

TALC, AND THE TALC DEPOSITS OF VERMONT.

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INTRODUCTION.

The purpose of this report is to present, for the information of those engaged in the talc industry, the mineralogical properties and the commercial uses of talc, its occurrence, statistics of production, and other useful knowledge. Furthermore, it has been attempted to describe in detail the talc deposits (but not the soapstone deposits) of the State in their geologic and economic relations and, by means of field studies, chemical analyses, and the microscopic study of many thin sections, to determine as far as possible the origin of these deposits.

The writer wishes here to acknowledge his indebtedness to the officers of the various talc companies in the State for much valuable information and for many courtesies; to the State Geologist for his encouragement and assistance; to Professors J. F. Kemp, A. W. Grabau, and C. P. Berkey, of Columbia University, for their advice; and to Mr. Max Roesler, of New York City, for his aid in the study of several of the thin sections.

The problem of the origin of the talc is admittedly a difficult one and its complete solution has by no means been reached. The writer expects to continue his studies and hopes, in a subsequent report, to reach a final conclusion.

University of Vermont, November, 1914.

THE MINERAL TALC.

The mineral talc, is described by Dana¹ as an acid meta-silicate of magnesium, whose formula may be written $H_2Mg_3Si_4O_{12}$, or $H_2O, 3 MgO, 4 SiO_2$. The theoretical chemical composition calls for 63.5% of silica, 31.7% of magnesia, and 4.8% of water. Talc is a very stable chemical compound, being practically insoluble in hydrochloric acid and giving up its water only at a red heat. It is uncertain whether the mineral crystallizes in the orthorhombic or the monoclinic system. It has perfect basal cleavage, is sectile, flexible but not elastic, has a greasy feel, and a pearly luster on cleavage surfaces. Its hardness in the mineralogical scale is from 1 to 1.5, while its specific gravity is from 2.7 to 2.8. The color of the massive and fibrous varieties varies from pure white to gray to greenish-gray or to dark green, while the foliated varieties afford beautiful sea-green tints. The foliated varieties are translucent while the massive forms are sub-translucent.

VARIETIES.

Foliated talc consists of thin, easily separable laminae. It is ground with difficulty and has no commercial use, but affords beautiful mineralogical specimens. Fibrous talc is pseudomorphous after the anhydrous enstatite or tremolite and, when pure, consists of a network of fine white fibres which gives it a particular value in paper-making. It is, as far as known, restricted in occurrence to St. Lawrence County, New York, where it is known as agalite.²

Regarding the third variety, massive talc, much looseness of nomenclature is found. Steatite, soapstone, potstone and, in Vermont at least, freestone, have been used as synonyms indiscriminately. The last named, while it correctly describes the ease with which talc may be cut, has long been in use as a "quarryman's name for those sandstones that submit readily to tool treatment,"³ and so should not be applied to the mineral under discussion. By soapstone we mean that greenish-gray to dark green, massive form of talc whose interlacing fibrous structure enables it to withstand high temperatures without cracking. It is the variety used for stoves, furnace linings, foot-warmers, and griddles. The other important variety of the mineral, for which the name "massive talc" might well be restricted, has little or no fibrous structure, is white or gray in color (except where stained by impurities) and is either a homogeneous, structureless mass or else has a more or less laminated structure. Associated with the talc is another substance, to which the term "grit" has been

¹ A System of Mineralogy, Dana.

² Genesis of the Talc Deposits of St. Lawrence County, N. Y., C. H. Smythe, School of Mines Quarterly, July, 1896.

³ A Handbook of Rocks, J. F. Kemp.

applied. It will be shown later that this is a mixture of talc and dolomite.

Under the name talc we have therefore to distinguish:

1. Foliated talc.
2. Agalite.
3. Steatite or soapstone.
4. Massive talc.

"French chalk" is a very fine grained, milk-white variety of massive talc used by tailors. "Indurated talc" is an impure, slaty variety, harder than the ordinary. "Talcose slate" is a dark, slaty, argillaceous rock, whose greasy feel is due to the presence of more or less talc.

Commercial talc is also known by various trade names: asbestine, talc clay, verdolite, albarene, etc.—names which of course have no scientific value.

HISTORICAL NOTE.

It is natural that a substance as resistant to heat and so easily wrought should long have been in use by mankind and that references to it should be found in the classic literature.¹ Theophrastus writes of "magnetis" as a stone of silvery lustre, occurring in large masses and easily cut or wrought. From this we get the word magnesia, or oxide of magnesium. Agricola gives as the German synonym for magnetis, "Talck." He mentions its resistance to fire and speaks of it as "lapis scissilis." Other writers derive the word talc from the Arabic "talk," while Androvandus (1648) states that it is of Moorish origin. Caesius ("De Mineralibus," 1636) writes the word in Latin, "talchus," while most other writers of this time write it "talcum." The word "steatitis" occurs in Pliny as the name of a stone resembling fat.

USES.

We may distinguish:

- (1) Sawed or manufactured talc (soapstone).
- (2) Ground talc.

(1) MANUFACTURED TALC.

The North American Indians early recognized the useful properties of talc and fashioned it into cooking utensils, pipes, and ornaments. In the modern industries the heat and acid resistant properties as well as the toughness of the mineral were first made use of in the manufacture of stoves, griddles, furnace linings, mantels, sinks for chemical laboratories, wash tubs, fireless cookers, etc. Soapstone has great dielectric strength, 30,000 to 40,000 volts being required to pierce a half-inch slab. Since

¹ Dana, A System of Mineralogy.

in the variety of the mineral known as steatite or soapstone these properties find their best expression, soapstone quarries were worked before uses for the "massive talc" were found. However, this "massive talc" near the surface appears tougher and harder than deeper down in the earth and the deposits of this variety at Rochester and Moretown were first worked fifty or sixty years ago for foot-warmers, while near Cambridge several houses have fireplaces built of blocks of impure massive talc. The very compact massive talc is also being manufactured into slate pencils, gas tips, insulators, etc.

(2) GROUND TALC.

Mr. J. S. Diller, in the "Mineral Resources of the United States" writes that the most important use of ground talc (meaning generally the non-steatitic varieties) is in the manufacture of paper, in which a white mineral filler has been found necessary in order to render the paper opaque. In the past the mineral kaolin (China clay) has been extensively used but experiments have shown that talc possesses decided advantages over this mineral and it is gradually replacing the clay in the paper industry. In an article¹ compiled by Heinrich Rosenberg, the advantages resulting from the use of talc as a filler are set forth and it is noted that 89% of French talc, 85% of American, and 90 to 95% of the Syrian talc, respectively, are retained by the paper pulp, while only about 35% of kaolin is held. For the best grades of paper the fibrous variety of talc known as "agalite," which, as mentioned before, is confined to St. Lawrence County, New York, is used almost exclusively. The purity and fibrous quality of this variety of talc lends not only whiteness to the product but also much strength and therefore durability. For newspaper, wrapping paper, wall paper, mortar and plaster, etc., the finely ground "massive talc" and "grit talc" are extensively used, while the more coarsely ground material is finding application in various grades of roofing papers.

Ground talc is also being used in the rubber industry, both as a filler and as a dressing for the surface to prevent the material sticking to the moulds.

Many of the cheap grades of cotton cloth are still being filled with talc, the product being of course a sham, easily discovered on washing the fabric. The whitest grades are used extensively in cotton bleacheries. In the past a good deal of the best grades of the mineral has found an unworthy use as a food adulterant, but it is the belief of the authorities at Washington that this practice has almost wholly ceased.

In the modern "talcum powders" the best grades of the American talc are used to some extent but the superior qualities

¹ Translation made by the U. S. Geological Survey. See "Mineral Resources" for 1912.

(whiteness and freedom from grit) of the French and Italian mineral lead to its importation for this purpose and for use in certain medicinal preparations.

Powdered talc is used in the manufacture of paints, especially those waterproof preparations for protecting iron ship bottoms. It is used, further, in electrical insulating material, in dynamite manufacture, in lubricants, in dressing skins, and for boiler and steam-pipe covering. The rather coarsely ground mineral is used in some soap preparations to give them a mildly scouring property.

The American Soapstone Finish Company of Chester Depot manufacture a wall finish preparation which is used for skim coating.

OCCURRENCE AND PRODUCTION.

Talc is a mineral of common occurrence and is mined to a greater or less extent in many parts of the world. The following table, taken from the "Mineral Resources of the United States" for 1912 shows the principal producing countries and the amount, in short tons, produced by each.

	1904.	1906.	1908.	1910.	1912.	1913.
United States*	91,189	120,644	117,644	150,716	159,270	175,833
France†	23,206	29,061	37,053	42,316	†	†
Italy†	7,716	9,624	12,048	13,727	13,580	†
Austria†					†	†
Canada†	840	1,234	1,016	7,112	8,270	12,250
German Empire† (Bavaria)	1,884	2,113	2,424	3,398	3,551	†
India§	19	11	856	274	†	†
Spain†	5,693	3,978	5,214	†	†	†

*Talc and soapstone.

†Talc.

‡Talc, soapstone, and asbestos.

§Soapstone.

¶Statistics not available.

To this list may be added Brazil, China, Japan, Australia, New Zealand, Mexico and Norway.

It will be seen that the United States is far and away the largest producer and that, after her, come France, Italy, Austria, and Canada. The United States imports considerable amounts of talc from these four sources and the growth of the imports is shown by the fact that in 1900 but 79 tons were received, while in 1912, 10,989 tons were admitted. The imports have fluctuated widely, showing:

In 1908	7,429	short tons.
1909	4,417	" "
1910	8,378	" "
1911	7,113	" "
1912	10,989	" "

This fluctuation is probably due to the varying supply and demand and also to tariff legislation. The imports from Europe are wholly of the finest grades of massive talc, which are probably superior to any that are mined in this country.

The following brief notes¹ on foreign occurrence may be of interest.

FRANCE: The principal deposits are in the French Pyrenees, in the Department of Ariege. The deposits at Luzech, about midway between Bordeaux and Marseilles are among the most valuable. "The deposits are large, of excellent quality, free from mica, and of a bluish-white color much appreciated by consumers." The beds are situated in contact with the St. Barthelemy granite and the old schist, about 4½ miles from Luzech. The deposits are operated as quarries. The French production of talc in 1911 was 46,312 tons.

ITALY: The deposits in this country are located in the Italian Alps, at Pinerolo, near Turin. Talc has also been mined in the valley of the Chisone and in the high valleys of Susa and Lauzo. The Italian talc is probably the finest in the world for color and freedom from grit. It brings the highest prices and is mainly used for toilet powders and medicinal purposes. In 1911 Italy produced 15,620 tons, the crude product being valued at the mines at \$7.13 per metric ton, while the finished product had a value of about \$12.00 per metric ton.

AUSTRIA: The mineral comes chiefly from the Province of Styria. Only a limited amount is exported to the United States. The production in 1911 was 13,800 metric tons.

Of the total imports of talc into the United States in 1912, 38% came from Italy, nearly 36% from France, 18% from Canada, and 7% from Austria-Hungary.

While the average value of imported talc is given by the United States Geological Survey as \$10.54 per short ton in 1897, \$13.50 in 1900, \$13.07 in 1908, \$12.71 in 1910, and \$12.38 in 1911, very much higher prices have been paid for the best grades. To illustrate, an American firm contracted in 1906 for a thousand tons at \$40.00 per ton. Talc varies so greatly from its best to its poorest grades that average figures are of small significance.

TALC PRODUCTION IN THE UNITED STATES.

The talc produced in the United States comes mainly from the belt of old metamorphosed rocks which extends from the Gaspé Peninsula of Canada down through the States of Vermont, Massachusetts, Connecticut, New York, New Jersey, Maryland, Pennsylvania, Virginia, and North Carolina, to Georgia. Talc has also been produced to some extent in California and Arkansas,

¹ The Mineral Industry.

while deposits are known in Texas. The following table¹ will show the increase in production since 1880. As stated before, the fibrous talc of New York (agalite) is unique. Hence the production in "all other states" will show the variation in production of the varieties of the mineral with which this report is concerned. The figures represent short tons.

	New York.	Value.	All other States.	Value.	Total tons.
1880	4,210	\$ 54,730	8,441	\$ 66,665	12,651
1885	10,000	110,000	10,000	200,000	20,000
1890	41,384	389,196	13,670	252,309	55,024
1895	39,240	370,897	21,495	266,495	60,735
1900	63,500	499,500	27,943	383,541	91,443
1902	71,100	615,350	26,854	525,057	97,954
1904	64,005	507,400	40,134	637,062	104,139
1906	61,672	557,200	58,972	874,356	120,644
1908	70,739	697,380	46,615	703,832	117,354
1910	71,714	728,180	79,006	864,213	150,720
1911	62,030	613,286	81,521	1,032,732	143,551
1912	66,867	.....	92,403	.....	159,270

It will be noted that the total production of talc has increased very rapidly and that the increase of the non-fibrous grades has been considerably greater than that of the fibrous agalite. This is due in part to the increasing number of uses found for the mineral. The average price obtained for the non-fibrous grades was about \$19.00 per ton in 1902 and has since declined to \$11.00 or \$12.00 per ton. The increased production and consequent sharp competition have been largely responsible for the decline in price. In 1902 the 26,854 tons brought on an average \$19.50 per ton. In 1903 the duty on ground talc was increased to 1c per pound. In 1904 the 40,134 tons of non-fibrous mineral averaged \$15.90 per ton, the increased duty having apparently stimulated supply above demand. It is unfortunate for the industry that competition has been so keen, for many of the mills are selling their product at a very small margin of profit.

The present tariff law (Schedule 69, Act of 1913) provides for a duty of fifteen percent, *ad valorem*, on "ground talc, steatite, French chalk, cut, powdered, washed, or pulverized," while "crude and unground talc" are admitted free. Former Acts (1897 and 1909) levied a duty of one cent per pound on "French chalk" and thirty-five percent, *ad valorem*, on "steatite blanks" and "soapstone." The looseness of terms caused much confusion and led to many decisions being handed down, one of them gravely asserting that "French chalk" was not talc at all. The present law is very clear.

¹ Mineral Resources of the United States, U. S. G. S. publication.

PRODUCTION IN THE DIFFERENT STATES.

In 1911 and 1912 the talc producing states, in their order of importance, were:¹ New York, Vermont, Virginia, New Jersey and Pennsylvania, Massachusetts, North Carolina, California and "Other States." The following table shows the marketed production in short tons and the value.

	1912.		1913.		Increase (+) Decrease (—)
	Quantity.	Value.	Quantity.	Value.	
New York	66,867	\$656,270	81,705	\$788,500	+14,838
Vermont	42,413	275,679	45,547	327,375	+ 3,134
Virginia	25,313	576,473	26,437	615,558	+ 1,174
New Jersey and Pennsylvania..	10,400	50,519	11,308	80,780	+ 908
Massachusetts ..	†	†	.....	.....	.....
North Carolina..	3,542	63,304	4,676	48,817	+ 1,134
California	1,169	15,653	952	6,000	— 217
Other States*...	9,566	69,065	5,158	41,067	— 4,408
Total	159,270	\$1,706,963	175,833	\$1,908,097	+16,563

*Includes California, Georgia, Maryland, and Rhode Island, in 1911; Georgia, Maryland, Massachusetts and Rhode Island, in 1912.
†Included in other states.

Analyzing the above figures, we see that New York is far and away the largest producer. As mentioned before, her product is the fibrous agalite, which is ground and largely used for paper-making. Vermont stands second in production. The average price received per short ton of mineral is as follows:

	1911.	1912.
New York	\$ 9.88	\$ 9.81
Vermont	6.78	6.49
Virginia	24.70	22.37
North Carolina	16.09	17.87
Other States	12.00	7.21

It may be noted that the Virginia product is almost wholly soapstone, which is sawed into slabs and sold for laundry tubs, sinks, etc. The North Carolina mineral is a very compact, massive variety which is used for the manufacture of pencils, gas tips, etc., and brings a high price. It is claimed that this variety is as good as the best imported talc.

As already stated, not too much value can be placed on average prices, since talc varies so much from its best to its poorest grades. A good deal of the Vermont mineral brings much more than the average prices shown above. On the other hand, so many new uses have been found for the poorer grades that much of this material, formerly discarded, is now being ground and sold, thus bringing the average down.

¹ Mineral Resources of the United States, 1912.

TALC PRODUCTION IN VERMONT.

In this report the terms, "steatite" or "soapstone," will be restricted to those greenish-gray to dark green varieties, with interlacing, fibrous structure, which are sawed into slabs, etc., while the term "massive talc" will be applied to the light colored, non-fibrous varieties which are ground.

With this distinction, it may be stated that the soapstone deposits of the State were worked long before uses were developed for the massive forms. Thus the soapstone deposits at Athens were worked eighty years ago; the deposits at Perkinsville were quarried and sawed as early as 1850; the old Pilgrim Talc Company worked the soapstone deposit near Stockbridge from 1870 to 1875; the soapstone deposits near Chester Depot have been worked to some extent for the last twenty-five years. In some places the massive variety, rendered harder and more resistant to heat by impurities near the surface, has been worked to a slight extent for foot warmers, as at Rochester and at Moretown on the Deavitt farm. It is stated that the Rochester deposit was worked in 1865 and 1866.

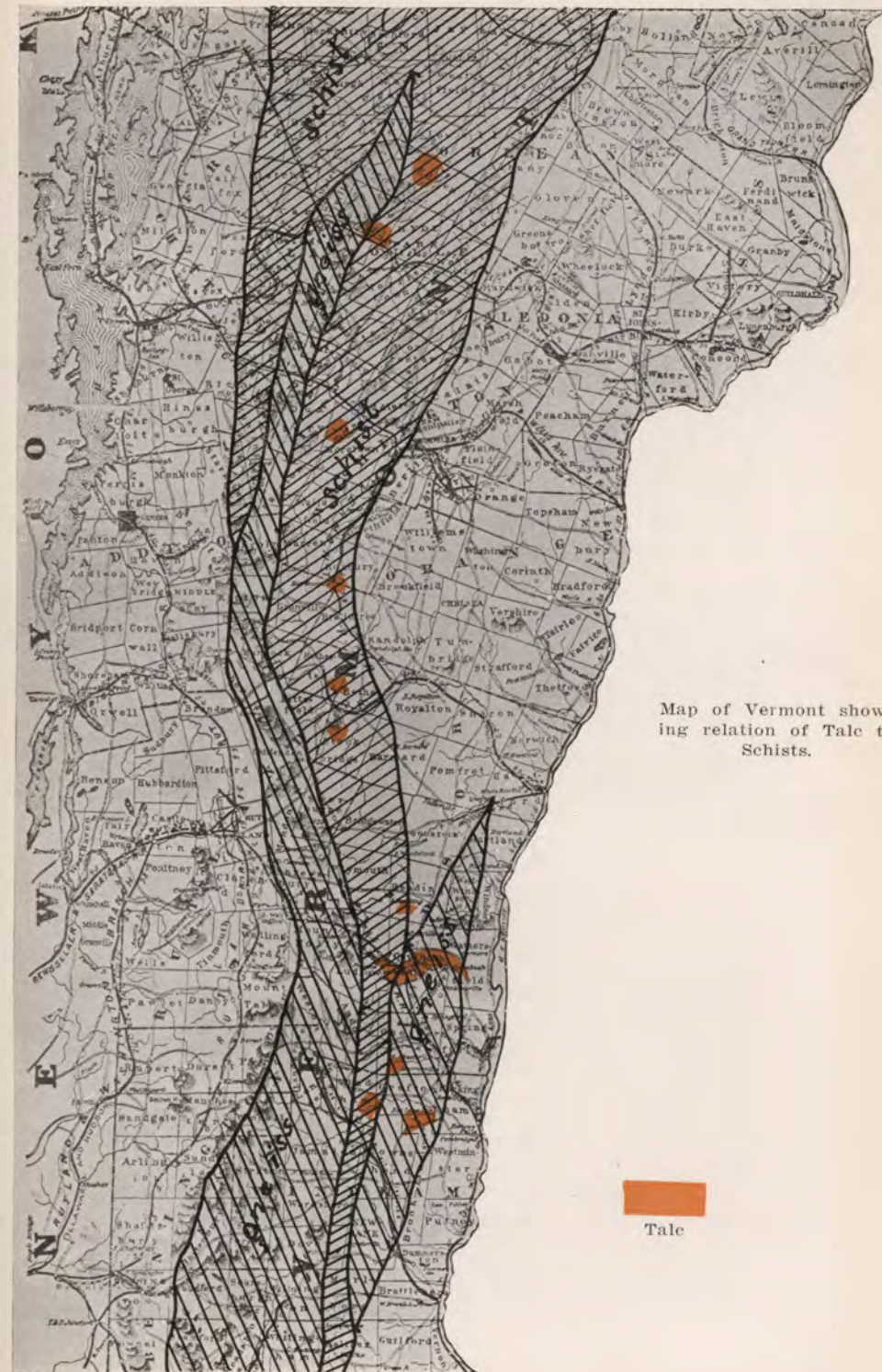
Activity in the mining and grinding of massive talc in Vermont seems to date back to about 1902, when the United States Talc Corporation commenced operations on the Rochester deposits. In 1903 two companies were active in Windsor County, while in 1904 three were at work.

The "Mineral Resources of the United States" gives the production and value of the talc deposits (including all grades) of Vermont, as a separate state, since 1905 as follows:

1.	Short tons.	Value.	(Average per ton).
1905	8,978	\$ 65,525	\$7.29
1906	10,413	101,057	9.70
1907	16,200	82,500	5.09
1908	10,755	99,741	9.27
1909	23,626	120,329	5.09
1910	25,975	136,674	5.26
1911	29,488	200,015	6.78
1912	42,413	275,679	6.49
1913	45,547	327,375	7.18

It will be noted that with the exception of 1908 there has been a steady increase in production, with an exceptionally great increase in 1912. The average price, if the figures be correct, has fluctuated widely. Keen competition, tariff changes, and periods of financial depression have all contributed to this variation. As before stated the low average price is due to the increasing amounts of low grade (grit) talc that are coming on to the market.

It has not been possible to classify the production among the different varieties, but it may be said that the deposits of soap-



Map of Vermont showing relation of Talc to Schists.

stone are being exhausted, at least one mill finding it necessary to import soapstone from Virginia, and that a very large part of the present production is from the massive talc deposits. These deposits are thought to be very widespread and there seems every reason to believe that Vermont will rank as one of the leading producers for many years to come.

GEOLOGICAL CONSIDERATIONS.

The chief structural feature of Vermont is the Green Mountain Range, which has its origin in the Gaspé Peninsula of Canada. The highlands are here known as the Shickshock Mountains. In the southern part of the Province of Quebec they are called the Notre Dame Hills and are the northwestward extension of the Green and White Mountains. The formation crosses Vermont in a generally north-and-south direction and, extending into Massachusetts, forms the Taconic Mountains. This system of crystalline rocks, therefore, constitutes the northern portions of the Appalachian Mountains which, generally following the coast, find their southern extremity in Georgia and Alabama.

The Green Mountain Range, which is about one hundred and fifty miles long, constitutes a great anticline, the axis of which appears as a broken chain of ridges of gneiss, rising to its greatest elevation at Mount Mansfield (4,453 feet) and to lesser heights at Killington Peak, Camel's Hump, and Jay Peak. The position of this gneissic backbone is outlined on the accompanying map. It may be noted here that a smaller area of gneiss occurs in the southeastern part of the State. Lying upon the flanks of the range are beds of metamorphic rocks: marbles, slates, schists, and phyllite.

THE FORMATIONS.

A comprehensive geological survey of the State was undertaken by Edward Hitchcock and his associates. The results of their work were published in 1861 in two volumes, entitled "Report on the Geology of Vermont." By means of thirteen cross-sections, the first near the Massachusetts State line and the last a few miles south of the international boundary, the formations of the State were studied and mapped. Hitchcock's map shows the following sequence from east to west: (1) a belt of "talcose schist" which constitutes a narrow strip following the Connecticut River till near the town of Waterford, where it widens out into a broader area; (2) a bed of "clay slate," extending for three-fourths of the length of the State with an extreme width of about four miles; (3) an area of "calciferous-mica-schist" which extends the whole length of the State. In this formation are located most of the granite areas. Professor C. H. Richardson has studied this area¹

¹ The Terranes of Orange County, Vt. Report of the Vermont State Geologist, 1901-1902.

and divided it into a limestone member on the west, which he called the Washington limestone (later changing the name to Waits River limestone), and a schist area on the east, which he named the Bradford schist (later changing this designation to Vershire schist). He states: "The widest part of the limestone belt is in Canada. Its greatest breadth in Vermont is in the northern part of the State, where it approximates forty miles. It narrows towards the south and in the town of Hartford it is divided by the intervention of the Bradford (Vershire) schist. The western member terminates suddenly in the southern part of Windsor County, in Cavendish, while the eastern member crosses Massachusetts and is known as the "Conway schist." (4) A second belt of "clay slate" which forms the western boundary of the "calciferous-mica-schist." It is known in Canada and extends to about the middle of Vermont, where it dies out. It follows a sinuous course and is about three or four miles wide at the maximum. Richardson has named this formation the Memphremagog slates. (5) A great central area of "talcose schist" (shown on the accompanying map, Plate LXXV) which is nearly divided into two parts by the "gneissic backbone." The formation extends the entire length of the State, narrowing to two and a half miles in width at the Massachusetts boundary. All the talc deposits of the State are found in this great "talcose-schist" area. All but one or two are found on the eastern side of the "gneissic backbone." (6) An area of "talcose-conglomerate" bounds the western part of the "talcose schist" belt and is succeeded by the "Georgia slates." (7) The marble area, which lies in a great syncline, west of the central gneiss belt. (8) The commercial slate area of the State, which lies in the southwestern part. There are other minor areas which do not concern the present discussion. It may be stated that most of these rock names have been discarded. The "clay slates" are probably shales, the "calciferous-mica-schist" has been called by Daly an ottrelite schist, while in the present article, "talcose schist" has been renamed quartz-sericite-schist.

SECTION BETWEEN WALLINGFORD AND PLYMOUTH.

In the southern part of the State, on opposite sides of the mountain range, lie the towns of Wallingford and Plymouth, about ten miles apart. Hitchcock studied the section¹ and showed the following relationships. (Fig. 35).

"The base of the section is the sea level and the heights are laid off from the same scale as the horizontal distance. This makes the Green Mountains (1,390 feet above the ocean at Mount Holly) appear of very diminutive height. . . . In the section, *ab* is the present surface, 'a' being at Wallingford, 'b' at Plymouth.

¹ Report on the Geology of Vermont, Vol. I, p. 37.

AB is 'talcose conglomerate';¹ BC, mainly gneiss with some schist and at least three beds of limestone; CD is gneiss with several trap dikes at 'H,' the summit level of the railroad; DE is gneiss, with



FIGURE 35.

'talcose schist,' and with at least two beds of limestone and several thin beds of quartz; EF, 'talcose conglomerate'; M, the relative height of Mount Mansfield." From the general correspondence of the beds and of the dips, Hitchcock concluded: (1) That the gneiss of the Green Mountains forms a great anticlinal fold; (2) that gneiss underlies the "talcose schist," the limestone, the quartz, and the conglomerate; (3) that these latter rocks once extended over the gneiss but have been eroded; (4) that the amount of erosion at Mount Holly cannot have been less than eight thousand feet, or nearly six times the present height of the mountain at the summit level of the railroad.

Dr. J. E. Wolff has studied the formations in the limestone area of the west-central part of the State,² his section extending from the Green Mountain gneiss westward through the Rutland, Center Rutland, and West Rutland valleys to the Taconic Range. (Fig. 36). He states: "In the high, abrupt, frontal range of the Green Mountains there occur crystalline schists, often gneissic, which pass eastward into the gneissic rocks proper of the Green



FIGURE 36.

Mountains. These schists contain beds of true conglomerate, with a metamorphosed crystalline cement (presumably Hitchcock's 'talcose conglomerate'), and pass westward, on the slope, into the quartzite of Vermont, which the discoveries of C. D. Walcott prove to be of lower Cambrian age (Olenellus zone). This is succeeded by a broad belt of limestone occupying the Rutland Valley; next, in Pine Hill, we find a partial repetition of the 'frontal' range, namely, massive quartzite underlain by a transitional gneissic series; then, on the west crest of the hill, a band of black schist in contact with a band of crystalline limestone

¹ Defined as "a coarse conglomerate, cemented with talcose grit."

² Bulletin of the Geological Society of America, 1891, p. 331.

which occupies the second, or Center Rutland Valley. The narrow ridge west of this valley is again formed by black schists, succeeded by a third band of crystalline limestone in the West Rutland Valley and finally, black and greenish schists form the slopes of the Taconic Range."

Wolff showed that, at its western edge, the limestone lies conformably in a trough of the quartzite, which dies out northward. The quartzite is about one thousand feet thick. Wolff and Foerste have shown that this limestone at its base is of lower Cambrian age. It is probable that all three beds represent the same formation, having been separated by folding. Augustus Wing showed that the beds of the West Rutland Valley were of Lower Ordovician age and Wolff and Foerste showed that the limestones of the Center Rutland and Tinmouth Valleys should be attributed to the same horizon. The limestones, about one thousand feet thick, are better known as the Stockbridge limestones. It is thus seen that we have in this section about a thousand feet of quartzite separated from the underlying schists by a conglomerate bed, and passing up, conformably, into a limestone of Lower Cambrian age. This passes up, disconformably, into the Lower Ordovician horizon. We have here, therefore, a hiatus, the Middle Cambrian being cut out by erosion.

Brainerd and Seeley have worked on the stratigraphy of Shoreham and have found there Beekmantown limestone (Ordovician) resting conformably on the Potsdam sandstone (Upper Cambrian). They report 1,151 feet of the sandstone, of which only the upper 251 feet are fossiliferous. This would indicate that the sands were accumulated at an earlier period and that the advancing Potsdam sea reworked only the upper portion.

The most complete section thus far discovered in Vermont is in Georgia and in Highgate Springs, Franklin County. The stratigraphy here, as everywhere else in the State, has been much obscured by faulting and has been much disputed by early writers on geology: Emmons, Barrande, and Logan. Dr. C. D. Walcott has given the Georgia formation close study.¹ He shows that the schists and quartzites of the southern part of the State are not exposed here. The formation "consists, as seen at the base, of a great thickness of limestones that passes, in its upper portions, into an arenaceous, magnesian limestone, which is overlain by a belt of arenaceous-argillaceous shales (the Georgia 'slates'), and this, by a great thickness of purer argillaceous shale that, higher up, carries a brecciated limestone conglomerate and lenticular masses of sandstone and limestone." This Georgia formation contains fossils of Lower Cambrian and Middle Cambrian age. The formation is overlain, conformably, on the west, near the lake shore, by the Hudson River series, of Ordovician age.

¹ Bulletin of the U. S. G. S. Nos. 24-30, 1885-86.

OTHER STRATIGRAPHIC RELATIONSHIPS.

In the northern part of the State, in the adjoining towns of Eden (Lamoille Co.) and Lowell (Orleans Co.), is an important area of chrysotile (commonly called asbestos) which lies in the belt of "talcose schist." The deposit is undoubtedly a continuation of the Thetford chrysotile formation of Canada, the schists of which are assigned by the Canadian Geological Survey to the Cambrian. It is not unlikely that they belong to the Lower Cambrian, equivalent therefore to the schists of the southern part of Vermont.

Mr. M. F. Marsters has reported on the Vermont chrysotile deposits.¹

Prof. B. K. Emerson² has studied the schists of Windham County, Vermont, and Old Hampshire County, Massachusetts, and considers them Ordovician (in the modern terminology) or possibly Cambrian in age.

Prof. C. H. Hitchcock, formerly of Dartmouth College, and Prof. C. H. Richardson,³ of Syracuse University, have studied the formations in Irasburg and Craftsbury which lie in the slate and "talcose schist" areas in the northern part of the State. Prof. Hitchcock considers the formations to be pre-Cambrian, while Richardson states that the "finding in this series of undivided metamorphics of many beds of Upper Cambrian quartzite has led the author to place this group definitely as Cambrian." In the Waits River limestone, which it will be recalled forms the western part of the "calciferous-mica-schist" belt, Richardson has found crushed graptolites (*diplograptus* and *climacograptus*) which fix the age of the limestone as Ordovician.

Regarding the slates of this area (which are really shales and not the metamorphic roofing slates of southwestern Vermont), which Richardson has named Memphremagog, Richardson states that they are more or less interstratified with the limestone. They would thus appear to be of the same age as the limestone. Furthermore, the Memphremagog slates are in all probability the southern extension of the graptolitic slates of Canada.

Richardson states that there is an erosional unconformity between this Ordovician series (Lower Trenton) of limestones and slates and the adjoining "talcose schists." This would argue a Cambrian age for the schists. Furthermore, these schists extend, with like lithographic character, into Canada, where Upper Cambrian fossils establish their age.

Dr. T. Nelson Dale has discussed very exhaustively the granite areas of Vermont⁴ which lie almost wholly in the belt of "calciferous-mica-schist." In the granite areas of Barre, Dr.

¹ Petrography of Asbestos Deposits of Belvidere Mt., G. S. A., Vol. 16.

² Mon. XXIV, U. S. G. S., pp. 115, 116.

³ Report Vermont State Geologist, 1911-12.

⁴ Bulletin 313, U. S. G. S., 1907.

Dale brings out several points of interest. He notes that the schists contain beds of quartzite limestone, which clearly show their sedimentary origin. He notes the difficulties in accurately fixing the age of the formations and is inclined to ascribe, provisionally, the schists and slates of central and eastern Vermont to the Ordovician. He notes the frequent inclusions of schist in the granite, thus showing the later age of the intrusive.

Prof. R. A. Daly has worked on the geology of Ascutney Mountain,¹ which lies in the towns of Windsor and East Windsor, in the "calciferous-mica-schist" belt. Basing his opinion on Richardson's results and inferences regarding this belt elsewhere, Daly regards the schists of this region as of Trenton or pre-Trenton age, while the intrusives are of much later (post-Carbonic or pre-Cretaceous) age.

Regarding later formations, Dr. G. H. Perkins states² that "there is a very small area in the extreme southern part of the State, in Vernon, which has been usually regarded as Silurian and another larger area near Owls Head, in Canada, which is Devonian. That there are other Devonian areas wholly within the State is very probable. Indeed, if Dr. Hitchcock's conclusions are correct, we have in Springfield and Charleston considerable areas of altered Devonian strata. No undoubted Devonian fossils have been found within the limits of Vermont."

The small isolated area of Tertiary represented by the Brandon lignites has been fully described by Dr. Perkins.³

From the above summary it is seen that there is general agreement that the metamorphic areas of the State, with very few exceptions, are of not later than Ordovician age, but that there is much uncertainty regarding their exact age. When it is remembered that these areas are for the most part covered with accumulations of glacial drift, that much folding and faulting have taken place, and that metamorphism has practically wholly obliterated all traces of organic life from a great part of the schist areas, this uncertainty is not to be wondered at. As Dr. Dale has shown for the schist areas around Barre, this report will point out that the "talcose schist" areas of the State are of undoubted sedimentary origin. It must be postulated that these enormous deposits of sediment were derived from the old land mass, called Appalachia, without which it is impossible to explain the sedimentary deposits of the Palaeozoic which extend over the eastern portions of the continent. It is generally agreed that the folding which resulted in the formation of the Green Mountain Range came at the close of the Ordovician and that this folding was repeated by the Palaeozoic revolution. Other periods of folding may also have taken place. From Hitchcock's cross sections it is

¹ Bulletin 209, U. S. G. S., 1903.

² Report of Vermont State Geologist, 1912-13.

³ Report of Vermont State Geologist, 1903-04 and 1905-06.

seen that the Vermont sediments were folded into a series of generally north-and-south-running anticlines and synclines, though, owing to the lack of "competence" of the strata, many departures from an orderly sequence are seen. Prof. C. H. Hitchcock has attempted to map these "principal axial lines in New Hampshire and Vermont."¹

As one goes about the State one is impressed with the irregularity of the gneissic and schistose structure of the hills and ridges. The rocks are bent and twisted, with many lenticular inclusions of quartz, and present an appearance of having been highly compressed while in a plastic condition. It has been noted that an enormous time interval of erosion has elapsed since Vermont land emerged from the sea—an erosion so great that Hitchcock calculated that Mt. Holly has been reduced from a height of at least 8,000 feet to its present elevation of 1,400 feet. We have, therefore, to deal with a formation that was once buried under many thousand feet of strata. According to modern theories of metamorphism, as enunciated by Van Hise, this present land surface was metamorphosed deep down in what he calls the "zone of flowage," where, under the influence of heat and pressure and probably only a small amount of water, the (probably arkose) sediments were subjected to a recrystallizing process. This, dissolving the particles of minerals under strain, and depositing them anew where the strain was lessened, or recombining the elements into other mineralogic species, produced the laminated rocks which we call schists and gneisses.

In these areas of so-called "talcose schist," talc was produced by some metamorphic process acting upon either some igneously intruded rock or upon a sedimentary deposit. The problem is, therefore, by studying these talc deposits, to determine their origin.

THE "TALCOSE SCHIST."

As stated before, the talc deposits of the State lie wholly in a belt of metamorphosed schistose or gneissoid rocks to which Hitchcock gave the name "talcose schists." He realized that this was a misnomer, for analyses by G. F. Barker² showed from a trace to 1.98% magnesia. Still, as the great belt of schist extending from Canada to Alabama was at that time known as the "talcose schists," he retained the name in order to avoid confusion.

Dr. T. Sterry Hunt was among the first to study these rocks as they occurred in Canada, and to decide that they were derived from slates. He also brought out the fact that the adjective, talcose, was unwarranted, his analysis of a sample from Saint Marie, Quebec, showing the following:

¹ Geology of New Hampshire, Vol. II, p. 672.

² Report on the Geology of Vermont, Vol. 2, p. 503.

Silica	66.70%
Alumina	16.20
Peroxide of iron	6.90
Lime .....	.67
Magnesia	2.75
Alkalies (by difference)	3.68
Water	3.10
	<hr/> 100.00

For the present investigation, a sample of the schist from Rochester, Windsor County, was analyzed. The sample was taken just east of the Williams mine, the largest talc working in the State.

The analysis gave the following results:

Silica	63.60%
Alumina	16.54
Ferric oxide	3.01
Ferrous oxide	3.88
Magnesia	2.05
Lime	trace
Potassium oxide	5.52
Sodium oxide .....	.48
Manganese oxide .....	.21
Titanium oxide .....	.61
Sulphur trioxide .....	.58
Loss on ignition	3.73
	<hr/> 99.21

The analysis agrees very well with Dr. Hunt's, the greatest difference being in the greater amount of alkalies. It is seen that the schists maintain their chemical character very closely.

A microscopic examination of the schist shows unaltered orthoclase, and quartz (the latter largely in excess), sericite, biotite, magnetite, graphite, titanite and pyrite (in small amounts) and considerable chlorite. There are no "soda minerals" and the sodium must therefore be considered a replacement of potash. No manganese-containing minerals are discernible, but the schists all over the State invariably give a reaction for manganese, which is thought to represent the remains of ferro-magnesium minerals. All the titanium is present as titanite (CaO , TiO_2 , SiO_2), hence the determination of the lime is in error. The amount necessary to combine with the .61% of titanium oxide is .427, and therefore the analysis may be corrected by this amount. The "loss on ignition" of course represents not only the water but also the graphite present in the sample.

With so many mineral constituents containing common ingredients a natural recasting of the analysis to represent percents of the constituents would be impossible, while a calculation to certain types or "norms" would add nothing of value to the problem. The chemical composition points clearly to the sedimentary origin of the schist, a conclusion which is strengthened by the

finding of primary calcite in the "calciferous-mica-schist" of Barre, as already noted.

Since the material is available, it may be of interest to compare these figures with the analysis of a sample of the Manhattan schists of New York City. This sample is described as a "gray gneissoid variety from Shaft No. 18, of the Catskill aqueduct tunnel." The analysis was made by Dr. Charles R. Fetteke, of the Carnegie Technical School, Pittsburg.

Silica	68.51%
Alumina	15.68
Ferric oxide .....	.71
Ferrous oxide	2.32
Magnesia	1.42
Lime	3.83
Potassium oxide	2.49
Sodium oxide	4.62
Titanium oxide .....	.58
Water .....	.58
	<hr/> 100.73

The chief points of difference between this analysis and that of the Rochester schist is in the smaller amount of iron oxide and the larger content of lime. Unfortunately the microscopic analysis of the Manhattan schist is not available. It may be stated, however, that the Manhattan schists are considered to be of sedimentary origin.

Schists have been examined from Waterville, Lamoille County, in the northern part of the State, to Windham, Windham County, in the southern portion. The talc deposits at Zoar, Mass., have also been visited and the country rock investigated.

The typical "talcose schists" are brownish-gray, lusterless, much folded and contorted, laminated rocks, which present the same general appearance throughout the schist belt. They are generally iron stained. In places they present the slaty appearance of a phyllite, while again they are more or less graphitic. That their acid constituent is in excess is shown by the frequent lenticular quartz inclusions and by the numerous quartz outcrops.

MICROSCOPIC EXAMINATION.

Thin sections were prepared representing the schists, from north to south, at Waterville, Cambridge, Johnson, Moretown, Waitsfield, Rochester, Perkinsville, and Windham, Vermont; and Zoar, Massachusetts. The Perkinsville sample was taken from the vicinity of the soapstone deposits, which lie, not in the belt of "talcose schist," but in the area of "calciferous-mica-schist" and gneiss, in the southeastern part of the State. Since this investigation was not concerned primarily with the schists, only a single slide was ground from each locality, as a rule, and

so the results of the microscopic examination will give chiefly an idea of the schists as a whole. (Plate LXXVI, A).

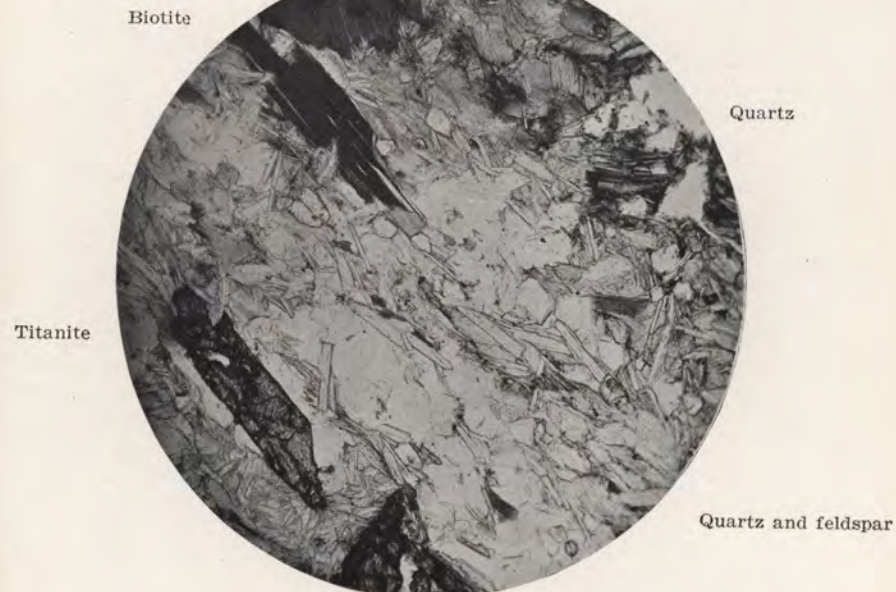
Microscopically, the rocks are seen to consist of grains of orthoclase and quartz, of varying size and irregular outline, with the quartz largely in excess of the orthoclase. The remarkable feature of the feldspar is its freshness, no alternation to kaolin or sericite being apparent on the surfaces of the grains. But in places, between the grains, are seen single rods of secondary muscovite (sericite); while in other parts of the sections there have been developed considerable areas of sericite which have almost entirely replaced the quartz and feldspar grains. By polarized light the sericite presents a brilliant appearance of yellow, red, and purplish rods, fibres and flakes; some straight, some curved, but all showing a general elongation in the direction of the schistosity. The graphite is seen in generally parallel streaks conforming to the general direction. In some of the slides there are only one or two such streaks, while in others, notably those from Moretown, the grains present a banded appearance and are associated with talc. The Moretown slides in which this talc is best shown represent a contact between the schist and the so-called "black-wall," which will be described later. Talc is also seen in a similar contact at Rochester. The slides disclose, further, small amounts of magnetite, varying quantities of biotite, and now and then a stray crystal of tourmaline. Titanite is generally present in small amount and is seen in its typically wedge-shaped, stubby rods, conforming to the direction of the schistosity. Patches of chlorite in all the slides from the "talcose schist" belt, testify to the former presence of a ferro-magnesian mineral. A good deal of iron stain is seen in all the slides and in many cases, where the little rods of sericite are lacking, it forms a cement between the grains of quartz and feldspar. In the section from Windham an intergrowth of garnet and quartz is noted, while in one or two slides a few fine needles of apatite are in evidence.

In the slide of the Perkinsville schist, outside of the "talcose schist" belt, there is a larger development of the constituent minerals, and a considerable amount of microcline is seen. The muscovite forms relatively large, well-cleaved patches and the biotite is present in larger flakes. Crystal terminations are, however, wanting and there is no evidence of a sequence of crystallization. Very little titanite and only a few specks of magnetite are to be found, while there is no graphite and no chlorite.

At Zoar we meet, for the first time, a hornblende schist, whose constituents are hornblende, augite, quartz, orthoclase, and a little magnetite.

Judging as much as may be from one or two sections at each locality, we may say that orthoclase occurs in largest amount in the Waterville region and at Perkinsville; that graphitic schists seem to be most prominent at Waterville, Johnson, Moretown,

PLATE LXXVI.



X 45
A. QUARTZ-SERICITE SCHIST.



X 45 (Polarized light)
B. EAST JOHNSON SERPENTINE AND TALC.

and Waitsfield (field observations bear out this fact); that biotite, titanite, and sericite appear in largest development at Rochester; and that there is much less evidence of a former ferromagnesian mineral in the gneiss area at Perkinsville than in the "talcose schist" belt.

CONCLUSIONS REGARDING THE ORIGIN OF THE "TALCOSE SCHISTS."

If we take into account the tremendous amount of erosion to which the state has been subjected, the discovery of primary calcite in the schists at Barre, the chemical composition (high silica, and alumina, low magnesia and lower lime), and the observation that titanite is a common constituent of sediments, the conclusion at present seems warranted that the gneiss or schist of the great belt in which the talc occurs has been derived from an arkose sediment, by a process of regional metamorphism deep down in the zone of flowage. Since the rocks present more the appearance of a schist than of a gneiss, the adjective, "talcose," will be dropped and the rocks will be called "quartz-sericite-schist" in the following discussion.

THE TALC DEPOSITS.

In the belt of sericite-schist, talc deposits are known from Canada to Massachusetts. Some prospects have also been discovered in Connecticut.

In Canada¹ numerous deposits are found associated with the so-called "Serpentine Belt" from the Vermont boundary northwards to the Chaudiere River.

In Vermont, from north to south, deposits are known in the following towns. Those marked "*" have been worked but are now idle, while those marked "**" are being actively mined.

North Troy,
Berkshire Center,
Berkshire, southwest part,
Enosburg, southeast corner,
Belvidere, northwest part, lenses in the serpentine,²
Waterville, northern part,*
Cambridge, northeast part in the gneiss area,
Stowe, near Sterling Pond,
Johnson, southwest part,**
East Johnson,**
Moretown, northwest corner ** associated with serpentine,
Moretown, near its junction with Fayston and Waitsfield,*
Warren, north and south center,
Roxbury,
East Granville,**
Braintree, several prospects,
Rochester, several deposits,**

¹ Communication from Dr. R. W. Brock.

² Marsters, Asbestos Deposits of Belvidere Mountain, p. 428.

Bethel,
 Pittsfield,*
 Stockbridge, northwest part,*
 Plymouth, southeast part,
 Reading, southwest corner,*
 Cavendish, western part,
 Gassetts,
 Chester, southwest part,**
 Chester, northwest part,**
 Andover,
 Windham, central part,**
 Windham, farther south,
 Marlboro, northern part.

Prospects have also recently been reported around Randolph. In Massachusetts there are several deposits in the town of Rowe. The deposit of the Foliated Talc Company is being actively worked, while that of the Massachusetts Talc Company is idle. These deposits are in line with the Vermont beds and no doubt belong to the same formation.

It may be mentioned here that the deposits of steatite or soapstone occur in the southeastern part of the State at Perkinsville, Athens, and Grafton, and seem to lie in the small area of gneiss seen on the map. A continuation of this soapstone belt is found at Frankestown, N. H. It is therefore seen that the formations of soapstone and massive talc are quite distinct.

GENERAL FIELD RELATIONSHIPS.

The talc deposits consist of irregular, lenticular masses, of widely varying length and breadth and of unknown depth, except in the case of the Johnson lens. The strike of these lenses is generally north and south and the dip is 60 or 70 degrees, sometimes to the east, sometimes to the west. Generally speaking these deposits form a chain running north and south through the schist belt. At times they overlap, while at others the outcrops are some miles apart and lie off the main line, as though faulted. The deposits lie almost wholly in the great central belt of sericite schist.

Where typically developed, the talc deposits consist of three parts: (1) A relatively wide central core of a mineral aggregate which is locally called "grit." This material is harder than the talc and has less "slip." It is white to gray in color and has a crystalline habit, often resembling dolomite. It merges gradually into the talc.

(2) A relatively narrow band of talc lying on either side of the "grit." This varies much in structure and quality. Near the surface it is at times very compact and impure, so that it may be cut into blocks and used for foot-warmers, fire-place linings, etc. This massive variety becomes purer with increasing depth and forms the most desirable quality of commercial talc. In other places the mineral is white and foliated, while again it is present

as the beautiful green foliated talc, more valuable in mineralogical cabinets than for commercial purposes. Both the talc and the grit contain more or less disseminated pyrite or pyrrhotite, while in the southcentral part of the State considerable chalcopryrite is developed. In places the talc contains a good deal of actinolite and in the mines whose mineral is ground and "bolted" the presence of this needle-like substance renders the talc unfit for milling, since it destroys the silk bolting cloth. In some of the deposits quite a little chrysotile is developed, generally near the outer edge of the talc.

(3) A narrow border of chloritic schist, which is known as "black wall." The talc lies against this schist but easily cleaves away from it. There is often seen a good deal of "slickensides"¹ between the talc and the black wall. This black wall varies much in thickness, in some places merging in a distance of only a few inches into the country rock, while in others it is found in considerable thickness and is studded with pyrite crystals, hornblende, etc.

SPECIAL LOCALITY RELATIONSHIPS.

QUEBEC.

"In Canada numerous talc deposits are found associated with the 'Serpentine Belt,' from the Vermont boundary northwards to the Chaudiere River. 'The Highlands' of Notre Dame Hills consist of three parallel, anticlinal ridges running in a northeasterly direction, with two broad intervening basins, each of which has a width of about 25 miles. The ridges are usually distinguished as the Sutton, Sherbrooke or Stoke, and Lake Megantic anticlines. . . . Closely bordering the southeast side of the Sutton ridge is a series of basic intrusive rocks. These rocks constitute the serpentine belt and contain the deposits of asbestos and chrome iron ore. They extend from the Vermont boundary line with little interruption northeasterly to the vicinity of the Chaudiere River. Representatives of this series of rocks appear at frequent intervals from Georgia to Newfoundland. In Quebec they consist of peridotite and serpentine, pyroxenite, gabbro, diabase, porphyrite, hornblende, granite, and aplite, all of which are regarded as differentiates of a single magma. . . . In the Thetford series, serpentine forms the country rock of all the mines and, with less altered peridotite, makes up many of the larger hills in the mining district. . . . The rocks of the Thetford series are obviously intrusive in their relations to the enclosing sediments. . . . The alteration of the sediments is sometimes shown by a hardening of a band near the contact, producing a hornstone rim. . . . The peridotite, pyroxenite, gabbro and diabase form a continuous

¹ More or less polished surfaces produced by the rubbing of two surfaces upon each other. They are caused by faulting, fracturing, etc.

series, passing by gradual transition from one variety to another in the order named. . . . In general, peridotite, or the serpentine derived from it, and diabase form the larger portion of a rock mass. At the other edge, the diabase, in places, passes into a hornblende porphyrite, and this occasionally into a hornblende granite, or aplite. . . . The minerals of economic importance that have been found in the serpentine belt are asbestos, chrome iron ore, talc, antimony, copper, and platinum. . . . It is difficult, and often impossible to distinguish peridotite and serpentine in hand specimens. In the field and in mining operations they are collectively called serpentine. The peridotite is composed of olivine, a small amount of pyroxene, and a little chromite and magnetite. The serpentine is merely an altered phase of the peridotite. The mineral serpentine is derived from olivine by hydration accompanied by loss of the iron content. Pyroxene may also alter to serpentine, but it changes less readily than olivine, having originally more silica in its composition, and more frequently alters to soapstone or talc. The olivine is sometimes completely altered to serpentine."¹

The largest talc deposit in Quebec is situated in Bolton Township. It is said to be a hundred feet long, about 20 feet wide at one end, and 60 feet at the other. Several other prospects are also mentioned.

BELVIDERE.

In Vermont, talc is found in the serpentine area which lies on Mount Belvidere, in the adjoining townships of Eden, Lamoille County, and Lowell, Orleans County. This area lies in the belt of sericitic schist. Mr. Vernon Freeman Marsters has studied the petrography of this area² and found that the associated rocks are schist, amphibolite, and serpentine. The main part of the serpentine deposit was found to be a fine-grained light grayish-green rock, sometimes exhibiting a tendency to become talcose. A number of talc-bearing lenses were found in which the talc was moderately pure. Marsters believed that the igneous contact found between the amphibolite and the serpentine furnished unmistakable proof of the intrusive origin of the rock from which the serpentine had been derived. The metamorphism of this primary rock had been so complete, however, that little idea of its character could be obtained.

WATERVILLE.

On the Curtis farm at North Waterville, Lamoille County, a deposit was worked for some years by the American Mineral Co. The marketing of the talc involved a haulage of eight or

¹ Robert Harvie's summary of J. A. Dresser's reports in the Canadian Geological Survey for 1907, 1909, and 1910.

² Bull. G. S. A. 16, pp. 419-446.

nine miles to the North Cambridge Railroad Station and the venture did not prove successful. The mine was full of water when visited, so that only a superficial examination was possible. The deposit was mined partly by an open cut and partly by a shaft. The strike of the deposit is a little east of north and the dip is easterly. Its length is over 200 feet while its width between walls is about 75 feet. The talc at the surface is compact and impure and has been sawed into blocks. The material found around the grinding machines indicates both talc and grit of good quality. Large masses of actinolite and some chrysotile were found on the dump.

JOHNSON.

The American Mineral Company, on abandoning its mine at Waterville, moved to Johnson and opened up a small talc deposit there in 1906. The deposit is at the base of French Hill within a stone's throw of the St. Johnsbury and Lake Champlain Railroad, so that the marketing of the product is very cheap. The deposit is a lens of mineral whose strike is approximately north-east and whose dip is about 65 degrees westerly. The length of the lens is 100 feet on the surface, its depth, measured on the foot wall, is about 200 feet, while the maximum width is about 60 feet. The lens has narrowed along both axes with increasing depth, till at the south end the east wall is said to bend under the deposit and form the west wall. At the north end of the mine, however, the bottom of the lens was not reached, the mine having been abandoned when the deposit became too narrow to permit profitable operations. The mine when recently visited was full of water, so that further examination was impossible. No other outcrops of talc have been found in the immediate vicinity but it is quite possible that other lenses may occur at depth, either beside the exhausted deposit or below it.

The country rock is the typical schist of the talc belt, though it contains rather an unusual amount of graphite. The talc lens is typically developed, consisting of a wide core of grit, bounded on either side by narrower zones of talc, which in turn are bounded by black wall. The grit is very white and "sparry" in appearance and has not much "slip." Actinolite seems to be wholly absent. The talc is of excellent color and more laminated in structure than is the case in the deposits further south. No masses of green, foliated talc are found here but some of the talc suggests by its color the presence of some of this form of the mineral. The talc is about four feet thick on the west wall and one foot thick on the east, although pockets occur in which there are much wider areas. The black wall is a soft, dark gray, laminated rock, of undetermined thickness, which merges into the country rock on the one hand and cleaves away from the talc

on the other. The contact between the talc and black wall is often a slickensided surface.

EAST JOHNSON.

In 1913 the American Mineral Company bought the Homer, Fox, Wood, and Fullington farms in East Johnson, about four miles northeast of the old mine, and on them has opened up extensive talc deposits. On the surface there appear to be two deposits, perhaps half a mile apart. Number one mine is being developed on the more southerly, number two on the more northerly. The strike of both deposits is approximately north, 30 degrees east, which puts them in line with the Johnson lens. Southwest of the shaft of number one mine there is an outcropping of serpentine rock, the microscopic character of which will be discussed on page 418. The southerly deposit is several hundred feet in length while the outcroppings of the black wall indicate a width of 250 feet. The deposit is therefore very large. The mine has been opened on the east (foot) wall by a vertical shaft, from which a forty-foot and an eighty-foot level have been driven for distances of 215 and 260 feet, respectively. The east wall is nearly vertical at the surface but soon dips to the west, the angle reaching 55 degrees. Beginning at the surface, where it touches the east wall, and extending vertically downward to an unknown depth, there is a great pillar of so-called "cinder," three or four feet wide and of undetermined length. This substance looks like serpentine. It will be discussed microscopically later (see p. 418). Talc or grit is found on either side of this pillar. The invariable black walls bound the deposit and merge into the country schist. There are lesser zones of "cinder" enclosed in the talc and grit in other parts of the mine. This deposit is also remarkable for the evidences of extensive faulting that it contains, the talc in one place being clearly sheared for a distance of several feet. The black wall is much slickensided. The talc and grit at the 80 foot level show a thickness of 36 feet. No attempt has yet been made at cross-cutting to reach the west wall. The mine is being worked chiefly for grit, which is of excellent quality and color.

The northerly deposit, on which number two mine is being opened up, has been traced 300 or 400 feet on the strike and is 30 or 40 feet in width. A shaft has been sunk 25 feet on the east wall which is vertical and has been polished by slickensiding to the smoothness of window glass. The talc which lies on this wall is three to four feet wide and, as regards color, slip, and massiveness of structure, is by far the best mineral yet found in this part of the state.

Both of these deposits look very promising.

MORETOWN.

About two miles from Waterbury village, in the northwest corner of Moretown, Addison County, there is a large talc deposit located on the Deavitt farm. This deposit has been known for many years, being one of those from whose outcrop foot warmers and fire place linings were cut in the old days. It is described by Hitchcock in his Report.¹

The property was acquired by the Magnesia Talc Co., of Burlington, in 1912. This company has opened up the deposit and constructed a modern mill, which has been running since July, 1913.

The deposit appears, not far from the Winooski River, as a bed of foliated talc. From here, following a strike of south, about 20 degrees east, the outcrop runs up a hill covered with glacial drift and river sand. The following sketch (Fig. 37) is taken from Hitchcock's Report.



FIGURE 37.

The west black wall is shown heavily shaded. The east wall, as far as can be determined, is about 125 feet away. The dip of the deposit is very steep, being about 75 degrees easterly. The talc is shown at A. It is bounded on the west by the black wall, which merges into the country schist, B. On the east it is bounded by great masses of serpentine, C, which seem to make up the great part of the material between the walls. A tunnel has been driven southward into the hill, at D (which is about 270 feet above the Winooski River), for a distance of 500 feet, following the talc. This tunnel is driven at a four per cent grade and its inner extremity is about 120 feet below the surface. Farther down the hill, near the mill site, a second tunnel has been driven for a distance of 300 feet. A vertical line from its inner extremity would reach the surface at a distance of 80 feet from, and at a point considerably north and below the mouth of the first tunnel. The talc vein varies in width from eight to thirty feet and follows a sinuous course, narrowing in places and again widening out into pockets. The development work so far accomplished has disclosed, therefore, a body of talc at least 1,000 feet long, 200 feet deep, and from eight to thirty feet wide, all on the foot wall. No effort has yet been made to discover talc on the east, or hanging, wall. The great central mass of the deposit,

¹ Vol. I, p. 541.

where one would expect to find grit, is apparently composed of serpentine rock, dark green in color and very hard. Furthermore, "cobblestones" of serpentine, varying from fist size to that of a bushel basket, have been found in the talc. The deposit is unique in its great serpentine development and in its small amount of grit. The conclusion that the talc has been derived from the serpentine is borne out by microscopic study (see p. 416). The mining is done by tunneling and overhead stoping. The talc cars run by gravity to the mill.

Five or six miles south of Waterbury in the valley of the Mad River, a tributary of the Winooski, at the junction of the towns of Moretown, Fayston and Waitsfield, there is a large deposit of talc on the farm of Mr. J. C. Bissbee. This deposit was opened up by the International Mining Company, whose mining operations, however, were confined to the immediate vicinity. A large mill of doubtful utility was erected and preparations were made to operate on a large scale. The affairs of the company are said to be in litigation and work is at a standstill. The deposit has been opened up by quarrying methods and consists of talc of good color and slip, though of rather foliated character. The strike varies, as the deposit curves from north to northeast. The walls converge, the talc and grit lying in the trough formed by them. The deposit is seen to consist of a central core of grit, with talc lying on either side and terminated by the black walls.

EAST GRANVILLE.

Continuing up the long, north-and-south-running valley of the Mad River, and crossing the "divide" in Warren, one comes to the next talc deposit, in the northeast corner of Granville. This deposit is some fifteen miles south of the International Company's mine, and lies in the hills just east of the Central Vermont Railroad's tracks. It consists of a chain of lenses varying from 50 to 400 feet in length and from 15 to 50 feet in width. Some of these lenses abut upon one another, while others are separated by distances of from 100 to 150 feet. Most of them are in line, but several are offset by considerable distances, in one case by 400 feet. The country rock is the typical schist. The talc is both foliated and massive but of a gritty variety. Black walls bound the deposit. No serpentine is seen about the mine but it is very likely that its presence in the talc would be shown on microscopic examination. The deposit is opened by two tunnels, one above the other, from which the mineral is carried by aerial tram to the mill beside the railroad tracks. This mine is one of a number operated by the Eastern Talc Company.

ROCHESTER.

South of the "divide" at Warren, the White River rises. It flows southeasterly through the towns of Granville and Rochester,

into the town of Stockbridge, where it turns to the northeast and joins the Third Branch at Bethel. Rochester Mountain, a low, north-and-south-running ridge, separates the valley of the Third Branch from that of the White River proper. At the foot of this ridge, at an elevation of 1,175 feet above the river, the country becomes a broad plain, sloping to the west for two and a quarter miles, when it descends precipitously about 500 feet to the river. West of the river the land rises again to irregular ridges which to the south contain intrusions of the Liberty Hill granite. The topography of the country is very rough and bears many evidences of glacial activity. The physiographic old age of the river is shown by the terraces along its valley and by its meandering course. The following sketch (Fig. 38) shows the general topography.



FIGURE 38.

At X, which is somewhat west of the base of the mountain, there is a series of talc lenses strung out over a distance of two miles or more. These lenses have the following relative positions (Fig. 39). Other outcrops of talc have been noted to the south. This Rochester district contains more of the mineral than any so far discovered in the State. The whole group of deposits is controlled by the Eastern Talc Company, of Boston.

The talc occurs in irregular, lenticular masses whose long axes lie about north and south, corresponding to the direction of the schistosity of the country rock, which is a quartz-sericite schist. The Williams mine, which forms the center of interest, lies about four miles southeast of Rochester village, measured over the roads. Both it and the McPherson mine are now connected with the company's two mills in lower Rochester by a narrow gauge railroad, which was completed in 1913. The Williams deposit was described in some detail by Hitchcock, in 1861, as the Williams steatite bed, it having been worked superficially to some extent for soapstone purposes.

Some five hundred yards north of this deposit (Fig. 39) there is a small, dome-shaped hill, perhaps 400 feet long, two hundred feet wide, and a hundred feet in elevation. The long

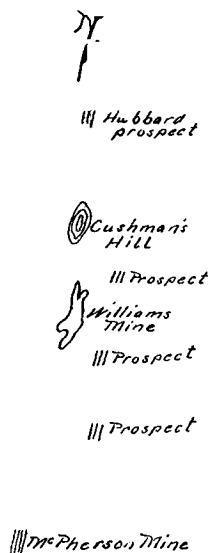


FIGURE 39

axis lies practically north and south. This hillock is shown petrographically to be the result of an extrusion of igneous rock through the country schists. The outcrops show it to be made of a great mass of serpentine, dark green, very hard—in fact just like the Moretown rock. Near the summit of the hill the serpentine is crossed by several dikes, from one to four feet wide, studded with octahedra of magnetite. So promising did this material seem to local experts that a tunnel was driven into the west base of the hill in the expectation of disclosing a considerable iron ore body. The tunnel at least had the merit of opening up the hill for study. Specimens from both the tunnel and the surface, examined microscopically, show the great mass of the extrusion to be made up of serpentine (or, more correctly speaking, antigorite), with small amounts of magnetite and either calcite or dolomite.

It may be noted here that serpentine is not an original mineral, but the decomposition product of the non-aluminous magnesian silicates: olivine, the orthorhombic pyroxenes, augite, and hornblende.

The dike material is seen, microscopically, to consist of chlorite studded with magnetite. Chlorite is a decomposition product of the igneous material of which the dikes were originally composed. Since these dikes cut across the serpentine, they must be younger in age.

On the east and west sides of the hillock there is some development of talc.

This whole igneous extrusion will be considered later in its probable bearing on the origin of the talc.

THE WILLIAMS MINE.

This is the largest deposit thus far developed in the State. The following plan of the fourth level (Fig. 40) and the profile of the mine at the shaft (Fig. 41), made from surveys kindly loaned by Mr. C. B. Hollis, Superintendent of the Eastern Talc Company, show the general relations.

The profile shows the cross section on the shortest axis of a great lens of mineral, dipping to the eastward at an angle of about seventy degrees and extending downward to a vertical depth of over 300 feet. The first level is a hundred feet below the surface, while the succeeding levels are driven at 50 foot intervals. At the surface the lens is probably 60 feet wide, at the second level, it is 65 feet, at the third, 55 feet, at the fourth, 58 feet, while at the fifth it narrows to about 10 feet, only to widen again below, where development work is in progress.

The plan of the fourth level, where the maximum development is found, shows the irregular character of the mineral lens on its longest axis. The strike is practically north and south. The total length is 432 feet. The thickness of the lens at the

shaft is 55 feet, at the northern end, 18 feet, and in the southern part, 70 feet. The shaft is shown on the hanging wall.

The country rock, as already stated, is a quartz-sericite-schist and the talc lens lies in the plane of its schistosity, in no place cutting across it—indeed, this may be said of all the talc deposits

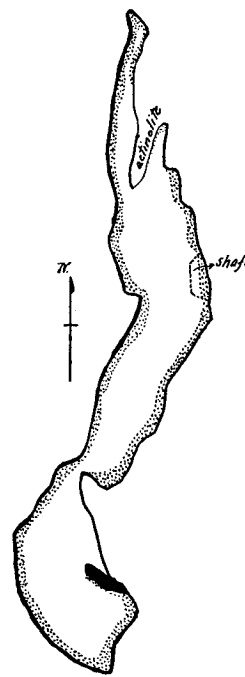


FIGURE 40.

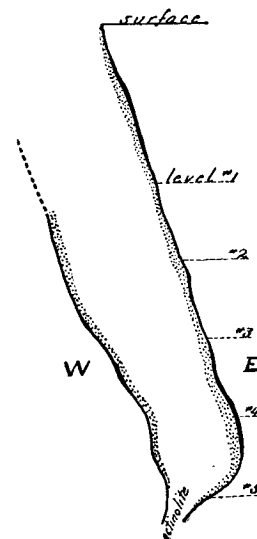


FIGURE 41.

of the State. In both plan and profile the central, unstippled area of the lens represents grit; the stippled zone, talc; and the heavily shaded borders, black wall.

The grit, which makes up the great mass of the deposit, is a gray, highly crystalline mass having the appearance of dolomite. That this mineral is a constituent of the grit is shown by its effervescence only in hot or concentrated acid. The grit also contains a good deal of talc and, when ground, possesses a good "slip." Quite a little pyrrhotite is disseminated through it. The ground grit finds a ready market. As indicated in the plan, the grit in the north end of the mine is highly impregnated with needles of actinolite, which render it worthless for grinding purposes. Again, in the fifth level, the grit becomes greatly contracted in width and is finally almost wholly replaced by a mass of actinolite, as shown in the profile. This mass continues downward for a distance of thirty feet, when it apparently gives way,

in turn, to another lens of very pure talc. We have here, therefore, evidence of the deep lying source of the deposit.

The grit, on either side, merges gradually into talc, which varies greatly in thickness and in places almost entirely disappears. It is about two and one-half feet thick on the east wall and six and one quarter feet on the west wall, but there are pockets where it is much thicker. The lower lens shows talc ten feet in thickness. The mineral is generally massive in structure but includes small areas of foliated talc accompanied by rhombs of dolomite. The talc increases in purity with depth and is of excellent color and "slip." It contains some disseminated pyrrhotite. Both talc and grit contain some small amounts of included "cinder" which, microscopically, is seen to consist of the same chloritic schist which composes the black wall. No masses of serpentine have been found in the mine but the presence of this mineral in the talc will be shown microscopically and chemically, later (p. 422). The talc lies against the bordering black wall, from which it cleaves easily, and along which it has moved to some extent, as shown by the slickensiding.

The black wall is in appearance a chloritic schist, dark, compact, more or less lustrous, and laminated. It seems to vary much in thickness, but not many measurements have been possible. In the southern part of the fourth level it is shown (Fig. 40) some ten feet in thickness, but for the most part it is much thinner and merges rapidly into the country schist. The east wall is rarely clean, being covered with a layer of actinolite two or three inches in thickness. In places the actinolite contains small quantities of fine white asbestos—or rather, chrysotile. The lateral pressure to which the deposit has been subjected is shown in the fifth level, where the black wall has been compressed into great, north-and-south-lying rolls. In the third level a similar roll of actinolite is seen.

The talc and grit are very compact and impermeable to water, but the black walls are wet, their smooth surfaces enabling water to percolate. There is no doubt that percolating water or aqueous solutions have been instrumental in producing the talc.

The amount of grit in the mine is enormous and will furnish an ample supply for many years to come. Mining is done by overhand stoping.

OTHER DEPOSITS.

The prospects shown northeast and southeast of the Williams mine are being developed and appear to be independent lenses. No other outcrops are seen between this group of deposits and Cushman's Hill but there may very well be buried lenses present. The presence of this hill of altered igneous rock suggests the probability of a connection between it and the talc lenses. The Hubbard prospect, lying to the north, has not yet received attention.

THE McPHERSON MINE.

About one mile south of the Williams mine, and perhaps faulted a quarter of a mile to the westward, is the McPherson mine, which has been in operation for about a year. This mine is opened by a tunnel, 150 feet long, and by a shaft. It is being worked chiefly for talc, which is of excellent quality and color. The field relations of this deposit have not been studied.

STOCKBRIDGE.

The next important deposit is found about five miles south of the Williams mine, on the other side of the river, in the north-east corner of Stockbridge. This deposit is known as the Greeley mine and is also owned by the Eastern Talc Company. The deposit lies near the base of the high land that rises above the valley, just south of the river. It has a north-and-south strike and the walls are very irregular, so that a great vaulted chamber has been opened up between them. The roof of this chamber has been blown off, facilitating the mining. The deposit consists essentially of grit, there being only a narrow band of talc between it and the black wall. In the grit, however, there are masses of green, foliated talc, intergrown with large crystals of dolomite. Chalcopyrite also occurs in the grit, in places as large as one's fist. The discovery of this copper mineral, not many miles away from the worked-out chalcopyrite deposits of Strafford and Ver-shire, occasioned no little excitement at the time. The chalcopyrite, however, seems to have no commercial possibilities. The deposit has been opened up by two tunnels, one above the other, the lower of which has penetrated the hill for 700 feet. As the work progressed, more and more serpentine, mixed with dolomite, was encountered, the grit diminishing correspondingly. It seems probably that the great mass of the rock is made up of this mixture of minerals, which approaches the composition of verd antique (or ophealcite). Time has not permitted a more careful study of this formation but the occurrence together of talc and serpentine is to be noted, in connection with similar relationships, elsewhere in the talc belt.

The company has discontinued work on this mine, since it has ample reserves at its other deposits, which can be much more economically mined and milled. In the past the mineral from this mine has been shipped to the company's mill in Lower Rochester, over the White River Railroad.

CHESTER.

At the Carlton quarry, two and a half miles from Chester village, there is a peculiar deposit of talcose material, which is being worked by the American Soapstone Finish Company. The deposit has been known for twenty-five years or more but has

been worked only since 1904. The quarry lies on a hillside. Its strike is about north, 15 degrees west, while the dip is 70 degrees west. The open cut is at present 100 feet long, 80 feet wide, and 64 feet in maximum depth. The country rock in the west wall of the quarry is gneiss, similar in appearance to that found at the Davis soapstone quarry, some ten miles away. The talcose material narrows at the north end of the quarry and merges into a hard, serpentinous rock. The east wall of the deposit has not been located but probably lies somewhere below the sandy surface soil, on which the road to the open cut is built. The deposit has a peculiar black wall which separates it from the gneissic country rock on the west. This black wall is a large green, very lustrous, highly foliated, chloritic schist. It is very soft and at times hangs down from the face of the gneiss like the leaves of an open book. Moreover, it is found studded with pyrite crystals (simple cubes and combination forms of cube and octahedron) sometimes an inch on the edge. Hornblende crystals have also been found. It may be noted that this black wall is identical in appearance with that in which the soapstone lenses occur at the Davis quarry.

The deposit itself consists mainly of a mixture of fine scales of foliated talc, and dolomite. (The presence of dolomite is proved by the fact that cold hydrochloritic acid produces no effect on the powdered mineral, while hot acid causes a lively effervescence of carbonic acid). This peculiar, scaly material has not been noted elsewhere in the talc belt. There is some development of large sheets of foliated talc.

WINDHAM.

The deposit here is worked by the Vermont Talc Company, which was formerly known as the Vermont Talc and Soapstone Company. The deposit is on the A. L. Stone farm, about nine and one-half miles southwest of Chester, at an altitude of 1,900 feet above sea level. As in other Vermont deposits, the gritty outcroppings were first worked for soapstone, but were found to be deficient in strength and fire resisting qualities. Later the deposit was worked as a source of ground talc and has yielded a very good product.

The deposit was first mined by open cutting. The cut is in the shape of a hollow rectangle, opening to the north, about 95 feet long by 47 feet wide. The east wall of the cut dips 65 degrees westward and is composed of a gritty talcose material containing dolomite, not at all like the usual black wall. Forty feet east of the cut there is a thick surface-showing of chloritic schist which is probably the true east wall. Beyond this appears the country schist. The west wall of the cut is nearly vertical and is made up of a hard, talcose grit, capped at the top with soft, iron-stained talc. About thirty feet west of this wall is the old quarry, where large blocks of hard, gritty talc, containing carbonate, have been

cut, in the attempt to use the material for soapstone purposes. The quarry is about twenty feet wide. West of it, the land slopes down to a swamp.

In this deposit there appears to be an unusual relationship. We have first the east black wall, then forty feet of grit, followed by about forty-seven feet of talc and fifty feet more of grit. It is reasonable to suppose that there is a west wall somewhere and that, lying against it, there is another zone of talc, as yet undiscovered. It is at present impossible to determine the maximum width of the deposit, though it has been put from 110 to 242 feet. On the surface the outcrop has been traced southward to the adjoining farm of Mr. Madison, a quarter of a mile away. Northward no outcroppings have been noted beyond the open cut.

In order to obtain a better grade of talc, which always comes with increasing depth, the company has sunk a vertical shaft in the middle of the open cut to a depth of 70 feet and driven a level 56 feet southward and 95 feet in a northerly direction. In this level, the east, or hanging wall, of grit, dips 65 degrees to the eastward (the same wall in the open cut dips at the same angle westward) which shows that the wall has curved considerably. The strike of the deposit is, in the south level, north, 45 degrees east; in the north level, north, 20 degrees east. The talc is very compact and massive. In the north level it has squeezed out, but in the south working it is from 7 to 56 feet in width—an enormous thickness. As stated before, no grit core has been found in the talc and it is probable that the west wall of the talc deposit marks the beginning of this zone. If this theory be true, a cross cut driven westward might discover another talc belt, with the country rock beyond.

The south level is being driven forward and it is proposed to sink the shaft deeper in order to start a second level. The daily output of the mine is about thirty tons of talc. No grit is being mined.

Prospects of talc are known on the neighboring Graves farm, and Warren Rhodes farm. The writer has visited the Graves prospect, which seems to indicate an enormous deposit.

INACTIVE DEPOSITS.

There are in the State a number of mines and mills which for one reason or another (insufficient capital, ignorance of proper mining and milling methods, remoteness from railroads, etc.) have suspended operations, probably permanently.

WATERVILLE.

At North Waterville the American Mineral Company developed a mine and constructed a mill on the A. M. Howes farm, several years ago. The talc is of excellent quality, but it is

said that the teaming charges were too great to make the enterprise successful. Operations ceased about seven years ago.

MORETOWN AND FAYSTON.

There is a large deposit of talc on the J. C. Bisbee farm, located in these towns. About eight years ago the International Mining Company, incorporated under Maine laws for one and one-half million dollars, built a very elaborate plant and started mining and milling. Owing it is said to litigation, operations soon ceased and the plant has lain idle for years. The long haul to Middlesex station, some nine miles away, may have been a factor in stopping operations. The talc seems to be of good quality.

PITTSFIELD.

Mineral Resources of the United States for 1905 contains the fullest information available concerning the deposit here. Talc and soapstone are used as synonyms though it is probable that the mineral is really talc. The deposit seems to be a large one. It was sold to the New England Talc Co. in 1897. This company operated the mine until 1905, shipping the mineral to its mill at Arlington, Mass. The reasons for suspending operations are not given. It is understood that the Eastern Talc Co. has recently bought the mine.

STOCKBRIDGE.

One mile west of the village, according to Mineral Resources for 1905, there is a deposit of soapstone, so poor in quality and with so much included talc, that it has been used mainly for grinding purposes. This deposit was first worked for soapstone between 1870 and 1875. Between 1895 and 1904 it was mined for talc intermittently. Since then the mine has lain idle. The property belongs to the Pilgrim Talc Co., of Boston.

READING.

The Reading Talc and Asbestos Company, of which Mr. J. E. Gay is president and manager, has a deposit in Hammondville, a hamlet in the town of Reading. A shaft has been sunk 65 feet, revealing a large deposit of mineral of excellent quality. A mill has been erected and some grinding has been done. In order to provide more working capital, the company has recently been reorganized; and it hopes soon to start operations anew.

MICROSCOPIC AND CHEMICAL EXAMINATION.

In problems of paragenesis, by which is meant the association of minerals with special reference to their occurrence and origin, the microscopic study of prepared thin sections of the substances

under examination and their chemical analysis are of the greatest aid. The microscopic study reveals the presence of the constituent minerals, often invisible to the naked eye, frequently shows the sequence in which these minerals crystallized from a cooling magma, may disclose the formation of one mineral from another by an invading solution, and in many other ways may throw much light on the problem at hand.

Chemical analysis shows us the proportions in which the component elements are present. By comparing the analysis of a rock with the analyses of many other rocks, igneous or sedimentary, we can draw reasonable conclusions regarding the igneous or sedimentary origin of this rock, as was done in the case of the sericite schists. Or, again, we can rule out certain rocks or minerals as possible sources of a mineral under investigation. Finally, by combining chemical and microscopic analyses, we can compute the percentages of the minerals which make up a rock or a mixture of minerals.

In this investigation many mineral sections were studied and several chemical analyses were made. The discussion of these studies follows.

EAST JOHNSON.

It was stated on page 406 that southwest of mine No. 1 there was an outcropping of serpentine rock. A photomicrograph of a small portion of a section of this rock appears on Plate LXXVI-B. The dark areas are serpentine (antigorite); the light, talc. The photomicrograph does not accurately show the relative proportions of these two minerals, for in reality, the ground-mass is mainly antigorite while the talc occurs either in dense patches or else in filaments crossing the antigorite. Scattered through the section (not seen in the plate) and always associated with the talc are small amounts of pyrrhotite and magnetite, which in places have been oxidized to limonite. There are a few small areas of dolomite, with its characteristic rhombohedral cleavage. The boundaries of the dolomite are invaded by flakes of talc and antigorite, which also appear in the cleavage cracks and on the surface of the carbonate mineral. Furthermore the antigorite, which in places appears in larger, columnar sections, also shows flakes of talc in its corroded outlines and in its cleavage cracks. No trace of a primary mineral is seen. Whether the talc has been derived from the serpentine, or whether both minerals owe their origin to the action of some invading solution on the dolomite, is an open question. There is evidence for both theories.

It was further noted, on page 406, that the East Johnson mine contains great pillars of so-called cinder and that zones or cores of this substance occur in the talc and grit. A thin section of this cinder shows a ground-mass of chlorite with many

minute grains of an isotropic mineral and fine flakes of talc. But chloritic schist is the substance which composes the black walls of all the deposits and we therefore see that this same substance also penetrates the talc and grit. In other deposits it occurs in these minerals in much smaller amounts.

MORETOWN.

It was noted on page 407 that in this deposit large masses of serpentine make up the core of the formation, that the talc lies against this serpentine, in the two tunnels which have been driven, that "cobblestones" of serpentine occur in the talc zone, that a relatively small proportion of grit has been encountered, and that the chloritic, black wall substance occurs to a small extent in the talc.

The serpentine has been examined microscopically both near the talc and remote from it.

Sections of the serpentine remote from the tunnels show a ground-mass of serpentine (antigorite) made up of fine fibres often crossing at right angles and giving a meshed appearance to the mineral. No trace of a primary mineral is to be found, however. In some of the sections no talc is seen, while in others a few flakes appear. All the slides show either pyrrhotite or magnetite and there are rusty streaks, due to the oxidation of these minerals. No carbonate mineral is seen in these sections. It appears, therefore, that in this part of the deposit we have simply unaltered serpentine.

But in the serpentine sections nearer the tunnels and in the serpentine forming the tunnel wall, there is a different condition. Here the antigorite appears not only in fine fibres but also in larger, prismatic sections. Mixed with these fibres, corroding the edges of the sections, and appearing in the cracks, are seen the fine flaked, brilliantly polarizing talc. It has obviously been derived from the serpentine. Pyrrhotite occurs chiefly in the talc, as though the invading solution which altered the serpentine to talc had also brought in the iron sulphide. No carbonate mineral, or at best, only a very small amount, is to be seen.

The photomicrograph, Plate LXXVII A, is taken from a section of the serpentine in contact with the talc in the lower tunnel. It shows how completely the talc (the light mineral) has replaced the antigorite (the dark mineral).

The section of the so-called "cobblestone" was cut at the contact between the serpentine core and the thin talc covering. On one side of the contact is seen antigorite thickly sprinkled with fine talc flakes; on the other, a mass of talc flakes containing a few fibres of antigorite. Pyrrhotite is disseminated through the slide and there seems to be some showing of sericite. No car-

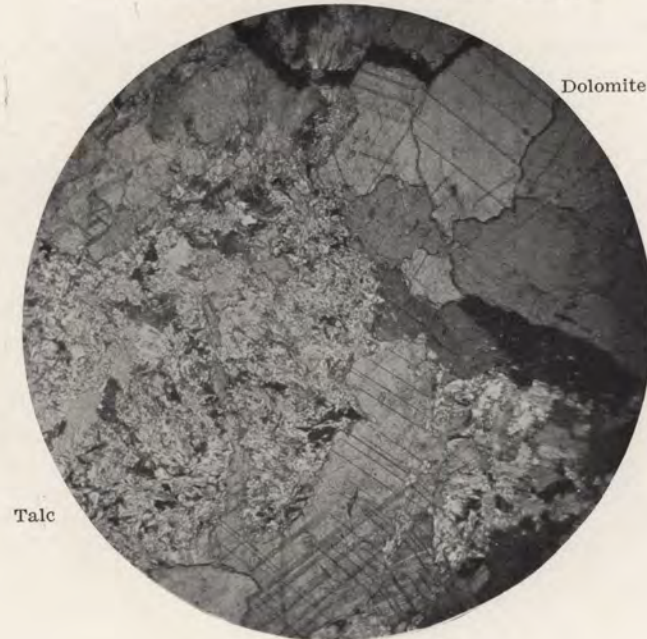
Talc



X 45 (Polarized light)

A. MORETOWN SERPENTINE AND TALC.

Dolomite



Talc

X 45 (Polarized light)
B. WILLIAMS GRIT.

bonate is seen. This section points to talc derived from serpentine.

No section of the grit was prepared but this material looks just like the Rochester grit, which will be described later.

The grit occurs as isolated masses in the talc, just as the "cobblestones" of serpentine do, and might represent a carbonation of the magnesian minerals.

The chloritic material of which the black walls are composed also occurs in the talc but in much smaller amounts than in East Johnson.

No section of the talc itself was made but a chemical analysis gave the following results:

SiO ₂	60.06%
Al ₂ O ₃	1.37
Fe	3.39
S (calculated for Fe ₂ S ₃)	1.85
MgO	28.80
H ₂ O	4.78
	<hr/>
	100.25

Recasting the analysis on the assumption that all the magnesia is present in the form of talc, we get for the mineralogical composition of the talc:

Talc	90.72%
Quartz	2.46
Pyrrhotite	5.25
Alumina in some form	1.37
	<hr/>
	99.80

It is clear that the Moretown talc has been derived from serpentine and that the alteration of the latter substance has been so complete that probably no trace of the parent mineral remains.

ROCHESTER.

As stated before, page 409, Cushman's Hill seems to be made up of a great mass of serpentine, crossed near its summit by one or more dikes of an igneous rock which has been altered to chlorite and contains crystallized magnetite. Sections of the serpentine from the surface of the hill and also from the tunnel in the hill reveal ground-masses of serpentine (antigorite) with a few small areas of dolomite and scattered flakes of talc. Magnetite also appears in the sections. In one of the slides there is a crystal section, with reaction rims, of calcite or dolomite, pseudomorphous after an orthorhombic mineral, possibly olivine. This is the only trace of a primary mineral that has been found.

It seems clear that this hill has resulted from the extrusion of a mass of igneous rock through the country schists, in the planes of their schistosity. It is probable that if this igneous

mass could be followed to the south, a connection between it and the Williams deposit would be found. It has been noted that in the Williams mine and elsewhere in the talc belt a good deal of slickensiding has taken place between the talc and the black walls, and a question as to the cause of this movement arises. The hill appears as a small monadnock above the surrounding country and the further question arises as to whether it has maintained itself because of its greater ability to resist erosion or for some other cause.

Prof. W. O. Crosby¹ has recently studied the serpentine highland of Staten Islands in an effort to account for its ability to maintain itself above the surrounding Cretaceous peneplain. He finds a sufficient explanation in the increase of volume due to the serpentinization of some massive, basic and highly magnesian igneous rock, such as a peridotite. This voluminal increase, according to Van Hise,² may amount to from 15 to 40 per cent. Crosby states that under the conditions surrounding an approximately vertical plug or stock, at great depth, this increase in volume would be manifested in an upward direction, giving rise to topographical relief and slickensiding. For this type of serpentine reliefs Crosby has coined the name, *statenlith*.

This theory may serve as a possible explanation for the observed conditions at Cushman's Hill.

THE WILLIAMS DEPOSIT.

THE GRIT.

The Williams grit has been described (page 410) as a gray, highly crystalline mass of talc and dolomite. A thin section of this substance shows dolomite or calcite (effervescence only in strong acid fixes it as dolomite), talc, antigorite, and pyrrhotite. The photomicrograph (Plate LXXVII, B) reveals large areas of dolomite, showing rhombohedral cleavage and twinning striae, with their fretted outlines filled partly with talc flakes. The section shows that antigorite also abuts on the dolomite. The pyrrhotite is disseminated through the talc and antigorite. The most plausible explanation seems to be that a silicate solution has invaded the carbonate mineral, changing it partly to antigorite, partly to talc, and bringing in the iron sulphide. Antigorite is a unisilicate; talc, a bisilicate. The formation of one or the other mineral would depend upon the abundance of the silicate solution, an excess producing talc; a dearth, antigorite. No trace of a ferromagnesian mineral could be found but it is to be noted that all the talc and grit in the State give strong reactions for manganese.

A chemical analysis of the grit gave the following results:

¹ Journal of Geology, XXII, 6, p. 582.

² U. S. G. S. Monograph 47.

SiO ₂	23.53%
Al ₂ O ₃	2.45
FeO	5.26
MgO	28.14
CaO	10.26
H ₂ O, by Penfield tube	1.40
Loss on ignition, excluding water	29.04
	100.08

Recasting the analysis in terms of the constituent minerals, we find:

Talc	36.88%
Pyrrhotite	6.76
Alumina, in some form	2.45
Residue of dolomite	53.91
	100.00

It is concluded that the grit is essentially a mixture of talc and dolomite, in which the talc has been derived from the carbonate mineral. This conclusion, taken by itself, argues a sedimentary origin for the talc.

THE TALC.

About a dozen sections of talc from different parts of the mine have been prepared and examined. Disseminated pyrrhotite is observed in all the slides. In the sections representing the east wall and the north workings of the mine, talc and actinolite are found associated, but there is no apparent genetic relationship. The actinolite, in basal sections and prismatic rods, is well bounded, and often separated from the surrounding talc by shrinkage spaces, showing that the mineral has crystallized independently.

In the sections taken near the grit core, a small amount of calcite or dolomite scattered through the talc is observable, but in those parts of the talc more remote from the core, practically no carbonate mineral is seen. The talc itself presents a varied appearance. In some of the slides a good deal of crushing is noted; in others the talc plates are in places large and show considerable cleavage. Shreds of these large plates continue through the slides, surrounded by the typical minute flakes of talc which seem to have been derived from them—in fact, it was at first thought that the large plates represented tremolite which had altered to talc. This was found however not to be the case. In some of the slides there are shredded remains of some former mineral or minerals which, unfortunately, have been almost entirely destroyed by alteration. In quite a number of the slides there are small areas of a mineral which resembles antigorite. The optical properties of several of these magnesian minerals have so much in common that a diagnosis, based wholly on microscopic examina-

tion, is exceedingly difficult; but, as will be seen, there seems good reason for believing that antigorite is present. No quartz could be found in the sections.

The chemical analysis of a sample of talc, taken near the grit, showed the following results:

SiO ₂	53.68%
Al ₂ O ₃	2.02
Fe	4.26
S, calculated to form Fe ₂ S ₃	2.78
MnO .....	.76
MgO	28.98
CaO	1.54
CO ₂ , calculated for CaCO ₃	1.21
H ₂ O, by Penfield tube	5.59
	100.82

The minerals present are talc, calcite or dolomite, pyrrhotite, and probably antigorite. If the analysis is recalculated on the basis that all the silica is in the talc, we find that there is an excess of magnesia over the requirements of the talc. Effervescence in cold dilute hydrochloric acid shows that the carbonate mineral is calcite, so that the excess magnesia must be present in the silicate form. Therefore the probability of there being antigorite in the talc is strengthened. Since the talc and antigorite both contain the same molecules, it is impossible to recast these on a percentage basis.

From the above microscopic and chemical examination, there seem good reasons for believing that the talc, antigorite and calcite have been derived from the grit.

THE BLACK WALLS.

Thin sections show the material of the black walls to be a chloritic schist, containing members of the chloritoid group, probably peninite. Some of the sections show talc in close association with the chlorite. Minute crystals of rutile or zircon are also seen. It has been noted that, in the southern part of the State, large crystals of pyrite occur in the black wall in considerable quantity, while hornblende crystals have also been found.

A partial chemical analysis of the black wall gave:

MgO	25.98%
FeO	13.85

The high magnesia and iron content of this black wall shows it to belong to the mineral or group of minerals from which the talc and grit were derived.

THE SCHIST.

This has already been considered. We may merely state here that the low magnesia and iron content precludes the pos-

sibility of the talc, grit, or black wall being derived from it.

No microscopic or chemical examinations of the other talc deposits have been attempted, since it is thought that they would add nothing new to the problem.

SUMMARY AND CONCLUSIONS AS TO ORIGIN.

It has been shown that the talc deposits of Vermont consist of mineral lenses which extend in a broken chain probably throughout the length of the State, with their longest axes lying generally north and south. It has been noted that, with one exception (the Moretown deposit), these mineral lenses consist of a core, composed of a mixture of talc and dolomite, surrounded on either side by relatively thin zones of talc (though in some places the talc is entirely lacking), which, in turn, are bounded by generally very thin bands of a chloritic schist, called black wall. This black wall material also occurs in the talc and grit, in at least one instance (at East Johnson) reaching large proportions. In the Moretown deposit great masses of serpentine form the core. Pyrrhotite has been found disseminated throughout the talc belt. Slickensiding has been generally noted between the black wall and the talc, and the smooth surfaces have offered ascending or descending solutions access to the deposits. The country rock has been shown to be a quartz-sericite schist of a very low magnesia content—probably of sedimentary origin. Evidences of the intrusion into the schists of basic, igneous magmas are found in the asbestos deposits on Mount Belvidere, at East Johnson, at Moretown, and in Cushman's Hill, in Rochester. Furthermore, the topography of the valley at Rochester suggests that faulting may have afforded opportunity for these intrusions.

Outside the State, it has been seen that the serpentine belt of Quebec, which is in line with the Vermont chain of deposits, has resulted from the alteration of a series of basic, intrusive rocks—peridotites, gabbros, diabases, etc. On Staten Island and in Hoboken, stocks of serpentine testify to the intrusive activity of igneous magmas, while other outcrops of a similar character, forming a series of isolated lenses, follow the Appalachian Mountain chain to Alabama.¹

It remains to formulate a satisfactory theory to account for the chain of Vermont deposits with their grit, serpentine, talc, and black wall members.

Since the country schists are far too poor in magnesia to have been the source of the material of these members, it follows that this source must have been within the mineral lenses themselves. These lenses must therefore represent altered igneous intrusions or else altered sedimentary carbonates.

¹ North Carolina Geological Survey, Vol. I, plate 4.

If we were to leave out of consideration for the moment those lenses whose cores are composed of dolomite, we should at once reach the conclusion that the deposits had resulted from the alteration of serpentine, which in turn had been formed from a basic, igneous rock, containing silicates of magnesium, iron, calcium, etc. On this theory, the chloritic schists would be explained as segregations of the iron and some of the magnesia along the borders of and in the mineral lenses.

But the occurrence of great masses of dolomite in the core of the deposits at East Johnson, Granville, Rochester, Windham, etc., and the evidence of Plate LXXVII B, that talc has been derived from dolomite, cast a doubt on this igneous origin. Dolomite may indeed result from the carbonation of serpentine, and many of the serpentine slides examined show the presence of small amounts of this mineral, but one is hardly prepared for such extensive and nearly complete carbonation.

The alternative hypothesis is that of the alteration of a magnesian sediment, in part to dolomite and in part to talc, perhaps through the intermediate formation of pyroxenes. Such an hypothesis Smythe¹ has found best to fit the conditions at Gouverneur, New York. Here there are areas of crystalline limestone (presumably Grenville) forming large, irregular belts, separated by gneiss. Smythe states that "the talc occurs in beds, lying wholly within the schist of the limestone formation. The beds range in thickness from a few feet to thirty feet and sometimes 'pinch out.' They conform in dip and strike to the rest of the formation and have schist for both the foot and hanging wall, with an intervening thin layer composed largely of quartz."

In attempting to apply this theory to our problem, we find it difficult to imagine a magnesian sediment confined so closely within our narrow chain of deposits, situated about in line, but separated by intervals of many miles (though of course future prospecting may serve to connect many of these links). Furthermore, the significance of the black wall, which always borders the talc, is difficult to appreciate on the theory of a metamorphosed sediment. Finally, no pyroxenic mineral can be found in the talc, while there is good reason to believe that serpentine is present.

On account of the great preponderance of evidence for an igneous origin, the tentative theory is advanced that the Vermont talc deposits owe their origin to a series of basic, magmatic intrusions into the sedimentary country schists and that metamorphic processes have produced the serpentine, grit, talc, and chlorite members of the mineral lenses.

* * * * *

There is one location that has not been examined. In Roxbury, which lies just north of East Granville, the Barney Marble

¹ Loc. cit.

Co. has for many years worked a series of lenticular deposits of verd antique. This material, more properly called ophicalcite, consists of irregular or rounded masses of serpentine, embedded in calcite or dolomite. Correspondence with the company elicits the facts that these lenticular deposits have a general strike of north, to north thirty degrees east, that they vary from 100 to 300 feet in length and from 30 to 100 feet in width, and that the greatest depth reached is 160 feet. Furthermore, the verd antique appears to occupy the position of the grit in the neighboring talc deposits, being bounded by zones of talc on either side. The lenses are spread out over a territory three miles long and one mile wide.

In a section of a drill core from one of these deposits there have been found undoubted primary minerals, which show the igneous origin of the serpentine at least.

Time has not permitted a further study of these deposits which apparently are intermediate in their structure between the Moretown or Williams formations. They appear to be rich in possibilities and will be further investigated.

ECONOMIC NOTES.

JOHNSON.

The deposit here is worked by the American Mineral Company of Boston. Mr. E. P. Jose, of Johnson, is president and general manager. The present company has been in operation since 1910. The mill is located beside the Central Vermont Railroad tracks, within a stone's throw of the shaft, from which the mineral is conveyed by an aerial tram. The grinding machinery, driven by a crude oil engine, consists of coarse jaw and rotary crushers and, for the fine grinding, buhrstones and Abbey mills. The products are ground talc, screened through silk bolting cloth, and ground grit, screened through wire mesh. The production is about thirty tons per day.

The mineral from the new mines at East Johnson is hauled to the mill by teams.

The Johnson deposits are remarkable for their white color and low content of iron.

MORETOWN.

The Moretown deposit, some two miles from Waterbury village, is operated by the Magnesia Talc Company, of Burlington. The officers are: President, Elias Lyman; vice-president, G. H. Holden; secretary and treasurer, J. S. Patrick.

The mine is on the D. P. Deavitt farm and is one of the oldest known deposits in the State. It was acquired by the Magnesia Talc Co. in 1912 and production began in July, 1913.

The mining and milling represent one of the most economical practices to be found in the State. This is due largely to the possibility of opening the mine by tunnels and to the location of the mill in a place where full advantage can be taken of the force of gravity. By driving the tunnel at the proper grade, it has been possible to have the cars, loaded at the tunnel heading, run by gravity to the storage bins of the mill, which is about 100 feet below. The mill is equipped with what is probably the best machinery yet devised for grinding talc, the Raymond Impact Pulverizer, used in conjunction with the Cyclone Separator. The mill is simple in operation, the fine material being "winnowed out" by adjustable air currents (thus avoiding the use of bolting cloths). The resulting product is remarkably free from grit. The newer mills of the State have been equipped with either this or the Sturtevant system, which is similar to it in essential details. The so-called "flow sheet" of these mills is as follows:

Storage bins,
Steam or air dryer,
Jaw crusher,
Rotary crusher,
Raymond or Sturtevant mill,
Cyclone separator, giving finest flume talc, caught in vertical textile bags, and fine grade talc which is bagged.

The coarser material is elevated and reground or else is screened, to extract a coarser product fit for roofing papers, and then reground. The capacity of these mills is from $1\frac{1}{2}$ to 2 tons per hour, depending upon the fineness of products desired. The finest, or "flume," talc is rather insignificant in amount. In some mills this is allowed to go to waste.

The Magnesia Company finds only a small amount of grit in its deposit, and so makes but one product. The capacity is at present 29 to 30 tons per day, but the mill may be easily expanded to yield two or three times this amount. There is also a buhrstone equipment, not at present used. The mill is driven by electric power.

EAST GRANVILLE.

The Eastern Talc Co., of Boston, by far the largest talc mining concern in the State, has been at work on the deposit here since 1906. The officers of the company are: President, Free-land Jewett, of Boston; mining superintendent, C. B. Hollis, of Randolph.

The company also operates several mines at Rochester and Stockbridge.

The mill is located near the railroad station, just east of the track. The mine is in the hills, several hundred feet above the mill, and is opened by tunnels, as at Moretown. The mineral,

which as stated before is a rather low grade of talc, is carried to the mill by an aerial tram, some 1,500 feet long.

Arriving at the mill the mineral is ground by the Sturtevant system of crushers and grinders, while the sizing is done by cyclone separators and New Eygo screens. The capacity of the mill is 25 to 30 tons per day. The product is used for filling paper pulp, rubber goods, etc.

ROCHESTER.

The Williams mine is the oldest in this region, having been worked superficially for soapstone purposes many years ago. Of late years this mine and the Greeley mine, five miles to the south, in Stockbridge, have been operated by the United States Talc Corporation and later, by the Standard Talc Company. The two mines were bought by the Eastern Talc Co. in 1911. Besides working these two properties, the Eastern Talc Co. has developed the McPherson prospect, which lies about one mile southeast of the Williams deposit, into a producing mine. Undeveloped prospects in the vicinity of the Williams mine promise an abundant supply of talc and grit for many years to come.

The company's old mill (No. 2) is located in Lower Rochester (now called Talcville), on the river, about west of and 1,175 feet below the Williams shaft house. Until about a year ago, the talc and grit from the Williams mine were teamed over the roads, about four miles, to the mill. This mill is driven by a crude oil engine and is equipped with buhrstones and Holmes-Blanchard pulverizers, while the sizing is done by screens and cyclone separators. A water-power, developed by damming the river, supplements the oil engine.

In 1913 the Eastern Company greatly increased its output and effected important economies in operation by completing a new mill (mill No. 3) about half a mile south of mill No. 2, and connecting it by a narrow gauge railroad with the Williams and McPherson mines. The road is four miles long and has an average grade of five per cent. The loaded cars are drawn by a locomotive to the lower terminus of the road, which is located on the top of an old river terrace. About 250 feet below, at the bottom of the terrace, stands the mill. The cars are lowered singly, by means of an inclined gravity railroad, to a lower track, along which they are pushed to the storage bins. The mill building is about two hundred feet long and is so arranged as to take full advantage of gravitational force, the raw material being received on the up-hill side and the final product being bagged and loaded onto cars at the level of the White River Railroad.

The mill is driven by steam power and is equipped with Sturtevant and Raymond pulverizers. It runs night and day and has a capacity, at present, of between 80 and 90 tons per twenty-four hours. Since the company finds a ready market for its

ground grit as well as for its talc, it is able advantageously to run one mill on each product. The material for mill No. 2 is teamed from the supply bins of mill No. 1.

The mining and milling force of the company is made up of trained engineers and the whole organization is a splendid example of a large enterprise, scientifically managed.

STOCKBRIDGE.

As before noted, the Greeley mine is a deposit of grit, containing considerable masses of green, foliated talc, calcite and some small amount of chalcopyrite. The mine has been worked by the Eastern Talc Co. up to within a short time, the mineral being brought to the company's No. 2 mill by the White River Railroad, which runs from Rochester down the valley to Bethel. With the advance of the tunnel into the mountain, the proportion of calcite to grit has increased until there has resulted a stone resembling verd antique. The company has discontinued grinding this material, since the supply of mineral from the Rochester region is ample.

CHESTER.

The Carlton quarry, about three miles from Chester Depot, has been worked for the past eight years by the American Soapstone Finish Co. Mr. C. P. Dodge, of Amherst, N. H., is the proprietor, and Mr. E. E. Holt, of Chester Depot, is the superintendent. The mineral, a low grade talc, is hauled in teams to the mill, which is located alongside of the Rutland Railroad tracks at Chester Depot. Here, by means of the usual coarse crushers and an emery mill, the material is ground to the requisite fineness to be bolted through brass and silk mesh. The mill is operated by electric power. The company also buys and grinds the waste material from the Union Soapstone Co., whose mill adjoins.

The capacity of the plant is about 30 tons per day. The products are used for filling roofing paper, plaster board, and also for several special purposes, developed by the company. One of these is a patent soapstone finish, said to be superior in many respects to ordinary plaster. Another is an artificial slate for blackboards.

WINDHAM.

The Vermont Talc and Soapstone Company, which has operated the Windham mine for a dozen years or more, has recently changed its name to the Vermont Talc Company, which more accurately describes its operations.

The president of the company is Mr. Nathan P. Avery, of Holyoke, Mass.; the general manager is Mr. T. P. Dean; and the mill superintendent is Mr. B. J. Monier.

The old mill was located near the mine, fuel and supplies being teamed from Chester, 10 miles over the roads, and the ground talc being drawn back to the railroad. In order to effect economies, a new mill was built at Chester, alongside of the Rutland Railroad tracks. It has been in operation since the fall of 1912. The new mill is a wooden structure, 300 feet long, with storage capacity of 3,000 tons, in order to provide reserves of mineral for the winter's grinding. The mineral is drawn by teams over the roads and the haulage charge is a heavy handicap. The company is considering the use of motor trucks as a substitute for horse haulage.

The talc is air dried, coarsely crushed in a jaw crusher and a Sturtevant mill, and then fed automatically to a Raymond roller mill. The resulting fine material is air lifted by a Cyclone separator. The product is of good color and "slip" and finds a use as a filler for paper and rubber goods. The mill is driven by electric power and is economically run, only three men being needed. The capacity is 20 tons per twelve hour shift.