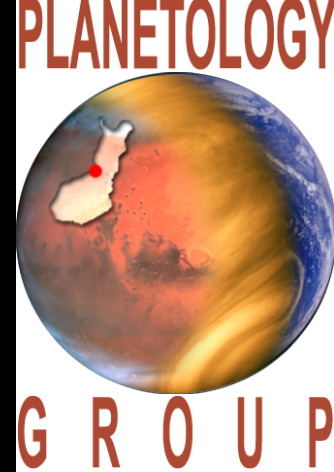




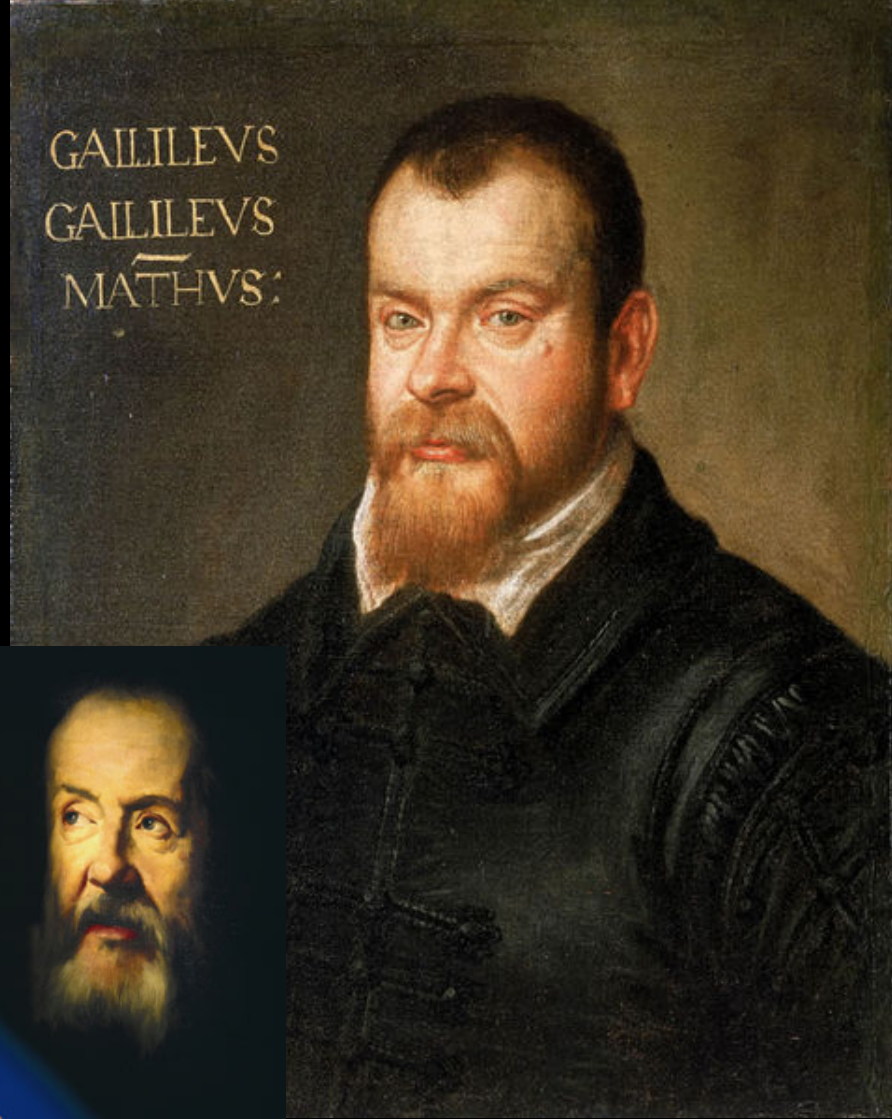
NIR Workshop, Gardnos – Gol, June 9<sup>th</sup> 2009



# Four Hundred Years of Hits and Misses in Scientific Impact Crater Research

Teemu Öhman

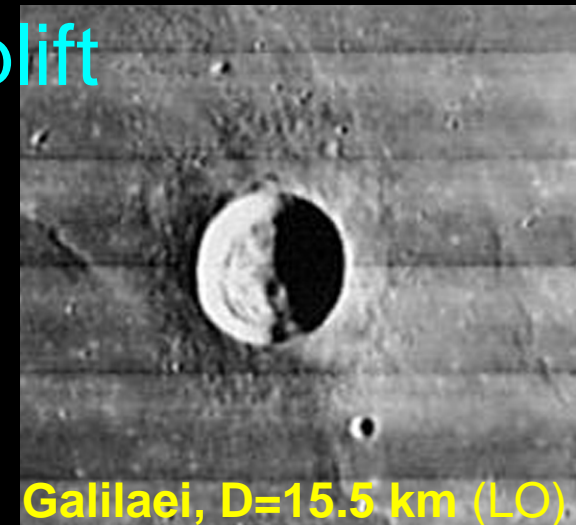
Division of Geology, Department of Geosciences and  
Division of Astronomy, Department of Physical Sciences  
University of Oulu  
Finland



**Galileo Galilei**

# Galileo Galilei (1564–1642)

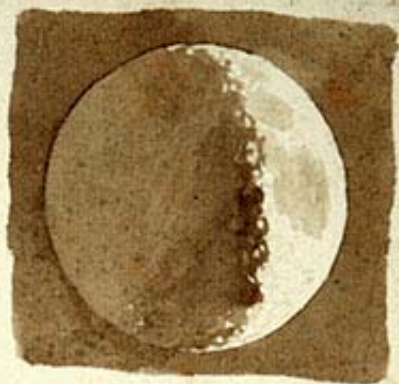
- First observer of lunar craters, late November 1609, Padua, Italy
- Surface previously supposed smooth can be divided to dark lowlands (“large spots”) and bright highlands, which are covered with pits that have uplifted rims
- A clear description of a central uplift



Galilaei, D=15.5 km (LO)



2,8



1

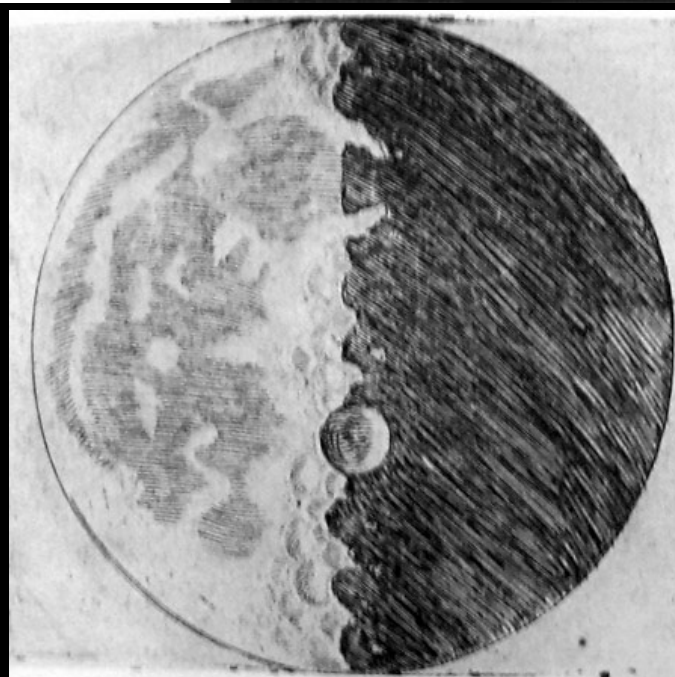
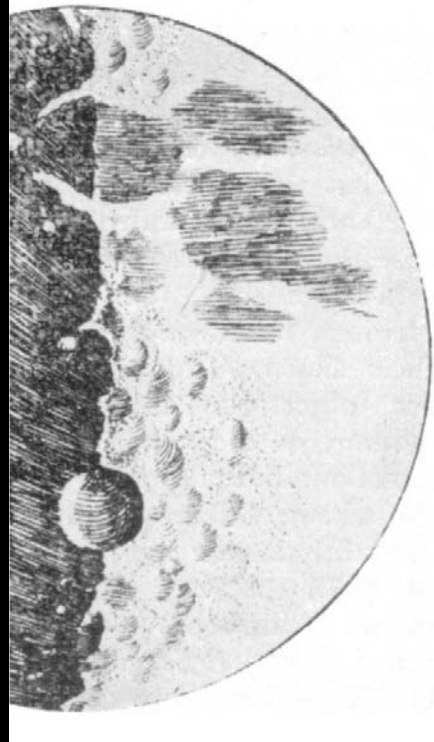


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3

4



# Johannes Kepler (1571–1630)

- Supposed, like e.g. Plutarch in 1<sup>st</sup> century A.D., that the lunar lowlands are filled with water
- Coined the terms “mare” and “terra”
- Believed meteor(ite)s to have a cosmic origin(?)



Kepler, D=32 km (LO)

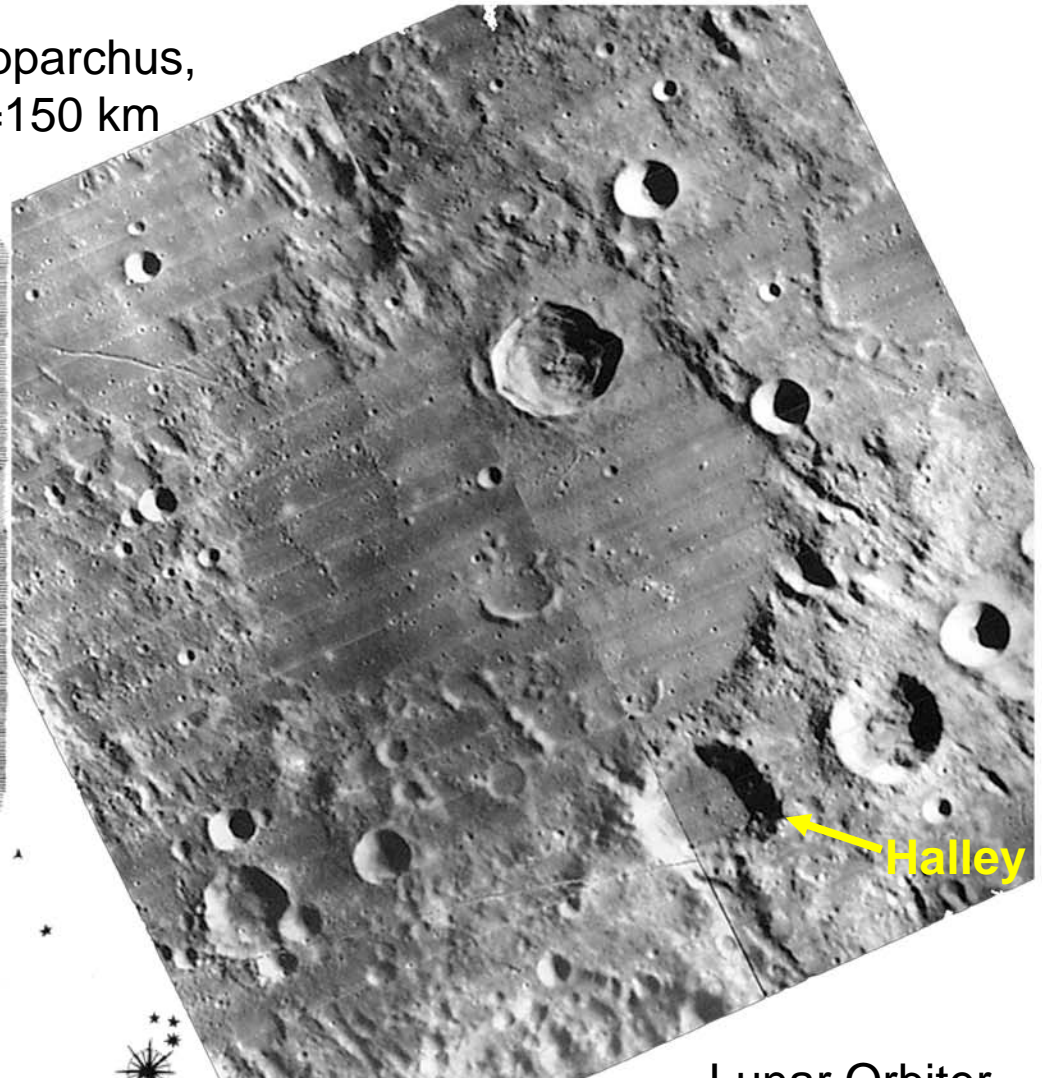
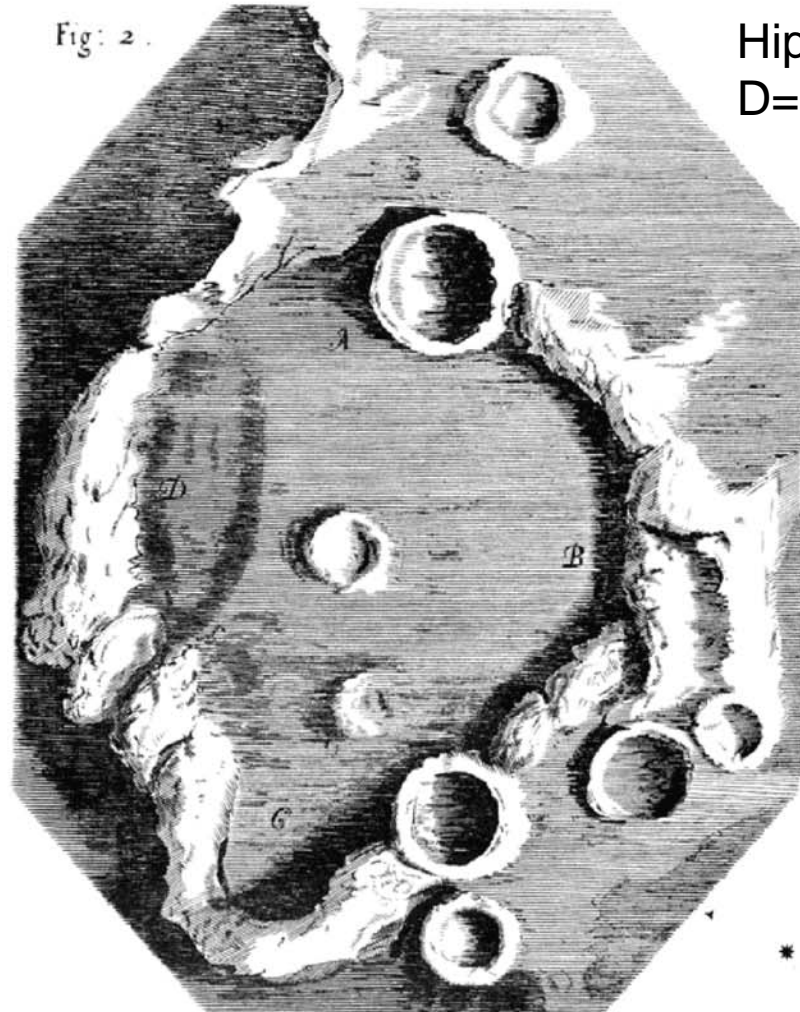


# Robert Hooke (1635–1703)

- Crater observer:

Fig: 2.

Hipparchus,  
D=150 km



*Micrographia*, 1665

Lunar Orbiter

# Robert Hooke

- First crater experimentalist:
  1. Dropping bullets to a mixture of tobacco pipe clay and water:
    - craters “not unlike these of the Moon; but considering the state and condition of the Moon, there seems not any probability to imagine, that it should proceed from any cause *analogus* to this; for it would be difficult to imagine whence those bodies should come; and next, how the substance of the Moon should be so soft;”

# Robert Hooke

2. A pot of boiling alabaster:
- When the boiling ceased, the surface was covered with craters
  - Compared these to terrestrial volcanoes
    - “...these pits in the Moon seem to have been generated much after the same manner that the holes in Alabaster, and the *Vulcans* of the Earth are made.”

Also believed the surface of the Moon to be covered with vegetation: “very fruitful place”

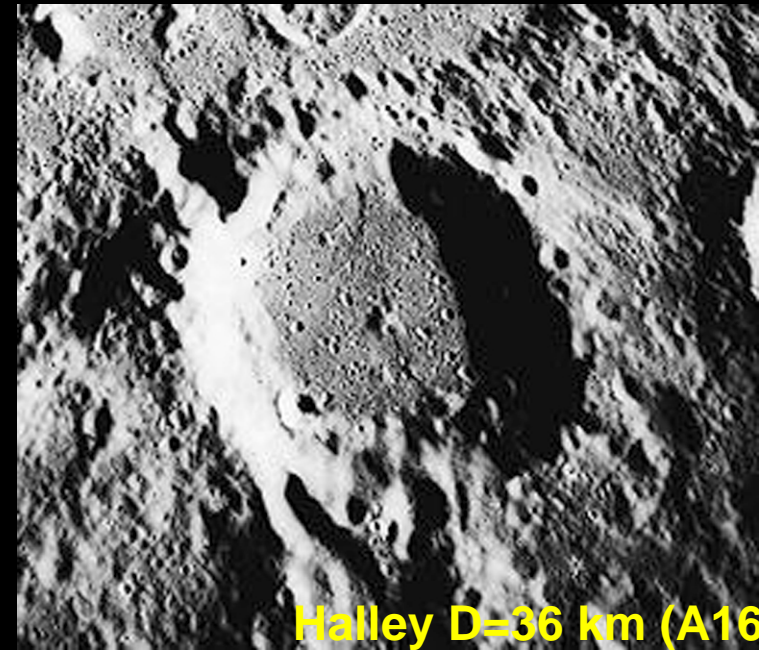


Hooke, D=37 km (LO)



# Edmond Halley (1656–1742)

- Suggested the Caspian Sea to be an impact structure
- Believed impacts being capable of causing world-wide catastrophes
  - Biblical flood couldn't have been caused by 40 days and nights of rain
  - Instead, an impact tilted the Earth's axis, causing oceans to shift
- Believed meteorites originated from space



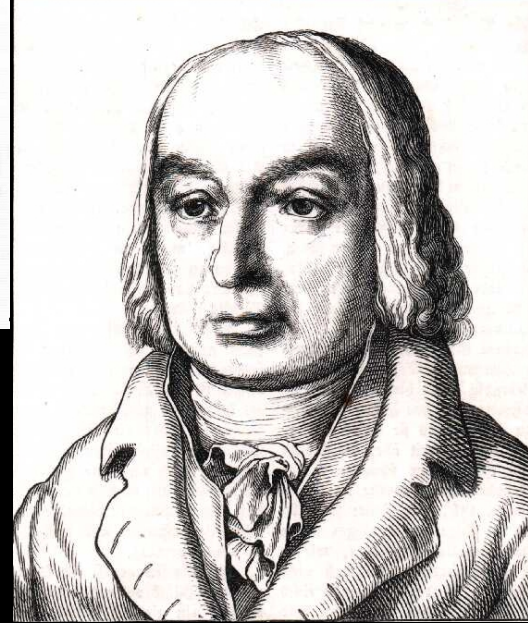
Halley D=36 km (A16)



EDMOND HALLEY LL.D.  
GEOM. PROF. SAVIL. & R.S. SECRET.

# Lunatic impacts

- Franz von Paula Gruithuisen (1774–1852)
  - Bavarian physician and professor of astronomy in Munich
  - onion-structured projectiles hit the plastic surface of the Moon and the Earth
  - “observed” fields, cows, and “lunites” worshipping stars in their star-shaped temple



Gruithuisen, D=16 km (A15)

# Lunatic impacts



T.J.J. See

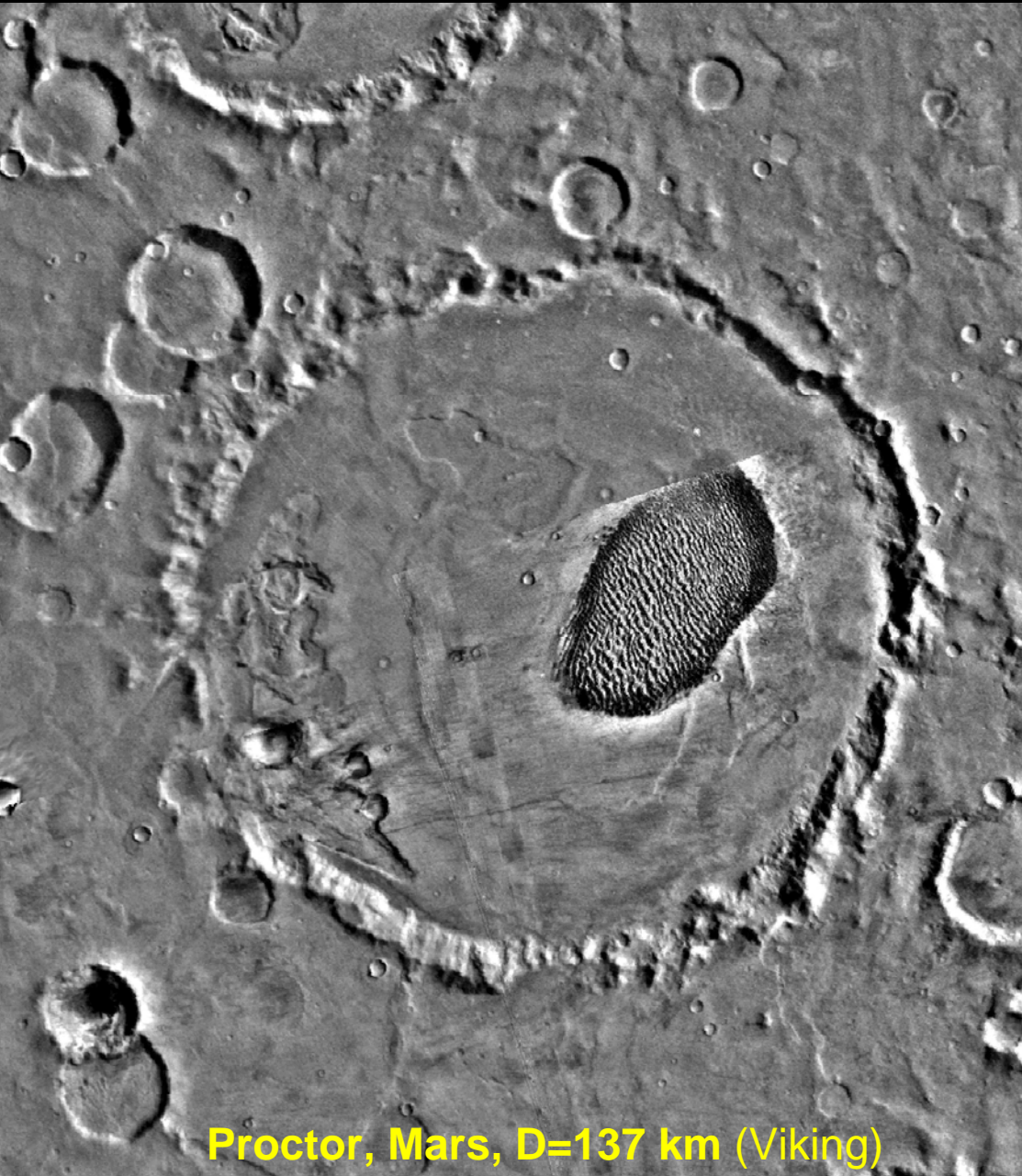
- Albrecht Meydenbauer, 1877 & 1882:
  - Cosmic balls of dust slowly hit the equally dusty Moon.
  - Maria originated when Earth-orbiting bodies of sulphur or phosphorus impacted the Moon.
- Thomas Jefferson Jackson See (1866–1962)
  - 1909: Meteorites sunk into the soft surface of the Moon, spread on the floor and thus lifted the rim
    - Light is made of egg-shaped particles
- Still in 1926 several English researchers believed lunar craters to be glaciers



# Richard A. Proctor (1837–1888)

- Ancient bombardment accreted the Moon, craters remaining as evidence
- Earth lacked craters only because they were demolished by active geologic processes
- Believed the projectiles are vaporised upon impact
- Presumed plastic lunar surface to explain the constantly puzzling circularity of craters
- Opinion shifted back and forth between volcanic and impact origin of craters

# Richard Anthony Proctor



Proctor, Mars, D=137 km (Viking)



*Rich<sup>d</sup>. A Proctor*

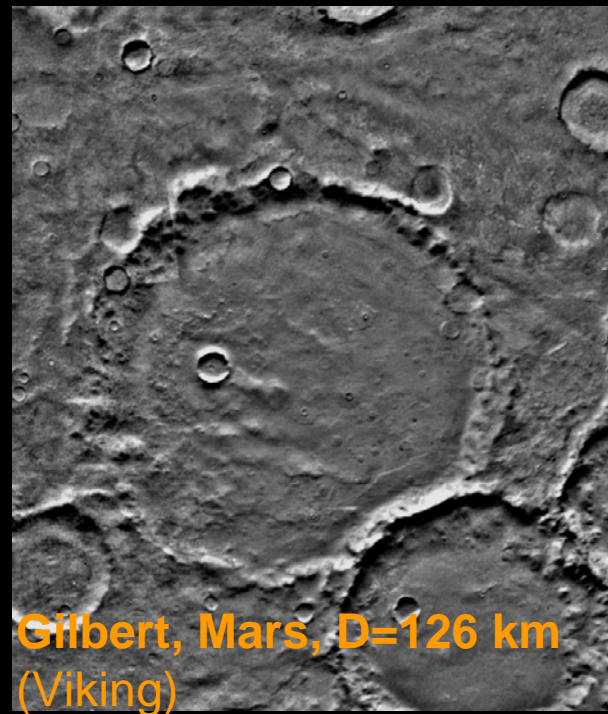




**Grove Karl Gilbert**



**Gilbert, Moon, D=112 km (LO)**

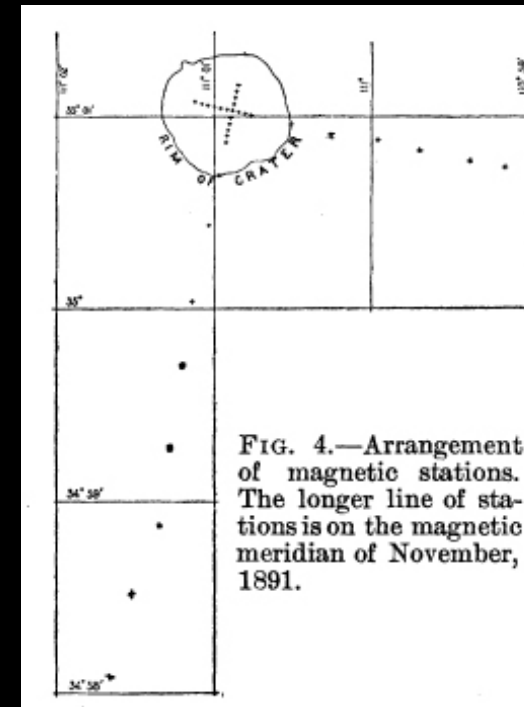


**Gilbert, Mars, D=126 km (Viking)**



# Grove Karl Gilbert (1843–1918)

- Highly respected chief geologist of the USGS
- August 20<sup>th</sup> 1891: heard about Coon Mountain (a.k.a.) Meteor Crater from Arthur E. Foote (1846–1895), who studied Canyon Diablo irons
- Over two weeks of field studies at the crater
- World's first magnetic survey of an impact crater
  - no large meteoritic mass
  - Canyon Diablo irons coincidentally surround the crater



➔ 1896: volcanic steam explosion crater

# G. K. Gilbert

- Advanced high-velocity impact experiments with muskets and slings to various target materials; also dropped marbles to porridge
  - Showed that  $45^\circ$  is the most probable impact angle
  - Assumed the Earth had a ring of particles accreting the Moon. The last particles hit the Moon vertically.
- circular craters

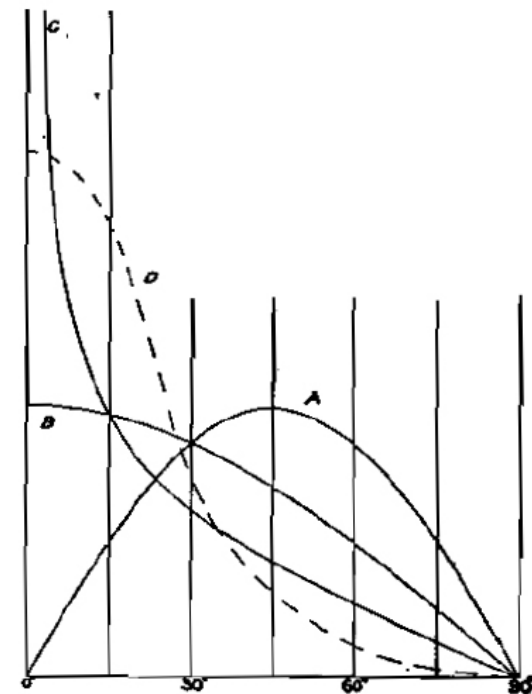


FIG. 12.—Distribution curves. Abscissas = angular deviation from verticality of bodies colliding with the moon. Ordinates = relative numbers of colliding bodies. A = curve for meteors. B = curve for bodies in a single plane. C = curve for moonlets, account being taken of the moon's attraction but not of the earth's. D = type of curve deduced from ellipticities of craters.

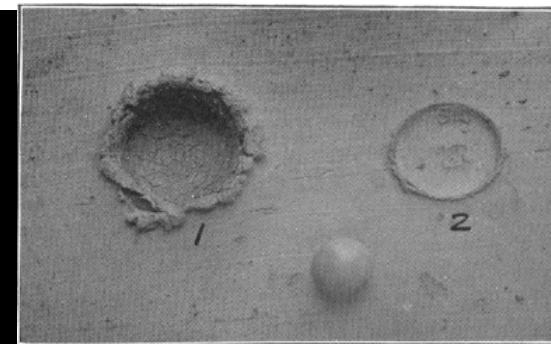


FIG. 6.—Craters made by throwing clay balls at a clay target. A ball of the same size is shown. 1 shows the effect of high velocity, 2 of low.

# G. K. Gilbert

- Observed the Moon during 18 nights

→ found the radial “Imbrium sculpture”, and understood its origin as ejecta as well as the possibilities it presented for relative dating of the lunar surface

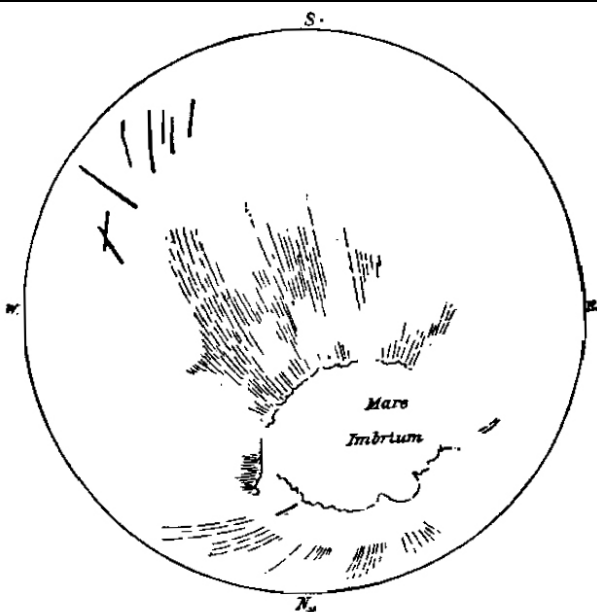


FIG. 14.—Trends of lunar sculpture. General sculpture is represented by shading; great furrows by heavy lines. Irregular lines show crests of uplands surrounding M. Imbrium.

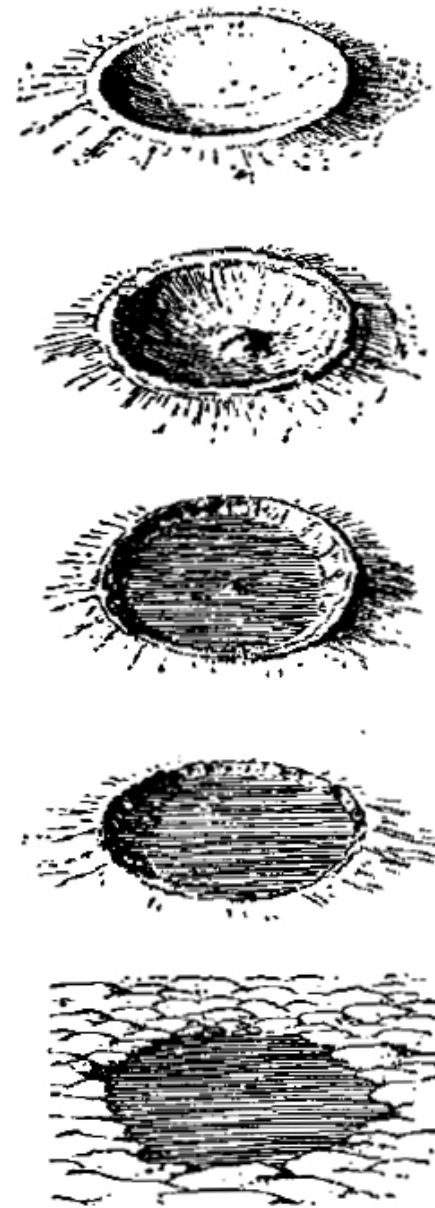
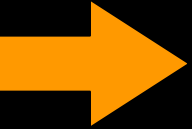


FIG. 4.—Varieties of lunar craters as related to size. The uppermost sketch represents the form of the smallest craters, the lowermost the form of the largest.



# G. K. Gilbert

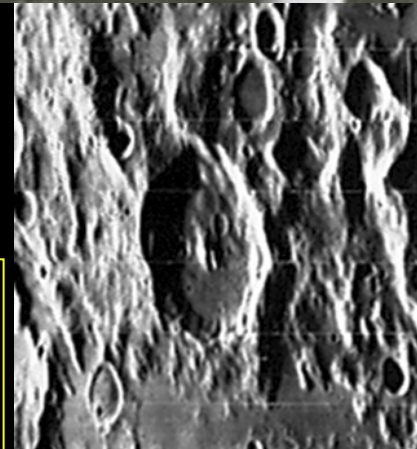
- Realised that the heat produced in the impact would be enough to melt silicates
    - Failed to understand the explosive nature of the heat release
  - Explained rim terraces being caused by faulting
  - Central peaks only in  $D=20-150$  km craters
  - In “geology”, where he was an authority, he was wrong, whereas in “astronomy”, where he was a dilettante, he was largely right, but completely ignored.
-  only negative influence on impact crater research at the time

# Daniel Moreau Barringer (1860–1929)

- Lawyer, mining engineer, geologist and entrepreneur
- Heard about Coon Mountain in 1902, and founded Standard Iron Company in 1903, but didn't visit the crater until 1904.
- Barringer and physicist Benjamin Chew Tilghman Jr. published in 1906 papers supporting the impact origin. They emphasised the vast presence of “quartz flour”, “shale balls” of oxidized meteoritic iron, and the reversed stratigraphy of the rim.

# D. M. Barringer

- Later they found shocked sandstone (“impactite”) that contained lechatelierite
- Gilbert and USGS remained silent
- Other scientists started to accept the impact origin of Meteor Crater
- Barringer never believed that the meteorite could have exploded



**Barringer,  
D=68 km  
(LO)**





Kring, 2007

**Meteor Crater, Coon Butte, Coon Mountain, Meteor Butte, Meteorite Mountain, Crater Mound, Franklin's Hole, Canyon Diablo Crater, Cañon Diablo Crater, Barringer Meteorite Crater, Barringer Crater, Arizona Crater... D=1.2 km**

# EXPLOSION!

- Several earlier suggestions that the projectile's evaporation by three researchers indicated that the projectile explodes upon impact
  - Estonian Ernst Julius Öpik (1893–1985): 1916
  - American Herbert Eugene Ives (1882–1953): 1919
  - Newzealander Algernon Charles Gifford (1861–1948): 1924
- craters' circularity became understandable
- All of these studies were completely ignored by the few astronomers who were interested in the Moon

- Young, unknown

- Worked in Tashkent, Uzbekistan

- Published in Russian, in an Estonian journal

- During World War I



**Öpik**



**Ives**



**Gifford**



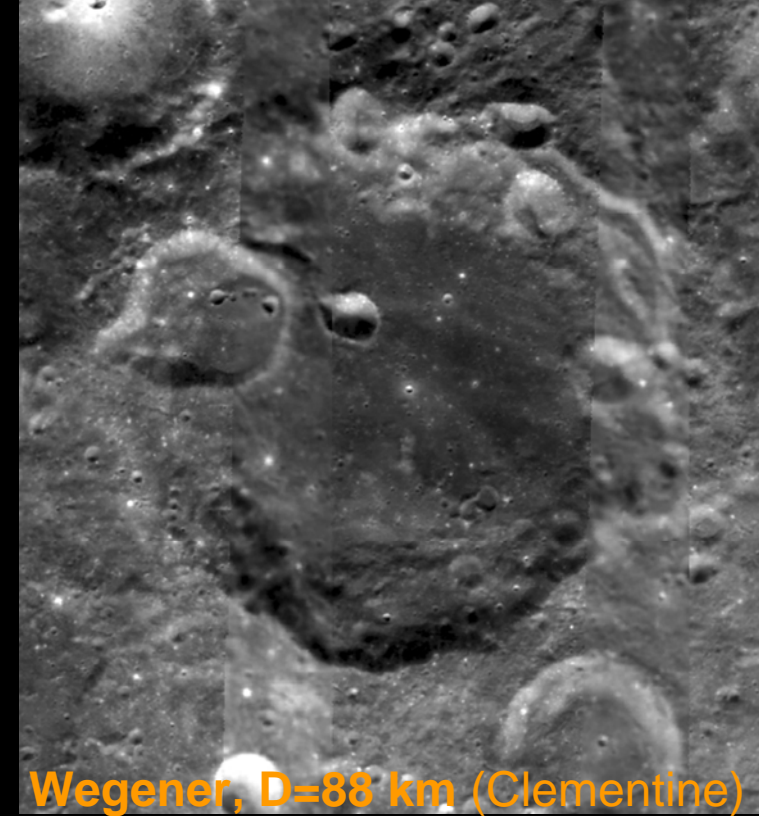
# Alfred Lothar Wegener (1880–1930)



- Arctic explorer, balloonist, astronomer (celestial mechanics), versatile meteorologist (thermodynamics, optics, tornadoes, measuring methodology...), geophysicist, co-founder of paleoclimatology, meteoriticist, and an impact researcher

# Alfred Wegener

- *Die Entstehung der Mondkrater* (The Origin of Lunar Craters, 1921)
  - Review of earlier studies
  - Review of other hypotheses for crater formation
  - Impact experiments with cement and gypsum powders
    - Morphometry, comparison to Moon and Earth



- Visited Kaalijärv in 1927 and with E. Kraus and R. Meyer strongly promoted impact origin, though didn't have any hard evidence

# Alfred Wegener

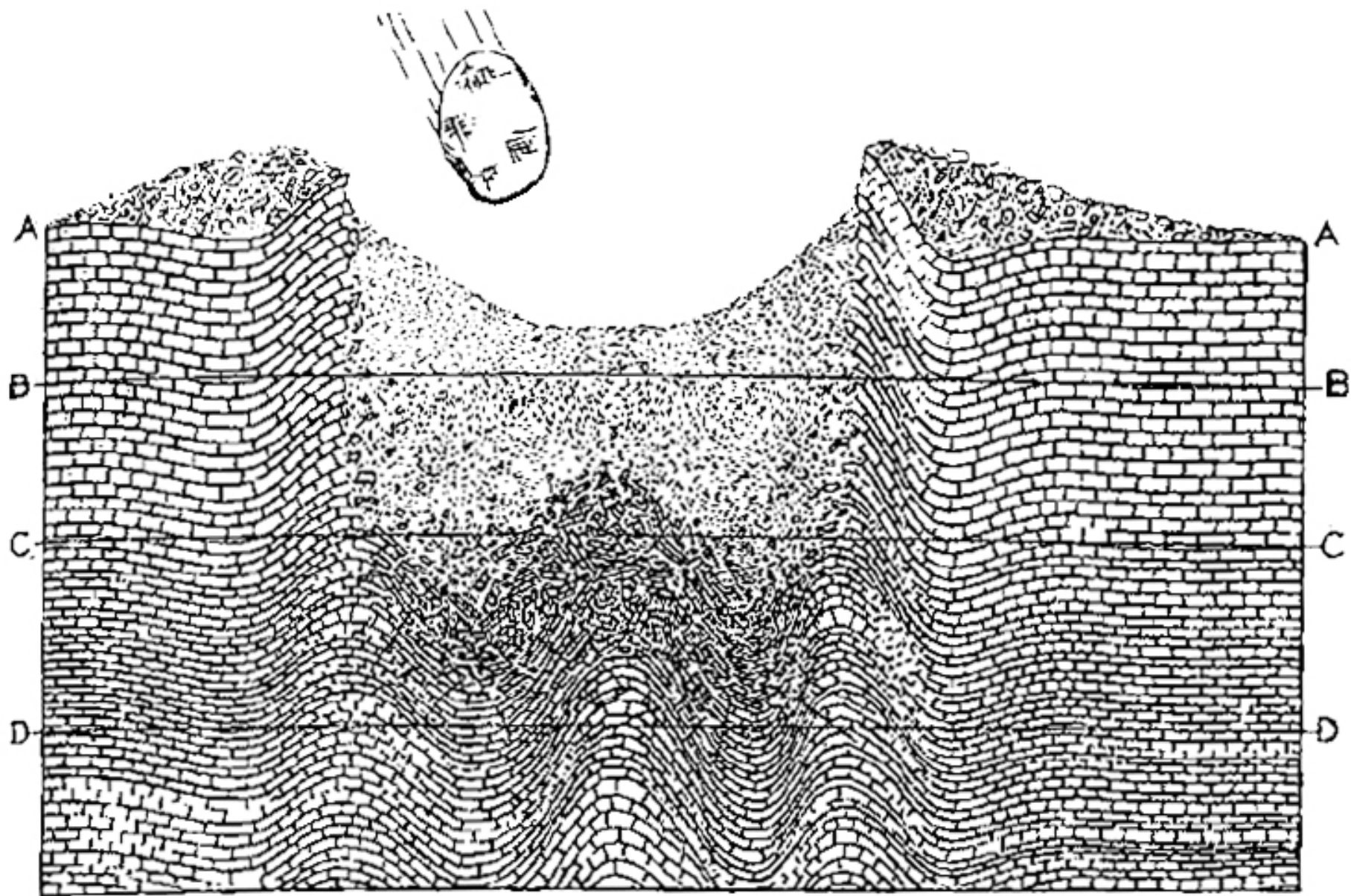
- Right: rays are ejecta; maria are filled by post-impact lavas; tektites are impact-induced (though he called them volcanic glass); impact flux; also other terrestrial craters than Meteor Crater must exist
- Wrong: impact velocities(!); no explosion; central uplift requires a layered target; lunar surface is covered by volcanic glass



# John D. Boon, Sr. (1874–1952) & Claude C. Albritton, Jr. (1913–1988)

- A series of papers in late 1930's in obscure *Field and Laboratory* → totally ignored
- Large, eroded impact structures must be present: Sierra Madera, Wells Creek, Flynn Creek, Vredefort, Upheaval Dome, Kentland, Decaturville
- *Elastic* structural uplift is about  $0.1 \times D$
- Oblique impacts can be identified from structures in the rock even if the crater itself is mostly eroded away





Boon & Albritton 1937

# Summary

- The first 300 years of scientific impact crater research was characterised by extremely slow development of ideas
- Even the good and correct ideas were ignored
  - The Moon was not interesting
  - The few who were interested in the Moon dogmatically believed the volcanic theories, though the differences were apparent for a long time
  - Prejudice, faith in authority

# Summary

- “Modern” impact research started in the 1930’s, and became significant in 1940’s with the works of Ralph Baldwin (1912–) and Robert Dietz (1914–1995)
- The last volcanists continued their loud arguments until Apollo-landings in late-1960’s.
- Despite claims to the contrary, impact crater research is still very much on the sidelines of geo- and physical sciences

# Thanks!

- Particularly to NIR, Henning, and Elin