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The French Atlantic margin and deep-sea submarine systems

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Abstract The sedimentary infill of the Bay of Biscay off Ireland, UK, France and Spain took place in four phases. The last one (35 Ma to present) is characterised by gravitational, pelagic, contouritic and glacigenic processes leading to the setup of three deep sea systems. To the North, the Celtic and Armorican fans are fed by a "canyon-dominated" margin and its connection with the "Manche" palaeoriver, which drained a large area of western Europe. To the South, the Cap-Ferret fan results from the evolution of a "tectonic-dominated" margin and the erosion of the Pyrenee mountains.

Geological Setting

The French northeast Atlantic margin extends along the northern passive margin of the Bay of Biscay for more than 1,000 km. Its history started with the opening of the Bay of Biscay. Conversely to the contemporaneous Atlantic rift, the opening ceased in this part of the margin. Basement seamounts represent the fossil rift which split the bay into a wide northern basin and a narrow southern basin. The infill of these basins took place in four phases: (1) syn-rift and black shale deposition during the opening phase (140 to 80 Ma), (2) syn-orogenic deposition during the Pyrenean compression (80 to 35 Ma) and (3) post-tectonic deposition (Thinon, 1999). The late sedimentation phase (4) is characterised by a strong activity of canyons, which homogenised the seafloor morphology of the continental rise. The sedimentary processes are numerous (downslope gravity processes as well as pelagic, contouritic and glacigenic sedimentation) and have led to the set up of several deep-sea clastic systems.

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Morphology of deep-sea systems

The French Atlantic margin can be subdivided into three parts: the Celtic margin in the north, and the Armorican margin and the Aquitaine margin in the south (Fig. 1). The major relief, however, is the continental slope with a "canyon-dominated" slope (Celtic and Armorican) and a "tectonic-dominated" slope (Aquitaine).

Celtic and Armorican margins

The Celtic margin extends from the Goban Spur to the Berthois Spur. The continental shelf is oriented N115°, and is wider than 250 km but delimited especially by a notched coast with two large indentations: the Irish Sea and the English Channel. The south part of the Celtic outer shelf is characterised by the presence of sandbanks, 40–180 km long, 5–10 km wide and 40 m high. These banks are oriented roughly N30°, i.e. in the present-day tidal current direction. For some authors, they represent the relics of the palaeodelta of the Manche River (Lericolais 1997) whereas for others (Reynaud et al. 1999; Marsset et al. 1999), they could be purely fossil tidal sandbanks. Below the sand-banks, a network of infilled palaeovalleys attests to a direct

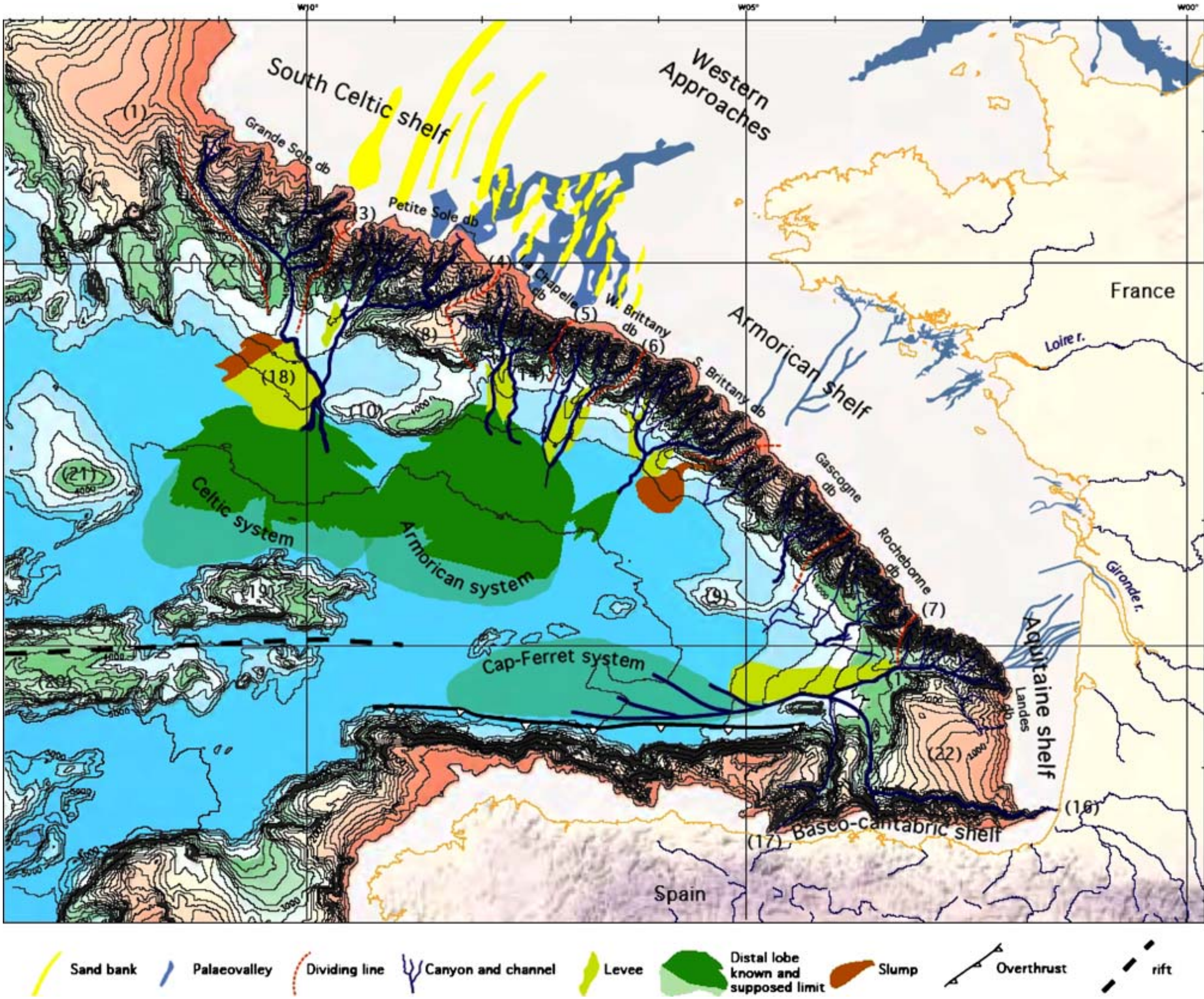

Fig. 1 Physiographic features of the French Atlantic margin of the Bay of Biscay: *1* Goban Spur, *2* Austell Spur, *3* Brenot Spur, *4* Berthois Spur, *5* Delesse Spur, *6* Bourcart Spur, *7* Conti Spur, *8* Meriadzek Terrace, *9* Gascogne Knoll, *10* Trevelyan Escarpment, *11* Whittard Canyon, *12* Shamrock Canyon, *13* Blackmud Canyon, *14* Guilcher Canyon, *15* Cap-Ferret Canyon, *16* Capbreton Canyon, *17* Llanes Canyon, *18* Whittard Ridge, *19* Biscay Seamount, *20* Charcot Seamount, *21* Armoricain Seamount, *22* Landes Plateau. Isocontours, structural features from Sibuet et al. (2004)

link between the slope and the palaeoriver “Manche”, with a likely Pliocene age for the valley incision (Bourillet et al. 2003; Gracia-Garay et al. 2004).

The Armorican margin extends from the Berthois Spur to the Conti Spur. The Armorican continental shelf is up to 200 km wide, with a shelf break oriented N140°. Palaeovalleys are very well developed up to the 40–70 m isobaths (Menier 2004; Chaumillon and Weber 2006), only a few reaching the shelf break (Pinot 1974; Bourillet et al. 2005).

The morphology of the continental slope (Fig. 1) is characterised by spurs and canyons organized in submarine drainage basins (Bourillet and Lericolais 2003). The southern Celtic margin includes two major drainage basins: (1) the Grande Sole drainage basin located southwards of the Irish Sea and limited by the Austell Spur and the Brenot Spur; (2) the Petite Sole drainage basin located seawards of the Western Approaches and limited by the Brenot Spur and the Berthois Spur. Both drainage areas fed the Celtic deep-sea system via the Whittard and Shamrock canyons. The Berthois Spur is continued seawards by the Meriadzek Terrace and the Trevelyan Escarpment. These two morphological features are oriented N105°, which is consistent with the general structural direction corresponding to the opening of the Bay of Biscay. Between the Berthois Spur and the Delesse Spur, the La Chapelle drainage basin fed the Armorican deep-sea system via the Blackmud and Guilcher canyons. The Meriadzek Terrace and the Trevelyan Escarpment form a deep morphological relief splitting sedimentary supply from the shelf either to the west towards the Celtic system or to the east towards the Armorican system.

The discovery of these deep-sea turbidite systems is recent. The initial work suggesting the presence of a clastic system off the Celtic and Armorican slope is that of Auffret (1983).

Between the Delesse Spur and the Conti Spur, four additional drainage basins can be identified and are all fed by canyons dissecting the continental slope and rise: (1) the western Brittany drainage basin, (2) the southern Brittany drainage basin, (3) the Gascogne drainage basin and (4) the Rochebonne drainage basin. No significant deep-sea fans are found at the mouth of the lower valleys but only small channel-levee complexes, slumps or small lobes.

Aquitaine margin

The Aquitaine margin extends from the Capbreton Canyon to the Conti Spur, with a narrow (70 km) subsident shelf. The Aquitaine Shelf is the continuation of the Armorican Shelf (Fig. 1). It is 60 km wide and is limited in the south by the Capbreton Canyon. The Gironde palaeovalley is poorly developed and tapers at the 70 m isobath (Lericolais et al. 2001), where pre-Pliocene palaeovalleys reached the head of the Cap-Ferret Canyon (Bellec 2003).

The Aquitaine continental slope is smooth and is extended by the marginal Landes Plateau dipping gently westwards. It is bordered by steep slopes forming the south flank of the Cap-Ferret Canyon in the north, the Capbreton Canyon in the south, and the Llanes Canyon in the west. In the south, the Capbreton Canyon is bordered by the Basco-Cantabrique continental margin with very steep slopes. This is an atypical canyon for the Bay of Biscay, showing a meandering course and a head directly connected to the fluvial river (Cirac et al. 2001). Even during highstands, Capbreton Canyon showed a behaviour similar to that during lowstand periods.

The only deep-sea clastic system in this southern part of the bay is the Cap-Ferret system. It is supplied by the canyons and channels draining the Landes drainage basin and part of the northeast Spanish continental slope, via the Capbreton Canyon and the S-N Llanes Canyon. These two canyons join downwards the prolongation of the Cap-Ferret Canyon.

Sedimentary accumulation in the Cap-Ferret system has been identified on the bathymetric map of Berthois and Equer (1974). During several cruises in the late 1970s, bathymetric, photographic, THR and HR seismic survey as well as Kullenberg core data were collected for this system. These data have been synthesized by Crémer (1983). Since then, no other cruises have been undertaken in this region. Consequently, this system remains poorly known, in contrast to those in the north part of the bay.

Tectonic, climatic and eustatic history of the margin

In the Bay of Biscay, there is an important morphological contrast between the north and the south margin. This contrast results from a geological history including two major tectonic phases (Dérégnaucourt and Boillot 1982): (1) a phase of crustal distension and rifting from the late Jurassic to the early Cretaceous (Sibuet et al. 2004) and (2) a phase of partial ocean closing during the Cainozoic. Since then, the south Celtic margin is characterised by a very low subsidence rate (5–6 mm year^{-1}; Bois et al. 1991).

The opening phase is at the origin of the deep part of the bay and its margins. The relics of this phase are clearly visible in the deep structure of the margin, including the presence of tilted blocks separated by listric faults and forming a typical half-graben morphology (Boillot et al. 1972, 1974) filled with Cretaceous sediments, and with the presence of isolated knolls (Gascogne) and seamounts (Biscay, Charcot, Armorican). The closing phase generated the shortening of the north Spanish margin bounded by the north Spanish marginal overthrust. The Eocene compressive phase and the subsequent Oligocene inversion (Pyrenean phases) generated the formation of several reliefs such as the Trevelyan Escarpment and the Gascogne Knoll. These represent the limit between the thinned continental crust and the oceanic crust (Thinon 1999).

The sedimentary history of the Celtic and Armorican turbidite systems began after the maximum inversion of the Early Miocene, marked by a hiatus on DSDP well 400 (Droz et al. 1999, 2003). Above this unconformity, the history of the systems is characterised by the deposition of three sediment units separated by minor unconformities. These units correspond to three phases in system evolution: (1) Miocene and (2) Pliocene phases, showing a basinward progradation of the system with frequent channel shifting; the system is fed mainly by the Manche palaeoriver with a high coarse particle load; regional debris flows occurred during the Pliocene; and (3) a Quaternary phase, associated with feeding from the Irish Sea showing a more important fine particle load generating a more permanent channel-levee system.

A particular feature of the Armorican and Celtic systems is their recent (LGM to late Holocene) turbidite activity. Turbidity currents in these systems were active mainly during the relative sea-level lowstand (Zaragosi 2001). Sediments were supplied by the Manche palaeoriver system (Lericolais 1997; Bourillet and Lericolais 2003) which drained the major rivers of western Europe, such as the Rhine, Seine and Thames, and by the British ice sheet. The direct influence of the British ice sheet and the Manche palaeoriver on the deep-sea clastic sedimentation ended during the early Holocene (between 10 and 8.7 ka B.P.). However, coarse-grained sporadic turbiditic activity has been recognised during the Upper Holocene due to the reworking of sand dunes at the shelf break by hydrodynamic processes such as swell, storm waves, tidal currents or internal waves (Zaragosi 2001).

The turbidite deposition of the Cap-Ferret system began during the Upper Eocene, after the Eocene tectonic phase (Crémer 1983). Clastic sediments were trapped in the Parentis Basin (below the Aquitaine Shelf and the Landes Plateau), and deposition in the Cap-Ferret Graben was low. Only distal turbidites transported by the Capbreton and Llanes canyons reached this area.

From the Upper Oligocene to the Lower Miocene, the north Spanish overthrust was filled. An important part of clastic sediment was still trapped in the Parentis Basin but the load was sufficient in the Cap-Ferret Graben to induce the formation of a channel-levee system. This system was fed by the Cap-Ferret Canyon.

During the Middle Miocene, the sea-level highstand prevented high turbiditic activity in the channel-levee system. The levee aggraded by the spilling of muddy turbidity currents originating from the Capbreton and Llanes canyons.

In the Upper Miocene, sea-level lowering induced an increase of terrigenous load, flowing through an incised network on the north Aquitaine shelf break (Bellec 2003). Westward slope progradation intensified and, simultaneously, turbidite activity increased.

The Plio–Pleistocene is the time of appearance of the distal Cap-Ferret system and especially the northern levee. The climate changed, from subtropical during the Cainozoic to an alternation of glacial (cold and dry) to interglacial (wet and temperate) during the Quaternary. These variations generated a reworking of the continental deposits, a rapid margin progradation, and frequent gravity processes at the origin of the system.

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