°	2·5–8·6	1200°	Dark red-brown
Boulder clays	30–60	47	17·1–39·6	28·8	900°	0·1–4·3	880°	Salmon pink, light brown
					1070°	2·5–9·4	1070°	Light chocolate brown, light brown

clay utilized in the U.S. brick manufacture accounted for 353,239 tons in 1987, though this number does not include proprietary data. If this number were accurate, it would suggest a strong downturn in brick manufacture, or kaolin clay usage since 1986 when kaolin amounted to over 645,000 tons. Residential sales in the U.S. account for about two-thirds of the brick market, therefore kaolin use is highly dependent on the strength of the residential-building economy.

Other Uses

Kaolin is one of the most common and one of the most widely used minerals on the Earth's surface. Although the previously listed uses of kaolin do consume most of the U.S. production, there are a number of other end-uses which also consume significant amounts of the mineral.

Of these other consumers, the most important in terms of volume is the chemical industry. Kaolin is mainly used by the chemical industry in the manufacture of aluminum compounds such as aluminum sulfate, phosphate and trichloride. In 1987 consumption of kaolin by the U.S. chemical industry was 210,609 tons. The primary chemical produced using kaolin is aluminum sulfate which is made by reacting kaolin with sulphuric acid. Aluminum sulfate accounts for about half of the chemical production using kaolin.

Another rather significant volume and high value end-use of kaolin is in making synthetic zeolites, or "sieve minerals." Zeolites are mainly used in the petroleum industry as cracking catalysts that increase the area of a catalyst exposed to a reaction which in turn increases its effectiveness. Zeolites can also be used as molecular sieves which allow filtration at very small scales.

Total use of kaolin in the production of catalysts in 1987 was 112,172 tons. This is also a rather high value end-use, due to the fact that most of the clay used is high quality calcined kaolin. Engelhard produces catalysts at a plant in Georgia using Georgia kaolins; other zeolite catalyst plants are located in Texas and California.

A relatively small end-use for kaolin is in the agricultural sector. Kaolins are used by the agricultural industry in the manufacture of fertilizers, pesticides, and animal feed, with a total combined yearly consumption for these three end uses of about 90,000 tons in 1987. Kaolin is used in feed and fertilizers mainly as filler to bring the product to the correct consistency, in pesticides as dilutants to dilute the toxic portion of the pesticide, and as dispersants to make the pesticide easier to apply. Kaolin is especially applicable to this last end-use because its flat particle shape allows the pesticide to adhere better to the sprayed plants.

Finally, a minor, in terms of volume, application of kaolin is in the pharmaceutical industry. The highest purity kaolin is used here mainly as an inert filler, but it can also be an active ingredient, such as in upset stomach remedies and cosmetic muds. Although total consumption by this industry amounted to only 3,241 tons in 1987, it is a high value end-use, which might be beneficial as a supplement to production of kaolin for other uses.

MARKETS FOR MINNESOTA KAOLINS

As in any other potential mining development, given the existence of extensive reserves, there are a few basic economic considerations that influence the price of the delivered commodity. These individual costs that largely manifest themselves in the final unit price are associated with: mining/extraction, processing/beneficiating, energy/power, labor, reclamation/environment, and transportation.

Mining, energy, and labor considerations were beyond the scope of this work, however, they eventually will need to be studied for completeness of the pertinent economic factors. Beneficiation and processing costs are most important, and they will largely depend on the findings of the processing elements of the LCMR project to be supplied by other participating agencies. Reclamation and environmental costs are rather site specific and are briefly addressed in the second DNR report that deals with the environment.

Given the long distance of the region from the primary sources of kaolin (southeast United States), it was felt that it was important to study the size of the market in which the potential advantage in transport costs may prove to be significant, given the possibility that the Minnesota clays may be costly to process and beneficiate. It is important to note that the results of the transportation examination should also provide a measure of the potential transport cost advantage when considering the large Pacific Northwest paper/pulp market, given its geographic location and the likely railroad routes to that region relative to the Upper Midwest.

Transportation Considerations

To study the probable transportation cost advantage of a Minnesota River Valley kaolin source, the current transportation costs from Georgia to a number of upper Midwestern paper mills were investigated by inquiries with the paper mills and railroad companies. Several railroad carriers, including Minnesota Valley Railroad, also quoted estimates on kaolin transport costs from the Minnesota River Valley to various paper producing areas.

Kaolin is transported by rail in three forms: in bulk form (typically water-washed clays) in hopper cars, in 20 lb. bags in boxcars, and as slurry in tank cars. The slurry is typically 70% clay, 30% water mixture for air-float and spray-dried clays; it is a 50% clay and 50% water mixture for calcined clays. It is noted that it is the 70% mixture that has been used here for the economic considerations. Kaolin can also be transported by truck, although this tends to be more expensive unless rail transport is unavailable or difficult. Railroads do not normally own tank cars, therefore when kaolin is bought in slurry form, payment must thus be made for also renting the tank car itself. Although this makes the kaolin more expensive per dry ton, many paper companies do prefer to buy kaolin in slurry form due to the fact that it arrives ready for use. For this reason, several large kaolin companies own a fleet of tank cars.

In this report, kaolin transport prices will be compared both in bulk and slurry form. Slurry prices will be quoted per dry ton of kaolin. The quoted projected costs from Fairfax, Minnesota (which is here assumed to be an average for the entire valley) to sites in northern Minnesota vary between $15 and $30 per net ton, and slightly more if transported as slurry. Due to this discrepancy, an average transportation cost of $25 has been taken as a compromise for the bulk rate to northern Minnesota locations. A cost of $30 can be taken as an estimated slurry rate.

The current cost of transporting a ton of kaolin from Georgia to Grand Rapids, Minnesota is about $53.50 a net ton in bulk, and about $65.30 per dry ton in slurry. Minnesota kaolin thus has an estimated cost advantage of about $28.50 per bulk ton and about $35.30 per dry ton in slurry to this location. This cost advantage is even greater for Wisconsin paper mills. Currently, the cost of transporting kaolin in slurry form from Georgia to Wisconsin Rapids, Wisconsin is $54. Estimated transportation costs per dry ton from Minnesota in slurry form are $13.50 at a minimum shipment of 95 tons, which is a cost advantage of $40.50 per ton. A mill in Kimberly, Wisconsin, currently pays $57 a dry ton to transport slurry kaolin from Georgia. Estimated costs per dry ton in slurry form from Minnesota to neighboring Appleton, Wisconsin, are $17.00, a savings of $40 a ton over the Georgia rates. Due to the lack of data, estimates to such Canadian locations as Sault Ste. marie and Thunder Bay are hard to give. Current costs from Georgia to Sault Ste. Marie are $68.00 per dry ton. If one estimates a cost from Minnesota at $40 a ton, which is probably higher than the actual price, the cost savings to this location are still substantial, about $28 a ton, and still higher for Thunder Bay. Going further east, the cost advantages grow smaller. Current freight costs from Georgia per dry ton in slurry to Kalamazoo, Michigan, for instance, are only $37.84 a dry ton, while estimated costs from Minnesota to nearby Battle Creek, Michigan are $27.50 a dry ton, a savings of only $10.34 a ton.

In addition to these Midwestern locations, a similar cost advantage would probably also exist for the Pacific Northwest. Although exact current costs from Georgia are not known, they will probably exceed the $70-75 dollars per dry ton in slurry and $65 a ton in bulk quoted by a major railway as an estimate cost from Minnesota.

The probable cost advantage is tabulated below:

	Costs, Dry Ton Basis		Cost Advantage	
	Slurry	Bulk	Slurry	Bulk
Georgia to Grand Rapids, MN	$65.50	$53.50		
			$35.50	$28.50
Minnesota River Valley to Grand Rapids, MN	$30.00	$25.00		
Georgia to Wisconsin Rapids, WI	$54.00	$46.80		
			$40.50	$34.75
Minnesota River Valley to Wisconsin Rapids, WI	$13.50	$12.05		
Georgia to Escananba, MI	$58.61	$48.46		
			$37.61	$30.36
Minnesota River Valley to Escanaba, MI	$21.00	$18.10		

It is obvious that there is a great cost advantage to upper Midwestern paper mills in terms of transportation costs from a Minnesota kaolin source. A single large plant, such as Blandin that uses over 100,000 tons of kaolin annually, could experience savings of about $3,000,000 a year or more on transportation costs alone. Although the cost advantage would probably be lessened due to downward pressure on kaolin prices from increased (new) capacity in Minnesota, and possibly by increased production costs, it is still quite substantial. The cost advantage would be less than $10/ton for any small amount of filler-type kaolin that would be shipped to northern Minnesota from Kentucky, from where the usual freight charge is about $37/ton.

Kaolin Consumption in the Upper Midwest

For a successful kaolin industry to develop in the Minnesota River Valley, there obviously must be a large enough kaolin market in the upper Midwest area where the transportation cost advantage exists in order to offset the potentially elevated kaolin processing costs, all other factors being equal. Unless the Minnesota kaolins have distinct properties which set them apart from other sources, the market for them will be limited by the extent of the transportation cost advantage which the Minnesota clays have over competing sources.

From the information gathered in the previous section, the area in which the Minnesota kaolin has a definite transportation cost advantage is defined as Minnesota, Wisconsin, Iowa, western Ontario, Michigan, and northern Illinois. A marketing survey of kaolin consumption in this area was completed, concentrating on the paper industry, which is by far the largest consumer of kaolin in this area. The Pacific Northwest region is also of interest, however, lack of consumption and transportation cost data comparable to those gathered for the Upper Midwest, make it diffuclt to form a definitive opinion. Pursuant to inquiries made to paper companies in this region, a fairly accurate estimate of kaolin consumption by the paper industry of the upper Midwest has been obtained, as outlined on pages 33 and 34.

Total consumption of kaolin by the paper industry of the upper Midwest is estimated at 1,024,648 tons a year. This is an extremely encouraging figure, considering that the average Georgia kaolin mine providing kaolin to the paper industry produces about 100,000 tons of kaolin a year. Even if consumption by the paper mills of lower Michigan, to which there would only be a limited transportation cost advantage, and the consumption by the two

Estimated Kaolin Clay Consumption by Midwestern Paper Companies, 1989

	#1 Coating Clay	#2 Coating Clay	Filler Clay	Calcined Clay	Delaminated Clay	Unspecified Clay	Total
Packaging Corp. of American Tama, IA	–	–	–	–	–	3,000	3,000
Fletcher Paper Co. Alpena, MI	2,880	2,880	–	8,640	–	–	14,400
Waldorf Corp. Battle Creek, MI	-	-	-	-	-	3,100	3,100
Mead Corp. Escanaba, MI	123,750	6,250	-	-	-	15,000[1]	145,000
James River Co. Parchment Kalamazoo, MI	-	-	-	-	-	5,400	5,400
S. D. Warren Co. Muskegon, MI	-	-	-	-	-	33,000[2]	33,000[2]
Converters Paperboard Rockford, MI	-	-	-	-	-	1,200	1,200
White Pigeon Paper Co. White Pigeon, MI	-	-	-	-	-	3,000	3,000
Potlach Corp.							
Brainerd, MN	7,000	3,500	-	-	3,000	-	13,500
Cloquet, MN	20,000	20,000	-	-	5,000	-	45,000
Lake Superior Paper Duluth, MN	-	-	67,546	-	-	-	67,546
USG Acoustical Products Cloquet, MN	-	-	4,000	-	-	-	4,000
Blandin Grand Rapids, MN	8,200	54,000	9,800	250	39,800	-	112,050
Boise Cascade International Falls, MN	1,890	1,890	29,400	1,890	-	-	34,860

	#1 Coating Clay	#2 Coating Clay	Filler Clay	Calcined Clay	Delaminated Clay	Unspecified Clay	Total
Champion International Sartell, MN	-	15,000	16,000	-	50,000	-	81,000
Waldorf Corp. St. Paul, MN	5,442	-	-	-	-	-	5,442
Midtec Paper Kimberly, WI	19,200	15,360	-	13,440	48,000	-	96,000
Niagara of Wis. Paper Niagara, WI	-	-	-	-	-	75,000	75,000
Consolidated Papers, Inc. Stevens Point, WI	-	-	-	-		250,000[2]	250,000[2]
Great Lakes Forest Prod. Dryden, Ont.	-	-	-	-	-	13,000	13,000
E. B. Eddy Forest Products Ltd. Espanola, Ont.	-	-	2,250	-	-	-	2,250
Boise Cascade Canada, Ltd. Fort Frances, Ont.	-	-	15,000	240	-	-	15,240
St. Mary's Peper, Inc. Sault Ste. Marie, Ont.	-	-	25,000	-	-	-	25,000
TOTALS							
Iowa	-	-	-	-	-	3,000	3,000
Michigan	126,630	9,130	-	8,640	-	60,700	205,100
Minnesota	42,532	70,890	126,746	2,140	97,800	-	340,108
Wisconsin	19,200	15,360	-	13,440	48,000	325,000	421,000
Ontario	-	-	42,250	240	-	13,000	55,490
GRAND TOTAL	188,362	95,380	168,996	24,460	145,800	401,700	1,024,698

1 #3 coating clay
2 Rough estimate, kaolin consumption assumed to be 30% by weight of total annual paper production

companies whose figures had to be estimated, were excluded, total consumption would still be over 700,000 tons a year.

By state, the market for upper Midwestern kaolin is dominated by Minnesota, Michigan, and Wisconsin. Consumption by Minnesota paper companies totals 340,108 tons annually, by Wisconsin 421,000 tons, and by Michigan 205,100 tons a year. Consumption is dominated by large companies. Three companies consume over 100,000 tons a year. Consolidated Papers consumes approximately 250,000 tons a year to lead the group of users, although it is noted that this figure is a rough estimate. The Mead Corporation's mill at Escanaba, Michigan consumes 145,000 tons a year, and Blandin Corporation of Grand Rapids, Minnesota consumes 112,050 tons a year and expects this figure to increase to 162,500 tons by 1990. In addition, three other companies consume at least 75,000 tons annually. These are Midtec Paper of Kimberly, Wisconsin, Niagara Paper of Niagara, Wisconsin, and Champion International of Sartell, Minnesota. These six companies account for 74.1% of the total demand.

The types of kaolin consumed varied greatly by plant. Number 1 and 2 coating clays probably accounted for the majority of the consumption, if it is taken into account that most of the unspecified clay is coating clay. However significant amounts of filler, calcined, and delaminated clay were also consumed. If Minnesota kaolin deposits are amenable to processing into these products, the current market will support mine development. If one additionally takes into account the Pacific Northwest consumption, it appears that not only is there a market for Minnesota clays in the paper industry, but also that the market is probably larger than the Minnesota kaolin production can forseeably be.

However, if the Minnesota kaolins prove not to be amenable to viable paper quality, the market transportation cost advantage will probably be of little consequence. Minnesota is attempting to break into a market which is totally dominated by one source region. Paper companies are used to the properties of Georgia kaolins, and have designed their plants around these materials. If the Minnesota kaolins are of comparable quality, however, the savings in the delivered kaolin unit price are significant so that the paper mills would probably proceed to make any structural changes that are needed to accommodate the new resource. If the Minnesota kaolins are not of sufficient quality, or cannot be economically beneficiated for paper use, however, alternate end-uses must be found for a profitable mine development.

A kaolin industry not producing clay for the paper industry would be a much smaller operation than a paper-grade operation, but this would not mean that it could not be profitable. The majority of the kaolin produced in South Carolina is used in the rubber industry, and kaolin mines in Texas and California specialize in production for plastics and catalysts.

Presently a fair amount, about 150,000 tons per year, bulk, of Minnesota kaolin is mined and used almost exclusively in the brick and cement industries. The mined kaolin seems to be ideal for these purposes and production could be expanded. There are three active kaolin clay operations in the immediate vicinity of the Minnesota River Valley. Northwestern Portland Cement Corporation of Mason City, Iowa, operates a pit near Redwood Falls, Minnesota. Recently, under lease, it also operates the adjacent pit of Nova Natural Resources Corporation of Salt Lake City, Utah. The combined production of these two pits, since 1986, has averaged about 115,000 tons per year. Almost all of the mined clay is shipped by rail to Mason City for use in cement manufacture.

Northern Con-Agg, Inc. from Brown County, Minnesota, came into production last year, and ships about 10,000 tons of clay per year to Mason City's cement industry. The clay from this mine is of slightly higher alkali and lower alumina content than that of Northwestern States', although both mine the same residuum. Additionally, Ochs Brick Company of Sprinfield, Brown County, Minnesota, operates two pits containing clay for the production of face bricks. Their primary pit, which has been in existence for about 100 years, is located in Springfield and contains kaolinitic shale of Cretaceous age. The shale is extracted at an average rate of about 50,000 tons per year, bulk, and is occassionally blended with sedimentary kaolin (secondary deposit) from a pit near Redwood Falls that produces about 20,000 - 25,000 tons, bulk, of clay per year. Residential brick sales in Minnesota account for about 50% of the total brick market.

Use of Minnesota kaolin in other industries has traditionally been limited by the lower level of chemical and related heavy industrial activity in the region, although if cities such as Chicago and Detroit are included, the market could increase substantially. It is estimated here that more than 90% of the kaolin imported into the state is utilized by the paper industry. The only large paint company in Minnesota, Valspar Inc., is transferring its operations to Chicago. The adhesives industry of Minnesota is small and refractories are mainly operating near steel producing centers. Gary, Indiana may be a possible market area for this end-use. The rubber industry of Milwaukee may be a possible market, although rubber manufacturers show a strong preference for South Carolina kaolin. Other possible markets include ceramics, plastics manufacturers, or special uses that would command high unit prices and yet require smaller deposits.

A smaller kaolin mine could subsist by producing clay just for these alternative, non-paper markets. These industries, however, consume much less kaolin than the paper companies. Since the total money these companies would save by using Minnesota kaolin would be much less than in the paper industry, companies in these industries are less likely to change their operations to accomodate a new type of kaolin. On the other hand, the specifications needed for the kaolin used in some of these industries are not nearly as rigid as those of the paper industry, thereby requiring lesser processing for improvement. From the above, it is reasonable to postulate that such smaller scale kaolin mining in the State could be profitable, under steady production levels and limited processing/beneficiation costs.

FUTURE OUTLOOK

The paper industry, the main consumer of kaolin clay, is currently undergoing a change in processing techniques which could significantly alter kaolin consumption. One of the most important processes in the production of paper is "sizing", by which the fibers are made non-absorbant. Until about 30 years ago calcium carbonates could not be used as a paper filler due to the acid environment produced by the resin/alum sizing systems used (the function of which is to make the paper more water resistant). Calcium carbonate fillers can be protected from these acid conditions by coating with starch and a polymer but the resultant product is expensive. Rosin, a type of starch, is soluble in an alkaline environment, but insoluble in water and acid systems. Kaolin, being inert, is an ideal material in such an acid environment.

Recently, however, synthetic sizing materials alternative to rosin have been introduced which can be used in neutral or alkaline environments. These new chemicals are claimed to produce stronger paper at a lower cost. The adaption of these alkaline papermaking techniques also makes possible the substitution of unprotected calcium carbonate fillers for kaolin. It is claimed that alkaline sizing increases sheet strenght thereby allowing the use of harder, cheaper pulp, while at the same time being less energy-intensive than acid sizing.

The switch to alkaline papermaking is one of the most important recent developments in the paper industry. It is possible that almost every paper mill in the upper Midwest could eventually make the switch, this does not, however, mean that use of kaolin will go into an irreversible decline. The type of kaolin use most likely to be affected by this switch is paper filler clay. Calcium carbonate is brighter but softer than kaolin. It is very good for use as a filler, but is usually combined with kaolin for use as a coater. Use of kaolin as paper filler may decline and eventually cease. Boise Cascade at International Falls, is in the process of replacing fully its filler clay with calcium carbonate. In addition, Consolidated and Mead are planning on switching partially or fully to alkaline processes. Both these companies will probably mix calcium carbonate and kaolin.

The switch to alkaline will definitely reduce demand, however kaolin will continue to be used. Mead estimates that even if their entire plant went alkaline, kaolin consumption would still be 60% of what it is today. Assuming the most restrictive set of circumstances, total Midwestern kaolin consumption levels might drop by 50% to about 500,000 tons in the distant future. Kaolin is still the premier coating material available that gives a glossier finish and better ink receiptibility than calcium carbonate, and can be delaminated for use in light papers. Kaolin is reasonably low in price, and will become cheaper for Midwestern paper mills if a new source is opened in Minnesota. Finally, some paper mills, such as Blandin, plan to increase rather than decrease their kaolin consumption. Overall, it is projected that kaolin will lose some of its market share in the 1990's but will remain the dominant coating and filler material for paper.

Other developments in the kaolin industry are less likely to create major changes in consumption or production. The Georgia deposits are very large, and are in no danger of running out, while the newly developed source in Brazil is unlikely to affect internal U.S. trade. New sources in Canada would be in direct competition with Minnesota, but would probably only affect Canadian consumption of Georgia clays, because the Minnesota source would still be closer to the mills of the upper Midwest, and because the Canadian clays are not likely to be of better quality than the Minnesota clays. Kaolin use in the plastics, adhesives, and fiberglass industries will probably continue to increase, as new developments in technology allow for wider use of mineral fillers in these materials. The development of advanced ceramics is unlikely to affect kaolin consumption greatly, because these new ceramics tend to use small percentages of clay, though they command a very high price. Finally, the use of refractories is declining, and kaolin use here will probably decline with the industry.

CONCLUSIONS AND RECOMMENDATIONS

Kaolin clay is one of the most abundant minerals at the earth's surface, however, world production is dominated by the United States and the United Kingdom. The U.S. production currently represents about one-third of the world market, and its level traditionally follows closely the trade and business cycles of the world's free market economy. U.S. kaolin production, 93% of which originates in the Georgia-South Carolina belt, has experienced a yearly growth of about 5% in the last 5 years.

Kaolin is one of the most versatile minerals and is used extensively in a number of industries such as paper, plastics, adhesives, rubber, paint, refractories, fiberglass, cement, bricks, and ceramics. The most important of these uses is in the paper industry, which accounts for over 60% of the total U.S. kaolin usage. Practically all of the kaolin imported in Minnesota is utilized in the manufacture of paper.

At present the market situation for expanding kaolin mining in the Minnesota River Valley appears to be good. There is a large demand from the paper industry in the Upper Midwest and possibly the Pacific Northwest for a new kaolin source nearby, since for all practical purposes the sole source of such clay is at great distance in the southeastern U.S. The region in which Minnesota kaolin has a definite transportation cost advantage over southeastern U.S. producers includes Minnesota, Wisconsin, Iowa, western Ontario, Michigan, and northern Illinois. This region's consumption of kaolin by paper manufacturers alone, is about 1 million tons per year, out of which Minnesota accounts for 340,000 tons. The potential transportation cost advantage that is a major factor in the renewed interest in Minnesota kaolins, is substantial and is estimated to be about \$28 - \$40/ton of clay delivered to various paper mills in the Upper Midwest region and possibly to the Pacific Northwest. Actual prices for kaolin have risen steadily in the last seventeen years, especially for value-added and paper-quality products, and it is projected that in the 1990's kaolin will remain the dominant coating and filler material for paper.

There are some developments, however, which, although would not preclude the development of a Minnesota kaolin industry, could greatly affect demand. The most important of these is the potential change in processing techniques from acid to alkaline papermaking which would affect mostly filler types of kaolin, such as the 127,000 tons per year which is consumed in Minnesota. Should Minnesota kaolin deposits prove to be viable paper-grade, demand from the paper companies in the Midwest, assuming most restrictive conditions, will be adequate to provide a market for about 500,000 tons a year mine development for the forseeable future, coupled with water-washing processing plant(s) nearby.

Demand for kaolin from non-paper industries in Minnesota has historically been relatively low. However, the existing kaolin production in the state for cement and face brick is expected to continue, given the trends in these two markets.

The vital question, therefore, that needs to be addressed soon concerns the physical characteristics of the Minnesota kaolin relative to the paper industry specifications, the necessary processing/beneficiating techniques and the associated costs. Similar investigations need to be carried out to identify the properties and processing of this clay relative to its use in non-paper industries, other than cement and face bricks.

Information on kaolin consumption in the Upper Midwest by non-paper industries is presently scant, but it will be eventually needed for a meaningful decision on the viability of Minnesota clay mining for alternative, non-paper end-uses. Should the examination of the physical characteristics of the Minnesota kaolins point towards a marginally profitable clay industry in the state, additional economic subjects will need to be investigated, such as: mining/extraction methodology and costs; power and labor costs; environment/reclamation costs; kaolin reserves; and economic incentives.

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PERSONAL COMMUNICATION

1. Jim Loudon, Consolidated Papers, Wisconsin Rapids, Wisconsin, February27, 1989.
2. Alex Biolo, Niagara Paper Co., Niagara, Wisconsin, February 28, 1989.
3. Glen Blumer, Boise Cascade Corp, International Falls, March 7, (International Falls going alkaline).
4. Gerry Rector, Lake Superior Paper, Minnesota, March 8, 1989.
5. Alan McCormick, University of Minnesota, Minneapolis, Minnesota, March 16 & 21, 1989.
6. Don Majerle, Blandin Paper Co., Grand Rapids, Minnesota, March 21, 1989.
7. Dan R. Christenson, St. Mary's Paper Company, Sault Ste. Marie, Ontario, March 21, 1989.
8. Jeff Wood, Minnesota Valley Association Railroad, March 21, 1989.
9. Mike Gardner, Valspar, Inc., Research Dept., Minneapolis, Minnesota, March 23, 1989.
10. Bob Laymer, Midtec, Kimberly, Wisconsin, April 11, 1989.
11. John Greenzwieg, H. B. Fuller Co., Minneapolis, Minnesota, May 8, 1989.
12. Don Murray, C & NW Railroad, Chicago, Illinois, May 12, 1989.
13. W. E. Schmidt, Burlington Northern Railroad, Fort Worth, Texas, May, 1989.
14. Vern Stussey, Northwestern States Portland Cement, Mason City, Iowa.
15. Rod Schutt, Plant Manager, Ochs Brick & Tile Co., Springfield, Minnesota.
16. R. L. Nall, Southern Railway System, Augusta, Georgia.
17. T. A. Hord, Norfolk Southern Corp., Roanoke, Virginia.