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Nature and range of mineral dusts in the environment

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[Plates 1–6]

Mineral dusts are pollutants in air, drinking water, foodstuffs and even some drugs. Inhalation of the asbestos minerals amosite, anthophyllite, chrysotile, crocidolite and tremolite occurs not only in areas adjacent to industrial and mining activities and in the households of those industrially exposed to these minerals, but also by the general public due both to airborne dusts from industrial areas, mines and mine dumps and to the household use of asbestos-containing commodities such as talcum-powders and do-it-yourself plasters, fillers and insulation material. Inorganic particles are also inhaled in cigarette and cigar smoke. These include cristobalite – a known fibrogen – and result from use, during manufacture, of clay minerals, diatomaceous earth, glass fibre and other additives. Ingestion of asbestos minerals has resulted from the dumping of the gangue of taconite ores into water supplies. Both talc and asbestos are ingested from toiletries and other household commodities as well as in foods such as rice coated with mineral dust. With some of the mineral dusts in the environment being known carcinogens, or associated with other diseases, their identification and the determination of their sources are important aspects of environmental health.

1. Introduction

Mineral and rock dusts are present in many industrial situations, as well as associated with mining, and causal relationships of certain dusts with particular human diseases is well established (Langer & Mackler 1972; Gilson, this volume). However, dust-related disease is not confined, in the occupational situation, solely to those working directly with dust-producing materials, or to those subjected to heavy and prolonged dust exposure (Jones, Pooley & Smith 1976). Nor is it confined only to the occupational situation; for example, asbestosis has been found in animals near asbestos operations (Webster 1963) and mesothelioma in family contacts of the occupationally exposed as well as those residing in the vicinity of an asbestos operation (Wagner, Sleggs & Marchand 1960; Newhouse & Thompson 1965; Rubino, Scansetti, Donna & Palestro 1972). In fact, the spillover of such dusts into the environment at large has often been recognized by the diagnosis of disease known to be related to dusts in the occupational situation.

The existence of mineral dusts in the atmosphere before their large-scale commercial utilization has been demonstrated by studies of the mineral content of the Greenland ice-cap (figure 1*a*, plate 1). However, the marked increase during the present century of the mining and the industrial use of a wide range of minerals leading to a greatly increased dust burden is indicated by these studies (figure 1*b*, *c*, *d*) as well as by studies of the dust particles in the atmosphere (Windom, Griffin & Goldberg 1967), particularly in urban areas (figure 1*f*, *g*;

Selikoff, Nicholson & Langer 1972). It is also shown by the nature and range of dust particles in the lungs of urban dwellers (figure 2*a*, *b*, *f*, plate 2; Langer *et al.* 1973).

On the basis of the accumulated knowledge and experience, legislation and codes of practice, together with improvements in industrial design, have to a considerable extent resulted in the reduction of dust levels in many occupational situations and so lessened its spillover into the general environment. However, despite the documentation of potential health risks related to the inhalation of asbestos in the environmental as well as the occupational situation, it was not until 1971 that the U.S. Environmental Protection Agency added asbestos to its list of hazardous air pollutants (Ruckelshaus 1971), while open spraying of asbestos insulation (figure 1*e*) was not banned in New York City until 1972 (New York City, Department of Air Resources 1971). Yet many other potential sources of environmental mineral dusts remain. Open-cast mining, quarrying and cement manufacture, for example, contribute to the atmospheric dust burden. Demolition associated with urban renewal, as in large cities in Great Britain, and the operation of automobile brakes, contribute dusts particularly in urban environments while the siting of houses and even schools adjacent to dumps of asbestos waste means that certain members of the general public are exposed to higher levels of mineral dust than others. The great increase in do-it-yourself activity in the home using a wide range of mineral based products, the increasing use of insulating materials as a result of the awareness of high-priced and limited energy resources and the increasing utilization of air conditioning and hot-air duct heating, which can result in the removal and circulation of mineral particles from wall-finishes, as well as from insulating material, are potential causes of increasing burdens of environmental mineral dust within buildings.

TABLE 1. DISEASES RELATED TO MINERAL DUSTS IN OCCUPATIONAL SITUATIONS

mineral dust	disease
asbestos – chrysotile; actinolite–tremolite, amosite, anthophyllite, crocidolite	asbestosis (pulmonary fibrosis) lung and mesothelial cancer gastrointestinal cancer
talc	talcosis (pulmonary fibrosis)
Fuller's earth – montmorillonite and quartz	pneumoconiosis
mica – phlogopite, muscovite, sericite	pneumoconiosis
silica – quartz, cristobalite, tridymite, opal (also in granite, pumice and slate dusts)	silicosis (pulmonary fibrosis)
diatomite (calcined)	progressive massive fibrosis
glass fibre	bronchitis, asthma, skin irritation

When considered in relation to human disease, those minerals present in environmental dusts that are inhaled and retained in the lungs, as well as those that are ingested, warrant special attention. Studies of the dust burden in lung tissue (Langer, Rubin, Selikoff & Pooley 1972; Ehrenreich, Mackler, Langer & Selikoff 1973) from both humans (figure 2*a*, *b*, *f*) and animals (figure 2*e*) that have not been subjected to occupational exposure, as well as from humans of the households of the occupationally exposed (figure 2*c*, *d*), show the presence of minerals that are known to be related to disease in the occupational situation (table 1). These include both amphibole and chrysotile asbestos, talc, clay, mica and other minerals with sheet structures as well as various forms of silica. Because of their disease potential this discussion of environmental mineral dusts is limited to these minerals together with glass fibre, which is known to be associated with bronchial, asthmatic and certain skin conditions. Carbonate dusts

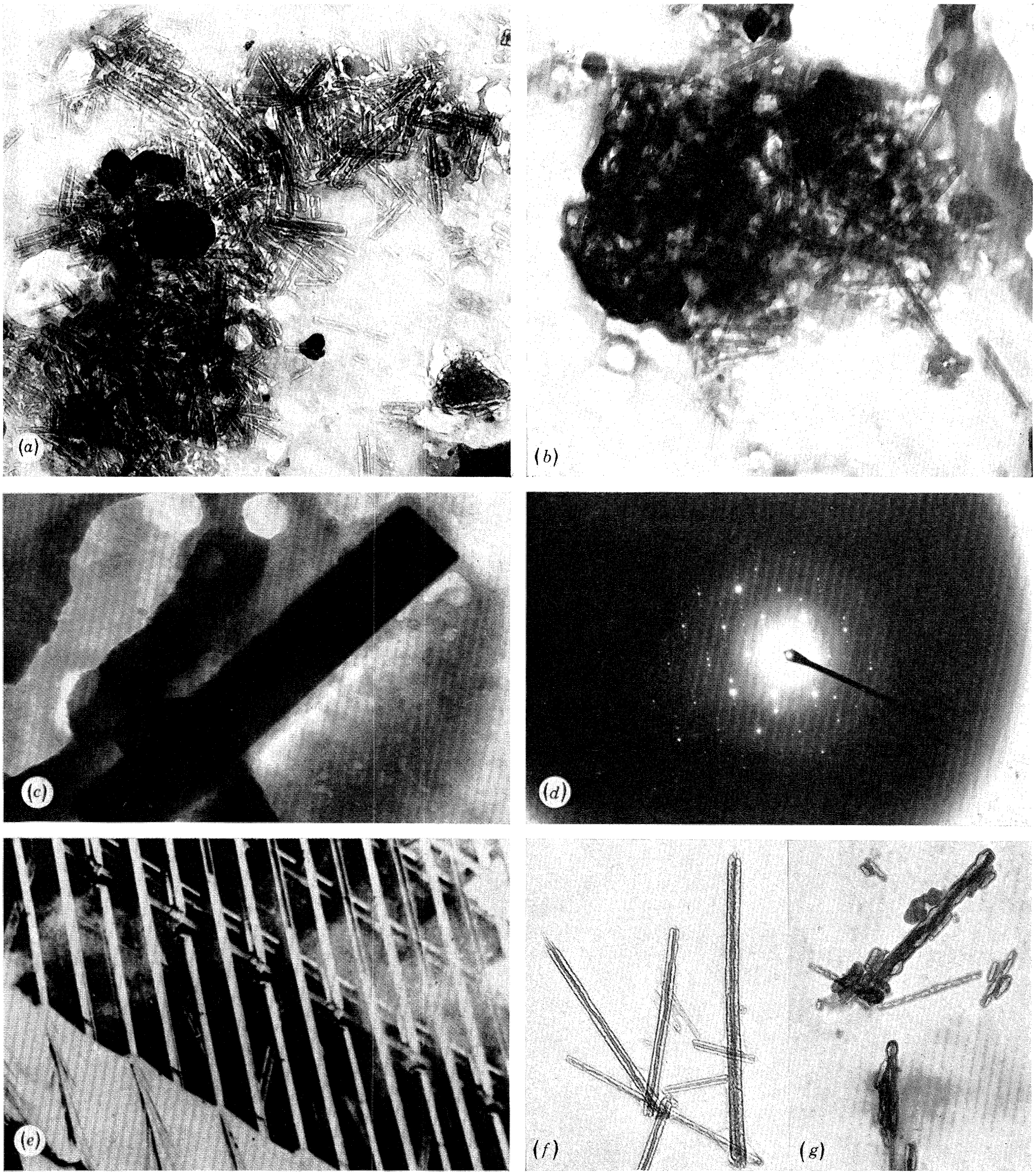

FIGURE 1. Mineral particles in the atmosphere. (*a*) Chrysotile in Greenland ice cap 1750; magn. × 55000. (*b*) Chrysotile in Greenland ice cap 1920; magn. × 40000. (*c*) Amphibole in Greenland ice cap 1920; magn. × 20000. (*d*) Selected area electron diffraction pattern of amphibole in (*c*). (*e*) Asbestos spray clouds at construction site, New York City. (*f*, *g*) Chrysotile in indoor air samples, New York City; magn. × 19000, × 15000.

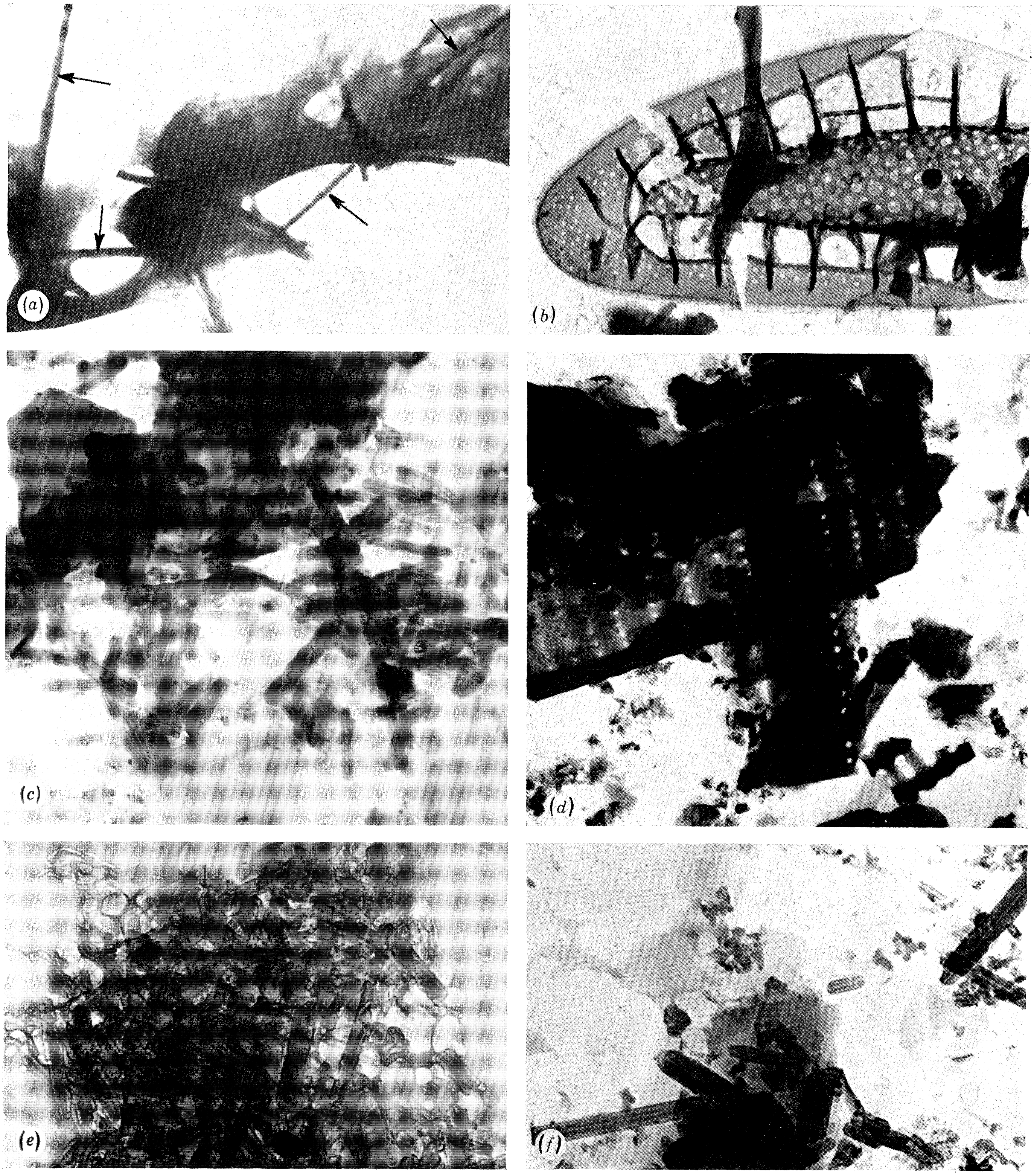

FIGURE 2. Mineral particles in human and animal lungs. (*a*) Amphibole asbestos in human lung tissue; magn. × 15000. (*b*) Diatom in human lung tissue; magn. × 25000. (*c*) Chrysotile in lung tissue of a family contact of an insulation worker; magn. × 50000. (*d*) Diatoms in lung tissue of a family contact of an insulation worker; magn. × 50000. (*e*) Chrysotile in lung tissue of a dog; magn. × 50000. (*f*) Chrysotile in lung tissue of a member of university academic staff without industrial exposure; magn. × 77500.

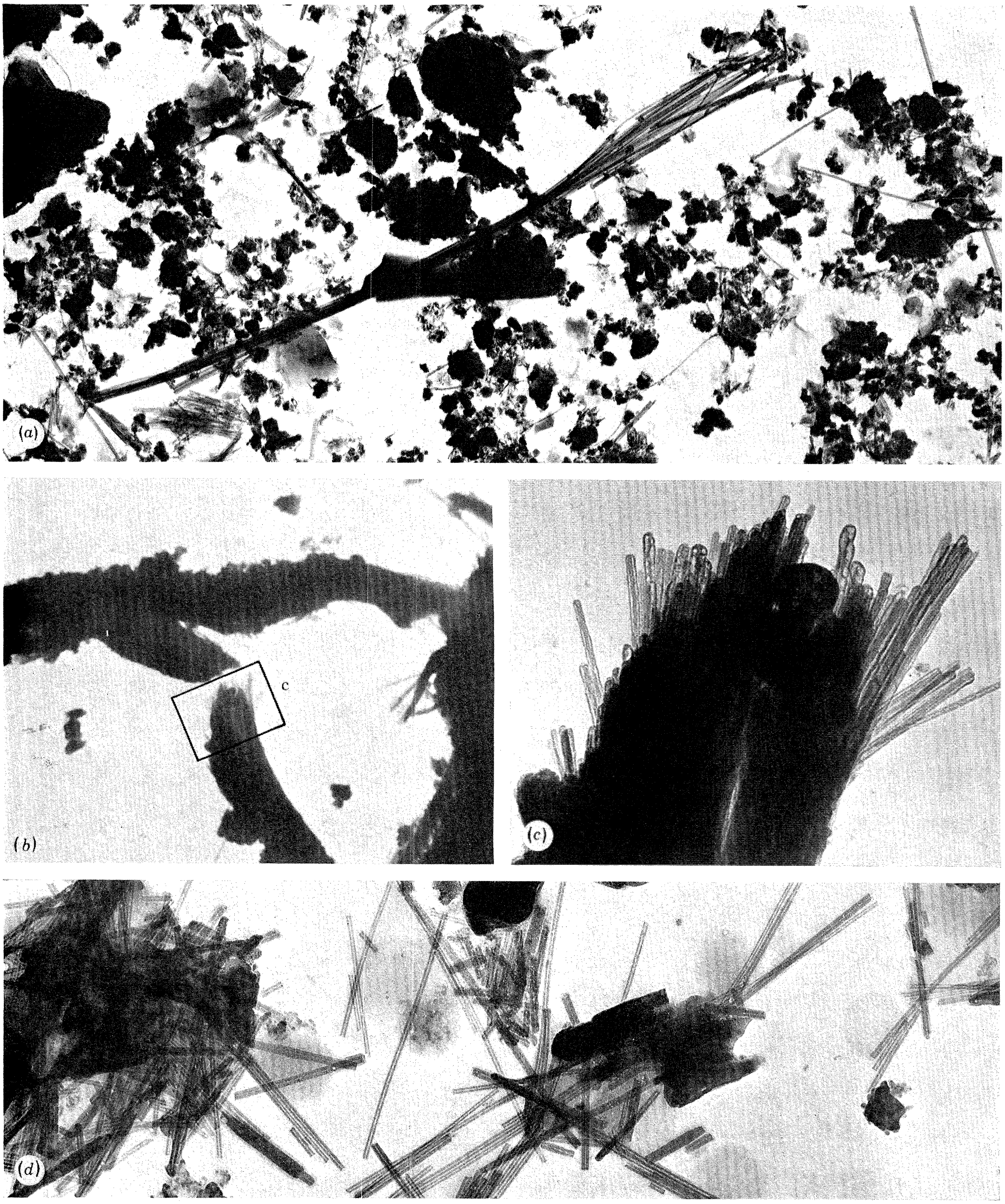

FIGURE 3. Mineral particles in dusts at the industrial–environmental interface. (*a*) Car brake dust containing chrysotile, resin binder and road dust, New York City; magn. × 25000. (*b*, *c*) Chrysotile in car brake dust, Birmingham, U.K.; magn. × 9000, × 55000. (*d*) Asbestos in dust of asbestos–vinyl floor tile factory; magn. × 50000.

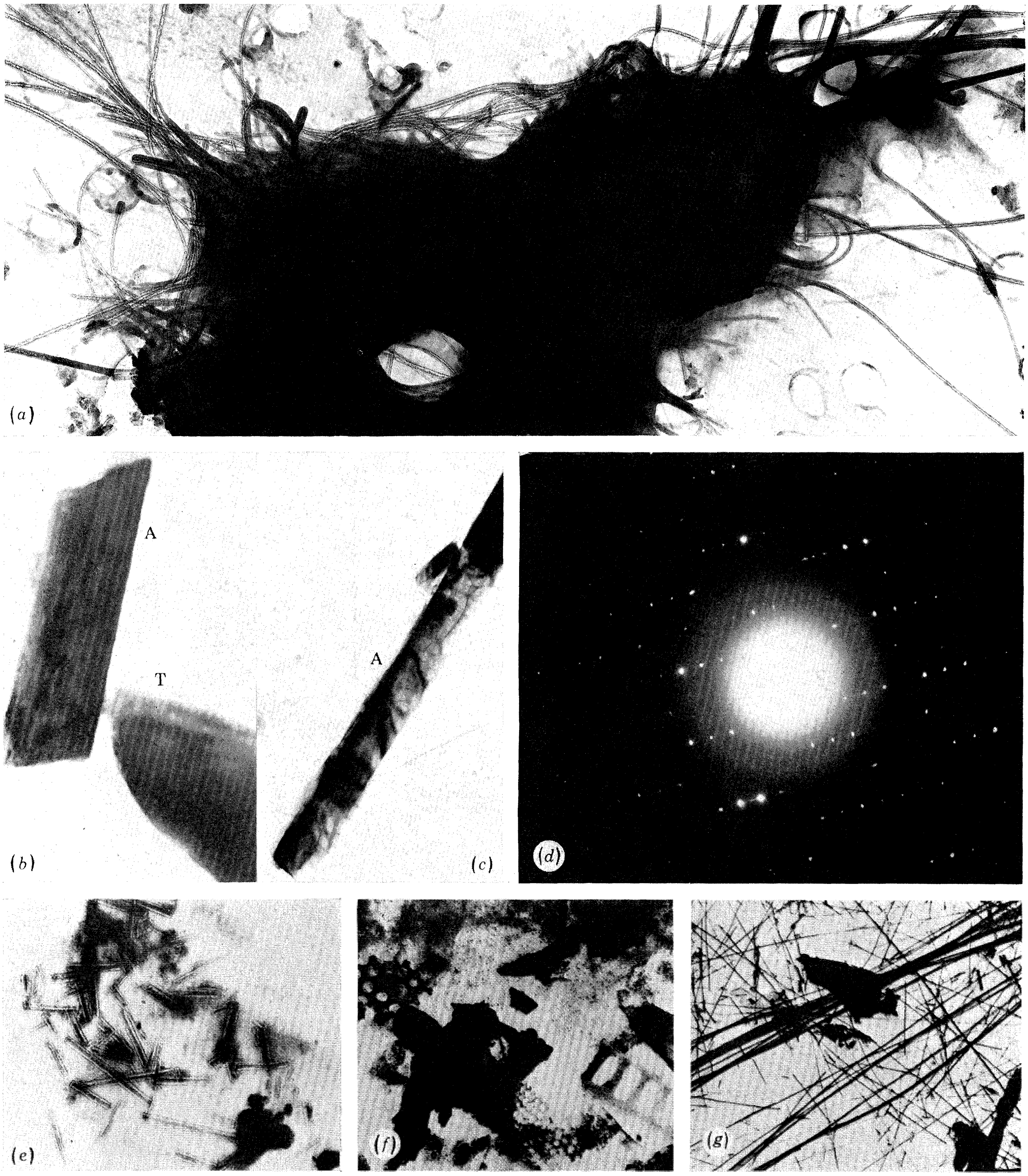

FIGURE 4. Mineral particles in water, food, drugs, tobacco sheet and clothing. (*a*) Chrysotile in water, Thetford, Canada; magn. × 40000. (*b, c*) Amphibole (*A*) and talc (*T*) on rice; magn. × 20000, × 15000. (*d*) Selected area electron diffraction pattern of amphibole in (*c*). (*e*) Asbestos in parenteral drug; magn. × 30000. (*f*) Diatom fragments and short fibres (arrowed) in low temperature ashed reconstituted tobacco sheet; magn. × 3000. (*g*) Chrysotile present (8 %) in a woman's coat; magn. × 2250.

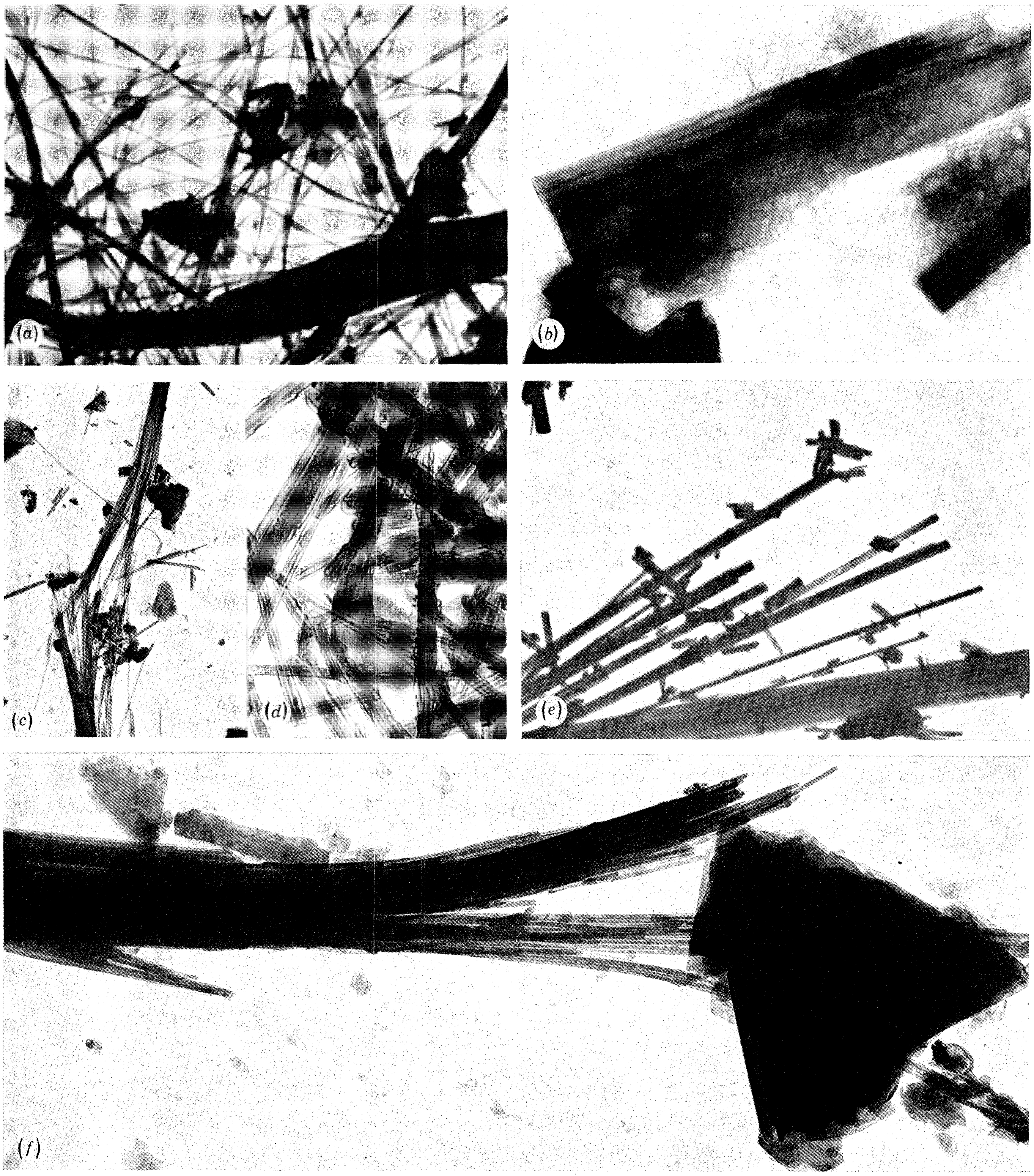

FIGURE 5. Mineral particles in leisure and domestic articles. (*a*) Chrysotile in papier maché; magn. × 4500. (*b*) Amphibole in children's modelling compound; magn × 17000. (*c*, *d*) Chrysotile in plaster patching compounds; magn. × 10000, × 100000. (*e*) Tremolite fibres in vermiculite; magn. × 10000. (*f*) Chrysotile fibre bundles in vermiculite; magn. × 40000.

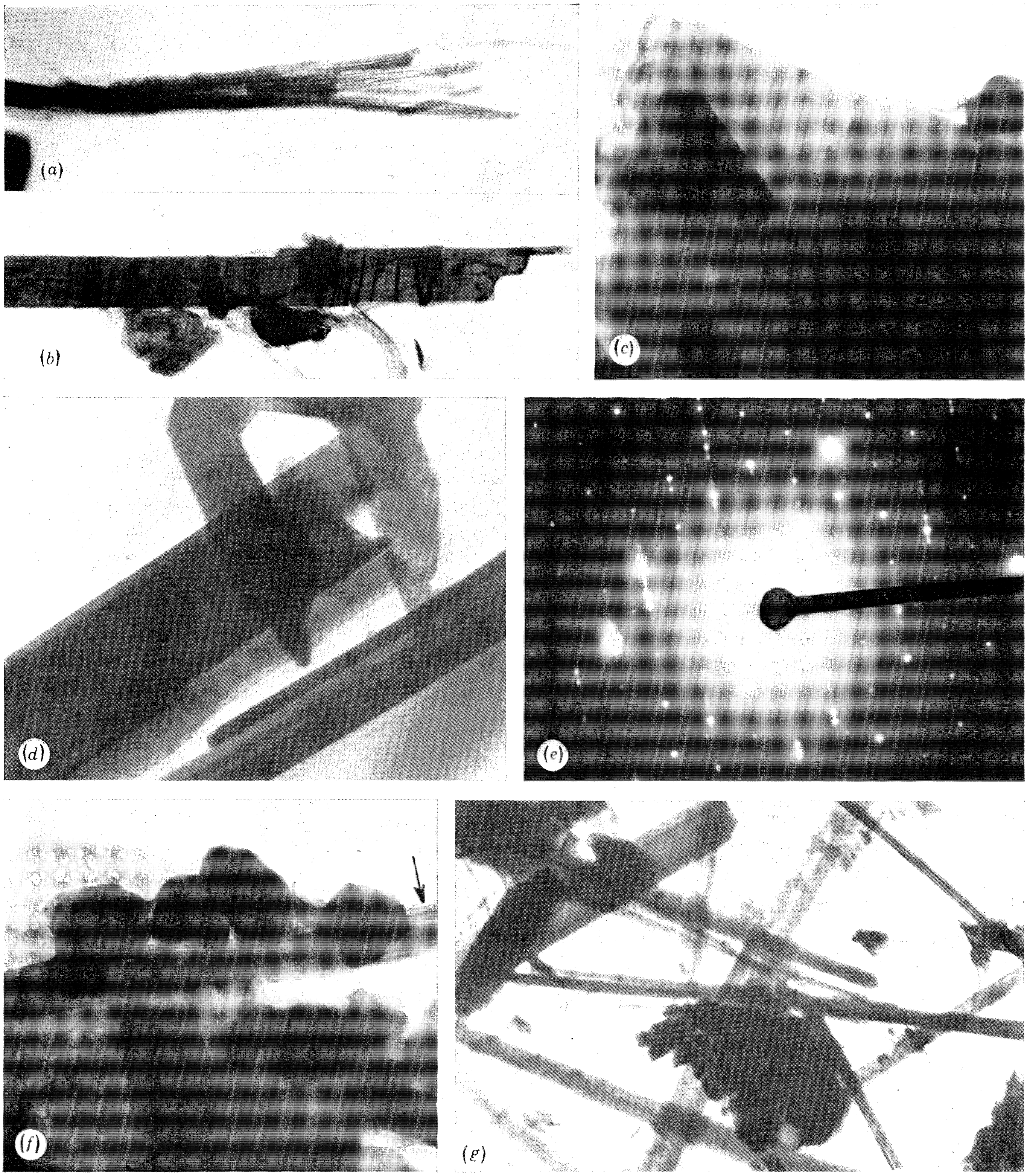

FIGURE 6. Mineral particles in consumer talcum products and commercial talc. (*a*) Chrysotile fibres in consumer talcum powder purchased in New York City; magn. × 66000. (*b*) Amphibole in consumer talcum powder purchased in New York City; magn. × 22500. (*c*) Small amphibole crystals in talc interlayer in consumer talcum powder purchased in New York City; magn. × 40000. (*d*) Amphibole in consumer talcum powder purchased in New York City; magn. × 25000. (*e*) Selected area electron diffraction pattern of amphibole in (*b*). (*f*) Chrysotile (arrowed) and talc in consumer talcum powder purchased in New York City; magn. × 75000. (*g*) Commercial talc containing elongate crystals of tremolite (60 %) and anthophyllite together with flakes of talc and chlorite, northeastern U.S.A.; magn. × 3500.

from quarrying operations, which can be termed 'nuisance dusts', feldspar and related dusts that are commonly used in the household as scouring powders as well as dusts resulting from the normal agents of erosion are excluded.

2. METHODOLOGY OF MINERAL DUST IDENTIFICATION

Optical microscopy, which is often useful for preliminary analysis of bulk samples of histologic tissue sections, does not possess adequate resolution for identification of many respirable dusts less than 5 μm in size (Langer 1974). X-ray diffraction (figures 7, 10), including step-scanning (figures 8, 9), can be used for the identification of mineral constituents of bulk samples of powder or ashed human tissue, with varied success in the latter case (Langer *et al.* 1973; Rohl & Langer 1974). Further analysis by transmission and scanning electron microscopy, with selected area diffraction (figures 1–6, plates 1–6) and energy dispersive X-ray analysis capability (cf. Pooley, this volume), is usually necessary. In the case of bulk material, characterization is also made on the bases of major and trace element composition determined using X-ray fluorescence, atomic absorption spectrometry, flame photometry, spectrophotometry, optical spectroscopy and volumetric and gravimetric analysis. Details of the application of these methods, detection limits and precision are given in Bowes, Skinner & Skinner (1973, pp. 162–163).

3. ASBESTOS

(*a*) *In the atmosphere*

The ubiquitous occurrence of mineral dusts in the environment is inferred from the demonstration of asbestos bodies in the lung tissue of residents of Cape Town, South Africa (25 % of 50 cases), in New York City (48 % of 3000 cases) and other cities of the world (figure 2*a*, *f*; Selikoff *et al.* 1972 and references therein). This and the presence of chrysotile asbestos fibrils in lung tissue in twenty-four out of twenty-eight cases examined by electron microscopy (Langer *et al.* 1971 *b*) is consistent with evidence of the mineral content of the Greenland ice cap. These studies also emphasize the importance of electron microscopy in the determination of the distribution of asbestos fibrils of sub-microscopic size in the environment.

In two hundred air samples taken in fifty cities in the U.S.A., all contained chrysotile (figure 1*f*, *g*), ranging from 0.1 to 100 ng/m^3. However, samples taken near a spray fireproofing operation in New York City (figure 1*e*) ranged from 10 to 400 ng/m^3 (Nicholson & Pundsack 1973). Other industrial point sources have contributed as much as 2000 ng/m^3 to ambient air levels of asbestos (Thompson & Morgan 1971). Air samples around an asbestos factory and on dump trucks had concentrations of 600–700 ng/m^3 (Environmental Protection Agency, personal communication) while demolition of buildings containing asbestos can locally increase concentrations markedly. Greatly increased concentrations of asbestos in the atmosphere have been measured in the vicinity of anthophyllite mining operations in Finland. The concentrations decrease with increasing distance but traces of anthophyllite have been identified 50 km away while it is estimated that as many as 10 % of the rural population in the immediate vicinity of the asbestos workings have pleural calcification like that found amongst the occupationally exposed (Kiviluoto 1960; Laamenen, Noro & Rannio 1965). The presence of grunerite fibres in the ambient air of Silver Bay, Minnesota has been attributed by Nicholson (1974, personal communication) to pollution from the nearby taconite mining operations.

Indoors, amosite fibres have been found in house dusts adjacent to a former asbestos plant (W. J. Nicholson, personal communication) and house dusts in the vicinity of some demolition sites would be expected to contain asbestos. This is particularly the case where boilers and hot-water pipes are being dismantled as much lagging contains asbestos, commonly amosite or chrysotile. The presence of chrysotile in the lungs of domestic animals (figure 2*e*) is evidence of its existence in the domestic environment.

Table 2. Concentrations of asbestos in the atmosphere

Sampling site	year	e.m. counts† (ng/m^3)	o.m. counts‡ (fibres/ml)
inside four buildings of City University of New York (cf. figure 1*f*)	1973–1975	3.5	
		5.1	
		0.2	
		38 ± 37 (20 samples)	
fifty cities in U.S.A.; 200 samples	1971	0.1–100	
New York City – various sites	1971	11–60	
200 m from spray fire-proofing site, New York City	1971	60	
nineteen asbestos insulated buildings in five major cities in U.S.A.; 116 indoor and outdoor samples (> 300 measurements)	1975	2–200	
inside Yale School of Art and Architecture	1975		
no activity			0.3 ± 0.2
custodial and repair activity			5–18
near construction site, New York City	1970		18–100

† e.m. counts by the rub out method (Nicholson *et al.* 1971).
‡ o.m. count by the OSHA technique (Bayer *et al.* 1975).

Table 3. Concentrations of asbestos during automobile brake service (fibres 5–100 μm length, counted by optical microscopy)

	sampling distance m	number of samples	range of fibre concentrations/ml
cleaning dust of car brake drums			
with air jet	1–1.5	4	7–30
	1.5–3	3	2.0–4.2
	3–6	2	0.4–4.8
with dry brush	0.3–1	2	1.3–3.6
background	3.5	3	0–0.2
repairing truck brakes			
grinding used linings	1–1.5	10	1.7–7
bevelling new linings	1–1.5	5	24–72
background	2.5–3.5	5	0.3–1.7
sweeping floor around grinder	1–1.5	1	3.6

After Rohl *et al.* (1976*a*).

Asbestos contamination in some building air supply systems is indicated by fibre levels of 2–2000 ng/m^3 in air samples in and adjacent to buildings in which there is cementitous or fibrous insulation (Nicholson, Rohl & Weisman 1975). Air-conditioning systems can also dislodge and circulate asbestos fibres from indoor wall finishes. The levels of asbestos in adjacent buildings, and in individual buildings have been found to vary considerably, with some levels varying dependent upon the amount of human activity at the time of sampling (table 2).

The possible contribution of asbestos to the general air burden from the action of automobile braking is indicated by an average of 27 ng/m^3 at toll plazas and bridges, in road tunnels and at other air-sampling sites in New York City (Nicholson, Rohl & Ferrand 1971). Measurable levels of chrysolite asbestos have been observed in garages where brake cleaning and repairs are carried out (table 3; Rohl, Langer, Wolff & Weisman 1976*a*) and corresponding levels can be expected in home workshops where the same cleaning methods are used. Resin binder and road dust, which includes halite in winter months in many countries, are present together with chrysotile in the brake dust (figure 3*a*). This asbestos occurs as single fibres or bundles of fibres (figure 3*c*), with magnifications considerably in excess of the limits of an optical microscope only barely revealing the existence of fibrous materials (figure 3*b*). Forsterite has not been positively identified in either the brake dust or air samples, but high magnification indicates features consistent with some dehydroxylation of the chrysotile (Rohl *et al.* 1976*a*). With approximately 47×10^6 and 2×10^6 kg of chrysotile used in brake linings and clutch materials, respectively, sold in the U.S.A. in 1973 (Jacko & DuCharme 1973) the potential atmospheric pollution from this source is considerable. A contribution to the asbestos burden in the London underground railway system from brake pads has been demonstrated while a recent preliminary investigation of brake materials on subway trains in New York found one type to contain 6 % chrysotile together with 30 % lead and lead compounds, including galena.

Table 4. Asbestos in water supplies

Canada		
Ottawa	2 m.f./l†	–
Toronto	0.7–4 m.f./l	3–51 µg/l
22 cities	0.1–4 m.f./l	0.9–21 µg/l
Thetford Mines‡		30 µg/l
river water	8–10 m.f./l	–
river snow	34 m.f./l	–
U.S.A.		
New York‡	–	0.2 µg/l
San Francisco‡	–	0.7–1.2 µg/l
U.S. cities	–	0.2–24 µg/l
Meredith, New Hampshire‡	–	1 µg/l
Duluth, Minnesota (amphibole)	20–75 m.f./l	–
during storm‡	> 500 m.f./l	–
Galapagos Islands§	100≥1000 m.f./l	–

† 10^6 fibres per litre.
‡ W. J. Nicholson (personal communication).
§ J. R. Kramer (personal communication).
Other data from G. H. Kay (1974).

The asbestos content of bedrock and soils in parts of Bulgaria, Czechoslovakia, Germany and the U.S.S.R. is implicated in the occurrence of respiratory disease among the general population (Burilkov & Michailova 1970; Ginzberg *et al.* 1970; Michailova 1972). An additional environmental exposure to some members of the rural population, at least in Great Britain, results from the utilization of mixed wood and asbestos dust from furniture factories (cf. Fletcher 1971) for the bedding of agricultural animals.

(*b*) *In water supplies*

Drinking water in regions with asbestos in the bedrock and soils, as well as where there are asbestos mines, contains a marked content of asbestos fibres, for example in the Thetford Mines district of Canada where the water supplies contain as much as 30 μg/*l* (figure 4*a*). Measurements on the water supplied to Toronto show variation from 3 to 51 μg/*l* but there is less in the supplies of twenty-two other Canadian cities (0.9 to 21 μg/*l* – 100000 to 4 million fibres per litre – table 4). A generally corresponding range of fibre concentrations is shown in the water supplies of U.S. cities, with that of New York City considerably lower. However, in Duluth, Minnesota, where the water of Lake Superior is polluted from waste dumping of taconite tailings from an iron ore refinery, the range of amphibole fibre concentrations is 20–75 million fibres per litre (Nicholson 1974). During a storm this concentration rose as much as tenfold to over 500 million per litre (W. J. Nicholson, personal communication).

The use of an asbestos cement reservoir as a local water collection system in the Galapagos Islands has resulted in the presence of fibre concentrations up to 10^9 fibres per litre (J. R. Kramer, personal communication). Asbestos cement pipe is commonly employed as water conduits (371000 km in the U.S.A.) but its contribution to pollution of water supplies has not been unequivocally established (Olson 1974).

(*c*) *In drugs, beverages and food*

Purification by passage through asbestos filters can cause contamination of parenteral drugs (figure 4*e*; Nicholson, Maggiore & Selikoff 1972). Asbestos filters used in the processing of wine and beer have been shown to produce fibre contamination (Biles & Emerson 1968; Cunningham & Pontefract 1973; cf. Spiel 1974) with Canadian wine, beer and soft drinks containing 1–12 million fibres per litre. Release of fibres from filters used in the preparation of home-brewed beer, as well as the use of loose asbestos to seek out and fill small holes in bulk liquid transporters, are additional sources of mineral fibres in the environment.

Asbestos filters are used in the processing of vegetable oil while the use of asbestos-containing talc during the processing of polished rice causes asbestos pollution of food (cf. Eisenberg 1974). Polished round rice purchased in New York City (figure 4*b*, *c*, *d*) had approximately 10 g of mineral dust per 1 kg of rice with up to 15 % of this being amphibole asbestos which is a common constituent of some bulk talc powders in the U.S.A. (figure 6*g*). Round rice imported from Australia and Italy and purchased at seven centres in various parts of the United Kingdom, contained no detectable mineral dusts. Only in a sample of long-grained rice purchased in an immigrant area of Bradford was any mineral dust detected, and this was calcium carbonate.

(*d*) *In consumer products*

Asbestos is present as a contaminant or principal constituent in many consumer products, particularly home repair and improvement supplies. It is present, mainly as chrysotile, in many wall and ceiling repair patching compounds (figure 5*c*, *d*; Rohl, Langer, Selikoff & Nicholson 1975). It is also present in some insulation material and vinyl floor tiles (figure 3*d*; Murphy *et al.* 1971) and as a major constituent in wall-plugging compounds. Dry grinding and smoothing of such products can produce large numbers of respirable fibres as can similar treatment or removal of the many asbestos-containing wall-finishes and plasters. As in the case of other situations where asbestos fibres settle, successive floor sweepings can result in considerable concentrations of respirable fibres.

Automobile body and boat-filling repair material, which is much used in home workshops and powdered by sanding and buffing, contains chrysotile, glass fibre and talc. Many household objects utilize asbestos as insulation, e.g. ironing boards, stove pads and hot-air blowing hair dryers. If frayed or poorly sealed, the asbestos can be a source of household contamination. Asbestos is also used in the household as artificial fireplace embers which glow when heated. Subsequently they are very easily made airborne by draughts.

Some children's arts and crafts materials have been found to contain asbestos, with some papier maché products consisting of as much as 50 % chrysotile (figure 5*a*). Such products have been widely used in primary schools in both the U.S.A. and U.K. (Aaronson & Kohl 1972; Dr J. S. P. Jones, personal communication). Some model-building substances contain bladed and fibrous amphibole (figure 5*b*).

Some fabrics and clothing products contain asbestos. Brushing or shaking of coats containing 8 % asbestos fibre (figure 4*g*) create asbestos dust levels equal to those encountered in occupational situations. In the case of one batch of women's coats, the asbestos was added to the cloth in an attempt to obtain the low import duty on asbestos textile products rather than the very high duty on reprocessed wool fabrics.

Asbestos is present in some consumer talcum products, its presence and proportion depending on geological provenance of the talc source and the subsequent refinement. Up to 20 % asbestos has been found in a commercial talcum product, but this is not the general case (see § 4).

4. TALC AND SOAPSTONE

Talc, soapstone and pyrophyllite (see § 5) are used as dry carriers of active pesticide chemicals (63400 tons in U.S.A. in 1971 – U.S. Bureau of Mines 1971). Some of these mineral carriers may be ingested together with the produce and some may be inhaled as the particle size (5 μm) is below the critical respirable diameter (K. Kay 1974). Windom, Griffin & Goldberg (1967) attributes the presence of as much as 1 % (by mass) of talc in air samples to contamination from these agricultural sources.

Localized increase in talc in the atmosphere occurs where talc- (and asbestos-) containing ornamental, textured spray paints are used. Ingestion of talc can occur by eating foods to which talc has been added, such as salami, or peanuts polished with talc, as well as talc-coated rice (see § 3). Talc is also used as an excipient and filler for pills and tablets (Blejer & Arlon 1973).

Talc as a lubricant for surgeons' gloves and contraceptive diaphragms has largely been pre-empted (cf. Hopkins & Taylor 1970), but a major household utilization is in cosmetic and body powders, spray deodorants and aerosol talcum products. Diagnosis of talcosis, known from the industrial situation (table 1), is very rare in the household situation but has been made where respiratory symptons followed the very heavy and persistent use of talcum powder (Nam & Gracey 1972).

Commercial talc is generally not a monomineralic material and its bulk chemical composition generally shows marked differences from that of the mineral talc (tables 5, 6). Schulz & Williams (1942) showed that not one of fifty-one 'talcs' analysed were 100 % talc and Pooley & Rowlands (1977) have determined that a range of bulk talc imports into the U.K. contained 42–96 % talc by mass. Other mineral proportions are carbonate (0.5–44 %), chlorite (0–55 %), quartz (generally 1–2 %), tremolite (over 30 % in one sample), rutile and magnetite (cf. table 6, cols. 3–8). Tremolite and anthophyllite are present in considerable proportions in a number of U.S.A. bulk talc powders examined (figure 6*g*; table 6, cols 3–6) while the source of the talc, either from altered serpentinized ultramafic rocks or metamorphosed carbonate rocks

(Turner 1968), is shown by trace and major element compositions as well as by mineralogical constitution. In this regard, high proportions of chromium (generally in chrome spinel or chlorite), nickel (commonly in the talc itself) and cobalt are indicators for bulk talc powders (table 6, cols. 7, 8), and nickel and cobalt in the mineral talc (table 5, col. 2, table 6, col. 2), of ultramafic source rocks. Serpentine minerals, including chrysotile, are common associates of talc in this geological situation while tremolite commonly occurs with talc in the metamorphosed carbonate rocks.

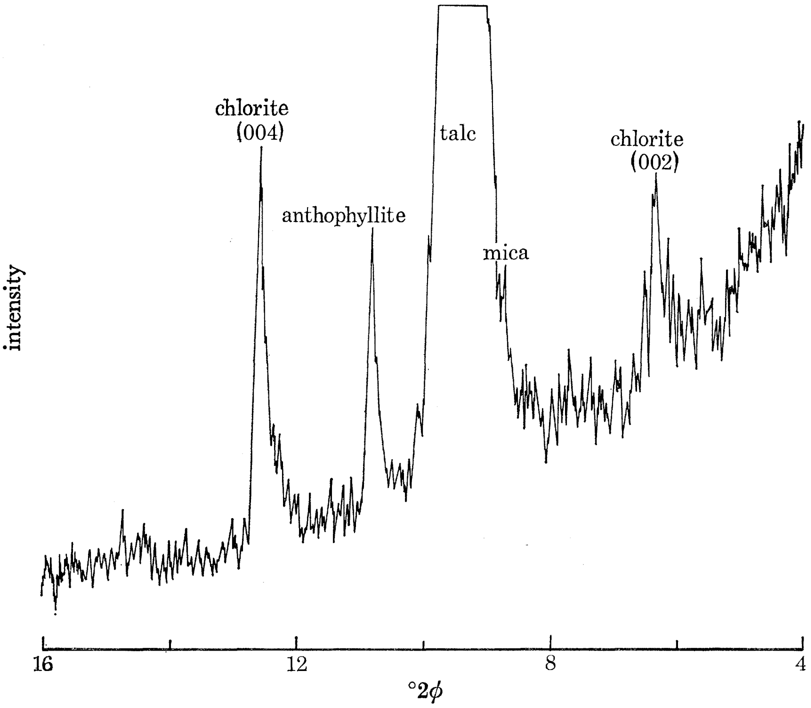

FIGURE 7. Continuous X-ray diffraction trace of consumer talcum powder purchased in New York City

A study by Cralley *et al.* (1968) of twenty-seven consumer talcum products showed that fibrous constituents were present in all of the samples, but their identification was not made. A further study has been carried out on forty-five consumer talcum products purchased during 1973 in retail stores in the U.S.A. (New York City) and U.K. (Glasgow). Mineralogical constitution has been determined by optical microscopy, X-ray diffraction, transmission electron microscopy, selected area electron diffraction and microchemical scanning electron microscopy. Major and trace element analyses were carried out on samples that had been extracted twice using boiling acetone, followed by two extractions with both benzene and ether. This was done to remove additives. (Samples found by X-ray diffraction to contain boric acid and/or zinc oxide had previously been extracted three times in warm water and/or dilute hydrochloric acid.)

Of the twenty-seven consumer talcum powders purchased in the U.S.A., eleven contained tremolite and/or anthophyllite (figures 6*b*, *d*, *e*, 7, 8*d*, *e*, 9*b*, *c*) in proportions ranging from 0.5 % to over 14 %, by mass, with the mean value being approximately 5 %. In four additional samples where X-ray diffraction, in the step scan mode of operation, suggested the presence of tremolite or anthophyllite near the detection limits (0.1 and 2.0 % respectively), electron microscopy was used for confirmation. Electron microscopy also indicated that some amphibole crystals occur in the talc interlayer (figure 6*c*). Three samples contained chrysotile (figure 6*a*,*f*) in the order of 0.5–1 %. Twelve samples contained quartz, generally from 2 to 6 %, but ranging up to 35 %. Chlorite is an abundant constituent in a number of the samples (e.g. figure 7) and carbonate minerals were identified. Kaolinite was found in four samples, presumably as an additive to provide the requisite lubricity, whiteness and absorbency consonant with talc. Rutile was present in a face powder and other minerals include micas (figure 7), feldspars and chrome spinel (table 5, col. 8). One 'baby powder' consisted of 98.7 % organic compounds (starch) and 1.3 % alumina (Rohl *et al.* 1976*b*).

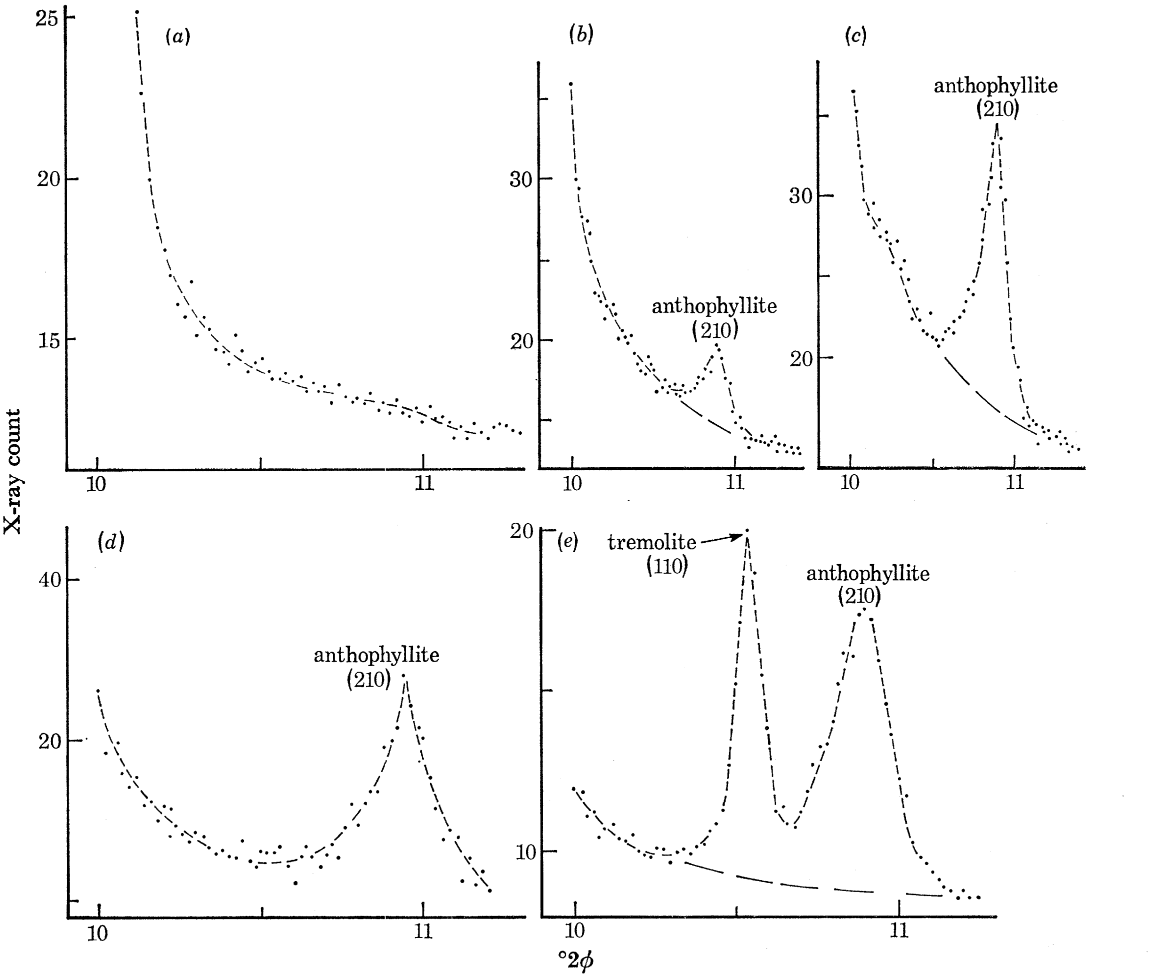

FIGURE 8. X-ray diffraction step scans of talc samples. (*a*, *b*, *c*) Representative dilution standards containing 1 %, 5 % and 10 % anthophyllite in talc. (*d*, *e*) Consumer talcum powders purchased in New York City.

The eighteen consumer talcum products purchased in the U.K. were more uniform in their mineralogical constitution than those purchased in the U.S.A., a lower proportion contained minerals found in asbestiform habit and quartz, and these minerals were generally present in lesser proportions. These features are consistent with the general differences in the bulk talc powders in the U.K. and U.S.A. (table 6, cols. 3–8, table 5, cols. 3–6). Tremolite was identified in only two of the U.K. consumer talcum samples (figure 9*a*), anthophyllite in only one and a serpentine phase positively identified in only one sample. Quartz was present in nine samples, generally in the proportion of 1 to 2 %, but one sample contained 8 % quartz. Chlorite and carbonate minerals were identified and kaolinite was a major constituent in three samples.

There is a systematic correlation between mineralogical constitution and major and trace element content of the samples from both the U.S.A. (table 5, cols. 7–13) and the U.K. (table 6, cols. 9–13). High alumina proportions and the high range of gallium proportions are linked to high chlorite, kaolin or feldspar proportions. Those analyses showing the highest proportions of CaO are of samples containing considerable proportions of calcium-bearing amphiboles, this being particularly the case for the U.S.A. samples and consistent with the nature of some of the bulk talc powders.

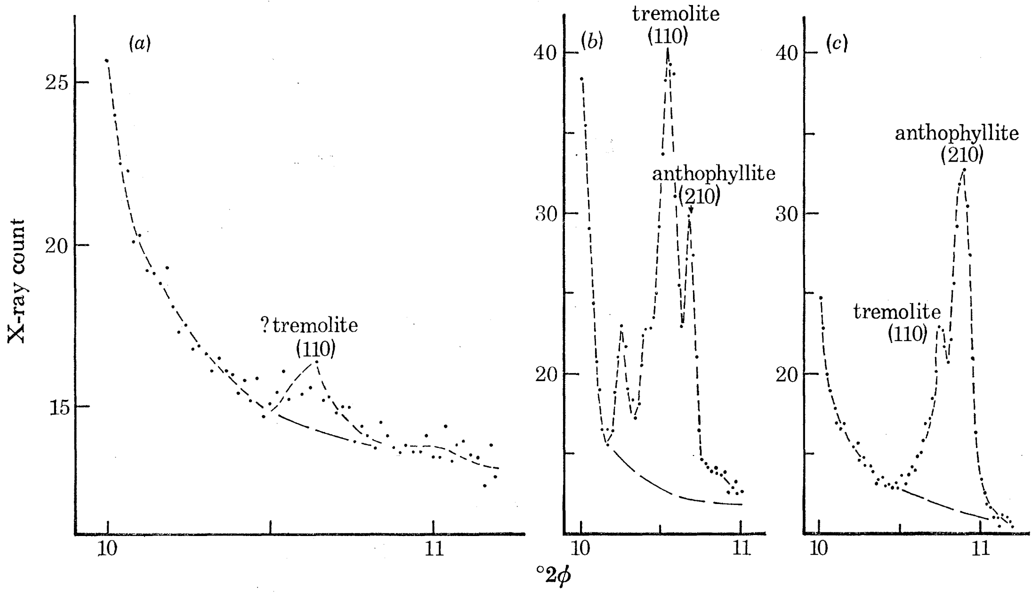

Figure 9. X-ray diffraction step scans of consumer talcum powders. (*a*) Purchased in Glasgow, U.K. and possibly containing tremolite. (*b*, *c*) Purchased in New York City and containing varying proportions of tremolite and anthophyllite.

Differences in the sources of consumer talcum products marketed under the same company label are illustrated by analyses 7 and 8 of table 5. The former, an import into the U.S.A. from the U.K., reflects the high quality of much of the bulk talc powder, derived from metamorphosed limestones, that is imported into the U.K. The latter, with its high proportions of nickel, chromium and cobalt, and the presence of chrome spinel, reflects the derivation from ultrabasic rocks of a considerable proportion of bulk talc powders in the eastern parts of the U.S.A. None of the U.K. consumer talcum products has a composition suggesting that talc derived from ultrabasic rocks (cf. table 6, cols. 7, 8) is used in them.

5. CLAY AND MICACEOUS MINERALS

Bentonite and fuller's earth have been used in insecticides and fungicides but their widest application is in absorbants, particularly animal litter (44 % of the 576000 tonnes absorbant demand in the U.S.A. in 1971). Vermiculite is also used in animal litter. It is extensively used as a packing material, in sprayed and do-it-yourself insulation material and in home horticulture as a soil extender and moisture retainer. Some vermiculite used contains significant proportions

TABLE 5. ANALYSES OF TALC, BULK TALC POWDERS AND CONSUMER TALCUM PRODUCTS

	1	2	3	4	5	6	7	8	9	10	11	12	13
						chemical analyses							
SiO_2	62.08	62.60	54.85	56.11	62.59	59.70	59.93	58.68	62.26	47.32	52.95	53.83	71.93
TiO_2	0.04	0.03	0.04	0.07	0.06	0.05	0.10	0.08	0.06	0.18	0.17	0.11	0.19
Al_2O_3	0.70	0.18	0.38	0.13	0.24	1.00	0.79	0.58	0.45	9.34	1.16	1.74	15.73
Fe_2O_3	0.03	0.17	0.10	0.08	0.05	0.20†	0.00	0.12	0.18	0.05	0.02	0.03	0.10
FeO	0.27	2.01	0.04	0.05	0.04	—	0.84	3.12	1.04	1.22	0.86	0.70	0.34
MnO	0.00	0.02	0.21	0.22	0.31	Tr	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	31.20	29.54	28.40	29.40	26.70	24.75	30.40	29.23	30.00	29.83	29.02	27.14	2.95
CaO	0.15	0.09	9.02	7.50	5.35	5.50	0.50	0.17	0.13	0.69	3.46	5.49	2.37
Na_2O	0.31	0.31	0.28	0.18	0.28	—	0.09	0.00	0.09	0.03	0.00	0.07	0.48
K_2O	0.00	0.00	0.10	0.10	0.17	Tr	0.02	0.00	0.05	0.05	0.05	0.00	1.37
P_2O_5	0.01	0.01	0.03	0.03	0.02	—	0.13	0.00	0.01	0.21	0.13	0.14	0.05
H_2O+	5.46	5.06	5.37	5.00	3.13	—	—	—	—	—	—	—	—
CO_2	0.00	0.02	1.35	1.03	0.70	0.60	—	—	—	—	—	—	—
loss on ignition	—	—	—	—	—	—	5.65	5.34	5.92	10.26	10.32	10.81	5.25
total	100.25	100.04	100.17	99.90	99.64	—	98.45	97.32	100.19	99.18	98.14	100.06	100.76
						trace elements (parts/10^6)							
Ba	< 20	< 20	137	134	855	70	< 10	< 10	< 10	< 10	< 10	< 10	50
Ce	< 10	< 10	n.d.	n.d.	n.d.	n.d.	< 10	< 10	< 10	< 10	< 10	< 10	10
Cl	115	110	—	—	—	—	130	115	165	120	200	430	130
Co	< 3	192	n.d.	n.d.	n.d.	n.d.	4	88	21	< 3	< 3	< 3	< 3
Cr	22	47	36	34	40	70	30	820	340	24	23	38	< 15
Cu	< 5	< 5	39	21	33	1	7	< 5	13	< 5	< 5	5	9
Ga	2	4	—	—	—	—	3	< 1	2	13	1	2	20
La	< 10	< 10	n.d.	n.d.	n.d.	—	< 10	< 10	< 10	< 10	< 10	< 10	40
Li	4.9	< 1	—	—	—	—	—	—	—	—	—	—	—
Nb	< 3	< 3	4	4	n.d.	n.d.	8	5	5	18	7	7	14
Ni	37	2200	18	16	22	24	20	2210	460	11	13	10	< 4
Pb	8	< 5	—	—	—	—	7	7	6	5	< 5	7	49
Rb	< 5	5	5.5	2.1	< 1	17	5	< 5	5	< 5	< 5	< 5	45
S	70	70	263	—	—	—	160	155	320	280	440	485	305
Sc	< 1	< 1	—	—	—	—	—	—	—	—	—	—	—
Sr	15	15	—	244	237	178	10	< 10	< 10	< 10	20	15	160
Th	< 5	< 5	—	—	—	—	< 5	< 5	< 5	< 5	< 5	< 5	6
V	1.4	< 1	11	14	4.1	2.7	—	—	—	—	—	—	—
Zn	< 3	39	36	41	14	37	8	37	73	—	12	35	20
Zr	< 10	< 10	n.d.	n.d.	n.d.	43	< 10	< 10	< 10	30	90	< 10	190

n.d., not detected.

† Total Fe as Fe_2O_3.

Analysts: 1–5, W. M. Neilson; 6, major elements from Rowlands (1974), trace elements – G. W. Robb & D. L. Skinner; 7–13, D. L. Skinner.

Mineral samples from source areas of U.S.A. bulk talc powders.
1: talc; Dillon, Montana.
2: talc; Georgia.
U.S.A. bulk talc powders.
3, 4, 5: Northeastern U.S.A. (Nytal 100, Nytal 400, Fibertal 2).
6: Warm Springs, California (as imported into U.K.).
U.S.A. consumer talcum products (purchased in New York 1973).
7, 9: baby powder.
8, 10–13: talcum powder.

TABLE 6. ANALYSES OF TALC, BULK TALC POWDERS AND CONSUMER TALCUM PRODUCTS

	1	2	3	4	5	6	7	8	9	10	11	12	13
						Chemical analyses							
SiO_2	62.85	63.13	61.90	58.26	61.22	60.50	53.10	43.80	57.28	53.74	56.68	58.50	52.87
TiO_2	0.06	0.04	0.07	0.08	< 0.05	< 0.05	< 0.05	< 0.05	0.03	0.13	0.00	0.12	0.57
Al_2O_3	0.14	0.31	1.00	1.40	1.20	0.20	2.10	1.60	0.21	0.82	4.67	1.77	2.46
Fe_2O_3	0.17	0.21	0.89†	1.02†	0.54†	0.21†	2.85†	6.09†	0.00	0.00	0.06	0.05	0.00
FeO	0.33	1.92	—	—	—	—	—	—	0.15	0.64	0.78	0.74	0.77
MnO	0.00	0.02	Tr	Tr	Tr	Tr	Tr	Tr	0.00	0.00	0.00	0.00	0.00
MgO	31.16	29.56	29.90	29.53	30.60	30.40	28.20	28.40	32.00	28.61	31.42	30.31	27.30
CaO	0.39	0.05	0.30	0.60	0.20	0.40	3.10	0.80	0.81	0.36	0.04	1.25	5.25
Na_2O	0.12	0.10	—	—	—	—	—	—	0.00	0.00	0.00	0.07	0.12
K_2O	0.00	0.04	Tr	Tr	Tr	Tr	Tr	Tr	0.00	0.00	0.00	0.00	0.09
P_2O_5	0.26	0.00	—	—	—	—	—	—	0.09	0.09	0.00	0.11	0.12
H_2O+	4.85	4.73	—	—	—	—	—	—	—	—	—	—	—
CO_2	0.06	0.27	0.40	1.20	0.06	1.60	11.40	23.00	—	—	—	—	—
loss on ignition	—	—	—	—	—	—	—	—	9.20	15.58	6.58	5.80	9.70
total	100.39	100.38	—	—	—	—	—	—	99.77	99.97	100.23	98.72	99.25
						trace elements (parts/10^6)							
Ba	< 20	55	36	34	25	30	115	32	80	< 20	< 20	30	720
Ce	< 10	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	< 10	< 10	< 10	< 10	< 10
Cl	160	—	—	—	—	—	—	—	470	210	170	120	120
Co	< 3	80	n.d.	n.d.	n.d.	n.d.	142	61	< 3	< 3	< 3	< 3	< 3
Cr	29	48	38	33	30	30	2865	1615	33	32	34	42	33
Cu	9	—	1	4	1	16	2	21	< 5	< 5	< 5	< 5	6
Ga	6	—	—	—	—	—	—	—	< 1	6	< 1	< 1	8
La	< 10	—	—	—	—	—	—	—	< 10	< 10	< 10	< 10	< 10
Li	4.9	—	—	—	—	—	—	—	—	—	—	—	—
Nb	< 3	n.d.	n.d.	n.d.	2	n.d.	3	5	< 3	< 3	9	< 3	5
Ni	14	2235	27	27	22	21	2530	1995	11	16	14	16	14
Pb	< 5	—	—	—	—	—	—	—	< 5	< 5	< 5	7	< 5
Rb	< 5	—	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	< 5	< 5	< 5	< 5	10
S	130	—	—	—	—	—	—	—	130	280	190	120	580
Sc	< 1	—	—	—	—	—	—	—	—	—	—	—	—
Sr	< 10	91	92	92	88	85	158	105	< 10	< 10	< 10	15	55
Th	< 5	—	—	—	—	—	—	—	9	< 5	< 5	< 5	< 5
V	< 1	—	4.7	4	1.6	< 0.1	11	7.6	—	—	—	—	—
Zn	< 3	—	n.d.	n.d.	< 0.6	< 0.6	3.1	< 0.6	< 3	32	< 3	< 3	< 3
Zr	10	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	15	15	20	20	30

n.d., not detected.

† Total Fe as Fe_2O_3.

Tr, trace.

Analysts: 1, 2, W. M. Neilson; 3–8, major elements from Rowlands (1974), trace elements – G. W. Robb & D. L. Skinner; 9–13, D. L. Skinner.

Mineral samples from source areas of U.K. bulk talc imports.
1: talc; Val Chisone, Italy.
2: talc; Brazil.
U.K. bulk talc powders (imported and indigenous).
3: extra super grade, Italy.
4: extra T grade, Sardinia.
5: 00 grade, France.
6: Hiachen, China.
7: 70 grade, Norway.
8: Shetland, U.K.
U.K. consumer talcum products (purchased Glasgow 1973).
9, 12: baby powder.
10, 11, 13: talcum powder.

of fibrous tremolite (figure 5*e*) and chrysotile fibre bundles (figure 5*f*). Such fibres may be inhaled in the domestic situation particularly from the fine dust of animal litter (cf. figure 2*e*).

Montmorillonite and bentonite are present, together with diatomaceous earth and glass fibres in reconstituted tobacco sheet (see below) and pyrophyllite is used as a pesticide carrier. Micas are used on a large scale in the production of roofing material and find their way into households as a constituent of some wall-finishes and some wall-papers (cf. table 1). The presence of sepiolite in the soil of certain regions has been related to the occurrence of endemic pleural calcifications there (Burilkov & Michailova 1972).

6. SILICA AND GLASS FIBRE

(*a*) *Quartz*

Quartz is an abrasive agent in scouring powders in which it is commonly present in proportions of 60–70 %. It is also used in abrasive soap, with exposure to silica in the manufacturing situation known to have led to silicosis (table 1). Since Na_2CO_3 is often mixed with the quartz, silicic acid, whose toxicity is well documented, may be produced in the domestic situation.

Quartz is a common constituent in many patching and plastering compounds used in home building and repairs (Rohl *et al.* 1975). Its proportions in these compounds was found to be 5–70 % with associated minerals being talc, clays, pyrophyllite and asbestos. Quartz is also commonly present in consumer talcum products sold in the U.S.A. The proportion generally ranges from 2 to 6 % but as much as 35 % has been found.

(*b*) *Diatomite*

Diatomaceous earth is a common and abundant constituent in filters, insulation material, toothpaste (as an abrasive agent) and extenders. It is also used in reconstituted tobacco sheet. Because of its widespread use, diatom fragments are frequently found in lung tissue (figure 2*b*), including that of family contacts of insulation workers (figure 2*d*).

(*c*) *Cristobalite*

Calcining of diatomite results in the production of cristobalite which is more fibrogenic than quartz and associated with progressive silicosis. It has been identified as the major mineral constituent of a children's modelling material (figure 10). Identification, by optical microscopy, of relict traces of diatoms is indicative of its source material and means of manufacture. X-ray diffraction indicates that the α-cristobalite is associated with gypsum, α-quartz and a hydrated copper sulphate.

Selected area electron diffraction patterns on diatom fragments in ash and smoke samples from cigars made of reconstituted tobacco sheet (figure 4*f*) have shown that the major structure is that of high cristobalite. Some reflexions suggest the additional presence of tridymite (Langer *et al.* 1971*a*).

(*d*) *Amorphous* (*precipitated*) *silica*

Amorphous opaline silica is used in foods as a desiccant conditioning agent and preservative. On the basic of information supplied by the (U.S.A.) Silica Manufacturing Ad Hoc Committee and Occupational Safety and Health Committee, and by various manufacturers, this variety of silica is found, up to 2 %, in table salt, baking powder, cereals, cake mixes, sugar, flour, spices, vitamins and dehydrated foods such as powdered milk.

(*e*) *Glass fibre and rock wool*

Man-made glass fibres have become the most common insulation material for domestic and industrial applications. With both the increasing use of insulation and the biological hazards of some alternative mineral insulating material, its utilization is likely to continue to increase, not least in the do-it-yourself household situation. Association of inhaled fibres with bronchitis and asthma is known as are its effects as a skin irritant (table 1). However, levels of exposure to respirable glass fibres and their biological potential warrant careful review.

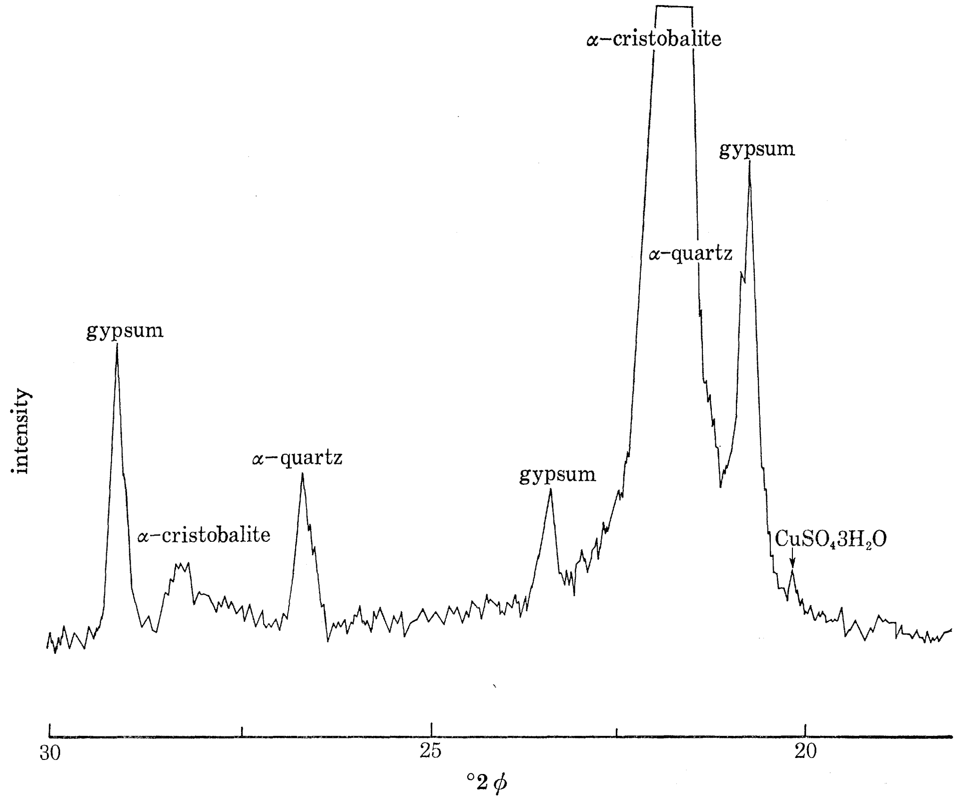

FIGURE 10. Continuous X-ray diffraction trace of children's modelling compound purchased in New York City.

7. OTHER MINERAL DUSTS

(*a*) *Rutile and anatase*

Rutile and anatase are widely used in paints, plastics, papers and cosmetic products, particularly face powders. As a result they are commonly present in house dusts.

(*b*) *Galena*

Brake linings containing 26 % galena, 6 % metallic lead powder and 6 % chrysotile have been used on subway trains in New York. Any large-scale use of such brake shoes could be a source of significant lead exposure to passengers as well as staff in addition to a source of exposure to chrysotile whose ability to survive braking action in automobiles has been demonstrated.

8. Discussion

The nature and range of mineral dusts in the environment is the combined product of a whole group of factors, many of which are intimately bound up with the life-styles of members of industrial societies as well as with the patterns of economic development which the expectations of these life-styles encourage. However, just as industrial exposure to mineral dusts spills over into environmental exposure, for example family contacts or residents near a factory with inadequate emission controls, so too does the burden of mineral dusts in the atmosphere of industrial areas become a general atmospheric dust burden that is not limited to a localized region, or even to a particular country.

While the effects of legislation have greatly reduced dust levels in industry, and hence in the environment generally, the multifarious utilization of mineral-containing materials in the domestic situation, the increase in the demolition of asbestos-containing buildings in urban renewal programmes and the increase in open-cast mining of relatively low-grade deposits have had the opposite effect in the particular as well as the general situation. Dust associated with open-cast mining includes that from inadequately controlled waste material. Many such dusts contain amphibole minerals, such as grunerite. These include those from metamorphosed ironstone deposits in North America (James 1955; Klein 1966) and from metamorphosed base metal deposits in South Africa which are just beginning to be exploited (cf. Bowes 1977) in remote areas much subject to strong winds.

Changing life-styles have spurred on the food industry to fulfil the aesthetic and convenience preferences of the public, partly by use of certain minerals in particular foodstuffs. The demand for other convenience products, such as spray deodorants containing very finely ground minerals for dryness and lubricity, has risen steeply as has the demand for mineral-containing do-it-yourself home repair and improvement products. The rising cost of fuel has added to the demand for mineral or synthetic insulation material, much of which is fibrous. Increase in automobile use carries with it an increased burden of asbestos in the air while, on an individual level, the inhalation of mineral dusts from tobacco products continues. In ways such as this the general public contribute to the spread of a whole range of mineral dusts, either locally, or generally, in the environment.

With the causal relationships of certain mineral dusts to particular human diseases (table 1), the evidence that such diseases do not solely affect those subject to heavy and prolonged dust exposure in an occupational situation, and the evidence of fibrous and other mineral dusts in the lungs of the general population (cf. figure 2*f*), it is important that environmental mineral dusts should be looked at more thoroughly in terms of their biological potential. In this examination the history of the study and understanding of asbestos-related disease provides much food for thought. Particularly to be noted is the long time that elapsed between the medical awareness of the problem in the United Kingdom and both the introduction of effective control procedures in many situations in industry and the initiation of intensive programmes of mineralogical and geochemical research (cf. Bowes 1974).

Research in association with medical scientists, as well as the monitoring of the nature and range of mineral dusts in the environment, appear to be vital rôles for mineralogists as the 21st century is approached. The resultant assessment of disease risk from mineral dusts and the extension of the effectiveness of remedial treatment, together with the development of methods of safe use and handling in the industrial situation, could be significant contributions in the field of preventative medicine. With preventative measures likely to be more effective than medical remedial measures, increased public awareness of these matters is very important. Hence the education of the general public in mineralogy and its applications is also a task to which mineralogists must set themselves.

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Discussion

J. ZUSSMAN (*Department of Geology, University of Manchester*). I should like to make a comment relevant to Professor Bowes's paper, on the subject of terminology. On environmental matters, mineralogists and geologists will be talking to medical and other environmental scientists, and it is important that they should understand each other's terms.

With regard to particle morphology, although mineralogists have no precise divisions there is general agreement about the use of the terms 'prismatic', 'acicular' and 'asbestiform' for particles with increasing aspect ratio. The terms 'fibrous' and 'fibre' are perhaps still less well defined, but are generally used to describe material ranging from acicular to asbestiform. For discussion of health hazards, however, a 'fibre' has been defined as a particle with aspect ratio greater than three to one. To mineralogists a particle with ratio near three to one would be termed prismatic and not even acicular, still less a fibre. We will have to get used to it being termed a fibre in the environmental context, however, where it refers to what aspect ratio is potentially harmful, and includes a margin of error to be on the safe side.

A recently published paper (not by Bowes) took this one stage further, and I feel too far, and gave the 'greater than three to one' ratio as defining 'asbestiform'. Professor Bowes referred to the grunerite in the Minnesota Iron Formations as asbestos. Geologists who have given petrographic descriptions of these taconite deposits have described the varied grunerite crystals as prismatic, acicular and fibrous but never as asbestiform or asbestos. The grunerite does not have the extreme aspect ratio or the kind of fibril aggregation characteristic of asbestos.

I would like to emphasize that the physiological effects of such material as compared with those of asbestos certainly need to be investigated, whatever the terminology, but it should be called fibrous grunerite not grunerite asbestos or asbestiform.

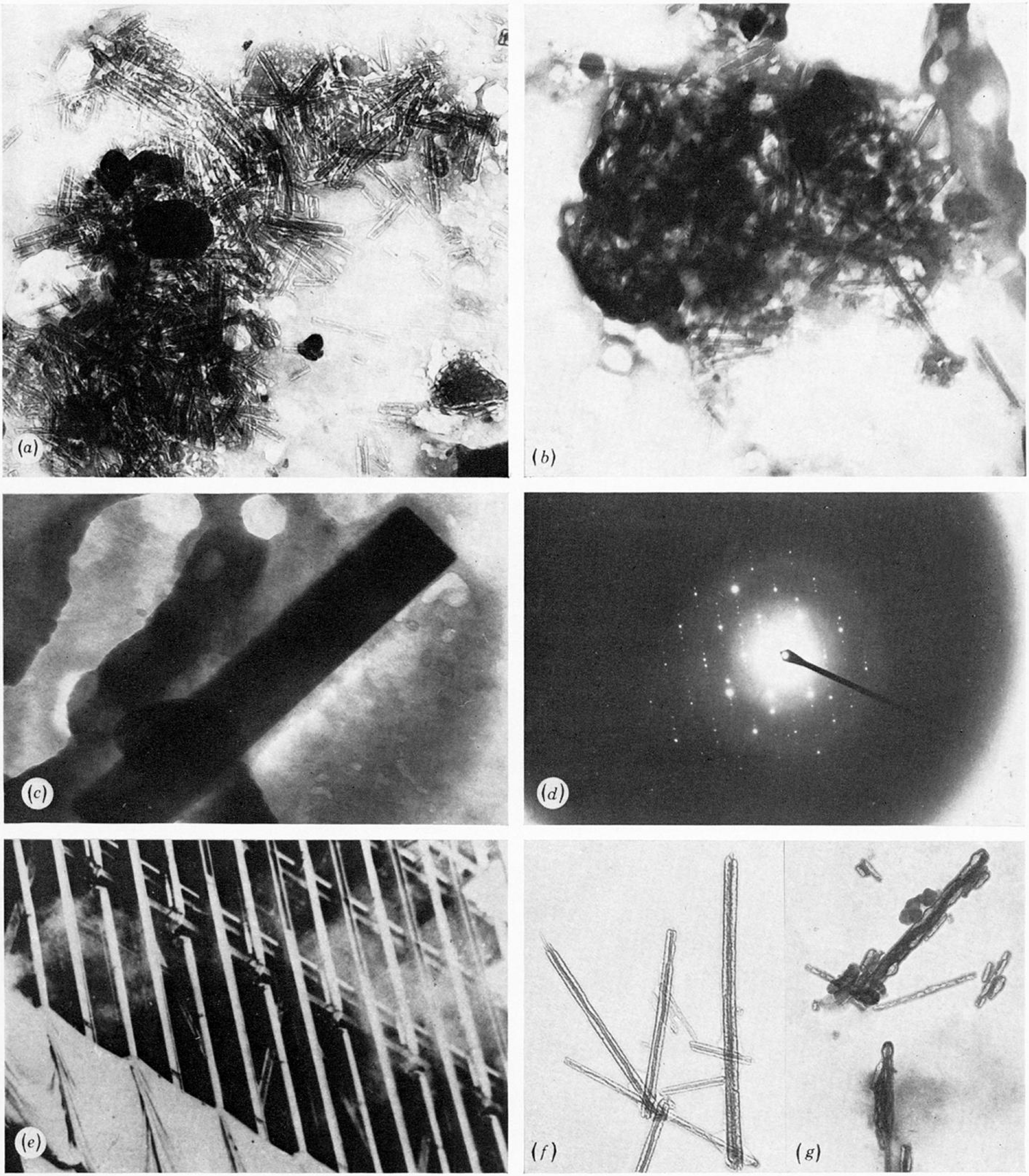

Figure 1. Mineral particles in the atmosphere. (*a*) Chrysotile in Greenland ice cap 1750; magn. × 55000. (*b*) Chrysotile in Greenland ice cap 1920; magn. × 40000. (*c*) Amphibole in Greenland ice cap 1920; magn. × 20000. (*d*) Selected area electron diffraction pattern of amphibole in (*c*). (*e*) Asbestos spray clouds at construction site, New York City. (*f, g*) Chrysotile in indoor air samples, New York City; magn. × 19000, × 15000.

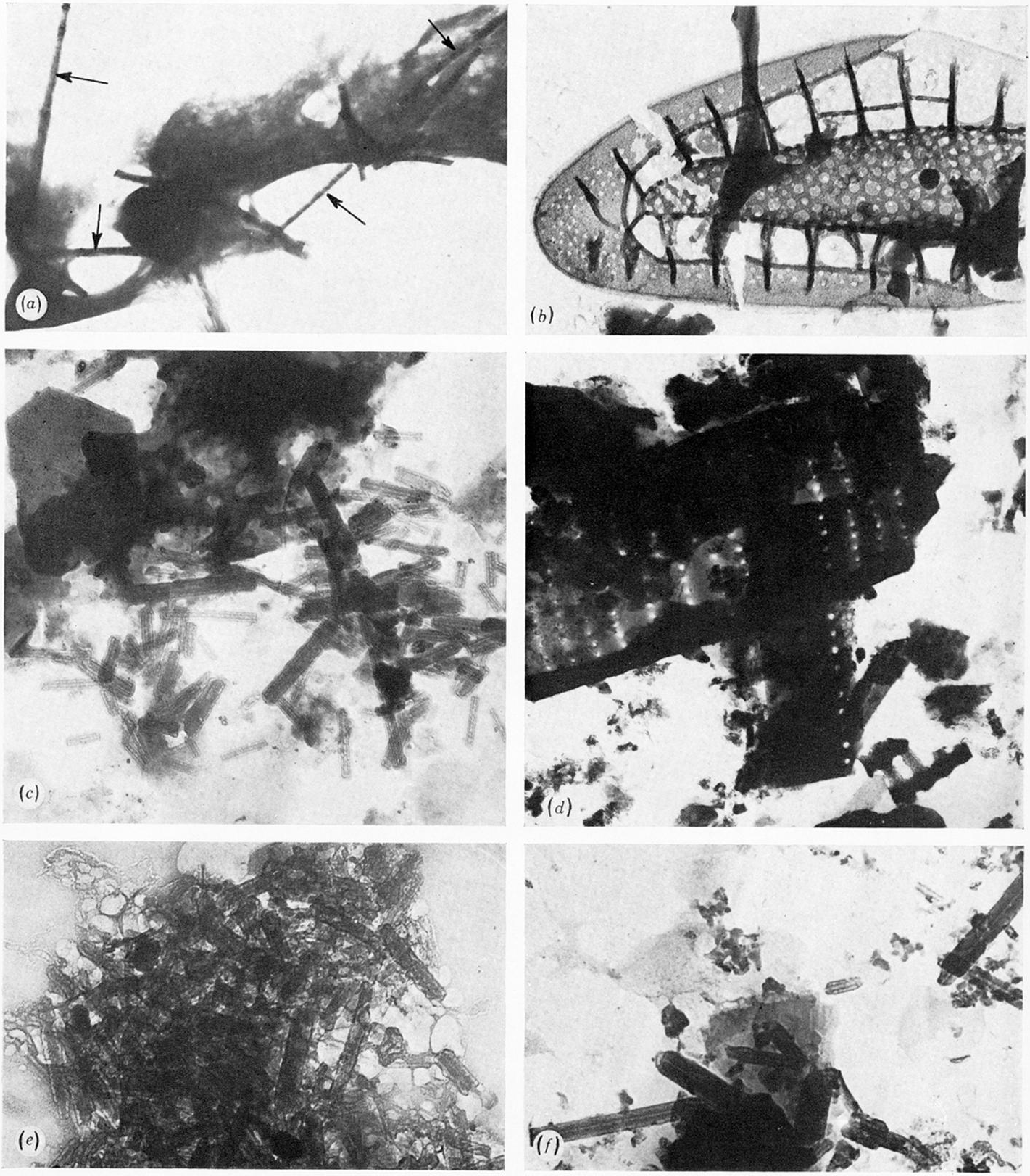

Figure 2. Mineral particles in human and animal lungs. (*a*) Amphibole asbestos in human lung tissue; magn. × 15000. (*b*) Diatom in human lung tissue; magn. × 25000. (*c*) Chrysotile in lung tissue of a family contact of an insulation worker; magn. × 50000. (*d*) Diatoms in lung tissue of a family contact of an insulation worker; magn. × 50000. (*e*) Chrysotile in lung tissue of a dog; magn. × 50000. (*f*) Chrysotile in lung tissue of a member of university academic staff without industrial exposure; magn. × 77500.

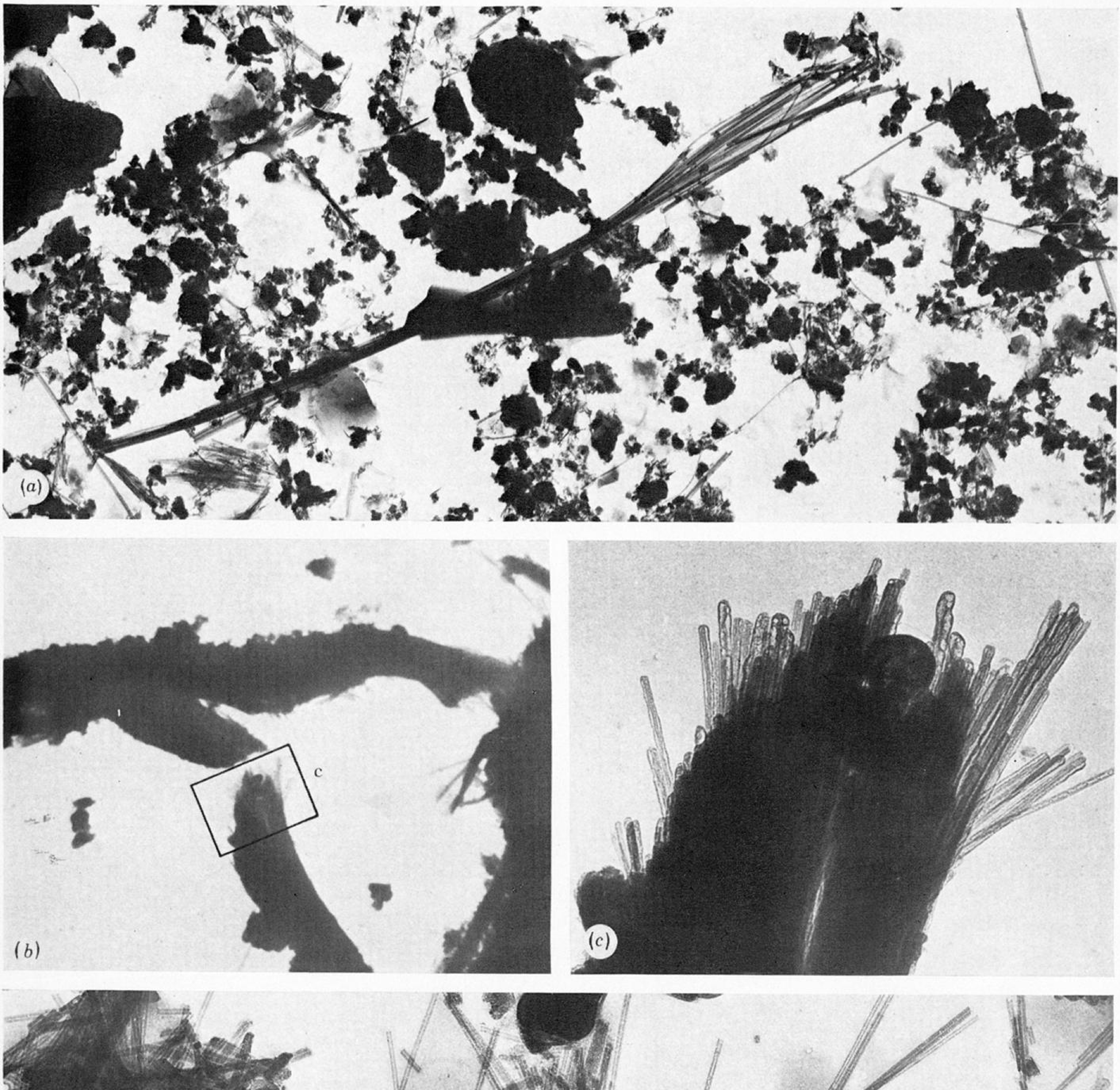

FIGURE 3. Mineral particles in dusts at the industrial–environmental interface. (*a*) Car brake dust containing chrysotile, resin binder and road dust, New York City; magn. × 25000. (*b*, *c*) Chrysotile in car brake dust, Birmingham, U.K.; magn. × 9000, × 55000. (*d*) Asbestos in dust of asbestos–vinyl floor tile factory; magn. × 50000.

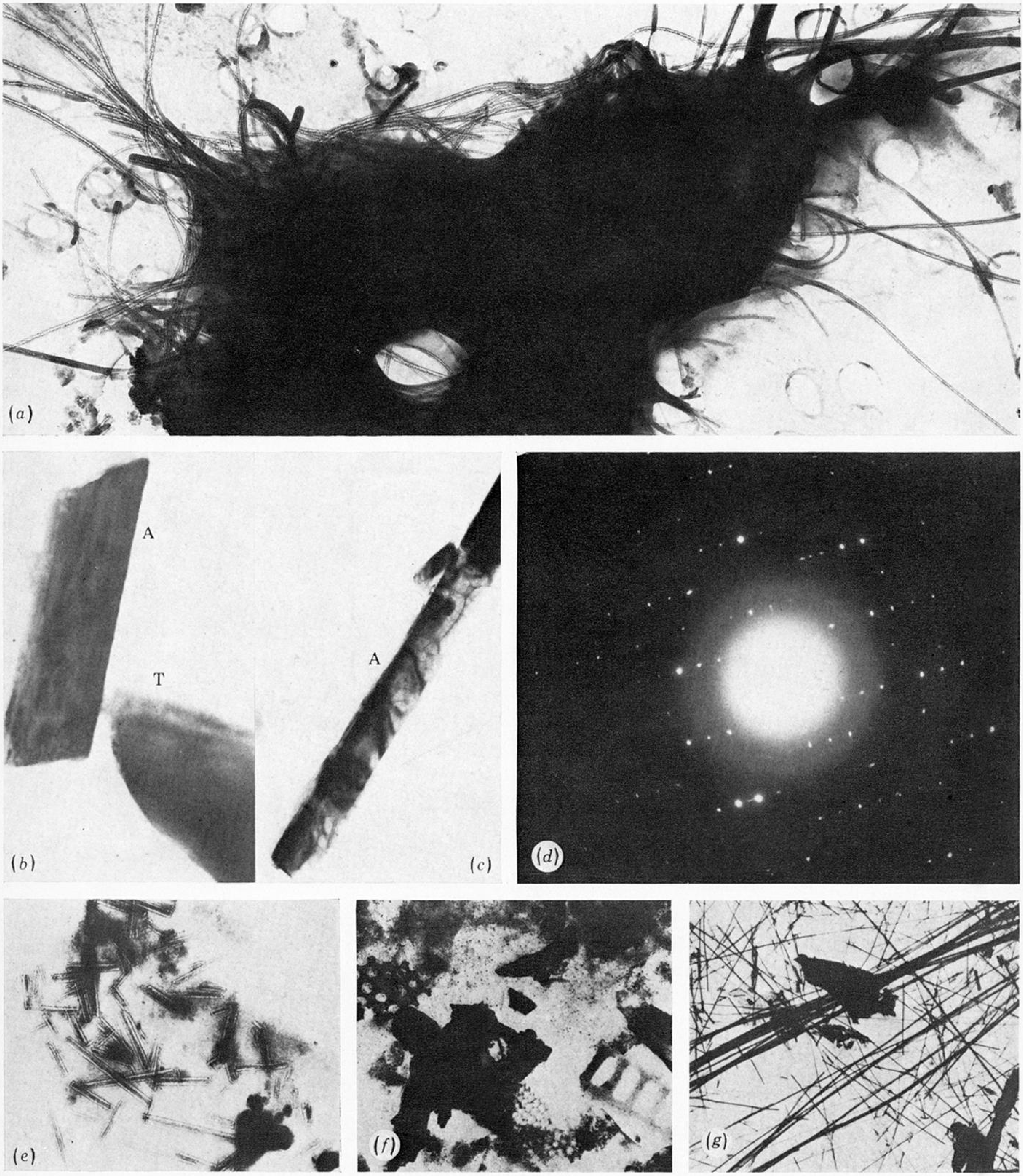

FIGURE 4. Mineral particles in water, food, drugs, tobacco sheet and clothing. (*a*) Chrysotile in water, Thetford, Canada; magn. × 40000. (*b*, *c*) Amphibole (*A*) and talc (*T*) on rice; magn. × 20000, × 15000. (*d*) Selected area electron diffraction pattern of amphibole in (*c*). (*e*) Asbestos in parenteral drug; magn. × 30000. (*f*) Diatom fragments and short fibres (arrowed) in low temperature ashed reconstituted tobacco sheet; magn. × 3000. (*g*) Chrysotile present (8 %) in a woman's coat; magn. × 2250.

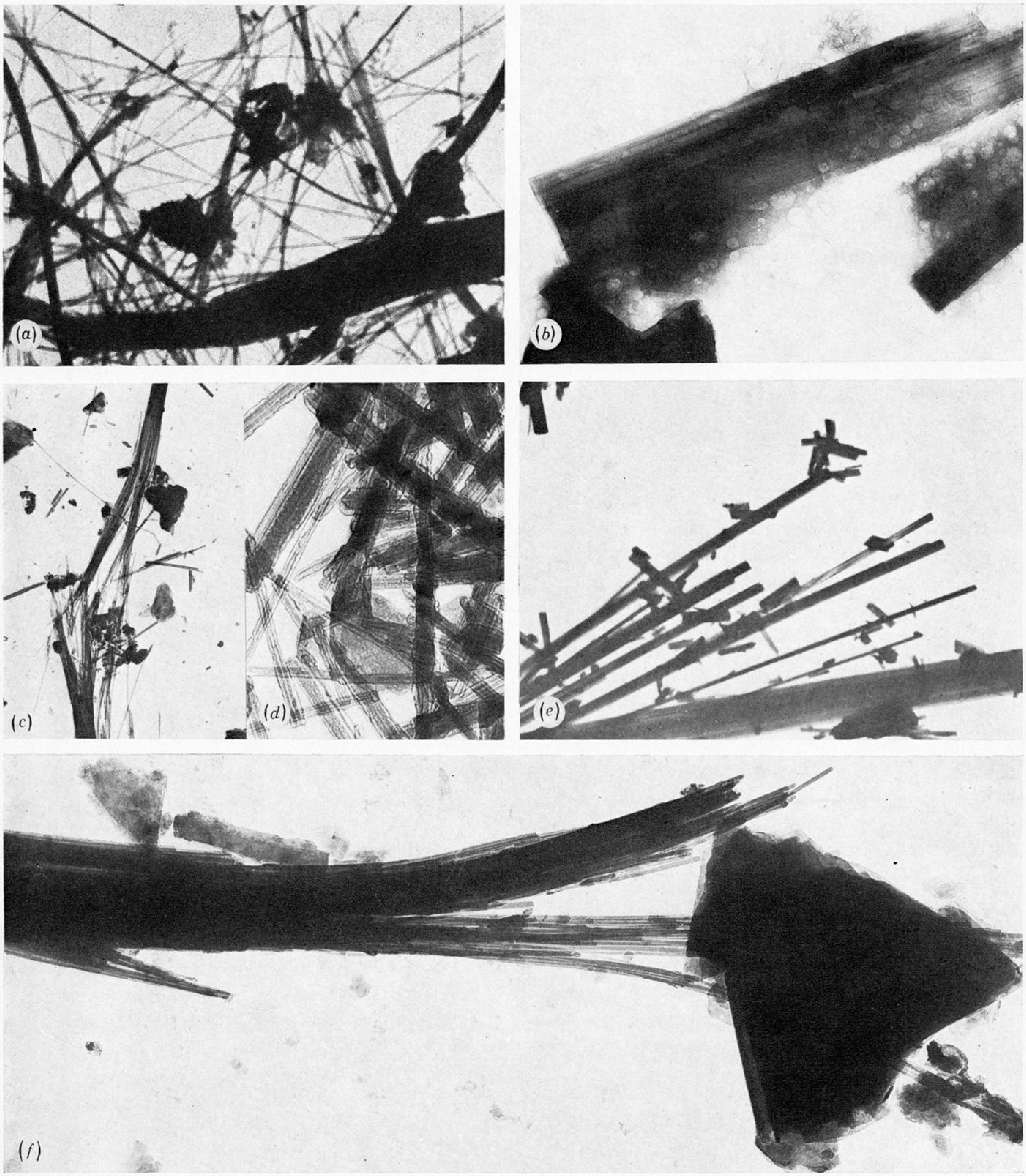

Figure 5. Mineral particles in leisure and domestic articles. (*a*) Chrysotile in papier maché; magn. × 4500. (*b*) Amphibole in children's modelling compound; magn × 17 000. (*c*, *d*) Chrysotile in plaster patching compounds; magn. × 10 000, × 100 000. (*e*) Tremolite fibres in vermiculite; magn. × 10 000. (*f*) Chrysotile fibre bundles in vermiculite; magn. × 40 000.

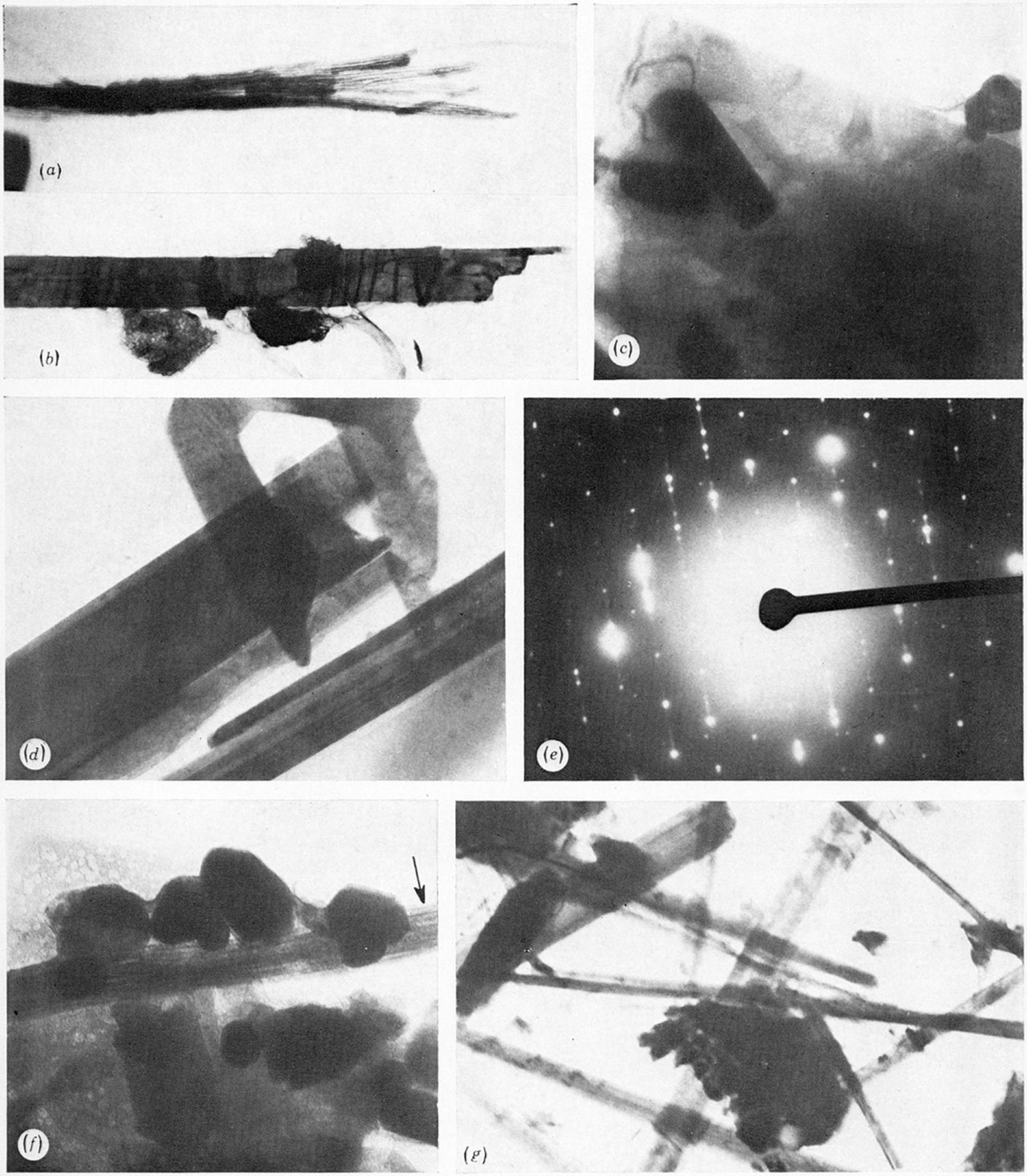

FIGURE 6. Mineral particles in consumer talcum products and commercial talc. (*a*) Chrysotile fibres in consumer talcum powder purchased in New York City; magn. × 66000. (*b*) Amphibole in consumer talcum powder purchased in New York City; magn. × 22500. (*c*) Small amphibole crystals in talc interlayer in consumer talcum powder purchased in New York City; magn. × 40000. (*d*) Amphibole in consumer talcum powder purchased in New York City; magn. × 25000. (*e*) Selected area electron diffraction pattern of amphibole in (*b*). (*f*) Chrysotile (arrowed) and talc in consumer talcum powder purchased in New York City; magn. × 75000. (*g*) Commercial talc containing elongate crystals of tremolite (60%) and anthophyllite together with flakes of talc and chlorite, northeastern U.S.A.; magn. × 3500.