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48.2. VALENCIA BASIN

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INTRODUCTION

The alignment of the Balearic Islands, stretching from the Spanish mainland towards the Corsican-Sardinian block, has long intrigued many geologists. Since Suess (1886), we know that the Balearic block (Ibiza, Formentera, and Majorca) is part of the Alpine system. Many authors (Kober, 1914; Staub, 1928; Kober, 1931) have subsequently attempted to comprehensively integrate the history of the Balearic block within the history of the Alpine chain.

In this paper, we will use data from marine geology and geophysics to define the location of the Balearic Islands during the diverse phases of distension, shearing, and compression between the European and African plates, which created the present western Mediterranean and the Alpine chain. In particular, we will try to explain the way in which the Balearic Islands have reacted to these diverse drift phenomena, and discuss the manifestations of these phenomena in this area.

In order to study the northern Balearic Basin, most of the geophysical techniques have been used (bathymetry, deep and shallow seismic reflection, seismic refraction, emplaced in the valley of a canyon where the layers at contact with the intrusive are thin and form a level.

The second rocky massif has a flat shape and presents different acoustical characteristics than that of the preceding massif because of the appearance of internal reflectors. In addition, we do not notice magnetic anomalies on this relief. Its nature is therefore uncertain. Site 123 is located in the valley of the canyon near this massif.

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magnetism, and gravimetry). Also, the results of two deep sea drilling operations during Leg 13 of the DSDP have been used in this investigation.

In this work, special emphasis will be placed upon developing a description, as precise and complete as possible, of the bathymetry, sedimentary cover, and acoustic basement. These descriptions will lead us to a discussion of the tectonic manifestations which have affected the northern Balearic Basin. Finally, we will attempt to put forth a model of the recent evolution of this area.

BATHYMETRY

The bathymetric map (Figure 1, after Ryan *et al.* 1970) defines two main zones in the northern Balearic area. The eastern zone is limited by the Minorca-Barcelona line, and the western zone extends to the extremity of the Gulf of Valencia.

The eastern zone is surrounded by the Spanish continental margins and the Island of Minorca. The Spanish continental shelf is relatively narrow (about 15 km) and the slope has an average slope of 2.5°. The continental rise off Minorca, 30 km wide at its northwest part, becomes smaller towards the northeast and its contact with the deeper portion of the Algerian-Provencal basin is marked by an abrupt slope (> 5°). In the axial zone of the depression starting from 3°E longitude, the topography becomes progressively steeper (average slope of 3°) until the deepest zones of the basin (2600 m).

The western zone is higher in relation to the eastern zone with depths between 0 and 2000 meters. The central channel (Valencia Trough) is made up of two large continental rises. The Spanish rise is large (30 km) towards the south of the Ebro River delta; it reaches 70 km at the extremity of the Gulf of Valencia. The slope in the direction of the central trough shows only a slight downward trend (about 2°). It is cut by a large number of canyons whose morphology and geography have been described by Mauffret and Sancho (1970). These canyons are directed towards the central trough located in the axis of the Valencia depression. The canyons widen and take the form of channels which form a submarine delta of the Ebro, similar to that of the Rhone described by Menard *et al.* (1965). The Balearic Rise, northeast of Majorca, shows an extension of about 40 km with a very slight slope (1.5°).

SEDIMENTARY UNITS

Numerous seismic reflection profiles have been made in this zone, and in particular A. Mauffret has published an exhaustive study (Mauffret, 1970; Mauffret and Sancho, 1970). During the cruise Polymède I, organized by the Centre Océanologique de Bretagne, several Flexotir seismic profiles have been made within this area. All these seismic reflection studies lead us to the following definition of a sequence of sedimentary types (Figure 2):

1) An upper unit (A) about 300 meters thick formed by a succession of more or less intense reflectors. This unit shows levels, discordances, and submarine channel indentations.

2) A unit (B) presenting different characteristics depending upon the type of seismic source used. With the air gun or sparker (high frequency source), it is a homogeneous and transparent unit, without any particularly reflecting levels. With the Flexotir (low frequency), a very complex bedding appears, particularly at the base where there are a large number of levels, discordances, and bottom current indications.

3) Unit B overlaps Unit C in such a manner that the upper part is formed by very strong reflectors (reflector B of Mauffret, 1970) which are affected by some discontinuities that may represent valleys of old canyons. Below these reflectors one finds, especially in the eastern part of the Balearic depression, a uniform transparent layer, or a layer affected by diapiric phenomena.

4) Finally, in the deep zones and in the direction of the Algerian-Provencal basin, there appears a sedimentary unit (D) formed by horizontal reflectors making up the series of the fill of the basin.

The sequence described above represents a cross-section of the observed sediments in the deep part of the Balearic depression. This sequence is complete only in the eastern basin, practically at contact with the deep part of the Algerian-Provencal basin. In the rest of the Balearic depression, the sedimentary thickness varies and certain of the above described units disappear, or have a reduced thickness. With the exception of the zones where the basement is very high, or even sometimes outcropping, one notices that Units A and B are present everywhere in the western and eastern basins, and with a thickness varying between 500 and 1200 meters. It seems that the thickness of Unit D is much less important in the western basin, where it varies between 0 to 500 meters, than in the eastern basin where this unit is more than 2 sec thick.

To trace the extension of Unit C, we must consider three zones (Figure 3). In the zone with horizontal hatching, Unit C is complete, or in other words it includes a roof formed by a succession of very strong reflectors. This roof overlies a homogeneous layer in which no stratification is observed. Unit C is often affected by diapiric phenomena and shows an average thickness of 500 meters. In the zone with vertical hatching, Unit C is formed by the "roof" reflectors and a homogeneous layer, but no diapirs are observed. Finally, in the gray zone, assemblage C is reduced to strong "roof" reflectors. The rest of the series is absent.

The sedimentary succession described above is analogous to that in the central part of the Algerian-Provencal basin, which has been interpreted as follows (Auzende *et al.*, 1971). Units A and B represent Plio-Quaternary deposits. Unit C is formed by a Messinian evaporitic layer, sometimes associated with a layer of flowing salt. Finally, Unit D is made up of Miocene or Oligo-Miocene sediments resting directly on the substratum.

DRILL SITES 122 AND 123

The seismic profile of Figure 4 (Polymède I), located approximately in the axis of the main canyon of the Ebro, cuts two apparently igneous massifs having different morphologies. The western massif has a seamount shape. Its summit seems to be covered by a thin film of sediments. The magnetic anomaly maps (Figure 5) show a strong positive anomaly corresponding to this structure. It seems, therefore, that it is a volcanic intrusion. Drill Site 122 was

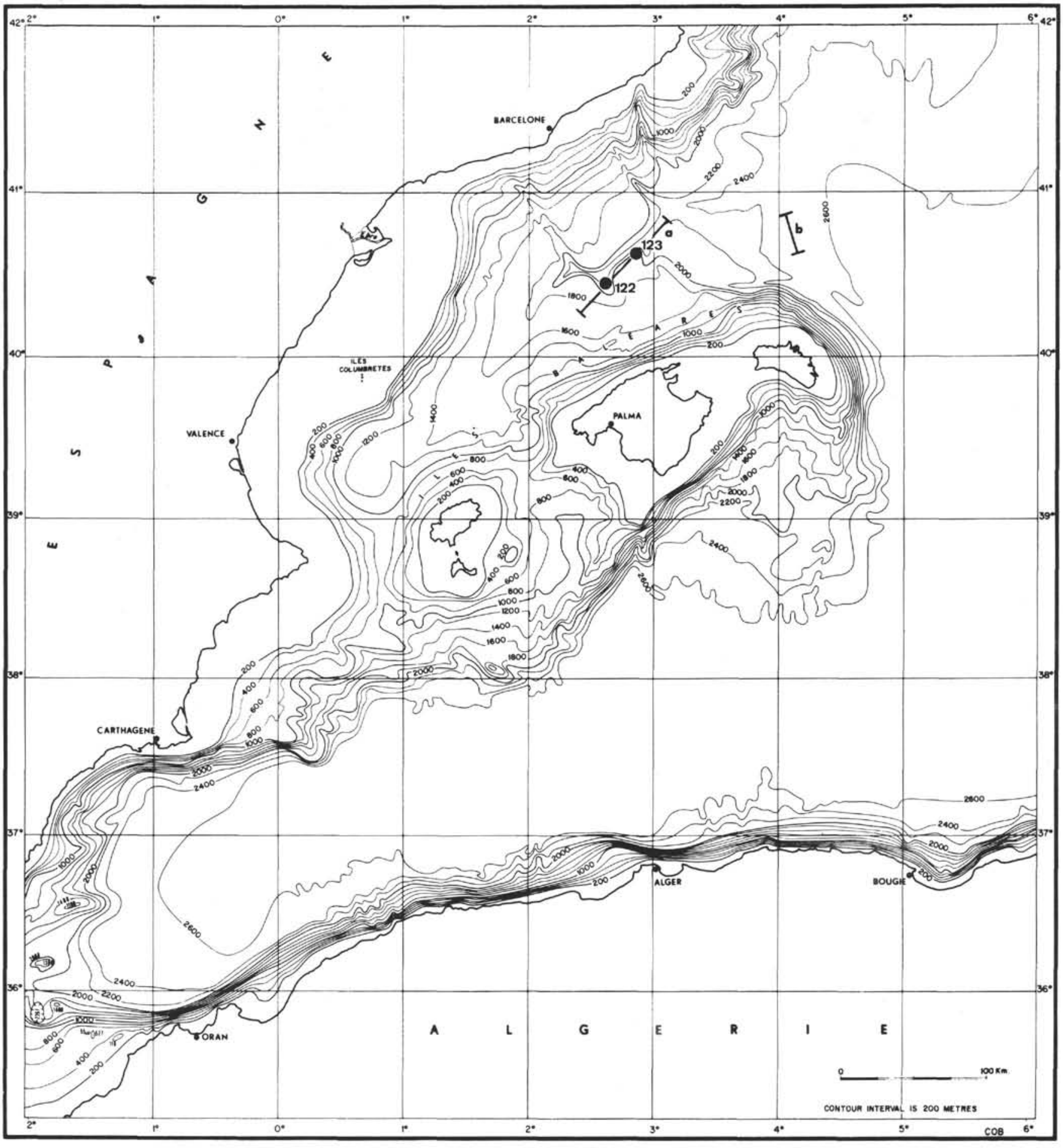

Figure 1. *Bathymetric map (Ryan* et al.*) with location of Drill Sites 122 and 123 and seismic profiles (a) profile of Figure 4, and (b) profile of Figure 7).*

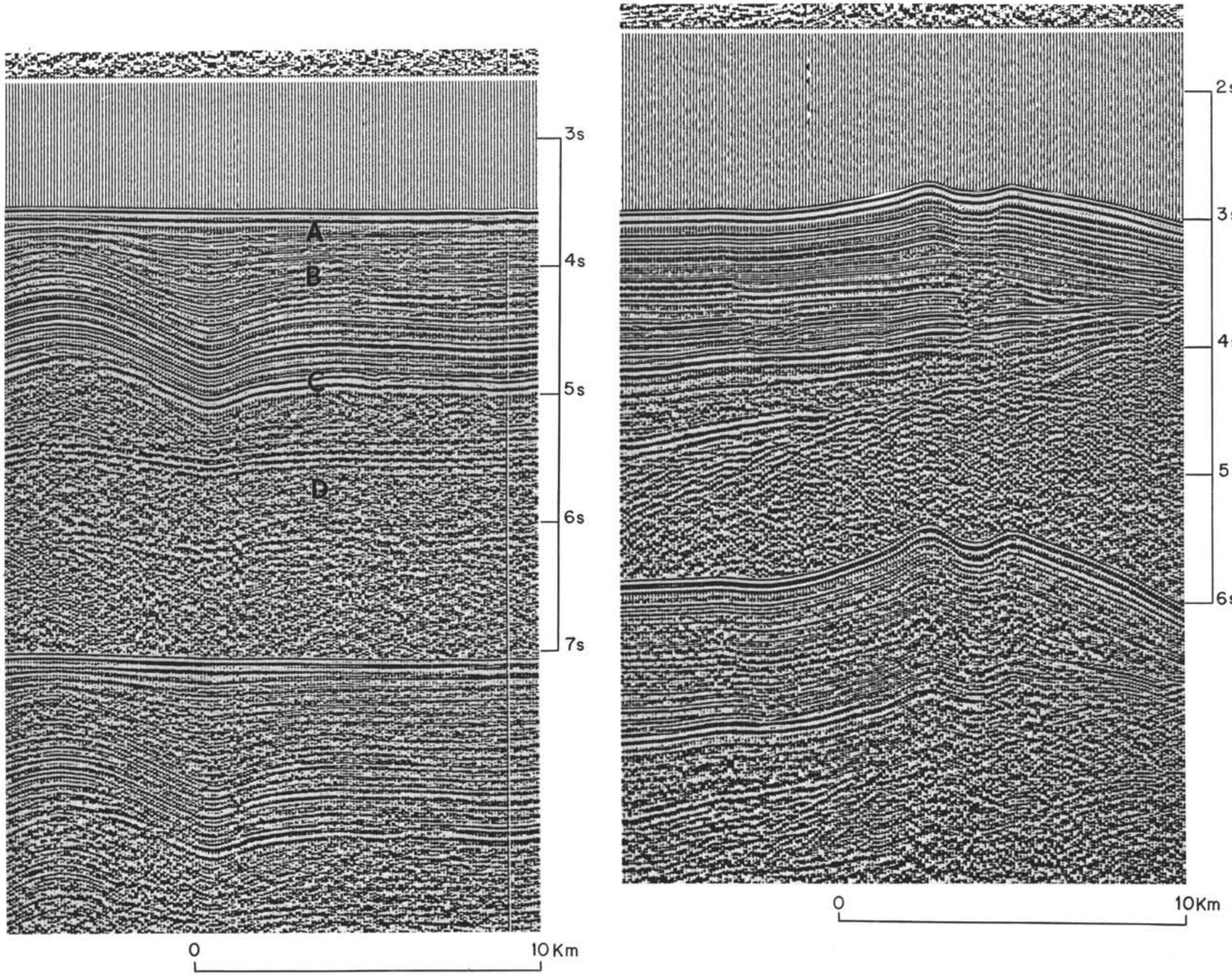

Figure 2. *Photograph of a typical sedimentary sequence in the north Balearic Basin: left, profile in the Oriental Basin; right, profile on substratum uplift. A and B: Plio-Quaternary sediments, C: Messinian salt layer, D: Pre-Messinian sediments.*

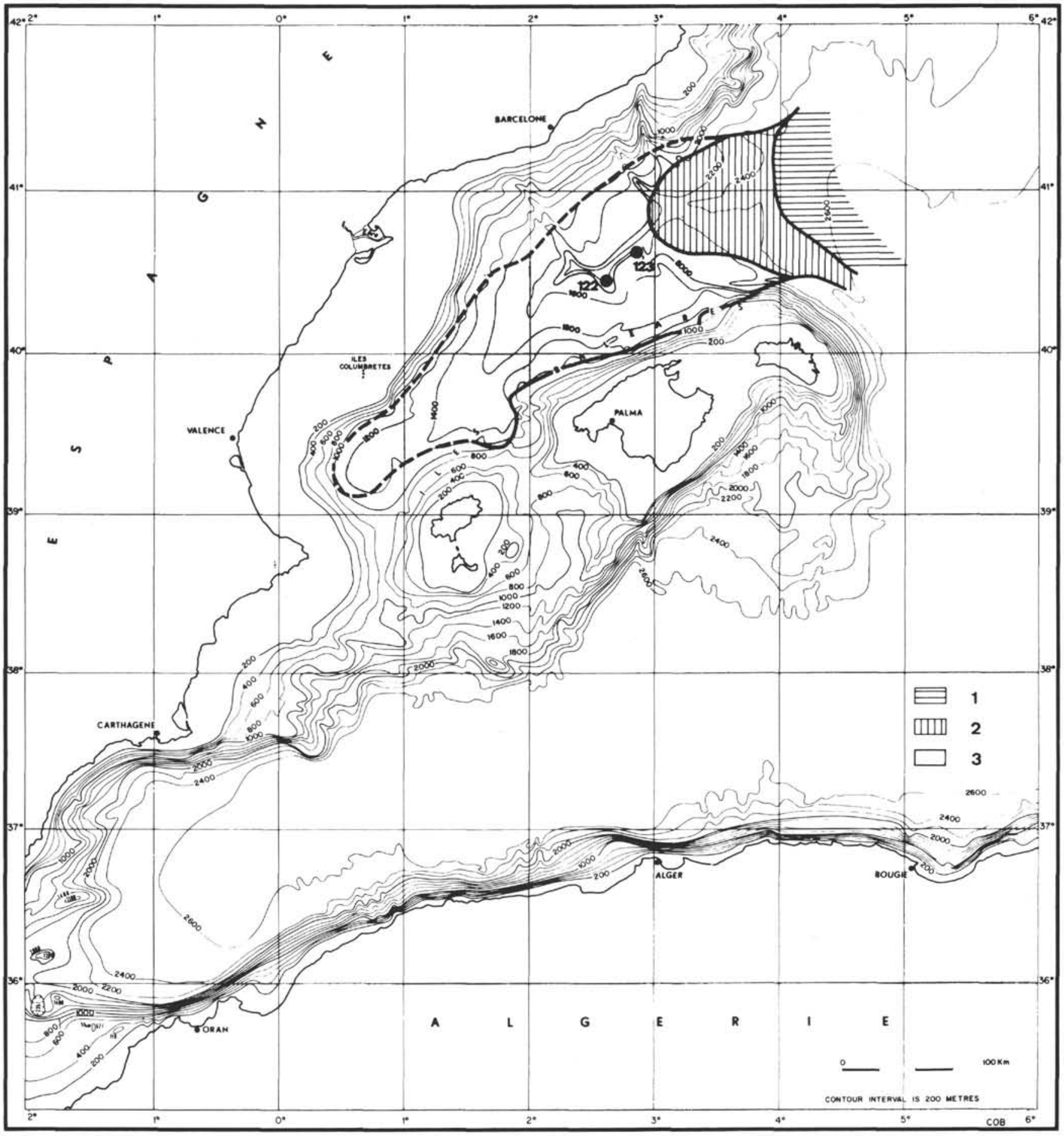

Figure 3. *Extension of the Messinian salt layer. Zone 1: salt layer is fully developed (evaporites and halite with halocinese phenomena). Zone 2: intermediate area where salt thickness is less developed with no 'halocinese' phenomena. Zone 3: only the upper part of the evaporitic series remains with no halite present.*

Schematic Results of Drilling Operations

Site 122 (see detailed description in this Volume) is located (water depth 2146 m) in the valley of the canyon at the point where it changes direction. From 0 to 100 meters, the drill passed through a series of graded sands, sandy silt laminae, and marl oozes of Quaternary age. At 150 meters, the same type of lower Pliocene sediment was cored. Between 150 and 162 meters, a lower Pliocene rubble blocked the drilling operation. When the equipment was raised, it was found that a massive block of gypsum, whose age is perhaps Messinian or lower Pliocene, was caught in the teeth of the drill. On the seismic profile (Figure 3) the

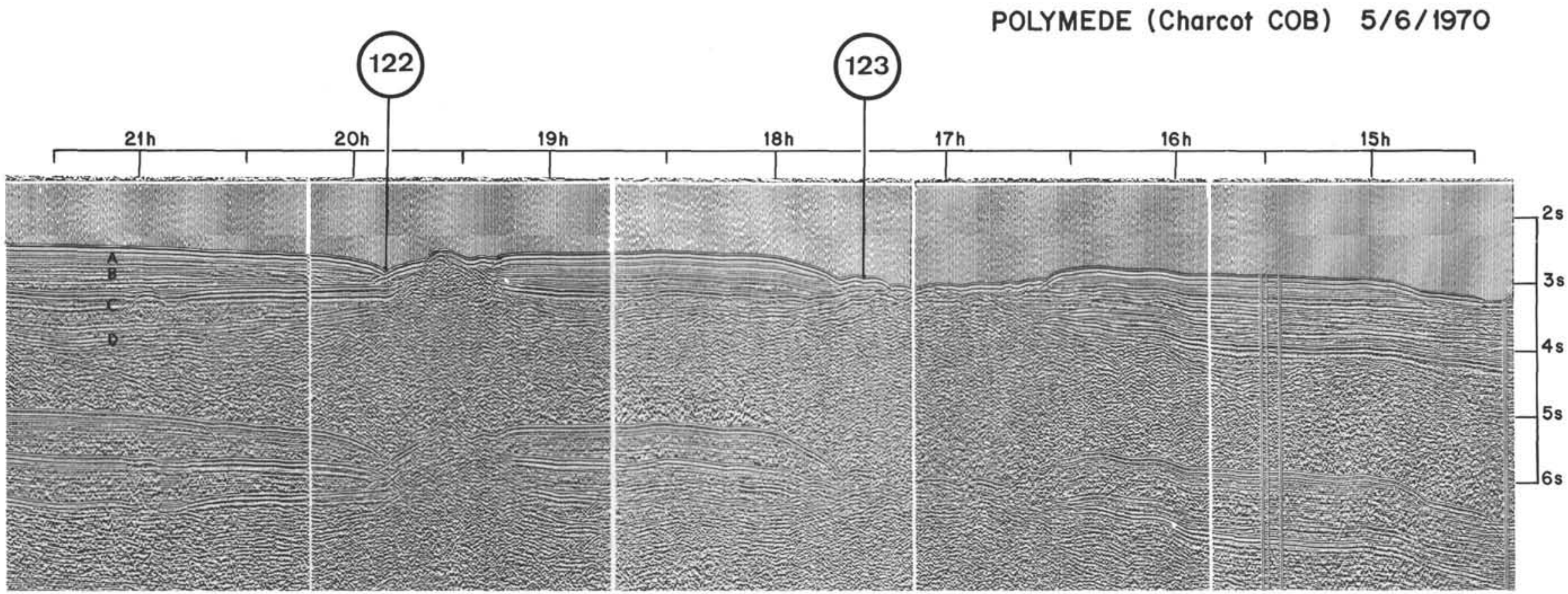

Figure 4. *Seismic profile (a) on Figure 1, across two basement highs lying in the center of the area studied. Drilling Sites 122 and 123 are indicated. Letters A, B, C, D refer to sedimentary layers of Figure 2.*

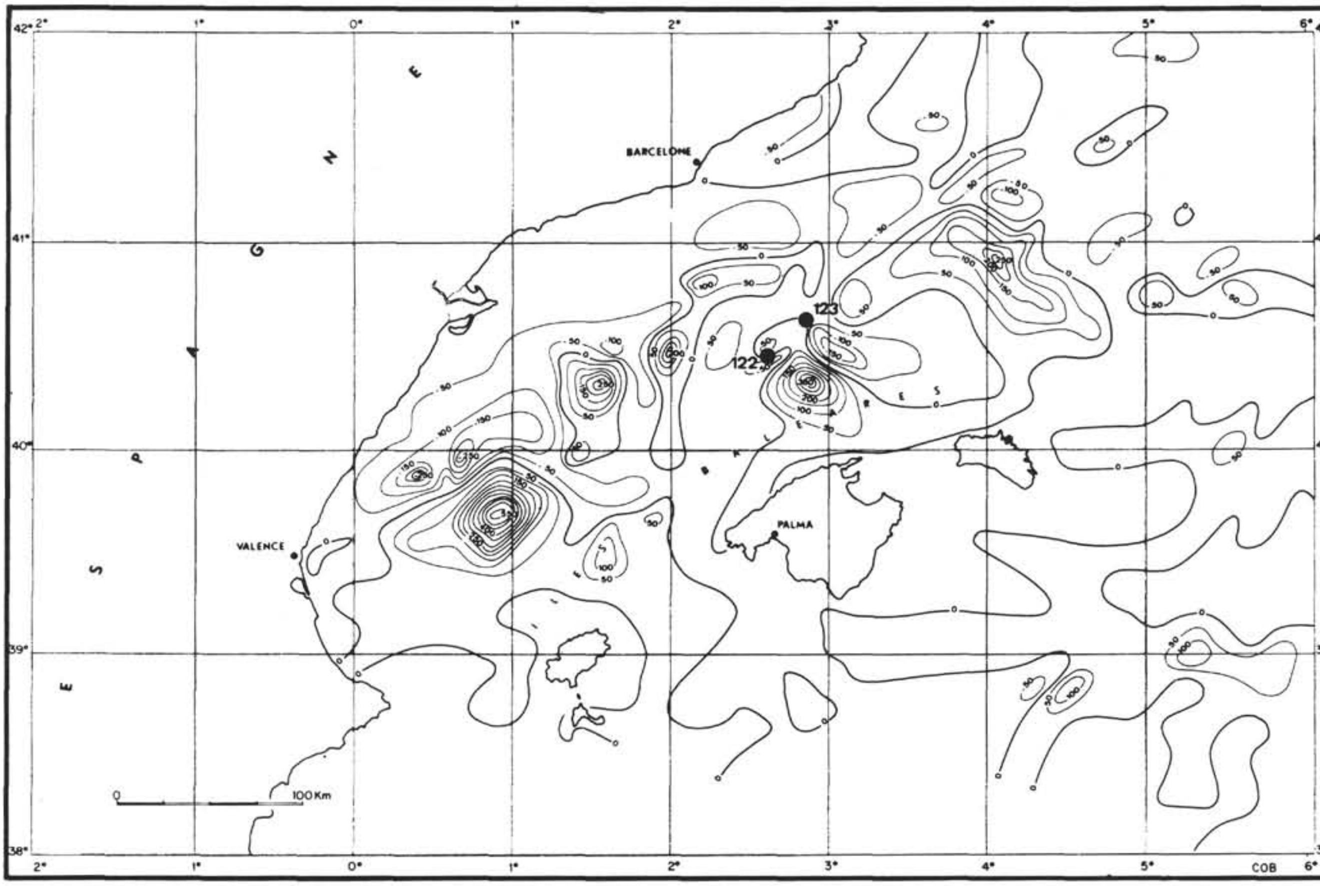

Figure 5. *Map of the residual magnetic field in the north Balearic basin (after Vogt, Higgs and Johnson, 1971). Contour interval is 50 gammas.*

previously deduced level of this gypsum was located at a point between Units B and C.

Site 123 is located in the valley of the canyon, in 2290 meters of water. The Plio-Quaternary layer seems to be more important here. As in the preceding drilling operation, we found a Quaternary sedimentary series consisting of gravel, graded sands, and marl oozes for about 100 meters. The Pliocene presents the same facies at 150 meters. At this level, the Pliocene base lies on a layer of andesitic volcanic glass whose apparent radiometric age is 22 my BP (See Chapter 28.4). The drilling operation was continued for 130 meters in this volcanic glass which is absolutely azoic. Drilling was stopped at 398 meters without having reached the basement.

EXTENSION OF THE SEISMIC BASEMENT

To place these drilling operations in a structural context, we present an isochron map of the acoustic basement (Figure 6) based on all the seismic profiles (air gun, sparker, and Flexotir) made in the northern Balearic zone. In the Gulf of Valencia between the Balearic Islands and Spain, the acoustic basement is everywhere visible under a sedimentary cover of variable thickness. On these reliefs, the Pliocene is in direct contact with the substratum and, in the basins, the more ancient series are visible under the Pliocene.

In this description, we distinguish three principal zones: a western zone to the west of a line connecting the northeast corner of Majorca to the vicinity of Barcelona; an eastern zone including the area between a Minorca-Barcelona line to the west and the deep part of the Algerian-Provencal basin; and an intermediate zone having a small area between the two.

Western Zone

In this sector, it is possible to continuously follow the acoustic basement on the Flexotir seismic profiles. In the northern part (Spanish margin), the absence of profiles stops us from delineating the outline of the margin and from defining the morphology of the basement. In the southern part, in the prolongation of Ibiza and Majorca, the basement can be followed under a sedimentary cover about 500 meters thick. It constitutes the shelf and continental slope of Ibiza and of Majorca, which has a regular but slightly hilly morphology. The slope is gentle (about 1.5°) and for this reason a large continental rise exists which extends to more than 40 km northeast of Majorca. North of Ibiza, in the axis of the Gulf of Valencia and following a southwest-northeast direction, a disturbed zone appears which is marked by a rise of the basement of more than 1 sec. This rise of the basement delineates a massif about 25 km long which is broken by three peaks separated by small

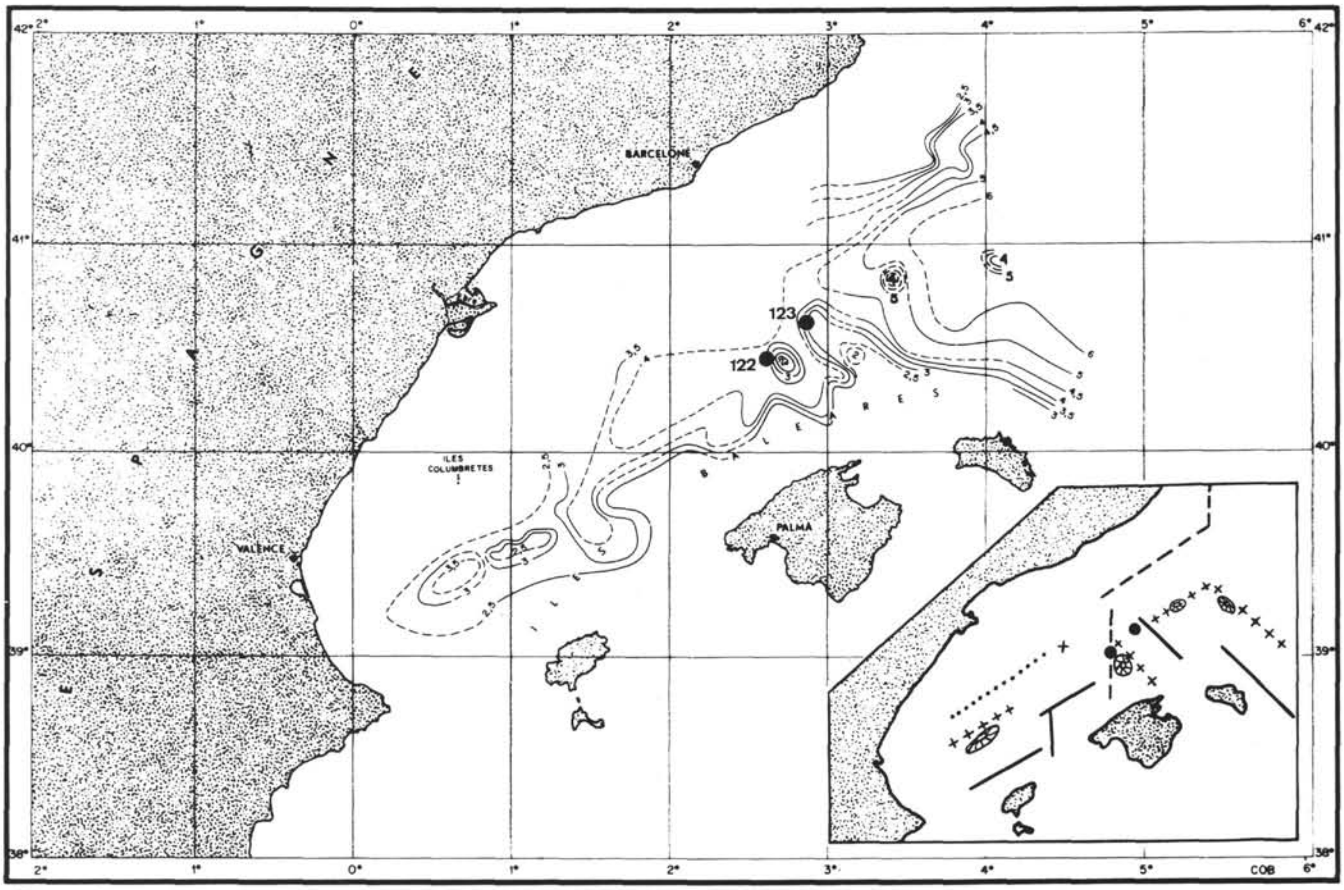

Figure 6. *Isochronous contour map of acoustic basement in the north Balearic Basin. Contour interval is 0.5 sec double travel time. In lower right corner, location of main accidents and lineations: dashed lines as suggested by bathymetry, dots for volcanic lineations, full line as suggested by basement, crosses for magnetic lineations. Circular features represent intrusive and volcanic structures outlines on seismic profiles.*

basins. These peaks, whose morphology is not very pronounced, could be a prolongation of the continental material of the rise. However, a strong magnetic anomaly appears at their level on Figure 5 (after Vogt *et al.*, 1971). Consequently, these peaks may instead represent a volcanic system analogous to that of the Columbretes located further north.

Between the Balearic and Spanish margins, the basement extends with a very flat and regular morphology beneath a large basin 3 to 4 sec deep.

The Eastern Zones

To the east of 3° longitude, the distance separating the Spanish and Balearic margins increases progressively, and the Balearic depression opens on the Algerian-Provencal basin. North of Minorca, the margin has a practically west-east orientation, and the basement progressively sinks towards the deep part with an average slope of 3 degrees. A steeper slope is located between 3 and 4 sec depth after which the deepening is slower until more than 6 sec. To the northeast of Minorca, the orientation of the margin changes to northwest-southeast. The width of the continental rise diminishes and the slope increases up to a value of 5 degrees. The slope is affected by important discontinuities some of which have an amplitude of more than 200 meters.

On the Spanish margin, the rising of the basement is regular until 3.5 sec. At this level, a sharp rise of the basement is observed in the form of two peaks (at less than 2.5 sec) separated by a small deep basin of 3.5 sec. In the direction of the Algerian-Provencal basin, the basement sinks to more than 6 sec depth, however it marks a large plateau between 3.5 and 4 sec on the Spanish margin.

In the axis of the basin, starting from 3°E, the very slow sinking of the basement may be followed. It is marked by a vast plateau between 4.5 and 5 sec on which a peak of 4 sec is located. At the eastern extremity of the depression, a peak of the basement reappears between 5 and 3.5 sec (Figure 7). It is marked on the magnetic map (Le Borgne, Le Mouel and Le Pichon, in press) by a strong anomaly oriented northwest-southeast which, according to Ryan *et al.* (1970), delineates a Balearic fracture zone.

Central Zone

Between the eastern and western basins, the basement indicates two large peaks, one at 2.5 sec depth (to the west) and the other at 3 sec depth (to the east). As shown in Figure 3, these rises of the basement have a very different morphology. The western peak is a cone whose large base is about 10 km, and whose sides are relatively steep. This peak is also noticed in the sea floor topography. The eastern peak shows less distinct limits, but it seems that its flanks are less inclined and its horizontal summit has a

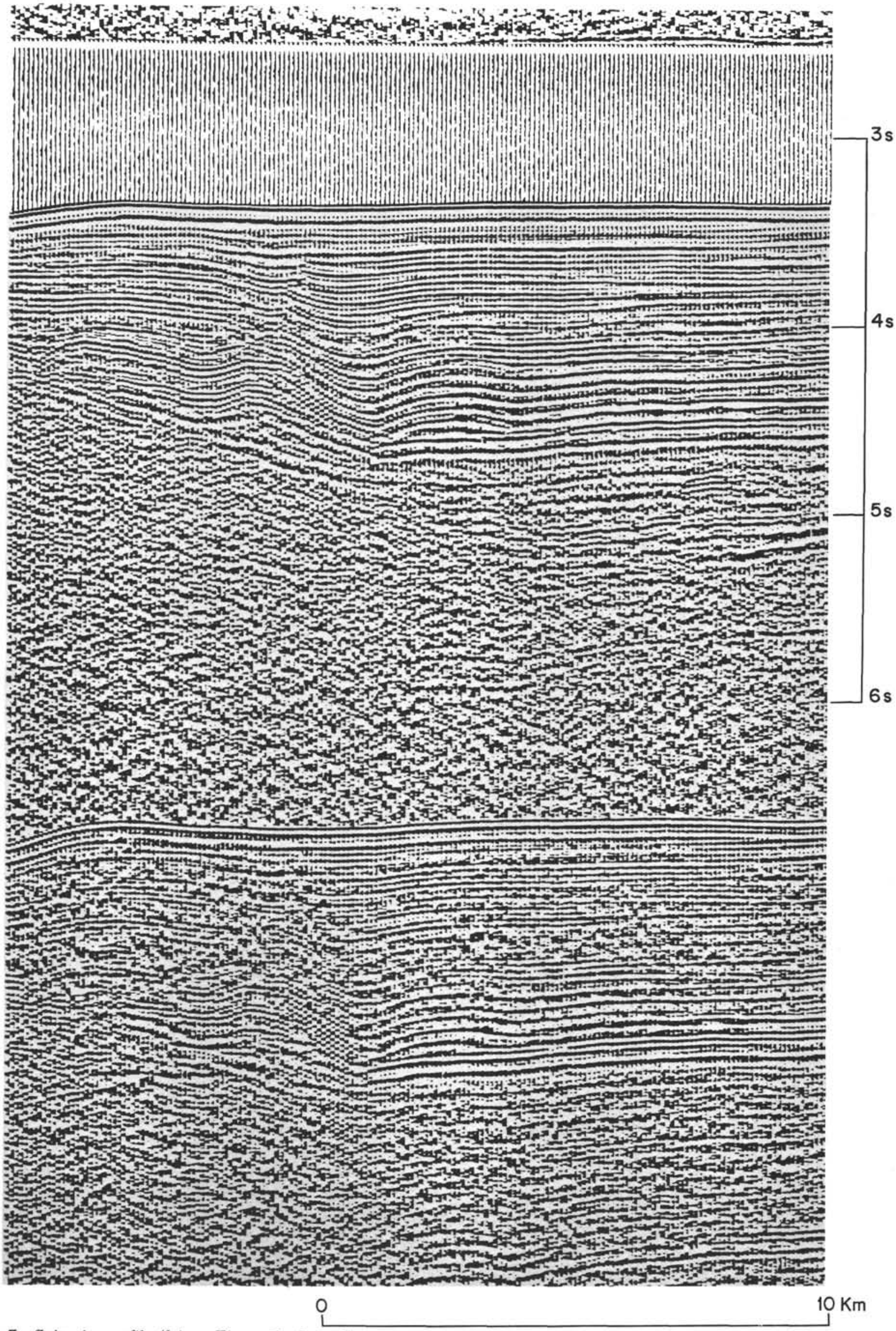

Figure 7. *Seismic profile (b) on Figure 1, the sedimentary cover of the oriental basin is interrupted by substratum uplift (at 4°E lat.).*

width of about 5 km. This peak corresponds in the sea floor topography to a depression due to a major canyon of the Ebro. In addition, in its southwest part it seems to be connected to an advance towards the northeast of the Minorcan margin.

Between these two structures, there is a sedimentary basin whose depth is greater than 4 sec. It is difficult to say if the peaks belong to the same massif, or to two distinct massifs. The magnetic map shows a strong positive anomaly over the western dome while there is nothing over the eastern. However, while drilling at Site 122 on the first structure was stopped in the Messinian gypsum, drilling at Site 123 on the second structure cut through 130 meters of volcanic glass. The nature of the basement forming these massifs is therefore difficult to define precisely. For the first, its morphology and magnetic anomaly favor the hypothesis that the dome is of igneous intrusive origin. For the second, its morphology, its position in continuation from the margin, and the absence of a magnetic anomaly would favor a continental nature, but the presence of volcanic glass is difficult to explain. The volcanic glass could have come from a neighboring volcano (a little more than 20 km) and so cover the continental basement, or it could be of a local origin and the eastern massif could be a caldera or a guyot whose central depression could be filled with volcanic glass and sediment. This would explain its flat summit, but not the absence of a magnetic anomaly.

Such a caldera, filled by about 1000 meters of sediment, has been described in the Alboran Sea by Gierman *et al.* (1968). On either side of this one, or these two, intermediate massifs, and practically in contact with them, the Spanish and Balearic margins come to an end at about 3.5 to 4 sec depth. On the margin of Majorca, the sinking of the basement shows some small undulations separated by basins which appear on Figure 6 as small northwest-southeast offsets.

In summary, the description of the acoustic basement in the Balearic depression shows two basins separated by an intermediate massif. The western basin is higher than the eastern basin. The sedimentary cover lies on a continuous basement which is regular and without important disturbances, except for the peaks located at the bottom of the Gulf of Valencia. From the Balearic to the Spanish margin, the slopes and the bottom of the basin seems to be composed of the same material which has collapsed in the central part. The results of recent seismic refraction studies (Hinz, 1971) have been interpreted as confirming the continental nature of this material. The eastern basin then would represent the collapse of the Balearic-Spanish basement toward the deep part of the Algerian-Provencal basin. It is difficult to determine the location of the contact between the continental and oceanic material, but if it exists, it must be east of 3°30′E.

Intermediate massifs are placed at a level where the Balearic margin and Spanish margins are very close. Several arguments (magnetism, drilling, morphology, position) favor a volcanic nature for the western massif and a continental nature for the eastern.

DISCUSSION – INTERPRETATION

The description of the Balearic depression basement (Figure 6) shows two significant structural directions. These directions appear in the outline of the margins, in the volcanic alignments, and also in the lineations of the magnetic anomalies.

The first orientation is in a northeast-southwest direction. At first, this appears in the outlines of the Spanish and Balearic margins. In the northern part, in other words along the Spanish margin, this northeast-southwest direction dominates until about 4°E longitude. From this point the margin takes a north-south orientation toward the end of the Gulf of Lyon. Along Ibiza and Majorca, that is, south of the western section of the Balearic depression, this direction is found until the level of the intermediate massifs.

From the point of view of volcanism, a southwest-northeast alignment is noted on the Spanish margin of the Gulf of Valencia carrying the Columbretes Islands and connecting different submarine hills which disturb the margin. This alignment appears on the magnetic map of Figure 5. Hernandez–Pacheco and Ascension Amor (1966) have already pointed out this alignment. Llopis–Llado (1954) described a similar type of volcanic lineament in Catalonia and in the region of Gerona. In the axial part of the north Balearic depression, there exists a volcanic alignment of this type (peaks at the bottom of the Gulf of Valencia, intermediate massif and intrusion at 4°E). However, this alignment does not correspond to a distinct orientation of the magnetic anomalies, and for this reason it is difficult to affirm the existence of a close correlation between these massifs.

The second significant direction is the northwest-southeast direction. In the basement's topography, this direction appears only to the east of the intermediate zone. It constitutes the limit of the eastern intermediate massif and the limit of the margin northeast of Minorca. This type of structure is found on land in Minorca where the Paleozoic and Cenozoic are separated by a fault in this direction (Obrador, 1970). The northwest-southeast foldings and faults have recently been described by Bourrouilh (Bourgeois *et al.*, 1970). Finally, the magnetic anomaly marking the Balearic "fracture zone" (Ryan, 1970) shows the same orientation. This orientation exhibits a maximum above the intrusion of 4°E longitude.

A final association of faults, whose existence and significance are less distinct, is that of the north-south faults. This orientation has been suggested by Bourcart (1960), Glangeaud (1966, 1968), and Mauffret and Sancho (1970). Of particular interest are the disturbances at the edge of the Spanish margin toward the extremity of the Gulf of Lyon, following a fault which has limited the intermediate western massif marked by the offset of the 2000 meters isobath, and finally a fault which shifts the margin of Majorca towards the north in relation to that of Ibiza.

These directions, according to which the North Balearic depression and the Balearic block itself seem to have been cut, certainly testify to their tectonic evolution. Drill Cores 122 and 123, an examination of the map of the basement, and the study of the sedimentary units permit us to attempt to retrace this evolution.

Two hypothesis can be put forward to explain the formation of the north Balearic Basin. This depression may be the result of either the subsidence of continental materials, or a distension between the Spanish continent and the Balearic block thus causing creation of an oceanic sea floor.

Some of us have stressed that the Balearic block might not have initially participated in the movement of the Oligocene opening of the Algerian-Provencal basin (Le Pichon, Pautot, Auzende and Olivet, in press). Indeed, it seems that at least all the region to the west of the Barcelona-Minorca line has not undergone, or if so, only very slightly, this opening by the drift of the Corsican-Sardinian block relative to the European block. The only manifestations of distension could be the peaks at the botto of the Gulf of Valencia (of an indeterminate age) and the volcano in the intermediate zone (Burdigalian andesite, 22 my BP). The southwest-northeast alignment from the Columbretes is more recent (Quaternary, Hernandez-Pacheco and Asensio Amor, 1966). On the other hand, the morphology of the basement and its position in continuation of the margins favor the existence at this level of a sunken continent as was proposed by Colom and Escandell (1960) and Llopis-Llados (1954). This hypothesis seems to be confirmed by seismic refraction (Hinz, 1971) which has been interpreted as showing a continental material injected by volcanic intrusions north of Majorca.

Our opinion is that the only part which may have been affected by the Oligo-Miocene drift of the Corsican-Sardinian block is the eastern basin. These intrusions at 3°30′ and 4°E longitude as well as the northwest-southeast magnetic anomaly are the manifestations with which one must associate the northwest-southeast faults which border the intermediate eastern massif and the northeast margin of Minorca. One may suppose that only the Minorca block has been affected by the movement and has been shifted towards the south following a northwest-southeast direction (Mauffret *et al.*, in press). After this phase, the Burdigalian andesitic eruptions of the intermediate volcano, with which we will associate the peaks of the bottom of the Gulf of Valencia which affect only the deep sedimentary series (Unit D), testify to an important phase noted around the rim of the entire Mediterranean (Roubault, 1934; Hilly, 1957; Robin, 1970). This phase in relation to the Alpine movements is felt until the Helvetian time on the Balearic block (Escandell and Colom, 1960). The sinking of the central part of the north Balearic depression probably began after this lower-Miocene and middle-Miocene phase. The thickness of the pre-Pliocene sedimentary series resting as the basement of the western basin is compatible with a beginning of subsidence at this period. The following episode is the episode of the basin's confinement in Messinian time (Le Pichon *et al.*, in press) which leads to the deposit of a layer of salt in the eastern basin which is identical to that in the deep part of the Algerian-Provencal basin (Auzende *et al.*, 1971). It also leads to the uplift of the central massifs, western basin, and margins according to the model proposed by Le Pichon *et al.* (in press). Because of this uplift, only a thin layer of evaporitic sediment is deposited in the western basin. It forms the surface on which Messinian erosion becomes established. The irregularities (channels, undulations) observed at the roof of Unit C could be due to traces of this erosion.

Finally, after the Messinian epoch, the northeast-southwest and north-south directions controls the resumption of subsidence of the depression and of the sinking of the Spanish and Balearic margins. The volcanic alignment of the Columbretes could be one of the manifestations of a recent marginal readjustment. In the Balearics, we know that uplift took place during the Pliocene and the Quaternary (Bourrouilh and Magne, 1963; Cuerda, Sacares and Colom, 1969). However, this recent tectonic activity is not evident within the sedimentary cover of the western and eastern basin.

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48.3. BALEARIC ISLANDS: SOUTHERN PROLONGATION[1]

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INTRODUCTION

In a recent note (Mauffret *et al.,* in press) we described the extension of the acoustic basement south of the Balearic mainland. One series of arguments (position, morphology, and magnetism) led us to advance the hypothesis that the acoustic basement represents a prolongation of the Balearic continental basement towards the south at least as far as 38° 30'N latitude. The prolongation appears to be marked by a large topographic rise between the 1000 and 2600 meter isobaths. Figure 1 (Mauffret *et al.,* in press) schematically shows the continuation toward the south of this supposed Balearic continent. DSDP Leg 13 Drill Site 124 was located near 5°E longitude and 39°N latitude at the inferred southeast extremity of the sunken "Balearic continent". With reference to seismic reflection profiles (Flexotir) taken during the survey Polymede I, we discuss here the morphology of the basement in this zone and describe the sedimentary cover.

MORPHOLOGY OF THE BASEMENT

The map of the basement (Figure 1) shows two distinctive zones. The *first zone* is north of 39°N latitude and shows the sinking of the basement in the direction of the Algerian-Provencal basin. The basement sinks along a generally north-south trend down to a depth of 5 sec where it disappears under the abyssal plain. Profile 1 (Figure 2) intersects the high part of the Balearic basement and shows a very complex morphology formed essentially by a series of peaks on the boundaries of small sedimentary basins. At least some of these peaks are probably of volcanic origin. Many are marked on a magnetic map (Vogt *et al.*, 1971) by strong positive anomalies (for example, the massif at 01:00 on Figure 2).

The *second zone* of basement morphology lies to the south of 39°N latitude. The basement sinks along the trend of a basin having a northeast-southwest orientation. It is evident from Profiles 2 and 3 (Figures 3 and 4) that the basement presents a relatively undisturbed morphology and slopes very gently (<2°) towards the center of the basin. The central part of the basin has a maximum depth of 5.2 sec in the North, and 5.7 sec in the south. This basin seems to be enclosed on its eastern border by an anticline striking north-northeast-south-southwest which separates it from the deep part of the Algerian-Provencal basin (Figure 1). The peaks of the basement, situated between 10:30 and 12:30 on Profile 2 (Figure 3), between 20:30 and 22:30 on Profile 4 (Figure 5), and between 4:30 and 7:30 on Profile 3 (Figure 4), may be aligned along this anticline and belong to an elevated platform whose width varies from 6 km in the northern area (Profile 2) to 18 km in the southern area (Profile 3). The platform is bordered by two practically symmetrical flanks whose inclination is about 3 degrees.

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