PEER-REVIEWED ARTICLE

Aguja Canyon – New approach added to the structural and morphological model in the continental margin of the Colombian Caribbean

Authors

Yerinelys Santos Barrera[1], María Fernanda Calderón Grande[1], Eliana Gutiérrez Rincón[2] and Johanna P. Vargas Morales[1]

Abstract

On the submerged continental margin of the Colombian Caribbean, the Aguja submarine canyon stands out, a structure formed by denudation processes that crosses the continental shelf and transports sediments to the deep waters in the Colombia basin. Using new hydrographic data and bathymetric analyses, this study shows a physical characterization of the canyon, which stretches for more than 197 km with depths of 10 m to 3,783 m and a width of 1 km to 8 km. Four segments controlled by regional structural geology are identified, each with a distinct channel direction. Aguja Canyon shows instability in its walls and surroundings with landslides, faults and mud volcanism, evidencing considerable tectonic and sedimentary activity along the continental margin.

Keywords

Aguja Canyon · submarine · morphology · Caribbean · bathymetry · roughness

Resumé

Sur la marge continentale submergée des Caraïbes colombiennes se distingue le canyon sous-marin de La Aguja, une structure formée par des processus de dénudation qui traverse le plateau continental et transporte des sédiments vers les eaux profondes du bassin de la Colombie. A l'aide de nouvelles données hydrographiques et d'analyses bathymétriques, cette étude présente une caractérisation physique du canyon, qui s'étend sur plus de 197 km avec des profondeurs de 10 m à 3 783 m et une largeur de 1 km à 8 km. Quatre segments contrôlés par géologie structurale régionale sont identifiés, chacun avec une direction de chenal distincte. Le canyon de La Aguja présente une instabilité de ses parois et de ses environs, avec des glissements de terrain, des failles et un volcanisme de boue, ce qui témoigne d'une activité tectonique et sédimentaire considérable le long de la marge continentale.

Resumen

En el margen continental sumergido del Caribe colombiano destaca el cañón submarino La Aguja, una estructura formada por procesos de denudación que atraviesa la plataforma continental y transporta sedimentos a las aguas profundas de la cuenca de Colombia. Usando nuevos datos hidrográficos y análisis batimétricos, este estudio muestra una caracterización física del cañón, que se extiende más de 197 km con profundidades de 10 m a 3.783 m, y una anchura de 1 km a 8 km. Se identifican cuatro segmentos controlados por la geología estructural regional, cada uno con una dirección de canal distinta. El cañón La Aguja muestra inestabilidad en sus paredes y alrededores con deslizamientos, fallas y volcanes de lodo, evidenciando una considerable actividad tectónica y sedimentaria a lo largo del margen continental.

✉ Yerinelys Santos Barrera · ysantosb@dimar.mil.co

[1] Dirección General Marítima de Colombia, Centro de Investigaciones Oceanográficas e Hidrográficas del Caribe (DIMAR-CIOH), Cartagena, Colombia

[2] Universidad Industrial de Santander (UIS), Bucaramanga, Colombia

https://doi.org/10.58440/ihr-30-2-a11

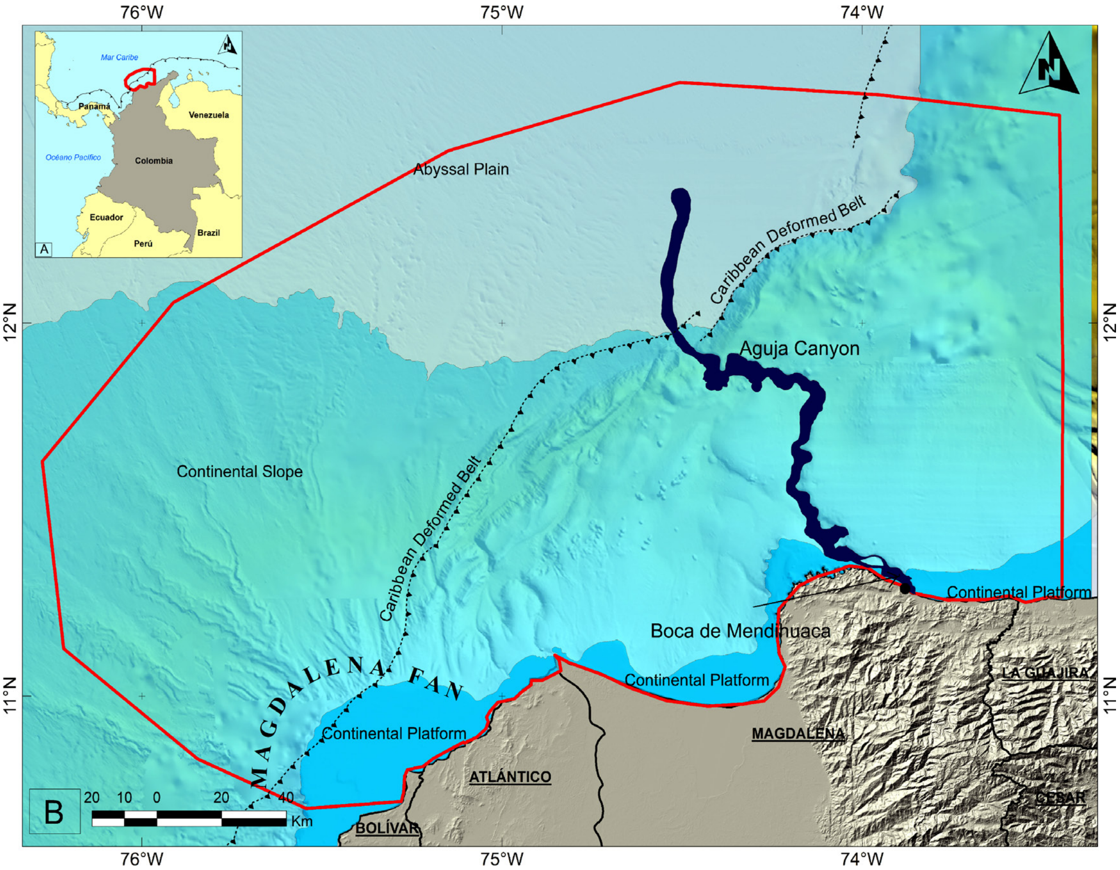

Fig. 1 Geographical location of the Aguja Canyon – department of Magdalena near the sector known as Boca de Mendihuaca. It crosses three parts of the continental margin: continental platform, continental slope and abyssal plain.

1 Introduction

A canyon identified north of the continental margin of the Colombian Caribbean is the Aguja Canyon, recognized from the vicinity of the coasts in submerged areas of the department of Magdalena, approximately 1.27 km from the point called Boca de Mendihuaca (Fig. 1). It extends between depths of 10 to 3,850 meters and covers a length of 197 kilometers based on the multibeam bathymetry conducted by the Caribbean Oceanographic and Hydrographic Research Center in 2020.Due to its morphological characteristics, this canyon can be classified, according to Goff (2001), as a large and mature canyon that breaks the edge of the shelf and zigzags downhill towards the abyssal plain, allowing access to the sediments of the continental shelf. However, current knowledge about the morphology and structural controls shaping this canyon remains limited, its configuration along the continental margin and its interaction with sediments from the continental shelf. While Aguja Canyon exhibits a meandering configuration with moderate to high sinuosity, the interactions between geological structures and hydrodynamic forces are not fully understood.

This paper addresses these knowledge gaps through a detailed analysis of the Aguja Canyon morphometry and structure, using multibeam bathymetry, 2D seismic data and Digital elevation model (DEM). Specifically, this research examines how the fault system Santa Marta-Bucaramanga (FBSM)- Oca (FOCA) (Cediel et al., 2003) and other local faults cut across this complex system influence the Aguja Canyons configuration, providing new insights into the structural and dynamic processes affecting the canyon's morphodynamics on both the shallow and deep seabed of the Colombian continental margin.

2 Physiographic characteristics of the area of the Aguja submarine canyon

Aguja Canyon (Fig. 1) spans the entire continental margin off the coast of the Colombian Caribbean, extending from the shallow coastal shelf at a depth of 10 meters down to the abyssal plain. It traverses three primary physiographic sections: the continental platform, slope, and deep-sea plain. Although it is not directly connected to nearby river systems, the canyon runs parallel to the Oca Fault (FOCA), suggesting tectonic influences on its morphology (Colmenares et al., 2007).

In the continental slope section (Fig. 2a), Aguja Canyon the canyon exhibits a meandering shape with structural features that redirect its course across four distinct directions, shifting from northwest to northeast (Arturo, R. F, 2009) This section is characterized by mass-wasting structures, including deposits and scarps, that shape the canyon walls and valley, indicating active sedimentary processes. (Rangel-Buitrago, 2010), as well as scarps aligned in a northeasterly direction in the elevations that are part of the accretion prism at the foot of the slope and in the

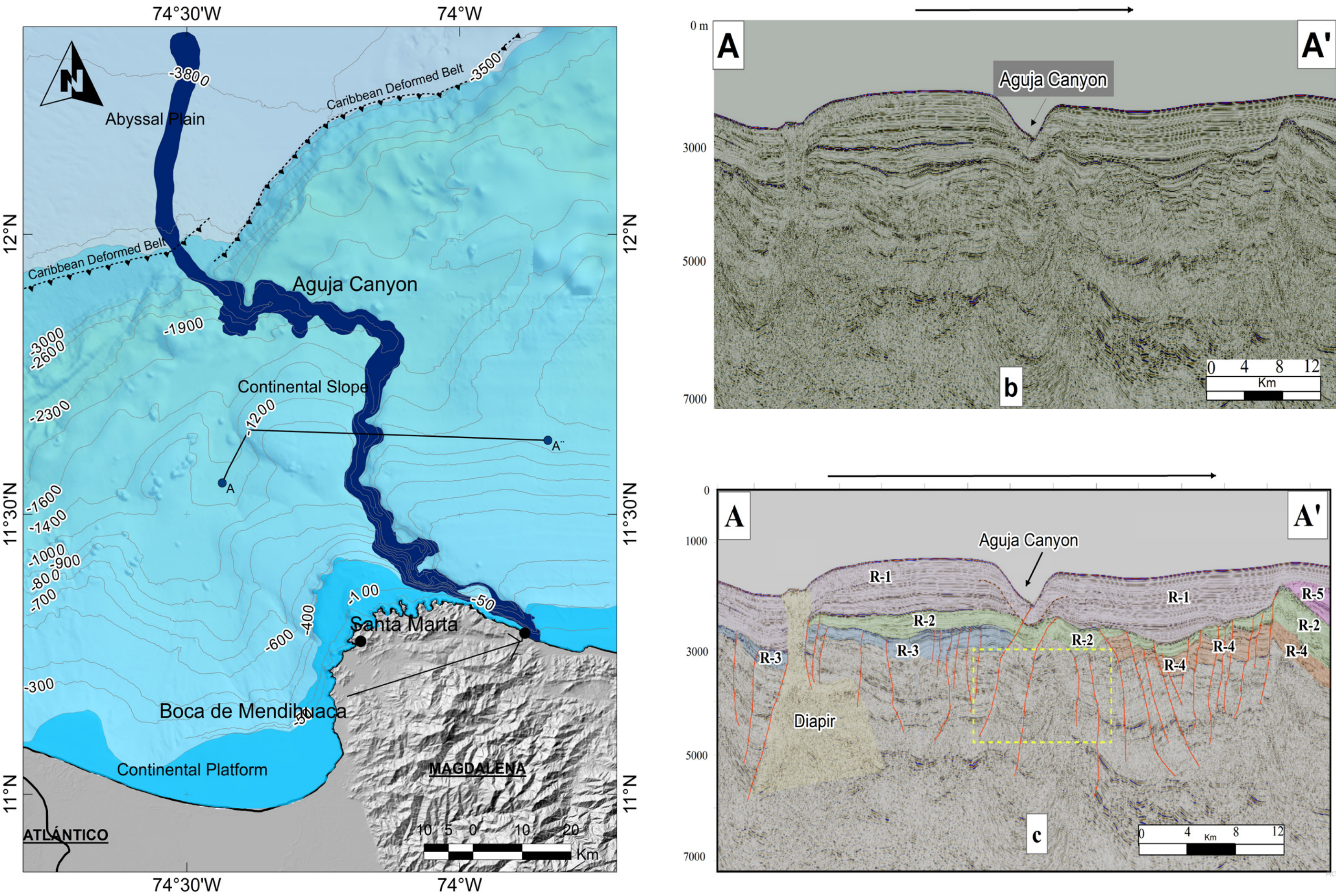

Fig. 2 (a) Location of seismic line A-A. The Aguja Canyon. (b) Original seismic line. (c) Interpretation of seismic line. The A-A' seismic line with W-E direction on the continental slope, reflects the discontinuities of the accretion prism in the area. The discontinuity on R-1, R-2, R-3, R-4 and R-5 seismic reflectors show normal and reverse fault jumps (red lines). The yellow box shows an area where the continuity of reflectors is not clearly identified.

walls of the main canyon, equally steep, with a predominance of mass removal phenomena

In the zone of influence of the Caribbean Deformed Belt lineament, the Aguja Canyon reaches its maximum depth at the abyssal plain, where it takes a northeasterly course (to the right) until it finally reaches a depth of 3,850 meters, visible through bathymetric and isobaths (Fig. 2a). Following the canyon from the shallowest part, in the coastal area, 10 meters deep, to the deepest part in the abyssal plain following the canyon valley, the Aguja Canyon it has a total extension of 197 km.

At its deepest point within the abyssal plain, the canyon reaches approximately 3,783 meters and follows a northeastward path influenced by the Caribbean Deformed Belt (CDB) lineament. Spanning a total length of 197 kilometers, the Aguja Canyon reflects complex interactions between tectonic and sedimentary processes

The AA' seismic line (Fig. 2b) exhibits significant discontinuities in its R-1, R-2, R-3, R-4, and R-5 reflectors, reflecting a sequence of normal and reverse faults covered by a sediment layer clearly visible in continuous reflectors (Fig. 2c).

The subduction of the Caribbean plate with the South American plate continues to be a topic of debate in the scientific community. Proposed models include subduction (Burke et al., 1984; Duncan & Hargraves, 1984; Ross & Scotesse, 1988), low-angle subduction (Taboada et al., 2000; Vargas & Mann, 2013; Galindo, 2016), obduction (Cediel et al., 2003), gravitational tectonics, and a combination of subduction and gravitational tectonics (Moreno et al., 2009). The current configuration of the continental margin crust is due to the east-northeast shift of the South American plate and the subduction of the Caribbean plate, which has generated a series of strike faults and displacements during the Cenozoic (Mantilla-Pimiento et al., 2009).

3 Methods

A 3D model of the Aguja Canyon section was generated using multibeam data obtained between 2010–2022. The bathymetric surface, in Csar format, was processed using the Caris Base Editor tool to create a base surface with a spatial resolution of 100 meters. This surface served as the foundation for generating additional elevation models (DEM).

The digital elevation model (DEM) was constructed from the bathymetric data (Fig. 3a). Using GIS tools, we then developed several other models: a digital slope model (Fig. 3b), a digital shadow model (Fig.

 https://doi.org/10.58440/ihr-30-2-a11

3c), and a digital roughness model (Fig. 3d). The roughness model provides a topographic roughness index, which was used to determine key morphometric values for the canyon structure.

To analyze geological processes in the bathymetric model, we interpreted five 2D images of seismic track, covering approximately 542.9 kilometers in the study area (Fig. 2) These seismic lines, provided by the Petroleum Information Bank (EPIS), were crucial for identifying major fault structures, sediment deposition, and mass-wasting events (Fig. 2b). The seismic data interpretation followed standard seismic stratigraphy procedures, with a focus on horizon picking and fault mapping (Fig. 2c)

Through the depth model, digital maps of slope, roughness, shadow, aspect, and others were obtained, which, added to the morphometric information of the Aguja Canyon, as well as the 2D seismic data, revealed structural factors that control the canyon channel and the different directions it takes when crossing the continental margin.

4 Results

Structurally, the area of influence of the Aguja Canyon is affected by two major fault systems processes that occurs in the near continental section. These are the Bucaramanga-Santamarta Sinestral Strike Fault (FBSM) from almost north-northwest to south-southeast (Pindell, 1998; Lopez, 2005; Vence, 2008; Álvarez, 2015) and the dextral direction Oca Fault (FOCA) (Cediel et al., 2003; Lopez, 2005; Pindell et al., 1998; Vence et al., 2008). The latter, extends into the deep marine part of the Caribbean.

From the results of the interpretation carried out at approximately 542.9 km of 2D seismic lines around of the Aguja Canyon, as well as from the bathymetry, the roughness model, and the slope model, it was identified that the two fault systems (FOCA and FBSM) extend from the mainland to the seafloor, forming a set of main faults of the dextral and sinestral strike type, respectively, with normal satellite faults (Fig. 4a). This is evidenced in the structural control of the Aguja Canyon, as represented by the changes in the direction of the main channel along the continental slope. At a depth of 1,254.5 m the channel trends northeast; at 2,005.2 m, it shifts to a northwest direction and at 3,285.6 m it returns to a northeast direction. In addition, similar structural control is observed in the abyssal plain, close to the area influenced by the accretionary prism.

The set of faults found next to the Aguja Canyon is added to the group of reverse faults associated with the deformation processes of the Sinú Deformed Belt (CDS) in its northern section, in the vicinity of the Magdalena Fan. These faults have developed due

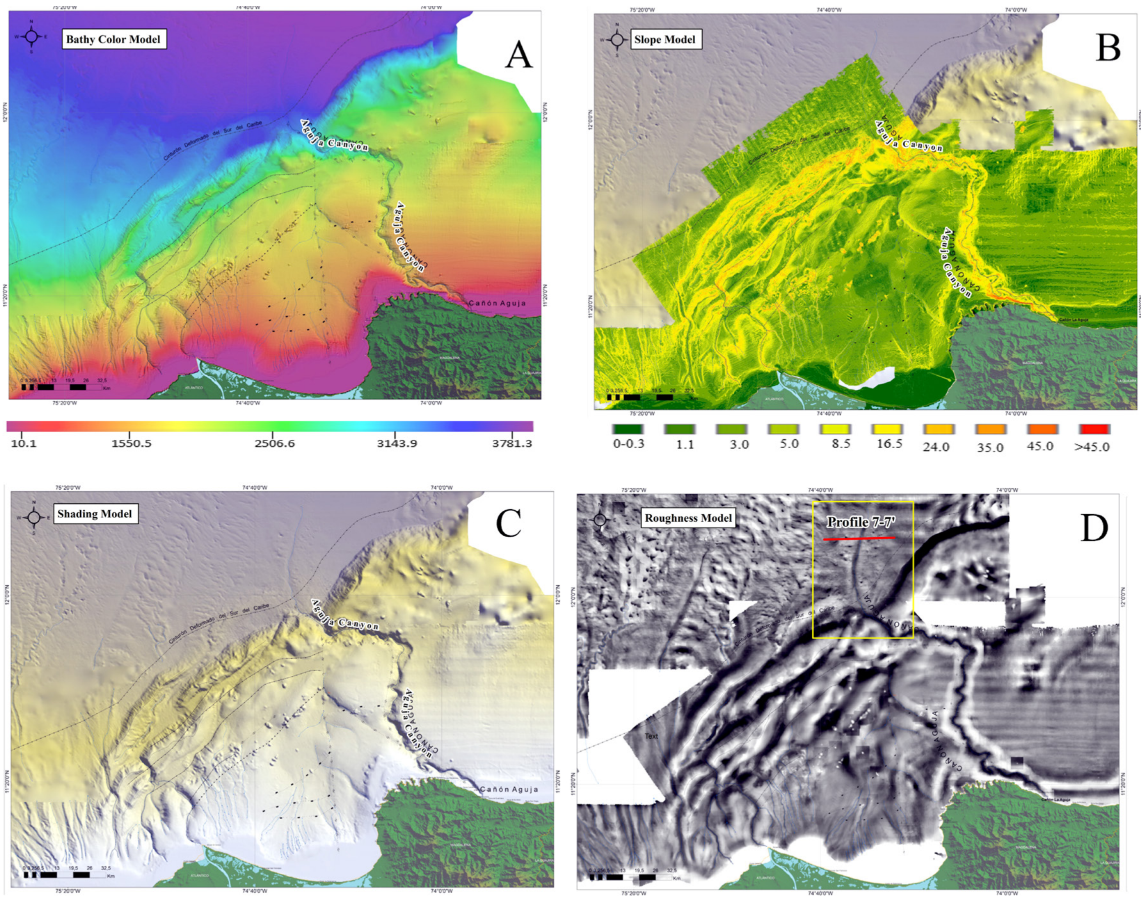

Fig. 3 (a) Depth model (meters). (b) Digital slope model (degrees). (c) Digital shadow model (d) Digital roughness model with profile 7-7' in red line; the red line marks the section of the canyon where it takes the shape of a channel as it sits over the abyssal plain. The segments correspond to fault lines, ridge channels and axes, or structural guidelines.

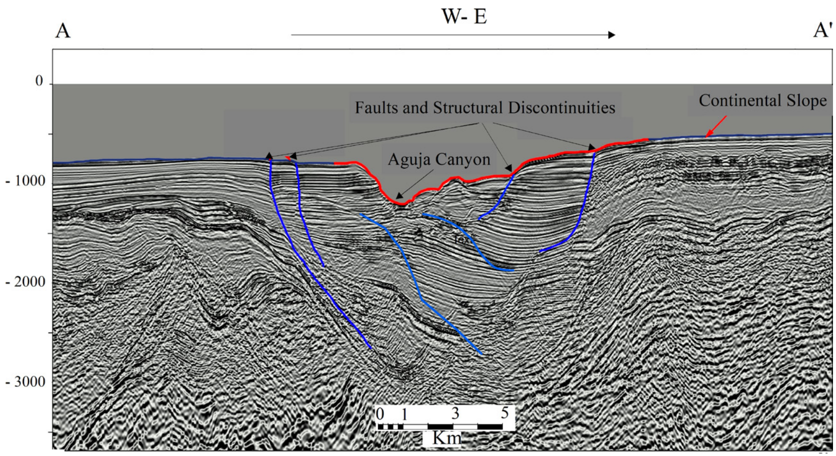

Fig. 4 Faulting and discontinuity of layers close to the section of Aguja Canyon. The 2D seismic profiles A-A' along with the interpretation of the reflectors show the faults, structural discontinuities.

to the dynamics and growth of the accretion prism, product of the interaction between the Caribbean plate and the South American plate, whose advance oscillates around 20 mm/year (Veloza et al., 2012).

The morphological conditions (Fig. 4) are consistent with zones whose characteristics are associated with faults, which often produce areas of instability and mass flow, or mass removal phenomena. To the southwest, there is a series of landslides whose origin is due to the structural folding of the layers, which are part of the accretionary prism and whose axis is oriented in a northeast-southwest direction, surrounded by valleys that form the deepest areas towards the Caribbean basin, represented by average elevation differences of 202.2 meters. These are located at the foot of the slope, becoming in areas of sediment accumulation from the different mass deposits transported from the platform and the slope (Cadena & Slatt, 2013).

In the bathymetry, the greatest deposition area of the Magdalena Submarine Fan was observed with complex mass transports (Galindo, 2016). The sediment load distributed in this section of the slope and observed in the 2D seismic, coincides with detrital and turbiditic deposits from the continental shelf, which generate an important slope deposit and landslides of large masses, which are also found forming part of the canyon walls.

5 Morphological and morphometric characteristics of the Aguja Canyon

The Aguja Canyon exhibits a varied morphological behavior along the continental margin, which allowed it to be divided into four sections because of this study, from the shelf to the abyssal plain in the north of the Colombian Caribbean. In addition, cross-sectional profiles showing the characteristics of the valley and its shape have been related (Fig. 5).

Aguja Canyon has a changing course, attributed to possible tectonic controls, which can be corroborated with the internal processes of the canyon valley in the different sections or stretches (Fig. 5). These controls are induced by regional structural processes in the area, mainly those related to activity in the fault system FOCA and the convergence deformation of the Caribbean and South American plates (Restrepo-Correa & Ojeda, 2020).

Within the depth model, the Aguja Canyon was divided into four sections (Fig. 5), which are distinguished by the direction of the main channel along the continental shelf until the abyssal plain. The different sections identified in this study area as follows:

Section A (upper): It is located at the top of the canyon or headwater, between the thin continental shelf of the area and the beginning of the continental slope, encompassing isobaths from 10 to 650 meters with direction of 64° north-west. In profile 1-1', points depths in the profile ends, vary between 14 and 126.7 meters. This section exhibits a sinuous morphology with moderate curves, highlighting a "U" shaped incision or valley inclined to the right, with an approximate depth of 367.3 meters and a width of 2.11 km. The 2-2' profile shows a variable morphology, with elevations and depressions within the valley and a marked difference in depth on both sides (profile ends) from 114 to 478.5 meters respectively, with a canyon width of 4.69 km and maximum depth 986.7 m.

Section B (middle): Located on the continental slope, it has a meandriform shape with an orientation of 14° north-east. In the 3-3' profile, depths vary from 867.0 to 767.8 meters in the profile ends. In this section, the canyon valley shows a very pronounced "V" shaped incision, with an approximate depth of 1,288.7 meters and a width of 3.65 km. At the lower end of this section, the 4-4' profile features depths ranging from 1,605.7 to 1,767.3 meters, where the shape of the valley changes to "U" shape with an open end to the left, reaching an approximate depth of 2055.1 meters and a width of 4.84 km.

Section C (medium-low): Located between the foot of the continental slope and the boundary with the abyssal basin, this section has an orientation of 86° north-west. In 5-5' profile, the depths vary from side to side of the canyon between 1857.7 and 2,271.2 meters. In this section the valley is 8.78 km wide and has an open "U" shape, with an approximate depth of 3072.8 meters.

In the abyssal plain area, section D, the canyon changes from a valley shape to a channel shape due to the slope and conditions of the basin, changing its course to 04° north-east. In 6- 6 profile with depths between 3,650.4 and 3,671.8 meters, the deepest section valley reaches approximately 3,698.6 meters. In the digital roughness model, you can see the depth of the canyon scar transformed into a channel and taking a deviation towards the northeast (Fig. 5)

Cross section profile 7-7' seen in Fig. 6, is the last profile of this study and is the representation of the deepest part of the canyon transformed into a channel that is noticeable in the bathymetry at a vertical exaggeration of 5X and in the roughness model.

The predominant slope (Fig. 3) throughout the

https://doi.org/10.58440/ihr-30-2-a11

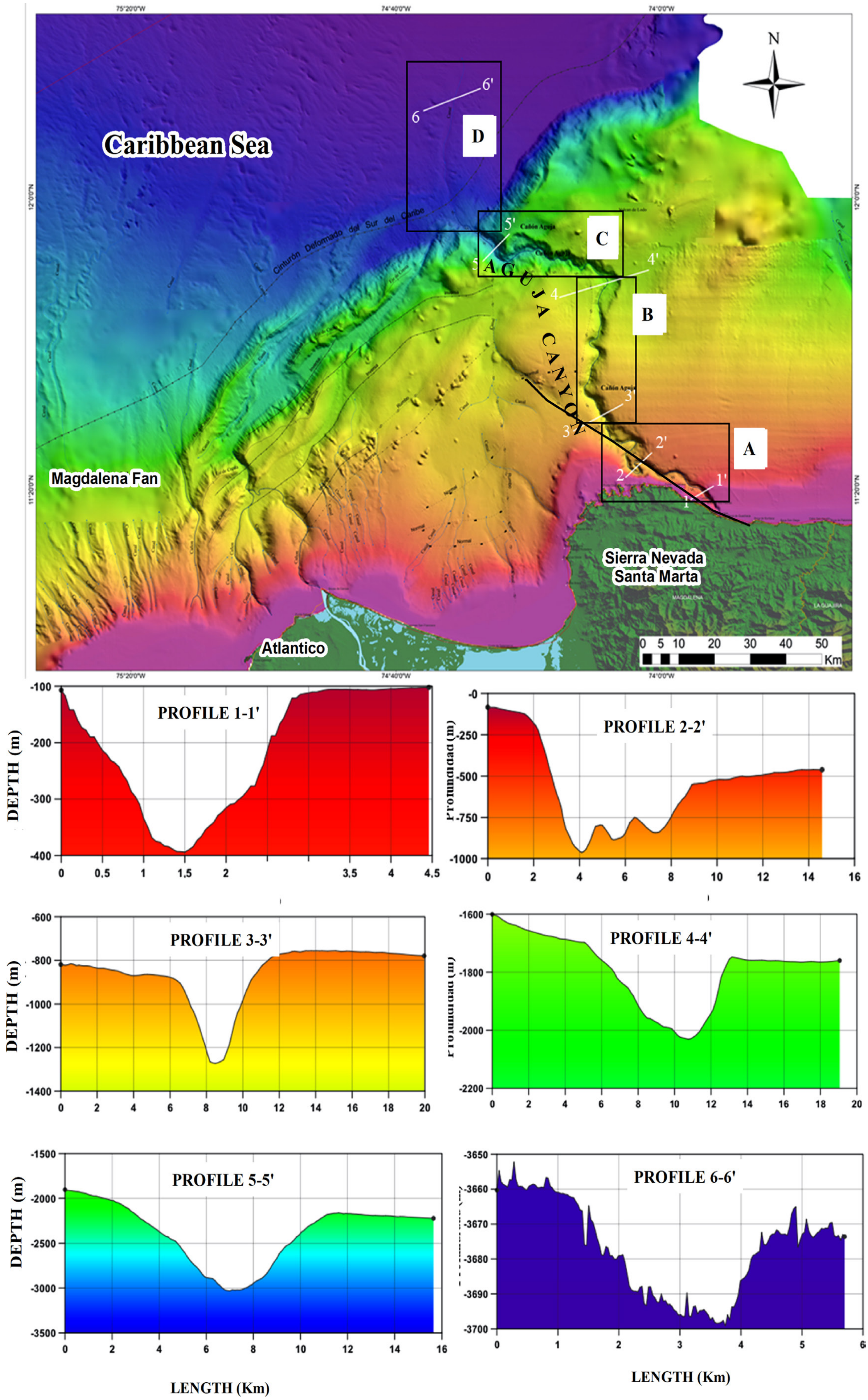

Fig. 5 Profiles transverse to the Aguja Canyon (VE.5X). The 1-1', 2-2', 3-3', 4-4', 5-5' and 6-6' cross-sectional profiles show the structural differences of the Aguja Canyon in the ocean floor. Sections A, B, C, and D shows the directional changes of the canyon along the continental shelf, continental slope, and abyssal plain (Colombia basin) due to structural processes.

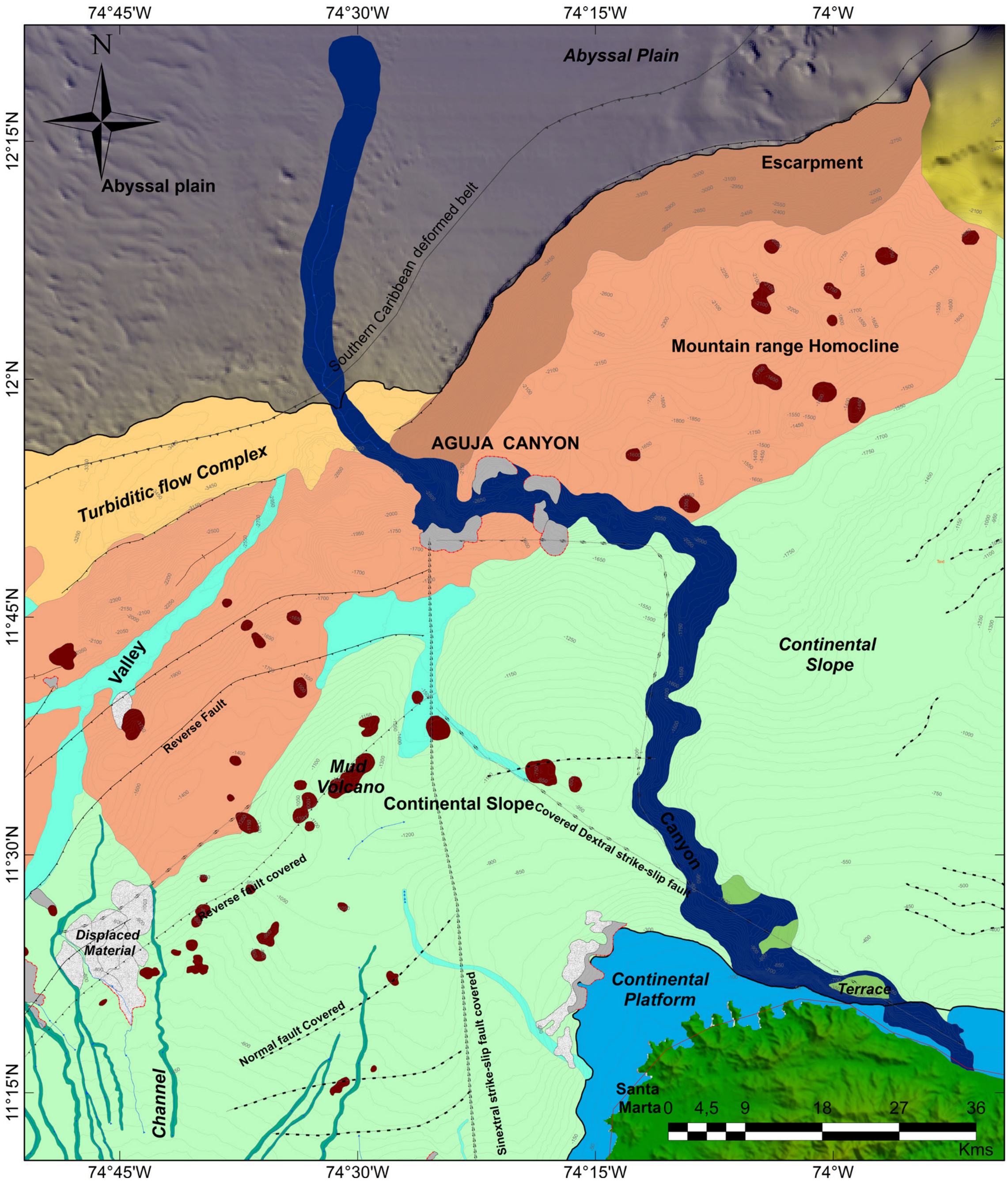

Fig. 6 Relief figures and faults around the Aguja Canyon and continental slope area: evidence of the variations in the direction of the main channel of the canyon. It crosses the continental margin and its final section in the Colombia basin forms a channel that is recognizable by bathymetry

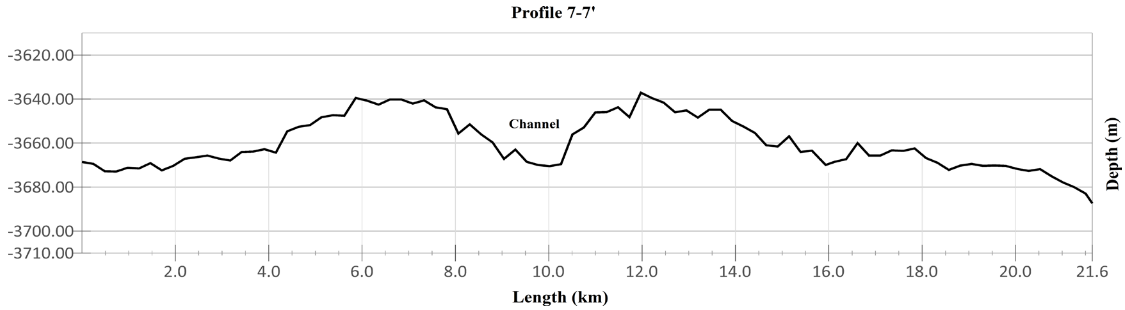

Fig. 7 A cross-sectional profile (7-7') of the Aguja Canyon in the abyssal plain area of the Colombia Basin at 74°31'37,093''W – 12°10'12,354''N, (EV 5.0). In the deepest and farthest part, the morphology of the Aguja Canyon change to a narrow 4 km channel.

https://doi.org/10.58440/ihr-30-2-a11

study area is relatively gentle, ranging from 0° to 8.5°, especially between the thin shelf boundary and the continental slope section. Moderate to high slopes are noted in the inner walls of the canyon (Fig. 5), as well as in the areas corresponding to the flanks of the elevations, which are presented as elongated homoclinal mountain ranges with northeast direction, located at the foot of the continental slope. These slopes vary between 16.5° and 45°, respectively.

The integration of data has made it possible to identify the morphology and structure of the study area. The continental shelf identified in the area is thin and it is affected by processes of flow transport and displacement material towards the continental slope. Adjacent to the continental shelf, in the continental slope, numerous mud diapirs (Isabel C. Restrepo Correa, Germán & Ojeda, 2020) and local fault systems are found; the slope is gentle and prolonged, which favors the development of thin flow channels that ends in the walls of homoclinal mountain ranges found at the foot of this continental slope, with an extension to the northeast, that is part of the Sinú accretion prism (Fig. 6).

The valley of the Aguja Canyon (Fig. 5a) presents identifiable terraces in the bathymetry, with erosive processes such as landslides and mass removal phenomena on the flanks, with the internal landslides being smaller compared to those in the areas adjacent to the canyon (Chaytor et al., 2009). A sinuous and meandriform behavior is observed mainly in the continental slope section, which changes markedly in the abyssal plain, where the bathymetric profile (Fig. 7) and the roughness model (Fig. 3d) show an important geomorphological change to a channel shape.

6 Discussion

Hay (2016) suggests that some submarine canyons may originate from rivers located in nearby continental areas, while others may be related to tectonic processes at active margins. On the other hand, Harris & Whiteway (2011) classified canyons into two main types. Type one: those that are connected to a continental river system. Type two: those that do not have a direct connection to a continental river system. According to this classification, type two canyons are more common in the continental slope compared to type ones. In the case of the Aguja Canyon, the bathymetric information does not allow a connection to be made with a nearby river or from any major fluvial system (Naranjo-Vesga et al. (2022), while its structural behavior allows it to be related as a canyon generated from tectonic processes that occurred on the continental slope.

The analysis of the structural and morphometric characteristics of the Aguja Canyon suggests important contributions in consideration of structural and connectivity factors, which are reflected in the results obtained for the study area. The Oca fault shows a downward strike displacement (Cediel et al., 2003; Lopez, 2005; Pindell et al., 1998; Vence et al., 2008), starting in the continental zone and continuing parallel to the continental shelf (Colmenares et al., 2017), plunging towards the Caribbean Sea in the head of the Aguja Canyon, where it takes a northwesterly course. Although this behavior does not allow a direct connection of the canyon with rivers or tributaries near the coastline, two rivers are identified in the vicinity: the Naranjo River and the Mendihuca River. Given the lack of precise evidence to establish a connection between these rivers and the canyon, the latter could be classified as type two according to Harris and Whiteway (2011). However, if there was a connection with any of the tributaries and structural displacements subsequently occurred, it could be considered as an abandoned or ancient canyon product of this structural process.

According to Harris et al. (2014), submarine canyons with strong geometric expressions are often associated with major faults, mainly of strike-slip. The Aguja Canyon is influenced by a significant number of strike-slip faults that control its course and behavior, primarily the FBSM and FOCA faults. These generate normal tensile satellite faults that affect the canyon's area of influence. This structural context is reflected in the morphological and morphometric features of Aguja Canyon, such as meanders, slope changes, course changes, and "V" and "U" valley shapes along its course.

On a regional scale, the displacements of the Aguja Canyon may be related to tectonic and connectivity processes in the continental zone, as well as to variations in course. These displacements could be the result of the relative displacement to the northeast of the Caribbean plate, the northern Andes plate, and the South American plate in the northern section of Colombia, according to the velocity vector model proposed by Wang et al. (2019). These tectonic processes are accompanied by a series of strike and reverse faults, such as the Bucaramanga-Santa Marta Fault System (SFBA) and the Oca Fault, whose displacements could also be influencing the behavior of the Aguja Canyon in its area near the continental shelf (Pousse Beltran et al., 2016).

7 Conclusion

The Aguja Canyon stands out as one of the prominent geographical features on the continental margin of the Colombian Caribbean after the Magdalena Submarine Fan in north direction, extending over 197 km with marked morphological expressions evident in the bathymetric surface. Its morphological characteristics suggest a structural context of compressive stress deformation, resulting from the activity and dynamics of displacement of regional and local faults in the area, as well as the subduction stress in the northern Colombian Caribbean.

Throughout its trajectory, the canyon exhibits changes in course, alternating between directions ranging from northwest to northeast, as well as variations in the profiles of the main channel, ranging from

"V" to "U" shapes. These behaviors can be attributed to the influence of strike fault systems and normal satellite faults generated by the inter-plate interaction affecting the zone, including the deep extension of the Oca fault margin, which impact the study area, along with the normal and reverse fault systems identified in this study and located around Aguja Canyon.

The geomorphological context reveals a zone of instability characterized by landslides, faults, volcanic mud activity, and channels, as well as a continental shelf with significant thinning due to the mass removal processes observed there. This dynamic points to considerable tectonic activity that has shaped the morphological character of the canyon and its variations along the continental margin.

The lack of a precise connection between the canyon and a nearby river on the mainland, as seen in bathymetry, suggests that the canyon may have been connected to one of the closest tributaries in the past, and its current disconnection could be attributed to tectonic shifts generated by the inter-plate dynamics area. This is supported by the presence of fault systems in the area, which also influence the changes on the canyon along the continental slope.

The differences in depth observed on both sides of the canyon, reflected in the profiles plotted in Fig. 5, could be related to tilting of subducted and other uplifted zones because of tectonic stresses controlled by regional and local processes, which may also be contributing to the changes in the path of the Aguja Canyon along the Colombian continental margin.

Acknowledgements

This publication is made with the support of the General Maritime Directorate, the Center for Oceanographic and Hydrographic Research of the Caribbean, Colombian Geological Survey and the Petroleum Information Bank, who provided the bathymetric and 2D seismic used to provide new information to the structural context of the Aguja Canyon.

References

Arturo, R. F. (2009). La morfología fluvial y su incidencia en la estabilidad de las obras viales. VIII *Congreso Internacional Obras de Infraestructura Vial, ICG, Lima*. https://www.imefen.uni.edu.pe/Temas_interes/ROCHA/Morfologia_fluvial_y_su_influencia.pdf (accessed 1 October 2022).

Burke, K., Cooper, C., Dewely, J., Mann, P. and Pindell, J. (1984). Caribbean Tectonics and Relative Plate Motions. In R. B. Bonini, R. B. Hargraves and R. Shagan (Eds.), The CARIBBEAN – South American *Plate boundary and Regional Tectonics* (pp. 31–63). Geological Society of America Memori, 162. https://doi.org/10.1130/MEM162-p31

Cadena, A. F. and Slatt, R. M. (2013). Seismic and sequence stratigraphic interpretation of the area of influence of the Magdalena submarine fan, offshore northern Colombia. *Interpretation, 1(*1), pp. 323–344. https://doi.org/10.1190/INT-2013-0028.1

Cediel F., R. Shaw y C. Cáceres. 2003. Tectonic assembly of the northern Andean Block. In C. Bartolini, R. T. Buffler and J. Blickwede (Eds.), *The Circum-Gulf of Mexico and the Caribbean: Hydrocarbon Habitats, Basin Formation and Plate Tectonics* (pp. 815–848). https://doi.org/10.1306/M79877C37

Chaytor, J. D., ten Brink, U. S., Solow, A. R. and Andrews, B. D. (2009). Size distribution of submarine landslides along the US Atlantic margin. *Marine Geology, 264*(1-2), pp. 16–27. https://doi.org/10.1016/j.margeo.2008.08.007

Colmenares, F., Mesa, A., Roncancio, J., Arciniegas, E., Pedraza, P., Cardona, A. and Vargas, A. (2007). Geología De La Planchas 11, 12, 13, 14, 18, 19, 20, 21, 25, 26, 27, 33 Y 34. In *Proyecto: Evolución Geohistórica de la Sierra Nevada de Santa Marta, Ministerio de Minas y Energía, Instituto Colombiano de Geología y Ministerio e Ingeominas*, pp. 71–134. https://recordcenter.sgc.gov.co/B12/23008010018162/documento/pdf/2105181621101000.pdf (accessed 13 November 2024).

Duncan R. A., and Hargraves R. B., (1984.) Plate tectonic evolution of the Caribbean region in the mantle reference frame. In W. E. Bonini, R. B. Hargraves and R. Shagam (Eds.), *The Caribbean-South American Plate Boundary and Regional Tectonics, 162* (pp. 81–93). https://doi.org/10.1130/MEM162-p81

Galindo, P. (2016). *Transtension and transpression in an oblique subduction setting: Evolution of the Bahia Basin, Colombian Caribbean margin* [Doctoral dissertation, Imperial College London]. https://doi.org/10.25560/31408

Goff, J. A. (2001). Quantitative classification of canyon systems on continental slopes and a possible relationship to slope curvature. *Geophysical Research Letters, 28*(23), 4359–4362. https://doi.org/10.1029/2001GL013300

Harris, P. T. and Whiteway, T. (2011). Global distribution of large submarine canyons: Geomorphic differences between active and passive continental margins. *Marine Geology, 285,* pp. 69–86. https://doi.org/10.1016/j.margeo.2011.05.008

Harris, P. T., Barrie, J. V., Conway, K. W. and Greene, H. G. (2014). Hanging canyons of Haida Gwaii, British Columbia, Canada: Fault-control on submarine canyon geomorphology along active continental margins. *Deep Sea Research Part II: Topical Studies in Oceanography, 104*, pp. 83–92. https://doi.org/10.1016/j.dsr2.2013.06.017

Hay, W. W. (2016). Submarine Canyons. In J. Harff, M. Meschede, S. Petersen, J. Thiede (Eds.), *Encyclopedia of Marine Geosciences* (pp. 807–808). Encyclopedia of Earth Sciences Series, Springer, Dordrecht. https://doi.org/10.1007/978-94-007-6238-1_150

Mantilla-Pimiento, A. M., Jentzsch, G., Kley, J. and Alfonso-Pava, C. (2009). Configuration of the Colombian Caribbean Margin: Constraints from 2D seismic reflection data and potential fields interpretation. *Subduction zone geodynamics, Springer, Berlin, Heidelberg,* pp. 247–272. https://doi.org/10.1007/978-3-540-87974-9_13

Naranjo-Vesga, J., Paniagua-Arroyave, J. F., Ortiz-Karpf, A., Jobe, Z., Wood, L., Galindo, P. and Mateus-Tarazona, D. (2022). Controls on submarine canyon morphology along a convergent tectonic margin. *The Southern Caribbean of Colombia. Marine and Petroleum Geology, 137,* 105493. https://doi.org/10.1016/j.marpetgeo.2021.105493

Pindell, J., George, R., Jr. Kennan, L., Higgs, R. and Cristancho, J. (1998). *The Colombian Hydrocarbon Habitat: Integrated Sedimentology, Geochemestry, Paleogeographic Evolution*. Geodynamics, Petroleum Geology, and Basin Analysis, Appendix 1, Text part 2 of 2: Plate Kinematics of plates affecting the evolution of Colombia, and Appendix 2, Text part 2 of 2: Synopsis of the evolution of the Caribbean Region. Tectonic Analysis, Inc. in research collaboration with Ecopetrol.

Pousse Beltran, L., Pathier, E., Jouanne, F., Vassallo, R., Reinoza, C., Audemard, F., ... and Volat, M. (2016). Spatial and temporal variations in creep rate along the El Pilar fault at the Caribbean-South American plate boundary (Venezuela). *Journal of Geophysical Research*: Solid Earth, 121(11), 8276–8296.

Rangel-Buitrago, N., Idárraga-García, J., and INVEMAR. (2010). Geología general, morfología submarina y facies sedimentarias en el margen continental y los fondos oceánicos del mar Caribe colombiano. In INVEMAR (Eds.), *Biodiversidad del Margen Continental del Caribe colombiano* (pp. 29–51). https://www.researchgate.net/publication/261154499_Geologia_general_morfologia_submarina_y_facies_sedimentarias_en_el_margen_continental_y_los_fondos_oceanicos_del_mar_Caribe_Colombiano (accessed 13 November 2024).

Restrepo-Correa, I. C. and Ojeda, G. Y. (2010). Geologic controls on the morphology of La Aguja submarine canyon. *Journal of South American Earth Sciences, 29*(4), pp. 861–870 https://doi.org/10.1016/j.jsames.2010.07.001

Ross, M. I., and Scotese, C. R. (1988). A hierarchical tectonic model of the Gulf of Mexico and Caribbean region. *Tectonophysics, 155*(1-4), pp. 139–168. https://doi.org/10.1016/0040-1951(88)90263-6

Taboada, A., Rivera, L., Fuenzalida, A., Cisternas, A., Philip, H., Bijwaard, H., Olaya, J. and Rivera, C. (2000). Geodynamics of the Northern Andes: subductions and intra-continental deformation (Colombia). *Tectonics, 19(5)*, pp. 787–813. https://doi.org/10.1029/2000TC900004

Veloza, G., Styron, R., Taylor, M. and Mora, A. (2012). Open-source archive of active faults for northwest South America. *Gsa Today, 22*(10), pp. 4–10. https://doi.org/10.1130/GSAT-G156A.1

Vence, E. M. (2008). *Subsurface basement, structure, stratigraphy, and timing of regional tectonic events affecting the Guajira margin of northern Colombia* [Master of Science Thesis, Universidad of Houston, Texas]. https://doi.org/10.1190/int-2020-0016.1

Wang, G., Liu, H., Mattioli, G. S., Miller, M. M., Feaux, K. and Braun, J. (2019). CARIB18: A stable geodetic reference frame for geological hazard monitoring in the Caribbean region. *Remote Sensing, 11*(6), p. 680. https://www.mdpi.com/2072-4292/11/6/680

Authors' biographies

Yerinelys Santos Barrera is a geological Engineer from the Pedagogical and Technological University of Colombia in 2008. She completed a specialization in Geomatics in 2011. Since 2012, she has been part of the Oceanographic and Hydrographic Research Center of the Caribbean (CIOH) and the National Hydrographic Service (SHN), where she serves as a lead researcher in marine geology, focusing on the geomorphological characterization of the seabed in the Caribbean and Pacific. Her main research activities include the analysis and interpretation of hydroacoustic data, as well as geophysical variables such as seismic, gravimetry, and magnetometry, aimed at understanding the structural deformation processes of the seafloor.

Yerinelys Santos Barrera

María Fernanda Calderón Grande graduated as a geologist from the Industrial University of Santander, began her career contributing to various projects for the Colombian Petroleum Institute (ICP). Following this experience, she completed further studies in Geographic Information Systems (GIS), expanding her expertise in spatial-temporal analysis, cartography, database management, spatial statistics, organic petrography, sedimentology, stratigraphy, and geochemistry. Since 2021, she has been a member of the Marine Geology research group at the Caribbean Oceanographic and Hydrographic Research Center, where she contributed to a deep-water multibeam hydrographic survey off the coast of La Guajira and a sub-bottom profiler survey for the National Hydrocarbons Agency. Currently, she applies her experience to the development of geomorphological mapping of the Colombian seafloor.

María Fernanda Calderón

Eliana Gutiérrez Rincón

Eliana Gutiérrez Rincón obtained her Master's degree in Geophysics from the Industrial University of Santander (Colombia). She specializes in marine geophysics, focusing on submarine geomorphology and underwater geo-hazards. Her professional career began at the Agustín Codazzi Geographic Institute, where she was involved in the geomorphological interpretation of Colombia's territory using remote sensing imagery. She then worked at the Colombian Petroleum Institute, interpreting subsurface geobodies based on geophysical data. Subsequently, she contributed to scientific marine research at the Caribbean Oceanographic and Hydrographic Research Center (CIOH), part of the Colombian Directorate General of Maritime Affairs (DIMAR). Her research includes the study of underwater geo-hazards and submarine geomorphology, with a focus on applying geophysical methods to understand and mitigate geological risks in coastal and offshore environments.

Johanna P. Vargas Morales

Johanna P. Vargas Morales graduated as a geologist from the Industrial University of Santander in 2014, she has experience in coordinating projects in applied geophysics for exploration and cartographic development. Since 2023, she has been part of the marine geology research team at the Caribbean Oceanographic and Hydrographic Research Center and the Hydrographic Service of Colombia, where she focuses on analyzing seabed geophysical data to create structural feature maps and geomorphological units of Colombian maritime territory.

https://doi.org/10.58440/ihr-30-2-a11