Life and Death by Impact

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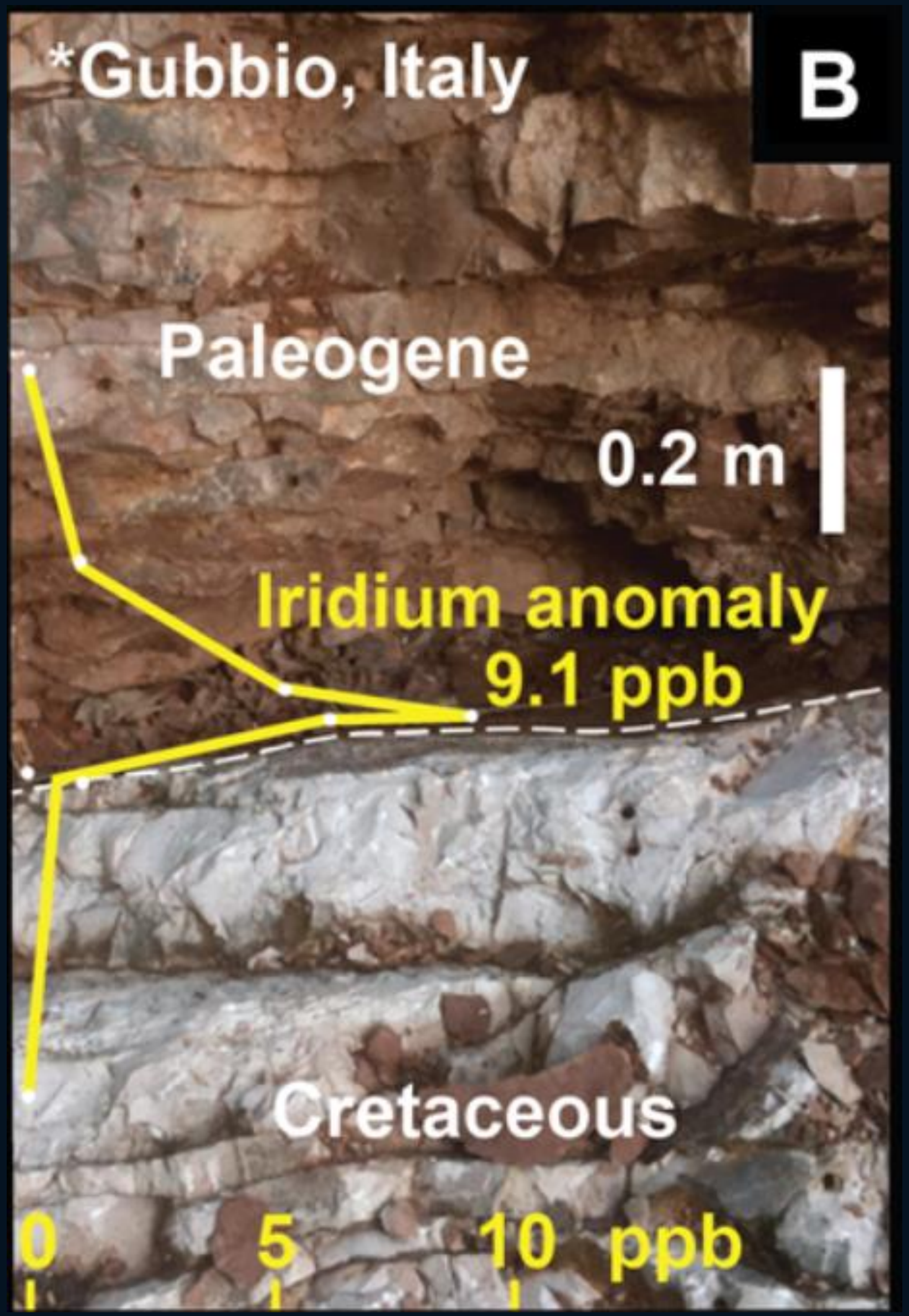
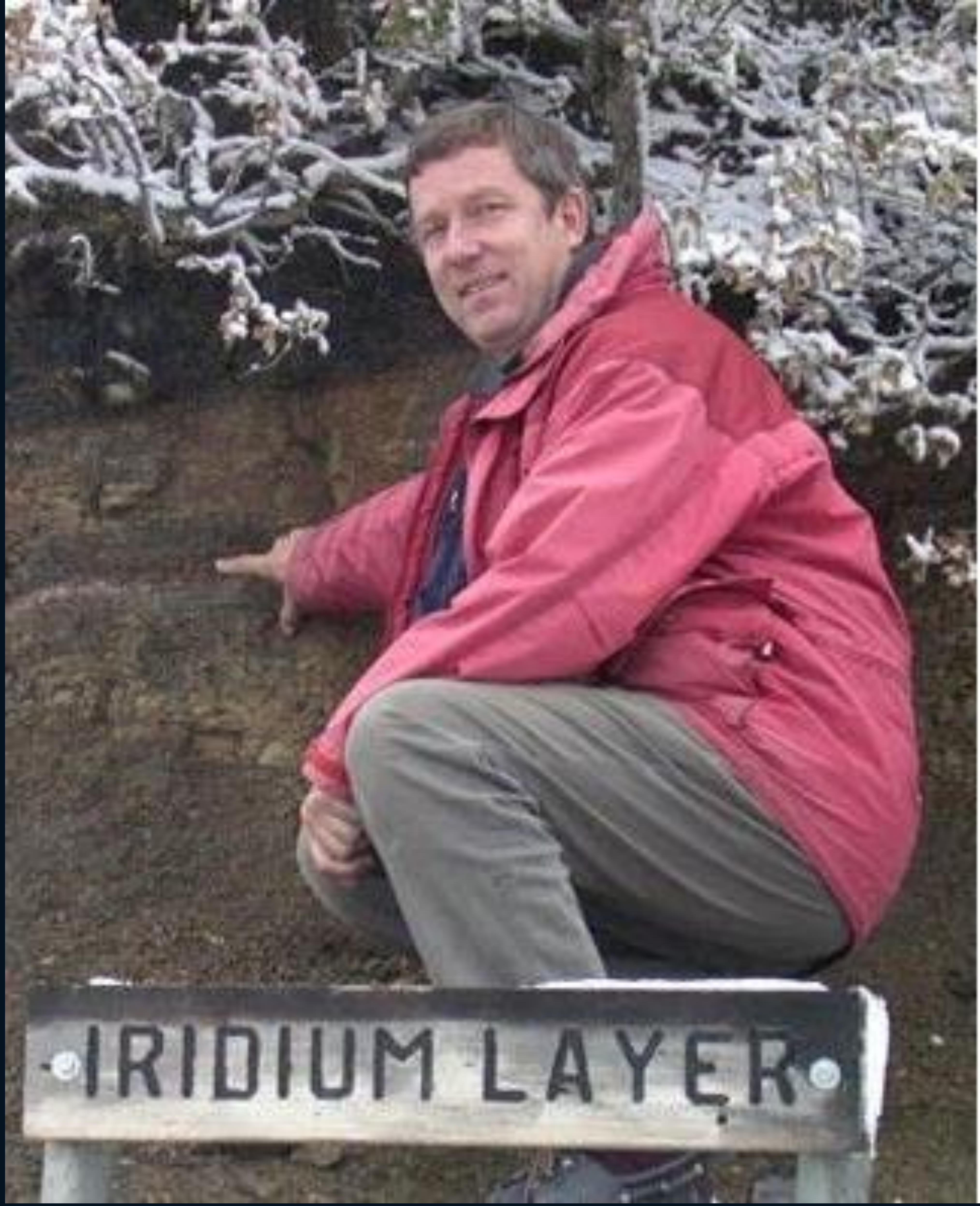
NASA NSF ECORD EUROPEAN CONSORTIUM FOR OCEAN RESEARCH DRILLING icdp IODP INTERNATIONAL OCEAN DISCOVERY PROGRAM

Alvarez et al.,
Science, 1980

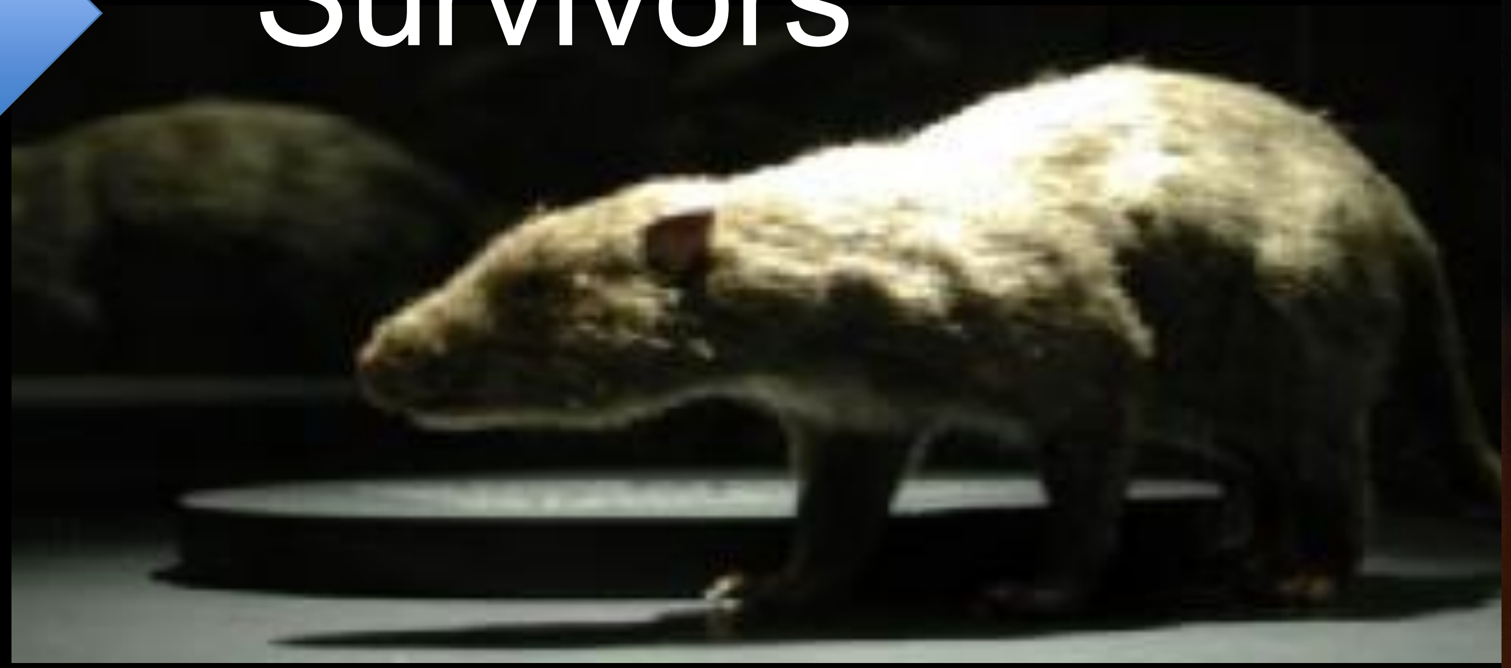




Smit & Hertogen,
Nature, 1980

66 million years ago

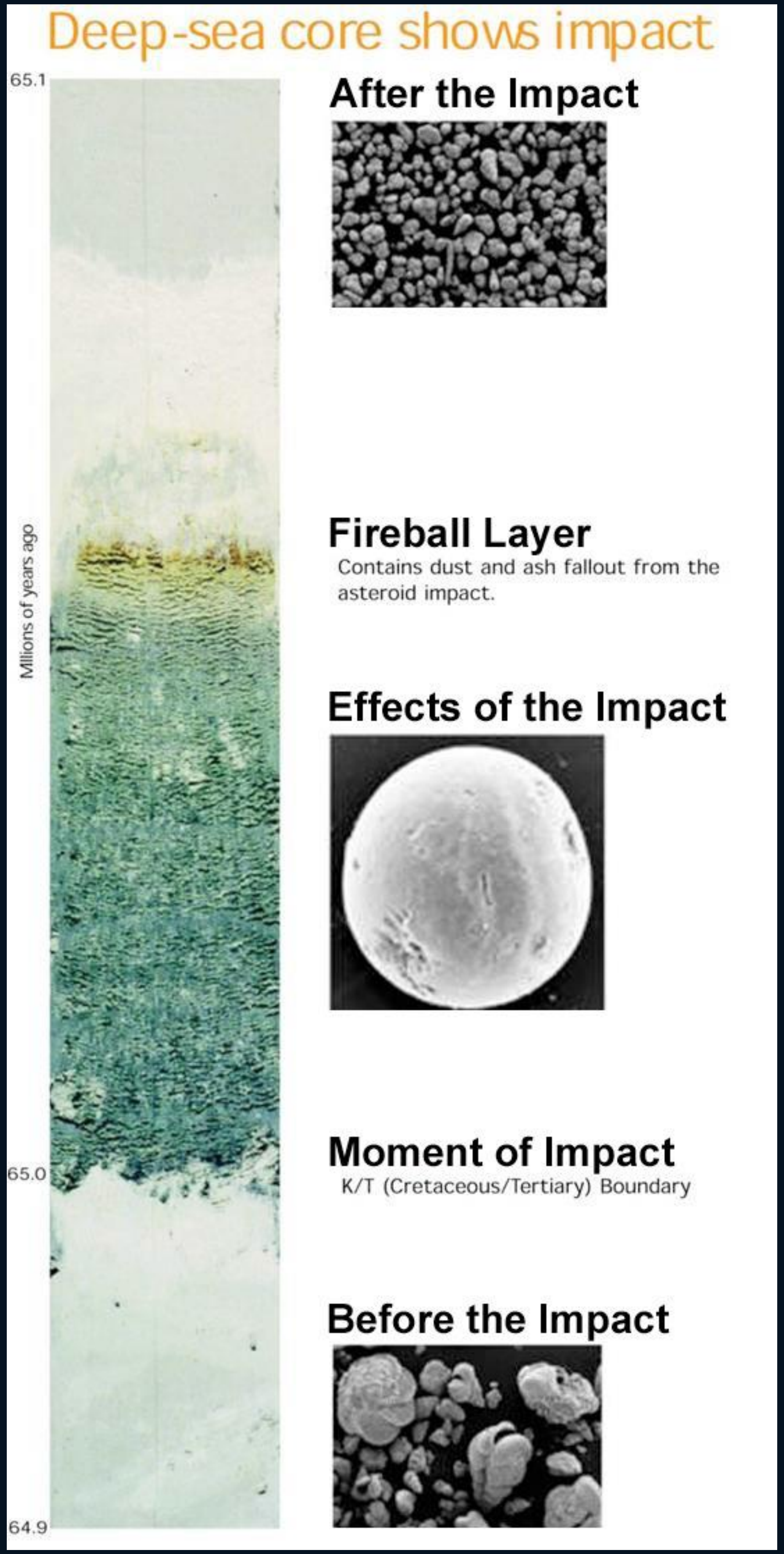
Survivors



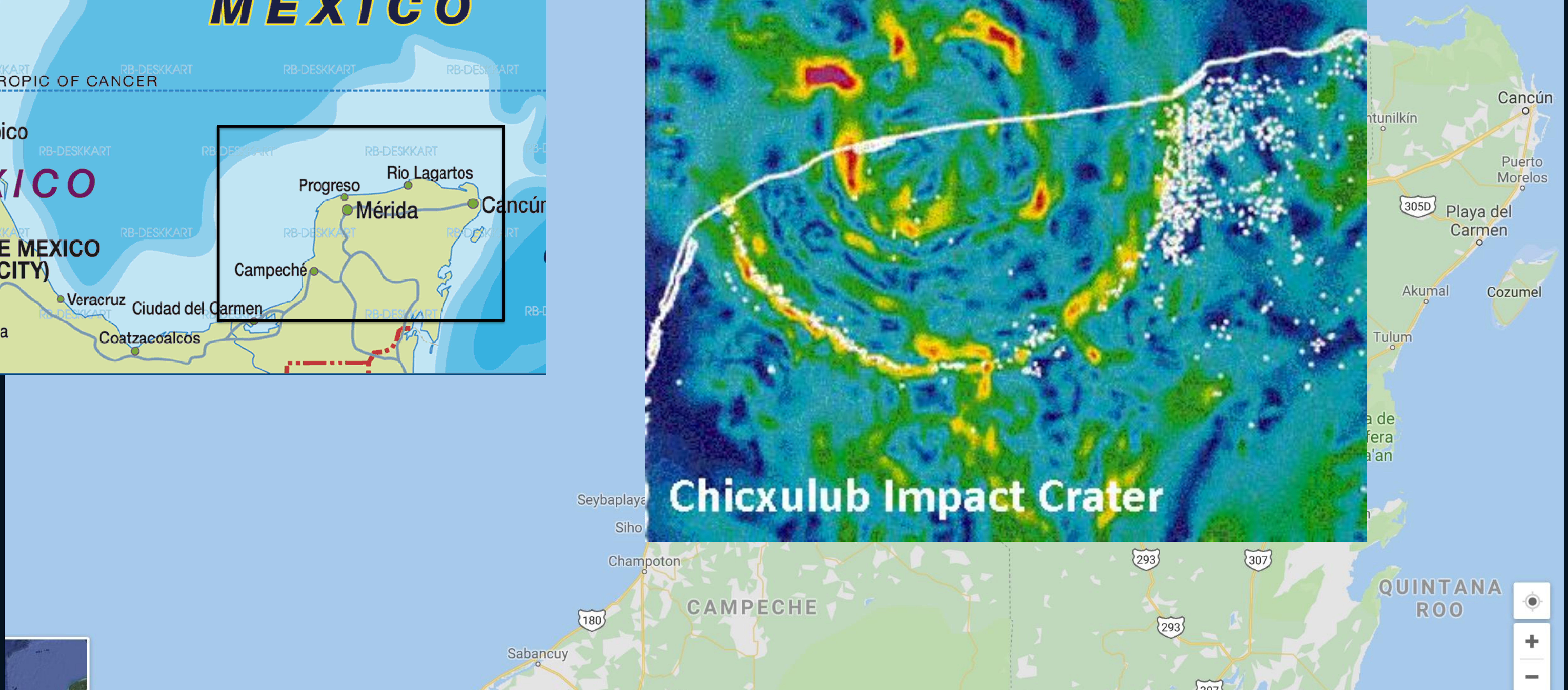
Today!

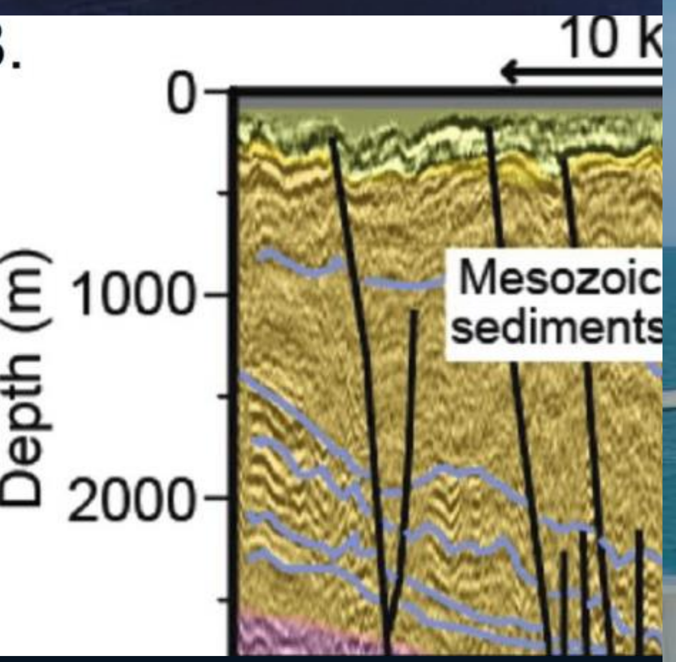
Evidence Correlating Chicxulub with K/Pg Boundary

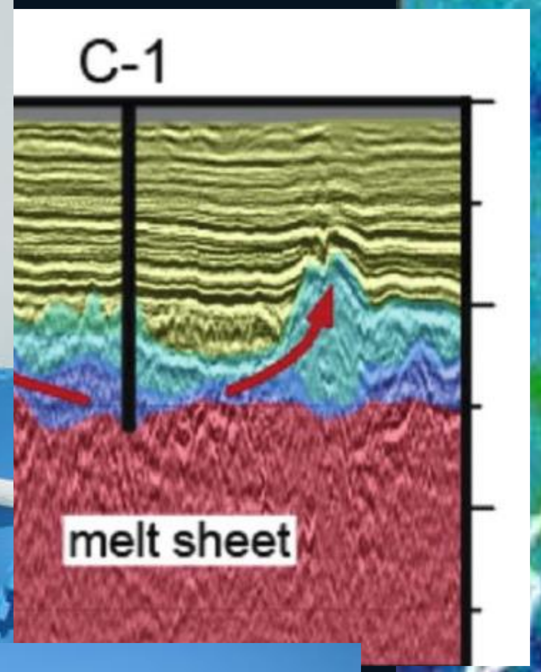
Schulte et al., Science, 2010

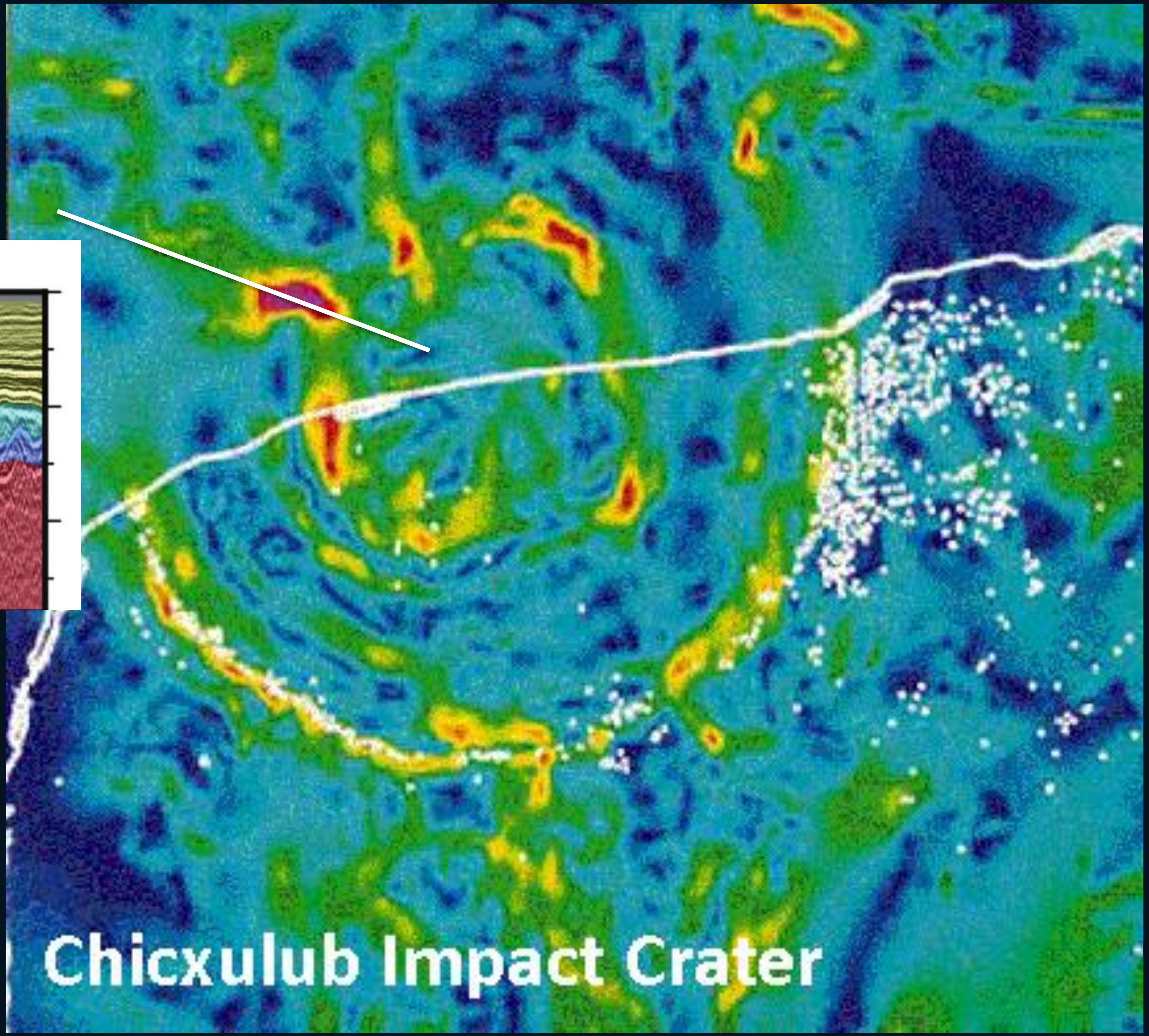


But where is the crater?

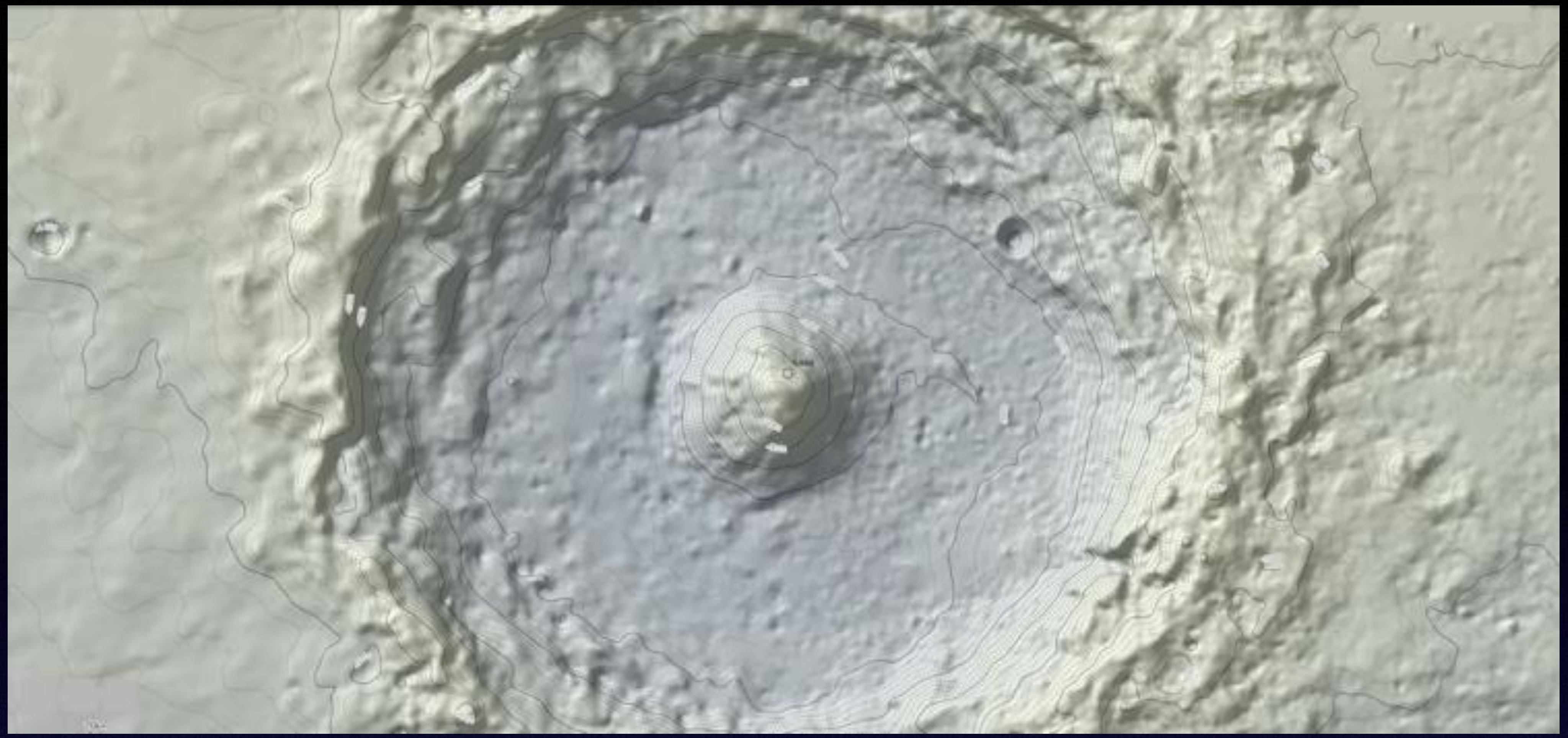



10 k
0
1000
2000
Depth (m)
Mesozoic
sediments

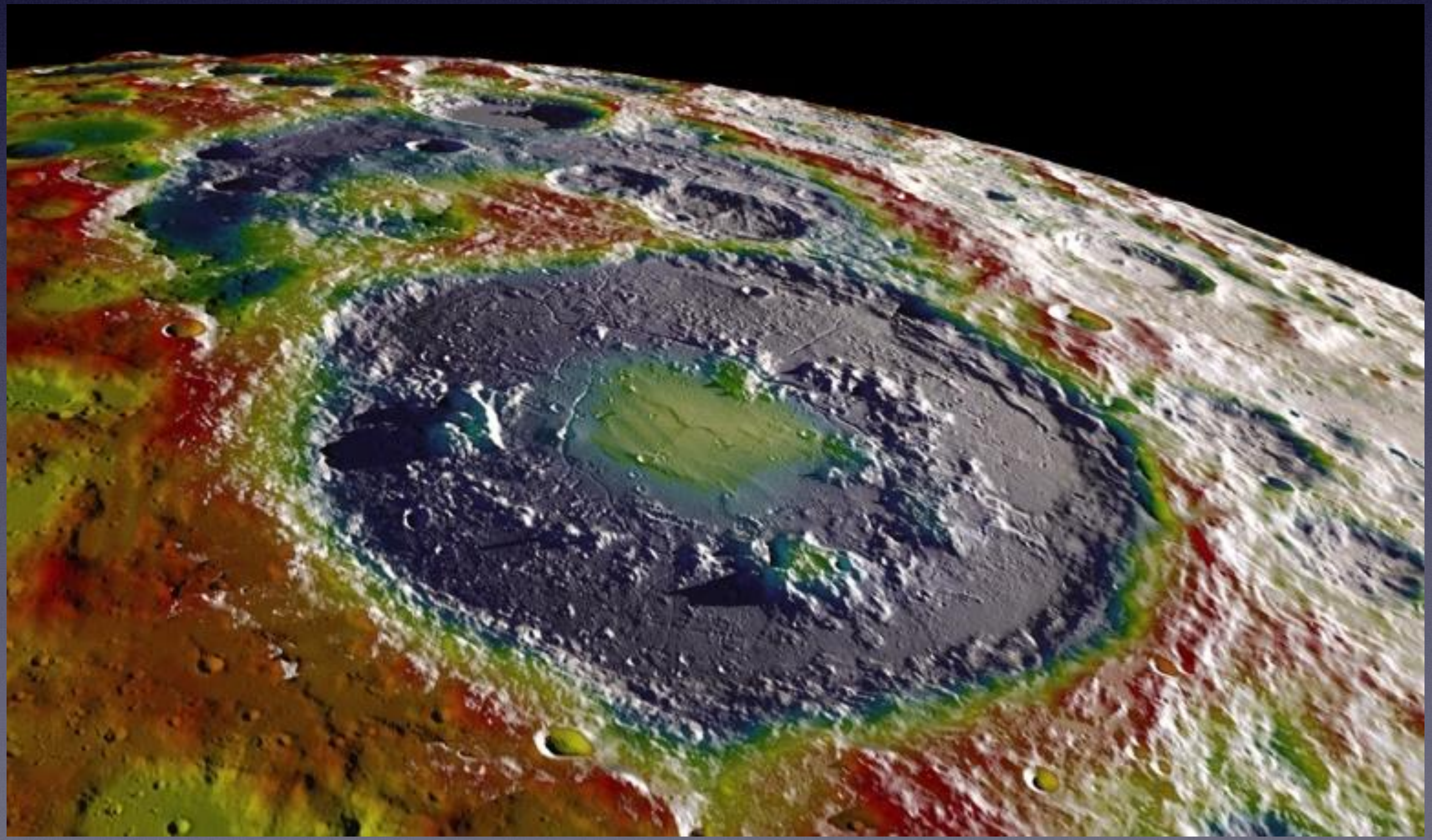

C-1
melt sheet


Chicxulub Impact Crater

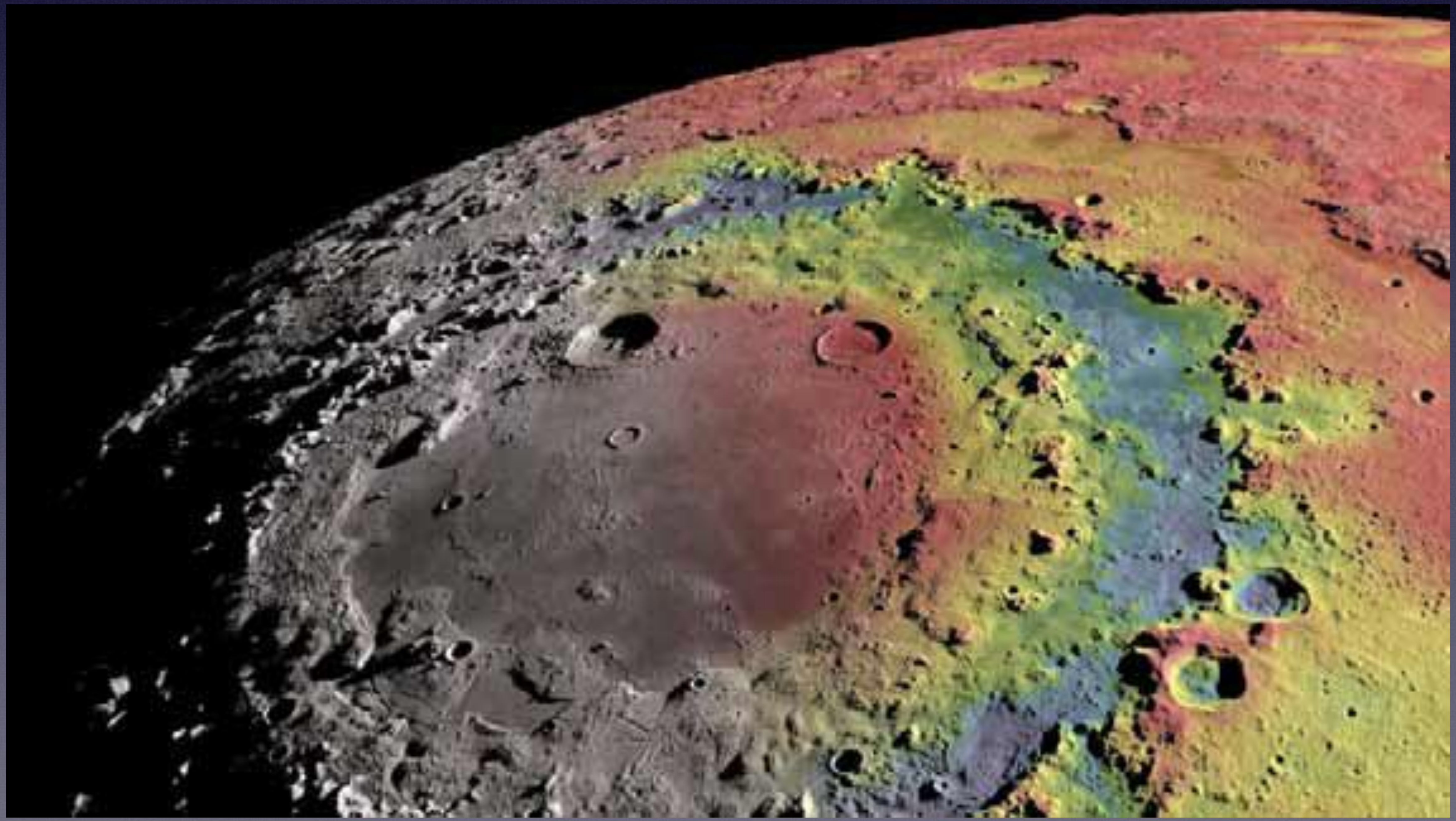
Simple



Complex: Central Peak

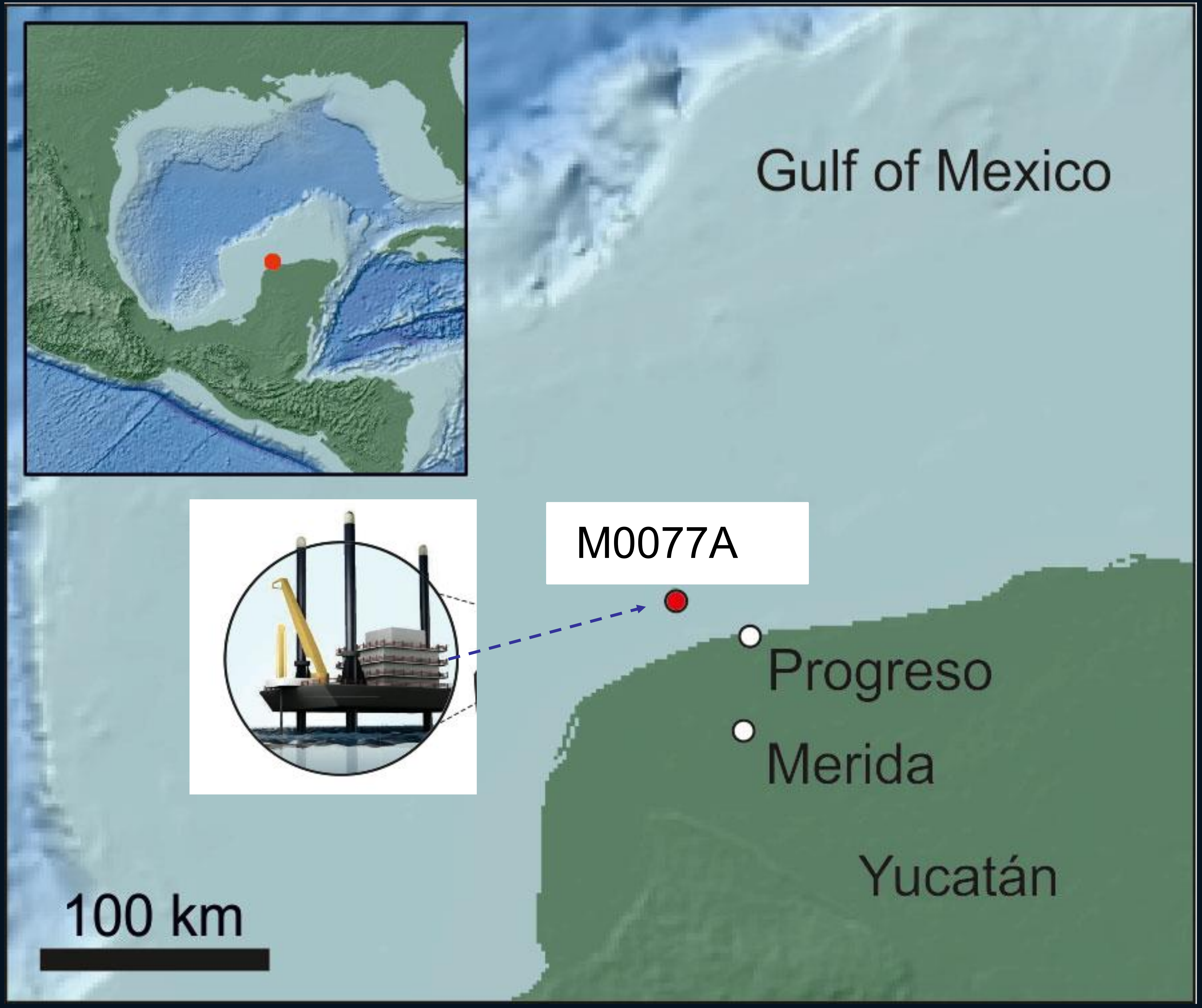


Complex: Peak Ring Basin



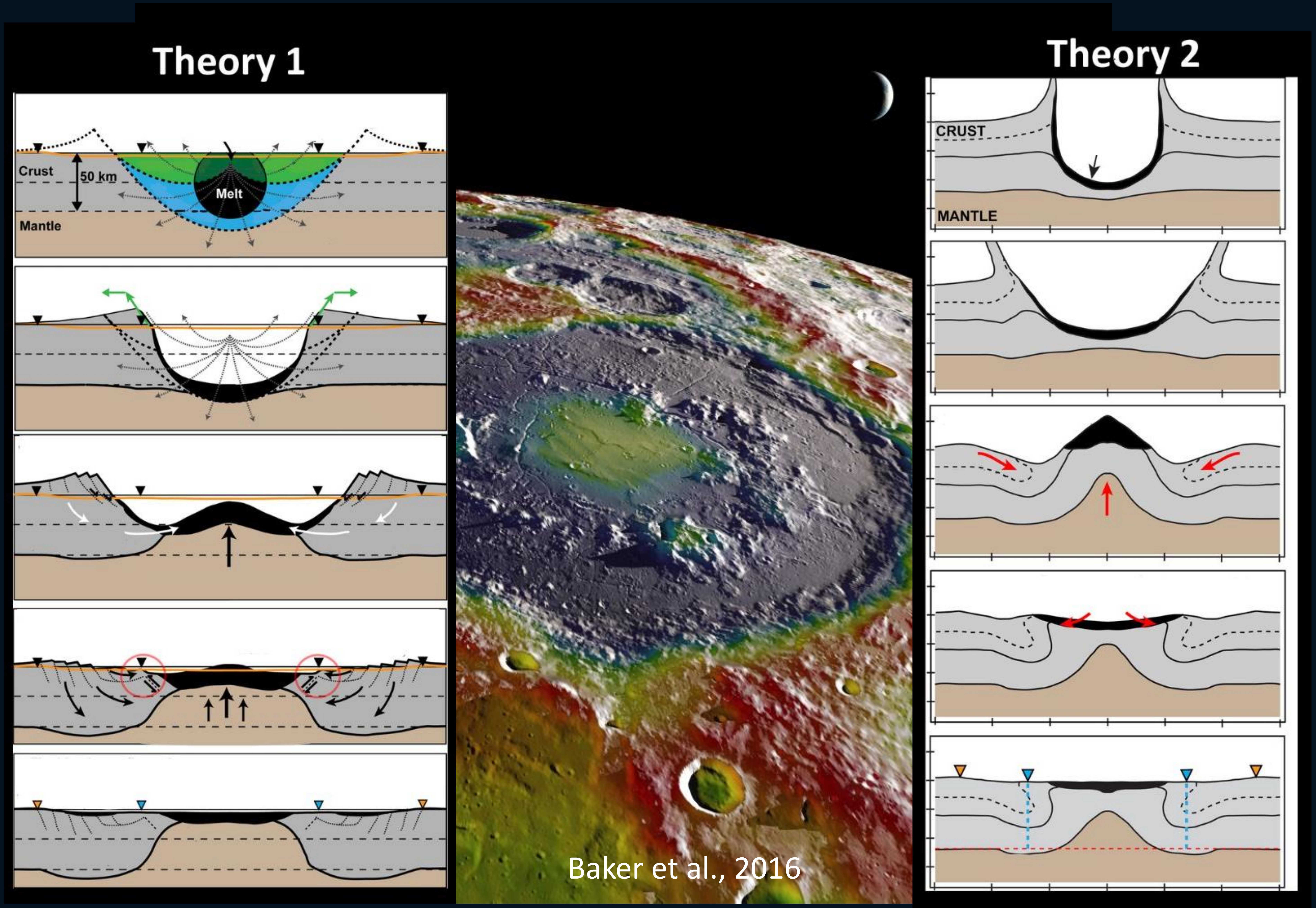
Complex: Multi-Ring Basin

International Ocean Discovery Program,
Expedition 364, Joint with Int. Cont. Drilling Project



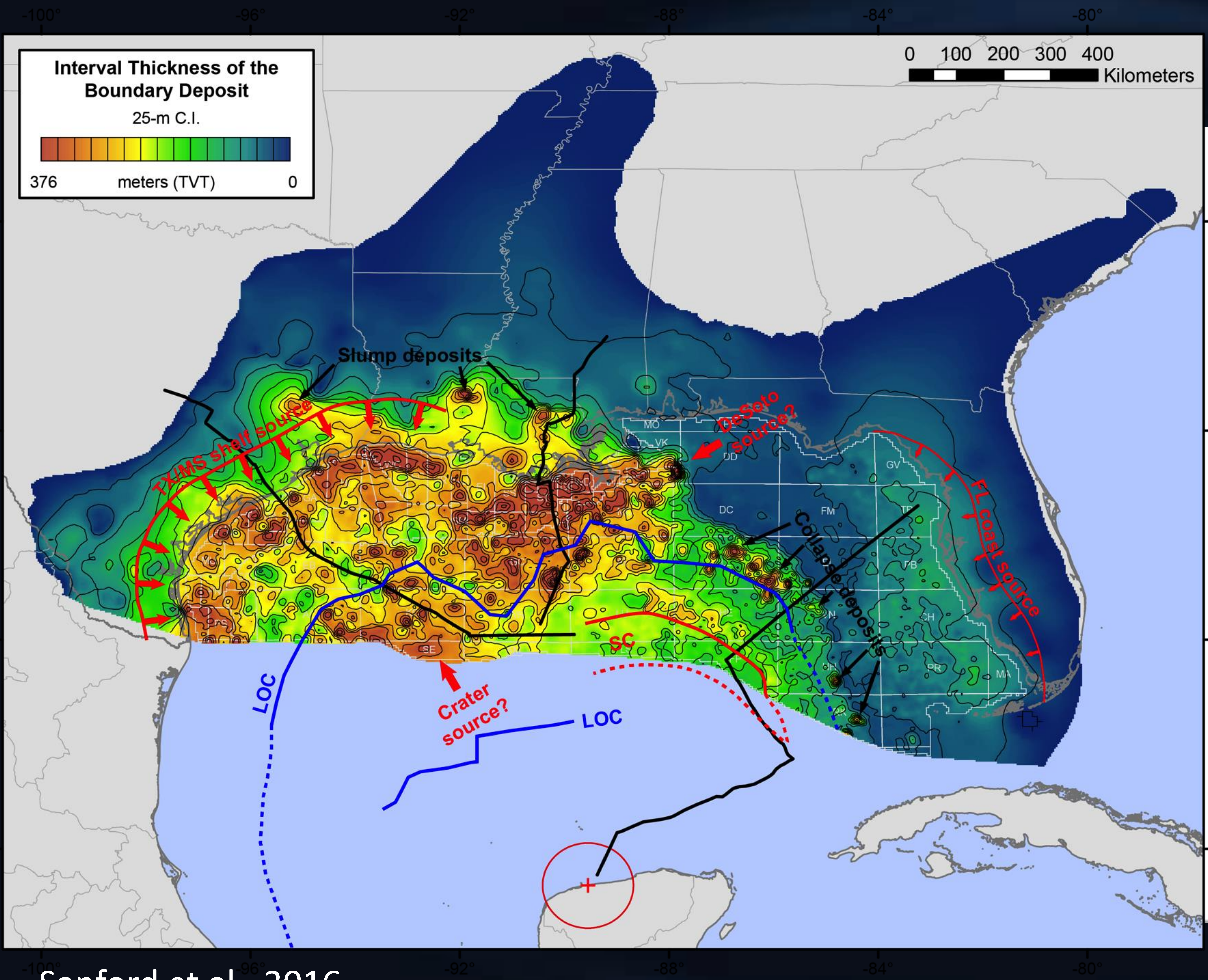
1. How are rocks weakened during large impacts to collapse and form relatively wide, flat craters? What rock comprise and how are peak rings formed?
2. What caused the environmental changes that led to a mass extinction and what insights arise from biologic recovery in the Paleogene?
3. Can impacts generate habitats for chemosynthetic life?

Objective 1: How are impact basins and peak rings formed?



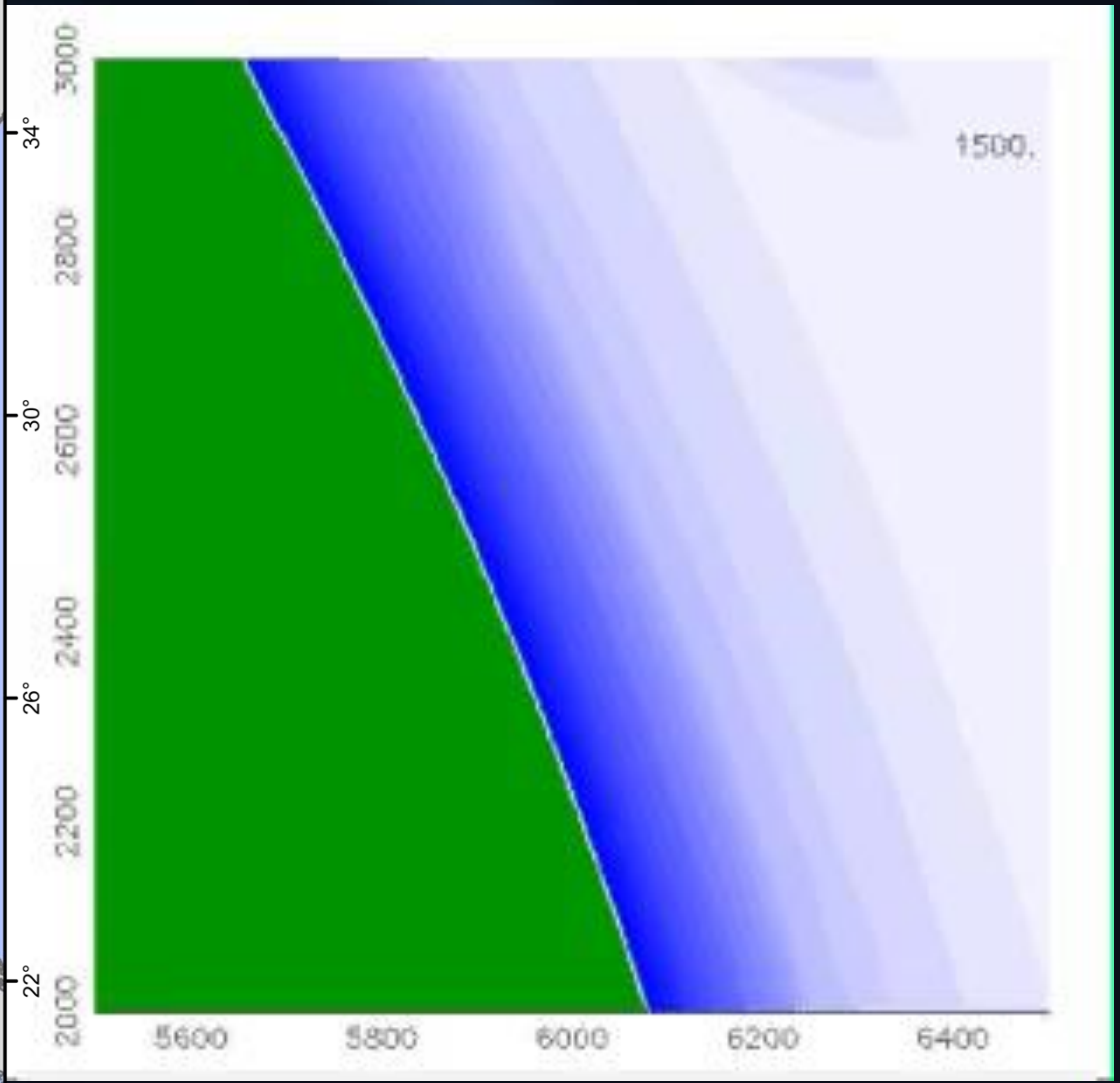
Schrödinger Basin (Moon)

Objective 2: What caused the mass extinction



Sanford et al., 2016

Arrival of Ejecta to Europe, ~6000 km from Chicxulub

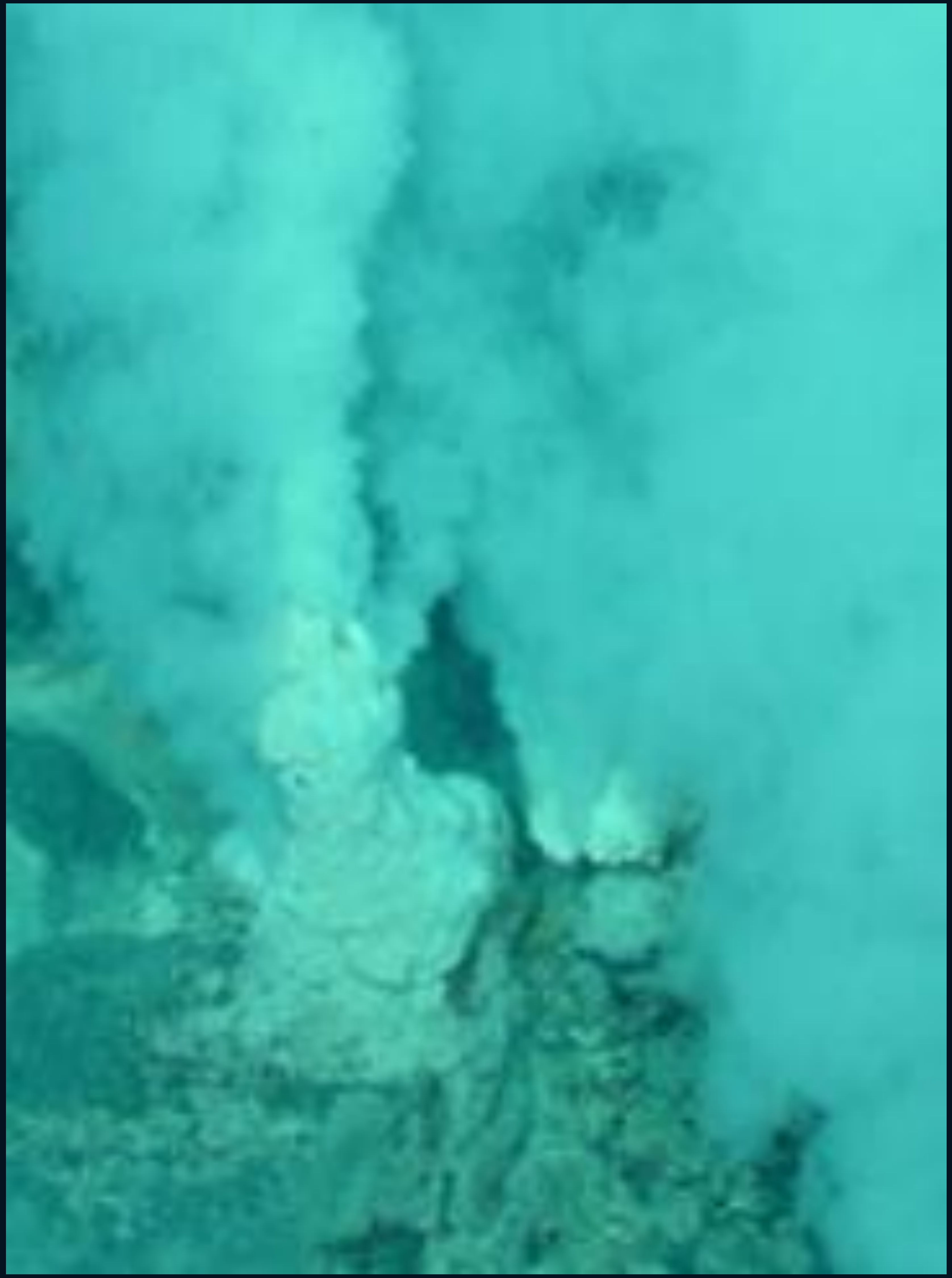


Artemieva and Morgan, 2009

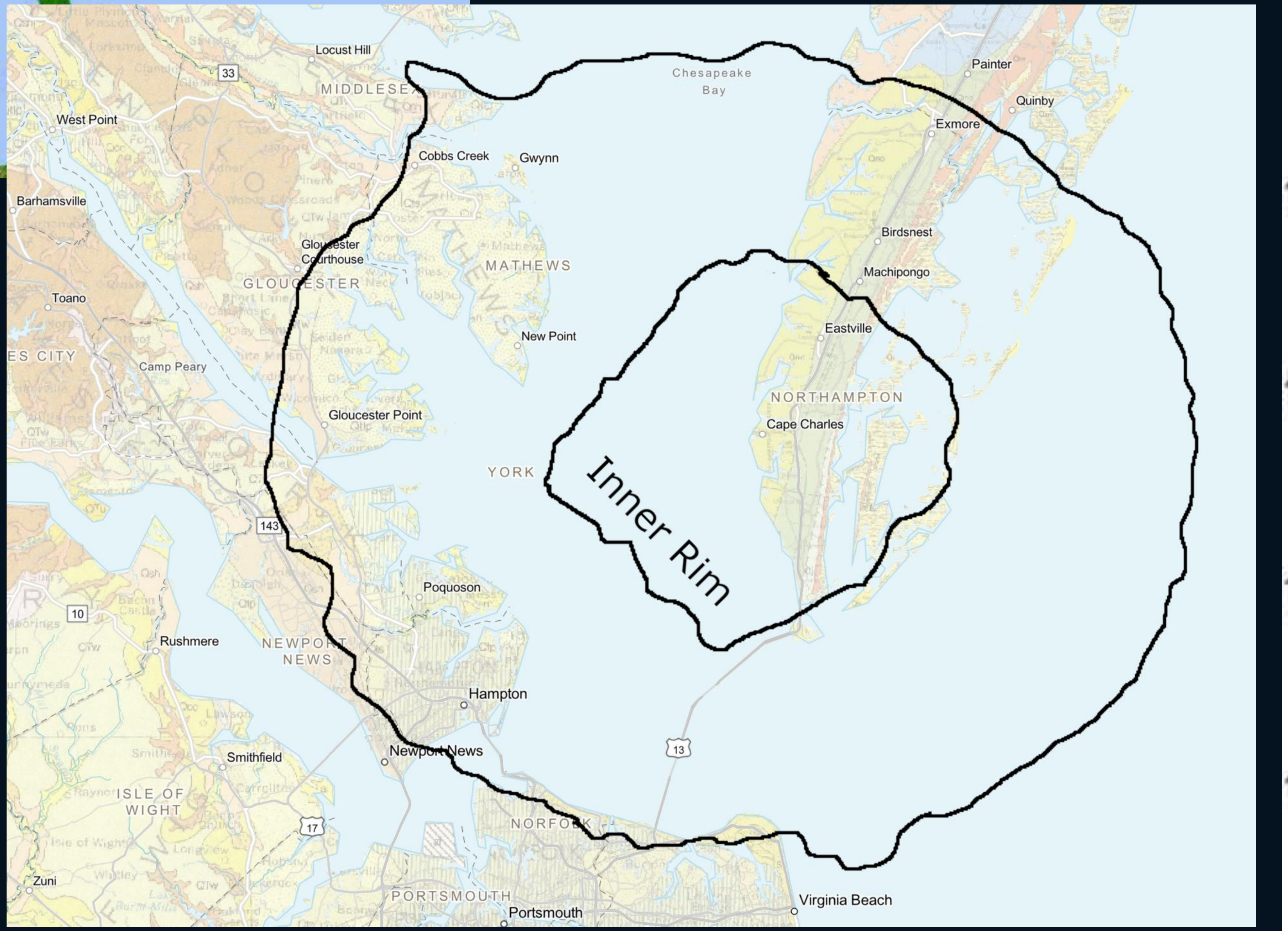
Objective 3: Impacts as a crucible for life?

Volcanic Hot Spring

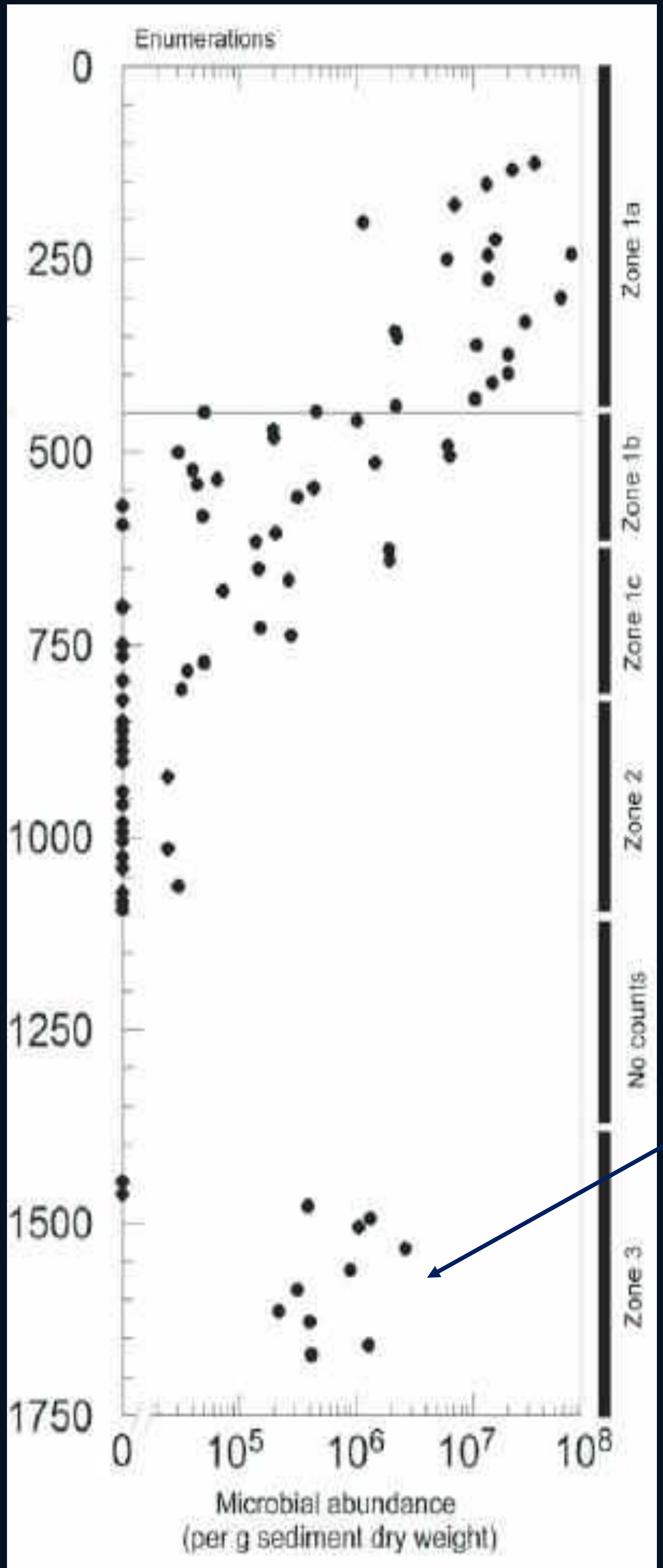
Seafloor Vent



Objective 3: Impacts as a crucible for life?



Cell counts



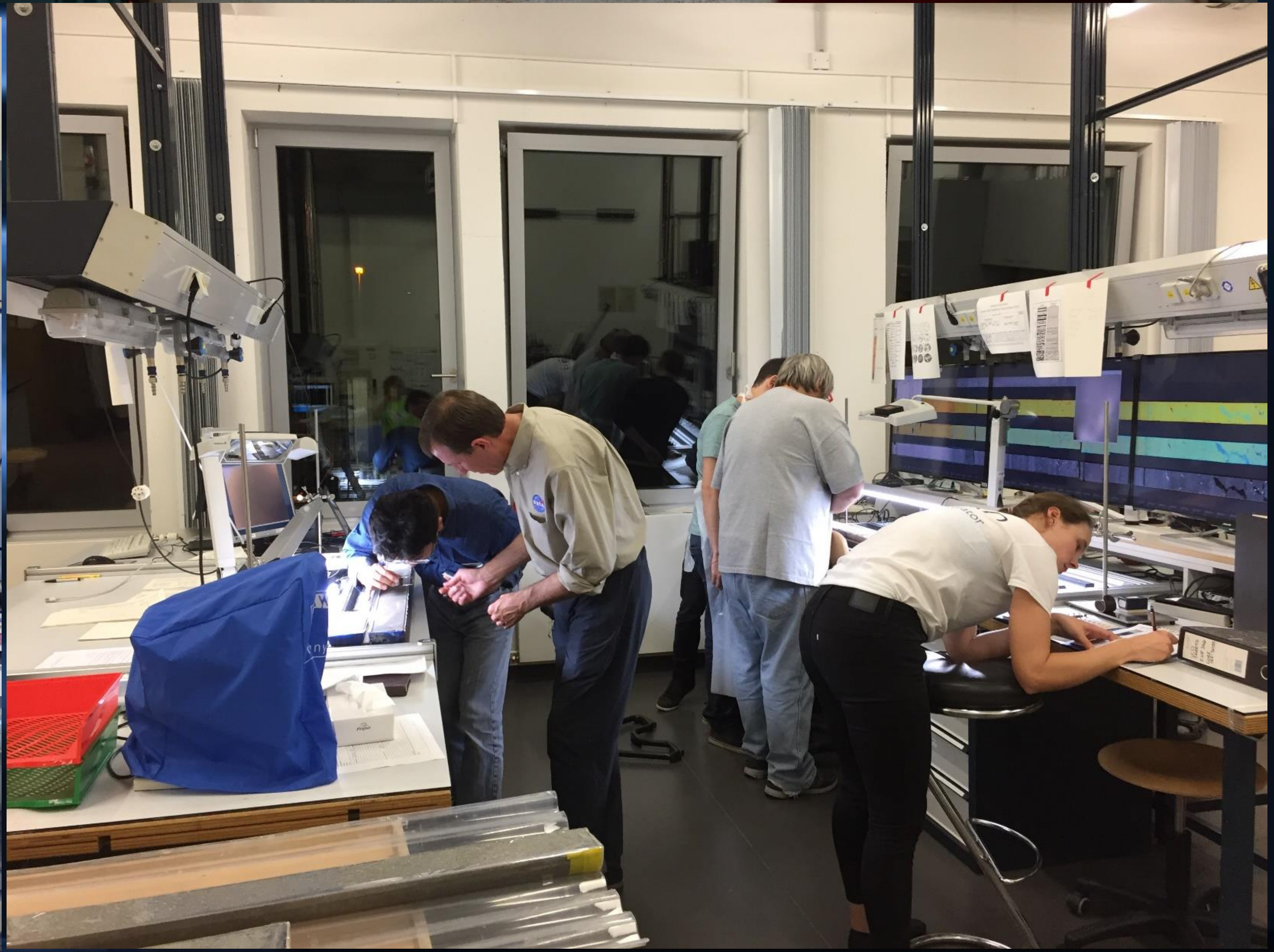
Modern life in the Chesapeake crater in deposits at 1500 m below the surface

Cockell et al., 2012

2016

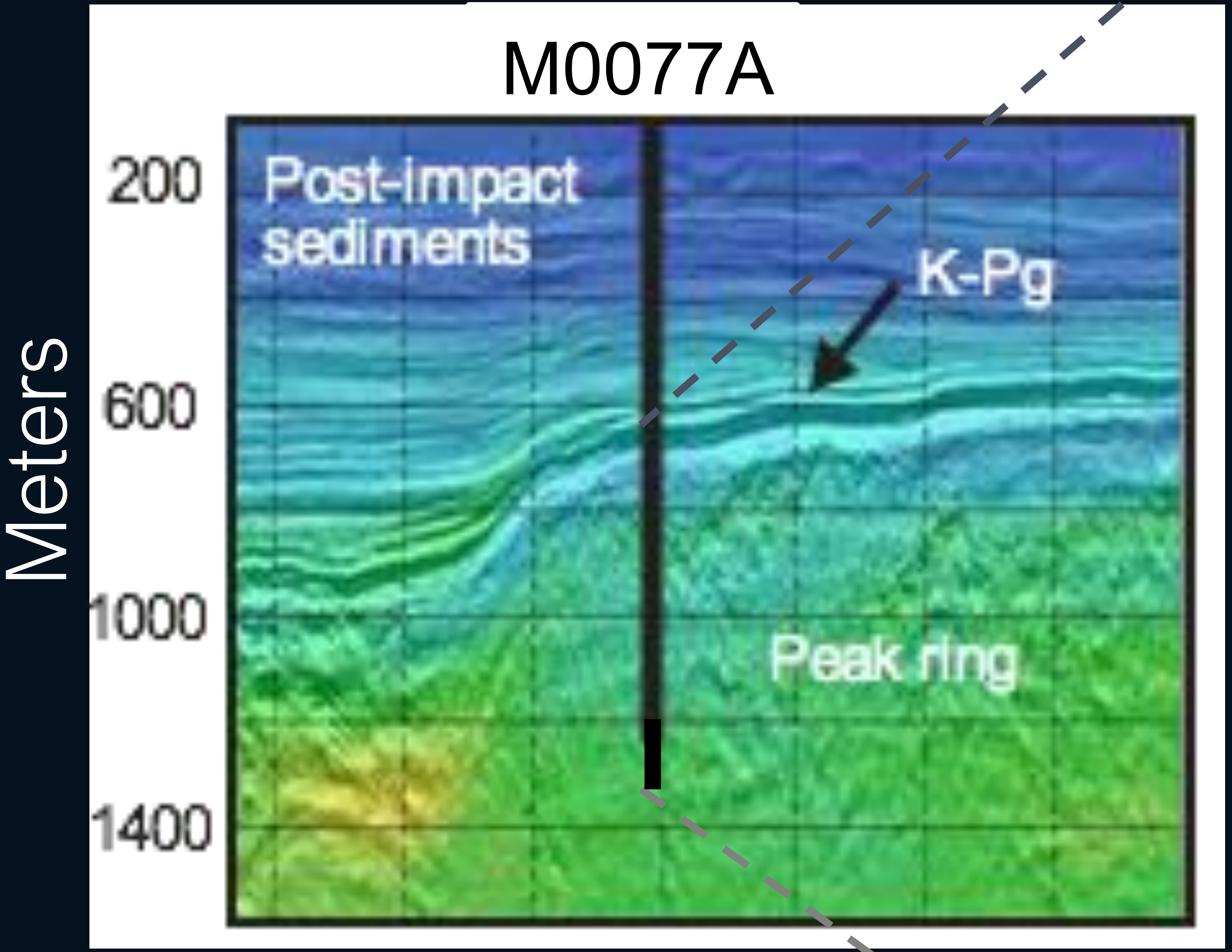
IODP Expedition 364:

Drilling the K-Pg Chicxulub Impact Crater

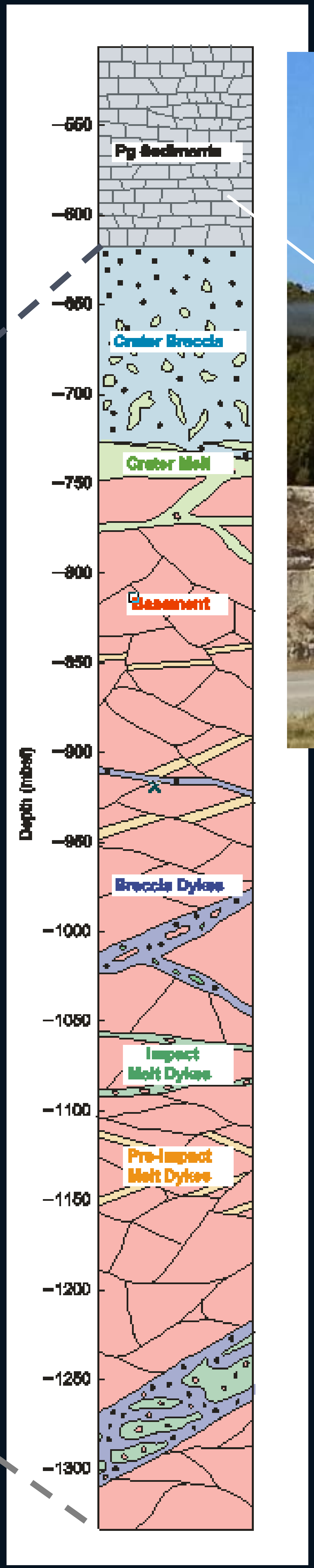


IODP-ICDP Expedition 364

- Core recovered from 503-1334.7 m
- The Chicxulub peak ring is formed from granitic basement covered by impact breccias and melt rocks

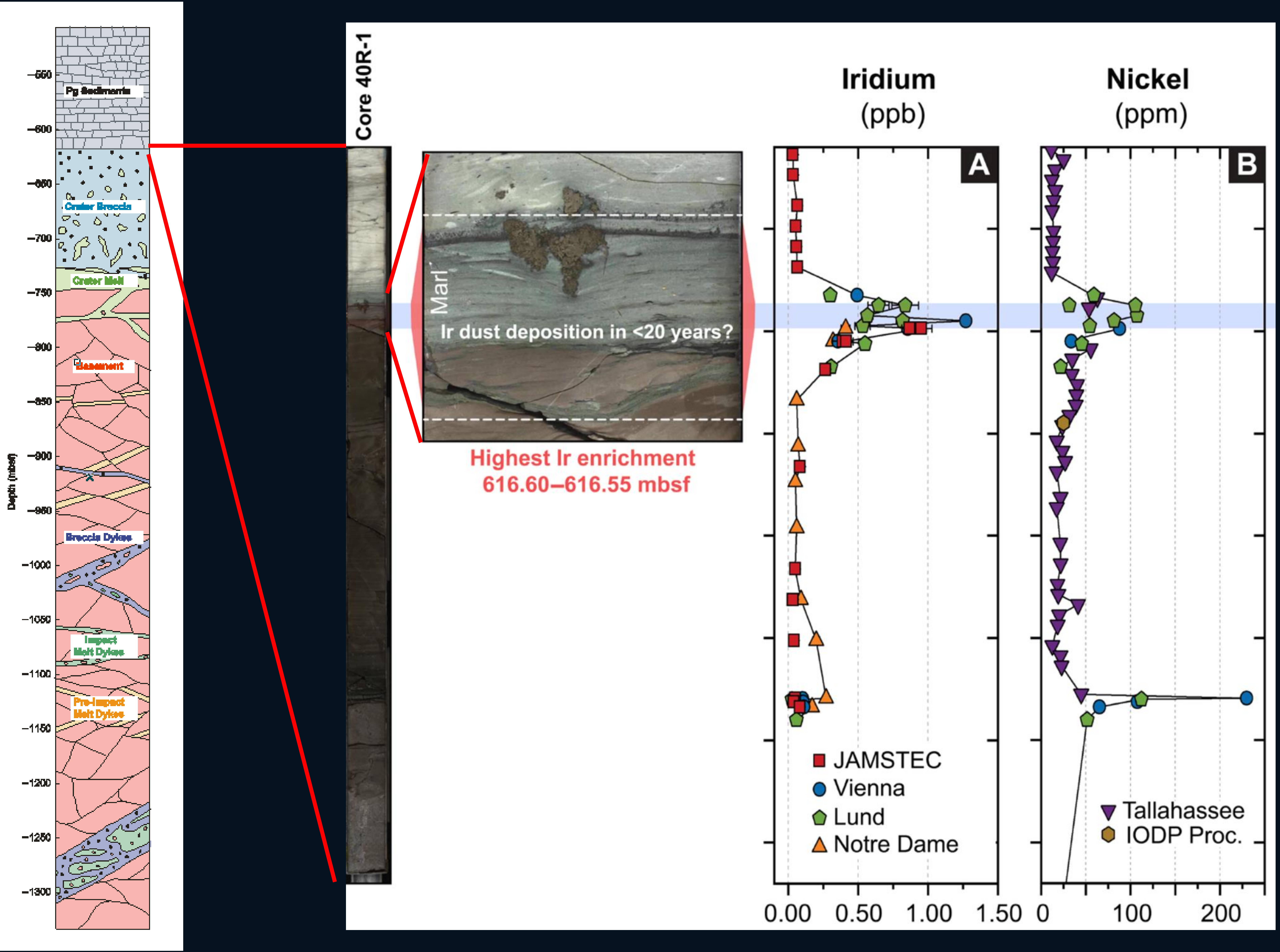


Morgan et al., 2011



Morgan et al., Science, 2016

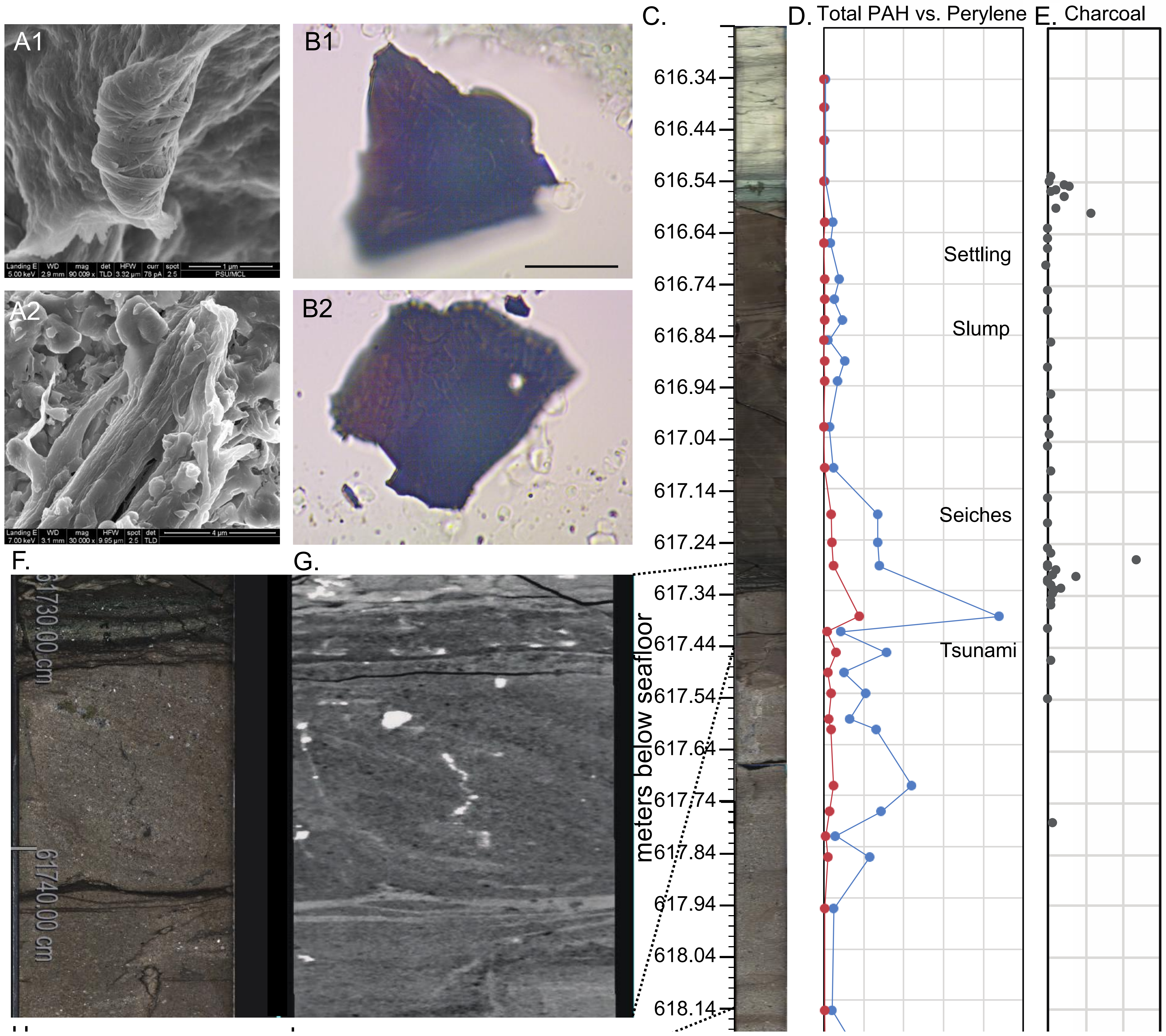
503-617 meters;
48-66 mill years

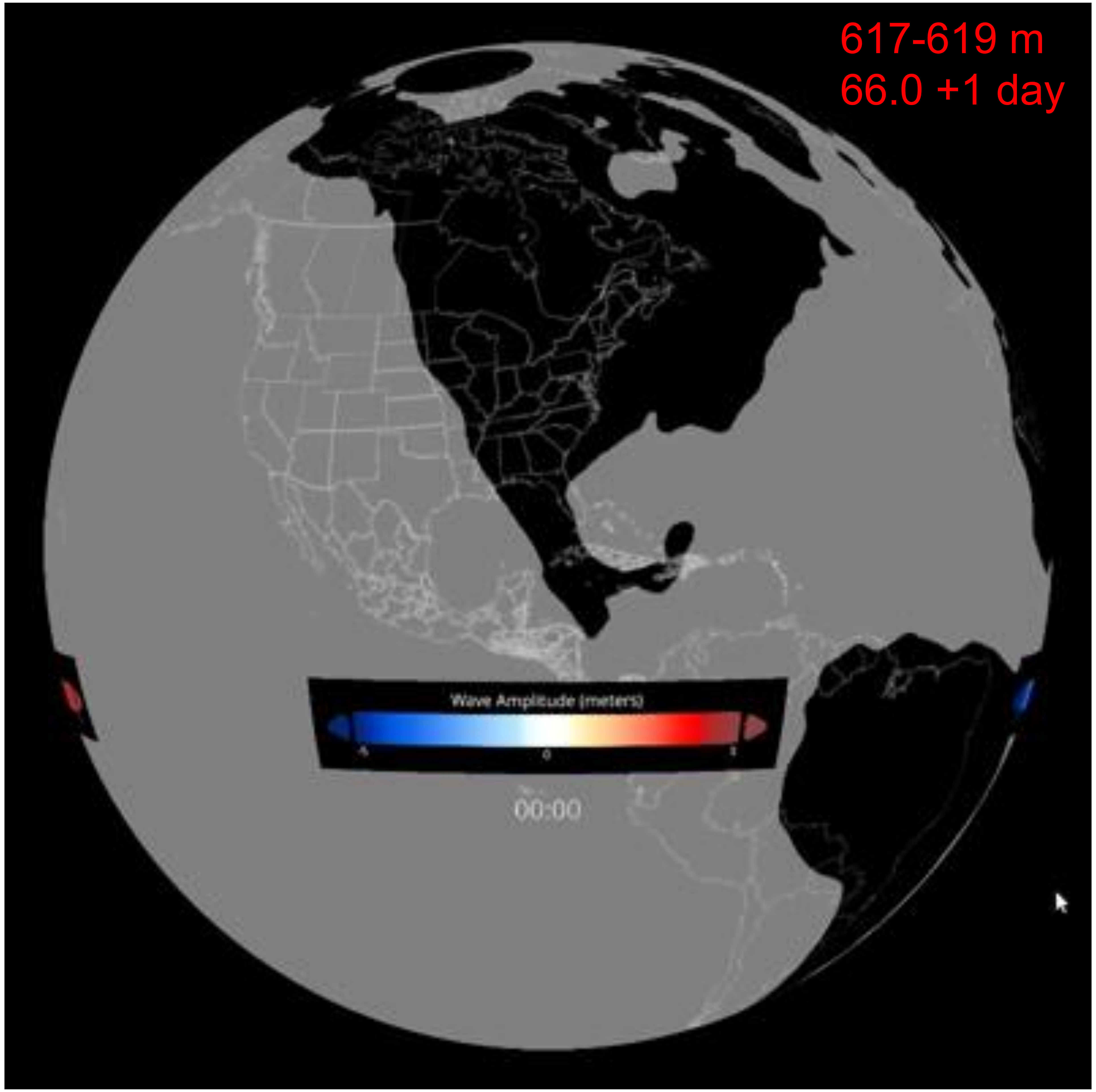


617-618 mbsf;
66.0 + 20 years

Goderis et al., 2021

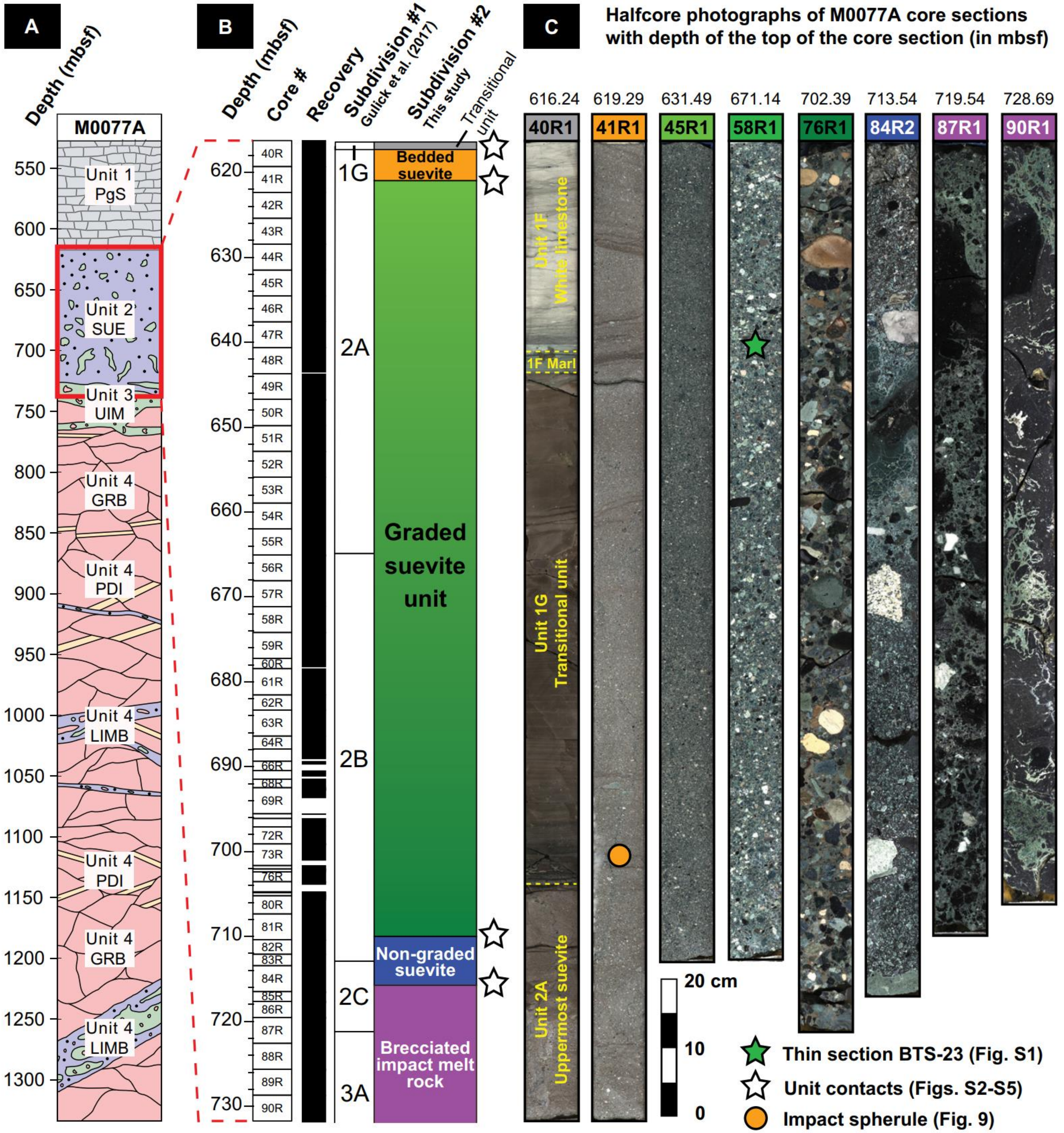
Range et al., 2022; Science on a Sphere Movie, NOAA



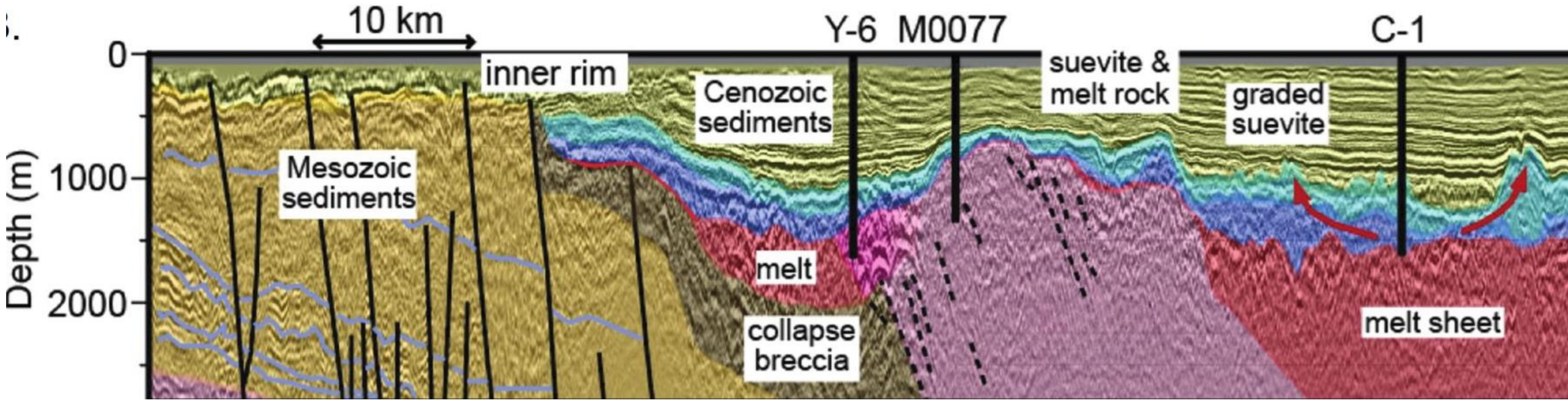


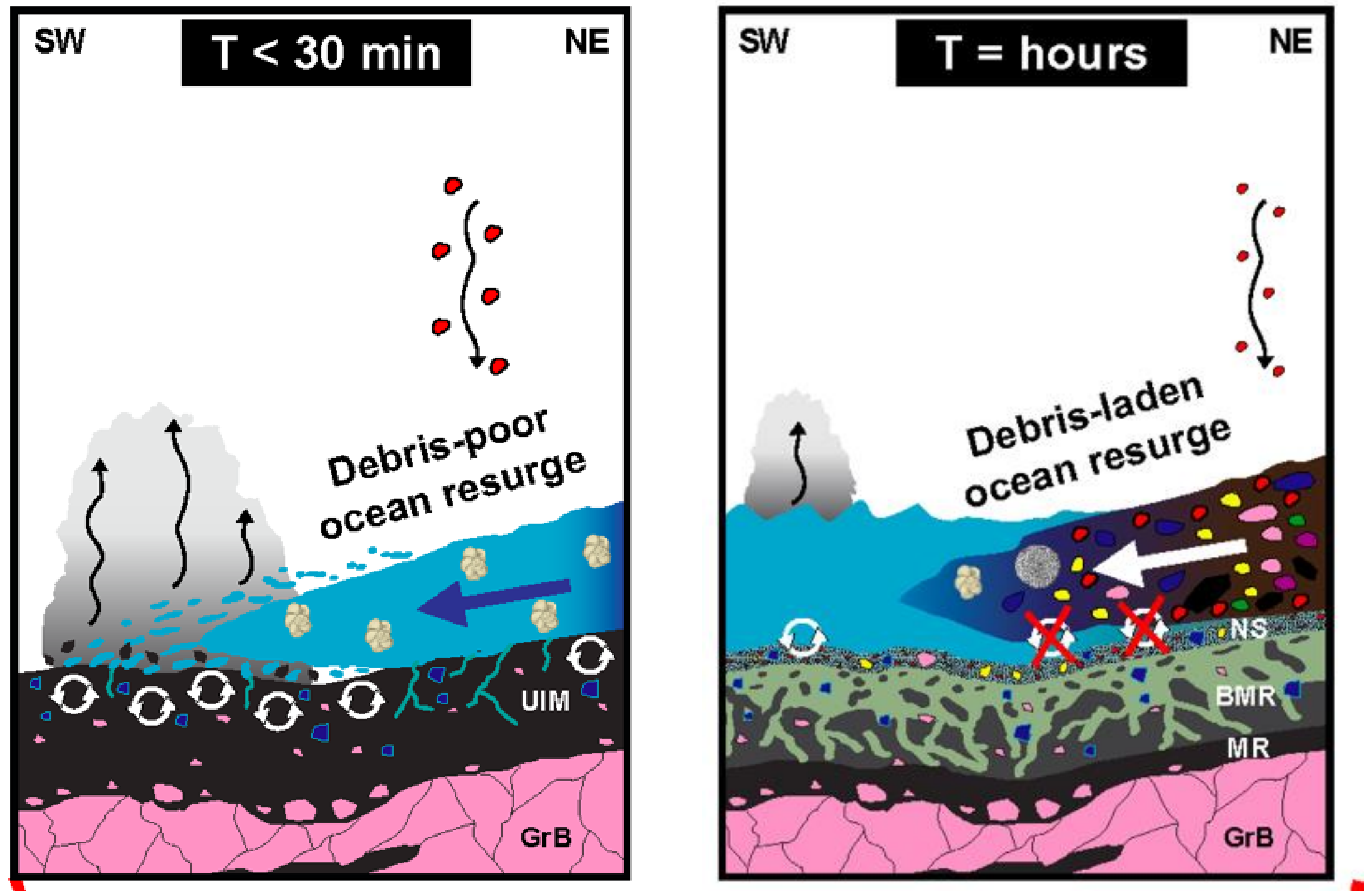
Gulick et al., PNAS, 2019

619-725 mbsf;
66.0 + minutes

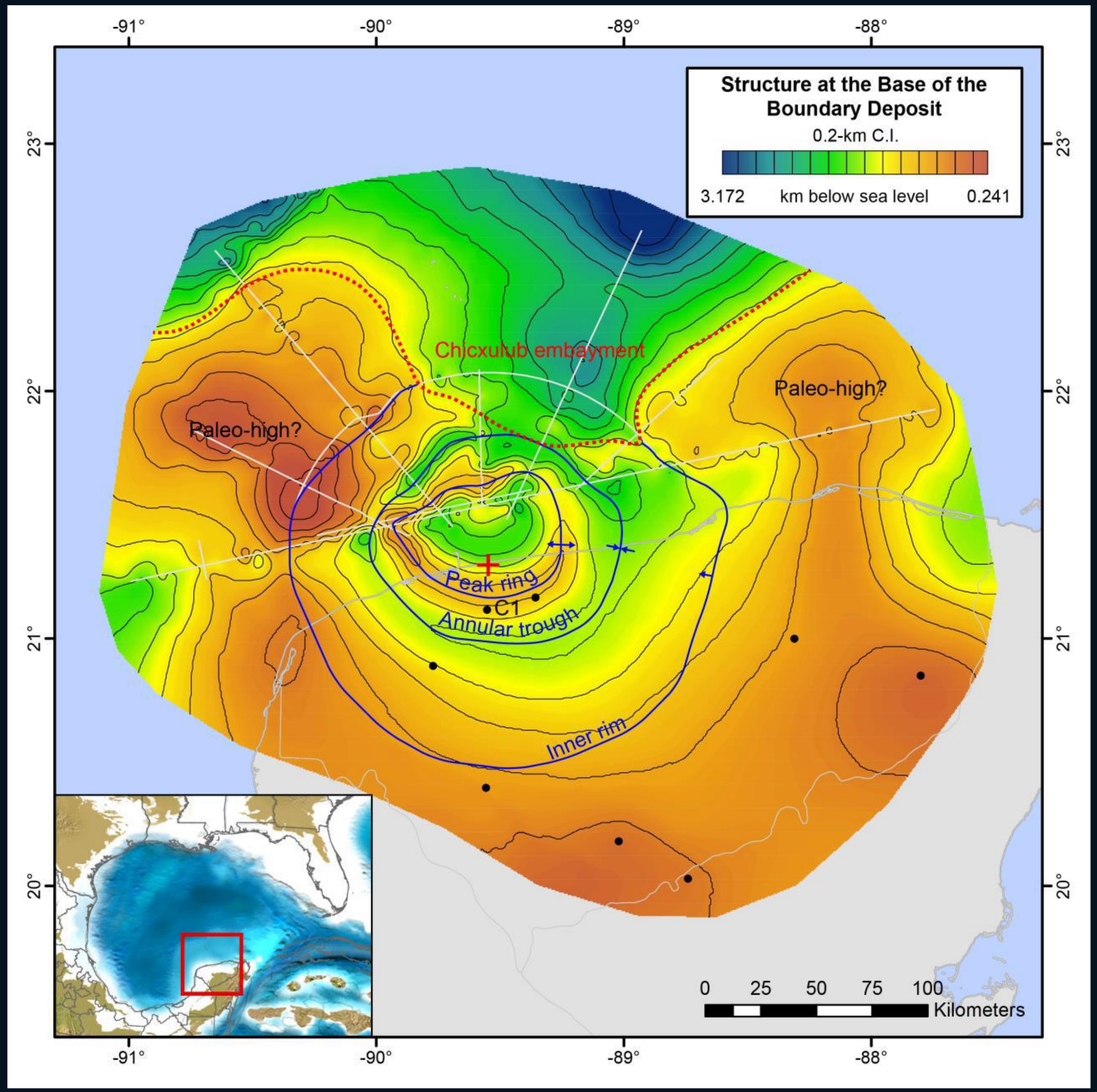


Kaskes et al., GSAB, 2021

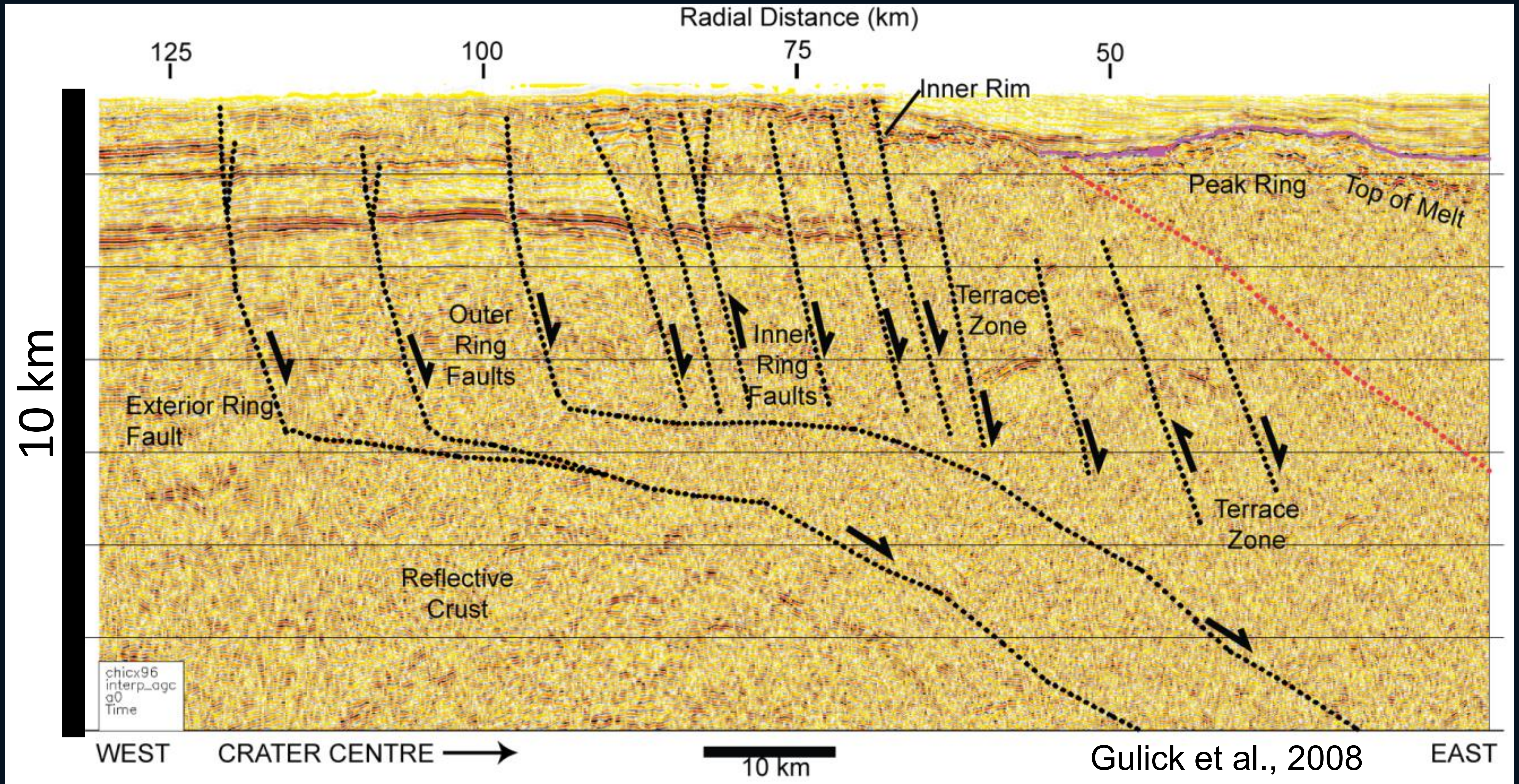




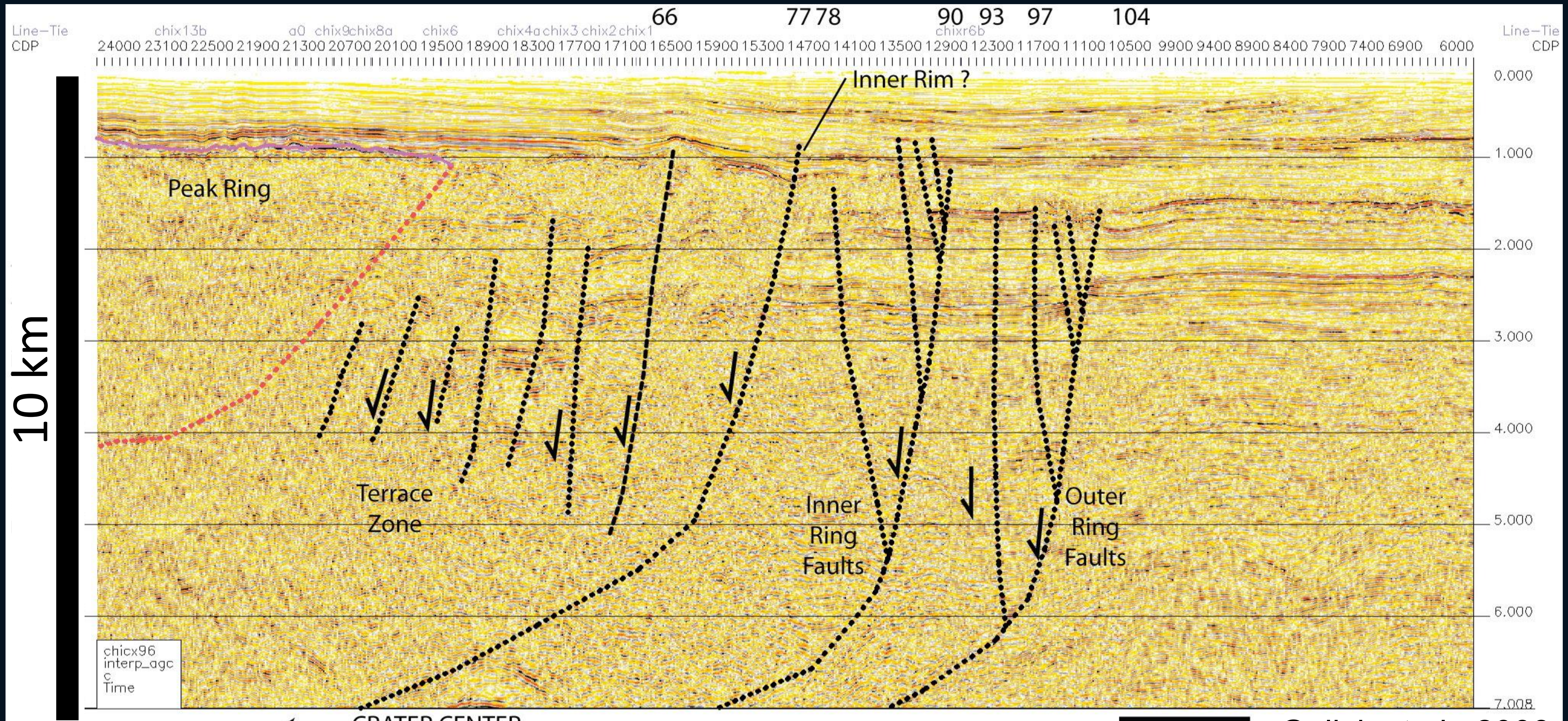
Gulick et al., Mar Geo, in press



Sanford et al., JGR 2016

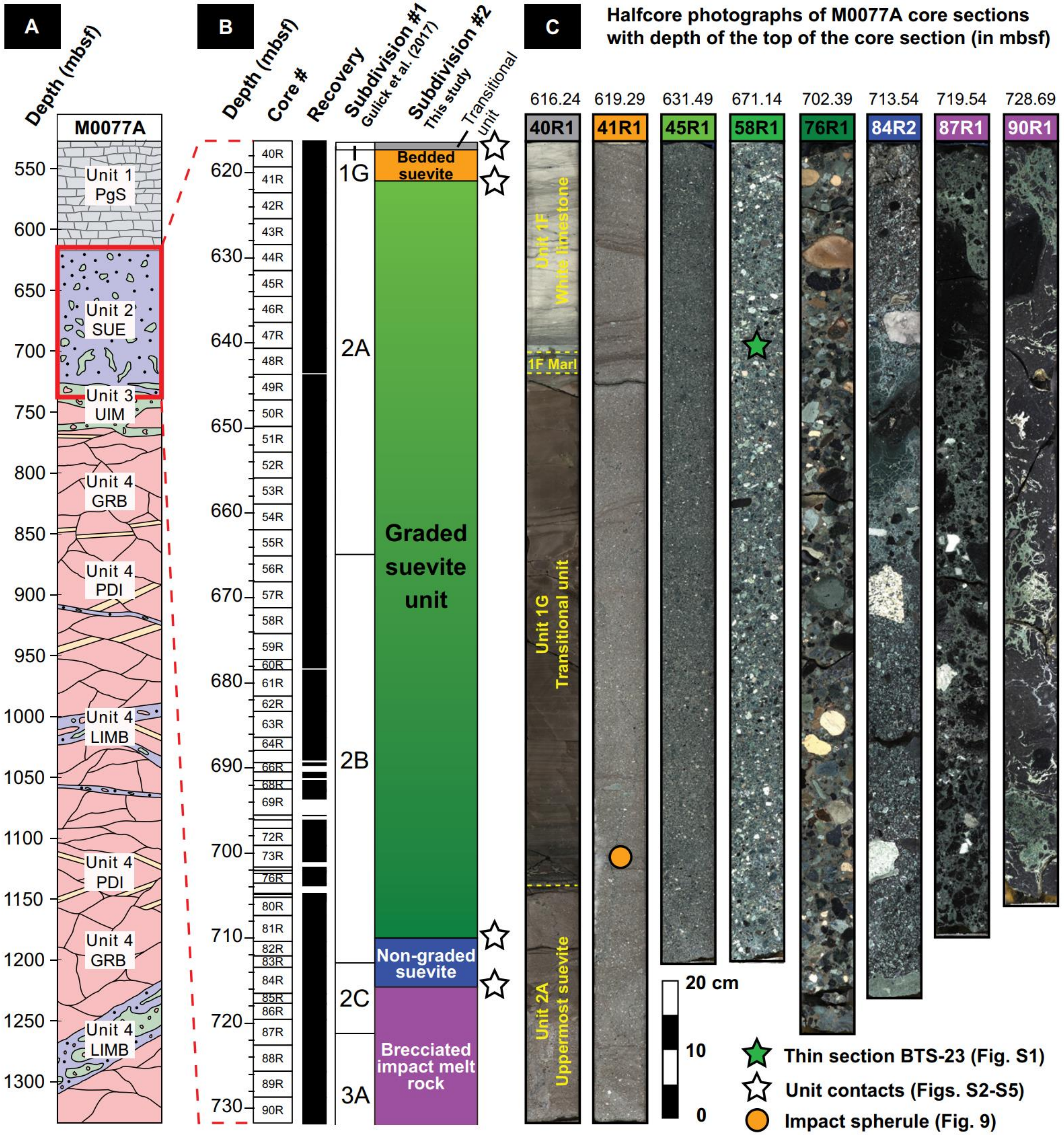


Gulick et al., 2008

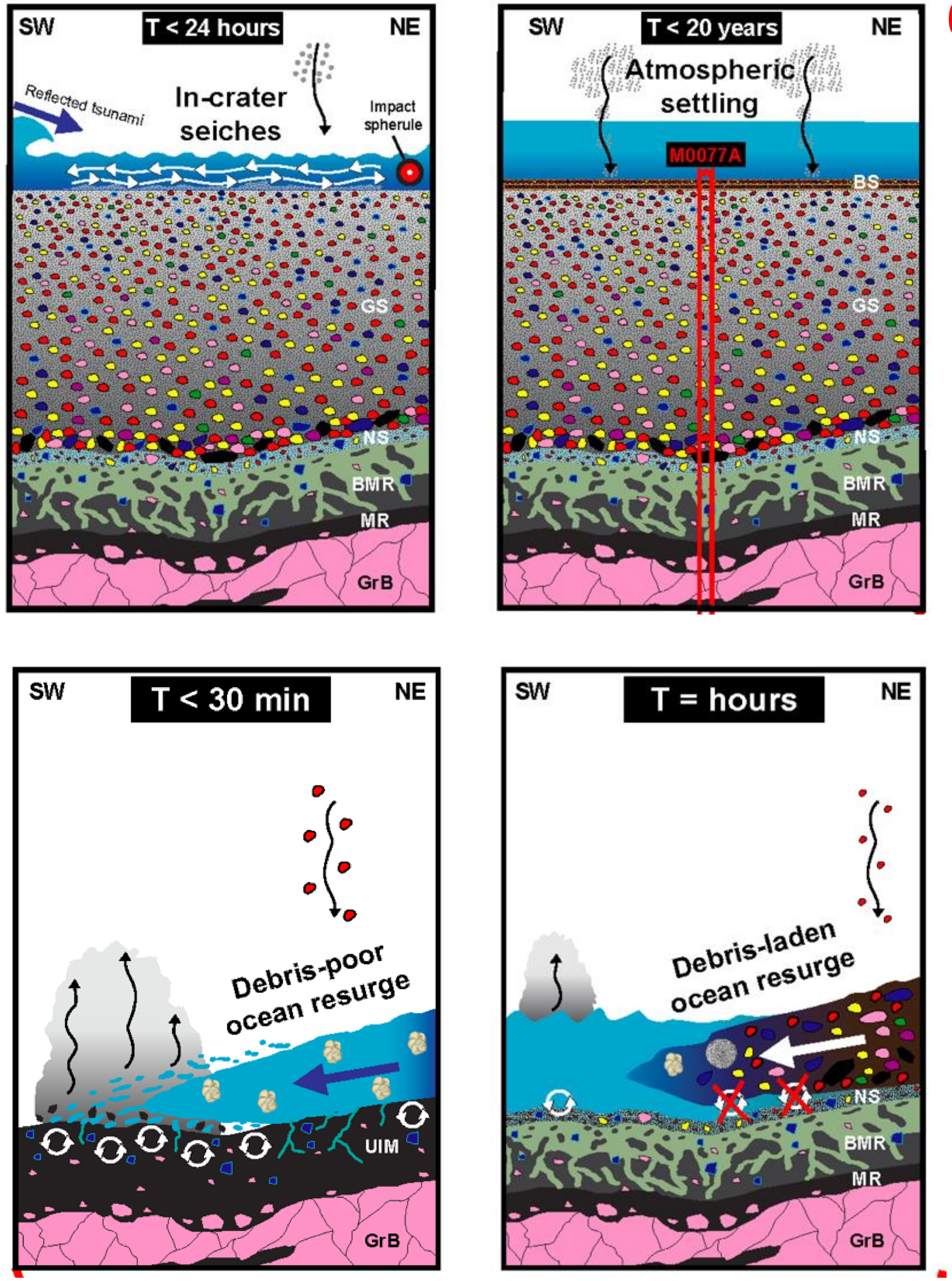


Gulick et al., 2008

619-725 mbsf;
66.0 + minutes

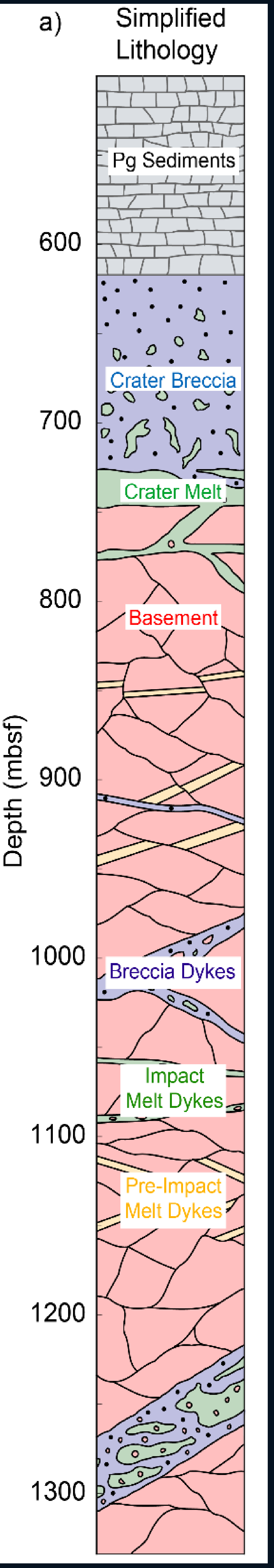


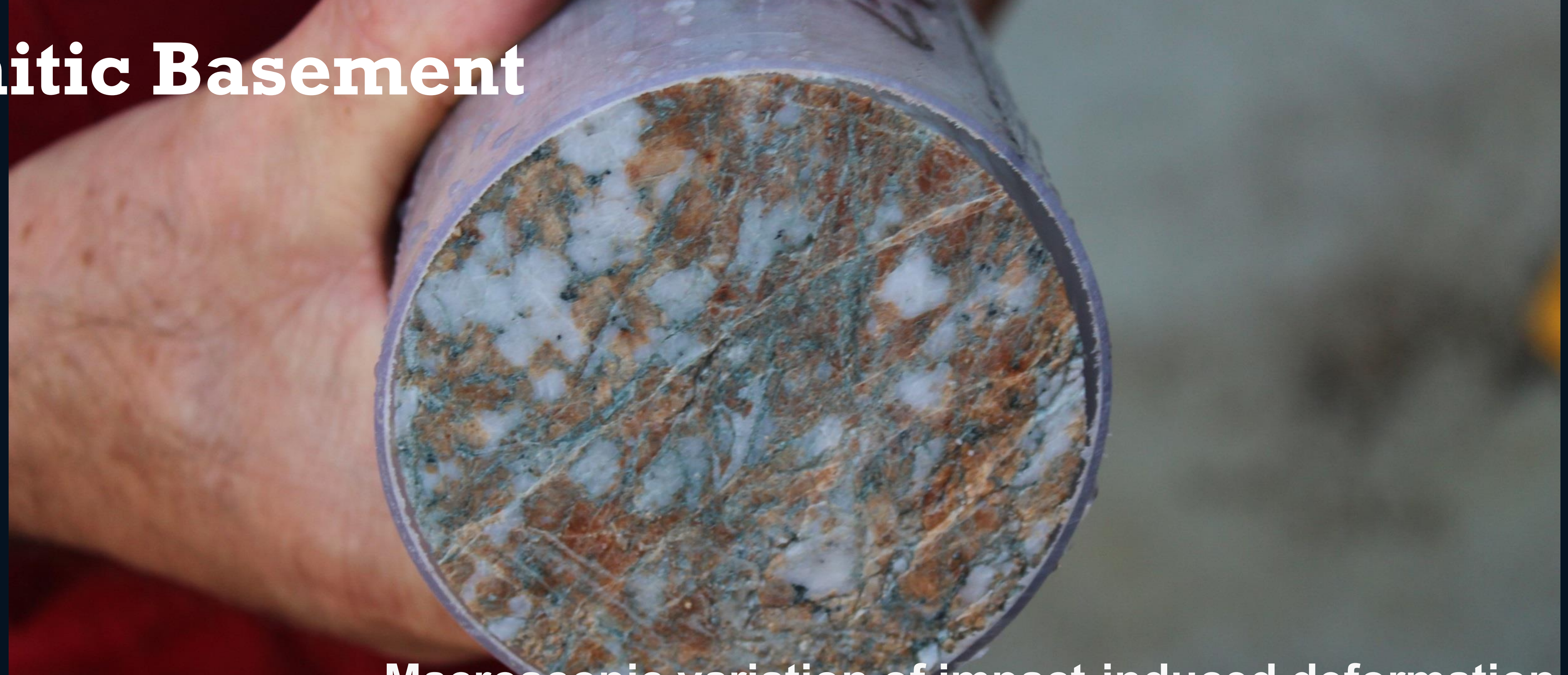
Kaskes et al., GSAB, 2021



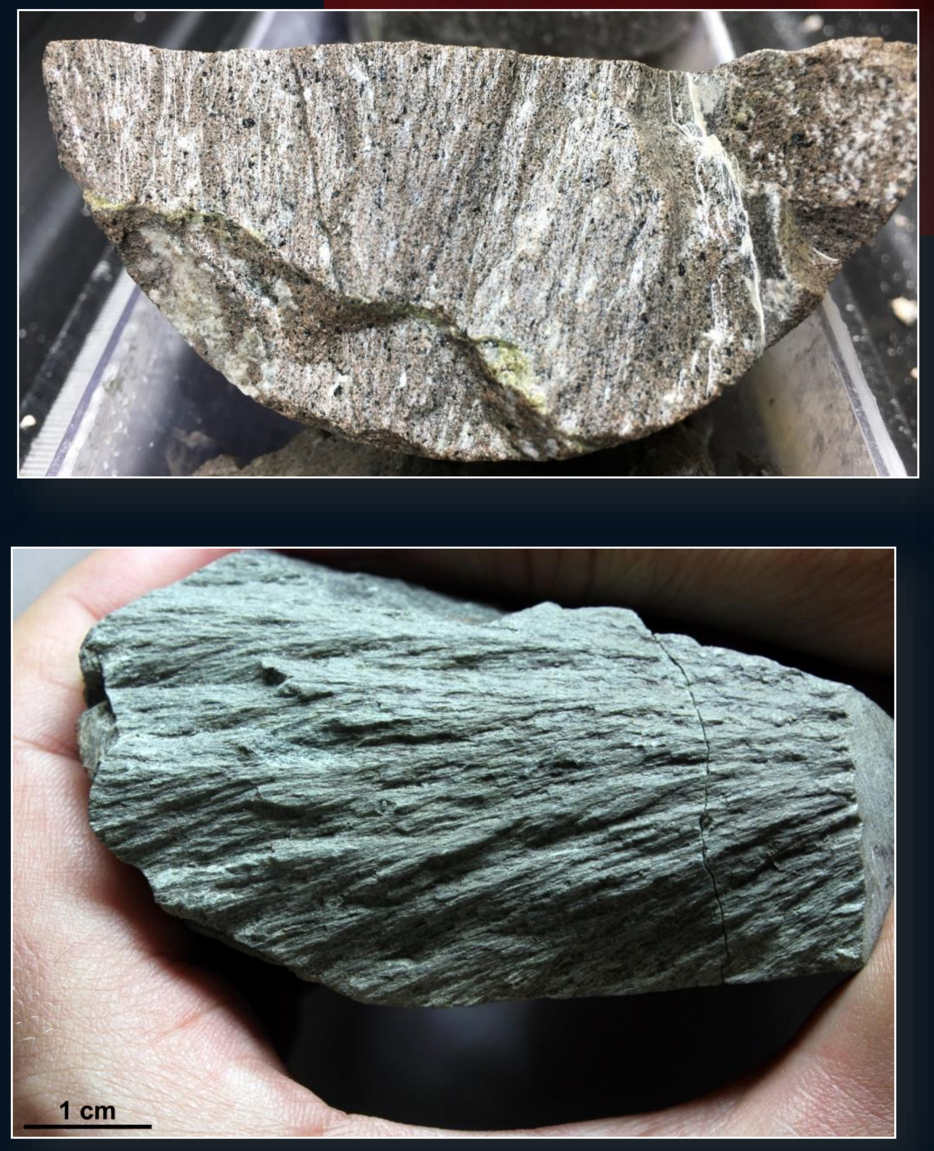
Gulick et al., Mar Geo, in press

Granitic Basement

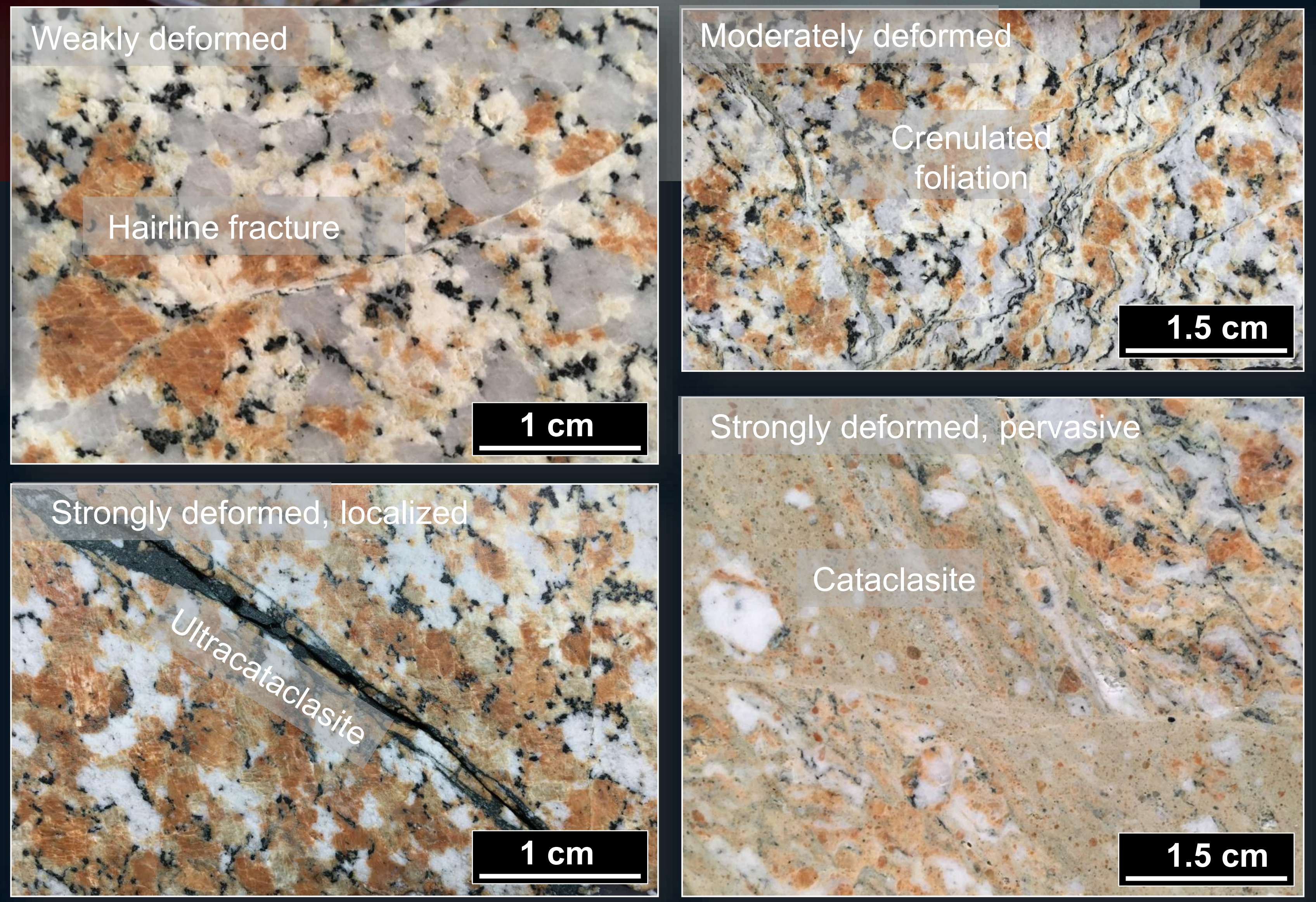




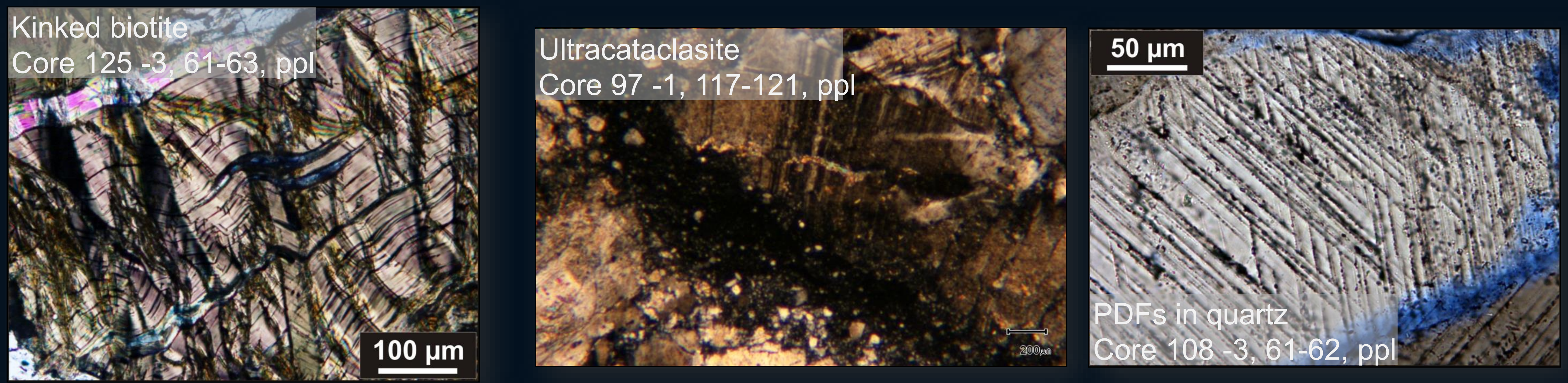
Shatter cones

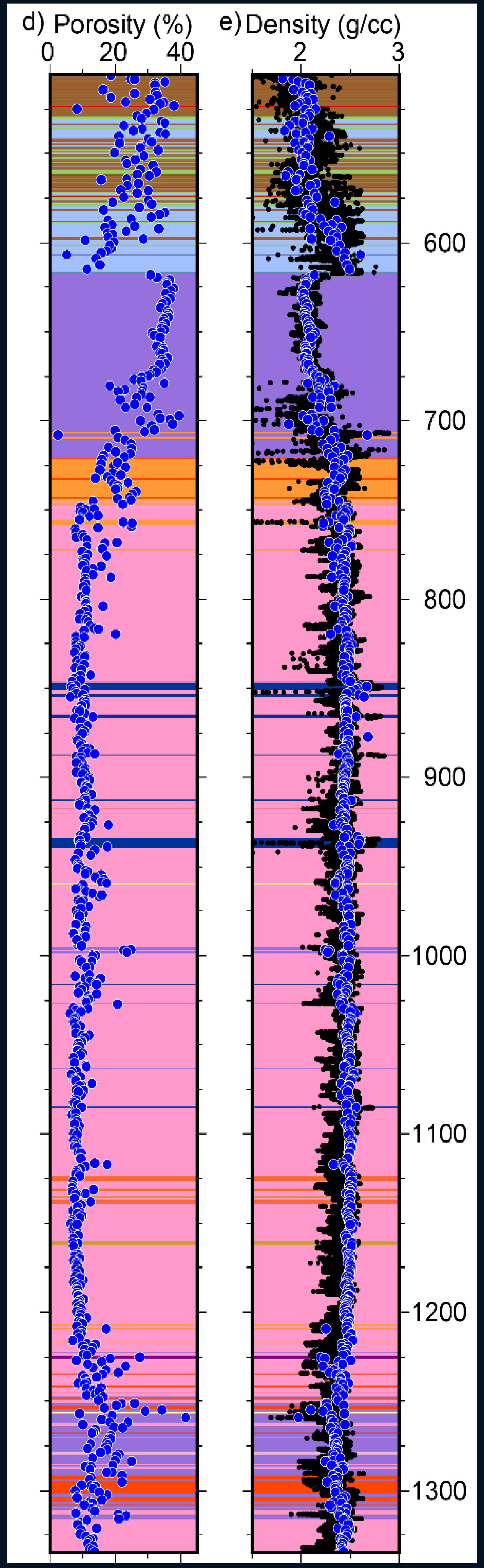


Macroscopic variation of impact-induced deformation



Microscopic variation of impact-induced deformation

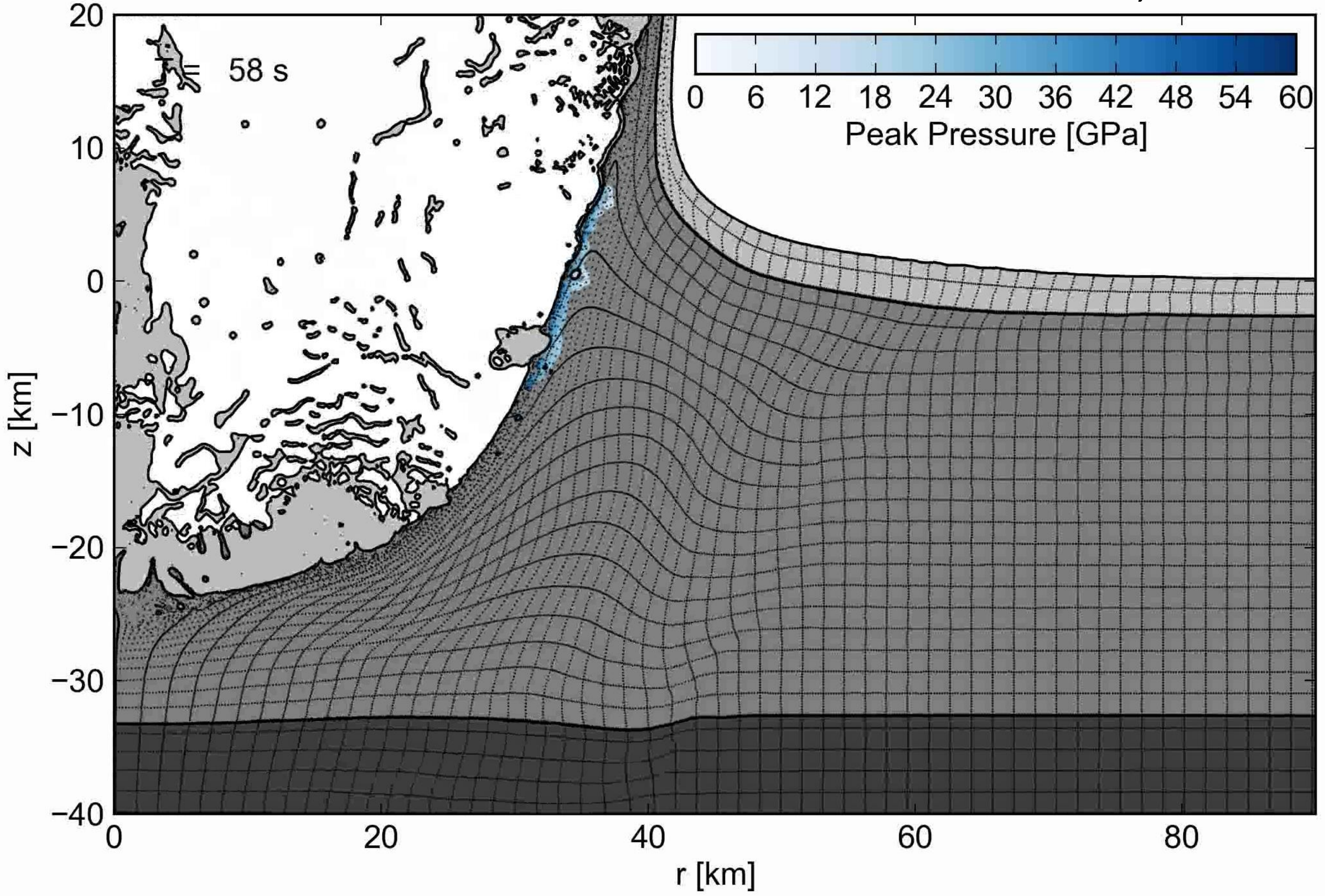




Christeson et al., EPSL 2018

Objective 1: Impacts cause target rocks to flow and resurface planets

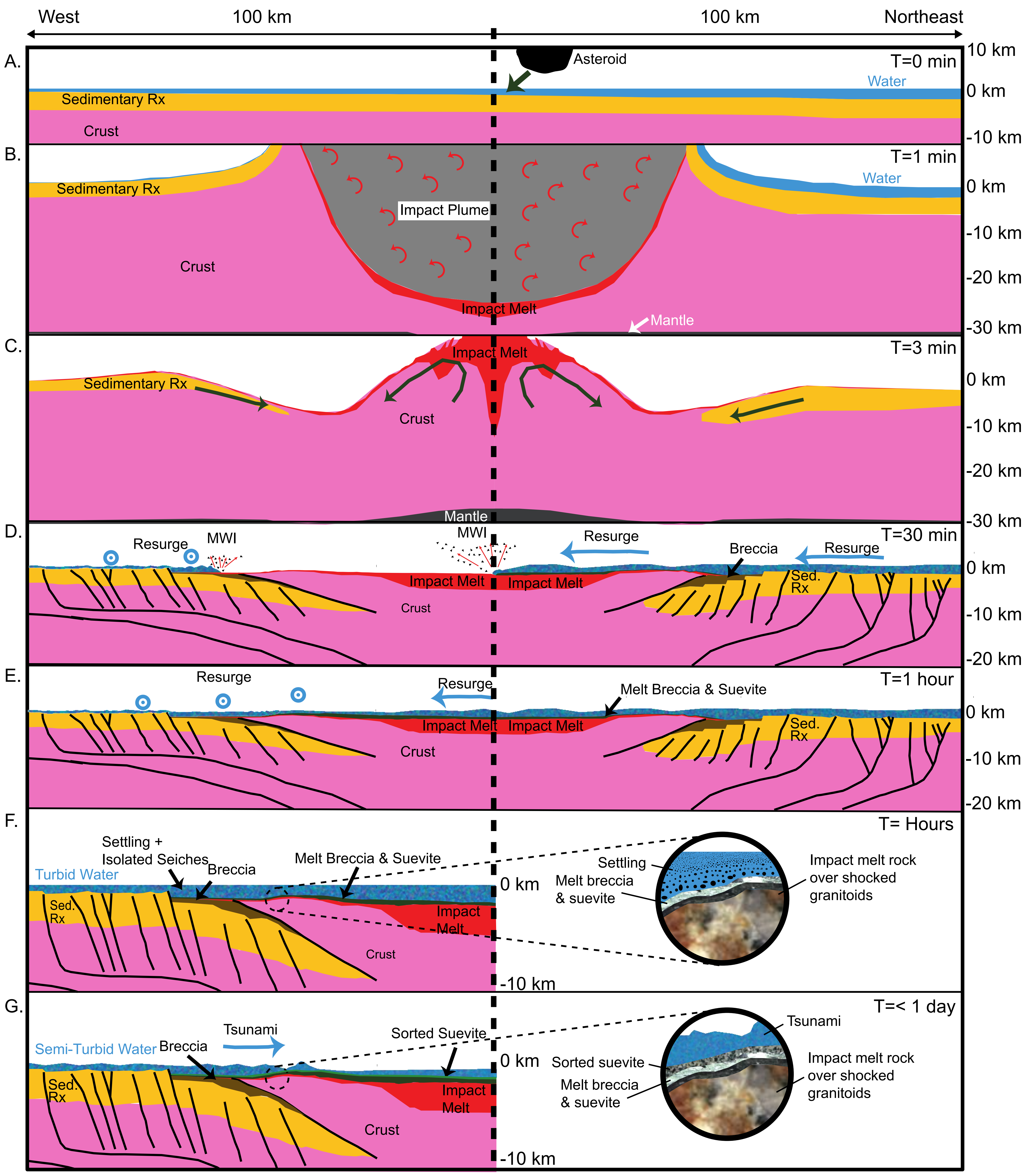
Morgan et al., Science, November, 2016



Energy= 10 Billion X WWII Nuclear Bomb

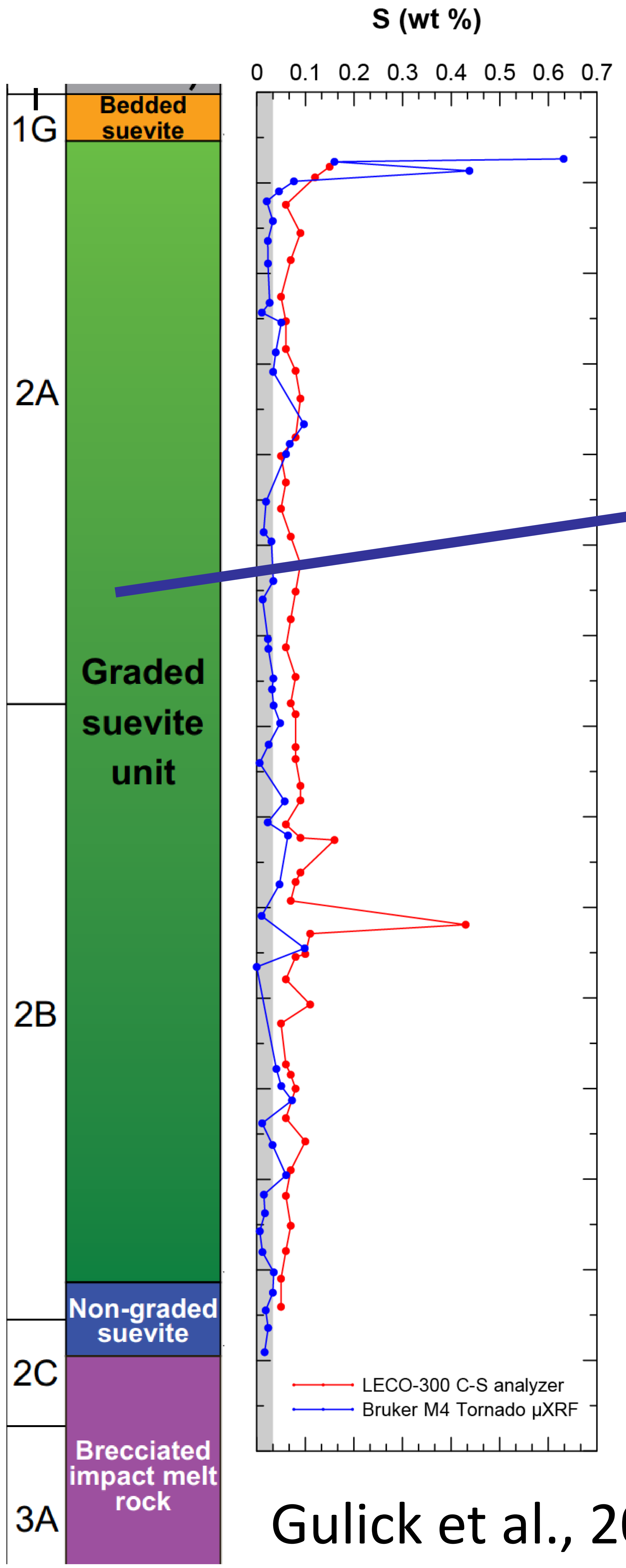
Earthquakes = Mw11

Tsunami = 1500 m high at site…

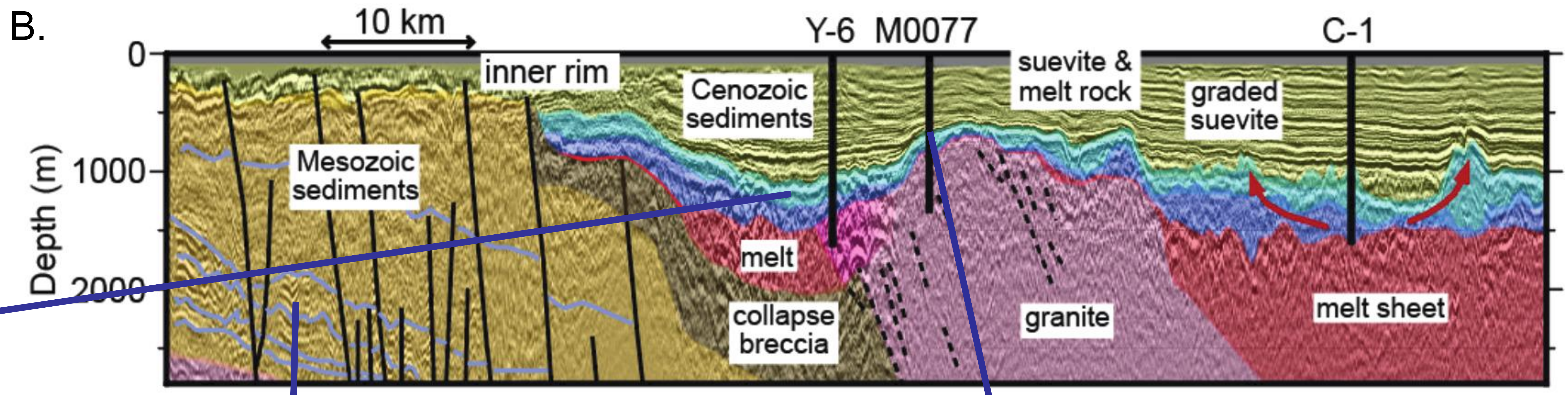


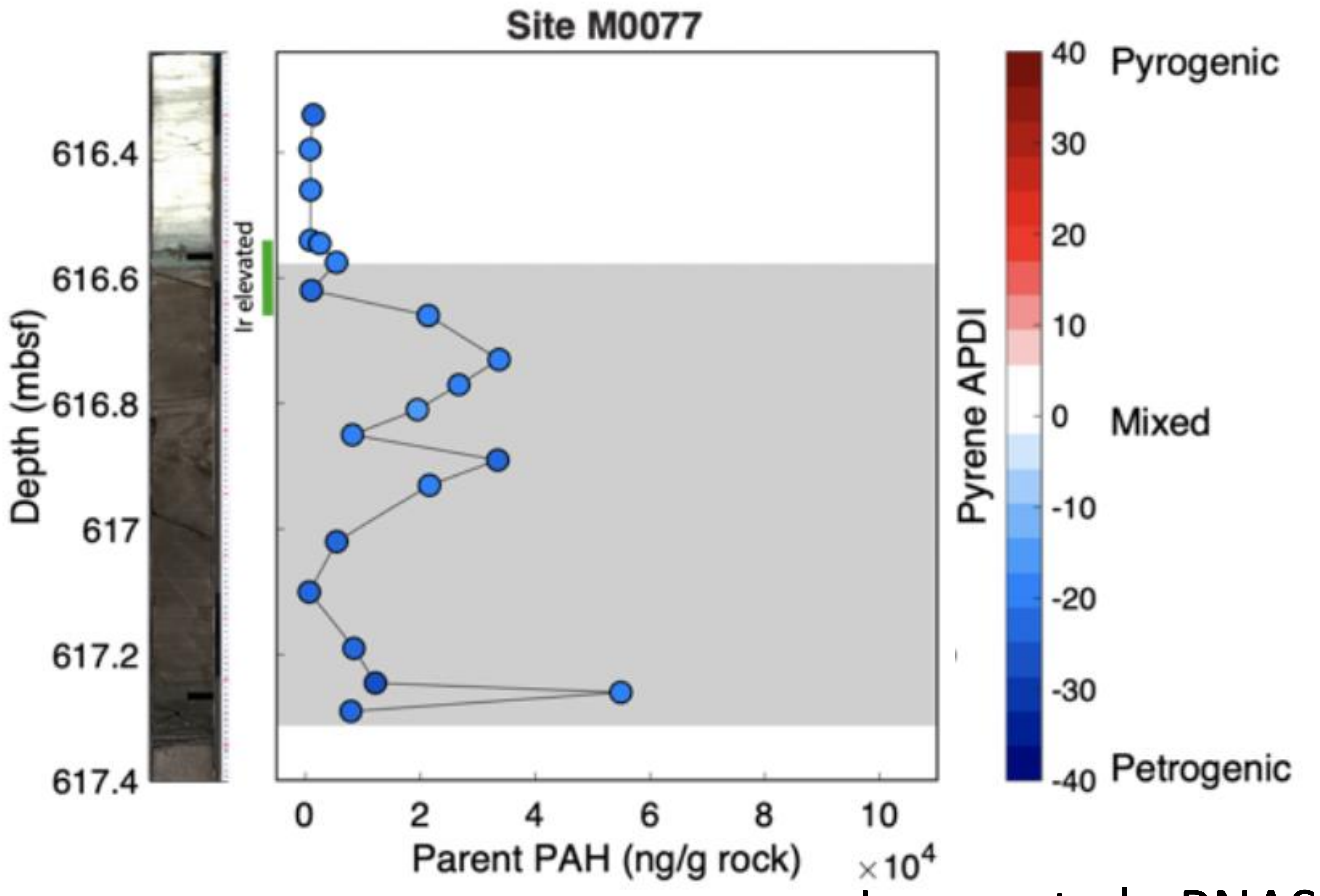
Gulick et al., PNAS, 2019

Obj. 2: Core data & modeling suggest impact winter driven sulfate aerosols, carbonate dust, and soot



Gulick et al., 2019





Lyons et al., PNAS, 2020

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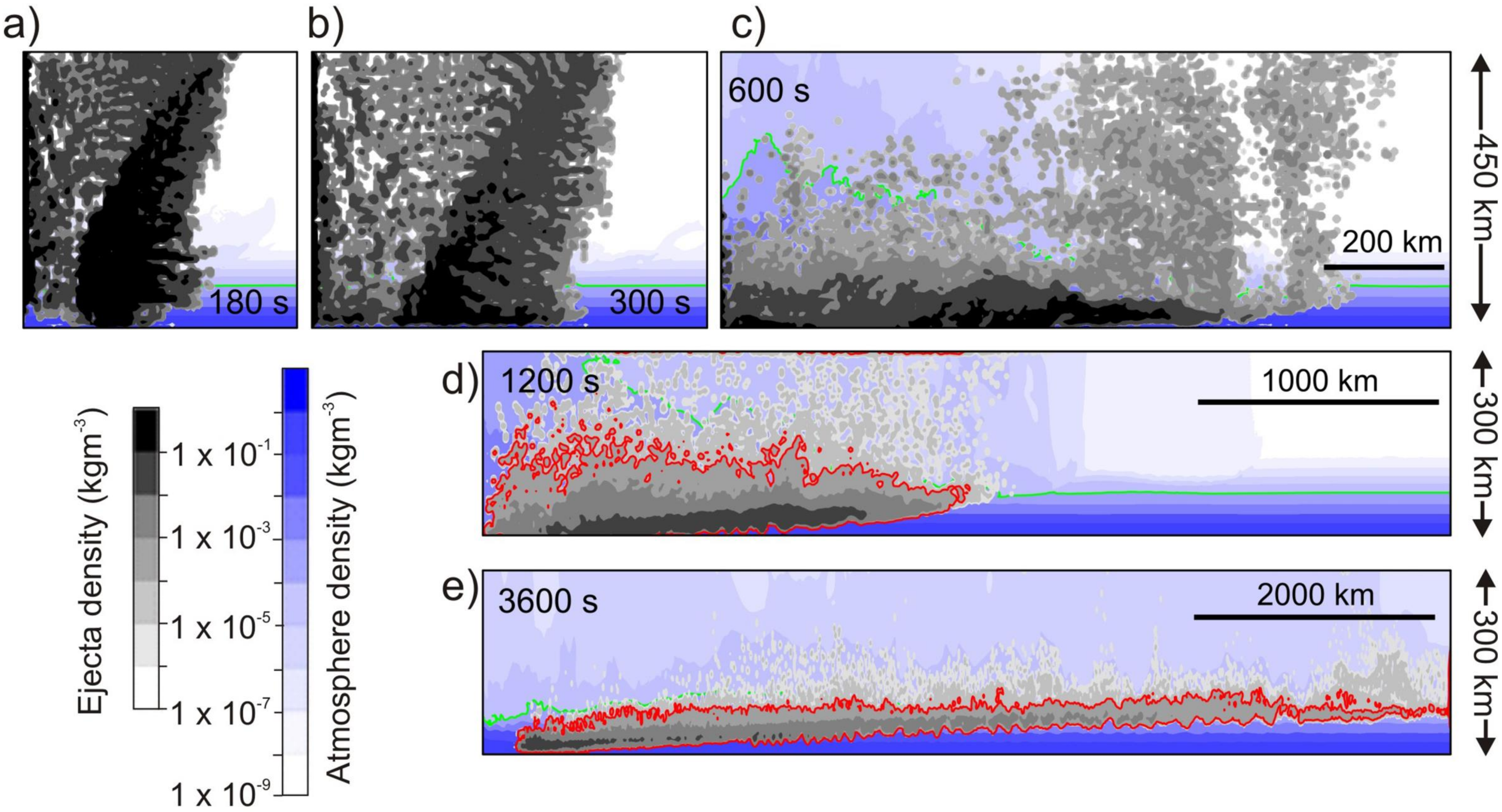
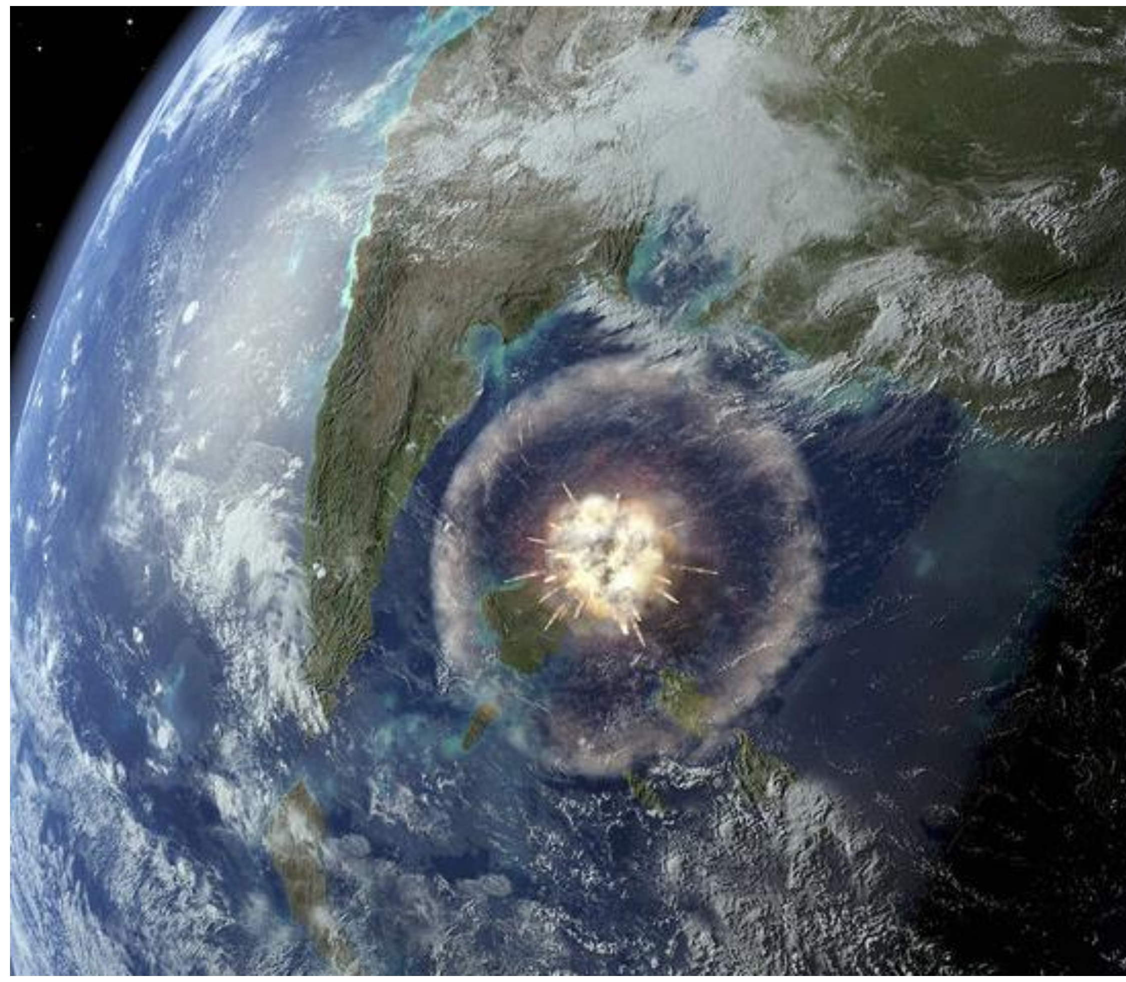
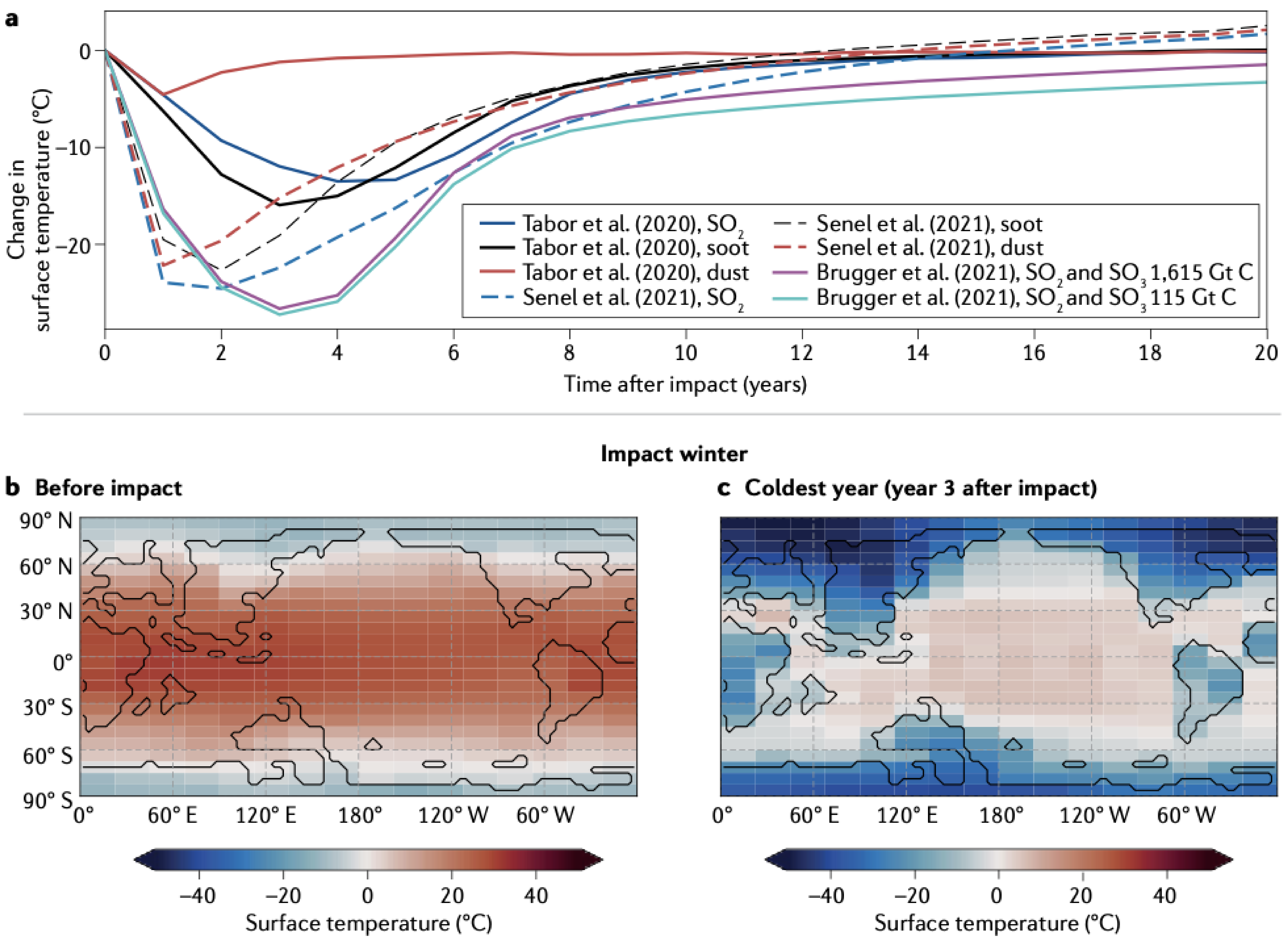




Artemieva & Morgan, GRL, 2020



Morgan et al., 2022

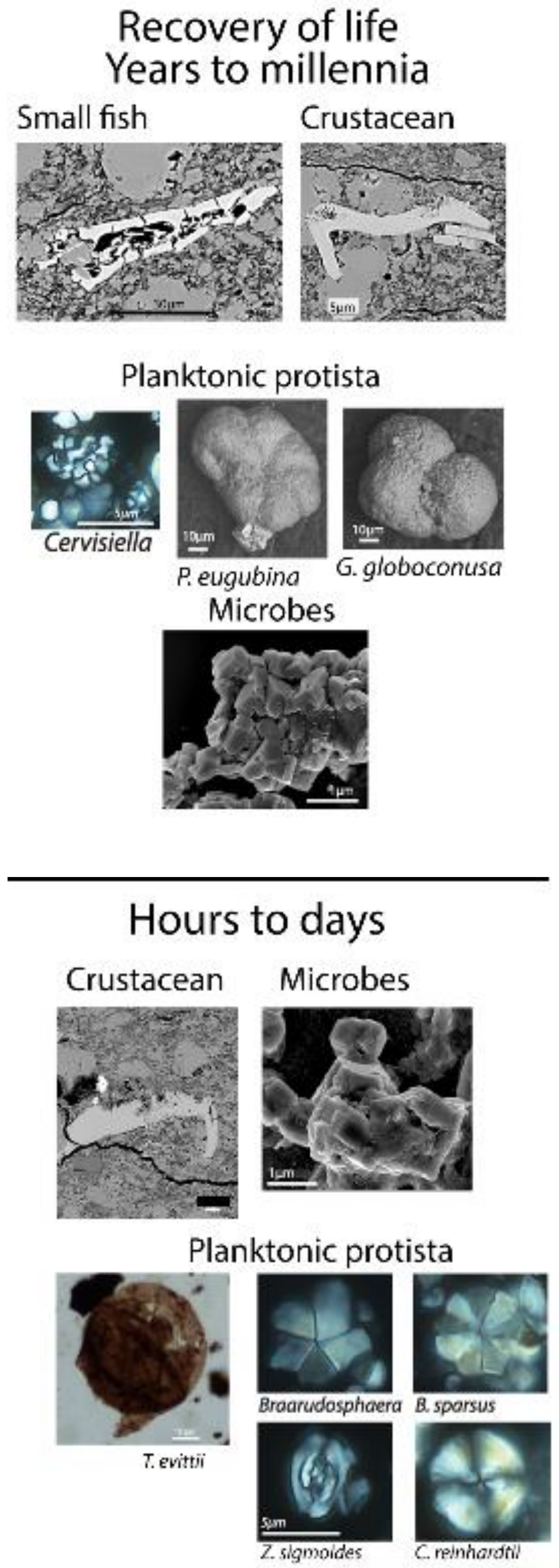
Key Questions:
Dust grain size, chemistry, density

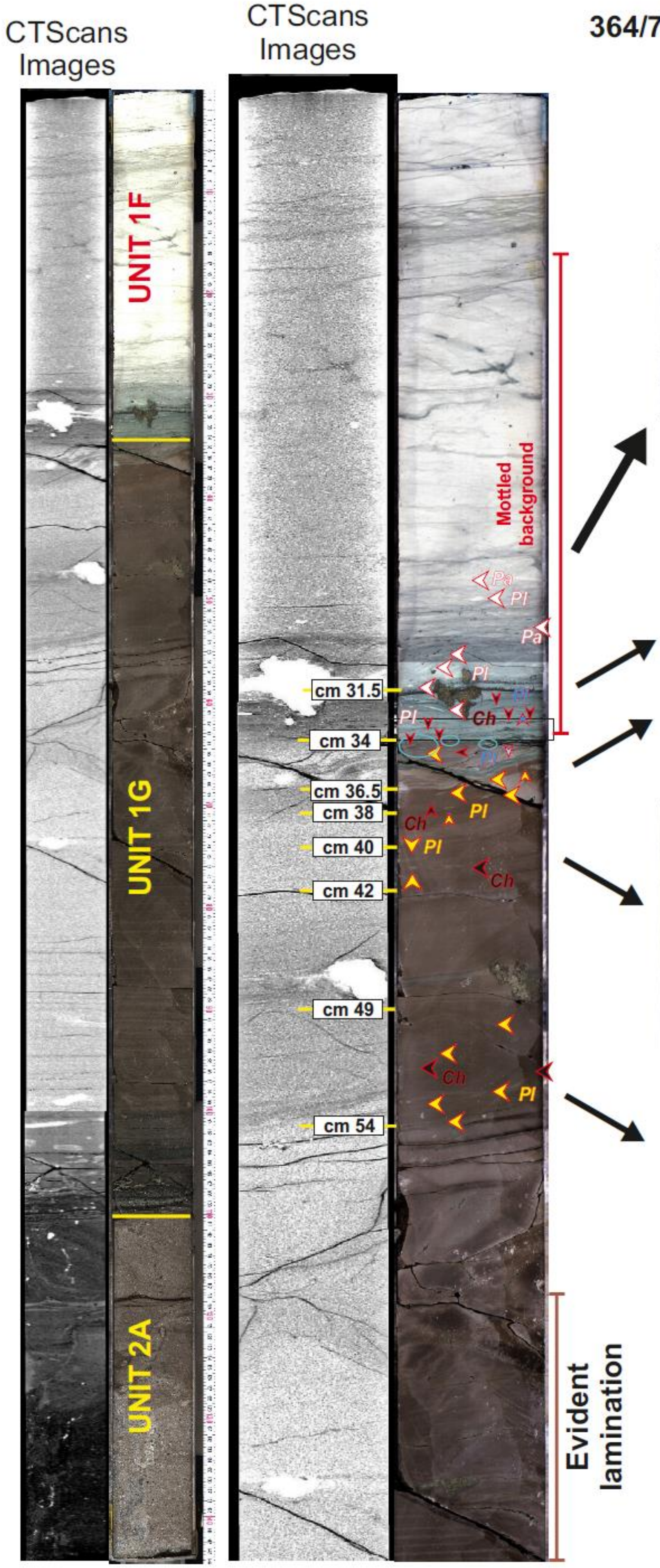
Sulfur species

Combined effects

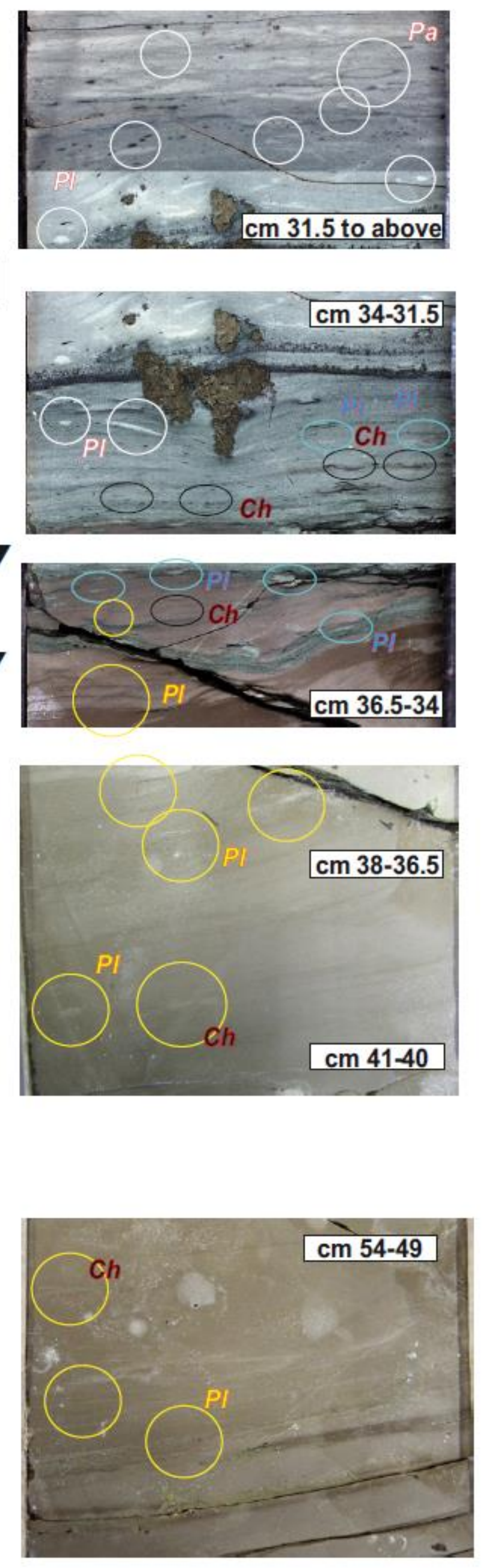
Transition Unit to Kyr: survivor species, trace fossils, algal biomarkers, Danian forams

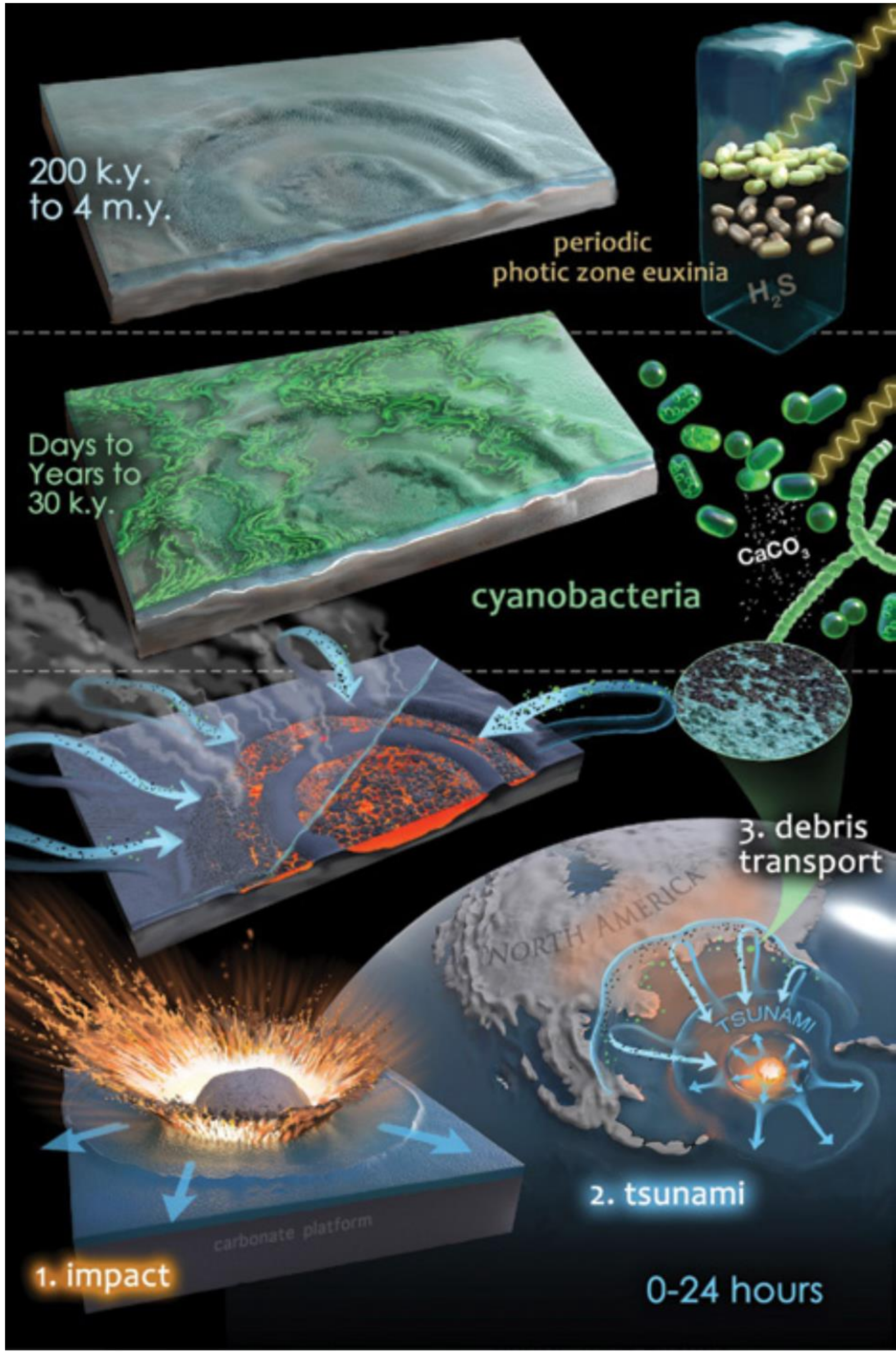
Lowery et al., Nat., 2018;
Jones et al., Geol., 2019;
Tovar et al., Geol., 2020;
Bralower, AGU Adv., 2020

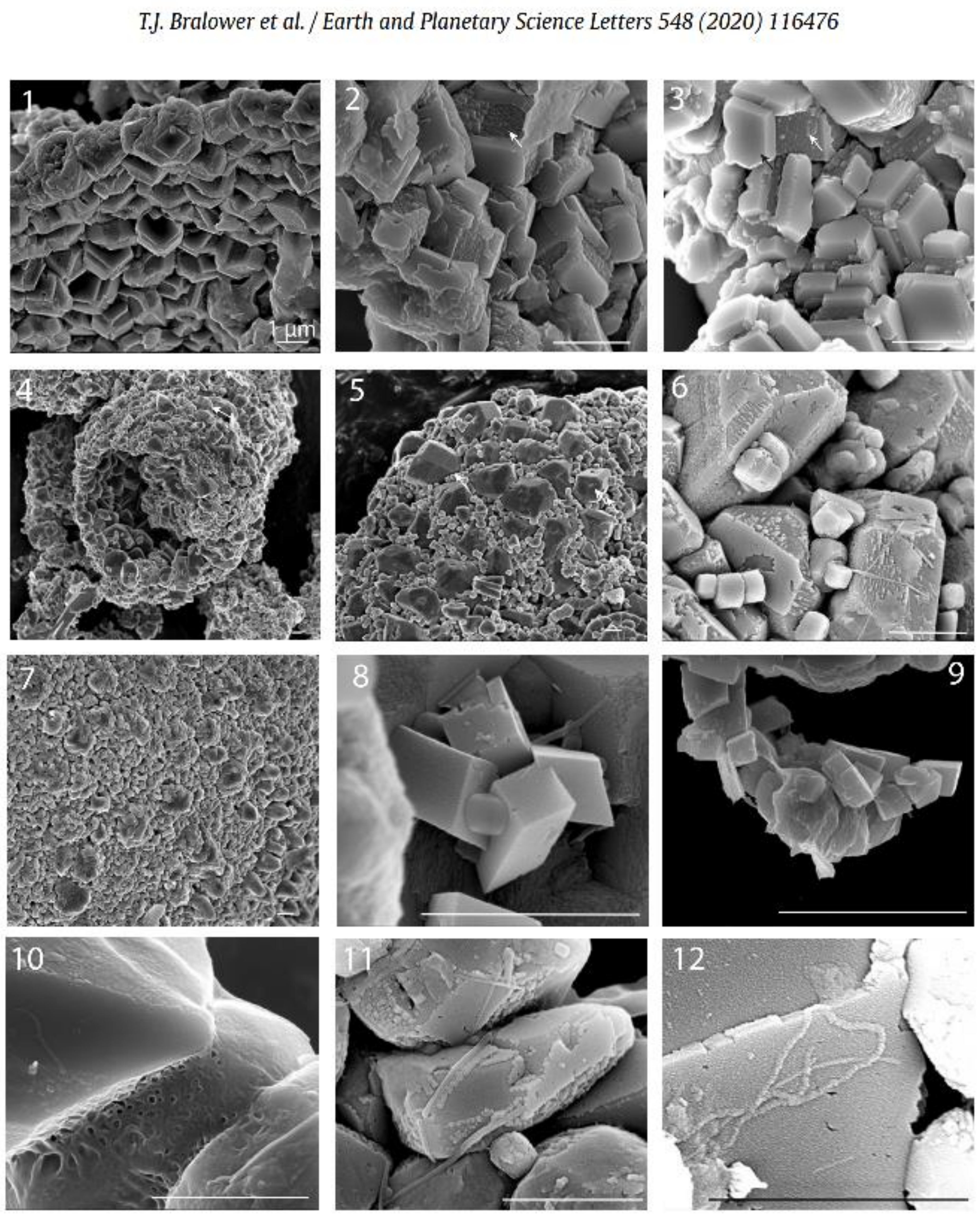




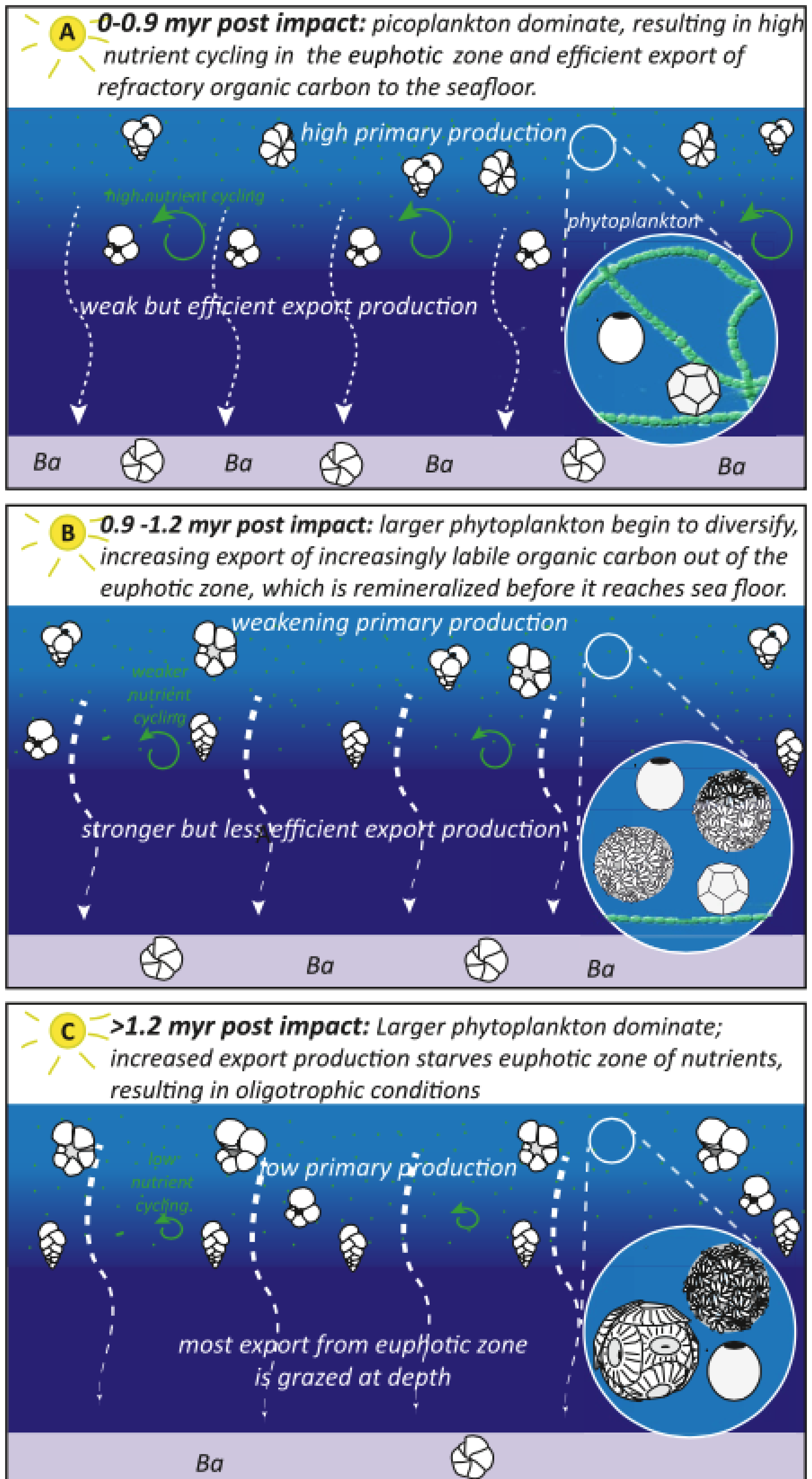
Schaeffer et al., Geol., 2020







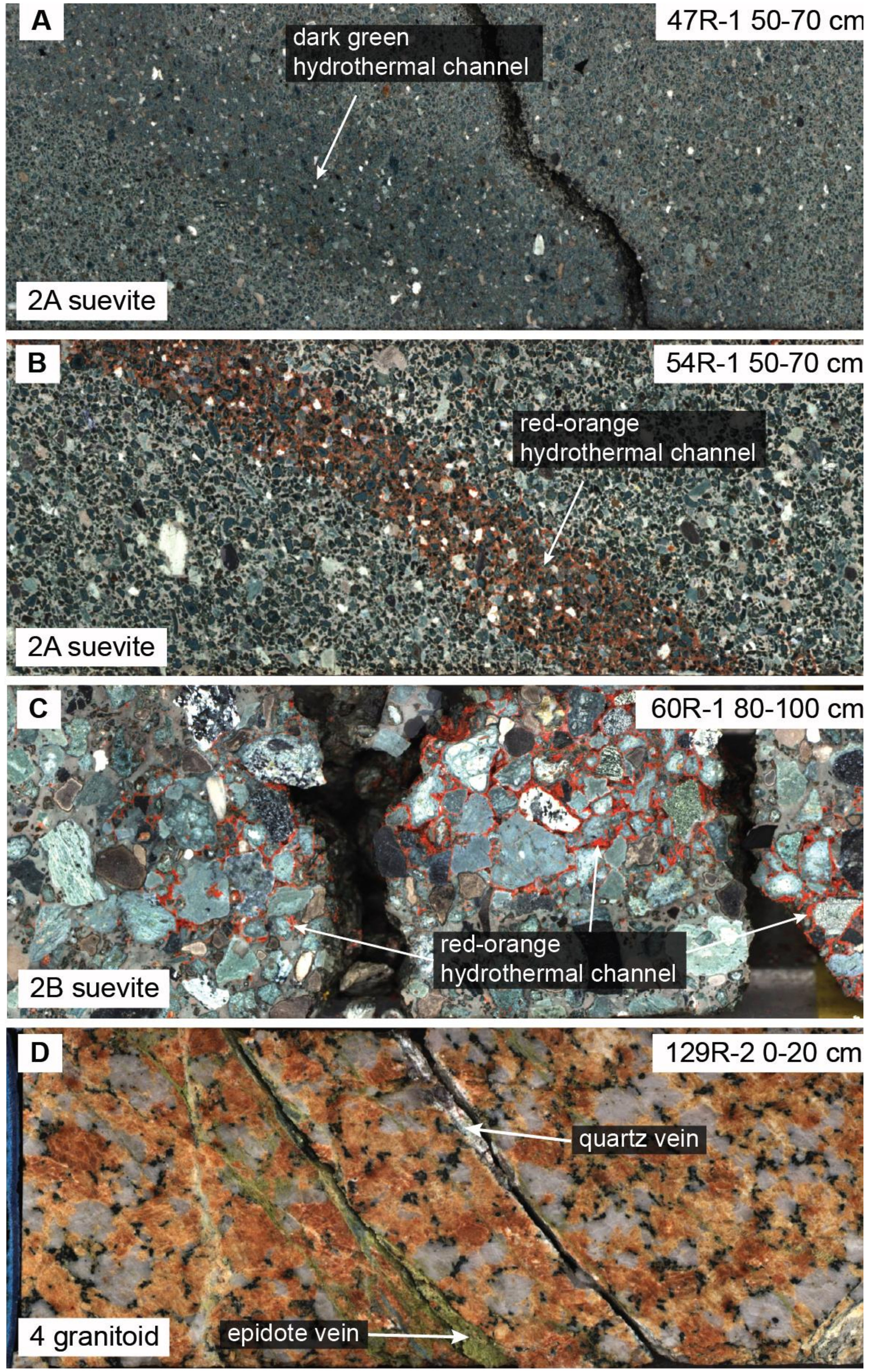
Bralower et al., EPSL, 2020



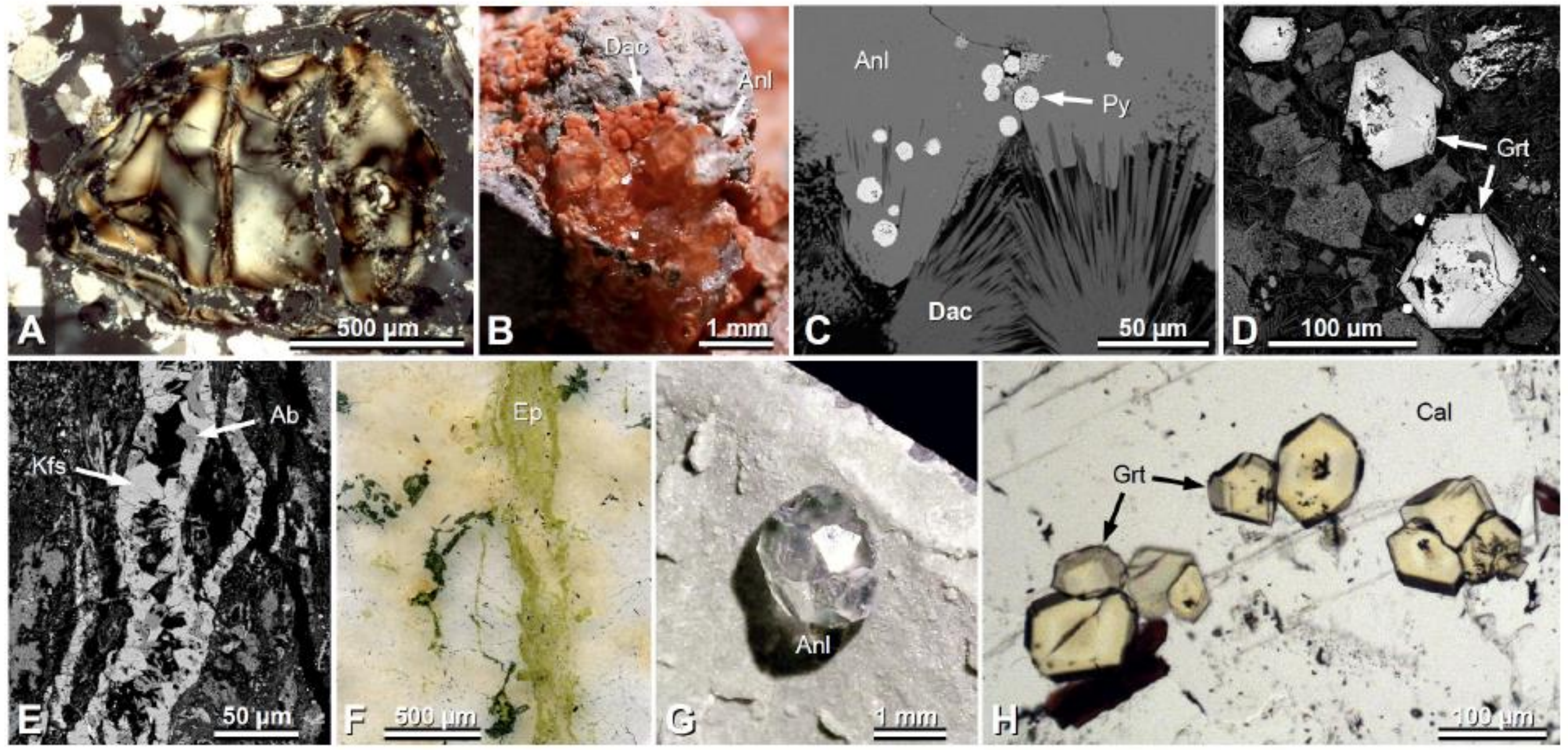
75% extinction event but Benthic habitats spared

Lowery et al., P&P, 2021

Objective 3: Hydrothermal system and Habitat for Thermophiles?



Gulick et al., Mar Geo, in press.



Temperature: >180° C < 400 ° C; Kring et al., Sci. Adv., 2020

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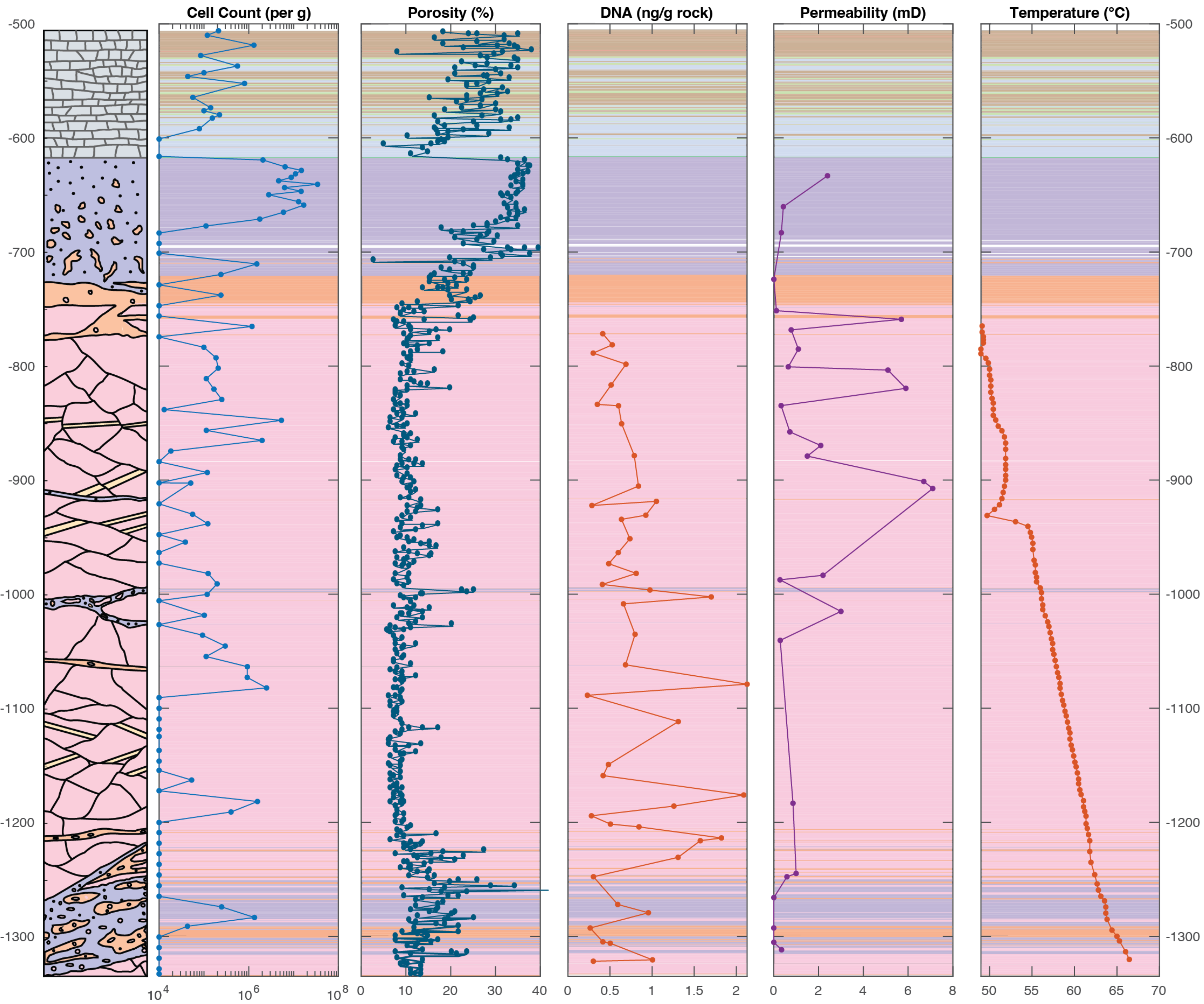
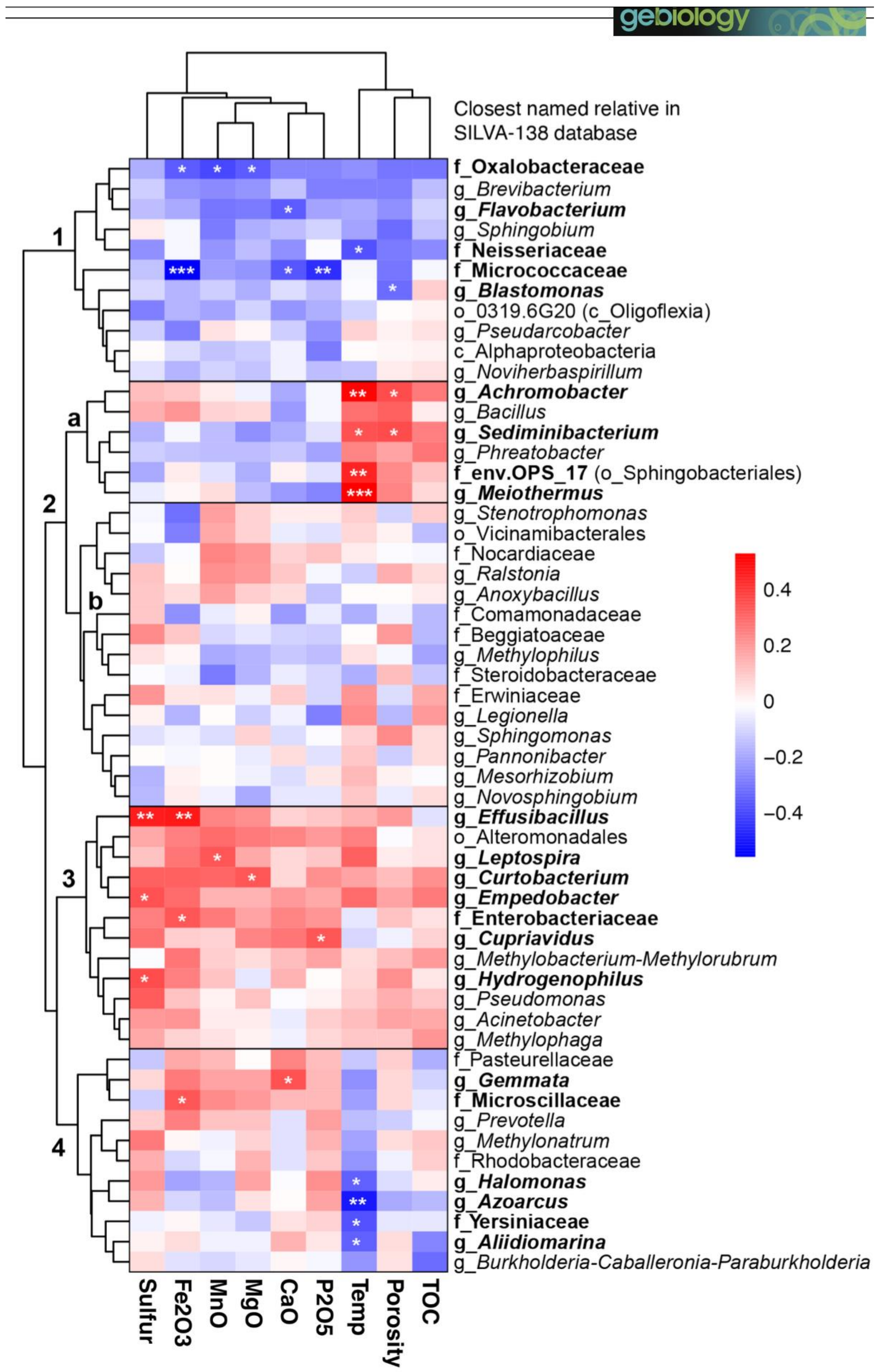


Gulick et al., Mar Geo, in press

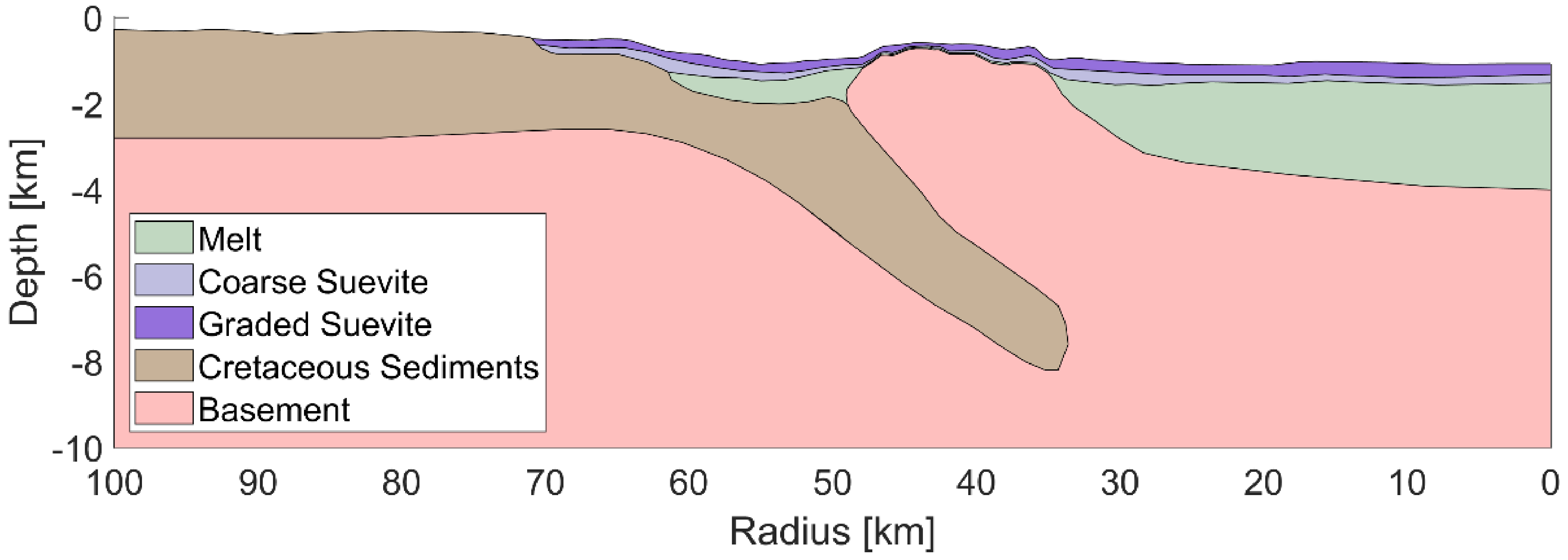
Cockell et al, 2021



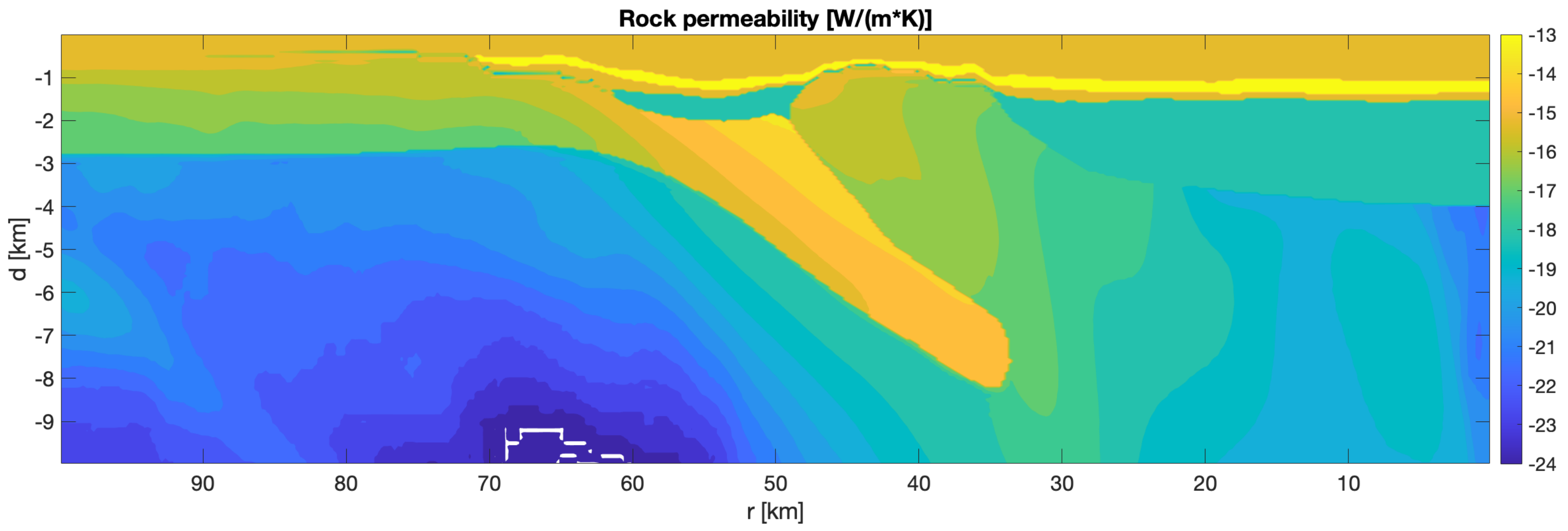
Quraish et al., 2024

Modelling Chicxulub's Hydrothermal System

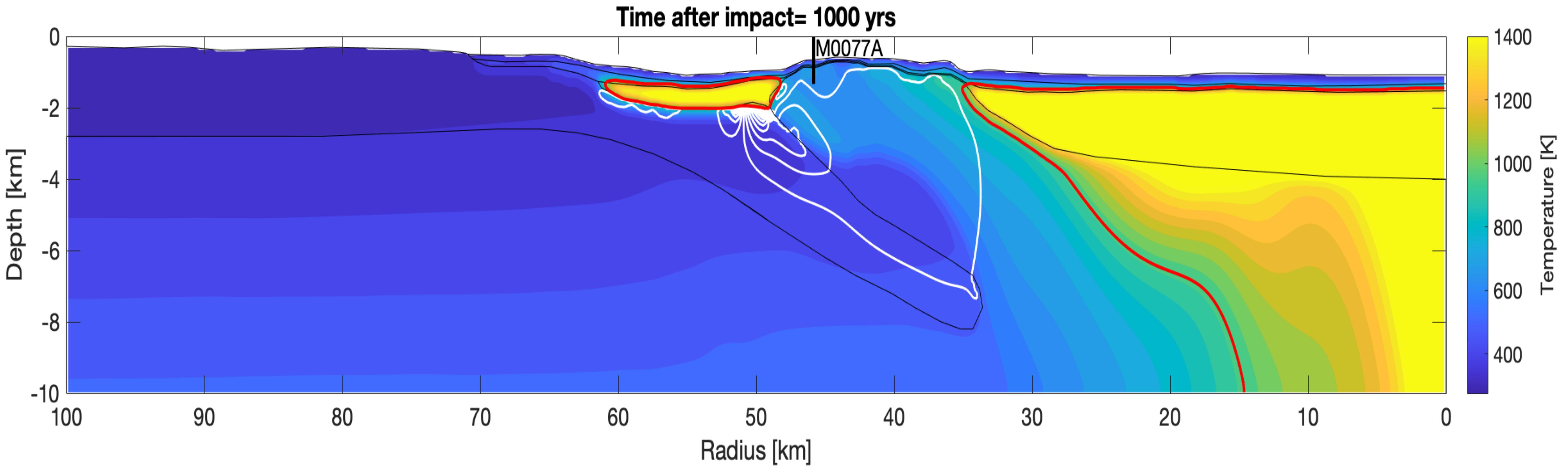
Model Geometry

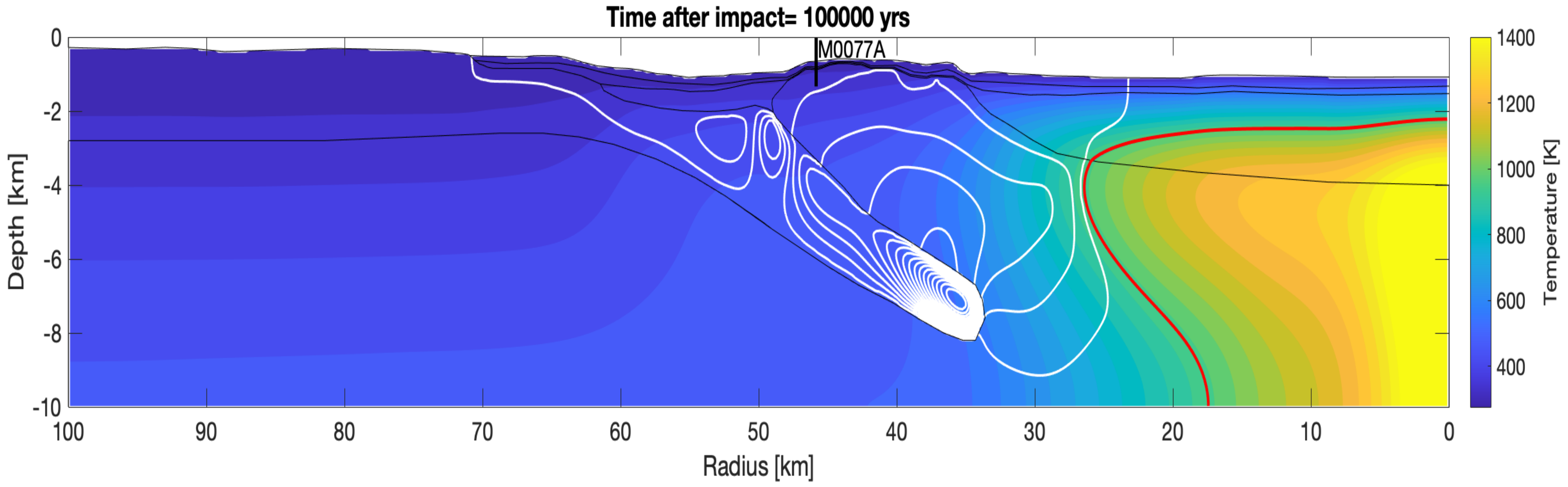


Rock Permeability



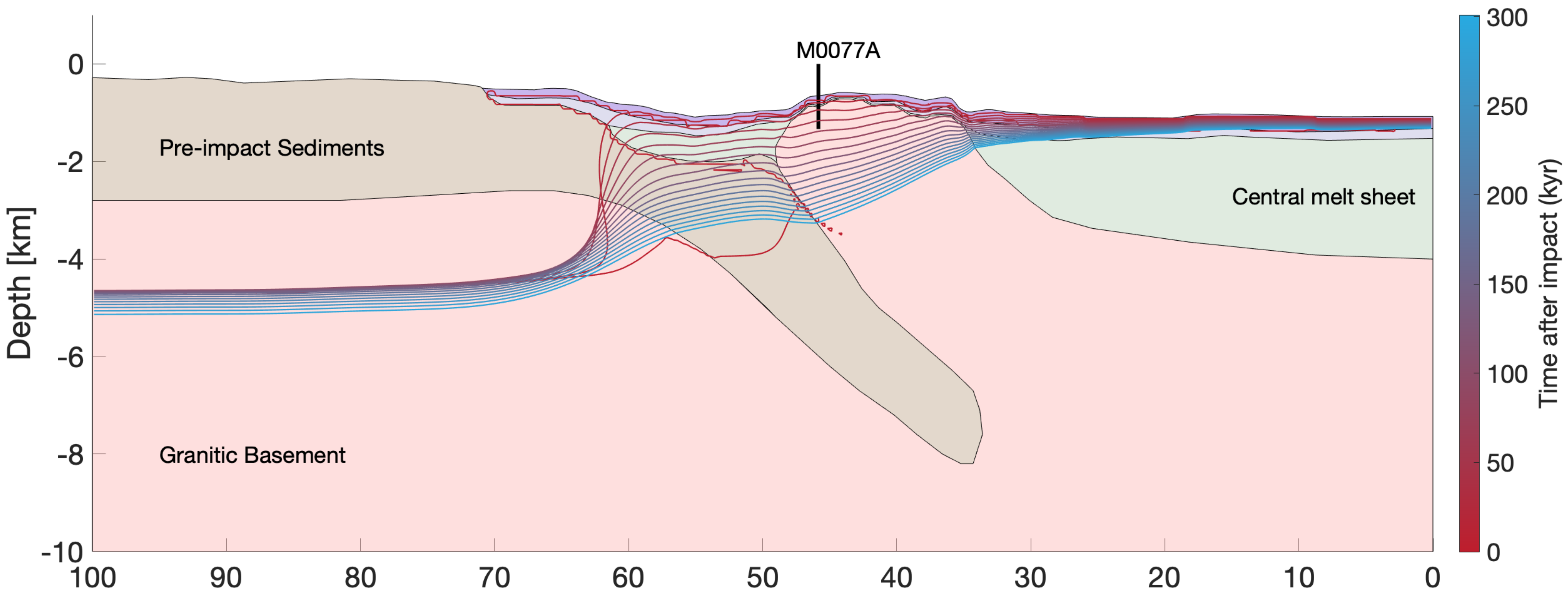
Simulation Results





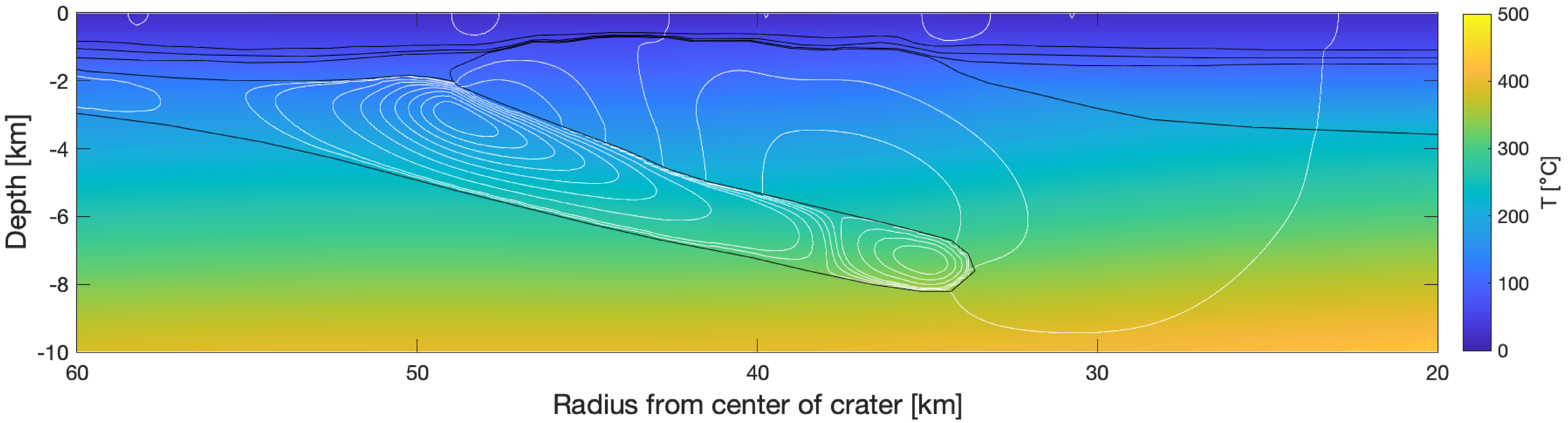
Alfred, Hesse et al., in prep.

Evolution of upper limit (122°C) for thermophilic life through time



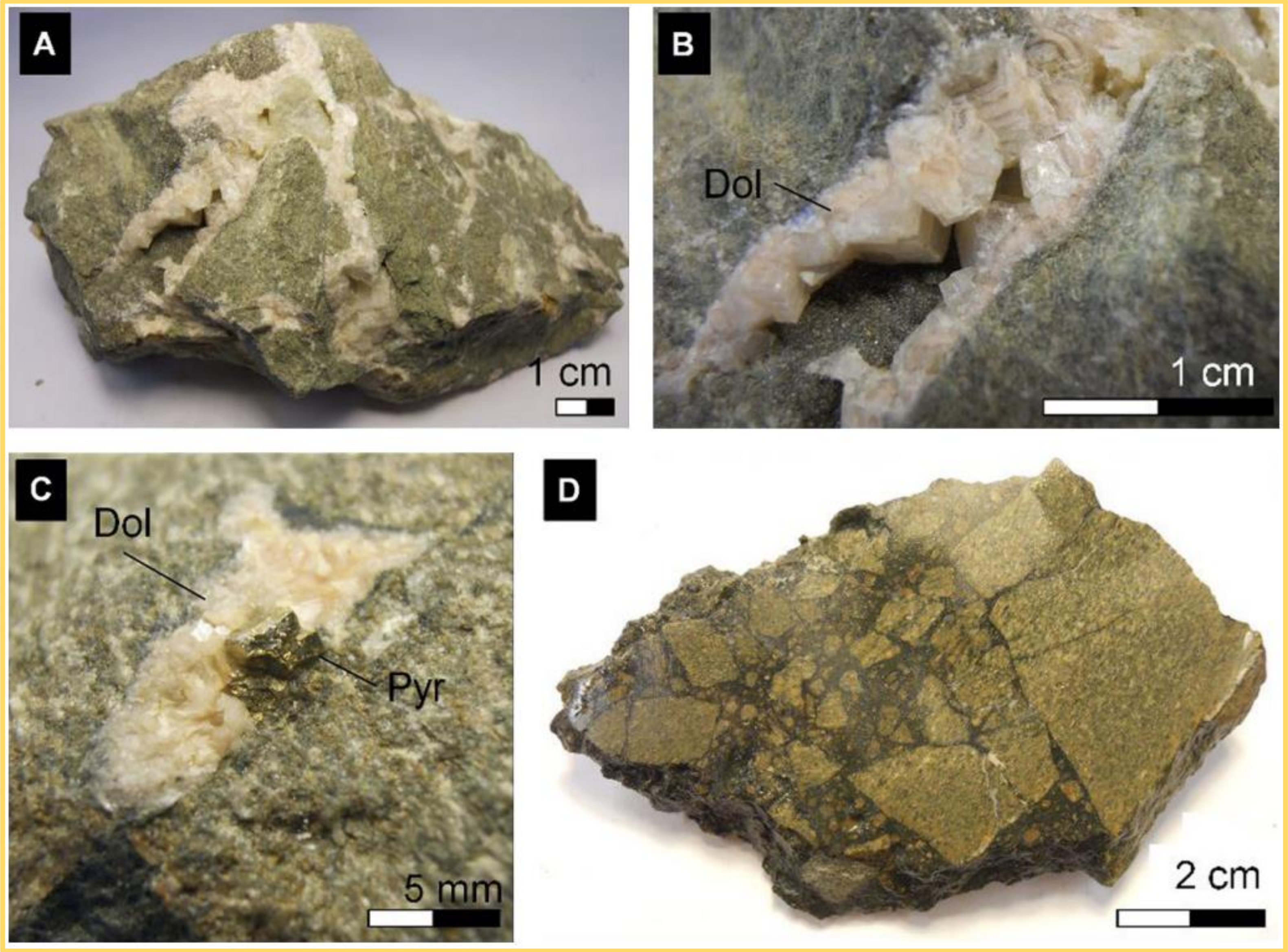
Based on temperatures and convection patterns, granitic peak ring is best region for microbial communities

Implications for Steady State- Perpetual Convection!

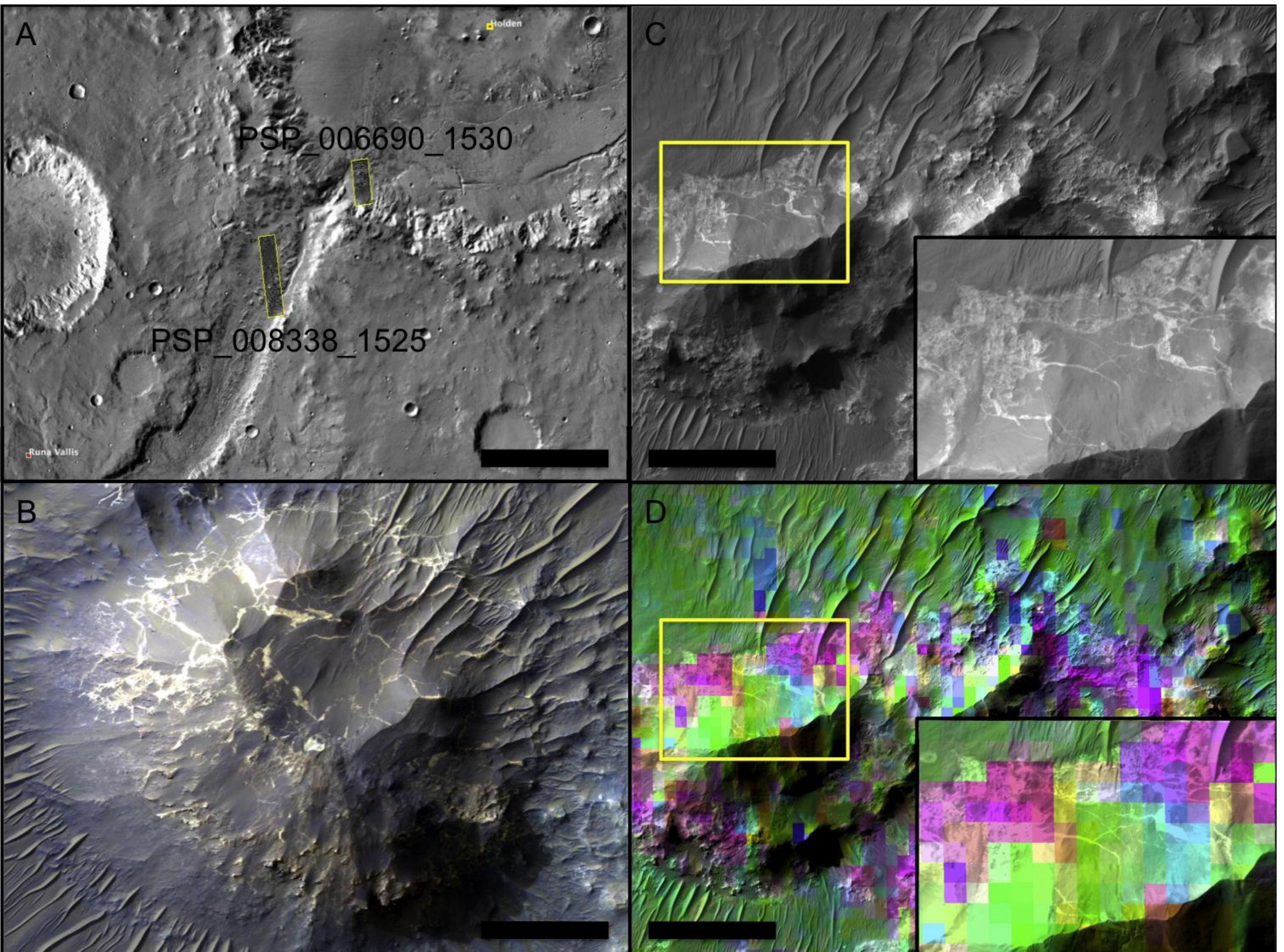


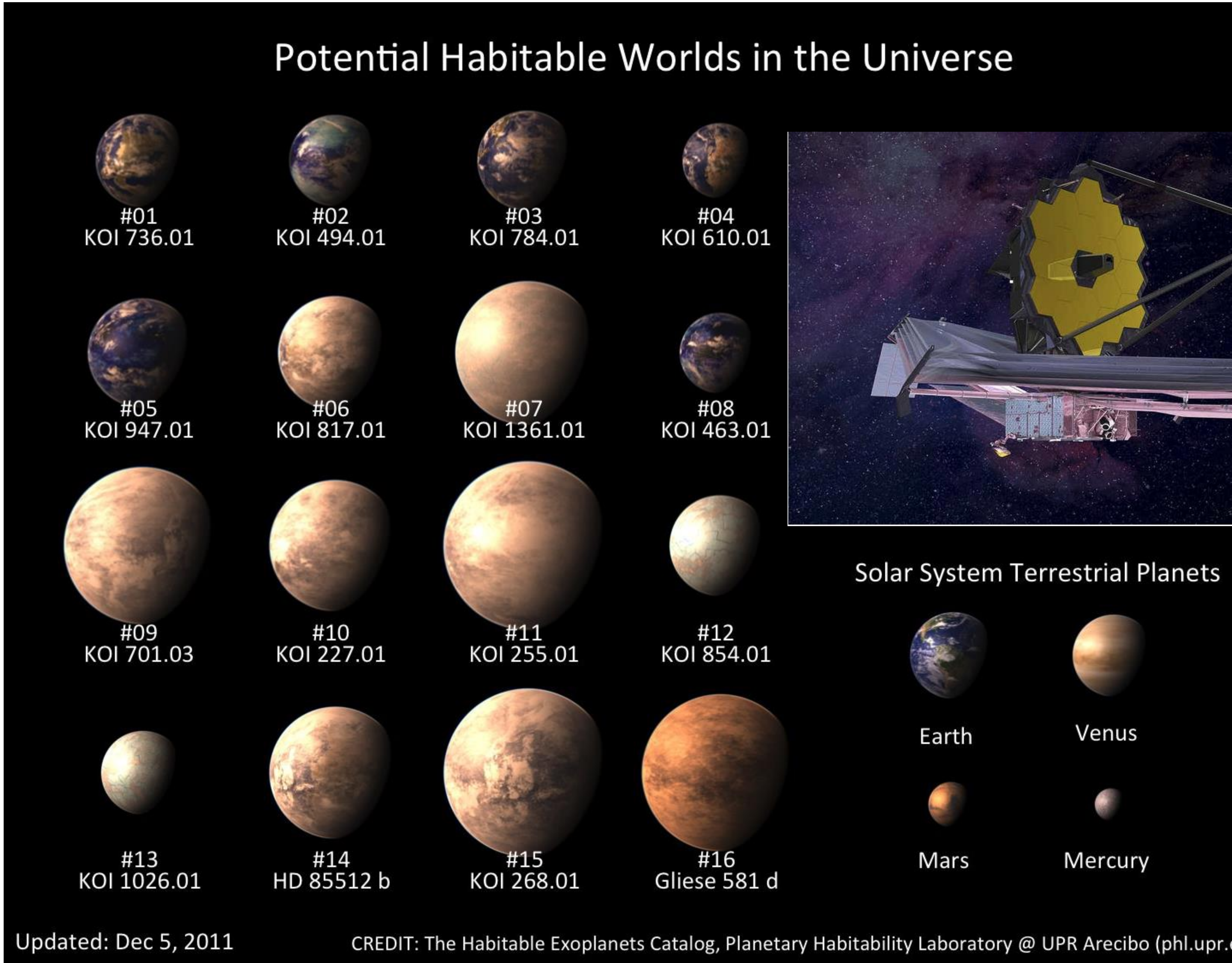
Why do we care: Impacts are ubiquitous and if a driver for life….

Rochechouart Crater, Earth



Holden Crater, Mars



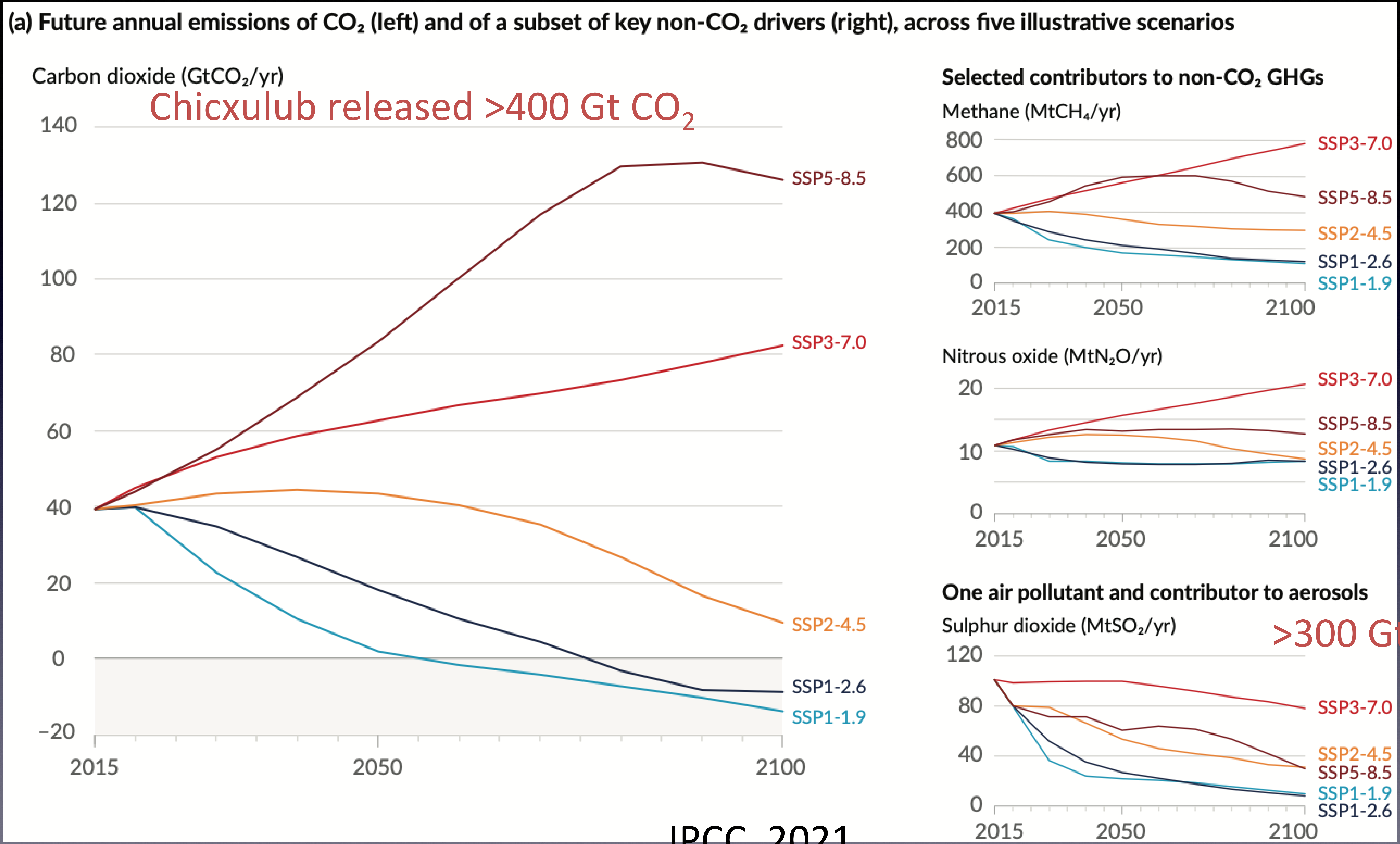


Impacts are a geologic process

&

Impacts are a biologic process

Questions?


(a) Future annual emissions of CO₂ (left) and of a subset of key non-CO₂ drivers (right), across five illustrative scenarios
Carbon dioxide (GtCO₂/yr)
Chicxulub released >400 Gt CO₂
140
120
100
80
60
40
20
0
−20
2015
2050
2100
SSP5-8.5
SSP3-7.0
SSP2-4.5
SSP1-2.6
SSP1-1.9
Selected contributors to non-CO₂ GHGs
Methane (MtCH₄/yr)
800
600
400
200
0
SSP3-7.0
SSP5-8.5
SSP2-4.5
SSP1-2.6
SSP1-1.9
Nitrous oxide (MtN₂O/yr)
20
10
0
SSP3-7.0
SSP5-8.5
SSP2-4.5
SSP1-2.6
SSP1-1.9
One air pollutant and contributor to aerosols
Sulphur dioxide (MtSO₂/yr)
>300 Gt S
120
80
40
0
SSP3-7.0
SSP2-4.5
SSP5-8.5
SSP1-1.9
SSP1-2.6

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