IS ASBESTOS PRESENT IN AGUA FRIA RIVER SAND AND GRAVEL?

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Introduction

During the past several years accusations have been made that sand and gravel operations along the Agua Fria River near Sun City are exposing nearby residents to asbestos. The Arizona Geological Survey (AZGS) received several calls in the past three years from citizens in the Sun City area asking if there could be asbestos in the Agua Fria River. Someone has convinced many people that they are being exposed to dangerous amounts of asbestos from sand and gravel operations. We have consistently and firmly told callers that there is no evidence of any asbestos deposits in the region. Despite assurances, the accusations have continued.

Allegation of asbestos exposure was made a topic in the 2002 State Mine Inspector election. A candidate for the office appeared in campaign commercials stating that mining along the Agua Fria River was giving residents lung cancer at one of the highest rates in the country, further fueling fear among area residents.

AZGS has reviewed the geologic setting relative to the claims put forth regarding asbestos in the Agua Fria River. This report presents evidence that refutes those claims in the hope of ending such unfounded and unsubstantiated statements and calming fears of residents of the region.

What is Asbestos?

Asbestos is a term applied to six different minerals that, when present in fibrous form, have special properties that make them useful for industrial applications. One of the asbestos minerals, chrysotile, is in the serpentine family. More than 95 percent of the asbestos used in the United States is the chrysotile type (Ross, 1982a, 1982b). The other five asbestos minerals are amphiboles. Table 1 lists the asbestos minerals and their chemical formulas.

Serpentine minerals are phyllosilicates, in which the molecules are arranged in sheets. In chrysotile, the sheets tend to curl into long tubes, forming hollow fibers (Campbell and others, 1977; Virta, 2002). One way chrysotile forms is by ultramafic rocks (very high in iron and magnesium) reacting with water, a process called serpentinization, to form one or more of the three types of serpentine minerals. The other way serpentine minerals can form is by reaction of magnesium-bearing limestone with hot silica-rich water adjacent to igneous intrusions in a process known as contact metamorphism, or more correctly, contact metasomatism. This latter process is responsible for all of Arizona's chrysotile deposits.

Amphibole minerals are inosilcates, or 'chain silicates' and are very common in igneous and metamorphic rocks. Of the numerous varieties of amphiboles, five may in certain cases grow in a fibrous form in metamorphic rocks. These five are amosite (the fibrous form of grunerite), crocidolite (fibrous form of riebeckite), anthophyllite, tremolite, and actinolite.

Tremolite and actinolite amphiboles form a continuous compositional series from pure tremolite, containing no iron [$Ca_2Mg_5Si_8O_{22}(OH)_2$], to actinolite, in which some iron substitutes for magnesium [$Ca_2(Mg,Fe^{2+})_5Si_8O_{22}(OH)_2$]. Because this type of amphibole has a variable chemical composition, it is often referred to generically as tremolite-actinolite unless it is known on which end of the spectrum the composition lies. Tremolite-actinolite is common in limestones that have been metamorphosed by igneous intrusions. A rare type of actinolite forms felt-like mats known as mountain leather.

Table 1. Fibrous (asbestiform) minerals and their formulas

Mineral	Traditional Formula	Stoichiometric formula
Serpentine minerals		
Chrysotile	$Mg_3Si_2O_5(OH)_4$	$3MgO▪2SiO_2▪2H_2O$
Amphibole minerals		
Grunerite (Amosite)	$(Fe^{2+})_2(Fe^{2+}, Mg)_5Si_8O_{22}(OH)_2$	$2FeO▪5(FeO, MgO)▪8SiO_2▪H_2O$
Riebeckite (Crocidolite)	$Na_2Fe^{2+}{}_3Fe^{3+}{}_2(Si_88O_{22})(OH)_2$	$2NaO▪3FeO▪2Fe_2O_3▪8SiO_2▪H_2O$
Anthophyllite	$Mg_7(Si_8O_{22})(OH)_2$	$7MgO▪8SiO_2▪H_2O$
Tremolite	$Ca_2Mg_5Si_8O_{22}(OH)_2$	$2CaO▪5MgO▪8SiO_2▪H_2O$
Actinolite	$Ca_2(Mg,Fe^{2+})_5Si_8O_{22}(OH)_2$	$2CaO▪5(MgO, FeO)▪8SiO_2▪H_2O$

These minerals are not always in a fibrous form. They more commonly occur in massive or granular crystalline form. In only rare instances conditions were right to produce the loosely-bound fibrous form of the mineral, and in quantities that can be mined (Campbell and others, 1977). In other words, the mere presence of one of these minerals in a rock does not automatically mean that the mineral is asbestiform, or that it constitutes a 'deposit'.

Although many minerals can occur in a fibrous form, only the one serpentine and five amphibole minerals discussed above constitute 'asbestos'. For example, gypsum commonly occurs in a fibrous form known as satin spar. Other common minerals that sometimes occur in a fibrous form include calcite, zeolites, the borate mineral ulexite (known as 'TV rock'), malachite, sillimanite, kyanite, and wollastonite. Skinner and others (1988) list 388 different minerals that may occur in a fibrous form but they point out that their list is by no means complete.

Asbestos became a popular material because it is plentiful, easy to mine and process, and has many beneficial properties. Asbestos minerals have high tensile strength and are nearly chemically inert, fireproof, and electrically nonconductive. These properties make asbestos ideal for industrial applications such as thermal and electrical insulation and fireproofing materials. Asbestos was also used in consumer items such as brake pads, ironing board covers, and floor tiles, and in building materials such as roofing and siding for homes. Asbestos, most commonly crocidolite, was used in cigarette filters in the 1950s (Longo and others, 1995; Hammar and others, 1997; Dodson and others, 2002). Asbestos was used in gas mask filters in the World War II era (Ross, 1982a, 1982b). Table 2 lists a few of the thousands of products that contained asbestos in the past. Asbestos has been replaced in most products by fibers composed of ceramic, cellulose, carbon, steel, glass, or other minerals such as wollastonite. Because it was used in so many applications in the past and can also result from the weathering of certain rocks, asbestos is ubiquitous in small amounts in the environment (Center for Disease Control, 2001).

Table 2. Past uses of asbestos

Industrial uses	Consumer products	
Pipe insulation	Brake pads	Acoustic ceiling tile
Structural steel insulation	Home siding	Vinyl floor tiles
Electrical insulation	Hair dryers	Roofing materials
Cement water pipes	Cigarette filters	Spackling compound
Boilers	Ironing board covers	

Health Effects of Asbestos Exposure

High levels of occupational asbestos exposure have been found to be associated with asbestosis, mesothelioma, and lung cancer. Most dust particles that are inhaled into the lungs are trapped by mucous and removed by the action of cilia, fine hair-like structures that act as a conveyor system carrying foreign bodies out of the lungs. Particles that enter the deepest parts of the lungs are also engulfed by scavenger cells (macrophages) that either carry the particles up to the cilia or move through the alveolar wall into the lymph channels. Fibers longer than 5 microns (µm) are not removed efficiently by the macrophages and may lodge in the lower respiratory tract or penetrate the lining of the lung (pleura). Eventually, lodged fibers within the lung trigger production of collagen that makes the lung tissue hard and fibrous, a condition called asbestosis (Ross, 1982a, 1982b).

Mesothelioma is a disease that results in tumors in the mesothelium (lining) of the chest (pleura), abdominal cavity (peritoneum) or heart (pericardium). Most cases of mesothelioma are caused by asbestos fibers that penetrate the lung and lodge in the pleura. The majority of mesothelioma cases are seen in males that have had occupational exposure to asbestos (American Lung Association, 2003).

The Occupational Safety and Health Administration (OSHA) defines an asbestos fiber as a particle that is 5 µm or longer, with a length-to-width ratio of 3 to 1 or longer" (29 CFR 1910.1001). Fibers less than 5 µm in diameter are the most likely to cause asbestos disease (National Institute for Occupational Safety and Health [NIOSH], 1977; Ross, 1982a, 1982b). By comparison, human hair is generally 80-100 µm in diameter.

Smoking greatly increases the risk of lung cancer from asbestos exposure (NIOSH, 1977 EPA, 2003), as much as 15 times that of non-smokers (Camus, 2001). Unlike asbestosis and lung cancer, the risk of mesothelioma from asbestos exposure has been found to be independent of smoking history (NIOSH, 1977; Ross, 1982a, 1982b).

Most studies have concluded that the incidence of disease is much higher in workers in amphibole asbestos industries than those in chrysotile asbestos industries. Chrysotile is the least harmful of the six asbestos minerals; crocidolite is considered the most harmful (Ross, 192a, 1982b; Hillerdal, 1999; Camus, 2001). Hodgson and Darnton (2000) report that the risk of developing mesothelioma from exposure to amosite is 100 times greater than from chrysotile, and exposure to crocidolite presents 500 times greater risk than from chrysotile. Despite overwhelming evidence that different types of asbestos minerals present much different health risks, the Environmental Protection Agency (EPA), Occupational Safety and Health Administration (OSHA), and Mine Safety and Health Administration (MSHA) regulate all types of asbestos the same.

Exposure to asbestos in harmful amounts was largely to those who worked in industries that involved asbestos. Such occupations included manufacture of boilers, steam locomotives, roofing materials, cement pipes, tiles, brake pads, clutch facings, filters, and gaskets. Ship builders and sailors during World War II were also exposed to asbestos because the material was used extensively for insulation throughout ships. Construction of buildings, where asbestos was used for thermal insulation in walls and on pipes, in floor and ceiling tiles, and roofing material may also have exposed workers to asbestos.

Asbestos diseases usually initiate at least 20 years after exposure, and peak about 30-40 years after exposure. Lung cancer begins to appear after 1-14 years and peaks about 30-35 years after exposure. Asbestosis appears 15-20 years after exposure, with peak onset of about 40-45 years (Ross, 1982a, 1982b). For mesothelioma, the period between exposure and peak onset of the disease is commonly more than 50 years (Hillerdal, 1999; Smith, 2002). The shortest latency period for mesothelioma from occupational exposure is 13.3 years (Skinner and others, 1988).

Median age at death from asbestosis nationwide increased from 60 years in 1968 to 74 years by 1992 (NIOSH, 1997, 2003). This increase is explained by the fact that there is a significant lag time between asbestos exposure and the onset of disease (typically 20-40 years), and that since the early 1970s, young people are no longer exposed to asbestos in the workplace as was the case in the past. In Arizona the number of deaths from asbestos increased from 6 in 1990 to 21 in 1999 (NIOSH, 2003). Arizona ranks in 31st place among the 50 states in age-adjusted mortality rate from asbestosis.

For asbestosis in particular, the age-at-death statistics are quite illuminating. Nationally, 1,905 deaths from asbestosis were recorded for 1991 and 1992 combined (NIOSH, 1997). Of these deaths, 96 percent were in men. Mean age at death from asbestosis was 73.1 years in 1991 and 73.5 years in 1992. In 1991, 76.9 percent of deaths were in people over 65 years of age and in 1992, 75.7 percent were over 65. Of the 1,905 deaths from asbestosis in those two years, only five were people under 45 years of age. In the 7 years from 1993 to 1999, a total of 8,061 asbestos deaths were recorded in the U.S. (NIOSH, 2003). Of these, 97 percent were in men. The median age of death increased from 73.1 years in 1991 to 77 years in 1999. Only 11 of the 8,061 deaths were in persons under 45 years of age, and only one was younger than 35 years old. This skewed distribution of 96-97 percent male deaths strongly argues against incidental or background exposure being responsible because if such low-level exposure caused asbestosis, the distribution of deaths would more equal between men and women. The increase in median age at death also points to less exposure in younger generations.

Asbestos was in common usage until the early 1970s and virtually the entire population was exposed to trace amounts, yet asbestos-related diseases are very rare in the general population. This observation reinforces the fact that incidental, non-occupational exposure to asbestos does not lead to disease.

The fact the nearly all asbestosis deaths are in older men shows that it is occupational exposure that results in disease. Some of the deaths in elderly women can be explained by the fact that some women worked in industries involving asbestos (such as being shipyard workers during World War II), or were exposed to asbestos fibers brought home in the clothing of family members who worked around asbestos (Hammar and others, 1997).

Uncertainties in determining exposure-response relationships and risks for asbestos-related disease include (MSHA, 2002a):

- Uncertainties in exposure estimates in studied workers that are both quantitative and qualitative.
- Extrapolation to low levels of exposure epidemiological data that involve only high levels of exposure.
- Variability among estimates of risks from various studies.
- Inconsistent or inappropriate adjustment for the possible confounding effects of tobacco smoking.
- Possibility of differences in potency among different types of asbestos.

The current OSHA health standard for *occupational* exposure to asbestos is 0.1 fibers per cubic centimeter (cm^3)(=100 fibers per liter) of air, time-weighted and averaged over an eight-hour work day, or, 1 fiber per cm^3 (1,000 fibers per liter) over a 30 minute period (29 CFR 1910.1001). Because of the decline in workplace exposure to chrysotile, the lifetime risk of chrysotile-exposed workers is about 1,000 times lower than in the past (Camus, 2001).

At a level of 0.1 fibers per cm of air, a worker would breath in about 333,333 fibers in an 8-hour work day. In a 250-day work year that worker would inhale more than 83.3 million fibers. If this worker spent 20 years breathing air with that concentration, he would inhale nearly 1.7 *billion* fibers. One asbestos worker who died had 3 billion crocidolite fibers per gram of dry lung tissue (Tossavainen and others, 1994).

The workplace standard of 0.1 fiber per cm^3 is believed to carry a risk of 2.3 asbestos related disease cases per 1,000 workers exposed for 20 years. The surge of lawsuits over asbestos in recent years is largely driven by the contention that a *single* fiber of asbestos can cause cancer, yet it is clear from the statistics that even after breathing *billions* of fibers only a few cases of disease will result.

Background asbestos concentrations in outdoor air range from 0.000003 fibers per cm^3 in rural areas to 0.003 fibers per cm^3 near sites where asbestos is mines or manufactured (CDC, 2001). A mean concentration of 0.00039 fibers per cm^3 has been determined in typical outdoor air in the United States (Mossman and others, 1990)

Extensive testing of schools in the U.S. has revealed that the mean concentration of asbestos is 0.00024 fibers per cm^3, which is *lower* than the mean concentration of asbestos in outdoor air, 0.00039 fiber per cm^3 (Mossman and others, 1990). For perspective, at that concentration the average person inhales 3,900 fibers of asbestos each day in outdoor air (Gunter, 1994). At the level of asbestos found in schools, an expected annual death rate of 0.005 to 0.093 per million has been calculated (assuming a no-threshold model), compared to an *actual* 10 deaths per million for playing high school football (Mossman and others, 1990). If true risks were the guideline, parents and regulators would, of course, work much harder to eliminate high school sports than to remove asbestos from school buildings.

One person proposed to MSHA that the government "establish a permissible exposure level at 0.0000" (MSHA, 2002c). Given that the average person breathes asbestos at a background level outdoors of 0.00039 fibers per cm^3, the proposal to lower the permissible exposure to zero is absurd.

Should the average person worry about non-occupational asbestos exposure? The World Health Organization (WHO, 1986) concludes the following: "In the general population, the risks of mesothelioma and lung cancer, attributable to asbestos, cannot be quantified reliably and are probably undetectably low. Cigarette smoking is the major etiological factor in the production of lung cancer in the general population. The risk of asbestosis is virtually zero." Hillerdal (1999) echoes the low risk of non-occupational asbestos exposure, concluding that with low-dose exposure "as occurs in the general population, the risk is very small, often impossible to measure."

The risk from ingestion of asbestos in water is negligible compared to inhalation and consequently the permissible limit for exposure is much greater. For water, the current EPA standard, used in Arizona, is 7 *million* fibers longer than 10 µm per liter. Asbestos in water originates from old cement pipes or from weathering of rocks. According to the World Health Organization, there is no convincing evidence that asbestos has any adverse effect on human health when ingested in water (WHO, 1986; 1994; 1996). Localities with high concentrations of asbestos in groundwater are invariably in areas where bedrock or adjacent sediments contain asbestos (Schreier, 1989). The City of Peoria (2003) tested their water supply for asbestos and found none.

Known Occurrences of Asbestos in Arizona

All known chrysotile asbestos deposits in Arizona are of the contact metamorphic type; none are from serpentinization of ultramafic rocks. These are limited to zones of alteration of magnesium-bearing limestones that are intruded by igneous rocks. By far the most productive area in the state is the Sierra Ancha-Salt River Canyon region of Gila County (Figure 1).

Asbestos deposits and occurrences in this district are too numerous to list in this report. In general, the deposits consist of veins and masses of chrysotile in Precambrian Mescal Limestone. Diabase, a dark igneous rock rich in iron and magnesium, intruded sedimentary rocks of the Apache Group, including the Mescal Limestone, in the form of sills and dikes. Isotopic age determinations on the diabase range from 1,050 to 1,140 million years old (Wrucke, 1989). The limestone reacted with silica-bearing fluids heated by the diabase, forming the serpentine mineral chrysotile.

Asbestos was discovered in the region in 1872, and the first claims were filed in 1913 (Stewart, 1955). About 75,000 tons of asbestos were mined from the Salt River region of Gila County from 1913 to 1966 from more than 160 mines (Shride, 1969). Another 60-70 occurrences from which there was no production are noted in the region. Production from the district ceased by the early 1980s (Peirce and Garcia, 1983).

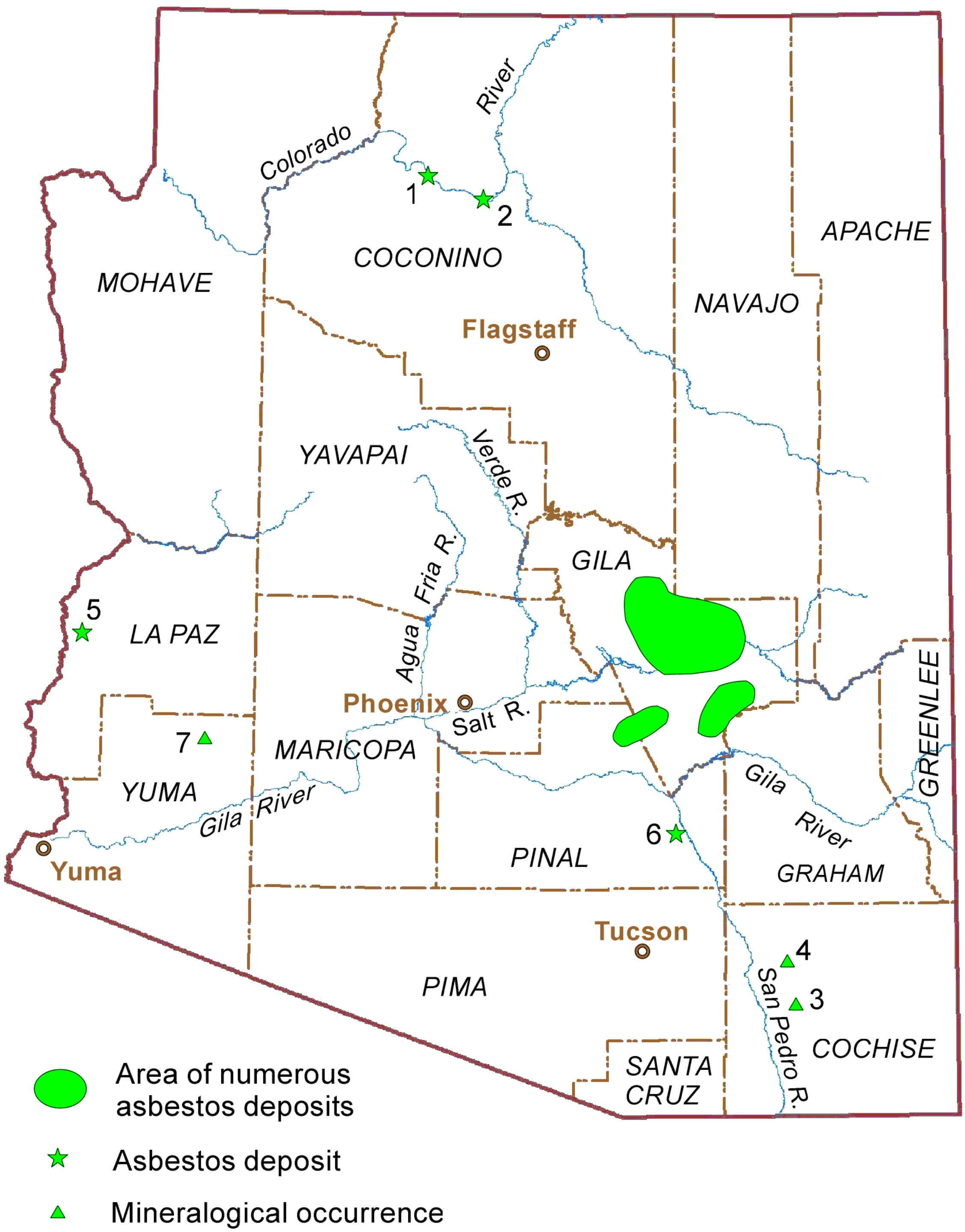
Asbestos occurs in small amounts other counties. Known deposits and notable mineral occurrences, are listed below.

Coconino County

Besides the Salt River Canyon region, the other important location where asbestos has been mined is in the Grand Canyon. Conditions that led to formation of asbestos were similar to those in the Salt River Canyon. In the Grand Canyon, limestone was intruded by mafic rocks during the late Precambrian. Asbestos was noted in early exploration of the Grand Canyon by the Powell expedition (Wilson, 1928). Two deposits, the Hance and Bass, were mined early in the last century (Allen and Butler, 1921; Shride, 1969; Billingsley, 1974). The deposits had good quality asbestos but, because they were fairly small and difficult to access, little production was recorded, probably amounting to a few tons (Shride, 1969).

Cochise County

Minor fibrous chrysotile occurs in a contact-metamorphic vein at the Abril zinc mine in the Dragoon mountains (Stewart, 1955; Phillips, 1987). The serpentine formed where Permian limestone was intruded by a mafic dike. Only a single vein was encountered in an adit and its average width was only ¼ to ½ inch (Stewart, 1955). In a detailed investigation of the Abril mine (Perry, 1964), neither serpentine nor chrysotile are mentioned. This locality should be considered a mineralogical occurrence rather than an asbestos ‘deposit’ because of its trivial extent.



Deposits and occurrences discussed in text:

1. Bass Mine
2. Hance Mine
3. Abril Mine
4. Empire No. 2 shaft
5. Dome Rock Mtns.
6. Putnam Wash
7. Cemetery Ridge

Asbestiform anthophyllite is reported at the Empire No. 2 shaft, two miles southwest of Dragoon, at the southeast edge of the Little Dragoon Mountains (Cooper and Silver, 1964). The anthophyllite is in cross-fiber veins in Horquilla limestone and "the fibers are readily separated but weak and easily broken." Ore deposits in this area are related to intrusion of the Texas Canyon quartz monzonite. This locality constitutes a mineralogical occurrence because of its insignificant extent; is not in any lists of asbestos deposits in Arizona (such as Funnell and Wolfe, 1964; Phillips, 1987). Serpentine and tremolite occur in this district but are non-asbestiform (Cooper and Silver, 1964).

La Paz County

One minor occurrence of asbestos about 13 miles northwest of Quartzite in the northern Dome Rock mountains is of the tremolite variety (Allen and Butler, 1921; Wilson, 1928; Phillips, 1987). This small occurrence consists of weak, flaky, and brittle tremolite in sedimentary rocks that have been metamorphosed to schist.

Pima County

Actinolite-tremolite occurs in the western Sierrita Mountains, in the Twin Buttes area of the eastern Sierrita Mountains, in the Rosemont area in the northern Santa Rita Mountains, and the western Empire Mountains (Phillips, 1987). In all of these occurrences the mineral formed in metamorphosed limestone. These locations represent small and scattered *occurrences* but are not economic 'deposits' that can be mined. Furthermore, primary references by those who have studied in detail the geology and ore deposits in these areas note the presence of actinolite-tremolite but none indicate that it is asbestiform. It cannot be assumed that the mention of tremolite or actinolite in a reference indicates that it is in the fibrous form. Tremolite and actinolite are more commonly in fine needles (acicular) and are rarely in truly fibrous form. Unfortunately, because Phillips (1987) did not list references, it is not possible to confirm the sources that refer to the mineral occurrences as being asbestiform. The 'asbestos' occurrences listed in Phillips (1987) for Pima County are here discounted because we could not find any indication in the extensive published literature (e.g., Schrader, 1915; Creasey and Quick, 1955; Journeay, 1959; Richard and Courtright, 1959; Creasey, 1966; Kinnison, 1966; Himes, 1973; Barter and Kelly, 1982; Anzalone, 1995) that the actinolite-tremolite was in the fibrous habit, or in pure amounts that constitute a 'deposit' rather than a mineralogical occurrence.

Pinal County

Several occurrences of chrysotile asbestos are reported in northernmost Pinal County near Superior (Phillips, 1987). The localities are a continuation of the asbestos belt of the Sierra Ancha-Salt River Canyon region of Gila County.

Chrysotile asbestos occurs in Putnam Wash, about one mile west of its confluence with the San Pedro River (Stewart, 1955; Krieger, 1968; Phillips, 1987). The low quality asbestos occurs where Mescal Limestone is intruded by Precambrian diabase and is of the same origin as the asbestos in the Salt River Canyon region.

Yavapai County

In references listing known asbestos deposits in Arizona, no deposits are indicated in Yavapai County. These references include Allen and Butler (1921); Wilson (1928); Stewart (1955, 1956); Funnel and Wolfe (1964); Shride (1969); Moore and Varga (1976) and Phillips (1987). At the Boggs Mine, near Poland Junction, where copper sulfide was the mineral of interest, actinolite is noted as being a "fine felted radiating amphibole" that, along with garnet and epidote, forms a rim around veinlets of quartz (Lindgren, 1926). The "radiating" actinolite is most likely in fine needles (acicular form), which is a more common habit for actinolite than fibrous. If this is the case, it is not asbestos because it is not fibrous. In any event, Lindgren does not call it asbestos nor does he explicitly describe it as fibrous and this is probably important because fibrous amphibole would be notable enough to mention. This occurrence is limited in size and does not contain enough actinolite to be of any interest other than as a mineralogical curiosity. Lindgren does not mention actinolite occurring anywhere else in the Bradshaw Mountains.

Yuma County

In the Cemetery Ridge area of northeastern Yuma County, altered mafic dikes that intrude schist contain irregular masses of magnetite and coarsely crystalline actinolite altering to chlorite. Near these dikes are veins containing asbestiform actinolite (Wilson, 1933; Phillips, 1987). The quality is low and the amount present is too small to be of commercial interest. This locality is considered here a mineralogical occurrence rather than a 'deposit' because there is no indication that there is sufficient quantity to be mined.

Is There Asbestos in the Agua Fria River Gravel?

Whether the Agua Fria River contains harmful amounts of asbestos depends on the geology of the drainage area upstream from the sand and gravel deposits. The type of asbestos allegedly present in the Agua Fria River was not specified by those who made claims of exposure to nearby residents. Whether this was because of a lack of awareness that there is more than one type of asbestos or that the type of asbestos is dependent on geology was not determined.

Geologic investigations of portions of the upper Agua Fria River have been conducted at various levels of detail and those studies are available in the published literature. Amphiboles are common in metamorphic rocks known as the Yavapai Schist in the upper Agua Fria River drainage area studied by Jaggar and Palache (1905) and Lindgren (1926); O'Hara (1981); Capps and others (1986); Stimac and others (1987); Wahl and others (1988). The most common amphibole in the schists of the region is hornblende, generally described as coarse grained. Hornblende is not one of the asbestos minerals. At the Boggs Mine, where copper sulfide was the mineral of interest, actinolite is noted as being a "fine felted radiating amphibole" that, along with garnet and epidote, forms a rim around veinlets of quartz (Lindgren, 1926). This occurrence is limited in size and does not contain enough actinolite to be of any interest other than as a mineralogical curiosity. No other occurrence of fibrous amphibole is noted in the literature for the Agua Fria River drainage.

The Mine Safety and Health Administration (MSHA) tested 28 sand and gravel operations in the Salt River drainage in the Phoenix area and found no asbestos in air samples (MSHA, 2002b) This result is important to the question of whether there is airborne asbestos being produced by sand and gravel operations along the Agua Fria River because the Salt River is downstream from a world-class asbestos district, yet asbestos was not found in dust around sand and gravel operations along the Salt River in the Phoenix region.

Conclusion

Based on geologic considerations, the Agua Fria River should not be suspected of harboring asbestos. The drainage area of the river contains no known asbestos deposits, nor any asbestos milling facilities. Sampling of 28 sand and gravel operations by MSHA revealed no asbestos in the air. The contention that there is a danger from airborne asbestos produced by sand and gravel operations along the Agua Fria River near Sun City is unfounded and continuing these allegations is irresponsible.

REFERENCES CITED

Allen, M.A., and Butler, G.M., 1921, Asbestos: Arizona Bureau of Mines Bulletin 113, 31 p.

American Lung Association, 2003, Estimated prevalence and incidence of lung disease by Lung Association territory: available on ALA website [http://www.lungusa.org/data/ep/EstimatedPrev03.pdf] accessed 9/24/03.

Anzalone, S.A., 1995, The Helvetia area porphyry systems, Pima County, Arizona, *in* Pierce, F.W., and Bolm, J.G., eds., Porphyry copper deposits of the American Cordillera: Arizona Geological Society Digest 20, p. 436-441.

Barter, C.F., and Kelly, J.L., 1982, Geology of the Twin Buttes mineral deposit, Pima mining district, Pima County, Arizona, *in* Titley, S.R., ed., Advances in geology of the porphyry copper deposits, southwestern North America: Tucson, University of Arizona Press, p. 407-432.

Billingsley, G.H., 1974, Mining in Grand Canyon, *in* Breed, W.J., and Roat, E.C., eds., Geology of the Grand Canyon: Flagstaff, Museum of Northern Arizona, and Grand Canyon Natural History Association, p. 170-176.

Campbell, W.J., Blake, R.L., Brown, L.L., Cather, E.E., and Sjoberg, J.J., 1977, Selected silicate minerals and their asbestiform varieties: U.S. Bureau of Mines Information Circular 8751, 52 p.

Camus, Michael, 2001, A ban on asbestos must be based on a comparative risk: Canadian Medical Association Journal, v. 164, no. 4, p. 491-494.

Capps, R.C., Reynolds, S.J., Kortemeier, C.P., and Scott, E.A., 1986, Geologic map of the northeastern Hieroglyphic Mountains, central Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 86-10, 16 p., 1 sheet, scale 1:24,000.

Center for Disease Control, 2001, Toxicological profile for asbestos: website [http://www.atsdr.cdc.gov/toxprofiles/tp61.html] accessed 9/24/03.

City of Peoria, 2003, Water report 2003: City of Peoria website [http://www.peoriaaz.com/Water03/docs/WtrRpt03_52103.pdf], accessed 9,24.03.

Cooper, J.R., and Silver, L.T., 1964, Geology and ore deposits of the Dragoon quadrangle, Cochise County, Arizona: U.S. Geological Survey Professional Paper 416, 196 p., 13 sheets, scales 1:600, 1:1,200, 1:2,400, 1:4,800, 1:12,000, 1:31,680, 1:125,000.

Creasey, S.C., 1966, Hydrothermal alteration, *in* Titley, S.R., and Hicks, C.L., eds., Geology of the porphyry copper deposits, southwestern North America: Tucson, University of Arizona Press, p. 51-74.

Creasey, S.C., and Quick, G.L., 1955, Copper deposits of part of the Helvetia mining district, Pima County, Arizona: U.S. Geological Survey Bulletin 1027-F, p. 301-323.

Dodson, R.F., Williams, M.G., and Satterley, J.D., 2002, Asbestos burden in two cases of mesothelioma where the work history included manufacturing of cigarette filters: Journal of Toxicology and Environmental Health, part A, v. 65, p. 1109-1120.

Funnell, J.E., and Wolfe, E.J., 1964, Compendium on nonmetallic minerals of Arizona: San Antonio, Tex., Southwest Research Institute, 374 p. [prepared for Arizona Public Service Company, Phoenix, Ariz.].

Gunter, M.E., 1994, Asbestos as a metaphor for teaching risk perception: Journal of Geological Education, v. 42, p. 17.
Hammar S.P., Roggli, V.L., Ovry, T.D., and Moffat, E.J., 1997, Malignant mesothelioma in women [abstract]: Lung cancer, v. 18, Supplement 1, August 1997, p. 236.
Hillerdal, Gunnar, 1999, Mesothelioma: Cases associated with non-occupational and low dose exposures: Occupational and Environmental Medicine, v. 56, p. 505-513.
Himes, M.D., 1973, Mineralization and alteration at Pima mine - a complex porphyry copper deposit: American Institute of Mining, Metallurgical, and Petroleum Engineers, Society of Mining Engineers, Transactions, v. 254, p. 166-174.
Hodgson, J.T., and Darnton, Andrew, 2000, The quantitative risks of mesothelioma and lung cancer in relation to asbestos exposure: Annals of Occupational Hygiene, v. 8, no. 8. p. 565-601.
Jaggar, T.A., Jr., and Palache, C., 1905, Bradshaw Mountains folio, Arizona: U.S. Geological Survey, Geologic Atlas of the United States, Folio no. 126, 11 p., 5 sheets, scale 1:125,000.
Journeay, J.A., 1959, Pyrometasomatic deposits at Pima mine, *in* Heindl, L.A., ed., Southern Arizona Guidebook II, combined with the 2nd annual Arizona Geological Society Digest: Arizona Geological Society, p. 197-199.
Kinnison, J.E., 1966, The Mission copper deposit, Arizona, *in* Titley, S.R., and Hicks, C.L., eds., Geology of the porphyry copper deposits, southwestern North America: Tucson, University of Arizona Press, p. 281-287.
Krieger, M.H., 1968, Geologic map of the Lookout Mountain quadrangle, Pinal County, Arizona: U.S. Geological Survey Geologic Quadrangle Map GQ-670, sale 1:24,000.
Lindgren, Waldemar, 1926, Ore deposits of the Jerome and Bradshaw Mountains quadrangles, Arizona: U.S. Geological Survey Bulletin 782, 192 p.
Longo, W.E., Rigler, M.W., and Slade. J., 1995, Crocidolite asbestos fibers in smoke from original Kent cigarettes: Cancer Research, v. 55, Issue 11, p. 2232-2235.
MSHA, 2002a, Testimony, Advanced Notice of Proposed Rulemaking, Measuring and Controlling Asbestos Exposure: MSHA hearing transcript, available online [http://www.msha.gov/regs/comments/asbestos/docket/hearings/charlottesville/ab%2D24%2Dhear%2D20.pdf], accessed 9/25/03.
MSHA, 2002b, In the Matter of: 30 CFR PARTS 58 AND 72 RIN 1219-AB24, Measuring and controlling asbestos exposure: Transcript of a public hearing, Phoenix, June 5, 2002 [available online at http://www.msha.gov/regs/comments/asbestos/Transcripts/phoenix06052002.pdf], accessed 7/11/03.
MSHA, 2002c, Memo to MSHA, no. AB24-HEAR-18: MSHA website [http://www.msha.gov/regs/comments/asbestos/docket/hearings/phoenix/ab24%2Dhear%2D18.pdf], accessed 9/22/03.
Moore, R.T., and Varga, R.J., comps., 1976, Maps showing nonmetallic mineral deposits in the Phoenix area, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-845-J, 1 sheet, scales 1:250,000, 1:500,000.
Mossman, B.T., Bignon, J., Corn, M., Seaton, A., and Gee, J.B.L., 1990, Asbestos: Scientific developments and implications for public policy: Science, v. 247, p. 294-301.

National Institute for Occupational Safety and Health, 1977, Revised recommended asbestos standard: U.S. Department of Health, Education and Welfare [available online at http://www.cdc.gov/niosh/pdfs/77-169d.pdf], accessed 9/27/03.
National Institute for Occupational Safety and Health, 1996, Work-Related Lung Disease Surveillance Report 1996: NIOSH Publication No. 96-134 [available online http://www.cdc.gov/niosh/docs/96-134/96-134.html], accessed 9/24/03.
National Institute for Occupational Safety and Health, 2003, The Work-Related Lung Disease Surveillance Report, 2002: [available online http://www.cdc.gov/niosh/docs/2003-111/2003-111.html], accessed 10/21/03.
O'Hara, P.F., 1981, The influence of mole fraction of CO2 on amphibole stability in the Bradshaw Mountains region, central Arizona: Arizona Geological Society Digest, v. 13, p. 21-23.
Peirce, H.W., and Garcia, M.M., 1983, Asbestos - Toward a perspective: Fieldnotes [Arizona Bureau of Geology and Mineral Technology], v. 13, no. 1, p. 1-9.
Perry, D.V., 1964, Genesis of the contact rocks at the Abril mine, Cochise County, Arizona: University of Arizona unpublished M.S. thesis, 97 p.
Phillips, K.A., 1987, Arizona industrial minerals: Arizona Department of Mines and Mineral Resources, 185 p.
Richard, K.E., and Courtright, J.H., 1959, Some geologic features of the Mission copper deposit, *in* Heindl, L.A., ed., Southern Arizona Guidebook II, combined with the 2nd annual Arizona Geological Society Digest: Arizona Geological Society, p. 200-204.
Ross, Malcolm, 1982a, The geological occurrences and health hazards of amphiboles and serpentine asbestos, *in* Veblin, D.R., ed., Amphiboles and other hydrous pyriboles – mineralogy: Mineralogical Society of America Reviews in Mineralogy, v. 9A, p. 279-323.
Ross, Malcolm, 1982b, A survey of asbestos-related disease in trades and mining occupations and in factory and mining communities as a means of predicting health risks of non-occupational exposure to fibrous minerals: U.S. Geological Survey Open-File Report 82-745, 41 p.
Schrader, F.C., 1915, Mineral deposits of the Santa Rita and Patagonia Mountains, Arizona, with contributions by J.M. Hill: U.S. Geological Survey Bulletin 582, 373 p., 3 sheets, scale 1:125,000.
Schreier, H., 1989, *Asbestos in the Natural Environment*: Amsterdam, Elsevier Studies in Environmental Science 37, 159 p.
Shride, A.F., 1969, Asbestos, *in* Mineral and water resources of Arizona: Arizona Bureau of Mines Bulletin 180, p. 303-311.
Skinner, H.CW., Ross, Malcolm, and Frondel, Clifford, 1988, *Asbestos and Other Fibrous Materials – Mineralogy Crystal Chemistry, and Health Effects*: New York, Oxford Press, 204 p.
Smith, D.D., 2002, Women and mesothelioma: Chest, v. 122, no. 6, p. 1885-1186.
Stewart, L.A., 1955, Chrysotile-asbestos deposits of Arizona: U.S. Bureau of Mines Information Circular I.C. 7706, 124 p.
Stewart, L.A., 1956, Chrysotile-asbestos deposits of Arizona (supplement to Information Circular 7706): U.S. Bureau of Mines Information Circular I.C. 7745, 41 p.
Stimac, J.A., Fryxell, J.E., Reynolds, S.J., Richard, S.M., Grubensky, M.J., and Scott, E.A., 1987, Geologic map of the Wickenburg, southern Buckhorn, and northwestern

Hieroglyphic Mountains, central Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 87-09, 13 p., 2 sheets, scale 1:24,000.

Tossavainen, A., Karjalainen, A., and Karhunen, P.J., 1994, Retention of Asbestos Fibers in the Human Body: Environmental Health Perspectives Volume 102, Supplement 5, p. 253-255 [abstract available online: http://ehpnet1.niehs.nih.gov/docs/1994/Suppl-5/toss-abs.html], accessed 9/22/03.

Virta, R.L., 2002, Asbestos: Geology, mineralogy, mining, and uses: U.S. Geological Survey Open-File Report 02-149, 80 p. [Available online http://pubs.usgs.gov/of/2002/of02-149/], accessed 9/22/03.

Wahl, D.E., Jr., Reynolds, S.J., Capps, R.C., Kortemeier, C.P., Grubensky, M.J., Scott, E.A., and Stimac, J.A., 1988, Geologic map of the southern Hieroglyphic Mountains, central Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 88-01, 6 p., 1 sheet, scale 1:24,000.

Wilson, E.D., 1928, Asbestos deposits of Arizona, with an introduction on asbestos minerals by G.M. Butler: Arizona Bureau of Mines Bulletin no. 126, 100 p.

Wilson, E.D., 1933, Geology and mineral deposits of southern Yuma County, Arizona: Arizona Bureau of Mines Bulletin no. 134, 234 p., 4 sheets, scales 1:4,500, 1:14,200, 1:24,000, 1:360,000.

World Health Organization, 1986, Asbestos and other natural mineral fibres: Geneva, World Health Organization International Program on Chemical Safety, Environmental Health Criteria 53, 194 p. [available online at http://www.inchem.org/documents/ehc/ehc/ehc53.htm], .

World Health Organization, 1994, Asbestos in drinking water – No health hazard: WHO Press Release WHO/17 - 25 February 1994 [http://www.who.int/archives/inf-pr-1994/pr94-17.html], accessed 9/24/03.

World Health Organization, 1996, Chrysotile asbestos evaluated by health experts: WHO Press Release WHO/51/REV.1 [http://www.who.int/archives/inf-pr-1996/pr96-51.html], accessed 9/24/03.

Wrucke, C.T., 1989, The Middle Proterozoic Apache Group, Troy Quartzite, and associated diabase of Arizona, in Jenney, J.P., and Reynolds, S.J., eds., Geologic evolution of Arizona: Arizona Geological Society Digest 17, p. 239-258.