Trabajos de Geología, Universidad de Oviedo, 29 : 260-265 (2009)

Oviedo (Spain)
1-3 July 2008
International Meeting of Young Researchers in Structural Geology and Tectonics
ORSGET

Structure and tectonic evolution of the eastern Cantabrian margin: results from the MARCONI multichannel seismic data

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Abstract: The Bay of Biscay formed during the Cretaceous as a consequence of the opening of the North Atlantic. The convergence between the Iberian and Eurasian plates during the Cenozoic resulted in its partial closure and the building of the Pyrenean-Cantabrian Mountains on land. Most of this deformation and shortening at the south-easternmost part of the Bay of Biscay concentrated in the North Iberian Margin, making this area a unique place to study the initial stages of deformation in a passive margin. In summer 2003, 11 deep seismic reflection profiles were acquired in the MARCONI seismic experiment, providing a new 3D image of the structure of the bay. This new dataset shows that the structure of this margin is characterized by a thick sequence of Mesozoic-Cenozoic sediments (up to 4 s TWT, up to 6 km) partially deformed by northward vergent thrusts and related folds. The interpretation includes three sedimentary sequences separated by unconformities that correspond to the pre-, syn- and post-tectonic units. A Mesozoic sedimentary basin imaged has indications of a Cenozoic tectonic inversion. Evidences of lateral and/or transfer structures coincide with two important N-S striking submarine canyons. The overall crustal structure of the south-easternmost part of the Bay of Biscay has been interpreted as a thinned continental or transitional crust underthrusted to the S below the extremely steep North Iberian continental slope.

Keywords: Bay of Biscay, Cantabrian margin, deep seismic reflection, MARCONI project.

From Permian to Cretaceous times, the opening of the Atlantic and Tethys oceans originated the passive margins surrounding the old Variscan European Massif of Iberia. In the NW of the Iberian Peninsula, several extensional episodes (mainly during the Permo-Triassic and later during the Late Jurassic-Early Cretaceous) ended up in the Late Cretaceous with the formation of new oceanic crust in the Bay of Biscay. These extensional processes formed the Cantabrian margin and isolated the Iberian plate (Srivastava *et al.*, 1990). During the Cenozoic, the approaching movement between the Iberian and European plates has been estimated around 150 km (Olivet, 1996) and transformed the plate boundary into an active margin whose shortening gave rise to the Pyrenean-Cantabrian realm and considerable deformation of the Cretaceous passive margin.

The Cantabrian continental margin is characterized by a narrow continental platform (30-40 km), a short and steep slope (10-12°), several deep cutting canyons, the presence of several marginal platforms (Le Danois, Santander, Ortegal, Landas) and a deep trench at the foot of the slope filled with sediments. These characteristics are a consequence of the Alpine compressional processes, which differentiated the

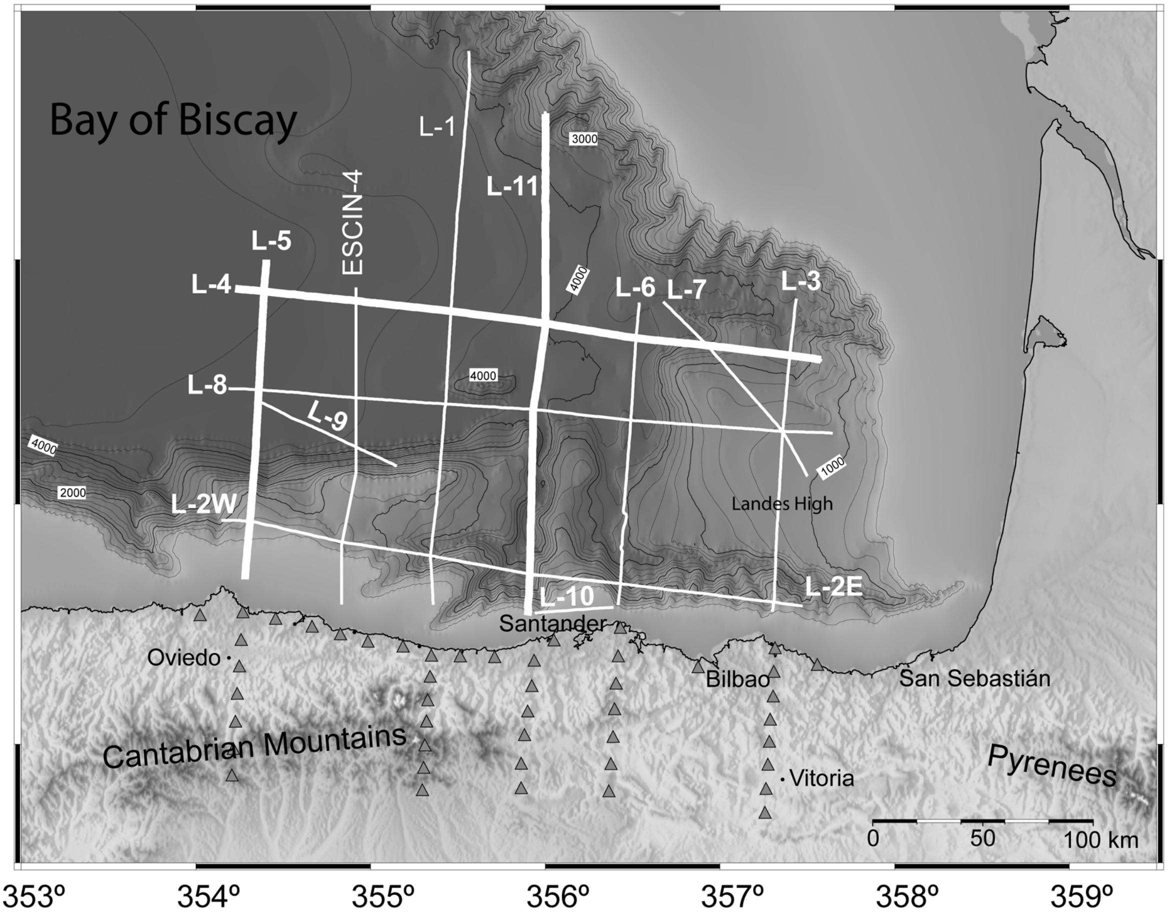

Figure 1. Location map of the MARCONI profiles in the Bay of Biscay.

Cantabrian margin from its conjugate in the north, the Armorican margin in France, where the Mesozoic basins have been only slightly inverted. The limited character of the deformation suffered by the Cantabrian margin makes this area a privileged setting to study the first stages of deformation along a passive margin evolving to an active one.

In summer 2003, the seismic experiment MARCONI (Acronym for MARgen COntinental Nor-Iberico) permitted the acquisition of 11 deep seismic reflection profiles using the Spanish R.V. Hespérides, providing a new 3D image of the crustal structure in the SE sector if the Bay of Biscay.

Acquisition and processing of the data

During the sea cruise, more than 18,000 km of seismic data were registered along 11 profiles (4 E-W-striking, 5 N-S-striking and 2 oblique) with a water layer depth variable between 100 and 5000 m (Fig. 1). The acquisition parameters have been imposed by the Hespérides equipment and also for

SOURCE		
Type: Air-guns BOLT	Power: 1935 in^3 (L2W, 7,8,11), 2435 in^3 (L2E, 3,4,5,6) and 2690 in^3 in L1	
Depth: 9 m.	Shot spacing: 40 s, aprox. 100 m	
STREAMER		
Type: Teledyne	Length: 2400 m.	Depth: 10 m.
Group number: 96	Group interval: 25 m.	Group length: 25 m.
RECORDS		
Length: 18 ms	Sampling interval: 4 ms	Navigation: Differential GPS

Table 1. Acquisition parameters of MARCONI deep seismic reflection data.

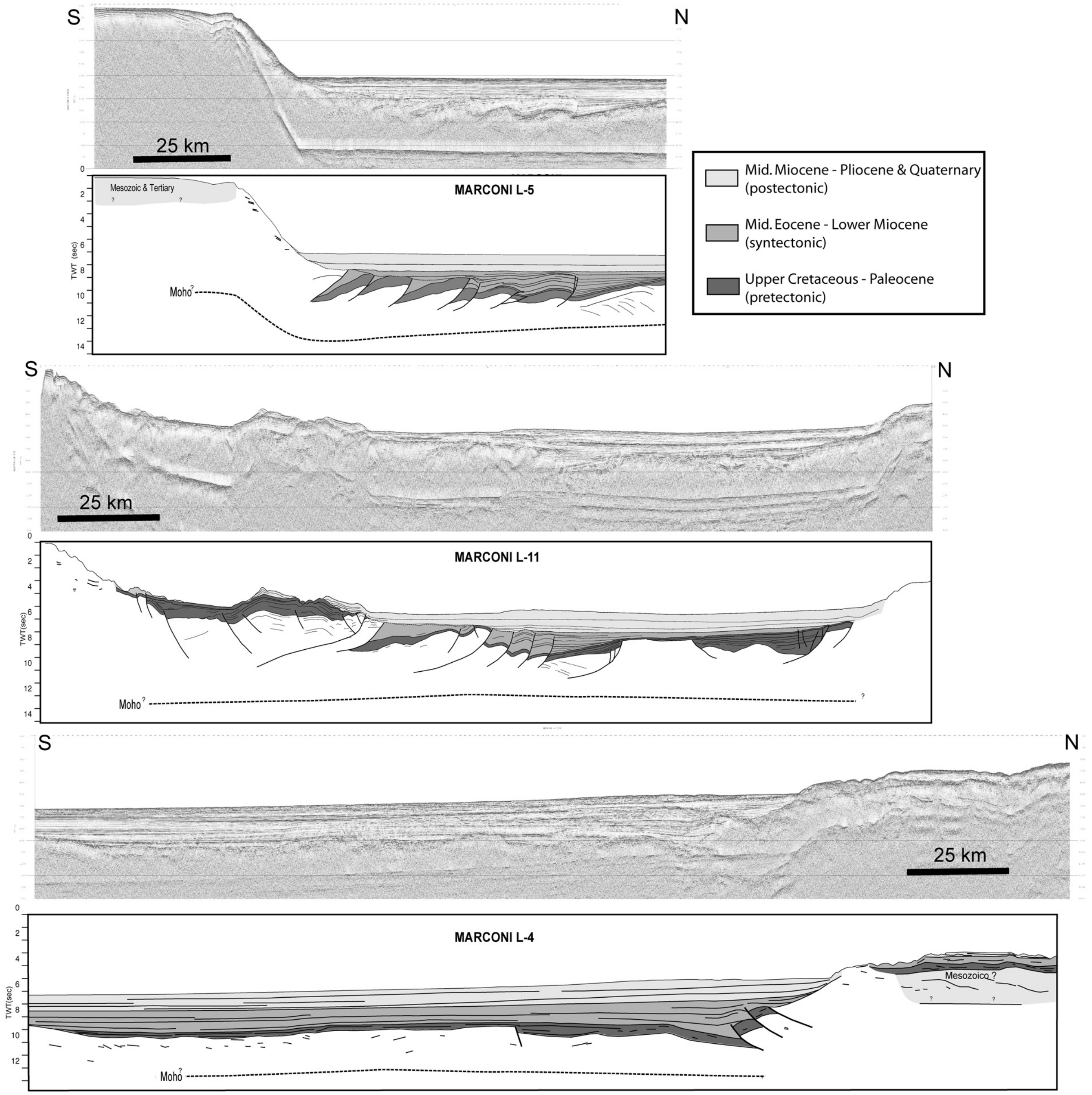

Figure 2. Seismic reflection profiles and interpretations (Marconi L-5, L-11 and L-4). Moho depth from Pulgar *et al.* (1996), Fernández-Viejo *et al.* (1998) and Ruiz (2007).

the simultaneous acquisition of refraction/wide angle profiles using OBS/OBH at sea and land stations (Table 1).

Data have been processed following a general routine for marine seismic data with the Globe Claritas software (Table 2). An example of the seismic profiles can be observed in figure 2. In areas with particular structural interest a pre-stack depth migration has been performed using Sirius from GX Technologies in order to obtain the real geometry and depth of structures.

Description and interpretation

The most outstanding structural features are those at the foot of the continental slope in the abyssal plain of the Bay of Biscay where the seismic profiles provide a good image of the sedimentary pile and the

PRE-STACK
1) Resampling 8 ms
2) Data editing
3) Geometry. CDP spacing 12.5 m, Fold: 12
4) Amplitude balancing
5) Filtering
6) Common offset section
7) Deconvolution in shot domain
8) CMP sorting
9) Brute stack
10) Velocity analysis, semblance and constant velocity stacks
11) Normal move out correction
12) STACK
POST-STACK
13) Trace mixing (7 traces, weigths:1,3,5,7,5,3,1)
14) Mute of water layer
15) Time migration
16) AGC for plotting

Table 2. General processing flow for MARCONI deep seismic reflection data.

deformation structures. Figure 2 shows two of the N-S profiles (L-5 and L-11) and one of the E-W profiles (L-4). Due to the lack of well log data at those depths or any other direct geological information, it is not possible to date or correlate the reflections with known geological formations. However, the detailed interpretation of reflections allowed us to define three stratigraphic sequences (pre-, syn-, and post-tectonic) related to the Alpine deformation. The tentative ages of the sequences, which are based on known ages of similar sequences studied inland and well data from the Cantabrian platform and Landes High are as follows: upper Cretaceous (or even younger) to Paleocene for the pretectonic sequence, Eocene to lower Miocene for the syntectonic sequence, and upper Miocene to present for the postectonic one.

Line 5 runs N-S across the Cantabrian continental platform and the continental slope towards the centre of the Bay of Biscay. Line 11, located further east, also runs N-S and reaches the bottom of the Armorican continental slope in the conjugate Armorican margin (Fig. 1).

Although the resolution of the profiles is not good enough along the continental slope, previous studies, which are also based on seismic exploration profiles, have shown that most of the Alpine deformation in the margin concentrates along that area. A set of N-vergent thrusts developed and they are responsible for the shortening, uplift and steepness of the slope (Gallastegui *et al.*, 2002).

The uppermost sedimentary sequence is almost tabular (≈1.2 s (TWT) thick). It is almost undeformed and it is characterized by sub-horizontal and parallel reflections that can be traced for distances as long as 90 km. We have interpreted it as the postectonic sequence that onlaps both continental slopes to the north and south and postdates the structures that affect the lower deformed sequence.

The syntectonic sequence (between 7 and 9.5 s TWT) shows significant lateral changes in the seismic facies and thickness. This sequence deposited during the emplacement of N-vergent thrusts and associated folds. As a result, the reflections are disrupted and folded in the area close to the continental slope. Local angular and progressive unconformities also developed. The real geometry of the structures and the angular relations between reflections, which are typical of growth structures, can be seen in Line-5 obtained after prestack depth migration (Fig. 3).

The geometry of this band of deformed sediments, that bounds the bottom of the continental slope, is similar to that of an accretionary prism and it has been interpreted previously in other parallel sections along the plain (Álvarez-Marrón *et al.*, 1996, 1997; Gallastegui *et al.*, 2002). The band extends about 70 km to the north in this profile and almost reaches the centre of the Bay where it changes to a wedged shape sequence. Beds thin rapidly to the north and reflections onlap in that direction onto the lower pretectonic sequence. This sequence is almost undeformed in the northern margin of the Bay where it lays nearly conformably on the pretectonic sequence (see L-4 in figure 2).

The lowermost sequence is pretectonic. In the south it forms a band of high amplitude reflections (0.2-0.3 s TWT) that is deformed at the same time as the overlying sequence. It lies on a diffractive basement and shows no lateral thickness variations. However, the thickness varies northwards and, despite the lower resolution of the data, a sedimentary basin bounded by normal faults has been imaged. This basin is filled by sediments from the rifting stage related to the opening of the Bay of Biscay. The

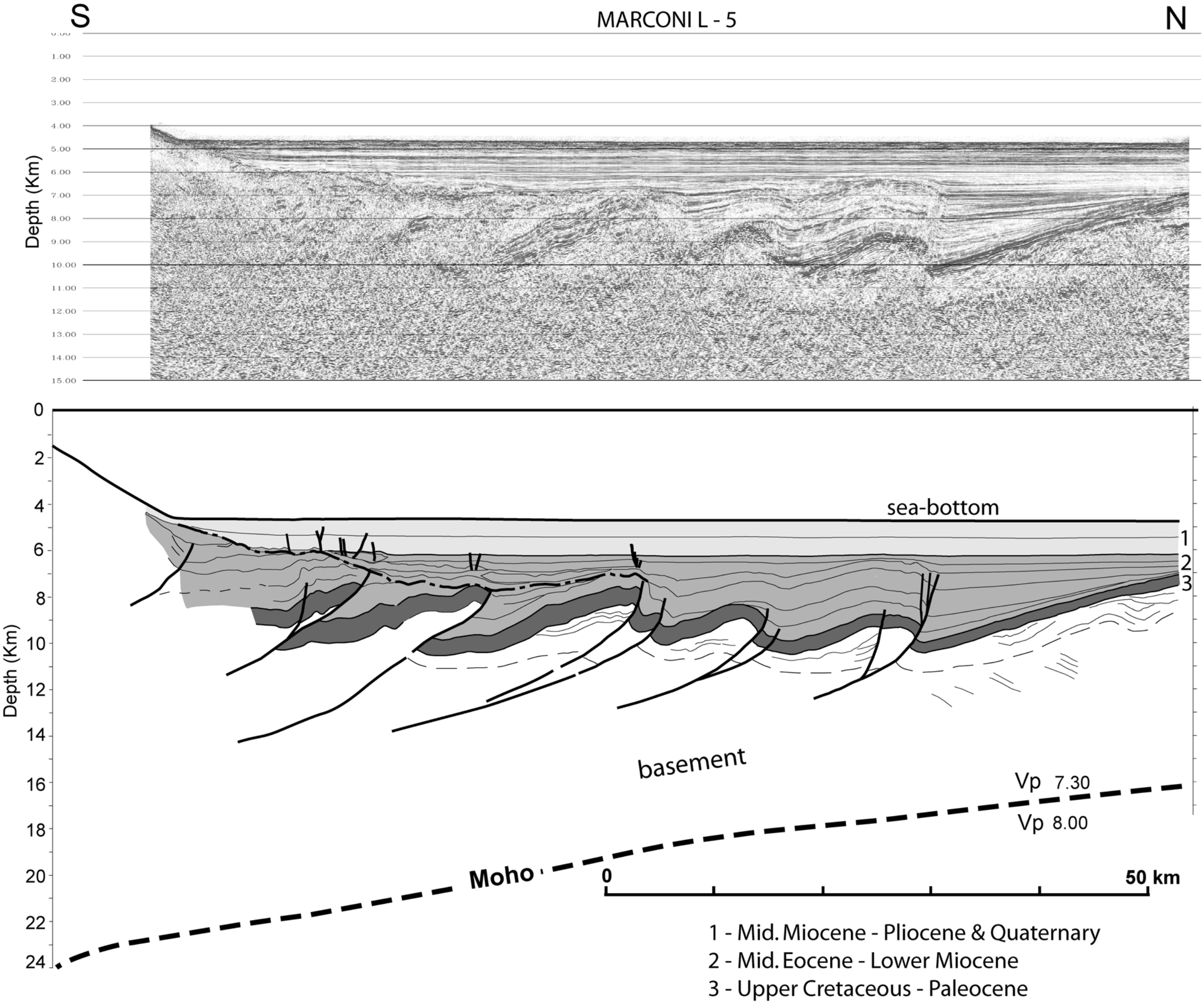

Figure 3. Pre-stack depth migrated profile Marconi L-5 and interpretation. Vp (P-wave velocity) and Moho depth from Ruiz (2007).

presence of Mesozoic basins supports the continental nature of the crust in this corner of the bay.

There is no image of a reflective Moho in the profiles due to the limited energy of the seismic source aboard the vessel and the strong water bottom multiple whose position is approximately coincident with the expected Moho location. The interpreted Moho in the profiles (Fig. 2) is derived from previous wide-angle reflection experiments (Pulgar *et al.*, 1996; Fernández-Viejo *et al.*, 1998) and the study of OBS data from this project (Ruiz, 2007).

Discussion and conclusion

The overall structure of the area is characterized by an important E-W area of deformation (thrusts and folds) at the foot of the Cantabrian continental slope, which almost reaches the centre of the Bay of Biscay in some areas. Its detailed structure shows lateral E-W variations that suggest the presence of lateral N-S structures that in some cases may coincide with present-day submarine canyons that cut the continental platform and slope. The almost undeformed Armorican margin evidences the important asymmetry of the Alpine convergence in the Bay of Biscay.

Acknowledgements

We wish to thank the MARCONI Team and crew of R.V. Hespérides in the acquisition of the data and Ministry of Education of Spain for funding the MARCONI Project: REN2001-1734-C03. This work is also part of the Consolider-Ingenio 2010 Programme, under project CDS2006-0041, “Topo-Iberia”. We thank revisions by an anonymous reviewer.

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