CAMILLE FLAMMARION

LA

FIN DU MONDE

Illustrations par JEAN-PAUL LAURENS, ROCHEGROSSE, E. BAYARD, ROBIDA, A.-P. LAURENS, SCHWABE, GRASSET, SAUNIER, MERWART, VOGEL, BACH, GUILLONNET, RUDAUX, MYRBACH, CHOVIN.

Gravure par MÉAULLE.

Je vis ensuite un ciel nouveau et une terre nouvelle; car le premier ciel et la première terre étaient passés.

APOCALYPSE, XXI, 1.

ERNEST FLAMMARION, ÉDITEUR

26, RUE RACINE, PARIS

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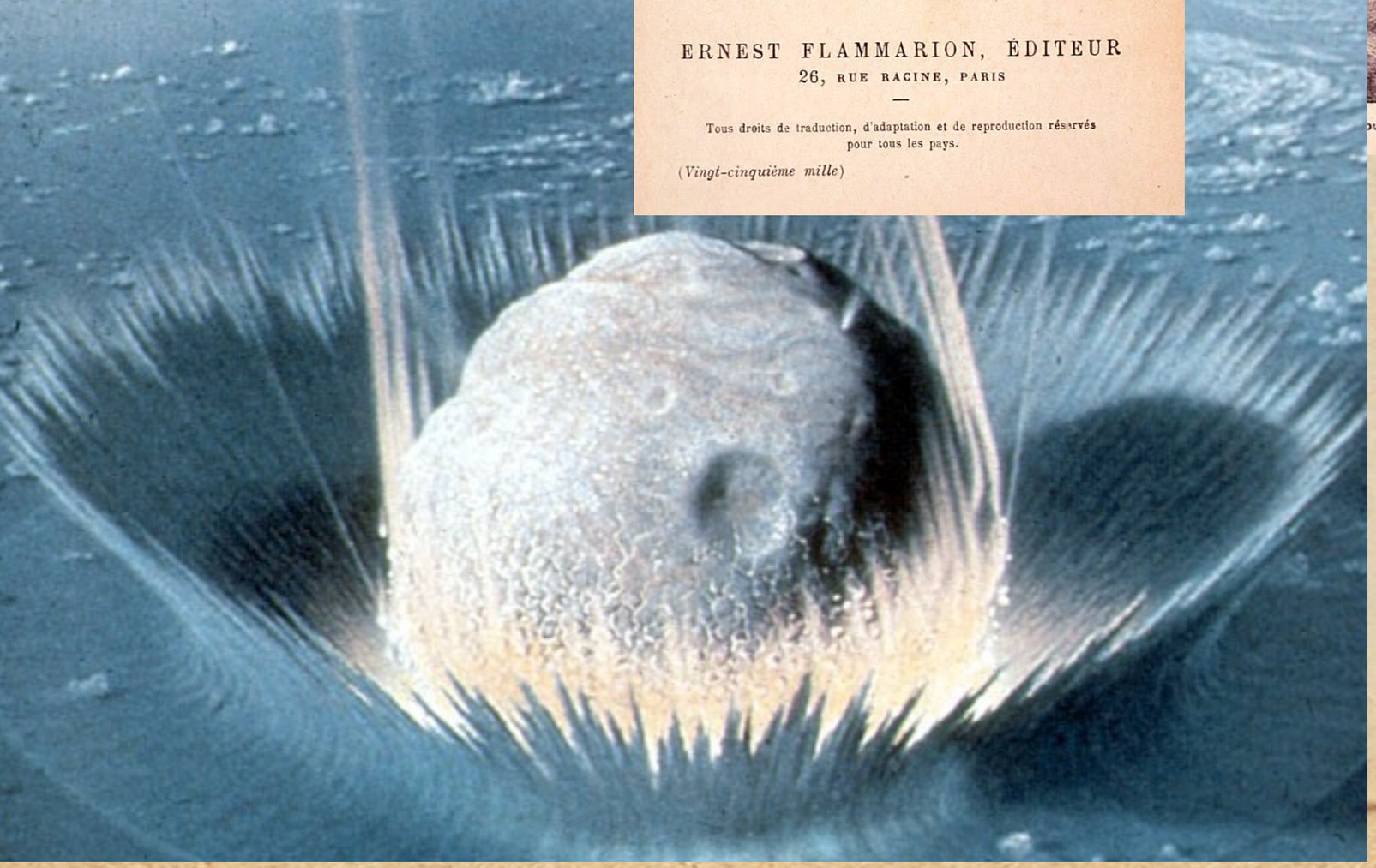
(*Vingt-cinquième mille*)

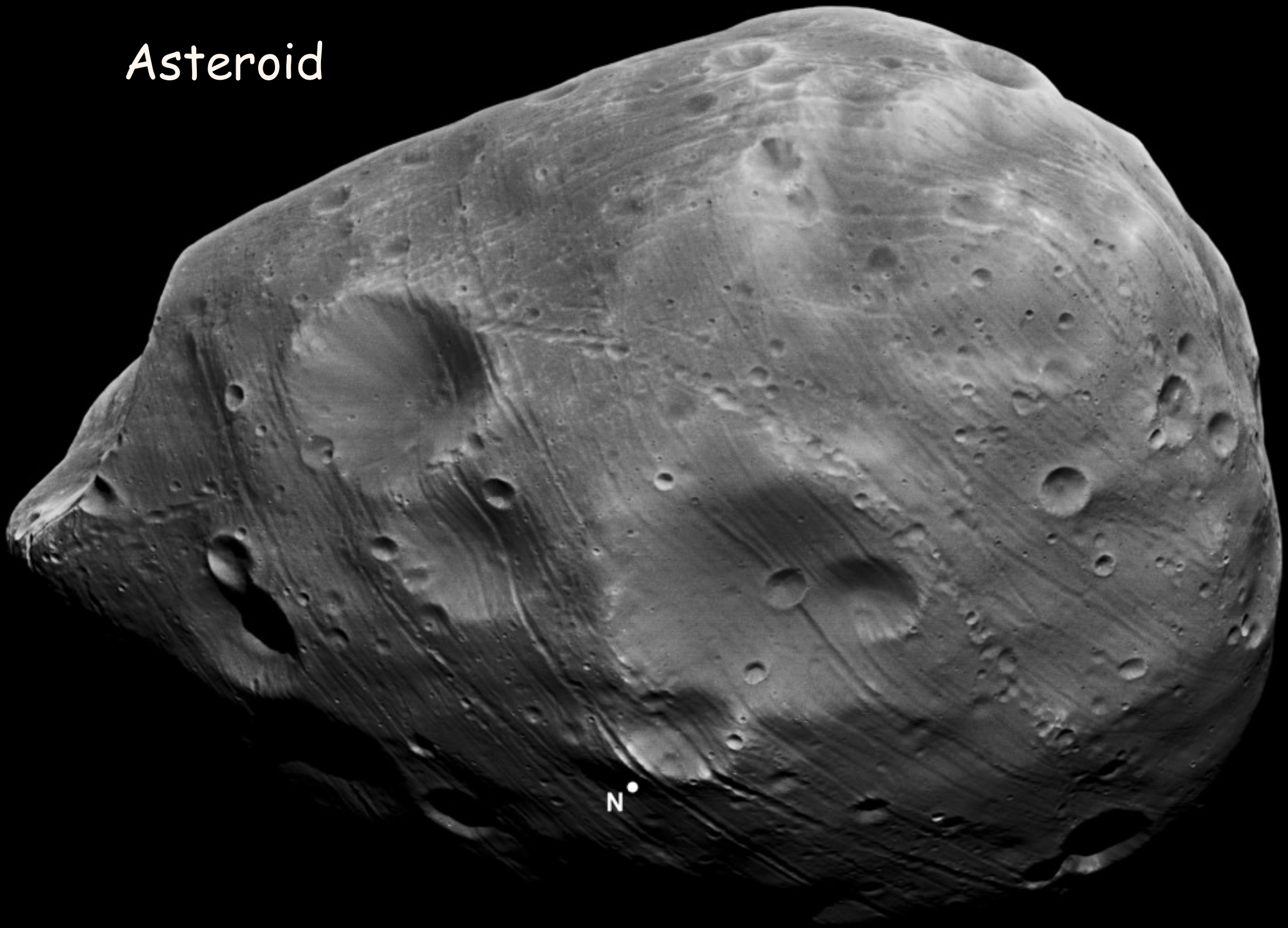


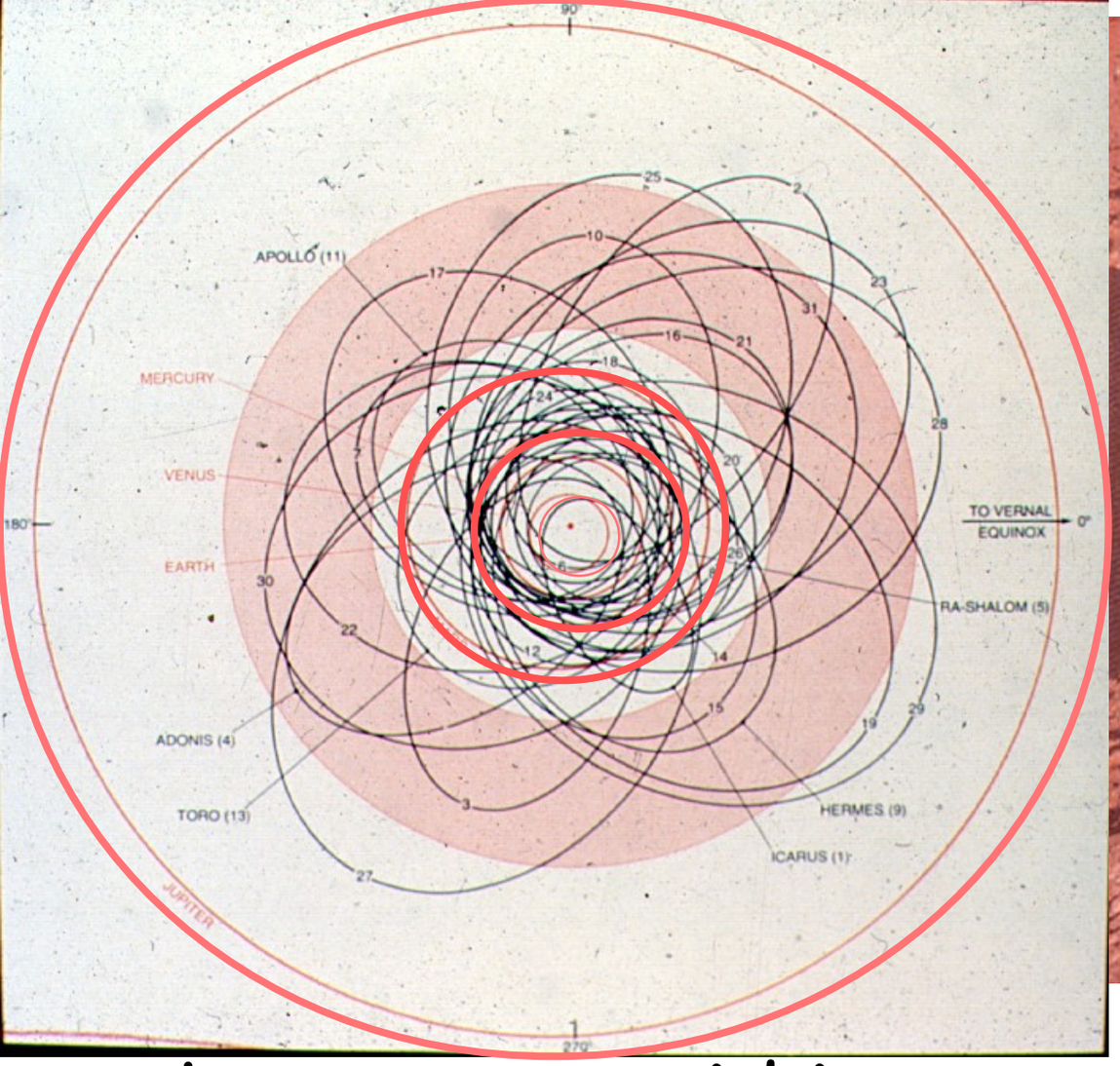
Mass-Extinctions at the K/Pg boundary:

Caused by climate changes induced by the Chicxulub impact

Merida, Mexico March 18, 2010

Asteroid

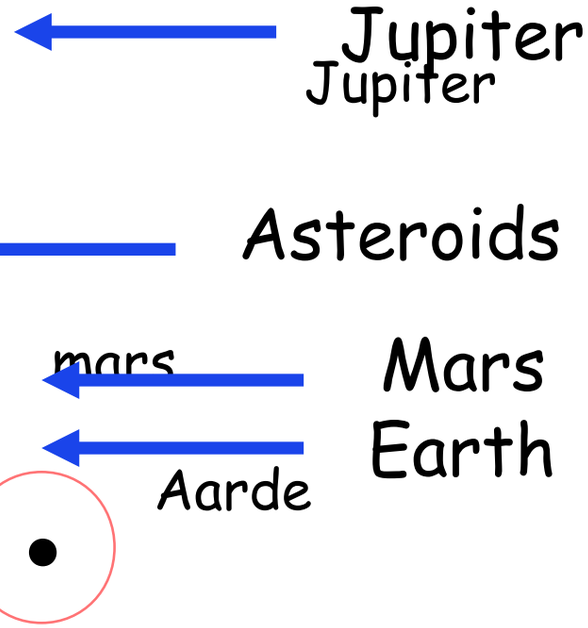




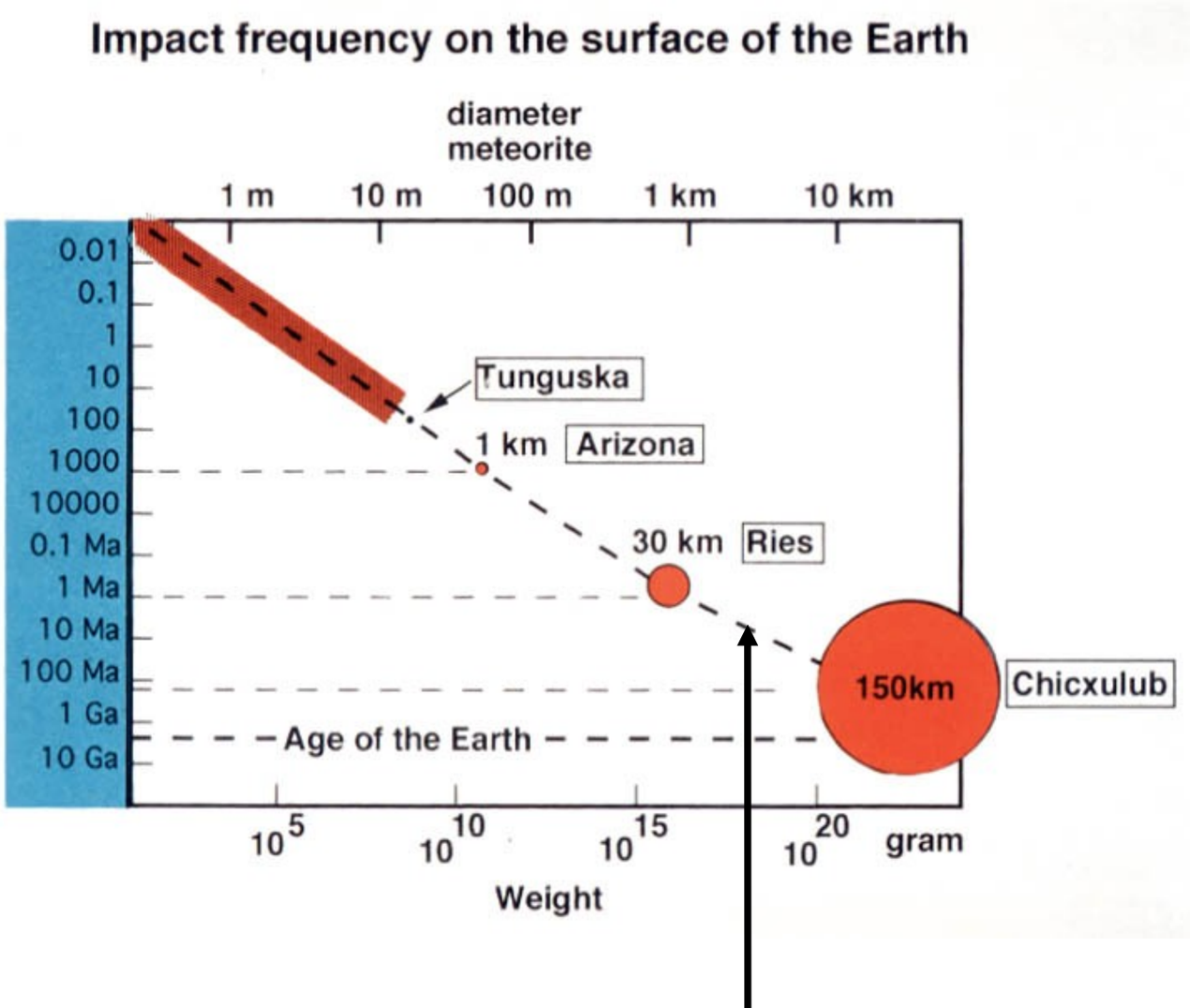
Large asteroid impacts occur frequently in earth history

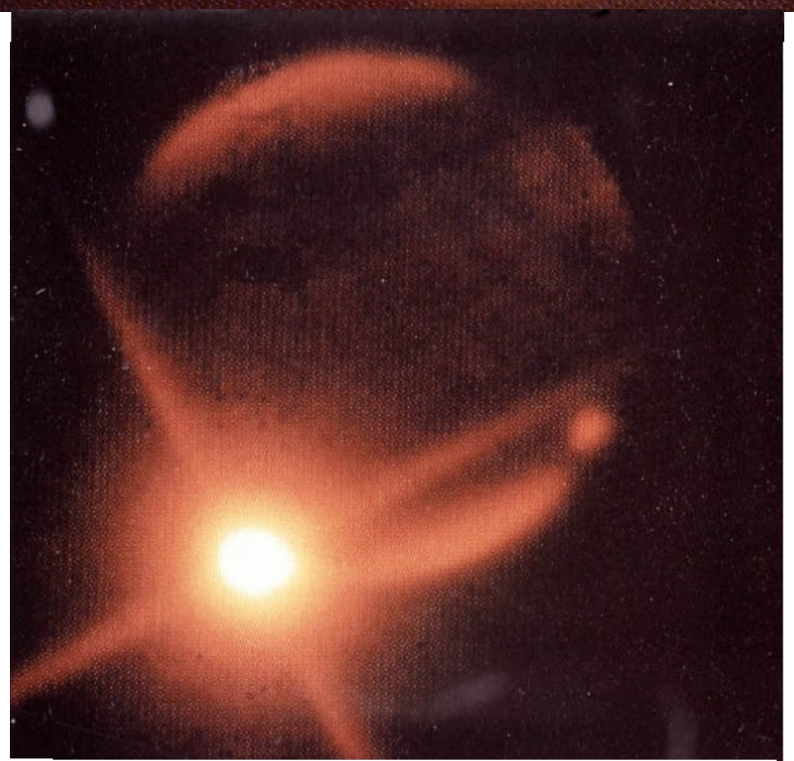
Clearwater Lake impact craters,
Canada
320 million years ago

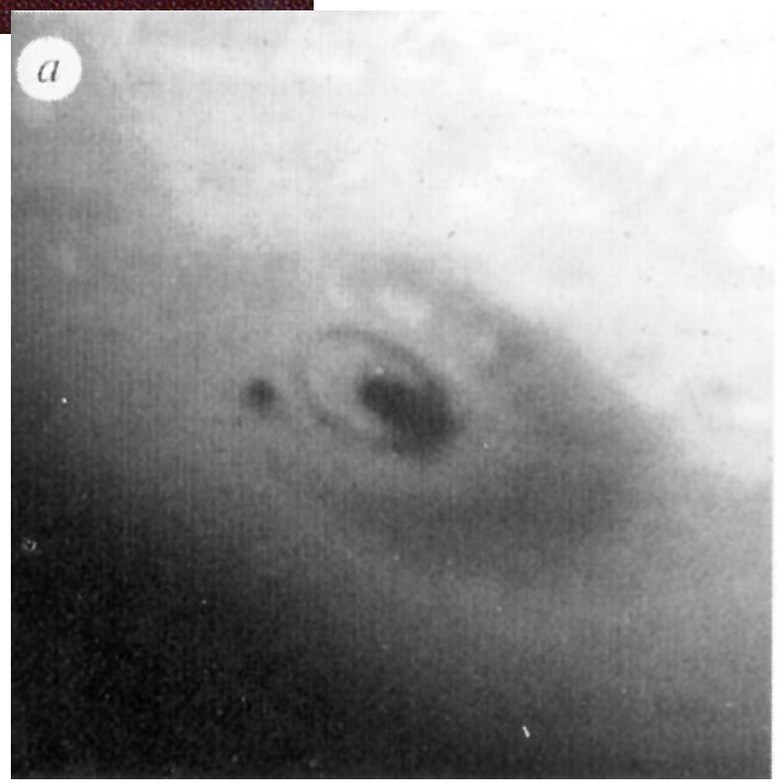
Apollo
Asteroids

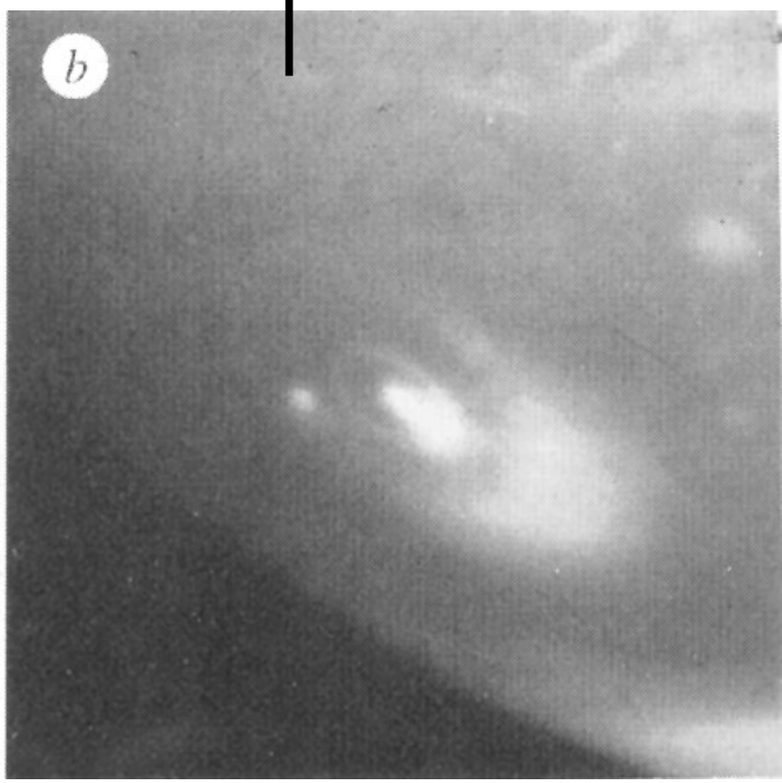


Comet Shoemaker-Levi collided with Jupiter in 1994

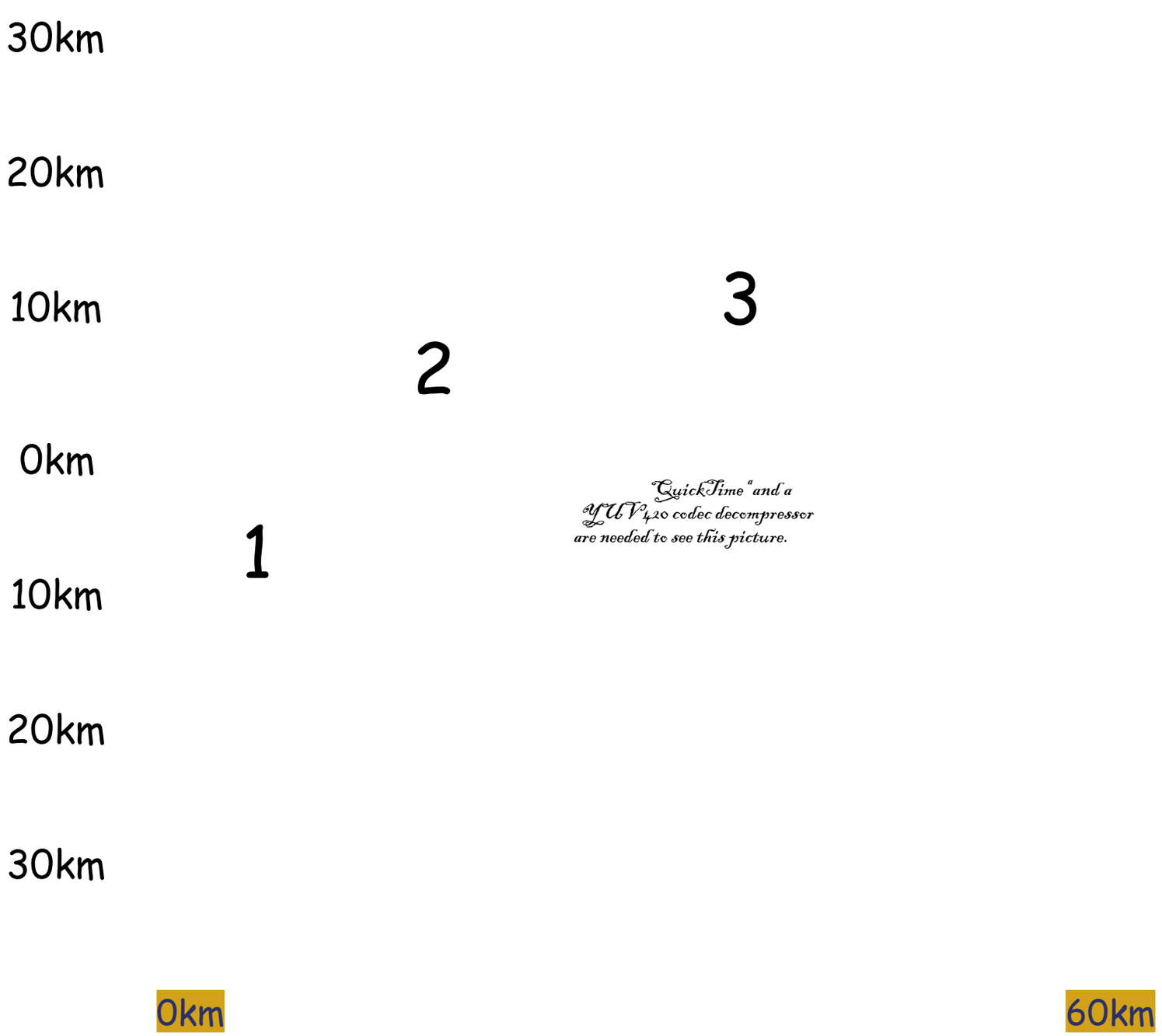








Model of an impact of a 3.3km diameter asteroid



Italy

Spain

OCEAN

To the Gulf of Mexico

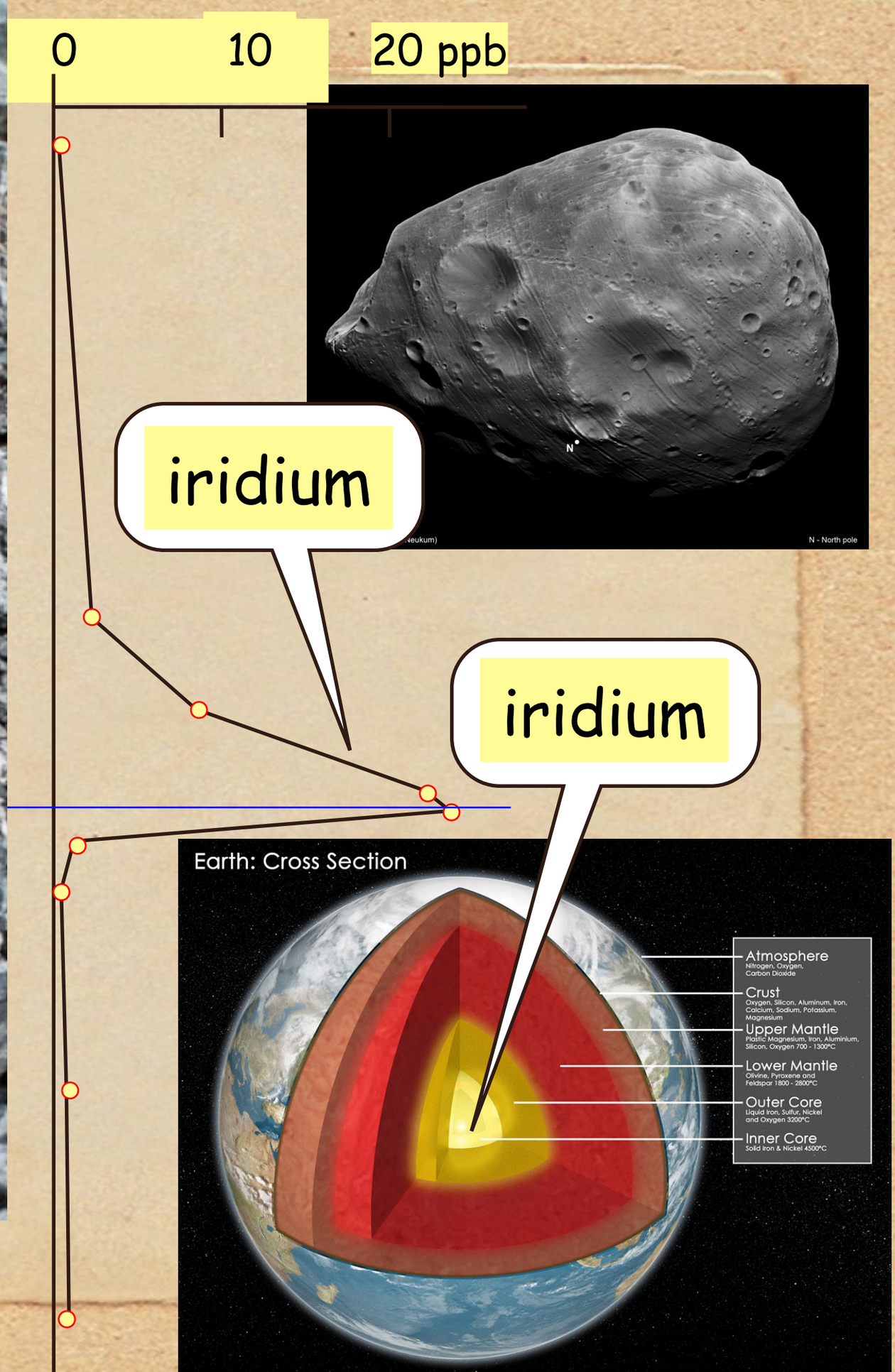
finally the Chicxulub crater

Image © 2006 TerraMetrics
Image © 2006 NASA

Agost and Caravaca, Spain: example of a detailed distal K/Pg transition

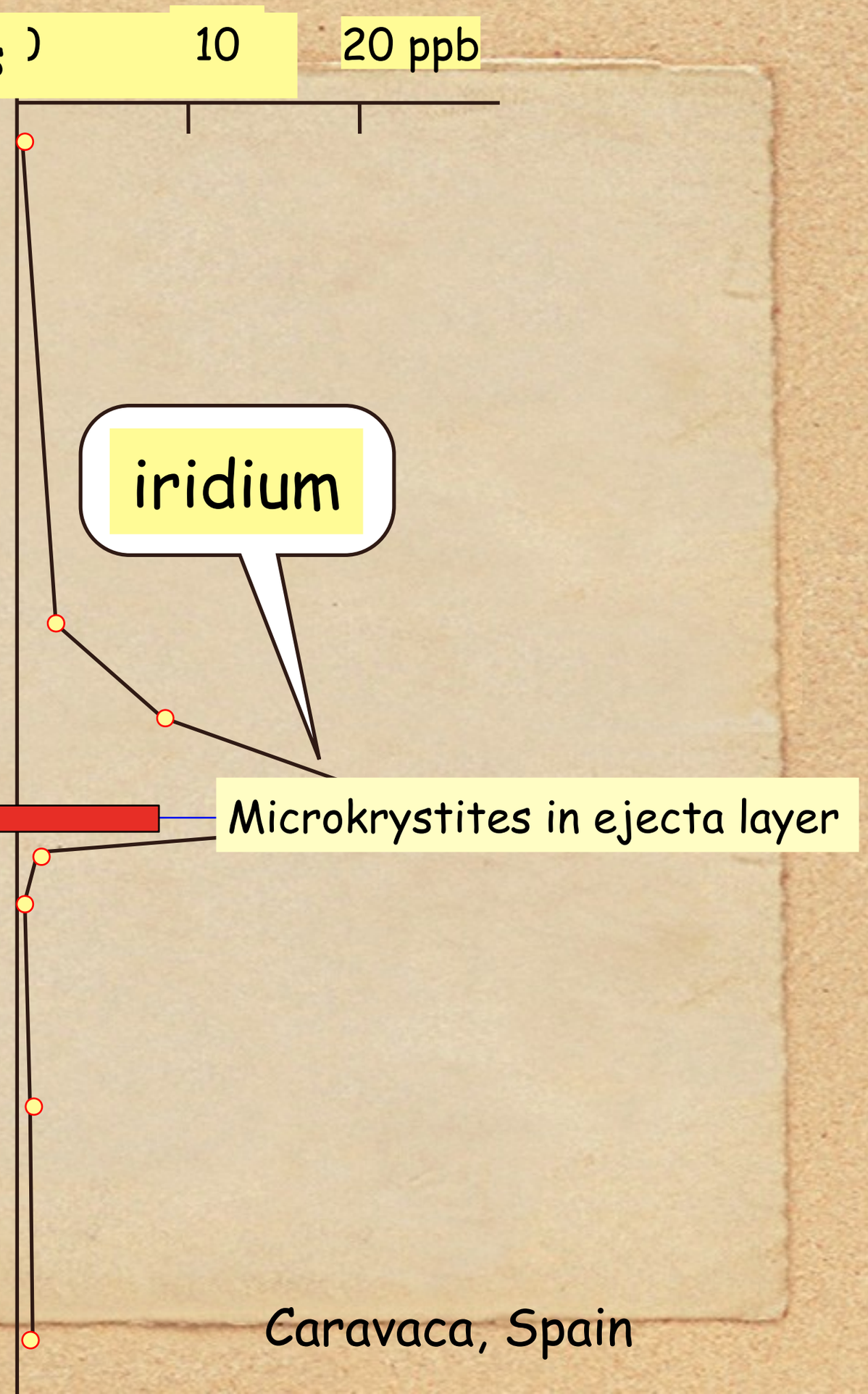
K/T boundary
Clay

(J. Hertogen and F. Asaro, 1979)



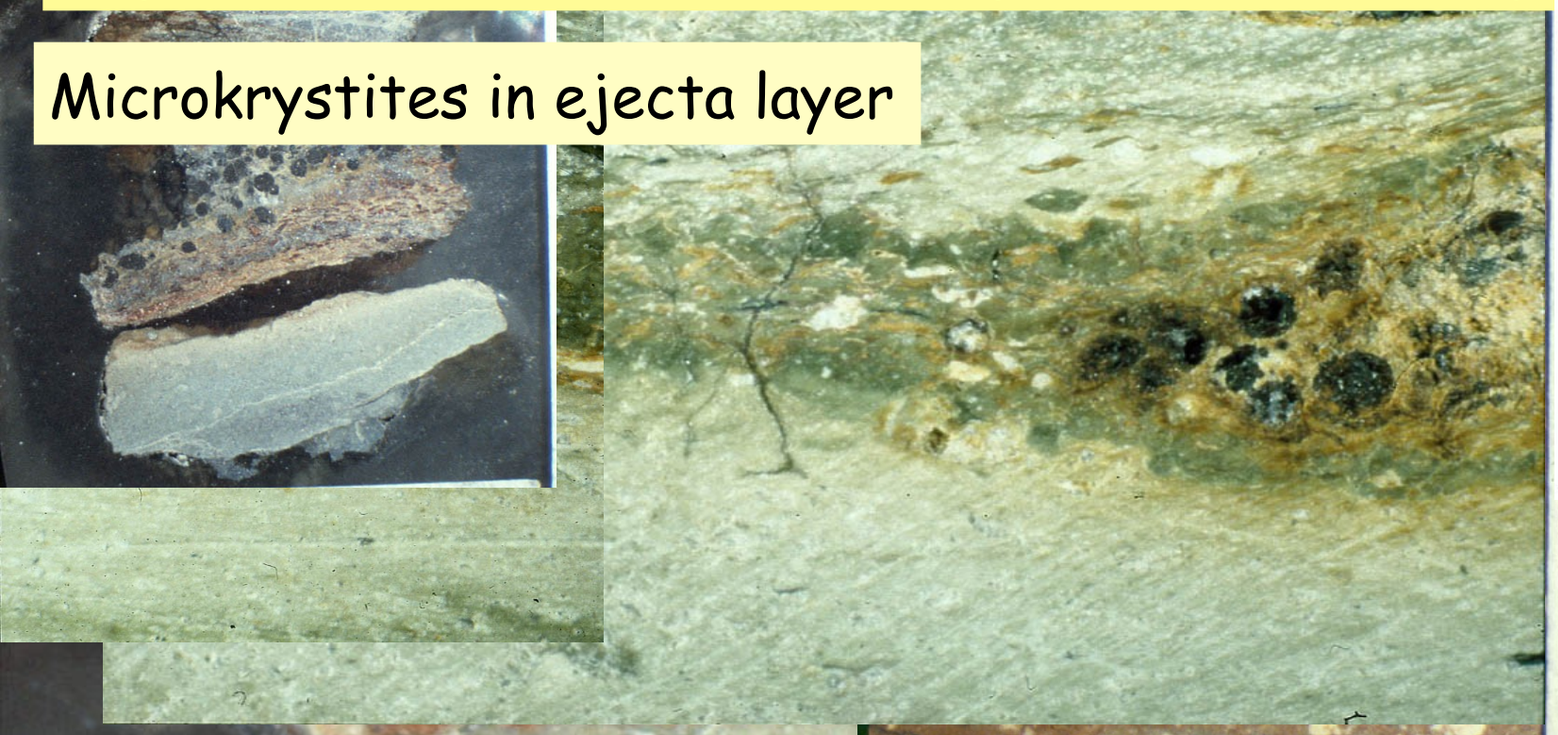
Impact evidence: iridium, microkrystites

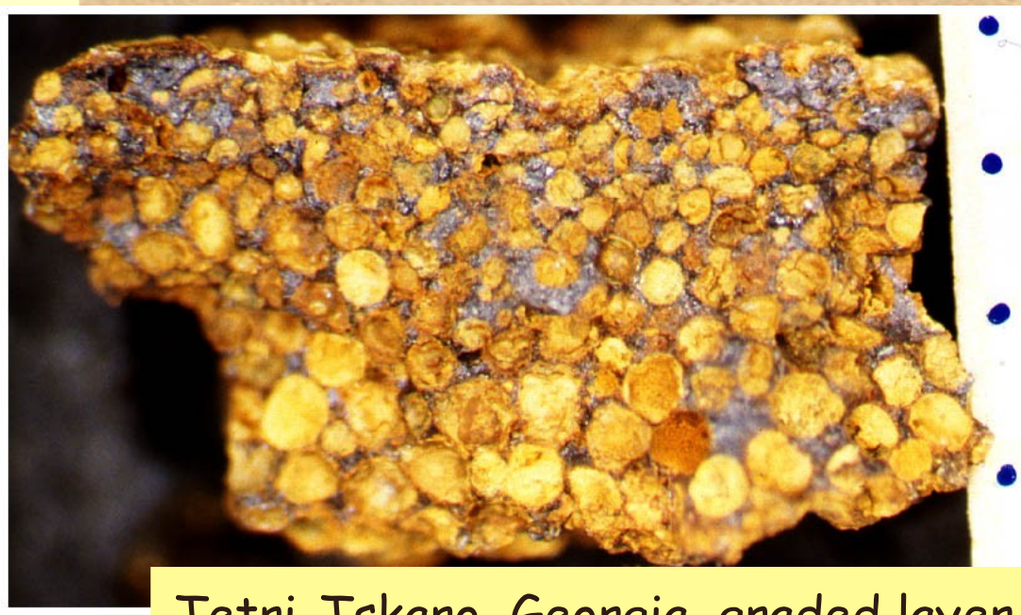
(J. Hertogen and F. Asaro, 1979)



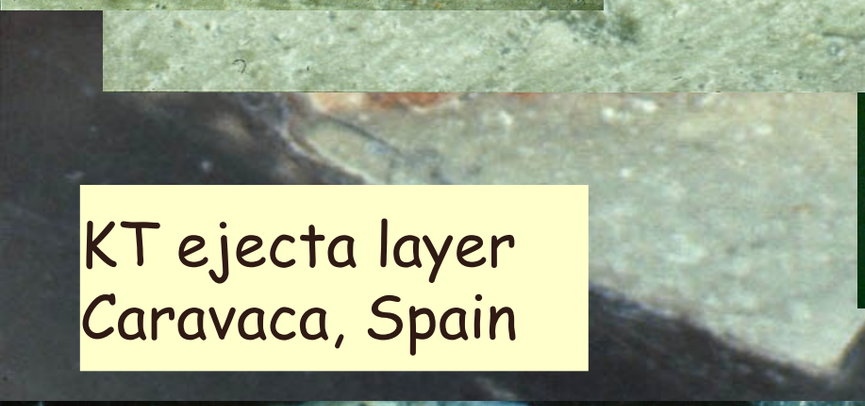
Impact evidence: iridium, Cr profile, microkrys

Microkrystites in ejecta layer

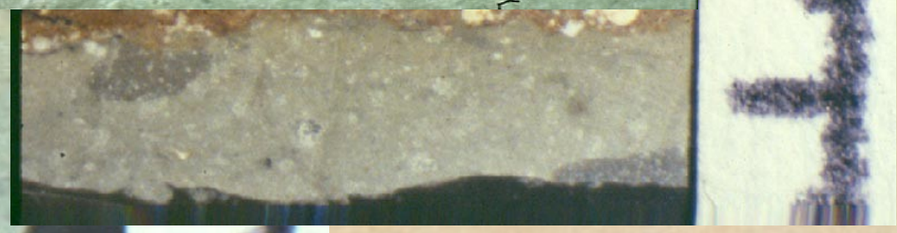




Tetri-Tskaro, Georgia, graded layer



KT ejecta layer
Caravaca, Spain

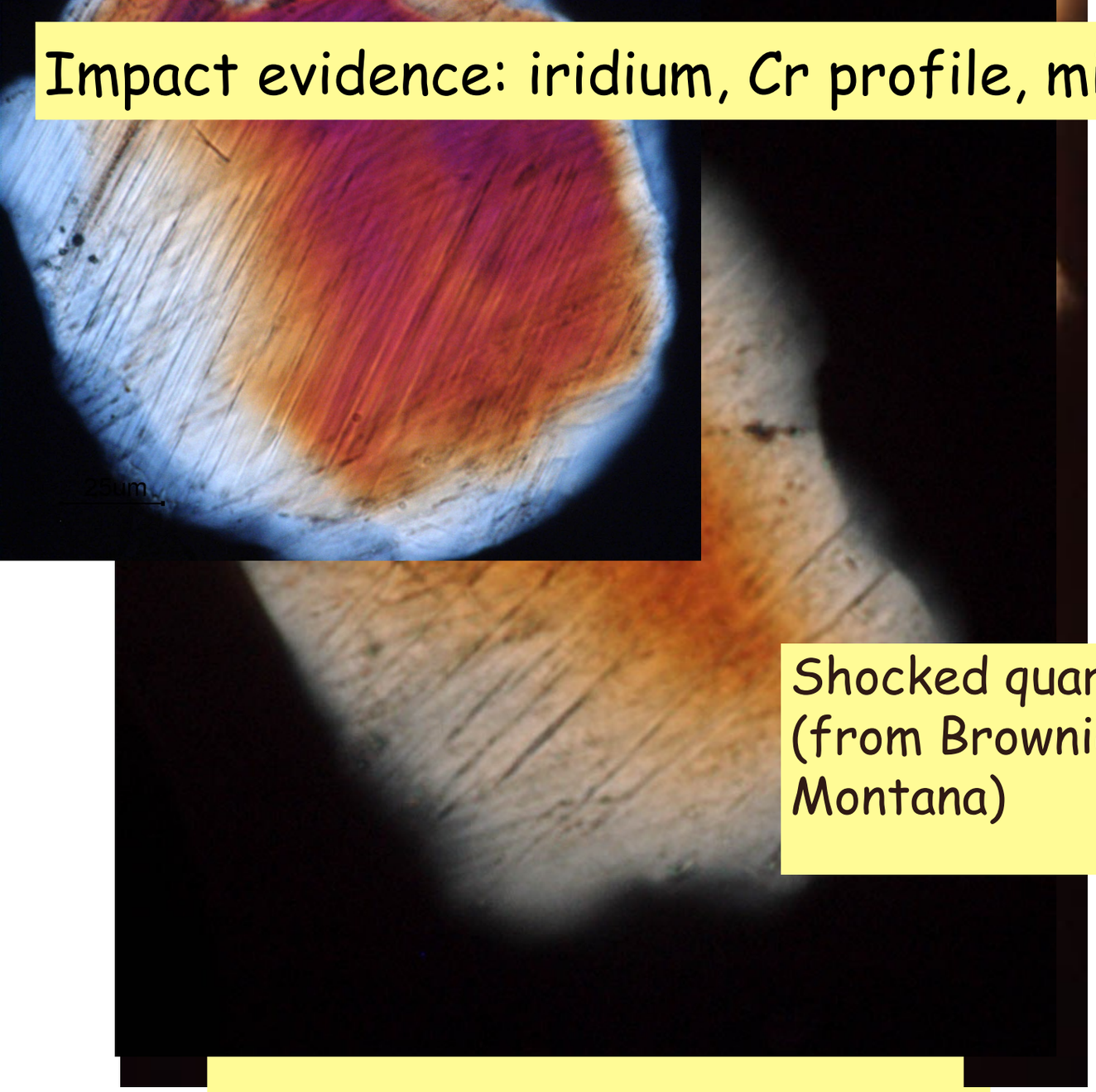


KT ejecta layer
Agost, Spain

Zumaya, Spain

Ca-rich Augite (cpx)

Impact evidence: iridium, Cr profile, microkrystites, shocked quartz



Shocked quartz
(from Brownie Butte
Montana)

Closer to Chicxulub, thicker ejecta layer.

CHICXULUB

Raton Basin, New Mexico

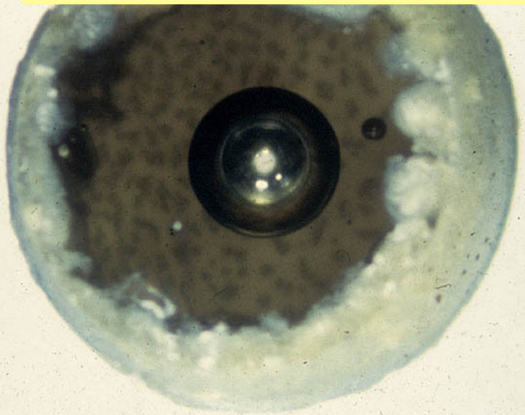
K/T boundary ejecta layer is a "Dual Layer"; exclusively in coals

In the Western Interior

Impact ejecta are always in coals

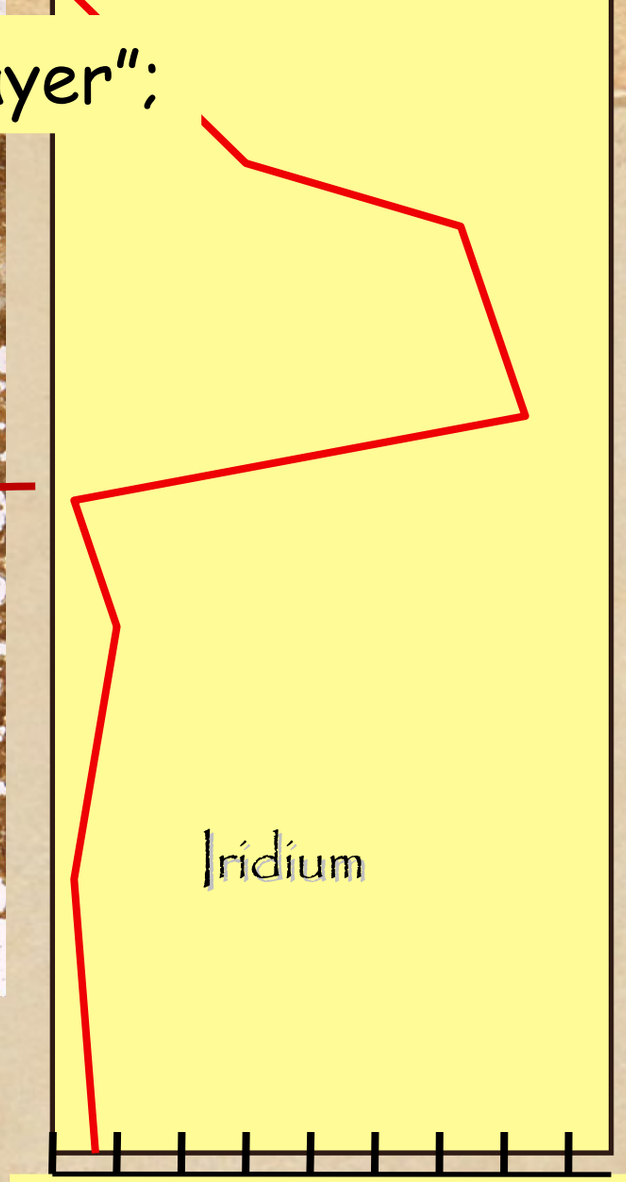
Madrid Railroad, Colorado

K/T boundary ejecta layer is a "Dual Layer";



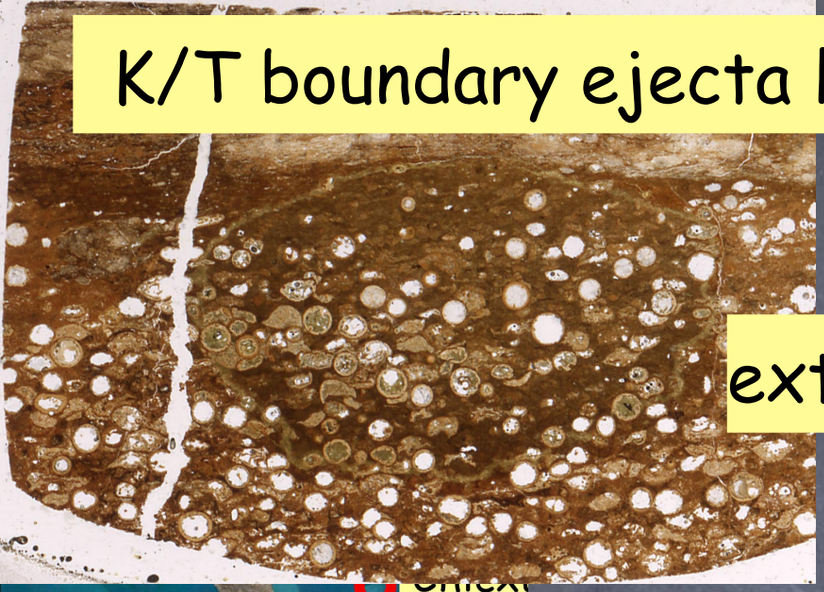
ridium-rich with

The lower layer is filled with tektites



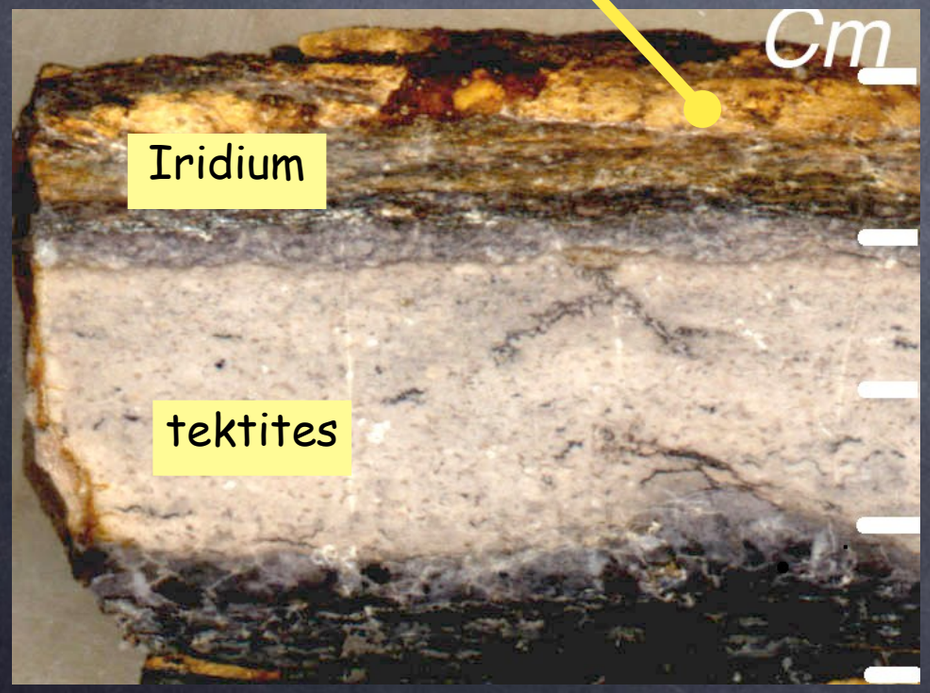
Dogie Creek, Wyoming

K/T boundary ejecta layer is a "Dual Layer";



extends for over 2000km in the western interior

Raton, Nw Mexico



Dogie Creek, Wyoming

Iridium

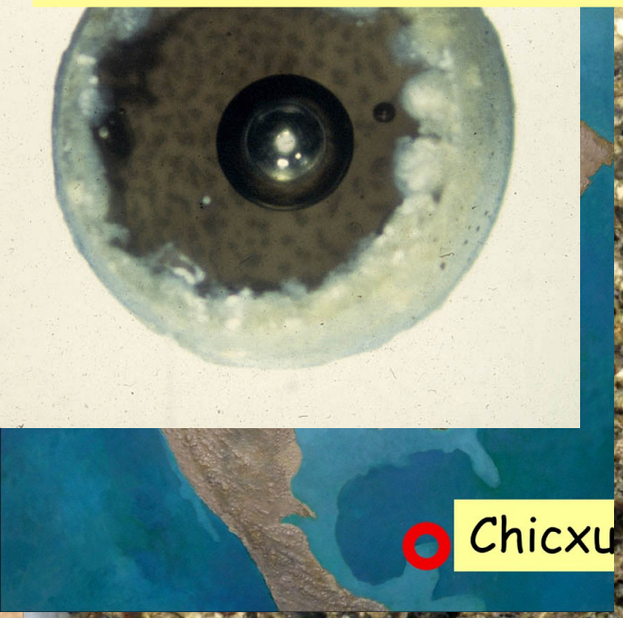
tektites

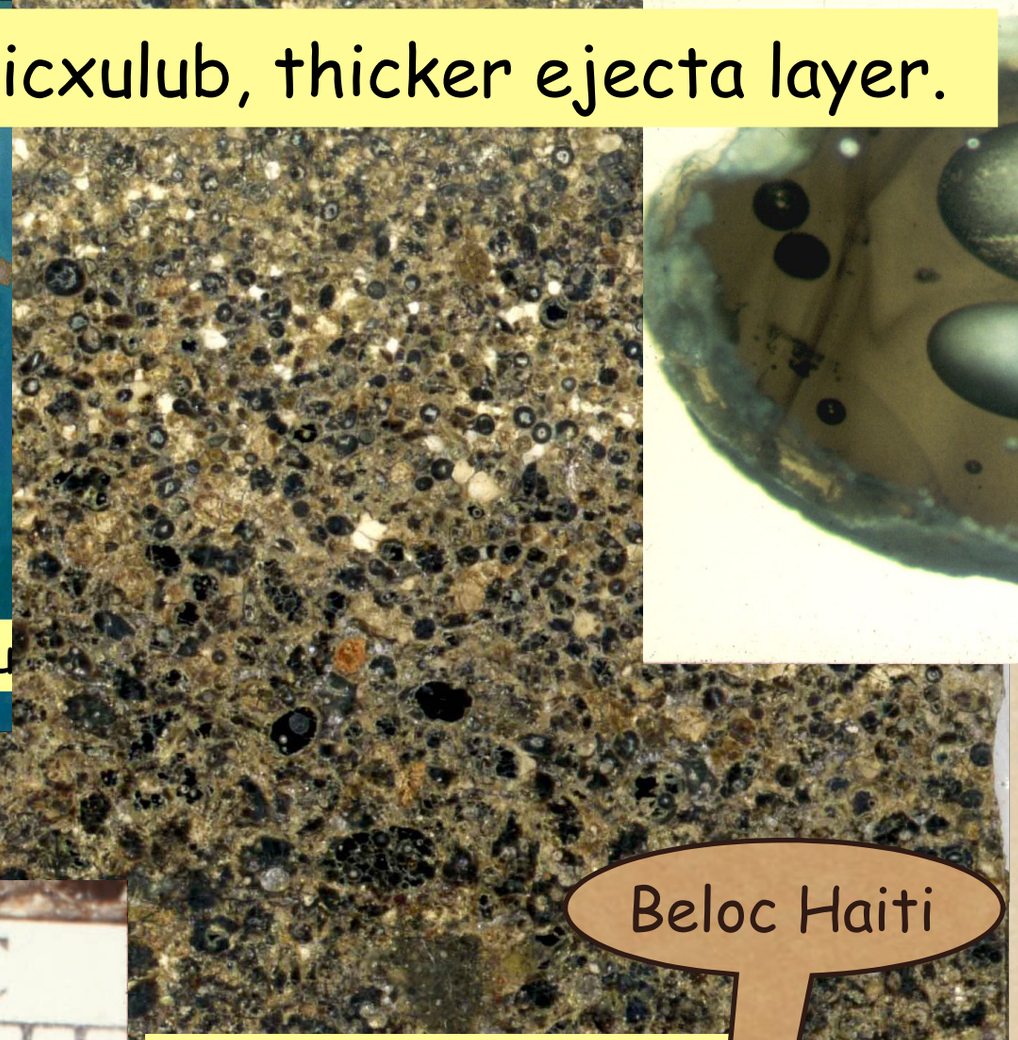
Brownie Butte, Montana

Iridium

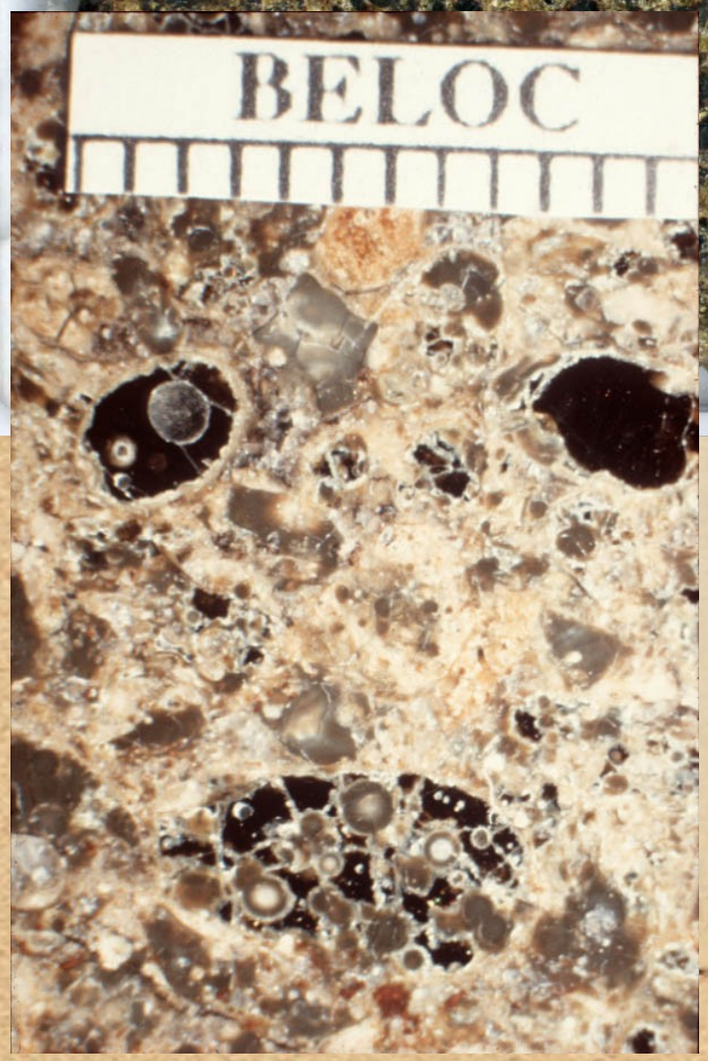
tektites

Even closer to Chicxulub, thicker ejecta layer.





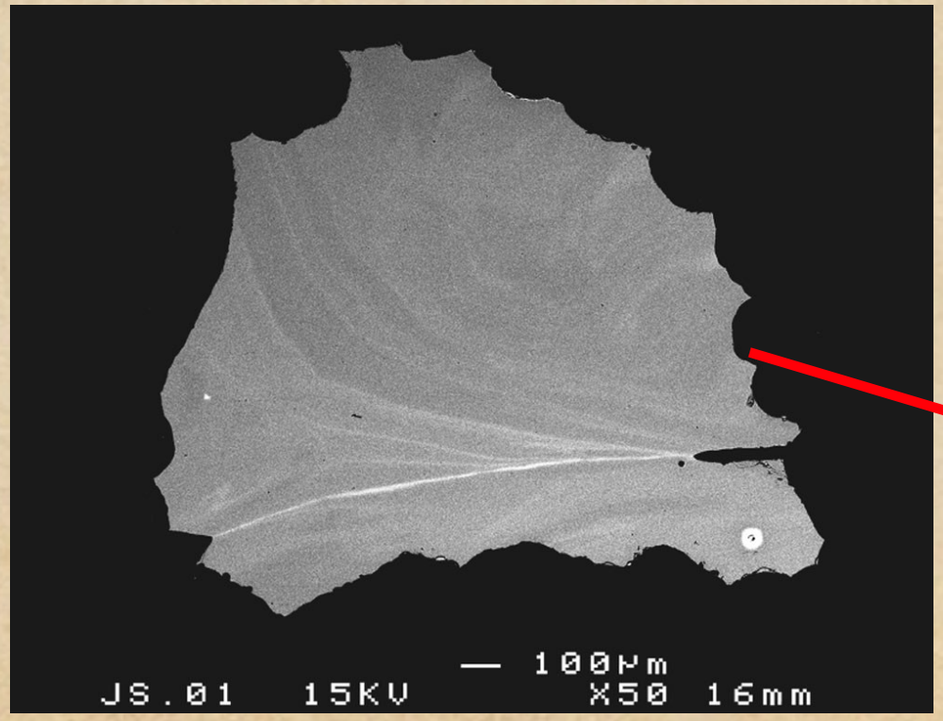
Tektites from Beloc, Haiti
Glass blebs ejected from
Chicxulub crater



Beloc Haiti

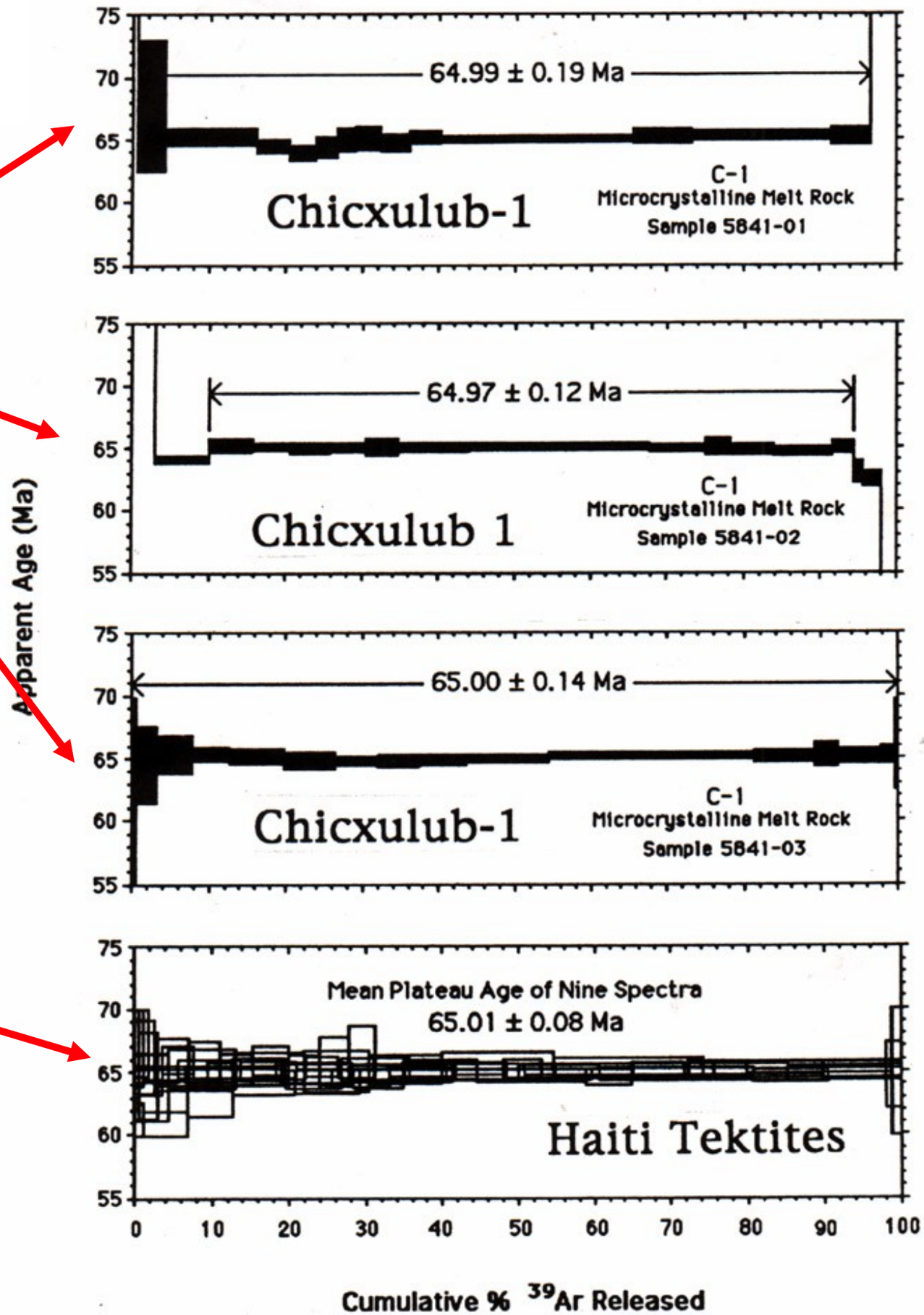
Ar/Ar ages from the tektites are indistinguishable from impact melt inside the crater

Impact melt from the crater



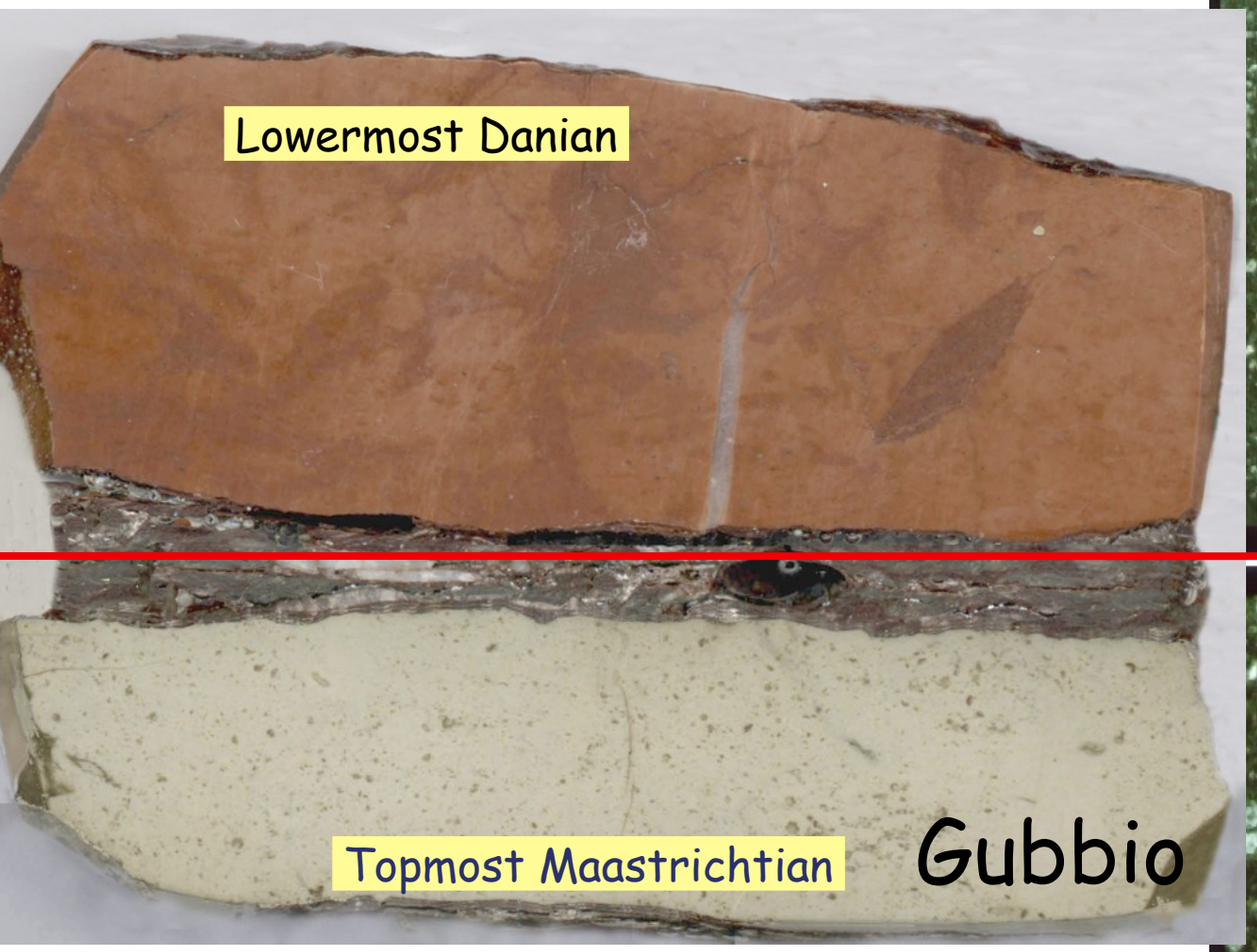
Haitian tektite

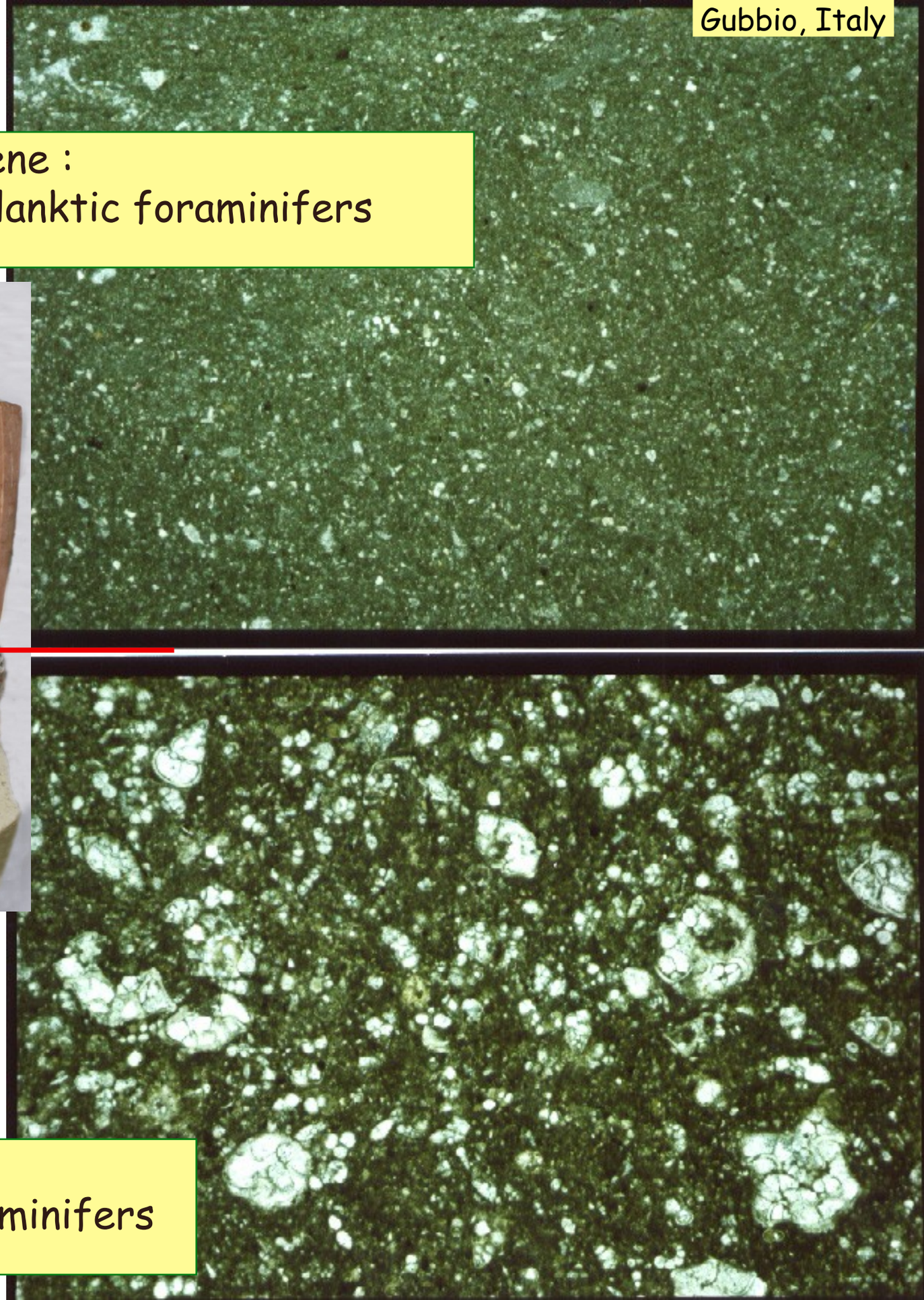
Figure 2. $^{40}Ar/^{39}Ar$ laser incremental heating spectra



Mass extinctions

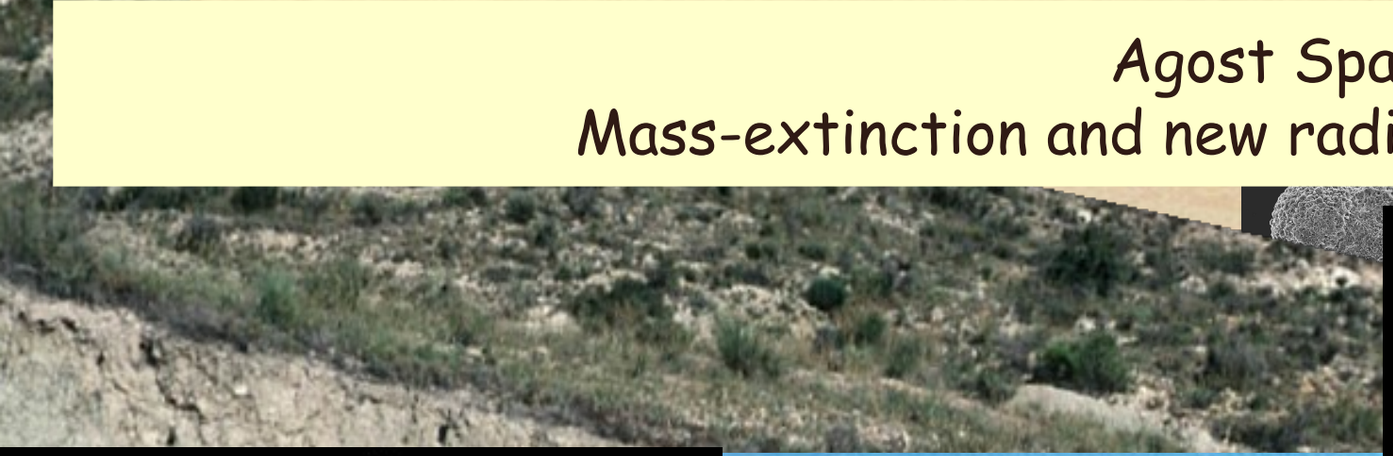
Lowermost Paleocene :
exclusively small planktic foraminifers

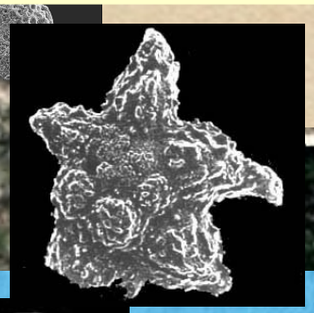


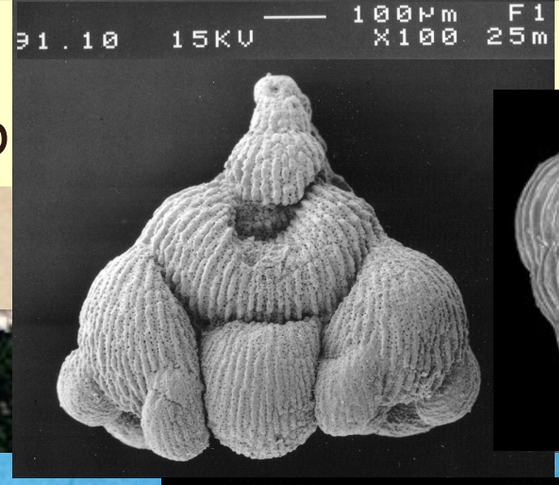


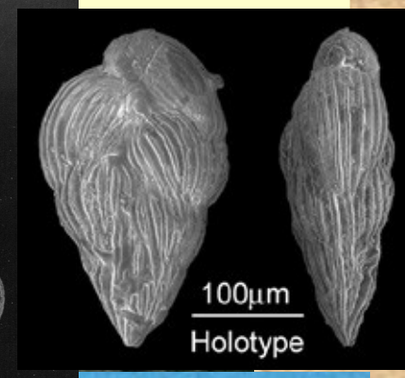
Uppermost Maastrichtian:
Abundant large, specialized planktic foraminifers

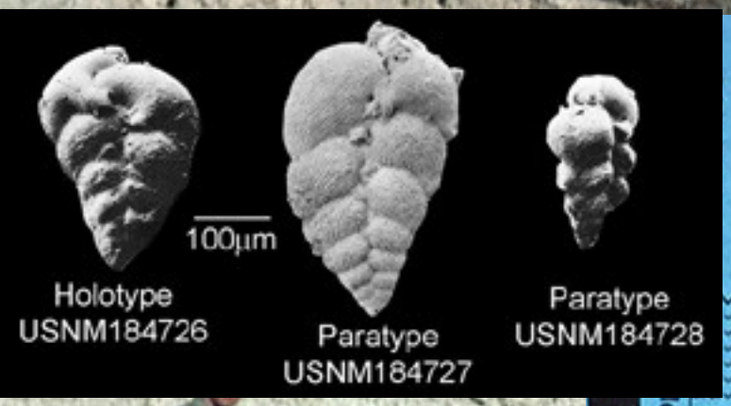
Agost Spain:
Mass-extinction and new radiation of Fo

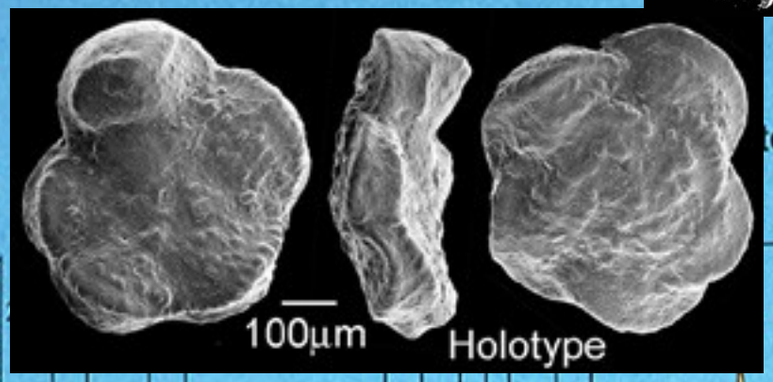


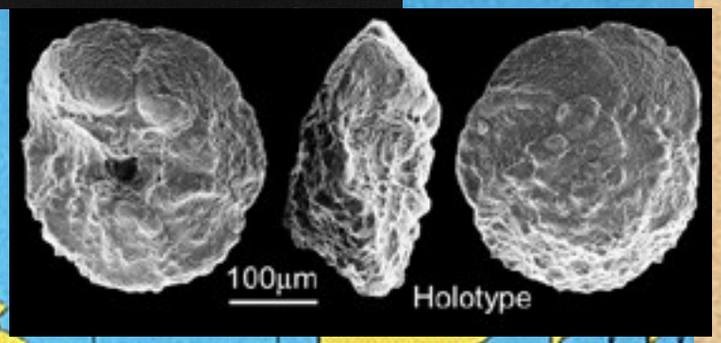






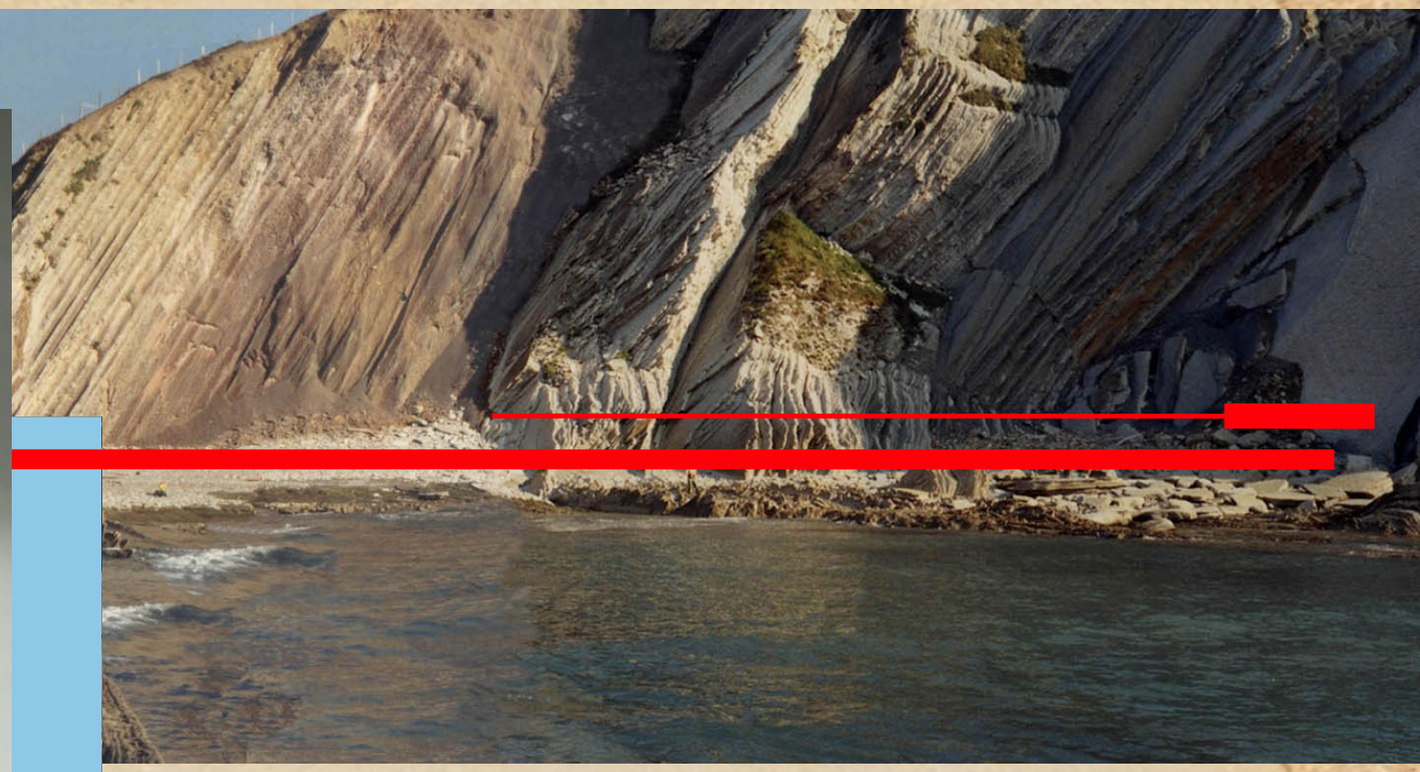






Zumaia, Bay of Biscaye ammonite and inoceramus ranges

Ammonites



Interior
l Mammal
Bug Creek
ana

There are two major problems:
A: Too many Z-coals (=K/T boundaries)
B: Cut off by rivers containing the mammalfossils

W- coal

Tertiary

Z-coal -coal

Cretaceous

Tullock fm. **(Paleocene)**

New (placental) mammals seemingly co-evol
disappearance of dinosaurs.....
.....Below the K/T boundary (?!)

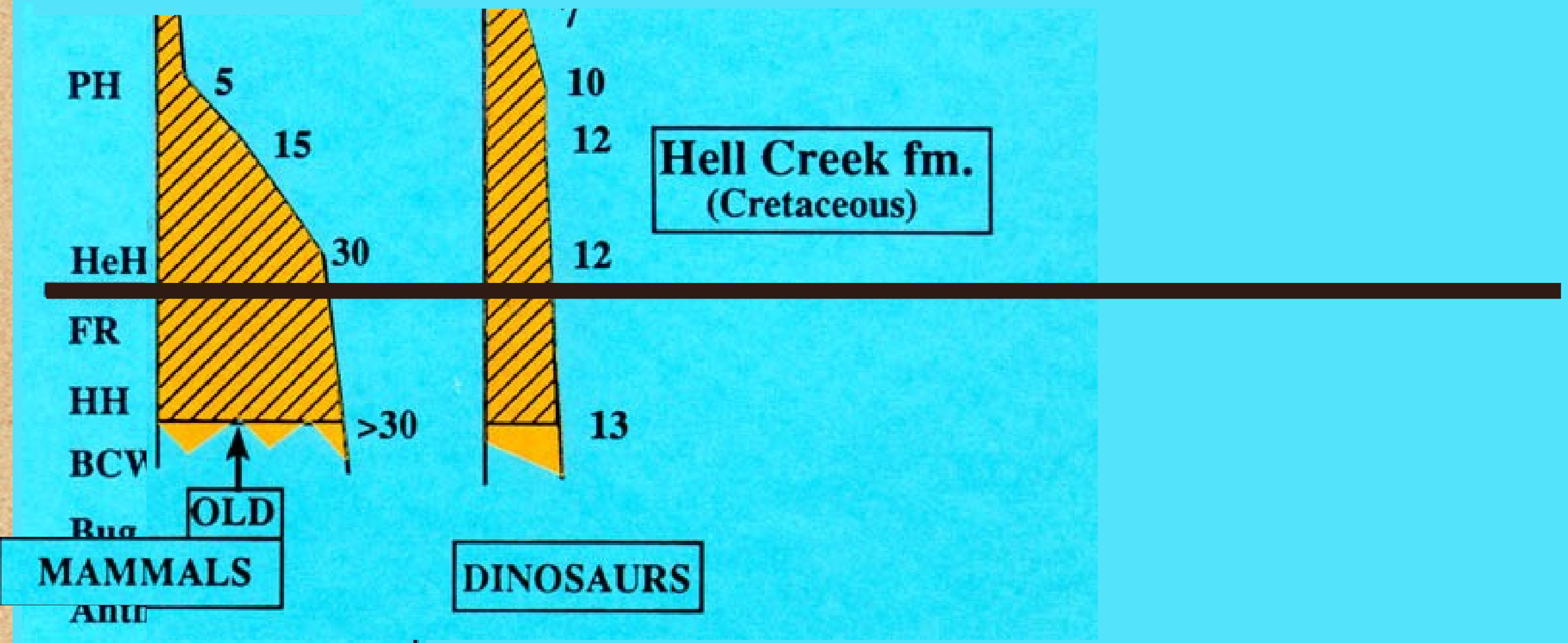
Textbook picture
of dinosaur extinction and
Mammalian evolution

Tulloch

So two changes had to be made:

1) Lower the KT boundary

2) Put the Paleocene mammals above the K/T boundary



Ken's Saddle

NEW

MAM

Deccan lava flows;
Cause of extinction?

Deccan traps, but where?

Zumaya, Spain

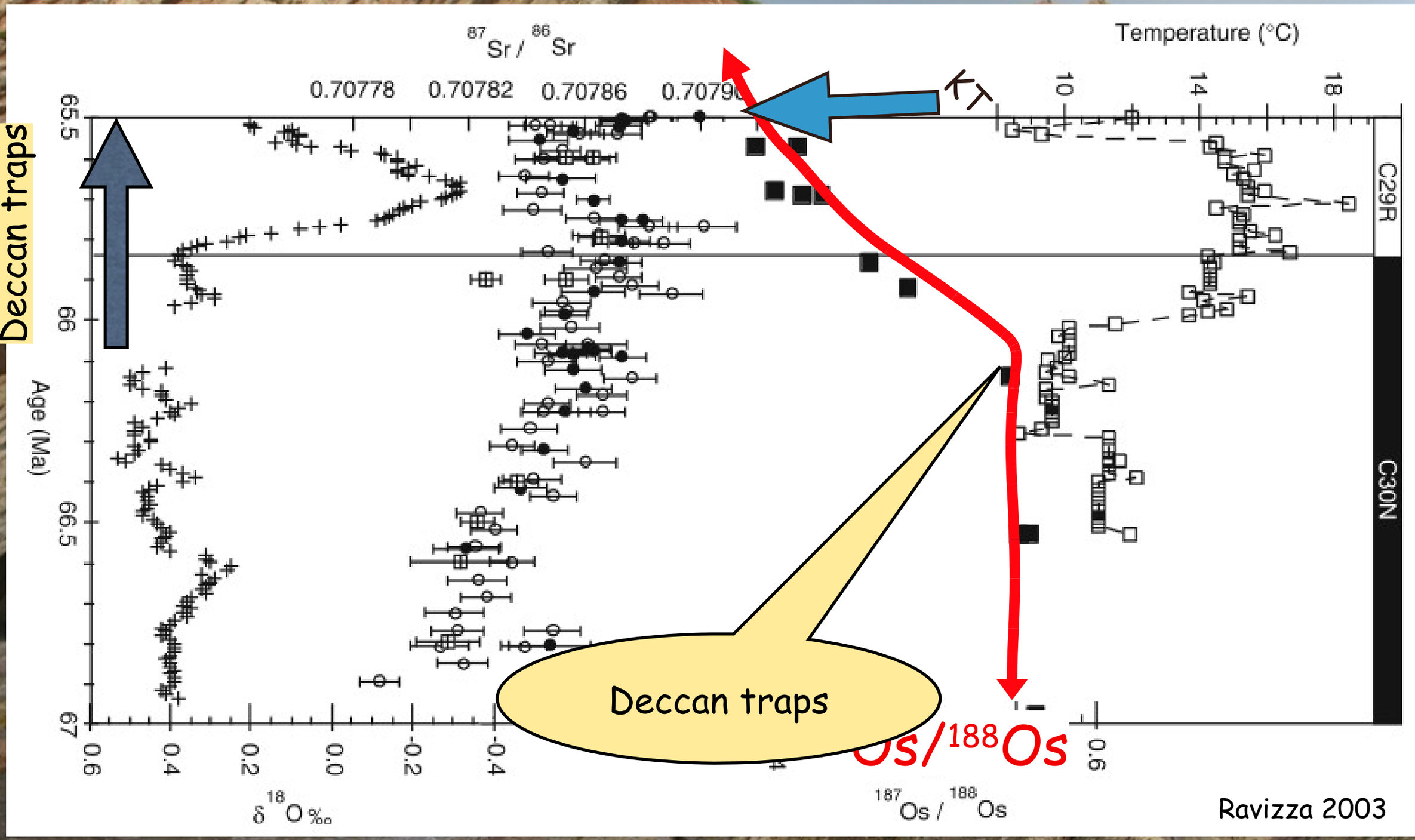
Deccan traps, but where?

Zumaya, Spain

Extinction, $\partial^{18}O$ stable isotopes, $^{187}Os/^{188}Os$, $^{87}Sr/^{86}Sr$ terrestrial temperatures

+/- 0.5 Ma before KT

KT



Ravizza 2003

Deccan traps, but where?

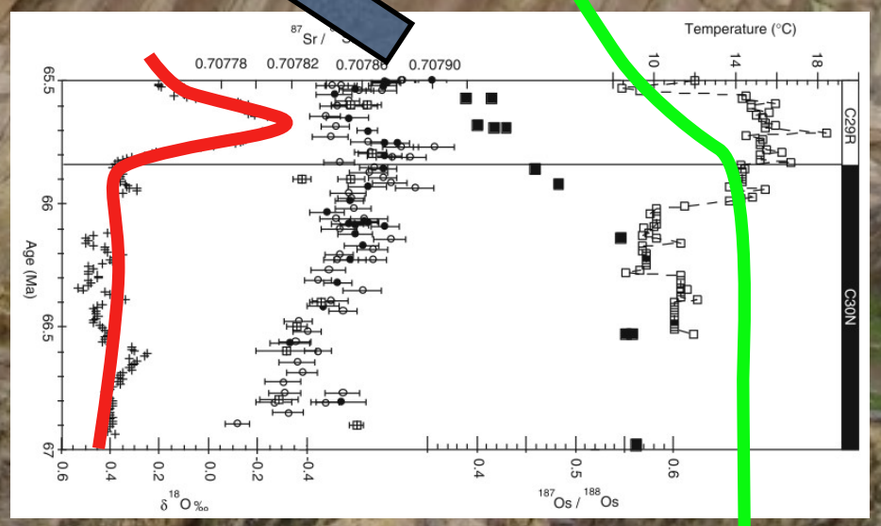
KT

temperature rise

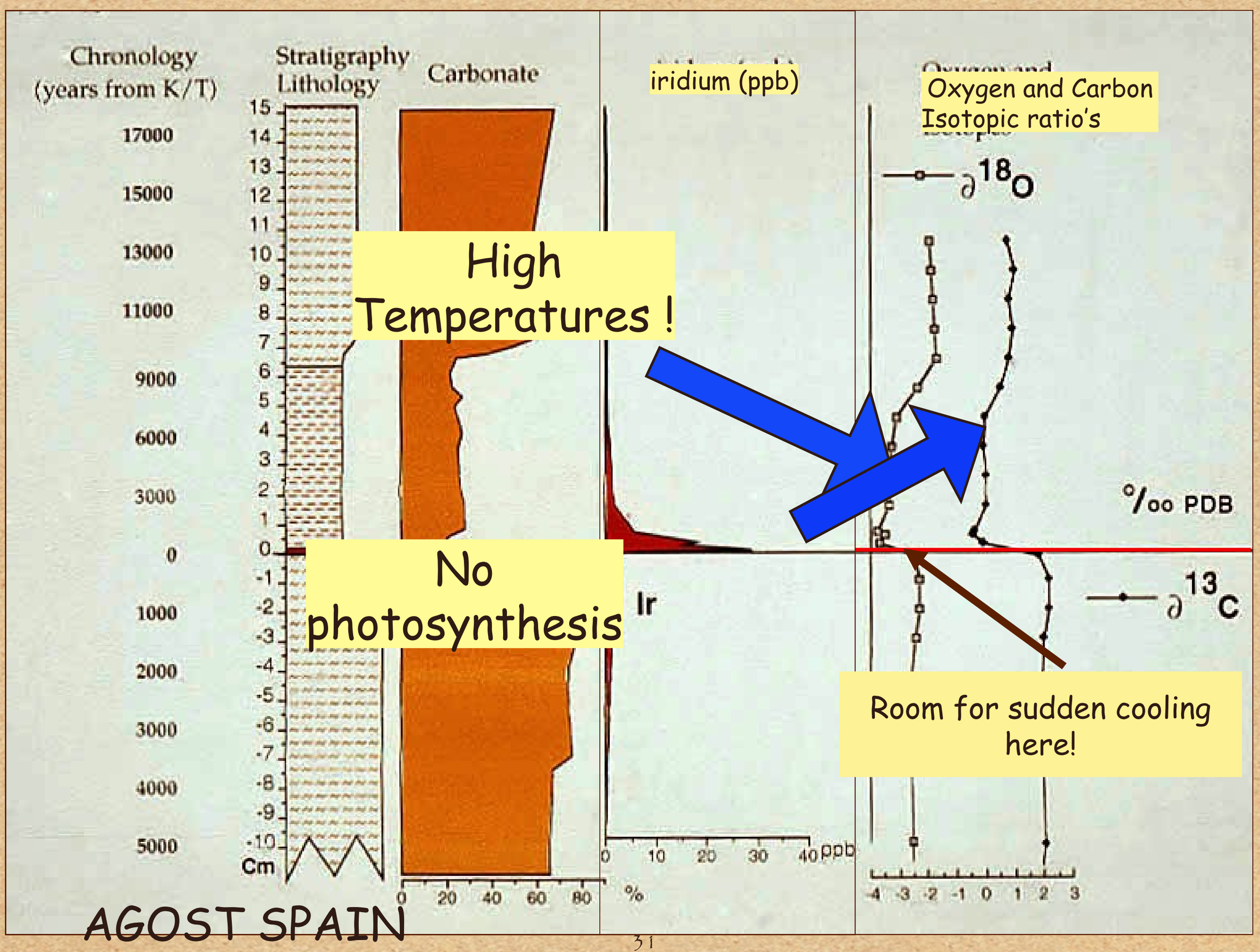
Deccan traps

osmium isotopes

73 72 71 70 69 68 67 66 65 64 63 62 61 60 59 58 57 56 55 54 53 52 51 49 48 47

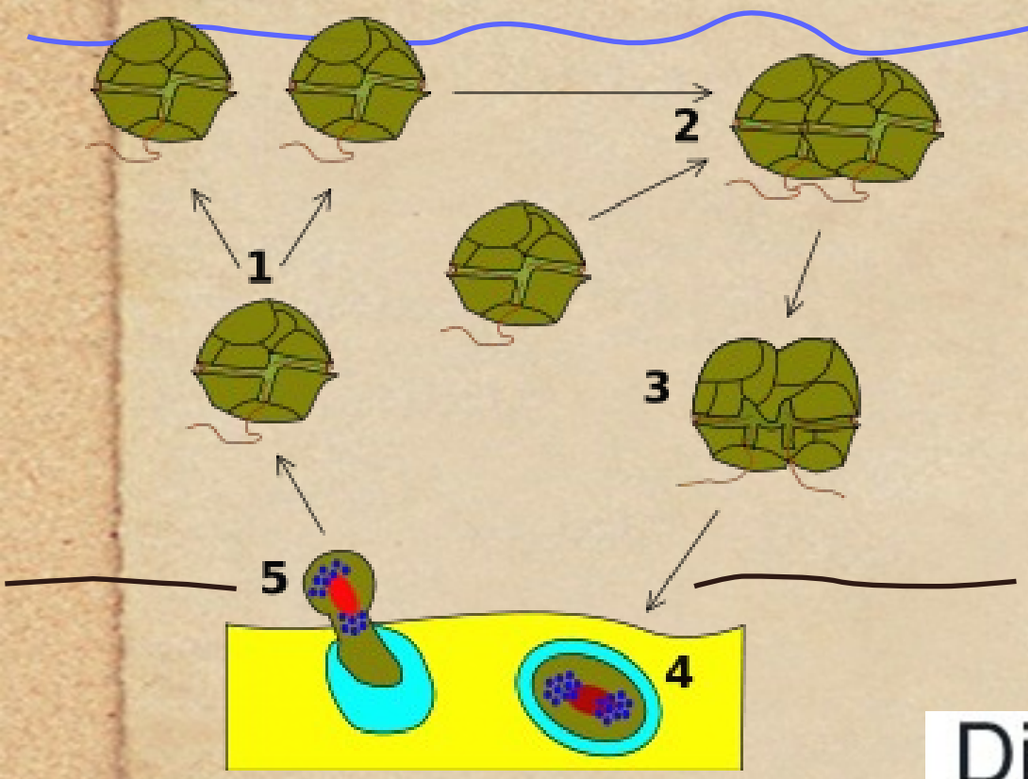


Zumaya, Spain

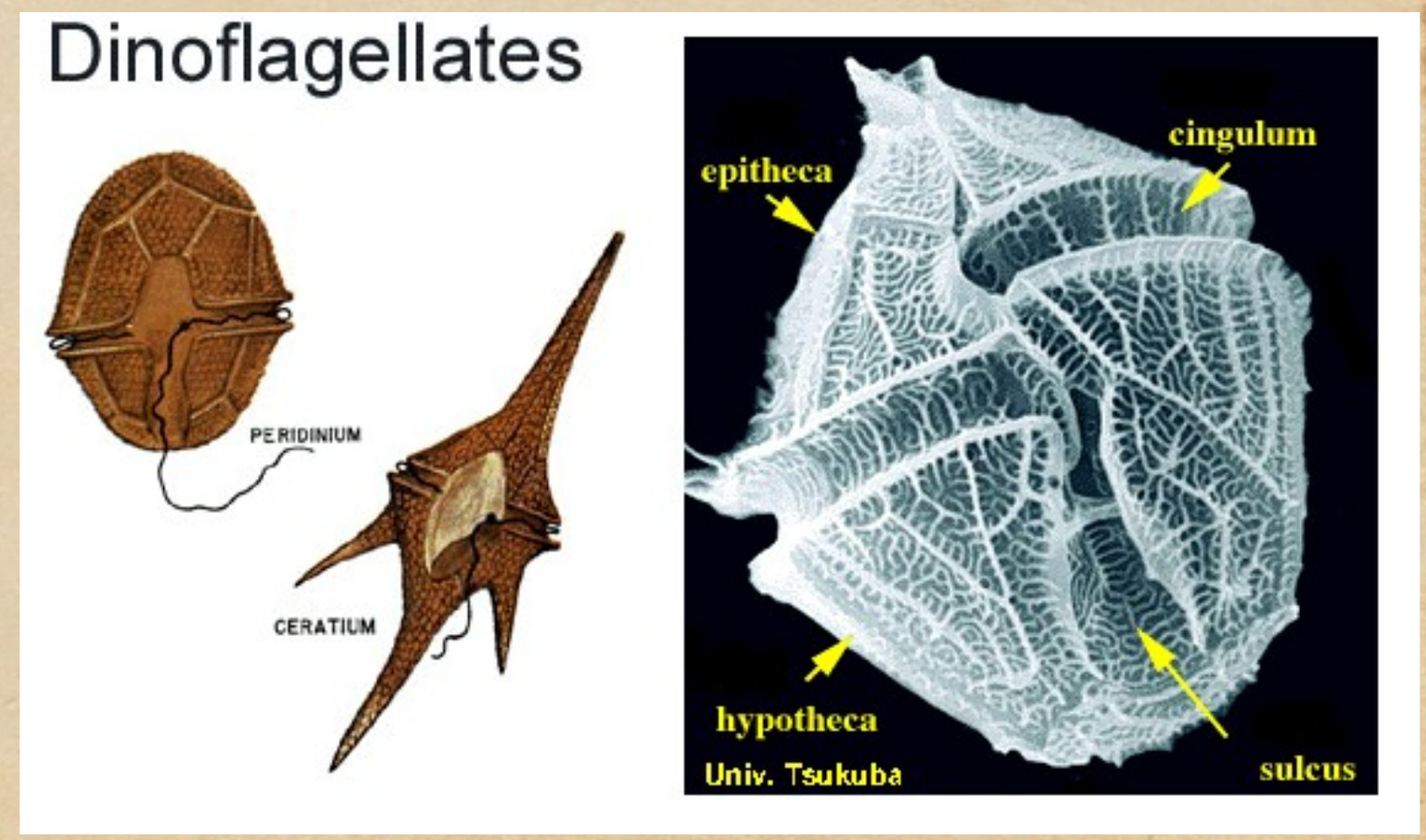

Chronology
(years from K/T)
17000
15000
13000
11000
9000
6000
3000
0
1000
2000
3000
4000
5000
Stratigraphy
Lithology
Cm
Carbonate
0 20 40 60 80 %
iridium (ppb)
Ir
0 10 20 30 40 ppb
Oxygen and Carbon
Isotopic ratio's
∂18O
‰ PDB
∂13C
-4 -3 -2 -1 0 1 2 3
High
Temperatures !
No
photosynthesis
Room for sudden cooling
here!

AGOST SPAIN

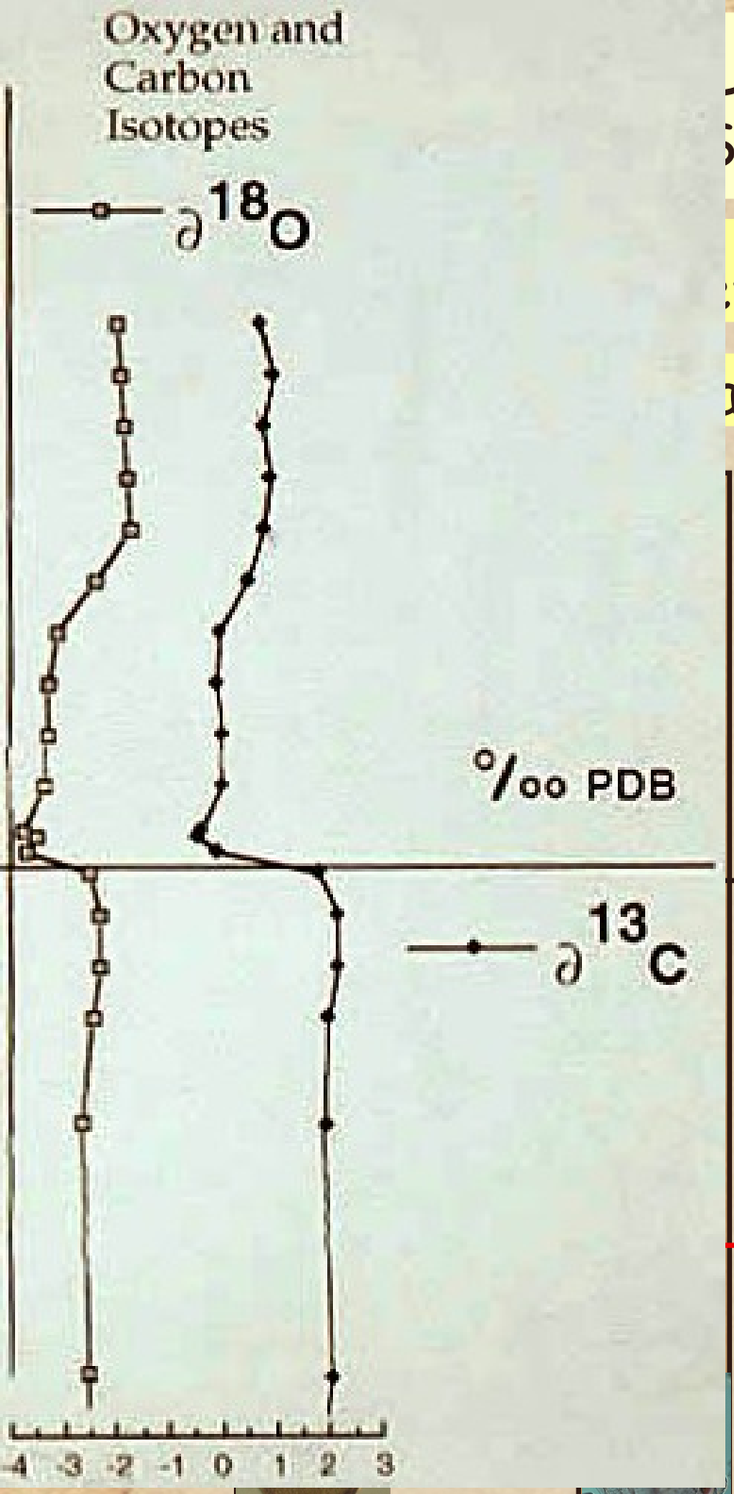
Dinoflagellates: NO species disappear!

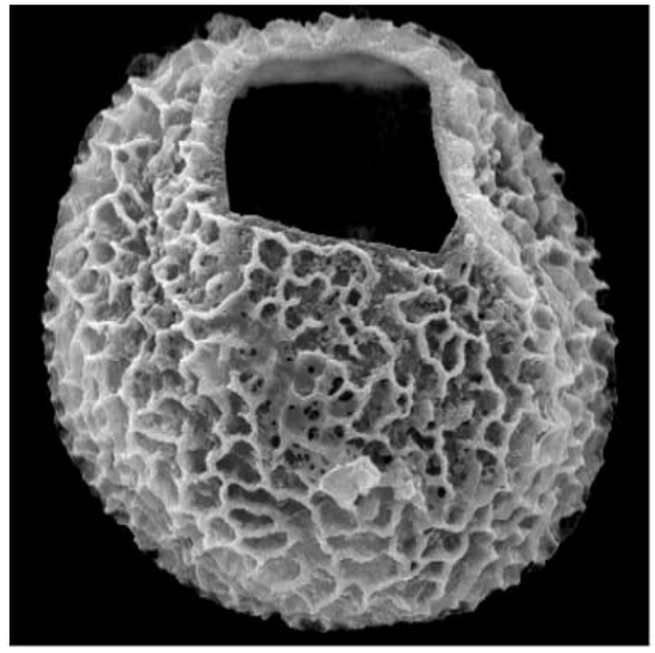


Thus, in contrast to forminifers, who become extinct, dinoflagellates can react to the changing circumstances after the Chicxulub impact



LATE CYST MIGRATIONS
S THE K/T BOUNDARY





f

Agost

Geulhem

a

Spain

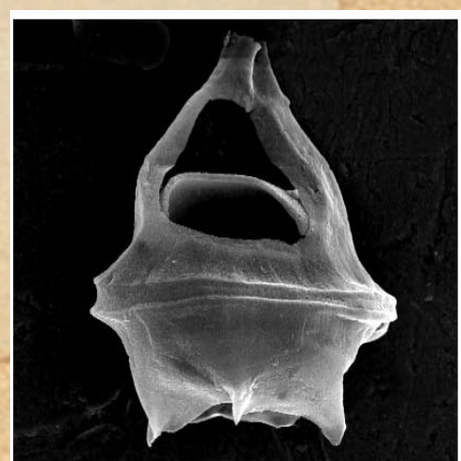
Holland

Denmark

5000yrs

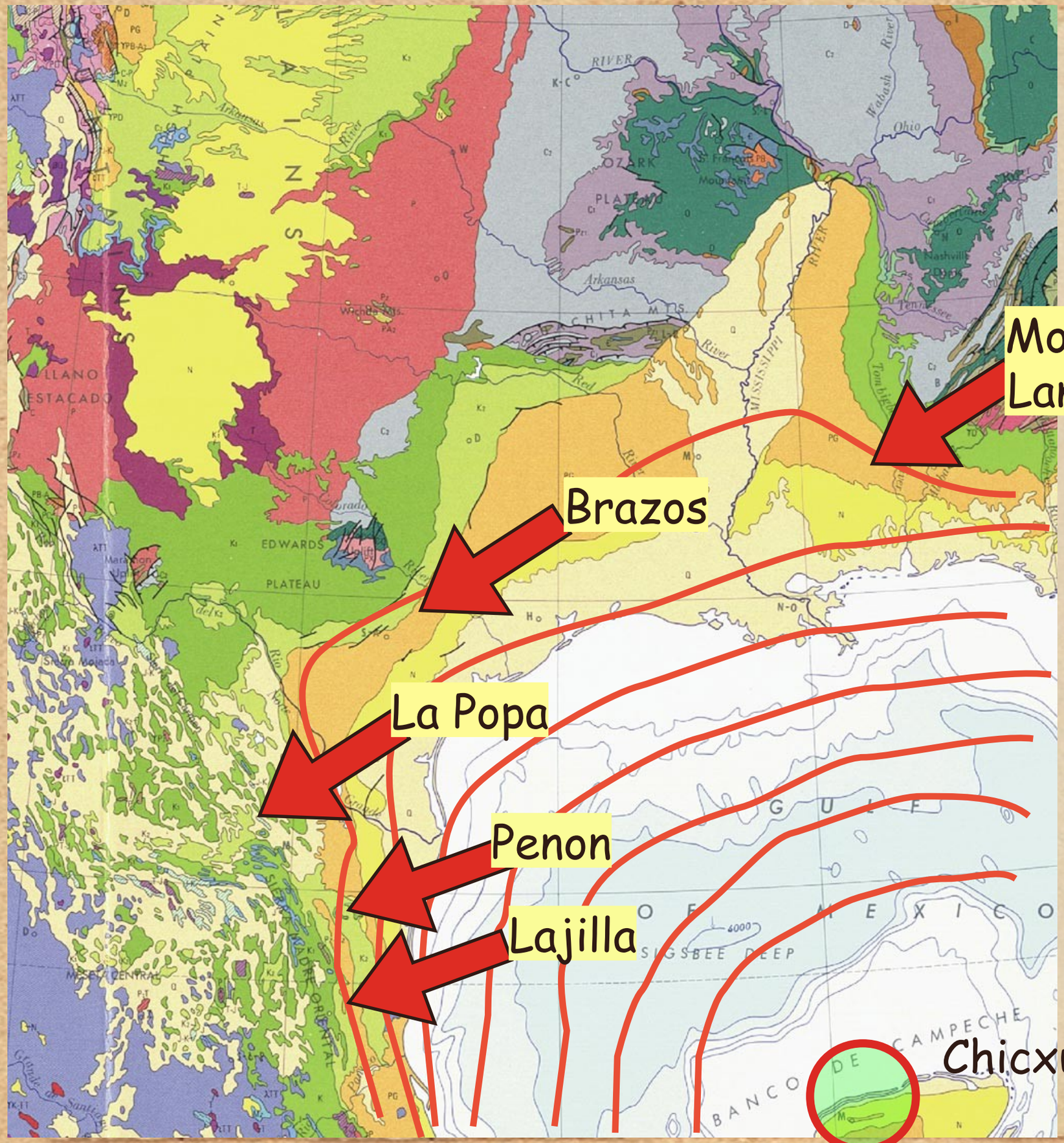
Cooling (?<50yr)

Warm
>1Ma



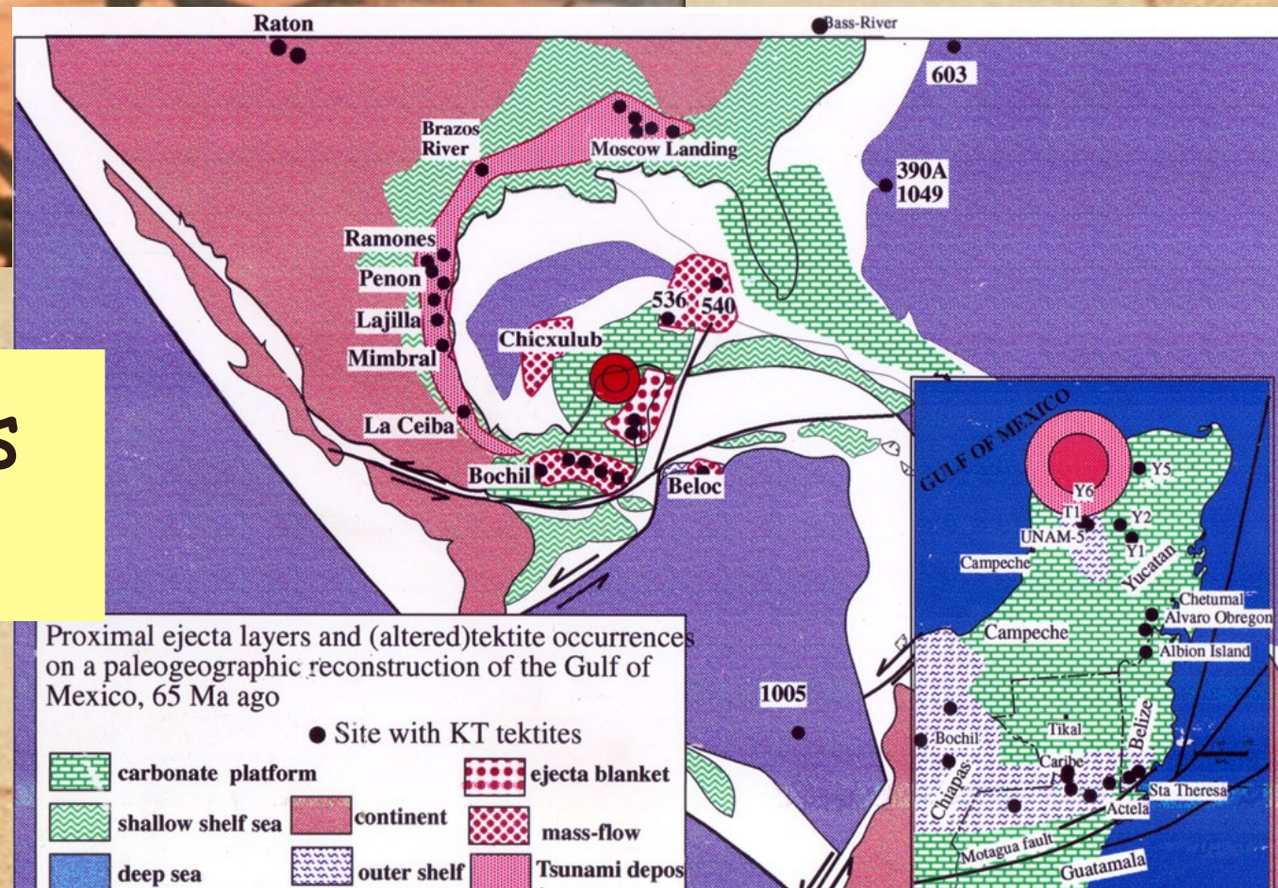
(Brinkhuis et al
1998 Paleo3x)

Where it gets complicated: the Gulf of Mexico

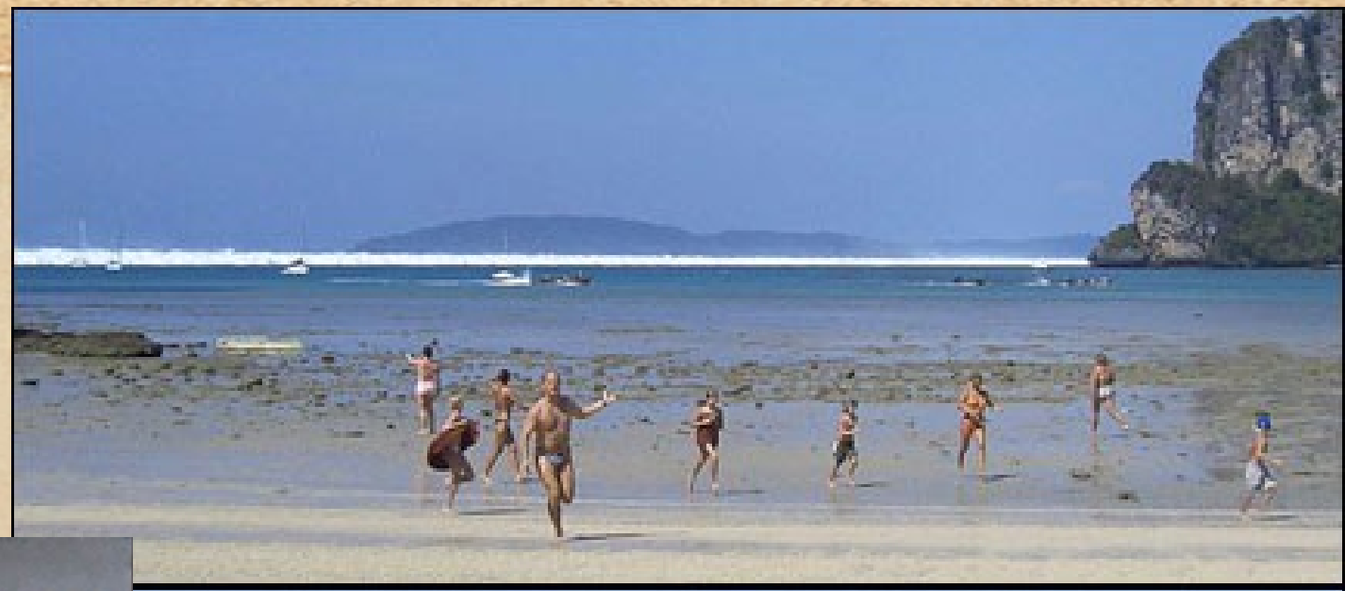


Tsunami deposits around the Gulf

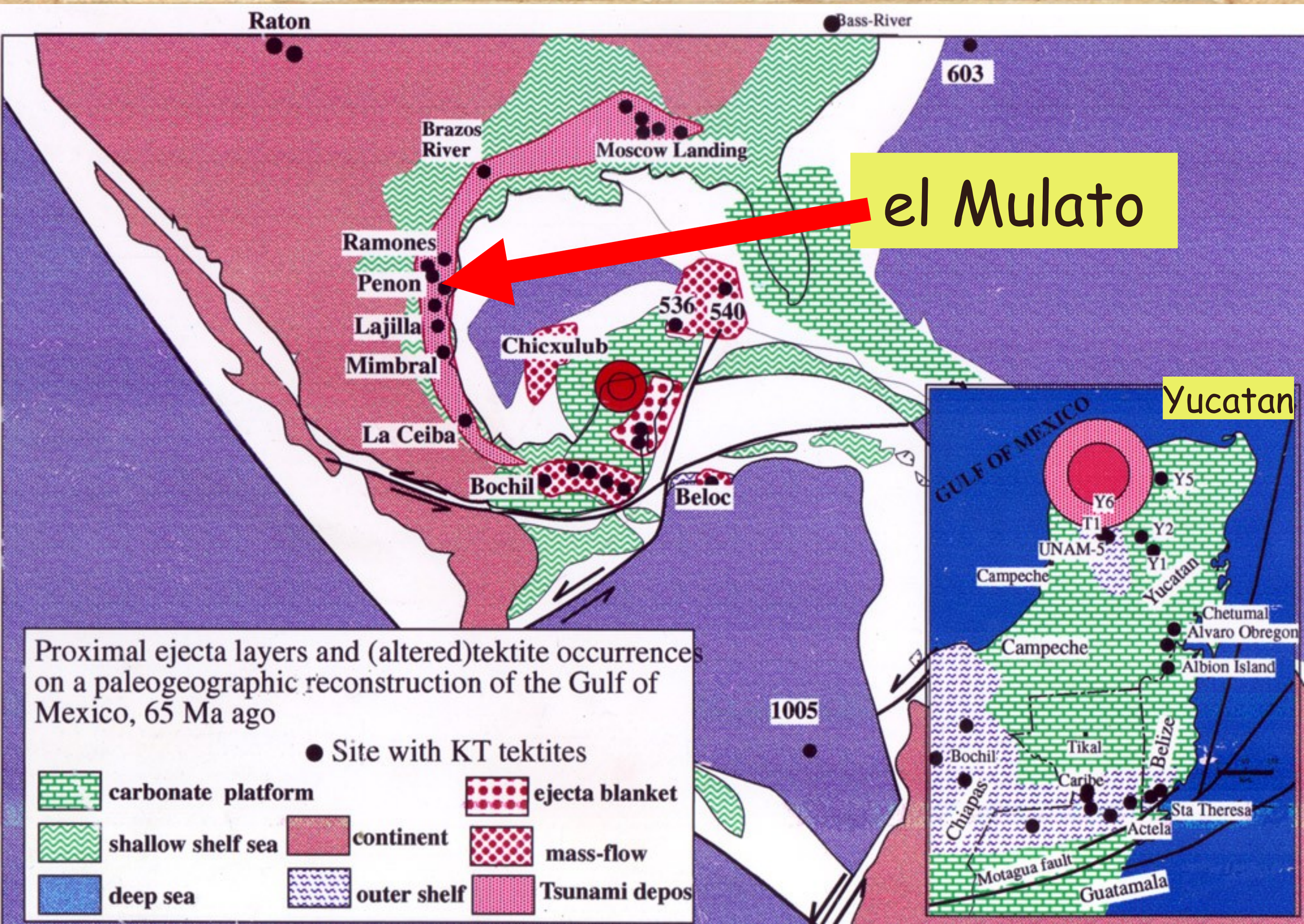
Impression of Tsunami waves around the Gulf of Mexico



TSUNAMI: Wall of water, strong tidal surges, not waves.



map of the Chicxulub impact region 65 Million years ago



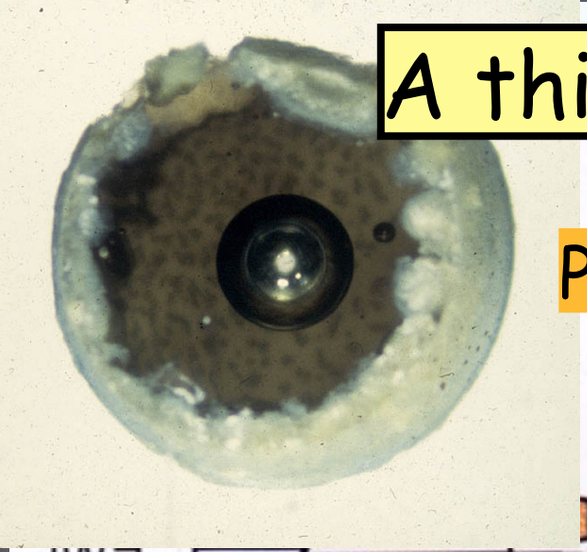
A thick, complex sandstone around the Gulf at K-Pg

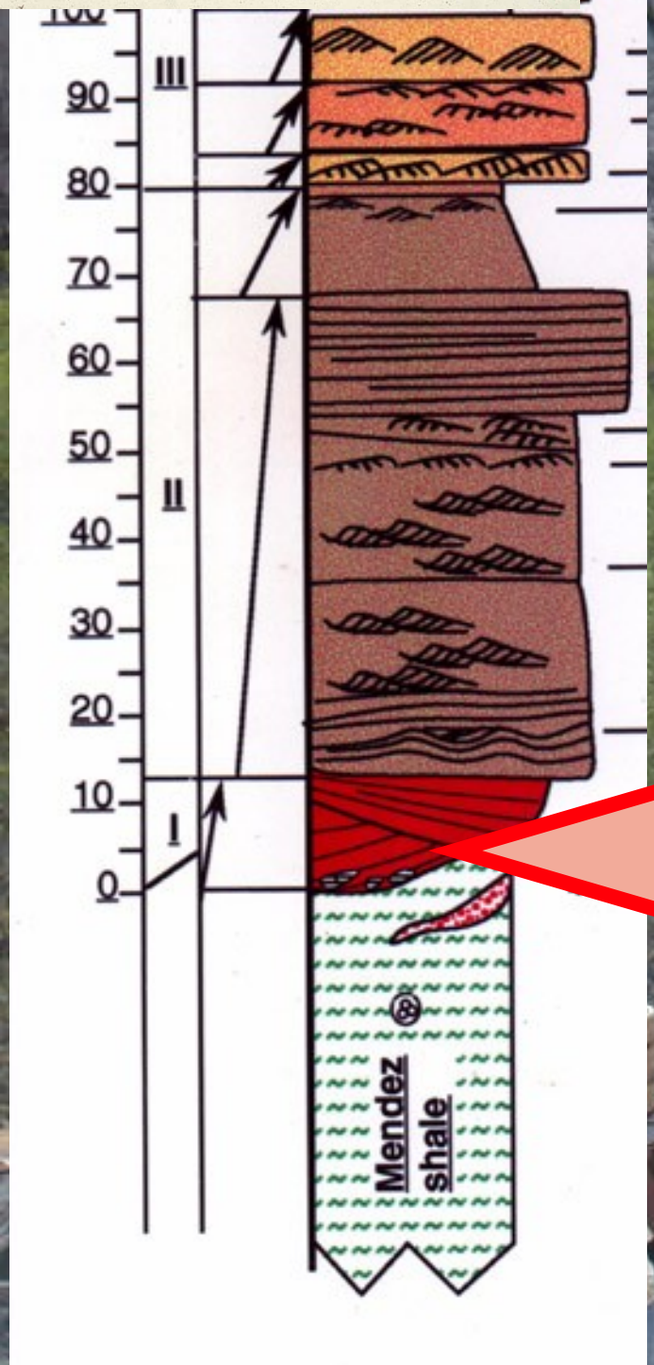
Paleocene

el Mulato

Maastrichtian

A thick, complex sandstone around the Gulf at K-Pg





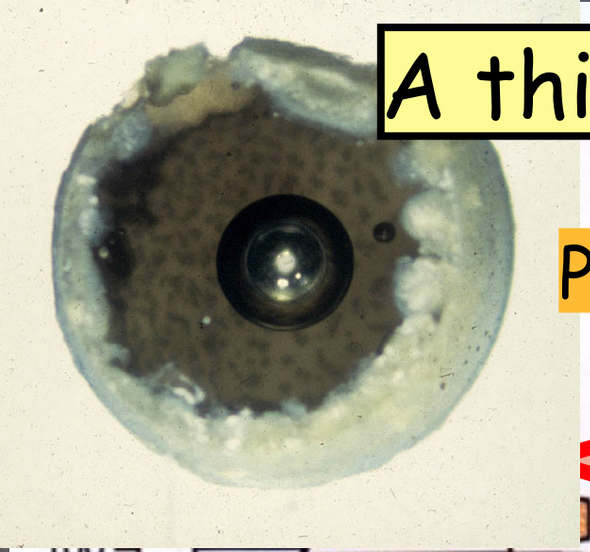
Paleocene

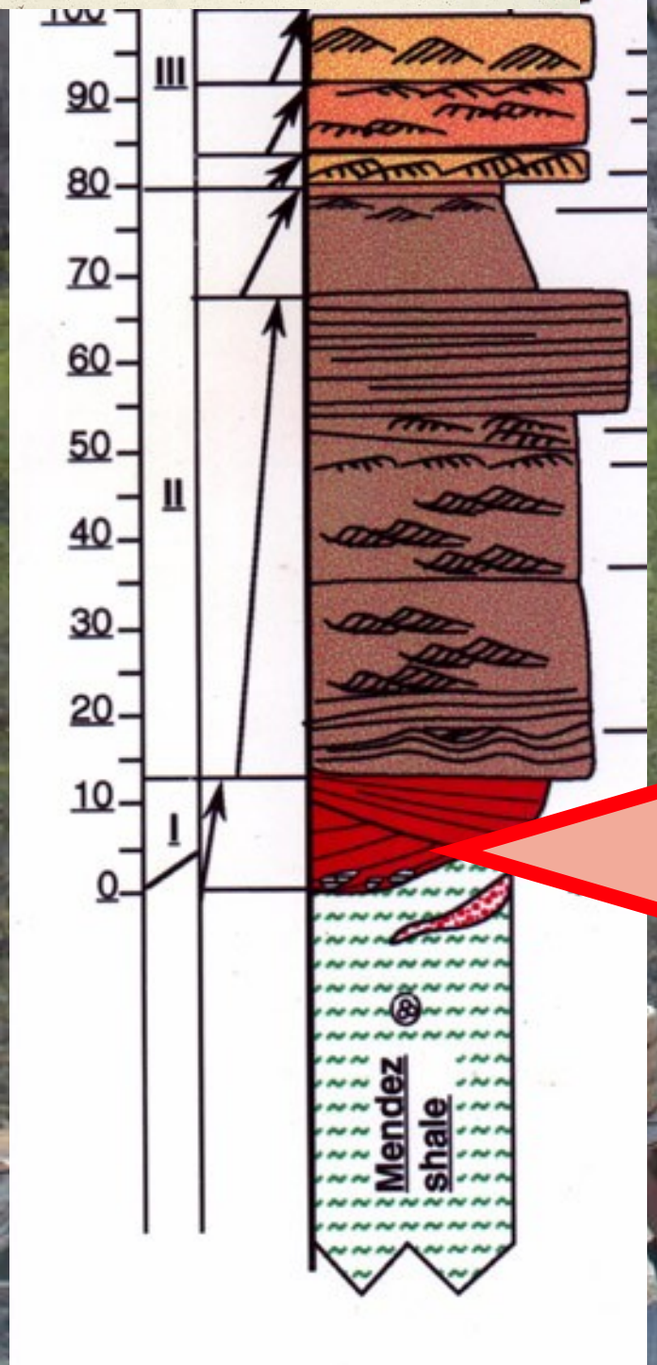
el Mulato

Maastrichtian

Impact spherules at bottom

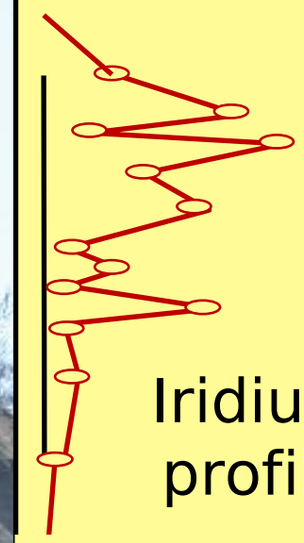
A thick, complex sandstone around the Gulf at K-Pg





Paleocene

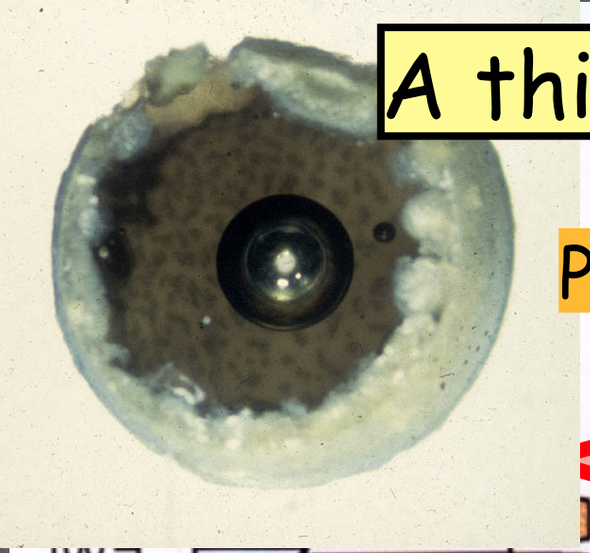
iridium at the top

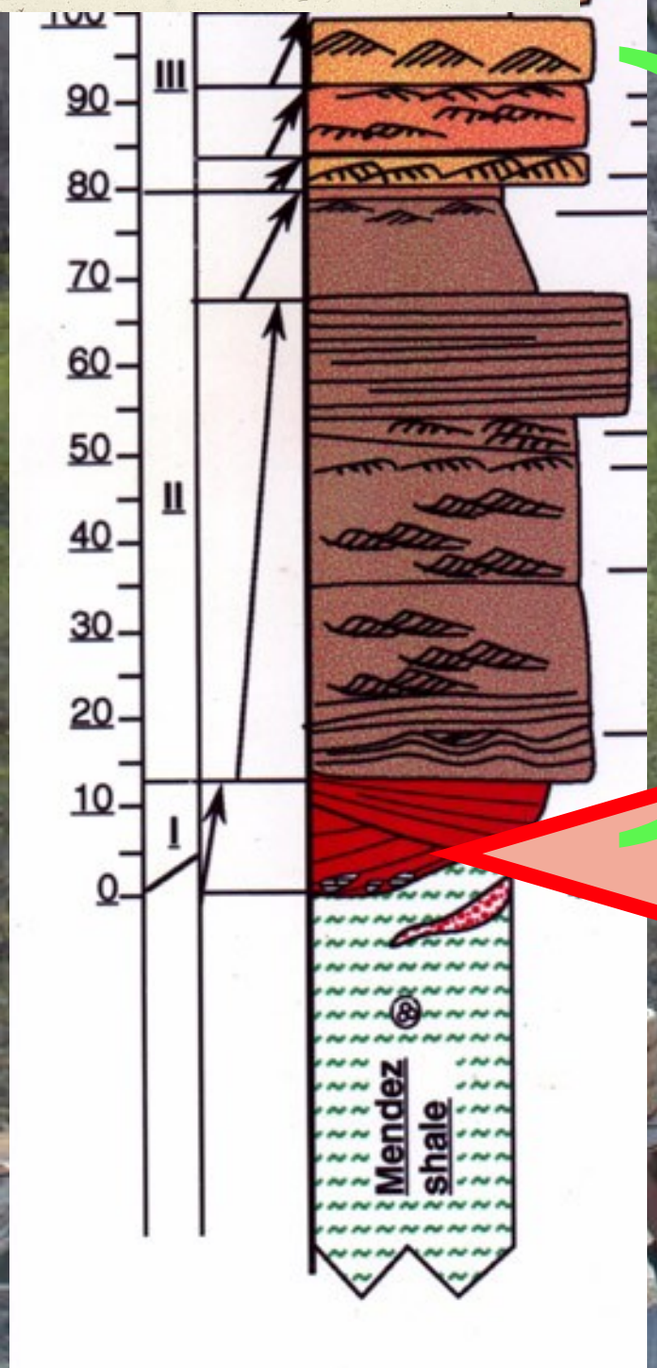


Maastrichtian

Impact spherules at bottom

A thick, complex sandstone around the Gulf at K-Pg





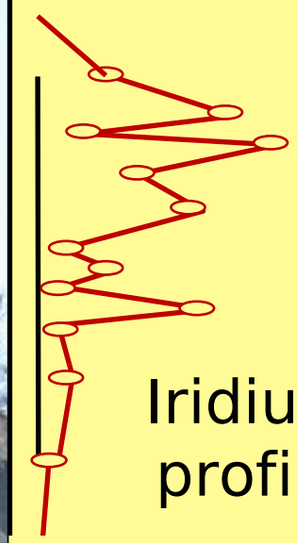
Paleocene

iridium at the top

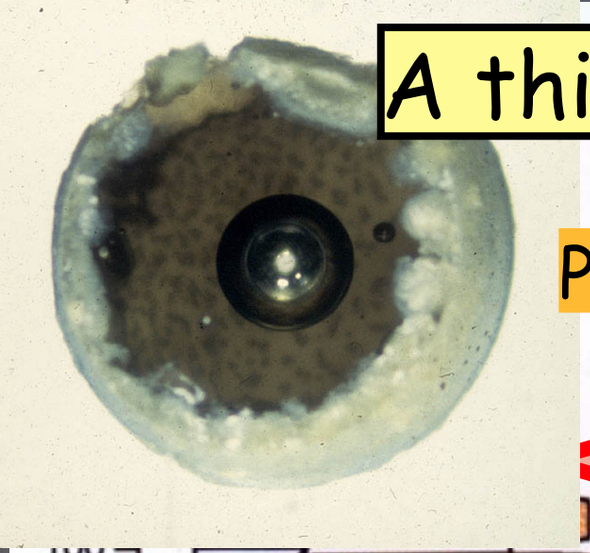
Sandstone in between

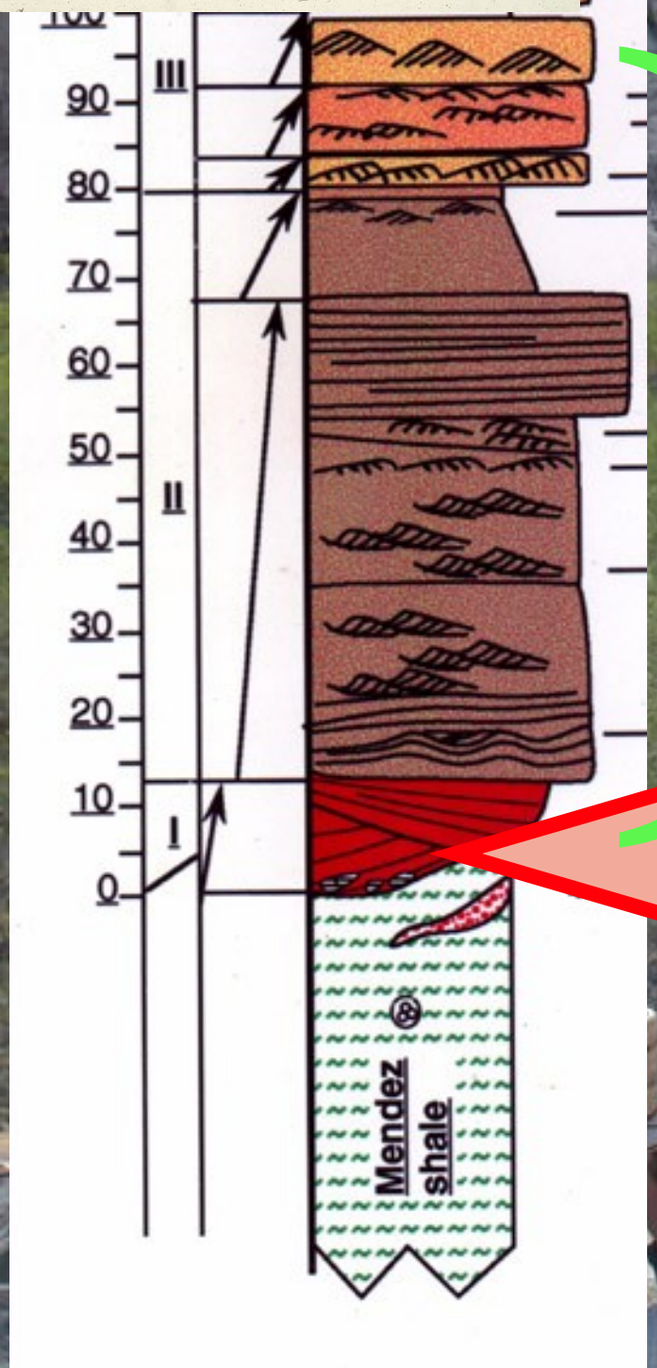
Impact spherules at bottom

Maastrichtian



A thick, complex sandstone around the Gulf at K-Pg





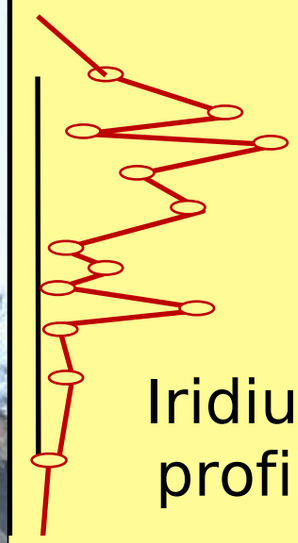
Paleocene

iridium at the top

Sandstone in between

Impact spherules at bottom

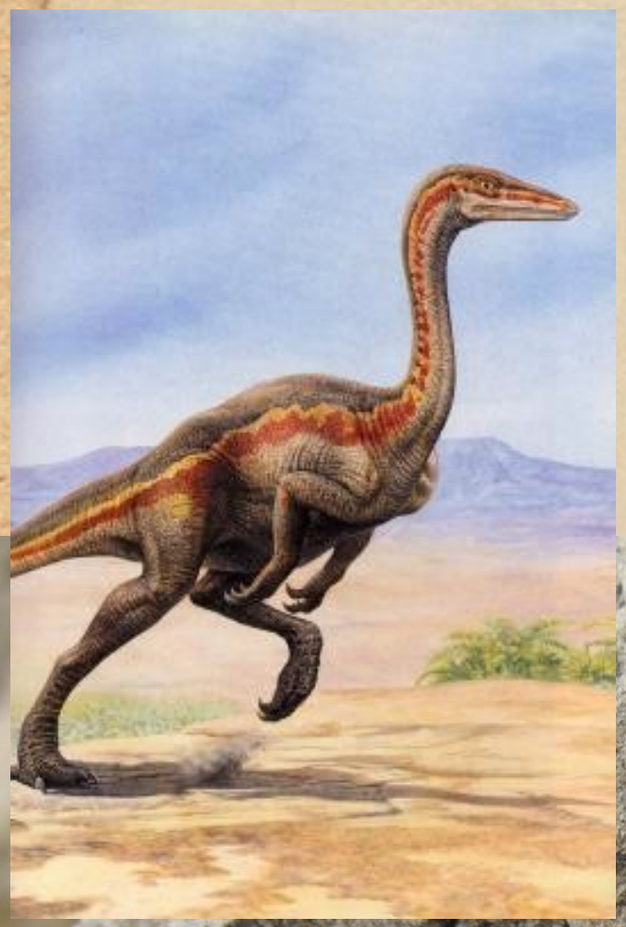
Maastrichtian



La Popa basin, Monterrey, Mexico tsunamiite

La Popa basin, Monterrey, Mexico tsunamiite

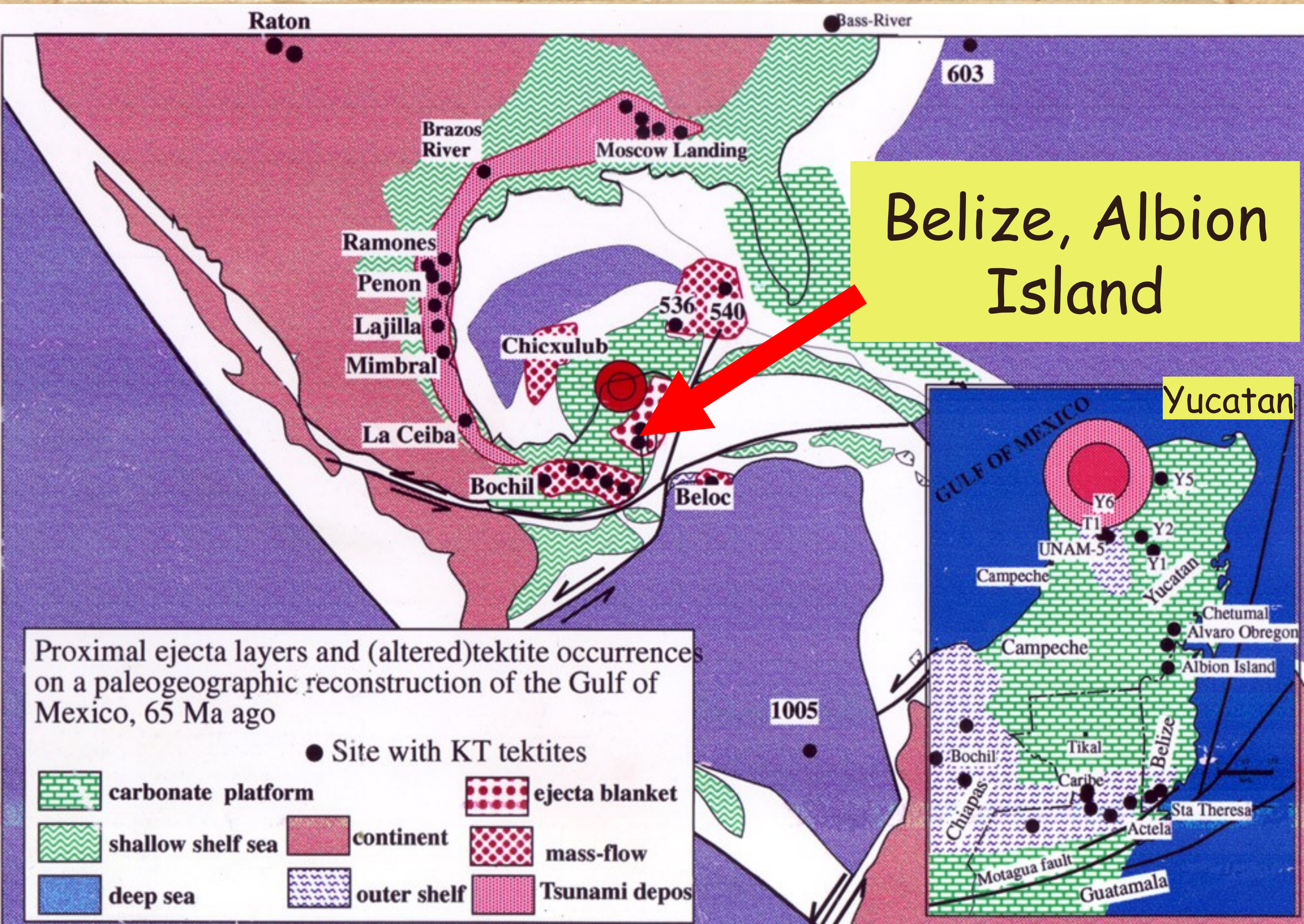
Mosasaur vertebra



Dinosaur (Ornithomimus) Tooth

Tektites

Map of the Golf of Mexico, 65.8 million years ago

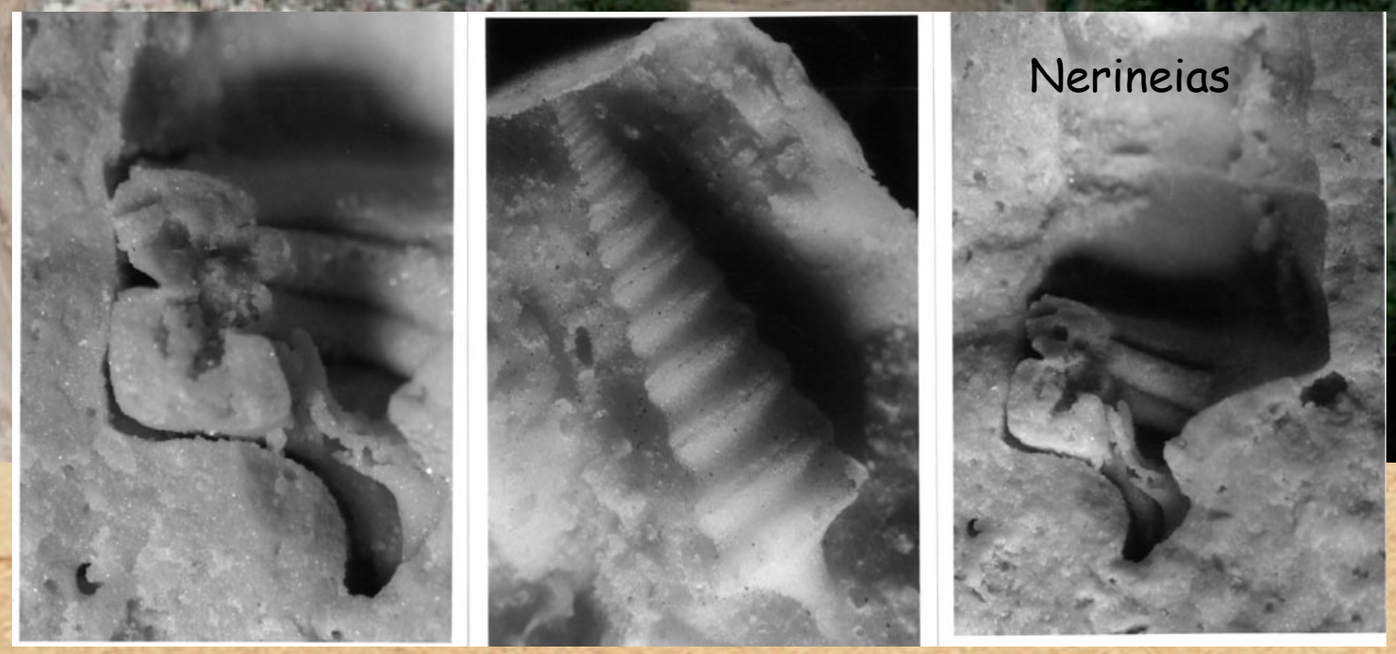


Dolomite quarry on Albion Island, Belize

Ejecta blanket

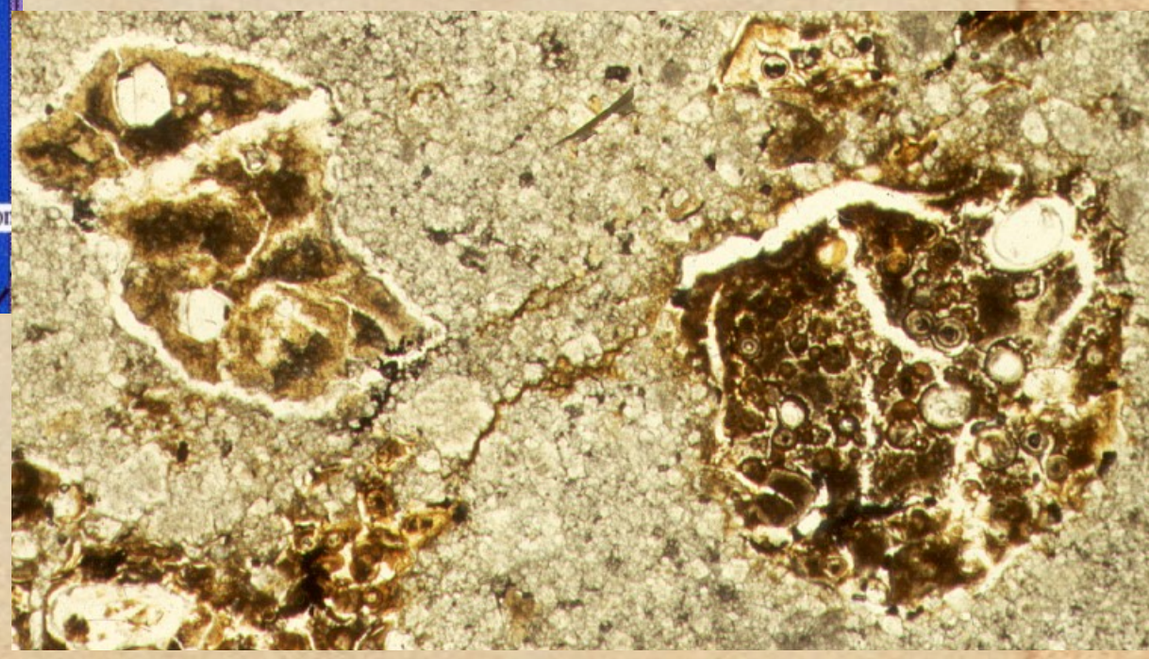
Barton Creek Dolomite

Basis ejecta blanket

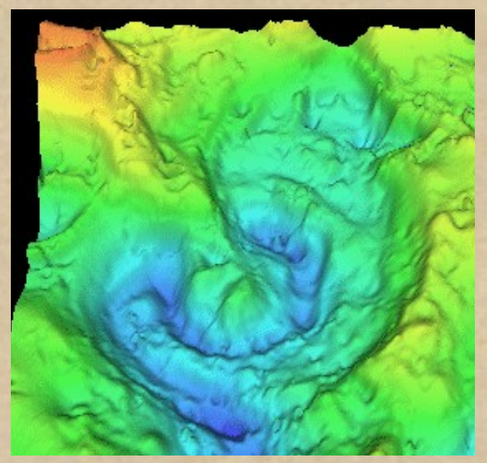


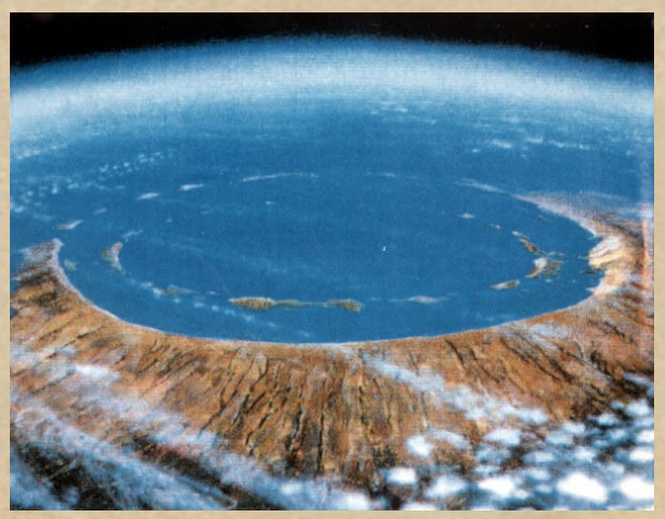
Rio Hondo bij Chetumal

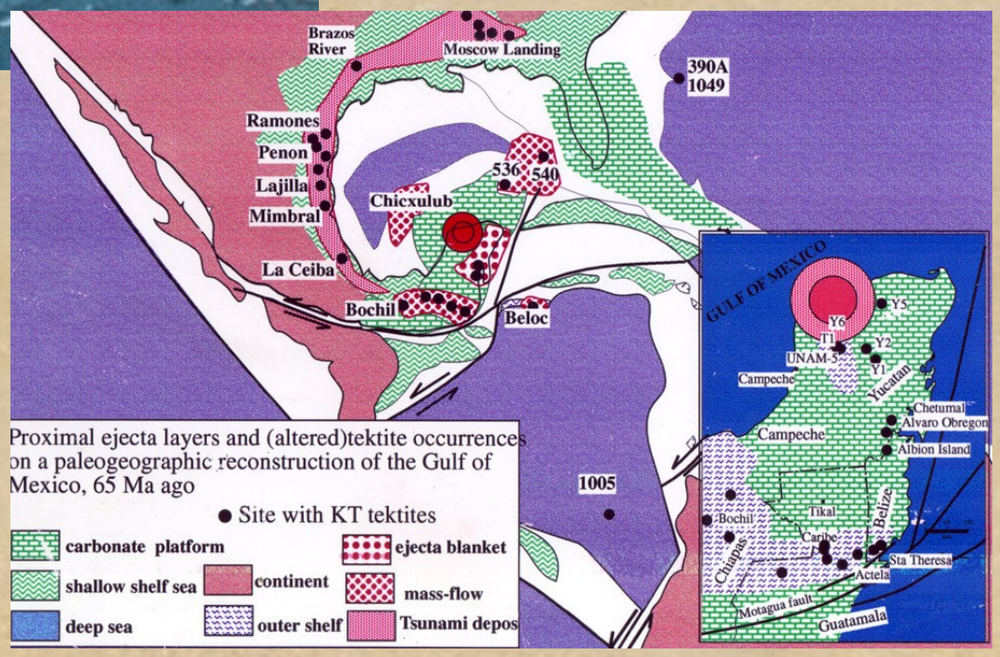
Green blebs of altered glass



The Chicxulub crater

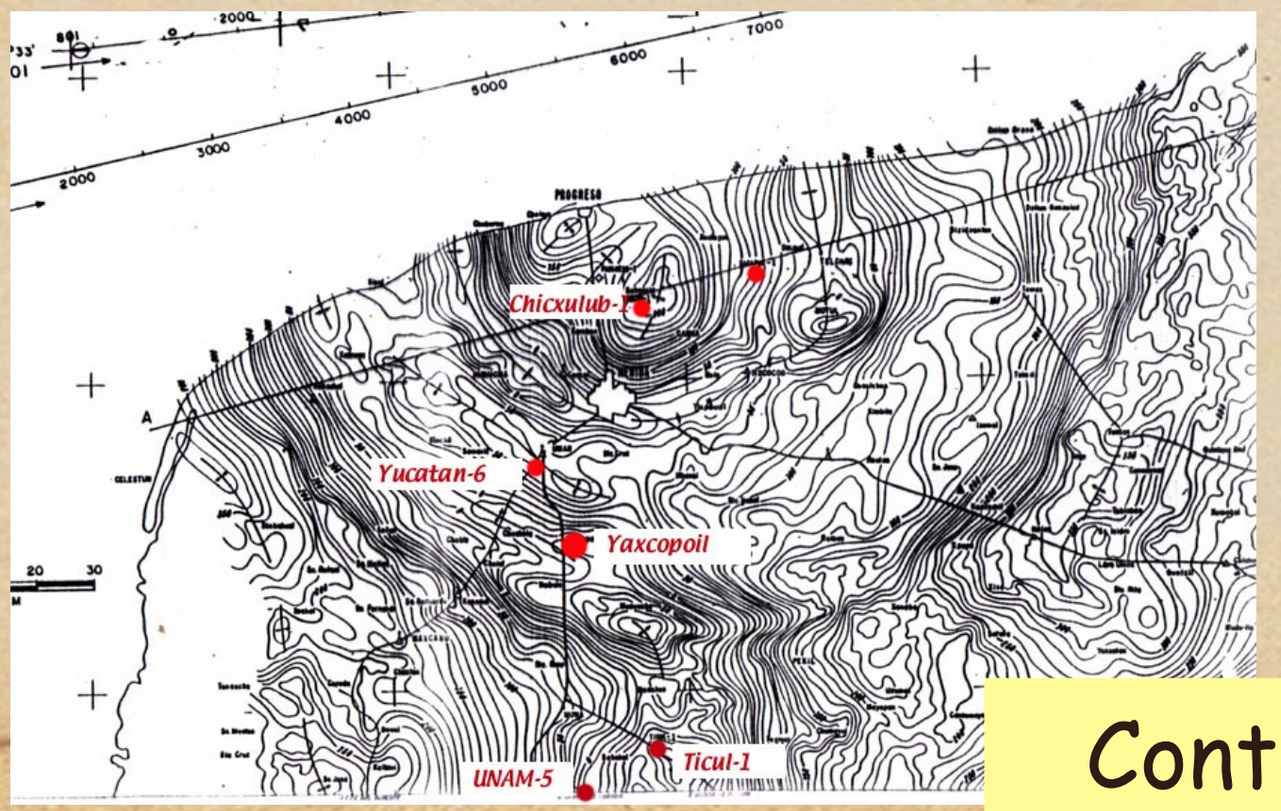


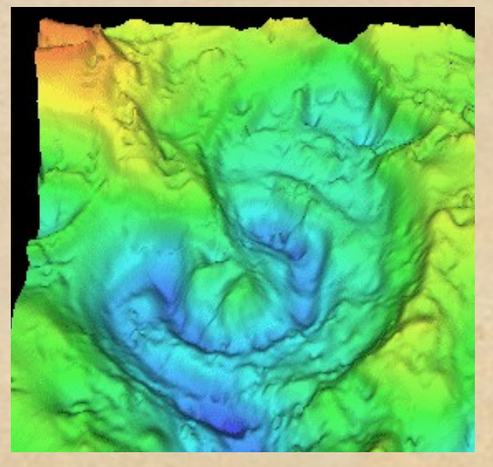




Geophysical discovery of the Chicxulub crater

Magnetic anomalies
Isomilligal contours



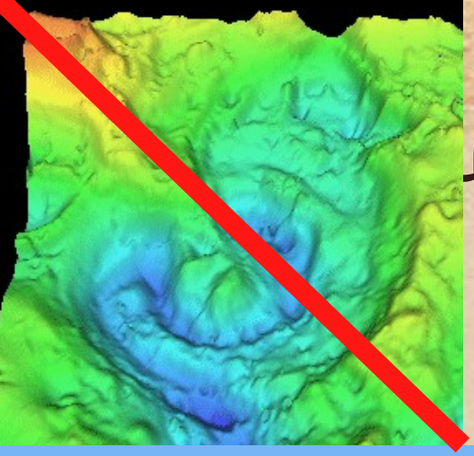


Contours of gravity anomalies

On Google Maps the Chicxulub crater is visible

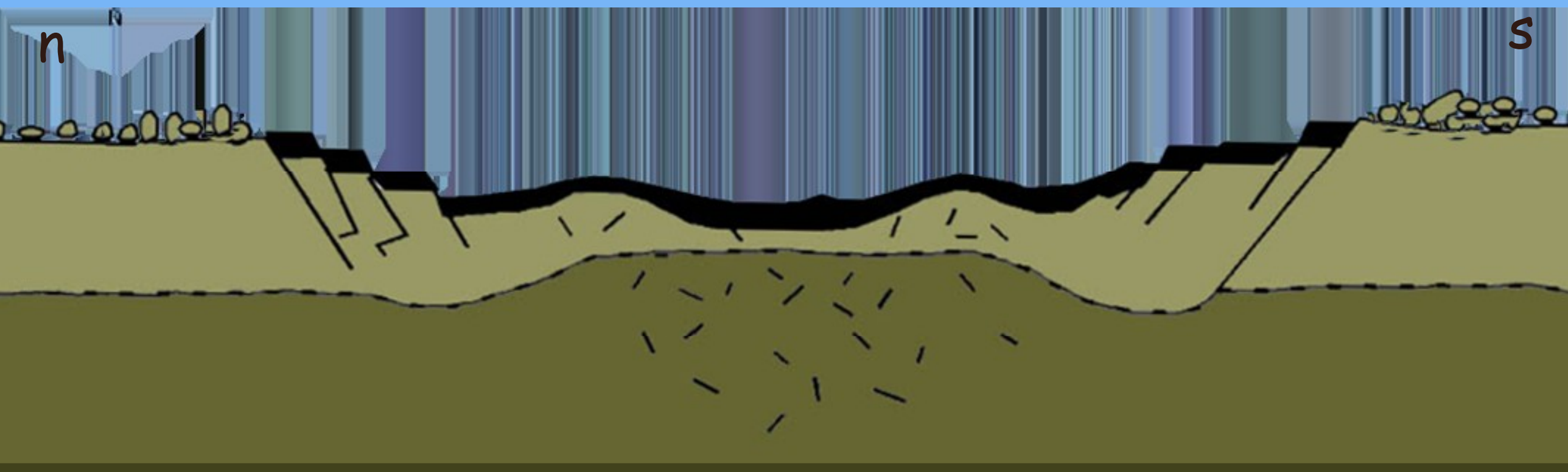
The cenote ring of the Chicxulub crater is well visible on Googe Earth!

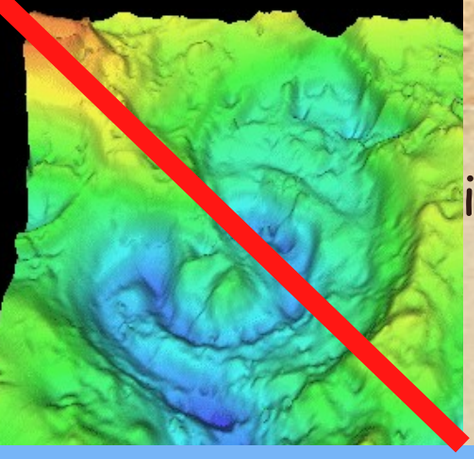
The cenote ring of the Chicxulub crater is well visible on Googe Earth!



ust after impact

YUCATAN





YUCATAN

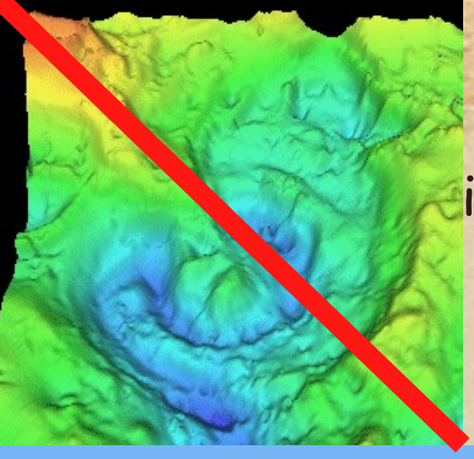
ills, while it subsides

n

s

n

s



ills, while it subsides

YUCATAN

n

s

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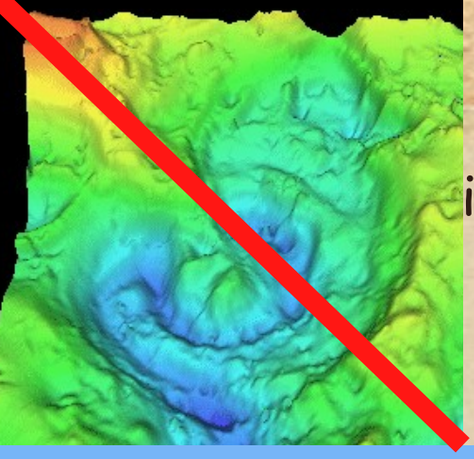
s



YUCATAN

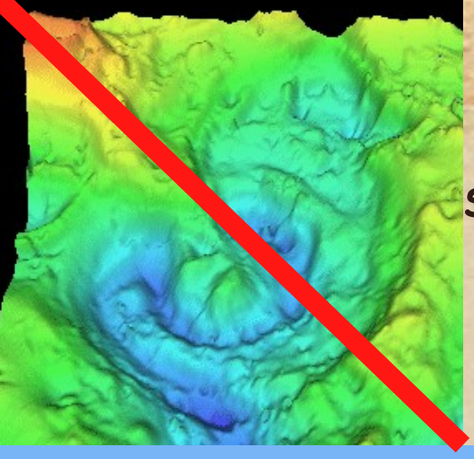
ills, while it subsides

n

s

n

s



YUCATAN

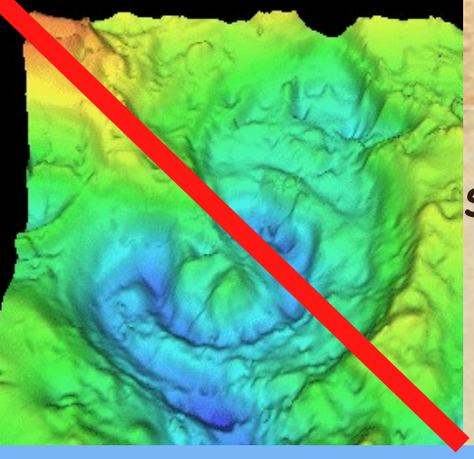
situation, half on land, half in the sea

n

Cenotes

n

s



YUCATAN

situation, half on land, half in the sea

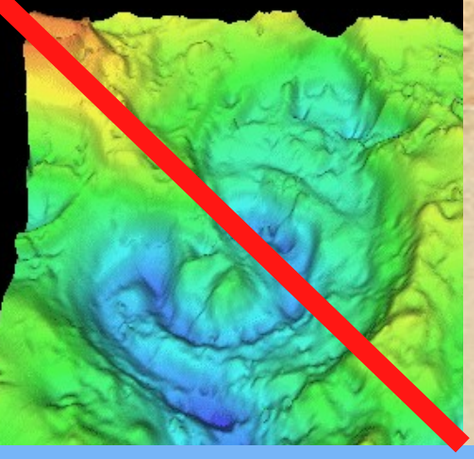
Yucatan-6

n

s

n

s



Chicxulub drilling project, CSDP initiated in 1995, excecuted 2001

Yucatan-6

Yaxcopoil-1

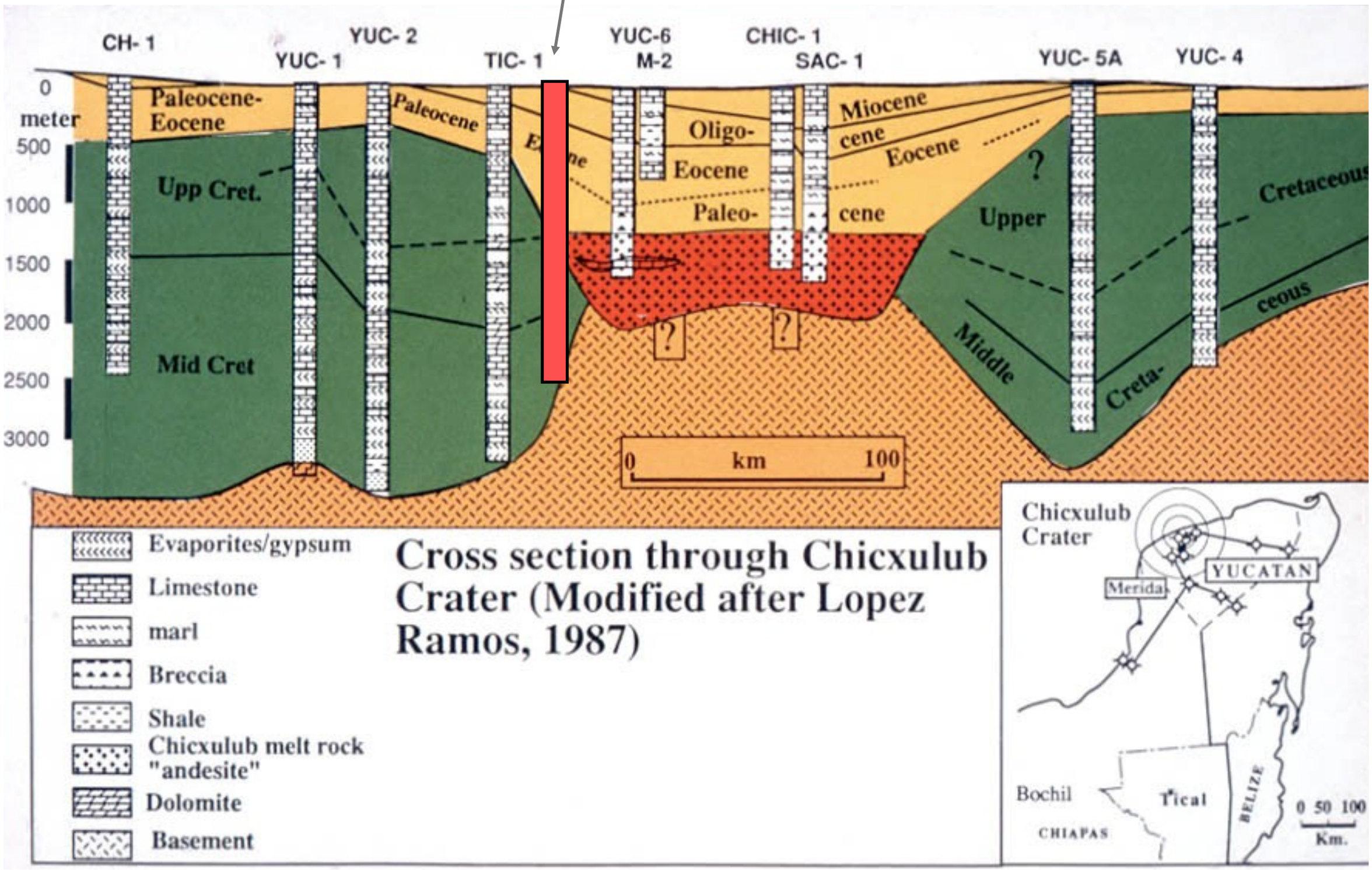
n

s

n

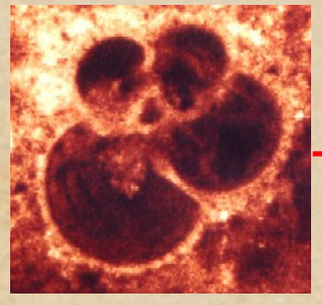
s

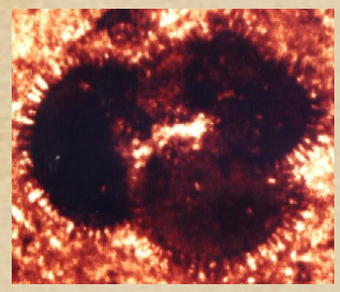
Yaxcopoil drillhole



cross section of the Chicxulub crater

Paleocene microfossils





>500m ejecta

Bits and pieces of different PEMEX drill holes are still preserved

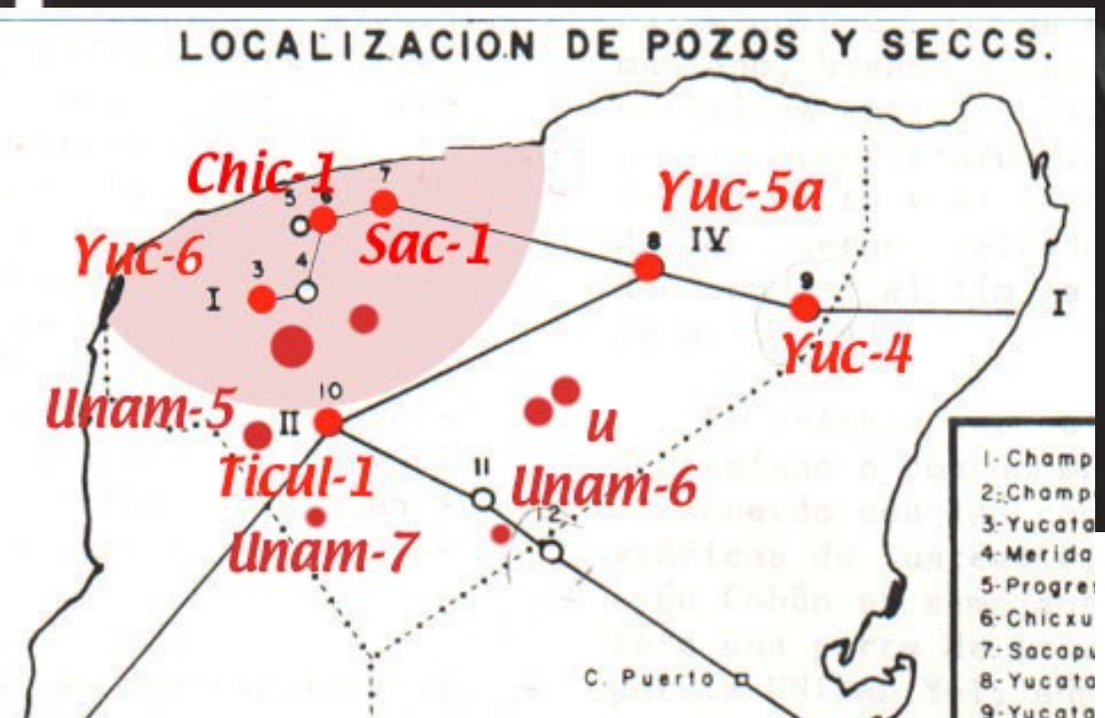
Yuc-6, N19

Yuc-6, N13

Chix-1-N10

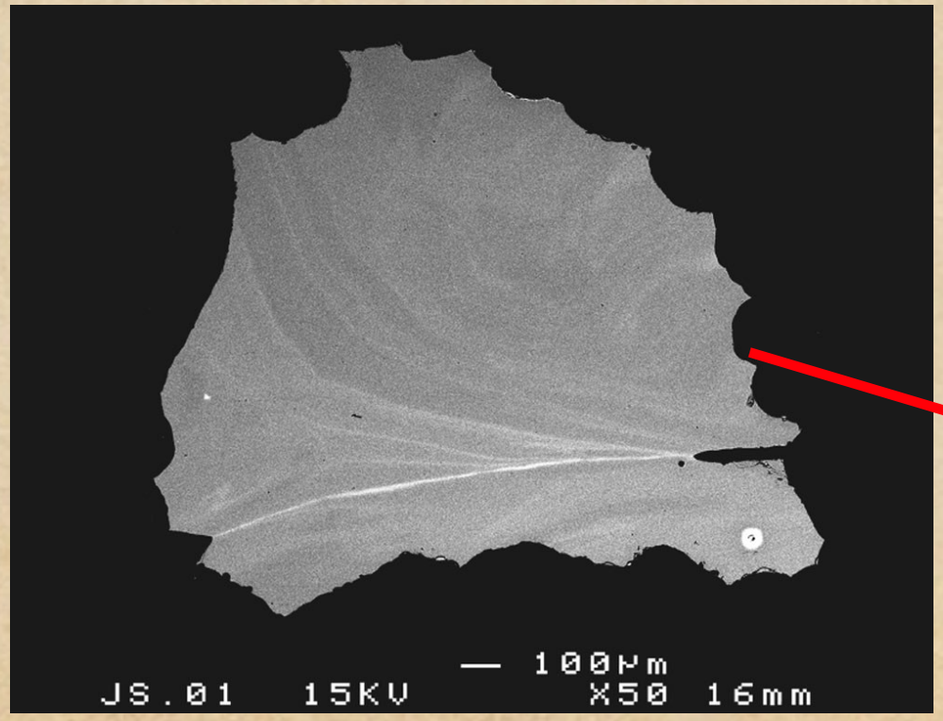
Yuc-6, N17

UNAM-5 boorkern met gesteente fragmenten net buiten de krater



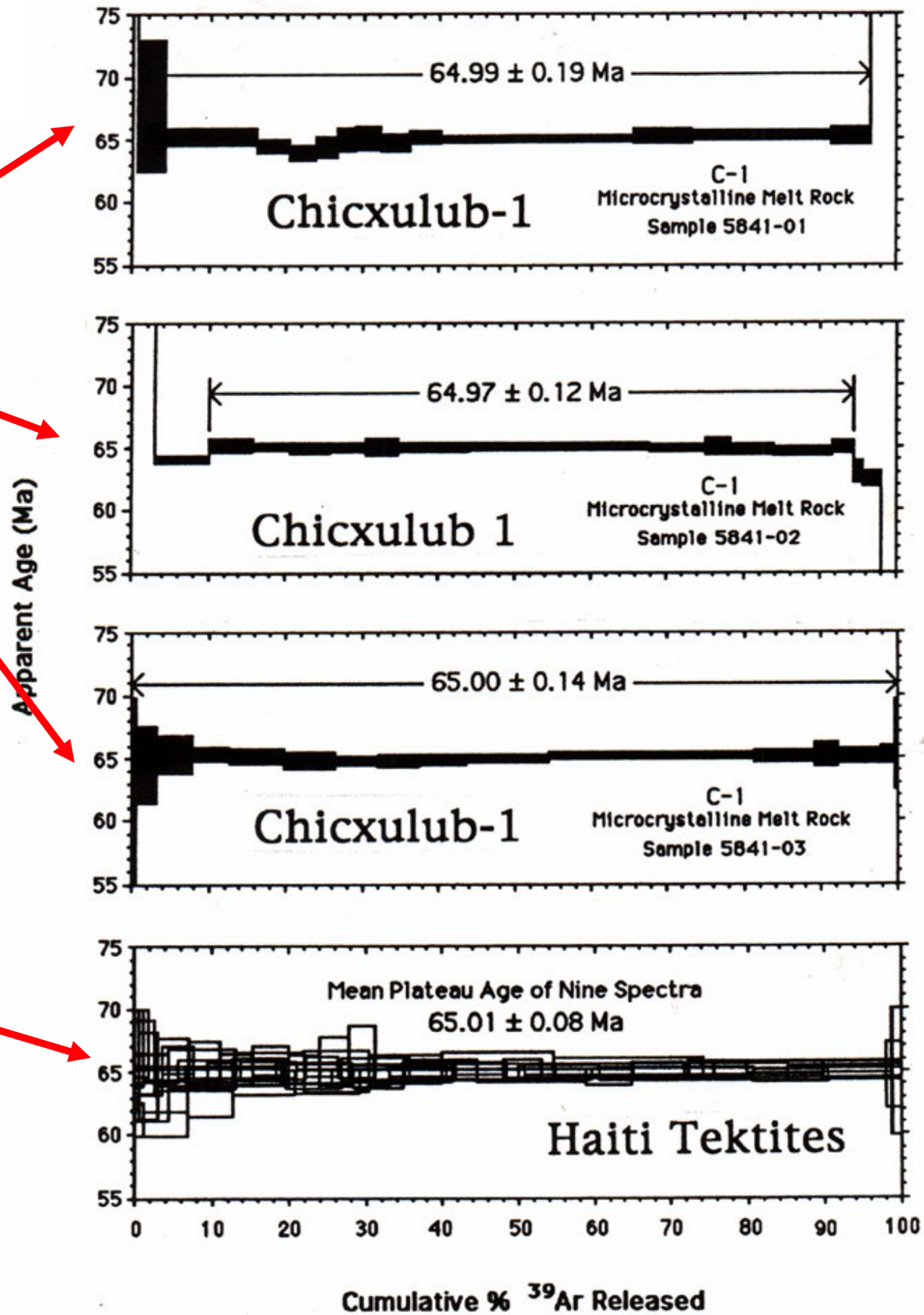
Ar/Ar ages from the tektites are indistinguishable from impact melt inside the crater

Impact melt from the crater



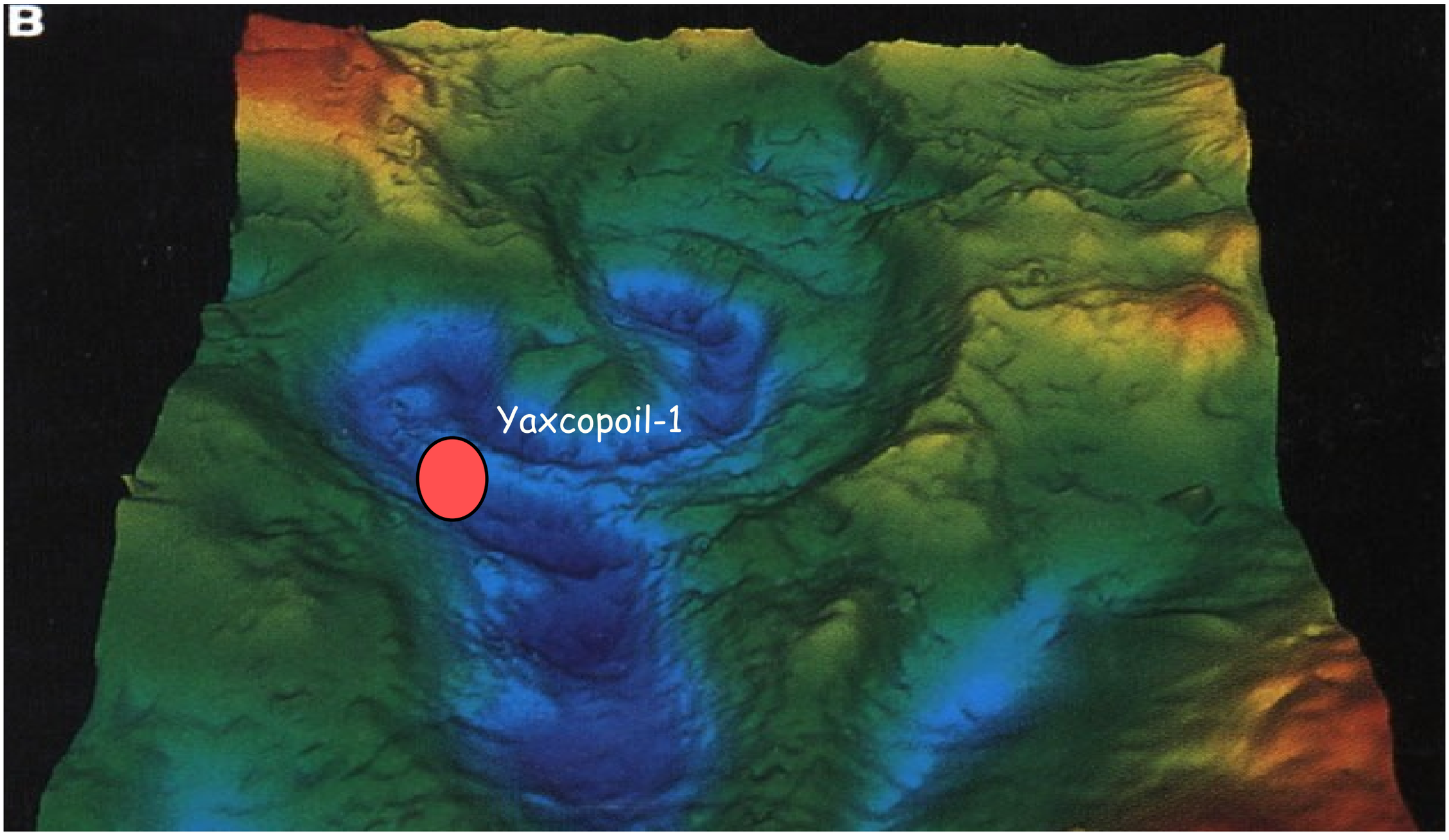
Haitian tektite

Figure 2. $^{40}Ar/^{39}Ar$ laser incremental heating spectra

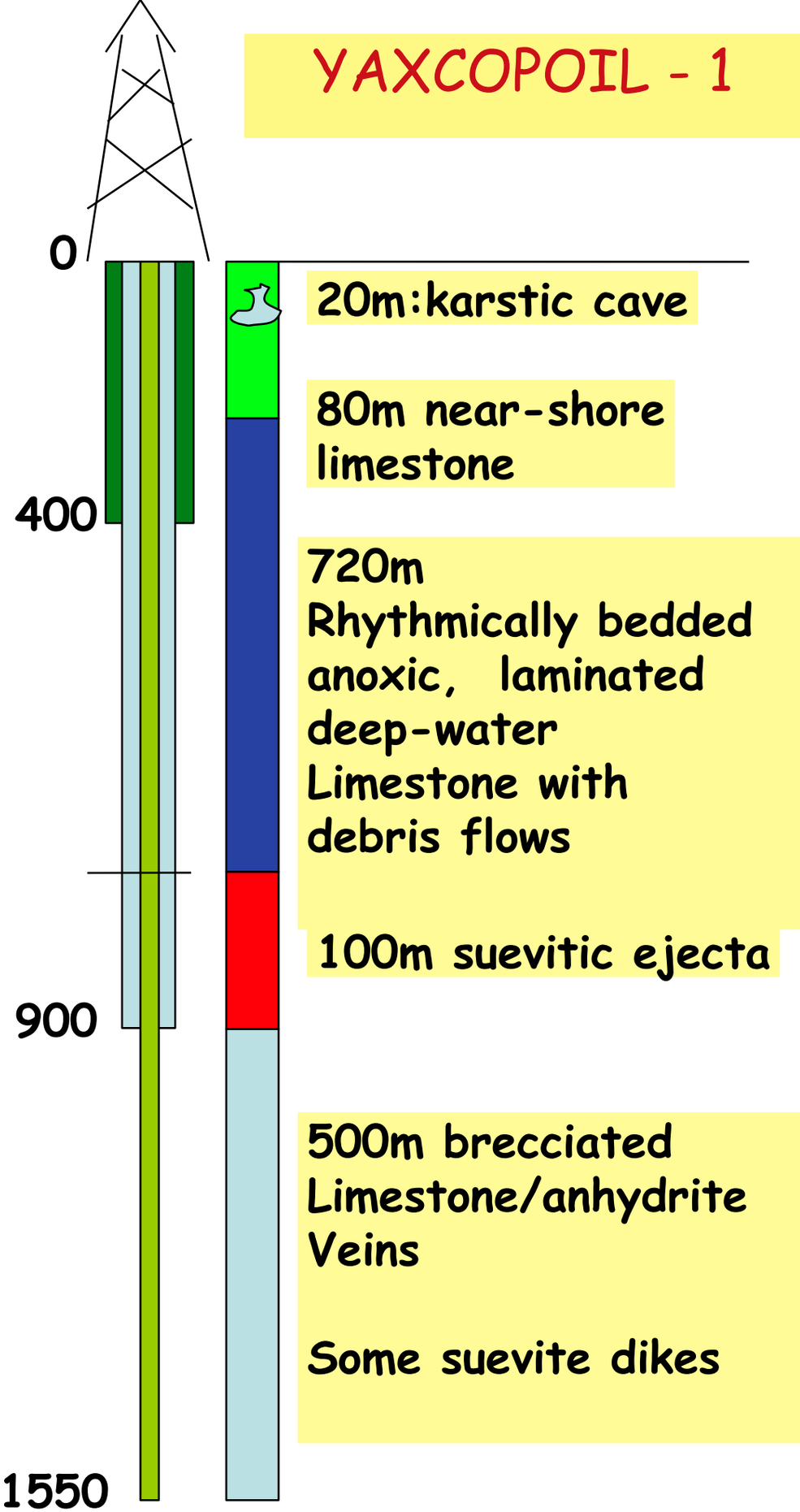


The Chicxulub Scientific Drilling Project (CSDP)

Yaxcopoil-1 drill hole



Chicxulub drilling project, CSDP initiated in 1995, excecuted 2001

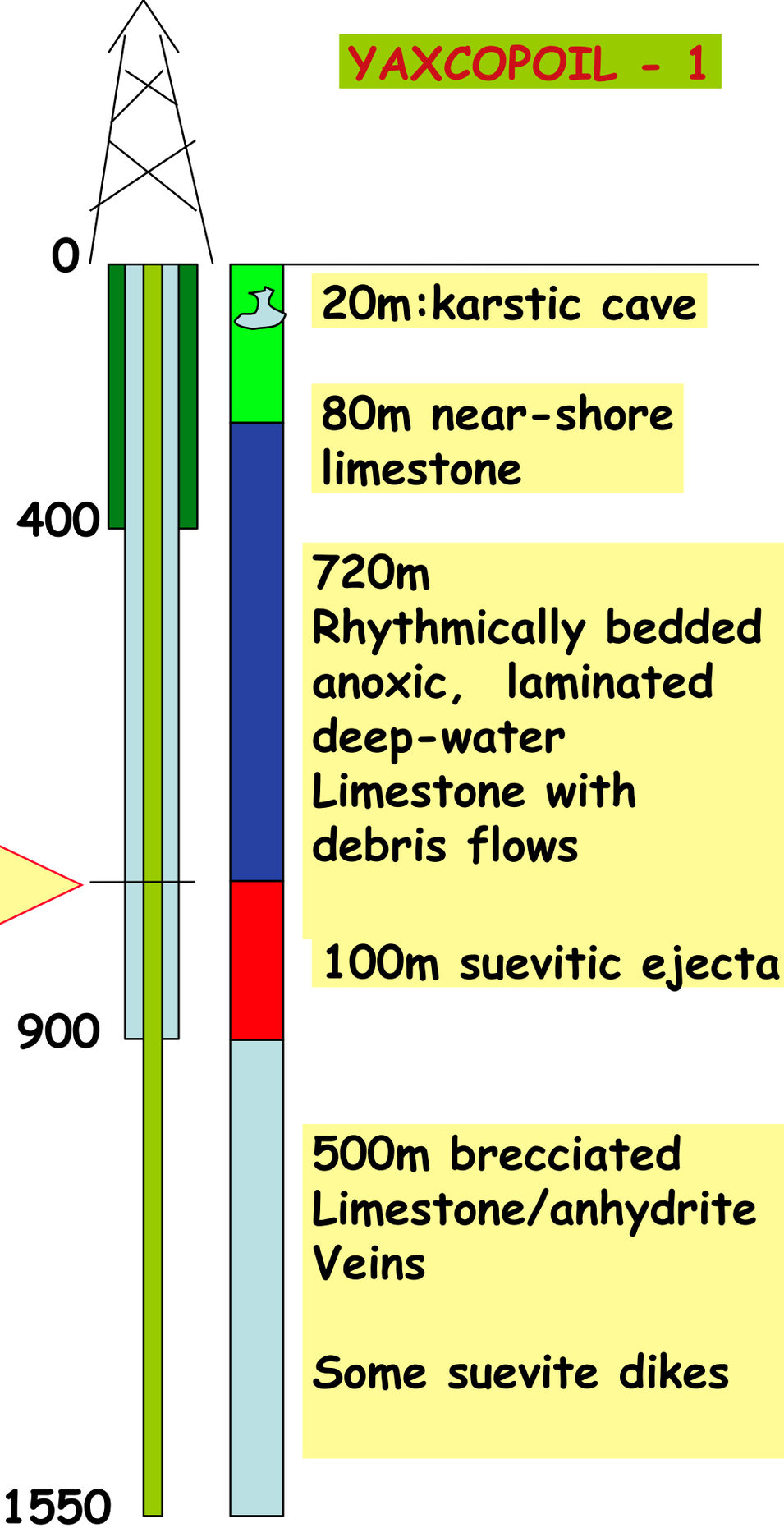


Chicxulub Scientific Drilling Project

CSDP

YAXCOPOIL - 1

CRUCIAL CORE SEGMENT



Yaxcopoil-1 core section: Impact to post-impact transition

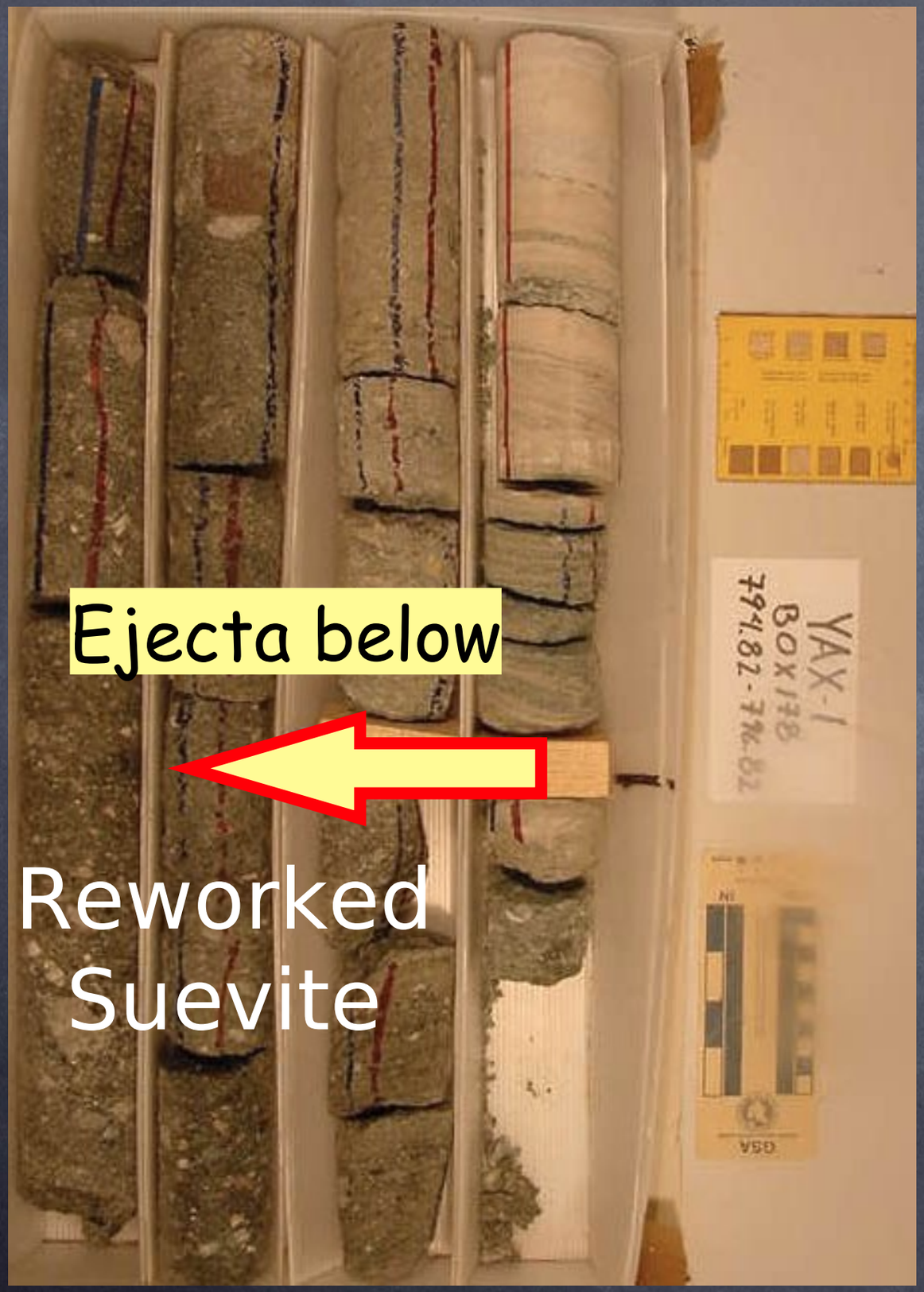
Reworked Suevite

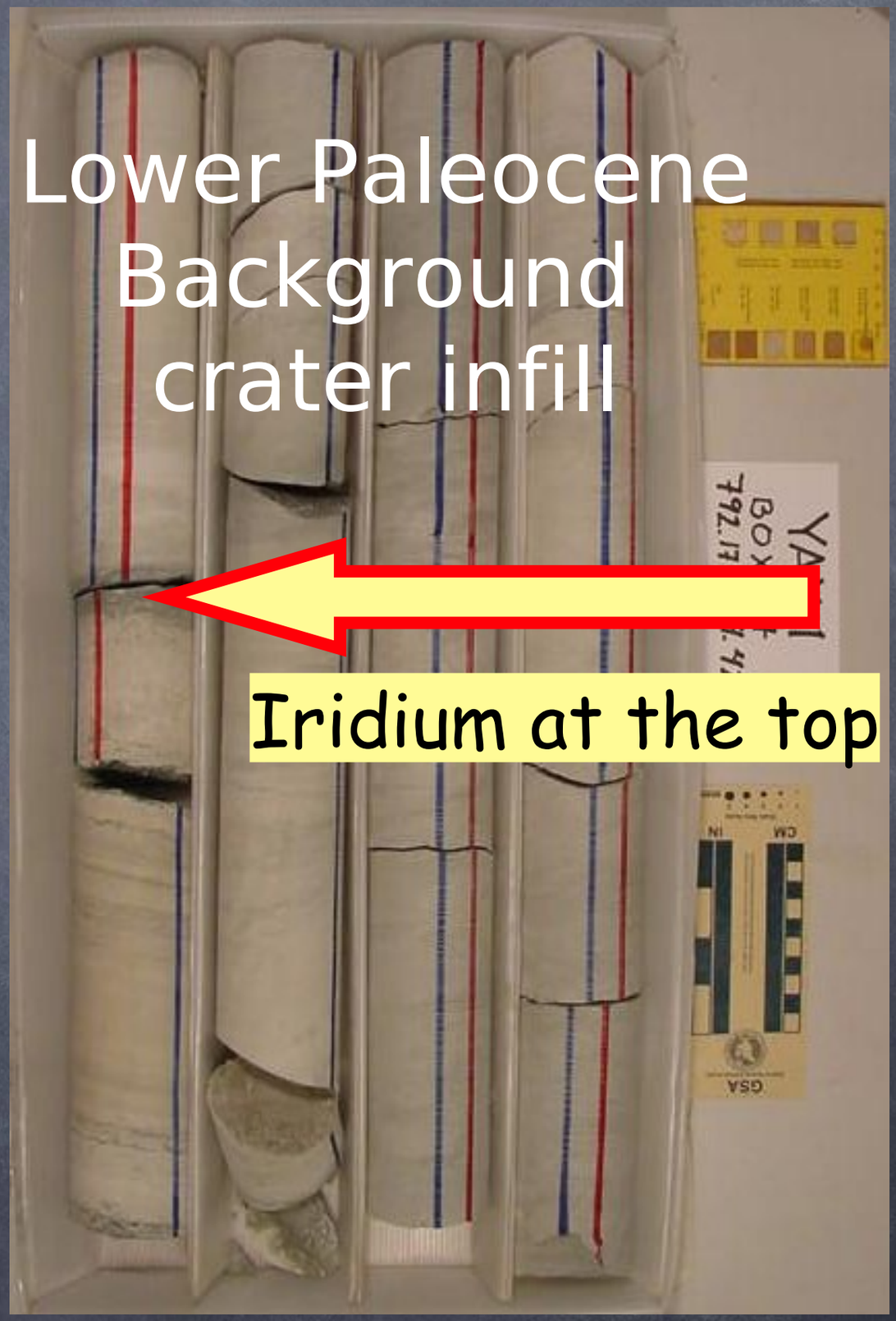
Yaxcopoil-1 core section: Impact to post-impact transition

Reworked
Suevite

Lower Paleocene
Background
crater infill

Yaxcopoil-1 core section: Impact to post-impact transition





Sandstone in between,

Lower Paleocene Background crater infill

Ejecta below

Iridium at the top

Reworked Suevite

Impact 2?

Impact 1?

Yaxcopoil-1 core section: Impact to post-impact transition

Sandstone in between, containing Maastrichtian forminifers?

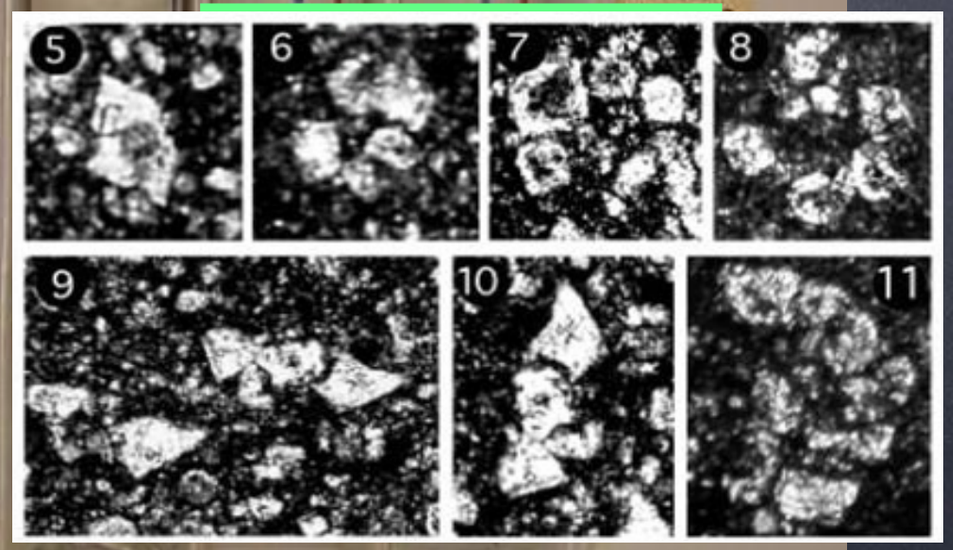
Ejecta below

Reworked Suevite

Impact 1?

wer Paleocene Background crater infill

Iridium at the top



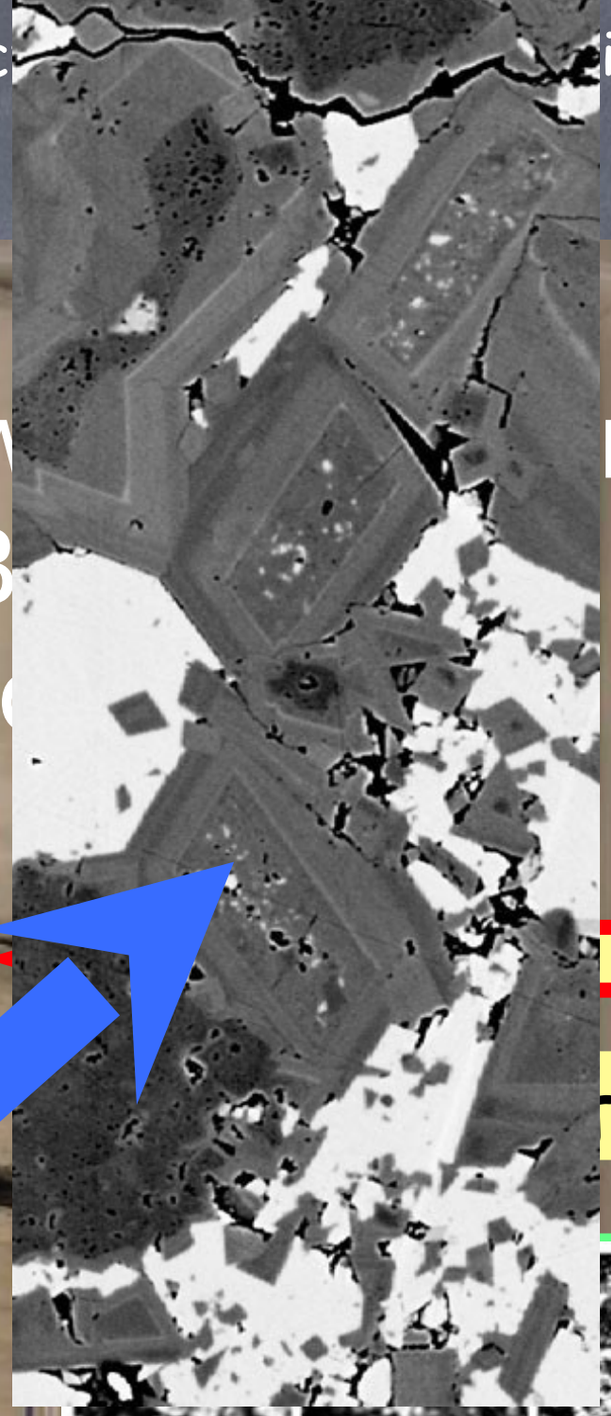
Keller et al 2004 PNAS

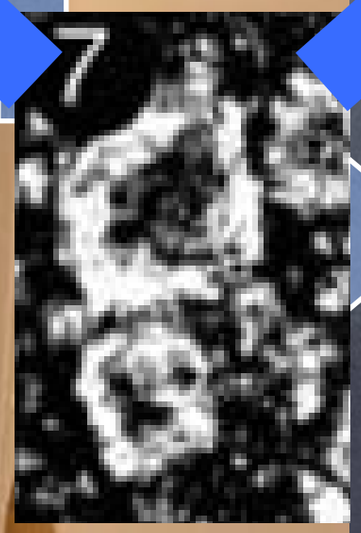
Yaxcopoil-1 core sec … impact transition

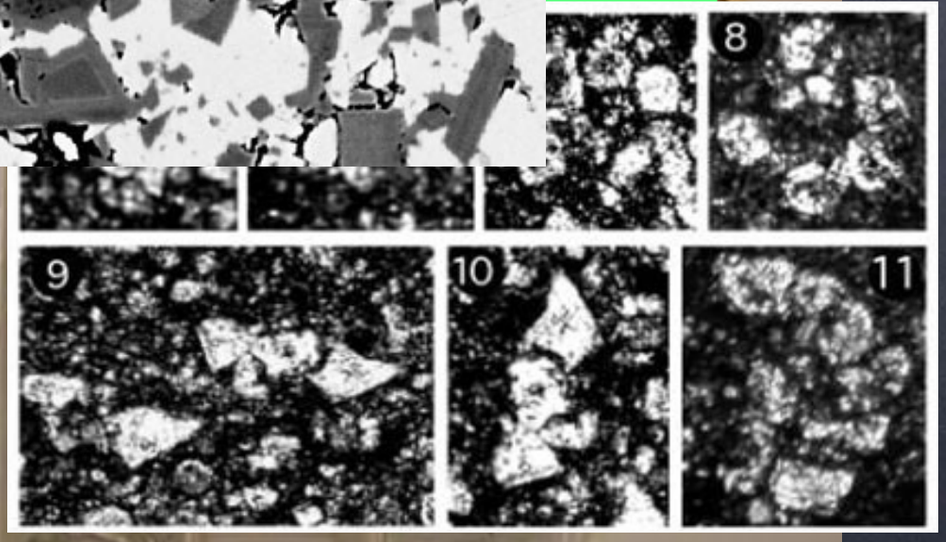
Sandstone in between, containing Maastrichtian forminifers?
No,
Just dolomite crystals

Reworked Suevite

Impact 1?



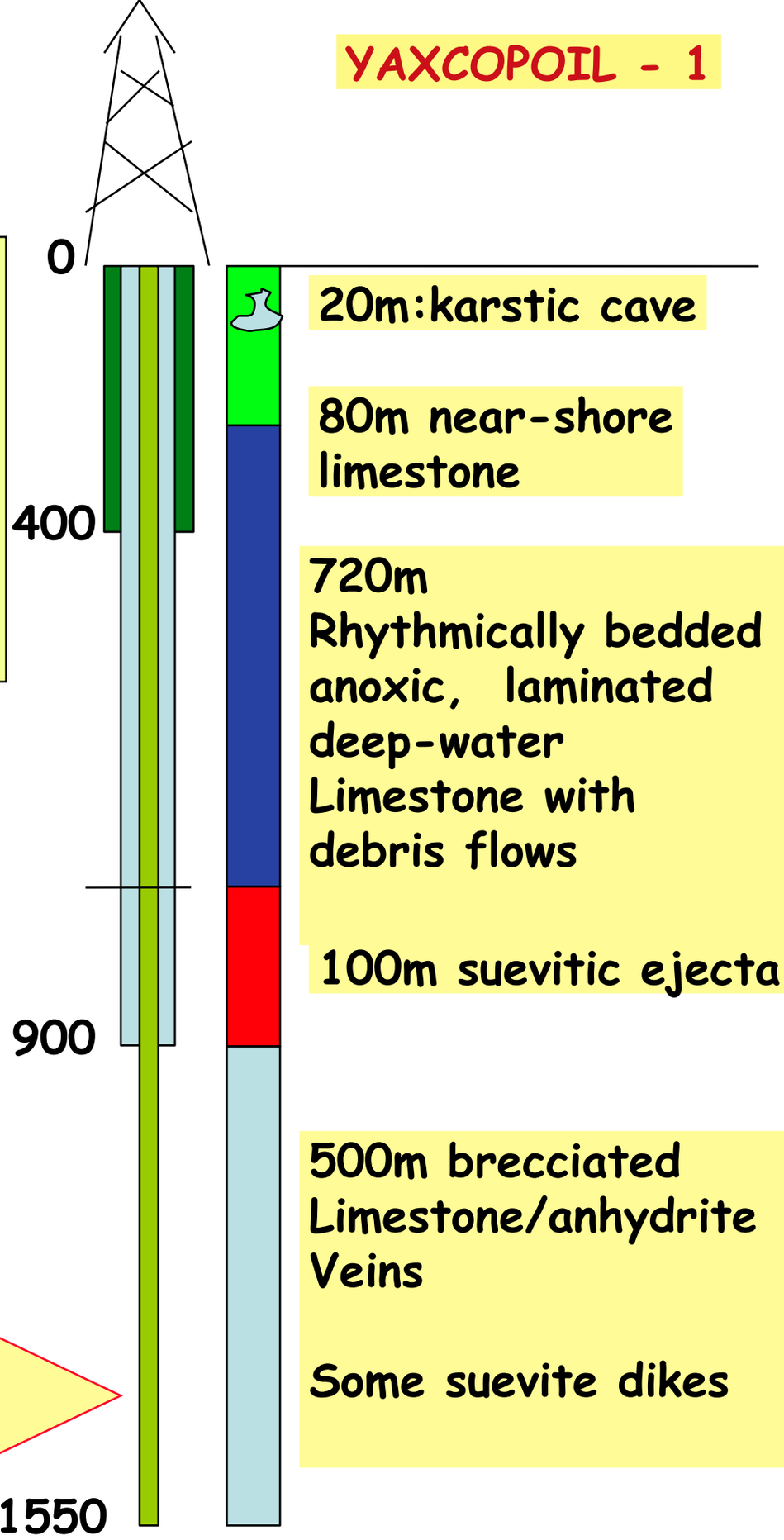




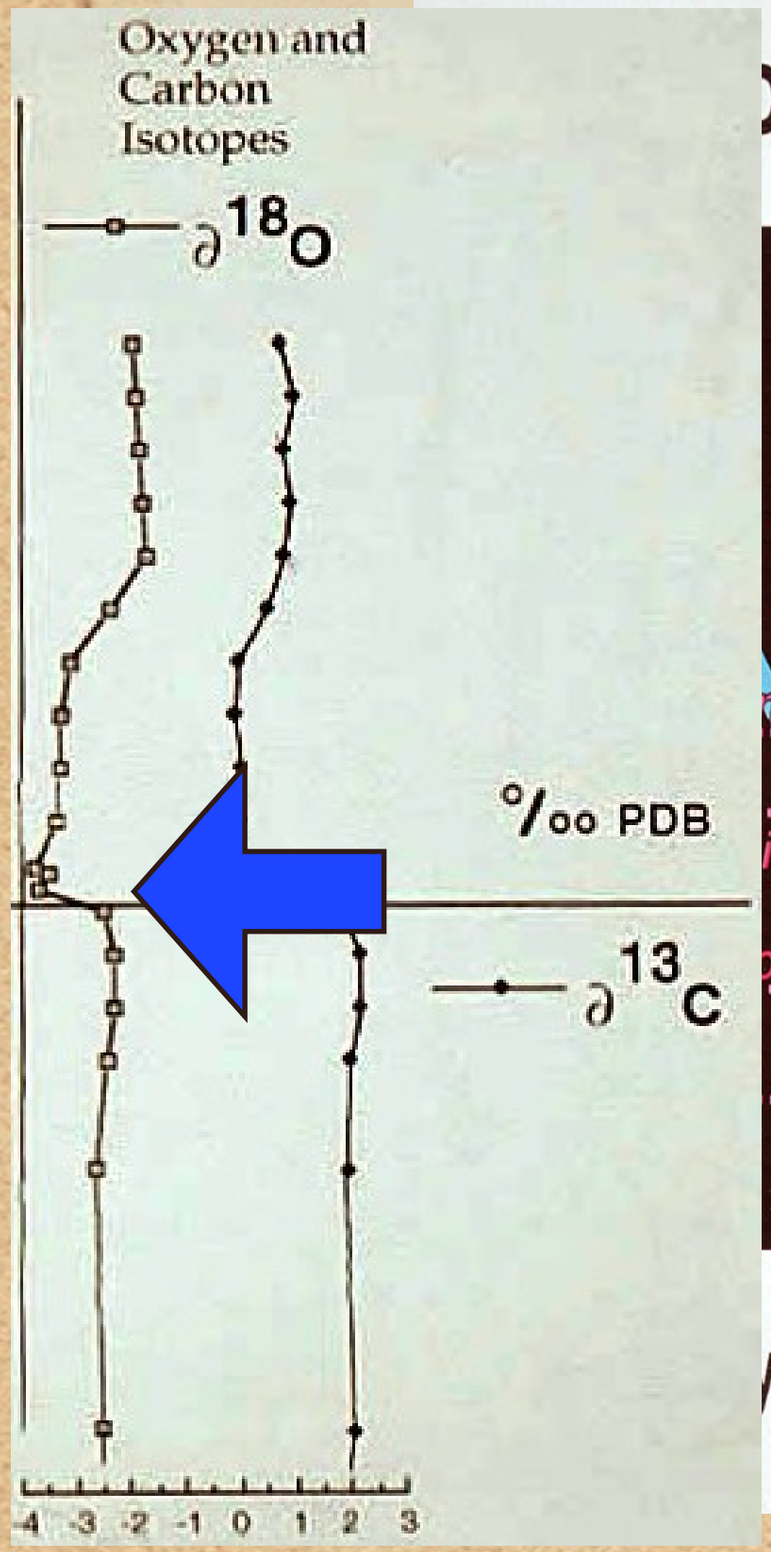
Keller et al 2004 PNAS

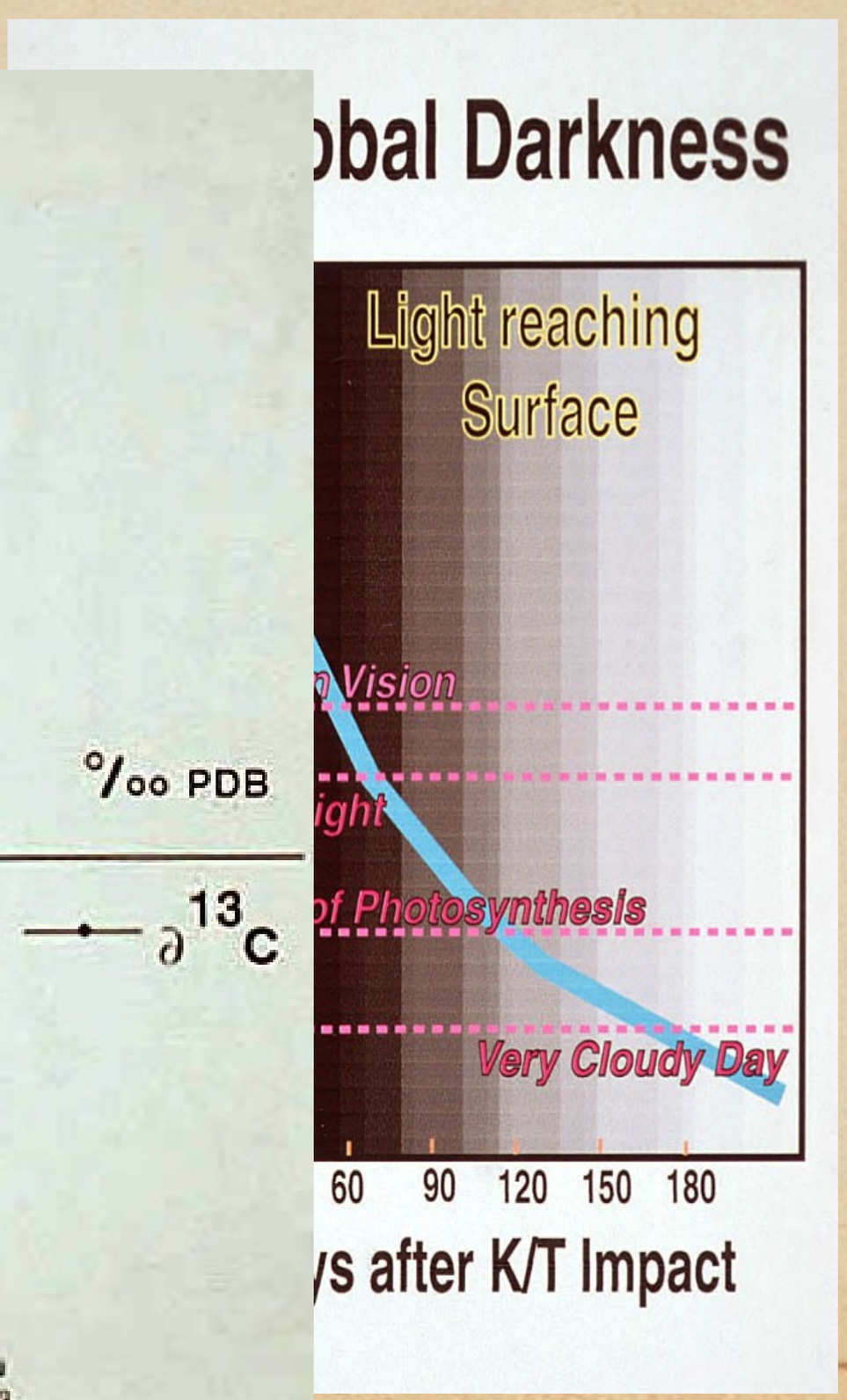
Shocked target rocks: Mega-Block zone.
Mixture Anhydrite (27%) and Carbonate (63%)

Anhydrite ($CaSO_4$):
approximately 250000mt SOx is “degassed” as aerosol (Pierazzo and Melosh, 2002)
By comparison: the Pinatubo eruption ejected 20mt sulphur
(0.5° C cooling over 1 year)

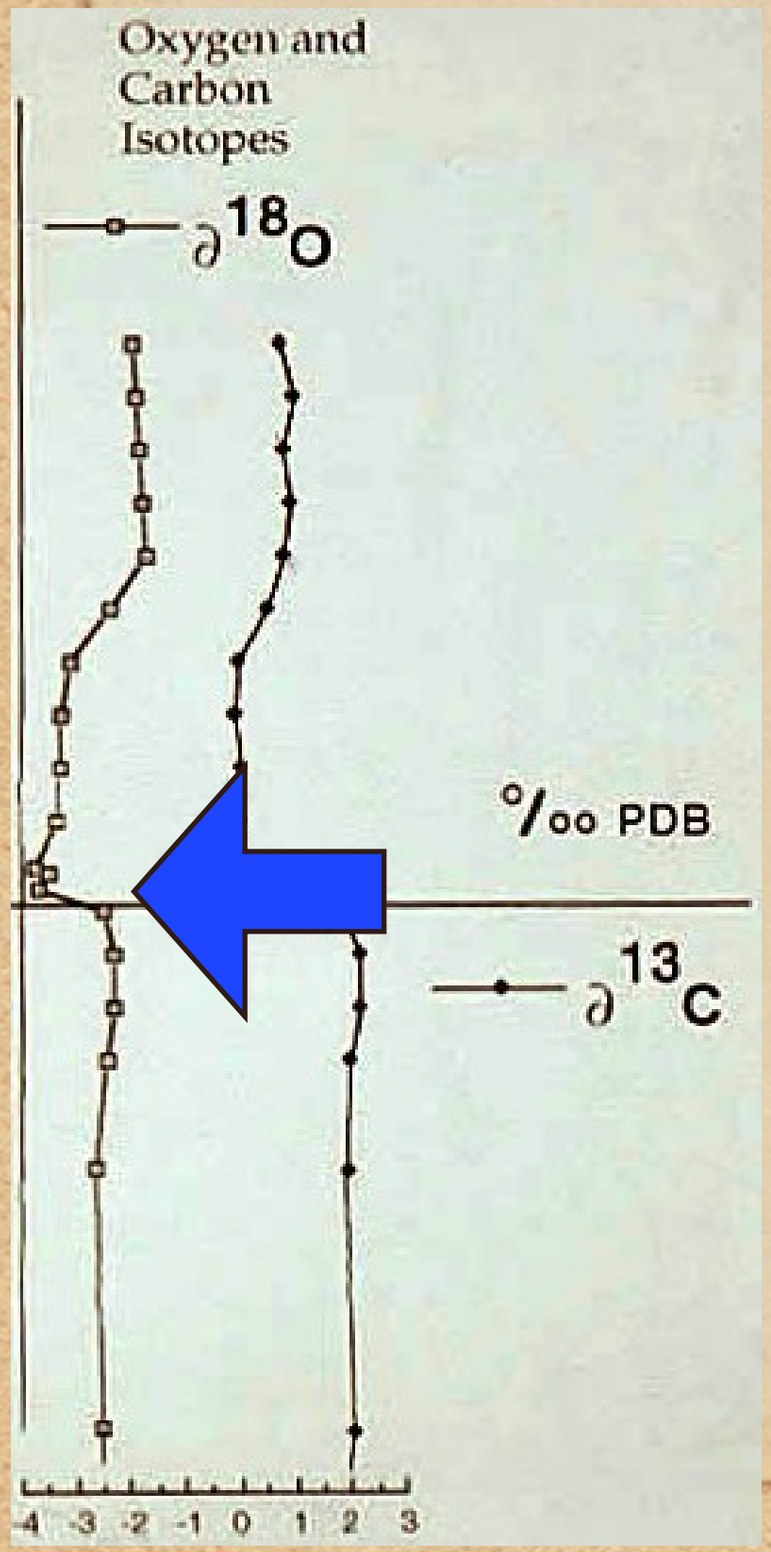


Why did the Chicxulub impact lead to mass-extinctions?





Probably because large amounts of dust and SOx aerosols reflected sunlight, and it became suddenly cold

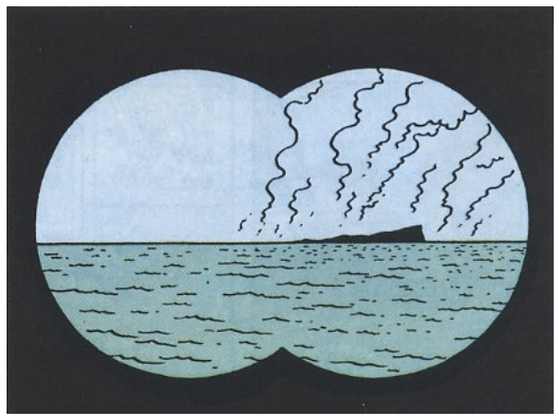


Why did the Chicxulub impact lead to mass-extinctions?

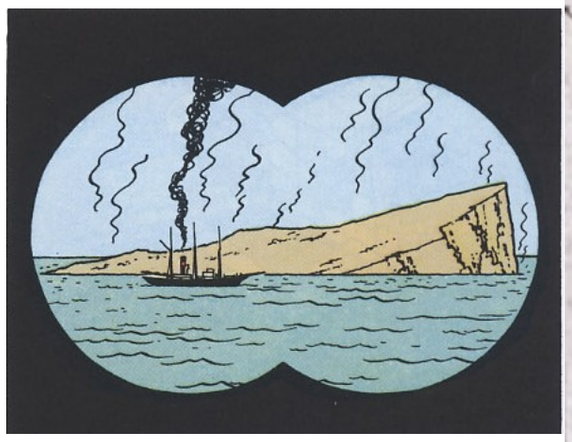
Probably because large amounts of dust and SOx aerosols reflected sunlight, and it became suddenly cold

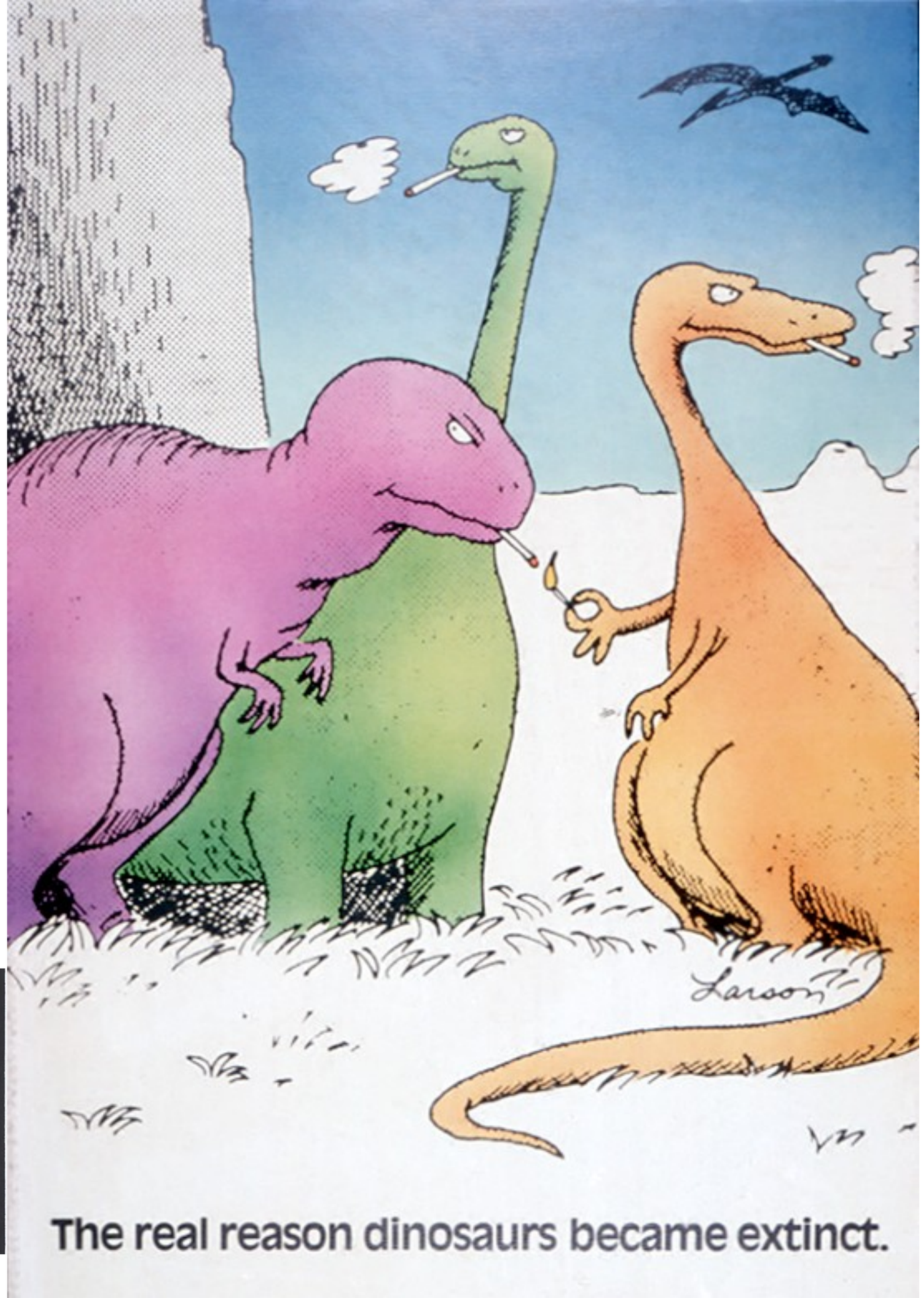
But due to the release of CO2 and other greenhouse gases it then became warm

meteorite



meteorite





tsunami

FIN