



The final Miocene carbonate crash in the Atlantic: Assessing carbonate accumulation, preservation and production

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ABSTRACT

In many palaeoceanographic studies low carbonate contents in Neogene deep-sea sediments are interpreted as dissolution events related to prominent shifts in intermediate and deep-water circulation. In the middle to late Miocene such carbonate crash events were a widespread phenomenon throughout the world's ocean basins. However, low carbonate contents may also derive from terrigenous dilution and carbonate production changes in surface waters as shown for late Miocene records of the South Atlantic (Diester-Haass et al., 2004; Westerhold et al., 2005). In order to contribute to solve this question we investigated the youngest of the Miocene crash events (10.5 Ma to 9.0 Ma) at a prominent key location of global deep water circulation, i.e. the Equatorial Atlantic Ceará Rise depth transect (ODP Sites 926, 927 and 928). By analysing different carbonate preservation proxies like carbonate content, silt grain size parameters, sand content, fragmentation index and mass accumulation rates we were able to quantify dissolution, dilution and production, and to assess previous conflicting interpretations. Critical evaluation of the different dissolution proxies and comparison to former studies revealed that silt preservation proxies do not entirely reproduce the depth dependant dissolution in the Miocene sediments, as indicated by foraminifer fragmentation. In the investigated late Miocene time slice three minima of carbonate accumulation were detected. The predominant control on these events changed from dissolution of carbonate to lowered production. The last event at 9.6 Ma is accompanied by an increased preservation but reduced carbonate accumulation. During this time the first prominent pulses of Northern Component Water (NCW) occurred, sourced most probably from the Labrador Sea. This may be understood as a first short term precursor of long time persistent and much stronger NCW production that is characteristic for younger periods and marks the turnover to the modern type of basin-to-basin fractionation between the Atlantic and Pacific. Furthermore, preservation trends of Caribbean and Ceará Rise records were in phase in contrast to former hypotheses that suggested antithetical preservation during carbonate crash events. The similarity of the preservation records in the studied ocean basins in conjunction with the inconsistency in timing of the CC-events and proposed NCW estimates indicates that changes in the carbon cycle other than dissolution controlled the CC events prior to ~9.9 Ma.

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1. Introduction

The carbonate crash events (CC events) were first recognised as distinct drops in carbonate content in Miocene sediments of the South Atlantic (DSDP Leg 3 – Shipboard Scientific Party). Subsequently, more cores in the time period from 12 to 9 Ma were retrieved that frequently showed carbonate minima. The most distinct carbonate crashes are recorded in sites located at both sides of the Panamanian Isthmus, which is the Equatorial East Pacific (ODP Leg 138) and the Caribbean (ODP Leg 165). Here carbonate accumulation dropped to zero several times between 12 and 9 Ma (e.g. Lyle et al., 1995; Roth et al., 2000). A comprehensive overview of previous studies dealing with CC events

is given in Table 1. A rise in CCD level of 800 m occurred at about 10 Ma and the CCD remained shallow east of the East Pacific Rise (EPR), while carbonate accumulation recovered at the western sites (Lyle et al., 1995). A variety of explanations were proposed: (1) Carbonate dissolution occurred as a response to the constriction of the CAS, which resulted in a significant reduction in the flow of carbonate saturated water entering the Pacific (Lyle et al., 1995, Table 1). (2) The productivity based hypothesis relates the CC-events in the Pacific to modern-like alternating El-Nino/La-Nina stages that are evidenced by consistent shifts in opal and carbonate production (Jiang et al., 2007; Nathan and Leckie, 2009; Table 1). This involves establishment of a Proto-West Pacific Warm Pool during La Nina like conditions. Due to high production of opal and carbonate, carbonate mass accumulation in the EEP at 11.6 to 10 Ma remained comparably high despite bottom waters may have been undersaturated (Nathan and Leckie, 2009). (3) A specific observation on the CC events in the Caribbean is, that in addition to the main carbonate minima between 12 and 9 Ma precursor

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Table 1
Overview of CC events in the literature. Grey shaded areas indicate the timing of CC-events. Note the different timing between sites located east *1 and west *2 of the EPR.

Location/Sites	Timing of events (Ma)			Proxies			Main implications for CC-events	Source
	9	10	11	Productivity	Dissolution	Circulation		
Pacific eastern equatorial ODP Leg 138 / DSDP sites	*1			MAR _{CaCO3}			Restriction of carbonate saturated waters due to shoaling CAS causing dissolution. Alternative scenario: influx of corrosive SCW. (*1 - east of EPR, *2 west of EPR)	Lyle et al. (1995)
	*2							
Eastern equatorial ODP Site 1241		*1		MAR CaCO ₃ /Opal/TOC	Foraminifer preservation		Increased productivity. Organic matter decay causing dissolution	Shipboard Scientific party (2003)
Eastern equatorial ODP Site 1256				fine fraction δ13C, δ18O	Nannofossil preservation		Decreases in nannoplankton productivity	Jiang et al. (2007)
ODP Sites 850, 846				MAR _{CaCO3} MAR _{Opal}	Foraminifer preservation		Elevated productivity from 11.6 Ma to 9.6 Ma delaying dissolution effects - decreased productivity from 9.6 on	Nathan & Leckie (2009)
Caribbean ODP Sites 998,999,1000				MAR _{CaCO3}	>63 μm wt. %	benthic δ ¹³ C, δ ¹⁸ O	Corrosive intermediate SCW contemporaneous with NCW formation	Roth et al. (2000)
ODP Sites 998,999, (Pacific 846, 1241)						ε _{Nd}	Corrosive Pacific deep to intermediate waters causing dissolution contemporaneous with NCW formation	Newkirk & Martin (2009)
Atlantic equatorial ODP Sites 925-929 Ceara Rise				MAR _{CaCO3}			Low MARCaCO ₃ from 11.8 to 10.5, increasing fluxes thereafter	King et al. (1995)
Benguela upwelling ODP Site 1085, 1087				MAR _{CaCO3} MAR _{TOC}	benthos/ plankton- ratio		High MARCaCO ₃ during the CC-events. Dilution via orange river. Possibly decrease of productivity at 9.5 to 9 Ma	Diester-Haass et al. (2001)
ODP Site 1085, 1087				MAR _{CaCO3}			MARCaCO ₃ decrease from 10.6 Ma to 10.1 Ma due to decreased productivity, drop at 9.6 to 9 Ma caused by productivity decreases and dilution	Kastanja et al. (2006), Krammer et al. (2005)
Walvis Ridge ODP Site 1265					CS mean/ foraminifer preservation/>6 3 μm wt. %		Preservation decrease at 10.1 Ma due to influx of corrosive SCW, NADW replacing SCW at 10.4 Ma	Kastanja et al. (2006)
Walvis Ridge ODP Sites 1262, 1264						ε _{Nd}	Changing deep water circulation through onset of deep convection in the Labrador Sea at 10.6-7.3 Ma.	Thomas & Via (2007)

Data from Shipboard Scientific party (2003).

events are recognised between 13.8 Ma to 12 Ma (Roth et al., 2000; Table 1). These events are ascribed to the influx of carbonate corrosive AAIW (or its precursor) replacing sinking waters in the northern hemisphere in times of re-established NCW formation (Roth et al., 2000). (4) Another hypothesis postulates the influx of corrosive Pacific intermediate waters triggering dissolution in the Caribbean (Newkirk and Martin, 2009; see Table 1). (5) Carbonate preservation and accumulation pattern in the SE Atlantic are partly explained by shifts in coccolith production rates in the Benguela upwelling system in the middle to late Miocene. Furthermore, local influences of terrigenous material from the Orange River caused lowered carbonate contents (Diester-Haass et al., 2004; Kastanja et al., 2006; Krammer et al., 2006; Table 1). (6) Several CC events are also recognised in the Ceará Rise sediments where a long-term shoaling of the lysocline took place from 14 Ma to 11.5 Ma (King et al., 1997).

Taking all evidences together, the middle to late Miocene ocean seems to be influenced by a larger re-organisation of the ocean circulation and chemistry, which might be associated with regional to global climate changes. However, the processes behind have still to be disentangled, and with the given study we try to contribute to this effort studying a transect of drill sites of the Ceará Rise, located in the western Equatorial Atlantic within the deep water masses of the global ocean conveyor.

Sediments from the Ceará Rise depth transect (ODP Sites 926, 927 and 928) were investigated in the time period from 10.5 Ma to 9.0 Ma coinciding with the occurrence of CC events in the Miocene ocean. Carbonate silt preservation proxies will be used to record preservation changes during the final phase of the CC events in order to distinguish between carbonate production, dissolution, and dilution at Ceará Rise.

2. Study area

Ceará Rise is an aseismic ridge located 700 km to the north-east of the Amazon River delta, ranging between 2600 and 4500 m water depth within the transition from North Atlantic Deep water (NADW) to Antarctic Bottom water (AABW) today. The chemical lysocline for calcite is located at a water depth of 4500–4600 m, and the foraminiferal lysocline is centred at 4400 m (Curry and Cullen, 1997; Fig. 1B). Since the sites are located in the oligotrophic subtropical West Atlantic gyre (Fig. 1A), their sediments are composed of calcareous nannofossils and foraminifers, diluted by various amounts of terrigenous matter brought by the Amazon River. The evolution of today's Amazon drainage system dates back into the middle to late Miocene uplift of the Andean mountain range (Hoorn, 1994). In the Pliocene discharge rates approached modern levels as revealed by a significant increase of terrigenous accumulation rates at Ceará Rise (Tiedemann and Franz, 1997).

Early studies on Miocene deep ocean circulation using global datasets of oxygen and carbon isotopes showed that deep waters aged from south to north with no significant NADW formation earlier than 14.5 Ma (Woodruff and Savin, 1989, for a summary see Bickert and Henrich, 2011). Afterwards, there might have been an early production of NADW, maybe related to the deepening of the Greenland–Scotland Ridge (Wright and Miller, 1996), however, the general overturning was still weak. The geochemical basin-to-basin-fractionation as known from the modern ocean is indicated by diverging δ¹³C gradients starting at 9.5–7.5 Ma (Billups, 2002; Bickert et al., 2004; Poore et al., 2006). ε_{Nd} values from the Walvis Ridge depth transect exhibits increasing gradients interpreted as a change in deep ocean circulation and the onset of deep convection in the Labrador sea between 10.6 and 7.5 Ma (Thomas and Via, 2007). The geochemical evidence for the onset of NADW

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