Hot Science Cool Talks

UT Environmental Science Institute

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The Rock that Changed the World

Dr. Sean Gulick

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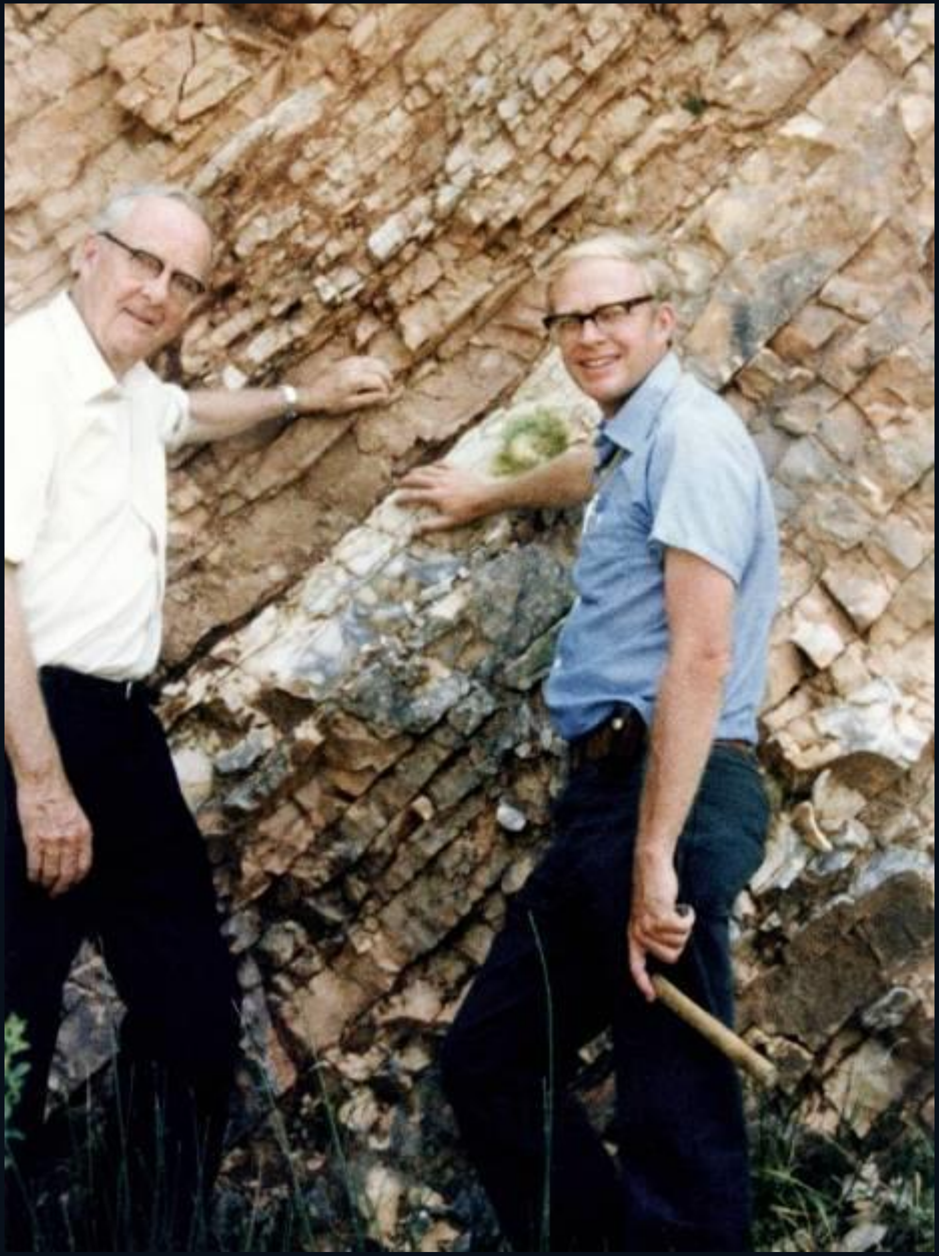
NSF
NATURAL ENVIRONMENT RESEARCH COUNCIL
CONSORTIUM FOR Ocean Leadership
DISCOVERY • UNDERSTANDING • ACTION
IODP INTEGRATED OCEAN DRILLING PROGRAM

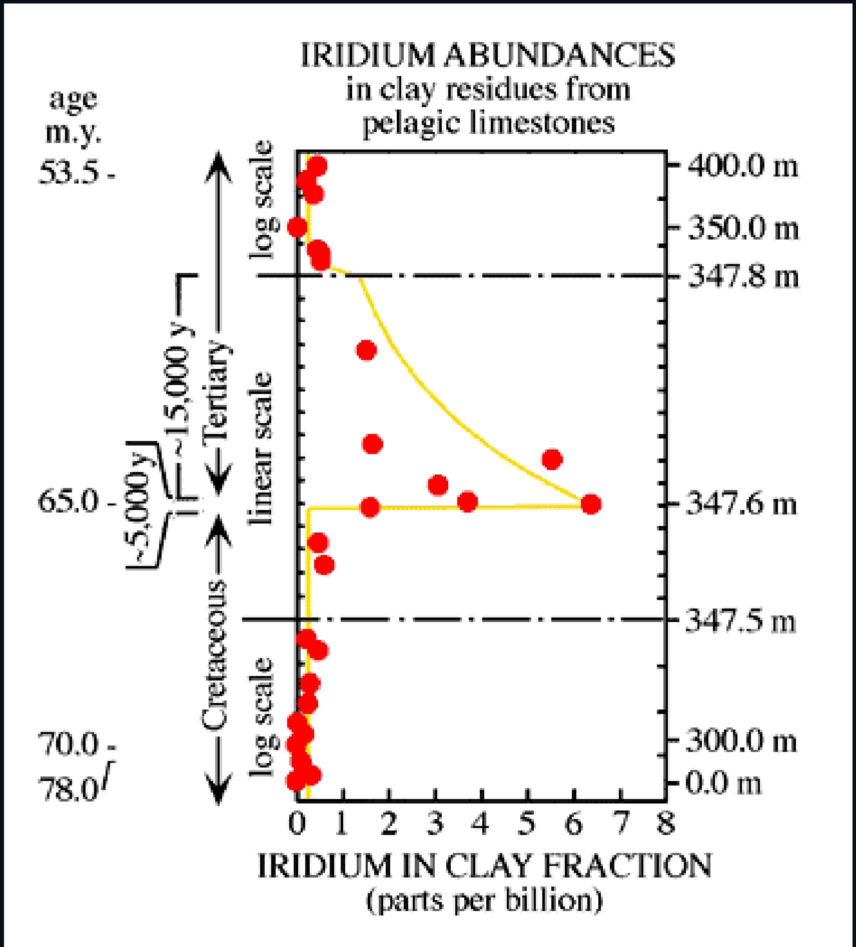
Story Outline

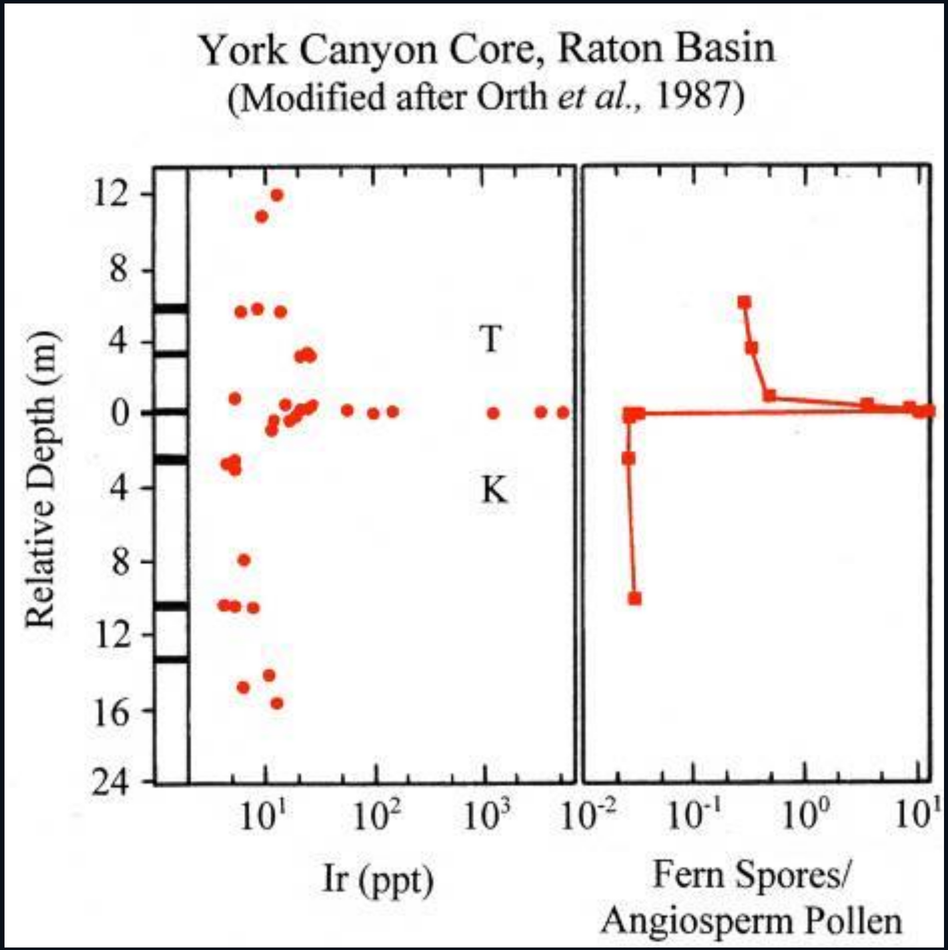
- K/T Mass extinction and the impact theory
- Discovery of Chicxulub & geology of impacts
- Chicxulub seismic experiment results
- Drilling for answers



Walter Alvarez (left) and Luis Alvarez (right) focused on a very thin layer of clay from rocks laid down in deep water in what is now central Italy.

Thin as this layer is, it separates the Cretaceous world from our modern, mammal-dominated world

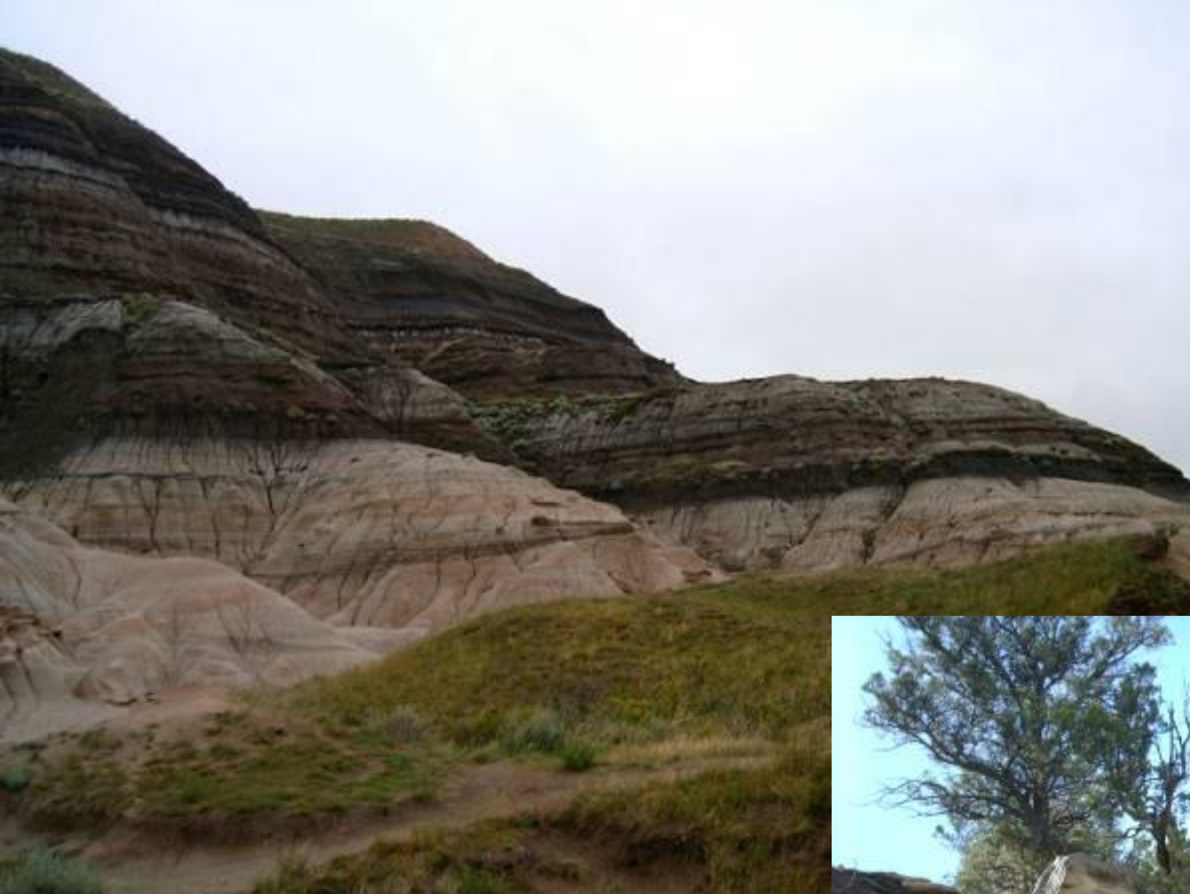




Right at the boundary, they found an enrichment in the rare element iridium - a strong indication of asteroid impact

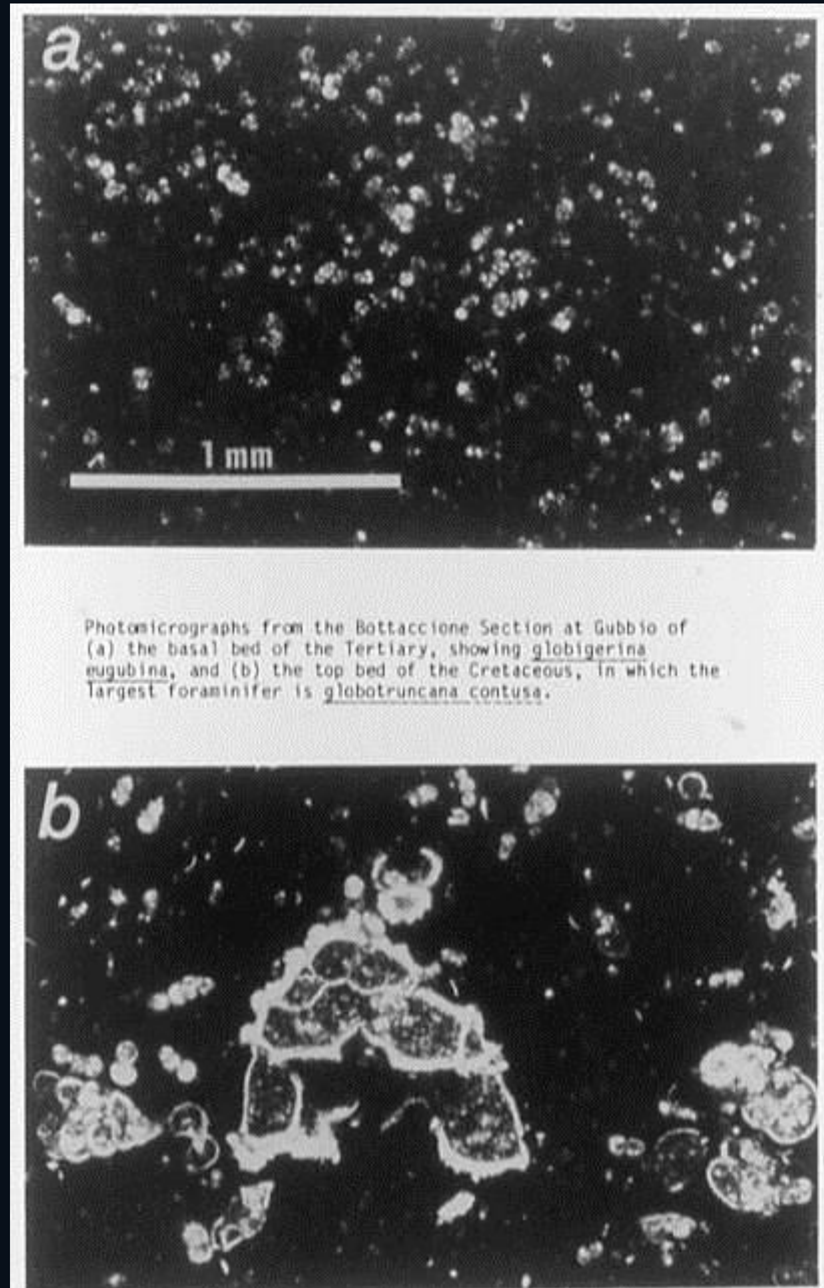
The Alvarez group was not alone. Jan Smit, working in Tunisia, made the same proposal at about the same time

Raton Basin, Colorado



Badlands, Alberta

Both groups found a profound change in the small oceanic organisms across the K/T boundary



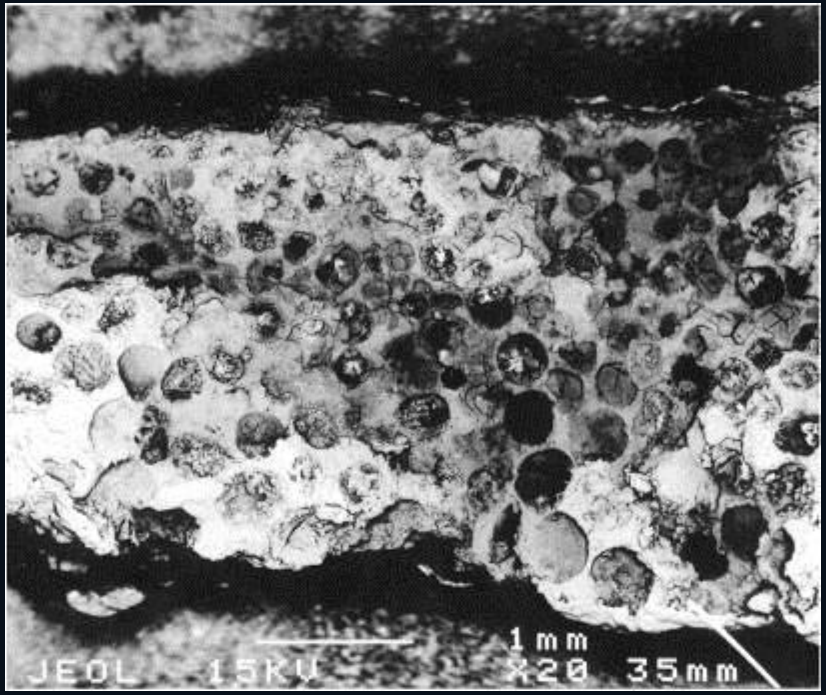
Photomicrographs from the Bottaccione Section at Gubbio of (a) the basal bed of the Tertiary, showing globigerina eugubina, and (b) the top bed of the Cretaceous, in which the largest foraminifer is globotruncana contusa.

Tertiary

Cretaceous

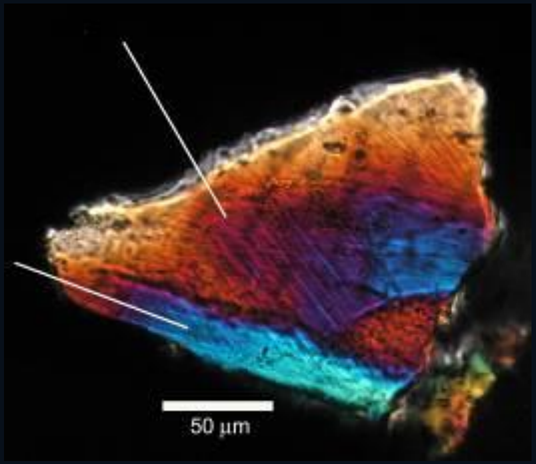
Soon, other sites were found from land locations. The boundary, where well preserved, was full of tiny glass spherules called “microtektites”

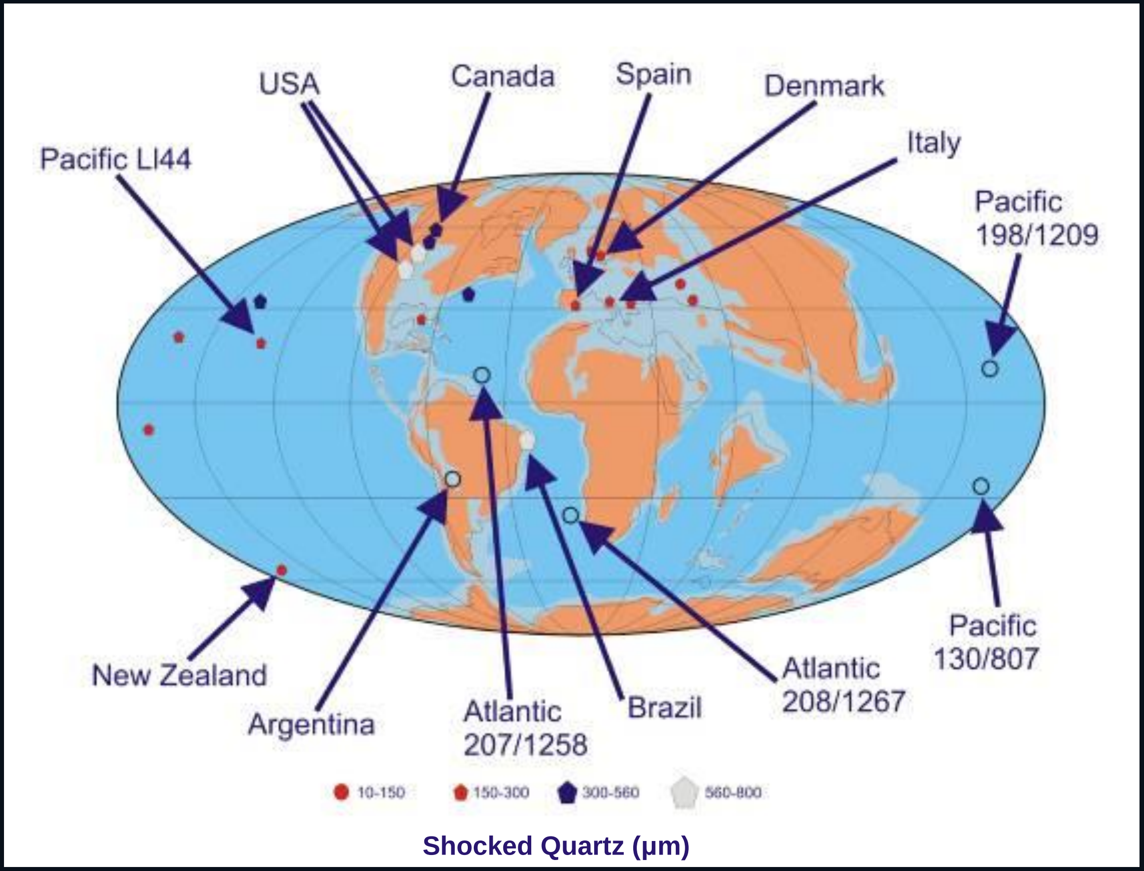
Raton, Colorado

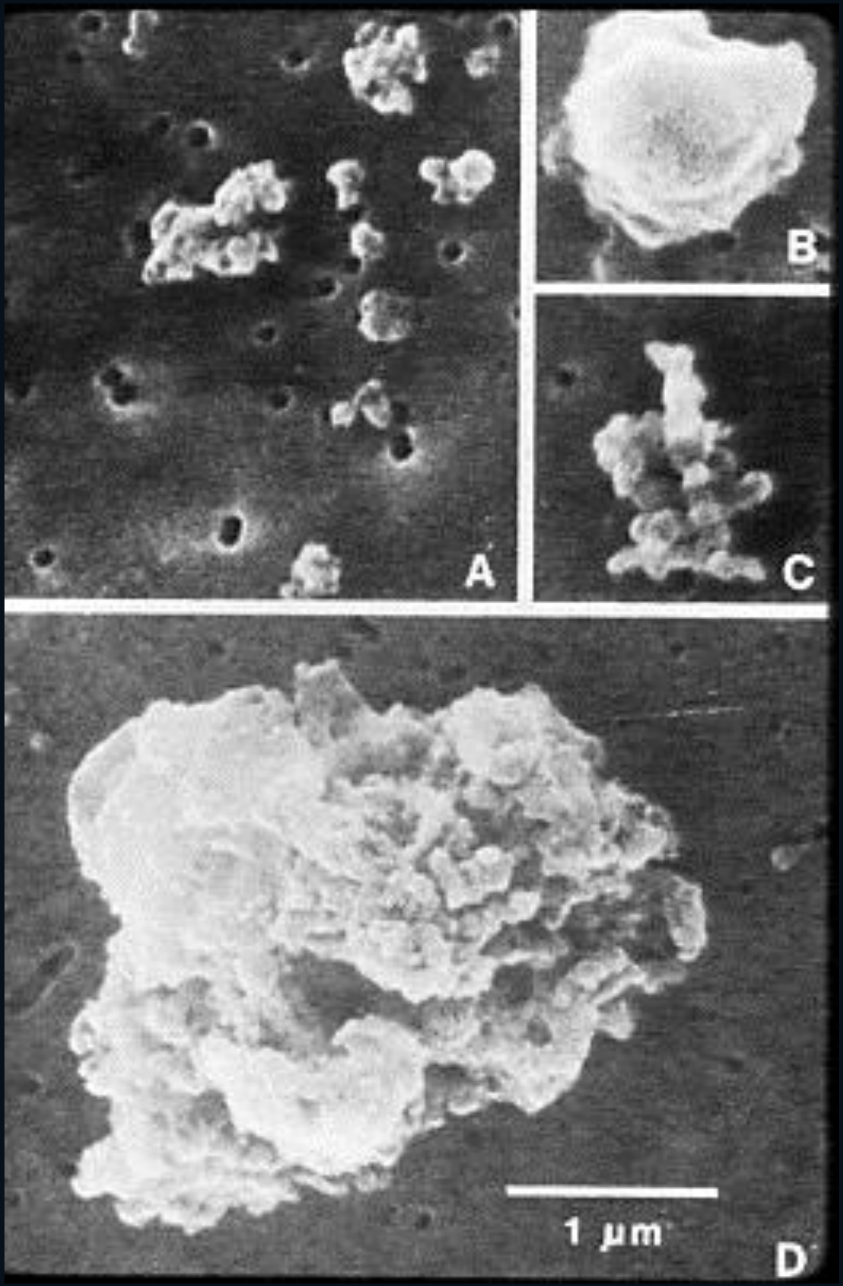


Caravaca, Spain

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



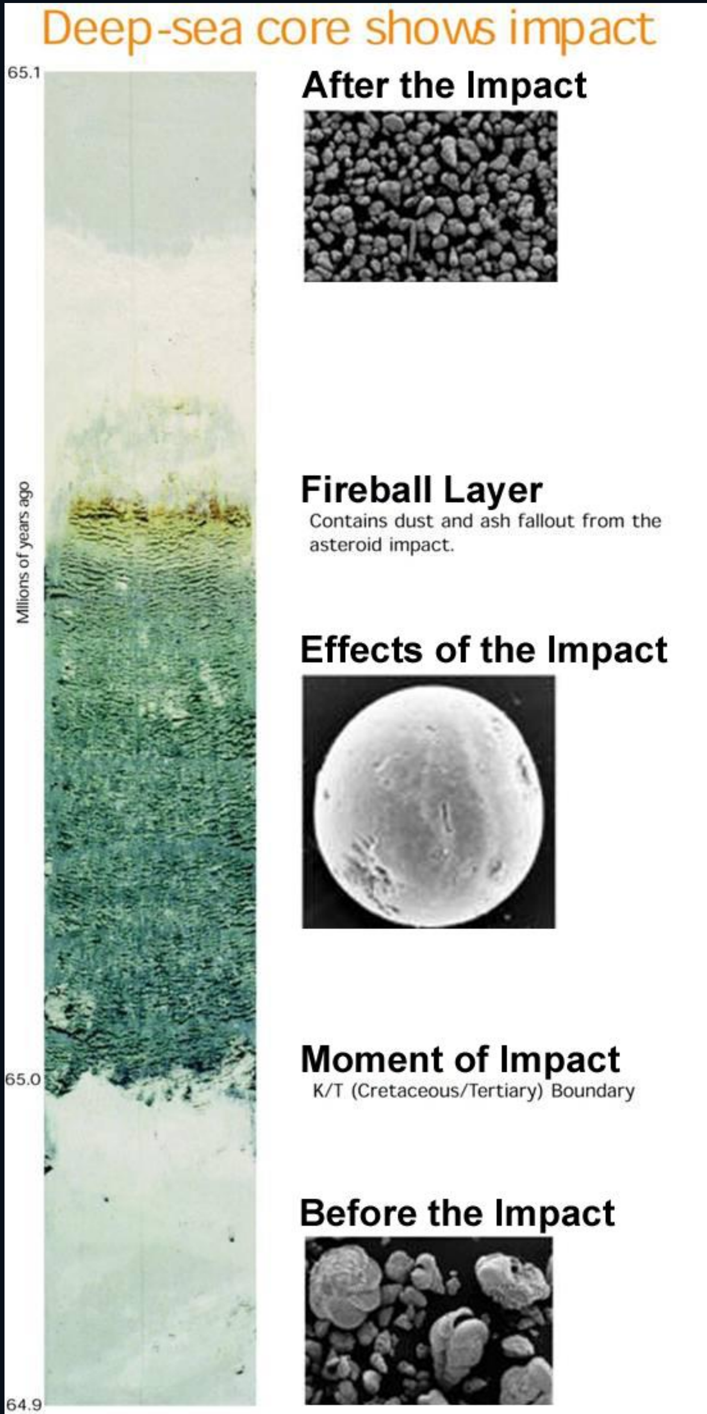


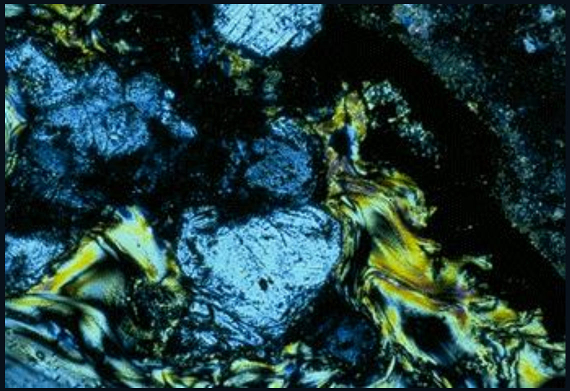


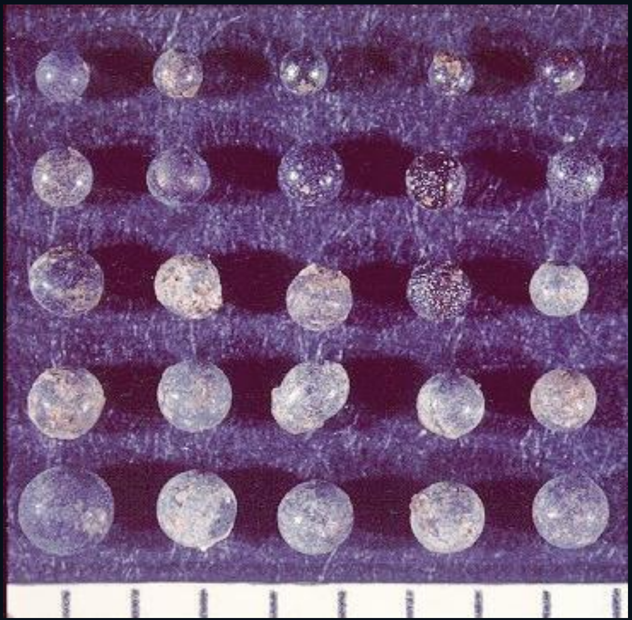
The boundary clay also contains massive amounts of soot, indicating global wildfires

Melosh et al. (1990)

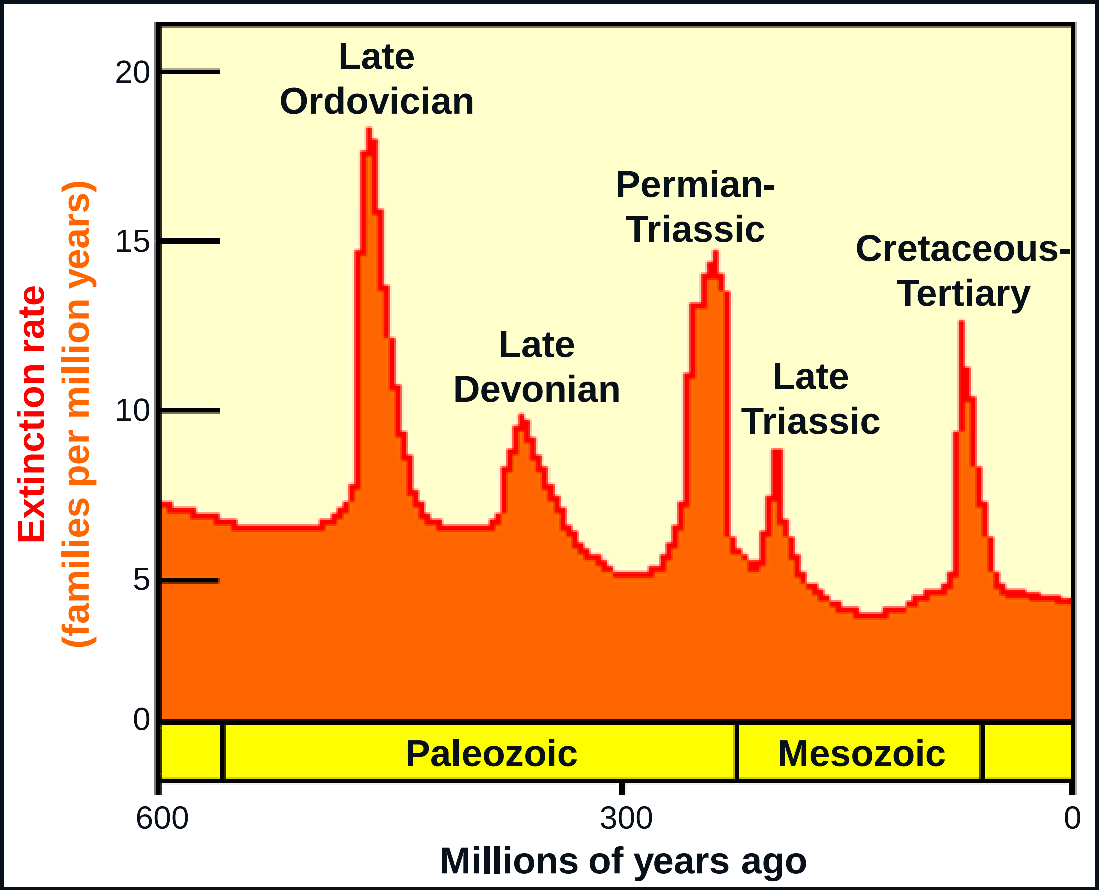
Drilling on the Blake Nose: ODP Leg 171B
Norris et al, 1999

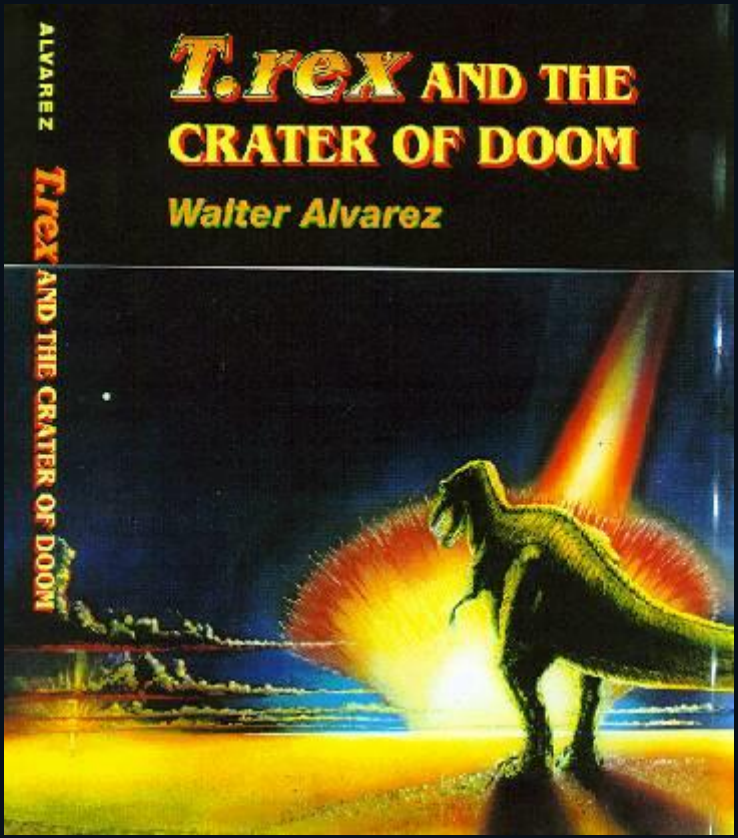






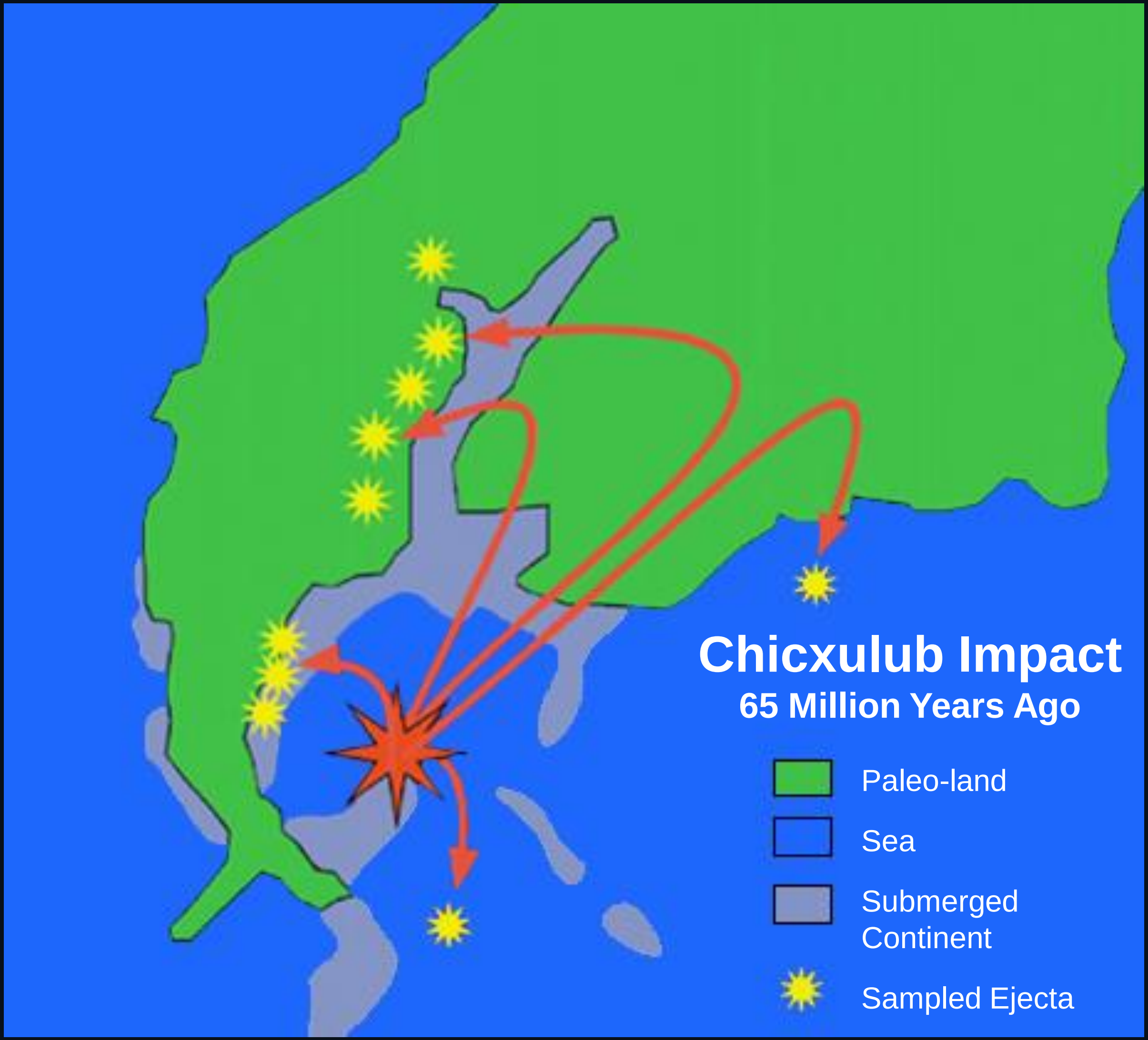
Extinction!



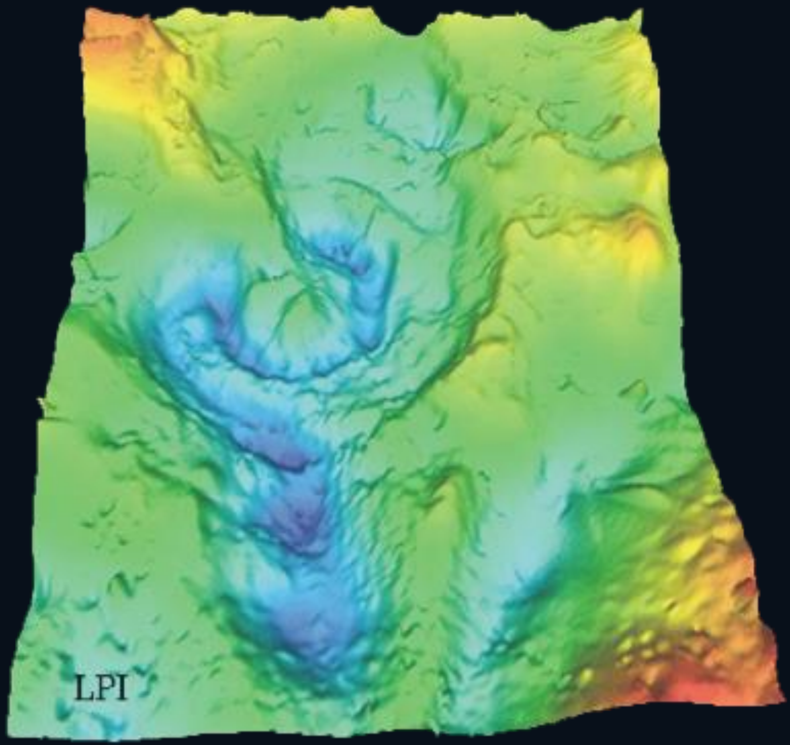


- 65 Ma K/T Boundary
- More than 70% of all species go extinct

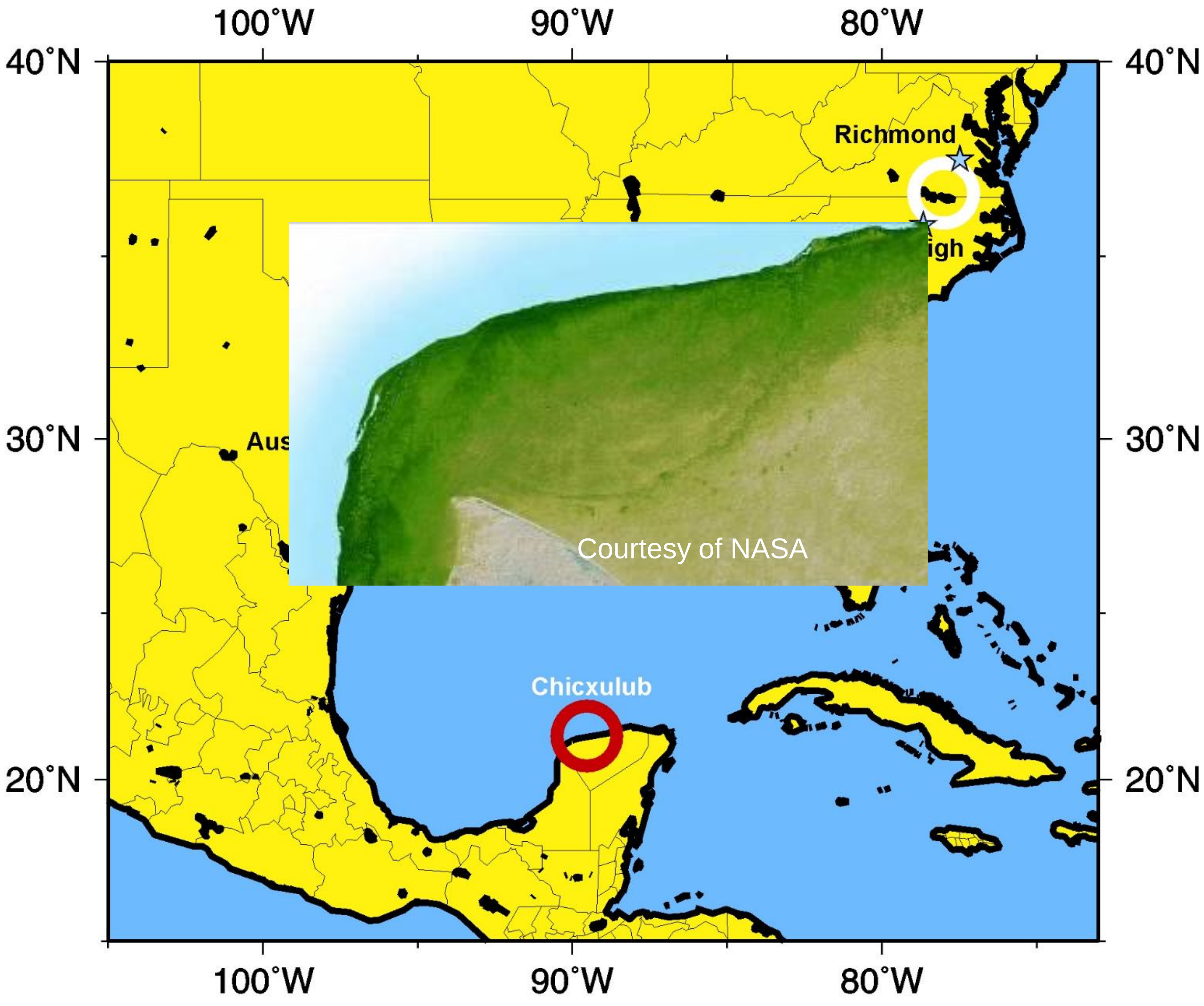
But if the extinction was caused by a big impact, where is the crater? It took a 10 year search until it was finally found - in the Yucatán!



Courtesy of Lunar & Planetary Institute



Courtesy of NASA

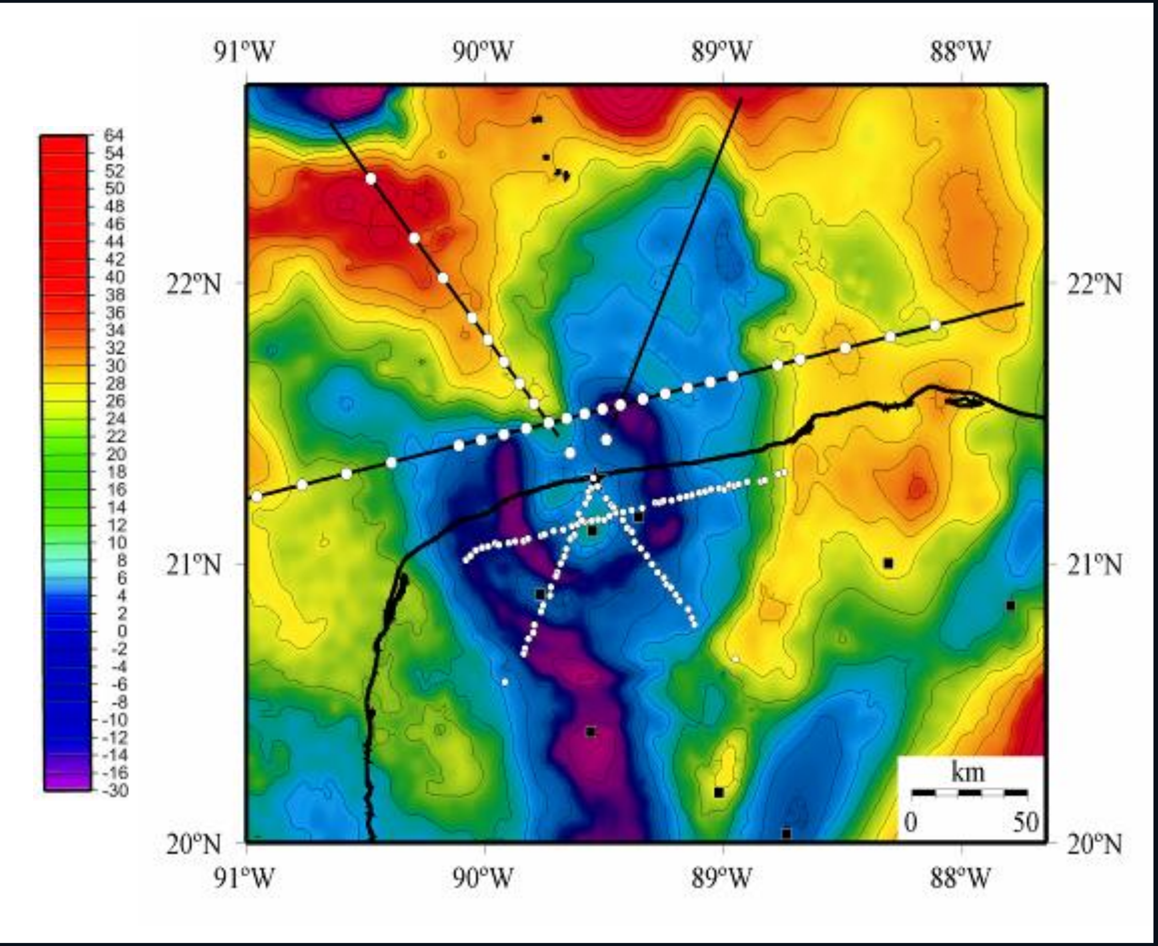


100˚W
90˚W
80˚W
40˚N
30˚N
20˚N
Richmond
Aus
Chicxulub
Courtesy of NASA

1996 Seismic Reflection and Refraction Study

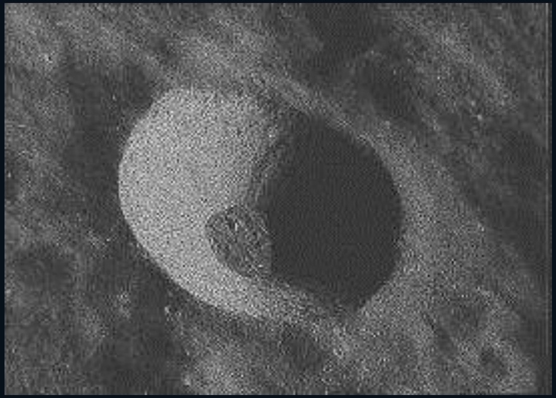
- Geophysical data can be used to model subsurface crater structure
- Structural data constrain numerical modeling of impact event
- Refraction data measures velocity
- Reflection data images subsurface

1996 BIRPS seismic reflection/refraction survey with Bouger gravity anomaly overlay



Crater Morphology

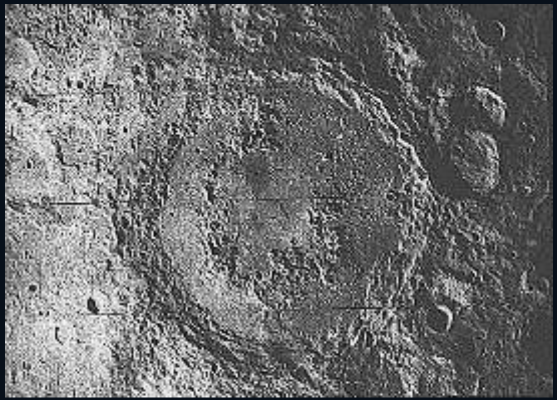
Lunar examples



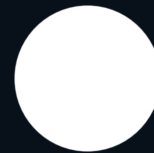
Alfrancus C -
10 km simple crater

Tycho – 85 km
complex crater

Orientale – 900 km
multi ring basin

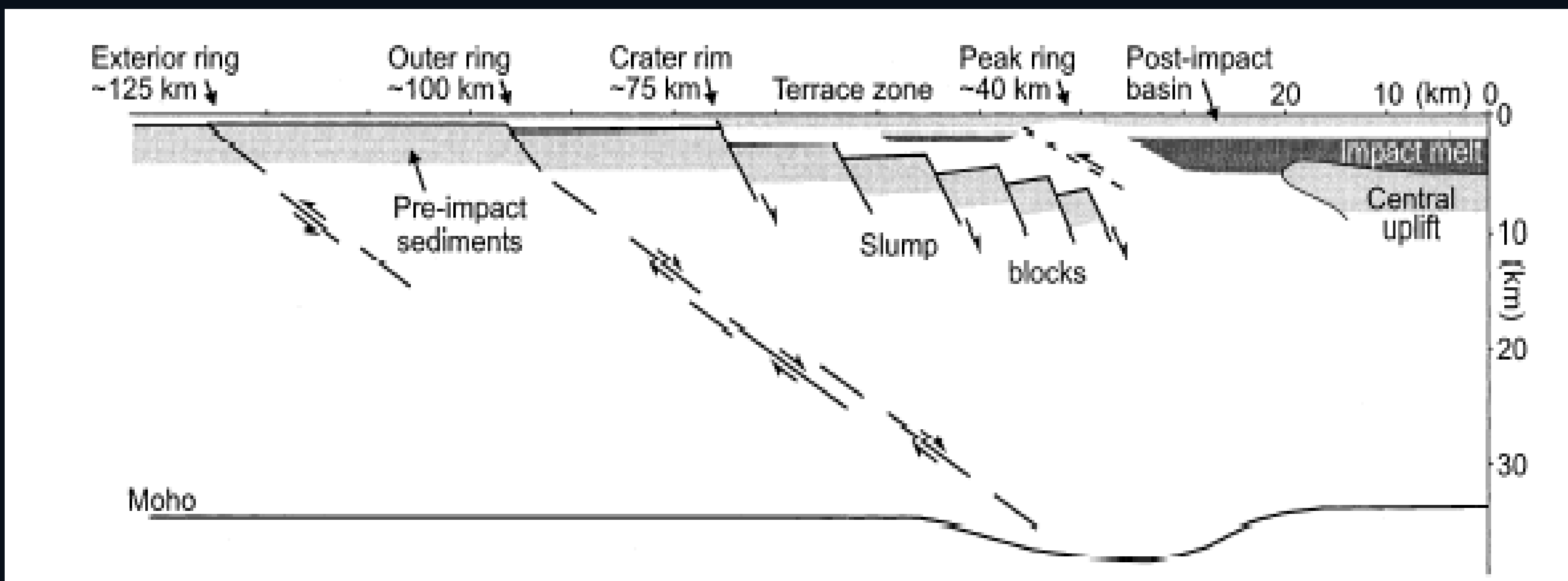


Schrodinger –
320 km peak ring basin



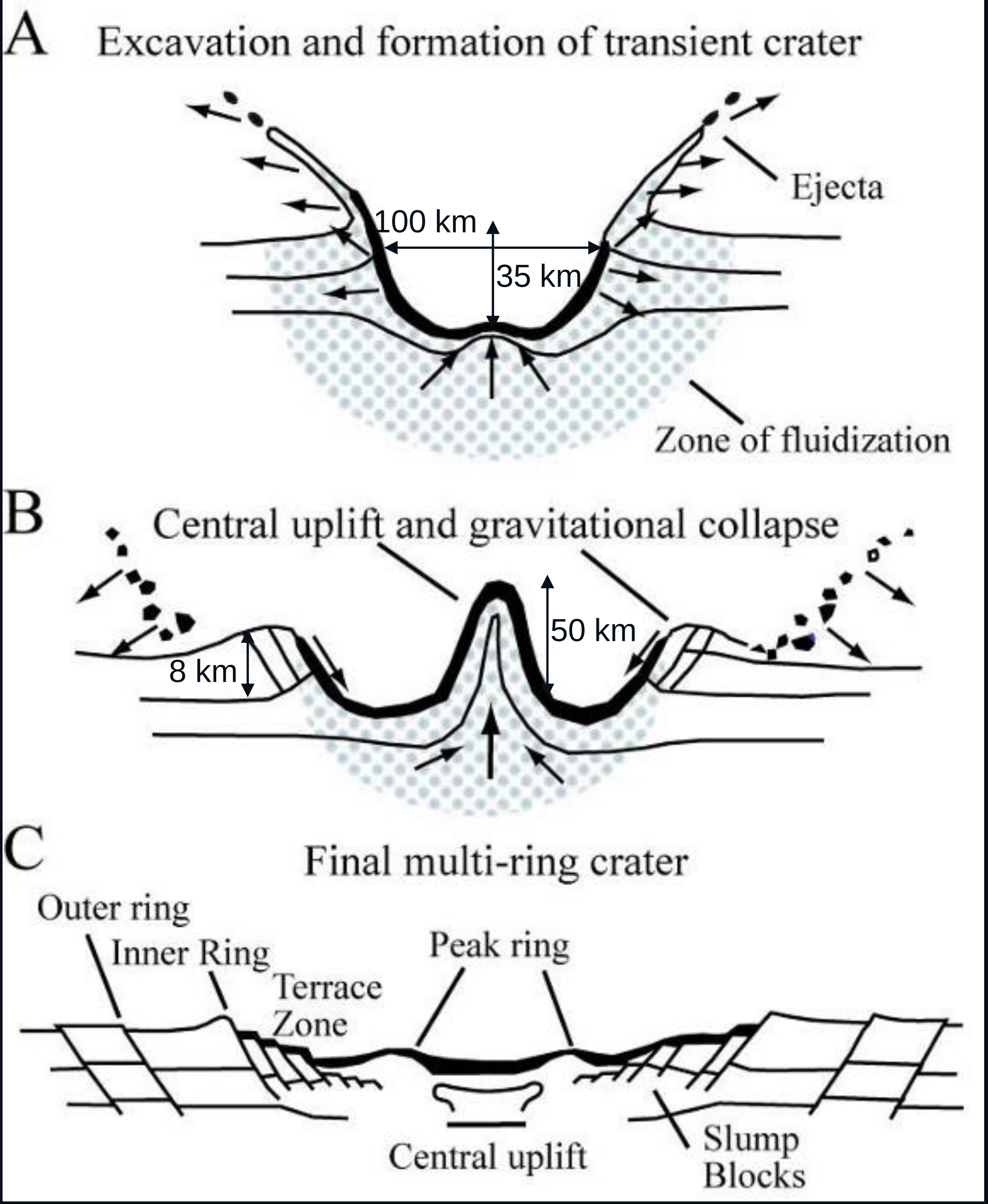
Bolide ~12 km in diameter

Transient Crater 35 km deep and 100 km across



Cross-section

Morgan et al. (1997)



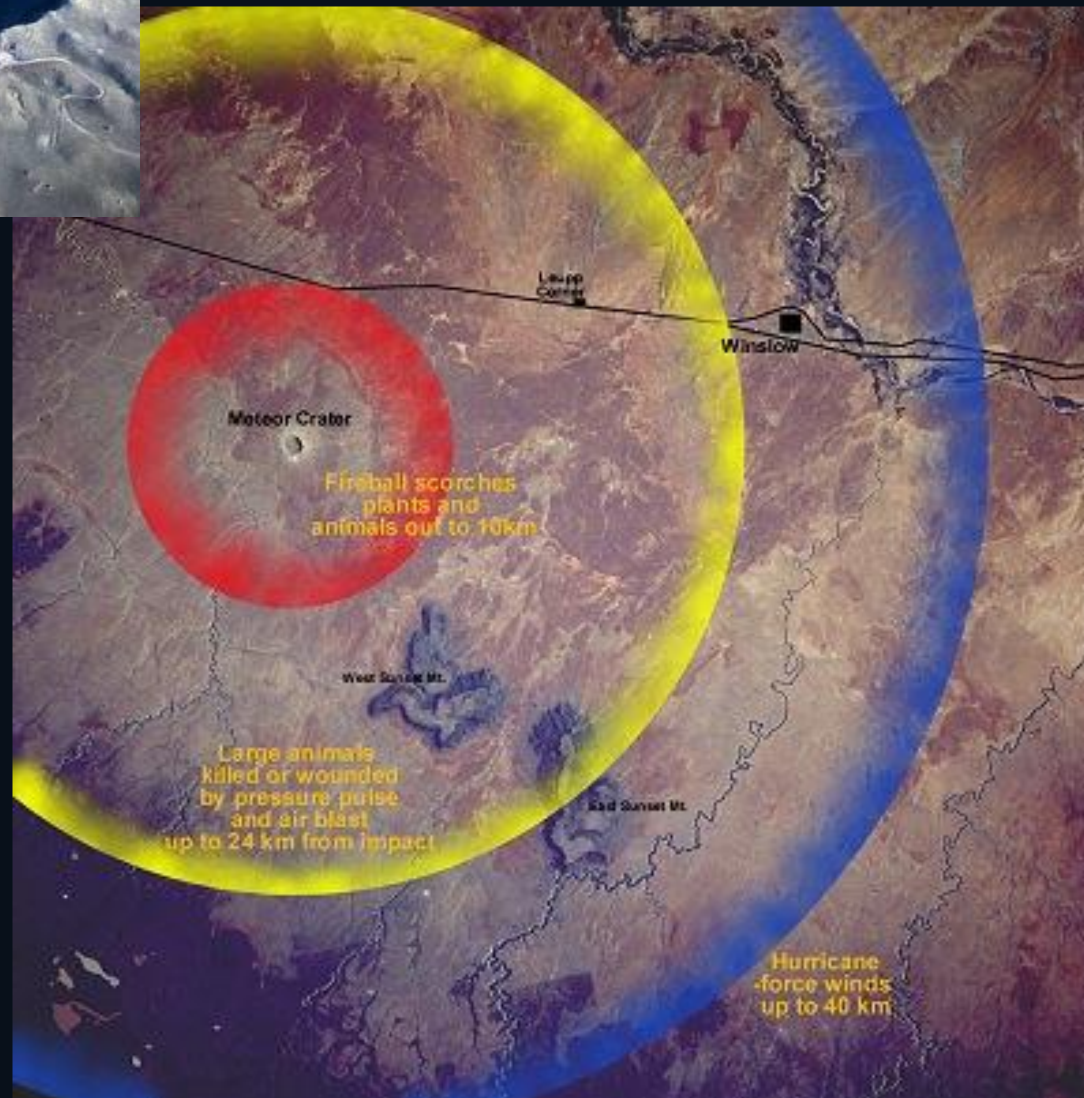
All in 300 to 600 sec!

Melosh et al. (1989)

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



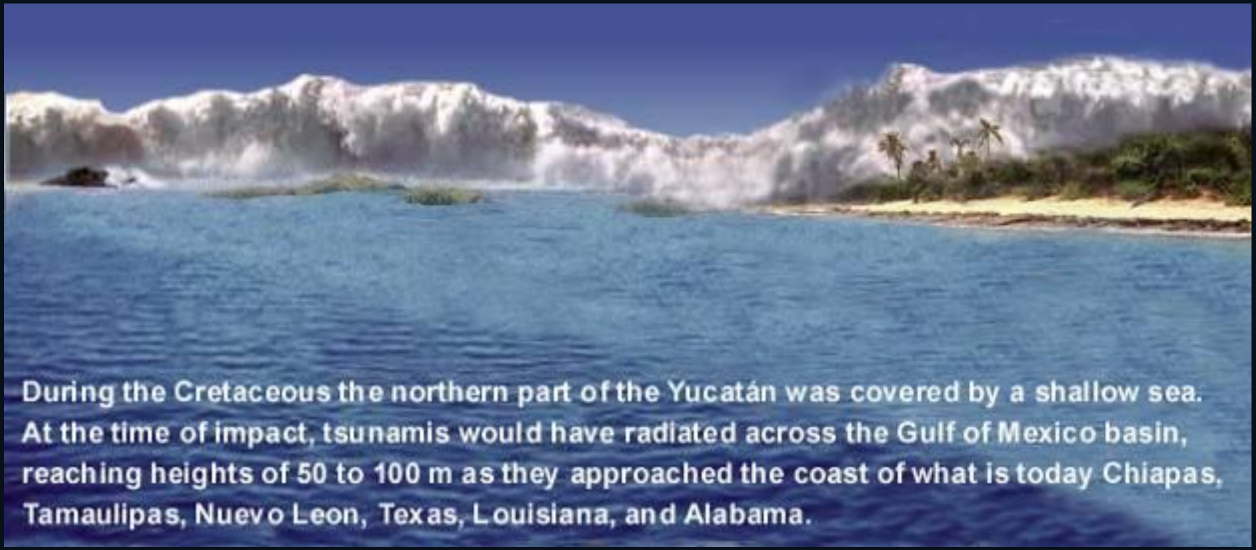
Energy = $\frac{1}{2} mv^2$

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

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

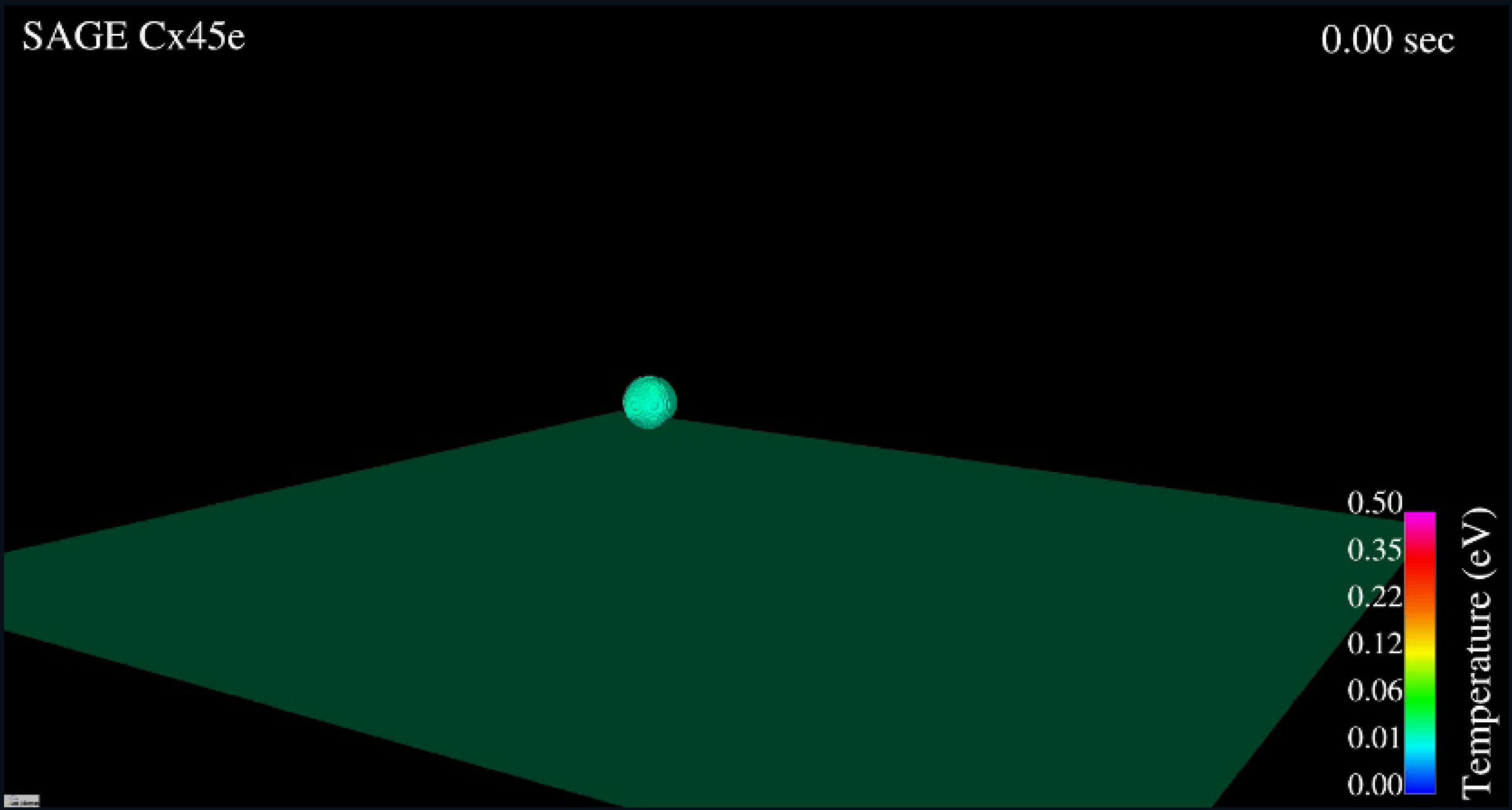
1% of energy turned into (200 m) tsunamis and hurricane force winds

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

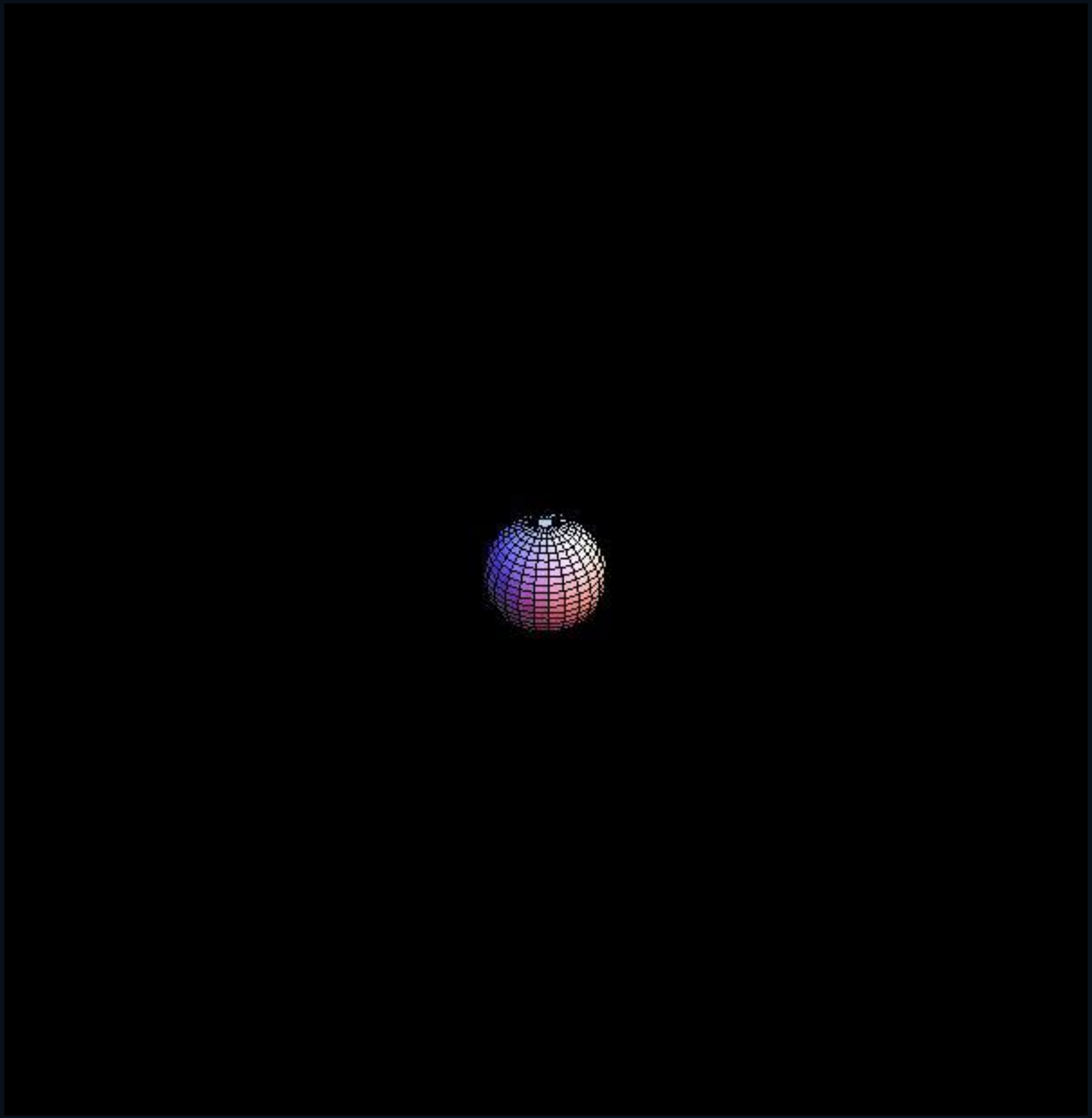


During the Cretaceous the northern part of the Yucatán was covered by a shallow sea. At the time of impact, tsunamis would have radiated across the Gulf of Mexico basin, reaching heights of 50 to 100 m as they approached the coast of what is today Chiapas, Tamaulipas, Nuevo Leon, Texas, Louisiana, and Alabama.

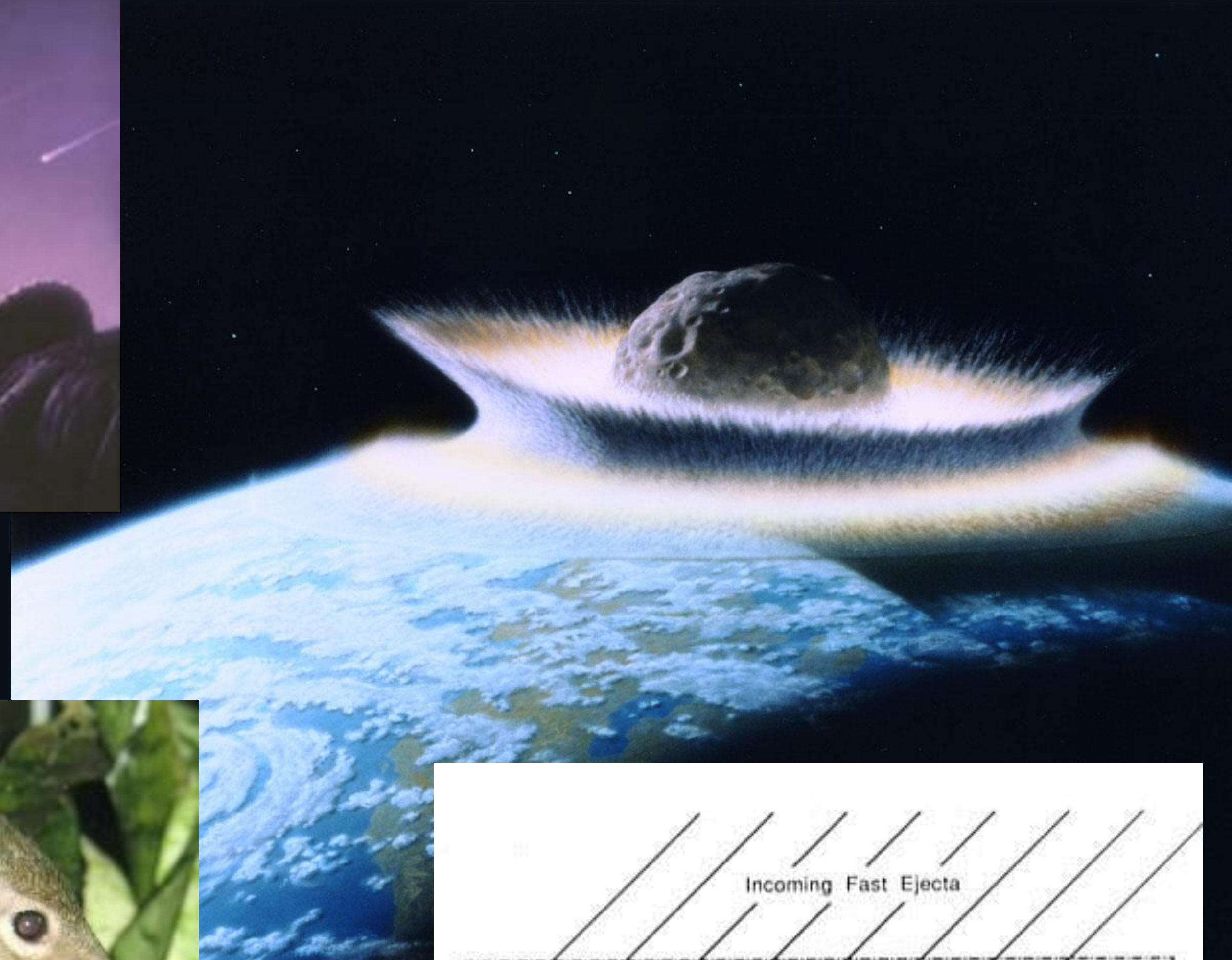
But the real problem was the ejecta…

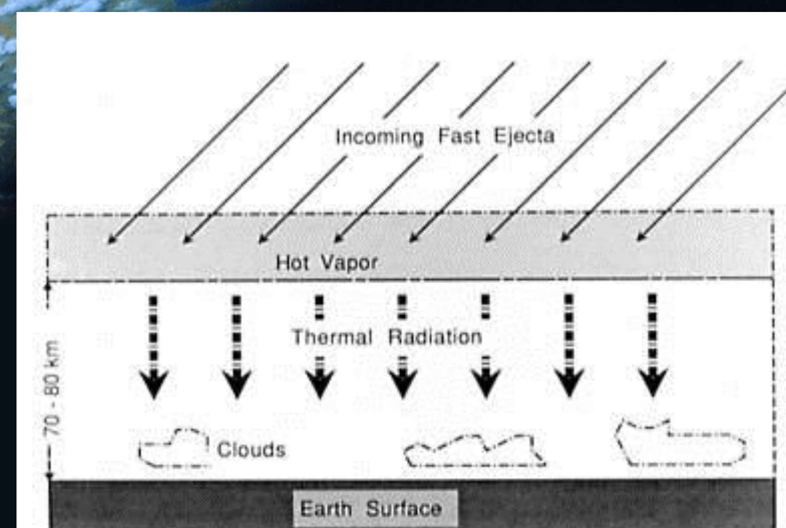


Courtesy of Los Alamos National Labs

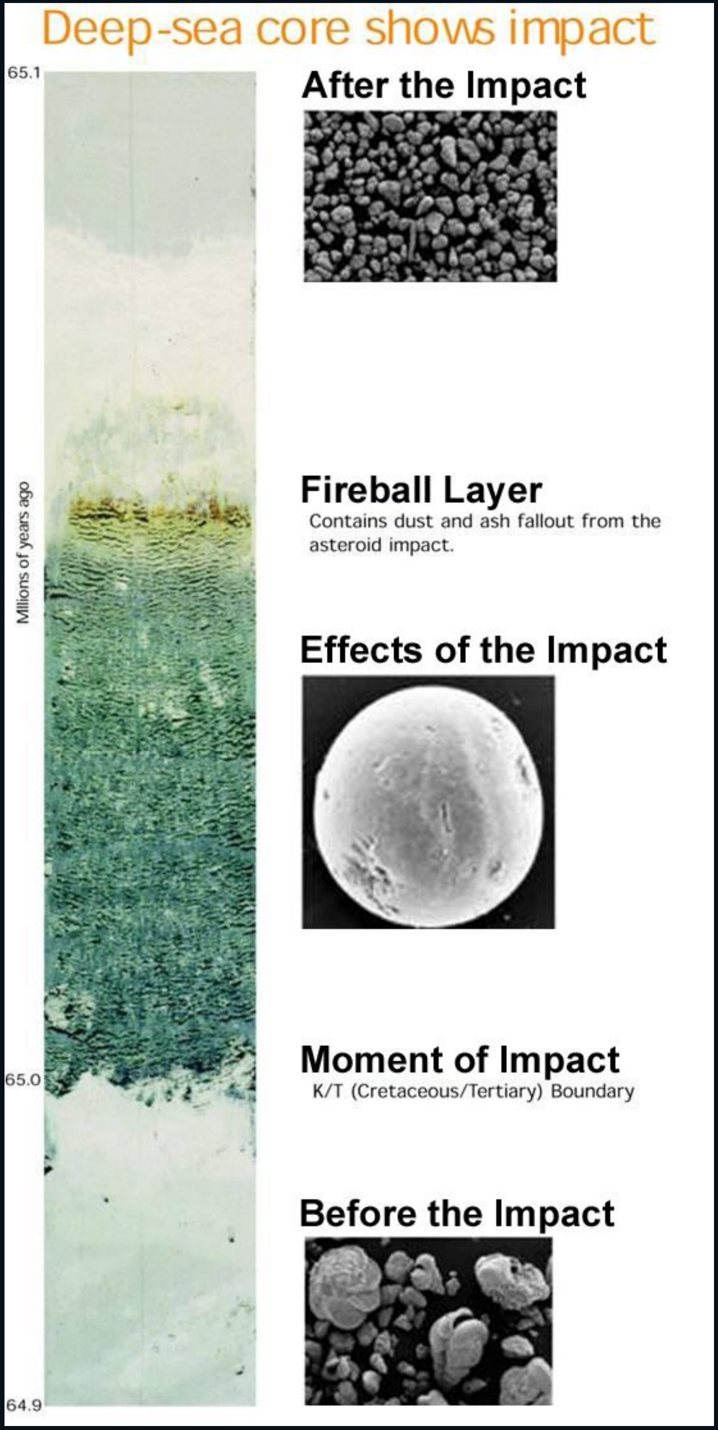


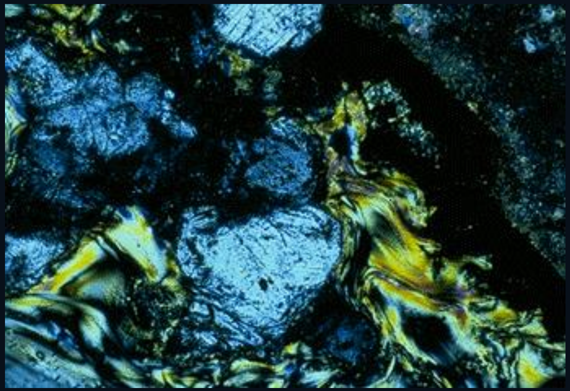
Courtesy of Melosh

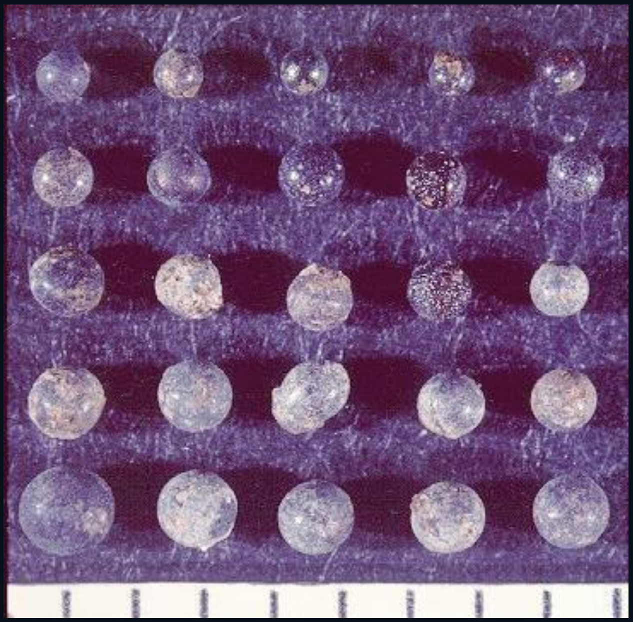



Incoming Fast Ejecta
Hot Vapor
Thermal Radiation
70 - 80 km
Clouds
Earth Surface

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



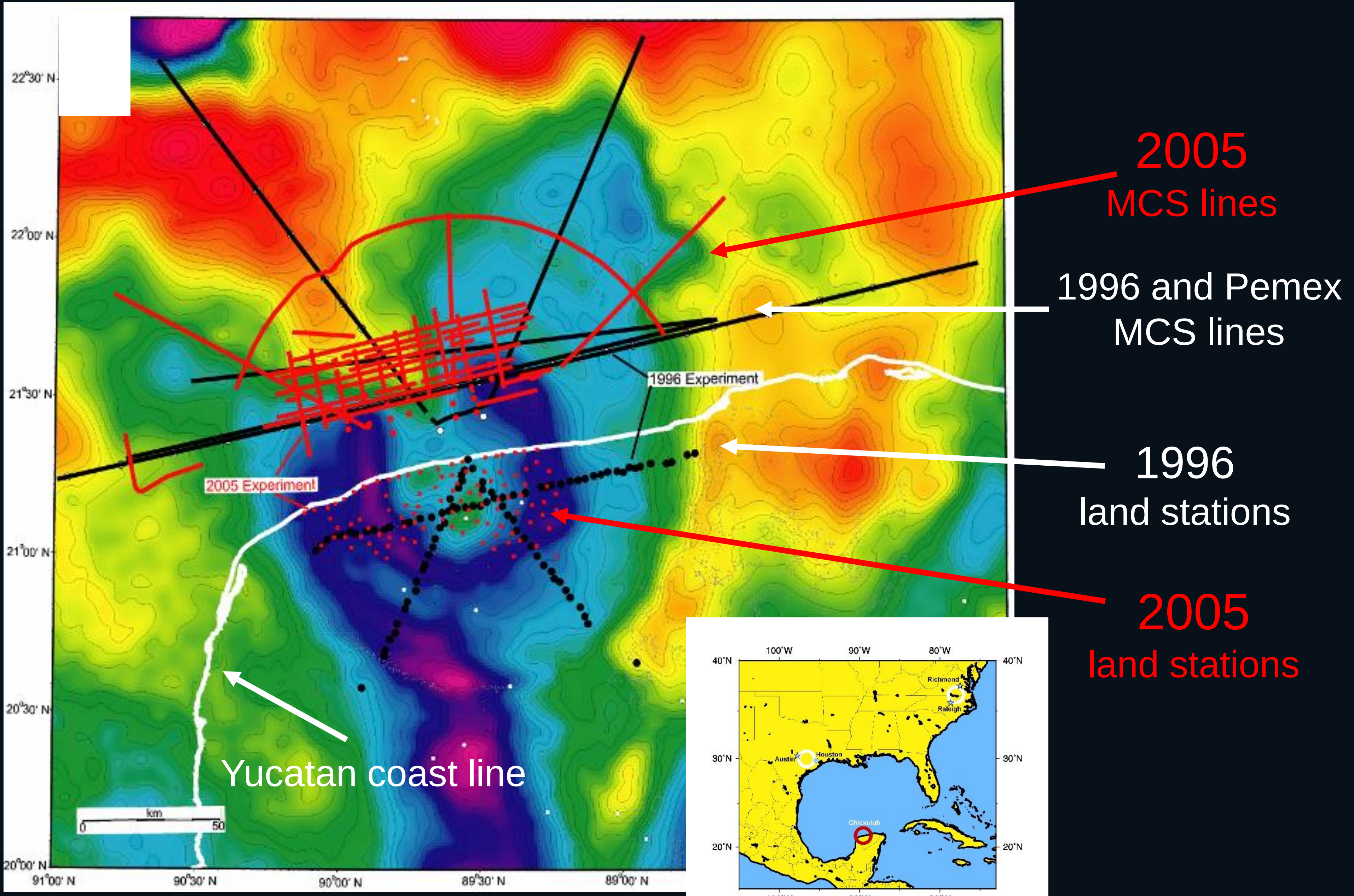




21st Century Surveying and Ground Truth

- Best preserved large impact on Earth
- Only impact conclusively linked to mass extinction
- Natural laboratory for impacts as a geologic process and impacts effect on life

Surveys in Preparation for Drilling



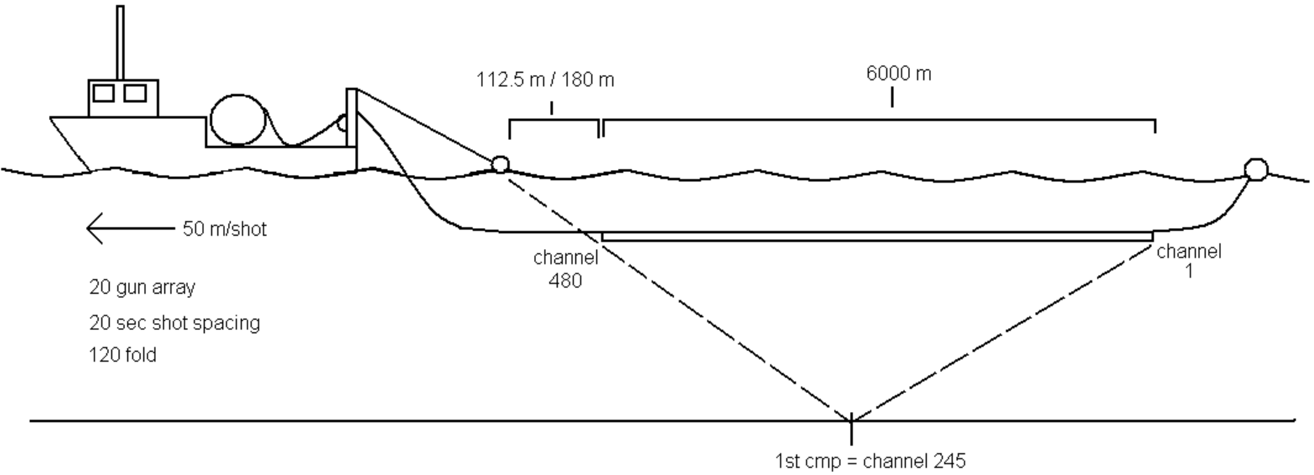
R/V Maurice Ewing Cruise EW0501

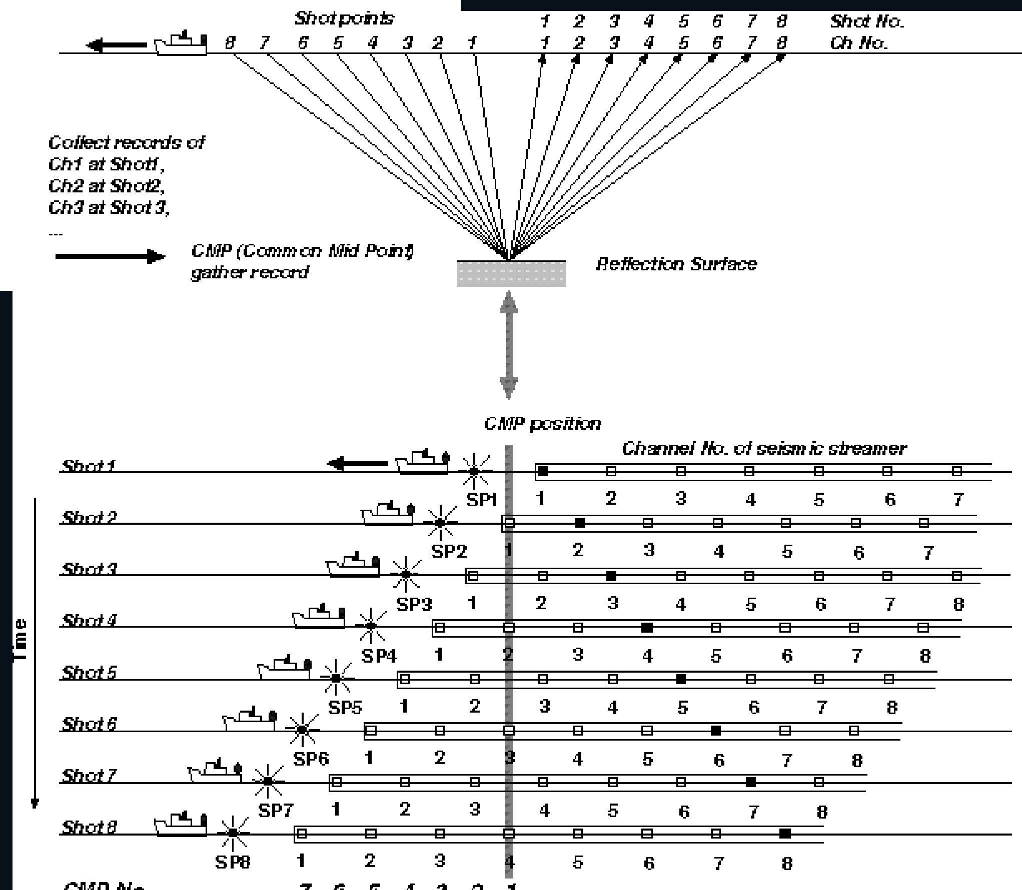
Jan 5, 2005 – Feb 16, 2005

Airguns

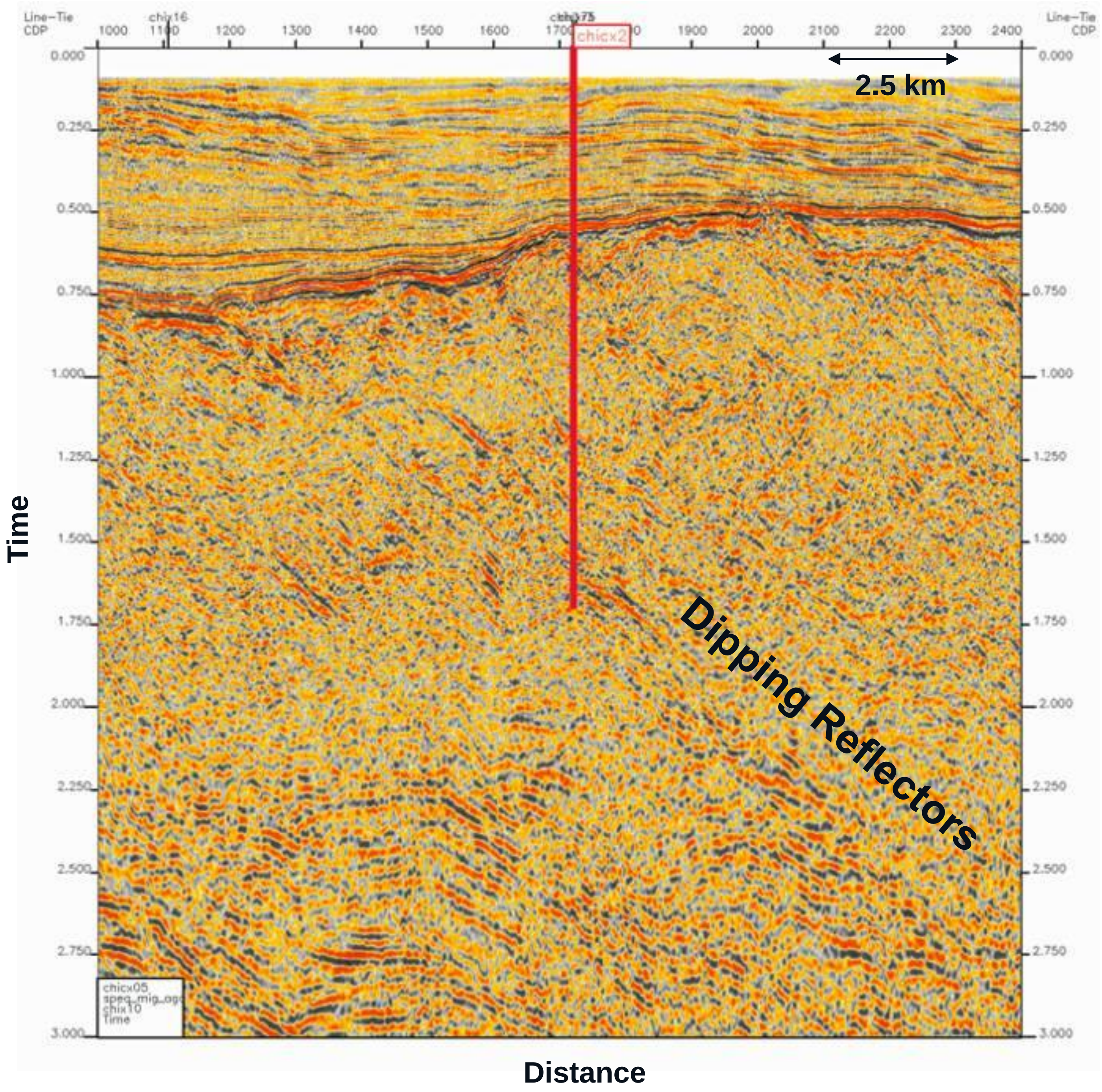
Hydrophone Streamer

Profiling!


112.5 m / 180 m
6000 m
50 m/shot
20 gun array
20 sec shot spacing
120 fold
channel
480
channel
1
1st cmp = channel 245


Shot points
Shot No.
Ch No.
Collect records of
Ch1 at Shot1,
Ch2 at Shot2,
Ch3 at Shot 3,

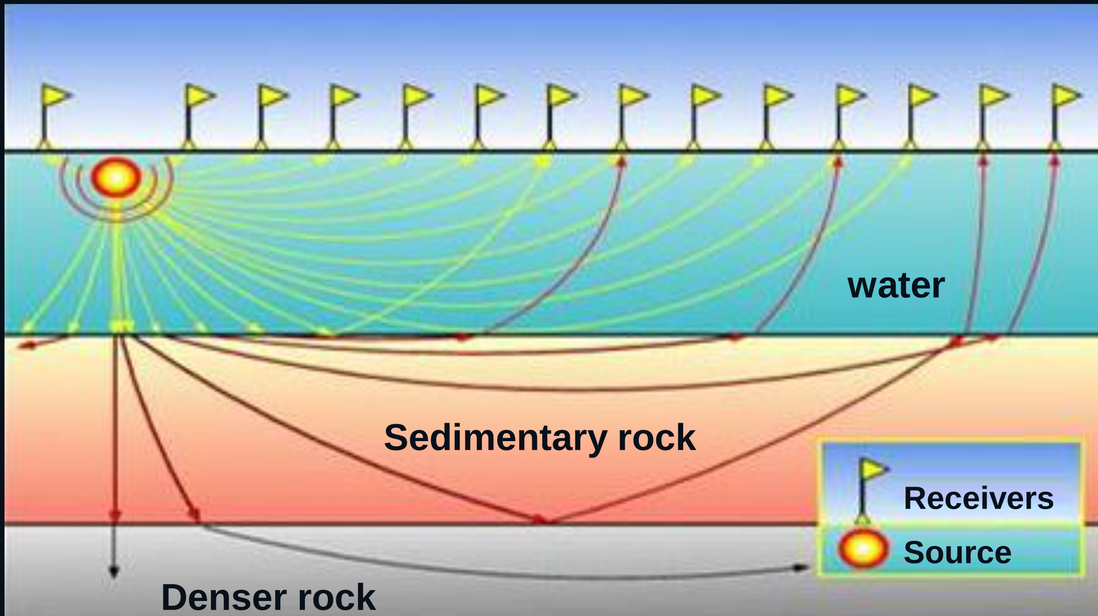
CMP (Common Mid Point)
gather record
Reflection Surface
CMP position
Channel No. of seismic streamer
Shot 1
Shot 2
Shot 3
Shot 4
Shot 5
Shot 6
Shot 7
Shot 8
SP1
SP2
SP3
SP4
SP5
SP6
SP7
SP8
Time
CMP No.



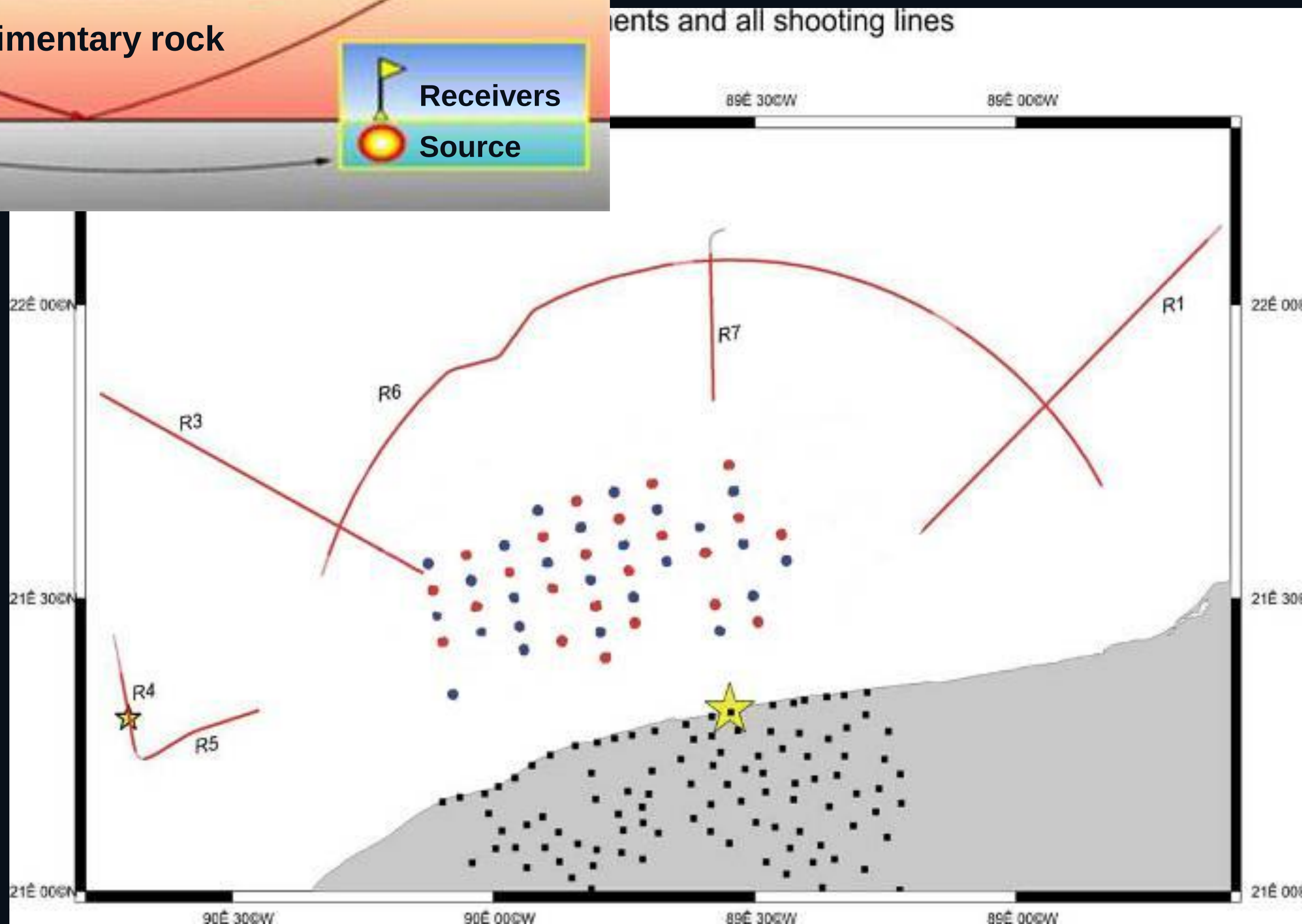
Line-Tie
CDP
chix16
1000
1100
1200
1300
1400
1500
1600
1700
chicx2
1900
2000
2100
2200
2300
2400
2.5 km
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
Dipping Reflectors
chicx05
chix10
Time
Time
Distance

Ocean Bottom Seismometers

Land Seismometers

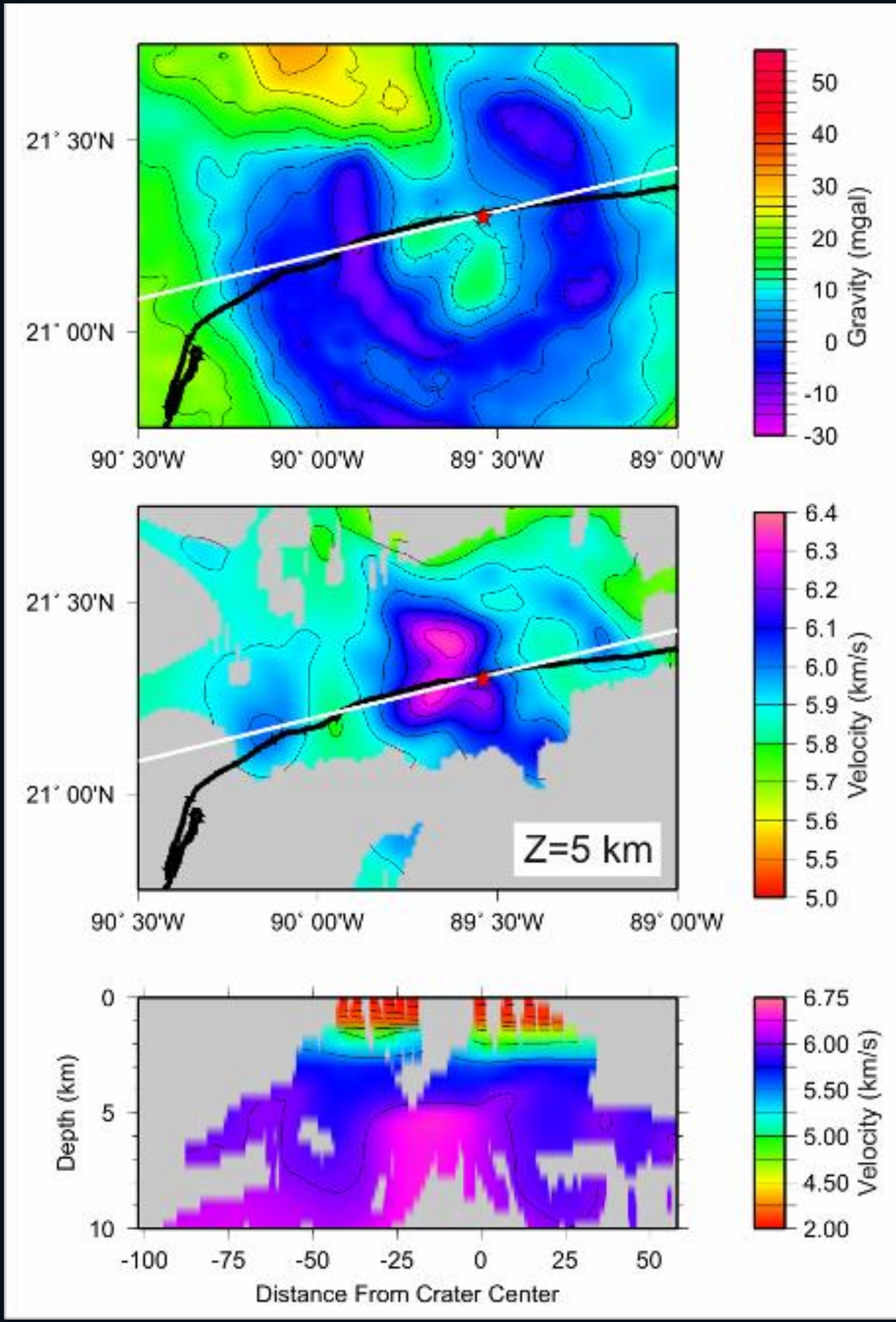


water
Sedimentary rock
Denser rock
Receivers
Source



ents and all shooting lines
89Ê 30©W
89Ê 00©W
22Ê 00©N
21Ê 30©N
21Ê 00©N
90Ê 30©W
90Ê 00©W
R1
R3
R4
R5
R6
R7

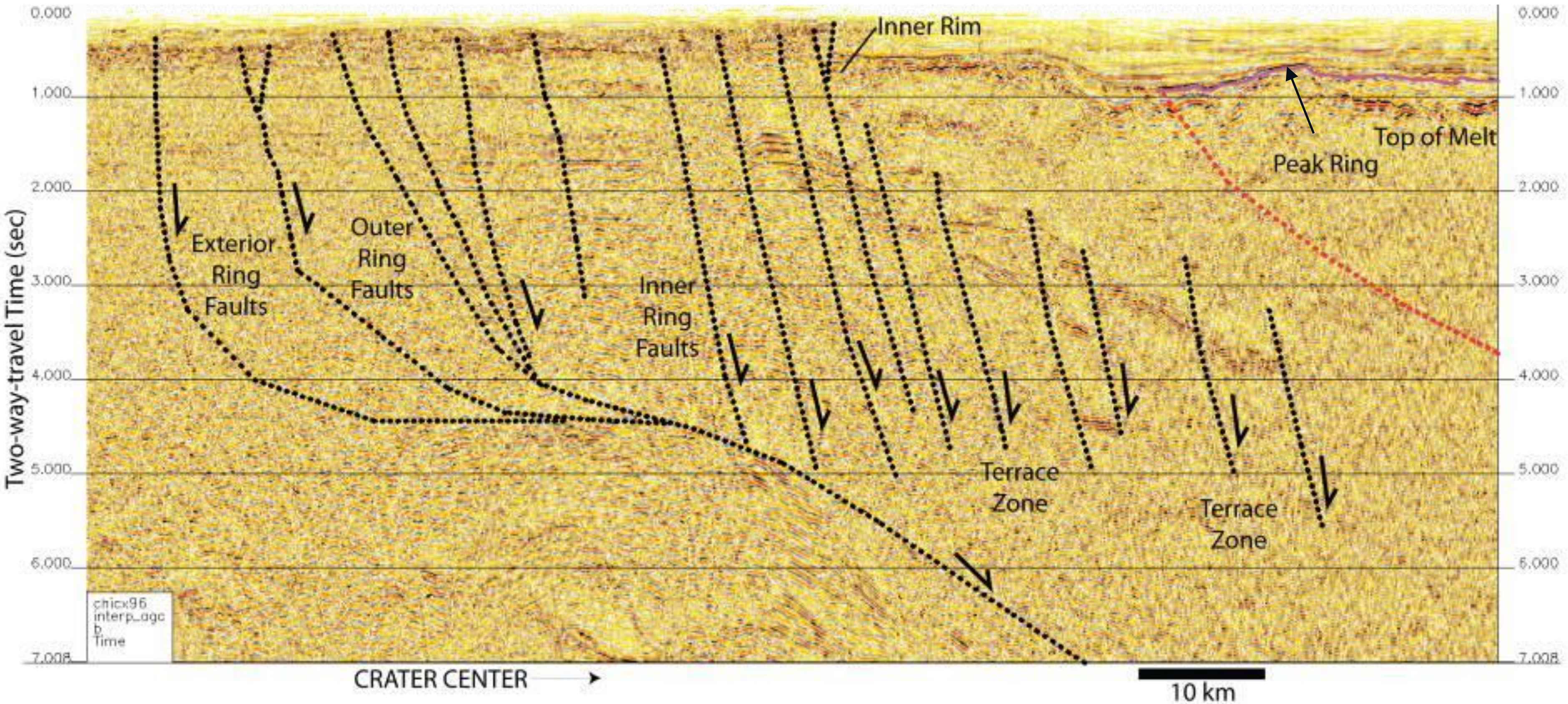
Gravity model of uplift

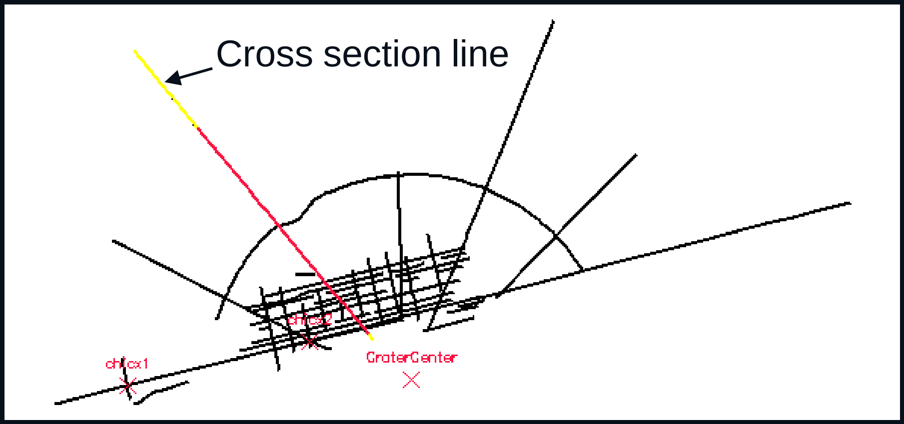


- Structural uplift near the crater center (red star) is constrained by gravity and velocity data.
- The uplift is offset west of the crater center.
- Velocities of 6.3 km/s occur at a depth of 5 km. Outside the crater these velocities are found at a depth of 15 km, suggesting a vertical uplift of ~10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

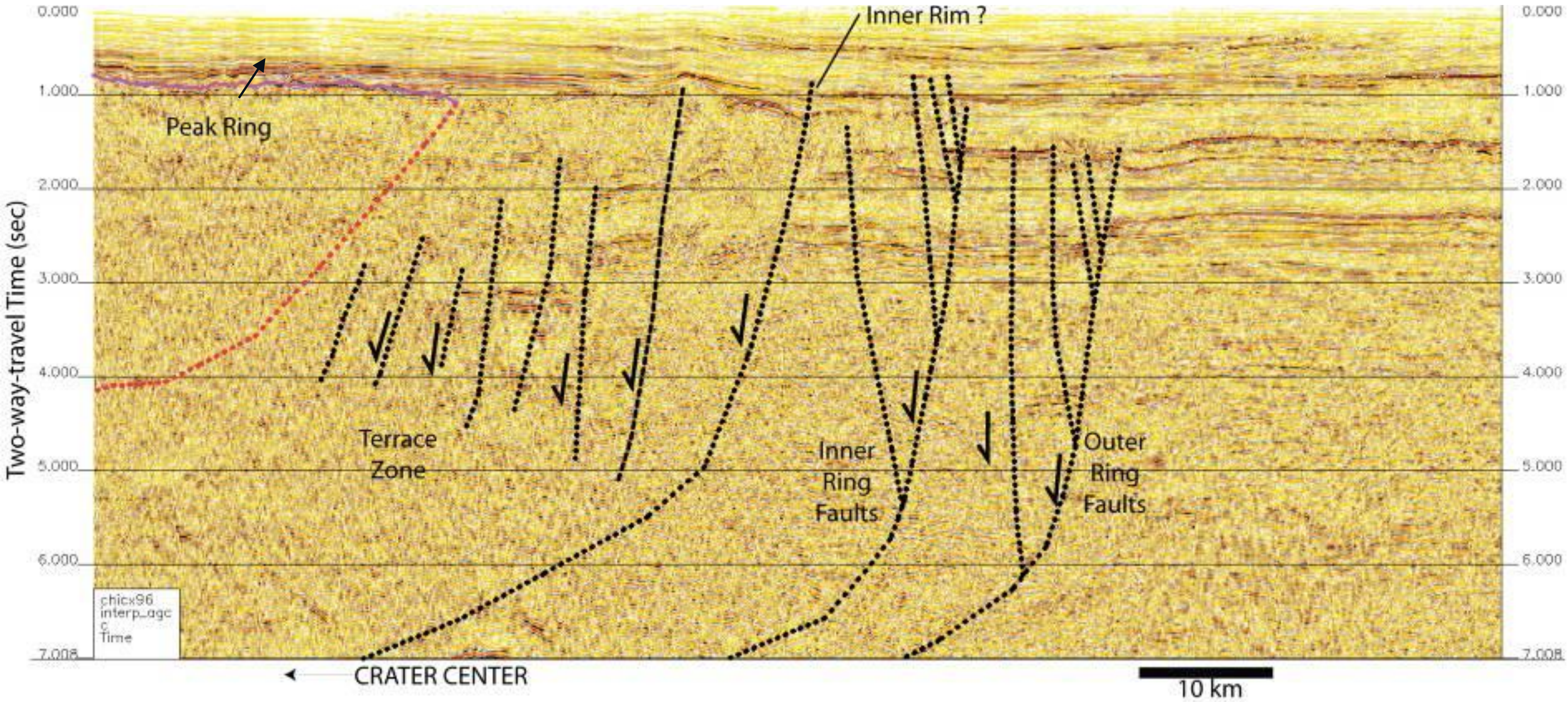
Christeson et al., in prep

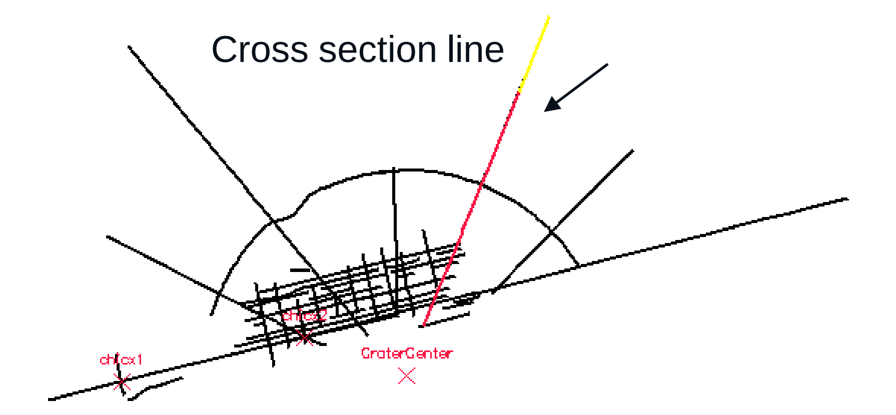
NW Cross Section through Crater



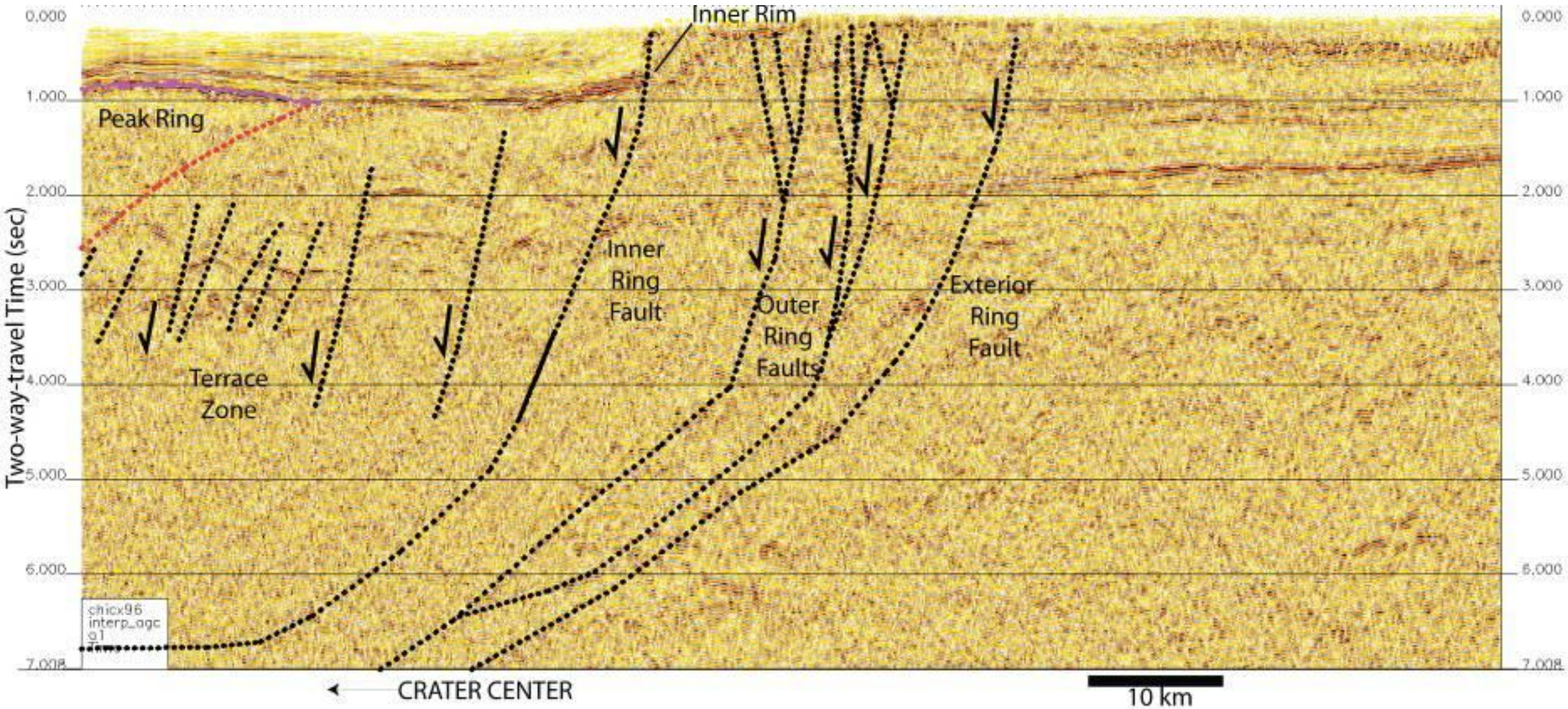


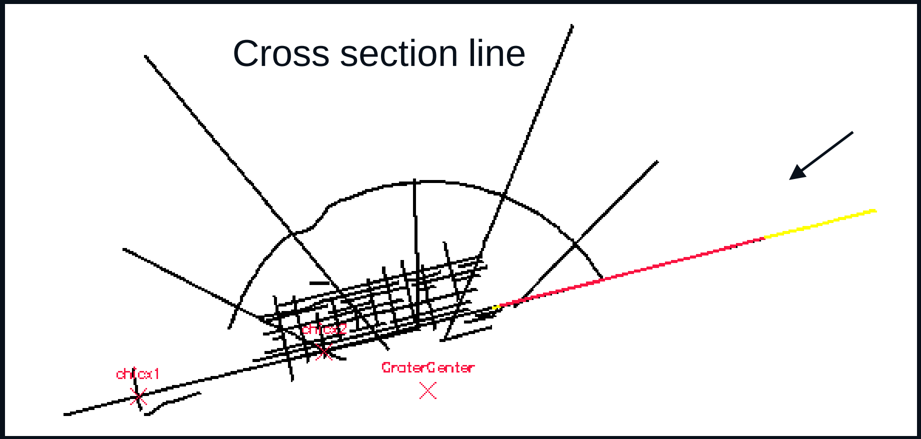
NE Cross Section though Crater





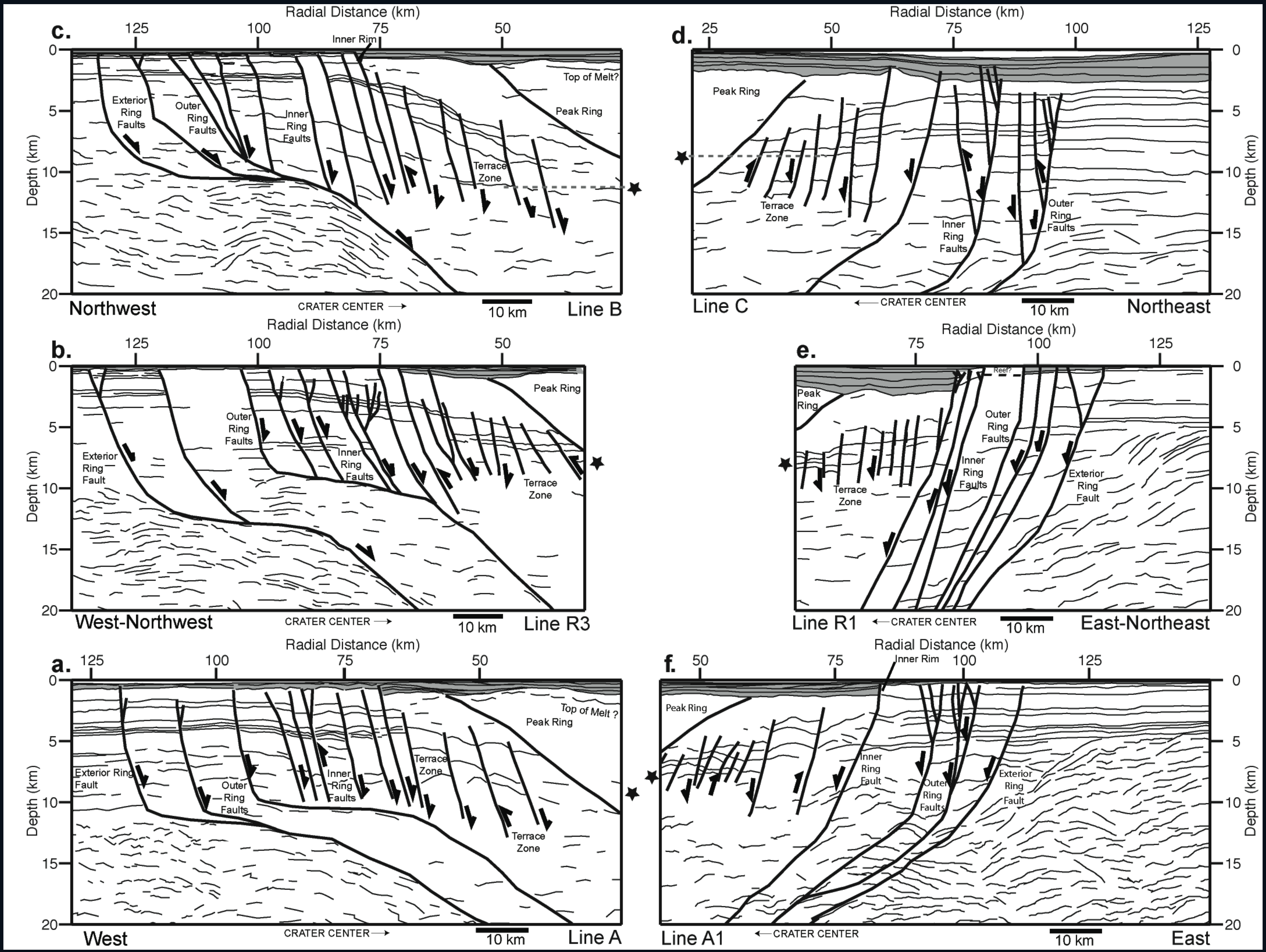
East Cross Section through Crater





~ West side

~ East side



Gulick et al. (2008)

Northwest Impact Direction

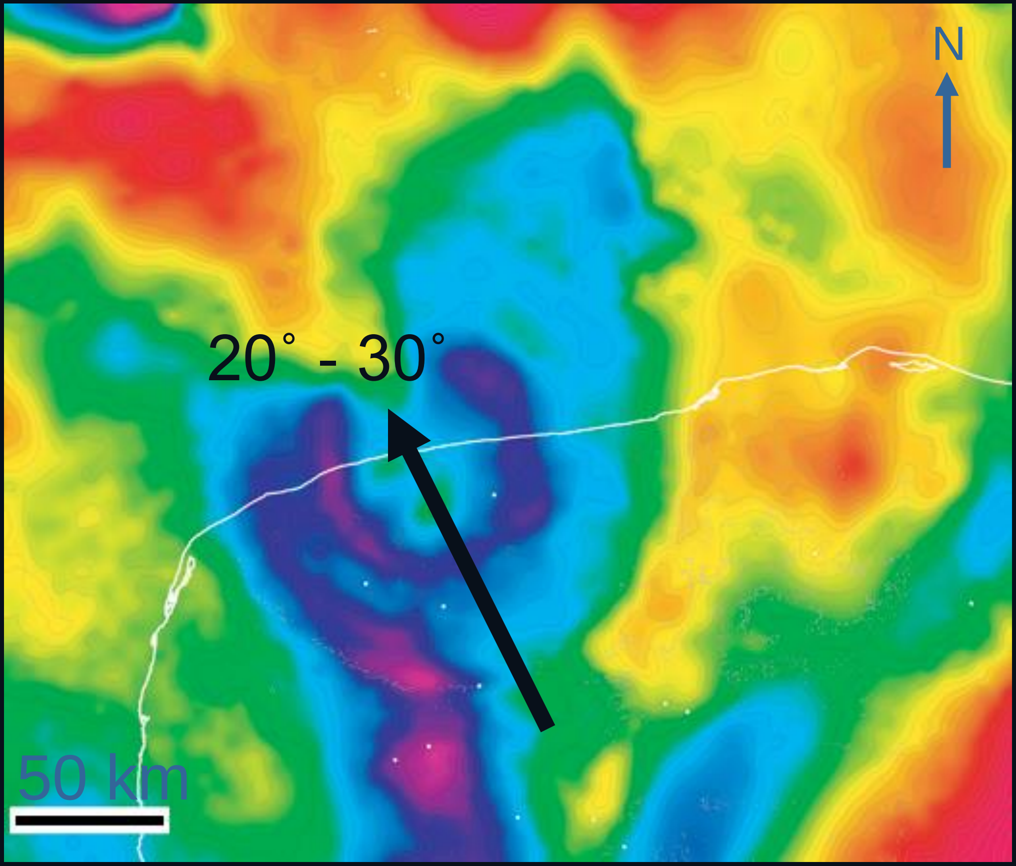
Schultz and D'Hondt et al. (1996)

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

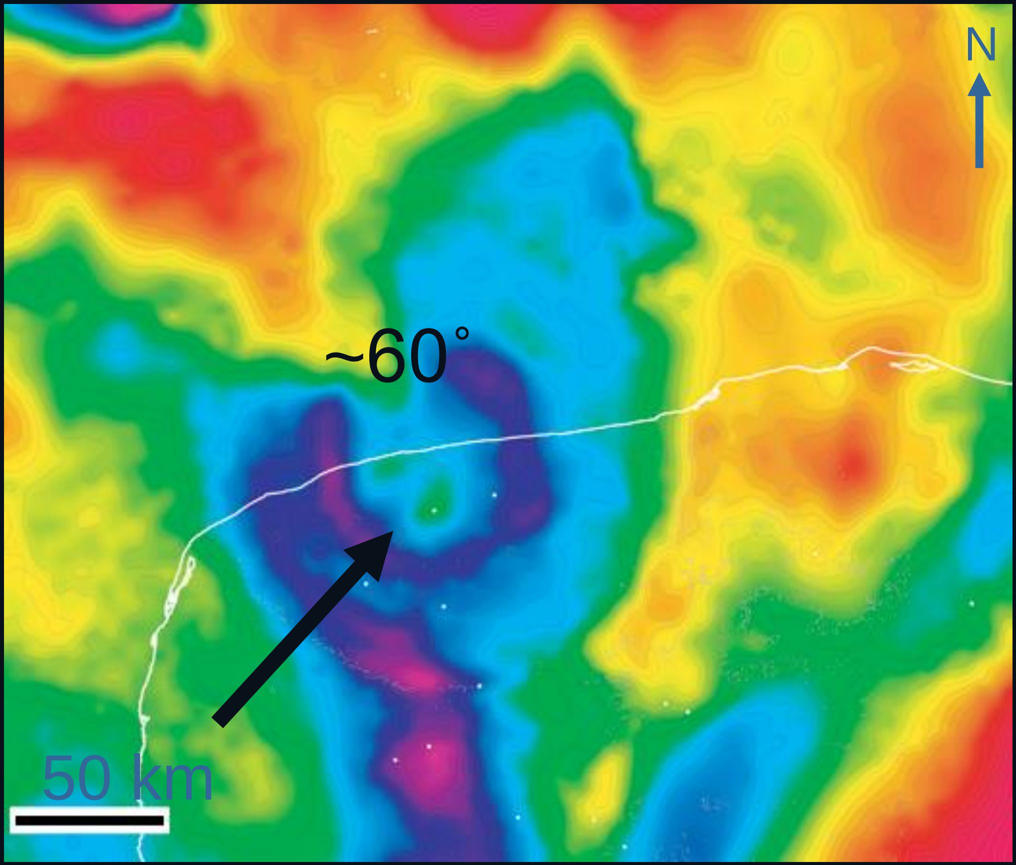


Northeast Impact Direction

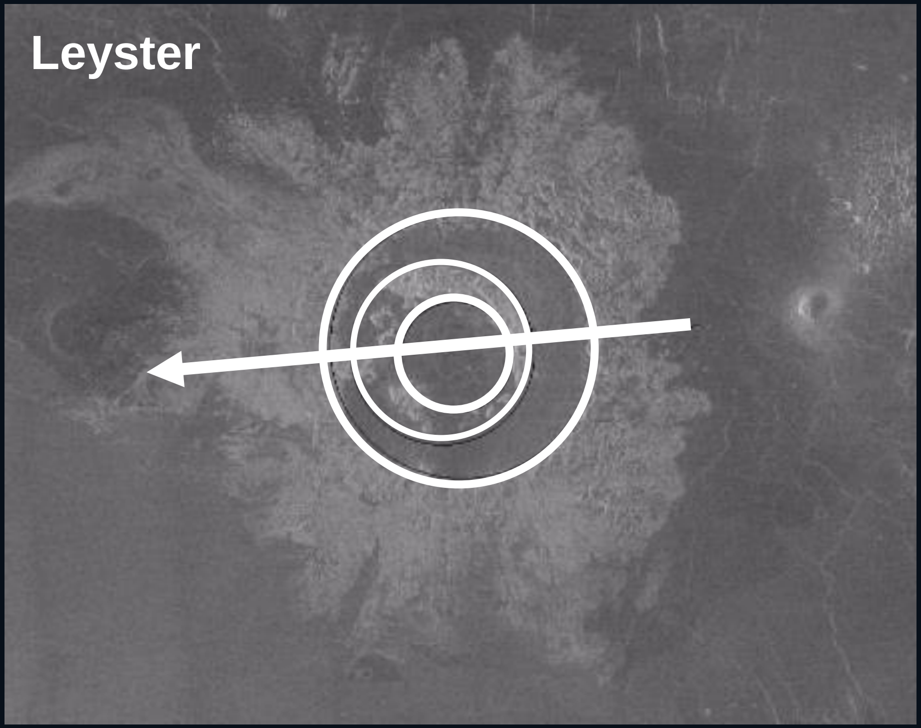
Hildebrand et al. (1998)

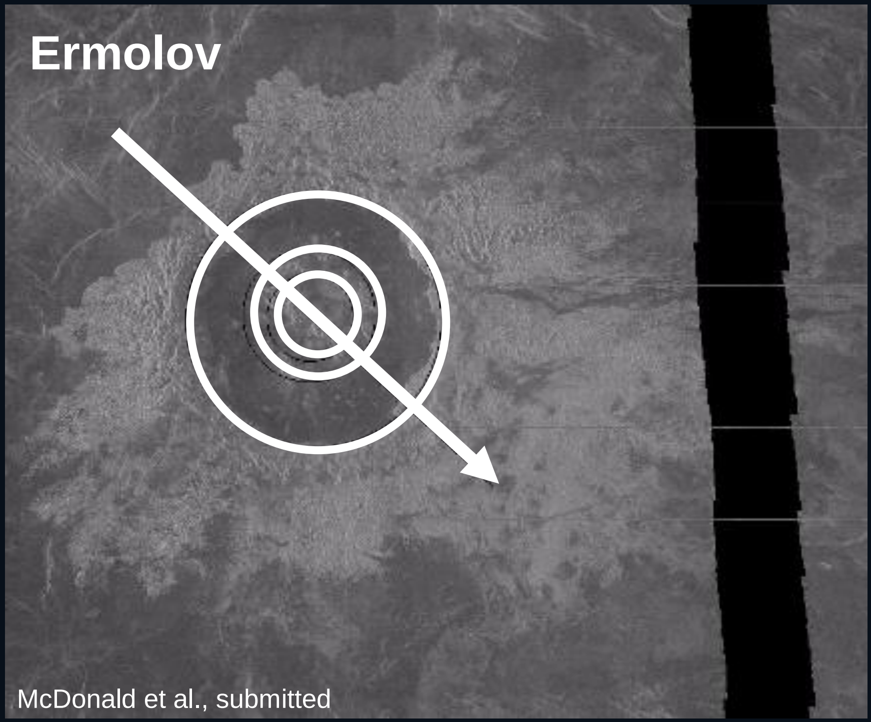
Gravity + Seismic Evidence

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



Craters on Venus

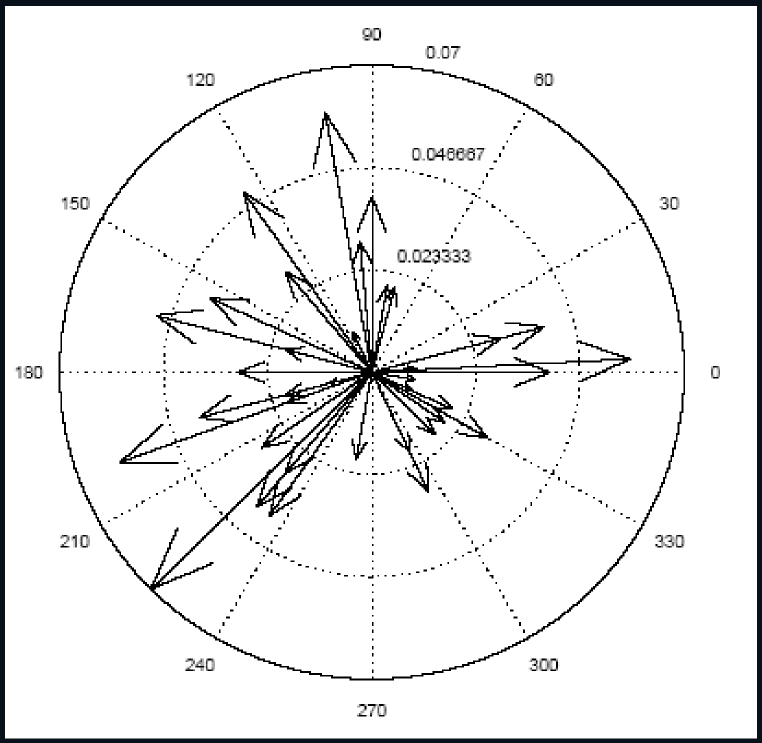




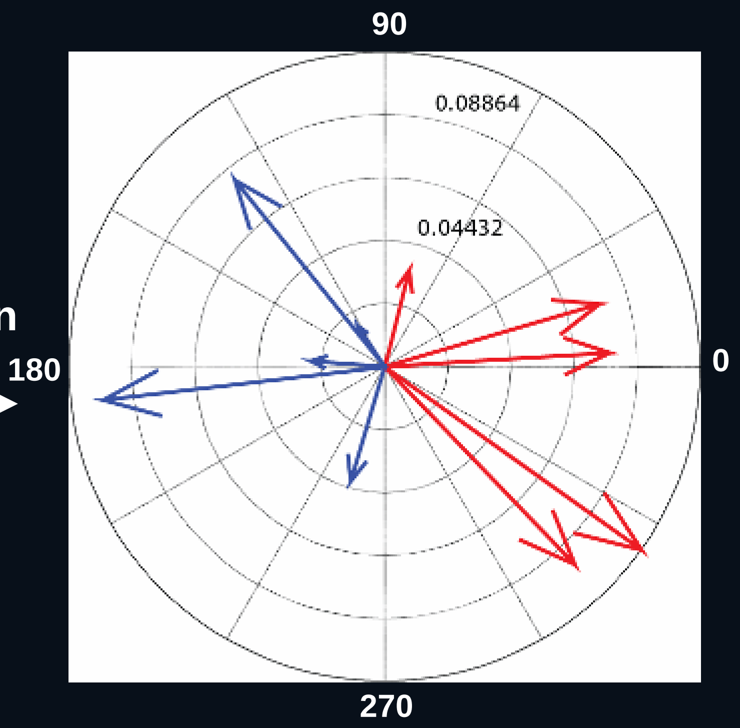
The surface morphology of craters where the direction of impact can be determined by pattern in the ejecta show structures at crater centers do not clearly indicate an impact trajectory.

Central peak offsets vs. peak ring offsets

central peak offsets



peak ring offsets



Impact direction →

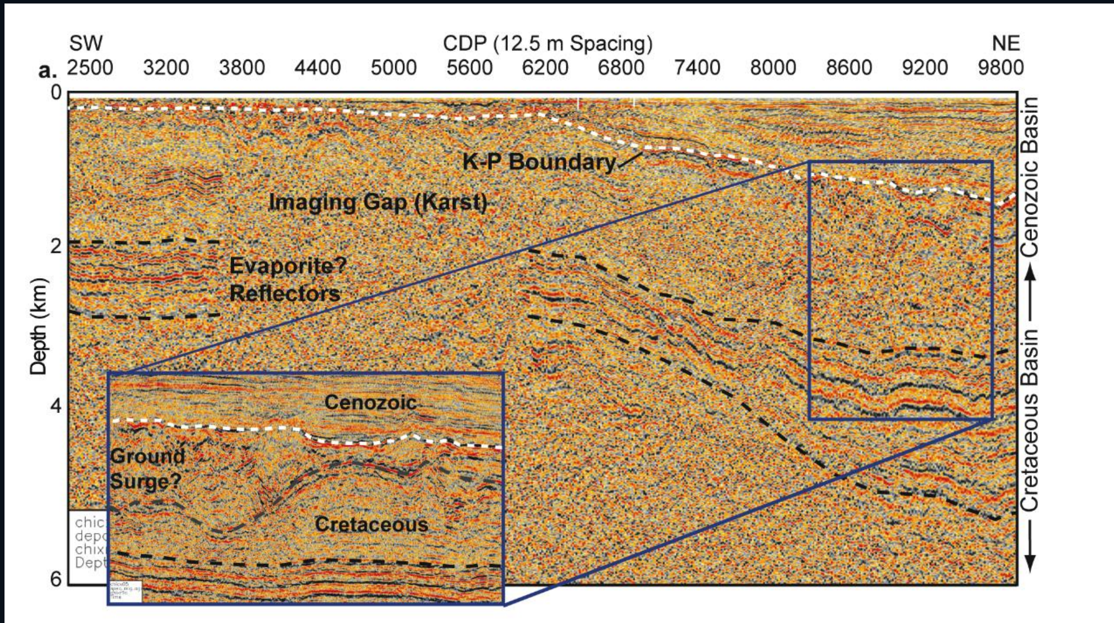
Impact direction →

Average offset: .031

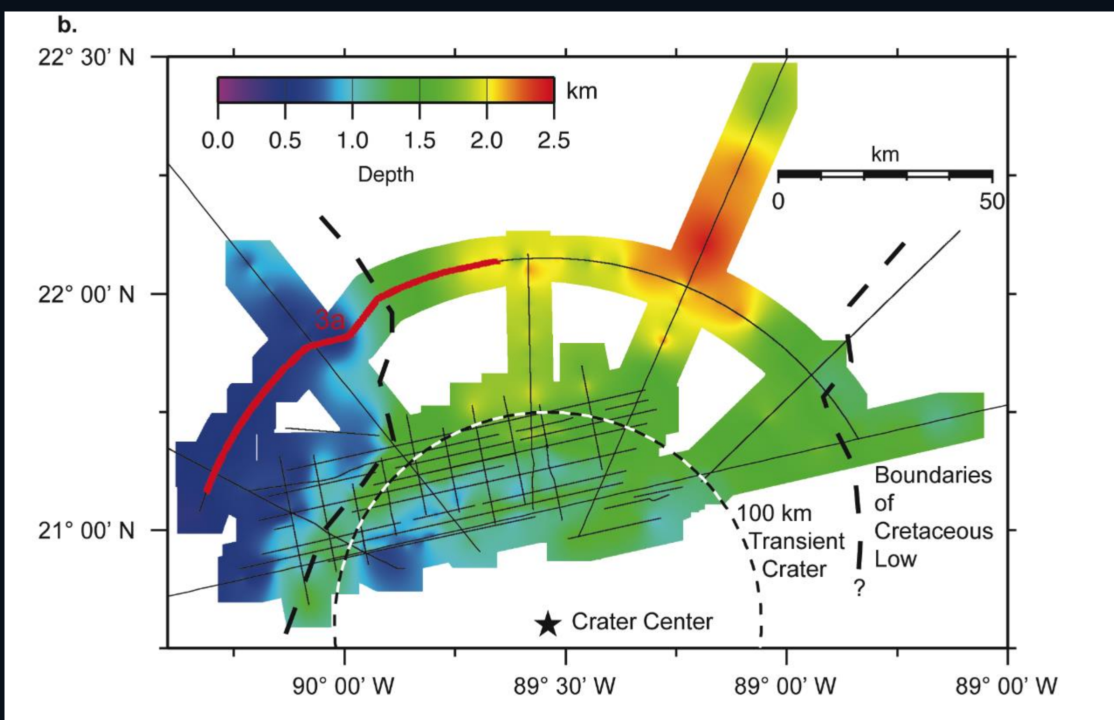
Average offset: .067

Ekholm & Melosh et al. (2000)

McDonald et al., submitted



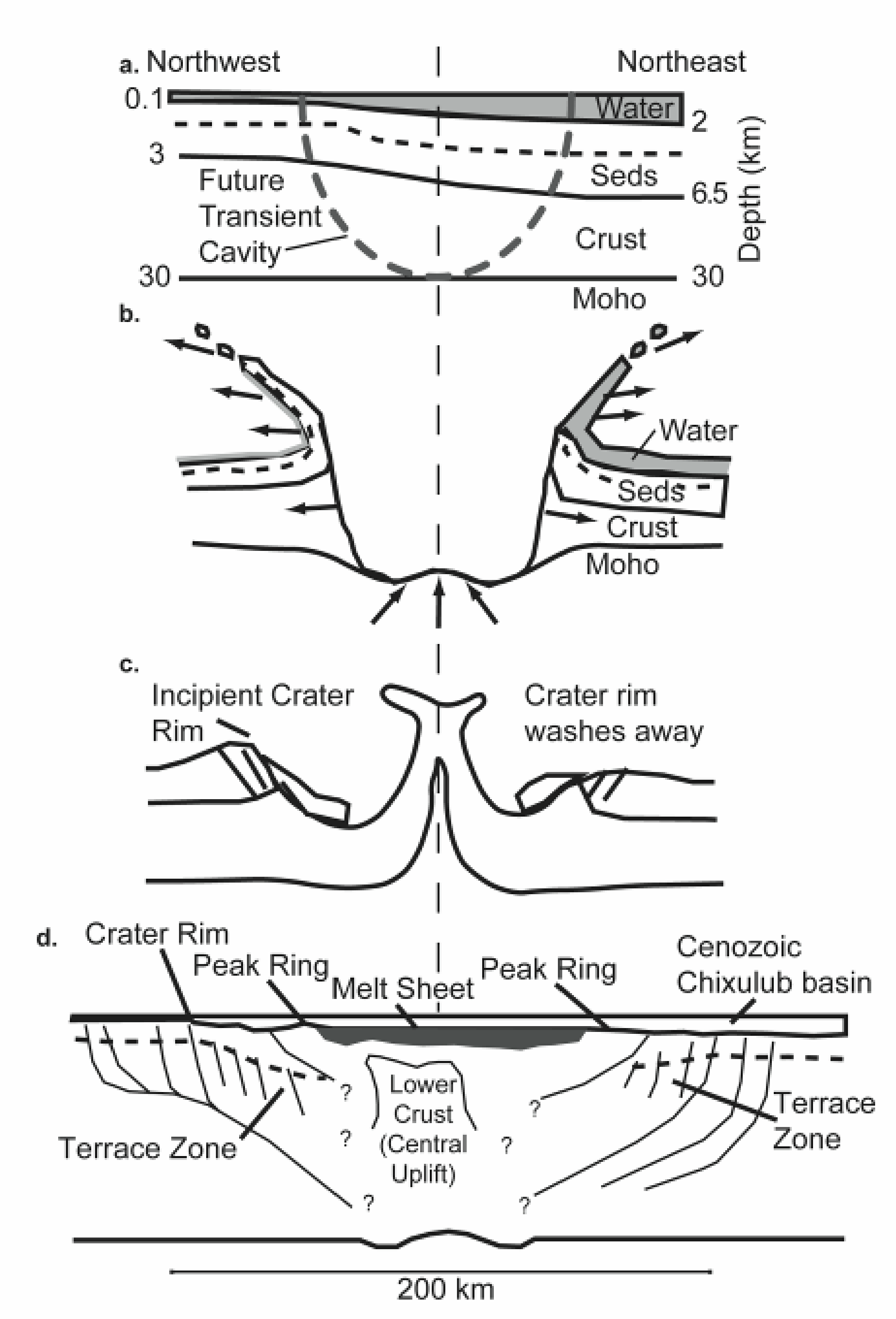
Cross-section of margin of **Chicxulub** crater



Map view of depth to Cretaceous ocean floor

Gulick et al. (2008)

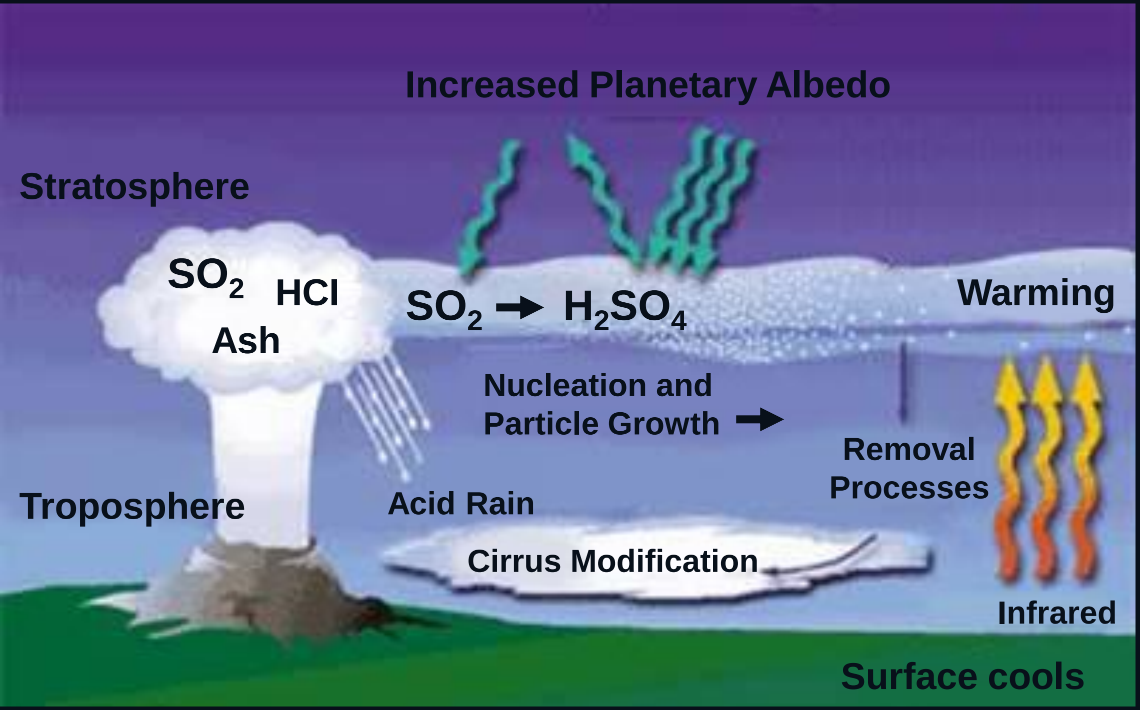
Results



- Asymmetries result from target structure rather than meteor trajectory
- Ring faults mapped at distances up to > 125 km
- Average water depth ~650 m

Gulick et al. (2008)

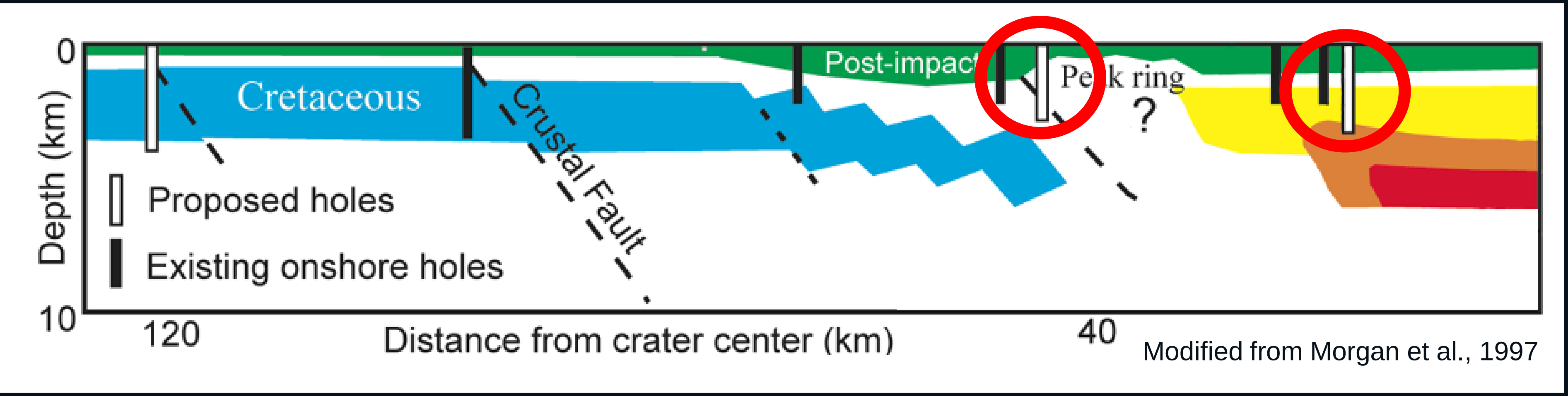
The Chicxulub impact may have been especially lethal because of an especially unlucky choice of target - Sulfur-rich rocks



Conclusions Thus Far

- Peak ring and terrace zone asymmetries are controlled by pre-existing shallow structure
- Ring asymmetries are dominated by initial crustal geometry
- Mapping at Chicxulub suggests that target heterogeneities dominate final crater structure
- Signature of impact direction and angle may be difficult to extract from final crater geometries in many cases
- The vapor plume at Chicxulub likely included a greater concentration of water than previously suggested and asymmetries in the amount of sediment ejecta should be expected independent of impact direction

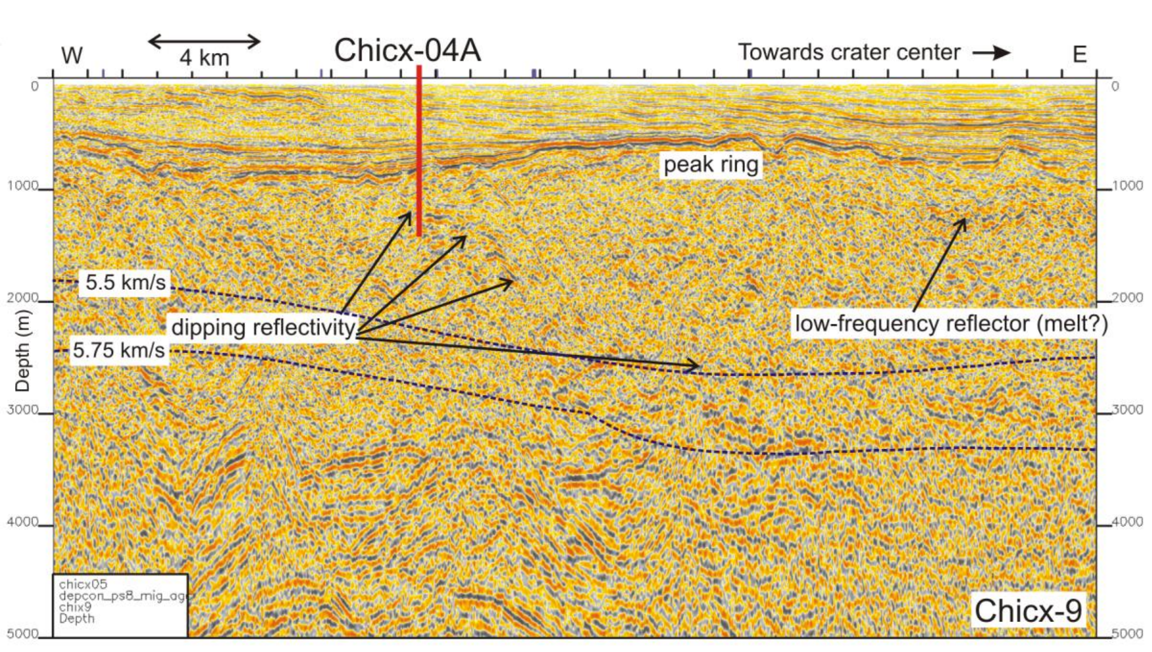
Chicxulub crater structure from geophysical models… more drilling would provide hard data!

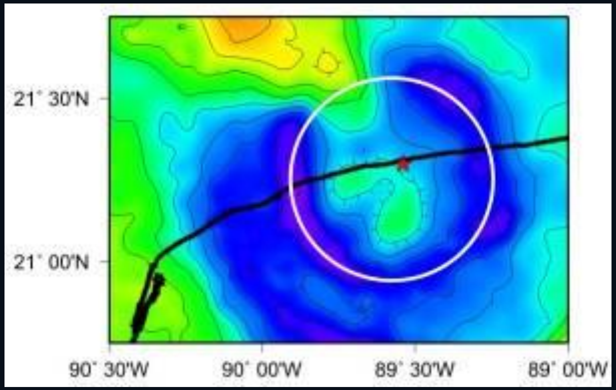


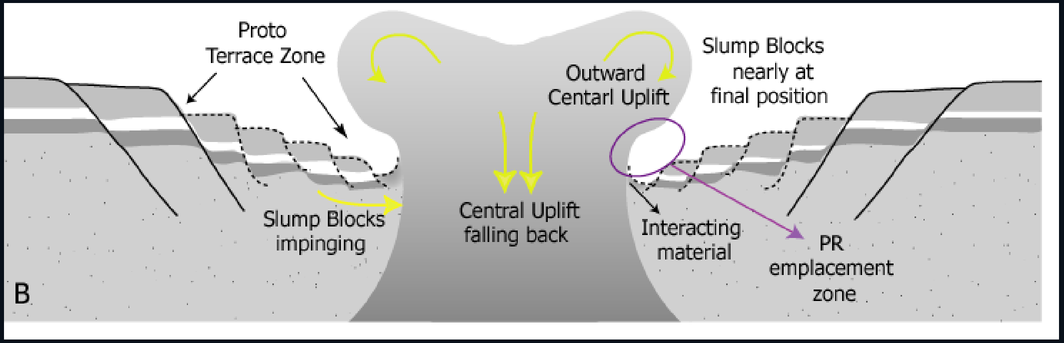
Key questions to address

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

What are the dimensions of the melt sheet?

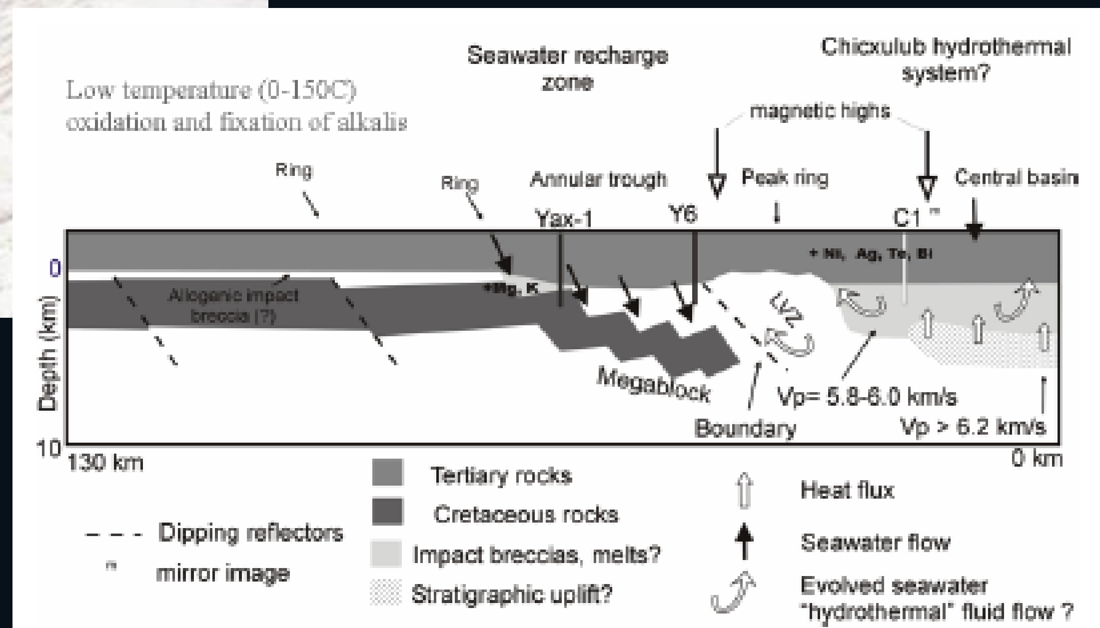






What is the dipping reflector? Is it a mineralized fault recording an old hydrothermal system?

Mendoza et al. (2007)



Was this system a haven for life?

Role of impacts as haven for early life?

Ames et al. (2006)

Stay Tuned!

1980s Impact Theory

1990s Chicxulub discovered

2000s Theory matures and crater revealed

2010s Drilling for Answers!

Thanks for listening…

With thanks to:

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