UN OCÉANO, UN FUTURO

IV Simposio Internacional de Ciencias del Mar
11 - 13 Junio de 2014 Las Palmas de Gran Canaria

1914-2014 CENTENARIO INSTITUTO ESPAÑOL DE OCEANOGRAFÍA

MORPHOLOGICAL FEATURE ANALYSES OF THE AVILÉS CANYON SYSTEM

Gómez Ballesteros, M.[1(*)], Druet, M. [1], González-Pola, C. [2], Sánchez, F. [3], García-Alegre, A. [3], Arrese, B. [1], and Acosta, A. [1]

1) Instituto Español de Oceanografía. C/ Corazón de María 8, 28002 Madrid (Spain). 2) Instituto Español de Oceanografía, C.O. de Gijón, Av. Príncipe de Asturias 70 bis, 33212 Gijón (Spain). 3) Instituto Español de Oceanografía, C.O. de Santander, Promontorio San Martín s/n, 39080 Santander (Spain). (*) Corresponding author: maria.gomez@md.ieo.es

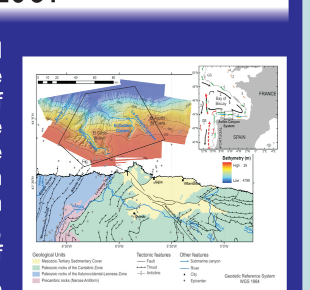
PROJECT

Morphological analysis was carried out on the north margin of Iberian Peninsula, in the Avilés Canyon System (ACS) a complex, structurally-controlled canyon and valley system (Gómez Ballesteros et al., 2014). Crossing the Cantabrian continental margin, from the shelf to the abyssal plain, is excavated the ACS between 6 º 50'W - 5 º 20' W and 43 º 40' -44 º 20' N. This region is part of the north compressive continental margin of the Iberian Peninsula (Boillot et al., 1979; Thinon et al., 2001; Gallastegui et al., 2002) and its morphology, especially the trace of the canyons that goes through the margin, is strongly influenced by the structural processes indicating a tectonic-controlled drainage pattern of the canyons. The ACS is constituted by three main canyons of different morphostructural character. They are, from east to west: La Gaviera Canyon, El Corbiro Canyon and Avilés Canyon. In addition to this ACS, a new canyon has been surveyed: Navia Canyon. Courses of submarine canyons converge at the foot of slope, where the transition to the abyssal plain occur very smoothly.

The water masses present in the study area are varieties (see Van Aken, 2000a, 2000b, Lavin et al., 2006 for recent reviews) from surface to bottom (Fig. Location Map): (1) The Eastern North Atlantic Central Water (ENACW) that extends from the base of the winter mixed layer (200 m) to depths of around 500-600 m. (2) The Mediterranean Outflow Water (MOW), found down to depths of about c.a. 1400 m (main core at 1000 m). (3) The Labrador Sea Water (LSW) enters the Bay of Biscay from the northwest (Pingree, 1973; Paillet et al., 1998) and the main core lies at 1800 m. (4) the North Atlantic Deep Water (NADW) is found, a water mass resulting from the mixture of different water sources mainly of Arctic origin and even an Antarctic component.

METODHOLOGY

Several datasets have been used for the present study, which were acquired within the framework of INDEMARES project. The study the geomorphologic features of the canyon is based on multibeam bathymetry, parametric system Topas high resolution profiles, sedimentological analyses of boxcore samples and submarine photographs. A high-resolution bathymetric map was obtained with the Kongsberg Simrad EM 300 multibeam system.



LOCATION MAP

The area of the Cantabrian margin studied during the present investigation extends from 43º 37.60'N to 44º 18.37'N in latitude and from 006º 46.75'W to 005º 18.70'W in longitude, with depths ranging from 40 to about 200-300 m on the Continental Shelf to more than 4700 m on the Abyssal Plain.

The geomorphologic detailed analysis is focused on swath bathymetry data and derivative products as shaded relief, and backscatter maps. The backscatter data obtained from multibeam data were processing with a Geocoder modul from Feldermaus software package. The seismic profiles were collected using 3.5 kHz topographic parametric source, TOPAS PS 18. The data were processing by standard seismic processing Topas packages software, design specially for the digital acquisition, processing and store.

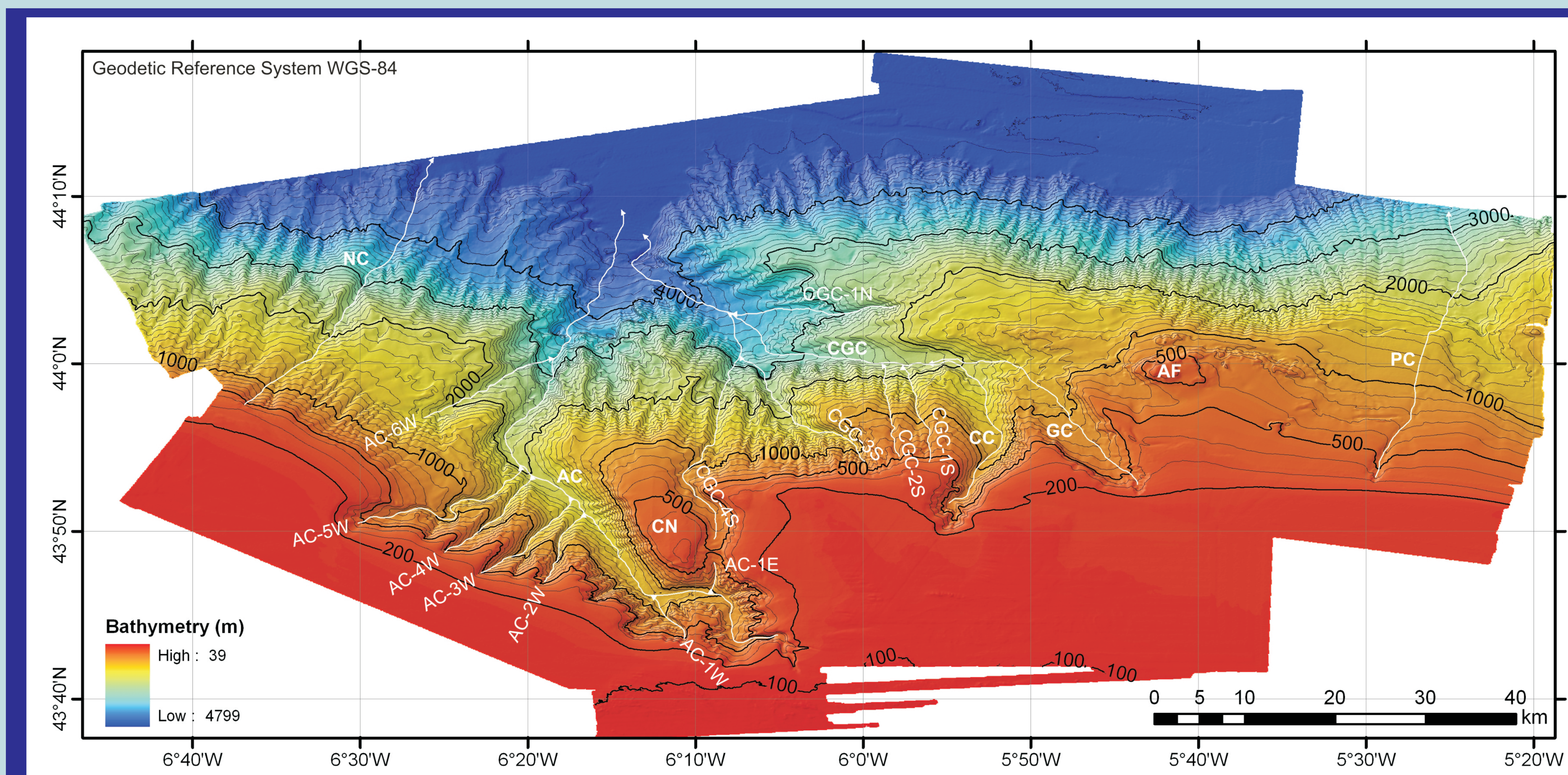


Figure 2 : Shaded bathymetric map of the study area with indication of the toponymy of canyons. CN = El Canto Nuevo marginal platform ; AF = El Agudo de Fuera High ; PC = Proto-canyon. AC = Avilés canyon. GC = Gaviera canyon. CB = Corbiro Canyon. NC = Navia canyon.

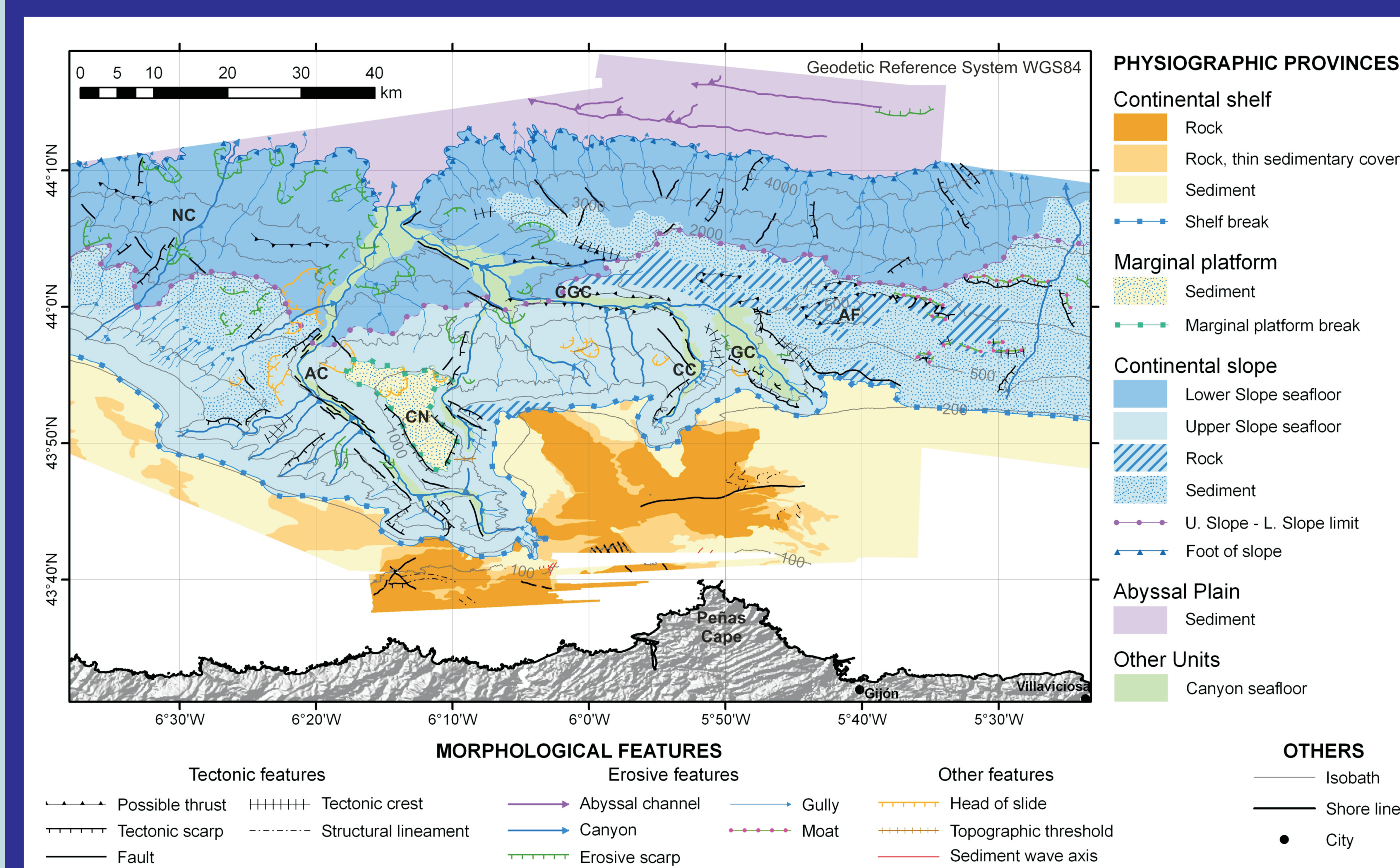


Figure 3 : Geomorphologic interpretation map of the ACS area

MORPHOLOGICAL ANALYSIS

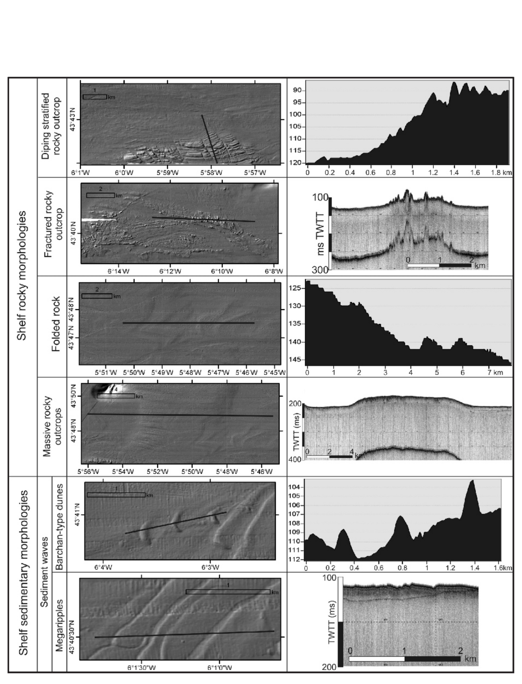


Figure 4: Sedimentary and rocky morphologies

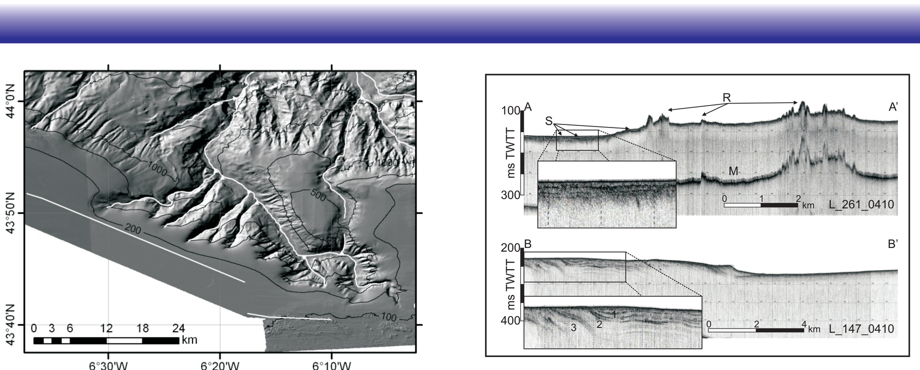


Figure 5: Upper panel: Shaded relief map showing the western part of the continental shelf, with indication of the toponymy of canyons. Ilmination from the NW. Lower panel: A-A´: Topas Profile over high relief rock outcrops (R). S = Very thin cover of unconsolidated sediment. B-B´ = Flat seafloor with high reflectivity passing at its western end to acoustic basement with 3 sedimentary units (1-3). M = Seafloor multiple.

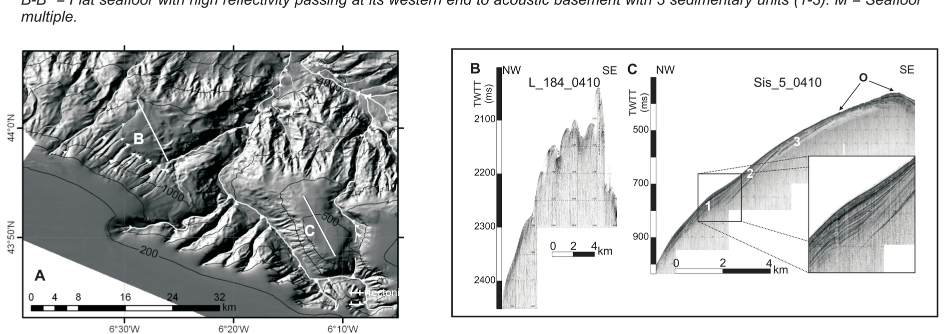


Figure 6: A: Shaded relief map of the west upper continental slope. Illumination from the NW. White dotted line = Sediment drift; White arrows = gullies and canyons; B: Topas profile L_184_0410 over sediment drift. Note the irregular surface due to erosional features. C: Topas profile Sis_5_0410 over El Canto Nuevo marginal platform. O = undulated sea-floor morphology indicating erosive processes. 1-2-3 = Sedimentary units dipping to the NW.

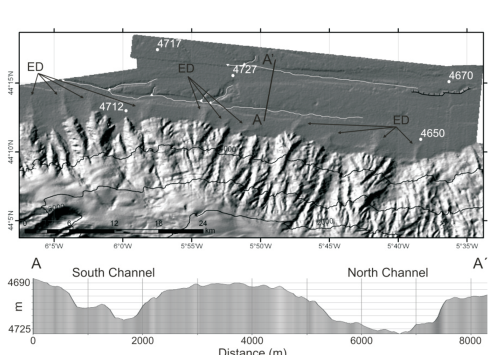


Figure 8: Upper panel: Shaded relief map of the Biscay Abyssal Plain east of ACS mouth. White arrows = North and South Asturias Deep Oceanic Channels (ADOC) axis; White dots with associated numbers = water depth in meters. A – A´ = S-N bathymetric profile. ED = eroded gully divides. Lower panel: Bathymetric S-N profile across ADOC.

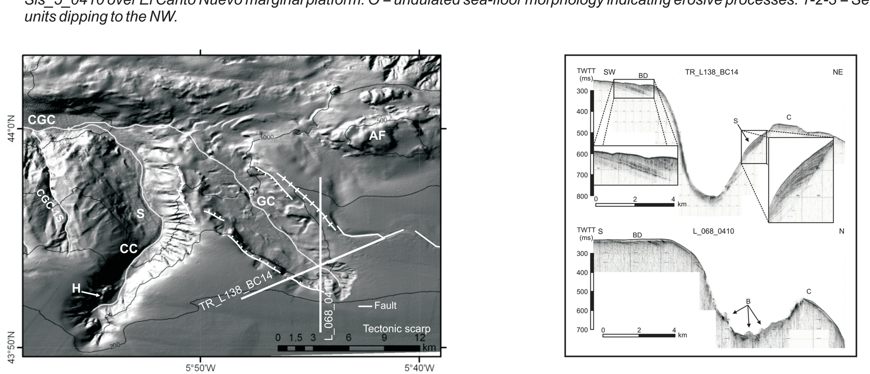


Figure 7: Upper panel: DTM of GC and CC area with indication of the toponymy of canyons. Illumination from the NW. H = Elongated rocky high; S = Sediment accumulation attached to the west wall; White lines indicate location of Topas profiles shown below. Topas profile TR_L138_BC14 : S = Sediment unit leaned against the east wall; C = Basement crest oriented S-N and parallel to GC axis. Note the strong asymmetry of the walls, the SW one being much steeper. Topas Profile L_068_0410, crossing GC S-N: B = circular mounds, possible bioherms; C = Basement crest oriented S-N and parallel to GC axis; BD = acoustic basement showing monoclinal strata dipping to the N.

1. CONTINENTAL SHELF

Shelf sedimentary morphologies: The continental shelf displays rocky outcrops of different reliefs and morphologies and a near horizontal surface corresponding to sedimentary areas with unconsolidated sediment cover or heavily eroded basement surfaces and some sedimentary features have been identified in certain areas of the continental shelf (Figure 4).

1. *Sediment waves:* Just south of AC head, and at the inner part of the shelf, there are localized areas where sediment waves showing erosional channels between.
   - i) *Megaripples* have been identified from multibeam bathymetry and high resolution seismic profiles that cut the rectilinear NE-SW oriented crest lines. The internal structure of these megaripples is defined mainly by the parallel to sub-parallel stratified facies.
   - ii) A small number of *barchans-type dunes* have been observed close to the megaripples area with same NE-SW orientation. They present a 170 m length between "horns" and 4 m in height. In cross-sections, the slip faces point eastwards with the steeper and shorter side face east.
2. *Sediment patches:* Located to the east of AC head, the continental shelf shows small patches of horizontal sedimentary zones situated between acoustic basement outcrops. Reaching the GC longitude and extending further east, sediment areas dominate on the shelf of this eastern part, surrounded by heavily eroded acoustic basement rocks.

Shelf tectonic and erosive morphologies: In the outer continental shelf, some hard bottom areas have been located consistent with tectonic origin, and differentiated into three types: *High relief rock outcrops, Massive low relief rock outcrops* with high reflectivity and *Low relief rocky outcrops* with evidence of fracturing and folding (Figure 4, 5).

2. UPPER CONTINENTAL SLOPE

Upper Continental Slope sedimentary morphologies

1. Some sedimentary areas identified through multibeam bathymetry and high resolution seismic profiles, on the continental slope. West of AC head, the presence of two *sedimentary bodies* on the Upper Continental Slope is striking, at depths ranging 1000-2000 m (Fig. 6, A).

2. On the continental slope east of the ACS (Fig. 2), other *sedimentary body* is found to a great extent over the Upper Continental Slope, in a depth range of less than 500 m to about 2000 m. It presents a convex relief with a very low gradient. The internal reflectors of the body present an internal structure on parallel and sub-parallel setup.

Upper Continental Slope tectonic and erosive morphologies:

1. *Moats:* At the north base of AF high, there is an E-W oriented moat with a ~60 m relief; at the base of an isolated rock boulder, 1300 m wide in SE-NW direction, there are two prominent moats with a relief of 60 m (SE moat) and 30 m (NW moat); on the northern side of an E-W oriented, 3500 m long linear rocky outcrop, there is a moat with 30 m relief; on the northeast side of the linear rocky outcrop west of the previous one, WNW-ESE oriented, ~4000 m long, there is a less marked moat of ~10 m relief; another moat of 30 m relief is found on the southeast side of the LR3 2000 m long linear rocky outcrop; north of the 1400 long, E-W oriented LR4, there is a moat of 10 m relief; at the base of the scarp Sc (see in Fig. 3), there is also a noticeable moat of 20 m relief.
2. *Gullies:* Several systems of gullies have been mapped in the western continental slope area with a linear pathway (Fig. 6). A total of 61gullies configured this system displayed a SW-NE trend and deepens from 500 to 1600 m water depth towards the NE. They are characterized by a main axis perpendicular to the bathymetric contours. The mean gully length is 4.9 km (range of 11.2 to 0.7 km).
3. *Navia Canyon:* a NE-SW rectilinear canyon with a V-shaped bottom, located to the west of the ACS, at a similar longitude to that of the Navia river mouth and running between two sedimentary. Its axial incision is 36.5 km long, and starts at the continental shelf break (~321 m deep), ending at the Biscay Abyssal Plain (4779 m deep) (Table 1).
4. *Proto-Canyon:* There is also a striking proto-canyon incised on the eastern part of the continental slope, eastwards from AF high that seems to be strongly influenced by tectonics, as its axial incision is rectilinear but with some abrupt direction changes.
5. *Submarine highs:* The presence of a seamount named El Canto Nuevo is located on the east slope of the AC with elongated shape on the NW-SE direction (15.4 km long, 5-6 km wide) and an approximately flat and tilted top with an area of 68 km^2 and depths ranging between 300 m and 1300 m. Its northwestern corner is affected by at least three *gravitational slides*, with recognizable scarps, and there is another *slide scarp* on its NE corner.The other remarkable structural high in the study area is El Agudo de Fuera, a rocky outcrop on the Upper Continental Slope, to the NE of GC. It has an approximate area of 40 km^2, and is elongated in an E-W direction (~16 km long, 1.5-3.5 km wide). Its surface and boundaries are irregular, with the top ~320 m depth. Associated to the north facade of AF, there is a parallel moat of ~50 m relief (Fig. 3).

3. LOWER CONTINENTAL SLOPE

The main feature that characterizes the lower continental slope is the presence of a dense and well-defined *network of gullies*, better developed on the east flank of the continental slope. East of the AC, it is 10-15 km wide, with a mean gradient of 11-12º and cut by an intricate gully network a total mapped at least 39 gullies, with a regular distribution (about 800 m between each one).

4. ABYSSAL PLAIN

The extension of the AP in the surveyed area is ~608 km^2 and includes the "triangular-shaped" mouth of the ACS in its contact with the Biscay Abyssal Plain. The most striking feature is the presence of two *deep sea channels*; Channel North and Channel South (Fig. 8), that we have named Asturias Deep Oceanic Channels (ADOC). At the FOS some eroded distal parts of the gully divides have been identified, showing a smooth and eroded morphology of the gully divide prolongation.

5. AVILES CANYON SYSTEM

The ACS includes three major submarine canyons that are: Aviles (AC), El Corbiro (CC) and La Gaviera (GC), and another twelve tributary canyons (Fig. 2, Table 1). The AC is characterized by a V-shaped bottom (Figs. 6 and 9), a well defined axial incision (~75 km long), with well differentiated walls and divided into three main sections (ACUS, ACMS and ACLS in Fig. 5). Its head is at a depth of about 128 m, reaches the abyssal plain at 4766 m (Table 1) and is extremely tectonic-influenced, being the offshore prolongation of the Ventaniella Fault zone (Boillot, et al., 1971, 1972; Gallastegui, 2000).

The CC (Fig. 2, 3) is part of the ACS. It is located between GC and AC and is characterized by a V-shaped bottom (Fig 7). It shows a pronounced axial incision at its head, less marked in its mouth. The first 12 km of the canyon (from the head) are SW-NW oriented, which then turns at a sharp angle, to show a SE-NW direction towards its mouth in CGC at a depth of 2108 m (Figs. 2 and7). Its head is indented in the shelf for more than 10 km, and its tip is located at a water depth of 176 m.

GC (Figs. 2 and 3) is located in the easternmost part of the system, characterized by a U-shaped irregular bottom, which does not exhibit a marked axial incision (Fig. 7) and shows two clearly differentiated walls. The west side is characterized by the incision of gullies (9) of different magnitude. The first one, which binds to the central gully, constitutes the start of the canyon and is the largest one. The east side clearly shows a more sedimentary character controlled by a sedimentary slope at the head, whit rocky outcrops in the form of "piano keys" and a flat roof and sharp edge.

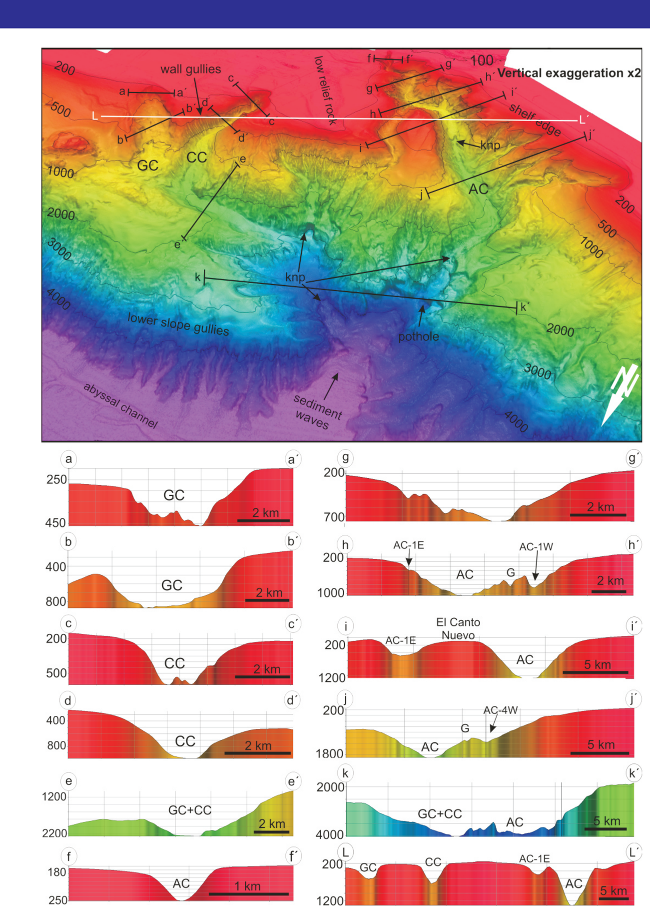


Figure 9: Upper panel: 3D view of the ACS. knp = knickpoints. Lower panel: bathymetric profiles, bathymetry shown in meters.

TABLE 1

Main morphometric characteristics of canyons and branches studied

Name	Length [1] (km)	Maximun Width (km)	Head depth[2] (m)	Conf. Depth [3] (m)	Area (km^2)	Sinuosity[4]	Gradient[5] (°)
Gaviera Canyon	23,34	6152	205	1913	76,92	1,36	3.7
Corbiro Canyon	23,26	7,828	176	2108	108,2	1,28	5.1
CGC-1S	10,32	1,89	532	2314	27,69	1,07	9.8
CGC-2S	11,86	1,972	405	2403	19,85	1,05	10.3
CGC-3S	19,21	2,457	424	3288	89,13	1,12	8.5
CGC-4S	26,85	5,36	436	3505	89,1	1,17	5.7
CGC-1N	15,17	5,84	1926	3878	61,54	1,03	6.2
AC-1E	4,64	2,731	518	1028	8,4	1,07	6.9
AC-1W	6,08	1,926	232	1167	19,04	1,09	7.1
AC-2W	9,48	2,947	343	1798	19,87	1,03	9.2
AC-3W	12,07	3,183	289	1840	38,61	1,03	7.8
AC-4W	11,8	3,442	340	1993	28,22	1,08	8.0
AC-5W	19,88	3,803	199	2017	61,58	1,20	5.8
AC-6W	18,18	2,28	468	2953	35,04	1,08	7.6
Navia Canyon	32,15	4,744	321	4779	109,79	1,08	7.5
Aviles Canyon	77,54	2,078	128	4766	784,22	1,43	4.6
Corbiro-Gaviera Canyon	58,21	9,545	806	4341	756,85	1,42	5.1

1) Total length of the main canyon/branch
2) Starting depth of the main canyon/branch
3) Depth of confluence, at which the branch joins the main canyon/depth of the main canyon at the mouth.
4) SI = channel axis length / length of the straight-line distance.
5) Mean gradient along the main canyon/branch.

CONCLUSIONS

Sedimentary processes in this part of the Asturian margin seem to be conditioned by strong hydrodynamic in the shelf, that permit the bypass of sediment to the Abyssal plain using the numerous canyons and gullies. The submarine canyons in this area are mainly controlled by tectonic activity. The ACS, which includes from east to west GC, CC and the AC, shows a clear tectonic imprint in its actual morphology. Sharp bends near 90º of their axes are indicative of their structural origin. GC, CC and the AC have an initial origin related with NW-SE structures (as Ventaniella Fault zone), but GC and CC are affected also by E-W structures (thrusts).. Presence of important gravity sliding is also remarkable in the across-slope erosive process. The existence of two Deep Oceanic Channels in the small area surveyed of the Biscay Abyssal Plain (ADOC, Figs. 12 and 13) of 30-45 m relief, running parallel to FOS, can be related to the distal fan of the Cap Ferret – Capbreton turbiditic system described by Faugères et al., 1998 and Ercilla et al., 2008. Finally, the sedimentary load transported to the abyssal plain is mobilized westwards by the presence of the ADOC, been the deep currents responsible of sediments

Acknowledgments

The study of Avilés Canyon System has been done within the framework of the EU-funded Nature +LIFE INDEMARES Project (07/NAT/E/000732). The Fundación Biodiversidad (Spanish Ministry of Agriculture, Food and Environment) was responsible for the coordination of this project, involving different scientific institutions and NGO's.We are indebted to the Captain, officers and crew of R/V Vizconde de Eza (Spanish General Secretariat of Fisheries, SGP) for their efforts during the cruises of the INDEMARES-AVILÉS project north of Asturias. We also wish to thank SGP, providers of ship time and technical support, and the members of the Spanish Oceanographic Institute (IEO) who participated in the cruises.

References

Boillot, G., Dupeuble, P.A., Lamboy, M., d'Ozouville, L., Sibuet, J.C., 1971. Structure et historie Géologique de la Marge Continentale au Nord de l'Espagne (entre 4º et 9º W), In : Debyser, J., Le Pichon, X., Montadert, L. (Eds.), Historie structural du Golfe de Gascogne. Publications de l'Institut Français du Pétrole. Collection du Colloques et Séminaires. Tome 2, V, V.6. 1-52.

Boillot, G., Dupeuble, P.A., Hennequin-Marchand, I., Lamboy, M., Lepetre, J.P., 1972. Carte géologique du plateau continental nordespagnol entre le canyon de Capbreton et canyon d'Aviles. Bull. Soc. Geol. Fr. 7 (2–3), 367–391 XV.

Ercilla, G., Casas, D., Estrada, F., Vázquez, J.T., Iglesias, J., García, M., Gómez, M., Acosta, J., Gallart, J., Maestro-González, A., Marconi Team, 2008. Morphosedimentary features and recent depositional architectural model of the Cantabrian continental margin. Mar. Geol. 247, 61–83.

Faugères, J.C., Imbert, P., Mézerais, M.L., Crémer, M., 1998. Seismic patterns of a muddy contourite fan (Vema Channel, South Brazilian Basin) and a sandy distal turbidite deep-sea fan (Cap Ferret system, Bay of Biscay): a comparison. Sedimentary Geology, 115. 81-110.

Gallastegui, J., Pulgar, J.A., Gallart, J., 2002. Initiation of an active margin at North Iberian continent-ocean transition. Tectonics, 21 (4), 15-1/15-13.

Gómez-Ballesteros, M., Druet, M., Muñoz, A., Arrese, B., Rivera, J., Sánchez, F., Cristobo, J., Parra, S., García-Alegre, A., González-Pola, C., Gallastegui, J., and Acosta, J., 2014. Geomorphology of the Avilés Canyon System, Cantabrian Sea (Bay of Biscay). Deep Sea Research II, in press.

Lavin, A., Valdes, L., Sánchez, F., Abaunza, P., Forest, J., Boucher, P., Lazure, P., Jegou, A.M., 2006. The Bay of Biscay. The encountering of the ocean and the shelf. In: Robinson and Brink (Eds.), The Seas, Harvard Press, pp. 933-1001.

Paillet, J., Arhan, M., McCartney, M.S., 1998. Spreading of Labrador Sea Water in the eastern North Atlantic. J. Geophys. Res. 103, 10223-10239.

Pingree, R.D., 1973. A component of Labrador Sea Water in the Bay of Biscay. Limnology and Oceanography, 18. 711-718.

Van Aken, H.M., 2000a. The hydrography of the mid-latitude Northeast Atlantic Ocean. Part I: The deep water masses. Deep-Sea Res. I 47, 757-788.

Van Aken, H.M., 2000b. The hydrography of the mid-latitude Northeast Atlantic Ocean. Part II: The intermediate water masses. Deep-Sea Res. I 47, 789-824.