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A Definition for Asbestos*

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ABSTRACT: The authors present a definition for asbestos, based in part on discussions held during a workshop on this subject.

KEY WORDS: health-related silicates, asbestos

Preface

The name asbestos, a Greek word mistakenly thought to mean incombustible,[4] was given to fibrous minerals hundreds of years before the science of mineralogy evolved. It did not then, nor does it now, have scientific validity as a complete term in itself. As a collective term applying to members of two distinct silicate mineral groups, it cannot be simply defined mineralogically; the only common characteristic of these minerals is their asbestiform habit. The term asbestos, however, has both commercial and health significance. It is in designating a commercial group of minerals that the term has validity. Very little documented human health hazard has been observed for some of the commercially available asbestos minerals, and extrapolation of data for some forms of asbestos to all asbestos is not scientifically valid. Extrapolation of such data to all "fibrous" mineral particles is particularly unjustified.

The British-devised membrane filter method of monitoring airborne fibers in asbestos factories was and is useful in environments where it is logical to assume that the vast majority of elongate particles present are indeed asbestos. The

* The definition for asbestos presented here is based on discussions held during a workshop on defining asbestos, arranged as part of the symposium on which this publication is based. There was no final consensus in the workshop discussions, and, therefore, a task group of three, composed of the authors of this definition, was assigned to write a definition based on the workshop deliberations and on the task group's best judgment.

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[4] The Greek word actually means unquenchable, inextinguishable—*not* incombustible. This is according to the *Oxford English Dictionary*, which is the recognized final authority on the etymology and history of words in the English language.

method is nonspecific, unfortunately calls anything having a 3:1 aspect ratio a fiber, and, in spite of refinements, remains too subjective for scientific accuracy. Its good points are that it is rapid, inexpensive, and requires little sophistication in instrumentation or personnel.

The only fully acceptable definition of asbestos would exclude the collective term asbestos and substitute the definitions of the individual minerals. If the term asbestos must be used, a definition is needed that is mineralogically correct, yet of sufficient simplicity to be understood by specialists and nonspecialists alike. It must exclude all materials that never were commercial asbestos, include all that were, exclude rock particles and cleavage fragments, and, if possible, permit usage (with slight modification) of the present monitoring system.

Definition

The authors believe the following definition fulfills these needs:

asbestos—a term applied to six naturally occurring minerals exploited commercially for their desirable physical properties, which are in part derived from their asbestiform habit. The six minerals are the serpentine mineral chrysotile and the amphibole minerals grunerite asbestos (also referred to as amosite), riebeckite asbestos (also referred to as crocidolite), anthophyllite asbestos, tremolite asbestos, and actinolite asbestos. [These minerals are defined in the sections that follow.] Individual mineral particles, however processed and regardless of their mineral name, are not demonstrated to be asbestos if the length-to-width ratio is less than 20:1.[5]

Mineralogical Definitions of the Commercial Asbestos Minerals

The six asbestos minerals are defined under two mineral groups: the serpentine group and the amphibole group.

Serpentine Asbestos

Chrysotile, the only commercial asbestos mineral belonging to the serpentine group, has an ideal chemical composition of $Mg_3Si_2O_5(OH)_4$. Moderate amounts of aluminum may substitute for silicon and moderate amounts of iron may substitute for magnesium. Small amounts of manganous oxide (MnO), calcium oxide (CaO), potassium monoxide (K_2O), and sodium monoxide (Na_2O) are also reported in the chemical analyses. Chemical analyses and ion compositions for chrysotile asbestos from four important mines are given in Tables 1*a* and 1*b* [*1*].[6]

[5] See the Appendix attached.
[6] The italic numbers in brackets refer to the list of references appended to this paper.

TABLE 1*a*—*Chemical composition of commercial chrysotile asbestos, weight percent* [1].

Component	King Beaver Mine, Thetford Mines, Quebec Province, Canada	Asbest, Ural Mountains, U.S.S.R.	Shabani Mines, Zimbabwe	Havelock Mine, Swaziland
SiO_2	38.75	39.00	39.70	39.93
Al_2O_3	3.09	4.66	3.17	3.92
Fe_2O_3	1.59	0.54	0.27	0.10
FeO	2.03	1.53	0.70	0.45
MnO	0.08	0.11	0.26	0.05
MgO	39.78	38.22	40.30	40.25
CaO	0.89	2.03	1.08	1.02
K_2O	0.18	0.07	0.05	0.09
Na_2O	0.10	0.07	0.04	0.09
H_2O^+	12.22	11.37	12.17	12.36
H_2O^-	0.60	0.77	0.64	0.92
CO_2	0.48	1.83	2.13	1.04
Total	99.79	100.20	100.51	100.22

The crystal structure of chrysotile asbestos consists of double layers, each consisting of a layer of linked SiO_4 tetrahedra coordinated to a second layer of linked $MgO_2(OH)_4$ octahedra through a sharing of oxygen atoms; the composite double layer rolls up, like a window shade, to form long hollow tubes. The diameters of the individual tubes are on the order of 25 nm, and the length-to-diameter ratio can vary from 10:1 to well over 10 000:1.

Chrysotile is characterized by a combination of (1) a distinctive shape, (2) a chemical composition close to $Mg_3Si_2O_5(OH)_4$, and (3) characteristic X-ray and electron diffraction patterns [2–5].

TABLE 1*b*—*Ion composition of commercial chrysotile asbestos, number of ions on the basis of oxygen = 5, OH = 4* [1].

Ion	King Beaver Mine, Thetford Mines, Quebec Province, Canada		Asbest, Ural Mountains, U.S.S.R.		Shabani Mines, Zimbabwe		Havelock Mine, Swaziland	
Si	1.845	2.000	1.851	2.000	1.885	2.000	1.882	2.000
Al	0.155		0.149		0.115		0.118	
Al	0.018	3.047	0.112	3.013	0.062	3.025	0.100	3.016
Fe^{3+}	0.057		0.019		0.010		0.004	
Fe^{2+}	0.081		0.061		0.028		0.018	
Mn	0.003		0.004		0.010		0.002	
Mg	2.823		2.704		2.853		2.827	
Ca	0.045		0.103		0.055		0.052	
K	0.011		0.004		0.003		0.005	
Na	0.009		0.006		0.004		0.008	

Amphibole Asbestos

Five of the six commercial asbestos minerals belong to the amphibole mineral group. These, with their ideal chemical formulas, are grunerite asbestos, $Fe_7Si_8O_{22}(OH)_2$ (usually but improperly referred to by the acronym amosite); riebeckite asbestos, $Na_2Fe_3^{2+}Fe_2^{3+}Si_8O_{22}(OH)_2$ (usually referred to by the varietal name crocidolite); anthophyllite asbestos, $Mg_7Si_8O_{22}(OH)_2$; tremolite asbestos, $Ca_2Mg_5Si_8O_{22}(OH)_2$; and actinolite asbestos, $Ca_2(Mg,Fe^{2+})_5Si_8O_{22}(OH)_2$ [*6*].[7] A considerable amount of substitution of other elements for Fe^{2+}, Fe^{3+}, silicon, sodium, calcium, and magnesium can take place in these minerals, as can be seen in Tables 2*a* and 2*b*, which give representative chemical analyses of amphibole asbestos from nine localities.

The crystal structures of the amphibole minerals, including the asbestiform varieties, are composed of strips or ribbons of linked polyhedra, which join together to form the three-dimensional crystal. The individual strips are composed of three elements: these are two double chains of linked $(Si,Al)O_4$ tetrahedra and a strip of linked MgO_6, FeO_6, or AlO_6 octahedra. The structural relationship between the upper double tetrahedral chain and the octahedral part of the strip is shown in Fig. 1. The three-dimensional arrangements of these strips ("I-beams") in orthoamphibole (anthophyllite asbestos) and in clinoamphibole (tremolite, actinolite, grunerite, and riebeckite asbestos) are shown in Fig. 2 [*7*].

Amphibole asbestos minerals are characterized by a combination of (1) a distinctive crystal habit with length-to-width ratios often of 20:1 or greater, (2) the typical chemical composition for that mineral, and (3) characteristic X-ray powder diffraction patterns [*8*] or electron diffraction patterns [*3,4*].

APPENDIX

With a method in current use for monitoring asbestos in the workplace that is totally nonspecific and uses only physical parameters to describe a fiber (asbestos), physical limits must be established that will minimize the inclusion of extraneous particles that are called asbestos only because of a superficial physical similarity. The object of monitoring is to get a true representative count of the asbestos present in the workplace air.

Serpentine rock is chemically identical to chrysotile asbestos and has the same crystal structure. Serpentine is a material that is commercially useful both crushed and as dimension stone and that cannot be removed from the ground and processed without creating many particles with aspect ratios of 3:1 or larger. To call these particles asbestos and to ascribe to them the health effects observed elsewhere from exposure to asbestos is invalid.

It is just as invalid to call these particles in the asbestos mines and mills asbestos when serpentine has to be crushed to liberate the chrysotile fibers. The lack of validity also

[7] The minerals tremolite and actinolite compose a continuous solid solution series. The name tremolite is given arbitrarily if the ratio of magnesium to magnesium plus Fe^{2+} is greater than or equal to 0.9; the name actinolite is given if the ratio is less than 0.9 and greater than or equal to 0.5 [*6*].

TABLE 2*a*—*Chemical composition of amphibole asbestos, weight percent* [1].[a]

Component	Grunerite Asbestos (Amosite)		Riebeckite Asbestos (Crocidolite)					Anthophyllite Asbestos,	Tremolite Asbestos,
	A	B	C	D	E	F	G	H	I
SiO_2	49.70	51.30	50.90	50.70	52.00	55.65	52.85	57.20	55.10
Al_2O_3	0.40	nil	nil	0.70	nil	4.00	0.18	. . .	1.14
Fe_2O_3	0.03	0.90	16.85	18.30	16.05	13.01	18.55	0.13	0.32
FeO	39.70	35.50	20.50	17.50	17.65	3.84	14.94	10.12	2.00
MnO	0.22	1.76	0.05	0.06	trace	trace	trace	. . .	0.10
MgO	6.44	6.90	1.06	3.05	4.28	13.09	4.64	29.21	25.65
CaO	1.04	0.95	1.45	1.30	1.20	1.45	1.07	1.02	11.45
K_2O	0.63	0.51	0.20	trace	0.06	0.39	0.05	. . .	0.29
Na_2O	0.09	0.05	6.20	5.30	6.21	6.91	5.97	. . .	0.14
H_2O^+	1.83	2.31	2.37	2.53	2.43	1.78	2.77	2.18	3.52
H_2O^-	0.09	0.05	0.22	0.29	0.26	trace	0.22	0.28	0.16
CO_2	0.09	0.25	0.20	0.45	0.09	trace	0.23	. . .	0.06
Total	100.26	100.48	100.00	100.18	100.23	100.12	101.47	100.14	99.93

[a]Key to symbols for locations:
A = Penge, Transvaal Province, South Africa.
B = Weltevreden, Transvaal Province, South Africa.
C = Koegs, Cape Province, South Africa.
D = Kuruman, Cape Province, South Africa.
E = Pomfret, Cape Province, South Africa.
F = Cochabamba, Bolivia.
G = Hammersley Range, Western Australia.
H = Paakkila, Finland.
I = Pakistan.

TABLE 2b—*Ion composition of amphibole asbestos, number of ions on the basis of oxygen = 22, OH = 2* [1].[a]

Ion	Grunerite Asbestos (Amosite) A	B	Riebeckite Asbestos (Crocidolite) C	D	E	F	G	Anthophyllite Asbestos, H	Tremolite Asbestos, I
Si	7.898	8.055	7.949	7.823	7.942	7.791	7.927	7.848	7.674
	7.973	8.055	7.949	7.950	7.942	8.000	7.959	7.848	7.861
Al	0.075	...	...	0.127	...	0.209	0.032	...	0.187
Al	...	...	...	...	...	0.451	...	...	...
Fe^{3+}	0.004	0.106	1.980	2.125	1.844	1.371	2.094	0.013	0.034
Fe^{2+}	5.277	4.662	2.678	2.259	2.254	0.450	1.874	1.161	0.233
Mn	0.030	0.234	0.007	0.008	...	...	...	...	0.012
	7.165	6.894	7.072	6.893	7.119	7.166	6.923	7.296	7.404
Mg	1.525	1.615	0.247	0.701	0.974	2.731	1.037	5.972	5.326
Ca	0.177	0.160	0.243	0.215	0.196	0.218	0.172	0.150	1.709
K	0.128	0.102	0.040	...	0.012	0.070	0.010	...	0.052
Na	0.028	0.015	1.877	1.585	1.839	1.875	1.736	...	0.038

[a]Key to symbols for locations:
A = Penge, Transvaal Province, South Africa.
B = Weltevreden, Transvaal Province, South Africa.
C = Koegs, Cape Province, South Africa.
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E = Pomfret, Cape Province, South Africa.
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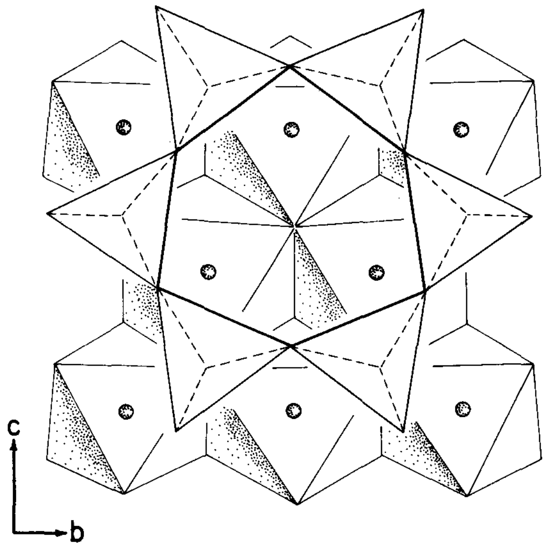

FIG. 1—*Structural relationship between the upper double chain of linked* $(Si,Al)O_4$ *tetrahedra and the octahedra part of the amphibole strip ("I-beam"). The circles represent magnesium, iron, or aluminum atoms in octahedral coordination; at the apices of the polyhedra are oxygen atoms. The tetrahedral silicon and aluminum atoms are not shown. The I-beams extend infinitely in a direction parallel to the* c*-axis (the fiber axis). The width of the I-beam in the* b*-axis direction is three octahedra. The figure is modified from one in Papike and Ross* [7].

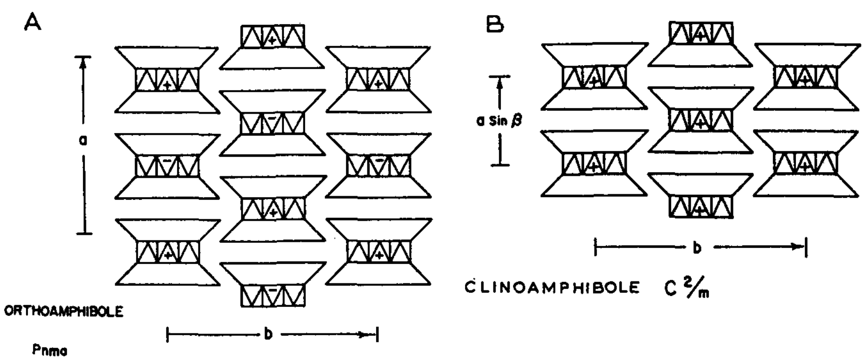

FIG. 2—*Arrangement of the amphibole strips or I-beams in* (left) *orthoamphibole (Space Group Pnma) and* (right) *clinoamphibole (Space Group C2/m). The I-beams are viewed end-on (parallel to the fiber* c*-axis). The central portion of the I-beam is composed of* $(Mg,Fe,Al)O_6$ *octahedra; the upper and lower portions are composed of double chains of* (Si,AlO_4) *tetrahedra. The I-beams are stacked in two ways: (1) + + + . . . (clinoamphibole) and (2) + − + − . . . (orthoamphibole). The figure is modified from one in Papike and Ross* [7].

TABLE 3—*Aspect ratio distribution of asbestos particles in an NIEHS study.*

	Chrysotile						
	COF-25	Plastibest	Total Chrysotile	Amosite	Crocidolite	Total Asbestos	Nonfibrous Tremolite[a]
Total particles, No.	1058	1389	2447	1023	1040	4510	615
Particles $\geq$3:1							
No.	963	1380	2343	1016	1032	4391	125
%	91	99	96	99	99	97	20
Particles $\geq$20:1							
No.	858	689	1547	469	523	2539	6
%	81	50	63	46	50	56	1

[a]Tremolite, serpentine, talc, and other minerals (only tremolite particles counted).

holds when serpentine is a minor constituent of another ore such as talc, which must be mined and processed for use.

An illustration of the invalidity of calling every particle having a 3:1 aspect ratio asbestos is apparent in data presented by the U.S. Bureau of Mines characterizing the materials used for an animal feeding study.[8] This was a National Institutes of Health study administered by the National Institute of Environmental Safety and Health (NIEHS) to ascertain the carcinogenicity of ingested asbestos. Two commercial chrysotile specimens of different origins were purchased, as were specimens of amosite and crocidolite. All these asbestos specimens were air-jet milled to reduce their fiber lengths to lengths that could be tableted in the food of the test animals. Air-jet milling is a much more rigorous kind of processing than that ordinarily used for asbestos. To achieve the desired end of length reduction this way, one must also reduce the length-to-width ratio. A fifth specimen was nonfibrous tremolite selected from a tremolitic talc mine and ground to minus 325 mesh. This specimen contained approximately 25% serpentine plus minor amounts of talc and other minerals. The aspect ratios of the ground asbestos specimens are shown in Table 3. (This table is derived from Tables A-2, A-6, A-9, A-12, and A-14 of the reference document.[8]) The data were gathered using a scanning electron microscope (SEM).

There are several significant details in the data:

1. Nearly all of the asbestos fibers had aspect ratios ≥3:1.
2. A significant 20% of the ground nonfibrous tremolite did also. This means, of course, that under the present system, these particles would be called asbestos and included in the count.
3. The use of an aspect ratio ≥20:1 would include only 1% of the nonfibrous tremolite particles erroneously counted as asbestos, but would include a majority (56%) of the total asbestos fibers (63 and 50% of chrysotile and crocidolite, respectively).

When added to Wylie's recommendation[9] of an aspect ratio of ≥20:1 as the minimum one for chrysotile and crocidolite (together comprising 98% of all asbestos in commercial use), these data present a reasonable case for this aspect ratio as a necessary limit.

References

[1] Hodgson, A. A. in *Asbestos,* Vol. 1, *Properties, Applications, and Hazards,* L. Michaels and S. S. Chissick, Eds., Wiley, New York, 1979, p. 79.
[2] Mumpton, F. A. and Thompson, C. S., *Clays and Clay Minerals,* Vol. 23, 1975, pp. 131–143.
[3] Champness, P. E., Lorimer, G. W., and Cliff, G., *Journal of Microscopy,* Vol. 109, 1976, pp. 231–249.
[4] Miller, J. L., *Norelco Reporter,* Vol. 25, No. 3, 1978, pp. 1–11.
[5] Wicks, F. J. in *Mineralogical Techniques of Asbestos Determination,* R. L. Ledoux, Ed., *Short Course Handbook,* Vol. 4, Mineralogical Association of Canada, Ottawa, Canada, 1979, pp. 35–78.
[6] Leake, B. E., *American Mineralogist,* Vol. 63, 1978, pp. 1023–1052.
[7] Papike, J. J. and Ross, M., *American Mineralogist,* Vol. 55, 1970, pp. 1945–1972.
[8] *Selected Powder Diffraction Data for Minerals,* L. G. Berry, Ed., Joint Committee on Powder Diffraction Standards, American Society for Testing and Materials, Philadelphia, 1974.

[8] Campbell, W. J., Huggins, C. W., and Wylie, A. G., "Chemical and Physical Characterization of Amosite, Chrysotile, Crocidolite, and Nonfibrous Tremolite for Oral Ingestion Studies by the National Institute of Environmental Health Sciences," U.S. Bureau of Mines R. I. 8452, Washington, D.C., 1980.

[9] Wylie, A. G., this publication, pp. 105–117.