Methane Blowout during the End-Cretaceous Meteorite Impact?

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***Abstract*- The asteroid impact associated with the demise of the dinosaurs triggered widespread failures of continental margins around the North Atlantic and created one of the largest deposits of submarine landslides known on Earth. One might expect a large-scale release of methane hydrates into the ocean and escape of methane into the atmosphere as a consequence of such slumping. However, there is no evidence for sustained input of methane in the carbon isotope record. Gravity slumping, by itself, apparently is not effective in triggering large-scale sustained degassing of hydrate reservoirs. Initial release during slumping, producing short-term effects, cannot be excluded from the available evidence. Subsequent continued degassing and leaking of hydrocarbons on a modest scale might have contributed to anaerobic conditions over large areas of the sea floor, which could help explain reduced productivity, from bacterial destruction of nitrate at depth.**

I. INTRODUCTION

Dramatic changes in methane content of the atmosphere during the last 400,000 years (Petit et al., 1999), and evidence for the presence of vast deposits of methane hydrates on the present sea floor (Kvenvolden et al., 1993) led to considerable speculation concerning the possibility of sudden methane release from the ocean to the atmosphere. Such release could significantly affect the radiation balance of Earth, since methane is a potent greenhouse gas (Haq, 1998). Large-scale methane release has been invoked, for example, for a rapid warming of the entire ocean about 55 million years ago, near the Paleocene-Eocene boundary (Dickens et al., 1995). This event, which introduced a major climate anomaly, lasted some 200,000 years. It is referred to as the Paleocene/Eocene Thermal Maximum (PETM). A shift in deep-sea temperatures by as much as 5-7°C is indicated. This warming was accompanied by a -3‰ shift in $\delta^{13}C$, ascribed to an estimated release of ~1200-1500 Gt of bacterial methane into the atmosphere and ocean. Carbon cycle perturbations of similar or larger magnitude in the Albian, Aptian and Toarcian have also been hypothesized to be a consequence of methane outgassing. Methane is implicated in these events by mass balance calculations that show that volcanic CO_2 or exchange of terrestrial biomass cannot fully explain the large magnitude of the $\delta^{13}C$ anomalies

Although gas hydrates are certainly a potential source of abundant volatile carbon with high $^{12}C/^{13}C$ ratios, it is not obvious just how methane is released from sedimentary reservoirs to cause noticeable perturbations of global $\delta^{13}C$. The coincidence of slump deposits associated with the onset of the PETM suggests that hydrate reservoirs may have been unloaded and degassed catastrophically by slope failure, a conclusion supported by observations that the main shifts in $\delta^{13}C$ occur on timescales of less than 1 kyr (Bains et al. 2000).

Here we discuss possible evidence for a 'methane blowout' associated with large scale mass wasting at the Cretaceous/Paleogene boundary.

II. SUBMARINE LANDSLIDES

There is substantial evidence for widespread slope failure around the North Atlantic, Caribbean and western North American margin triggered by the Richter scale 10-13 earthquake associated with the Chicxulub impact event. An excellent example for slumping at the K/T boundary is found in seismic profiles across Blake Nose [Fig. 1].

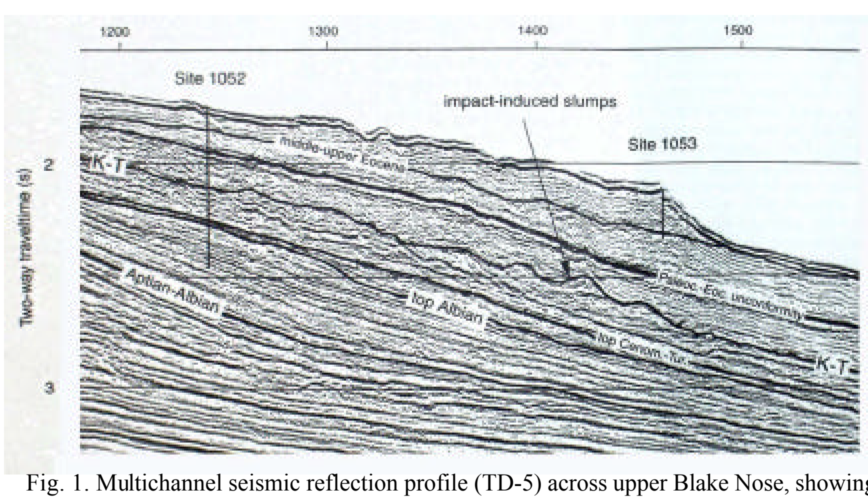

Fig. 1. Multichannel seismic reflection profile (TD-5) across upper Blake Nose, showing evidence for mass wasting immediately below the K-T boundary. From Klaus et al. (2000).

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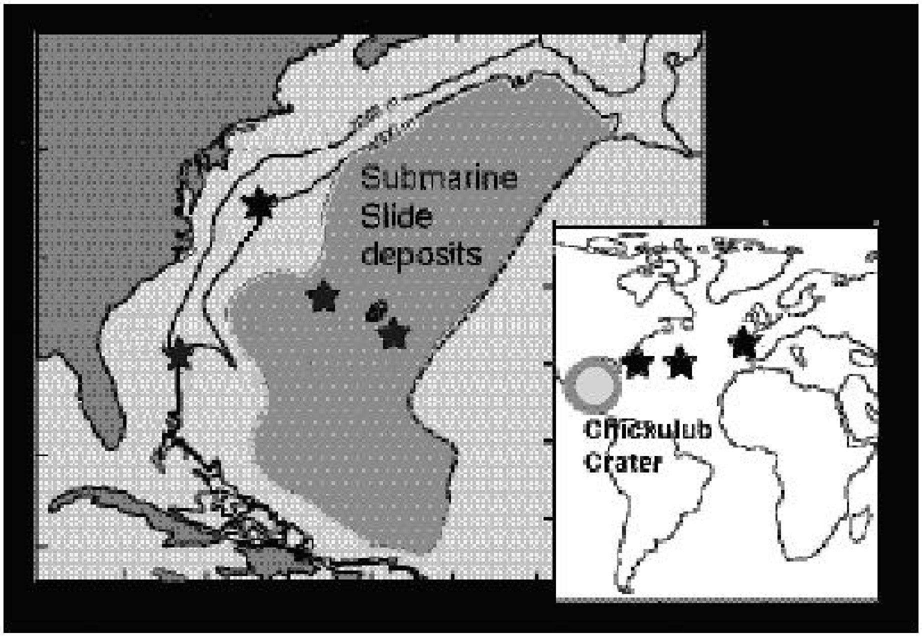

Fig. 2. Map showing the distribution of end-Cretaceous submarine slides (shaded region) inferred from drill sites (stars) and geophysical evidence. Slide deposits cover the abyssal plain from the Grand Banks to the Bahamas suggesting the widespread failure of the eastern margin of North America during the end-Cretaceous impact event

Additional evidence for widespread slumping comes from widespread turbidite deposits (Norris et al., 2000; Norris and Firth, 2002). In the Western North Atlantic alone, acoustic evidence suggests that turbidites generated from slope collapse cover an area of about 4 million square kilometers, making these by far the largest submarine slide deposits on the surface of the Earth [Fig. 2].

Across the Atlantic, the record in Hole DSDP 398D provides additional evidence that mass wasting preceded the arrival of impact debris on the seabed. The slump preserved below the K/T boundary at DSDP Hole 398D must have been locally derived since it contains microfossils and sediment similar to that preserved below the slump. The microfossil assemblages lack uniquely shallow water species unlike the turbidite sequence at DSDP 387. The folded sediment did not travel long distances since it remained partly coherent.

III. CARBON ISOTOPE VALUES

Max et al. (1999) have pointed out that the relatively cool climate of the Maastrichtian should have promoted the widespread formation of gas hydrate deposits along the continental margins. Today, gas hydrates are found primarily on the continental slopes and rises where the combination of high organic matter input and high sedimentation rates contribute to gas hydrate formation and preservation (Kvenvolden et al., 1993). The evidence for massive slope failure on both sides of the Atlantic suggests that many hydrate reservoirs on these margins could have been catastrophically vented, presumably by releasing buoyant ice to the surface of the sea, where it would have melted very quickly, giving up the enclosed methane to the atmosphere.

The large scale venting of bacterial methane (with $\delta^{13}C$ less than -50‰) should manifest itself in carbon isotope records throughout the biosphere, as postulated for the Paleocene-Eocene boundary where marine carbonates typically show a -2.5 to -3‰ decrease in $\delta^{13}C$. In principle, the K/T slope failure could have precipitated a release at least as large, if not larger than the Paleocene-Eocene event. The added carbon should persist as a recognizable geochemical anomaly for more than 100 kyr, as it did in the case of the Paleocene-Eocene event. Thus, we should have no trouble identifying a carbon isotope excursion related to large-scale methane hydrate decomposition at the K/T boundary.

There is a well documented –1‰ to -1.7‰ decrease in the $\delta^{13}C$ of planktic foraminifera and bulk carbonate at the K/T boundary (Zachos and Arthur, 1986). The shift to low values is in essence instantaneous (D'Hondt and Zachos, 1993). There are two possibilities to explain the shift: one is that the type of plankton changed and now produced carbonate with lower $\delta^{13}C$ values. Since there was a drastic change in plankton species, this is a very reasonable scenario. The other is that the composition of the surface water changed, with respect to carbon isotope ratio. A decrease in nutrient content of the entire ocean could explain the fact that the difference of $\delta^{13}C$ values between the plankton carbonate and the benthic carbonate was substantially reduced after the K/T event. A general warming of the deep ocean, for example, would have decreased its ability to hold oxygen, which in turn would have decreased its ability to regenerate nutrients. A smaller range for apparent oxygen utilization (AOU) would necessarily follow and restrict the range for $\delta^{13}C$ values at depth (that is, they would look more like surface values, as is observed).

When contemplating the low-nutrient scenario, one realizes that an effect from methane on both planktic and benthic carbon isotope signals cannot be categorically excluded, until the overall record of the *weighted mean* values of the $\delta^{13}C$ of marine carbonates has been established. Nevertheless, the observations so far do not favor a scenario of large-scale methane release. The planktic $\delta^{13}C$ (produced largely by stress-related species in the earliest Paleocene) does not recover appreciably for more than two million years, while the difference to benthic foraminifers stays roughly constant (D'Hondt and Zachos, 1993). One would like to see the mean change toward heavier values, as the system recovers from any methane input. (The mean in the sea, presumably, would be close to benthic values.)

Rather than to any effects from gas hydrates, the $\delta^{13}C$ changes at the K/T boundary are commonly attributed to the biotic extinction and reduction in surface-to-bottom carbon export as a consequence of the mass extinction (Hsü and McKenzie, 1985; Zachos et al., 1989). To be sure, the site studied by Zachos et al. (1989) (DSDP 577 in the Pacific) has very low sediment accumulation rates of less than ~0.25 cm/kyr and so may not preserve as complete a record of the $\delta^{13}C$ changes at the boundary as originally thought. However, even at these low sedimentation rates, a $\delta^{13}C$ anomaly due to methane hydrate decomposition should be evident in the lower 38 cm of the Danian, representing the first 150 kyr of the Cenozoic. The absence of a major negative shift in $\delta^{13}C$ of benthic foraminifera across the boundary in any site suggests that the massive failure of continental margins around the North Atlantic was not a source for release of climatologically significant amounts of methane hydrates. Either gas hydrates were not widespread in Maastrichtian sediments in the North Atlantic after all, or slope collapse was ineffective at venting them to the ocean and atmosphere.

IV. POSSIBLE EFFECTS FROM ESCAPE OF FLUIDS

The question arises whether other environmental effects would have resulted from the observed major slope failures, effects that could have retarded recovery of the marine biosphere. There is no question, of course, that gases and fluids were released from the slumping; the only question is whether this release persisted on an important scale through a considerable time. The instant release of gases, especially of hydrogen sulfide, would have added to the stress immediately following the impact. Sulfide release would have added to the scenarios postulating input of large amounts of acid to the system (D'Hondt et al., 1994). Release of large amounts of carbon dioxide also would have added to acidification.

Continuous release of methane and sulfides from large regions on the continental slope, even at a modest level, would have contributed to oxygen deficiency, and hence to the destruction of nitrate by denitrification. Such a process would have opposed the usual negative feedback, whereby a decrease in production results in a decrease in oxygen utilization, and therefore in preservation of nitrate. We may postulate, for a period after the K/T event and the associated submarine slumping, a sea floor widely covered with anaerobic bacteria oxidizing methane, sulfides and hydrocarbons. A release of hydrocarbon fluids in seeps is very likely, as well. These would have risen to the surface, fouling shallow-water regions to the detriment of any surviving corals, mollusks and seabirds there.

It is interesting that marine bivalve extinctions were equally intense in tropical and extratropical localities (Raup and Jablonski, 1993), while plant extinction decreased in high latitudes (G.R. Upchurch in Donovan 1989). What made the surface ocean so vulnerable to damage? Introduction of acids and hydrocarbons from the sea floor may be part of the story. Marine slumping presumably was not restricted to the North Atlantic. It should have been equally intense in the Indian Ocean, where the seismic energy from the impact converged after traveling around the globe.

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