Letter

# Amphibole asbestos soil contamination in the U.S.A.: A matter of definition†

**Brittani D. Thompson,[1] Mickey E. Gunter,[1,2,*] and Michael A. Wilson[3]**

[1]Department of Geological Sciences, University of Idaho, Moscow, Idaho 83844, U.S.A.
[2]Marsh Professor-at-Large, University of Vermont, Burlington, Vermont 05405, U.S.A.
[3]USDA-Natural Resources Conservation Service, 100 Centennial Mall North, Lincoln, Nebraska 68508, U.S.A.

## Abstract

Recent concerns surrounding asbestos exposure have extended from occupational settings into natural settings. These developments have caused us to examine the distribution of amphiboles, which are potential asbestiform minerals, within the soils of the U.S.A. Evaluation of mineralogical data from selected sand and/or silt fraction of soils from the USDA-NRCS National Cooperative Soil Survey database shows that soils in all states (except for Rhode Island) contain amphiboles. In 41 of the 50 states, 10% or more sampled pedons contain amphiboles. Overall, 4396 pedons out of the 34 326 pedons (about 13%) sampled in the U.S.A. contained amphiboles. Pedons containing amphiboles ranged from less than 1 to 49% of the pedons among all states. While amphibole asbestos deposits occur in mafic and ultramafic provinces, soil amphiboles occur evenly distributed across the U.S.A. The majority of the amphiboles found in the soils would likely not meet the mineralogical definition of asbestos (i.e., they would not have been derived from asbestiform amphiboles); however, the majority would likely meet a commonly used regulatory definition of a fiber (i.e., are over 5 μm in length with a greater than 3 to 1 aspect ratio). Based on the regulatory definition, 13% of soil pedons and 5% of soil horizons in the U.S.A. are "naturally contaminated."

**Keywords:** Asbestos, soils, amphiboles, asbestiform

## Introduction

Within the past decade, concerns in asbestos exposure have spread from the occupational setting to the natural environment. The focal point for this new concern was in El Dorado Hills, California, when a resident "discovered" what has unfortunately become known as "naturally occurring asbestos" or NOA for short. However, it appears the original meaning of NOA was "natural occurrences of asbestos" (Gunter 2009). Regardless, issues stemming from El Dorado Hills spawned this new concern. Meeker et al. (2006) analyzed the morphology and composition of amphiboles in soils in the vicinity of asbestos-bearing rock outcrops in the El Dorado Hills area. They concluded that three main types of amphiboles were found, including tremolite, actinolite, and magnesiohornblende, all with fibrous morphology. Tremolite was usually found with fibrous morphology, and actinolite and magnesiohornblende had morphologies ranging from prismatic to fibrous. Amphibole asbestos exposure is often more of a concern than chrysotile exposure as amphibole asbestos is regarded as the more hazardous (McDonald et al. 2004). While is it somewhat beyond the scope of this paper to discuss the reasons why, interested readers should see Gunter et al. (2007) and Plumlee et al. (2006) and references therein. It is, however, the goal of this paper to discuss the geographic distribution of amphiboles in the U.S.A., as amphiboles compose about 5% of the Earth's crust (Dyar and Gunter 2008), which makes them more common than chrysotile in the natural environment.

Generally, there are two types of possible asbestos exposure: (1) occupational (concentrated in products such as insulators) and (2) natural (asbestos in rock outcrops or soil). The simple presence of amphibole asbestos does not pose a risk until it is disturbed and particles of respirable size are suspended in the air. Such disturbances include mining, road construction, agriculture, forestry, urban development, and natural weathering processes (Hendrickx 2008). Populations most at risk of exposure to asbestos in nature are workers and communities associated with activities that disturb rocks or soils containing asbestos (Hendrickx 2009). Recent studies have shown somewhat conflicting results for exposure to asbestos occurring in its natural setting. For example, Pan et al. (2005) showed an increased risk of mesothelioma relating to residential proximity to ultramafic rocks in California, whereas de Grisogono and Mottana (2009) showed no correlation between residential proximity to natural occurrence of asbestos and mesothelioma in Italy. Interestingly, almost 30 yr ago, Ross (1982) showed no increase of asbestos-related diseases for non-occupational exposure to individuals living in asbestos mining areas.

The definition of asbestos differs between its use in commercial products in the built environment and potentially asbestiform minerals occurring in their natural settings (Gunter 2010). For example, there are 46 different definitions of asbestos included

* E-mail: mgunter@uidaho.edu
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in Lowers and Meeker's (2002) "Tabulation of Asbestos-Related Terminology." In the glossary of Reviews in Mineralogy *Health Effects of Mineral Dusts* (vol. 28), asbestos is defined as "A term applied to asbestiform varieties of serpentine and amphibole, particularly chrysotile, crocidolite, amosite, asbestiform tremolite, asbestiform actinolite, and asbestiform anthophyllite. The asbestos minerals possess asbestiform characteristics (Guthrie and Mossman 1993)."

The crux of this issue is the differing use of the word "fiber" between the regulatory and mineralogical community. The term fiber, from a regulatory standpoint, is a particle that is 3 times longer than wide with a length greater than 5 μm (Glenn et al. 2008). However, this definition was originally meant to be used as counting criterion for fibers found in occupational settings rather than a way to define asbestos (Gunter 2010). Using this counting criterion, Wylie (1988) showed 47 and 78% of two milled non-asbestiform amphiboles would be counted as "fibers." It should be noted that milling, in general, reduces the aspect ratio of non-asbestiform amphiboles (Campbell et al. 1977). Thus, most non-milled, amphibole particles (i.e., those occurring in nature) would be counted as fibers, due to their elongate morphology. Of course this elongate physical property of amphiboles is taught to students in beginning geology and mineralogy classes. From a mineralogical standpoint, a fiber is a mineral particle with elongate morphology (Guthrie and Mossman 1993; Glenn et al. 2008). The mineralogical term "asbestiform" refers to a flexible mineral fiber easily separable and arranged parallel to other fibers (Guthrie and Mossman 1993).

Unfortunately the debate on asbestos nomenclature continues and shows no sign of ending. In fact, in a recent US government document (NIOSH 2010), the term "elongate mineral particle" was coined and defined as any mineral particle with an aspect ratio greater than 3 to 1 and 5 μm in length or longer, with an implied concern that this group of minerals presents a health risk. As pointed out almost 30 yr ago (Skinner et al. 1982), slightly over 10% of the known mineral species can occur in this shape. More recently Gunter (2010) showed SEM photographs of quartz, feldspars, sheet silicates, and calcite occurring in soils that would also meet this shape definition. Thus, while the definition of asbestos should be refined as we move from the built to natural environment, it appears to be broadening.

## METHODS

Our goal herein is to examine an existing database to determine the amphibole content of soils. This is part of a larger study in which we are determining both the amphibole content and morphology on a suite of USDA soil samples from various locations in the United States. Each sample in the USDA-NRCS database (USDA-NRCS 2010) represents a horizon within a unique pedon, whose location is given by latitude and longitude. A horizon is a layer within the soil with unique macromorphological characteristics. A pedon is a three-dimensional body of soil that consists of all the horizons at that location. Mineral content of each horizon is determined by a point count of 300 particles in a grain mount made from a sand or silt fraction using a polarizing light microscope (Burt 2004). In this study, there are a total of 212 839 horizons within 34 326 pedons that were sampled in the U.S.A. In a separate set of studies, Van Gosen (2005, 2006, 2007, 2008, 2010) gave the location of asbestos deposits throughout the U.S.A., except for California, Alaska, and Hawaii. Data sets for California and Alaska are being prepared and currently there are no known occurrences of asbestos in Hawaii (Van Gosen, personal communication). Van Gosen also differentiated chrysotile locations from amphibole asbestos locations, and we have only used the latter herein for comparison to soil amphibole locations.

To determine the distribution of amphiboles in the U.S.A., a query was run in the USDA-NRCS National Cooperative Soil Survey database to determine the extent of soils containing amphiboles. The amphibole minerals were not discriminated by species in all of their samples, so we grouped all amphiboles together. The number of horizons and pedons containing amphiboles were obtained for each state and compared with the total number of units sampled (Table 1). Using the counts of amphibole-bearing horizons for each state, we calculated the percentage of horizons containing amphiboles. Similar methods were applied to calculating percentages of amphibole-bearing pedons (Table 1). Last, we plotted the location of these amphibole-containing soils along with known locations of amphibole asbestos from Van Gosen (2005, 2006, 2007, 2008, 2010) in Figure 1.

**TABLE 1.** State-by-state listing of total number sampled horizons and pedons and the numbers (and percentages) containing amphiboles

| State | Total units sampled | | Units w/ amphiboles | | % Units containing amphiboles | |
|---|---|---|---|---|---|---|
| | Horizons | Pedons | Horizons | Pedons | Horizons | Pedons |
| Alabama | 884 | 147 | 65 | 32 | 7% | 22% |
| Alaska | 3965 | 637 | 401 | 150 | 10% | 24% |
| Arizona | 3658 | 650 | 57 | 33 | 2% | 5% |
| Arkansas | 1918 | 166 | 451 | 81 | 24% | 49% |
| California | 11423 | 2060 | 786 | 393 | 7% | 19% |
| Colorado | 5210 | 901 | 590 | 250 | 11% | 28% |
| Connecticut | 830 | 119 | 39 | 16 | 5% | 13% |
| Delaware | 799 | 225 | 37 | 23 | 5% | 10% |
| District of Columbia | 56 | 7 | 3 | 2 | 5% | 29% |
| Florida | 1280 | 228 | 11 | 9 | 1% | 4% |
| Georgia | 2060 | 376 | 73 | 45 | 4% | 12% |
| Hawaii | 2197 | 405 | 100 | 54 | 5% | 13% |
| Idaho | 5826 | 1018 | 461 | 156 | 8% | 15% |
| Illinois | 22738 | 3028 | 409 | 87 | 2% | 3% |
| Indiana | 18156 | 2729 | 378 | 107 | 2% | 4% |
| Iowa | 8236 | 1081 | 391 | 61 | 5% | 6% |
| Kansas | 7355 | 884 | 542 | 122 | 7% | 14% |
| Kentucky | 1840 | 298 | 80 | 43 | 4% | 14% |
| Louisiana | 2768 | 364 | 179 | 84 | 6% | 23% |
| Maine | 1331 | 286 | 84 | 46 | 6% | 16% |
| Maryland | 2285 | 499 | 144 | 74 | 6% | 15% |
| Massachusetts | 1302 | 215 | 62 | 30 | 5% | 14% |
| Michigan | 3933 | 652 | 149 | 91 | 4% | 14% |
| Minnesota | 2631 | 438 | 224 | 73 | 9% | 17% |
| Mississippi | 1658 | 228 | 108 | 30 | 7% | 13% |
| Missouri | 3612 | 540 | 242 | 66 | 7% | 12% |
| Montana | 5971 | 1087 | 219 | 80 | 4% | 7% |
| Nebraska | 9848 | 1497 | 215 | 77 | 2% | 5% |
| Nevada | 4518 | 731 | 320 | 114 | 7% | 16% |
| New Hampshire | 1209 | 187 | 137 | 44 | 11% | 24% |
| New Jersey | 1782 | 252 | 60 | 33 | 3% | 13% |
| New Mexico | 4958 | 708 | 494 | 146 | 10% | 21% |
| New York | 3000 | 638 | 152 | 93 | 5% | 15% |
| North Carolina | 3394 | 595 | 335 | 177 | 10% | 30% |
| North Dakota | 5100 | 745 | 198 | 82 | 4% | 11% |
| Ohio | 1077 | 160 | 18 | 6 | 2% | 4% |
| Oklahoma | 3144 | 465 | 223 | 89 | 7% | 19% |
| Oregon | 6347 | 1401 | 702 | 240 | 11% | 17% |
| Pennsylvania | 1843 | 413 | 92 | 45 | 5% | 11% |
| Rhode Island | 149 | 18 | 0 | 0 | 0% | 0% |
| South Carolina | 1119 | 245 | 75 | 38 | 7% | 16% |
| South Dakota | 3931 | 660 | 78 | 35 | 2% | 5% |
| Tennessee | 2520 | 389 | 206 | 109 | 8% | 28% |
| Texas | 9544 | 1312 | 393 | 193 | 4% | 15% |
| Utah | 4199 | 750 | 205 | 117 | 5% | 16% |
| Vermont | 2098 | 449 | 120 | 66 | 6% | 15% |
| Virginia | 2071 | 542 | 130 | 72 | 6% | 13% |
| Washington | 4629 | 887 | 293 | 93 | 6% | 10% |
| West Virginia | 2259 | 325 | 163 | 81 | 7% | 25% |
| Wisconsin | 6446 | 1004 | 218 | 104 | 3% | 10% |
| Wyoming | 3732 | 685 | 189 | 104 | 5% | 15% |
| | | TOTALS | | | AVERAGES | |
| | 212839 | 34326 | 11301 | 4396 | 5% | 13% |

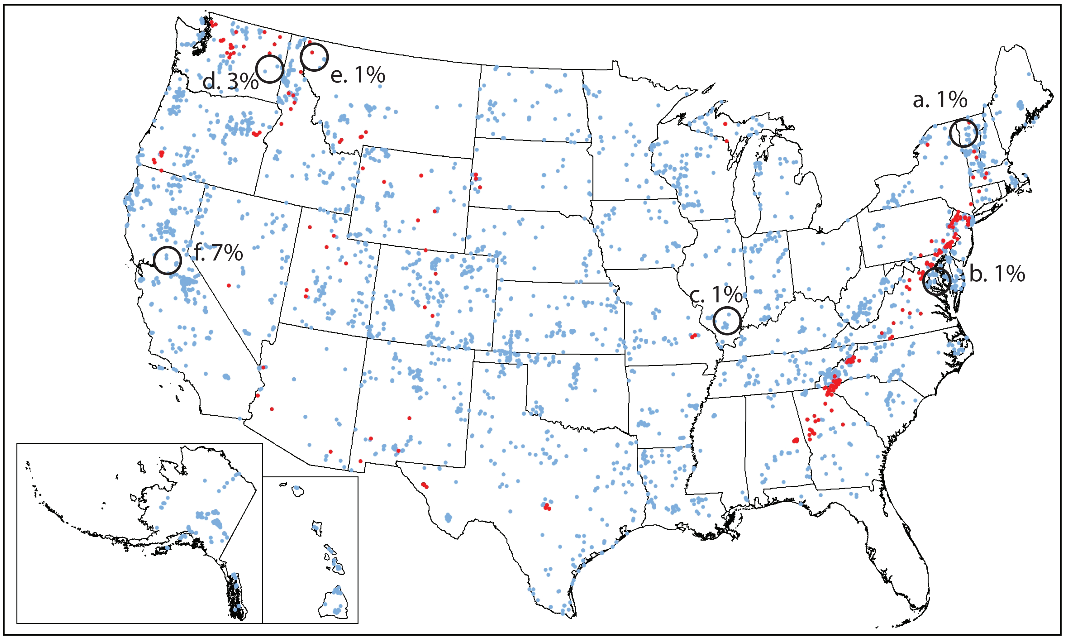


**FIGURE 1.** Map of the U.S.A. showing amphibole-containing pedons (blue circles) and natural occurrences of amphibole asbestos as documented in a series of USGS reports marked with red circles (Van Gosen 2005, 2006, 2007, 2008, 2010). USGS data sets for California and Alaska are in preparation, and there are no known occurrences of asbestos in Hawaii. Also shown are six larger circles (labeled a–f, with associated percent amphibole content of soil next to each). As part of a larger on-going study, soil samples were collected from these circled areas and their amphibole content determined by powder XRD. Examples of amphibole particles from locations "a–d" are shown in Figure 2. For location "e" see Figures 3 to 5 (Gunter and Sanchez 2009) and location "f" is shown in Figure 25 (Gunter et al. 2007).

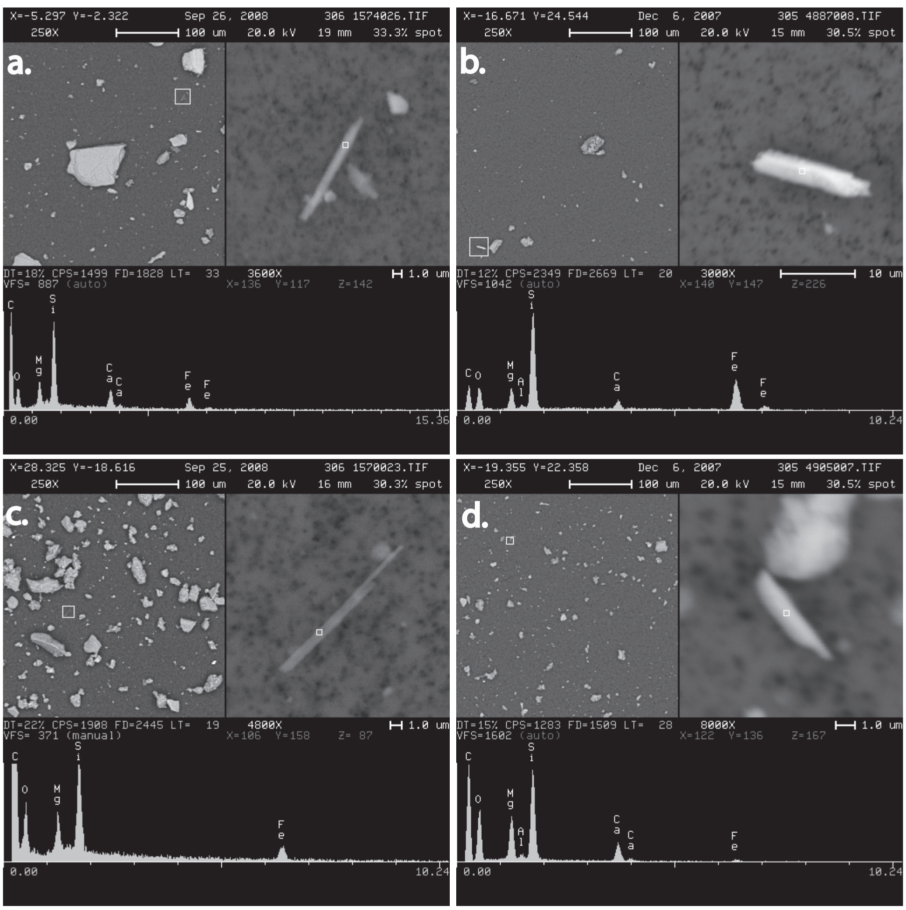


**FIGURE 2.** SEM photographs and EDS data of amphibole particles: (**a**) actinolite from Vermont; (**b**) ferroactinolite from Washington, D.C.; (**c**) amphibole (either grunerite or gedrite) from southern Illinois; and (**d**) tremolite from eastern Washington state.

## Results and discussion

Based on our results, amphiboles within soils in the U.S.A. are ubiquitous; soils in every state, except for Rhode Island, contained amphiboles. Five percent of horizons and 13% of pedons contained amphiboles (i.e., they contained at least one counted amphibole particle of the 300 in the PLM point count). The state percentages ranged from a low in Florida (1% of horizons and 4% of pedons) to a high in Arkansas (24% of horizons and 49% of pedons). In 41 out of the 50 states, 10% or more pedons contain amphiboles. States with few pedons containing amphiboles (less than 10% pedons) are intermingled with states that have more pedons containing amphiboles (Fig. 1).

Figure 1 also shows circled areas sampled by Gunter and coworkers as part of a separate ongoing study to determine the amphibole content and amphibole morphology in soils. The percentages on the map refer to the amphibole content determined by powder X-ray diffraction as discussed in Sanchez et al. (2009). Each of these samples represents a different geologic setting within the country. Although some of samples are not from mafic or ultramafic provinces, where amphibole-bearing rocks are typically found, all of them contain amphiboles at the 1% or greater level. SEM photographs of example amphibole particles from those soils are shown in Figure 2; all of these particles would meet the counting criteria to be considered a fiber.

Occurrences of amphiboles asbestos (Fig. 1) have been documented in association with metamorphic rocks, such as in the Appalachians, the Rocky Mountains, or along the western coast of the U.S.A. (Van Gosen 2005, 2006, 2007, 2008, 2010). However, the USDA database shows that soils containing amphiboles are not constrained to outcrops of potential host rocks and are generally distributed across the U.S.A. This makes geological sense, as many of these soils would contain minerals derived from amphibole-bearing rocks that were either the underlying parent rock or had been transported by normal geological processes (i.e., wind, rivers, and glaciation).

The results herein may not be surprising to the geological community (i.e., that amphiboles are ubiquitous in the natural environment). However, many outside of that community (e.g., those in the medical, industrial hygiene, and regulatory fields) should find these results useful in helping them to understand that definitions applied to asbestos in the occupational setting cannot be applied to the natural setting. And if these occupational definitions are applied to the natural environmental, then many of our farmlands, by definition, will be considered "asbestos contaminated."

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