Submarine Erosion in North Spanish Atlantic Sea

Several surveys were carried out on board the R/V <i>HespÃ©rides</i> in the north Spanish Atlantic Sea in order to obtain detailed hydrographical and geological information on the Prestige wreck area (the Galicia Bank) and the Bay of Biscay. The surveys show submarine erosion playing an important role in sculpting the morphology of these margins and deep-sea areas.

The Research Vessel (R/V) *HespÃ©rides* offers the facility of combining high and ultra-high resolution acoustic methods (multi-beam, parametric echo sounder, single-channel seismics) during oceanographic surveys. After the Prestige oil tanker sank on the Galicia Bank, a comprehensive hydrographic and geological study was carried out for engineering activities planned to control oil spilling into the sea. Similar surveys were also made in the neighbouring Bay of Biscay in order to increase understanding of the history of motion between the European and Iberian plates and the formation of the Pyrenees (Figure 1).

R/V *HespÃ©rides*
The R/V HespÃ©rides (A-33) is manned and operated by the Spanish Navy (Figure 2). It is a multi-role oceanographic research vessel that operates globally, including in ice. Her dome in the keel houses several sensors and her ice-strengthened hull is capable of breaking first-year ice up to 45cm thick at 5 knots. The research on this vessel is directed and funded mainly by the National RDI Plan and its activities are carried out mainly in the Mediterranean, the Atlantic and Antarctic Seas. The vessel is equipped with modern systems for hydrographic and geological investigations and, after mid-life upgrade in 2004, the software and hardware of these systems were improved significantly. The vessel is capable of operating in shallow to deep-sea areas. Under the auspices of the Spanish Navy it also performs distinct yet complementary activities, such as surveys for the EEZ and evaluations for extending the Spanish continental shelf.

Data Collection
The hydrographic and geological data collected in the two areas were similar. Bathymetric mapping was undertaken with a Simrad EM12 swath-bathymetry echo sounder of 12kHz and 120Â° opening, providing 81 values of bathymetry across the ship track, corrected for the geometric propagation of sound in the stratified water column. The system simultaneously recorded acoustic backscatter amplitude for each depth value. Simrad Neptune, Triton and Poseidon software was used for data processing. Ultra-high resolution (tens of centimetres) seismic profiling was carried out with the TOPAS PS 018 Simrad Parametric echo sounder, a hull-mounted seabed and sub-bottom echo sounder based on the parametric acoustic array, which operates using non-linear acoustic properties of the water. This system transmitted according to water depth, averaging about 2s (≈ 5m at cruise speeds of 5 knots) with a beam angle of approximately 5 degrees and modulated-frequency sweep of between 1.5 and 4kHz. In addition, high-resolution seismic records were collected using a sleeve-gun array (140c.i.) with a short frequency of 8s. The penetration of the acoustic signal was < 2s two-way travel time, and the resolution was tens of metres. A GeoAcoustics Sonar Enhancement System (SES) was used for acquisition and processing of seismic signals. The navigation system was differential GPS.

Prestige Wreck Area
Before the Prestige sinking on 19th November 2002 there was little high-resolution geological information of the area. What there was indicated that the wreck lay on the south-western flank of a submarine seamount named the Galicia Bank, the summit of which was at < 500m water depth (Figure 1). The stern is located at a depth of 3,565m and the bow at a depth of 3,830m (Figure 3). New high and ultra high-resolution acoustic methods employed by R/V *HespÃ©rides* have allowed detailed mapping of the features making up this complex topography.
The wreck area is characterised by a steep (up to 29Â°) structural scarp with N-S trend in the easternmost sector (Figure 3). This scarp has an irregular seafloor, with positive and negative relieves tens to hundreds of metres in scale. The negative relieves suggest gullies, while the positive relieves may be related to slope failures. The backscatter of this scarp is variable but always higher than the surroundings; this is mainly due to the outcropping of ancient consolidated deposits. The TOPAS and airgun records display a high-reflectivity surface without acoustic penetration. The absence of acoustic penetration is related to steeper slope gradients that affect the acquisition and performance of the seismic systems, and also to the consolidation of deposits. The backscatter map also reveals the location of the Prestige wreck, showing relatively high values. The stern is located on the scarp and the bow at the foot.
Westwards of the scarp, the seafloor topography is different (Figure 3). It is gentler (12 to 3Â°) and the orientation of bathymetric lines change, displaying an E-W trend. Here the common bathymetric features are elongate bodies with positive relief ranging from hundreds of meters to a few kilometres long. The TOPAS and airgun records suggest these bodies being formed by chaotic, transparent and discontinuous stratified facies, reflecting different degrees of re-mobilised material and/or grain size. Between the elongate bodies there are rectilinear corridors that run down slope, resembling gullies. These elongate bodies and gullies are prolonged up the scarp wall and/or foot and all together resemble a gully-depositional network cut distally by a relatively large NE-SW valley. The origin of this network seems to be related to erosion of the structural scarp, leading to formation of instability deposits along the foot.

Bay of Biscay
The mapping of seabed features in the Bay of Biscay comprises the Spanish continental margin (from GijÃ³n to Bilbao) and the adjacent Biscay abyssal plain, covering water depths from 50 to > 4,600m water depth (Figure 1). The new acoustic data obtained onboard the R/V *HespÃ©rides* shows that submarine erosion has sculpted the main topographic features. The seafloor of the continental shelf is characterised by an irregular, highly reflective surface which cut, folded and fractured deposits (Figure 4). Here erosion seems to have

conditioned the lack of recent sedimentation and outcropping of ancient deposits. The interplay between Alpine uplifting and multiple Pliocene-Quaternary sea-level fluctuations probably favoured sub-aereal/submarine erosion.
On the seafloor of the continental slope, with very variable gradients (≈ 1 to 30Âº) several types of feature indicative of erosion have been mapped: canyons, gullies, mass movements and furrows (Figures 4 and 5). The dimensions of these features are variable, ranging from tens of metres to a few kilometres in width, and few to tens of kilometres long. Canyons are the most prominent features in this margin. They are practically eroding the continental slope, some reaching the Biscay abyssal plain. Truncation of reflections against the canyon walls can be observed, suggesting their erosive character. A dense network of gullies mostly affects the canyon walls, resembling bad-land topography. On the other hand, several types of mass-movement in the form of slides and mass/debris flow deposits occur in the canyons and inter-canyon areas and on the walls of structural seamounts (Figure 5). These involve sediment thickness ranging from tens to hundreds of metres.
The bottom currents also contribute to erosion of the continental slope seafloor (Figure 5). Their action has led to the formation of an erosive furrow defined by a highly reflective surface that erodes and reworks the underlying deposits. This occurs at the foot of a structural seamount, paralleling its trend. The furrow, which corresponds to the zone of current flows, is about 1.3km wide, 100m deep and 45km long.
Finally, the Biscay abyssal plain also shows a great variety of erosive features at differing scales (from tens of metres to several kilometres), as turbidity channels and leveed channels, scours of channel-lobe transition and mass-movements. These features suggest that the eroded material coming from the continental shelf and slope continues to be evacuated and transported westward through the abyssal plain.

Conclusions

The investigations using a combination of modern high and ultra-high resolution acoustics onboard the R/V *HespÃ©rides* have revealed how submarine erosion has been responsible for the general topography and microtopography of the north Spanish Atlantic margins and deep-sea areas. This erosion seems to have resulted from the complex interaction between tectonics, physiography, sea-level change, sediment sources and bottom currents.
Spainâ€™s important navy and her history of sea trade, in addition to the fact that today Spanish seas contain important international trade routes, stand in sharp contrast to the evidence of these surveys. These demonstrate that Spainâ€™s privileged situation is in inverse proportion to a low level of hydrographic and geological knowledge of its continental margins and deep-sea areas, especially those of the Atlantic Sea. The results of this study are not only of scientific interest for understanding the continental margins and deep-sea areas that surround our country, but also have important applications for engineering activities, military operations (in shallow waters) and evaluation for extending the continental shelf.

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