SILICATE PNEUMOCONIOSIS

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INTRODUCTION

Silicates comprise about 25% of known minerals, nearly 40% of the common minerals, and well over 90% of the earth's crust. If the constituents of the earth's crust are pictured in terms of space they occupy, the crust is a "boxwork of oxygen ions bound together by the small, highly charged silicon and aluminum ions. The interstices of this more or less continuous oxygen-silicon-aluminum network are occupied by ions of magnesium, iron, calcium, sodium, and potassium"(5). Silicates are the most important mineral class, largely constituting the soil from which we get our food. The construction material in our buildings (brick, stone, concrete, glass) are silicates or largely derived from silicates.

Silicate minerals have a crystal structure containing the SiO_4 tetrahedron arranged as isolated units, as single or double chains, as sheets, and as three-dimensional networks. Because of the diversity of these minerals, and no recognized disease entity attributable to silicate minerals, we Thave organized this chapter around the following mineralogical classification scheme:

Island Structures: olivine, kyanites

Isolated Group Structures: beryl, cordierite, tourmaline

Chain Structures: spodumene, wollastonite, amphiboles

Sheet Structures: kaolin, serpentines, talc, bentonite, fuller's earth, sepiolite, mica, sericite, vermiculite

Framework Structures: silica minerals, feldspar, nepheline, zeolites

Rocks in the earth's crust exhibit wide variation in chemical and mineral composition. Most occupational exposures to silicates will not be to a pure silicate but to a mixture of silicates. A discussion of individual silicates follows.

Two silicates of common occurrence and high toxicity will be discussed separately in this section. These are asbestos (serpentine and amphibole) and silicon dioxide or quartz. Talc, containing significant concentrations of free silica and/or asbestos, will not be discussed in this chapter on silicates, as the effect on health is that of silicon dioxide and asbestos. In reported studies where an association of some health effect with exposure to some silicate is observed, the difficulty of precisely defining the concentration and assemblage of minerals must be considered. Often the probable causative agent is silica, and other silicate minerals may have little or no noticeable toxic effect. In some cases the other silicate may, in fact, be diluting or modifying the effect of silica.

Asbestos is a category of natural silicate minerals existing in fibrous form and associated with known disease patterns. There are also fibrous "rock forming silicates," variously described as acicular, asbestiform, elongate, fibrous, bladed, lamellar, filliform, prismatic, and columnar. If the 1975 OSHA standard for asbestos (length ≥ 5 mμ; maximum diameter ≥ 5 mμ; length/diameter ratio ≥ 3) is applied, the crushing and milling of any rock usually produces "asbestos" fibers, and many of the silicates discussed in this section would contain "asbestos" in significant quantities.

At present, there is no concurrence on the effects of silicate mineral particles on humans by minerals not generally regarded as asbestos. Nicholson, Langer, and Selikoff summarize the situation as follows (3): "The varietal nature of asbestos, its broad range of mineralogical properties, suggests that other nonasbestos silicate fibers may be active as well. The argument centering on crystal face and cleavage plane difference extrapolated to biological potential requires study. The fact that a mineral fiber is nonasbestos does not extrapolate to its being non-active biologically."

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ISLAND STRUCTURES $(SiO_4)^{4-}$

Olivine Group $(Mg,F_2)_2\ SiO_4$

Definition

No disease or pneumoconioses from olivine mineral has been observed in humans. Animal studies reveal a foreign body type reaction and fibrosis when asbestos is present.

List of Causative Agents

Definite: —
Probable: Serpentines
Possible: Olivine

List of Occupations and Industries Involved

The olivine group of igneous rocks are iron and magnesium silicates with a low proportion of silica. They form a complete series ranging from forsterite to fayalite. The olivines vary in amounts from accessory to main constituent and are often associated with pyroxene, calcic plagioclase, magnetite, corundum, chromite, and serpentine.

Olivine is used principally in foundries, primarily as a special sand for mold-making in brass, aluminum, and magnesium foundries. It is used as a refractory material (bricks), in mixes for furnace linings, and as a source of magnesium in fertilizer. There is interest in using olivine as a source of magnesium compounds and metallic magnesium.

Epidemiology—No studies.

Estimate of Population at Risk and Prevalence of Disease

The United States (Washington and North Carolina) produces only about 60,000 tons per year, but in Europe, larger quantities of olivine are used in foundry sand applications as a silica sand replacement, partly to avoid the risk of silicosis. Overall, the mining population is small and prevalence is unknown, but the lack of any reports of disease in humans together with olivine's low toxicity suggests prevalence is low.

Pathology

No reports in humans. Tracheal injection of olivine in rats reveals a foreign body type reaction with phagocytic cells congregating in the alveoli and lymphatics of the alveolar wall, with subsequent alveolar wall thickening, and with slight increase in reticulin fibers in lymph nodes.

Tracheal injection of phoscorite (which contains olivine and serpentine as major minerals and quartz and magnetite as minor constituents) produced no or grade 1 fibrosis in rats. Grade 1 fibrosis was defined as cellular lesions with some loose reticulin but no collagen.

Clinical Description—No reports.

Diagnostic Criteria

If quartz or asbestos are present, the diagnosis is that of silicosis or asbestosis.

Methods of Prevention

Keep exposures low. Olivine is less toxic than quartz and serpentine, which are both possible contaminants.

Research Needs

There are no epidemiologic studies of miners. At present the population at risk is small, and toxicity appears low. If olivine gains greater use as a silica substitute and source of magnesium, such a study should be undertaken.

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Alumino-Silicate Group (Aluminum Silicate)

Definition

This group of three kyanite minerals (kyanite, andalusite, sillimanite) occurs as accessory minerals in gneiss (hornblende) and mica schist. Mild fibrosis or pneumoconiosis may result from exposure to kyanite. Silicosis is possible if cristobalite is present.

List of Causative Agents

Definite: ---
Probable: Cristobalite, mullite
Possible: Kyanite, andalusite, sillimanite

List of Occupations and Industries Involved

Kyanite is often associated with garnet, staurolite, corundum, pyrite, layulite, rutile, mica, biotite, and feldspar. Since 1920 this group of three minerals has been in great demand for making high-grade refractories, such as in spark plugs, laboratory ware, thermocouple tubing, and refractory bricks in electric and forging furnaces and cement kilns. The process for making the ceramic ware involves calcining the raw minerals at 1500° for 24 hours, producing mullite, cristobalite, and glass. The absolute consumption of kyanite minerals will probably remain at its present level.

The largest use of kyanite is in the manufacture of refractory mortars, cements, castables, and plastic ramming mixes where it constitutes 10% to 40% of the mixture. Other uses include the manufacture of silicon-aluminum master alloys, in floor and wall tile, kiln furniture, blown aluminum silicate high-temperature insulation, brake linings, foundry mold facings, glass batch addition for alumina content, spinnable mullite fibers, ceramic honeycomb, mortars, grinding media, extrusion dies, welding rod coatings, and spark plugs.

Andalusite is less common, but deposits in California are mined for use in the manufacture of spark plugs and other highly refractory porcelains.

Sillimanite is also uncommon although large deposits are being developed in Assam, India.

Epidemiology

Examination of 13 out of 15 workers employed in a refractory and exposed to sillimanite revealed some increase in the extent or density of hilum shadows. Four workers had slight changes on x-rays that might have been due to dust. No definite conclusions are warranted because of the small number of people, short exposure time, and dubious significance of the radiographic changes.

Estimate of Population at Risk and Prevalence of Disease

Commercial deposits of kyanite are in North Carolina and Georgia where, in 1968, about 190 employees produced kyanite (65% in processing plants, 25% in mines, and 10% in mine and plant offices). In 1978, 36 miners (open pit), 100 preparation plant workers, and 18 office workers constituted a total population of 154 kyanite workers.

Prevalence of disease is unknown.

Pathology

Small irregular nodules that may have been from mullite rather than sillimanite were observed in one furnace worker. Rabbits exposed to sillimanite did not develop silicotic type nodules. A foreign body type reaction with some fibrosis was observed.

Clinical Description—No reports

Diagnostic Criteria

Diagnosis should include a history of exposure, chest x-ray read for pneumoconiosis, and spirometry for obstructive and/or restrictive disease. The occurrence of silicotic type nodules would suggest exposure to mullite and/or cristobalite or some other silicate. Diagnostic criteria are not generally accepted as there is no well defined disease associated with kyanite minerals.

Methods of Prevention

Keep exposures low. The greatest danger is from mullite and cristobalite which form when kyanite is heated to greater than 1000°C.

Research Needs

The effects of exposure to kyanite minerals themselves are unknown. If chest x-ray records of past and current workers are available (as in North Carolina), they should be examined for pneumoconiosis.

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ISOLATED GROUP STRUCTURES $(SiO_3)_6^{12-}$

The three silicate minerals considered here are beryl, cordierite, and tourmaline.

Definition

Beryl (a beryllium-aluminum silicate): No disease has been associated with exposure to the ore. Berylliosis (see Beryllium disease in this section) is commonly designated in pneumoconiosis; in actuality it is a systemic poison affecting many organs. The etiologic agent is thought to be beryllium rather than the silicate. Acute berylliosis resembles chemical pneumonia. Chronic berylliosis resembles chronic sarcoidosis.

Cordierite and tourmaline: No identified disease entity.

List of Causative Agents

Definite: Metallic beryllium, simple salts of beryllium, complex silicates of beryllium.

Probable: ---

Possible: ---

List of Occupations and Industries Involved

Beryl is a common and widely distributed mineral. It usually occurs in granitic rocks of pegmatites; it is also found in mica schists and is associated with tin ores. Prior to 1935, beryl was mined as a by product of mining other minerals like feldspar and mica. As late as 1960, 20% of domestic production was still obtained as a by-product. In 1974, domestic beryllium ore was produced at only one site in Utah. Consumption of ore over the past few years was 7.8-10.4 thousand short tons, and imports were from 1.4-4.9 thousand short tons. Since 1969, when the plant in Utah was completed, the Utah deposit has increased the domestic source of beryl ore.

Cordierite is frequently found in steatite clay and is used as a gemstone. Tourmaline is commonly associated with china clays and granite pegmatites. It is a semi-precious gem and is used in the manufacture of pressure gauges.

Epidemiology—No studies.

Estimate of Population at Risk and Prevalence of Disease

There is only one active bertrandite mine (in Utah), so the population at risk for the ore is quite small. Prevalence is unknown. The risk of berylliosis is in the refining of beryl and the subsequent use of beryllium.

Pathology

There are no reports in humans, but long-term exposures of rats and monkeys are said to result in lesions consistent with beryllium disease.

Clinical Description—No reports

Diagnostic Criteria

No disease entity. Berylliosis is not considered in this chapter. (See "Beryllium Disease" in this section.)

Methods of Prevention

The risk of disease from beryl is unknown.

Research Needs

Workers at the new beryl mine in Utah should be followed for any signs of beryllium disease.

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CHAIN STRUCTURES ($Si_2O_6^{-4}$ or $Si_4O_{11}(OH)$)

The pyroxenes and amphiboles form chains bound together by covalent oxygen bonds. The crystallographic, physical, and chemical properties of the two groups are similar. The crystals of both are lathe or needle shaped and in some cases, fibrous. The pyroxene crystals, however, are commonly stout prisms, whereas amphiboles tend to form elongated, often acicular crystals.

Pyroxene Group $(SiO_3)^{2-}$, $(Mg,Fe)SiO_3$

None of the pyroxenes is mined in great quantity. Augite is the most common pyroxene, occurring in many igneous rocks, but apparently only spodumene and wollastonite are commercially mined.

Spodumene, a comparatively rare mineral, is one of the commercial sources of lithium. Lithium is used in grease, ceramics, storage batteries, air conditioning, and as a welding flux. Lithium is extracted by sulphating the ore and heating the leached sulfate with ammonium fluoride and ammonium sulfate and then treating with CO_2 and ammonia. Lithium compounds are toxic to the kidneys. The major source of spodumene is in North Carolina. Located in at least eight pegmatites, the spodumene on average constitutes 20% if the rock. The rest is quartz (32%), muscovite (6%), feldspar (41%), and trace minerals (2%).

The greatest hazard in the open pit mines is from silica and not from the spodumene itself. There are no epidemiological, pathological, or clinical studies. There is no described disease, and the population at risk is quite small.

Wollastonite

Definition

Wollastonite is calcium metasilicate with an acicular crystalline shape. Particle lengths may average 7 to 15 times the diameter. There is no known disease associated with exposure.

List of Causative Agents

In New York State the wollastonite deposit is interbedded with iron garnet and iron diopside. Limestone is also likely to be present.

Definite: ---

Probable: Wollastonite, if a disease is found.

Possible: ---

List of Occupations and Industries Involved

Wollastonite is used in the ceramic industry; in paint and bonding cement; as an extender for asbestos, or replacement for nonfibrous materials in brake linings, cements, adhesives, urethane, rubber, caulking compounds, phenolics, vinyls, epoxies, plastics; in fiberglass yarn, glass, insulation for electronic equipment and thermal insulation such as mineral wool; as a filler in floor tile, cements, and plastics; in laminates, athletic field markers; marking crayons; matches; mild abrasives; oil filters; wallboard; surface coating of bricks and clay sewer pipe.

Epidemiology

The miners and millers producing most of the wollastonite in the United States were recently studied by NIOSH (1). An unpublished environmental study was performed in 1964 by the New York State Division of Industrial Hygiene. Airborne fibers had a median diameter of 0.22 μm (0.2-5.2) and a median length of 2.5 μm (0.3-41). Mean fiber counts (LM) from the two studies averaged 1.4 and 20.2 fibers/cc in the mine and mill respectively. Less than 2% free silica was found in bulk samples (1)(2).

In the prevalence study, 87 current employees and five ex-employees were administered a respiratory questionnaire, chest x-ray, physical examination, and spirometry (and diffusion capacity for workers $\geq$ 15 years worked). There was no association of years worked with any adverse effects on health from these examinations. Thus no adverse findings were observed in this study of wollastonite miners and millers, except perhaps an increased prevalence of industrial bronchitis in smokers and ex-smokers. While the population was small (only 13 workers had worked 20-25 years and 24 had worked 15-19 years), there was no evidence of any effects on symptoms, x-ray, or pulmonary function that suggested wollastonite, at these exposure levels, was acting like asbestos. Since wollastonite has only been mined for 20-30 years, the exposure history was short. The population was barely adequate for morbidity and was too small and had too short an exposure to assess possible carcinogenic effects.

Estimate of Population at Risk

It is not possible to estimate the exposures of workers using the finished product. The mines and mills producing most of the product are in New York state, and comprise 90-100 workers. The prevalence of work-associated disease is, to date, zero.

Clinical Descriptions

There are no pathological or clinical descriptions of any health effects associated with wollastonite.

Diagnostic Criteria

No disease entity has been identified. Based on morphological characteristics of wollastonite, the criteria that should be applied are those of pneumoconiosis and specifically asbestosis.

Methods of Prevention

There are at present no reports of disease.

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Amphibole Group $(Si_4O_{11})^{6-}$ $Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$

The amphibole mineral family is similar to the pyroxenes. The amphiboles readily break lengthwise. This does not fully explain the asbestiform nature of certain amphiboles, for there are varieties that are nonasbestiform, and other varieties form crystals that are roughly equidimensional (hornblende). Other factors of possible importance in the formation of asbestos fibers are the substitution of aluminum for silicon, pressure and temperature conditions, rates of cooling or heating, and trace element concentrations during formation. The major asbestiform varieties of minerals used for asbestos are chrysotile (a serpentine) and the amphiboles tremolite-actinolite, cummingtonite-grunerite (commercially known as Amosite), anthophyllite, and crocidolite. These silicates are discussed in the separate chapter on asbestos.

Clay minerals called palygorskite (attapulgites) are complex hydrated magnesium silicates that are usually fibrous and have a structure similar to the amphiboles. They will be discussed with the montmorillonite minerals in fuller's earth. Sepiolite and meerschaum are also hydrated magnesium silicates with a similar amphibole structure. However, since they too have the adsorptive properties of fuller's earth, they will also be discussed with the montmorillonite clays.

SHEET STRUCTURES $(Si_2O_5)^{2-}$

The minerals in this group are important for several reasons. They are products of rock weathering and, therefore, comprise the bulk of soil constituents. The structural unit of this group is the siloxane sheet which exhibits a platy or flaky habit, prominent cleavage, softness, relatively low specific gravity, and the flexibility of cleavage lamellae of these minerals. The kaolinite members of this class of silicates exhibit excellent cleavage, easy gliding, and a greasy feel as in pyrophyllite and talc.

In the true micas, the sheet-cation-sheet bonds are stronger, layers are more firmly held together, ease of gliding is diminished, hardness is increased, and the greasy or slippery feeling is lost. Brittle micas result from further chemical changes.

Minerals with a sheet structure comprise the principal constituents of clay, which is composed primarily of hydrous aluminum silicates. The most common clay minerals belong to the kaolinite, montmorillonite, attapulgite, and hydromica groups, and occur in varying proportions. In the discussion of sheet structures we will discuss the pure mineral. It must be remembered, however, that there may be significant proportions of "impurities" in the clay minerals. We will also discuss the known health effects of clay. Because of the complicated chemical composition of clay and clay minerals, the principal chemical components in clay are listed:

1. **Silica**—Free silica occurs in most types of clay.

2. **Alumina**—Alumina (Al_2O_3) occurs in clays in the form of clay minerals, feldspars, mica, hornblende, tourmaline. Other clays may contain alumina as gibbsite, diaspore (AlO·OH) or a colloid.

3. **Alkali-bearing minerals**—The chief alkalies in clay occur as silicates or alumino-silicates (feldspars, micas, hydrous micas), adsorbed cations, and soluble salts (K_2SO_4, Na_2SO_4,NaCl).

4. **Iron compounds**—The principal iron compounds in clay include ferric and ferrous oxide, magnetic iron oxide, iron sulfite, iron carbonates, ferrous and ferric hydroxides, ferro silicates, ferro-alumino-silicate, ferrous aluminate, soluble iron salt (ferrous sulfate), and chlorites.

5. **Calcium compounds**—The chief calcium compounds in clay include $CaCO_3$ (as calcite or aragonite, limestone), and calcium and alumino silicate. Gypsum ($CaSO_4 \cdot 2H_2O$) and apatite (crystalline calcium phosphate) occur in lesser amounts.

6. **Miscellaneous compounds**—Compounds of less frequent occurrence include barytes ($BaSO_4$), celestine ($SrSO_4$), magnesite ($MgSO_3$), dolomite ($(MgCa(CO_3))_2$), chlorites, spinel, cordierite, rutile (TiO_2), chromite, manganese oxide, pyrite, fluorspar, topaz.

The principal minerals in clays are the following:

1. **Primary minerals**—in clays derived from igneous rocks, quartz, feldspars, and micas are the most important; olivines and pyroxenes may also be present.

2. **Secondary minerals**—clay minerals of the kaolin and montmorillonite group, chlorites, vermiculites, and hydrous micas occur commonly. Under acid conditions, the granite igneous rocks form kaolin minerals; under alkaline conditions, they can form montmorillonite minerals.

Single Layer Group

Trivalent Cations (Kaolin)

Definition

Kaolinosis is a pneumoconiosis produced by kaolin (china clay). The pneumoconiosis as seen on chest radiographs is mainly nodular or massive fibrosis of the lungs. Symptoms are dyspnea on exertion and productive cough. Pulmonary tuberculosis and emphysema are often found if there is also a history of long exposure to kaolin, with at least part of the history involving high exposure levels. A benign pneumoconiosis is more commonly seen on chest radiographs. The characteristic finding in the benign form is a fine discrete nodulation throughout both lungs, without significant fibrosis, associated symptoms, or impairment of pulmonary function.

List of Causative Agents

Definite: Kaolin

Probable: In some instances there has probably been silica exposure, so free silica is a probable causative agent.

Possible: For kaolin in the United States, silica may only be a possible causative agent, because U.S. kaolin is secondary in origin and has less (possibly no) free silica with it. Progressive massive fibrosis develops only in the presence of tuberculosis infection.

Kaolin is known to be a good adjuvant to immune reaction and to actively adsorb antigens. It has thus been proposed (without evidence of its occurrence in man) that kaolin particles with attached antigens might localize an antigen-antibody reaction.

The causative agents then are a large kaolin load in the lungs, with quartz or tuberculosis infection important in at least some cases, and immunological factors possibly playing a role.

List of Occupations and Industries Involved

The leading consumer of kaolin is the paper industry where it is used to fill and coat the surface. Kaolin is used as a filler in both natural and synthetic rubber, as a paint extender, a filler in plastics, in the manufacture of ceramics (whitewares, wall tile, insulators, refractories). Kaolin has a wide variety of other uses for which the tonnage requirement is small: ink, adhesives, insecticides, medicines, food additives, bleaching, adsorbents, cement, fertilizers, cosmetics, crayons, pencils, detergents, porcelain enamels, paste, foundries, linoleum, floor tiles, textiles. Probably the only significant exposure occurs in the processing of kaolin when the product is dry.

Epidemiology

Epidemiologic evidence to date:

1. Kaolin does produce pneumoconiosis as determined by chest x-ray and work history. The

prevalence of complicated pneumoconiosis is low and is probably due to very high exposures in the past.

2. Simple pneumoconiosis does not correlate with disability. Complicated pneumoconiosis is associated with severe disability; it can cause death and can occur in the absence of any evidence of quartz exposure and/or pulmonary tuberculosis (although it is possible both occurred).

3. The latent period for pneumoconiosis is generally greater than 15 years.

In Georgia none of the silicon dioxide in the kaolin was in the form of free silica (2); refining the kaolin did not change the chemical composition, only the physical state. Georgia kaolin is secondary in origin and is, therefore, almost completely pure and free from grit, mica, and other accessory minerals. the particles are small (96% are less than 43 mμ and 49% less than 2 mμ), but because the particles tend to clump together, the dust itself does not approach this particle size distribution. The highest exposure occurred when the kaolin was dry—in the bagging and car-loading operations. Prior to 1940 a "dry process" was used, and dust concentrations reached as high as 2 bppcf (2 billion particles per cubic foot). Since 1940, a "wet process" has been in operation, with bagging and car-loading dust concentrations generally being kept below 50 mppcf (2).

There were no cases of active pulmonary tuberculosis or neoplasms in any of these U.S. workers (2). There were 44/1130 (3.9%) classified as having some degree of pneumoconiosis: 31 (2.7%) had Stage I, 7 (0.6%) Stage II, and 6 (0.5%) Stage III. In Stage I, or simple pneumoconiosis, the roentgenograms showed fine discrete nodulation (1-2 mm) generally distributed throughout both lungs. Stage II had the same fine nodulation of Stage I, plus some small confluent shadows in the upper lobes. In Stage III pneumoconiosis there was fine nodulation in the lower lobes and massive conglomerate fibrosis of the upper lobes. All with Stage III had worked longer than 20 years and in the highest exposure areas (car-loading and bagging). Of the 44 with some degree of pneumoconiosis, 2 had worked in the kaolin industry less than 10 years, 23 had worked 10-20 years, and 19 had worked longer than 20 years. Rates were not given.

Workers with Stage I and II pneumoconiosis had no symptoms, and there was little tendency for progression over 3-12 years (when x-rays were available). The fibrotic lesions of Stage III had been gradually progressive over the 3-12 years that past x-rays were available. The lesions resembled PMF in some Welsh coal miners and were associated with disabling symptoms and very high dust exposure. The author suggested the combination of heavy kaolin dust exposure and tuberculosis produced the fibrosis. Several of the men with Stage III pneumoconiosis had cough and dyspnea on exertion and had been transferred to jobs requiring less activity. The majority of the lung changes (Stage I) were not associated with any decreased function. The author stated the prevalence of lung disease was no different than in the general population.

This was the first epidemiological study of kaolin workers (2). A standardized questionnaire and a known scheme for roentgenographic interpretation of pneumoconiosis were not used, and smoking histories were not available. Thus one cannot evaluate the severity of the effects, nor compare them with other populations. Emphysema and progression of the pneumoconiosis were seen in workers with massive fibrosis. The author tried to build a case for the combination of tuberculosis and heavy dust exposure as the causative factor in those cases with PMF. The evidence, however, was circumstantial and could not prove causation. Whether [the author's assertion that] reduced dust levels over the last 15 years will cause kaolin pneumoconiosis to disappear should be investigated. In this population there was no known free silica exposure.

If a calcining process is used in treating kaolin, it is converted to mullite, silica alumina spinel, and cristobalite. Lesser, Zia, and Kilburn reported that total airborne dust samples from a bagger, bulk loader, and calcine operator in a Georgia kaolin mill had free silica concentrations of 1.04%, 1.2%, and 1.1% in 1976 (6). Threshold limit values and time-weighted-average concentrations were not calculated, however.

Warraki and Herant took chest x-rays of 914 men working in an Egyptian industrial plant processing kaolin (14). The clay was dug and brought to the factory where it was ground and sieved in a closed chamber. The ground dust was then mixed with water to form the clay used in the manufacture of chinaware, refractories, and ceramics. Grinding and sieving were the dustiest operations. No quantitative estimate of exposure was available. Analysis of bulk samples revealed that all particles were less than 3.4 μm, and that 83-86% of the dust was potassium aluminum silicate with 1-2% free silica.

The prevalence of pneumoconiosis (ILO 1950 classification of pneumoconiosis) was 0% (0/397) in those working less than 15 years, 1% (4/326) in those working 15-20 years, and 1% (2/191) in those working greater than 20 years. In the group working 15-20 years, there was one each of category 1, 2, and 3 simple pneumoconiosis, and one case of PMF who also had active TB. In the greater-than-20-years-worked category, both cases were classified as PMF. There was poor correlation of clinical and radiographic findings, except for one of the cases of PMF, and there was no progression in radiographic appearances over 2½ years. Four of the workers with pneumoconiosis had dyspnea and productive cough. Except for two with category 2 pneumoconiosis, the ability to work did not seem to be affected. The symptoms of the one smoker were thought to be due to smoking. The prevalence of adverse x-ray findings and respiratory symptoms was low. There was not enough information provided on how symptoms were evaluated and whether they were related to smoking. Using the author's method for measuring the health of the population, there was no apparent hazard.

Sheers conducted a survey of 1,394 men employed by one company in England which produced over 75% of the total product of the China clay industry (12). The study population was divided into exposure groups; no environmental data were available. There were no cases of kaolinosis in men with less than 5 years employment. Among the 255 workers with continuous high exposure, 32 (13%) had kaolinosis. Except for one individual in the 25-34 year age group (and 15-24 year exposure group), all cases were over 34 years of age. Prevalence was 6% (9/153) in those working 5-14 years; it rose to 23% (23/102) when the number of years worked was greater than 15 years. In the workers with intermittent exposure to kaolin dust, the overall prevalence of pneumoconiosis was 5% (16/298). The prevalence was 3% (7/244) in those with 7-24 years exposure, and 18% (9/54) among those with ≥25 years exposure.

The rate of massive fibrosis was lower in this population than in Egypt or the United States and was attributed to the lower prevalence of pulmonary TB and the high rate of preventive antituberculosis chemotherapy given the men in this survey. The severity of symptoms was low, and there was no conclusive evidence that disability was caused by kaolin.

These are the only three epidemiological studies of kaolin workers reported in the literature. The overall prevalence of radiological change was low:

Simple Pneumoconiosis

U.S.A. (2)—13/1130 (1.3%)
Egypt (14)—3/914 (0.03%)
England (12)—36/553 (7.7%)

Complicated Pneumoconiosis

U.S.A (2)—6/1130 (0.5%)
Egypt (14)—3/914 (0.03%)
England (12)—12/553 (2.2%)

Symptoms and disability were not associated with simple pneumoconiosis but were with complicated pneumoconiosis. Progression to complicated pneumoconiosis was thought to be due to the combined effects of kaolin and pulmonary TB. Although environment levels were not measured in any of these studies, they appeared to be high.

These studies have several deficiencies:

1. No smoking histories were taken, so the potential for synergistic effects with smoking are not known.
2. There were no measures of functional loss; i.e., there was no measurement of lung function. Thus, we cannot objectively assess disability, nor assess the correlation of x-ray findings with disability. The assessment of disability had apparently been done on the basis of clinical findings and symptoms, but the methodology was not given.
3. Exposure was not measured; in many cases it was apparently high, at least for the older workers. Recently, dust levels have been reduced by the introduction of wet methods, exhaust ventilation, enclosure, and vacuum cleaning. In the United States, these measures have proven successful in reducing the amount of dust seen in the plants.

With these caveats in mind, the following conclusions apply:

1. The major symptoms are dyspnea on exertion and productive cough; these occur sometimes in workers with progressive massive fibrosis.
2. Normal pulmonary function would be expected, except in workers with PMF, in which case there is both fibrosis and emphysema, i.e., both obstruction and restriction.
3. The prevalence of pneumoconiosis by radiographic appearance is low and generally occurs after greater than 15 years exposure. The range of abnormal opacities is similar to that seen in coal workers' pneumoconiosis. A small proportion of workers with a high exposure at an early age and who continued to work, developed PMF with emphysema and in some cases, severe disability. There is some evidence that the development of these cases may be a thing of the past.

Estimate of Population at Risk and Prevalence of Disease

In 1972, 5,317,637 tons of kaolin were produced and sold in the United States. In 1978, the number of workers mining and preparing various kinds of clay is listed, as well as the grand total which includes office workers, underground and aboveground workers, and preparation plant workers. The latter three groups are at greatest risk.

	Underground Mining	Above Ground	Preparation Plants	Grand Total
Fire Clay	144	380	1,049	2,100
Common Clay	17	3,182	7,795	12,783
Clay, ceramic, and refractory. Not elsewhere classified.	20	68	112	243
Total	181	3,630	8,956	15,126

The prevalence of the disease is not known but based on the U.S. study, is less than 2%. Significant impairment should be less than 1%. These estimates of prevalence assume dust exposures have not increased.

Pathology

Kaolin: There are five autopsy reports of advanced pulmonary fibrosis in kaolin workers reported in the literature (2)(4)(7).

One case from England was in a 45-year-old man who had bagged kaolin powder for 28 years and had severe dyspnea (4). Autopsy revealed extensive caseous tuberculosis and emphysema. The pleura and nodular lesions were similar to that seen in silicosis. The lungs contained about 18 gm of dust that was 85% kaolinite and 15% amorphous silica.

Two cases were reported from a kaolin processing plant in South Carolina (7). Soda ash, trisodium phosphate, and sodium pyrophosphate were sometimes added to the kaolin. The men were 36 and 35-years-old and had worked for 17 and 21 years respectively. Their chest x-rays were similar to that seen in silicosis. Gross examination of both lungs revealed emphysema, fibrous nodules, and thickened pleura.

Edenfield reported two cases in Georgia (2). Both were Negroes, aged 44 and 39, with 23 and 17 years exposure respectively. Both had severe dyspnea, and the lesions in their lungs resembled the massive fibrotic lesions seen in South Wales coal miners. Large areas of the lung were replaced by dense fibrosis; in other areas the alveoli were filled with macrophages containing kaolinite particles 1-2 μm in diameter. Both had numerous pleural adhesions and emphysematous blebs. Upper portions of the lungs were almost solid with massive lesions of dense collagen; adjacent satellite nodules of fibrosis and emphysema were evident in the remainder of the lung tissue. Dust and dust-laden macrophages were in alveoli, among collagen fibers, and around bronchioles and blood vessels.

These cases of kaolinosis were not those of a "benign pneumoconiosis." Where clinical evidence was available, the disability (dyspnea and cough) was severe. Permanent destruction of the alveolar walls was observed, as well as collagen fibrosis and permanent scarring of the lung. Exposure was high and over a long time period. Whether tuberculosis was a necessary factor in the progression to massive fibrosis was not answered by these data.

Ruttner, Spycher, and Sticher reported a case of diffuse interstitial fibrosis resembling asbestosis in a 70-year-old woman exposed to small amounts of mica, kaolin, and feldspar for 14 years (11). Chemical analysis of her lung revealed 13% of the dust was these 3 minerals. Quartz content was 7%; no asbestos was found. The author suggests the platy shape of mica, kaolinite, and feldspar act similarly to the fibers of asbestos to produce the diffuse fibrosis.

Thomas reported a case of silico-tuberculosis in a Cornish china clay worker who had worked for 20 years in the mill and for 5 years had trucked dry china clay from the drying kilns to the mill (13). He may have been exposed to silica for the 3 years he worked grinding china stone and feldspar. China stone may contain up to 30% free silica; china clay contains less than 3% free silica.

Lesser, Zia, and Kilburn report autopsy and lung biopsy findings on 2 patients selected from hospitalized patients with roentgenograms consistent with pneumoconiosis and occupational exposure to kaolin (6). They had not been exposed to asbestos or quartz. The first patient was 54-years-old, had 20 pack-years of cigarette smoking, a negative tuberculin test, and a 4 year history of working as a kaolin sacker in the 1940's. The second patient was 67-years-old, had 60 pack-years of cigarette smoking, a negative tuberculin test, and 30 years of kaolin exposure. The diagnosis of these 2 patients (particularly the first one) was consistent with silicosis and suggested an exposure to high concentrations of free silica and/or cristobalite. Their clinical description follows.

Clinical Description

Hale et al. reported the clinical findings of six kaolin workers with x-ray findings of pneumoconiosis (4). In the cases where massive fibrosis (coalescence) was seen on the chest x-ray, there was also dyspnea and productive cough (without blood), and often there was chest tightness, clinical signs of emphysema, and reduced vital capacity. In several of the cases, the severity of the symptoms increased rapidly. In the cases where there was no massive fibrosis, the presence of symptoms and disability was variable.

Lynch and McIver briefly reported the clinical history of the two South Carolina workers exposed to kaolin (7). Both died having "advanced pneumoconiosis with infection." In both cases their most recent exposure to dust was considered to be nonhazardous, but their initial exposure was high (and occurred when both men were in their teens). Although this suggested progression can occur after high exposure, exposure at the time of these workers' deaths was not known and may have been high by today's standard. There was no chemical analysis of the lung for kaolin or free silica. Total dust from airborne samples taken in 1976 from a South Carolina kaolin mill (2 bagger samples) revealed a free silica concentration of 1.04% and 1.01%, which was above the TLV in both cases (6).

Lesser, Zia, and Kilburn described 9 hospital patients with roentgenograms consistent with pneumoconiosis (2 with massive conglomeration) and an occupational exposure to kaolin from work at a firebrick factory (6). Their mean age was 64 (54-73) and they had worked an average of 19 years (2-48). Two were nonsmokers and 4 had restriction (VC less than 60% of predicted). All had obstruction: FEV_1/FVC ratio ranged from .25 to .70. Average percent predicted diffusing capacity was 62% (35-100%). Environmental samples from a typical Missouri firebrick factory (and presumably similar to jobs held by the 9 patients at an earlier time period) suggested they had been exposed to kaolin, free silica, and cristobalite. Some workers' exposure to free silica could have been as high as 4.5% with TWA levels frequently above the TLV (respirable air samples). A single clay sample had 4.5% free silica. Cristobalite levels were as high as 8.9% in air samples and 15% in settled dust samples.

Diagnostic Criteria

The criteria for diagnosis of kaolinosis are nodular mottling on chest x-ray and a history of exposure (at least greater than 5 years and generally greater than 10 years).

Complicated pneumoconiosis from kaolin exposure may look similar to PMF in coal and hematite miners, or it may look more like silicosis (without the characteristic fibrosis in the hilar glands). Simple pneumoconiosis looks similar to any of the other pneumoconioses that primarily have rounded opacities. Although reductions in VC and DL_{CO} have not generally been reported, this finding (in complicated pneumoconiosis) would be expected.

Methods of Prevention

Reduction of exposure, particularly of free silica and cristobalite.

Research Needs

Kaolin (and/or accompanying silica) is known to produce silicosis, and the population at risk is substantial. Early prevalence studies did not report excessively high rates of pneumoconiosis, but some progressive massive fibrosis was present. A recent study reports (hospital) cases are still occurring. None of the studies report environmental exposures, so dose-response relations cannot be estimated. The possible presence of silica and/or cristobalite increases the hazard. A prevalence study using spirometry in addition to chest roentgenograms should be conducted in the kaolin industry.

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Divalent Cations—Serpentine (Chrysotile, Antigorite)

Divalent cations can replace the aluminum ions in kaolinite. When the ions are magnesium, serpentines are formed. Two important minerals are in this group—chrysotile and antigorite.

Chrysotile is the fibrous variety of serpentine and is a major source of asbestos. It is discussed in the chapter on asbestos. Antigorite is the platy variety of serpentine. Serpentine, as a rock name, usually refers to rocks containing antigorite. Serpentine is a widely distributed, common mineral and is an alteration of magnesium silicates (especially olivine, pyroxene, and amphibole). It is frequently associated with magnesite, chromite, magnetite, and sepiolite.

Rohl, Langer, and Selikoff recently investigated environmental asbestos pollution as a result of using crushed rock from a Maryland quarry (2). The bulk of the serpentine rock was antigorite, in both platy and fibrous forms, with veins or lenticular bodies of chrysotile, tremolite, deweylite, talc, anthophyllite, chlinozoizite, penninite, and other silicate minerals. Chlorite commonly replaced antigorite. This type of crushed serpentine rock has widespread and large-scale use in the United States. The rock from the Maryland quarry has been used for road metal, base course, and resurfacing of highways, parking lots, and driveways; as concrete aggregate and other materials in the construction industry; and as filler-binder for asphalt. Air samples taken in the vicinity of roads paved with the serpentine rock showed concentrations of chrysotile about 10^3 times higher than concentrations typically found in urban ambient air in the United States.

Frank et al. examined the effect on cell growth of extracted chrysotile and ground rock samples of platy serpentine from the Maryland quarry (1). The ground serpentine had no effect. The extracted chrysotile was cytotoxic at 72 hours, but less so than when compared to UICC standard reference samples of Canadian chrysotile.

There is, at present, no other data on biological effects of serpentine rock. A current NIOSH project is investigating the mortality of crushed-stone workers. This is an important study because of the potential exposure to asbestiform minerals and the large group of potentially exposed persons (both in the community and at work).

Chlorites are a group of minerals with wide variations in chemical composition due to substitution of aluminum, ferrous and ferric iron for magnesium in the talc and brucite layers, and of aluminum for silicon in the siloxane layer. Chlorite is a common mineral, forming as an alteration of iron or magnesium silicates (pyroxenes, biotite, garnet, idocrase). It is not mined as such, and there are no medical data on the chlorites.

There are no clinical descriptions, pathology reports, or epidemiological studies of the divalent cation group (except for the asbestos mineral chrysotile). There is no described disease, no diagnostic criteria; exposure is to mixed dusts.

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Double Layer Group

Pyrophyllite

Definition

Pneumoconiosis but without characteristics specific to pyrophyllite.

List of Causative Agents

Definite: ---
Probable: Silica
Possible: Talc, pyrophyllite

List of Occupations and Industries Involved

Pyrophyllite has uses similar to talc as it is used in refractories, rubber, ceramics, insecticides, plastics, paint, and roofing. Minor amounts are used in bleaching powder, textiles, cordage, wallboard, and cosmetics. Commercially, pyrophyllite is classified and used as talc because of its similarity in physical properties.

Epidemiology

Of 101 pyrophyllite miners and millers in North Carolina, 35% with ≥2 years exposure had chest x-rays characterized by "massive tumor-like shadows bilaterally situated in the subapical region or by granular densities distributed throughout the lungs." These findings were undoubtedly due to the 25-35% quartz content of the pyrophyllite dust.

Hogue and Mallette reported on 20 rubber workers exposed to whiting ($CaCO_3$) about 90% of the time with approximately 10% exposure to pyrophyllite containing 65% free silica (2). Vermont talc replaced pyrophyllite for six years prior to the study. Exposure periods ranged from 10-25 years, age from 42 to 64 years. Average dust exposures for the last six years ranged from 30 to 150 mppcf (median = 50 mppcf) and were thought to be higher prior to that. None of these men complained of symptoms (dyspnea, cough, shortness of breath). There was no finger clubbing or cyanosis; six had a reduced vital capacity. One former coal miner (5 years) with 24 years in the rubber industry and an average exposure of 150 mppcf had Grade III pneumoconiosis, reduced vital capacity (68% of expected), but no disability. All other chest roentgenograms were "normal."

The pyrophyllite exposure in the rubber study was small when compared to whiting and silica and is therefore unlikely to be the causative agent in the one case of pneumoconiosis or in the cases of reduced vital capacity.

Estimate of Population at Risk and Prevalence of Disease

Pyrophyllite is mined primarily in North Carolina by about 200 miners. Several cases of silicosis have been noted in this population.

Pathology

No reports related exclusively to pyrophyllite.

Clinical Description

No reports related exclusively to pyrophyllite.

Diagnostic Criteria

The criteria for diagnosis include a history of exposure and a chest x-ray with features characteristic of pneumoconiosis (most probably characteristic of silicosis).

Methods of Prevention

Maintain silica exposure below standard.

Research Needs

The current work force needs to be studied for the prevalence of silicosis. There was a high prevalence of disease among miners 40 years ago, but the population has not been studied since.

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Talc

Definition

The character of pneumoconiosis associated with "talc" exposure depends on the composition of the talc dust inhaled. When asbestos is the dominant mineral, the disease is characteristic of asbestos-induced disorders. When talc is associated with quartz, the reaction of the lung to quartz is modified—giving rise to localized fibrocellular lesions—and is called talco-silicosis.

Talcosis (foreign body granulomas) is pneumoconiosis caused by deposition of "pure" talc (i.e., talc free from asbestos and quartz). Granulomas have been observed in pulmonary arteries and arterioles as a result of drugs injected with talc as a carrier, and in the peritoneum, fallopian tubes, and ovaries from talc used on surgical gloves.

List of Causative Agents

Definite: Asbestos (fibrous amphiboles, tremolite, actinolite, and anthophyllite) for talco-asbestosis. Silica for talco-silicosis.

Probable: Talc for talcosis.

List of Occupations and Industries Involved

Talc is an extremely versatile mineral that has found a steadily increasing number of uses, despite the relative impurity of most of the ores mined. Except for pure steatite grades, hand-picked platy cosmetic talcs, and a few products from wet processing plants, industrial products are really mixtures of many minerals. For example, much of the talc used by the ceramic industry is a mixture of platy talc and tremolite; most of the talc used by the rubber, plastic, and paper industry is, at best, about 90% talc with the balance being dolomite, calcite, chert, clays, serpentine, chlorite, actinolite, iron and manganese-containing minerals, and carbonaceous material. Since industry is (in general) interested in the physical characteristics of the talc rather than the chemical composition, the occupations and industries involved will include uses of both "fibrous" and "nonfibrous" talc without distinction between the two.

The principal uses of talc include: extender and filler pigment in the paint industry; coating and filling of paper; ceramic products; filler material for plastics; roofing products.

Miscellaneous uses of talc include: binders and fillers in textiles; fillers in integral foamed latex rubber backings for carpets, rugs, and parquet hardwood floor panels; filler for upholstery fabric backing and draperies; lubricant in extreme temperature range greases; use in corrosion proofing compositions; 10-15% in dry fire-extinguishing powders; loading and "bleaching" materials such as cotton sacks, cordage, rope string; cereal polishing (rice, corn, barley); bleaching agents; food odor absorber; floor wax; water filtration; leather treatment (oil absorption); joint fillers and grouts; insecticides; shoe polishes; welding rod coatings; printing inks; encapsulant for acceleration testing artillery shells up to 50,000 g., coating for iron ore pellets in direct reduction processes; source of magnesium in plant foods; pigment in white shoe polishes and white glove cleaners; dusting powder for salami; admixture for certain concretes; polishing medium for peanuts, gunpowder grains, turned wooden articles; to prevent sticking of bottle, rubber, and candy molds; and to impact a finish to wire nails and leather.

In 1977, the percentage uses of talc were 22% for ceramics, 17% for paints, 8% for paper, 6% for refractories, 5% for building materials, 5% for insecticides, 4% for toilet preparations, 2% for rubber products, and 31% for all other uses of which only a fraction are listed here (other uses number at least 100).

The most significant exposure occurs in milling talc. The exposure to talc in users is largely unknown.

Epidemiology of Talc Without Asbestos Minerals or Quartz

Descriptions of "talc" pneumoconiosis commonly resemble asbestosis or less commonly, silicosis. There is usually no description of the fiber or free silica content of the talc. When exposure is to "pure" talc (no asbestiform fibers, no free silica), there are few or no symptoms or impairment in lung function. The lack of disability together with long exposures to talc dust suggests talcosis should be designated a "benign pneumoconiosis."

Merewether reported that rubber tire workers exposed to French chalk showed "diffuse interstitial fibrosis" by chest x-ray and nothing more than "peribronchial increase in the fibrous tissue" after 30 years. Exposure ranged from 10 to 32 years. Examination of 13 additional workers with exposures of 4-1/2 months to 40 years supported the previous finding.

Hogue and Mallette reported on 20 rubber workers exposed to talc (among other things) containing no free silica, tremolite, chrysolite, chrysotile, or actinolite (18). Years worked ranged from 10 to 36 years, and for a 6-year period prior to publication of the report, exposure averaged 20 mppcf for 6 tube machine operators, 35 mppcf for 3 tube bookers, 15 mppcf for 10 tube curemen, and 50 mppcf for 1 liner reroller. None of these men had dyspnea, cough, shortness of breath, cyanosis or clubbing of the fingers. Chest x-rays were all normal, and the range of percent predicted VC was 71%-122% with a median of 105%. The authors concluded that "long exposure to talc does not appear to produce pathologic changes in the lungs."

Fristed et al. reported 5 cases of talcosis (defined by x-ray and history) in workers manufacturing inner tubes and water hoses and exposed to "Scandinavian granular talc" (11).

Quartz content of the talc as measured at the time of the study was consistently less than 1%; the percentage of needle-shaped particles 5-20 μm in length was 0% to 1.2%, and for needle-shaped particles greater than 20 μm, the percentage was 0.02% to 0.05%. X-ray diffraction analysis revealed no tremolite or other steatites. Mean concentrations of dust in the 2 inner tube departments was 61 mppcf (22-75) and 66 mppcf (32-99) and was 37 mppcf (10-121) in the water hose department.

The authors described these cases of talcosis occurring on exposure to granular talc and characterized this type of talcosis as similar to slow progressing silicosis; i.e., nodular changes with involvement and blockages of the lymphatic system and an increased risk of tuberculosis. All cases had negative tuberculosis culture tests. Crystallographic examinations of the lymph nodes showed high levels of talc and 5% quartz, which is about twice that of persons not exposed to quartz. The average latency for the development of talcosis, presumably determined by chest x-ray, was 35 years. Based on current levels, exposure was high (2-3 times the 20 mppcf TLV for talc). Past exposure could have been even higher, and there could have been intermittent past exposure to higher levels of asbestos minerals (e.g., actinolite, tremolite) and quartz. Detrimental effects on health appeared to be minimal although the description of the syndrome was meager. Smoking status of these workers was not given. Biopsy revealed fibrosis of mediastinal lymph nodes. No information was given on the population at risk, so prevalence is unknown.

Scansetti, Gaido, and Rasetti in a cross-sectional study, examined 72 Italian rubber workers exposed to talc containing no free silica or asbestiform fibers (42). They had no other dust exposure. Based on clinical examination and chest radiograph, the prevalence of bronchitis, emphysema, and pleural compartmentation was 8%, 5%, and 4% respectively. The prevalence of bronchitis was low compared to extractive industries (mining). The prevalence of bronchitis, emphysema, and abnormal radiographs increased with years worked. At least 9 workers with less than 3 years exposure had abnormal radiographs and bronchitis; all workers with greater than 16 years had abnormal radiographs. The authors stated that increased pulmonary marking developed early, and did not get any worse. However, they provided no evidence to support this assertion.

The association of radiographic and clinical findings with years worked was undoubtedly confounded by age, smoking, and free silica exposure, although no information was provided. Unfortunately, there were no environmental measurements, and the criteria used for evaluating abnormalities was inadequately defined and so cannot be compared with other populations. It appeared, however, that effects of exposure were mild as there was no fibrosis and no reduction in respiratory function of working capacity.

Scansetti, Rasetti, and Ghemi reported a prospective study of Italian talc miners (43). The talc was not characterized but was presumed to contain no asbestos and less than 1% quartz, although on occasion free silica exposure could have been quite high. The initial group of 236 workers had an average of 4.9 years exposure; subsequent examinations of this same group were made 9.4 (n = 229), 11.6 (n = 55), and 14.6 (n = 22) years later. Bronchitis and emphysema were determined by clinical examination. Diagnostic criteria were not clear. The prevalence of bronchitis, emphysema, right heart involvement, reduced predicted VC, reduced ventilation, Tiffeneau index, and pneumoconiosis increased as years worked (and age) increased. There was a good correlation of radiographic findings and reduction in pulmonary function. The authors commented that while the incidence of abnormality was high, the severity of the disease was slight. It is not possible to determine disability from the data presented, nor is it possible to evaluate the effects of age, smoking, natural selection (the attrition rate was quite high), or dose-response relations. Further, the drillers may have been exposed to significant quantities of free silica.

Rubino et al. conducted a historical prospective mortality study of male talc miners and millers (41). Air samples had been collected since 1948, and environmental levels in the mine had been at or below the TLV since about 1950-1955 and in the mill since about 1960. The talc was from the same region as the previous two studies and contained very little asbestiform fibers. Environmental exposures to free silica in the mill were less than 1% but in the mine ranged from 1% to 18%. The highest exposure to quartz occurred in drilling (12% to 18% free silica) due to the high quartz content in the rock and inclusions. In mucking and carrying jobs the percent free silica was 1% to 3%. In this study and the previous one, some talc miners had a significant exposure to free silica. Therefore, in this study, millers were analyzed separately, and workers with any experience in the talc mines were not included in the miller category. When compared to control subjects in a nearby town, the overall SMR was significantly less than 1 (.89 and .88 for miners and millers respectively), and there was no dose-response relation, i.e., there was no relationship of increased SMR (both overall and by cause of death) with increasing interval between first exposure and death (latency) nor with increasing cumulative exposure. Overall, miners had a significant excess of silicosis (observed/expected = 62/30.9) and silicosis with tuberculosis (observed/expected = 18/9.1).

Rubino et al. subsequently reanalyzed this data using the entire white male population as controls (40). In this comparison, SMR's for both miners and millers were elevated. Overall, the miners showed no consistent relationship with exposure. The SMR's for both miners and millers were elevated and the SMR's decreased with increasing exposure. Respiratory disease (primarily pneumoconiosis) increased with increasing exposure among the miners, but decreased with increasing exposure among the millers (as did lung cancer among the millers). Of the four cases of pneumoconiosis among the millers, 2/4 had known previous exposure to free silica, and for 1/4 previous dust exposure was not known. The latent period ranged from 29 to 41 years, duration of exposure ranged from 3 to 23 years. Thus there was no association by cause of death with cumulative dust exposure among the millers, and the association of death due to nonmalignant respiratory disease and tuberculosis with exposure was attributable to quartz exposure.

Rubino et al. also examined all currently (1975-76) employed talc millers who did not have other exposures to inorganic dust and who were employed at the same location as the workers in the mortality study (40). Chest radiographs of the 43 millers showed that grade 1/0 pneumoconiosis (ILO/UICC classification scheme) appeared after an estimated cumulative exposure of greater than 160 mppcf and grade 1/1 and 1/2 after 320 mppcf. Mean duration of exposure was 22 and 29 years respectively: a mean exposure of 7.3 mppcf/year for grade 1/0, and 11 mppcf/year for grade 1/1 and 1/2.

Delaude examined French workers exposed to talc that was chemically pure and contained chlorite, calcite, traces of pyrite, quartz (less than 3.5%), and no asbestos (6). Among 94 exposed workers, 15 cases of pneumoconiosis were found; 8 with minimal radiographic signs. Mean exposure was 25 years (range of 11-36 years). Exposure in the past was high, in certain jobs as high as 800 mppcf. One of the 15 cases had reduced pulmonary function. In smokers, the effect of exposure was increased: the prevalence of chronic bronchitis among nonexposed smokers over 40 years of age was 27%, compared to 58% for a similar group of [presumably smoking] exposed workers. The authors characterized the syndrome caused by French talc as a benign pneumoconiosis. It had none of the characteristics of asbestosis or silicosis, but was the result of very high and prolonged exposure to pure talc that in itself can "cause a ventilatory insufficiency and. . . aggravate an obstructive bronchopneumopathy." No increase in lung or pleural cancer or gastrointestinal cancer was observed although no details were given.

Katsnelson and Mokronosova compared the mortality of Russian talc miners and millers employed between 1949 and 1975 with the mortality of a comparison population from the same town (21). Cause-specific mortality was limited to death from tumors of all sites, lung cancer, and gastric cancer. Talc workers with less than 2 years exposure were put in the control population. Relative risk (R.R.) (the ratio of death rates in the 2 populations after standardization for age) was elevated in both males and females (except for lung cancer in females). The R.R. increased with age for all tumors, although the increase was greatest for lung cancer. The talc contained no tremolite, no nonasbestiform actinolite (it was present in one bedding only and then only up to 6%), and 0.2%-1.6% quartz. The main minerals other than talc were carbonate minerals (up to 42%).

The conclusions from this paper may not be correct for the following reasons:

—The control or comparison group was not defined.

—The calculation of rates may be erroneous as the denominator of the study cohort did not represent the population at risk. If the worker population at the plants had been declining over time, the cancer rates would have been overestimated. It is also not clear if the numerator for the control group was derived correctly, and if not, there could be a serious underestimate of the control cancer rate.

—There is not enough detail on the methodology used to determine whether the conclusions are valid.

El-Ghawabi, El-Samra, and Mehasseb conducted a cross-sectional study of 50 Egyptian talc millers (9). The talc contained no free silica, but it is unknown whether asbestiform fibers were present. All environmental measurements were above the TLV. Average exposure levels in front of the mill were 68.5 mppcf (54-83), $n = 12$); behind the mill, 30 mppcf (25-35, $n = 12$); and in the package area, 92 mppcf (73-111, $n = 12$). Pulmonary function was not reduced in this population (one reduction in FVC, none for FEV_1), and symptoms did not correlate with radiographic findings. The overall prevalence of radiographic findings was high (88% for those with ≥15 years worked) although there appeared to be little disability associated with them.

These studies comprise the total number of epidemiological studies (performed outside the United States) of workers exposed to nonasbestiform talc with a low silica content. Pulmonary function in exposed workers with pneumoconiosis was only marginally reduced, if at all. The severity of symptoms and radiographic changes were, in general, minimal. Latency was generally greater than 20 years. Exposure was well above the standard of 20 mppcf, and in some cases quartz was present in significant quantities.

The remaining epidemiological studies were done in the United States. In 1958, 15 talc miners and 46 talc millers in Lewis County, New York were studied (31). Average free silica content of 10 samples was 1.4% (0.2-4%). Microscopic examination revealed irregular aggregates of scaly or granular particles but no tremolite. Average dust counts obtained in 1940-48 in the mill ranged from 171 mppcf to 537 mppcf (the range for single dust counts was 47 to 1090 mppcf). After controls, the mean dust counts in 1958 for the same jobs ranged from 23 to 96 mppcf (the range for individual dust counts was 13 to 113 mppcf). Levels were much lower in the mine, as average dust counts for drilling and mucking in 1958 were 1-5 mppcf. The highest individual sample was 7.5 mppcf. None of the 15 miners had pulmonary fibrosis; 2/46 millers had increased bronchovascular markings. Their average exposure was greater than 50 mppcf for 31 years worked. Two other workers with fibrosis had worked for more than 20 years at exposures greater than 50 mppcf. The authors compared these findings to talc workers exposed to tremolitic talc (this talc probably also contained anthophyllite). The Lewis County millers had a minimal degree of fibrosis (less fibrosis than the workers exposed to tremolitic talc), and the incidence of fibrosis was significantly lower, despite the same (and, at times greater) dust exposure and longer years worked (31 versus 19.6 years). Exposure to this nonfibrous talc produced minimal fibrosis at very high exposure levels. The authors concluded that if exposures were less than the TLV of 20 mppcf, it would probably produce no fibrosis.

In a cross-sectional study, Fine et al. administered pulmonary function tests, chest x-rays, and respiratory questionnaires to 80 rubber workers exposed to industrial grade talc and 189 nontalc exposed rubber workers (10). This study showed an increased prevalence of cough, phlegm, and wheezing in talc-exposed workers compared to nonexposed workers. There were no abnormal radiographic findings or cases of restrictive lung disease, but there was evidence of mild obstruction in those exposed compared to controls in the greater-than-10-years-worked group. There was a clear increase in symptoms in the exposed compared to control group, but it is not known whether this occurred in the less-than-10-years group, greater-than-10-years groups, or both. The characteristics of the talc used in the past were not mentioned; it could have contained both asbestos fibers and/or free silica. Exposure is not known because the reported environmental measures did not correspond to the job the exposed talc workers actually performed.

Wegman, Burgess, and Peters administered an MRC questionnaire, chest x-rays, and spirometry to talc miners and millers in Vermont in a one year prospective study (56). The talc was considered free of asbestos and free silica. In the initial cross-sectional study of 117 talc miners and millers, percent predicted FEV_1 and FVC were 97% and 104% respectively (standardized by comparison with the prediction equations of Kory et al.). Percent predicted FEV_1 and FVC were reduced in current smokers compared to ex-and nonsmokers and in the group working ≥20 years compared to the group working less than 20 years. Heavier smokers (≥1 pack/day) had a better percent predicted FEV_1 and FVC than did light smokers (less than 1 pack/day). A similar relationship was observed for MMEF and RV/TLC. There was a general tendency for percent predicted FEV_1, FVC, and MMEF to become smaller as estimated cumulative exposure (dust years and years exposed) increased. Unfortunately, this relationship was confounded with smoking, as the group smoking longer than 20 years probably also had more cumulative exposure than the less-than-20-years smoking group. Multiple regressions with age, height, years smoked, and years employed had statistically significant associations ($p<.05$) of age, height, and years smoked with percent predicted FEV_1 and a significant association of age with percent predicted FVC. Mean percent predicted FVC for smoking or exposure category ranged from 98.7% to 108.7%; for mean percent predicted FEV_1 the range was 87.9% to 107.9%.

The prevalence of abnormal x-ray findings in this study was higher than in previous studies (6% with 2/1 small rounded opacities, 4% with 2/1 small irregular opacities, and 9% with pleural abnormalities) and was associated with years worked and estimated cumulative exposure. The authors stated that talc could be causing obstruction, but this apparent association is more likely due to smoking. This longitudinal study was too short (one year) to adequately document dose-response relationships. If anything, it showed no relationship of talc exposure (as measured by current job exposure) with changes in FEV_1, FVC, and MMEF.

Selevan et al. conducted a mortality study of Vermont talc miners and millers exposed to talc containing no asbestos and less than 1% free silica in both bulk and air samples (50). This study showed an association of pneumoconiosis with talc exposure that was well above the current TLV. Whether current exposure levels can produce the same degree of pneumoconiosis is not known. The possible interaction of cigarette smoking and talc could not be evaluated.

An unpublished prospective study of 70 Vermont talc miners is reported by Hildick-Smith (17). The talc was cosmetic grade, 90% pure, and after processing in the mill, was free from asbestos and silica. Average dust exposure was 7.6 mppcf, and average work duration was 4.6 years. This study showed that smoking talc miners exposed to low concentrations of talc for a short period of time did not differ from a smoking population not exposed to dust, and that the smoking talc miners differed only slightly from a nonsmoking population. As exposure time was short, and the population was young, the effects of long-term exposure are still not known.

In an unpublished epidemiological-industrial hygiene study of talc workers, a higher than ex-

In an unpublished epidemiological-industrial hygiene study of talc workers, a higher than expected prevalence of bilateral pleural thickening was found in a group of 299 talc miners and millers from Montana, Texas, and North Carolina, who were examined in a cross-sectional study of respiratory symptoms, lung function, and chest x-rays. Lung function parameters associated with the affected subgroup were significantly reduced. Personal respirable dust samples were collected for all jobs, and cumulative exposures were calculated. Average time worked was short; average exposure was 2.6 mg/m^3. Free silica content of bulk samples was low. No fibers were observed with light microscopy. With transmission electron microscopy, tremolite and antigorite fibers were observed in the Texas talc, acicular particles in North Carolina talc, and no fibers in the Montana talc. Differences in age corrected symptom prevalences (cough, phlegm, and dyspnea) between regions, when compared by both smoking categories and exposure groups, were not statistically significant. None of the symptoms showed any consistent association with years worked or cumulative exposure. Symptom prevalence was not elevated compared to blue collar workers and potash miners. However, the prevalence of bilateral pleural thickening was elevated in workers 40 or older compared to blue collar workers and potash miners. No nonsmoker had bilateral pleural thickening. Workers with bilateral pleural thickening had lung function 10-20% below workers with no pleural thickening. They had also worked twice as long (13 years). There were no demonstrated differences in prevalence when the subjects in this study were compared to workers exposed to New York talc which contains tremolite and anthophyllite. For this sampled talc population, no association of reduced lung function with exposure was demonstrated; there were no significant increases in symptoms or pneumoconiosis, no significant reductions in lung function. After adjustments for age, height, and smoking, FEV_1 and FVC were not detectably different compared to potash miners and blue collar workers. However, flow rates at low lung volumes were 4-19% less than all of those comparison populations. The prognostic significance of the pleural thickening awaits prospective evaluation.

Estimation of Population at Risk and Prevalence of Disease

The total number of workers mining talc, soapstone, and pyrophyllite in 1978 was 144 underground, 243 on the surface, 683 in preparation plants, and 173 office workers for a grand total of 1,243. This total includes fibrous talc, which totals at least 200 workers. The number of workers exposed in secondary industries is unknown.

Pathology

In vitro tests suggest that pure crystalline talc is less pathogenic than free silica or asbestos. Inhalation experiments with animals suggest that talc may produce some pulmonary fibrosis, however, other minerals in the "talc," including quartz and asbestos fibers, probably contributed to the pulmonary injury. Several investigators have introduced talc and other particulates intratracheally into experimental animals. No significant pulmonary fibrosis developed in rats exposed to talc without quartz contamination, but in animals exposed to talc with 10% silica, an intense pulmonary fibrosis was noted. Schepers and Durkan introduced various combinations of minerals into the tracheas of guinea pigs once weekly for three weeks and sacrificed the animals up to 2 years after exposure (46). The authors concluded the basic reaction to talc, quartz, tremolite, and anthophyllite dust was an outpouring of macrophages into the alveolar spaces with phagocytosis of the particulate matter. Although the macrophages might become immobilized and, therefore not removed from the lung, no necrosis or fibrosis was stimulated unless the particulate matter was in the form of long fibers. Damage to small airways and vessels was produced by the talc exposure, but the reaction was mainly accumulations of cells with little deposition of collagen. The authors contrasted this with diffuse interstitial fibrosis which was associated with exposure to the fibrous materials. Quartz increased the pathogenic potential of the talc-asbestos mixture.

Although useful, animal exposures as described above are subject to certain limitations. In inhalation experiments, the doses used are often massive compared to usual human exposures. The introduction of the material in solution intratracheally may produce artifactual lesions. Gross and co-workers found that materials producing no lesions inhaled caused polypoid fibroblastic lesions in the brochioles and alveolar ducts of rats when injected intratracheally (4). The stroma of these lesions consisted of reticulin fibers and dust with an occasional giant cell. The lesions disappeared after 6 months. When quartz, asbestos, or talc were injected intratracheally, similar lesions were found, but the lesions progressed to collagenous fibrosis and distortion of bronchioles. Thus experiments conducted with intratracheal injections might produce artifactual lesions not associated with the material when inhaled.

In persons exposed to talc by inhalation, gross examination of the lungs may reveal diffuse pleural thickening and fibrous adhesions of the pleural surfaces. In some cases, localized pleural plaques, which may calcify, are located on the costal parietal pleura and the diaphragmatic surfaces. The lungs themselves may contain multiple small nodular lesions less well defined than those usually seen in persons exposed to free silica. Large fibrotic masses which undergo central necrosis and cavitation have been reported. Diffuse interstitial fibrosis with cystic changes in the lower lobes may be the predominant lesion. Microscopically, pulmonary parenchymal lesions may be classified in 3 general groups.

1. There may be a diffuse interstitial fibrosis with collagen deposition in the alveolar walls and dust-laden macrophages both in the alveolar septa and free in the alveolar spaces. Bronchi and bronchioles may be distended and distorted, and normal lung architecture may be obliterated with dilated spaces lined with cuboidal metaplastic cells replacing the alveoli. Elongated brownish beaded or clubbed shaped "asbestos bodies" are often found in respiratory bronchioles or in masses of fibrous tissue in lungs with the changes just described, suggesting that asbestos played a significant role in the pathogenesis of the lung damage.
2. A second type of lesion is that of widespread, ill-defined nodules. These nodules consist of stellate collections of macrophages and fibroblasts with birefringent particles both inside macrophages and lying free. There may be some fine reticulin, but little collagen is found in these lesions. The lesions may center on medium and small pulmonary vessels and around small bronchi and bronchioles. There is generally no diffuse deposition of collagen in the alveolar septa and no alveolar septal cell hyperplasia. Large pulmonary vessels are normal, and although there may be some endarteritis obliterans in smaller arterioles, the elastic lamina is intact and capillary circulation appears relatively undisturbed. In those lungs found to have a higher quartz content, much more pronounced and diffuse collagen deposition is found. Some of the nodular lesions may take on a partially whorled appearance resembling lesions found in classical silicosis, and vascular compromise is more pronounced. Nodules may coalesce, form large fibrotic masses, and eventually cavitate due to ischemic necrosis. Pulmonary lymph nodes containing macrophages filled with particulate material, fibrosis, and sometimes calcification may be seen in lungs with high quartz content. In patients with extensive lesions (as just described) or severe diffuse interstitial fibrosis, right ventricular hypertrophy (cor pulmonale) may be found.
3. The third type of lesion seen in the lungs of persons exposed to talc is that of foreign body granulomata. These granulomata consist of epithelioid cells and foreign body giant cells often containing birefringent crystals. Granulomata may be found in association with nodular fibrosis or isolated in the alveolar interstitium with normal thin alveolar septa intravening. They may also be found in fibrotic and thickened pleura. In persons exposed to talc by intravenous injection (see below) granulomata may be found predominantly in vessel walls.

The pulmonary pathology found in workers with inhalational exposure to "talc" varies, depending on the composition of the dust inhaled. When silica content is significant, the lesions resemble those in silicosis. When fibrous materials such as tremolite are present, diffuse interstitial fibrosis resembling that of asbestosis may be found Whether pure mineral talc itself causes any permanent reaction in humans is open to debate. Talc particles which penetrate into the airspaces beyond the level of terminal bronchioles are phagocytosed by macrophages. If the total dust burden is not too high, migration of the macrophages into the alveolar spaces and ultimately into the lymphatic system may not leave any (essentially) permanent changes in the lung parenchyma. Where dust burdens are higher, all dust bearing macrophages may not be cleared, and focal collections of macrophages—some coalescing into foreign body giant cells—may result. As usual, individual differences in susceptibility probably affect the exact nature of the response. There is strong evidence that the reaction to dusts containing a predominance of the mineral talc is more cellular and less fibrotic than that to free silica or asbestos fibers. Pure talc alone may be capable of inciting a foreign body granuloma although granulomata are also seen in classical silicosis.

Clinical Description

The development of pathologic changes in the lungs and subsequent symptoms depends upon the intensity and duration of exposure as well as individual differences in reaction to dust. Symptoms in talc workers generally take longer to develop than in persons exposed primarily to asbestos or silica. The earliest symptom appears to be chronic cough which may be accompanied by production of small to moderate quantities of clear sputum. This may be a manifestation of nonspecific "industrial bronchitis" and is seen most often in workers who smoke cigarettes. As the disease progresses, dyspnea on exertion becomes the most common feature. Wheezing is usually not a prominent feature but may be present during episodes of acute bronchitis. Severe dyspnea is more commonly associated with the diffuse interstitial fibrosis pattern than the nodular type but may be seen in patients with conglomerate lesions.

Early in the course there may be no abnormal physical signs. With the diffuse interstitial fibrosis pattern, breath sounds may become harsh, chest expansion diminished, and basilar crepitations may be present. As impairment progresses, resting tachypnea, worsening with exercise, and peripheral cyanosis may develop. If cor pulmonale is present, the usual signs of this condition including peripheral edema, elevated venous pressure, and gallop rhythm on auscultation of the heart may be present. Clubbing of the fingers is commonly present at this stage.

For those with nodular type disease, physical examination may remain normal, but when confluent conglomerate lesions are present, dullness and diminished breath sounds occur over the lesion. Generalized limitation of chest expansion, decreased breath sounds, and prolonged expiratory time may also be present.

The radiographic appearance is variable. Patients may have completely normal chest x-rays and yet be found to have numerous granulomatous lesions in the alveolar interstitium. Diffuse reticulo-nodular opacities often predominate in the mid zones. In some instances, the lesions may be relatively discrete, rounded opacities 3-5 mm in diameter, whereas in others, the shadows may be more linear or irregular and occur predominantly in the bases. The radiographic appearance probably varies between that of classical silicosis and asbestosis, depending on the predominance of free silica or asbestos in the dust inhaled. Occasionally, the shadows may be diffuse, small nodules simulating miliary tuberculosis. These shadows may be due to miliary granulomata with little intervening interstitial fibrosis. As the condition advances, nodular opacities may coalesce and eventually form large confluent shadows with irregular borders. These lesions may eventually cavitate. Pleural thickening is common in workers exposed to talc. It may take the form of diffuse thickening (especially in the lower zones), obliteration of the costophrenic angles, and in some instances pleural plaques located on the diaphragms or parietal thoracic pleura. Calcified pleural plaques were commonly seen on x-ray in cases where "asbestos bodies" were present in the lungs.

The radiographic appearance in advanced disease may resemble that in end-stage silicosis with progressive massive fibrosis, loss of volume, and over-distention in the remaining lung. Advanced interstitial fibrosis resembling asbestosis may result in obscuration of the cardiac borders, loss of volume, and cystic changes, especially in the lower zones. Signs of cor pulmonale with right ventricular prominence and enlarged central pulmonary artery segments may also be present.

Early studies of pulmonary function in talc workers frequently did not take into account the effects of smoking and thus are difficult to interpret. Many of the studies also did not adequately document the asbestos and silica content of the talc. Pulmonary function testing may reveal normal function in those with minimal involvement on chest x-ray. In those with significant interstitial fibrosis, a diminished FVC and FEV_1 and/or decreased DL_{CO} may be the first manifestation. With more advanced disease, hypoxemia during exercise and later at rest may be found. In those, the predominantly nodular disease function impairment may be less severe. Progression, however, may occur and result in significant restrictive and perhaps obstructive lung disease, especially when conglomerate lesions are visible on chest x-ray. A subtle gas exchange impairment may progress to produce clinically significant blood gas abnormalities in advanced cases.

There are no other laboratory examinations which are specifically helpful in the evaluation of patients with pneumoconiosis due to the exposure of talc. Routine examinations such as complete blood counts provide no specific information (but, of course, may be useful in the management of the patient). Electrocardiograms are usually normal, but in cases with severe disease and cor pulmonale, signs of right ventricular hypertrophy may be present. Lung biopsy may establish the diagnosis in unusual cases but should seldom be necessary.

The development and progression of pneumoconiosis due to talc depends upon the intensity of exposure and individual differences which are not well known at the present time. More complete discussion of possible immunologic and pulmonary defense mechanism differences accounting for variations in response to inhaled dust have been given in other chapters on the pneumoconioses. In general, pneumoconiosis associated with talc tends to progress more slowly than that due to silica or asbestos.

Pneumoconiosis associated with talc exposure presents a spectrum of natural history ranging from rapidly progressive pulmonary impairment leading to cor pulmonale and death to relatively benign dust deposition producing few symptoms or functional changes and probably not progressing once exposure ceases. Significant exposures to free silica and/or asbestos appear to predispose to the more severe and rapidly progressive forms of the disease while exposure to the pure mineral talc may have little functional significance. No unique complications have been associated with talc pneumoconiosis. Although an increased risk of tuberculosis has been clearly demonstrated in workers exposed to a significant quantity of silica, this has not been unequivocally demonstrated in workers exposed to talc. Possible carcinogenicity will be discussed in another section.

In general, treatment for pneumoconiosis associated with talc exposure does not differ from that for other pneumoconioses. Efforts to prevent further damage by removal from exposure is certainly indicated when functional impairment can be demonstrated. Treatment of intercurrent infections, bronchospasm, and congestive heart failure by standard means may produce symptomatic improvement but probably do not alter the progress of the pneumoconiosis itself. Two cases have been reported which suggest that the granulomatous reaction may be reversible by the use of steroids.

Diagnostic Criteria

There are no pathognomonic symptoms or signs of the pneumoconiosis associated with talc exposure. As in other pneumoconioses, diagnosis is based upon obtaining a history of significant exposure and finding one of the chest radiographic patterns described above. Although mild functional abnormalities have been described in persons without radiographic abnormalities, this appears to be unusual. In most instances, the radiographic appearance in association with a history of talc exposure should allow a clinical diagnosis to be made with some certainty. In cases where a specific etiologic diagnosis is necessary and the exposure history is inadequate or atypical features are present, lung biopsy can be performed. None of the pathologic patterns described are pathognomonic and particulate matter should be identified by the use of electron microscopy, x-ray diffraction, and lung ashing techniques.

Methods of Prevention

Reduction of exposure, particularly when the talc contains asbestos and/or quartz.

Research Needs

A followup study of workers exposed to nonfibrous talc at least five years after the initial studies would provide information on the incidence of pneumoconiosis, natural history, progression, and provide some estimate of dose-response relationships.

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Montmorillonite Minerals (Smectites)

Montmorillonites are clay minerals. Montmorillonite is the specific name of a clay mineral found originally near Montmorillon, France. The term is now restricted to hydrated aluminum silicates. Bentonite is a commercial term for clays containing montmorillonite type minerals formed by the alteration of volcanic ash. Fuller's earths resembles clay but lacks plasticity and has a higher water and magnesia content. Fuller's earth are commonly magnesium aluminum silicates, but their distinguishing characteristic is their adsorptive qualities; e.g., their ability to decolorize oils and fats by retaining the coloring matter. Attapulgite is quarried as a fuller's earth and has the adsorptive characteristics of fuller's earth.

In most of the studies and case histories reported, the silica and total dust exposures were quite high. Medical findings in these cases were similar to silicosis. In the case of bentonite (and other fuller's earths) the quartz can also be converted to tridymite and cristobalite if high enough drying temperatures are achieved. There is some evidence that montmorillonite itself can cause pneumoconiosis, but its fibrogenic potential is low. If pneumoconiosis occurs as a result of fuller's earth exposure, it is only after long exposure to high concentrations. Disability is slight.

Bentonite

Definition

Silicosis has been reported in bentonite workers. No disease has been associated with bentonite alone.

List of Causative Agents

Definite: Quartz
Probable: Cristobalite
Possible: Tuberculosis

List of Occupations and Industries Involved

Bentonite is used as a foundry sand bond; drilling mud where penetrated rocks contain only fresh water; bleaching clay (oil refining, filtering, clarifying, and decolorizing); pelletizing of taconite ore. Minor and specialty uses include: filtering agents (for wine, waste water); water impedance (preventing seepage loss from reservoirs, irrigation ditches, waste disposal ponds, and seepage through basement walls, tunnel walls); ingredient in cosmetics, animal feed, pharmaceuticals; colloidal fillers for certain types of paints; additive to ceramic clays to increase plasticity; fire retarding materials; catalysts for petroleum refining; bleaching oils and making multiple-copy paper requiring no carbon paper.

The major uses of bentonite are in foundry sand (37%), iron ore pelletizing (32%), drilling mud (29%), others (2%).

Epidemiology

Phibbs, Sundin, and Mitchell reviewed the chest films of 32 men who had worked in two bentonite processing plants in Wyoming (2). These films were from the local hospital and physicians and were not a random sample of bentonite workers. An average of 53 men worked at the processing plants in the towns where these films were reviewed. Three physicians—one a radiologist—reviewed the films. Examination of the biased (nonrandom) sample of bentonite workers revealed silicosis in 14 (44%), including 2 cases of progressive massive fibrosis. One of these had worked only 12 years in the mill and was only 40-years-old. Environmental surveys of bentonite processing plants revealed that the free silica content of the airborne dust was between 5-10%, and the airborne dust levels exceeded the TLV for silica; in one plant the dust levels were 3 to 10 times over the TLV. The free silica content of Wyoming bentonite clays ranged from 0-24%, and varied widely in both settled and airborne dust. This variability conformed with the industry's product information that the chemical composition of the finished product may vary. Tests in the early 1950's showed that some samples contained appreciable amounts of cristobalite but not tridymite. It is not clear whether the cristobalite originated in the parent rock or was formed in the drying process. The dust levels in most cases greatly exceeded the TLV of 20 mppcf for inert dust.

Estimate of Population at Risk and Prevalence of Disease

In 1975 bentonite was produced in 12 states. Almost 3/4 of it was mined in Wyoming. A total of 3,299,267 short tons were sold or used in 1975, a 2% decrease from 1974. The total mining force is probably less than 1,000 workers. The prevalence of silicosis among bentonite workers is unknown, but could possibly be quite high if the result of Phibbs, Sundin, and Mitchell's study is any indication (2).

Pathology—No reports.

Clinical Description

Clinical descriptions of symptoms (dyspnea) and chest x-rays (nodules and fibrosis) are consistent with silicosis. FVC, FEV_1, and MMEF were reduced only in some cases and not others. Progression of the disease was noted in at least 2 cases with severe disability.

Diagnostic Criteria

Same as for silicosis.

Methods of Prevention

Bentonite clay is mined in open pits. In the mill, moisture is removed by kilns or dryers. The dry product is ground in roller mills and the product is then loaded or bagged. The largest exposure is in the bagging and loading operations, although it appears that all mill operations presently get some exposure. Adequate ventilation to remove the dry product is essential to control exposure levels. The federal standard for free silica and cristobalite should be enforced.

Research Needs

An epidemiological morbidity study should be conducted among the miners and millers of bentonite to determine the prevalence of silicosis.

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Fuller's Earth

Definition

The disease is pneumoconiosis, often resembling silicosis. There is no recognized disease specific for fuller's earth.

List of Causative Agents

Definite: Montmorillonite
Probable: Quartz
Possible: —

List of Occupations and Industries Involved

Fuller's earth is a porous colloidal aluminum silicate. The term is a catch-all for clay or other fine-grained earthy material suitable for use as an adsorbent and bleach. Most uses of fuller's earths refer to its adsorbent properties, although other properties are required for some uses (e.g., drilling muds and fillers). Attapulgus clay (attapulgite, palygorskite) is a crystalline hydrated magnesium aluminum silicate and is the principal member of sorptive clays known collectively as fuller's earth. In the United States, attapulgite is mined only in the Georgia-Florida area. Colloidal grades of attapulgite are used in water-base and oleo-resinous paints as thickening, antisag, and leveling agents, and in latex paints as a thickener. Attapulgite effectively prevents bleeding in putties and glazing compounds, is a thickener for adhesives, and is used in joint-sealing compounds and microcrystalline wax. Oil well drilling mud contains 2-30% clay, and attapulgite is extensively used in salt formations. Attapulgite is used to prevent sedimentation of solids in suspensions and emulsions such as liquid fertilizer suspensions, pesticide dispersions, and emulsions, resin, dispersions, oil-in-water emulsions, graphite dispersions, cosmetic preparations, and portland cement slurries for cementing oil wells. Attapulgite efficiently thickens aqueous and organic liquids such as lubricating oils, alcohols, ketones, ethers, esters, chlorinated aliphatic hydrocarbons, linseed oil, soybean oil, wax compositions, liquid polyesters, and fire retardants. The binding power of attapulgite is utilized in oil-bonded foundry sands, bauxite granules for sugar refining, molecular sieves, and cosmetic preparations such as rouge and bath powders. In concentrations of 9-10%, modified attapulgite improves compression characteristics and increases the volume of elastometers and polyurethane foams.

Attapulgite has a variety of sorptive uses. It is used to purify oils, fats, waxes, resins, vitamins, brewery products, water, industrial wastes, and sewage by the adsorption of impurities. Attapulgite has been used with success in reclaiming rubber, oils, solvents, fiber from scrap waxed paper and is an excellent adsorbent for radioactive wastes. Allapulgite prevents caking, sticking, and gumming of fertilizers, chemicals, and resins. Attapulgite coatings are used on ammonium nitrate prills for explosives, and conditioning urea with 5-50% attapulgite increases the utilization of urea in animal feeds. The most widely used solid carrier for insecticides, herbicides, and soil fumigants is granular attapulgite. Attapulgite is being developed for use as a filter aid for sugar refining and water treatment. Because of its lack of toxicity and high adsorption, about 10% attapulgite is used in pharmaceuticals, particularly intestinal preparations. In antacid preparations, attapulgite helps control the neutralization rate. Attapulgite is used as an adsorbent for the removal of water, grease, oil, dirt, dust, and odors in factories, farms, canning plants, butcher shops, tanneries, garages, grocery stores, greenhouses, power plants, warehouses, and for litter and bedding for laboratory animals, poultry, and pets. Other sorptive applications include: 5-15% attapulgite in dry-powder fire extinguisher for lithium and other light metals; addition of 5-10% to tobacco to reduce the inhaled tar content; thin coatings as a dielectric capacitator.

Catalytic applications include its use in NCR (no carbon required) paper; in petroleum refining; and chemical processing (polymerization of styrene, depolymerization of isobutylene, carrier in the radiation synthesis of chemicals). The primary uses are for absorbents (65%), pesticides and related products (~15%), oil treatment (~5%), and other (15%).

Epidemiology

There are no epidemiological studies of workers exposed to attapulgite. A mortality study by NIOSH is currently being analyzed and a morbidity study is planned.

An epidemiological study of workers exposed to fuller's earth was conducted in a plant in Olmstead, Illinois (2). The dominant mineral being mined was the silicate montmorillonite. Other constituents in order of abundance were quartz, muscovite (1-2%), glauconite (1-2%), and amorphous silica (≤1%). The amount of quartz in fuller's earth is variable ranging from 0-20% (3)(7). Occasionally albite, sillimanite, staurolite, common hornblende, ilmenite, microcline, kyanite, tourmaline, zircon, rutile, epidote, and leucoxene are also found. Five years prior to the medical survey of the workers, impinger samples were collected. Dust counts were as high as 57 mppcf and as low as 2 mppcf. Chest roentgenograms were available on 49 men. The authors concluded fuller's earth can cause a pneumoconiosis similar to silicosis. The prevalence of bronchial markings of fuller's earth workers seen were 1/4 that seen among soft coal miners.

Unfortunately, this study is difficult to interpret. Aside from the difference in numbers between the text and the table, there is no indication of how the x-rays were classified. No information on the comparison group of coal miners was given (e.g., age, years, exposure), so the validity of the comparison is unknown. It is not known whether symptoms (many present only slight clinical findings) were related to exposure and no smoking histories were available. The x-ray findings were highly correlated with age and apparently not related to exposure. It is also possible that other occupational exposures could have produced the observed effects including exposure to quartz as part of inhaling fuller's earth.

Estimation of Population at Risk and Prevalence of Disease

Probably the only significant exposure occurs in mining and milling. The production of fuller's earth was reported in 9 states with Georgia and Florida accounting for 70% of domestic production. Production from Decatur County, Georgia, and Gadsden County, Florida, is predominantly attapulgite, and employs 400-500 workers. Most of the fuller's earth produced in other areas of the United States contains varieties of montmorillonite and comprises 30% of 1975 production. The total population of workers mining and milling about 1,200 short tons is tons is about 800-1000 workers. The prevalence of disease is unknown.

Pathology

Only four cases of pneumoconiosis from fuller's earth with autopsy have been reported in the literature and all worked in the Nutfield district of Surrey in England (1)(4)(6). The milled product contained 85% montmorillonite and 0.8% quartz. Other constituents were calcite, feldspar, sphene, apatite, barytes, and other miscellaneous minerals. None of these cases showed any evidence of tuberculosis. The main lesions were primarily in the upper lobes and consisted of round, firm (but not hard) black nodules. Aggregations of macrophages were enmeshed in reticular fibers and contained birefrigent particles of montmorillonite, the major mineral in fuller's earth. Mild collagenous fibrosis was sometimes present. The fibrosis tended to be reticular rather than nodular. Particle deposition was most common in the bronchioles and air spaces, though a considerable number also reached the lymphoid tissue. The deposition pattern of montmorillonite particles was intermediate to silica and asbestos, presumably because they are larger than silica particles but smaller and shorter than asbestos fibers. Montmorillonite is less irritant and produces less collagenous fibrosis than silica and asbestos. No quartz was noted in these studies. Emphysema was generally present, but no notice was taken of smoking habits. Exposure was not documented except by types of jobs, although it seems reasonable to assume it was quite high. Exposure duration was lengthy; in three cases it was ≥35 years; in the fourth case it was unknown. Productive cough and dyspnea were of concern only in the last two years before death (in the two cases where symptoms were noted). There were no data on pulmonary function.

MSHA reported two cases of pneumoconiosis related to the processing of fuller's earth in South Carolina (5). Both worked in the bagging and serving area of the processing plant and were exposed to free silica concentrations considerably in excess of the TLV. Total dust levels over an eight hour shift were also high (6.2-49.6 mg/m^3). Respirators had been provided by the company, but they "were not very effective or comfortable," and it was not a company rule that they were to be worn.

The fatal case was a black 40-year-old female who had worked for 5 years, 1 month and had no other dust exposure. The death certificate showed the immediate cause of death as respiratory insufficiency, the underlying cause as pulmonary fibrosis (Hamman-Rich syndrome). The autopsy report listed "extensive pulmonary fibrosis, most likely secondary to silica or mixed dust pneumoconioses and acute Pseudomonas Aeruginosa pneumonia."

The other case was a 40-year-old female who after 6 years employment was awarded 100% disability because of a "chronic restrictive condition which indicated pneumoconiosis." She was originally thought to have tuberculosis.

Although descriptions of the medical status of these two workers is limited, the probable causative agent was the extremely high airborne silica exposures. The role of attapulgite and/or hematite is not known, although attapulgite dust levels were also very high during the working lifetime of these two women.

Clinical Description

Middleton describes five cases of men working on the grinding and sieving of fuller's earth (2). The x-rays of 3 men working 4, 5, and 19 years were normal. The man working 35 years had definite changes, and the man with 39 years exposure had "shadows suggesting nodulation with a linear arrangement," and resembled films of hematite iron-ore miners.

McNally and Trostler also describe 6 case histories of the 49 workers they examined in their cross-sectional epidemiological study and a 7th worker not in the study (2). No mention of symptoms in workers with an x-ray less than grade 4 was mentioned, and no pulmonary function was available on any of the workers. In two cases x-ray changes appeared minimal; exposure times were less than four years. Where x-ray changes were grade 1 and 2, findings indicated exposure and dust deposition rather than any disability. Disability occurred after extensive and lengthy exposure as indicated by extensive opacities on the x-ray.

Appropriate laboratory investigations should include spirometry, chest x-ray, and perhaps DL_{CO}.

Treatment is primarily preventive and should include removal from exposure and cessation of smoking.

Diagnostic Criteria

Diagnosis is made on the basis of x-ray changes and a history of exposure. Diagnosis without an occupational history could be confused with other pneumoconioses (e.g., asbestosis, silicosis).

Methods of Prevention

The greatest hazard from fuller's earth appears to be quartz. Exposure to free silica should be kept below the TLV.

Research Needs

There are no epidemiological studies of workers exposed to fuller's earth. The prevalence of silicosis should be estimated in this population.

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Sepiolite

Definition of Disease

Pleural plaques are a common occurrence. The disease may resemble either asbestosis or silicosis.

List of Causative Agents

Possible: Sepiolite; tremolite and anthophyllite asbestos; quartz.

Probable: ---

Definite: ---

List of Occupations and Industries Involved

The principal fuller's earth deposits other than bentonite and attapulgite is that of sepiolite. The only sepiolite mined is in Spain, although economic deposits have been discovered in Nevada. The greatest hazard is from soil in certain regions of Bulgaria. Meerschaum is the compact variety of sepiolite. The only deposits of potential development in the United States are in Arizona and New Mexico. Meerschaum is easily carved and is used in making pipes, cigar and cigarette holders, and a variety of decorative and ornamental items.

Epidemiology

Burilkov and Michailova found the soil from the yard and field of a family with three pleural plaque carriers contained up to 5% sepiolite (2). Anthophyllite and tremolite asbestos were scarce. The authors suggest that sepiolite was probably involved in the formation of endemic pleural plaques.

In 1970 these authors analyzed soil samples from a tobacco growing region with endemic pleural plaques (region A) and compared it with the soil from another area (region B) without "endemic asbestosis" (1). The rocks of region A were mainly shale, marble, and gneiss with the occurrence of serpentinized ultrabasic rocks containing talc and asbestos. Other minerals included quartz, feldspar, mica, hydromicas, and kaolin.

X-ray diffraction analysis of fibrous particulate revealed kaolinite, montmorillonite, anthophyllite, and tremolite. Sepiolite was found in all samples. The soil in region B was mainly sedimentary rock (conglomerates, sandstone, shale, limestone); the minerals were chiefly quartz, mica, and altered feldspars. No fibrous mineral components were found.

Fluorographic examination of 3,325 persons over 6 years of age in this region of Bulgaria revealed 155 (4.9%) cases of "pleural asbestosis" (5). The radiographic findings included discrete minimal calcifications, clearly defined plaques, and extensive calcified areas. Plaques were nearly always found on the diaphragmatic and mediastinal pleura. Symptoms of chronic cough, expectoration, and chest pain were rare; some patients complained of dyspnea and lassitude at work. The prevalence of plaques was less than 1% in the 20-29 year age group, and increased steadily to over 50% in the 70-79 year old group.

The prevalence was slightly lower in females than males, but the rate of increase with age was similar for the two sexes. The results of the physical examination, blood sedimentation rate, leucocyte count, and tuberculin test on the persons with abnormal fluorograms were not reported. Spirometry was apparently not performed. No information was provided on the association of symptoms with radiographic findings, although it may be inferred that disability was slight and that there were few symptoms. Whether sepiolite was the causative agent remains speculative as asbestos was also present in the soil.

Estimate of Population at Risk and Prevalence of Disease

The population at greatest risk are persons in Bulgaria where the soil contains serpentine rock and where the prevalence of pleural plaques is 5% (but over 50% in older age groups). Industrial exposure is to meerschaum. The prevalence of disease is unknown, as well as whether this compact variety of sepiolite is even causing disease. The population exposed to meerschaum is small, and essentially zero in the United States.

Pathology—No reports.

Clinical

Sepiolite, in one case, has been cited as causing "silicatosis" which appeared on the x-ray as diffuse shadowing (4). *In vitro* experiments showed that sepiolite (and palygorskite) increased acid phosphatase, and decreased lactic acid production in rat macrophages to a greater extent than did chrysotile, actinolite, antigorite, and crocidolite. The hemolytic effect was also greater than the asbestos dusts. Intratracheal injection of 40 mg sepiolite killed 3 rats, whereas antigorite had little effect (3). While the relation between cytotoxicity and hemolysis is not known, it does show that in this system sepiolite is even more potent than asbestos.

Diagnostic Criteria

Pleural plaques and calcification, particularly on the diaphragmatic and mediastinal pleura are characteristic. These pleural changes are similar to those seen in asbestosis.

Methods of Prevention

The etiologic agents are in the soil, and so the total population is exposed. Reducing cultivated crops (e.g., tobacco) and growing more cover crops might reduce dust exposure.

Research Needs

Sepiolite is a general product of weathered serpentine rock and cannot be seen under the light microscope. It is important to know whether the serpentine rock mined or quarried in this country contains sepiolite (and asbestos), and if so, whether pleural plaques are occurring as a result.

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Mica Group

Mica

Like the montmorillonites, micas are also based on the structure of pyrophyllite or talc. However, they are different from montmorillonites in that layers of mica cannot be expanded by water (changed) other than by decomposition. There are three important groups of micas: muscovites, lepidolites, and biotites. Muscovite is a wide-spread and common rock-forming mineral and is common in granites, granite pegmatites, metamorphic rocks. Sericite is a variety of muscovite and occurs as fibrous aggregates of minute scales and is usually an alteration product of feldspar. Paragonite occurs with muscovite and is physically indistinguishable from it. Only muscovite and phlogopite are commercially in demand. Lepidolites and biotites have no commercial use.

Definition

Exposure to mica can produce radiographic changes consistent with pneumoconiosis, but the fibrotic changes may be due to silica and/or asbestos.

List of Causative Agents

Definite: Mica
Probable: Silica
Possible: Asbestos

List of Occupations and Industries Involved

The term "mica" refers to a family of minerals of similar chemical composition and to some extent, physical properties. The predominant minerals are potassium aluminum silicates with variable amount of magnesium, iron, and lithium. The better known members of the mica group include muscovite, phlogopite, biotite, and lepidolite. Only muscovite and phlogopite are used commercially.

Deposits of sheet mica in the United States that can be economically mined are found in pegmatites composed primarily of feldspar, quartz, and mica and often with accessory minerals such as garnet, tourmaline, and beryl. Scrap and flake mica is found in granitic rock known as alaskite and is also recovered as a co-product from the production of clay, feldspar, and spodumene.

Sheet mica has excellent electrical and thermal insulating properties which are the basis for its major uses. Historically, sheet mica was used as a thermal window in stoves and shades for oil lamps, as an insulator for early electrical apparatus such as generators and motors, and for vacuum tubes and capacitors. Mica has been used (and in some cases continues to be used) as a liner for gauge glasses for high pressure steam boilers, in the production of small-size heating equipment, as diaphragms for oxygen-breathing equipment, as quarter-wave plates for optical instruments, and as a base for platinum wire resistance thermometers, stove windows, phonograph diaphragms, and lamp chimneys.

Some scrap mica is made into mica paper for electrical insulation. The remaining scrap and flake mica is ground up and used in oil well drilling mud; as artificial snow and flocking material on Christmas ornaments and display materials; as decorative finishes on concrete, stone, and brick; in the manufacture of roll roofing and shingles; as protective coating on welding electrodes, wire, and cable; as a filler to improve the physical properties of asphalt products, pipeline enamels, mastics, cements, adhesives, texture paints, acoustical plaster, ceiling tile, concrete block fillers, and wallboard joint cements.

Finer particle size mica is used for lubrication and mold release in the manufacture of rubber products and in the manufacture of paints and plastics. Some talcum powders also contain mica (1).

Of the mica sold or used by U.S. producers, 2% was sheet mica, 53% was scrap and flake mica, and 45% was ground mica.

Epidemiology

Dreessen et al. conducted a cross-sectional study of 57 men exposed to mica dust almost completely free from quartz, 31 men and 78 women fabricating sheet mica, and 741 men mining pegmatite and sorting it into its constituents of mica, quartz, and feldspar (3). There were no cases of pneumoconiosis in the 109 men and women fabricating sheet mica. All average dust concentrations were less than 3.2 mppcf. The first and third group were combined "because the relation of silicosis to pegmatite-dust concentrations and the relation of pneumoconiosis to mica-dust concentrations seemed to be much the same, and because mica is a constituent of pegmatite dust."

The probability of finding pneumoconiosis in the 57 mica-exposed men and 741 pegmatite-exposed men working for comparable lengths of time, approximately doubled with each twofold increase in dust concentrations above 10 mppcf. No cases of pneumoconiosis were observed in workers exposed to less than 10 mppcf. The number of years before pneumoconiosis occurred was 15 to 19.9 years when average exposure was 10-14 mppcf, 10 to 14.9 years when average exposure was 25-49 mppcf, and 5 to 9.9 years when average exposure was ≥50 mppcf.

The most characteristic x-ray finding in the mica-induced pneumoconiosis was a fine granulation of uneven density that was not readily observed until the usual linear pulmonic markings were more or less obliterated. They were mostly localized in the middle or lower thirds and resembled x-rays of workers in the dry breakers of anthracite mines exposed to dust of low quartz content in concentrations between 200 and 300 mppcf. The markings in the mica-induced pneumoconiosis were qualitatively different from classical silicosis, with a tendency for coalescence of shadows in some cases.

The results of this study indicate that exposure to greater than 10 mppcf of the silicate mica can result in a pneumoconiosis that is distinct from silicosis. Dyspnea, cough, weakness, loss of weight, diaphragmatic fixation, rales, and abnormal breath sounds increased with increasing fibrosis.

Vestal, Winstead, and Joliet, in a cross-sectional study examined 1,121 men employed in the mica industry in western North Carolina (19). Environmental dust counts in grinding and in the underground mines were sometimes as high as 1 billion particles per cubic foot! The population was divided into four groups: (1) a comparison group of 222 with no mining experience; (2) a comparison group of 443 who had worked in mining or mineral grinding of feldspar, iron, copper, asbestos, kaolin, etc., but not mica; (3) 456 men with any exposure to mica—on the average, 54% of their exposure time was to mica and 46% was similar to the second group; (4) a subset of the third group comprising 79 men with no mining experience or silica exposure, who had worked only in mica grinding plants. Mica exposure was presumably quite high. The prevalence of pneumoconiosis in each group was 0%, 5%, 9%, and 11% respectively. The percent pneumoconiosis increased with age and years worked in mining, and the rates were higher in the third group with (any) mica exposure than in the second group with no mica exposure. Whether this was due to the mica, however, cannot be evaluated because the mica group had also worked longer (almost twice as long) in all mining, even though they were the approximate same age. Thus, the mica group had more overall exposure to dusts that could cause pneumoconiosis.

Group 4 (exposed to mica without free silica) appeared to have a higher prevalence of pneumoconiosis than did group 3 (exposed to mica and quartz). A direct comparison cannot be made between these two groups, however, because the age grouping of the "clean mica" group was not available. Results from the fourth group, exposed only to mica, showed that working in plants grinding mica, could result in chest x-ray changes in a relatively short time. The severity of the changes and whether there was associated disability are unknown. Information on symptoms, spirometry, and smoking history were not obtained. Environmental levels were very high (nearly as high as 50 times the recommended standard of 20 mppcf). It is thus not possible to estimate the hazard of mica at lower exposure levels.

Smith examined 302 men making mica insulators (18). A number of the operations were "dusty," including sawing, sanding, and drumming of the insulators. No pneumoconiosis was observed, but 5 workers (1.6%) had pleural calcification. No exposure data were available.

Heimann et al. examined 329 male mica miners in India (7). The mica in the Bihar mines was in pegmatites that ranged in content from almost pure feldspars to almost pure quartz. Nine random samples of drilling revealed a free silica content ranging from 11% to 67%, with a median of 42%. Minor minerals such as tourmaline, beryl, and garnet were also present. Some mines were dry, others moist; some used dust control and some did not. The mean exposure (mppcf) at different jobs in dry rock ranged from 7 to 1,000 mppcf, and from 5.3 to 600 mppcf in moist rock. There was a decided dose-response effect, with the severity of the x-ray changes increasing with the dose. The dustiest job was that of pneumatic drilling without control. The rate of silicosis among the 177 miners who had never done such drilling was 25%, whereas 44% of the 152 who had done pneumatic drilling without control had nodular or conglomerate silicosis. The rate of nodular or conglomerate silicosis was 40% in those who had worked as drillers for less than 6 years (n = 51), 67% in those who had worked 6-10 years (n = 14), and 100% in the 2 workers with more than 10 years as a driller. Roentgenographic and clinical data revealed that 18.6% of the miners had pulmonary tuberculosis. These same authors also examined 61 workers who processed only muscovite mica containing less than 1% free silica (7). The exposure of most workers average 10 mppcf (2-21 mppcf range); dust concentrations in the job of sizing mica splittings (sieving) average 40 mppcf (6-130 mppcf range), and the averaged exposure in the job of pulverizing scrap mica into powder mica was 135 mppcf (44-300 mppcf range). Mean exposure for the entire group was 360 mppcf (range = 50-1440). Most of the workers had exposure for less than five years. None had conglomerate silicosis, although 44% had x-ray changes suggestive of an occupational effect.

It would appear from these two studies that mica in the absence (less than 1%) of free silica is not as likely to produce nodular or conglomerate fibrosis on x-ray as mica containing significant amounts of silica. The accumulated time of exposure was short in the second study, however, and so it is not possible to determine whether nodular or conglomerate fibrosis would develop with higher and/or longer exposure to mica in the absence of free silica. It does appear that relatively short exposure times can produce x-ray changes. There is no indication in either paper about disability, pulmonary function, symptoms, or smoking.

Mica can cause pneumoconiosis in exposed workers. In some cases the latency is short, i.e., within five years. The epidemiological studies have been confined to x-ray changes, so there are very few data on the relation of x-ray changes to symptoms and pulmonary function. Even the x-ray changes have been poorly described, and cannot be compared to present-day classification systems. There is no information on smoking in any of the studies. Quartz and other silicates are commonly associated with mica exposure for the miner. Thus, other exposures to fibrogenic minerals confound the analysis of dose-response relations. This is less true in processing where the exposure is to relatively pure mica. The interaction of tuberculosis and mica in producing fibrosis is not known, but tuberculosis does not seem to be as important as it is for silicosis.

Sericite

In 1933 Jones attempted to show that sericite, a variety of muscovite mica, was the cause of silicosis. Muscovite occurs as platy crystals and scales, whereas sericite occurs as minute scales and as fibrous aggregates.

Hurlbut and Beyer compared the silica and sericite content in dust from two foundries located in the same town (8). Foundry A had had more than a score of deaths due to silicosis and silico-tuberculosis. Foundry B had no silicosis claims over the same period. The characteristics of the two foundries were similar except that foundry A used fine "facing" sand that was not used by foundry B. One of these facing sands made up 7% of the molding sand and over 75% of the total number of particulates in this sand were sericite; all of it was of respirable size. This study supports the conclusions of Jones (9). Unfortunately no data on x-ray findings were given.

Several animal and *in vitro* studies support the view that sericite cause fibrosis. Drinker, Field, and Drinker observed changes in lymph nodes injected with sericite that were similar to the changes produced by silica (4). Policard observed that phagocytes exposed to mica dust behaved like phagocytes exposed to dusts of rock containing quartz and various silicates (including sericite) (16). In both studies needle-like mica particles were seen in the plaques. Cummins observed similar changes (2).

Intratracheal injections of ground-up sericite in animals did not produce a fibrotic response resembling that produced by quartz (5)(12). No pictures were provided, but the fibrous nature of the sericite may have been destroyed. King, Gilchrist, and Rae showed that if the sericite or mica were pre-treated with sodium chloride, it would produce a fibrotic reaction when injected into the trachea of white rats, but would not do so when untreated (10).

Despite the prevailing dogma that free silica is the causative agent in silicosis, Jones' theory deserved further investigation. The negative findings in several animal studies (all intratracheal injection) of ground-up sericite are not sufficient reasons to drop Jones' idea, particularly in the face of positive data on human subjects.

Estimate of Population at Risk

MSHA estimates that in 1978 there were 72 open pit miners, 267 workers in preparation plants, and 43 office workers, or a grand total of 382 workers involved in the mining and processing of mica. The number exposed may be larger, however, as sheet mica (from North Carolina) was not mined as the primary product. Scrap and flake mica were produced from the beneficiation of pegmatite ores, clay deposits, and weathered pegmatite and schist areas. The prevalence of disease among current workers is not known.

Pathology and Clinical Description

Middleton described a study by Ferguson of 12 workers exposed to mica dust (13). Five of the 12 had worked for more than 5 years, and 4 of the 5 had slight symptoms of cough and dyspnea. The fifth man had more severe cough and dyspnea, "well-marked" pulmonary fibrosis, and emphysema. Another man employed 8 years had "quite definite fibrosis." Chest x-rays of 2 of the 5 men revealed "increased hilum shadows with increased linear striation and fine diffuse shadows in the middle zones." The chest x-ray of another man employed 32 years "showed fibrosis, largely peribronchial in type, chiefly in the middle zones, with increased hilum shadows, and at one or two points, nodule formation." Ferguson tentatively concluded that mica dust may be capable of causing pulmonary fibrosis. No information was given as to exposures other than mica.

Dreessen et al. described two cases of pneumoconiosis due to mica (3). One was a 55-year-old white male who had worked for 24 years in a mica grinding plant with a weighted average dust exposure of 50 mppcf. He had had slight dyspnea the year prior to examination. Breath sounds were diminished over all portions of the chest and there was slight restriction of diaphragmatic movement. The x-ray revealed diffuse ground-glass appearance, most pronounced at the bases, and obliteration of the left costophrenic sulcus. The other case was a 51-year-old white male who had worked in a mica mill for 10 years and a mica mine for 10 years. His estimated weighted dust exposure was 20 mppcf; he had some quartz and pegmatite exposure as a miner. He had no symptoms. His x-ray showed second-degree diffuse granular appearance, shallow left costophrenic angle, and pleural thickening in the extreme left apex.

Vorwald described a case of "chronic proliferative pneumonitis" in a rubber worker who was exposed to dusting powder (20). After about 30 years, he developed progressive shortness of breath and a bilateral "pronounced diffuse increase in linear markings, particularly in the lower portions of the upper lobes." Autopsy revealed diffuse, widespread pigmented fibrosis, emphysema, and some "irregular massive lesions." Tracheobronchial lymph nodes were mildly pigmented, small, and soft. The pigmented crystals were mainly biotite mica; some could have been talc. No free silica was found. Whether the mica caused the fibrosis would not be determined because of the probability of other fibrogenic agents in the occupational environment.

Kleinfeld described two cases of silicatosis in individuals exposed to muscovite mica. One had symptoms, reduced lung function, and an x-ray abnormality while the other did not. Both had pleural calcification (11).

Pimentel and Menezes reported a case of a 46-year-old woman who for 7 years was exposed to mica dust during grinding and packaging operations (15). Dyspnea on exertion, progressive weakness, and loss of weight appeared after a "common cold" and five years exposure. After 7 years exposure, physical examination revealed fine crackles in both lungs and an enlarged liver. The chest radiograph showed some nodular densities in the LLL and bilateral reticulomicronodular shadows. Diffusion capacity and FVC were reduced, and there was hypoxemia and hypocapnia. Three years later the patient died in respiratory failure. On autopsy the lung showed extensive areas of diffuse fibrosis, emphysematous foci, and honeycombing with a proliferation of histiocytes and fibroblasts and the formation of reticular and collagen fibers. Within the thickened interalveolar septa of the lung were identified plate-like crystals of muscovite mica; dark brown or black material in the lesions were not identified. Sarcoid-like granulomas in the liver also contained crystals (mica) and dark brown inclusions. There was no history of exposure to other dusts or other respiratory diseases, and no other contaminants were found.

The findings in mica pneumoconiosis are similar to other pneumoconioses; i.e., restriction and shortness of breath, and reduced diffusion. X-ray findings are of a diffuse fibrogenic pneumoconiosis.

Appropriate laboratory investigations should include spirometry and chest x-ray.

Diagnostic Criteria

Criteria for diagnosis should include: history of exposure of ≥5 years; chest x-ray with reticular nodular shadows; restriction and reduced diffusion.

The disease may be confused with sarcoidosis.

Methods of Prevention

Reduce exposure.

Research Needs

The prevalence of disease among present-day workers is unknown and should be determined.

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Hydrous Micas and Illites

These are micas of secondary origin. They contain silicates of potassium, aluminum, iron, and magnesium with water. The terminology of the group is not well established, being variously called illites, hydromica, hydrous micas, hydromuscovite, and hydrated micas. These minerals are the predominant alkali-bearing constituents of many sedimentary clays, shales, and fireclays. The illites are secondary minerals, which commonly occur in clays; they are not mined as minerals.

Vermiculites

Vermiculites are ferromagnesium aluminum silicates that exfoliate to a low density material when heated. In its natural state vermiculite resembles mica in that it splits readily into thin, flexible, but inelastic laminae. The space between layers can be penetrated by electrostatically neutral molecules, such as water. When heated rapidly, the water between the layers turns to steam, and the vermiculite expands into worm-like pieces. The increase in bulk volume is 8-12 times.

Definition

No described disease entity. If disease does occur, it would be pneumoconiosis.

List of Causative Agents

Definite: ---

Probable: ---
Possible: Asbestos

List of Occupations and Industries Involved

Vermiculites have no exact formula or composition but are families of related minerals, mainly hydrated magnesium silicates. The term vermiculite has been applied to the columinous, bloated products of calcined and bleached phlogopite. Most of the uses of vermiculite are for the expanded form, and 80% of this is in construction (loose fill insulation, treated granules for insulation of masonry walls, lightweight aggregates combined with setting materials such as gypsum, asbestos, portland cement, acoustical plaster formulations, components in rigid board or tile products). Nonconstruction uses include a carrier for fertilizers and agricultural chemicals, soil conditioner; industrial uses include cryogenic insulation, insulation of appliances, coolers, safes, insulating component in prefabricated chimneys, oil-less lubricant, aggregate in refractory components, slow cooling of steel, cushioning material in packaging applications, insulation of underground steam or hot water lines, window display material, grease or oil absorbent, sound-deadening applications, nuclear waste disposal, and animal litter. Vermiculite is particularly important as a potential substitute for asbestos.

Epidemiology

Brooks and Lockey, in a preliminary report of workers exposed to vermiculite containing tremolite-actinolite asbestos, identified benign pleural effusion and possibly a high prevalence rate of pleural and parenchymal lung disease. They suggest the adverse health effects are a result of the asbestos contamination rather than the vermiculite itself. There are 2 animal studies that report effects of vermiculite. Hunter and Thomson exfoliated and ground South African vermiculite so that the majority (97%) of the particles were less than 20 mμ (3). Twenty-five mg of vermiculite were injected into the pleura of 50 rats. There was no disturbance of growth rate or survival over the 104 days of the study. The rats injected with vermiculite were similar to the control saline injected rats except for the presence of pleural adhesions and abscesses which were observed in rats injected with vermiculite. This was attributed to accidental infection during the injection and exacerbated by the presence of the foreign material. No lung tumors were observed in either the control or vermiculite injected rats.

Goldstein and Rendall injected rat tracheae with South African vermiculite containing 1.4% quartz and serpentine, apatite, calcite, and magnetite as minor constituents. (Dose was 600 sq cm/ML and 50 mg/ML) (2). Four months later, the degree of fibrosis was evaluated on a scale of 0-4, where 4 was a relatively acellular collagenous fibrosis produced by quartz. In grade 1 fibrosis the lesions were cellular, with some loose reticulin but no collagen. The vermiculite exposures produced a grade of from 0 to 1.

Thus, on the basis of animal studies, the vermiculite does not appear to produce tumors (as did asbestos) or fibrosis (as did quartz).

Estimate of Population at Risk and Prevalence of Disease

There are 2 major producing deposits in the United States. The Montana deposits contain biotite, several amphiboles near hornblende in composition, and apatite in some areas. The South Carolina deposit contains the accessory minerals feldspar, actinolite, tremolite, hornblende, and quartz with minor amounts of apatite, zircon, magnetite, and talc. Some vermiculite contains significant proportions of fibrous tremolite and chrysotile (1). Three-hundred sixty-five thousand tons were produced in the United States in 1973. In 1978, an estimated 101 open pit miners, 215 workers in preparation plants, and 66 office workers were employed in the vermiculite industry. The occurrence and prevalence of disease are unknown. An oral communication without details or documentation reports a prevalence of 20% abnormal x-rays in an asbestos-contaminated vermiculite mine in Montana.

Pathology — No reports.

Clinical Description — No reports.

Diagnostic Criteria

The criteria for pneumoconiosis should be used on chest x-ray and spirometry. The presence of asbestos and/or quartz as contaminants could produce a disease similar to asbestosis and silicosis.

Methods of Prevention

Keep exposure to silica and asbestos below standards.

Research Needs

There are no studies on the effect of either expanded or nonexpanded vermiculite in human populations. A prevalence study should be conducted in populations exposed to both types of vermiculites, particularly in light of the potential for increased use as an asbestos substitute.

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FRAMEWORK STRUCTURES

This group is important because nearly ¾ of the rocky crust of the earth is composed of these minerals, which are stable and strongly bonded.

Silica Minerals (SiO_2)

The silicon dioxide group of silica has the simplest structure, but even in this group there are at least 9 different possible structural arrangements and, therefore, 9 different polymorphs. Quartz, tridymite, and cristobalite are the three principal crystalline polymorphs of silicon dioxide and can be transformed from one to the other under different conditions of temperature and pressure.

Cryptocrystalline varieties may be divided into fibrous and granular. A general term for the fibrous varieties is chalcedony; the varieties of chalcedony include carnelian, chrysoprose, agate, onyx, heliotrope. Granular varieties include flint, chert, and jasper. All of these varieties can contribute to the "free silica" rock. If silicon dioxide is part of the structure of a silicate, it is not free silica but is known as combined silica. The fibrogenic potential of free silica is considerably greater than that of combined silica. When the chemical analysis of a rock gives "total silicon dioxide," the contribution of free and combined silica is not known. Free silica will be discussed later.

Quartz, when present as a contaminant (greater than 1%) with other inorganic dusts, may increase the effect of the associated dust, at least for coal and iron ore (2). The presence of other cations in the quartz structure (e.g., aluminum, iron) reduces the biological activity of quartz (2). The relation of quartz to other silicates and their fibrogenic potential should be investigated.

Minerals Isostructural with Silica Minerals

Nephelite is a mineral structurally similar to tridymite. Nephelite is used extensively in the ceramic industry as a substitute for feldspar. It is a by-product of apatite mining in Russia where it is also used in leather, textile, wood, rubber, and oil industries. It is the commonest of the feldspathoid minerals and will be discussed there.

Feldspars

Feldspars are the most important of the mineral groups as they are the most abundant minerals of igneous rocks. There are two major groups of feldspars: (1) the potassium feldspars based on orthoclase, and (2) sodium-calcium feldspars (plagioclase group) which form a series from albite and anorthite. The common feldspars are solid solutions of these three components.

Granite is a granular igneous rock containing quartz, much feldspar, and most of the time, smaller amounts of mica (biotite and muscovite), hornblende, and pyroxene. The complete series ranges from granite (feldspar, almost entirely potash varieties) to granodiorite (feldspar, mostly plagioclase). The boundary is arbitrarily set such that granites contain more potash feldspar than plagioclase, and the reverse is true for granodiorites. The quartz content averages greater than 25% and presents the greatest risk to health. Since silicosis is the health hazard from granite, it is discussed in the chapter on silicosis.

Feldspathoids are chemically like feldspars in that they are alumino-silicates of sodium, potassium, and calcium. However, they contain two-thirds less silica than the corresponding feldspar. The most common feldspathoids are leucite and nepheline. Leucite is a natural potassium-aluminum silicate found in certain recent lavas but never in rocks containing quartz. Although not presently mined, it is a possible source of potash.

Nepheline (nephelite) contains microcline, orthoclase, oralbite, feldspars, nepheline, and ferromagnesium minerals (principally hornblende, pyroxene, biotite). Commercial deposits contain at least 20% nepheline, 60% feldspar, and usually less than 5% accessory minerals. The most common accessory minerals are magnetite, ilmenite, calcite, garnet, zircon, and corundum. Quartz is not present.

Feldspar

Definition

No described disease. If present, it would be pneumoconiosis, and because of the free silica content, would resemble silicosis.

Causative Agents

Definite: Free Silica

Probable: —

Possible: Feldspar may neutralize effect of quartz.

List of Occupations and Industries Involved

Feldspar (or "spar") is composed of three silicate minerals: microcline or orthoclase, albite, and anorthite. Feldspar is used as a flux and a source of alumina in the manufacture of glass, porcelain enamel, and ceramic products (pottery, plumbing fixtures, electrical porcelain, ceramic tile, dinnerware, art pottery). Finely ground feldspar can be used as a filler in latex, paint, methane, and acrylics. About 65% is used in the glass industry, 30% in ceramics and 5% in fillers and other applications.

Feldspar is obtained primarily from granite and pegmatitic rock, with quartz and mica being the other principal constituents. Other accessory minerals include sand, beryl, spodumene.

Epidemiology—No studies

Estimate of Population at Risk and Prevalence of Disease

In 1978 there were 5 underground feldspar mines, 75 open pit miners, 250 workers in preparation plants, and 41 office workers for an estimated grand total of 371 workers employed in mining and processing feldspar. The prevalence of disease is unknown.

Pathology

Rotter and Gartner described a case of a worker with extensive tuberculosis exposed to feldspar containing 38% to 45% quartz with many of the particles being less than 5 μm (6). Nodules were like those found in silicosis but were more widely disseminated. There was less collagenous tissue and reticular fibers than in silicosis. They hypothesized that aluminum, potassium, sodium, and calcium ions had leaked into solution and exerted a neutralizing effect on the quartz.

Animal experiments (intratracheal and intraperitoneal) showed that feldspar produced a less fibrogenic reaction than did quartz (1)(4)(7).

Meiter and Toering and Nagelschmidt observed that feldspar may act like quartz because alkali feldspar has a crystal structure similar to quartz (3)(5).

There is very little published information on the effects of feldspar in humans. Animal experiments show little fibrogenic activity from feldspar. Quartz is always associated with feldspar exposure, and the risk is from quartz, with feldspar perhaps providing a diluting or neutralizing effect.

Clinical Description—No reports.

Diagnostic Criteria

If disease occurs, it is similar to silicosis.

Methods of Prevention

Keep silica exposure below the standard.

Research Needs

The prevalence of disease among feldspar miners and millers is unknown and should be determined.

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Nepheline

Definition

No recognized disease entity.

List of Causative Agents

Definite: ---
Probable: ---
Possible: Feldspar, mica

List of Occupations and Industries Involved

Nepheline syenite is a crystalline rock consisting of the feldspars albite and microcline; it contains no free silica. The principal ferromagnesium minerals present are hornblende, pyroxene, and biotite. The most common accessory minerals (usually less than 5%) are magnetite, ilmenite, calcite, garnet, zircon, and corundum. Nepheline syenite is used in the manufacture of glass products (container glass, fiberglass, opal glass, plate glass, sheet glass, tableware glass), whiteware (dinnerware, sanitary ware, floor and wall tile, electrical, chemical and dental porcelain, art pottery, porcelain balls, mill liners), extender pigment and fillers (interior and exterior latex and alkyd paints, traffic paints, metal primers, exterior wood stains, sealers, undercoats, hardboard ground coats, PVC, epoxy and polyester resins systems, foam carpet backing). In the USSR, it is also used to manufacture alumina for aluminum, sodium and potassium carbonates, and portland cement. There are two mines in the United States (in Arkansas), and the rock from these mines is used only for construction aggregate and roofing granules.

Epidemiology—No studies

Estimate of Population at Risk and Prevalence of Disease

As there are only two operating mines in the United States, the mining population is quite small. Nepheline used for other purposes is imported primarily from Canada. The prevalence of disease is unknown.

Pathology and Clinical Description

Barrie and Gosselin reported a case history of a man exposed to massive quantities of Canadian nepheline rock (1). He worked for four years at a mill where hematite was removed from finely powdered nepheline. The dust was dry and exposure was "extremely high." In his fourth year of work he noticed increased dyspnea. Two years later he was found to be easily cyanosed on exercise and to have increased peribronchial markings on x-ray. Pulmonary function (ventilation, lung volume, gas mixing) were within normal limits, and there was a moderately severe reduction in diffusion. The effects of exposure were complicated by a duodenal ulcer existing prior to exposure, and Cushing's Syndrome that began while exposed to nepheline dust. Four years after cessation of exposure he had three bouts of pneumonia. He was believed to have died of respiratory failure. Deposition and associated pathological changes in the lungs were related to the amount of dust accumulation in the lung. In a small portion of each lung there was slight deposition with dust in phagocytes, normal alveolar walls and bronchi, diffuse emphysema, and no collagen but an intercellular net of argyrophil fibers. Where there was abundant dust accumulation encircling the mouths of alveolar dusts, atria, and alveolar sacs, there were occasional collagen fibers and a more pronounced argyrophil network, manifested by progressive involvement of the smallest and some of the larger pulmonary arteries by the argyrophil net, fibrous thickening of intima, and pigment penetration of vessel walls. Where there was massive dust accumulation, the pathological changes were similar, with the addition of intra-alveolar exudates of fibrin and branching plugs of connective tissue extending as far as the respiratory bronchioles. The plugs contained dust which was both in and out of macrophages, and there were many coniophages mixed with fibrinous exudate. In addition, small pulmonary arteries were frequently occluded and there was some focal necrosis and cavitation. Small particles and acicular crystals were both observed. The authors suggested that the fibrosis and massive pneumoconiosis were caused by the acicular crystals. The massive pneumoconiosis differed from anthrosilicosis and fuller's earth pneumoconiosis in that the area of consolidation was white, and lesions were in the lower lobes.

Because there is probably no milling of nepheline in this country, there are unlikely to be exposures of the same magnitude. The authors commented on the relatively small amount of fibrosis, which may have been related to the cortisone treatment for Cushing's Syndrome. The disturbances in both function and structure of the lung were quite small considering the amount of dust deposition. Thus nepheline would appear to present little hazard at low dust levels.

Diagnostic Criteria

The criteria for diagnosis should be the same as for pneumoconiosis.

Methods of Prevention

Hazard appears to be low. Disease will be prevented if exposures are not excessive, but the standard should probably be less than for nuisance dust.

Research Needs

There is little data on the hazard for nepheline. In the United States, the number of people with high exposure is not large, and exposure among secondary users is probably not significant.

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Zeolites

The zeolites are a large group of hydrous silicates with aluminum, sodium, and calcium as important bases. The gross composition of zeolites resembles that of feldspars. Zeolites have the important (commercial) property of reversible selective adsorption. Today, any aluminosilicate with this property is referred to as a zeolite, as well as clay minerals and synthetic organic ion exchange resins.

Synthetic zeolites have many advantages over natural zeolites for use as molecular sieve adsorbents and exchange and catalytic processes; they have been produced commercially since the early 1950's. In this country natural zeolites have had only limited use.

Definition

Pleural thickening and calcification and pleural mesotheliomas are associated with persons living in regions where the soil contains erionite zeolites.

List of Causative Agents

Definite: ---
Probable: Erionite
Possible: Asbestos

List of Occupations and Industries Involved

Zeolites are crystalline, hydrated aluminosilicates of sodium, potassium, magnesium, calcium, strontium, and barium. Natural zeolite can occur as a fibrous or nonfibrous form; fibrous forms include erionite and mordenite. Ferrierite and phillipsite are sometimes fibrous. Present and potential uses include the following: drying cracked gas, ethylene, butadiene, ethanol, natural gas; liquid paraffins, and solvents; CO_2 removal from natural gas; n-paraffin recovery from naphtha and kerosene; aromatic separation; dimension stone; pozzolanic cements and concrete; lightweight aggregate; filler in paper; concentration and isolation of radioactive wastes; extraction of ammonia from sewage and agricultural effluents; enhance nitrification in activated sludge processes (sewage treatment); production of high-purity oxygen for secondary-smelting operations, river and pond aeration; pollution control in paper and pulp industries; dietary supplements for swine and poultry; neutralization of acidic soils; agglutinizing agents for mixed fertilizers; carriers for fungicides and pesticides; removal of SO_2 and other pollutants from stock gases of oil and coal-burning power plants; sorbent in oil-spill cleanups; purification of natural gas; heat exchangers in solar radiation for air conditioning and water heating; control of moisture content of animal manure odor; soil conditioner; polishing agent in fluoride-containing toothpaste; drying HCl, chlorine, reformer hydrogen, petroleum solvents; catalyst on catalyst carriers in reactions (such as hydrocracking, hydroisomerization, alkylation, and reforming in the petroleum industry); methane recovery for synthetic fuel production.

Epidemiology

Boris et al. investigated pleural mesotheliomas and chronic fibrosing pleurisy together with the environmental conditions in the small village of Karain, Turkey (3). There were no deposits of asbestos in the area and volcanic rock samples contained calcite, feldspar, quartz, volcanic glass, biotite, chlorite, muscovite, and augite. A more recent report described finding respirable fibers (5-70 μm long) or erionite type zeolite in rock samples, street and field soil, and water (1). The erionite fibers were apparently found only in Karain and not in the neighboring villages 4 and 7 km away. The volcanic rock is used as a building stone, making stucco to plaster the walls, for clearing wine, and making sweetmeat. In the summer, most of the villagers help grow potatoes and onions and are exposed to the dust from the area between the river and the village, as well as dust from the road, which is unpaved. Over the period 1970-1974, 24 of 55 deaths (44%) were due to pleural mesothelioma, and in 62% of the cases, the cause of death was due to malignancy. In 1974 neighboring villages with about 11 times the population of Karain had no deaths due to pleural mesothelioma compared to 11 for Karain. In 1975-1976 there were 16 cases of pleural disease in 8 men and 8 women with ages ranging from 27-65 years. All had chest pain and breathlessness.

In Tuzkoy, Turkey, 312/1126 of the persons over 25 years of age were randomly selected and given chest x-rays (2). The prevalence of abnormalities were as follows: 16% calcified pleural plaques, 10.5% pleural thickening, and 12.5% fibrosis. Of those with pleural thickening, two were later diagnosed as malignant pleural mesothelioma and one as chronic fibrous pleuritis. Erionite type zeolite fibers of respirable size were found in the rock samples, street and field soils of Tuzkoy, but not in the village of Kizilkoy, 5 km away. None of the chest abnormalities seen on x-rays in Tuzkoy were found in Kizilkoy.

Surveys of many villages in several regions of Turkey have revealed a prevalence of calcified pleural plaques ranging from zero to as high as 14% (2)(6). There were also some cases of chronic fibrosing pleuritis and malignant pleural mesothelioma. Some villagers with pleural disease lived in villages which had asbestos deposits; some did not. The asbestos observed in the stucco was mainly tremolite (and chrysotile, actinolite, and anthophyllite in some areas); in other areas, mica, talc, limestone, kaolin, and other silicatous minerals were also found along with tremolite asbestos.

Yazicioglu attributed the calcified plaques to chrysotile asbestos (7). Boris et al. originally thought asbestos was causing the mesotheliomas in Karain and elsewhere, despite the absence of asbestos in the rocks, soil, and water (and tissue) (1)(3). Boris, Artuninli, and Sahin now argue that both the mesotheliomas and calcified plaques may be caused by the fibrous zeolite, erionite (2). This thesis is based on the presence of erionite in at least some of the areas where the pleural changes are endemic, and where asbestos may or may not be present. Environmental factors (albeit unknown) other than asbestos have been associated with a high prevalence of pleural plaques (5). Thus, finding pleural plaques is not necessarily a sign of asbestos exposure.

There is little doubt that there is an endemic of pleural findings and, of particular concern, of mesothelioma in two villages in Turkey. The actual prevalence and incidence may differ from the percentages presented since the methods for calculating rates appear subject to bias (in some cases they are not random selections; in others it is not clear how the surveys were conducted). The more important deficiency in these studies involves assessment of exposure. There are no quantitative estimates of the presence of zeolite, asbestos, and other minerals in the air, soil, and water, although samples have apparently been analyzed for these minerals in some areas. To determine the etiology of these pleural changes, a comprehensive evaluation of the environment where the medical surveys are being conducted is needed.

While the studies in Turkey have not "proven" fibrous zeolites may be carcinogenic and have an effect on the pleura similare to asbestos, they provide plausible evidence. Erionite zeolites are needles 10-20 μm in length and 0.5-1 μ wide; mordenite needles are 5-20 μm long and 0.5-1 μm wide (4). The physical properties of fibrous zeolites and asbestos are similar, and all are silicates. Whether the biological activity is similar needs further study.

Estimate of Population at Risk and Prevalence of Disease

The use of natural zeolites is limited at present. Mining and milling occurs on an intermittent basis. The number of potentially exposed workers using zeolite is small because it is packaged, transported, handled, and used in enclosed systems to avoid contact with contaminants that would destroy its properties. The prevalence of disease is unknown.

Pathology and Clinical Description

Boris reported on 120 cases of malignant-pleural mesothelioma (108), asbestos pleurisy (9), and benign pleural mesothelioma (3)(1). Two of the 120 had had occupational exposure to asbestos (automobile industry, construction worker). All the rest were farmers; 52 had used the soil (containing the zeolite erionite) as stucco, food (in their sweets), and for toilet needs as children. Sixteen patients had come from districts in Turkey with asbestos in the soil. The other 50 had no "known chance to inhale asbestosic material," although analysis of the soil from several of the districts revealed the presence of tremolite asbestos along with "considerable amounts of other silicates such as mica, talc, feldspar, and kaolin." In this article, asbestos was assumed to be the causative agent, but subsequent analysis of (at that time) unidentified asbestiform fibers led the author to suggest erionite was the causative agent (2).

The main symptoms associated with malignant pleural mesothelioma and "asbestos pleurisy" were chest pain and dyspnea. Physical and radiological examination revealed pleural thickening or effusion, and four of the cases with mesothelioma also had pleural calcifications. At the time of diagnosis, the average age of the 72 males was 43 years (15-71); for the 48 females, 51 years (12-69). Boris felt that both pleural plaques and asbestos pleurisy might be precursors of pleural mesothelioma, although the number of cases where both were present was small. He also found it difficult to distinguish between asbestos pleurisy and malignant pleural mesothelioma, even after examination of tissue with the electron microscope.

Thoracotomy, radiology, thorcoscopy, and needle biopsy were diagnostic procedures for "asbestos pleurisy" and mesothelioma. Cytologic examination of pleural fluids and sputum, protein level of pleural fluid, and erythrocyte sedimentation rate (ESR) were also utilized in some of the patients. None of these diagnostic tests were clearly preferable. The importance of showing asbestos fibers in the tissue by EM examination was stressed. Apparently only 5 of the 120 cases had pleural tissue examined, and only one of the five had asbestos fibers (amphobole, chrysotile, talc, feldspar, quartz, mica, and kaolinite) in the pleura.

Progression was variable. Cases of pleurisy and calcification did not progress in some cases; in others they developed into benign mesothelioma or fatal malignant mesothelioma. In the population in Turkey where exposure begins at birth, the pleural changes may be observed quite early (in the teens) although most cases involved older people. Both sexes are affected. An appropriate screening test is the chest x-ray; diagnosis includes a biopsy. Symptoms of chest pain and dyspnea occur, although it is not clear whether symptoms are an early sign.

Malignant mesothelioma is invariably fatal; the prognosis for pleurisy, calcified plaques, and pleural thickening may be quite good—assuming they do not progress to malignant mesothelioma.

Diagnostic Criteria

Pleural changes (thickening, calcification, mesothelioma) are the most characteristic feature of nonoccupation exposure in Europe. These changes are nonspecific and are identified with those caused by asbestos.

Methods of Prevention

There is no known medical problem of industrial exposure in this country. The high prevalence of mesothelioma due to community exposure points to a potential hazard from at least one variety of zeolite.

Research Needs

Better characterization of the dose and the zeolite and asbestos content of the soil in Europe is necessary.

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