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ASBESTIFORM AND/OR FIBROUS MINERALS IN MINES, MILLS, AND QUARRIES

by

Walter Bank¹

ABSTRACT

One theory of mineral-fiber-induced lung damage holds that the shape and size of the responsible inorganic materials are significant factors. Asbestiform minerals, fibrous minerals, or elongated cleavage fragments, irrespective of the mineral name applied or definitions employed may, therefore, become significant in a health evaluation of airborne dust. Many minerals in ore deposits and quarries exist in variable habits, including the fibrous shape. Names of such minerals vary, depending on locality, availability of analytical equipment and personnel, traditional usage, and other factors. Because of these factors workers in the mining and associated industries unknowingly may be exposed to asbestiform or fibrous minerals.

Appendix I lists many minerals that occur in asbestiform or fibrous habits or which tend to cleave into elongated fragments. Appendix II lists some selected mines, arranged by commodities and scattered throughout the conterminous United States, where fibrous minerals may be found. Actual mine visitations have confirmed the presence of such fibrous minerals.

INTRODUCTION

Experiments on animals and human pathology indicate that the size and shape factors of inorganic substances are significant in the etiology of asbestosis, other pneumoconioses, and various cancers. Many miners, mineral processors and quarry workers may unknowingly be exposed to asbestiform and/or fibrous minerals which are hazardous to their health. Industrial minerals, sold directly in the form of consumer products, may also constitute health risks to the consumer.

This report discusses mineral assemblages found in ore deposits and quarries, cites potential hazardous minerals, and predicts where fibrous mineral health hazards might exist.

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REVIEW OF MEDICAL ASPECTS

Mining and milling industrial-type asbestos has produced both the pneumoconiosis called asbestosis and neoplasms specifically attributed to asbestos; yet after more than 40 years of published research on biological aspects, many questions remain, particularly the dose-disease response relationship with respect to cancers. At an international conference on the biological effects of ingested asbestos held in Durham, North Carolina, in November 1973, Dr. Paul F. Holt of Reading University, England, alluded to some of the uncertainties with the question, "Does asbestos matter, or doesn't it?" (1)²

The term asbestos is ambiguous, because it includes many natural inorganic minerals, all with an asbestiform habit, that differ from each other in chemical composition, particle-size ranges, morphology, and probably biological effects. The definition of and discussion of the term asbestos will be reserved for the mineralogy and petrology section of this report.

The pneumoconiosis called asbestosis is characterized by, among other things, the presence of an abnormally high quantity of ferruginous bodies or "asbestos" bodies in the lungs. These are generally golden-brown ferro-coated formations, usually symmetrical and segmented with clubbed ends, 3 to 5 microns in cross section and 20 to 50 microns in length. The core consists of a fiber which may or may not be asbestos (16). The ferruginous bodies, are in fact, nonspecific. The core fibers may be synthetic materials such as fibrous glass or other inorganic materials.

Recent animal experimental work, as stated in the literature, demonstrated that fibrous glass, palygorskite, nemalite (brucite), pectolite as well as asbestos, caused fibrosis and/or abdominal tumors and mesotheliomas. Some experimenters stressed the importance of particle-size ranges and shapes, and were drawn to the conclusion that the pathologic reaction to asbestos, fibrous glass and other fibrous materials seems primarily related to the shape, size and durability, rather than to other parameters, such as surface properties and chemical composition (34), (22), (9), (6), (25), (36), (7), (23), (38).

Some investigators believe that the longer fibers (longer than 5 micrometers) are more hazardous as demonstrated by the ferruginous bodies described above, which are found in connection with asbestosis and some cancers; other investigators believe that the shorter fibers are significantly hazardous with respect to mesotheliomas (17). The shorter fibers tend to reach the mesothelial linings. Also, smaller fibers tend to migrate to other organs once inhaled and/or ingested.

²Underlined numbers in parentheses refer to items in the list of references preceding the appendixes.

Welsh investigators believe that the fibrous zeolite, erionite, is responsible for an epidemic of mesothelioma observed in the Turkish village of Rarians. This belief was expressed at the meeting of the Society for Occupational and Environmental Health, held December 4-7, 1977, in Washington, D.C. The work of Stanton (34) suggests that any durable fiber within a given range of length and diameter may be carcinogenic.

The discussion in the previous paragraphs indicates that a quandry exists in medical knowledge concerning "asbestos" exposure and resulting disease. Tumors have been produced when various fibrous minerals and inorganic fibers have been injected into the pleural cavities of experimental animals. These tumors occur when the fibers are longer than eight micrometers and less than 0.25 micrometer in diameter. According to some authorities, shorter fibers do not produce such tumors; other authorities disagree. Shorter fibers would be important contributors to cancer induction if a biochemical mechanism for cancer were involved.

Other animal experiments with fibrous dusts have also resulted in fibrotic lung reactions. When the fibers have been carefully prepared and characterized, the longer fibers are considered responsible for the fibrotic reactions when the animals are exposed through inhalation or intra-tracheal instillation.

Because a method of transport of fibers inhaled by humans from the airways of the lung into the pleura is not known, these animal experiments are often discounted for interpreting human data. However, mesotheliomas occur in humans who are associated with at least three of the commercial asbestos types, namely chrysotile, amosite, and crocidolite. No cases of mesothelioma have been reported among Finnish miners who were exposed only to anthophyllite asbestos, but an excess of lung cancer exists.

Aside from shape and size factors, biochemical mechanisms for cancer induction merit serious consideration. A paper summarizing possible biochemical mechanisms has been given by Langer and Wolff (17).

Because of the unknown mechanism for cancer induction, the properties of fibrous minerals that are important to disease production are not known. With the present state of our knowledge, it is not possible to examine a particle either physically or chemically and be able to say whether it may or may not be biologically active. Indeed, the several different diseases resulting from asbestos exposure may result from different particle properties. But among all the possibilities of health hazards causes, the Stanton and Wrench (34) work currently appears to be most acceptable as a consensus opinion.

MINERALOGY AND PETROLOGY

Definitions

As stated earlier, the term "asbestos" is ambiguous. Asbestos is a generic term for a variety of hydrated silicate minerals which have one common

attribute, namely the ability to be separated into relatively soft, silky fibers. Minerals which fit the above description are described as asbestiform minerals (32), whereas the term asbestos is generally applied to the commercial product. Recently, mineralogists have been applying more refined definitions to such terms as asbestos, fibers and their associated terminology (30), (3).

Commercial production and applications of asbestos fibers are considered usually to be the significant source of asbestos fibers entering the environment, but this may be a misleading over-simplification. The thesis of this report is that, potentially, many workers in the mining and associated industries unknowingly may be exposed to asbestiform or fibrous minerals which occur as gangue minerals.

Cralley et al (5) report over 100 different minerals with some degree of fibrous structure; their examples include, and rightly so, minerals other than hydrated silicates. These minerals may be found in ore deposits, rock quarries or soils not normally associated with commercial asbestos, and may become airborne by natural atmospheric conditions (32) or by conventional mining and milling operations.

Nomenclature Inconsistencies

A mineral, by definition, is a natural inorganic substance with a given chemical composition and with a given atomic structure which is expressed by its crystalline form and other physical properties. Presumably, it is also homogeneous.

This definition of a mineral is loosely applied and has many exceptions. As more sophisticated analytical equipment has been employed, many so-called minerals have turned out to be mixtures of intergrown minerals; the old names however, often are retained. Serpentine, for example, can be a single mineral or mixture of several minerals, but the term serpentine is still in common usage...as a mineral group name and as a rock name (serpentinite generally is used as the rock name). This loose practice is particularly true when exact mineral identification is economically unwarranted or difficult to obtain.

Some diversely named minerals from different localities have turned out to be variations of the same mineral, with the result that the same crystalline material may have two or more names. When so identified, one name is given priority, but the other names are retained also -- particularly when localities or personalities are involved. For example, williamsite, the gem serpentine material now is identified as antigorite; bowenite and picrolite also turn out to be antigorite; and yet all names are employed in the mineral literature.

The chemical nature of the minerals may become quite complex, with different elements substituting for each other in varying ratios. When only a few elements are involved, one may have family mineral groups with end members carrying the names. For example, actinolite is the iron-rich member of the tremolite-actinolite series, with a division point established at

10 percent iron, according to one authority; whereas another authority restricts the name actinolite to members with the iron content between 10 and 90 mol percent, and applies the name ferro-actinolite to the iron-rich end of the series. Other authorities have their own ranges and nomenclature for mineral families. Also, the variable nature of amphiboles, pyroxenes and chlorites (the common "ferro-magnesian") makes it necessary to classify a particular sample as "most closely resembling" a specific mineral species or variety. And it must be noted that conclusive identification is very difficult, often requiring electron microscopy, X-ray and/or electron diffraction, and other ultra-sophisticated analytical methods.

Adjectival prefixes may be used with mineral names, two examples being soda-asbestos and iron-rich tourmaline; or more specific names such as eckermanite or schorl may be used interchangeably for those two minerals respectively.

Sometimes economic or technologic conditions determine the mineral's name; for example, if the minerals of the cummingtonite-grunerite series are of economic value as asbestos, the names amosite or montasite are used, depending on the mineral deposit's location or the mining company working the deposit.

Some mineral names are used both as a group name and as a specific mineral name; montmorillonite is such an example, and because of the confusion this engenders, attempts are made to apply the name smectite as the group name. Currently, mineral names of the montmorillonite group are used without much agreement in nomenclature.

Rock names compound the confusion caused by mineral nomenclature. By definition, a rock consists of one or more minerals, and makes up a structural unit of the earth's crust. It generally has a sufficiently definite mineral composition and physical character so that it can be distinguished from its neighbors -- but not always; gradations in composition and alteration effects are pronounced on a local level. For example, pyroxene is a "family" name for numerous ferro-magnesium minerals; pyroxenite is the name applied to the rock unit when it is composed predominantly of pyroxene minerals and/or their alteration products, that is, serpentine, chrysotile, etc. Amphibole likewise is a "family" name for numerous other ferro-magnesium minerals; amphibolite is the name applied to the rock unit when it is composed predominantly of amphibole minerals.

For the most part, ore deposits are freaks of nature. They represent concentrations of mineral substances that can be mined at a profit. Such deposits may occur in igneous, sedimentary or metamorphic rocks, which are the three major classifications of rock systems. Asbestiform or fibrous minerals also are found in the major types of rocks and are associated with ore deposits. These asbestos minerals may be obvious to the eye and may even be mined for their value, or their presence may be recognized only by trained personnel or even be entirely overlooked.

Sampling and Evaluation of Fibrous Dusts

At this point, a digression as to industrial hygiene sampling techniques and sample evaluation is in order. For asbestos-hazard evaluation, Mine Safety and Health Administration (MSHA) personnel employ the air sampling and counting method established by the U.S. Public Health Service (2). This involves collecting airborne dust on a cellulose ester membrane (Millipore) filter at a known air flow rate, preparing microscope slides of the sample, and counting fibers with phase contrast microscope optics at approximately 400-450 diameter magnification. Only particles with a 3 to 1 length-to-width ratio or greater, and longer than five micrometers in length are counted; shorter particles are not counted although they may be present in large numbers. Presumably, fibers with a width as small as two-tenths micrometer can be detected by this method; thinner fibers are present which can be seen with the electron microscope. Thus, our counting technique, although standardized, is only an index of the total exposure. It must also be noted that different Government agencies have different standards for health-hazard evaluation; the Food and Drug Administration states that there are many asbestos minerals but only six are of commercial importance (13)³ and limits their presence in a product to a specific percentage of its composition; the Occupational Safety and Health Administration (OSHA) and MSHA enforce standards for asbestos based on time-weighted averages of airborne fibers greater than five micrometers in length per milliliter of air; and the Environmental Protection Agency has other standards or guidelines. The MSHA standard, including the minerals specified as asbestos, is published in Title 30, Code of Federal Regulations, Part 55.5-1(b).

Airborne dust does not necessarily have the same mineral composition percentages as the parent rock. The fine, fibrous fraction may comprise a greater proportion of the airborne dust than the parent rock. In addition, the nature of fibrous minerals is such that small amounts of fibrous minerals may not be detected by conventional analytical methods - yet when the material is crushed and becomes airborne, significant amounts of fibers or elongated cleavage fragments are observed on the filters. For example, Speil and Leineweber (32) cite and illustrate a sample of pure serpentine considered to be of nonfibrous composition based on petrographic examination; yet this "museum grade" translucent serpentine yielded 20 percent fibers under the electron microscope.

Mineral Fiber Identification Problems and Some Examples

Fibrous minerals collected on filters are often difficult to identify. For example, chrysotile and its host rock "serpentine" yield identical X-ray diffraction patterns but can be distinguished from each other by optical microscopy or electron microscopy. Under the electron microscope, some "granular" or massive serpentine probably will turn out to be fibrous in part, as in the Speil and Leineweber (32) example cited above.

³A deposit of richterite, one of the amphibole minerals not usually listed as a commercial asbestos, reportedly is contained in the Diablo Asbestos Deposit near Van Horn, Texas. This deposit is suitable for strip mining.

The energy dispersive X-ray analysis (EDXRA) and the selected area electron diffraction (SAED) methods used in conjunction with the transmission and scanning electron microscope are useful tools for identifying fine fibers, but have limitations such as not being readily available.

Visually insignificant amounts of fibrous material are found with vermiculites from the Carolinas, yet reportedly significant amounts of fibrous material are found in airborne dust samples. The important vermiculite ore deposit at Libby, Montana contains easily recognizable fibrous tremolite in hand specimens, and airborne dust samples under the phase contrast microscope show numerous fibers which are inferred to be tremolite, but electron microscope pictures prepared by Mt. Sinai Hospital personnel demonstrate that chrysotile fibers also are definitely present (personal communication). Recently a published paper describes vermiculite altering to chrysotile (19). Chrysotile is one of the few fibers which usually can be identified under the transmission electron microscope when finely divided.

It is important to specify the method of analysis when stating analytical results. McCrone and Stewart (18) cite a talc analysis as follows:

- "1. X-ray diffraction shows no chrysotile or amphiboles.
2. A phase-contrast method (similar to the NIOSH procedure to determine the number of fibers per milliliter of air) shows 1,500 fibers greater than $5\mu\text{m}/\text{m}^3$ of sample.
3. The scanning electron microscope with energy dispersive X-ray analyzer shows about 10^4 fibers/liter suspected of being amphibole asbestos.
4. Dispersion staining shows 150 anthophyllite fibers/gram of sample.
5. Transmission electron microscopy shows 5×10^6 anthophyllite fibers/liter of sample."

Fibrous minerals generally are present in talc deposits, but until recently have not been suspected as a public health problem in the general population. Now the importance of these fibers has been recognized for talc of cosmetic grade, and analytical X-ray and electron diffraction methods have been developed to determine the quantity of fibers down to a quarter or a half of a percent (33), (30). Reportedly, this applies to tremolite and other asbestiform minerals.

Many minerals adopt different habits or shapes in nature. They may be platy in one deposit, equant crystals in another deposit, or acicular (needle-like) or threadlike in yet another. In short, most asbestiform minerals have their different shaped counterparts with the same chemical composition.

Finally, as indicated earlier, a mineral substance may be assigned any one of several names, depending on the degree of completeness of analysis and upon the analyst's definition of terms.

Discussion of Minerals Which May Occur in Fibrous Form

Mining literature contains many references where minerals that may occur in fibrous form or cleave into elongated fragments are associated with ore deposits or quarried rock. Certain industrial mineral or ore deposits characteristically contain asbestiform minerals as an impurity or, as in the case of some talcs, as a desirable ingredient (for example, as a paint extender). An admittedly incomplete list of minerals that may occur in fibrous habits and which occur in rocks or ore deposits together with some synonyms and rock terms that immediately imply the presence of fibrous minerals is tabulated in appendix I.

Appendix I requires further explanation. Certain rock types, particularly where "alteration" has occurred, tend to have minerals which easily replace others of a somewhat similar chemical composition. If other chemical elements have been introduced into the rock during the alteration process, still other minerals will be formed. Alteration effects vary in degree from "fresh" rocks to completely altered material. The size of the new-formed minerals may range from relatively huge crystals to grains or fibers recognizable only under the high magnification of the electron microscope.

Discussion With Predictions of Ore Deposits Which May Contain Fibrous Minerals

As mentioned earlier, the three types of rocks (igneous, sedimentary, and metamorphic) all carry ore deposits. Rocks of each type, when altered, have certain characteristics in common - sometimes. And these characteristics include the formation and presence of minerals which might have the asbestiform or fibrous habit. Knowing the generalized mineral associations that may occur in these ore-containing rocks, it is possible to infer the presence of certain minerals that may or may not occur in fibrous habit in the size range of hygienic interest. But whether the mineral actually is fibrous in a particular deposit can be determined only by direct observation or careful analysis; only occasionally can the fibrous habit be definitely predicted. For example, most talc deposits contain one or more fibrous minerals or minerals which cleave into elongated fragments, but some deposits are relatively fiber-free. Another example, ultrabasic igneous rocks alter easily, and a reasonably certain prediction can be made that serpentinites will be found that carry some fibrous minerals.

To demonstrate the thesis that many workers in the mining industry may be exposed to asbestiform or fibrous minerals, a list of some well-known mines, or mining areas, was prepared; this listing, by commodity, and noted as appendix II, was selected largely from a recently published book entitled, Ore Deposits of the United States, 1933-1967 (26). This publication was selected because of its timeliness and accessibility; and specific pages are referenced for localities of mines or commodities where minerals are noted which commonly occur in the asbestiform or fibrous habit. These examples were selected specifically to demonstrate the wide geographic range in which ore deposits carrying fibrous or asbestiform minerals may occur. To amplify the examples from this publication, other specific references also are cited in appendix II.

Possible Fibrous Mineral Occurrences in Different Rock Types

Basic Igneous Rocks

Basic igneous rocks, meaning igneous rocks which are relatively low in silica, usually contain "ferro-magnesium" minerals. Such rocks alter easily, with the minerals changing to other ferro-magnesian. In this process, many of the minerals formed may be of fibrous character. Serpentine or serpentinites are a common alteration product with their usual complement of fibrous minerals. Also, zeolite minerals and their associated minerals often are found in basic rocks.

Medium-Basic Igneous Rocks

Medium-basic igneous rocks also carry ferro-magnesium minerals in the form of amphiboles or pyroxenes. When these rocks are altered, as occurs commonly when ore minerals are introduced, for example, as in the so-called porphyry coppers of the Southwest, these ferro-magnesium minerals may alter to minerals with a fibrous habit.

Sedimentary Rocks

Among sedimentary rocks, some clay minerals such as attapulgite, palygorskite, meerschaum, etc., are normally fibrous; or they may become so under very low-grade metamorphic conditions. Some soils are known to contain fine fibrous palygorskite of nondetrital origin (31). In limestones and dolomites of the Northwest U.S.A., certain areas, such as the Metaline Falls country, Washington, have been mineralized and yield lead ores; fibrous palygorskite or "mountain leather" which is classed as a clay mineral is a common gangue constituent. Tremolite, also, has been described (oral communication, John Currie, MSHA) as a component of these rocks.

Reportedly, the Abril Zinc Mine (Cochise County, Arizona) has asbestos in the Permian limestone (35). Sometimes sedimentary beds of pyroclastic origin (volcanic ashes, etc.) yield considerable amounts of zeolite minerals (20), (21).

Metamorphic Rocks

When igneous or sedimentary rocks are metamorphosed; that is, altered significantly, minerals of a fibrous character can develop. Basic igneous rocks become decomposed dunites or kimberlites, or altered pyroxenites, grading over into serpentinites and amphibolites to "greenstones," or even to vermiculite-biotite-tremolite assemblages of minerals; in turn these often develop into mineral assemblages that also may contain other fibrous minerals. Limestones and dolomites are altered to "tactites" or ferro-magnesian assemblages under certain conditions, with later alteration to minerals of fibrous habits; or they may alter in part or completely to serpentinites with fibrous assemblages as in the asbestos deposits of Arizona (35). Limestones or dolomites may be altered to talc deposits in which occur platy and/or fibrous amphiboles plus, sometimes, chrysotile.

Some of the so-called "marble" or verd antique, an ornamental stone used as facing material, is actually a serpentine or a serpentine-calcite complex. Such rocks may contain significant amounts of fibrous minerals. Other quarries developed for construction materials in rocks, such as limestones, dolomites, serpentinites, trap rock, and tuffs may carry fibrous or cleavable minerals, such as tremolite, chrysotile, or zeolite minerals and associates. One asbestos open-pit mine in California sold its serpentinite waste rock for road-bed material; and some parking lots, or equivalent, are filled with serpentinite waste rock from the old chrome mines in the Pennsylvania-Maryland area. Homestake, a gold mine with a country rock consisting largely of cumingtonite-grunerite, uses some of its waste rock locally to fill in low spots or in parking areas. Quarried serpentinite has been used as road-bed and driveway gravel in the Washington, D.C., area (29).

Shales and siltstones alter to schists, gneisses, and quartzites; when admixed with limestones or dolomites, talc deposits may form. Sillimanite schists, pyrophyllite schists, and other similar metamorphic rocks containing fibrous minerals are derived, generally, from shales.

SUMMARY AND CONCLUSIONS

The pneumoconiosis called asbestosis and neoplasms such as lung cancer, gastro-intestinal cancer, and mesothelioma, are attributed to asbestos as a causal agent, but the exact mechanism of the insult is not known. Hence it is not possible to examine a particle either physically or chemically and be able to say whether it may or may not be biologically active.

Among the various theories proposed, one theory is assuming strong support; it holds that the shape and size and durability of inorganic fibers are important factors.

Therefore, fibrous minerals or elongated grains or elongated cleavage fragments, irrespective of the composition and other physical characteristics, may possess significant potential hazard in airborne dust. Many minerals in ore deposits and quarries exist in varied habits, including the fibrous shape, or break into elongated fragments. The names of such minerals may vary, depending upon identification requirements, the availability of analytical equipment and personnel, and local terminology.

The term asbestos is indefinite. If we think more in terms of "asbestiform" or fibrous or elongated fragments, then many minerals become suspect. A list of potential fibrous minerals and rocks carrying fibrous minerals is appended. Many of these minerals, if fibrous, may go unnoticed to the average observer.

A literature search revealed that many ore deposits contain gangue minerals which may occur in a fibrous form. A list of mines or mining areas, arranged by commodity and selected to express the wide, geographical range of deposits, is appended together with references to document these occurrences of suspect minerals. This list represents selected mine examples only, and is by no means to be considered comprehensive. Also one must recognize that the minerals cited may or may not be fibrous. In many cases, only an

analysis by an electron microscope will confirm whether asbestiform or fibrous minerals are present in the airborne dust.

Many uncertainties exist concerning the mineral terminology and many medical differences of opinion are expressed in the field of asbestos or mineral fiber pathology. MSHA and the National Institute for Occupational Safety and Health (NIOSH) have cooperatively undertaken several studies to further define the hazards of fibrous mineral exposures. Although not complete, these studies involve talc, wollastonite and attapulgite mining as well as the mining of recognized asbestos minerals. NIOSH also is attempting to simplify fiber-count evaluation (11). It is important that persons exposed to fibrous minerals understand the potential for disease, and therefore, the Mine Safety and Health Administration (MSHA) is providing this information to the mining industry. MSHA inspectors are actively attempting to identify all probable exposures to fibrous minerals and have collected airborne dust samples, following the NIOSH standardized procedures (2), to evaluate the hazard and suggest remedial action.

Mine operators should be alert to the possibility of illness that may be associated with any fibrous mineral. Those operators whose employees are exposed to recognized asbestos minerals should conduct air sampling programs and take suitable action to assure that the employees are not exposed to asbestos dust exceeding applicable standards. When employees are exposed to other fibrous minerals, the operators should also take air samples to evaluate exposures using the same techniques as for asbestos.

Employees should also be fully informed regarding their exposures and the potential for disease as well as the necessary controls and actions they may take to prevent unnecessary exposure.

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APPENDIX I.--MINERALS THAT MAY OCCUR IN FIBROUS HABITS, THEIR
SYNONYMS, AND ROCKS AND MINERAL SUITES GENERALLY EXPECTED
TO CONTAIN MINERALS OF A FIBROUS HABIT.

1. Chrysotile
2. Amosite
3. Crocidolite
4. Tremolite asbestos
5. Actinolite asbestos
6. Anthophyllite asbestos
7. Cummingtonite

Specified as an asbestos by MSHA.

Do.

Do.

Do.

Do.

Do.

An end member of the cummingtonite-grunerite series. Industrial forms of this mineral are called (2) amosite or (8) montasite.

See (2) and (7) above.

See (7) cummingtonite.

The fibrous, commercial material is called (3) crocidolite.

8. Montasite
9. Grunerite
10. Riebeckite
11. Magnesioriebeckite
12. Amphibole

A family name for a group of silicate minerals, many of which are asbestiform or break into elongated cleavage fragments. Includes (2), (3), (4), (5), (6), (7), (8), (9), (10), (11), (13), (14), (15), (16), (17), (18), (19), (20), (21), (23).

13. Glaucophane

A fibrous variety of glaucophane.

14. Rhodusite

15. Richterite

16. Hexagonite

A manganese tremolite.

17. Tirodite

18. Nephrite jade

Tremolite or actinolite, fine-grained, massive and felted in hand specimens which yields jade-like material.

19. Byssolite An olive-green variety of fibrous amphiboles.
20. Sodz asbestos
21. Eckermanite Also soda asbestos (20).
22. Pyroxene Used as a family name for a group of silicate minerals (which includes fibrous jadeite). Often alters to amphiboles or to serpentine minerals.
23. Uralite An alteration product of pyroxene minerals, generally a fibrous amphibole of undetermined composition.
24. Wollastonite A common rock-forming pyroxenoid mineral.
25. Bustamite A pyroxenoid mineral.
26. Pectolite A pyroxenoid mineral often found with zeolites.
27. Zeolites and associated minerals (see 26) including: (21).
28. Mordenite (see Amer. Min., v. 58 (1973), pp. 287-290) (20).
29. Clinoptilolite A zeolite.
30. Natrolite Do.
31. Mesolite Do.
32. Scolecite Do.
33. Thompsonite Do.
34. Gonnardite Do.
35. Edingtonite Do.
36. Stilbite Do.
37. Epistilbite Do.
38. Okenite A zeolite associate.
39. Ferrierite A zeolite.
40. Rhodesite A zeolite relative.

41. Gmelinite A zeolite.
42. Laumontite A zeolite.
43. Erionite A zeolite suspected of being the cause of an epidemic of mesothelioma in a Turkish village.
44. Serpentine A catch-all name for the serpentine minerals; see (1) chrysotile; (45) clino-chrysotile; (46) para-chrysotile; (47) ortho-chrysotile; (48) antigorite; (49) lizardite.
45. Clino-chrysotile See (44).
46. Para-chrysotile Do.
47. Ortho-chrysotile Do.
48. Antigorite Do.
49. Lizardite Do.
50. Picrolite A fibrous "serpentine," probably fibrous antigorite (48).
51. Deweylite Often determined to be any one of various serpentine minerals.
52. Gymnite A form of deweylite (51).
53. Williamsite A massive, translucent semi-precious variety of serpentine.
54. Bastite Probably mainly lizardite (see 49).
55. Baltimorite Probably mainly antigorite (48) and chrysotile (1).
56. Metaxite
57. Bowenite Antigorite (48).
58. Palygorskite A fibrous clay mineral (see Grim, Clay Mineralogy, 2nd edition, p. 182) (15).
59. Attapulgite A fibrous clay mineral (see Grim, p. 181) (15).
60. Sepiolite See Grim (15).

61. Meerschaum
62. Hectorite
63. Endellite
64. Halloysite
65. Illite
66. Vermiculite
67. Sericite
68. Pinite
69. Gumbelite
70. Talc
71. Pyrophyllite
72. Minnesotaite
73. Stilpnomelane
74. Brucite
75. Nematite
76. Magnesite
77. Hydromagnesite
78. Gypsum
79. Anhydrite
80. Aragonite
81. Calcite
82. Apatite
83. Phosphorite
84. Vivianite
85. Sillimanite
86. Buchholzite

See Crim (15).

Do.

Do.

Do.

A mica-like clay mineral.

Do.

Belongs to the mica group.

Do.

A fibrous mica.

A fibrous iron-talc.

A magnesium hydroxide.

The fibrous form of (74) brucite.

A fibrous variety of (85) sillimanite.

87. Fibrolite A fibrous variety of (85) sillimanite
88. Tourmaline
89. Zoisite
90. Epidote
91. Limonite A catch-all name for hydrous iron oxides and iron hydroxides.
92. Mountain leather A tough variety of asbestos occurring in thin, flexible sheets made of interlaced fibers; also fibrous minerals such as (60) sepiolite or (58) palygorskite.
93. Mountain cork A white or grey variety of asbestos consisting of thick, interlaced fibers and resembling cork in texture and lightness.
94. Amianthus A synonym for asbestos.
95. Ferro-magnesium minerals A term referring to iron- and magnesium- containing silicates; usually the amphiboles, the pyroxenes, the olivines, biotite micas, and chlorites.
96. Basic rocks Igneous rocks, often altered in part, consisting essentially of iron-, magnesium-, and/or calcium rich minerals, and relatively low in silica.
97. Serpentinite A rock composed largely of serpentine minerals.
98. Amphibolite A rock composed predominantly of amphibole minerals.
99. Pyroxenite A rock composed predominantly of pyroxene minerals and/or their alteration products, i.e., serpentine, chrysotile, etc.
100. Peridotite A basic, igneous rock composed largely of olivine, a mineral which alters easily to the serpentine minerals.

- 101. Talc schist
- 102. Pyrophyllite schist
- 103. Steatite
- 104. Soapstone
- 105. Agalmatolite

An impure talc rock.

A massive, fibrous talc rock.

A soft, waxy mineral or rock composed largely of (68) pinites.

- 106. Marble, when impure
- 107. Verd antique

Called (106) marble in the trade, but actually an impure serpentine or a serpentine-calcite rock.

- 108. Thermophyllite

A serpentine that exfoliates when heated.

- 109. Ophite

A synonym for a mottled serpentinite.

- 110. Ophicalcite

A serpentine marble

- 111. Ophiolite

Do.

In a volume entitled "Encyclopedia of Minerals" (27), devoted to descriptions and illustrations of minerals mainly as micro-mounts, the following minerals were noted in fibrous form:

- 112. Aegerine
- 113. Agardite
- 114. Artinite
- 115. Aurichalcite
- 116. Bariandite
- 117. Bismuthinite
- 118. Boulangerite
- 119. Brannockite
- 120. Brochantite
- 121. Cacoenite

- 122. Carpholite
- 123. Connellite
- 124. Cyanotrichite
- 125. Curite
- 126. Erythrite
- 127. Goethite
- 128. Guillemite
- 129. Honessite
- 130. Ianthinite
- 131. Jamesonite
- 132. Johannsenite
- 133. Kermesite
- 134. Legrandite
- 135. Liebethanite
- 136. Linarite
- 137. Malachite
- 138. Millerite
- 139. Mimetite
- 140. Mixite
- 141. Olivenite
- 142. Pharmacolite
- 143. Pyrite
- 144. Rockbridgeite
- 145. Schoepite
- 146. Scholzite

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- 147. Semseyite
- 148. Stibnite
- 149. Strunzite
- 150. Tyrolite
- 151. Uranophane
- 152. Wakabayashilite

APPENDIX II.--MINING OPERATIONS AND/OR LOCALITIES, BY COMMODITIES,
WHERE "FIBROUS" MINERALS MAY POSSIBLY BE FOUND

Unless otherwise specified, the pages listed refer to one or more of the following: Chrysotile, amosite, crocidolite, anthophyllite, tremolite, and actinolite. Page numbers refer to reference (26). See text, page--.

Iron

- | | | |
|------|---|--|
| (26) | 1. Cornwall Mine, PA,
pp. 81-85 | Refers also to zeolites, serpentine,
and byssolite. |
| (26) | 2. Grace Mine, PA, pp. 110,
117-118 | Refers also to serpentine and talc. |
| (26) | 3. Mesabi Iron Range, MI,
pp. 525 and 528 | Refers also to stilpnomelane,
minnesotaite, cummingtonite, and
amphiboles. |
| (26) | 4. Iron Mountain, MO, p. 299 | Refers also to amphiboles. |
| (26) | 5. Eagle Mountain Deposit, CA,
pp. 1604-1605 | Refers also to serpentines. |

Copper

- | | | |
|------|--|---|
| (26) | 6. Ducktown District, TN,
pp. 162-163, 222 | Refers also to amphiboles, talc, and
asbestos. |
| (26) | 7. Copper King Mine, CO,
p. 574 | Refers also to cummingtonite. |
| (26) | 8. Christmas Mine, Banner
District, AZ; p. 1204 | Refers also to serpentine. |
| (26) | 9. Mountain City Copper Mine,
NV, p. 1080 | Refers also to uranitized gabbro. |

Lead-Zinc

- | | | |
|------|---|---|
| (26) | 10. Balmat-Edwards District,
NY, pp. 13, 39, 41 | Refers also to talc and serpentine. |
| (26) | 11. Van Stone Area, Stevens
Co., WA, pp. 1515-1517 | Refers also to brucitic fiber,
palygorskite, and talc. |

- (25) 12. Couer-d'Alene District, ID, p. 1429 Refers to grunerite needles.
- (26) 13. New Idria Group, CA, pp. 1628-1630, 1646-1647 Refers also to serpentine and asbestos.
- (24) 14. New Almaden Mine, Santa Clara County, CA Refers to serpentine.

Chromite

- (26) 15. Mistake Mine, CA, pp. 1648-1649 Refers also to asbestos and serpentine.
- (12) 16. Low's Pit (State Line Pits), PA Refers to williamsite.
- (12) 17. Woods Chrome Mine Lancaster County, PA Refers to clino-chrysotile, and deweylite (stevensite).

Gold

- (26) 18. Homestake Mine, SD, p. 1437 See also Denver Technical Support Center memo dated 12/4/72. Refers to cummingtonite schist.

Tungsten

- (26) 19. Bishop Tungsten District CA, p. 1549 Refers also to talc, wollastonite and pectolite.

Rare Earths

- (26) 20. Mountain Pass, CA, p. 1528

Asbestos

- (26) 21. Clear Creek (New Idria) CA, pp. 1628-1630, 1647-1648 Refers also to serpentine and asbestos.
- (26) 22. Franklin-Somerset Area, MA, p. 137 Refers also to serpentine and asbestos.
- (4) 23. Webster and Spruce Pine, NC, (vicinity)
- (35) (24) 24. Arizona, near Globe Refers to serpentine.
- (12) (4) 25. Bare Hills area, MD

- (12) 26. Staten Island, NY Refers to serpentine.

Magnesite

- (26) 27. Magnesite-brucite deposit Gabbs, NV, pp. 1617-1618. Refers also to talc, brucite and serpentine.

(37) (10)

28. Gouverneur, NY vicinity Refers also to talc and serpentine.

(37) (39)

29. Barstow, CA vicinity Refers also to talc and steatite.

Vermiculite

30. Libby MT vicinity

31. North & South Carolina deposits.

- (28) 32. Green Springs, Charlottesville, VA, deposit Refers also to amphibolites.

Crushed Stone

- (29) 33. Rockville Quarry, Rockville, MD Refers also to serpentine, talc, and deweylite.

() See References

NOTE: Since this report was begun, mineral fibers were confirmed to exist at (1) the Eastern Mesabi Iron Range county; (The Reserve Mining Company tailings disposal problem); (2) the Homestake Mine where a health hazard exists (14) (8); and (3) at the Mountain Pass, rare-earth deposit. In addition, questions have arisen re: (4) the wollastonite deposits of New York; (5) the attapulgite deposits of Georgia; (6) the Rockville Quarry (serpentine) near Washington, D. C.; and (7) Green Springs vermiculite deposits, VA.