EXPLORING RESPIRABLE SILICA PARTICLE SIZE AND SURFACE CONDITION

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NIOSH/MSHA Silica Exposure and Lung Disease in the Mining Industry Workshop

22 Oct 2020

Acknowledgements

- This research is funded by CDC/NIOSH (contract 75D30119C05528), and includes dust samples collected during several previous projects funded by the Alpha Foundation for the Improvement of Mine Safety and Health

- We are grateful to our numerous industry partners, who have provided mine access and support for dust sampling

- Views expressed here are those of our research team, and do not necessarily represent the views of sponsors or our industry partners

Research motivation

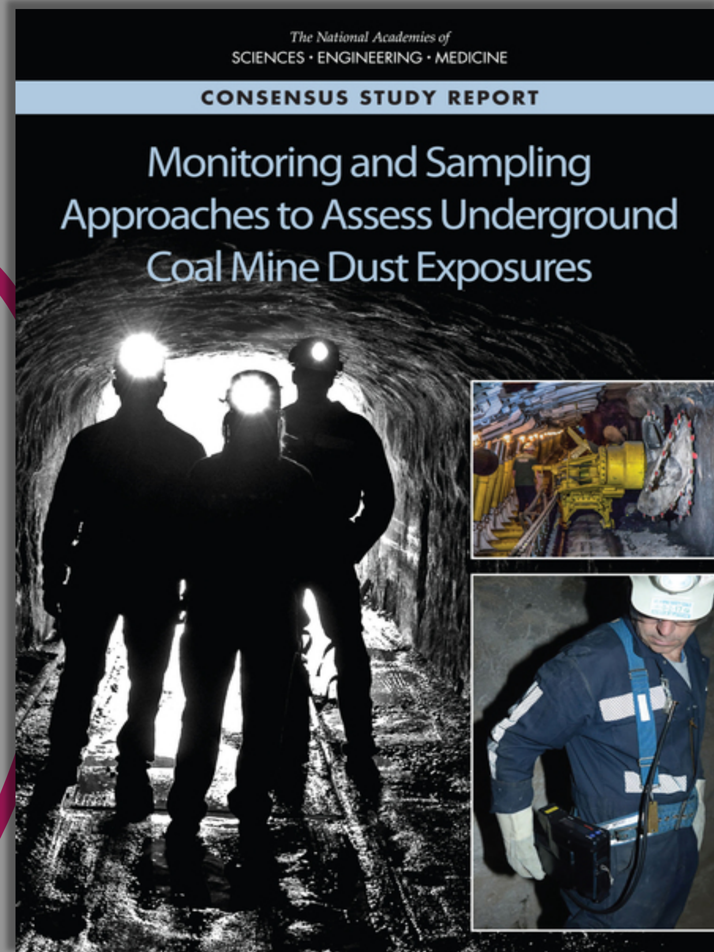
RCMD Exposure and Disease Rates

Association of Changes in Mining Technology and Activities with the Occurrence of Disease Hot Spots

Recommendation 8: Conduct a systematic evaluation of changes in mining technology and activities to determine the extent to which those changes have caused increased extraction of rock and the extent to which past rock extraction had been co-located with disease hot spots. The evaluation should identify important focus areas for optimal sampling and monitoring strategies in the future. *(see Chapters 1 and 5)*

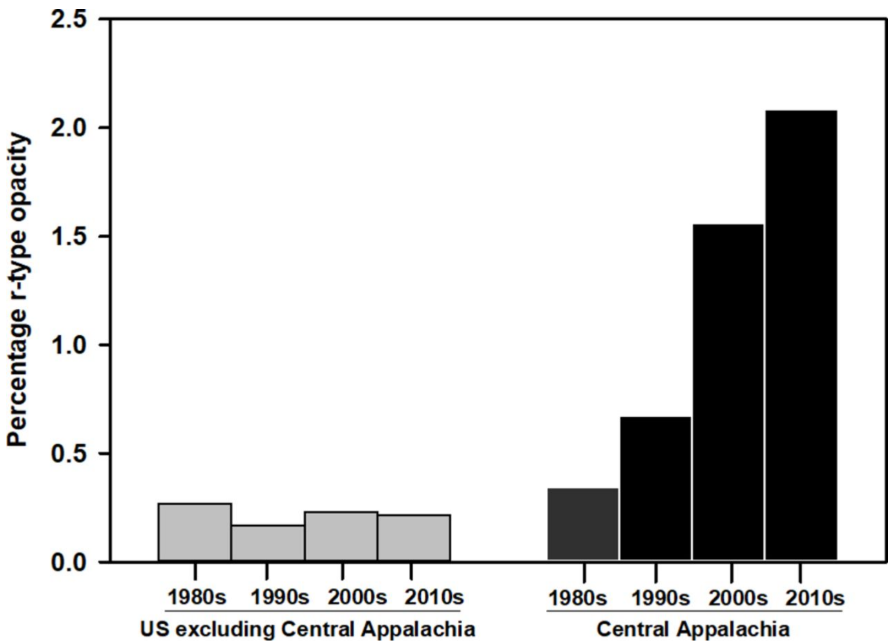
Key Characteristics of RCMD Particles to Be Monitored by Future Exposure Studies

Recommendation 9: NIOSH should conduct or facilitate a comprehensive assessment of RCMD particle characteristics, including their variability, to help target future exposure studies, because different particle characteristics (for example, composition and surface area) can pose different health hazards. In addition, the assessment should characterize and quantify important source contributions to airborne RCMD, including rock dusting and extraction of



National Academies of Sciences, Engineering, and Medicine. (2018) Monitoring and Sampling Approaches to Assess Underground Coal Mine Dust Exposures. Washington, DC: The National Academies Press.

Silica as a primary culprit



Hall et al. (2019) Continued increase in prevalence of r-type opacities among underground coal miners in the USA, Occup Environ Med. 76:479-481.

Examples of Types of PMF

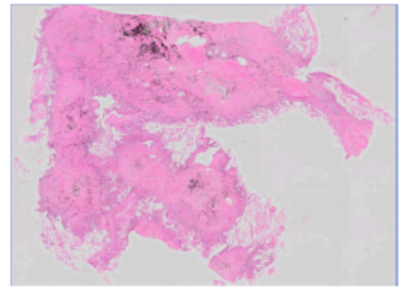


Figure 1. Area of silicotic type PMF. The areas is composed of fused silicotic nodules, very little black dust.

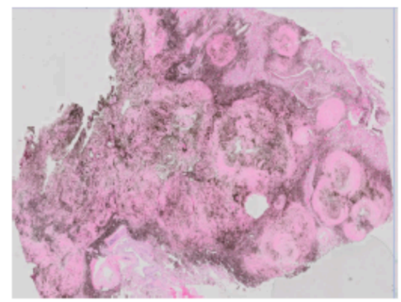


Figure 2. Area of mixed type PMF. Classic silicotic nodules at right, coal dust type at left.

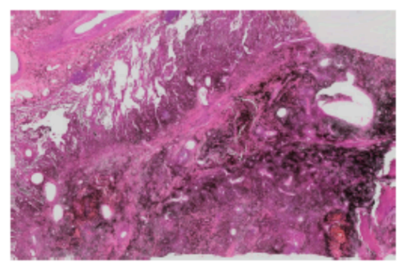
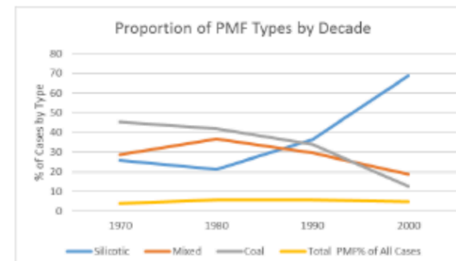


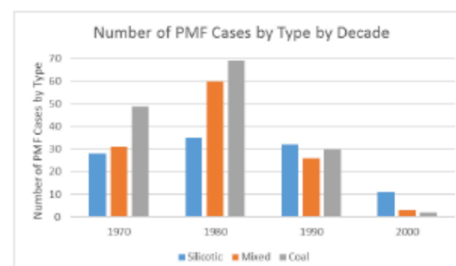
Figure 3. Area of predominantly coal type PMF with < 25% silicotic nodules. Heavy coal pigmentation.

Summary of Preliminary Results

- 4,690 of 7,200 NCWAS cases had adequate lung tissue and evidence of pneumoconiosis
- 487 cases had been classified as PMF by NIOSH pathologists
- Only 376 had materials currently available for review.
- There was no difference in mining tenure (33 years) or age at death (71) between types of PMF groups.
- The majority of miners came from VA, WV, and PA
- There was a significant increase in the proportion of silicotic PMF occurring after 1990 – 40% vs. before 1990, 24%, (p=0.002).

PMF Type	Pre 1990	Post 1990
Coal	118	32
Mixed Dust	91	29
Silicotic	65	41
Total	274	102





Cohen et al. (2019) Pathology of Progressive Massive Fibrosis in the National Coal Workers' Autopsy Study 1971-2012, In proceedings of the ATS Annual Meeting, Dallas, TX (May 17-22).

MSHA data shows relatively high quartz in Appalachia…

respirable dust ***% samples exceeding quartz PEL*** ***quartz %***

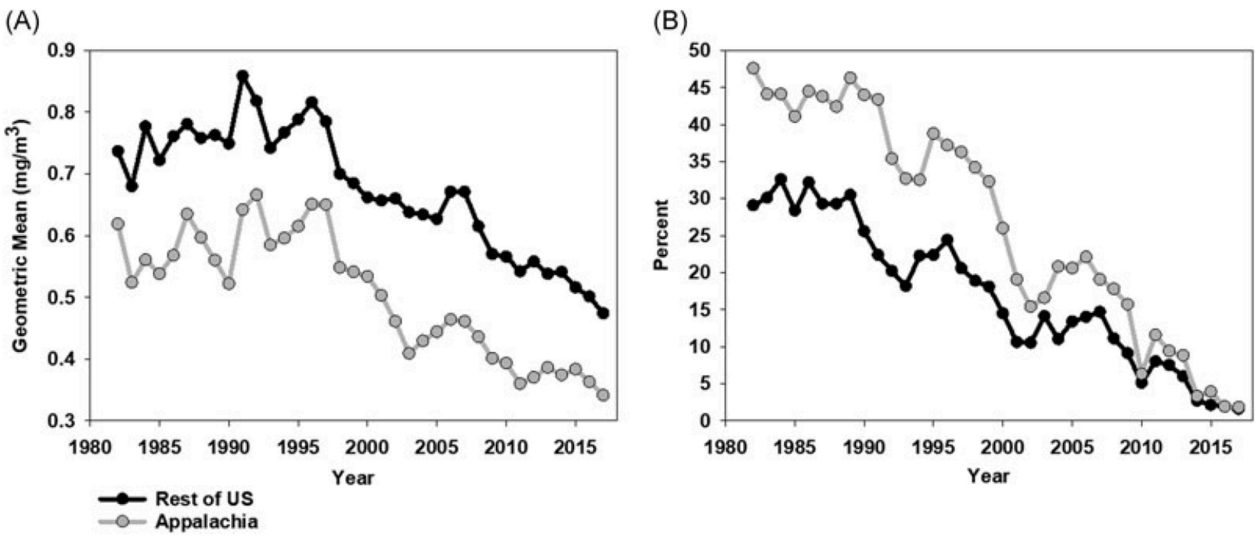


FIGURE 3 Comparison of annual geometric mean (A) respirable dust and (B) percent respirable dust samples containing quartz exceeding the permissible exposure limit for central Appalachia (MSHA Districts 4, 5, and 12 combined; gray line) and the rest of the United States (MSHA Districts 2-3, 7-10 combined; black line) by year. MSHA, Mine Safety and Health Administration

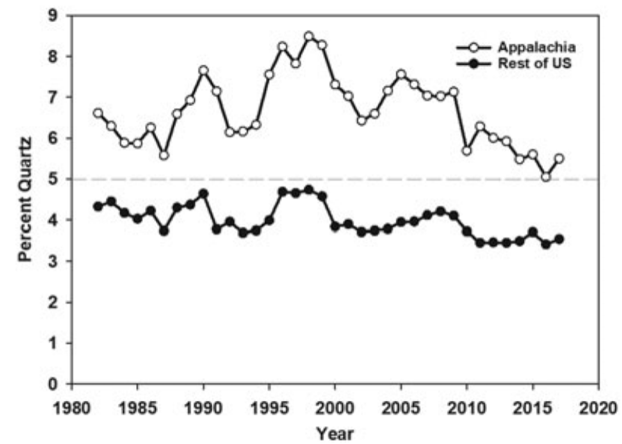


FIGURE 4 Mean percent quartz in samples for central Appalachia (MSHA Districts 4, 5, and 12 combined) and the rest of the United States (MSHA Districts 2-3, 7-10 combined) by year. MSHA, Mine Safety and Health Administration

Doney et al. (2019) Respirable coal mine dust in underground mines, United States, 1982-2017, Am J Ind Med. 62(6): 478-485.

… also indicates quartz concentration has been declining

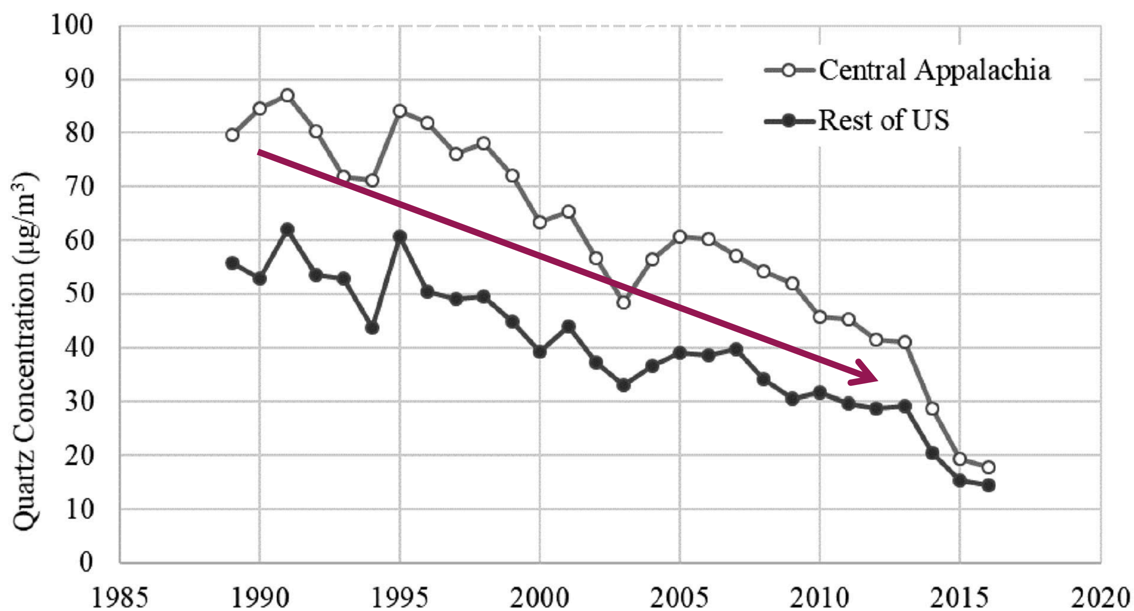


Figure 1. Geometric mean quartz concentration (µg/m^3) in respirable dust samples collected in underground coal mines in central Appalachia (MSHA districts 4, 5, and 12) and the rest of the US between 1989–2016. Original dataset publicly available from MSHA (2017) and includes all operator and inspector dust samples taken and analyzed for quartz between 1986–2016 (Only two samples were available for 1986–1988, so analysis for the plot was limited to samples taken in 1989 or after.)

Agioutanti et al. (2019) A thermogravimetric analysis application to determine coal, carbonate, and non-carbonate minerals mass fractions in respirable mine dust, J. Occup. Enviro. Hygiene, DOI: 10.1080/15459624.2019.1695057.

How do we explain contradiction between dust and health data?

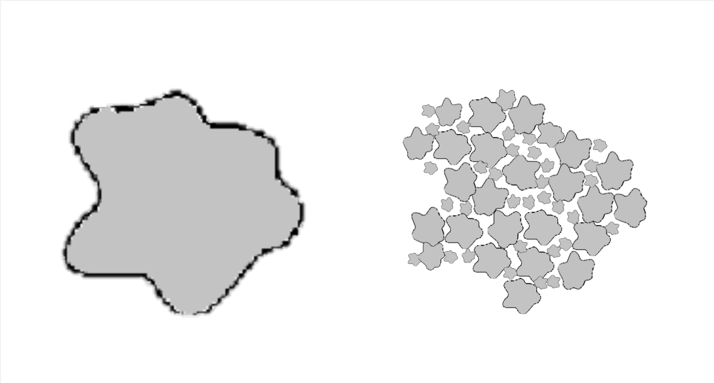
- Monitoring is too infrequent?
- Data is otherwise not representative?

- Maybe there are other important metrics?

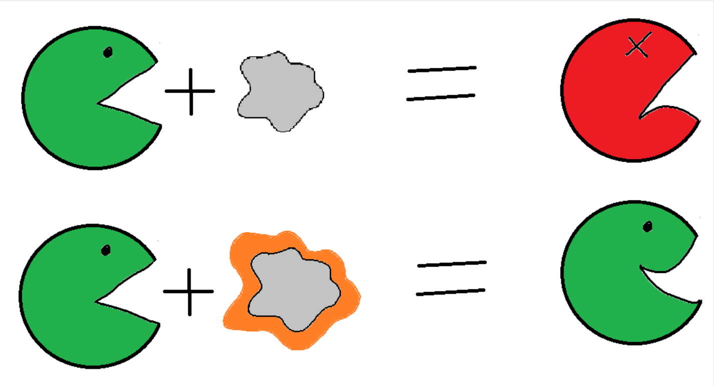
Some evidence to suggest that silica toxicity is related to particle characteristics – including size and surface condition

Silica size and surface condition

- For equivalent masses, smaller particles might result in more severe lung response due to
  - increased surface area
  - increased retention/clearance time
  - increased penetration depth



- All else equal, silica particles with free (un-occluded) surfaces might be to be more toxic than particle with occluded surfaces, likely due to
  - increased chemical reactivity

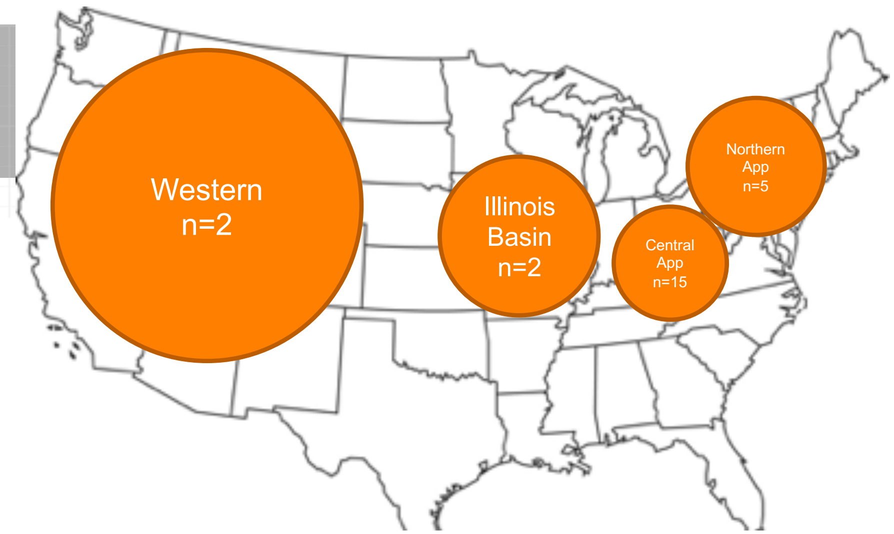


Research

Respirable silica characteristics in US coal mines

Mine dust samples

Location	Description
Intake	In the fresh airways, upstream of any bolting or mining activities
Roof bolter	Just downwind of an active roof bolter
Feeder	Adjacent to the feeder breaker, or along the main conveyor belt or transfer points
Production	Just downwind of an active continuous miner, or on the longwall face
Return	In the exhaust airway, including downwind of ventilation tubing exhaust where present



zefon.com

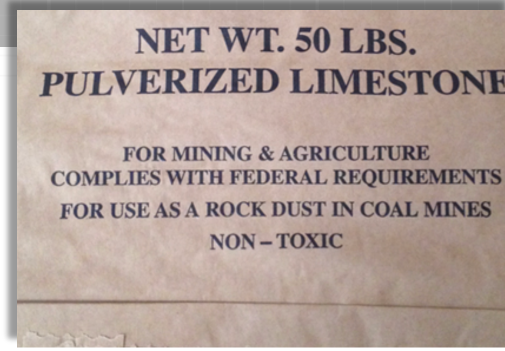
TOTAL INVENTORY:
166 samples from 24 mines (107 unique sampling locations)

Dust source materials

Run of mine (ROM) materials

TOTAL INVENTORY:
40 materials from 15 mines

Rock dust products



Material from roof bolter dust collection systems

Photo: Colinet & Thimons (2007) Dust Control Practices for Underground Coal Mining, In Proceedings of the 32nd International Conference of Safety in Mines Research Institutes, 28-29 September 2007, Beijing, China.

Research objectives

1. ***Characterize respirable silica in real coal mine dust samples, in terms of its particle size distribution and presence / absence of particle surface occlusion***

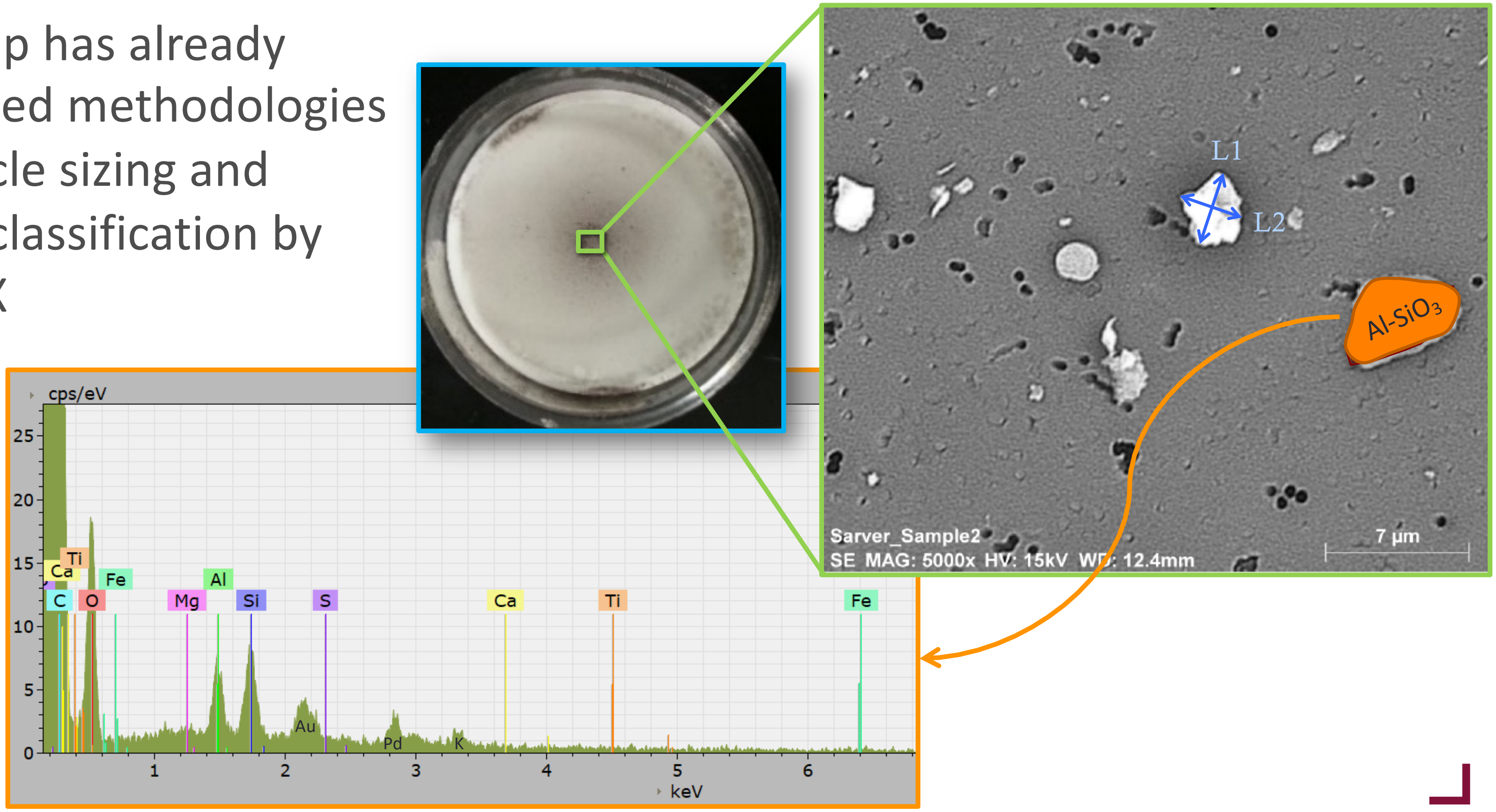
2. Evaluate major silica source contributions by comparison of these characteristics between mine dust and source-dust samples

3. Compare particle-based measures of respirable silica to conventional and emerging mass-based measures (i.e., MSHA P7 and portable FT-IR)

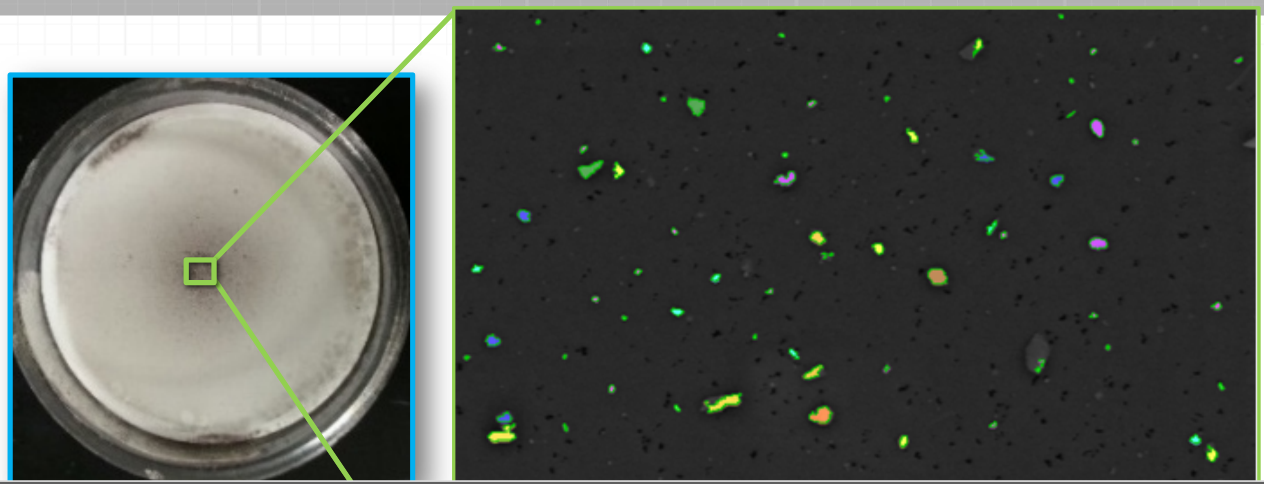
Silica content and size distribution

Dust particle analysis by SEM-EDX

- Our group has already established methodologies for particle sizing and mineral classification by SEM-EDX

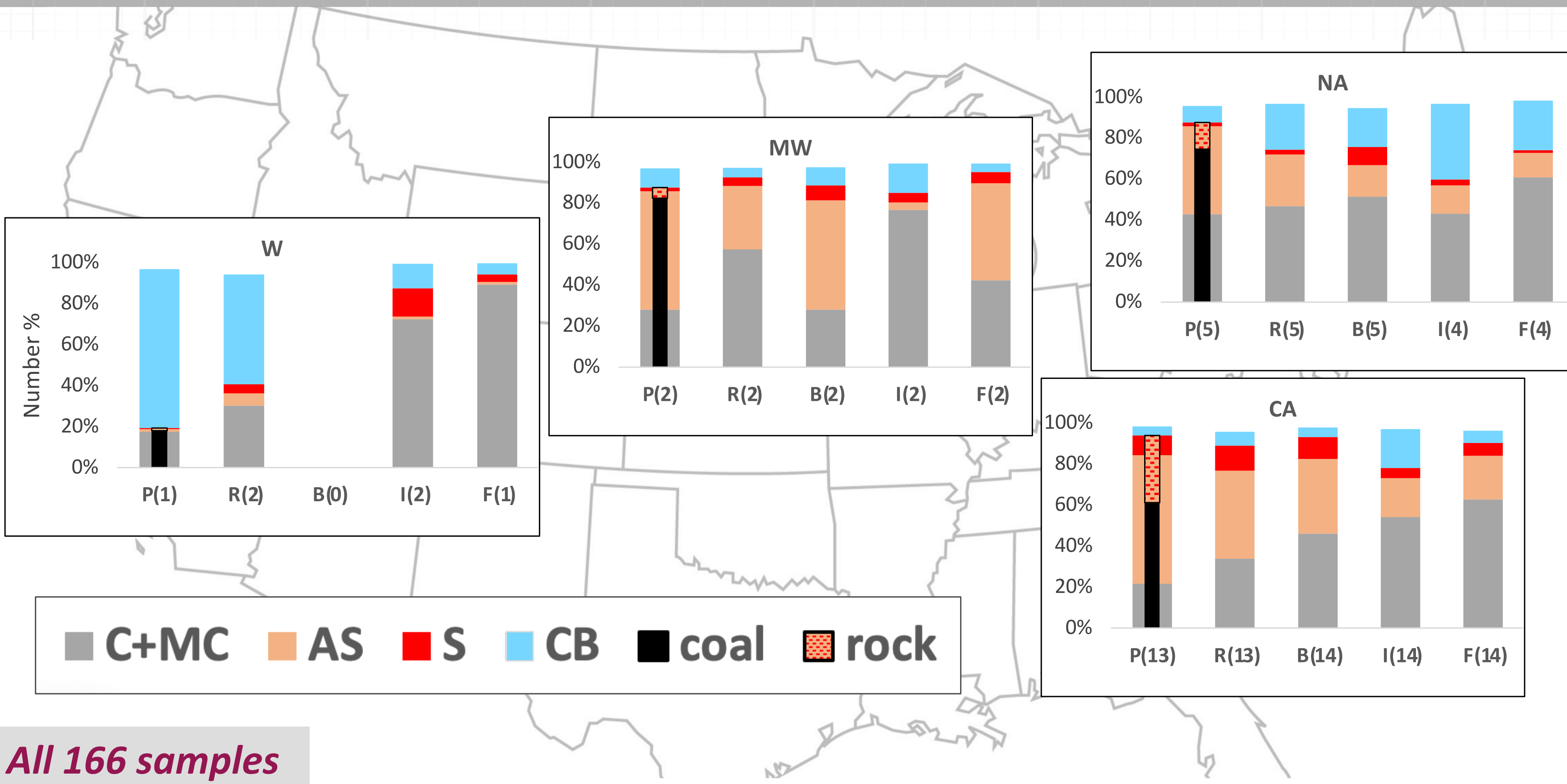


Silica particle identification, counting and sizing



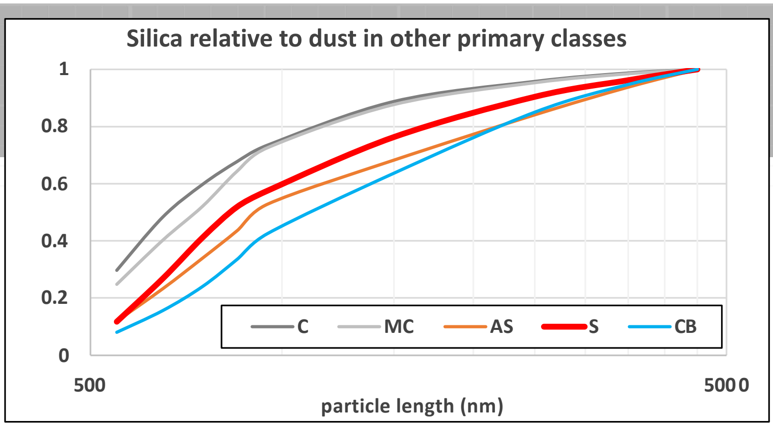
Mineralogy Class		Sources
Carbonaceous	C	coal strata and diesel particulates
Mixed carbonaceous	MC	coal, roof/floor rock strata
Alumino-silicates	AS	roof/floor rock strata
Silica	***S***	***roof/floor rock strata***
Carbonates	CB	rock dusting products
Heavy minerals	HM	metal sulfides/oxides in coal or rock strata, metallic particles from equipment, diesel particulates?
Other	O	other minerals, biological particles, etc.

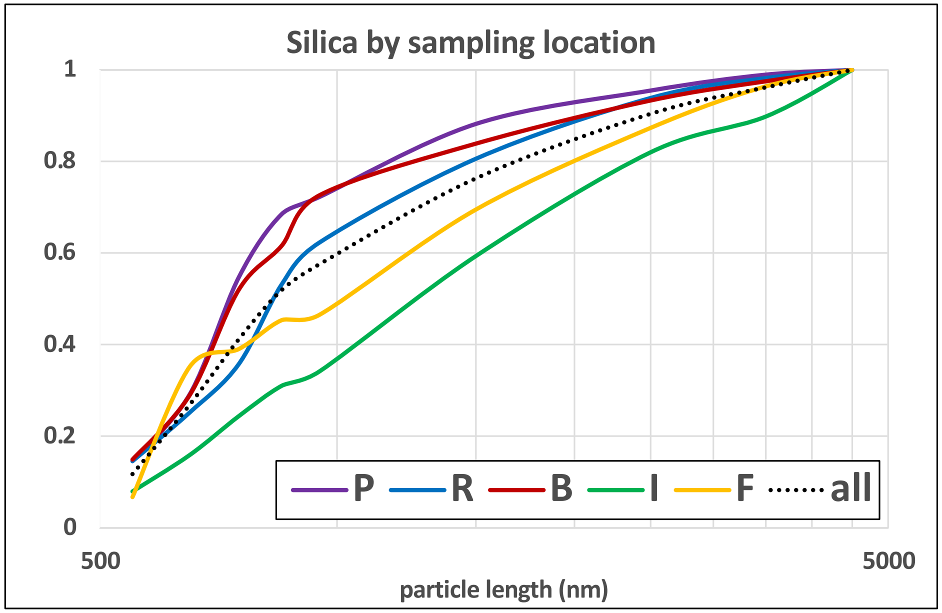
Relative silica content by mine region and sampling location

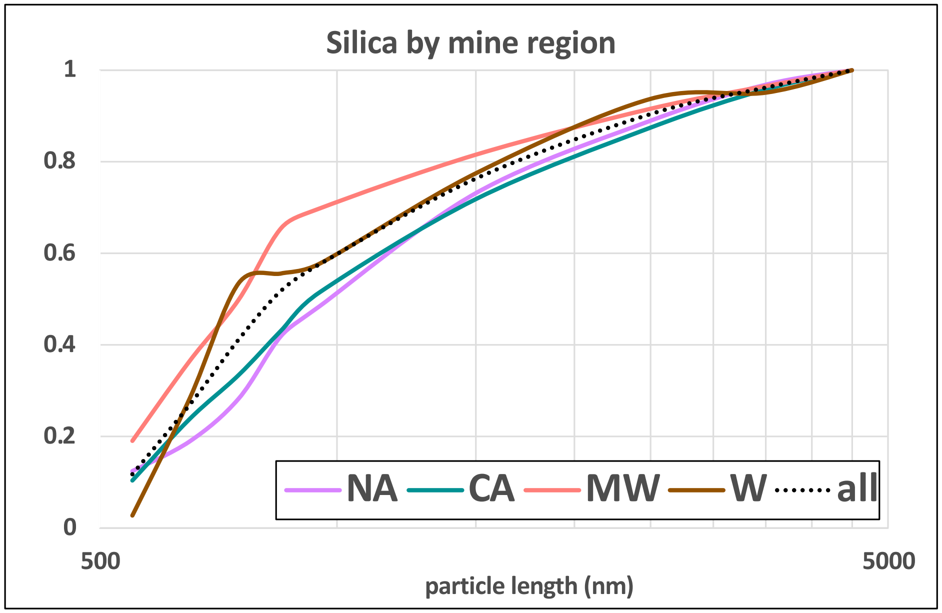


All 166 samples

Silica particle size distribution





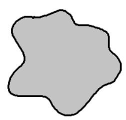


All 166 samples

Silica occlusion

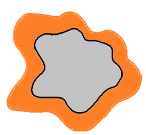
Analysis of silica particle occlusion

free silica

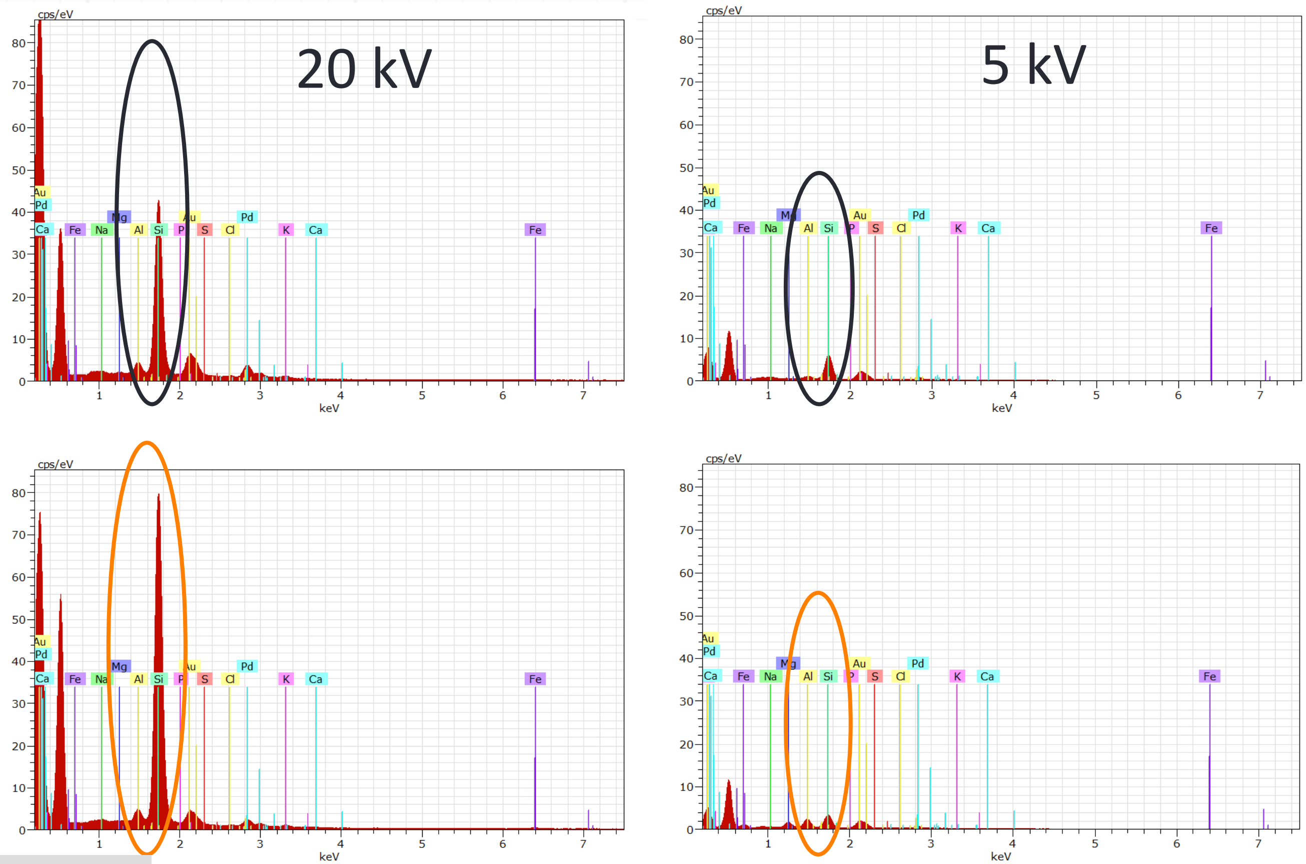


$$\left(\frac{Si}{Al+Si}\right)_{20kV} - \left(\frac{Si}{Al+Si}\right)_{5kV} \approx 0$$

occluded silica



$$\left(\frac{Si}{Al+Si}\right)_{20kV} - \left(\frac{Si}{Al+Si}\right)_{5kV} \gg 0$$



Analysis planned for ~100 samples

Silica particle occlusion – results from Harrison et al. (1997)

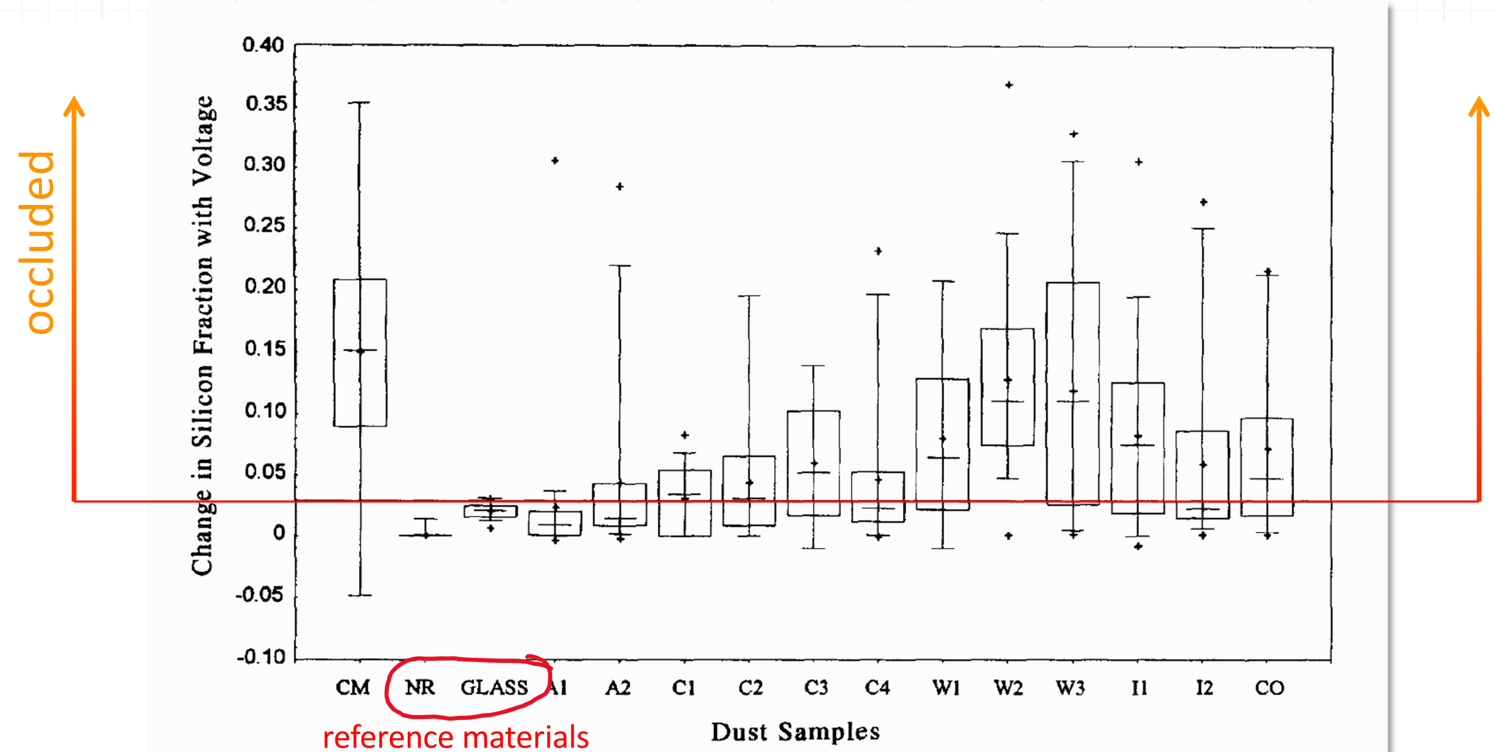
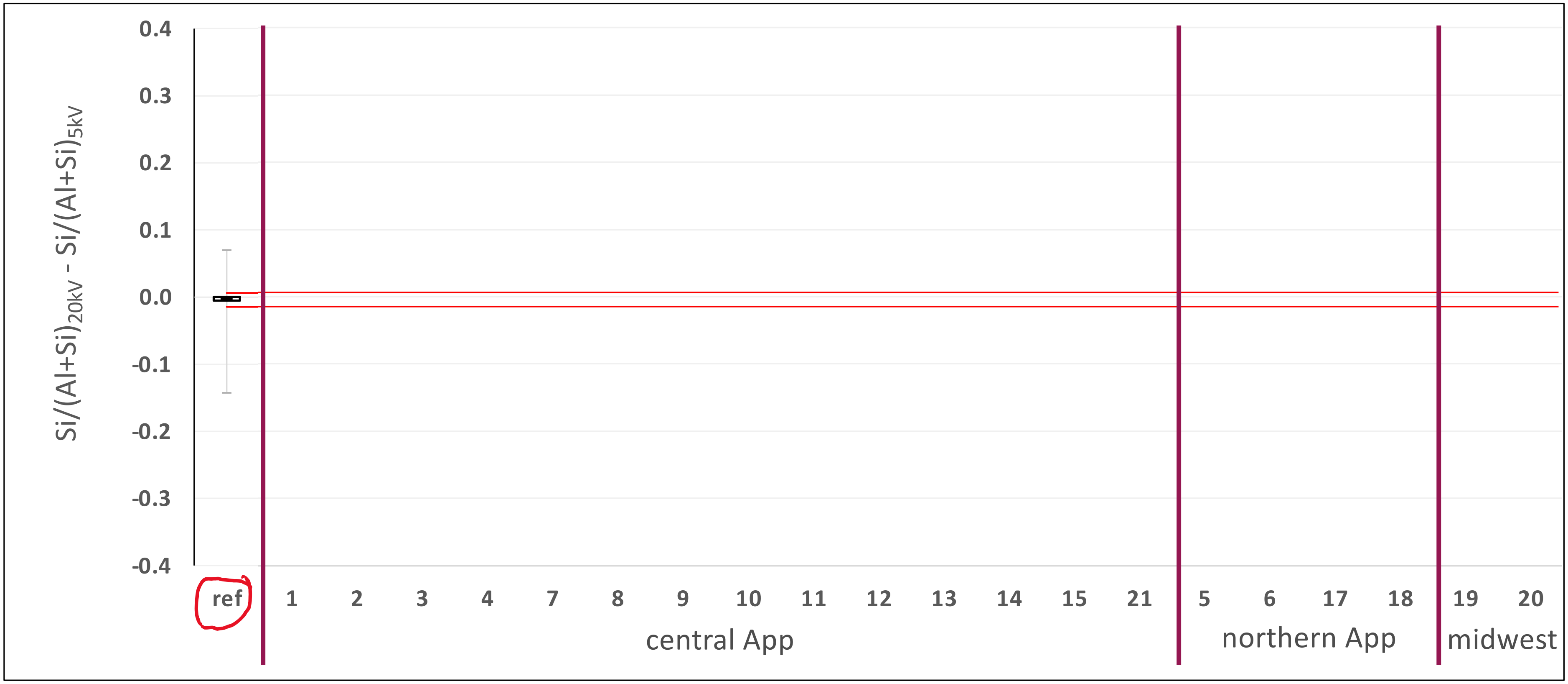


Fig. 1. Distribution of the change in measured silicon fraction with reduction in voltage of the average repeated measurement per particle for each dust sample.

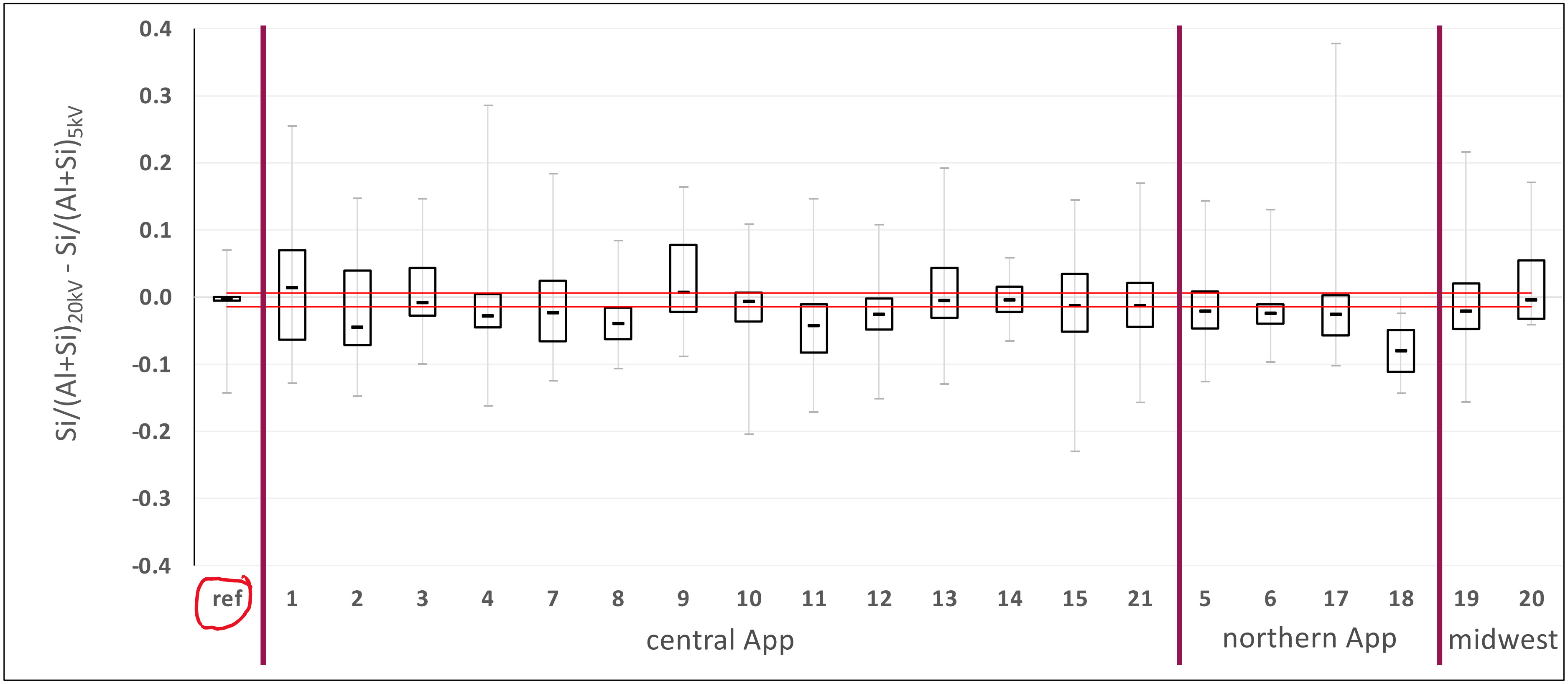
Harrison, J. et al. (1997). Surface composition of respirable silica particles in U.S. anthracite and bituminous coal mine dusts, J. Aerosol Sci., 28(4): 689-696.

Silica particle occlusion – results by mine/region



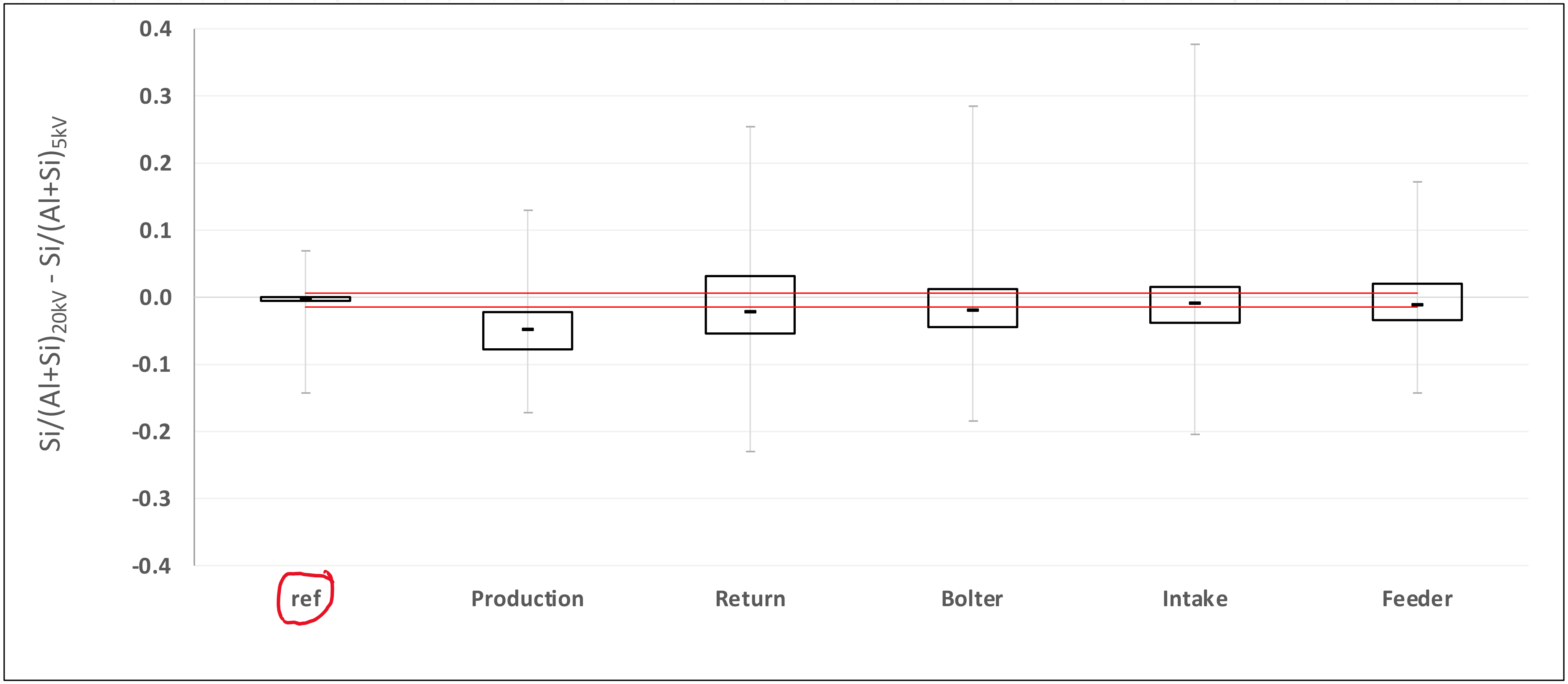
49 samples from 20 mines

Silica particle occlusion – results by mine/region



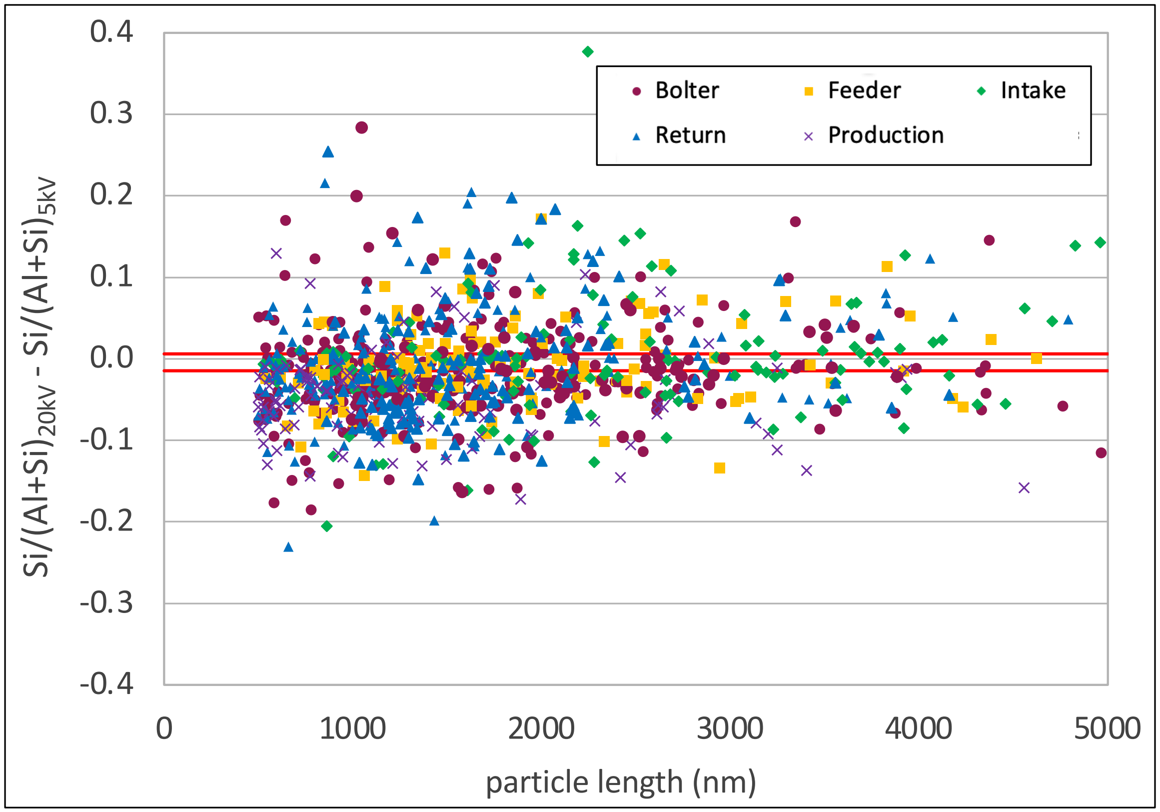
49 samples from 20 mines

Silica particle occlusion – results by sampling location

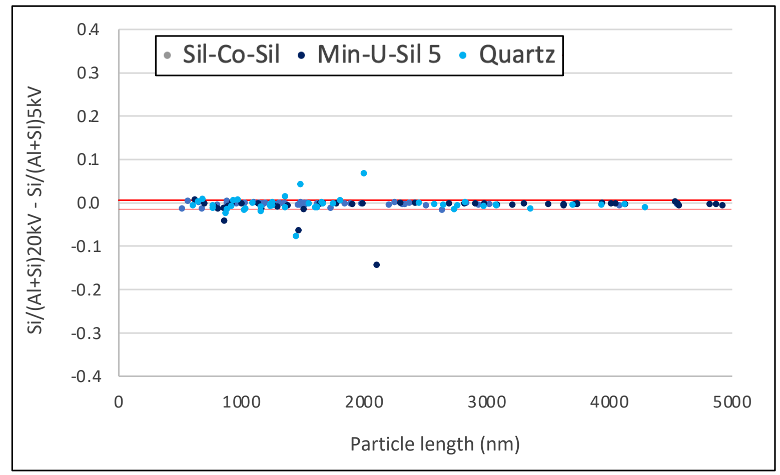


49 samples from 20 mines

Silica particle occlusion – results by particle size



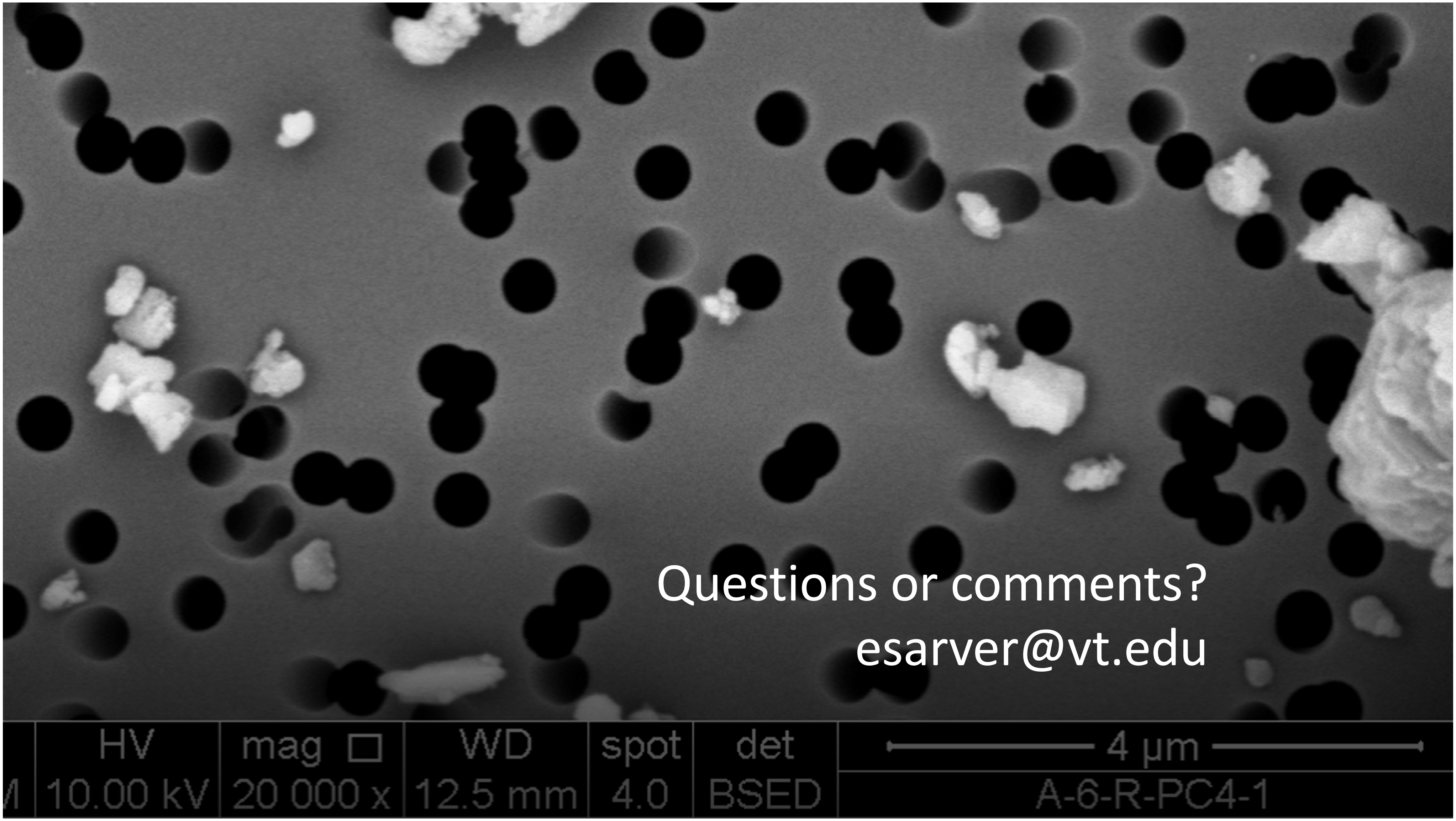
Reference particles



49 samples from 20 mines

Concluding remarks

- Silica is one mineral component of respirable coal mine dust
- Analysis of modern mine dust samples indicates
  - silica particles are somewhat finer than other mineral particles and
  - size distributions can vary between and within mines
- Work is ongoing to understand the degree of variability in silica particle surface occlusion – but results to date suggest silica particles in mine dust may be quite different from pure particles
- Future work will also compare silica particles from dust source materials to those in mine dust samples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