Implications of dielectric breakdown weathering for the lunar polar regolith

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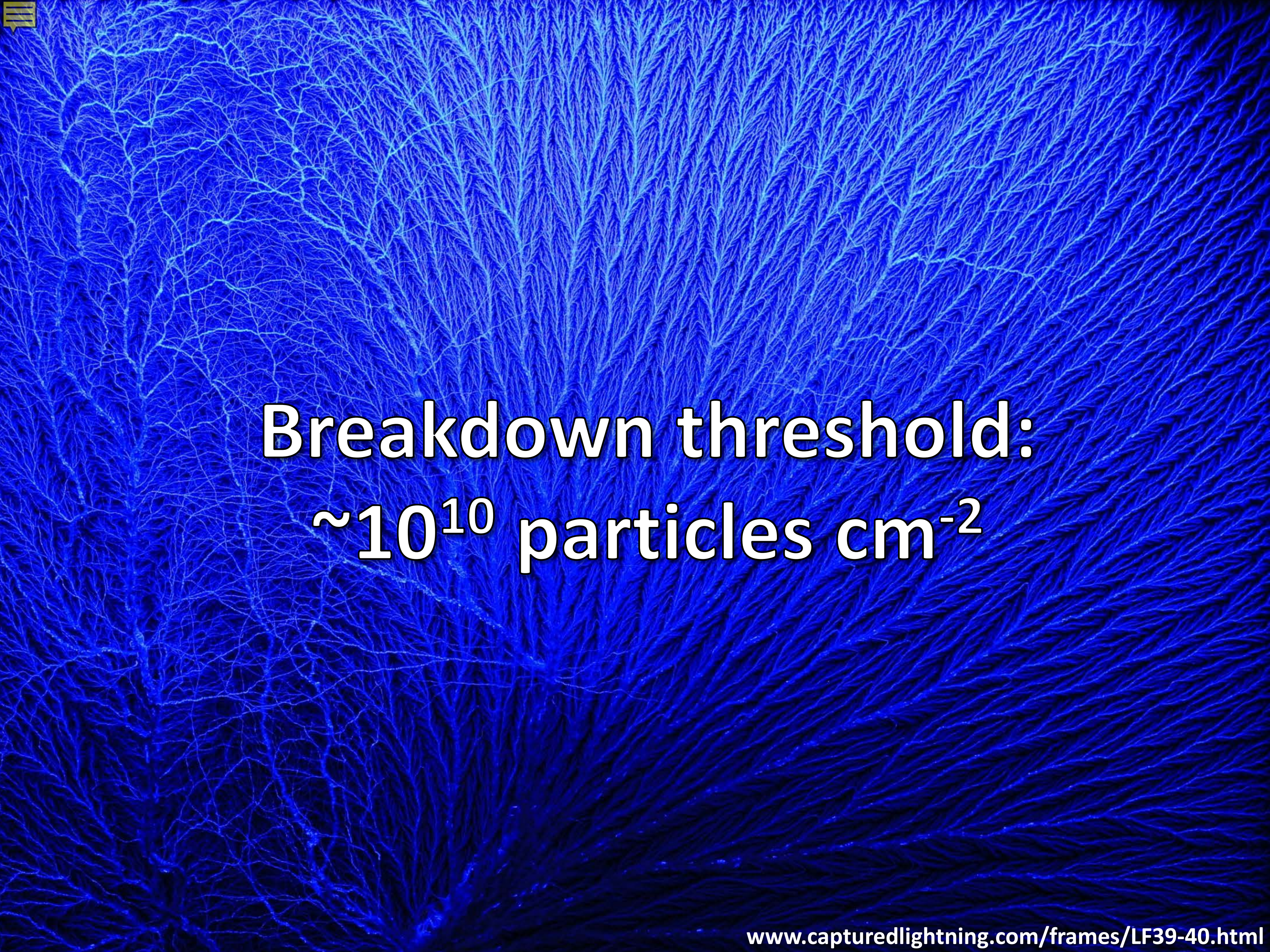
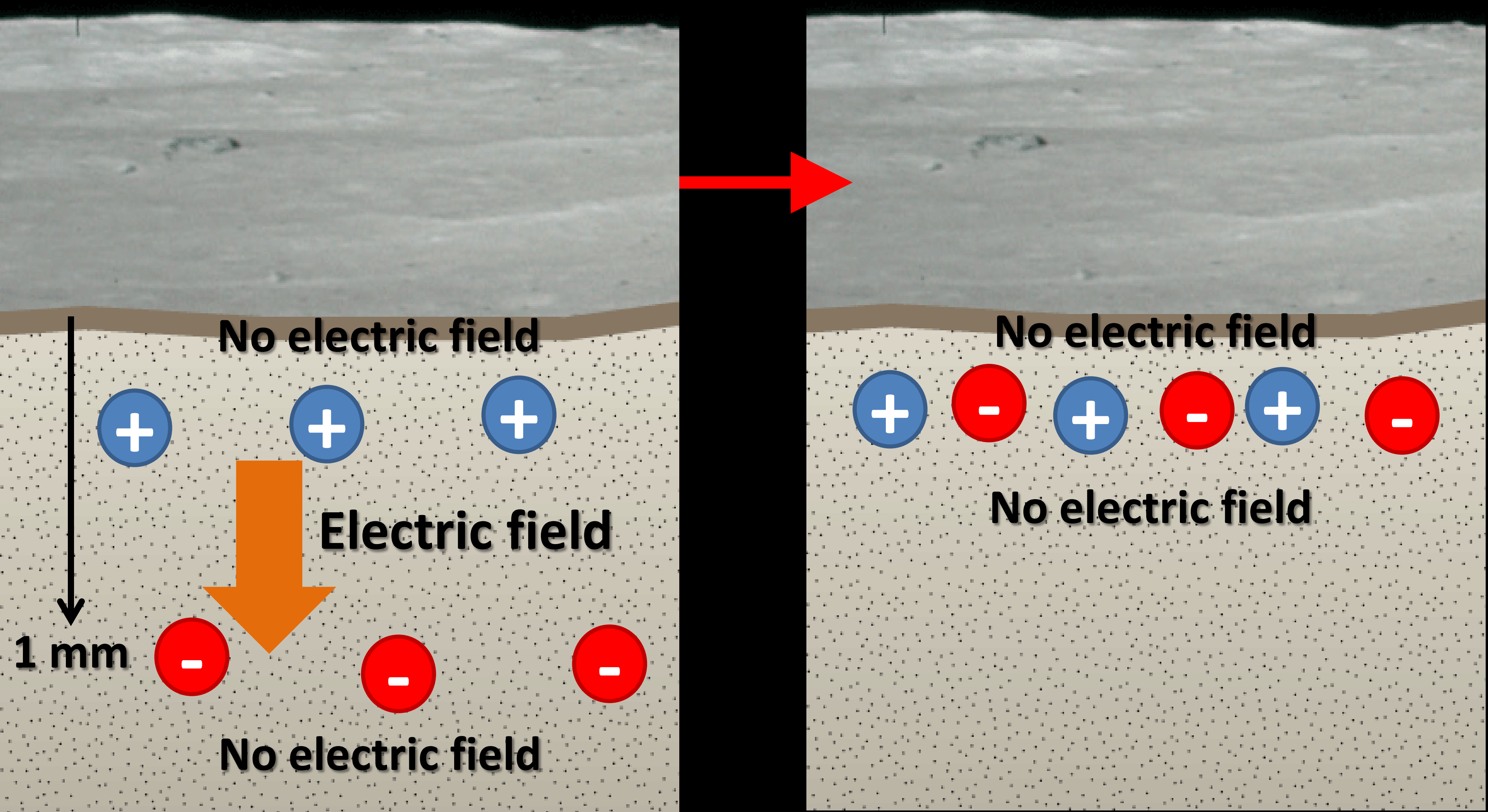

Breakdown threshold:
~10^{10} particles cm^{-2}
www.capturedlightning.com/frames/LF39-40.html

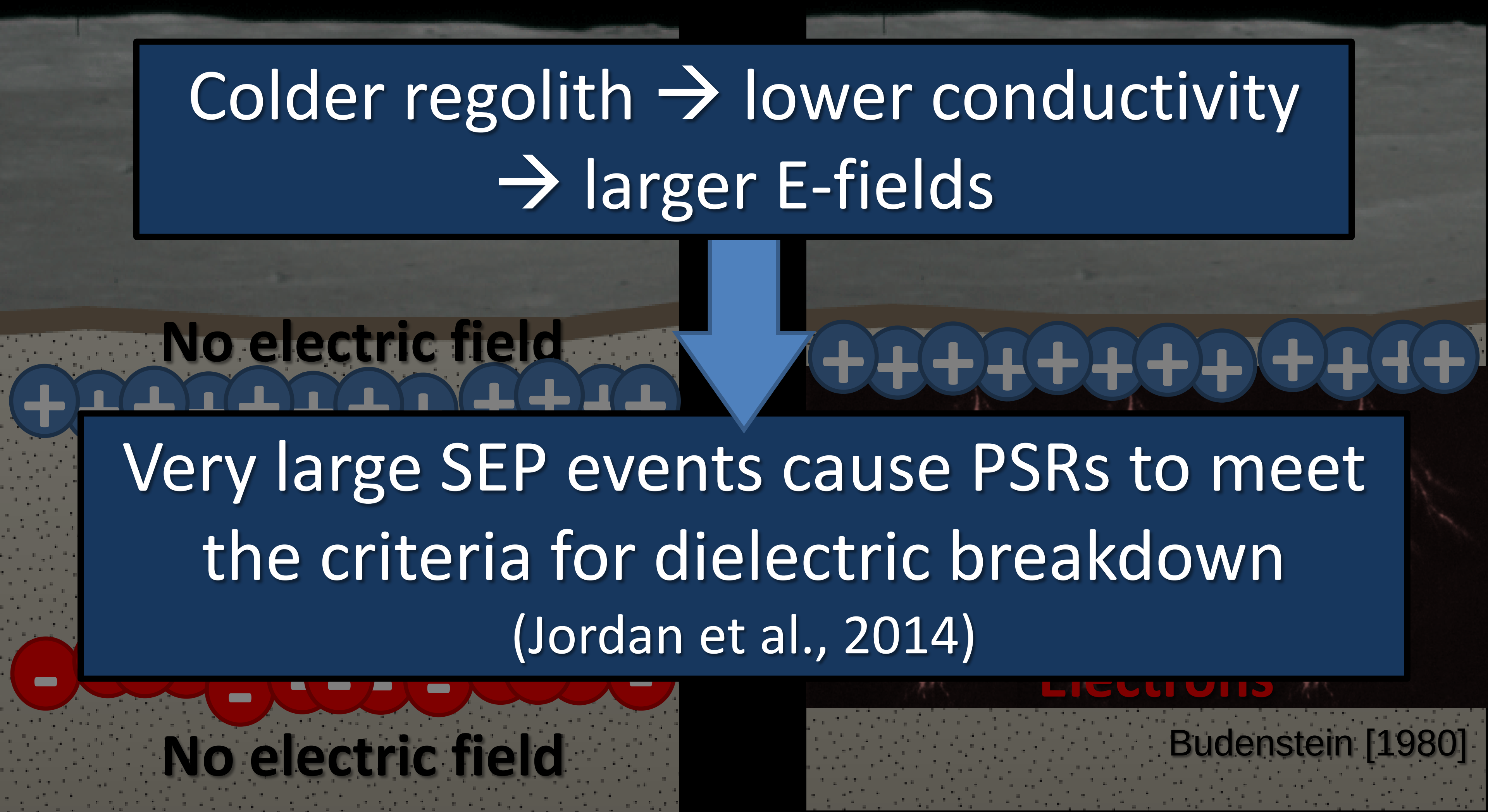
1) SEPs charge the subsurface, setting up a capacitor-like situation

2) Charging dissipates as in a capacitor



If SEPs charge regolith faster than it can discharge (fluence of 10^{10}-10^{11} cm^{-2})…

… electric field can increase to threshold for dielectric breakdown (10^6-10^7 V/m)



Colder regolith → lower conductivity → larger E-fields

Very large SEP events cause PSRs to meet the criteria for dielectric breakdown

(Jordan et al., 2014)

How much energy has breakdown deposited in PSR regolith?

Event's E-field energy density (function of SEP fluence)

Event rate (function of SEP fluence)

Rate at which energy density is deposited

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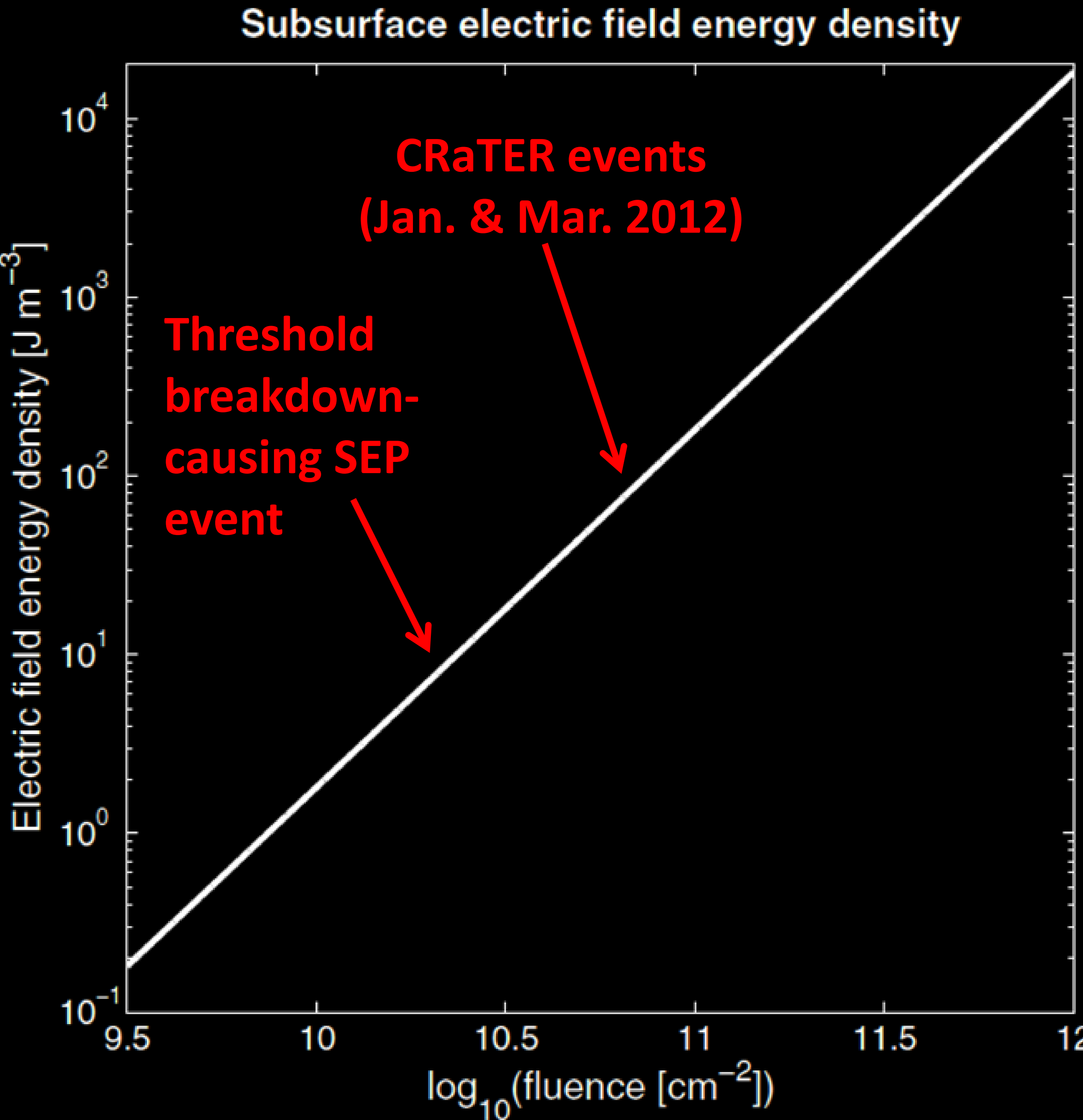

Jordan et al. (under review)

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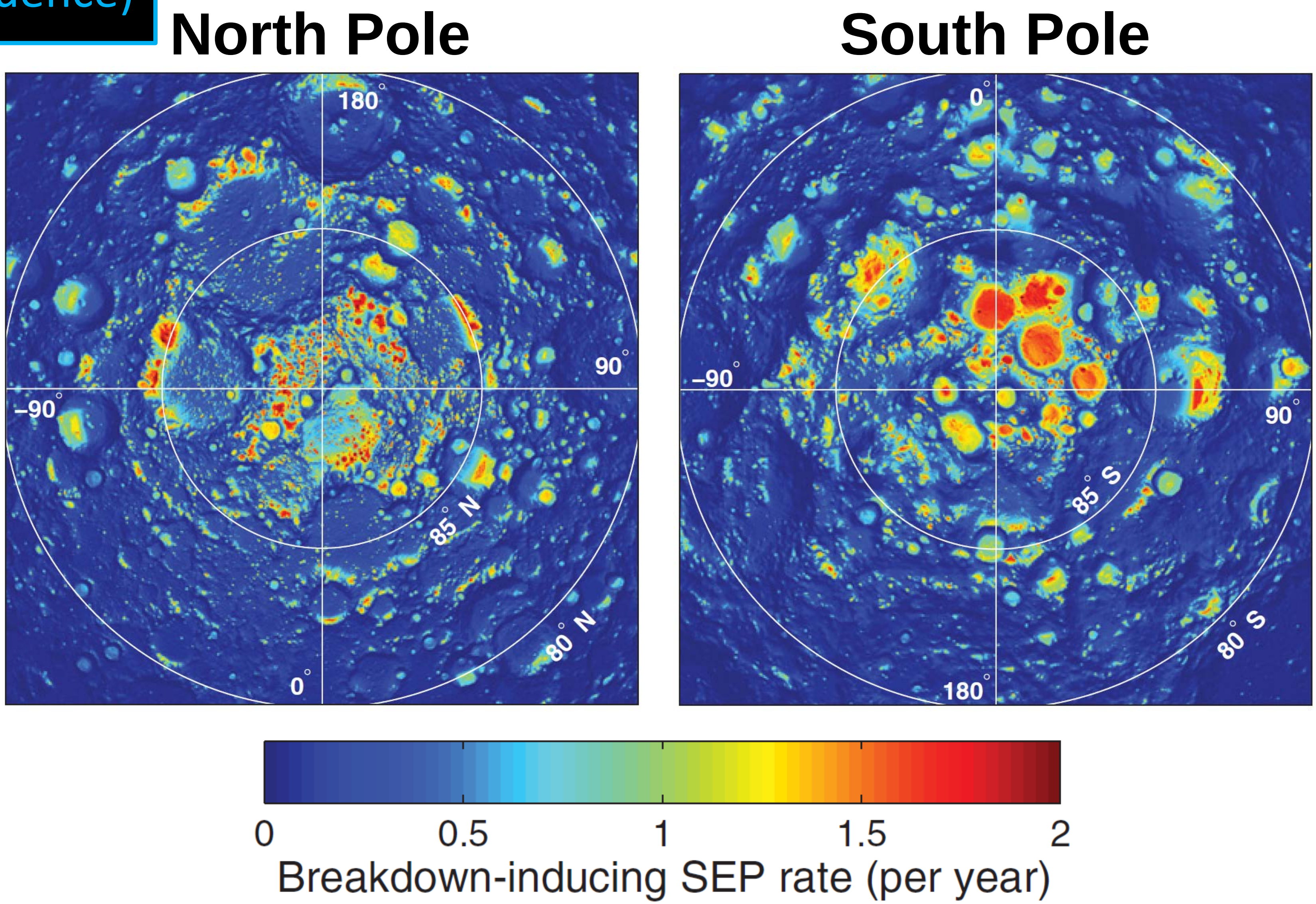

(Jordan et al., 2015)

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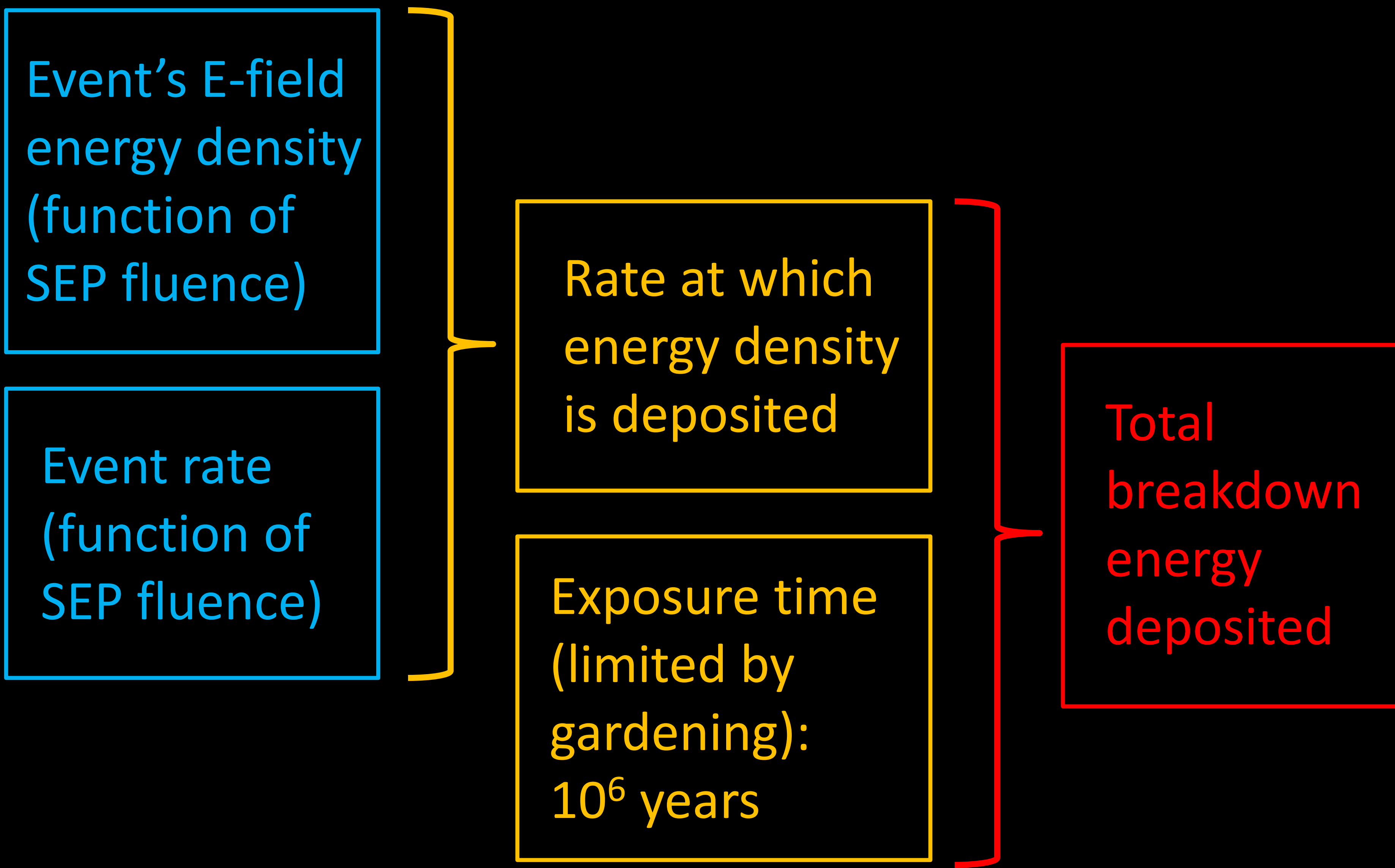


Energy density deposited over 10^6 yr of exposure (10^6 SEP events):

8.8×10^8 J m^{-3}

Energy density needed to vaporize all regolith:

$\rho_{reg}\, c_p\, (T_{vapor} - T_{PSR}) =$

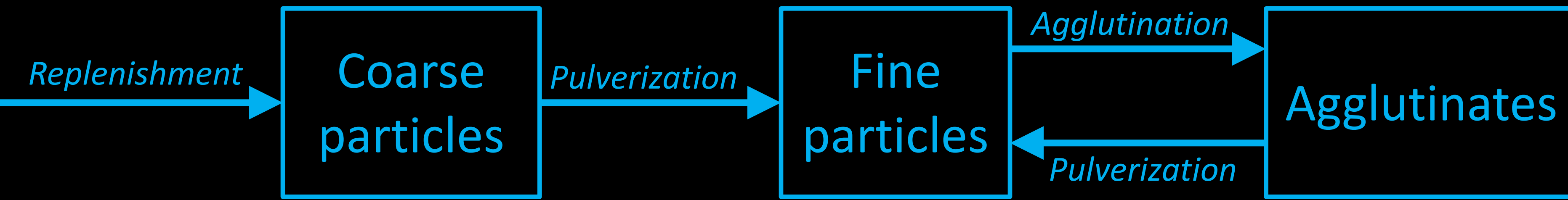
7.3×10^9 J m^{-3}

Weathering process	Energy flux (J m^{-2} yr^{-1})	Vapor + melt production (kg m^{-2} yr^{-1})	% Gardened soil melted or vaporized
Impact	1.2	2.1×10^{-7}	~10%
Breakdown	0.88	$1.8 - 3.5 \times 10^{-7}$	~10-25%

Jordan et al. (under review)

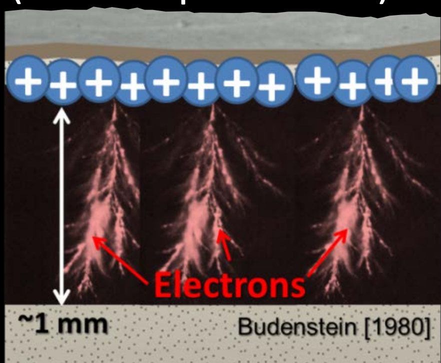
Breakdown weathering may be comparable to impact weathering in PSRs

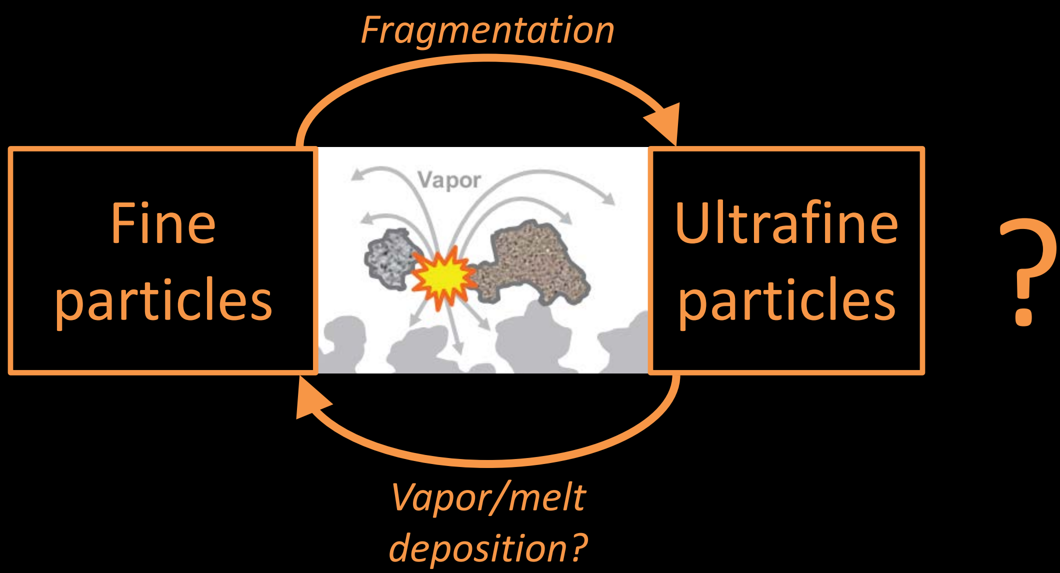
Impact model of soil evolution (McKay et al., 1974):



Breakdown model of soil evolution:

What probably happens (need experiments):

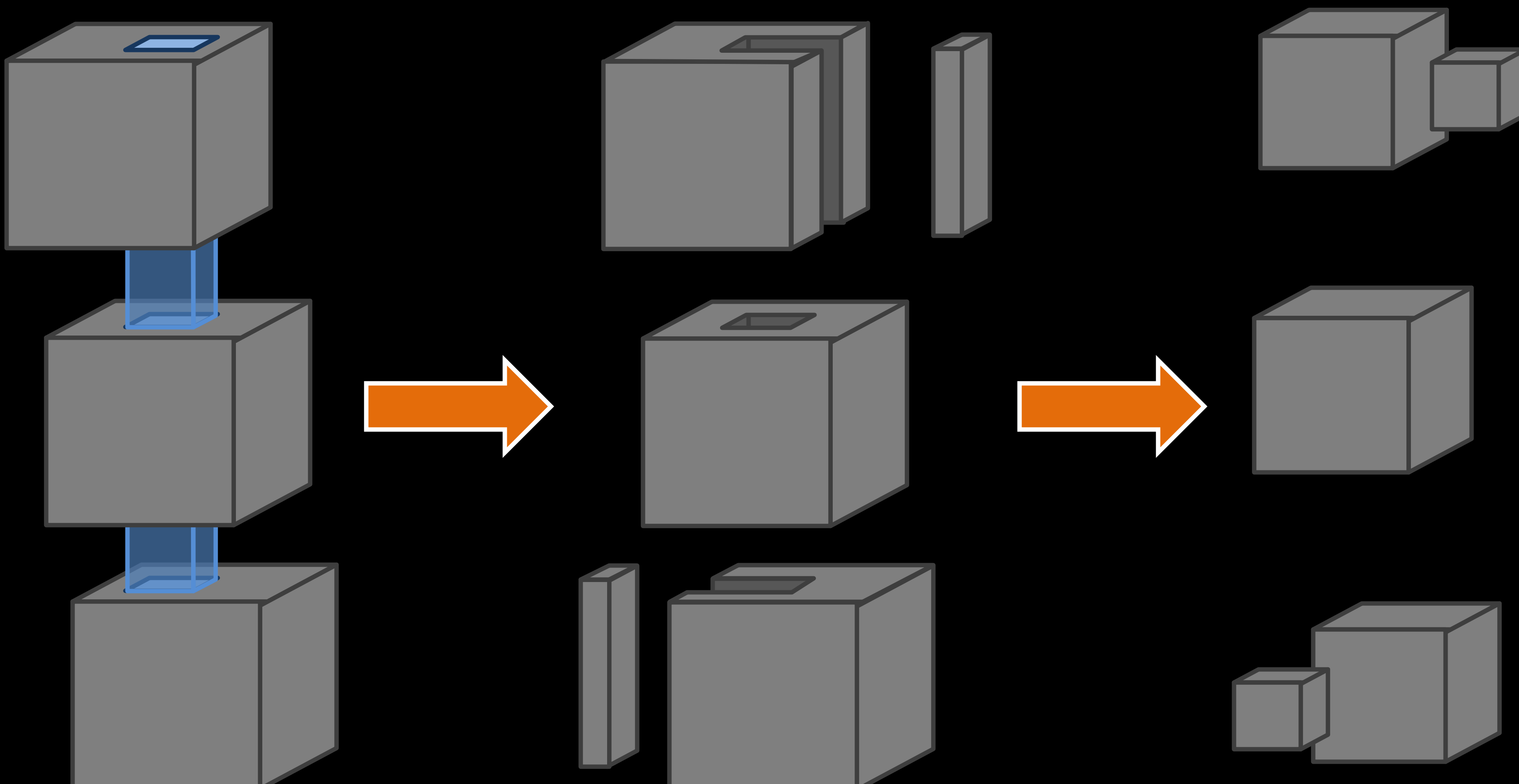




Breakdown vaporizes channels

Expanding gas fragments some grains; vapor deposited on other grains

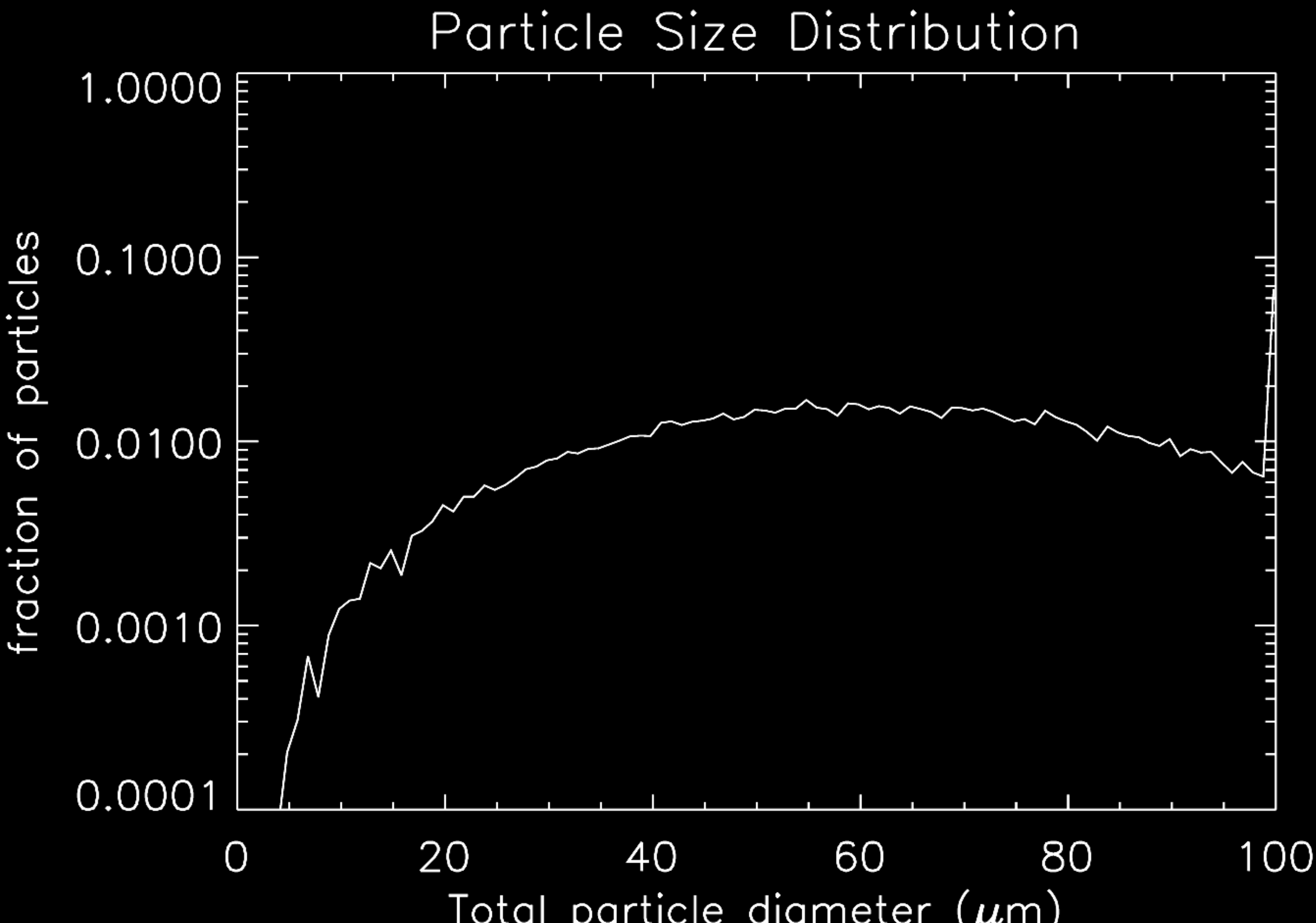
Recube new grains



Preliminary Monte Carlo Results

Starting particle size: 100 μm

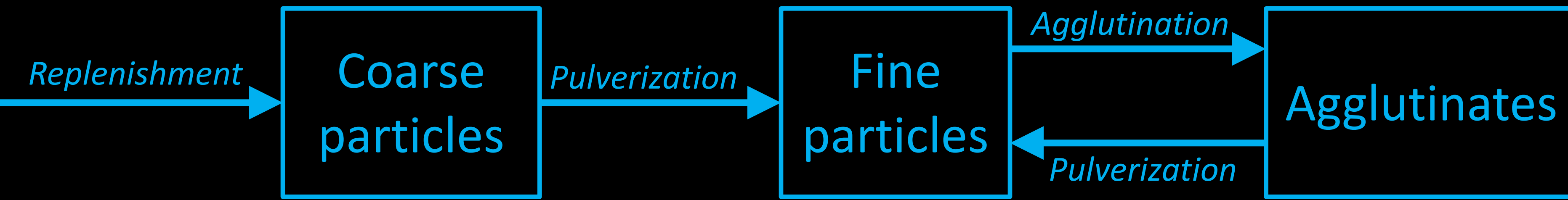
Input breakdown energy: 10^9 J m^{-3} (~10^6 yr)



Without impacts, decrease mean grain size by ~40 μm throughout gardened layer

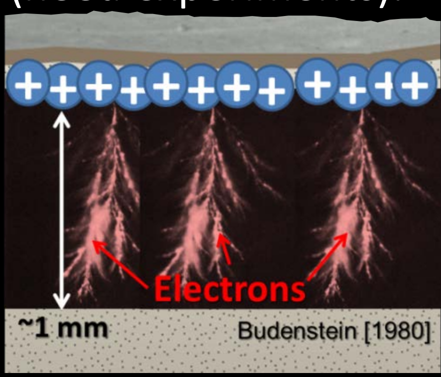
May increase porosity and thus affect trafficability

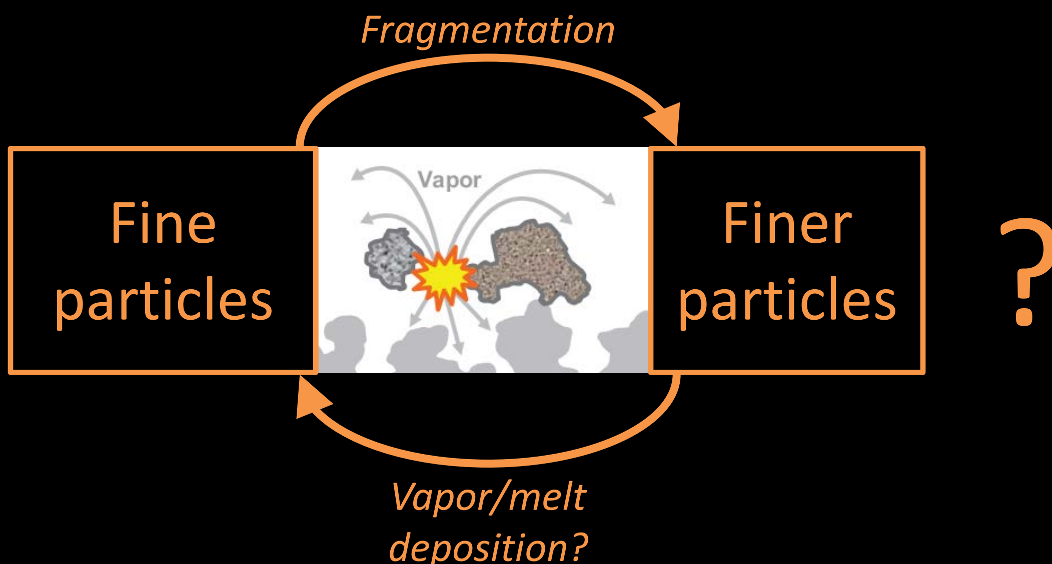
Impact model of soil evolution (McKay et al., 1974):



Breakdown model of soil evolution:

What probably happens (need experiments):





Impact + breakdown soil evolution: ?

Conclusions

Breakdown weathering in PSRs

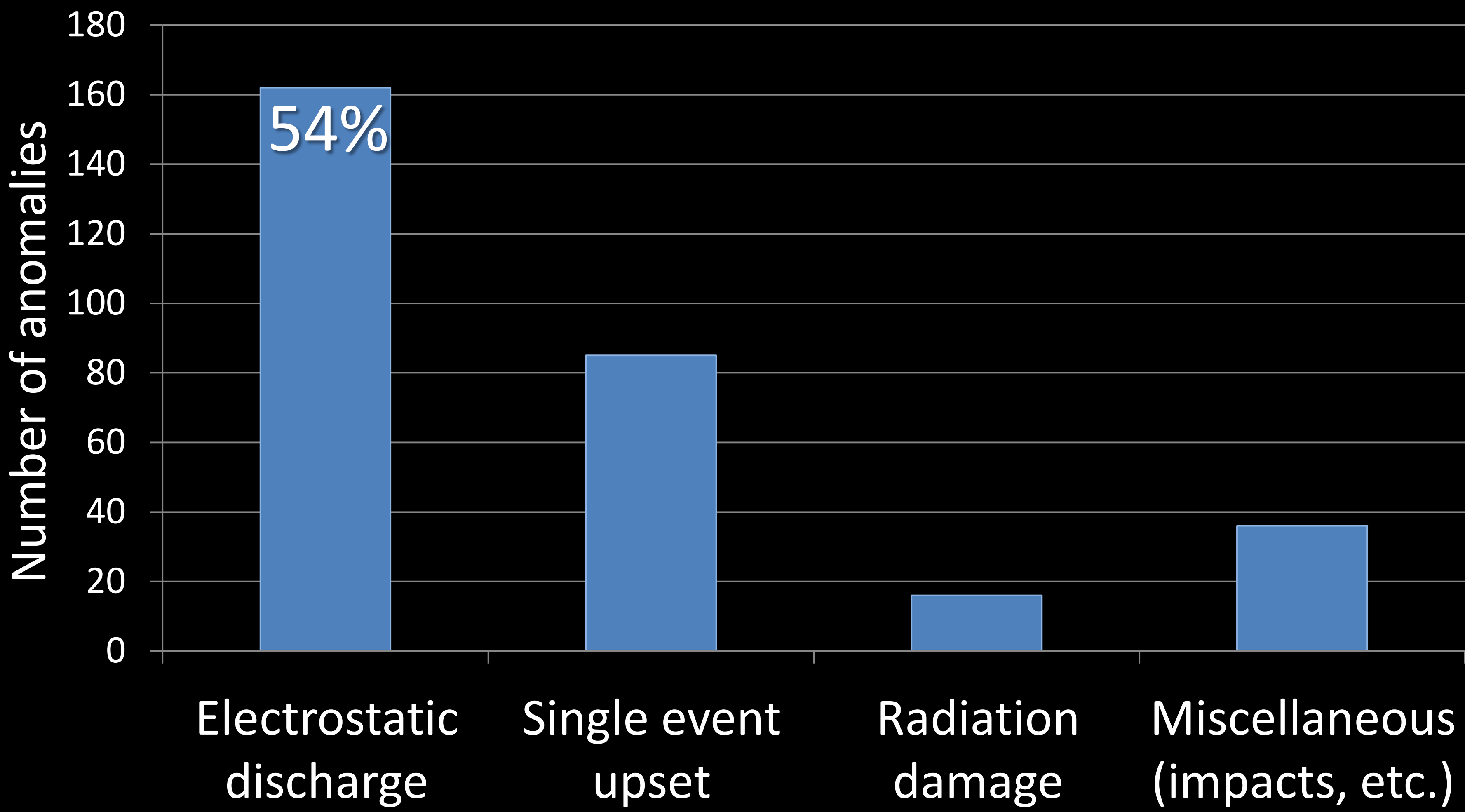
- may produce vapor/melt comparable to impact weathering
- may have affected 10-25% of gardened regolith
- may augment comminution and thus affect trafficability

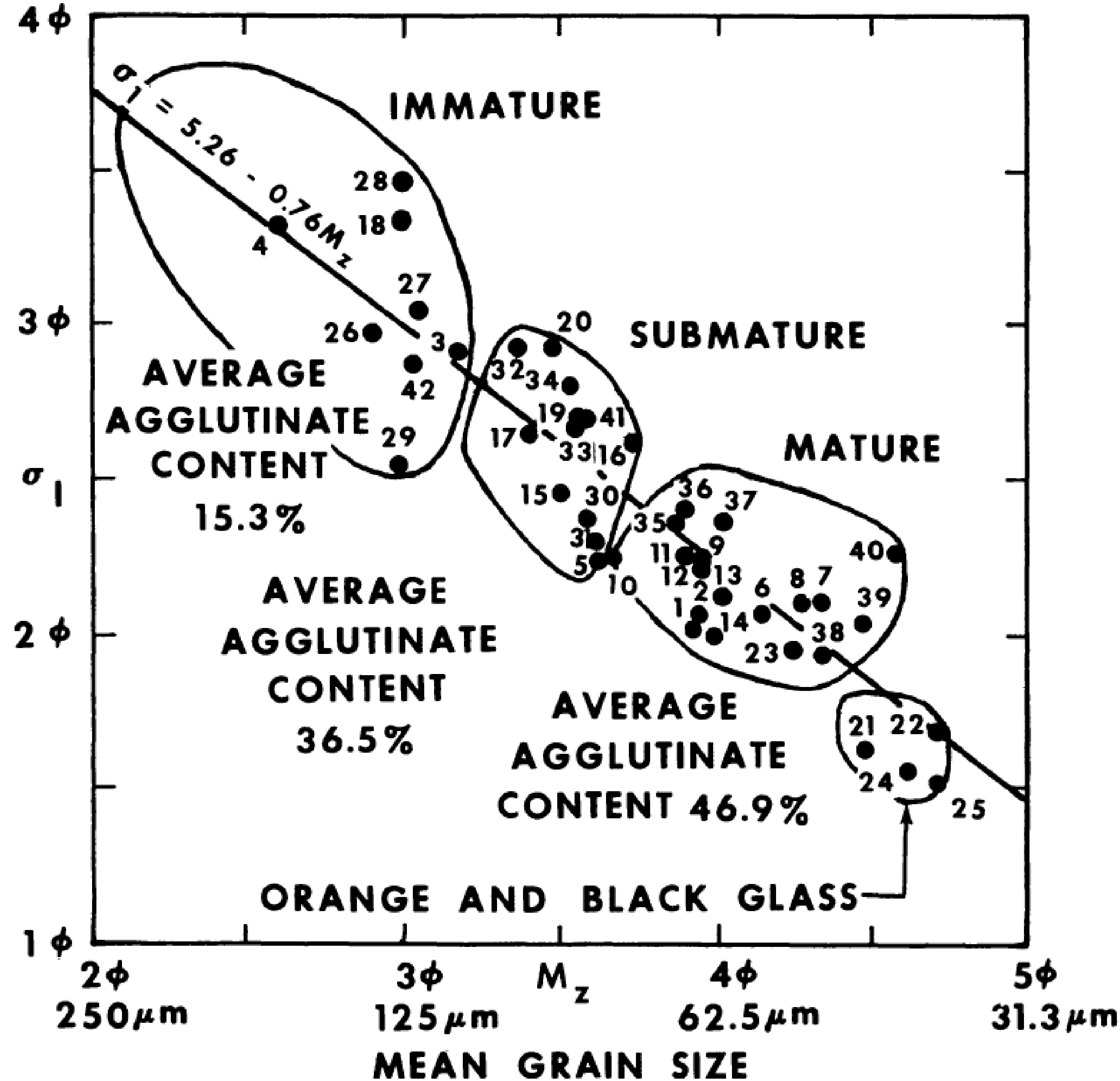
Future work

- Could LRO or in situ instruments detect breakdown?
- Could those observations + lab work differentiate its weathering effects from those of other processes?
- Could “sparked” material be in the Apollo samples?

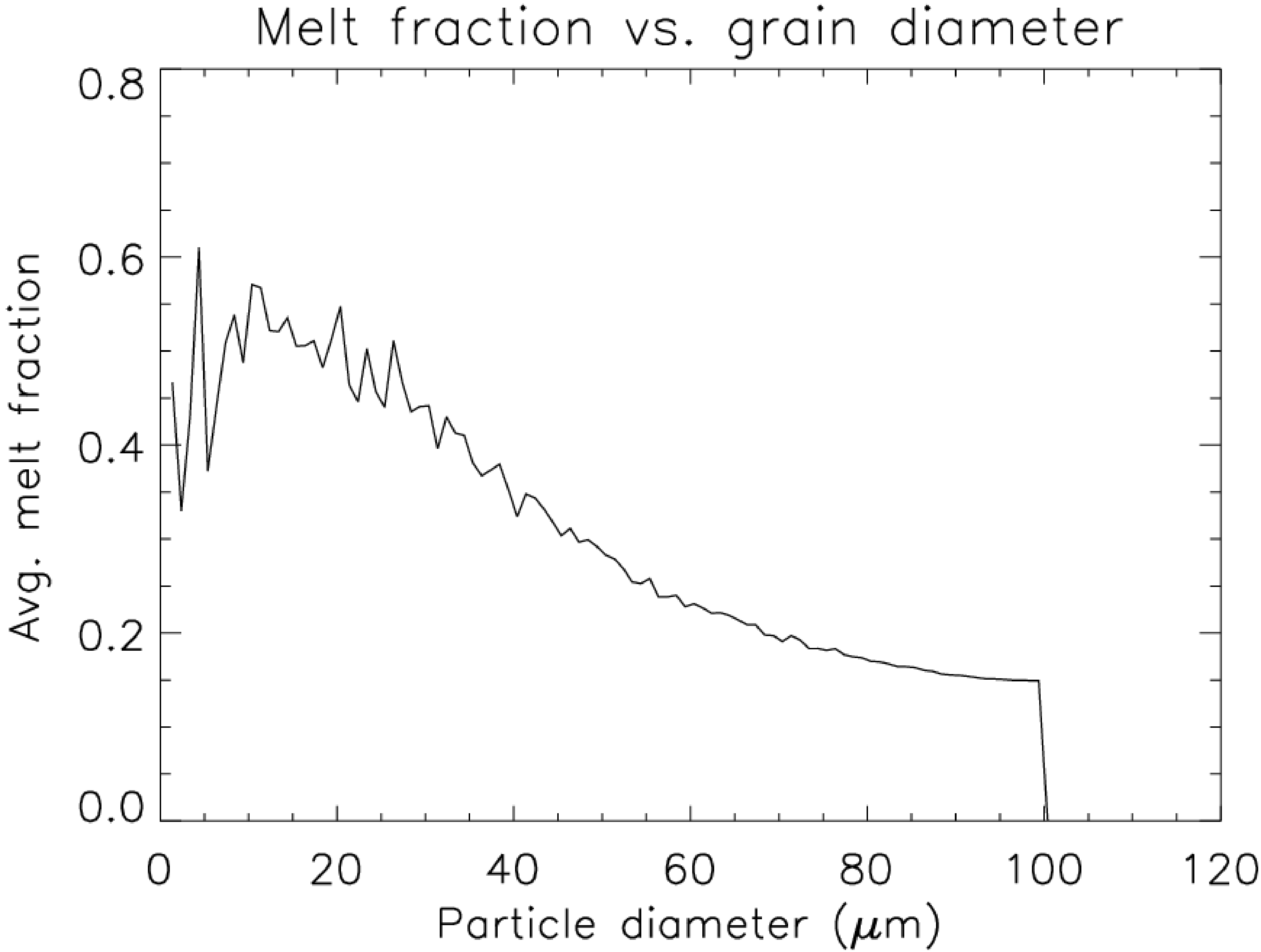
Backup slides

Spacecraft anomalies caused by the space environment
(Koons et al., 1998)





McKay et al. (1974)


Melt fraction vs. grain diameter
Avg. melt fraction
0.0
0.2
0.4
0.6
0.8
0
20
40
60
80
100
120
Particle diameter (μm)

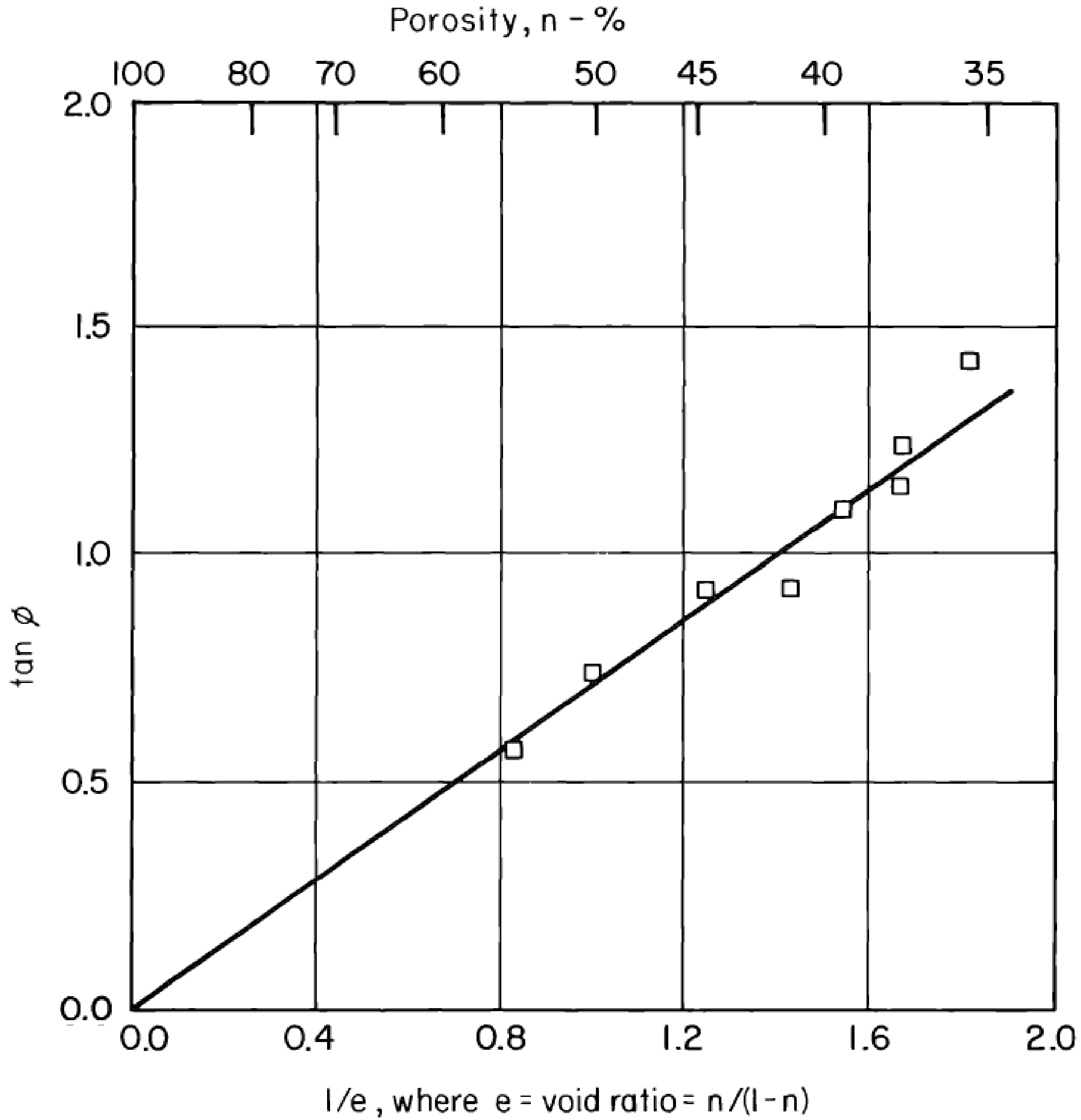


Fig. 2. Friction angle as a function of porosity for a lunar soil simulant (ground basalt).

Mitchell et al. (1972)

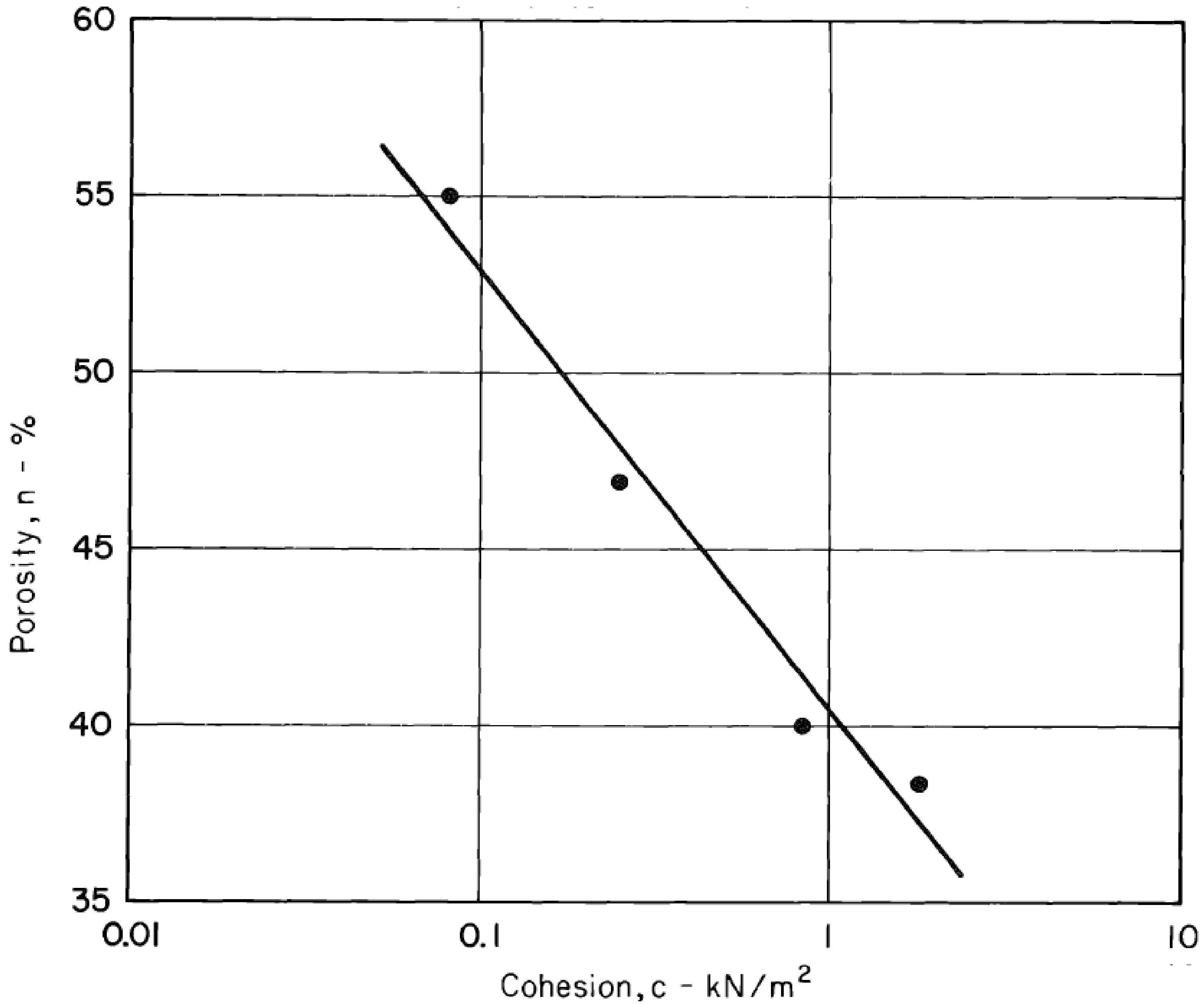
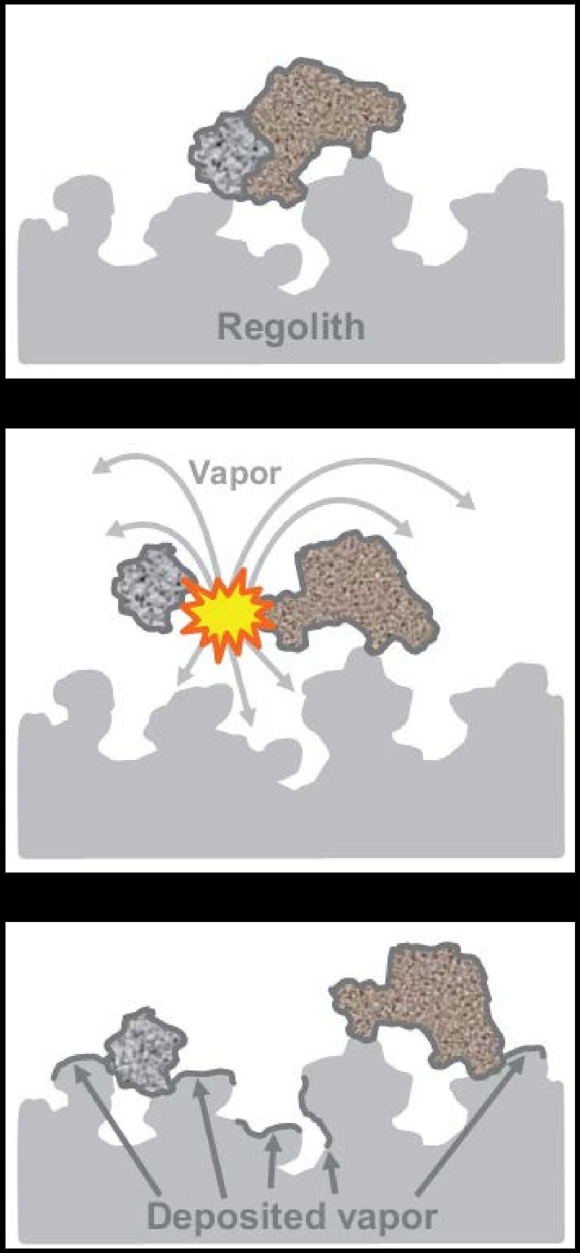


Fig. 3. Cohesion as a function of porosity for a lunar soil simulant (ground basalt).

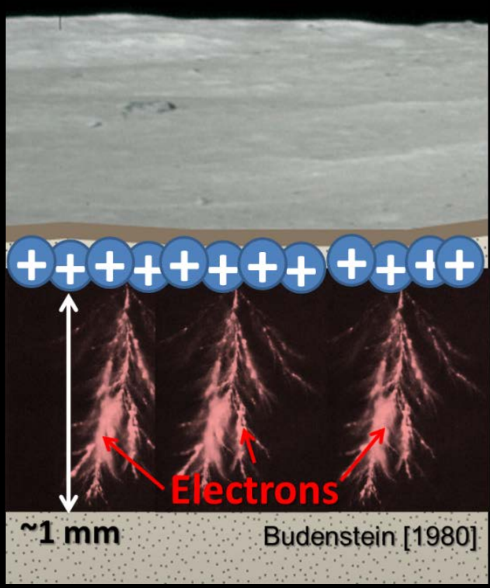
Mitchell et al. (1972)



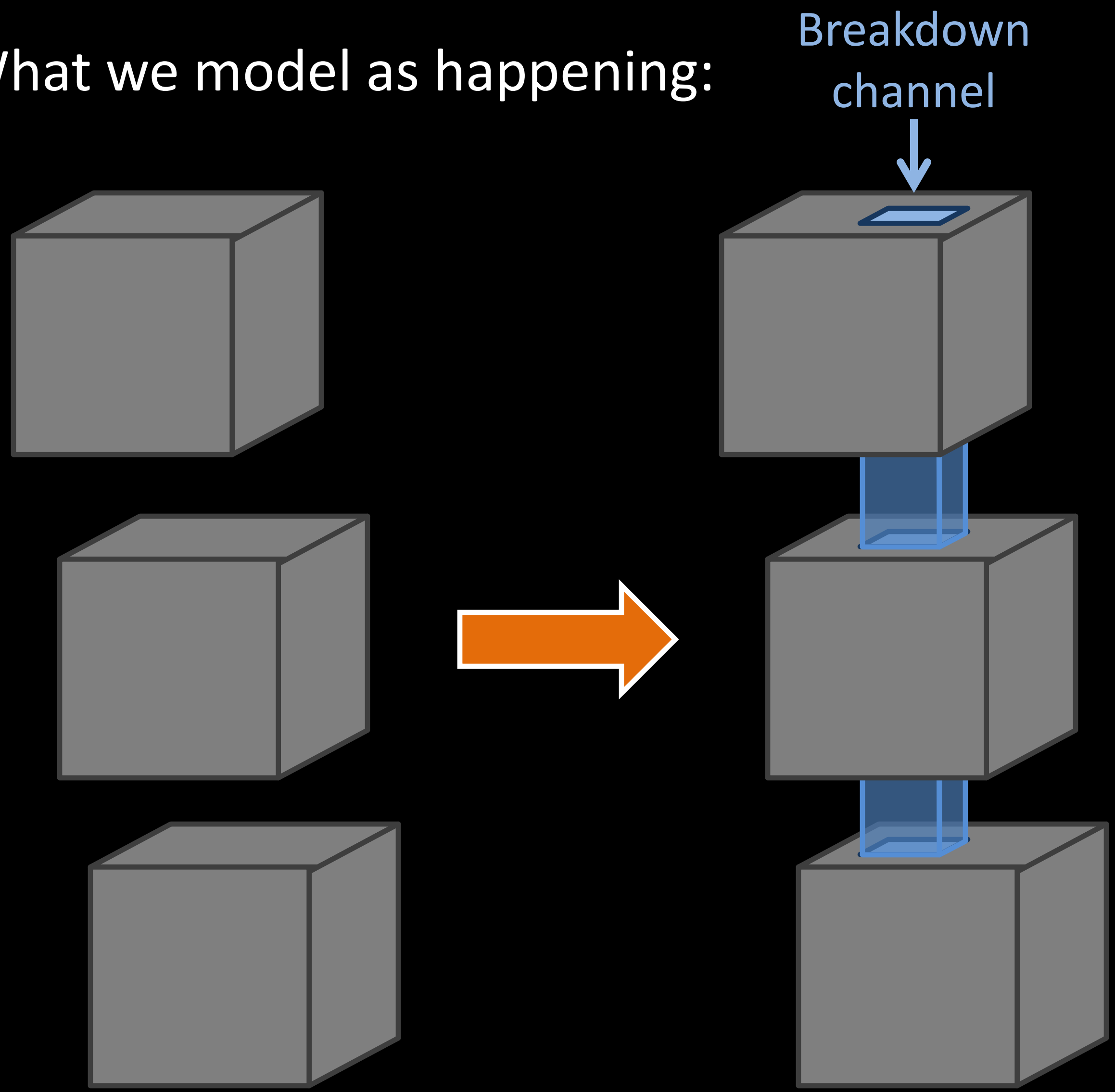
Jordan et al. (2015)

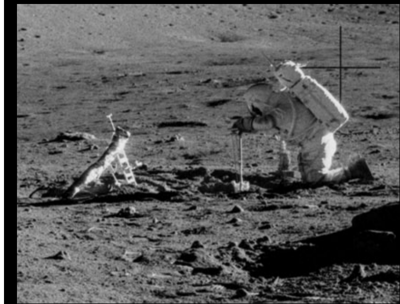
- Porosity is the main influence on cohesion and angle of internal friction (Costes et al., 1972)
- PSRs may have porosity of ~70% (Gladstone et al., 2012)
- Breakdown weathering may increase porosity in PSRs (Jordan et al., 2015)
- Since breakdown has affected all *gardened* regolith, the affected layer could reach ~1 m

What probably happens (need experiments):



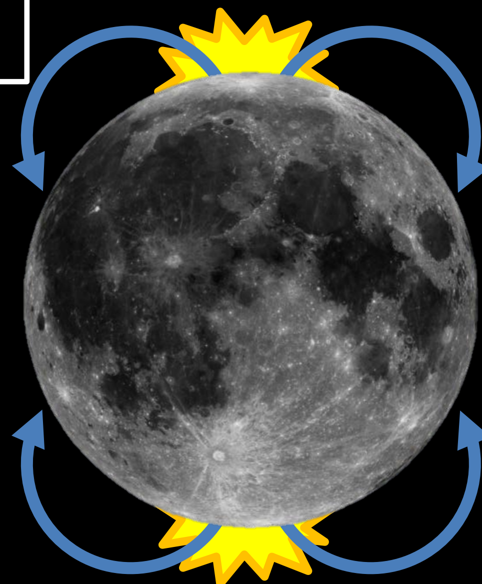
What we model as happening:





Is it in Apollo samples?

Impacts could spread breakdown-affected regolith to lower latitudes.



~0.01% of all gardened regolith may have experienced breakdown, but only a fraction of this would make it to lower latitudes.

Breakdown may occur on the nightside, which can be < 100 K.

If so, 3-6% of all gardened regolith may have experienced breakdown.

For a given lunar soil, the void ratio or porosity appears to be the most important single variable controlling the cohesion and the angle of internal friction of the material. (Costes et al., 1972)

The most probable values of cohesion appear to be in the range of 0.1 to 1.0 kN/m2. The angle of internal friction appears to range between 30 and 50 deg, with the higher values associated with the lower porosities. (Costes et al., 1972)