PS Cenozoic Shelf to Slope Transition along a Passive Continental Margin: Suriname, South America*

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Abstract

The Demerara margin off Suriname, South America is highly prospective in light of hydrocarbon exploration and production successes to the south, off Brazil and to the north, off Venezuela and Trinidad. Regional 2D seismic reflection data and a few offshore wells set the stage for the latest phase of exploration activity. A 3D volume bridging the shelf to slope transition allows for detailed investigation of Cenozoic stratigraphy, to improve understanding of shelf to slope linked depositional systems. Understanding forcing functions, sediment pathways and depositional processes are expected to provide insights into exploration models for passive clastic margins.

Exploration seismic data off Suriname show sedimentary sequences of subsidence infill and overall progradation. Early post-rifting conditions were highly anoxic, resulting in a thick (~90 m) interval of Cretaceous black shale that provides excellent hydrocarbon source rock. Several significant regional deep water unconformities indicate episodes of extensive erosion, such as during the Mid-Miocene. Outboard, the Cenozoic section is thin as a result, yet on the upper slope, the section is expanded with classic shelf-to-slope progradational architecture. Based on the position of the shelf-to-slope hinge line, it is apparent that progradation slowed during the Paleogene. In the Neogene, a regional Pliocene unconformity marks the return to rapid progradation that continued into the Quaternary.

Although sea level is no doubt a primary control on establishing the broad stratigraphic framework, lack of major erosional phases creating canyons and channels on the upper continental slope during the Cenozoic suggests other sedimentation processes dominate

between major sea level excursions. Rapid Pliocene progradation, for example may be related to increased sediment supply, due to uplift of the Andes, outpacing relative sea-level rise and increasing accommodation space in the basin. Rapid progradation and sediment loading on the shelf, presumably lead to over-steepening of unconsolidated sediments at the critical location of the shelf-slope transition zone. Extensive faults with seafloor offsets, in some cases paralleling the shelf edge, may be a consequence of such loading. Gullies along the shelf edge, probably cut by turbidity currents, and the shallow margin-parallel faults suggests seafloor instability and mass-transport processes are responsible for moving sediment to deep water.

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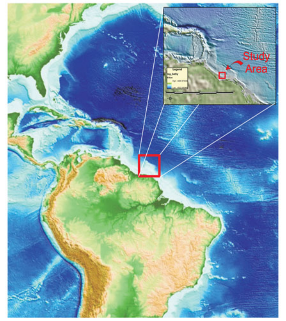
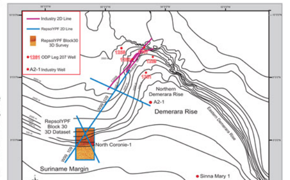
Abstract

Construction of the Demerara margin off Suriname, South America represents a classic interplay between sediment supply and sea level change. The Neogene shelf to slope transitional environments allows for detailed investigation of the Cenozoic seismic sequence stratigraphy to improve understanding of shelf to slope linked depositional systems. Understanding forcing functions, sediment pathways and depositional processes are expected to provide insights into exploration models for passive clastic margins.

The Suriname margin shows sedimentary sequences of subsidence infill and overall progradation. Early post-rifting is characterized by sediment infill of horst and graben blocks followed by a major Early Cretaceous erosional angular breakup unconformity. Mid to Late Cretaceous conditions were highly anoxic, resulting in a thick (~90 m) interval of Cretaceous black shale that provides excellent hydrocarbon source rock (~30% TOC). During the Miocene, several regional deep water unconformities indicate episodes of extensive erosion. Global deep water oceanographic processes, such as strong bottom currents, were likely responsible for developing these unconformities. In the Neogene, a Pliocene unconformity marks commencement of rapid progradation that continued into the Quaternary. This rapid progradation is likely related to sediment supply outpacing relative sea-level rise during uplift of the Andes Mountains. On the modern seafloor, minor gullies along the shelf edge, probably cut by hyperpycnal flows as off-shelf turbidity currents, indicate this sedimentary process may be the principal one responsible for sedimentation along the margin. Modern extensive shallow margin-parallel faults in the shelf region may be the result of sediment loading and gravitational extension. Faults open to the free slope at the shelf break may represent a significant geohazard because of possible detachment and mass failure. Mass-transport processes and turbidity deposits identified throughout the lower Cenozoic intervals indicate a history of margin instability responsible for transporting sediment to deep water; significantly contributing to the overall development of the Suriname margin.

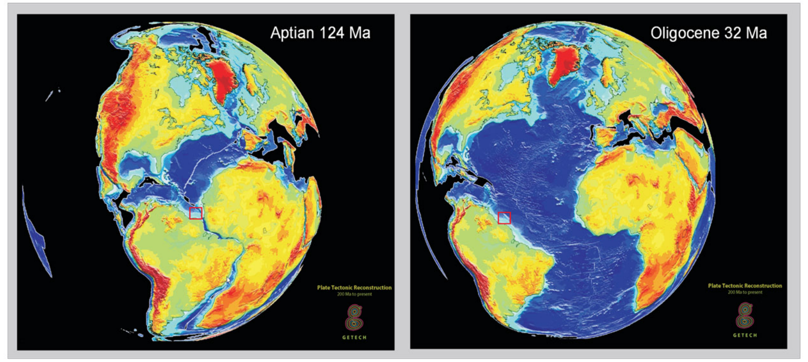


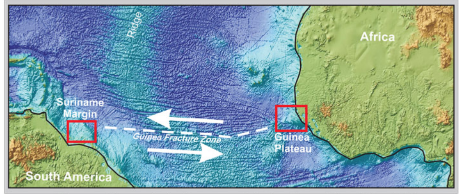


Introduction

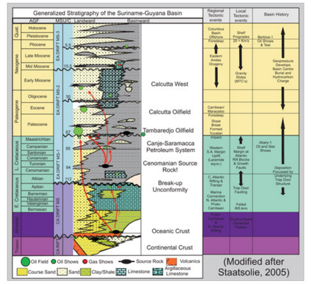
The Suriname margin (SM) represents the location of the last vestige of the proto-Atlantic, before West Africa's final rifting from South America (Gouyet et al.,1994). Along the margin is the Demerara Rise(DR); a deep water plateau that is a fragment of continental crust that sheared from its conjugate, the Guinea Plateau (GP) of West Africa. This Cretaceous rifting resulted in formation of a passageway between the North and South Atlantic Oceans. The SM therefore is ideal to study the youngest record of rifting and passive margin development in the Atlantic. It's equatorial setting allows investigation of Cenozoic ocean scale deep and shallow water current development and recent margin progradation. The purpose of this investigation is to understand the interplay of sediment supply and relative sea level change along this late stage rifted passive margin. 2D and 3D seismic reflection data contributed from industry, in combination with drill results from Ocean Drilling Program (ODP) Leg 207 and industry well data, provide information on the distribution, structure, and thickness of the sedimentary formations; helping to understand it's geologic evolution.

Tectonics

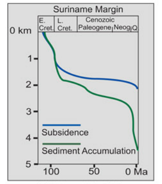




Topographic map indicating present day locations of the SM and GP.

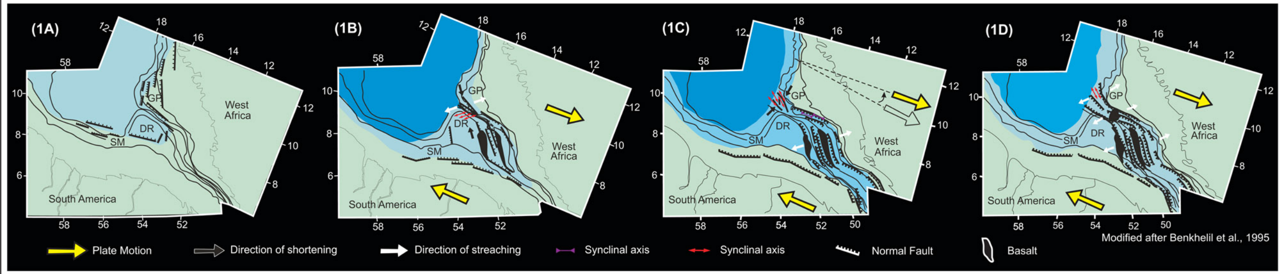


(Modified after Staatsolie, 2005)



de Flicoteaux et al., 1988

During the Jurassic prior to rifting and opening of the Atlantic gateway the SM, DR and GP formed the southern border of the central Atlantic margin **(1A)** (Benkhelil et al. 1995; Erbacher et al. 2004). North-south rifting initiated about 180 Ma resulting from east-west extension with a large component of dextral shearing **(1B)** (Mascle et al. 1986; Gouyet et al, 1994). In the late Albian, complexities caused by plate rotation resulted in a late compressional phase before final rifting. Subsidence of the margin followed rapidly, initially due to thermal cooling of the crust **(1C)** (Benkhelil et al., 1995; Pindell and Kennan 2005). Following the minor recurrence of compressive tectonics, an extensional regime ensued during the Late Cretaceous. Extension is characterized by a general collapse of the margin resulting in the final parting of the African and South American continental plates and the creation of oceanic crust **(1D)** (Benkhelil et al. 1995). Largely east-west separation of the West African and central South American margins continued resulting in its present day configuration.

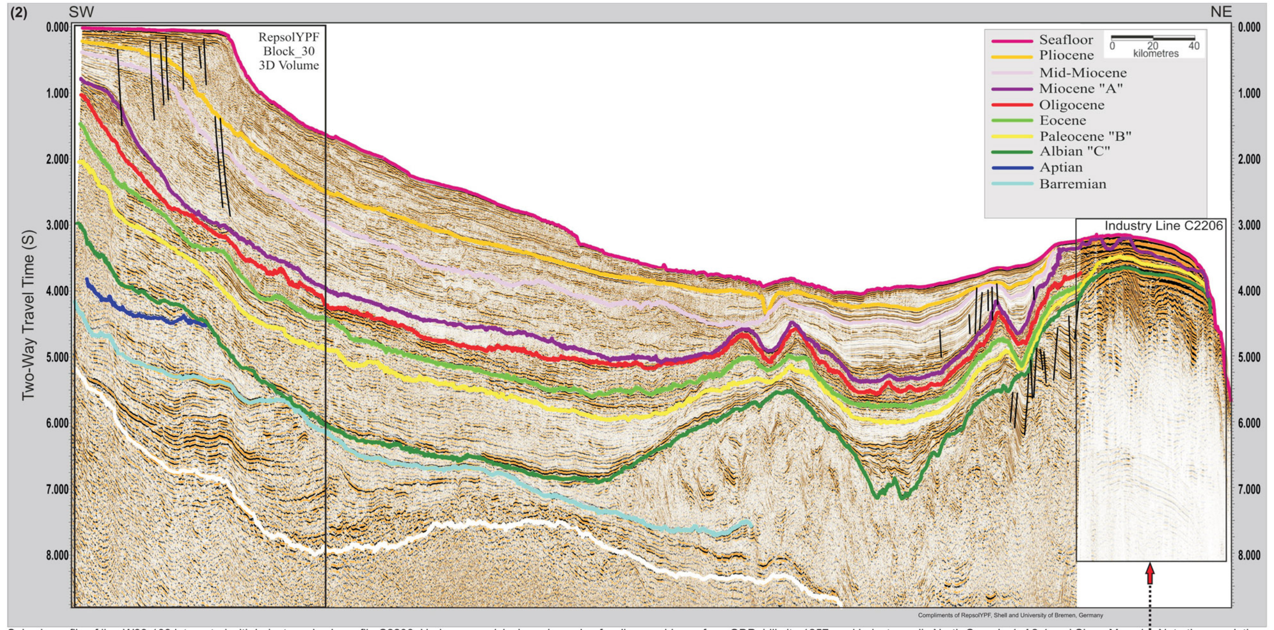


Modified after Benkhelil et al., 1995

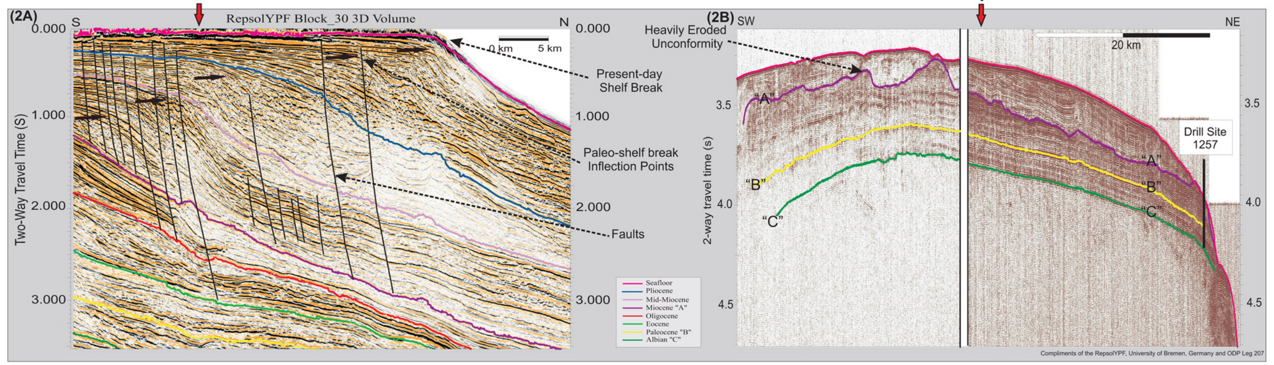
Seismic Stratigraphic Results:

Significant regional unconformities are demonstrated across the entire SM and outer DR **(2)**. Two major Mesozoic unconformities are best observed over the outer DR where Mid to Late Tertiary sequences are shallowly buried and well preserved **(2, 2B)**.

The Cenozoic section is thin to absent on the DR but thickens substantially inboard to nearly 2.5 s thick beneath the Suriname shelf. In general description of the seismic data, the entire sequence forms a progradational wedge from the shelf to basin **(2)**. Paleo-shelf edges are obvious throughout the section, observed as inflection points in the seismic horizons. Tracing mapped positions of the paleo-shelf break through the seismic volume, it is apparent that progradation was likely relatively slow during the Paleogene **(2A)**. During the Miocene, several significant regional deep water unconformities indicate episodes of extensive erosion. Deep water processes such as strong current erosion in combination with significant sea level lowstands were likely responsible for the development of these unconformities. Within the Neogene, a regional Pliocene unconformity marks commencement of rapid margin progradation that continued into the Quaternary. This phase is likely related to sediment supply outpacing relative sea level rise **(2)**. Increased sediment supply was the result of increased topographic relief (~1 -2 km) during build up of the Andes Mountains (Hoorn et al., 1995).

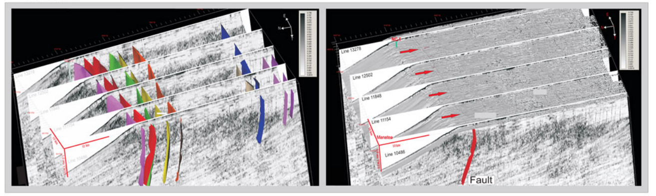


Seismic profile of line W99-109 integrated with industry seismic profile C2206. Horizon age picks based on microfossil assemblages from ODP drill site 1257, and industry wells North Coronie-1, A2-1 and Sinna Mary 1. Note the correlation of "A" "B" &" "C" uncomformities from the northeastern Demerara Rise to the RepsolYPF Block 30 Seismic Volume



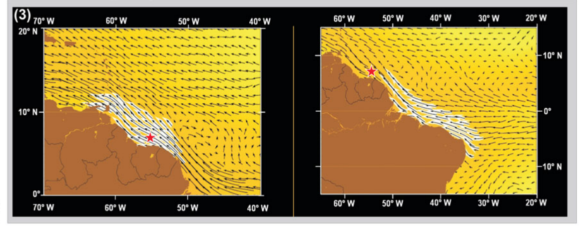
(Above Left) Seismic dip profile of Repsol Block 30 indicating the distribution of faulting in the shelf region. Note the sediment thickness above the Pliocene horizon relative to the underlying units, and the classic shelf-to-slope progradational bedding structures. **(Above Right)** High resolution seismic profile of the northeastern DR. The "C" unconformity to the overlying "B" interval corresponds to a significant amount of Cenomanian to Santonian claystone rich in organic matter (black shales) containing up to 30 % TOC.

Faults



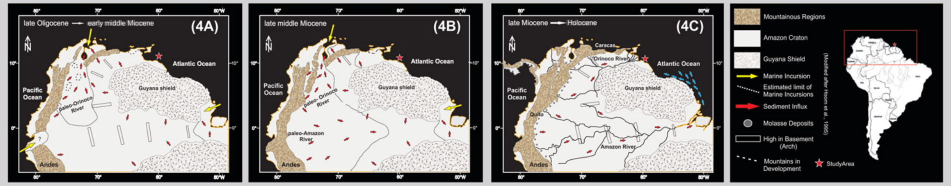
(Above Left) Five seismic profiles spanning the entire shelf and shelf-break region of the 3D seismic volume indicating listric fault chacteristics. **(Above Right)** Fault trace, with a seafloor expression demonstrated (red arrows), that parallels the shelf break for the full extent of the survey. It is not known whether these faults represent splays of a master fault system or represent gravitational extension of the shallow margin due to subsidence. This particular case is adjacent to a free slope and subsequently there is a risk of detachment and mass failure.

Oceanographic Influence



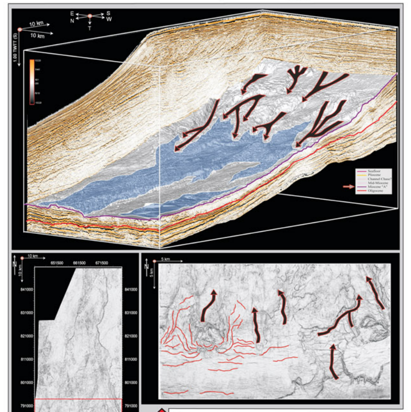
Two northward flowing equatorial bottom currents that a presumably responsible for transporting and reworking sediment on the SM. **(Above Left)** Guiana Current **(Above Right)** North Brazil Current

Neogene Drainage Basin Development

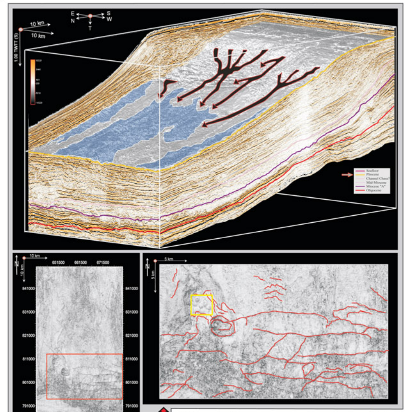


Schematic stages of the South American drainage basin development. In the Late Oligocene to Early Miocene, fluvial systems drained the central Cordillera and northwest Amazonia with an eastward flowing transport direction that probably formed tributaries of the ancient Orinoco river system **(4A)**. During the Late Miocene, the first effects of rise of the eastern Cordillera were noticable with the development of the Amazon River. At this time, however, no connection existed to the Atlantic **(4B)**. Between the Late Miocene and the Holocene, the Andes attained their present configuration. During this time the Amazon River evolved as a transcontinental drainage system, transporting sediment to the Atlantic Shelf **(4C)**.

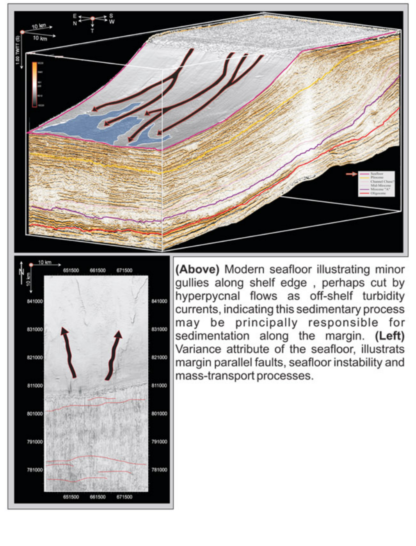
Seismic Geomorphology and Depositional Processes



(Above) Miocene unconformity indicating the morphological characteristics and erosional nature within the 3D seismic volume. Arrows indicate direction of downslope sediment pathways and blue polygons define areas of deposition. **(Left)** Variance attribute of Miocene surface. **(Lower Right)** Enhanced view of Miocene variance surface illustrating radial fault patterns associated with slump features, arrows indicate the direction of sediment evacuation paths carrying sediments downslope to deep water regions.



(Above) Pliocene unconformity rendering indicating the morphological characteristics and erosional nature within the 3D seismic volume. **(Left)** Variance attribute of the Pliocene surface. **(Right)** Enhanced view of Pliocene variance rendering illustrating fault patterns associated with listric normal faults observed in seismic dip profiles in the region shelf. Note the presence of gas escape features clustered within the yellow box.



(Above) Modern seafloor illustrating minor gullies along shelf edge , perhaps cut by hyperpycnal flows as off-shelf turbidity currents, indicating this sedimentary process may be principally responsible for sedimentation along the margin. **(Left)** Variance attribute of the seafloor, illustrats margin parallel faults, seafloor instability and mass-transport processes.

Conclusions

- The SM of equatorial South America is an ideal location for studying late stage continental rifting and margin development in the equatorial Atlantic.
- Shelf to slope stratigraphy is solely the result of interplay of sediment supply and relative sea level position, unaffected by glaciations or dramatic tectonic episodes.
- Cenozoic deposition was largely progradational with several significant regional unconformities developing in the Oligocene and again in the Miocene.
- Under the continental shelf and slope, the Cenozoic section is expanded with shelf-to-slope progradational stratigraphic architecture.
- Stratigraphic analysis and seismic-geomorphologic features suggest sediment supply dominates the Cenozoic stratigraphic record, resulting in progradation.
- Off-shelf sediment transport and sediment mass-failure (MTD's) on the slope represent the primary processes responsible for margin construction during the Cenozoic.
- Northward flowing equatorial currents have a significant impact on transporting and reworking sediments on the SM.
- Shallow margin parallel faults identified in the shelf region may represent a significant geohazard resulting detachment and mass failure.

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