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Climate and sea-level controls on turbidity current activity on the Tanzanian upper slope during the last deglaciation and the Holocene

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A B S T R A C T

Turbidity current is one of the most important mechanisms for rapid transportation of terrigenous sediments from the continental margin to the deep sea. Although extensive work on turbidite systems has been carried out globally, the Tanzanian margin, off East Africa, is poorly understood. This paper will therefore use a well-dated high-resolution marine core (GeoB12624-1), obtained during RV *Meteor* Cruise M75/2, from the upper Tanzanian continental slope, offshore the Rufiji River delta, to demonstrate which environmental parameters, e.g., climate versus sea level, control the temporal distribution of the turbidite deposits during the last deglaciation and the Holocene. Results show that the turbidite deposits are composed of coarser-grained sediments with normally graded bedding. The thickness, mean grain size and frequency of the turbidite beds were estimated to detect turbidity current activity since the Last Glacial Maximum (LGM). A total of 12 turbidite beds (TI-T12) was recognized and divided into three intervals, based on the presence and intensity of the turbidite deposits. (I) a glacial sea-level lowstand (LGM and Heinrich Stadial 1; 19.3–14.6 ka): suppressed turbidity current activity due to arid conditions in the hinterland and sea-level lowstand. (II) A deglacial sea-level rise period (Bølling-Allerød interval to the early Holocene; 14.6–8 ka): turbidity current activity started to be strengthened during the Bølling-Allerød warming interval (T1), followed by a first increase in turbidite frequency, thickness and mean grain-size during the Younger Dryas (T2–T4) and a second increase during the early Holocene (T5–T10). (III) An interglacial sea-level highstand period (mid-to late Holocene; 8–2.5 ka): turbidity current activity diminished from the mid- (T11, T12) to late Holocene. This temporal distribution of turbidite deposits indicates that turbidity currents were most active during the last sea-level rise, synchronous with more humid climate in the hinterland, than during a sea-level lowstand (e.g., LGM) when climate was more arid. Thus, we propose that it is the climate conditions in the hinterland that form the primary controlling factor for turbidity current activity of Tanzanian slope. The remobilization of lowstand sediments on the Tanzanian continental margin during a sea-level rise, combined with shedding sediments towards the study area from the main canyon/channel, also plays a role in supplying new sediments to the turbidite system. These new data demonstrate that, in specific continental margin, high fluvial discharge will promote sediment transfer along the shelf and slope even during sea-level rise and highstand.

1. Introduction

Turbidity currents are one of the most important mechanisms that transport terrigenous sediments from the continental margins to the deep sea (Talling et al., 2015). Linkages between turbidity current activity and external factors such as sea level and climate changes, and tectonic activity, have been demonstrated along global continental margins (Kolla et al., 1980; Prins and Postma, 2000; Reeder et al., 2002; Mutti et al., 2009; Piper and Normark, 2009; Toucanne et al., 2012). According to the classical sequence stratigraphic model, turbidite deposition occurs predominantly during sea-level fall and lowstand, and turbidity current activity is diminished during sea-level highstand (Posamentier and Kolla, 2003). Further studies suggest that submarine turbidite deposition also occurred during periods of sea-level rise and highstand (Weltje and de Boer, 1993; Prins et al., 2000b; Covault et al., 2007; Boyd et al., 2008; Ducassou et al., 2009; Romans et al., 2009; Covault and Graham, 2010) during the late Quaternary, which highlights the influence of climatic and tectonic conditions, in the

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terrigenous sediments source area, on the development of turbidite deposition.

Quaternary turbidite systems have shown that, at high latitudes, turbidity current activity reaches a maximum during deglacial sea level rise because of the significant increase in meltwater discharge of rivers in response to the decay of ice sheets. Such examples include the sandy turbidite sedimentation on the Mississippi Fan (Kolla and Perlmutter, 1993); the Var turbidite system in the Ligrian Sea, southeastern France (Piper and Savoye, 1993; Jorry et al., 2011); and the Armorican turbidite system in the central part of the Bay of Biscay, northern France (Toucanne et al., 2008, 2012). At low latitudes, turbidity current activity is related to high terrigenous input by river discharge or aeolian dust (Prins and Postma, 2000; Henrich et al., 2010b). Romans et al. (2009) and Covault et al. (2010) found that the Newport turbidite deposition was linked to an increased discharge by the Santa Clara River as a result of an increase in the magnitude of the North American monsoon and frequency of El Niño-Southern Oscillation. Nile and Makran turbidite systems are affected primarily by the climate of the hinterland which controls the amounts of sediments via fluvial discharge that feed the turbidite system (Prins et al., 2000b; Ducassou et al., 2009; Bourget et al., 2010, 2011). Turbidity current activity in the Cap Timiris Canyon off Mauritania (Zühlsdorff et al., 2008; Hanebuth and Henrich, 2009; Henrich et al., 2010a) and the Dakar Canyon off Senegal (Pierau et al., 2010, 2011) shows that climatic parameters control their deposition. The sediment records of both canyons demonstrate a high frequency in turbidity current activity during the deglacial sea-level rise, which were caused by the remobilization of aeolian dune fields that had expanded close to the shelf edge during the glacial periods. During the glacial periods, sporadic turbidites occur in the Cap Timiris Canyon in the late phase of Heinrich events, which is related to an increase in the dust supply and remobilization of aeolian dunes (Henrich et al., 2010b). Many case studies show that turbidite system growth depends on the physiographic (shelf width, slope gradient), feeder system (point source, multiple, littoral cell), sediment discharge, tectonic setting, however the turbidite system on the East African margin during the late Quaternary remains poorly understood. Based on one ^{14}C age derived from *Globorotalia menardii*, Bourget et al. (2008) reported that the last turbidite deposited in the Tanzania Channel corresponded to the last sea level rise. These data obtained from the lower part of the turbidite system suggest that turbidity current activity was shut down by the onset of sea-level rise. This is consistent with other “fans” such as the Indus and Zambezi, where there is no significant turbidite system growth on the slope after deglacial (Kolla et al., 1980; Prins et al., 2000a; Prins and Postma, 2000; Bourget et al., 2013). In order to better understand turbidity current activity on the Tanzanian slope on millennial time scale during the late Quaternary, we present a high-resolution sediment record off the Rufiji River delta, which allows us to establish 1) the sedimentological properties of the turbidite deposits in this region (the grain-size distribution pattern); 2) the temporal distribution of turbidite deposits during the last deglaciation and Holocene; 3) the factors influencing turbidity current activity during the late Quaternary (e.g., climate, sea level, and tectonic activity); and 4) a sedimentological model for occurrence of turbidite deposits.

2. Regional setting

2.1. Present climate system

In East Africa, the rainfall patterns are characterized by two pronounced wet seasons (Nicholson, 2000): a short one in September to November (the short rains) and a longer one from March to May (the long rains). Both rainy seasons occur during the monsoon transitional month corresponding to the longitudinal migration of the Intertropical Convergence Zone (ITCZ; Nicholson, 2000), which moves back and forth across the equator (Fig. 1a). The climate system is complex due to deliver of moisture from both the Atlantic and Indian Oceans (Tierney et al., 2011), which are separated by the Congo Air Boundary (CAB). Rainfall during the long rains season is less variable than that during the short rains season, which is caused by a slower northward movement of the ITCZ and a more rapid southward migration of the ITCZ (Black et al., 2003).

2.2. Oceanographic and geological setting

South Equatorial Current (SEC) passes the northern part of Madagascar and continues westward to the coast of East Africa near 11°S (Swallow et al., 1991), where it splits into the north-flowing East African Coastal Current (EACC) and the south-flowing Mozambique Current (MC, Fig. 1b). The velocity of the EACC is influenced by a strong seasonal monsoon winds (Beal et al., 2013), which can reach a velocity of up to 2 m/s and less than 0.2 m/s during the southeast and northeast monsoon, respectively (Newell, 1957). The EACC moves away from the coast near 3°S and combines with the southward flowing Somali Current (SC) to form the Equatorial Counter current (ECC, Fig. 1b) during the northeast monsoon (Kohn and Zonneveld, 2010).

East African coast is fed by several major rivers (e.g., Pangani, Rufiji, and Ruvuma Rivers; Fig. 1b) and numerous minor rivers (Shaghude, 2007). Specific to our research location, the major sediment discharge comes from the Rufiji River draining the rift mountains in East Africa. The discharge of the Rufiji River has been estimated with a sediment yield of 95 t/km^2/yr to the present day (Milliman and Syvitski, 1992). In the Rufiji deltaic sediments, the banks of distributaries are mostly composed of mud, but some southern distributaries banks consist of clean sands which are transported by the Rufiji River to the western Indian Ocean (WIO) (Punwong et al., 2013). The coastal plain of Tanzania is part of the south-eastern branch of the East African rift system (Chorowicz, 2005), so tectonic activity of the East African Rift also plays a key role in sediment delivery to the deep sea.

2.3. Climate changes during the last deglaciation and the Holocene

In tropical Africa, north of 8–9°S, the Last Glacial Maximum (LGM; Fig. 2) was cooler and drier than today (Gasse, 2000). The glacial to Holocene increase in monsoonal precipitation is primarily related to precessional summer insolation in the Northern Hemisphere (Kutzbach and Street-Perrott, 1985; Gasse et al., 2008), or a seasonal insolation contrast between the Northern and Southern hemispheres (Verschuren et al., 2009; Berke et al., 2012).

The wet phase during the early and mid- Holocene (African Humid Period: AHP) was driven by increased low-latitude summer insolation (deMenocal et al., 2000; Kröpelin et al., 2008). The AHP was caused by strengthening of the African monsoon in North Africa (Fig. 2c), or increases in precipitation during the dry summer season and a reduction in precipitation seasonality in East Africa (Barker et al., 2011; Tierney et al., 2011). However, when the Northern Hemisphere was relatively cold (Fig. 2a), such as during the Younger Dryas (YD: ~12.8–11.5 ka; Barker et al., 2009) and Heinrich Stadial 1 (HS1: ~18–14.6 ka; Barker et al., 2009), high-latitude forcing may have dominated the humid and arid phases in this area by controlling the strength of the Atlantic Meridional Overturning Circulation (AMOC). The AMOC was weakened during these cold periods (Fig. 2b), and the southward migration of ITCZ resulted in arid conditions in equatorial and northern tropical