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Mass-Transport Deposit In Deep Water Setting, Offshore Cameroon, West Africa

Anh Ngoc Le

Hanoi University of Mining and Geology, Vietnam

Corresponding author: lengocanh@humg.edu.vn
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Abstract - Mass-transport deposits (MTDs) have been analyzed over an area of 1,500 km^2 in the deep-water setting of West Africa, focusing on the Early Tertiary sequence using high resolution of 3D seismic data. Observed MTD is about 10 km wide and 20 km long, up to 140 m thick, on the high gradient slope of 3.4^o, extending from east to west. Internal seismic facies of the mass consist of extensional imbrication facies in the upslope area, thrusted facies downslope area. The MTD likely was triggered by a combination of mechanisms. Uplift in the Tertiary, dated at about 30 - 40 Ma, corresponding to the unconformity KS_5 may be the main reason that causes slope failure. Besides, possibly releasing gas from the gas hydrate stability zone may contribute to triggering mass-transport deposition in the study area.

Keywords: Mass-transport deposit (MTD), Tertiary, West Africa

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Introduction

Mass-transport deposit (MTD) occurrences involving large volumes of sediment are known across continental slopes worldwide, along active and passive margins, and volcanic islands (Masson, 1998; Collot *et al*., 2001; Canals *et al*., 2004; Astuti *et al*., 2019). MTD is being more systematically studied than in the past, because of hazards of mass failures of the continental slope and at deep-water drilling sites, as well as their significance in hydrocarbon exploration and development (Sutton and Mitchum, 2011). It includes a wide range of gravity-induced deposits, including slides, slumps, and debrites (Moscardelli *et al*., 2006). MTD processes, however, are still poorly understood because of their unapproachability, lack of samples, and general lack of knowledge of their detailed geometries and morphologies (Mosher and Campbell, 2011). High-quality 3D seismic reflection data, however, provide the necessary geometric and geomorphologic information needed for detailed interpretation of submarine mass movements (Posamentier and Kolla, 2003).

This paper describes a submarine mass-transport deposit from the western African Slope, offshore Cameroon, based on 3D seismic reflection data (Figure 1). This study will focus on the occurrence of MTDs of Early Tertiary age, as well as the morphology, internal reflection character, and triggering mechanisms of failure.

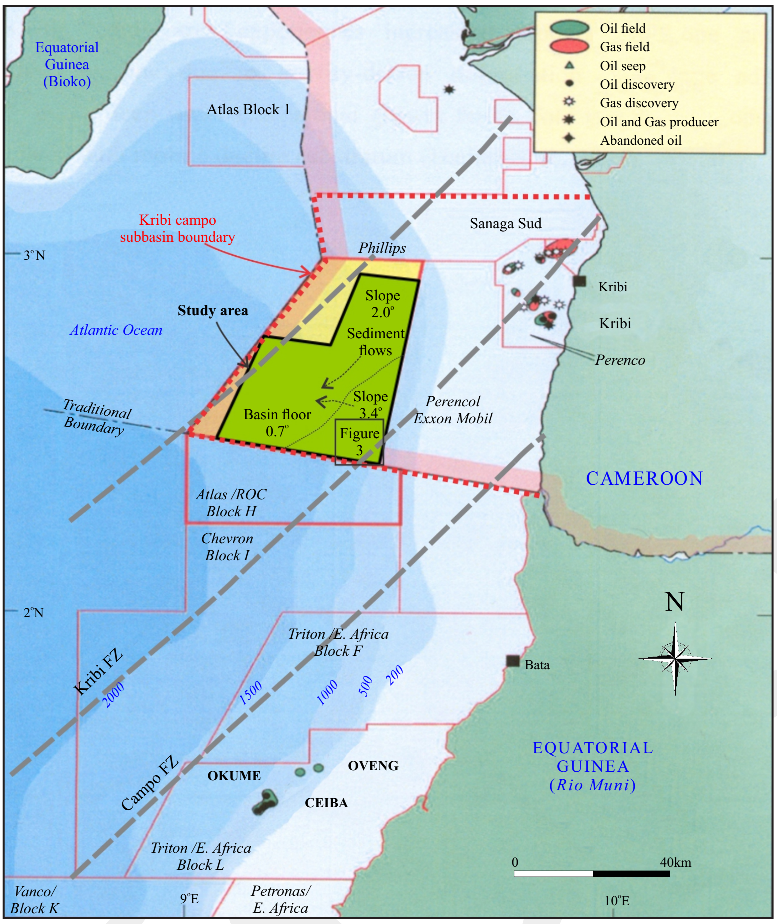

Figure 1. Location of the studied area in the water depth ranging from 600 - 1900 m (from internal reports of Sterling Energy Company).

Geological Setting

The Kribi-Campo Subbasin is located between 2°20'N and 3°20'N, and extends over 6,150 km^2 offshore and 45 km^2 in a triangular onshore area (Ntamak-Nida *et al*., 2010). The studied area is part of the offshore Kribi-Campo Subbasin, cover an area of 1,500 km^2, on deep-water ranging from 600 - 1900 m of the continental slope. The slope gradient varies from 3.4° associated with Kribi High in the SE to 0.7° in the deepest area. The seismic data contains a sedimentary section up to 6.5 km thick, ranging in age from Upper Cretaceous to present (Figure 2). This study focused on the deep section of Early Tertiary age in the interval of 3,500 – 5,000 ms TWT (Figure 3).

Kribi-Campo Subbasin is one of a series of Early to Mid-Cretaceous rift segments that underlie the Atlantic Coast of West Africa (Figure 1). The evolution of the basin can be divided into several phases, including the Albian-Aptian break-up unconformity (115 Ma), Santonian uplift (85 Ma), and resumed Eocene-Oligocene uplift (c. 45 Ma) (Figure 2) (Ntamak-Nida *et al*., 2010). During the Early Tertiary, relative sea-level fall resulted in slumping and collapse of shelf-slope sediments and deposition of mounds on the Rio-Muni basin floor (Dailly, 2000). The Palaeocene is absent in most of the wells on the Kribi-Campo shelf (Pauken, 1992). An intra-Miocene unconformity marks an incision surface, with the development of canyons cutting down into underlying sediments. It is overlain by a Plio-Pleistocene progradational shelf (Dailly, 2000). The Tertiary sequence comprises a series of marine mudstone-dominated sequences with interbedded sandstones and limestones (Dailly, 2000).

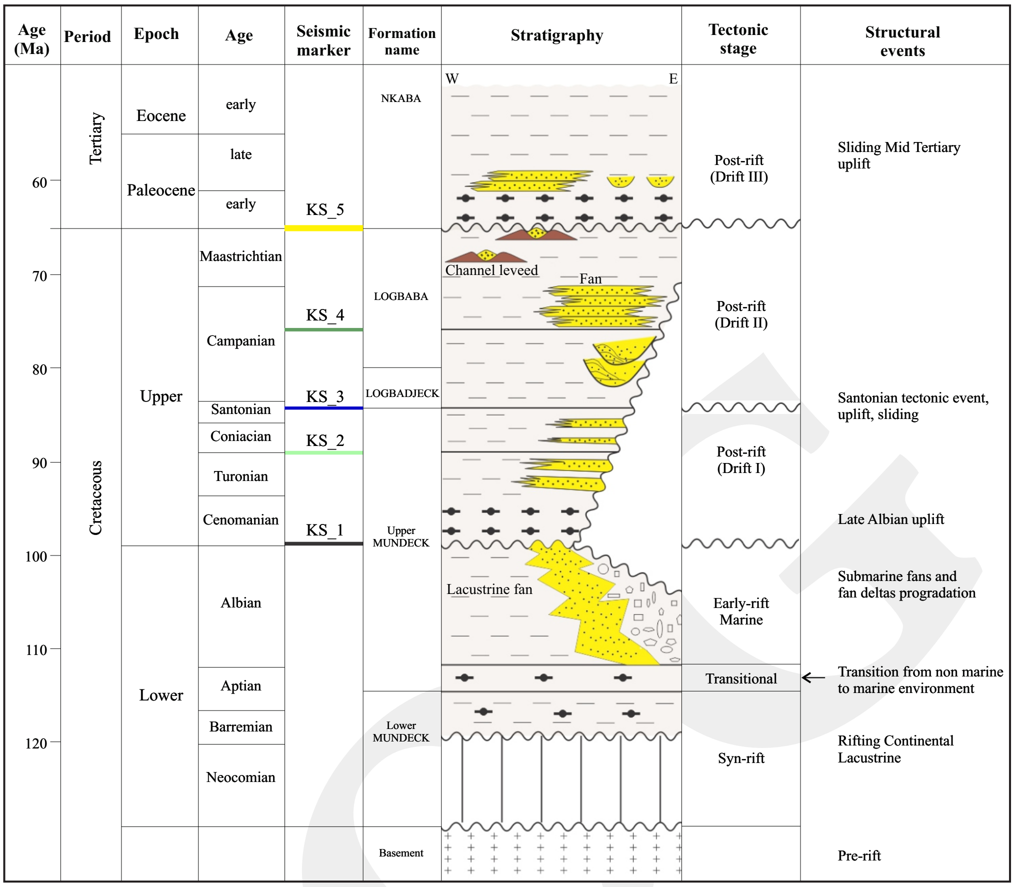

Figure 2. Stratigraphic column of the Cretaceous syn-rift to post-rift sequences based on this data and modified from Ntamak-Nida *et al*. (2010).

Data and Methodology

The studied area is located offshore Cameroon in the deep-water setting. The dataset is a 3D seismic volume which was acquired in a northeast-southwest orientation, covering an area of 1,500 km^2, with a bin spacing of 25 m and a total record length of 6.6 sTWT. The interval focused on this study is c. 1,000 ms corresponding to the Early Tertiary (Palaeocene to Eocene) sequence (Figure 3). The seismic data are displayed as a zero phase, SEG normal polarity, *i.e*., orange/brown peak indicating an increase in acoustic impedance.

The analysis of MTD was undertaken focusing on the seismic facies and the timing of the tectonic events that trigger the MTD. The 3D seismic data was interpreted using Schlumberger Petrel software. The thickness map of MTD has been generated combined with a series of attribute maps to visualize the MTD in the map view.

Results and Discussion

The base of the Tertiary sequence is marked by an unconformity KS_5, characterized as high amplitude and good continuity. Unconformity KS_5 is a major unconformity, marked the significant change in seismic facies from low frequency, continuous, high amplitude reflections below to high frequency, discontinuous, low to high amplitude reflections above. A package of imbricated to chaotic reflections is observed near the Kribi High, to the southeast of the studied area, with the length of c. 20 km and width of 10 km (Figure 3 and 4). Upslope region of this seismic facies is characterized as discontinuous reflection package, which is characterized by parallel, gently (1^{o} to 1.7^{o}) landward (upslope) dipping, reflections, separated by offsets of up to 27 m (Figure 4a). This is a series of small scale thrust imbricates (zone above the marker A) propagating basin-

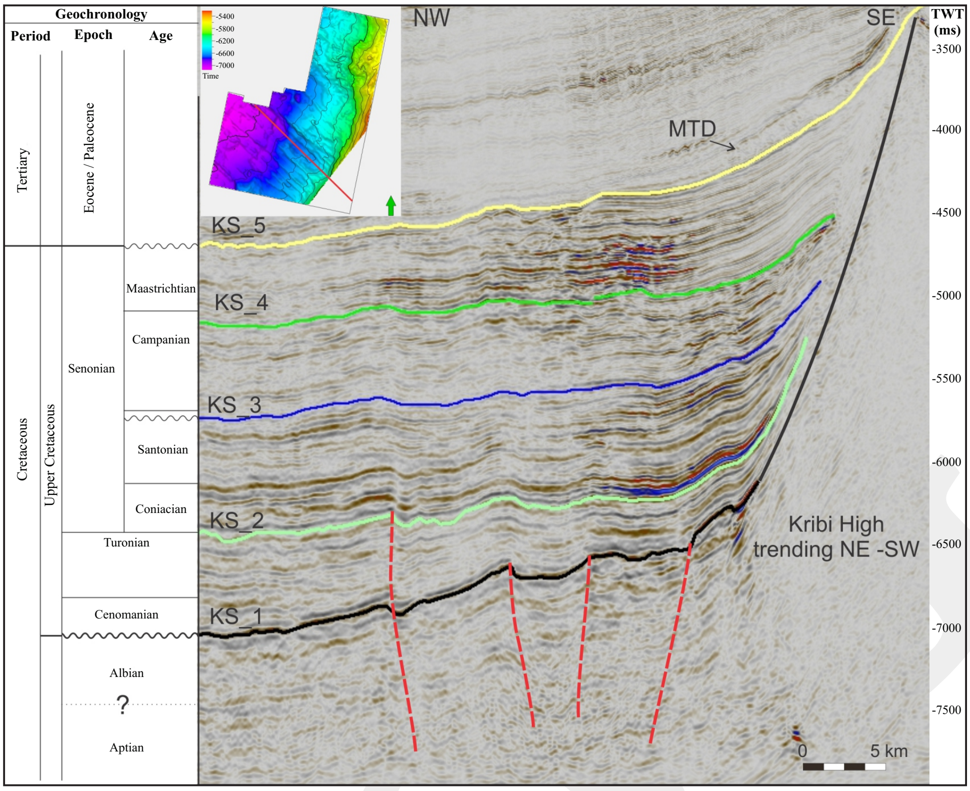

Figure 3. NW - SE seismic section. There are number of fault-related folds in the Upper Cretaceous. The Upper Cretaceous sequence is limited by the yellow horizon. Mass-transport deposit (MTD) was developed in the Early Tertiary age. The TWT map at the base Cretaceous sequence (black horizon) shows the seismic line location.

ward. The ending of this imbrication reflections is clearly observed on the variance attribute map (Figure 4b) with a shape contrast from high to low variance, approaching an area of c. 10 km in length and 6 km wide with a maximum thickness of 140 ms (Figure 4c). Downslope region, the seismic facies was changed to discontinuous, and low-amplitude reflection (zone above the marker B) is interpreted fine-grained debris flow deposits, which is pinchout and downlap on the KS_5 surface (zone above the marker C, Figure 4d). This seismic package is interpreted as mass-transport deposit (MTD). The imbricate thrusts are formed due to compression at the toe of MTD. The similar MTD feature has been observed in offshore Norway (Bull *et al.*, 2009). These authors have identified thrusts by *pressure ridges*, a surface expression of thrusts that are below the resolving power of data. Mass transport deposit facies has also been observed as submarine landslides offshore Angola (Gee *et al.*, 2006) and Brunei (Gee *et al.*, 2007).

MTDs form when shear stress oriented downslope exceeds the shear strength of the slope-forming materials (Hampton *et al.*, 1996). Therefore, slope failure can be the result of a downslope-oriented increase in shear stress, a reduction in sediment strength, or a combination of both (Lee *et al.*, 1991). Several factors of sea-level change, gas-hydrate destabilization, and rapid sedimentation of shelf-margin deltas can combine to cause slope instability.

In the studied area, there are a number of possible factors triggering the MTD. First, the third drift stage (Eocene - Pliocene) has been linked to late gravity sliding caused by uplift and sea-level fall in the Tertiary (Figure 2) (Dailly, 2000). The uplift and erosional unconformity are dated at about 30 - 40 Ma (Ntamak-Nida *et al.*, 2010), possibly corresponding to unconformity KS_5. The development of MTD locally on the KS_5, at high gradient slope, close to the Kribi High indicated for a period of re-activation of Kribi fracture zone (Figure 1) and sea-level fall

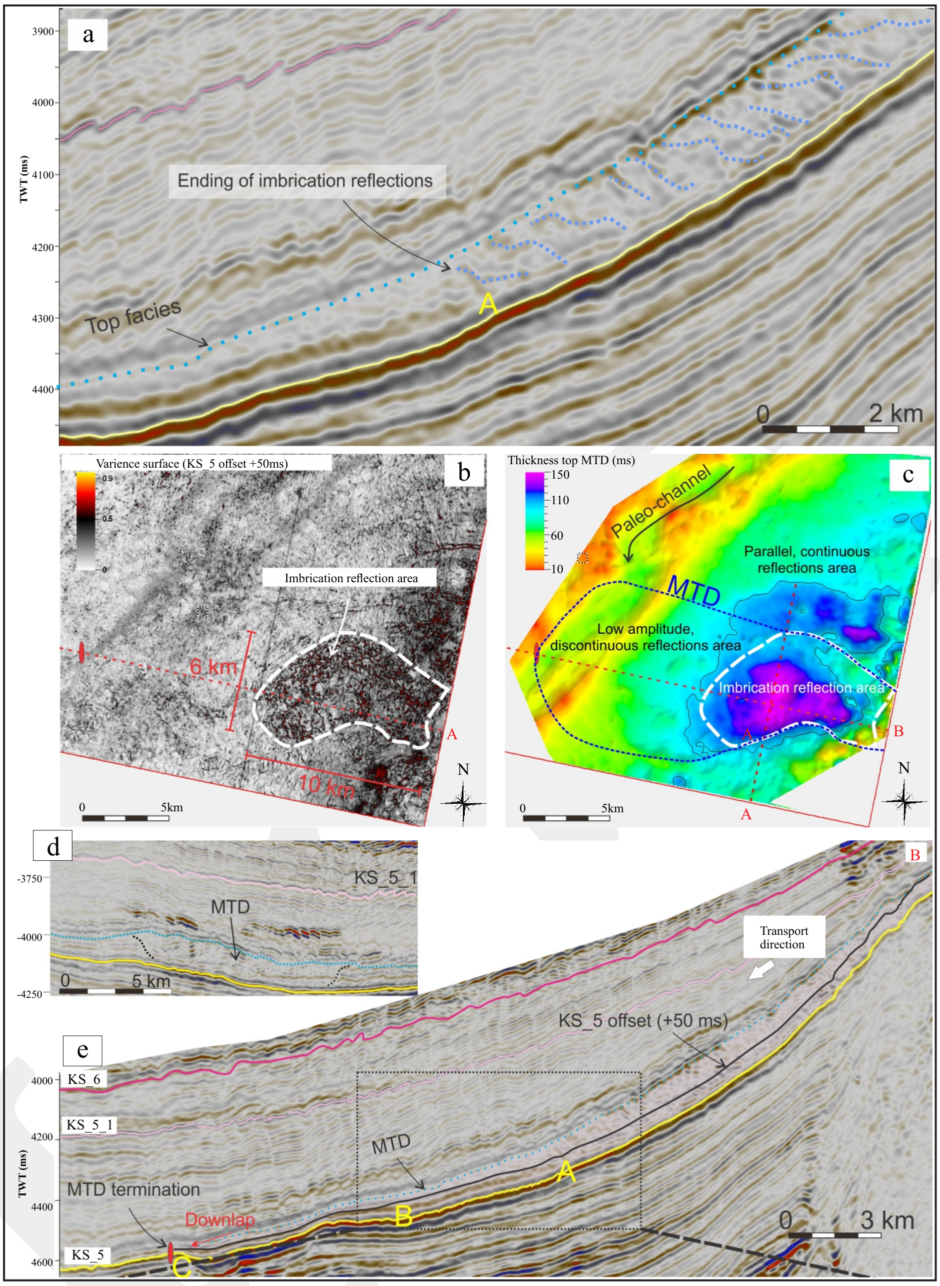

Figure 4. Mass-transport deposits detected in the high gradient slope to the east, within a highly faulted interval. (a) Variance map of KS_5 offset +50 ms highlighting the imbrication reflection area. This area has coincided with the thicker area in the thickness map between the top and the base of the MTD seismic facies (b). See the map location on Figure 1. (c) Cross-section of the MTD showing the wide limit of the MTD on the slope. (d) Dip seismic section along the MTD illustrates the MTD seismic facies detected just above the KS_5 surface. (e) Close up image to show the transition from imbrication reflections upslope to parallel reflection downslope.

results in slope instability. Besides, gas-hydrate destabilization may also cause slope failure. During this period, the area was in a shallow marine environment. It is difficult to predict precisely the area that has gas hydrate potential due to the deep burial sequences. To do that, there will be a lot of assumptions needed to be made that will affect the estimation results, such as paleo-temperature, seismic velocity, and gas component. According to Brownfield and Charpentier (2006), it seems that most of the Lower Mundeck source rock becomes mature prior to the Senonian uplift due to the thick overburden of the Upper Mundeck (Figure 2). Thus, the area may have sufficient thermogenic gas/biogenic gas to form gas hydrate if it satisfies the gas hydrate stability condition. The evidence of gas hydrate occurrence in the shallow section has been reported by Le *et al.* (2015) that supports the occurrence of gas hydrate in the studied area during the Early Tertiary time.

Conclusions

Mass-transport deposits have been observed in Early Tertiary, high gradient slope, associated with the Kribi High to the southeast. The MTD is c. 10 km in length and 6 km wide with a maximum thickness of 140 m. Internally, it comprises low to high amplitude reflections which are upslope dipping and abruptly end downslope. The development of MTD in the Early Tertiary has been linked to a period of slope instability that was caused by uplift in the Tertiary, dated at about 30 - 40 Ma, corresponding to the unconformity KS_5. Gas-hydrate destabilization may also cause the slope failure as, by this time, the source rock may have been matured to generate hydrocarbon to supply for the gas hydrate stability zone. Gas hydrate may be formed by both thermogenic gas and biogenic gas. To have a more precise answer to this, more analysis of the paleo-environment will need to be addressed.

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