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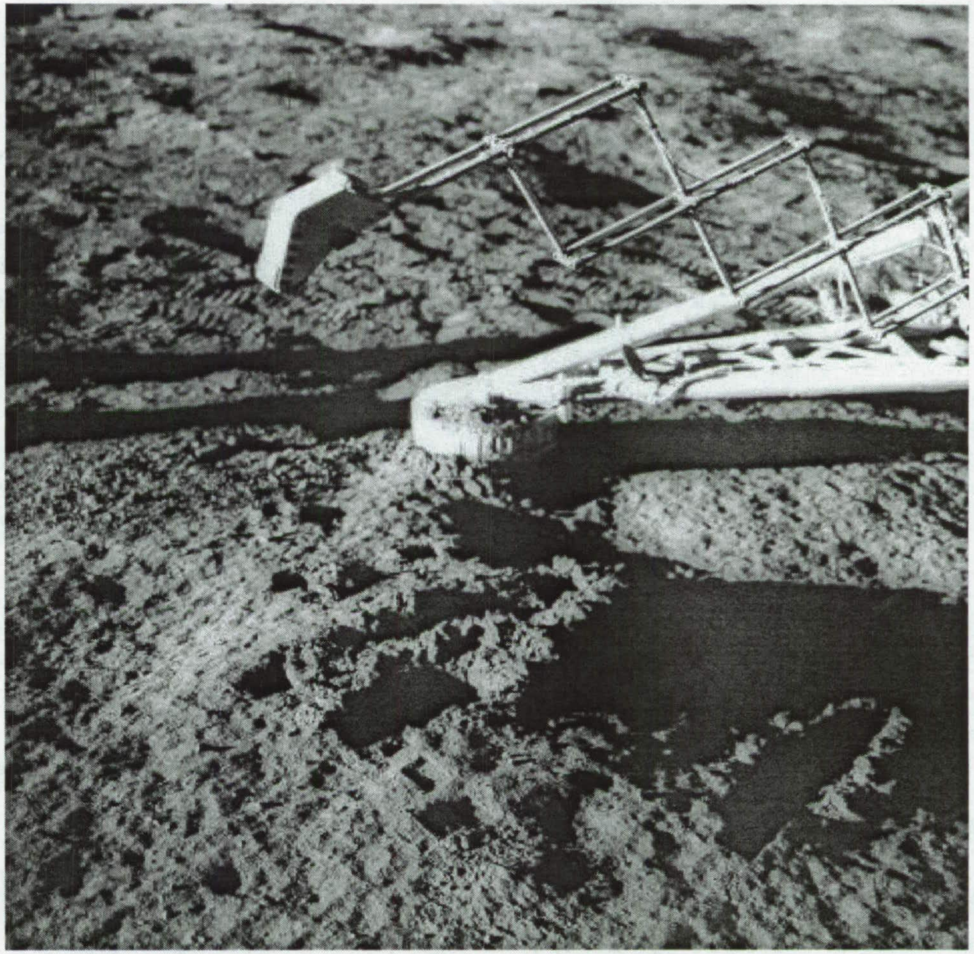
Background

- During the Apollo and Viking programs, NASA needed to know how the rocket exhaust would affect the soil on the Moon and Mars.
- A number of studies were done during the 50's through 70's
- Existing models are crude and do not predict mass-rate or trajectories of ejected material

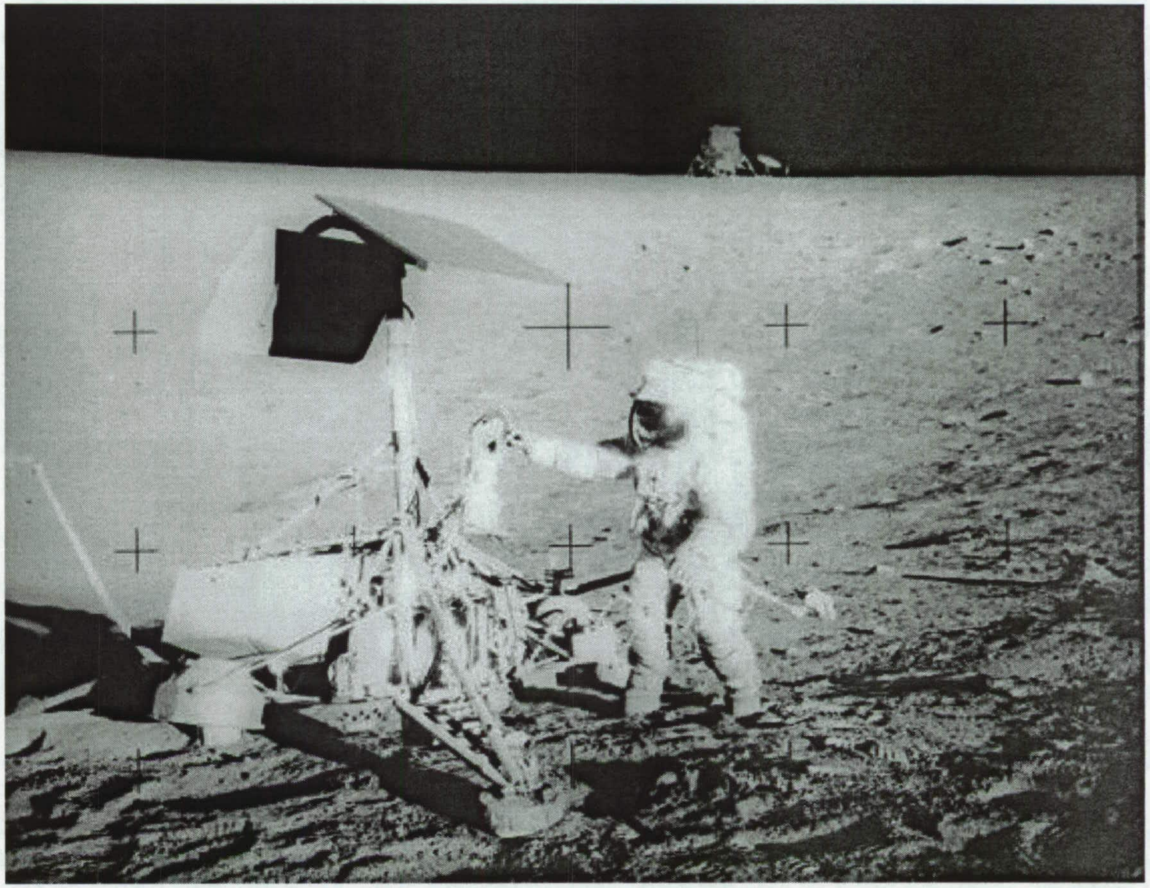
Must Protect Spacecraft from Itself

- Landing visibility
- Contamination of mechanisms
- Jamming or spoofing sensors
- Erosion of coated surfaces
- Pitting of optics



Must Protect Surrounding Hardware

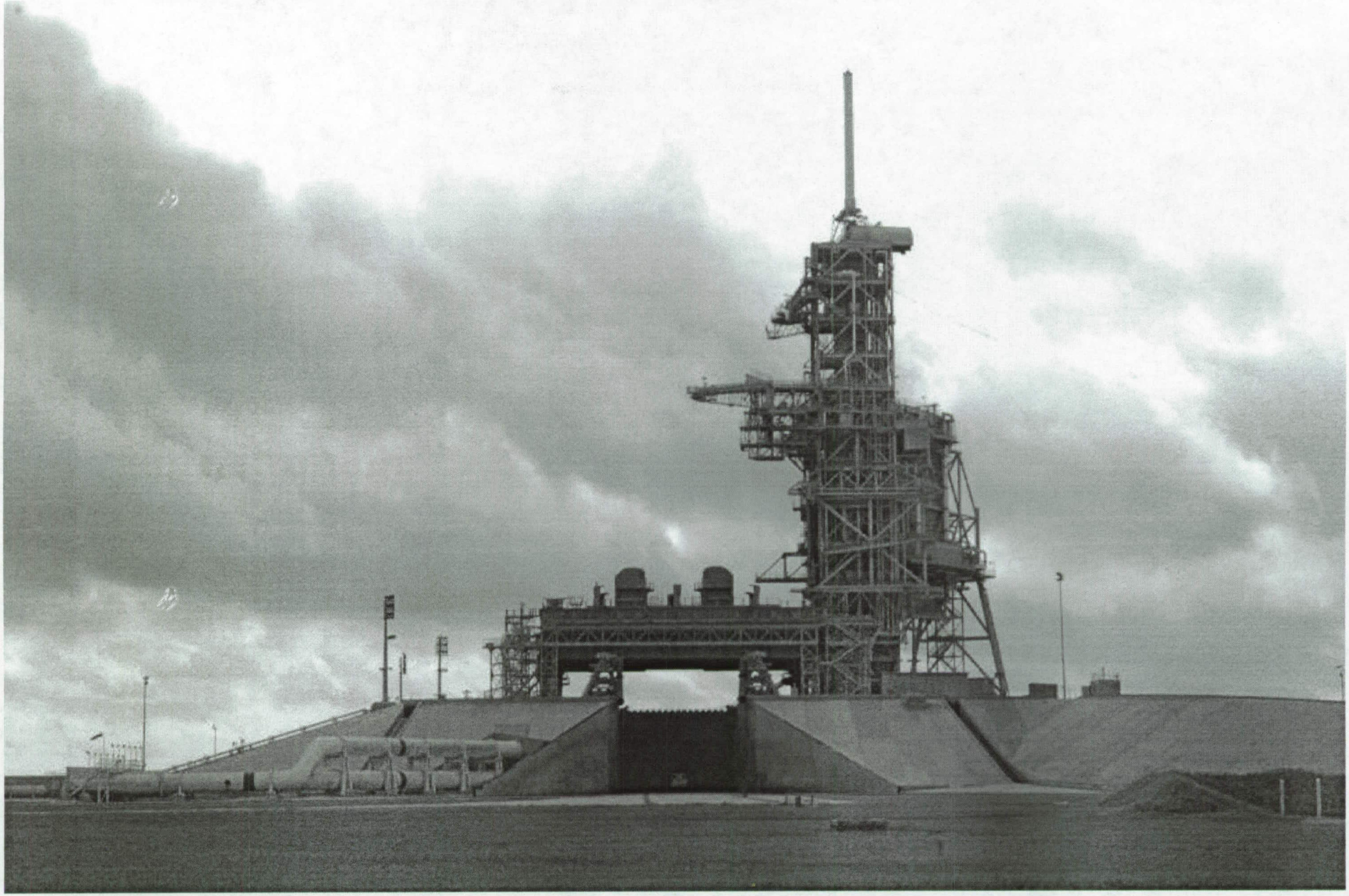
- Land too close:
  - Damage
  - Contamination
  - Excessive blast hardening required



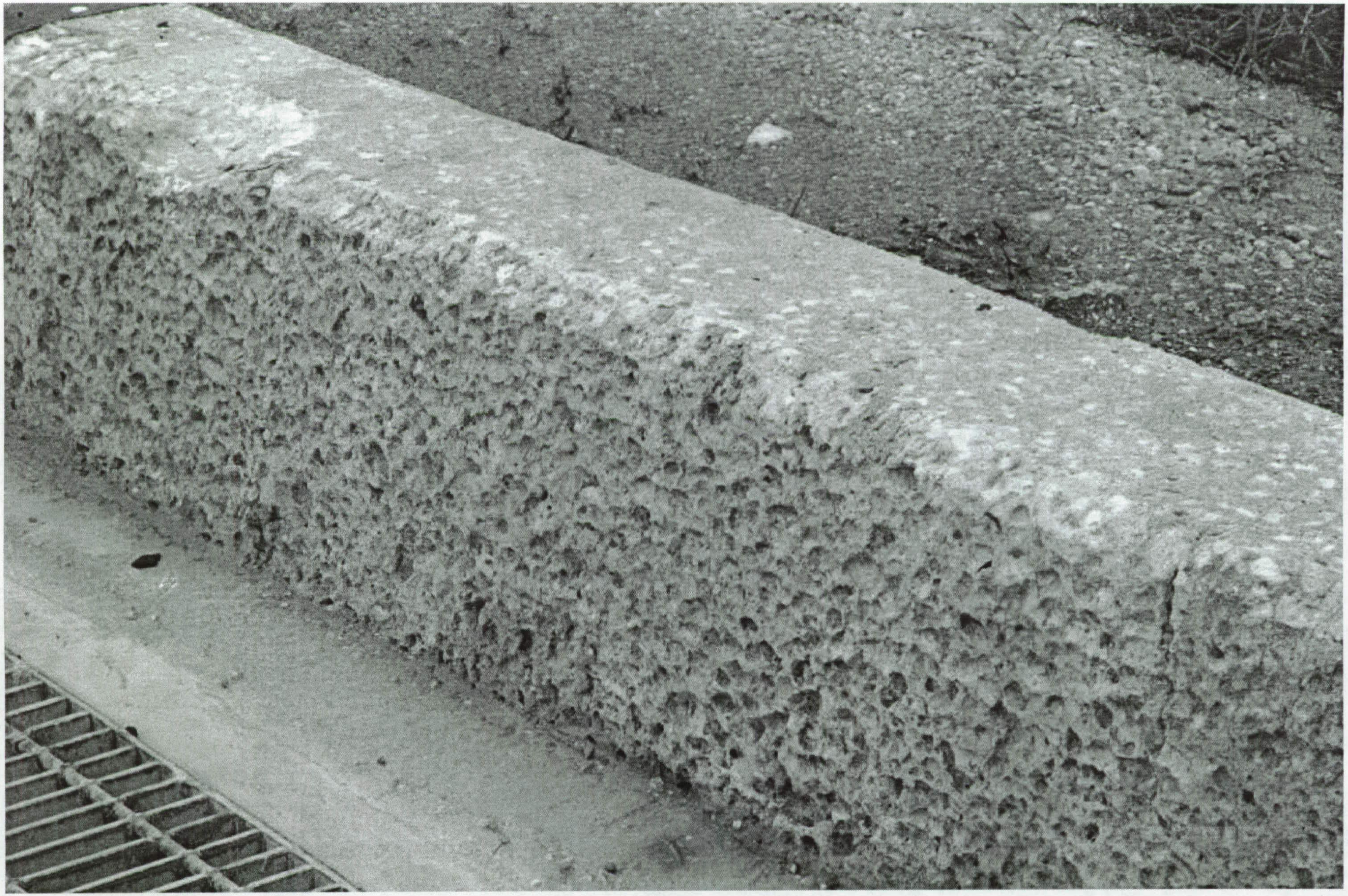
- Land too far away:
  - Excessive umbilical lengths & mass
  - Excessive travel between sites

Early Need to Validate Protective Measures

- Currently unable to specify berm height and radius
- Berm size drives excavator size and operating time
- Must specify surface asset hardening requirements in design phase



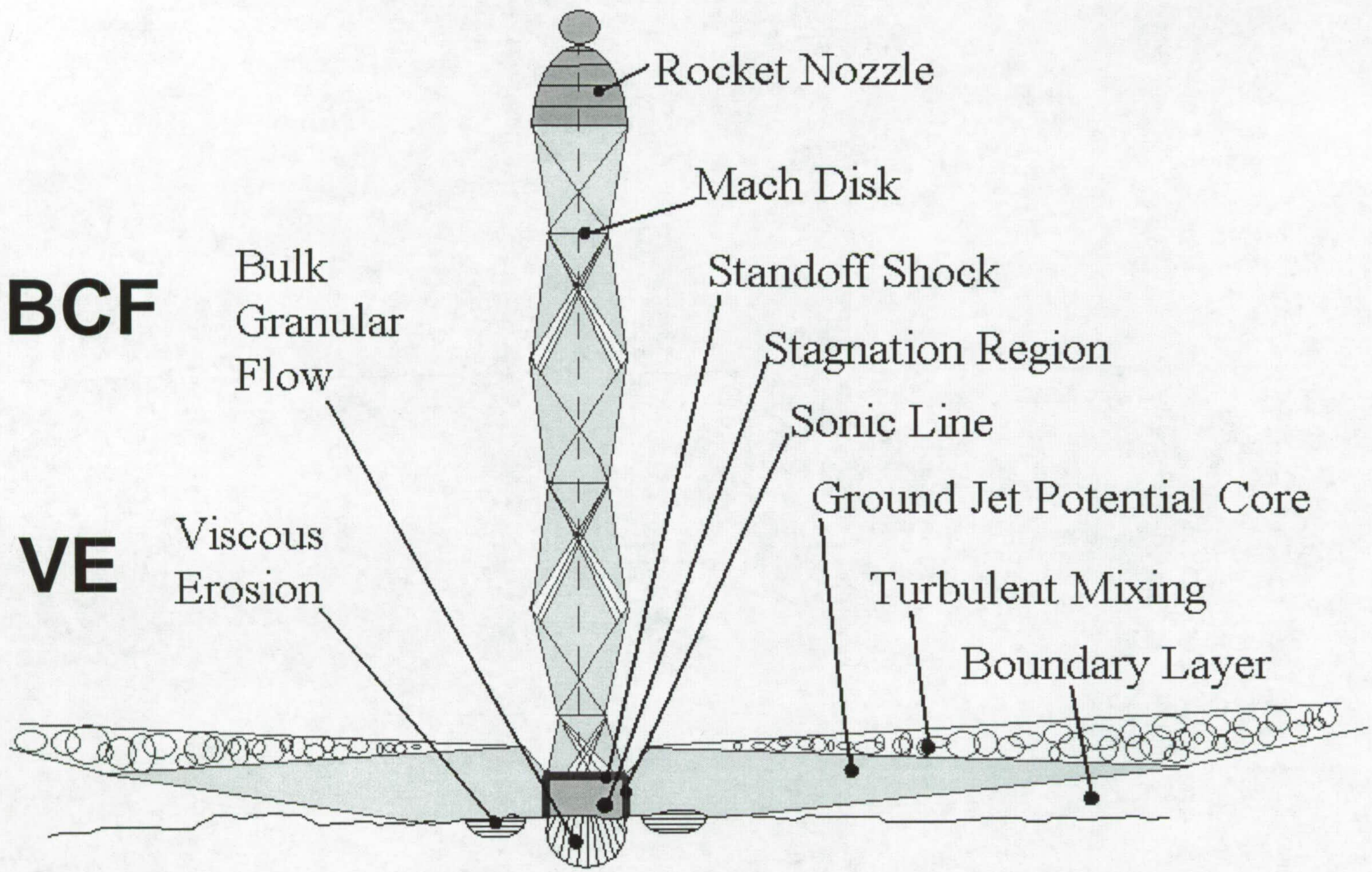
Damage to Pad perimeter fence from chunks of martite blown out of the flame trench



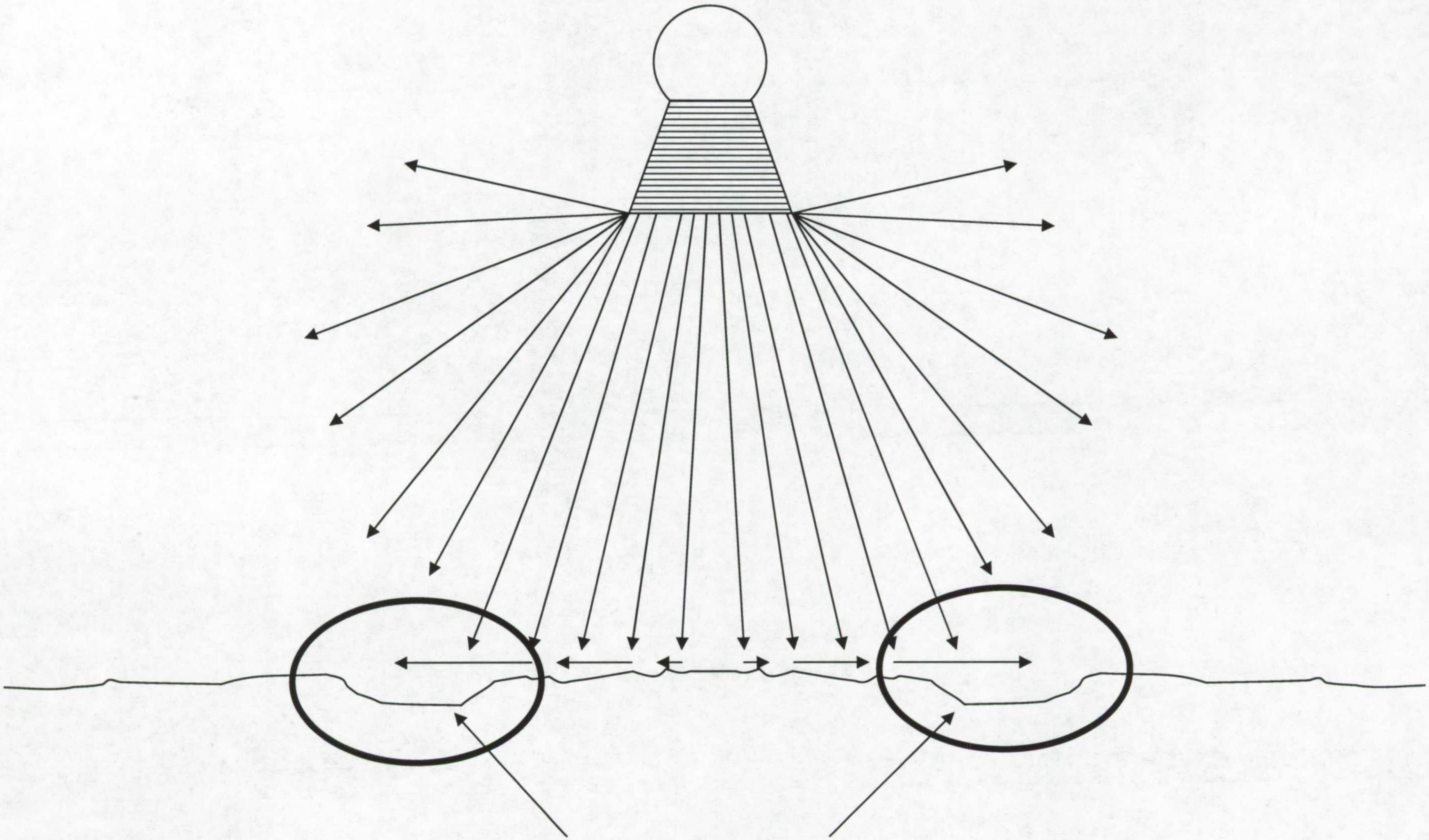
Erosion of concrete in
front of flame trench

Damage to concrete wall due to
FOD caught in the launch blast

Plume / Regolith Interactions



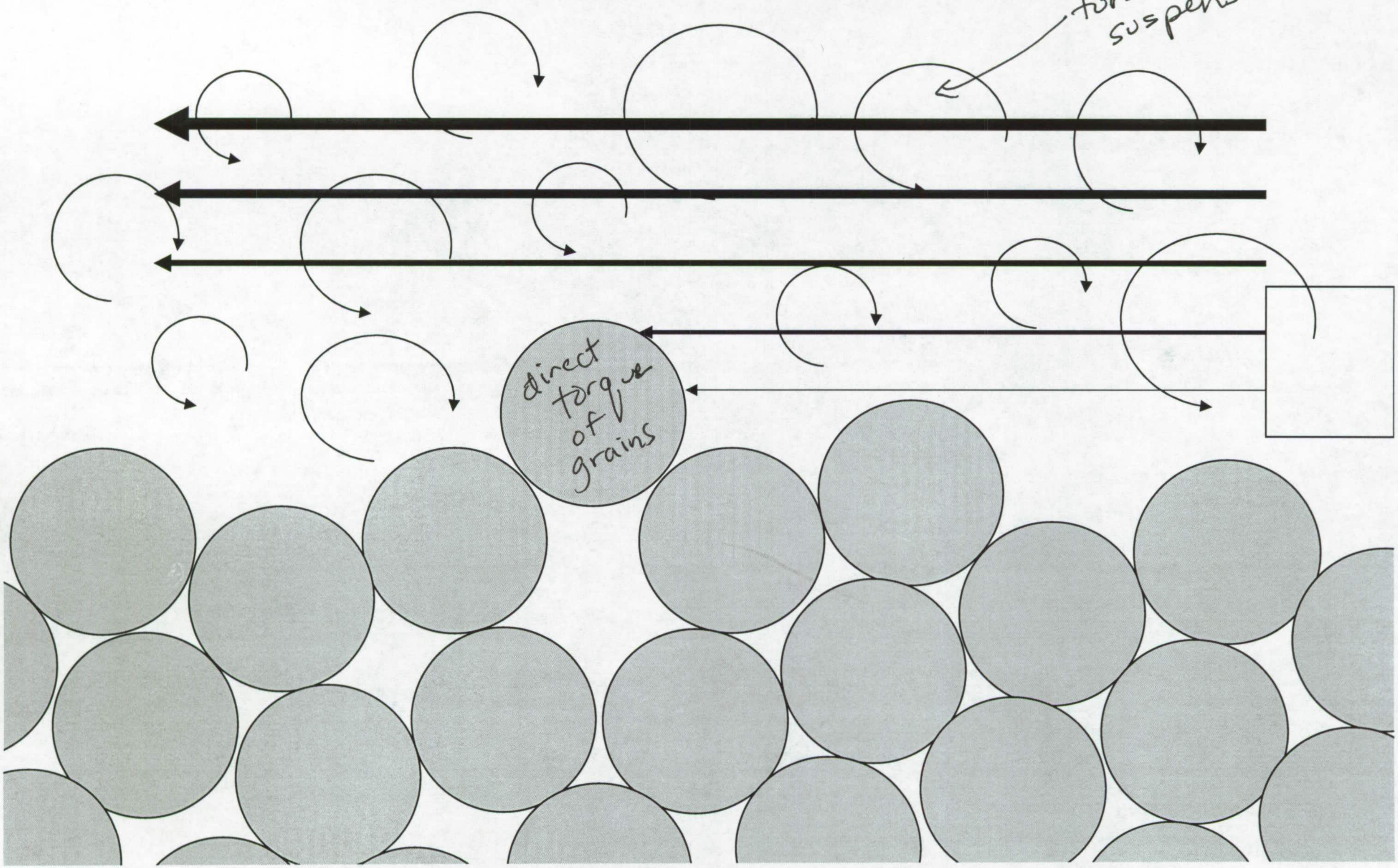
Viscous Erosion



Regions of maximum traction

Mechanisms of

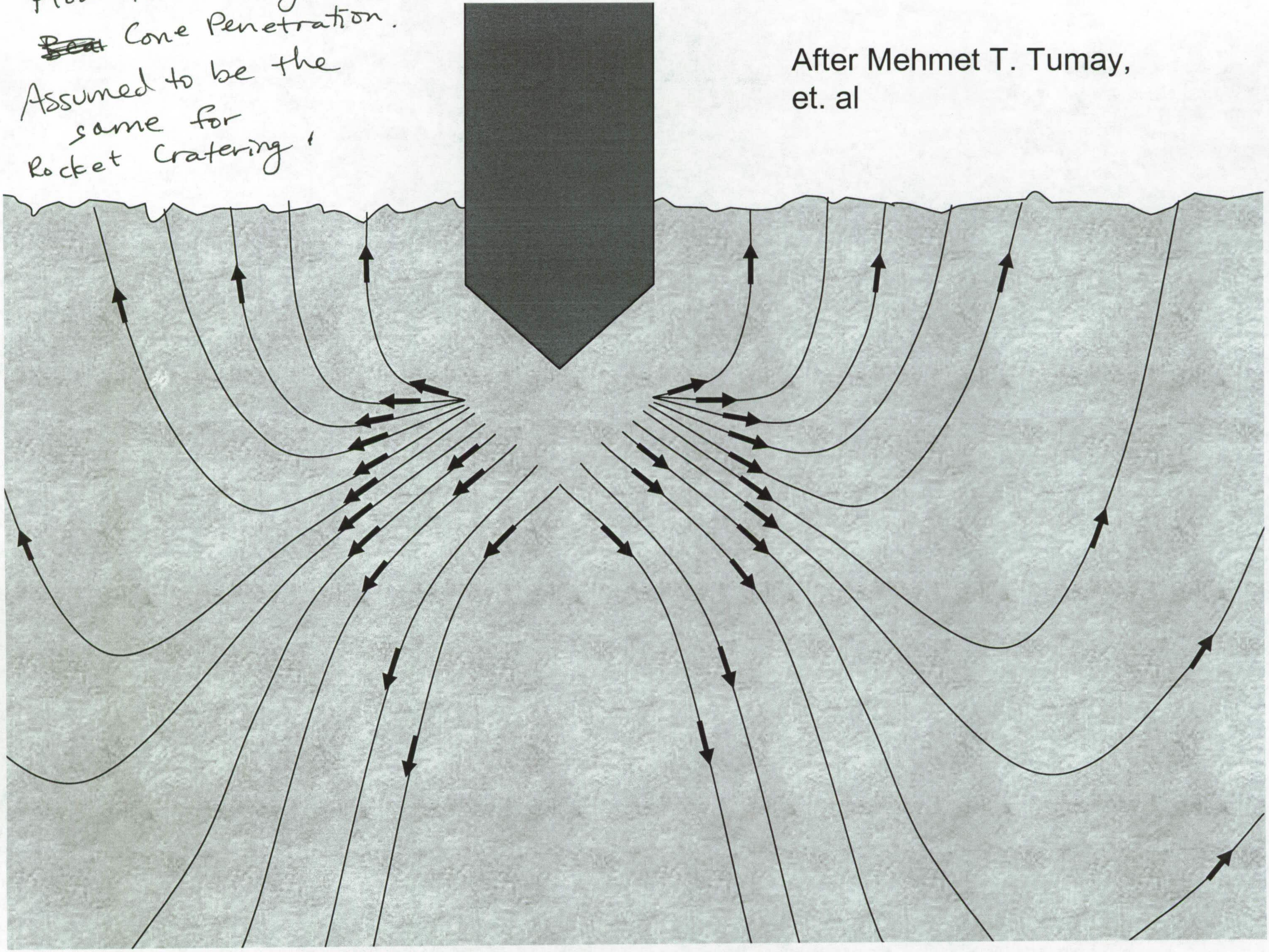
Viscous Erosion



Studies of VE

- Bagnold: *The Physics of Blown Sand and Desert Dunes*
  - Fudge factors that cannot be extrapolated
  - Slow wind, terrestrial atmosphere, log-normal particle size distributions of *sand*
- Leonard Roberts
  - Assumes mechanical surface shear stress
- Experimental Work in Vacuum Chambers

well-know
Flow field during
~~Bea~~ Cone Penetration.
Assumed to be the
same for
Rocket Cratering!

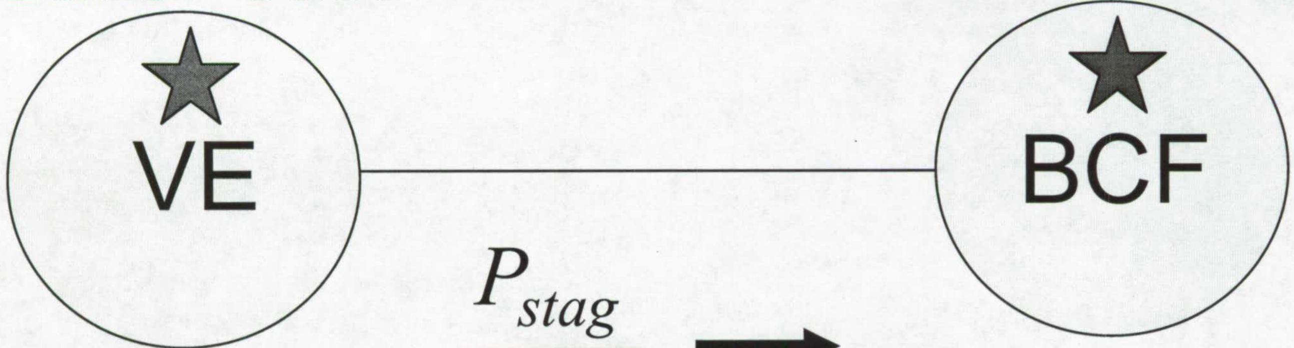


After Mehmet T. Tumay, et. al

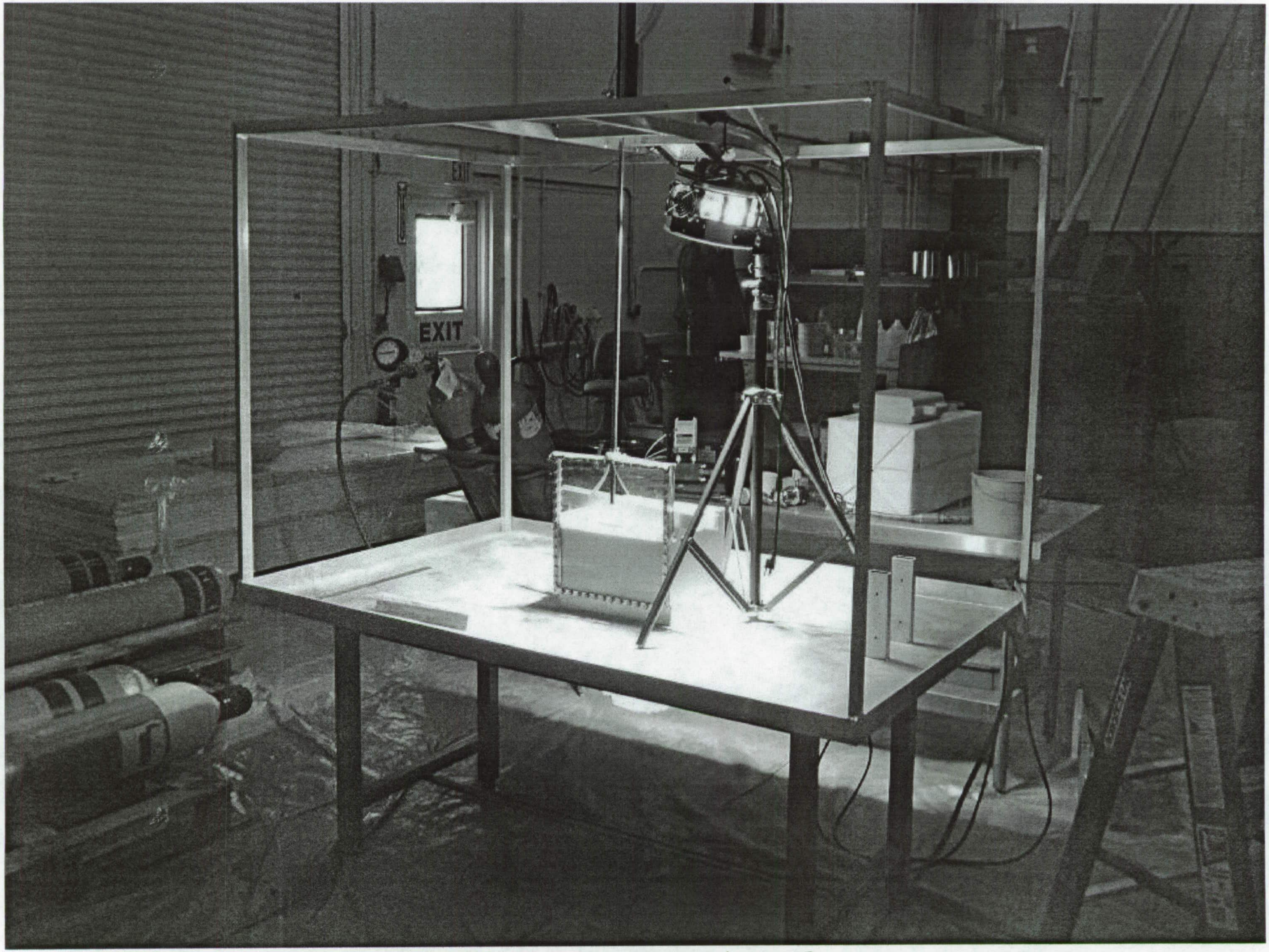
Paradigm ca. Apollo Program

Lower Thrust	Higher Thrust
Higher Shear Strength	Lower Shear Strength

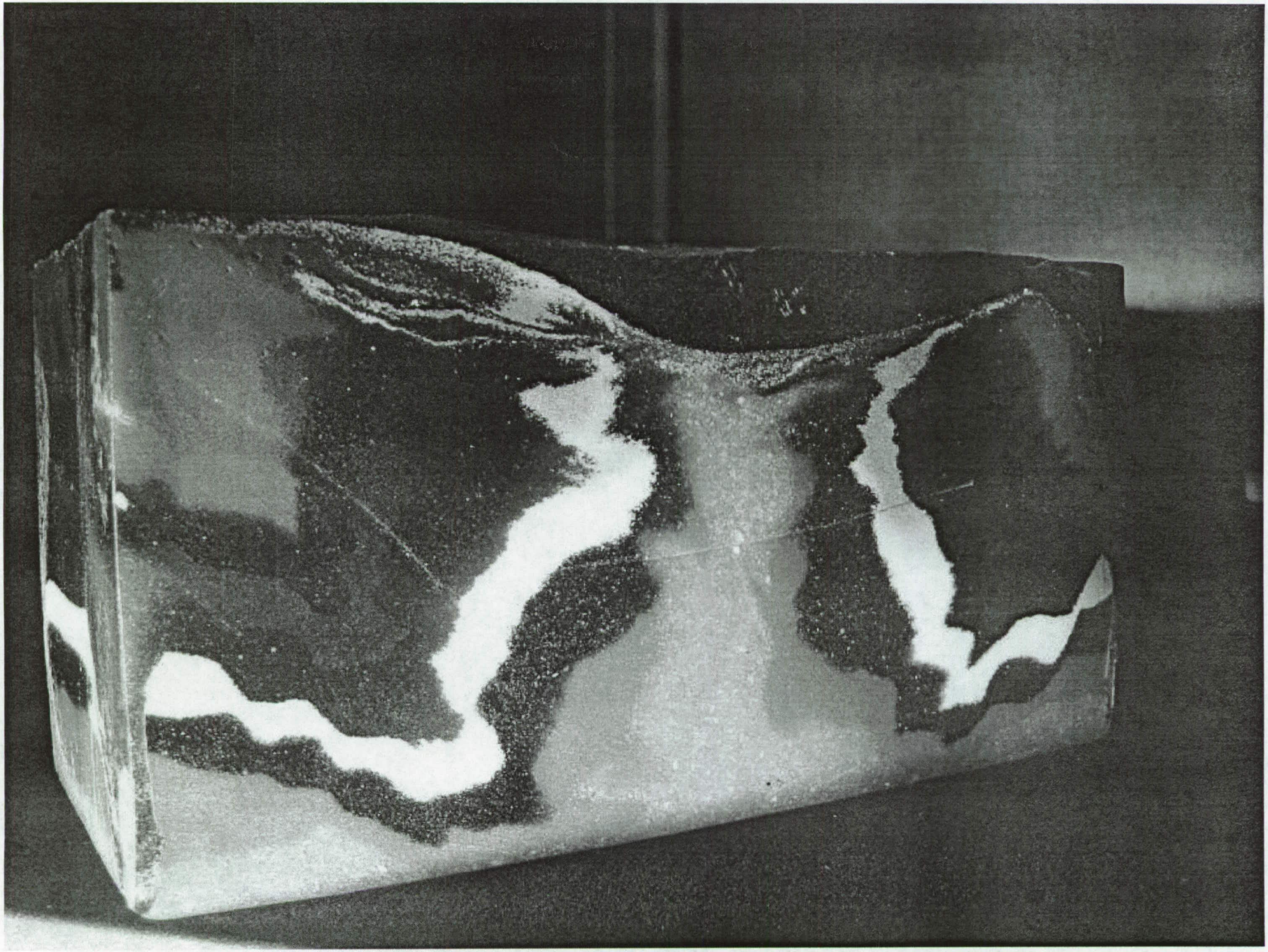
Lunar Case	Martian Case



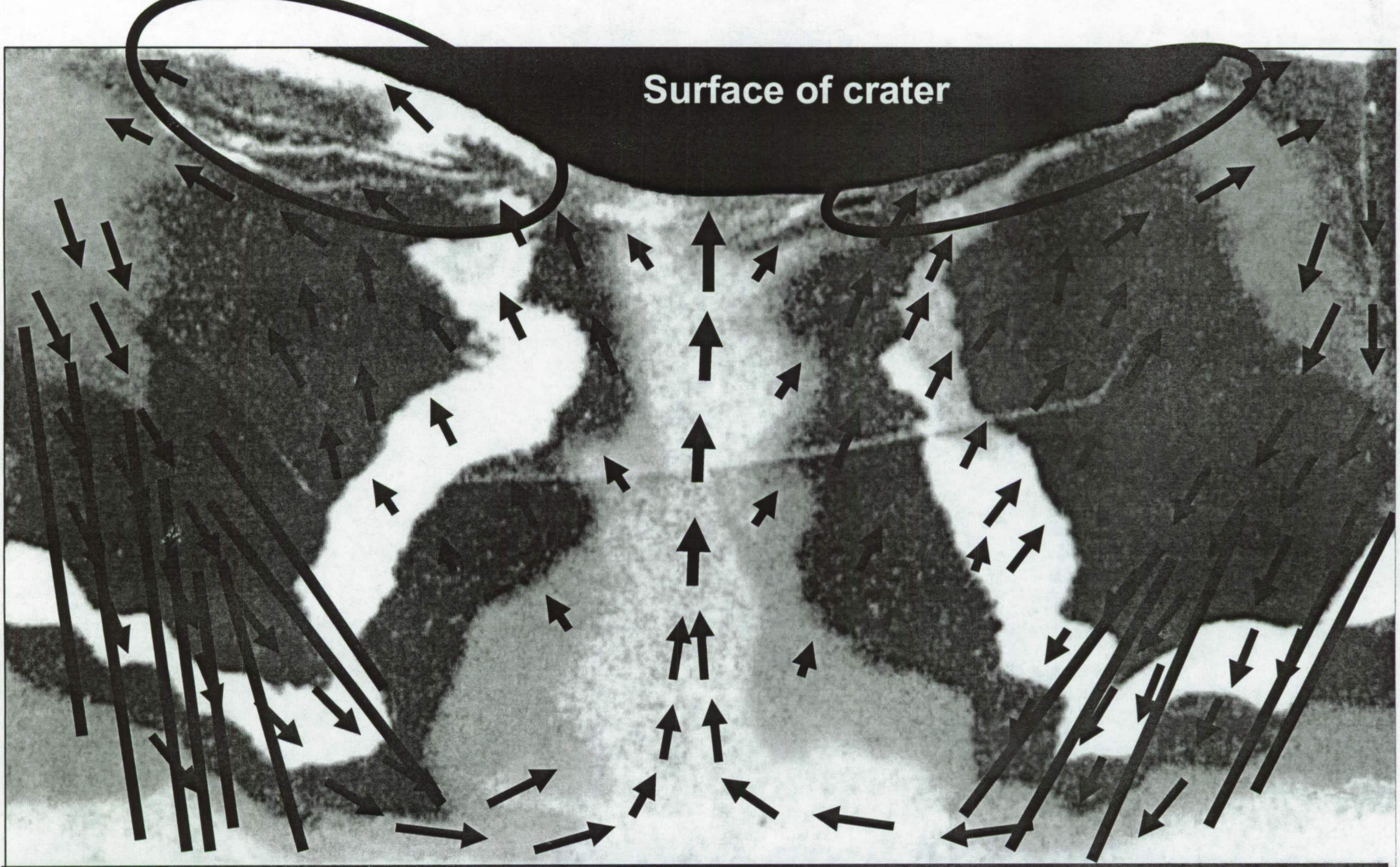
$$\frac{P_{stag}}{\tau} \longrightarrow$$



Test Setup at KSC



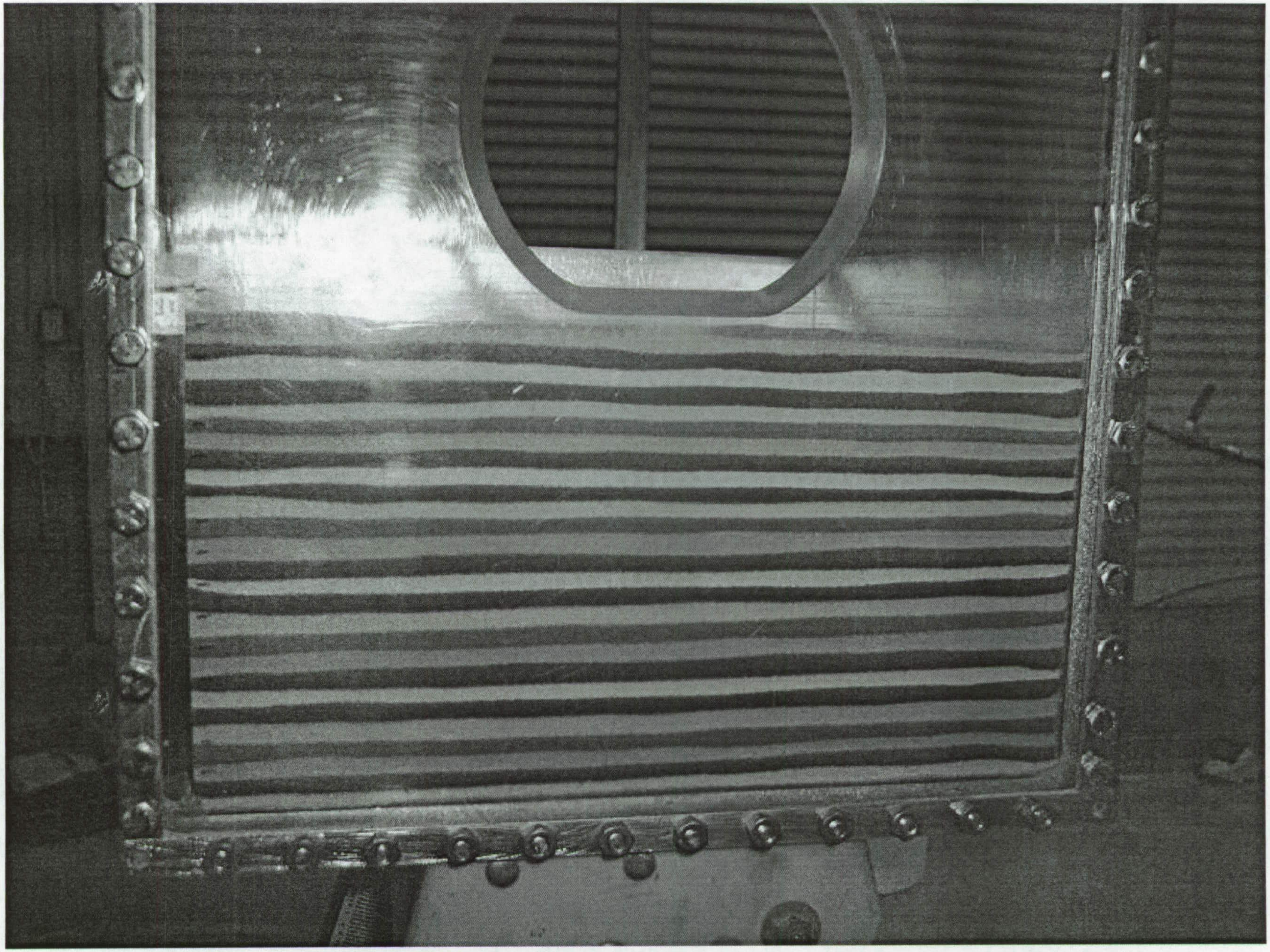
Test result - epoxied sand block



Deepest sand layer brought up through center of crater

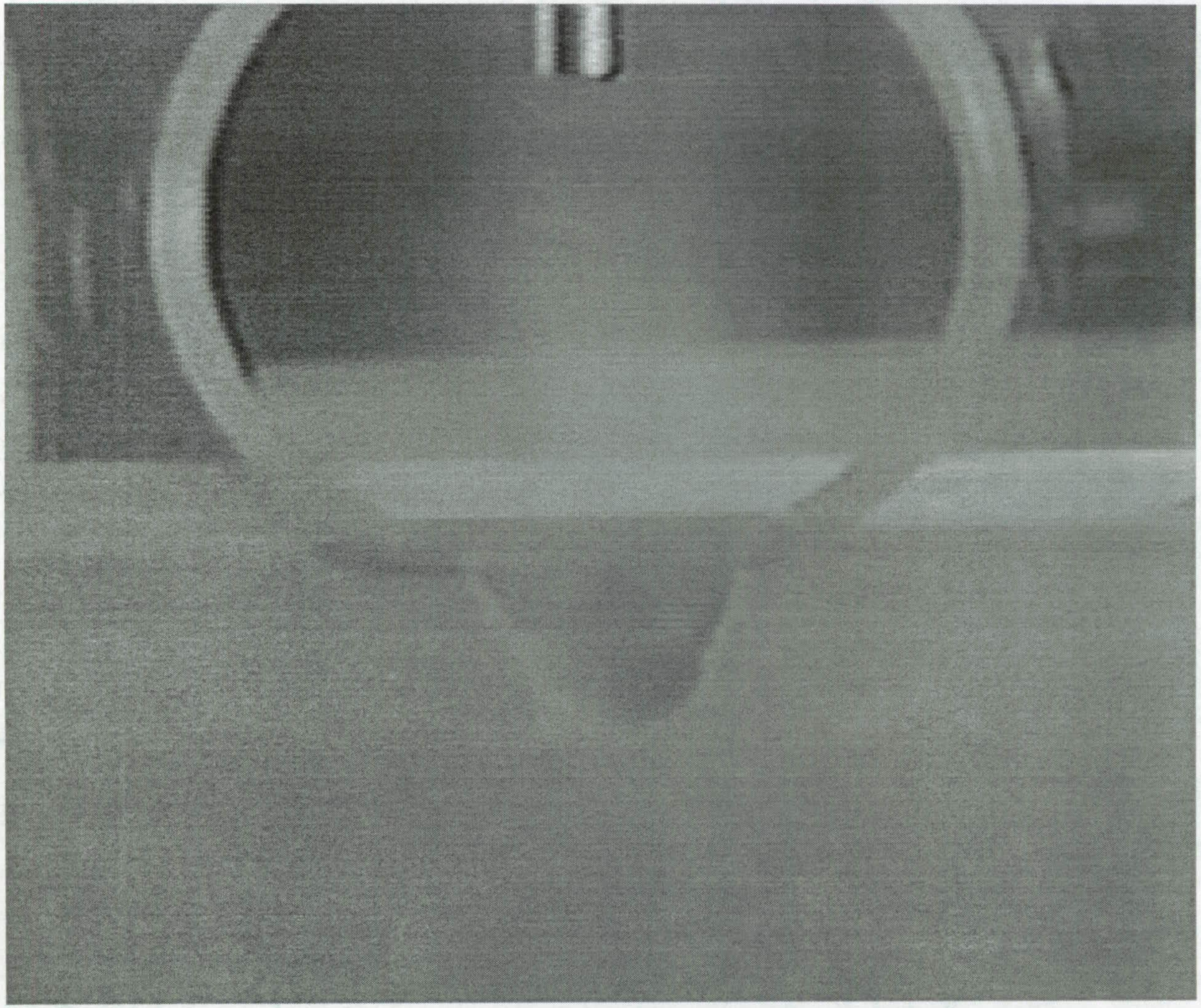
How do we explain this

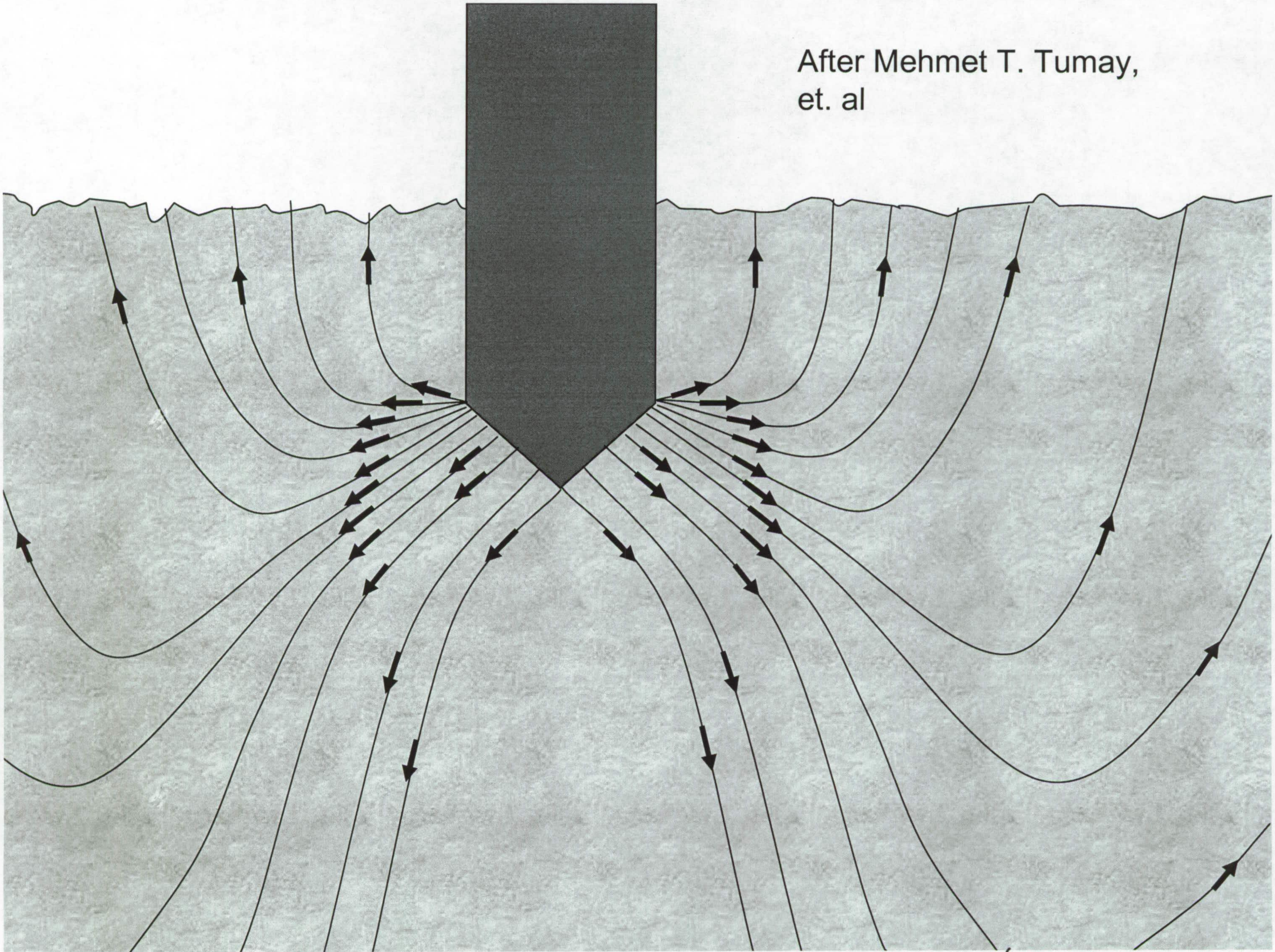
Movie of deep cratering



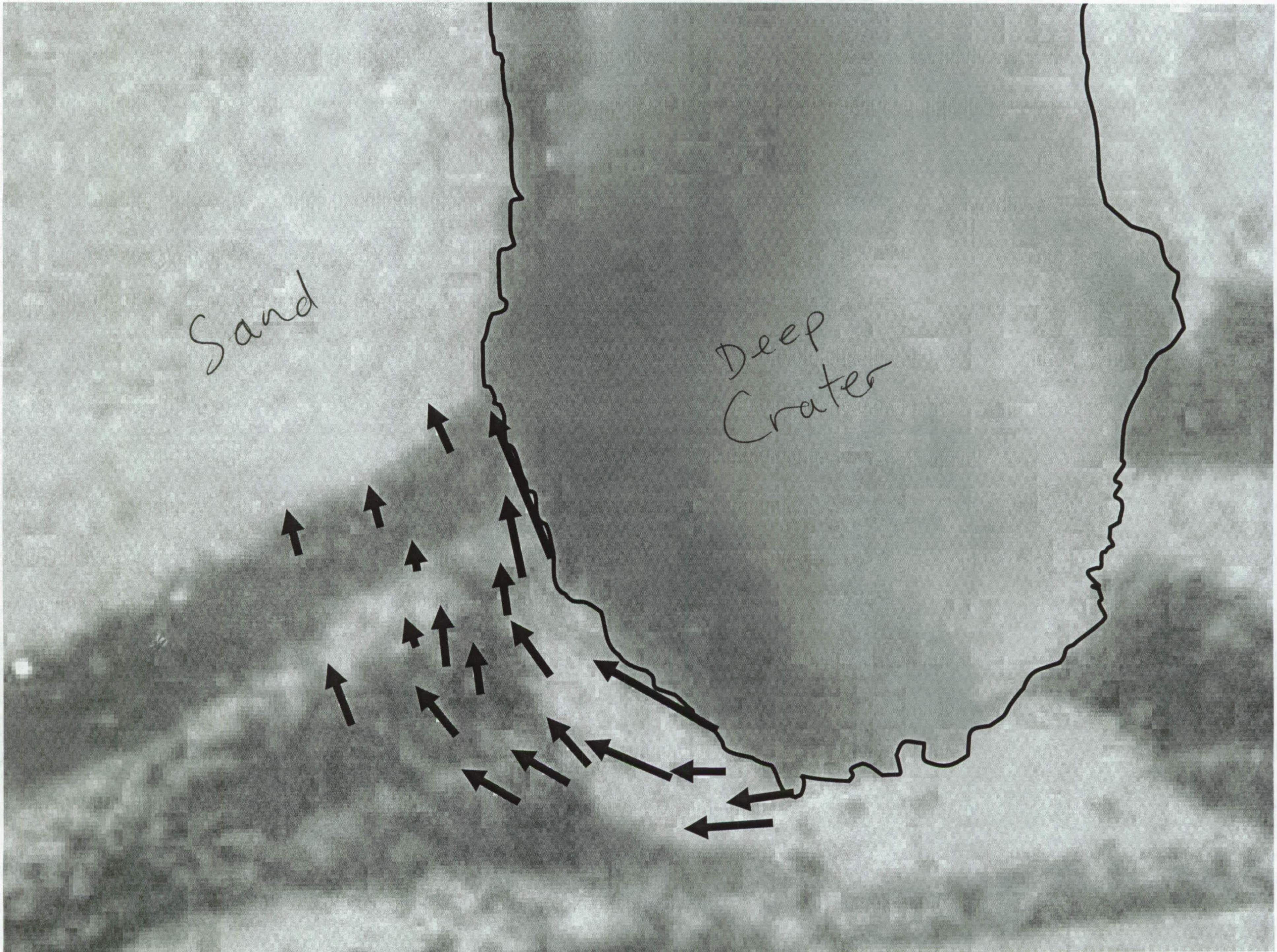
Movie showing how previous page occurs

Movie of “slower” deep cratering

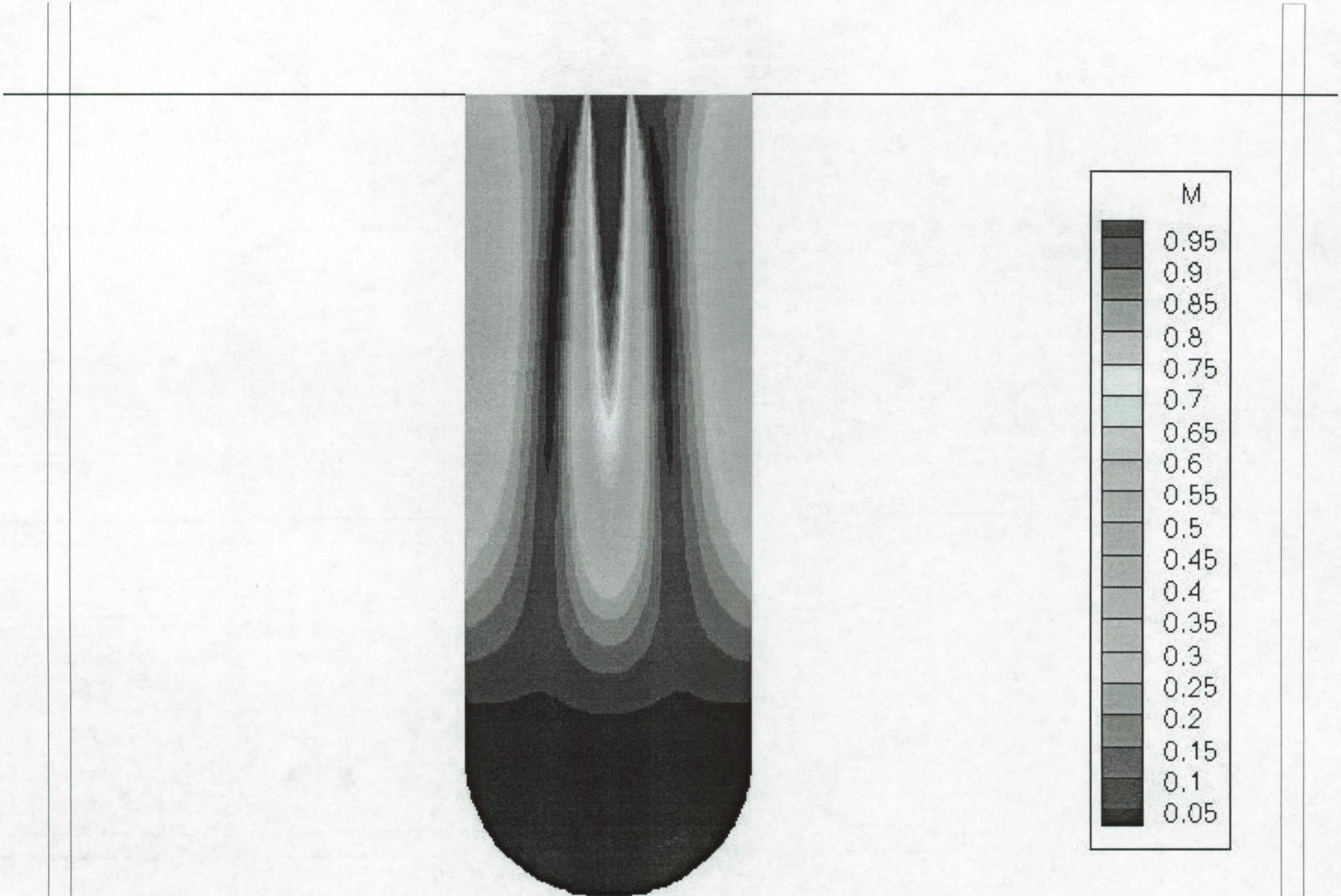




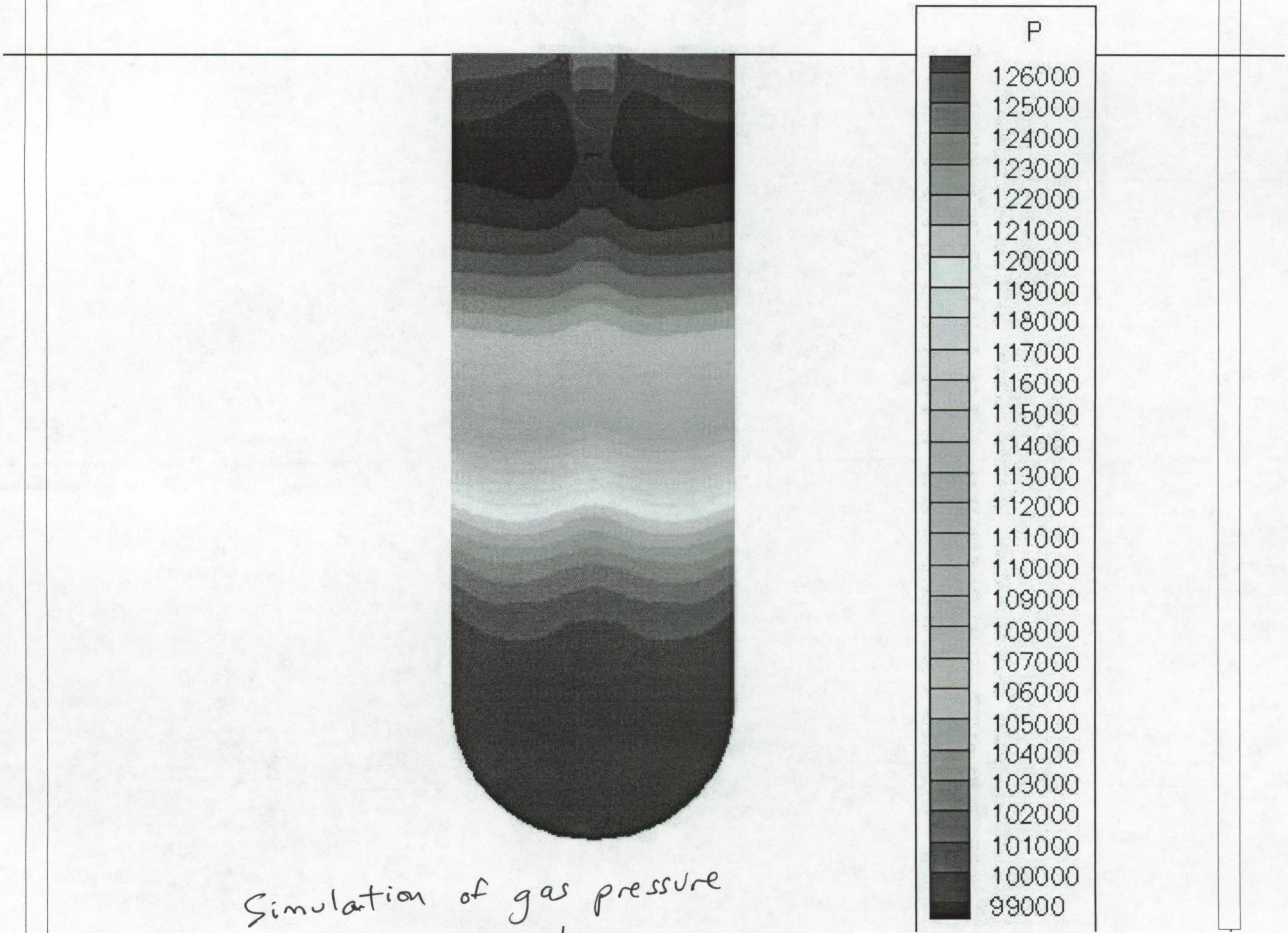
But we expected this to happen! (It did not)



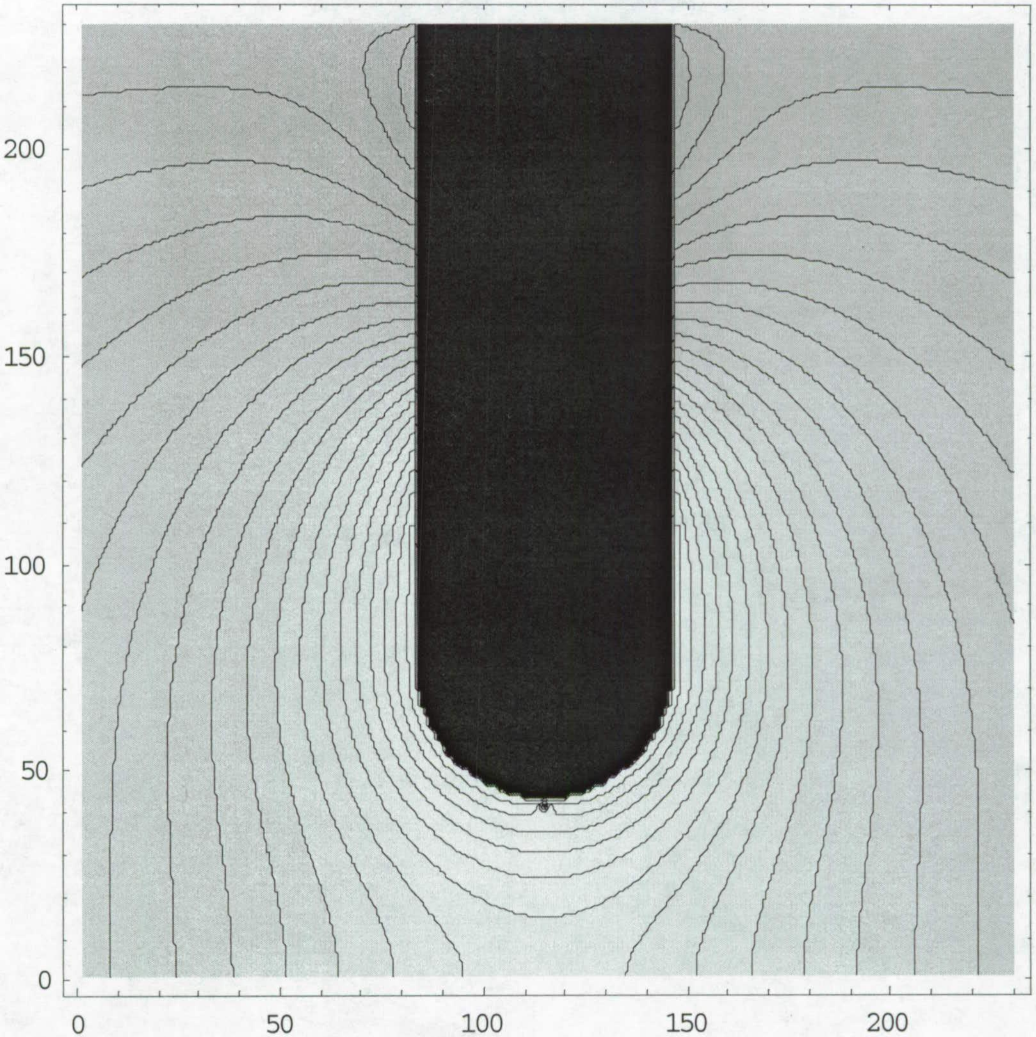
The flow is tangential to the crater! Why?



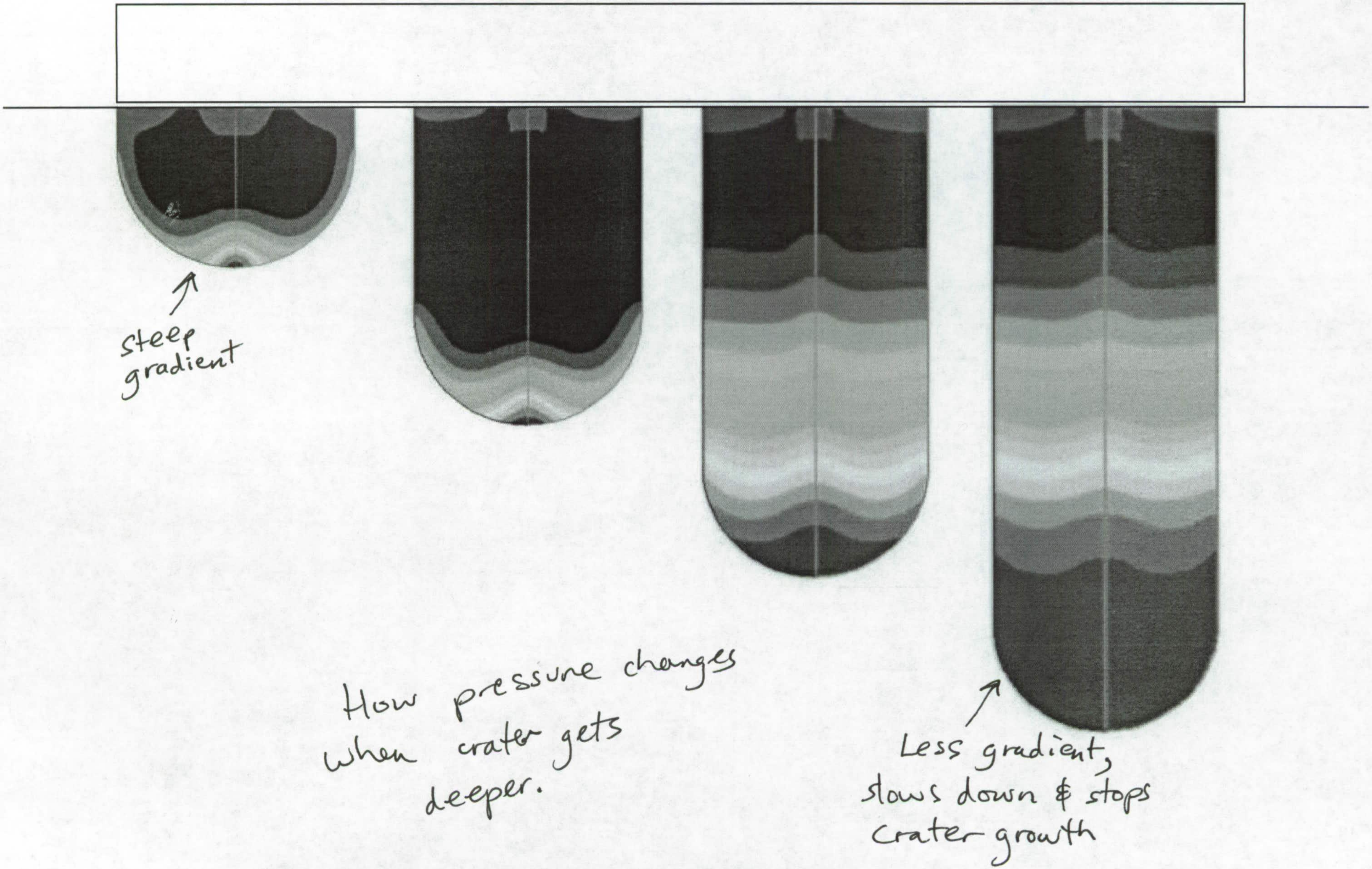
Simulation of flow velocity



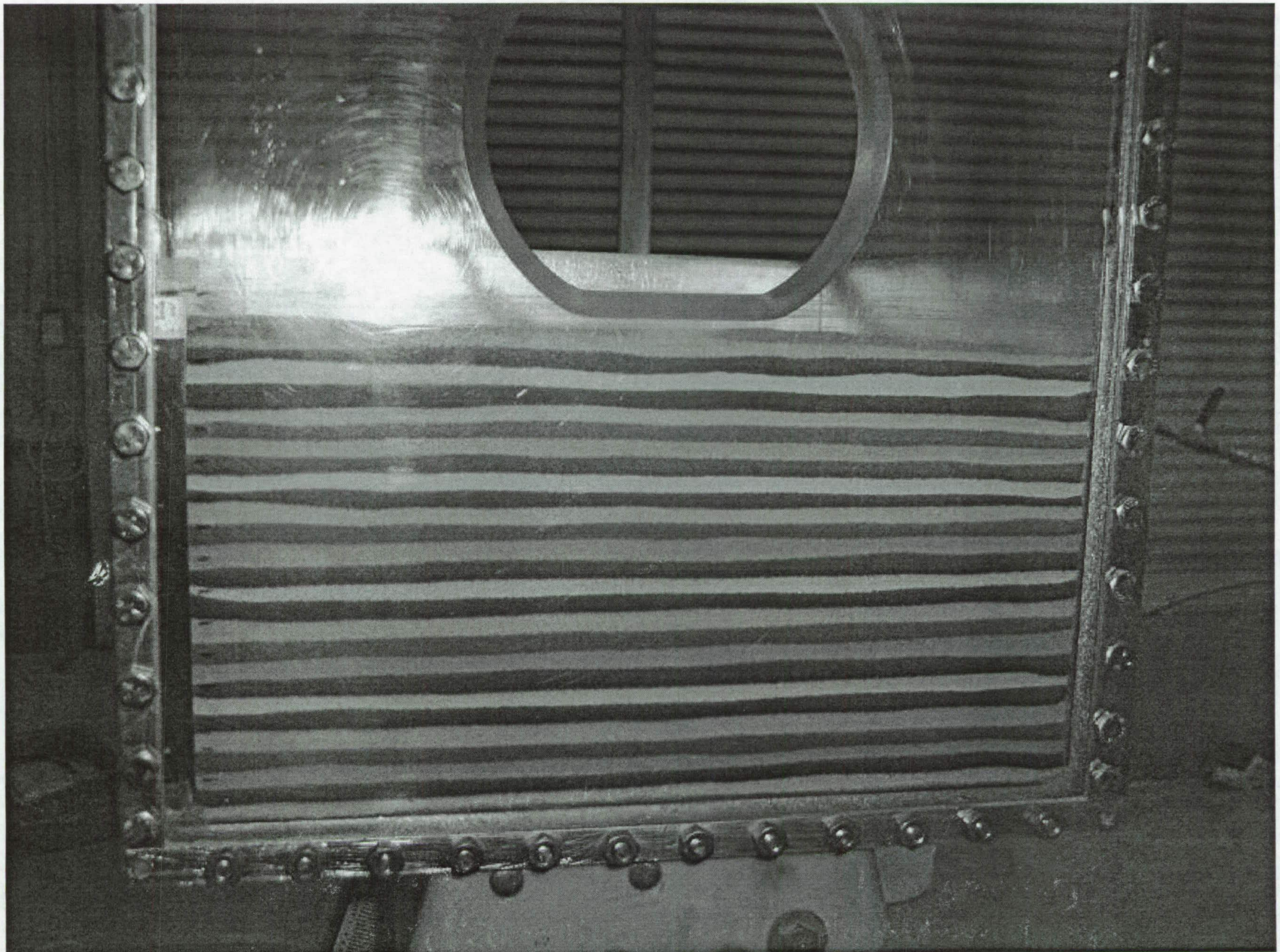
Simulation of gas pressure in crater



Simulation of gas pressure
between the sand grains

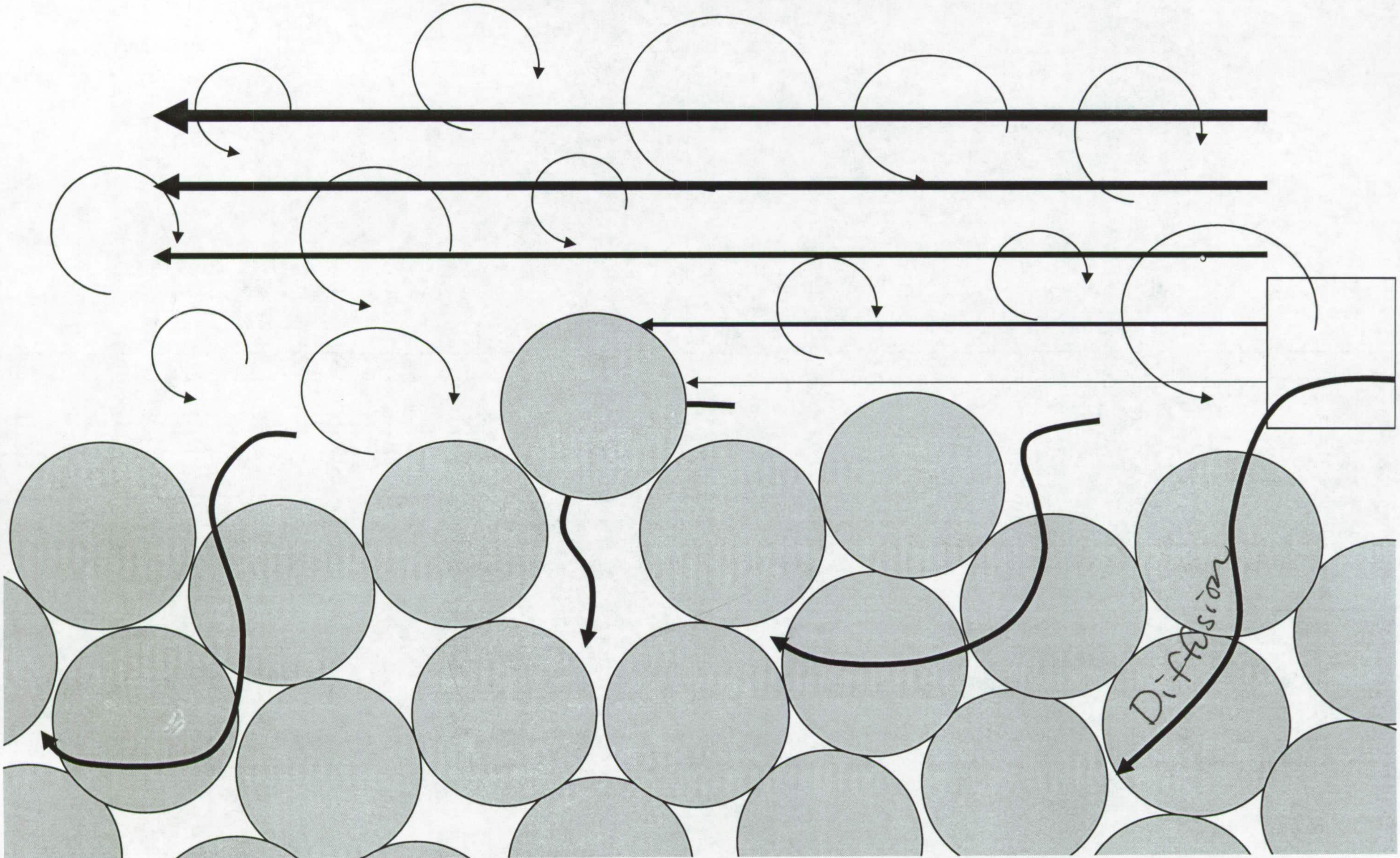

steep gradient
How pressure changes when crater gets deeper.
Less gradient, slows down & stops crater growth

Movie of self-limiting cratering



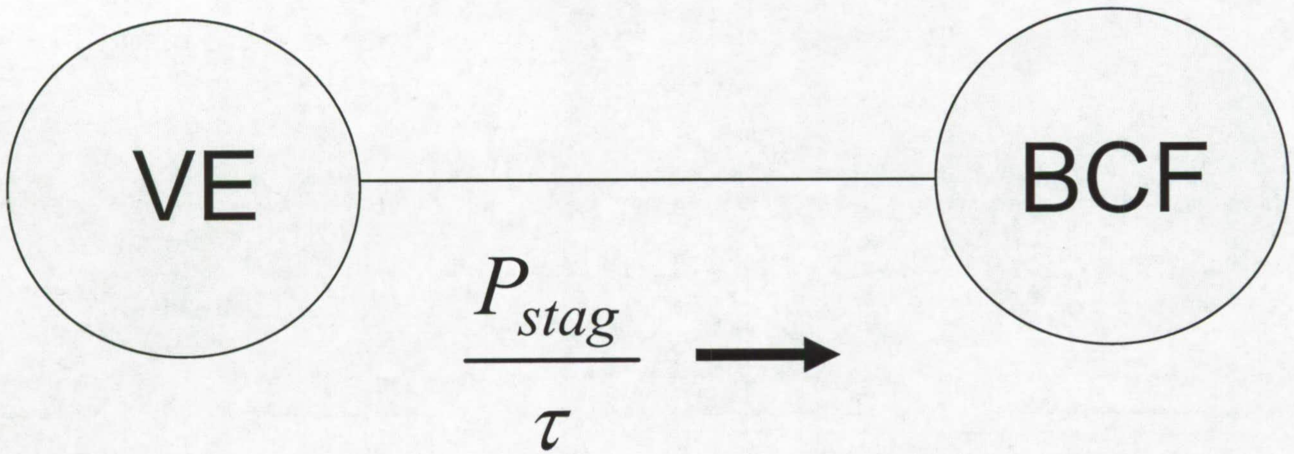
watch how crater self-limits its depth

Viscous Erosion



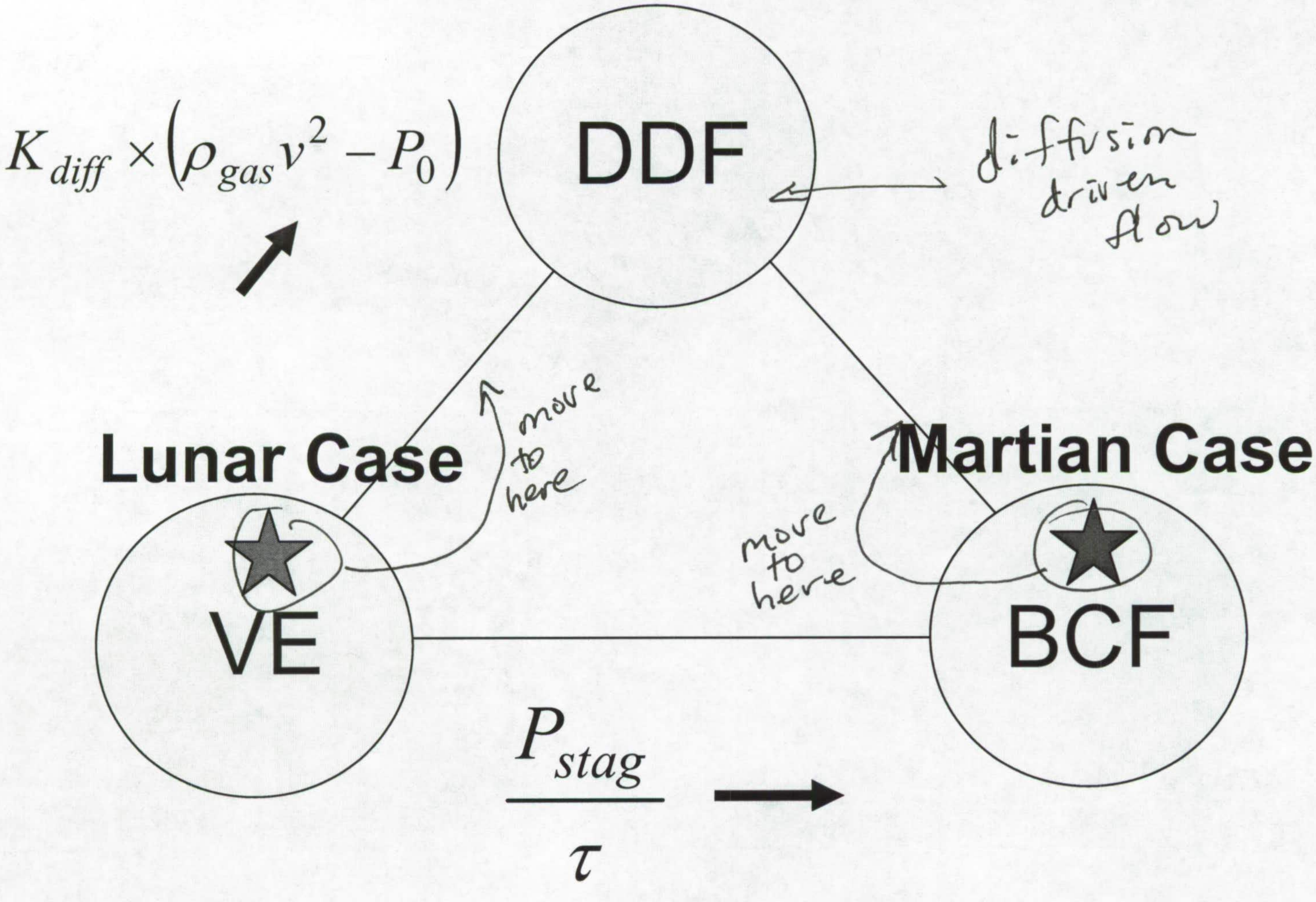
Now we can add a new erosion mechanism, Diffusion-Driven Flow

Paradigm ca. Apollo Program

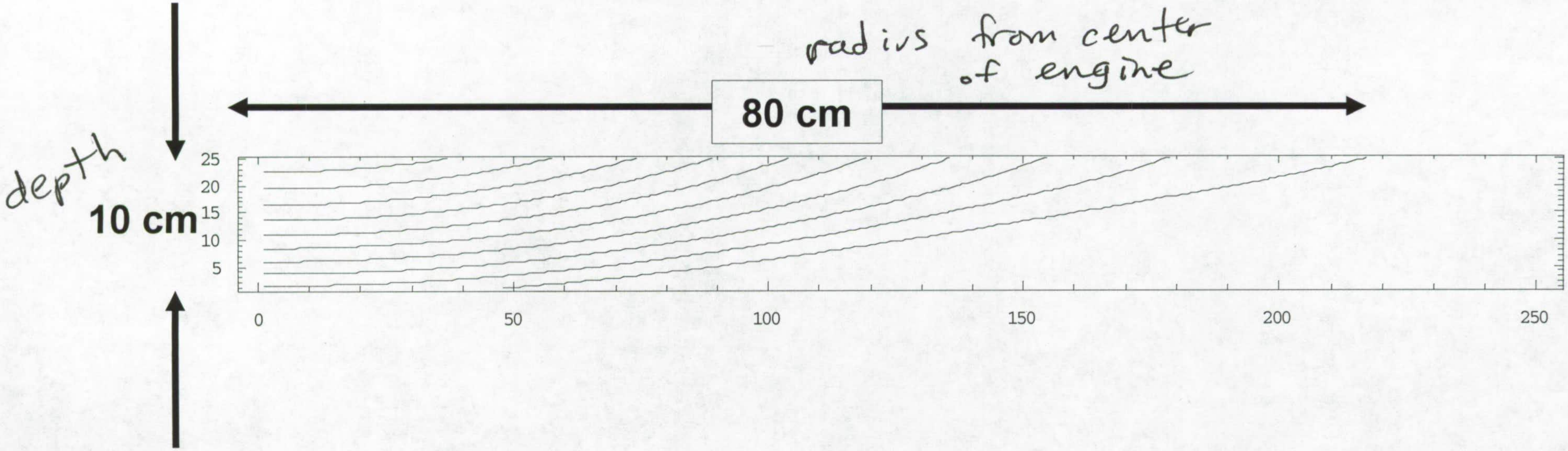


<u>Old</u> Paradigm

New Paradigm



New paradigm



Simulation of diffusion into soil beneath a lunar lander engine, using typical parameters but not for any specific spacecraft.