An Investigation of Aerosolization and Associated Phenomena Resulting from the Detonation of Explosives

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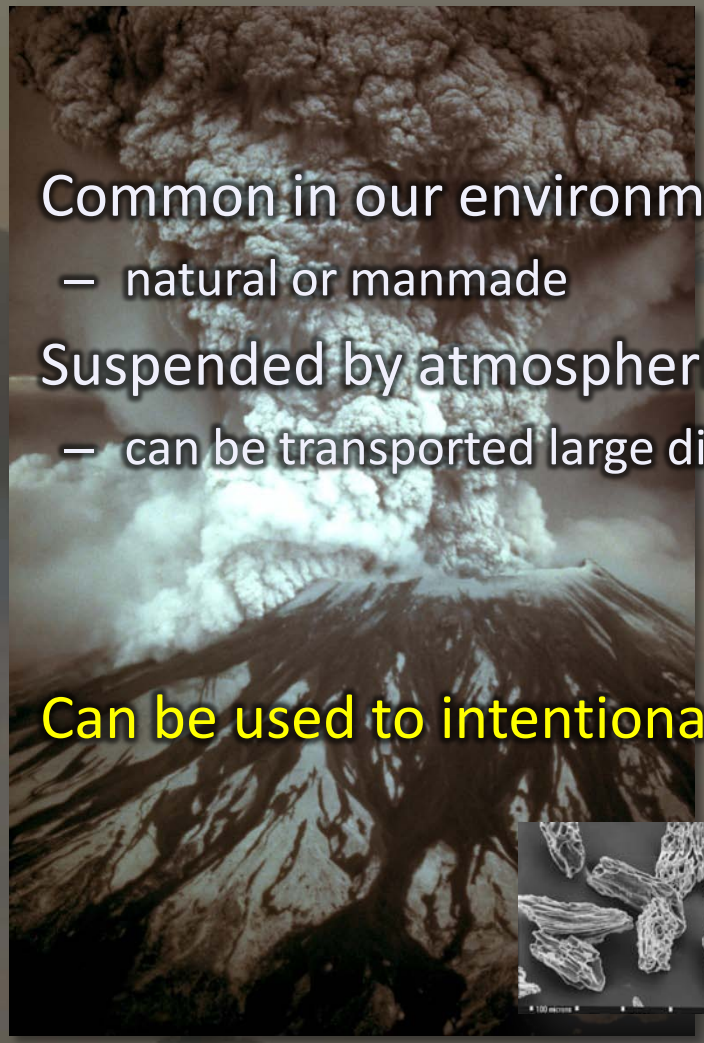
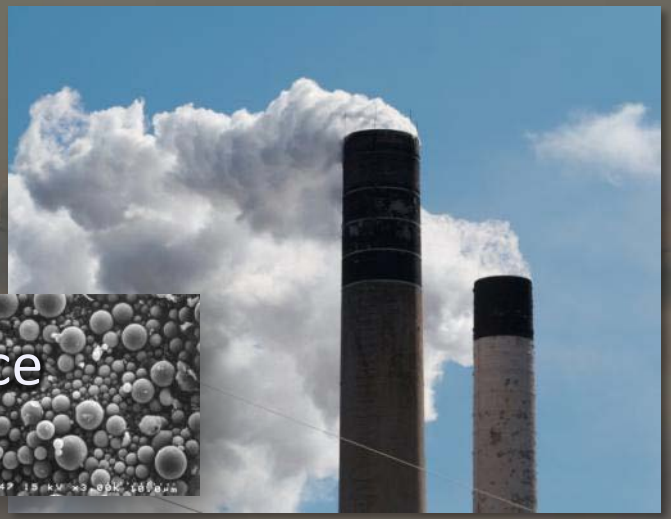
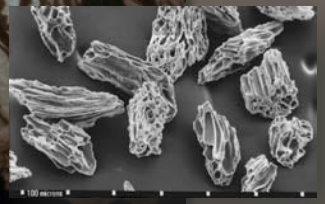
Aerosols





- Common in our environment
  - natural or manmade
- Suspended by atmospheric turbulence
  - can be transported large distances
- Can be used to intentionally disseminate hazardous materials



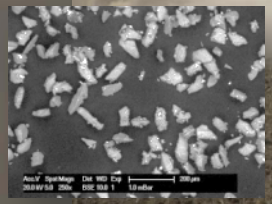


Image Sources: [1] Mila Zinkova, "San Francisco in fog with rays" September 26, 2009 via Wikimedia Commons. [2] Austin Post, USGS, "MSH80 Eruption mount St Helens 05-18-80-dramatic edit" may 18, 1980 via Wikimedia Commons. [3] Dori, "Smokestacks, in Champaign, IL" February 10, 2008 via Wikimedia Commons. [4] Michael Trolove, "September dust" September 25, 2009 via Wikimedia Commons. [5] Federal Highway Administration, "Fly ash" July 14, 2006 via Wikimedia Commons. [6] A.M. Sarna-Wojcicki, "SarnaSem_60-000_large" April 19, 2010 via volcanoes.usgs.org. Creative Commons Attribution. [7] Luke Lebel, "Fine sand SEM" September 24, 2010.

Outline

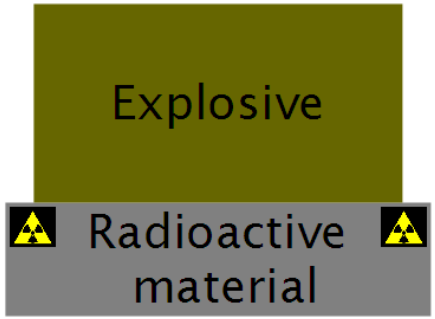
1. Background
2. Closed Vessel Experiments
3. Experimental Results
4. Conclusions

Outline

1. Background
   1.1 Aerosols
   1.2 Explosive Aerosolization
   1.3 Fireball Mechanics
   1.4 Impetus of Research
2. Closed Vessel Experiments
3. Experimental Results
4. Conclusions

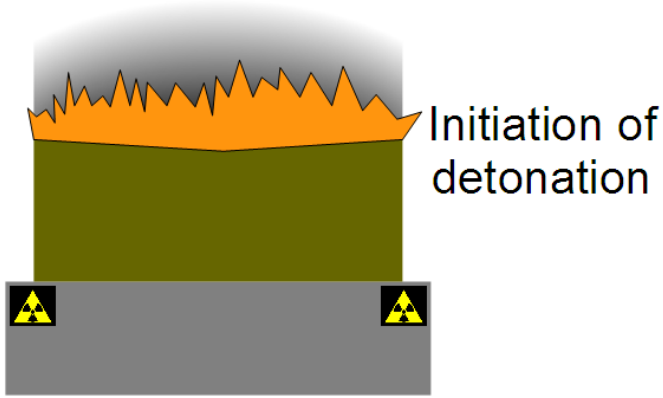
Explosive Aerosolization

Time = 0



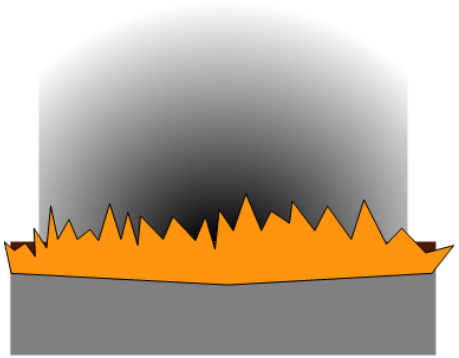
Explosive Aerosolization

Time = ~10 μs



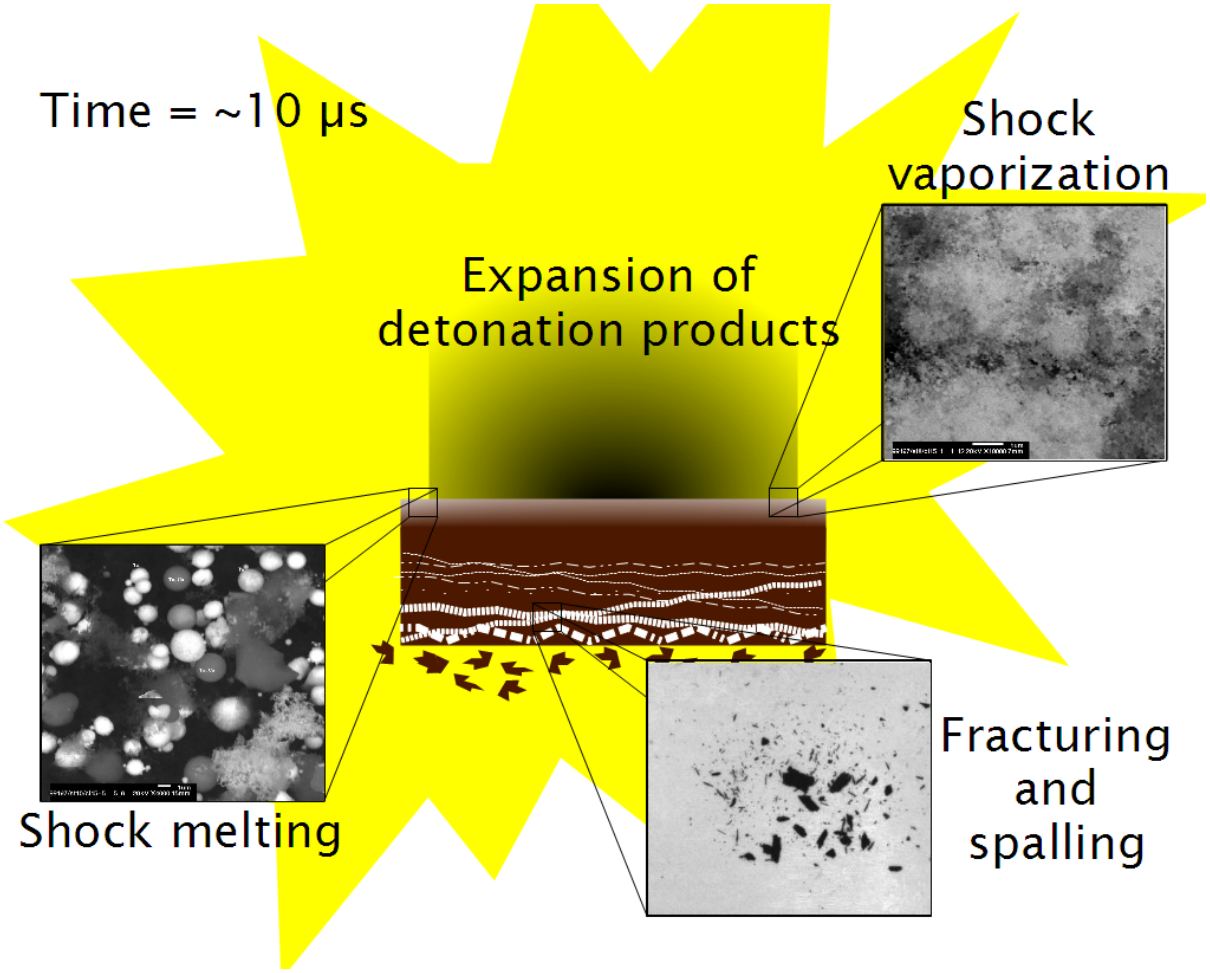
Explosive Aerosolization

Time = ~10 μs

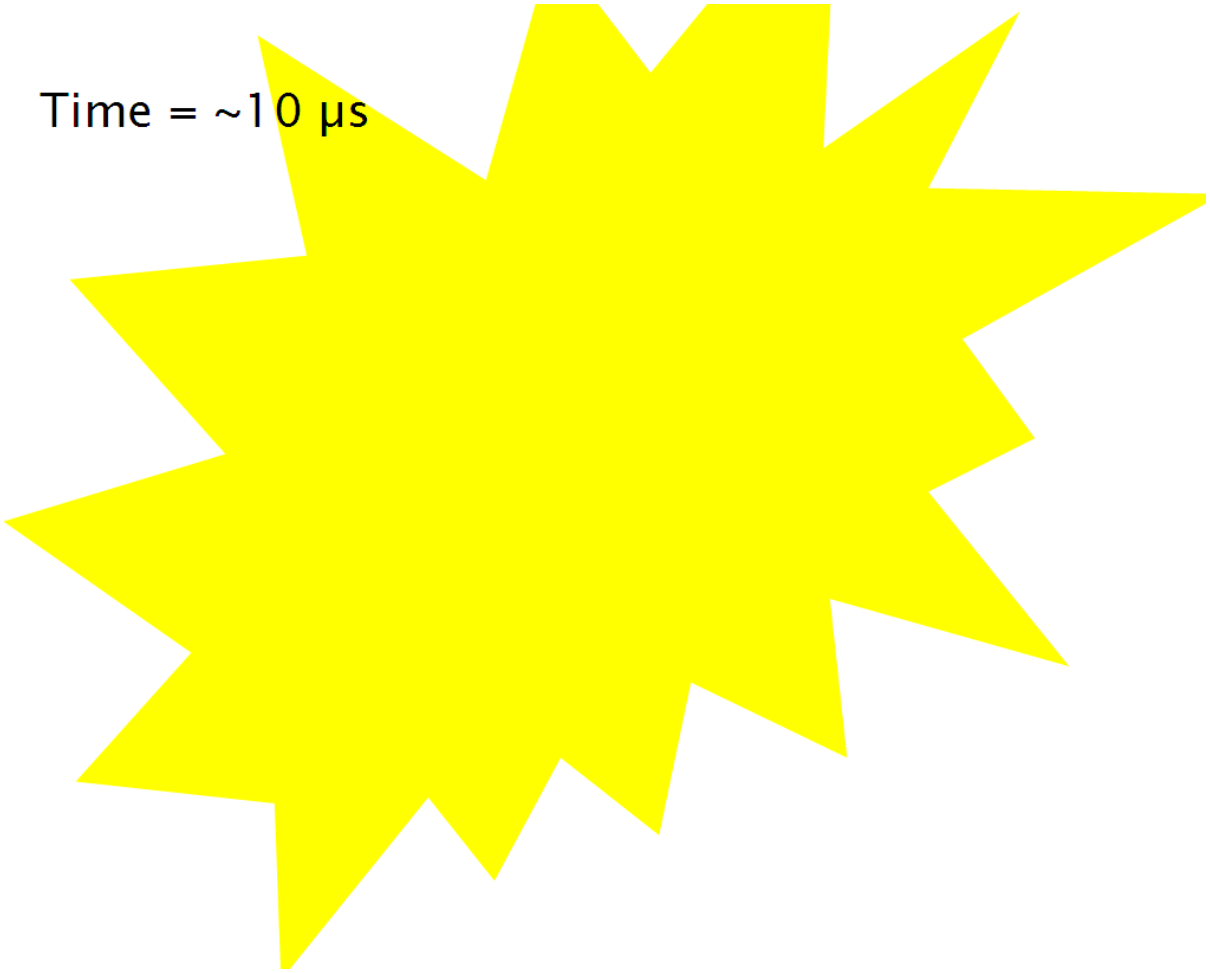


Detonation wave propagates to target material

Explosive Aerosolization

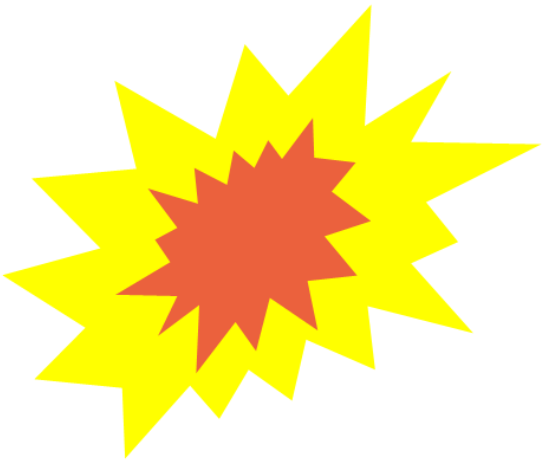


Fireball Mechanics



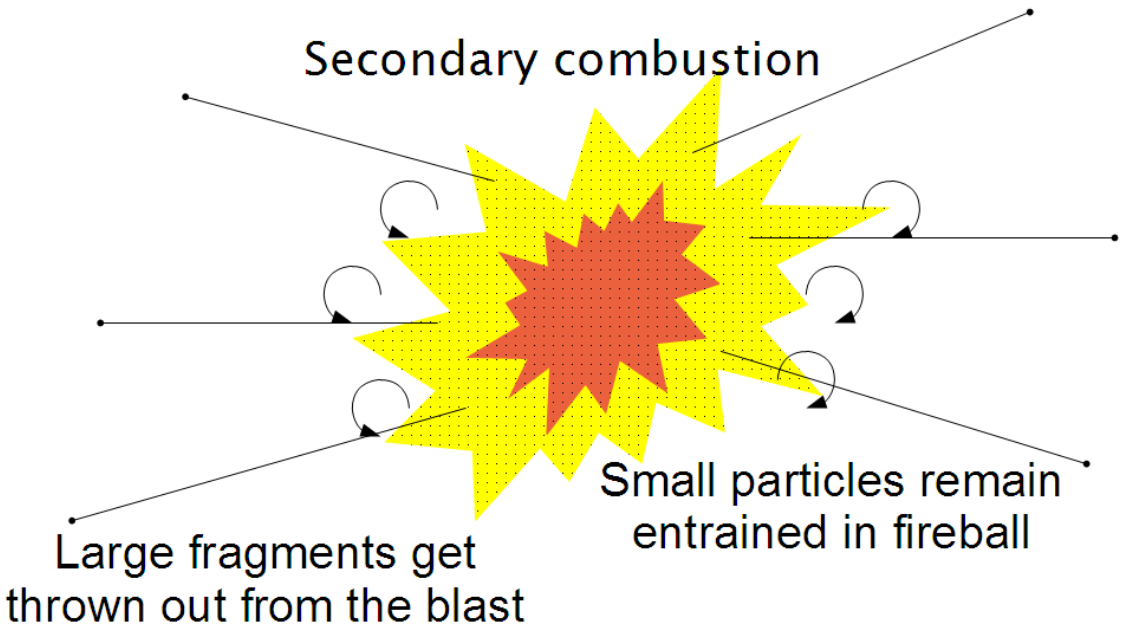
Fireball Mechanics

Time = ~10 ms



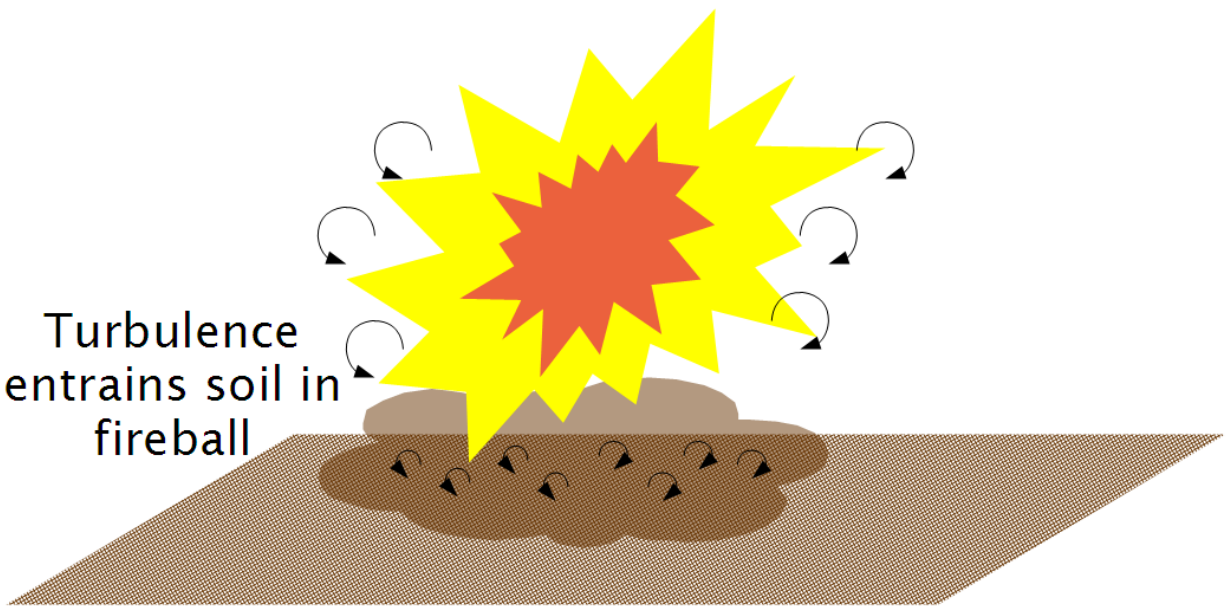
Fireball Mechanics

Time = ~10 ms

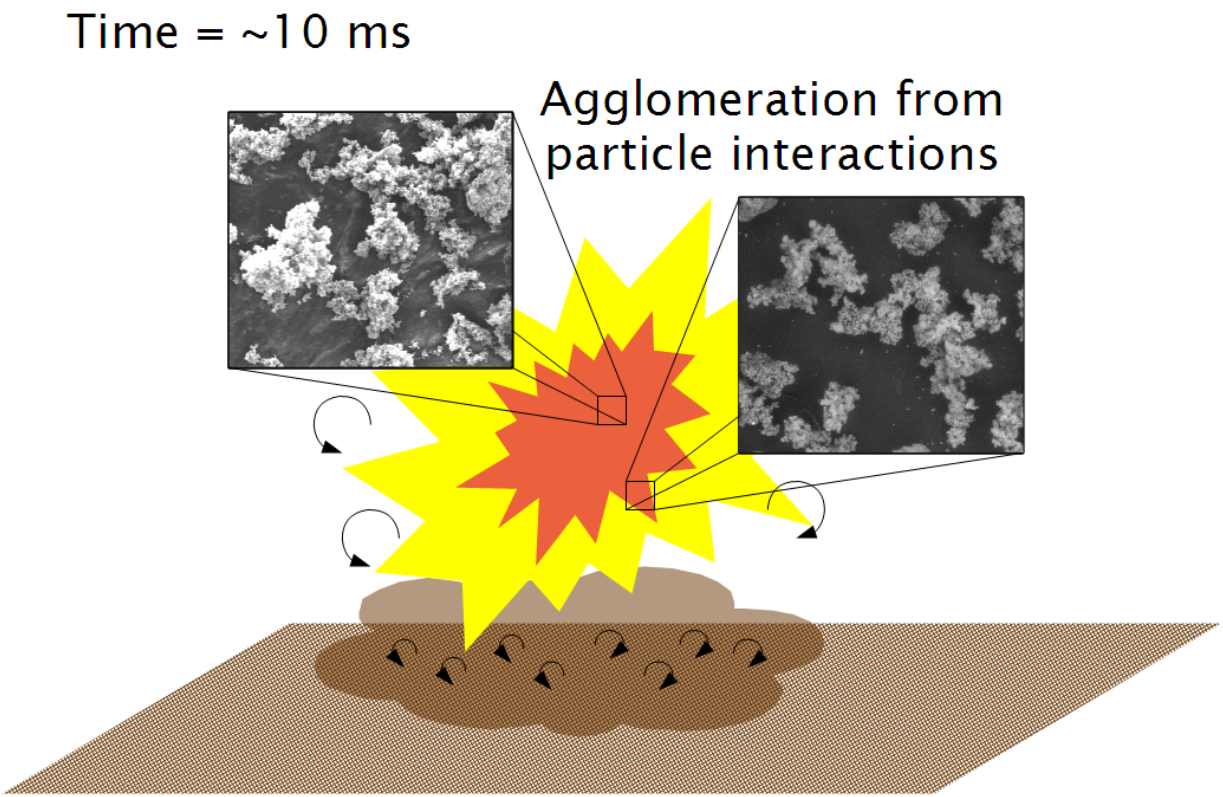


Fireball Mechanics

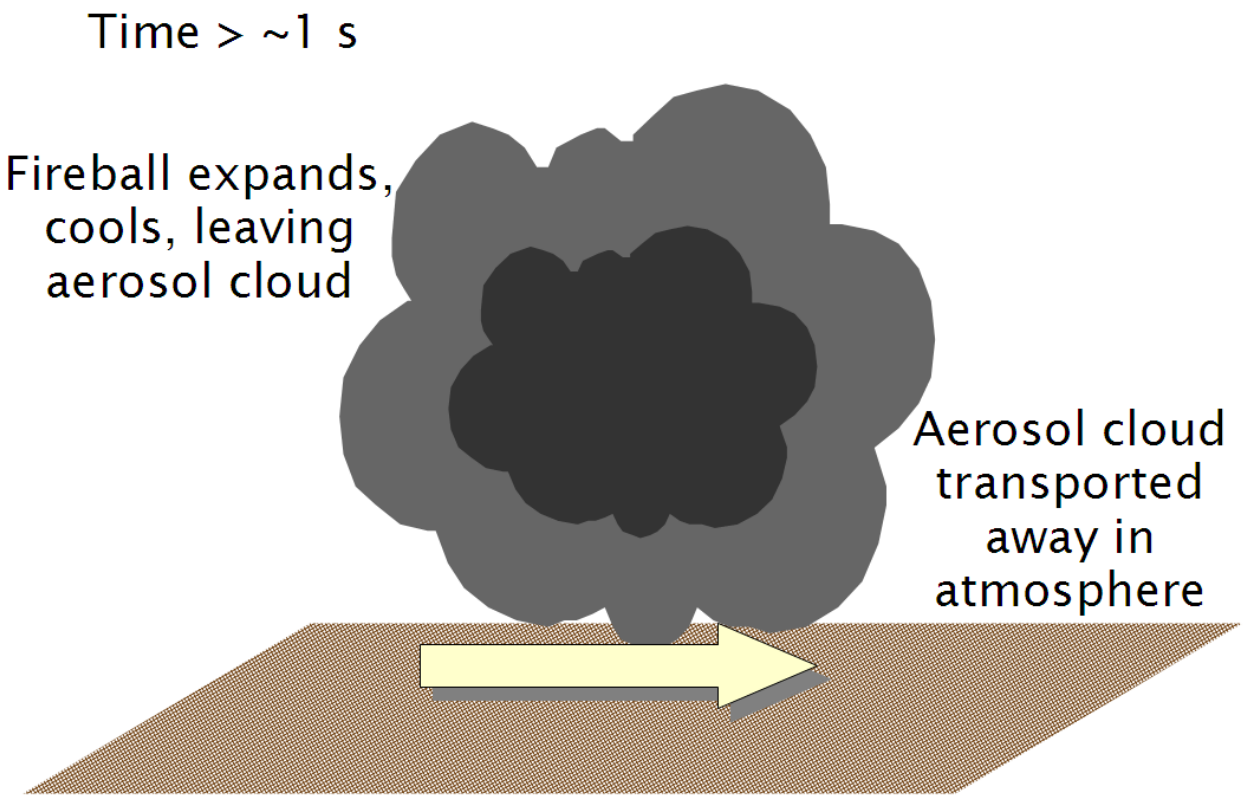
Time = ~10 ms



Fireball Mechanics



Fireball Mechanics



Impetus of Research

- What kind of particles are generated during the initial detonation?
- What role does secondary combustion in the fireball play?
- How do particles interact with entrained material (e.g. soil)?
- What effect does soil entrainment have on explosive aerosolization?

Outline

1. Background

2. Closed Vessel Experiments
   - 2.1 Detonation Calorimetry
   - 3.1 Experimental Design

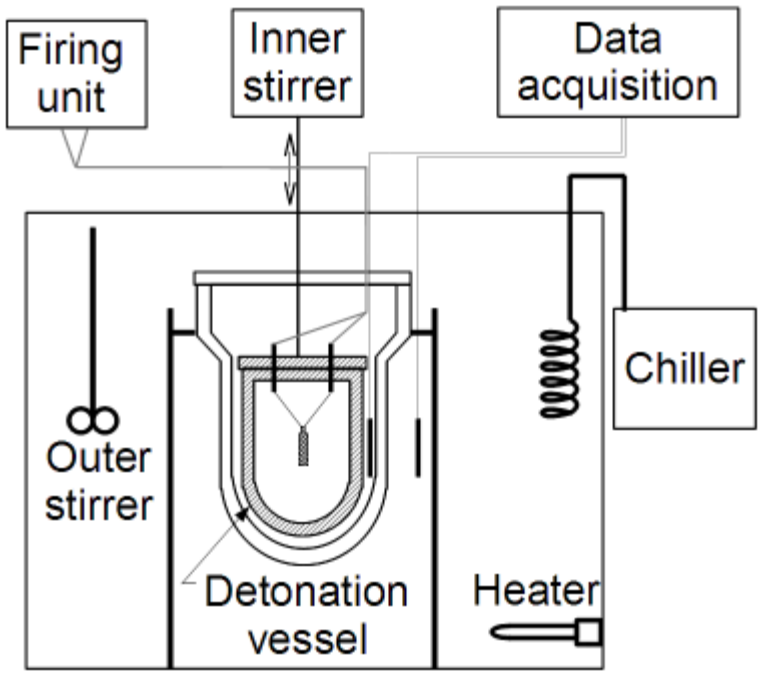
3. Experimental Results

4. Conclusions

Detonation Calorimetry

Detonation calorimeter

Detonation Calorimetry



Schematic of detonation calorimeter

- Small charge detonated in closed container
- Characterize energy release from secondary combustion reactions
- Identify particle characteristics
  - with explosives alone
  - with target material
  - with different soils

Experimental Design

Explosive types used for different experimental conditions

Initial Oxygen Partial Pressure (kPa)	Entrained Soil Type				
	None	Coarse Sand	Fine Sand	Black Earth	Clay
0 (pure N_2)	C-4/detasheet	C-4/detasheet	C-4/detasheet	C-4/detasheet	C-4/detasheet
70	-	C-4	C-4	C-4	C-4
100	-	C-4/detasheet	C-4/detasheet	C-4/detasheet	C-4/detasheet
140	C-4/detasheet	C-4/detasheet	C-4/detasheet	C-4/detasheet	C-4/detasheet
200	-	detasheet	detasheet	detasheet	detasheet

- Calorimetry for energy release
- SEM particle morphology analysis
- Particle size analysis → (mechanical sieve + laser diffraction EPCS)

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   - 3.1 Calorimetry Results
   - 3.2 Quartz Sand Particle Analyses
   - 3.3 Black Earth Particle Analyses
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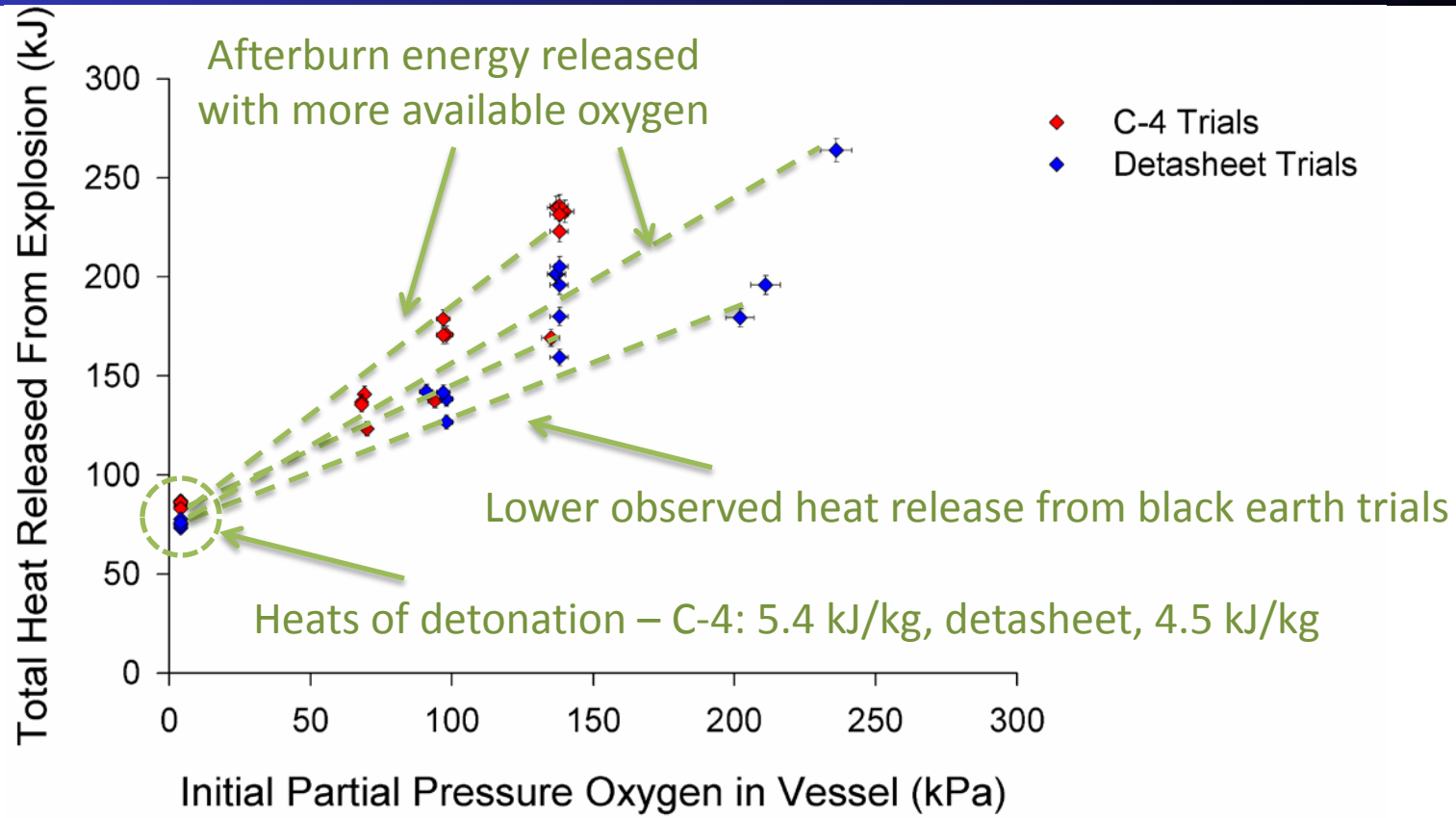
Calorimetry Results



Energy release from explosions as a function of oxygen partial pressure

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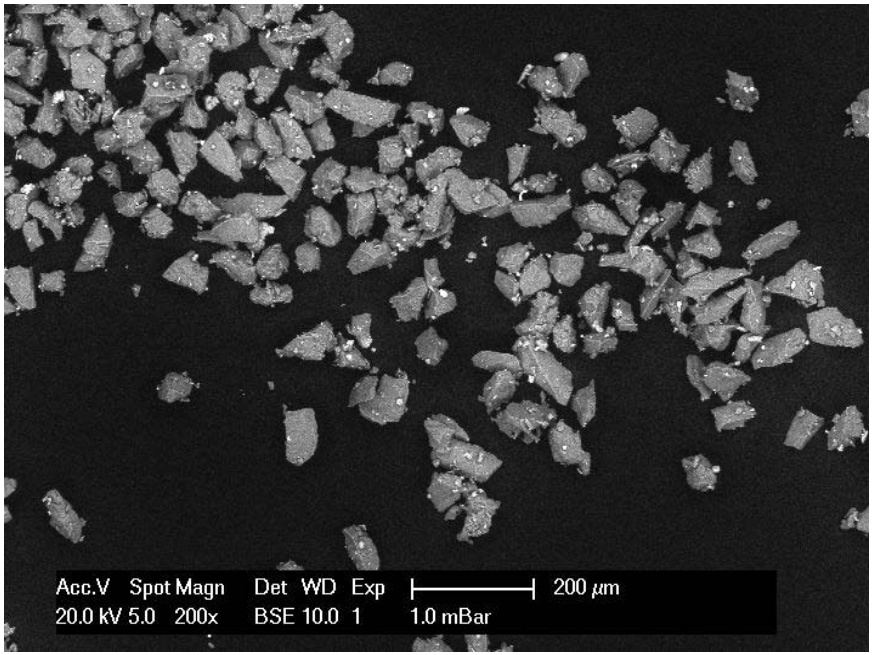
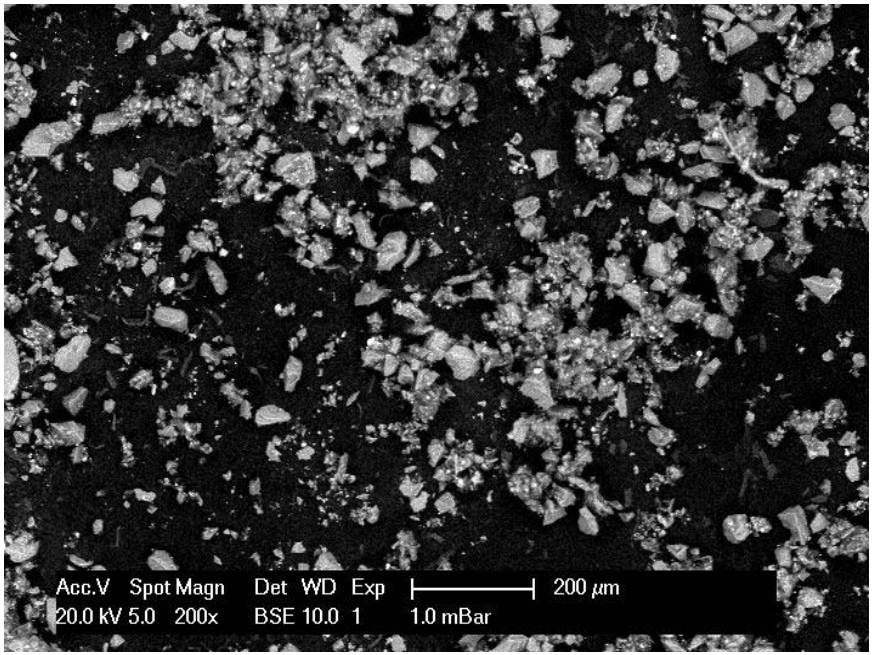
Particle Morphology – Fine Quartz Sand



Undetonated – screened to pan

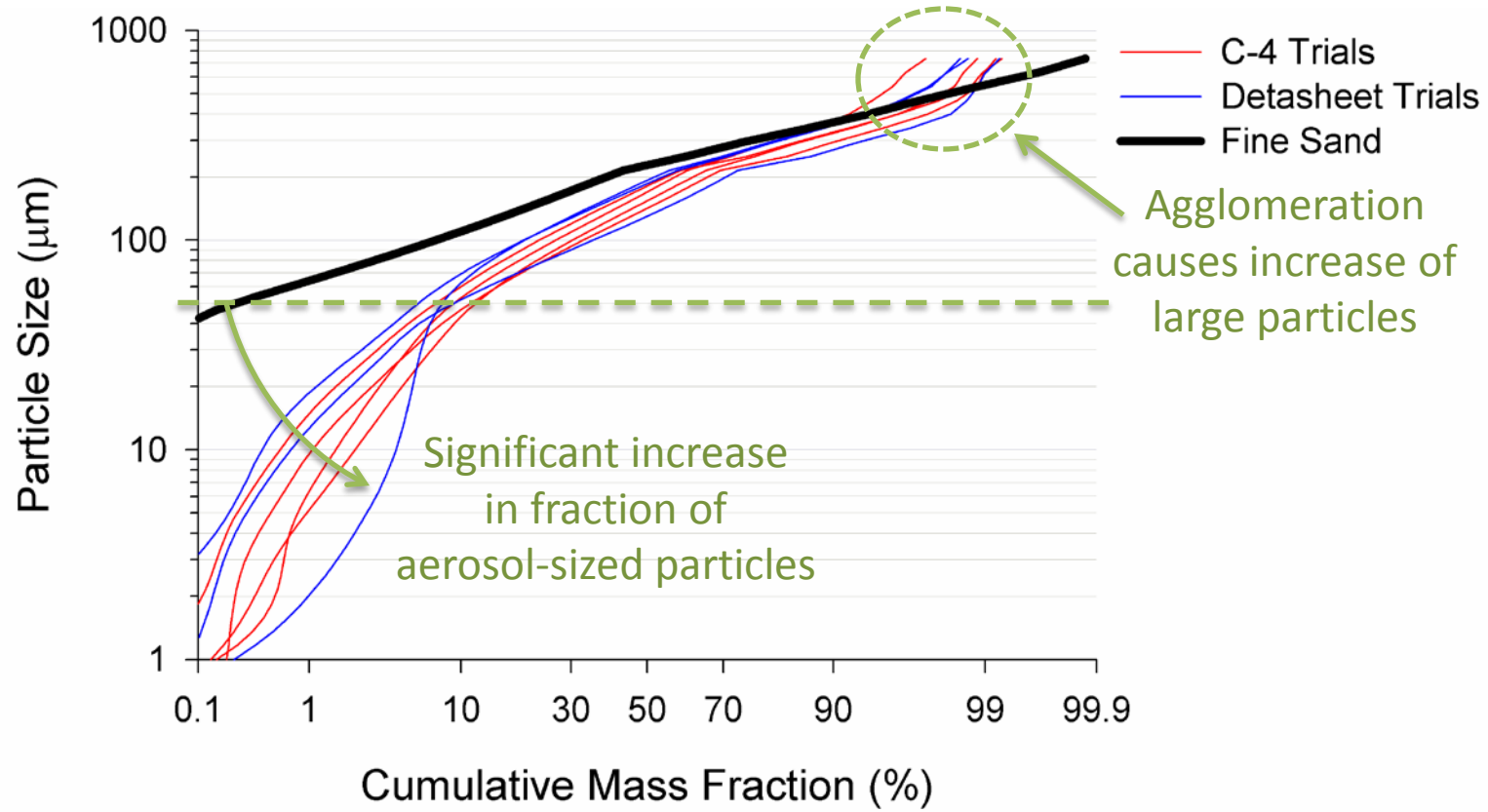


Detonated without O_2 – screened to pan

- Angular grains
- Smooth surface

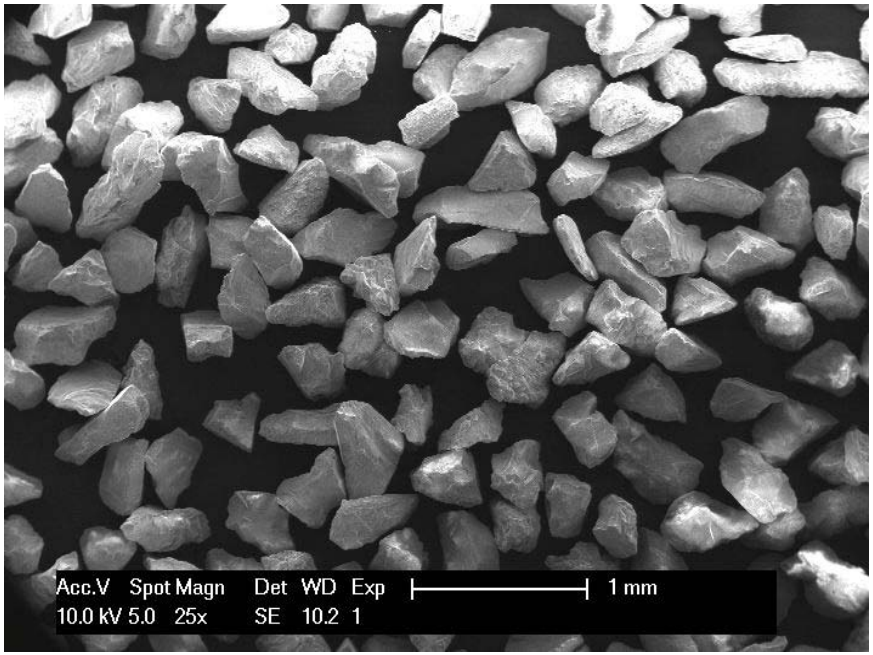
- Highly angular particles
- Carbonaceous soot

Particle Size Distribution – Fine Quartz Sand

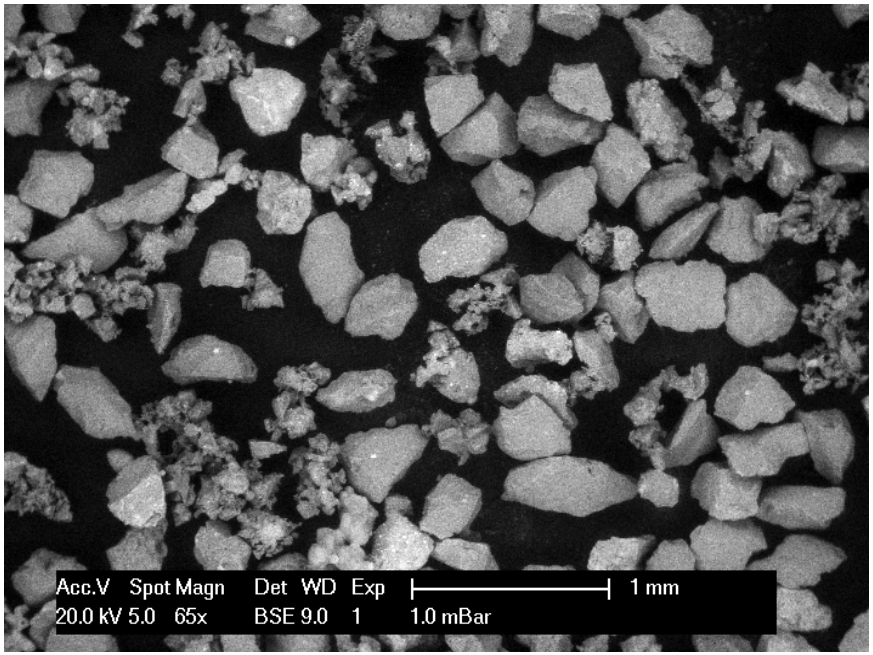


Particle size distribution for fine quartz sand

Particle Morphology – Coarse Quartz Sand



Undetonated – screened to no.60 mesh



Detonated in presence of O_2 – screened to no.60 mesh

- Similar morphology to undetonated fine sand

- Fused sand grains
- Deposition of explosive residue

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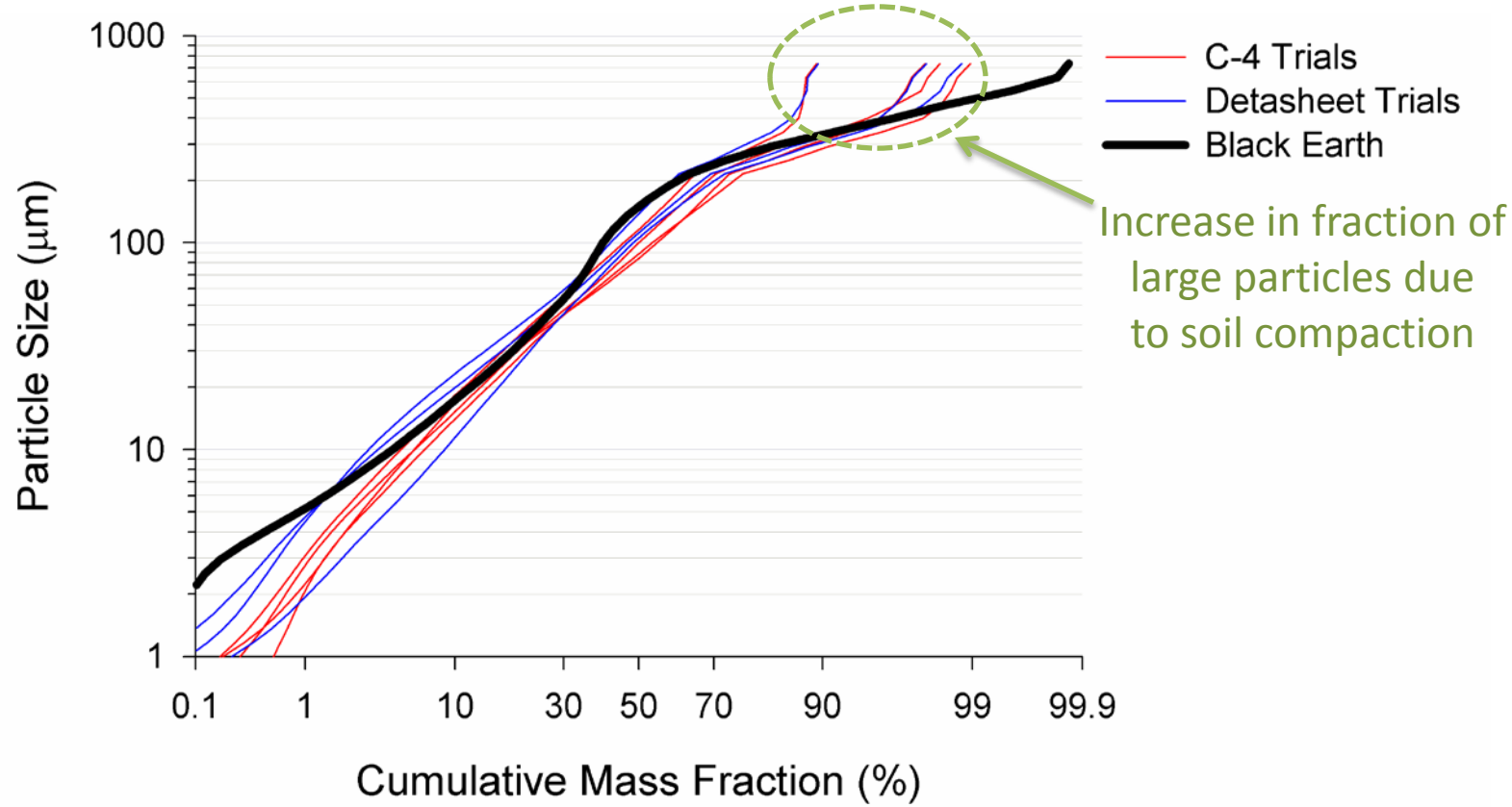
   - 3.4 Clay Particle Analyses

4. Conclusions

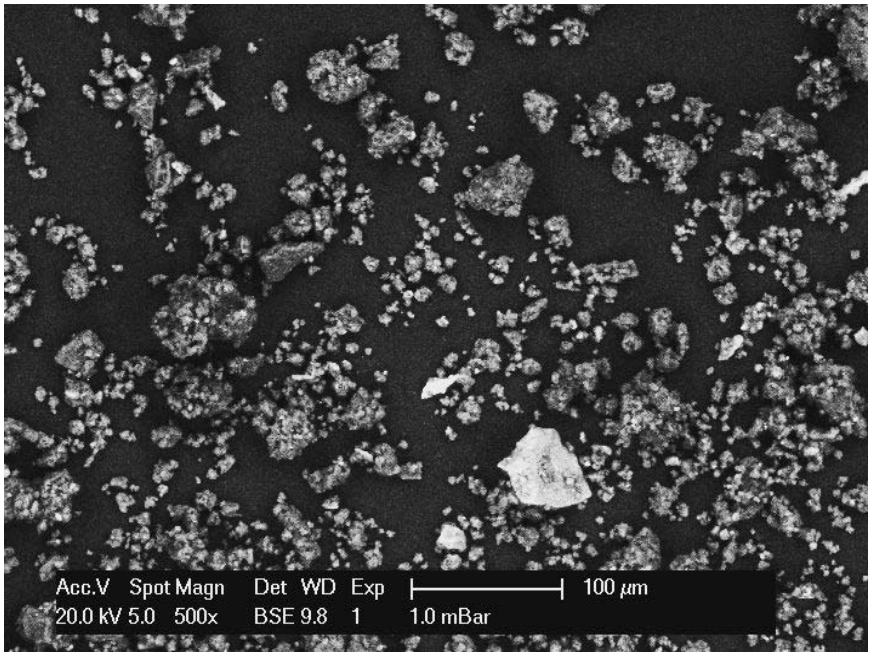
Particle Size Distribution – Black Earth



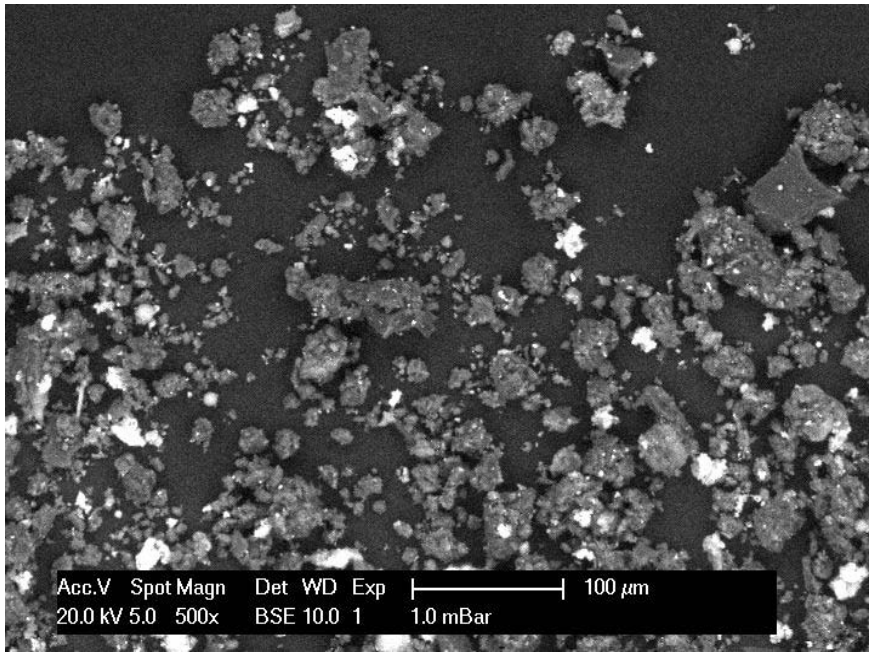
Particle size distribution for black earth

- Little change over most of particle size distribution

Particle Morphology – Black Earth



Undetonated – screened to pan



Detonated without O_2 – screened to pan

Essentially no difference in undetonated vs. detonated black earth morphology

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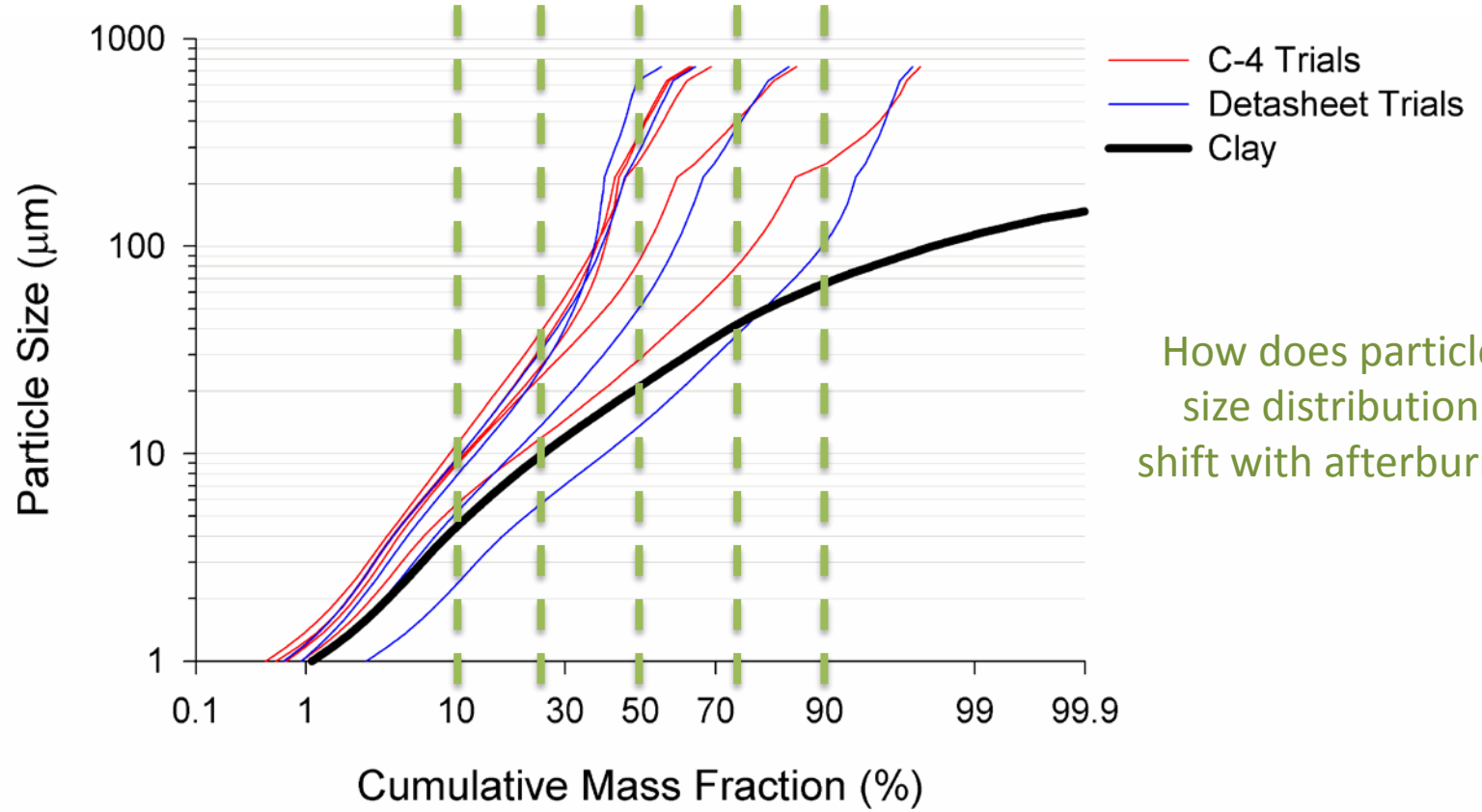
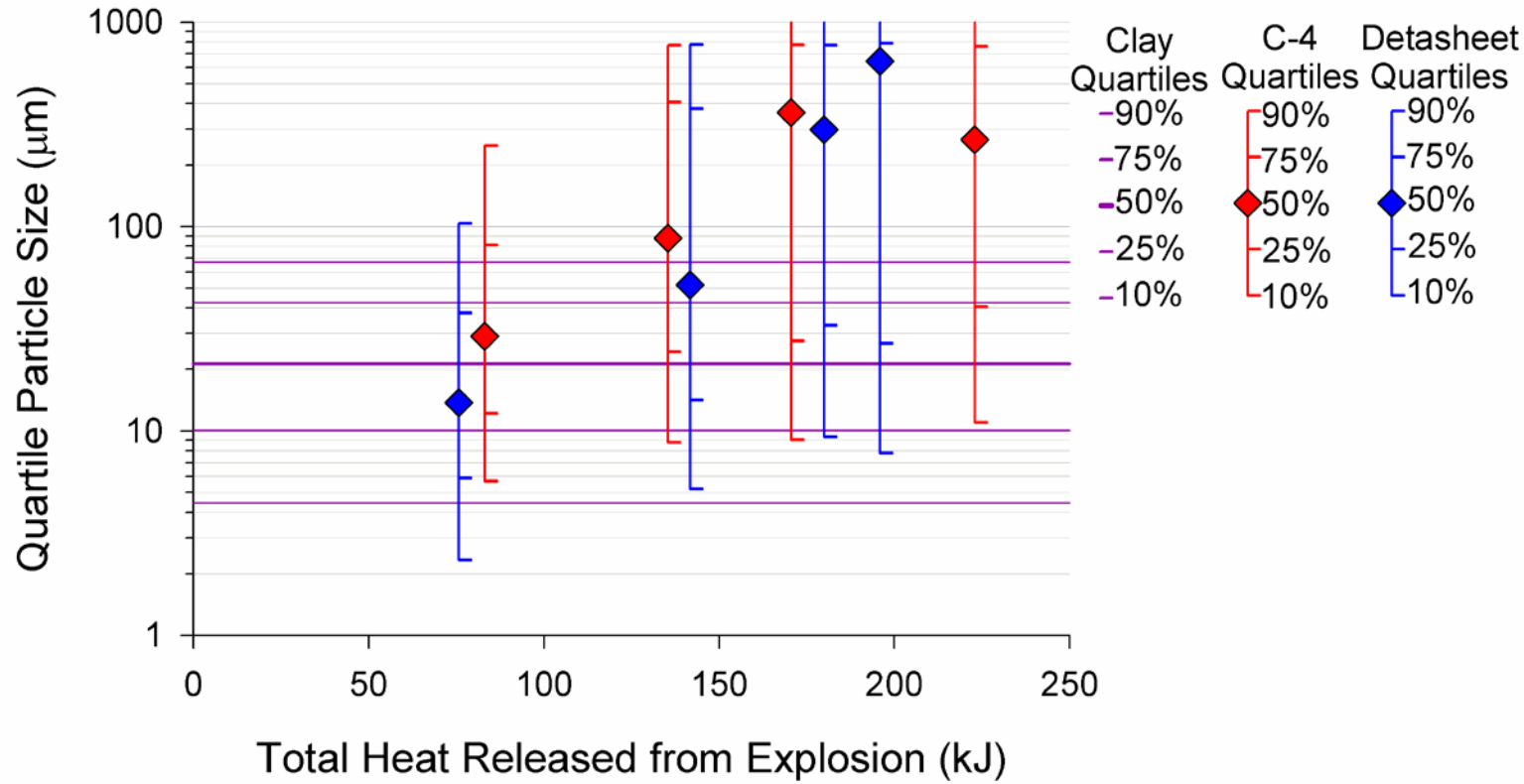
Particle Size Distribution – Clay



How does particle size distribution shift with afterburn?

Particle size distribution for clay

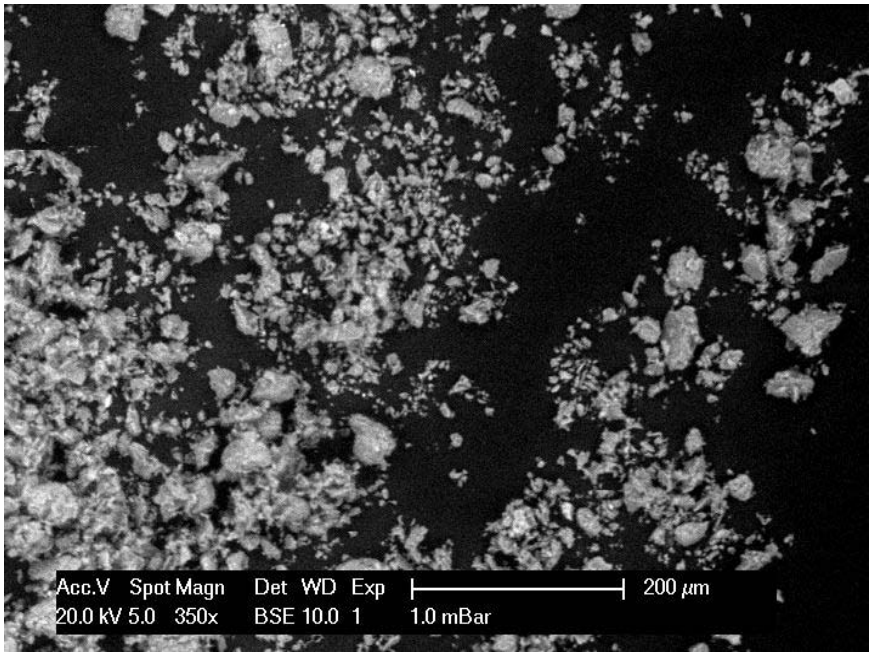
Particle Agglomeration in Clay



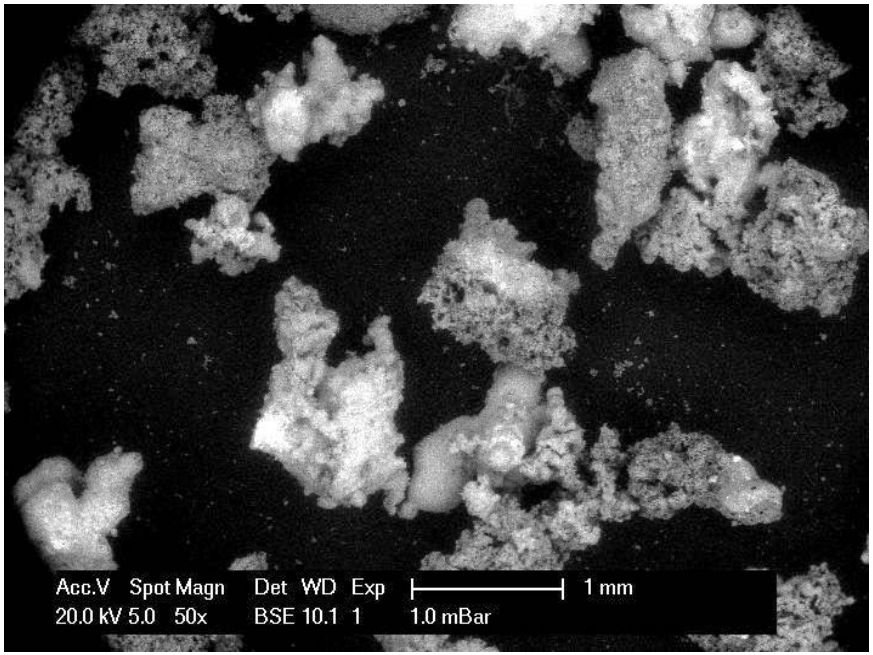
Quartile plot of entrained clay

- With afterburn, particle size increases by orders of magnitude

Particle Morphology – Clay



Undetonated clay



Detonated in presence of O_2 – screened to no.30 mesh

- Small, loose agglomerates
- Huge, porous agglomerates

Outline

1. Background

2. Closed Vessel Experiments

3. Experimental Results

4. Conclusions
   - 4.1 Summary
   - 4.2 Future Work
   - 4.3 Acknowledgements

Summary

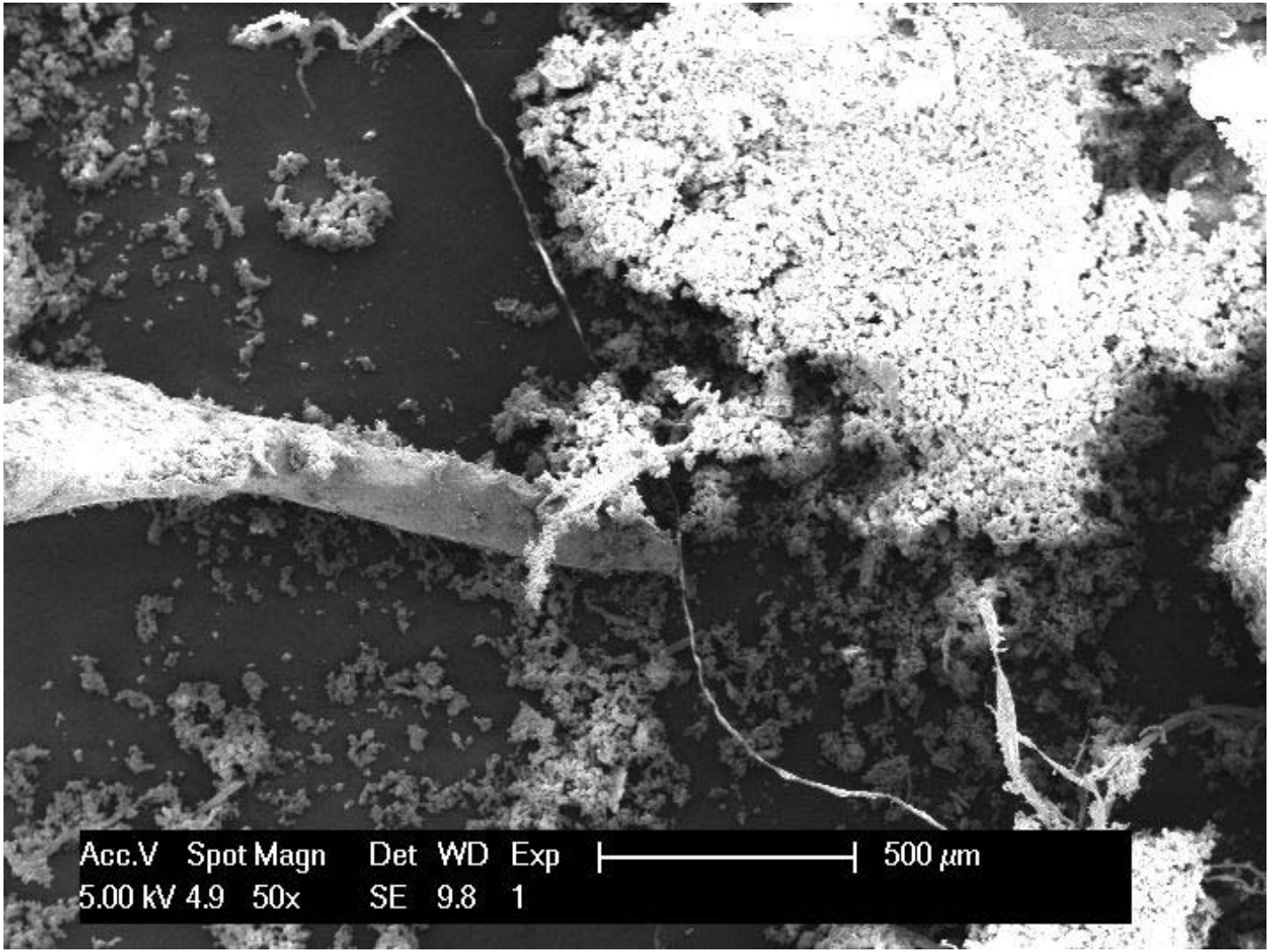
- What kind of particles are generated during the initial detonation?
- What role does secondary combustion in the fireball play?
- How do particles interact with entrained material (e.g. soil)?
- What effect does soil entrainment have on explosive aerosolization?
- How is material that is aerosolized during the detonation distributed throughout entrained soil?
- Can results from closed vessel trials be extrapolated to an open air explosion?

Future Work

- Trials with addition of La_2O_3 powder being carried out
  - analyze elemental composition in different particle size ranges
  - determine how target powder becomes dispersed through entrained soil

- Open air trials planned to supplement closed vessel experiments
  - observe detonations over soil
  - separate real effects from artifacts of closed vessel explosions
  - measure quenching/boosting effects of soil entrainment on fireball

Acknowledgements

- Logistics Support Services, Canadian Forces Base Kingston
- Energetic Materials Section, Defence R&D Canada – Valcartier
- CBRNE Research and Technology Initiative
- Canadian Department of National Defence, Director General Nuclear Safety
- Natural Science and Engineering Research Council of Canada

Thank You!