Characterizing Atmospheric Aerosols from Mining Operations

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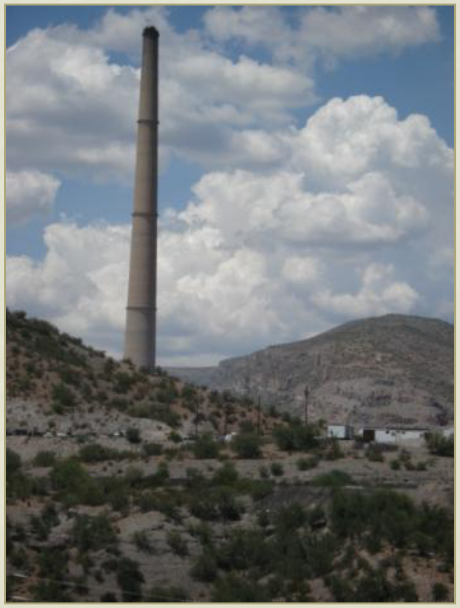
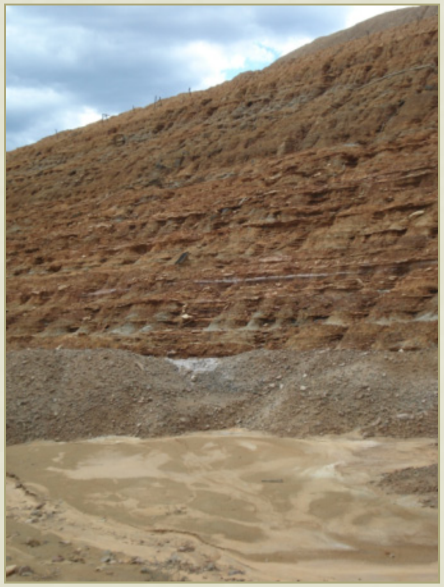
Research Supported by NIEHS Superfund Research Program

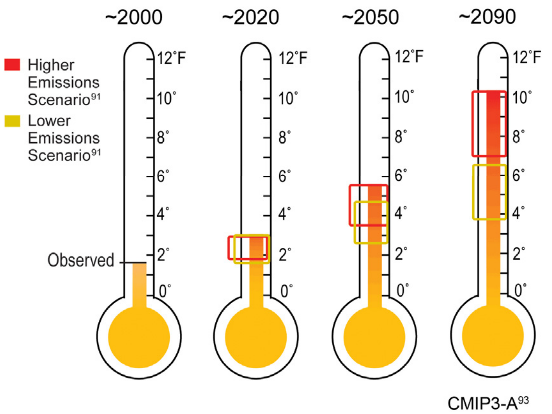
Superfund Research Program



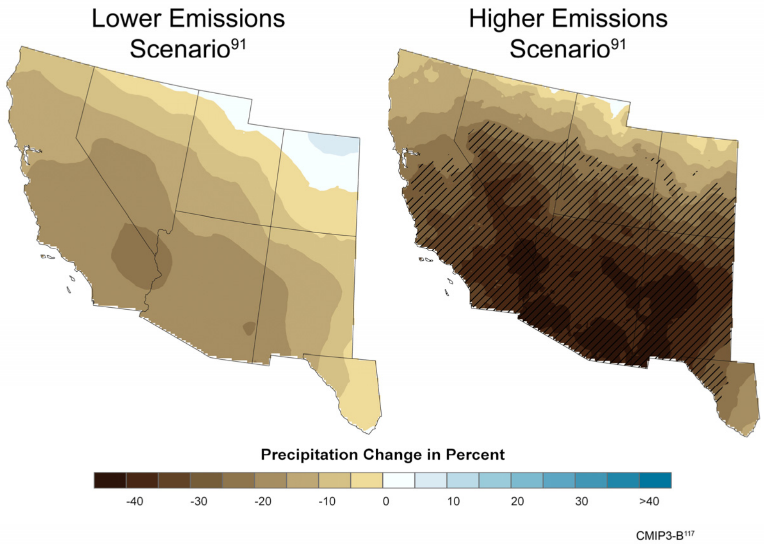


ARIZONA

Climate Change in the Desert Southwest



The average temperature in the Southwest has already increased roughly 1.5°F compared to a 1960-1979 baseline period. By the end of the century, average annual temperature is projected to rise approximately 4°F to 10°F above the historical baseline, averaged over the Southwest region. The brackets on the thermometers represent the likely range of model projections, though lower or higher outcomes are possible.



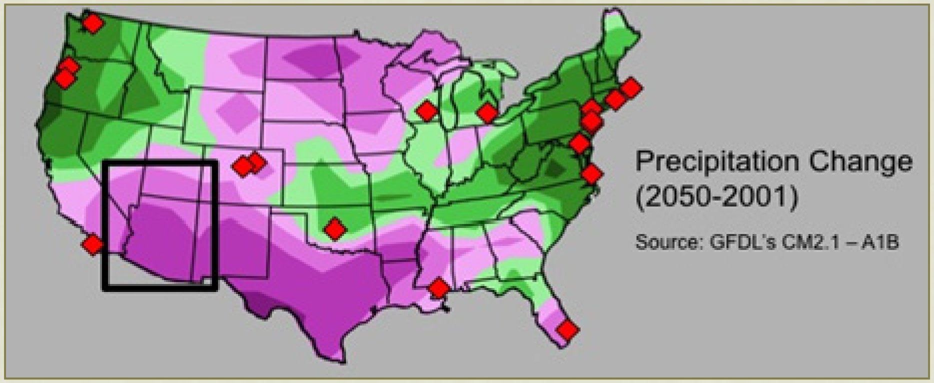
Percentage change in March-April-May precipitation for 2080-2099 compared to 1961-1979 for a lower emissions scenario[91] (left) and a higher emissions scenario91 (right). Confidence in the projected changes is highest in the hatched areas.

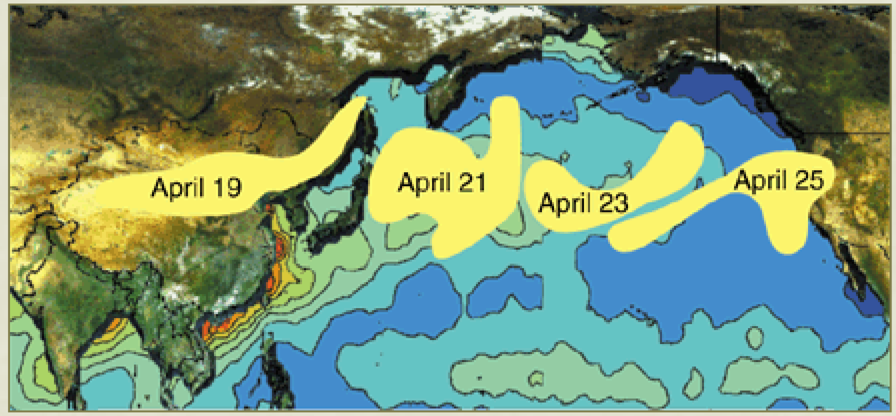
From "US Global Change Research Program"

www.globalchange.gov/usimpacts

[91]"Lower emissions scenario" refers to IPCC SRES B1, "higher emissions scenario" refers to A2.

Why do we care about mining operation particles?





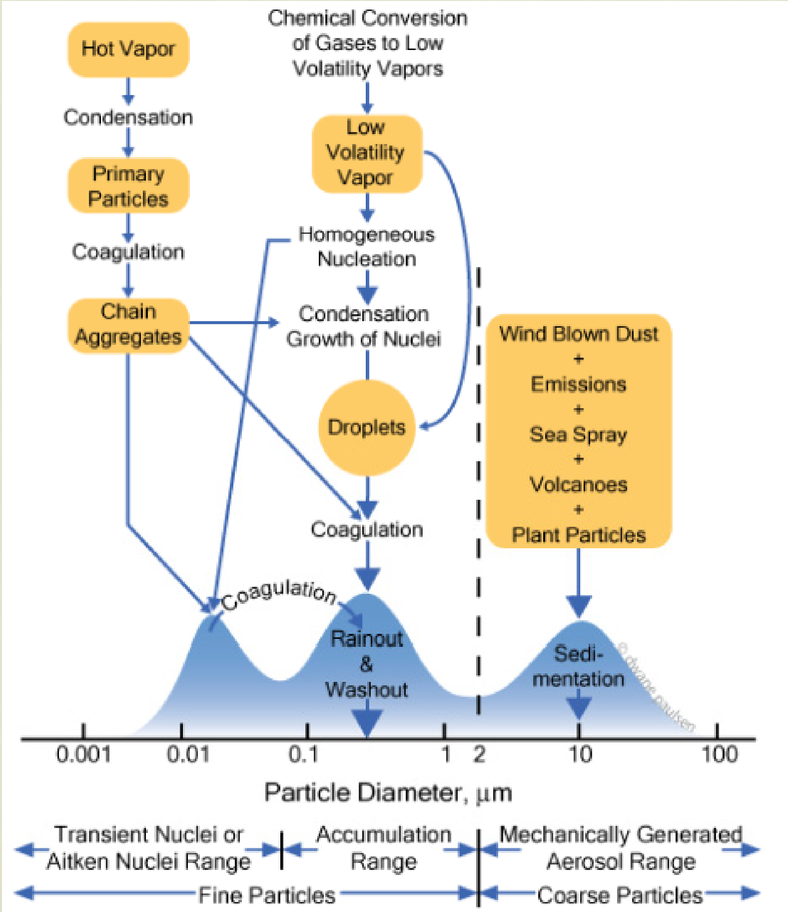
(Wilkening et al., 2000)

A mine tailings site in northern Mexico showing erosion of the tailings on a windy day. (Courtesy Blenda Machado)

- Dust Transport
  - Contaminant transport by atmospheric aerosols in arid and semiarid climates, such as the Southwestern US, may become increasingly more important with predicted regional climate change.
  - Fine particles disperse more readily into environment than coarser soil dusts.

Mining Operations & Particle Size

- Crushing, Grinding, Mine Tailings Management
  - Coarse >2.5 µm *(mechanical action)*
- Smelting, Refining
  - Ultra-fine <0.1 µm *(gas to particle conversion)*
  - Accumulation 0.1-2.5 µm *(coagulation of ultrafine and condensation growth)*

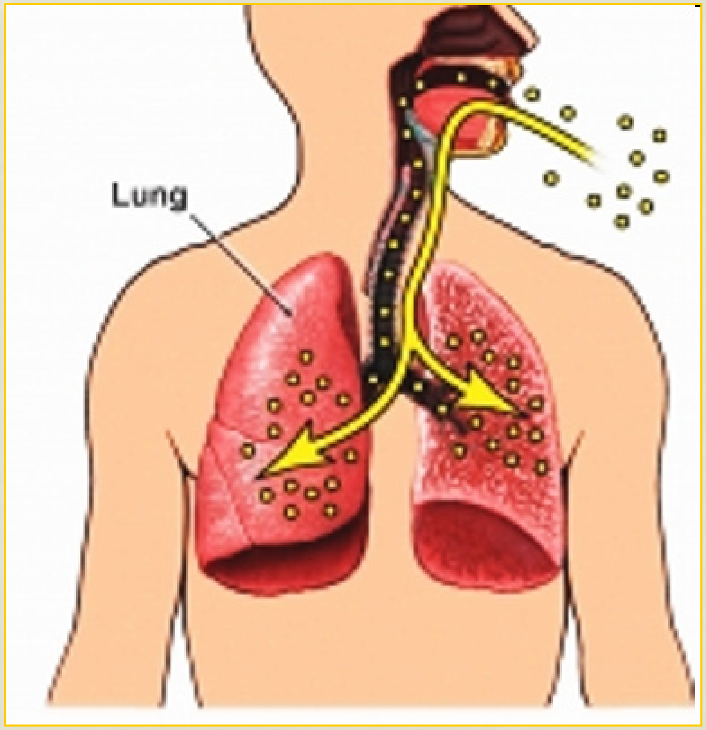


(Seinfeld and Pandis 1998)

Why do we care about mining operation particles?

- Particle Size & Inhalation:
  - <2 μm deposits in your lungs
  - >7 μm deposits in your upper respiratory tract

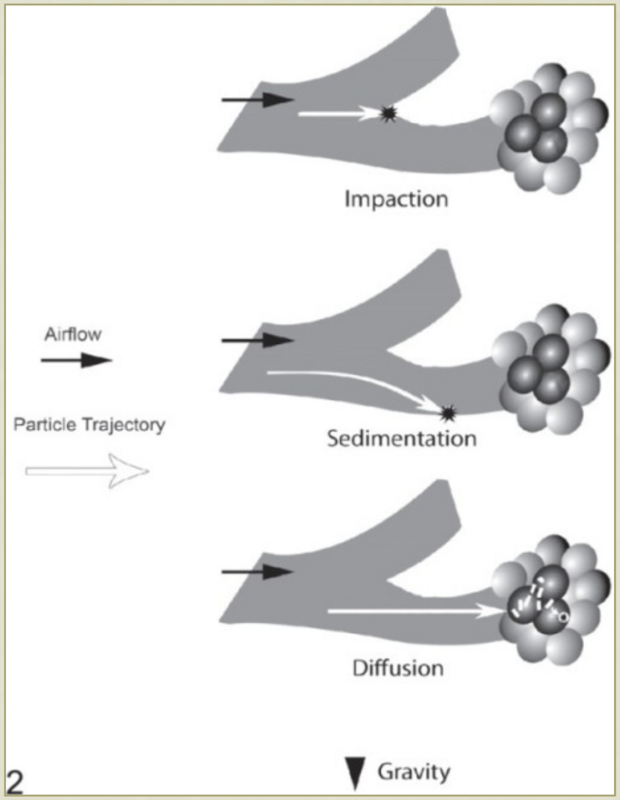
  (Park and Wex, 2008)
- Particles Contents
  - Metal and metalloid contaminants (some toxic)
- Incidental Ingestion
  - Children (pica)

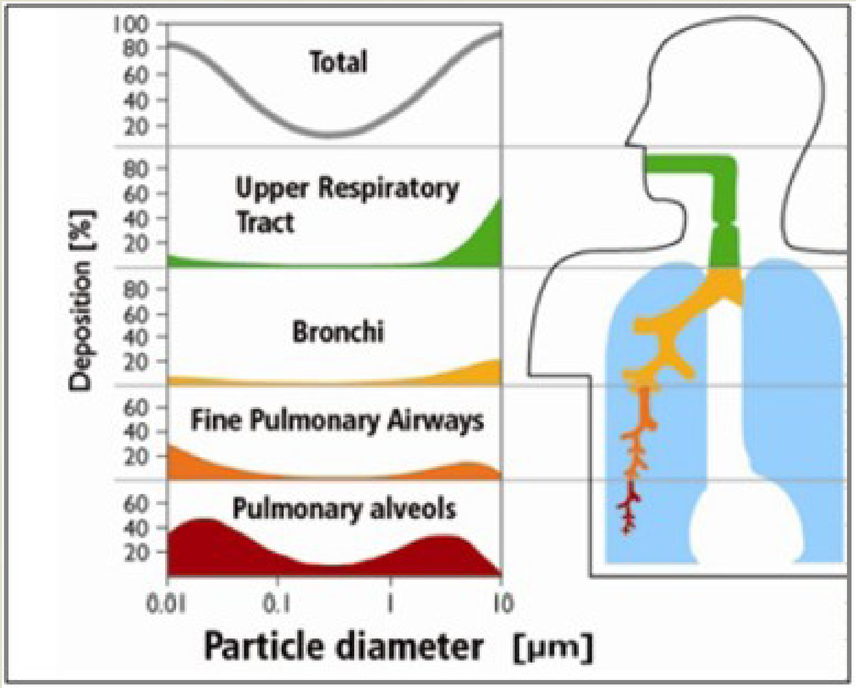


Ambient Air Guidelines

- **NAAQS**
  - **PM_{10}:** 50 μg/m^3
  - **$PM_{2.5}$:** 15 μg/m^3
  - **Pb:** 150 ng/m^3 (2015)
- **WHO**
  - **As:** 6.6 ng/m^3
  - **Pb:** 500 ng/m^3
  - **Cd:** 5 ng/m^3

Aerosol Deposition in Respiratory System

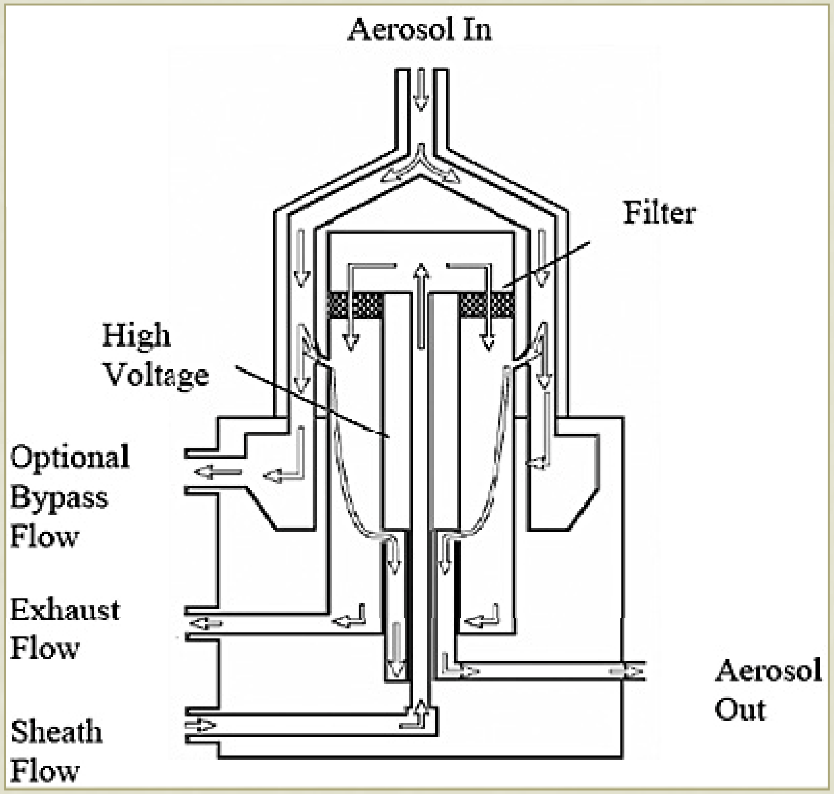


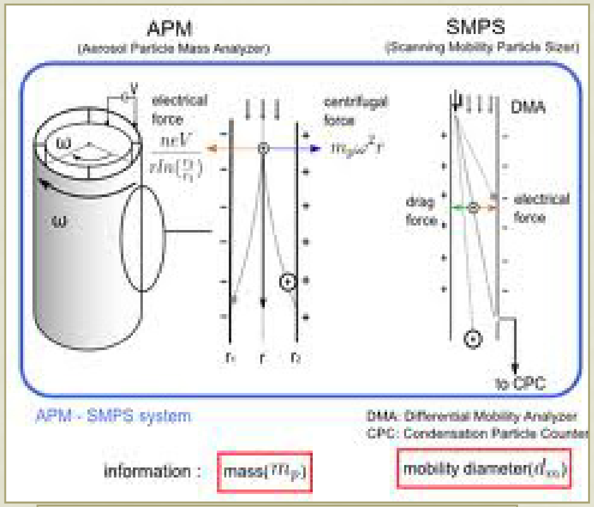


Ambient Particulate Survey
Arizona, US

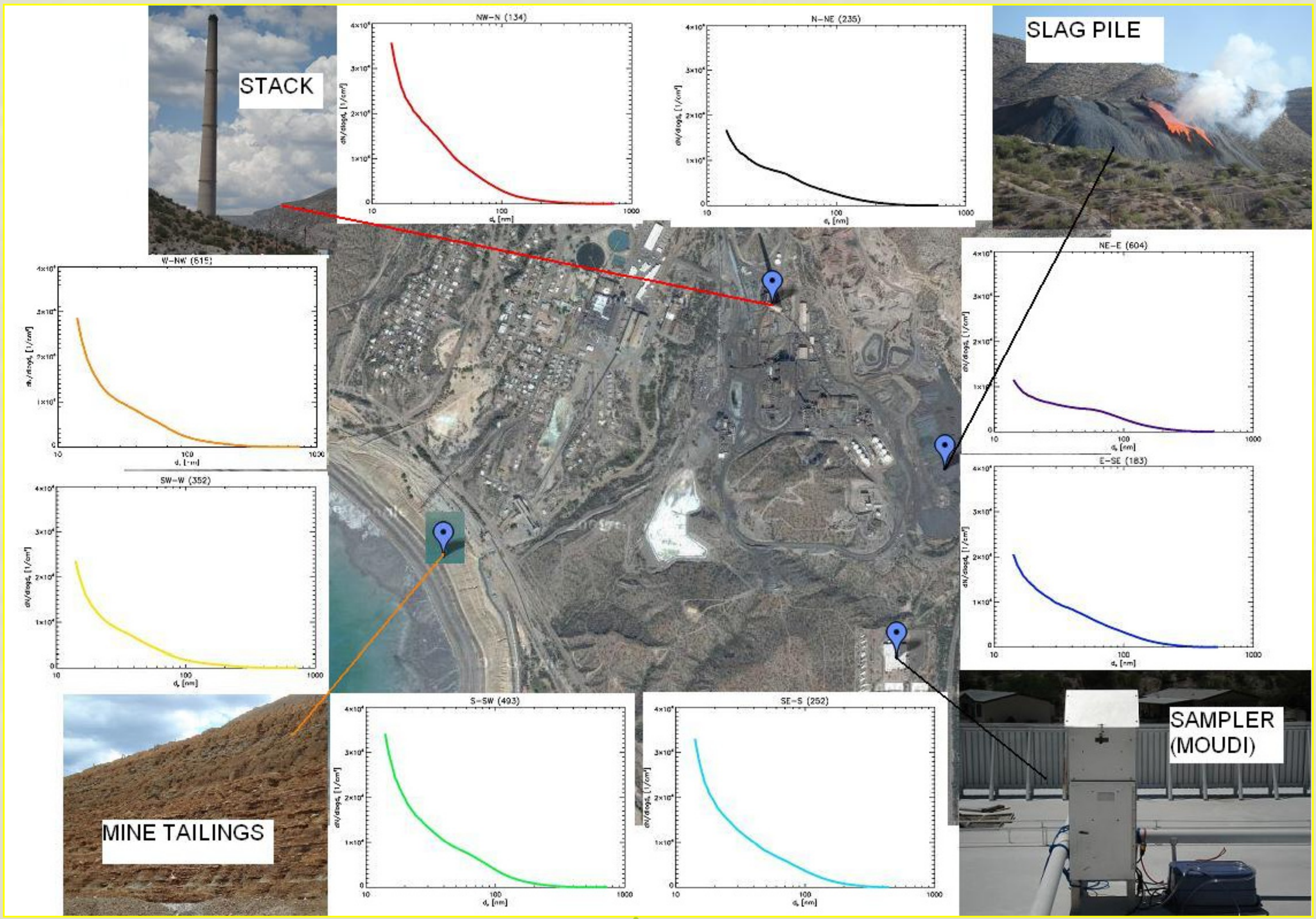
- **Contaminated Sites**
  - **Iron King** - Inactive copper mine now a Superfund site with arsenic and lead contaminated mine tailings
  - **Hayden & Winkelman** - ASARCO active copper mine with smelter, arsenic and lead contaminated mine tailings
- **Comparison Sites**
  - **Mount Lemmon** - Natural background
  - **Tucson** - Urban sample
  - **Green Valley** - Inactive copper mine with low metals in mine tailings
  - **Wilcox Playa** - Important natural source of dust

Scanning Mobility Particle Sizer
(particle number concentration)

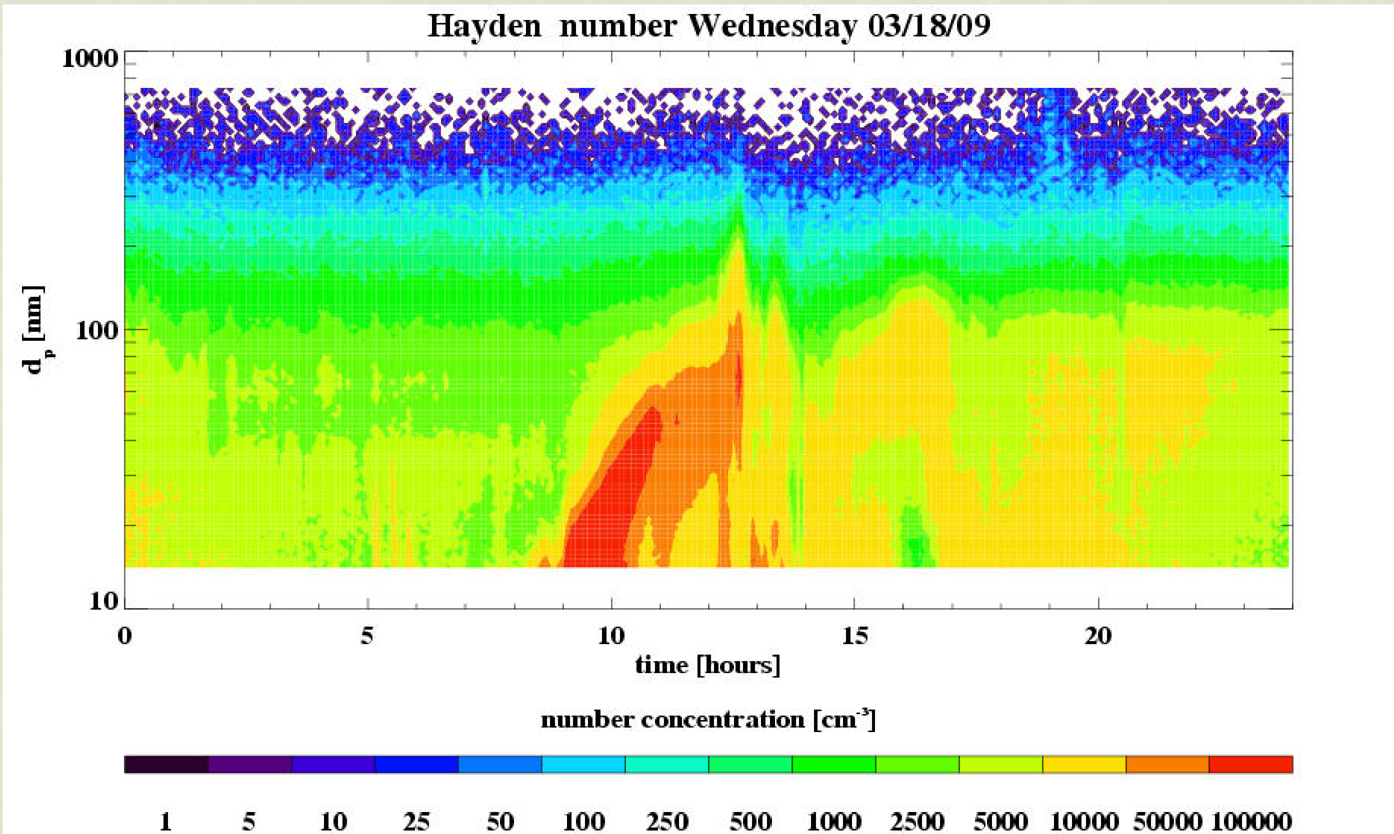




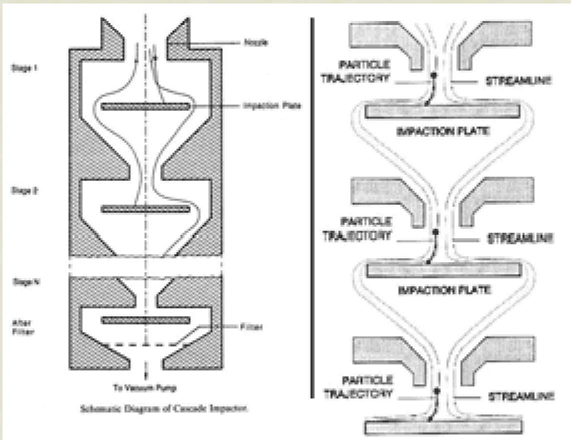
Typical SMPS Results (source apportionment)



Time-Dependent Particle Number Concentration



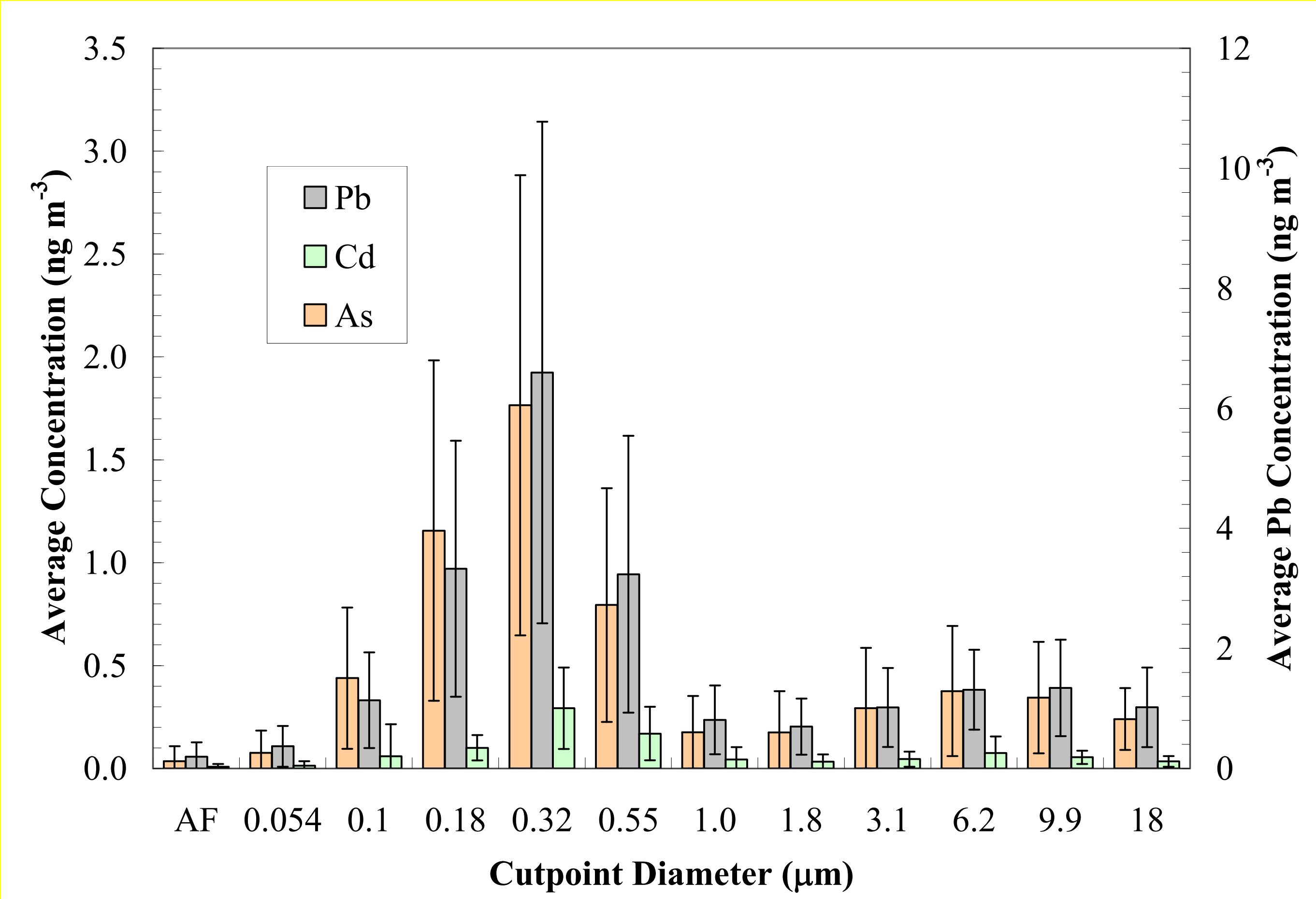
MOUDI



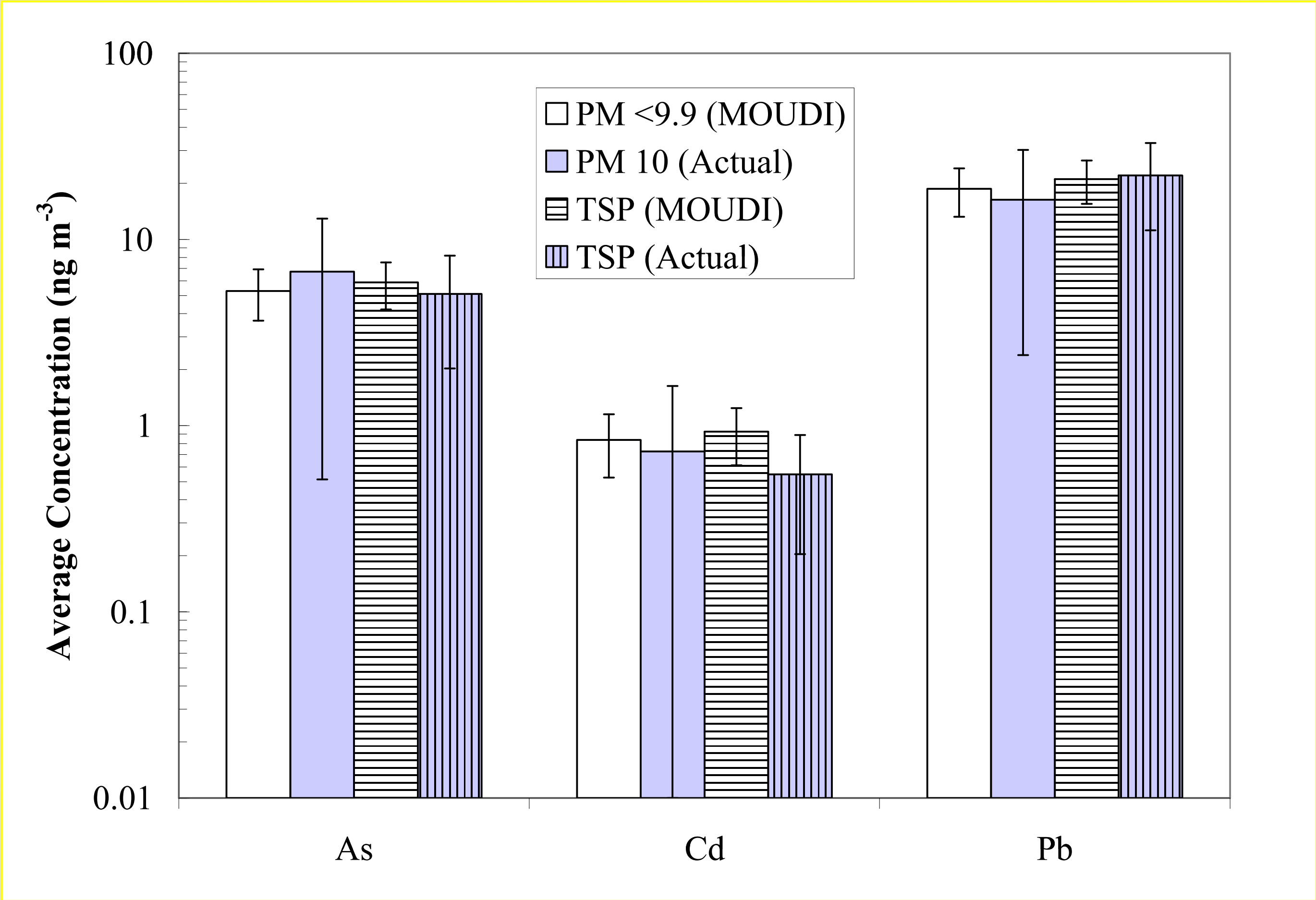
- **MOUDI (Micro-Orifice Uniform Deposit Impactor)**
  - 10 aerosol size fractions on separate stages
  - Cut-point diameters of 18, 10, 5.6, 3.2, 1.8, 1.0, 0.56, 0.32, 0.18 μm, 0.1 and 0.056 μm
  - 30 L/min flow rate
- **SMPS (Scanning Mobility Particle Sizer™)**
  - Number concentration from 1 to 10^8 particles/cm^3
  - Dp from 2.5 nm to 1.0 μm
- **TSP (Total Suspended Particulate)**
  - High volume sampler (14 ft^3/min)
  - Mass concentration for ambient particulate
  - 24 hour sampling period
- **Weather Station**
  - Wind speed/direction, temperature, relative humidity
- **Dust Flux Monitors**
  - Optical PM-10 measurements

Hayden MOUDI
2009 Annual Average (ng m^{-3})

- Note:
  Pb concentration on secondary access
- 96 hour sampling period
- Bimodal distribution with maxima at 0.32 µm

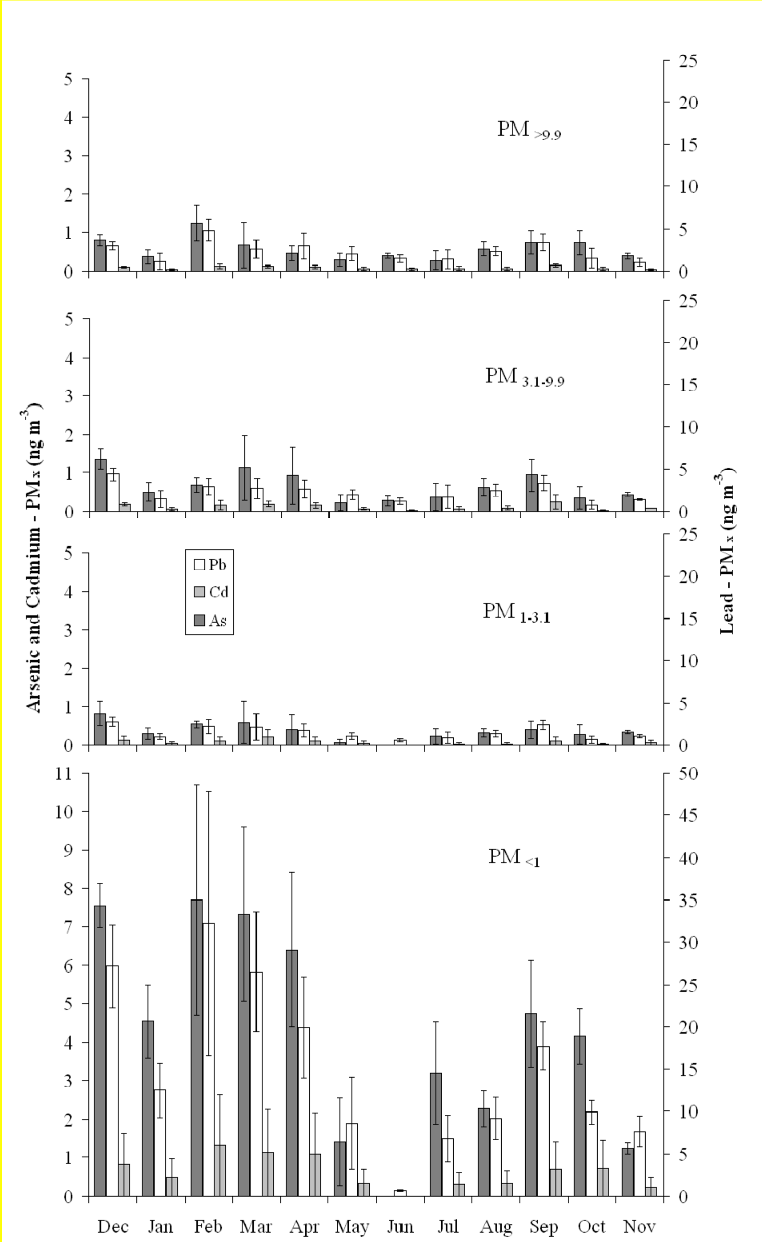


Hayden MOUDI Measurement Verification (ng m^{-3})

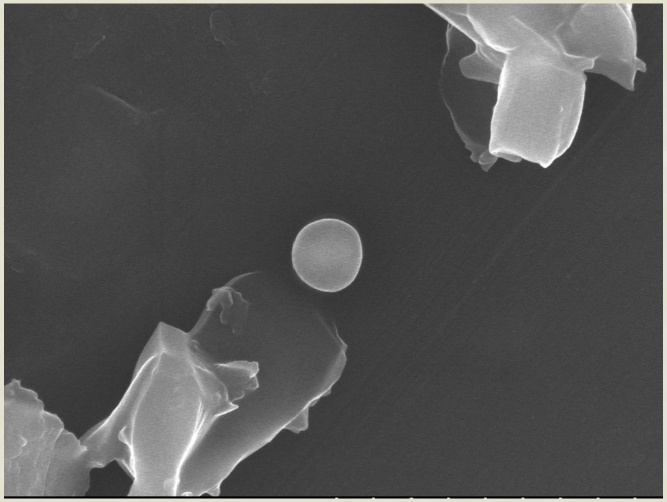


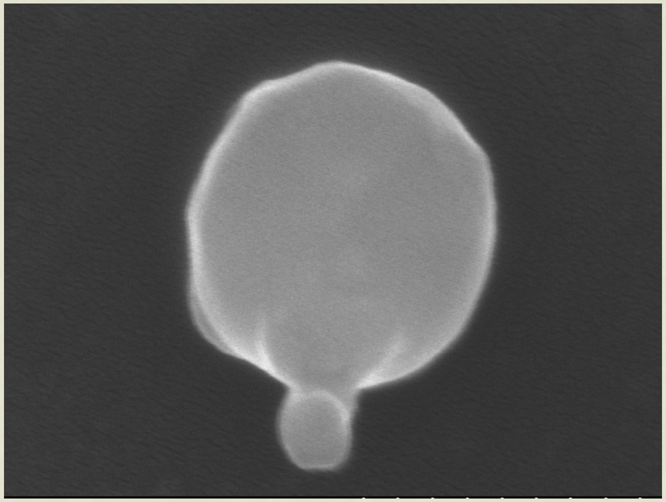
Hayden MOUDI 2009 Seasonal Average (ng m^{-3})

- MOUDI Results for Pb, Cd, and As with monthly averages.
- Notice majority of metals in fine size fraction.
- Higher mixing height occurs in summer months.
- Variability in mine productivity unknown to relate to observations.



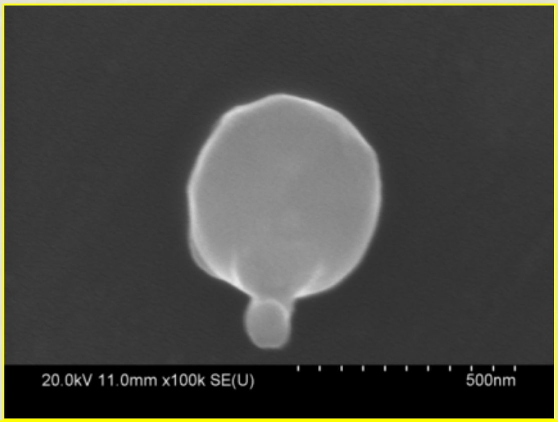
Scanning Electron Microscopy





The spherical nature of the arsenic- and lead-containing particles strongly suggests that they were originally molten, i.e., a product of smelting. The angular nature of the arsenic-free particles (seen in upper image) is more typical of those expected from airborne finely ground mine tailings. The lead particle shows direct evidence of coagulation with a smaller spherical particle.

Hayden Source Apportionment
SEM with EDS
Particles Containing Lead and Arsenic

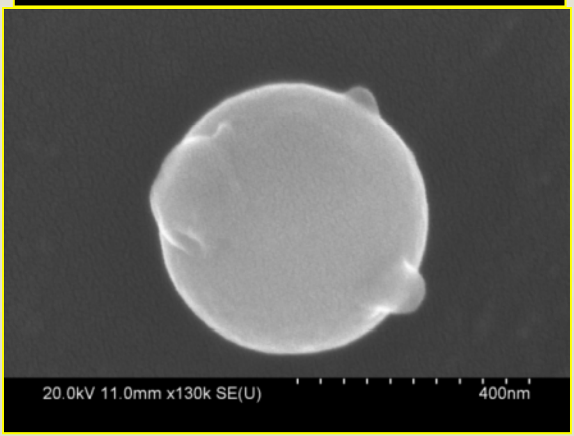


Weight %

	C-K	O-K	Al-K	S-K	Fe-K	Zn-K	Zr-L	Pb-L
Base(13)_pt1	7.47	20.72	54.87	2.06	0.54	1.53	1.93	10.88

Weight % Error (+/- 1 Sigma)

	C-K	O-K	Al-K	S-K	Fe-K	Zn-K	Zr-L	Pb-L
Base(13)_pt1	+/-1.85	+/-0.52	+/-0.19	+/-0.29	+/-0.10	+/-0.22	+/-0.22	+/-1.00



	C-K	O-K	Al-K	Si-K	S-K	Cl-K	Fe-K	Cu-K	As-K	Pt-L
Base(11)_pt1	10.83	22.27	52.12	1.12	0.56	0.24	0.24	9.31	2.32	0.99

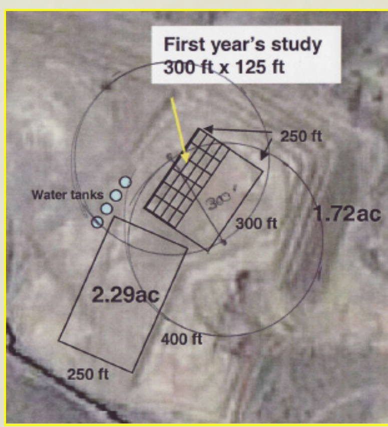
Weight % Error (+/- 1 Sigma)

	C-K	O-K	Al-K	Si-K	S-K	Cl-K	Fe-K	Cu-K	As-K	Pt-L
Base(11)_pt1	+/-1.02	+/-0.29	+/-0.18	+/-0.10	+/-0.06	+/-0.02	+/-0.03	+/-0.18	+/-0.31	+/-0.25

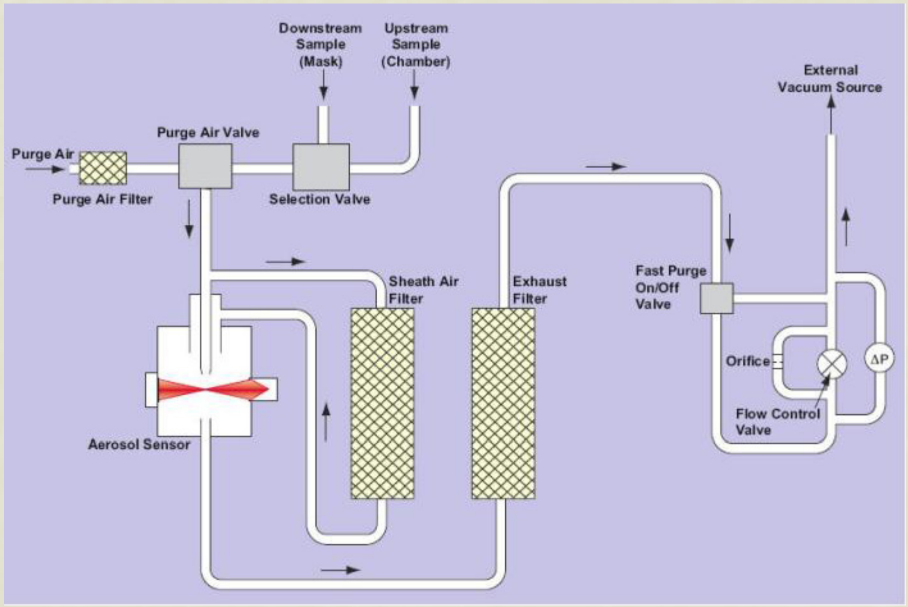
Energy-dispersive X-ray microanalysis imagery with SEM of MOUDI samples collected at Hayden showing the existence of arsenic- and lead-containing particles. The elemental analysis is for the areas targeted with a square on each particle.

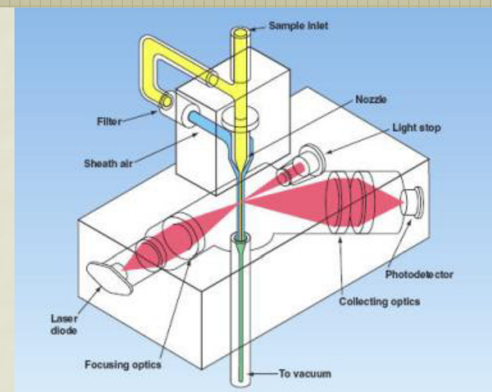
Dust Flux Monitors

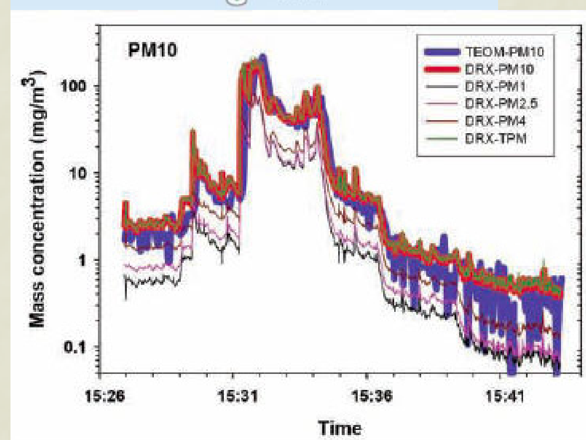
- Dust Flux towers will be installed at Iron King to track the phytoremediation of mine tailings.
- Through monitoring PM10, we hope to show a decrease of dust loading due to the bioremediation of the tailings.
- Passive samplers will also be installed to help characterize horizontal flux.



DustTrack Optical Particle Monitor





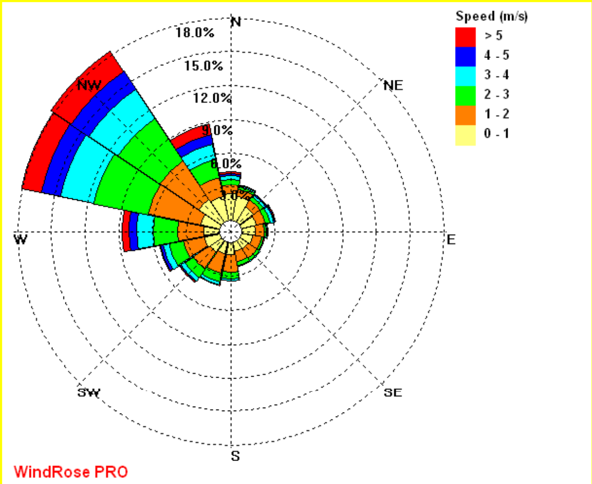


TSI's DustTrak Aerosol Monitor provides reliable exposure assessment by measuring particle concentrations corresponding to PM10, PM2.5, PM1.0 or respirable size fractions. The DUSTTRAK Aerosol Monitor is a portable, battery-operated, laser-photometer that measures and records airborne dust concentrations

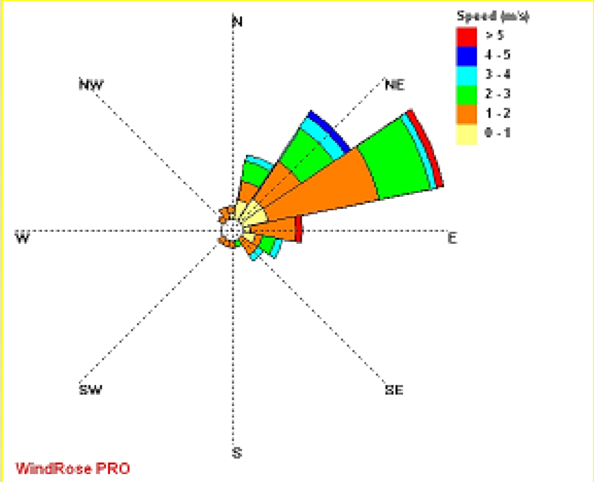
Comparison of Arizona Road Dust (A1) mass concentration measured by the DUSTTRAK DRX and the TEOM with a PM10 impactor.

Wind Direction Controlled MOUDI

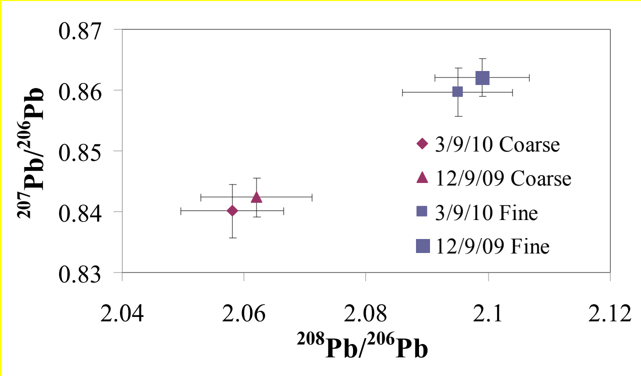
"Source" collection



"Background" collection

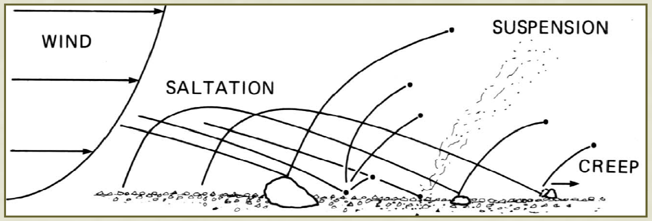


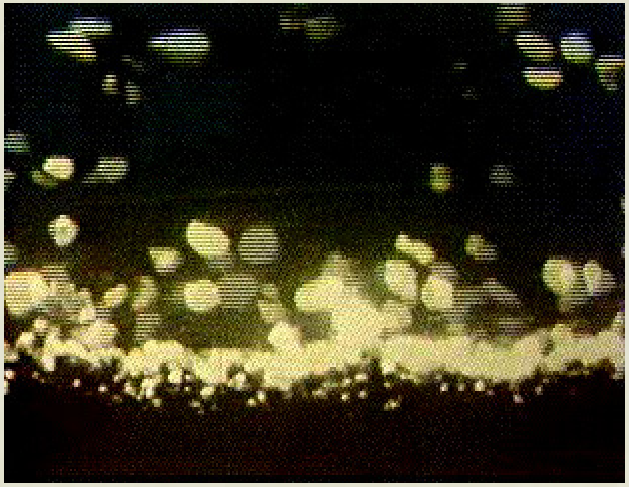
- Ratios between the four stable Pb isotopes are often ore specific used as a measure of age of ore formation or to fingerprint anthropogenic Pb.
- Below: Lead isotope ratios for two sampling periods at the Hayden site.



- MOUDI turns on according to wind direction.
- Waiting for analysis for these sampling periods.
- Future work will include controlling the MOUDI for high wind events.

Wind Erosion Modeling



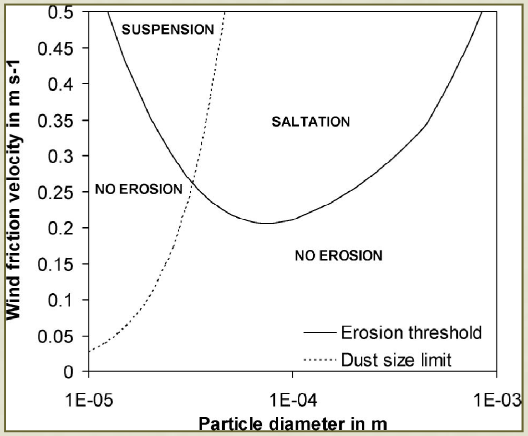


Saltating sand dune particles in wind tunnel

Kansas State University http://www.weru.ksu.edu/new_weru/multimedia/movies/dust003.mpg

Mass flux:

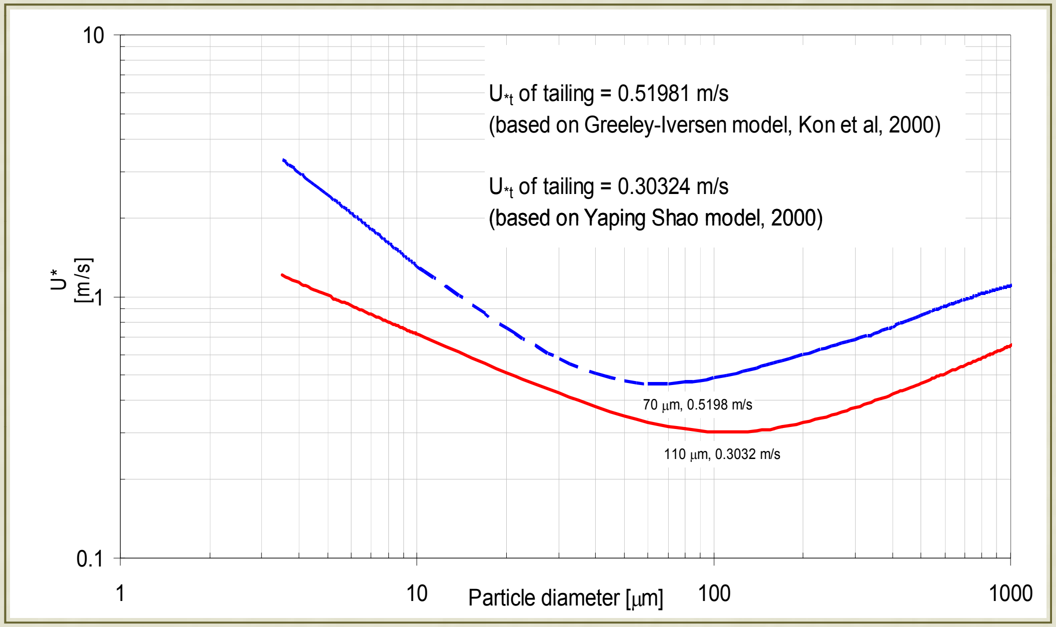
- Creep (rolling): 800-2000 μm D_p
- Saltation (hopping): 100-800 μm D_p
- Suspension (wind blown dust): <100 μm D_p



Greeley-Iversen erosion threshold curve

Kon *et al.*, *Int. J. Min. Reclamation & Env.* **21**, 198 (2007)

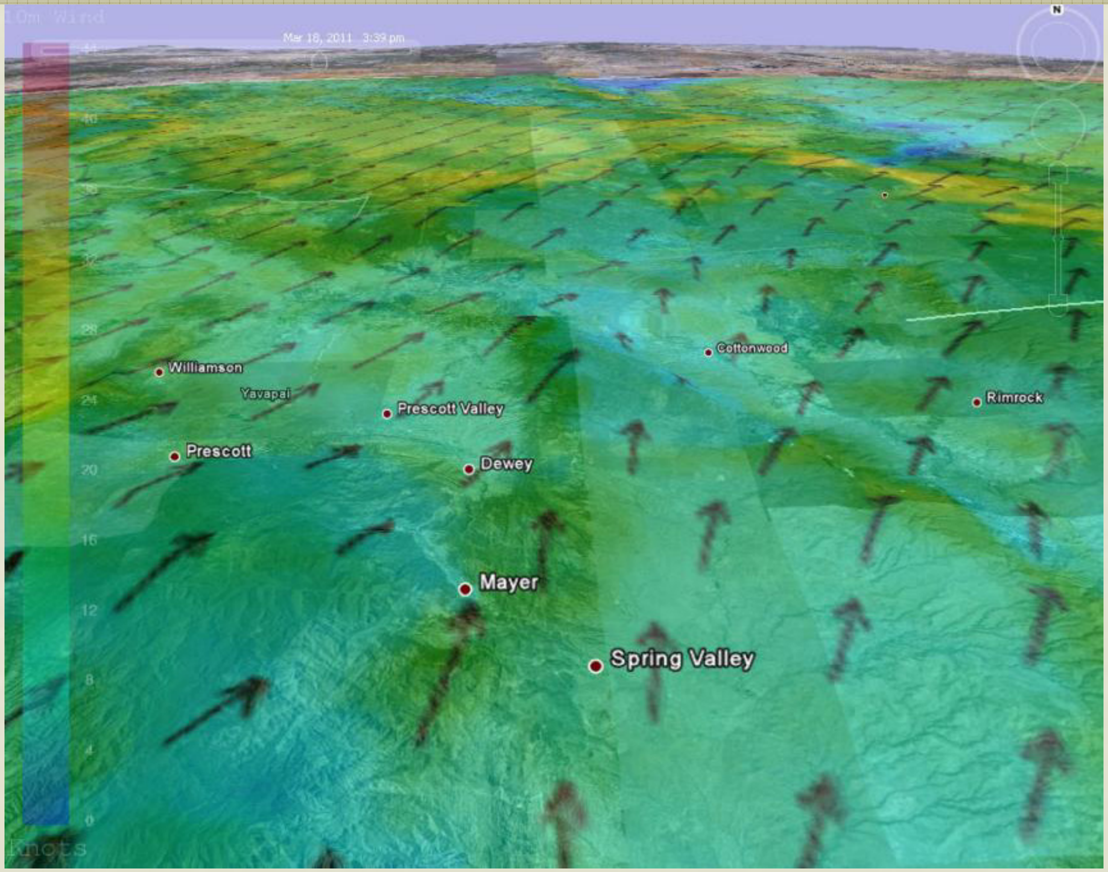
Threshold Velocity
Iron King Tailings



Calculated wind threshold friction velocity at the Iron King site assuming a bed composed of uniform grains with different densities (d_{50} = 3 mm, r = 4.16 g/cm^3)

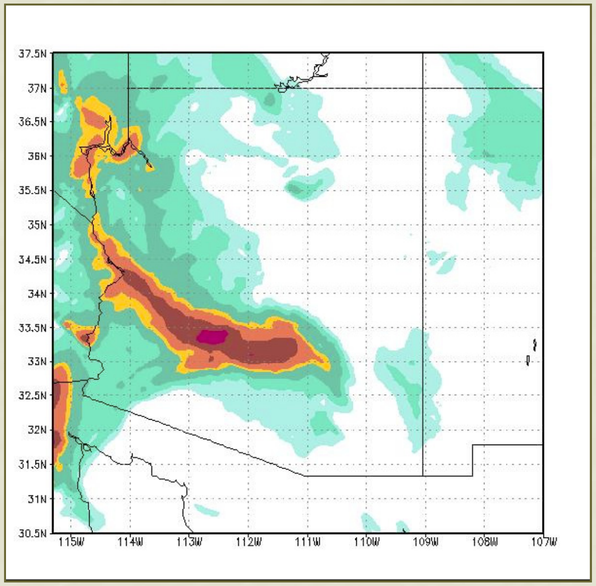
- The minimum of U_{*t} occurs between d = 70 mm and 110 mm. For particles larger than this, U_{*t} increases with increasing *d* due to increasing dominance of gravity. For smaller particles, U_{*t} increases rapidly with decreasing d due to interparticle cohesive forces.
- Erosion occurs if wind speed measured at a height of 10 m is greater than 8.7 m/s (Greeley-Iversen model), and 13.3 m/s (Yaping Shao model)

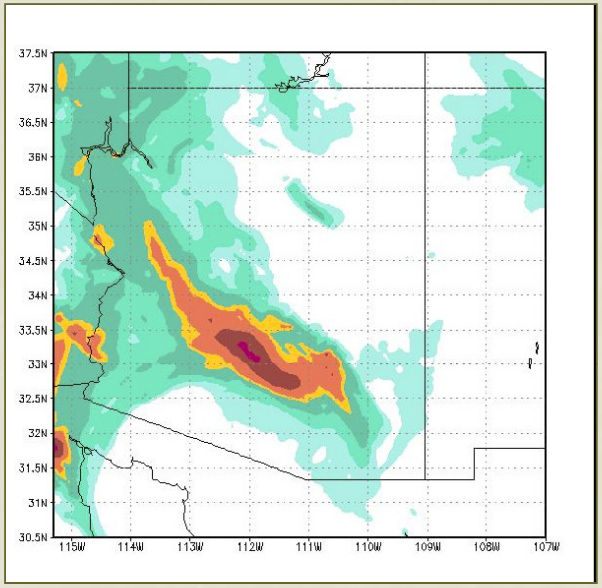
Weather Research and Forecast Model (WRF)



10-meter wind forecast on Google Earth

Desert Dust Modeling





Hindcast of 18 July 2007 dust storm across Arizona in the early morning hours in two time steps. Near-surface Air Quality Index contributed by desert dust in color gradations from light blue (AQI 1: 1-50 mg/m3) to red (AQI 6: >300 mg/m3). (Sprigg, et al., 2008)