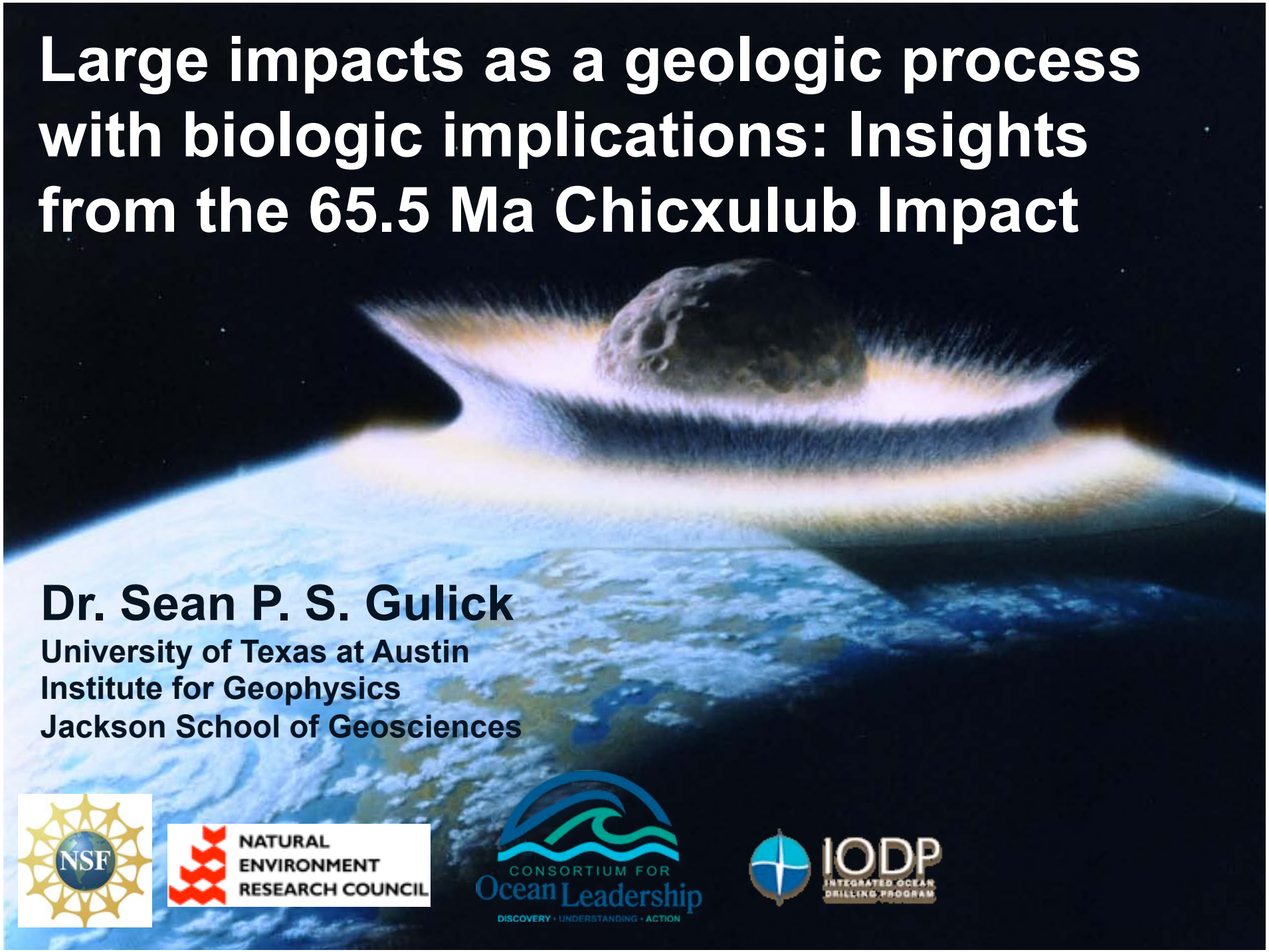
Large impacts as a geologic process with biologic implications: Insights from the 65.5 Ma Chicxulub Impact



Dr. Sean P. S. Gulick

University of Texas at Austin
Institute for Geophysics
Jackson School of Geosciences

NSF

NATURAL ENVIRONMENT RESEARCH COUNCIL

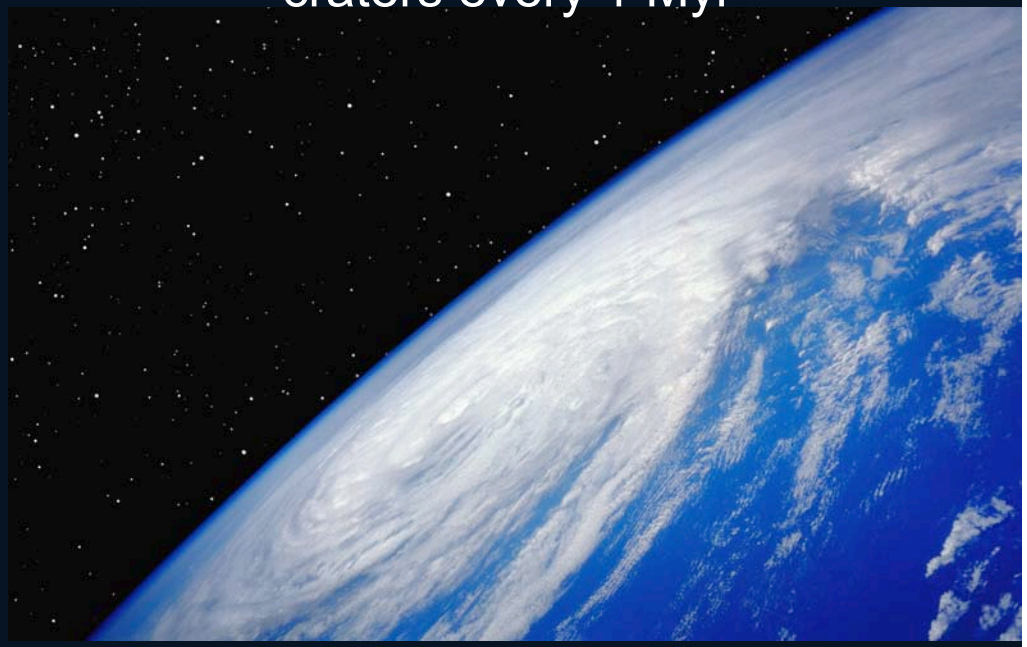
CONSORTIUM FOR Ocean Leadership
DISCOVERY • UNDERSTANDING • ACTION

IODP
INTEGRATED OCEAN DRILLING PROGRAM

CRATERING: A UBIQUITOUS PROCESS

Earth should have 25X more craters than the Moon

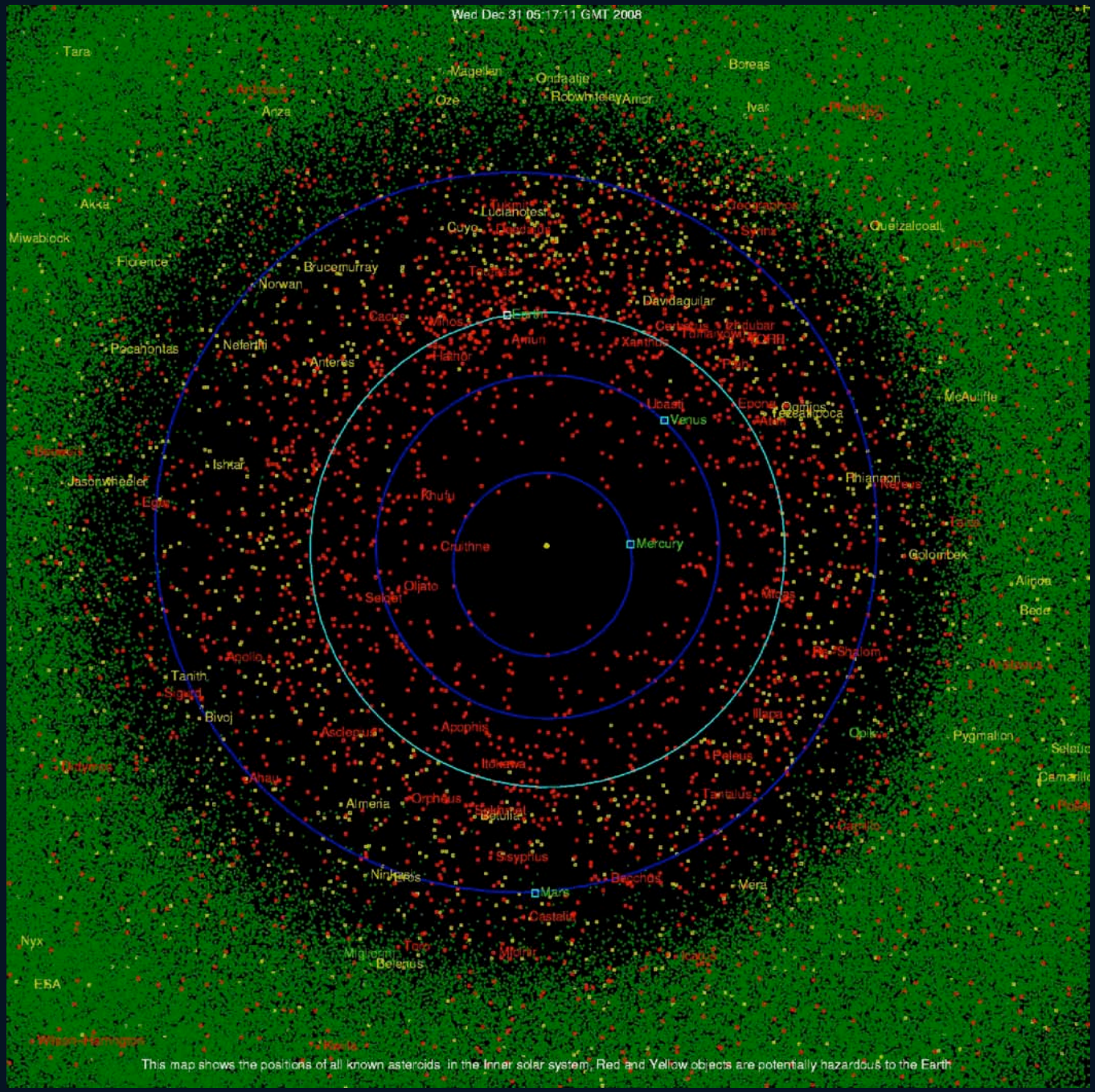
3 ± 2, 20 km or greater diameter craters every 1 Myr

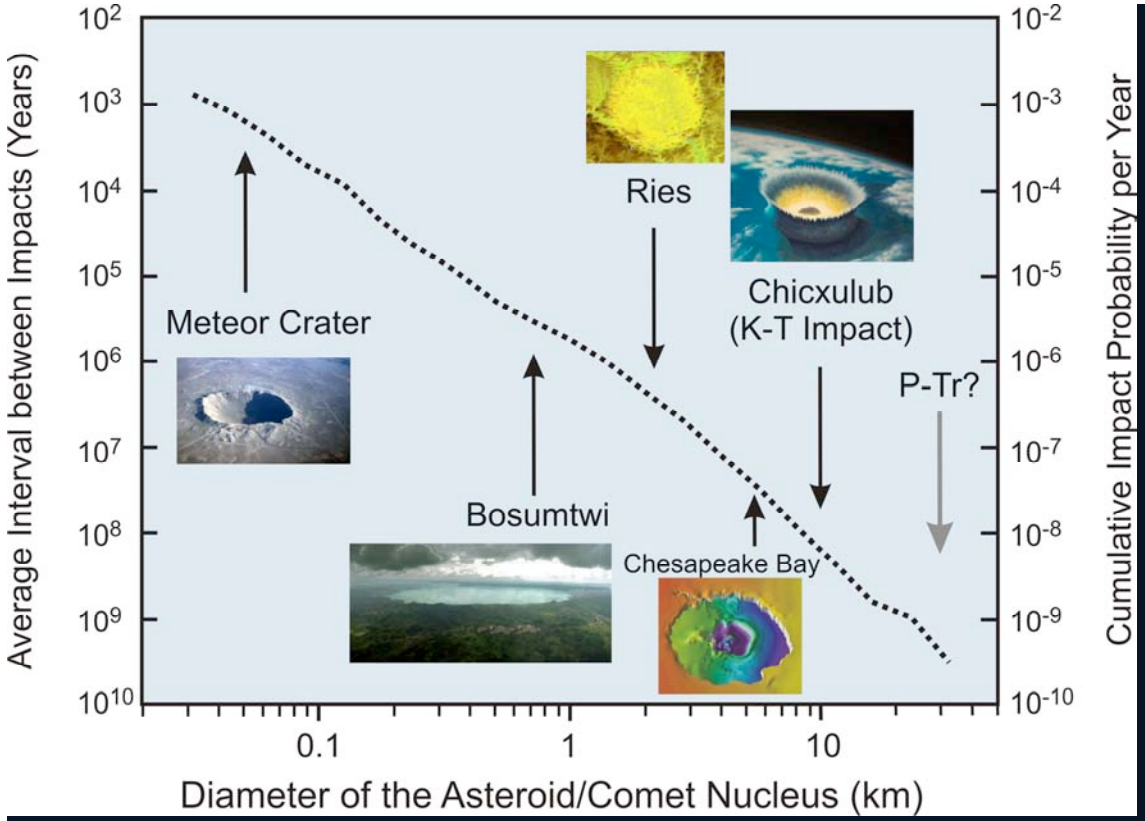


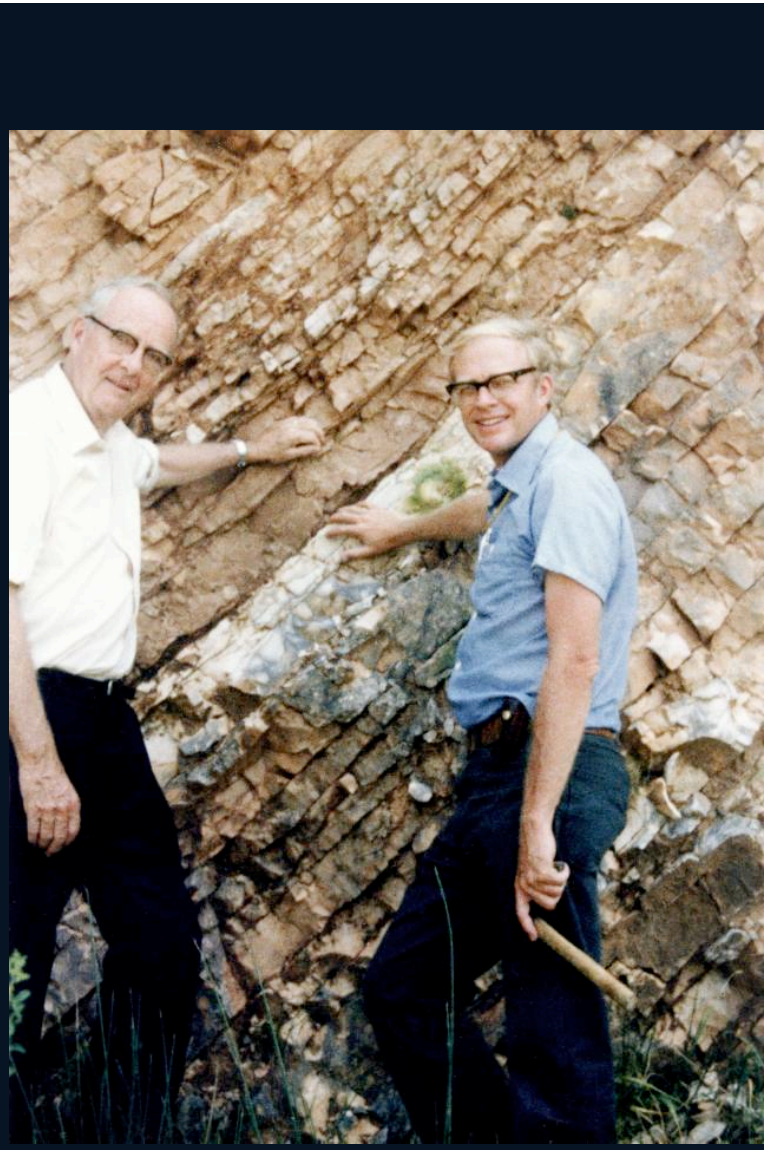
Only ~175 discovered (see http://www.unb.ca/passc/ImpactDatabase/)

Our Neighborhood

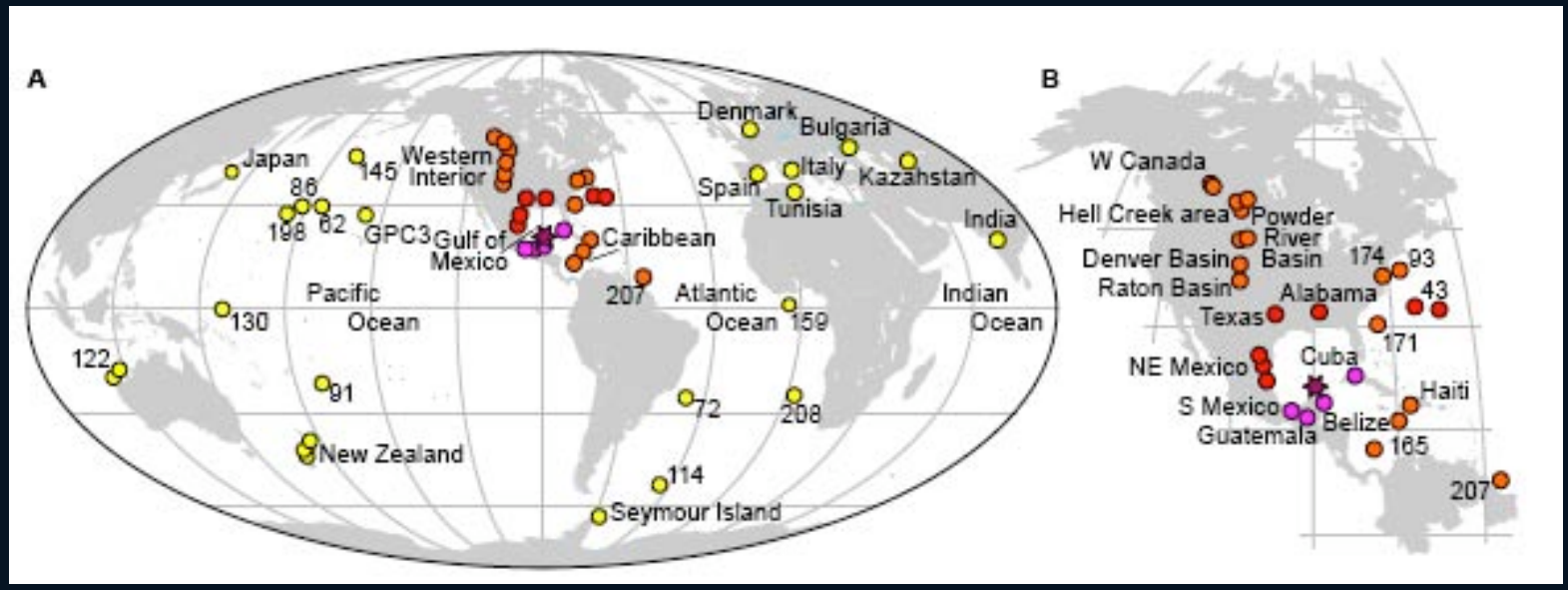
Lots of potential to leave a mark!

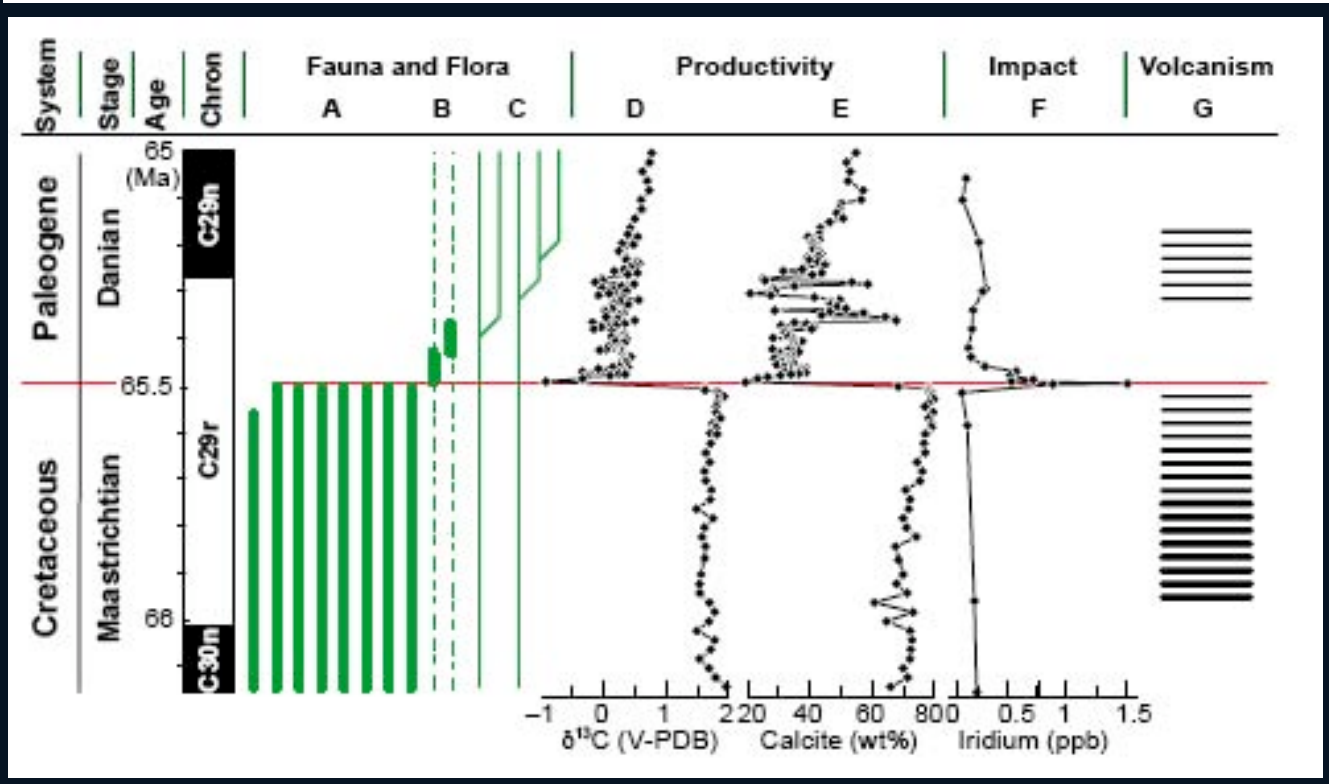



Average Interval between Impacts (Years)
Cumulative Impact Probability per Year
Diameter of the Asteroid/Comet Nucleus (km)
Meteor Crater
Ries
Chicxulub
(K-T Impact)
P-Tr?
Bosumtwi
Chesapeake Bay
0.1
1
10




IRIDIUM LAYER





Schulte et al, Science, in review

Geophysical Surveys of Chicxulub

2005
MCS lines

1996 and Pemex
MCS lines

1996
land stations

2005
land stations

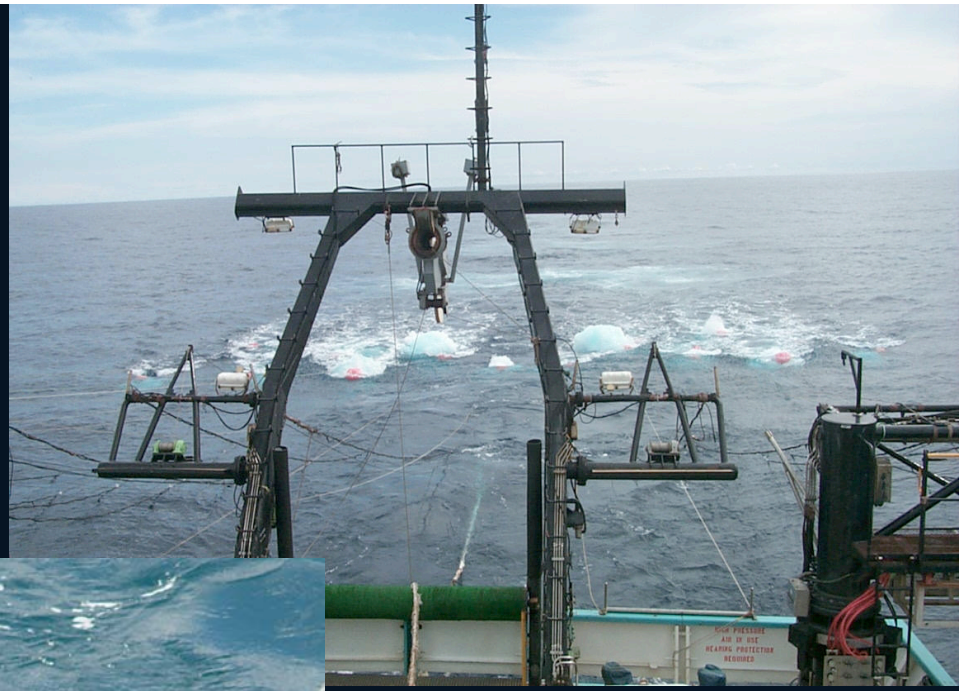
1996 Experiment

2005 Experiment

Yucatan coast line

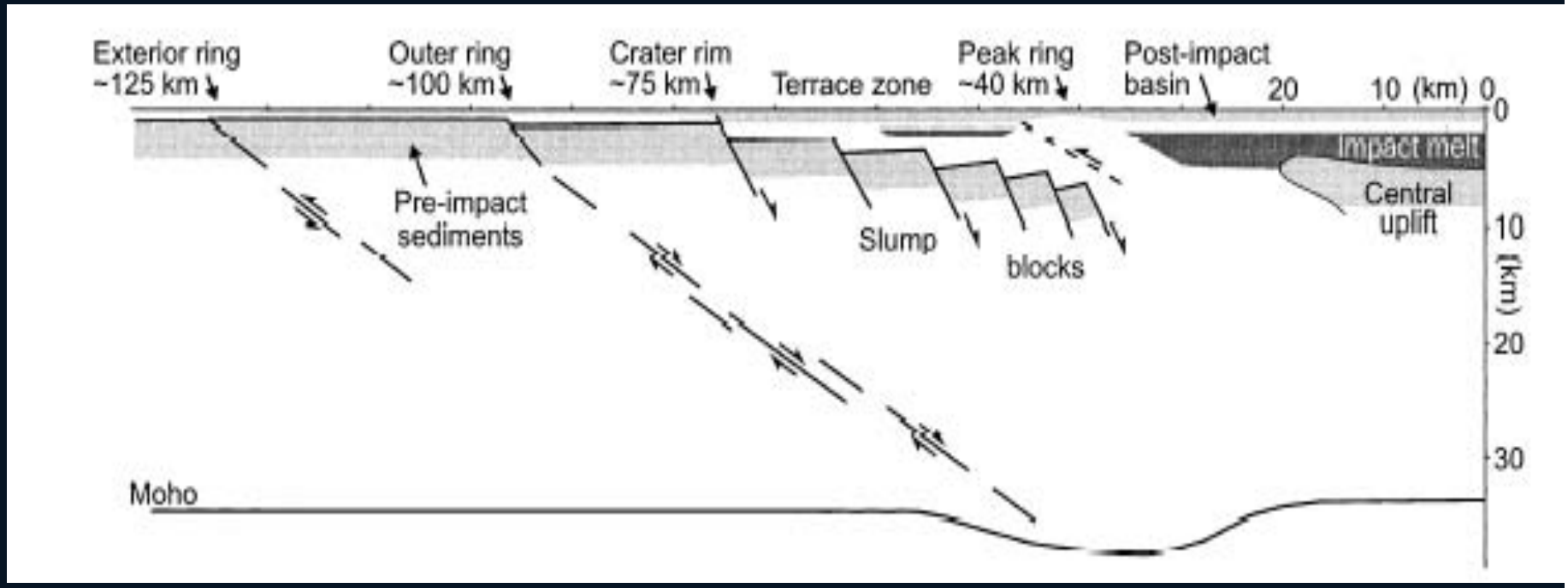
km
0
50

22°00' N
21°30' N
21°00' N
20°30' N
20°00' N
91°00' N
90°30' N
90°00' N
89°30' N
89°00' N
88°30' N
88°00' N



Bolide ~12 km in diameter

Transient Crater 35 km deep and 100 km across

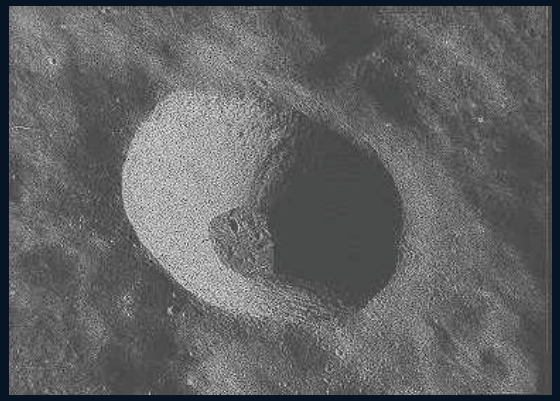


Cross-section

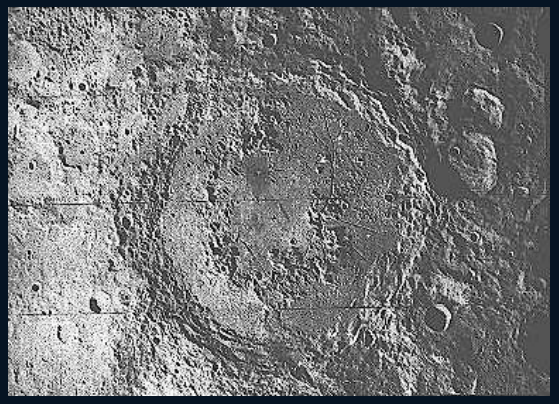
Morgan et al. (1997)

Crater Morphology

Lunar examples



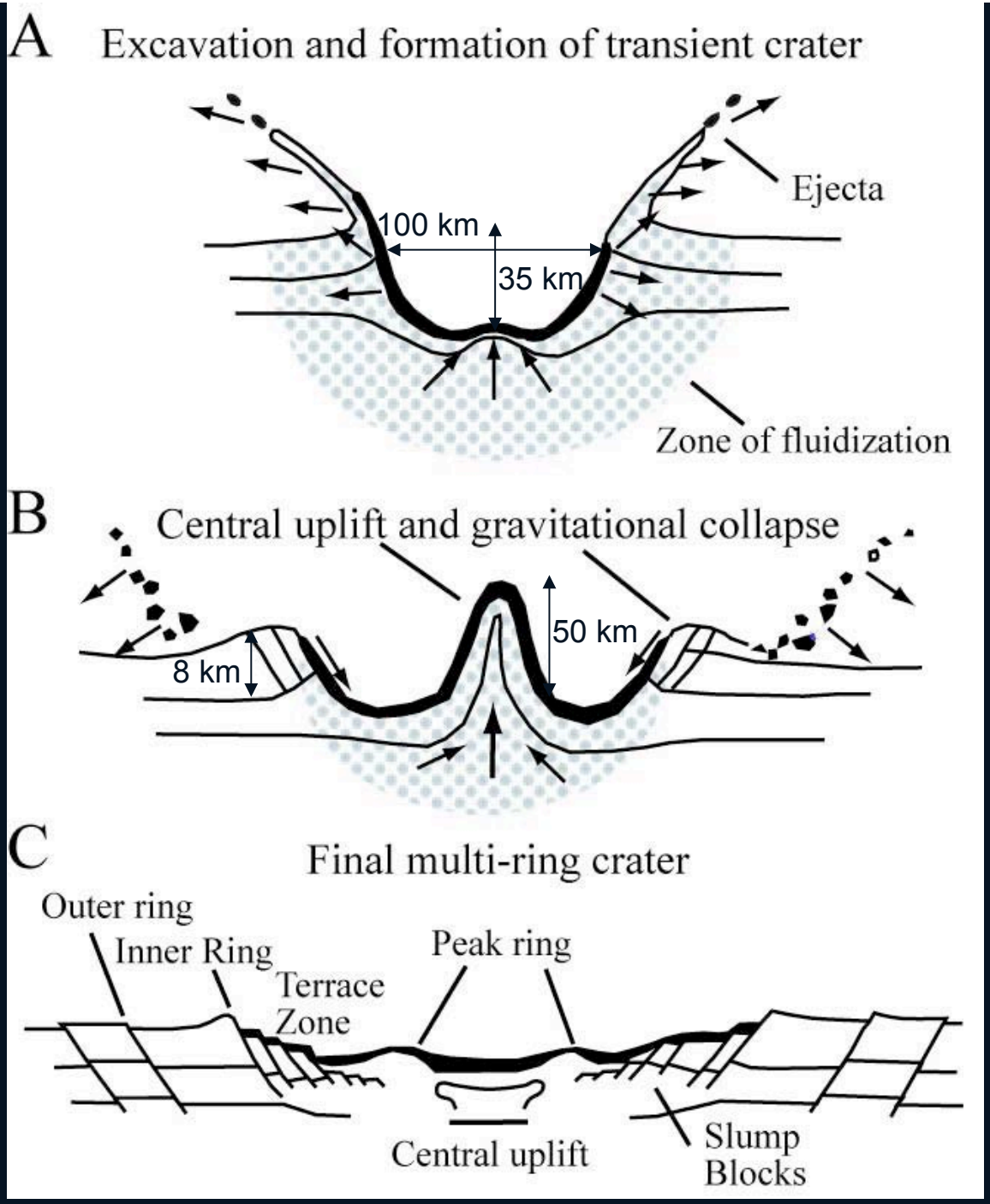
Alfrancus C -
10 km simple crater



Schrodinger –
320 km peak ring basin

Orientale – 900 km
multi ring basin

Tycho – 85 km
complex crater



All in 300 to 600 sec!

Melosh et al. (1989)

Geophysical Surveys of Chicxulub

2005
MCS lines

1996 and Pemex
MCS lines

1996
land stations

2005
land stations

1996 Experiment

2005 Experiment

Yucatan coast line

km
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22°00' N
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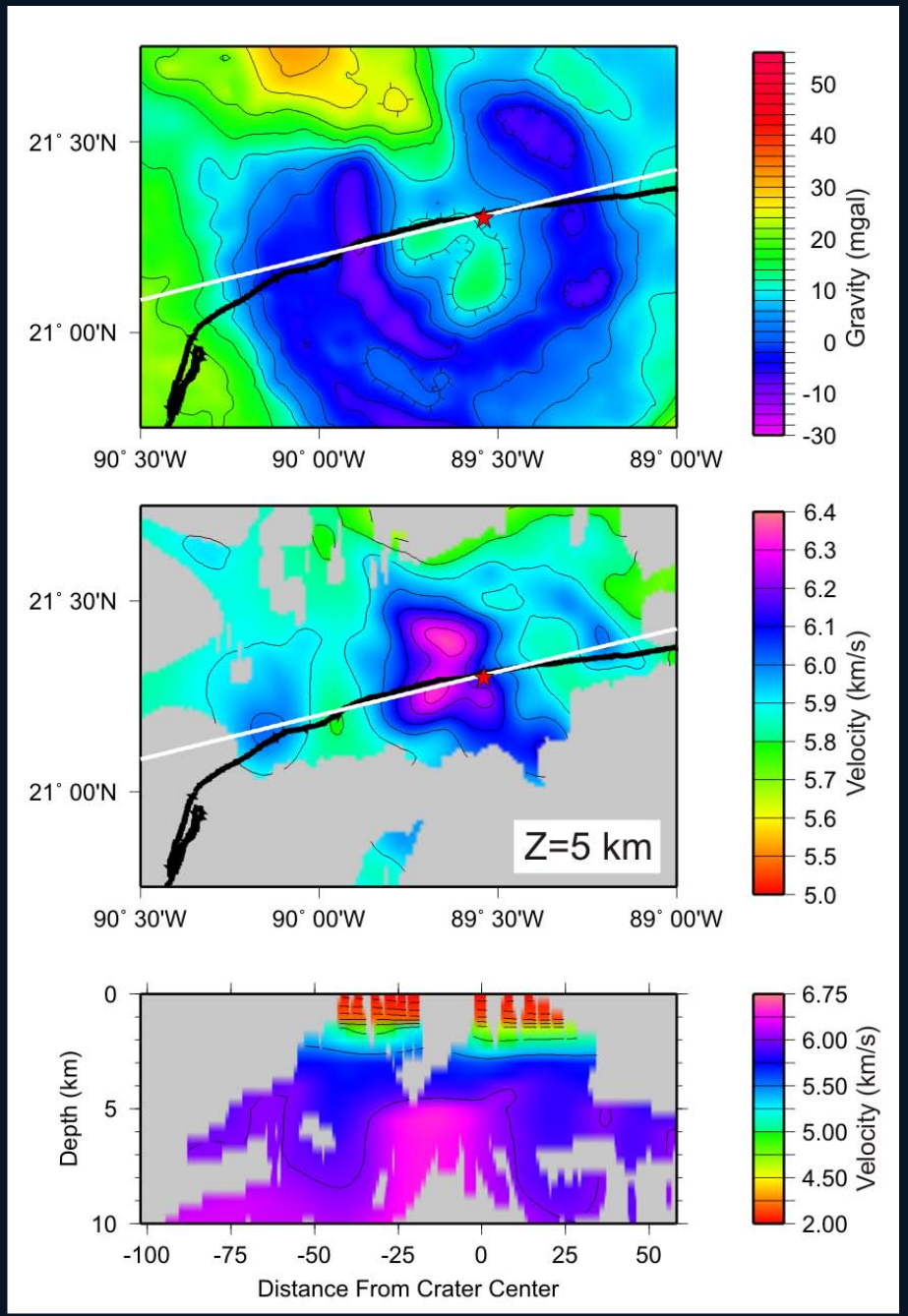
89°00' N
88°30' N
88°00' N

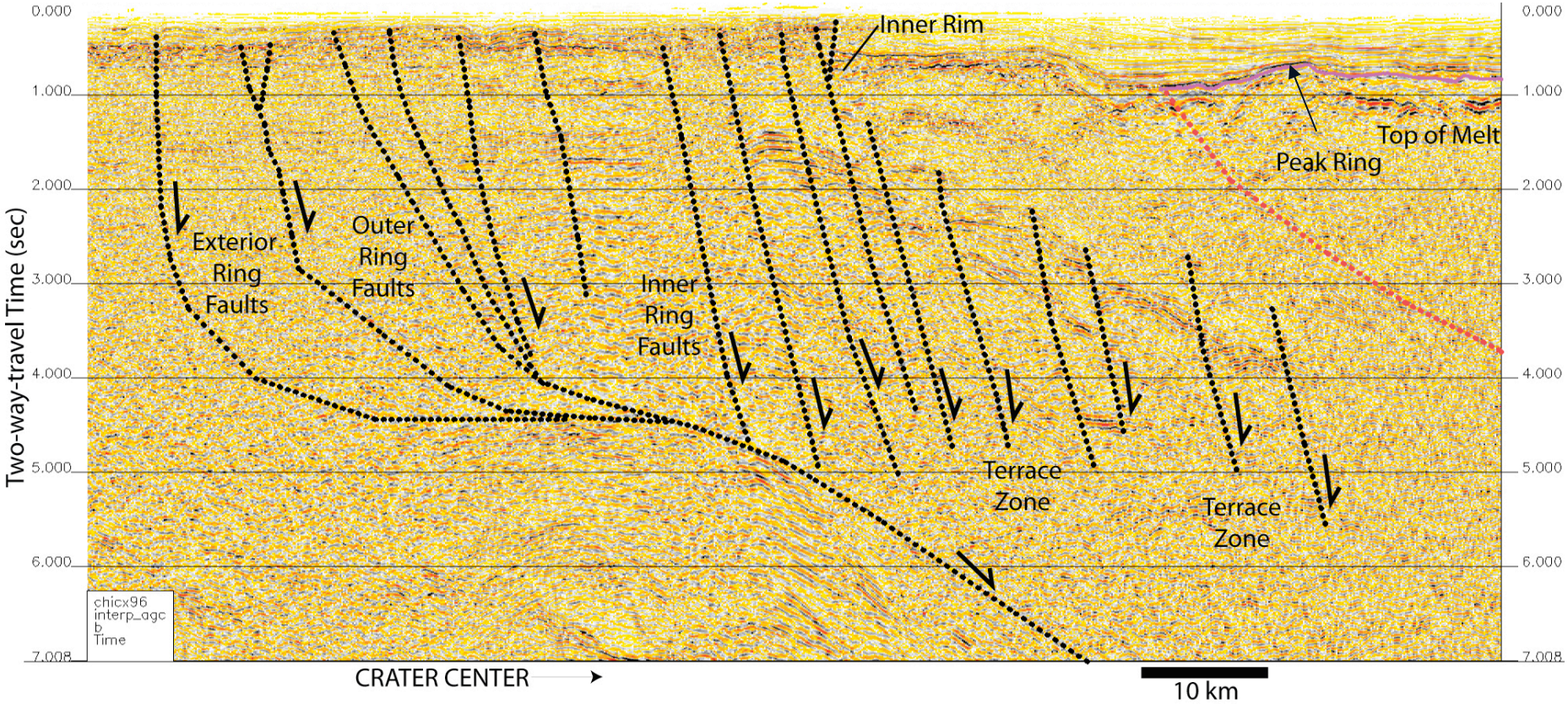


Refraction Results

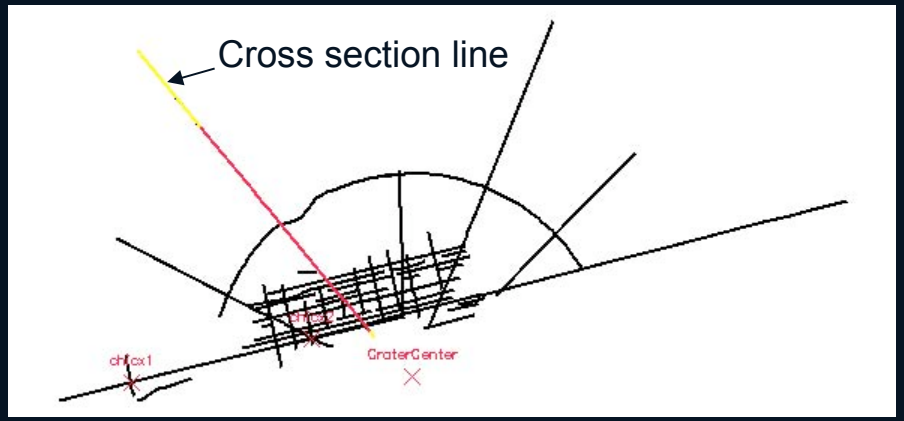
- Structural uplift near the crater center (red star) is constrained by gravity and velocity data.
- The uplift is offset west of the crater center.
- Velocities of 6.3 km/s occur at a depth of 5 km. Outside the crater these velocities are found at a depth of 15 km, suggesting a vertical uplift of ~10 km.

Christeson et al., EPSL, 2009

NW Cross Section through Crater

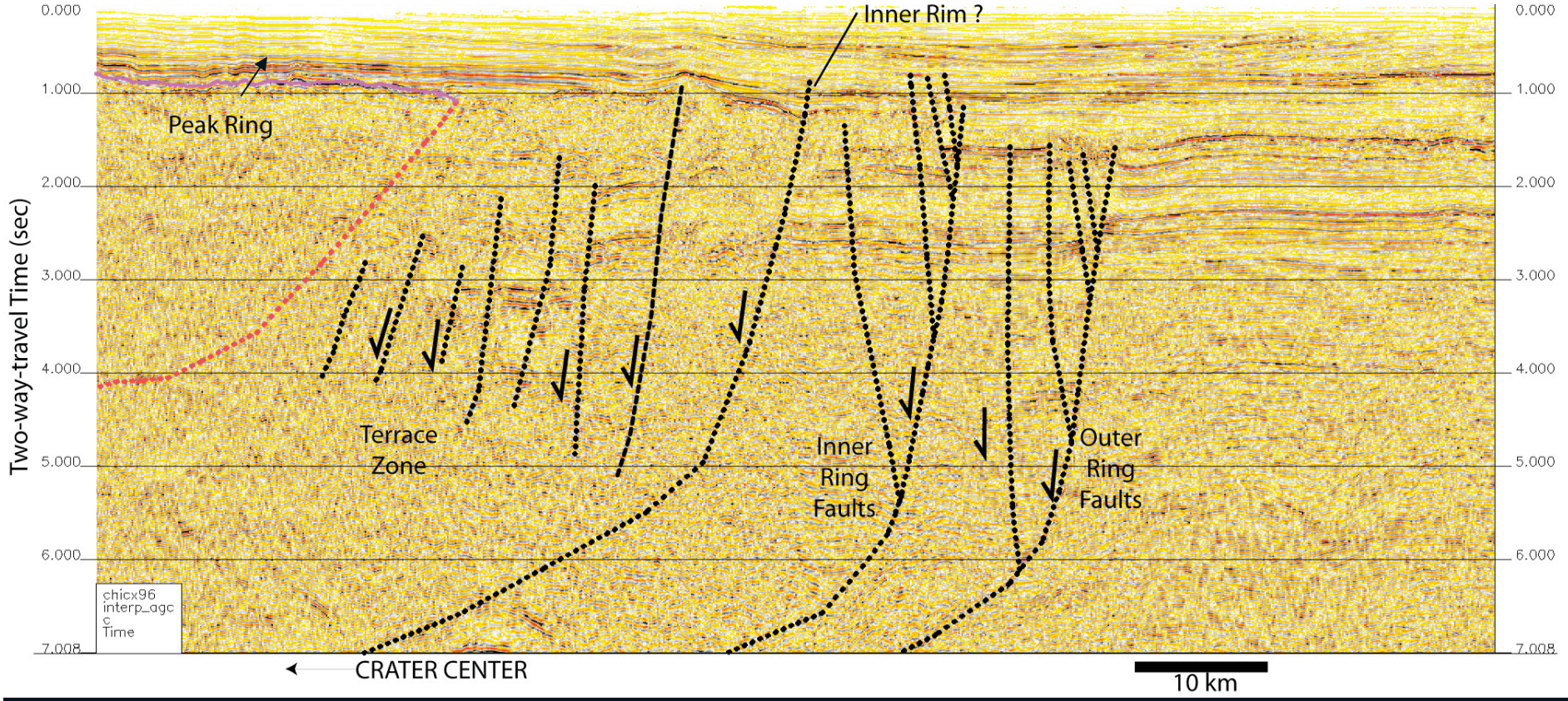


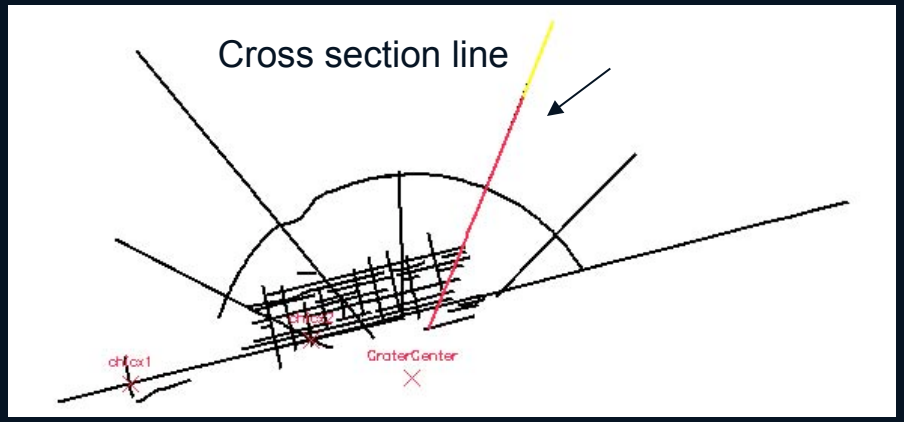
Reflection Results



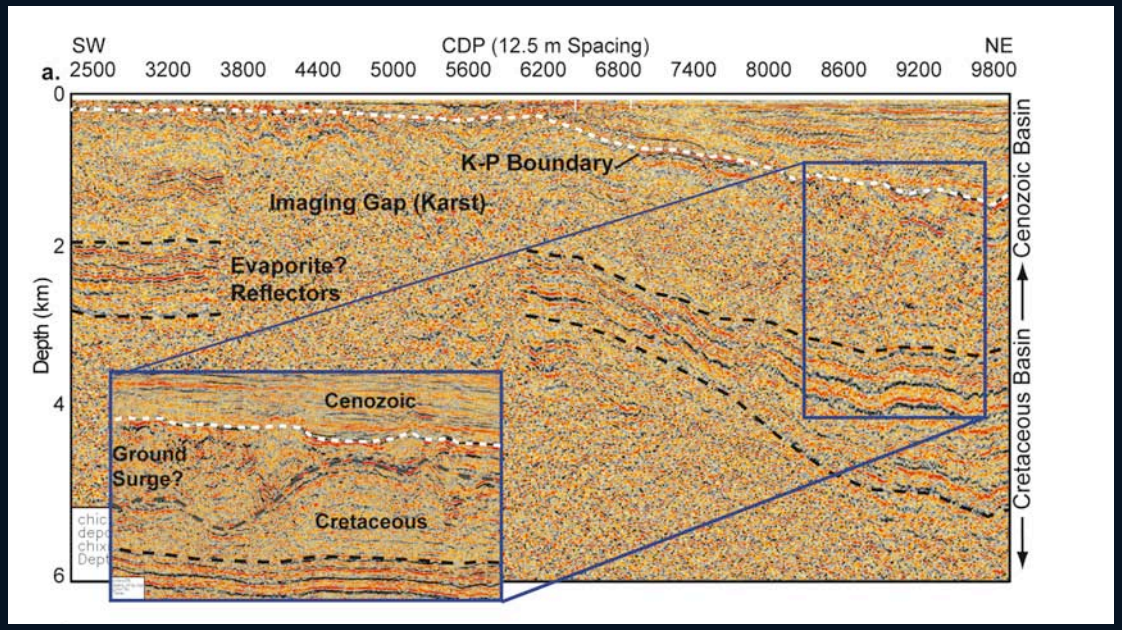
Gulick et al., Nature Geoscience, 2008

NE Cross Section though Crater

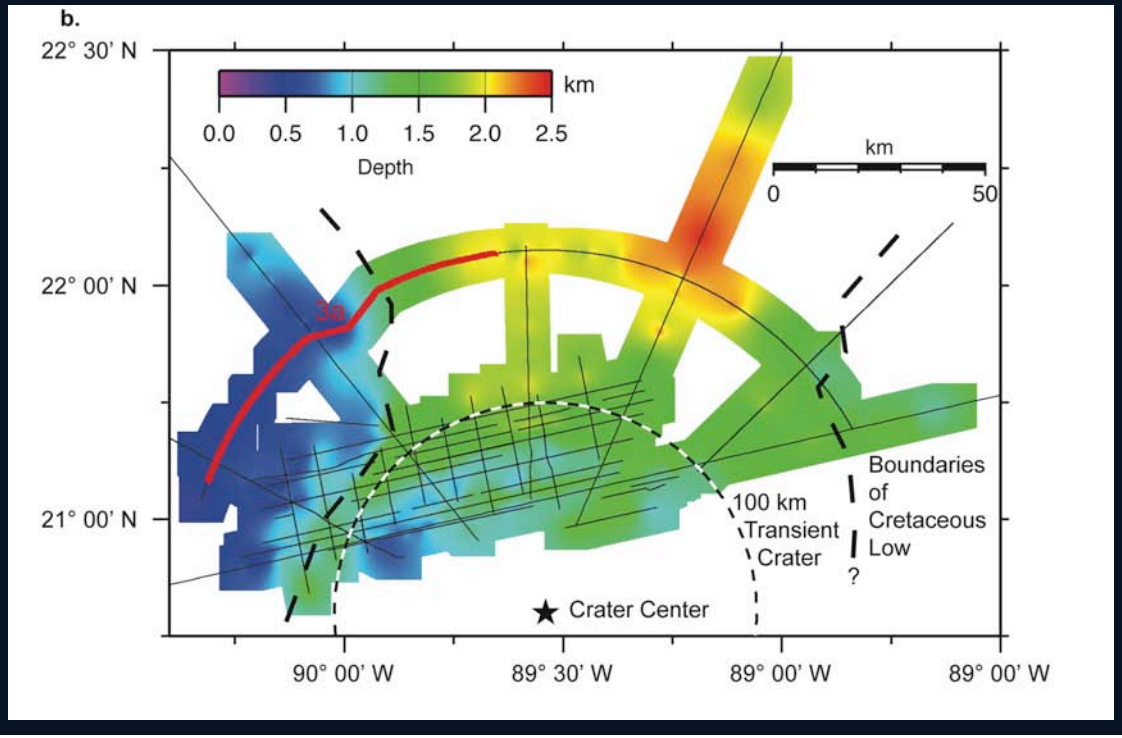




Gulick et al., Nature Geoscience, 2008

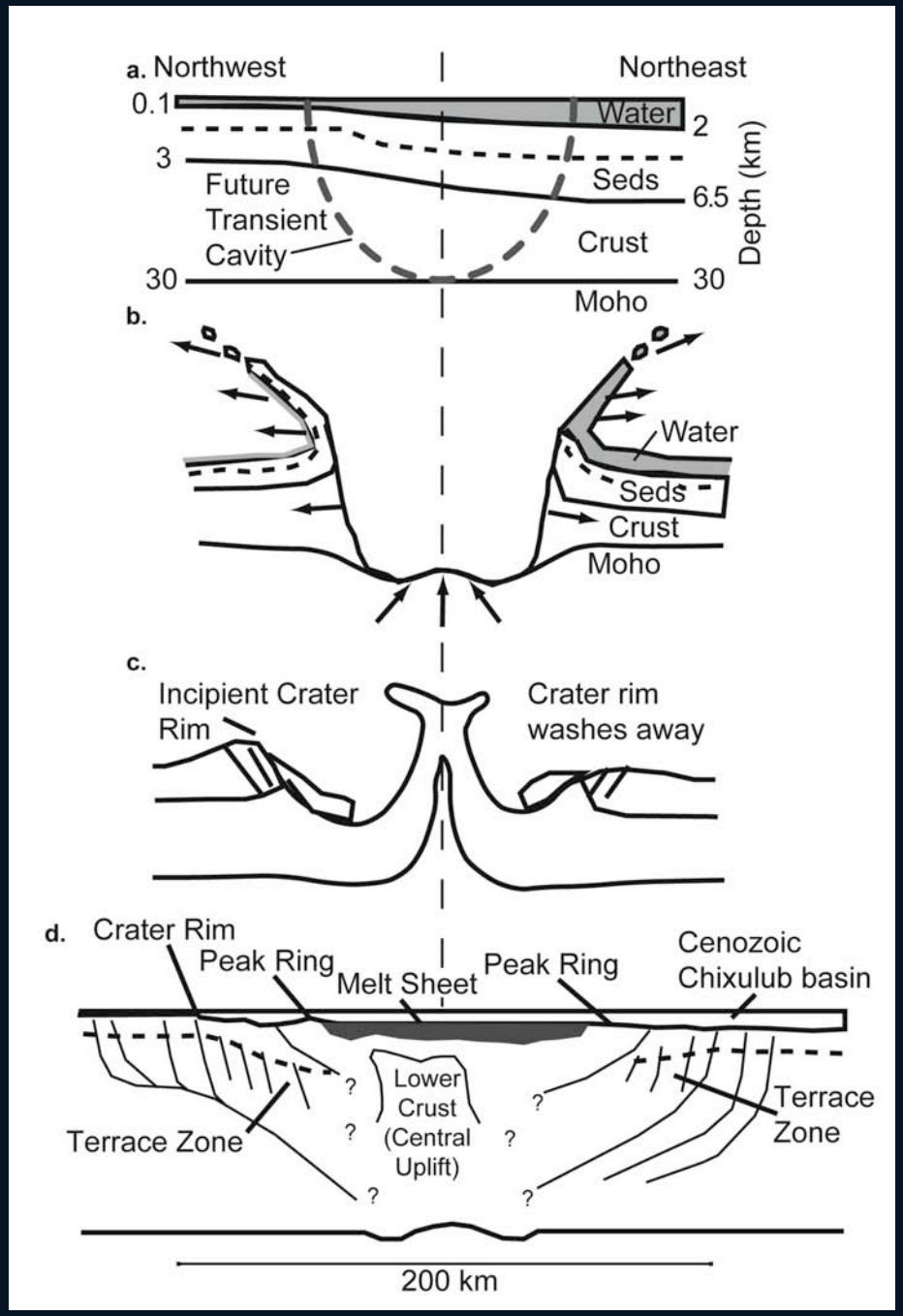


Cross-section of margin of **Chicxulub** crater



Map view of depth to Cretaceous ocean floor

Gulick et al., Nature Geoscience, 2008



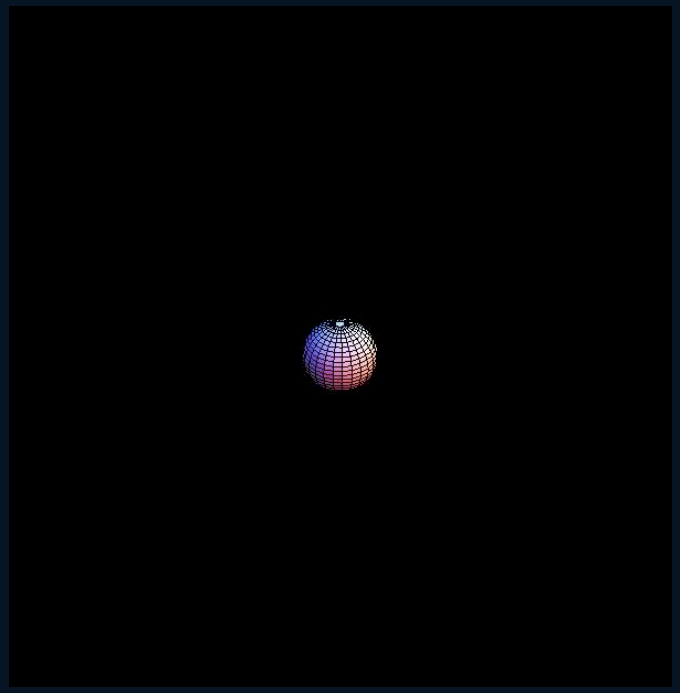
Conclusions

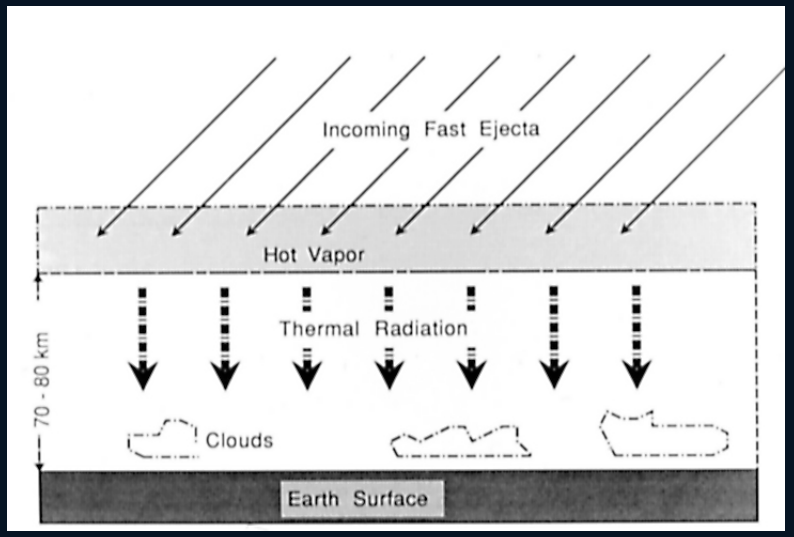
- Impact resulted in a 100 km transient crater that collapsed into the 200 km final crater
- Asymmetries result from target structure rather than meteor trajectory
- Ring faults mapped at distances up to > 125 km
- Average water depth ~650 m, with significant implications

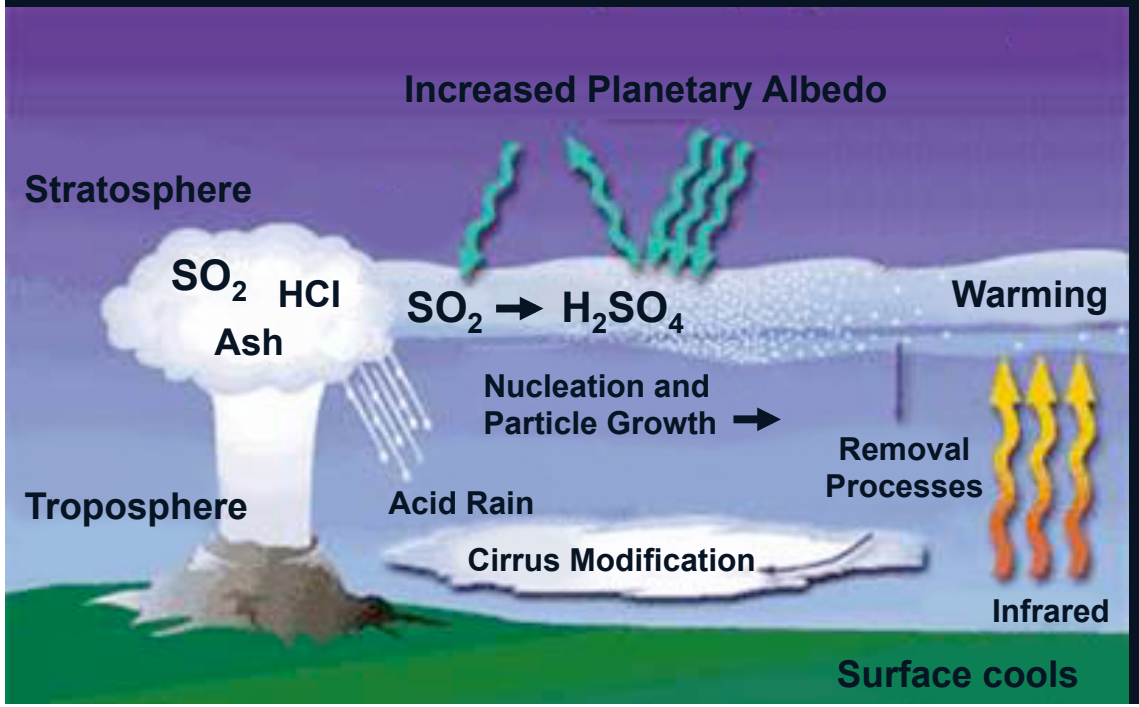
Gulick et al., Nature Geoscience, 2008

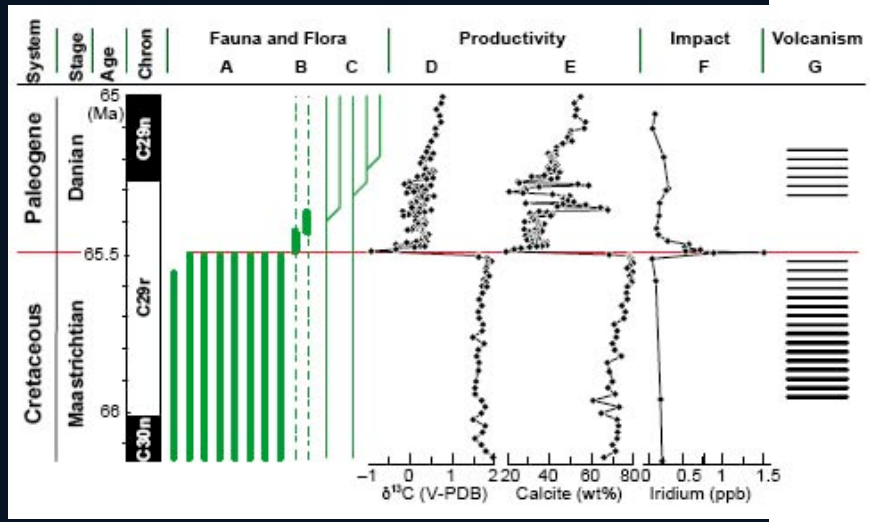
Extinction

Mechanisms & Implications of Target

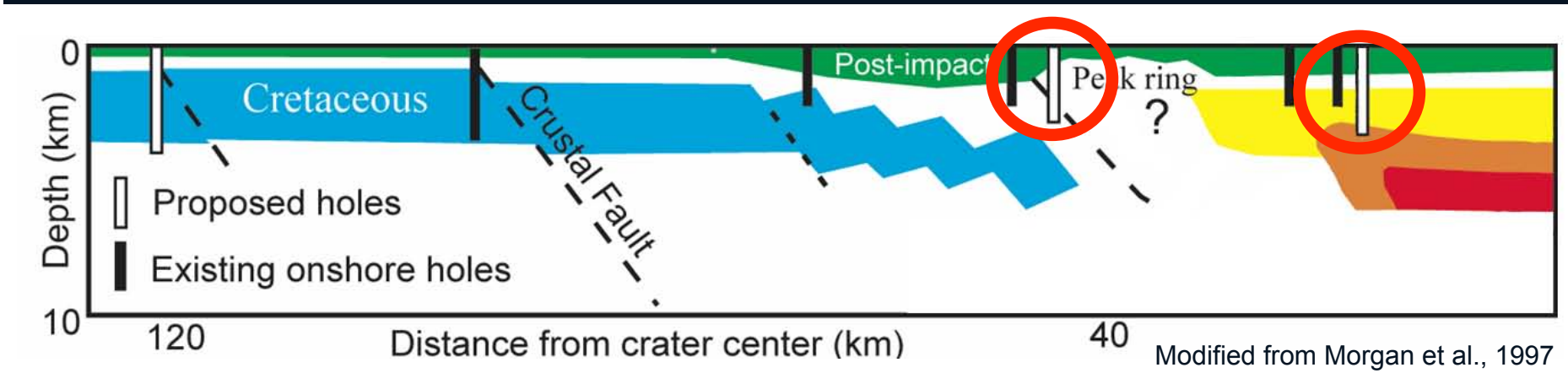








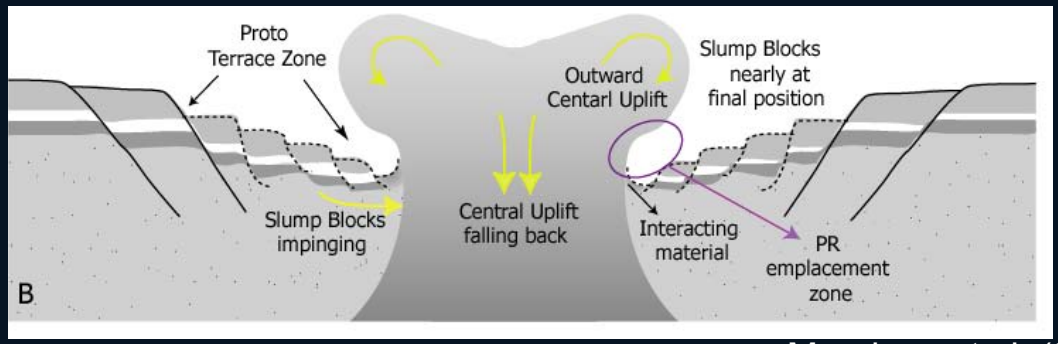
Future Research: IODP Drilling



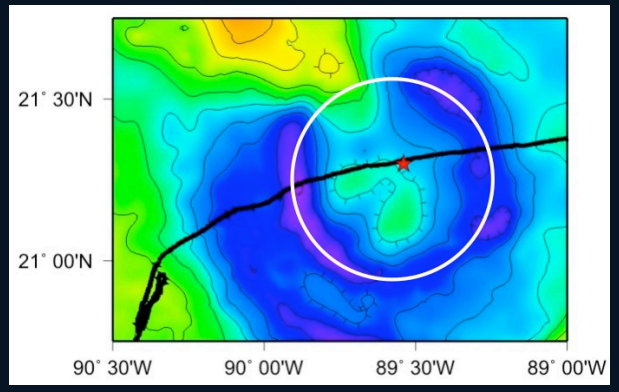
Modified from Morgan et al., 1997

What are the dimensions of the melt sheet? (Proxy for energy release)

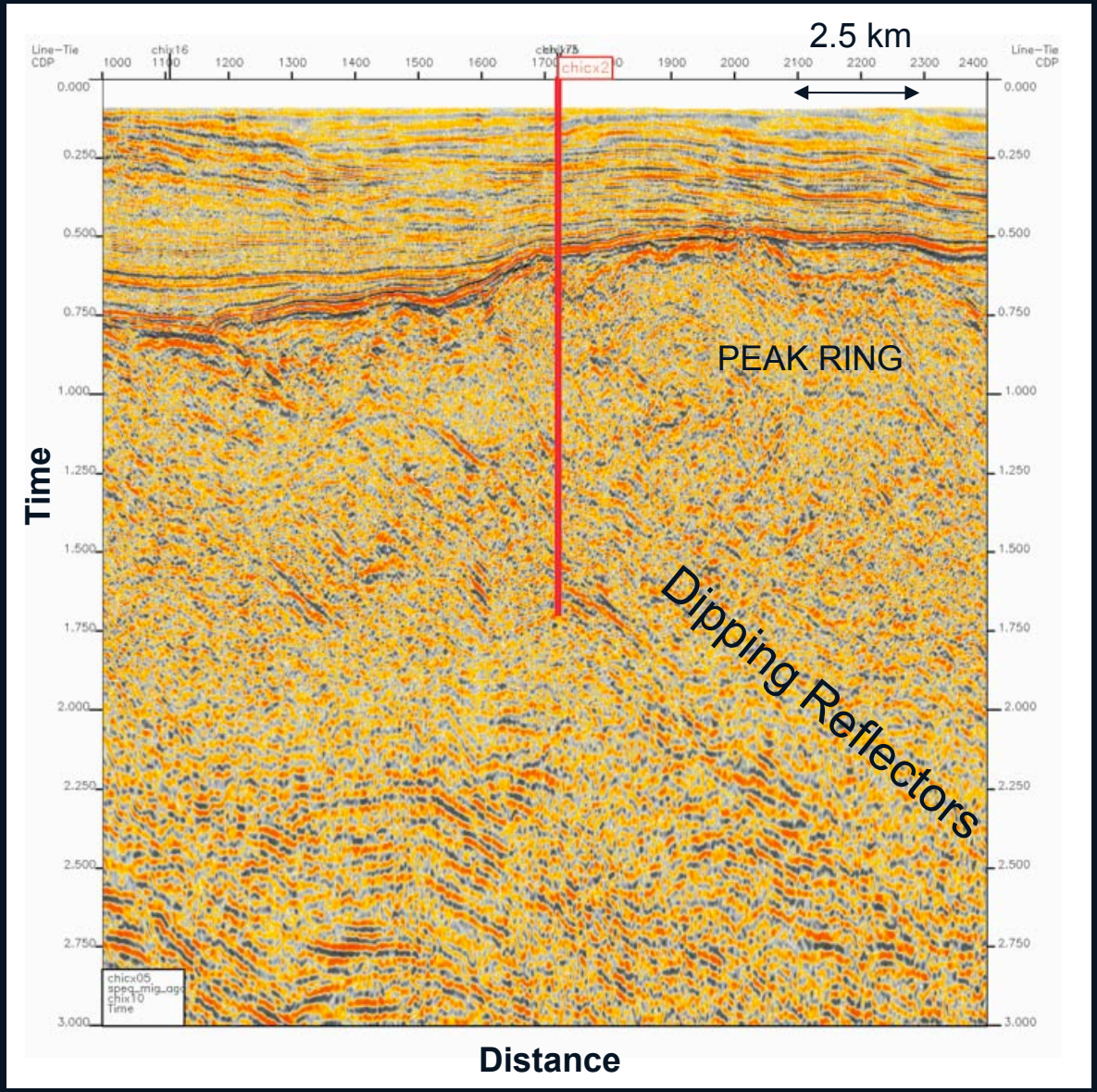
Is the peak ring associated with a thickened layer of melt-rich impact breccia? Is it formed by collapse of the central uplift?



Mendoza et al. (2007)

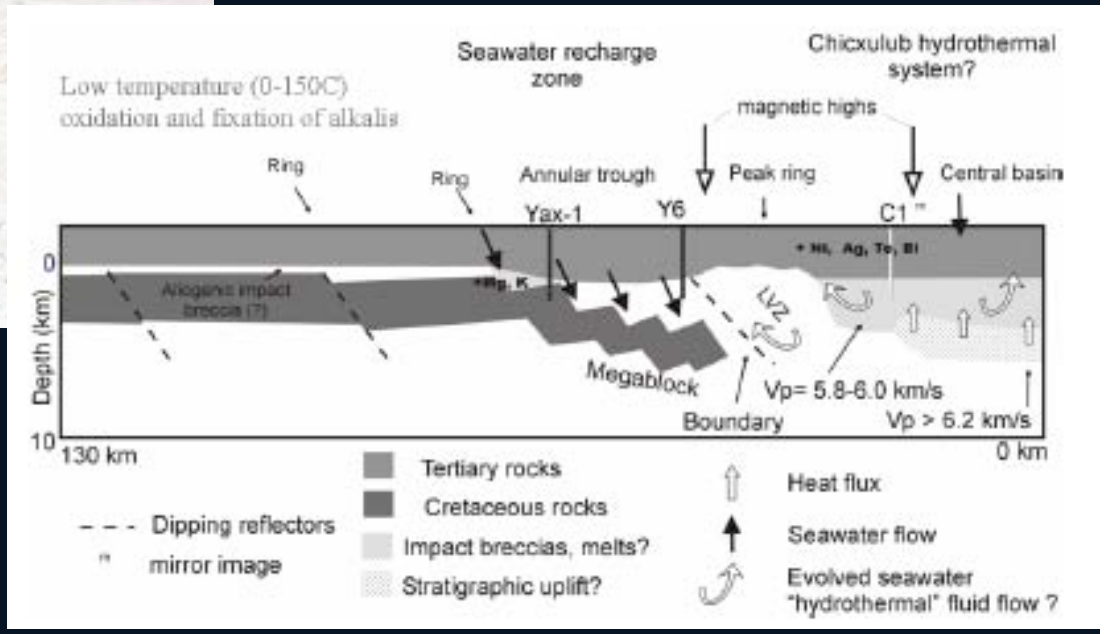


What is the dipping reflector? Is it a mineralized fault recording an old hydrothermal system?



Was this system a haven for chemosynthetic life?

Implication: role of impacts as habitat forming events? Important for Hadean Earth? Other planets?



Ames et al. (2006)

With thanks to:

Gail Christeson, Matt McDonald, Peggy Vermeesch

Jo Morgan, Mike Warner, Gareth Collins

Jaime Urrutia, Keren Mendoza

Michael Whalen, Zulmacristina Pearson

Penny Barton, Anusha Surrendra

Jay Melosh, Betty Pierazzo

Christian Koerberl

Thanks for listening!

Sean Gulick

sean@ig.utexas.edu

471-0483

Southeast Impact Angle?

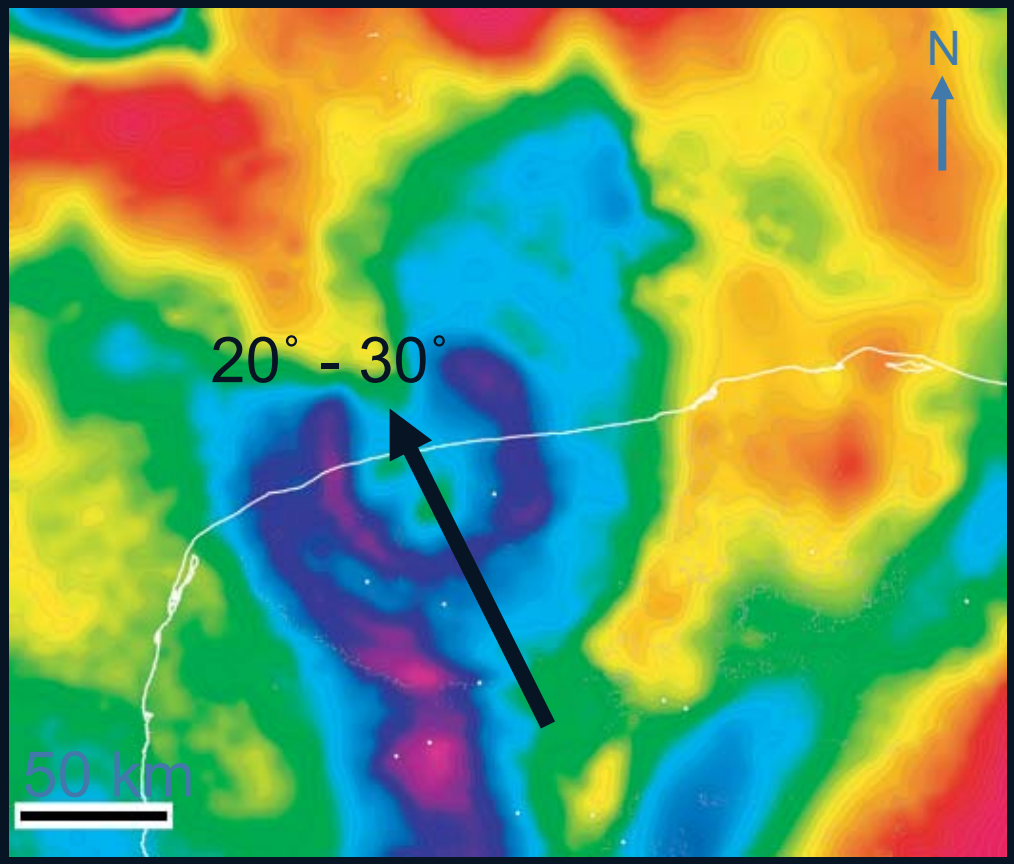
Schultz and D'Hondt et al. (1996)

Environmental Evidence

- "Fern spike" in North America due to lack of competition
- Higher flora extinctions in North America

Gravity Anomaly Evidence

- Elongate central structure
- Central structure is offset uprange (SE)
- Widening of the 180 km ring transverse to trajectory

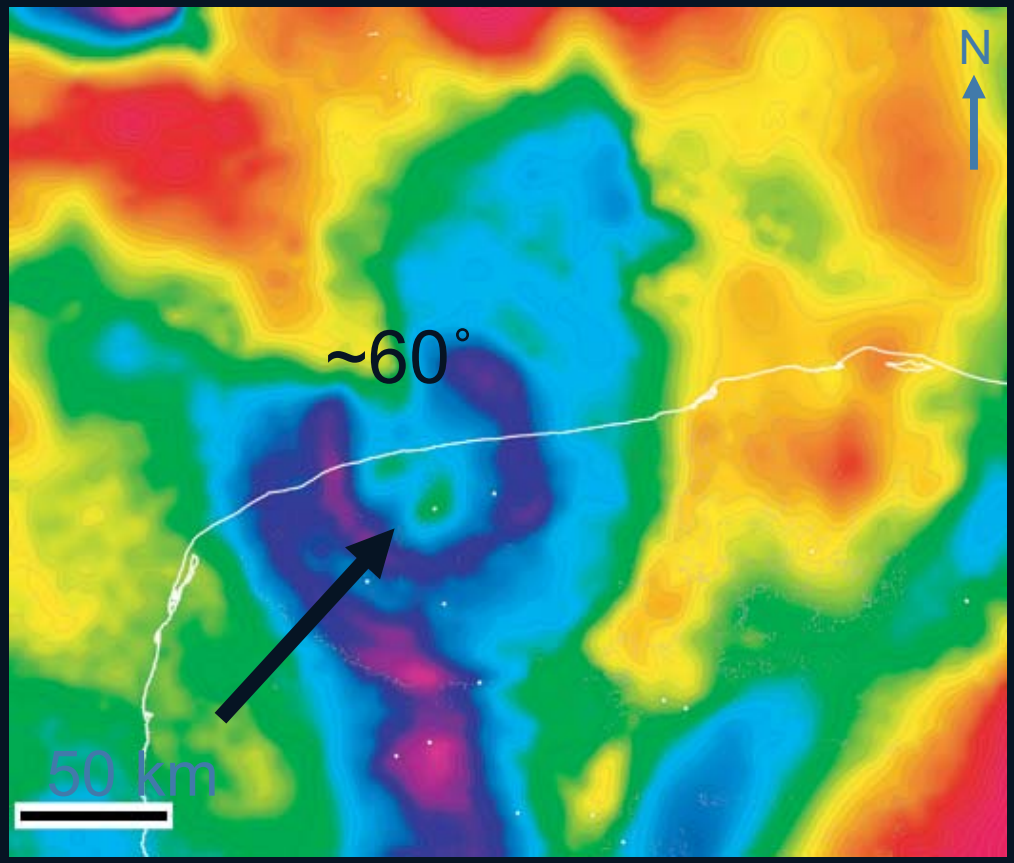


Southwest Impact Angle?

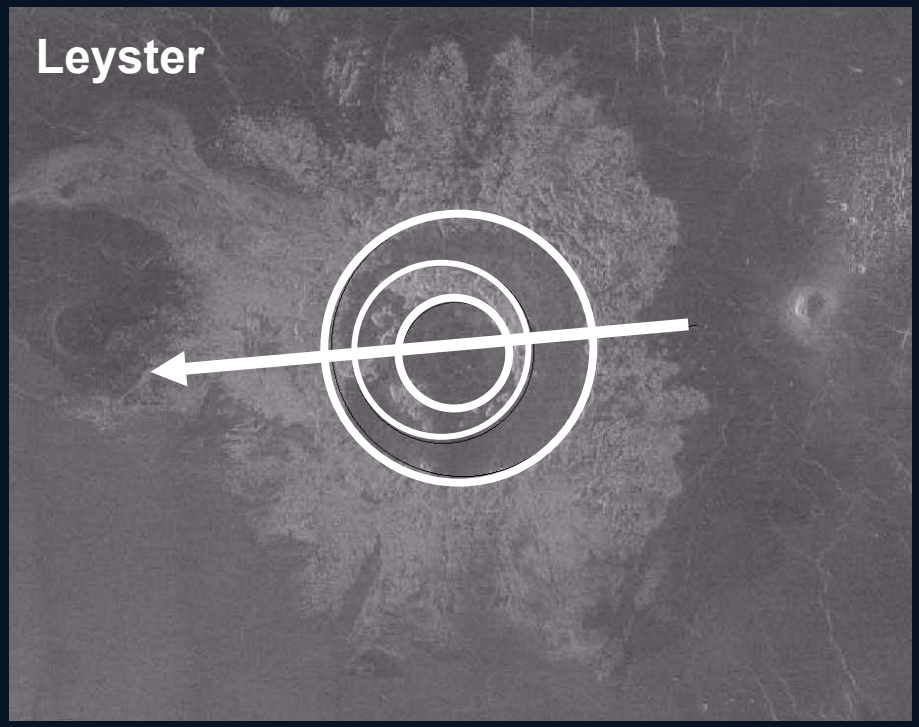
Hildebrand et al. (1998)

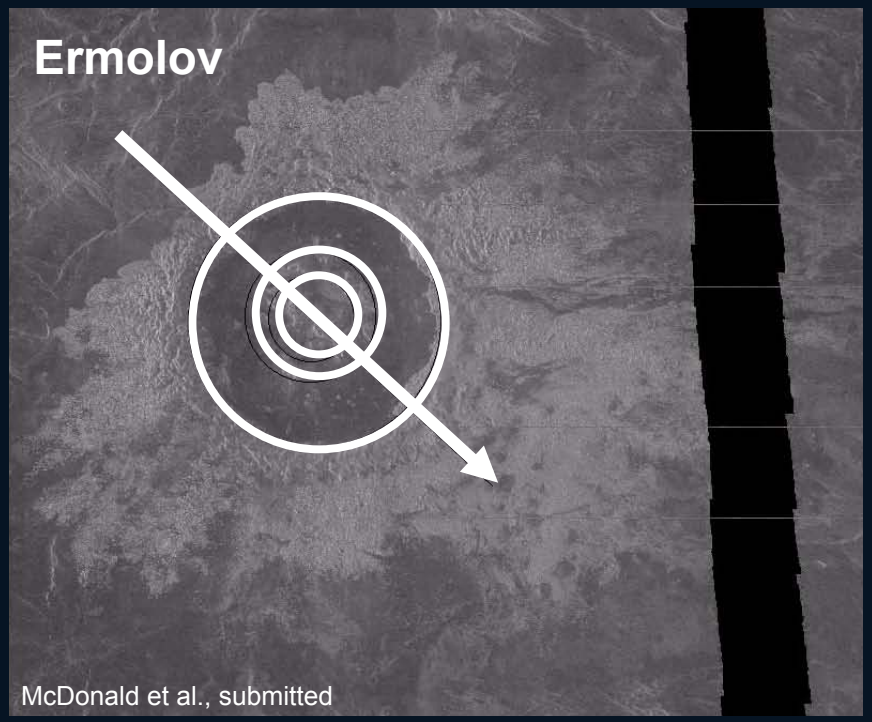
Gravity + Seismic Evidence

- “twin peaks” alignment
- Asymmetry in inner ring and peak ring
- Thrusting downrange
- Downrange depression
- NE compressional shearing



Craters on Venus



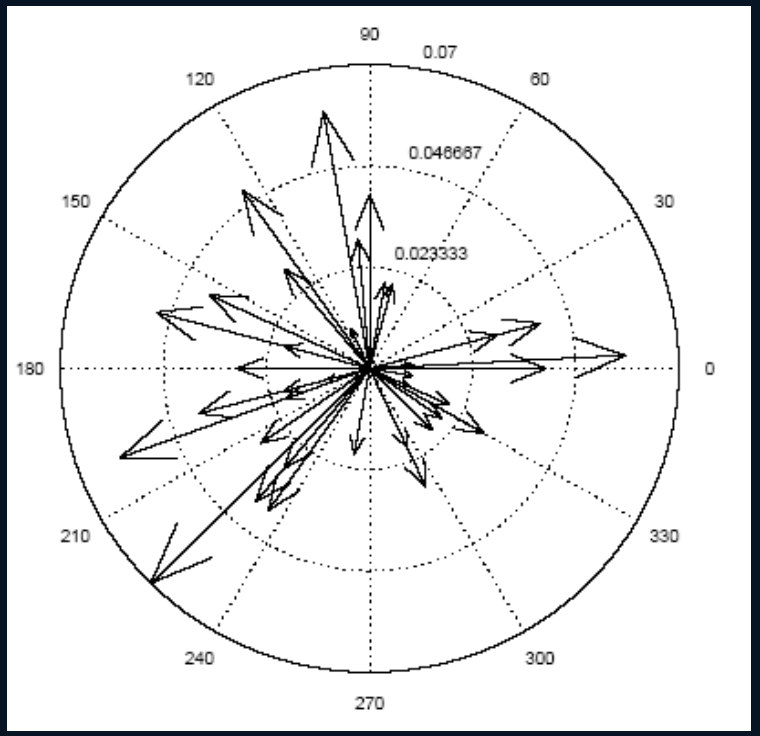


The surface morphology of craters where the direction of impact can be determined by independent means do not clearly indicate an impact trajectory.

Central peak offsets vs. peak ring offsets

central peak offsets

Impact direction

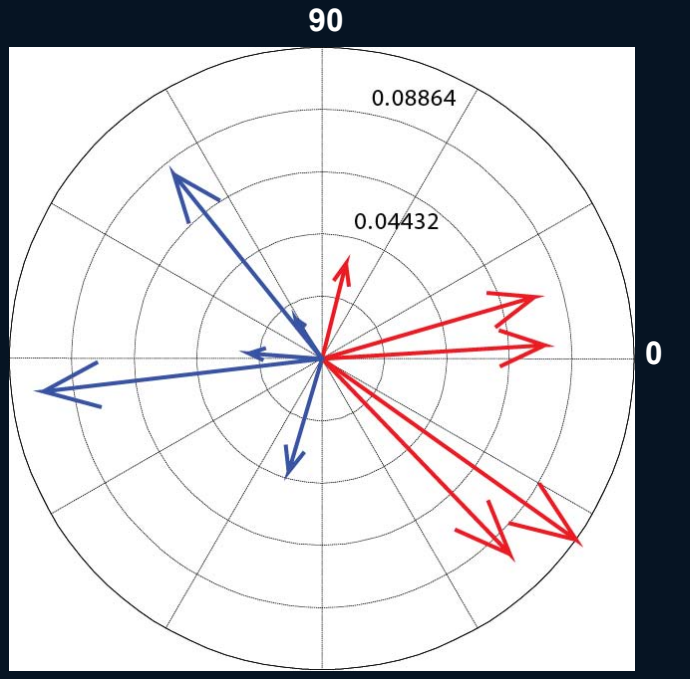


Average offset: .031

Ekholm & Melosh et al., GRL, 2000

peak ring offsets

Impact direction

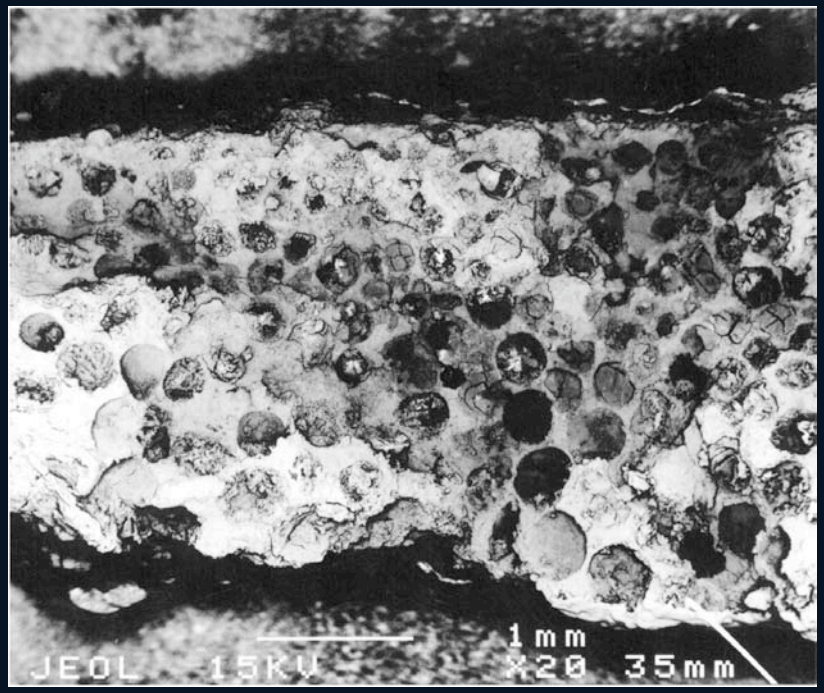


Average offset: .067

McDonald et al., GRL, 2008

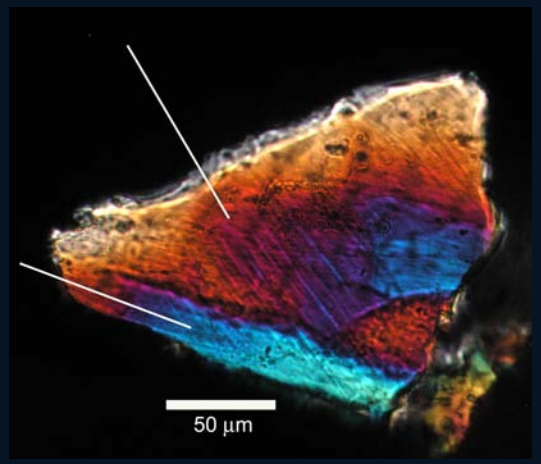
Soon, other sites were found from land locations. The boundary, where well preserved, was full of tiny glass spherules called “microtektites”

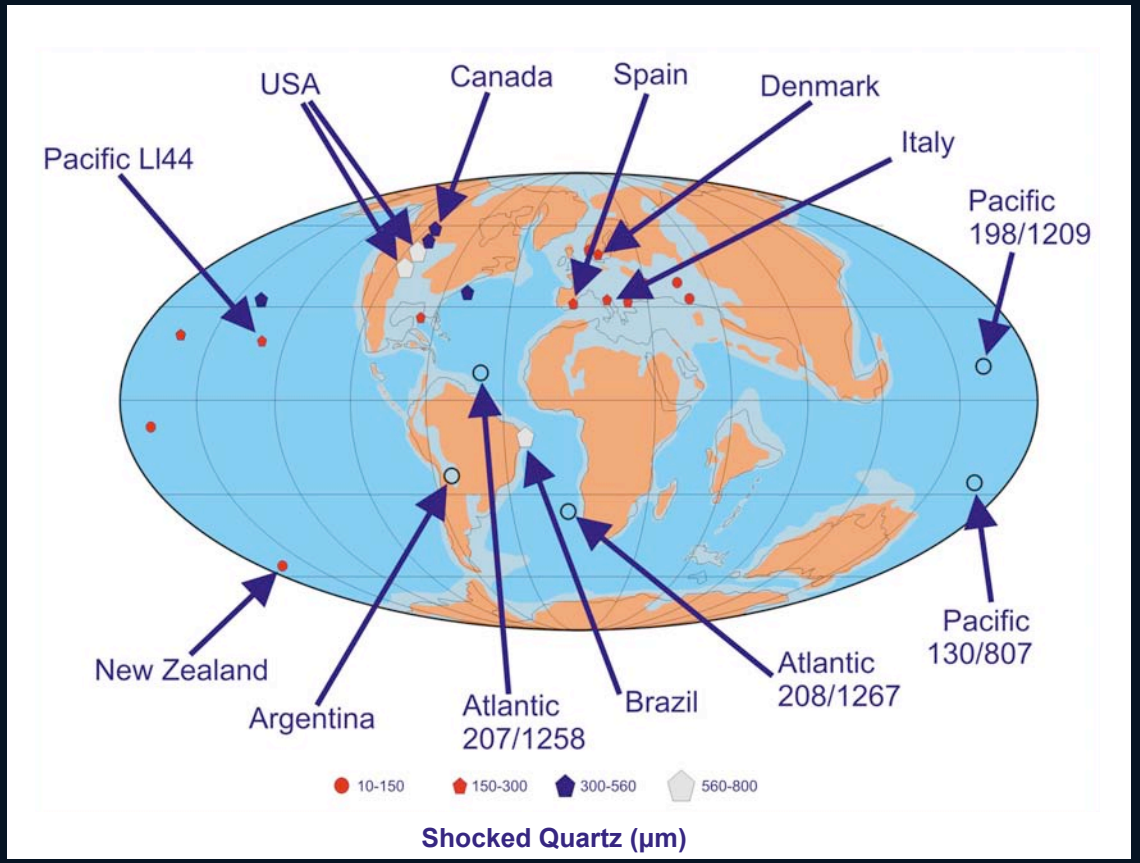
Raton, Colorado

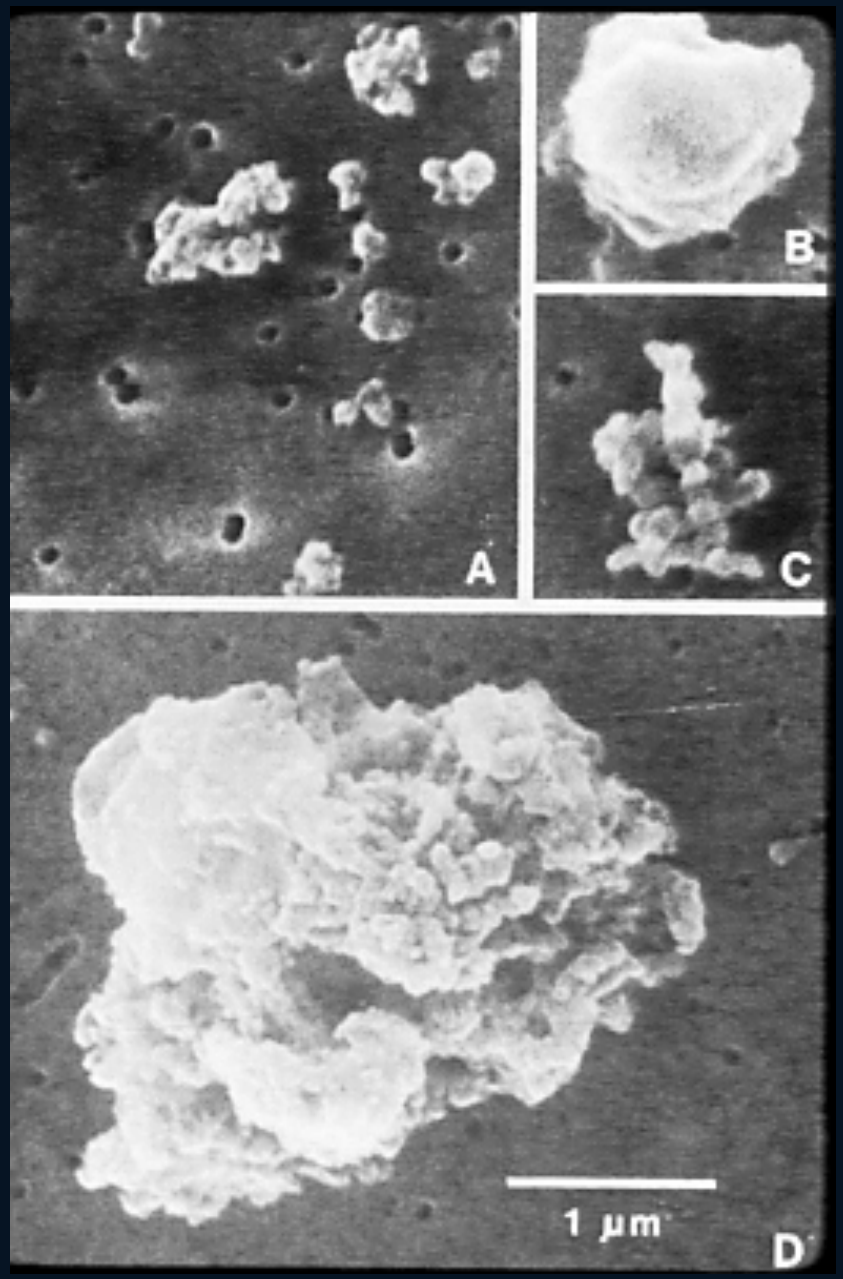


Caravaca, Spain

Both shocked quartz, another indicator of impact, and iridium are now found at hundreds of sites worldwide, all located exactly at the extinction horizon



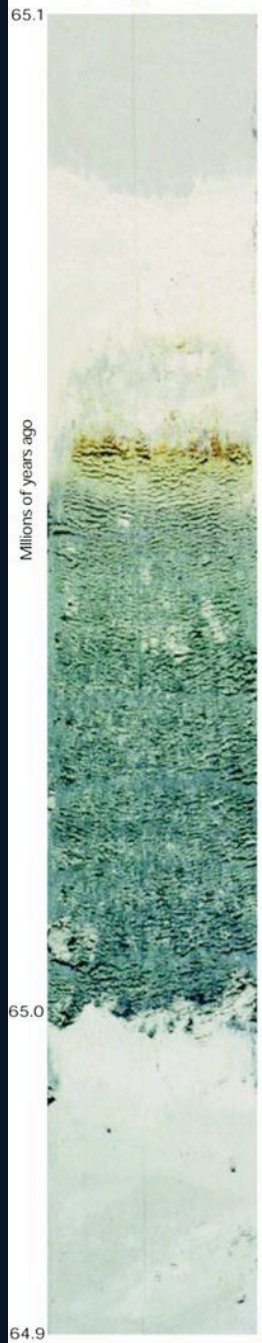




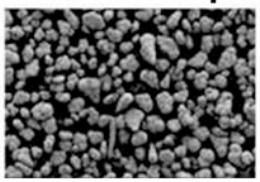
The boundary clay also contains massive amounts of soot, indicating global wildfires

Melosh et al. (1990)

Deep-sea core shows impact



After the Impact



Fireball Layer

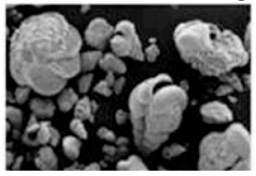
Contains dust and ash fallout from the asteroid impact.

Effects of the Impact

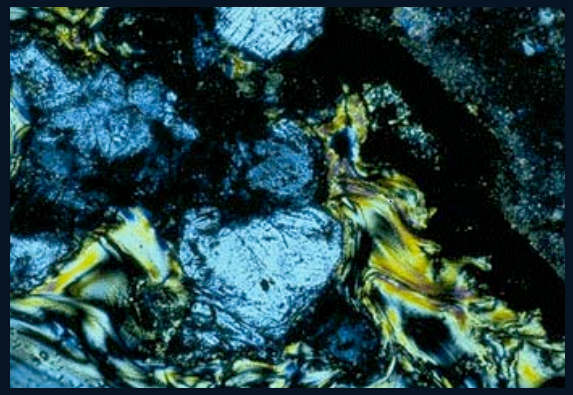
Moment of Impact

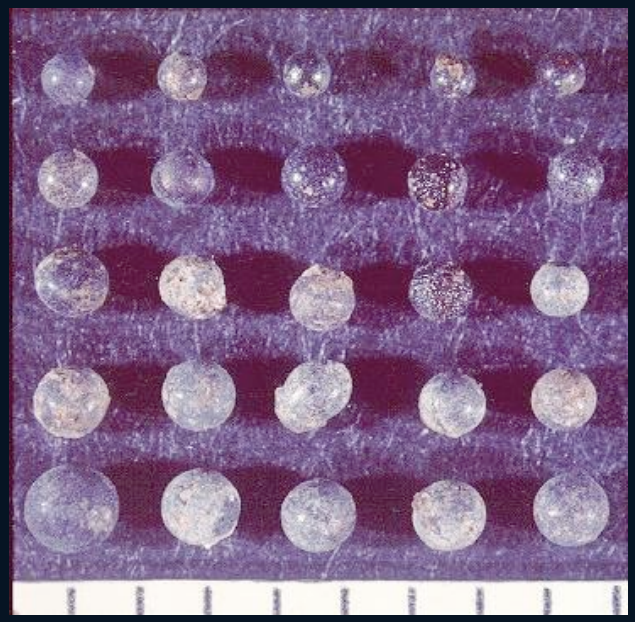
K/T (Cretaceous/Tertiary) Boundary

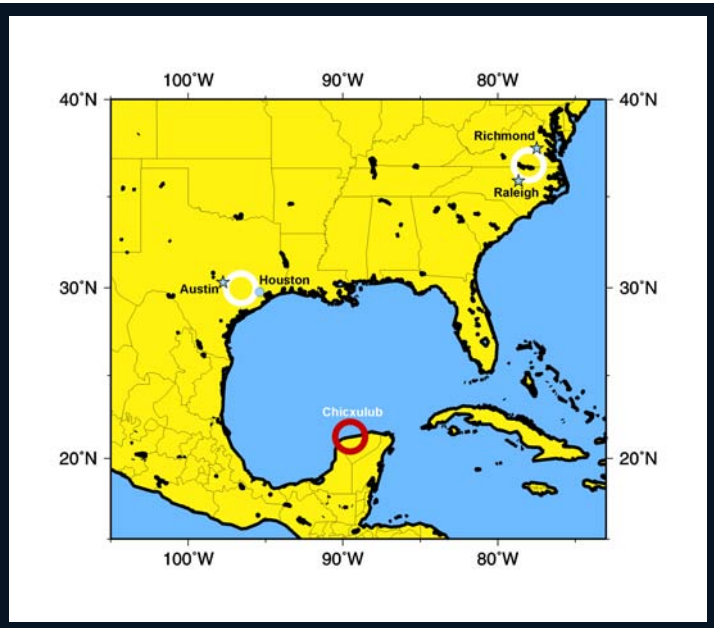
Before the Impact

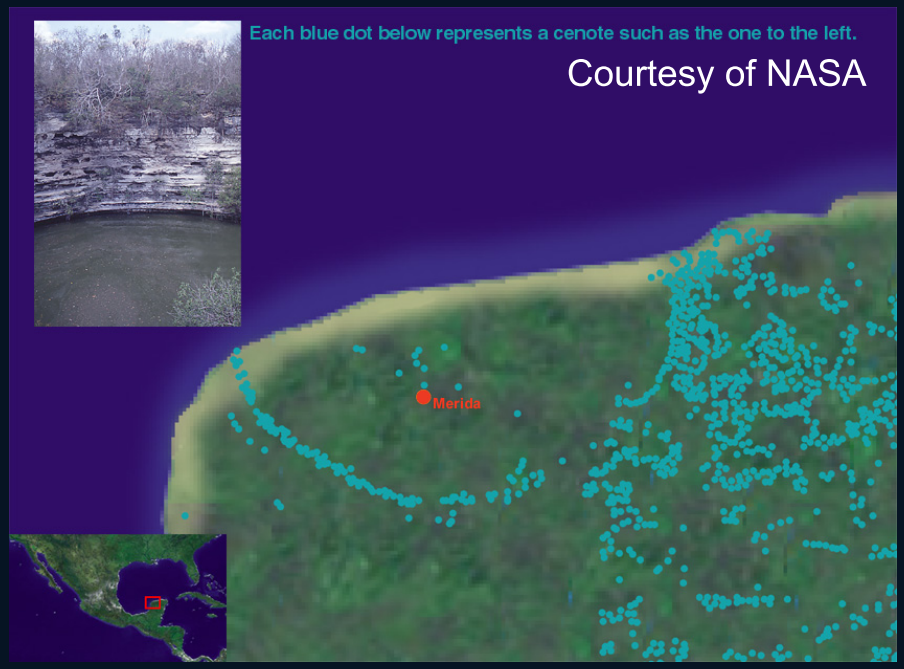


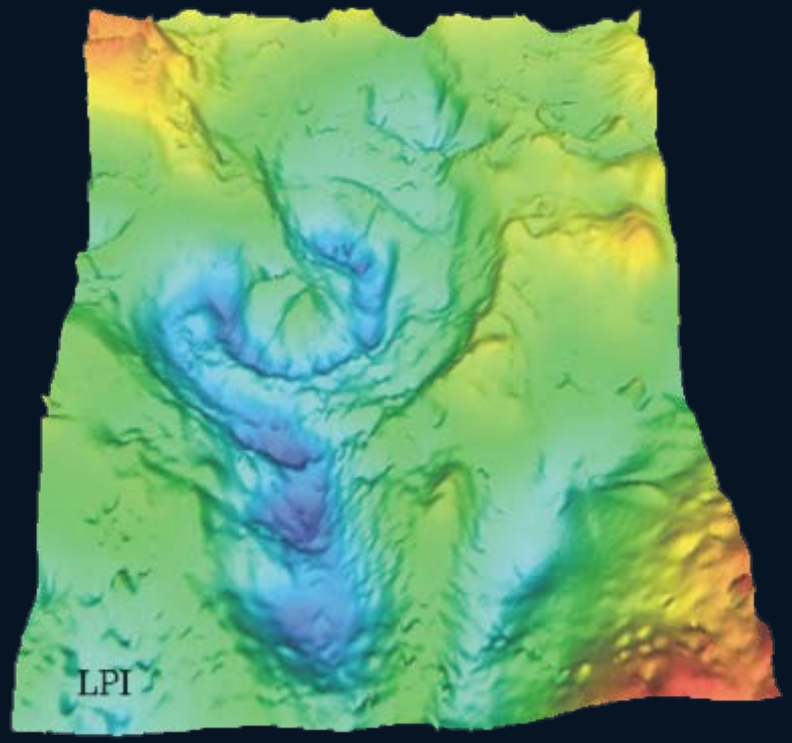
Drilling on the Blake Nose: ODP Leg 171B
Norris et al, 1999






100°W
90°W
80°W
40°N
30°N
20°N
Richmond
Raleigh
Austin
Houston
Chicxulub

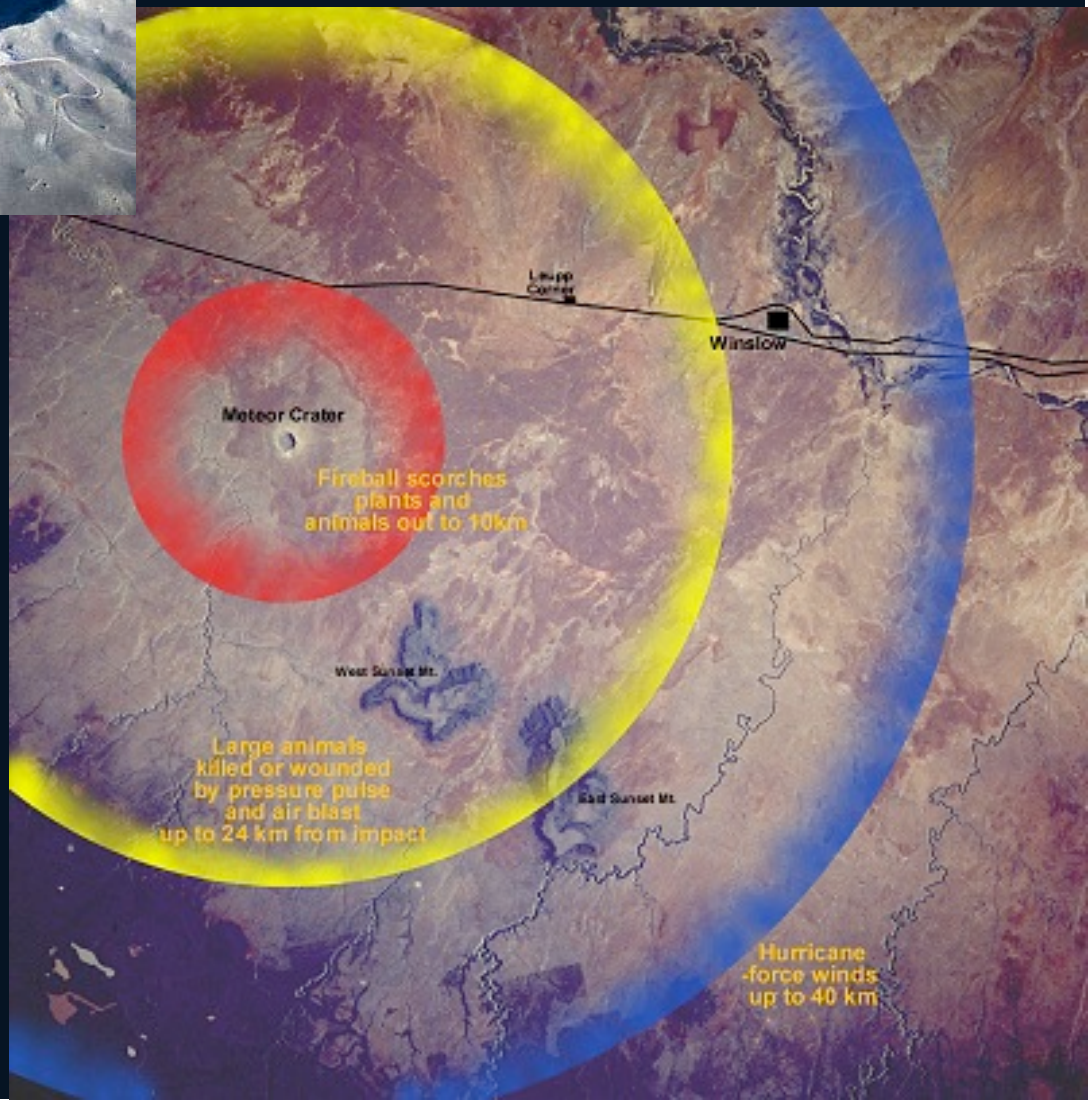

Each blue dot below represents a cenote such as the one to the left.
Courtesy of NASA
Merida


LPI

Meteor Crater: A small one

St. Stephens Cathedral in Vienna (137 m high) in Meteor Crater, Arizona (1.2 km diameter)

July 8, 1956: 1.9 MT Apache nuclear fireball



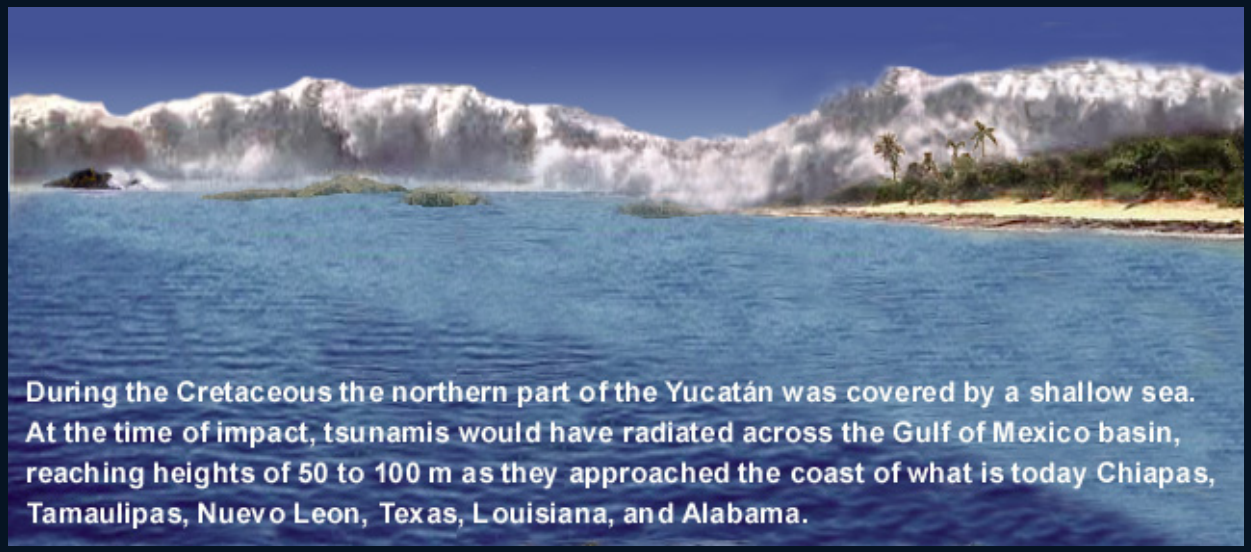
Energy = ½ mv^2

Mass = 1 x 10^{15} kg
Velocity = 20 km/sec

Energy = 2 x 10^{23} J ≈
100 million Atomic bombs

1% of energy turned into (200 m) tsunamis and hurricane force winds

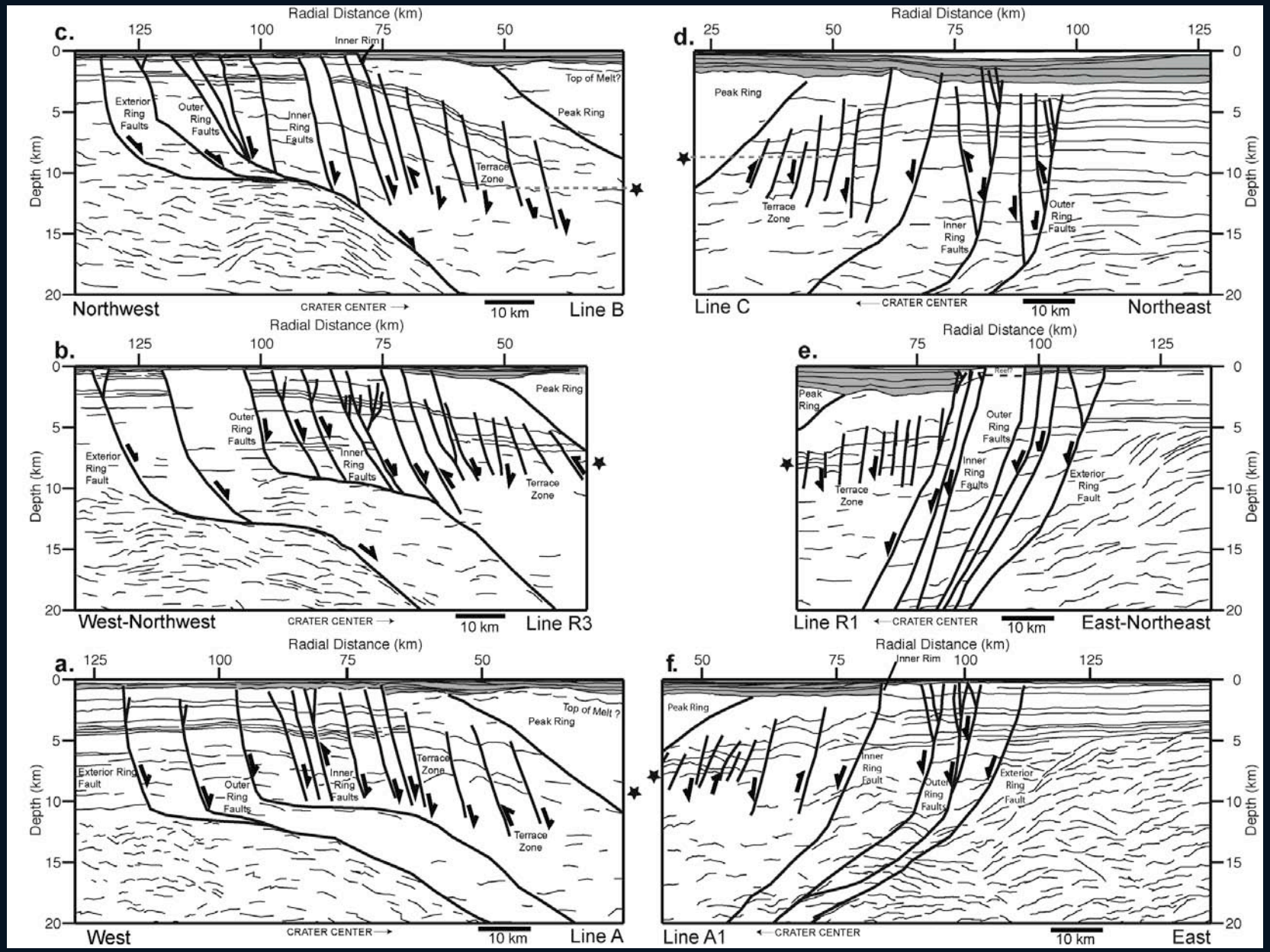
99% of energy caused melting, vaporization, ejecta, and magnitude 13 earthquakes



But the real problem was the ejecta…

~ West side

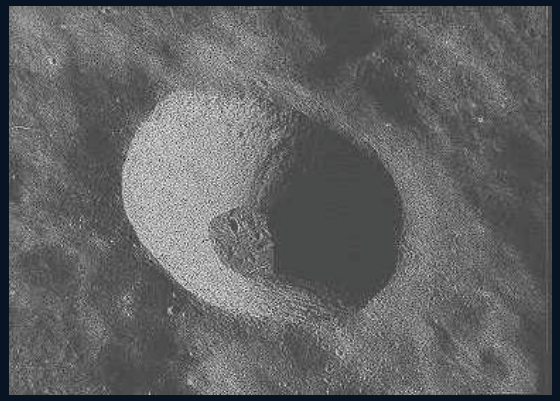
~ East side



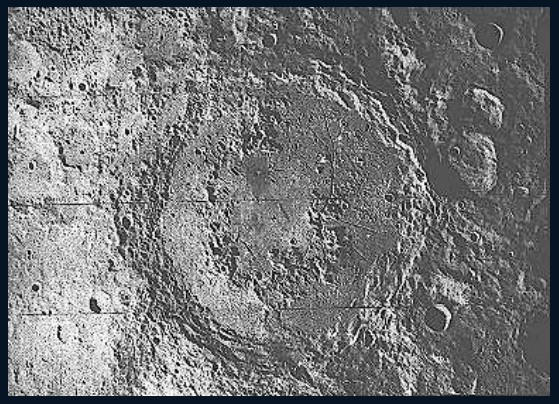
Gulick et al, 2008

Crater Morphology

Lunar examples



Alfrancus C -
10 km simple crater



Schrodinger –
320 km peak ring basin

Orientale – 900 km
multi ring basin

Tycho – 85 km
complex crater