Geo-Marine Letters (2001) 20: 219–232
DOI 10.1007/s003670100061

S. Zaragosi · R. Le Suavé · J.-F. Bourillet
G.A. Auffret · J.-C. Faugères · C. Pujol · T. Garlan

The deep-sea Armorican depositional system (Bay of Biscay), a multiple source, ramp model

Received: 29 May 2000 / Revision accepted: 4 December 2000 / Published online: 22 March 2001

Abstract The deep-sea Armorican depositional system, located in the central part of the Bay of Biscay, is a medium-sized turbidite system with a surface area of more than 30,000 km^2. The whole system is a mud/sand-rich submarine ramp on a passive margin. The medial ramp is characterised by the presence of six distinct tributary channels which form three systems: the Guilcher, Crozon and Cornouaille systems. The distal ramp corresponds to divergent braided secondary channels and associated lobes. Variations in hydrodynamic conditions on the outer Armorican Shelf during the last climatic cycle are the major factor controlling facies shifts and system growth. Thus, the Armorican depositional system is a delta-fed submarine ramp during low sea-level glacial conditions, and an outer shelf-fed submarine ramp at times of sea-level rise.

Introduction

Following recent studies on the Celtic Fan (Droz et al. 1999; Auffret et al. 2000; Zaragosi et al. 2000), the Armorican depositional system remained as the last uninvestigated turbidite system in the Bay of Biscay. It is located in the central part of the bay (Fig. 1) and lies at the foot of the Armorican passive margin, at water depths of 4,100 to 4,900 m. With a length of approximately 200 km and a width of 230 km, it covers more than 30,000 km^2. The Armorican turbidite system is bordered to the northwest by the Celtic Fan and to the southeast by the Cap Ferret Fan (Crémer et al. 1985; Faugères et al. 1998). The survey of the area by IFREMER was completed in 1997 (Le Suavé 2000). This work complements studies on the Armorican continental shelf (Kenyon and Stride 1970; Belderson et al. 1986; Lericolais 1997; Berné et al. 1998; Marsset et al. 1999; Reynaud et al. 1999a, 1999b, 1999c, 1999d), the outer shelf and continental slope (Belderson and Kenyon 1976; Kenyon et al. 1978; Bourillet and Loubrieu 1995), and the fans and basin plain (Crémer et al. 1985; Reid and Hamilton 1990; Faugères et al. 1998; Auffret et al. 2000; Zaragosi et al. 2000).

This study provides an opportunity not only to investigate a modern deep-sea turbidite system but also to study the sedimentary processes which are involved in the development of this type of depositional deep-sea system as well as the relationships with the paleoenvironmental conditions on the shelf. A large data set available for the area (multibeam echosounder data, 3.5-kHz seismic records, and Küllenberg cores) was examined in order to undertake a detailed investigation of seafloor morphology and surficial sediment distribution of the Armorican depositional system and adjacent areas.

Material and methods

The bathymetry and acoustic imagery were derived from the multibeam echosounder (SIMRAD EM12) survey of the area conducted onboard the R/V Atalante (IFREMER) during the ZEE GASCOGNE cruises (Le Suavé 2000), and onboard the R/V Espérance (SHOM). In all, 2,500 km of hull-mounted 3.5-kHz seismic lines was collected during these cruises.

The four sediment cores presented here were collected during the cruises GEOGAS and MARGAS (Table 1, Figs. 2, 3). In addition to previous studies on these cores (Berthois et al. 1973; Duplessy et al. 1981; Auffret 1983), thin slabs (15 mm thick) were sampled

S. Zaragosi (✉) · J.-C. Faugères · C. Pujol
Université de Bordeaux I, Département de Géologie et Océanographie, UMR 5805 EPOC, 33405 Talence Cedex, France
E-mail: s.zaragosi@geocean.u-bordeaux.fr

R. Le Suavé · J.-F. Bourillet · G.A. Auffret
IFREMER, DRO/GM, Laboratoire Environnements Sédimentaires, BP 70, 29280 Plouzané Cedex, France

T. Garlan
SHOM, Centre Hydrographie, BP 426, 29275 Brest Cedex, France

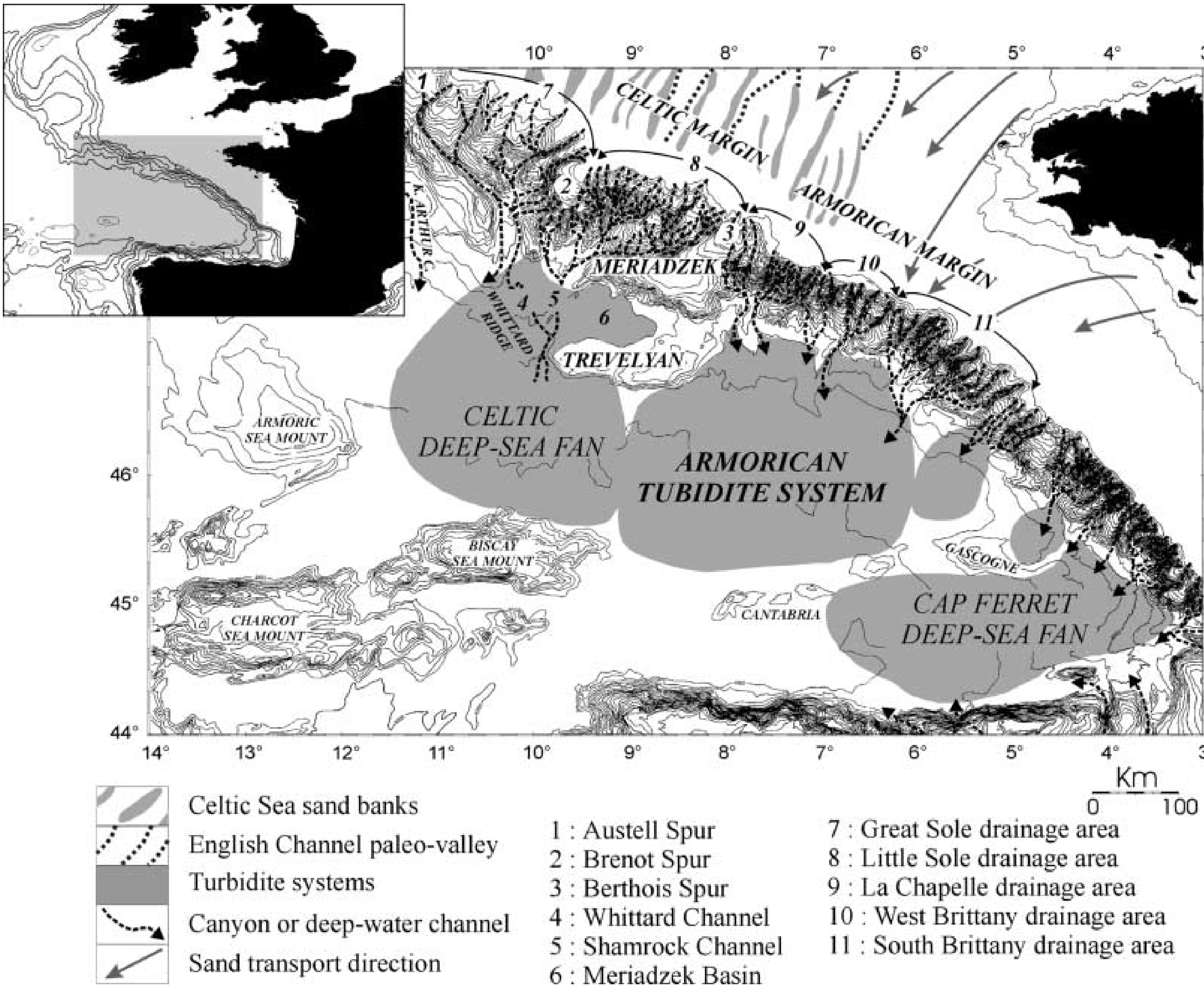

Fig. 1 Bathymetry and morphological setting of the Bay of Biscay (bathymetry after Sibuet et al. 1994; sand transport direction after Kenyon and Stride 1970)

and analysed with the Scopix X-ray image processing tool (Migeon et al. 1999). Subsamples were taken in order to measure (1) carbonate content using gasometric calcimetry, and (2) grain size using a Malvern Mastersizer S.

The stratigraphic framework is based on planktonic foraminifer investigations, δ^{18}O isotopic analysis, and AMS ^{14}C dating. The IMAGES core MD95–2002, located on the Meriadzek Terrace (Figs. 1, 3), was used as a reference record for the Bay of Biscay (Zaragosi et al. 2000).

Results

Morphology

The Armorican depositional system is connected with the Armorican margin slope via six major channels from three main drainage areas: (1) the Shamrock and Guilcher channels which are fed by the Chapelle drainage area linked to the central part of the English

Table 1 Location of cores

Core number	Latitude	Longitude	Depth (m)	Cruise	Year	Institute
MD952002	47°27.12′N	08°32.03′W	2,174	IMAGE 1	1995	IFREMER
Ma KS02	46°48.30′N	06°44.50′W	4,252	MARGAS	1975	IFREMER
Ma KS03	46°31.70′N	07°03.60′W	4,499	MARGAS	1975	IFREMER
Ma KS04	46°14.00′N	07°12.40′W	4,682	MARGAS	1975	IFREMER
G 72104	46°54.50′N	08°05.10′W	4,400	GEOGAS	1972	IGBA

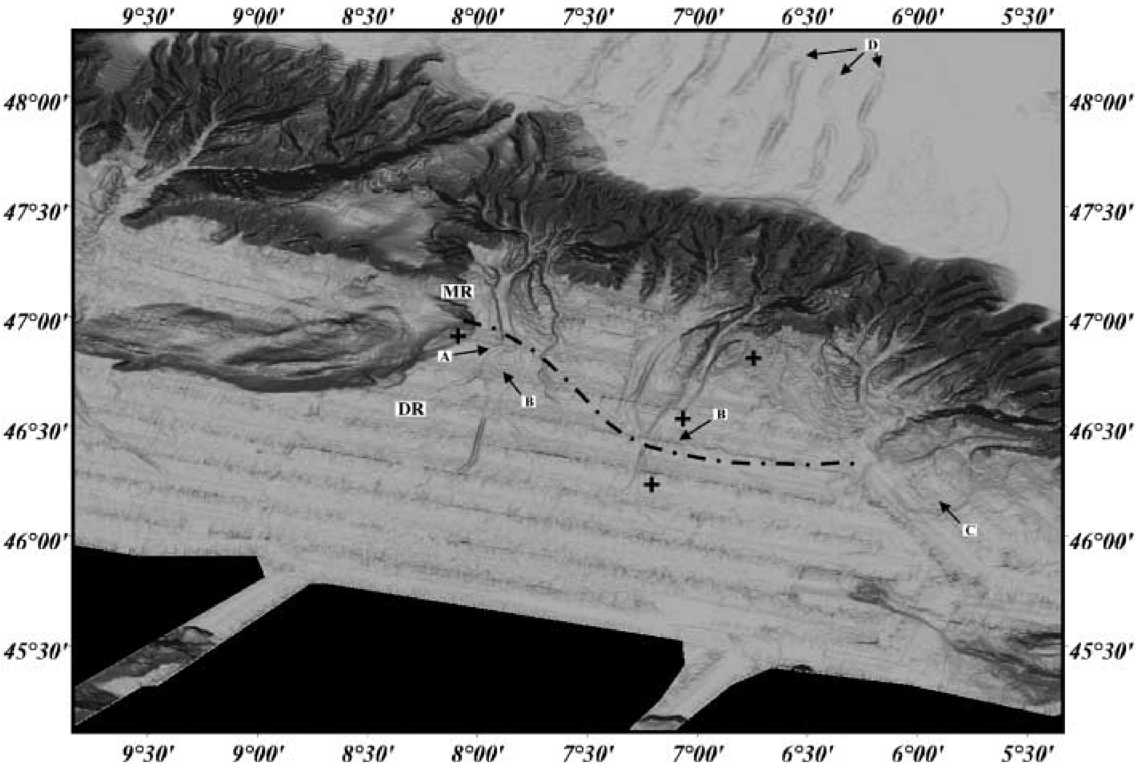

Fig. 2 Shaded bathymetric map of the Armorican depositional system and adjacent areas. *MR* Medial ramp. *DR* Distal ramp. *Dotted line* Medial-distal ramp boundary. *A* Blackmud Channel mouth with a westward trend implying a channel avulsion. *B* Sand bodies located beyond the channel mouths. *C* Morbihan Slide. *D* Celtic Sea sand banks. *Crosses* Core locations (see Fig. 3 for core numbers)

Channel system (Figs. 1, 4), (2) the Brest and Crozon channels which are fed by the West Brittany drainage area linked to the south of the English Channel system, and (3) the Audierne and Blavet channels extending southward into the Cournouaille Channel, and which are fed by the South Brittany drainage area linked to the southern end of the English Channel system.

Based on drainage area as well as morphological and acoustical characteristics, these channels form three distinct systems: two major systems, the Guilcher system to the west and the Crozon system in the central part, and a smaller system to the east, the Cornouaille system (Figs. 4, 5).

The medial ramp water depths extend from 4,100 to 4,650 m, and the area is characterised by the presence of main channel levee systems. Beyond the medial-distal ramp boundary, which corresponds to the disappearance of these channel-levee systems, major lobes begin to develop, associated with secondary channels. The medial ramp slopes gently (average gradient of 0.05°).

The shaded bathymetric maps and the 3.5-kHz seismic analysis (Figs. 2, 6, 7, 8) show an important slide located to east of the Armorican depositional system: the Morbihan Slide (Figs. 4, 8). This deposit from a large-scale mass movement is located on the lower slope at water depths of 3,800 to 4,700 m.

Sediment distribution

Sedimentary facies

Five sedimentary facies were recognised in the cores from the Armorican depositional system (Figs. 9, 10, 11). These facies have been defined using (1) photography and X-ray imagery, (2) grain-size analysis and $CaCO_3$ content, and (3) comparisons with the Celtic Fan core lithologies (Zaragosi et al. 2000).

Facies 1: homogeneous, structureless marly ooze; pelagic to hemipelagic marly ooze

Facies 1 is composed of structureless light grey to light brownish grey marly ooze. The mean grain size is smaller than 10 μm, and the $CaCO_3$ content varies between 30 and 60%. This facies, forming the modern seafloor, is interpreted as pelagic to hemipelagic drape deposits. It was observed in the uppermost parts of cores within the marine isotopic stage 1 (MIS-1) interval.

Facies 2: homogenous, structureless clay; hemipelagic clays

Facies 2 consists of thin (a few centimetres) to thick (1-m) intervals of structureless olive grey clay. The mean

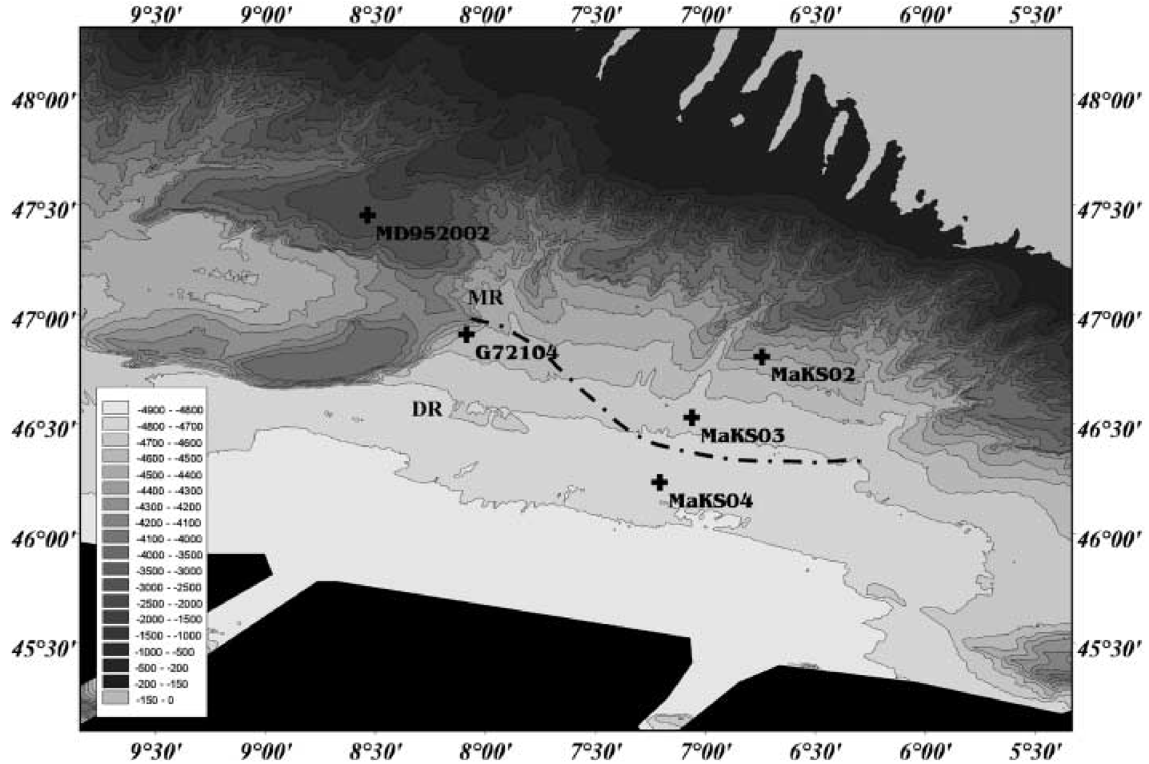

Fig. 3 Detailed bathymetric map, based on multibeam echosounder survey (Le Suavé 2000) of the Armorican depositional system, with location of cores. *MR* Medial ramp. *DR* Distal ramp. *Dotted line* Medial-distal ramp boundary. On the shelf, 150 and 200-m isobaths are shown. Contour intervals are 500 m on the slope (500–4,000 m), and 100 m in the deep sea (4,000–4,900 m)

grain size is smaller than 10 μm, and the $CaCO_3$ content is lower than 30%. This facies is present during the MIS 2, and it is interpreted as hemipelagic drape deposits.

Facies 3: laminated silt and clay and very fine sand; fine-grained turbidites

Facies 3 consists of alternating silt and clay laminae. The mean grain size varies from 50 (silt laminae) to 5 μm (clay intervals). This facies frequently shows a basal layer of very fine sand to coarse silt less than 5 cm thick. The $CaCO_3$ content is lower than 30%. This facies, observed during both the MIS 1 and 2, is interpreted as fine-grained turbidites ($T_{c\text{-}d\text{-}e}$ divisions of the Bouma turbidite sequence; Bouma 1962) deposited by low-density turbidity currents.

Facies 4: Thick-graded sands; turbidites

Facies 4 consists of medium sand to very fine sand, with a layer thickness of up to 10 cm. The layers are normally graded, and can be associated with facies 3 to form a complete turbidite sequence ($T_{a\text{-}b\text{-}c\text{-}d\text{-}e}$), or a top ($T_{a\text{-}b}$) or a base cut-out ($T_{b\text{-}c}$) sequence. Facies 4 is interpreted as being deposited by high-density turbidity currents. These sandy layers were observed only during the MIS 1.

Facies 5: thin-bedded sorted silt; fine-grained turbidites or bottom-current reworked deposits

Facies 5 consists of well sorted silty beds, 5–10 cm thick, showing generally parallel or cross laminations and sharp or gradational contacts at the base and top. The mean grain size varies from 18 to 50 μm. These silty layers, dated at 5720 years B.P. in core MaKS04, are localised on the medial and distal ramp. The sedimentary processes involved in the deposition of facies 5 are still uncertain, but possibilities include low-density turbidity currents or bottom-current reworking.

Seismic echofacies

In this study, the 3.5-kHz echofacies has been classified according to Damuth's methodology (Damuth 1975; Damuth and Hayes 1977; Damuth 1980). Echo-type mapping and interpretation are also based on the multibeam echosounder data (bathymetry and imagery) and the core lithologies. In the study area, six types of echofacies were recognised on the hull-mounted seismic lines: (1) "IB" sharp continuous echo with numerous parallel sub-bottom reflectors, (2) "IIA" semiprolonged echo with intermittent parallel sub-bottom reflectors, (3) "IIB" very prolonged echo with no sub-bottom

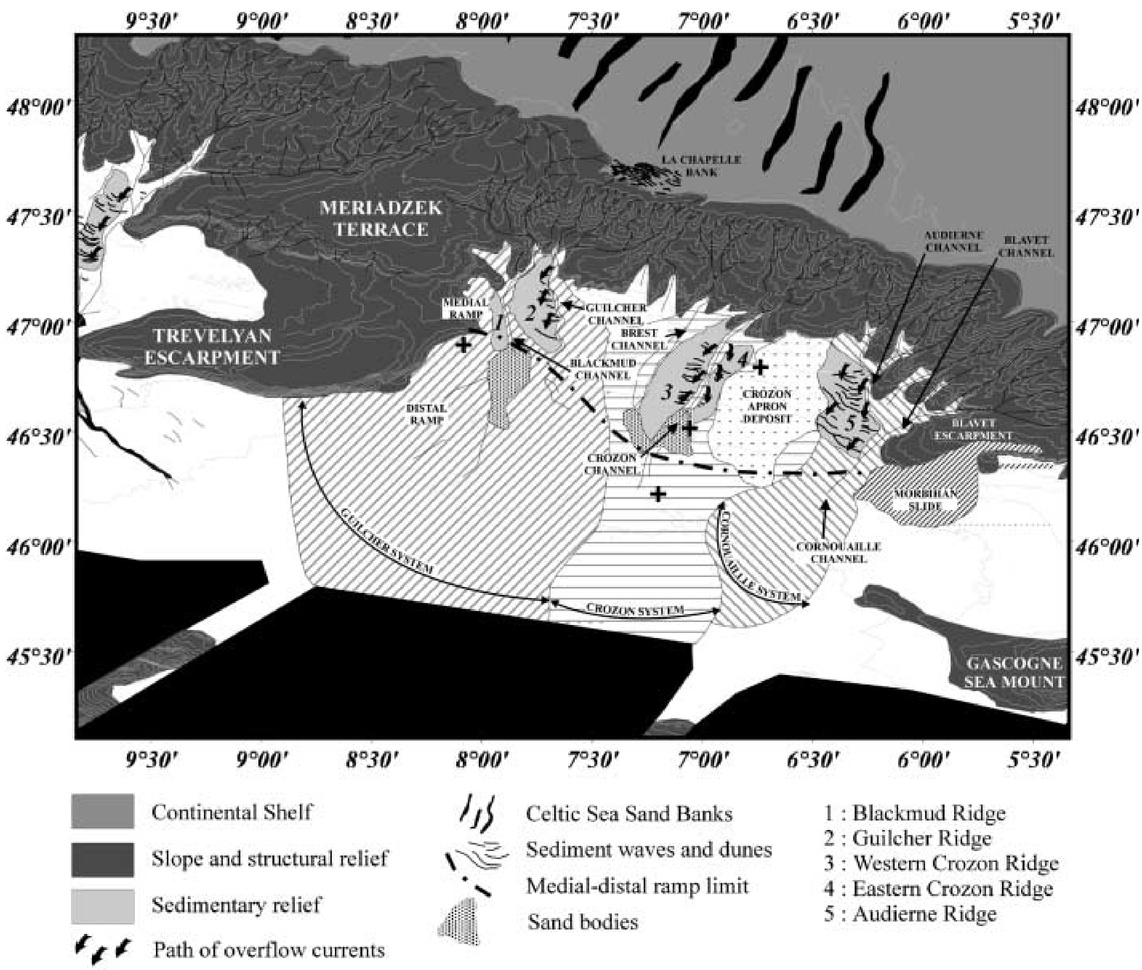

Fig. 4 Geomorphologic map of the Armorican depositional system and adjacent areas. *Crosses* Core locations (see Fig. 3 for core numbers)

reflectors, (4) "IIA/IIB" intermediate between IIA and IIB, (5) "IIIC" regular overlapping hyperbolae with varying vertex elevations, and (6) "DF" acoustically transparent unit with surficial prolonged echoes or regular overlapping hyperbolae approximately tangent to the seafloor. The map of the echofacies distribution (Fig. 6) is a compilation of the available 3.5-kHz data, and defines the sediment distribution discussed below.

Sediment distribution on the medial ramp

On the medial ramp, the Guilcher, Crozon and Cornouaille systems are made up of the feeder channels associated with sedimentary levees. These channels are of two morphological types: (1) several straight and relatively large channels (the Blackmud, Brest, Crozon, Audierne, Blavet and Cornouaille channels); (2) a single sinuous channel (the Guilcher Channel).

The straight channels are 3,000–5,000 m wide, approximately 45 km long and have a relief of 30–200 m from the channel floor to the levee crests. The Brest Channel has a small levee in its central part, and is then divided into two distinct 30-km-long branches. Core MaKS03, located just downstream of the Crozon Channel mouth, contains a thick (65 cm) complete turbidite sequence (facies 3–4; Fig. 11) overlying silt and clay laminae (facies 3). Despite the absence of cores from the bottom of the channels, the sandy nature of the channel-fill deposits can be inferred from (1) the presence of sandy layers along the edge of the channels (core MaKS03) and, (2) the IIB echo (very prolonged without sub-bottom reflectors) backscattered from the floors of all of these channels (Fig. 6). Downstream from the medial-distal ramp boundary, the Blackmud, Brest and Crozon channels are assumed to be filled by massive sand bodies. Downstream of the Blackmud Channel, one of these assumed sand bodies, visible on the shaded bathymetric map (Figs. 2, 4), leads to a recent westward avulsion of the Blackmud Channel mouth.

The Guilcher Channel, located to the east of the Guilcher system, is a prominent sinuous channel extending downslope from the Guilcher Canyon. This channel is 2,500 m wide, 75 km long, and has a relief of 90 m from the channel floor to the Guilcher Ridge crest. As channel sinuosity seems to reflect supply characteristics (Clark et al. 1992; Reading and Richards 1994; Galloway 1998), the sinuous nature of the Guilcher

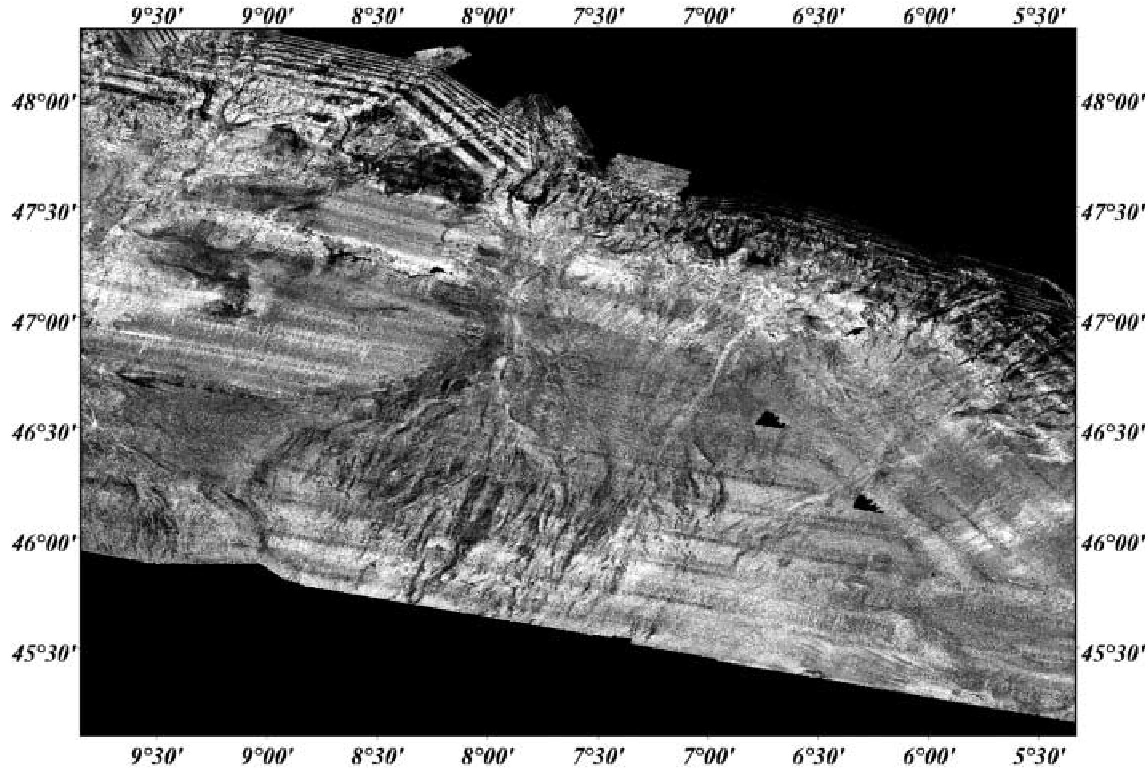

Fig. 5 Multibeam echosounder mosaic covering the Armorican depositional system and the Morbihan Slide (Le Suavé 2000). The mosaic is displayed in inverse polarity, i.e. high backscatter values have darker tones

channel-levee system implies finer grained turbidity currents than in the other channels.

The levees bordering the upper part of the channels are strongly asymmetrical. The Guilcher, Crozon and Audierne channels show substantially higher and better developed right levees, i.e. the Guilcher Ridge, the Western Crozon Ridge, and the Audierne Ridge, respectively. The Guilcher Ridge is 18 km wide and covers a surface of about 700 km^2. The Western Crozon Ridge is 15 km wide and covers a surface of about 1,000 km^2. The Audierne Ridge is 30 km wide and covers a surface of about 700 km^2. Fields of sediment waves cover these levees. Their wavelengths range from 1,000 to 4,000 m, and their amplitudes from 5 to 80 m. All the ridges are essentially of the IIA echo type. The occurrence of overbank deposits on the ridges is suggested by (1) the location of the ridges along the channels, (2) the presence of sediment waves, and (3) the orientation of the sediment wave crests which are perpendicular to the assumed path of overflow currents (Figs. 2, 4).

The upper part of the Cornouaille system is characterised by two main straight tributary channels, the Audierne and the Blavet channels (Fig. 4). To the south, the Audierne Channel and the Blavet Channel converge toward the narrow passage between the Blavet Escarpment and the Audierne Ridge, and merge into a single channel, the Cornouaille Channel. This channel feeds a single small lobe deposit on the distal ramp (Figs. 5, 6).

An isolated sedimentary body without any canyon or channel connection is present in the eastern part of the Crozon Channel and constitutes the Crozon Apron Deposit (Fig. 4). Identified by 3.5-kHz seismic analysis (Fig. 6), this apron deposit covers a surface of more than 3,000 km^2 and presents a very low relief. The echofacies range from IIB to IIA, with local DF echoes. The absence of any connection suggests a slope origin. Sediment could come from an unnamed spur located upstream.

Sediment distribution on the distal ramp

The distal ramp includes the area of secondary channels and their related lobes. The secondary channels do not show any significant levees but feed a complex network of small-scale finger-like sublobes (Figs. 5, 6). Successive lobe elements, without significant surface expression, coalesce to form widespread lobes possibly generated during periodic avulsions of medial and distal ramp channels.

On the medial ramp the channel-levee system sizes are similar, but on the distal ramp the surface area of the lobes linked to each system decreases eastwards. This trend seems to be related to the increasing distance from the English Channel system axis (Fig. 1).

The Morbihan Slide

This large-scale mass movement deposit (Figs. 2, 4, 6, 8) of about 1,800 km^2 and 50 km^3 is smaller than several

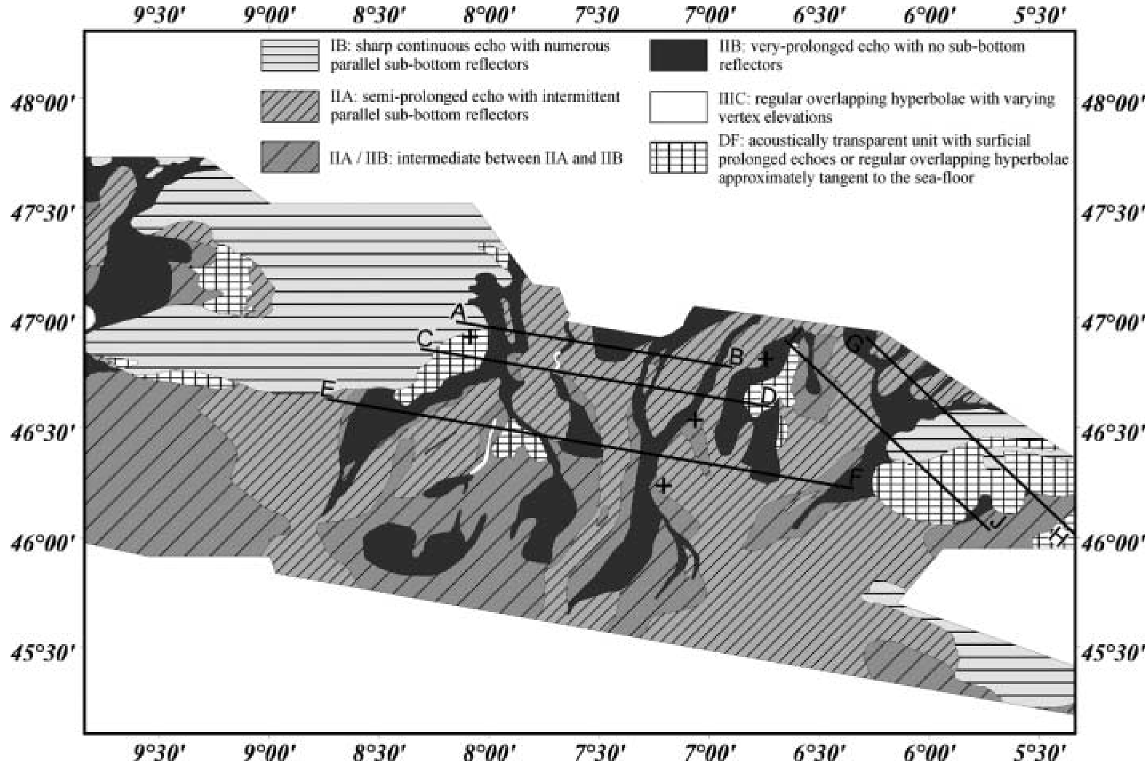

Fig. 6 Map of echofacies distribution in the Armorican depositional system, and location of profiles *AB*, *CD*, *EF*, *GH* and *IJ*. *Crosses* Core locations (see Fig. 3 for core numbers)

other western European slides (e.g., the Storegga, Trænadjupet, Andøya, and Bjørnøyrenna giant slides; Kenyon 1987; Laberg et al. 2000). This failure deposit is seismically transparent (Fig. 7). The 3.5-kHz echofacies presents fairly regular overlapping hyperbolae approximately tangential to the seafloor (DF). On the multibeam echosounder imagery (Fig. 5), this failure deposit is characterised by a relatively homogeneous signature identical to the neighbouring seafloor. The absence of any connection with the shelf break suggests a slope origin for this deposit.

Discussion

Turbidite system models and processes

In the 1980s, the classical fan models (Normark 1970; Mutti and Ricci Lucchi 1972; Walker 1978) were improved with the development of multiple-source models (Chan and Dott 1983; Heller and Dickinson 1985; Reading and Richards 1994). Unlike the point-source submarine fan fed by a single feeder channel, the multiple source submarine ramp model describes systems which are fed by multiple sources.

The Armorican depositional system is fed by 33 canyons draining a 360-km stretch of shelf edge. These canyons merge into six main channels on the lower slope. Downslope, the channels maintain their isolation, and thus the system keeps a multiple-source pattern. In this way, the whole Armorican turbidite system corresponds to a mud/sand-rich multisource ramp. It is slightly different from the Celtic Fan to the north, with the same sedimentary context but displaying intermediate patterns between submarine fan and submarine ramp (Zaragosi et al. 2000).

On the medial ramp, the majority of the channels present a straight pathway with a large U-shaped cross section. The occurrence of sand bodies at the outflow of these channels, and of sandy turbidite in core MaKS03 (Fig. 11) indicate the high-density nature of the last turbidity currents.

The complete Bouma sequence is extremely rare, both in the modern and in the ancient rock records. Most of the observed Bouma sequences are top-cut out (T_a or T_{a-b}) or base-cut out (T_{c-e} or T_{d-e}). Core MaKS03, located beyond the Crozon Channel (Fig. 3), presents a complete Bouma sequence (Fig. 11). The same unit is sampled by core MaKS02 (Fig. 9) located upslope at the eastern end of the Eastern Crozon Ridge (Figs. 3, 4), but it is a top-cut out sequence (T_a). At the site of core MaKS03 at the mouth of the channel, there is a rapid decrease in flow speed, promoting the deposition of a complete sequence. The sand bodies located beyond the Blackmud, Brest and Crozon channel mouths (Figs. 2, 4) seem to result from the same depositional processes.

The sinuous nature of the Guilcher Channel, indicating finer grained supplies for most of the turbidity flows, could be explained by the nature of the source area. Indeed, the Guilcher Channel drains the southeast part of the Chapelle drainage area. This section of the

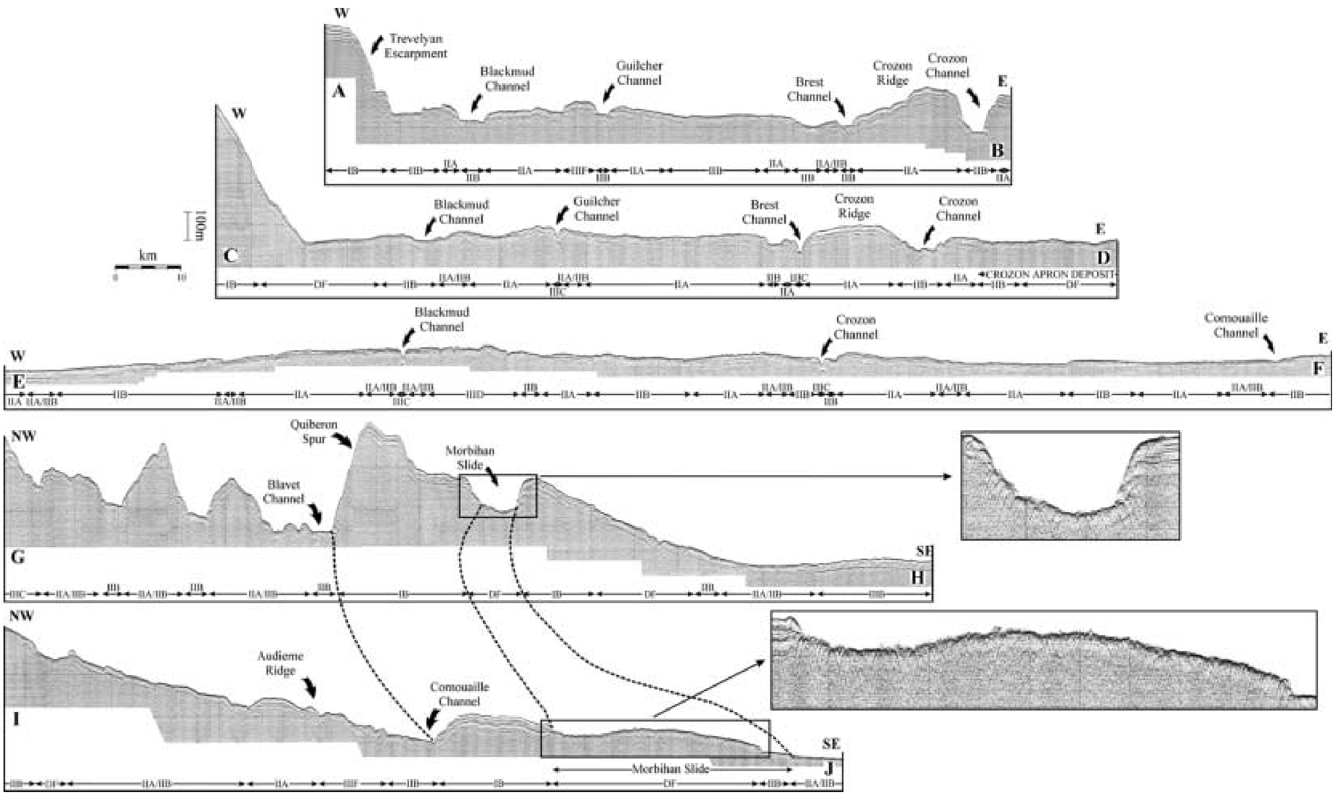

Fig. 7 Selected 3.5-kHz profiles across the Armorican depositional system and the Morbihan Slide (for location see Fig. 6). Profiles were recorded with a hull-mounted sounder

outer shelf, named the Chapelle Bank (Bourillet and Loubrieu 1995), corresponds to a shoal covered by a field of dunes parallel to the shelf break (Fig. 4). On the Celtic and Armorican shelves, the Celtic sand banks are located very close to the shelf break (< 10 km). Chapelle Bank is a fairly isolated low-relief feature, and represents an obstacle for the direct delivery of sand to the slope. This probably reduces the sand supply to Guilcher Channel, and thus favours a sinuous course.

On the distal ramp, the spreading of individual sheet flows produces small lobes without significant surface expression. These lobes are generated through periodic avulsions resulting from channel infill at the medial-distal ramp boundary.

The Cornouaille system is characterised by the existence of two sedimentary sources on the medial ramp. However, just before the distal ramp, the two channels merge into a single channel, generating a single source (Fig. 4). Hence, the Cornouaille system shows a pattern similar to the Celtic Fan (Zaragosi et al. 2000). The eastward migration of the Celtic Fan and the Cornouaille system, as a consequence of the Coriolis effect, is prevented by a structural feature. In this way, the channels are confined between the right levees and the structural features, and have not migrated over long periods, thus producing highly developed right levees. As a result, avulsion frequencies of such systems are lower. For this reason, the Audierne Ridge is well developed despite having a lower sedimentary supply than the Guilcher and Crozon systems.

Evolution of sedimentary processes

To determine the evolution of the sediment supply to the Armorican depositional system, cores MaKS02 and G72104 (Fig. 3) were sampled for sedimentological and paleontological analyses (Fig. 10).

Core MaKS02, located to the east of the left levee of the Crozon Channel, provides information about the evolution of sediment supply since the last glaciation. During the MIS 2 and the beginning of the MIS 1 (Bølling Allerød and Younger Dryas events), the presence of thin-bedded, very fine sands and laminated silt and clay (facies 3) indicates the occurrence of overflow processes on the Crozon levees. At the Pleistocene-Holocene boundary (10,000 years B.P.), the occurrence of hemipelagic sedimentation (facies 1) points to the cessation of overflow processes. Cores MaKS02, MaKS03 and MaKS04, representing a N-S transect from the medial to the distal ramp, record predominantly hemipelagic sedimentation over the past 10,000 years. However, two distinct layers, interbedded in the hemipelagic deposits (facies 1 and 2), can be correlated between the three cores (Fig. 9). The first layer, deposited during the Younger Dryas event, is a thick sandy turbidite (facies 4). The second layer, made up of thin-bedded sorted silts of uncertain origin (facies 5), is dated at 5720 years B.P.

Core G72104 (Duplessy et al. 1981), located to the west of the Blackmud Ridge, records the evolution of

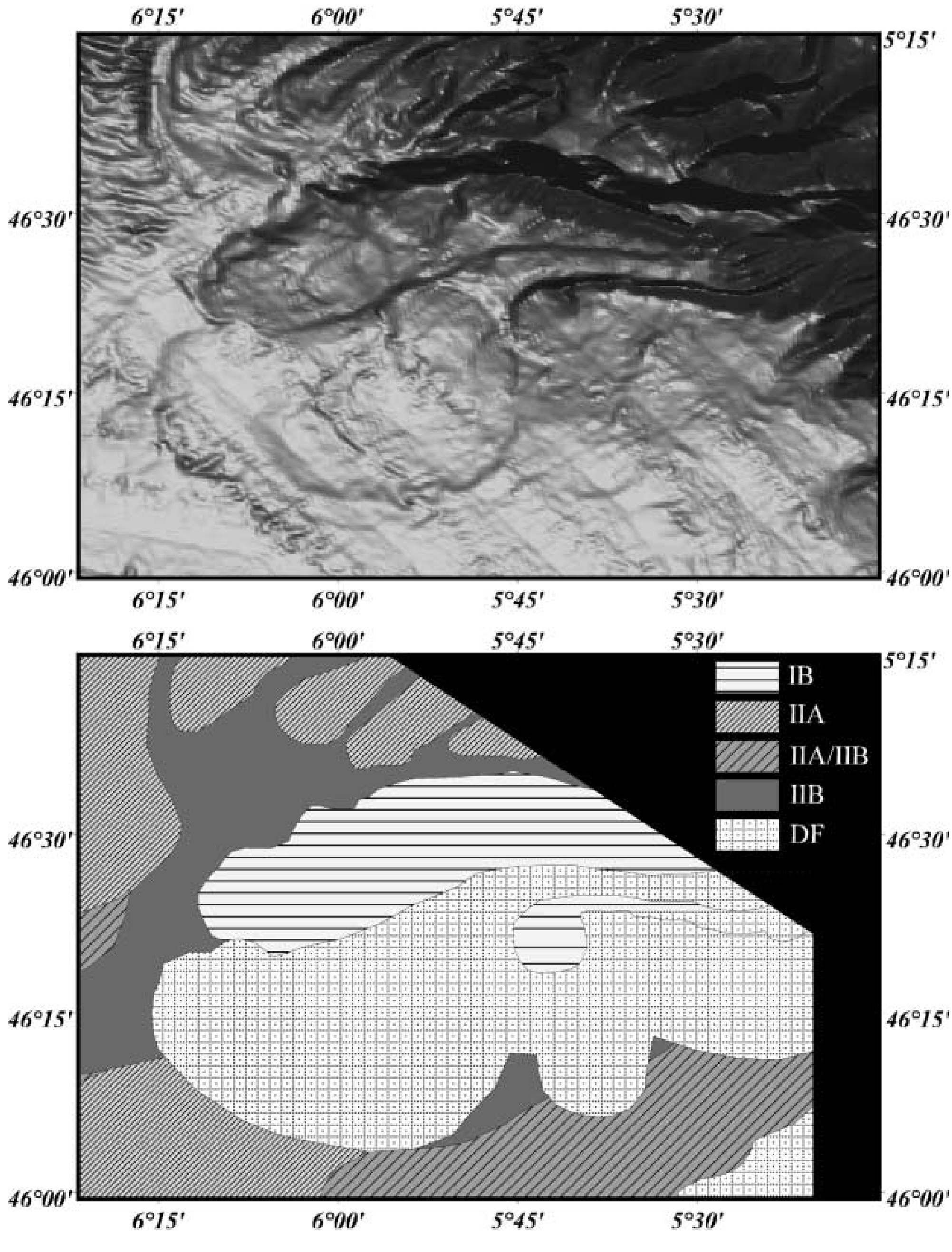

Fig. 8 Detailed shaded bathymetric map and echofacies distribution for the Morbihan Slide

sediment supply to the Blackmud Channel. Because of its great distance from the channel axis, this core should have recorded only the deposits of the more important gravity flows. As for the Crozon system, during the MIS 2 and the beginning of the MIS 1 (Bølling Allerød and Younger Dryas), the presence of silt laminae (facies 3) indicates the occurrence of relatively low-density turbidity currents at the core site. The Pleistocene-Holocene boundary is marked by the cessation of low-density turbidite deposits and the occurrence of homogeneous marly ooze (facies 1), indicating hemipelagic sedimentation. At the base of the Holocene, the occurrence of a normally graded sand layer indicates a high-density turbidite event.

Cores MaKS02 and G72104 present the same facies vertical distribution, with relatively low-density turbidity currents during the MIS 2 and the beginning of the MIS 1 (24–10,000 years B.P.), and hemipelagic sedimentation during the Holocene with episodic high-density turbidity currents at the base of the Holocene.

Paleoceanographic control on the development of the Armorican turbidite system

The available cores allow the historical reconstruction of the Armorican depositional system during the MISs 1 and 2 (0–24,000 years B.P.). Like the Celtic Fan

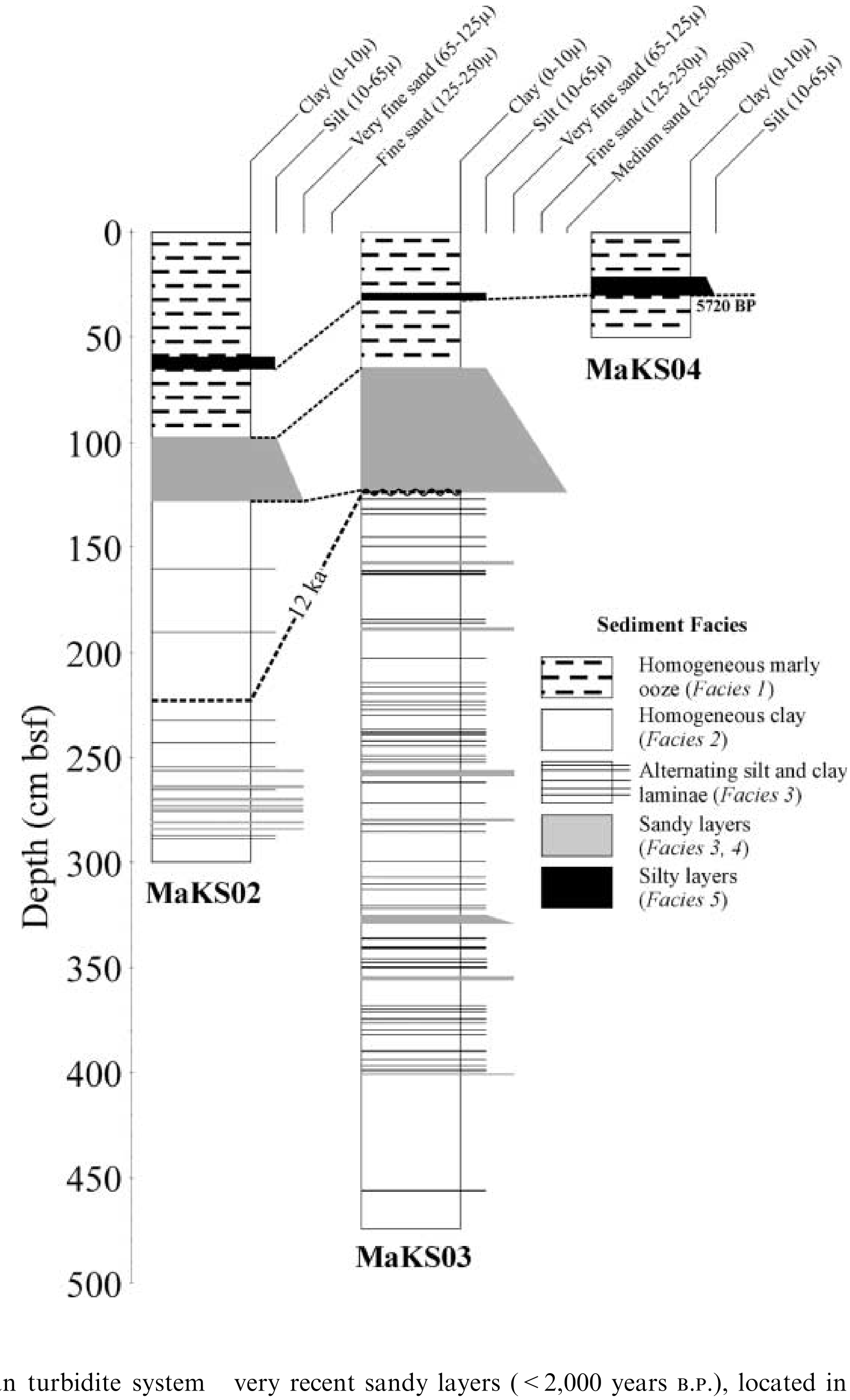

Fig. 9 Sedimentological core logs from the Crozon system, showing grain-size variation, lithology and bed thickness. (see Fig. 3 for location of cores)

(Zaragosi et al. 2000), the Armorican turbidite system does not appear to have been built at a gradual or constant rate. There are distinct episodes of growth characterised by various depositional processes.

On the Celtic Fan (Zaragosi et al. 2000), the overflow deposits present on the upper fan during the MIS 2 and the beginning of the MIS 1 (Bølling Allerød, Younger Dryas and lower Holocene) indicate the occurrence of relatively low-density turbidity currents which would have originated at the front of a deltaic environment on the outer shelf (periods of low and rising sea level). The very recent sandy layers (< 2,000 years B.P.), located in the middle and lower Celtic Fan, indicate episodic high-density turbidity currents. These upper Holocene supplies are derived from reworked outer shelf sands due to the high-energy conditions (storms and spring tidal currents) on the outer shelf during high sea-level periods.

As on the Celtic Fan, similar differences between sea-level lowstands and highstands occur in the Armorican depositional system. The passage between the lowstand low-density turbidity currents and the highstand hemipelagic sedimentation with episodic high-density

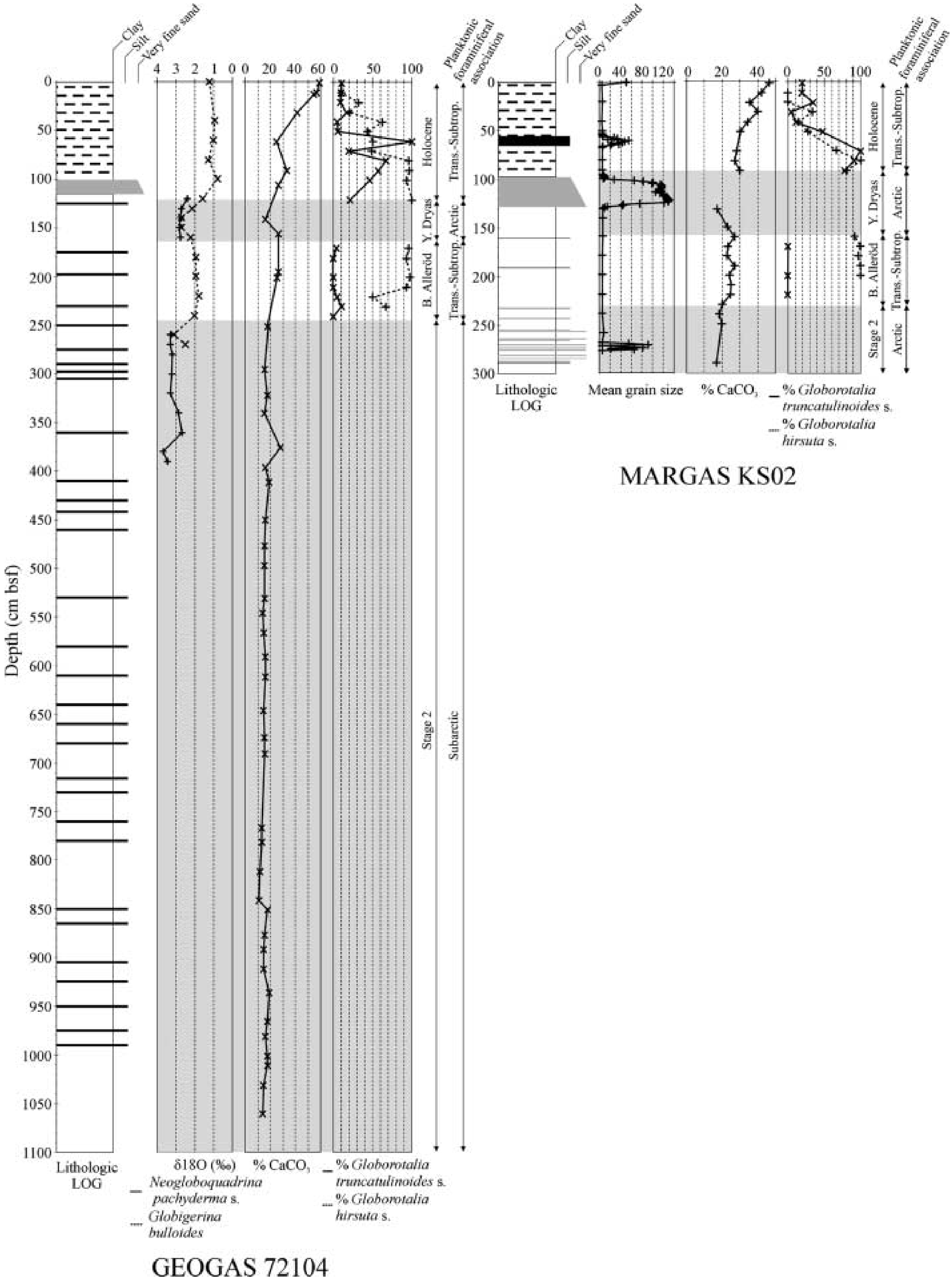

Fig. 10 Core GEOGAS 72104 from the Guilcher system, showing $\delta^{18}O$ record, $CaCO_3$ contents, and abundance (%) of the Foraminifera *Globorotalia truncatulinoides* s. and *Globorotalia hirsuta* s. Core MARGAS MaKS02 from the Crozon system, showing mean grain size, $CaCO_3$ contents, and abundance (%) of the Foraminifera *Globorotalia truncatulinoides* s. and *Globorotalia hirsuta* s.

turbidity currents occurs at the Pleistocene-Holocene boundary (~10 thousand years B.P.). On the Celtic Fan, the same change is dated at 7,028 years B.P. This shift through time of the end of deltaic environment influence, and the transition to present hydrodynamic conditions, can be explained as follows. The Armorican depositional system is located in the southeastern part of

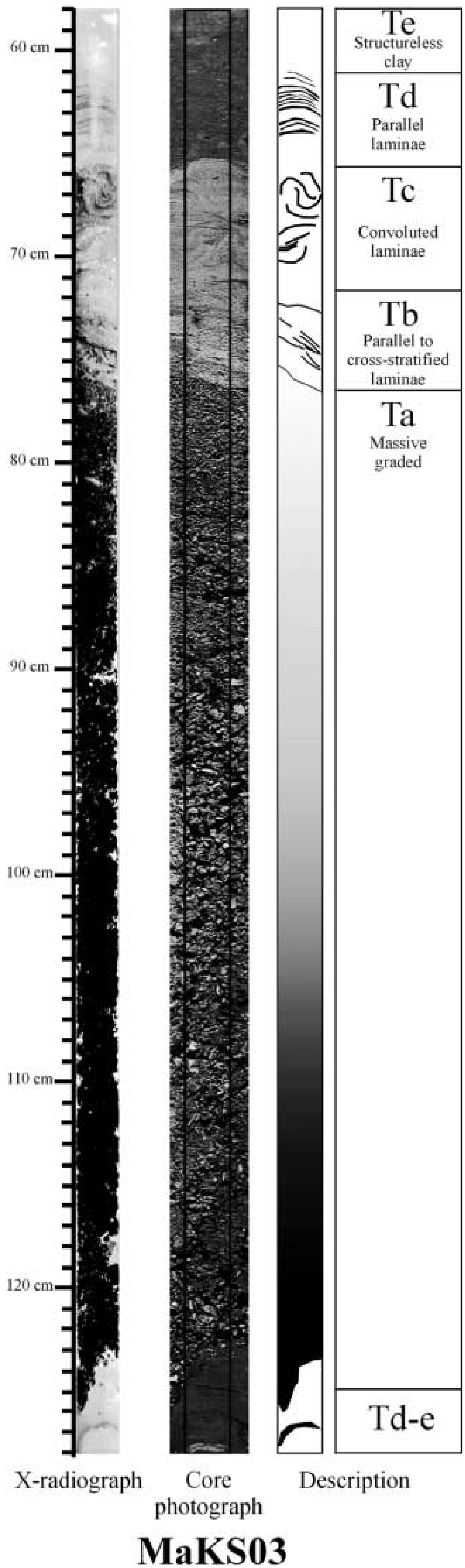

Fig. 11 Section of core MaKS03 (58–128 cm), consisting of a complete Bouma sequence from medium sands (T_a) to laminated silt and clay (T_d), and homogeneous clay (T_e)

the area influenced by the English Channel Delta (Fig. 1). It is the first to record the cessation of deltaic supplies (~10,000 years B.P.). These supplies may have continued up to the lower-upper Holocene boundary (~7,000 years B.P.) along the main axis of the English Channel system and then fed the Celtic Fan located just downstream from this axis. This cessation of deltaic supply to the deep sea at about 7,000 years B.P. is synchronous with the development of fully marine conditions in the Straits of Dover and in the Southern Bight of the North Sea (Eisma et al. 1981; Lericolais 1997).

The main difference with the Celtic Fan is observable during the Holocene. On the Celtic Fan, episodic high-density turbidity events occur during all the MISs 1. For the Armorican turbidite systems, the equivalent sand layers were located during the Younger Dryas and at the base of the Holocene. No more important turbidite event occurred during the main part of the Holocene. Sampling the lobe area downwards from the six tributary channels is necessary to confirm such a hypothesis.

The eustatic cycles thus constitute the major factor controlling the timing and type of sedimentation in the Armorican depositional system. During the last low sealevel period, sediments derived from the Channel River and the Channel Delta were transported into the deep basin via submarine canyons and deposited as channel-levee systems and distal lobes. During this low sea-level configuration, the Armorican turbidite system was a delta-fed ramp. This configuration ceased about 10,000 years ago. The episodic turbidite supplies derived from reworked shelf sands at the base of the Holocene seem comparable to the upper Holocene sandy layers of the Celtic Fan. Sedimentary processes during the high sea-level stand are uncertain, i.e. it is unclear whether the deep-sea Armorican depositional system is totally inactive or whether it is currently still being supplied from the outer shelf.

Conclusions

The Armorican depositional system is a medium-sized turbidite system with a surface area of more than 30,000 km^2. The entire system corresponds to a mud/sand-rich multisource submarine ramp on a passive continental margin. The medial ramp is characterised by the presence of six distinct tributary channels which form three systems: (1) the Guilcher system, linked to the central part of the English Channel system; (2) the Crozon system, linked to the southern part of the English Channel system; and (3) the Cornouaille system, linked to the southeastern part of the English Channel system. The medial ramp displays well developed channel-levee systems with large levees modelled by sediment waves and channels which are either linear or sinuous, depending on the amount and textural characteristics of the sediment supply. The distal ramp corresponds to divergent braided secondary channels and associated lobes. Successive small lobes are generated during periodic avulsions of the channels and coalesce to form broad lobes.

The lithological, palaeontological, and geochemical analyses of four cores document the evolution of sedimentation since the last glaciation. The fine-grained turbidites, which are the dominant deposits on the medial ramp during the marine isotopic stage 2 and at the beginning of the marine isotopic stage 1, indicate the occurrence of relative low-density turbidity currents which must have been initiated at the front of a deltaic environment on the outer shelf during a period of low sea-level stand and subsequent sea-level rise. The occurrence of sand layers during the Younger Dryas and at the base of the Holocene points to episodic high-energy turbidity current supply related to outer-shelf sand reworking. In this way, the Armorican depositional system is a delta-fed submarine ramp during low sea-level glacial episodes. Sedimentary processes during the high sea-level stand are uncertain, i.e. it is unclear whether the deep-sea Armorican depositional system is totally inactive or whether it is currently still being supplied from the outer shelf.

Acknowledgements The authors are grateful to IFREMER and SHOM for data. Multibeam bathymetry and acoustic imagery data collected during the projects conducted by IFREMER (Sedimanche and ENAM programmes, coordinated by J.F. Bourillet and G. Auffret, respectively, and the Bay of Biscay EEZ programme coordinated by R. Le Suavé) have been compiled and processed by A. Normand, B. Loubrieu, J.P. Mazé and E. Le Drézen. The authors are also grateful to F. Vinçent, J. St. Paul, D. Poirier, G. Chabaud, R. Kerbrat, R. Apprioual, G. Floch, J. Kervern, P. Guyomard and S. Lucas for technical assistance. This is an U.M.R./EPOC C.N.R.S. no. 5805 contribution no. 1376.

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