Asbestiform sepiolite has been found in a zinc deposit at Franklin, New Jersey. The host rock is Precambrian Franklin marble. Pseudomorphous foliated texture and cross-cutting relationships indicate replacement of talc by sepiolite. Sepiolite is managanous, while talc contains little manganese, suggesting differences in manganese substitution in these minerals and providing evidence against solid-state replacement. Sepiolite from Franklin is of moderate crystallinity and consists of soft, flexible mass-fiber. Comparison with other sepiolite samples suggests that increased crystallinity among sepiolites parallels increased fiber length, while disorder appears to be associated with flexibility. Length and aspect ratio (length/width) distributions support toxicological equation of asbestiform sepiolite with the regulated asbestos minerals.

The data presented here suggest that talc can be unstable in a low-temperature hydrothermal environment, altering under certain conditions to form sepiolite. In a wider context, sepiolite may be expected to precipitate at the end-stages of hydrothermal mineralization in some talc deposits and in carbonate and calc-silicate rocks. Many occurrences of sepiolite in these rocks may have been overlooked due to similarities with other minerals. The fact that sepiolite has been previously unrecognized and misidentified at Franklin is a case in point. Since there is evidence suggesting that sepiolite is fibrogenic and carcinogenic, its potential occurrence in consumer talcs and crushed-stone products has environmental health implications. Similarities in composition and other analytical parameters may cause sepiolite to be mistaken for fibrous talc or chrysotile in environmental samples. © 1987 Academic Press, Inc.

INTRODUCTION

Existing U.S. Federal regulations define asbestos as the fibrous or asbestiform varieties of a serpentine mineral (chrysotile) and five amphibole minerals (ribeckite, grunerite, anthophyllite, tremolite, and actinolite). These are the asbestiform minerals which, prior to the advent of asbestos regulation, were exploited commercially and thus were the varieties of interest in occupational health. It had long been recognized by mineralogists, however, that there were asbestiform varieties of many other minerals, the list of which now includes other members of the amphibole group, several zeolites, sepiolite, palygorskite (Zoltai, 1981; National Research Council, 1984; Deer et al., 1963), and rutile (Germine, 1985). In addition, it has been recognized that a complete continuum exists between the asbestiform and non-asbestiform varieties of most of these minerals. The problems that have arisen from this recognition have been twofold: (1) a parallel continuum appears to exist between development of asbestiform habit and biological activity (Palekar et al., 1979), presenting severe scientific and philosophical problems to the application of uniform standards, and (2) in regulatory practice it
is difficult, if not impossible, to distinguish fibers derived from asbestiform and non-asbestiform minerals, much less to define the continuum between these hypothetical end-members. The confusion between “asbestos” and “non-asbestos” has led to a regulatory stalemate which has often translated into inaction on occupational and environmental health problems. One such problem has been the gangue occurrence of asbestiform minerals in rocks, rock products, and soils (Greene, 1976; Langer et al., 1979; Rohl et al., 1976; Sheehan, 1981). Another problem has been the use of asbestos substitutes, which include non-regulated asbestiform minerals such as sepiolite and palygorskite (U.S. Federal Register 42, 63357 (1977); Rohl et al., 1982). The concern is that these non-regulated asbestiform minerals may have biological properties similar to those of the regulated asbestos varieties.

Continuing research has provided a potential foundation for the resolution of many of the above regulatory problems. It appears that many relatively insoluble materials, when in the forms of particles of sufficient thinness and length, are capable of eliciting the biological responses characteristic of asbestos (Pott et al., 1974; Stanton and Layard, 1978). Work has been done on development of analytical criteria relevant to the above findings in the area of fiber-size analysis (Campbell et al., 1977; Siegrist and Wylie, 1980). Fibrillar morphology and aggregation have been shown to affect respirability (Becklake, 1976; Bignon et al., 1978; Kotin, 1978), and work has been done on descriptive and analytical parameters for these and other environmental variables (Germaine, 1982; National Research Council, 1984). There is a need to conduct basic geological studies which stress factors related to biological activity of asbestiform minerals and which examine mineral paragenesis and distribution as it relates to potential human exposure.

In this study, the association of asbestiform sepiolite and talc at Franklin, New Jersey, is described in terms of (1) textural and geochemical relationships of sepiolite and talc, (2) development of crystallinity, fibrous habit, and asbestiform morphology, (3) paragenesis and potential distribution of asbestiform sepiolite, and (4) analytical observations relevant to identification of sepiolite fibers in environmental samples. The relevance of these factors to human health is then discussed in the context of available evidence on the toxicity of sepiolite and of asbestiform minerals in general.

PREVIOUS WORK

The occurrence described here adds sepiolite to the long list of minerals known to be associated with the Franklin zinc ore deposit (Frondel, 1972). Mineralogically, this deposit is one of the most studied localities in the world. The deposit consists mostly of silicate and oxide minerals rich in Zn, Fe, and Mn. The host rock is the Precambrian Franklin marble, and the gangue consists predominantly of calcite, with zones rich in Ca, Mg, and Mn carbonate and silicate minerals (Frondel and Baum, 1974).

The fibrous clay minerals, sepiolite and palygorskite, are hydrated magnesium silicates with structural characteristics of both the chain silicates (Zoltai, 1981)
and the sheet silicates (Martin-Vivaldi and Robertson, 1971). These minerals are described as clays because of their typical occurrence in earthy form as a component of sediments and as a weathering product (Grim, 1953).

There have been several previous reports of asbestiform varieties of sepiolite and palygorskite (Aurola, 1956; Zoltai, 1981; Martin-Vivaldi and Robertson, 1971; Caillere et al., 1948; Stephen, 1954; Millot, 1970; Dings and Whitebread, 1965; Huggins et al., 1962; Vassiliou and Puffer, 1975). The asbestiform varieties of these minerals are probably more common than is generally believed. During a recent survey of asbestiform serpentine and amphibole occurrences in the northern New Jersey area (Germine and Puffer, 1981), one occurrence of asbestiform palygorskite and four of asbestiform sepiolite were noted (M. Germine, unpublished), including the one discussed here. Matted aggregates of sepiolite fibers from one of these locations were being marketed as “mountain leather.” Although previous reports of sepiolite or palygorskite in the area were not found, it is believed that a number of the reported occurrences of “mountain leather” in the Wappinger marble of southeastern New York (Zodac, 1939; Buyce and Dunn, 1980; Tervo, 1967) may be matted aggregates of asbestiform sepiolite, since such material was identified as sepiolite in examinations of samples from the marble. “Mountain leather” is commonly assumed to be amphibole (Zodac, 1939; Buyce and Dunn, 1980), while parallel-fiber aggregates of sepiolite have been confused with chrysotile (Caillere et al., 1948).

Because of similarities in composition and origin, talc is frequently associated in nature with chrysotile and amphiboles (including asbestiform varieties). Attention has been focused on the occurrence of these minerals in consumer and industrial talcs (Rohl et al., 1976; Rohl and Langer, 1974; Dement, 1978) and on the possible hazards attendant with exposure to such contaminated talcs by inhalation (Kleinfield et al., 1967; Schepers, 1974) and ingestion (Merliss, 1971). The occurrence and potential health effects of fibrous clay minerals in association with talc have, however, been largely overlooked.

The fibrous clays, sepiolite and palygorskite, are among the minerals that have been noted in commercial talcs and talc deposits (Parmentier and Gill, 1978; Berg, 1979; Aurola, 1956; Brindley, 1959). The association of sepiolite and talc has been previously described in fractures cutting talc deposits in Montana (Berg, 1979), in veins cutting dolomite in Nevada (Ehlmann et al., 1962), and as late veins in steatized skarn in Finland (Aurola, 1956). Sepiolite has also been noted in association with talc at Governor, New York (Brindley, 1959), and in Japan (Imai and Otsuka, 1984). Available descriptions suggest that it is the asbestiform variety of sepiolite which is associated with talc at these locations, as is also suggested by the hydrothermal nature and occurrence in veins.

MATERIALS AND METHODS

The sepiolite standard used here is from Eski Chehir, Turkey, and was obtained from the collection of the Morris Museum of Arts and Sciences, Morristown, New Jersey (sample #14.4.39.1). Analyses of sepiolite from this locality have been published by Brindley (1959) and Grim (1953). X-ray diffraction data from
the standard were indexed after Brindley (1959) and were used to confirm sepiolite reflections initially identified using the Joint Committee on Powder Diffraction Standards pattern #13-595 (JCPDS, 1974). Talc was identified on the basis of JCPDS pattern #5-631.

Eski Chehir sepiolite was used as a representative of the claylike, non-asbestiform variety of sepiolite known as meerschaum. The sample chosen to represent long-fiber, asbestiform sepiolite is from Shaft 13, Katonah, New York. It is a slip fiber on a matrix of Wappinger marble (Shuberth, 1968) and is also from the Morris Museum collection (sample #16.7.21.2). The sample has a very highly developed fibrous texture, with individual fibers over 10 cm long.

Chemical analyses were conducted on Franklin sepiolite and talc using a JEOL Superprobe 733 electron microprobe at Whitaker Laboratory, Lehigh University, Bethlehem, Pennsylvania. Because of its texture, the sepiolite could not be adequately polished in raw form. The sample was therefore fused rapidly in a carbon arc and quenched in distilled water to form a pinkish-white, translucent glass bead. Some water was assumed to have been lost in the fusion process, and therefore raw data were recalculated to 100% assuming stoichiometric water content. Talc was analyzed in raw form.

Samples were prepared for electron microprobe analysis by embedding in polyethylene and polishing to 0.05 μm with alumina and diamond paste. Data were collected on the microprobe using a 1-μm beam size and counting times of 5 to 40 sec per element. These data were fully corrected using the Bence–Albee computer program. Each spot was probed in triplicate. Eight spots were probed on the sepiolite and six on the talc. Means and standard deviations (σn−1) of these analyses are presented.

Standards employed for microprobe analyses were as follows: augite (SiO2, MgO, TiO2, Al2O3, FeO, CaO, Na2O), fused basalt (K2O), ilmenite (MnO), and synthetic zincite (ZnO). Augite and ilmenite were provided and analyzed by the U.S. National Museum. Basalt is the USGS standard B.H.V.O. 1. Zincite is from the collection of Whitaker Laboratory.

Qualitative chemical data were gathered using the scanning and transmission electron microscopes (SEM and TEM). Analyses were conducted using energy dispersive X-ray fluorescence (EDX). These data were used for microchemical characterizations and as an indication of elements present for microprobe analysis.

TEM samples were prepared by ultrasonifying in distilled water for ½ hr, withdrawing a sample of the suspension with a disposable hypodermic syringe, and applying a drop to a 400-mesh, carbon-coated, parlodian-membrane-covered copper grid. Fiber measurements were conducted from fields near the center of photographic negatives, at a magnification of approximately 5000, employing a measuring microscope and measuring magnifier. Counting rules of Anderson and Long (1980) were followed to ensure unbiased statistics. A total of 100 fibers were measured on each sample.

X-ray diffraction (XRD) data were gathered using a General Electric XRD-5 diffractometer, employing a Ni filter and CuKα radiation. TEM work was conducted using a JEOL 100S TEM and a Phillips 400 STEM.
Sample Description

The sample of Franklin sepiolite is from the collection of the American Museum of Natural History in New York (sample #18392). The specimen is a roughly tabular mass about 20 cm long consisting mostly of tan-colored talc, which is covered by shallow depressions measuring 1/2 to 1 cm in diameter. These depressions are filled by leathery masses of sepiolite which do not quite cover the surface, leaving talc exposed between some depressions. Sepiolite is of very light tan color and is composed of wooly aggregates of matted fiber and flat-lying fiber bundles up to 8 mm in length (Fig. 1). Individual mats of sepiolite often have a finely layered texture which is pseudomorphous after talc foliation. The sepiolite fiber is soft and flexible. On the basis of its texture and properties, the material is the equivalent of mass-fiber asbestos (Zoltai, 1981). The sample was catalogued at the Museum as serpentine, apparently having been thought to be chrysotile asbestos.

Sepiolite masses contain abundant smooth, lenticular inclusions of talc measuring up to at least 3 mm in diameter, which have foliation parallel to paper-thin layers of sepiolite. This texture is indicative of replacement and is similar to textures noted in sepiolite replacements of serpentine (Caillere and Henin, 1949), carbonate minerals (Ehlmann et al., 1962), and silicic volcanic ash (Hathaway and Sachs, 1965).

RESULTS AND CONCLUSIONS

Under the petrographic microscope, Franklin sepiolite appears as a mass of tangled fibers, with occasional aggregates of long strands. The fiber has moderate birefringence, parallel extinction, and refractive indices of $n_\alpha = 1.505 \pm 0.002$ and $n_\alpha = 1.515 \pm 0.002$. These data are consistent with the optical properties of sepiolite (Kerr, 1959).

Chemical analyses (Table 1) indicate that sepiolite from Franklin is manganoan, as are many of the other magnesium silicate minerals from the ore deposit (Frondel, 1972; Klein and Ito, 1968). The talc contains little manganese and is chemically similar to two other talc samples from district ore that were analyzed by SEM–EDX. The differences in manganese content between Franklin sepiolite and talc may be due to limited substitution of manganese for magnesium in talc (Deer et al., 1963). This variation in manganese is evidence against a restructuring mechanism of replacement of talc by sepiolite. Such a mechanism sometimes operates in pyrobes (Veblen and Buseck, 1980).

Small (<0.1 μm diameter), electron-dense particles rich in sulfur were noted as a minor constituent of disaggregated sepiolite during TEM examinations. Traces of sulfur were also noted in EDX scans of some sepiolite fibers. These findings suggest that sepiolite alteration was brought about by sulfur-rich solutions.

Extent of development of X-ray diffraction maxima has been shown to reflect degree of crystallinity in sepiolites (Brindley, 1959). The diffraction pattern of Franklin sepiolite indicates a moderate degree of crystallinity, that of earthy sepiolite a low degree of crystallinity, and that of long-fiber sepiolite a high degree of crystallinity (Fig. 2). Small particle size has an effect similar to that of crystal-
FIG. 1. Electron micrographs of Franklin sepiolite. (Upper left) SEM of typical wooly aggregate removed from sample. White bar represents 1 mm. (Upper right) TEM of disaggregated sepiolite, showing large fiber bundle. Scale bar represents 5 µm. (Bottom) TEM defocused to show diffraction contrast features: (A) fiber with tubular appearance, (B) beam-damage features, (C) periodic fringes. Scale bar represents 0.5 µm. Photographs by A. Kasper, E. Traeger, and M. Germine, respectively.
<table>
<thead>
<tr>
<th></th>
<th>(1) Sepiolite</th>
<th>(2)</th>
<th>(3) Talc</th>
<th>(4) Talc</th>
<th>(5) Sepiolite</th>
<th>(6) Talc</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>58.65 (2.46)</td>
<td>54.07</td>
<td>55.65</td>
<td>62.23 (1.21)</td>
<td>Si</td>
<td>11.83</td>
</tr>
<tr>
<td>MgO</td>
<td>25.77 (2.20)</td>
<td>23.75</td>
<td>24.89</td>
<td>30.72 (1.48)</td>
<td>Mg</td>
<td>7.75</td>
</tr>
<tr>
<td>MnO</td>
<td>3.16 (0.20)</td>
<td>2.92</td>
<td>0.0</td>
<td>0.23 (0.07)</td>
<td>Mn</td>
<td>0.54</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.0 (0.0)</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0 (0.0)</td>
<td>Ti</td>
<td>0.0</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>0.06 (0.03)</td>
<td>0.06</td>
<td>0.0</td>
<td>0.11 (0.06)</td>
<td>Al</td>
<td>0.01</td>
</tr>
<tr>
<td>FeO</td>
<td>0.05 (0.04)</td>
<td>0.05</td>
<td>0.0</td>
<td>0.06 (0.04)</td>
<td>Fe</td>
<td>0.01</td>
</tr>
<tr>
<td>ZnO</td>
<td>0.0 (0.0)</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0 (0.0)</td>
<td>Zn</td>
<td>0.0</td>
</tr>
<tr>
<td>CaO</td>
<td>0.07 (0.03)</td>
<td>0.06</td>
<td>0.0</td>
<td>0.0 (0.0)</td>
<td>Ca</td>
<td>0.01</td>
</tr>
<tr>
<td>NaO</td>
<td>0.13 (0.03)</td>
<td>0.12</td>
<td>0.0</td>
<td>0.07 (0.03)</td>
<td>Na</td>
<td>0.03</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.02 (0.01)</td>
<td>0.02</td>
<td>0.0</td>
<td>0.00 (0.00)</td>
<td>K</td>
<td>0.00</td>
</tr>
<tr>
<td>H₂O⁺</td>
<td>—</td>
<td>8.22</td>
<td>8.34</td>
<td>4.65</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>H₂O⁻</td>
<td>—</td>
<td>10.96</td>
<td>11.12</td>
<td>n.d.</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>87.91</td>
<td>100.00</td>
<td>100.00</td>
<td>98.07</td>
<td>—</td>
<td></td>
</tr>
</tbody>
</table>

Note. (1) Franklin sepiolite. (2) Analysis 1, recalculated to 100% assuming 8H₂O⁺ and 6H₂O⁻ per molecule. (3) Theoretical composition of sepiolite, based on 8H₂O · Mg₆(H₂O)₄(OH)₄(Si₁₂O₃₀) (Hathaway and Sachs, 1965). (4) Franklin talc. H₂O⁺ calculated assuming 2H₂O⁺ per molecule. H₂O⁻ not determined (n.d.). (5) Franklin sepiolite, atoms per molecule based on 32(O). (6) Franklin talc, atoms per molecule based on 22(O). Analyses 1 and 4 presented as mean ± standard deviation. Total iron as FeO.

Line disorder on diffraction maxima (Zussman, 1967). However, since crystal thickness is similar in these samples, particle size should not be a major factor in the observed trends.

Selected-area electron diffraction data gathered using the TEM also indicate moderate crystallinity. Spots are clearly defined, as in highly crystallized sepiolites (Brindley, 1959). However, only spots lying in the pseudohexagonal net...

![Fig. 2. X-ray diffraction patterns of sepiolites from Katonah, New York (top), Franklin, New Jersey (middle, speckled), and Eski Chehir, Turkey (bottom). Peak labeled T on the Franklin sample (2θ = 9.4) is a talc reflection.](image-url)
characteristic of sepiolite’s talclike sublattice (Martin-Vivaldi and Robertson, 1971) are present \((b = 9.0, \ c = 5.3 \ \text{Å})\). Weaker reflections characteristic of very well crystallized sepiolites (Brindley, 1959; Martin-Vivaldi and Robertson, 1971) are absent \((b = 27.0, \ c = 5.2 \ \text{Å})\).

Degree of crystallinity parallels extent of development of fibrosity and, on a general basis, mode of origin. Sepiolites which are formed in near-surface environments display low crystallinity and lack of megascopically fibrous texture, while sepiolites from hydrothermal environments have more marked crystallinity and fibrous texture (Brindley, 1959; Martin-Vivaldi and Robertson, 1971).

Under TEM, disaggregated Franklin sepiolite consists of thin, somewhat curved fibers and fiber aggregates (Fig. 1). Individual fibrils have widths ranging from 190 to 400 Å. Periodic fringes are visible upon defocusing under TEM. Fringes run the length of fibrils, usually having spacings of about 27.5 Å. Periodic fringes have been observed at similar spacings in other sepiolites and may be explained as diffraction contrasts caused by crystalline disorder (Martin-Vivaldi and Robertson, 1971). These fringes become more distinct with exposure to the electron beam, and it is uncertain whether they represent actual structures or are beam-damage artifacts.

Franklin sepiolite is subject to beam damage under the TEM. Damaged fibers often have the appearance of tubules (i.e., have a central band of low electron density) due to expansion between periodic fringes and appearance of coalescing cavities within or between fibrils. Some undamaged fibers also have a TEM appearance which suggests a central hollow (Fig. 1), but this is probably caused by variations in fiber thickness. These features may help explain reports of tubular structure in sepiolite (Grim, 1953; Kerr, 1959). Beam-damaged fibers often have a TEM appearance similar to that of beam-damaged chrysotile. This, together with similarities in composition, could make the two minerals difficult to distinguish by TEM in the absence of electron diffraction data. This ambiguity could lead to errors in identification of chrysotile which relies on morphology, composition, and/or beam-damage characteristics. Such techniques have been used for identification of chrysotile in environmental samples (Beaman and File, 1976; Lee et al., 1978), talc products (Rohl et al., 1976), and rock samples (Germine and Puffer, 1981; Puffer et al., 1980). In the case of Franklin sepiolite, it was found necessary to use step-scanning XRD (Rohl et al., 1976) and electron diffraction to confirm the absence of chrysotile.

Distinction may also not always be possible under TEM between sepiolite and talc fibers, even when both electron diffraction and EDX data are available. The pseudohexagonal sublattice of sepiolite has spacings and geometry essentially indistinguishable from those of talc in the plane commonly encountered in TEM examination of particulate samples (see previous section), relative intensities of elemental maxima in EDX spectra are indistinguishable, and beam-damage characteristics are similar. These factors could lead to underreporting of sepiolite in talcs and environmental samples. Talc fibers are reported to be among the most common in human lung tissues (Churg, 1983), and fibrous talc is very common in commercial talc deposits (Langer, 1974), often forming by replacement of asbestiform silicates.

TEM measurements of sepiolite fibers from Franklin indicate aspect-ratio prop-
erties characteristic of asbestos (Wylie, 1979), with a large proportion of fibers having aspect ratios greater than 20 and a significant number greater than 100. As with asbestos, fiber widths are strongly skewed toward the lower values, indicating strong fibrillar development (Siegrist and Wylie, 1980). A large percentage of fibers (>5%) are in the “optimum carcinogenicity” range (length greater than 8 μm and width less than 0.25 μm) described from experimental work by Stanton and Layard (1978). Fibers in this size range are said to be characteristic of asbestos (Campbell et al., 1979). A small percentage (<1%) of such fibers are also found in the earthy sepiolite standard. Both the standard and Franklin sepiolites have approximately log-normal aspect-ratio and length distributions (Figs. 3 and 4). Both log distributions have similar shapes, as evidenced by their slopes on the cumulative frequency diagrams. The standard has a modal aspect ratio of about 15 and a modal length of about 0.5 μm. Franklin sepiolite has a modal aspect ratio of about 32 and a modal length of about 1.5 μm. Aspect ratio (l/w) is related to length (l) in the standard by the equation

$$\log_{10} \frac{l}{w} = 0.78 \left( \log_{10} l \right) + 1.38,$$

and in Franklin sepiolite by the equation

$$\log_{10} \frac{l}{w} = 0.92 \left( \log_{10} l \right) + 1.38.$$

These equations are in the form $y = mx + b$. The value of $m$, termed the index of fibrosity by Wylie (1979), can be used to distinguish asbestos from non-as-
bestos. A high correlation coefficient ($r$) for the above relationship is also characteristic of asbestos (Siegrist and Wylie, 1980). In the standard, $m = 0.78$ and $r = 0.72$, placing the sample just below or in the lower range of asbestos samples by either criterion. In Franklin sepiolite, $m = 0.92$ and $r = 0.90$, placing the sample in the middle to upper range of asbestos samples (Siegrist and Wylie, 1980).

**DISCUSSION**

Experimental data on cytotoxicity (Palekar et al., 1979; Reiss et al., 1980) and carcinogenicity in laboratory animals (Campbell et al., 1979; Davis et al., 1985) suggest a close relationship between development of asbestiform habit and toxicity in mineral fibers. This relationship is also suggested by the limited data available for the fibrous clays. The earthy variety of palygorskite exhibits "minimal cytotoxicity" (Reiss et al., 1980), while the asbestiform varieties of sepiolite and palygorskite produce "severe biological effects" (Hayashi et al., 1969), including cytotoxicity well in excess of that exhibited by chrysotile and amphibole asbestos. In experimental studies, palygorskite had tumor-producing characteristics exceeding those of similarly administered long- and short-fiber chrysotile (Pott et al., 1974). Inhalation of palygorskite has been related to fibrosis in man (Bignon et al., 1980). It has also been suggested that inhalation of sepiolite from soils is related to endemic pleural asbestosis (Burilko and Michailova, 1970).

Asbestiform sepiolite from Franklin has flexibility and fibril aggregation characteristics similar to those of chrysotile asbestos. The long-fiber sepiolite sample, although having a higher degree of crystallinity, is a harsher, less flexible fiber,
with less tendency toward fibril-bundle structure. Crystalline disorder in Franklin sepiolite may increase its relative flexibility. A similar relationship has been suggested for amphibole fiber flexibility (Veblen et al., 1977; Zoltai, 1981).

The replacement of talc by sepiolite provides evidence for the instability of talc in hydrothermal systems. Such instability does not appear to have been previously documented in nature, although stevensite alteration of talc has been produced experimentally (Whitney and Eberl, 1982), and the stability of talc formed at low temperatures has previously been considered uncertain (Hemley et al., 1977; Whitney and Eberl, 1982). Talc has been classically considered the end-member in retrograde alterations among biopyroblases (Hess, 1933; Veblen and Buseck, 1980). The evidence presented here suggests that sepiolite is a low-temperature-stable analog of talc, as has been previously suggested by Aurola (1956). On the basis of textural and geochemical evidence, the following paragenesis is proposed for the sepiolite studied here: (1) precipitation of talc in a low-temperature hydrothermal environment, (2) shifting of solutional equilibrium away from the talc stability field, leading to dissolution of talc, and (3) precipitation of sepiolite from dissolved talc and residual solutions.

Since most commercial talc deposits form under low-temperature hydrothermal conditions (Berg, 1979), sepiolite may form in such deposits under favorable conditions. Sepiolite may also be expected to occur as a low-temperature hydrothermal precipitate in calc-silicate, magnesium silicate, and carbonate rocks, forming in place of talc. The occurrence of sepiolite in these rocks may have environmental health implications, since they are used in consumer products and by the crushed stone industry.

ACKNOWLEDGMENTS

I thank Joseph Peters, of the American Museum of Natural History, New York City, for help in obtaining the sample material; David Calvert and James Kerner, of Lehigh University, Bethlehem, Pennsylvania, Professor Andrew Kasper of the Botany Department, Rutgers University, Newark, New Jersey, and Dr. Francis J. Traeger, formerly of Mercy Hospital, Pittsburgh, Pennsylvania, all for technical assistance (with STEM, microprobe, SEM, and TEM, respectively); Dr. Pete J. Dunn, of the Smithsonian Institution, Washington, D.C., for his review of mineralogical segments of the manuscript and many useful suggestions; and Professor John H. Puffer, of the Rutgers University Geology Department, Newark, New Jersey, for his review of the draft manuscript, useful suggestions, and technical assistance.

REFERENCES


