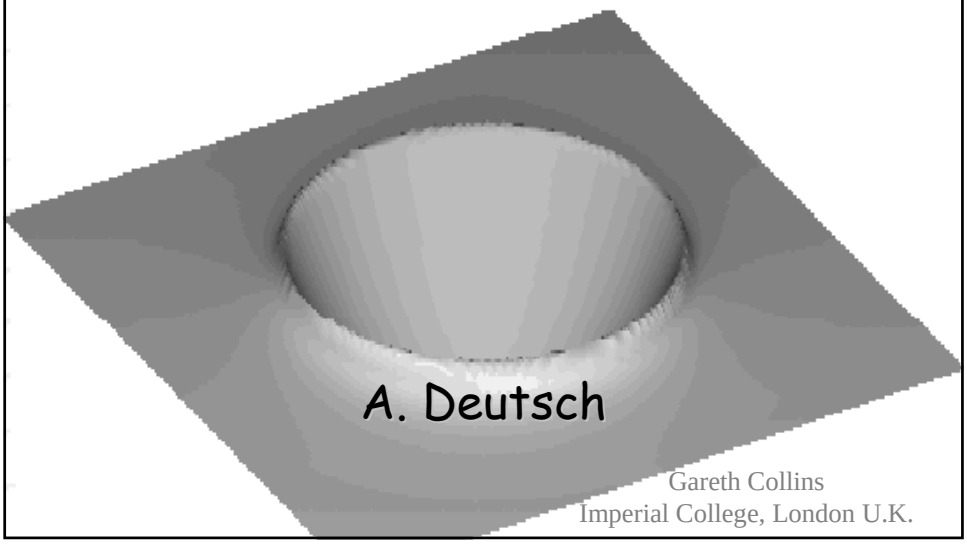
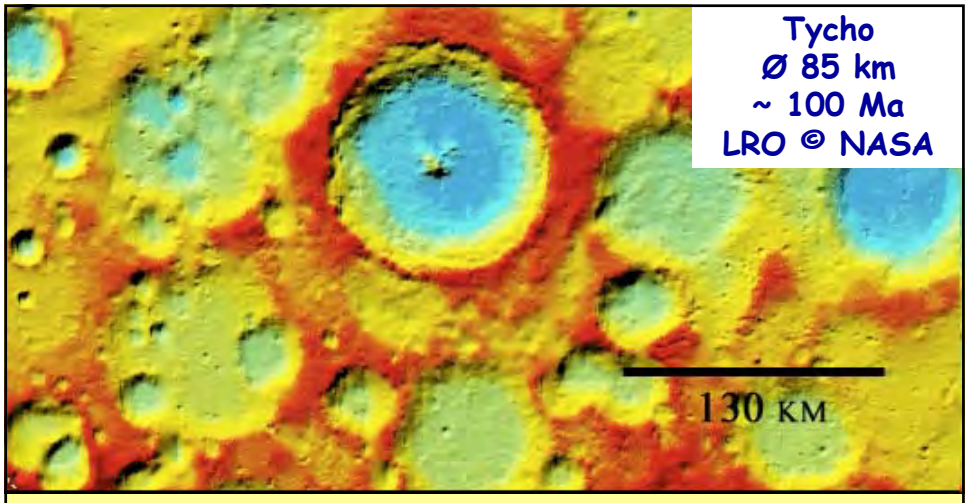
BSc – Impaktprozesse

SS 14



A. Deutsch

Gareth Collins
Imperial College, London U.K.



User: 143326
Passwort: 14Impakt
https://www.uni-muenster.de/Planetology/ifp/lehre/143326/143326.html



Wenige grundlegende Prozesse bestimmen Morpholgie - Geologie - geochemische Zusammensetzung planetarer Oberflächen:

Endogen

Magmatismus Intrusionen – Vulkanismus

Gezeitenreibung

z.B. Jupitermond Io, Saturnmond Enceladus

Wenige grundlegende Prozesse bestimmen Morpholgie - Geologie - geochemische Zusammensetzung planetarer Oberflächen:

Endogen

Magmatismus Intrusionen – Vulkanismus

Gezeitenreibung

Tektonische Aktivitäten

Verwerfungen/Bruchtektonik

Plattentektonik mit Gebirgsbildung + Gesteinsmetamorphose

„crustal overturn" (Venus)

Wenige grundlegende Prozesse bestimmen Morpholgie - Geologie - geochemische Zusammensetzung planetarer Oberflächen:

Exogen

Verwitterung

aquatisch – äolisch - glazial

Erosion

Massentransport und Sedimentation

Impaktprozesse



G. Karl Gilbert
1843 – 1918



In 1891 Gilbert, chief geologist for the U.S. Geol. Survey, decided to test whether the crater in Arizona was created by the impact of a meteorite or the result of volcanic activity (explosion of superheated steam).

Die

Entstehung der Mondkrater

Von

Dr. Alfred Wegener

Privatdozent der Geophysik an der Universität Hamburg

Mit 9 Abbildungen im Text und auf 3 Tafeln

SAMMLUNG VIEWEG

Braunschweig

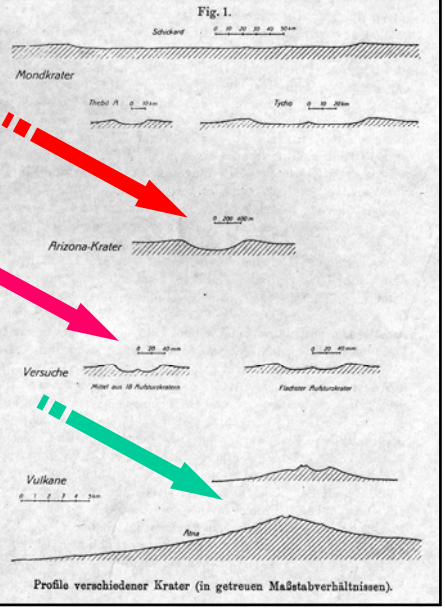
Druck und Verlag von Friedr. Vieweg & Sohn

1921

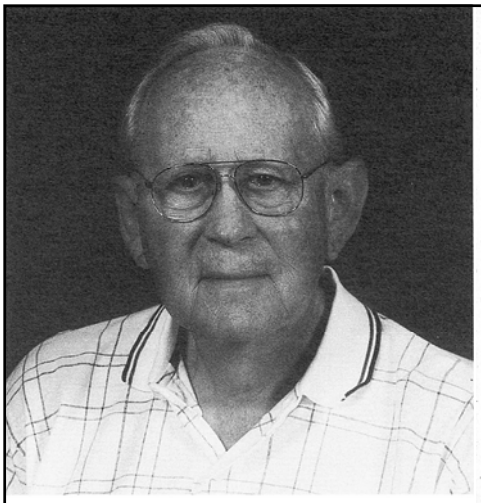
UBT017052511222

die lehrreiche Zusammenstellung bei J. Schmidt (Der Mond, S. 103, Leipzig 1856) oder bei v. Wolff (Der Vulkanismus I, S. 450, Stuttgart 1914). Z. B. hat der Ätna nach Schmidt eine Seehöhe von 3274 m, eine Krateröffnung von 485 m und eine Kratertiefe von 105 m. Dies ist die weitaus überwiegende Form. Daneben

Fig. 1.



Profile verschiedener Krater (in getreuen Maßstabverhältnissen).



Ralph Belknap Baldwin

(1912 -2010)

The

FACE

of the

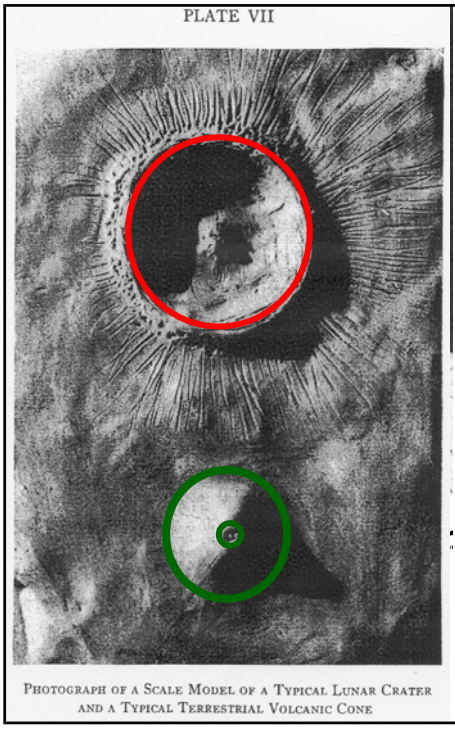
MOON

BY RALPH B. BALDWIN

Institut für Planetologie
Inv.-Nr. III PL-MO 52
1769
Universität Münster

THE UNIVERSITY OF CHICAGO PRESS

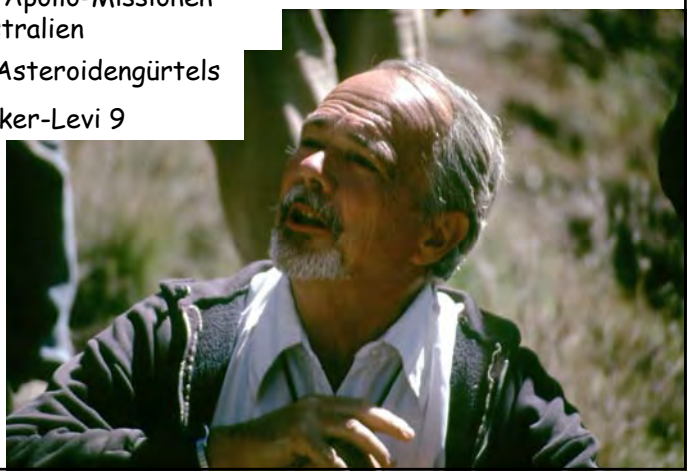
1949

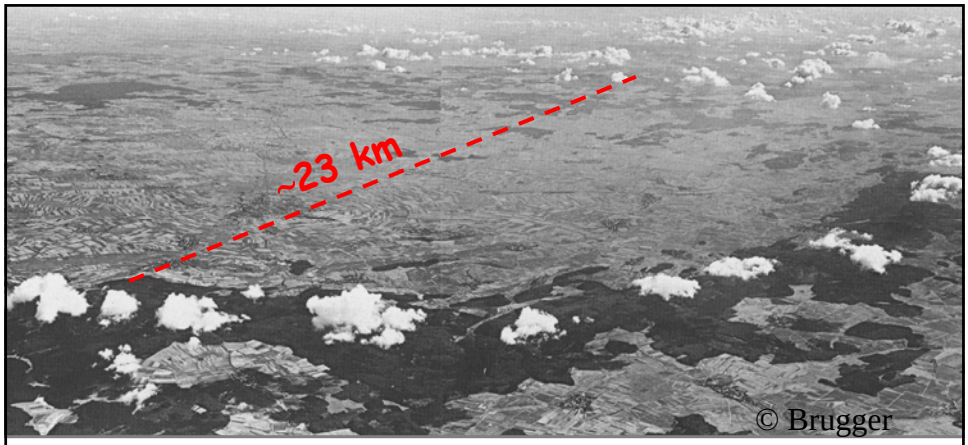


The Face of the Moon appeared in **1949** With nine prominent exceptions, the book was ignored for a few years... I could not understand this. The observations were clear and definitive. The Moon's craters and many terrestrial examples had to be of impact origin. Yet many otherwise excellent scientists read or listened to the evidence and remained of the same opinion, that the Moon's craters were some form of volcanism. It didn't make sense.....

Eugene Shoemaker 1928 - 1997

- Krater der Atomwaffentests Jangle U - Teapot Ess (1.2 kton)
- Meteorkrater
- 1961 gemeinsam mit E.C.T. Chao: Nachweis von Coesit und Stishovit im Ries
- Astrogeology Branch - USGS Flagstaff
- Vorbereitung der Apollo-Missionen
- Kraterjagd in Australien
- Erforschung des Asteroidengürtels
- → Komet Shoemaker-Levi 9





1961 **Nördlinger Ries**

= Komplexer Impaktkrater mit Ringwall

Alter: 15 Mio. Jahre

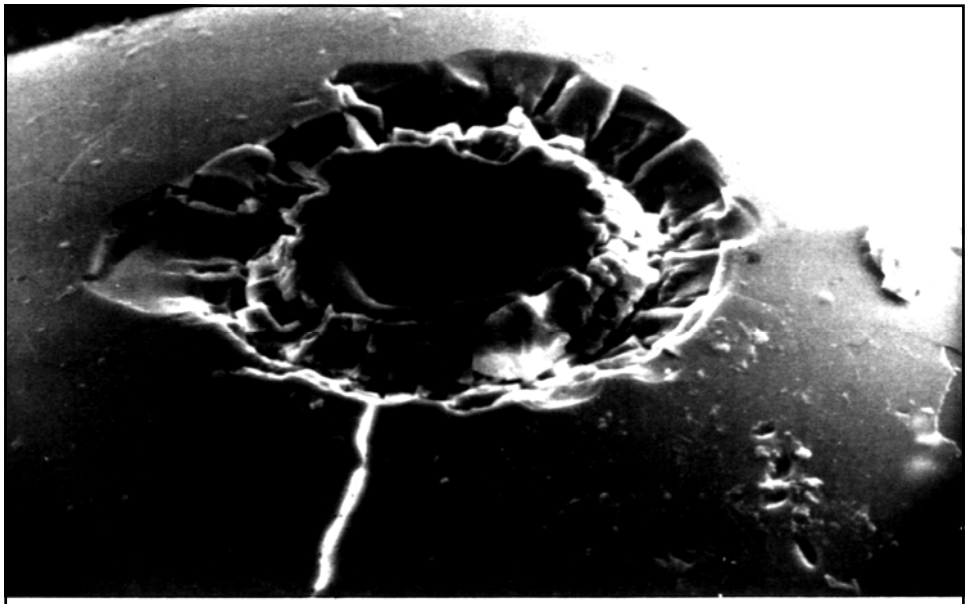
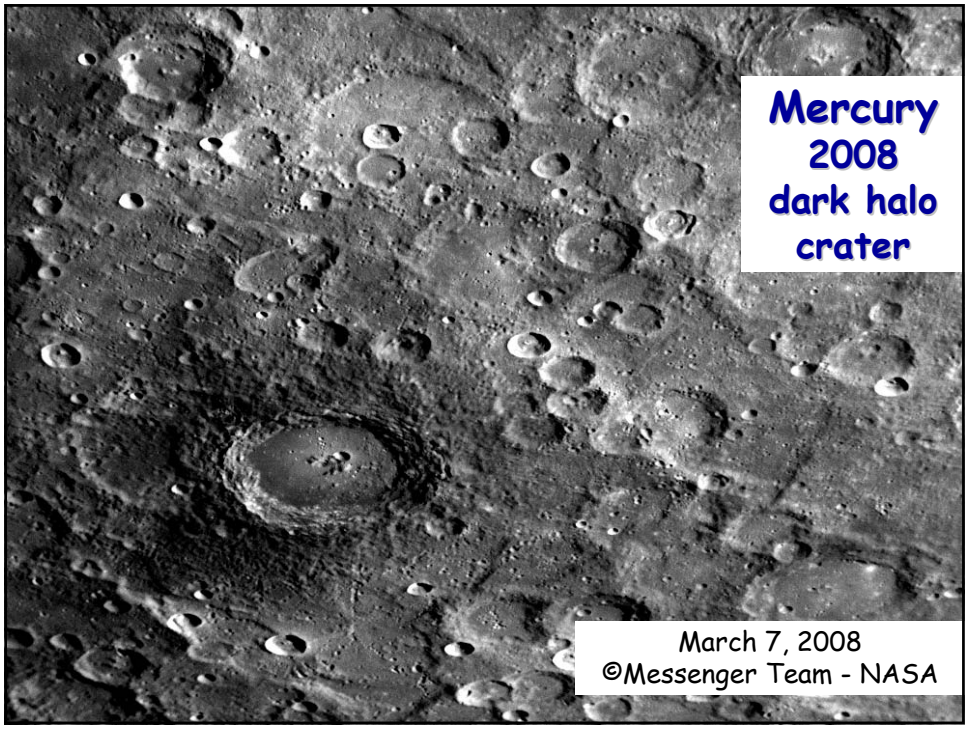
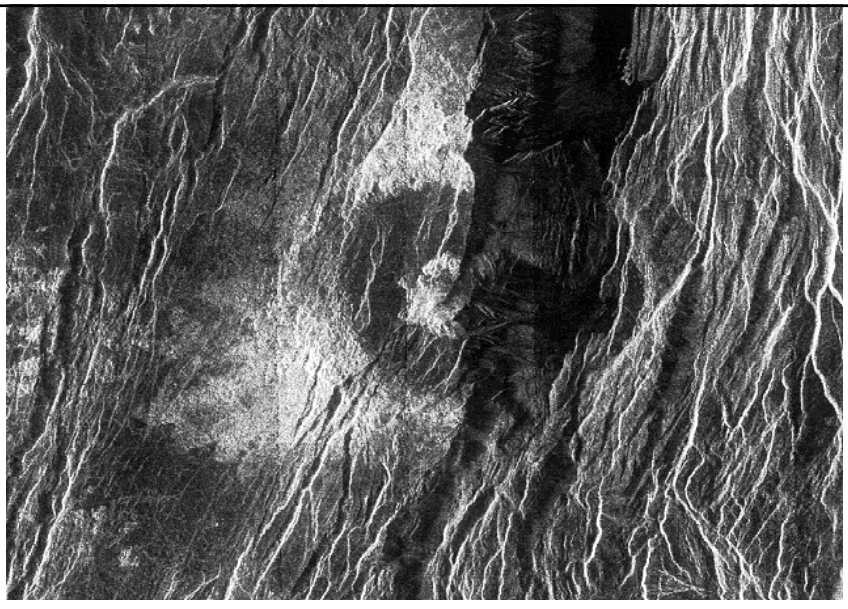


Fig. 2.1 This scanning electron microprobe photograph shows a microcrater 30 μm in diameter on an Apollo 11 glass sphere. The central glass-lined pit is surrounded by an extensive spall zone. NASA S70-18264 (Courtesy D. McKay.)

Microcrater – Apollo 11 glass sphere





Venus "Halb"-Krater, Ø 37 km

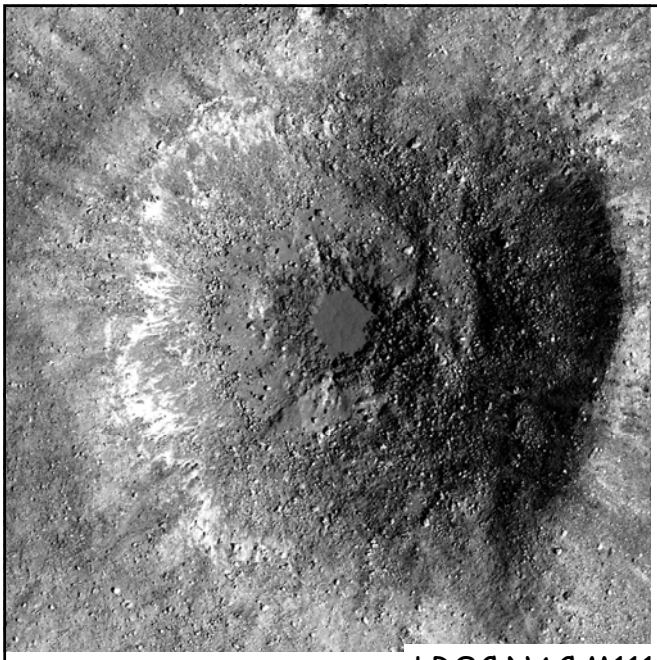
©NASA 1991 Magellan



Venus

Krater Dickinson
Ø 69 km

©NASA 1992 Magellan



Moon

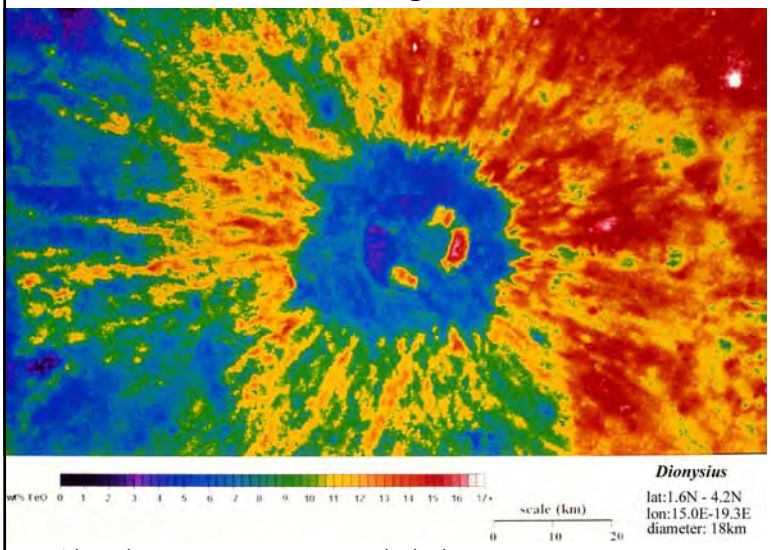
frozen impact melt pool on the floor of a young unnamed crater

(90 x 70 m).

LROC NAC M111972680LE©
NASA/GSFC/Arizona State University

FeO (wt%) map

UV/Vis images



blue = low

red = high

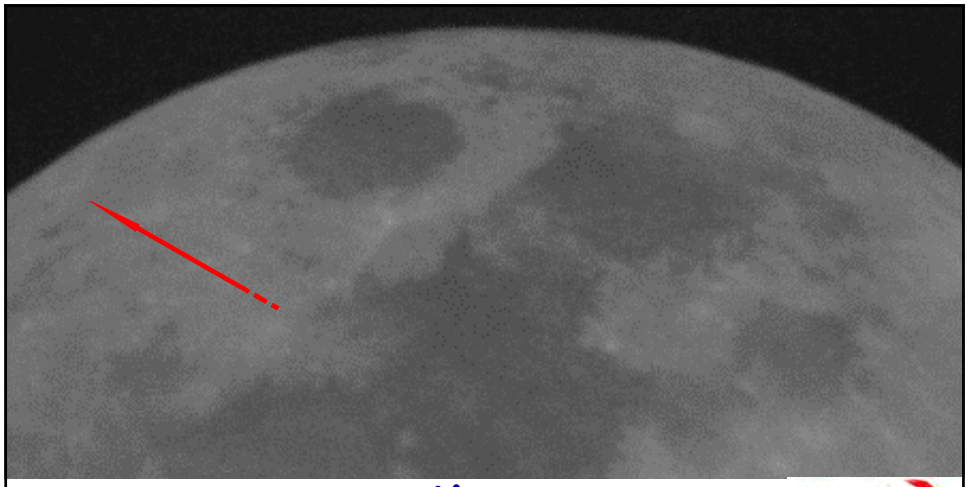
Moon

crater Dionysius

Ø 18 km

Clementine (1994)

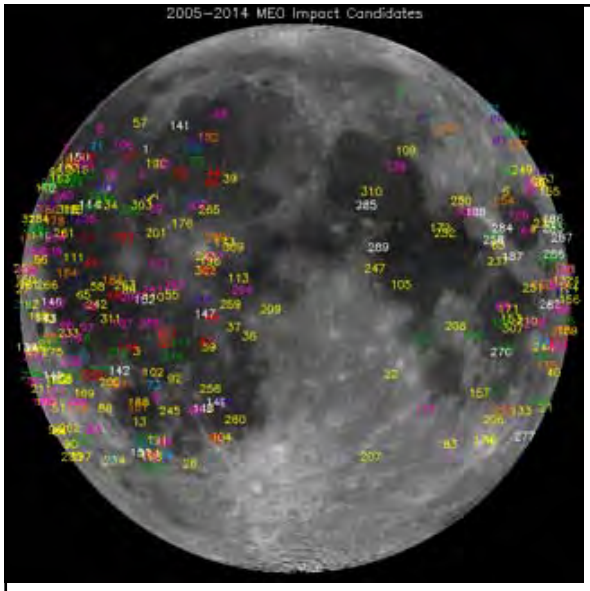
Giguiere et al. 2006 JGR111



Moon

spaceweather.com

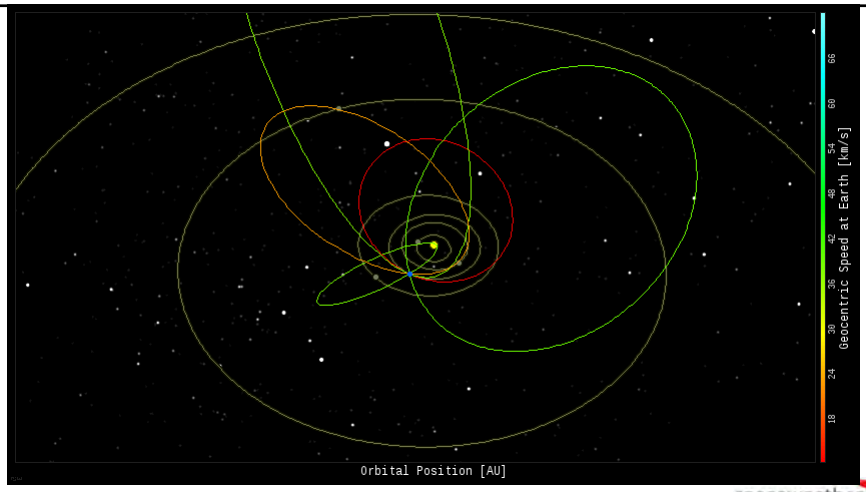
Earth-based observations of the dark portion of the moon to establish rates and sizes of large meteoroids (>500 grams in mass) striking the lunar surface.



Moon

2005 – 05.2014: 319 documented impact events

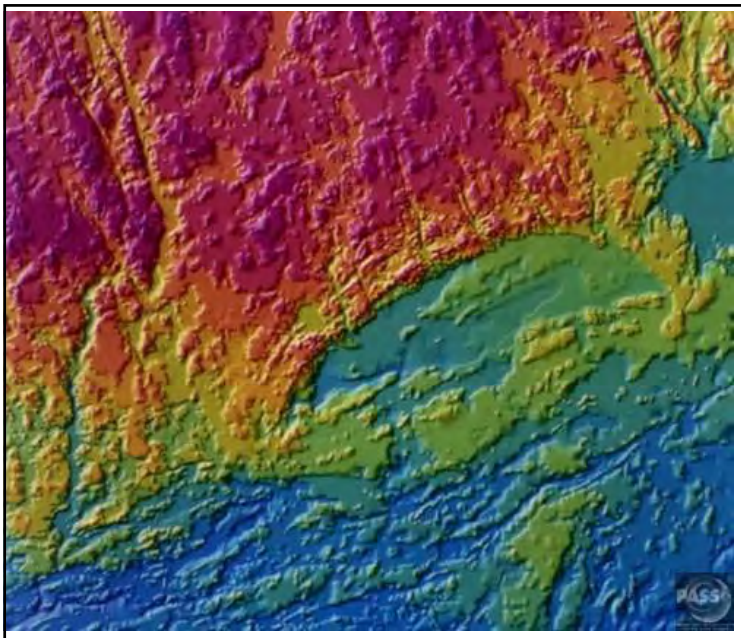
www.nasa.gov/centers/marshall/news/lunar/index.html#.U3s3pSitvuG



Earth

May 19, 2014, the network of NASA all-sky cameras reported 5 fireballs.

Automated software maintained by NASA's Meteoroid Environment Office calculates e.g., orbits, velocity, penetration depth in Earth's atmosphere.



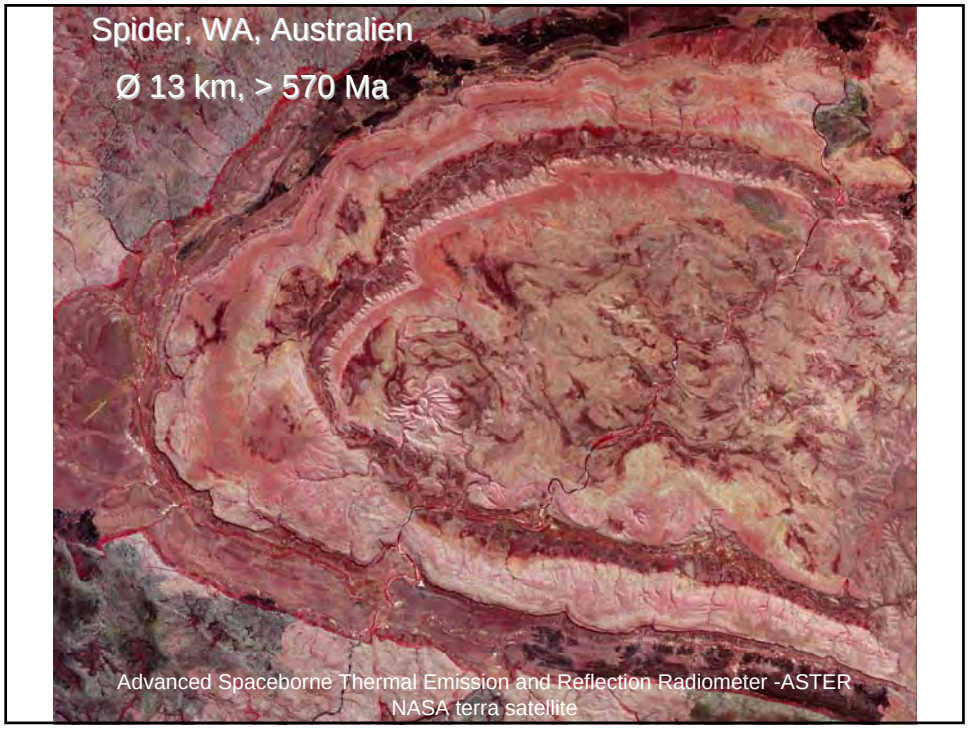
Sudbury Multiring-Becken

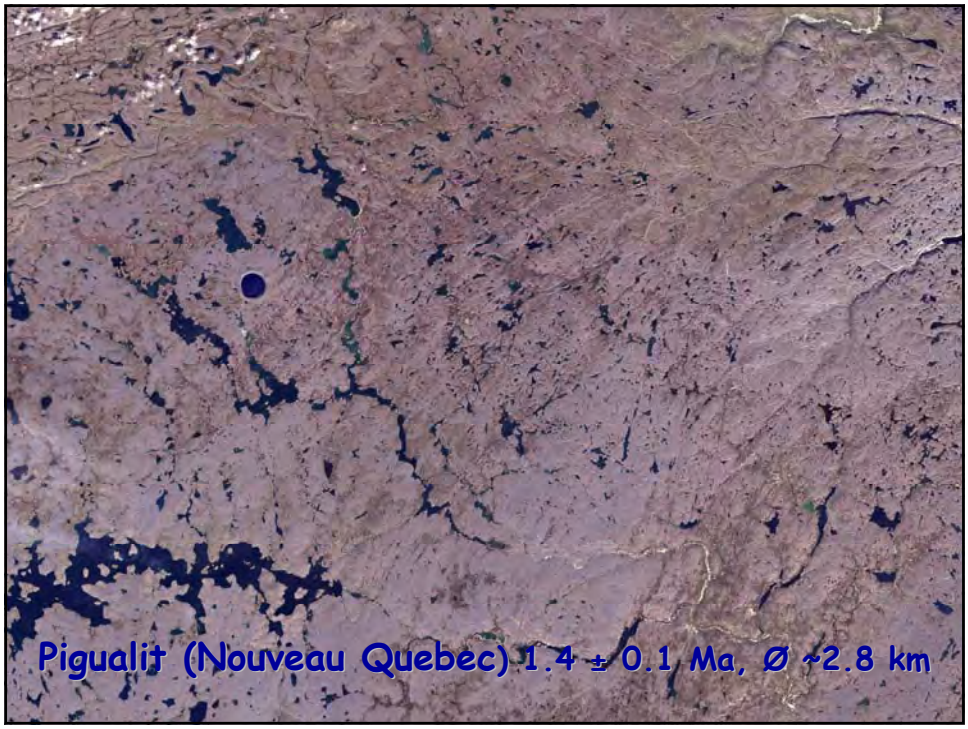
Ontario
Kanada

DEM



Clearwater Lakes Quebec Canada ©Reiff
Ø 32 – 17 km


Spider, WA, Australien
Ø 13 km, > 570 Ma
Advanced Spaceborne Thermal Emission and Reflection Radiometer -ASTER
NASA terra satellite


Pigualit (Nouveau Quebec) 1.4 ± 0.1 Ma, Ø ~2.8 km

Tunguska, Sibirien; 30.6.1908

Explosion in 8 km Höhe, Energie ~750 kton TNT
~ 60 Hiroshima-Atombomben (12.5 kton TNT)
Verwüstung von 2150 km² Taiga, 80 Mio. Bäume geknickt



© William K. Hartmann



Projektil

V = 15 km s^{-1}

Ø = 30 m

Gesamtenergie = 4.8 x 10^{15} Joule

½ der Energie wird an die Atmosphäre abgegeben
(Abbremsung, Fragmentierung …)

Tscheljabinsk, Ural; 15.2.2013

Meteor verglüht in einer Höhe von 23 - 30 km
Energie ~ 400-600 kton TNT
1200 Verletzte (Glasbruch)



© Space.com

Projektil

Ø > 20 m

Gesamtenergie ~ 3.11 x 10^{15} Joules

Nature 503, 238–241, 14 November 2013
doi:10.1038/nature12741

SIGNIFICANCE OF IMPACT CRATERING



Carancas, Peru - youngest crater on Earth
Sept. 15, 2007

Planning deflection of hazardous N E O s EU/FP7 Project



Chelyabinsk, Ural
Feb. 15, 2013

Asteroid 2012 DA 14 (~55 m Ø), 27500 km distance from Earth
Feb.15, 2013

27

2007

39th LPSC, March 10-14, 2008 #1094

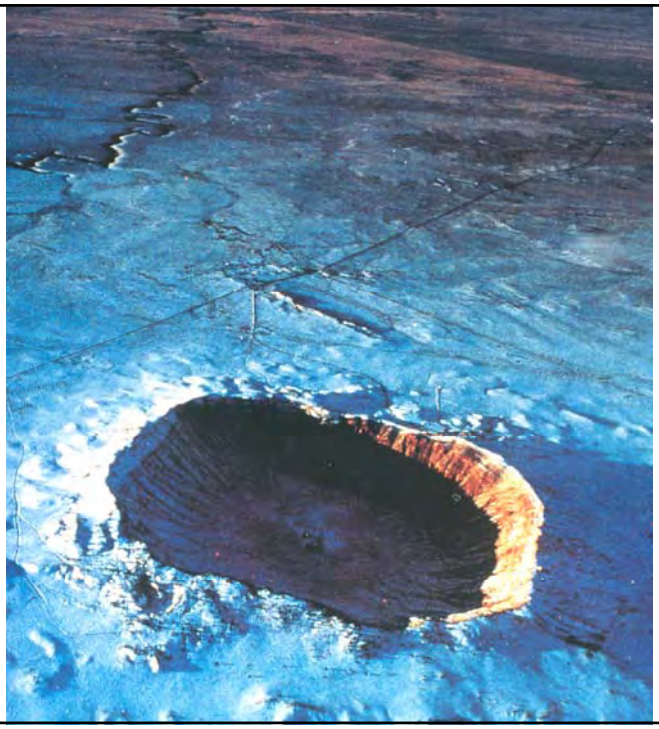
museum für naturkunde

(i) Atmospheric modeling, (ii) Crater modeling, (iii) Field analysis

- Atmospheric entry at shallow angle and low cosmic velocity
- Steep impact at 70-75° with terminal velocity (200-300 ms^{-1})
- Impact of a chondritic body with 0.7-1m Ø and 0.7-1.4 tons mass
- No shock features, minor fracturing (50-100 MPa)

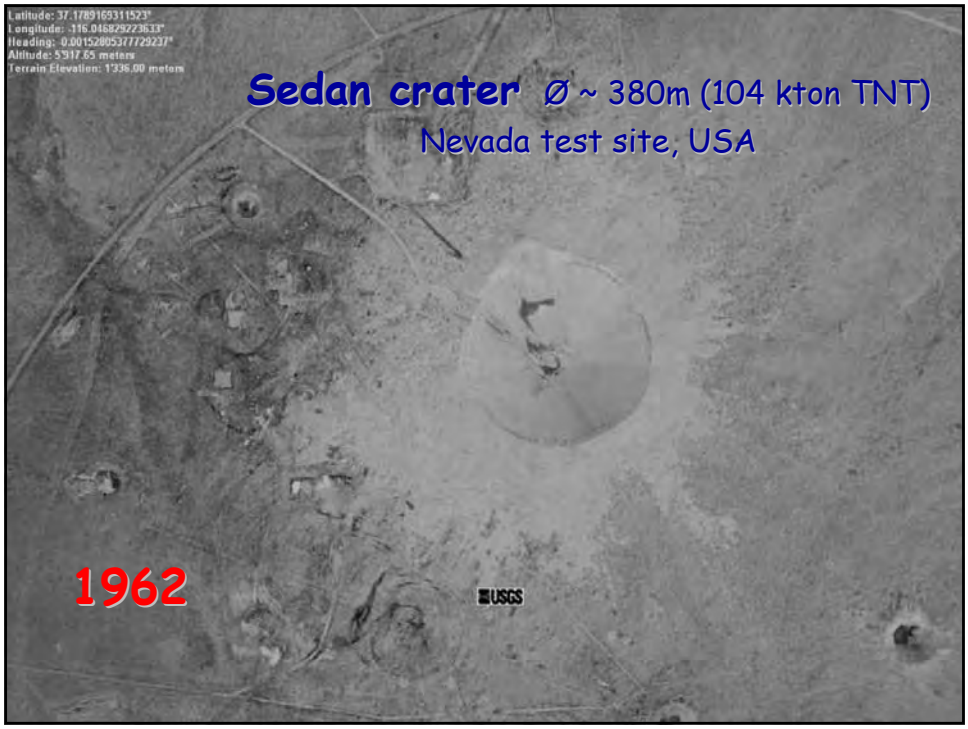
•Crater size D at crest:	14.2 m Ø
•Crater volume V:	160 m^3
•Crater efficiency π_V:	~320
•Kinetic energy E_{kin}:	6.3 x 10^7 J (15 kg TNT equivalent)

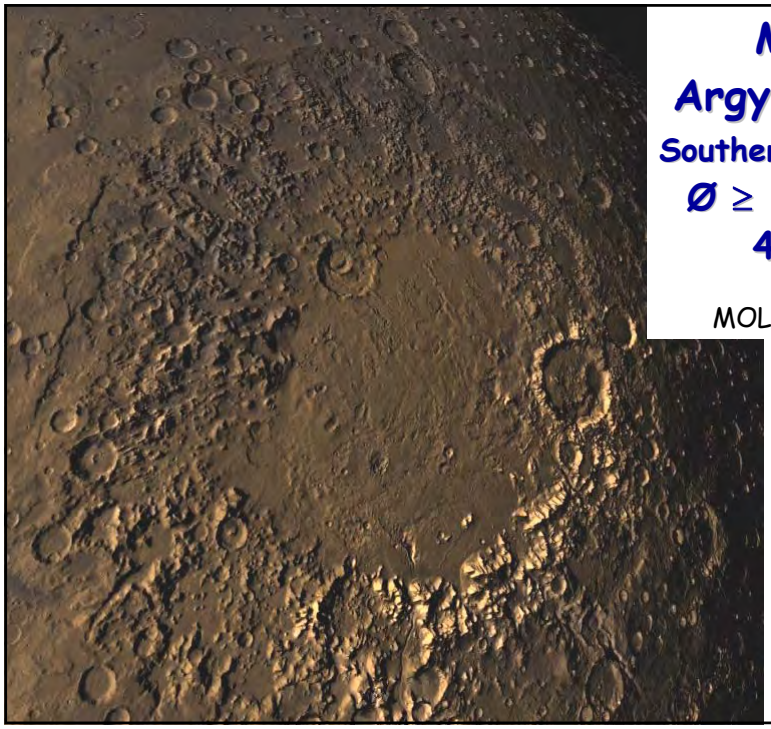
Carancas is the youngest and smallest impact crater on Earth!
Impact risk has to be re-evaluated!



Meteor (Barringer) crater

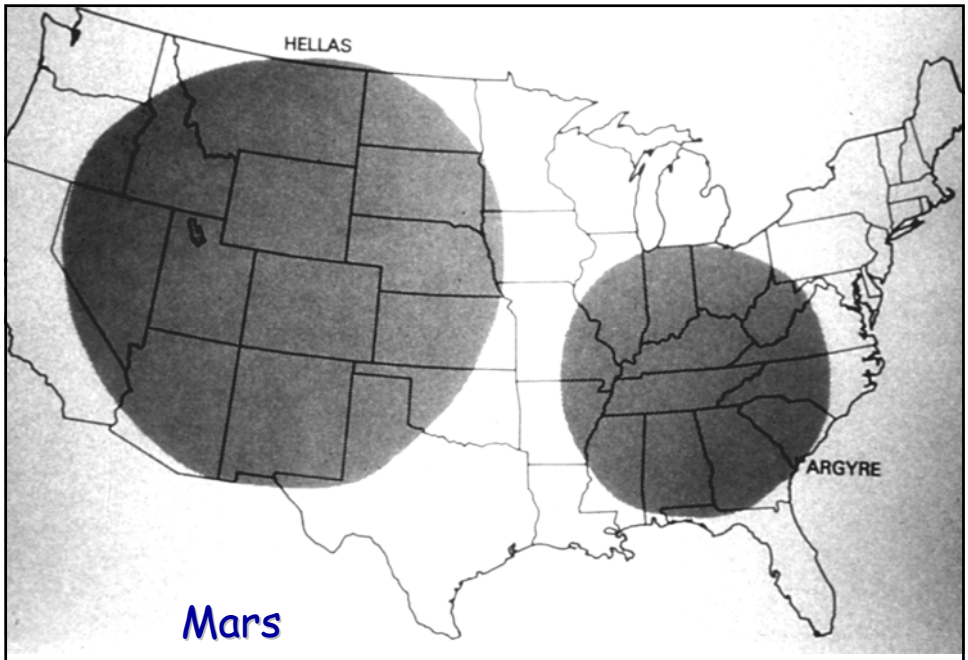
Ø 1.3 km, 47 ka, AZ, USA





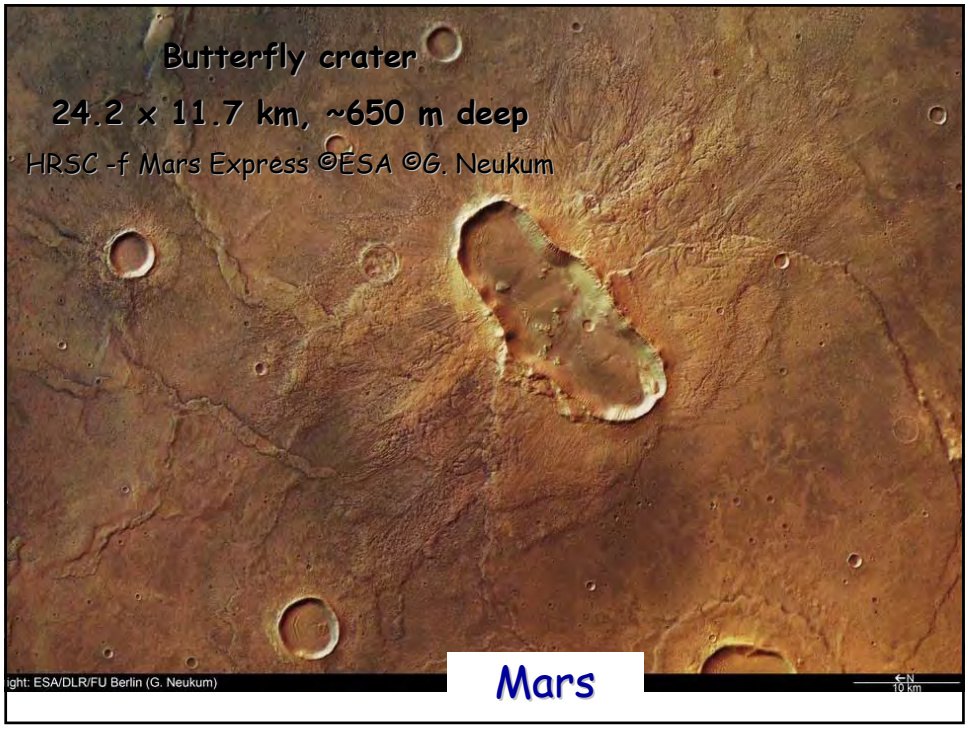
Mars
Argyre Basin
Southern highlands
Ø ≥ 1500 km
4 Ga?

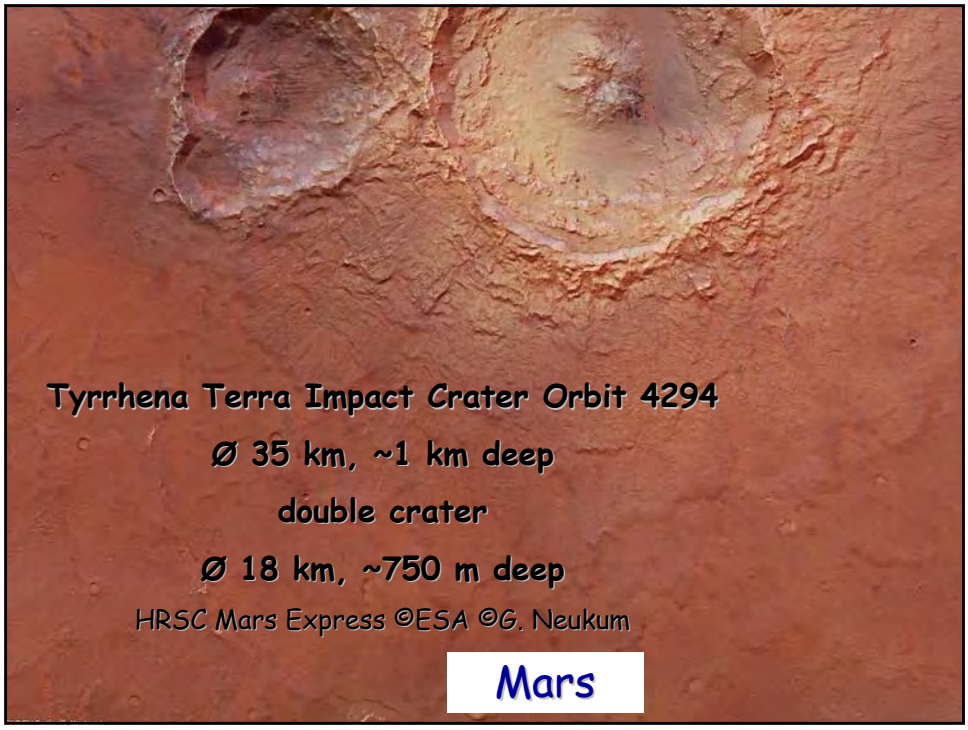
MOLA ©NASA

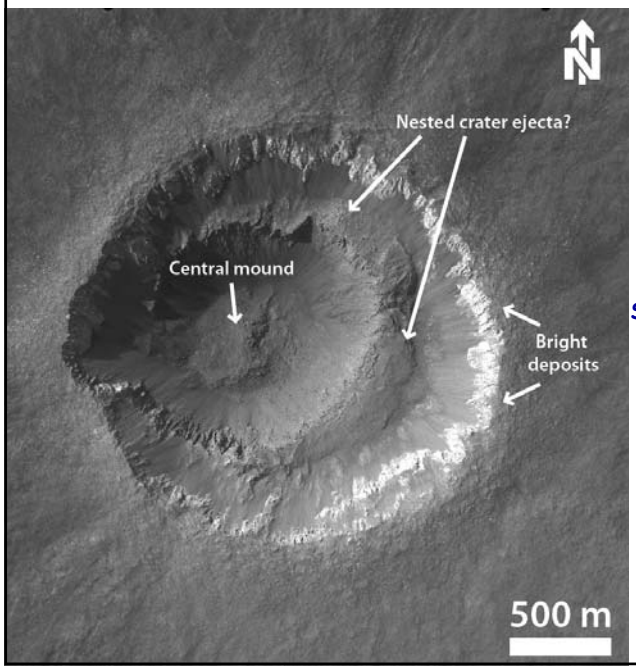


Mars

Hellas – Argyre basins


Butterfly crater
24.2 x 11.7 km, ~650 m deep
HRSC -f Mars Express ©ESA ©G. Neukum
ight: ESA/DLR/FU Berlin (G. Neukum)
Mars


Tyrrhena Terra Impact Crater Orbit 4294
Ø 35 km, ~1 km deep
double crater
Ø 18 km, ~750 m deep
HRSC Mars Express ©ESA ©G. Neukum
Mars

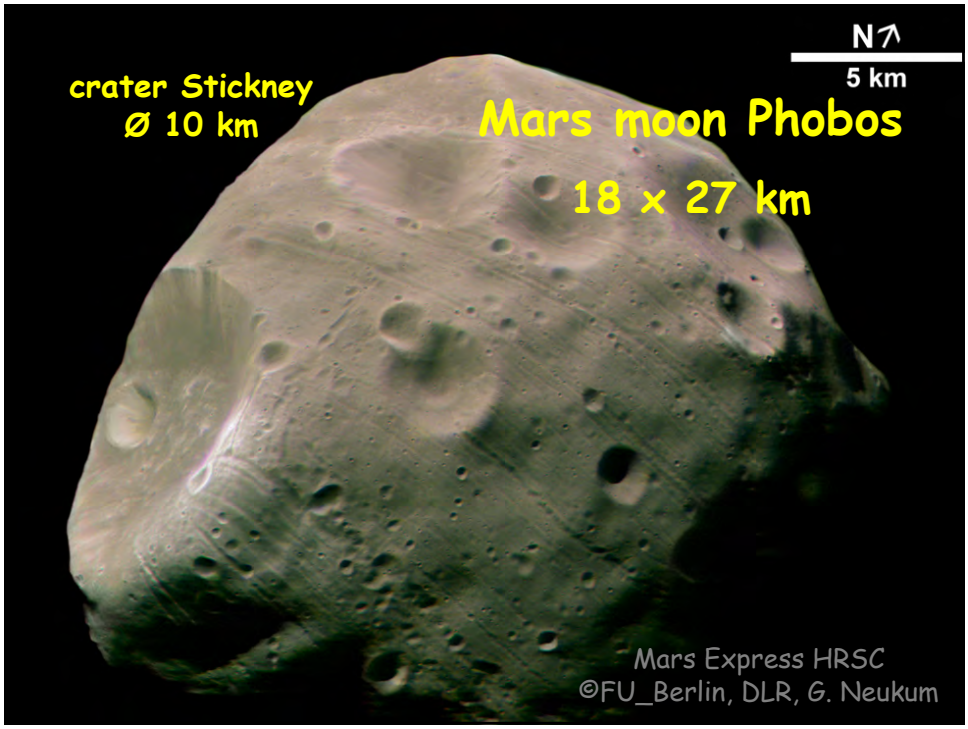


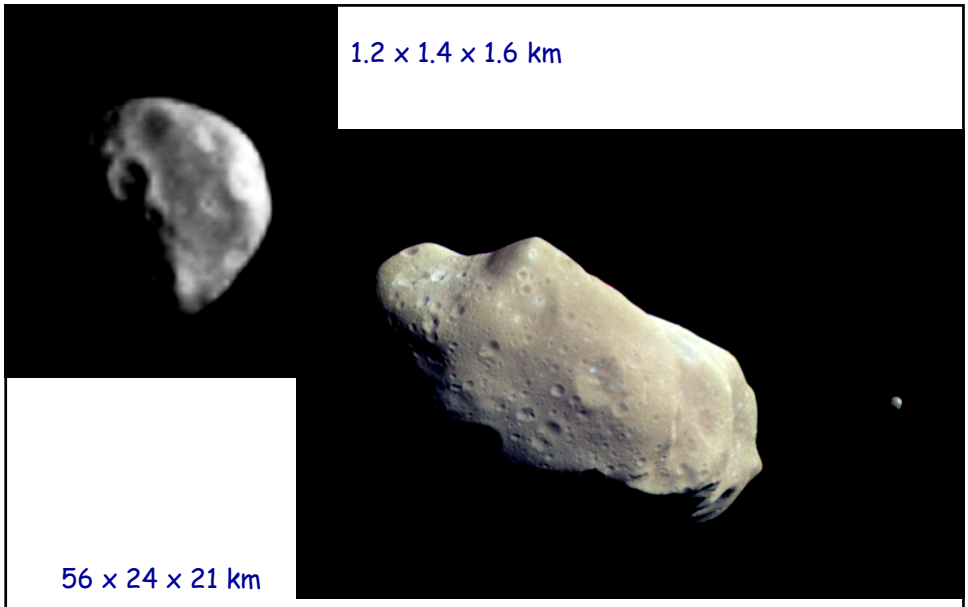
Mars

wider (unnamed) crater in a weaker layer surrounding a smaller nested crater with an irregular ejecta deposit

Reconnaissance Orbiter (MRO)
Context Camera (CTX)

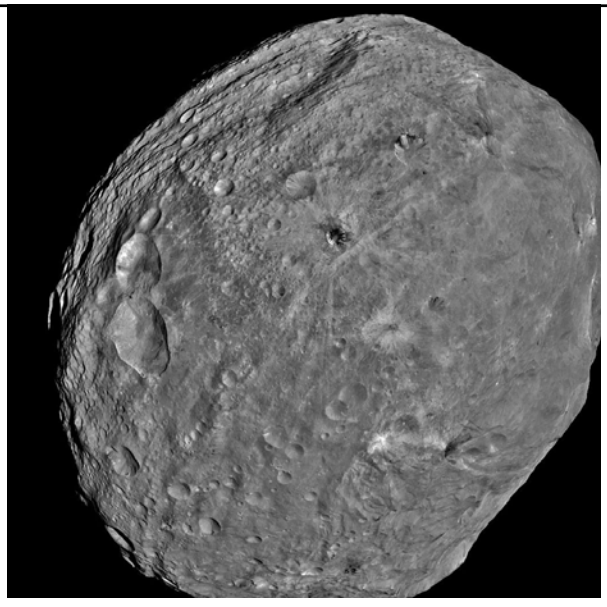
Ormö et al. 2013 MAPS





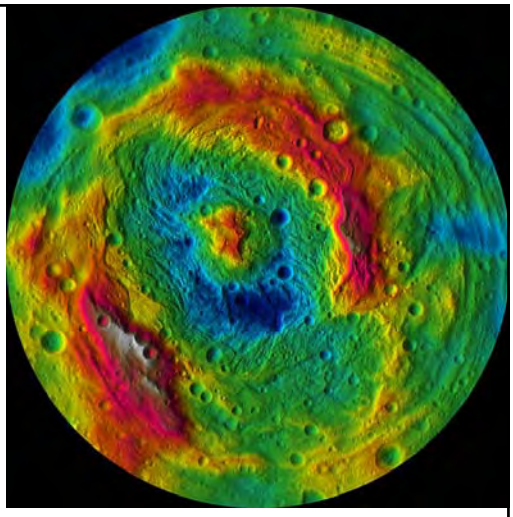
Asteroid Ida + Dactyl

Galileo 1993 ©NASA



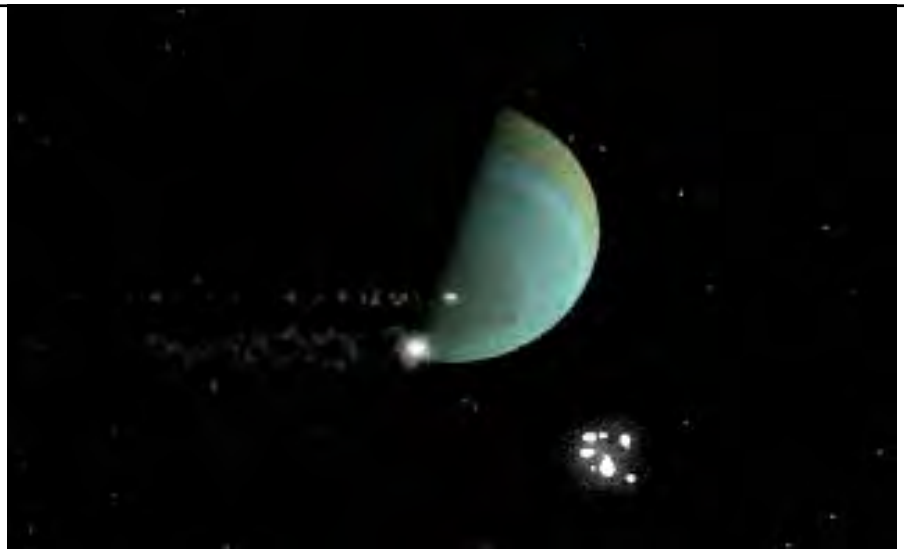
Asteroid (4) Vesta Ø 516 km

DAWN©NASA



Asteroid (4) Vesta

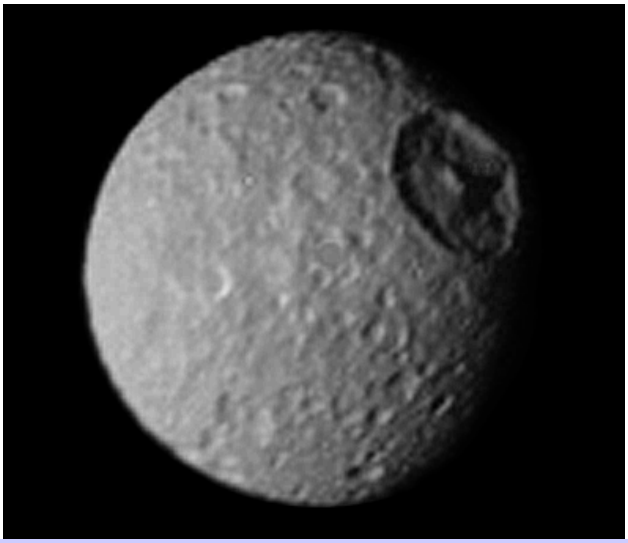
Rheasilivia crater Ø 500 km



Jupiter; Einschlag des Kometen Shoemaker-Levy 9 auf den Jupiter - Fragment R, 21.7.94, 5:30 der Feuerball leuchtete ~8 Minuten

Shoemaker-Levi 9 Fragment G
Hurrikan Linda 9.9.1997





Saturn
Eismond
Mimas

Ø 390 km

Krater
Herschel

Ø 130 km



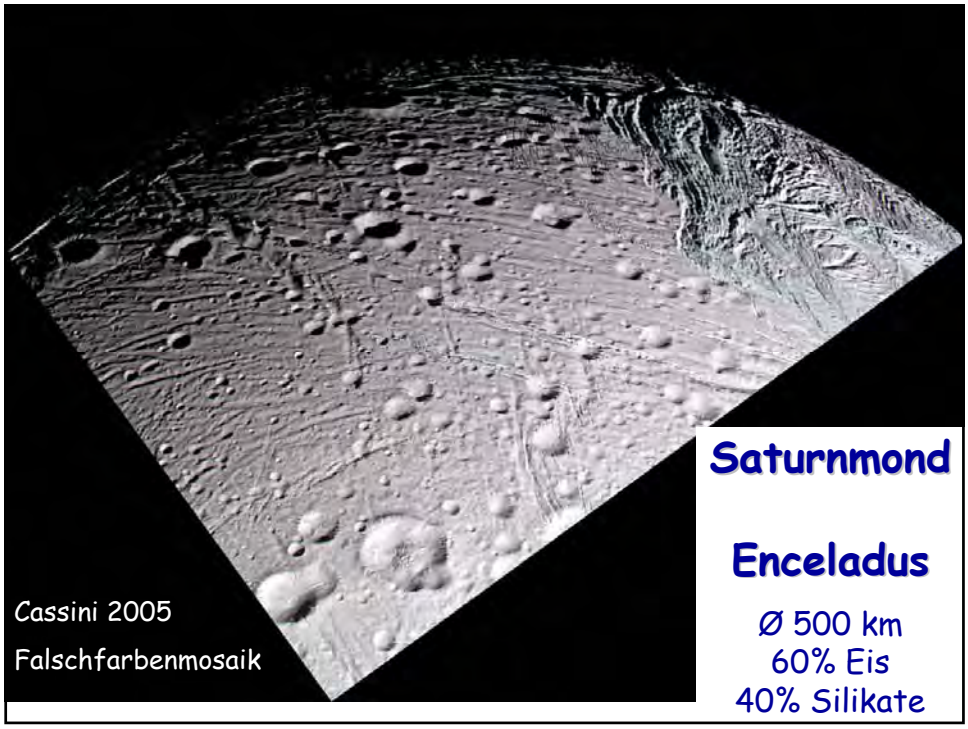


Saturnmond

Tethys

Ø 1050 km
Wassereis

Voyager 1
1980



Cassini 2005
Falschfarbenmosaik

Saturnmond

Enceladus

Ø 500 km
60% Eis
40% Silikate



Rhea's Cratered Surface © Copyright Calvin J. Hamilton

Saturnmond

Rhea

Ø 1530 km
50% Eis
50% Silikate

Voyager 1
1980

Deep Impact Mission



Komet Tempel 1

67 Sek nach der Kollision mit dem Impaktor

Krater ø 100-250 m, 30 m tief

kinetische Energie ~ 5 Tonnen TNT

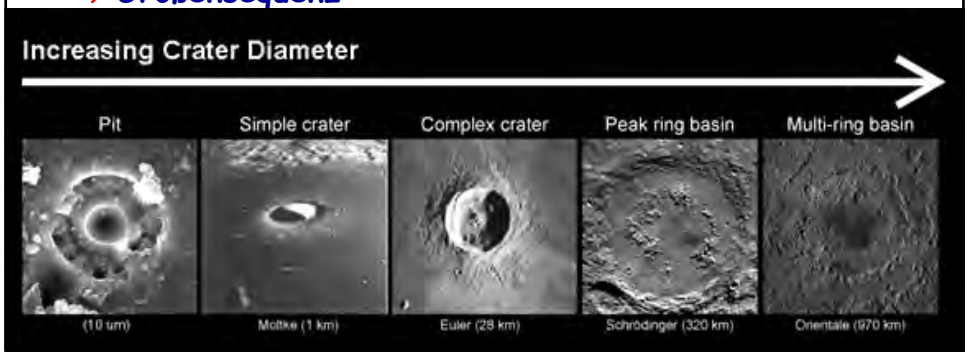
©NASA 2005-2007

Planetare Krusten - Impaktkrater

Fernerkundungsdaten & Weltraummissionen

- Kratergröße von x µm (z.B. Spaceshuttlefenster; Aerogel/ Al-Folie Stardust-Misson) bis >2000 km (z.B., South Pole-Aitkins-Becken – Erdmond; Valhalla – Callisto)

⇒ **Größensequenz**



Morphology of impact craters

increasing size

simple bowl-shaped crater

pre-historic **meteor craters** with remnants of the projectile

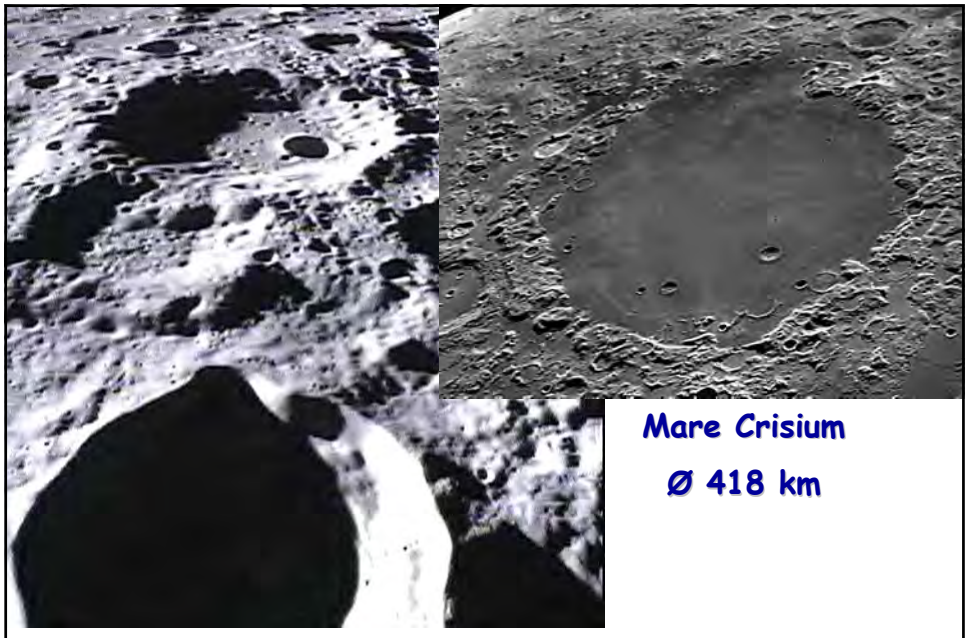
crater with a central uplift

peak ring crater

multi-ring impact structure (Multi-Ringbecken)

this size-related succession is valid for all planetary bodies

anomalously shaped craters



Mare Crisium

Ø 418 km

Mondhochland Rückseite

GRAIL ©NASA <42 km>

footootjes.nl/Astrophotography_Lunar/Astrophotography_Lunar.html

Planetare Krusten - Impaktkrater

Fernerkundungsdaten & Weltraummissionen

- Kratergröße von x µm bis >2000 km

  ⇒ **Größensequenz**

- Superposition (Überlagerung) von Impaktkratern auf planetaren Oberflächen

⇒ **Altersabfolge**

- unterschiedliche Kraterdichte (Häufigkeit/Flächeneinheit) auf planetaren Oberflächen

⇒ **Zeitfaktor**

Planetare Krusten - Impaktkrater

Fernerkundungsdaten & Weltraummissionen

- Abnahme von Impakthäufigkeit wie Projektilgröße seit der Bildung des Sonnensystems

⇒ **Änderung der „Kollisionsrate" (Impakthäufigkeit pro Zeiteinheit)**

⇒ **nicht lineare Änderung von extrem hohen zu den niedrigen heutigen Werten**

- Änderung der Kollisionsrate mit der Zeit

⇒ **Impaktkraterstatistik liefert eine relative, eichbare Zeitskala für die geologische Entwicklung planetarer Körper.**

⇒ **crater retention ages**

Planetare Krusten - Impaktkrater

Fernerkundungsdaten & Weltraummissionen

- Kratergröße

⇒ **Größensequenz**

- Superposition

⇒ **Altersabfolge**

- Kraterdichte

⇒ **Zeitfaktor**

- Kraterform

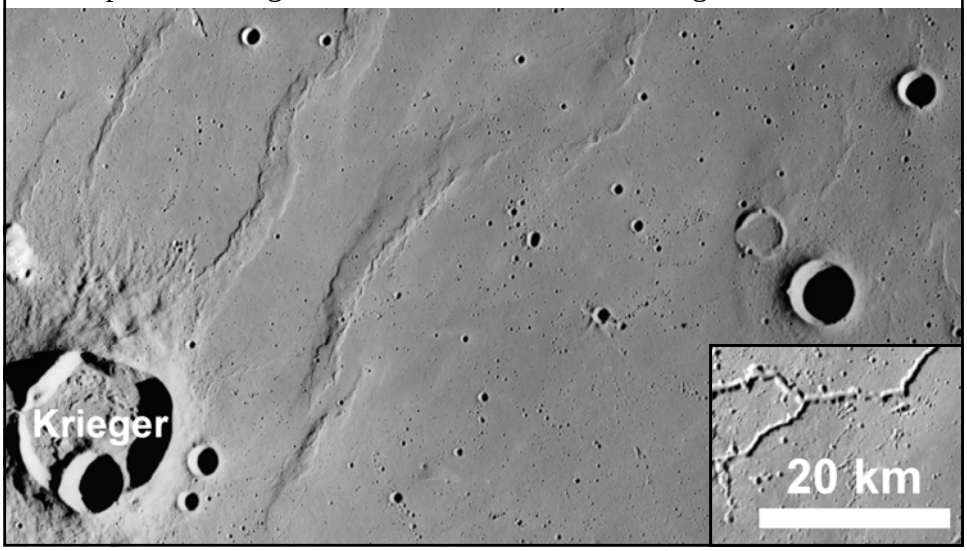
⇒ **Größe & Einfallswinkel des Projektils, (alte Bruchmuster)**

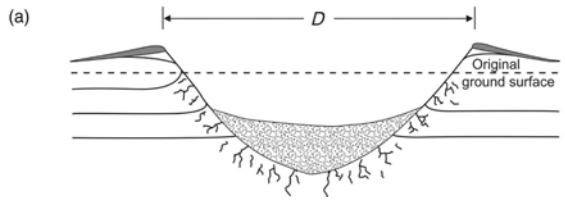
- Variation der Kraterform und/oder der Auswurfsdecke

⇒ **Materialbeschaffenheit des Targets, Lagenbau**

Crater morphology
simple bowl shaped

Apollo 15 image AS15-M-2081 Rimae Prinz region © NASA





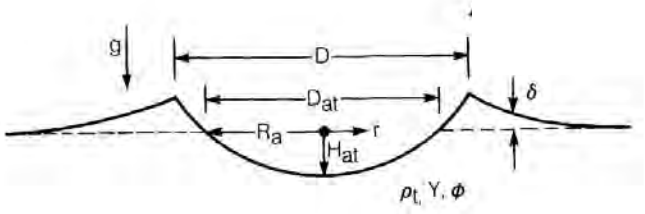
Ejecta (impact melt rocks and/or impact breccias)

Crater-fill deposits (impact melt rocks and/or impact breccias)

Impact Cratering: Processes and Products, First Edition. Edited by Gordon R. Osinski and Elisabetta Pierazzo.
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Figure 4.1 Typical schematic cross-sections of a simple (a) and complex crater (b). Note that ballistic ejecta is present inside the crater rim in complex craters because it originates from the transient cavity, which is largely destroyed during crater collapse. *D* is the rim (or final crater) diameter, which is defined as the diameter of the topographic rim that rises above the surface for simple craters, or above the outermost slump block not concealed by ejecta for complex craters (Turtle *et al.*, 2005).

Crater morphology – simple crater



D = Durchmesser am Kraterrand, rim-to-rim diameter

D_{at} = scheinbarer D, apparent D (Erosion!!)

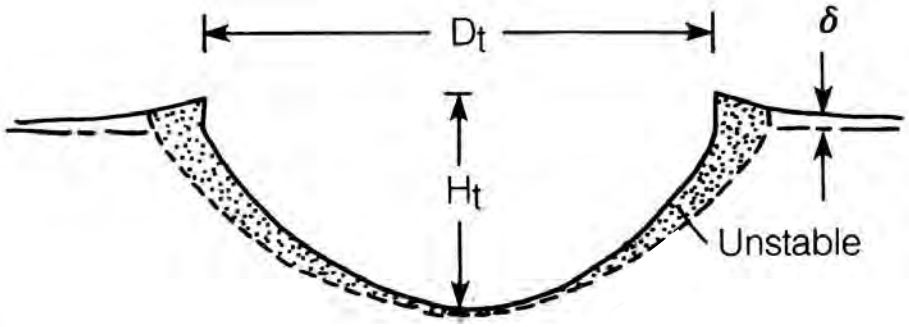
R_a = $D_{at}/2$ (r = Distanz zum Kraterzentrum)

H_{at} = Kratertiefe, apparent depth (Brekzienlinse!!)

δ = Mächtigkeit der Auswurfsdecke, thickness of ejecta blanket

g = „Erd“beschleunigung, acceleration of gravity

Morphology – simple bowl-shaped crater

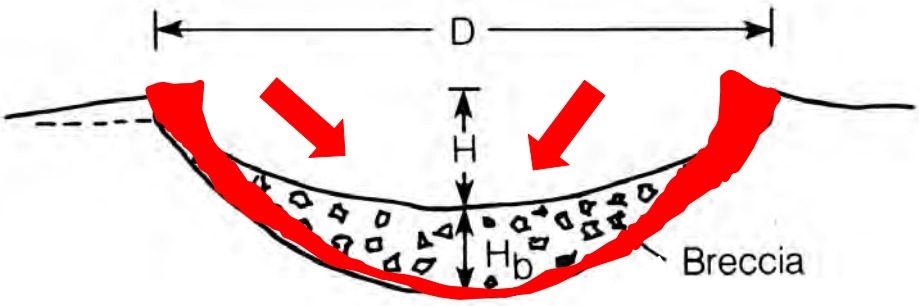


D_t = Durchmesser, diameter

H_t = Tiefe der vorübergehenden Kraterhohlform, transient crater

δ = Mächtigkeit des Auswurfes, ejecta thickness

Morphology – simple bowl-shaped crater



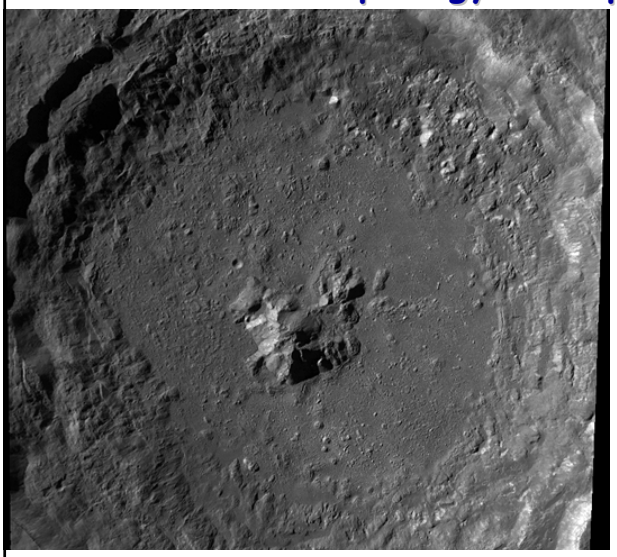
D = Durchmesser am Kraterrand, rim-to-rim diameter

H = Kratertiefe, depth

H_b = Mächtigkeit der Brekzienlinse, breccia lens thickness

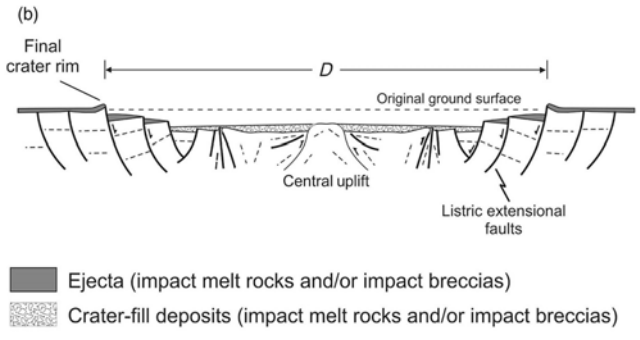
Abrutschung/Abgleiten, slumping

Crater morphology – complex crater



Erdmond
Tycho
Ø 85 km
~ 100 Ma

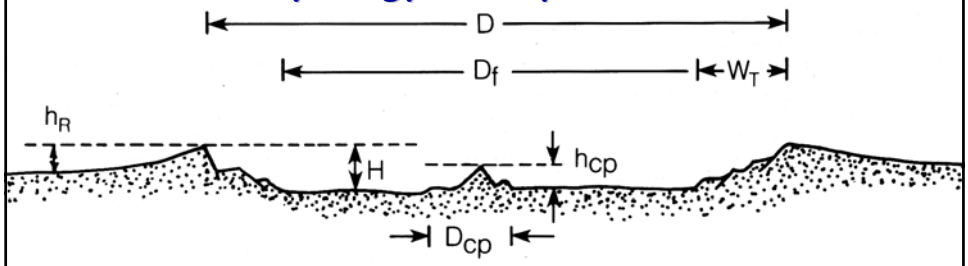
LROC WAC © NASA/Goddard/Arizona State University
http://wms.selene.jaxa.jp/selene_viewer/en/observation_mission/tc/012/tycho_20mbps.html



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Figure 4.1 Typical schematic cross-sections of a simple (a) and complex crater (b). Note that ballistic ejecta is present inside the crater rim in complex craters because it originates from the transient cavity, which is largely destroyed during crater collapse. *D* is the rim (or final crater) diameter, which is defined as the diameter of the topographic rim that rises above the surface for simple craters, or above the outermost slump block not concealed by ejecta for complex craters (Turtle *et al.*, 2005).

morphology – complex crater



D = Durchmesser am Kraterrand, rim-crest diameter

D_f = D des Kraterbeckens, D crater floor

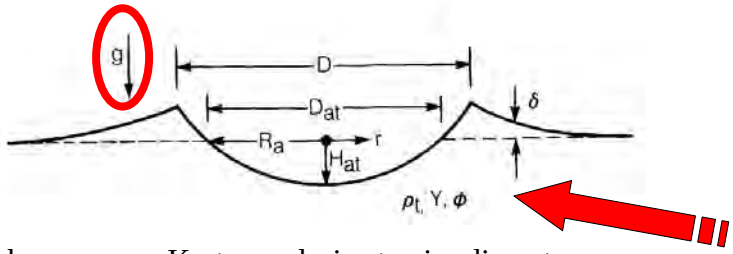
W_t = Breite des terrassierten Kraterrandes, width of the terrace zone

H = Kratertiefe, crater depth

h_{cp}, D_{cp} = Höhe, D des Zentralberges (central uplift) auf Höhe des Kraterbeckens

h_r = Höhe des Kraterrandes, crater rim

Crater morphology



D = Durchmesser am Kraterrand, rim-to-rim diameter

D_{at} = scheinbarer D, apparent D (Erosion!!)

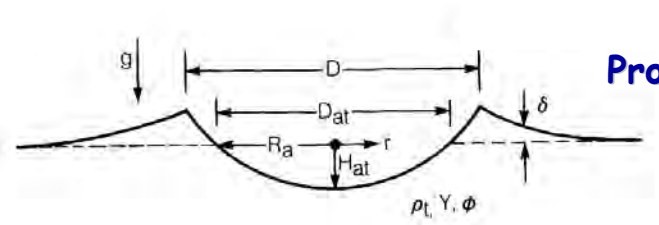
$R_a = D_{at}/2$ (r = Distanz zum Kraterzentrum)

H_{at} = Kratertiefe

δ = Mächtigkeit der Auswurfsdecke, thickness of ejecta blanket

g = „Erd“beschleunigung, acceleration of gravity

Target properties



Projectile

das beaufschlagte Material, target

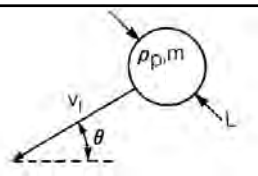
ρ_t = Dichte, density

Y = Materialfestigkeit, yield strength

Φ = Porosität, porosity

+ Korngröße, grain size; H_2O-/Fluidgehalt, H_2O/fluid saturation; Textur, texture

Projectile



L = Durchmesser

V_i = Einschlagsgeschwindigkeit, impact velocity

Θ = Einschlagswinkel, angle of impact

ρ_p = Dichte, density

m = Masse

Welche grundlegenden Parameter bestimmen die Morpholgie eines Impaktkraters?

Target	Projektil
ρ_t = Dichte	L = Durchmesser
Y = Druckfestigkeit	V_i = Impaktgeschwindigkeit
Φ = Porosität	Θ = Einschlagswinkel
Korngröße, Textur	ρ_p = Dichte
Fluidgehalt	M = Masse
	W = kinetische Energie

g

Wenige grundlegenden Parameter bestimmen die Morpholgie eines Impaktkraters? W

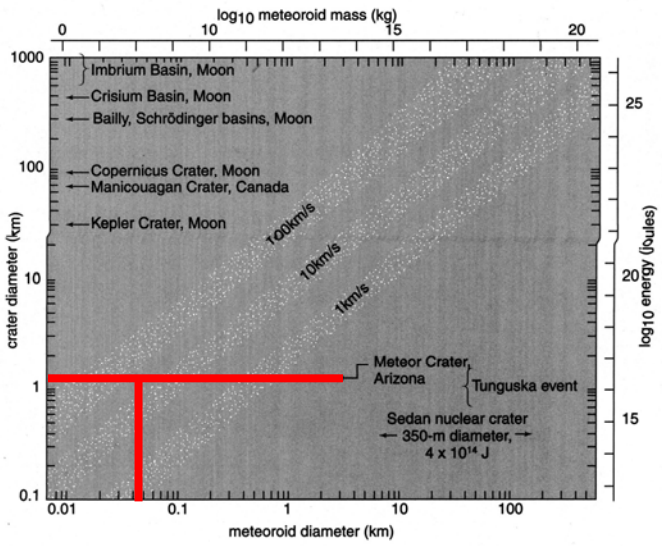
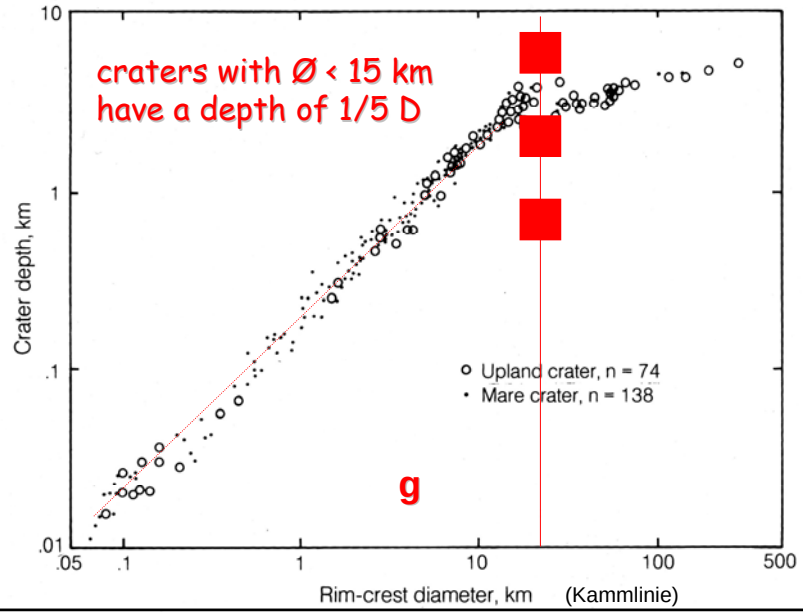
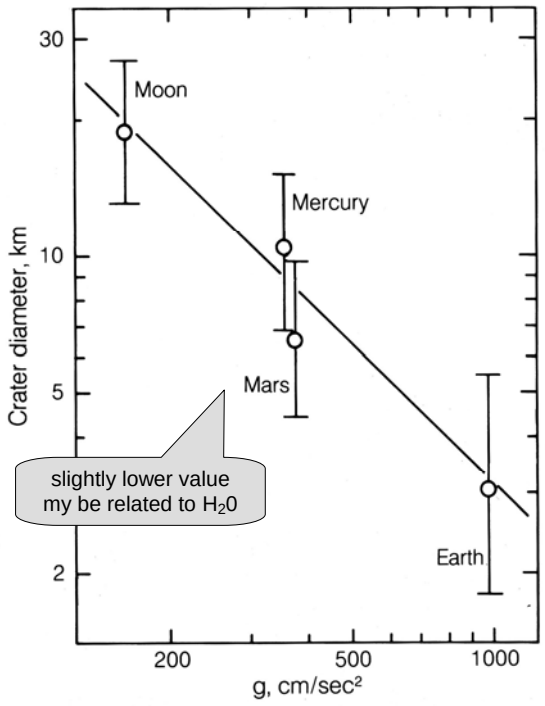


Figure 9-6. The diameter of an impact crater as a function of meteorite size for three different impact velocities. Scale at right gives the estimated energy required to make each crater. Documented craters on Earth and the moon are shown. The assumed meteorite density is 3 g/cm³. (Crater energy and diameter data from Baldwin, 1963; Wasson, 1974, p. 145; Vortman, 1977)

W = kinetische Energie

Moon: transition simple ⇒ complex impact craters





Crater diameter at the simple-to-complex transition

=

f (1/g)

g

Kollisionen im Sonnensystem

- sind der grundlegende Prozess der Akkretion (d.h., Akkumulation von Materie zur Bildung unterschiedlich großer Körper);

Wir leben in der Spätphase der Akkretion!

(Kosmischer Staub, Mikrometeorite, Meteorite, Impakte)

- verursachen die Entstehung „neuer" planetarer Körper (z.B. Asteroide, Monde);
- steuern die dynamische Entwicklung planetarer Körper (Einfluss auf Umlaufbahnen und retrograde Rotation, z.B. Venus, Neptunmond Triton);
- dominieren die geologische Entwicklung der Krusten terrestrischer planetarer Körper (vor allem im Zeitraum 4.56 -> ~3.6 Ga).