

THE MINERAL TALC

By

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T H E M I N E R A L T A L C

CHEMICAL PROPERTIES

Composition. - The formula of talc is $(OH)_2 Mg_3 (Si_4 O_{10})$. It belongs to that group of silicate minerals which are characterized by $Si_4 O_{10}$ structural sheets¹. These sheets, which are hexagonal in aspect,

¹W. L. Bragg, Atomic Structure of Minerals, Cornell University Press, Ithaca, New York, pp. 203- 212, 1937.

are bound together into double sheets by the Mg atoms and to some extent by the (OH)'s forming a comparatively strong unit. These double sheet units, however, have no linking atoms between them, hence the binding force is weak. It is to this atomic arrangement that many of the properties of talc, such as the excellent cleavage, the softness, the leafy habit, the pseudohexagonal symmetry, the greasy feel, the pearly luster, etc., are due.

The percentage chemical composition of the mineral is silica 63.5%, magnesia 31.7%, and water 4.8%. There are commonly present, however, small amounts of alumina, iron, lime, and soda, and, in some cases, nickel, potash, titanium, phosphorous, sulphur, and manganese.

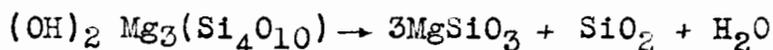
Characteristics. - Talc is very inert chemically.

It is not attacked under laboratory conditions by either acids or alkalies. Clarke and Schneider¹ found it to

¹Clarke, F. W. and Schneider, E. A., U. S. G. S. Bull. 78, 1891.

be remarkably stable in the presence of HCl, both aqueous and dry.

When decomposed by heat, talc gives up water and silica and forms enstatite, according to the following formula:



The water is driven off in appreciable amounts at high temperatures only. The results obtained by Clarke and Schneider¹ are --

Temperature	105°C	250°-300°C	Red heat	White heat
Water driven off	0.07%	0.06%	4.43%	0.35%

While talc is not an end-product of weathering, it is a very stable mineral under surface conditions.

PHYSICAL PROPERTIES

Talc crystallizes in the monoclinic system. It rarely occurs as well-defined crystals, being commonly foliated, massive, or fibrous, and in places globular or stellate aggregates. Pseudomorphs after amphiboles,

pyroxenes, mica, sepiolite, spinel, topaz, chiastolite, staurolite, dolomite, cyanite, garnet, vesuvianite, olivine, chlorite, epidote, muscovite, calcite, magnesite, and gehlenite are recorded.

The color of talc is typically apple green to white or silvery white, although it may be pale green, dark green, greenish gray, dark gray, brownish, light yellow, or reddish, depending on the impurities present. It has a hardness of 1 to 1.5, a greasy or soapy feel, an excellent slip, a white to light colored streak, a pearly luster on the cleavage surfaces, a translucent to semi-transparent diaphaneity, and a perfect basal cleavage. It is sectile and flexible but not elastic. Talc has a low heat and electric conductivity, and a fusion point of over 1100°C.

Soapstone has a great dielectric strength, 30,000 to 40,000 volts being required to pierce a slab one-half an inch thick. A very valuable property of soapstone is the ease with which it can be sawed into blocks, and an equally valuable one of talc is the usual absence of grit in high grade material.

According to Redlich¹, the greenish color of talc

¹Redlich, K. A., The Coloring Subjects in Talc, Centr. Min. Geol., 1914, 65-66.

may be caused by the presence of ferrous iron, the apple

green by nickel, the bluish to sap-green by copper, and the bright sap-green by chromium. Although it is often stated that chromium occurs only in association with basic igneous rocks or their alteration products, Redlich contends that such an association is not essential. Both acid and basic rocks may contain chromium, which may produce a green color in secondary minerals.

OPTICAL PROPERTIES

Talc is a biaxial, negative mineral with the optic plane parallel to {100} and the acute bisectrix X nearly normal to the cleavage laminae {001}. The optic angle is variable, being $2V = 0^\circ$ to 30° according to Winchell¹,

¹Winchell, A. N., Elements of Optical Mineralogy, 2nd ed., Pt. II, John Wiley & Sons, N.Y., 1927.

 and 6° to 30° according to Rogers and Kerr¹; whereas

¹Rogers, Austin F., and Kerr, Paul F., Thin-section Mineralogy, McGraw-Hill Book Co., Inc., N. Y., 1933.

 $2E = 6^\circ$ to 40° according to Iddings¹. It may, however,

¹Iddings, J. P., Rock Minerals, 1st ed., John Wiley & Sons, N. Y., 1906.

frequently seem to be 0° because of the superposition of laminae of varying orientation. The dispersion is noticeable, "r" being greater than "v". The indices of refraction are fairly low, the double refraction high, - $N_g = 1.575 - 1.590$, $N_m = ?$, $N_p = 1.538 - 1.545$, and $N_g - N_p = 0.030 - 0.050$. The maximum interference colors are upper third order. The extinction is parallel to the cleavage traces in most sections; in a few sections the extinction is $2^{\circ} - 3^{\circ}$, hence talc is probably monoclinic¹. Cleavage traces and shreds are length-slow.

¹Rogers, Austin F. and Kerr, Paul F., Thin-section Mineralogy, McGraw-Hill Book Co., Inc., N. Y., 1933.

The mineral is colorless in thin section.

Talc differs from pyrophyllite and muscovite in its smaller optic angle; from brucite in its biaxial character, its negative sign, and its birefringence.. It is not readily distinguished from any of these minerals if they are fine grained or in shreds. Accurate determination of indices of refraction may be helpful, since one index of talc is somewhat lower than those of the other minerals.

DISTINGUISHING CHARACTERISTICS

Talc may at times be confused with pyrophyllite, white mica, chlorite, brucite, selenite, and other minerals;

but it is usually rather easily distinguished by one or more of the following properties:

1. Extreme softness - easily scratched with the finger nail.
2. Soapy or greasy feel.
3. Excellent slip.
4. White to apple green color when pure.
5. Pearly luster.
6. Foliated structure.
7. Laminae flexible, but not elastic.
8. Insolubility in acids and alkalies.
9. Pink color developed when heated intensely on charcoal before the blowpipe after moistening with cobalt nitrate solution.
10. Optical properties. (See preceding section.)

VARIETIES

There are a great number of terms in use, many of them local, describing varieties of talc. Most of these are based on some special characteristic of the material under consideration. Among the names which one frequently encounters in the literature are talc, foliated talc, talc schist, steatite, soapstone, rensseleerite, pyrallolite, talcoid, potstone, hydrosteatite, agalmatolite, pagodite, agalite, beaconite, peridosteate, massive talc, indurated talc, asbestine, freestone,

French chalk, talc clay, gavite, and pycrosmine. In this work, only those terms which have a more general application and usage will be discussed. It happens, however, that these are the only terms which are in common use among talc and soapstone people in Virginia. These terms are "talc", "talc schist", "steatite", and "soapstone". They have been quite loosely used in the past, but contact with the industry and a careful survey of the literature indicates that the following limitations are those which are more desirable to apply to the respective varieties.

Talc. - "Talc" is the term that is frequently used to include all forms of the comparatively pure mineral, but it seems better to restrict this term to the foliated, laminated, or micaceous variety of the mineral. It commonly occurs in sheets several inches in diameter, is apple green to white when typically developed, and usually exhibits all the other properties that one finds in mineralogical textbooks under the heading "Talc".

Talc schist. - "Talc schist" is a rock composed entirely or partly of talc flakes having a parallel orientation. This variety is often of no commercial value, although it may be ground, but it is frequently associated with workable deposits.

Steatite. - "Steatite" is the term more properly applied to the massive, compact, cryptocrystalline to

finely granular variety. It is commonly light green, gray, cream, or white in color and is the most sought-after variety of the mineral, because of its suitability for use in the manufacture of pencils, gas tips, and other articles which require material of limited specifications, and because of the readiness with which it is ground into a fine, smooth powder. The name "steatite" is sometimes applied to soapstone.

Soapstone. - "Soapstone" is the name applied to a dark gray, bluish gray, or greenish rock composed essentially of talc, but carrying varying amounts of chlorite, serpentine, tremolite or other amphiboles, pyroxenes, olivine, mica, magnetite, pyrite, pyrrhotite, quartz, and carbonates of calcium, magnesium, and iron. This rock is commonly partially foliated, has a soapy or greasy feel, and is soft enough to be cut with a knife or to be sawed into slabs. The "hard" variety of soapstone, which is not soapstone in the restricted sense of the term, is composed chiefly of amphibole and chlorite with small percentages of carbonate, talc, and magnetite, and manifests only to a limited extent the properties stated. This latter property together with its resistance to heat, acids, and alkalies, and its low electric conductivity are the chief reasons for its widespread use. On prolonged exposure to the atmosphere,

Steatite

the impurities commonly weather out leaving a mass of porous, limonite-stained talc which often has a partial parallel orientation. This weathered mass is frequently ground as "yellow talc" or "red talc". Many basic, igneous rocks, rendered soft enough by weathering to be cut with a knife, are erroneously called soapstone.

Gavite and pycrosmine, according to the experiments of Foshag and Wherry¹, are not separate mineral species,

¹Foshag, W. F. and Wherry, E. T., Notes on Composition of Talc, Am. Min., Vol. 7, Oct. 1922, p. 168.

but are merely talc with about 4% water held "loosely bound" between the cleavage flakes by electrostatic forces. It is the additional water that renders this talc susceptible to attack by acids.

CONDITIONS OF FORMATION

Talc is essentially an alteration product of other minerals. Its formation has been assigned by various writers to conditions of temperature and pressure ranging all the way from rather intense conditions to actual surface weathering. There seems to be little doubt, however, that talc is formed under lower conditions of temperature and pressure than the so-called anhydrous silicates, such as olivine, enstatite, and tremolite, and under higher conditions of temperature and pressure

than actual surface weathering. The fact that talc alters from the so-called anhydrous silicates indicates that it forms under conditions less intense than they do. In support of the statement that talc forms under conditions more intense than actual weathering, the author has seen talc exposed to the elements which was losing its luster and greasy feel and breaking down to simpler compounds.

On this subject, Smyth¹ says in regard to the talc

¹Smyth, C. H., Jr., Genesis of the Zinc Ores of the Edwards District, St. Lawrence County, N. Y., N. Y. St. Mus. Bull. 201, p. 31, 1917.

 and serpentine associated with the zinc of the Edwards District, St. Lawrence County, N. Y.: "On one hand, it is argued that they (talc and serpentine) are products of weathering; on the other, that they are due to the action of magmatic waters on magnesian silicates. As thus baldly stated, both views are rather extreme, but the writer.....is strongly in sympathy with the latter. It seems highly probable that the formation of talc and serpentine is a process that goes on below, rather than in, the 'belt of weathering' within which latter these two minerals, while relatively resistant, are by no means end products, but tend to break down

into simpler compounds. There is no doubt that talc and serpentine are formed below the belt of weathering by both magmatic and meteoric waters. When once formed, the minerals are stable and may be regarded as end products, so far as these conditions are concerned.....

"If the varying intensity of the metamorphic processes were represented by a curve, with a vertical coordinate for intensity and horizontal coordinate for time, its summit would indicate the formation of diopside, tremolite and calcite, this aggregation of minerals constituting the typical products of metamorphism. Minerals formed during the period represented by the ascending portion of the curve would tend to be destroyed or recrystallized at its summit, and might or might not be present in the rock now.

"The minerals formed under maximum intensity of metamorphism, at the summit of the curve, are, as a rule, stable through a wide range of conditions and thus persist to a large extent throughout the descending portion of the curve. But even these yield considerably to the new conditions and, thus, the descending portion of the curve represents the alteration of diopside and tremolite into talc, serpentine, etc., which, though also silicates, are evidently later than, and derived from, the primary silicates first named.....

"If the curve were continued down far enough to represent weathering conditions and their products, the

gap between these and the hydrous silicate would, it is thought, be much greater than between the latter and the diopside.....

"As talc is less hydrated than serpentine, it might be expected to form at a higher temperature, that is, higher up on the descending portion of the curve of metamorphism; and such is the fact, talc being distinctly the older of the two minerals. This is shown by the way in which serpentine eats into, or cuts squarely across, tufts and plates of talc and, even more strikingly, by crystals of tremolite or diopside, altered to talc, traversed by a network of serpentine. In these cases, serpentine has grown at the expense of, and replaced, talc and, to this extent, talc has been an intermediate stage in the production of serpentine. The same may be true of the large nodules of talc surrounded by serpentine.....

"While, however, the alteration of diopside to serpentine sometimes passes through the intermediate stage talc, this is evidently not essential to the process as, in nearly every section where the change can be seen, the passage is direct from diopside to serpentine..... So far as rather limited data indicate, the latter mineral (serpentine) is formed very largely from diopside, and the talc from tremolite."

Further substantiation of the fact that talc is formed under conditions of temperature and pressure more

intense than serpentine yet less intense than the so-called typical anhydrous silicates is offered by S. G. Gordon¹ in his paper on the albitites along the

¹Gordon, S. G., Desilicated Granite Pegmatites, Proc. Acad. Nat. Sci. of Phila., Pt. 1, 1921, pp. 176-180.

Pennsylvania-Maryland boundary line. These albitite dikes cut a serpentine mass, and there are commonly developed three distinct zones of minerals formed by the reaction of the pegmatitic solutions with the serpentine walls. In passing from the albitite to the serpentine these zones are the vermiculite (a weathered biotite) zone, the actinolite zone carrying more or less talc, and the talc zone. Beyond the talc zone lies the serpentine. The author believes that pegmatitic solutions of the composition which would normally form quartz, microcline, albite or oligoclase, muscovite, and biotite intruded the serpentine and lost in the process all the constituents except those which went to form the albite. These constituents, with the aid of rising temperatures and pressures, converted the serpentine to the minerals of the various zones. In this process, talc was formed from serpentine by the addition of silica and the subtraction of water, but

it was also formed from serpentine by the intensification of conditions of temperature and pressure. Again it is to be noted that the actinolite formed under still more intense conditions than did the talc.

Gillson¹, in discussing Gordon's paper, suggests

¹Gillson, J. L., Origin of the Vermont Talc Deposits, Econ. Geol., XXII, No. 3, May 1927, p. 281.

that hydrothermal solutions from the pegmatite formed the minerals in the serpentine at some time during the introduction of the pegmatite or in its later stages of albitization. He lists talc, chlorite, and amphibole but says nothing of the paragenesis.

Larsen², in his paper on the origin of albitite

²Larsen, Esper S., A Hydrothermal Origin of Corundum and Albitite Bodies, Econ. Geol., Vol. XXIII, No. 4, June - July, 1928.

and plumasite bodies, cites the almost invariable alteration of the ultrabasic rock (not uncommonly serpentinized) adjacent to the dikes. This alteration typically is arranged in three zones consisting of phlogopite, biotite, chlorite (probably derived from biotite), and(or) vermiculite (altered biotite) adjoining the dikes; talc adjacent to the ultrabasic rock or serpentine; and actinolite or anthophyllite as an

intermediate zone between the former two. The dikes may be pegmatite composed of quartz, potash feldspar, and sodic plagioclase with borders of nearly pure sodic plagioclase and in places an intermediate layer of potash feldspar and sodic albite, or of nearly pure plagioclase with borders rich in corundum; or they may be entirely absent with mica or (and) its alteration products comprising the center of the vein. Larsen considers that these deposits (the albite and the minerals of the zones) were formed as high temperature veins and replacements, probably approaching pegmatite or hydrothermal contact metamorphic deposits in their condition of temperature and concentration, although he is uncertain of the concentration of these solutions. The solutions moved along channels and deposited either in the channels or in the adjoining wall rock a part of their material and at the same time took up some material from the wall rock and carried it away. The dikes proper are conceived to have been intruded in some cases before and in others after the formation of the zones. It is to be noted that the talc is farthest from the source of heat and, in some cases, derived from the amphibole by alteration, and that it is also in part apparently derived from the serpentine by intensification of conditions. This further substantiates the contention that talc is deposited under conditions lower than the

amphiboles, etc., yet higher than serpentine.

Stuckey¹, in his recent description of the talc

¹Stuckey, J. L., Talc Deposits of North Carolina, Econ. Geol., Vol. XXXII, No. 8, Dec., 1937.

deposits of North Carolina, finds talc replacing tremolite through the action of hydrothermal solutions. His series of events are in part: (1) Silicification of marble; (2) development of tremolite, hornblende, actinolite, and chlorite; (3) deposition of talc by replacement of tremolite and marble; (4) development of pyrite and magnetite with or closely following talc.

Several authors suggest that dynamic pressure is a factor in the formation of talc. Arnold Heim², in

²Heim, Arnold, Der Talk bergham von Disentis in Graybunden, Zeit. f. prakt. Geol., Vol. 26, pp. 2-11, 1918, summarized by Wilson, loc. cit.

describing some talc deposits of Disentis, Switzerland, states that they were formed from serpentine by solutions under intense horizontal pressure; Wilson³ thinks that

³Wilson, M. E., Talc Deposits of Canada, Dept. Mines, Geol. Surv., Econ. Geol. Series 2, 1926.

deformation may have been a factor in the formation of the talc of Eastern Townships of Quebec; and Bonney, in discussing Finlayson's paper on some rocks of New Zealand¹, gave his opinion that a talc rock is a con-

¹Finlayson, A. M., Nephrite and Magnesian Rocks of New Zealand, Quat. Jour. Geol. Soc. London, Vol. 65; pp. 351-81, 1909.

 dition to which a much crushed serpentine is reduced.

† Gillson¹, on the other hand, considers that the talc

¹Gillson, J. L., Origin of the Vermont Talc Deposits, Econ. Geol., XXII, No. 3, May 1927, p. 246.

 deposits of Vermont are a kind of contact metamorphic deposit, formed by hot alkaline solutions low in silica, and toward the last rich in magnesia and carbon dioxide, but that dynamic metamorphism did not assist in the process of talc formation. He finds talc following tourmaline, quartz, biotite, apatite, amphibole, chlorite, titanite, and dolomite, and preceding magnetite and pyrrhotite in sequence of formation. After a critical study of the literature and of numerous thin sections of specimens from widely distributed localities, he states that, in most deposits, dynamic stress was not active during talc formation, but that the mineral

was formed through the agency of hot, alkaline solutions, which were at first siliceous and carried iron and calcium and some aluminum in addition to magnesium, and later became less siliceous and rich in magnesium. These solutions formed an amphibole, a serpentine, or a chlorite before the deposition of talc. Hess¹ believes that talc

¹Hess, H. H., Hydrothermal Metamorphism of an ultrabasic Intrusive at Schuyler, Virginia, Am. J. Sc., Vol. XXVI, Oct., 1933.

¹Hess, H. H., The Problem of Serpentinization and the Origin of Certain Chrysotile Asbestos, Talc and Soapstone Deposits, Econ. Geol., Vol. XXVIII, Nov., 1933.

is formed by dilute, hot, aqueous (hydrothermal) solutions usually bearing CO₂, which are derived commonly from acid intrusions but which may come from source rocks of any composition. These solutions deposit talc and carbonate with decreasing temperatures as the low temperature end-members of the series hornblende, actinolite, chlorite, talc, and carbonate. In some cases, olivine and pyroxene are the original minerals; in others, serpentinized ultrabasics are the original material. In the latter case, enstatite is the first hydrothermal mineral formed in some localities¹. Under

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¹Dresser, J. A., Communication on The Problem of Serpentinization, Econ. Geol., Vol. XXIX, No. 3, May, 1934.

¹Bain, George W., Communication on Serpentinization: Origin of Certain Asbestos and Soapstone Deposits, Econ. Geol., Vol. XXIX, No. 4, June - July, 1934.

¹Hess, H. H., Communication on The Problem of Serpentinization, Econ. Geol., Vol. XXX, No. 3, May, 1935.

certain conditions, biotite, anthophyllite, tourmaline, and(or) corundum may develop in addition to, or instead of, the characteristic series. Stress had little or no effect in the process of talc formation. Serpentine derived from ultrabasics is "not only autometamorphic but largely deuteritic in the most restricted sense (Sederholm's definition)".

The writer, in an earlier publication on the origin of the talc and soapstone of Virginia², expressed the

²Burfoot, J. D., Jr., The Origin of the Talc and Soapstone Deposits of Virginia, Econ. Geol., Vol. XXV, No. 8, December, 1930.

opinion that these deposits were typically formed by the action of cooling hydrothermal solutions upon pyroxenites, peridotites, and dunites forming in order amphibole, biotite in some localities, chlorite, serpentine, mag-

netite, and carbonate. The solutions were then rejuvenated followed by continued cooling with the formation of tremolite, and then talc, magnetite, carbonate, pyrite, and some little chrysotile. In one locality secondary growth tremolite with slightly later specularite were formed subsequent to the talc stage as a secondary rejuvenation of solutions. The talc is thought to have been deposited under deep or intermediate vein zone conditions. Differential stress is not necessary for its formation.

HISTORY

It is to be expected that a substance so resistant to heat and to corrosion and so easily wrought as is talc would have long been in use by mankind. This is actually the case; for talc, in one form or another, but **mainly** as cooking utensils, ornaments, and pipes, has been used for centuries by the Arabians, the Egyptians, and the Chinese, as well as by the North American Indians and the Eskimos. In fact, it is probable that talc has been used by most of the aborigines of the lands in which it occurs in any quantity. References to it are found in the classic literature, in regard to which Dana¹ writes: "A white steatite of a silvery-

¹Dana, E. S., The System of Mineralogy of James Dwight Dana; 6th ed.; John Wiley & Sons, N. Y.; 1892.

pearly luster was the 'Magnetis' of Theophrastus - a stone, according to this author, of silvery luster, occurring in large masses, and easily cut or wrought. The word is the origin of the modern 'magnesia'. Agricola, in his 'Interpretatio Rerum Metallicarum' appended to his works (1546), gives as a German synonym of Magnetis, 'Talck'; and he adds, as other synonyms, 'Silberweiss' and 'Katzensilber', and also 'Glimmer', the German now for 'mica', evidently confounding the two minerals. He mentions its resistance to fire, and speaks of it as 'lapis scissilis'.

"Other later writers derive the word 'talc' from the Arabic 'talk'; and Aldrovandus (1648) states that it is of Moorish introduction (into England), adding 'Hoc nomen apud Mauritanos stellam significare dicitur', 'Stella Terrae' - Star of the Earth - being one old name of the mineral, given it because 'like a star and with silvery luster it shines'. Caesium ('De Mineralibus', 1636) writes the word in Latin, 'Talchus', but most other writers of that century, 'Talcum'.

"The word 'steatitis' occurs in Pliny as the name of a stone resembling fat; but no further description is given that can with certainty identify it."

G E O G R A P H I C D I S T R I B U T I O N

Talc is a mineral of very wide distribution. It occurs in at least small amounts in most areas of metamorphic and igneous rocks, but is seldom found in quantities large enough to work.

In North America we find talc in the eastern area of folded and metamorphic rocks, in the Cordilleran Region, and in Laurentian Shield. In the United States, the states which are producing talc or soapstone are California, Georgia, Maryland, New York, North Carolina, Pennsylvania, Vermont, Virginia, and Washington. Massachusetts and New Jersey are at times producers. In Canada, Ontario, Quebec, and British Columbia are producers. Ontario is, however, by far the largest producer, and the Madoc District is the most important district of Canada.

The foreign countries, other than Canada, which produce talc and soapstone are Argentina, Australia, Austria, Bulgaria, China, Egypt, Finland, France, Germany, Greece, India, Indochina, Italy, Japan, Morocco, Norway, Rumania, Spain, Sweden, Union of South Africa, United Kingdom, and Uruguay.

G E O L O G I C O C C U R R E N C E

Talc is commonly associated with igneous and metamorphic rocks. It is, therefore, found in regions where igneous rocks occur and where metamorphism has taken place. The rocks with which it is associated are usually old, being pre-Cambrian or lower Paleozoic in age. In them the bodies of talc rock occur as lenses or irregular-shaped masses. In addition vein talc is commonly associated with and cuts these masses. The dimensions of the workable bodies are usually to be measured in scores of feet. They vary from few tens of feet to hundreds of feet in length and breadth. The two soapstone bodies most successfully worked in Virginia are about 1,200 and 2,000 feet in length and vary up to 300 feet in width.

The recognized modes (or types) of occurrence are¹--

¹Following Wilson, M. E., Talc Deposits of Canada, Dept. Mines, Geol. Surv., Econ. Geol. Series 2, 1926, modified and expanded by the writer.

1. White or light colored talc, frequently high grade, associated with crystalline dolomite or limestone. This talc occurs as lenses, pockets, and irregular shaped masses, which tend to parallel the bedding or

banding of the enclosing rock and are often separated from it by silicate zones. The minerals commonly found with these deposits are tremolite, enstatite, actinolite, diopside, serpentine, quartz, chlorite, magnetite, pyrite, tourmaline, phlogopite, calcite, dolomite, and probably ankerite. Igneous rocks thought to be of about the same age as the talc are commonly found close by. Where these are not actually found, it is in places necessary to infer their presence to explain certain conditions present in the country rocks.

Under this heading belong the deposits of Gouverneur, N. Y.; of eastern Pennsylvania and New Jersey; of extreme southwestern North Carolina, and Fannin and Gilmer counties, Georgia; of California; of the Madoc District, Ontario; and of Mt. Whympet and New Chaumox, B. C.

2. Gray or green talc, often impure, associated with basic igneous rocks. This talc occurs as lenses, pockets, and irregular-shaped masses in the igneous rocks, being frequently located in the center or along the edges of the bodies.

The minerals frequently found associated with this type of occurrence are much the same as those found associated with the foregoing type and include enstatite, tremolite, hornblende, hypersthene, actinolite, olivine, biotite, white mica, phlogopite, tourmaline, apatite,

titanite, quartz, serpentine, chlorite, magnetite, pyrite, pyrrhotite, and the carbonates calcite, dolomite, and ankerite.

To this class belong at least many of the deposits of Vermont; those of the Piedmont District of the eastern U. S., including parts of Maryland, Virginia, North Carolina, and Georgia; and numerous deposits in Canada, including several in British Columbia and in northwestern and southeastern Ontario, and those of the Eastern Townships of Quebec.

3. Replacements in schists and gneisses. Three areas are known to the writer which might possibly be assigned to this mode of occurrence. They are the deposits near Mautern in Styria, Austria; those of the Eagle Claim, Vancouver Island; and, according to Gillson, some of the deposits of Vermont.

The deposits of Eagle Claim occur as lenticular masses interbedded with argillite and schist almost on the line of the Leech River fault. Wilson¹ states that

¹Wilson, M. E., Talc Deposits of Canada, Dept. Mines, Geol. Surv., Econ. Geol. Series 2, 1926.

these may be similar to the deposits of Mautern, Austria, described by Weinschenk as replacements in schist, but recognizes the possibility of their being an alteration

product of basic volcanics. Carbonate, magnetite, and pyrrhotite are known to be associated with talc in these deposits.

Gillson¹ states that some of the talc deposits of

¹Gillson, J. L., Origin of the Vermont Talc Deposits, Econ. Geol., XXII, No. 3, May 1927, p. 246.

Vermont occur as replacements in quartz-muscovite-chlorite schist and in quartz-mica-amphibole gneiss. These deposits carry tourmaline, quartz, biotite, apatite, amphibole, chlorite, titanite, dolomite, talc, magnetite, and pyrrhotite. Hess¹, on the other hand,

¹Hess, H. H., The Problem of Serpentinization and the Origin of Certain Chrysotile Asbestos, Talc and Soapstone Deposits, Econ. Geol., Vol. XXVIII, Nov., 1933.

believes that "the overwhelming proportion of the talc found (in Vermont) is a replacement of an ultrabasic, and, in the few cases where it is not, it is a replacement of the intensely chloritized country rock within a few feet or, more commonly, a few inches of the contact of the ultrabasic. Talc deposits as replacements of gneiss and schist entirely apart from ultrabasics do not exist in Vermont."

In all these cases, igneous rocks which are thought to have furnished the active solutions are either found outcropping in the vicinity of the deposits or their presence at depth is strongly suspected.

Definite evidence as to whether or not talc in some places in Virginia occurs as replacements in schist is lacking. Several occurrences were seen in which the talc appeared to grade into the country schist in a manner suggesting replacement, but the outcrops were so badly weathered that accurate megascopic or microscopic evidence was unobtainable.

4. Foliated talc in veins, rarely over a few inches in width, usually cutting serpentine or one of the more massive or impure varieties of talc. This type is very pure but is of little commercial importance. It does, however, afford beautiful museum specimens. Magnetite, pyrite, and the carbonates calcite, dolomite, and ankerite are commonly found in these veins associated with the talc.

Reference is made to vein talc in North Carolina by Keith¹, in New York by Newland², in Canada by

¹Keith, Arthur, Talc Deposits of North Carolina, U.S. G.S., Bull. 213, pp. 433-38, 1903.

²Newland, D. H., New York State Museum Bulletin No. 223-4, Min. Res. of St. of N. Y., 283-295.

Wilson¹, and in Switzerland by Heim² The author has seen

¹Wilson, M. E., Talc Deposits of Canada, Dept. Mines, Geol. Surv., Econ. Geol. Series 2, 1926.

²Heim, Arnold, Der Talk bergham von Disentis in Graybunden, Zeit.f. prakt. Geol., Vol. 26, pp. 2-11, 1918, summarized by Wilson, loc. cit.

dozens of veins of foliated talc associated with the talc and soapstone deposits of Virginia. This variety commonly occurs in or immediately associated with one of the other types of occurrence.

5. Many of the older writers have stated that talc is found as a weathering product of magnesium-bearing minerals. The author is not familiar, however, with any recent investigator of the geology of talc who recognizes this mode of occurrence.

THEORIES OF ORIGIN
CLASSIFICATION OF THEORIES

The following theories of origin have been assigned to the various occurrences of talc¹:

¹Following Wilson, M. E., Talc Deposits of Canada, Dept. Mines, Geol. Surv., Econ. Geol. Series 2, 1926, modified and expanded by the author.

1. The transformation of a crystalline limestone, usually dolomitic, to talc either directly or with the intermediate stage of the formation of tremolite or other magnesian silicates.

2. The conversion of ultrabasic igneous rocks to talc either directly or with the intermediate stage of the formation of an amphibole, chlorite, serpentine, etc.

3. The replacement of schists and gneisses by talc either directly or with the intermediate stage of the formation of chlorite or an amphibole.

4. Deposition in veins.

5. Weathering of magnesium-bearing minerals.

The several theories listed above will now be considered in more detail.

1. The derivation of talc from magnesian limestone is considered by the various authors to take place in one of the four following ways:

a) The transformation of a dolomite, commonly siliceous, to a silicate, usually tremolite, enstatite, or actinolite, by regional metamorphism, and the alteration of this silicate to talc by surface waters carrying CO₂ either at some depth or under surface weathering conditions. This theory was applied by C. H. Smyth, Jr.¹

¹Smyth, C. H. Jr., Sch. of Min. Quat., XVII, No. 4, 333-341, 1896, Genesis of the Talc Deposits of St. Lawrence County, N. Y.

¹Smyth, C. H. Jr., Report on the Talc Industry of St. Lawrence County, N. Y., N. Y. St. Mus., Ann. Rept., Vol. XLIX-2, 661-71, 1898.

¹Smyth, C. H. Jr., Preliminary Examination of the General and Economic Geology of Four Townships in St. Lawrence and Jefferson Counties, N. Y., N. Y. St. Mus., Ann. Rept. XLVII, 685-709, 1894.

in 1893, 1895, and 1896 to the talc deposits of New York; apparently J. H. Pratt² in 1900 to some of the deposits

²Pratt, J. H., Talc and Pyrophyllite Deposits in North Carolina, N. C. Geol. Surv., Econ. Papers, No. 3, 1900.

of North Carolina; and by O. B. Hopkins¹ in 1914 to

¹Hopkins, O. B., Asbestos, Talc, and Soapstone Deposits of Georgia, Geol. Surv. of Ga., Bull. 29, 1914.

to those of Fannin and Gilmer Counties, Georgia.

Smyth assigns the formation of the talc from the silicates to deep circulation; whereas Hopkins thinks that the talc of Georgia was formed from the silicates in the belt of weathering. Pratt does not state the conditions of talc formation.

b) Formed directly from a siliceous dolomite by regional metamorphism.

Keith² in 1902 called upon this theory to explain

²Keith, Arthur, Talc Deposits of North Carolina, U. S. G. S., Bull. 213, pp. 433-38, 1903.

the talc disseminated through marble in southwestern North Carolina. He apparently applies this theory also to the talc in lenses and sheets, but has difficulty in understanding the process by which it was concentrated in these forms.

Hopkins³ in 1914 applies this theory to the dis-

³Hopkins, O. B., Asbestos, Talc, and Soapstone Deposits of Georgia, Geol. Surv. of Ga., Bull. 29, 1914.

seminated scales in talcose quartzite of the Fannin-Gilmer County deposits of Georgia. The shreds and foliae of talc wrap around and project into grains of quartz. This relationship suggests to him that the talc was formed directly from the siliceous material without the intermediate product amphibole through the agency of a probable dolomitic material which cemented the grains together. The position of the talc in the quartz grains may be explained by the crushing and recrystallization of the quartz, which is clearly shown, and which appears to be subsequent to the formation of the talc.

c) Contact or high temperature hydrothermal metamorphism of a dolomitic limestone to magnesian silicates such as tremolite commonly through the agency of a granite, and the subsequent alteration of these silicates to talc by the somewhat cooled emanations from this same intrusive or by regional metamorphism. This theory was advanced by Peck¹ in 1905 to explain the occurrence

¹Peck, F. B., The Talc Deposits of Phillipsburg, New Jersey and Easton, Pa., N. J. Geol. Surv., Ann. Rept. 1904, pt. 3, p. 163-185, 1905.

of the deposits of eastern Pennsylvania and western New Jersey, by Diller¹ in 1913 for those of California, by

¹Diller, J. S., Talc and Soapstone, U. S. G. S. Min. Res. of U. S., 1912, Pt. II, p. 1148, 1913; and 1913, pp. 157-160, 1914.

 Miller and Knight² in 1913 to explain the deposits of

²Miller and Knight, The Pre-Cambrian Geology of South-eastern Ontario, Ann. Rept., Ont. Bureau Mines, Vol. XXII, p. 113.

 Madoc, Ontario, by Smyth³ in 1918 to explain ~~to~~ those

³Smyth, C. H., Jr., Genesis of the Zinc Ores of the Edwards District, St. Lawrence County, N. Y., N.Y. St. Mus. Bull. 201, p. 31, 1917.

 of St. Lawrence County, N. Y., and by Stuckey⁴ in 1937 to account for those of southwestern North Carolina.

Peck thinks that the phlogopite and tremolite of the Pennsylvania-New Jersey deposits were formed by the contact action of pegmatite dikes, but that the talc was formed from these silicates during regional metamorphism. Gillson⁵ examined a specimen from this

⁵Gillson, J. L., Origin of the Vermont Talc Deposits, Econ. Geol., XXII, No. 3, May, 1927, p. 246.

⁴Stuckey, J. L., loc. cit

locality and found that it was not at all schistose but that the serpentine and talc had a random orientation. From this and from a study of the literature, he came to the conclusion that dynamic metamorphism could not be held responsible for the formation of the talc, but that it seemed very probable that the talc and serpentine are connected with the process of contact metamorphism that formed the tremolite.

Diller¹ describes the talc deposits of California

¹Diller, J. S., Talc and Soapstone, U. S. G. S. Min. Res. of U. S., 1912, Pt. II, p. 1148, 1913; and 1913, pp. 157-160, 1914.

as irregular masses typically lying between diorite and banded limestone. The diorite is thought to be later than the limestone and may have been a factor in the origin of the talc. In places a derivation from tremolite and actinolite is indicated. Gillson,² ~~after a~~

²Gillson, J. L., Origin of the Vermont Talc Deposits, Econ. Geol., XXII, No. 3, May 1927, p. 246.

after a study of specimens from La Moine in the Siskiyou Mountains near the Oregon line, concluded that very probably some or all of the deposits are due to emanations

from the dioritic rocks as suggested by Diller.

Miller and Knight¹ suggest that the solutions re-

¹Miller and Knight, The Pre-Cambrian Geology of South-eastern Ontario, Ann. Rept., Ont. Bureau Mines, Vol. XXII, p. 113.

 sponsible for the Madoc, Ontario, talc deposits were derived from a granite. They note the formation of talc from tremolite.

Smyth² supposes the deposits of St. Lawrence County,

²Smyth, C. H., Jr., Genesis of the Zinc Ores of the Edwards District, St. Lawrence County, N. Y., N. Y. St. Mus. Bull. 201, p. 31, 1917.

 New York to be formed by the action of magmatic solutions from granite upon crystalline dolomite starting with contact metamorphism and cooling to conditions normal to depth, and, in doing so, depositing diopside, tremolite, pyrite, sphalerite, galena, talc, and serpentine in this order and under control of decreasing temperature. In the talc deposits proper, the ores are mainly missing. It is also probable that Newland in 1919 intended to assign this method of origin to the formation of these deposits, for he states that the talc

was formed from the alteration of tremolite schist by deepseated circulation. He shows limestone, tremolite schist, talc, and a granite in a section presented but makes no reference to contact action.

Gillson¹ in 1927 studied the literature relative to the talc deposits associated with the Murphy Marble in southwestern North Carolina and the adjacent portion of Georgia and arrived at the conclusion that they were probably formed by the contact metamorphic action of a granitic intrusion instead of by the process described in the foregoing section which was used by Hopkins and intimated by Pratt. Recently these deposits in North Carolina have been described by Stuckey² (in 1937)

²Stuckey, J. L., Talc Deposits of North Carolina, Econ. Geol., Vol. XXXII, No. 8, Dec., 1937.

as having been formed by the action of solutions from quartz diorite dikes upon the Murphy crystalline dolomite producing in order: (1) silicification of the marble; (2) tremolite, hornblende, actinolite, and chlorite by replacement of quartz and marble; (3) talc by replacement of tremolite and marble; (4) pyrite and magnetite with or closely following talc. Moneymaker²

¹Gillson, J. L., loc. cit.

²Moneymaker, Berlen C., Communication of the Talc Deposits of North Carolina, Econ. Geol., Vol. XXXIII, No. 4, June-July, 1938, pp. 461-463.

takes exception to the statement that the active solutions are derived from quartz diorite dikes, citing Keith and Ross and expressing himself as being of the opinion that the quartz diorite bodies are in reality pseudodiorite formed by metamorphism and not of igneous origin at all.

d) Formed directly from a dolomitic limestone by the emanations from a granite.

Wilson¹ in 1926 suggests this mode of origin for

¹Wilson, M. E., Talc Deposits of Canada, Dept. Mines, Geol. Surv., Econ. Geol. Series 2, 1926.

the talc deposits of the Madoc district of Ontario. He is inclined to omit the usual intermediate amphibole stage, because of lack of evidence of the transformation of tremolite to talc and because of the preservation of what he assumes to be the bedding of the original dolomite.

Stuckey² found some of the talc of southwestern

¹Stuckey, J. L., Talc Deposits of North Carolina, Econ. Geol., Vol. XXXII, No. 8, Dec., 1937.

North Carolina replacing the dolomitic marble directly.

2. The second general type of theory falls into the three following subdivisions:

a) The transformation of an ultrabasic igneous rock directly to talc by regional metamorphism. This theory was apparently intended by Keith¹ in 1902 in reference

¹Keith, Arthur, Talc Deposits of North Carolina, U. S. G. S., Bull. 213, pp. 433-38, 1903.

to the soapstone of North Carolina and by Jacobs² in

²Jacobs, E. C., Reports of Vermont State Geologist, 1913-14, pp. 382-429, and 1915-16, pp. 232-280.

1914 and 1916 to explain the occurrence of talc in Vermont.

Keith states that the soapstone and talc are derived from the metamorphism (alteration) of a very basic intrusive rock, which, in most cases, also forms other silicates containing magnesia, such as tremolite,

that dynamic metamorphism did not assist in the process of talc formation. It is thought possible that a granite magma may have given rise to the active solutions. Hess¹ agrees with Gillson's conclusions with two ex-

¹Hess, H. H., The Problem of Serpentinization and the Origin of Certain Chrysotile Asbestos, Talc and Soapstone Deposits, Econ. Geol., Vol. XXVIII, Nov. 1933.

ceptions: (1) He believes that the overwhelming proportion of the talc found is a replacement of an ultrabasic, and, in the few cases where it is not, it is a replacement of the intensely chloritized country rock within a few feet or, more commonly, a few inches of the contact of the ultrabasic. Talc deposits as replacements of gneiss and schist entirely apart from ultrabasics do not exist in Vermont. (2) He would have the solutions hot, dilute, and aqueous usually carbonate-bearing, and cooling. In view of the first exception, Hess' concept of the origin of these deposits would embody with the modifications that of Gillson's stated above plus that of his included in the following section "The replacement of schists and gneisses".

The talc associated with the albitites along the Pennsylvania-Maryland boundary line, as described by Gordon¹, Gillson², and Larsen³ belongs here. The origin

¹Gordon, S. G., Desilicated Granite Pegmatites, Proc.
Acad. Nat. Sci. of Phila., Pt. 1, 1921, pp. 176-180.

²Gillson, J. L., Origin of the Vermont Talc Deposits,
Econ. Geol., XXII, No. 3, May 1927, p. 246.

³Larsen, Esper S., A Hydrothermal Origin of Corundum
and Albitite Bodies, Econ. Geol., Vol. XXIII, No. 4,
June-July, 1928.

of this talc is discussed in the section entitled "Con-
ditions of Formation".

The writer⁴ has expressed the opinion that the *talc*,

⁴Burfoot, J. D., Jr., The Origin of the Talc and Soap-
stone Deposits of Virginia, Econ. Geol., Vol. XXV,
No. 8, December, 1930.

~~talc and soapstone deposits of Virginia were typically
formed by the action of cooling hydrothermal solutions,
which started at approximate contact metamorphic in-
tensity, upon pyroxenites, peridotites, and dunites
forming in order amphibole, biotite in some localities,
chlorite, serpentine, magnetite, and carbonate. The
solutions were then rejuvenated followed by continued~~

The writer (81) has expressed the opinion that the talc, soapstone, and steatite and the associated metagabbros and metapyroxenites of Virginia were formed by the action of hydrothermal solutions upon gabbros, pyroxenites, and peridotites. These solutions started at approximately contact metamorphic intensity and cooled to the temperature of the surrounding country rocks, following which there was a second invasion of hydrothermal solutions.

In the gabbro group, the following mineral changes took place: Pyroxene was altered to amphibole. Basic plagioclase was changed to albite, albite-oligoclase, epidote, and clinozoisite. Ilmenite was reworked. Ilmenite was altered to titanite. Amphibole was replaced by chlorite. Probably after the second invasion of solutions, amphibole and chlorite were replaced by talc and magnetite. Secondary quartz was deposited.

In the pyroxenite-peridotite group, the following transformations occurred: Pyroxene was altered to amphibole in some cases preserving the external form of the pyroxene. Biotite was introduced in some localities. Amphibole and biotite were replaced by chlorite. In the former reaction, the interstitial, aluminous amphibole was apparently more susceptible to the chlorite replacement than the pyroxene-shaped bodies. Olivine was changed to serpentine and magnetite, and the pyroxene-shaped amphibole bodies were serpentinized with the cleavage of the amphibole and the external form of the pyroxene being preserved. The interstitial chlorite was but slightly affected by this

replacement. Some magnetite and carbonate were probably released during the serpentinization of the amphibole. At this stage there was a rejuvenation of solutions with the water becoming hotter and the conditions more intense, followed by continued cooling. Tremolite developed around the edges of the serpentinized uralite bodies, replacing serpentine and to some extent chlorite. Talc, magnetite, carbonate, pyrite, and a little chrysotile were developed. In the rocks which previously bore olivine, the talc worked in along and spread out from the old olivine cracks, replacing the serpentine; in those which bore pyroxene, the talc replaced tremolite, serpentine, chlorite, and uralite. In one locality, secondary growth tremolite with slightly later specular^(a) pyrite were formed subsequent to the talc stage as a secondary rejuvenation of solutions.

The active solutions are thought to have carried carbon dioxide and locally oxygen with silica, lime, and possibly magnesia released from mineral alterations. The sources of these solutions were conceived to be the magmas of some of the igneous rocks in the region, even the magma that gave rise to the basic rocks themselves being recognized as a possibility. The presence or absence of talc was dependant in part at least upon the occurrence of the correct segregation product, the presence of feeding channels leading to these rocks, and the invasion of solutions of the necessary chemical character with the requisite temperature and pressure. This study suggests the following conclusions relative to the conditions of forma-

tion of talc: (1) Differential stress is not necessary for talc formation; (2) The mineral is formed under deep to intermediate vein zone conditions of temperature and pressure.

cooling with the formation of tremolite, and then talc, magnetite, carbonate, pyrite, and some little chrysotile. In one locality secondary growth tremolite with slightly later specularite were formed subsequent to the talc stage as a secondary rejuvenation of solutions. The active solutions are thought to have carried carbon dioxide and locally oxygen with silica, lime, and possibly magnesia released from mineral alterations. The sources of these solutions were the magmas of some of the igneous rocks in the region. Differential stress is thought not to be necessary for the formation of talc.

Hess¹ believes that the soapstone deposits at

¹Hess, H. H., Hydrothermal Metamorphism of an Ultrabasic Intrusive at Schuyler Virginia, Am. J. Sc., Vol. XXVI, Oct., 1933.

¹Hess, H. H., The Problem of Serpentinization and the Origin of Certain Chrysotile Asbestos, Talc and Soapstone Deposits, Econ. Geol., Vol. XXVIII, Nov., 1933.

Schuyler, Virginia were formed by the action of dilute hydrothermal solutions bearing CO₂ on basic igneous rocks, which were intruded as sheets and differentiated in situ to gabbro, picrite, basic pegmatite, and acid

pegmatite. The mineral sequence is pyroxene, olivine, and plagioclase; hornblende, actinolite, and tremolite; two chlorites; and talc and carbonate, with magnetite accompanying the formation of the chlorites, talc and carbonate. There is considerable overlapping of these minerals with the development of chlorite accompanying the progression of hornblende toward tremolite, and talc and carbonate overlapping chlorite and to a limited extent tremolite. However, Hess lays stress on rock facies changes rather than on mineral changes and finds the following transformations: picrite to hornblende amphibolite to actinolite amphibolite to steatite. During these changes, so-called poikilitic texture is thought to have been developed by pyroxene crystals with inclusions of olivine being altered to single crystals of hornblende with slightly different compositions in areas which were olivine from those which were pyroxene. This hornblende was in turn replaced by two chlorites,- one in olivine areas and one in pyroxene areas. Talc and carbonate then replaced the chlorite in olivine areas rather completely and the chlorite in pyroxene areas slightly. These changes took place under conditions of decreasing temperature with talc being formed as the low temperature end-members of the series. The evidence

indicates that the active solutions were derived from acid intrusions. The formation of talc was not dependent on conditions of differential stress.

3. This theory was used by Weinschenk¹ in 1900

¹Weinschenk, E., Abhandl., Beyer. Akad. d. Wiss., Vol. 21, pt. 2, p. 270, 1901.

Quoted by Lindgren, W., Min. Deps., p. 394, 1919.

 to account for the talc deposits near Mautern, Austria; by Wilson² in 1926 to account for those of the Eagle

²Wilson, M. E., Talc Deposits of Canada, Dept. Mines, Geol. Surv., Econ. Geol. Series 2, 1926.

 Claim, Vancouver Island, Canada; and by Gillson³ in

³Gillson, J. L., Origin of the Vermont Talc Deposits, Econ. Geol., XXII, No. 3, May, 1927, p. 246.

 1927 to account for some of those of Vermont.

Weinschenk⁴ holds that talc near Mautern, Austria

⁴Weinschenk, E., Abhandl., Beyer. Akad. d. Wiss., Vol. 21, pt. 2, pp. 270-78, 1901, summarized by Gillson, loc. cit. and Wilson, loc. cit.

developed by the replacement of schist composed of quartz, chlorite, chloritoid, and graphite along its contact with limestone and believes that this transformation is the result of the action of waters carrying magnesia following the intrusion of large igneous bodies. The source of the emanations was possibly a granite. Redlich and Cornu¹ cite evidence opposed to

¹Redlich and Cornu, Zeitschrift fur Praktische Geologie, Vol. XVI, p. 152, 1908.

 this ^{view} and suggest that the basic intrusives of the region are the source of the magnesia.

The talc deposits of Eagle Claim, Vancouver Island, Canada occur, according to Wilson citing MacKenzie, as lenticular masses interbedded with argillites and schists situated almost on the line of the Leech River Fault. From this association, he sees the probability of the talc being formed by magnesia-bearing solutions percolating along the fault plane in a manner somewhat similar to that suggested by Weinschenk for the deposits near Mautern, Austria. He believes that the solutions probably came from the basic intrusives that occur in the region. Nevertheless, he recognizes the possibility of the talc forming as an alteration product from basic volcanics which occur in the district.

Gillson finds the talc occurring in a quartz-muscovite-chlorite schist and in a quartz-mica-amphibole gneiss. He states that it never replaced these schists or gneisses directly, but that the talc formation was preceded by the replacement of the country rock by a chlorite or an amphibole. The sequence of mineral formation in this process was: tourmaline, quartz, biotite, apatite, amphibole, chlorite, titanite, dolomite, talc, magnetite, and pyrrhotite. He considers that the talc lenses are a kind of contact metamorphic deposit formed by hot, alkaline solutions, low in silica, and toward the last rich in magnesia and carbon dioxide. The random orientation of all the minerals in the talc lenses indicates that dynamic metamorphism did not assist in the process of talc formation. He also suggests that granite was possibly the source of the active emanations.

4. With talc being formed by the action of solutions on certain rocks, it is quite natural to expect that some of this talc will be taken into solution and deposited in nearby cracks and fissures. This actually happens, and we find every gradation between the talc that is deposited in situ and that which is transported some distance and deposited in veins. This vein material is found around talc deposits of all types, but in only few instances has it been worked. Reference

is made to vein talc by Keith¹ in 1902 in his description

¹Keith, Arthur, Talc Deposits of North Carolina, U. S. G. S., Bull. 213, pp. 433-38, 1903.

of the talc of North Carolina and by Newland² in 1921

²Newland, D. H., New York State Museum Bulletin, No. 223-4, Min. Res. of St. of N.Y., 283-295.

in his account of that of New York. The writer has seen dozens of veins associated with the talc and soapstone deposits of Virginia.

Heim³ in 1918 describes veins of pure, translucent,

³Heim, Arnold, Der Talk bergham von Disentis in Graybunden, Zeit f. prakt. Geol., Vol. 26, pp. 2-11, 1918, summarized by Wilson, loc. cit.

iceberg-blue-green secretion talc in Switzerland. This has been segregated from talcose rock and, like veins of dolomite, etc., is secondary in origin. It occurs either in coarse flakes or in fibres, the latter standing at right angles to the wall of the fracture.

Wilson⁴ in 1926 describes two veins in Canada, one

⁴Wilson, M. E., Talc Deposits of Canada, Dept. Mines,
Geol. Surv., Econ. Geol. Series 2, 1926.

up to a foot and the other up to eighteen inches in width occurring with carbonate and cutting respectively soapstone and serpentine. He states that its occurrence in a vein cutting soapstone indicates that it is a secondary form resembling the columnar graphite that occurs in veins cutting deposits of disseminated flake graphite. Like the columns of the graphite, the micaceous structure of the vein talc generally stands at right angles to the vein wall.

5. A number of geological writers have held the view that talc is formed extensively by the weathering of magnesium-bearing minerals. Thus, Van Hise¹ in 1904

¹Van Hise, C. R., A Treatise on Metamorphism, U. S. G. S. Mono. XLVII, 351, 1904.

stated that talc "is especially likely to form under conditions of weathering", while Hall² in 1918 made a similar

²Hall, A. L., The Geology of the Barberton Gold Mining District, U. S. Africa, Geol. Surv., Mem. No. 9, pp. 310-12, 1918.

statement. Hopkins¹ in 1914 stated that "the change

¹Hopkins, O. B., Asbestos, Talc, and Soapstone Deposits
of Georgia, Geol. Surv. of Ga., Bull. 29, 1914.

(from other silicates, such as tremolite, to talc) is
thus characteristic of the belt of weathering". And
Emmons², in his table published in 1908 giving the

²Emmons, W. H., A Genetic Classification of Minerals,
Econ. Geol., Vol. III, p. 611, 1908.

conditions under which certain minerals may be formed,
lists talc and steatite as forming under conditions of
"surface alteration" and "surface weathering".

There is, however, considerable opposition to this
point of view. Thus Julien³ in 1914 pointed out that

³Julien, A. A., Ann. New York Acad. of Sci., Vol. 24,
p. 25, 1914.

"in the decay of olivine, for example, on weathered
outcrops of dunite or other peridotite,.....not a
trace of newly formed talc has ever been distinguished
among the products of decay", and Smyth⁴ in 1918 states

⁴Smyth, C. H., Jr., Genesis of the Zinc Ores of the Edwards District, St. Lawrence County, N. Y., N. Y. St. Mus. Bull. 201, p. 31, 1917.

that "it seems highly probable that the formation of talc and serpentine is a process that goes on below, rather than in, the 'belt of weathering' within which latter these two minerals, while relatively resistant, are by no means end-products, but tend to break down into simpler compounds. There is no doubt that talc and serpentine are formed below the belt of weathering by both magmatic and meteoric waters". Newland¹ in

¹Newland, D. H., New York State Museum Bulletin No. 223-4, Min. Res. of St. of N. Y., 283-295.

1921 holds that "it is certain that the talc (of New York State) is not a product of surface weathering", and again, Wilson² in 1926 states that "it would be

²Wilson, M. E., Talc Deposits of Canada, Dept. Mines, Geol. Surv., Econ. Geol. Series 2, 1926.

difficult to prove that talc does not form by weathering, but in the case of most extensive deposits at least,

there is ample evidence that the talc has been formed as an accompaniment of either igneous intrusion or deformation, or of both these agencies". In substantiation of these statements, the writer has seen talc exposed to the elements which was losing its luster and greasy feel and apparently breaking down to simpler compounds. This weathered talc grades downward into fresh talc of normal luster and slip. Jacobs¹, also,

¹Jacobs, E. C., Reports of Vermont State Geologist, 1913-14, pp. 382-429, and 1915-16, pp. 232-280.

in 1914 states that "this 'massive talc' near the surface appears tougher and harder than deeper down in the earth". In fact, no recent investigator of the geology of talc, known to the writer, supports this mode of origin in his publications.

The reader may note that the works of many of the older writers are not included in this classification. The reason for these omissions is that, in many cases, the statements of the mode of origin are not sufficiently complete to be amenable to inclusion in this scheme.

DISCUSSION OF THEORIES

It should be remembered in considering the above theories that if no material is added from the outside except in some cases H_2O and CO_2 , a dolomite with only silica as an impurity would tend, under proper environmental conditions, to metamorphose to tremolite, diopside, or some other iron and alumina-free silicate, which in turn would alter to pure talc. Likewise, an enstatite or other magnesian igneous rock free from iron and alumina would tend to go to pure talc. On the other hand, if the dolomite is very impure, carrying considerable argillaceous and ferruginous material, or if the igneous rock is composed of iron-rich and alumina-rich minerals, such as augite or hornblende, the final result will tend to be a chlorite rather than talc. If, however, the composition of the original rock is between the two conditions outlined above, the final result will be an impure talcose rock, or soapstone, the amount of chlorite developed depending on the amount of alumina and iron in the original rock.

Another significant thing to be noticed in relation to these theories is the trend of the modern writers away from regional metamorphism, meteoric waters, or surface conditions and toward magmatic waters and con-

ditions of some depth as factors in the formation of talc. Several points that might be advanced in favor of this change are:

1. The presence of such minerals as magnetite, pyrite, titanite, and pyrrhotite either accompanying the formation of the talc or subsequent to it points to the fact that talc was formed under conditions of rather high temperature and pressure and probably by magmatic waters.

2. The presence of veins of talc, magnetite, pyrite, and carbonates in the more massive varieties of talc and, therefore, contemporaneous with or later than the massive varieties indicates again that conditions of some temperature prevailed during and slightly subsequent to the formation of the talc. Also, for the talc to be deposited in veins, it must have been in solution. But talc is a very inert mineral. It is very stable in the presence of both acids and alkalis and under aqueous, surface conditions. It seems, therefore, that the conditions under which talc would go into and remain in solution are more nearly the intense conditions of temperature and pressure with the existence of strong mineralizers which accompany igneous intrusions than the less intense conditions which accompany the movements of meteoric waters either at the surface or at depth.

3. There is some doubt as to whether or not meteoric water can reach the depths necessary for talc formation in sufficient quantities to form talc and to transport and deposit it in veins.

4. The random orientation of the fibers and flakes commonly seen in talc deposits indicates strongly that dynamic metamorphism is not necessary in the process of talc formation. If, however, the minerals have a parallel orientation, magmatic waters may have been the agent directly responsible for the talc formation, while regional pressure may have been responsible for this parallel arrangement.

5. The presence of diopside, tremolite, phlogopite, biotite, tourmaline, and apatite as minerals formed secondarily in the original rock yet prior to the formation of the talc indicates that the first step in the formation of talc took place under conditions of high temperature and pressure. This assemblage also strongly indicates magmatic waters under conditions of contact metamorphism as the agent of their formation.

6. The frequent presence of igneous rocks of the same age as the talc in the vicinity of the deposits or the presence of conditions strongly indicating that such rocks are close by not only offers a source for magmatic solutions but also indicates that these solutions were the active agents in talc formation.

Chemistry of Changes.- Below are given some of the equations which have been used to account for the changes that go on in the formation of talc. These equations are not to be taken as showing precisely or completely ^{the} changes involved. For it is possible that, were no water involved, the substances would not pass through the molecular state. Yet, in this case, the reactions would indicate the percentage compositional changes. Also, these reactions do not show the volume changes involved. These volume changes vary somewhat with each locality and are dependent on the relative amounts of material added and removed and on the relative densities of the minerals involved. Neither do they show the part played by temperature, pressure, or other substances in solution. In these equations, only the simplest and purest materials are considered. The ever-present impurities are not taken into account. Regardless of all this, however, they do serve to give us a general idea of what goes on during the changes in mineral composition in a manner that nothing else can.

1. $\text{Ca Mg} (\text{CO}_3)_2 + 2 \text{SiO}_2 \rightarrow \text{Ca Mg} (\text{SiO}_3)_2 + 2 \text{CO}_2$
 Dolomite Diopside
2. $\text{Ca Mg} (\text{CO}_3)_2 + \text{SiO}_2 \rightarrow \text{Mg SiO}_3 + \text{CaCO}_3 + \text{CO}_2$
 Dolomite Enstatite
 Reactions # 1 & # 2 take place with decrease volume.
3. $\text{Ca Mg}_3 (\text{SiO}_3)_4 + \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2 \text{Mg}_3 (\text{SiO}_3)_4 + \text{CaCO}_3$
 Tremolite Talc
 CaCO_3 may be carried away in solution.
4. $6 \text{Ca Mg}_2 \text{Fe} (\text{SiO}_3)_4 + 4\text{H}_2\text{O} + 6 \text{CO}_2 + 3 \text{O} \rightarrow$
 Actinolite
 $4\text{H}_2 \text{Mg}_3 (\text{SiO}_3)_4 + 6 \text{Ca CO}_3 + 3\text{Fe}_2\text{O}_3 + 8 \text{SiO}_2$
 CaCO_3 and Fe_2O_3 may go to form ankerite or ferrocalcite.
5. $4 \text{Mg SiO}_3 + \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{Mg}_3 (\text{SiO}_3)_4 + \text{MgCO}_3$
 Enstatite Talc
6. $3 \text{Ca Mg} (\text{SiO}_3)_2 + \text{H}_2\text{O} + 3\text{CO}_2 \rightarrow \text{H}_2\text{Mg}_3 (\text{SiO}_3)_4 +$
 Diopside Talc
 $3\text{CaCO}_3 + 2 \text{SiO}_2$
7. $3 \text{Ca Mg} (\text{SiO}_3)_2 + 2 \text{H}_2\text{O} + 3 \text{CO}_2 \rightarrow \text{H}_4 \text{Mg}_3 \text{Si}_2\text{O}_9 +$
 Diopside Serpentine
 $3 \text{CaCO}_3 + 4 \text{SiO}_2$
8. $4 \text{MgFe SiO}_3 + \text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{H}_2\text{Mg}_3 (\text{SiO}_3)_4$
 Hypersthene Talc
+ Mg Fe CO_3
9. $4 \text{Mg}_2\text{SiO}_4 + \text{H}_2\text{O} + 5 \text{CO}_2 \rightarrow \text{H}_2 \text{Mg}_3 (\text{SiO}_3)_4 + 5 \text{Mg CO}_3$
 Forsterite Talc
10. $12(\text{Mg,Fe})_2 \text{SiO}_4 + 3 \text{H}_2\text{O} + 5 [\text{O}] \rightarrow 3\text{H}_2\text{Mg}_3 (\text{SiO}_3)_4$
 Olivine Talc
+ $5\text{Fe}_3\text{O}_4$

11. $3\text{Mg}_2\text{SiO}_4 + 2\text{CaCO}_3 + 5\text{SiO}_2 \rightarrow 2\text{Ca Mg}_3(\text{SiO}_3)_4 + 2\text{CO}_2$
 Forsterite Calcite Tremolite
12. $2\text{Mg}_2\text{SiO}_4 + \text{CO}_2 + 2\text{H}_2\text{O} \rightarrow \text{H}_4\text{Mg}_3\text{Si}_2\text{O}_9 + \text{MgCO}_3$
 Forsterite Serpentine Magnetite
13. $3\text{Mg}_2\text{SiO}_4 + \text{SiO}_2 + 4\text{H}_2\text{O} \rightarrow 2\text{H}_4\text{Mg}_3\text{Si}_2\text{O}_9$
 Forsterite
14. $\text{Mg}_2\text{SiO}_4 + \text{MgSiO}_3 + \text{H}_2\text{O} \rightarrow \text{H}_4\text{Mg}_3\text{Si}_2\text{O}_9$
 Forsterite Enstatite Serpentine
15. $3\text{Mg}_3\text{Fe}(\text{SiO}_4)_2 + 6\text{H}_2\text{O} + 0 \rightarrow 3\text{H}_4\text{Mg}_3\text{Si}_2\text{O}_9 + \text{Fe}_3\text{O}_4$
 Fe-bearing Serpentine Magnetite
 forsterite
16. $3\text{MgSiO}_3 + 2\text{H}_2\text{O} \rightarrow \text{H}_4\text{Mg}_3\text{Si}_2\text{O}_9 + \text{SiO}_2$
 Enstatite Serpentine
17. $\text{H}_2\text{Mg}_3(\text{SiO}_3)_4 + \text{H}_2\text{O} \rightarrow \text{H}_4\text{Mg}_3\text{Si}_2\text{O}_9 + 2\text{SiO}_2$
 Talc Serpentine
18. $\text{H}_4\text{Mg}_3\text{Si}_2\text{O}_9 + 2\text{SiO}_2 \rightarrow \text{H}_2\text{Mg}_3(\text{SiO}_3)_4 + \text{H}_2\text{O}$
 Serpentine Talc
19. $2\text{H}_4\text{Mg}_3\text{Si}_2\text{O}_9 + 3\text{CO}_2 \rightarrow \text{H}_2\text{Mg}_3(\text{SiO}_3)_4$
 Serpentine Talc
 $+ 3\text{MgCO}_3 + 3\text{H}_2\text{O}$

In general, when the minerals involved change from a lower to a higher silica ratio, there must be either an addition of silica or a subtraction of base or both. This means that there must be available free quartz or aqueous solutions carrying silica in the first case, or solutions bearing carbon dioxide or in some cases oxygen in the second to take care of the base removed where all the base removed is not hydrogen. These solutions may be of either meteoric or magmatic source.

If there is a mineral of a higher silica ratio changing to a mineral of a lower silica ratio, either silica must be freed or base added or both. In the first case, plain water to act as a medium of interchange is all the reaction calls for, although CO_2 and other substances are usually present. In the second case, if hydrogen is the sole base added, water is sufficient to effect the change. If, however, some other base is added, a solution carrying that base is necessary. Either meteoric or magmatic waters may effect these changes.

If the same silica ratio is retained, as in the formation of talc from a metasilicate, either silica must be added or base subtracted, because, in the formation of talc, hydrogen must be added. Of course, where bases other than magnesia are present, they must

be subtracted in the process of talc and serpentine formation.

To be more specific, if enstatite (MgSiO_3) were to change to talc ($\text{H}_2\text{Mg}_3\text{Si}_4\text{O}_{12}$), water must be added to supply the hydrogen of the talc. This frees one atom of magnesium (really one molecule of magnesia). To satisfy this, silica must be added, in which case talc will probably form, or carbon dioxide to form magnesium carbonate. The active solution must, therefore, contain silica or carbon dioxide.

In the case of tremolite altering to talc, H_2 replaces one Ca, which usually goes to form calcium carbonate. Therefore, an aqueous solution carrying CO_2 is necessary for this reaction.

In a like manner, all these equations can be analyzed.