BULLETIN 56

Geologic Series

The Mineral Wool Industry in New Jersey

by

JOHN MILLER VAN VOORHIS

DEPARTMENT OF
CONSERVATION AND DEVELOPMENT
STATE OF NEW JERSEY

Trenton, N. J.
1942

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CONSERVATION AND DEVELOPMENT
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Charles P. Wilber, Director and Chief of the
Division of Forests and Parks

Meredith E. Johnson, Chief of the Division of
Geology and Topography

Trenton, N. J.
1942

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LETTER OF TRANSMITTAL

Mr. Charles P. Wilber, *Director,*
Department of Conservation and Development,
Trenton, N. J.

Sir:

The fastest-growing mineral industry in New Jersey is the manufacture of mineral wool, an insulating material composed of mineral fibers and used to an increasingly large extent in home insulation as well as in industry. As an aid to such manufacturers now located in the State, as well as to others contemplating the erection of new plants, the writer suggested several years ago that an investigation be made of our mineral resources suitable for use in this new industry. Failing to obtain the necessary funds, the matter was discussed with Professor A. O. Hayes of the Department of Geology, Rutgers University, through whose cooperation the investigation was assigned as a thesis problem to John M. Van Voorhis, a graduate student. The accompanying excellent report on "The Mineral Wool Industry in New Jersey" embodies the results of Mr. Van Voorhis' work and has been made available to us for publication by Rutgers University. I take great pleasure in recommending its publication as Bulletin 56 of the Geologic Series.

Yours very truly,

Meredith E. Johnson,
State Geologist.

PREFACE

The insulation business appears to be in its infancy and at the present time is undergoing development and expansion. Many different types of insulating material are manufactured and placed on the market, each having advantages and disadvantages in its properties, uses, and price. One of the most important insulating materials is mineral wool which, because it is low in cost, fireproof, vermin-proof, and possesses high insulating value, can reasonably be expected to improve its present position in the competitive market.

At the present time, the mineral wool industry in New Jersey is still being expanded. Plants located in this state are well situated because New Jersey possesses or is close to major markets, it has excellent transportation facilities, and it is near adequate fuel resources.

In order to facilitate this expansion, a survey was undertaken to determine the availability of raw materials in quantity and of a suitable quality which could be used in the production of mineral wool in New Jersey. This survey was made in partial fulfillment of the requirements for the degree of Master of Science.

The author gratefully acknowledges the cooperation of executives in the mineral wool industry, of owners of slag and quarries, of the State Geologist, Mr. M. E. Johnson, who was helpful in the location of raw materials, and the members of the staff of the Department of Geology who have contributed to any success this investigation may attain in stimulating the expansion of the mineral wool industry.

JOHN M. VANVOORHIS.

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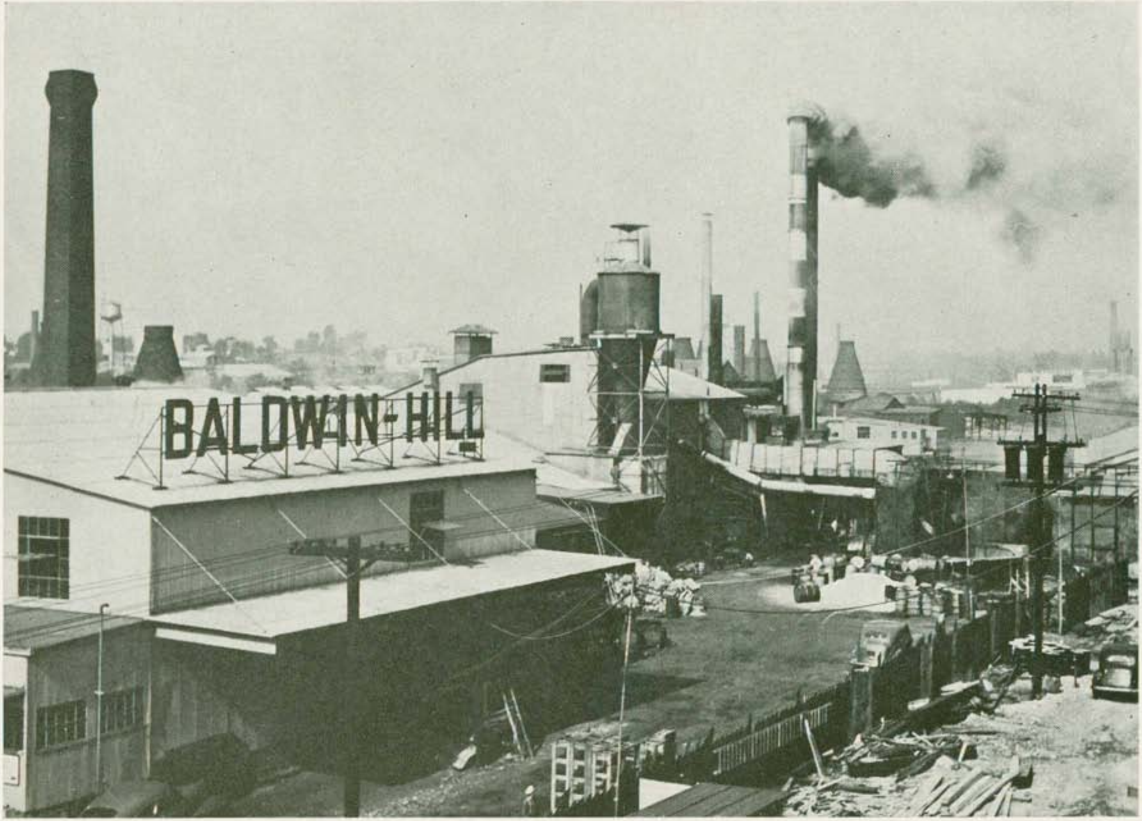

A mineral wool plant in New Jersey.
(Courtesy of Baldwin-Hill Company, Trenton, New Jersey.)

THE MINERAL WOOL INDUSTRY IN NEW JERSEY

ABSTRACT

An increasing realization of the value of mineral wool for heat or acoustical insulation has led to a rapid increase in productive facilities and a demand for greater information of the sources and varieties of raw materials which can be used in its manufacture. A statement of the types of raw materials that can be used is followed by a description of those available in New Jersey, together with tonnage estimates and analyses.

The technical aspects of manufacturing processes are fully described and this discussion is closed with a description of actual operating practices. Specifications designed to protect consumers are analyzed and constructive suggestions given. The report closes with a discussion of the economics of the industry and the prediction that it will continue to grow in New Jersey because of the large market, available sources of satisfactory raw materials, and excellent transportation facilities.

I. INTRODUCTION

DEFINITION OF TERMS

The term "mineral wool" is a generic one which designates insulating materials of various types. Within the name itself, the origin of the material is rather obscure. The various products which are classified under this term are differentiated chiefly by the raw materials from which they are made. Thus there is slag wool—which is made from iron, copper, or lead metallurgical slag; glass wool, which is made from silica sand, soda ash, and with or without glass: rock wool, which is made from natural woolrocks or a combination of various minerals. These products are manufactured with or without the use of a flux.

Many definitions of mineral wool have been formulated, and they all include essentially the same prerequisites. One of these definitions, as proposed by J. R. Thoenen,[1] states that mineral wool is a substance composed of very fine interlaced mineral fibers having the appearance of loose wool or cotton. The product is a fibrous glass-like substance which is composed principally of the silicates of calcium, aluminum, and magnesium with other minor constituents.

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[1] J. R. Thoenen, "Mineral Wool," *Information Circular No.* 6984, *United States Bureau of Mines,* Jan., 1938.

MARKETABLE FORMS AND USES

The most important uses for mineral wool are heat and accoustical insulation. Some of its advantages are: (1) most commonly available heat insulating material; (2) deterioration is practically nil; (3) inert towards moisture in comparison with organic materials, thus the insulating properties have a much smaller tendency to fluctuate with changing weather conditions; (4) fireproof and verminproof; (5) fabrication is possible; (6) relatively inexpensive.

Its uses include:

(1) heat insulation
  (a) Building walls, floors, ceilings, Pullman cars
  (b) Pipe coverings
  (c) Refrigerators—including refrigeration plants on trains, ships, etc.
  (d) Ovens, steam boilers, annealing, baking, and enameling ovens, metallurgical and chemical furnaces

(2) accoustical insulation—accoustic tiles and mats. (Extensively used in broadcasting stations, auditoriums, and offices.) Fabricated forms are used in some types of military equipment.

(3) Miscellaneous—filter mediums for corrosive fluids, fire prevention, vermin prevention, lining between metal and wood portions of ships, components of insulating cements.

For different uses, special qualifications, specifications, and forms are required and prepared for the market.

For home insulation, the important feature is coverage, while strict uniformity of fiber and the moisture resistance of the material are secondary in importance. But the special products used in Pullman cars, refrigerator cars, and various military and naval equipment (ships, tanks, and airplanes) have their own rigid specifications. Thus there is no such thing as a typical mineral wool. The various compositions of the wool are designed specifically for the purpose intended.

The finished products include loose wool, granulated wool, insulating cement, rock felt, bats, pipe covering, blocks, and blankets.

The initial product, as blown from the furnace, is called loose wool and is used primarily on new constructions. A large portion of the crude wool is run through granulators that break up the fibers and free them from the tiny glass globules called "shot." After the separation from the shot, the fibers are rolled into small pellets half an inch or less in diameter. This is called granulated wool, and is used principally in the insulation of buildings already constructed. The wool is blown into the voids between the inside and the outside walls of the house by compressed air.

The many commercial fabrications are made for specific uses. The short-fibered wool, which results from the freeing of the shot, is mixed with other materials to make insulating cement. Blocks of the loose or granulated wool are made in various sizes and thicknesses for refrigerator lining. Granulated wool is mixed with other ingredients, various binders, and water to form a stiff mud; it is then placed on pallets and subjected to low pressure and currents of hot air which dry it. This same mixture is also molded into forms for pipe coverings.

High temperature insulation is made from a mixture of refractory binders and wool, and then compressed into bricks. Such material is used in glass and metallurgical furnaces, annealing and enameling ovens.

HISTORY

The first knowledge of the substance was obtained in 1788 when several scientists from the United States visited the crater of Kilauea, a volcano in Hawaii.[1] A fibrous rock was found, the origin of which the natives ascribed to their native goddess Pelé. When she became angry, Pelé pulled out her hair and threw it out of the volcano. A sample of Pelé's hair was brought back for observation and testing, but it produced no recorded results.

The first reports of any mineral wool production came from Germany and Wales about the year 1840.[2] Mr. M. Guenther of the United States Mineral Wool Company, Stanhope, New Jersey, advises me that their company has been operating since 1875. This would establish them as the oldest company producing in the United States today. There are also records of wool being produced in Cleveland, Ohio, around 1888.[3]

In 1897, it was successfully produced by Mr. C. C. Hall. At that time he was employed by a St. Louis steel company. While searching for a rock suitable for fluxing purposes in a steel plant, he discovered local deposits around Alexandria, Indiana, which he thought

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[1] J. R. Thoenen, "Mineral Wool, The Mining Industry's Fastest Growing Product," *Mining and Metallurgy*, Feb., 1939.

[2] "The Origin of Rock Wool," *Stone*, Vol. 57, No. 12, December, 1936.

[3] *Ibid.*, Vol. 59, No. 12, December, 1936.

would melt and make a fiber. Realizing the possibilities, he organized the Crystal Chemical Company with the cooperation of some of his friends. This organization ultimately became the General Insulating and Manufacturing Company. After several failures and other company connections, he organized the Banner Rock Products Company, and it has operated continuously since January, 1907. It is now owned and operated by the Johns-Manville Corporation.[1]

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[1] J. R. Thoenen, "Mineral Wool," *Information Circular No.* 6984, *United States Bureau of Mines,* Jan., 1938.

II. RAW MATERIALS

TYPES OF RAW MATERIALS USED

As previously mentioned, the type of wool produced depends upon the nature of the raw materials. At present, the only wool produced in New Jersey is a slag wool. However, since the first wool manufactured was a rock wool, it seems timely that a brief description of the natural raw materials, which are used in other areas, be included.

Mineral wool can be considered in terms of a four component system consisting of silica, lime, alumina, and magnesia within which there are definite composition limits.[1] Provided the composition is correct, it is immaterial whether the wool is produced from a single raw material or from a mixture of raw materials. Given the desired range of composition, the amount of additional ingredients required to produce a satisfactory product can be calculated.

From the preceding statement, two general classes of raw materials are evident: (1) natural woolrocks, (2) rock mixtures or sub-woolrocks. Because of the close relation between the properties of the finished product and the chemical composition of the raw materials from which it is made, woolrocks should be uniform in character. There also should be a uniformity of sources of raw materials for the mixtures. The natural woolrocks and the sub-woolrocks are further classified into consolidated and unconsolidated forms.

The natural woolrocks are broken down into two general groups: (1) a single type of rock—consolidated limestone, dolomites high in silica and silt grains, certain conglomerates, cherty limestones, dolomites with a calcareous mixture, and calcareous shales; (2) a series of thin, interbedded, dissimilar strata that together, not individually, have the proper constituents in sufficient quantities—i. e., interbedded shale with dolomite or limestone, and sandstone with dolomite or limestone. These sources are not necessarily pure, for they may be clayey, sandy, or calcareous. The unconsolidated rocks are the unindurated equivalents of the above consolidated rocks. Some igneous and metamorphic rocks will qualify. Certain peridotites, pyroxenites, talcose and serpentinous rocks, wollastonite and amphiboles, which contain the required amounts of lime and magnesia with approximately equal amounts of silica, can be used. However, the iron content is usually too high for the best production.

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[1] J. E. Lamar, "Rock Wool from Illinois Mineral Resources." *Illinois State Geological Survey,* Bul. 61, 1934.

The sub-woolrocks are any calcareous rocks, consolidated or unconsolidated, that contain approximately 65% calcium carbonate, or calcium carbonate and magnesium carbonate.

There are several deleterious materials which are found in the woolrocks. Iron and sulphur are the most common substances that may actively affect the color, odor, or stability of the wool. When iron or sulphur are present, the wool ranges in color from light tan through brown to black. Calcium sulphate may generate bad odors and substances corrosive to steel.

In order to get a better insight to the many different materials used for the manufacture of rock wool, let us examine some of the material and sub-woolrocks used in the plants now in operation.

Since Indiana has been the pioneer state in the development of the industry and contains the largest number of plants, its natural woolrocks will be discussed first.[1] In the northern part of the state, the production is from the Missessewana shales and associated beds of the Upper Silurian which are a highly siliceous, lime series. In the southern part of the state, the Salem limestone of Mississippian age is quarried for the raw material. Typical analyses of the woolrocks are as follows:

	#1	#2	#3	#4
SiO_2	36.40%	40.88%	34.07%	28.08%
R_2O_3[1]	12.16%	12.55%	11.14%	8.64%
CaO	32.67%	28.92%	44.08%	19.90%
MgO	18.77%	17.70%	10.57%	12.18%

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[1] $Al_2O_3 + Fe_2O_3$.

In Illinois, the consolidated woolrocks and sub-woolrocks consist principally of impure limestones or dolomites, highly cherty limestones and dolomites, calcareous or dolomitic shales, shales interbedded with dolomites or limestones.[2] Included in the Ordovician System are the following: (1) Shakopee dolomite, (2) Galena dolomite, (3) Maquoketa-Richmond shales. The Silurian consists of the Alexandrian limestones, shales, and dolomites, and the Niagaran Series of cherty dolomites. In the Pennsylvanian there are several woolrocks associated with the coal beds.

From the Niagara Peninsula of Ontario, Mr. M. F. Goudge has described two areas where deposits are found from which rock wool is being made.[3] That area between the Niagara River and Thorold

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[1] W. N. Logan, "Mineral Wool Industry in Indiana," *A. I M. E. Reprint*, Feb., 1932.

[2] M. M. Leighton, *Ill. State Geological Survey*, Bul. 61, 1934.

[3] M. F. Goudge, "Raw Materials for the Manufacture of Rock Wool in the Niagara Peninsula," *Canada Department of Mines, Bul. No. 727*, 1931.

contains a belt of impure, greyish, blue, fine-grained dolomite which is a woolrock. The area between Thorold and Hamilton contains the Rochester and the Cabot Head shales which have the constituents of a sub-woolrock.

J. T. Thorndyke has described a wollastonite deposit in Kern County, California, which has potentialities.[1] He claimed that it made an excellent, white wool with extra long fibers and had a greater mechanical strength than many wools. However, there is no verification of production from this material in commercial quantities. A typical analysis of the material is as follows:

SiO_2	49.20%
CaO	44.30%
MgO	2.63%
Al_2O_3	2.46%
Fe_2O_3	0.64%

One notices here the substantial absence of alumina and magnesia heretofore considered as essential constituents of a satisfactory wool.

In a personal communication with Mr. G. H. Wagner of the Aluminum Company of America, it was learned that mineral wool has been experimentally produced from bauxite residue, after the extractable alumina has been removed from the bauxite by digestion with caustic soda.[2] This residue, or filter cake, is known as "red mud," and has approximately the following composition:

SiO_2	9-12%
CaO	12-15%
Al_2O_3	18-22%
Fe_2O_3	15-20%
TiO_2	8-12%
Na_2O	5-8%
Loss on ignition	15-18%

In producing wool, it was melted in an electric furnace, and blown in the usual procedure. For best results, the composition was adjusted by the use of silica, limestone, and in some cases by using the low grade bauxite.

The wool made was of good quality, but frequently it ran high in shot, which was credited to faulty technique in production rather than to any inherent property of the material.

However, the work was not carried beyond the pilot plant stage for several reasons. The red mud, coming from the slime pond, contains a considerable amount of both free and combined water. It is

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[1] J. T. Thorndyke, "Mineral Wool from Woolastonite," *Mining and Metallurgy,* March, 1936.

[2] Personal communication with Mr. G. H. Wagner, Chief, Aluminum Ore Company Division, East St. Louis, Illinois.

a fine powder, and also has a comparatively high melting point. These latter two facts eliminated the use of a cupola for melting, and necessitated an electric furnace.

In consideration of these handicaps, it is quite obvious that wool made from this red mud could not hope to compete in price with wool made from some of the readily available raw materials which can be melted in a cupola.

After considering the descriptions of the many deposits which have been used for the manufacture of rock wool, it is quite evident that many different types of rocks may be used. However, there are certain definite chemical limits which must be observed in order to produce a marketable wool. For comparison the following table is given, which depicts the chemical limits as prescribed by the various parties.

	Logan	Thoenen	Goudge	Illinois Survey
SiO_2	22.5-49%	39-46%	34-44%	35-65%
R_2O_3	5.5-15.4%	13-16%	13.7-21%	0-33%
CaO	21-68%	31-32%	21.5-30.5%	5-50%
MgO	4-18.8%	11.6-16.8%	13-18.9%	0-32%

RAW MATERIALS IN NEW JERSEY

The reasons for using slag in New Jersey are because it is available and cheaper, and because suitable rocks are not found in sufficient quantities. There also is a decided economic advantage in the use of slag. There are numerous slag reserves in New Jersey, and companies which are producing slag in quantity. A ton of this slag can be bought and transported to the plant for the amount of money ($2.50) that it would take to quarry a ton of rock. Thus the industry in this area has grown up with slag as its basic raw material.

The following paragraphs will include a synopsis of the slag reserves and the slag production of industries in New Jersey which are available to the manufacturers of mineral wool.

SLAG RESERVES

Considerable reserves of blast furnace slag have accumulated in various parts of the state where iron ore was smelted in former years.

In order to facilitate a classification of the types of slag, the author has used the terms—primary and secondary slags. The principal characteristics of primary slags are: (1) the chemical composition remains relatively constant within certain limits; (2) fragments are approximately uniform in size and are suitable for immediate use in the cupola. No hand picking or sorting is required. The secondary slags have a variable chemical composition, may have certain undesirable constituents in various portions of the supply, and are quite varied as to size.

Primary Slags

An important reserve of some five million tons, located at Oxford, New Jersey, is leased at present by Mr. F. Sorjento of Metuchen, and is only now being used in the production of mineral wool.

The fragments range from 1½" to 2" in diameter. It is high in lime-magnesia and low in silica as shown by the following analysis:[1]

	CaO	SiO_2	MgO	Al_2O_3	Fe_2O_3
1.	38.59%	15.48%	16.23%	8.77%	2-4%

The addition of a silica flux makes this an excellent raw material.

The American Smelting and Refining Company of Barber, near Perth Amboy, New Jersey, has a reserve of 750,000 to 1,000,000 tons of blast furnace slag. The size of the material ranges from 1½" to 5" in diameter. The lime-silica content is very high, with the percent of iron variable. However, the major part of the reserve has a composition suitable for mineral wool production. The first analysis listed is the most prevalent.[2]

	CaO	SiO_2	FeO
1.	42-45%	39-43%	4-6%
2.	30%	15%	25%

The same company has a supply of approximately 3,000 tons of copper slag on hand, and they are adding to it at the rate of about 8,500 tons per year.

This product has a suitable chemical composition, and it is as follows.[3]

	CaO	SiO_2	MgO	Al_2O_3	Fe_2O_3	Zn
1.	25-40%	32-42%	1-5%	6-8%	5-13%	2-8%

When the lime content is high, the percentage of iron runs about 4%. It can be seen that the composition is rather variable, but the ingredients are present in good proportions. With strict chemical control, it seems as if this slag would require very little fluxing material in order to produce a satisfactory wool.

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[1] Analysis furnished by Mr. F. Sorjento, Metuchen.

[2] Analysis furnished by Mr. T. F. McBride, American Smelting and Refining Company, Barber, New Jersey.

[3] Analysis furnished by Mr. T. F. McBride, American Smelting and Refining Company, Barber, New Jersey.

Copper slag produced by the United States Metals Company of Carteret, New Jersey, was used sometime ago in the preparation of mineral wool and is still sold for this purpose. The company has a reserve of approximately 1,000,000 tons. The slag is in a granulated form and will usually pass a ½″ mesh. The percentage retained on the different mesh are as follows:

12%	retained on the	#6 mesh
46%	" " "	#16 "
13%	" " "	#20 "
19%	" " "	#40 "
3%	" " "	#60 "
7%	" " "	#100 "

Chemically the material is exceedingly low in lime, and has a high iron content. But for some types of commercial wools, it should prove useful. The composition of the slag is as follows:[1]

	CaO	SiO_2	MgO	Al_2O_3	Fe_2O_3	Misc.
1.	2-3%	35-40%	1-2%	4-7%	36-45%	4-6%

A small reserve of approximately 216,000 tons of primary slag is located at Pequest, New Jersey, and is owned by Mr. P. S. Kramer. The supply is composed of iron slag which varies between ¼″ and 3″ in diameter. The chemical composition is rather constant, with these limits being observed:[2]

	CaO	SiO_2	MgO	Al_2O_3	Fe_2O_3
1.	28-32%	33-40%	12-15%	9-12%	6-15%

Secondary Slags

As previously stated, these slags have a chemical composition which is quite variable, and the size is not uniform. In order to use them, careful sampling and strict chemical control would have to be exercised.

A supply of approximately 1,000,000 tons is located at Stanhope, and it is owned by the Salmon Brothers of that town. The material is of many and varied sizes, ranging from fine granulated material to the lump slag, and would require careful sorting before use. The first analysis is an average, and is not to be considered constant for any given quantity.[3]

	CaO	SiO_2	MgO	Al_2O_3	Fe_2O_3
1.	29-32%	31-40%	20.5%	5.14%	6-8%
2.	25.4%	36%	16.5%	8.4%	14%
3	30%	29-65%	18.3%	6.5%	5%

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[1] Analysis furnished by Mr. M. W. Merril, United States Metals Company of Carteret, New Jersey.

[2] Analyst—J. Van Voorhis, 1941.

[3] Analysis furnished by R. L. Kilgore, National Gypsum Company, Dover, New Jersey.

Several samples were tested, and two of the analyses are recorded in No. 2 and No. 3 in the preceding table.[1]

At Wharton, New Jersey, there is a supply of slag which totals over 1,000,000 tons. This stock pile is owned by the Grey Construction Company of Morristown. Here again the material is quite irregular and inconsistent. In comparison to the previously mentioned supply at Stanhope, the general characteristics of the slag are of a lower quality. The chemical composition covers approximately the same range, with certain portions running quite high in sulphur. A typical analysis is as follows:[1]

CaO	SiO_2	MgO	Al_2O_3	Fe_2O_3	S
30%	37.6%	12.50%	15.60%	8.5%	6%

In the southern part of the state, several accumulations of slag have resulted from the old blast furnaces which used the bog iron ores as raw materials. These supplies are found at Atsion, Batsto, Martha's Furnace, and Weymouth. These reserves will be grouped together because the quantity is comparatively small, and the material is rather inaccessible. The quantity, from the four localities, totals about 100,000 tons. This figure is only a rough estimate, because large quantities of the material are buried, or partially so, by sand and marsh land. At Atsion the material is scattered over considerable swampy ground, and at the other localities there are difficulties of similar aspect present. These reserves would also require considerable sorting. The chemical composition of the material is extremely variable. Naturally the iron percentage is quite high because the blast furnaces of the revolutionary days were not so efficient in extracting the metal from the ore. Silica percentages vary, but are generally quite high. Several analyses of the material are as follows:[1]

	CaO	SiO_2	MgO	Al_2O_3	Fe_2O_3
1.	8-12%	40-44%	4-6%	6-10%	38%
2.	12%	47%	10%	3-5%	24.6%
3.	16.5%	37.8%	12.5%	14%	28%

The Raritan Copper Company of Perth Amboy have a small reserve of secondary slag. The supply has been sampled by several companies previously, but it has never been used. There is no production of slag at this plant at the present time, for their blast furnace work is now done elsewhere.

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[1] Analyst—J. Van Voorhis, 1941.

The supply here consists of the granulated slag and the lump slag. There is approximately 2,500 tons of the former type and 1,950 tons of the latter. One advantage of the material is the uniformity of sizes for the respective types. However, judging from the analysis, the metallic content seems too high to be used for ordinary mineral wool production. For certain specifications the material might be used, thus it is recorded. An analysis of the lump slag follows. The chemical composition of the granulated material is quite similar.[1]

CaO	SiO_2	MgO	Al_2O_3	FeO	Cu	ZnO
1.6-6.0%	16-33%	....	12-24%	17-27%	6-12%	16-33%

In summation, portions of these secondary slags of Stanhope and Wharton appear most promising, but the expense of control analyses and culling may prove to be too high to justify exploitation.

Slag Production

Slag currently produced in New Jersey totals approximately 43,000 tons annually, but the whole quantity will not prove chemically suitable for mineral wool production. Following is a brief description of these slags, and their relative importance to the problem at hand.

The American Agricultural Chemical Company of South Amboy, New Jersey, produces slag from the reduction of a pebble phosphate rock imported from Florida. The annual production is approximately 18,000 tons. The slag is crushed and screened before delivery, making it about egg size. At the present time this supply is contracted for.

The chemical composition of the slag is quite constant. Practically the only component which varies is the percentage of the phosphate radical, P_2O_5. This ranges from 1.5% to 5%. The high silica and lime content make it an excellent raw material. A typical analysis contains the following substances:[2]

	CaO	SiO_2	MgO	Al_2O_3	Fe_2O_3	P_2O_5	H_2O
1.	43.76%	48.74%	....	1.27%	0.36%	2.25%	0.04%

The United States Metals Company of Carteret, New Jersey, produce two types of slag—copper and lead. The former is granulated while the latter is in lump form. The production of the copper slag is approximately 3,600 tons per year, with a reserve of 1,000,000 tons. This copper slag has been adequately described on Page 16 under Primary Slags. A complete chemical analysis is listed there.

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[1] Analysis furnished by N. C. Kennedy, Raritan Copper Company, Perth Amboy, New Jersey.

[2] Analysis furnished by H. L. Martin of the Agricultural Chemical Company, South Amboy, New Jersey.

The lead slag production is approximately 4,800 tons per annum. The chemical composition runs rather high in iron. This fact will certainly limit its use for the production of specified wools, but for a brown or black wool it would be satisfactory. There would have to be some compensation for the low lime and silica content. A representative analysis contains:[1]

	CaO	SiO_2	MgO	Al_2O_3	Fe_2O_3	Pb	ZnO
1.	12.0%	23%	2.5%	6.0%	38.4%	1.4%	7.56%

The American Smelting and Refining Company produces three types of slag at Barber, New Jersey. Approximately 8,500 tons of copper slag (No. 1) appear to have an excellent composition for the manufacture of mineral wool. The composition of Nos. 2 and 3 run lower in the lime and silica components, but have a higher percentage of iron. There is approximately 4,000 tons of each type coming from their furnaces yearly. Typical analyses of the different types are as follows:[2]

	CaO	SiO_2	MgO	Al_2O_3	Fe_2O_3	Zn	Pb
1.	25-40%	32-42%	1.5%	6-8%	5-13%	2-8%	0.5%
2.	17-25%	22-28%	1.5%	7%	18-22%	..	0.1%
3.	20-25%	22-28%	1.5%	7-7.5%	14-19%	5%	....

It might be re-stated here that when the lime is high in No. 1, the percent of iron is approximately 4%. When this situation exists, the slag has a characteristic red color. The reserve supply of 3,000 tons of the slag has been previously mentioned on Page 15.

The graphs[3] are intended to portray the various compositions of the available slags. The total compositions have been broken down into the four primary components which are found in mineral wools, in order to show the relative proportions of these components in slags which are now being used in production and those which are available for production.

Summary

The dominant factors which have caused the mineral wool industry of New Jersey to use slag as its fundamental raw material have been previously mentioned. The location of the slag reserves of the state is recorded graphically on Figure 11.

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[1] Analysis furnished by M. W. Merril, United States Metals Company, Carteret, New Jersey.

[2] Analysis furnished by T. F. McBride, American Smelting and Refining Company, Barber, New Jersey.

[3] See Appendix—Figures 1, 2, 3, 4 on pp. 67-70.

In New Jersey there are approximately 6,969,000 tons of reserve primary slags. This tonnage includes materials which could be used with the addition of only small amounts of flux rock, and those materials which could be used to blow only wools of particular specifications. The analyses show that the reserves at Oxford, those of the American Smelting and Refining Company, and the small amount at Pequest would appear to be the most suitable.

SLAG RESERVES

1.	Oxford Furnace	5,000,000 tons
2.	United States Metals	1,000,000 "
3.	American Smelting and Refining	750,000 "
4.	Pequest	216,000 "
5.	American Smelting and Refining	3,000 "
	Total	6,969,000 tons

The secondary slag reserves approximate 2,119,500 tons. Their direct use as a raw material in the industry is doubtful because of their variable composition and size, but with no restrictions on the color of the wool, some mixtures might be worked out which would satisfy certain specifications. Production from these substances would necessitate constant chemical control.

SECONDARY SLAG RESERVES

1.	Wharton	1,000,000 tons
2.	Stanhope (Salmon Brothers)	1,000,000 "
3.	Martha's Furnace, Burlington Co.	50,000 "
4.	Batsto, Burlington Co.	25,000 "
5.	Atsion, Burlington Co.	20,000 "
6.	Weymouth, Atlantic County	20,000 "
7.	Raritan Copper Company	4,000 "
	Total	2,119,500 tons

The slag produced annually in New Jersey totals approximately 42,900 tons. The slag of the Agricultural Chemical Company appears most suitable for mineral wool production, but it is contracted for at the present time.

The No. 1 slag of the American Smelting and Refining Company is available and appears to be chemically adequate. Mixtures of either their No. 2 or No. 3 slag with portions of the No. 1 or other compensating components would make a mixture which would have the ingredients in sufficient proportions to blow a wool with good commercial qualifications.

SLAG PRODUCTION

1.	Agricultural Chemical Company	18,000 tons
2.	American Smelting and Refining	8,508 "
3.	" " " "	4,000 "
4.	" " " "	4,000 "
5.	United States Metals (#1)	3,600 "
6.	" " " (#2)	4,800 "
	Total	42,908 tons

The slag reserves[1] known to be available for the manufacture of mineral wool in the state of New Jersey, based upon statistics of 1940 and the early months of 1941 are as follows:

1.	Primary slag reserves	6,969,000 tons
2.	Secondary slag reserves	2,119,500 "
3.	Slag production	42,908 "
	Total	9,131,408 tons

With the increased emphasis upon production, the total quantities of the slag produced may be decidedly larger in the near future. There is a tremendous drain placed upon the slag reserves of the state by the five mineral wool plants which are now operating. These slags now being produced will help provide a margin of safety for the manufacturers' source of raw materials.

NATURAL RAW MATERIALS

Paleozoic Limestones

The mineral wool industry in New Jersey is based upon slag as the principal raw material, and the reasons have been previously mentioned. Nevertheless, a brief description of the limestones which might prove useful in the industry is included.[2]

While most of the limestones in New Jersey do not appear to have the chemical prerequisites of a woolrock, and the high percentage of magnesium oxide is a disadvantage, there are several formations of limestone which might be classified as sub-woolrock and might prove adequate with the addition of a silica component.

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[1] See Appendix—Table No. 3, p. 64.

[2] The major part of the following information is based upon reports of the Geological Survey of New Jersey.

The following analyses of the Jacksonburg limestone (Ordovician in age) are the ones which are the most likely to prove to be of value in the mineral wool industry.[1]

	CaO	SiO_2	MgO	R_2O_3	CO_2	Location
1.	39.86%	20.57%	....	....	31.9%	Near Phillipsburg; ¼ mi. west of D. L. & W. roundhouse.
2.	48.04%	2.62%	2.84%	2.38%	....	Hainesburg — near R. R. station.
3.	52.58%	4.30%	0.65%	1.23%	....	½ mi. S. E. of Columbia—East of the Paulinskill Creek.
4.	54.00%	2.62%	1.00%	0.38%	....	Beaver Run—south of Deckertown; near Pond schoolhouse, 2 mi. north of Beaver Run.
5.	31.00%	27.08%	1.83%	8.76%	26.37%	Near Hope and ⅔ mi. south of Bridgeville station.
6.	35.00%	24.45%	2.21%	....	29.89%	Vicinity of Belvidere.

Analyses Nos. 1, 5, and 6 seem to have the constituents of a woolrock. The CO_2 content is approximately 30%, which has proven to be the upper limit of that component for a good woolrock. The exact quantity of these formations present is not known, thus necessitating core drilling to insure a workable deposit.

Analyses Nos. 2, 3, and 4 would appear as excellent sub-woolrocks or could be used to advantage as flux rocks. The high percentage of lime compares favorably with the percent of lime in the Franklin Limestone, which is now being used as a flux rock.

According to Kümmel, both northeast and southwest of Newton, the Jacksonburg beds are well developed. Several analyses from the northeast area are as follows:[2]

	CaO	SiO_2	MgO	R_2O_3
7.	41.72%	13.88%	3.78%	2.44%
8.	30.46%	20.24%	9.82%	2.37%
9.	37.95%	....	11.68%	1.04%

The localities represented by this suite of samples certainly deserve further investigation in order to determine the amount of purer beds available. It would be impossible, without trenching or drilling the areas, to make any definite statement as to the commercial aspects of the deposits.

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[1] H. B. Kümmel, "Report on the Portland Cement Industry," *Annual Report of the State Geologist, Geological Survey of New Jersey,* 1900.

[2] *Ibid.*

There are certainly large quantities of the Kittatinny Limestone (Cambro-Ordovician in age) available in New Jersey. However, the percentage of lime in the various samples taken was generally lower than the percentages of lime in the Jacksonburg formation.

Several samples were taken in the now abandoned Penwell quarry and at several points southwest of this location. Analyses gave the following results:[1]

	CaO	SiO_2	MgO	R_2O_3	CO_2	Location
10.	32.50%	3.50%	12.80%	5.00%	46.50%	Penwell quarry.
11.	28.50%	2.00%	14.80%	....	....	" "
12.	29.30%	6.00%	13.50%	....	....	" "
13.[2]	28.27%	16.90%	15.30%	0.98%	38.90%	Gano's quarry—Annandale.
14.[3]	30.30%	9.80%	16.20%	0.60%	51.60%	Property of Ed. Lewis, Wantage, Sussex County.

It is the usual occurrence of the Kittatinny limestone to run rather high in magnesium carbonate as portrayed by these analysis. It is the opinion of the writer that the Kittatinny Formation should certainly be considered as a second-class flux rock for the mineral wool industry of New Jersey. Unless a plant was located in the immediate vicinity of such a deposit, where transportation costs would be negligible, it would seem illogical to develop such a low grade lime deposit.

On the other hand, if used with slag high in lime, only a small amount of the lime flux would be needed and if the melt can accommodate the magnesia content, several well-chosen deposits of the Kittatinny limestone might prove to be of some use to the individual manufacturer.

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[1] Analyses (Nos. 10, 11, 12) checked by J. Van Voorhis, 1941.

[2] *Annual Report of State Geologist,* 1868.

[3] *Annual Report of State Geologist,* 1878.

White Marls

Shell marl deposits of varying size occur in Sussex and Warren Counties, and their analyses suggest suitability for use in the mineral wool industry. No recent studies of the deposits have been made, but following are several partial analyses from the Annual Report of the State Geologist for 1877:[1]

	$CaCO_3$	$MgCO_3$	Sand and Clay	H_2O	Description	Location
15.	98.33%	....	0.90%	0.67%	White, very fine	Andover, Sussex
16.	97.73%	....	0.60%	1.59%	White, dense, fine	Shiloh, Warren
17.	95.34%	2.18%	0.98%	1.50%	Surface marl, white, solid, fine	Shiloh, Warren
18.	96.54%	1.47%	2.05%	....	White, very fine, med. dense	Newton, Sussex
19.	99.04%	....	0.55%	0.41%	White, light ...	Near Lincoln, Warren
20.	94.75%	....	0.71%	4.54%	White, light ...	Monroe Corners, Sussex
21.	64.20%	....	16.21%	16.59%	White shells and clay	Centerville, Sussex
22.	92.25%	2.98%	1.56%	3.21%	Shell marl	White Pond, near Marksboro

The marls usually occur beneath wet meadows and muck swamps and are widely distributed in these two counties. The areas vary in size from a few acres to localities of 100 acres or more, with the thickness ranging from 3 or 4 feet to more than 30 feet. The deposits of the White Pond area (No. 22) are large. For a detailed list of the occurrences, the Annual Report of the State Geologist for 1900 should be consulted.

It is with hesitancy that these marls are suggested as a possible sub-woolrock to be used in mineral wool production. The purity and the small expense in quarrying are the main advantages. However, the fineness of the marls might cause gross inefficiency in cupola operation. Nevertheless, granulated slags are being used in cupolas at the present time and their use is proving economically satisfactory.

If this material were to be used as a sub-woolrock, the components added would have to include quantities of silica. Perhaps a mixture of the marls and the sandstones of the upper portion of the Green Pond Formation (Silurian) would prove satisfactory.

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[1] Kümmel, *op. cit.*, pp. 98-101.

The latter formation makes up almost entirely Copperas, Kanouse, Green Pond, and Bowling Green Mountains, which are located in the northeastern part of the state. In the southwestern part of this area, in the isolated hills southwest of the Rockaway river, the rock is a much softer and friable sandstone. This friable phase is now quarried by the Berkshire Silica Company of Netcong, New Jersey, from the Delaware, Lackawanna, and Western railroad cut, west of Port Oram, and at several other pits in the vicinity of Flanders. Samples were taken in and around Succasunna and in several isolated hills of the formation in a southwesterly direction along the strike. It was found that the percent of silica ranged between 93% and 99%, with the majority of the samples containing 97% SiO_2. Therefore the quantity and quality of silica rocks in New Jersey are quite adequate.

The postulation that these marls could be used as a sub-woolrock is strictly hypothetical. In order to ascertain the definite proof, the marl-silica mixtures would have to be used in a pilot plant. Even then the commercial application would require careful engineering control to insure a profitable enterprise.

It seems probable, however, that these marls would serve as excellent fluxing materials. Because of their high lime content and the comparative ease with which they might be quarried, many of these deposits could be put to use. Since all of the wool produced in this state is of the slag variety, the use of the marls as a flux would appear much more practical. For the small manufacturers, it seems plausible that they might obtain control of such a deposit. Their location is suitable to the present plants, and the cheap quarrying costs might alleviate their expenditures for a lime flux.

Franklin Limestone

The chief source of a lime flux for the mineral wool industries in this state has been the white, crystalline Franklin limestone of Pre-Cambrian age. At the present time the Limestone Products Corporation of America, located at Newton, New Jersey, is operating a quarry in this formation and selling the material to the mineral wool manufacturers.

"This formation forms a continuous narrow belt (½ to 1 mile in width) from Glennwood, southwestward nearly to Sparta. There are several separate areas southwest of Odgensburg and west of Sparta. There are a number of small areas located at the following localities: (1) one-half mile north of Andover, (2) just east of the central portion of Cranberry Lake Reservoir, (3) along the northeast side of Jenny Jump mountain, (4) along Pophandusing Brook, east of Oxford Church (Hazen P. O.), (5) one-quarter mile southeast of Roxbury, and (6) near Lower Harmony." Of these, the area near Jenny Jump Mountain and the locality near Oxford Church are the largest and the most important.[1]

Several of the active quarries are located at McAfee, Rudeville, Franklin, Pinkneyville, and east of Oxford Church. These sites are all within the limits previously mentioned. There are probably other quarries in operation at the present time.

Locations No. 3 and No. 4 seemed to be the most important, and so they were investigated further as to their use in the mineral wool industry. Of these two, the areas of the limestone occurring along the northeast side of Jenny Jump Mountain seemed the most practical.

Typically, in the Jenny Jump area, the limestone is a coarsely crystalline rock. It is usually white in color, but it often has a bluish tinge ranging to a blue grey. Two miles northwest of Danville, just south of the road from Hope to Danville, the formation is a marble which is mottled pink. Here the rock contains small scales of graphite, biotite, and grains of various silicates—diopside and chrondrodite.[2]

Lithologically the formation varies greatly, but mainly in the abundance and character of the accessory minerals. Calcite is the principal, and sometimes the only, mineral present. Accessory minerals are present in varying amounts. Of such accessory rock constituents, magnetite is one of the most important. Quartz and a nearly colorless pyroxene (diopside) occur quite abundantly. Besides these, biotite, hornblende, pyrite, and serpentine are also found in abundance in local horizons.[3]

Frequently there are intrusive masses of pegmatitic granites and dark colored basic dikes in the limestone. In the southern part of the Jenny Jump area, the limestone seems to be interbedded with the Pochuk gneiss. Varying amounts of silica, alumina, and iron are always present. Dolomitization and silicification has taken place in many localities, with the latter having affected a greater percentage of the formation in this area.

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[1] H. B. Kümmel and R. B. Gage, "The Chemical Compositions of the White Crystalline Ls. of Warren and Sussex Counties,". *Annual Report of the State Geologist of New Jersey*, 1905, p. 176.

[2] *Ibid.*, p. 177.

[3] L. G. Westgate, "Geology of the northern part of Jenny Jump Mt., Warren County, New Jersey," *Annual Report of the State Geologist of New Jersey*, 1895, p. 39.

The occurrence or non-occurrence of these intrusive rocks is a matter of considerable economic concern in the development of quarries in this area. The possibility of their occurrence within the formation must be recognized, and a thorough examination of the prospective site should be carried out.

Following are recorded analyses of the Franklin formation along Jenny Jump Mountain and at several other localities:[1]

					(Calculated)	
	CaO	SiO_2	MgO	R_2O_3	CO_2	Location
1.	43.36%	4.98%	4.62%	1.82%	45.13%	At N. E. end of Jenny Jump Mt. near the Howell mine.
2.	44.67%	4.36%	3.81%	1.98%	45.37%	Marble quarry, S. E. slope of Jenny Jump, 2 mi. N. W. of Danville.
3.	49.36%	0.80%	1.58%	0.64%	47.31%	1 mi. south of Buttzville, along railroad to the Ahles mine.
4.	49.09%	1.08%	1.80%	0.86%	46.32%	½ mi. east of Hazen P. O. on north side of Pophandusing brook, between Belvidere and Oxford.
5.	49.55%	0.90%	1.89%	0.41%	47.81%	Crabtree farm—1 mi. west of Sand Hills; large belt—1000′ x 200′.

Check analyses were run on samples from the locations represented by Nos. 1, 2, and 4.

Opposite the old Howell mine, and for several hundred feet in a N. E.-S. W. direction, there is an excellent exposure of the formation. It is dipping about 65 degrees to the southeast. These exposures seem to run rather constant in chemical composition. Northeast of this location about .3 of a mile is another exposure about one hundred feet high, with the same attitude. Portions of the limestone have been highly silicified. There is a vein of pure quartz about 12 feet thick. In the immediate area is also a portion of the formation which has the usual lime content of the Franklin limestone. It is quite plausible that this location would make an excellent quarry site for a mineral wool producer who wished to have independent supplies of both lime and silica flux rocks. It might even, with the proper chemical control, fulfill the requirements of a woolrock.

Approximately 1.1 miles northeast from the previously mentioned exposure, there are several isolated knobs which are composed of a

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[1] H. B. Kümmel, *Annual Report of the State Geologist of New Jersey*, 1905, p. 184.

high lime content portion of the Franklin formation. These also might be developed as quarry locations for individual manufacturers.

At the present time, there is a large quarry located about 2 miles northwest of Oxford—being between that town and Belvidere. It is owned and operated by the Edison Cement Company. They are quarrying out portions of the Franklin limestone which they can use in their process. Naturally they follow that part of the formation which runs high in lime and is exceptionally free from silica, magnesium oxide, and other deleterious ingredients. Therefore, a huge supply of the Franklin limestone is accumulating which they have quarried out, and it has proven unfit for their use.

Some of this already quarried material might be used in the mineral wool industry. The majority of the material contains quantities of silica, magnesium oxide, iron, and zinc, with the latter two ingredients being in the minority. Analysis No. 4 (page 27) depicts the average composition of the material in the vicinity. Several test analyses were made, and the silica composition ranged from 2% to 18% and the calcium carbonate percentages were between 80 and 84 percent. The majority of the cast-off material has been silicified to some extent.

This material might be used to a very good advantage. It seems highly probable that the dump of the cement company could be used as a sub-woolrock or a flux rock. The addition of a silica flux would seem to make this material chemically adequate to blow a commercial wool. Raw material costs would certainly be at a minimum, thus making this source a seemingly good supply of a sub-woolrock. Perhaps this supply could be used to the mutual advantage of both the Edison Cement Company and a mineral wool manufacturer.

Unconsolidated Materials

There are also several deposits of sand and gravel formations which are partially suitable from the standpoint of chemical composition, but the feasibility of using these materials for mineral wool production depends upon the solution of engineering problems involved in the melting process and other economic factors.

The Red Bank, Tinton, and Marshalltown Formations of Upper Cretaceous age are found in the area southeast and northeast of Burlington. The Red Bank and Tinton formations are a coarse, rusty sand which has been partly indurated by iron oxides,[1] while the lower

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[1] H. B. Kümmel, "Geology of New Jersey (Revised)," *Geological Survey, New Jersey, Bul.* 50, 1940, p. 118.

phases are somewhat clayey. Portions of the Marshalltown formation, which are a black sandy clay, have also been experimented with. In fact, several experimental batches of wool were blown from this material by a New Jersey company. The resulting wool was dark brown in color and the percentage of shot was rather high.

Northeast of Princeton Junction is an outlier of the Raritan Formation, also Upper Cretaceous in age. This phase appears quite sandy, and the clay components are in the minority. Trial batches from this material were also blown by the same company, and the resultant wool was rather short of fiber and contained approximately 50% shot. The high iron content may have caused these results.

III. TECHNOLOGY

THE USE OF MIXTURES IN THE PRODUCTION OF MINERAL WOOL

All materials do not contain the components which are necessary for the production of a satisfactory wool. A rock source or slag may have a high silica content, with a corresponding low percentage of lime. This material could be used, provided that the chemical composition is corrected to fall within the range of suitable compositions. Thus the use of mixtures in the mineral wool industry has been rapidly developed.

The material required to compensate for the lack of essential ingredients is termed a "flux rock." If natural sub-woolrocks are being used for the basic raw material, the fluxing materials are usually highly siliceous shales, sandstone, and limestones. If the raw materials are slags, a secondary slag, which is rich in the desired constituents, may serve as a flux. A natural occurring flux may also be employed with the slag in order to correct the composition. The Illinois Survey has suggested that the material used as silica flux contain a minimum of 60% silica and 25% R_2O_3,[1] and have an ignition loss of approximately 10%. They similarly advocate that the lime flux average 60% calcium carbonate, 35% magnesium carbonate, and 5% impurities.[2] However, these compositions could vary. If the percentages of the flux were either higher or lower, the amount of material required would have to vary accordingly. For example, five pounds of the Franklin limestone (50% CaO) would serve the same purpose as 10 pounds of the Kittatinny limestone (30%), all impurities remaining essentially the same.

As previously discussed, the percentage of added ingredients can be calculated approximately if the range of suitable compositions is known, but the practicality of the product should be proved in a pilot plant before final operation is commenced. The changeable elements of production are intimately related to the viscosity and fusibility of the melt, which are in turn affected by the chemical composition.

The composition of mineral wool can be sub-divided into four basic ingredients—i. e., silica, lime, alumina, and magnesia. Wools have been blown from materials in which the latter two have been absent;

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[1] $R_2O_3 = Al_2O_3 + Fe_2O_3$.
[2] C. H. Fryling, *Ill. State Geological Survey, Bul.* 61, 1934.

nevertheless, the major portion of raw materials contain alumina and magnesia in varying quantities, so they are included in the calculations.

A reference for calculations has been proposed by the Illinois Survey, and I wish to include portions of the same for completeness and any practical use to which this report might be applied.

The four component system can be represented by a solid tetrahedron. "In such a tetrahedron, pure components are represented by the apexes; binary systems by the edges; tenary systems by the triangular exterior surfaces; and the various compositions comprising the quaternary systems are represented by points within the tetrahedron."[1] A suitable composition for the production of mineral wool can be obtained from any sub-woolrock, slag, or flux rock containing any or all of the four ingredients enumerated above, provided that a straight line passing from the point representing the composition of the calcined sub-woolrock to one of those three parts of the tetrahedron, intersects the region of suitable composition. It is also possible to secure a satisfactory composition from two sub-woolrocks or secondary slags, the calcined composition of which lies on opposite sides of the region of suitable composition, provided that a straight line joining the points representing the compositions of the calcined substances intersects the region of suitable composition.

Triangular diagrams are included to represent the ranges of satisfactory compositions for the production of mineral wool.[2] Each diagram represents a certain percentage of silica. This method has been tried experimentally and in the industry has proven highly satisfactory.

These diagrams (Figs. 5, 6, 7) represent plane sections of an equilateral tetrahedron. The representative figures are parallel cross-sections of the tetrahedron on which are plotted mixtures containing amounts of silica constant for each cross-section.

The areas of suitable composition were all determined at one temperature—1500 degrees centigrade. "At lower temperatures the shaded areas should contract, and the average fiber diameter of the wool should increase. Higher temperatures would affect an expansion of the shaded areas towards compositions high in silica and alumina."[3]

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[1] *Ibid.*, p. 189.

[2] *Ibid.*

[3] *Ibid.*, p. 199.

In determining the correct proportions, one can calculate the amount of flux rock required per ton of slag or sub-woolrock to give a mixture which will contain, on a calcined basis, a percentage of silica equal to that represented by one of the diagrams. The percentages of the remaining components can then be calculated on a calcined basis, and reference to the diagram for the percentage of silica chosen will show whether the mixture lies within the shaded portion of the diagram that represents the region of satisfactory composition.

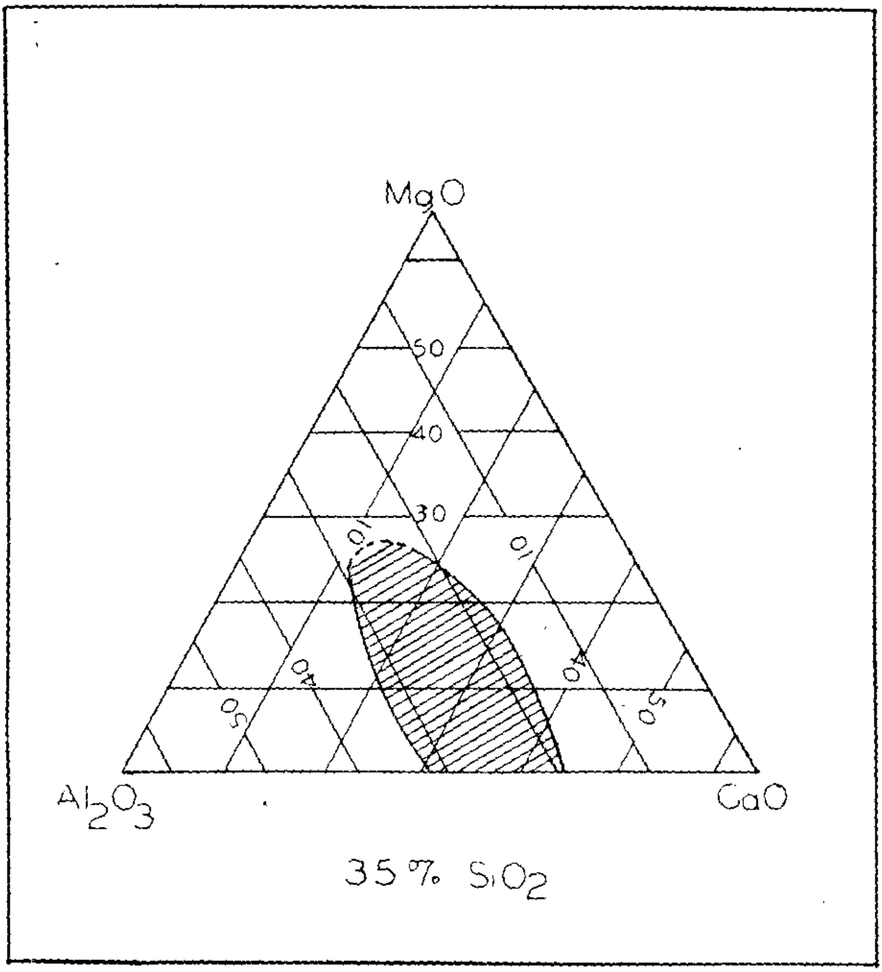

FIGURE 5. Diagram showing range of compositions suitable for mineral wool production in the quaternary system at 35% silica. (After the Illinois Survey.)

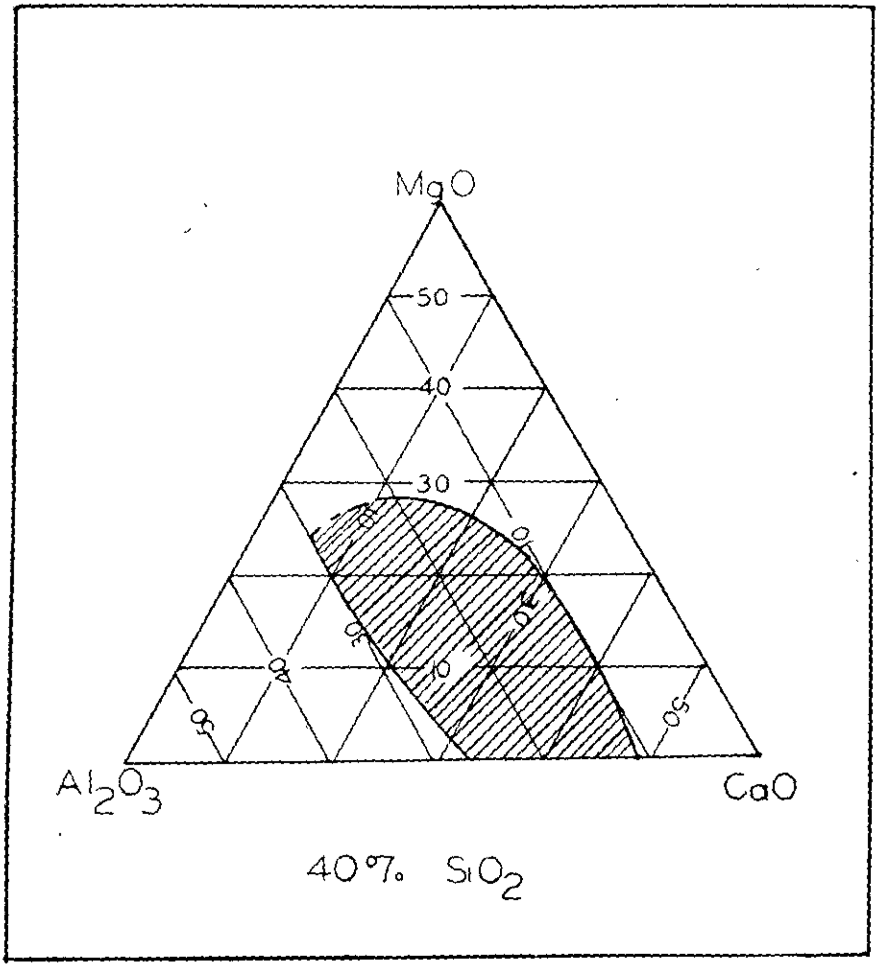

FIGURE 6. Diagram showing range of compositions suitable for mineral wool production in the quaternary system at 40% silica. (After the Illinois Survey.)

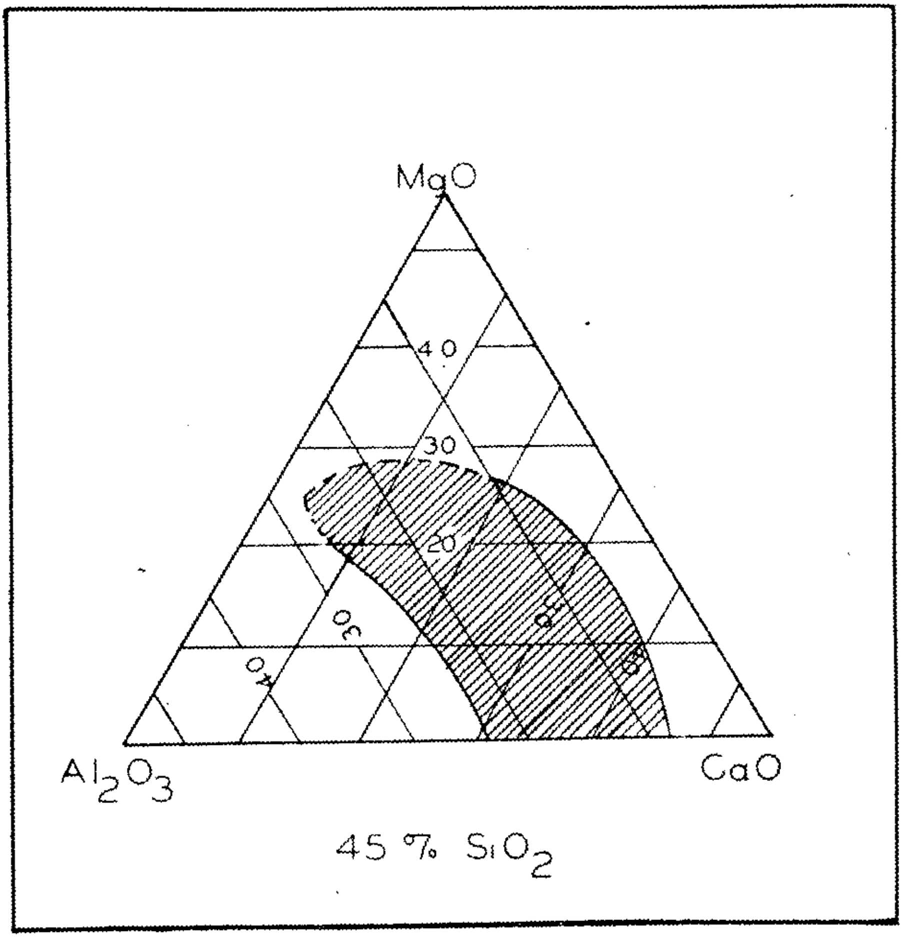

FIGURE 7. Diagram showing range of compositions suitable for mineral wool production in the quaternary system at 45% silica. (After the Illinois Survey.)

A formula has been derived for securing the pounds per ton of material which are necessary to meet the chemical requirements.[1] This formula is expressed as follows:

$$y = 2000 \frac{f_1}{f_2} \left\{ \frac{C - Af_1}{Bf_2 - C} \right\}$$

y = weight of flux rock in pounds required per ton of material.
A = fraction of silica in the sub-woolrock = % $SiO_2/100$.
B = fraction of silica in the flux material = % $SiO_2/100$.
C = fraction of silica desired in the calcined mixture = $SiO_2/100$.
f_1 = the ratio of the weight of the sub-woolrock to the weight of the calcined sub-woolrock.
f_2 = the ratio of the weight of the fluxing materials to the weight of the calcined flux rocks.

Because f_1 and f_2 represent ratios, it is immaterial in which units they are expressed. These ratios are readily calculated from the analyses, in which case they would be 100 ÷ the sum of the percentages of the permanent oxides, i. e. 100 ÷ (% SiO_2 + % MgO + % CaO + % misc. oxides.)

Another method of determining the proper amounts of fluxing materials is based on the carbon dioxide content of the materials. It has been proposed by several different people and companies that raw materials which contain between 20% and 30% CO_2 are usually satisfactory. Sub-woolrocks or secondary slags can have a CO_2 content as low as 12-15% or as high as 36-40%. Thus in order to get a satisfactory mixture, the weight of the flux rock required to give a carbon dioxide content of 20-30% is calculated. The results of this method can be applied to uncalcined mixtures only.

There are two distinct disadvantages to this method, however. The first is that the carbon dioxide determination has not proved as accurate as that method which is based on the SiO_2 content. It is not as diagnostic in regard to the definite limits which have been found advisable to observe. Because of this inaccuracy, it does not adapt itself so readily to an estimation of the minimum amount of flux rock required.

Nevertheless, the rapidity with which this test can be made has one definite attribute. The carbon dioxide test can be run on prospective raw materials, and if they average between 20-30%, they can be further analyzed in order to determine whether they are primary raw materials. If the carbon dioxide tests do not satisfy the aforementioned prerequisites, the samples can be discarded.

This process of calcination is carried on between temperatures of 400 degrees and 1000 degrees centigrade. A preliminary heating at 400 degrees removes the moisture and any other volatile materials which might be present. After heating to a constant weight, the

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[1] *Ibid.*, p. 171.

material is heated to 1000 degrees centigrade. The difference between the two constant weights approximates the carbon dioxide content of the sample. "This test is based on the effect that sedimentary rocks generally contain a molecule of CO_2 for each molecule of lime or magnesia. Thus a measurement of the amount of carbon dioxide in a sample is a rough measurement of the basicity of the sample."[1]

The formula which has been worked out is as follows:[2]

D = % of CO_2 in the sub-woolrock.
E = % of the CO_2 in the flux rock.
X = the number of pounds of flux rock required per ton of sub-woolrock.

$$\frac{2000\,D}{100} = \text{the weight of } CO_2 \text{ in the sub-woolrock.}$$

$$\frac{XE}{100} = \text{the weight of } CO_2 \text{ in the flux.}$$

$$\frac{(2000 + X)\,25}{100} = \text{the weight of } CO_2 \text{ in the mixture.}$$

$$\text{Now } \frac{2000\,D}{100} + \frac{XE}{100} = \frac{(2000 + X)\,25}{100}$$

$$\text{Therefore: } X = \frac{2000\,(25 - D)}{(E - 25)}$$

The flux requirements of several of the slags and sub-woolrocks have been calculated and are listed in Table 1. The table records the amount of fluxing materials required, as calculated on both the bases of the carbon dioxide content and the silica content. Examination of the respective columns will show the discrepancy between the two methods of calculation. The calculated compositions of the resultant wools, based on the silica content, are recorded in the last four columns.

THE EFFECT OF VARIABLES UPON PRODUCTION

Chemical Composition

Mineral wool is blown from a melt consisting of four principal constituents—i. e., silica, alumina, lime, and magnesia. Iron, sulfur, and manganese are often present in the woolrocks and sub-woolrocks. Slag wools may contain considerable amounts of these materials plus calcium sulphate, lead, zinc, phosphorous pentoxide, etc., depending on the type of slag used.

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[1] *Ibid.*, p. 196.
[2] *Ibid.*, p. 172.

TABLE 1

FLUX-ROCK REQUIREMENTS FOR RAW MATERIALS[b]

No.	Raw Materials and Type of Flux	Pounds of flux rock per ton of sample		Calculated composition of resultant wool on SiO_2 basis			
		CO_2 Basis	SiO_2 Basis	SiO_2	CaO	MgO	R_2O_3
1	American Smelt. Slag #2[a]	360	400	38.5	23	1.76	33.2
2	" " " #3[a]	221	368	37.5	24.90	1.76	33.2
3	Oxford Slag[a]	800	1440	39	26	10.9	20.0
4	Salmon Bros. Slag[a]	108.5	265	37	32	16.2	15.8
5	Pequest Slag[a]	92	470	35	35	13.9	18
6	Trenton Ls. (#5)[a]	12.40	22.8	41	41	2.5	12.2
7	" " (#6)[a]	38.50	25.7	35	30.5	3.2	....
8	" " (#8)[a]	550	428.15	40	45	14.2	11.3
9	Kittatinny Ls (#1)[a]	1620	1475	41	30	11.1	18.0
10	" " (#4)[a]	1000	640	40	34.1	17.6	9.8

[a] Theoretical composition of silica flux: $SiO_2 = 60\%$; $R_2O_3 = 25\%$; Impurities = 5%; Ignition loss = 10%.

[b] For a list of the sub-woolrocks and slags, see Appendix, Tables 3 and 4.

In a general consideration of the woolrocks, the silica is free or combined as sand, silt particles, and mica. This ingredient is quite important for the production of good wool. The alumina is combined with the silica to form clay or mica. The necessity of the presence or non-presence of this ingredient in the raw material is a debatable question, for wools have been blown under both conditions. The iron is present in the form of oxides (hematite, limonite), sulphides (marcasite, pyrite), and carbonates (siderite). The carbon dioxide is expelled from the calcium carbonate, while the lime enters into the melt. The lime tends to produce a melt of lower temperature, but if extremely large amounts of lime are present, fusion is retarded because lime is refractory in amounts too large for proper union with the other constituents.[1] The magnesium carbonate also loses its carbon dioxide, while the resultant MgO usually acts as a flux.

The same ingredients are present in slags in varying amounts, but not in the aforementioned manner. For this material has already been subjected to heat. The carbon dioxide content is a much smaller quantity in the slags. It would seem that the total CO_2 content would be driven out of the slags when the material was first melted. From the analyses acquired from the various companies and those which were run by the author, there seems to be between 10% and 15% of the sample unaccounted for except by the presence of carbon dioxide and moisture.

In considering raw materials which are suitable for the production of mineral wool, the ratio of acids to bases is quite helpful. This ratio is more diagnostic for the natural occurring raw materials than for the slags, for the rocks consist chiefly of SiO_2, CaO, Al_2O_3, and MgO, with Fe_2O_3, Na_2O, etc., present in minor quantities. Slags may have quantities of iron, manganese, lead, or zinc, depending upon the type of slag. Thoenen has recorded the following ranges in the acid-base ratios for the various raw materials:[2]

	A	B
(1) Lead Slag	1.20	1.00
(2) Iron Slag	1.10	1.00
(3) Woolrock	0.93	1.00

A number of mineral wool analyses are presented in Table 2. These analyses show that the finished product does justify the use of the acid-to-base ratio as a criteria in determining the relative merits

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[1] W. N. Logan, "Mineral Wool Industry in Indiana," *A. I. M. E. Preprint,* February, 1932.

[2] J. R. Thoenen, *United States Bureau of Mines, Information Circular No.* 6984, 1938.

of the raw materials. One notes that the slag wools tend to show a wider range in the ratio because of the more pronounced variability of the ingredients.

Goudge[1] and Logan[2] maintain that mineral wool consists of approximately a 50-50 mixture of acidic and basic oxides. These ratios were calculated for the various analyses of mineral wool following Goudge's method—i. e., the ratio of the sum of the gram-mols of the acidic oxides to a corresponding sum of the basic oxides. A is the sum of the number of gram-mols of silica, alumina, and iron present in 100 grams of material. B is the sum of the number of gram-mols of lime and magnesia present in 100 grams of material. If the iron content is very high in the raw materials, it should be considered as a base, but in the woolrocks, the iron content is usually negligible.

The ratio was expressed in terms of gram-mols instead of the percentage composition because of experiments carried on by C. H. Fryling of the Illinois Survey.[3]

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[1] M. F. Goudge, "Raw Materials for the Manufacture of Rock Wool in the Niagara Peninsula," *Can. Dept. of Mines, Bul. No.* 727, 1931.

[2] W. N. Logan, *A. I. M. E. Preprint,* Feb., 1932.

[3] C. H. Fryling, *Illinois Geological Survey, Bul.* 61, 1934.

TABLE 2
ANALYSES OF COMMERCIAL WOOLS

No.	Commercial Wools	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Misc.	A/B[e]
1	Slag wool	34.8%	16.7%	[d]	30.2%	18.4%	...	.656
2	Slag wool	38.6	18.6	[d]	27.9	15.5	...	.804
3	Slag wool	38.6	18.0	[d]	27.7	15.5	...	.814
4	Slag wool	37.7	12.0%	1.0%	30.0	12.0	5.0%	1.016
5	Slag wool[a]	38.0	11.0	1.0	28.0	19.0	3.0	.770
6	Slag wool	36.4	12.2	[d]	32.7	18.8	...	.692
7	Mineral wool[c]	40.1	18.6	1.7	28.1	11.1	0.4	1.110
8	Mineral wool[c]	40.8	12.6	[d]	28.9	17.7	...	.842
9	Rock wool[b]	36.9	19.5	1.14	33.8	7.8	0.6	1.021
10	Rock wool[b]	34.5	16.1	0.7	29.8	18.2	0.7	.749
11	Rock wool[b]	44.0	10.3	1.9	41.8	0.6	1.4	1.113
12	Rock wool[a]	42.8	1.4	...	51.7	2.8	1.3	.734

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[a] Thoenen, J. R. "Mineral Wool," *Information Circular No.* 6142, *United States Bureau of Mines,* June, 1929.
[b] Fryling, C. H. *Illinois Geological Survey, Bul.* 61, 1934.
[c] Logan, W. N. *A. I. M. E. Preprint,* February, 1932.
[d] $Al_2O_3 + Fe_2O_3$.
[e] A = gram-mols of SiO_2, Al_2O_3, and Fe_2O_3 in 100 grams of material.
B = gram-mols of CaO, and MgO in 100 grams of material.

It is stated that when fiber diameters of synthetic rock wools are plotted as a function of the molecular ratio of the acids to bases, a smoother curve results than when they are plotted against the percentage ratio of acids to bases.

Viscosity and Fusibility

Of all the deleterious ingredients, the percentage of iron seems to have the greatest effect on both the process and the resultant wool. The fusibility of the melt and the relative quantities of shot and fiber are directly affected.

According to Lang[1] and Thornbury,[2] slags rich in iron will blow into shot without any trace of fibers. Basic slags produce only short fibered wools. In order to produce a long fibered wool, a slag is required which has a long range of viscosity—i.e., a wide temperature range between softening and complete fusion. "This phenomena is best illustrated by glass, and this fact helps to explain the excellent wools which can be made from glass batches."[3] If a slag is employed as a raw material, the use of copper smelting slags rather than blast furnace slags has been recommended.[4]

The fusibility and the viscosity of the melt seem to be definitely related to the chemical composition. Plumer has suggested that the proportion of the alumina and silica, and the ratio of the acids to the bases affect the fusibility.[5] A high alumina content in proportion to the silica tends to raise the fusion temperature and to increase the viscosity of the melt. Raw materials, which have a relatively large proportion of silica to alumina tend to fuse more readily and produce a less viscous melt.[6]

Experiments have been carried on in order to determine the effect of fluorspar upon the melt, and it has been established that an addition of fluorspar up to 10% causes a reduction in the viscosity.[7] The theory advanced is that the fluorspar promotes an interaction of lime and silica to form $CaSiO_3$ with or without the help of the intermediate compound SiF_4. The authors claim that there is also the possibility that the reduction in viscosity may be caused by low melting eutectics.

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[1] H. Lang, "Some Problems Encountered in Designing and Operating a Mineral Wool Plant," *Chem. & Met. Eng.*, Vol. 29, No. 9, p. 365. (1923).

[2] W. D. Thornbury, "Mineral Wool Industry of Indiana," *Proc. of the Ind. Academy of Science for* 1937, Vol. 47, pp. 162-175. (1938).

[3] *Ibid.*, p. 170.

[4] Lang, *op. cit.*, p. 365.

[5] N. Plumer, "Rock Wool Resources of Kansas," *Mineral Resources Circular No. 5, Kansas, Geological Survey*, Vol. 38, 1937, p. 66.

[6] *Idem.*

[7] J. S. Machin and J. F. Vanecek, "Effect of Fluorspar on Silicate Melts with Special Reference to Mineral Wool," *Report of Investigations, No. 68, Ill. State Geological Survey,* 1940.

CHARACTERISTICS OF MINERAL WOOL

The finished product has two important properties: (1) low heat conductivity, and (2) low bulk density. The basis of this relationship is correlated with the physical characteristics of the individual fibers.[1] The fiber characteristics are subjected to alteration only because of the variability of the mechanical process; while other characteristics of the wool—i. e., the ratio of the weight of shot to the weight of fibers, and the fiber lengths—are subject to alteration by processes used in refining the crude wool. Thus the fiber characteristics (especially the fiber diameter) remain relatively constant.

Fiber Characteristics

Under the microscope, the fibers present a symmetrical ornamentation. They appear as thin glass rods in a criss-cross pattern, and vary in thickness from that of spun glass to an extreme tenuity represented by thousandths of an inch (microns). The shot are bulbous like in shape, and are generally solid bodies, but at times they are vesicular in nature. When the fibers are crowded close together, they form interstices of angular shape, so that free motion of encased air is impossible. It is generally believed that because of this complex network, air is entrapped in such small spaces that the heat is not transferred by convection.[2] These minute air spaces account for both the low heat conductivity and the low bulk density.

According to one authority, the fiber itself controls the insulation values instead of the "dead air spaces."[3] The property of surface tension in the fibers seems to be of prime importance, and this is in direct proportion to the fiber diameter. When the individual surface of a fiber is broken through, the insulation properties cease to act. For example, the wool with a fiber diameter of 25 microns has a heat conductivity coefficient of .36; a similar wool with a fiber diameter of 6 microns will have a heat conductivity coefficient of .24.[4] Fryling points out that wools having a fiber diameter between 2 and 10 microns have a satisfactory bulk density, are soft, and have a degree of resiliency.[5] If two wools of the same density, chemical composition, etc., are tested, the conductivity coefficient is nearly a straight line graph in terms of fiber diameter.

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[1] Fryling, *op. cit.*

[2] *Ibid.*, p. 180.

[3] Personal communication with Mr. E. R. Richards, Director of Research, Johns-Manville Corp., Manville, New Jersey.

[4] *Ibid.*

[5] Fryling, *op. cit.*

The factors governing the fiber diameter are: (1) mechanical and operating conditions—pouring temperatures, blast pressures, nozzle characteristics, rate of pouring, angle at which the wool is blown; (2) physical properties of the melt—viscosity, surface tension, presence of iron, density, and homogeneity. The latter is a function of the composition and density. A high content of iron in the melt tends to form large fibers when blown.[1]

The experiments carried on by Machin and Vanecek were to determine the effect of viscosity on the fiber diameter.[2] They found that fiber diameters may be reduced considerably by the addition of fluorspar. However, there appears to be a lower limit, for when the melt is fluid enough to produce fibers of 1, 2, and 3 microns in diameter, the additional fluorspar has little effect. The fluorspar is much less effective in a basic melt than in a melt which is dominantly acidic.

Thus it appears that the proper manipulation of operating variables and the regulation of operating conditions as a function of the physical properties of the melt are two important phases of mineral wool production.

Color

The influence of color on the finished product is relatively slight. Experimental production has shown that when the fibers are fine, the wool is usually light in color.[3]

White wools are usually composed of the four major components, *i. e.,* silica, alumina, lime, and magnesia, but small amounts of particular compounds will affect the wool. Iron, manganese, zinc, and sulfur will tend to color the wool—the range being from light tan to dark brown. Often comparatively high percentages of iron oxide will have little effect upon the color, but when sulfur is also present in the same wool, a dark brown will result.

Experimental work by various companies have discovered that if a brown wool is treated at a higher temperature and for a longer period of time, the sulfur will be driven off and the resultant wool will be white.

OPERATING TECHNIQUE

The operating technique of the individual plant cannot be discussed here for obvious reasons, but generalizations can be made for the industry as a whole. This data has been compiled from personal communications, references to the literature, and visits to some twenty

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[1] Personal communication with Mr. E. R. Richards.
[2] Machin and Vanecek, *op. cit.*
[3] Fryling, *op. cit.* p. 179.

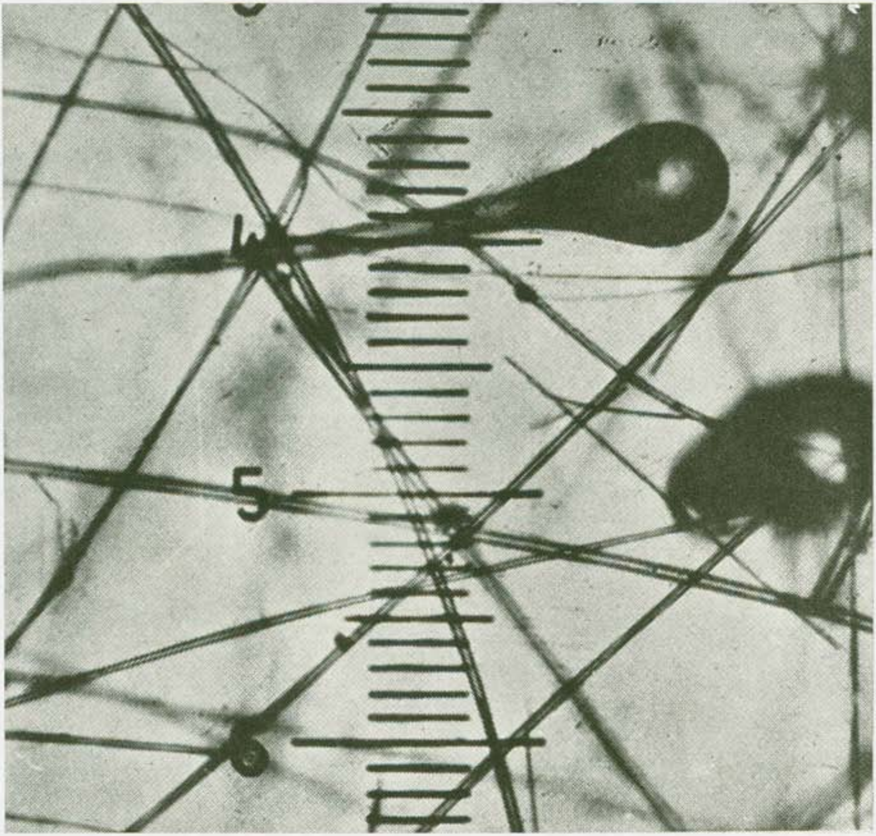

FIGURE 8. Photomicrograph of mineral wool. (One division of the scale equals 10 microns.)

mineral wool plants in New Jersey and Ohio. As in other phases of the industry, plant practices throughout the United States and Canada vary. A brief discussion of the types of furnaces, the blowing process, and the factors involved follows.

Types of Furnaces

There are many different types of furnaces used in the present production of mineral wool. The most widespread practice is the use of the water jacketed cupola.

They range in size from twenty-six inches to seventy-two inches in diameter and from seven feet to sixteen feet in height. The water jacket varies from three to six inches in diameter.[1] Water circulates under pressures ranging from twenty-five to one hundred pounds per square inch, and the quantity used varies from twenty-five to fifty gallons per minute per cupola. The furnace is set on end on a brick or concrete foundation. The lower end is closed with a sheet iron plate, while the upper end is housed in a fire brick hood containing the charging opening and surmounted by a metal stack. At a point near the base, an automatic fixture permits the fluid slag to escape in a small stream.

The charge of raw materials is preferred in lump form, with an assortment of sizes prevalent in order to prevent excessive chameling within the cupola.

The cupola uses either coal or coke for fuel. The use of coal has been abandoned to a large extent because of the impurities present—particularly the high sulfur content. The ratio of raw materials to fuel averages three to one but ranges between one to one and one to eight.

In loading the furnace, there is first the addition of a layer of raw material, then one of coke, another layer of raw material and flux, then another layer of coke. This sequence is continued until the cupola is entirely filled.

The reverberatory furnace has been used successfully in the manufacture of mineral wool. Oil is used as a fuel, and the furnace burns approximately 50-60 gallons per hour.[2] Producers have found that fine materials can be used in this type of furnace, because it is unnecessary for the furnace gases to pass through them.

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[1] J. R. Thoenen, *Information Circular* 6984*R*, United States Bureau of Mines, 1939.

[2] *Ibid.*

An electric arc furnace has been described in connection with the utilization of wollastonite as a raw material.[1] This type of furnace has been used by several manufacturers, but the practice is not widespread. The furnace is usually a one ton, arc type, tilting furnace which is charged and tapped continuously.

The Blowing Process

As the material is melted, it is drawn from the furnace in a single, double, or triple stream. The distance that the slag has to fall to the blowing nozzle ranges from 4 to 15 inches. This factor seems to have multiple effects upon the resultant wool, for temperature, viscosity, and the diameter of the slag stream are directly related. Producers claim that the greater distance they can allow the slag to fall without its excessive cooling, the better wool they can make. To satisfy these conditions and still maintain the most consistent slag stream diameter, a drop of eight to twelve inches is found to be the maximum distance in practice.

The diameter of the slag stream is closely related to the efficiency of the stream in blowing the materials into fibers. This dimension is hard to measure; but Thoenen records a diameter varying between ¼ and ¾ inch.[2] At the point of blowing the diameter approaches ⅜ inch.

In order to fiberize the product, compressed air or combined air and steam is blown against the falling slag stream. This jet is emitted through an orifice, which is in a shape designed by individual preference. Usually the orifice is a U-shaped or a V-shaped nozzle.

The angle at which the wool is blown is again a matter of individual practice. The usual procedure has the slag falling from the vertical, with the steam directed at a slight acute angle from the horizontal. Thus the angle of blowing approaches a right angle, for this seems to give a maximum of fibers and a minimum of shot.

The steam pressure is approximately 100 pounds per square inch when issuing from the nozzle. If air pressure is used in the blowing, it ranges from 1.7 ounces to 1.5 pounds per square inch. The quantity of air varies from sixty to twelve hundred cubic feet per minute per cupola.[3]

If an electric arc furnace is used, the molten material falls on a rapidly spinning disk (4,000 r.p.m.) In combination with the steam

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[1] J. T. Thorndyke, "Mineral Wool from Wollastonite," *Mining and Metallurgy*, March, 1936. pp. 133-135.

[2] Thoenen, *Information Circular* 6984.

[3] *Ibid.*

FIGURE 9. The Blowing of mineral wool. (Courtesy of Baldwin-Hill Company, Trenton, New Jersey.)

and the whirling disk, the material is thrown off tangentially—thus the formation of the fibers.

When the air or steam comes in contact with the stream of slag, it is broken up into small droplets which are propelled into a collecting chamber. During their flight through the air, each droplet drags out into small threads before cooling. That portion of the droplet which does not pass into fiber is called shot.

Melting and Blowing Temperatures

The total amount of heat required for the melting depends upon the chemical composition and the physical structure of the raw materials, the type of fuel, the method of applying the heat, the method of placing the materials in the cupola, the rate at which the heat is applied, and the moisture content of the raw materials. The fact that different temperatures would be required to blow materials with different ingredients seems reasonable, but actually different temperatures are recorded to blow similar raw materials.

From a survey of the plants, the range was found to be from 2,500 degrees to 3,800 degrees Fahrenheit—with the most prevalent melting temperature being around 3,000 degrees Fahrenheit. The actual blowing temperatures range from 2,200 to 3,000 degrees Fahrenheit, with the average operation being carried on at approximately 2,600 degrees Fahrenheit.

The exact temperatures at which the wool is melted is extremely difficult to determine because of the complexity of the apparatus used, and the skill required to operate it. A thermocouple in the walls of the furnace or near the melting zone has been employed. The blowing temperatures are even more inaccurate, for they are generally judged by color, and the ability of different people to detect colors increases the scope of inaccuracy. Radiation pyrometers can be used to determine temperature. One type measures, with a special photometer, the intensity of monochromatic light emitted by the incandescent body whose temperature is being measured.

Collecting the Wool

The arrangements for collecting the wool are devised to give the maximum accumulation of wool with a minimum amount of attached shot. The wool may be blown straight into square rooms, or it may be projected at such an angle so the shot will become loosened from the fiber.

There are quantities of the wool which are carried away with the exhaust steam out through the stack, and it is the aim of every plant operator to decrease this loss. A baffle arrangement of the collecting chambers has been devised which saves approximately one ton of wool per day.[1] The wool passes through such a circuitous route that all of the wool in suspension is dropped into two or three chambers. the speed of the particles is arrested to the point where practically

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[1] Bror Nordberg, "Improved Rock Wool Manufacture," *Rock Products*, January, 1938, pp. 94-98.

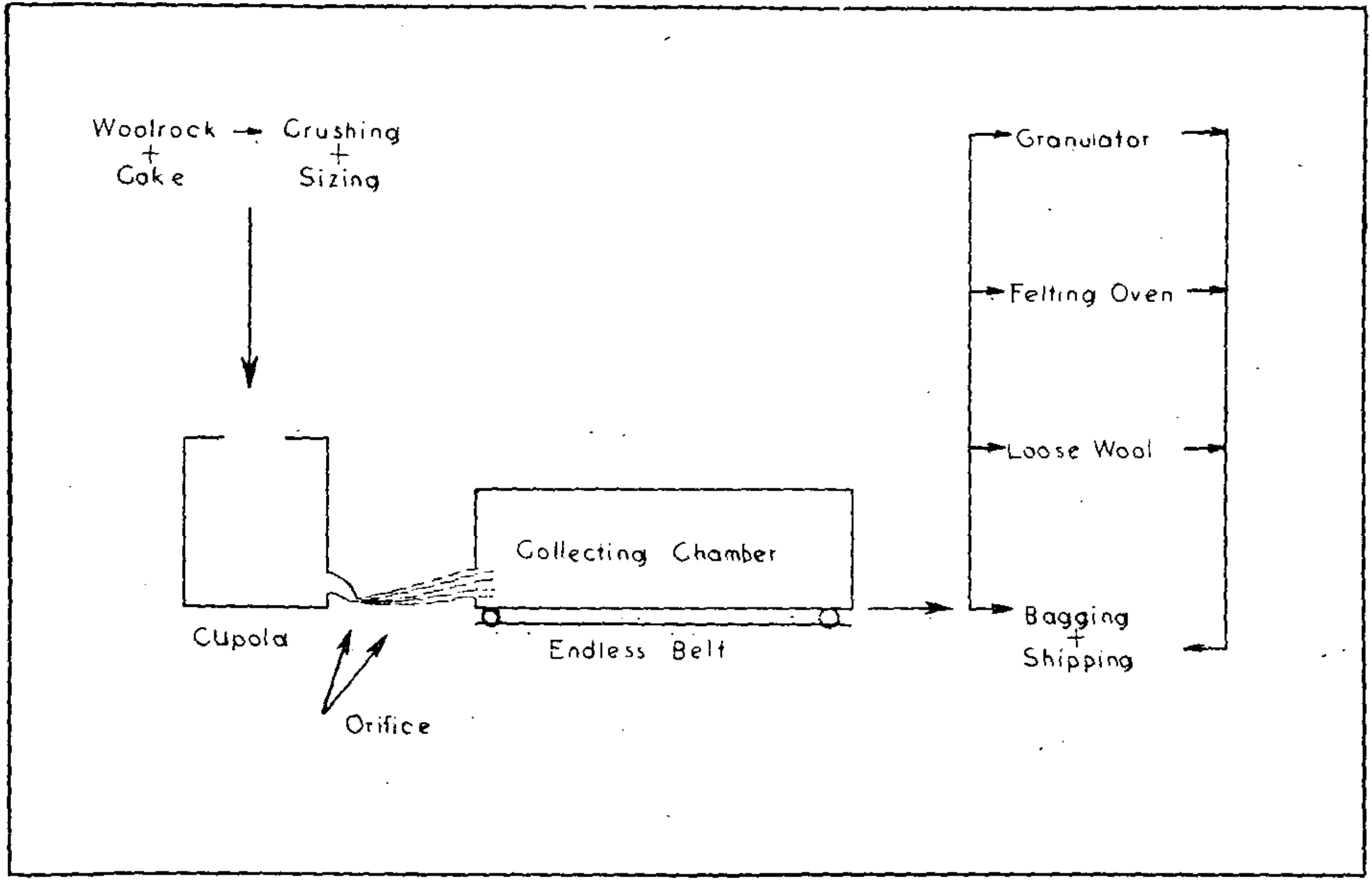

FIGURE 10. Flow chart of a mineral wool plant.

IV. CONSUMERS' SPECIFICATIONS

In order to obtain the desired material, certain criteria have been defined by the United States Bureau of Standards. These specifications have been devised to protect the customer. In general they apply to the loose fill and the bat or strip forms. The field of industrial insulation requires wool which must satisfy certain rigid specifications that are not applicable to the wools used in home insulation.

The qualities of a suitable wool which the consumer should be familiar with are: (1) chemical composition, (2) shot content, (3) fiber size (length and diameter), (4) ductility or softness, (5) waterproofing, (6) thermal conductivity.

The impurities which might be present in the wool are of some concern. Specifications should indicate the percentage of lime and sulfur present in the wool and the chemical form in which the sulfur occurs. It has been reported that if the lime content is too high, slow disintegration under atmospheric conditions takes place, and the wool loses its resiliency.[1] The installed wool may slump and close the minute air spaces, thus decreasing its insulating value.

The presence of sulfur can be harmful. If this ingredient is present as a sulphide, moisture may unite with it and form acids which might be corrosive. The United States Bureau of Standards specify that the sulfur content shall not exceed 0.75 percent.[2]

The shot in the wool has no insulating value and it decreases the total insulating value by obstructing the free air spaces. The customer should be aware of the total percentage of shot and the size of the particles.

The waterproofing of the wool is unnecessary as far as improving the wool for home insulation is concerned. There is a light paraffin oil applied to all wools in order to keep the dust at a minimum while handling. It also serves as a lubricant between the fibers, thus reducing internal friction and making the wool more resilient. The Bureau of Standards states that the material shall contain not less than 0.35 percent of mineral oil which shall be added while the material is being fiberized.[3]

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[1] Thoenen, *Information Circular* 6984.

[2] Federal Specifications for Insulation, HH-I-521B, August 27, 1937.

[3] *Ibid.*

Other processes required to make the wool waterproof are generally trade secrets. The practicality of this phase has been questioned, for the addition of superfluous materials would tend to reduce the insulating value.

Thermal conductivity is caused by air entrapped by the entangled fibers and the conductivity of the solid individual fibers. It has been suggested that the thermal conductivity is directly related to the density of the wool.[1] Fryling points out that when the bulk density is low, heat is transferred by convection through the larger air pockets; if the wool is closely compressed, the heat can be readily conducted by the solid glassy portions. Therefore the lowest heat conductivity is found at some intermediate density. This critical density appears to be between 10 and 15 pounds per cubic foot.

The Bureau of Standards has also published specifications on this feature.[2]

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[1] Fryling, *Ill. Geological Survey*, Bul. 61, 1934.

[2] Federal Specifications for Insulation, HH-I-521B, August 27, 1937.

V. ECONOMIC ASPECTS OF THE INDUSTRY

GENERAL

The manufacture of mineral wool in Canada and the United States has been the most rapidly growing industry of the insulation field during the past ten years. It was not used for home insulation until 1927, and the pneumatic method of installing the wool in dwellings already constructed was not perfected until 1930. The expansion of the industry has been especially evident since 1937, and has been manifest by an increase in the number of plants, the tonnage produced, and operating technique. In 1928, there were 8 plants operating with a production of approximately 50,000 tons; in 1940, there were 68 plants producing approximately 350,000 tons of mineral wool.[1]

The exact number of plants is difficult to ascertain because new plants are opening and some new ones are closing down. In 1938, Indiana had 16 plants, Ohio 9, Illinois 7, and New Jersey 7.[2] The distribution of the nation's producers is shown on Figure 12, page 74.

Five companies produce slag wool in New Jersey, another company is preparing to operate soon, and one is idle. The location of these plants is shown on Figure 11. This is over 7 percent of the plants operating in the United States. The plants vary in size from 4 to 14 cupola installations, and 36 cupolas are in operation in the state.

The following table gives the name and the location of the plants:

Name of Company	Location
1. American Rock Wool Company	South Plainfield
2. Baldwin-Hill Company	Trenton
3. Eagle-Picher Company	Newark
4. Johns-Manville Corporation	Manville
5. Miller Rock Wool Company	Hackettstown
6. United States Gypsum Company	Dover
7. United States Mineral Wool Company	Stanhope

As the business is competitive, producers are reluctant to supply accurate production data, but the following information is available from the Biennial Census Reports. In 1900, the value of the mineral wool produced in the United States was approximately $60,000.[3]

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[1] National Mineral Wool Association.

[2] W. D. Thornbury, "The Mineral Wool Industry of Indiana," *Proceedings of the Indiana Academy of Science,* 1938, pp. 162-175.

[3] *Ibid.,* p. 174.

Since that time the value of the products has steadily increased until in 1939, the total value of mineral wool was $8,530,020. The following table indicates the rate of growth:[1]

Year	Value of Product
1900	$60,000
1910	84,012
1929	2,377,324
1931	2,873,230
1933	1,714,171
1935	7,672,096
1937[2]	8,040,482
1939[3]	8,530,020

From the records, there appears to be a decrease in the production of rock wool and a corresponding increase in the production of slag wool. This change is manifest in the following table:[3]

	Years	Tons	Value
Rock Wool	1937	141,262	$5,525,628
	1939	139,455	3,771,110
Slag Wool	1937	55,180	2,514,854
	1939	163,135	4,758,910

These figures also indicate the recent trend towards complete insulation and the increased use of bats and strips rather than loose wool. During 1940 the latter trend offset a substantial price reduction, with the result that compared with 1939 figures the total value of sales increased somewhat more than the increase of approximately 25 percent in tonnage sold.[3]

FUTURE OF THE INDUSTRY IN NEW JERSEY

The continued expansion of the mineral wool business in New Jersey depends upon the production and delivery of a satisfactory product to the market at a cost lower than materials coming from competing districts and at a price that will not turn the customer to a competing product made from other materials.

In order to analyze the economic possibilities of the industry in New Jersey, a conception of the available markets, of the transportation facilities, and of the conditions of production in the state, is necessary.

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[1] *Ibid.*
[2] *Minerals Yearbook for* 1940, p. 1420.
[3] *Idem.*

Available Markets

The potential demand for mineral wool in the housing field is difficult to estimate quantitatively due to the complex nature of the market. Insulation of new constructions is practically accepted, and this market will continue to grow in proportion to the rate of building. The government alone has approved 200,000 dwelling units through its defense housing program.[1] Existing structures, also, can be insulated successfully and will offer an expanding market. This phase of the market varies with the value of the house, whether it is occupied by the owner or is rented, and whether the location is urban or rural.

Market areas differ in potentialities because of the unequal distribution of the population. The markets which are nearest the New Jersey industry are definitely urban concentrations.

The metropolitan area of New York and the adjoining areas of Newark, Jersey City, and Elizabeth provide an extremely versatile market. For within these areas not only will home insulation be of prime importance, but also the needs of industrial insulation will be large. Airplane factories, shipyards, and other industries now working at full capacity will give added impetus to the industry. Other urban areas include Trenton and Camden in New Jersey, Easton and Philadelphia in Pennsylvania, and possibly such areas as Wilmington in Delaware, Baltimore in Maryland, and Washington, D. C. The New England States will also provide an extensive market.

Transportation Facilities

The railroad transportation is well equipped to distribute mineral wool from the producing areas of New Jersey to the market districts. The Pennsylvania Railroad, the Delaware, Lackawanna, and Western Railroad, the Susquehanna and Western, the New Jersey Central Railroad and affiliated companies make connections with the metropolitan areas. From New York direct connections are made to the New England markets. Similar connections radiate to the south and west.

The principle variable in the cost of delivering the manufactured product is the freight rate. The rates vary according to means of transportation and they are also affected by the bulk and weight factors. The material is bulky, and a standard box car accommo-

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[1] P. M. Tyler, "Home Insulation," *Information Circular* 7166, *United States Bureau of Mines*, April, 1941, p. 4.

dates only 12 tons of mineral wool. The average cost of transporting by rail one ton of wool from a New Jersey plant site to New York is $5.00.

Conclusions

New Jersey offers a comparatively low cost for assembling raw materials including fuel, and markets provide favorable delivery costs.

Sufficient raw materials are available. Slag reserves and slag production in New Jersey total 9,130,400 tons. Slag producing industries are favorably located in nearby Pennsylvania. The quantities of slag production certainly will not decrease in the next few years, and the increased tempo of production involved in the national defense efforts will tend to offset the depletion of the slag reserves.

Flux materials are available in sufficient quantities. The Franklin Limestone (50% CaO) serves as an excellent lime flux; various portions of the Green Pond Formation (97% SiO_2) satisfy the silica flux requirements. Kittatinny limestone and white marls are also promising sources of lime, and if suitable mixtures of these materials can be combined a satisfactory wool could be produced.

In addition to the fluxing materials, fuel is the most important raw material that is required in the production process. Coke is the form of fuel generally used, but anthracite coal is used in several of the plants. These fuels are available from several areas in Pennsylvania. The second largest anthracite producing area in the world is available to the mineral wool manufacturers of New Jersey.

Transportation facilities by rail, truck, and possibly water are adequate to take the product to the diversified markets with efficiency and a minimum of cost.

In view of the aforementioned factors, it seems probable that the mineral wool industry of New Jersey will continue to expand, and this expansion will be accompanied by a product which will continue to meet the increasing rigidity of specifications in a highly competitive industry.

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APPENDIX

TABLE 3
SLAG RESERVES OF NEW JERSEY[c]

No.	Location	SiO_2	CaO	MgO	Al_2O_3	Fe_2O_3	Misc.	Tonnage
1	U. S. Min. Wool	35.2	26.1	17.9	20.50[b]		....	5,300 tons
2	" " " "	36.76	31.92	3.92	14.11	12.94	....	2,000 "
3	American Agric. Chemical Co.	48.74	43.76	....	1.27	0.36	2.25	1,500 "
4	Raritan Copper	16-23	1.5-6	12-24	....	17-27	6-35	4,500 "
5	U. S. Metals Co. Copper Slag	35-40	2-3	1-2	4-7	36-45	3-5	1,000,000 "
6	U. S. Metals Co. Lead Slag	23.0	12.0	2.5	6.0	38.4	....	4,800 "[a]
7	American Smelting #1 Copper Slag	32-42	25-40	1.5	6-8	5-13	2-8	3,000 "[a]
8	American Smelting #2 Slag	22-28	17-25	1.5	7	18-22	....	4,000 "[a]
9	American Smelting #3 Slag	22-28	20-25	1.5	7-7.5	14-19	5	4,000 "[a]
10	American Smelting #4 Slag	42-45	39-43	....	....	4-6	....	750,000 "
11	Oxford Furnace	15.48	38.59	16.23	8.77	2-4	....	5,000,000 "
12	Salmon Brothers	30-46	18-28	14-20	13-18[b]		....	1,000,000 "
13	Wharton	35-44	22-28	12-20	15-18[b]		....	1,000,000 "
14	Riegelsville (Pa.)	39	28	20		9[b]	....	......
15	Pequest	28-38	30-38	12-15	18-25[b]		....	216,000 "
16	Hackettstown	28-40	24-35	10-15	20-25[b]		10-15	10,000 "

[a] Annual tonnage produced.

[b] $Al_2O_3 + Fe_2O_3$.

[c] Numbers refer to Figures 2, 3, and 4.

TABLE 4
ANALYSES OF CALCAREOUS ROCKS OCCURRING IN NEW JERSEY

No.	Formation	Location	CaO	SiO₂	MgO	R₂O₃	CO₂	Misc.
1	Jacksonburg Ls.	Phillipsburg	39.86	20.57	....	....	31.90	....
2	“ “	Hainesburg	48.04	2.62	2.84	2.38	....	....
3	“ “	Columbia	52.58	4.30	0.65	1.23	....	....
4	“ “	Deckertown	54.00	2.62	1.00	0.38	....	....
5	“ “	Hope	31.00	27.08	1.83	8.76	26.37	....
6	“ “	Belvidere	35.00	24.45	2.21	....	29.89	....
7	“ “	Newton	41.72	13.88	3.78	2.44	....	....
8	“ “	“	30.46	20.24	9.82	2.37	....	....
9	“ “	“	37.95	....	11.68	1.04	....	....
10	Kittatinny Ls.	Penwell Quarry	32.50	3.50	12.80	5.00	46.50	....
11	“ “	“ “	28.50	2.00	14.86	......	....	....
12	“ “	“ “	29.30	6.00	13.50	....	....	....
13	“ “	Annandale	28.27	16.90	15.30	0.98	38.90	....
14	“ “	Wantage	30.30	9.80	16.20	0.60	51.60	....
15	White Marl	Andover	55.06	0.90	....	....	43.27[a]	0.67
16	“ “	Shiloh	54.83	0.60	....	....	42.90[a]	1.59
17	“ “	“	53.34	0.98	2.18	....	42.00[a]	1.50
18	“ “	Newton	54.04	2.05	1.47	....	42.50[a]	....
19	“ “	Lincoln	55.59	0.55	....	....	43.50[a]	0.41
20	“ “	Monroe Corners	53.25	0.71	....	....	41.50[a]	4.54
21	“ “	Centerville	34.80	16.21	....	....	29.40[a]	16.59
22	“ “	Marksboro	51.75	1.56	2.98	....	40.50[a]	3.21
23	Franklin Ls.	Jenny Jump Mountain	43.36	4.98	4.62	1.82	45.30[a]	....
24	“ “	Danville (N. W.)	44.67	4.36	3.81	1.98	45.37[a]	....
25	“ “	Buttzville	49.36	0.86	1.58	0.64	47.31[a]	....
26	“ “	Oxford	49.09	1.08	1.80	0.86	46.32[a]	....
27	“ “	Sand Hills	49.55	0.90	1.89	0.41	47.81[a]	....

[a] CO_2 content calculated.

Key to graphs, Figures 1 to 4, inclusive

1. Oxford
2. Raritan Company
3. United States Metals Company (Lead slag)
4. American Smelting and Refining Company (Copper slag No. 2)
5. American Smelting and Refining Company (Copper slag No. 3)
6. Pequest
7. United States Mineral Wool (No. 1)
8. United States Mineral Wool (No. 2)
9. American Smelting and Refining Company (Copper slag No. 1)
10. Hackettstown
11. United States Metals Company (Copper slag)
12. Salmon Brothers
13. Riegelsville
14. Wharton
15. American Smelting and Refining Company (Slag No. 4)
16. American Agricultural Chemical Company

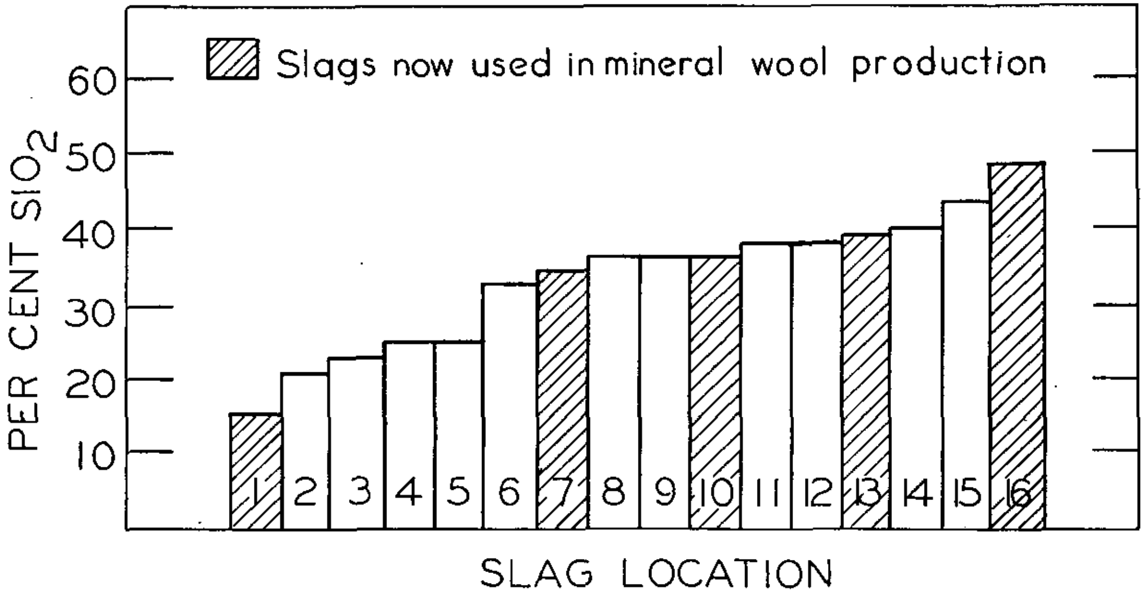

Fig. 1-VARIATION OF SIO_2 IN SLAGS

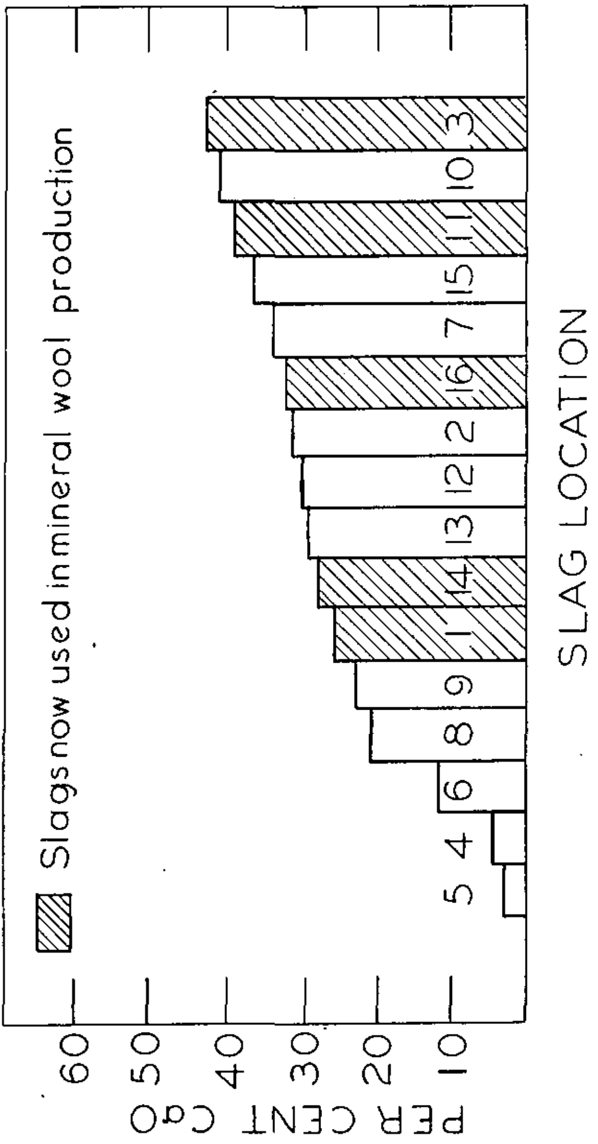

Fig. 2-VARIATION OF CaO IN SLAGS

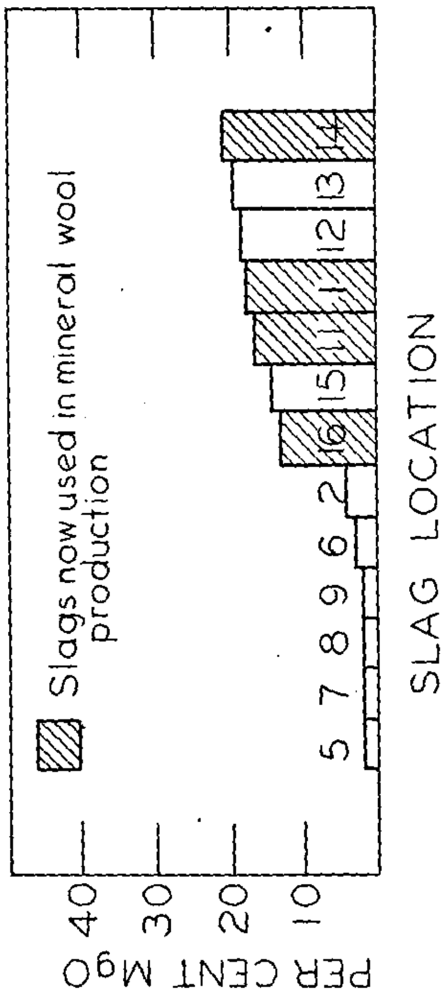

Fig. 3-VARIATION OF MgO IN SLAGS

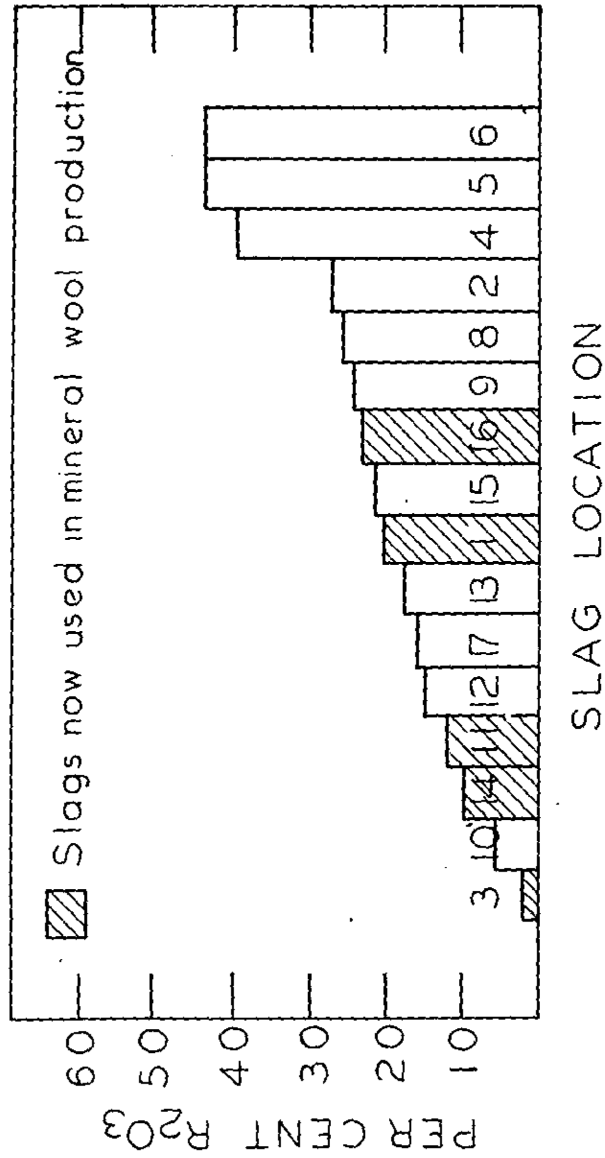

Fig. 4—VARIATION OF R_2O_3 IN SLAGS

Key to Figure 11

MINERAL WOOL PLANTS IN NEW JERSEY

1. Dover
2. Hackettstown
3. Manville
4. Newark
5. South Plainfield
6. Stanhope
7. Trenton

LOCATION OF SLAG PILES IN NEW JERSEY

1. Atsion
2. Batsto
3. Carteret
4. Hackettstown
5. Oxford
6. Pequest
7. Perth Amboy
8. Riegelsville (Pa.)
9. South Amboy
10. Stanhope
11. Weymouth
12. Wharton

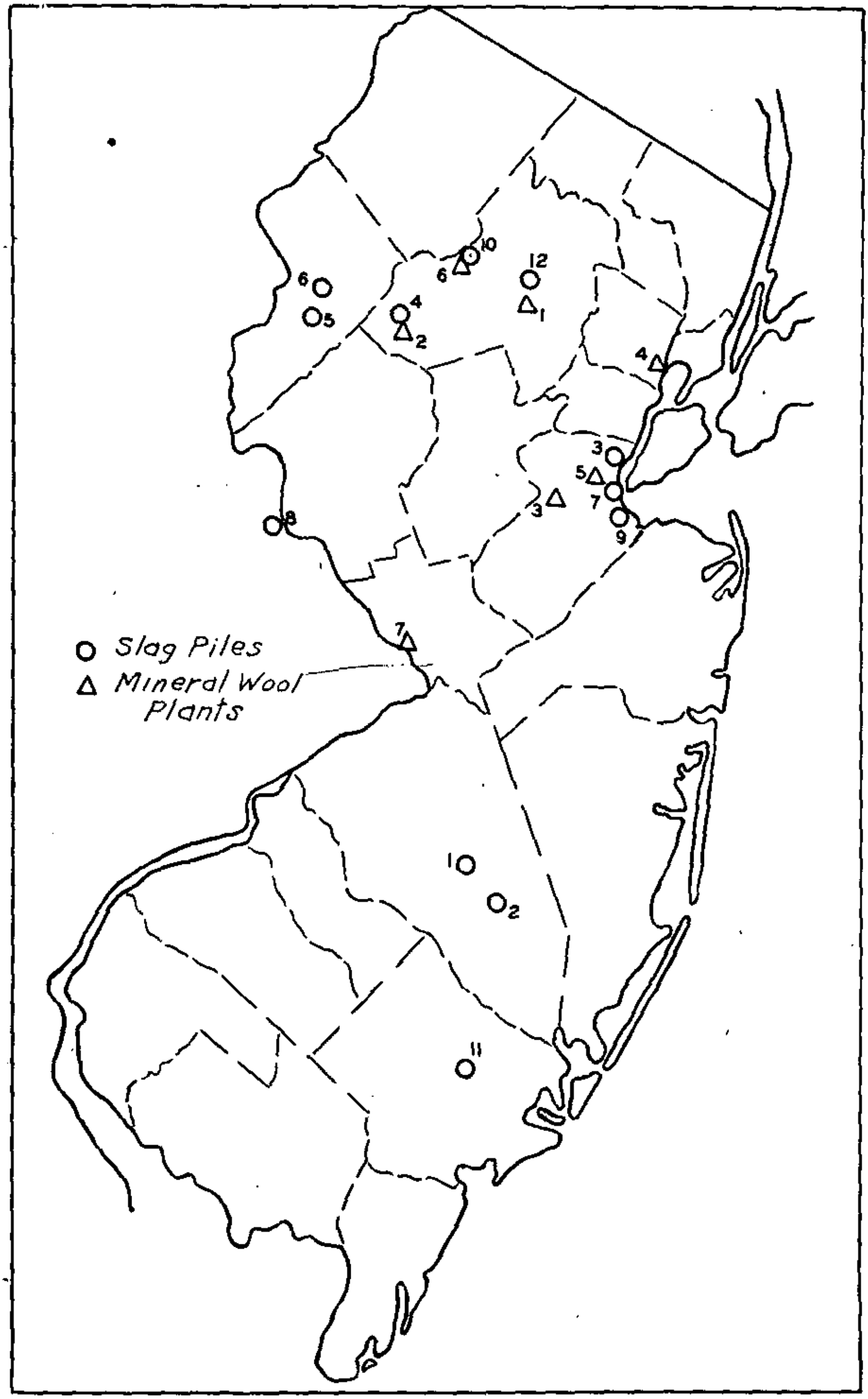

FIGURE 11. Location of the mineral wool plants and slag piles in New Jersey.

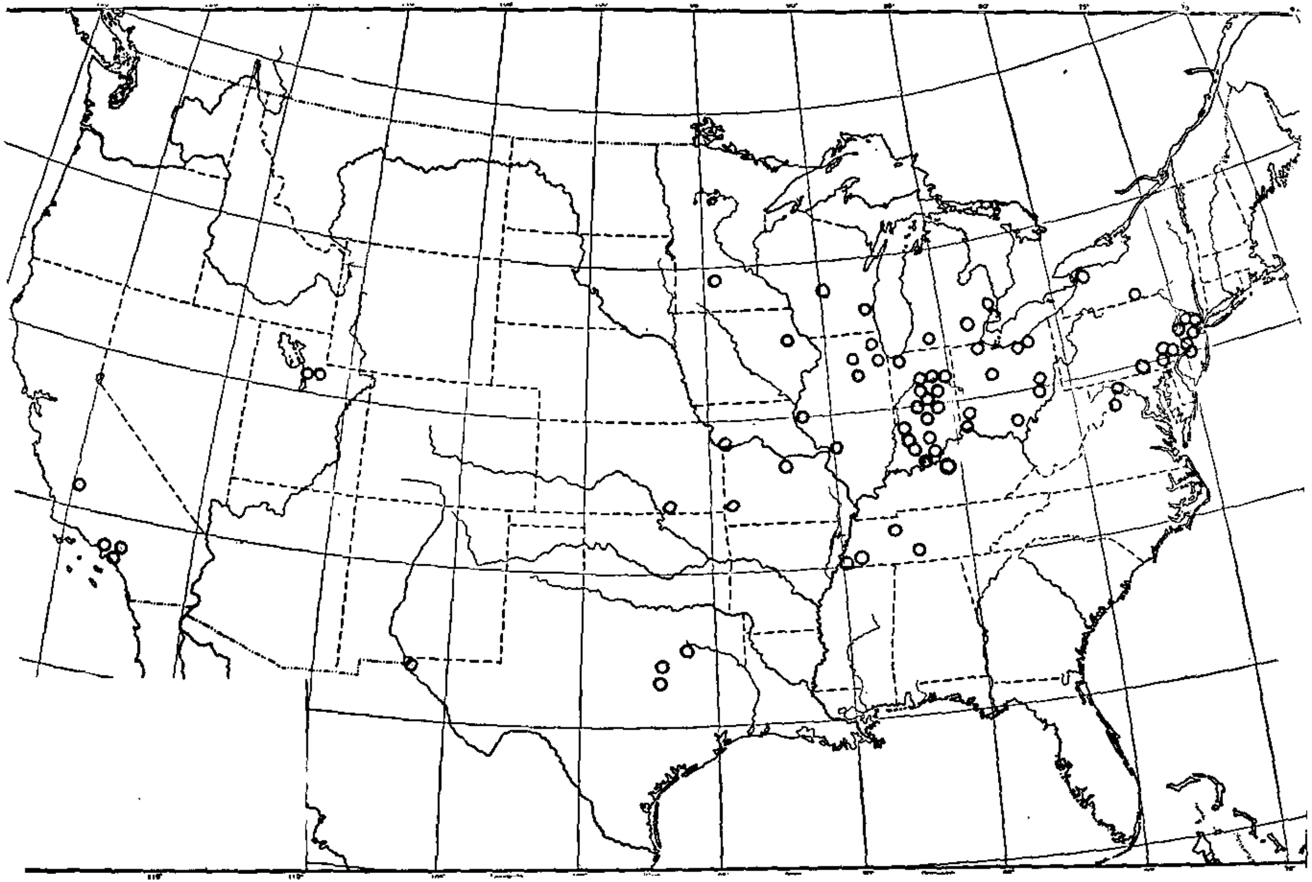

FIGURE 12. Distribution of the mineral wool plants in the United States.