The geology of natural asbestos deposits and its application to public health policy

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Abstract: A growing body of evidence in the 20th century led to the realization that inhalation of asbestos-bearing dusts was the cause of several serious respiratory diseases (asbestosis, lung cancer, and mesothelioma) among workers of asbestos-related occupations, such as asbestos mining, shipbuilding, and asbestos product fabrication. As a result, a number of regulations were developed to govern asbestos dust exposures in specific manufacturing, mining, and other occupational sites. Less straightforward is the regulation and management of "naturally occurring asbestos" (NOA), which has recently gained the attention of regulatory agencies, health agencies, and citizen groups. NOA includes minerals described as asbestos that are found in-place in their natural state, such as in bedrock or soils. NOA is 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, mining, crushing, and milling, as just a few examples).

Natural asbestos deposits range widely in size, from thin, scattered veinlets to large ore bodies. Their geographic distribution is directly linked to geology. The geologic settings in which asbestos occur are Mg-rich host rocks altered by relatively low pressure and temperature metamorphism. Specifically, the rock types known to host asbestos include metamorphosed and metasomatized ultramafic rocks (particularly serpentinite) and some mafic igneous rocks, metadolostones, and metamorphosed iron formations. Asbestiform amphiboles can also occur as accessory minerals in several hydrothermally altered types of alkaline igneous intrusions.

Recognizing that asbestos forms in predictable and identifiable geologic environments is information that allows public health agencies to conduct an informed asbestos screening and management program. The first steps involve locating and describing the known (reported) asbestos deposits, at a regional or national scale. Next, the geologic units that host known asbestos are mapped, which delineates the extent of possible additional asbestos mineralization. This geological approach allows agencies to plan for the possibility of encountering asbestos where appropriate, while also sparing the unneeded expense of asbestos regulation in regions that are unlikely to contain asbestos deposits. A basic understanding of the geology of asbestos can be applied beforehand at any rock and soil excavation project, regardless of scale. This scientific approach to asbestos management will help alleviate the need to continually respond to surprise discoveries of natural asbestos deposits uncovered by excavation projects. Thus, by mapping the terrains most likely to host asbestos mineral deposits, planners can develop dust-control procedures appropriate for the regions where workers and nearby residents are most likely to be exposed to airborne asbestos.

Key Words: asbestos; geology; public health management

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1 Background

Due to health concerns stemming largely from high levels of asbestos-related diseases in occupationally exposed workers, the use of commercial asbestos has greatly diminished in recent years. A growing body of evidence gathered during the 20th century led to the realization that occupational exposures to asbestos fibers were linked to asbestosis, lung cancer, and mesothelioma in workers from asbestos-related occupations, such as asbestos mining, shipbuilding, and asbestos product fabrication [1-4]. As a result, asbestos is no longer mined in the United States.

Especially during the last decade, increasing interest within the United States and in other countries has focused upon the potential human exposures to the non-commercial deposits of asbestos, in which asbestos minerals are naturally intergrown with a mineral commodity of value or within an asbestos-bearing bedrock in general. While asbestos is no longer mined in the United States as a primary commodity, it occurs as an accessory mineral in some types of mined deposits. Airborne exposures to “contaminant” (accessory) asbestos, caused by excavation, crushing, and processing of an asbestos-bearing mineral deposit, can occur (1) at the mine site, (2) at processing facilities on-site or off-site, (3) in adjacent communities, (4) during ore transport, and (5) in products that use these materials. Asbestos mineralization can also be released airborne by a number of other types of human activities, such as road building, general building excavation, and agriculture. Any activity that disaggregates the asbestos-bearing rock, including natural erosion and wind, has the potential to release the microscopic asbestos fibers into the surrounding air and potentially into the breathing zone of workers and surrounding communities.

Asbestos mineral fibers can also be a constituent of soils that formed from the erosion of the asbestos-bearing bedrock. These fibers can be carried down gradient in the disaggregated rock by landslides, glaciers, and alluvial processes (streams, rivers, alluvial fans). Any mineral described as asbestos that occurs in-place in its natural state or was transported by natural processes, has been commonly referred to as “naturally occurring asbestos”, or NOA.

Given this context of potential asbestos exposures and concerns, it benefits the regulatory and health communities to understand the basics of the geology of asbestos in order to recognize mineral deposit types and geologic environments that may contain asbestos. While this approach assists in the effort to identify asbestos-bearing areas, it also allows managers to recognize the geologic terrains that are unlikely to contain asbestos mineralization, which are typically much larger in aerial extent than the asbestos-bearing regions. This saves on the efforts and costs of asbestos monitoring and regulation in areas where it is not necessary.

2 Defining asbestos

Asbestos has been mined and used commercially for centuries, particularly for its insulating and fire-resistant properties in many types of products [5-6]. 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—have made it well suited for a number of commercial applications.

Unfortunately, the term “asbestos” is still not consistently applied, particularly in regards to non-commercial asbestos deposits (meaning asbestos deposits that are not adequate in size and/or fiber quality for commercial applications). “Asbestos” is not a formal mineralogical term, but rather a commercial and industrial term historically applied to a group of silicate minerals that form as long, very thin mineral fibers, which usually form bundles. When handled or crushed, the asbestos bundles readily separate into individual mineral fibers. This type of mineral growth form or “habit” is called asbestiform. The many different ways that asbestos and asbestiform and other related terms have been described are summarized in [7].

The term "asbestos" has been applied at some localities 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[8]. However, the distinction between "fibrous" amphibole and "regulatory" amphibole asbestos is not health-based, is often not clear-cut in natural deposits, and can be highly subjective [8]. It is noteworthy that while decades of research have yielded significant insights into the epidemiology of asbestos-related diseases and asbestos toxicity, there are many uncertainties and debate that remain as to the specific characteristics of asbestos minerals that are most responsible for inducing disease [1,3,4,9,10].

Currently, most commercial and regulatory definitions of asbestos include chrysotile, which is the asbestiform member of the serpentine group, as well as several members of the amphibole mineral group, including 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[11-15]. A recent decision by the 9th United States Court of Appeals has broadened the definition of asbestos for the Clean Air Act by including winchite, richterite, and presumably other asbestiform amphiboles not previously listed in regulations.

To reach well informed policies and solutions for the very complex issues surrounding the toxicity and "definition" of asbestos, the regulatory communities need to work with those who conduct health studies related to fibrous and asbestiform mineral dusts. These studies include in vivo and in vitro toxicity tests, pathology analyses, biomonitoring, and epidemiology studies [3,9]. Logically, earth scientists are needed as participants in this process because the characteristics and geographic distribution of asbestos and other fibrous minerals are based on geologic processes. The physical and chemical characteristics of the asbestos minerals, which thereby influence toxicity, can be studied in increasing level of detail by mineralogists, geochemists, and micro-analytical specialists [9,10]. When the fibrous mineral types deemed toxic are well defined and described, geologists can determine the geologic environments that form these deposit types and then accordingly delineate the geologic terrains and deposits that are worthy of more detailed scrutiny [16,17].

3 A sbestos deposits of the United States

In 2004, the U.S. Geological Survey (USGS) began a study designed to identify and locate the natural asbestos deposits in the United States, using descriptions found in the geologic literature. The study identified about 750 natural asbestos occurrences in the conterminous United States (see Figure 1); the reported asbestos deposits in Alaska will be catalogued in the next part of the study and no known asbestos deposits occur in Hawaii. Asbestos deposits have been reported in 35 of the 50 States. These asbestos deposits vary considerably in size and character, from scattered, thin veinlets of asbestos minerals to large ore bodies. The deposits of the conterminous United States have been catalogued and described in four published reports of similar format, divided into the deposits of the Eastern United States [18], the Central United States [19], the Rocky Mountain States [20], and the Southwestern United States [21]. A report for the West Coast States is in preparation. These reports are intended to provide government agencies and other stakeholders with geologic information on natural occurrences of asbestos in the United States. In total, for the conterminous United States (lower 48 States) the studies found descriptions of 143 former asbestos mines, 218 former asbestos exploration prospect sites, and 384 other asbestos occurrences.

The former asbestos mines in the United States ranged from small-scale operations during the first half

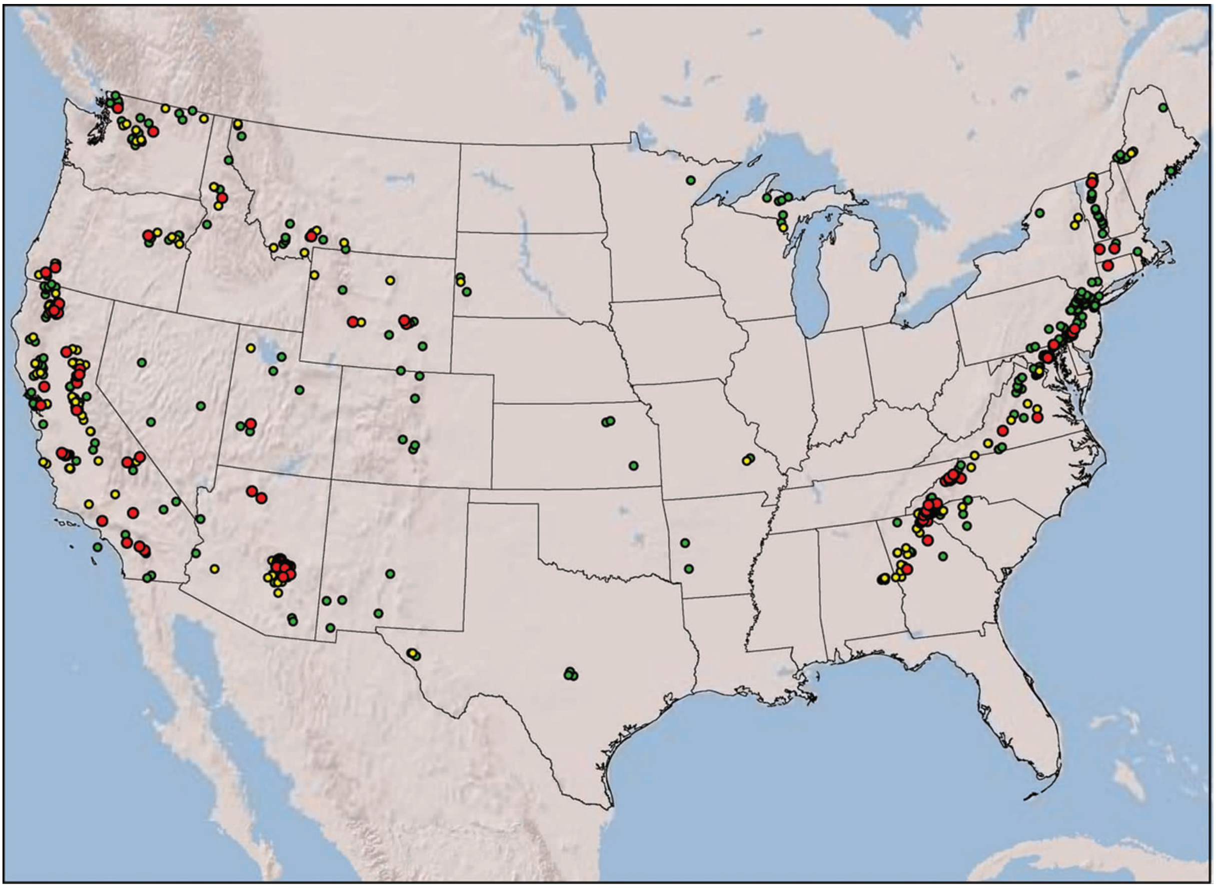

Fig.1 Index map of reported asbestos deposits (about 750) in the conterminous United States
(Former asbestos mines shown as red dots; former asbestos exploration prospect sites shown as yellow dots; other types of asbestos occurrences shown as green dots)

of the 20th century to large open-pit chrysotile mines in the States of California and Vermont during the last few decades of the century. Asbestos has not been mined in the United States since the last asbestos operation closed in 2002; this mine produced chrysotile from the Coalinga district of central California. Ten of the former asbestos mines in the United States produced tremolite asbestos, all of which were small operations that supplied local niche markets. The other 133 former asbestos mines in the United States were split almost equally between chrysotile producers and anthophyllite asbestos producers. In the United States, no mine has ever produced a product described as actinolite asbestos, amosite, or crocidolite.

The known (reported) asbestos deposits in the United States are dominated in size and number by chrysotile deposits and asbestiform anthophyllite deposits. Asbestiform tremolite occurs locally as small deposits in the contact aureole of contact-metamorphosed dolostones. Actinolite asbestos, fibrous to asbestiform cummingtonite-grunerite (amosite), and fibrous to asbestiform riebeckite (crocidolite) have each been described at a few localities. Asbestiform varieties of the amphiboles winchite and richterite have not been reported at many localities in the United States. However, the fibrous to asbestiform winchite and richterite that is intergrown with the vermiculite ore once mined near Libby, Montana [13], has been linked to the serious respiratory diseases and resulting mortality experienced by Libby vermiculite miners, mill workers, and residents [22] and those who processed this particular vermiculite elsewhere in the United States[23].

4 The geology of asbestos

Geologists have documented that asbestos deposits form in specific and predictable geologic settings[17]. The rocks that host asbestos minerals are consistently magnesium-rich (and often also iron-rich) rock types that have been altered in form and composition by metamorphic geologic processes. All asbestos minerals contain magnesium, silica, and water (hydroxyl) as essential constituents, and some also contain iron and (or) calcium as major constituents. Thus, the rocks that host asbestos are enriched in these components. Asbestos deposits 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. As is documented in [17], the following rock types can locally contain asbestos:

(1)Metasomatized ultramafic rocks, which have been altered by processes of regional or contact metamorphism, such as dunite, peridotite, amphibolite, and pyroxenite, and especially their alteration equivalent, serpentinites.

(2)Metamorphosed mafic extrusive rocks, especially metabasalt (“greenstone”), and metamorphosed mafic intrusive rocks, especially metagabbro (“diabase”, “trap rock”), which have been subsequently sheared and silicified.

(3)Dolostones (dolomite, dolomitic marble) and dolomitic limestone that have been metamorphosed and metasomatized by contact or regional metamorphism.

(4)Iron formation that has been metamorphosed by thermal (contact) metamorphism.

(5)Alkaline igneous intrusions and carbonatites that are internally metasomatized by magmatic fluids.

Other rock types appear unlikely to contain asbestos. The reported asbestos deposits and occurrences in the United States are hosted by one of the combinations of rock type and geologic setting listed above. The same geologic characteristics and relationships found in the asbestos deposits of the United States hold true worldwide. It is important to emphasize that even in these rock types, asbestos occurrences are relatively rare and are confined to areas in which ideal asbestos-forming conditions were present, including microfracturing, siliceous fluid flow, specific pressure and temperature conditions, and subsequent preservation.

5 Applying the geology of asbestos to the management of natural occurrences

A number of governmental regulations address worker exposure to asbestos released during the manufacture of asbestos products, at shipbuilding and general construction sites, during building demolition or remodeling where asbestos products may be encountered, and during the repair or replacement of commercial asbestos-based products, such as asbestos brake components. There also are regulations governing the release of asbestos into the environment from manufacturing, mining, and other occupational sites. Less straightforward is the regulation and management of “naturally occurring asbestos” (NOA), which has recently gained the attention of regulatory agencies, health agencies, and citizen groups. NOA includes minerals described as asbestos that are found in-place in their natural state, such as in bedrock or soils. NOA is 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, mining, crushing, and milling, as just a few examples). Several examples of environmental exposures to naturally occurring asbestos are described in [8,15,22,24-28]. United States federal asbestos regulations do not specifically address exposures to natural occurrences of asbestos, or to every variety of asbestiform amphibole, or to fibrous yet non-asbestiform amphiboles.

While the administration of the natural asbestos deposits in non-occupational settings is not addressed by specific regulations in the United States, this issue has become of concern to regulatory and health agencies at a variety of administrative levels (local and federal). A basic understanding and application of the geology of asbestos will assist any agency in their attempt to manage asbestos-dust exposures to workers and communities caused by the disturbance of natural deposits. Recognizing that asbestos forms in predictable and identifiable geologic environments is information necessary for local and regional public health agencies to develop and carry out an informed asbestos screening and management program.

The application of asbestos geology to the regulation of asbestos deposits requires only a few preliminary steps. The first steps involve locating and describing the known (reported) asbestos deposits at a regional or national scale. Next, the geologic units that host known asbestos are mapped, which delineates the extent of possible additional asbestos mineralization. Understanding the geology of the asbestos-forming environments [17] allows one to define and map the bedrock units (and related soils) that have the potential to contain asbestos minerals, whether the asbestos occurs as a primary constituent of the rock or as an accessory mineral. As a result, the geologic unit known to host asbestos deposits, along with the remainder of the bedrock unit likely to contain additional asbestos, can be outlined and described. Then, public health and regulatory agencies can develop policies that protect workers and communities that are potentially exposed to dusts created by the excavation of these rock-soil units.

This geological approach allows agencies to plan for the possibility of encountering asbestos where appropriate, while also sparing the unneeded expense of asbestos regulation in regions that are unlikely to contain asbestos deposits. This scientific approach to asbestos management will help alleviate the need to continually respond to surprise discoveries of natural asbestos deposits uncovered by excavation projects.

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天然石棉矿床地质学及其在公共卫生政策中的应用

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提要：20 世纪，越来越多的证据使人们意识到，吸入含石棉的灰尘会使从事与石棉有关的几种职业（如石棉采矿、造船和石棉产品组装）的工人患上几种严重的呼吸道疾病（石棉沉着病，肺癌和 mesotheliuma）。为此已经制定了若干规定，以控制工人们在特殊的制造、采矿和其他工作地点与石棉尘埃的接触。比较间接的是控制和管理“天然产生的石棉”（NOA），这一问题近年来也引起了管理机构、健康机构和居民团体的注意。NOA 包括在自然状态下原地找到的被描述为石棉的矿物，例如在基岩或土壤中的这种矿物。NOA 之所以引起关注，是因为如果含石棉的岩石受到自然侵蚀或人类活动（例如修路、城市开挖、农业、采矿、压碎和碾磨）的影响，就有可能暴露并变成空中尘埃的微小纤维。

天然石棉矿床的规模差异很大，从薄的四散的细脉一直到大的矿体。它们的地理分布与地质条件直接有关。石棉产出的地质背景是含镁丰富的主岩，这些岩石受到低压低温的变质作用蚀变而成。已知的容矿主岩包括变质的和已被交代的超基性岩（尤其是蛇纹岩）、一些基性火成岩、变质白云岩和变质的铁建造。石棉形状的角闪石在几种热液蚀变型的碱性火成侵入体中也能作为副矿物存在。

石棉形成于可预见和可鉴别的地质环境。这种认识是一种信息，而这种信息使公众健康机构可以执行有情报根据的屏蔽和管理规划。第一步是在区域的或国家规模的尺度上确定和描述已知的（报道过的）石棉矿床。第二步是对容纳已知石棉矿的单位进行填图，以划定可能的其他石棉矿化的范围。这种地质研究使有关机构对遇到石棉的可能性做出规划，而尽量节省在不太可能遇到石棉矿的地区的管理费用。对石棉地质条件的认识可以事先应用于岩石和土壤的挖掘项目，而不管挖掘的规模有多大。这种对石棉管理的科学探索能有助于缓解对挖掘所发现的自然石棉矿床的连续不断地做出反应。因此，通过对很可能含有石棉矿床的地区做填图，规划者可开发出一些控制尘埃的程序，这些程序适用于工人和附近居民最容易暴露于空气携带的石棉的地区。

关　键　词：石棉，地质学；公众健康管理

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