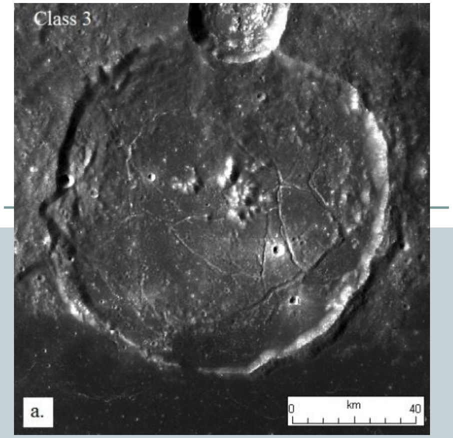
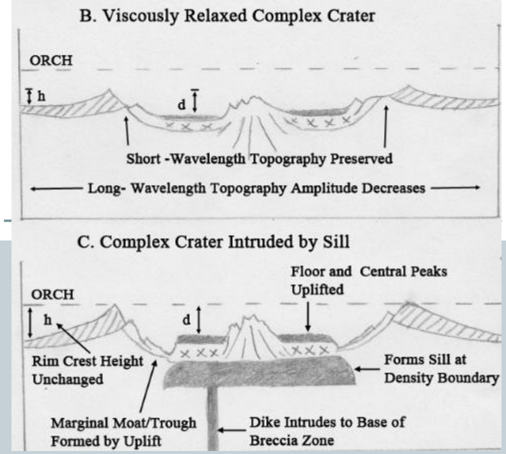
Lunar Floor-Fractured Craters: Sill Emplacement Models





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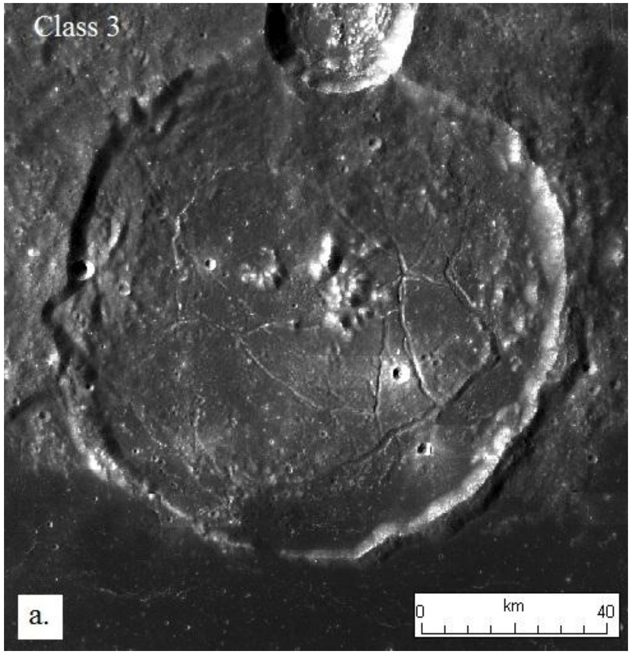
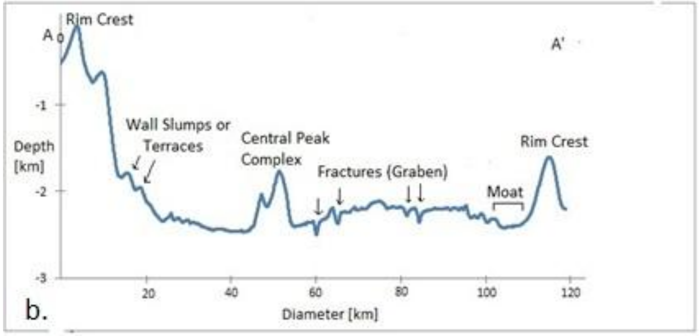
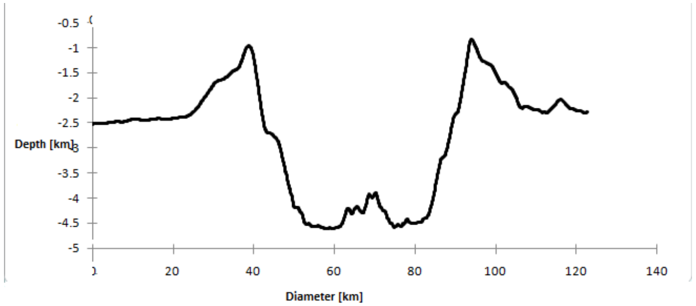
NLSI Lunar Science Forum
NASA Ames
July 18, 2012



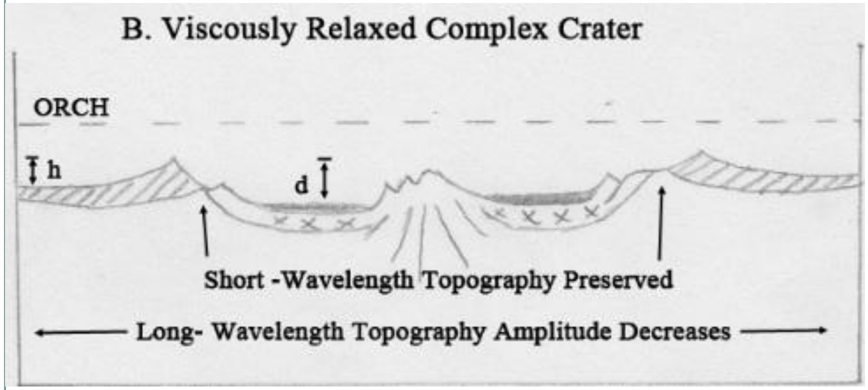


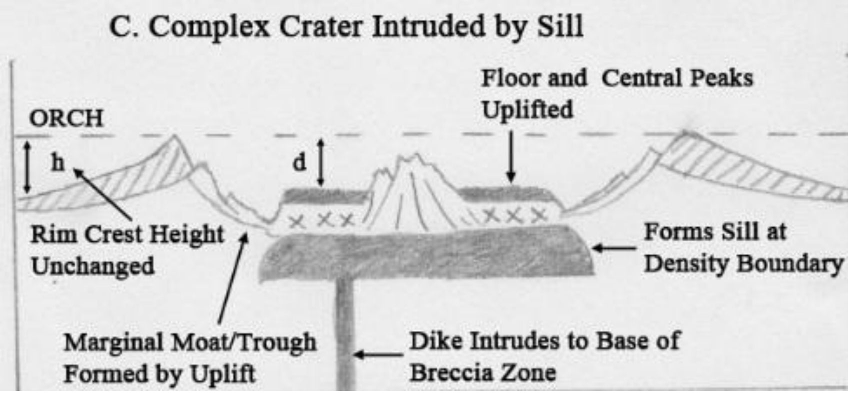
Floor-Fractured Crater



Fresh Crater

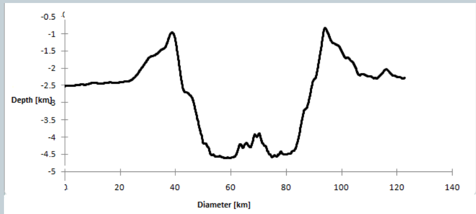
Modes of Emplacement

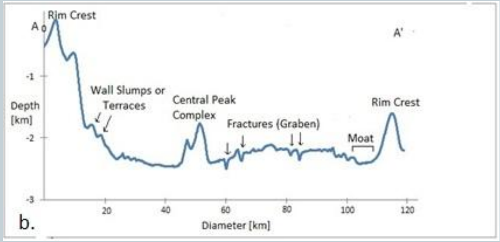

B. Viscously Relaxed Complex Crater


C. Complex Crater Intruded by Sill

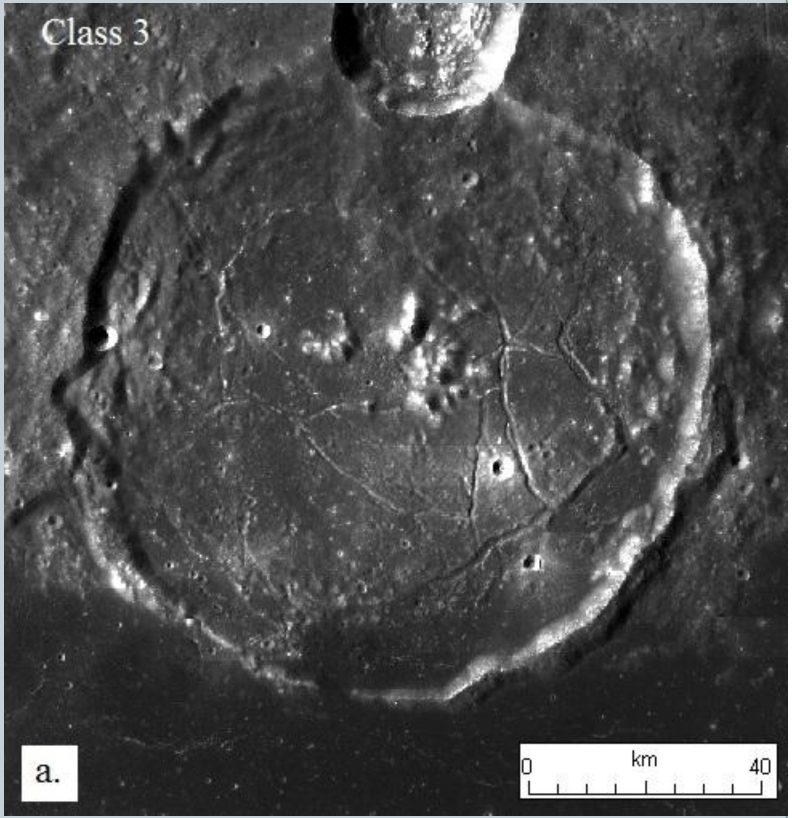
Floor-Fractured Craters (FFCs)

- Anomalously shallow craters with fractured floors [Schultz, 1976].
- Other Characteristics
  - Floor moats
  - Ridges
  - Mare patches
  - Dark halos



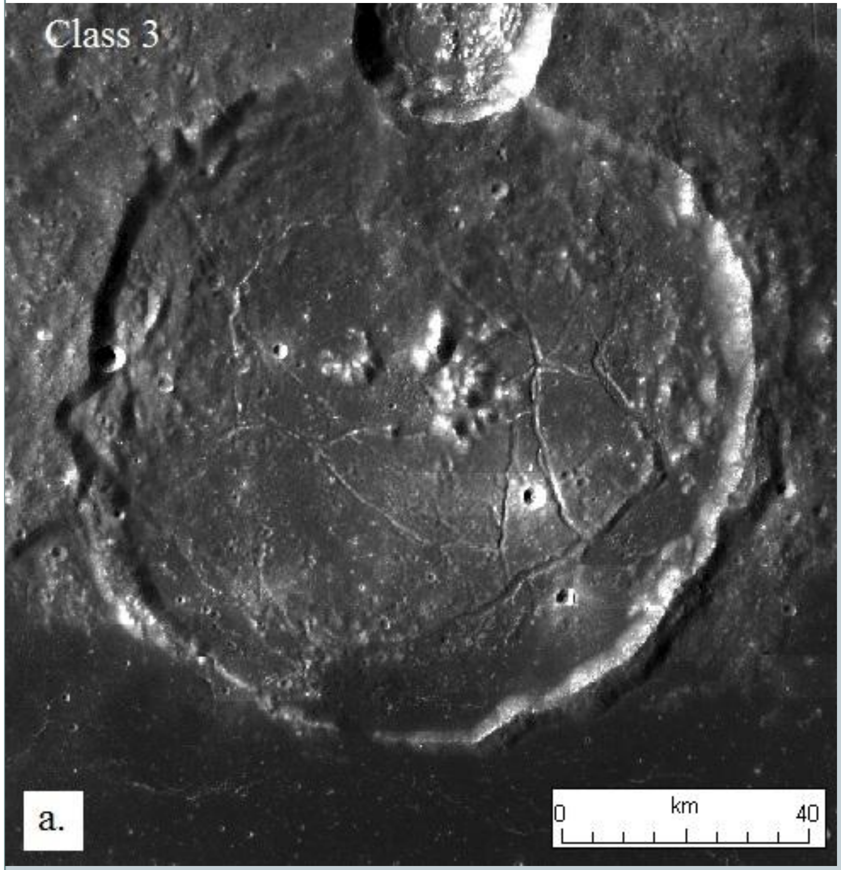


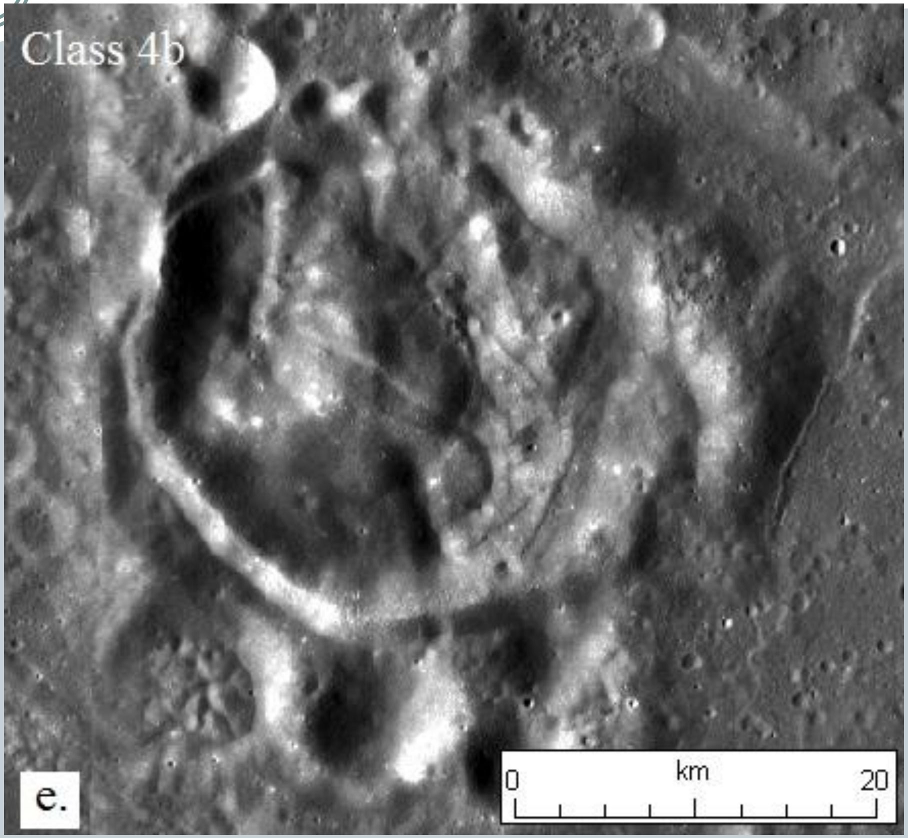
- Characteristics define the morphologic classes.



Crater Gassendi, LROC-WAC

Examples of FFC Classes

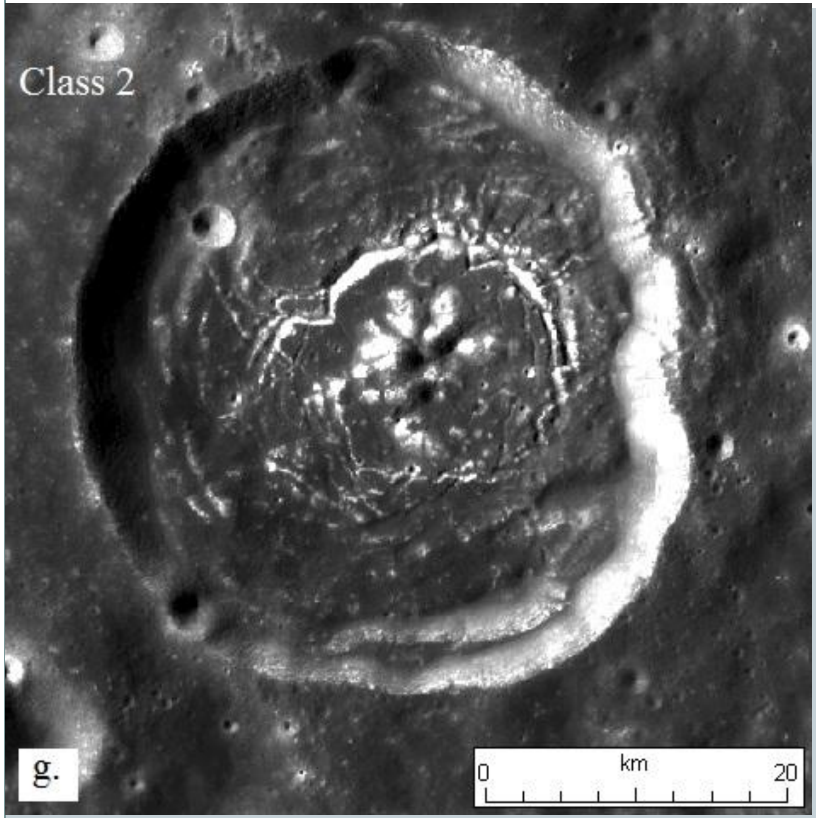


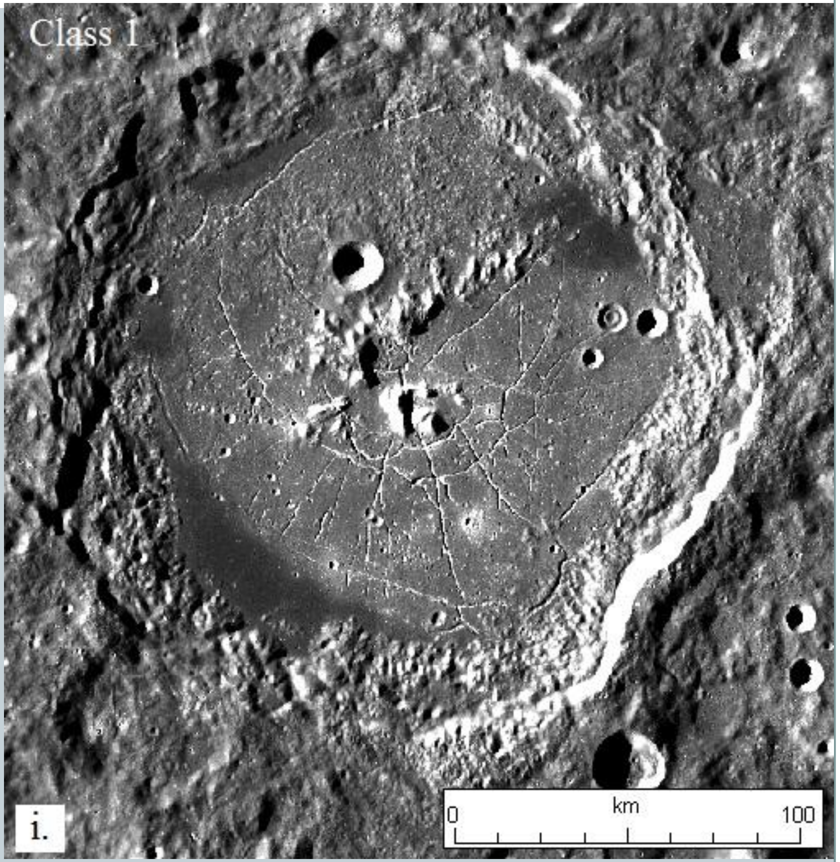


Crater Gassendi
Class 3, Wide Moat

Crater Gaudibert
Class 4b, High Ridge V Profile

Examples of FFC Classes



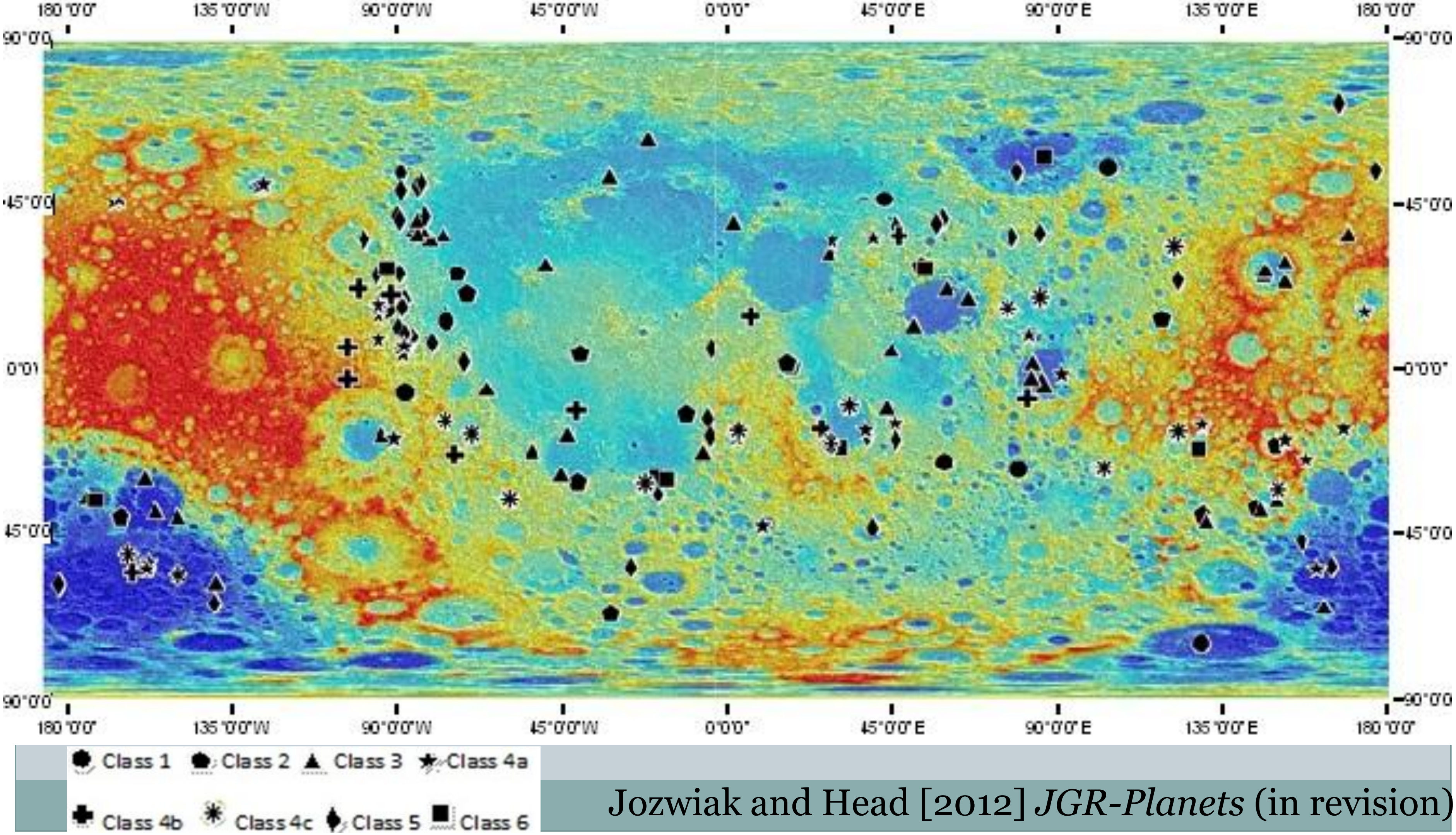


Crater Vitello
Class 2, Concentric Central Uplift

Crater Humboldt
Class 1, Mare Patches

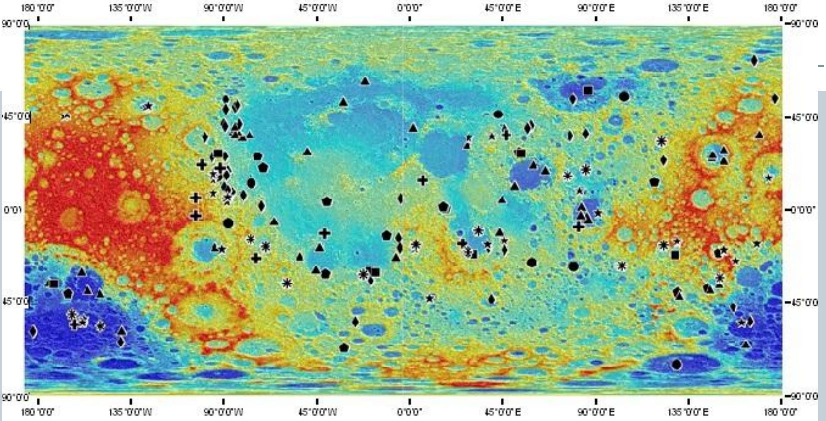
Distribution of Lunar FFCs

N=183



Jozwiak and Head [2012] *JGR-Planets* (in revision)

Distribution



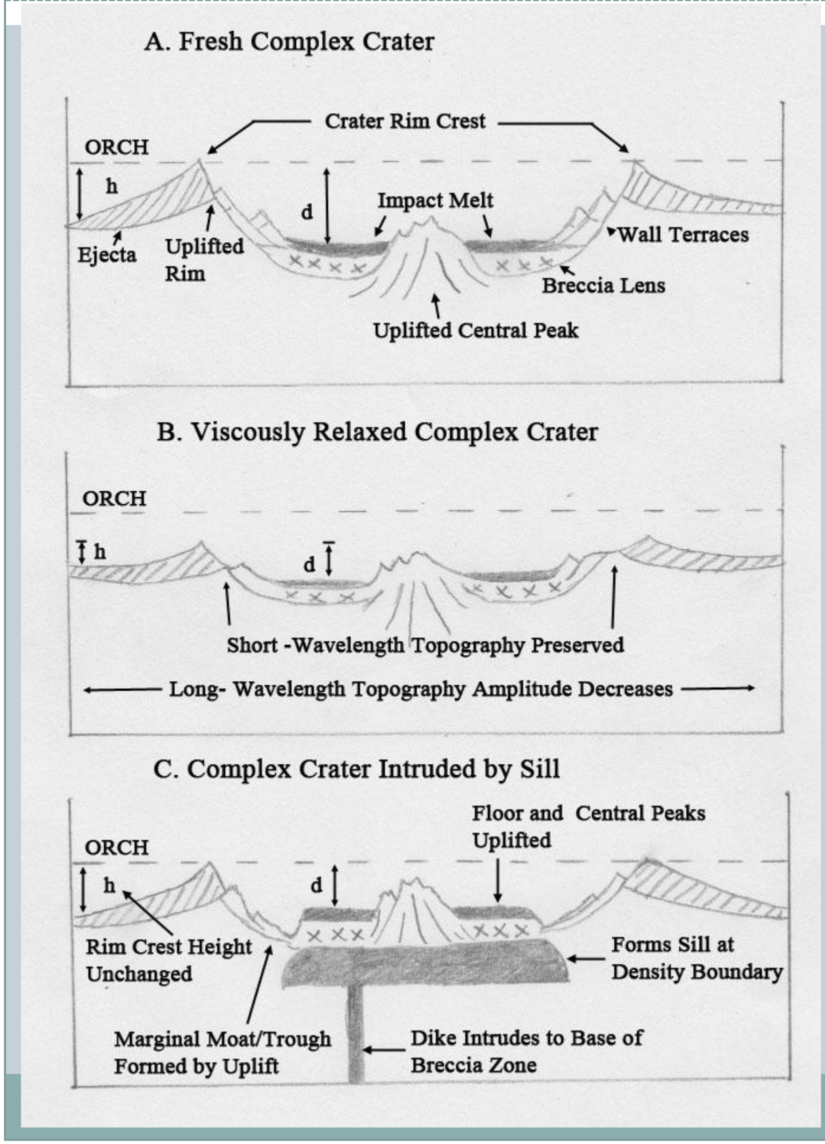
- Using LOLA and LROC data, classified all FFCs and plotted the areal distribution.

[Jozwiak and Head, 2012, In Revision]

- Observed relationship between FFC class and its areal distribution.
  - Craters close to basin edges typically have flatter floors, more uplift, and more fractures.
  - Craters farther in the highlands have more convex up floors, less overall uplift.
  - Could be due to 1) thermal effects close to impact basins

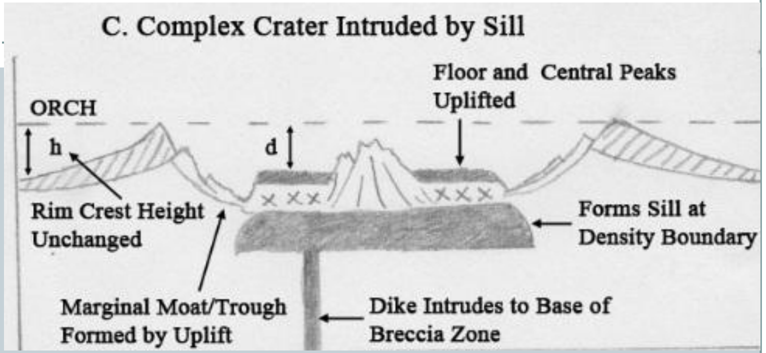
    2) intrusion effects close to maria and source of magma

Testing Proposed Formation Mechanisms



- Two proposed formation mechanisms.
- LOLA and LROC have allowed thorough investigation.
- Magmatic Intrusion most probable formation mechanism, supported by:
  - •Significant decrease in floor depth
  - •Unchanged Rim Crest Height
  - •Lack of crater symmetry
  - •Moat features
  - •Location far from basin edges
  - •Significant population of small craters

Testing the Mechanics of Magmatic Intrusion



1)Dike propagates from the mantle,

driven by a certain pressure.

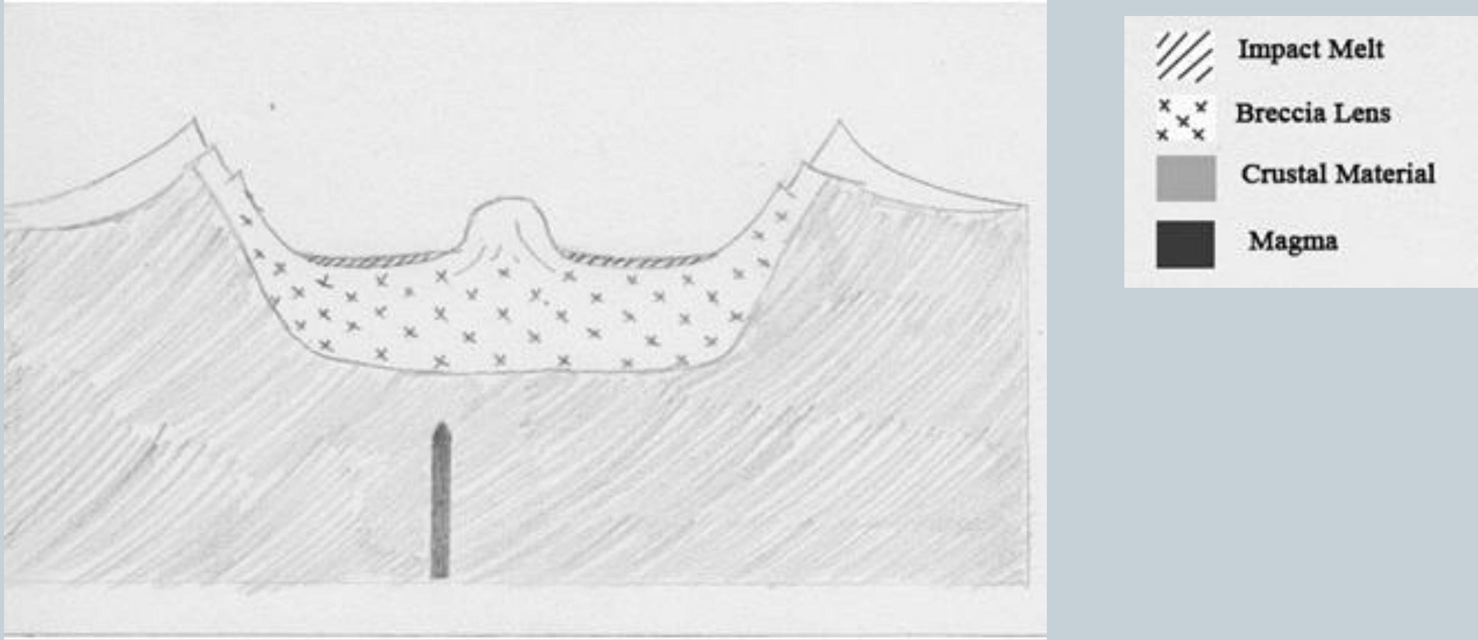
2) Dike stalls at a density barrier caused by the brecciated lens beneath the crater.

3) Dike propagates laterally, forming a sill beneath the brecciated lens.

4a) Sill inflates, forming a laccolith, and bowing the overlying crater floor.

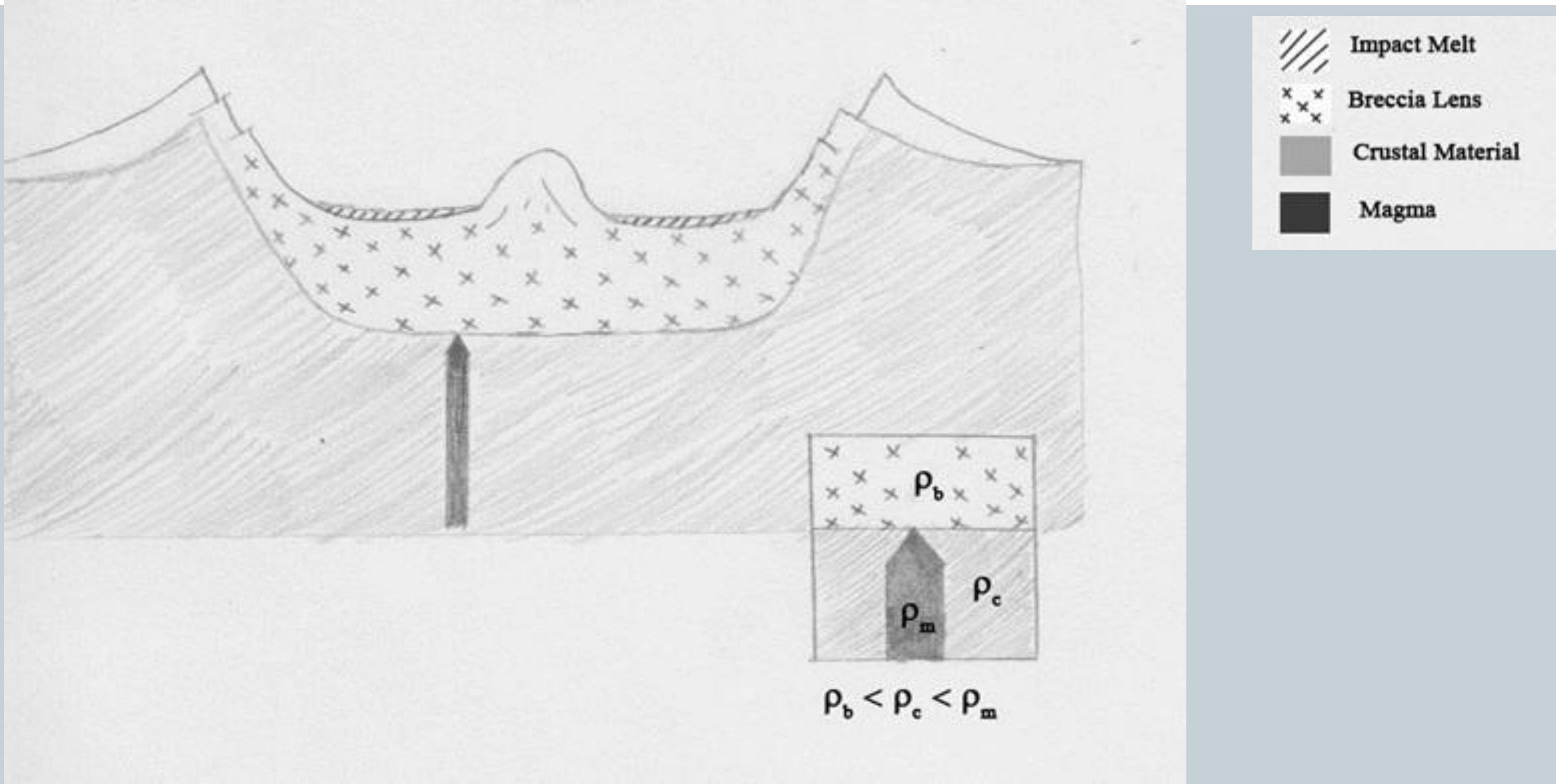
4b) If the yield stress is exceeded at the edges of the laccolith, faulting occurs and uplifts the entire crater floor.

Dike Propagation- Step 1



Dike propagates from the mantle with a driving pressure equal to the total magma pressure minus the lithospheric pressure.

Breccia Lens Boundary-Step 2



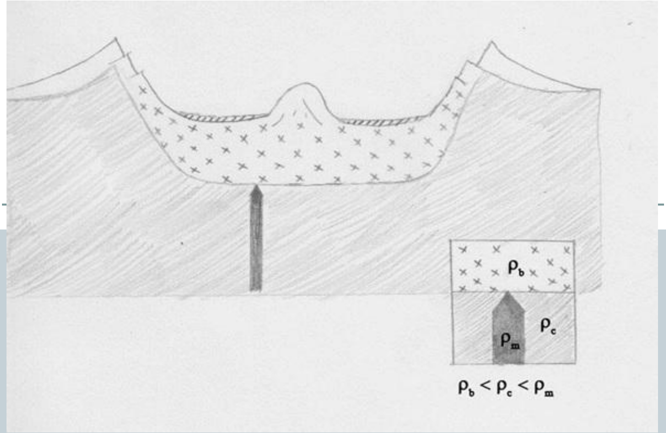
$\rho_m = 3300$ kg/m3

$\rho_b = 2750$ kg/m3

$\rho_c = 2900$ kg/m3

[Huang and Wieczorek, 2011]

Breccia Lens

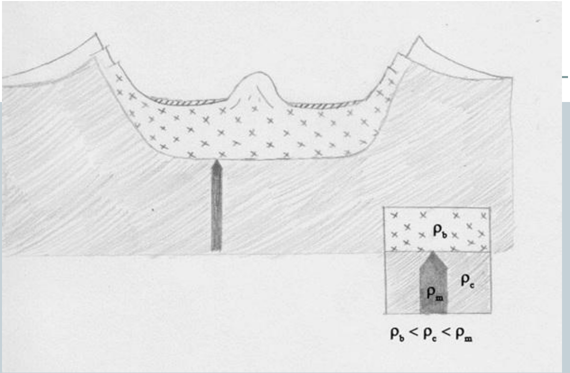


$$K^{+a} = P_d\, a^{1/2} + [(\pi^{-1} + 0.25)*g*(\Delta\rho)]a^{3/2}$$

- For a given height, *a*, above the dike origin, a driving pressure of *Pd* is required to fracture rock with the fracture toughness *K*.
- *Δρ* is the density difference between the intruding magma and the host rock.

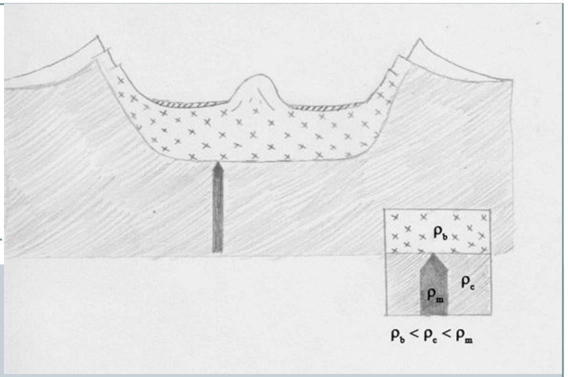
[Rubin and Pollard, 1987]

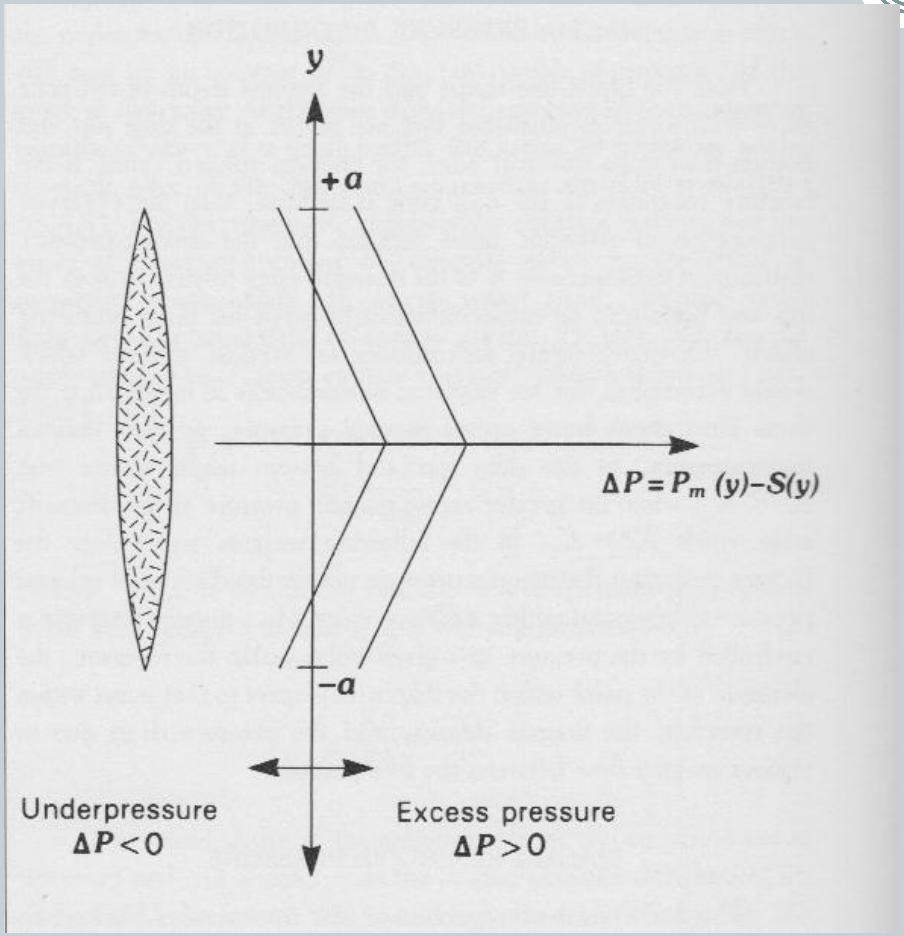
Breccia Lens and Driving Pressure



- Driving Pressure to Reach surface
  - 27 MPa through lunar crustal material
  - 32 MPa through breccia lens material
- Driving Pressure at Breccia Lens Barrier
  - 21 MPa for intrusion to continue into lunar crustal material
  - 29 MPa for intrusion to continue into breccia lens material
- Dike would require an additional 8MPa of driving pressure to continue propagating through the breccia lens.
  - This driving pressure would be high enough to reach the surface if the overlying crater and breccia lens structure were not present
- Therefore: Crater Floor Breccia Lens Density Barrier is a viable means of halting vertical propagation

Lateral Propagation

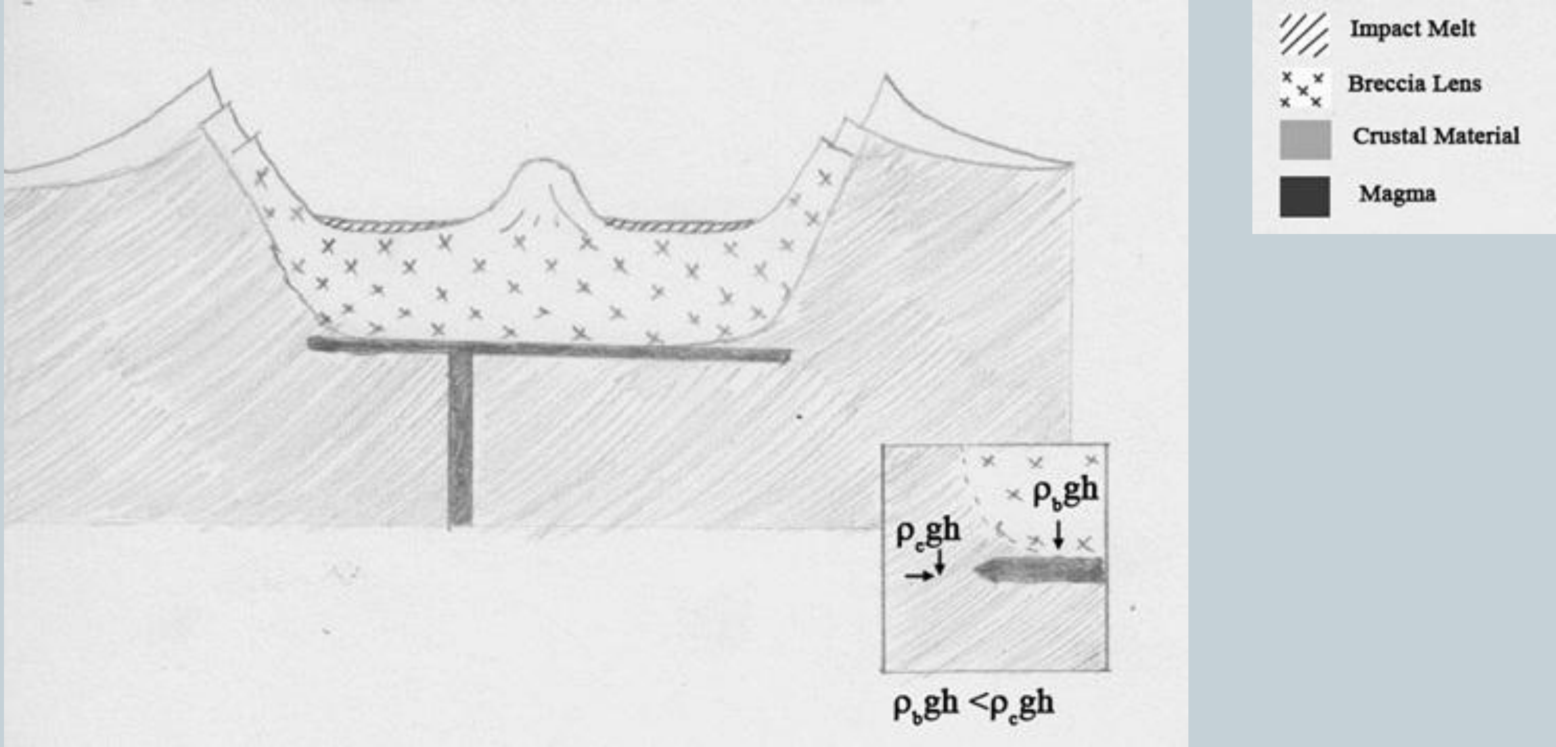




[Rubin and Pollard, 1987]

- Unable to continue vertical propagation, pressure builds below the dike tip.
- This pressure then exceeds the lithostatic pressure, and begins to fracture laterally.
- A lower stress intensity factor on the upper part of the propagating dike ensures that the dike propagates along the base of the breccia lens.

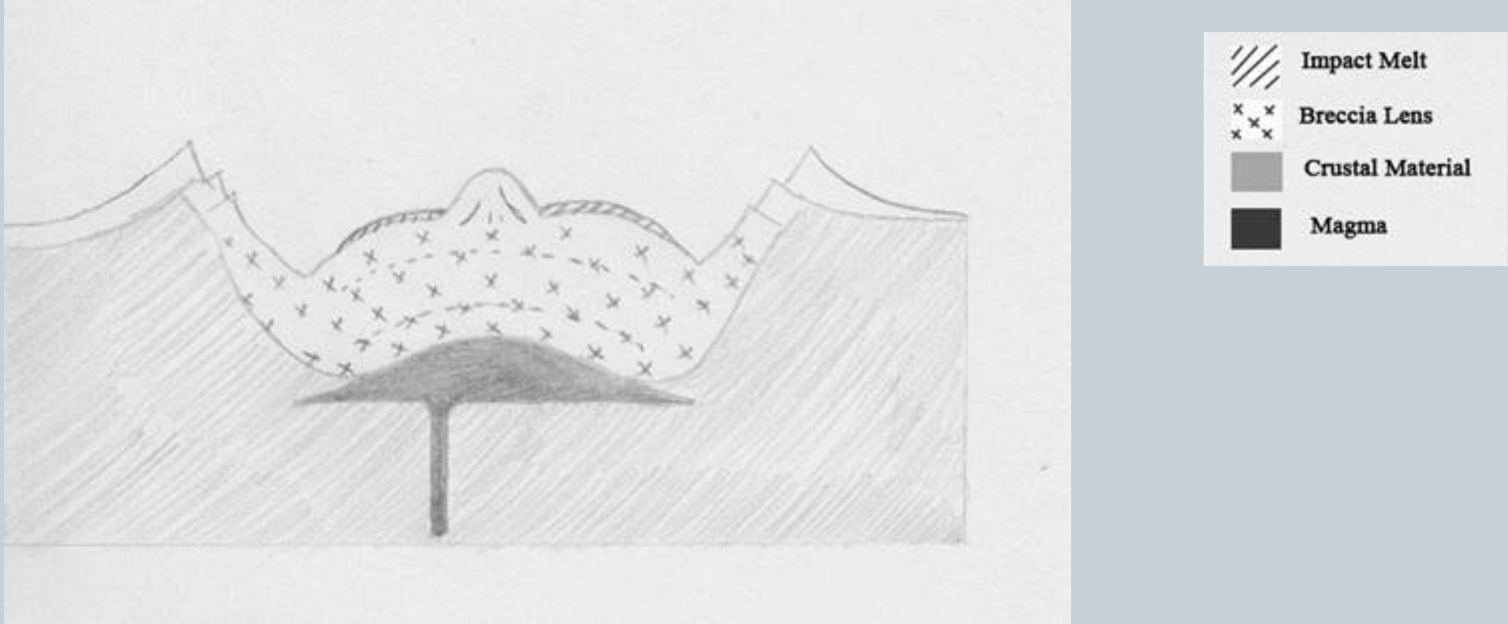
Sill Formation- Step 3



- The sill propagates until it reaches the end of the breccia lens.

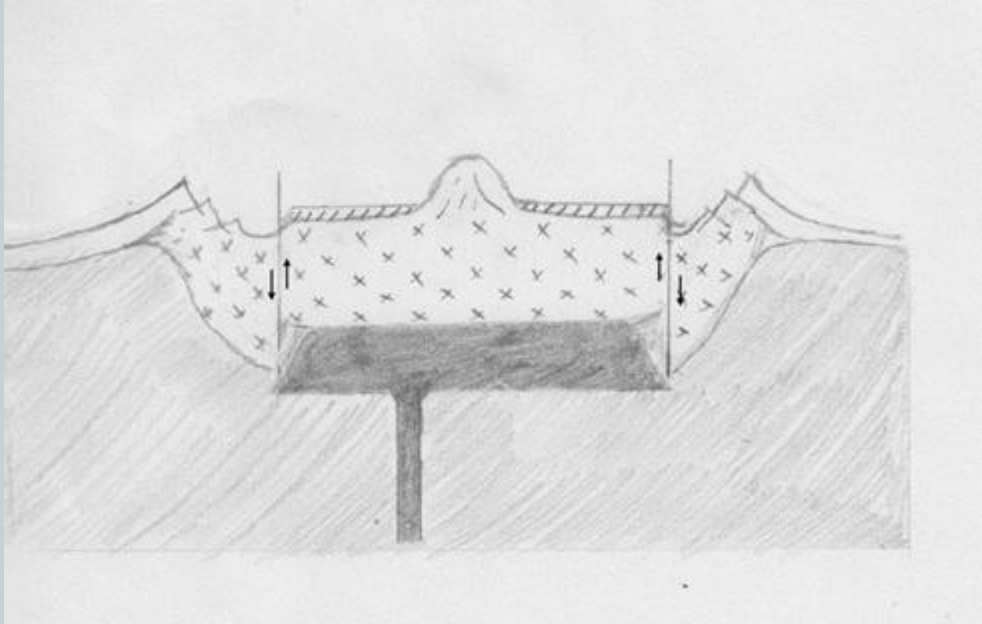
- Past the breccia lens, the overburden pressure increases, and the dike encounters a uniform stress state, halting propagation.

Sill Inflation (Laccolith)- Step 4a



- Magma continues to fill the sill.
- Crystallization of magma at the periphery causes a concentration of magma in the center of the intrusion.
- Extreme flexure in the overlying crater floor, and a convex up floor profile.

Sill Inflation and Faulting-Step 4b



▨ Impact Melt
× Breccia Lens
🟫 Crustal Material
⬛ Magma

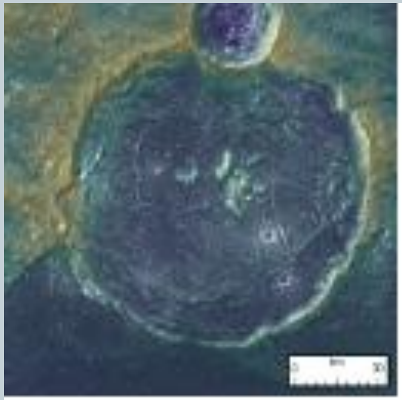
Rapid filling of the sill distributes magma throughout the intrusion volume.

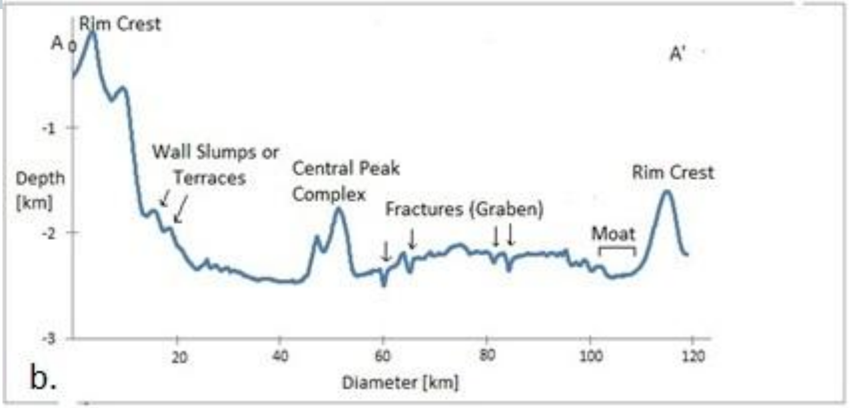
Increased edge stresses overcome the breccia yield stress, and faulting occurs at the periphery.

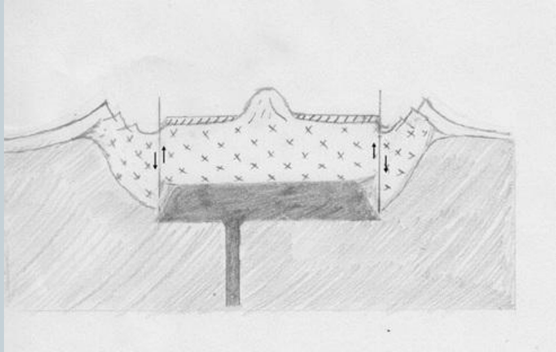
- Piston-like uplift of the floor replaces flexure with brittle faulting and yields a flatter profile.
- Therefore: Both the Flexural Doming and Piston Uplift are clear consequences of sill intrusion

Further Assessing Mode of Origin and Style

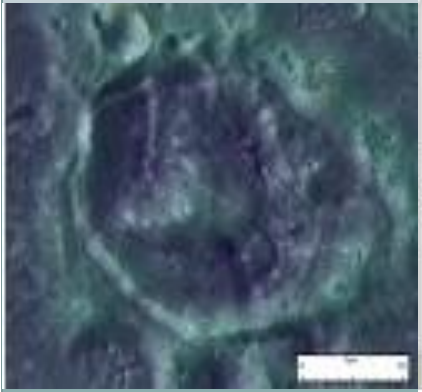
Faulting and Piston Uplift

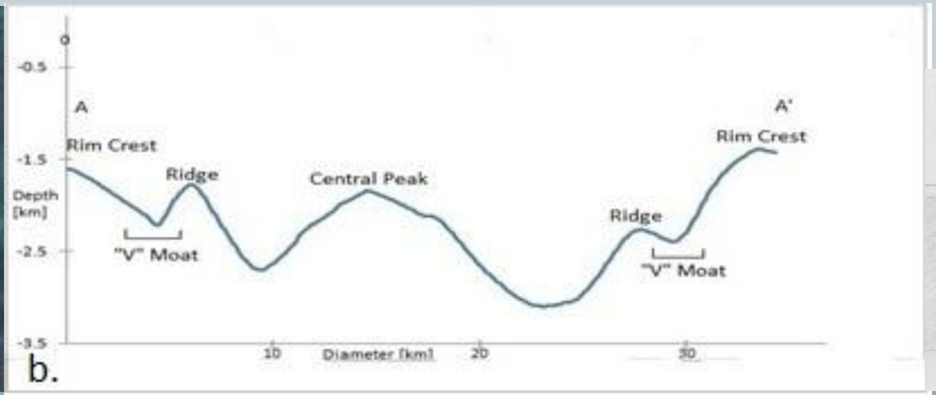


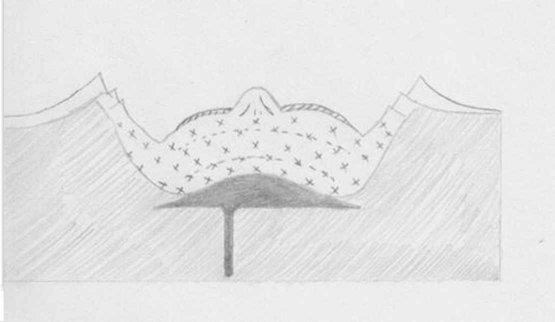




Flexure and Flexural Doming

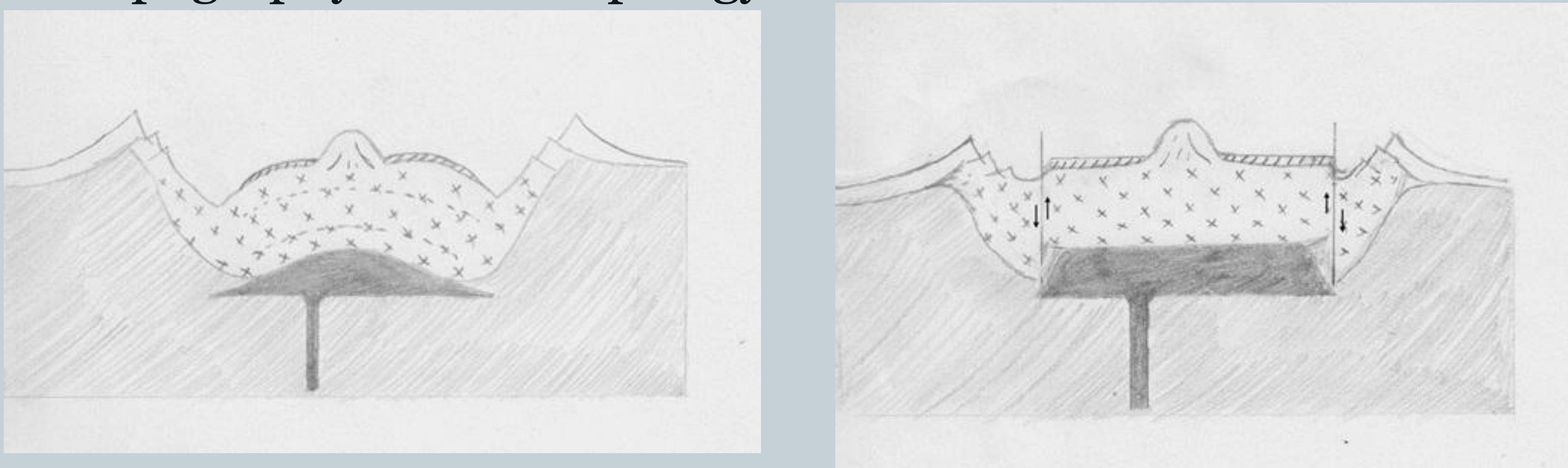


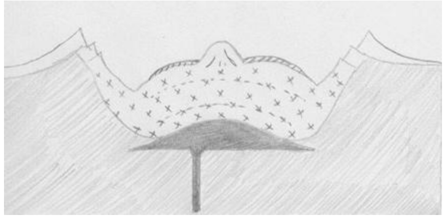




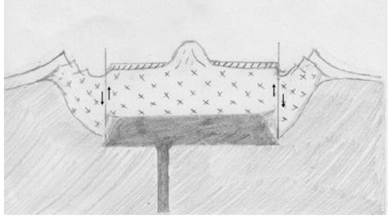
Distinguish by Shape of the Intrusion

- What do the tails of the intrusion look like?
  - Thin and tapered vs. blunt and snub nosed?
  - Are both present?
  - What determines their shape, and does this affect the crater topography and morhpology?





GRAIL Applications



- Plotting intrusion and crater dimensions to estimate intrusion mass, and associated gravity anomaly, providing predictions to be tested by GRAIL.
- GRAIL can also determine intrusion shape—is the anomaly under a small portion of the crater floor, or the entire floor region? Is this linked to the overlying crater morphology?
- Crater Size Dependence and Intrusion Morphology: look at range of anomaly sizes and shapes with comparison to crater sizes.