The Mesozoic Era came to an end 65 million years ago,

when the Earth had a very bad day

From the top to the bottom of the food chain, land and sea species became extinct during this massive event. Dinosaurs, who had ruled the land for 160 million years disappeared forever.

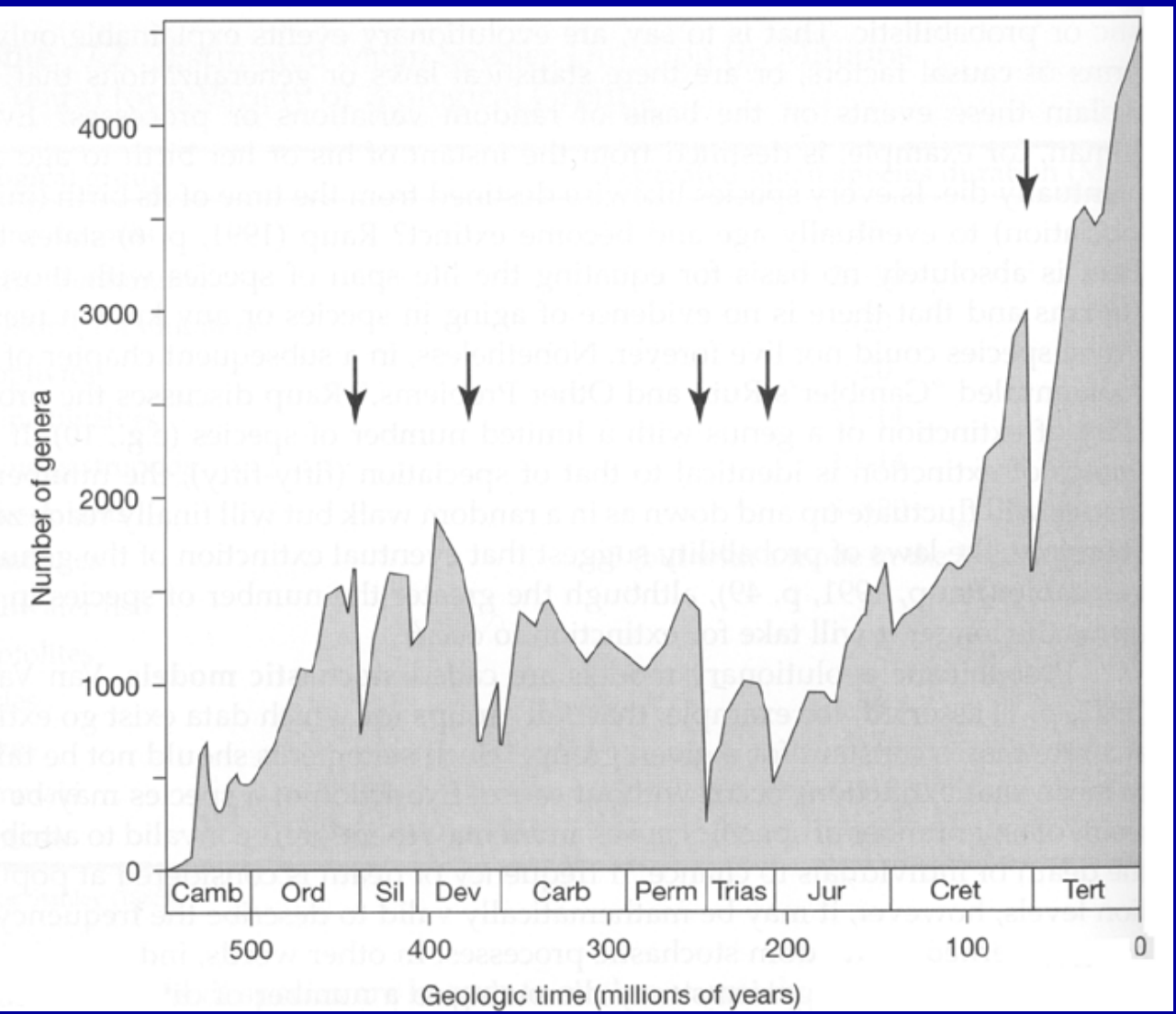
Cretaceous: “The Chalk”

White Cliffs Dover

K = Cretaceous

K/T or K/P (Paleogene) boundary

One of the big 5 mass extinctions



K/T Cretaceous/Tertiary boundary

One of the largest mass extinctions in history **Sepkowki (1994)**

extinction

25% of families,

50 % species

Large flying reptiles, including the pterodons and pterodactyls, also suffered complete extinction.

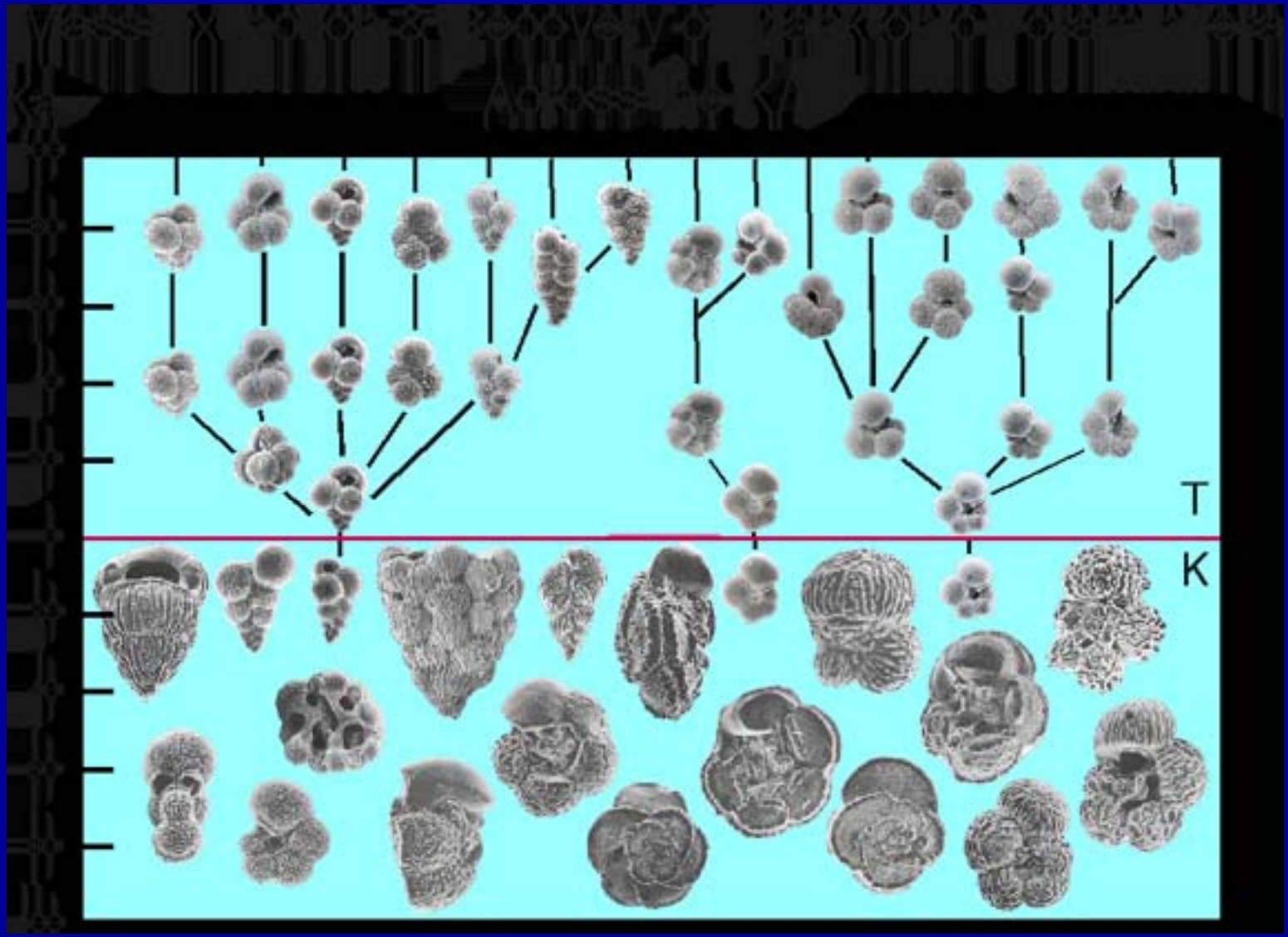
http://www.ucmp.berkeley.edu/diapsids/pterosauria.html

QuickTime™ and a
Cinepak decompressor
are needed to see this picture.

http://www2.gasou.edu/musenews/mosasaur50.gifa

Ammonites, mososaurs, pterodactyls

Marine reptiles, including ichthyosaurs, plesiosaurs, and mosasaurs, disappeared

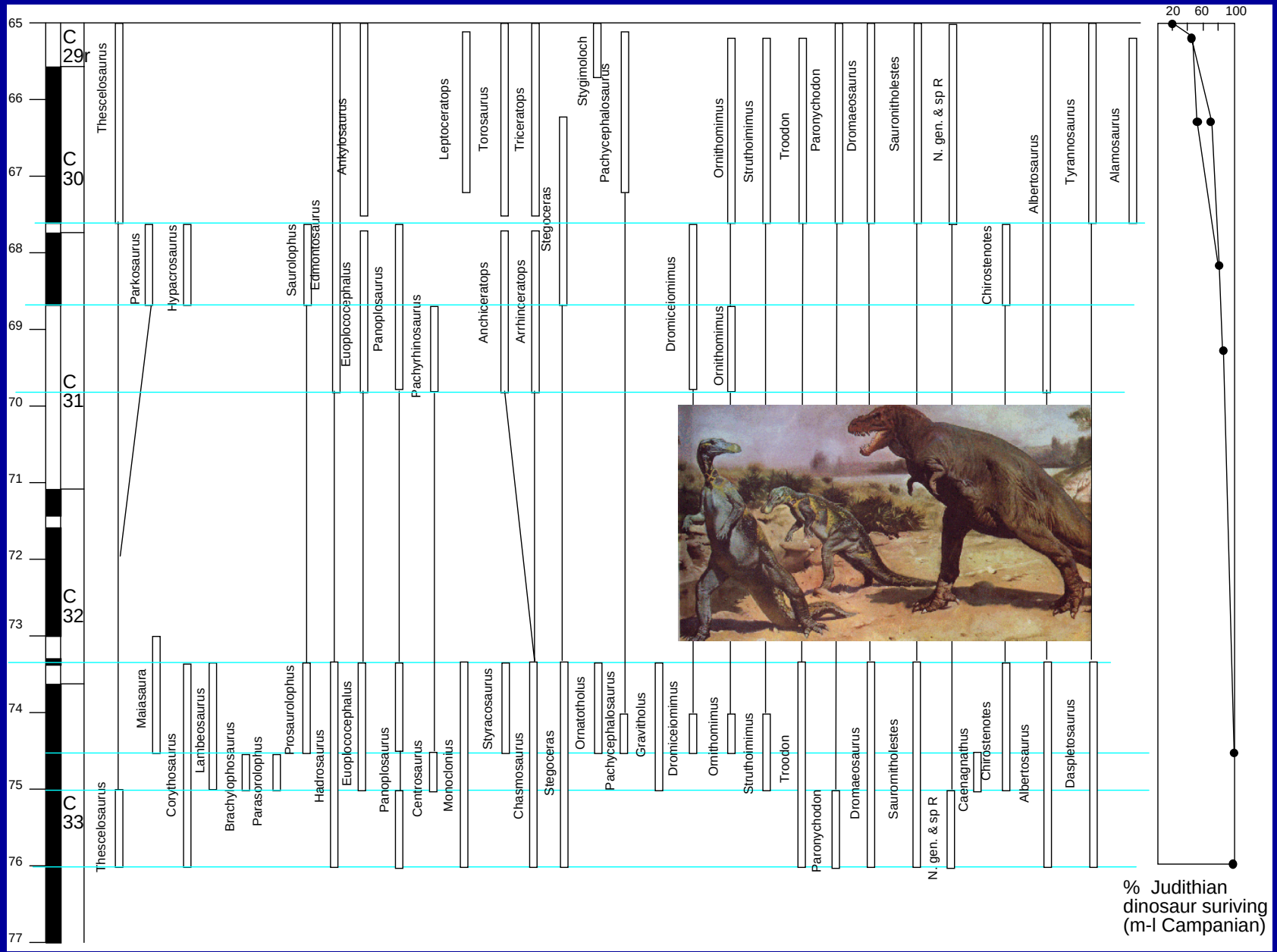


severely affected
planktonic foraminifers: three species survived out of >23
Guembelitria cretacea, *Hedbergella monmouthensis, H. holmdelensis*
nannofossils

Cretaceous/Tertiary (K/T) boundary

extinction of 25% of families, 50% species
Dinosaurs
marine reptiles
flying reptiles
ammonites and belmnites
rudists
75% marsupials

planktonic foraminifers: three species survived out of >23
Nannofossils 90+% extinction
coral, bivalves, gastropods, bryozoans severely affected
not affected: most land plants??
mammals (1/9 extinction's)
crocodiles, lizards, snakes, turtles survived
?most benthic organisms



Were dinosaurs on the decline? Sloan's (1986) data indicate they may have been. Yet, they became extinct at a knife's edge (vs. Archibald's arguments for Paleocene dinosaurs!)

What caused the K/T extinct

causes speculated on over the

1) cosmic radiation due to supernova

untestable

2) sea-level change

our work: no change

3) change in fertility/productivity of ocean

an effect, not a cause

4) magnetic field collapse

no, boundary in a reversed polarity

5) climate changes: CO_2 Greenhouse warming (McLean, 1978)

surprisingly small climate change;

our data confirms this

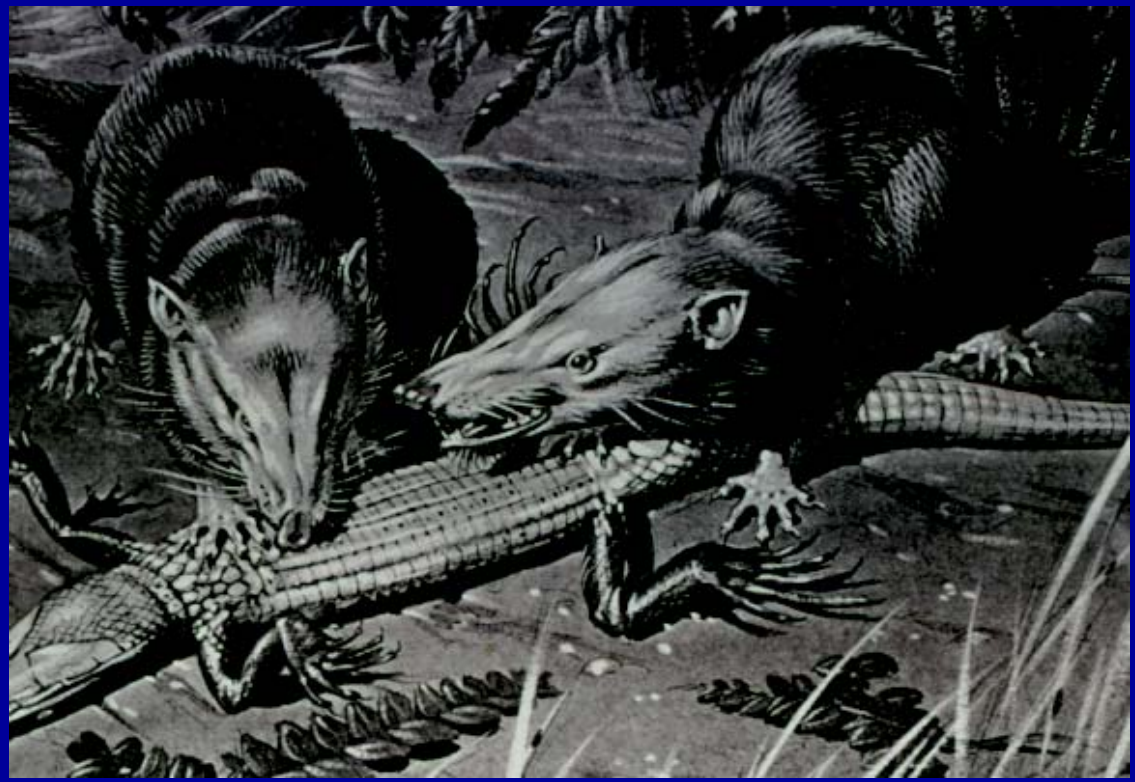
6) Arctic spillover (Theirstein & Berger; Gartner & Keany, '78)

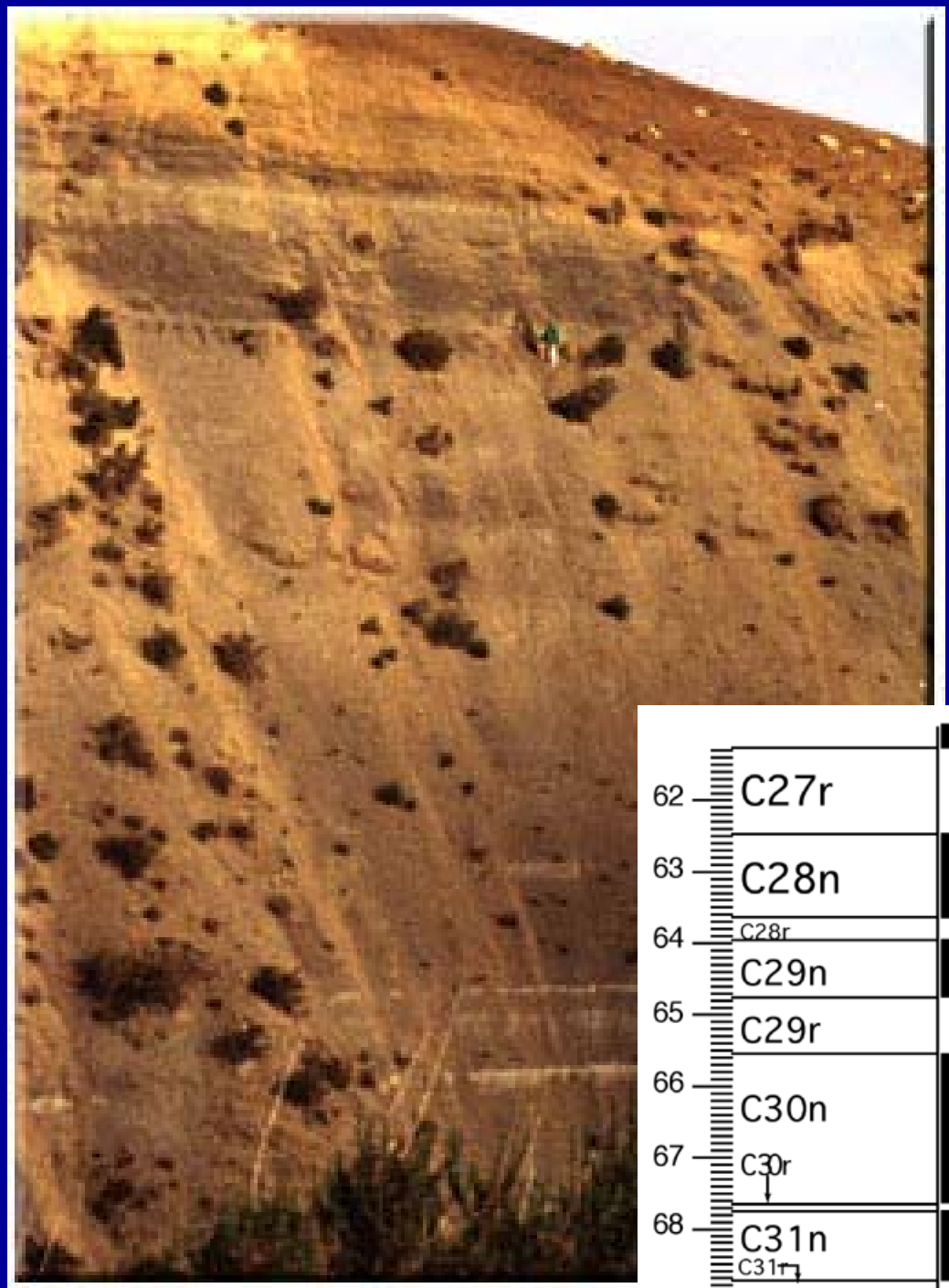
bad data

Two theories have dominated thought since 1978:

Impact (Alvarez et al., 1980)

Volcanic outpouring (McLean, 1978; Officer and Drake, 1981)

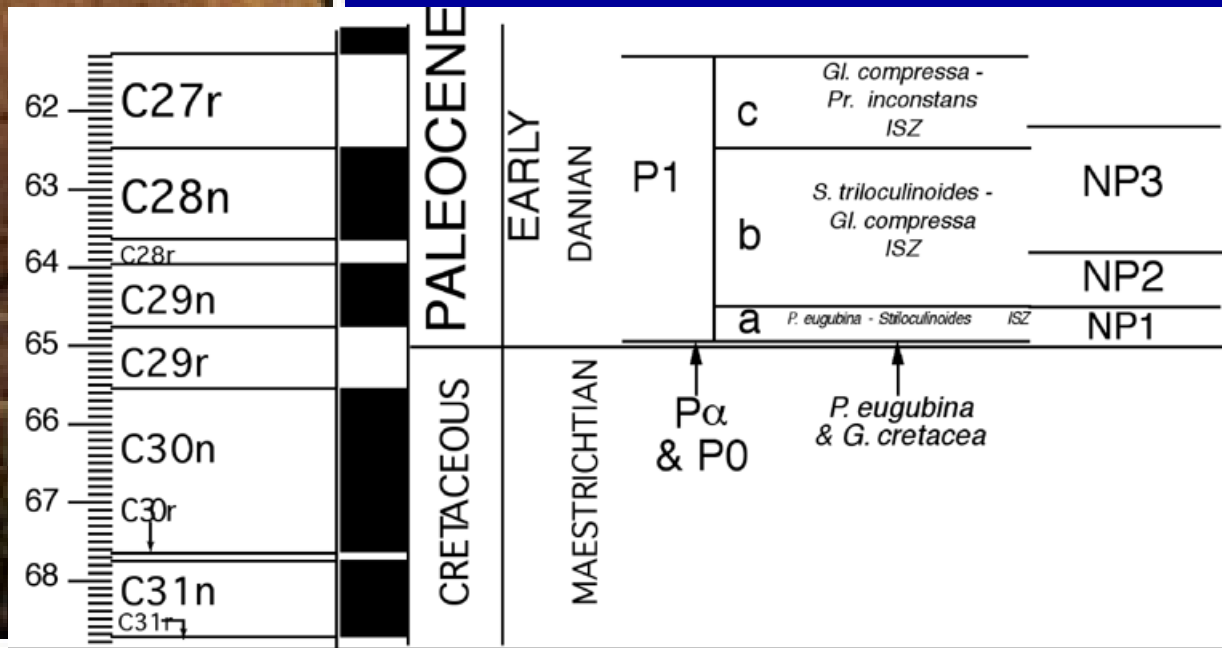


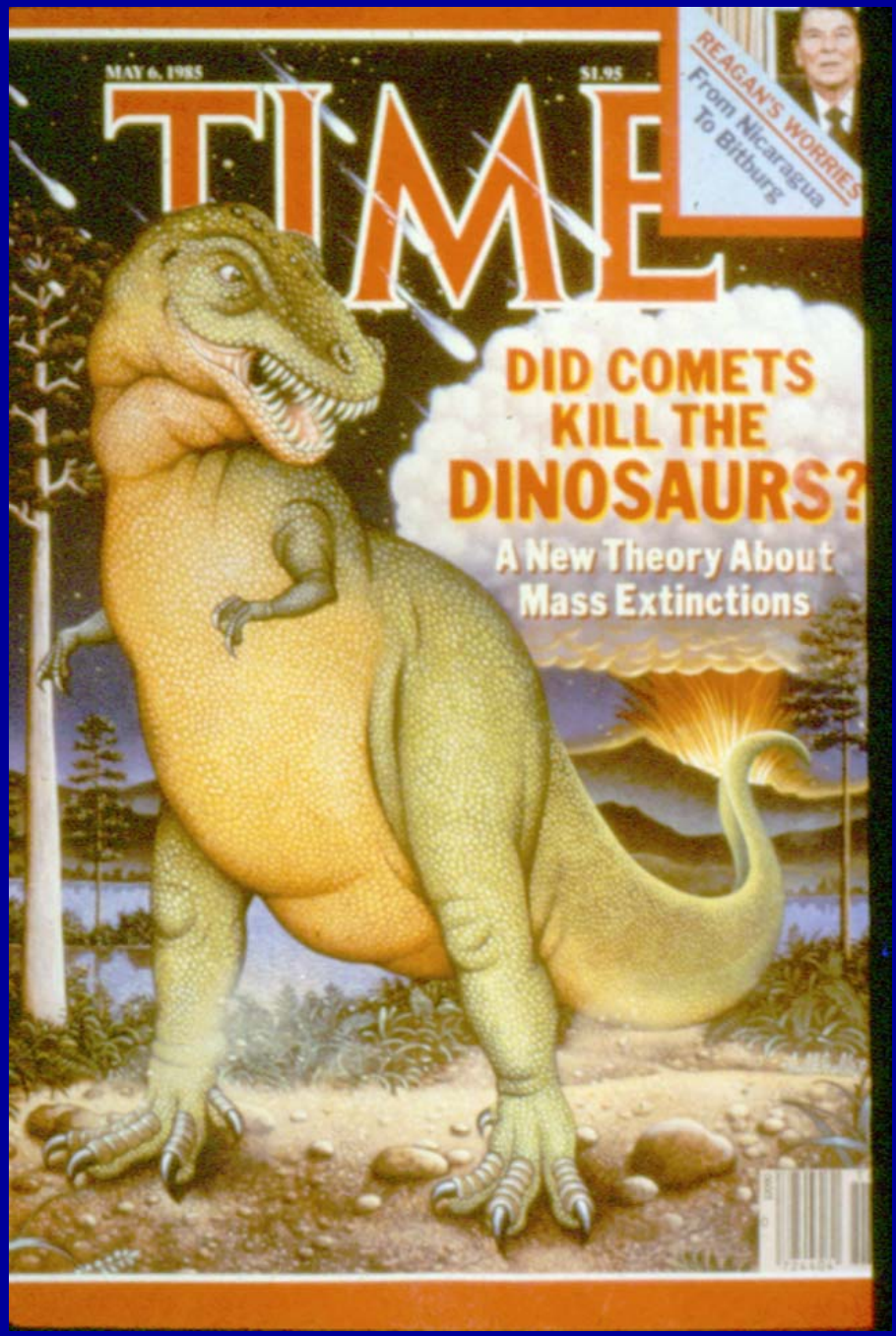


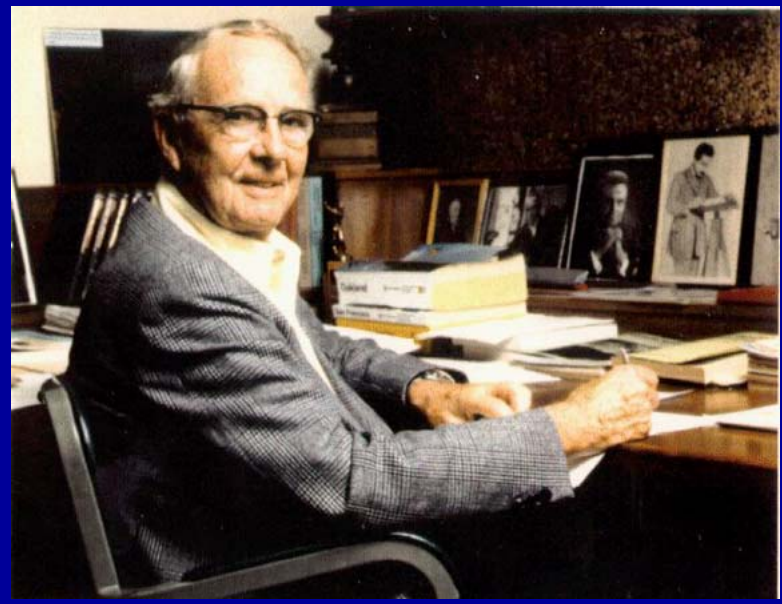
Boundary stratotype at El Kef, Tunisia

Bottom: time scale showing K/T boundary in C29r at 65.0 Ma

Kent (1972): mass extinction occurred in <0.5 m.y. (Chron C29r)

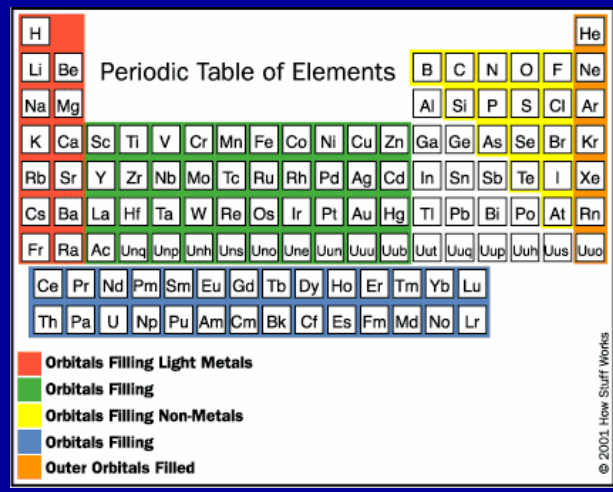



MAY 6, 1985
$1.95
TIME
REAGAN'S WORRIES
From Nicaragua
To Bitburg
DID COMETS
KILL THE
DINOSAURS?
A New Theory About
Mass Extinctions



Iridium Element 77

Iridium is found enriched in extraterrestrial material (comets, asteroids) and deep within the Earth



http://www.planetary.org/html/news/Italy/whyitaly.html

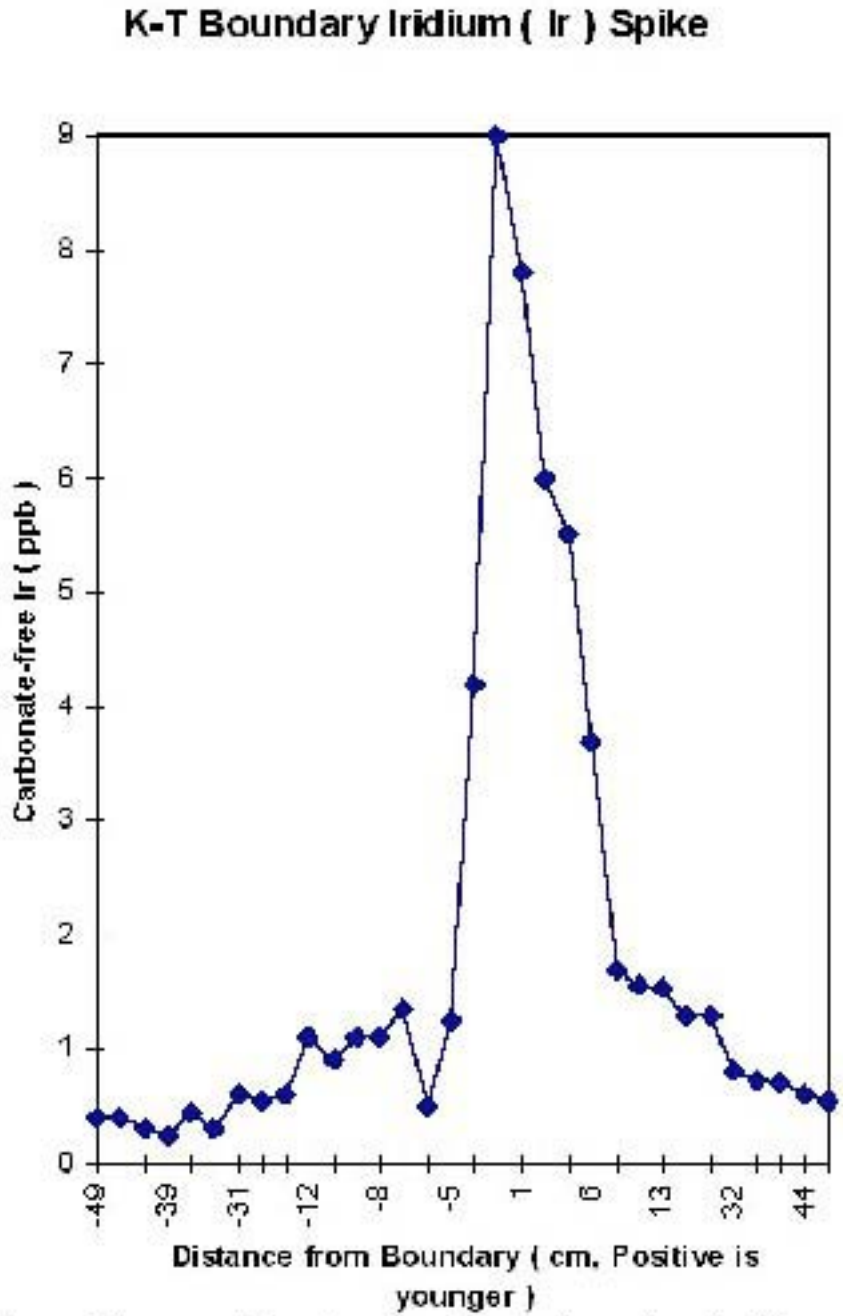


Diagram of the K-T Ir spike. Redrawn from Alvarez and Asaro (1990). Iridium levels shown by the peak are characteristic of mantle or meteoritic origin.

Iridium Anomaly at Gubbio

Extraterrestrial impact

Asteroid or comet

10 km in diameter

http://palaeo.gly.bris.ac.uk/Communication/Lee/irspike.html

Meteor crater, Arizona
1 km diameter
Impact ~50 ka

Alvarez measured Ir

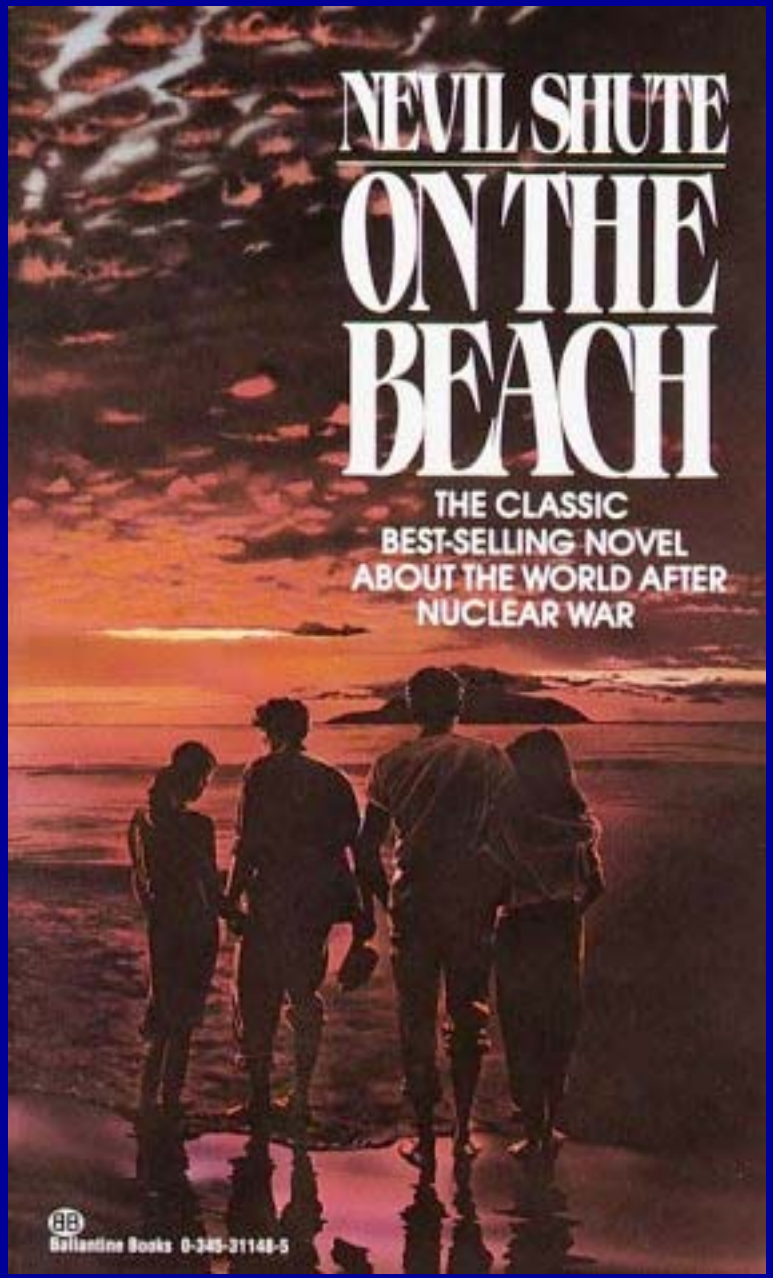
Expected slight enrichment due to hiatus (time gap)

Found huge Ir increase (Ir-anomaly)

Hiatus cannot explain Ir

Postulated impact of ~6-10 km asteroid

Dust blocks out sun, disrupts food chain

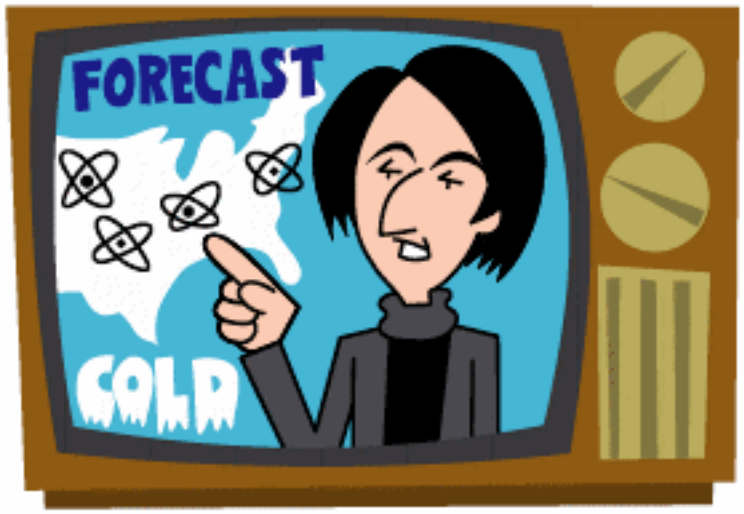


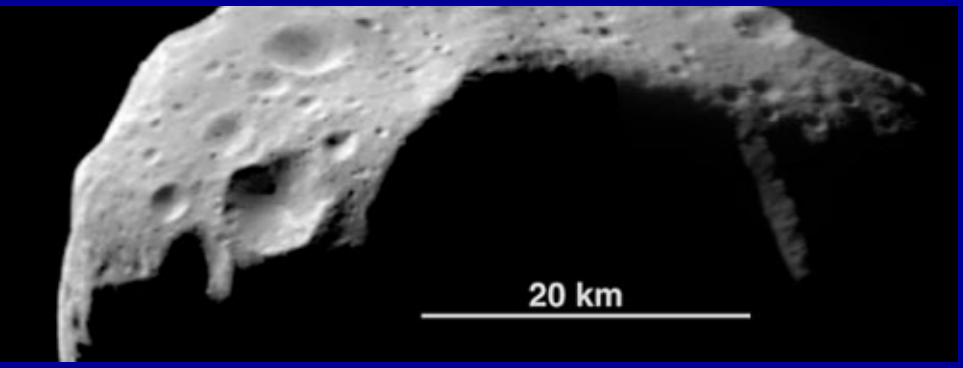
Global distribution of dust shuts down photosynthesis:

~3 months.

TTAPS study (Turco, Toon, Ackerman, Pollack, and Sagan) that suggested the possibility of drastic dust-induced climatic cooling ("Nuclear Winter") as a consequence of large scale nuclear war.

Science Vol. 222, 1983, *Global Atmospheric Consequences of Nuclear War*, pg. 1283.





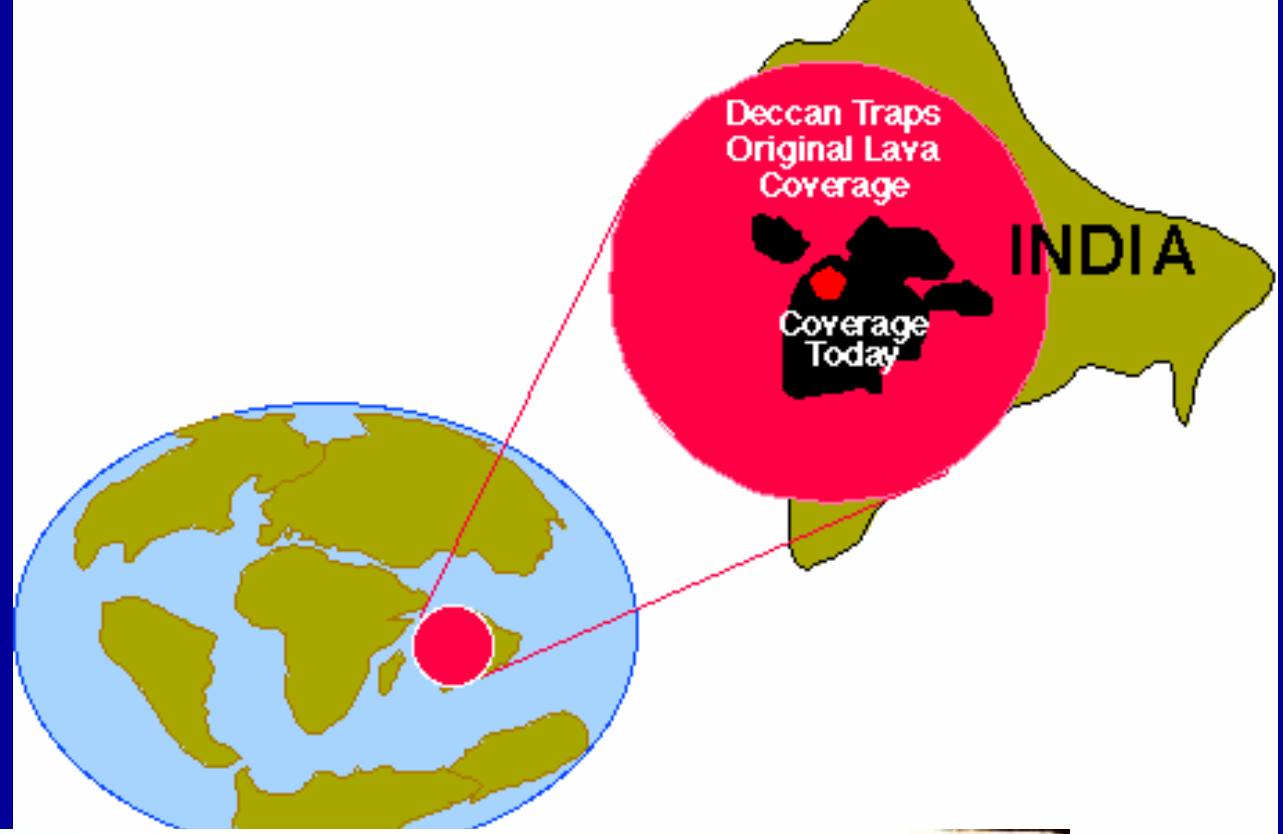
http://www.phy.mtu.edu/apod/ap970701.html

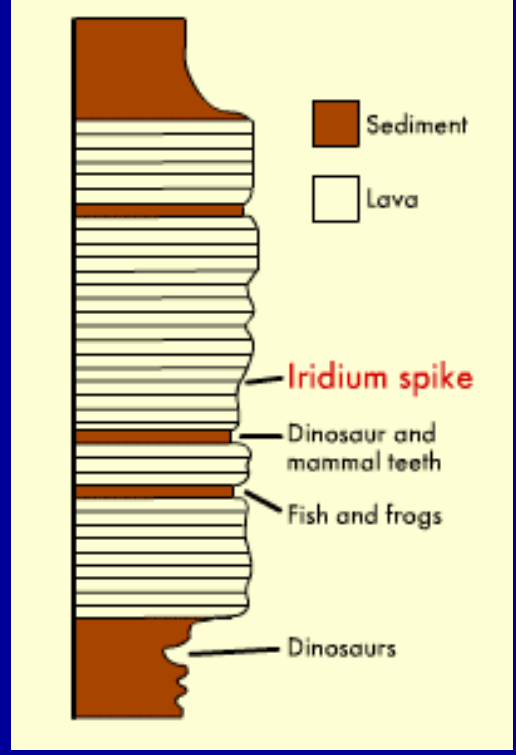
Asteroid 253 Mathilde:'s Large Craters

Impact or Volcanism?

Image of the subglacial eruption in Vatnajökull, Iceland

http://www.norvol.hi.is/eruptimg.html





counter hypothesis: great outpouring of basalt lava (Deccan Traps)

caused outpouring of CO_2 and warming that killed dinosaurs?
cause outpouring of dust

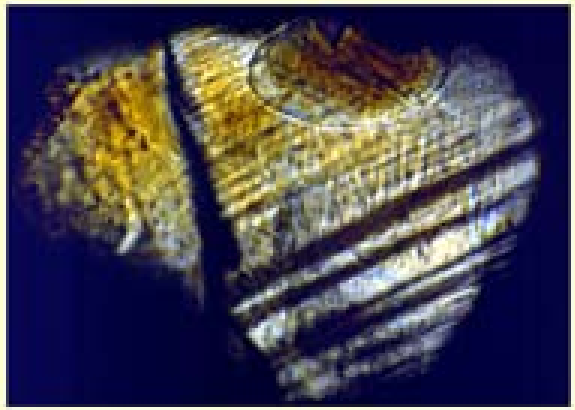
The Asteroid vs. Volcano Debate
Dewey McLean vs. Luis Alvarez
http://filebox.vt.edu/artsci/geology/mclean/Dinosaur_Volcano_Extinction/index.html

So Dewey is now a forgotten person in the field, or when he is remembered, it is only for a few good laughs, at the cocktail party at the end of the Deweyless meeting . . . . I'm sorry to say I see you going down the Dewey McLean lane.
—Luis Alvarez, letter of intimidation, 1984

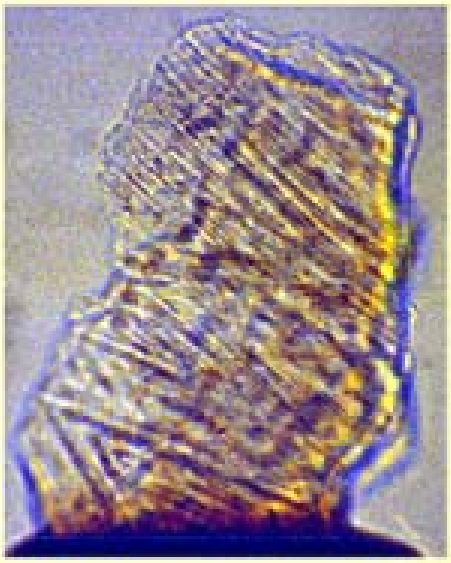
If [asked what] I thought about Dewey McLean, I'd say he's a weak sister. I thought he'd been knocked out of the ball game … nobody invites him to conferences anymore.
—Luis Alvarez, The New York Times, 19 January 1988

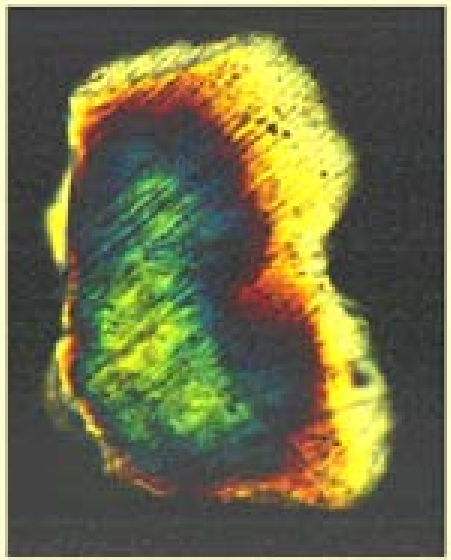
Operating in a science you do not comprehend, you publicly insult paleontologists. In the New York Times you abased paleontologists as "not very good scientists...more like stamp collectors," and attacked opponents by name as "weak sister," "incompetent," and "publishing scientific nonsense." —Excerpt from McLean's Open Letter to Luis Alvarez, 1988

Shocked minerals from Bass River spherule layer



Orthoclase feldspar



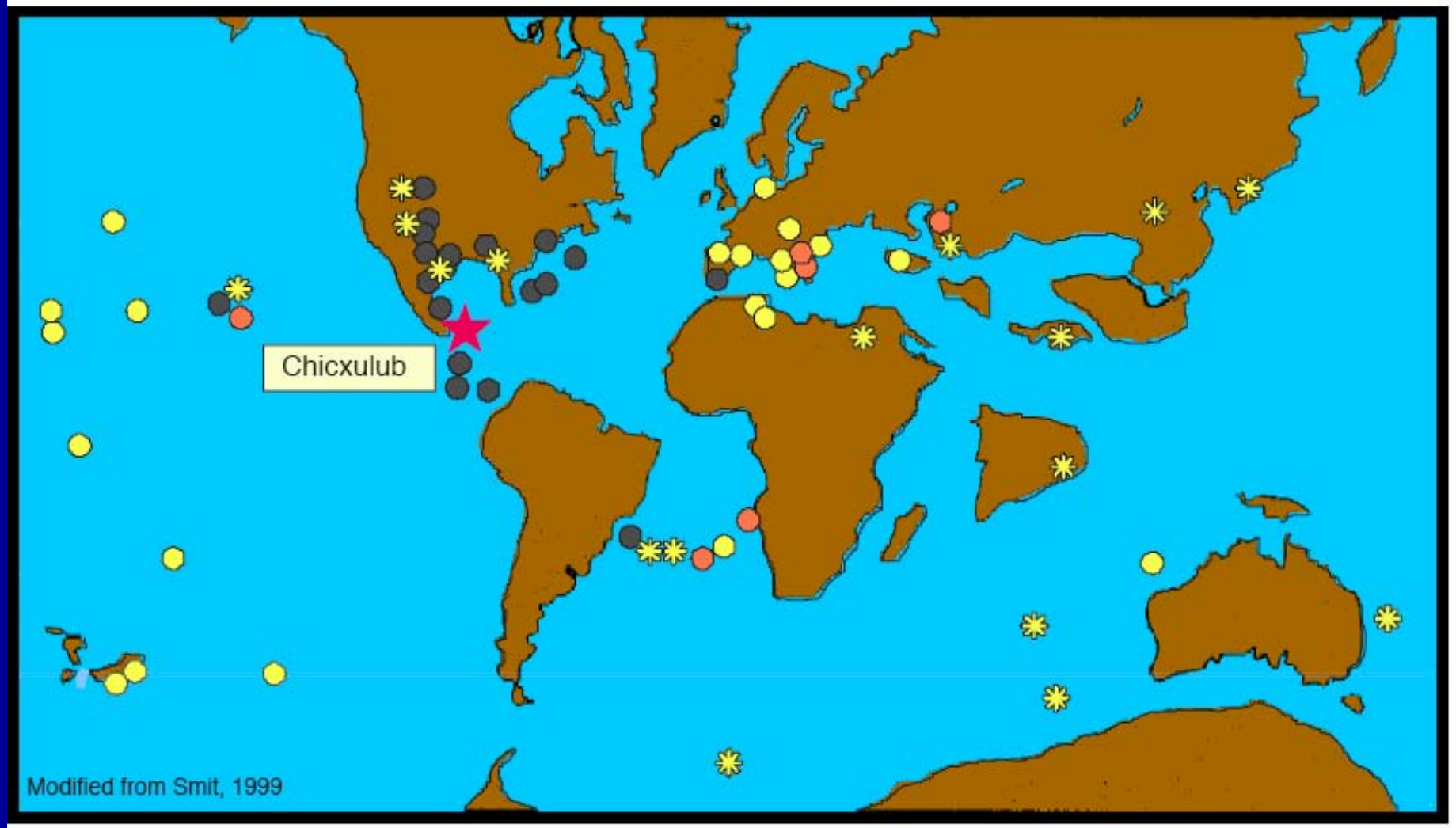


Quartz

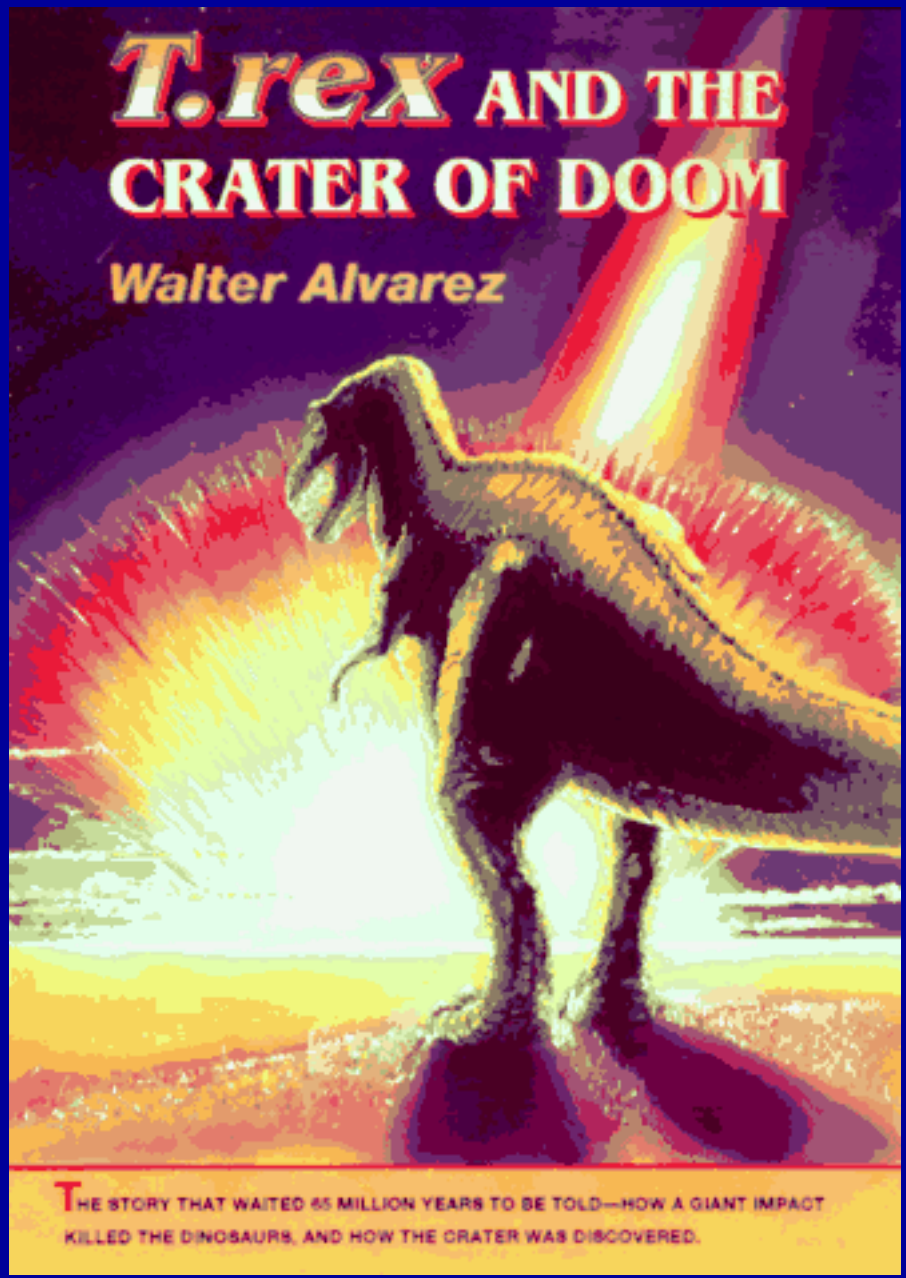
Bohr (1984) first identification of shocked quartz

Bass River, New Jersey photos and identifications from Izett

K/T boundary sites 65 Ma



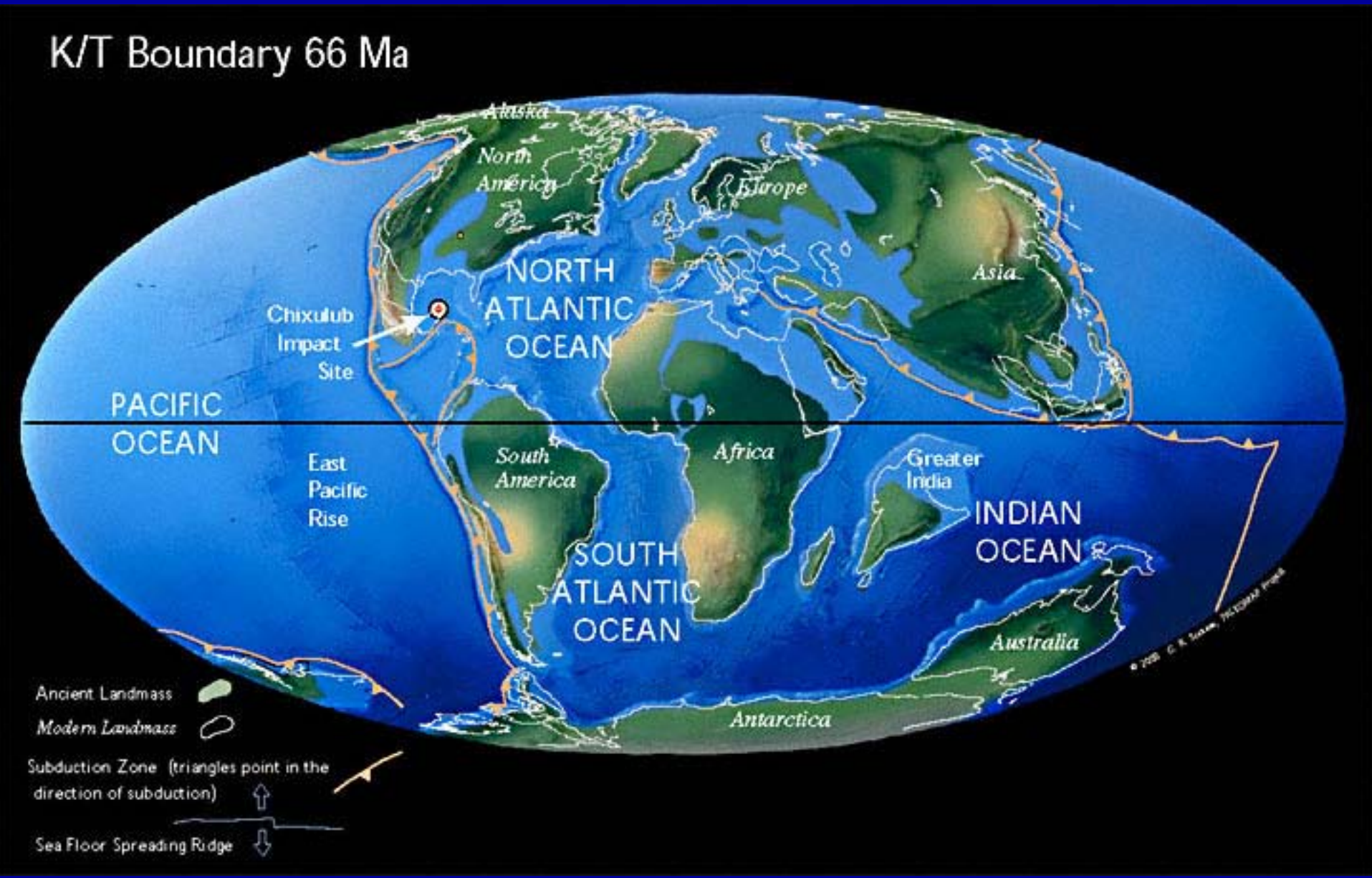
● Tectites & iridium anomaly ● microkrystites & iridium anomaly ✱ iridiium anomaly
● microkrystites only

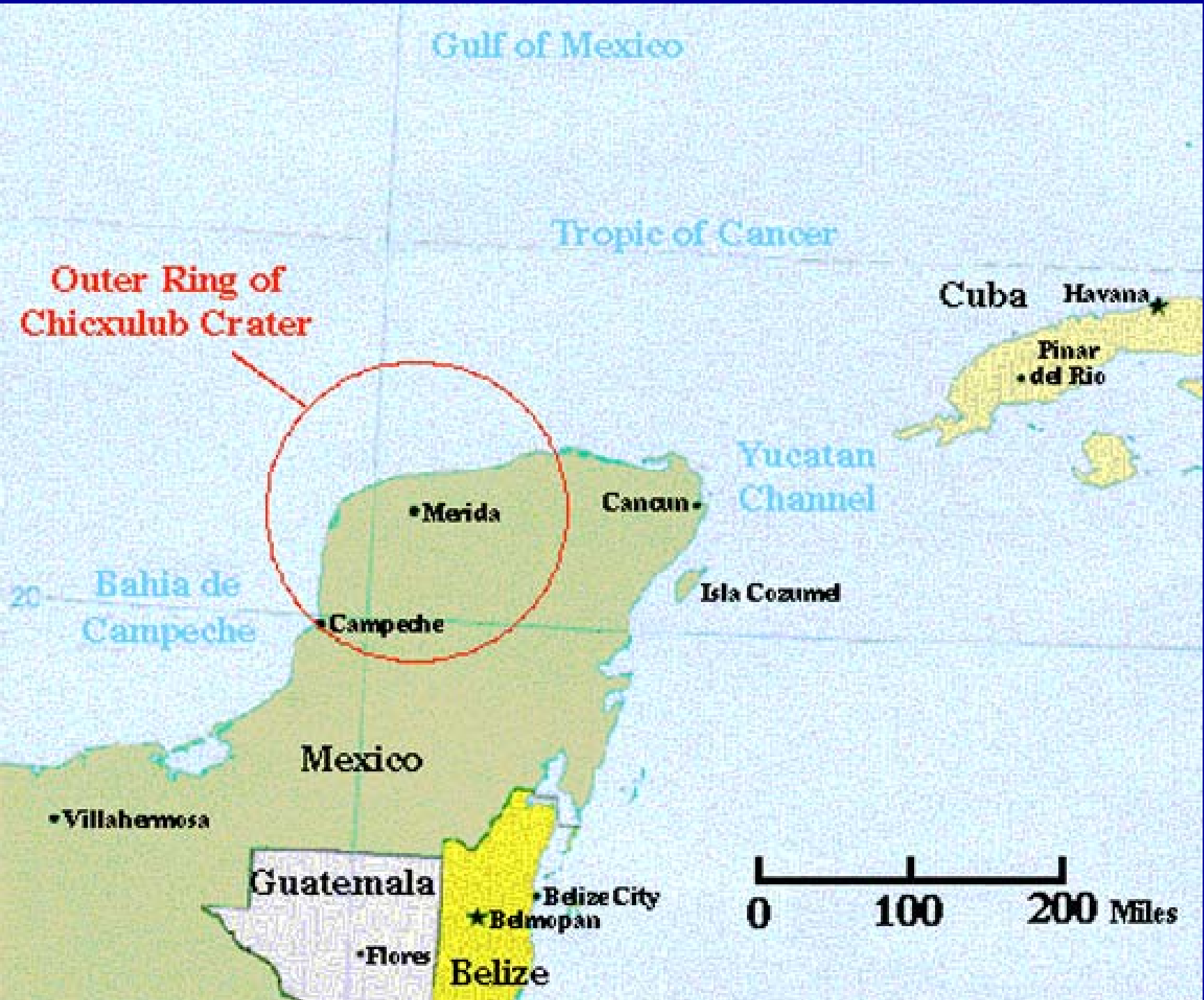


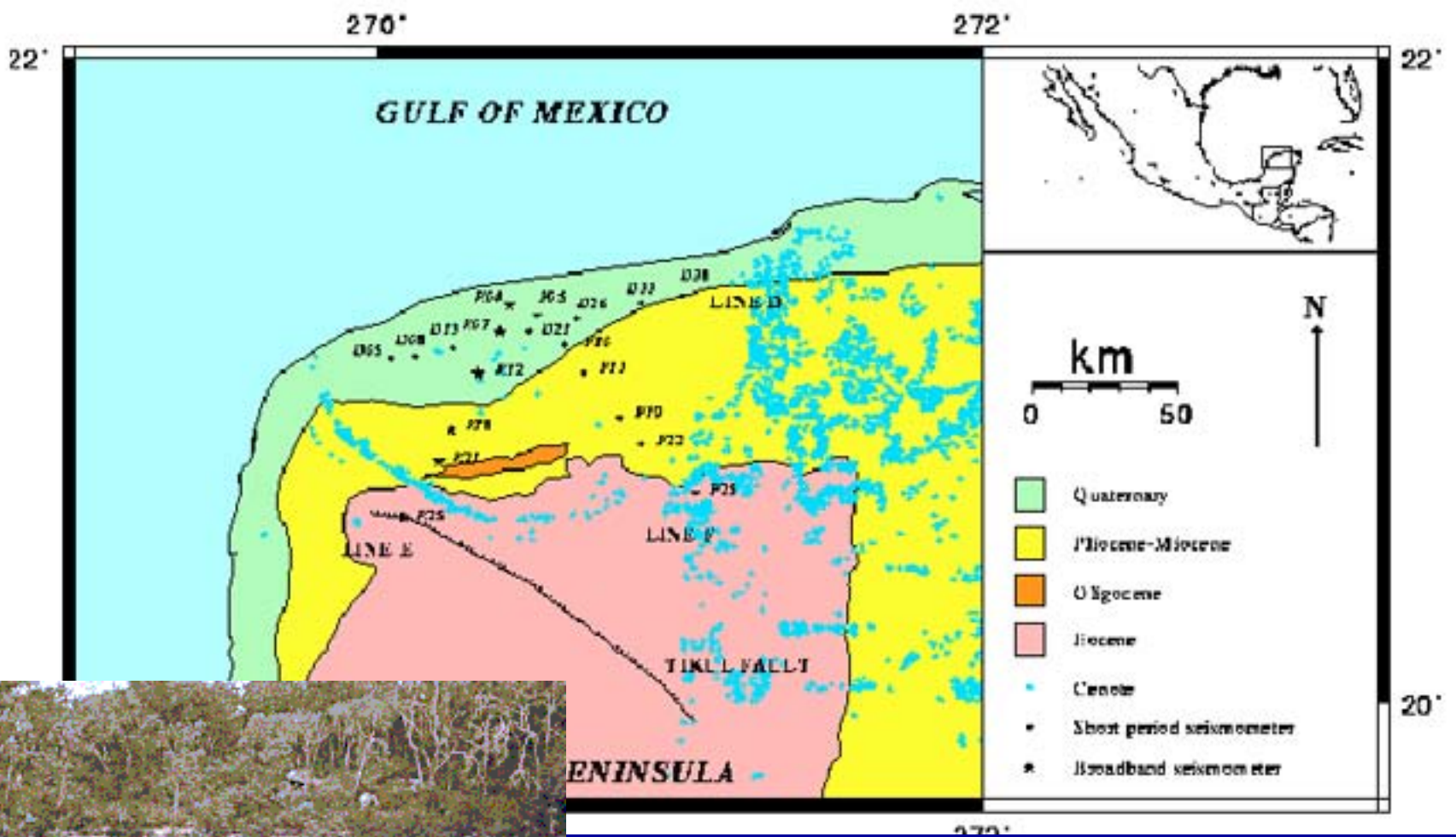
The discovery of the cause of this mass extinction event is one the of the great scientific detective stories of the 20th century.

Walter Alvarez tells his part of the story in "*T. rex and the Crater of Doom*."

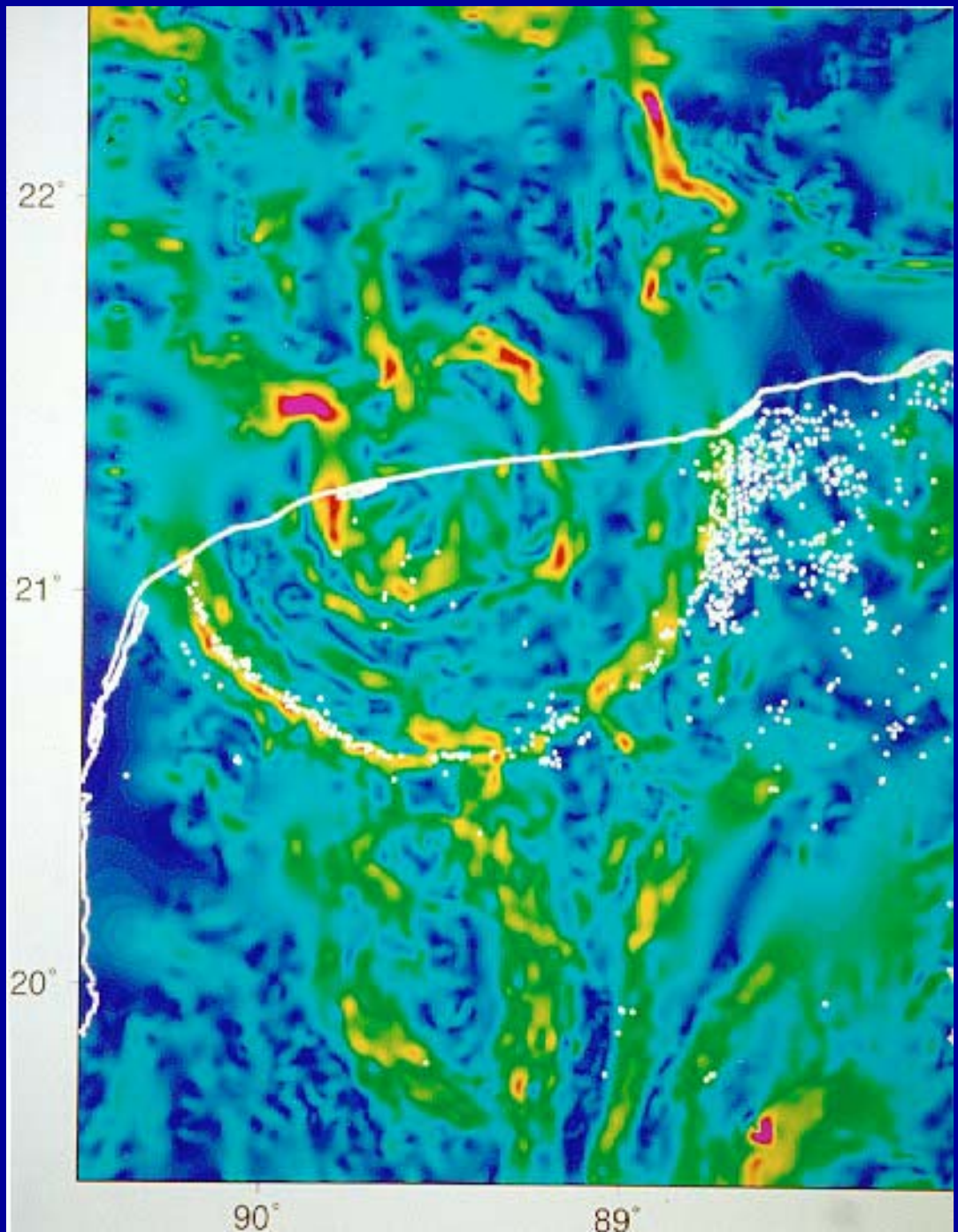
Where was the impact crater?

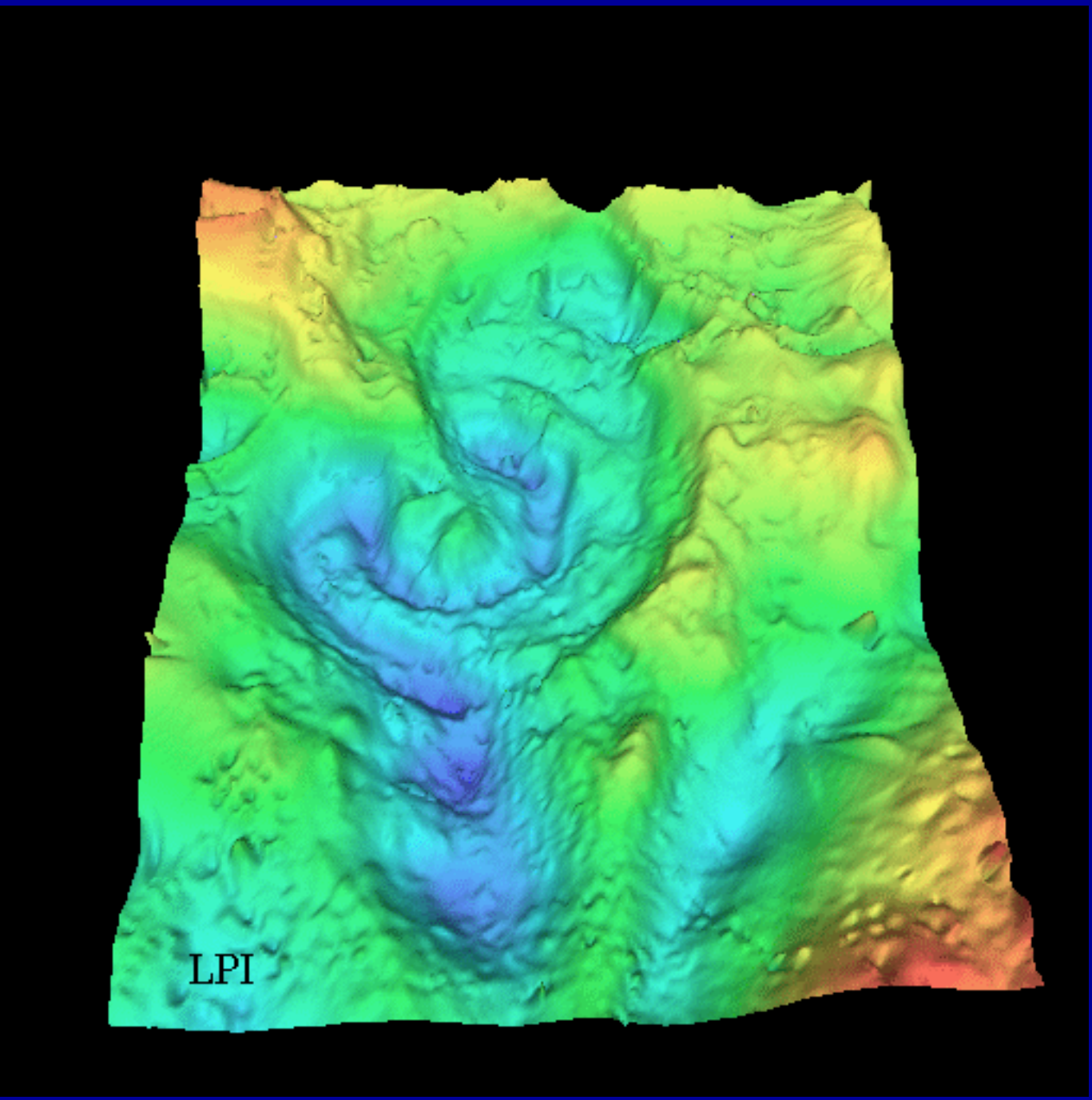

K/T Boundary 66 Ma
Alaska
North America
Europe
Asia
NORTH ATLANTIC OCEAN
Chixulub Impact Site
PACIFIC OCEAN
East Pacific Rise
South America
Africa
Greater India
INDIAN OCEAN
SOUTH ATLANTIC OCEAN
Australia
Antarctica
Ancient Landmass
Modern Landmass
Subduction Zone (triangles point in the direction of subduction)
Sea Floor Spreading Ridge


Gulf of Mexico
Tropic of Cancer
Outer Ring of
Chicxulub Crater
Cuba
Havana
Pinar
del Rio
Yucatan
Channel
Merida
Cancun
Isla Cozumel
20
Bahia de
Campeche
Campeche
Mexico
Villahermosa
Guatemala
Belize City
Belmopan
Flores
Belize
0
100
200 Miles

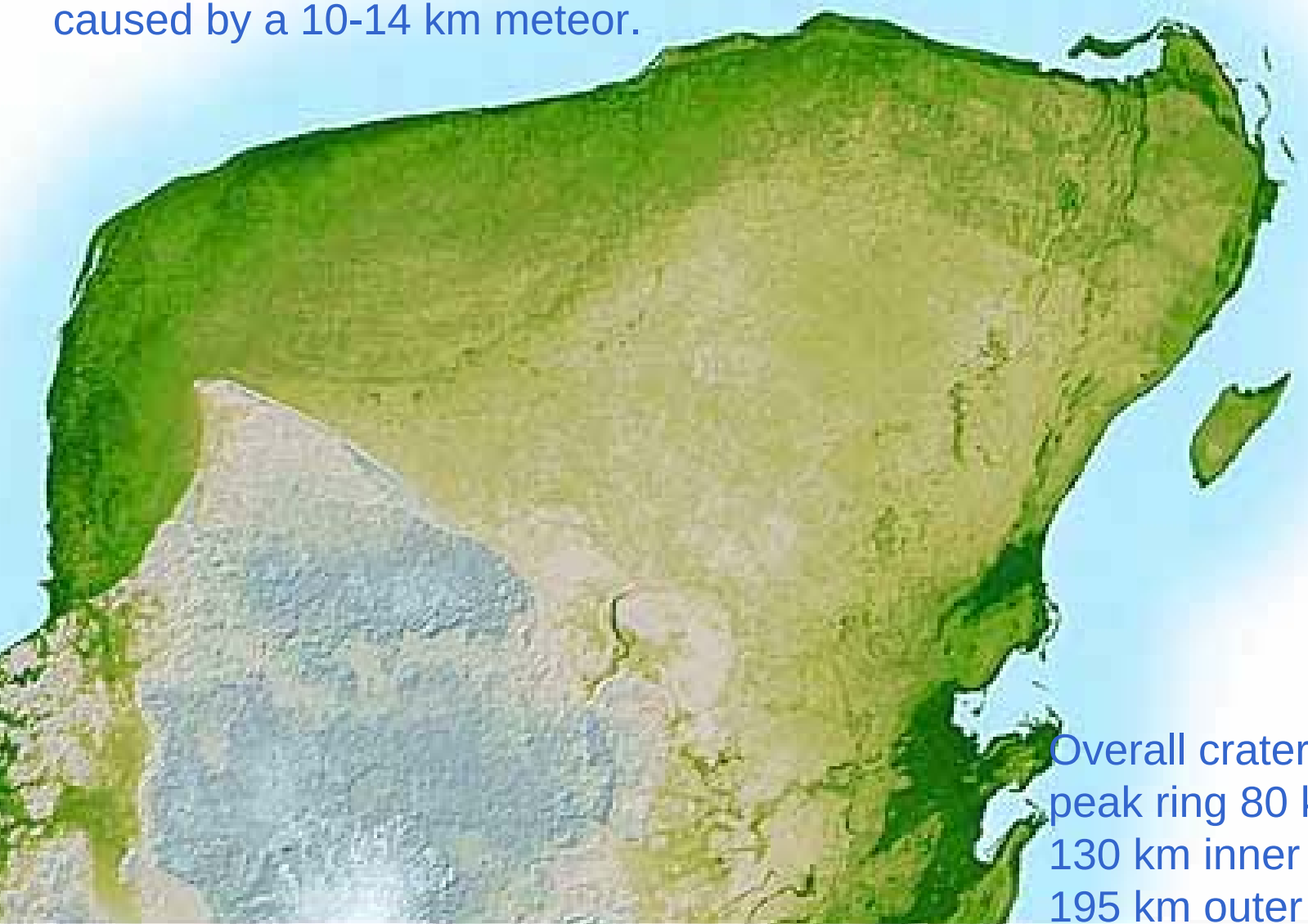


The cenote at Chizchén Itzá Mayan site in Yucatán
http://www.athenapub.com/crater1.htm


22°
21°
20°
90°
89°


LPI

Transient crater 85 km diameter,
caused by a 10-14 km meteor.



Overall crater three rings:
peak ring 80 km
130 km inner ring, and
195 km outer

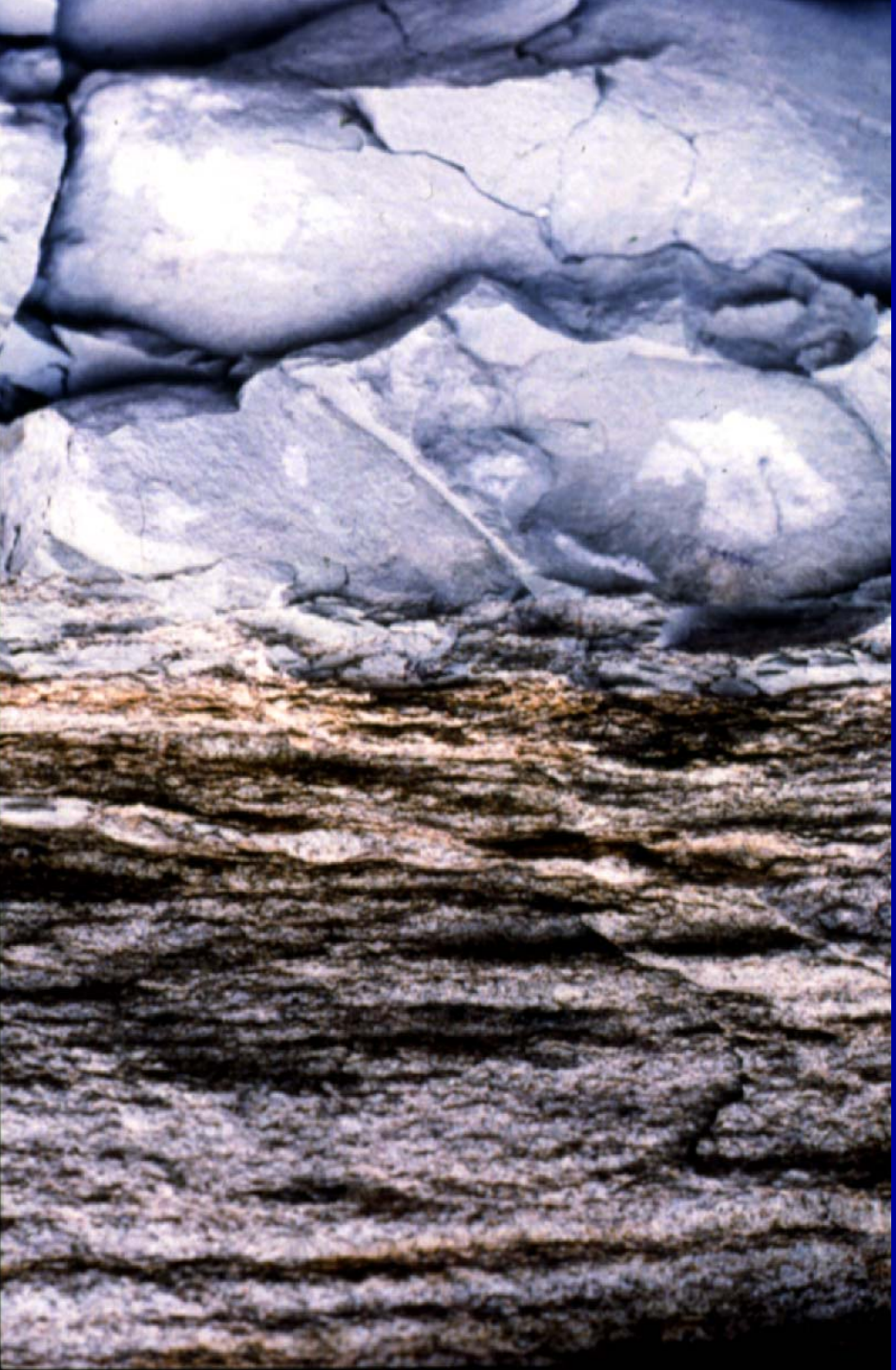
most scientist now discredit volcanic cause, favor impact

but the plot took a twist

Although foraminiferal micropaleontologists had for years shown that the extinction of planktonic foraminifera was at a knife edge (Olsson, 1960 in NJ; Premoli-Silva and Luterbacher at Gubbio; Smit at Caracava & Gubbio others at Stevns Klint), Keller and coworkers muddied the waters by claiming that the foraminiferal extinctions were stepped and somewhat gradual.

Keller has and continues to work on the Mexican sections that contained mega-tsunami deposits.

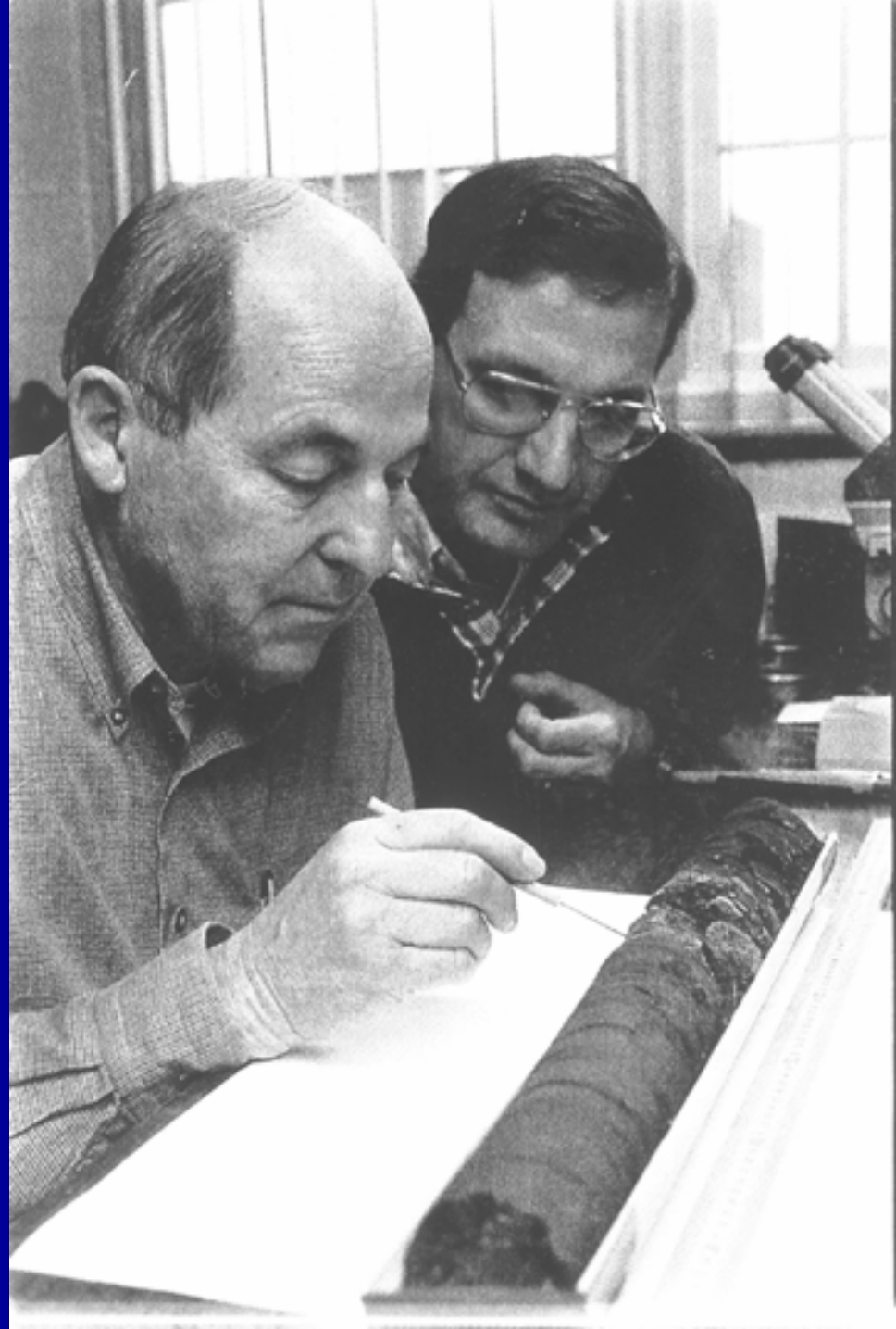
Keller argued that the highest occurrence of Cretaceous planktonic foraminifera were above the Ir anomaly in the Mexican/Texan sections especially those at El Mimbral

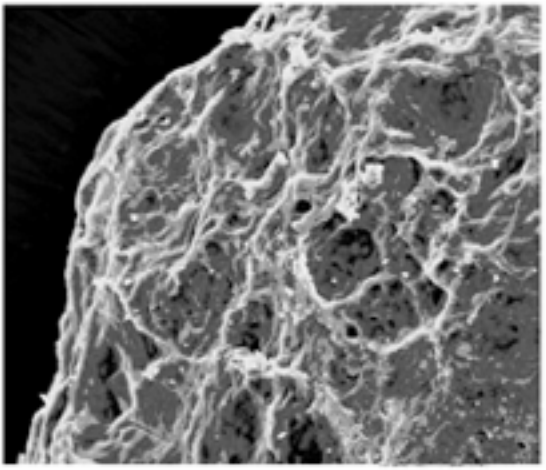


Tsunamite overlying spherule bed
at El Mimbral, Mexico

The direct effects of the impact of an asteroid at Chixulub resulted in intense stratigraphic mixing in the Caribbean/Gulf of Mexico region and made the record in this region debateable

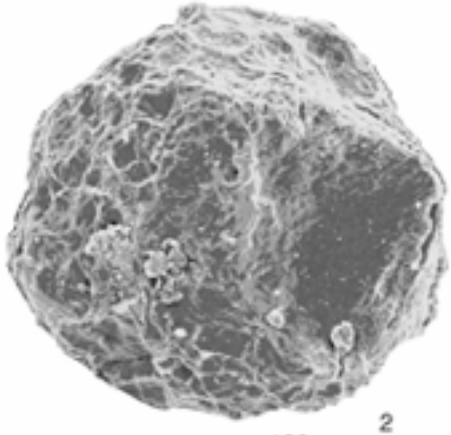
The good guys from New Jersey to the rescue!





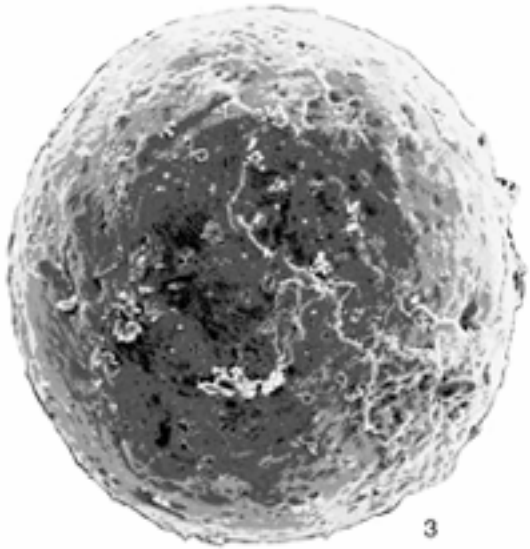
5 µm

1



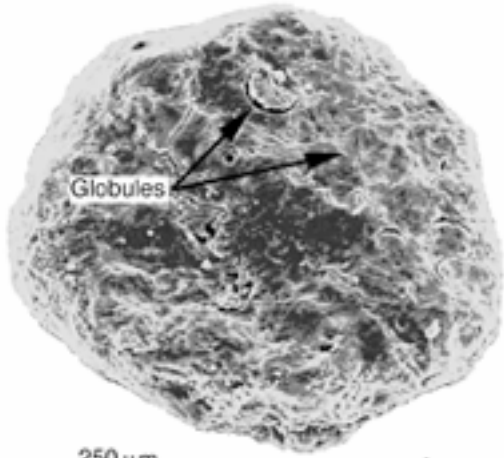
100 µm

2



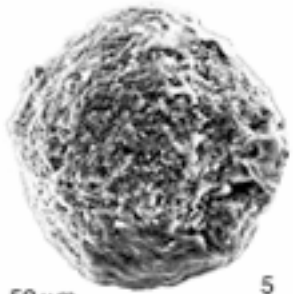
3

100 µm



250 µm

4

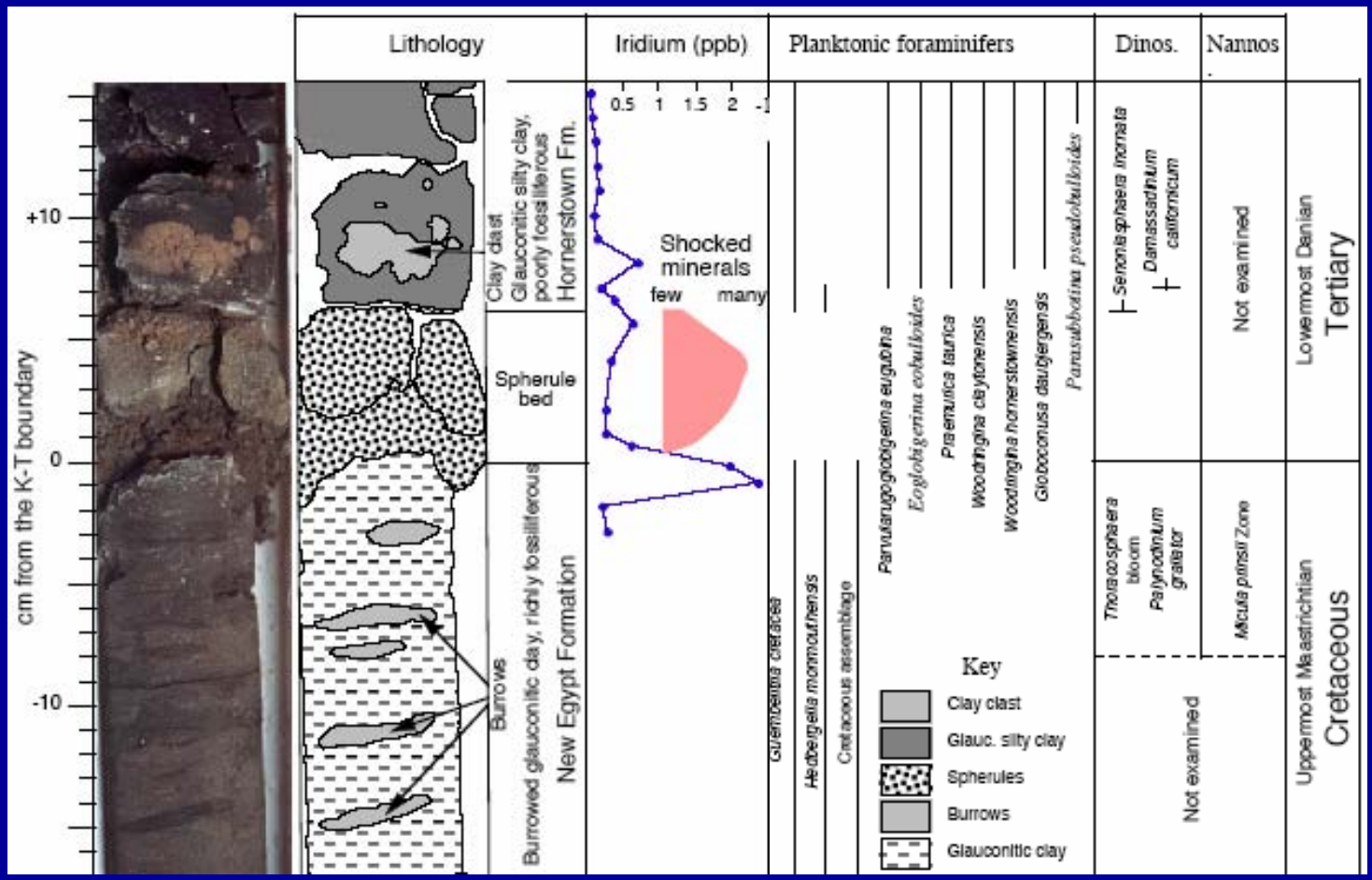


50 µm

5

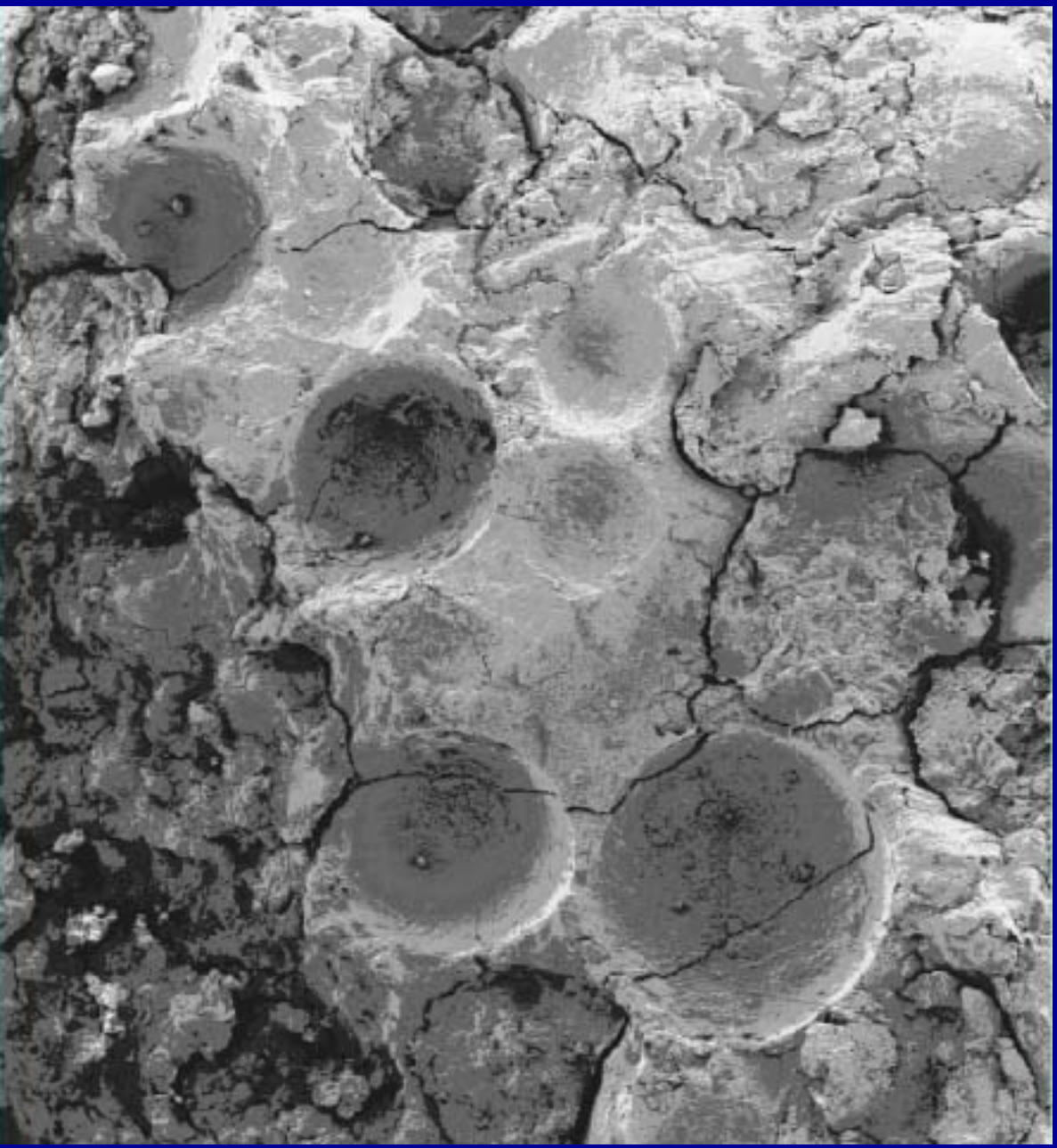
Olsson et al. Fig 3

K/T Mass Extinction, Bass River, NJ



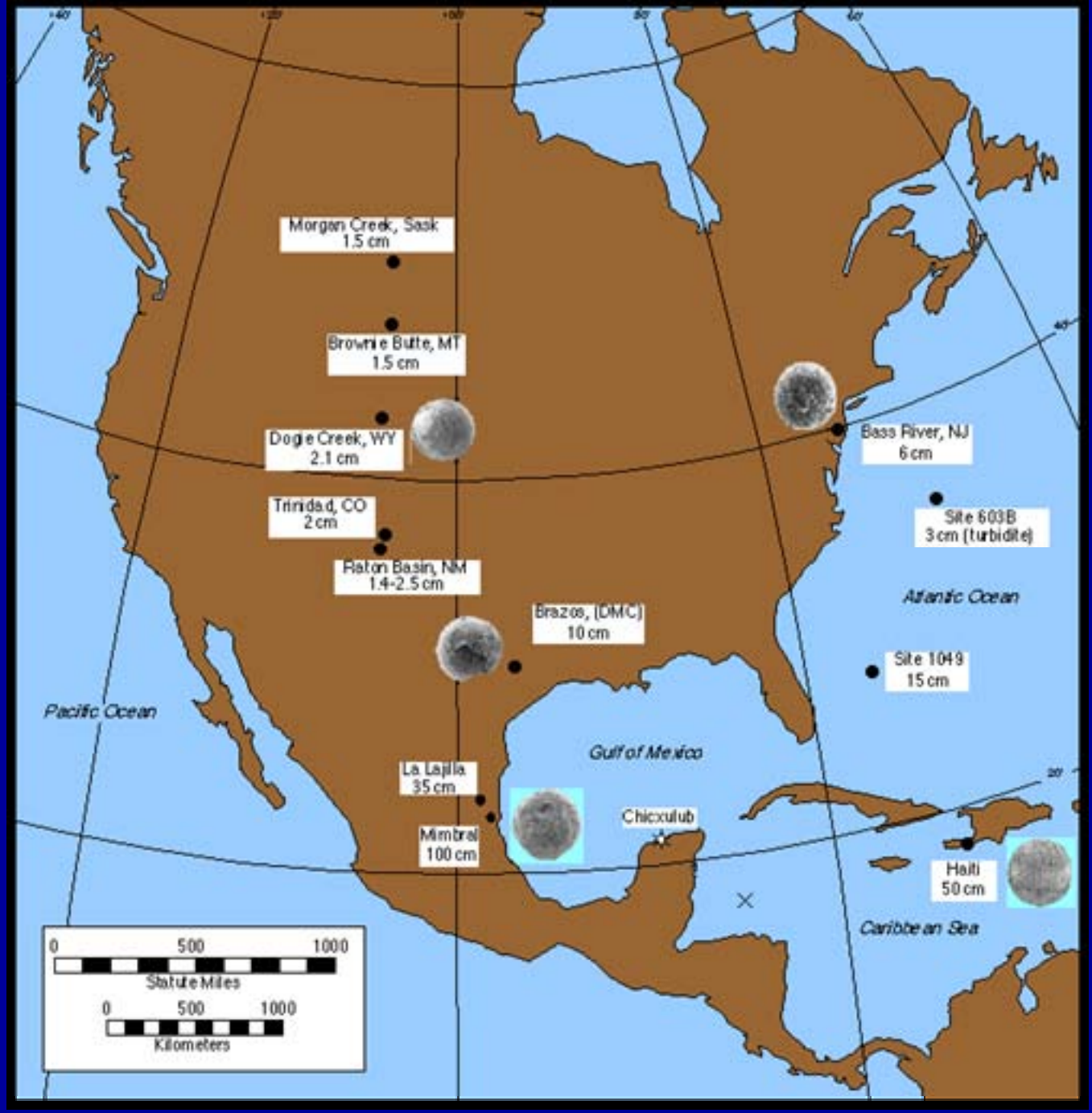
R.K. Olsson, K.G. Miller, J.V. Browning, P.J. Sugarman, 1997

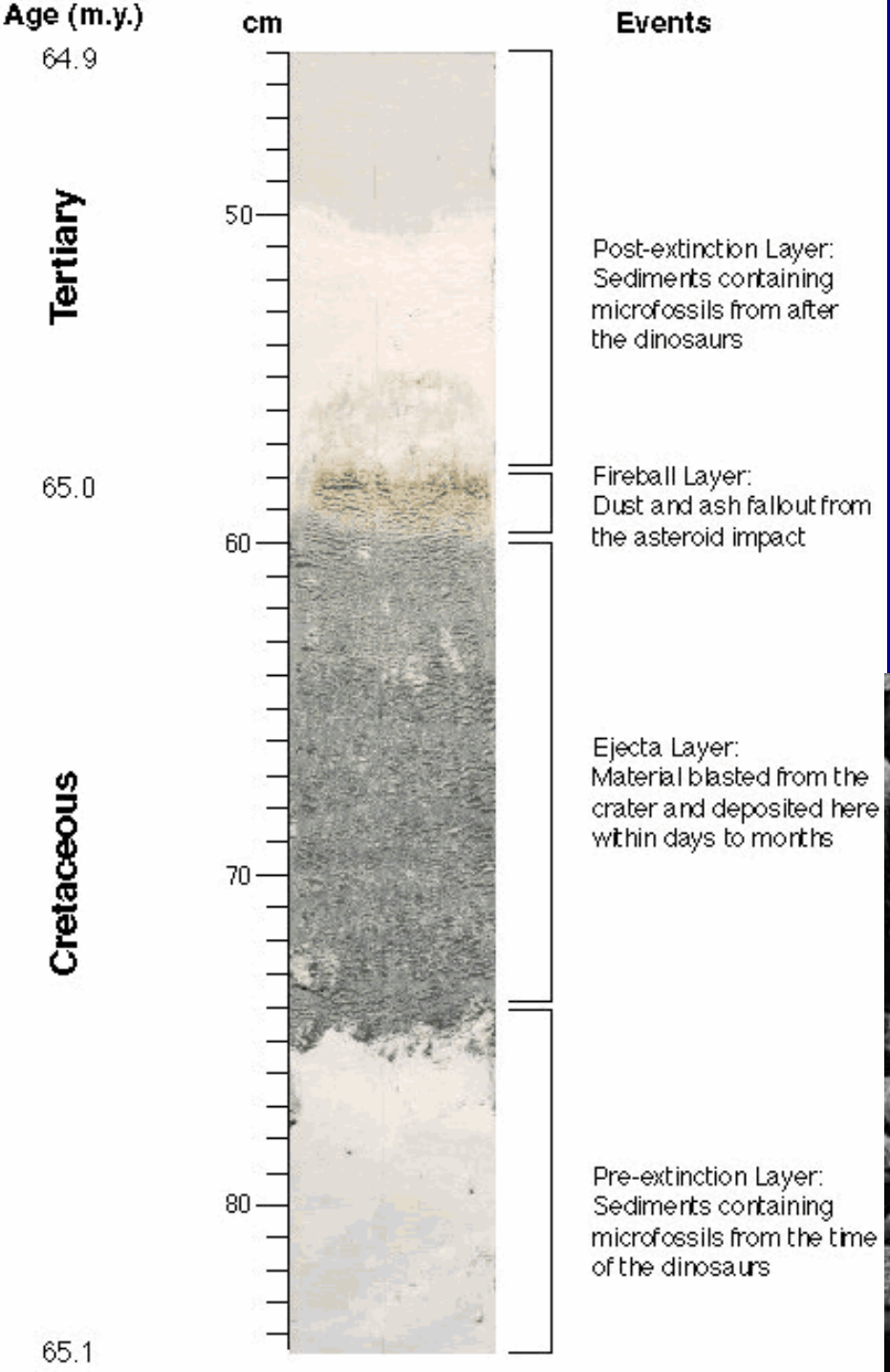
Spherule layer (~6 cm thick) fallout of impact ejecta from Chicxulub Crater in Yucatan, Mexico. (incineration of terrestrial organisms and settling though the water column of 100 m beginning at ~10 minutes after impact Furthest north that a distinct layer has been identified (some 2500 km from the crater)



Confirmation of "continuous" deposition across the K/T boundary on the Atlantic seaboard.Uppermost Cretaceous strata are overlain by lowermost Tertiary Zone P0, indicating that deposition was continuous on a scale of 10's of thousands of years.

Continuous deposition was interrupted by the abrupt fallout of the ejecta layer. Because the NJ boundary is far enough from "ground zero," it provides clear identification of the K/T boundary and its relationship to the effects of the impact, versus the Gulf of Mexico, where proximity to the impact obscures these relationships.

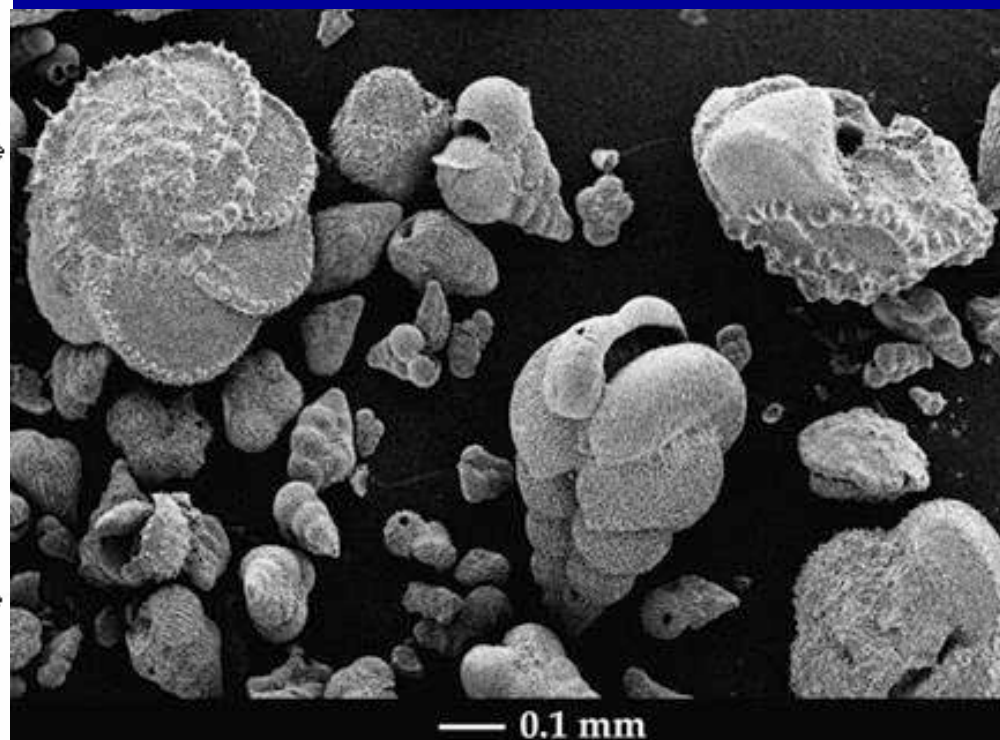

Morgan Creek, Sask
1.5 cm
Brownie Butte, MT
1.5 cm
Dogie Creek, WY
2.1 cm
Trinidad, CO
2 cm
Raton Basin, NM
1.4-2.5 cm
Brazos, (DMC)
10 cm
Bass River, NJ
6 cm
Site 603B
3 cm (turbidite)
Site 1049
15 cm
Atlantic Ocean
Pacific Ocean
Gulf of Mexico
La Lajilla
35 cm
Mimbral
100 cm
Chicxulub
Haiti
50 cm
Caribbean Sea
0 500 1000
Statute Miles
0 500 1000
Kilometers



Ocean Drilling Program Leg 171A, Site 1049

Similar story
Prettier core
Better PR agent than RU

“the most significant scientific discovery of the last 20 years” NSF Geoscience Director



Still bucking theory of how dinosaurs died

Princeton geoscientist calls Mexican meteor idea flat-out wrong.

By Tom Avril
Inquirer Staff Writer Oct. 25, 2006

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Press Release 06-150

More Than a Meteor Likely Killed Dinosaurs 65 Million Years Ago

Growing evidence shows a series of natural events caused extinction

Geologists drilling in the Brazos River region of Texas found new evidence for dinosaur extinction.
Credit and Larger Version

Geologist Gerta Keller looks at sediment samples along the Brazos River in Texas.
Credit and Larger Version

October 17, 2006
Growing evidence shows that the dinosaurs and their contemporaries were not wiped out by the famed Chicxulub meteor impact alone, according to a paleontologist who says multiple meteor impacts, massive volcanism in India and climate changes culminated in the end of the Cretaceous Period.

The Chicxulub impact may have been the lesser and earlier of a series of meteor impacts and volcanic eruptions that pounded life on Earth for more than 500,000 years, say Princeton University paleontologist Gerta Keller and her collaborators Thierry Adatte from the University of Neuchatel, Switzerland, and Zsolt Berner and Doris Stueben from Karlsruhe University in Germany.

A final, much larger and still unidentified impact 65.5 million years ago appears to have been the last straw, said Keller, exterminating two-thirds of all species in one of the largest mass extinction events in the history of life. It's that impact - not Chicxulub - that left the famous extraterrestrial iridium layer found in rocks worldwide that marks the impact that finally ended the Age of Reptiles, Keller believes.

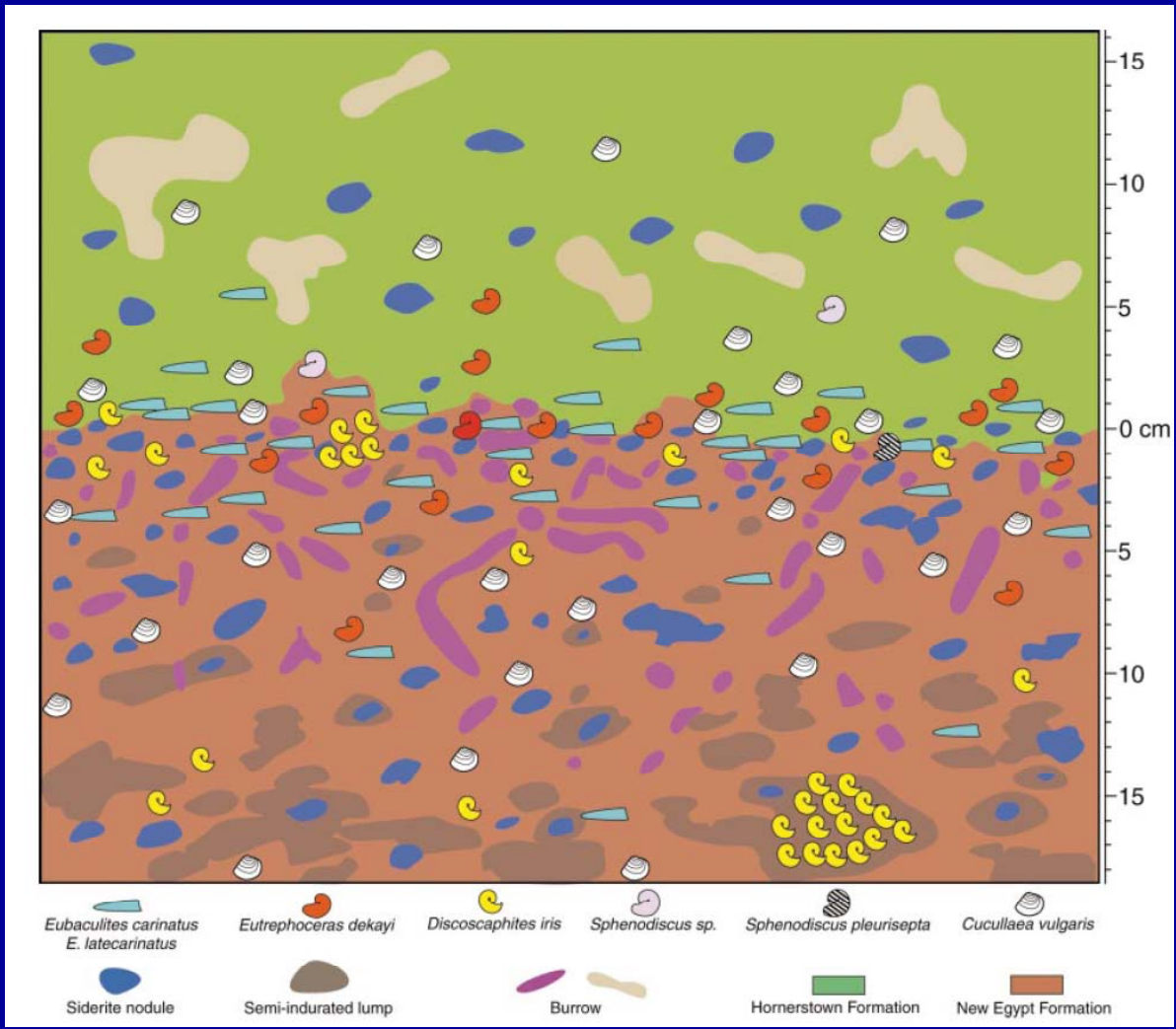
Brazos, TX corehole. Keller et al. (2006) yields a surprising history:

a series of 3 spherule beds,

an overlying “event bed” of reworked spherules (sea-level fall),

an overlying 80-cm thick clay interpreted as *in situ*, and the K/T boundary/extinction event.

Keller et al. (2006) interpret this as one or more impacts at Chicxulub time with no effect on life, a sea-level lowering, a sea level rise, and another “killer” impact.



20-cm thick bed diverse, well-preserved, ammonite (including *Discoscaphites iris*, a marker for the top of the Maastrichtian , mollusk, and shark fauna and the mollusk genus *Pinna*), interpreted as autochthonous facies.

The life position of the *Pinna* shells argues against any transport.

The bed contains dinocyst markers indicative of the latest Maastrichtian (including *Palynodinum grallator*)

Overlying is a bed of clay clasts of reworked Cretaceous material including fragments and spectacular, nearly whole specimens of reworked *D. ir s*. We suggest these reworked clasts are the equivalent of the clay clasts found in Leg 174AX coreholes.

No spherules were reported from the outcrop section, but a modest Ir anomaly (~0.5 ppb) was measured at the base of the *Pinna* bed

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE (If not in response to a program announcement/solicitation enter NSF 04-23)

NSF 04-512 11/15/06

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TITLE OF PROPOSED PROJECT Drilling the Cretaceous/Paleogene boundary in NJ: Testing the relationship of geochemical anomalies to event beds

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 159,820	24 months	04/15/07	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

☐ BEGINNING INVESTIGATOR (GPG I.A)
☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C)
☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.B, II.C.1.d)
☐ HISTORIC PLACES (GPG II.C.2.j)
☐ SMALL GRANT FOR EXPLOR. RESEARCH (SGER) (GPG II.D.1)
☐ VERTEBRATE ANIMALS (GPG II.D.5) IACUC App. Date _____
☐ HUMAN SUBJECTS (GPG II.D.6)
Exemption Subsection _____ or IRB App. Date _____
☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j)
_____
☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.G.1)

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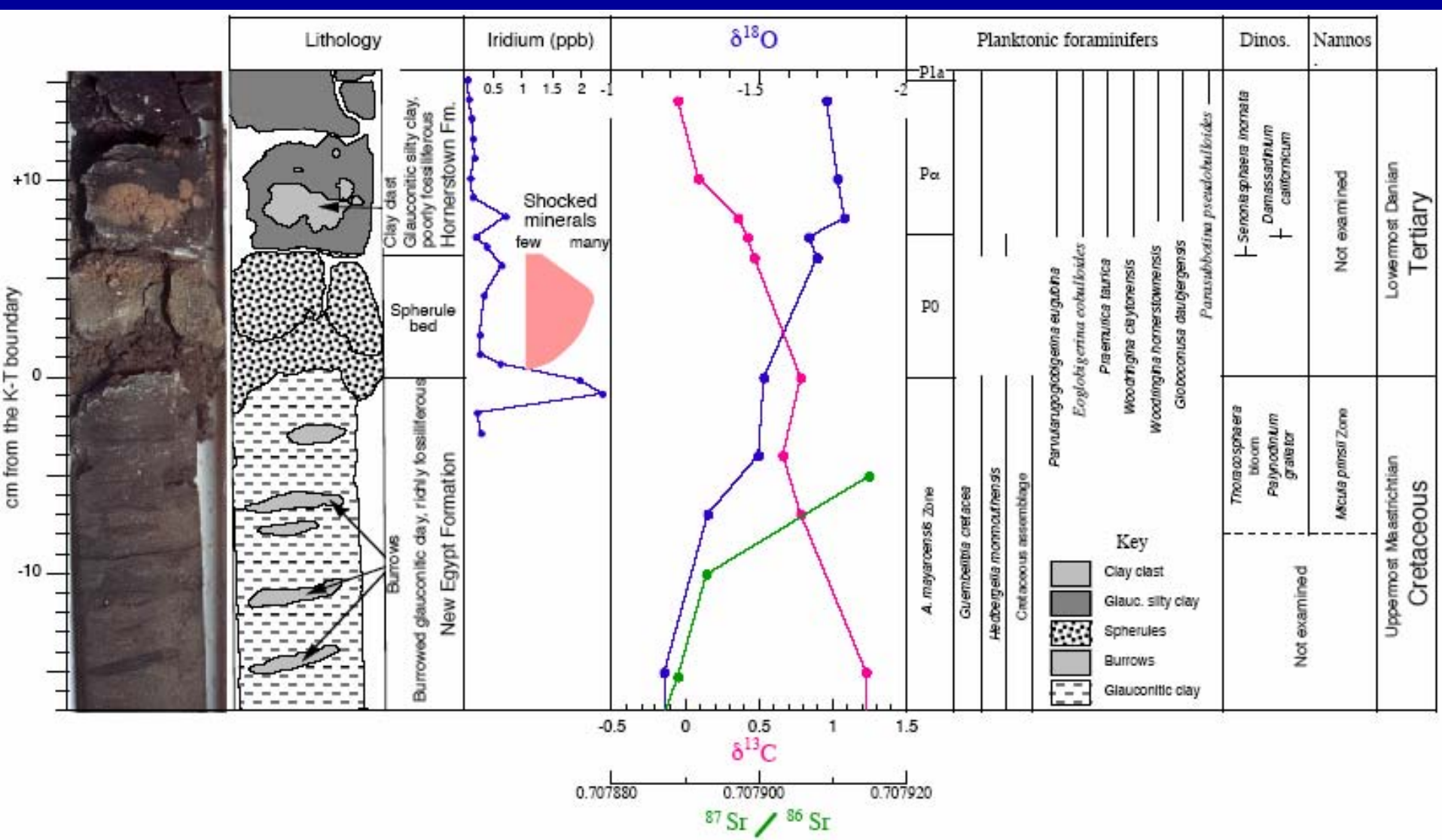
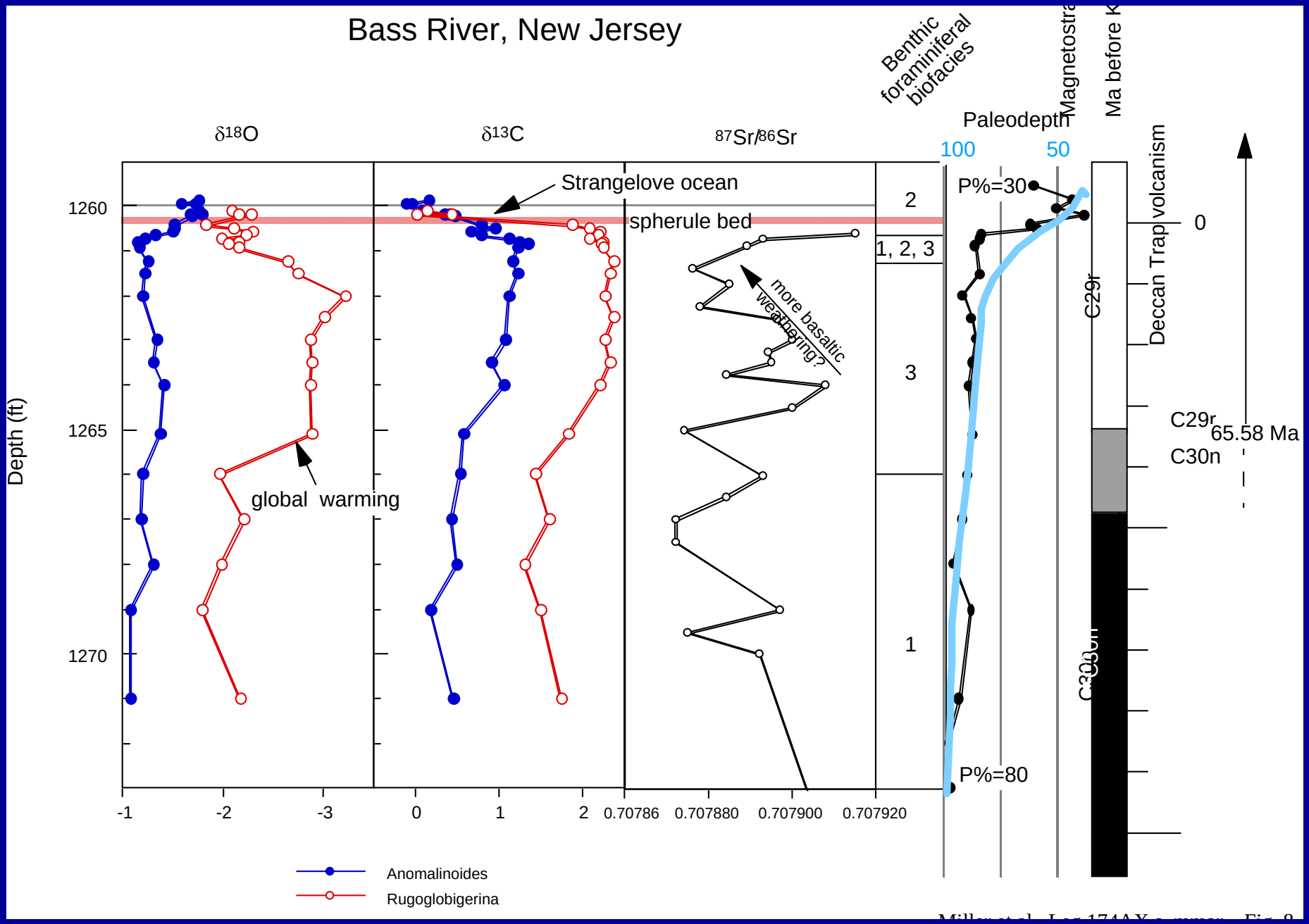
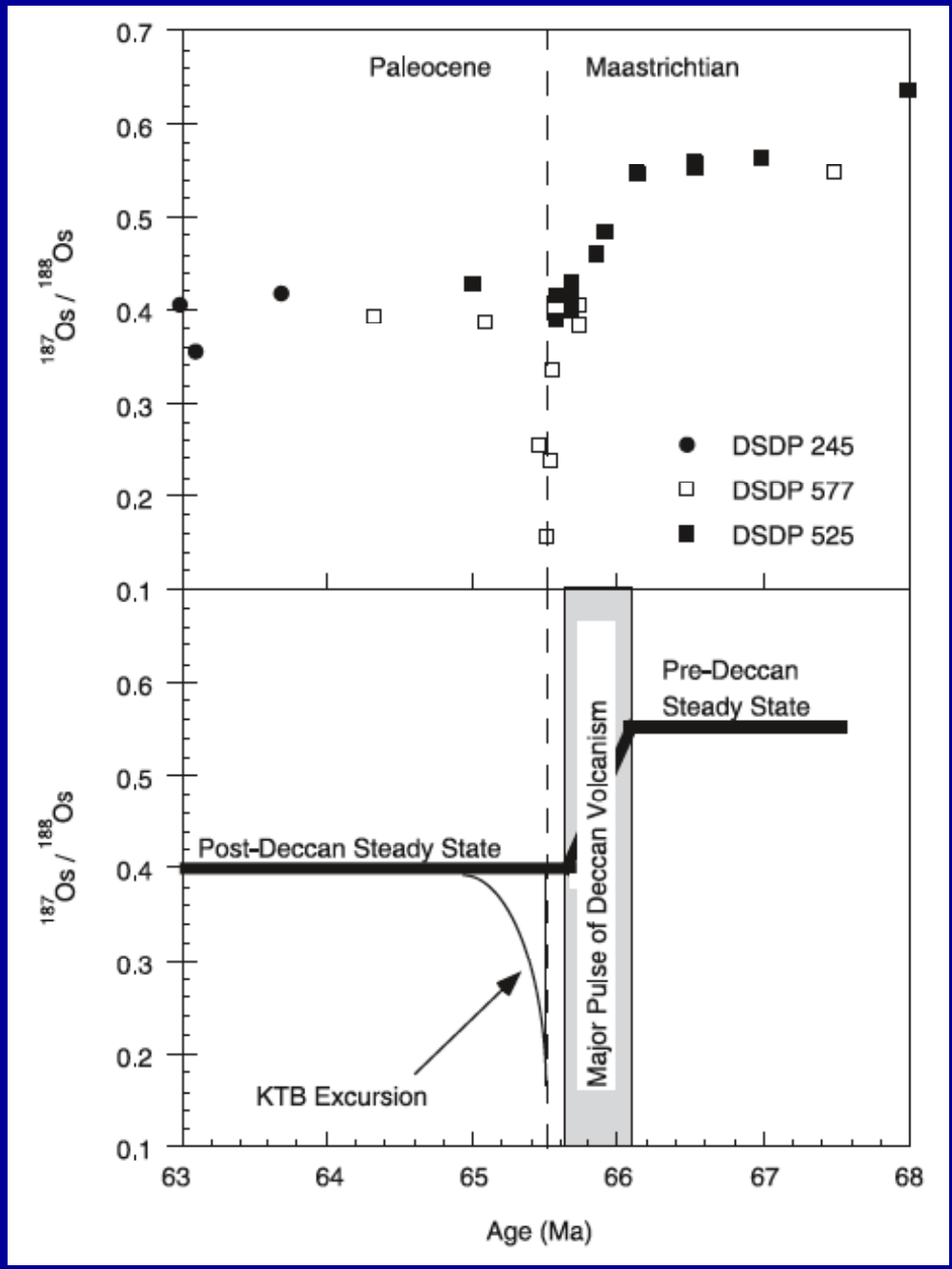


Little climate change across the K/T boundary, k.y. and m.y. scales. Long-term climates may have warmed (note oxygen isotopic decrease), but the dramatic warming/cooling predicted were too short (< <10 k.y.) to be recorded.


Bass River, New Jersey
Benthic foraminiferal biofacies
Magnetostra
Ma before K
δ18O
δ13C
87Sr/86Sr
Paleodepth
100
50
Strangelove ocean
spherule bed
2
1, 2, 3
3
1
more basaltic weathering?
P%=30
P%=80
C29r
Deccan Trap volcanism
0
C29r
65.58 Ma
C30n
Depth (ft)
1260
1265
1270
global warming
-1
-2
-3
0
1
2
0.70786
0.707880
0.707900
0.707920
Anomalinoides
Rugoglobigerina


Paleocene
Maastrichtian
DSDP 245
DSDP 577
DSDP 525
$^{187}Os / ^{188}Os$
Pre-Deccan
Steady State
Post-Deccan Steady State
Major Pulse of Deccan Volcanism
KTB Excursion
Age (Ma)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
63
64
65
66
67
68

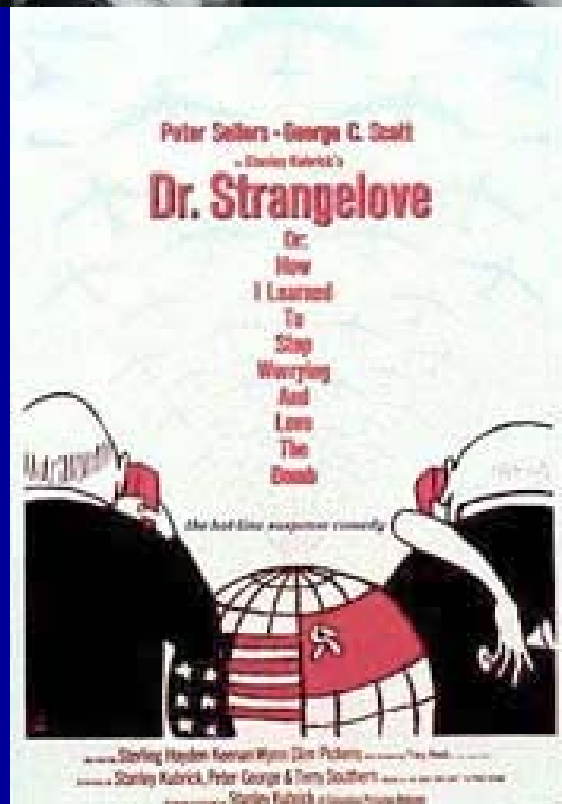
what happened to ocean productivity?
evidence for a dramatic shutdown in ocean productivity:
Strangelove Ocean

benthic and planktonic $\delta^{13}C$ difference maintained by the biological pump of productivity.

planktonics have high $\delta^{13}C$ values due to photosynthesis,
benthics low due to organic C regeneration in deep water

This surface to deep $\delta^{13}C$ difference (i.e., the biological pump) disappeared in the earliest Paleocene: shutdown of primary export productivity

confirmed at Bass River



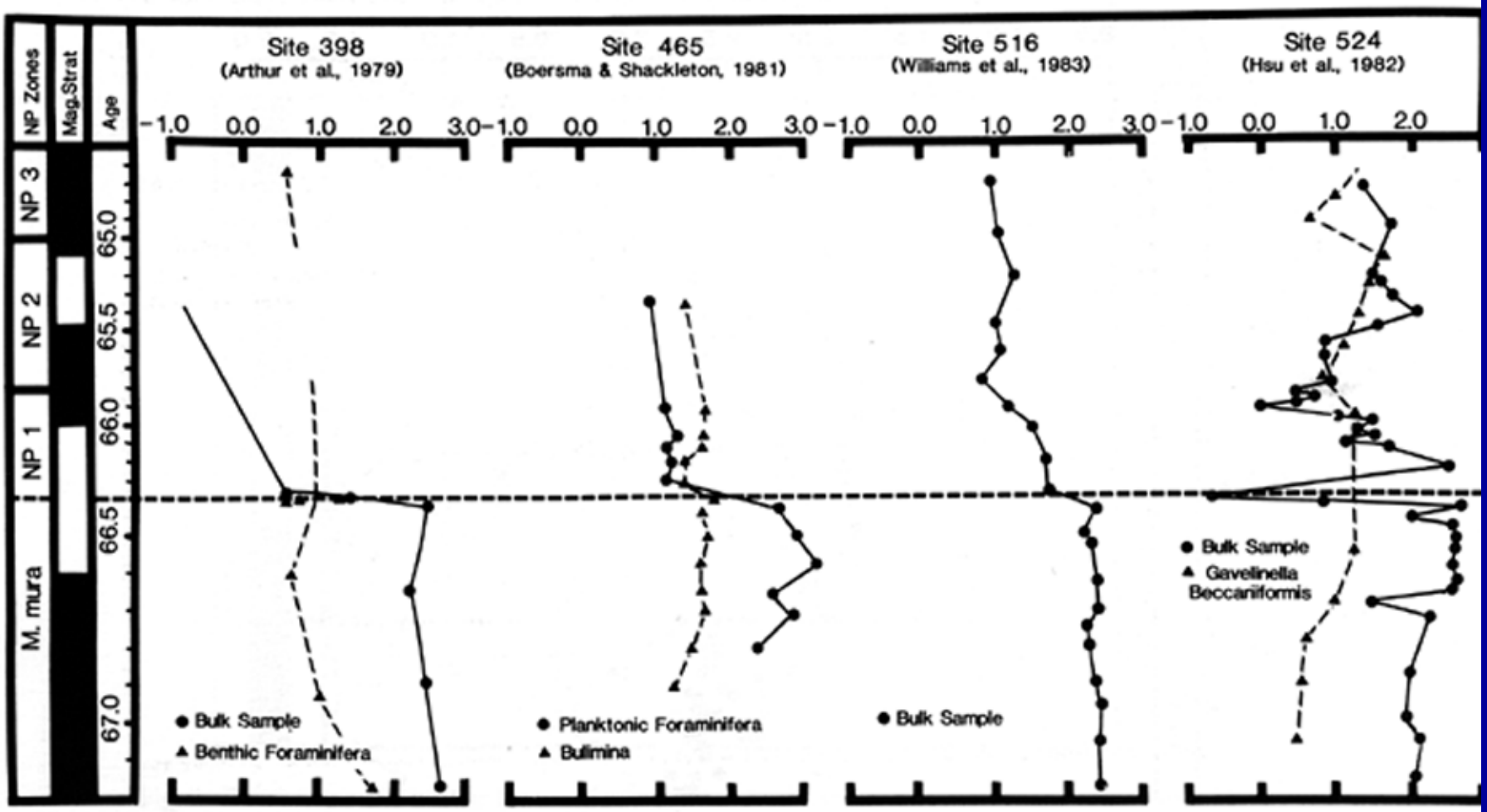
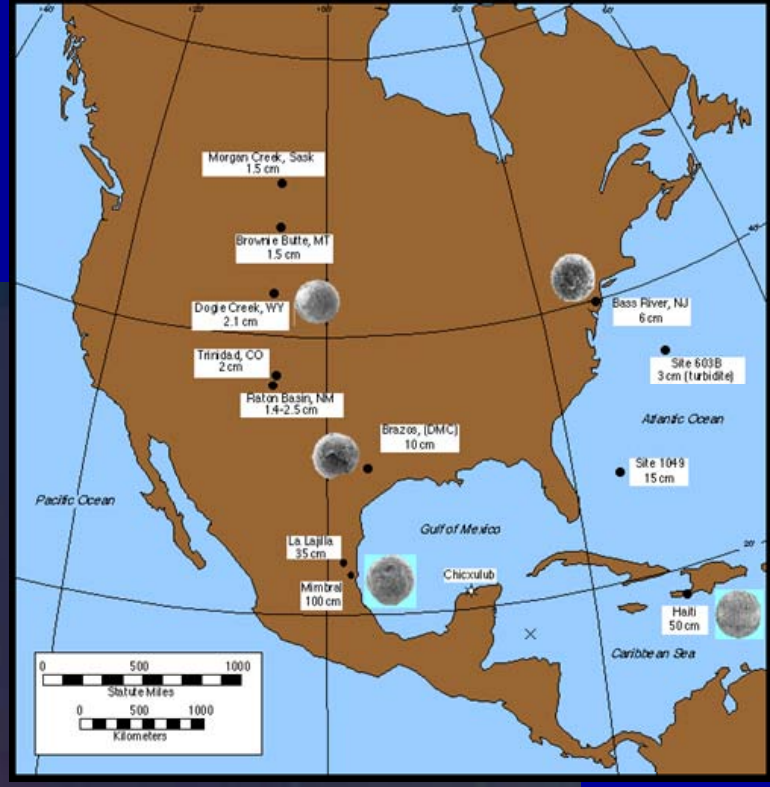
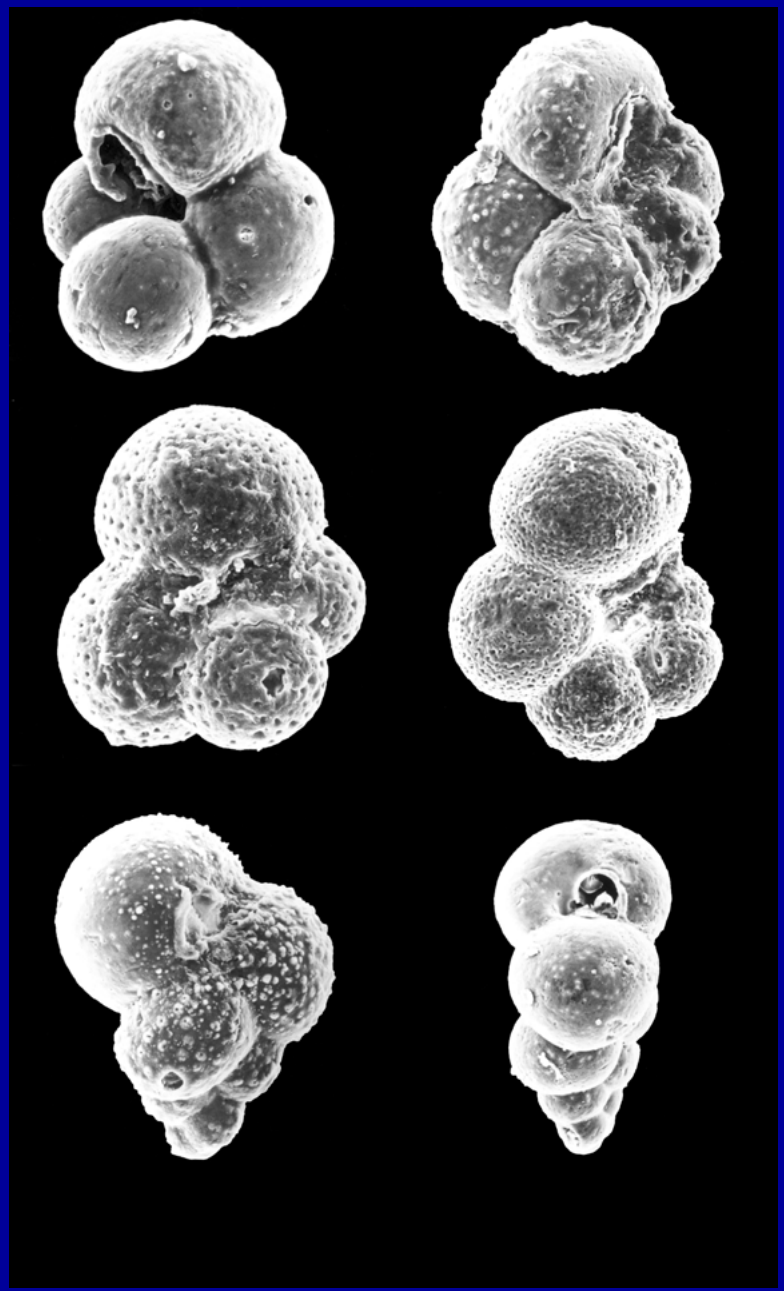


Fig. 13. Carbon isotope stratigraphy across the K/T boundary for previously published data. Circles represent values for planktonic foraminifera and bulk carbonate values. Triangles represent values for benthic foraminifera. The Paleocene time interval is compressed in relation to the Cretaceous scale.

Was the impact oblique as suggested by Schultz and D'Hondt (1996)? Simulation of impact of bullet in dolomite shown.. Distribution of the thickness of the spherule layer is consistent with this interpretation.





Who survived and why?

Opportunistic taxa such as *Guembelitria cretacea*

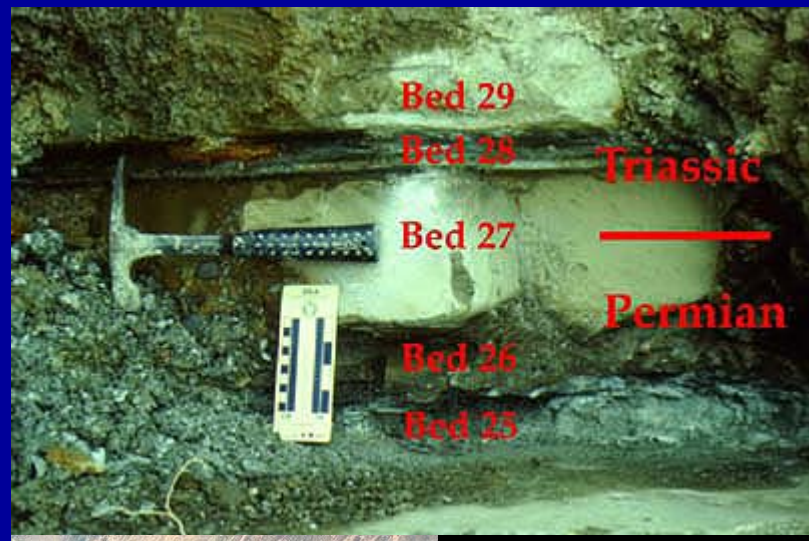
What other impacts and mass extinctions?

251 Ma Permian/Triassic

Great Dying

Little firm evidence

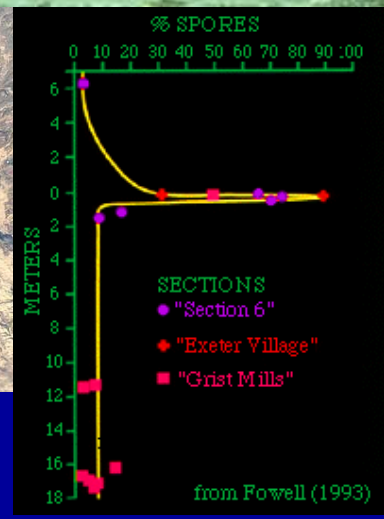
for impact



201 Ma Triassic/Jurassic

Some evidence for impact

Manicouagan slightly older

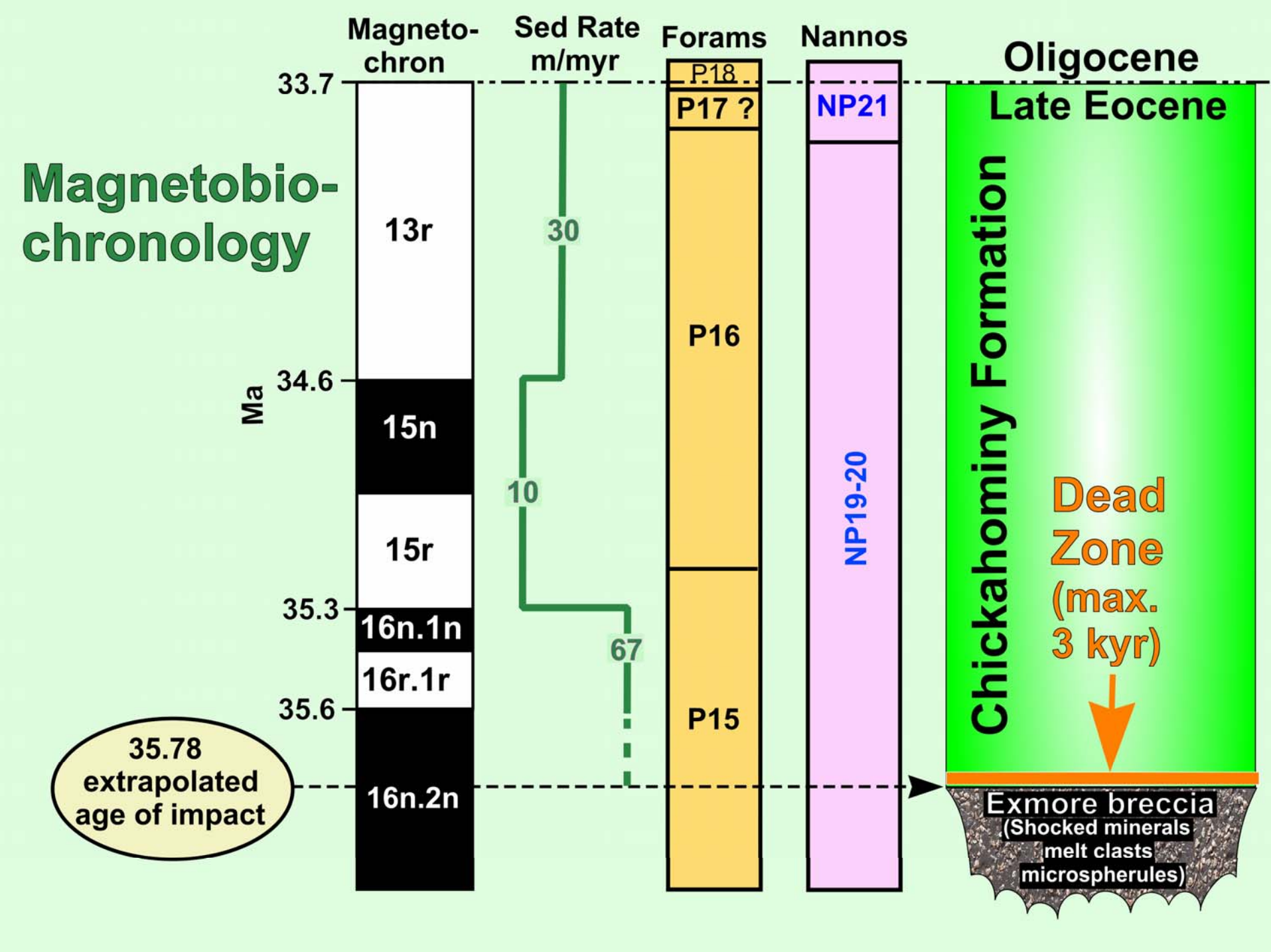


35.7 Ma Chesapeake Bay impact (80 km) &

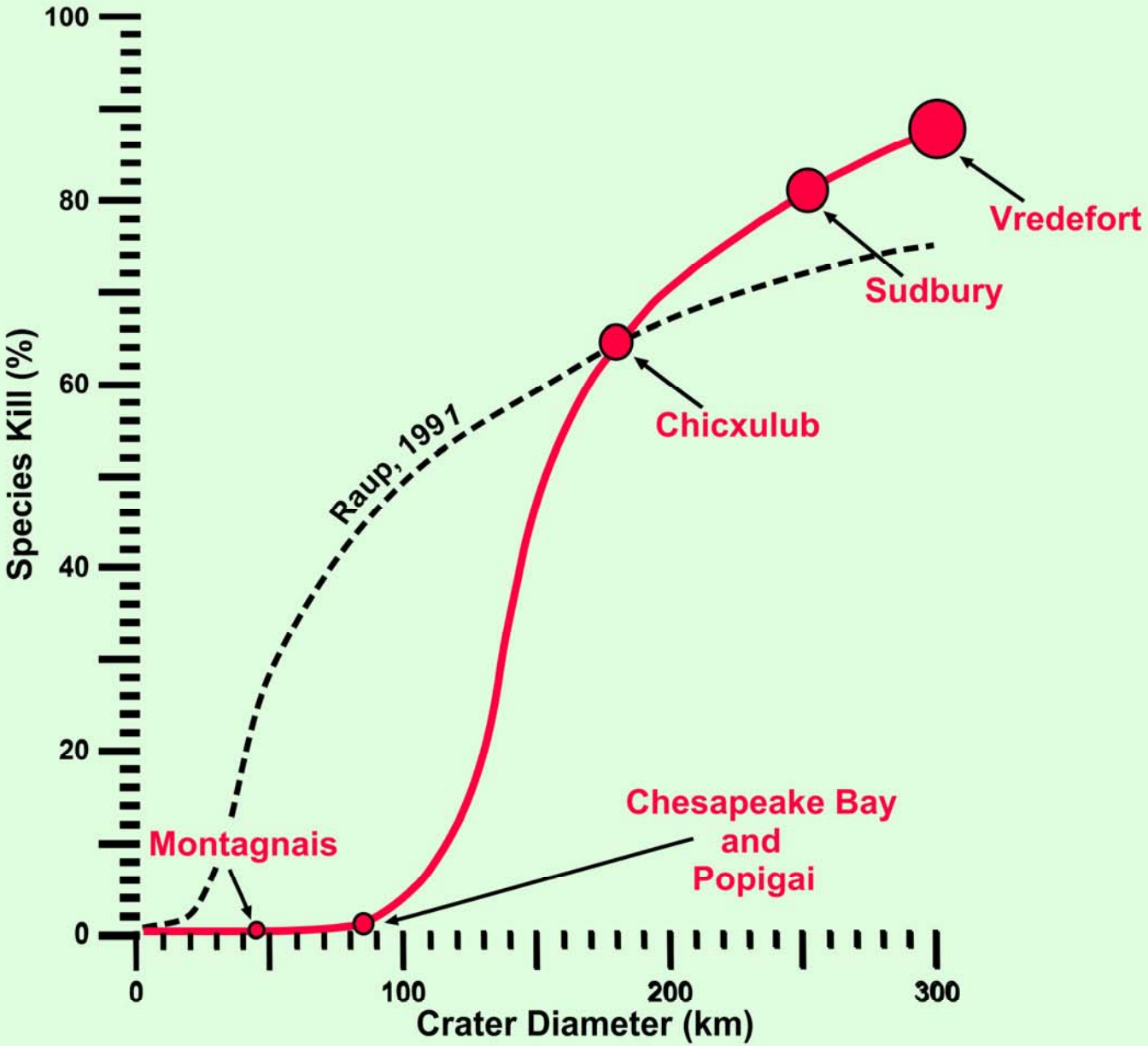
Popagai (Siberia): Shoemaker/Levy style?

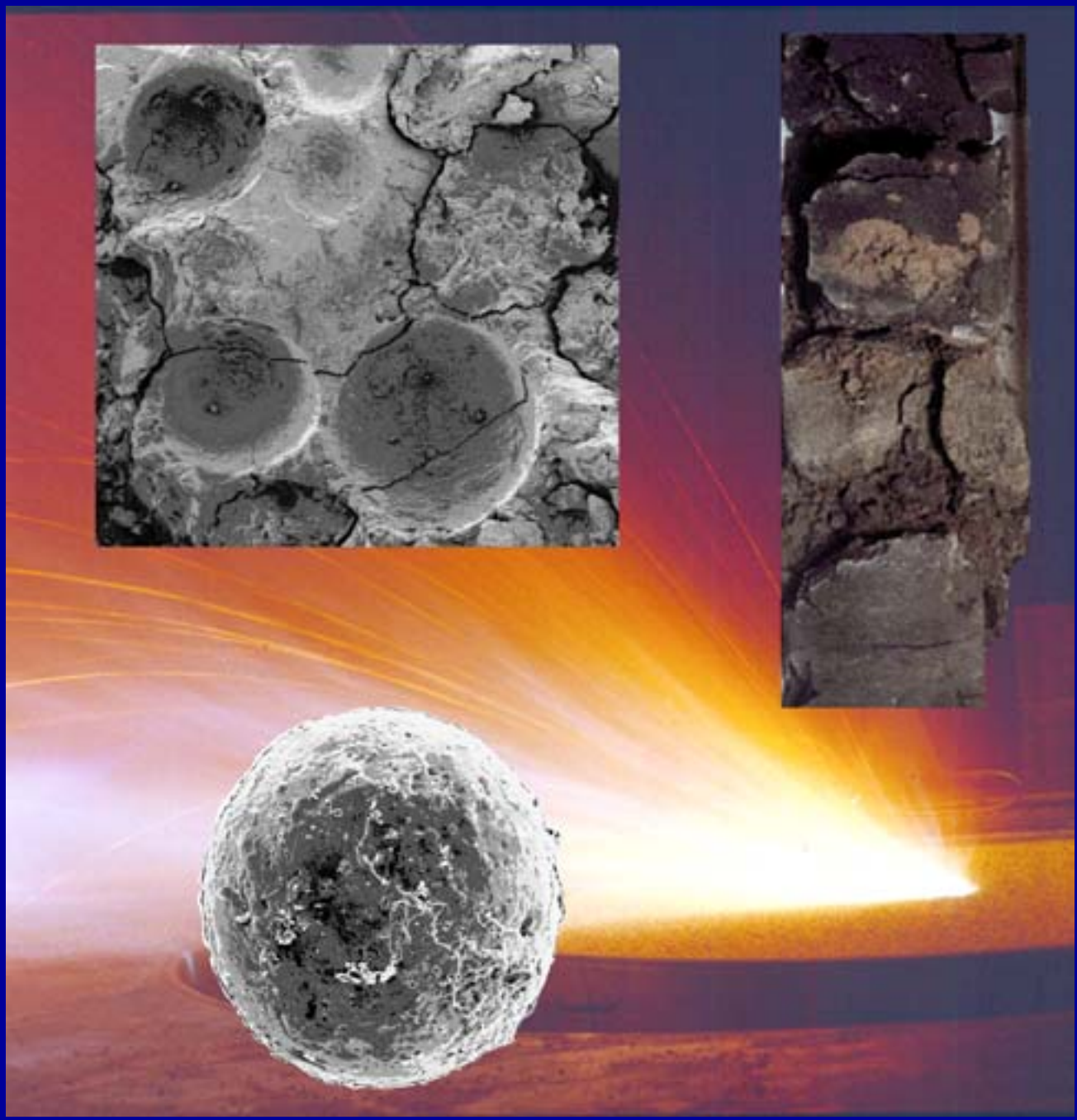
No evidence for extinctions!!!


Rappahannock R.
Windmill Point
Delmarva Peninsula
Exmore
Virginia
York R.
Cape Charles
Newport News
Hampton
James R.
Atlantic Ocean
Norfolk
Virginia Beach
0
50

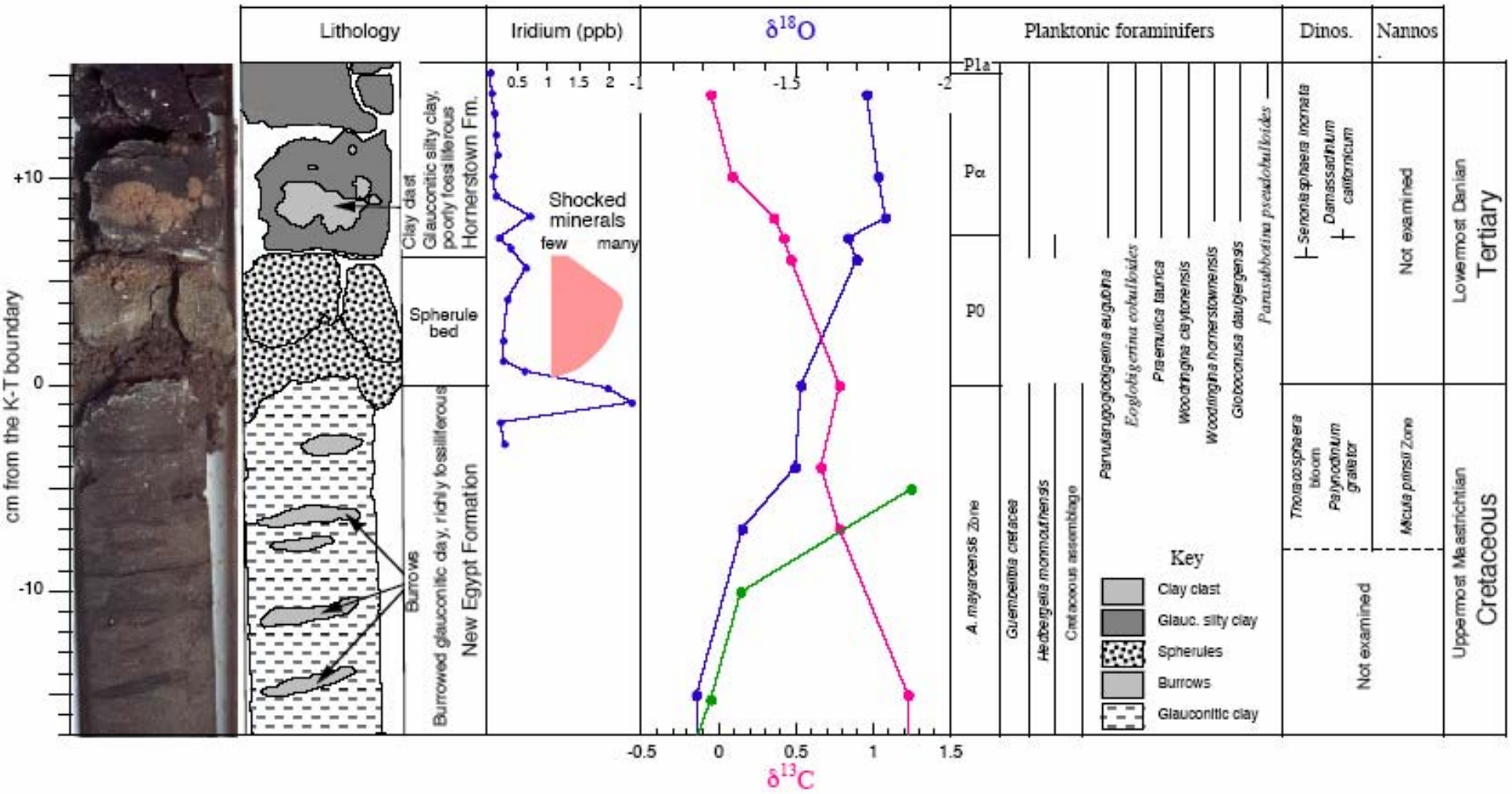

Magnetobio-chronology
Magneto-chron
Sed Rate m/myr
Forams
Nannos
Oligocene
Late Eocene
33.7
34.6
35.3
35.6
Ma
13r
15n
15r
16n.1n
16r.1r
16n.2n
30
10
67
P18
P17 ?
P16
P15
NP21
NP19-20
Chickahominy Formation
Dead Zone (max. 3 kyr)
35.78 extrapolated age of impact
Exmore breccia
(Shocked minerals melt clasts microspherules)

Extinction Effects





ASTEROID IMPACT:
THE NJ RECORD ON
THE DEATH OF THE
DINOSAUR



A spherule layer (~6 cm thick) resulted from fallout of impact ejecta from Chicxulub Crater in Yucatan, Mexico. This layer represents extremely rapid deposition (incineration of terrestrial organisms and settling though the water column of 100 m beginning at ~10 minutes after impact, smothering the bottom within 30-60 minutes). This is the furthest north that a distinct layer has been identified (some 2500 km from the crater)

Surviorship (Emiliani, Kraus, Shoemaker 1981)

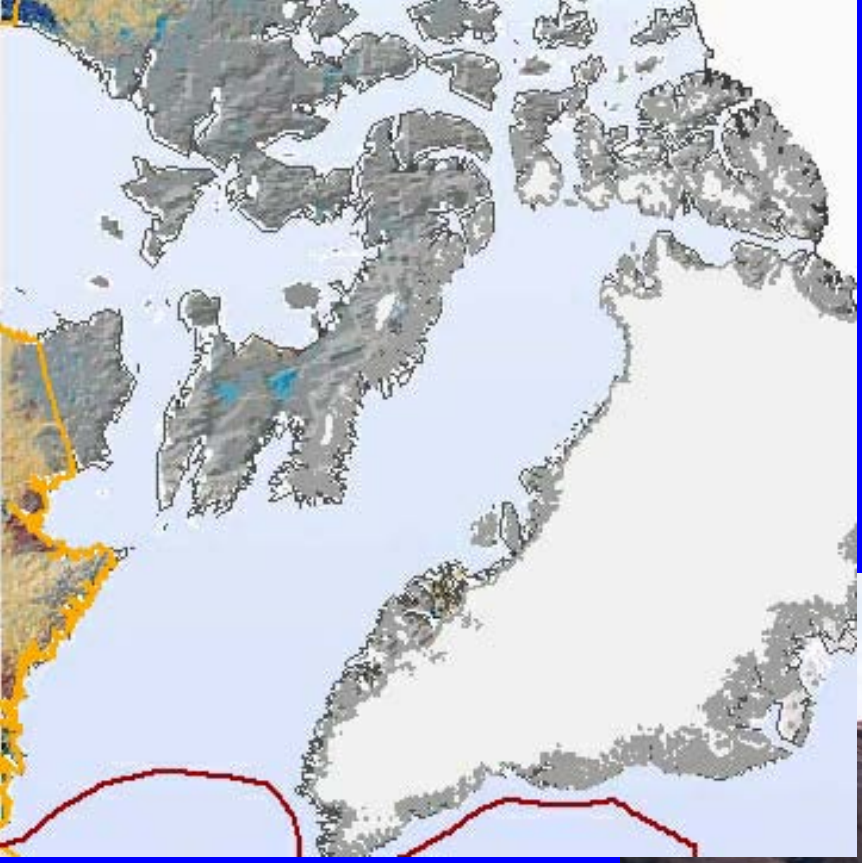
Planktonic	
Coccolithophoridae	13
Foraminifera	13
Diatoms	31
Dinoflagellates	78
Radiolaria	93
Nektonic	
Ammonoids	0
Belemnoids	0
Nautiloids	50
Elasmobranchii	67
Osteichthyes	4
Ichthyosauria	0
Plesiosauria	0

http://www.chez.com/extinctions/fourthemassextinctionatthektlimit.htm


TAMAULIPAS
Encuentro CIENTIFICO MUNDIAL
Bienvenidos - Welcome
SITIO GEO - PALEONTOLOGICO "EL MIMBRAL"
VILLA DE LLERA 6 DE FEBRERO DE 1994
2 6 94

As the World Warms:

65 Million Years of Hot and Cold



The Geologic Recor
Ellesmere Island`

Ellesmere Island 50 Ma

Mary Dawson of the Carnegie Museum with ~50 million year old fossil of an alligator

Is this Possible?

Eocene Forests in the Arctic

Metasequoia stumps at Axel Heiberg Is.

Metasequoia stumps Axel Heiberg Is.

Eocene Fossils from Wyoming

Crocodile

Borealosuchus

Sycamore

Platanus wyomingensis

The Arctic

Then

Now

The Geologic Evidence

- Paleontological and Paleobotanical Remains

- Marine Records
  - Large Geographic Coverage - 70% of Earth
  - Net Repository of Sediments
    - Continuous recorder climate change
  - Heat Transport and Carbon Storage

The Oxygen Isotope Recorder

- Stable Isotopes of Oxygen
  - ^{16}O = 99.76%
  - ^{17}O = 0.04%
  - ^{18}O = 0.20%

Stable Oxygen Isotopes

$$\delta^{18}O\ ‰ = \frac{{}^{18}O/{}^{16}O_{sam} - {}^{18}O/{}^{16}O_{std}}{{}^{18}O/{}^{16}O_{std}} * 1000$$

Stable Oxygen Isotopes

- Paleo-temperature Equation

$$T°C = 16.9-4.2*(\delta^{18}O_{CaCO_3} - \delta^{18}O_{water})+0.1*(\delta^{18}O_{CaCO_3} - \delta^{18}O_{water})^2$$

Stable Oxygen Isotopes

Changes in $\delta^{18}O_{calcite}$

$\Delta\delta^{18}O_{calcite} = -0.23 * \Delta T°C$

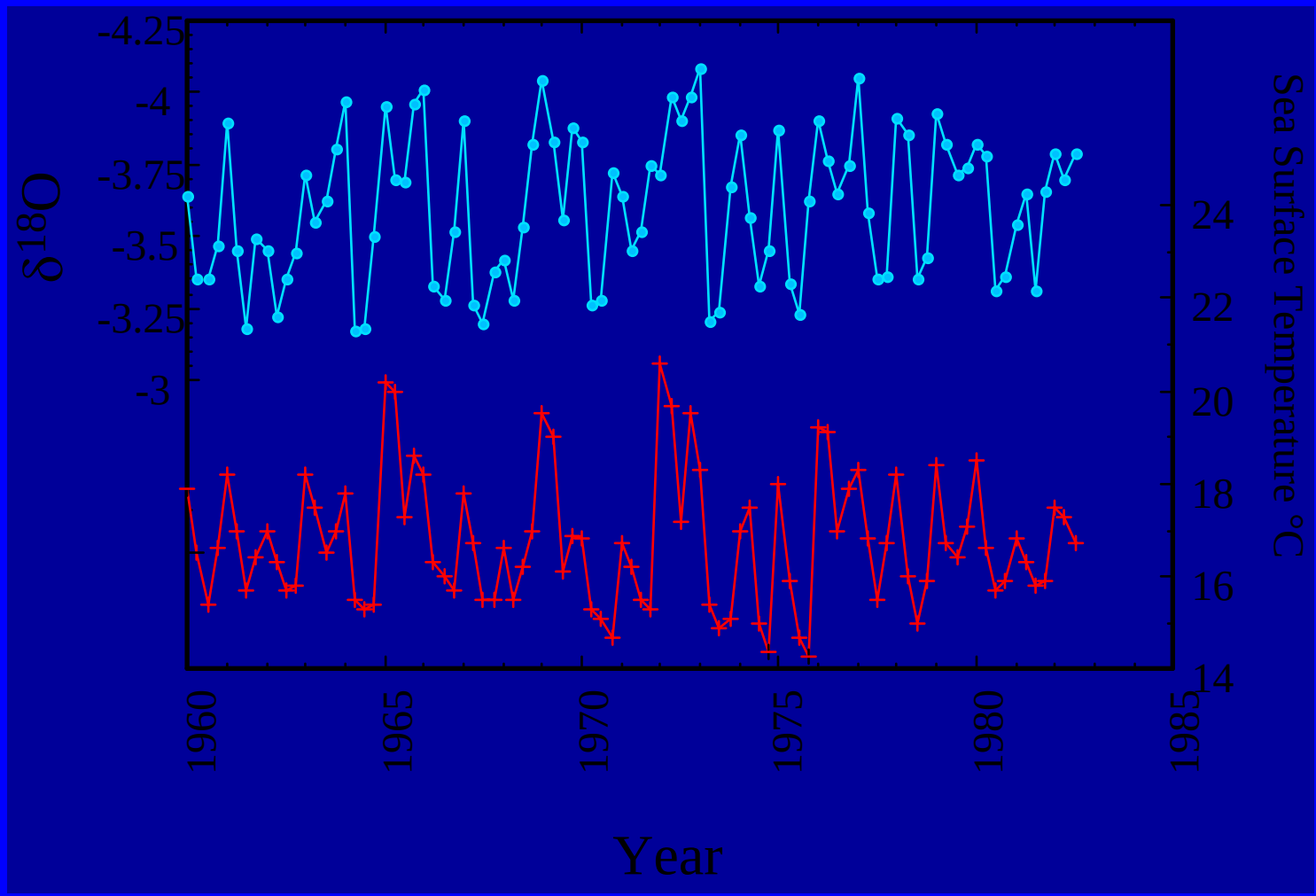
for every 1°C warming, $\delta^{18}O_{calcite}$ will decrease by 0.23‰

$\Delta\delta^{18}O_{calcite} = \Delta\delta^{18}O_{water}$

for every 1‰ increase in $\delta^{18}O_{water}$, $\delta^{18}O_{calcite}$ will increase by 1‰

Temperature Effect

Galapagos SSTs and Coral $\delta^{18}O$

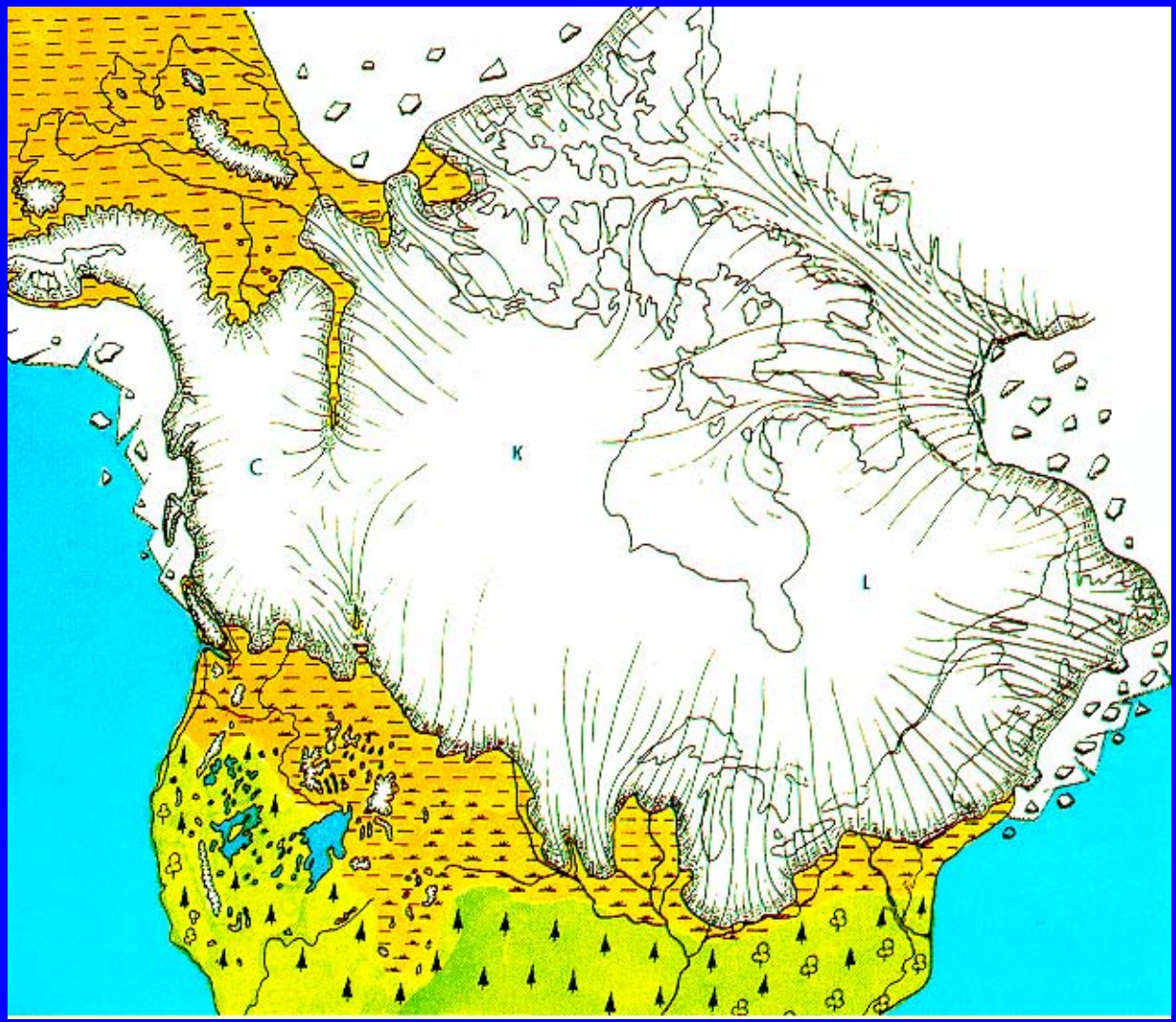


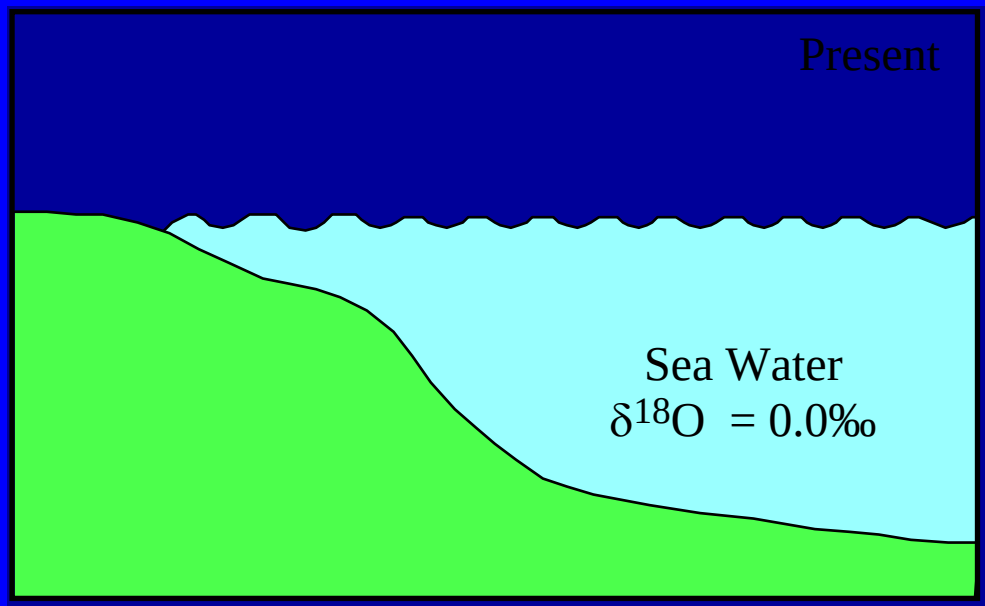
The $\delta^{18}O_{water}$ Effect

Ice Volume = ~ 1‰ for 100 m of sea level equivalent

Local Salinity Effect

Variable, but is most pronounced near rivers/estuaries

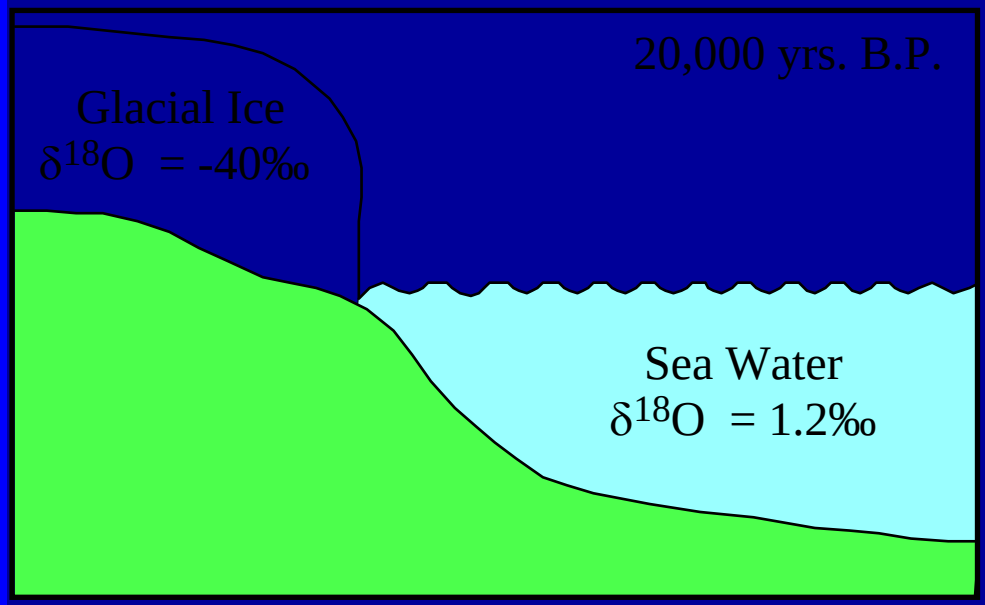

C
K
L



Mean Depth of Oceans

= 4000 m

$\delta^{18}O$ = 0.0‰

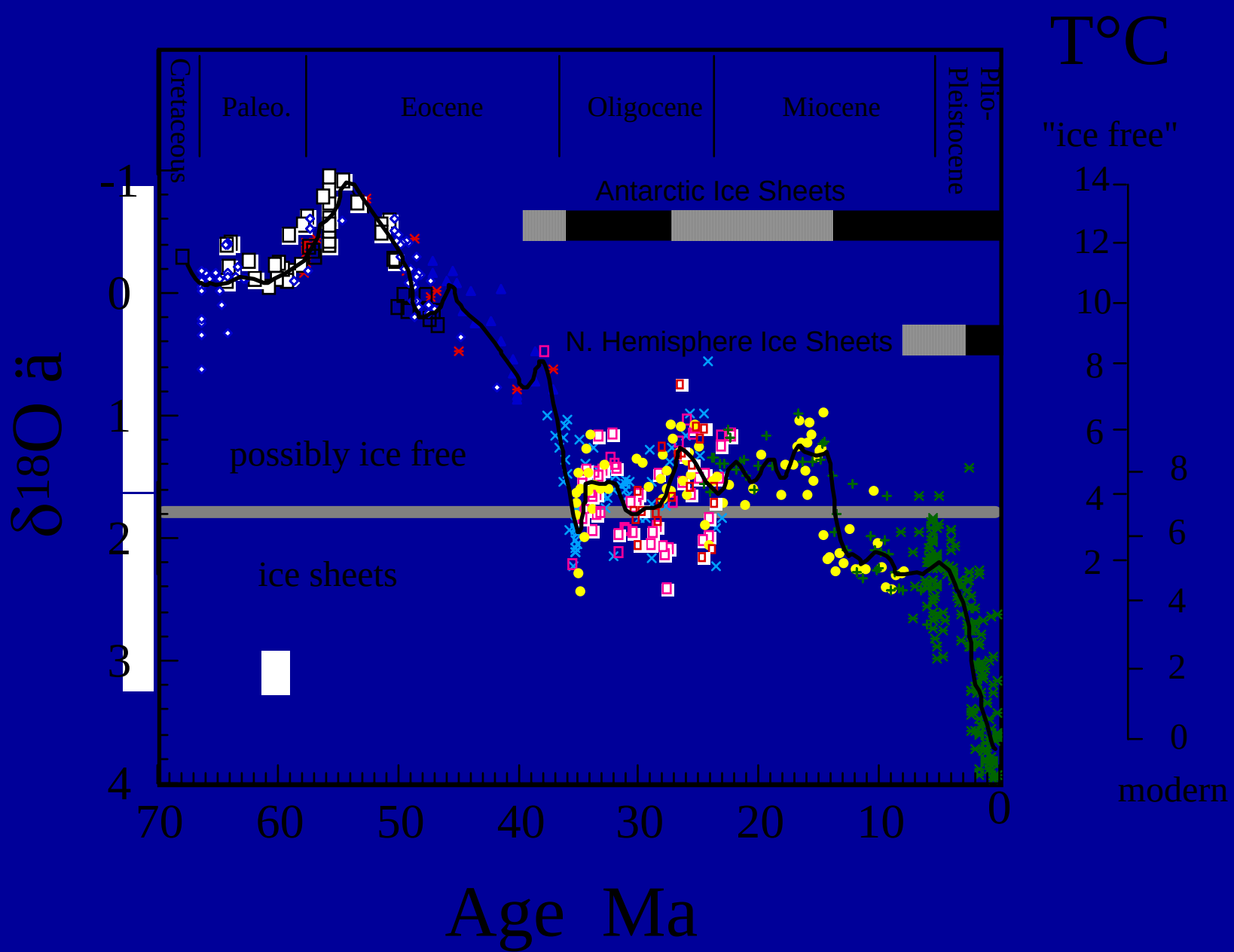


ΔSea Level = 120 m

120m/4000m = 0.03

$\Delta\delta^{18}O_{water}$ = 1.2 ‰

0.0‰ - (-40‰ x 0.03)

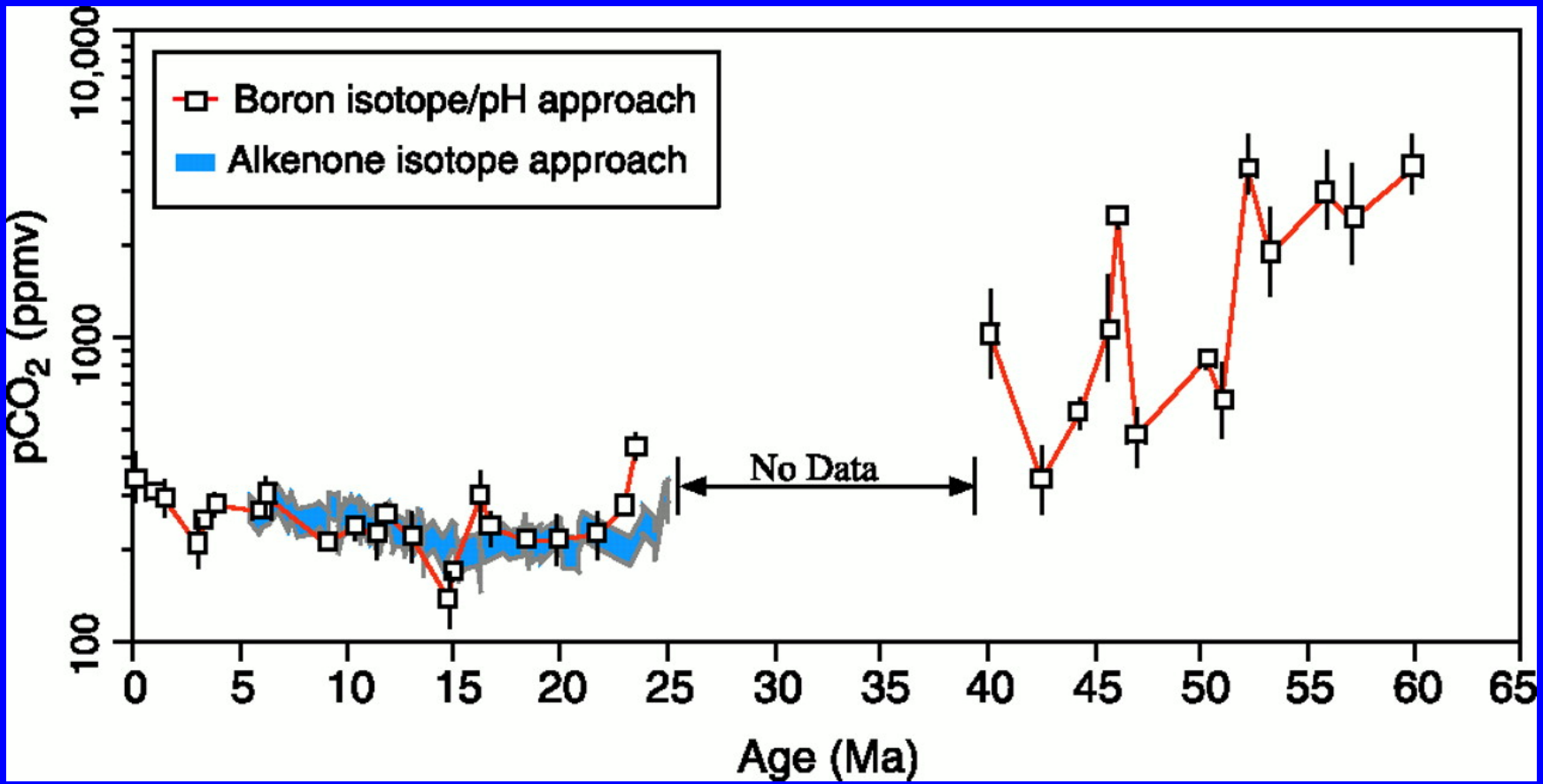


Modified after Miller et al., *Paleoceanography*, *2*, 1-19, 1987.

The Hot House to Ice House Transition

- Greenhouse gases
- Thermohaline circulation
- Continental Configurations

Greenhouse gases



What caused the pCO_2 to change?

- High pCO_2 during early Eocene could have resulted from:
  - Seafloor spreading changes
  - Large-scale volcanism

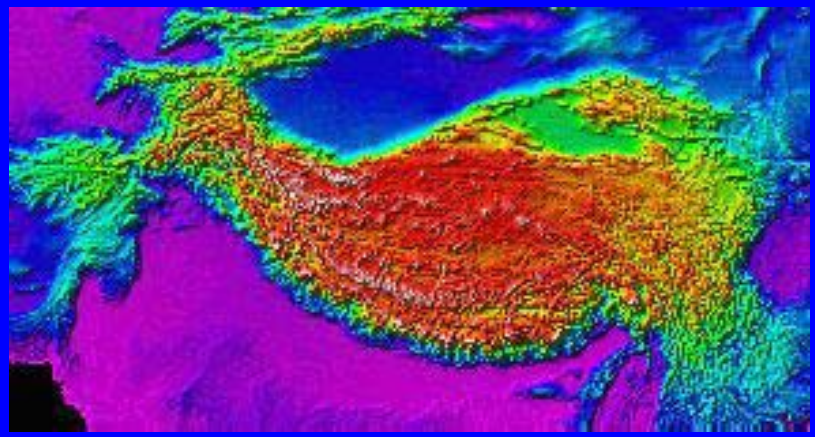
High pCO_2 during early Eocene

- Large-scale volcanism
- Giant's Causeway in N. Ireland
- Early Tertiary age
- Columnar Basalts

Decreasing pCO_2 after ~50 Ma

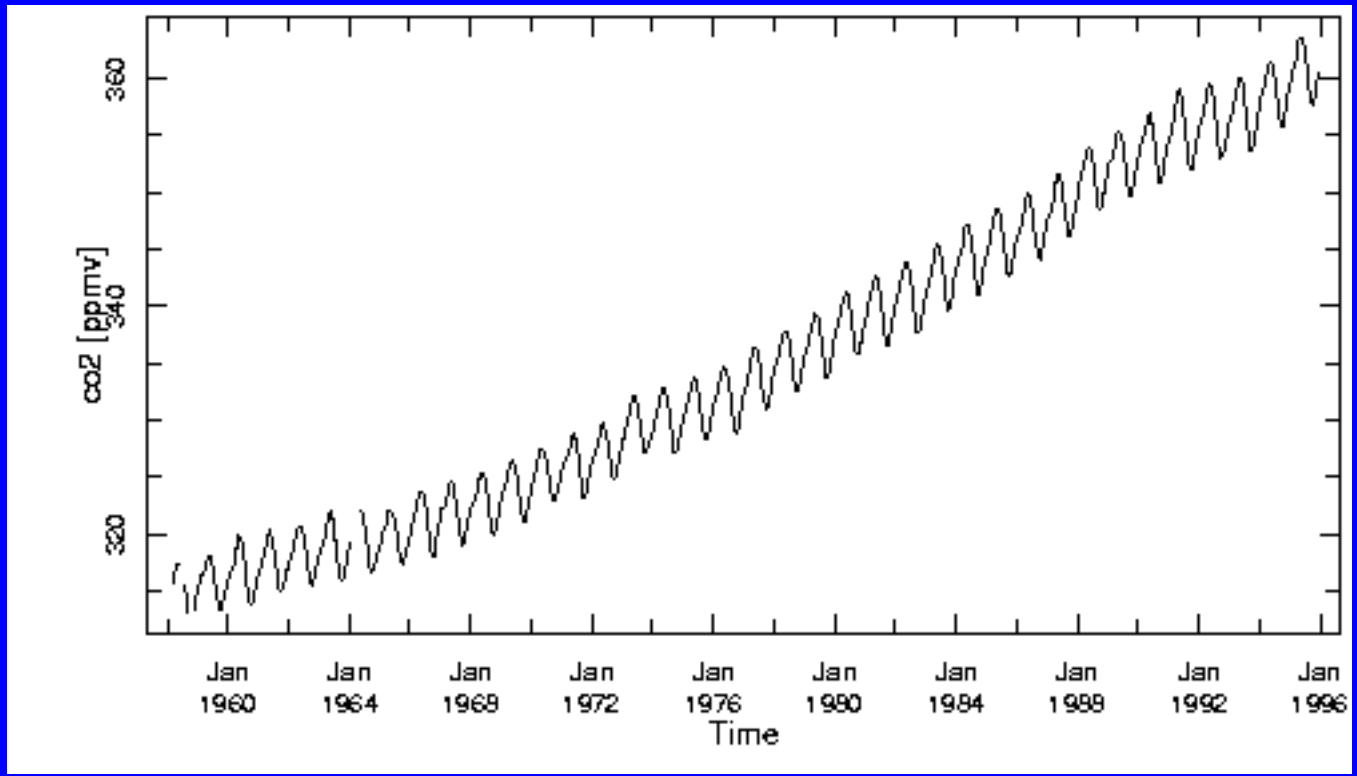
Mt. Everest

Decreasing pCO_2 after ~50 Ma



- Collision began ~50 Ma
- Accelerated in Miocene
- Increased weathering = Atm. CO_2 decrease
- $CaSiO_3 + CO_2 = CaCO_3 + SiO_2$

Atmospheric pCO_2



Many myths about dinosaurs and their disappearance….

Did dinosaurs become extinct 65 million years ago or did they live on with humans, as maintained by “creation scientists”?

H. sapiens appearred ca.100,000 years ago

Recent evidence that humans and dinosaures lived together from CN (Cartoon Network)!