The Celtic and Armorican Margins – a New View

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Introduction

The Celtic and the Armorican margins constitute an important part of Europe's western frontier at middle latitudes. Since the pioneering work of Berthois and Brenot which began in the early 1950s (Berthois and Brenot 1962; Berthois 1974) and the first maps including data obtained by Seabeam surveys (Pastouret et al. 1982; Lallemand et al. 1985; Sibuet et al. 1994), the Western Approaches and the northern Bay of Biscay margin sea floor have been intensively investigated as part of French (IFREMER, EPSHOM), Belgian and European programmes (RESECUSED, STARFISH, ENAM I and II, CORSAIRES, OMEX). Each of these phases have benefited from technical advances, such as: (a) the transition from single beam echo-sounding based on astronomic and radar dead recognitions to radio assisted navigation (DECCA); (b) seabeam (2/3 of water depth) and satellite-assisted navigation; (c) multibeam (up to 15 km range) and (d) high resolution Global Positioning System (GPS).

Contributions of the Different Programmes

French Programmes

In 1992 IFREMER initiated the exploration of the Economic Exclusive Zone (EEZ), with the *RV Atalante* equipped with the multibeam EM12 dual system and DGPS. This work started in 1992 (ZEE Gascogne 92 cruise, G. Pautot) and was completed in mid 1997 with the ZEE Gascogne 2 cruise (R. Le Suavé).

Six bathymetric charts at 1:250,000 scale (Normand and Mazé 2000), two sea-bottom reflectivity charts at 1:500,000 scale (Le Drézen 2000), as well as an introduction (Le Suavé et al., in Le Suavé 2000) have been produced. This work, which includes the bathymetric data provided by SHOM (Service Hydrographique et Océanographique de la Marine), on the continental plateau provides an accurate survey of the whole area, especially the Celtic and Armorican margins and the associated deep-water basin. One of the most spectacular discoveries, identified through EM12 seabottom reflectivity, is the Armorican Deep-Sea Fan (Le Suavé et al. 1999; Le Suavé et al. 2000; Zaragosi et al., this volume) (Fig. 1).

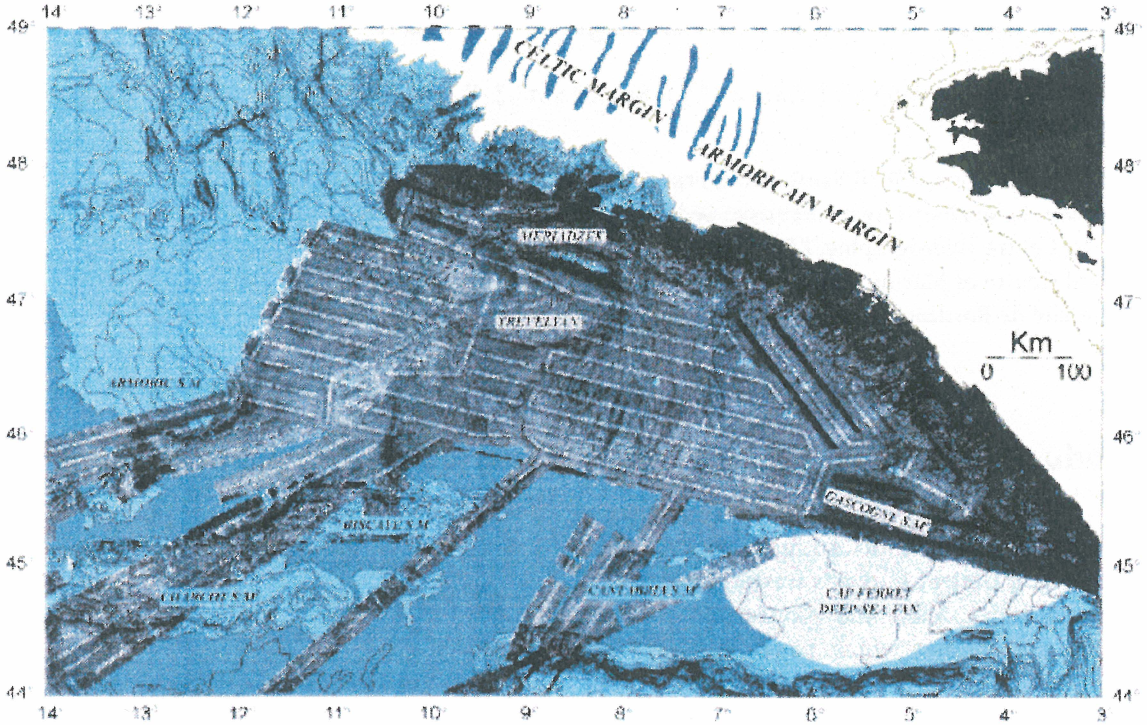

Fig. 1. Coverage of the work carried out on the Celtic and Armorican margin and the Biscay Bay deep basin under the French EEZ progammes (Le Suavé 2000), with additional works from SEDIMANCHE (Bourillet and Loubrieu 1995), ENAM II (Auffret et al. 2000) and surveys from the French Hydrographic Office. The bathymetric contours are from Sibuet et al. (1994)

Sedimanche

During the 1990s, an integrated study of the 'Manche' system was carried out within the framework of the French SEDIMANCHE programme. During two cruises (Sedimanche 1, *RV L'Atalante* 1992; Sedimanche 2, *RV Le Suroit* 1993) detailed surveys from the outer shelf to the upper slope were performed.

SHOM

The Service Hydrographique et Oceanographique de la Marine (SHOM) has acquired bathymetric, geophysical and sedimentological data for the deeper part of the Bay of Biscay over several years. 15 profiles, 150 nautical miles long with multibeam EM12 dual system, 3.5 kHz data and cores allowed the study of the Bay of Biscay from the Celtic fan to the abyssal hills (Unterseh 1999; Zaragosi 2001).

Belgian and European Programmes

Belgica

Within the framework of the European projects STARFISH, CORSAIRES and ENAM II, and with support of national projects (Belgian deeptow development projects), cruises on *RV Belgica* were organised in 1994 and 1996 on the outer shelf and upper slope of the Celtic margin. High-resolution reflection seismic data were acquired from the Kaiser-I-Hind bank, the transition zones between large buried palaeovalleys and the upper slope, and two downslope transects. Site surveys have been performed on proposed scientific drilling sites, also with deep-towed and seabed seismic arrays.

ENAM II

Within the objectives of this programme, which aims to study sediment transfer from the European continent to the ocean, the Celtic margin was selected as the non-glaciated end member. The possible existence of two deep sea fans at the foot of the margin was recognised during the first phase of the programme (1991–1995) and illustrated on the ENAM I map (Evans et al. 1996). The Celtic Deep Sea Fan has been intensively surveyed during cruises SEDIFAN1 and 2 (*RV L'Atalante* and *RV Nadir*, 1997).

The New View of the Margin

Regional Setting

There are two main sedimentary pathways from the NW European continent to the deep sea. The northern pathway leads from the North Sea, through the Norwegian Channel to the North Sea Deep Sea Fan, and the southern one from the English Channel to the Celtic Deep Sea Fan (Belderson and Kenyon, 1976; Auffret et al. 2000). Contrary to the northern transfer path, the southern path has not been affected directly by ice sheets, except at its NW boundary where the maximum extension of the British ice sheet has been located on the Melville bank (Scource et al. 1990). The large amplitude of the migration of the shoreline (Lambeck 1995) has also played an important role. This is particularly true at time of lowest sea level when the River Channel drained a large basin, including the Rhine, Maas and Thames (Gibbard 1988) and a large delta, the Celtic Sea delta, was developed in the Celtic sand banks area (Lericolais 1997).

The existence of an extensive paleovalley network has been described in the eastern Channel (Larsonneur et al. 1982). No such evidence exists in the western Channel floor, with the exception of local troughs of possible fluvial origin, at one time occupied by lakes such as the Hurd Deep (Lericolais 1997). However, an incised paleovalley network reappears near the shelf break (Bourillet and Loubrieu 1995; Bourillet et al. 1998). Some of the buried valleys have superimposed sand banks (Trenteseaux 1993; Reynaud et al. 1999a) which could be former channels of the River Channel delta (Berné et al. 1998; Reynaud et al. 1999b). In some cases, a direct connection between the incised valleys and the upper course of canyons has been demonstrated (Bourillet and Loubrieu 1995). To the NW there is apparently no evidence of incised paleovalley networks within the sea floor of the southern Irish Sea.

The New Physiography

The results of the last phases of research have provided new bathymetric and acoustic views of the margin, which are based on a 100 % coverage and precision and resolution better than 100 m.

The transfer paths from the continent to the margin and the canyon networks at the margin have been well recognised (Bourillet and Lericolais, this volume). The reconstruction of the history of erosion and filling of paleovalleys at the shelf – continental slope transition still needs control by bore holes within the valley infills and on the superimposed sand banks. It is presently postulated (Droz et al., this volume) that the Celtic Deep Sea Fan building was initiated during the early Miocene. Three development phases are recognised: Phase 1 – Miocene; Phase 2 – Pliocene; Phase 3 – Quaternary.

On the upper slope (Bourillet and Lericolais, this volume) three formations are present. From top to bottom these are: (1) Little Sole Formation; (2) Cockburn Formation and (3) Jones Formation. Based on a limited amount of samples, ages have been proposed for these formations, which range from early Miocene to Plio-Pleistocene. Unequivocal correlation of the deposition of these three formations with the three development phases of the Celtic Deep Sea Fan cannot be provided at present.

Sedimentological synthesis of the acoustic imagery and the nature of the sediments concerning the Celtic Deep Sea Fan area (Zaragosi et al., this volume) and the Armorican Turbidite System (Zaragosi et al., this volume) shows that both systems share common characteristics.

The Celtic Deep Sea Fan contains morphological characteristics of multiple-source and single-source deep sea fans. It is also characterised by a prominent sedimentary levée (the Whittard Ridge) which has mainly built up during the Quaternary (Droz et al. 1999, this volume).

The Armorican Deep Sea Fan is fed by a number of contributory canyons which, according to the nomenclature of Reading and Richards (1994), is representative of turbiditic systems such as ramps (Zaragosi et al. 2001).

Unlike point-source submarine fans fed by a single feeder channel, the Celtic and Armorican fans are connected to the continental slope via several canyons merging with different channel levée systems. Beyond the channel mouths, spreading of individual sheet-flows produces divergent braided secondary channels and small lobes without significant surface expression. These characteristics have led Zaragosi (2001) to consider that both systems are part of a larger depositional system, the 'Celtic ramp'.

New core studies and new investigations on archived cores (Zaragosi 2001) have allowed reconstruction of the history of gravity inputs into the deep basin during Stages 2 and 1. Turbidity currents have been very active on these margins during the low sea level stages characteristic of the last Glacial Maximum. This activity ended earlier at the Armorican margin (10 ka BP) than at the Celtic margin at 7 ka BP. One very important point confirming the earlier hypothesis is that turbidity current activity has occurred in recent history. The last events to occur in the Celtic Deep Sea Fan are dated from ^{14}C ages of foraminifera picked in the underlying hemipelagic marly oozes at about 1880 and 1220 BP respectively. This 'present day' activity in a situation of high sea level is most probably related to the high energy levels (swell-induced reworking, tidal currents and possibly internal tides) to which the shelf break is exposed.

Perspective

In the past decade, the knowledge of the floor of the Celtic and Armorican margins has been set to a level of precision where any future changes related to seafloor instability or large-scale slope instability would be identified. The acoustic imagery has also brought new images of the sea floor, the significance of which, in terms of nature of sediment and sedimentary processes responsible for their deposition, remains to be calibrated. However the lack of appropriate sampling (long cores and boreholes) has, until now, prevented stratigraphic interpretation of very high resolution seismic lines obtained from the shelf break to the deep basin. The reconstruction of the geological history of this western frontier and the development of well-constrained conceptual models are still awaiting a new research phase. The main objective of future projects should be the recovery of the upper 300 m of sedimentary deposits on a transect from the Celtic Bank to the deep basin. This project will not only add value to the numerous seismic surveys performed in the area, but should also provide clues for the assessment of slope stability in an area of high economical interest (communication cables, oil and gas exploration, maritime routes, etc.).

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