Chemical and Pathology Studies of Particulate Matter

A Medical Geology Perspective

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OVERVIEW

- **Introduction**
- **From dust to disease: a review of toxicological pathways**
- **Health outcomes of bio-reactive dust-borne elements:**
  - ** **Respiratory effects**
  - ** **Carcinogenic effects**
  - ** **Indirect health effects**
- **Case Studies in Military Medical Geology**

KEY VARIABLES IN RELATION TO HEALTH IMPACTS OF MINERAL DUSTS

ENVIRONMENTAL MECHANISMS	EXPOSURE PATHWAYS	PROGRESSION TO HEALTH END-POINTS
ANTHROPOGENIC	DISCRETE / DEFINED	WELL-ESTABLISHED DISEASE PROCESSES/ READILY MEASURABLE HEALTH END-POINTS
GEOGENIC/ GEOCHEMICAL	DIFFUSE / MIXED	POORLY-DEFINED DISEASE PROCESSES/ HEALTH END-POINTS DIFFICULT TO IDENTIFY OR MEASURE

SOURCES

Toxicological Pathways

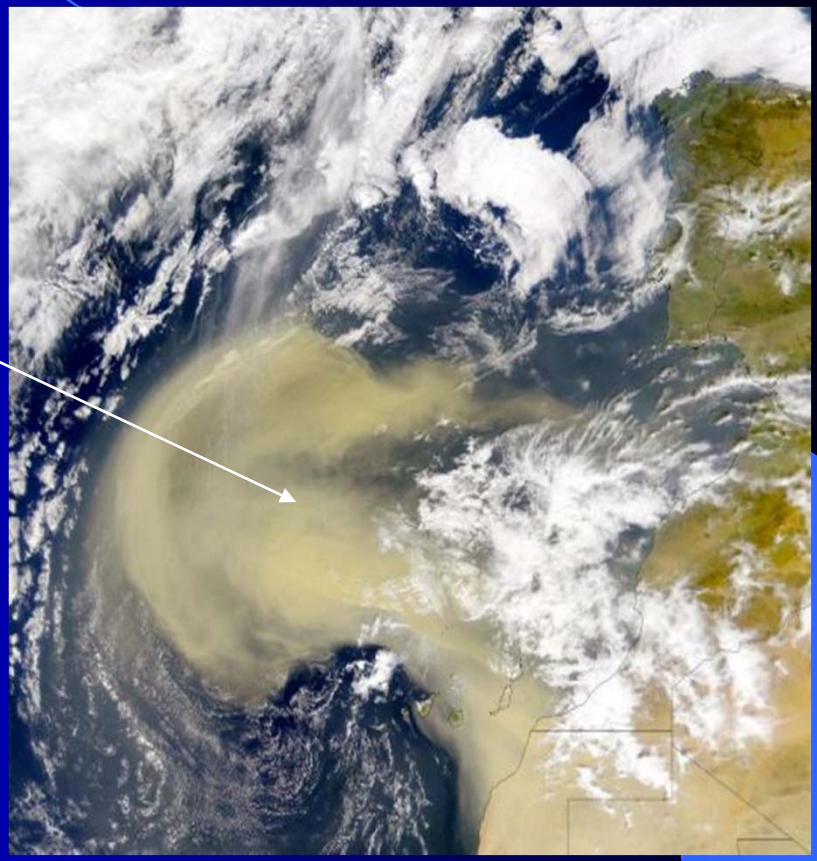
Including:

- **Volcanoes**
- **Dust storms (regional storms)**
- **Long-range transport episodes of desert dust (intercontinental dust)**
- **Displacement through natural processes such as landslides and earthquakes**
- **Mine tailings spills**
- **Chemical or industrial spills**
- **Terrorist attacks**

Dominant dust source regions around the world (in brown) .
Courtesy of Prof. Dr. Edward Dervishire, UK and Dr. Geoffrey Plumlee, USGS

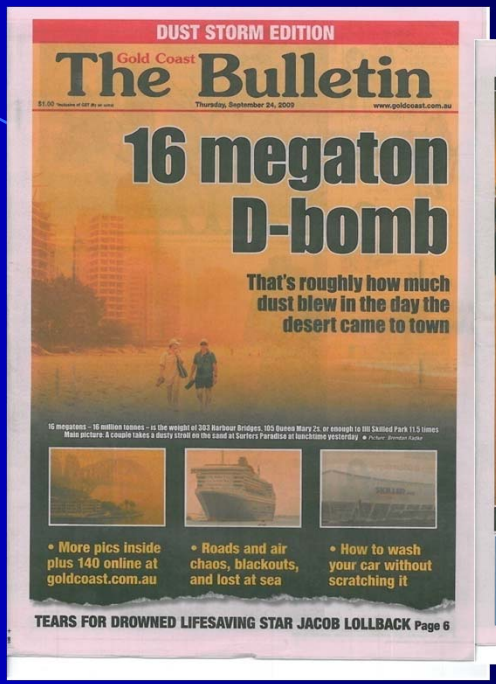
Long-range transport episodes of desert dust (intercontinental dust)

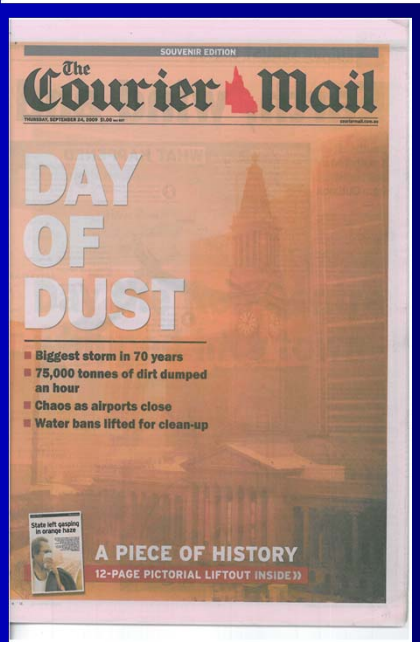
- Annual volumes at over 1 billion tons from the main African deserts alone



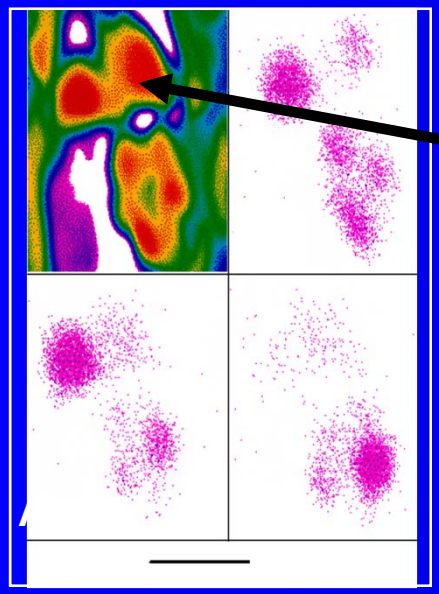
- Anthropogenic influences (such as from farming and irrigation) have contributed to dust formation by enhancing the process of desertification, with losses of over 10 million hectares (~29 million acres) of farmland per year

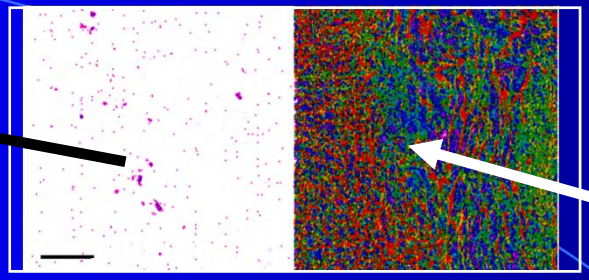
- Dispersal phenomena occur on all the major continents:
  - → mobilization of Saharan dust to southern Europe and the Americas
  - → inundation of Chinese cities and Japan with dust from central Asia
  - → regular dispersal in Australia and south-western parts of the US

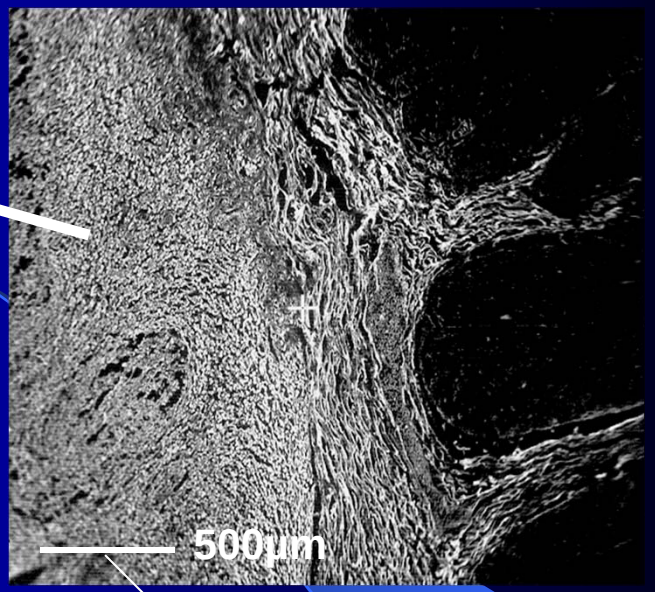




Australia under a dust storm – September 14, 2009







Absorption of particulate materials from soil, food and water has been established as an additional avenue of exposure via the Lymphatic system (i.e. 1,2,3). In the example above microprobe mapping has enabled the analysis of microscopic Al-Si-Fe particles concentrated within human gut associated lymphoidic tissue (i.e. Peyer's patches). The presence of such particles have been associated with tissue damage, immune suppression and parallels have been drawn with lung pneumoconiosis.

1 Shepherd et al., 1987, Hum Pathol, 18, 50-54.
2 Blundell, Henderson and Price, 1989, Ann Trop Med and Parisitology, 83, 381-385
3 Ziegler, 1993, The Lancet, 342, 1348-1351

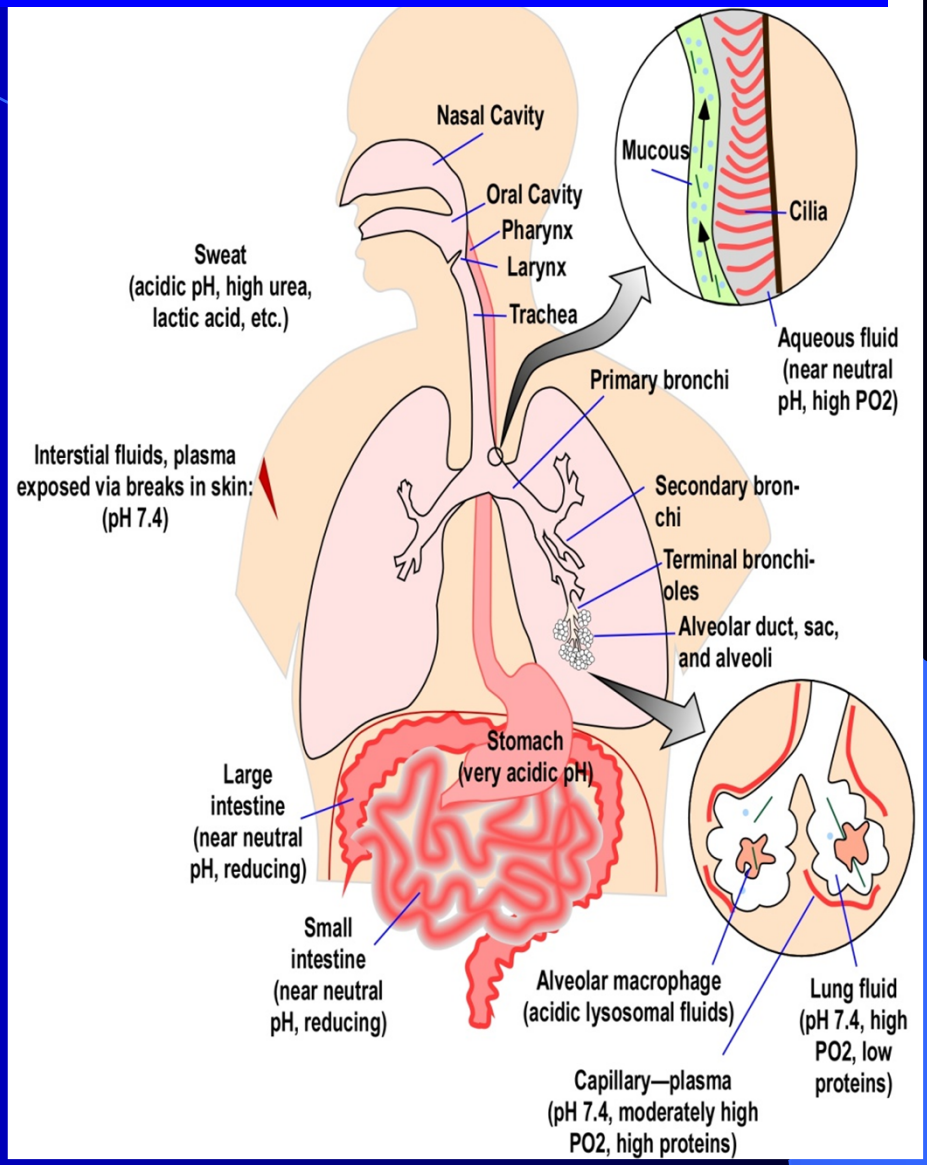
Sample courtesy of J.Powell, Rayne Institute, St Thomas's Hospital, London

Pathological Effects of Inhaled Mineral Dust

The process of inhalation of mineral aerosol particles leads to deposition in the pulmonary alveoli. *The process varies* with several factors, notably:

- mineral type (composition) and inclusions;
- dust particles size and shape:
  - < 10 - 20 µm (inhaled)
  - < 2 µm (respired)**
- Length of exposure;
- Certain lung and immune system functions.

**Atmospheric dust finer than 2.5 µm is of particular importance with respect to community health, as in the PM standard.



Pulmonary alveoli: out-pouchings on the fine lining passages in which oxygen exchange with the blood stream occurs.

The PM (particulate matter) standard of the U.S. Environmental Protection Agency is based on the total mass of particles measuring 2.5 microns or less observed in a 24-hour period.

Pathological effects of inhaled mineral dust

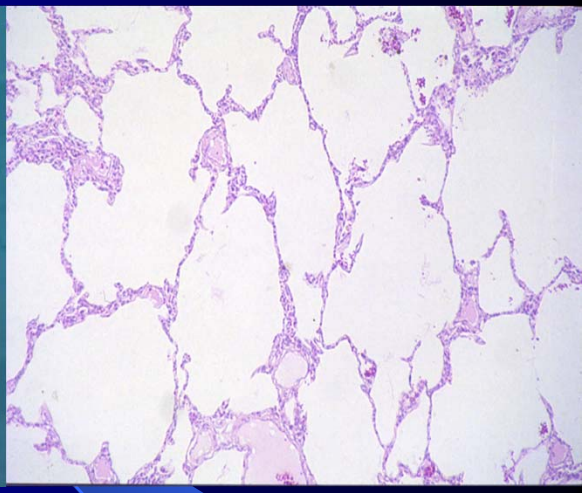
Particles <4 µm frequently penetrate more deeply into the lungs…….

prolonged exposure can lead to the pneumoconioses (including silicosis*, asbestosis+, and other lung conditions)…….

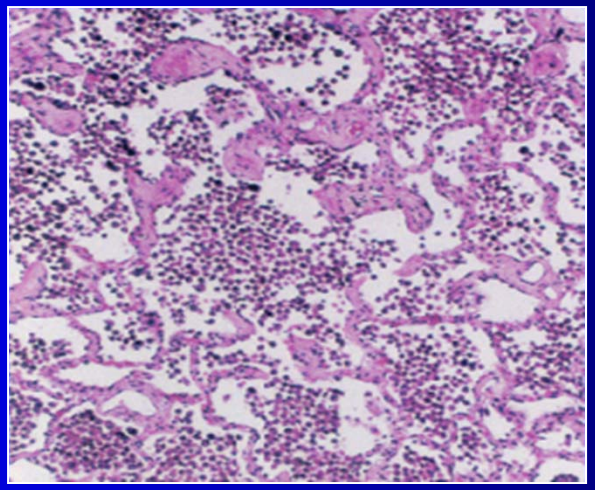
…..many symptoms are non-specific in the absence of radiography.

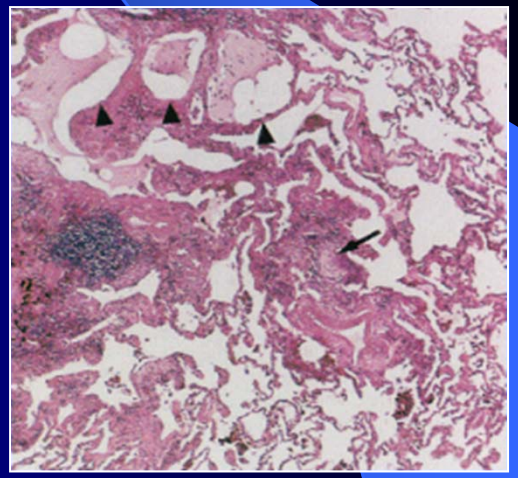
[Crystalline silica is WHO listed as a human carcinogen]

Alveoli - site of gas exchange in the lung



Cross-section through healthy alveoli





**Silicosis: inflammation of the lung, leading to fibrosis, caused by foreign bodies, notably inhaled silica particles*
+Asbestosis: degenerative fibrosis of the lung resulting from chronic inhalation of asbestos fibers.

[Courtesy of Claire Horwell]

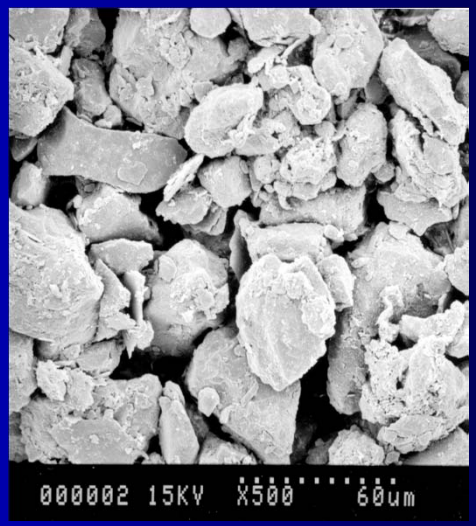
Pathological Effects of Inhaled Mineral Dust
Potential Composition

✓ Airborne dust may contain asbestos, silica, chromium, nickel, arsenic, cadmium, well known carcinogenic for the respiratory system.

Silica is the most significant cause of dust-associated morbidity and mortality

✓ Airborne dust may absorb harmful gases, disease-generating bacteria and even carcinogenic hydrocarbon compounds (eg, benzo(a)pyrene).

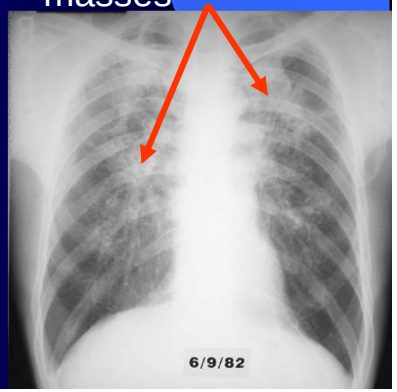
✓ Respiratory disease may exacerbate cardiac problems.



SEM-Dust quartz particles

Silicates

Silicosis ; nodules have coalesced to form conglomerate masses



Cook AG, Weinstein P, Centeno JA (2005). Health Effects of Natural Dust – Role of Trace Elements and Compounds. *Biol Trace Elem Research* 103;1-15.

- Another major groups of toxins which may be contained within, or adsorbed to, dust particles are the ***metals and metalloids.*** Among the best characterized are aluminum (Al), lead (Pb), zinc (Zn), mercury (Hg), arsenic (As), chromium Cr), cadmium (Cd), copper (Cu), and iron (Fe).

WTC

Tracing Lung Ailments That Rose With 9/11 Dust

Angel Franco/The New York Times

Some of the people working in the cleanup and recovery effort after Sept. 11 wore masks, but the most effective ones were effective for no more than 20 minutes.

By ANTHONY DePALMA
Published: May 13, 2006

E-MAIL

Pb-rich

Zn-rich

SEM : Dust from the WTC

SEM Courtesy Dr. Geoffrey Plumlee, USGS

Exposure to Metals and Metalloids may produce a wide spectrum of respiratory effects, including:

- upper airway injury or sensitivity, such as rhinitis and sinusitis from arsenic and mercury;
- lower airway inflammation, including tracheitis, bronchitis and asthma from mercury, zinc and numerous other inhaled metals;
- acute inflammation, edema, and fibrosis of the lung parenchyma with inhalation of such elements as cadmium

- Patterns of toxicity vary considerably with the forms, valences and formation (“species”) of compounds:
  - Although the process of lung injury has often been attributed to silicates, **the action of divalent iron (Fe^{2+}) trapped on dust surfaces may play a role.**
    - In this reactive form, iron may result in catalyzing reactions and the production of free radicals (reactive oxygen species), leading the tissue injury.

- A number of metals and metalloids, including cadmium, aluminum, and nickel, are classified as confirmed or suspected carcinogens using the IARC classification

- Arsenic, for example, is a group I carcinogen and has been linked to an extensive list of cancers, including those of the skin and most abdominal viscera, as well as angiosarcomas and hemato-lymphatic malignancies.

Arsenical-induced keratotic lesions of the hands

Force Health Protection: Integrating Environmental Earth Sciences and Human Health

Needs, Benefits and Military Relevance

Problems Related to "Place":

Air: Sand & Dust Clouds

- Kuwait Oil Fires
- Desert Dust Storms

Water

- Arsenic, Mercury, Radon
- Lead, Uranium

Soil

- Leishmaniasis
- Valley Fever

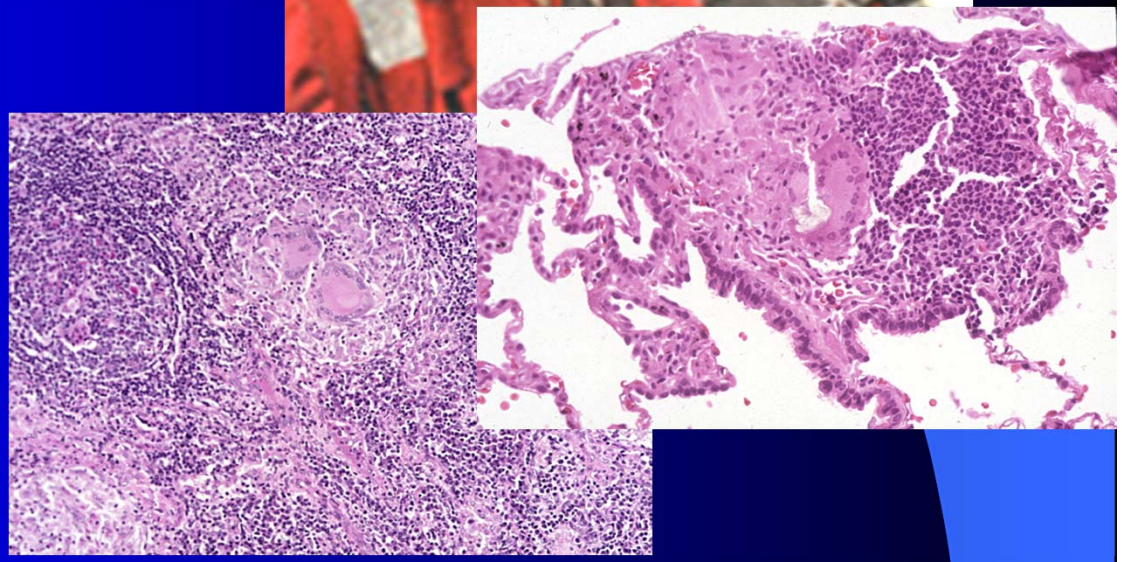
The Health Effects of Dust

Military Medical Geology

Pulmonary Sarcoidosis

Definition: multisystem granulomatous disease of unknown etiology.

Possible association with exposure to silicates and toxic metals (Al, Pb, Hg)



Gorham ED, Garland CF, Garland FC, Thomas R, Kaiser K, Travis WD, **Centeno JA**, and Hasibuan F. Trends and Occupational Associations in Incidence of Hospitalized Pulmonary Sarcoidosis and Other Lung Diseases in Navy Personnel: A 27 Year Historical Prospective Study, 1975-2001. *Chest* 2004;126:1431-1438.

Health Effects of Middle East Sand (Dust)

A *Medical Geology Research Case*

- Evidence of microbial transfer of pathogens via African Dust. **(EA Shinn, *et al*., African Dust and the Demise of Caribbean Coral Reefs, *Geophys Res Lett*. 27, (2001) p.3027-32)**

- **Description of novel condition triggered by exceptionally fine sand of the central and eastern Saudi Arabian peninsula. Concludes that immunosuppression aggravated by opportunistic infections and other non-microbial ailments brought on by exposure to the ubiquitous fine sand of the area cause Persian Gulf Syndrome. (Korenyi-Both, *et al*., Al Eskan Disease: Persian Gulf Syndrome, *Military Medicine*, 162, (1997), p.001).**

- **Obstructive bronchitis and bronchiolitis in 86 autopsied casualties from Kuwait, with observation of sand particle in lung parenchyma. (NS Irey, Kuwait Casualties: Morphologic and Toxicologic Findings, NIH Technical Assessment Statement, April 27-29, 1994).**

- From March through August 2003, 19 US military personnel developed pneumonia severe enough to warrant medical evacuation and mechanical ventilation; two died. **(AF Shorr, *et al*., Acute eosinophilic pneumonia among US military personnel deployed in or near Iraq. *JAMA*. 2004 Dec 22;292(24):2997-3005.)**

- **Constrictive Bronchiolitis in Soldiers Returning from Iraq and Afghanistan. King MS et al (2011) N Engl J Med 365(3);222-230.**

Health Effects of Dusts

Military Medical Geology

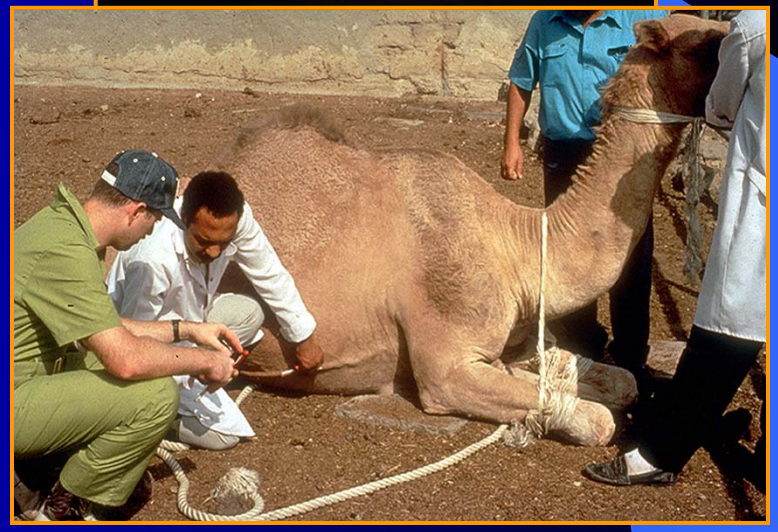
Operation Desert Storm (April 1991)

Health Impact of the Kuwait Oil Fires

AFIP Studies on:

1. Animal Tissues (Kuwait City vs Ahmadi)
   a. Histologically – anthracotic pigment
   b. Analysis of Toxic Metals-
      Ni, V, Cr, Cd, Pb, Cu, Zn, Mn

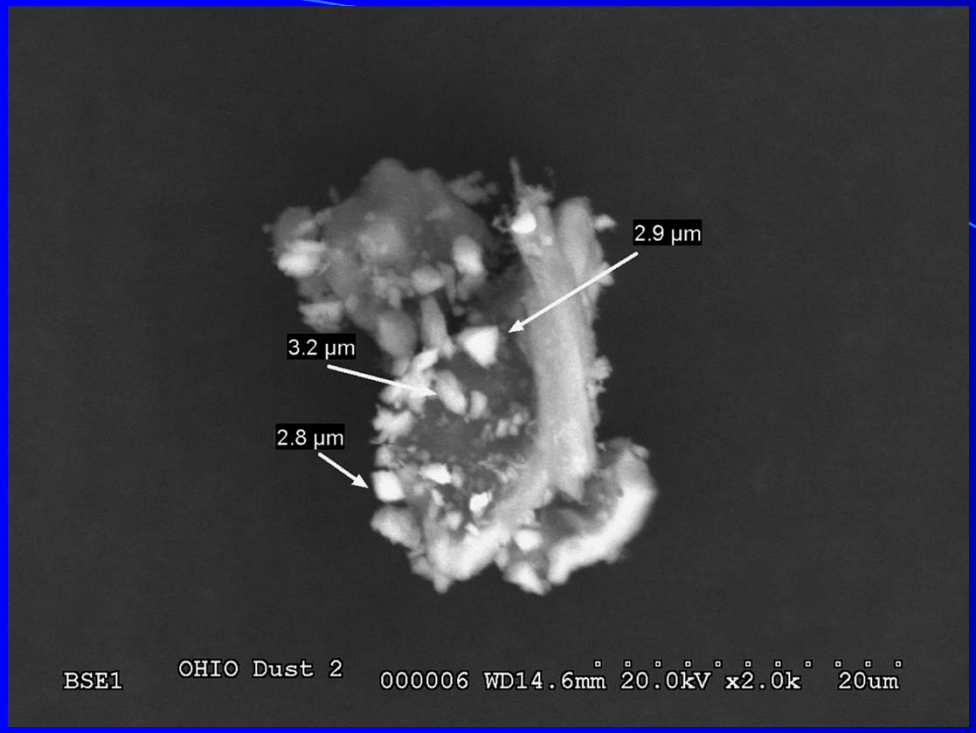
2. Biological Surveillance
   a. Epidemiology, clinical assessment, chemical toxicology

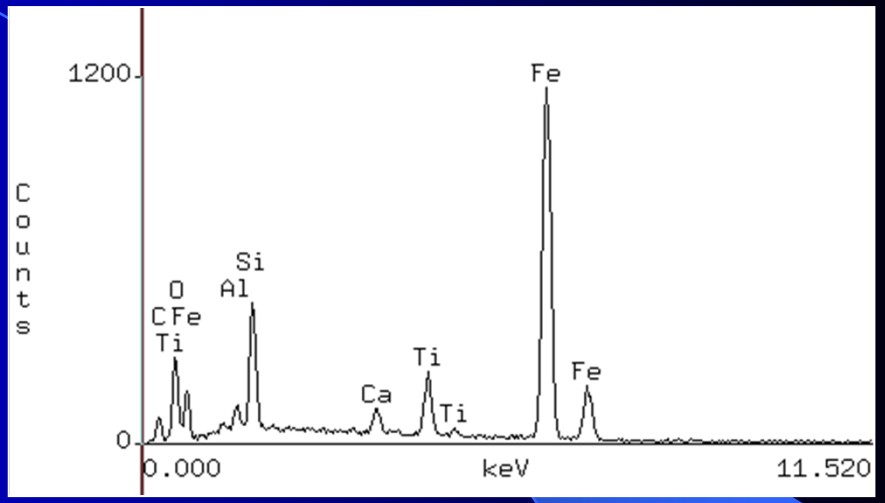


Results: Inhalation of air contaminated with smoke from the oil fires had little or no long-term effects.

Moeller RB, et al. Assessment of the Histopathological Lesions and Chemical Analysis of Feral Cats to the Smoke from the Kuwait Oil Fires. *J Environ Path Tox and Onc* 13(2):137-149 (1994).

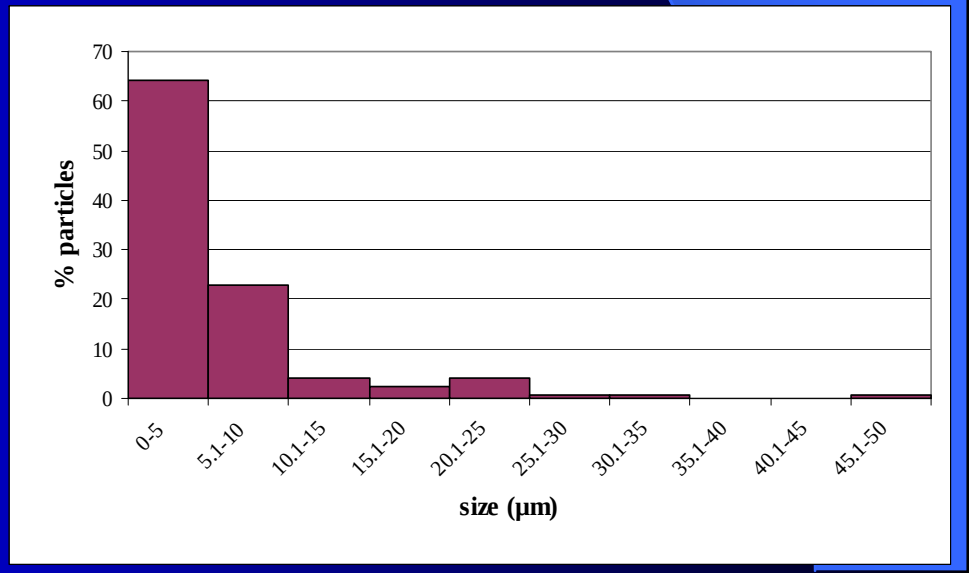
Chemical and Microscopy (Particle Size) Analysis of Middle East sand (dust)





# particles	123
average (µm)	6.4
median (µm)	4.3
max (µm)	46.1
min (µm)	1.1

Other metals detected: Al, As, Cd, Co, Ni, Cr, Mn, Pb



Lyles M, Centeno JA et al. unpublished results

Middle East Dust – Trace Composition

Links between selected elements and some known lung function conditions and diseases

	Desert Dust <10 µm	Desert Dust 20-40 µm
Mn (ppm)	450	331.98
Fe (ppm)	25500	18111.61
Co (ppm)	11.72	8.24
Pb (ppm)	17.22	9.45
Cu (ppm)	220	152.64
Cd (ppm)	1.24	0.70
Mg (ppm)	13230.49	10572.70
Al (ppm)	15912.39	13154.60
Ca (ppm)	139577.64	140250.15
Na (ppm)	1098.28	1476.86
Cr (ppm) [but species critical]	181.32	187.36
Zn (ppm)	105.18	72.30
Ni (ppm)	93.28	60.44
Ti (ppm)	1095.52	539.81

Cancer | Cancer suspected | Cancer & asthma | Emphysema | Asthma

SUMMARY

- Dust and other particulates ("Dust" is used here to cover dust and other finer particulates) from both natural and anthropogenic sources have major implications for human health, agriculture and livestock and the natural environment.

- Several studies have demonstrated that fine particles may contain relatively high concentations of transition metals implicated to catalyzed the formation of oxygen radical species, increasing the oxidative stress burden and tissue damage.

- Substantial research has been undertaken on aspects of this subject, but an integrated understanding of these materials from an inter-disciplinary point of view is still lacking. It is important for risk assessment studies, quantifying the public health impact of fine-particulate exposure using a multi-disciplinary approach.

Photo by David Fitzpatrick, NYPD