The question arises of how the advection of resuspended particles is translated into a vertical flux at the Panama Basin mooring site so that smectite particles, which are among the finest clays, can be deposited in the trap. The concentration of suspended clay particles at this station was as small as that at other ocean gyre areas and did not change throughout the water column (*10*). One explanation is that the smectite particles were highly concentrated into small patches or aggregates, which were not caught by ordinary water samples or nephelometer optics because of their relative spatial scarcity. Formation of macroscopic amorphous aggregates, which have been reported from neritic and pelagic environments as "marine snow" (*11*) or "fecal matter" (*12*), is one means by which the settling rate of clay particles may be greatly enhanced. They acquire their clay load by physical scavenging and agglutination. This packaging must occur at mid-depths in the ocean, rather than by surface filter feeders incorporating fine particles into fecal pellets (*13*).

SUSUMU HONJO
DEREK W. SPENCER
JOHN W. FARRINGTON
Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543

References and Notes

1. S. Honjo, J. Connell, P. Sachs, *Deep-Sea Res.* **27**, 745 (1980).
2. A sediment trap intercomparison was carried out at this station with 32 sediment traps and 12 different configurations and sizes [D. W. Spencer, Ed., *Woods Hole Oceanogr. Inst. Tech. Memo WHOI-1-81* (1981)].
3. Jannasch, Zafiriou, and Farrington time series sediment trap [H. W. Jannasch, O. C. Zafiriou, J. W. Farrington, *Limnol. Oceanogr.* **25**, 939 (1980)].
4. The JZF trap was deployed during the same period on a separate mooring at 1267 m, 4.8 km east of the Parflux trap, and obtained an average flux of 91 mg m^{-2} day^{-1}, somewhat smaller than the flux of 104 mg m^{-2} day^{-1} at a Parflux trap deployed at 1268 m. However, a comparison of the particle size fractions and contents of the samples from the Parflux and JZF traps indicated similar trapping efficiencies, so that a comparison of flux between these traps was valid. [S. Honjo, *Woods Hole Oceanogr. Inst. Tech. Memo WHOI-1-81* (1981), p. 40].
5. An instrument error was suspected because such a small flux during this period appeared unrealistic compared to the large flux generally observed in the previous increment. However, on replay of the instrument we have not found an indication of mechanical or electronic malfunction in the time series collector in this trap which might have occurred during this increment.
6. G. R. Heath, T. C. Moore, G. C. Roberts, *J. Geol.* **82**, 145 (1974).
7. W. S. Plank, R. V. Zaneveld, H. Pak, *J. Geophys. Res.* **78**, 7113 (1973); W. D. Gardner, P. E. Biscaye, J. Bishop, *Woods Hole Oceanogr. Inst. Tech. Memo WHOI-1-81* (1981), p. 35.
8. S. Honjo, *J. Mar. Res.* **36**, 469 (1980); P. G. Brewer, Y. Nozaki, D. W. Spencer, A. P. Fleer, *ibid.* **38**, 703 (1980).
9. D. W. Spencer and P. G. Brewer, in preparation.
10. S. Honjo, S. J. Manganini, L. Poppe, in preparation.
11. N. Suzuki and K. Kato, *Bull. Fac. Hokkaido Univ.* **4**, 132 (1953); M. W. Silver, A. L. Shanks, J. D. Trent, *Science* **201**, 371 (1978); J. D. Trent, A. L. Shanks, M. W. Silver, *Limnol. Oceanogr.* **23**, 625 (1978); A. L. Alldredge, *ibid.* **24**, 855 (1979).
12. J. K. Bishop, J. M. Edmond, D. R. Ketten, M. P. Bacon, W. B. Silver, *Deep-Sea Res.* **24**, 511 (1977).
13. For example, S. Honjo, *Mar. Micropaleontol.* **1**, 65 (1976).
14. We thank J. F. Connell, S. J. Manganini, and L. Poppe for field and laboratory assistance. W. Gardner's help was indispensable in deploying and recovering the JZP trap. We thank J. Hathaway, I. N. McCave, and J. Cole for their suggestions and discussions. Supported by NSF grant OCE8025429 and ONR contract N00014-74-CO-262-NR-083-009 to S.H. and ONR contract N00014-74-CO-262-NR-083-004 to J.W.F. Woods Hole Oceanographic Institution Contribution 5007.

30 October 1981; revised 10 March 1982

Endemic Pleural Disease Associated with Exposure to Mixed Fibrous Dust in Turkey

Abstract. *Pleural mesothelioma, lung cancer, pleural calcification and fibrosis, and interstitial parenchymal fibrosis have been observed among inhabitants of several villages in south-central Turkey. Earlier reports have stated that environmental and lung tissue samples from this area contained the fibrous zeolite mineral erionite, and this mineral has generally been assumed to be the agent responsible for these endemic pathological conditions in the absence of asbestos outcroppings and usage. Several different kinds of asbestos minerals in addition to erionite have now been found in environmental samples taken from the villages where these diseases occur. The lung tissues of mesothelioma patients from these villages contain both fibrous zeolites and asbestos minerals.*

In several villages in an area of central Anatolia known as Cappadocia, a very high incidence of pleural mesothelioma has been reported in recent years in a small population. In addition to mesothelioma, other chest diseases, including calcified pleural plaques, pleural fibrosis, interstitial parenchymal fibrosis, and lung cancer, occur frequently. Peritoneal mesothelioma has also been found. Elsewhere the clustering of these diseases generally has been associated with exposure to asbestos, both occupational and environmental (*1*). Geologists and other investigators have not reported the occurrence of asbestos in Cappadocia. Asbestos is not fabricated nor is it used in any manufacturing process in the area (*2–4*), and the household use of asbestos has not been observed.

The focus of this problem is the village of Karain with a population of about 600. Pleural mesothelioma was reported as the cause in 11 out of 18 deaths in the village in 1974. In the preceding 5 years, 25 cases of pleural mesothelioma were reported in Karain (*3*). In the nearby village of Tuzköy, with a population of approximately 3000, the incidence of pleural mesothelioma is approximately six cases per year, or almost three orders of magnitude greater than might be expected (*2*). The ages of these individuals at the time of mesothelioma diagnosis tended to be unusually young, and the incidence occurred with equal frequency in both males and females. These circumstances support the working hypothesis that an etiological agent existed in the environment, with exposures beginning at birth. The occurrence of exceptionally high attack rates of mesothelioma in this rural agrarian society warrants particular attention since (i) mesothelioma in the past has been a "signal" disease indicating prior asbestos exposure, (ii) the high mesothelioma prevalence points to a significant exposure to asbestos fiber, and (iii) the age-sex distribution of tumors (27 to 50 years of age with an equal frequency of male and female occurrence) suggests exposure to an environmental agent beginning in early childhood.

The villages in which mesothelioma was observed, as well as much of Cappadocia, are built upon, and into, tuff, a volcanogenic rock that consists predominantly of volcanic glass, plagioclase feldspars, hornblende, biotite, and pyroxene. Locally, these phases have been altered to form both montmorillonite and a variety of zeolite minerals. The tuff is easily cut into dimension stone and is extensively quarried for building construction. Erosion of the tuff results in conical and beehive-shaped landforms. In Karain, these landforms have been excavated extensively and used for dwellings, animal pens, and storage pens for food and fodder. In the stone houses, contact is made directly with the soft rock surface. It is a common practice in the region for villagers to whitewash their dwellings. Preparation and application of the whitewash produces dust which may persist.

The populations of these villages are exposed throughout their lives to unusually high concentrations of inorganic dust, originating largely from local rocks and soils. Our investigation thus focused

 0036-8075/82/0430-0518$01.00/0

on the mineral characterization of the tuffs, the whitewash, and other inorganic dusts (5, 6). Two of us (A.N.R. and G.M.) visited this area in 1979 to make geological studies and to collect geological, environmental, and tissue samples for mineralogical characterization. These samples, numbering 123, were obtained in villages in which mesothelioma was known to occur and also in villages where mesothelioma was not known to occur. Environmental samples included settled house dust, whitewashes, soil, tuff outcroppings, and building stone. Lung tissue specimens of patients with mesothelioma who lived in the villages of Karain, Tuzköy, and Sarihidir were obtained from physicians responsible for their care.

Environmental specimens and inorganic lung tissue residues were analyzed by polarized light microscopy (PLM), x-ray powder diffraction (XRD), and transmission electron microscopy (TEM) (the electron microscope was equipped with an energy-dispersive x-ray spectrometry system). Lung tissues obtained from patients with mesothelioma were prepared for electron microscopic analysis by both carbon extraction and bulk digestion techniques (7).

The volcanic tuff is reported to contain zeolite minerals, including fibrous erionite (8). Measurement of erionite fibers taken in Karain showed them to be fine and short, approaching the dimensions of some asbestos fibers. Seventy-five percent of the erionite fibers observed were less than 0.25 μm in diameter, and virtually all were less than 3 μm long (9). In another study, erionite fibers 0.5 to 1.5 μm in diameter and up to 50 μm long were found (10). The fibers were respirable and apparently are durable in vivo.

Erionite has been found in environmental samples taken in three villages in Cappadocia where cases of pleural mesothelioma have been reported (2–4, 11). Such observations have led some investigators to conclude that these fibers are the agents producing the pleural diseases that have been observed. However, erionite has also been found in environmental samples taken in villages with no reported cases of mesothelioma or other pleural or pulmonary diseases (10). The life-style of the people in all these villages appears to be very similar, yet the pattern of pleural disease in these villages exhibits distinct differences.

Detailed examination of the environmental samples showed that they contained several different kinds of fibrous minerals, including both asbestos minerals and fibrous erionite (Table 1). Tuff in a shear zone in Karain was found altered to a suite of minerals containing both tremolite and chrysotile (Fig. 1a). The physical size of the zone of alteration is small. Corroborative results by PLM, XRD, TEM, and microprobe analysis confirm that up to 30 percent, by weight, of one specimen consists of tremolite and chrysotile. The presence of chrysotile and an asbestiform amphibole is consistent with reports (12) that these minerals were found in Karain drinking water and in ashed pleural tissue. Other environmental samples taken in Karain showed small amounts of chrysotile and tremolite.

Analysis of pleural and parenchymal tissues obtained from the mesothelioma patients showed that the lung burden also included both asbestos and erionite fibers. Approximately 90 percent of the fibrous particles in lung tissues from Karain patients consisted of sodium-potassium-calcium aluminosilicates, a composition consistent with that of erionite. A smaller amount (approximately 1 to 5 percent by volume) of fibrous mineral was identified as tremolite (Fig. 1b).

Tremolite fibers in tissue were typically less than 10 μm long. Chrysotile, both in fiber bundles and unit fibril form, was also found in small amounts. The high proportion of erionite in the lung burden is consistent with the much greater amounts of erionite observed in environmental samples. Tremolite and chrysotile fibers were also found in household and road dust samples taken in Karain. Tremolite fibers generally were less than

Table 1. Results of an examination of environmental and lung specimens from five Cappadocian villages. Major is defined to mean 3 percent or more by weight, as determined by PLM and XRD; trace is defined to mean detectable and present at up to 3 percent by weight, as determined by PLM and XRD.

Specimen types	No.	Fibrous zeolite (erionite)*	Nonfibrous zeolites	Chrysotile–tremolite
		Karain, mesothelioma reported		
Environmental samples	54	Major	Major	Trace to major
Lung specimens	8	Major	Undifferentiated	Trace to major
		Tuzköy, mesothelioma reported		
Environmental samples	24	Trace to major	Major	Trace to major
Lung specimens	10	Trace to major	Undifferentiated	Trace to major
		Sarihidir, mesothelioma reported		
Environmental samples	6	Trace to major	Major	Trace to major
Lung specimens	4	Trace to major	Undifferentiated	Trace
		Karlik, no mesothelioma reported		
Environmental samples	9	Trace	Major	None detected
No tissue available				
		Yezilöz, no mesothelioma reported		
Environmental samples	8	Trace	Major	None detected
No tissue available				

*Detected by PLM and XRD; confirmed by TEM, selected area electron diffraction, and energy-dispersive x-ray analysis.

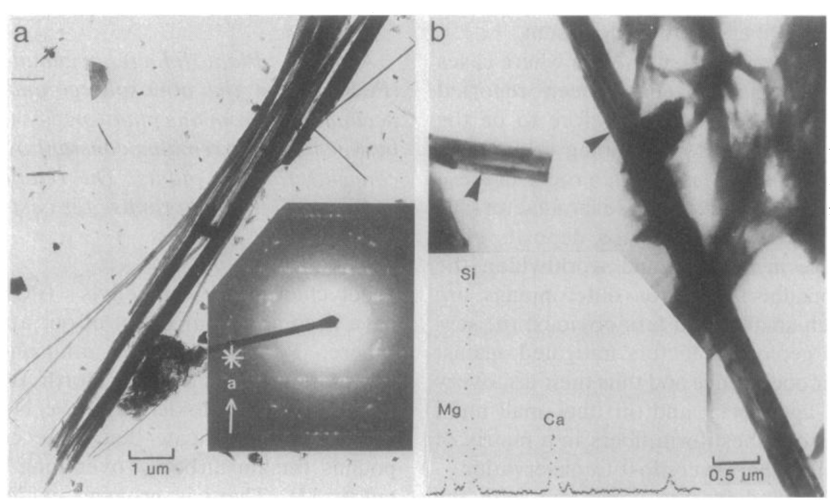

Fig. 1. (a) Electron photomicrograph and selected area electron diffraction pattern (inset) of chrysotile fiber bundle from altered rocks in a shear zone in Karain. (b) Electron photomicrograph of tremolite fibers (arrows) in the lung tissue of a patient from Karain with mesothelioma. Inset shows the characteristic chemical spectrum of tremolite obtained by analysis with a scanning transmission electron microscope. Amphibole structure was established by selected area electron diffraction.

1 μm in diameter and ranged from several micrometers to 20 μm in length.

The "clustering" of mesothelioma within certain families in Karain and Tuzköy has been noted, but genealogical surveys indicate that blood relationship was not a factor (*3, 4*). On the other hand, if such families live in close proximity to a small asbestos outcropping, in effect a point source, or are otherwise exposed to environmental asbestos, they might jointly be at greater risk to asbestos disease. As in Karain, quarried rock, building stone, and other environmental samples were also taken in the two nearby villages (Karlik and Yezilöz) where no mesothelioma has been reported. No asbestos was found in specimens obtained from these villages. In Tuzköy (with mesothelioma) samples of the whitewash ore used extensively by the villagers as material for whitewashing were examined. One of these was essentially a tremolitic talc with high aspect ratios, 10:1 or more, and most tremolite fibers had diameters of 1 μm or less. Tremolite fibers were also observed in settled dust samples from Tuzköy. The dimensions of these fibers were very similar to those of the tremolite fibers in the whitewash material. In lung tissue specimens obtained from patients in this village with pleural disease, fibrous zeolite predominated in the lung burden but tremolite fibers were also found.

Pleural mesothelioma has recently been diagnosed in a third Cappadocian village, Sarihidir (*4, 11*). Cases of calcified pleural plaques and chronic fibrosing pleuritis in this village have been described in (*2*). Samples of street dust collected in Sarihidir contained as much as 5 percent chrysotile and tremolite, by weight. In addition, palygorskite and erionite fibers were also present.

The Cappadocian villages where cases of mesothelioma have been reported have not been known before to be the sites of asbestos-containing rocks. The absence of reports of such rocks in these villages may be due to several factors: (i) compared with asbestos deposits elsewhere in Turkey (and worldwide), the Cappadocia asbestos outcroppings are much smaller and less obvious; (ii) several geological factors mitigated against their occurrence and thus their discovery in Cappadocia; and (iii) the small numbers of asbestiform fibers in a matrix of zeolite fibers were lost to observation.

Our findings are consistent with the relationship established in other circumstances between asbestos exposure and pleural disease. However, animal experiments have shown that erionite alone is capable of producing tumors (*13*). Whether an enhanced tumorigenic effect may exist as a result of exposure to both asbestos and erionite or possibly other durable fibers is presently unknown and warrants investigation.

A. N. Rohl, A. M. Langer
Environmental Sciences Laboratory, Mount Sinai School of Medicine, New York 10029

G. Moncure*
Department of Geology, University of Wyoming, Laramie 82071

I. J. Selikoff, A. Fischbein
Environmental Sciences Laboratory, Mount Sinai School of Medicine

References and Notes

1. J. C. Wagner, C. A. Sleggs, P. Marchand, *Br. J. Ind. Med.* **17**, 260 (1960); M. L. Newhouse and H. Thompson, *ibid.* **22**, 261 (1965); I. J. Selikoff, J. Churg, E. C. Hammond, *J. Am. Med. Assoc.* **188**, 22 (1964); J. C. Cochrane and I. Webster, *S. Afr. Med. J.* **54**, 279 (1978).
2. M. Artvinli and Y. I. Baris, *J. Natl. Cancer Inst.* **63**, 17 (1979).
3. Y. I. Baris, M. Artvinli, A. A. Sahin, *Ann. N.Y. Acad. Sci.* **330**, 423 (1979).
4. ———, T. Savas, M. L. Erkan, *Rev. Fr. Mal. Respir.* **7**, 687 (1979).
5. The possible relationship between a high incidence of pleural disease and exposure to mineral fiber in Cappadocia has bearing on a troubling public health question that has been unresolved for nearly a decade. With the definition of significant hazards associated with exposure to asbestos and a concomitant search for substitutes, concern has been expressed that replacement fibers might have a similar biological potential. This concern was heightened with the publication of the hypothesis of Stanton *et al.* (*6*), based on experimental data, that the carcinogenicity of inorganic fibers depends more on their size and shape than on their crystal structure, surface character, or chemical composition. The finding that intrapleural implantation into animals of fibrous materials of diverse types and size distributions produced malignant tumors was attributed to fiber shape and a narrow size range of fibers; the "simplest incriminating feature for both carcinogenesis and fibrogenesis seems to be a durable fibrous shape, perhaps in a narrow size range" (*6*). Stanton observed that long, thin (that is, on a micrometer scale) fibers produced proportionally more mesotheliomas when implanted in the chest of the rat. The experiments of F. Pott and K. H. Friedrichs [*Naturwissenschaften* **59**, 318 (1972)] and F. Pott, F. Huth, and K. H. Friedrichs [*Environ. Health Perspect.* **9**, 313 (1974)] also suggested that the carcinogenic (mesothelioma) potency of a mineral depended upon shape factors, fibrous forms tending to be more carcinogenic than their nonfibrous counterparts. These observations were limited to animal studies. Adequate data on human experience with fibers other than asbestos were not available, and asbestos remained the only fiber known to produce mesothelioma in man.
6. M. F. Stanton *et al.*, *J. Natl. Cancer Inst.* **58**, 587 (1977).
7. A. M. Langer, I. B. Rubin, I. J. Selikoff, F. D. Pooley, *J. Histochem. Cytochem.* **20**, 735 (1972); M. J. Smith and B. Naylor, *Am. J. Clin. Pathol.* **58**, 250 (1972).
8. G. Ataman, *C.R. Acad. Sci.* **287**, 207 (1978).
9. F. D. Pooley, in *Dusts and Disease: Proceedings of Conference on Occupational Exposures to Fibrous and Particulate Dust and Their Extension into the Environment*, R. Lemon and J. M. Dement, Eds. (Pathotox, Park Forest South, Ill., 1979), p. 41.
10. F. A. Mumpton, unpublished report of a reconnaissance study of the association of zeolites with mesothelioma cancer occurrences in central Turkey (March 1979).
11. Y. I. Baris, personal communication.
12. ———, A. A. Sahin, M. Ozemi, I. Kerse, E. Ozen, B. Kolacan, M. Altinors, A. Goktepeli, *Thorax* **33**, 181 (1978).
13. Y. Suzuki, A. N. Rohl, A. M. Langer, I. J. Selikoff, *Fed. Proc. Fed. Am. Soc. Exp. Biol.* **39** (Abstr.), 3 (1980).
14. We are particularly grateful to Y. I. Baris, Department of Chest Diseases, School of Medicine, Hacettepe University, Ankara, for his generous assistance in reviewing clinical evidence and in obtaining environmental and tissue samples. We thank the staff of the Thoracic Medicine Department of the Karolinska Hospital, Stockholm, Sweden, for providing tissue specimens. We thank G. Boman and V. Schubert for providing clinical information about some of the patients from whom tissue specimens were obtained for analysis in this report. We also particularly thank R. Lilis for her many valuable clinical observations. This study was supported by grant ES 00928 from the National Institute of Environmental Health Sciences. We gratefully acknowledge assistance from the Mobil Foundation.
* Present address: Conoco, Inc., Ponca City, Okla. 74603.

28 July 1981; revised 9 November 1981

Accumulation of Airborne Polychlorinated Biphenyls in Foliage

Abstract. *Plant foliage accumulates the vapor of polychlorinated biphenyls (PCB's) from the atmosphere, and there is a variation in the amount that is accumulated from one plant species to another. This differential accumulation factor between species remains constant over more than two orders of magnitude of PCB concentrations in plants. The relationships between foliar and atmospheric PCB concentrations hold promise for cost-effective atmospheric PCB monitoring through foliar analyses.*

Polychlorinated biphenyls (PCB's) have become a component of our atmosphere. Reports on the atmospheric transport of PCB's over the North Atlantic, the Gulf of Mexico, and the North Pacific Ocean indicate that these compounds remain airborne over long distances (*1*). There is growing evidence that atmospheric transport is the primary mode of global distribution of PCB's from sites of use and disposal (*2*). Airborne PCB's are often associated with suspended particulates in urban areas, but over rural areas of North America more than 99 percent of the atmospheric PCB's are in the vapor phase (*3*).

The estimated domestic production of PCB's in North America between 1930 and 1975 was 570×10^6 kg, and an additional 1.4×10^6 kg was imported. Further manufacture in the United States was banned in 1979. The PCB's were used primarily as coolant-dielectric fluids in transformers and capacitors; as plasticizers in coatings, adhesives, and printing and copy papers; and as addi-

0036-8075/82/0430-0520$01.00/0