Volcanic ash particles: first look towards the radiative impact

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Eruption: atmospheric effects

- Magma, gases, and ash ejected
  - Gases: H_2O, CO_2, SO_2 (→ H_2SO_4)
- Estimated cooling of the climate related to volcanic eruptions: *mainly* due to H_2SO_4 droplets!
  - Small → long atmospheric residence

- Atmospheric residence of ash: hours to months
  - Impact on radiation balance (unknown, probably cooling)
  - Hazard to aviation: malfunction of machinery

Single scattering → radiative impact

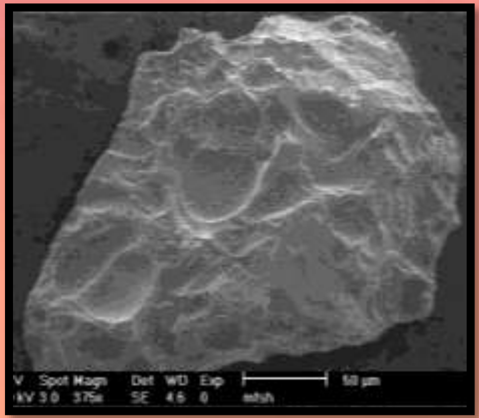
- Light scattering by a single particle is a key starting point when considering:
  - Interpretation of lidar and satellite observations (lookup tables)
  - Estimation of the radiative impact of aerosol particles (and direct impact on climate)

- Scattering by single particles (size ~ wavelength) cannot be solved analytically (exceptions: spheres, infinite cylinders, …)
  - Numerical, nearly exact methods exist → time-consuming computations
  - Single-scattering measurements in laboratories

Single scattering: function of particle size, shape, orientation, and material (refractive index), and wavelength of light!

$$x = \frac{2\pi a}{\lambda}$$

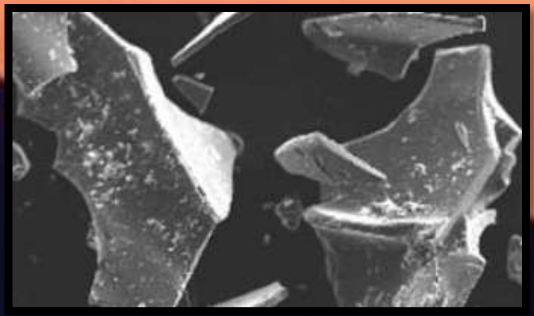
Physical characteristics

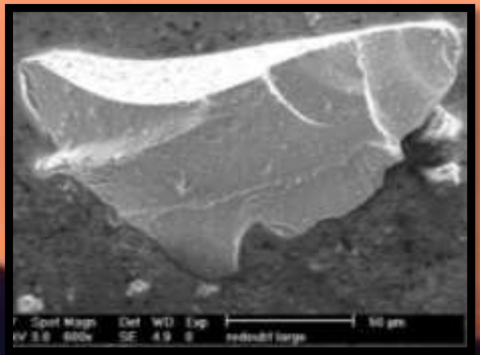


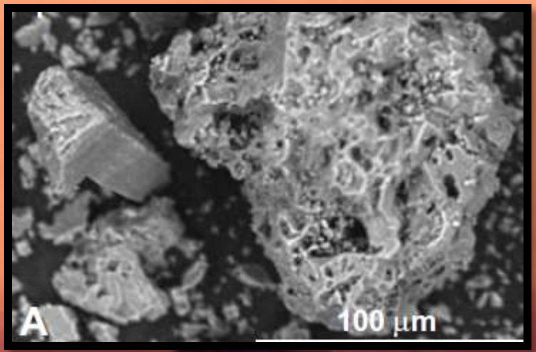
- Diameter: submicron to mm
  - Diameter < 63 µm = DUST; 63 µm – 2 mm = ASH
  - Particles coarser than 1 mm fall out in one hour
  - Smaller than 10 µm airborne for days to months

- Nonspherical shapes
  - Quite angular, irregular, parachute-shaped bubble wall shards, vesicular pumice clasts (fragments)

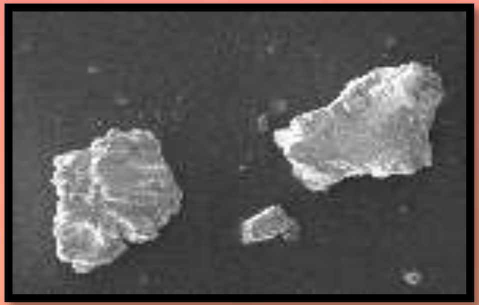
- SEM images: vesicular / nonvesicular
  - Vesicles = cavities formed by gas bubbles when material cools to glass



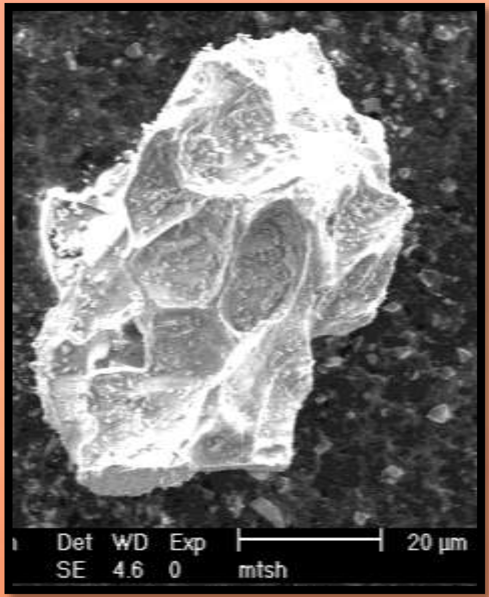




Physical characteristics

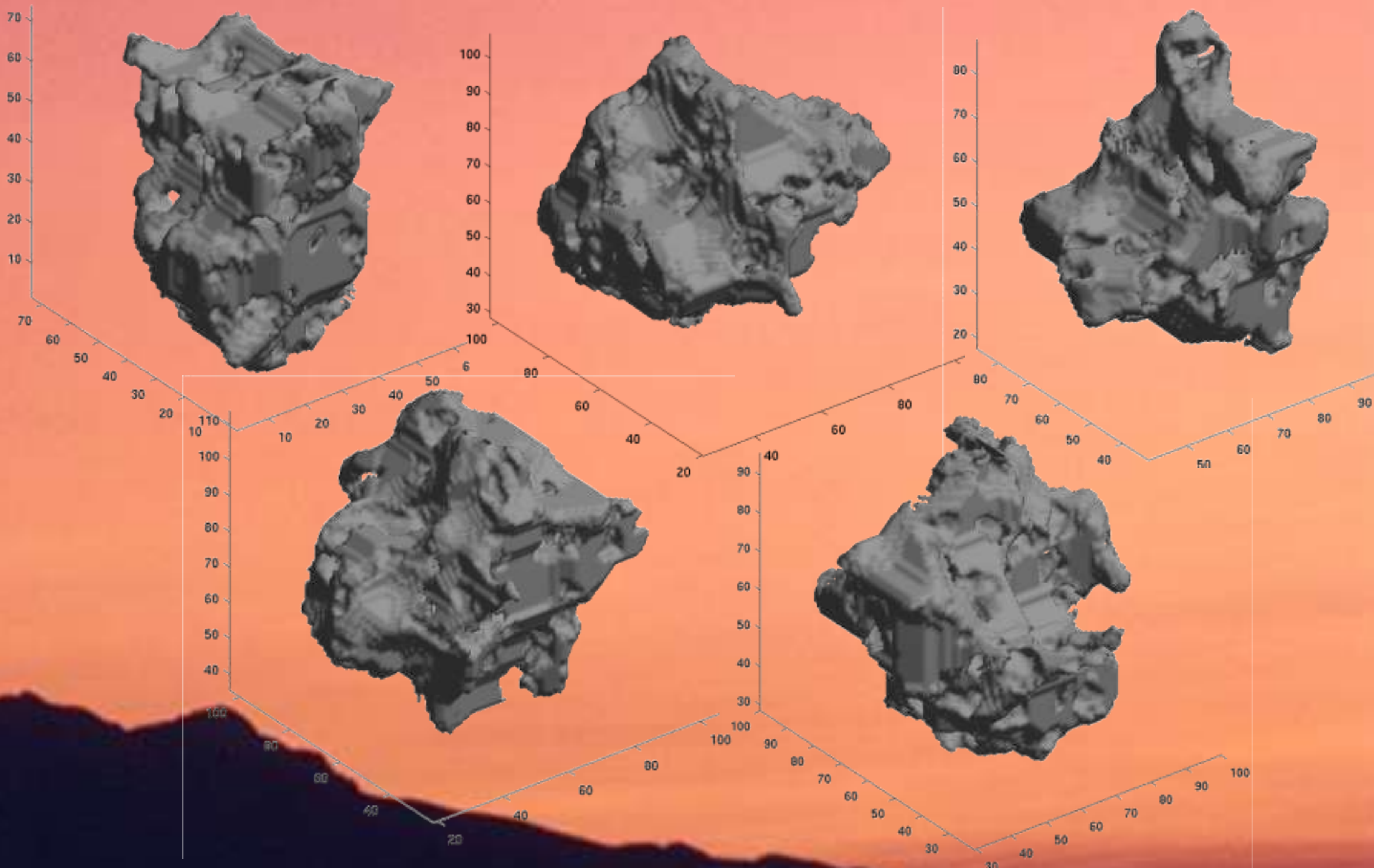


- Composition: complex mixture of silicate glass and crystallized silicate mineral phases
- Refractive index of silicate glass:
  - Real part: 1.48 – 1.56
  - Imaginary part: 0.001 – 0.004
- Refractive index is comparable to that of mineral dust aerosols!
  - Difference in shape → would it be possible to distinguish mineral and volcanic dust based on their scattering properties?



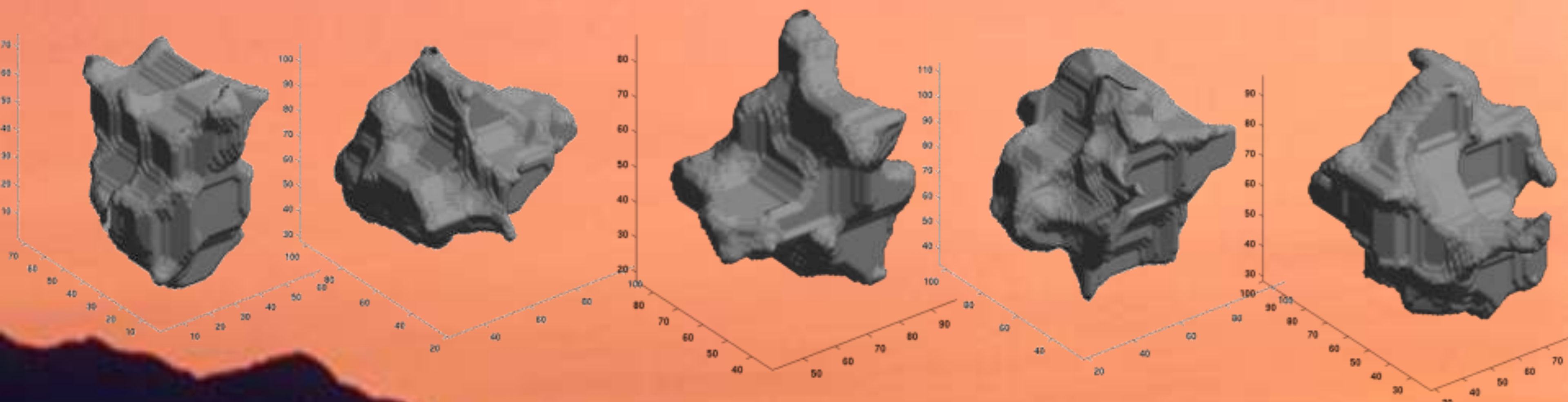
Porous sample particles

= volcanic dust



Compact sample particles
= mineral dust

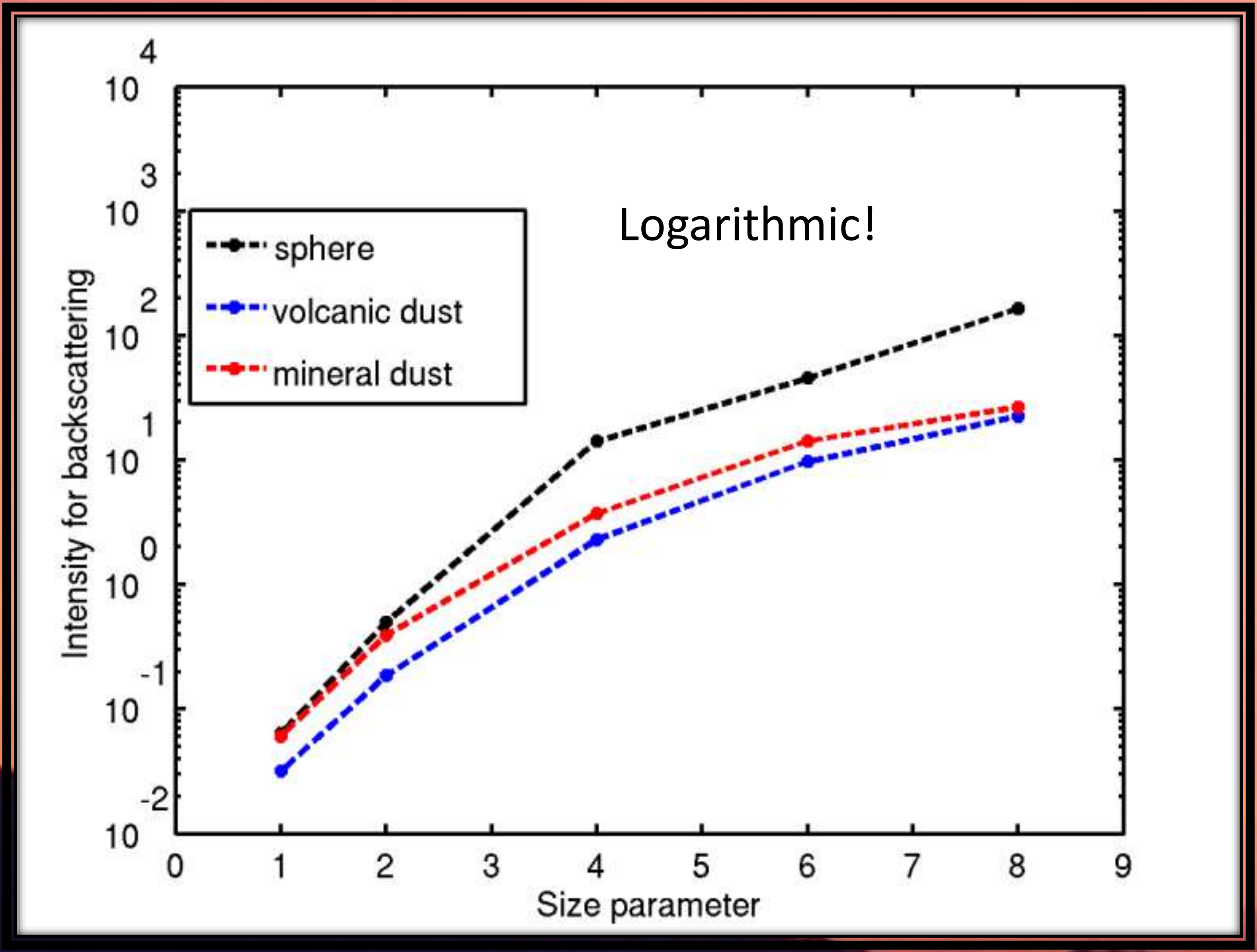
- Identification of the effects of internal porosity on scattering
  - Differences between scattering by mineral dust and volcanic dust



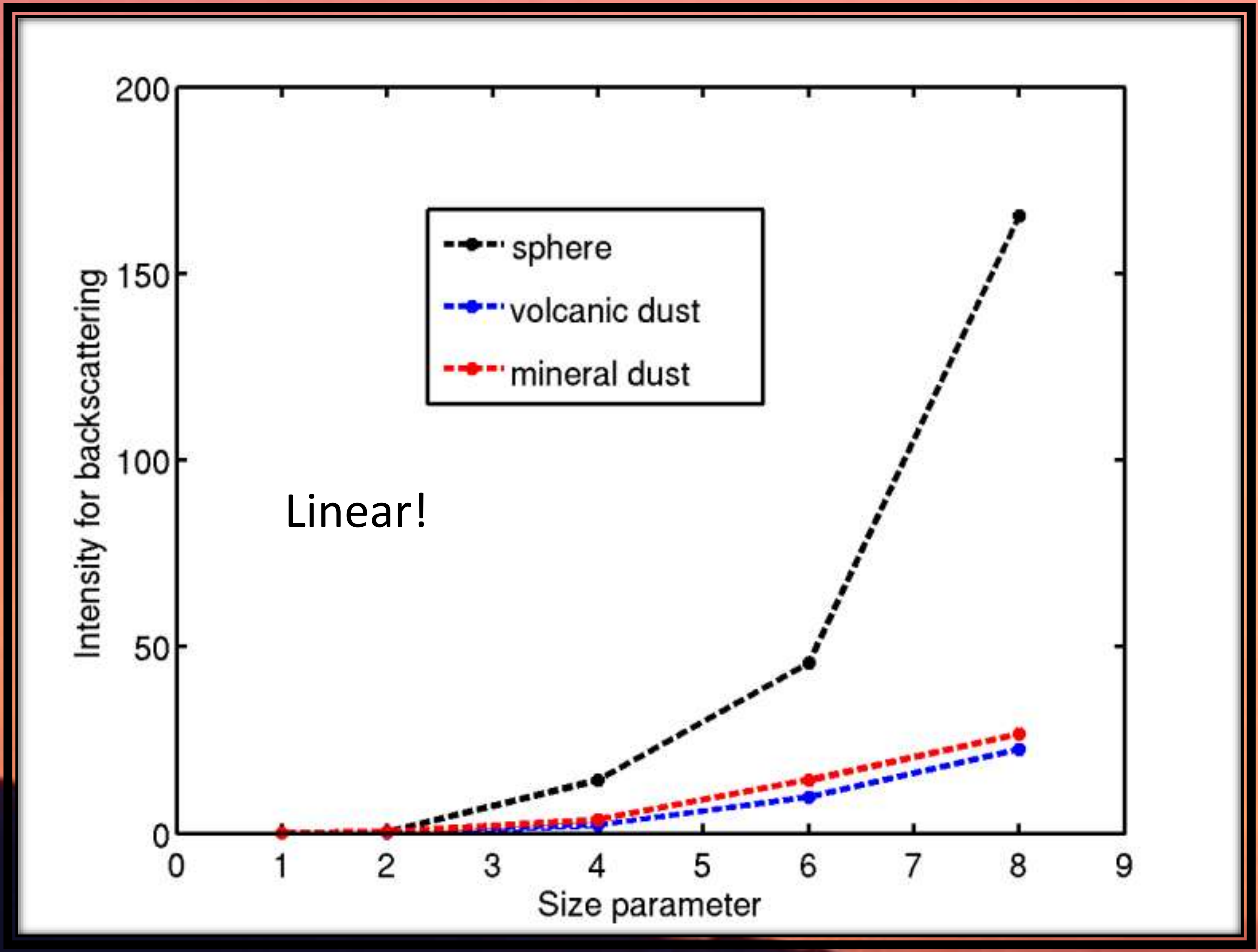
Light-scattering computations

- Particle sizes
  - Size parameter $x = 1.0 – 8.0$ for compact particles (0.2 – 1.8 µm vis.)
  - Outer dimensions constant → porous: slightly smaller x
- Discrete dipole approximation
  - Shapes presented with 50 000 – 130 000 volume elements; dipoles
- Average over 5 sample shapes

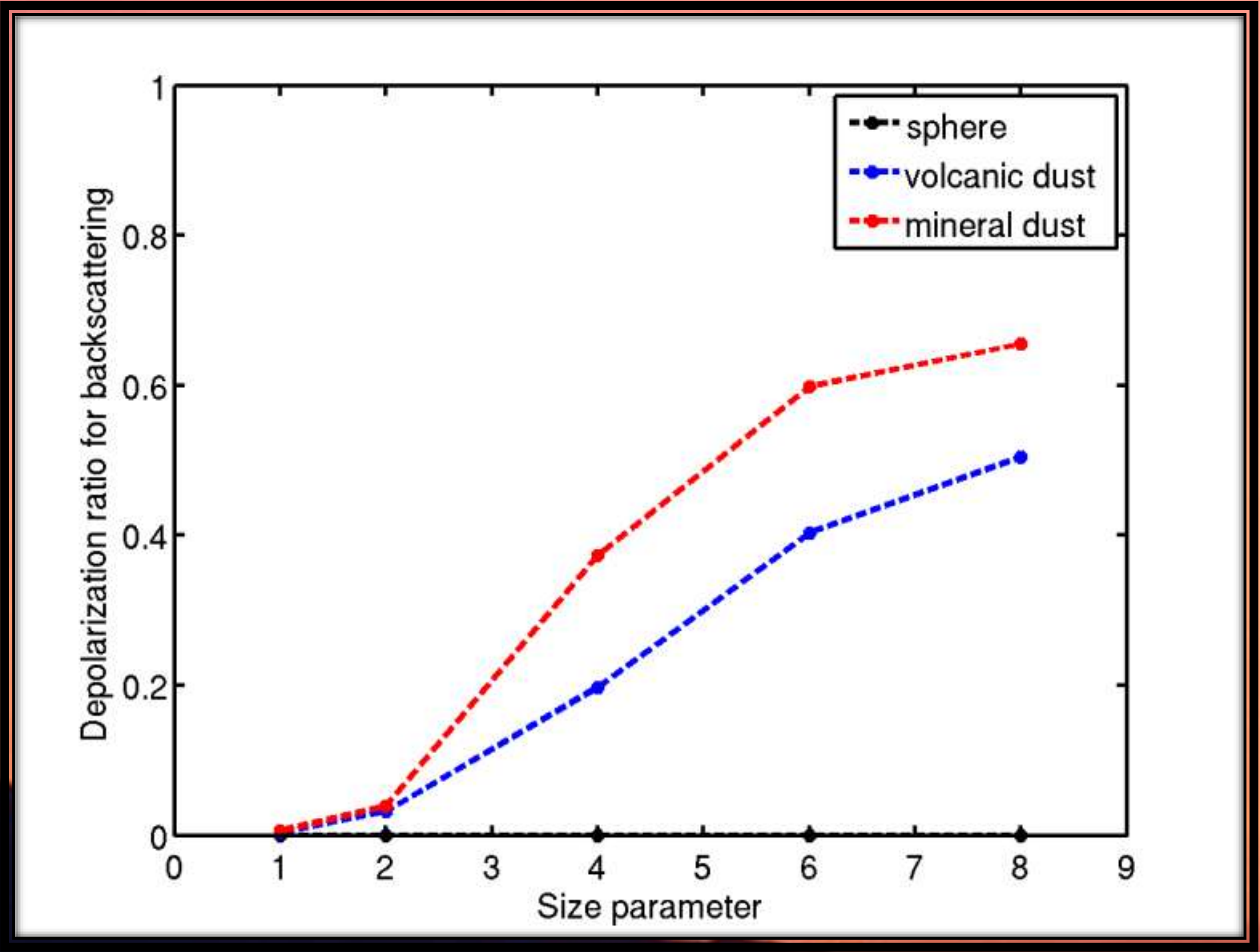
Scattered intensity in the backscattering direction



Scattered intensity in the backscattering direction

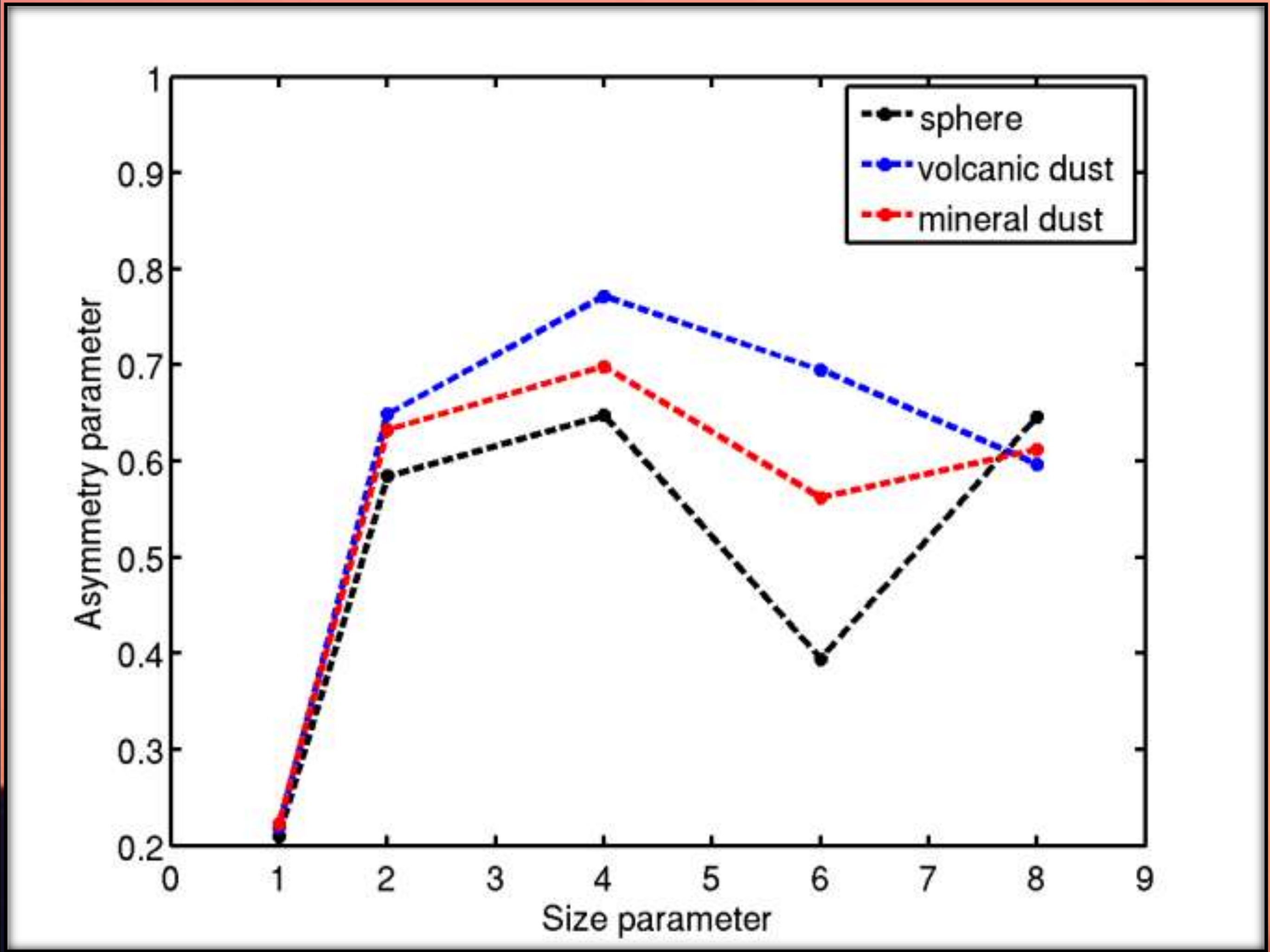


Depolarization ratio in the backscattering direction



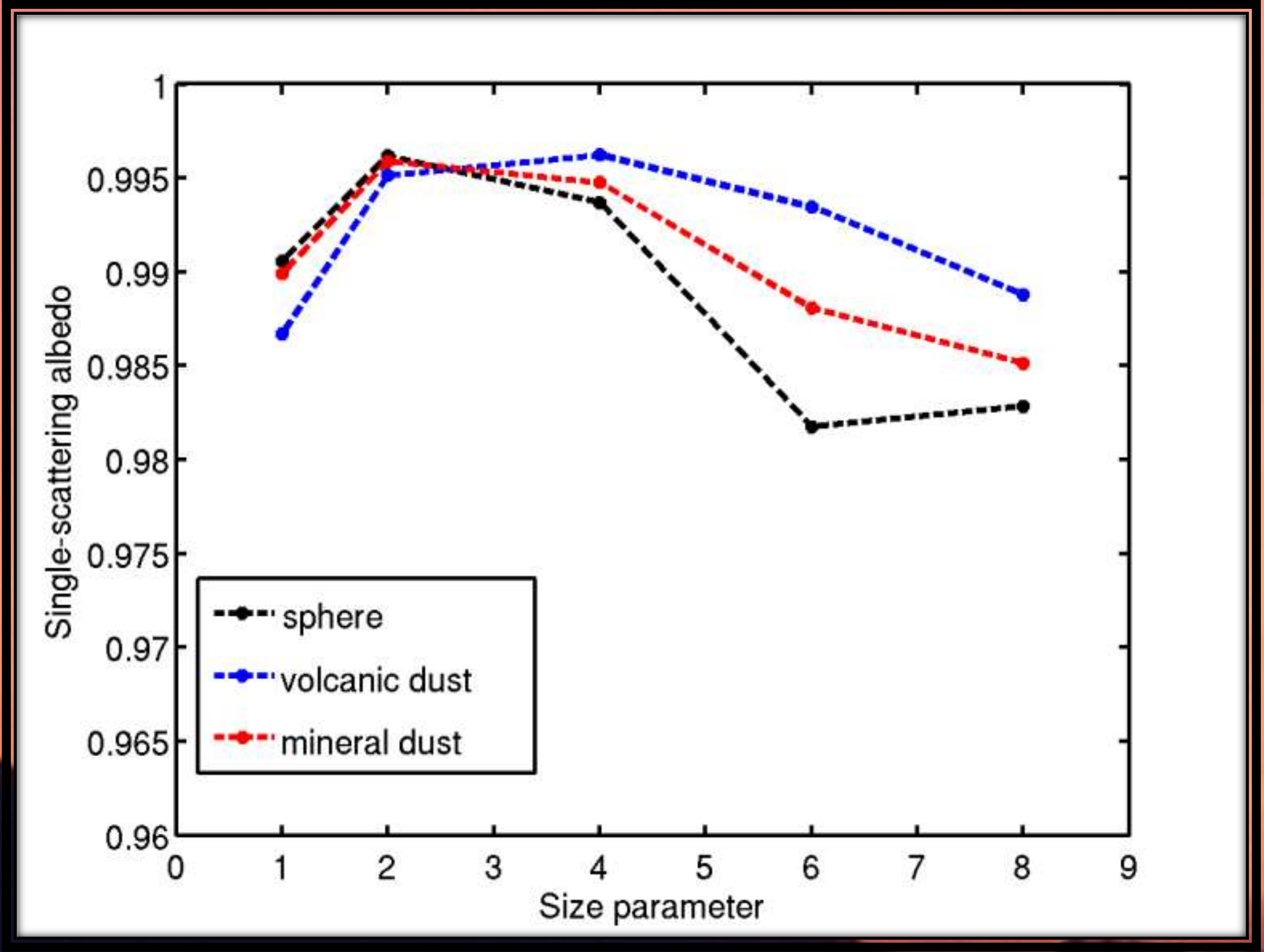
Asymmetry parameter

How much is scattered in the forward hemisphere compared to the backward hemisphere



Single-scattering albedo

How much energy is scattered compared to absorption



Summary of the results

- Volcanic dust appears to be difficult to distinguish from mineral dust when considering their scattering properties.
  - Methods that work for mineral dust should also work for volcanic dust: for instance, volcanic dust could most likely be seen with depolarization lidars as well as mineral dust.
- Spheres are strongly backscattering → assumptions of spherical shapes for single particles can lead to over/underestimations of certain parameters (e.g., size of the particles).
  - Nonspherical shapes should be used because it is possible!

References:
- Riley et al. Quantitative shape measurements of distal volcanic ash. JGR 108 (2003).
- Muñoz et al. Scattering matrices of volcanic ash particles of Mount St. Helens, Redoubt, and Mount Spurr volcanoes. JGR 109 (2004).

Extra:
Modeling the shape of volcanic dust

1. Ballistic cluster of spheres
   - Power-law size distribution
2. Concave hull
3. Spheres → Gaussian random spheres
4. Volcanic dust material = volume in between the concave hull and the Gaussian random spheres
5. Cratery surface obtained by peeling operations

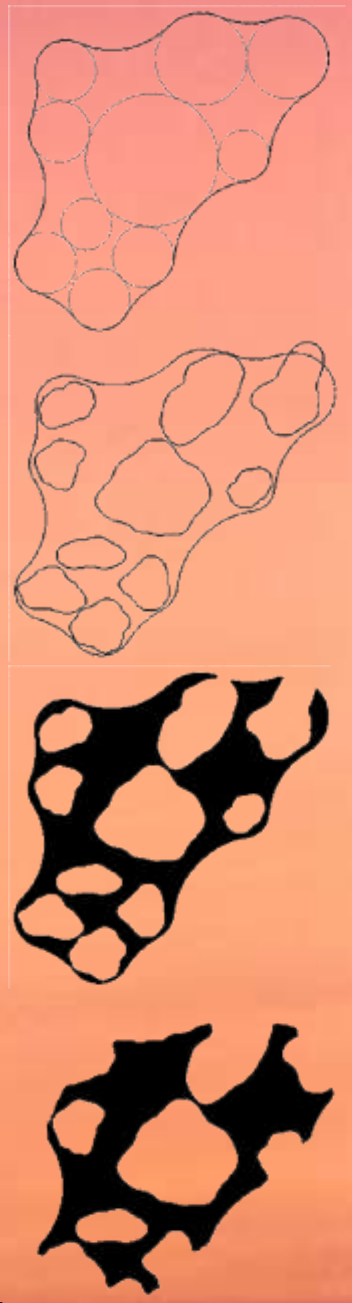


Fig. 2-D version of shape construction.