Deep Earth Academy
CONSORTIUM FOR OCEAN LEADERSHIP

The PETM in Review

The PETM was likely triggered by the rapid emission of greenhouse gases, probably methane (CH_4), which was rapidly oxidized to carbon dioxide (CO_2). Abrupt global warming was the consequence. This conclusion is based on the sharp negative carbon isotope excursion (CIE; >2.5‰ in deep-sea sequences and 5-6‰ in terrestrial and shallow marine settings). The leading hypothesis for the trigger of the greenhouse gas emissions is the rapid dissociation of shallowly buried methane hydrate deposits along continental margins. One of several compelling arguments in favor of this hypothesis is that the magnitude of the CIE requires a highly depleted carbon source in order to affect the entire carbon reservoir very rapidly. An unrealistically large volume of a less depleted CO_2 source, including volcanism or combustion of previously buried organic matter, would have been required to generate the CIE. Microbially generated methane (degradation of organic matter by methanogenic bacteria) has a $\delta^{13}C$ of <-60‰. This highly depleted $\delta^{13}C$ signature led to the hypothesis that microbially generated methane in hydrate deposits was the source of the CIE. The event may have occurred in pulses of carbon release (likely methane) over a period of 10,000 to 37,000 years, with individual pulses occurring very rapidly, likely 1000 years or less.

While the methane release hypothesis is a very attractive way to explain the CIE, there are several remaining uncertainties. 1) It is very important to note that the greenhouse impact associated with the amount of methane release required to explain the CIE is not sufficient to explain the magnitude of global warming. Thus there must have been some additional carbon input or climate feedbacks that we do not yet recognize. 2) We do not know where the methane release occurred nor what triggered the release.

How fast?

Possible rates of temperature change at the onset of the PETM:

- If temperatures increased by 5°C in 1000 years: translates into a rate of 0.5°C per century.
- If temperatures increased by 5°C in 10,000 years: a rate of 0.05°C per century.
- If temperatures increased by 8°C in 1000 years: a rate of 0.8°C per century.

How do these rates compare with global warming today?

The consequences of the PETM are significant in magnitude and global in distribution:

- Global warming; atmospheric temperatures warmed by 5°-9°C globally (6°-9°C warming of southern high latitude sea surface temperatures, 4°-5°C warming of the deep-sea, tropical sea surface temperatures, and Arctic Ocean, and ~5°C warming mid-latitude continental interiors).
- Ocean acidification (the carbonate compensation depth [CCD] rapidly shoaled by more than 2 km [<10,000 years] and recovered gradually (>100,000 years)).
- Increased intensity of the hydrologic cycle and erosion rates (based in part on changes in clay mineral assemblages).
- Major extinction of benthic foraminifera in the deep-sea (30-50% of species).
- Migration of terrestrial organisms to the high latitudes.
- Turnover and evolution of terrestrial animals and plants.
- Turnover and evolution of calcareous plankton (calcareous nannofossils and planktic foraminifers).
- New mammal lineages first appear in the earliest Eocene, including the earliest horse (*Hyracotherium* or "eohippus") in North America.

Select references

These are overview papers. Details can be found in the references cited therein.

Bowen, G.J., Bralower, T.J., Delaney, M.L., Dickens, G.R., Kelly, D.C., Koch, P.L., Kump, L.R., Meng, J., Sloan, L.C., Thomas, E., Wing, S.L., and Zachos, J.C., 2006. Eocene hyperthermal event offers insight into greenhouse warming, EOS, 87(17):165, 169.

Thomas, E., Brinkhuis, H., Huber, M., and Röhl, U., 2006. An ocean view of the Early Cenozoic Greenhouse World, Oceanography, 19(4):94-103.

Wing, S.L., Harrington, G.J., Smith, F.A., Bloch, J.I., Boyer, D.M., and Freeman, K., 2005. Transient floral change and rapid global warming at the Paleocene-Eocene boundary, Science, 310:993-996.

Zachos, J.C., Pagani, M., Sloan, L., Thomas, E., and Billups, K., 2001. Trends, rhythms, and aberrations in global climate change 65 Ma to present, Science, 292:686-693.

Zachos, J.C., Röhl, U., Schellenberg, S.A., Sluijs, A., Hodell, D.A., Kelly, D.C., Thomas, E., Nicolo, M., Raffi, I., Lourens, L.J., McCarren, H., and Kroon, D., 2005. Rapid acidification of the ocean during the Paleocene-Eocene Thermal Maxium, Science, 308:1611-1615.

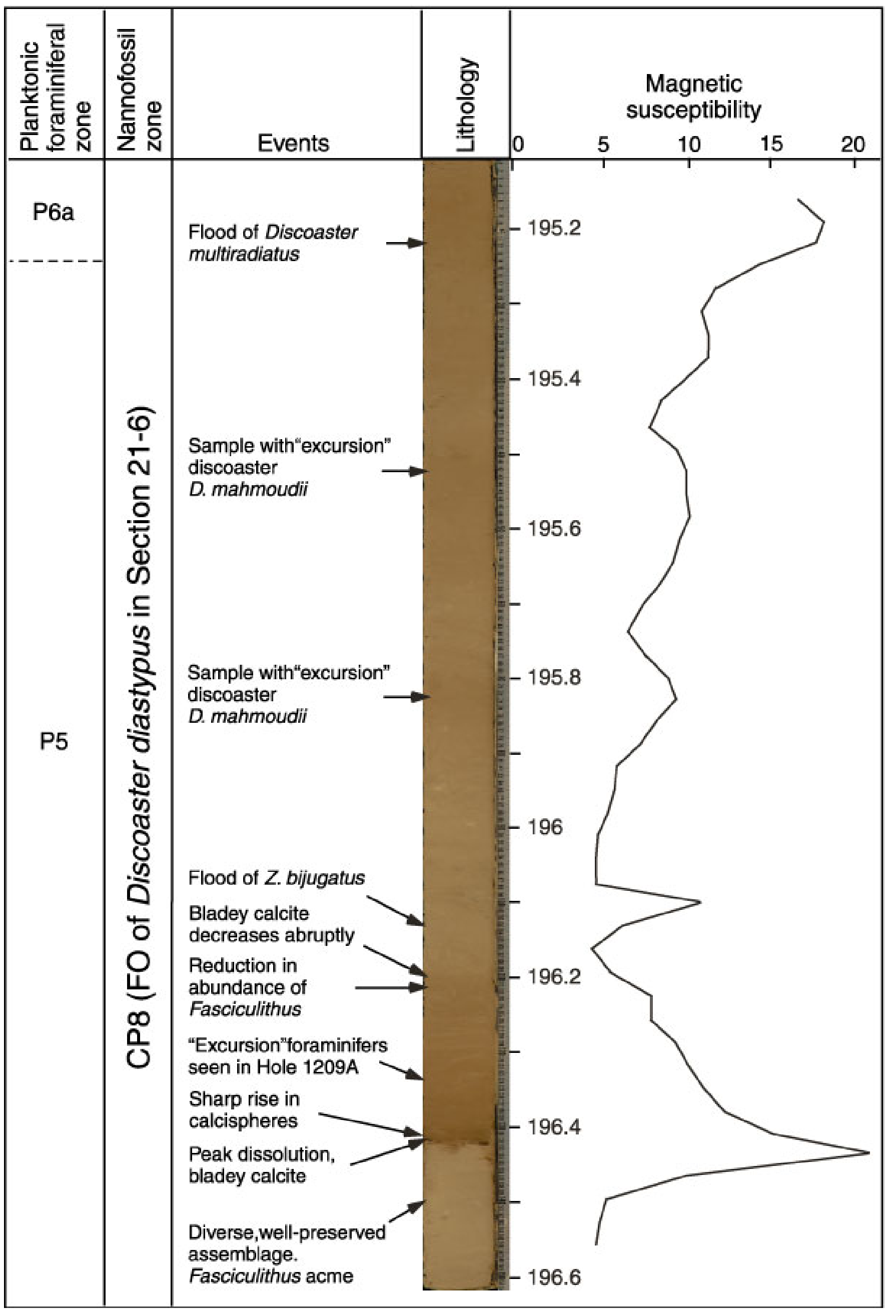

Figure 1. *Paleontological summary of the PETM interval in Section 198-1209B-22H-1, ODP Leg 198. Depths listed along the lithology column are in meters below seafloor (mbsf). FO = first occurrence.* http://www-odp.tamu.edu/publications/198_IR/chap_01/chap_01.htm

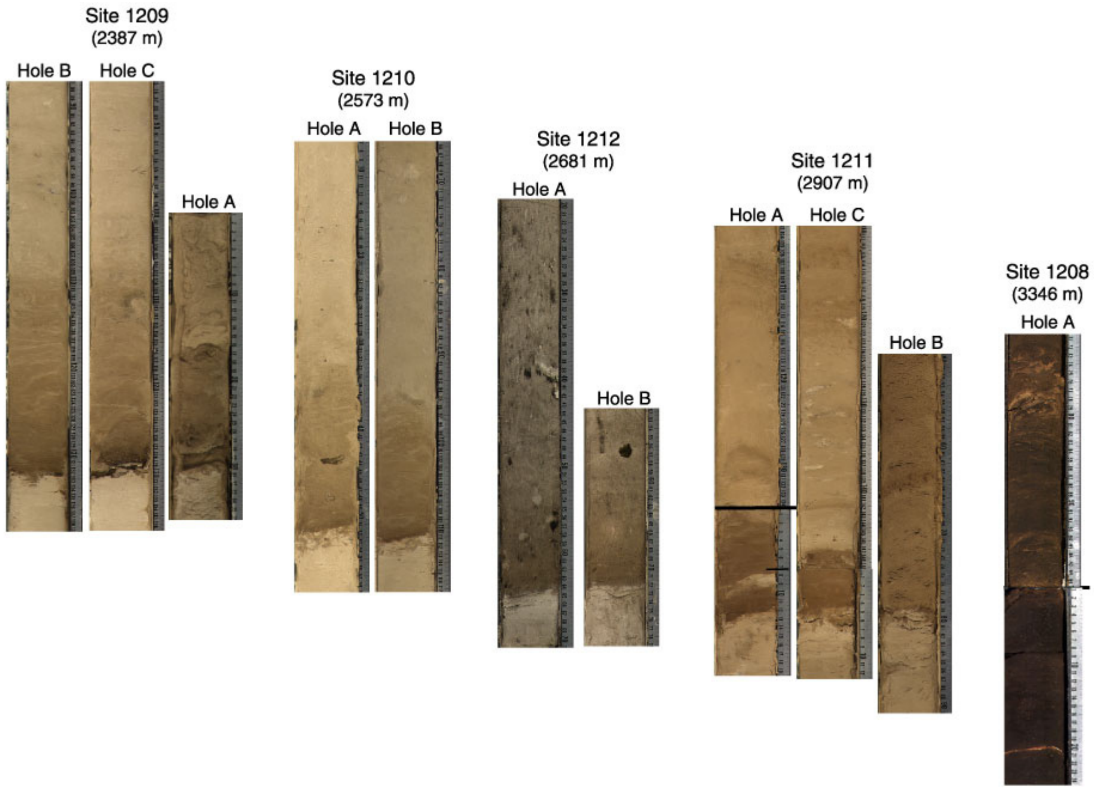

Figure 2. *PETM on Shatsky Rise in the northwest Pacific (ODP Leg 198): Sections 198-1208A-36X-2, 198-1208A-36X-CC, 198-1209A-21H-7, 198-1209B-22H-1, 198-1209C-11H-3; 198-1210A-20H-6 and 198-1210B-20H-3; 198-1211A-13H-6, 198-1211A-13H-5, 198-1211B-13H-4 (unconformity above clay-rich seam), 198-1211C-13H-2, and 198-1211C-13H-3; and 198-1212A-10H-1, 198-1212B-9H-5. Sites are ordered according to present water depths, from shallow on the left to deep on the right.* http://www-odp.tamu.edu/publications/198_IR/chap_01/c1_f53.htm#873593

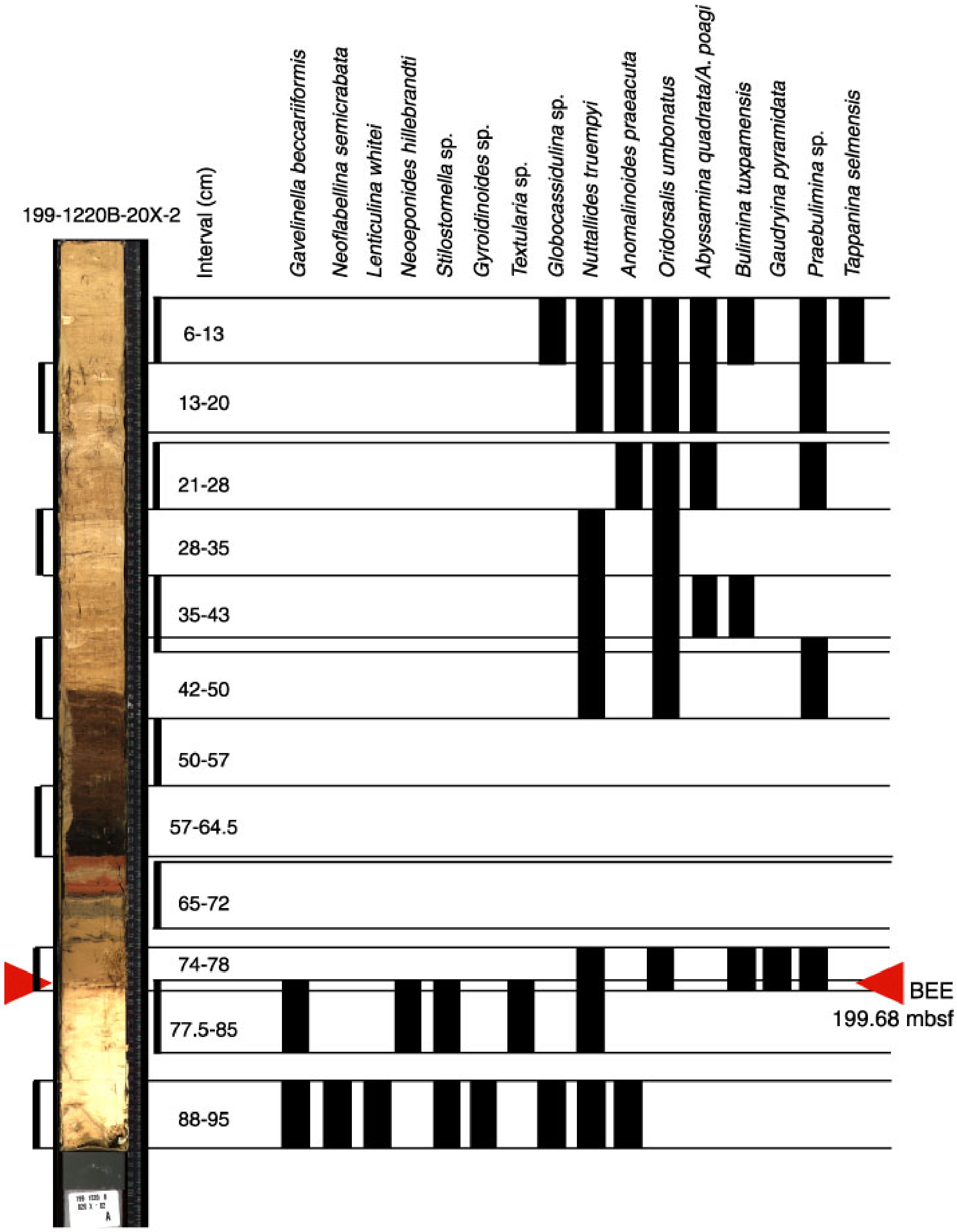

Figure 3. *Digital photograph and* ***stratigraphic distribution of benthic foraminifers in Section 199-1220B-20X-2*** *(198.90-199.85 mbsf), ODP Leg 199. Red triangles at 199.68 mbsf = P/E boundary as represented by the* ***benthic extinction event (BEE)****. http://www-odp.tamu.edu/publications/199_IR/chap_01/c1_f32.htm#538074*

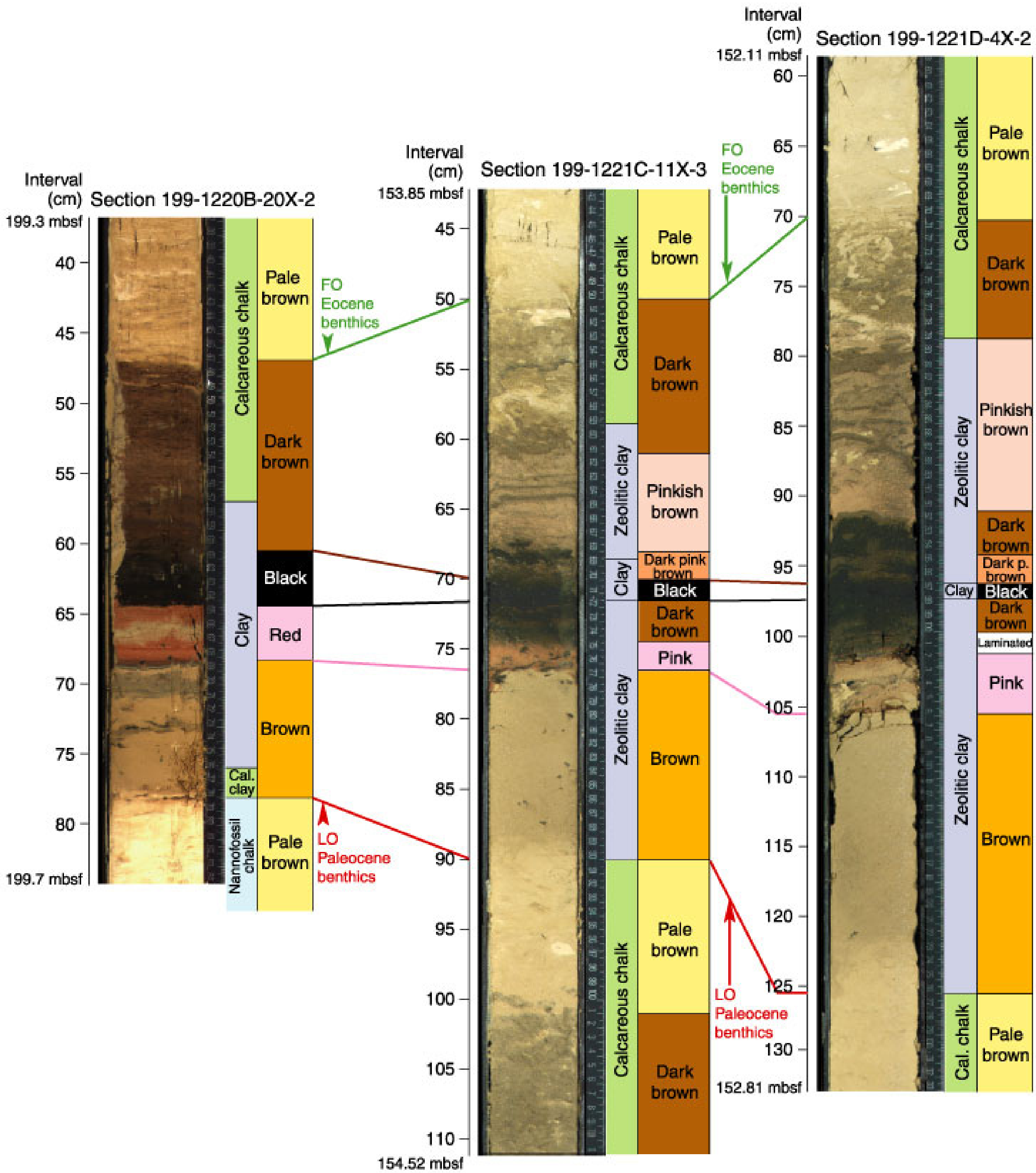

Figure 4. Digital photographs of the ***P/E (Paleocene/Eocene) boundary sediments recovered at Sites 1220 and 1221 in the equatorial Pacific (ODP Leg 199)****. Lower Eocene calcareous chalks grade downcore into multicolored clay-rich lithologies. The* ***last occurrence (LO) of Paleocene benthic foraminifera*** *is recorded at the base of the brown clay, and the first occurrence (FO) of Eocene age benthic foraminifera is at the top of the dark-brown clay. Calcareous fossils are barren to poorly preserved in the multicolored clay layers, and percentage CaCO3 values are very low. Cal = calcareous. P. = pink.* http://www-odp.tamu.edu/publications/199_IR/chap_01/chap_01.htm

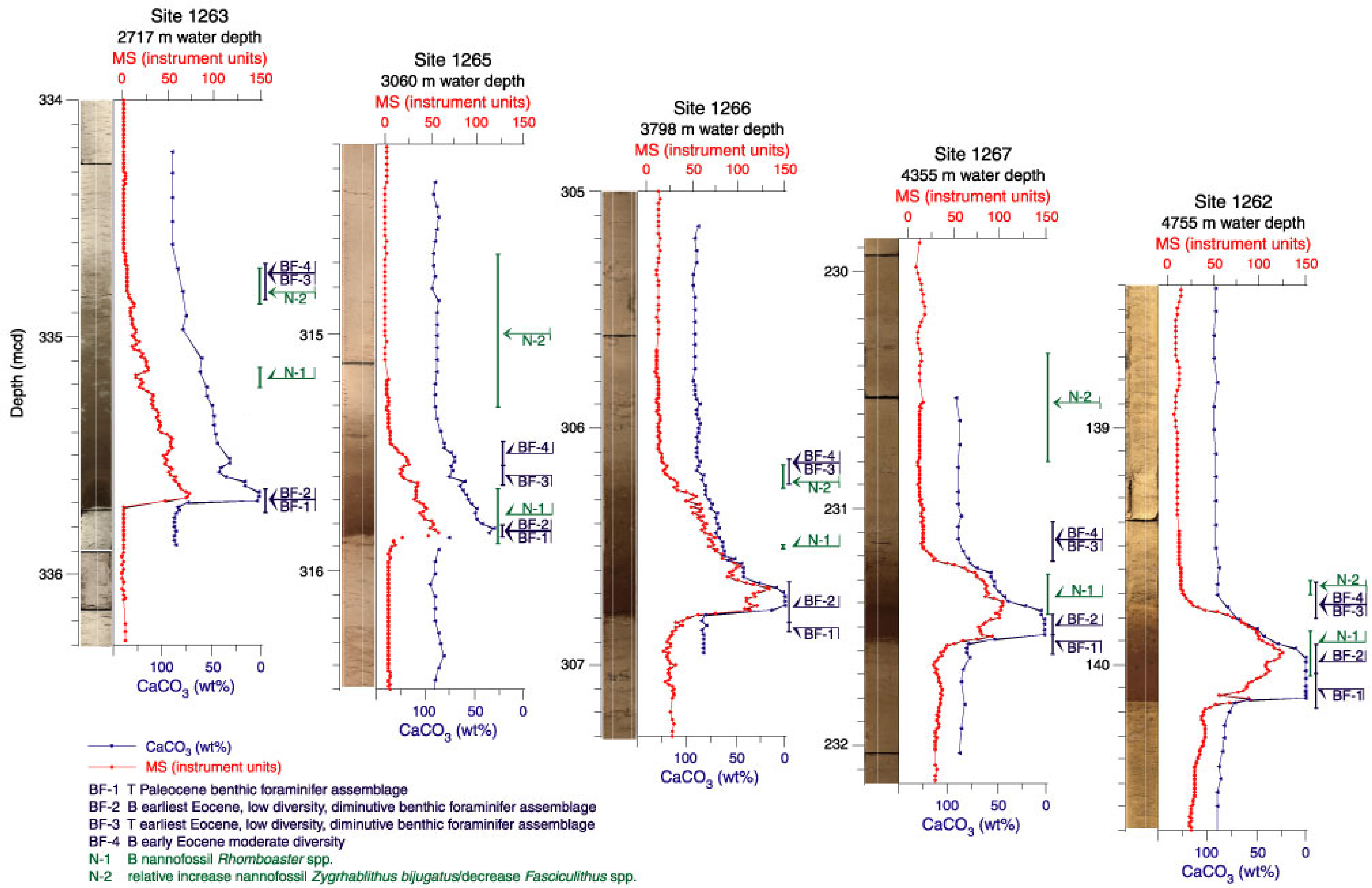

Figure 5. Composite digital images, magnetic susceptibility (MS), and CaCO3 through the Paleocene–Eocene transition at the shallow to deep transect on Walvis Ridge, southeast Atlantic (ODP Leg 208). *Also shown are the major changes in benthic foram assemblages (BF) and key species of calcareous nannofossils (N). The MS graphs represent both point magnetic susceptibility (PMS) data measured on the split core and loop sensor (MSL) data measured on the whole core.* ***The depth-transect reveals that the deeper sites were affected longer by dissolution due to shoaling of the CCD than the shallower sites.*** *T = top (last occurrence), B = bottom (first occurrence).*
http://www-odp.tamu.edu/publications/208_IR/chap_01/c1_f48.htm#1036493

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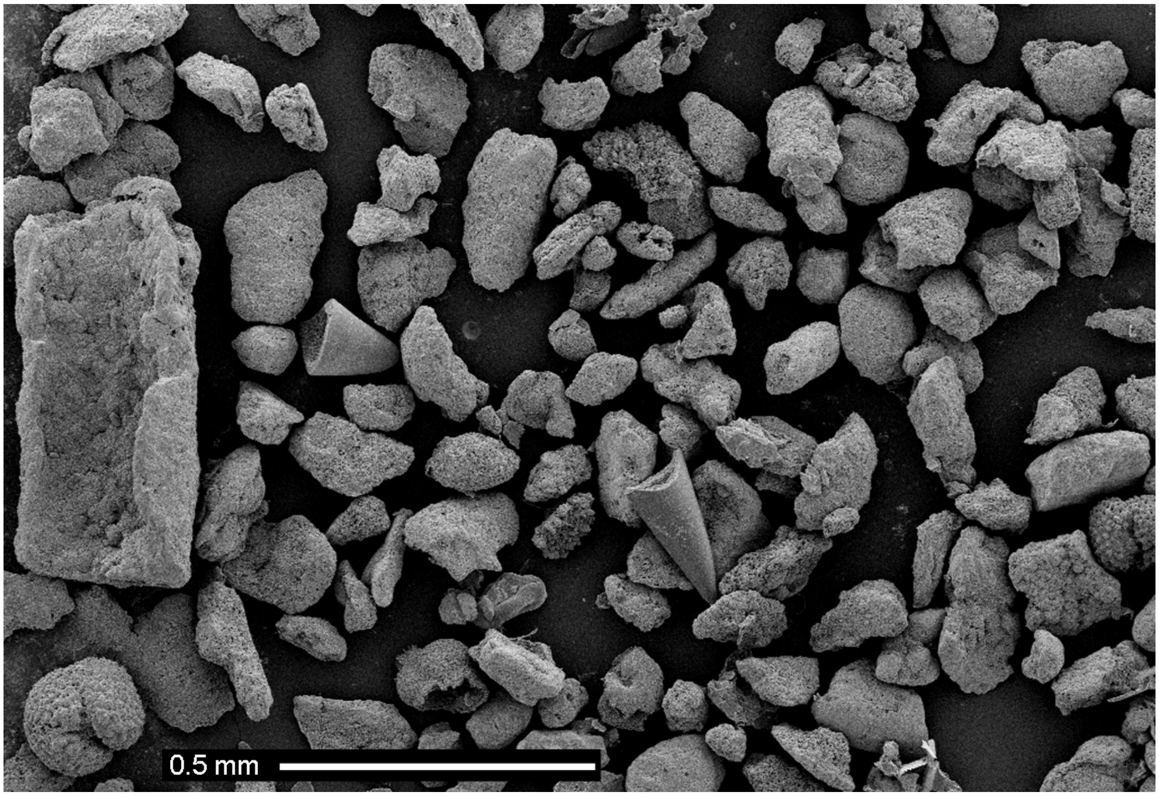

Figure 6a. *Pre-PETM planktic foram assemblages from Walvis Ridge (1262B-15H-3, 133 cm). Note well-preserved specimens. Scanning electron micrograph image courtesy of Brian Huber.*

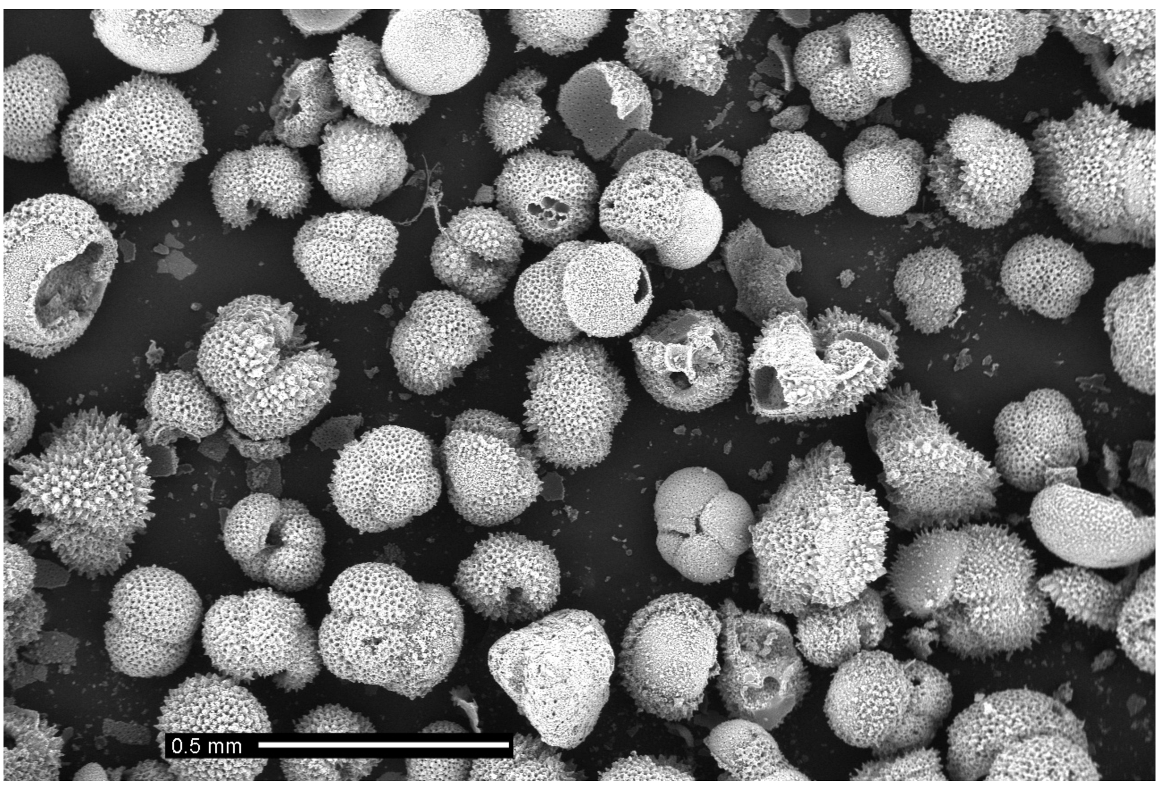

Figure 6b. *Post-PETM planktic foram assemblages from Walvis Ridge (1262B-15H-3, 51 cm). Note fewer more poorly preserved forams, together with fish teeth, and metal oxide fragments. Scanning electron micrograph image courtesy of Brian Huber.*