Impact Craters on Earth and in the Solar System

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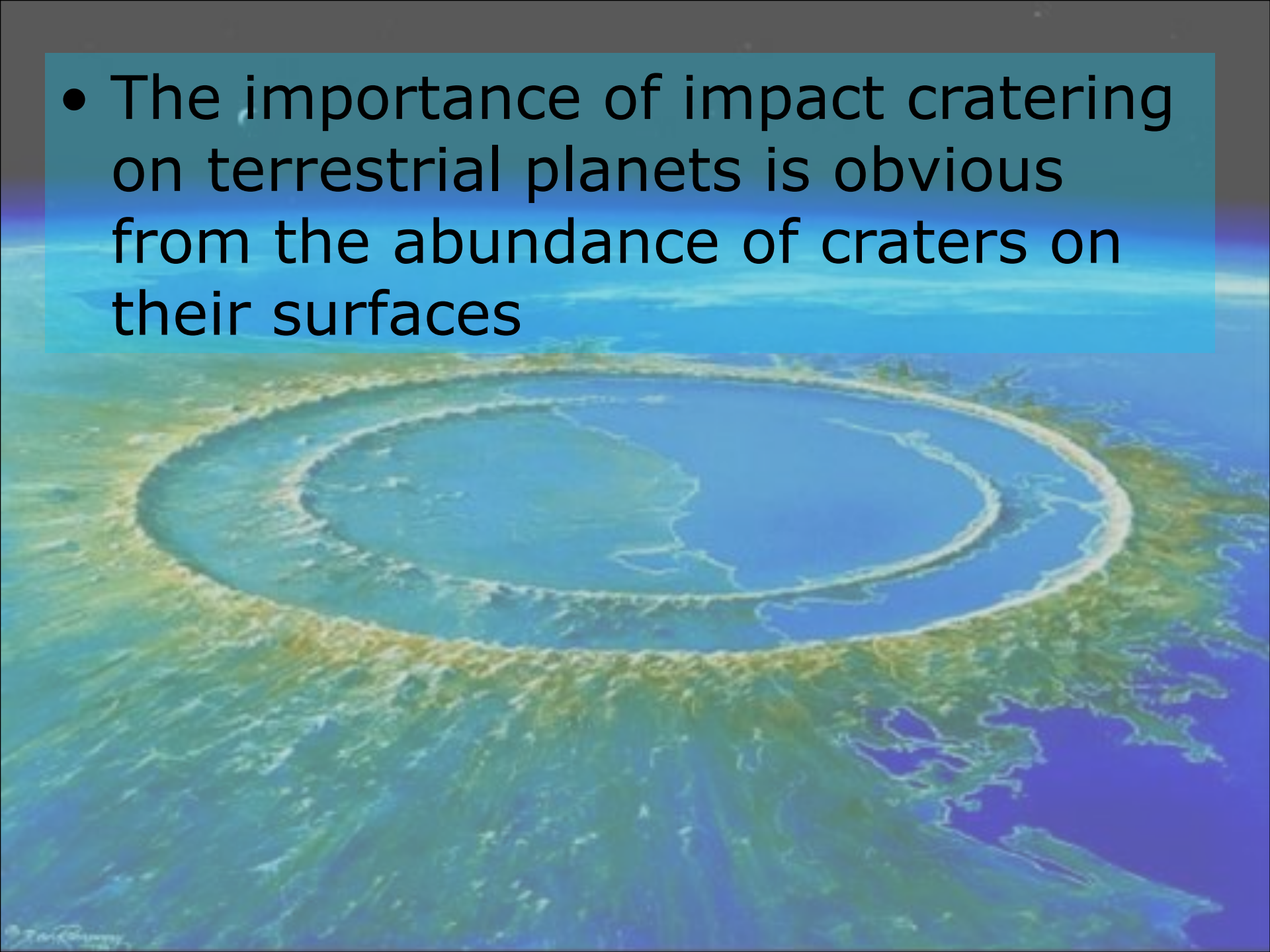
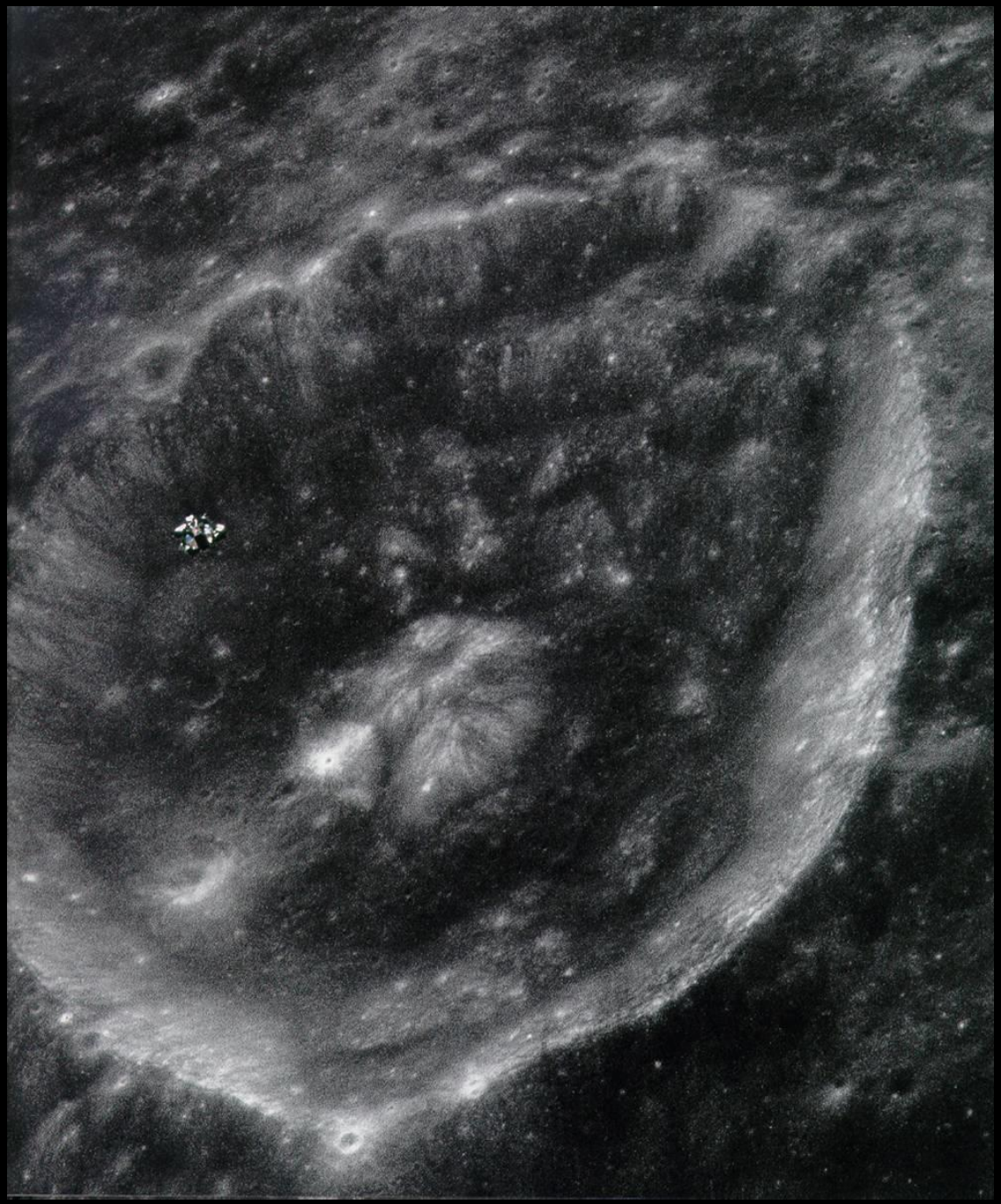
- The importance of impact cratering on terrestrial planets is obvious from the abundance of craters on their surfaces



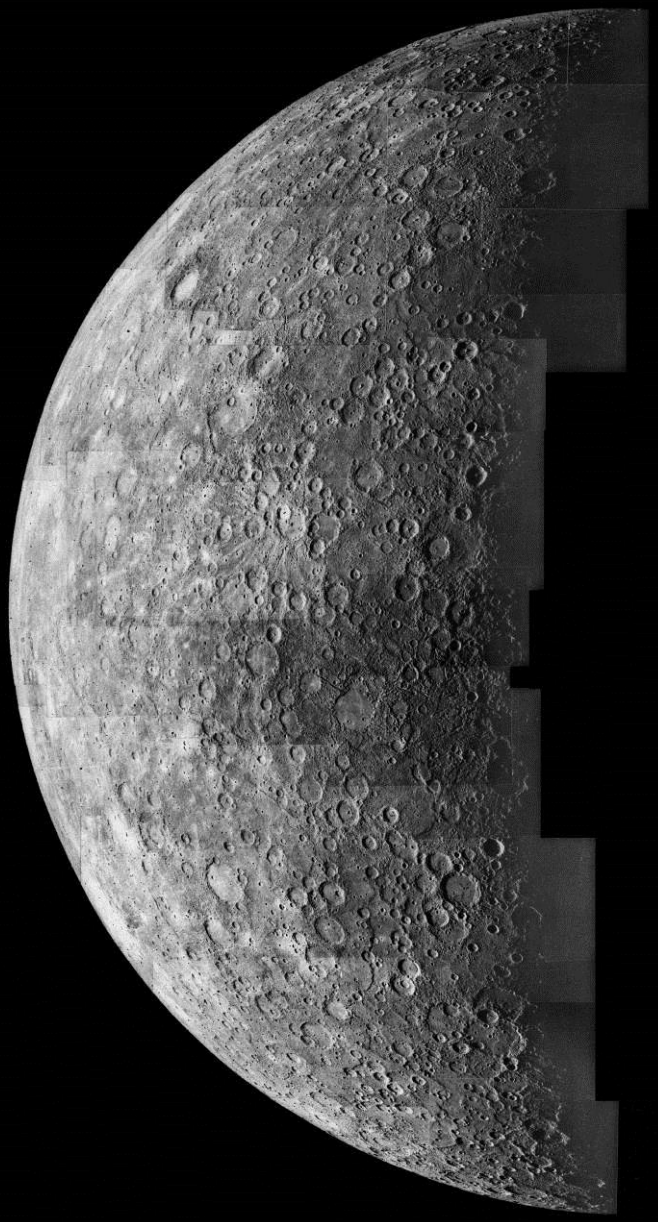
Studying Impact Craters on Earth:

- Only source for ground/truthing impact processes in the solar system
- Connection with early Earth processes – importance for origin and evolution of life
- Importance for, and connection with, mass extinction events
- Exposure of deep crust at central uplifts of large impact structures

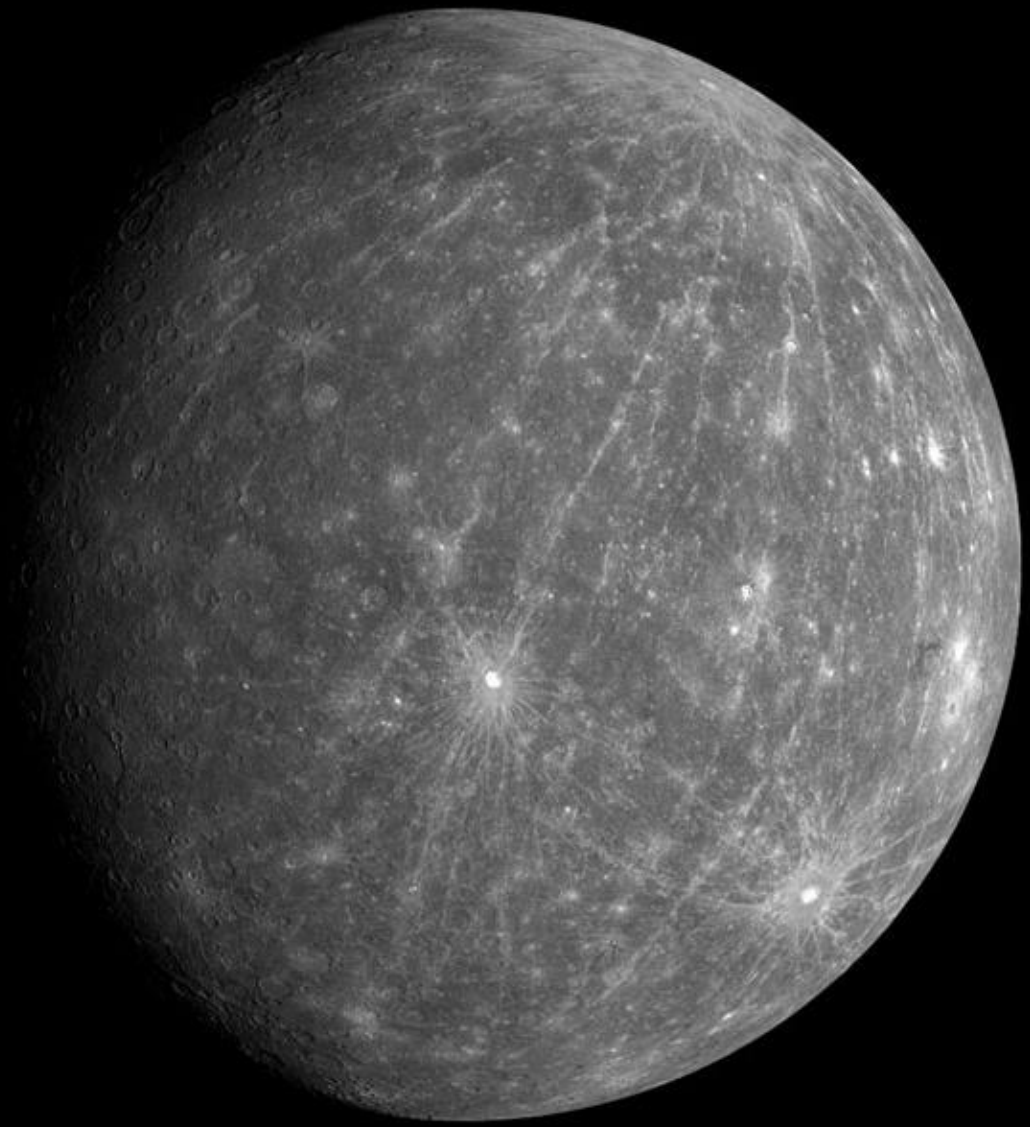


Mercury

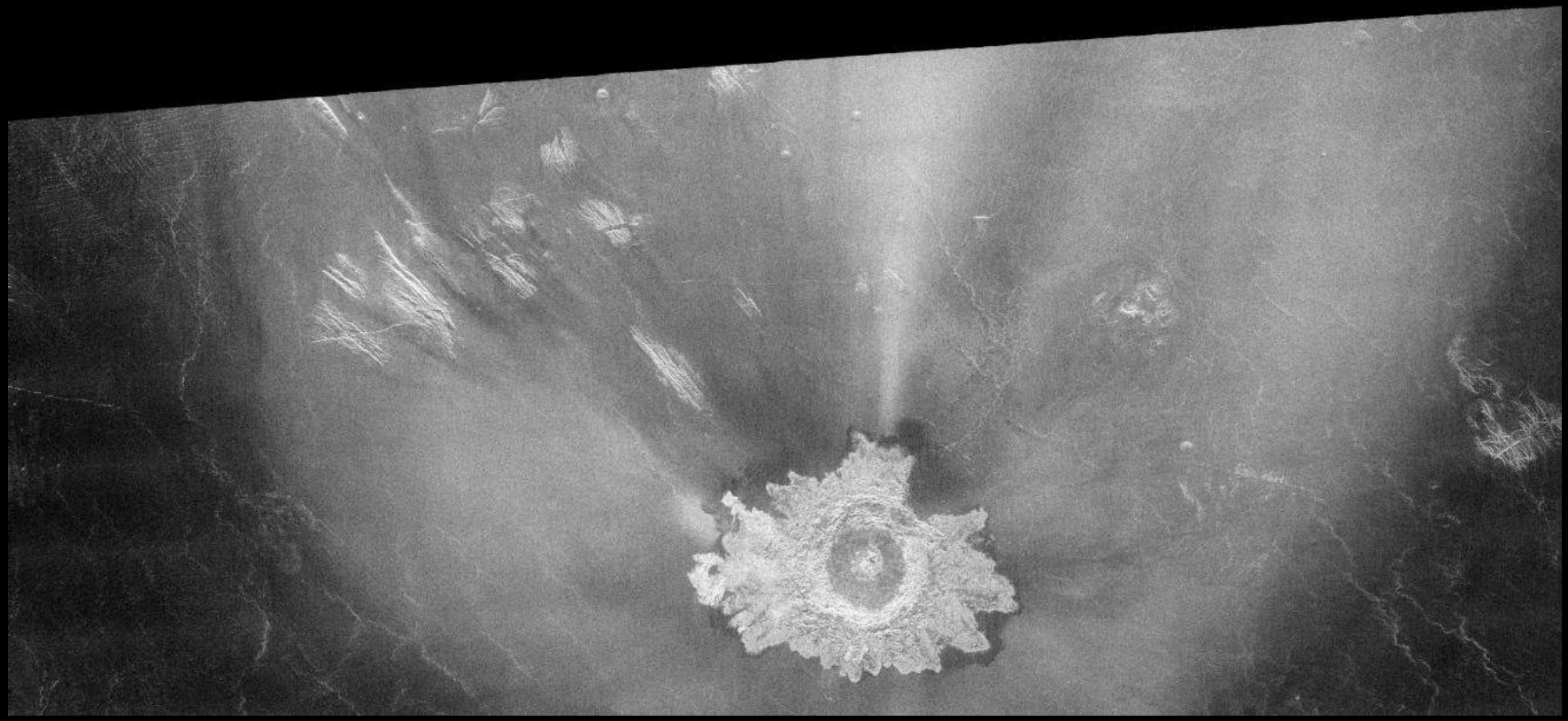
Mariner 10 (1974)



Messenger (2008)



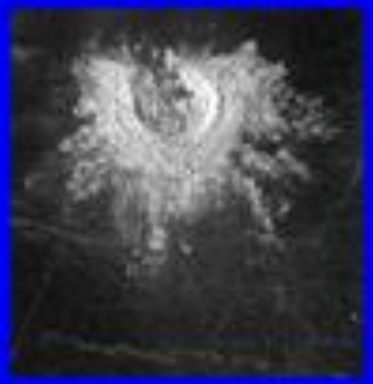
Venus – 30 km crater



4 km

10 km

Margit



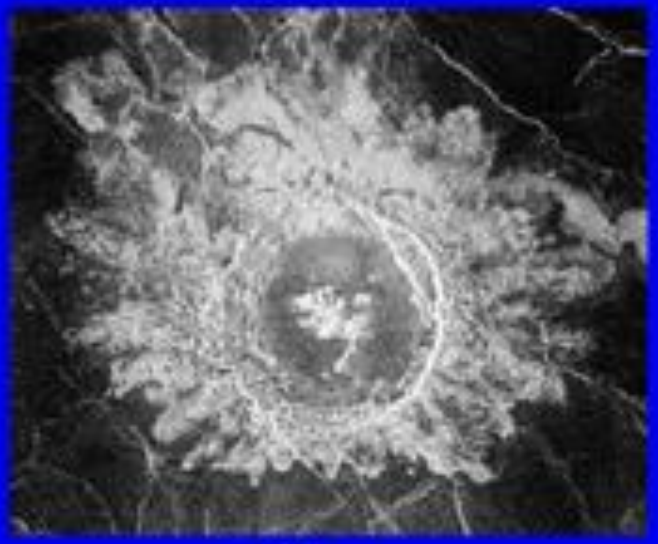
14 km

53 km

Zhilova

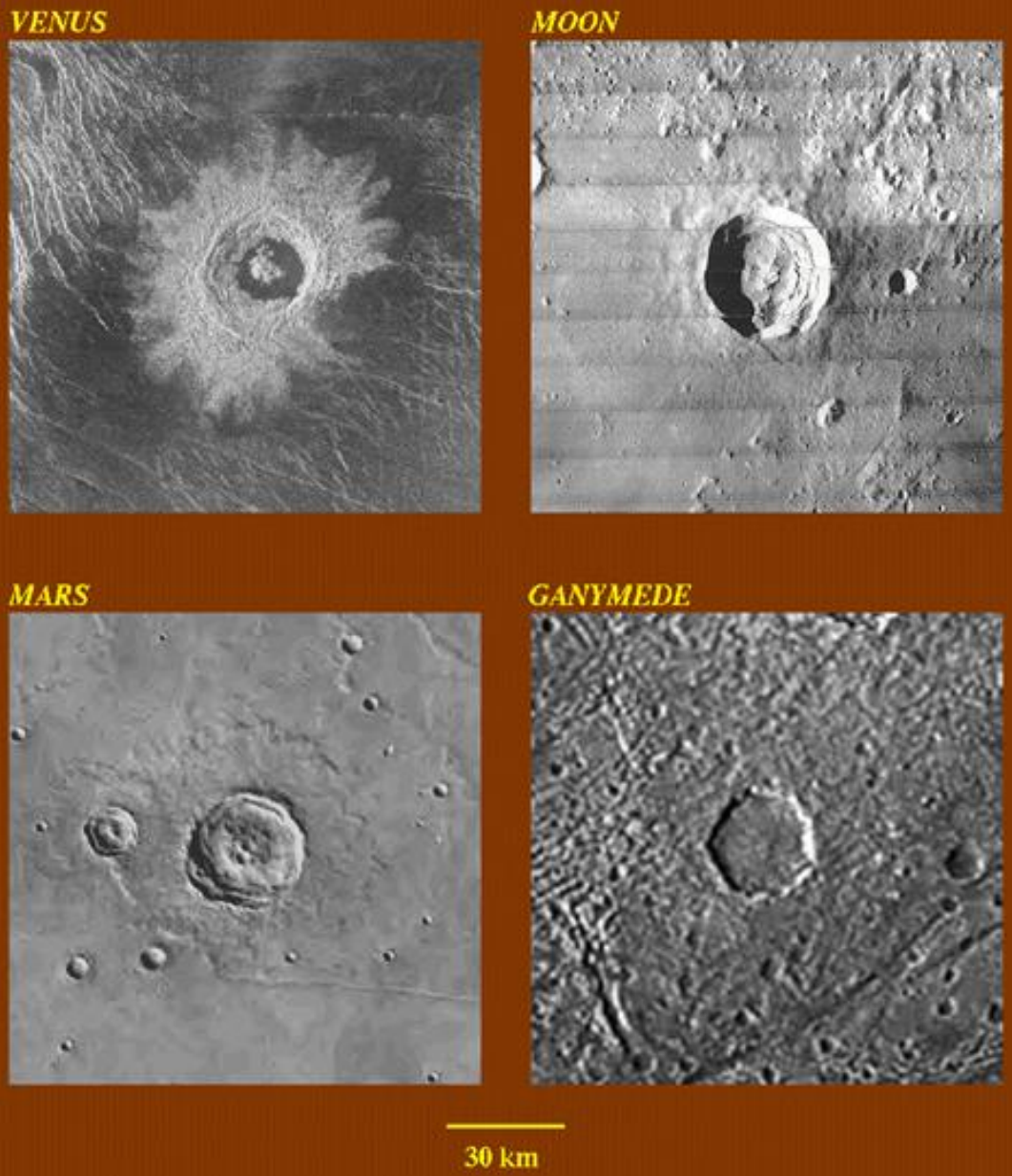
24 km

Sikibu



38 km

Caccini



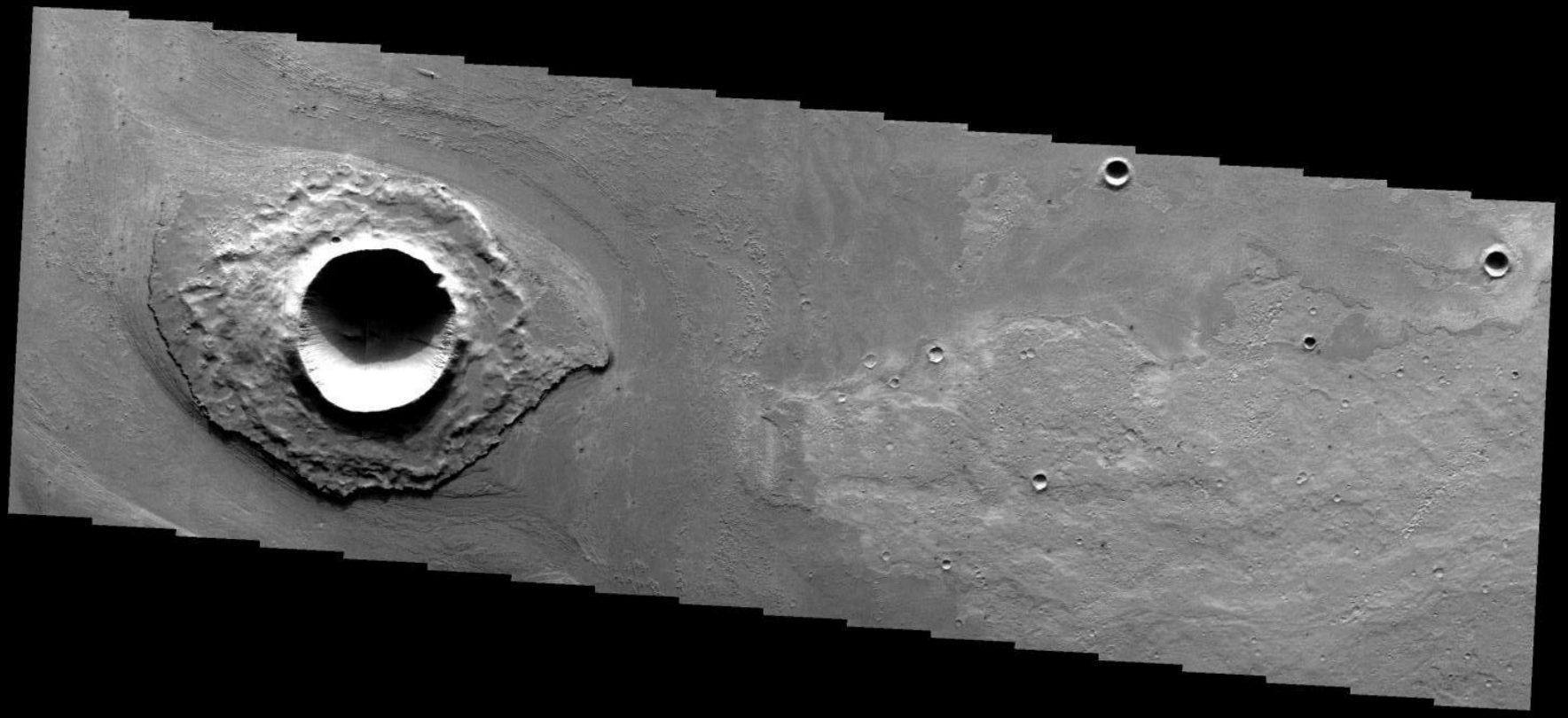
A comparison of ~30-km diameter impact craters on several planetary bodies. All craters are shown at the same scale and have been rotated so that the light source is from the left. This rotation puts north at the bottom of the images of the lunar crater and the Ganymede crater.

Names and locations of the four craters are as follows: Golubkhina (Venus), 60.30N, 286.40E; Kepler (Moon), 8.10N, 38.10W; (Mars), 20.80S, 53.60E; (Ganymede), 29.80S, 136.00W.

Mars

Small simple crater on Mars

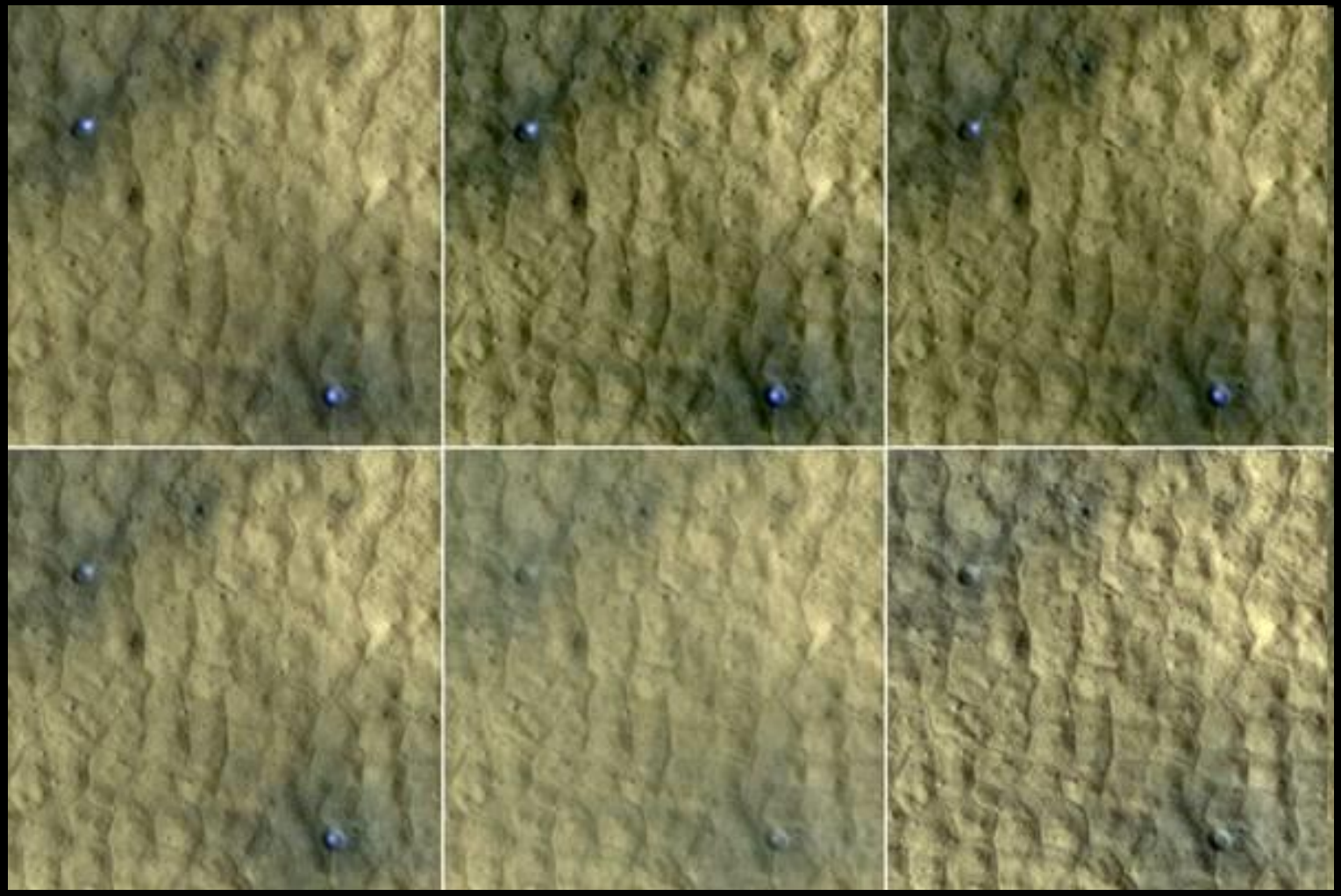
Mars – crater in stream



New impact craters observed on Mars

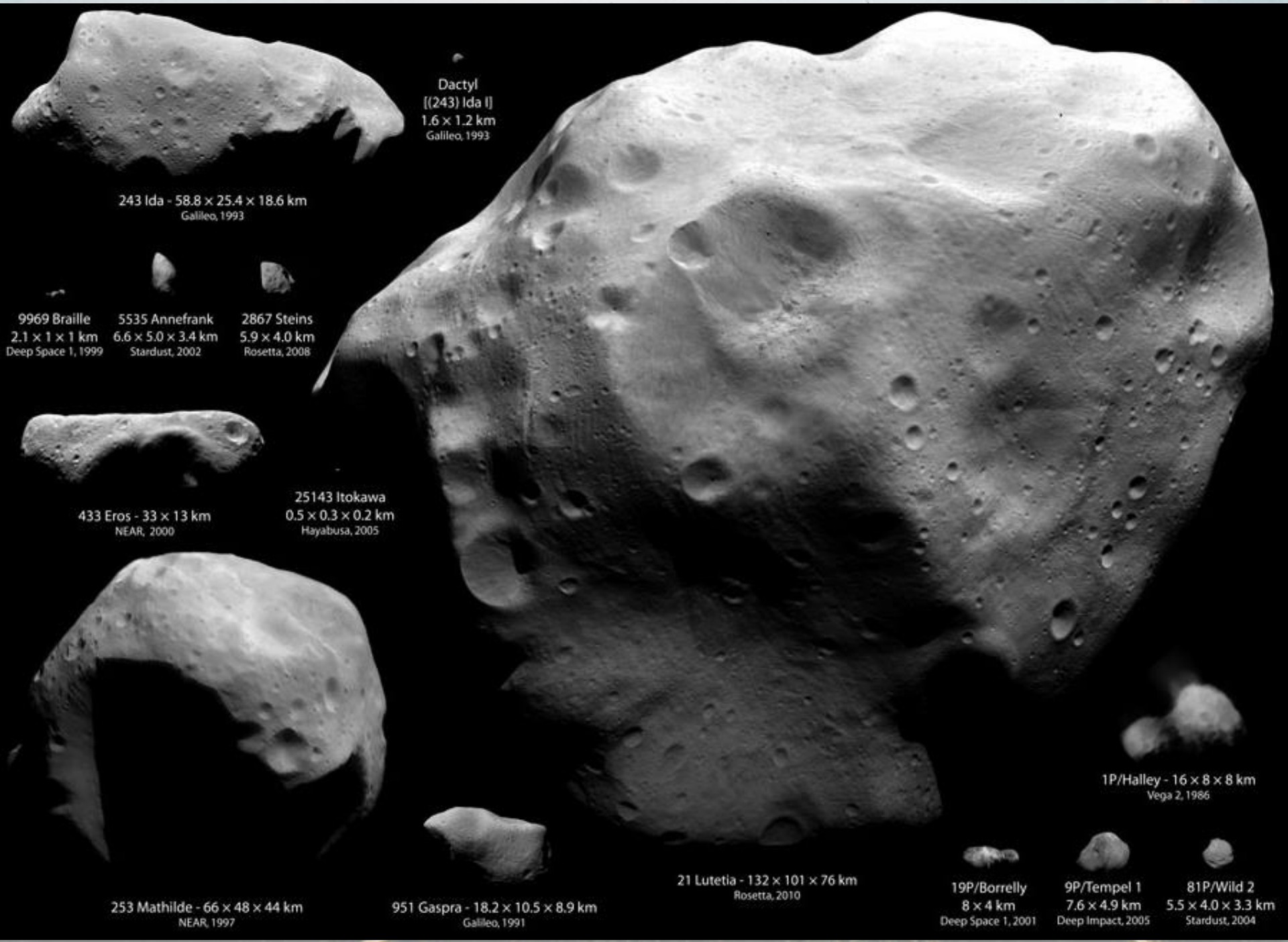
new impact crater south of Echus Chasma, Mars (2011 image; not in 2009 image)

Ice in Pair of Fresh Craters on Mars Fades with Time

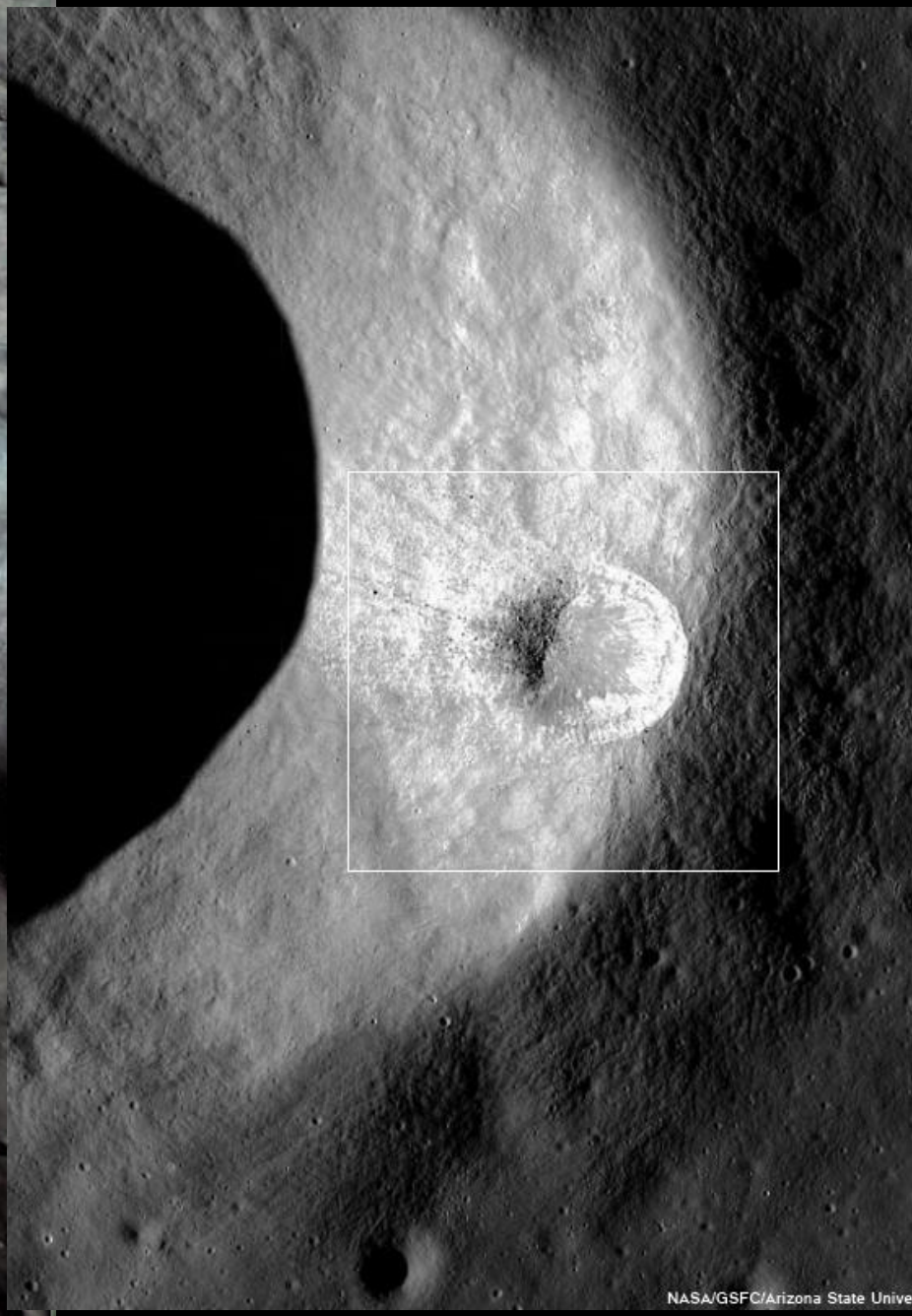


This series of HiRISE images (75 m wide) spanning a period of 15 weeks shows a pair of fresh, middle-latitude craters on Mars in which ice apparent in the earliest images disappears by the later ones. The two craters are each about 4 m in diameter and half a meter deep.

Mathilde and Eros

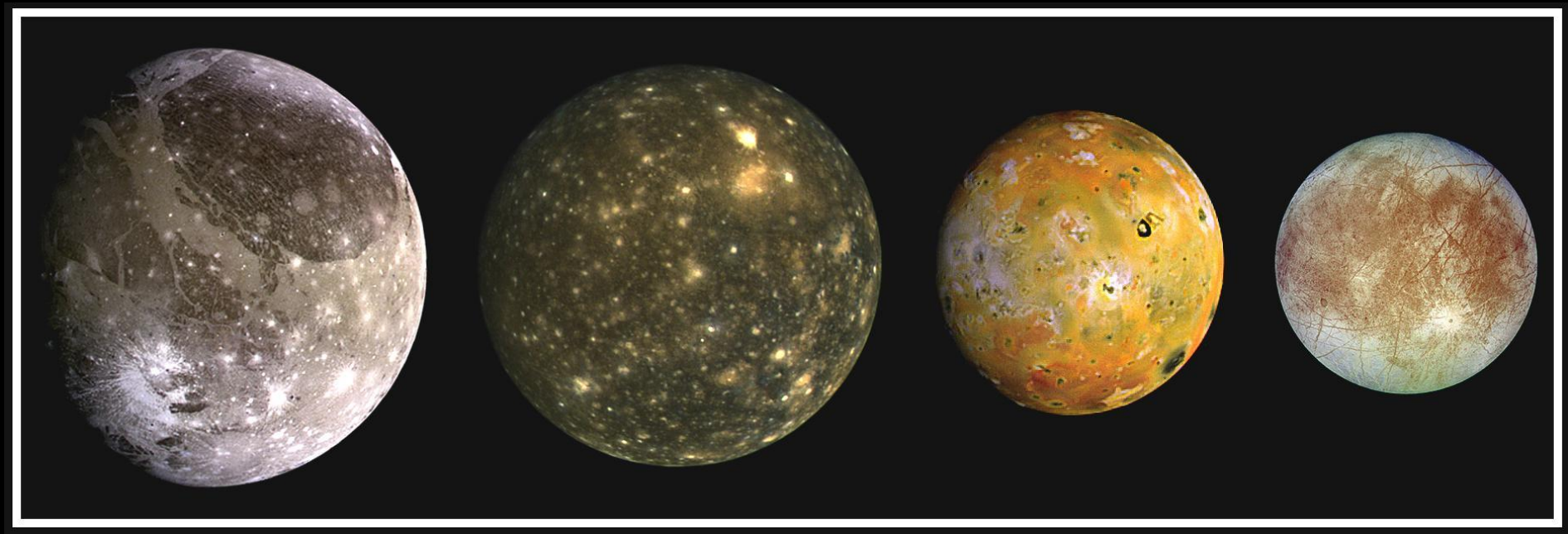

Dactyl
[(243) Ida I]
1.6 × 1.2 km
Galileo, 1993
243 Ida - 58.8 × 25.4 × 18.6 km
Galileo, 1993
9969 Braille
2.1 × 1 × 1 km
Deep Space 1, 1999
5535 Annefrank
6.6 × 5.0 × 3.4 km
Stardust, 2002
2867 Steins
5.9 × 4.0 km
Rosetta, 2008
433 Eros - 33 × 13 km
NEAR, 2000
25143 Itokawa
0.5 × 0.3 × 0.2 km
Hayabusa, 2005
1P/Halley - 16 × 8 × 8 km
Vega 2, 1986
253 Mathilde - 66 × 48 × 44 km
NEAR, 1997
951 Gaspra - 18.2 × 10.5 × 8.9 km
Galileo, 1991
21 Lutetia - 132 × 101 × 76 km
Rosetta, 2010
19P/Borrelly
8 × 4 km
Deep Space 1, 2001
9P/Tempel 1
7.6 × 4.9 km
Deep Impact, 2005
81P/Wild 2
5.5 × 4.0 × 3.3 km
Stardust, 2004

Snowman, Vesta (Dawn)

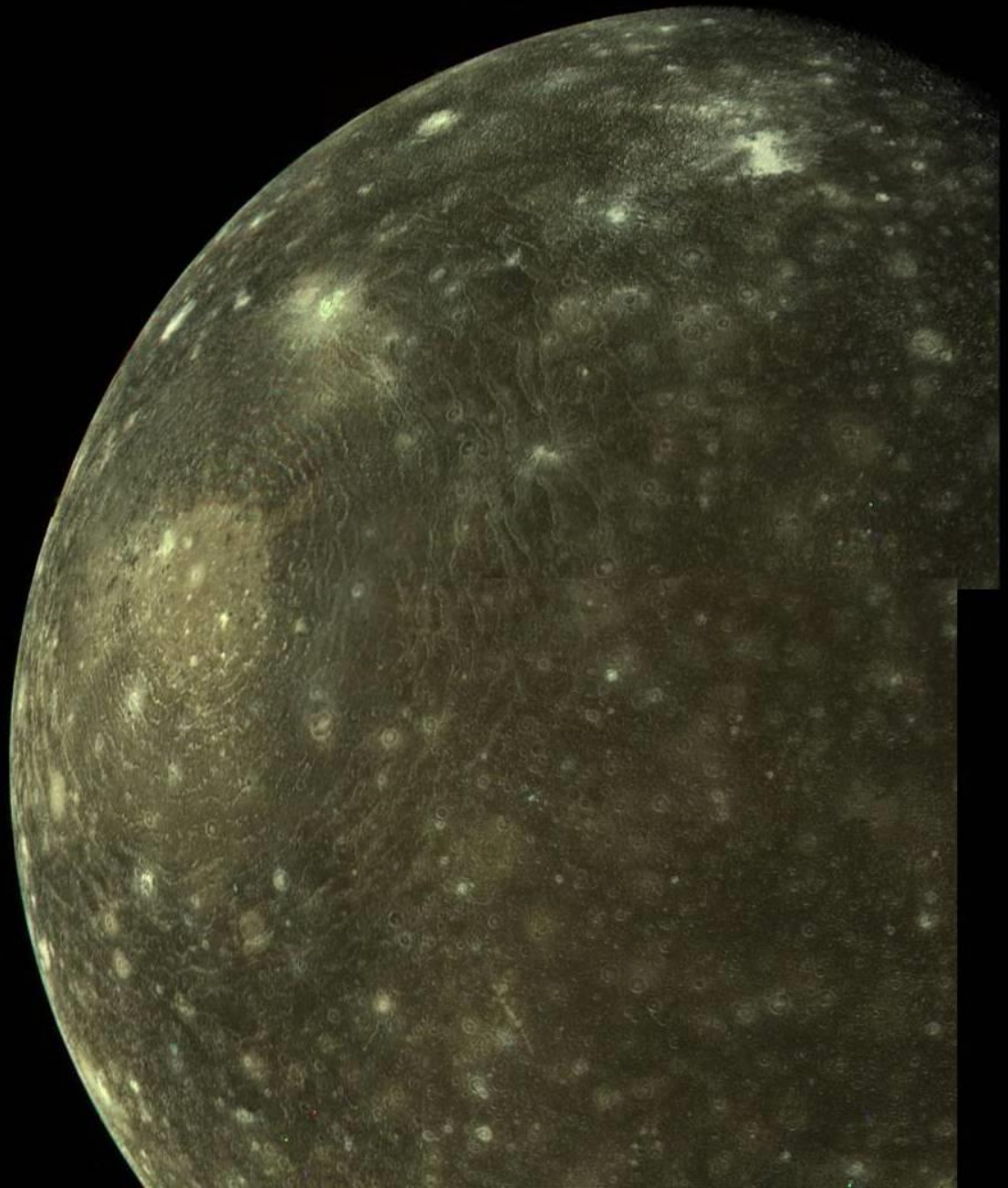


LROC/Herman B, Moon

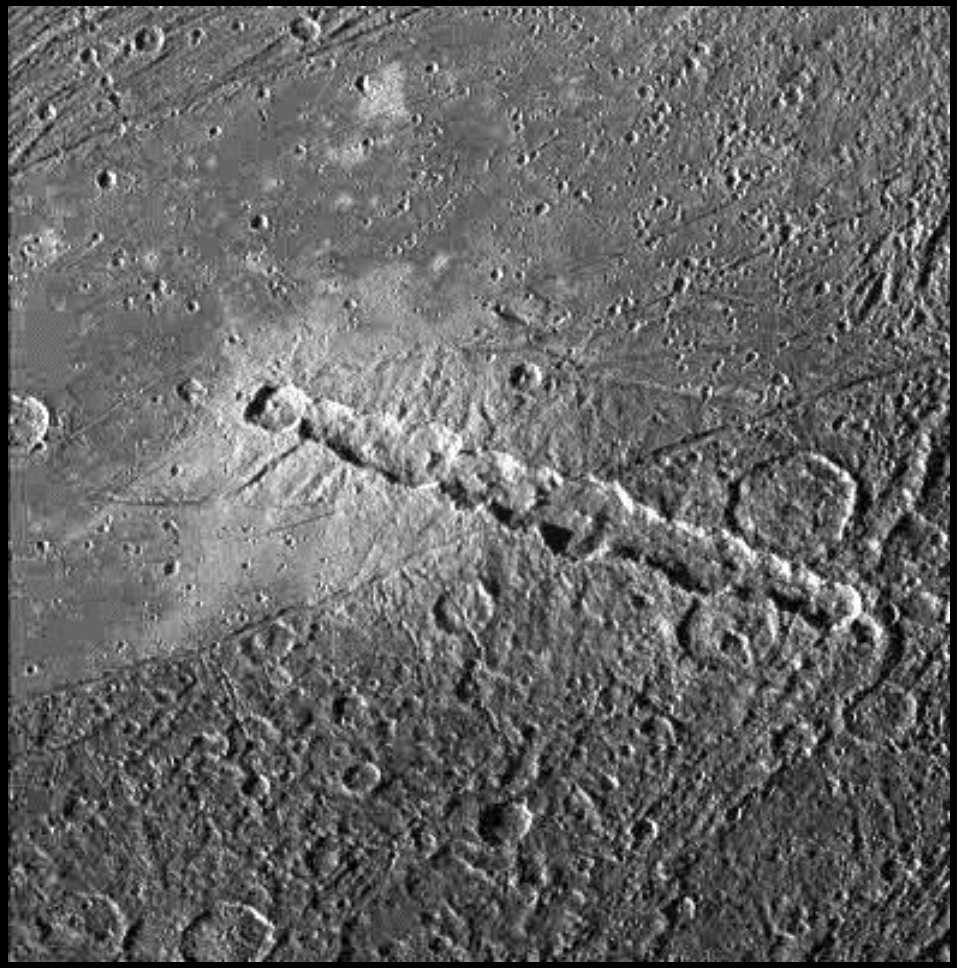
The 4 Galilean Satellites of Jupiter

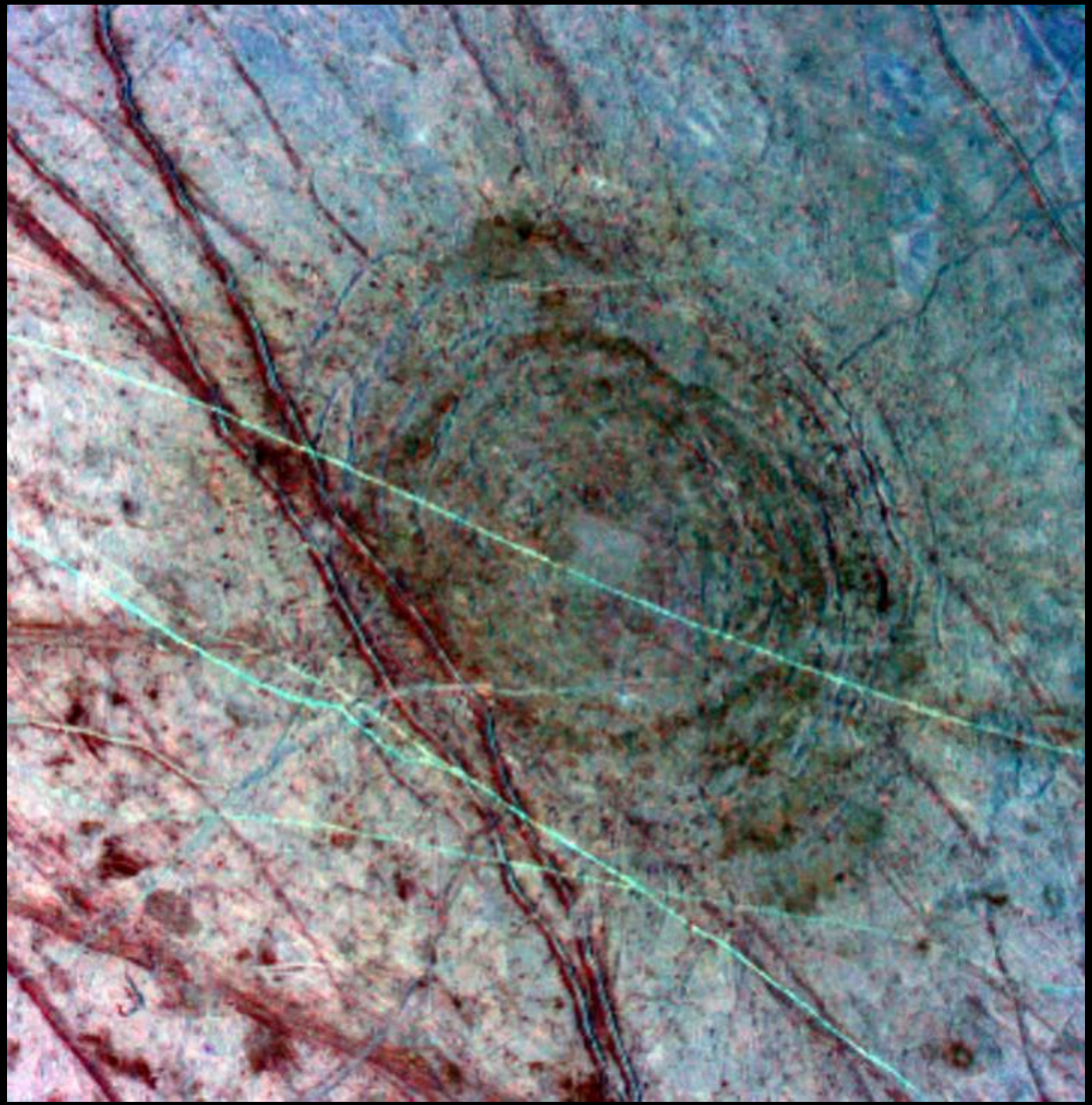


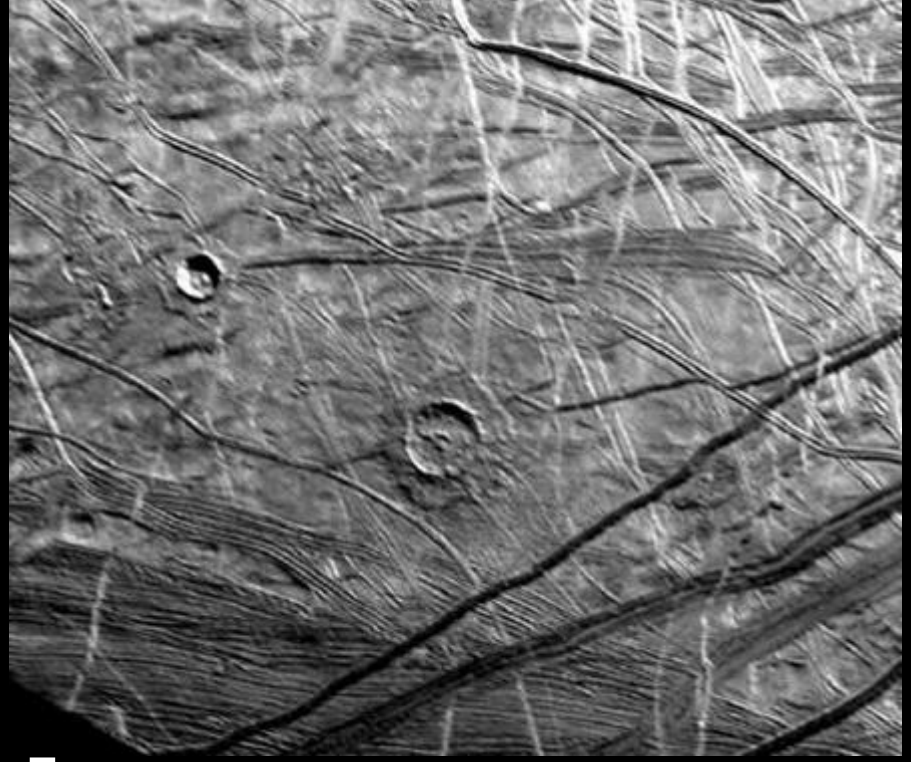
Callisto



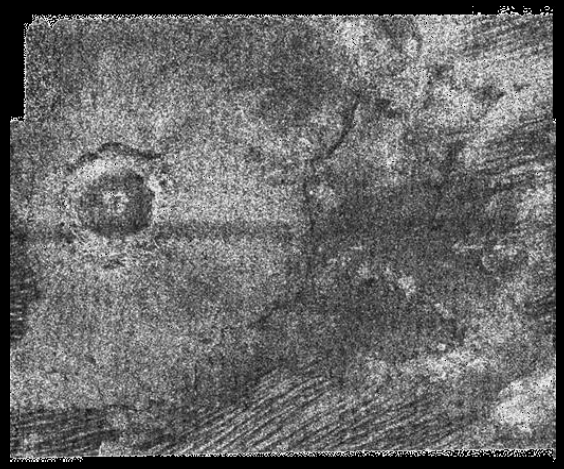
Ganymede crater chain



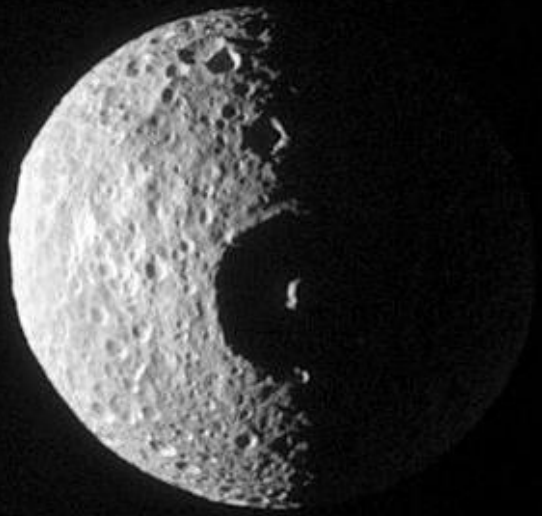




Europa

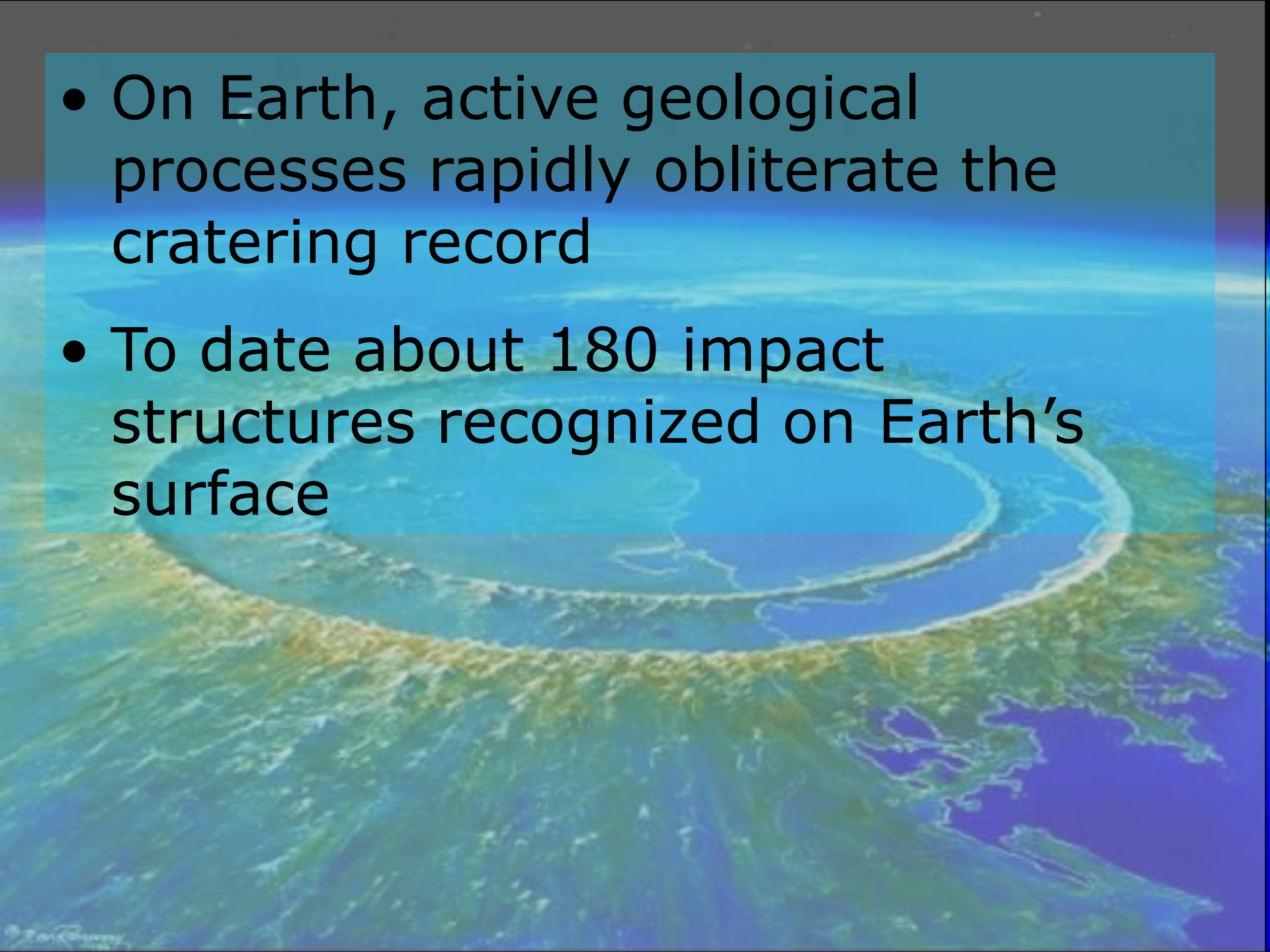


Titan



Mimas

Phoebe



- On Earth, active geological processes rapidly obliterate the cratering record
- To date about 180 impact structures recognized on Earth's surface

Meteor Crater, Arizona

Tenoumer, Mauritania

Roter Kamm, Namibia, 2.5 km

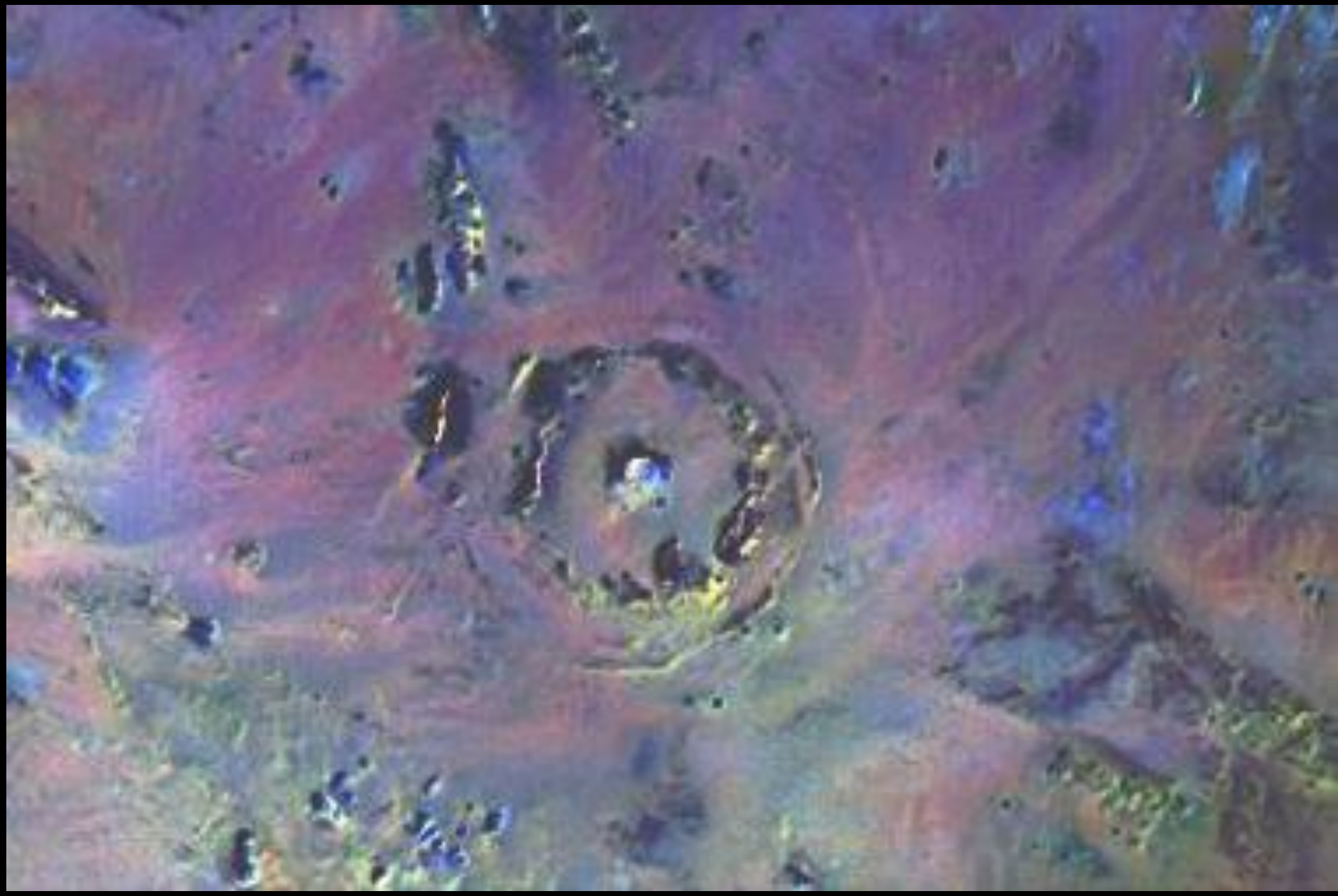
Wolfe Creek, Australia, 0.88 km

Tswaing, South Africa, 1.2 km

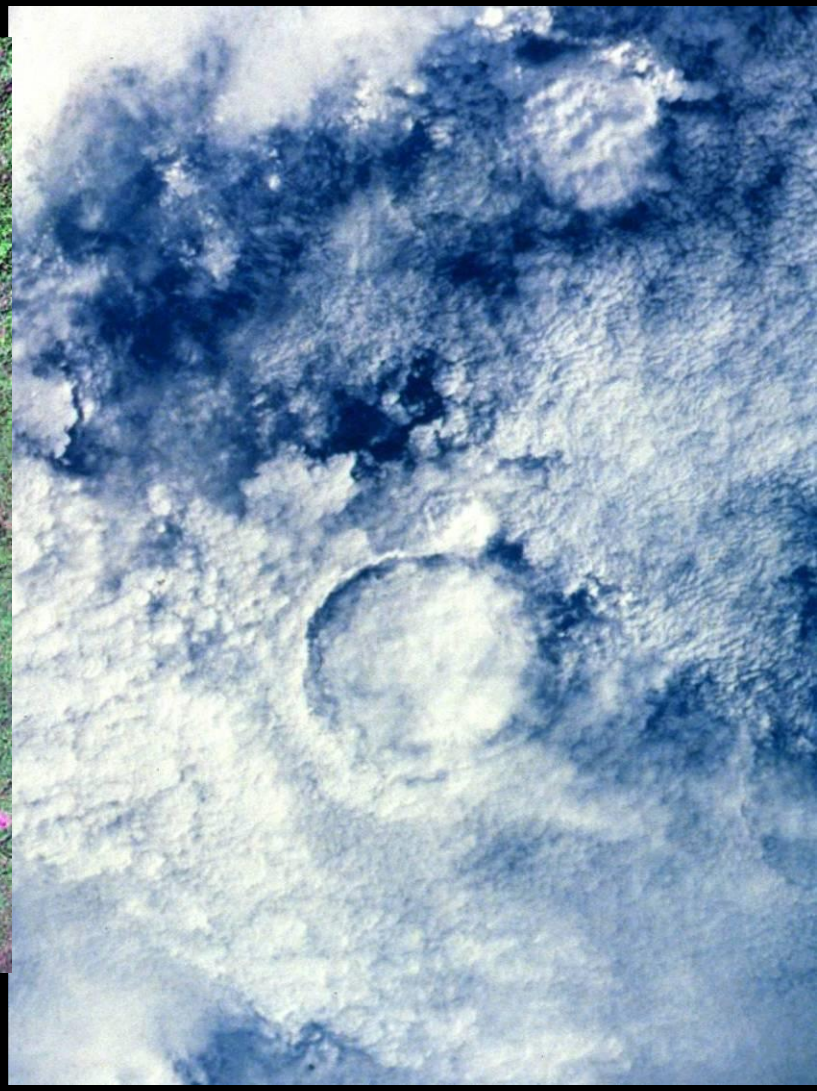
Meteor Crater, USA,
1.2 km

Amguid, Algeria, 1 km

Lonar, India, 1.8 km



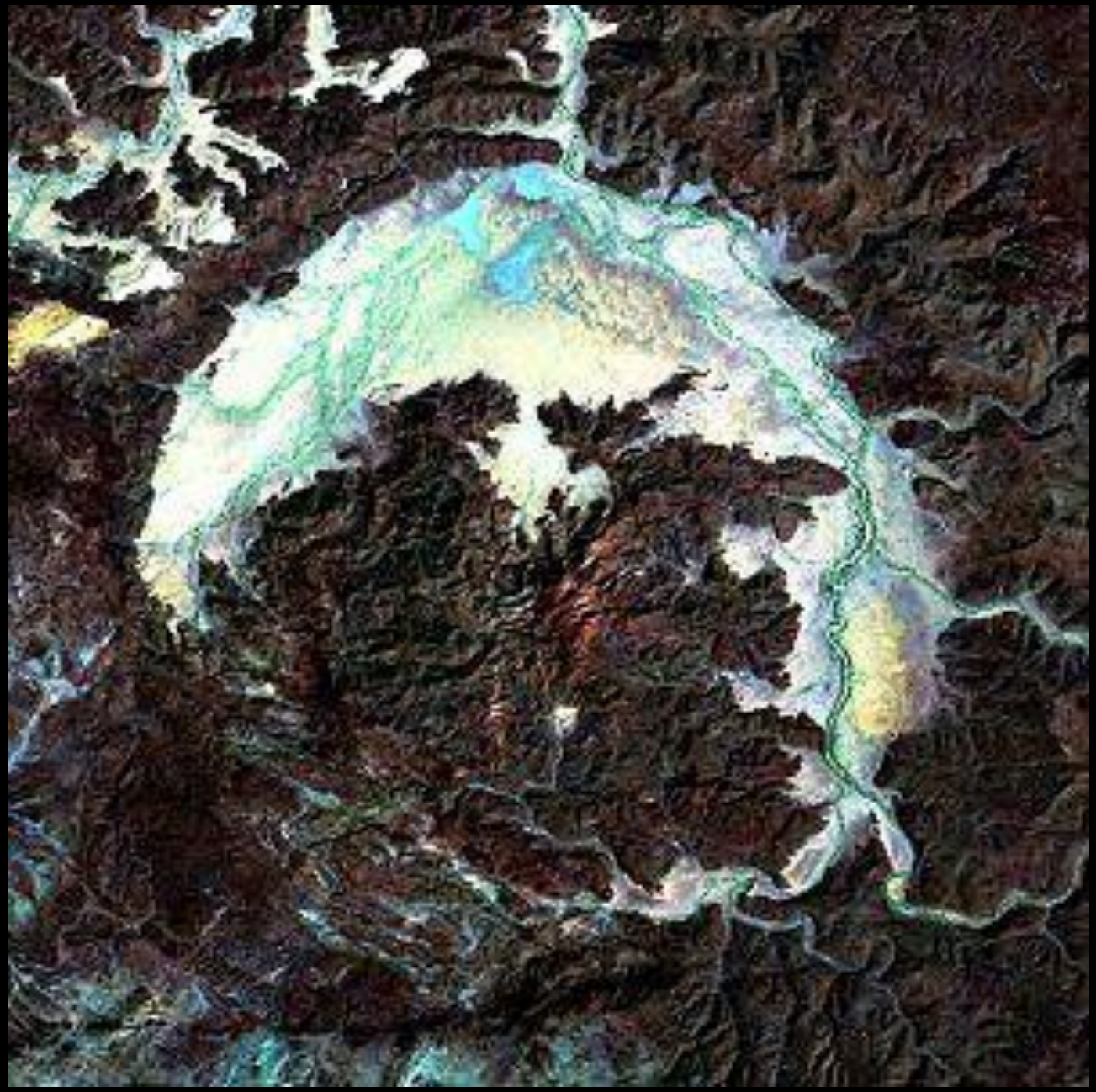
BP, Libya, 2 km



Bosumtwi, Ghana, 11 km

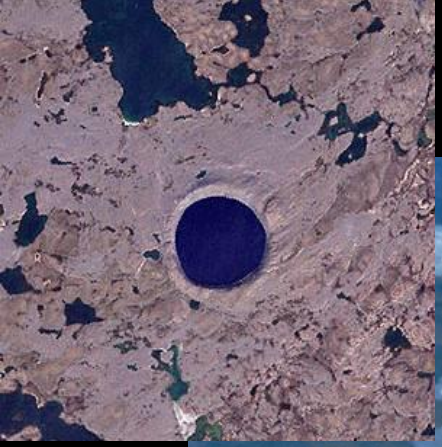
El’gygytgyn, Russia, 18 km

Aorounga, Chad, 18 km



Gweni Fada, Chad, 20 km

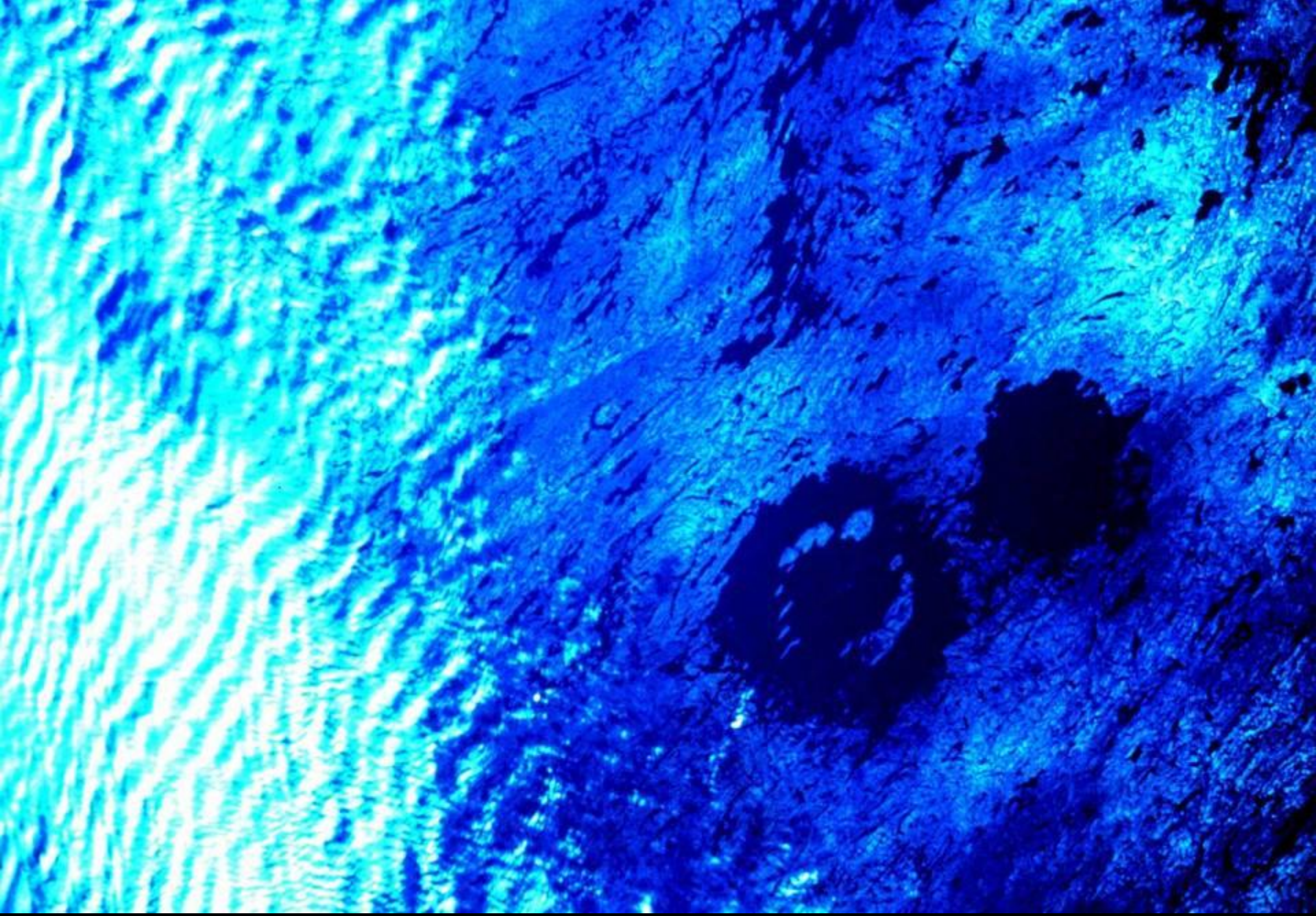
New Quebec, Canada, 3.4 km



New Quebec, Canada, 3.4 km

Summer and Winter

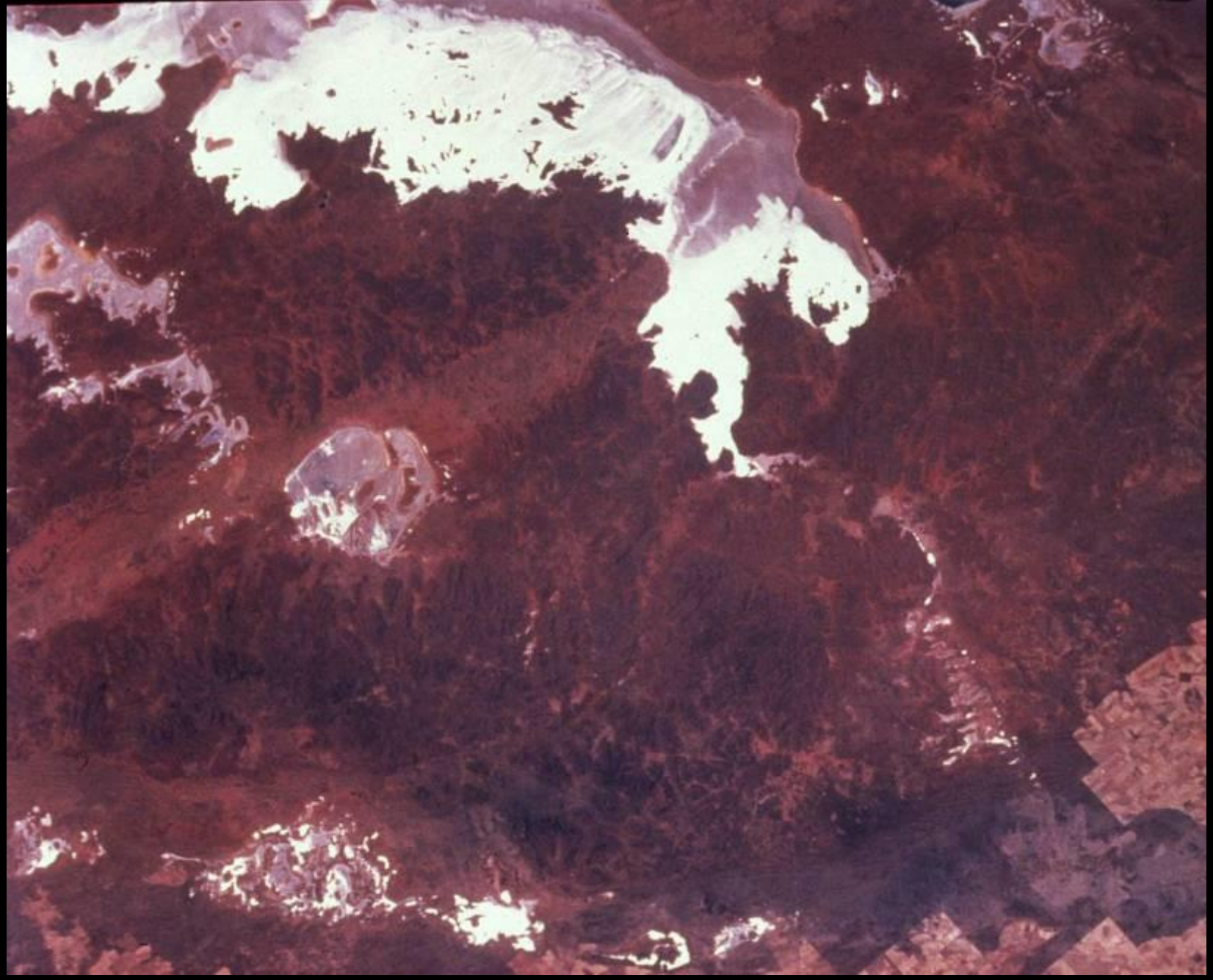
Deep Bay, Canada, 13 km



Clearwater East and West,Canada, 24+32 km

Manicouagan, Canada, 100 km

Gosses Bluff, Australia, 22 km

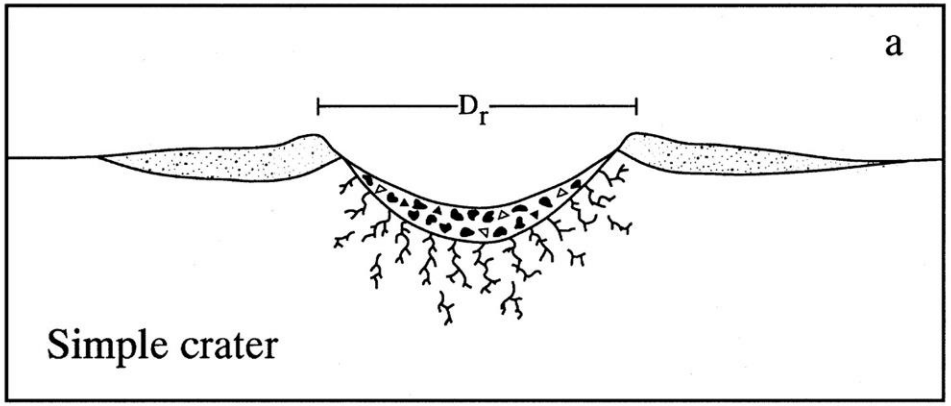


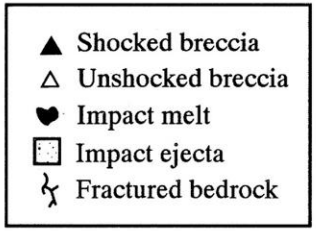
Acraman, Australia, ca. 90 km

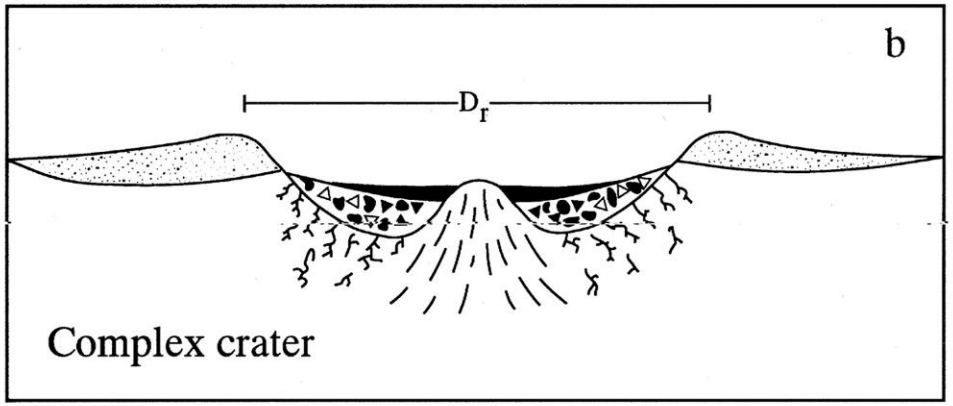
Spider, Australia, 13 km

Teague, Australia, 30 km

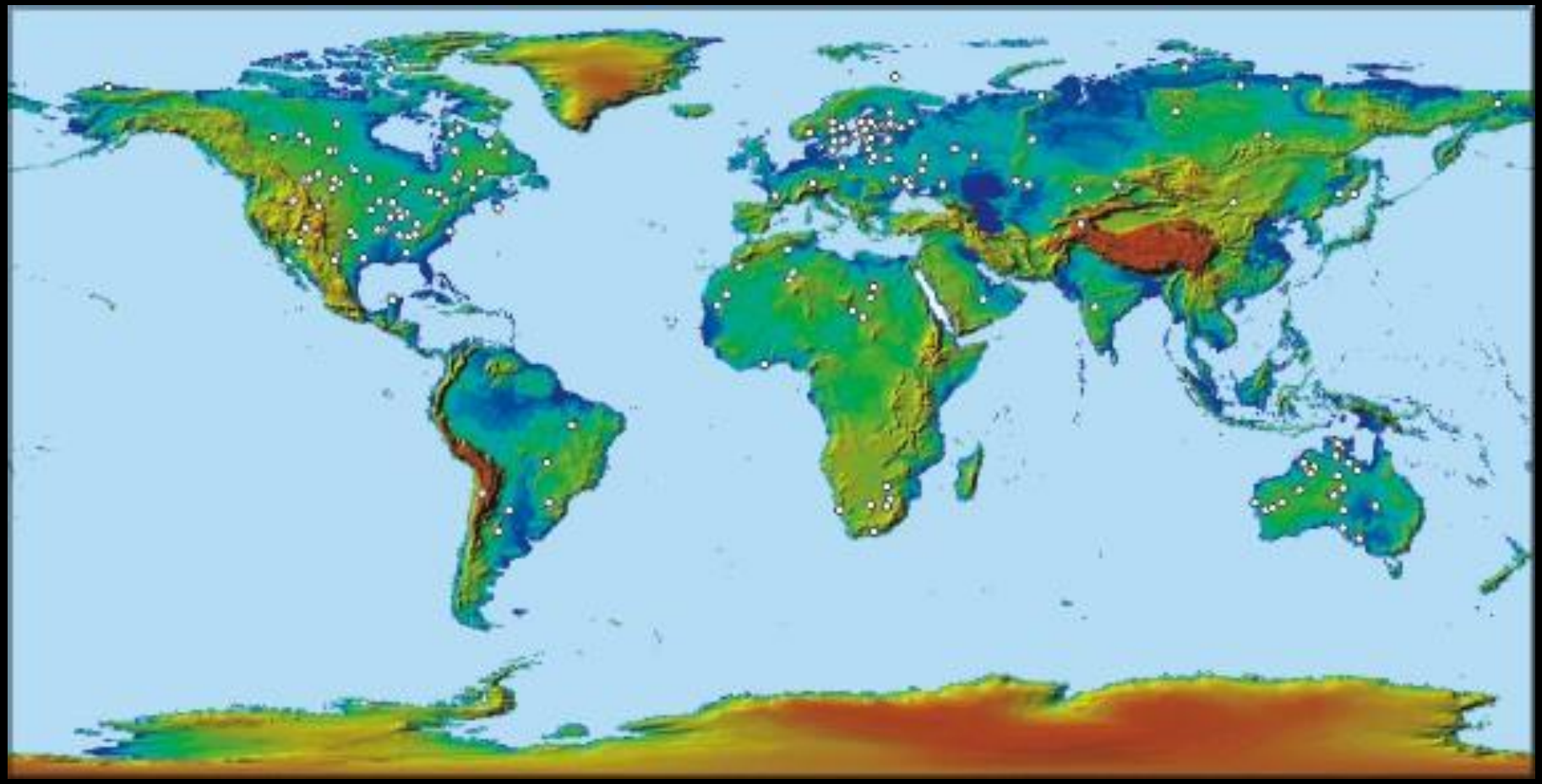
Vredefort, South Africa, 300 km


a
D_r
Simple crater

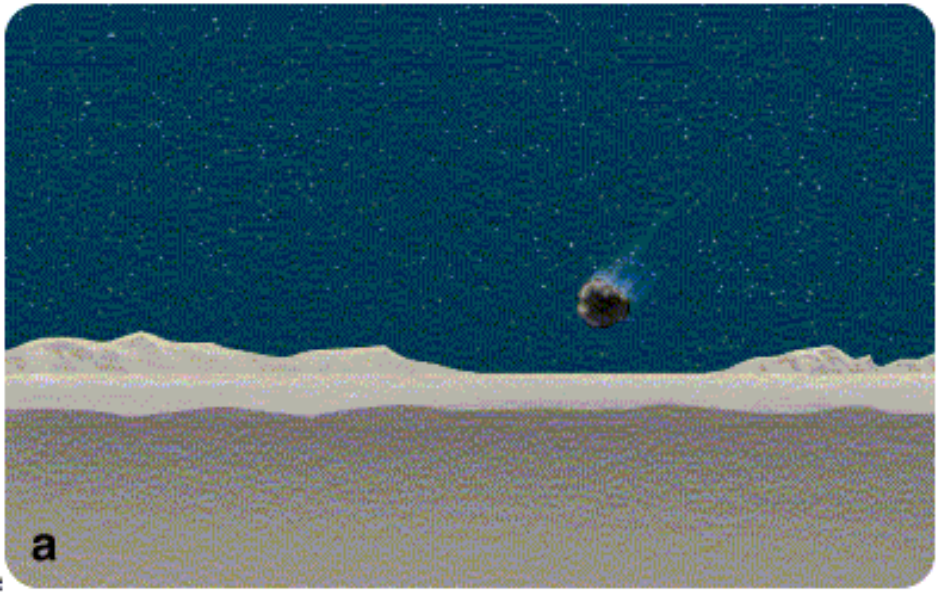

Shocked breccia
Unshocked breccia
Impact melt
Impact ejecta
Fractured bedrock

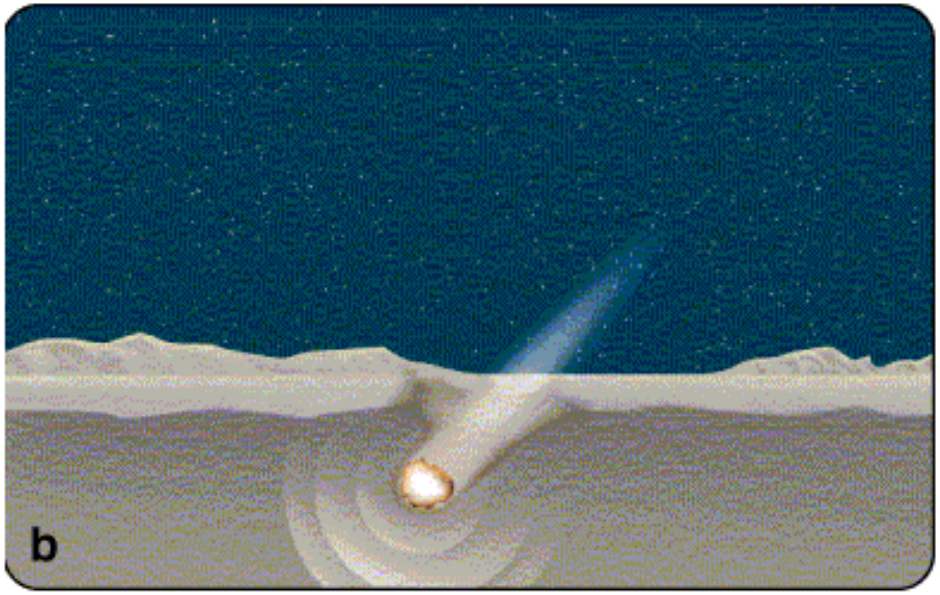

b
D_r
Complex crater

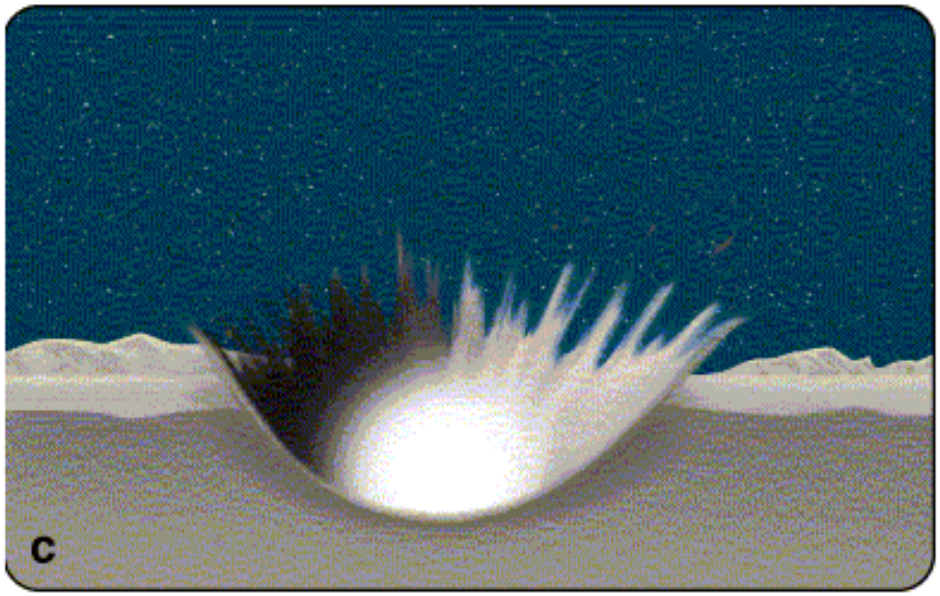
Impact Craters on Earth

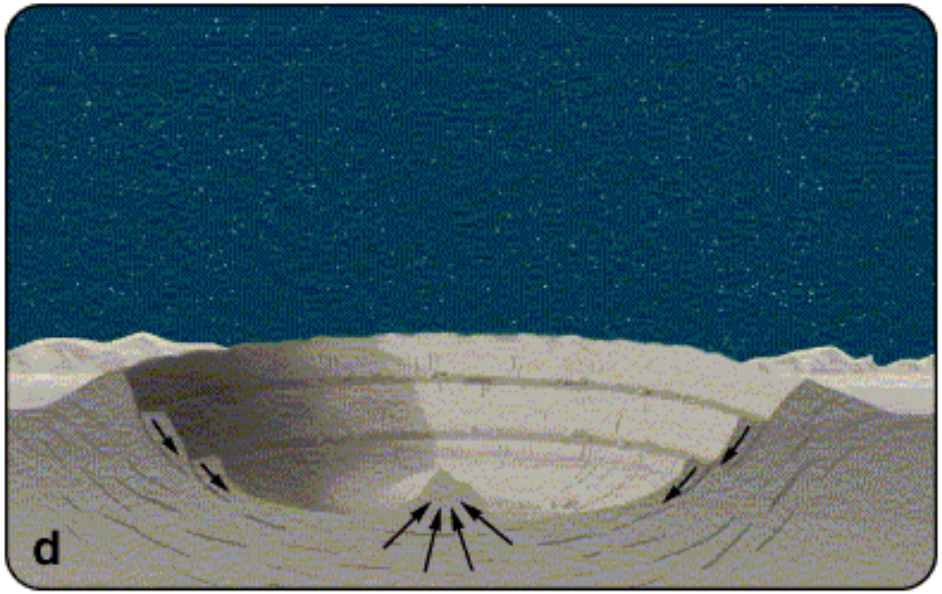


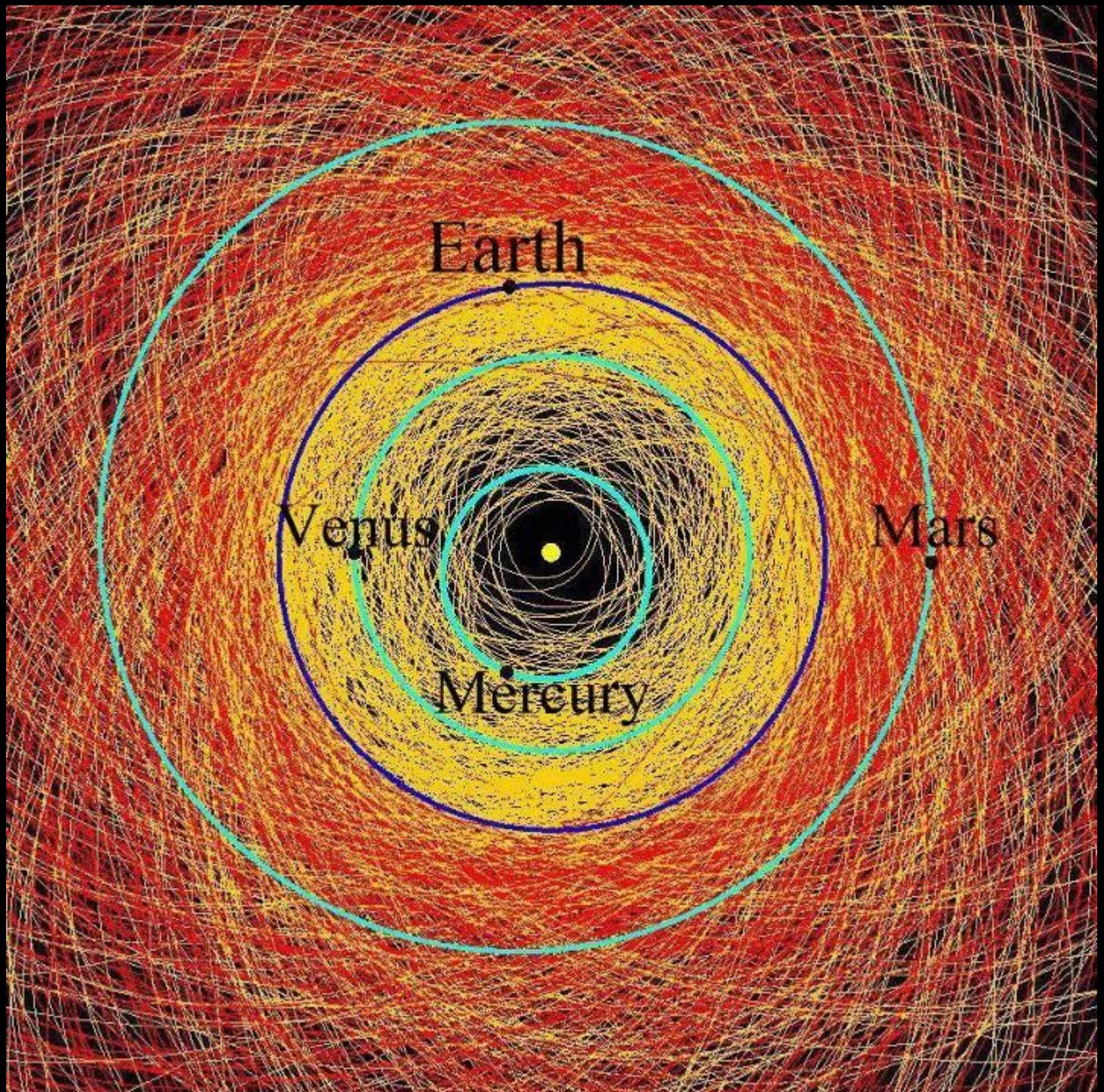
- About one third are not exposed on the surface and can only be studied by geophysics or drilling.
- Geophysical studies and drilling are crucial to establish the 3D distribution of various rock types within impact structures, no matter if they are exposed on the surface or not.


a


b


c


d



Orbits of known asteroids >1 km in diameter (yellow are earth-orbit crossing)

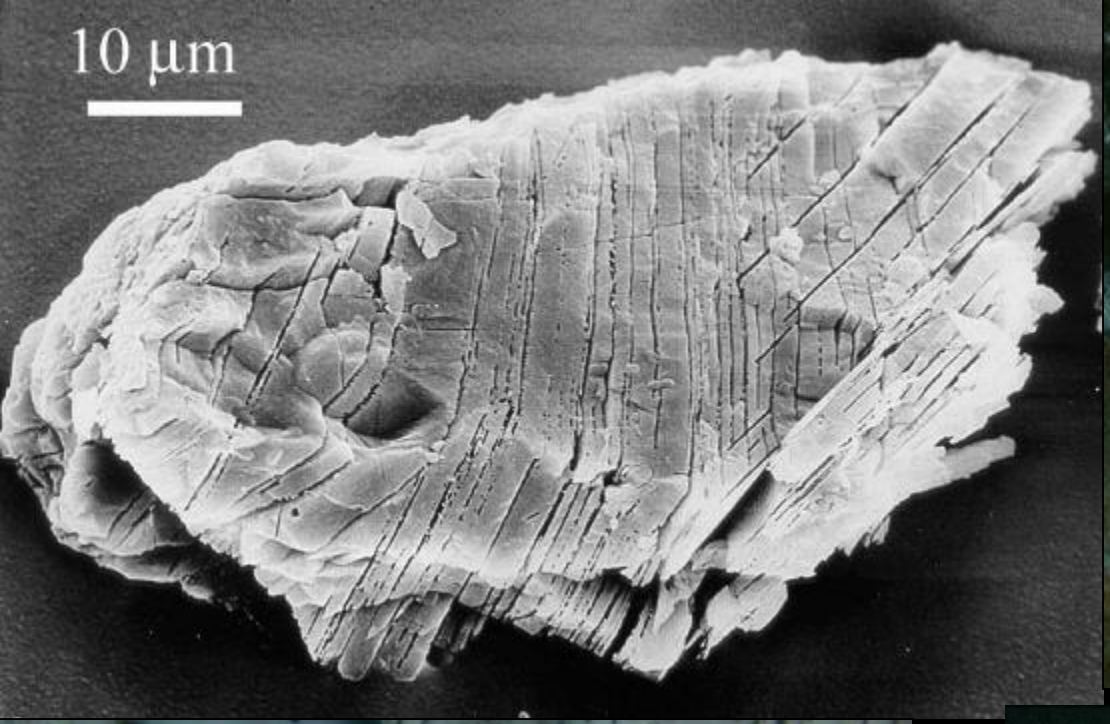
CRITERIA FOR IDENTIFICATION OF IMPACT STRUCTURES

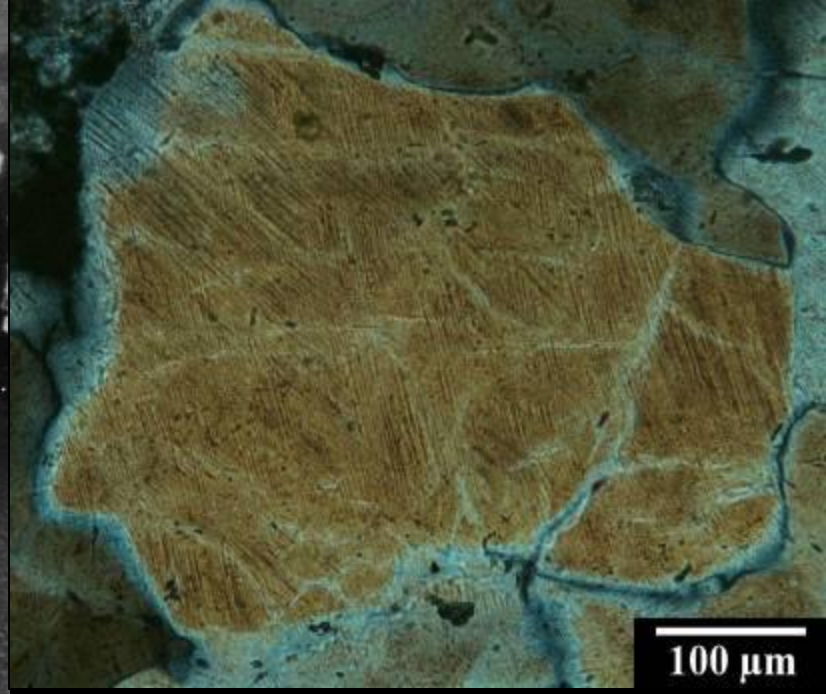
A. Morphology
- Circular Outline
- Rim Structure
- Central Structure

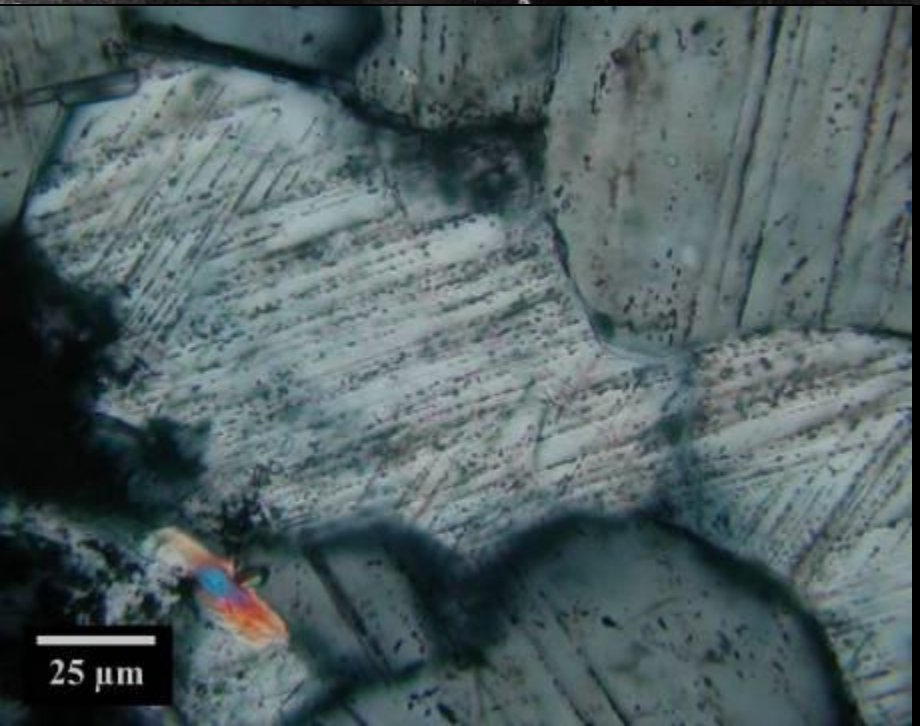
B. Geophysics
- Gravity
- Magnetics
- Seismics

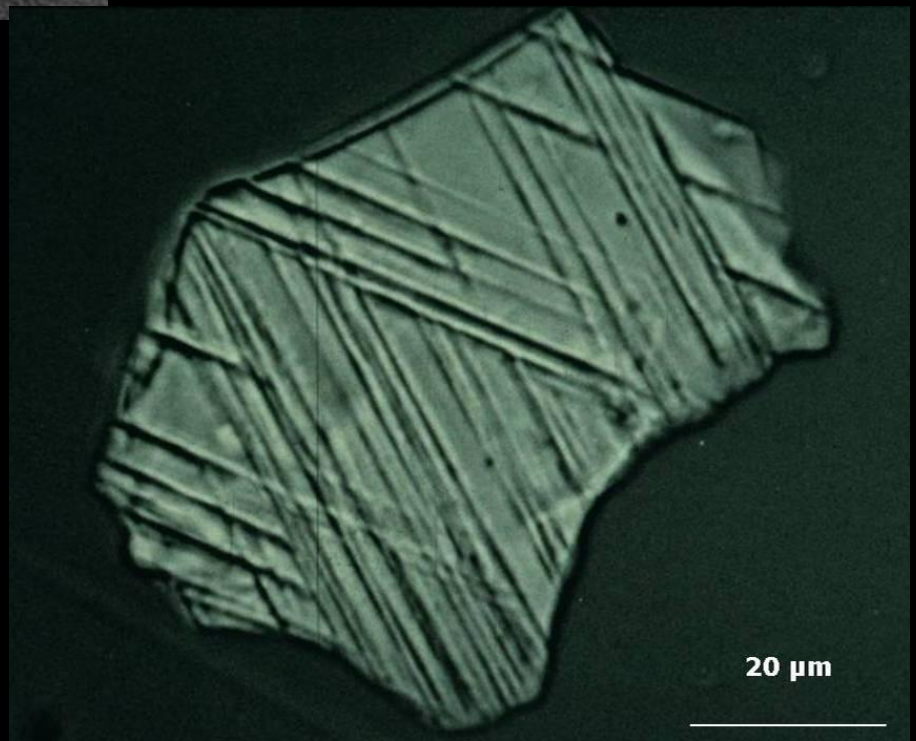
C. Mineralogy and Geochemistry
- Brecciation
- Shock Metamorphism
- Traces of Meteoritic Material

Suevite (polymict glass-bearing impact breccia)


10 µm


100 µm


25 µm

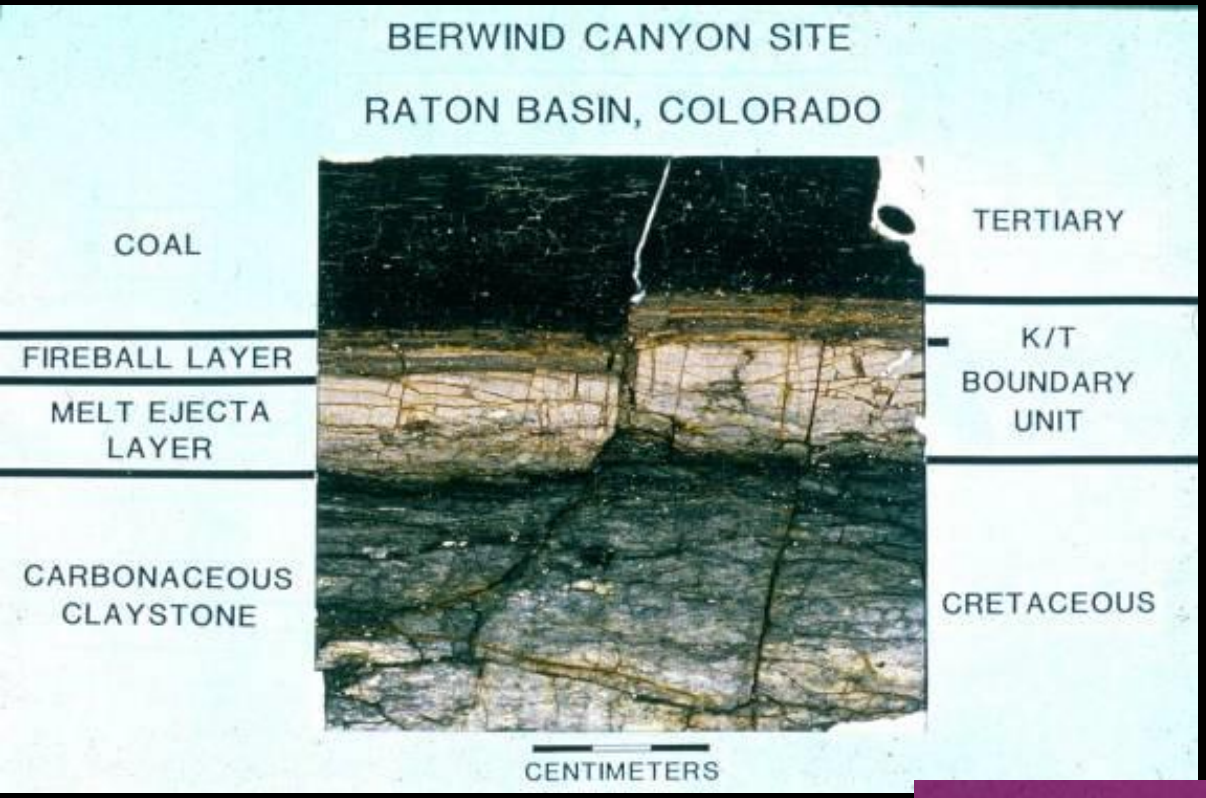

20 µm

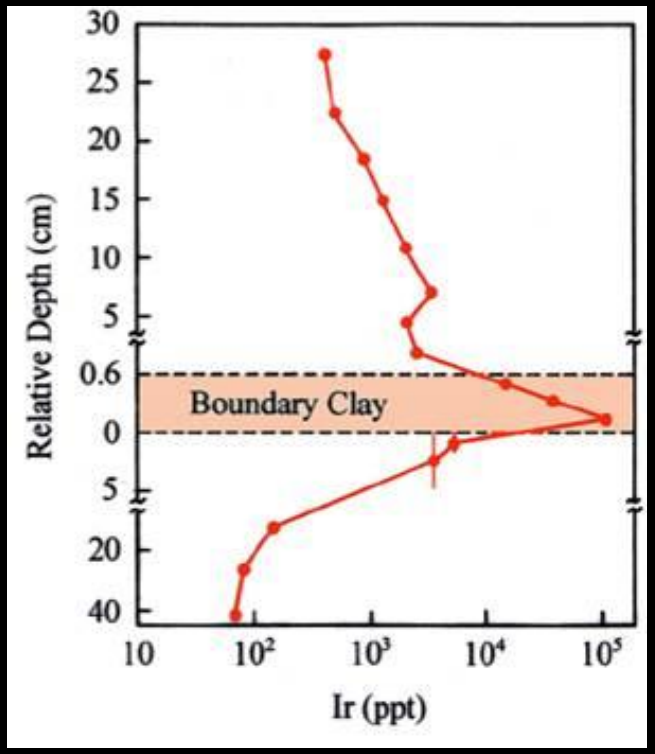
Meteoritic Components in Impactites:

Second possibility (apart from shock metamorphism) to confirm impact origin of a geological structure or of an ejecta deposit

- **Siderophile element abundances (Ir and others)**
- **Ni-spinels**
- **PGE interelement ratios**
- **Os isotopes**
- **Cr isotopes**

K-T boundary at Frontale di Apiro, Italy

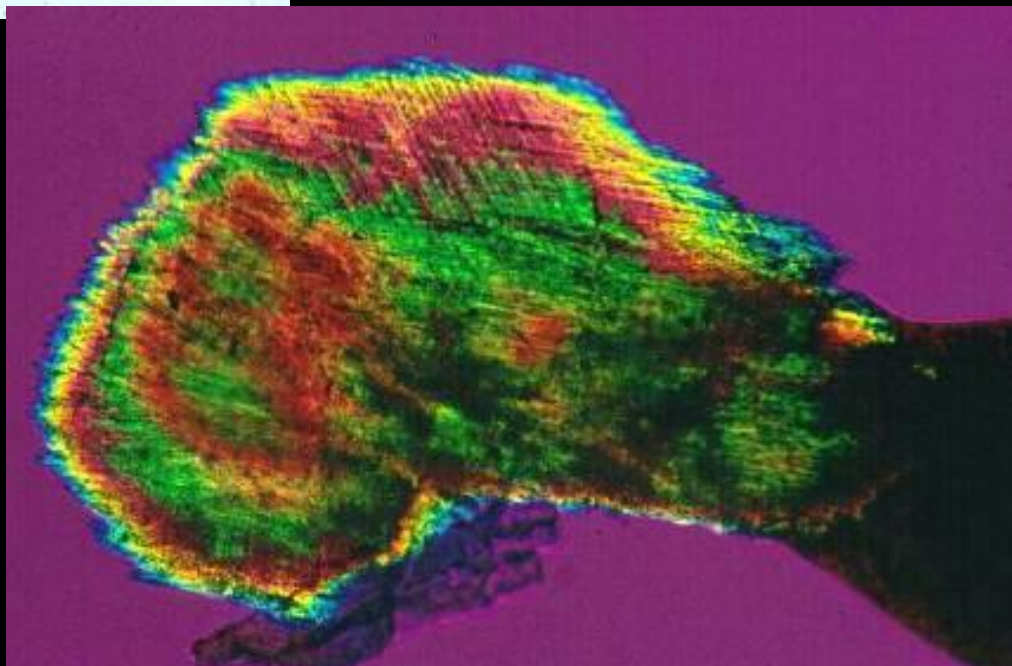




K-T boundary:

Siderophile element anomaly, soot, diamonds, shocked minerals, high pressure polymorphs, impact glass….

(all in proportion to each other)

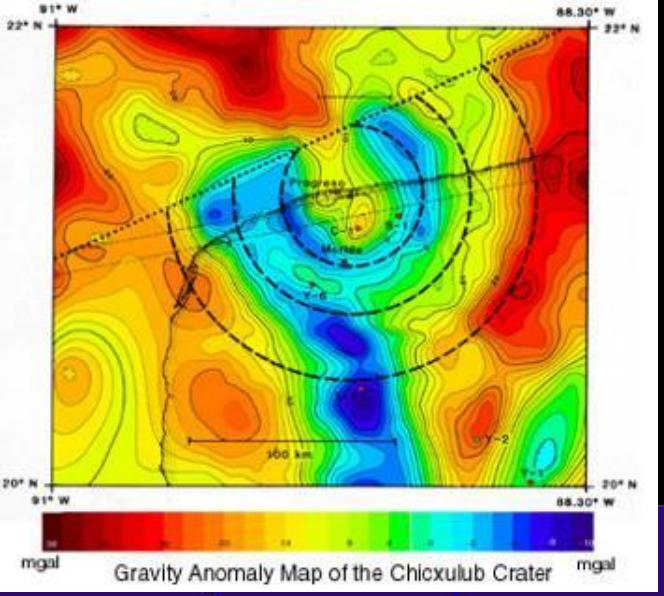


Chicxulub Impact Structure, Mexico

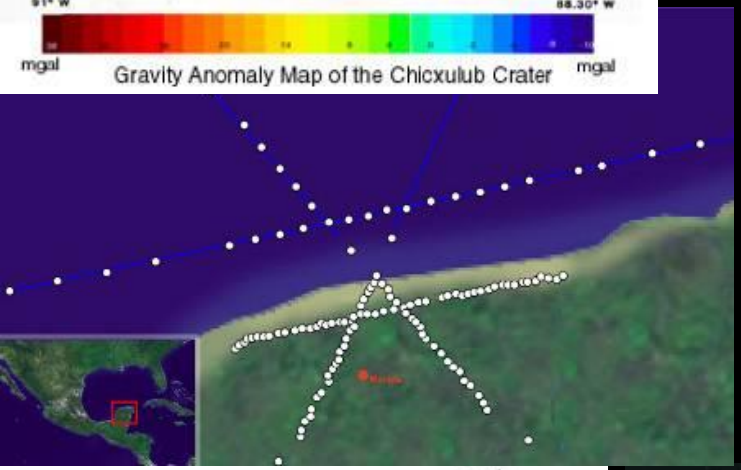
ca. 200 km diameter, 65 Ma

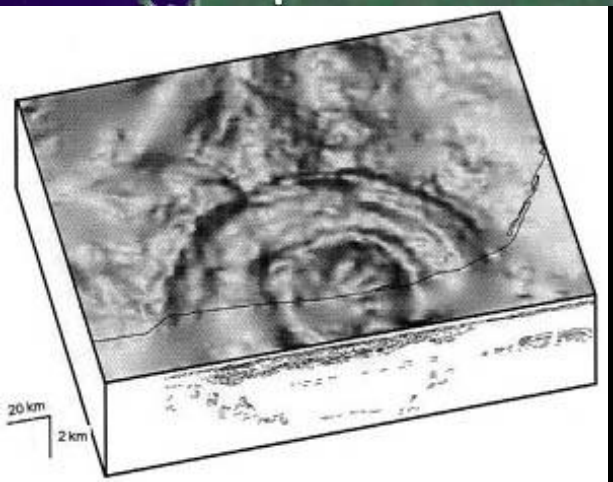
Is the K-T boundary impact crater:

- Distribution of ejecta led to Chicxulub location
- Geochemistry (isotopic composition) of ejecta identical to melt rock composition; ejecta mineralogy fits with source region
- Zircon isotopics in ejecta and in melt rocks the same

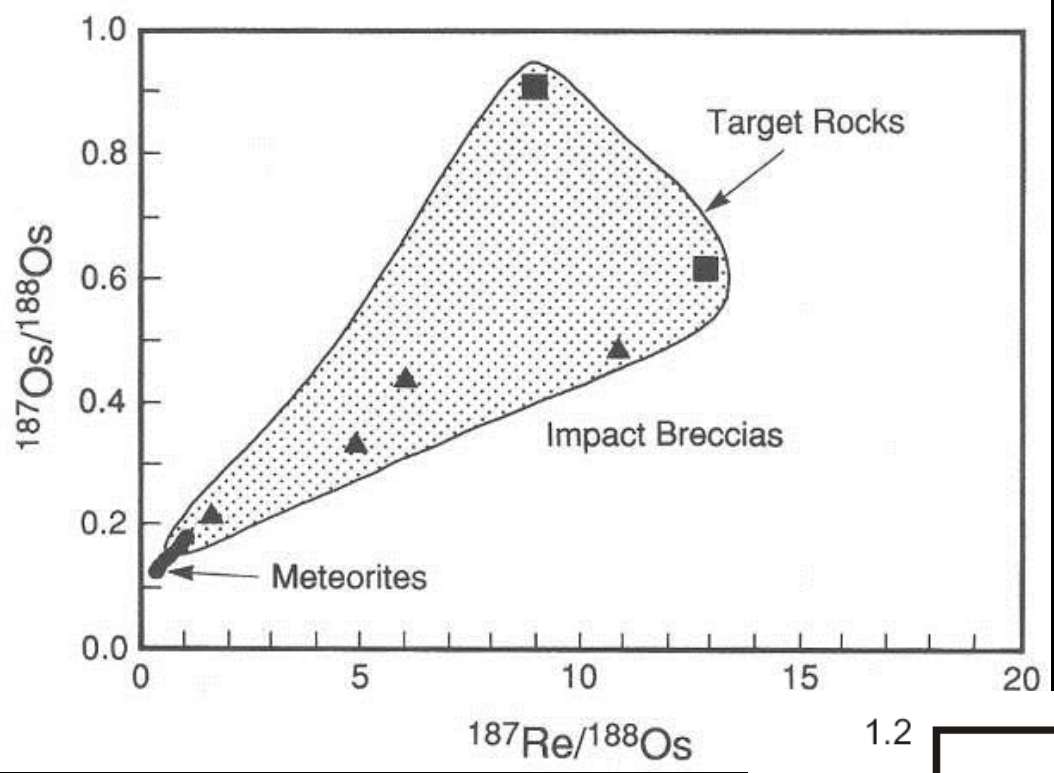


Gravity Anomaly Map of the Chicxulub Crater

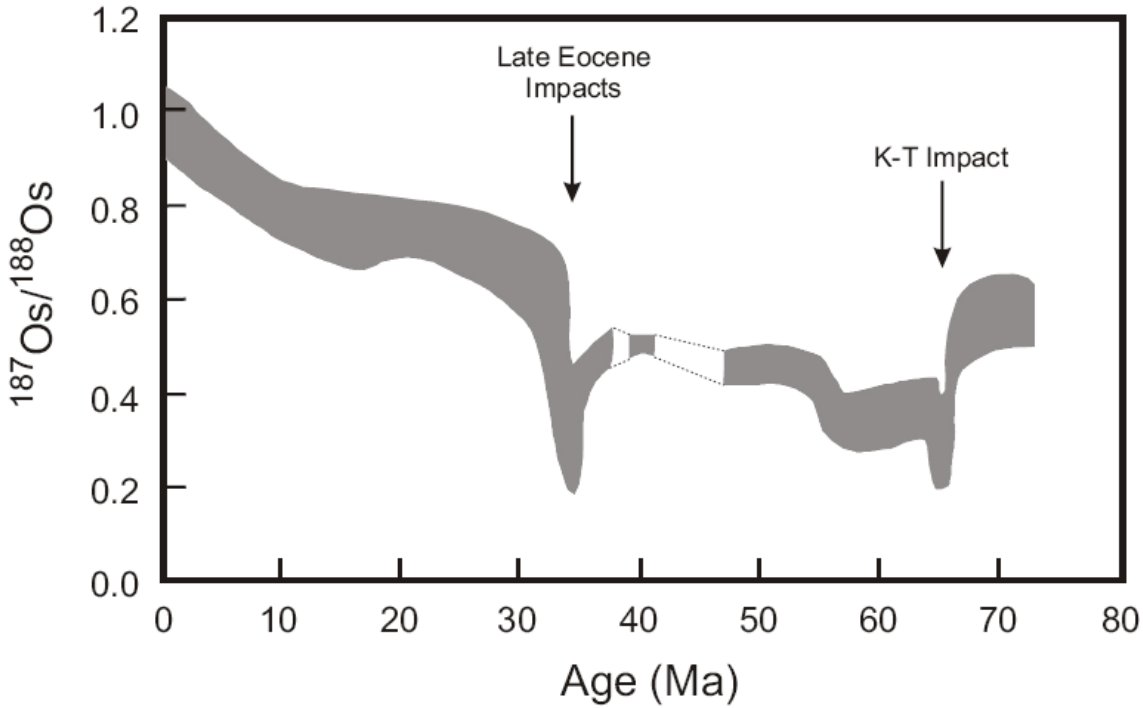


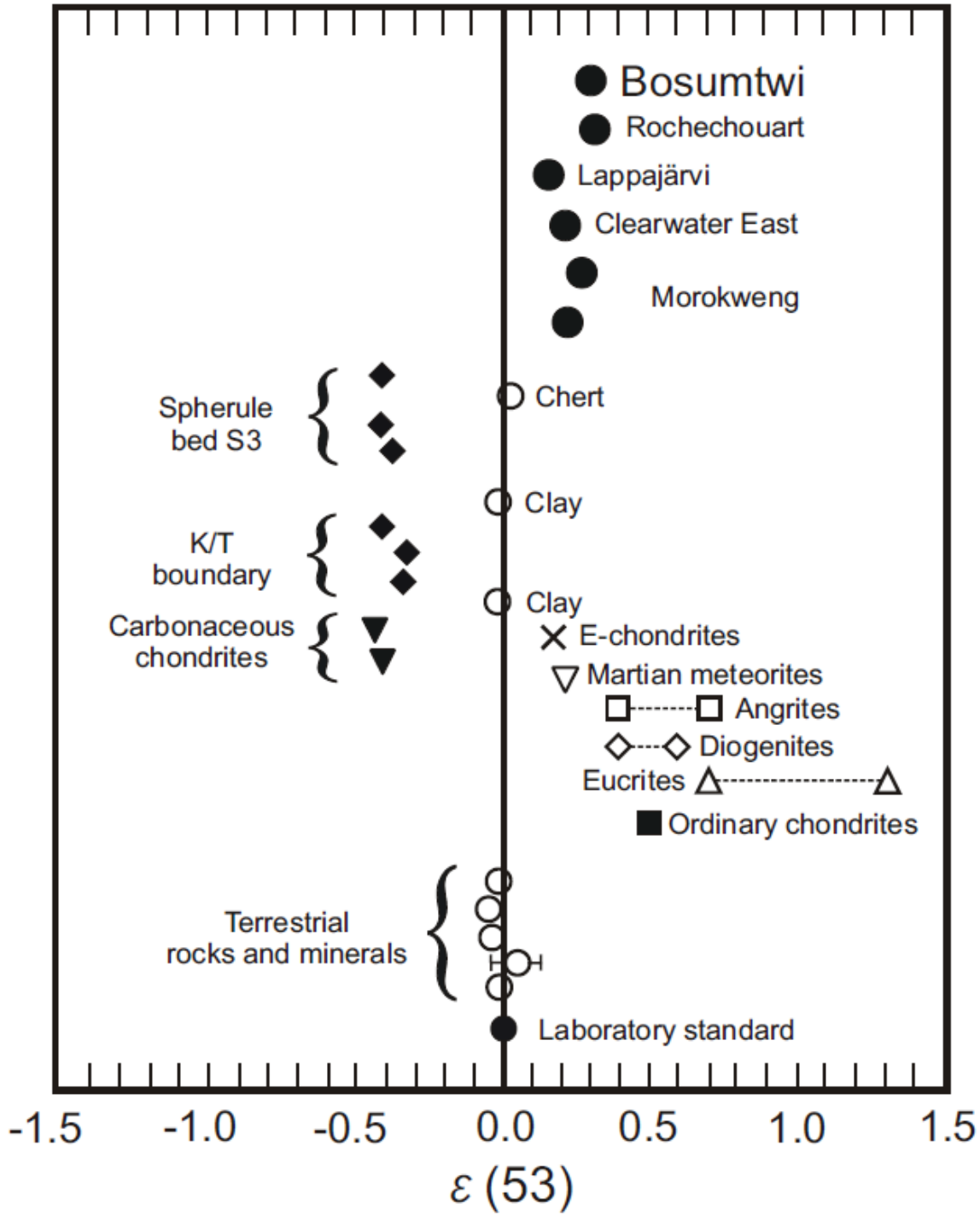


- Largest crater during past several 100 Ma (similar crater statistics on Venus); two craters implausible; need two ejecta layers
- High-resolution and quantitative planktic foraminiferal biostratigraphy of ejecta

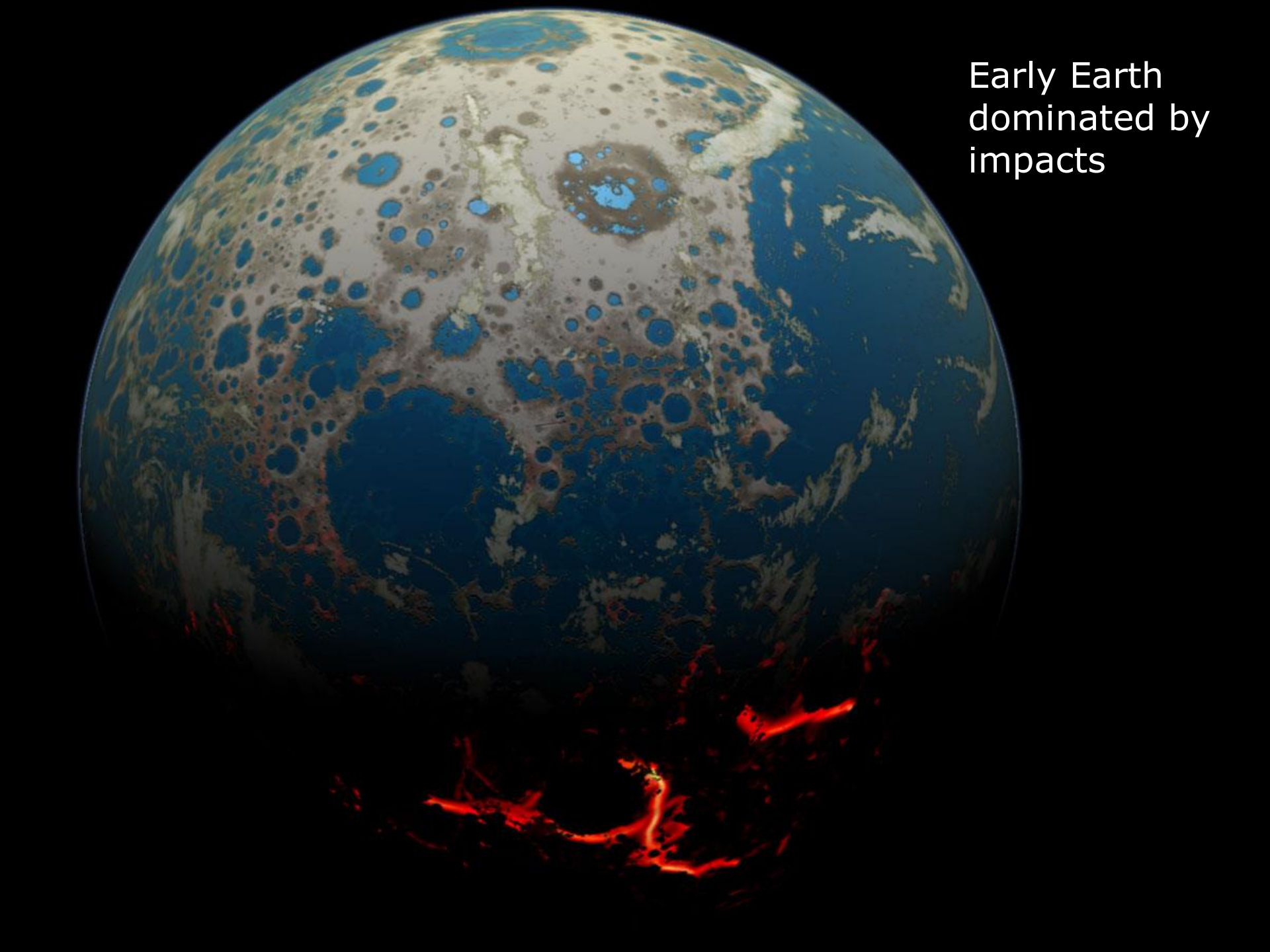


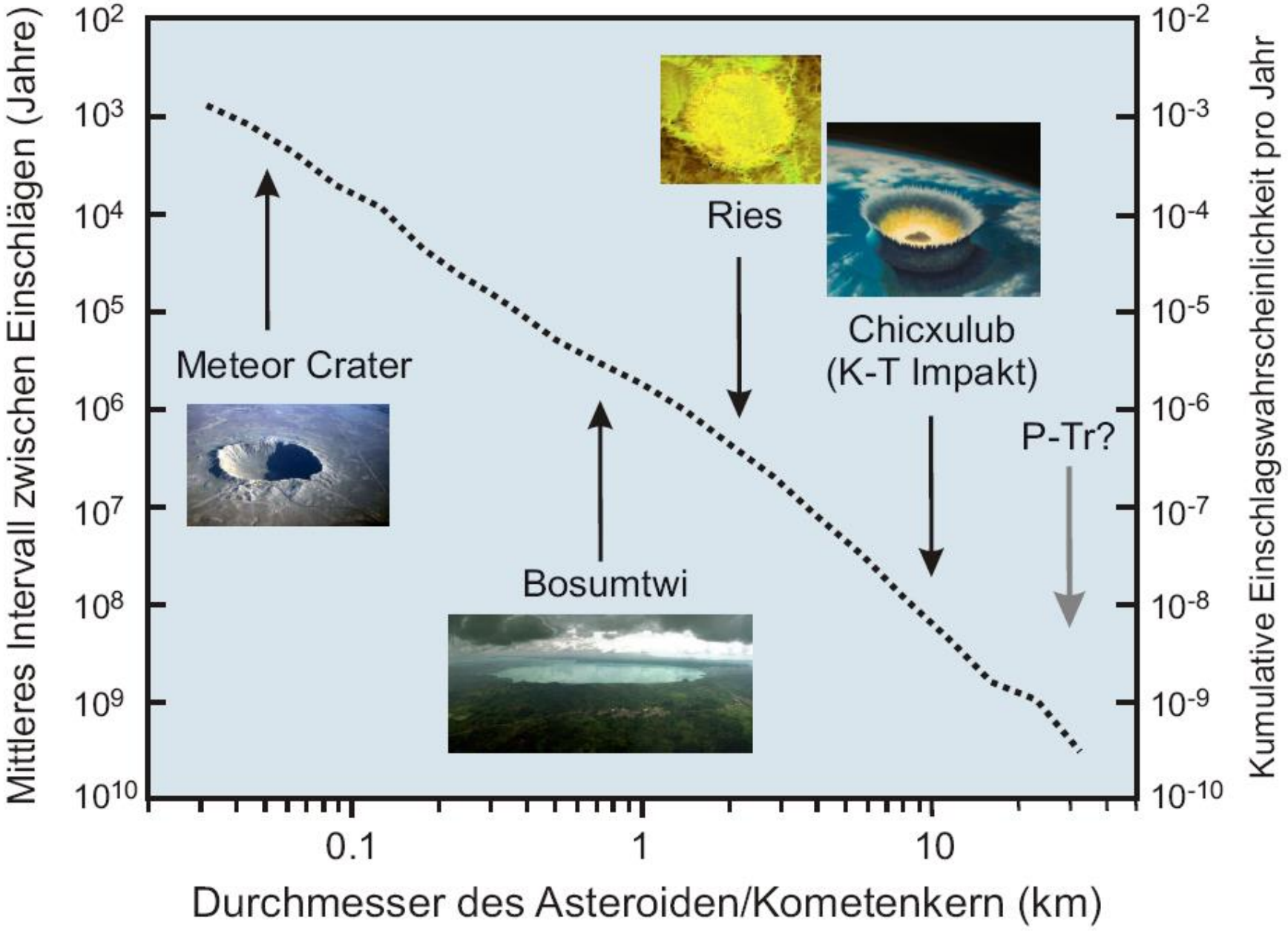
Characteristic Os isotopic composition





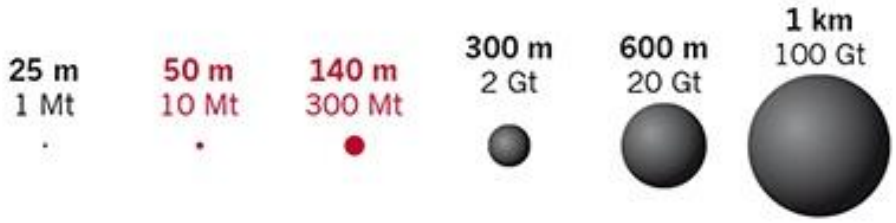
Distinct Cr Isotopic Composition

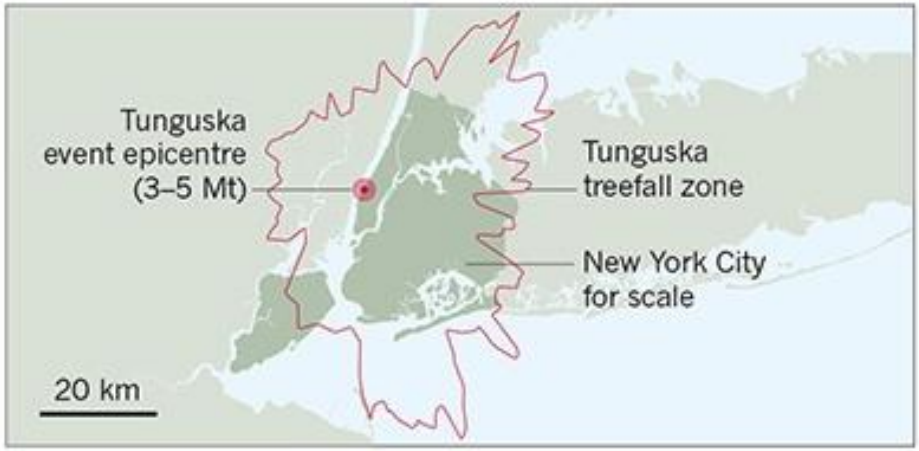

Early Earth
dominated by
impacts

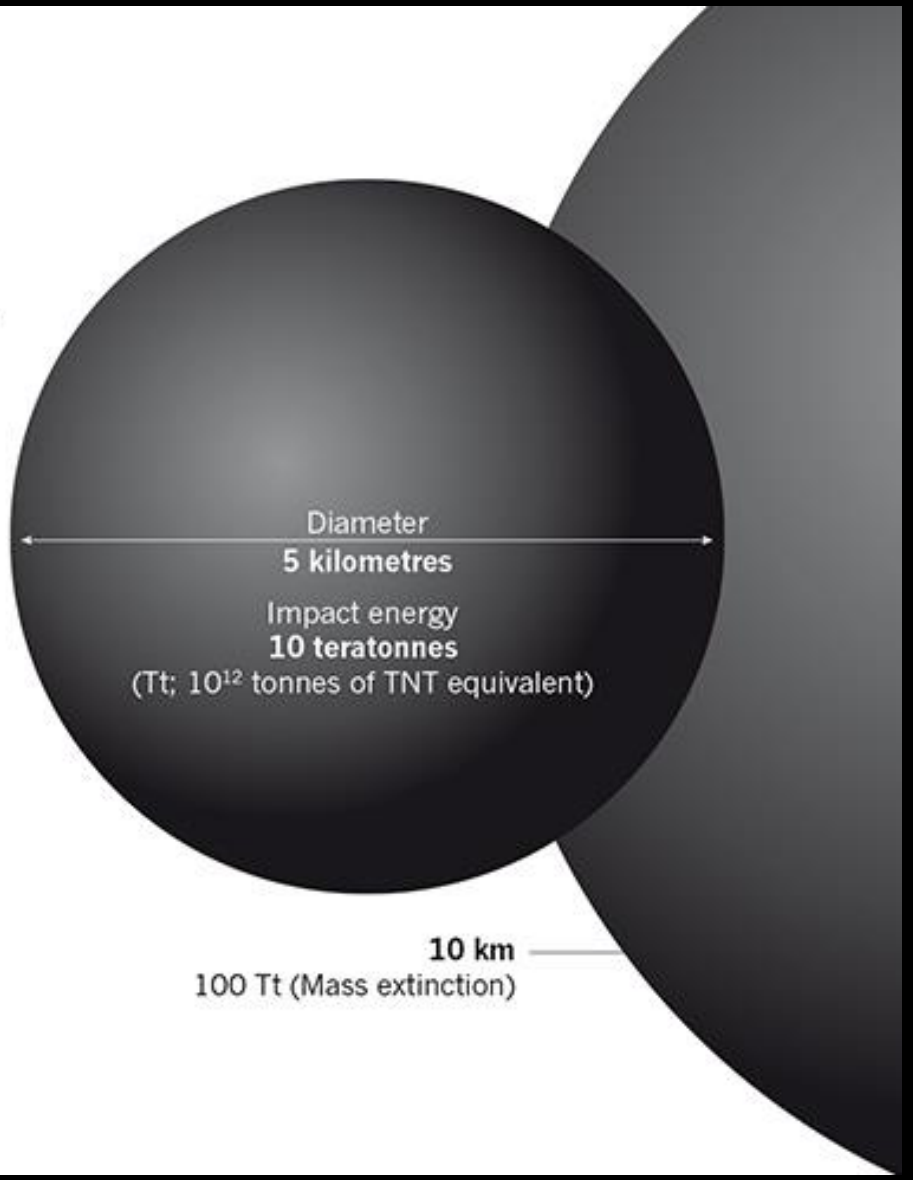

Mittleres Intervall zwischen Einschlägen (Jahre)
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^{10}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
Kumulative Einschlagswahrscheinlichkeit pro Jahr
Meteor Crater
Ries
Chicxulub
(K-T Impakt)
P-Tr?
Bosumtwi
0.1
1
10
Durchmesser des Asteroiden/Kometenkern (km)

DIRECT HIT

In the 1908 Tunguska event, an object exploded over Siberia, damaging trees across 2,000 square kilometres. If a similar event occurred above New York City, the damage would hit all five boroughs and beyond. Impact energies for different sized objects are shown.



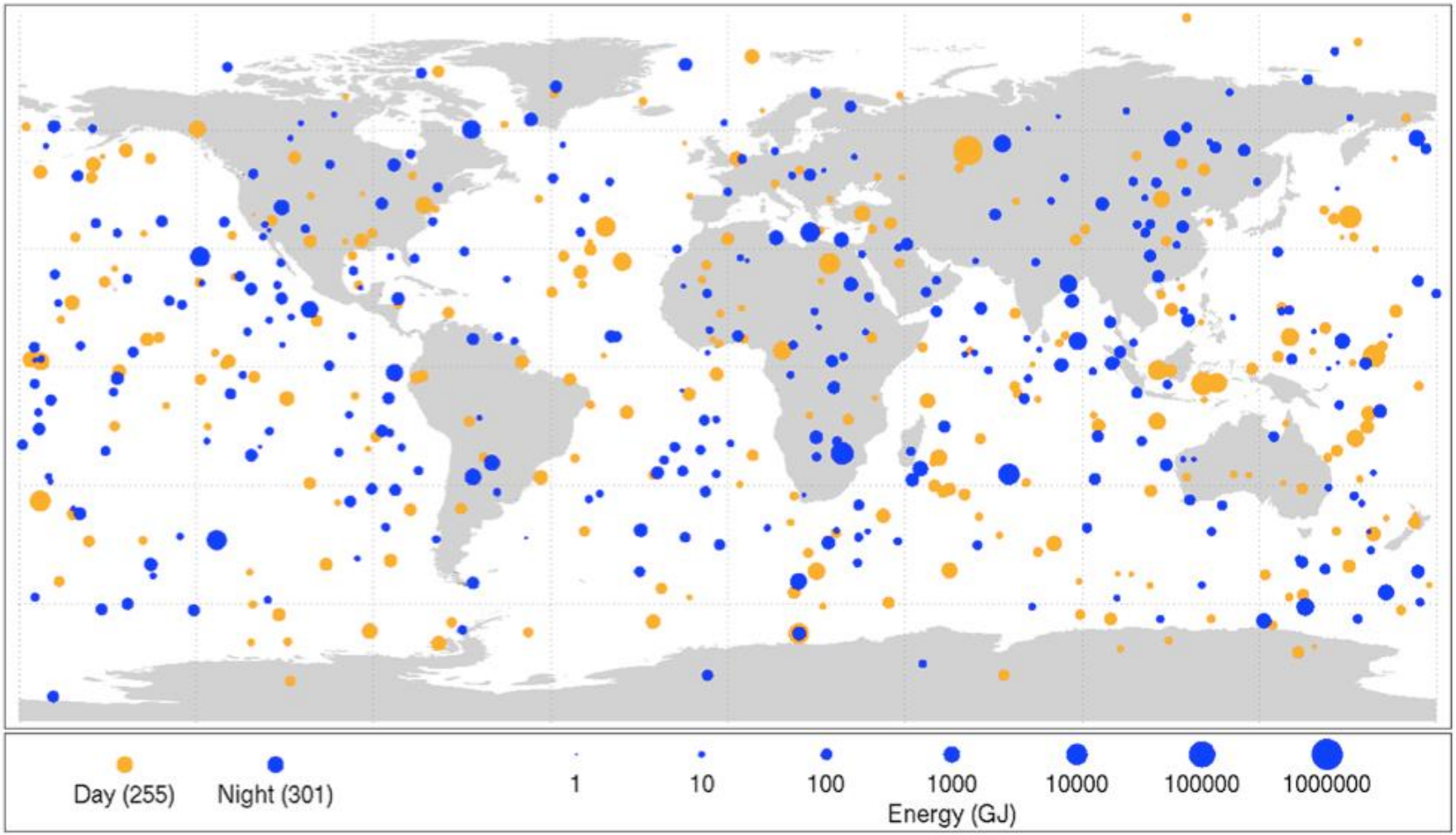




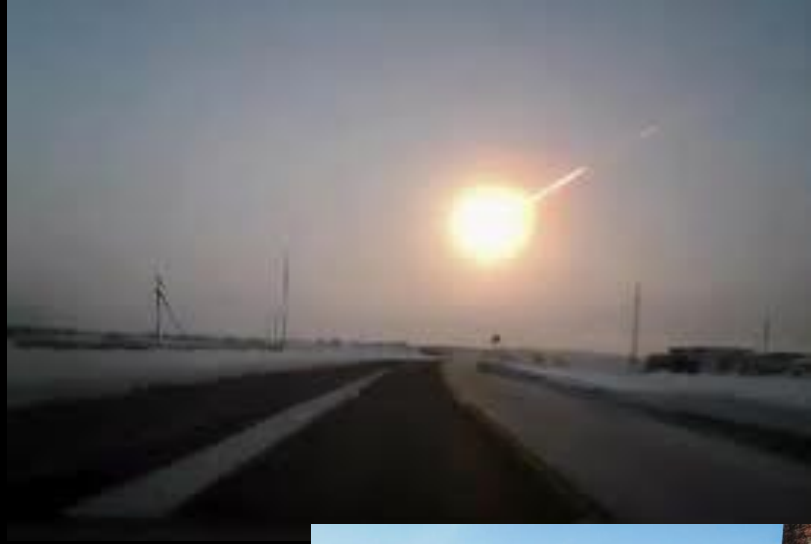
Hiroshima (1945) Atomic bomb: 15 Kilotons TNT (0.015 Mt)

Bolide Events 1994 – 2013

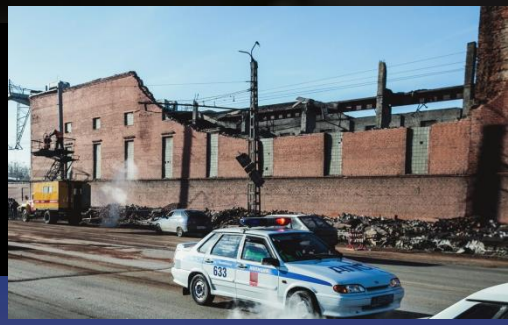
Small Asteroids that Disintegrated in Earth's Atmosphere

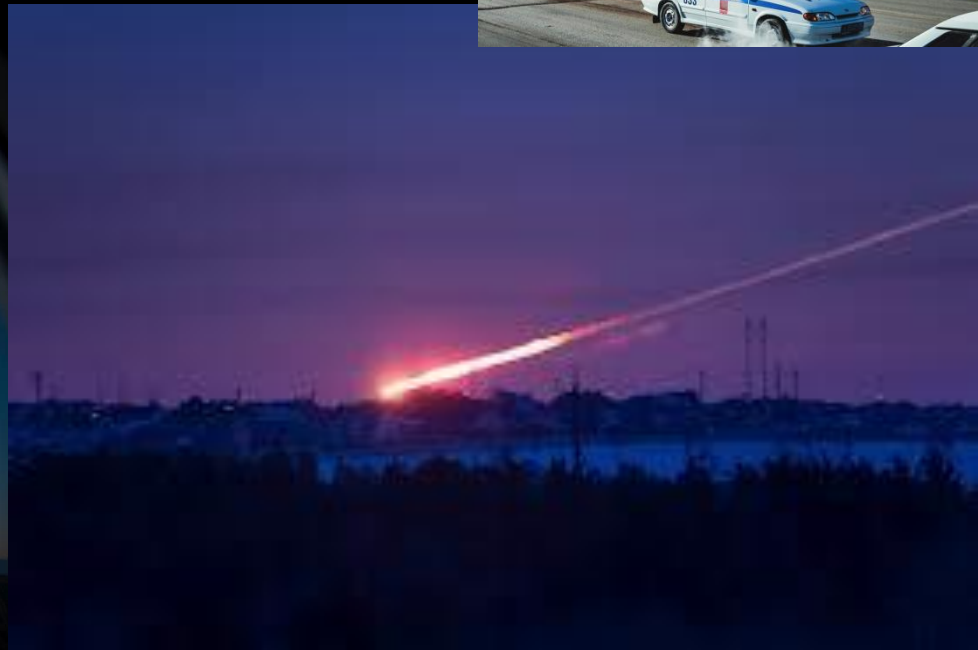


This diagram maps the data gathered from 1994-2013 on small asteroids impacting Earth's atmosphere and disintegrating to create very bright meteors, technically called "bolides" and commonly referred to as "fireballs". Sizes of orange dots (daytime impacts) and blue dots (nighttime impacts) are proportional to the optical radiated energy of impacts measured in billions of Joules (GJ) of energy, and show the location of impacts from objects about 1 meter (3 feet) to almost 20 meters (60 feet) in size.

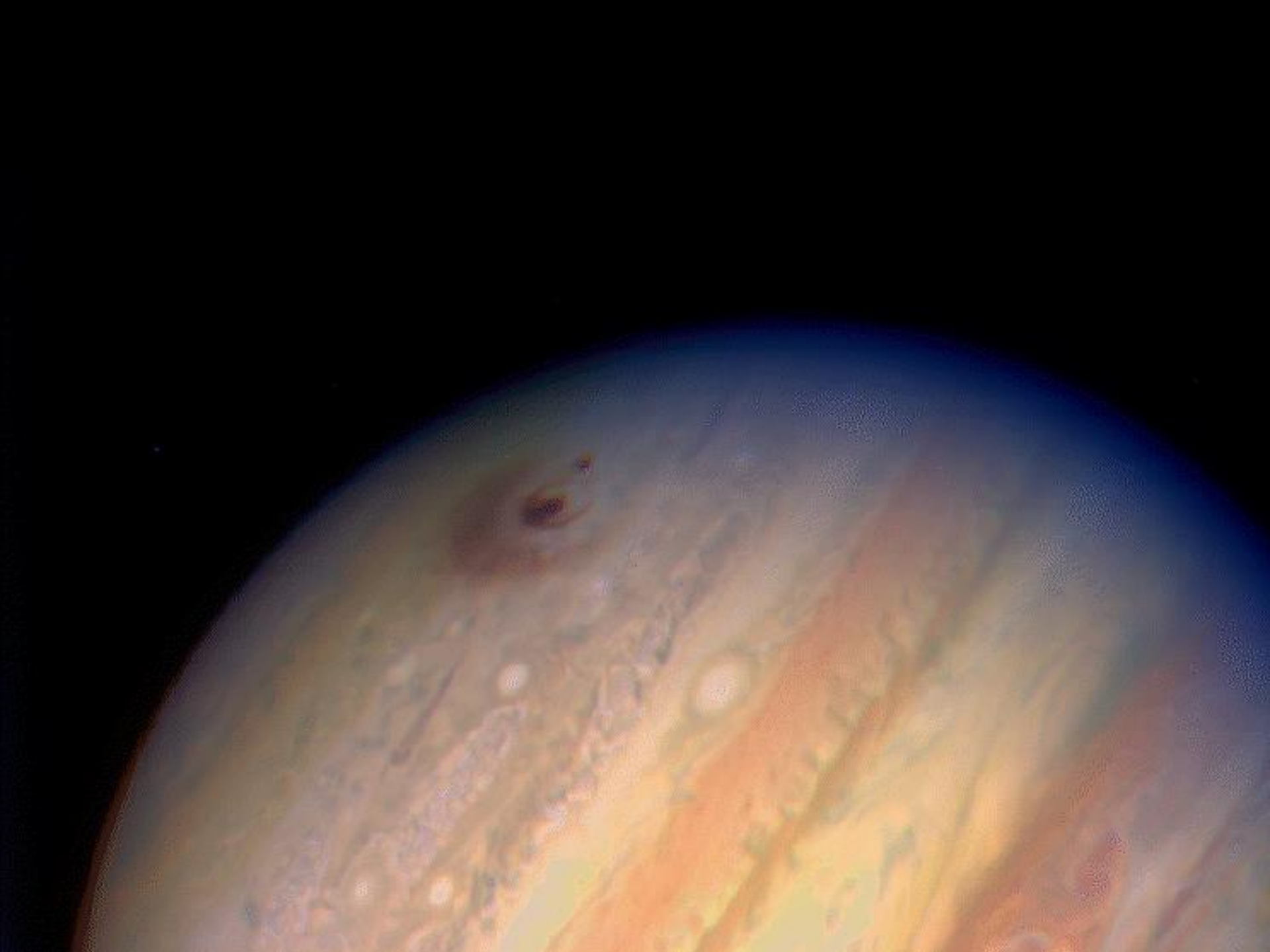


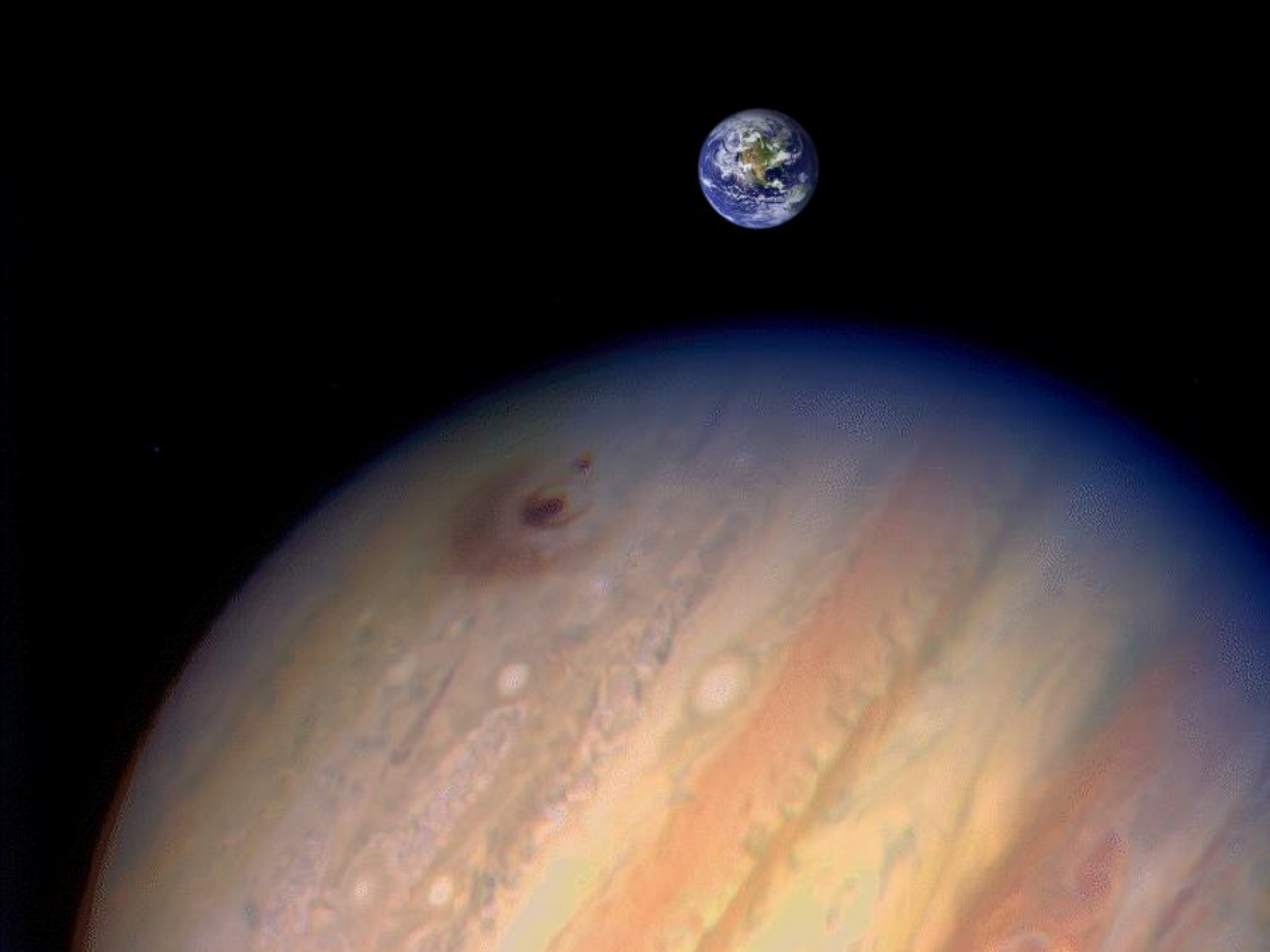
Chelyabinsk meteor
(Russia), 15. Feb. 2013





Today…..





Studying Impact Craters on Earth:

- Impact structures are unique geological features on Earth
- Allow us to study a short-time violent process that is the most important one shaping the surfaces of almost all planets and satellites in our solar system
- Drilling of impact craters is essential to understand their 3D structure and their formation
- Forms the basis of understanding impact hazards


Thank you for
your attention!