INDONESIAN JOURNAL ON GEOSCIENCE
Geological Agency
Ministry of Energy and Mineral Resources

Journal homepage: http://ijog.geologi.esdm.go.id
ISSN 2355-9314, e-ISSN 2355-9306

Striations at The Base of The Paleo-Fan and Channel Revealed by 3D Seismic Data, Offshore Cameroon

Anh Ngoc Le

Hanoi University of Mining and Geology, Vietnam

Corresponding author: lengocanh@humg.edu.vn
Manuscript received: June, 09, 2020; revised: August, 28, 2020; approved: September 29, 2020; available online: March, 08, 2021

Abstract - The 3D seismic data, offshore Cameroon, reveal the evidence of a Pliocene fan and a channel with a series of striations at their base. The fan and channel developing in Early Pliocene, were characterized by high amplitude reflections with bi-directional downlap on the base of the Pliocene sequence, and interpreted to be deep-water sand-rich fan and channel. Pliocene channel flowed from east to west in the High Gradient Slope (HGS), whereas, the fan extended from NE to SW on the Low Gradient Slope (LGS). Individual striations have been imaged that are 20 - 50 m wide, c. 10 - 20 km long, and 4 - 8 m deep, trending NE - SW and E - W, slightly divergent patterns toward downslope. Striations are observed at the base of fan and channel suggesting the beginning of a period of unstable slope creating NE - SW slides in LGS and erosion in HGS. They were followed by the deposition of large scale fan deposits on the LGS and a series of parallel aggradational channels in the HGS. The striated unconformity at the base of the Pliocene sequence may be the result of a major tectonic uplift event or significant climate changes.

Keywords: deep-water fan, sand-rich fan, slope, divergent pattern

How to cite this article:
Le, A.N., 2021. Striations at The Base of The Paleo-Fan and Channel Revealed by 3D Seismic Data, Offshore Cameroon. *Indonesian Journal on Geoscience*, 8 (1), p.101-107. DOI: 10.17014/ijog.8.1.101-107

Introduction

Submarine landslides are common features of an ocean margin playing an important role in the evolution of the ocean margins (Gee *et al*., 2007). Those landslides are capable of transporting sediment across the whole width of the continental rise to the abyssal plain (Hampton *et al*., 1996). Some of the largest known submarine landslides involving hundreds to thousands of cubic kilometers of material have been documented on Atlantic margins, which extend for > 700 km, such as the Saharan Slide (Embley, 1976) and the Storegga Slide (Bugge *et al.,* 1988). Recent advances in three dimensional seismic techniques are allowing new insights into slope processes, improving our understanding of submarine landslide structure, flow mechanics, and triggering (Gee *et al*., 2006). The term 'landslide' is used as a general term to describe a slope failure with no implication of specific process or geological setting (Gee *et al*., 2007). Submarine slides are common in five environments: (1) fjords, (2) active river deltas, continental margins, (3) submarine canyon-fan systems, (4) open continental slope, and (5) oceanic volcanic islands (Hampton *et al*., 1996).

The study of landslide and debris flow revealed the presence of an extensive shear layer underlying more than 450 km of deposit, upon which the flow appeared to have gained enhanced run out (Masson *et al*., 1993; Gee *et al*., 2001). The mechanism of generation for this basal layer was speculated to have been erosion and shearing of the substrate by the overriding flow, resulting in the basal striations (Gee *et al*., 2006).

This paper describes a newly discovered Pliocene submarine fan and channels on the deep water slope of Cameroon (West Africa), using 3D seismic data. A detailed analysis of the paleo-submarine fan and channel is presented with insight into their striated bases and possible triggering processes.

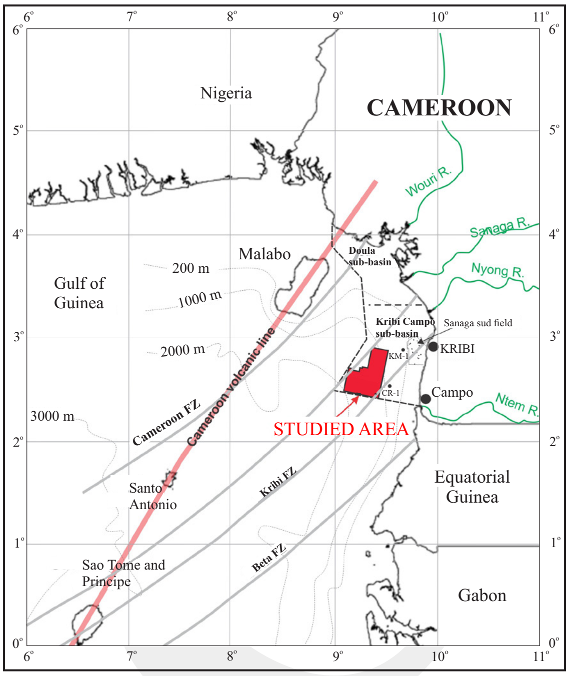

Figure 1. Bathymetry map of the continental slope on the Cameroon margin. It shows the location of the studied area, the two wells that have been drilled within the basin (Pauken, 1992), and the location of the fracture zone system (Hornbach *et al.,* 2008). The coastline and river system is extracted from the National Geophysical Data Centre (NGDC) (http://rimmer.ngdc.noaa.gov/mgg/coast/getcoast.html).

Geological Background

Located in Kribi-Campo Subbasin on the present day deep-water continental margin slope, the studied site covers an area of 1,500 km^2, and contains a sedimentary section of up to 6.5 km thick, ranging in the age from Upper Cretaceous to present (Figure 1). This study is focused on the shallow section, from Pliocene to Pleistocene. The area is divided into a High Gradient Slope (HGS) and Low Gradient Slope (LGS) based on slope gradient. The high gradient slope dips to the west (3.4^o to 1.6^o), associated with the Kribi High; whilst the low gradient slope (2^o to 0.7^o) dips southwest. These two geomorphic areas are separated by a line trending approximately NE - SW that varies slightly in location at different stratigraphic level, but retains the same trend (Figure 2).

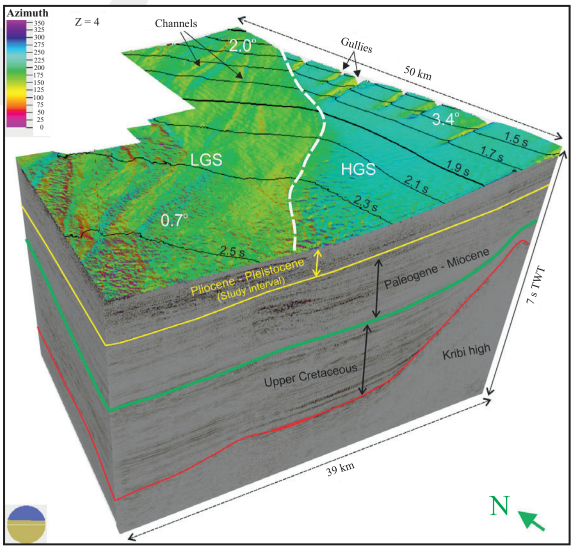

Figure 2. The figure showing a 3D view of the studied area, which is located in a water depth ranging from 1.4 to 2.6 s TWT. The slope area is divided into two slopes, a High Gradient Slope (HGS) dipping southeast (3.4^o down to 1.6^o) and a Low Gradient Slope (LGS) dipping west (2^o down to 0.7^o). The seafloor is imaged by an azimuth attribute map, showing a number of gullies derived from the east northeast. The basin fill sequence is divided into three mega sequences; Upper Cretaceous, Paleogene-Miocene, and Pliocene-Pleistocene (focus of this study).

The Kribi-Campo Subbasin is the northernmost of a series of salt basins on the West Africa margin. It is bounded to the east by Precambrian basement outcrops that occur close to the shoreline, whereas the southern margin is limited by the Kribi Fracture Zone (KFZ) (Figure 1), which separates the Kribi-Campo Subbasin from the Equatorial Guinea Rio-Muni Basin. The northwest limit of the basin is bounded by another fracture zone, and a further c. 100 km to the northwest is the Cameroon Volcanic Line (CVL), a NE–SW trending feature that extends onshore. The basin extends south offshore, across a shallow shelf into the deep water area of Equatorial Guinea.

The basin was initially a rift branch of the proto-Atlantic, which includes the Rio-Muni, North Gabon (West Africa), and Sergipe-Alagoas (Brazil) (Davison *et al*., 1997). During the later passive margin phase, the basin experienced several additional regional tectonic events resulting in inversion and folding in the Santonian, and gravity sliding during Early/Mid/Late Tertiary time. These events are marked by major unconformities including the Albian-Aptian break up unconformity (115 Ma), Middle Cretaceous (Santonian - ~ 85 Ma), Late Cretaceous (K/T boundary - ~ 70 Ma), and Mid-Oligocene (~ 30 Ma), Mid-Miocene (~ 15 Ma), and Late Tertiary event (~ 5.3 Ma) (Turner, 1995; Lawrence *et al*., 2002; Brownfield and Charpentier, 2006) (Figure 3).

Data and Methods

The data used for this study comprises a high-resolution 3D seismic dataset, covering an area of 1,500 km2 (Figures 1 and 2). It includes c. 1,581 inlines and 2,051 crosslines with a line spacing of 25 m, and a record time of 6.6 s TWT. The study interval ranges from Pliocene to Pleistocene in age. Standard seismic processing was applied to the data provided by Sterling Energy Company (and no further processing has been attempted as part of this study). The seismic data is zero-phase, and displayed in this study such as red, yellow or

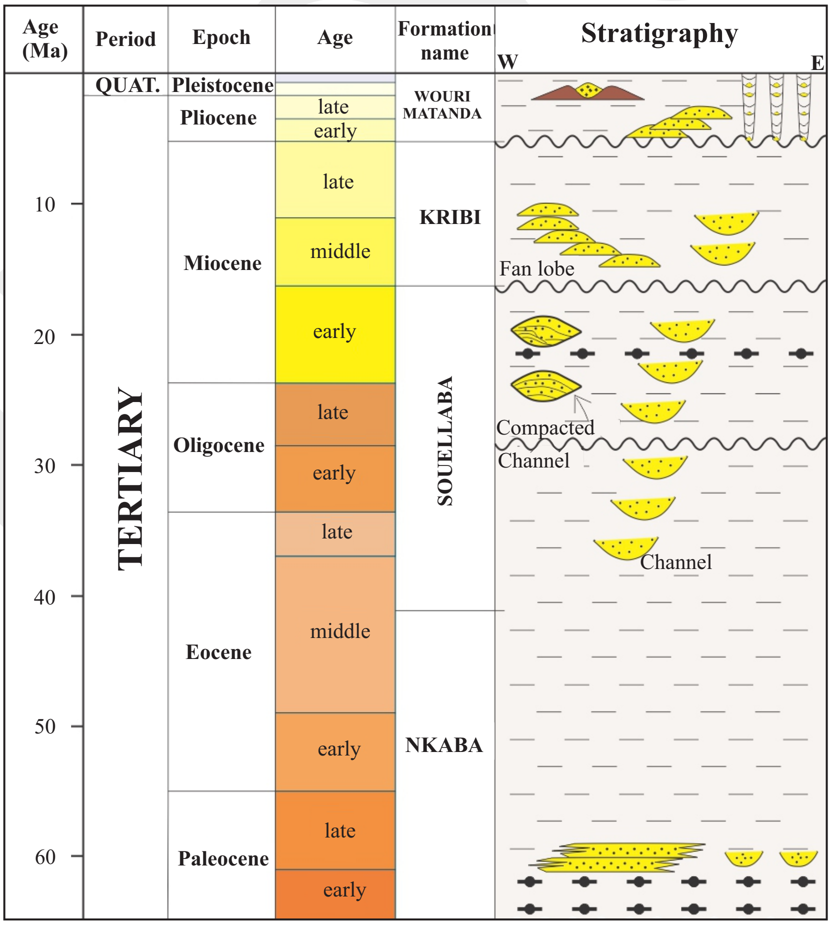

Figure 3. Basin stratigraphy from Paleocene to Pleistocen of Kribi-Cambo Basin. Stratigraphy of the basin is interpreted from 3D seismic data with the inference age from Gulf of Guinea and 2D seismic interpretation of Kribi-Cambo Basin (Lawrence *et al*., 2002; Iboum Kissaaka *et al*., 2016).

orange corresponds to positive polarity and light blue to negative polarity.

Due to the lack of well data in the basin, depth conversion assumes a similar lithological composition to the Rio-Muni Basin, and a Vp velocity of 1,850 m/s has been used for the Tertiary sediments (Turner, 1995). That velocity and the dominant frequency of 45 Hz in the Tertiary give a vertical resolution (λ/4) of ~10 m. The interpretation of the seismic data has primarily used the Schlumberger™ Petrel software. Interpretation has been carried out using a manually picked fine interpretation grid, then followed by auto-tracking where there is a good quality surface.

Analysis and Result

Striations are observed on the basal surface of the Pliocene sequence, on both the HGS and LGS (Figure 4). Individual striations can be imaged that are c. 50 m wide, c. 30 - 50 km long, and 5 - 30 ms TWT deep. Striations developed at the base of the NE-SW Pliocene fan (Figures 4a and b) and E-W trending channel (Figure 4c) (see more disciptions of the channel and fan in Le *et al.*, 2015).

Striations at Base of Pliocene Fan in The LGS

High amplitude reflections observed in Early Pliocene correspond to areas with increased thickness downslope. Its dimensions range from c. 2 - 15 km wide, 60 km long, and up to 250 ms TWT thick (Figure 4a). Internally, it is composed of low to high amplitude, continuous upward convex reflections, which bi-directional downlap onto the base of Pliocene sequence. Widen high amplitude pattern downslope and bi-directional downlap which characterized the feature suggest the interpretation of submarine fan deposits. The variance map at the base of the Pliocene surface reveals a series of striations at the base of a fan deriving from NE. Individual striations can be imaged that are 20 - 50 m wide, c. 20 km long, and 4 - 8 m deep, trending NE - SW, slightly divergent patterns toward downslope. In the cross-section, this reflector marks the base of a mixed low to high amplitude, bi-directional downlap reflection package (Figure 4d). The origin of the striations is interpreted to be a catastrophic slope failure event, in which sliding was the main process.

Striation at The Base of The Pliocene Channel in The HGS

In the HGS, series of concave features are observed trending E - W (Figure 4b). In the cross-section, these concave features are characterized by an alternation of aggradational low to high amplitudes, onlapping onto the flanks. High amplitude reflections have linear patterns in the map view and are interpreted E−W channels (Le *et al.,* 2015). This is similar to the observation of Pilcher and Argent (2007) and Jobe *et al*. (2011) of data from a similar setting in Gabon and Equatorial Guinea. Among those channels, at the base of the largest channel, striations are observed. They have similar dimensions to the striations at the base of the Pliocene fan, but shorter. Individual striations can be imaged that are 20 - 50 m wide, c. 10 km long, and 4 - 8 m deep. There is no obvious divergence in the striation patterns.

Discussion

Striation bases of Pliocene sequence are interpreted to be the result of a catastrophic slope failure event, in which sliding was the main process. They are all large scale, very straight trending northeast to southwest and east to west. This suggests a period of a major failure, possibly associated with high energy and high sedimentation rate with sediment sourced from the northeast and east. The high sedimentation rate from NE is possibly related to the Paleo Senaga and Nyon River deltas. Meanwhile, the channel in HGS is possibly associated with the break-off-slope failure along the continenal shelf margin, related to resedimentation process.

Deposition of Pliocene sequence began with a period of unstable slope deposits characterized by NE - SW slides in LGS and erosion in HGS, followed by the deposition of large scale fan

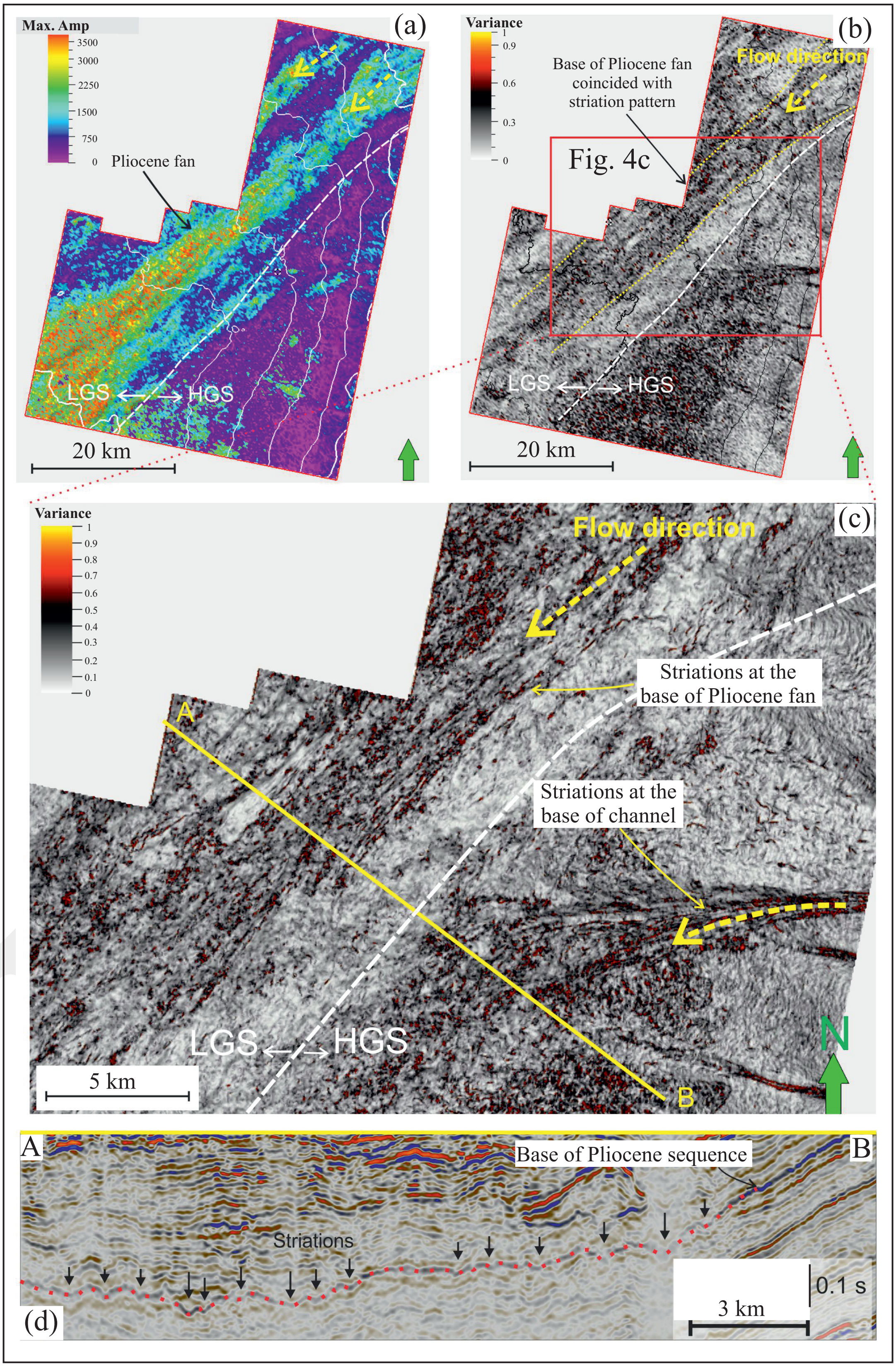

Figure 4. (a) Maximum amplitude map of 300 ms above the Pliocene base showing deep water fan. (b) Variance map of base of Pliocene showing the coincidence of fan and striation location. (c) Variance map of base of Pliocene sequence showing a series of striations at the base of a fan derived from NE and a W-flowing channel. Striations are associated with the pattern of the Pliocene fan and at the base of E - W trending channel. (d) Striations are shown on seismic cross-section.

deposits on the LGS and a series of parallel aggradational channels in the HGS. The lithology is significantly different in both slopes, where the LGS is dominated by high amplitudes associated with channels and fan lobes, interpreted to be a deep-water sand-rich fan system, and in the HGS low amplitude reflections are associated with polygonal faults, interpreted to be a mud-rich system. The unconformity at the base of Pliocene sequence is striated and overlain by a large scale fan, suggesting a period of slope failure and high sediment which is possibly the result of a major tectonic uplift event or significant climate changes.

Conclusions

There are two sets of striations observed in the studied area, on the unconformity surface defined as the base of the Pliocene sequence. Striations are coincided with the area of the Pliocene fan in LGS and large scaled-channel in HGS. They developed at the base of Pliocene fan and channel. Under the Pliocene fan, the striations have longer length (up to c.20 km) compared with the striations underneath the large scaled-channel (up to c.10 km). Individual striation can be imaged that are 20 - 50 m wide and 4 - 8 m deep. The occurrence of striated unconformity at the base of the Pliocene sequence, overlain by a large scale fan and channel suggests a period of slope failure and high sedimentation rate which is possibly the result of a major tectonic uplift event or significant climate changes. The area was supplied by two sediment sources, from northeast and east.

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