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# ASBESTOS

## SELECTED CANCERS

Committee on Asbestos: Selected Health Effects

Board on Population Health and Public Health Practices

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Willing is not enough; we must do."*
—Goethe

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This report has been reviewed in draft form by persons chosen for their diverse perspectives and technical expertise in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards of objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following for their review of this report:

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Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Paul D. Stolley, University of Maryland, School of Medicine, Baltimore, and by Edward B. Perrin, University of Washington, Seattle. Appointed by the National Research Council and Institute of Medicine, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

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# 3

# Background Information on Asbestos

## INTRODUCTION

Asbestos is a term applied to several mineral species when they occur in a fibrous form (asbestiform). When the mineral species are asbestiform, they have the physical characteristics associated with asbestos, such as large aspect ratio of fibers, flexibility, separability and weavability of fibers, and chemical and physical durability. However, in addition to those common properties, each asbestos mineral species has unique chemical and physical properties that make it distinct from the others. Details about the nature and limitations of techniques used to identify and characterize asbestos fibers will not be discussed here, but can be found in reference sources such as Spurny (1994) and Roggli et al. (1992).

This chapter provides an overview of asbestos mineralogy, focusing on characteristics of asbestos fibers that are potentially relevant to carcinogenicity. In particular, the various asbestos mineral species are described, with an emphasis on the characteristics and properties related to their unique biologic properties. Minerals are known to interact dynamically with their environment particularly when they are in contact with a fluid. Such interactions often occur at the interface between the mineral and its environment, in other words, at the mineral's surface. These interactions are critically important in many natural environments and include such phenomena as dissolution and precipitation (which alter the fluid's composition), oxidation and reduction of species in the fluid, sorption, and ion exchange. Each of those phenomena has a potential role in mineral-induced pathogenesis, including carcinogenesis and fibrosis, although understanding of the relationship between mineralogic properties and pathogenesis remains incomplete.

The concept of *mineral species* is fundamental to mineralogy. A mineral species is a crystalline solid with a specific atomic structure and a specific chemical composition (or compositional range). The specific crystal structure and chemical composition of each mineral species imparts a unique set of properties, including how the species interacts physically and chemically with its environment. In a system paralleling that for the plant and animal kingdoms, mineral species are classified hierarchically. A mineral group is roughly equivalent to the *family* classification and consists of minerals with similar compositions or structures. Minerals may also exhibit variability within a species with respect to a particular property. For example, some mineral species may occur with an asbestiform habit (physical form) or a non-asbestiform habit. Those are typically not given distinct mineral-species names but instead are referred to as varieties of the same species; sometimes, they are given varietal names, as in the case of crocidolite, which is the asbestiform variety of the mineral species riebeckite.

Other mineral groups may have species with occasional asbestiform varieties, but the primary mineral groups for asbestos are *amphibole* and *serpentine*. Each species of these groups has a distinct crystal structure, but chemical compositions vary between species within the group. The principal mineral species constituting asbestos are detailed below; they include asbestiform serpentine (chrysotile) and asbestiform varieties of amphibole, such as tremolite, actinolite, anthophyllite, grunerite, riebeckite (also known as crocidolite), winchite, and richterite. Table 3.1 lists the mineral species, varietal names, and mineral groups associated with the common asbestos minerals. Although the three chrysotile mineral species all have the same ideal chemical formula, these polymorphs (or polytypes) differ in the nature of the stacking relationship between successive layers, with clinochrysotile being the most abundant type (Gaines et al. 1997).

## "FIBROUS" AND "ASBESTIFORM"

Many minerals may occur as small particles, including particles in the respirable size range, which is less than about 10 μm in aerodynamic diameter. Of these, some may include particles with aspect ratios (length: diameter) of 5:1 or more, usually reflecting a characteristic of the underlying crystal structure. For example, asbestiform amphiboles have fibers that are elongate parallel to the underlying silicate chains in the structure.

*Fibrous* is a term applied to minerals that consist of fibers, that is, exhibit a large aspect ratio. Although the minimal aspect ratio of a mineral fiber may be debated, for the purpose of definition observed aspect ratios in general are very large (for example, over 5:1 and sometimes over 100:1).

TABLE 3.1 Asbestos Minerals

| Mineral Group | Mineral Species | Asbestiform Variety | Ideal Chemical Formula[a] |
|---|---|---|---|
| Serpentine | Clinochrysotile | Chrysotile | $Mg_3Si_2O_5(OH)_4$ |
| Serpentine | Orthochrysotile | Chrysotile | $Mg_3Si_2O_5(OH)_4$ |
| Serpentine | Parachrysotile | Chrysotile | $Mg_3Si_2O_5(OH)_4$ |
| Amphibole | Riebeckite | Crocidolite | $Na_2Fe_5Si_8O_{22}(OH)_2$ |
| Amphibole | Grunerite | Amosite | $(FeMg)_7Si_8O_{22}(OH)_2$ |
| Amphibole | Cummingtonite | Amosite | $(MgFe)_7Si_8O_{22}(OH)_2$ |
| Amphibole | Gedrite | Amosite | $(MgFe)_5Al_2(Si_6Al_2)O_{22}(OH)_2$ |
| Amphibole | Anthophyllite | Asbestiform anthophyllite | $(MgFe)_7(Si)_8O_{22}(OH)_2$ |
| Amphibole | Tremolite | Asbestiform tremolite | $Ca_2Mg_5Si_8O_{22}(OH)_2$ |
| Amphibole | Actinolite | Asbestiform actinolite | $Ca_2(MgFe)_5Si_8O_{22}(OH)_2$ |
| Amphibole | Richterite | Asbestiform richterite | $Na_2Ca(MgFe)_5Si_8O_{22}(OH)_2$ |
| Amphibole | (Alumino)winchite | Asbestiform winchite | $CaNa(MgFe)_4AlSi_8O_{22}(OH)_2$ |
| Amphibole | Ferriwinchite | Asbestiform winchite | $CaNa(FeMg)_4Fe^{3+}Si_8O_{22}(OH)_2$ |

[a]Simplified representation of the overall stoichiometry of a mineral species. Mineral species typically have chemical modifications, such as substitutions of similar cations and sometimes anions (common examples are $Mg^{2+}$<->$Fe^{2+}$ and $Si^{4+}$<->$Al^{3+}$). Substitutions may cause substantiated deviations from the ideal chemical formula. Limits of chemical variation are defined for each mineral species in Table 3.2.

SOURCE: Gaines et al. (1997).

*Asbestiform* refers to a subset of fibrous minerals. Among fibrous minerals, some exhibit the additional qualities of flexibility and separability (which contribute to weavability). Such minerals are referred to as asbestiform. Typically, asbestiform minerals also have relatively small fiber diameters (usually under 1 μm) and large fiber lengths (such as 5-10 μm). The asbestiform characteristics are related to properties of the underlying crystal structures, with the specific relationship according to the mineral group. For example, it has been suggested that flexibility is related to defects in the crystal structure of the asbestiform varieties of amphibole (Veblen and Wylie 1993), whereas flexibility in asbestiform serpentine (the various forms of chrysotile) may be related to the hydrogen bonding between concentric sheets of 1:1 layers, as described below.

Some mineral species have both asbestiform and non-asbestiform varieties, and these varieties may have properties beyond just their flexibility that differ. For example, consider the grain boundaries in asbestiform amphibole. Asbestos fibers typically occur as parallel bundles of fibrils (filaments consisting of individual crystals) that are bound together along grain boundaries. The material along the grain boundaries typically is not amphibole but rather a layer silicate, such as talc or mica. When the material is processed, fibers are produced by the breaking apart of packets of fibrils by separation along the structurally weaker grain boundaries, which allows the layer-silicate material to become the surface of the fiber. It is this crystalline material that interacts with the biologic system after inhalation or ingestion. In contrast, the surface of a non-asbestiform variety of amphibole (either an acicular crystal or a cleavage fragment) is often amphibole (and not layer silicate) because the particles are formed either by growth of the original amphibole crystal in the case of acicular fibers or by fracture along weaker atomic planes in the amphibole structure. Hence, asbestiform amphibole is likely to have a different surface structure and composition from non-asbestiform amphibole. Those differences in surface material result in different surface properties between asbestiform and non-asbestiform minerals of the same species, which may in turn result in different biologic responses.

Some fibrous but non-asbestiform minerals also pose potential concern with respect to human exposure. For example, the fibrous zeolite erionite has been associated with human cases of mesothelioma after environmental exposure (Baris et al. 1987).

## SERPENTINE ASBESTOS (CHRYSOTILE) MINERALOGY

Chrysotile—sometimes called white asbestos—is the most common type of asbestos to be used commercially, accounting for about 85% of world asbestos production in 1977 (Liddell 1997, Schreier 1989). At present, chrysotile is the only type of asbestos used in manufacturing in the United States (ATSDR 2001). In addition, chrysotile and other serpentine minerals are common naturally, particularly in hydrothermally altered, magnesium-rich rocks, such as altered basalt, peridotite, and dunite. Many such rocks have been almost completely altered to serpentine and are referred to as serpentinites. Although lizardite is the most common form of serpentine in these rocks, chrysotile can also be present, typically having formed as a late-stage mineral filling veins and sometimes replacing the bulk rock. Chrysotile has been commercially exploited in Canada (Quebec and Ontario), the United States (Vermont and California), Zimbabwe, Russia, South Africa, Australia, and elsewhere (Ross 1981), and it has been used in various products, including insulation, friction materials (such as brake pads), and fiber-reinforced composites (such as concrete) (Harrison et al. 1999, Ross and Virta 2001). In addition to synthetic chrysotile-bearing materials, natural deposits are possible sources of exposure to chrysotile, either by direct exposure to chrysotile-bearing rocks and soils or by redistribution of chrysotile fibers from large natural deposits, such as occurs at Coalinga, California (Klein 1993). It has been argued that atmospheric processes have redistributed Coalinga chrysotile over the entire Northern Hemisphere from its occurrence in soils in a 50-$mi^2$ area (Klein 1993).

Serpentine minerals belong to a family of 1:1 layer silicates, which are composed of a sheet of polymerized $SiO_4^{4-}$ tetrahedra (with silicon at the center of each tetrahedron and oxygen at each apex) that is bonded to a sheet of polymerized $Mg(OH)_6^{4-}$ octahedra (with magnesium at the center of each octahedron and oxygen at each apex) (Figure 3.1). This ratio of tetrahedral to octahedral sheets gives the 1:1 layer silicates their name. The

FIGURE 3.1 Lizardite structure viewed down the a-axis. Polymerized silica tetrahedra form a sheet at the bottom of each 1:1 unit (two units are shown stacked vertically), and magnesium hydroxide octahedra form a sheet drawn as ball-and-stick. In chrysotile, the 1:1 units curl with the slightly smaller tetrahedral sheets to the inside, exposing an octahedral sheet to the outside of the particle.
SOURCE: Mellini (1982).