Abstract

Most submarine canyons are erosive conduits cut deeply into the world’s continental shelves through which sediment is transported from areas of high coastal sediment supply onto large submarine fans. However, many submarine canyons in areas of low sediment supply do not have associated submarine fans and show significantly different morphologies and depositional processes from those of ‘classic’ canyons. Using three-dimensional seismic reflection and core data, this study contrasts these two types of submarine canyons and proposes a bipartite classification scheme (Figure 12).

The continental margin of Equatorial Guinea, West Africa during the late Cretaceous was dominated by a classic, erosional, sand-rich, submarine canyon system (Figure 2). This system was abandoned during the Paleogene, but the relict topography was re-activated in the Miocene during tectonic uplift. A subsequent decrease in sediment supply resulted in a drastic transformation in canyon morphology and activity, initiating the ‘Benito’ canyon system (Figure 1). This non-typical canyon system is aggradational rather than erosional, does not indent the shelf edge and has no downslope sediment apron. Smooth, draping seismic reflections indicate that hemipelagic deposition is the chief depositional process aggrading the canyons. Intra-canyon lateral accretion deposits indicate that canyon concavity is maintained by thick (> 150 m), dilute, turbidity currents. There is little evidence for erosion, mass wasting, or sand-rich deposition in the Benito canyon system. When a canyon loses flow access, usually due to piracy, it is abandoned and eventually filled. During canyon abandonment, fluid escape causes the successive formation of ‘cross-canyon ridges’ and pockmark trains along buried canyon axes.

Based on comparison of canyons in the study area, we recognize two main types of submarine canyons: ‘Type I’ canyons indent the shelf
edge and are linked to areas of high coarse-grained sediment supply, generating erosive canyon morphologies, sand-rich fill, and large downslope submarine fans/aprons; ‘Type II’ canyons do not indent the shelf edge and exhibit smooth, aggradational morphologies, mud-rich fill, and a lack of downslope fans/aprons (Figure 12). Type I canyons are dominated by erosive, sandy turbidity currents and mass wasting, whereas hemipelagic deposition and dilute, sluggish turbidity currents are the main depositional processes sculpting Type II canyons. This morphology-based classification scheme can be used to help predict depositional processes, grain size distributions, and petroleum prospectivity of any submarine canyon.

Selected References


Figure 1. Comparison of submarine canyon morphologies and their downslope evolution, shown by a time structure map of the modern Equatorial Guinean seafloor. The stark contrast between canyon morphologies south of and north of the Ceiba canyon results from differing sediment supply. In the south, high sediment supply forms steep slopes and shelf-indenting, sand-rich Type I canyons with erosive morphologies and downslope submarine fans. The capture of sediment by the Type I Ceiba canyon starves the area to the north, where the Type II Benito canyon system is developed. The low sediment supply creates shallower slopes and Type II canyons, which have smooth, aggradational morphologies, no shelf-edge indentation, mud-rich fill, and no downslope sediment accumulation. White box in inset photo is the location of the study area (see Figure 2).
Figure 2. Location of the Benito canyon system. (A) The Gulf of Guinea and the Rio Muni Basin, an obliquely sheared rift basin associated with the Ascension fracture zone. Major rivers are labeled and modern wind (orange arrows) and longshore drift (pink arrows) are indicated. Muddy river plumes from the south drift northward into the study area and coarse-grained sediment is provided by local rivers and northbound longshore drift. (B) Offshore Equatorial Guinea, denoted by black rectangle in (A). Orange shading indicates African craton while unshaded area indicates onshore Rio Muni Basin sediments. The extent of Figure 1 is shown by the high resolution bathymetry and the study area is indicated by a black rectangle. Note the narrow shelf, variably indented shelf edge, and location of the Benito and Mitemele rivers. Compiled from Burke, 1972; Emery et al., 1974; Servain et al., 1985; Mariano et al., 1995; Meyers et al., 1996; Jourdin et al., 2006.
Figure 3. Stratigraphic evolution of the Rio Muni Basin. The Cretaceous canyon system was erosive and sand-rich. The Paleogene was a time of quiescence, when the canyon system aggraded via hemipelagic deposition. The early Miocene reorganization of the margin during basin-wide tectonism led to the initiation of the modern Benito canyon system, a muddy and aggradational canyon system. The upward decrease in sand and canyon margin faulting is likely related to changes in sediment supply. Note the transitional crust underlying the basin, a result of the sheared, extended nature of the margin. CVL - Cameroon Volcanic Line. Modified from Turner (1995) and Meyers et al (1996).
Figure 4. Time structure diagram of the seafloor derived from the 400 km$^2$ 3-D seismic reflection dataset used in this study. View is to the southeast. The “U” shaped canyons head in water ~ 280 m water depth and show smooth morphologies. The seismic cross-section demonstrates the aggradational nature of the margin. The active “B-North” and “B-South” canyons and the abandoned “B-Central” canyon on the modern seafloor are labeled and the thalwegs identified with a thin black line on the inset. Abandoned canyons are denoted on the seafloor by pockmark trains in various stages of development.
Figure 5. RMS (root mean square) amplitude map of the seafloor and shallow subsurface cores. Canyon thalwegs are filled with high-amplitude reflection elements (HARs), suggesting coarse-grained deposition via turbidity currents. The inter-canyon areas consist of low amplitude conformable reflection elements (CREs) that are demonstrably muddy in cores C4 and C5. Shelfal cores contain various amounts of sand related to the coastal northbound longshore drift; this sand is likely the source for the HARs.
Figure 6. Seismic reflection profiles of the Benito canyon system.

(A) A dip profile shows the aggradational and slightly progradational character of the margin. CREs, deposited by hemipelagic deposition, comprise the majority of the study area. The C5 core demonstrates that these CREs are composed predominantly of clay. Horizons 1-9 are also shown; Horizon 3 (23 Ma) is the initiation of the Benito canyon system.

(B) A strike profile displays the two active B-North and B-South canyons as well as the abandoned B-Central canyon that overlie the ancestral Cretaceous canyons. The Benito canyon system has aggraded more than 800 m since its inception at Horizon 3. Note the vertical to off-vertical canyon trajectories, indicating little to no migration during aggradation. Canyon-margin faulting/sliding identified in pink was related to the underlying Cretaceous canyon system, but does not affect the modern Benito canyon system.
Figure 7. CLAP (canyon lateral accretion packages) elements, which are deposited by thick, dilute, low-density turbidity currents. (A) and (B) show the modern seafloor, where the low sinuosity (1.07) B-South canyon and the CLAPs associated with its meandering. The direction of accretion is always towards the outer bend of the canyon, indicating downslope directed turbidity currents. The canyon trajectory is slightly migrational in the direction of the CLAPs - right to left in (A) and left to right in (B). (C) CLAPs in the subsurface, where two straight, slope-oblique canyons in Horizon 5 (teal line and inset) display accretion downslope. Thick, dilute turbidity currents flowing downslope encounter these canyons and deposit mud on the upslope bank and erode the downslope bank. (D) CLAPs in the modern B-North canyon, showing inner- to outer-bend accretion and the presence of sediment waves adjacent to the outer bend, indicating flow-stripping of dilute turbidity currents. Horizon 8 is shown by the dashed line and inset map.
Figure 8. Thalweg HAR elements, deposited by erosive turbidity currents. The HARs are concentrated in the thalwegs of the canyons and are stacked on and truncate each other, indicative of flows able to erode locally the beds over which they moved. The temporal correlation of HARs, notably between Horizons 5 and 6, may be related to a period of coarse-grained sediment influx into the basin. Note the location of the Cretaceous canyons and the evolution of that topography into the modern Benito canyons.
Figure 9. Benito canyon system evolution. Hot and cool colors on these time structure maps represent topographic highs and lows, respectively.

(A) - (B) Horizons 1 and 2 shows the ancestral Cretaceous canyon system and the associated canyon margin faults. Note the locations of the northern, central, and southern Cretaceous canyons.

(C) - (D) Horizons 3 and 4 are the initiation and early development of the Benito canyon system, related to erosion and uplift associated with emplacement of the Cameroon volcanic line. Note the re-activation of the ancestral Cretaceous canyon topography, forming the B-North, Central, and South canyons.

(E) - (F) Horizons 5 and 6 show the migration of the B-North canyon head above the B-Central canyon, causing the abandonment of the B-Central canyon due to loss of upslope flow access. Note the infilling of the canyon from Horizons 5 to 7.

(G) - (I) Horizons 7-9 exhibit the development of the modern seafloor and the progradation of the canyon heads along with the shelf edge. Also, the two parallel canyons adjacent to the B-South canyon are abandoned in this interval, leading to the formation of cross-canyon ridges and pockmark trains overlying the canyons.
Figure 10. Pockmark association with Benito canyons.

(A) The modern seafloor documents canyons in all three stages of abandonment, and the numbers correspond to these stages: 1) cross-canyon ridges in an abandoned canyon; 2) thinning canyon with ridges and coalesced pockmarks; and 3) discrete, circular pockmarks aligned in a train above the abandoned canyon. The central Cretaceous canyon displays Stage 1 while the two parallel canyons are in Stages 2 and 3.

(B) Down-canyon seismic section of the lower parallel canyon, documenting the evolution from an active canyon to a pockmark train. Horizon 5 shows the development of HARs and irregular ridges in the canyon, but after Horizon 6 (see Figure 9F), this canyon was abandoned and filled in with CREs. Note the development of a cross-canyon ridge from an intra-canyon bump, the location of the ridge through time, and the location of pockmarks on its flanks.

(C) Across-canyon seismic section, showing both parallel canyons were abandoned after Horizon 6 and were infilled with CREs. Note the location of the seafloor pockmarks that directly overlie the ancient canyons.

(D) The time structure of the seafloor and the color of Horizon 5 are juxtaposed on each other to demonstrate that pockmark trains and ridge development overlie the axes of abandoned subsurface canyons.
Figure 11. Stages of canyon abandonment. After succumbing to upslope flow capture, an abandoned canyon forms cross-canyon ridges (Stage 1). These ridges develop over small intra-canyon irregularities and are formed by fluid escape from compacting, underlying sediments. The ridges do not move, and form the flanks of pockmarks (see arrows). In Stage 2, the thinning, infilling canyon develops pockmarks, which are located in the lows between the ridges and also related to fluid escape. These pockmarks evolve into a train of discrete, circular pockmarks that overlies the abandoned canyon.
Figure 12. Canyon classification scheme. Type I canyons indent the shelf edge, are sand-rich, associated with high sediment supply, and terminate into a sandy submarine fan. Type II canyons, on the other hand, do not indent the shelf edge, are mud-rich, and have no downdip sediment accumulation due to their location in an area of low sediment supply. It seems that just enough erosion occurs to keep the canyons open, but not enough to generate a downslope sediment apron.