

## Letter Section

# Discovery of a giant deep-sea valley in the Indian Ocean, off eastern Africa: The Tanzania channel

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## ABSTRACT

During the *FanIndien* 2006 cruise of *R/V 'Beautemps-Beaupré'*, high resolution multibeam bathymetry, sub-bottom profiling and sediment coring was carried out along the East African margin, offshore Tanzania and Mozambique (Indian Ocean). The newly acquired data reveal the presence of a giant deep-sea valley (the Tanzania channel) that is more than 10 km wide at 4000 m water depth, along the continental rise. The valley remains ~70 m deep and 7 km wide at 800 km from the Tanzania coast. Morphological comparison with worldwide submarine channels show that the Tanzania channel is one of the largest known submarine valleys. This discovery brings new light on development of submarine valleys that drain sediments originated from the East African Rift System (EARS) highlands (i.e. the Tanzania channel and its neighbor Zambezi channel located ~1000 km southward). Both of the systems have a morphology markedly different to the classical sinuous, V-shaped channels located at similar latitudes (e.g. the Zaire or Amazon channels). Their submarine drainage system consists of a downslope converging tributary canyons joining a central trunk channel in the continental rise. The presence of such giant deep-sea drainage systems is probably linked to a strong structural control on the sediment pathway, associated to a massive sediment transfer towards the Indian Ocean in relation with the tectonic activity of the East African Rift System (i.e. the uplift periods trough mid-Miocene and Plio-Pleistocene times) and its interplay with the East African equatorial climate changes.

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## 1. Introduction

The importance of submarine channels as preferred pathways for sediment transfer from the continents to deep-water environments has been recognized since the 1950's and the first discoveries of large deep-sea turbidite systems, e.g. the Amazon, Zaire, NAMOC systems and many more (Hesse et al., 1987; Flood et al., 1991; Piper and Normark, 2001; Babonneau et al., 2002). Although their morphology and internal architecture has been intensively studied since they are considered as important targets for oil exploration (Wynn et al., 2007), many recent works have also proved that the record of sediment flux to deep water turbidite systems can provide high resolution records of the land climate, sea-level changes and tectonics that affect the source area (Flood and Piper, 1997; Hesse and Khodabakhsh, 1998; Baztan et al., 2005; Maslin et al., 2005; Zühlendorf et al., 2007; Piper et al., 2007; Toucanne et al., 2008). During the last few decades, many deep-sea research projects have focused on the west and northwest African

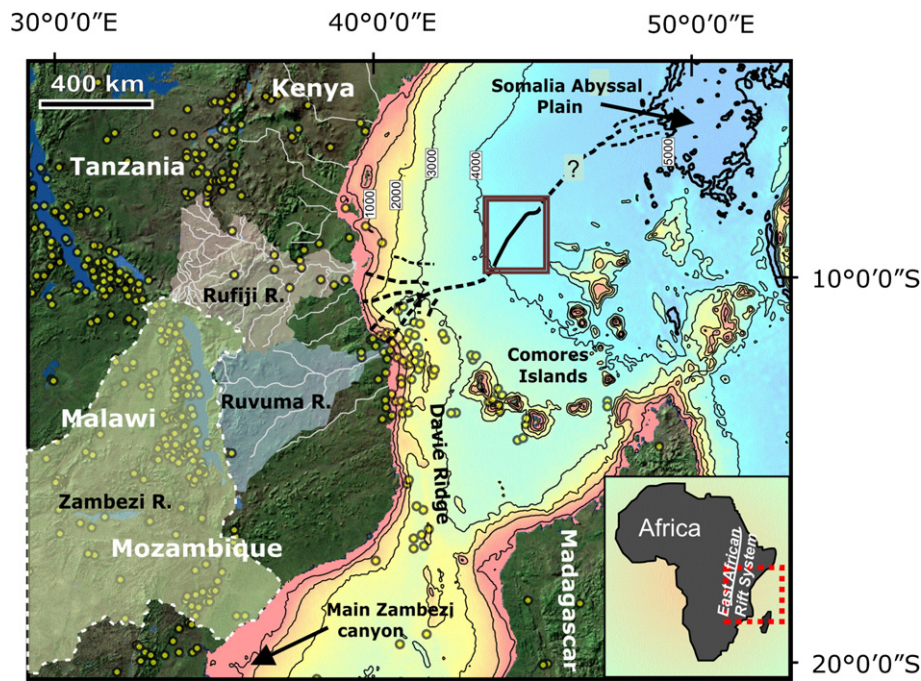
margins, of major interest for both the petroleum industry and academia (Wynn et al., 2000; Babonneau et al., 2002; Saugy and Eyer, 2003; Antobreh and Krastel, 2006). The eastern African margin, however, remains very poorly studied. The recent *FanIndien* explorative cruise (*R/V Beautemps-Baupré*, SHOM, 2006) crossed the western Indian Ocean from the Ormuz Strait (Gulf of Oman) to the Mozambique Strait. During this survey, a giant submarine valley (more than 10 km wide) was discovered offshore Tanzania (Fig. 1). Using EM120 multi-beam bathymetry and imagery, high resolution 2D seismic and piston coring, the Tanzania channel could be described in detail along the 260 km of survey. Here we present the first results concerning its morphology between 4000 and 4500 m water depth.

## 2. Regional setting

The eastern African margin formed during the break-up of Gondwana and relative drifting of the Africa and Madagascar continental blocks during Mesozoic and Cenozoic times (Salman and Abdula, 1995). The formation of the Indian Ocean at the end of the Mesozoic induced the creation of several marginal sedimentary basins,

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**Fig. 1.** Location map of the study area. Bathymetry data is from the ETOPO2 bathy charts. Bathymetric contours are in meters. The Somalia Abyssal plain is defined by the  $\sim 5000$  m contour. Onshore topography is derived from the NASA Shuttle Radar Topography Mission elevation model (<http://www2.jpl.nasa.gov/srtm/index.html>). Location of the main rivers (solid white lines) along the East African margin and localization of the Rufiji (shaded grey), Ruvuma (shaded blue), and Zambezi (shaded light green) rivers watersheds. Dashed line indicates the proximal and distal supposed trajectory of the Tanzania channel. Solid line indicates the position of the Tanzania channel along the 260 km of survey. Yellow circles indicate recent earthquake distribution in the area (Chorowicz, 2005). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

which finally formed the single system of the East African marginal sedimentary basin after the Late Cretaceous. The coastal plain of Tanzania and the Davie submarine ridge (Fig. 1) are also part of the south-eastern branch of the East African rift system (Chorowicz, 2005). At present day, the East African rift system is still propagating southward (Fig. 1), inducing consequent seismic activity (Fairhead and Stuart, 1982; Chorowicz, 2005).

The Tanzania continental shelf is very narrow (from 3 to 10 km), except off the Rufiji delta where it extends on more than 40 km. The upper continental slope develops from  $\sim 100$  m to  $\sim 2500$  m, with average slope values of  $1.5$  to  $2^\circ$ , that locally steepen to more than  $4.5^\circ$ . From  $\sim 2500$  to  $\sim 4000$  m the lower slope develops with gentler gradients ( $\sim 0.25^\circ$ ). Then the slope passes to the continental rise (with an average slope of  $\sim 0.08^\circ$ ) and finally reaches the Somalia abyssal plain down to 5000 m water depth.

The Tanzania channel is located basinward of a large drainage system, mainly composed by the Rufiji river ( $180,000$  km<sup>2</sup> drainage basin), the Ruvuma river ( $163,500$  km<sup>2</sup>), and smaller rivers (Fig. 1). Both the Rufiji and Ruvuma rivers mouth are constituted by large deltas extending over more than  $1400$  km<sup>2</sup>. The regional climate is controlled by the seasonal variability of the intertropical convergence zone (ITCZ), which brings rains during one single season corresponding to the austral summer (months of November–April) with prevailing NE monsoon associated with a southern position of the ITCZ (Gasse, 2000). The dry and windy season occurs in winter months (from May to October), when the region experiences a complete reversal in wind direction and stronger SE monsoon winds prevail. Cyclones are also a common regional feature, occurring generally during the months of January to March.

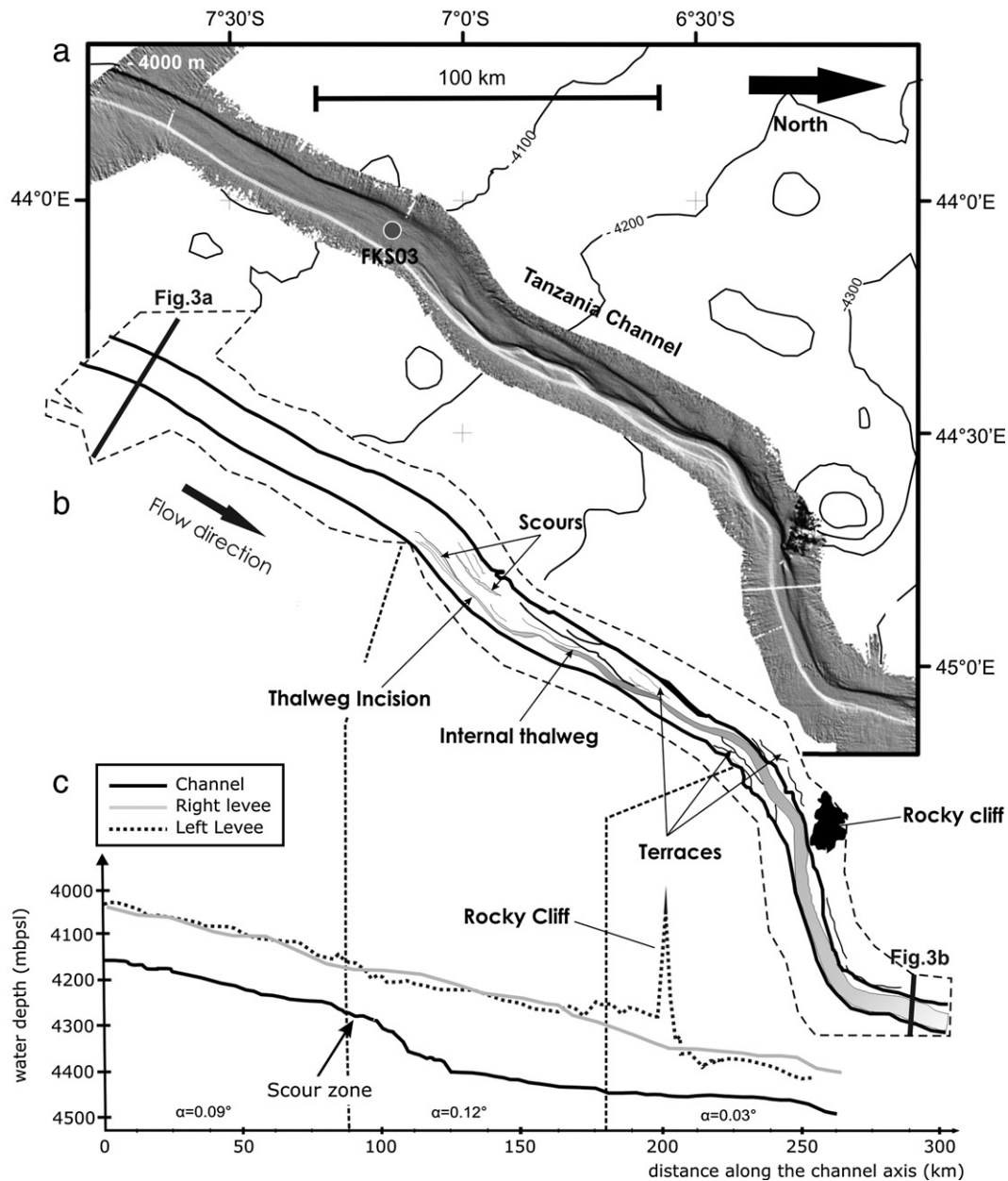
### 3. Results and discussion

Bathymetry and acoustic imagery were collected using the multi-beam echosounder SIMRAD EM120 (12 kHz). Sub-bottom seismic lines were collected using the SBP 120 profiler, which offers deeper

penetration and higher resolution ( $\sim 1$  m) than conventional sub-bottom systems, with sweep frequencies between 2, 5 and 7 kHz.

The data acquired between 4000 and 4500 m water depth show that the Tanzania channel is characterized by a rectilinear course (Fig. 2). A higher sinuosity is only observed where a rocky sea mount deflects the channel course (Fig. 2). At 4000 m water depth, the Tanzania channel is a relatively flat bottomed valley up to 12 km wide and  $\sim 100$  m deep, with steep walls (max.  $15^\circ$ ), that develops along a very gentle slope ( $0.09^\circ$ , Fig. 2). Down-flank mass transport deposits (Fig. 3a) are observed, as well as small scour-like features (or internal channels), suggesting that erosion and by-pass dominate. The 100 m high levees are symmetrical, showing parallel, low amplitude to transparent acoustic facies (Fig. 3a), and large scale sediment waves that suggest overflow of the finest part of the channelled flows. However, it is also possible for sediment waves to be formed by bottom currents and sedimentological data would be needed to confirm the dominance of turbidity current processes on the channel flanks. Between 4100 to 4300 m water depth, the Tanzania channel floor is marked by an abrupt break of slope (reaching a maximum of  $0.23^\circ$ ), associated with a deflection in the channel course (Fig. 2). Detailed bathymetry data show large and elongated incisions in the channel floor (scours): the largest one borders the right flank of the channel (Fig. 2). Downstream, this scour enlarges and forms a central thalweg, associated with the onset of an asymmetrical morphology and the development of internal terraces. In the third channel section, the slope values decrease to  $0.03^\circ$  and the internal thalweg deepens and migrates laterally. The Tanzania channel course is then deflected by a 500 m high and 30 km long rocky mound (Fig. 2). Downstream, the internal channel becomes large enough to join both levees and to form a unique U-shaped, 5–7 km wide and 60–70 m deep valley (Figs. 2 and 3b). The flanks are steep, bordered by levees associated with low amplitude to transparent drape-like facies and sediment waves (Fig. 3b).

Our data do not cover the proximal and distal part of the Tanzania channel. However, the more recent bathymetric charts from ETOPO2



**Fig. 2.** a) Shaded bathymetry (EM12) of the Tanzania channel between 4000 and 4500 m water depth; bathymetry contour from the ETOPO2 database (in meters); b) Interpretative cartoon with the main morphological features, positions of the two Sbp120 seismic lines (Fig. 3) and the FKS03 piston core (black circle); c) Slope profile plotted in the channel axis and along both right and left levees. Water depth is in meters below present sea level (mbpsl). Dashed vertical lines delimit the three morphological sections that have been determined based on average slope changes and general morphology. Average slope values for the three sections are indicated. Note the break of slope only observed in the channel axis. The presence of the rocky seamount is well observed along the left levee.

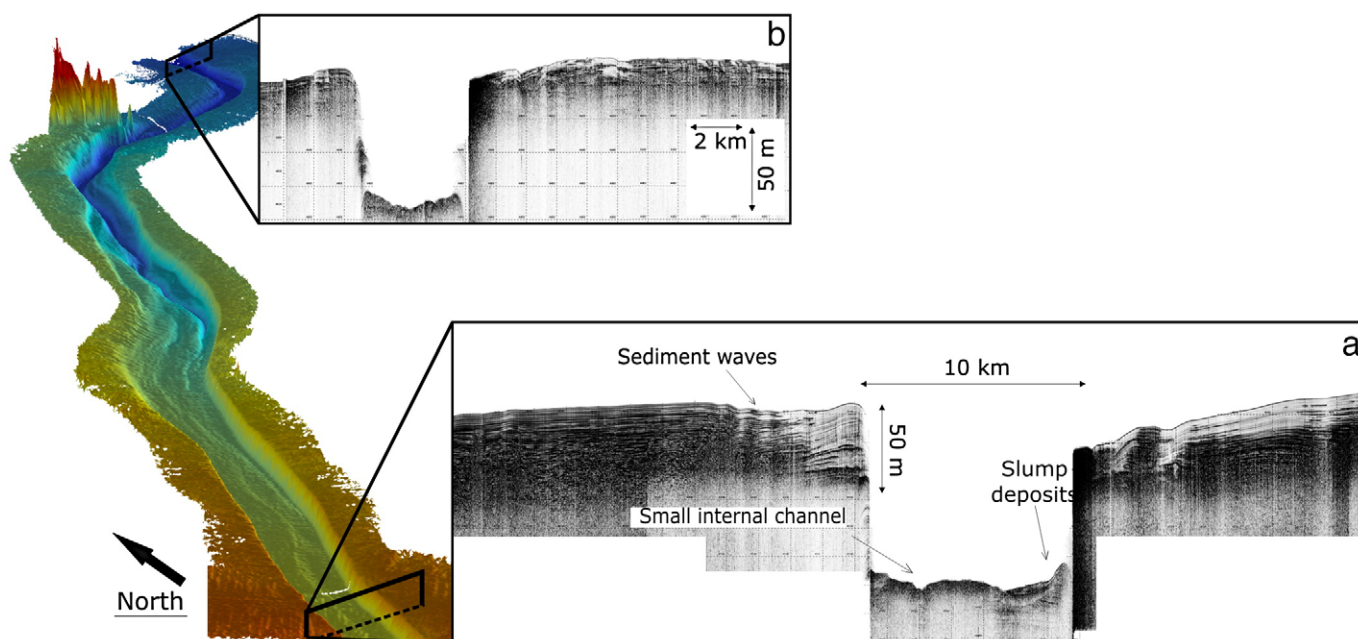
data show that the Tanzania channel is probably connected to a tributary canyon network (Fig. 1) that develop between a northern source off the actual Rufiji delta and a southern source off the Ruvuma river (Fig. 1). Distally, its basinward development is directly limited by the north–southward trending sea mounts delimiting the Somalia abyssal plain (Fig. 1), but the total system length could exceed 1000 km (Fig. 1).

Core FKS03 was recovered from the channel floor (Fig. 2). It is mainly composed of coarse grained sandy beds (mean grain sizes vary from 150  $\mu\text{m}$  to 365  $\mu\text{m}$ , Fig. 4) that commonly show planar lamination and are vertically stacked through a sharp or slightly erosional contact (Fig. 4). The beds are found massive or slightly normally graded, suggesting a deposition by concentrated density currents and/or turbidity currents (Mulder and Alexander, 2001). The top of the core is constituted by thick, slightly bioturbated hemipelagic mud (Fig. 4).

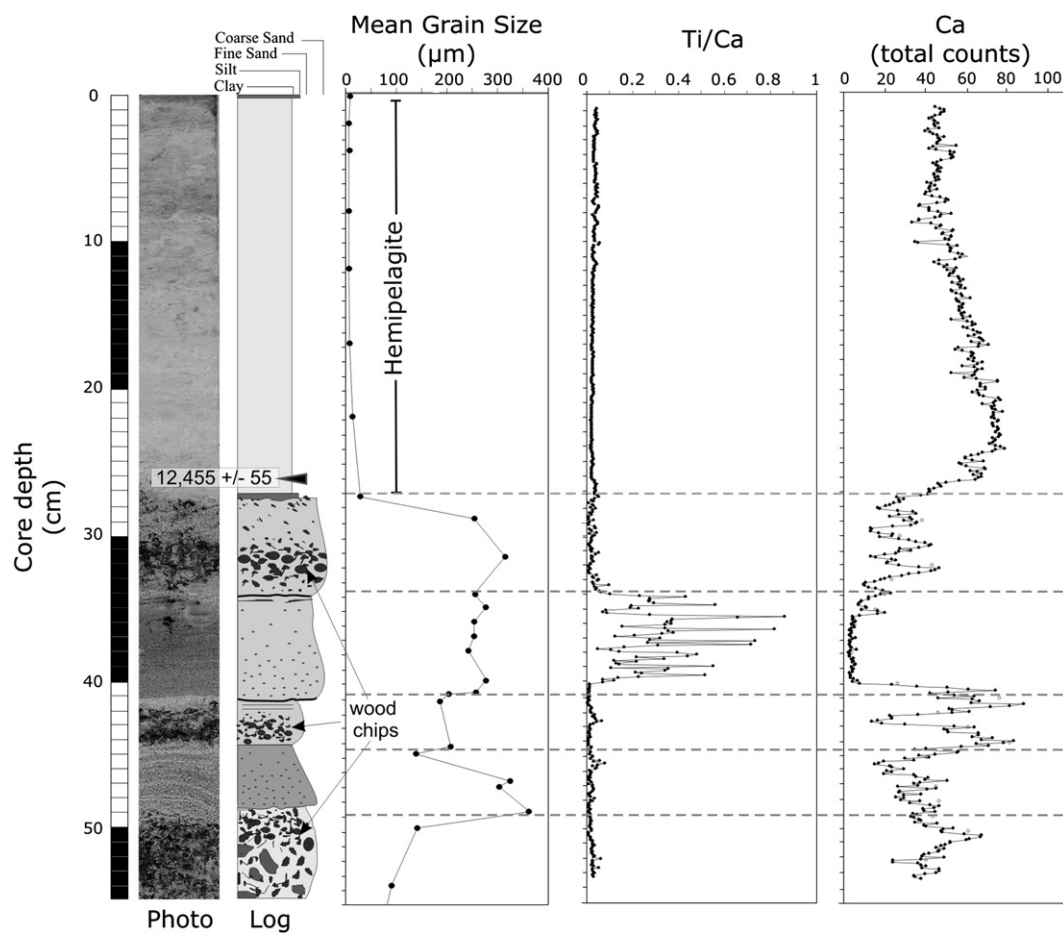
Petrographical analysis and geochemical parameters measurements using millimeter-scale XRF analysis (Richter et al., 2006; Fig. 4) show that the sandy beds have a variable composition, i.e. foraminifer-rich turbidites (with high Ca content), detrital-rich sands (with abundant quartz and mica and high Ti/Ca ratio), and mixed deposits with abundant organic matter mainly composed of large wood fragments (Fig. 4). This variability may indicate several sources of re-worked material for the gravity flows, although more data is required to detect the potential source areas.

Accelerator-mass-spectrometry (AMS) radiocarbon dating has been undertaken in hemipelagic beds immediately overlying the uppermost turbidite deposits (planktonic foraminifera *Globorotalia menardii* were separated from the >150  $\mu\text{m}$  fraction). The sample provides an age of 12,455  $\pm$  45 years (uncalibrated), that yields an approximate age for the last turbidite activity in the Tanzania channel.





**Fig. 3.** 3D shaded bathymetry of the Tanzania channel along the 260 km of survey and SbP120 seismic at  $-4000$  m depth (a) and  $-4500$  m (b). Note the wide and deep flat-bottomed morphology of the channel upward and downward the incision zone (with initiation of a deep sinuous internal thalweg associated with terraces). Note also the rocky seamount that diverts the channel course.

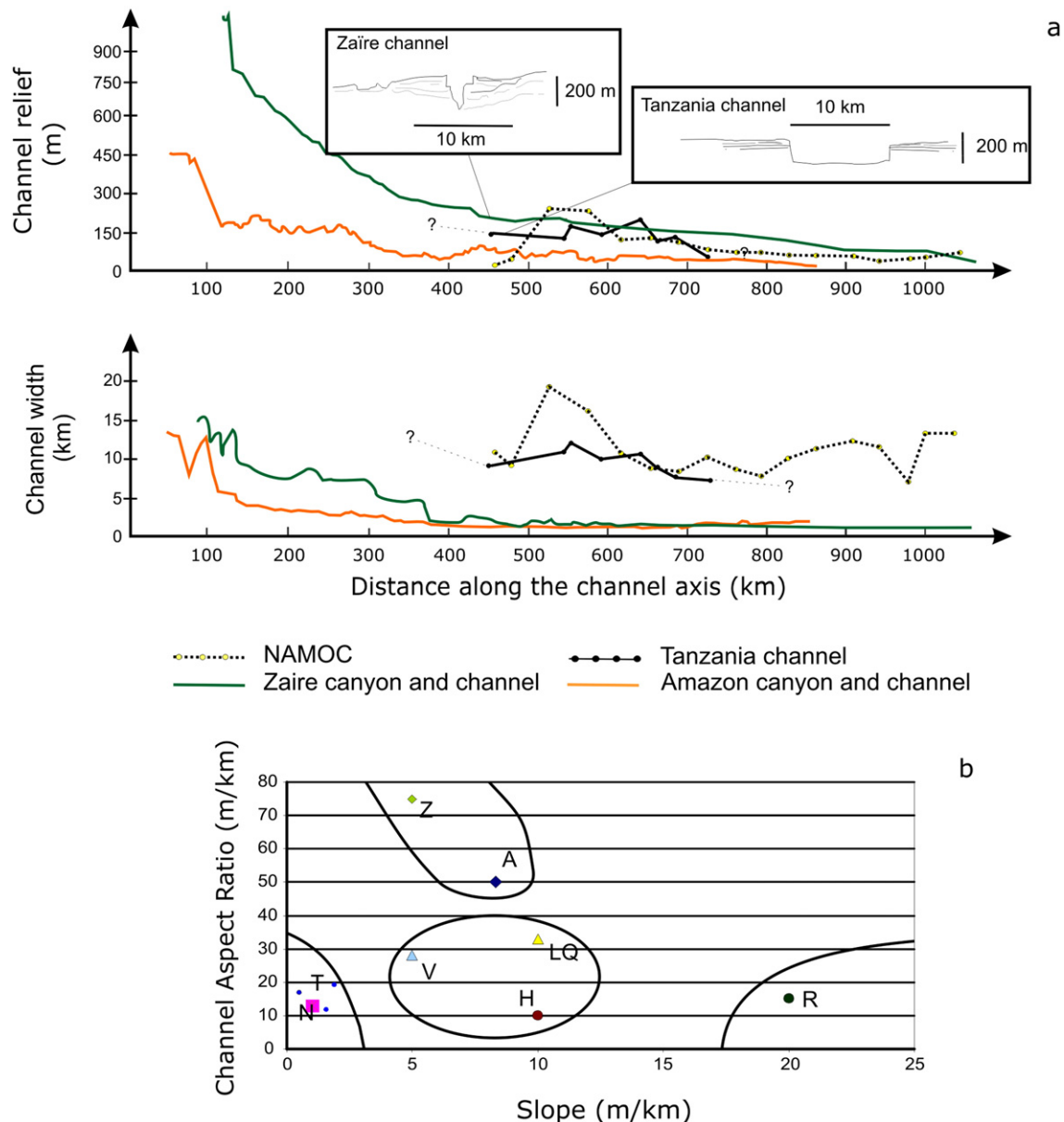


**Fig. 4.** Photography, graphic log, mean grain size ( $\mu\text{m}$ ), Ti/Ca and Ca content (total counts) of the core FKS03, recovered in the channel floor (see location in Fig. 2). XRF data (semi quantitative measurements) have been obtained from the Avaatech XRF scanner (Richter et al., 2006). Black arrow indicates the position of the hemipelagic/pelagic clay sampled for AMS-radiocarbon dating (see text for more details) and the age obtained (uncalibrated age).

This age corresponds to the period of postglacial sea level rise (Fairbanks, 1989; Siddall et al., 2003), commonly associated to sub-aerial delta development and sediment storage onto the shelf (Posamentier and Vail, 1989). Hence, this period corresponds to a decrease in sediment input and the end of turbidite activity in many turbidite systems, including the Indus and Zambezi fan in the Indian Ocean (Kolla et al., 1980; Prins and Postma, 2000).

The Tanzania channel morphology has been compared with the best known deep water turbidite systems (Fig. 5a). For similar water depths, it appears clearly that the Tanzania channel differs from point source submarine channels such as the Amazon or Zaire channels that are typically V-shaped (mixed erosional and depositional), and have a meandering shape similar to subaerial rivers (Pirmez and Flood, 1995; Peakall et al., 2000; Babonneau et al., 2002; Wynn et al., 2007; Fig. 5a).

In addition, the deep and wide morphology of the Tanzania channel show similarities with the Northwest Atlantic Mid-Ocean Channel (NAMOC), which is the longest (3800 km long) and widest deep-sea channel in the world, located in the Labrador Sea (Hesse et al., 1987; Hesse and Rakofsky, 1992; Klauke et al., 1998). These similarities become even clearer when using the classification method developed by Skene and Piper (2006) based on the plot of the downchannel slope gradient versus the channel aspect ratio (Fig. 5b). Hence, grouping of the points for the Tanzania channel parameters is very close to those corresponding to the NAMOC, i.e. they are both mostly rectilinear and develop along very gentle slopes. Even more remarkable is the presence of the Zambezi submarine valley, located only 1000 km south from the Rufiji delta, which develops over 1800 km along the Indian Ocean (Kolla et al., 1980; Droz and Mougnot, 1987; Fig. 1). It is



**Fig. 5.** Comparison of the Tanzania channel with some of the most studied deep-sea turbidite channels. a) Channel relief (average depth calculated from the bottom to the average height of the levees crest) and channel width (distance between the levees crest) plotted as function of the distance along the channel axis. Data from the Tanzania channel has been calculated at eight locations along the 260 km of survey. They are compared with the data from the Zaire channel (Babonneau et al., 2002), the Amazon channel (Pirmez and Flood, 1995), and the NAMOC channel (Hesse et al., 1987). b) Classification method developed by Skene and Piper (2006): plot of the channels aspect ratio (e.g. channel depth (m) / channel width (km)) versus the average slope gradient (m/km) calculated along the channel floor. Data from the Tanzania channel have been calculated from 5 profiles for each of the three morphology sections (see Fig. 2). Data from other systems e.g. the NAMOC (N), the Zaire channel (Z), Amazon channel (A), Var channel (V), the Laurentian Quaternary Channel (LQ), the Hueneme channel (H), and the Reserve fan (R) are obtained from Skene and Piper (2006).

also characterized by a wide, mostly rectilinear “trunk-channel” morphology, similar to the NAMOC or Tanzania channels.

The occurrence of such giant deep-sea valleys along equatorial passive margins is unusual, considering other deep-sea systems located at same latitudes and hydroclimatic settings (e.g. the Amazon or Zaire fan; Fig. 5). The NAMOC development was largely controlled by successive melting of continental ice-sheets that fed glacial ice-streams delivering very large amounts of glacial material basinward (Hesse et al., 1997, 1999). Such basin drainage is characterized by huge volumes of sediment yield (Andrews and Syvitski, 1994). However, the sediment yield related to the present day Rufiji has been estimated to 95 t/km<sup>2</sup>/yr (Milliman and Syvitski, 1992). This value is equal or slightly larger than values calculated for the Zaire, Danube, Mississippi, or Nile rivers, and is also similar to those from the Zambezi River (Milliman and Syvitski, 1992). Hence, the present day values of sediment input into both the Zambezi and Tanzania systems cannot explain their unusually large development (i.e. “ice-sheet-fed” like morphology).

From the data available, the Tanzania channel is clearly “multi-sourced” (Fig. 1), i.e. several distributaries join the central valley in the continental rise. Similarly, the Zambezi valley is fed by a large network of distributaries (including canyons located off the Zambezi delta but also from the Madagascar continental slope). Furthermore, the Zambezi turbidite system is highly structurally controlled, as expected for the Tanzania channel system (i.e. both systems are flanked by morphological barriers such as the Davie Ridge and islands). The observation of sea-mounts bordering the flanks of the Tanzania channel (Figs. 1 and 2) is additional evidence of the probable structural control on the sediment pathway. Although of lesser extent, both the Tanzania and Zambezi systems have similarities with high-latitude turbidite systems such as the NAMOC, which submarine drainage system consists of downslope converging tributary canyons joining a central trunk channel, and that is also basement controlled and constrained by sea mounts (Hesse and Rakofsky, 1992). Hence, such giant valleys are composed of a multi-sourced, migrating upstream part and a stable, single downstream part (Droz and Mougenot, 1987; Hesse, 1989; Escutia et al., 2000). Inversely, the V-shaped, high sinuosity channels such as the Zaire, Cap Timiris, or Angola channels (Wynn et al., 2007) are “point-sourced” systems, with a stable upstream part and a divergent, migrating downstream part.

The multi-source character of the feeder system and a strong structural control on the sediment pathway, probably associated to a large volume of sediment transferred, are likely to generate wide and stable, mostly ‘rectilinear’ valleys that develop along low gradient abyssal plains. Thus, occurrence of multi-sourced, giant turbidite valleys is not restricted to high-latitude, glacially-fed systems but may also occur at low-latitudes in tectonically active areas where a strong structural control highly confined the sediment pathways.

Both the Tanzania and Zambezi channels are sediment-fed by basin catchments that drain the East African Rift System highlands (Fig. 1). Droz and Mougenot (1987) showed that in the Zambezi case, the upstream migration and activation of the feeder system and the sediment infilling history were closely related to the East African Rift development. Hence it is likely that the Tanzania turbidite system development is similarly linked to the tectonic history of the EARS. Indeed, the development of the Zambezi valley in the middle Miocene (Droz and Mougenot, 1987) is synchronous with intense canyon incision off the Ruvuma delta (Walford et al., 2005), that has been attributed to a period of important increase in erosion and sediment supply to the Indian Ocean, in response to the uplift of the Tanzania craton and the East African Rift (Foster et al., 1997; Walford et al., 2005; Nicholas et al., 2007). The uplift phases of the East African Rift, that enhanced a huge transfer of sediment towards the East African marine basin, are likely to have contributed of the development of two giants, structurally-controlled turbidite valleys off East Africa.

#### 4. Conclusion

Preliminary results show that the Tanzania channel is one of the largest submarine valleys in the world. Comparison with other deep water systems drainage suggests that its development is linked to an efficient source and feeder system, a strong structural control on its morphology and frequent and/or large volumes of sediment supply. The latter is possibly related to the strong earthquake activity upslope (Fig. 1), close to the possible canyon head location. Ongoing acquisition of geophysical and sedimentological data will document the system in its entire length, and provide further insight into how this system has developed in the particular climatic and tectonic East African margin context.

Both the Tanzania channel and its neighbour the Zambezi valley are multi-sourced, ‘rectilinear’ giant channels, which morphology is markedly different to the classic high-sinuosity channels present at similar latitudes, e.g. the Zaire, Cap Timiris or Angola systems along the West African margin, or the Amazon channel in South America.

Furthermore, discovery of a second giant turbidite valley offshore East Africa supports the ideas of a direct link between the development of the East African Rift System, climate changes, and massive sediment load supply to the East African marine basin. Future investigations in the area will undoubtedly provide new perspectives on the timing and frequency of the last million year's basin filling and paleoenvironmental changes in East Africa.

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