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Serge Lallemand, Jean-Claude Sibuet. Tectonic implications of canyon directions over the Northeast Atlantic Continental Margin. *Tectonics*, 1986, 5 (7), pp.1125-1143. 10.1029/TC005i007p01125 . hal-01261558

HAL Id: hal-01261558

<https://hal.science/hal-01261558>

Submitted on 25 Jan 2016

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TECTONIC IMPLICATIONS OF CANYON DIRECTIONS
OVER THE NORTHEAST ATLANTIC CONTINENTAL
MARGIN

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Abstract. The basis of this study is a new bathymetric map of the northeast Atlantic compiled from previously published maps made from conventional echosounder data, plus all Sea Beam data acquired on board the R/V JEAN CHARCOT since 1977. As most of the Sea Beam data have been obtained on the continental margin from Porcupine Seabight to the south of the Iberian Peninsula, a precise picture of the continental slope is given. A statistical analysis of the canyons, based on 750 measurements, reveals that many of the canyons present sharp changes in their direction, indicating a structural control mainly linked to the late Hercynian trends, especially around the Iberian Peninsula. Nevertheless, the paths of canyons may merely reflect recent gravity processes, as in the Porcupine Seabight. Canyons locally follow the directions of listric and associated transecting faults (Permian to Triassic and upper Jurassic to lower Cretaceous), as on the Celtic

margin, and every type of tectonic lineament—for example, the North Pyrenean Paleogene thrust front which fringes the Gouf of Cap Breton. A comparison of diagrams for the northern and southern Bay of Biscay margin (especially trends predating the opening) is compatible with a 25° rotation of Iberia with respect to Europe.

INTRODUCTION

Reliable bathymetric maps of the northeast Atlantic Ocean have been available since the early 1960s. The continental margins, largely cut by down slope canyons, were systematically surveyed by Berthois, who implemented tracklines in a direction parallel to the continental margin trends [e.g., Berthois and Brenot, 1960, 1964; Berthois et al., 1968]. Then an exhaustive compilation of conventional data in the northeast Atlantic was done by Loughton et al. [1975]. Ten years after, continental margins from the Porcupine Seabight to Gibraltar were largely surveyed by the Institute of Oceanographic Sciences (IOS) using the GLORIA Mark II [e.g., Kidd and Roberts, 1982], a dual-scan sonar towed at shallow depths with a maximum scanning range of 30 km on each side of the fish track [Somers et al., 1978] and by the R/V JEAN CHARCOT equipped with a multibeam echo sounder [Renard and Allenou, 1979] since 1977. Both Sea Beam and GLORIA are

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Paper number 6T0399.
0278-7407/86/006T-0399\$10.00

tools which provide precise information on morphologic trends. Twenty Sea Beam cruises or transits have been carried out, mainly on continental margins, which allow us to produce a new detailed bathymetric map (Plate 1) [Lallemand et al., 1985 a,b]. Most of the Sea Beam data have been acquired along the continental margins (Plate 2), which provides a fairly good picture of the morphology of the northeast Atlantic continental margins, especially along the slopes. Many of the canyons cross the margins obliquely and present sharp changes in their directions. This indicates that the canyon trends are not only controlled by gravity processes, but they are also largely influenced by the structural pattern [e.g., Boillot et al., 1974; Kenyon et al., 1978; Sibuet and Berthois, 1979]. We propose to perform a statistical study of the direction of canyons and to correlate these directions with the structural pattern known on land and on the continental shelf.

GEOLOGICAL EVOLUTION OF THE NORTH ATLANTIC OCEAN

Tensional episodes occurred from Permian to Lias in the areas of the future plate boundaries between Europe, North America, and Iberia. The continental crust was thinned, sometimes with formation of very limited amount of oceanic crust [e.g., Foucher et al., 1982], but the complete structural outline of all continental margins of the northeast Atlantic Ocean was mainly acquired during the late Jurassic-early Cretaceous phase of rifting which occurred simultaneously with the opening of the central Atlantic Ocean.

The oldest magnetic anomalies identified in the northeast Atlantic Ocean are M0 (late Aptian) west of Galicia Bank and 34 (upper Santonian) in the Bay of Biscay and west of the British Isles [Sibuet and Ryan, 1979; Guennoc et al., 1978, 1979] (Figure 1). Nevertheless, oceanic crust still exists between the oldest identified magnetic anomalies and the continent-ocean boundary. From drilling results the first appearance of oceanic crust has been dated lower Albian at Goban Spur [Masson et al., 1984], early Albian near the Meriadzek terrace in the northern Bay of Biscay [Montadert et al., 1979a,b; Pastouret et al., 1981] and late Aptian west of Galicia Bank [Sibuet and Ryan, 1979]. This indicates that the

initial emplacement of oceanic crust propagated from south to north.

The formation of the Bay of Biscay results from the rotation of Iberia with respect to Europe around a pole located in southwest Europe [Le Pichon et al., 1971; Olivet et al., 1984] from late Jurassic-early Cretaceous to the time of anomaly 33 (Campanian) [Sibuet and Ryan, 1979] or during the Cretaceous Quiet Magnetic Zone (Albian to Santonian) for Olivet et al. [1984]. No conclusive evidence from land geology in the Pyrénées and Aquitaine Basin allows us to discriminate between these two hypotheses. Simultaneously, the North Atlantic opening was going on. From late Cretaceous to late Eocene, the compressive movements resulted in the uplift of Pyrénées and the formation of the North Spanish subduction zone with a paroxysmal phase during Eocene [Sibuet and Le Pichon, 1971; Le Pichon and Sibuet, 1971a].

MAIN PHYSIOGRAPHIC PROVINCES ON CONTINENTAL MARGINS

The northeast Atlantic continental margins can be divided into six main domains (Figure 1) on the basis of the following criteria: (1) general trend of the margin; (2) structural and kinematic arguments; and (3) orientation of canyons.

The presence of specific trends families of canyons allows us to distinguish several subzones in areas 2, 3, 5, and 6.

Area 1. The Goban Spur continental margin, oriented N330°, was formed in lower Cretaceous during the separation of Europe and north America along a N70° direction [Masson et al., 1984; Sibuet et al., 1984a,b].

Area 2. The Celtic continental margin, oriented approximately N110°, resulted from the southeastward movement of Iberia with respect to Eurasia in lower Cretaceous [e.g., Le Pichon et al., 1971].

Area 3. The Armorican continental margin, oriented N135°, was also formed during the rotation of Iberia but corresponds to a sheared continental margin [Le Pichon et al., 1971]. It presents a narrower continental slope than the Celtic margin.

Area 4. The Landes Plateau is bounded to the north and south by the Cap Ferret Canyon and the Gouf of Cap Breton, respectively, which are both oriented

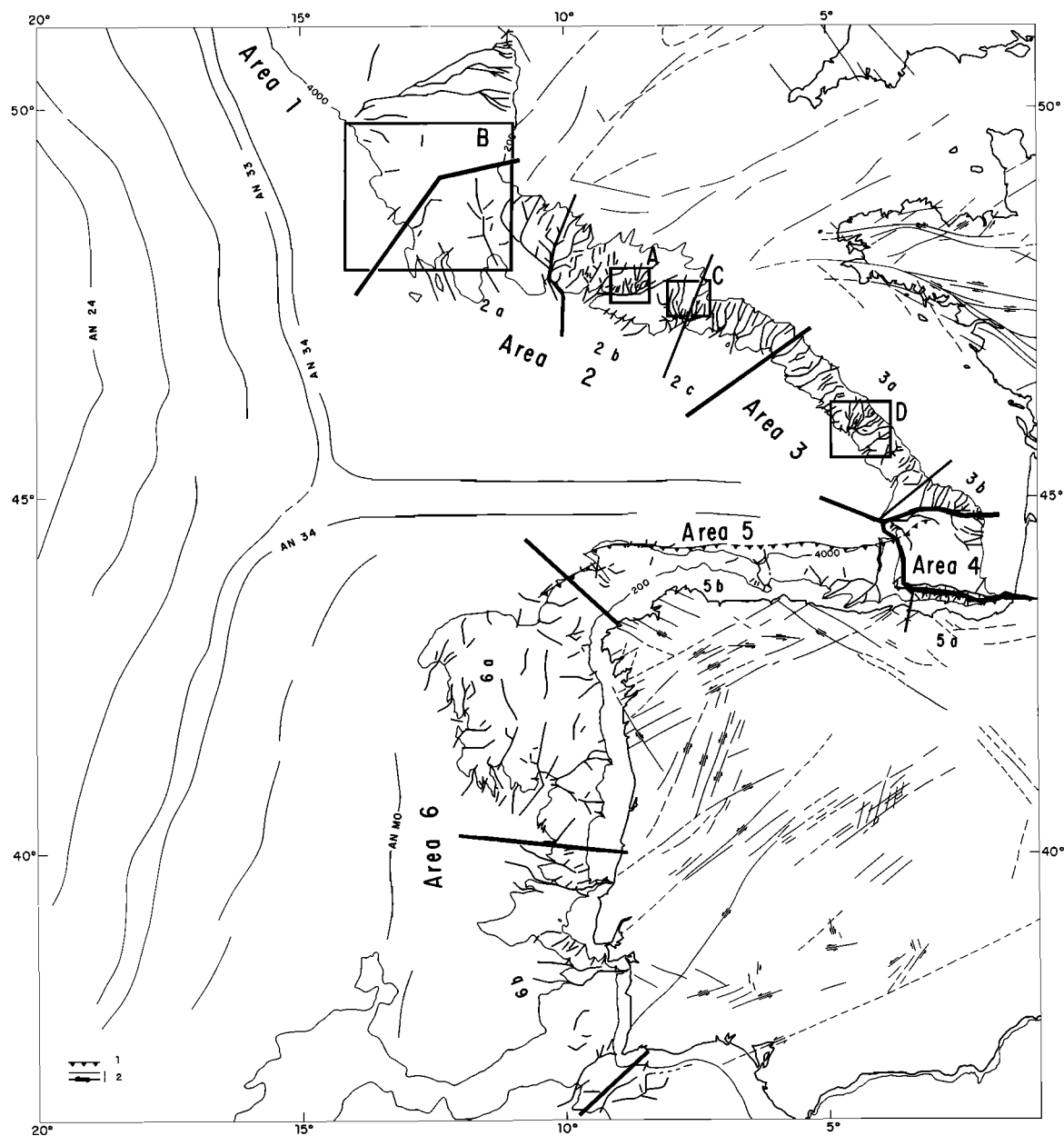


Fig. 1. Simplified structural map of the northeast Atlantic region. The main physiographic provinces of the continental margin and the location of canyons and their tributaries used in this study are shown. Identified magnetic anomalies from Guennoc et al. [1978, 1979]. 1, North Iberia Paleogene thrusting front; 2, Late Hercynian faults [Parga, 1969; Arthaud and Matte, 1975; Pegrum and Mounteney, 1978; Montadert et al., 1979a; Sibuet et al., 1948b].

N100°, and to the west by the Santander Canyon which is roughly north-south in trend.

Area 5. The North Spanish continental margin is the counterpart of

the Celtic margin but was largely tectonized during the lower Tertiary compressive phase (100-150 km of amplitude) which gave rise to the formation of the North Spanish marginal

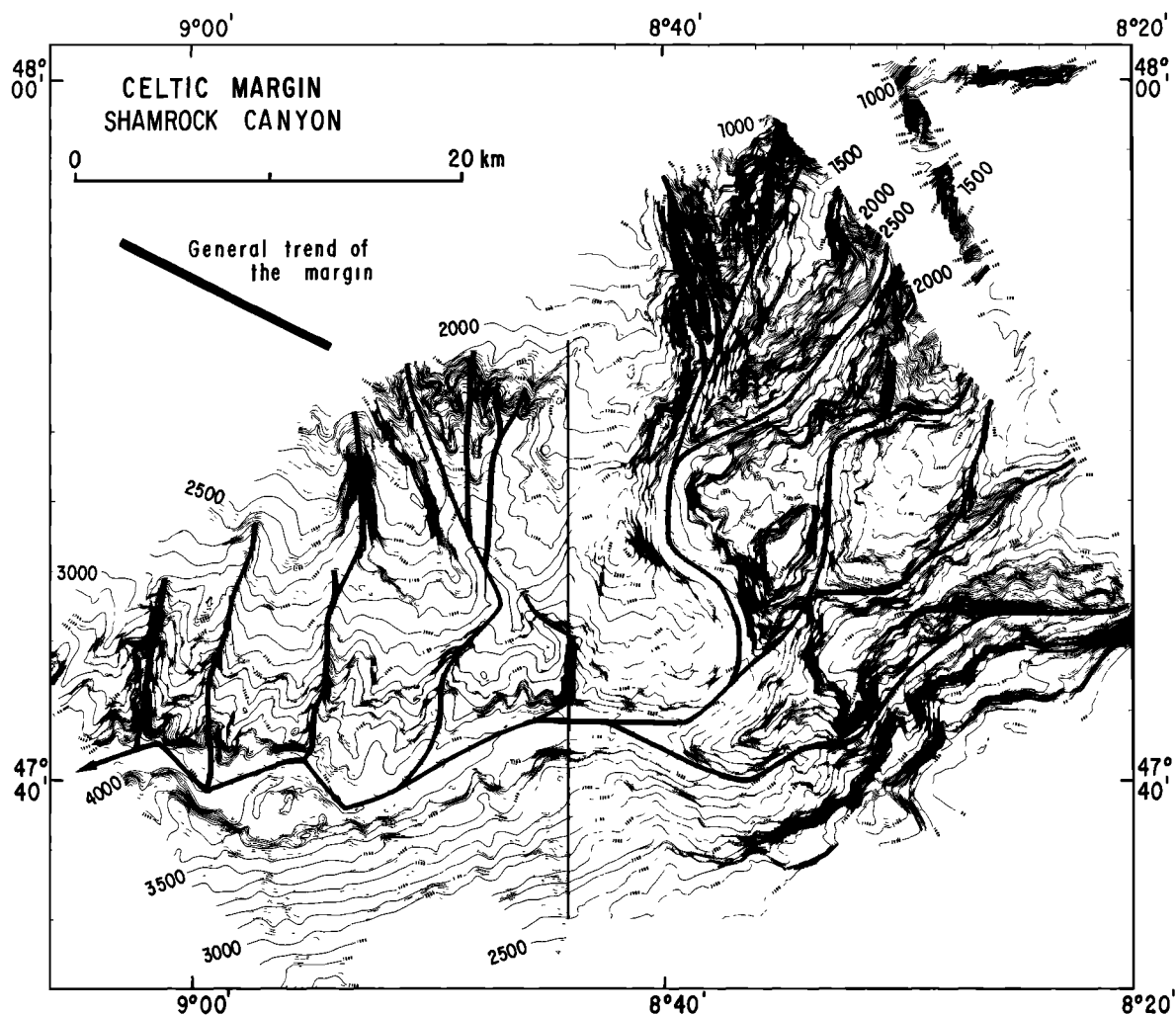


Fig. 2. Straight lines corresponding to linear segments of the Shamrock canyon axis and its tributaries superimposed on the Sea Beam map [Pastouret et al., 1982] located as box A on Figure 1. Depths are in uncorrected meters (1500 m/s). Isobath spacing 20 m.

trough [Sibuet and Le Pichon, 1971; Sibuet et al., 1971].

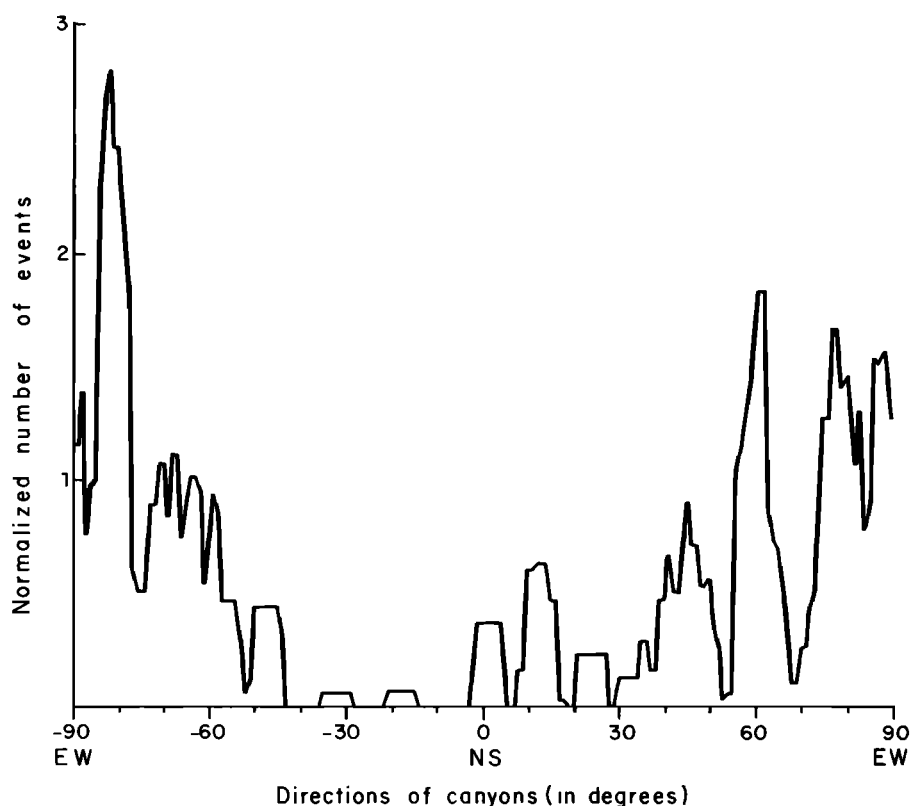
Area 6. The west Iberian continental margin which is roughly oriented north-south presents, in its northern portion, a large promontory named Galicia Bank (subarea 6a) that is separated from the continental shelf by the Interior Basin filled up with sediments [Auzende et al., 1979].

METHODOLOGY

Most of the tectonic lines which appeared during the formation of the continental margins represent preferential

erosional guides for incipient channels and canyons. Nevertheless, especially during the Plio-Quaternary period, important sedimentary gravity processes occurred along the major gradient of slopes, giving rise to canyons oriented perpendicularly to the margin. A statistical analysis of the orientation of the canyons was undertaken in order to discriminate between tectonic and gravity directions and to compare these tectonic trends with onland and offshore structural trends.

Seven hundred and fifty measurements of orientation and length of segments of canyon axes have been made along the whole continental margin. Accuracy of



**Area 1 : Porcupine Seabight and Goban Spur
continental margin (82 values)**

Fig. 3. Diagram of normalized number of events as a function of the direction of canyons, for area 1 defined in Figure 1.

measurements is about 3° for the orientation and about 2 km for the length of segments. Generally, this precision is better when measurements have been carried out on Sea Beam bathymetric maps. If the canyon is sinuous, we divide it into short segments taking into account the surrounding morphological directions if necessary. Thus each measurement corresponds to a portion of canyon and not to the entire canyon (see the example of the Shamrock canyon, Figure 2). Data have been normalized as follows in order to compare them between areas.

If L_i is the cumulative length of canyons following the i direction (expressed in degrees from -89° to +90°)

$$\text{in an area, } F_i = \left(\frac{L_i}{\sum_{i=-89}^{+90} L_i} \right) \times 100$$

F_i being the frequency of cumulated length of canyons following the i direction.

Curves have been then smoothed using mobile averaging over 7°.

Results appear in a set of six diagrams (Figures 3, 5, 8, 9, 10, and 11) showing the distribution of canyons for each of the six areas. Superimposed on the curves are the directions of onland structural trends likely to extend offshore and gravitational directions perpendicular to the local trend of continental slopes. For example, if the trend of the continental slope is N120°+10°, the gravity direction of the main canyons would be N30°+10°.

DISCUSSION OF RESULTS

Area 1: Porcupine and Goban Spur Margins

The presence of channels on the eastern slope of the Porcupine Seabight was first suggested by Berthois and Brenot [1960]

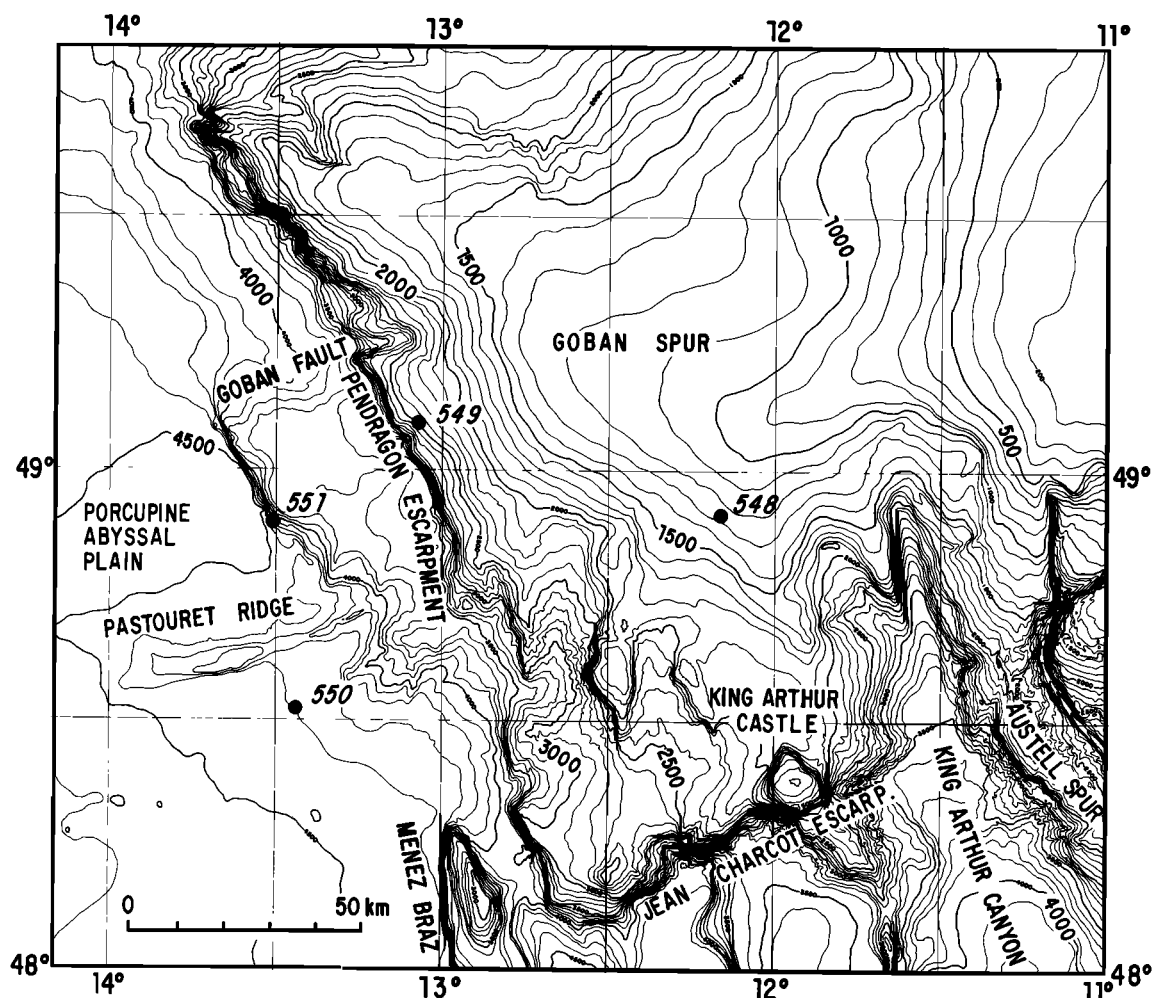


Fig. 4. Bathymetric map of the Goban Spur continental margin [Sibuet et al., 1984a, b] established from Sea Beam, conventional and unpublished GLORIA data and located as box B in Figure 1. Depths are in uncorrected meters (1500 m/s). Contour spacing every 100 m. Locations of DSDP leg 80 drilling sites are shown. The JEAN CHARCOT escarpment and the Goban fault are late Hercynian features oriented N70° and reactivated during the lower Cretaceous rifting phase. Between these two features, the NNW-SSE trending Pendragon escarpment and another parallel escarpment on which DSDP site 551 is located correspond to the crest and oceanward side of tilted fault block created during the rifting phase.

and then confirmed by the side-scan sonar survey of Kenyon et al. [1978]. The system, roughly E-W oriented, was named the Gollum Channel system and corresponds to the main contribution to Figure 3. Inasmuch as numerous slump folds are observed in the vicinity of these channels (N.H. Kenyon, personal communication, 1985) and as the heads of canyons are mainly oriented perpendicularly to the subcircular shape of the upper slope (see the main peak on Figure 3), these trends

are likely close to gravity directions and do not suggest any tectonic control.

On the Goban Spur continental margin (Figure 4), the NW-SE trending Pendragon Escarpment and another parallel escarpment located 35 km southwestward correspond to the fault planes which limit the tilted fault blocks. They are offset or interrupted by ENE-WSW trending faults such as the Goban fault and the JEAN CHARCOT escarpment [Sibuet et al., 1984b]. Nevertheless, as almost no canyon exists

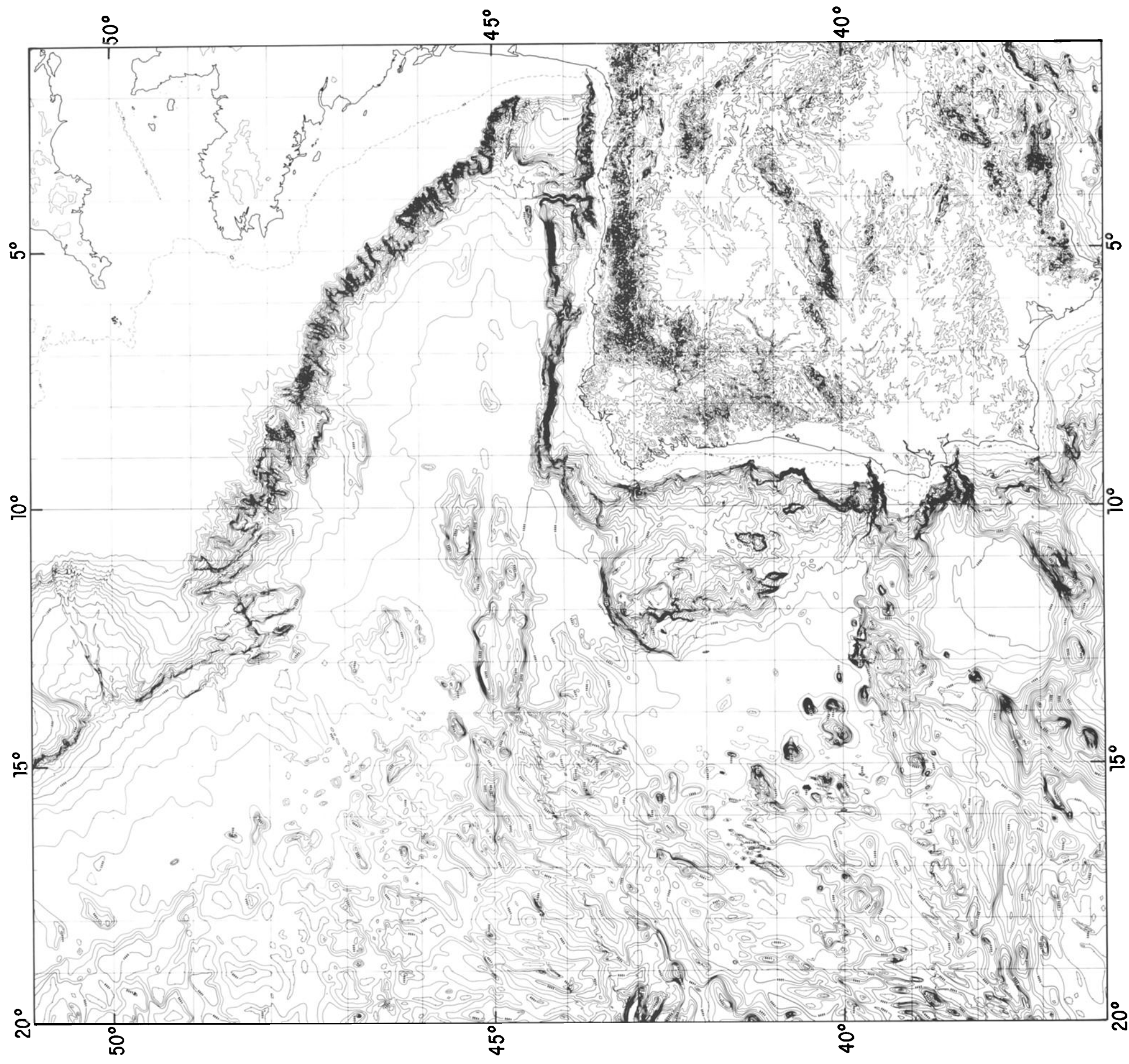


Plate 1. Bathymetric map of the northeast Atlantic. Mercator projection (W.G.S. 72 ellipsoid). Contour spacing 200 m [Lallemant et al., 1985b].

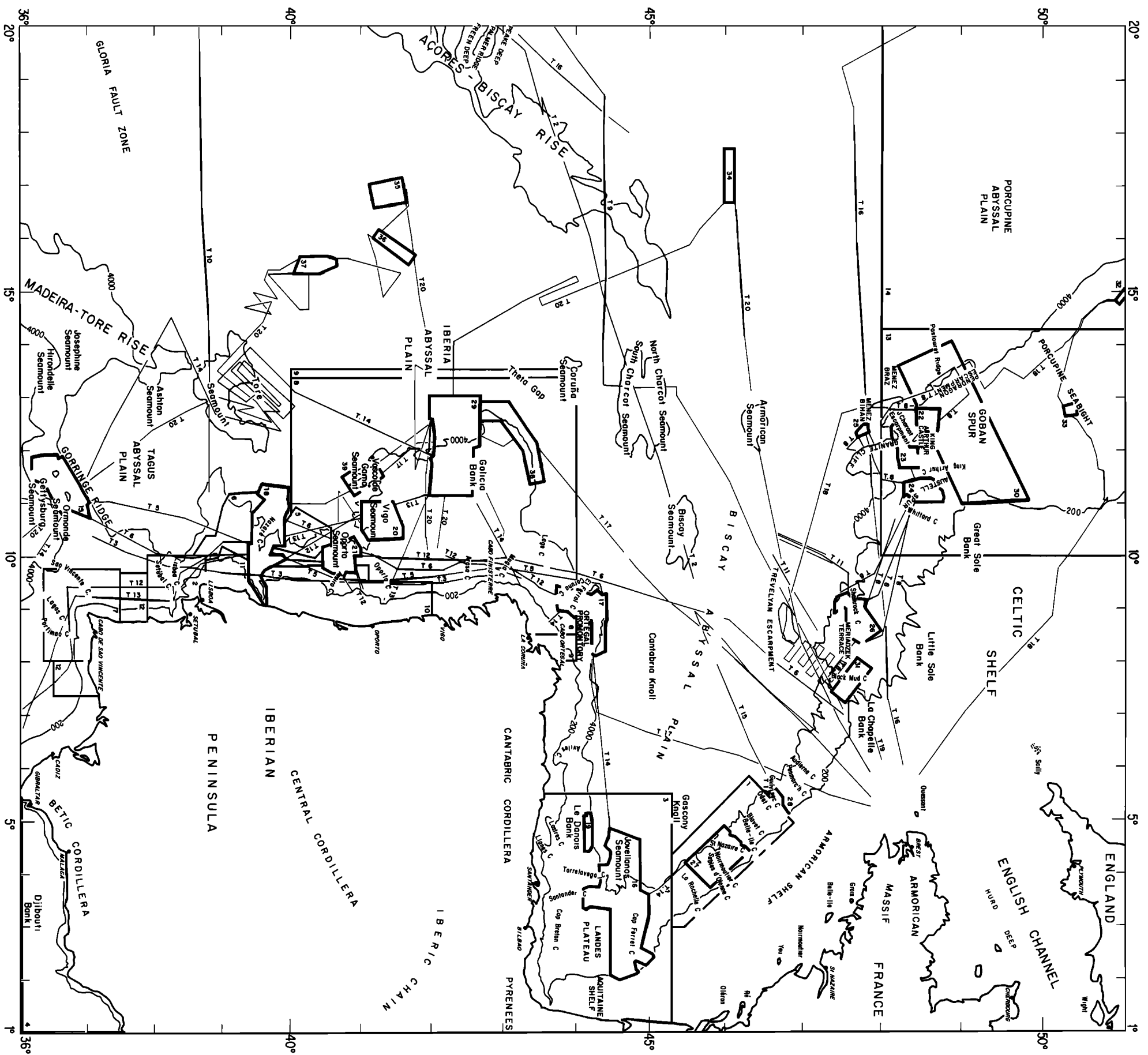
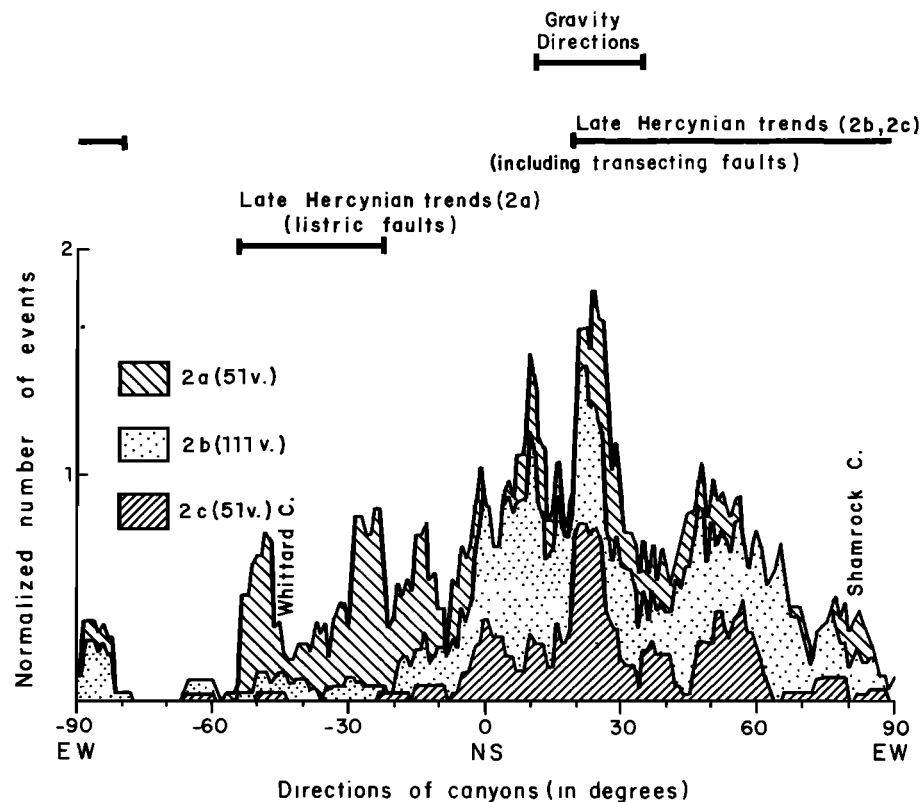


Plate 2. Location of recent conventional maps, Sea Beam detailed maps and transits used to establish the bathymetric map of Plate 1. (See Lallemand et al. [1985a, b] for references.) Toponymy of features is given.



Area 2: Celtic continental margin (213 values)

Fig. 5. Diagram of normalized number of events as a function of the direction of canyons for area 2 defined in Figure 1.

along this margin (Figure 4), there is no contribution to the diagram of these Caledonian or late Hercynian tectonic trends reactivated during the late Jurassic-early Cretaceous rifting phase.

Area 2: Celtic Margin

Subzone 2a represents the connection between the Goban Spur and Celtic margins and is marked by several topographic features such as Granite Cliff, Menez Braz, Menez Bihan, and Austell Spur, separated by large NW to NNW trending canyons (Plates 1 and 2 and Figure 4). Three peaks at -15° , -25° , and -50° appear in Figure 5 (Subzone 2a). For both the Goban Spur margin and the transition zone 2a, the trends of the listric faults along which the tilted blocks glide are oriented -25° (e.g., the Pendragon Escarpment, Figure 4) and follow the strike of the margin [Montadert et al., 1979a; Sibuet et al., 1984b]. The -50° direction is mainly

due to the contribution of the Whittard canyon and its tributaries (Plates 1 and 2 and Figure 1). This canyon continuously changes of direction from 60° in its upper portion to -45° along its main course and cuts the Tertiary sedimentary cover.

Subzone 2b presents large topographic features such as the Meriadzek terrace, the Trevelyan escarpment, and the Shamrock canyon. Subzone 2c has the same regular slope as the Armorican margin (subzone 3a), but its general direction is clearly linked to that of the Celtic margin. Figure 5 shows that the main peaks occur from -5° to 40° and from 45° to 65° for both subzones 2b and 2c. These peaks are linked to the directions of late Hercynian faults in Brittany and on the continental shelf, directions which vary from NNE-SSW to E-W in azimuth. The major peak at $N20^\circ$ corresponds to the gravity trends but also to the direction of transecting faults located in the Meriadzek area by Montadert et al. [1979a] and reactivated during the

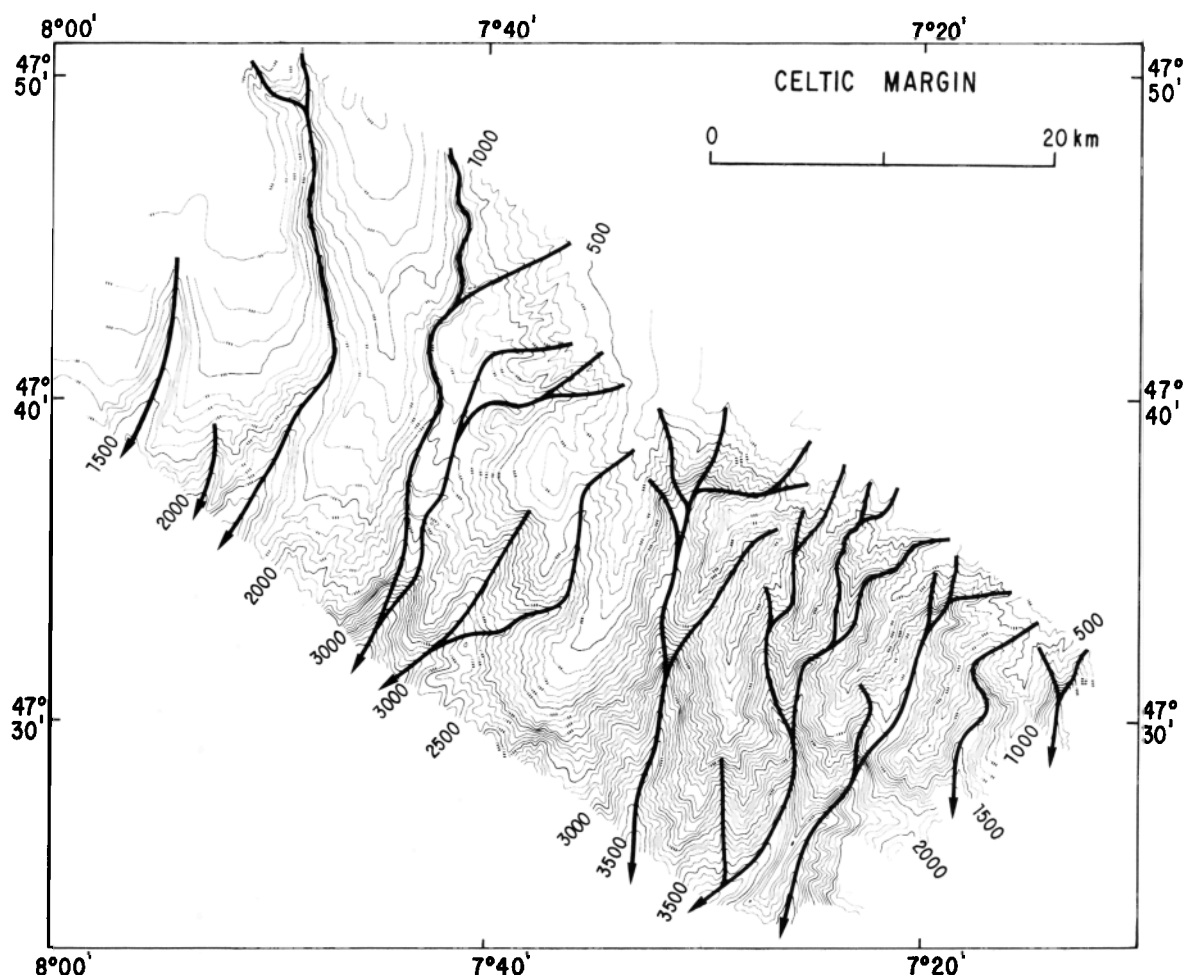


Fig. 6. Sea Beam bathymetric map of the eastern part of the Celtic margin located as box C in Figure 1. Depths are in uncorrected meters (1500 m/s). Isobath spacing is 100 m. Note the N20°-30° general trend of canyons corresponding to the main peak in Figure 5.

lower Cretaceous rifting phase. Figure 6 displays the Sea Beam bathymetry of the upper part of the Celtic margin (subzone 2c). The general N20° orientation of the numerous canyons illustrate that it is a major contribution to Figure 5. Nevertheless, the degree of downcutting and the path of canyons also depend of the lithology as it was demonstrated for the Shamrock canyon notching the chalk and calcareous marl and changing of directions in the vicinity of horsts [Auzende et al., 1981; Pastouret et al., 1982] (Figure 2). Our conclusion is that in any case, even if gravity processes exist, as shown by the presence of the N25° peak, the structural control remains for the major

canyons such as the Shamrock canyon which is clearly oblique (N80°) to the slope trend and presents sharp changes in directions which are compatible with the late Hercynian trends.

Area 3: Armorican Margin

In contrast with the Celtic margin, the Armorican margin is a linear, narrow, steep margin oriented N135° which follows the early Cretaceous transform direction of opening of the Bay of Biscay [e.g., Le Pichon et al., 1971; Olivet et al., 1984]. The overall dendritic canyon pattern is due to the numerous secondary valleys and side-gulleys as evidenced on the detailed

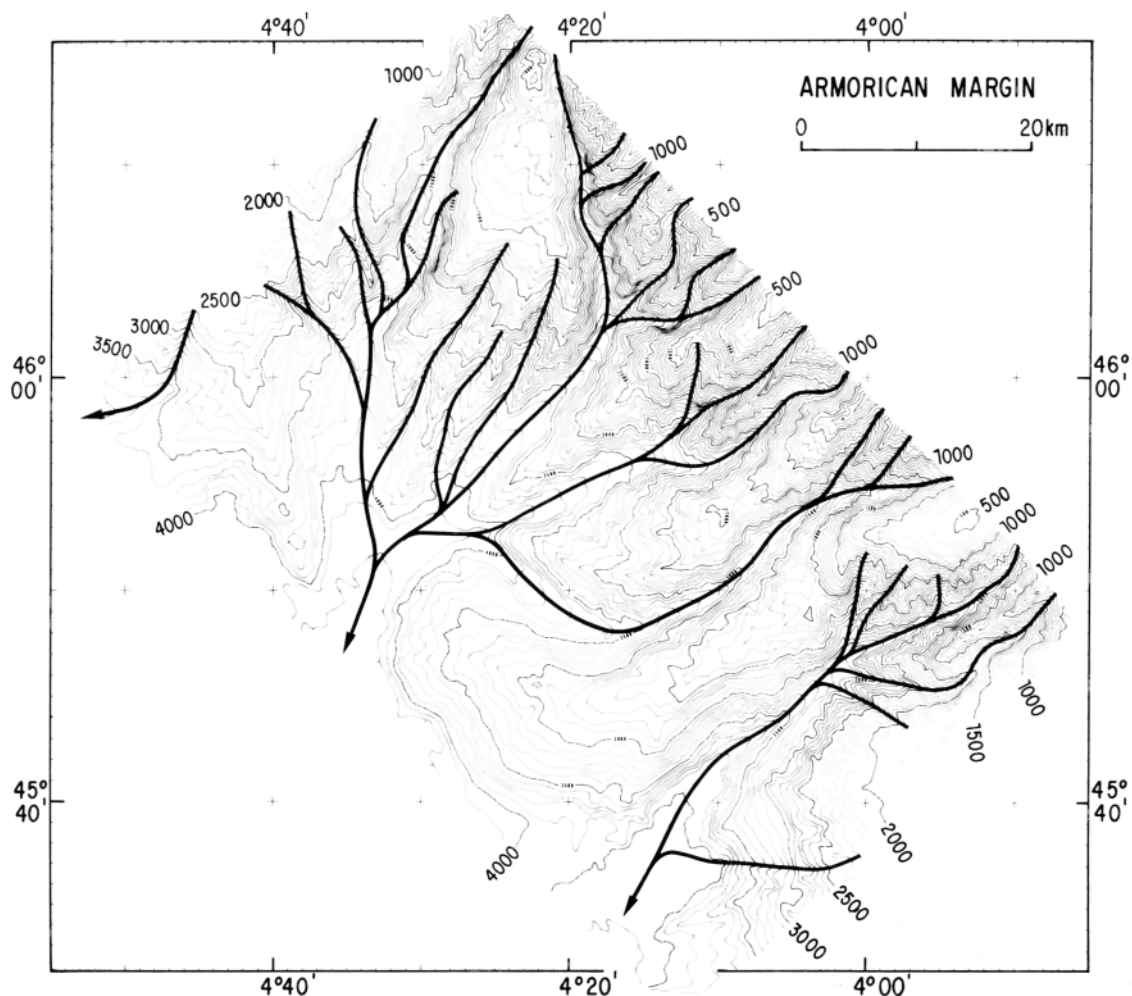
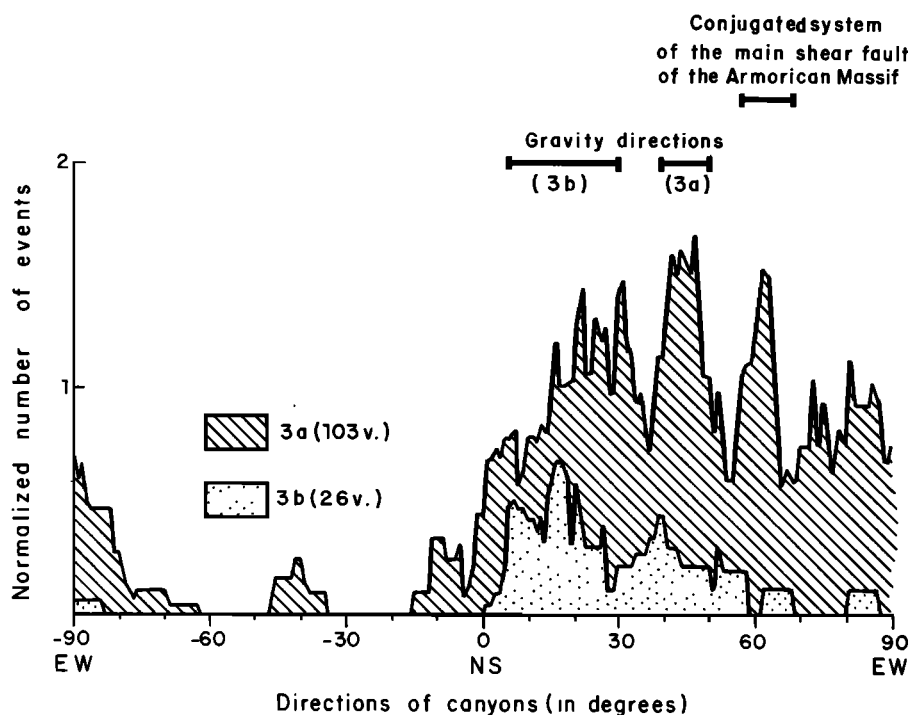


Fig. 7. Sea Beam bathymetric map of a portion of the Armorican margin located as box D in Figure 1 [Pastouret, 1984]. Depths are in uncorrected meters (1500 m/s). Isobath spacing is 100 m. The canyon pattern is characterized by numerous tributaries.

Sea Beam bathymetric map of Figure 7. The canyon axes themselves change from sinuous to straight and present frequent sharp turns (Figures 1 and 7). Figure 8 shows that the directions of canyons vary from N-S to N100°, with a major peak which corresponds to the general gravity trend between N40° and N50° for subzone 3a and between N-S and N30° for subzone 3b. On the continental shelf, most of the faults are oriented N55° to N65° (Figure 1). They are conjugated faults of the large shear system which affects the Hercynian basement of the Armorican massif. Their orientations correspond to the major N55° to N65° peak appearing on the diagram (subzone 3a).

Area 4: Landes Plateau

In the southeast corner of the Bay of Biscay, the Landes Plateau lies on the prolongation of the Aquitaine basin and can be considered as a prograding Tertiary structure over a promontary that includes Triassic to Mesozoic terranes [Valéry et al., 1971; Derégnaucourt and Boillot, 1982]. It is limited to the north and south by the Cap Ferret canyon and the Gouf of Cap Breton respectively. Both show a structural control: the Cap Ferret canyon following normal faults reactivated during Tertiary [Derégnaucourt and Boillot, 1982] corresponds to the extension of the onland Parentis basin,



Area 3: Armorican continental margin (129 values)

Fig. 8. Diagram of normalized number of events as a function of the direction of canyons, for area 3 defined in Figure 1.

and the Gouf of Cap Breton fringes the front of the North Pyrenean Paleogene thrust [Boillot et al., 1974]. These features correspond to the main peaks which appear between $N70^\circ$ and $N110^\circ$ on the diagram (Figure 9). The NW-SE lower Cretaceous dextral faults, located on the plateau itself and south of it (such as the Bilbao fault trending NW-SE from Bilbao) [Derégnaucourt and Boillot, 1982], were reactivated during the lower Tertiary Pyrenean phase of compression and may have controlled the canyon pattern corresponding to the -40° peak of Figure 9.

Area 5: North Spanish Margin

The North Spanish margin, which consists of a narrow shelf (30–40 km) and a steep slope (17°) rising directly from the Bay of Biscay, was largely tectonized during the late Cretaceous to late Eocene phase of compression resulting in the formation of the North Spanish marginal trough presently filled up with sediments

[Sibuet and Le Pichon, 1971; Sibuet et al., 1971; Le Pichon and Sibuet, 1971a]. The Bilbao fault and its possible extension offshore limit the two domains (subzones 5a and 5b) of the North Spanish continental margin, characterized by an oceanic subduction to the west and a continental collision with two overthrusting fronts to the east [Boillot and Capdevilla, 1977].

Subzone 5a includes tributaries of the southern flank of the Gouf of Cap Breton. The main peaks occurring between -40° and -30° and between 0° and 30° (Figure 10) are linked to the presence of early Cretaceous and early Tertiary tectonic features [Groupe Cybère, 1984] but also to gravity processes for the second family of canyon trends.

Within subzone 5b, the North Spanish margin is globally oriented E-W, and no major peak corresponds to the gravity directions. This area displays a broad variety of canyon trends (Figure 10).

From the Cybère diving cruise, performed in 1982 on the western part of the North Spanish margin, five principal

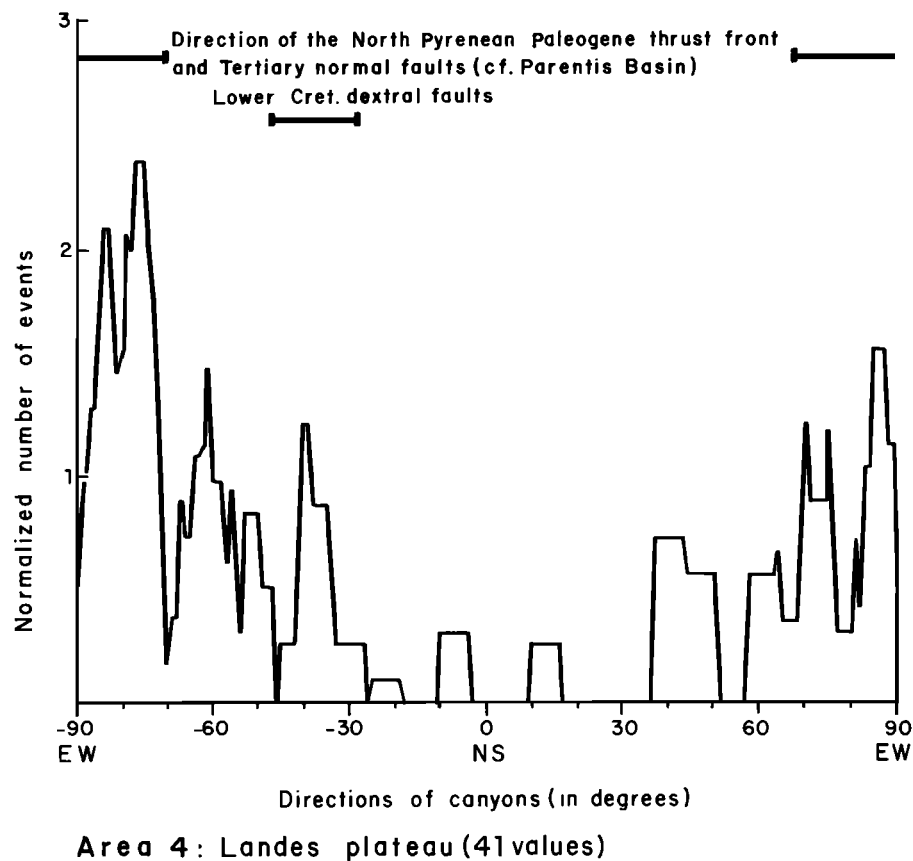


Fig. 9. Diagram of normalized number of events as a function of the direction of canyons, for area 4 defined in Figure 1.

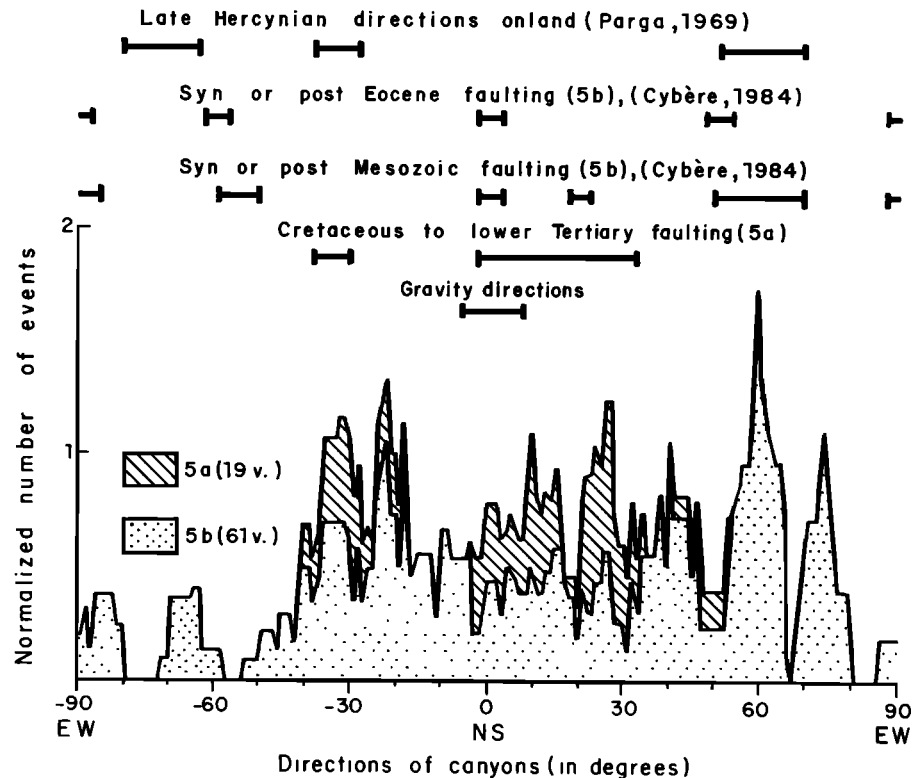
directions of fracturing were observed in the Mesozoic terranes: 0° , 20° , 50° to 70° , 90° and -50° to -60° [Groupe Cybère, 1984]. Directions of fracture observed in the Eocene terranes are 0° , 50° , 90° and -60° . As both sets of directions are similar (except $N20^\circ$), this suggests that the same net of fracturing was reactivated during the Eocene compressive phase. The 20° , 50° to 70° , and -50° to -60° directions are parallel to those measured in the Mesozoic basement of Galicia and attributed to the Hercynian and late Hercynian tectonics [Parga, 1969; Arthaud and Matte, 1975]. Consequently, it seems that the formation of the margin and the succeeding Tertiary deformation mainly occur along previous fractures in the substratum [Boillot et al., 1974; Groupe Cybère, 1984]. Figure 10 clearly shows all these structural directions. The major $N60^\circ$ peak corresponds to one of the well-known late Hercynian tectonic lines

of Parga [1969] reactivated during Cenozoic time [Boillot et al., 1974].

Area 6: West Iberian Margin

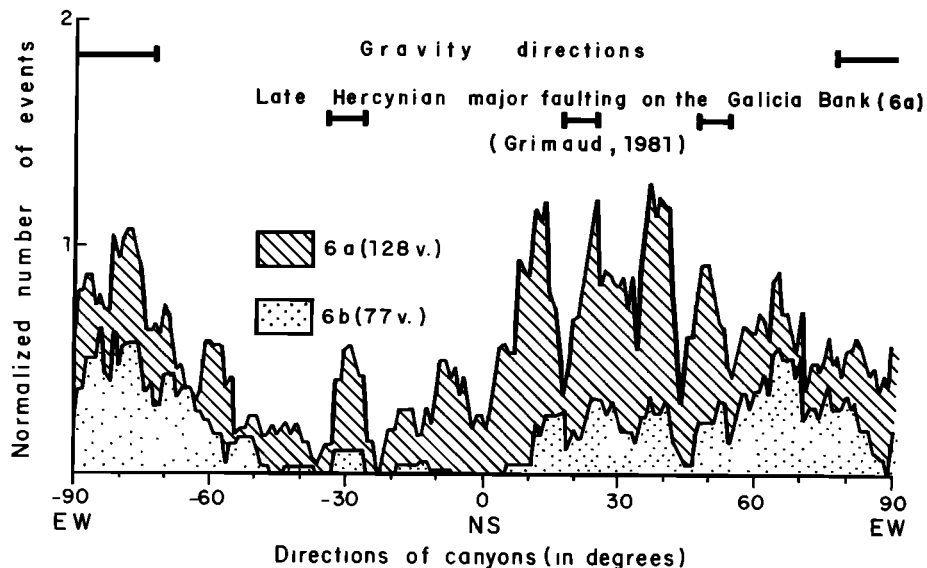
The west Iberian margin can be considered as two contrasting physiographic provinces divided at $40^\circ N$. North of this latitude lies a large continental plateau which includes the Galicia bank sensu-stricto, but also several other seamounts such as Vigo, Porto, and Vasco da Gama which may represent horsts formed during the early Cretaceous rifting episode [Auzende et al., 1979; Montadert et al., 1979a].

On the Galicia bank s.s. the major directions of faults at -30° , 20° , and 50° [Grimaud, 1981] correspond to the late Hercynian directions (Figure 11). On the southern Portuguese margin, Mougnot et al. [1979] and Sibuet et al. [1986] have shown that the late Hercynian fracture



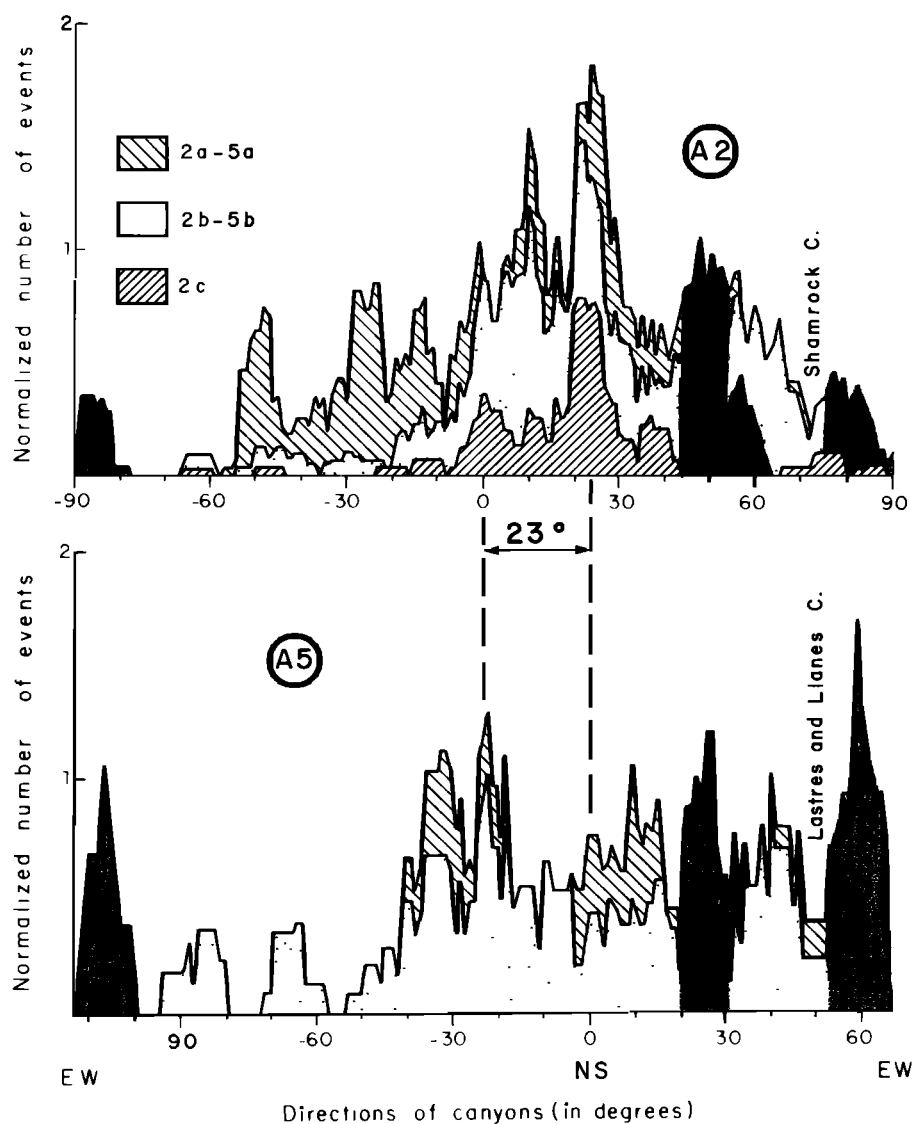
Area 5: North Spanish continental margin (80 values)

Fig. 10. Diagram of normalized number of events as a function of the direction of canyons, for area 5 defined in Figure 1.



Area 6: West Iberian continental margin including Galicia Bank (205 values)

Fig. 11. Diagram of normalized number of events as a function of the direction of canyons, for area 6 defined in Figure 1.



Area 2: Celtic continental margin.

Area 5: North Spanish continental margin.

Fig. 12. Correspondence of diagrams of the Celtic and north Spanish margins based on a 23° rotation of Iberia with respect to Europe in order to illustrate the match between the late Hercynian fracture patterns of each side of the Bay of Biscay. The dark peaks underline three main late Hercynian structural directions followed by canyons.

pattern have been reactivated several times since the first Permo-Triassic tensional episode, along the NE-SW, ENE-WSW, and NW-SE strike-slip directions. Thus the large prominent Nazaré, Lisboa, Setubal, and Sao Vicente canyons (subzone 6b) are obviously controlled by the late Hercynian fracture pattern [e.g., Boillot

et al., 1974], at least in their upper portion.

Figure 11 shows a great variety of directions which reflects the influence of a complex tectonic pattern, largely similar north and south of 40°N latitude in subzones 6a and 6b, while the physiographic character of these two subzones

differs considerably. The general N-S trend of the margin corresponds roughly to E-W gravity directions which do not come out clearly in the diagram. Major peaks appear between -90° and -55° , and 5° and 70° and at -30° . They correspond to the late Hercynian and early Cretaceous set of faults reactivated during the post tectonic phases [Sibuet et al., 1986].

ARGUMENTS IN FAVOR OF A 23° ROTATION OF IBERIA WITH RESPECT TO EUROPE

The currently accepted hypothesis about the formation of the Bay of Biscay is the one initially proposed by Le Pichon et al. [1970, 1971]. Since that time, several authors have proposed slight modifications which concern the timing, the pole position or the rotation angle [e.g., Le Pichon and Sibuet, 1971b; Choukroune et al., 1973; Olivet et al., 1984; Savostin et al., 1986]. Published angles of rotations vary from 30° [Le Pichon et al., 1971] to 23° [Le Pichon and Sibuet, 1971b]. Olivet et al. [1984] adopted an angle of 24° . Values of this angle depend on the position of the rotation pole but also on the choice of fitted isobaths or features. In all these reconstructions, the North Spanish margin was initially connected to the Celtic margin. It is tempting to look at the angular correlation between lineaments predating the opening of the Bay of Biscay: in this case, the late Hercynian fracturation pattern even if it was reactivated later.

We saw indeed that the geological and tectonic evolutions of both margins differ considerably after their creation and separation, especially during the Eocene compressive phase which affected the southern margin. Consequently, correlation between peaks must not be done on a criterion of amplitude, but on a criterion of global correspondence of peaks without the influence of gravity processes.

Figure 12 shows such a correspondence between peaks belonging to the late Hercynian fracture pattern on both the Celtic and North Iberian Peninsula margins. Each dark peak represents identified late Hercynian trends (Figure 5 and 10). Peaks in subzones 2c and 2a, 2b correspond respectively to peaks in subzones 5a and 5b. The peak at 55° (with respect to area 2) is common between subzones 2c and 5a and three peaks at -85° , 50° and 82° (with respect to area 2)

are common between subzones 2a, 2b, and 5b. A 23° shift of the North Spanish margin diagram with respect to that of the Celtic margin accounts for this correspondence. The error in the determination of the rotation angle cannot be evaluated but is probably a few degrees. This type of attempt, derived for example from the idea that one can constrain initial fits by the correspondence of older lineaments located on both sides [e.g., Le Pichon et al., 1977], brings an independent constraint to the fitting of continents before the initiation of the rifting phase, as discussed by Le Pichon and Sibuet [1981] and Savostin et al. [1986].

CONCLUSIONS

The new bathymetric map of the northeast Atlantic is mainly based on Sea Beam data acquired during 20 cruises on the R/V JEAN CHARCOT in this area. From the precise picture of the morphology of the northeast Atlantic continental margins, a statistical analysis of the orientation of canyons, based on 750 measurements, brings the main following conclusions:

1. The canyon trends of the continental slopes generally correspond to lineaments identified on land or on the continental shelf.
2. Gravity processes play a more important role from the Porcupine Seabight to the Landes plateau than they do around the Iberian peninsula, but in general, most of the canyons are structurally controlled by the late Hercynian features or by features created during or after the formation of these continental margins.
3. A 23° rotation of Iberia with respect to Europe is in good agreement with the correspondence of identified late Hercynian lineaments on both sides of the Bay of Biscay.

Acknowledgements. We greatly acknowledge the captains and the crews of the R/V JEAN CHARCOT and the chief scientists of the 20 oceanographic cruises during which Sea Beam data were collected. J.-P. Cadet and N. H. Kenyon critically reviewed the manuscript and offered helpful suggestions. S. Monti and J.-P. Mazé drew all the bathymetric maps. IFREMER contribution 70.

REFERENCES

- Arthaud, F., and P. Matte, Les décrochements tardi-hercyniens du Sud-Ouest de l'Europe. Géométrie et essai de reconstitution des conditions de la déformation, Tectonophysics, 25, 139-171, 1975.
- Auzende, J.-M., H. Jonquet, J.-L. Olivet, J.-C. Sibuet, J.-L. Auxiètre, G. Boillot, J.-P. Dunand, A. Mauffret, O. de Charpal, V. Apotolescu, and L. Montadert, The continental margin off Galicia and Portugal: Acoustical stratigraphy, dredge stratigraphy and structural evolution, Initial Rep. Deep Sea Drill. Proj., 47 (2), 633-662, 1979.
- Berthois, L., and R. Brenot, La morphologie sous-marine du talus du plateau continental entre le sud de l'Irlande et le Cap Ortegal (Espagne), J. Cons. Cons. Int. Explor. Mer, 25, 111-114, 1960.
- Berthois, L., and R. Brenot, Bathymétrie du Golfe de Gascogne et de la côte du Portugal, I, Commentaires sur le levé complémentaire des feuilles 9 et 10 des abords du plateau continental; II, Bathymétrie du talus du plateau continental à l'Ouest de la péninsule ibérique du Cap Finistère au Cap St-Vincent, paper presented at the 52nd meeting, Cons. Int. pour l'Explor. de la Mer, Sept.-Oct. 1964.
- Berthois, L., R. Brenot, and J. Debyser, Remarques sur la morphologie de la marge continentale entre l'Irlande et le Cap Finistère, Rev. Inst. Fr. Pet. Ann. Combust. Liq., 23, 1046-1049, 1968.
- Boillot, G., and R. Capdevilla, The Pyrénées: Subduction and collision?, Earth Planet. Sci. Lett., 18, 151-160, 1977.
- Boillot, G., P.-A. Dupeuble, I. Hennequin-Marchand, M. Lamboy, J.-P. Leprêtre, and P. Muselec, Le rôle des décrochements "tardi-hercyniens" dans l'évolution structurale de la marge continentale et dans la localisation des grands canyons sous-marins à l'Ouest et au Nord de la péninsule ibérique, Rev. Géogr. Phys. Géol. Dyn., 16 (1), 75-86, 1974.
- Choukroune, P., X. Le Pichon, M. Séguret, and J.-C. Sibuet, Bay of Biscay and Pyrénées, Earth Planet. Sci. Lett., 18, 109-118, 1973.
- Derégnaucourt, D., and G. Boillot, Structure géologique du Golfe de Gascogne, Bull. Bur. Rech. Géol. Min., 2, 1, 3, Géol. Gites Miner. Fr., 149-178, 1982.
- Foucher, J.-P., X. Le Pichon, and J.-C. Sibuet, The ocean-continent transition in the uniform stretching model: role of partial melting in the mantle, Phil. Trans. R. Soc. London, Ser. A, 305, 27-43, 1982.
- Grimaud, S., La marge ibérique au Nord et à l'Ouest du banc de Galice (Espagne), thesis, 90 pp., Paris VI Univ., Paris, 1981.
- Groupe Cybère, La marge déformée du Nord-Ouest de l'Espagne, Publ. Cent. Natl. Exploit. Océans, Résultats Campagnes Mer, 29, 135 pp., 1984.
- Guennoc, P., H. Jonquet, and J.-C. Sibuet, Carte magnétique de l'Atlantique nord-est, anomalies du champ total; échelle 1/2.400.000 CNEXO, Paris, 1978. (Available from BRGM, Serv. Promotion et Vente, Orléans, France.)
- Guennoc, P., H. Jonquet, and J.-C. Sibuet, Présentation d'une carte magnétique de l'Atlantique nord-est, C. R. Acad. Sci., sér. D, 288, 1011-1013, 1979.
- Kenyon, N.H., R.H. Belderson, and A.H. Stride, Channels, canyons and slump folds on the continental slope between southwest Ireland and Spain, Oceanol. Acta, 1 (3), 369-380, 1978.
- Kidd, R.B., and D.G. Roberts, Long-range sidescan sonar studies of large-scale sedimentary features in the North Atlantic, Bull. Inst. Géol. Bassin Aquitaine, 31, 11-29, 1982.
- Lallemand, S., J.-P. Mazé, S. Monti, and J.-C. Sibuet, Présentation d'une carte bathymétrique de l'Atlantique nord-est, C. R. Acad. Sci., sér. 2, 300, 145-149, 1985a.
- Lallemand, S., J.-P. Mazé, S. Monti, and J.-C. Sibuet, Carte bathymétrique de l'Atlantique nord-est, scale 1/2.400.000, IFREMER, Paris, 1985b. (Available from BRGM, Serv. Promotion et Vente, Orléans, France.)
- Laughton, A.S., D.G. Roberts, and R. Graves, Bathymetry of the northeast Atlantic: Mid-Atlantic Ridge to southwest Europe, Deep Sea Res., 22, 791-810, 1975.
- Le Pichon, X., and J.-C. Sibuet, Western extension of boundary between European and Iberian plates during the Pyrenean orogeny, Earth Planet. Sci. Lett., 12, 83-88, 1971a.
- Le Pichon, X., and J.-C. Sibuet, Comments

- on the evolution of the northeast Atlantic, Nature, 233, 257-258, 1971b.
- Le Pichon, X., and J.-C. Sibuet, Passive margins: A model of formation, J. Geophys. Res., 86, 3708-3720, 1981.
- Le Pichon, X., J. Bonnin, and J.-C. Sibuet, La faille nord-pyrénéenne: Faille transformante liée à l'ouverture du Golfe de Gascogne, C. R. Acad. Sci., 261, 1941-1944, 1970.
- Le Pichon, X., J. Bonnin, J. Francheteau, and J.-C. Sibuet, Une hypothèse d'évolution tectonique du Golfe de Gascogne, in Histoire structurale du Golfe de Gascogne, edited by J. Debyser et al., pp. 1-44, Technip, Paris, 1971.
- Le Pichon, X., J.-C. Sibuet, and J. Francheteau, The fit of the continents around the North Atlantic Ocean, Tectonophysics, 38, 169-209, 1977.
- Masson, D.G., L. Montadert, R.A. Scrutton, and J.-P. Gruvel, Evolution of the Goban Spur: History of a starved passive margin, Initial Rep. Deep Sea Drill. Proj., 80, 115-140, 1984.
- Montadert, L., O. de Charpal, D. Roberts, P. Guennoc, and J.-C. Sibuet, Northeast Atlantic passive continental margins: Rifting and subsidence processes, in Deep Drilling Results in the Atlantic Ocean: Continental Margins and Paleoenvironment, Maurice Ewing Ser., vol. 3, edited by M. Talwani et al., pp. 154-186, AGU, Washington D.C., 1979a.
- Montadert, L., et al., Site 401, Initial Rep. Deep Sea Drill. Proj., 48, 73-124, 1979b.
- Mougenot, D., J.H. Monteiro, P.-A. Dupeuble, and J.-A. Malod, La marge continentale sud-portugaise; évolution structurale et sédimentaire, Cienc. Terra, 5, 223-246, 1979.
- Olivet, J.-L., J. Bonnin, P. Beuzart, and J.-M. Auzende, Cinématique de l'Atlantique Nord et Central, Pub. Centr. Natl. Exploit. Océans, 108 pp., 1984.
- Parga, J.-R., Sistemas de fracturas tardihercínicas del macizo hesperico, Trab. Lab. Geol. Lage, 37, 1-15, 1969.
- Pastouret, L., Carte bathymétriques des canyons sud-armoricains de St-Nazaire, de Noirmoutier, des Sables d'Olonne et d'Oléron, CNEXO, Paris, 1984. (Available from BRGM, Serv. Promotion et Vente, Orléans, France.)
- Pastouret, L., G.A. Auffret, J.-M. Auzende, P. Beuzart, P. Dubois, M. Séguret, J. Sigal, and J.-R. Vanney, La marge continentale armoricaine, résultats d'observation en submersible et de dragages dans le canyon Shamrock, C. R. Acad. Sci., Sér. 2, 292, 741-748, 1981.
- Pastouret, L., P. Beuzart, and S. Monti, Présentation de cartes bathymétriques de la marge continentale armoricaine et celte, Golfe de Gascogne, Bull. Soc. Geol. Fr., 24, 407-411, 1982.
- Pegrum, R.M., and N. Mounteney, Rift basins flanking North Atlantic Ocean and their relation to North Sea area, Am. Assoc. Petrol. Geol. Bull., 62, 419-441, 1978.
- Renard, V., and J.-P. Allenou, Le Sea Beam, sondeur à multifaisceaux du N/O JEAN CHARCOT: Description, évaluation et premiers résultats, Rev. Hydrogr. Int., 56, 35-71, 1979.
- Savostin, L.A., J.-C. Sibuet, L.P. Zonenshain, X. Le Pichon, and M.-J. Roulet, Kinematic evolution of the Tethys belt from the Atlantic Ocean to the Pamirs since the Triassic, Tectonophysics, 123, 1-35, 1986.
- Sibuet, J.-C., and L. Berthois, Dominant structural trends on the western continental margin of Iberia: Implications on initial rifting, Initial Rep. Deep Sea Drill. Proj., 47 (2), 753-760, 1979.
- Sibuet, J.-C., and X. Le Pichon, Structure gravimétrique du Golfe de Gascogne et le fossé marginal nord-espagnol, in Histoire structurale du Golfe de Gascogne, 9, edited by J. Debyser et al., pp. 1-18, Technip, Paris, 1971.
- Sibuet, J.-C., and W.B.F. Ryan, Site 398: Evolution of the west Iberian passive continental margin in the framework of the early evolution of the north Atlantic Ocean, Initial Rep. Deep Sea Drill. Proj., 47 (2), 461-475, 1979.
- Sibuet, J.-C., G. Pautot, and X. Le Pichon, Interprétation structurale du Golfe de Gascogne à partir des profils de sismique, in Histoire structurale du Golfe de Gascogne, 10, edited by J. Debyser et al., pp. 1-32, Technip, Paris, 1971.
- Sibuet, J.-C., B. Mathis, and P.M. Hunter, La ride Pastouret (plaine abyssale de Porcupine): Une structure éocène, C. R. Acad. Sci., Sér. 2, 299, 1391-1396, 1984a.
- Sibuet, J.-C., B. Mathis, L. Pastouret, J.-M. Auzende, J.-P. Foucher, P. M.

- Hunter, P. Guennoc, P.-C. de Graciansky, L. Montadert, and D.G. Masson, Morphology and basement structures of the Goban Spur continental margin (northeastern Atlantic) and the role of the Pyrenean orogeny, in Initial Rep. Deep Sea Drill. Proj., 80, 1153-1165, 1984b.
- Sibuet, J.-C., J.-P. Mazé, P. Amortila, and X. Le Pichon, Physiography and structure of the western Iberian continental margin off Galicia from Sea Beam and seismic data, leg 103, Ocean Drilling Program, part A, in press, 1986.
- Somers, M.L., R.M. Carson, J.A. Revie, R.H. Edge, B.J. Barrow, and A.G. Andrews, Gloria II: An improved long-range sidescan sonar, in Oceanology International, 78, Technical Session J, pp. 16-24, B.P.S. Exhibitions Ltd, London, 1978.
- Valery, P., J.-R. Delteil, A. Cottençon, L. Montadert, B. Damotte, and J.-P. Fail, La marge continentale d'Aquitaine, in Histoire structurale du Golfe de Gascogne, 8, edited by J. Debyser et al., pp. 1-24, Technip, Paris, 1971.
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(Received September 20, 1985;
revised June 10, 1986;
accepted June 26, 1986.)