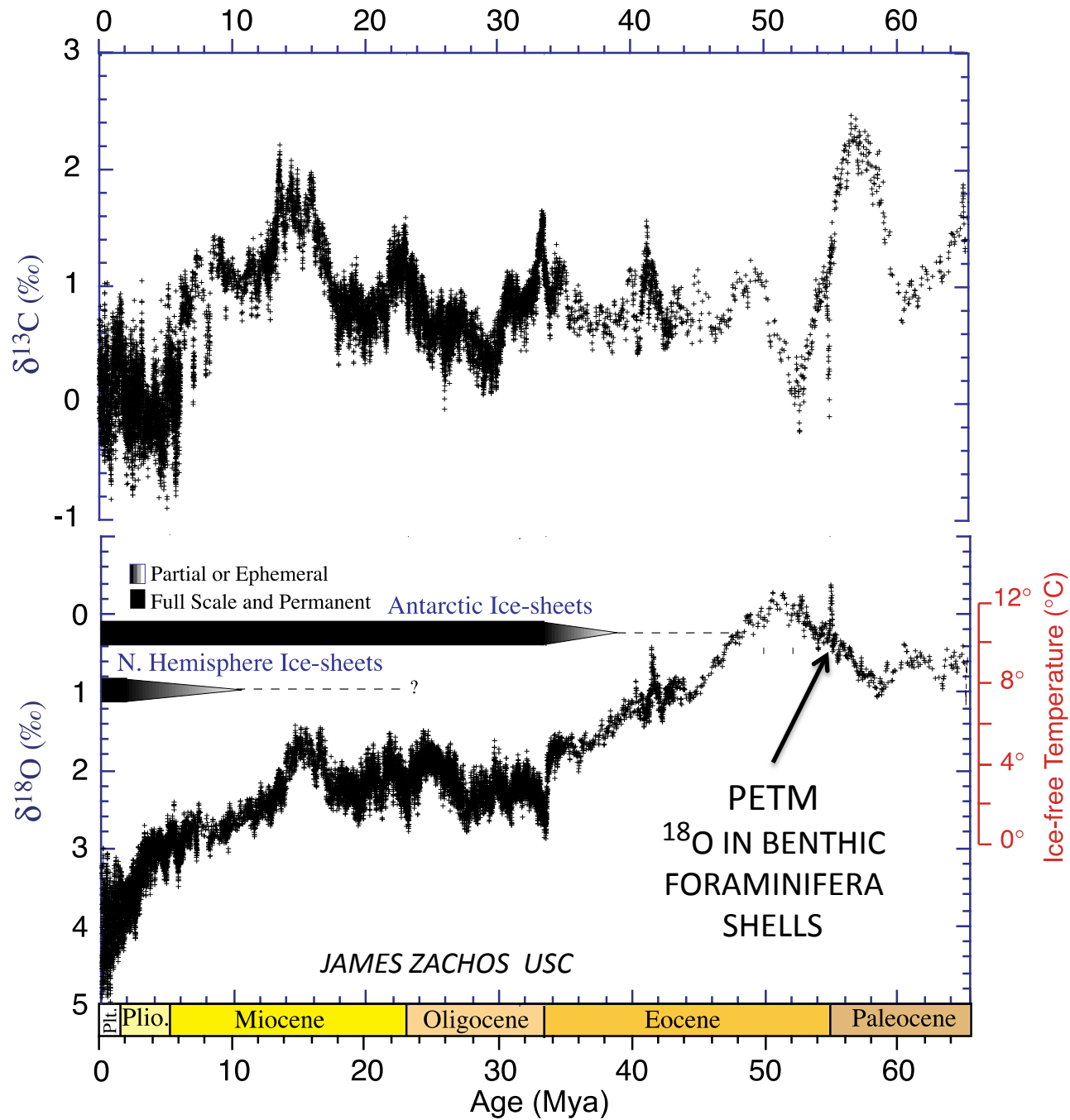


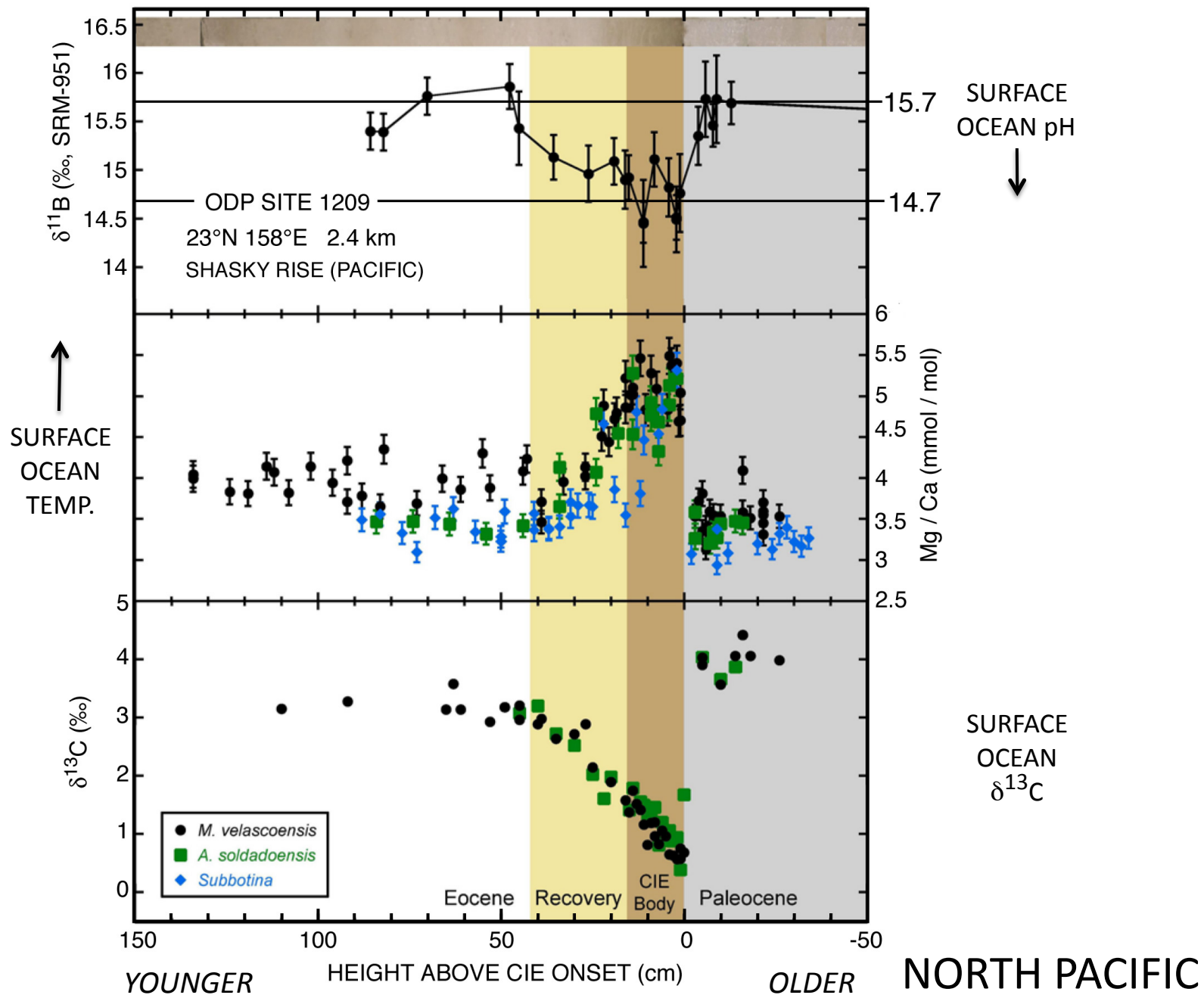
**WHAT CAUSED THE ABRUPT
5°C PETM WARMING?**

WALLY BROECKER

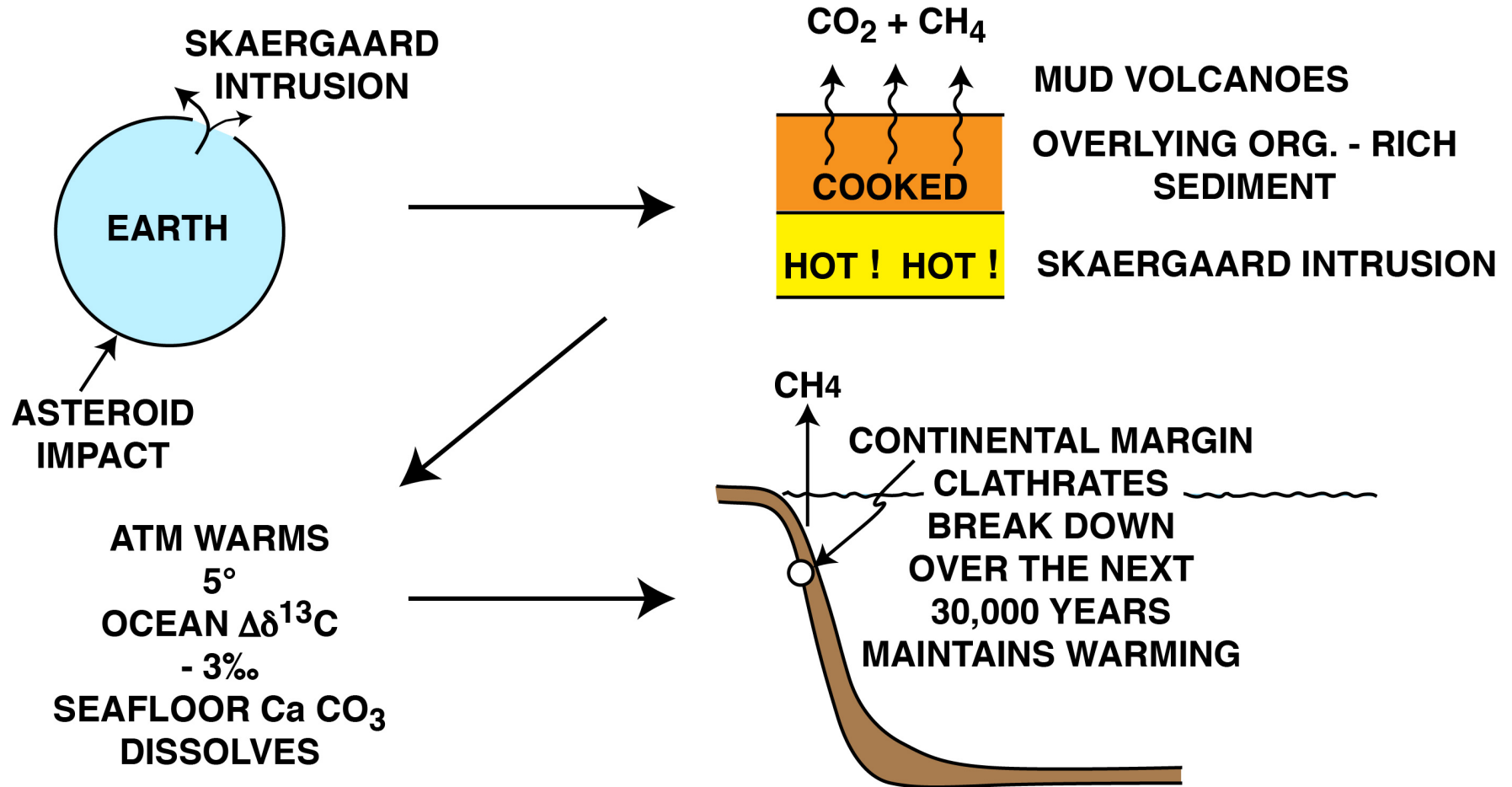
ARIZONA STATE UNIVERSITY

JANUARY 20, 2011

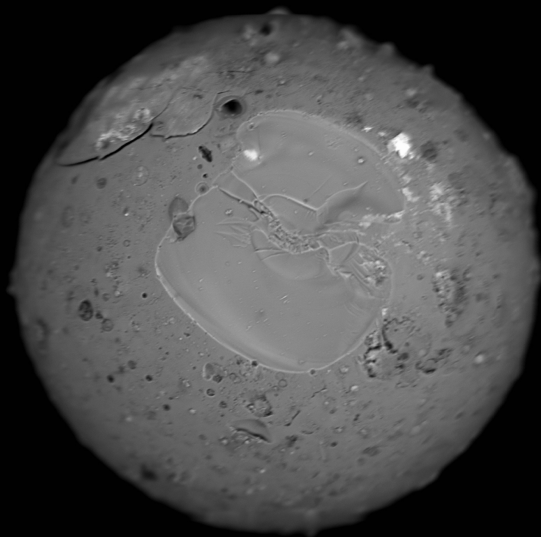




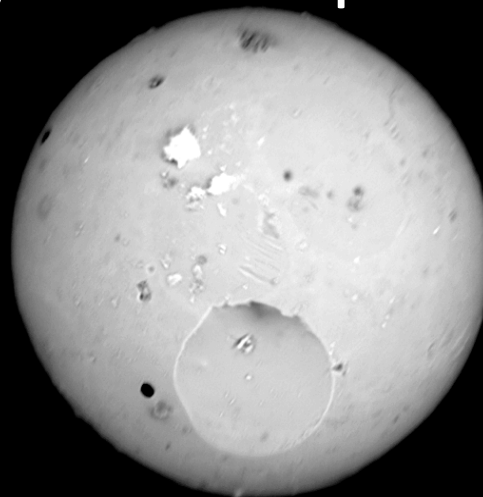
55.8 MILLION YEARS AGO ABRUPT WARMING



Paleocene/Eocene Spherules:

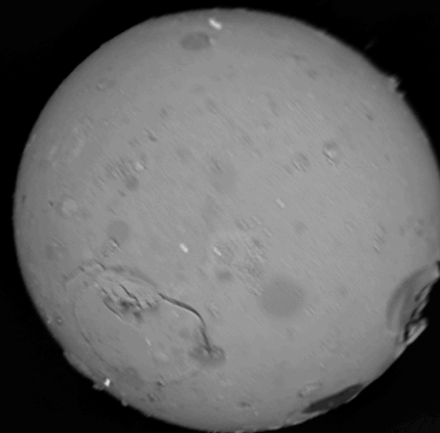


200. μm BSE 15. kV

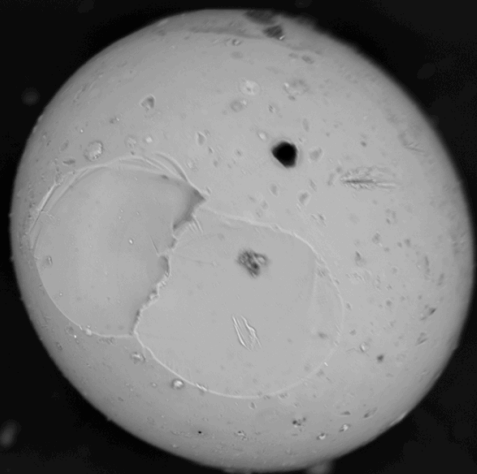


200. μm BSE 15. kV

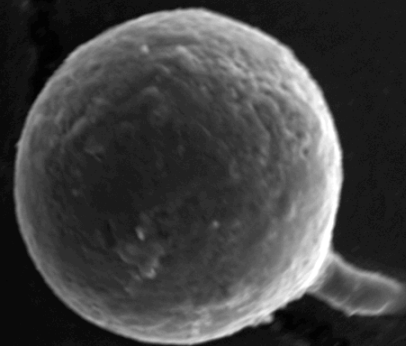
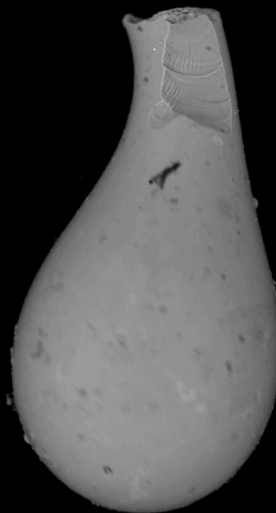
200. μm BSE 15. kV



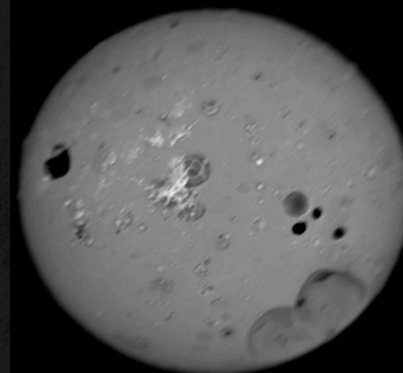
200. μm BSE 15. kV



200. μm BSE 15. kV



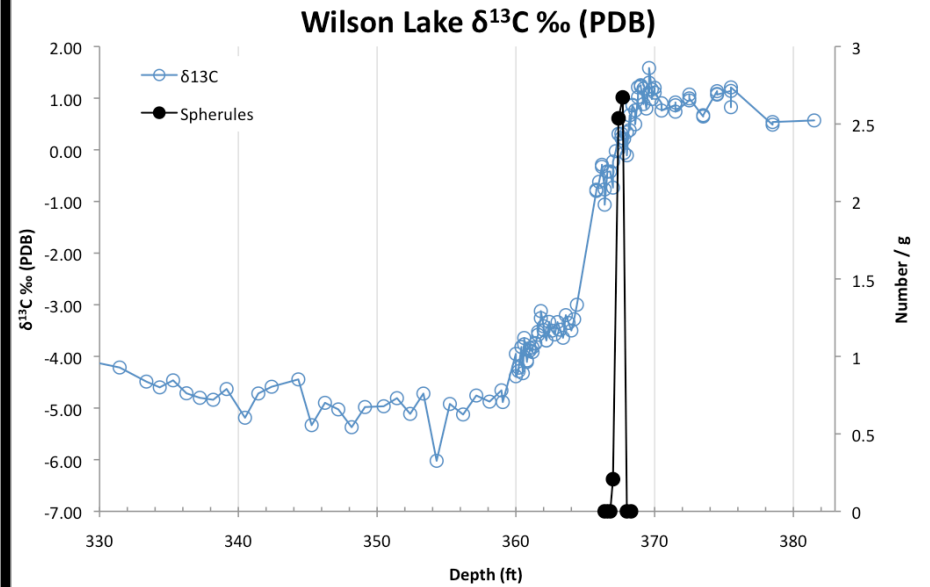
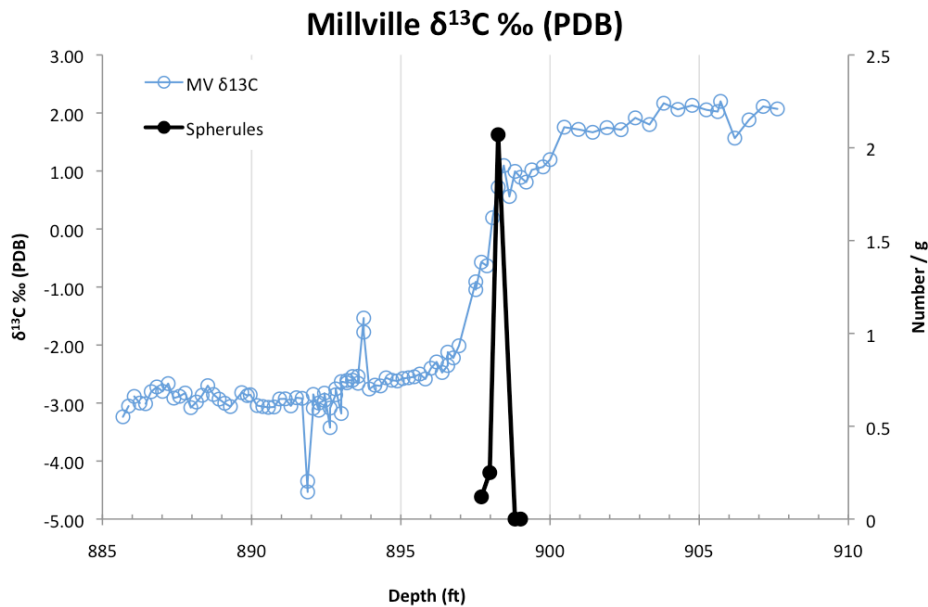
50. μm SE 15. kV



200. μm BSE 15. kV

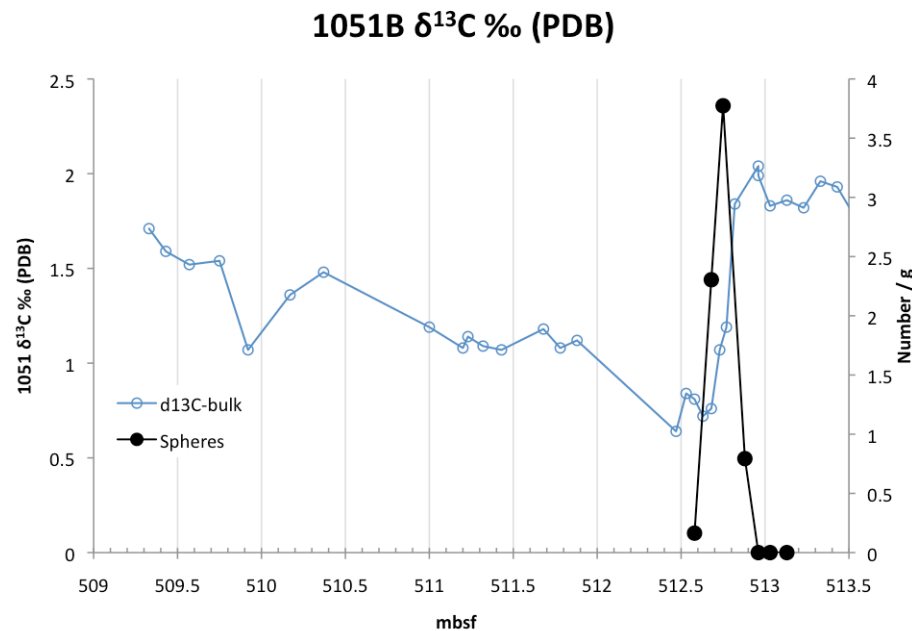
Morgan F. Schaller
Rensselaer Polytechnic Institute

Stratigraphic Distribution



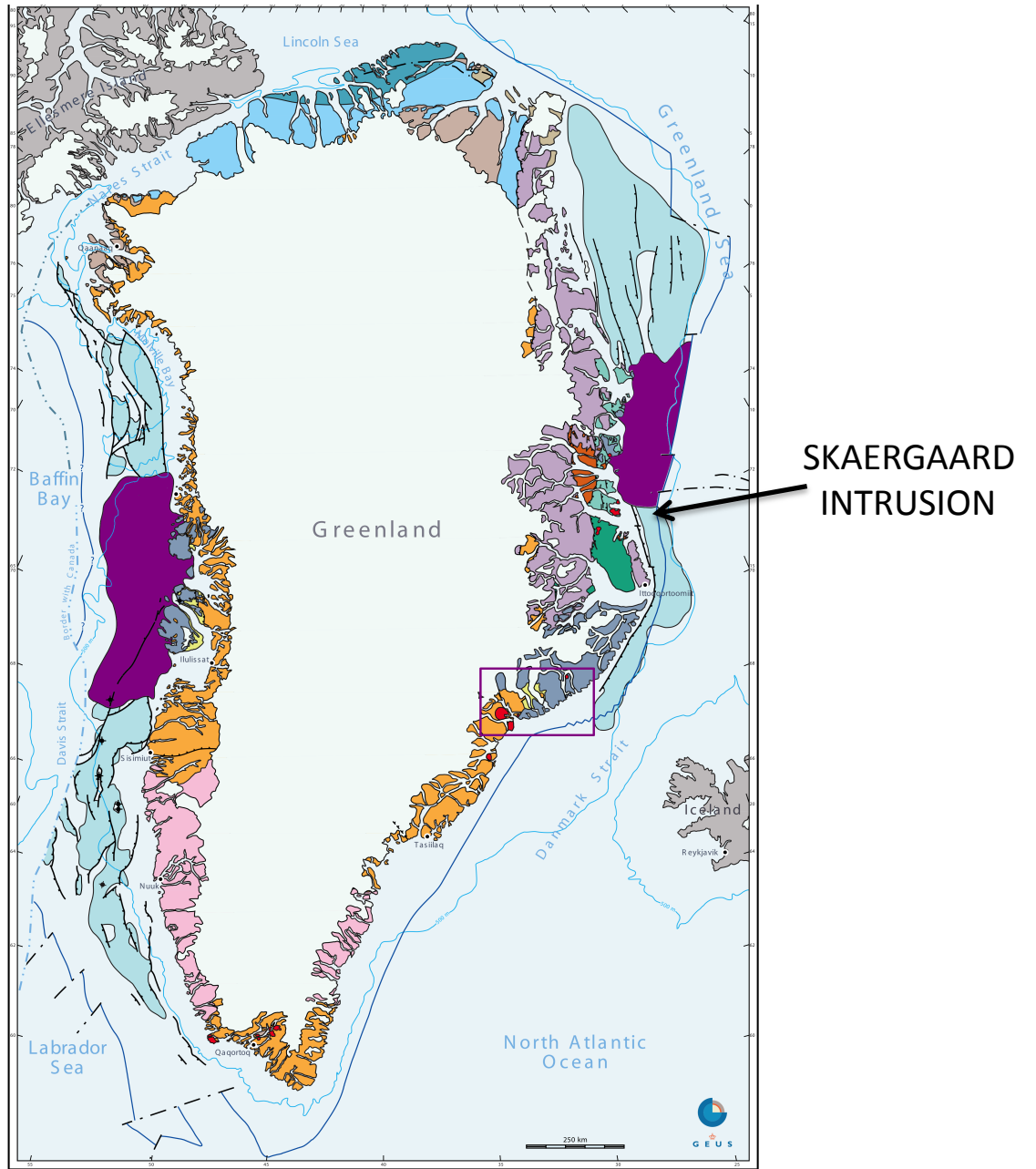
Have to stress, those
"0" values are real!

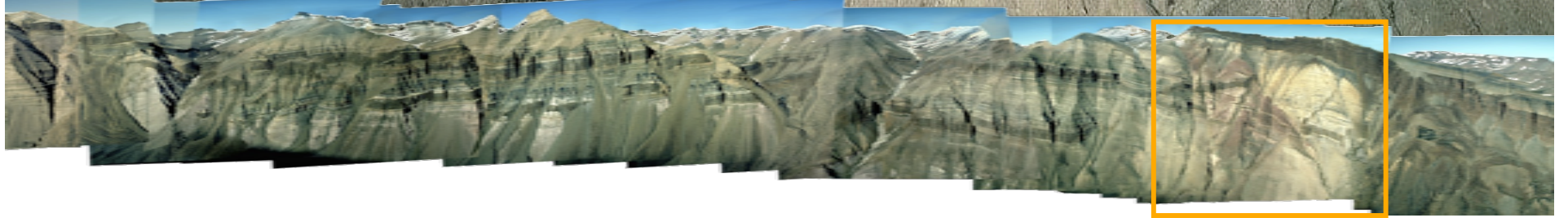
Single air-fall event,
bioturbated



Morgan F. Schaller
Rensselaer
Polytechnic Institute

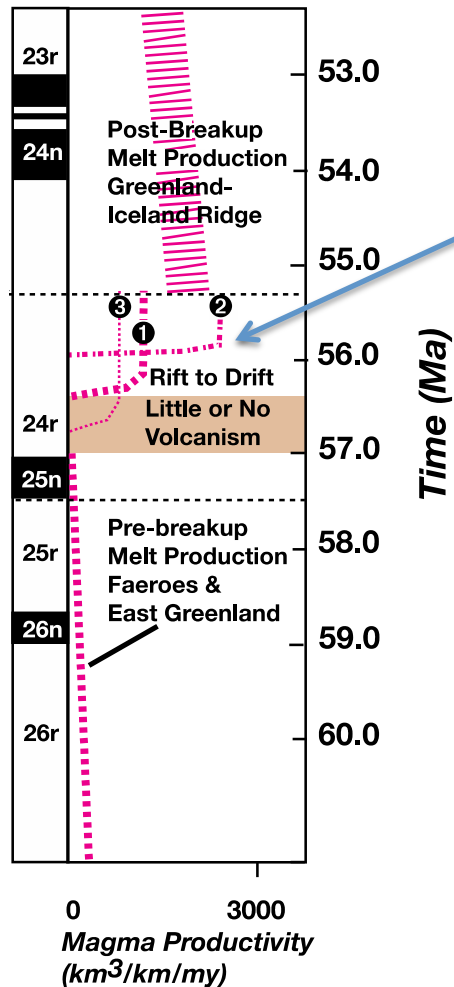
Greenland Sedimentary Basins





Kangerlussuaq Basin magma production, rift-drift transition and the PETM

COURTESY MICHAEL STOREY COPENHAGEN

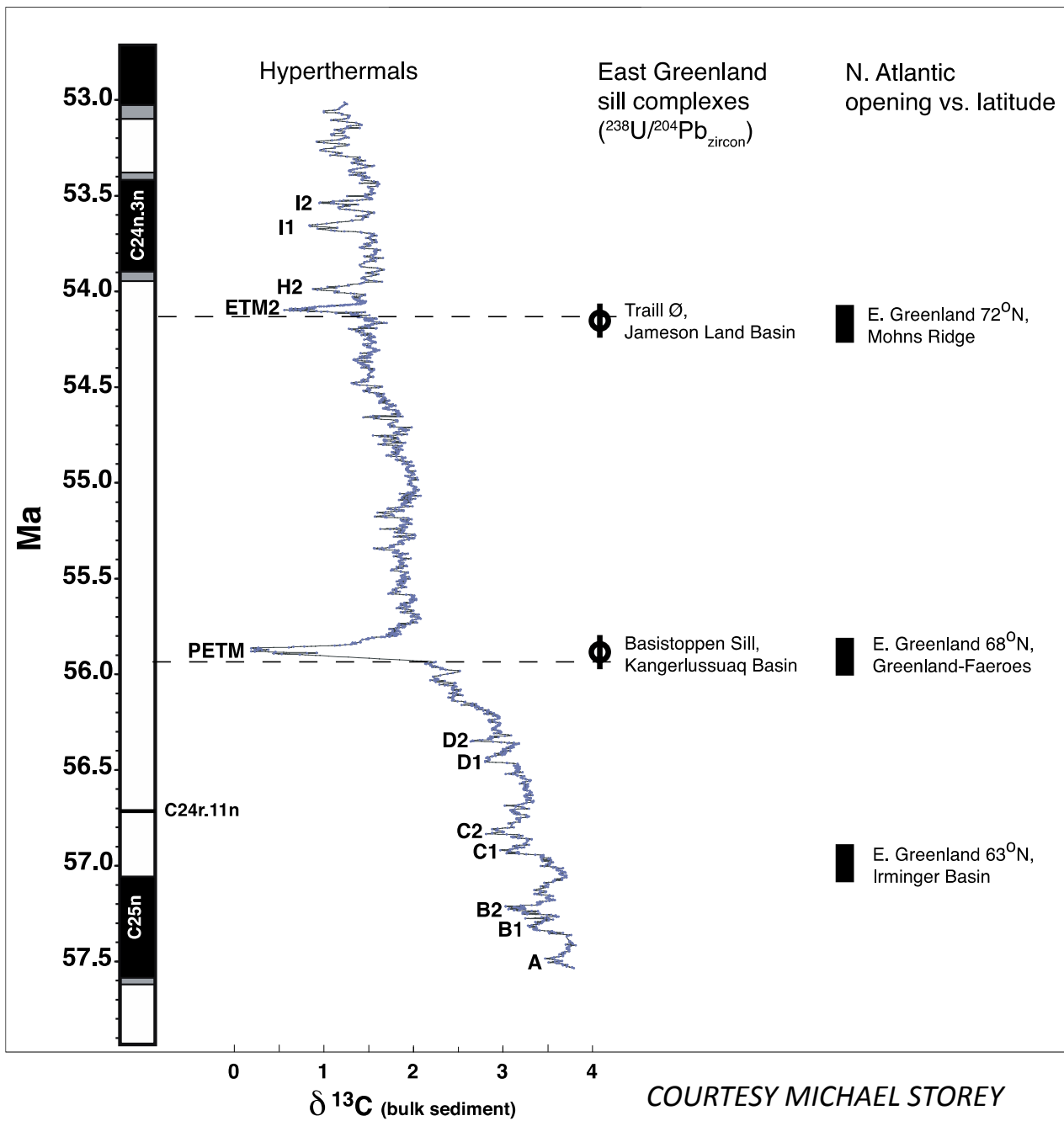


Rift to Drift transition at 55.8 ± 0.3 Ma, marked by the eruption of mid-ocean ridge basalt-like flows and surge in magma production (Storey et al., 2007)

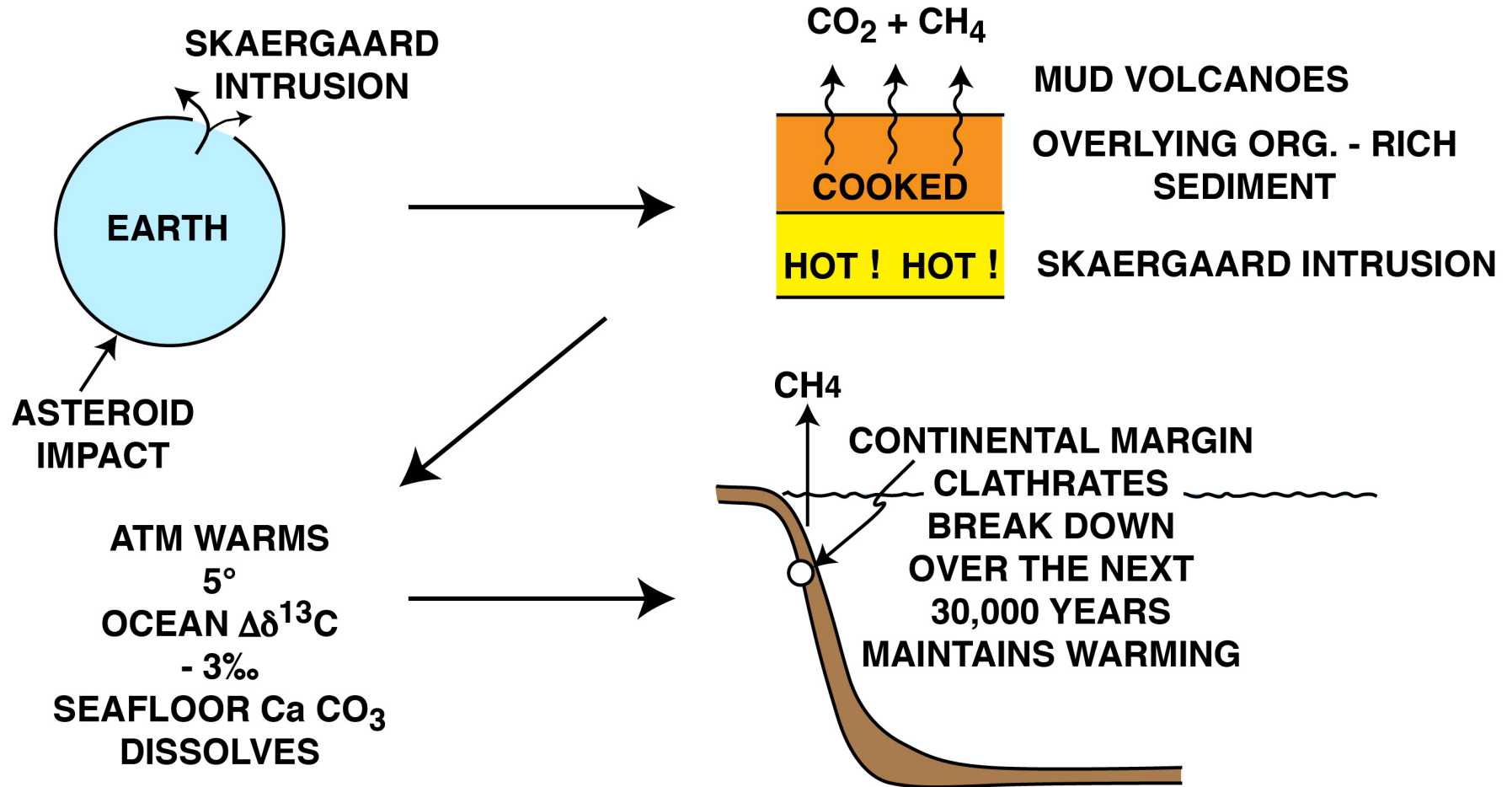
Basistoppen Sill U/Pb zircon age 55.895 ± 0.018 Ma (Wotzlaw et al., 2012)

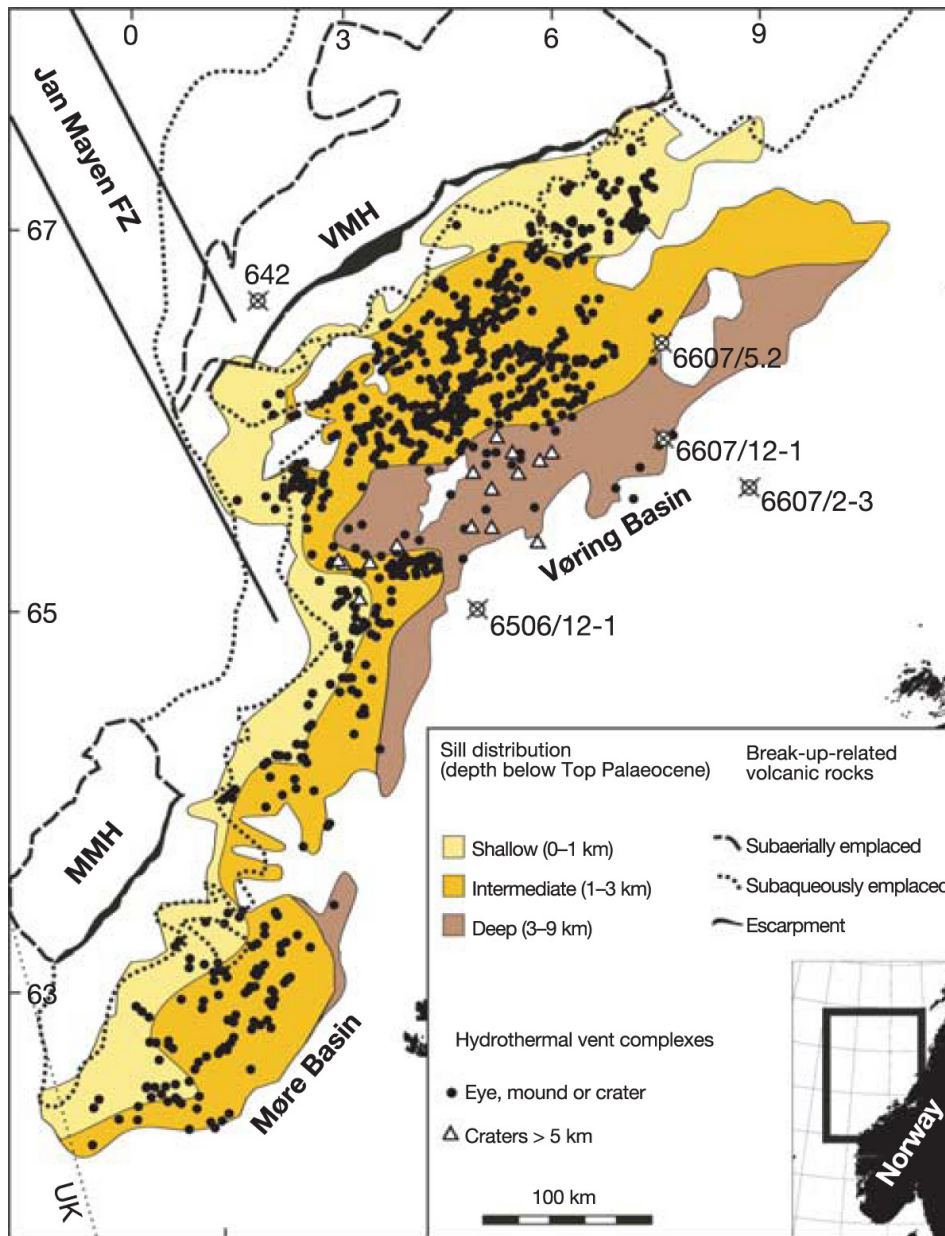
PETM combined U/Pb and cyclostratigraphy age 55.83 or 55.87 ± 0.10 (Charles et al., 2011)

PETM astronomical age (option 2) 55.93 (Westerhold et al., 2007)



55.8 MILLION YEARS AGO ABRUPT WARMING

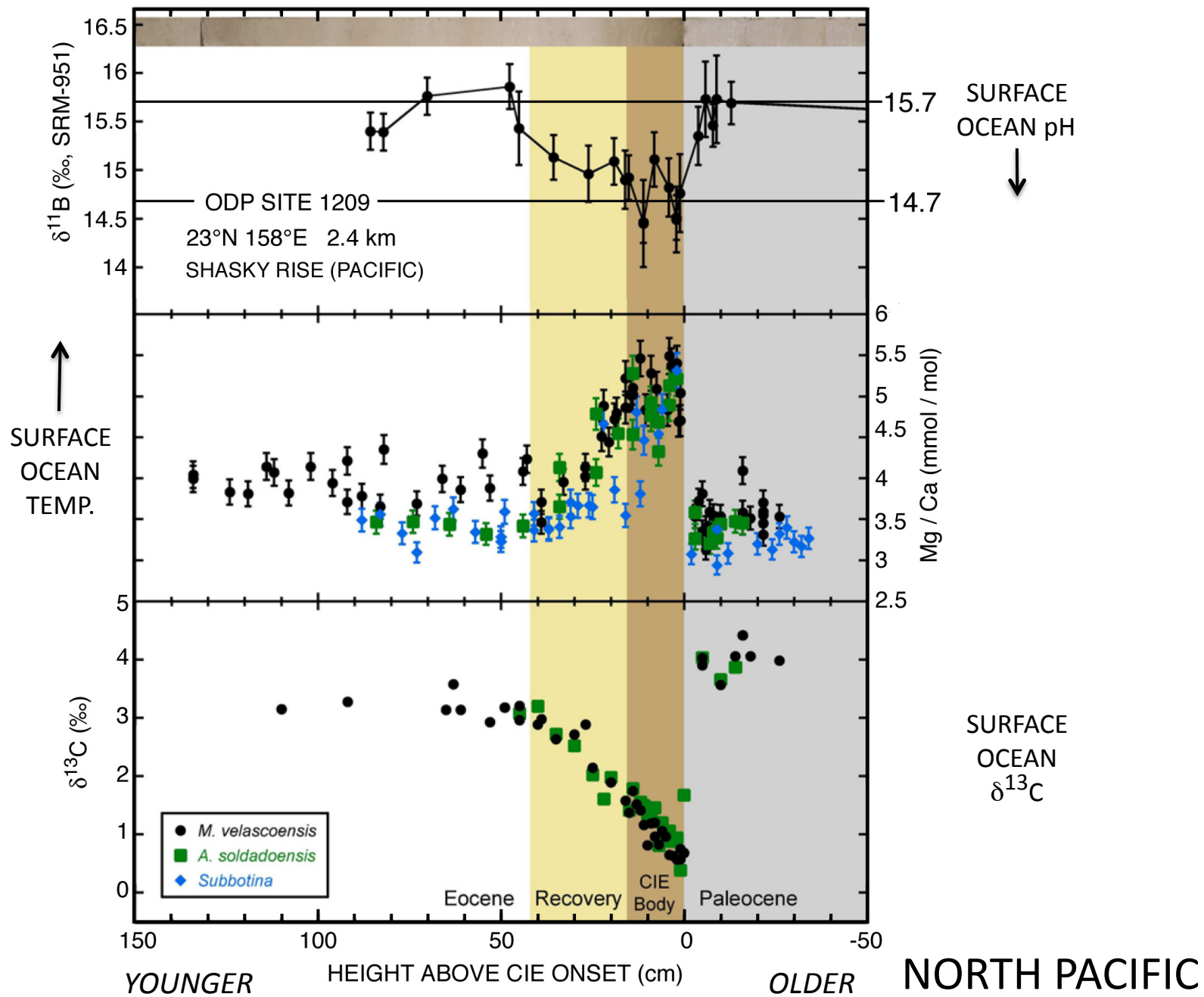


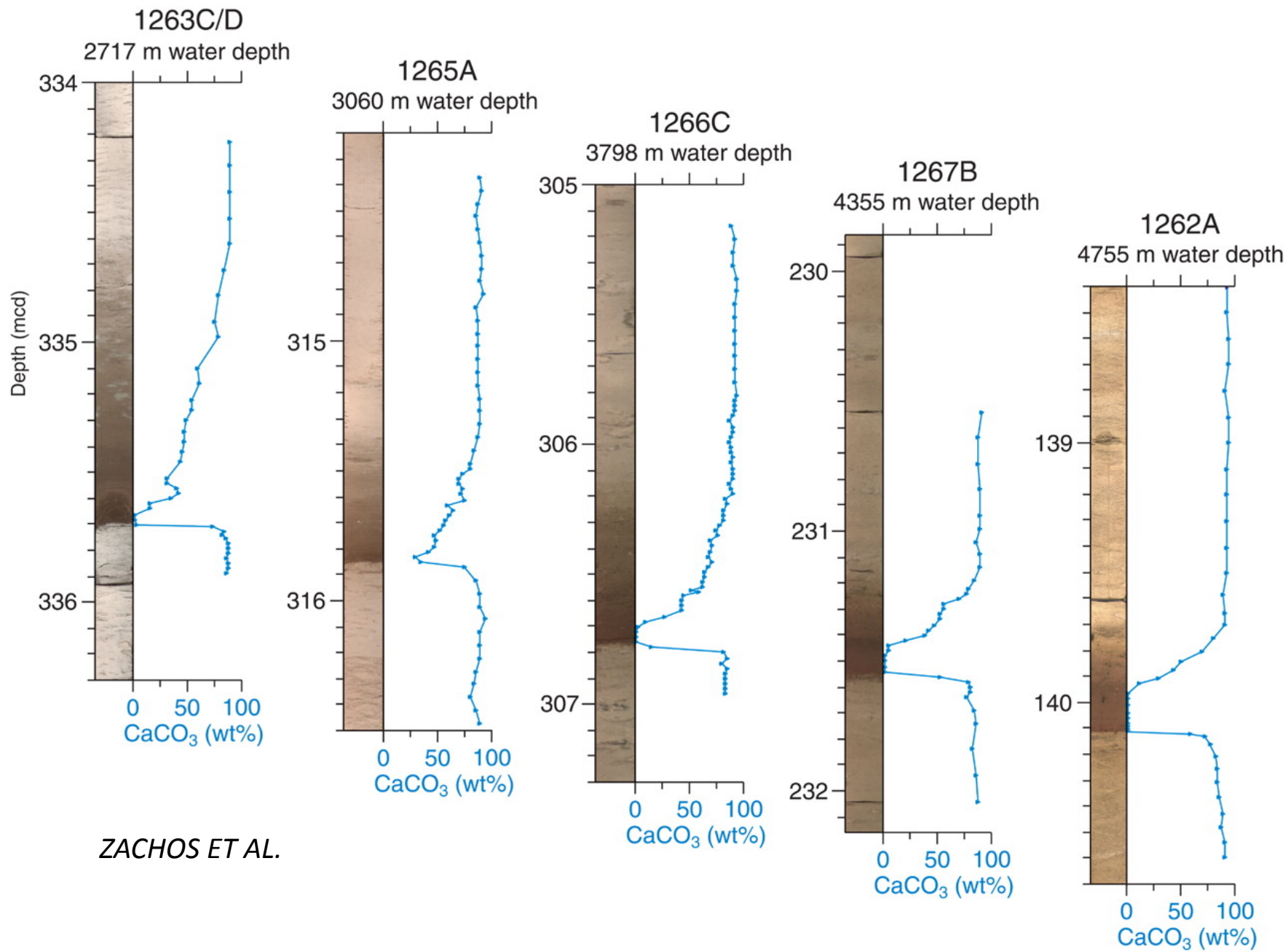


MEGA COOKING OFF NORWAY

**TIMING
JUST RIGHT**

SVENSEN ET AL.





ZACHOS ET AL.

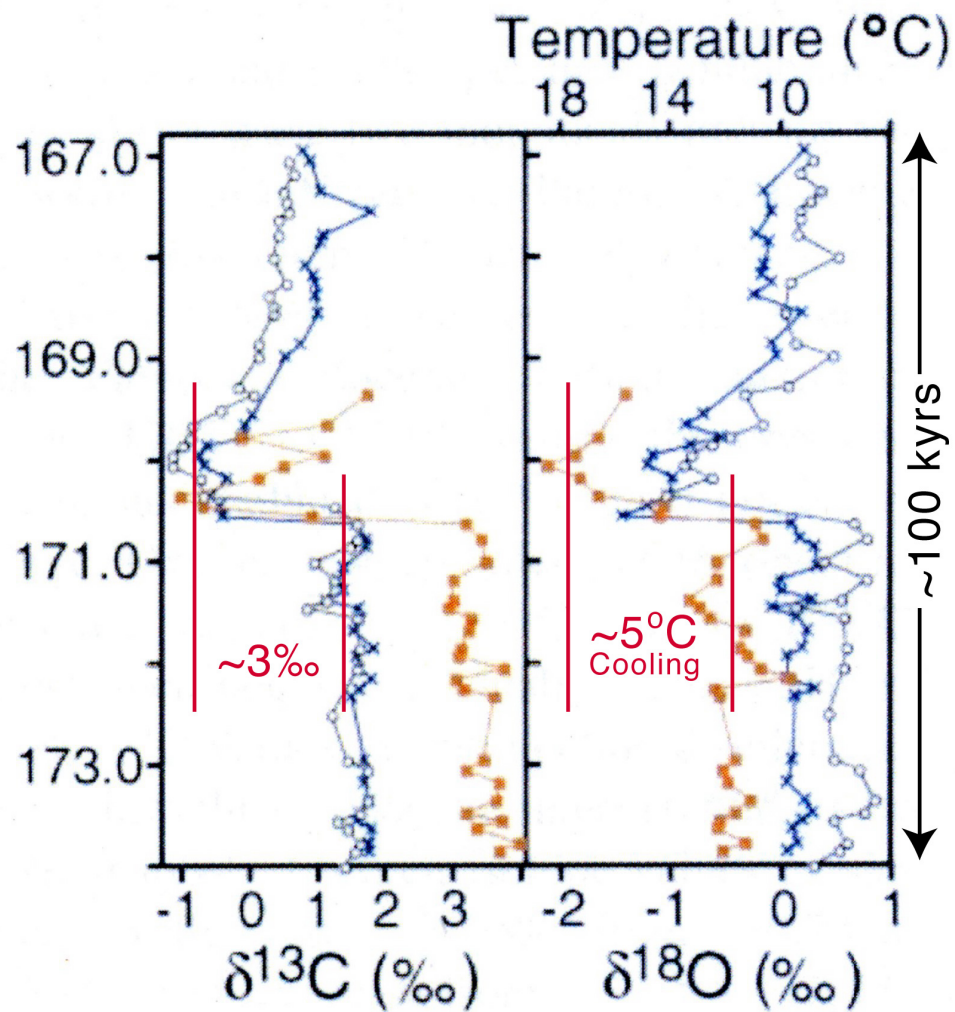
$\delta^{13}\text{C}$ (THEN AND NOW)

SURFACE OCEAN	+ 2‰
ATMOSPHERE	- 6‰
ORGANIC MATTER	- 27‰
VOLCANIC CO₂	- 5‰
METHANE	- 40 to - 60‰

PETM SHIFT IN $^{13}\text{C} / ^{12}\text{C}$ - 3‰

TODAY' OCEAN 36,000 Gt C  **billions of tons**

**THE ADDITION OF 3,600 Gt C WITH
 $\delta^{13}\text{C} = -30\text{‰}$ WOULD CAUSE A 3‰
DROP IN OCEAN $\delta^{13}\text{C}$.**



■ Surface

× Thermocline

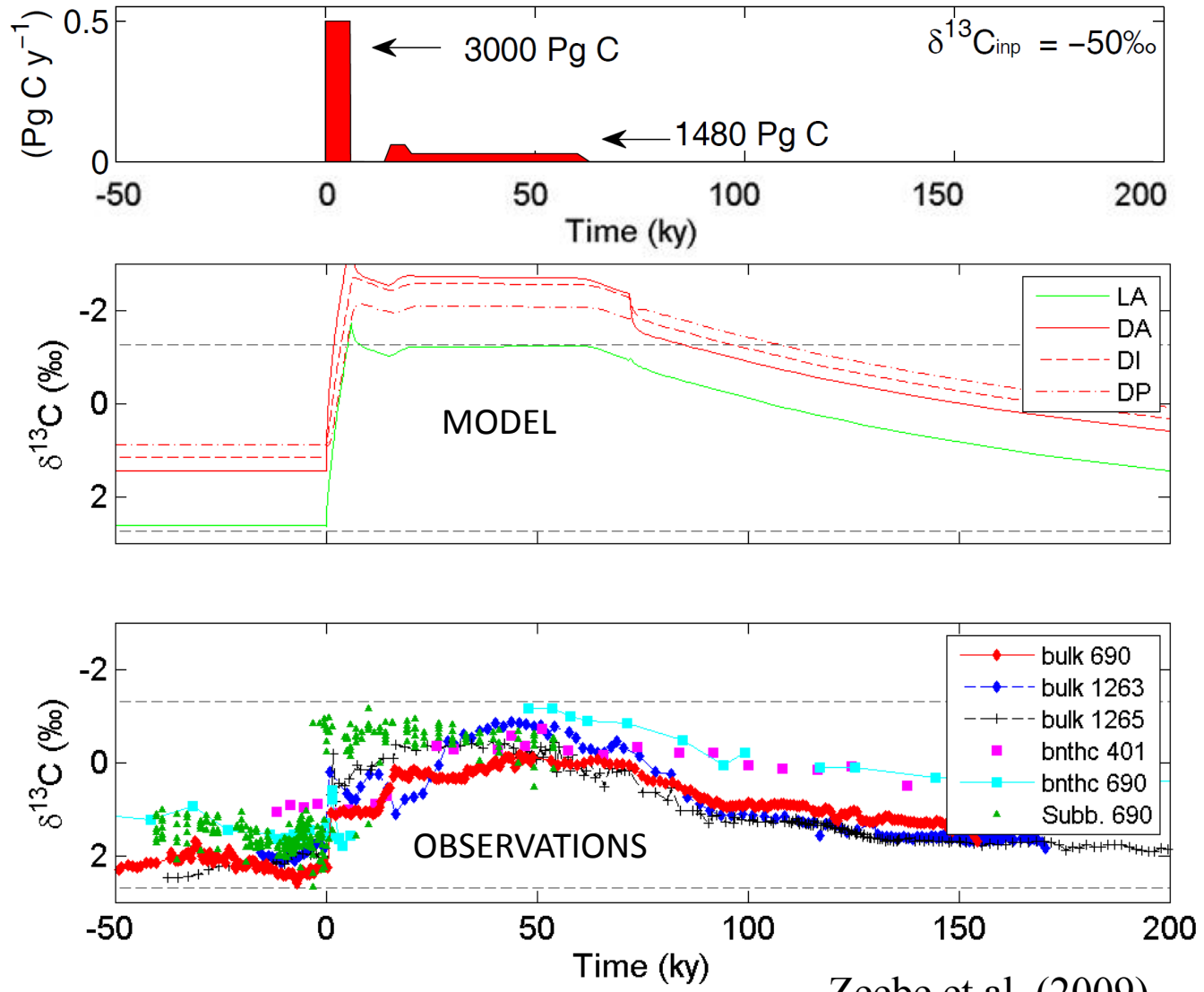
○ Benthic

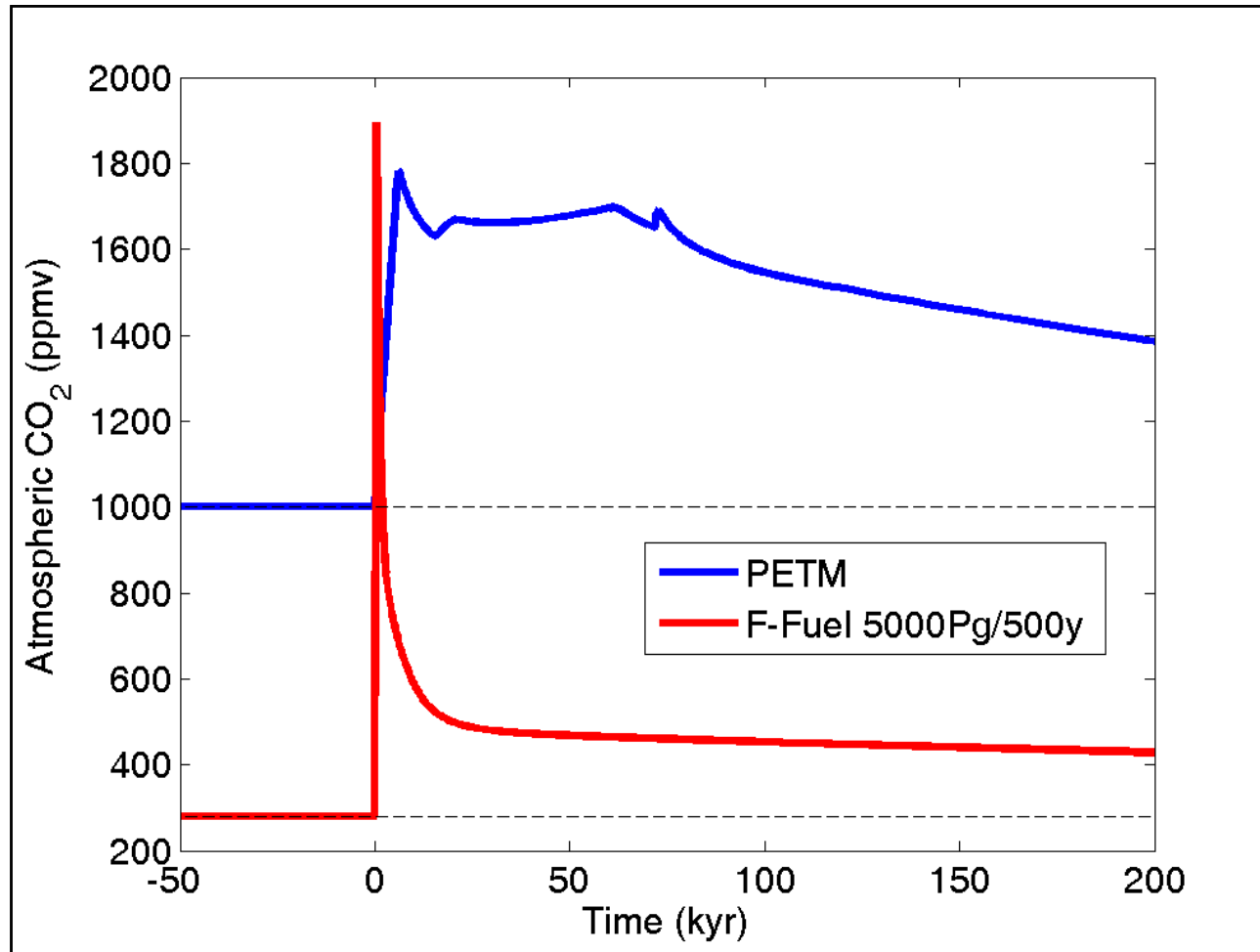
Southern Ocean

ODP Site 690

Kennet and Stott 1991

4,000 years





Zeebe & Zachos (2013)

PETM CONSEQUENCES

- 1) NO EXTINCTIONS**
- 2) BIG ECOLOGICAL SHIFT
LAND AND SEA**
- 3) GREATLY ENHANCED EROSION**

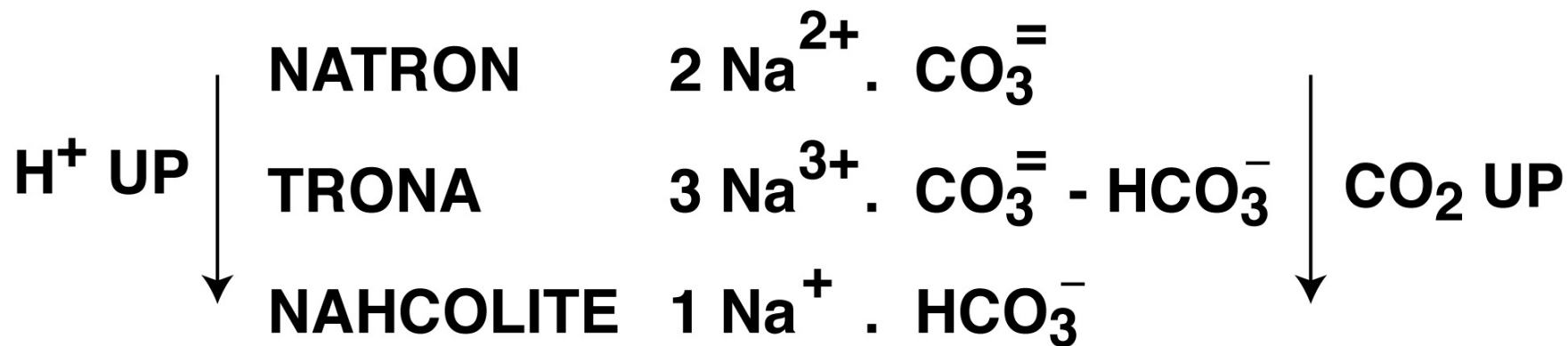
CONSTRAINTS ON THE MAGNITUDE OF THE CO₂ INJECTION

- 1) 5 °C WARMING**
- 2) $\Delta\delta^{13}\text{C}$**
- 3) NAHCOLITE**
- 4) $\Delta\delta^{11}\text{B}$**

ATM CO₂ RISE

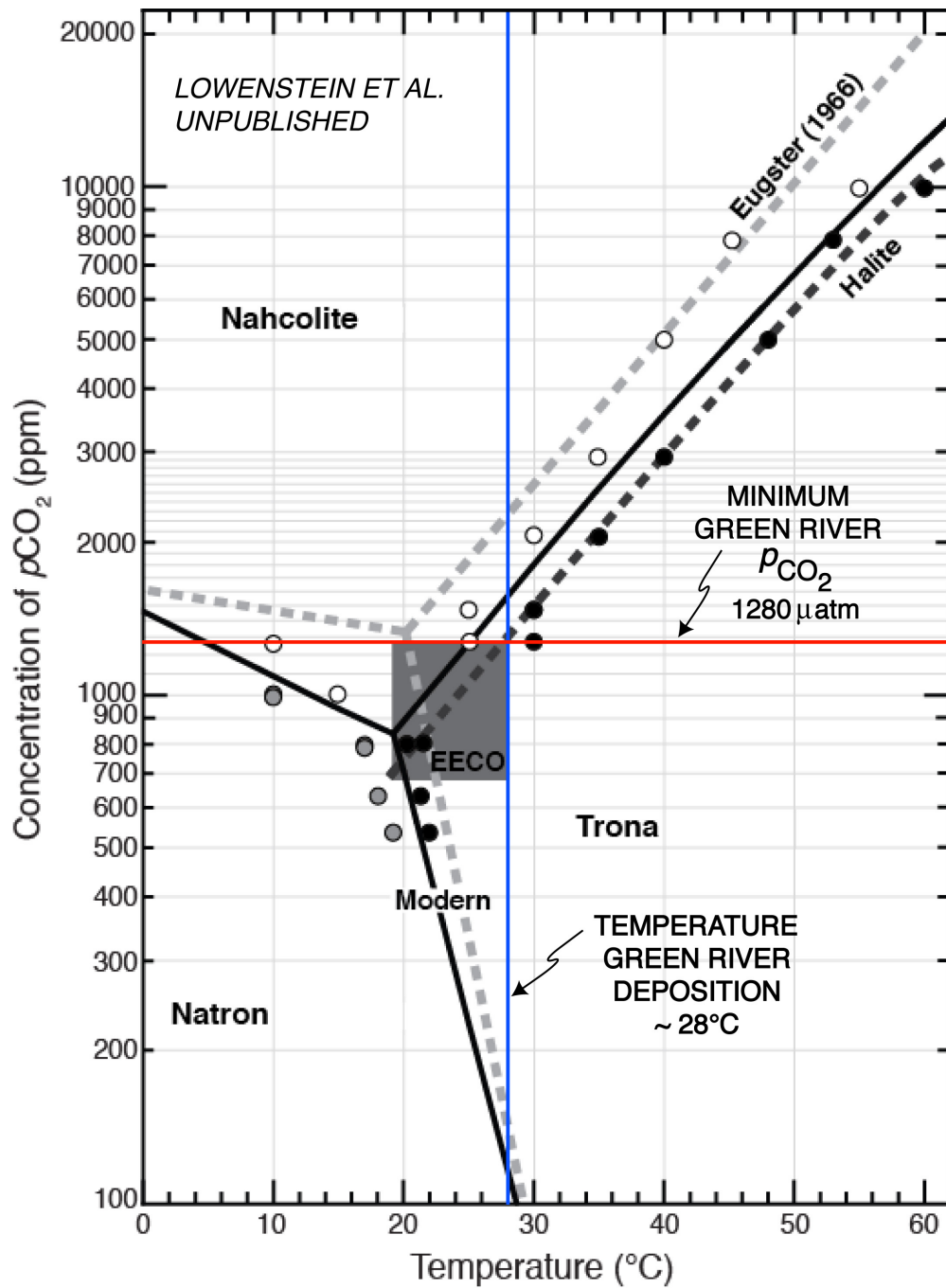
5°C

CO₂^{DURING} \cong 3 CO₂^{BEFORE}



THICK NAHCOLITE DEPOSITS
~ 50 x 10⁶ YEARS IN AGE
ARE FOUND IN WYOMING AND CHINA

NO OTHER SUCH DEPOSITS
HAVE BEEN FOUND



55.8 MILLION YEARS AGO ABRUPT WARMING

