World Trade Center Dust
Its Potential to Interact with Artifacts & Works of Art

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(This information is also available at http://aic.stanford.edu/health/wtc1.html)

Dust residues from the collapse of the World Trade Center (WTC) buildings may carry a mix of components not normally encountered with urban street dust[1]. Currently the Environmental Protection Agency (EPA) [4], the New York Committee for Occupational Safety and Health (NYCOSH) [6], Occupational Safety and Health Administration (OSHA) [8] are focusing on potential toxic contaminants in the air, on health hazards, and on suitable protocols for cleanup. This review focuses on the characterization of the dust, its potential to interact with artifacts and works of art in the vicinity, and the possible contamination of the conservation studio.

Dust refers to the mixture of airborne materials that settle upon surfaces. These airborne materials may have organic components but are most often inorganic in character. Because of variations in density, micron size, air currents, wall barriers, and filtration methods, the exact quantitative ratio of one component to another will not necessarily be consistent across a room, throughout a building, nor in a neighborhood [11]. While the chemical interaction of WTC dust with artwork is possible with certain dust components, the physical interaction (abrasion) is an important feature of small and hard materials. The EPA is monitoring small and large **particulates**, dividing them into two category sizes: under 10 microns and over 10 microns. The air quality index is based on the 24 hour accumulation of fine particles: more than 40 micrograms (millionths of a gram) in a cubic meter of air [$\mu g/m^3$] is considered harmful to sensitive individuals.

No differentiation is being made among the ‘non-hazardous’ particulates for chemical composition, crystalline structure, or size [4]. Of particular interest to conservators would be the smallest (less than 2.5 micron) particles since they are lightest and most difficult to control in a work space or studio[4]. They are generally too small for identification by conventional light microscopy. A precise analysis of dust components on a particular object can be carried out by commercial chemical analysis[2]. Qualitatively, the components of the WTC dust residues are known to include the following materials:

Asbestos, in one of its forms, is a naturally-occurring, mineral fiber composed of hydrated magnesium silicate, $Mg_3(Si_2O_5)(OH)_4$ [5]. It is chemically inert up to 500^o C: it does not burn (combust)[9]. The chrysotile fiber form was widely used in building construction for its fire retarding and heat insulating properties until it was determined to be carcinogenic and hazardous to the lungs. Optical light microscopy is insufficient for a positive identification of the fine fibers, as they may measure only 0.5 micron in width [10]. The chrysotile form reacts to heat in a two stage manner: in the range of 600-780^o C, the compound dehydrates (looses water). At 800-850^o C, the anhydride breaks down into forsterite and silica. Chrysotile asbestos has a Mohs hardness of 2.5-4.0[3] [5].

Using phase contrast microscopy upon bulk samples on debris and rubble at the WTC site 9/13-9/27, OSHA found asbestos contents ranging from non-detectable to 1.9 fibers/cubic centimeter (f/cc) with 50% of the asbestos found in the chrysotile form [8]. Settled dusts containing 1% measurable asbestos are listed as regulated material for handling and disposal under federal and state laws [4, 6]. Test samples by the EPA vary from non-detected to near 5% asbestos fiber [6, 4].

Silica and silicates occur in many forms. Synthetic vitreous fibers (SVF) or "fiberglass" are widely used for insulation and have a presence at the site[8]. When these staple glass fibers have dusts less than 3.5 microns (diameter) x 10 microns, they are considered a health hazard [5, 8]. Voluntary OSHA exposure limits are 1 f/cc during an 8 hour period. Specific monitoring of airborne silica by OSHA at the WTC site found ranges from twice the OSHA limit to less than detectable quantities [8]. Another amorphous form of material largely composed of silica is window glass. In this instance, it would be present as a silica dust, also monitored.

Other crystalline silicate powders normally occur in cities as buildings weather. The "canyons of Wall Street" and, Manhattan generally, have large quantities of cement and concrete. As a construction material, concrete is a mixture of portland cement, sand, gravel, and crushed stone, reinforced with steel rods and mesh [2]. Portland cement is a hydraulic cement: water activated, set, and hardened into non-water soluble material, containing the hydrated forms of tricalcium silicate (3CaO"SiO_2) and dicalcium silicate (2CaO"SiO_2) [5]. Thus, non-fibrous forms of silicates and other inorganic minerals are typically present in urban dust. Concrete, cement, and mortar dusts, become alkaline when moisture is present; materials susceptible to alkaline degradation or alkaline-triggered reactions could be affected. Some dust samples are showing 30-60% silicates [1]. On the Mohs scale, glasses and polycrystalline silicates lie between 5 and 7, and thus are capable of scratching copper, iron, aluminum, mild steel, and marble [5].

Air pollutants OSHA has found trace levels of nitric oxide and nitrogen dioxide at the WTC site; sulfur dioxide levels were also below OSHA limits [8]. These are reactive gases that may combine with particulates and also affect the pH of the settled dust, making it acidic when combined with moisture. These gases are typically found as components of urban atmospheres.

Organic compounds. Volatile organic compounds, emanating from the fires burning on the rubble, have been monitored by OSHA at the WTC site. **Dioxins** were also found at the site as were trace amounts of **polychlorinatedbiphenyls** (**PCB's**) [8]. Again, these are ubiquitous in urban environments. The EPA is monitoring the smoke plumes at the WTC site for these materials [4]. Other organic solvents used in air conditioning systems, like Freon R-22, and their thermal decomposition products, like hydrofluoric acid and phosgene, have not been found at detectable levels at the site by OSHA [8].

Other problems. Similarly no ionizing radiation has been detected at the site. OSHA has monitored for latent radiation with attention to "-radiation [8]. **Metal dusts**, including those of cadmium, copper, iron oxide, lead, arsenic, and mercury, are being monitored by OSHA at the WTC site[8].

Summary Unlike typical soot or urban dust, soiling upon objects as a result of the World Trade Center's collapse will contain the "settling" of dust with levels of abrasive materials, possibly injurious to conservators and to objects, and additionally subject to hazardous waste procedures. This siliceous dust is particularly hard and potentially sharp. It can scratch bone and horn, bronze and marble, as well as cut yarns and fibers. Painted and coated surfaces are not immune from this damage. Under these circumstances, the disturbance or spreading of the dust in the work space should be avoided, restricted. Special attention must be paid to preventing contamination. While conservators are working, personal protective equipment is recommended. Safety procedures are essential for a successful treatment program (see "World Trade Center Dust, Safe Work Practices").

In order to prevent the WTC dust from damaging artwork, special care must be taken to avoid sweeping, brushing, or other actions that might lift the dust into the air of the work space and across the surface of an object. The goal is to remove the dust vertically without incidental imbedding or indention into the surface. Careful HEPA vacuum cleaning will collect dust from the object (see HEPA article). Aqueous and solvent treatments may increase rather than diminish the quantity of hazardous waste. Disposal should follow legally required procedures, as discussed in the recent article on Waste Management in *AIC News* [7].

Sampling and analysis of dust residues before and after treatment is strongly advised. General directions for sampling and for types of analytical request are outlined in Appendix 2 along with a short list of firms. Despite the desire to treat an object promptly, current information on the character of the WTC dust residues indicate that they are largely inert to fragile objects as long as this dust is not smeared, rubbed, or brushed in a manner that would allow it to act as an abrasive powder. The dust may contain disproportionate quantities of alkaline or acidic or carcinogenic material. Analysis will provide necessary data to develop the appropriate treatment for the individual object.

References and Websites

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[4] Environmental Protection Agency www.epa.gov
[5] *Kirk-Othmer Encyclopedia of Chemical Technology*, 3rd edition. New York: John Wiley & Sons, 1978.
[6] New York Committee for Occupational Safety and Health www.nycosh.org
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[8]Occupational Safety and Health Administration www.osha.gov
[9] Stoves, J.L. *Fibre Microscopy: Its Technique and Application* London: National Trade Press, 1957, pp. 258-9.
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World Trade Center Dust: Safe Work Practices for Conservators *(Based on data available as of December 6, 2001)*

Appendix 1. Normal Industrial Urban Dirt

It is useful to review briefly the general nature of soil, and especially soil on woven textiles which attract dust. Standard soil cloths have been developed by manufacturers to determine the efficacy of cleaning equipment and detergents; these are based upon studies of dirt and soiling[4]. Museum conservators and scientists have also studied the soiling environment, as have industrial engineers for cleaning equipment. An early major study[5] of street soil showed variations of soiling among different American cities (Table I). The soils have fairly uniform inorganic components, perhaps due to a similarity of city building materials and street pavements; the non-combustible ash content is slightly over half the material. The most variable is the solvent soluble component --the oiliness of the soil-- which was as low as 4.9% in Detroit and as high as 12.8% in St. Louis.

At the time this chart was developed, the dinginess caused by soiling could only be measured indirectly as a carbon black equivalence, compared visually to tinctorial pastes. However, a National Institute of Drycleaning study found that an 0.5 equivalence of carbon black as a pigment[6] reduced the reflectance on white cotton by 81.1% and on white wool by 85.5%. Carbon black has excellent covering power[7].

Table I: Analyses of Normal Urban Dust from Various U.S. Cities (after Sanders & Lambert)

Component	Pittsburgh	Detroit	Cleveland	Buffalo	St. Louis	Boston
Water-soluble	15.4	13.5	15.9	11.4	14.9	15.4
Ether-soluble	10.8	4.9	7.1	6.5	12.8	7.7
Moisture	---	1.7	3.0	--	--	2.1
Total Carbon	26.4	24.7	24.0	26.9	25.6	28.9
Ash	53.8	57.8	56.3	52.0	51.2	50.5
SiO_2 (total)	25.6	25.5	26.4	24.0	21.4	21.4
R_2O_3 (total)[a]	11.6	9.9	11.1	9.5	9.4	11.1
CaO (total)	6.2	8.4	7.7	6.9	7.4	6.4
MgO (total)	1.7	2.0	1.7	2.0	1.6	1.7
CaO (water-soluble)	0.3	0.4	0.7	0.3	0.4	0.7
MgO (water-soluble)	0.1	0.2	0.2	0.2	0.2	0.2
N	--	1.6	--	--	--	2.1
pH (10% slurry)	7.0	7.3	6.7	7.2	7.0	7.3
Carbon black (.)	0.8	0.6	0.55	0.5	0.5	0.6

[a] i.e., R is something other than Si, Ca, Mg, Ca.

The particle size of the street dirt less than 75 microns was also analysed (Table II).

Table II: Particle Size Analysis of Street Soil (after Sanders & Lambert)

Size range (microns)	0-4	4-8	8-12	12-16	16-20	>20
Percentage	53%	8%	7%	8%	7%	17%

The majority of city soil particles are surprisingly small; this is particularly important for museums since the smaller particles can travel farther with lighter breezes. Recent studies of soil deposited in museums have focused on modeling the velocity and deposition rate of airborne particles[8]. Here the soil inside the museums is divided into elemental carbon (soot) and soil dust into grades with a 2.0 µm diameter cut-off point. Ventilation and filter systems can reduce the level of indoor soils to 15-20% (fine) or even less than 5% (coarse), although one museum has more measured elemental carbon inside than out[9]. In a related article, the authors correlate the velocity and turbulence of mechanical ventilation registers, temperature and circulation currents near windows or doors to the level of soil disposition[10]. An earlier study on the physical components of air-borne dirt, as determined by a dry filter in an industrialized area found (Table III) a high level of organic matter, 55%, comparable to that found in the various cities, but ether-soluble oily matter in the air-borne dirt was over 20%[11].

Table III: Analysis of Air-Borne Dirt From a Dry Filter (after L.F. Hoyt)

Dirt Fraction	Ether Soluble	Hot water Soluble	Hot, dilute HCl Soluble	Loss on ignition of insoluble residue[12]	Acid-insoluble inorganic residue	Total Organic Material
Percentage	22.1	14.2	11.2	32.8	19.7	54.9

If the soil contains both a dirt and an oily component, the soil cannot be entirely removed by vacuuming. Hence the need for aqueous or nonaqueous cleaning treatments. There are various treatment methods that can be used to remove certain soils and/or ameliorate deleterious conditions.

Soils can be divided into categories as a function of how they are removed, although there is often more than one removal system: i.e., vacuum removable soils, magnetizably removable soils, aggregated or electrostatically removable soils, soils removed by solvent (aqueous or nonaqueous) solubility and soils removed by emulsification (detergency) methods.

Solid extraneous particles are removed by vacuum suction; in earlier times they were removed by beating[13]. An analysis by the Hoover Company found that 45% of "natural soils" picked up by vacuum cleaners were sand and clay, as seen in the Table below. Vacuum cleaners picked up the particles in the size range of 0.3 to 35 µm, but the soil left on the fibers of carpets is smaller: 0.2 to 4 µm[14].

Table IV: Composition of Typical Carpet Soil (after G.R. Getchell)[15]

Component	Moisture	Sands, clays	Limestone dolomite	Animal fibers	Cellulosic materials	Resins, gums, starch, etc	Fats, oils, rubber, tar	Undeter-mined
Percentage	3	45	5	12	12	10	6	2

Occasionally, soils can be magnetized, like iron filings. More often, soils can be aggregated on dust cloths by means of simple static attraction, moisture, or a topical coating to remove loosely held, fine particulate soil[16]. A variety of moist powders including fullers earth, corn starch, and breadcrumbs have been employed domestically for woolen fabrics, cottons, and fabric-covered walls[17]. Rubber and synthetic rubber erasers and eraser crumbs can be useful to assist the removal of soft soils.

Aqueous (water) or non-aqueous liquids can remove a number of damaging or discoloring materials, like adhesives, oils, or resins, simply by rinsing them away. The liquids are often chosen to match the physical properties of the problem by using the "solubility parameters" of liquids. The most suitable solvent is the one that best removes the offending material yet least affects the fundamental nature of the fabric substrate, dyes, finish[18].

Appendix 2. Analysis of Dust for Chemical Content

Samples can be taken with a pipette attached to an aspirator and syphoned into a glass vial. The vial should be sealed, labeled with date and object location. Silicate content, percentage ash, and pH would serve as initial analytical test requests. Asbestos content would be a separate and more specialized matter. For additional firms, consult the American Chemical Society (www.acs.org) or the American Council of Independent Laboratories (www.acil.org). Be advised that the analysis of dust for purposes of worker and workplace safety should be carried out separately by firms allied to industrial hygiene. Listed below are some analytical chemical firms.

1. Chemir/Polytech Laboratories, Inc., 2672 Metro Blvd., Maryland Heights, MO 63043
tel: 800-659-7659 or 314-291-6620, fax 314-291-6630

2. Micron Inc. Analytical Services 3815 Lancaster Pike Wilmington, DE 19805
tel: 302-998-1184, fax 302-998-1836, website: www.microanalytical.com

3. Schwarzkopf Microanalytical Laboratory 56-19 37th Ave., Woodside N.Y. 11377
tel: 718-429-6248

Appendix 3. Hardness and the Mohs Scale

Hardness is a relative term combining three properties: stress, strain, and elastic modulus. It is dependent upon the crystalline structure of the material. In the Mohs scale the harder material (higher in number) will deform–scratch, indent, abrade, wear–the material with a lower value.[5] Pencil graphite, for example, lies between 1 and 2; graphite lubricants, below 1.[2]

Table V: Mohs Scale of Hardness[a]

Mohs Scale Number	Standard Mineral	Other Equivalent Materials or Common Name
1	Talc	----
2	Gypsum	Human Fingernail
3	Calcite	Copper
4	Fluorite	Iron
5	Apatite	Cobalt, Hard portion of teeth
6	Orthoclase	Rhodium, Tungsten, Silicon
7	Quartz	----
8	Topaz	Chromium, Hardened Steel
9	Corundum	Sapphire
10	Diamond	----

[a]After G.L. Kehl, *The Principles of Metallographic Laboratory Practice*. New York: McGraw-Hill, 1949, p. 233.

1 For a review of "normal urban dust" please see Appendix 1.
2 A list of such firms is found in Appendix 2.
3 For a table of the Mohs Hardness Scale, please see Appendix 3.
4 Testfabrics, West Pittson, PA produces standard soil cloths of various types for the textile and cleaning industries.
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10 Nazaroff, W.W. and G.R. Cass, "Protecting Museum Collections from Soiling due to the Deposition of Airborne Particles," *Atmospheric Environment*, vol. 25 #5/6 (1991): 841-852.
11 Hoyt, L.F. "Detergents for Cleaning Air Conditioning Filters," *Soap Sanit. Chemicals*, vol. 24 (1948): 42-44, 59 as cited by N.F. Getchell, "Cotton Quality Study III: Resistance to

Soiling," *Textile Research Journal*, vol. 25 (1955), p. 160.
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13 Carpets were hung and beaten; today carpets are commercially treated in rug-beater machines to loosen and drop out loose dirt.
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