VEIN QUARTZ PSEUDOMORPHS OF CROSS-FIBER ASBESTOS IN VIRGINIA

Lincoln R. Thiesmeyer, *Harvard University, Cambridge, Mass.*

Contents

Introduction

The Fibrous Habit. In addition to the asbestos of commerce, which includes several varieties of amphibole and serpentine, many minerals occur in the asbestiform or fibrous habit, a few much more commonly than others. Dana (1922, p. 690) records more than forty such minerals, and states (p. 182) that "there are many gradations between coarse columnar and fine fibrous structures." This implies that any mineral which develops a columnar form during primary crystallization might assume a fibrous habit under certain conditions. Peacock (1928, p. 276) points out that the beginnings of crystallization in amorphous media and hydrogels are commonly fibrous crystallites which may finally develop into non-fibrous crystals. This observation leaves Taber's statement (1916A, p. 659), that all asbestiform minerals are secondary and, therefore, limited to metamorphic rocks, open to question. Both these writers agree, however, that because all fibrous minerals also show well-developed crystals, their fibrous structure must be due to special conditions of growth.

Warren (1932) demonstrates that the tendency to form somewhat flexible and extremely elongated crystals is inherent in the molecular pattern of some minerals, especially certain varieties of asbestos. In other words, a few minerals adopt an asbestiform outline very readily in response to intramolecular forces peculiar to them. This is not true of the great majority of minerals. Consequently, their appearance in fibrous form must be a result of conditions outside the space-lattice.

Numerous examples are known of a fibrous habit among minerals to which this habit is inherently foreign. Most of these are vein occurrences in which fibers of a rarely-fibrous mineral are inter-grown with one or more commonly-fibrous ones, and explanations proposed to account for specific instances of this circumstance have been:

A. Infiltration—in which either (1) the minerals crystallized simultaneously, one of them attaining the fibrous condition because it occupied and was moulded by space between growing fibers or bundles of fibers of the other; or (2) later solutions permeated an asbestiform vein and deposited material whose form was determined by space it secured through displacement (of fibrous masses), just as the shape of a dike or vein is often controlled by the walls of the fracture along which it has penetrated. Renard and Klement (1884), Hall (1918A, p. 35), Peacock (1928, p. 247) and Reinecke and McClure (1933, p. 31) have described examples of minerals made fibrous through infiltration, but only Renard and Klement are very definite in stating that the infiltration did not result in replacement.

B. Pseudomorphism—in which the asbestiform structure is inherited through replacement. It is conceivable that in this process one fiber of palasome may be succeeded by one (fiber) of metasome—that is, that the new fibers are *unit* pseudomorphs. Usually, however, the replacement proceeds *en masse*, whole bundles of fibers giving rise to much coarser fibers of the replacing substance—that is, the new fibers are *aggregate* pseudomorphs. Klaproth (1815) and Wibel (1873) conclude that coarse fibers of quartz in the famous tiger-eye of South Africa are aggregate pseudomorphs of the crocidolite with which they are intergrown. E. L. Perry (1930) describes fibrous magnetite pseudomorphs of chrysotile from Wyoming in which (p. 178) "only the coarser structure of the [chrysotile] fibers (0.1 mm.) is preserved." This, likewise, is obviously an example of aggregate pseudomorphism; and numerous others could be cited. No instance of unit pseudomorphism among fibrous minerals has yet come to the writer's attention, but, as noted above, no *a priori* reason precludes the possibility of its occurrence.

Since metasomatism is frequently a highly selective process, influenced by minute and little-understood physico-chemical differences in the material suffering attack, all gradations may exist between unit pseudomorphs which inherit microscopic details of the fibers they replace and coarse aggregate pseudomorphs which preserve only the major outlines and structural features of fiber bundles, or even of entire fibrous veins.

Petrified wood presents an analogous variability in the intricacy of original structures retained. Furthermore, since all stages of replacement from incipient to complete are possible in any instance, residual fibers may or may not be present in all proportions within such aggregate pseudomorphs. Consequently, material having a decidedly fibrous aspect in the field and in hand specimens may appear as a granular mosaic of non-fibrous units in thin section. Because of this it is well to bring into clearer focus what the geologist has in mind when using the terms *fiber* and *fibrous*.

Dana (1922, p. 182) says, "The structure . . . is called *fibrous* when the mineral is made up of fibres, as in asbestus, also the satin-spar variety of gypsum." Precise limits to the dimensions of a fiber have not been established, and would be purely arbitrary inasmuch as fibrous forms grade into columnar ones. A fiber of inorganic substance may consist of: a single, imperfectly crystallized and much elongated crystal, a series of such individuals placed end to end, a series of unelongated crystalline grains or plates whose lateral dimensions (i.e. normal to the fiber length) are equivalent, or a single threadlike mass of glass or amorphous material. Strict adherence to Dana's rigid definition of *fibrous structure* would prevent us from applying the term to the aggregate pseudomorphs described above, in which there are no individual fiber units.

Fibrous Quartz a Rare Phenomenon? Quartz has been considered among the minerals to which the fibrous habit is abnormal and, therefore, of uncommon occurrence. Fibrous quartz has been known for more than a century, and there are divers references to it in the literature of geology. Most of these, however, are descriptions of the same few instances by writers who disagree on the nature and origin of the fibrous structure. The first discovery of fibrous quartz is attributed by Hintze (1897, p. 1265) to Klaproth (1815) who believed, as noted above, that the quartz; of the African tiger-eye forms aggregate pseudomorphs of the associated crocidolite. Wibel (1873) supports this conclusion; Renard and Klement (1884) describe the occurrence without discussing the origin of the quartz; Hall (1918B) speaks of "infiltrated quartz" (p. 23), but does not specify whether infiltration involved replacement or displacement; and Peacock (1928, p. 247), from his study of material collected by Palache in Africa during 1922, says, "Although it might be held that the fibrous quartz . . . has replaced fibrous asbestos, the impression gained from the sections is that the two minerals grew concurrently"—that is, that the quartz was *moulded* by the contiguous asbestos. A similar controversy has occurred over fibrous quartz in Massachusetts and Rhode Island. Although the authorities agree thus far that each deposit described represents quartz developed through pseudomorphism (which appears to be of the aggregate type), they disagree about the identification of the palasome mineral. Emerson (1917, p. 63) holds that fibrous quartz in veins in phyllite near Worcester, Massachusetts (described previously by J. H. Perry and Emerson, 1903, p. 17) and in veins in the western part of the Narragansett Basin replaced "a prochlorite, possibly made fibrous by pressure"—a very uninformative statement. Hawkins (1918) concludes from extinction angles and color that the original mineral in veins of fibrous quartz in Carboniferous sediments near Providence, R. I., was actinolite asbestos. Richards' (1925) study of the same occurrence reveals that the wallrocks are graphitic schists and that the quartz replaced aphrosiderite.

The conglomerates of the auriferous Witwatersrand are known to contain fibrous quartz of secondary origin. I. Thord-Gray (1905, p. 72) refers to it as "honeycomb quartz with a very minutely fibrous structure"; Young (1907, p. 18) calls it a "fibrous form of secondary silica" which he later (1914, pp. 31–38) terms "fibrous quartz"—specifying still later (1917, p. 42) that it is the "infilling of a cavity" between secondary pyrite nodules (pseudomorphs of detrital quartz grains) and secondary massive quartz. No mention is made of an associated or preexisting fibrous mineral in this example of fibrous quartz. Young does record a radially-fibrous structure in some of the pyrite (1917, p. 65), but it is clear that the quartz has neither replaced this structure nor been molded by it. This, then, seems to be an illustration of a secondary, fibrous mineral which, apparently, achieved its unusual form free from the influence of another. Two other examples of the same type of phenomenon—that is, quartz made fibrous through some as yet obscure conditions attending its independent growth, deserve notice here as samples of what, the writer suspects, will eventually be found of common occurrence. (1) Howchin (1912, p. 197) notes veins of fibrous quartz traversing boulders of quartzite in the Permo-Carboniferous tillite of Australia. He does not describe the veins or discuss their origin, but no associated fibrous mineral is specified. (2) The writer recently found a vein of fibrous quartz with no associated asbestiform material in a boulder of quartzitic arkose within the Squantum tillite at Squantum, Mass.

Within recent months several additional cases of fibrous quartz which either grew concurrently with, filtered into and displaced, or replaced asbestiform amphibole have come to the writer's attention, viz.: in coarse veins from Wyoming (W. De Laguna);[1] in metamorphosed volcanic

---

[1] Names in parentheses indicate persons who discovered these examples and have discussed them with the writer. Details and conclusions concerning them will be published eventually by those named or by the writer.

rocks at Newton Upper Falls, Mass. (Dr. M. P. Billings); in femic dikes within the Roxbury conglomerate in Boston, Mass. (B. F. Buie) and in Chestnut Hill, Mass. (R. W. Sayles); in the Brighton Melaphyre in Allston, Mass. (L. R. Thiesmeyer); in basic volcanics in Dover, Mass. (R. F. Wiggins and R. A. Chandler); and in an altered Pre-Cambrian granite in Virginia (L. R. Thiesmeyer).

From a consideration of the remarks above, several generalizations may be made concerning fibrous quartz:

(A) Its occurrence is not limited to any particular type of rock, geological horizon, obvious mineral association, or geographic position.
(B) It is not always clearly associated with an asbestiform mineral in origin.
(C) It is, apparently, always a secondary mineral.

Further investigation of known occurrences and of new ones may disprove these statements, but, to the writer's knowledge, they stand at present unchallenged.

From (A) it follows that fibrous quartz may be expected almost anywhere. However, because there may be confusion about the application of the term *fibrous*, and because (except to the economic geologist)quartz veins are often easily-overlooked, incidental features of the rocks which contain them, references to fibrous quartz are scattered and relatively few. Nevertheless, the writer believes that fibrous varieties of quartz are far more common than has been supposed. One aim in offering this paper is to summarize the present state of knowledge regarding a feature which, regardless of the frequency or rarity of its existence, always requires special explanation. By thus focusing attention upon it, the writer hopes to stimulate the search for further illustrations of fibrous quartz which may confirm or disprove the suggestion just made.[2]

Significance of Fibrous Quartz Veins in Virginia. The presence of amphibole asbestos seams in the Catoctin greenstones of the northern Piedmont and Blue Ridge was recorded for Virginia long ago by Rogers (1884) and confirmed by Keith (1894) and others. Stose and Bascom (1929, p. 5) report them in Pennsylvania, and Furcron (1934, p. 402) notes "green, fibrous asbestos and quartz" in the Shenandoah National Park area. Furcron does not describe this material or state clearly whether the quartz is also fibrous; but Thiesmeyer (1936, p. 198) calls attention to fibrous quartz representing all stages of replacement and aggregate pseudomorphism of similar amphibole asbestos seams in the Blue Ridge of northwestern Fauquier County, Va., a few miles northeast of the area studied by Furcron. Further study of this material and

---

[2] The writer will welcome criticism of this paper, information regarding new occurrences, references which may have escaped his attention, and especially specimens of fibrous quartz to augment his small collection.

of the geology of Fauquier County has disclosed: (1) that such seams are widely distributed through the Catoctin greenstones in this vicinity (Fig. 1); (2) that the asbestos seams are chiefly cross-fiber actinolite—which Merrill (1896) and Taber (1917, p. 84) consider rare; (3) that the veins of cross-fiber quartz range up to 2½ feet wide (Fig. 2)—which makes them the largest veins of fibrous quartz yet described; (4) that the original actinolite seams clearly developed by replacement of the wallrock rather than by pushing it aside through the pressure of growing crystals, as Taber (1917) claims is true of most asbestiform veins; and (5) that this example of fibrous quartz represents an indubitable case of pseudomorphism rather than concurrent growth or infiltration without replacement. In addition to the regional character of the fibrous quartz in Virginia, these generalizations deserve proof through a more detailed description of the material here. This may help to clarify the nature and

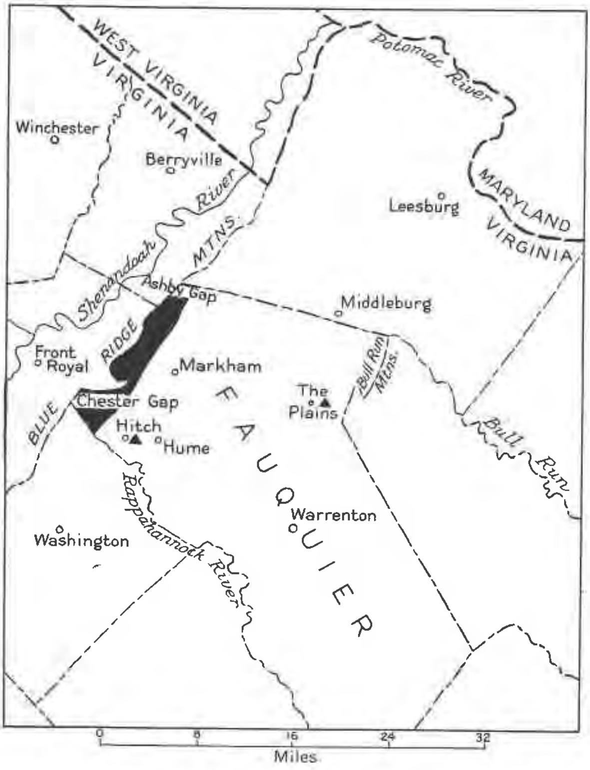
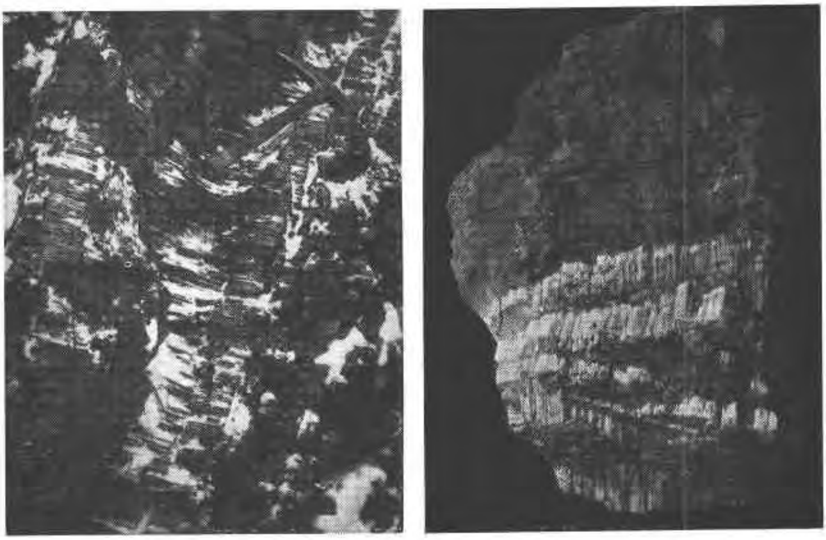


FIG. 1—Sketch map of northern Virginia, showing location of Fauquier County and districts in which fibrous quartz is abundant (black).

origin of other occurrences of fibrous quartz, and point the direction of emphasis in their investigation.

THE VIRGINIA DEPOSITS

Distribution, Size and Character of the Veins. Traverses along and across the belt of Catoctin greenstones which cap the Blue Ridge in Fauquier County, Virginia, disclosed literally thousands of lenticular seams of cross-fiber actinolite asbestos in all stages of replacement by transparent to milky quartz. These were found at irregular intervals all the way from Ashby Gap to Chester Gap, a distance of about thirteen miles. Similar veins were found in metabasalt dikes intruding gneissose granites between Hitch and Hume; and still others were noted a half mile east of the Plains in Catoctin greenstones which comprise a broad belt just west of the Bull Run Mountains. This latter exposure is more than twelve miles east of the Blue Ridge occurrences. It is entirely possible that many examples of such veins were overlooked by the writer throughout northwestern Fauquier County before his curiosity was stimulated by their profusion and magnitude in the Ridge country, and that they are an even more characteristic feature of certain facies of the Catoctin greenstones than is thus far suggested. At any rate, their distribution, as



(FIG. 2*a*) (FIG. 2*b*)

FIG. 2—(*a*) The largest known vein of fibrous quartz in the world. Snow serves to accentuate the fibrous appearance. 4 miles northwest of Markham, Va.

FIG. 2—(*b*) Boulder of Catoctin greenstone from the Blue Ridge, containing quartz pseudomorphs of cross-fiber actinolite veins up to 2 inches wide.

indicated in Fig. 1, shows that they are of regional rather than local importance.

These veins range from almost microscopic, hairlike films up to 2½ feet wide (Fig. 2*a*) and are arranged in subparallel groups which bear a somewhat en echelon relationship. Single boulders little more than a foot in diameter may contain dozens of them (Fig. 2*b*). Though the veins appear over many square miles of territory, as units they are small and local, ranging in length from a few millimeters to a few yards. Most of the veins are of the cross-fiber type (i.e., fibers oriented normal to the walls), but gradations to oblique fiber and to slip-fiber are common. Branching, bulging, bifurcation, central partings of wallrock of angular outline, monoclinal flexures—in fact, most of the features listed by Diller (1910), Taber (1924) and others as characteristic of asbestiform veins, are displayed in these Virginia deposits and have been inherited in varying detail by the pseudomorphous quartz which they contain (Fig. 3*a*).

(Fig. 3*a*)

(Fig. 3*b*)

Fig. 3—(*a*) Fibrous quartz pseudomorph of a monoclinal flexure developed through post-vein deformation of the original asbestos. ×1½.

Fig. 3—(*b*) Photomicrograph showing granulated mosaic of quartz, lacking asbestos inclusions, embedded in fibrous quartz crowded with residual asbestos. Nicols crossed. ×118.

About four miles northwest of Markham seams of a rather pure asbestos without fibrous quartz were found. They consist of dark-green, silky actinolite in bundles of readily-separable and inelastic fibers in which are embedded scattered aggregates of massive, opalescent to smoky, granulated quartz. Nearby veins of essentially the same character have numerous irregularly-spaced, fiber-like bands of quartz between the fiber-bundles, most of them only visible through a hand lens. Residual threads of actinolite which they enclose impart a greenish tinge to these quartz "fibers," the shade of green varying with the proportion of such material. These veins represent an incipient stage in the replacement of the asbestos veins by fibrous quartz. All stages of transition were found from veins of this type to those consisting of about 95% milky quartz (Figs. *2b*, *3a*), colored only locally by actinolite needles, and representing complete pseudomorphs of entire asbestos veins.

Nature of the Wallrocks. The Catoctin greenstones which contain these geological curiosities are a group of highly altered, volcanic rocks of basaltic affiliations which have been complexly folded, faulted and invaded by plutonic injections. Despite their involved history many remnants of original texture and structure suggest that these rocks were largely of extrusive character, and included flows, amygdaloids and pyroclastics. Keith (1894) described and named them and assigned them to the Pre-Cambrian. Recently Furcron and Woodward (1936) discovered that part of what had been mapped as Catoctin greenstone farther south is actually a basal Cambrian flow. Keith recognized two major subdivisions of the Catoctin, one invaded by granites, the other extrusive upon a floor of the same granites. Later workers have not followed this subdivision but have apparently regarded the Catoctin greenstones as a single unit of Pre-Cambrian volcanics, which some consider older and others declare younger than the adjacent granitic rocks. Incomplete studies by the writer suggest strongly that the Catoctin greenstones are divisible into a series of basaltic rocks whose eruption occurred periodically throughout late Pre-Cambrian and continued well into Lower Cambrian time.

Detailed descriptions of the Catoctin greenstones have been given by Keith (1894), Stose and Bascom (1929, p. 5), Furcron (1934) and others. The asbestos seams are present in massive, amygdaloidal, brecciated and highly schistose facies, but seem to be more common in the amygdaloids.

Thin sections of a moderately schistose wallrock from the Blue Ridge show its composition as: 20% feldspar (calcic oligoclase) in microlites arranged in somewhat ophitic pattern; 20% mosaic-textured quartz, most of which is secondary and is crowded with inclusions of the other minerals; 15% chlorite and epidote, the former oriented in a crude schistosity; 15% *actinolite in hairlike fibers having a random orientation, or in plumose, radiate groups;* 10% opaque oxide in subhedral, scattered grains; and 20% fine interstitial material of indeterminate nature (index and birefringence suggest carbonate for much of it). Of these constituents only the feldspar could be considered primary, the others having developed through metamorphism of what was probably an andesite or basalt. The amygdules consist of mosaics of anhedral quartz intergrown with subhedral to euhedral epidote. Both minerals enclose hairs of actinolite which often extend uninterrupted and undeformed across their mutual grain boundaries. Selvages of fibrous actinolite along the margins of the amygdules are invaded irregularly by the quartz filling. These relations indicate that the quartz and epidote of the amygdules formed later than and replaced former fillings of asbestos in some cases.

Replacement Origin of the Original Asbestos Veins. From a protracted study of asbestiform veins of many types, and from laboratory experiments in which he reproduced many of their essential features, Taber (1916A) concluded that most fibrous veins are the result of lateral secretion from the wallrocks, and that they make room for themselves by forcing their walls apart through the pressure exerted by the crystallization of their growing fibers. He agrees[3] with the writer, however, that this hypothesis is not applicable to the original asbestos veins of these Virginia deposits, which must have developed, rather, through replacement of the wallrocks. Proof of this is indicated in the relations outlined below.

No sign of even an incipient fracture was discernible beyond the ends of the veins; and no pressure effects within the wallrocks, or in adjacent veins which could be interpreted as results of forcible injection, or the wedging action of growing crystals, were discovered. The monoclinal flexures, gradation to slip-fiber and other irregularities, which Taber (1917, p. 83) would ordinarily attribute to differential movement of the walls during vein growth, are, in this case, clearly an effect of post-asbestos deformation because the individual fibers are shattered and strained. No sutures within the veins which might represent the original fracture that localized them, or might mark the boundary between fibers growing from opposite walls, were seen. Although macroscopically the vein walls appear very sharp, the vein material is not easily separable from the wall rock; and, in thin section under high power, the wall contact is a ragged border (with asbestos needles penetrating irregularly into the wallrock minerals) of the type attributed to replacement.

Several seams were located in a boulder northwest of Markham which afford striking megascopic proof of the replacement nature of the fibrous veins (Fig. 4). These consist of quartz pseudomorphs of actinolite seams.

---

[3] Personal communication.

arranged, in this instance, normal to the schistosity of an epidotized flow. The amygdules have been elongated and flattened parallel to this foliation, and some of them have curious dumb-bell shapes where two have coalesced in a narrow bottle-neck. A few of the amygdules are embedded within the vein, others are partly in vein and partly in wallrock, while some extend completely across into wallrock on either side. Thus they are analogous to unsupported inclusions in a dike which has not disturbed their regional orientation in the least. Gradual replacement of the wallrock around them, so that at no time were they actually unsupported, seems the only satisfactory explanation of their unique relations. No fracturing could be seen in the amygdules within the vein, and they have not been attacked by either the original asbestos or the quartz which replaced it.

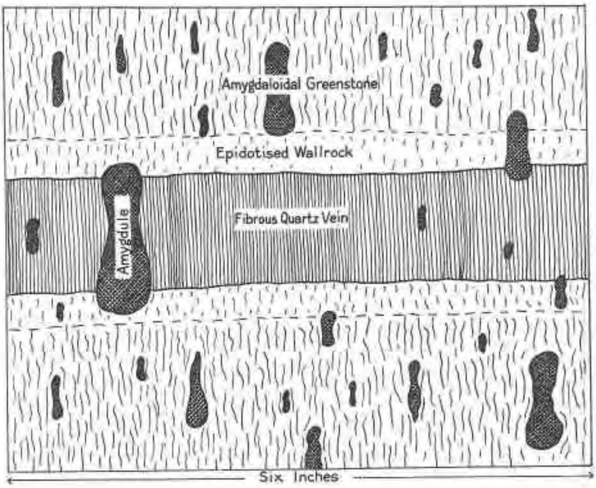


Fig. 4—Sketch of fibrous quartz seam enclosing amygdules whose orientation parallel to the schistosity has not been disturbed by replacement of the wallrock surrounding them.

Character of the Pseudomorphous Quartz. This fibrous quartz, unlike that described by Richards (1925), is not readily separable with the fingers, but does have a coarsely fibrous outline. A thin section cut parallel to the fiber-length was examined before it was completed, while still too thick for ordinary petrographic work. It showed masses 0.75 mm. wide by fifteen times as long which extinguished as units between crossed nicols. Upon slight warming of the balsam they could be separated longitudinally rather easily. However, when the section was ground to customary thinness, these units were seen to consist of a mosaic of smaller quartz grains—some elongated parallel to the thicker units, but many not elongated at all. They extinguished in all positions, indicating that the apparent unit extinction of the thicker mass is really the result of an overlapping of grains.

In transverse section the fibrous quartz appears as a mosaic of anhedral grains enclosing scores of residual actinolite fibers and sharing unreplaced bundles of them (Fig. 5). Delicately scalloped borders of these grains, revealed at high magnification, show that the quartz has inherited irregularly the transverse outlines of fiber-bundles. Out of 254 quartz grains measured with the Fedorov stage only $5\frac{1}{2}\%$ had their *c*-axes parallel to the fiber-length of the original asbestos, while the remainder were oriented at random. This indicates that the fibrous structure of the original vein had little influence on the orientation of the metacryst, even though its features were inherited in the aggregate. This was noted by Richards (1925), Reinecke and McClure (1933, p. 31) and Peacock (1928) in other examples of fibrous quartz. Peacock observes that the quartz fibers of the tiger-eye extinguish at all angles to their direction of elongation and says (p. 247), "It would thus seem that when quartz either replaces another fibrous mineral or grows concurrently with it, the elongation of the fibers is determined solely by the fortuitous orientation of the first quartz to crystallize, and is independent of the usual prismatic habit of quartz."

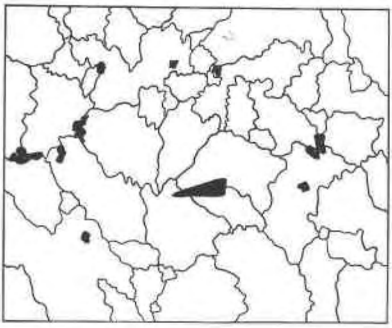


Fig. 5—Sketch made from a photomicrograph showing granular mosaic of quartz grains enclosing and sharing unreplaced bundles of actinolite (black). Section cut transverse to the fiber-length. Scalloped borders of the quartz suggest the outlines of asbestos bundles which it replaced. ×89.

In longitudinal section the fibrous quartz shows innumerable threads of included asbestos which extend uninterrupted across quartz-grain boundaries. The fibrous quartz is fractured and strained locally, but is not granulated or strained so severely as is the massive quartz of the original asbestos vein which occasionally appears in the midst of the pseudomorphous quartz (Fig. 3*b*).

Granular, secondary, subhedral to euhedral iron oxide scattered through the sections probably represents iron residue from the replacement process; while epidote concentrated along fractures within and traversing the quartz is obviously of later introduction.

Evidences of Secondary Introduction and Replacement Origin of the Fibrous Quartz. Proof that the fibrous quartz was not concurrent with the asbestos but was introduced after deformation of the latter is contained in the following facts:

A. The fibrous quartz shows none of the shattering and deformation common to the asbestos, but, on the contrary, encloses bent and broken residuals of it within the boundaries of a single grain.

B. Adjacent to veins which contain fibrous quartz the wallrock is thoroughly epidotized and silicified. The width of the zone of such alteration and its intensity are directly proportional to the amount of fibrous quartz present in the vein, and this alteration is totally absent along veins which lack this mineral. In other words, along with the introduction of quartz into the veins went the formation of quartz and epidote in the wallrock.

C. The features outlined below prove conclusively that, as has been already stated for the sake of clarity in description, the fibrous quartz is a secondary pseudomorph of the asbestos.

D. Actinolite inclusions are totally lacking in the original massive quartz of the veins, but are very abundant in the fibrous quartz, as noted above.

The universal absence of phenomena of displacement, varying in complexity with differing amounts of fibrous quartz present, argues strongly against any suggestion that the latter developed through pure infiltration without replacement. In addition to this negative evidence there is the positive evidence of replacement seen in thin sections, which show fibrous quartz invading bundles of actinolite laterally at several places and penetrating irregularly longitudinally from these points of attack, so that here only shreds of the bundles are left embedded in quartz, while farther along the same bundles are complete and unreplaced though surrounded by bundles which have suffered total replacement. Furthermore, the appearance in quartz of deformed structures like those of Fig. 3 is difficult if not impossible to explain except as an inheritance through replacement. Pressure great enough to have deformed the quartz plastically into such curious shapes would have left an indelible record of its operation in the wallrocks; indeed, it would probably have destroyed original minerals and textures.

Non-fibrous Quartz of Secondary Introduction and Replacement Origin. Poorly-defined veinlets with ragged margins which extend obliquely from the fibrous quartz veins into the wallrock can be seen in some thin sections. These consist of a mosaic of granular, massive quartz and epidote which preserves remnants of the textural pattern of the wallrock by enclosing ophitic feldspar laths, plumose groups of actinolite etc. Some of these included units are shared by adjacent grains of quartz or of quartz and epidote, and their original orientation has not been disturbed. Such veins are clearly developed by replacement, and their minerals are not granulated or strained. Presumably such veins were introduced contemporaneously with the fibrous quartz. Their lack of a fibrous character may be attributed to the absence of a uniform, well-oriented fibrous structure in the material which they replaced.

Some Problems

Origin of the Asbestos Veins. The regional distribution of asbestos seams in this vicinity is a feature which demands explanation in terms of a cause or process of regional influence. Since fibrous amphibole, the dominant constituent of the veins, is almost universally present in the greenstones, it is reasonable to consider that the vein material developed at the same time and through operation of the same processes as those which produced the fibrous amphibole within the wallrock. Recrystallization of original pyroxene in the rock to produce the stellate, actinolite "mass-fiber" suggests that during metamorphism solutions of actinolitic composition, which might migrate into potential openings to form veins, were made available. Keith's statement (1894, p. 364) that the metamorphism of these rocks was "mainly chemical and has not affected the original proportions of the rock to a marked extent" strengthens such a postulate by indicating that the metamorphism was accomplished by reorganization of materials in situ without introduction of foreign material. According to Sederholm (1926, p. 131) such a condition invariably implies diffusion and interchange of solutions within the rock mass. Taber (1924, p. 482) notes that the minerals in cross-fiber veins are also commonly present in their wallrocks, and his hypothesis of a lateral secretion origin for such veins reveals that he conceives of essentially the circumstances just outlined. Apparently, however, the Virginia deposits are inharmonious with his statement (1917, p. 84) that asbestos minerals are "rarely found in cross-fiber veins" because the "conditions prevailing at the time of their formation are not, as a rule, favorable for the solution and transportation of these minerals to a new place of deposition."

Although these veins may have resulted from lateral secretion during metamorphism, clear evidence of their replacement nature precludes the concept that they filled open fissures or forced their walls apart, as has been emphasized above. Furthermore, the irregular penetration of vein asbestos into the minerals along wall contacts suggests a process working outward by chemical attack from localized channels rather than one in which amphibole solutes migrated through the wallrock to concentrate in veins. There seems to be no obvious reason for postulating that the asbestos was introduced from a source outside the greenstones themselves, and the circumstances just mentioned argue that it was not derived by migration directly outward from the walls immediately adjacent. Therefore, we seem forced to the speculation that the vein-forming solutions were produced at somewhat lower levels in the greenstones (where, under greater temperature and pressure, they would achieve greater mobility and chemical potency) and migrated upward along certain permeable zones as replacing media. However, the discontinuous, lenticular character of thousands of seams of almost microscopic dimensions, which are not visibly interconnected or fed by larger ones, prevents ready acceptance of such an hypothesis and favors the alternative one of lateral secretion almost in situ. Yet these tiny veins offer the same objections to the latter as do their larger relatives. Consequently the source of the vein-forming material remains an open question.

Cause of the Fibrous Structure. Taber's explanation (1916A, p. 660) that fibers result from growth of crystals to which material is added *only at the base* by lateral secretion through closely-spaced openings in the wall-rock could, obviously, only apply to the Virginia veins if the solutions migrated laterally directly from the walls opposite the ends of the fibers. Since there is some doubt concerning such migration, as pointed out above, his theory is also of questionable application on this point. Moreover, the writer has failed to find indications that the asbestos veins grew inward from opposite walls.

Peacock (1928, p. 279) points out that "the tendency for crystalline substances to develop normal to their bounding surfaces is too common and consistent to be insignificant." He conceives of a process in which the first thin layers of material deposited consist of crystals, oriented normal to the walls, which become elongated into cross-fiber veins as successive accretions are deposited in crystallographic continuity with them. Since, as Warren (1932) shows, actinolite has a ready tendency to develop an asbestiform habit because of its molecular structure, the mechanism suggested by Peacock seems more plausible and calls for less special conditions to produce cross-fiber veins of asbestos than does that of Taber. However, this mechanism as stated applies to the formation of amphibole veins by crystallization from a saturated solution in which the new material is added to the growing fibers on the ends which extend into the vein; whereas in replacement veins it is, presumably, added at the opposite ends, at the surfaces of contact with the material undergoing attack.

The writer ventures to suggest, therefore, a modification of Peacock's idea which might explain the fibrous structure of these Virginia deposits. He assumes (1) that the amphibole solutions migrated longitudinally along potential openings rather than laterally into them from the wallrock, and (2) that they permeated outward from such channels into the walls to form and widen veins by replacement. Then incipient crystals of the first thin film of actinolite to form were oriented normal to the bounding surfaces and had an inherent molecular tendency to develop fibers. Since the solutions were saturated, not with respect to these newly-deposited crystals, but, rather, with respect to the wallrock minerals, they did not precipitate directly upon the amphibole. Neither did they clog the grain boundaries or pores between the first layer of crystals with new material, but used them as avenues of penetration (and might even have diffused through the actinolite space-lattice) to reach the zone of attack on the opposite side of this first layer. Here, effecting an exchange of their substance for that of the feldspar, pyroxene, etc., they deposited another layer of actinolite whose crystalline masses obeyed the impulse to form in crystallographic continuity with those adjacent. Through continuous repetition of this process elongated fibers developed. Their length became varied somewhat because of differential permeability relations between them. Consequently, their contact with the wallrock very soon became highly irregular and remained so until the cessation of the process. Further study is required before this suggestion can be applied to the origin of those bodies of oblique-fiber and slip-fiber which are clearly not the result of post-vein deformation; but the suggested explanation seems reasonable for cross-fiber, and might need only minor qualifications to explain the others.

It should be noted, in passing, that no suggestion known to the writer regarding causes for fibrous structure is adequate to explain the fibers of non-uniformly oriented amphibole so abundant in these wallrocks. The conditions under which actinolite (and other minerals) sometimes appears fibrous, though commonly it is not, are but vaguely understood. Also it seems more than likely that the reason (or reasons) for uniformly-oriented fibers in fibrous veins constitutes a wholly separate problem.

Possible Influence of Subjacent Intrusives on the Origin of the Fibrous Quartz. The regional replacement of these asbestos seams by fibrous quartz must, likewise, involve a regional process. That the quartz was introduced from an external source after the metamorphism of these rocks is seen in the associated silicification and epidotization of the vein walls. Since such alteration partially obliterates foliated structures in the greenstones, the quartz must have been introduced later than the regional metamorphism.

Downward-moving meteoric waters operating near the surface could scarcely have had the chemical power to effect a widespread disappearance of amphibole and substitution of quartz. Moreover, nearly as many veins of almost pure asbestos, or of asbestos only partially replaced by quartz, are exposed as of fibrous quartz with residual actinolite. If near-surface waters were the agents, presumably they could operate at present and during the recent past as well as formerly, and almost no unreplaced veins should be found.

Hydrothermal solutions from magmatic sources would surely be capable of the transformation represented here, but would probably leave indications of their source in minerals of magmatic association within the veins or wallrocks. Since these have not been found, we must consider the alternate possibility that meteoric waters, heated and charged with chemical force in depth, or driven upward by approaching large, subjacent, intrusive masses of considerable areal extent, could attack the asbestos veins along certain zones determined by permeability relations.

The presence of such subjacent intrusive bodies younger than *part* of the Catoctin has been repeatedly indicated by several writers. Keith (1894) emphasizes the widespread injection of (his lower) Catoctin by granite; Weed and Watson (1906) reported "syenite" intruding greenstone farther south along the Blue Ridge; Miss Jonas (1927) stated that granite intrudes metabasalt in northern Virginia; the Geologic Map of Virginia 1928 lists the Catoctin as intruded by Hypersthene Granodiorite and Marshall Granite; Furcron (1934) emphatically insists that the Catoctin is intruded by granitic rocks, and shows (p. 404) dikes of granite in the greenstone; and the writer observed greenstone invaded by granite in northwestern Fauquier County.

Therefore, if we must appeal to magmatic sources for the heat and potency of the fibrous quartz solutions, they are clearly indicated in the literature. Further study is needed to settle the matter, but it is quite reasonable to consider that fibrous quartz in northern Virginia owes its presence to a sort of "sweating" in the greenstone roof over major plutonic injections.

Summary

Brief consideration of the fibrous habit leads to the conclusion that some minerals are commonly asbestiform because of intramolecular forces peculiar to them, whereas others acquire it through special conditions of growth. Rarely fibrous minerals, usually associated with commonly-fibrous ones, derive their unusual features by concurrent growth, infiltration-molding, or replacement. All gradations are found between unit and aggregate pseudomorphs, the latter predominating among known occurrences; and residuals of the original mineral exist in all proportions within and between grains of the metacryst. Usage among

geologists has extended Dana's definition of *fibrous* to include material which is fiber-like in gross outline only.

Published descriptions and the writer's studies of fibrous quartz indicate: that it is far more common than has been supposed; that it is not restricted to any type of rock, geologic horizon, mineral assemblage, or geographic location; that it is always of secondary origin. Recent discoveries of fibrous quartz in Virginia, Wyoming, and at five separate localities near Boston, Mass., are reported.

A widespread occurrence of fibrous quartz in cross-fiber actinolite seams (which were believed rare) is described in some detail, and the origin of both the asbestos and the quartz is considered. The wallrocks are chiefly extrusive metabasaltic, Pre-Cambrian volcanics, and the quartz-asbestos veins, more common in amygdaloidal facies, display most features typical of asbestiform veins. The fibrous quartz formed through aggregate replacement pseudomorphism of the asbestos in all stages. Earlier massive quartz, embedded in the fibrous quartz, lacks residual amphibole and is severely granulated. Although fibrous in major outlines, the later quartz is a granular mosaic in thin section. This paper shows that the asbestos exerted very little control on the character of its successor, that the fibrous quartz followed post-asbestos deformation and was accompanied by epidotization and silicification of the wallrocks, during which non-fibrous quartz permeated them as replacement veins.

That the asbestos veins formed by replacement, rather than by displacement of wallrocks through pressure developed by the growing fibers, is clear. The writer believes that the asbestos formed during regional metamorphism by lateral secretion. Objections are noted, however, both to the concept of a fiber-growth through additions from the walls directly opposite the fiber-ends and to that of an upward migration of amphibole solutes along vein channels.

A mechanism to explain the fibrous habit of the vein material is outlined, but conditions governing development of fibrous amphibole in the wallrocks are thought to constitute a wholly separate problem. The ababsence of fibrous quartz within the wallrocks is attributed to their lack of uniformly-oriented asbestos.

No minerals of magmatic origin, which would suggest that hydrothermal solutions direct from subjacent plutonic injections substituted fibrous quartz for amphibole, were observed. The writer emphasizes that several authorities agree on the invasion of part of the Catoctin greenstones by large granitic masses, and concludes that such bodies would have occasioned wholesale migration of heated meteoric waters as potential media of replacement through them to form the fibrous quartz.

ACKNOWLEDGMENTS

During this study and the preparation of this paper numerous individuals have given the writer invaluable assistance through comment, criticism and suggestion, as well as in the mechanical details of laboratory procedure, photographic technique and typing. Space does not permit specific reference to the contributions made by each, but the writer is eager to acknowledge his indebtedness to: Drs. M. P. Billings, C. H. Burgess, E. B. Dane, Jr., C. S. Hurlbut, Jr., E. S. Larsen, Jr., K. F. Mather, M. A. Peacock, E. L. Perry, S. Taber; Messrs. B. F. Buie, C. A. Chapman, E. Schmitz; Col. and Mrs. A. E. Peirce; Mrs. L. R. Thiesmeyer; and Miss Doris Mann.

REFERENCES

Dana, E. S. (1922): *Textbook of Mineralogy*—New York.
Diller, J. S. (1910): *U. S. Geol. Surv., Bull.* **470.**
Emerson, B. K. (1917): *U. S. Geol. Surv., Bull.* **597.**
Furcron, A. S. (1934): *Jour. Geol.*, **42,** 400–410.
——— and Woodward, H. P. (1936): *Jour. Geol.*, **44,** 45–51.
Hall, A. L. (1918A): *Geol. Soc. S. Africa, Mem.* **12.**
——— (1918B): *Proc. Geol. Soc. S. Africa*, **21,** 1–36.
Hawkins, A. C. (1918): *Amer. Min.*, **3,** 149–152.
Hintze, C. (1897): *Handbuch der Mineralogie*, **2** (2), 1265–1266.
Howchin, W. (1912): *Jour. Geol.*, **20,** 193–227.
Jonas, A. I. (1927): *Geol. Soc. Amer., Bull.* **38,** 83–846.
Keith, A. (1894): *U. S. Geol. Surv., 14th Ann. Rep.*, **II,** 293–395.
Klaproth, M. H. (1815): *Beiträge z. Chem. Kenntniss d. Mineralkörper*, **6,** 233.
Merrill, G. P. (1896): *Proc. U. S. Nat. Mus.*, **18,** 281–299.
Peacock, M. A. (1928): *Amer. Min.*, **13,** 241–286.
Perry, E. L. (1930): *Amer. Jour. Sci.*, **20,** 177–179.
Perry, J. H. and Emerson, B. K. (1903): *The Geology of Worcester, Mass.*—Worcester.
Reinecke, L. and McClure, L. (1933): *Proc. Geol. Soc. S. Africa*, **36,** 29–39.
Renard, A. F. and Klement, C. (1884): *Bull. Acad. Roy. Belgique*, **8,** (3), 530–550.
Richards, G. (1925): *Amer. Min.*, **10,** 429–433.
Rogers, W. B. (1884): *Geology of the Virginias*—New York.
Sederholm, J. J. (1926): *Comm. Géol. Finlande, Bull.* **77.**
Stose, G. W. and Bascom, F. (1929): *U. S. Geol. Surv., Folio* **225.**
Taber, S. (1916A): *Proc. Nat. Acad. Sci.*, **2.** 659–564.
——— (1916B): *Amer. Jour. Sci.*, **41,** 532–556.
——— (1917): *Trans. Amer. Inst. Min. Eng.*, **57,** 62–98.
——— (1918): *Jour. Geol.* **26,** 56–73.
——— (1919): *Trans. Amer. Inst. Min. Eng.*, **61,** 3–41.
——— (1924): *Econ. Geol.*, **19,** 475–486.
——— (1926: *Econ. Geol.*, **21,** 717–727.
Thiesmeyer, L. R. (1936): *Amer. Min.*, **21,** 198.
Thord-Gray, I. (1905): *Proc. Geol. Soc. S. Africa*, **8,** 72.
Warren, B. E. (1932): *Indus. & Eng. Chem.*, **24,** 419.
Wibel, F. (1873): *N. Jb. Min.*, 367–384.
Young, R. B. (1907): *Proc. Geol. Soc. S. Africa*, **10,** 18–19.
——— (1914): *Proc. Geol. Soc. S. Africa*, **17,** 31–38.
——— (1917): *The Banket*—London.