Prepared in cooperation with the California Geological Survey

Reported Historic Asbestos Mines, Historic Asbestos Prospects, and Other Natural Occurrences of Asbestos in California

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Contents

Figures

Table

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What is Asbestos?

Defining Asbestos

"Asbestos" is not a formal mineralogical term, but rather a commercial and industrial term historically applied to a group of silicate minerals that form long, very thin mineral fibers, which generally form bundles. When handled or crushed, asbestos bundles readily separate into individual mineral fibers. This type of mineral growth form or "habit" is called asbestiform. The special properties of commercial-grade asbestos—long, thin, durable mineral fibers and fiber bundles with high tensile strength, flexibility, and resistance to heat, chemicals, and electricity—made it well suited for a number of commercial applications (Bowles, 1955; Ross, 1981; Zoltai, 1981; Cossette, 1984; Ross and others, 1984; Skinner and others, 1988). Asbestos has been primarily used for its insulating and fire-resistant properties in many types of products (see Virta, 2006a; Ross and Virta, 2001).

Currently, most commercial and regulatory asbestos definitions include chrysotile, the asbestiform member of the serpentine mineral group, and several members of the amphibole mineral group, which are the asbestiform varieties of (1) riebeckite (commercially called crocidolite), (2) cummingtonite-grunerite (commercially called amosite), (3) anthophyllite (anthophyllite asbestos), (4) actinolite (actinolite asbestos), and (5) tremolite (tremolite asbestos). Other amphiboles are known to occur in the fibrous and (or) asbestiform habit (Skinner and others, 1988), such as winchite, richterite (Wylie and Huggins, 1980; Meeker and others, 2003), and fluoro-edenite (Gianfagna and Oberti, 2001; Gianfagna and others, 2003).

Historically, chrysotile has accounted for more than 90 percent of the world's asbestos production and now accounts for over 99 percent of the world production (Ross and Virta, 2001; Virta, 2002, 2006b). Mining of crocidolite and amosite deposits, primarily in South Africa and Australia, accounted for most of the other historic asbestos production, and small amounts of anthophyllite asbestos were mined in Finland and the United States in the past (Ross and Virta, 2001; Ross and Nolan, 2003; Van Gosen, 2005, 2007a; Virta, 2006b). Asbestos has not been mined in the United States since the last U.S. asbestos operation closed in 2002. This mine—the KCAC mine in San Benito County—worked a large chrysotile deposit in the Coalinga district of west-central California (fig. 1).

Figure 1. Photograph taken in 1998 of KCAC mine, Joe Pit, in the Coalinga asbestos district of San Benito and Fresno Counties, west-central California. This large chrysotile mine was the last asbestos operation in the United States; the mine closed in 2002. Photograph by California Geological Survey.

The term “asbestos” is not consistently applied in the scientific literature, particularly in regards to noncommercial asbestos deposits (meaning asbestos deposits that are not adequate in size and (or) fiber quality for commercial applications). “Asbestos” has been used to describe some occurrences where fibrous or elongated amphibole particles occur in a natural setting, even when the amphibole particles may not fit all of the compositional, morphological, or physical characteristics of commercial-grade asbestos (Meeker and others, 2006). The distinction between fiber-like amphibole particles formed by crushing (often called cleavage fragments), "fibrous" amphibole, “asbestiform” amphibole, and "regulatory" amphibole asbestos is not health-based and not clear-cut (Meeker and others, 2006; Harper and others, 2008; Aust and others, 2011; Case and others, 2011). The many different ways that asbestos and asbestiform and other related terms have been described are summarized in Lowers and Meeker (2002).

Health Effects and Regulation of Asbestos

Mounting evidence in the 20th century indicated that inhalation of asbestos fibers caused respiratory diseases that have seriously affected many workers in certain asbestos-related occupations (Tweedale and McCulloch, 2004; Dodson and Hammar, 2006). Airborne exposures to asbestos have been linked to a number of serious health problems and diseases, including asbestosis, lung cancer, and mesothelioma. Information on the health effects of asbestos is available online at *http://www.epa.gov/asbestos/* and *http://www.atsdr.cdc.gov/asbestos/*. It is noteworthy that, while decades of research have yielded significant insights into the epidemiology of asbestos-related diseases and asbestos toxicity, many uncertainties and debates remain about the specific characteristics of asbestos minerals that are most responsible for inducing disease (Roggli and others, 2004; Dodson and Hammar, 2006; Fubini and Fenoglio, 2007; Plumlee and others, 2006; Aust and others, 2011; National Institute for Occupational Safety and Health, 2011).

In addition to the commonly regulated asbestiform amphiboles, occurrences of asbestiform winchite, richterite, and fluoro-edenite have been associated with clusters of respiratory disease through industrial and environmental exposures to these mineral fibers. For example, high incidences of respiratory disease and mortality in vermiculite miners and their family members and residents of Libby, Montana, have been linked to asbestiform winchite and richterite intergrown with vermiculite once mined near the town (Peipins and others, 2003; Sullivan, 2007; Horton and others, 2008). Miners and nearby residents exposed to asbestiform fluoro-edenite in volcanic rocks that were quarried near Biancavilla, eastern Sicily, Italy, have an abnormally high number of incidences of mesothelioma (Burragato and others, 2005; Bruno and others, 2006).

A number of United States governmental regulations address worker exposure to asbestos released during the handling of asbestos-containing products, including those used in shipbuilding and general construction; building demolition or remodeling, where asbestos-containing materials (“ACM”) may be encountered; and the repair or replacement of commercial asbestos-based products, such as some vehicle brake components. There also are regulations governing worker exposure to, and environmental release of, asbestos during the mining, processing, and manufacturing of asbestos and asbestos-containing products. Federal regulations are listed in the Code of Federal Regulations, which are available online at *http://www.gpoaccess.gov/cfr/*.

Less straightforward is the regulation and management of noncommercial, natural occurrences of asbestos, often referred to as "naturally occurring asbestos" (NOA). These natural “in-the-ground” asbestos occurrences have gained the attention of regulatory agencies, health departments, and citizen groups. NOA includes minerals described as asbestos that are found in place in their natural state, such as in bedrock or soils (Harper, 2008). Natural occurrences of asbestos are of concern due to potential exposures to microscopic fibers that can become airborne if asbestos-bearing rocks are disturbed by natural erosion or human activities (road building, urban excavations, agriculture, and mining are just a few examples). The geology of asbestos and its application to identifying and managing natural deposits is explained in Van Gosen (2007b). Several examples of occupational and environmental exposures to natural asbestos occurrences are described in Nolan and others (2001), Gianfagna and others (2003), Peipins and others (2003), Ross and Nolan (2003), Burragato and others (2005), Bruno and others (2006), Meeker and others (2006), Sullivan (2007), Horton and others (2008), and Case and others (2011).

The history and study of asbestos and its many complex issues are discussed in Campbell and others (1977), Ross (1981), Stanton and others (1981), Zoltai (1981), Levadie (1984), Skinner and others (1988), Mossman and others (1990), Occupational Safety and Health Administration (1992), Guthrie and Mossman (1993), van Oss and others (1999), Virta (2002), Dodson and Hammar (2006), Fubini and Fenoglio (2007), and National Institute for Occupational Safety and Health (2011).

Natural Occurrences of Asbestos in California

California Asbestos Regulations

In California, concern over potential public exposure to NOA has led to guidance documents and various regulations for NOA. In 1986, asbestos was identified as a toxic air contaminant by the

California Air Resources Board (CARB). In 1990, the CARB issued an Airborne Toxic Control Measure (ATCM), which prohibited the use of serpentine aggregate for surfacing if the asbestos content was 5 percent or more.

In March 1998, the Sacramento Bee newspaper began a series of articles on potential health risks from naturally occurring asbestos in El Dorado County, California. Government agency and general public concerns about public health resulting from these articles led to the formation of a task force to provide information and advice on asbestos to county officials. These concerns over potential health issues associated with exposure to NOA led to new regulations and guidance regarding NOA:

- In July 2000, the CARB adopted amendments to the existing ATCM prohibiting the use or application of serpentine, serpentine-bearing materials and asbestos-containing ultramafic rock for covering unpaved surfaces unless it has been tested using an approved asbestos bulk test method and determined to have an asbestos content that is less than 0.25 percent. These amendments took effect on November 13, 2001.
- In July 2001, the CARB adopted a new ATCM for construction, grading, quarrying, and surface mining operations in areas with serpentine or ultramafic rocks. This ATCM became effective on November 19, 2002.
- In October 2000, the Governor's Office of Planning and Research issued a memorandum providing guidance to Lead Agencies in analyzing the impacts of naturally occurring asbestos on the environment through the California Environmental Quality Act (CEQA) review process.
- In November 2000, the California Department of Real Estate added a section to subdivision forms that included questions related to NOA on property proposed for development.
- In 2004, as part of its school-site review program, the California Department of Toxic Substances Control's School Property Evaluation and Cleanup Division released interim guidance on evaluating NOA at school sites.

In addition to these requirements, some counties also have adopted ordinances or requirements regarding the use of asbestos-containing materials for surfacing or pertaining to excavation and grading activities in areas likely to contain NOA.

Other areas in California where concerns have been raised over potential public exposure to NOA include the Salinas Valley in Monterey County, where asbestos was discovered in soil samples in 2001, and the Clear Creek Management Area (CCMA) within the New Idria serpentinite body in San Benito and Fresno counties. The New Idria body contains the largest known chrysotile occurrence in California; chrysotile asbestos was mined there sporadically prior to 1960 and continuously from 1961 to 2002. The CCMA is a popular recreational area for hikers and campers and also contains a popular off-road vehicle recreational area, which is under the jurisdiction of the Bureau of Land Management (BLM). On the basis of a U.S. Environmental Protection Agency study of the area to protect public health and safety, the Hollister BLM Field Office issued a Temporary Closure, effective May 1, 2008, to all forms of entry and public use for approximately 31,000 acres of public lands in the CCMA (*http://www.blm.gov/ca/st/en/fo/hollister/clear_creek_management_area.html*). Studies are ongoing and a final decision on access restrictions has not been reached at this time.

California Asbestos Occurrences

Asbestos occurrences in California range widely in character and size, from thin veins only millimeters in thickness to some of the largest chrysotile deposits known in the world, covering several tens of square miles. All reports of asbestos mineralization in California found in the geologic literature (with adequate location information) were included in this study, regardless of the apparent size of the occurrence. The references cited for each asbestos site entry provide the most complete descriptions of these occurrences that we found in the literature. The descriptions range in detail from large, detailed geologic reports to a single sentence. While every attempt was made to compile a comprehensive dataset, this compilation cannot represent a complete list of all natural occurrences of asbestos in California, but rather, only those found in a systematic search of the available published geologic literature. It is possible that some published sources were missed and it is likely that unpublished sources exist that could supplement this inventory, or that occurrences exist that have not been documented in either the published or unpublished literature.

The information contained in the datasets compiled for this report (***asbestos_sites.xls***, ***fibrous_amphiboles.xls,*** and ***Death_Valley_talc.xls***) indicate that:

- At least one occurrence of asbestos is reported in 41 of California's 58 counties.
- Four additional counties (Merced, Sacramento, San Luis Obispo, and Santa Barbara) are reported to have asbestos occurrences, but the location data was not detailed enough to place these occurrences in ***asbestos_sites.xls***.
- Fibrous amphiboles are described in 12 counties, 11 that also have reported asbestos occurrences and one, Santa Cruz County, which had no reported asbestos occurrences. The presence of fibrous amphibole indicates that geologic environments favorable for asbestos formation may exist in these counties.

In addition, areas of exposed ultramafic rocks or serpentinite, common host rocks for asbestos, are present in 51 of 58 counties (table 1). The accompanying map (***Plate.pdf***) shows occurrences of these rocks in 42 counties. The occurrences of these rock types in the remaining 9 counties are too small to show at the scale of the accompanying map. The counties with ultramafic rock/serpentinite occurrences include 7 of the remaining 13 counties that lack reported asbestos. The presence of ultramafic rock or serpentinite in these remaining counties, and the existence of asbestos in similar rock types and geologic environments in adjacent counties, suggests that they may contain asbestos occurrences that simply have yet to be discovered or reported in the geologic literature.

Overall, 53 of the 58 California counties contain reported asbestos occurrences, fibrous amphibole occurrences, and (or) ultramafic rock/serpentinite. The five counties with no reported asbestos occurrences, fibrous amphibole occurrences, and (or) ultramafic rock/serpentinite are Alpine, Lassen, Modoc, Sutter, and Ventura Counties. This information is summarized in table 1.

In some instances, the occurrence of asbestos in a county is known or is mentioned in the literature, but the location descriptions are too vague to include in this study or are not in generally available documents. Examples follow:

- In Merced County, Laizure (1925a, p. 175) reported that "Asbestos is said to occur in Townships 7 and 8 S., Range 16 E., near the Mariposa County line. The deposits are undeveloped and of doubtful value".
- In San Luis Obispo County, "Asbestos of uncertain quality and in unknown amount occurs in the mountains between Poso and Hasbroucks" (Laizure, 1925b, p. 504).
- In Santa Barbara County, Dibblee (1966, p. 12) reported that serpentine in sill-like masses in the San Rafael Mountains is commonly cut by thin fibrous veinlets of asbestos less than two millimeters wide.
- Occurrences of amphibole asbestos have been reported from several locations in eastern Sacramento County. To date, these occurrences have been found in areas mapped as metamorphosed mafic volcanic rocks in the Folsom area. The presence of NOA in these metamorphic rocks are mentioned in several unpublished consulting reports, related to construction projects in the Folsom area, that are on file with the Sacramento Metropolitan Air Quality Management District (Higgins and Clinkenbeard, 2006b).

Table 1. Summary of asbestos-related features in the 58 counties of California, including the presence of ultramafic rocks or serpentinite, reported natural occurrences of asbestos, and reported fibrous amphibole. X, Counties in which ultramafic rocks or serpentinite are shown on the accompanying map; U, Counties with occurrences too small to show at the scale of the accompanying map.

COUNTY	ULTRAMAFIC ROCKS OR SERPENTINITE[1]	ASBESTOS[2]	ASBESTOS (nonspecific location in County)[3]	FIBROUS AMPHIBOLE[4]
Alameda	X	X		
Alpine				
Amador	X	X		
Butte	X	X		
Calaveras	X	X		X
Colusa	X	X		
Contra Costa	X	X		
Del Norte	X	X		
El Dorado	X	X		
Fresno	X	X		X
Glenn	X	X		
Humboldt	X			
Imperial	U	X		
Inyo	U	X		
Kern	X	X		
Kings	X	X		
Lake	X	X		
Lassen				
Los Angeles	X	X		
Madera	U	X		X
Marin	X	X		X
Mariposa	X	X		
Mendocino	X	X		X
Merced	X		X	
Modoc				
Mono	U	X		
Monterey	X	X		X
Napa	X	X		
Nevada	X	X		
Orange	U			
Placer	X	X		
Plumas	X	X		

Table 1. Summary of asbestos-related features in the 58 counties of California, including the presence of ultramafic rocks or serpentinite, reported natural occurrences of asbestos, and reported fibrous amphibole. X, Counties in which ultramafic rocks or serpentinite are shown on the accompanying map; U, Counties with occurrences too small to show at the scale of the accompanying map.—Continued

COUNTY	ULTRAMAFIC ROCKS OR SERPENTINITE[1]	ASBESTOS[2]	ASBESTOS (non-specific location in County)[3]	FIBROUS AMPHIBOLE[4]
Riverside	U	X		X
Sacramento			X	
San Benito	X	X		X
San Bernardino	U	X		X
San Diego	U	X		X
San Francisco	X	X		
San Joaquin	U			
San Luis Obispo	X		X	
San Mateo	X			
Santa Barbara	X		X	
Santa Clara	X	X		
Santa Cruz				X
Shasta	X	X		
Sierra	X	X		
Siskiyou	X	X		
Solano	X			
Sonoma	X	X		
Stanislaus	X			
Sutter				
Tehama	X			
Trinity	X	X		
Tulare	X	X		
Tuolumne	X	X		X
Ventura				
Yolo	X	X		
Yuba	X	X		
Totals	**51**	**41**	**4**	**12**

[1] Ultramafic rocks or serpentinite identified on geologic maps or mentioned in the literature.
[2] Counties with locatable asbestos occurrences reported in the literature.
[3] Counties with asbestos occurrences reported in the literature, but with locations not specific enough to show on the accompanying map. These occurrences are not listed in ***asbestos_sites.xls*** or ***Death Valley_talc.xls***.
[4] Occurrences listed in ***fibrous_amphiboles.xls***.

The Geology of Asbestos in California

Geologists have documented that asbestos deposits form in specific and generally predictable geologic settings (Van Gosen, 2007b). The rocks that host asbestos minerals are consistently magnesium-rich (and often also iron-rich) and have been altered by metamorphic geologic processes. All asbestos minerals contain magnesium, silica, and water (hydroxyl) as essential constituents. Some also contain iron, calcium, and (or) sodium as major constituents. Thus, the rocks that host asbestos are enriched in these components.

Asbestos deposits are formed through the metasomatic replacement of magnesium-rich rocks. The asbestos-bearing rocks also typically display evidence of shear and (or) the influx of significant amounts of hydrothermal silica-rich fluids. The asbestos mineralization can be driven by regional metamorphism, contact metamorphism, or magmatic hydrothermal processes. The following rock types can locally contain asbestos (Van Gosen, 2007b):

- Metasomatized[1] ultramafic rocks, which have been altered by processes of regional or contact metamorphism, such as partially altered dunite, peridotite, amphibolite, and pyroxenite, and especially their more completely altered equivalent, serpentinite.
- Metamorphosed mafic extrusive rocks, especially metabasalt (greenstone), and metamorphosed mafic intrusive rocks, especially metagabbro and metadiabase, which have been subsequently sheared and silicified.
- Dolostones (dolomite, dolomitic marble) and dolomitic limestone that have been metamorphosed and metasomatized by contact or regional metamorphism. This can result in the formation of serpentinite or talc bodies that may host asbestos.
- Iron formation or ferruginous chert layers that have been altered by contact metamorphism.
- Alkaline igneous intrusions and carbonatites that are internally metasomatized by magmatic fluids.

Other rock types appear much less likely to contain asbestos because their chemistry, geologic setting, and history are not favorable to the formation of asbestos. The reported asbestos deposits and occurrences in California are hosted by one of the combinations of rock type and geologic settings listed above; serpentinite hosts the most asbestos occurrences.

The most common host rocks for asbestos mineralization in the United States are ultramafic rocks that were altered by processes of contact or regional metamorphism. This geologic relation holds true in California. Ultramafic rocks are those igneous rocks composed mainly of iron-magnesium silicate minerals, such as olivine and pyroxene. Ultramafic rocks form in high-temperature and high-pressure environments deep beneath the earth's surface. By the time they are exposed at the earth's surface, ultramafic rocks have typically undergone a type of metamorphism known as serpentinization (a form of metasomatism). This process alters the original iron-magnesium minerals to one or more water-bearing magnesium silicate minerals (lizardite, antigorite, chrysotile) that belong to the serpentine mineral group. Serpentinite (or serpentine rock), a metamorphic derivative of ultramafic rocks, is composed mainly of serpentine-group minerals. The serpentine-group mineral chrysotile, a type of asbestos, is often present in small amounts in the resulting rock. Metamorphism of ultramafic rocks and serpentinite may also lead to the formation of amphibole-asbestos minerals. Conditions favorable for asbestos formation or breakdown may occur repeatedly during the metamorphic process and, consequently, it is very common for at least a small quantity of asbestos to be present in metamorphosed ultramafic rock bodies. Partial or extensive serpentinization of an ultramafic rock may occur, and either

[1] Metasomatism is "the open-system metamorphic process in which the original chemical composition of a rock is changed by reaction with an external source. The process is commonly thought to occur in the presence of a fluid medium flowing through the rock" (Neuendorf and others, 2005, p. 408). Serpentinite is an example of a metasomatic rock.

instance can form asbestos. It is important to emphasize that even in the favorable rock types, asbestos occurrences are relatively rare and are confined to areas where ideal asbestos-forming conditions were present, including microfracturing, siliceous-fluid flow, and specific pressures and temperatures, and where subsequent conditions have been favorable for preservation.

The data in ***asbestos_site.xls*** show that at least 70 percent of the reported asbestos occurrences in California occur within altered ultramafic rock/serpentinite. At more than half of these sites the source literature described the host rock as serpentinite. Because of the importance of ultramafic rocks and serpentinite as hosts for asbestos mineralization, the general distribution of mapped ultramafic rocks and serpentinite in California is shown on ***Plate.pdf*** for reference; many small exposures of such rocks are not displayed because of the scale of the map. The map sources for the ultramafic bodies shown are Blake and others (2000, 2002), Graymer and others (2002), and Saucedo and others (2000). A digital geologic dataset of ultramafic rocks in the conterminous United States, which includes the ultramafic rock units in California shown on ***Plate.pdf***, is available for download in Krevor and others (2009).

The most common asbestos mineral reported in California is chrysotile. Many of the descriptions also report asbestos without further classification. Tremolite–actinolite asbestos appears to be the most common amphibole-group asbestos described in California. The coexistence of chrysotile with tremolite–actinolite asbestos in serpentinized ultramafic rock has been observed at sites in California. Anthophyllite asbestos and crocidolite (asbestiform riebeckite) are described at a few sites each.

Asbestos-Bearing Talc Deposits of the Southern Death Valley Region

Probably the best examples of talc orebodies formed within a geologic setting of contact metamorphism in the United States are the 55 deposits of talc-tremolite rock once mined and prospected in the southern Death Valley region of California (see dataset ***Death_Valley_talc.xls***). The talc mines, most of which are now inactive and (or) abandoned, are clustered in widely separated but discrete districts across a region of southeastern Inyo County and northeastern San Bernardino County. The USGS collected and analyzed talc ores from 10 of these deposits and found that all contained trace amounts of asbestiform tremolite intergrown with the talc (Van Gosen and others, 2004a,b,c).

The talc-tremolite deposits of the southern Death Valley area are geologically similar across the region and are consistently associated with a carbonate-rock horizon of the Crystal Spring Formation of Proterozoic age. In this horizon, thick regionally persistent gabbroic sills intruded dolomite about 1,087 to 1,069±3 Ma (Heaman and Grotzinger, 1992) and formed laminated talc-tremolite-rich rock along the sill-dolomite contacts. Metasomatic reactions during intrusion of the sills caused the massive replacement of dolomite by talc-tremolite-rich bodies, which are approximately 500 to 5,000 ft long and 10 to 100 ft thick. Relative proportions of talc versus tremolite vary across the deposits and either mineral can predominate within any particular deposit. Petrographic examinations of the ore suggest the talc and tremolite grew simultaneously.

Samples of talc-tremolite rock collected from the 10 deposits were analyzed by X-ray diffraction and examined by scanning electron microscopy accompanied by energy-dispersive spectroscopy. These analyses found asbestiform tremolite, including bundles of fibers and loose fibers, to be common in talcose rock from all of the sample sites. Asbestiform amphiboles with compositions consistent with winchite and (or) asbestiform richterite were identified in 5 talcose samples examined by this study. The geological and mineralogical characteristics of these deposits, as well as the USGS study methods and results, are presented in Van Gosen and others (2004a,b,c).

The talc deposits sampled by the USGS study represent only about one-fifth of the former talc operations of the southern Death Valley region. However, the similarities in general geology and mineralogy amongst the talc deposits of this region suggest that all could contain amphibole asbestos and thus deserve detailed mineralogical investigation if they are to be disturbed by excavation in the future. The study's observations suggest that, in particular, the mining and milling of the southern Death Valley talc deposits could produce asbestos-bearing dusts; therefore, the mine site materials should be handled with care. In addition, strong winds in this region can dispense these materials over larger areas even without additional mining activity.

Fibrous Amphiboles in California

During this study, several examples were noted in the geologic literature that mentioned the presence of fibrous amphiboles in developed mineral deposits (such as metal or industrial mineral mines and prospects) or in undisturbed outcrops. These examples are shown on ***Plate.pdf*** and described in the separate dataset ***fibrous_amphiboles.xls***. Amphibole asbestos was not specifically mentioned in the descriptions of these deposits. However, descriptions of these sites indicate geologic settings with the potential to host asbestos. The geologic settings for these examples of fibrous amphiboles are similar to those that elsewhere form and host asbestos. Thus, a discovery of asbestos in these areas would not be unexpected from a geologic standpoint. Also, the distinction between fibrous amphibole, asbestiform amphibole, and regulatory amphibole asbestos is often not clear-cut in natural amphibole-bearing deposits. The regulatory criteria for the analyses of commercial-grade amphibole asbestos do not always apply well to the natural occurrences of fibrous to asbestiform amphiboles; thus, these occurrences require site-specific detailed microscopic analyses. This complex issue is discussed in detail by Meeker and others (2006).

History of Asbestos Discovery and Mining in California

Among the earliest reports of asbestos or related minerals in California are the occurrences of "Asbestus" in Salt Spring Valley in Calaveras County and in Los Angeles County, chrysotile near San Francisco and at New Almaden in Santa Clara County, and fibrous tremolite in limestone at Columbia in Tuolumne County (Blake, 1866). In the early 1880s, asbestos deposits were reported in Butte, San Bernardino, San Diego, Calaveras, Placer, Fresno, Los Angeles, Tulare, Mariposa, Shasta, Yolo, Inyo, and Del Norte Counties (Williams, 1883, 1885; Hanks, 1884). As early as 1883, at least one company, the United Asbestos Manufacturing Company, had incorporated in California to mine, manufacture, and market asbestos products (Hanks, 1884). While some small production from these deposits may have occurred in the early 1880s, the first reported asbestos production in State records appears in 1887.

Asbestos production in California can be divided into two time periods, pre-1960 and 1960 to 2002. Prior to 1960, demand for asbestos as a raw material for manufacturing in California was limited. Most plants that manufactured asbestos products were in the eastern United States, where asbestos was readily available from eastern U.S. deposits or from the chrysotile deposits in Quebec, Canada. The greater distance to market for the California deposits made the California asbestos uneconomic for manufacturers in the eastern U.S. In addition, many of the California asbestos deposits known in the early days were small, and the asbestos was often lower grade compared to Canadian asbestos. The population and industrial boom that followed World War II led to expansion of existing plants and construction of new manufacturing facilities to produce products in California, such as asbestos-cement construction materials, insulation materials, and composition flooring and roofing. These products utilized the shorter-length ("short-fiber") grades of chrysotile asbestos that were more common in California deposits (Rice, 1957, 1963, 1966).

From 1887 to 2002, California's total asbestos production likely exceeded 1,650,000 short tons. Of this production, more than 99 percent was chrysotile produced between 1960 and 2002. From 1887 to 1959, only 9,049 short tons of asbestos production were reported in California, which is less than 1 percent of the total cumulative State production. Much of the early production (pre-1940) was likely amphibole asbestos and was probably used as filter material (Rice, 1966); all asbestos production prior to 1900 is thought to have been amphibole asbestos (Wiebelt and Smith, 1959). The last commercial production of amphibole asbestos in the State was probably from Inyo County or Shasta County in 1959. Production in these early years was often sporadic and production from any one deposit typically amounted to only a few tens or hundreds of short tons.

In some cases, reports of asbestos production may have in fact represented test batches of hand-sorted ore sent to potential buyers to see if the product met their specifications. These tests may or may not have led to subsequent commercial-scale production. Examples follow:

- At the Copsey and Jones chrysotile prospect in Lake County: "The Johns-Manville Co. is said to have done a few hundred feet of development work on the deposit and to have taken out 7 to 8 [short] tons of asbestos early in 1928" (for material testing) (Wiebelt and Smith, 1959, p. 15–16).
- For the Burro Mountain chrysotile prospect in Monterey County, Hart (1966, p. 26–27) provides this description: "This deposit was first developed in 1920 by Walter R. Harris of Bryson and J. E. Barrett of San Luis Obispo. They continued to develop the prospect by open cuts and adits until 1923, making several small shipments to the U.S. Asbestos Company, Downey, for testing . . . Additional exploration and testing apparently was done in 1930, but did not result in commercial production. Many years later Asbestos Development, Inc., acquired the prospect and developed additional cuts. In 1953 and 1954, samples were reported tested, but apparently no development work has been done since then." This description likely accounts for the minor asbestos production from Monterey County during 1921 to 1923 as reported in table 1 of Wiebelt and Smith (1959).
- At the Premier asbestos mine in Tuolumne County, Wiebelt and Smith (1959, p. 49) reported that "A few tons of antigorite were shipped to Los Angeles, Calif., for testing in 1953"; however, they do not suggest that commercial production came from this property.

In these types of examples, our dataset ***asbestos_site.xls*** lists the site as a past prospect rather than a past producer.

Early production was reported in the literature from localities in 22 California counties: Alameda, Amador, Butte, Calaveras, Contra Costa, El Dorado, Fresno, Inyo, Monterey, Napa, Nevada, Placer, Riverside, San Benito, San Diego (uncertain), Shasta, Siskiyou, Trinity, and Tuolumne (Wiebelt and Smith, 1959); Lake (Averill, 1947); Los Angeles (Gay and Hoffman, 1954); and San Bernardino (Tucker and Sampson, 1943). The production reported from San Diego County in 1894 is considered questionable (Weber, 1963) and thought to more likely have come from Riverside County. Of these counties, eight appear repeatedly in literature from this time period (primarily the Reports of the State Mineralogist and the U.S. Bureau of Mines Minerals Yearbook), possibly indicating that production from these counties may have been more significant than those mentioned only once or twice. The eight counties with repeat mentions are El Dorado, Inyo, Napa, Nevada, Placer, Riverside, San Benito, and Shasta. Brief descriptions of many of California's early asbestos mines can be found in Bowles (1955), Wiebelt and Smith (1959), and the other references listed in ***asbestos_site.xls***.

Noteworthy is that while historic asbestos production is reported county-by-county in some older California literature, the specific mines were not always mentioned. For example, Aubury (1909a,b) and Wiebelt and Smith (1959, table 1) list small amounts of asbestos production from Amador County during 1908 (10 tons) and 1909 (2 tons), but they do not indicate from which properties this mining occurred. Similarly, Bradley (1916) and Wiebelt and Smith (1959, table 1) list asbestos production from Contra Costa County during 1915, but they do not specify the asbestos mine(s) in their descriptions of deposits within the county.

From 1958 to 1960, exploration for asbestos deposits in Calaveras, Fresno, and San Benito Counties led to the development of several large commercially viable chrysotile deposits. By 1964, four new asbestos mills were constructed to meet the growing demand for asbestos in California and elsewhere (Rice, 1963, 1966).

In Calaveras County in early 1959, exploration was conducted on a chrysotile deposit about seven miles southeast of Copperopolis. The Jefferson Lake Asbestos Corporation was formed to develop this deposit and a mill was completed in 1962. Others had attempted to develop the deposit as early as 1904 and again in 1918, but the lack of a strong market for asbestos in California at the time made these early attempts uneconomic (Rice, 1963). Under various owners the Jefferson Lake mine operated almost continuously from 1962 to 1987 (fig. 2). The mine site was later converted to an asbestos disposal site (fig. 3).

In the southeastern part of the New Idria serpentinite body in Fresno and San Benito Counties, very large deposits of short-fiber chrysotile asbestos were prospected and, in 1959, United Carbide Nuclear Company staked more than 300 claims in the area. In the resulting "rush", several other companies acquired claims in the area. By 1965, three mills with a combined capacity of about 50,000 short tons of asbestos per year were in operation (Rice, 1963, 1966). In addition to the Union Carbide Nuclear Company mine in San Benito County, the Coalinga Asbestos Company and the Atlas Corporation developed mines and mills in Fresno County. The Coalinga Asbestos Company mine stopped production in 1975, and the Atlas operation closed in 1979. The Union Carbide Nuclear Company mine, sold to King City Asbestos Company (KCAC) in 1985, ceased operation in 2002 and was the last operating asbestos mine in the United States when it closed. With the exception of a small amount of chrysotile that was produced in Napa County in 1960 to 1965, almost all of the chrysotile production in California came from a few mines in Calaveras, Fresno, and San Benito Counties.

Studies by the California Geological Survey of Natural Occurrences of Asbestos in California

Over the years, the California Geological Survey (CGS) has provided objective technical information and advice on the geologic occurrences of asbestos in California to local agencies (counties, local air pollution control districts), the public, and several State and Federal agencies:

Federal agencies

U.S. Environmental Protection Agency
U.S. Geological Survey
U.S. Forest Service

State agencies

California Environmental Protection Agency
California Air Resources Board
Department of Toxic Substances Control
Office of Environmental Health Hazard Assessment
Department of Transportation
Department of Parks and Recreation
Department of Forestry and Fire Protection

Figure 2. Photographs taken in 1963 of the Copperopolis chrysotile mine of the Jefferson Lake Asbestos Company, located in Calaveras County, California. From the photo collection of the California Geological Survey Library. *A*, View to the east toward the Stanislaus River Canyon and the future site of the New Melones Dam. *B*, View to the south showing the open-pit mine benches.

Figure 3. Photograph showing the former Copperopolis chrysotile mine, as viewed in 1995 looking west. The mine closed in 1987. The open pit is now used as an asbestos disposal site. Photograph by California Geological Survey.

The CGS began its involvement in environmental issues related to NOA in the late 1980s, when the California Air Resources Control Board (CARB) requested assistance in understanding the nature and occurrence of asbestos deposits in California. At that time, concern was raised over potential public exposure to asbestos in aggregate used to surface rural roads in the foothills region of the Sierra Nevada. In 1986, asbestos was officially recognized by the CARB as a toxic air contaminant. In 1990, the CARB issued an Airborne Toxic Control Measure (ATCM), restricting the use of serpentinite for surfacing applications to materials that contained less than 5 percent asbestos.

In the late 1990s, concern was again raised over potential public exposure to NOA in El Dorado County due to grading and construction activities in areas of asbestos-bearing bedrock and soil. This concern led to debates over the level of public health risk that could result by disturbing this type of rock and the related soils. The CGS participated with local, state, and federal agencies on a task force to (1) provide advice to the County and general public about potential risk, (2) make mitigation recommendations, and (3) identify areas of western El Dorado County more likely to contain NOA. These endeavors focused attention on a variety of dust-generating activities, such as road grading, excavation and mining in areas of potentially asbestos-bearing rock, and the use of suspect aggregate as surfacing materials on unpaved roads and driveways. Concurrently with the task force, and in the following years, State agencies (Air Resources Board, Office of Environmental Health Hazard Assessment, Department of Toxic Substances Control) and Federal agencies (Environmental Protection

Agency, Agency for Toxic Substances and Disease Registry) conducted studies designed to better define the potential health risks associated with environmental exposure to NOA.

After the NOA task force concluded its work, the CGS conducted a pilot NOA mapping study, applied to western El Dorado County (in response to a task-force recommendation). This work resulted in publication of a 1:100,000-scale map and report, Areas More Likely to Contain Natural Occurrences of Asbestos in Western El Dorado County, California (Churchill and others, 2000), which was released in May 2000. This study identified areas in western El Dorado County where NOA has a greater or lesser likelihood to occur based on the geology. This publication was followed by A General Location Guide for Ultramafic Rocks in California—Areas More Likely to Contain Naturally Occurring Asbestos (Churchill and Hill, 2000). In 2002, the CGS published guidelines that can be used by geologists who are required to evaluate the NOA potential of a property (Clinkenbeard and others, 2002); these guidelines apply to site investigations regardless of the scale of development, disturbance, and level of previous geologic observation.

Requested and funded by the counties, the CGS produced maps and accompanying reports that delineate the potential for NOA in Placer County (Higgins and Clinkenbeard, 2006a) and eastern Sacramento County (Higgins and Clinkenbeard, 2006b) through interagency agreements with those counties. These maps and reports identify and discuss the areas within these counties where NOA is most likely to occur, moderately likely to occur, and least likely to occur based on the geology of asbestos. The areas determined most likely to contain NOA are those areas with ultramafic rocks and serpentinite and their associated soils. The areas deemed moderately likely to contain NOA are those areas with one or more of the following rock types: metamorphosed mafic volcanic rocks; metamorphosed intrusive rocks; gabbroic (mafic intrusive) rocks; and some structurally complex assemblages that contain intermixed metamorphic rocks of different origins. Areas of substantial faulting and shearing superimposed upon these bedrock types are predicted to increase the likelihood for the presence of NOA. Areas thought unlikely to have NOA are those with little or no serpentinite or ultramafic rocks (or related soils), metamorphic rocks away from fault zones, nonmetamorphic rocks, and granitic intrusive rocks.

The CGS also collaborated with the USGS in a preliminary evaluation of a remote-sensing instrument, the Airborne Visible/InfraRed Imaging Spectrometer (AVIRIS), as a potential tool for mapping the occurrence and distribution of asbestos-bearing rocks (Swayze and others, 2004, 2009).

Digital Datasets

The report dataset ***asbestos_sites.xls*** summarizes information found in geologic references examined by the authors. The entries in the database are sorted by county and ascending order of latitude (south to north). The dataset includes these data fields:

State

“CA” indicates that the site occurs in California.

County

Name of the county in which the site is located.

Historic site name as reported

The name of the former asbestos mine, former asbestos prospect, or reported occurrence, matching the nomenclature used in the source literature.

Development

This field indicates whether the asbestos site is a former asbestos mine, former prospect, or an occurrence. "Past producer" indicates that the deposit was mined and produced asbestos ore for commercial uses sometime in the past. "Past prospect" indicates that the asbestos deposit was once prospected (evaluated) for possible commercial use, typically by trenching and (or) drilling, but the deposit was not further developed. "Occurrence" indicates that asbestos was reported at this site. The occurrence category includes (1) sites where asbestos-bearing rock is described in a geologic map or report and (2) asbestos noted as an accessory mineral or vein deposit within another type of mineral deposit.

Latitude

The latitude of the site's location in decimal degrees, measured using the North American Datum of 1927. The number of significant figures following the decimal point indicates the believed accuracy of the location: (1) two significant figures (for example, 44.03) indicate an approximate location based on a general description; (2) three significant figures (for example, 44.094) indicate a fairly accurate location based on a detailed description or location shown on a small-scale map (1:50,000 scale or smaller); and (3) four significant figures (for example, 42.5586) indicate a precise location based on a detailed description or a location shown on a large-scale map (1:24,000 scale or larger).

Longitude

Longitude was calculated in the same manner as latitude.

Asbestiform mineral(s) reported

This field identifies the type of asbestos present as described in the source literature.

Associated minerals reported

Minerals mentioned in association with the asbestos, as they were described in the source literature. The order in which each mineral is listed does not necessarily indicate its relative abundance in the deposit, but rather its order of mention in the source report.

Host rock(s) reported

The host rock type(s) for the asbestos is (are) listed when available as described in the source literature.

References

The references used to compile the site information are listed in this field. The full reference citations are provided in the accompanying digital files ***References.pdf*** and ***References.xls***.

A second dataset, ***Death_Valley_talc.xls***, lists 55 talc deposits of the southern Death Valley region in which trace amounts of amphibole asbestos are likely to be intergrown with the talc. The data fields in this dataset—State, County, Historic site name as reported, Latitude, Longitude, and References—are used in the same manner as those in the dataset ***asbestos_sites.xls***.

A third dataset, ***fibrous_amphiboles.xls***, lists 16 localities where fibrous amphiboles are described in the geologic literature.

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