THE FORAMINIFERAL ASSEMBLAGES OF THE MOROCCAN SIDE OF THE ALBORAN SEA AS A RECORD OF CLIMATIC CHANGES IN THE UPPER PLEISTOCENE-HOLOCENE*

A. El Khanchoufi[1], J. Civis[2] and B. El Moumni[3]

[1]*Dept. Geol. Fac. Des Sciences, D.H. Mehraz B.P. 1796-Atlas (Maroc) (E-mail: abdesl@hotmail.com)*
[2] *Dpto. Geol Univ. Salamanca, 37008 Salamanca (Spain) (E-mail: civis@gugu.usal.es)*
[3] *Dept. Geol. FST Tanger,. 416 Tanger (Maroc) (E-mail: Moumni@hotmail.com)*

* ***Trabajo presentado en el 11th Meeting of the Association of European Geological Societies (MAEGS-11, Alicante, 1999)***

Summary: The changes in foraminiferal assemblages during the Upper Pleistocene and Holocene in a core obtained at a depth of 750 m (Alb.K.09) on the Moroccan side of the Alborán Sea reflect climatic variations that affected surface (variations in plankton) and deep waters. The change in the assemblages of benthic foraminifera can be correlated with the climatic recovery that occurred in the Upper Pleistocene as from 15,000 B.P. The most characteristic benthic foraminiferal species, together with the bathymetry, reflect stratification characteristics of the waters at the glacial maximum and changes in diversity during the Holocene. Variations in the plankton corroborate changes in temperature as from the start of the Holocene.

Key Words: Benthic foraminifera, planktonic foraminifera, climatic changes, Pleistocene, Holocene, Alborán.

Resumen: El cambio en las asociaciones de foraminíferos durante el Pleistoceno superior y Holoceno en un testigo obtenido a 750 m de profundidad (Alkb.K.09), en el margen marroquí del Mar de Alborán, refleja las variaciones climáticas que afectan a las aguas superficiales (variaciones en el plancton) y a las aguas profundas. El cambio en las asociaciones de foraminíferos bentónicos se puede correlacionar con la recuperación climática en el Pleistoceno superior, a partir de los 15.000 años B.P. Las especies más características de formaníferos bentónicos reflejan, junto a la batimetría, características de estratificación de las aguas en el máximo glacial y cambios en la diversidad en el Holoceno. Las variaciones en el plancton corroboran los cambios de temperatura a partir del comienzo del Holoceno.

Palabras clave: Foraminiferos bentónicos, planctónicos, cambios climáticos, Pleistoceno, Holoceno, Alborán

El Khanchoufi, A., Civis, J. and El Moumni, B. (2000): The foraminiferal assemblages of the moroccan side of the Alboran sea as a record of climatic changes in the upper Pleistocene-Holocene. *Rev. Soc. Geol. España*, 13 (1): 157-163

The southern shore of the Alborán Sea (western Mediterranean) is also known as the margin of Ceuta or the western Moroccan margin. It has been the object of many sedimentological, seismic and hydrodynamic studies (El Moumni, 1987; Ammar, 1987; Tesson *et al.*, 1989), although the northern margin is not very well known as regards micropaleontological aspects (benthic foraminifera).

Morphologically, it can be divided as follows: a continental platform (0 to -120 m) slope (up to -300m) marginal platform (from -300 to -600 m) marginal slope: up to –900 m, and basin (Ammar, 1987; El Moumni, 1996)

The aim of the present study was to gain insight into the micropaleontological assemblages on the basis of the benthic foraminifera and their variations in response to different environmental parameters and, in particular, to the climatic change that occurred in the Upper Pleistocene and the Pleistocene-Holocene transition in a transitional area between the Mediterranean and the Atlantic domains.

With this mind, core Alb.K09 (coordinates: N 35° 42´77´´ and W 4° 44´85´´) obtained at a depth of 750 m (marginal slope) and with a length of 6.60 m (Fig. 1) was analysed.

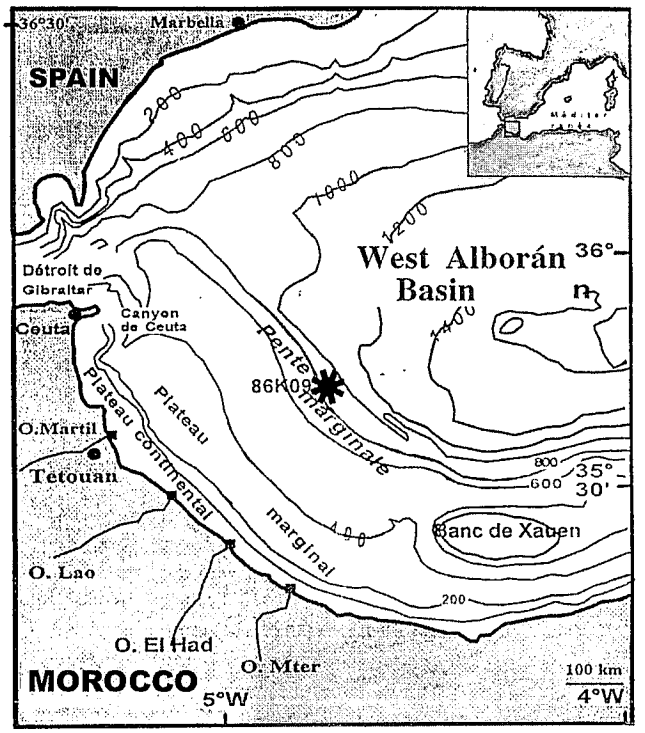

Figure 1.- Location of Core Alb-K-09

Lithological description of the core and technique used to study its microfauna

From top to bottom, the lithological characteristics of the core are as follows: from 1-110 cm, beige clays; 110-195 cm, grey clays; from 195-200 cm, there is a level with a concentration of shells and from 200-660 cm, there are grey clays with the presence of monosulphides whose concentration increases towards the base.

According to the sedimentological and mineralogical studies carried out by other authors (El Moumni, 1987), the clay fraction is the dominant one throughout the core and is generally above 50% of the total, and $CaCO_3$ is relatively constant, with values ranging between 10 and 20%.

To study the benthic foraminifera, a total of 25 samples was analysed (Fig. 2), taking the fraction greater than 40 μm for the qualitative data and the 125 μm fraction for the quantitative results.

The amount of residue used varied as a function of the richness of the samples (counting up to 250 specimens per sample and fraction) and ranged between 0.03 and 0.07 g.

Likewise, together with the analysis of the assemblages of foraminifera different indices –the diversity index,a, the P/B ratio, dominant textures, etc- were obtained.

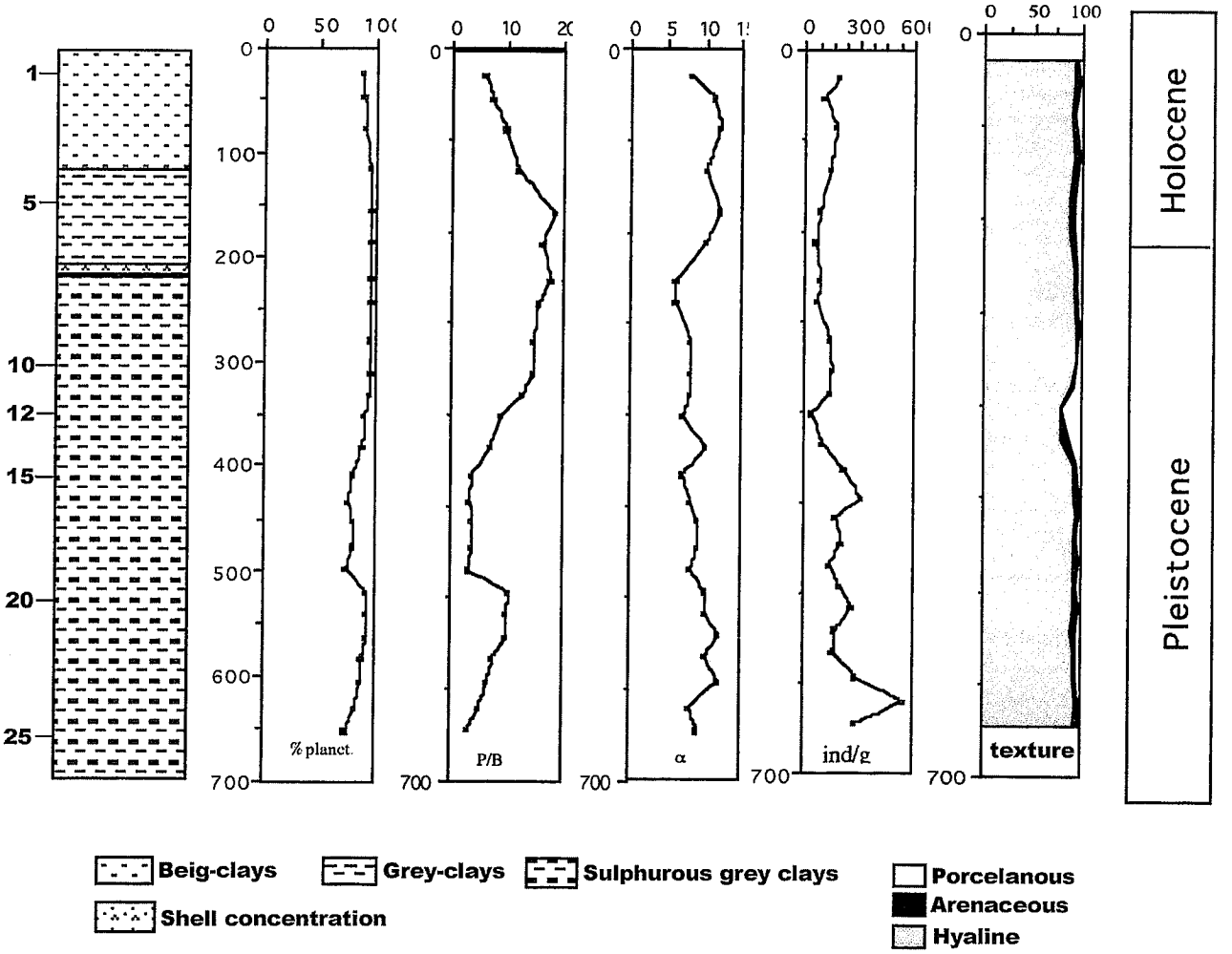

Figure 2.- Percentage of plancktonic Foraminifera, P/B index, α diversity index and texture

Species/Depth (cm)	26	47	77	116	156	186	222	243	281	311	332	351	381	408	435	453	477	498	520	541	562	583	607	631	653
Angulogerina angulosa			-	2						1			1	-	-	1		-	-	-				1	-
Angulogerina fornaseni	-	1																							
Anphycorina scalaris	2	1	1	3		1	1		2	1									1	2	4	1	1		
Brizalina subaenariensis															1	1		-	-		-		8	3	6
Brizalina difformis	2	4	-	2	1		1	1		1			-	1	-		-							1	-
Bigenerina nodosaria	-				1					1	3								1	2	1	-	-		-
Brizalina alata	-	1	-						-					2	-	1	1	-			-		3	4	4
Brizalina spatulatha	1	1	1		1					-		4	19	25	25	33	29	43	-	1	2	8	28	46	22
Bulimina costata	4	2	4	5	4	2	7	1	2	5	10	1		6	-	-	3		16	17	2	4	3		1
Bulimina elongata							1			-				-		-									
Bulimina marginata	2	1	2	2	7		3		5	1	2			-	1	-	-			7	13	14	5	3	
Cassidulina laevigata	12	9	9	7	1	2	3	6	4	2	2	7	26	5	3	2	1	2					2	3	1
Cassidulina crassa	6	3	11	12	3	3	8	2	4	10	8	1	1		-	-		-	9	6	4	-			
Clavulina crustata		2	-	2	1	2													1	1	2	4			
Cibicidoides pseudoungerianus	2	2	2	3	4	5							3	7	5	3	6	2	2	1	1	3	5	2	8
Cibicoides sp.													1	2	1	1	2	2							2
Discorbinella bertheloti			-						-	1	1	1	-						4	1	1	-	1	2	1
Epistomella rugosa									5	5	4								1	-					
Elphidium aculeatum																					-		-		
Elphidium complanatum								1	-			1				-						-		-	
Fissurina sp.	1							1					2	2	-	-	1	1	-				-	-	
Fursenkoina complanata					1								-		-	-	1	1					-		
Globobulimina auricularis	1	4	-	1	1	3			2	-	1	12	1	1	1	1	1	1		-	2	2	2	-	4
Globocassidulina subglobosa			1	2		4	5	1	3	1			-		-										
Globobulimina affinis	-	2	-									12	1	-		-	1	-		-	1	1	-	-	1
Hansenisca soldani	3	5	6	7		3	6		1	4	4	-		-	-			-	14	11	7	5	4	2	
Hoglundina elegans			-	1	1	1						-							1	-					-
Hyalinea balthica	11	9	9	3	1	1	1	2	2	2	1	14	11	14	21	20	19	26	3	3	4	4	9	8	16
Lagena acuticosta			-							1															
Lagena nebulosa								1					-				-		-				-		
Lagena cf.sulcata						1			1							-		-		1		1	-		
Laevidentalina elegans					1										-						-		-		-
Lenticulina auricularis	1	2	2		1	1					1					-	-	-	3	1	2	-	-	-	1
Lobatula lobatulus			-									13	3				1						-		-
Lenticulina peregrina			-	1															1			1		-	
Melonis barleanum	11	6	10	10	4	6	11	6	9	9	9		-	1	2	2	1	2	9	17	14	5	3	5	4
Melonis pompilinoides		1	-		1						1		-	1	-	-	-	-			-			1	1
Miltolinella subrotunda													1				1	1	1	-	-		-	-	1
Nummoloculina sp				1																					
Nonionella turgida												2													
Oolina hexagona	-				1													-						-	
Gyroidina orbicularis								9	7	7	4								3		2				
Planularia armenensis	1	2	1	1		8				-		1		-	1	1	1	1	-		1	-	1		1
Pullenia bulloides	1		1	1	1			1	1					1	-				1	1					
Quinqueloculina lamarkiana	3		1		1	3			-	1	1	3	-	-	1	1	-	-	-	-	1		-	-	
Quinqueloculina sp2														-			-					1	1	1	
Quinqueloculina seminula												9	6	1	1	-	1							-	-
Robertinoides subters																-	-		1	-					
Quinqueloculina sp 1	1										1	1	-	-	-	-	1	-		1	1	1			
Rectobolivina zitteli	-	1	-	1	1																				
Rectouvigerina phlegerie													-												
Chistomella ovoida		1	1	1	5	8	3		1	2	2	2	5		1	-	-	-	-	1	1	4	1	1	1
Sigmoilina elliptica	-	1	3	2	3	3	5	3	2	3	3		1		-	1			2	-	2	-		-	
Sigmoilopsis schlembergie	1	1	2	3	1								-				-		-	1		-	-	2	2
Siphonina bradyana						3													1	1	-	-			
Spiroloculina canaliculata					1															-	1				
Spiroloculina depressa						1			-																
Spiroloculina excavata													-												
Siphonotextularia concava														3	2	1	3	3					-	1	
Textularia earlendi	-					1							1	-	-						-	-	-		
Textularia conica	-							1		-	1							1	-	-	-		1		
Eggerella bradyi												2	-	-	-	-	1								1
Textularia truncata	1		-	1		1	2		-																
Triloculina trigonula					1							7	6	3	1	-	-	-			-				
Triloculina tricarinata	-																-	-	-		-				
Uvigerina mediterranea	29	35	26	28	39	34	43	58	44	40	38		1	11	16	16	12	10	18	18	18	26	14	10	14
Uvigerina peregrina		1	-									2	-	11	13	10	11	3	1	1	4	8	12	4	12
Uvigerina proboscidea								1	1	-							-		3	2	8	4	-		
Glandulina sp													1												
Others	1	2	2	2	7	3	1	4	3		2	2	4	1	1		2	-	1	1	-	-		1	-
Bentonic	326	136	234	177	76	100	109	97	257	285	148	90	416	516	601	493	520	672	273	427	247	209	261	498	254
Planktonic	1817	976	2214	2072	1397	1608	1923	1485	3659	4143	1847	778	2844	1857	1815	1755	1800	1886	2757	4263	2453	1575	1625	2480	742
% Bentonic	15	12	10	8	5	6	5	6	7	6	7	10	13	22	25	22	22	26	9	9	9	12	14	17	26
% Planktonic	85	88	90	92	95	94	95	94	93	94	93	90	87	78	75	78	78	74	91	91	91	88	86	83	74

Table I.- Quantitative results of benthic Foraminifera.

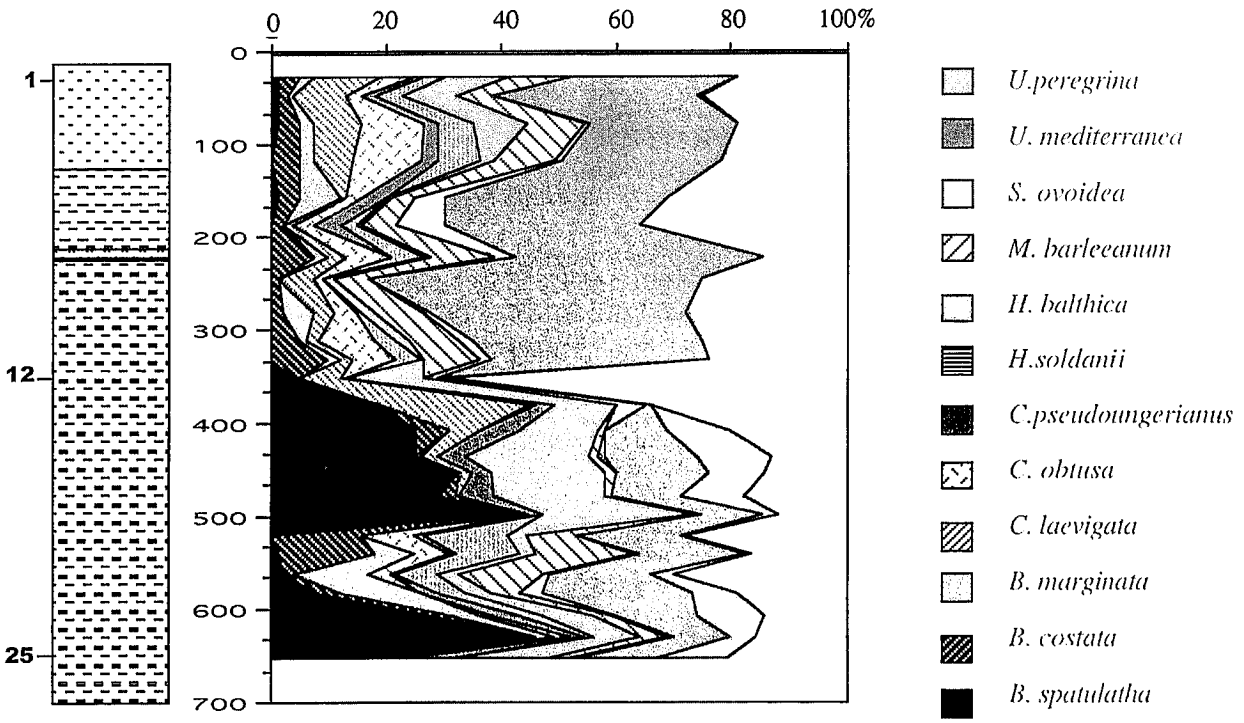

Figure 3.- Distribution of selecte benthic Foraminifera

SEM micrographs were made at the General Microscopy Service of the University of Salamanca.

Figure 2 offers a schematic view, together with the lithology of the core, of the sampling points and complementary data related to the microfauna.

Planktonic foraminifera

Planktonic foraminifera, studied by El Moumni *et al.*, 1997) are relatively abundant throughout the core, an increase in the P/B ratio being evident as from 350 cm up to a maximum value in the level corresponding to 150 cm and a slight decrease towards the roof. Together with these changes, the variation in the assemblage of plankton is significant, two quite different sets being clearly patent:

In one part of the core, from wall to roof, the most typical forms correspond to *Neogloboquadrina pachyderma* (Ehrenberg) together with *Globigerina bulloides* d'Orbigny, the former taxon representing more than 50% of the planktonic foraminifera. This trend changes towards the top of the core, with a stronger increase in other species such as *Globorotalia inflata* d'Orbigny and *Globigerinoides ruber* (d'Orbigny) such that in the lowest 200 cm of the core, *Globorotalia inflata* is practically absent while it is one of the most abundant forms in the upper part of the core. By contrast, *N. pachyderma* is a very minor form in the upper part of the core. Additionally, fluctuations are seen in the first part of the core and in general, in agreement with different authors and with the results obtained in neighbouring cores of similar age, the assemblages of planktonic foraminifera can be grouped as follows:

Between 0 and 120 cm, the assemblage of planktonic foraminifera has a warm or subtropical character. According to different authors and the results obtained in neighbouring areas, it can be dated up to 7000 BP (Cossment *et al.*, 1984; Duveaux, 19985; Pujols and Vergnaud-Grazini, 1989).

The segment between 120 and 200 cm is characterised by an assemblage of cold-water, subarctic species, with a progressive reduction towards the top; this has been dated at between 7,000 and 10, 000 years BP.

According to El Moumni *et al* (1997), the Pleistocene-Holocene limit would lie at approximately 200 cm.

Between 200 and 450 cm, the assemblage comprises typically cold-water forms, with a few less pronounced fluctuations, as is seen for the assemblages of benthic foraminifera.

Benthic foraminifera

Studies on benthic foraminifera were based on the 125 μm fraction and a total of 70 species was determined (the list of taxa and absolute values are shown in Table I). The systematics proposed by Loeblich and Tappan (1988) was used, hyaline forms, at textural level, clearly being the dominant ones. Likewise, the most representative species are shown in Plate I.

The absolute abundance of benthic foraminifera (specimens/g of sediment) tends to decrease from top to bottom, varying between 550 specimens/g at 631 cm to 30 at 351 cm. Towards the top, this abundance increases again up to values of 150 specimens/g of sediment. The sedimentation rate may be one of the factors contributing to the dilution of the specimens in the initial samples.

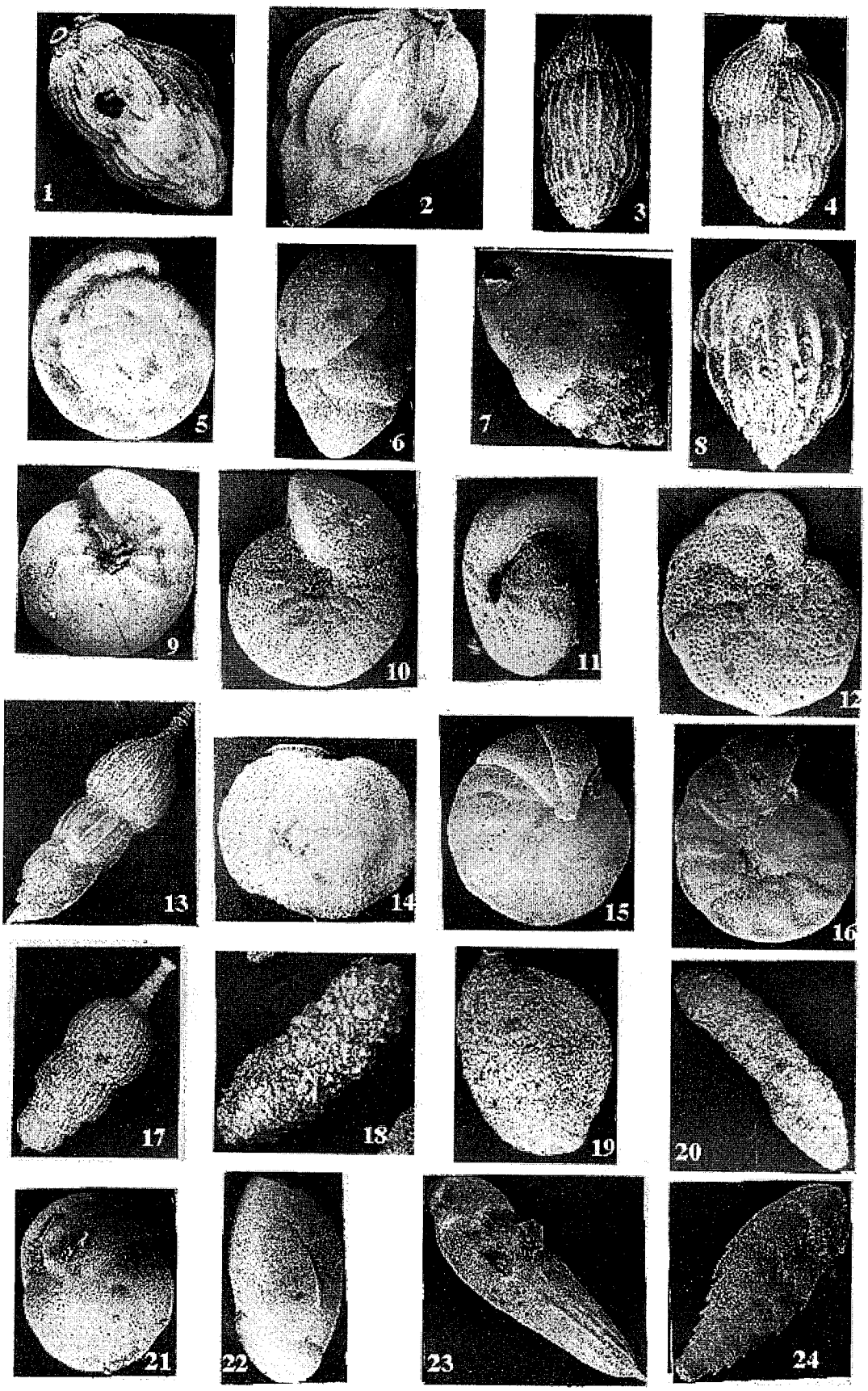

Plate I.- 1.2: *Uvigerina mediterranea* x 180. 3.4: *Uvigerina peregrina* x 180. 5-9: *Hansenisca soldanii* (=*Gyroidina soldanii*) x 130. 6: *Globbobulimina auriculata* x120. 7: *Bulimina marginata* x180. 8: *Bulimina costata* x140. 10.11: *Melonis barleeanum* x 150. 12: *Planulina ariminensis* x80. 13. 17: *Amphicoryna scalaris* x120 (13) and x100 (17). *Siphonina bradyana* x150. 15: *Cibicidoides pseudoungerianus* (= *Cibicides pseudoungerianus*) x130. 16: *Hyalinea balthica* x 125. 18: *Clavulina crustata* x60. 19: *Sigmoilopsis schlumbergeri* (=*Sigmolina schlumbergeri*) x130. 20: *Bigenerina nodosaria* x80. 21: *Cassidulina laevigata* x 150. 22: *Quinqueloculina seminula* x 100. 23: *Brizalina striatula* x 150. 24: *Brizalina alata* x 150.

Among the most representative hyaline benthic foraminiferal forms are the following:

Bulimina costata d'Orbigny
B. margnata d'Orbigny
Brizalina spatulatha (Williamson)
Uvigerina mediterranea (Hofker)
U. peregrina Cushman
Cassidulina laevigata d'Orbigny
C. obtussa Williamson
Globocassidulina subglobosa (Brady)
Hyalinea balthica (Schröter)
Melonis barleeanum (Williamson)
Hansenisca soldanii (d'Orbigny)
Cibicidoides, especially *C. pseudoungerianus* (Cushman).

The arenaceous foraminifera are represented by:
Clavulina crustata (Cushman)
Bigenerina nodosaria d'Orbigny
Syphotextularia concava (Karrer)

Porcelanoids are represented by:

mainly *Quinqueloculina* (Q. seminula (Linné) and *Triloculina*.

The distribution of the benthic foraminifera and the results of the quantitative analysis are shown in figure 3, in which two clearly differentiated parts can be seen:

In the lower part of the core the most outstanding forms are different species of Buliminidae, Uvigerinidae and *Hyalinea balthica*. Among the species of Bolivinidae, of special importance is the high percentage of *B. spatulatha*, which represents more than 40% of the set of benthic foraminifera and, as may be seen in the figure, it is almost completely absent from the middle part of the core (as from 350 cm) (see table of absolute values).

Another outstanding feature is the strong representation of *Uvigerina peregrina*, which is also almost completely absent in the upper part of the core. Furthermore, *Hyalinea balthica* is much better represented in this part of the core than in the upper part, reaching values close to 20% of the set.

In the upper part of the core (350-0 cm), together with the above absences, there is an extraordinary abundance of *Uvigerina mediterranea*, together with an increase in the diversity of the benthic foraminifera.

Changes in the microfauna and climatic fluctuations

Several authors have reported the presence of deep waters rich in Uvigerinid foraminifera during the Pleistocene and the relationship between this and the characteristics of ocean dynamics (Balsam, 1981; Caralp, 1987; Corliss *et al.*, 1986; Francés *et al.*, 1990; Streeter, 1976). Also, although there is no generalised consensus as regards the parameters affecting the distribution of such organisms, the abundance of *Uvigerina peregrina* in oxygen-deficient waters is patent. Similar characteristics can be applied to other dominant taxa in the assemblage, such as *B. spatulatha* (Mathiew, 1986-1988; Van der Zwaan, 1982), a taxon that, as seen in the figure, accompanies *Uvigerina peregrina* in the levels in which both are predominant (Fig. 3).

These results on the assemblage of benthic foraminifera can be interpreted as representing a model of circulation that can be characterised as displaying cold waters and little oxygen as a result of the modification to the circulation: a slowing down (stagnation) or lower degree of renewal of bottom waters in cold periods, possibly coinciding with the period of the last glacial maximum.

The change in the assemblage would be consistent with the installation of different characteristics as regards temperature, oxygen and nutrients and, therefore, a different model of circulation of deep-water dynamics that in the core is located at about 350 cm, transiently corresponding to climatic recovery as from 15,000 years B.P (Zazo, 1999).

Moreover, the fluctuations recorded in the lower part of the core could be attributed to lower fluctuations, as has been detected in other Pleistocene cores.

In the upper half of the core the fluctuations are minimum and, as mentioned above, the extraordinary abundance of other species of *Uvigerina* (*U. mediterranea*) is outstanding (Fig. 3); its maximum abundance could be related, among other parameters, to a greater bathymetry (Jorissen, 1987), which would be consistent with a greater presence of *Planulina ariminensis*, as may be seen in the figure.

Funds for stays by the Moroccan colleagues were provided by the Spanish Agency for International Collaboration and also by Project DGES PB96-11319.

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Manuscript received 10 February 2000
Accepted 28 May 2000