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STUDIES IN TERTIARY BENTHONIC FORAMINIFERA IN BELGIUM

door
H.J.F. HOOYBERGHS

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CONTENTS.

Quantitative distribution and paleoecology of benthonic foraminifera in the Brussels Formation, the Lede Formation and the Asse Formation (Eocene) at Haacht (Belgium)

H.J.F. HOOYBERGHS.

CONTENTS.

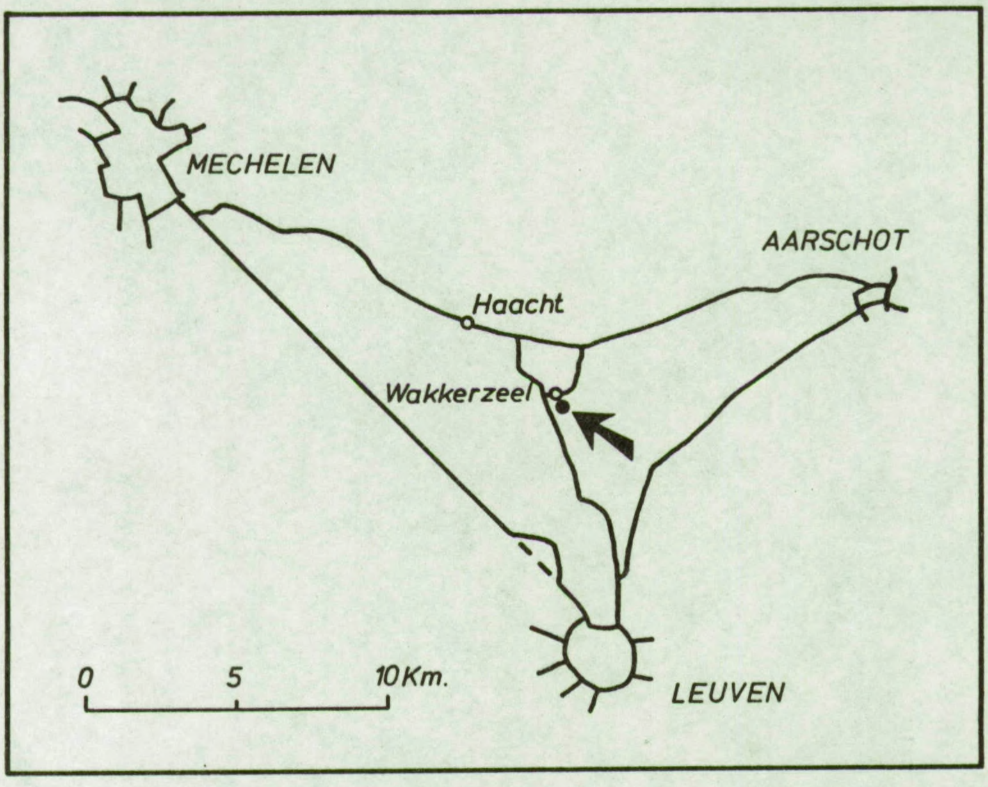

Fig. 1 : Location map.

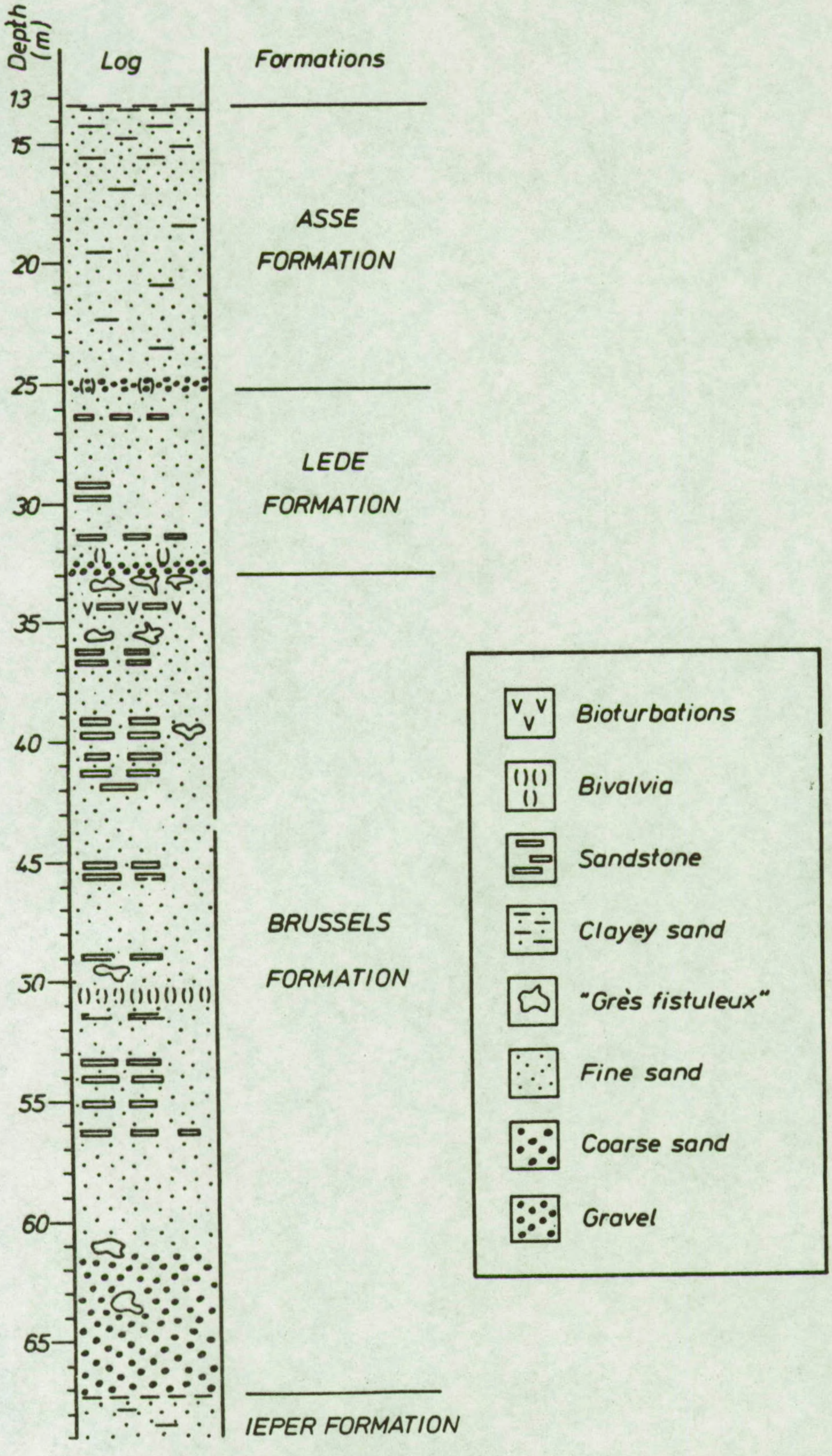

Fig. 2 : Development of the Brussels, Lede and Asse Formations in well P.3

1. ABSTRACT.

The benthonic foraminiferal populations in the Brussels Sands, the Lede Sands and the Wemmel Sands have been studied in a borehole at Haacht. Quantitative countings of up to 200 individuals per sample are made. By successive use of the following methods : quantitative distribution, triangular plot of suborders, similarities, Fisher α index, dominance index, percentage dominance and paleoecological significance of the occurring taxa, it has been possible to interpret the faunal assemblages paleoecologically.

2. INTRODUCTION.

The "Nationale Maatschappij der Waterleidingen" bored several wells in the vicinity of Haacht for ground water exploration. One of these wells, P.3 is treated here. This well is situated in the Dijle valley, near the hamlet of Wakkerzeel (fig.1, location map). Three different deposits have been sampled in detail : the Brussels Sands, the Lede Sands and the Wemmel Sands. The samples were washed on a 0,074mm sieve. In each residue, countings to 200 individuals of benthonic foraminifera have been made. For a systematic description of the taxa, we refer to KAASSCHIETER (1961).

3. LITHOLOGICAL DESCRIPTION OF THE DEPOSITS.

Three lithological units have been studied in the P.3 well at Haacht : the Brussels Formation, the Lede Formation and the Asse Formation (KAASSCHIETER, 1961). In the Asse Formation, only the Wemmel Sands Member was sampled (text.fig.2).

1) Brussels Formation.

The Brussels Sands are developed between-67.25m and -33m. They overlie the sandy top of the Ieper Formation. In the lower part of the Brussels Sands, between- 67.25m and -61.50m, a coarse glauconitic sand is observed. Irregular sandstone concretions, known as "grès fistuleux" occur at-63m. Between-61.50m and -33m, fine calcareous yellow-grey sands are developed. At different levels, sandstone beds and "grès fistuleux" concretions occur. The level at-61m is rich in *Nummulites*. Bivalvia have been observed at-51m. In the upper part of the Brussels Sands, at-34.50m, the deposit is bioturbated.

2) Lede Formation.

The Lede Sands occur between-33m and -25.25m. At the base of these sands, a fine gravel bed is observed. It contains irregular quartz grains, shell fragments and partly reworked *Nummulites*. Higher up, the Lede Sands are silty and homogeneous, green-grey in colour, with scattered *Nummulites*. Calcareous sandstone layers are developed at different levels.

3) Asse Formation.

The Wemmel Sands Member of the Asse Formation in well P.3 is developed between-25.25m and -13.50m. The lowermost part contains a fine gravel layer with shell fragments and reworked *Nummulites*. These sands in P.3 are fine glauconitic, slightly clayey and grey-green in colour. *Nummulites* occur in the whole interval. At lesser depths, the deposit becomes more and more clayey.

4. DISTRIBUTION OF BENTHONIC FORAMINIFERA IN WELL P.3.

Table 1 shows the quantitative frequencies of the benthonic

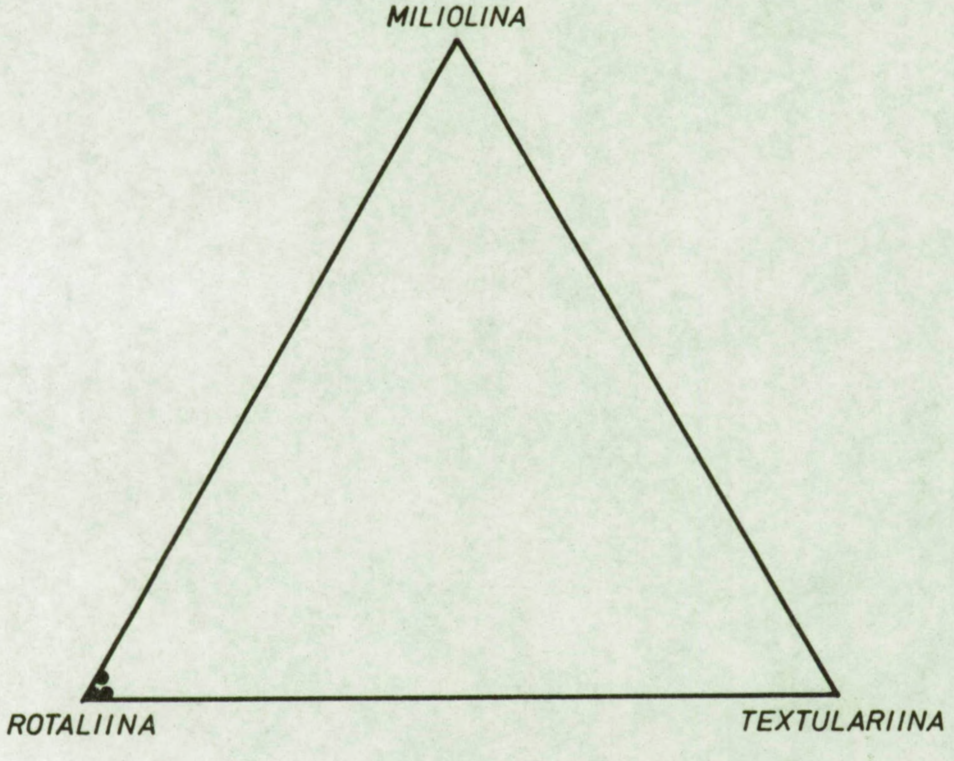

Fig. 3 : Triangular plot of the three suborders in the Brussels Sands.

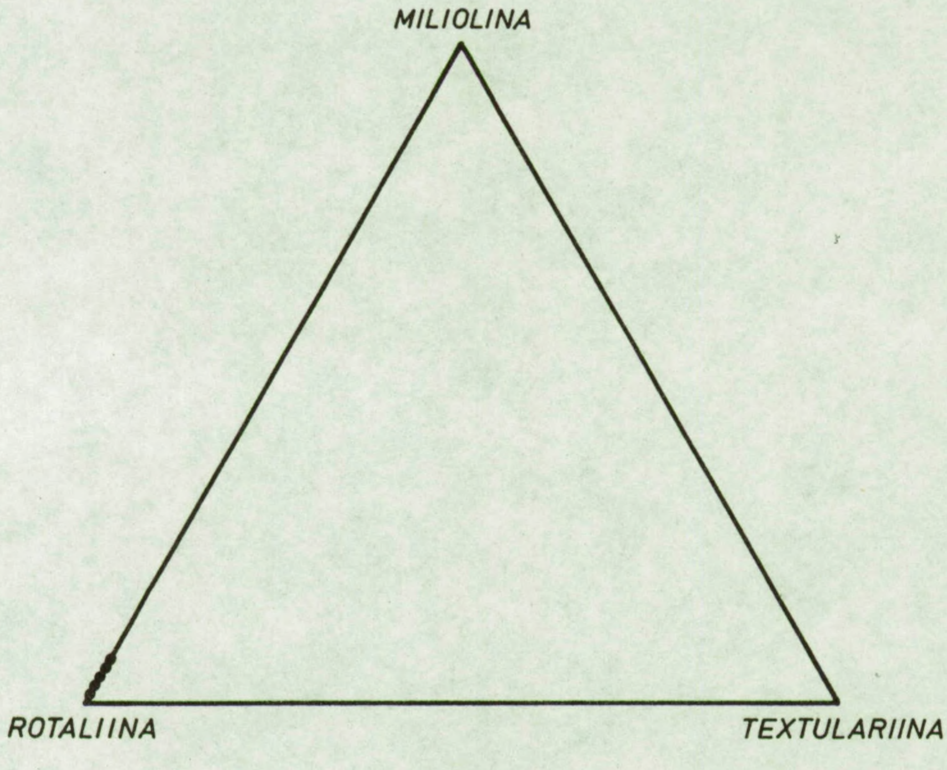

Fig. 4 : Triangular plot of the three suborders in the Lede Sands.

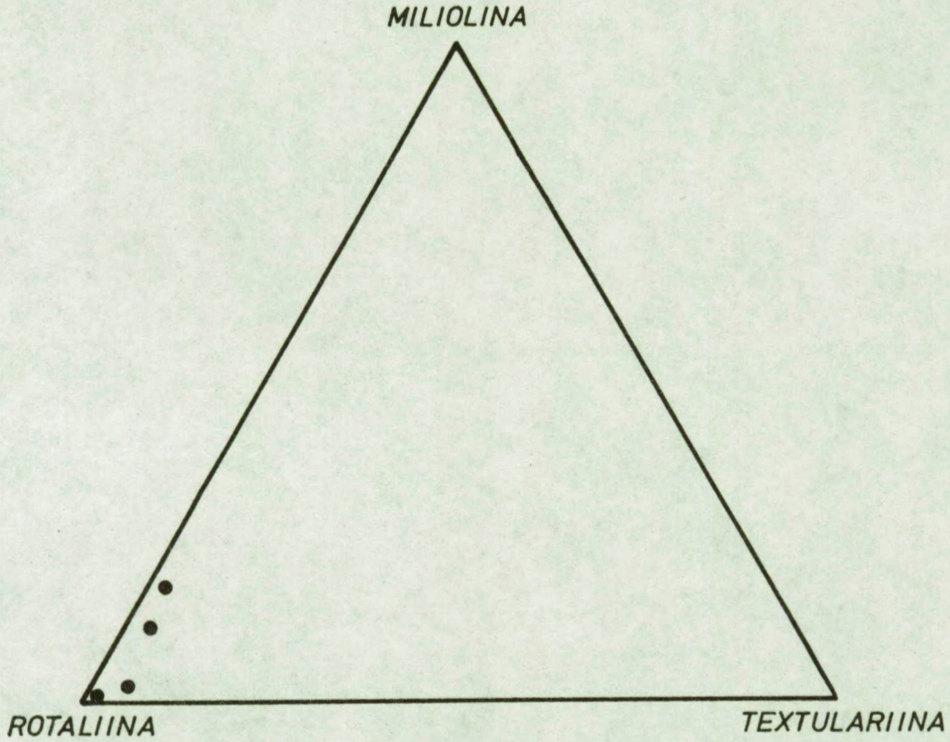

Fig. 5 : Triangular plot of the three suborders in the Wemmel Sands.

foraminifera in 200 individuals per sample. Table 2 gives the relative abundance of the taxa. We shall discuss here the fluctuations in the frequencies of the species in the different deposits.

1) Brussels Formation.

The Brussels Sands contain a rather homogeneous population in the different samples. Those populations are dominated by several species of the genus *Cibicides* : *C. lobatulus (0-4%)*, *C. mauricensis (4-21%)*, *C. proprius acutimargo (2-12%)*, *C. proprius proprius (15-44%)*, *C.* sp *(0-14%)*, *C. sulzensis (0-4%)*, *C. tallahatensis (0-14%)*, *C. tenellus (0-21%)* and *C. westi (2-21%)*. The fluctuations in the frequency of *C. tenellus*, which shows three maxima : 21% (depth 67.20m), 20% (depth 45.60m) and 15% (depth 33.80m) are noteworthy.

The genus *Elphidium* is a fairly important component of the associations : *E. subnodosum (1-19%)* and less frequently *E. laeve (0-3%)*.

Rotalia audouini represents a maximum of 10% of the populations, in which some other perforated calcareous benthonic foraminifera occur regularly : *Guttulina lactea (0-4%)*, *Gyroidina octocamerata (0-4%)*, *Hanzawaia boueana (0-3%)*, *Trifarina wilcoxensis (0-2%)*, *Globulina gibba (0-2%)* and *Asterigerina bartoniana (0-2%)*.

2) Lede Sands.

The Lede Sands are characterized by a remarkably high frequency of *C. tenellus (39-59%)*. Other *Cibicides* species occur regularly but less frequently : *C. lobatulus (2-6%)*, *C. mauricensis (0-4%)*, *C. proprius acutimargo (1-3%)*, *C. proprius proprius (0-3%)*, *C.* sp *(3-8%)*, *C. tallahatensis (0-2%)* and *C. carinatus (0-3%)*.

Different perforated calcareous taxa occur regularly in the succeeding samples : *Bolivina anglica (0-5%)*, *Elphidium laeve (0-3%)*, *Eponides schreibersi (1-5%)*, *Guttulina lactea (0-7%)*, *Rotalia audouini (0-3%)*, *Bolivina carinata (0-5%)*, *Reussella limbata (0-2%)*, *Nonionella wemmelensis (0-6%)* and *Reussella terquemi (0-6%)*.

FORMATIONS	Depth (m.)	Asterigerina bartoniana	Asterigerina cf. guerrai	Bolivina anglica	Cancris auriculus primitivus	Cibicides dutemplei	Cibicides lobatulus	Cibicides mauricensis	Cibicides proprius acutimargo	Cibicides proprius proprius	Cibicides sp.	Cibicides sulzensis	Cibicides tallahatensis	Cibicides tenellus	Cibicides westi	Elphidium laeve	Elphidium subnodosum	Eponides schreibersi	Eponides toulmini	Globulina gibba	Guttulina lactea	Guttulina problema	Gyroidina octocamerata	Hanzawaia boueana	Nonion affine	Nonionella spissa	Rotalia audouini	Trifarina wilcoxensis	Guttulina pulchella	Trifarina abbreviata	Cibicides carinatus	Guttulina irregularis
ASSE	22,6	3	3	8	1		1	2	16	2	8			18		3	1			8	16				2		9	12				
	23	8	4	14			4		4	1	17	1	2	60		2	1				7		1		2	4	1	11			2	
	24	19	7	7	1		2		6	2	6			40		5	8	3			3				1		3	13			1	1
	25	9	2	4	1		8		4	2	2	1		61		1	4	1		1	7				2		4	1			1	
LEDE	25,7	6	1	4	1		5		3		13		5	113		6		3		1	2	1					6	3				
	26	11		6	1		11		3	2	8			102		3		11		1	3						3				2	
	26,8	4		5	1		8		2	2	12		2	84		2		10		1	7						6	1			5	
	27,5	2		1	2	1	7		5	1	7		3	102		2	2	9		1	6					1	5	1		1	5	2
	28,1	7		8	1		5	1	5		8			86		1		11		3	4					3	4				2	1
	28,7	3		7	4		7	3	2	6	16		1	78		3	1	6		1	10				3	1	6	1			4	
	28,9	3		3	1		8	3	3	7	8			118		2		5			1			1			2	2				1
	29-29,5	2		8	1		7	3	7	3	12		1	87	1	1	1	7		2	2			1			2	1	1		3	2
	30,9	1		9			7	4	4	6	12		1	88			3	8		3	4			2	1		2	1			5	
	32	2		11			5	6	3	3	11		1	98		5		11			5			1	1		4	1			7	
	32,5	1		1			13	9	6	6	7		3	89		6	1	3		2	14				2	2					6	
BRUSSELS	33,8	1	2				4	23	5	79	16	2	5	31	13	2	8				1		3	1								2
	34,2						11	17	17	71	15	2	11	5	16		11		1	4	5		1	4	2			1				1
	35	1	1	1		1	8	17	12	46	21	5	9	20	18		25			1	4		1	1			3		2			
	35,7	1					17	18	8	52	19	3	15	4	23		23				1		7	2			3		1	1		
	36,5	1	1	1			7	13	13	55	29	6	15	7	28		18						1	7			2	1				
	37,2	1					6	24	11	53	14	3	16	12	20		21		3		3		6	5	1							
	38,2						12	21	14	57	14	1	14	2	32		15			3	4		4	3	1				1			
	38,7			1			8	18	11	74	9	1	9	8	43		8		2		4		1	2	1							
	39,5	1		1			12	15	12	76	18	5	16	4	27		10			1	1				1							
	39,8	1					15	22	10	55	11	3	7	7	33		22			1	2		3	4					1		1	
	40,2	1	1				7	20	14	79	12	9	16	4	13	1	13				2		6					1		1		
	40,7				1		3	27	8	85	18	1	16	5	11		13				1		2	3	1	1	1	1				
	41		1				4	27	10	88	17	1	19	3	12	1	7							2				2				
	41,3						3	21	8	77	16	2	17	10	24		12						2	2			4	2				
	41,7						6	25	8	71	16	2	19	4	29	1	13		2				5		1		1	2				
	42,2	1					12	21	14	65	14	5	13	10	20		10	1	1		2		4	3	1		3					
	43,5		1				5	22	13	55	16	6	10	28	14	1	16		1	1			1	1			3					
	45,6	1		1				38	12	51	21	4	8	40	8		3	1	1			1		4	1		8	2				
	45,9				1		14	25	8	49	21	5	12	16	19	1	6	1	1		3		3	4			4			1		1
	46,3		1				3	23	15	59	20	4	7	31	7	2	4			1	1		1	1	1	1	11					
	49,3	2	1				9	18	16	56	18	2	1	21	20	2	9			1	3	1	6	1		2	1		1		4	
	49,4			1			9	11	16	47	15	2	5	11	26	2	15			2	6		8	1	1		13	3	1			1
	49,6					1	1	10	11	70	26	4	13	12	10	3	25				1	1	4	3			1	1				
	49,9					1	7	8	9	70	13	3	7	19	19	2	18		2	2			5	4	1	1	7	1				
	50,2		1	1	1		13	15	24	65	20	4	6	10	13		11				1		6	2	2		1	2				
	50,7			1	1		5	14	11	85	25		7	8	14	1	12			1	2		2	2			4		1			
	51,4						14	17	7	82	21		10	14	12	1	5	2		1	2		2	1	1		7					
	51,7	1		2			8	21	8	66	26	1	12	10	18		2		1		3		7	2			4					
	52,3						8	11	10	74	23	4	10	18	7	2	14	1					4	3	1		4	1				1
	53					1	10	12	11	73	15	1	12	8	23	3	15	1				2	4	1			4	1				
	53,8	1					4	11	10	77	18	4	15	10	26		7		1	1	2		4	1			4					
	55	1			1		8	18	13	53	23	2	21	8	12	1	22			1			3	5	1	1						
	55,7					1	4	15	6	66	34		12	4	20		20			2	3	1	3	3			3					
	56	1					5	13	9	54	27		10	5	21		27	1			5	2	4	3	1		2					3
	57,1	1					4	16	7	66	22	4	11	5	19	3	24	1		1	1		5	4			9					1
	58,1	2					5	11	8	60	13	2	15	5	24		38		1		2	1	9	5	1		5	1				
	59						6	19	9	66	20	5	22		9	4	20			1	1	2	4	5			3	1				
	59,2						8	26	9	50	15	6	16	7	26		10			2	8		5	3	1		3	1	2			
	59,8	1			1		9	20	12	60	10	4	13	10	16		21		1		2	1	1	6			5	2				
	60,2						5	28	20	46	5	3	20	7	21	1	13				1	2	1	3		3	6				7	
	60,3	2	1	1			12	25	24	57	1	5	18	4	14	5	16			1	2		2	2				1	1			2
	61,5	2					3	29	15	56	9	7	16	5	24	1	12		1		1		4		1		7	1				
	62-62,1		1				1	22	18	70	15	3	7	11	13	7	9				1		1	7	1		9				1	1
	62,75	1		1			7	43	17	83	13	7	28	1	5	7	8			1			8	1				1				
	64			1		1	3	32	16	71	6	7	16		17	5	15						2	2			2			1		
	64,6		1	2		2	10	31	14	51	12	5	10	6	18	2	13						4	1			2	4		-	6	1
	65	5				5	9	23	11	66	13	7	22		12	2	7				2		3	2	3		1				2	1
	67	1		3			7	14	7	43	12	3	7	23	20	1	23	1			2	2	1	4			20	4	1	1		
	67,2	1	1	2	1	2	7	15	11	30	14	4	14	43	21	3	7	2	2	3	2	2	5	1	1	1	4	1	[illegible]			

Table 1 : Quantitative distribution of benthonic foraminifera.

FORMATIONS	BRUSSELS																												
TAXA / Depth (m)	67.2	67	65	64.6	64	62.75	63-62.1	61.5	60.3	60.2	59.8	59.2	59	58.1	57.1	56	55.7	55	53.8	53	52.3	51.7	51.4	50.7	50.2	49.9	49.6	49.4	49.3
Lenticulina sp.			1							1																1			1
Textularia agglutinans			1	1					1																				
Quinqueloculina carinata				2						1																			
Bolivina carinata					1		1			4												2					1		
Globulina gravida					2	1		2					1	1	2		1	2	1	1	1	3	1	2			2		
Spiroplectammina carinata deperdita							1																						
Eponides umbonatus						1		2								1	1	1	1		1	2		1	1				
Bolivina brabantica									1				1		1	1				2							1	1	
Dentalina inornata								1																					
Siphonina lamarckina								1			1		1		1	1									1				
Alabamina wolterstorfi									1																				
Bulimina parisiensis										1																			
Lagena striata										1									2										1
Quinqueloculina ludwigi																													
Oolina orbignyana											2																	2	
Lagena globosa											1																		
Pyrulina thouini											1																		
Discorbis limbata												2																	
Reusella elongata														1		1	1												
Quinqueloculina costata															1														
Lagena isabella																		1											
Spiroloculina tricarinata angulifera																		1											
Reusella limbata																		1											
Spiroloculina tricarinata belgica																					1								
Trifarina muralis																					1								
Nonion scaphum																						1							
Articulina terquemi																								1				1	
Miliolacea																													3
Quinqueloculina seminulum																													
Eponides polygonus																													
Bifarina selseyensis																													

FORMATIONS	BRUSSELS																			
TAXA / Depth (m)	46.3	45.9	45.6	43.5	42.2	41.7	41.3	41	40.7	40.2	39.8	39.5	38.7	38.2	37.2	36.5	35.7	35	34.2	33.8
Lenticulina sp.						1														2
Textularia agglutinans																				
Quinqueloculina carinata																				
Bolivina carinata																		1		
Globulina gravida	2	3		1				3												
Spiroplectammina carinata deperdita																				
Eponides umbonatus	2					1		1										1	1	
Bolivina brabantica	3			2															1	
Dentalina inornata															1					
Siphonina lamarckina																				
Alabamina wolterstorfi																				
Bulimina parisiensis																				
Lagena striata											1									
Quinqueloculina ludwigi																				
Oolina orbignyana				2																
Lagena globosa																				
Pyrulina thouini																			1	
Discorbis limbata																				
Reusella elongata																	1			
Quinqueloculina costata																				
Lagena isabella																				
Spiroloculina tricarinata angulifera																				
Reusella limbata		1	1																	
Spiroloculina tricarinata belgica																				
Trifarina muralis						1		1	2							1		1	1	
Nonion scaphum																				
Articulina terquemi											1								1	
Miliolacea				1										2						
Quinqueloculina seminulum		1																		
Eponides polygonus						1		1									1			
Bifarina selseyensis																				

FORMATIONS	LEDE											ASSE			
TAXA / Depth (m)	32.5	32	30.9	29-29.5	28.9	28.7	28.1	27.5	26.8	26	25.7	25	24	23	22.6
Lenticulina sp.				1	1										1
Textularia agglutinans												5	7	4	13
Quinqueloculina carinata	1					1	7	1	1		4	1	4		
Bolivina carinata		9	6	5	3	6	2	6	10	2	1	3	3	4	1
Globulina gravida															
Spiroplectammina carinata deperdita															
Eponides umbonatus														5	5
Bolivina brabantica															
Dentalina inornata															
Siphonina lamarckina															
Alabamina wolterstorfi															
Bulimina parisiensis	1									1			1		1
Lagena striata															
Quinqueloculina ludwigi															
Oolina orbignyana		1				2						4			2
Lagena globosa															
Pyrulina thouini															
Discorbis limbata															
Reusella elongata		1	1	1	1								1		
Quinqueloculina costata												2			
Lagena isabella															
Spiroloculina tricarinata angulifera												1			
Reusella limbata			5	2		2	2	4	3	2	3	1	2	1	3
Spiroloculina tricarinata belgica										1		9	2		1
Trifarina muralis	1	1	1	2	1		1	1	1	1		1	1	2	1
Nonion scaphum	1			1		1	1				1	2	4	2	7
Articulina terquemi												2			
Miliolacea	3			2	3		3	1	9	7	4	16	6		
Quinqueloculina seminulum	3		1			1		2	4	4	3	10	6		
Eponides polygonus															
Bifarina selseyensis	1			1	2						1	2	6	12	16

Table 1 : Quantitative distribution of benthonic foraminifera.

FORMATIONS	Depth (m.) \ TAXA	Bolivina crenulata	Buliminella pulchra	Glandulina laevigata	Nonionella wemmellensis	Reusella terquemi	Triloculina trigonula	Asterigerina sp	Cibicides pygmeus	Oolina sp	Quinqueloculina juleana	Lamarckina cristellaroides	Dentalina elegans	Dimorphina sp	Spiroloculina tricarinata	Spiroloculina costigera	Bolivina cookei	Quinqueloculina tricarinata	Dentalina ewaldi
ASSE	22,6		5		26			3							1		6		
	23	2	3		10			5							1		3		
	24	2			12			5			1	1			4	1	2		1
	25		3		8			4			2	2			1	2	2	1	
LEDE	25,7				1	2					2	2				1	2		
	26		1		1	3	1	2			2	2	1	1	1				
	26,8		4	1		11	2		1	1									
	27,5		1	2	6	6		1	3										
	28,1	6	4		13	11													
	28,7	3	1	1	12	2					2	2							
	28,9	5	1		2	13													
	29-29,5	2	4		5	13			3	1									
	30,9	1	3		5	11		1	4										
	32		4		3	8													
	32,5	3	1	1	11	1	1												
BRUSSELS	33,8																		
	34,2																		
	35																		
	35,7																		
	36,5																		
	37,2																		
	38,2																		
	38,7																		
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	39,8																		
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	41																		
	41,3																		
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	42,2																		
	43,5																		
	45,6																		
	45,9																		
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	56																		
	57,1																		
	58,1																		
	59																		
	59,3																		
	59,8																		
	60,2																		
	60,3																		
	61,5																		
	62-62,1																		
	62,75																		
	64																		
	64,6																		
	65																		
	67																		
	67,2																		

Table 1 : Quantitative distribution of benthonic foraminifera.

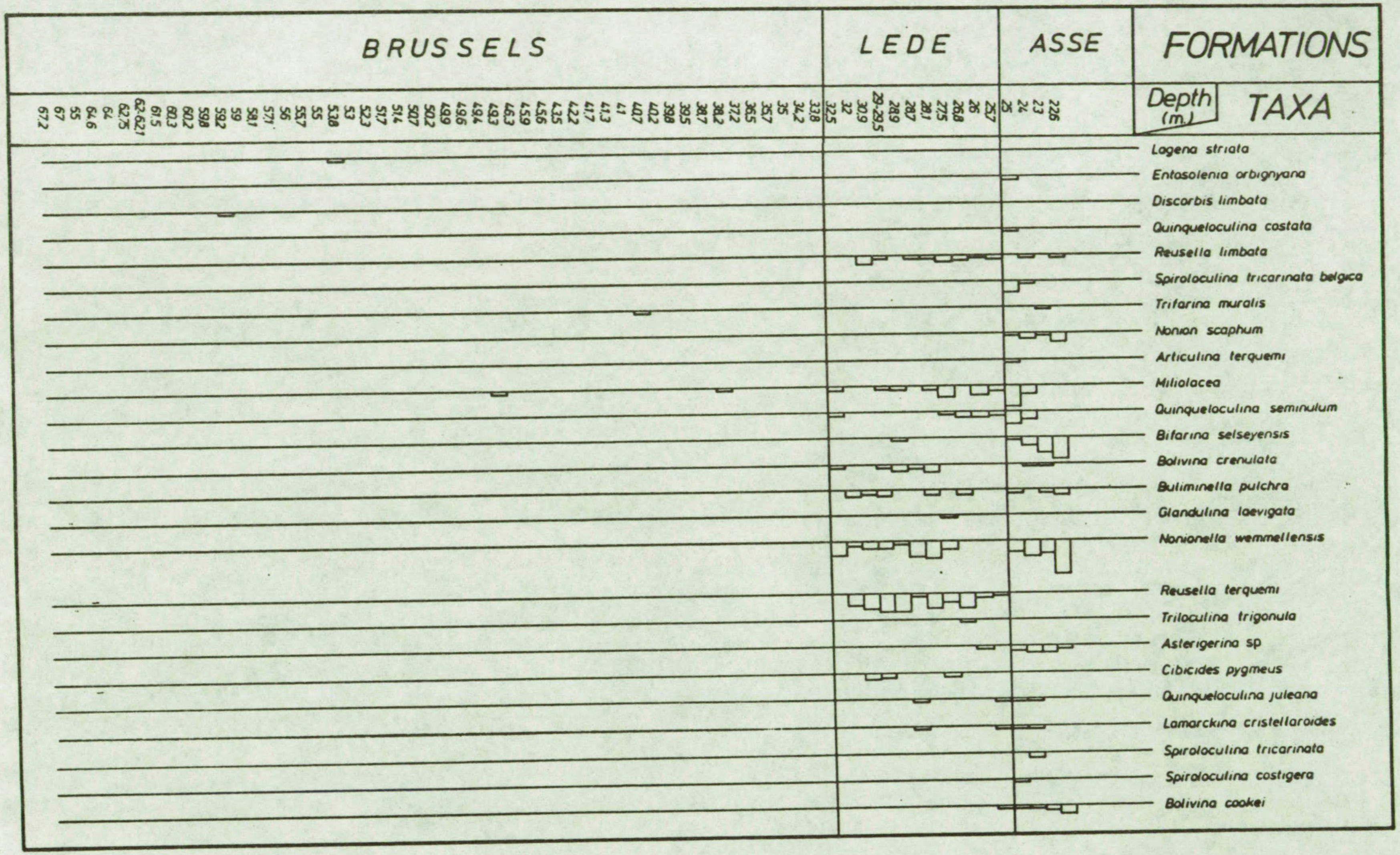

Table 2 : Relative abundance of benthonic foraminifera.

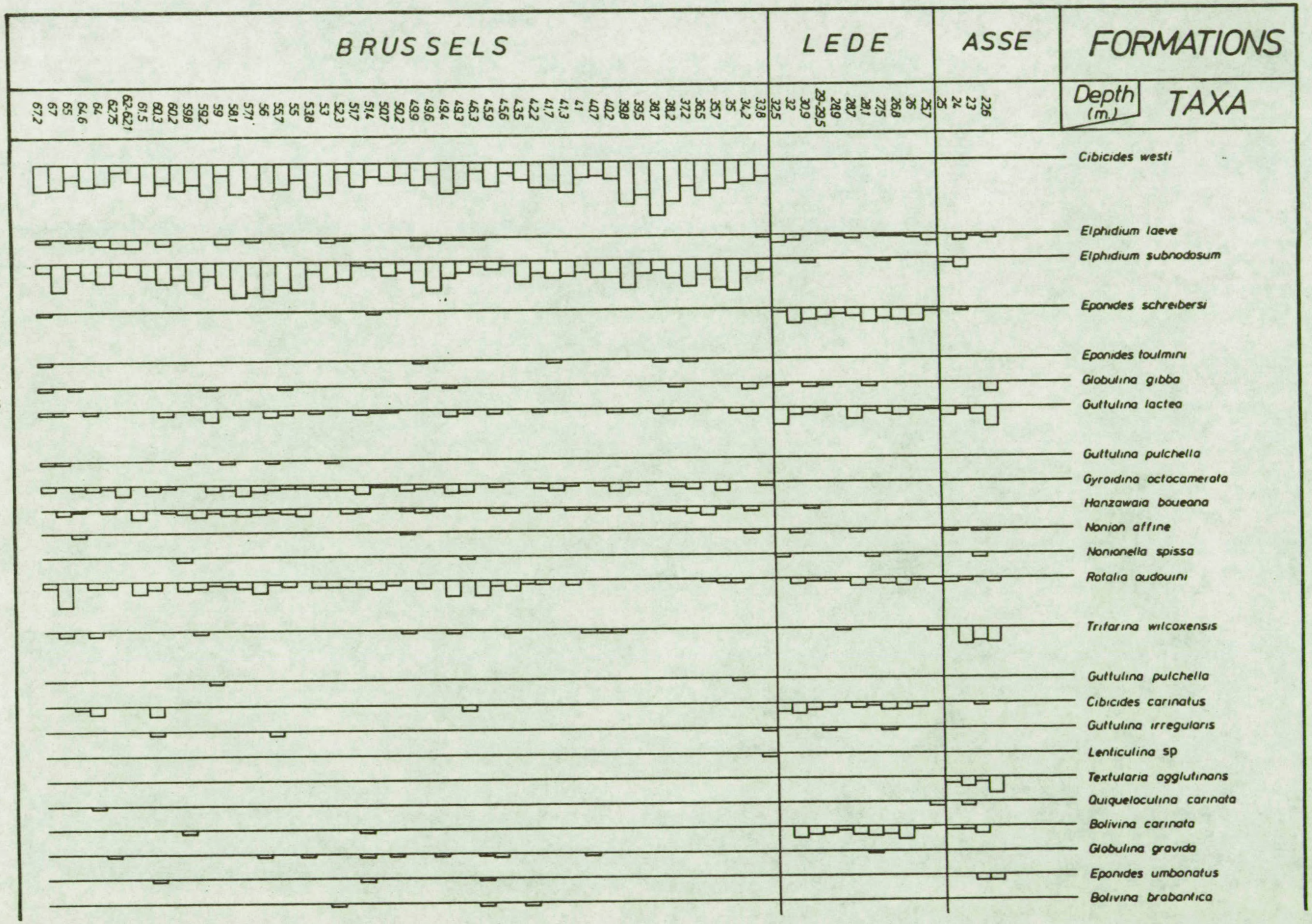

Table 2 : Relative abundance of benthonic foraminifera.

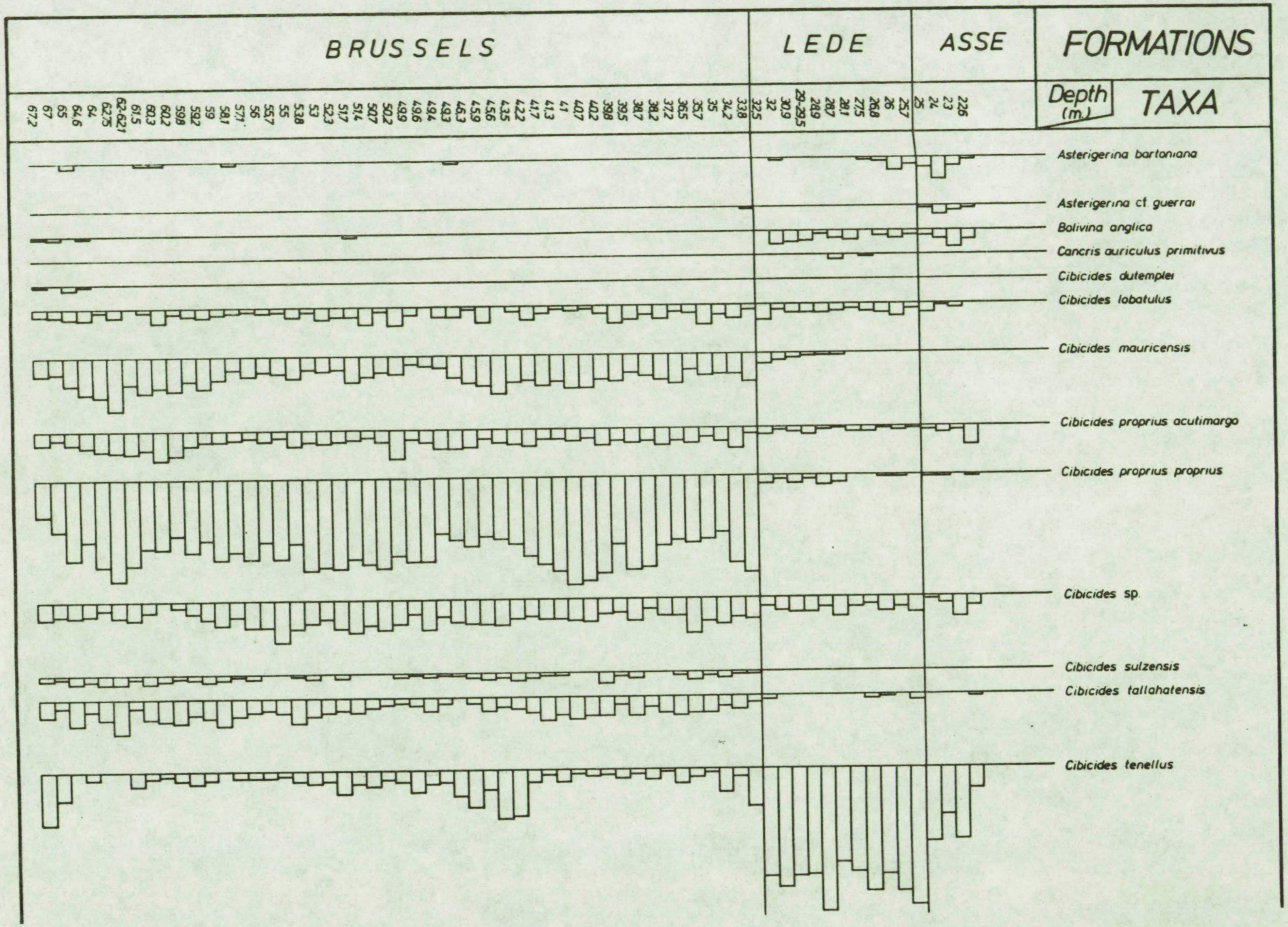

Table 2 : Relative abundance of benthonic foraminifera.

Asterigerina bartoniana occurs especially in the upper part of the Lede Sands (0-5%). Less important taxa are *Cancris auriculus primitivus (0-2%)*, *Elphidium subnodosum (0-1%)*, *Globulina gibba (0-1%)*, *Quinqueloculina seminula (0-2%)*, *Bolivina crenulata (0-3%)*, and *Buliminella pulchra (0-2%)*. The appearance of *Miliolacea (0-4%)* is of note.

3) Wemmel Sands.

The frequency of *C. tenellus* in the Wemmel Sands is lower (9-30%). Other *Cibicides* species occur less frequently : *C. lobatulus (0-4%)*, *C.* sp *(1-8%)* and *C. proprius acutimargo (2-8%)*.
A number of perforated calcareous benthonic foraminifera appear regularly in The Wemmel Sands : *Asterigerina* cf. *guerrai (1-3%)*, *Asterigerina* sp. *(2%)*, *Trifarina wilcoxensis (0-6%)*, *Textularia agglutinans (2-6%)*, *Nonion scaphum (0-3%)*, *Bifarina selseyensis (1-8%)*, *Bolivina cookei (1-3%)* and *Eponides umbonatus (0-2%)*.
Some taxa from the Lede Sands still occur in the Wemmel Sands : *Asterigerina bartoniana (1-8%)*, *Bolivina anglica (2-7%)*, *Elphidium laeve (0-2%)*, *Elphidium subnodosum (0-4%)*, *Guttulina lactea (3-8%)*, *Rotalia audouini (0-4%)*, and *Nonionella wemmelensis (4-13%)*. We also note the presence of *Miliolacea (0-8%)*, *Quinqueloculina seminula (0-5%)* and *Spiroloculina tricarinata belgica (0-2%)*.

5. Triangular plot of suborders.

The foraminiferal populations represent three suborders : *Textulariina*, *Miliolina* and *Rotalina* (LOEBLICH & TAPPAN, 1964), which can be plotted on a triangular diagram. MURRAY (1973) marks out the fields for the different possible environments in this diagram. In the deposits studied here, the different assemblages can be situated near the *Rotalia* corner (figs.3,4,5). According to the interpretation by MURRAY, these assemblages can occur in the following environments : hypersaline marshes, normal marine marshes, hypersaline lagoons, continental shelf and hypersaline lagoons and marshes.

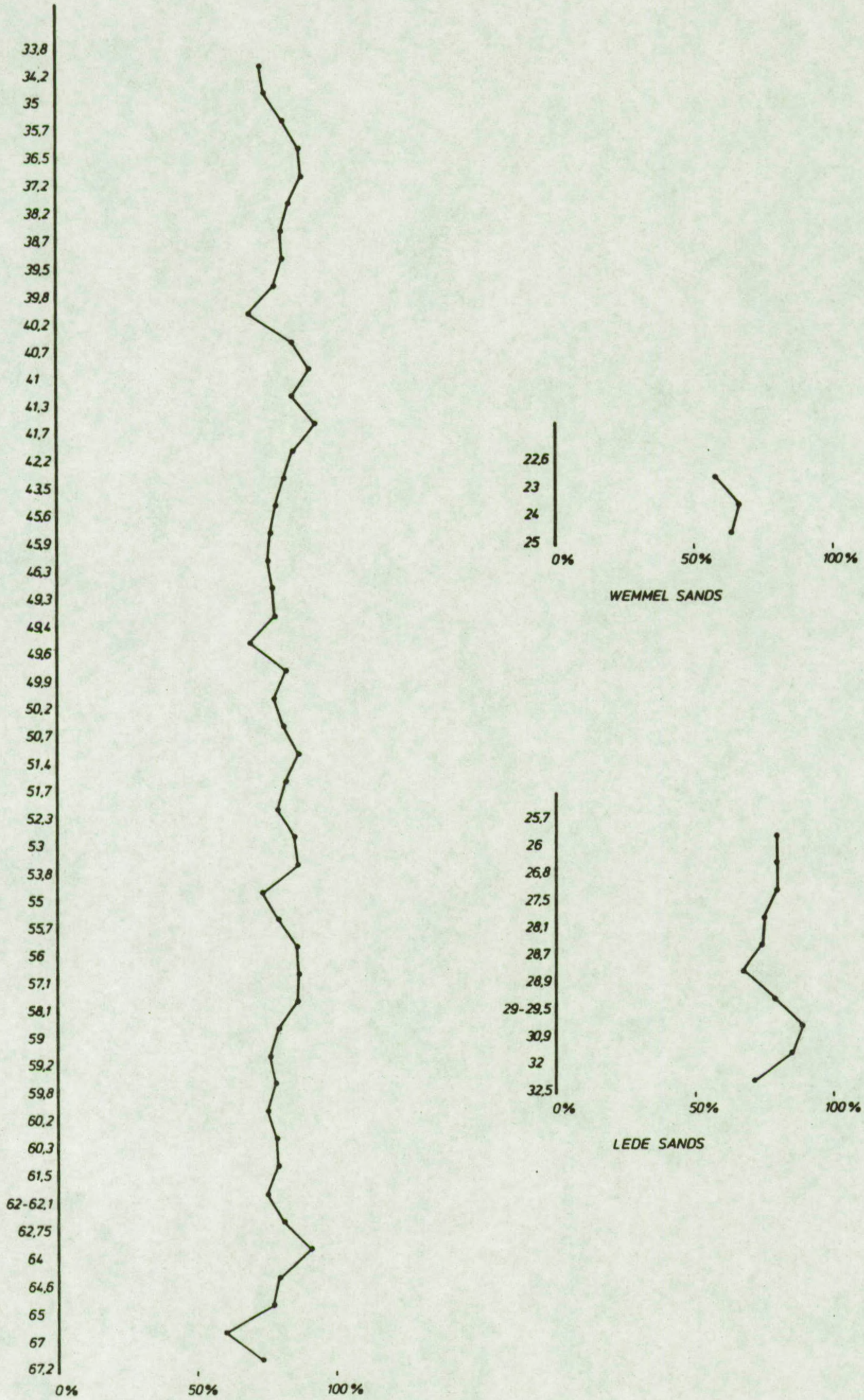

Fig. 6 : Similarity index.

6. SIMILARITIES.

This method of SANDERS (1960) measures the similarity between the successive samples in a section. To compare two samples, the percentage occurrence of the species common to the two samples are listed. For each species common to the two samples, the lowest percentage is noted. The total value of all these lowest percentages gives the similarity index. The populations in the two samples are nearly identical when the total value is higher than 80. The associations differ progressively as the similarity index diminishes.

The similarity index for the succeeding samples in the three different deposits is given in fig.6.

In the Brussels Sands, most of the values are between 70% and 93%. Those high values underline the homogeneity of the populations within this deposit. The similarity index is only lower between samples -67 and -65 : 60%.

In the Lede Sands, the values are slightly lower than in the Brussels Sands : between 67% and 88%, but the species associations remain still rather homogeneous.

In the Wemmel Sands, the similarity index lies between 57% and 66%. Those values are lower than in the two other deposits. The similarity index decreases progressively in the successive deposits and the population differences increase progressively.

7. DIVERSITY INDEX OR FISHER α INDEX.

The diversity index or fisher αindex gives the relationship between the number of individuals and the number of species in a population. The αvalue can be determined by plotting the number of species against the number of individuals in the base-graph constructed by FISHER, CORBETT & WILLIAMS (1943). WRIGHT & MURRAY (1972) and MURRAY (1973) draw up the interpretation of the different environments corresponding to the various αvalues.

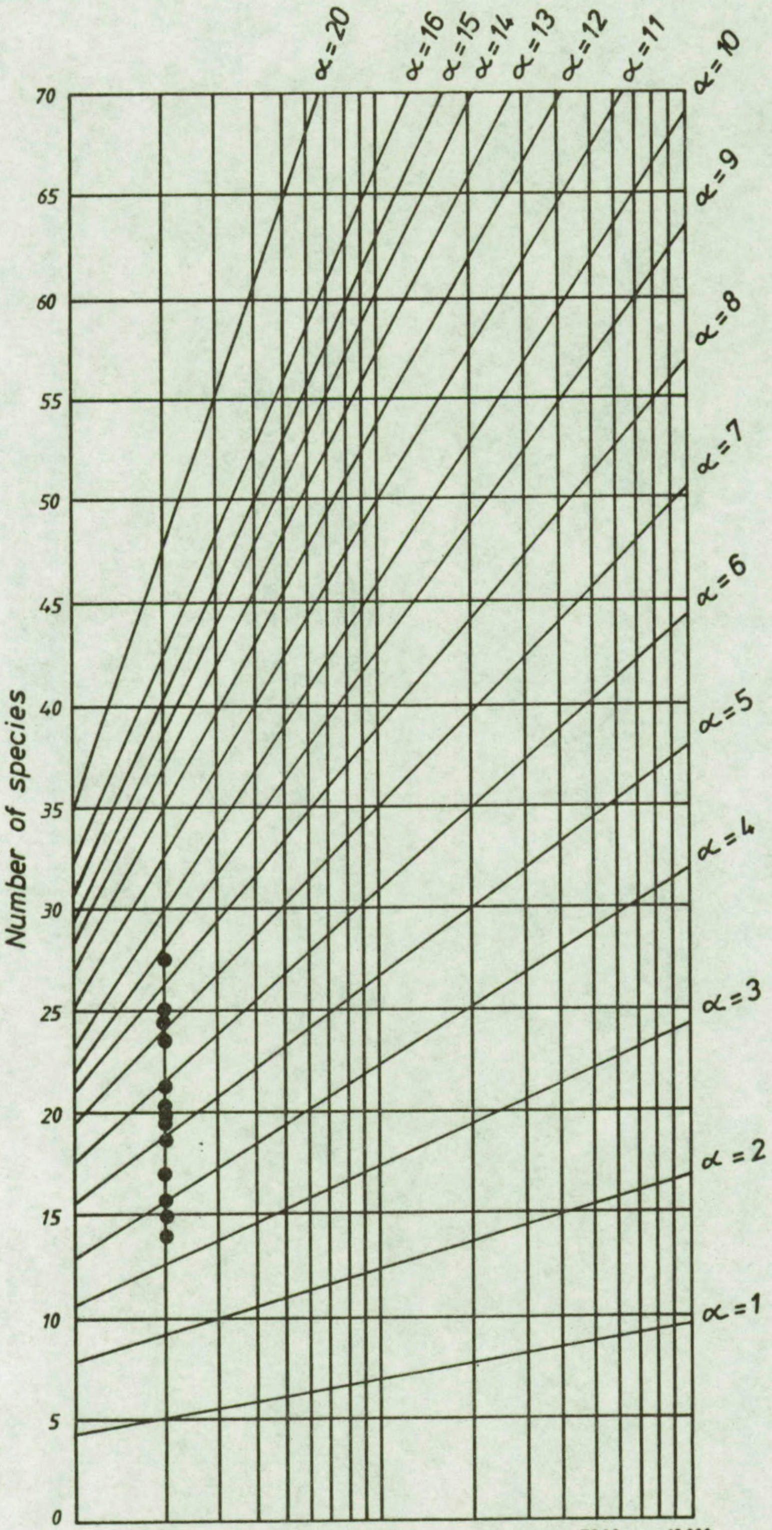

Fig. 7: Fisher α index in the Brussels Sands.

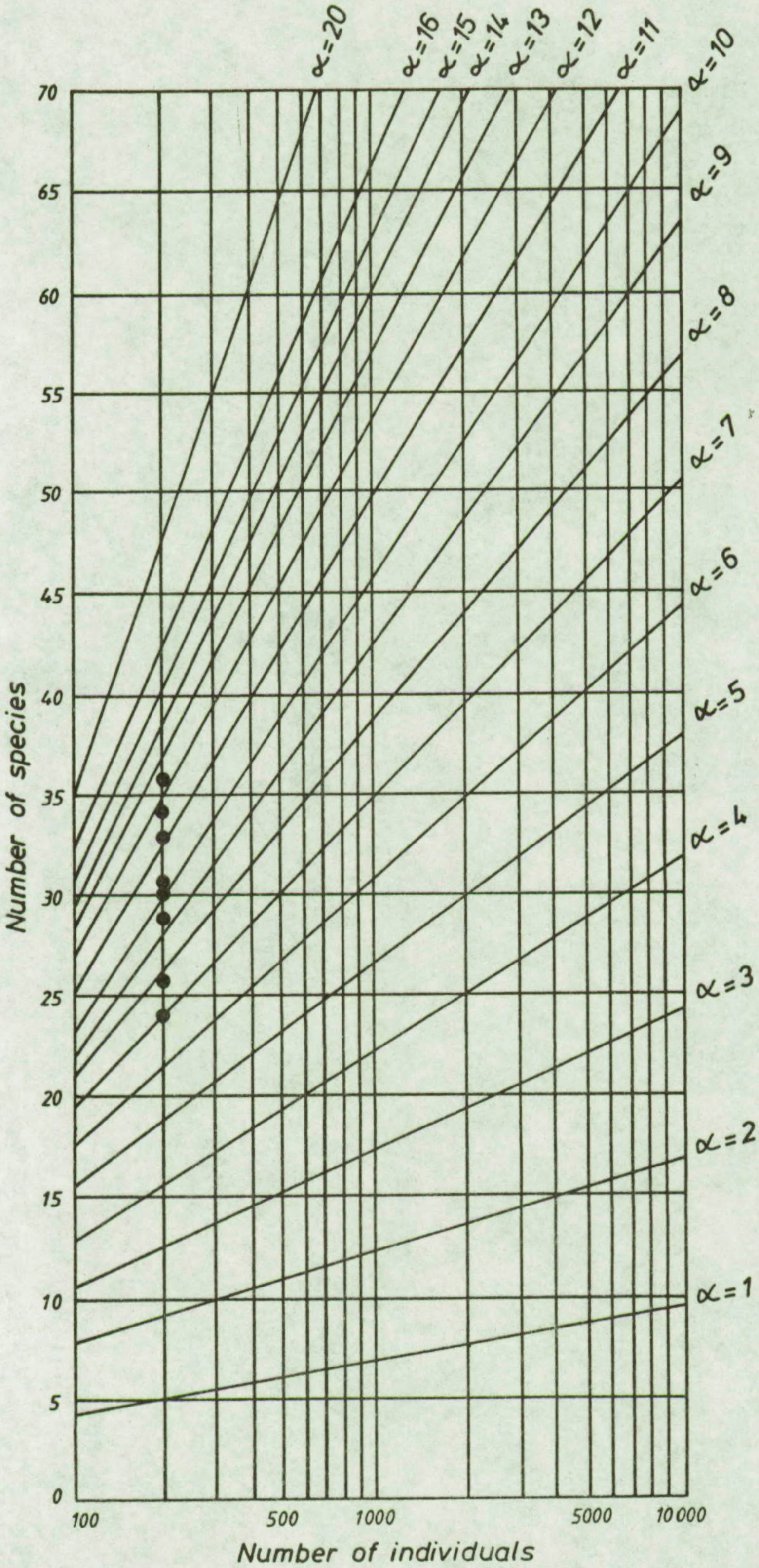

Fig. 8: Fisher α index in the Lede Sands.

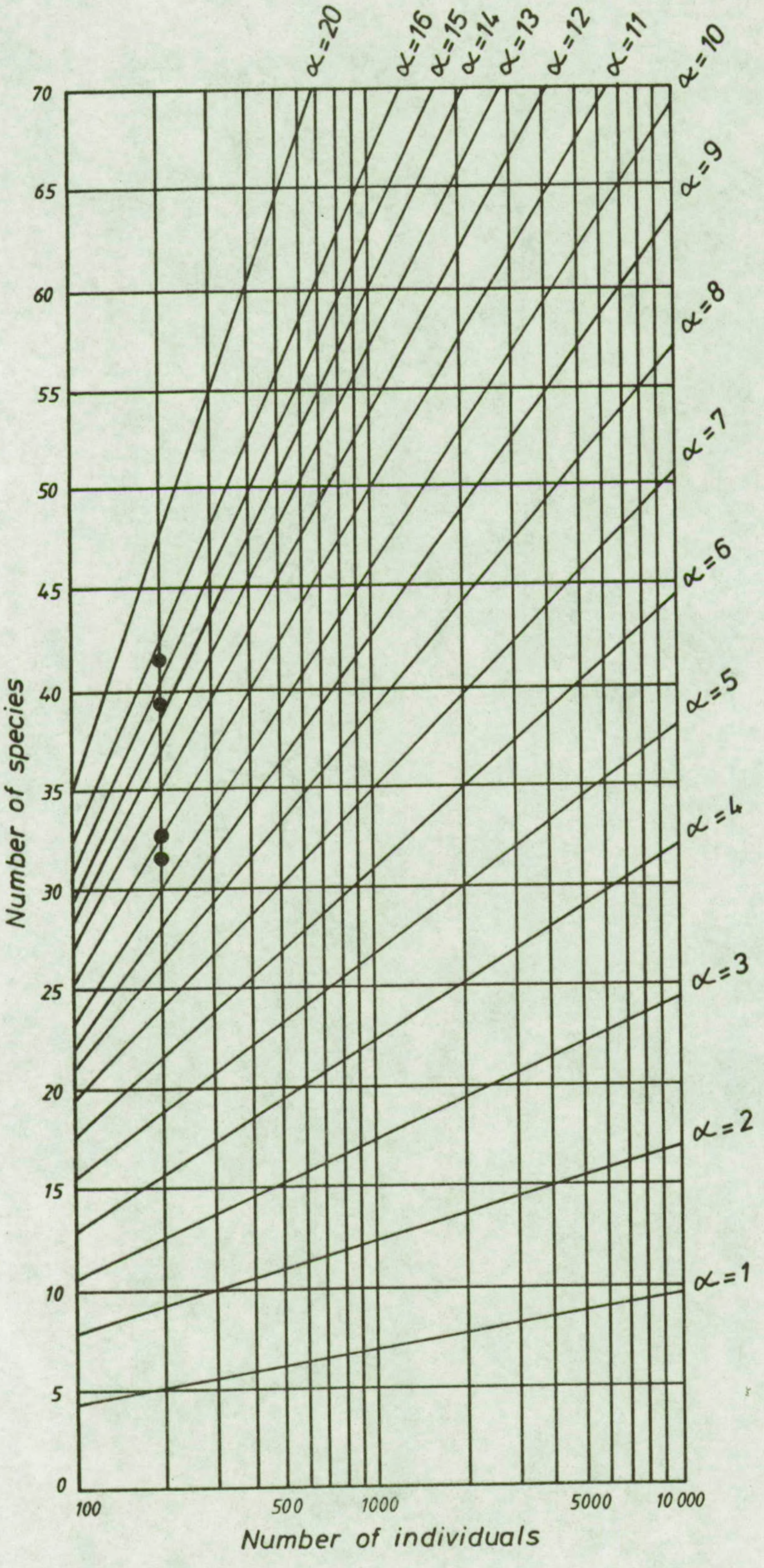

Fig. 9 : Fisher α index in the Wemmel Sands.

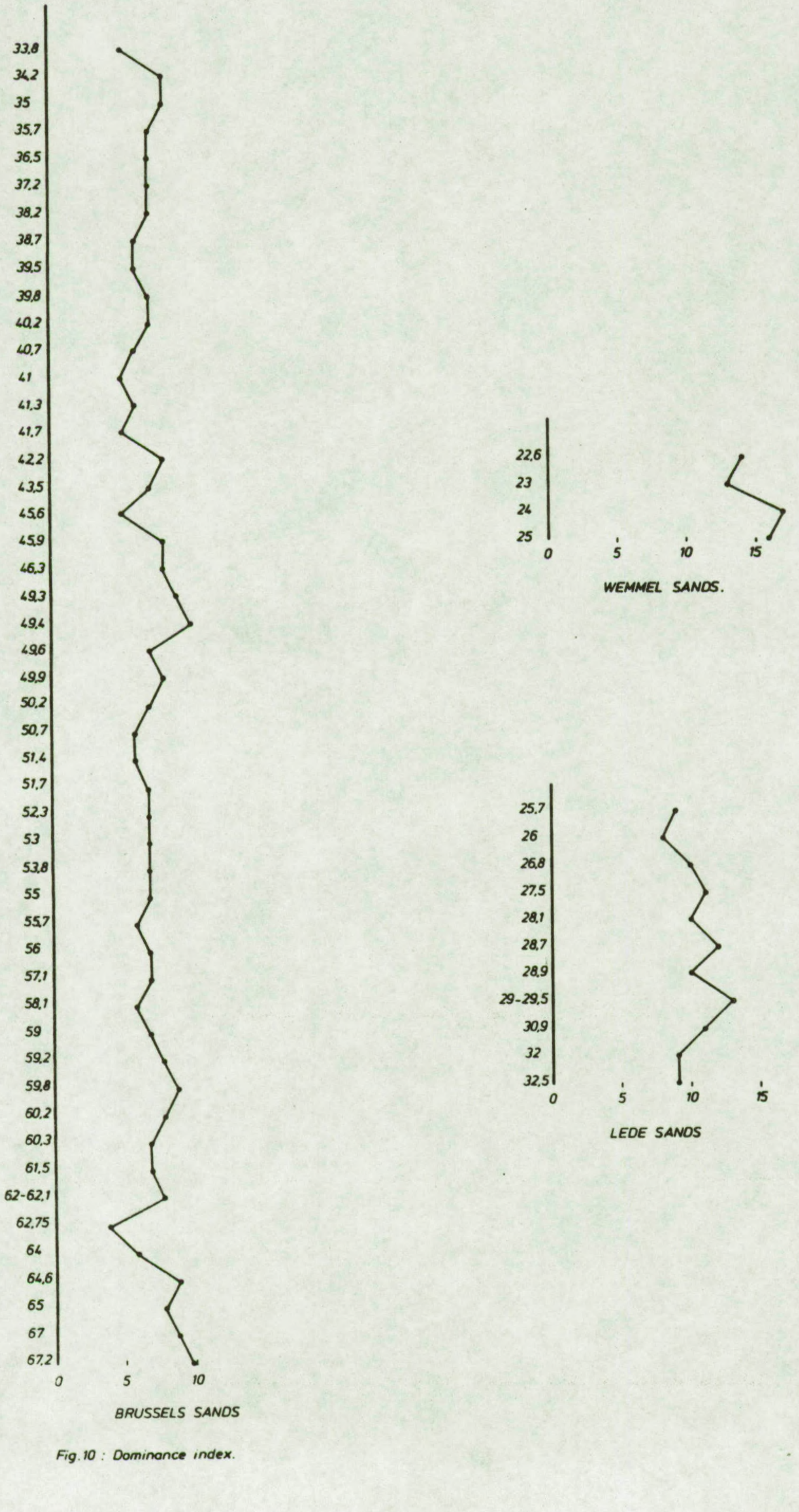

Fig. 10 : Dominance index.

Fig.7 shows the αvalues in the Brussels Sands. The α index varies between 3.5 and 9. The possible environments are a hyposaline and nearshore shelf sea or lagoon and a shelf sea of normal salinity. The αvalues in the Lede Sands are given in fig.8. The αindex lies between 6 and 12.5, distinctly higher than in the Brussels Sands. These values fall in the field of the shelf seas of normal salinity. The salinity was probably higher than in the Brussels Sands.
The αvalues in the Wemmel Sands (fig.9) are still higher : between 10.8 and 16. They correspond to a shelf sea of normal salinity. The higher values could indicate a greather depth than in the other two deposits (BANDY & ARNAL, 1960).

8. DOMINANCE INDEX.

This index gives the number of species in 80% of the total population. The percentages are summed starting whit the most abundant species. When a total of 80% is reached, the number of species needed is noted (WRIGHT, 1972). High values, corresponding to many species whit low percentages, indicate a stable environment. A low index corresponds to an unstable or marginal environment.
Fig.10 shows the dominance index in the Brussels Sands, in the Lede Sands and in the Wemmel Sands.
In the Brussels Sands, the values lie between 4 and 10. The index increases in the Lede Sands (8 to 13) and reaches maximum values in the Wemmel Sands (13 to 17). We conclude that the environment becomes gradually more and more stable in the successive deposits.

9. PERCENTAGE DOMINANCE.

The percentage dominance corresponds to the percentage of the most abundant species in a sample. WALTON (1964) notes that this percent percentage dominance depends of the sea. It increases with decreasing depth.

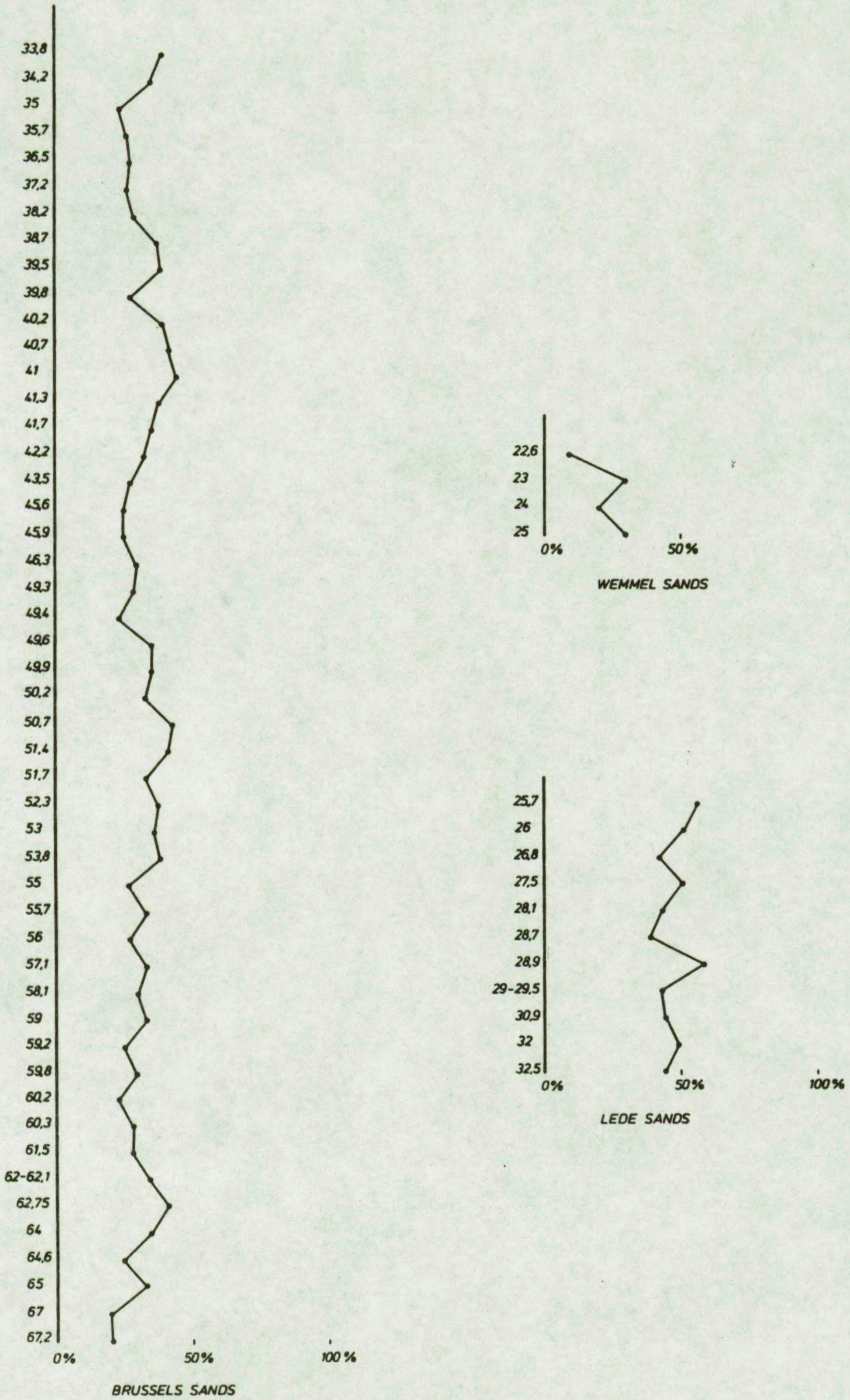

Fig. 11 : Percentage dominance.

The percentages dominance in the different deposits are given in fig. 11. In the Brussels Sands, the values vary between 21% and 44%. In the Lede Sands the percentages are higher : 39% to 59%, but in the Wemmel Sands they decrease distinctly : 9% to 30%.
The fairly high values in the Brussels Sands indicate a rather shallow marine environment. The sea depth probably decreases slightly in the Lede Sands, while the Wemmel Sands were deposited in a more open marine environment whith a greater sea depth.

10. PALEOECOLOGICAL INTERPRETATION OF THE TAXA.

Studies on Recent foraminiferal associations prove the influence of the environment on the composition of the benthonic populations. We can accept that, especially at the generic level, the influence of the different facies did not change significantly during the Tertiary. Information on the (paleo-)ecological significance of the occurring taxa is found in e.g. : PHLEGER (1960), BANDY (1960, 1964), WALTON (1964), WRIGHT & MURRAY (1972), MURRAY (1973), WRIGHT (1972-1973), MURRAY & WRIGHT (1974), BOLTOVSKOY & WRIGHT (1976) and GERITS, HOOYBERGHS & VOETS (1981).

1) Brussels Sands.

The population in the Brussels Sands are dominated by *Cibicides*. This is a common inner shelf genus living in a wide variety of temperature and salinity conditions. It is attached to all types of substrates : vegetation, stones, shells, living animals. *Cibicides* occurs from arctic to tropical areas, but is currently most abundant in temperate seas. Especially *C. lobatulus* occurs most frequently in the transition zone between a protected bay and the open ocean. The absence of *Miliolina* indicates a normal salinity or hyposaline conditions
The presence of planktonic foraminifera (HOOYBERGHS, 1983) indicates the proximity of open marine conditions.
Another important genus is *Elphidium*. It occurs most abundantly in very shallow environments : tidal marshes and lagoons or nearshore,

but in oxygen-rich water. A few other hyalin calcareous taxa occur regularly but less frequently in this deposit. *Guttulina* and *Gyroidina* are typical genera in shelf environments. *Hanzawaia* and *Rotalia* occur most frequently in rather shallow, nearshore to inner shelf conditions.

2) Lede Sands.

Cibicides is still a dominant genus in the Lede Sands. The presence of *Miliolids* indicates higher salinities : normal marine to hypersaline. The *Miliolids*, particularly *Quinqueloculina* and *Triloculina* become abundant in shallow shelf seas and in channels and bays. They rarely occur in hyposaline conditions. The temperature also becomes higher in the Lede Sands. *Miliolids* especially occur in temperate to tropical waters. The frequency of broken *Miliolids* indicates a rather turbulent environment.

Rotalia and *Guttulina* still occur regularly in the Lede Sands. A few new genera appear significantly in this deposit. Small smooth species of *Bolivina (B. anglica, B. carinata, B. crenulata)* prefer a inner shelf zone with normal salinities (33% → 37%).

Buliminella mainly occurs on the shelf in normal marine, temperate conditions. *Nonionella* preferably appears in temperate to subtropical waters in normal marine conditions.

Eponides and *Reussella* occur in an inner shelf to bathyal environment. *Asterigerina*, which appears especially in the upper part of the Lede Sands, normally dominates in an inner shelf zone under conditions of stable salinity.

3) Wemmel Sands.

Different taxa from the Lede Sands still occur in the Wemmel Sands : *Bolivina, Elphidium, Guttulina, Rotalia, Reussella, Miliolacea, Quinqueloculina* (lower part), *Buliminella* and *Nonionella*. The frequency of *Asterigerina* increases in an environment with more stable salinity.

Cibicides occurs less frequently, being replaced by the other hyalin calcareous benthonic foraminifera. A few species appear for the first time at a significant frequency. *Trifarina* and *Textularia* occur in normal marine environments on the shelf and in the upper bathyal zone. *Nonion* is a common genus on the shelf of normal marine seas. The presence of striate *Bolivina*'s *(B. cookei)* indicates an increasing sea depth (central and outer shelf) in subtropical to tropical areas.

11. CONCLUSIONS.

The Brussels Sands were deposited in a sea with moderate temperature and salinities on an inner to central shelf (50- 100m). The seawater was rich in O_2. An important vegetation probably favoured the development of *Cibicides*. The presence of planktonic foraminifera indicate an opening to the ocean. The regression of the Brussels sea was followed by a new transgression. The salinity of the sea increased slightly during deposition of the Lede Sands to normal marine or hypersaline conditions. At the same time the temperature increased to tropical-subtropical values. The sedimentation took place on an inner shelf environment, where the water was more turbulent than in the Brussels sea.
The depth of the sea increased quickly in a new trangression of the Wemmel sea to a central to outer shelf environment (100-150m), which is indicated by the occurrence of striate *Bolivina*'s. The salinity and the temperature remained fairly high.

12. ACKNOWLEDGEMENTS.

The author owes gratitude to the "Nationale Maatschappij der Waterleidingen" and to Dr. P. Laga of the Belgian Geological Survey for permission to study the samples from the borehole at Haacht.

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Quantitative distribution and paleoecology
of benthonic foraminifera in the Eocene
Brussels Sands Formation at Diegem (Belgium)

H.J.F. HOOYBERGHS

CONTENTS.

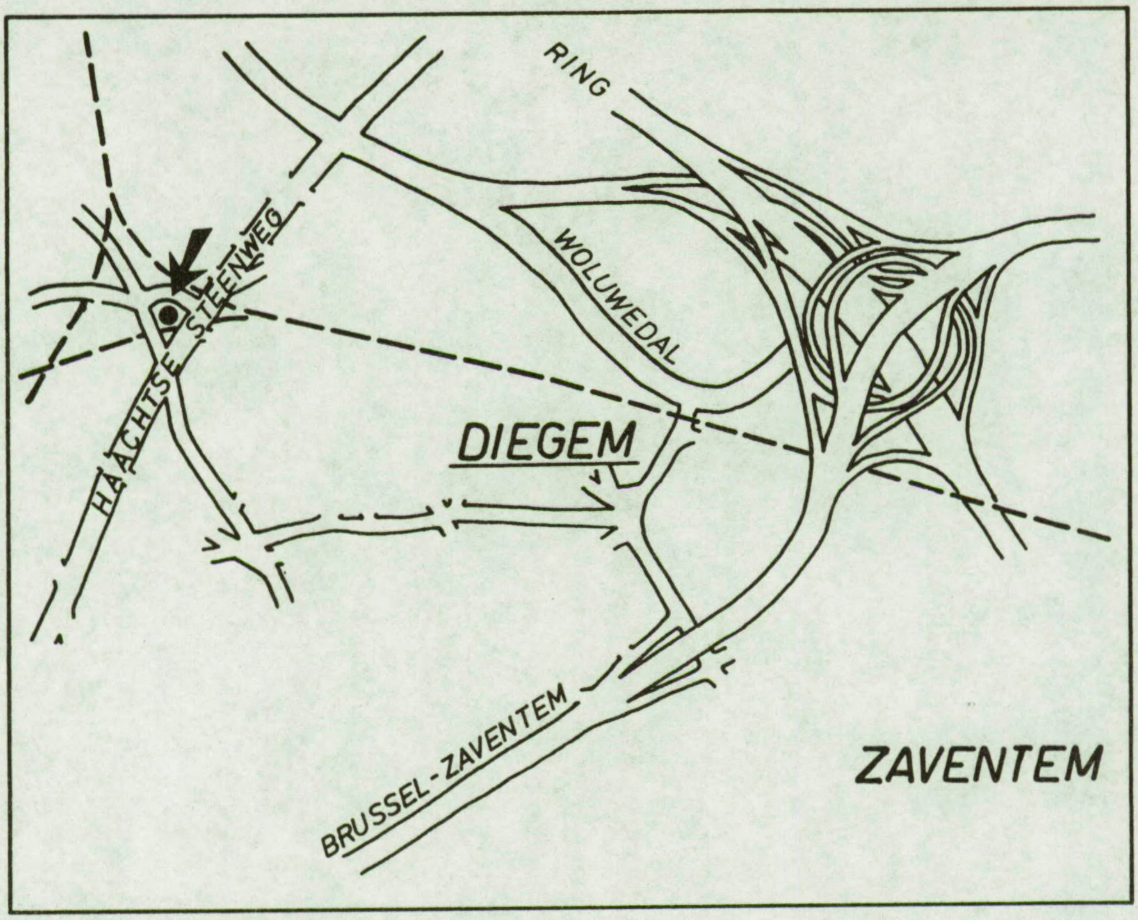

Fig. 1 : Location map.

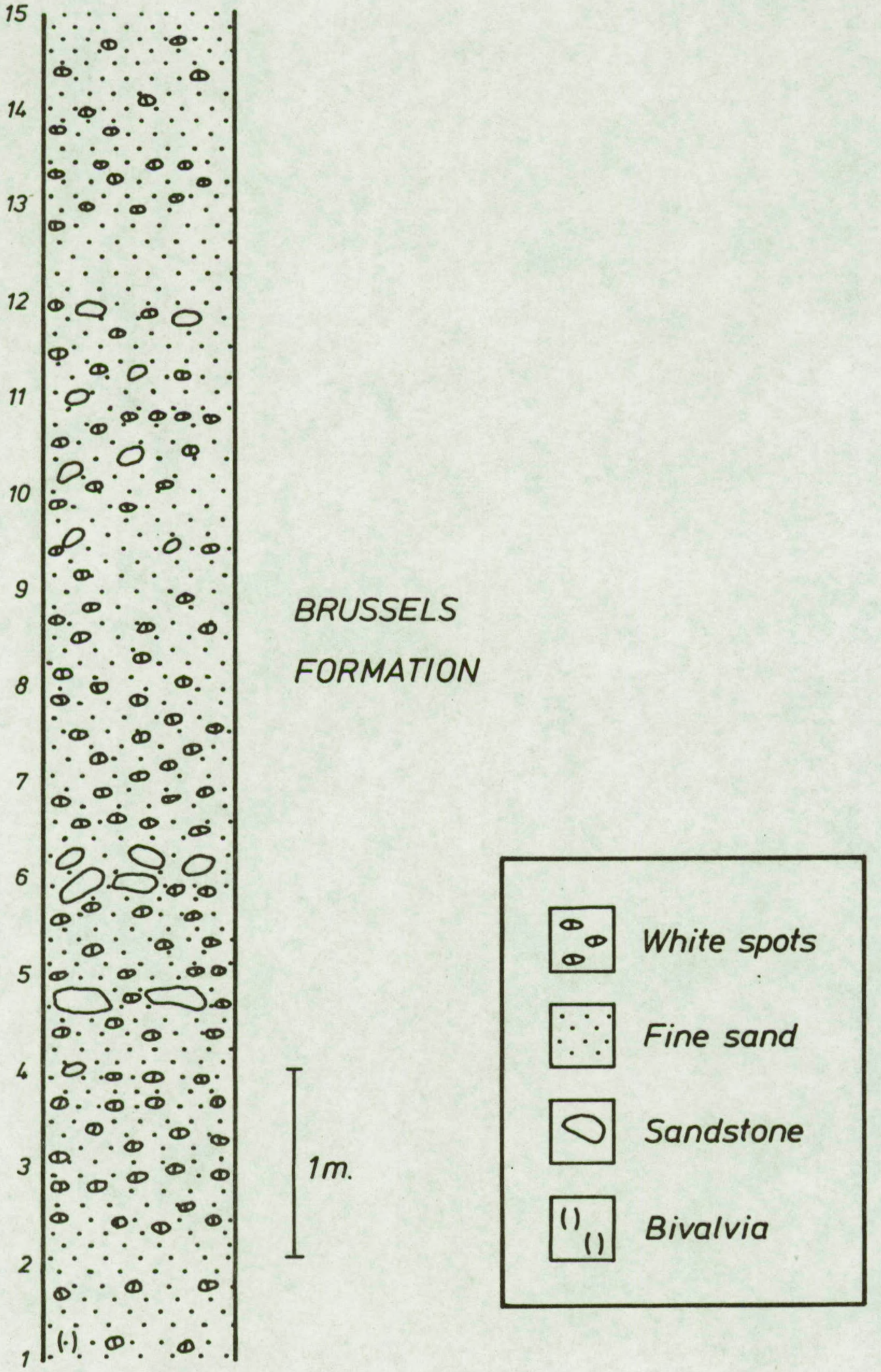

Fig. 2: Development of the Brussels Sands Formation at Diegem.

BRUSSELS FORMATION — SAMPLES / TAXA	Guttulina lactea	Pyrulina thouini	Trifarina wilcoxensis	Elphidium subnodosum	Eponides schreibersi	Cibicides proprius proprius	Cibicides westi	Gyroidina octocamerata	Hanzawaia boueanum	Cibicides lobatullus	Cibicides proprius acutimargo	Guttulina pulchella	Lagena hexagona	Guttulina irregularis	Bolivina anglica	Nonion affine	Cancris auricullus primitivus
15	2			8		28	17	4	34		4			3			
14	4	1		9		26	13	3	41		3						
13	6	1		11		23	12	3	41		3						
12	8			9	1	12	17	4	40		8	1					
11	3	1		7		13	12	2	59		2						
10	5			9		17	7	1	51		7			2			1
9	2			4		24	22	2	47		4		2				
8	3			12		7	11	4	57		6						
7	2	1	1	9	1	9	7	5	55	2	6	1		1			
6	5			3	1	14	16	4	53	1	3						
5	2		3	8	1	10	13	3	55		5						
4	4			9	1	9	15	2	51		4	1	1	2	1	1	
3	2		1	9		12	9		58		8	1					
2	3			6	1	14	13	4	57	1	1						
1	3	1	2	11	1	16	10	1	55								

Table 1 : Distribution of benthonic foraminifera in the Brussels Sands Formation at Diegem .

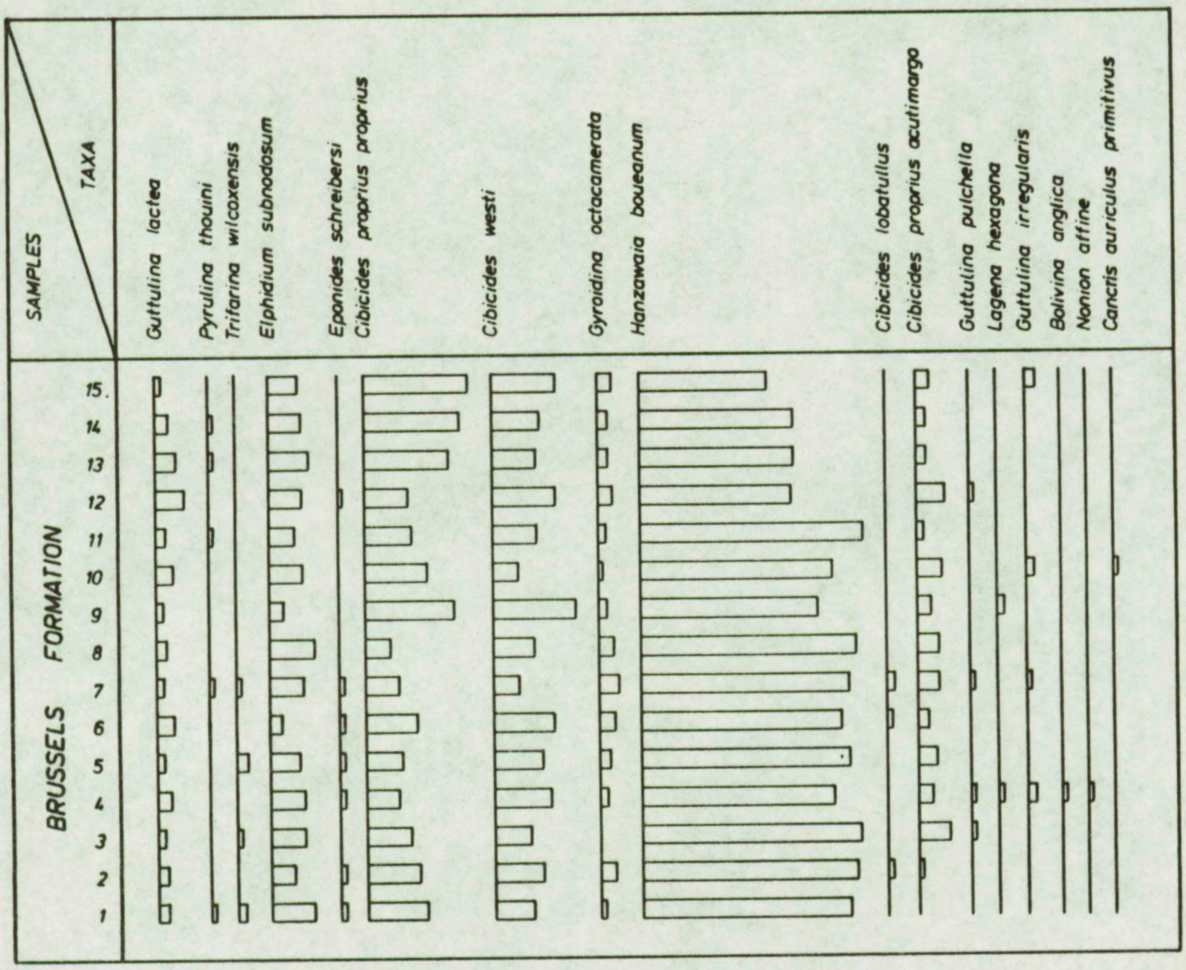

Table 2 : Relative abundance of benthonic foraminifera in the Brussels Sands Formation at Diegem

1. ABSTRACT.

The benthonic foraminiferal populations in the Eocene Brussels Sands Formation have been studied in a temporary outcrop at Diegem. Countings to 100 individuals per sample have been made. By successive use of quantitative distribution, triangular plots of suborders, similarities, Fisher α index, dominance index, percentage dominance and paleoecological significance of the occurring taxa, it has been possible to interpret the faunal assemblage paleoecologically.

2. INTRODUCTION.

During excavations along the railway Brussels - Leuven at Diegem (fig.1, location map), the Brussels Sands Formation was temporarily exposed. The samples have been treated with H_2O_2 and sieved on a 0.074mm sieve. In each residue, countings to 100 individuals of benthonic foraminifera have been made. For a full systematic description of the occurring taxa, we refer to KAASSCHIETER (1961).

3. LITHOLOGICAL DESCRIPTION OF THE BRUSSELS SANDS FORMATION AT DIEGEM.

Fig.2 shows the developement of the Brussels Sands in the locality studied. In the lower part of the section, these sands are yellowish with many small white spots. *Bivalvia* have been observed at the base of the interval. Sandstone concretions occur at discontinuous beds at levels 7 and 8. Higher up, the Brussels Sands become more green due to a higher glauconite percentage. Spots of white sand still occur in the higher part of the section. Between levels 9 and 12 different scattered sandstone concretions have been observed.

4. QUANTITATIVE DISTRIBUTION OF BENTHONIC FORAMINIFERA.

Tables 1 and 2 show the relative frequenties of the occurring taxa. The populations in this interval are rather homogeneous.

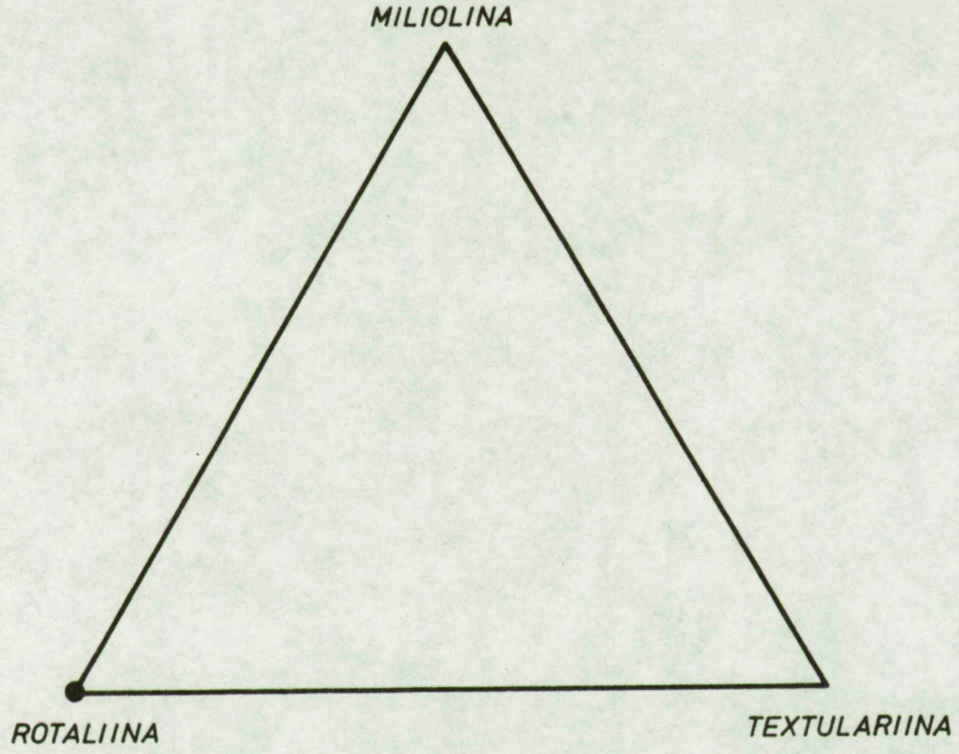

Fig. 3 : Triangular plot of suborders in the Brussel Sands at Diegem .

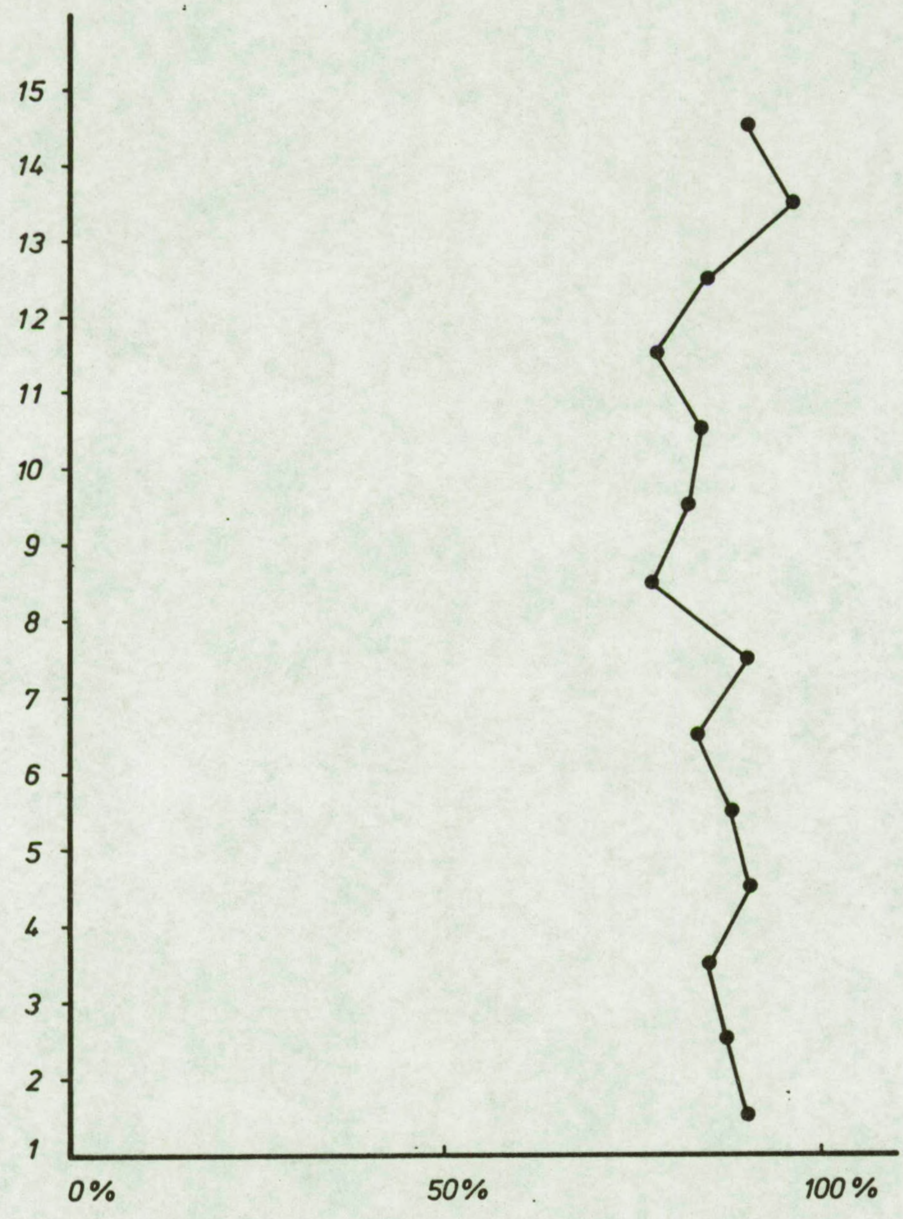

Fig. 4 : Similarities.

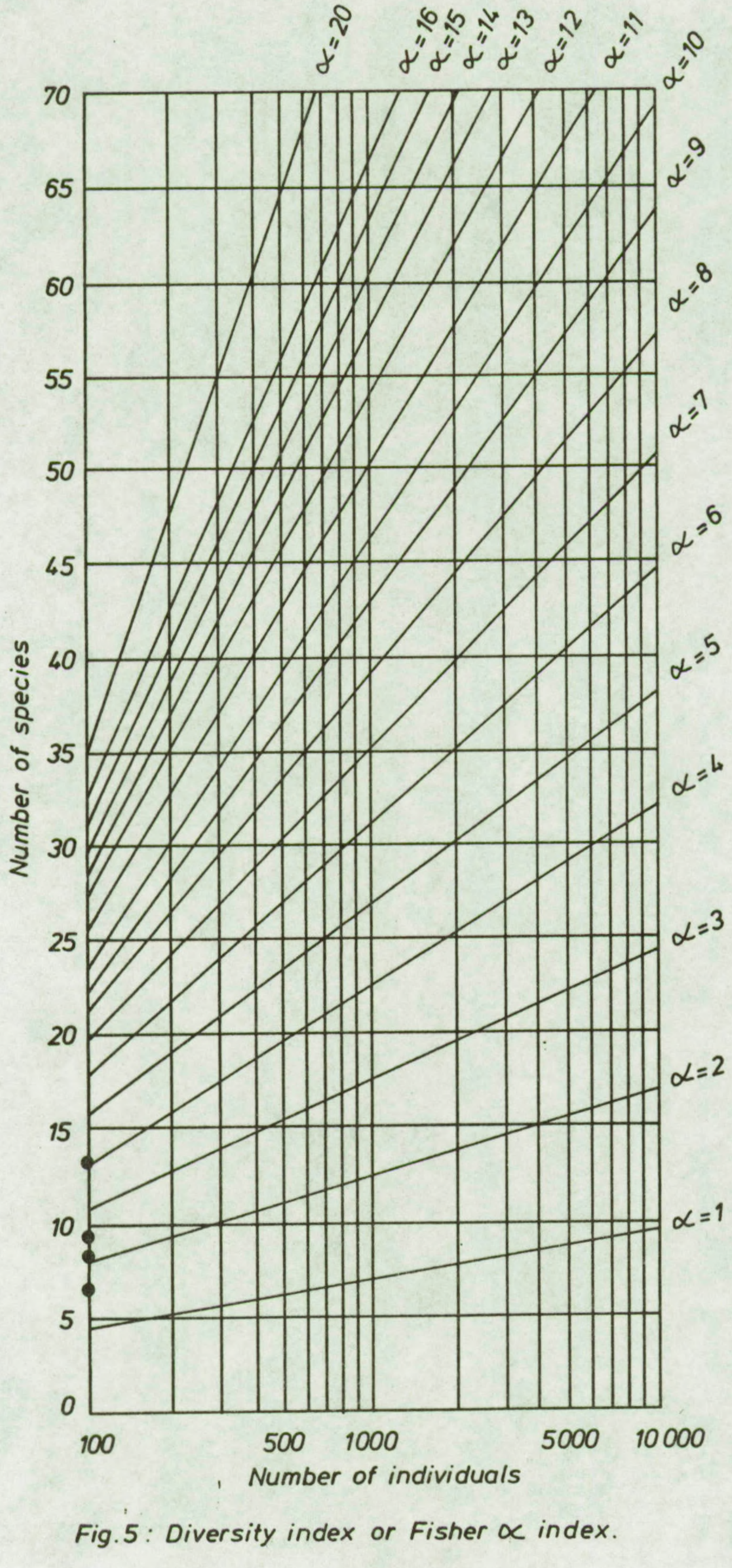

Fig.5 : Diversity index or Fisher α index.

Hanzawaia (34-59%) is the dominating genus. However, its frequency decreases slightly in the upper part of the section.
The *Cibicides* species are also important. The frequency of *C. westi* varies from 7 to 22% and *C. proprius acutimargo* reaches 0-8% in the assemblages. *C. proprius proprius (7-28%)* becomes more frequent especially at the top of the interval.
A few other hyalin calcareous benthonic foraminifera are fairly constant components of the associations : *Guttulina lactea* (2-8%) and *Elphidium subnodosum*.

5. TRIANGULAR PLOT OF SUBORDERS.

Since no *Miliolina* or *Textulariina* occur in the section studied, the triangular plot of suborders lies on the *Rotalia* corner (fig.3). According to the interpretation of the different ecological fields by MURRAY (1973), the following environments are possible : hypersaline marshes and lagoons, hyposaline lagoons, normal marshes and shelf sea of normal salinity.

6. SIMILARITIES. (SANDERS, 1960).

Fig. 4 represents the similarity index between successive samples. This index varies between 77 and 96%. These high values underline the homogeneity of the different populations.

7. DIVERSITY INDEX OR FISHER α INDEX. (FISHER, CORBETT & WILLIAMS, 1943).

In fig. 5, the number of species is plotted against the number of individuals. The diversity index or Fisher α index varies between 1.5 and 4.
According to the interpretation of the different environments corresponding to the various α values by WRIGHT & MURRAY (1972) and MURRAY (1973),

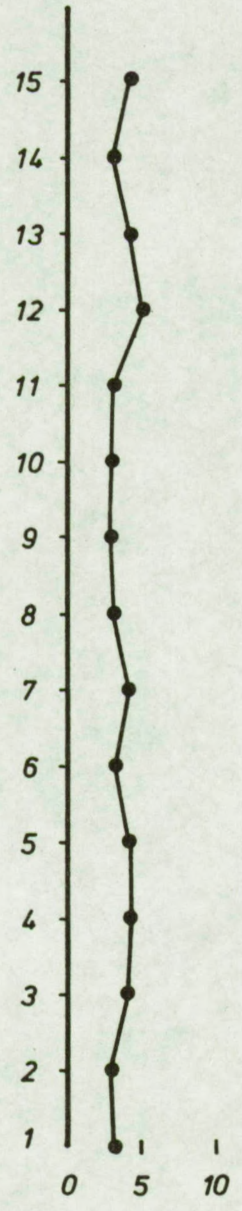

Fig. 6 : Dominance index.

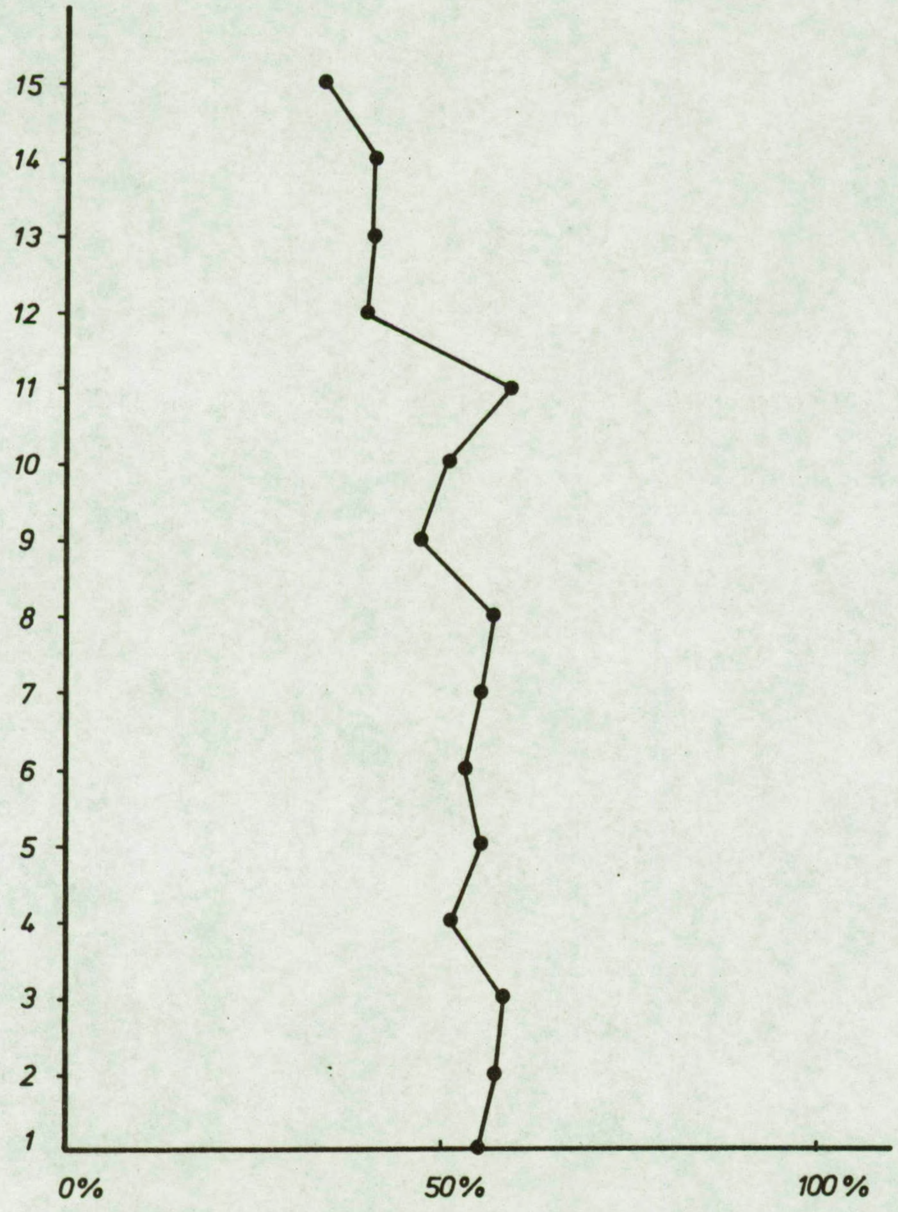

Fig. 7: Percentage dominance.

the following environments are possible : hyposaline and nearshore shelf seas, hypersaline lagoons and marshes, hyposaline lagoon and marshes and normal marine marsh.

8. DOMINANCE INDEX. (WRIGHT, 1972).

Fig. 6 represents the number of species in 80% of the populations. The dominance index is fairly constant and varies from 3 to 5. These low values indicate a rather shallow sea or marginal environment in which the sedimentation took place.

9. PERCENTAGE DOMINANCE. (WALTON, 1964).

The percentagesof the most abundant species in the different samples are given in fig. 7. In the lower part of the section, these percentages are fairly constant. They vary between 51 and 58. These high values indicate a rather shallow environment.
From sample 9 to sample 15, the percentages become more variable. They vary from 34 in sample 15 to 59 in sample 11. The generally lower values in the uppermost part of the section probably suggests a slight deepening of the sea.

10. PALEOECOLOGICAL SIGNIFIANCE OF THE OCCURRING TAXA.

Information on the (paleo-) ecological significance of the occurring taxa is found in e.g. PHLEGER (1960), BANDY (1960, 1964), WALTON (1964), WRIGHT & MURRAY (1972), MURRAY (1973), WRIGHT (1972-1973), MURRAY & WRIGHT (1974), BOLTOVSKOY & WRIGHT (1976) and GERITS, HOOYBERGHS & VOETS (1981).
Hanzawaia, the most abundant genus prefers a shelf environment.
Cibicides is currently most abundant on shelves of temporate seas, where it is attached on all types of substrates such as vegetation.
Elphidium occurs most frequently on a shallow inner shelf in oxygen-rich waters with a lot of algae.

Guttulina is a typical inner shelf genus and *Gyroidina* is found especially on a normal marine shelf.
The absence of *Miliolina* suggests a low salinity. *Quinqueloculina* and *Triloculina* do not suffer salinities below 30%.

11. CONCLUSIONS.

In this locality, the Brussels Sands were deposited on a shallow inner shelf. Later, the sea depth probably increased slightly. The water was oxygen-rich and the revival of algae was favoured. The salinity of the temperate waters was rather low (below 30%).

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Quantitative distribution and paleoecology of benthonic foraminifera in the Eocene Lede Formation at Balegem (Belgium)

H.J.F. HOOYBERGHS

CONTENTS.

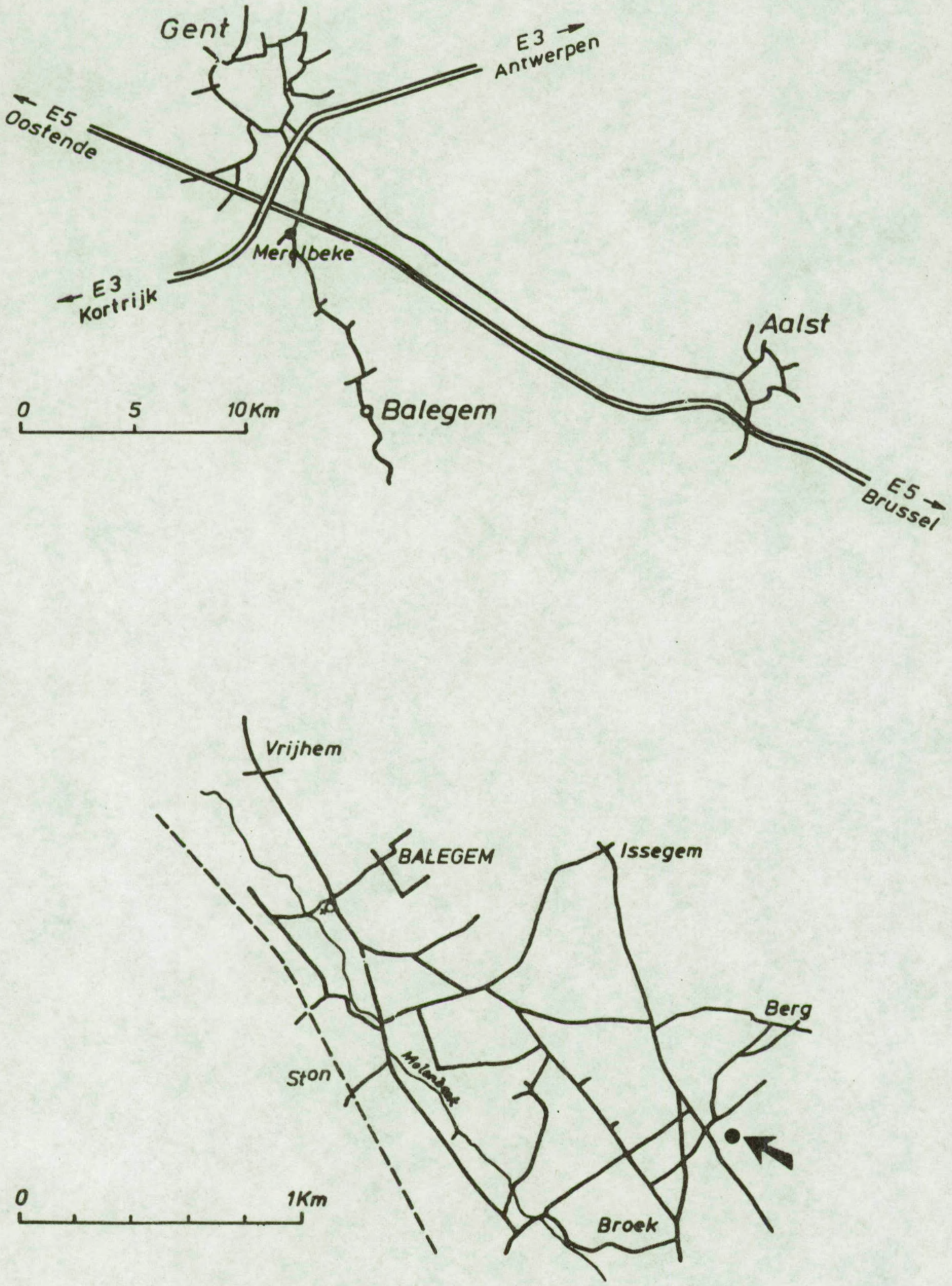


Fig. 1 : Location map.

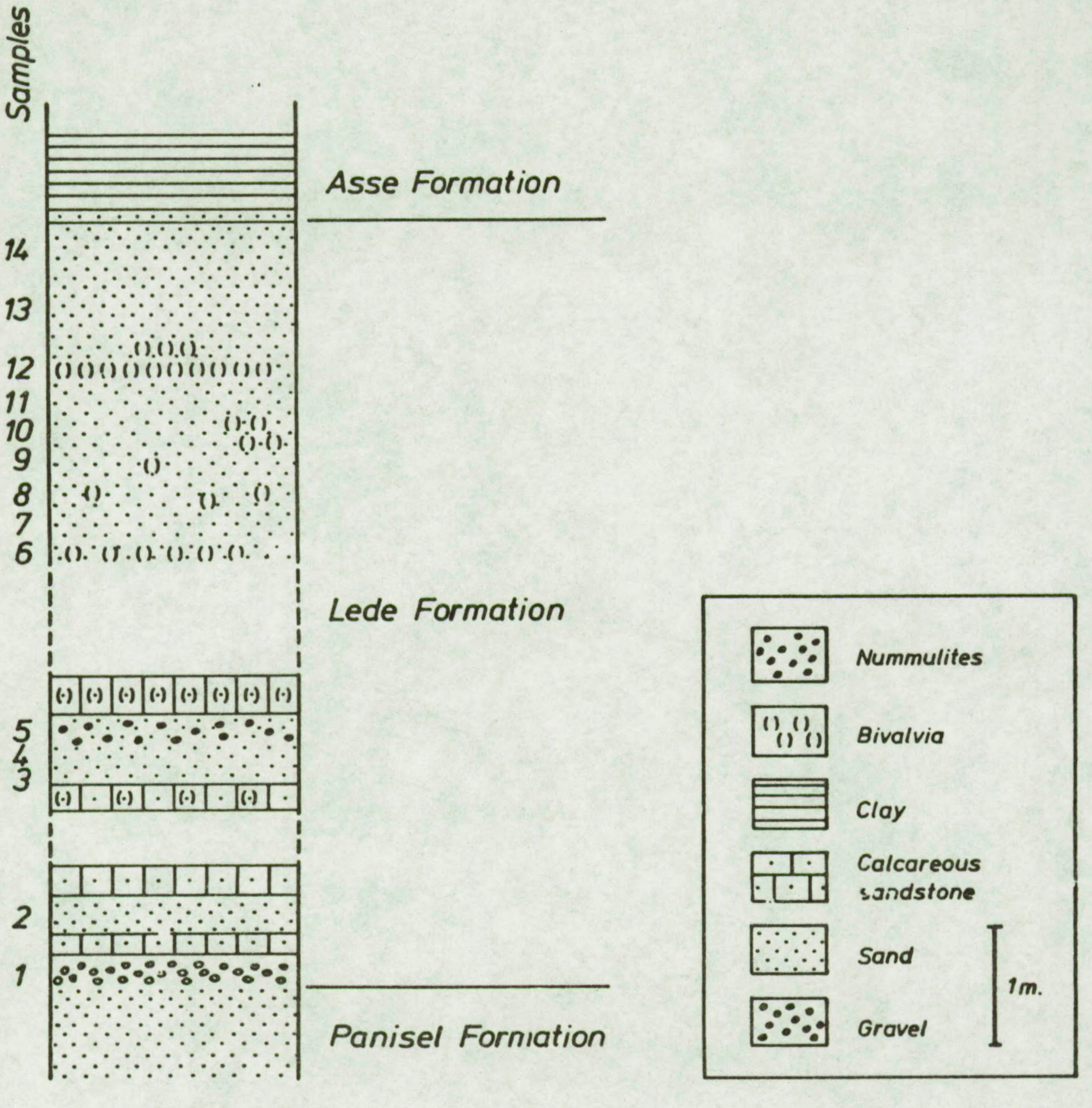


Fig. 2 : Outcrop of the Lede Formation at Balegem.

1. ABSTRACT.

The benthonic foraminifera in the Eocene Lede Sands Formation have been studied in a quarry at Balegem. Quantitative countings of up to 100 individuals per sample are made. Successive use of quantitative distributions, triangular plots of suborders, similarities, Fisher α index, dominance index, percentage dominance and paleoecological significance of the occurring taxa, allowed us to interpret the faunal association paleoecologically.

2. INTRODUCTION.

The Lede Sands Formation is exposed in a quarry at Balegem (fig. 1, location map). The outcrop was sampled in 1982. The samples were washed on a 0.074 mm sieve after treatment with H_2O_2. In each dried residue, countings to 100 individuals of benthonic foraminifera have been made. For a full systematic description of the occurring benthonic taxa, we refer to KASSCHIETER (1961).

3. LITHOLOGICAL DESCRIPTION OF THE LEDE SANDS FORMATION AT BALEGEM.

In the Balegem quarry, the Lede sands cover the glauconitic sands of the Panisel Formation (fig.2). At the base of the Lede Sands, a thin gravel layer occurs which yields many reworked fish teeth. The lower part of the Lede Sands is white in colour and four calcareous sandstone beds are observed, two of which are rich in Bivalvia. Level 5 contains many *Nummulites*.

The middle part of the section was not exposed when it was sampled. Higher up (levels 6-12) Bivalvia occur scattered in the Lede Sands or more concentrated in levels 6 and 12. In the uppermost part, the Lede Sands become yellow in colour (levels 13 and 14), but here they are completely decalcified. The Lede Sands are covered by the Cassel Clay Member of the Asse Formation.

Table 1.

LEDE FORMATION

TAXA \ SAMPLES	1	2	3	4	5	6	7	8	9	10	11	12
Textularia agglutinans	3	7	13	4	7	2		2	1	1	1	
Dentalina inornata	1			1					1			
Globulina gibba	1		8		1			2	1		2	1
Globulina gravida	6	3	3	1	1						1	
Guttulina irregularis	2	4	4	1	1	2	2				1	1
Guttulina lactea	7	4	2	3	4	4	3	5	5	7	8	1
Guttulina problema	2		2		1							
Oolina orbignyana	1				1				1			
Buliminella sp. cf. *B. pulchra*	2		1	1	2							
Bolivina crenulata	1	3	2	4	2		1		5	1		1
Asterigerina sp.	1					1		1	7			1
Rotalia audouini	39	27	26	34	24	6	6	10	25	12	13	8
Elphidium laeve	6	3	2	7	6			2	4	7	3	6
Bifarina selseyensis	3	1		1	1				1	1		1
Cibicides tenellus	17	17	16	21	26	3	3	20	15	31	31	28
Nonionella wemmelensis	5	1	1	3					5	5	5	5
Lamarckina cristellaroides	2	6		2	2	3	6	8	3	6	3	4
Quinqueloculina ludwigi		2				19	14	5	1		3	4
Lenticulina sp.		2		2				1	2		1	

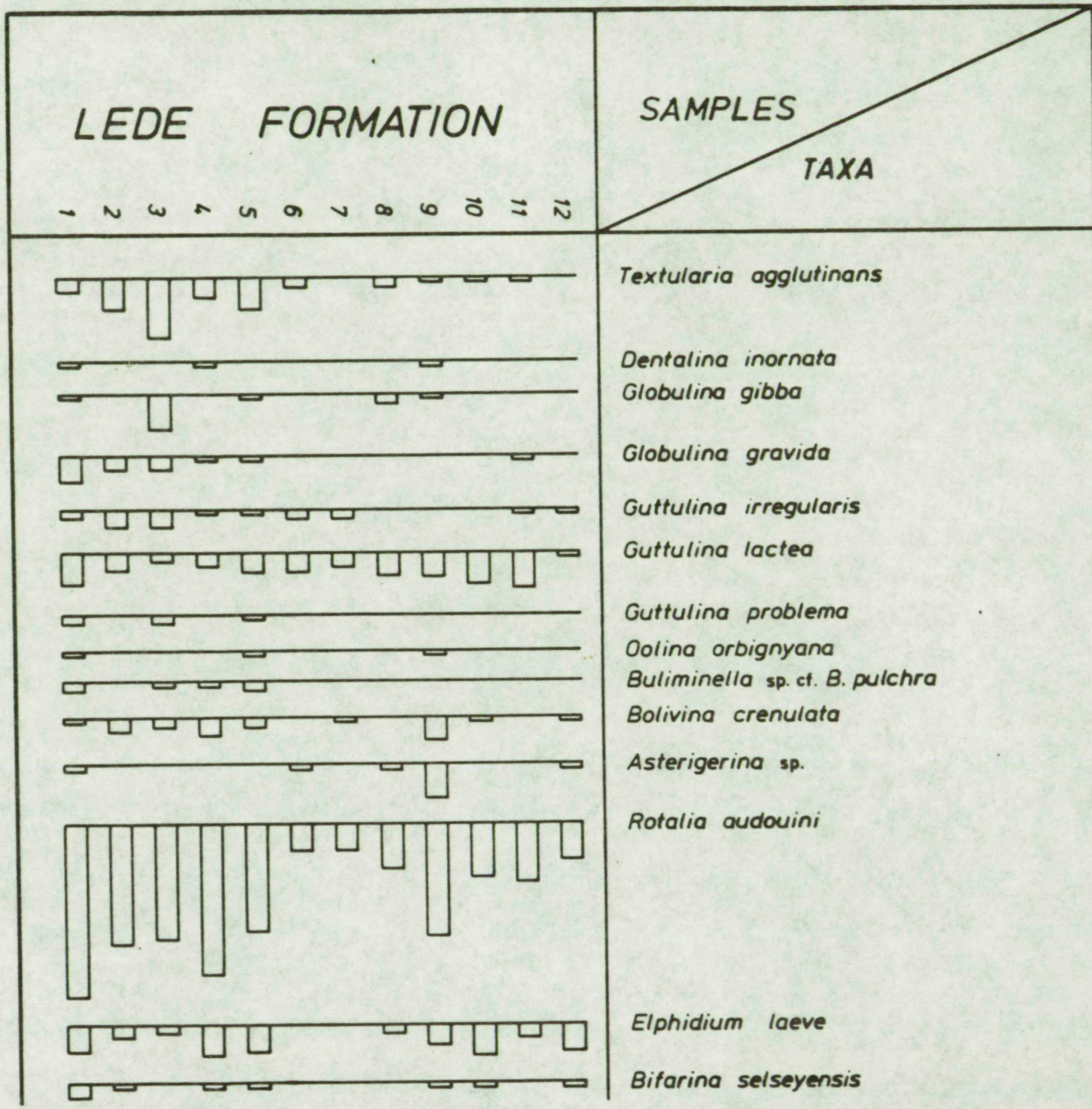
Table 1.

SAMPLES / TAXA	LEDE FORMATION 1	2	3	4	5	6	7	8	9	10	11	12
Bolivina anglica		1			1					2	2	
Cancris subconicus		3	1	3	2				3			
Cibicides lobatulus		10	6	2	5	2	10	3	5	5	5	4
Cibicides proprius proprius		3	6	1	3	1			3	5	3	4
Cibicides proprius var. *acutimargo*		2	3	4	3		1					
Spiroloculina costigera var. *nuda*			2				1	2	2	1		2
Pyrulina thouini			1	1	3							
Glandulina laevigata			1			1					1	
Triferina muralis			1	1	1							
Lagena striata				2	1							
Reussella limbata				1	1							
Miliolacea					1	10	11	9	2	4	5	11
Quinqueloculina bicarinata						1	1					
Quinqueloculina carinata						9	5	10		1	1	4
Quinqueloculina juleana						3		1				
Quinqueloculina seminula						13	6	7	1	1	4	9
Triloculina angularis						10	17	6	3	1	1	
Triloculina trigonula						7	8	2				
Bulimina parisiensis						1		1			1	2

Table 1.

LEDE FORMATION												SAMPLES / TAXA
1	2	3	4	5	6	7	8	9	10	11	12	
					1		1			1	2	*Bulimina parisiensis*
					2			1				*Cibicides carinatus*
						1						*Articulina terquemi*
						2	1	1	8	5	1	*Nonion scaphum*
							1	1				*Spiroloculina canaliculata*
								1				*Reussella terquemi*
									1			*Nonion graniferum*
											1	*Hanzawaia boueanum*

Table 2.



LEDE FORMATION
SAMPLES
TAXA
1 2 3 4 5 6 7 8 9 10 11 12
Textularia agglutinans
Dentalina inornata
Globulina gibba
Globulina gravida
Guttulina irregularis
Guttulina lactea
Guttulina problema
Oolina orbignyana
Buliminella sp. cf. B. pulchra
Bolivina crenulata
Asterigerina sp.
Rotalia audouini
Elphidium laeve
Bifarina selseyensis

Table 2.

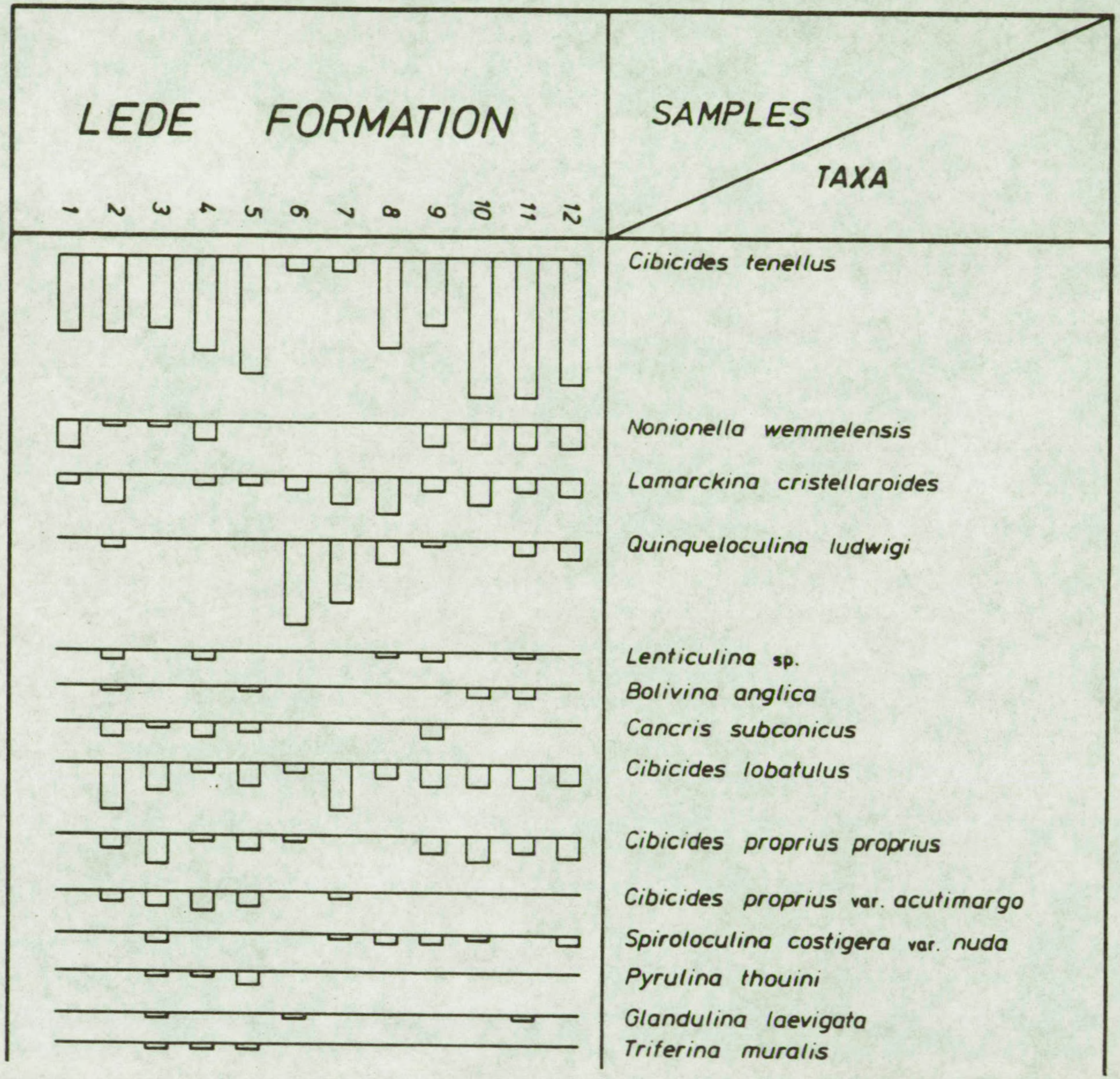
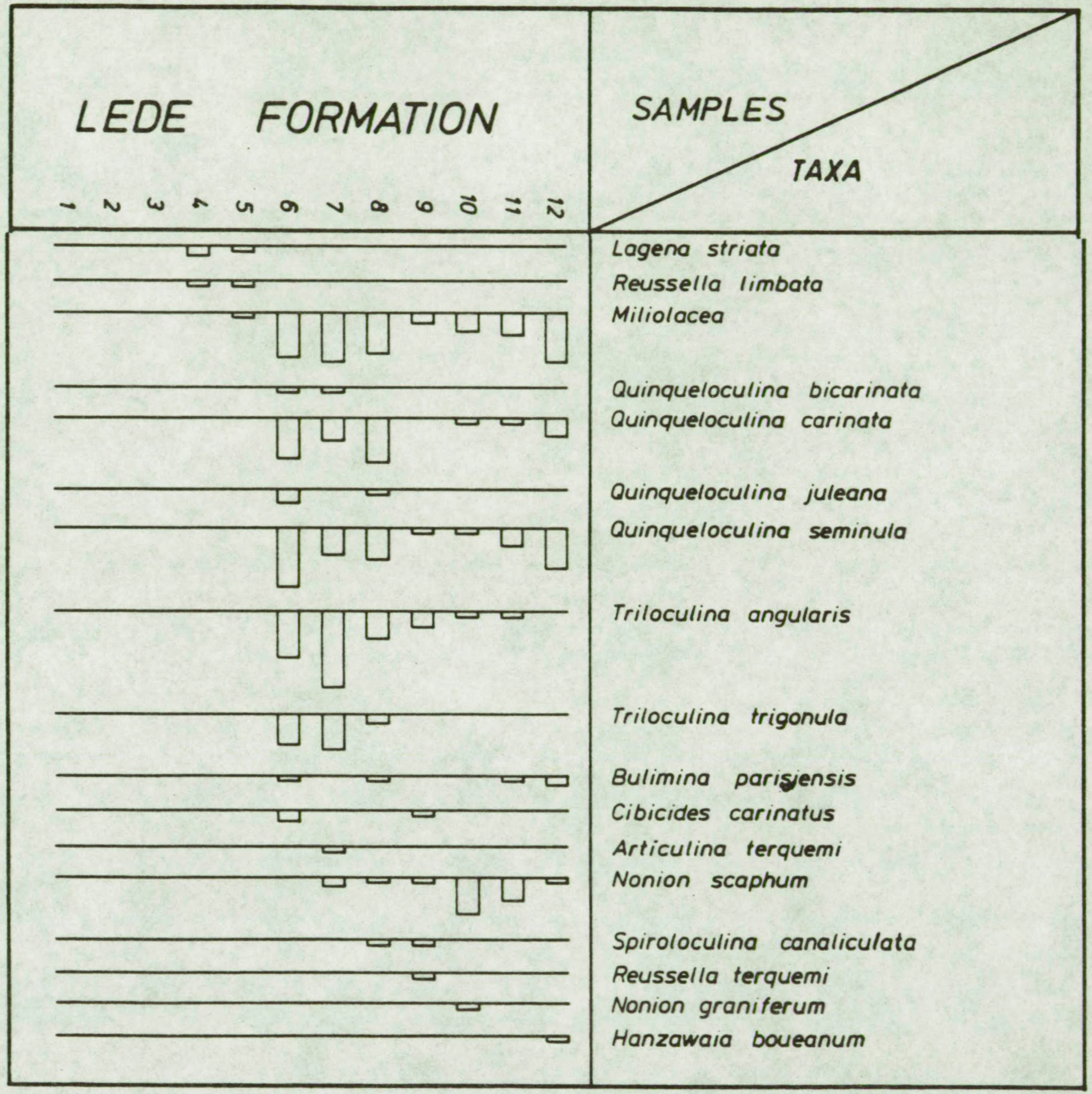

LEDE FORMATION
SAMPLES
TAXA
1 2 3 4 5 6 7 8 9 10 11 12
Cibicides tenellus
Nonionella wemmelensis
Lamarckina cristellaroides
Quinqueloculina ludwigi
Lenticulina sp.
Bolivina anglica
Cancris subconicus
Cibicides lobatulus
Cibicides proprius proprius
Cibicides proprius var. acutimargo
Spiroloculina costigera var. nuda
Pyrulina thouini
Glandulina laevigata
Triferina muralis

Table 2.


LEDE FORMATION
SAMPLES
TAXA
1 2 3 4 5 6 7 8 9 10 11 12
Lagena striata
Reussella limbata
Miliolacea
Quinqueloculina bicarinata
Quinqueloculina carinata
Quinqueloculina juleana
Quinqueloculina seminula
Triloculina angularis
Triloculina trigonula
Bulimina parisiensis
Cibicides carinatus
Articulina terquemi
Nonion scaphum
Spiroloculina canaliculata
Reussella terquemi
Nonion graniferum
Hanzawaia boueanum

4. QUANTITATIVE DISTRIBUTION OF THE BENTHONIC FORAMINIFERA.

Tables 1 and 2 show the relative abundance of the benthonic foraminifera in the Lede Sands at Balegem. It is possible to distinguish three different faunules in this section. We shall discuss here the relative frequencies of the different taxa in the three faunules.

Faunule 1 (levels 1-5).

Rotalia audouini is the most abundant species in this faunule : 24 to 39%. *Cibicides tenellus* also reaches relative high frequencies : 16-26%. The agglutinated *Textularia agglutinans* is a significant component of the assòciations : 3-13%. Different hyalin calcareous taxa occur in this interval in smaller quantities : *Globulina gravida* (1-6%), *Guttulina irregularis* (1-4%), *Guttulina lactea* (2-7%), *Bolivina crenulata* (1-4%), and *Elphidium laeve* (2-7%). Some other hyalin calcareous species appear in part of the interval : *Nonionella wemmelensis* (0-5%), *Lamarckina cristellaroides* (0-6%), *Cancris subconicus* (0-3%), *Cibicides lobatulus* (0-10%), *Cibicides proprius proprius* (0-6%), *Cibicides proprius acutimargo* (0-4%) and *Buliminella* cf. *B. pulchra* (0-2%).

Faunule 2 (levels 6-7).

The frequencies of *Rotalia audouini* (6%) and *Cibicides tenellus* (3%) diminish distinctly in these samples. The sudden appearance of different *Miliolids : Quinqueloculina ludwigi* (14-19%), *Spiroloculina costigera* var. *nuda* (0-1%), broken *Miliolacea* (10-11%), *Quinqueloculina bicarinata* (1%), *Quinqueloculina carinata* (5-9%), *Quinqueloculina juleana* (0-3%), *Quinqueloculina seminula* (6-13%), *Triloculina angularis* (10-17%) and *Triloculina trigonula* (7-8%) is noteworthy.
Cibicides lobatulus (2-10%) and *Lamarckina cristellaroides* (3-6%) still occur significantly. Several hyalin calcareous taxa disappear completely or occur in small quantities : *Guttulina irregularis* (2%), *Guttulina lactea* (3-4%), *Cibicides proprius proprius* (0-1%),and *Cibicides proprius*

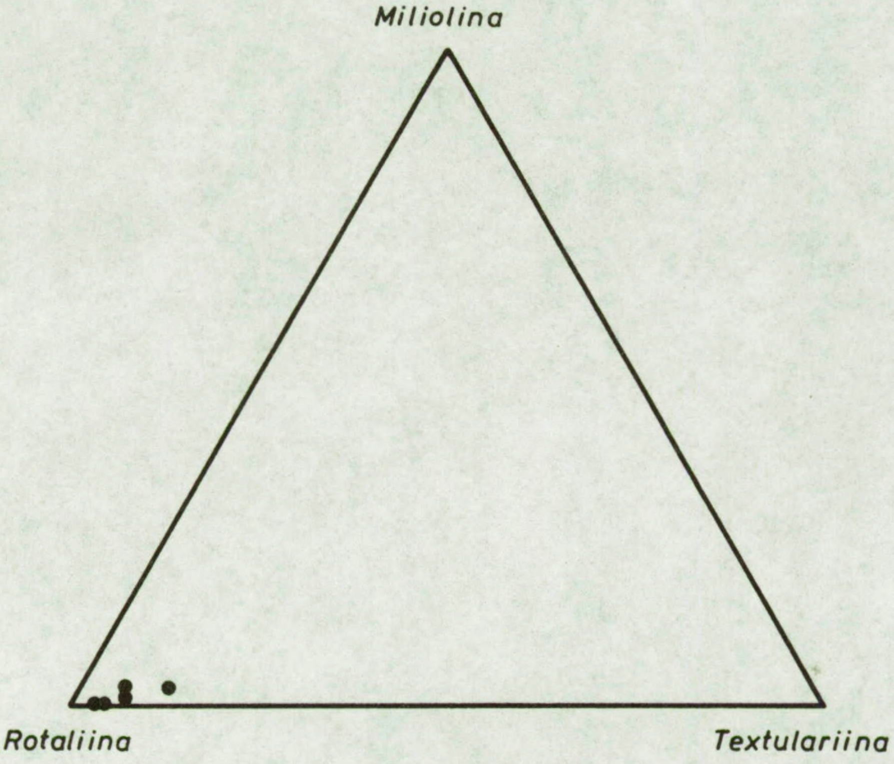


Fig. 3 : Triangular plot of suborders in faunule 1.

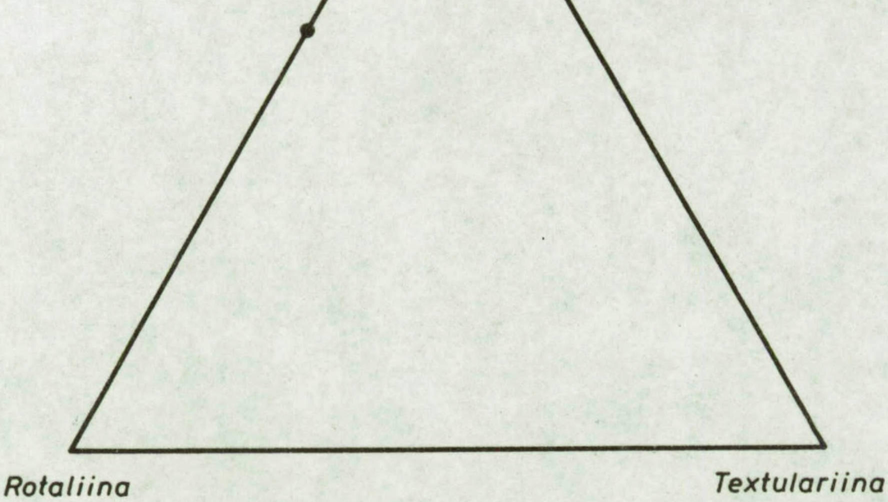


Fig. 4 : Triangular plot of suborders in faunule 2.

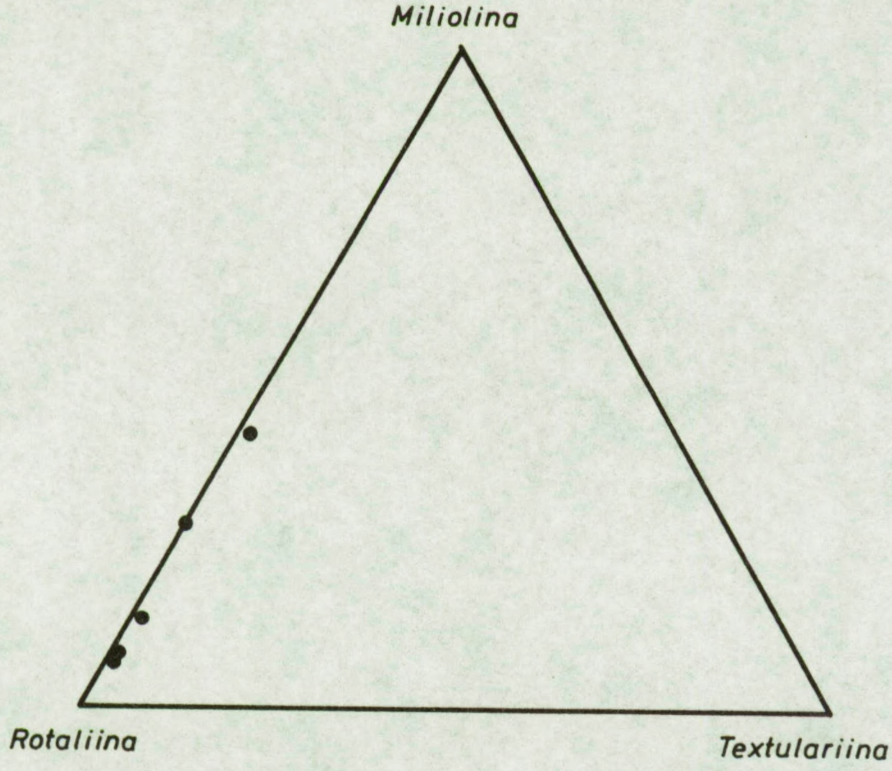


Fig. 5 : Triangular plot of suborders in faunule 3.

acutimargo (0-1%). *Nonion scaphum* first appears (0-2%). The agglutinated *Textularia agglutinans* occurs but sporadic (0-2%).

Faunule 3.

Faunule 3 is characterized by new high frequencies of *Rotalia audouini* (8-25%) and *Cibicides tenellus* (15-31%) and by the presence of different *Miliolids*, mostly less abundant than in faunule 2 : *Quinqueloculina ludwigi* (0-5%), *Spiroloculina costigera* var. *nuda* (0-2%), broken *Miliolacea* (2-11%), *Quinqueloculina carinata* (0-4%), *Quinqueloculina seminula* (1-9%), *Triloculina angularis* (0-6%) and *Triloculina trigonula* (0-2%). The agglutinated *Textularia agglutinans* occurs in restricted quantities (0-2%). *Elphidium laeve* is again distinctly present in faunule 3 (4-7%). Also *Guttulina lactea* (2-8%) and *Lamarckina cristellaroides* (3-8%) commonly occur (2-8%). Some other hyalin calcareous foraminifera are represented in small quantities : *Globulina gibba* (0-2%), *Bolivina crenulata* (0-5%), *Nonionella wemmelensis* (0-5%), *Cibicides lobatulus* (3-5%) and *Cibicides proprius proprius* (0-5%). The more significant appearance of *Asterigerina* sp. in part of the interval (0-7%) and of *Nonion scaphum* (1-8%) is of note.

5. TRIANGULAR PLOT OF SUBORDERS.

The three suborders of benthonic foraminifera, *Textulariina*, *Miliolina* and *Rotaliina*, can be plotted on a triangular diagram. MURRAY (1973) marks out the fields for the different possible environment in this diagram.

The triangular plots of suborders in the three faunules are show in figs. 3,4 and 5.

In faunule 1, the values lie in the vicinity of the *Rotalia* corner, on or near the *Rotaliina* - *Textulariina* line. The possible environments for these plots are : hypersaline marshes or lagoons, normal marine marshes, shelf seas and hyposaline lagoons.

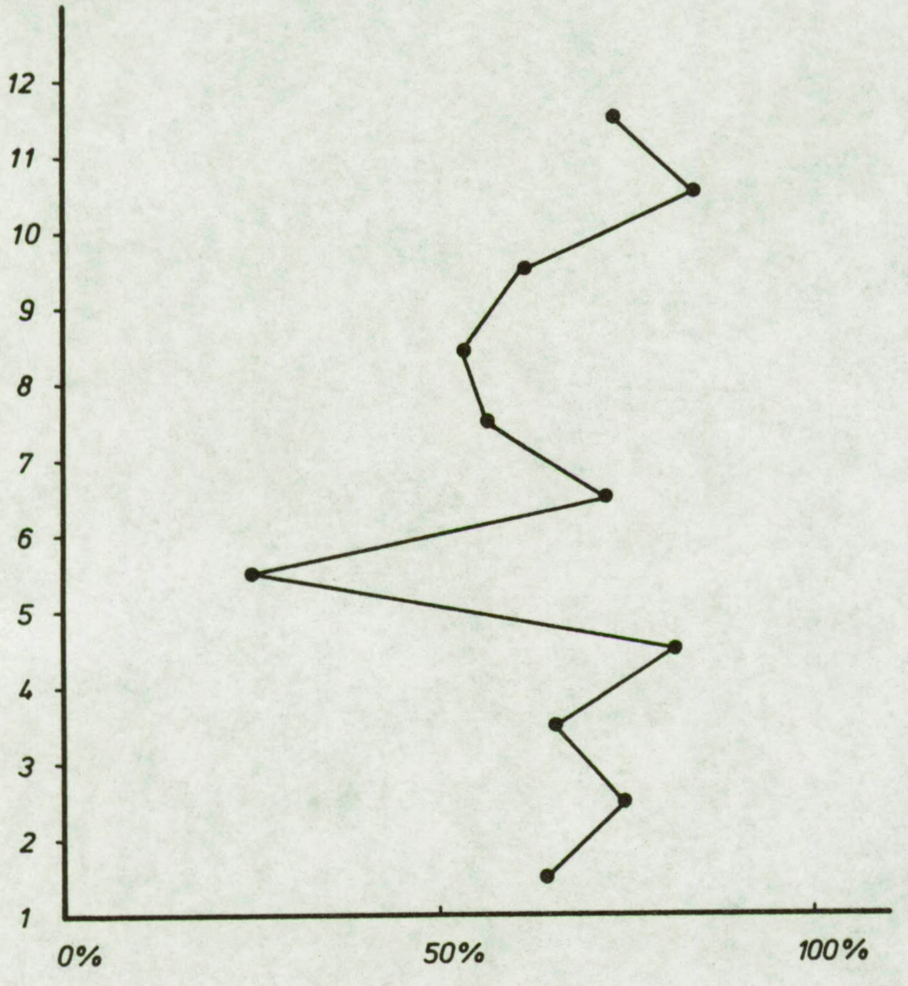


Fig. 6 : Similarity between the successive samples.

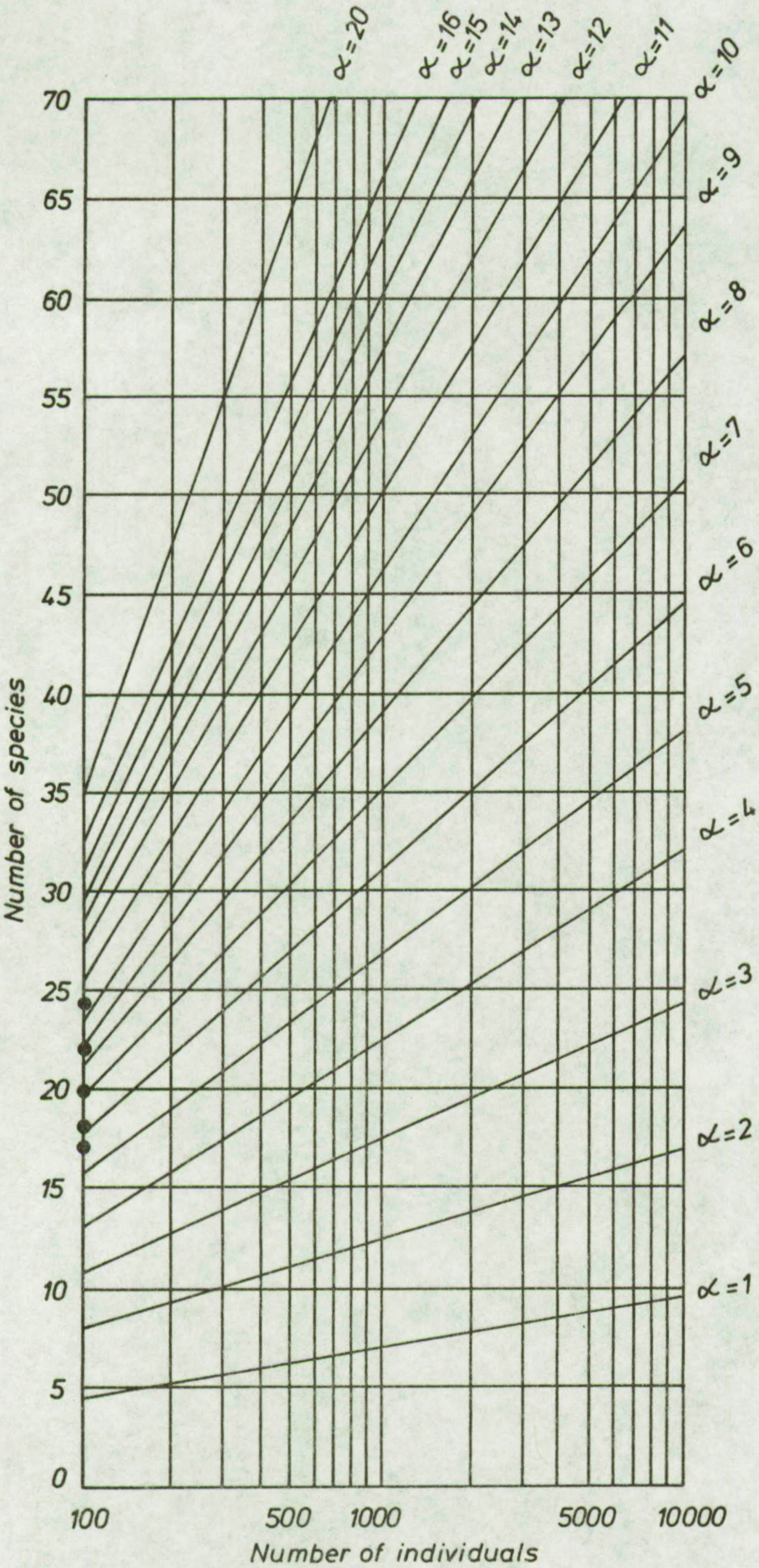


Fig. 7: Fisher α index in faunule 1.

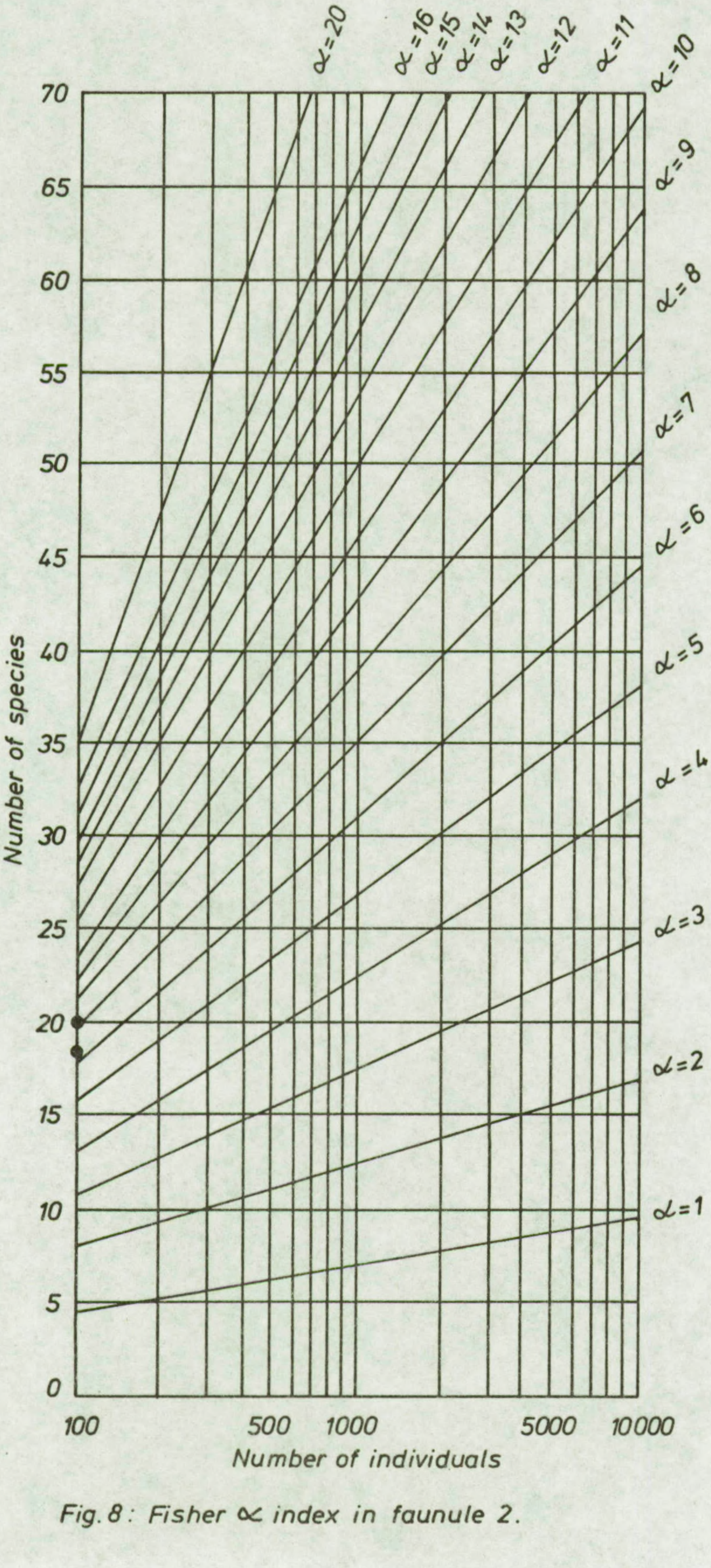


Fig. 8: Fisher α index in faunule 2.

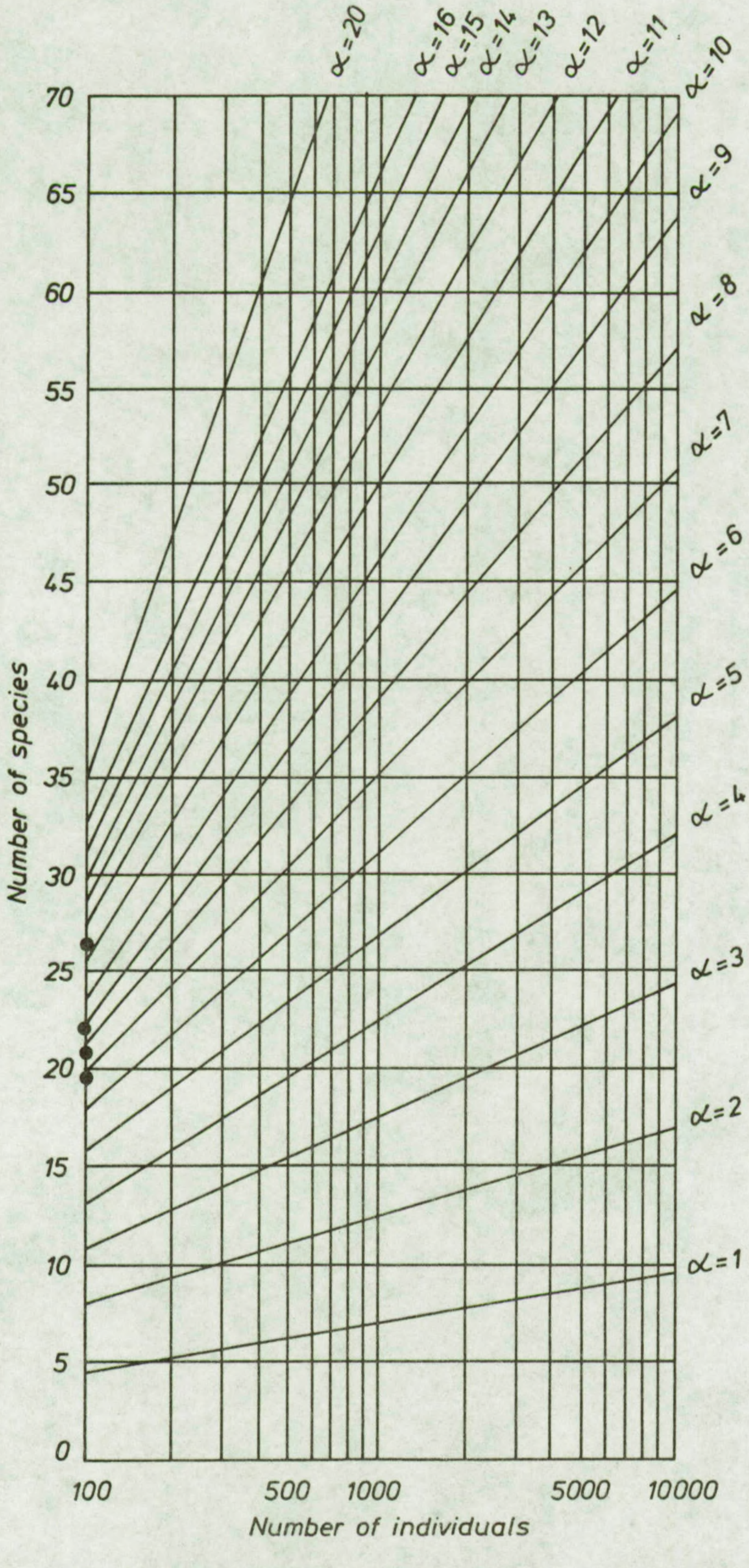


Fig. 9: Fisher α index in faunule 3.

The points for faunule 2 fall on or near the *Rotaliina* - *Miliolina* line, much closer to the *Miliolina* corner. These populations occur in hypersaline lagoons and marshes or normal marine lagoons.

In faunule 3, the values also lie on or near the *Rotaliina* - *Miliolina* line, but closer to the *Rotaliina* corner. These associations survive in hypersaline lagoons or marshes, normal marine lagoons, hyposaline lagoons or on the continental shelf.

6. SIMILARITIES. (SANDERS,1960).

Fig. 6 gives the similarities between the successive samples.

In faunule 1, the similarity index varies between 61 and 84%. Especially in the upper part of this interval, the populations ressemble each other well, less so in the lower part.

The transition from faunule 1 to faunule 2 is marked by a distinct decrease of the similarity index (25%), which indicates an important change in the composition of the populations.

The similarity index between the two samples in faunule 2 is fairly high (72%). The associations in these samples differ only slightly.

A new decrease of the similarity index is noted at the transition from faunule 2 to faunule 3 (56%) and even more (53%) between samples 8 and 9, which is explained by the relatively high frequencies of *Miliolids* in sample 9, in which *Cibicides tenellus* however occurs already more abundant.

Higher up in faunule 3, the similarity index increases to maximum 84%. The smaller value in the uppermost part (73%) is explained by the occurrence of more *Miliolids* in sample 12.

7. DIVERSITY INDEX OR FISHER α INDEX. (FISHER, CORBETT & WILLIAMS, 1943).

The relationship between the number of individuals and the number of species in the populations of the three faunules is given in figs. 7,8 and 9. In faunule 1, the Fisher α index varies between 5.5 and 9.5. In faunule 2, the values lie between 6.2 and 7.2. The Fisher α index is slightly higher in faunule 3 : between 6.8 and 11.2.

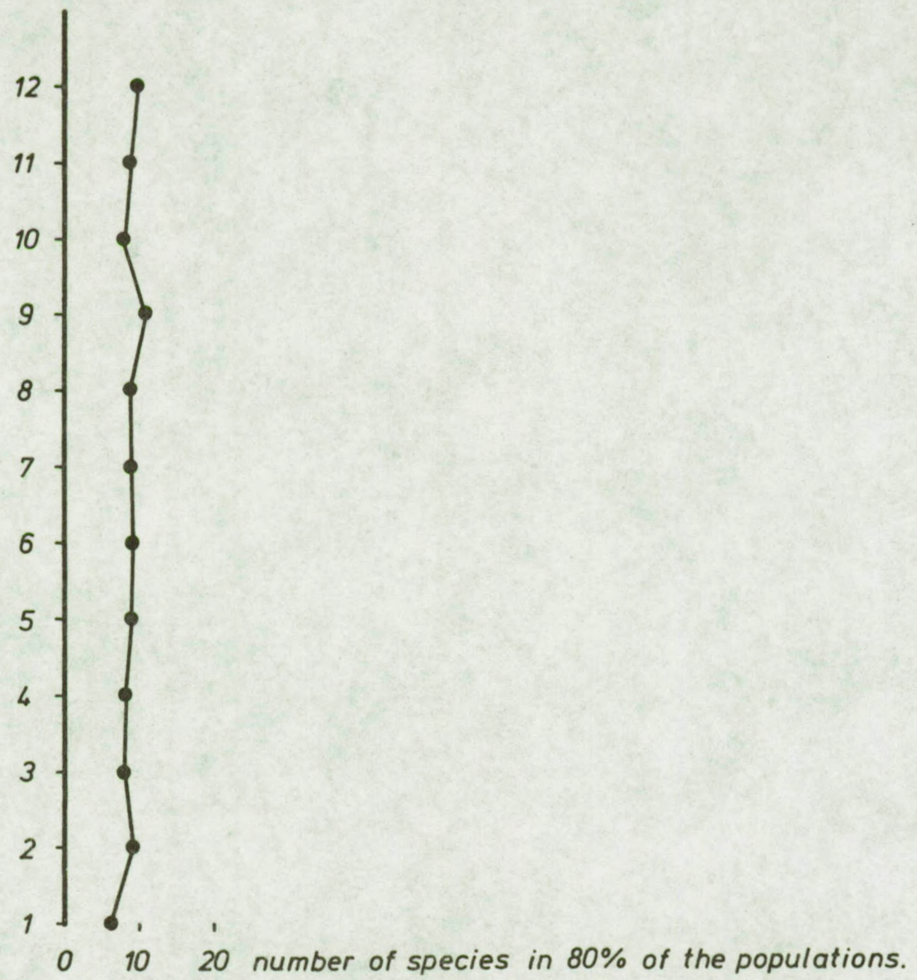


Fig. 10 : Dominance index

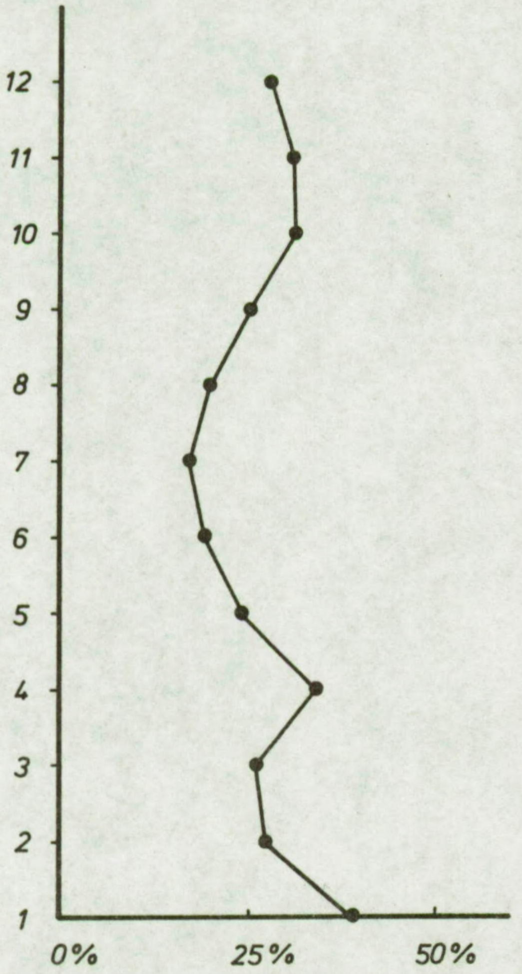


Fig. 11 : Percentage dominance

According to the interpretation of the different fields corresponding to the various α values by WRIGHT & MURRAY (1972) and MURRAY (1973), we conclude that the possible environments for the three faunules are : hypersaline or normal marine lagoons and shelf seas of normal salinity.

8. DOMINANCE INDEX. (WRIGHT, 1972).

Fig. 10 gives the number of species in 80% of the total population. The dominance index is fairly constant in the different samples. It varies mostly between 8 and 11. Only in the lowermost sample, the index is lower : 6. The environment during deposition of the Lede Sands was moderately stable. It is impossible to distinguish different faunules on the base of the dominance index.

9. PERCENTAGE DOMINANCE. (WALTON, 1964).

Fig. 11 shows the percentages of the most abundant species in the different samples.
In faunule 1, these percentages vary betwenn 24 and 39. The highest value is noted in the lowermost sample (39), which corresponds to the trangression level of the Lede sea.
In faunule 2, the percentage dominance is lower (17-19), indicating a deepening of the sea in a second impulse in the transgression.
The percentage dominance increases again in faunule 3 to maximum 31%. After a slight deepening of the sea in a second transgressive phase, the sea starts to regress slowly.

10. PALEOECOLOGICAL INTERPRETATION OF THE TAXA.

Information on the (paleo-) ecological significance of the occurring taxa is faund in e.g. PHLEGER (1960), BANDY (1960, 1964), WALTON (1964), WRIGHT & MURRAY (1972), MURRAY (1973), WRIGHT (1972-1973); MURRAY & WRIGHT (1974), BOLTOVSKOY & WRIGHT (1976) and GERITS, HOOYBERGHS & VOETS (1981).

Faunule 1.

Rotalia, which occurs frequently, prefers shallow waters with a lot of algae and seagrass.
Cibicides is a common inner shelf genus, living in a wide variety of temperature and salinities. It is attached to all types of substrates. *Cibicides* occurs from arctic to tropical areas, but is currently most abundant in temperate seas. *Cibicides lobatulus* prefers most frequently a transition zone between a protected bay and the open ocean.
Elphidium occurs in greatest abundance in shallow, oxygen-rich water, in tidal marshes and lagoons or nearshore.
Cancris is a subtropical genus living most frequently on a normal marine shelf. *Globulina* and *Guttulina* are inner shelf taxa in temperate to tropical seas. The agglutinated *Textularia* occurs preferabely on normal marine shelfs, in arctic to tropical conditions.
Small, not striated species of *Bolivina* prefer a marginal to shelf environment. The absence of *Miliolids* can be explained by low salinities. Especially *Quinqueloculina* does not tolerate salinities below 30%.
The presence of planktonic foraminifera (HOOYBERGHS, in press) however indicates an opening to the ocean.

Faunule 2.

The sudden appearance of *Miliolids* indicates an icreasing salinity in the second impulse of the transgression, which starts between samples 5 and 6. The deepening of the sea explains the low frequency of *Rotalia*. *Cibicides tenellus* does not tolerate here well the increasing salinity. Only a few hyalin calcareous genera as *Guttulina* and *Lamarckina* survive. Also the agglutinated *Textularia* disappears nearly completely. The presence of several broken *Miliolacea* is caused by a more turbulent water.

Faunule 3.

The occurrence of *Asterigerina* indicates a more stable salinity.

Rotalia audouini and *Cibicides tenellus* occur more frequently again. Also *Elphidium* and *Nonionella* reappear in this shallow water. The frequency of *Miliolids* decreases slightly with increasing depth but they occur quickly more frequently again during the regression of the sea. The frequencies of *Guttulina (G. lactea)* and *Cibicides lobatulus* are less influenced by the changing environments.

11. CONCLUSIONS.

In this locality, the transgression of the Lede sea first led to a hyposaline marginal deposit or lagoon. Although there was a connection with the open ocean. The water was oxygen-rich and contained much algae or seagrass. The temperature was fairly high. The sedimentation took place in a subtropical- tropical environment. The salinity increased to normal or hypersaline values during a second impulse in the transgression. The sea remained however rather shallow. The second transgression was only of short duration. A regression of the sea followed quickly.
The existence of two impulses in the transgression of the Lede sea has also been proved by GERITS, HOOYBERGHS & VOETS (1981).

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Quantitative distribution and paleoecology of benthonic foraminifera in the Wemmel Sands Member of the Asse Formation (Eocene) at Strombeek-Bever (Belgium)

H.J.F. HOOYBERGHS

CONTENTS.

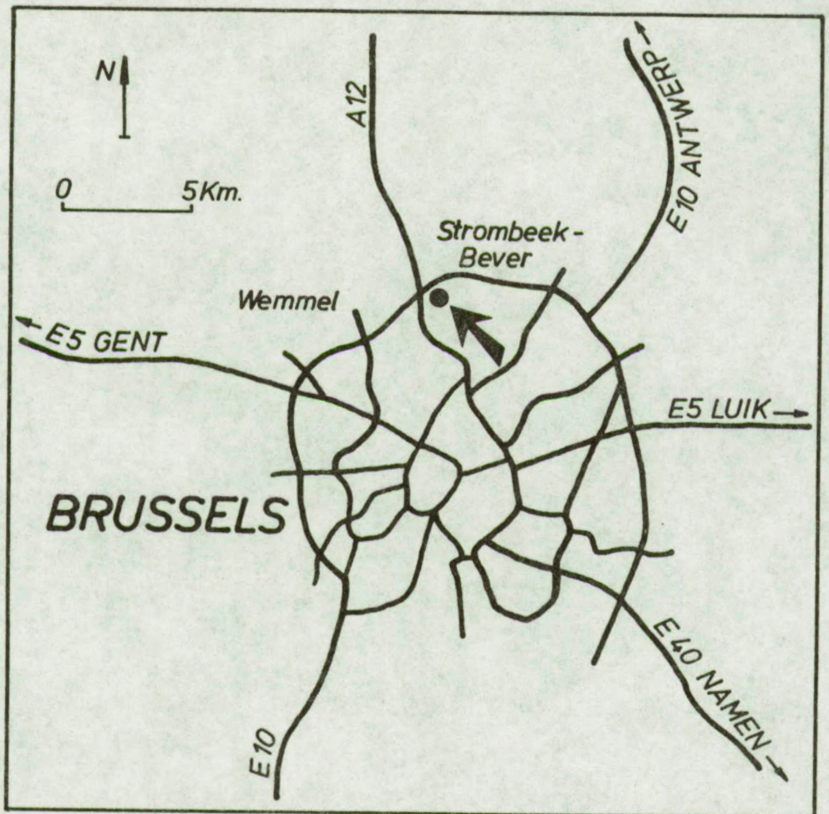

Fig.1 : Location map.

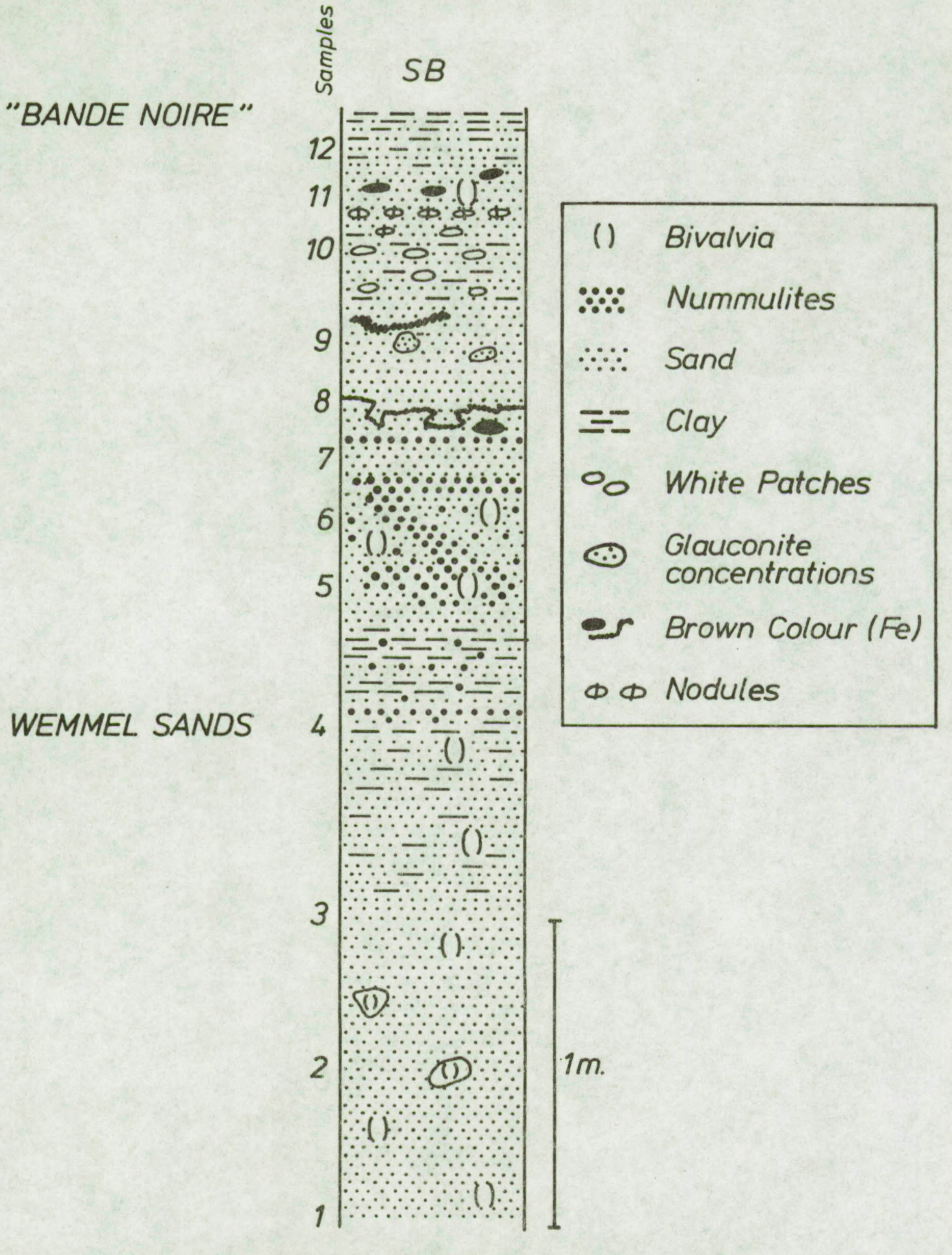

Fig.2 : Temporary outcrop of the Wemmel Sands at Strombeek-Bever.

1. ABSTRACT.

The benthonic foraminiferal populations in the Wemmel Sands Member of the Asse Formation have been studied in a temporary outcrop at Strombeek-Bever. Quantitative countings of up to 100 individuals per sample are made. Successive use of quantitative distribution, triangular plot of suborders, similarities, Fisher α index, dominance index, percentage dominance and paleoecological significance of the occurring taxa allowed us to interpret the faunal assemblages paleoecologically.

2. INTRODUCTION.

During excavations on the highway around Brussels, the Wemmel Sands were temporarily exposed in 1982 (fig.1, location map). The samples were treated with H_2O_2 and sieved on a 0.074 mm sieve. In each dried residue, countings of up to 100 individuals were made. For a full systematic description of the occurring taxa, we refer to KAASSCHIETER (1961).

3. LITHOLOGICAL DESCRIPTION OF THE WEMMEL SANDS AT STROMBEEK-BEVER.

In the lower part of the outcrop (fig.2), the Wemmel Sands are homogeneous, brown to green-yellow and glauconitic. Although few Bivalvia are disposed throughout these sands, in several areas of about 10cm diameter there are Bivalvia concentrations. Higher up, the Wemmel Sands become slightly clayey. *Nummulites* occur frequently in the middle part of the section. The sands show a cross-lamination at levels five and six. They become grey in colour and fragments of Bivalvia occur scattered in the sediment. The amount of glauconite increases upwards. In the upper part of the section, patches of white sand are observed and one level (11) is rich in small concentrations of limestone nodules. At the top of the section, there is a dark-brown clayey, very glauconitic band, which is the "Bande Noire".

SAMPLES / TAXA	WEMMEL SANDS 1	2	3	4	5	6	7	8	9	10	11
Textularia agglutinans	4		1								
Spiroloculina bicarinata	1			1		2		1			
Spiroloculina costigera var. nuda	1						3	4			
Quinqueloculina carinata	1	2				1	1				
Quinqueloculina juleana	1										
Quinqueloculina ludwigia	1	2	1			1		1		1	
Quinqueloculina seminula	2				1			1			
Dentalina elegans	1									1	
Bolivina cookei	1								1	9	1
Buliminella cf. B. pulchra	2										
Bulimina parisiensis	1		1				4	3	2		4
Trifarina muralis	2					1		2	1		1
Discorbis parisiensis	1										
Cancris subconicus	4	2	3	3	1	10	11	11	5		6
Siphonina lamarckina	1	1	2	1							
Asterigerina bertoniana	13	25	31	66	26	3		2	1	2	3
Bifarina selseyensis	10	12	6		1						
Eponides schreibersi	1	1	1								
Eponides toulmini	5	3	14	3	23	3	4	3	12	5	1
Planulina burlingtonensis	2										
Cibicides dutemplei	5	1		1						3	1
Cibicides sp. cf. C. mauricensis	2		2	1					1		
Cibicides proprius acutimargo	4	10	1	1	1	9	8	7	1		7

Table 1: Distribution of benthonic foraminifera in the Wemmel Sands.

SAMPLES / TAXA	WEMMEL SANDS 1	2	3	4	5	6	7	8	9	10	11
Cibicides proprius proprius	13	7	7	9	9	18	12	17	11	18	6
Cibicides sulzensis	3	2					1		1		
Cibicides tenellus tenellus	9	20	14	5	23	10	11	5	4	11	13
Nonion affine	7	3	2	1	1	3	15	14	10	5	6
Nonionella wemmelensis	2	2	1	2				2	1	4	2
Lenticulina sp.		1	1			1	2	4	1		
Guttulina lactea		1		1		4	2	6	2	6	12
Guttulina problema		1		1	1	7	1				3
Bolivina anglica		1	6	1	2	3	4		18	15	11
Bolivina carinata		1	1	2	5		1	1	2	4	
Reusella limbata		1	1								
Asterigerina sp.		1	1		1	2	2	1			1
Spiroplectammina carinata var. deperdita			1		3	5	4	3	3	3	
Oolina marginata			1								2
Elphidium subnodosum			1								
Globulina gibba				1		2	2	5	2		1
Pyrulina thouini					2	1	1				
Karreriella siphonella						3		2	1		1
Elphidium laeve						3	7	1	1	3	3
Cibicides lobatulus						2	2				
Anomalina acuta						6	1	2	3	1	1
Glandulina laevigata							1	1		2	

Table 1: Distribution of benthonic foraminifera in the Wemmel Sands.

SAMPLES / TAXA	WEMMEL SANDS 1	2	3	4	5	6	7	8	9	10	11
Uvigerina farinosa								1	15	3	12
Spiroplectammina carinata									1	2	
Trifarina wilcoxensis										2	
Cibicides pygmeus											2

Table 1: Distribution of benthonic foraminifera in the Wemmel Sands.

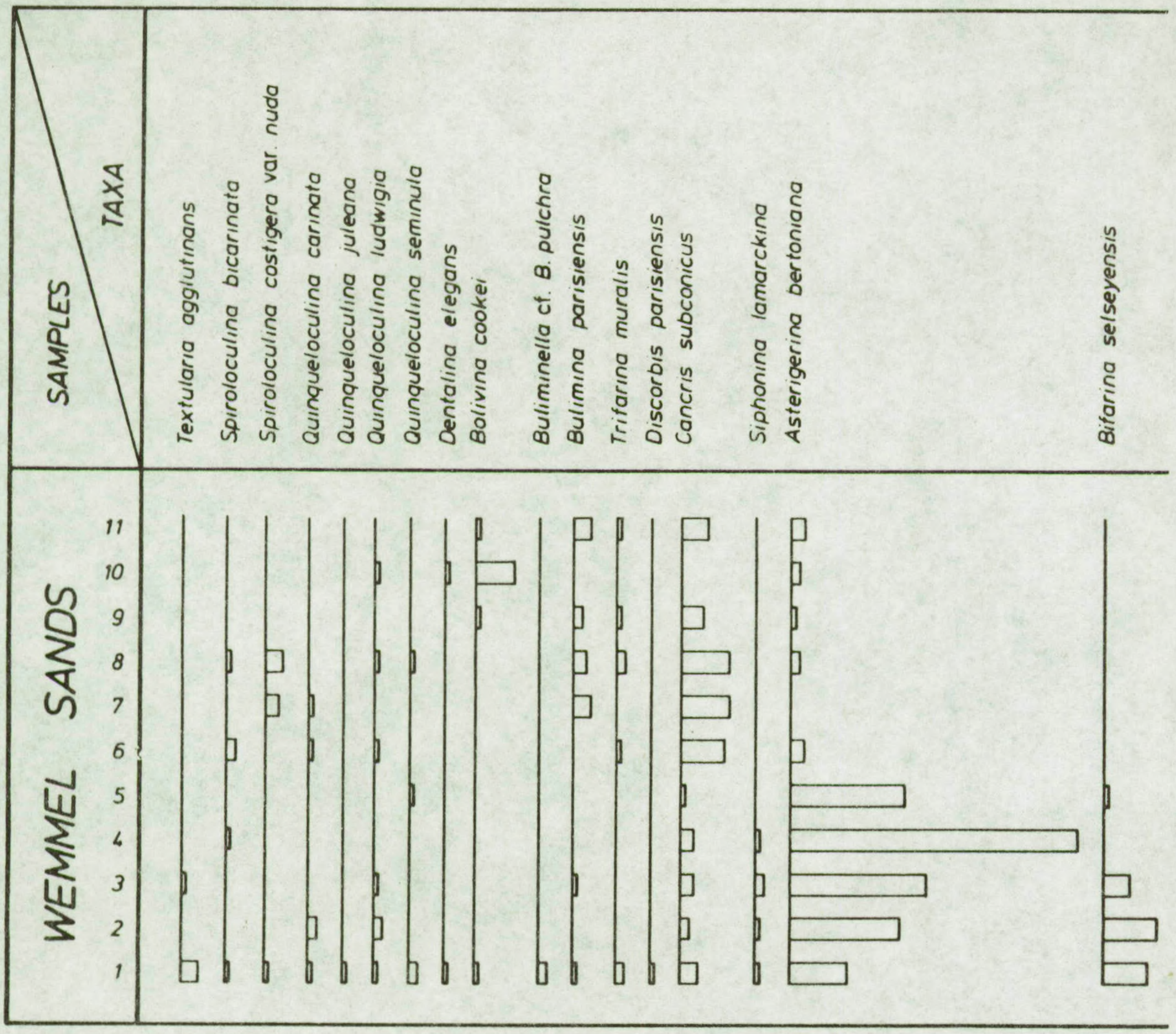

Table 2: Relative frequencies of benthonic foraminifera in the Wemmel Sands.

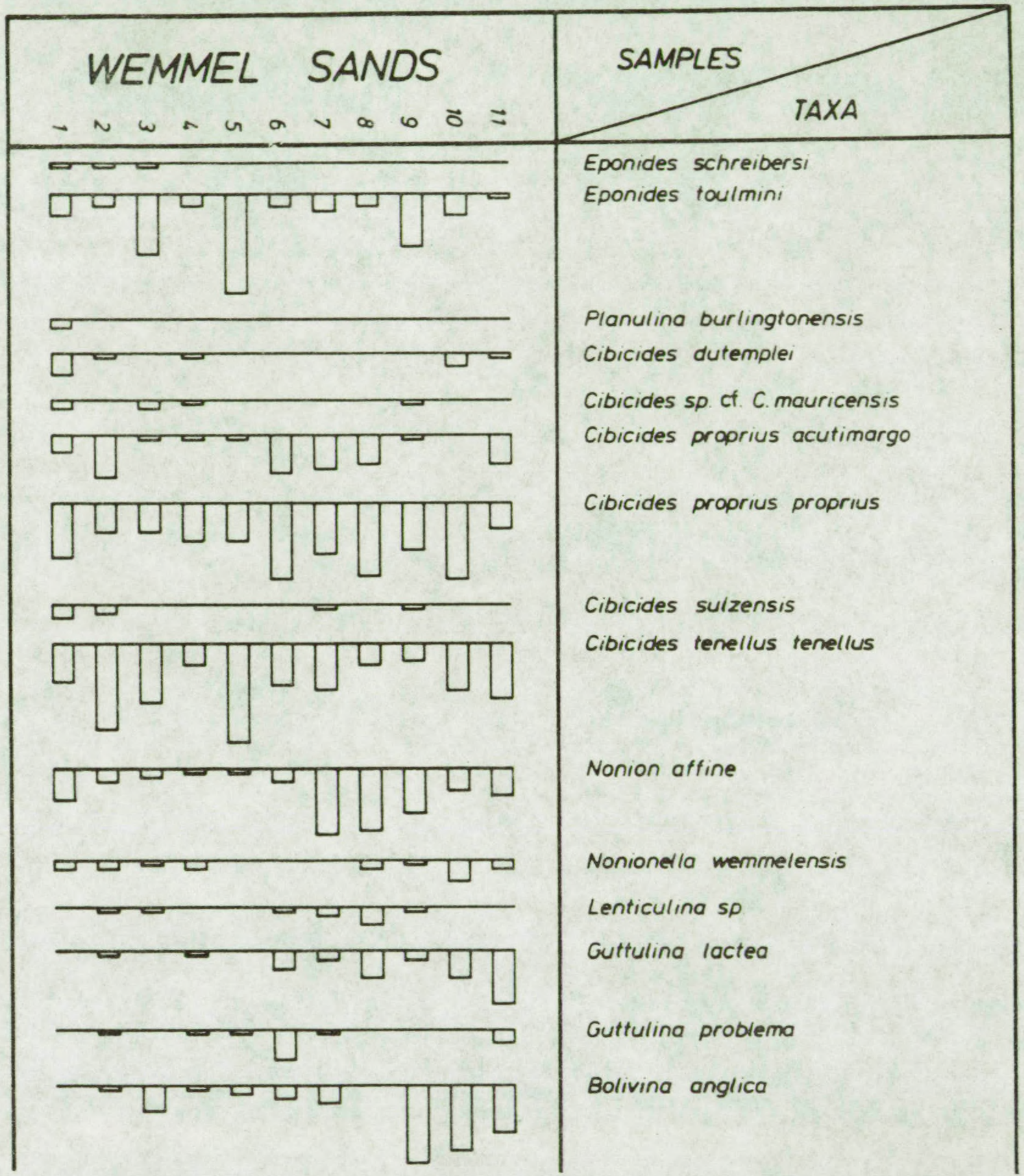

Table 2: Relative frequencies of benthonic foraminifera in the Wemmel Sands.

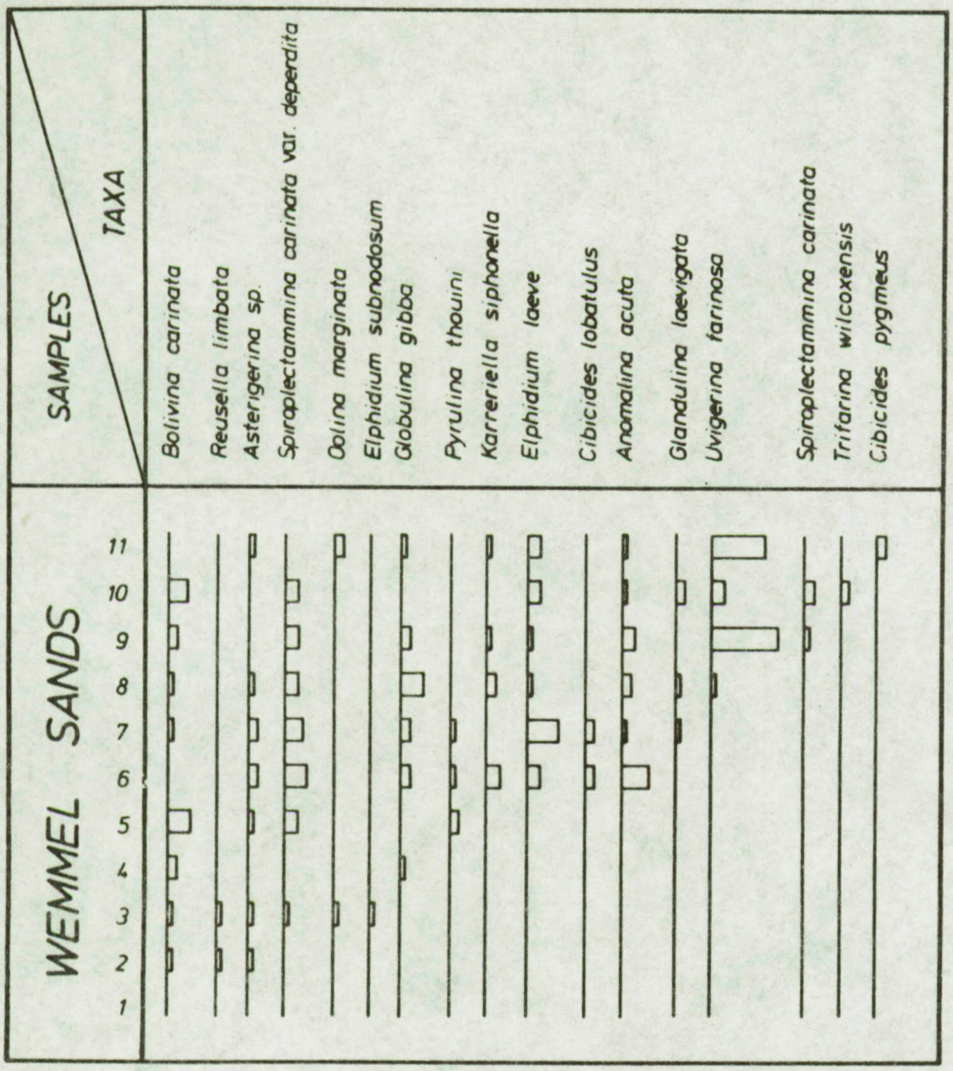

Table 2: Relative frequencies of benthonic foraminifera in the Wemmel Sands.

4. QUANTITATIVE DISTRIBUTION OF THE BENTHONIC FORAMINIFERA.

The relative abundance of the occurring taxa is given in tables 1 and 2. In the interval studied, we can distinguish two different faunules.

Faunule 1. (levels 1-5)

In this faunule, *Asterigerina bartoniana* dominates the populations. The frequencies however vary considerably (13-66%).
Cibicides tenellus is another important component of the associations, with variable frequencies (5-23%).
Some other *Cibicides* species also occur commonly : *C. proprius proprius* (7-13%) and *C; proprius acutimargo* (1-10%).
The frequency of *Eponides toulmini* changes very much (3-23%).
Different hyalin calcareous species as *Nonion affine* (1-7%), *Nonionella wemmelensis* (1-2%), *Bolivina anglica* (1-6%), *Bolivina carinata* (1-5%) and *Cancris subconicus* (1-4%) occur regularly but less frequently. *Bifarina selseyensis* (0-12%) is represented especially in the lower part of the section. The presence of different *Quinqueloculina* species in the lowermost sample is of note. At the top of the interval, *Spiroplectanunina carinata* var. *deperdita* appears distinctly (0-3%).

Faunule 2. (levels 6-11)

The importance of *Asterigerina bartoniana* diminishes distinctly (0-3%). The maximum frequency of *Cibicides tenellus* is also lower than in faunule 1 (5-13%). Different other hyalin calcareous taxa become more important in (part of) this second interval : *Cancris subconicus* (0-11%), *Nonion affine* (3-15%), *Nonionella wemmelensis* (0-4%), *Bolivina anglica* (0-18%) and *Cibicides proprius proprius* (6-18%).
Bolivina carinata (0-4%), *Cibicides proprius acutimargo* (0-9%) and *Eponides toulmini* (1-12%) still occur regularly.
Some new hyalin calcareous species appear fairly regularly : *Lenticulina* sp. (0-2%), *Guttulina lactea* (2-12%), *Globulina gibba* (0-5%), *Elphidium*

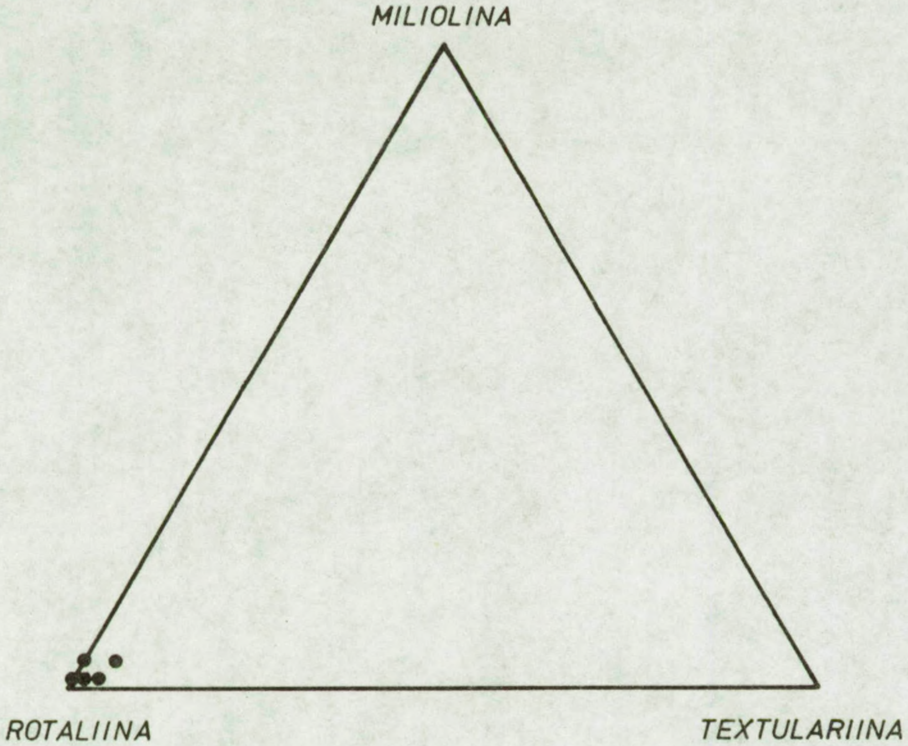

Fig. 3 : Triangular plot of suborders in faunule 1.

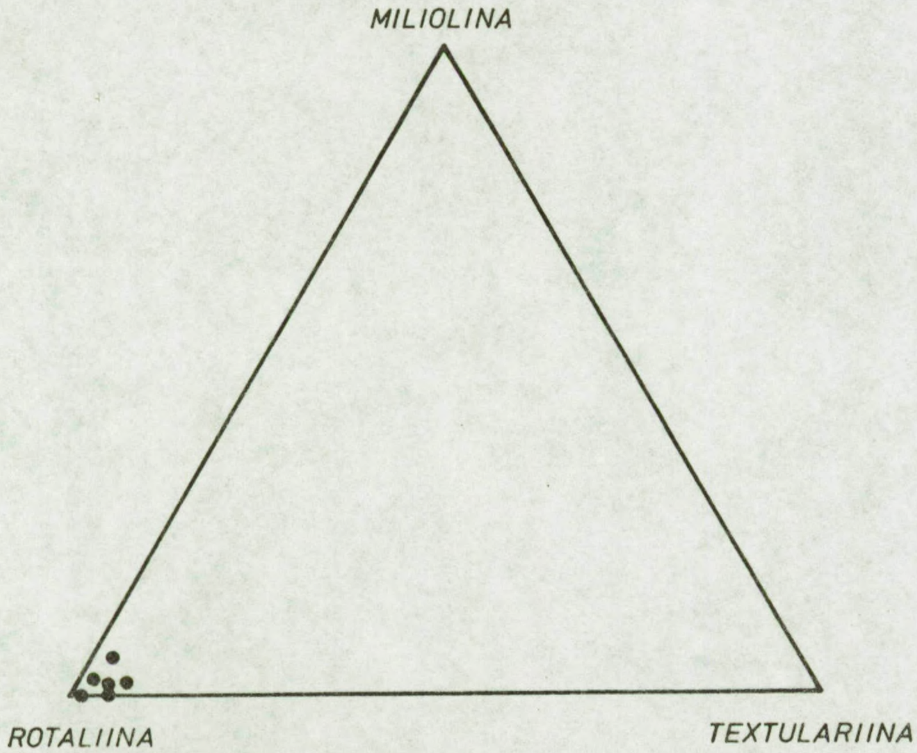

Fig. 4 : Triangular plot of suborders in faunule 2.

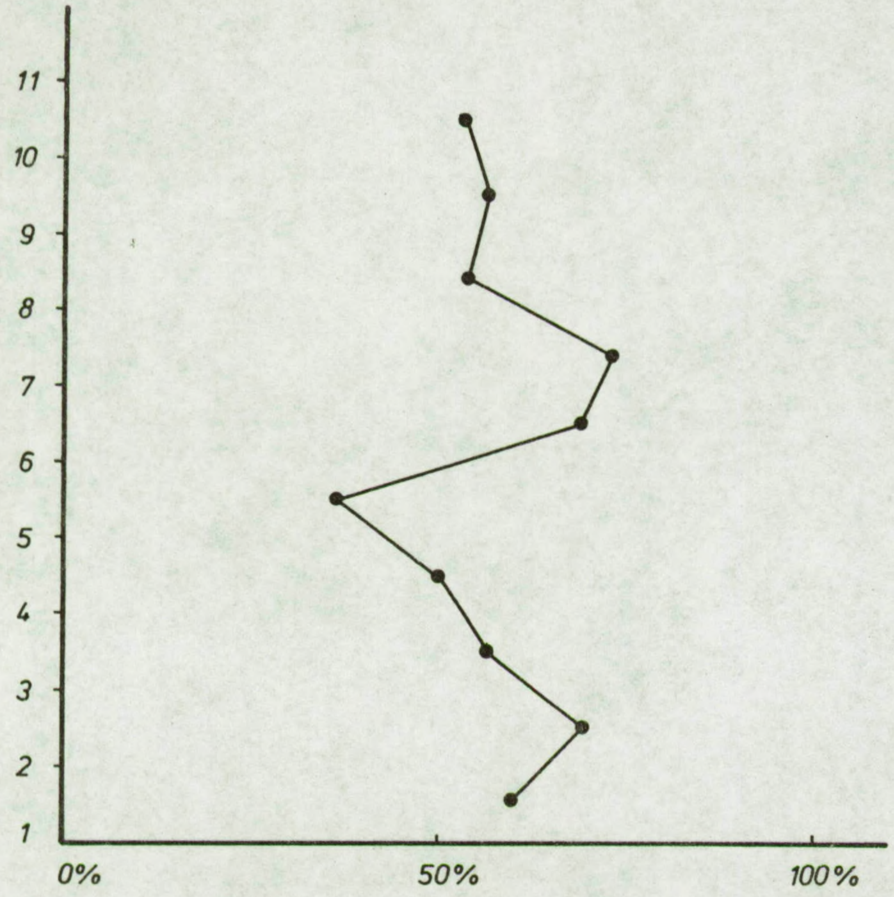

Fig. 5: Similarities.

laeve (1-7%), *Anomalina acuta* (1-6%), *Uvigerina farinosa* (0-15%), *Bulimina parisiensis* (0-4%) and *Bolivina cookei* (0-9%).
The presence of agglutinated species as *Karreriella siphonella* (0-3%) and *Spiroplectammina carinata* var. *deperdita* is noteworthy.

5. TRIANGULAR PLOT OF SUBORDERS.

Textülariina, *Miliolina* and *Rotaliina* represent the three suborders of benthonic foraminifera. We can plot them on a triangular diagram. The ecological interpretation of the different fields for the various possible environment is worked out by MURRAY (1973).
Figs.3 and 4 show the triangular plot of suborders in the two faunules. In both faunules, the points lie in the vicinity of the *Rotaliina* corner. The populations contain only a few *Textulariina* and *Miliolina*. They can occur in the following possible ecological conditions : hypersaline marshes and lagoons, normal marine marshes, hyposaline marshes and lagoons, and on the continental shelf.

6. SIMILARITIES. (SANDERS, 1960)

The similarities between successive samples are represented in fig.5.
In faunule 1, the similarities varie between 50 and 69%. The lower values are explained by the distinct change in frequency of some taxa.
The transition from faunule 1 to faunule 2 is marked by a very low similarity (36%), due to a sudden renewal in the associations of benthonic foraminifera.
The similarity increases to 73% in faunule 2. The populations differ only slightly in the lower part of this faunule. Higher up, the values decrease again to 53%, which is caused by a generally more abundant but variable occurrence of some taxa.

7. DIVERSITY INDEX OR FISHER α INDEX. (FISHER, CORBETT & WILLIAMS, 1943)

Figs.6 and 7 represent the relationship between the number of individuals

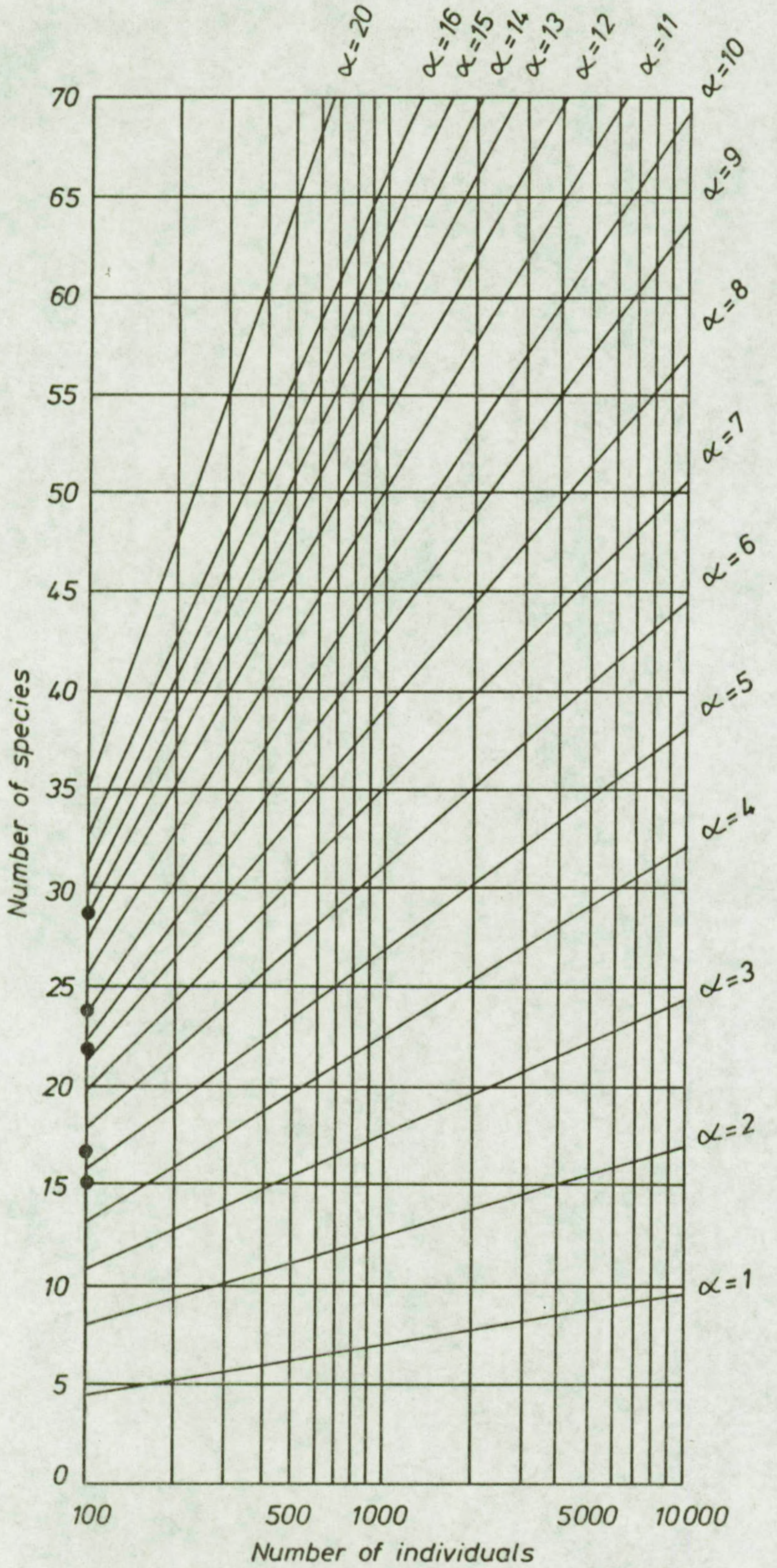

Fig. 6 : Fisher α index in faunule 1.

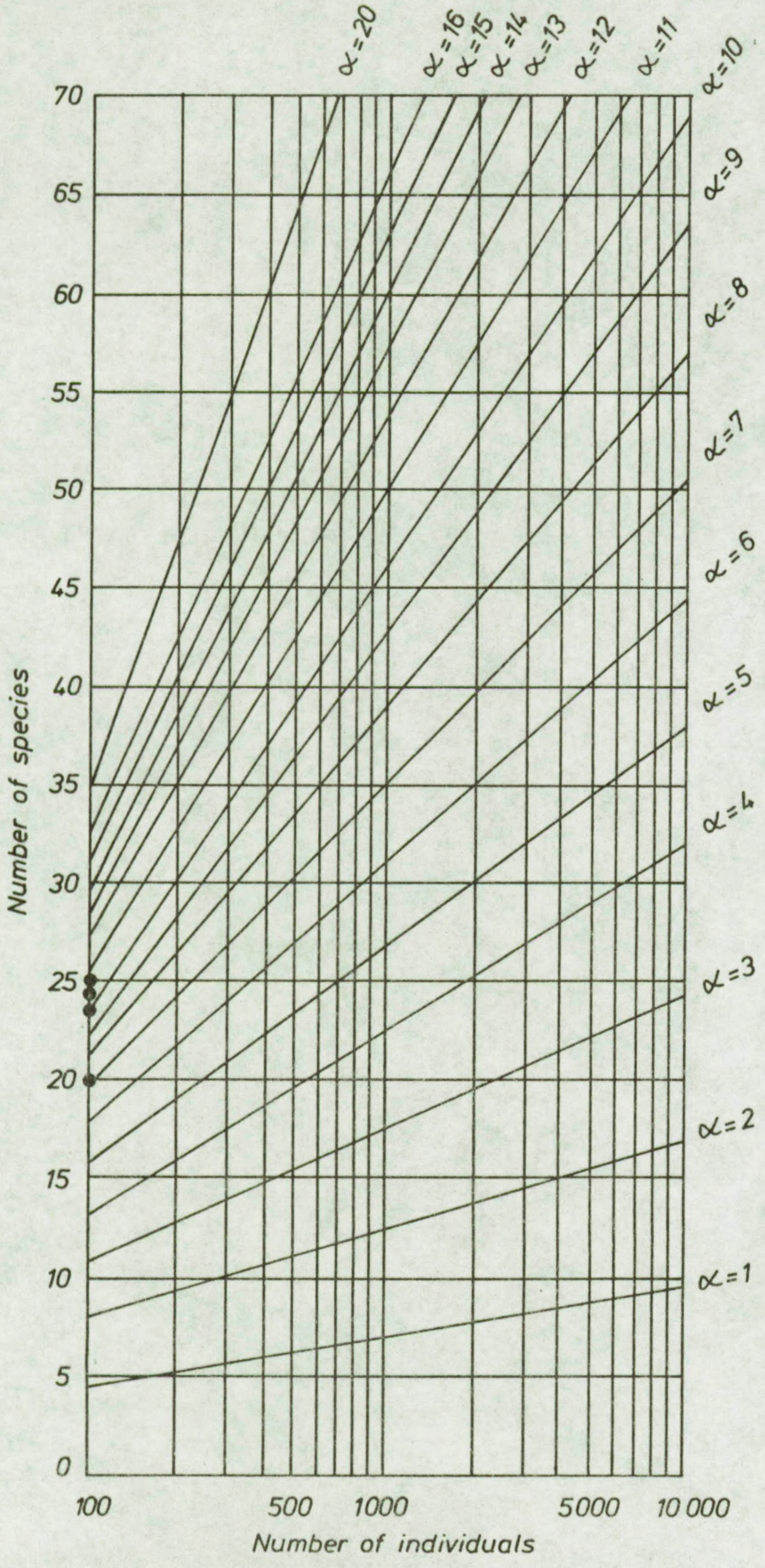

Fig. 7 : Fisher α index in faunule 2.

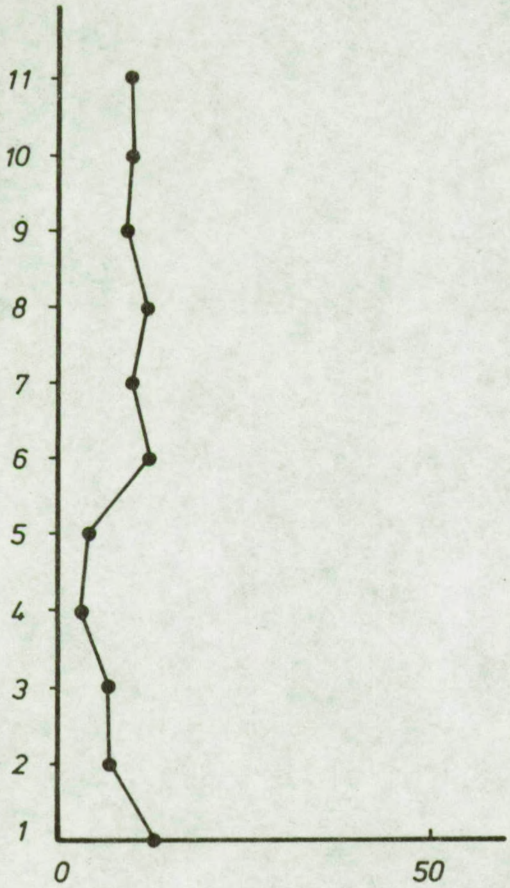

Fig. 8 : Dominance index.

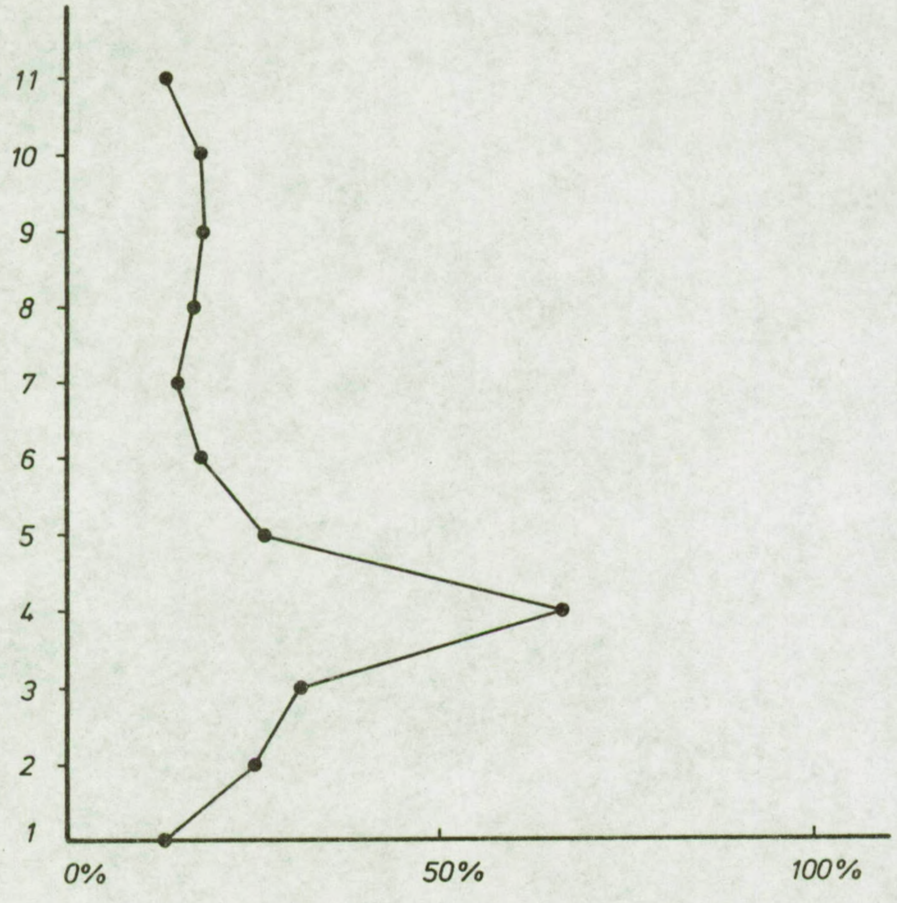

Fig. 9 : Percentage dominance.

and the number of species in the associations of the two faunules.
In faunule 1, the α index varies between 4,8 and 13. The α values lie between 7 and 11 in faunule 2.
The interpretation of the different ecological fields corresponding to the various α values is worked out by WRIGHT & MURRAY (1971).
The possible environments for faunule 1 are : shelf seas of normal marine salinity or, for the lowest value, a hyposaline and nearshore shelf sea.
The populations in faunule 2 prefer a shelf sea of normal salinity.

8. DOMINANCE INDEX. (WRIGHT, 1972)

Fig.8 shows the number of species in 80% of the total population. The dominance index in faunule 1 varies between 3 and 13. The distinctly different values are probably due to an unstable environment in which the sedimentation took place.
In faunule 2, the dominance index is generally higher and less variable. It changes between 9 and 12. During a second impulse in the transgression, the sea bottom became more stable. The deepening of the sea took place gradually.

9. PERCENTAGE DOMINANCE. (WALTON, 1964)

The percentages of the most abundant species in the different samples are represented in fig.9.
Faunule 1 shows distinctly changing frequencies. They vary from 13 to 66. Again, this can be explained by an unstable sedimentation environment.
The values for faunule 2 are less variable. Here they lie between 13 and 18. A second impulse in the transgression led to a more stable continental shelf.

10. PALEOECOLOGICAL SIGNIFICANCE OF THE OCCURRING TAXA.

Benthonic foraminifera occur in specific ecological conditions. Information on the (paleo-) ecological significance of the occurring taxa is faund in : PHLEGER (1960), BANDY (1960,1964), WALTON (1964),

WRIGHT & MURRAY (1972), MURRAY (1973), WRIGHT (1972-1973), MURRAY & WRIGHT (1974), BOLTOVSKOY & WRIGHT (1976) and GERITS, HOOYBERGHS & VOETS (1981).

Faunule 1.

The dominant genus *Asterigerina* is a typical inner shelf genus, where it occurs under conditions of stable salinity in a normal marine environment with tropical-subtropical temperature.
Cibicides is currently most abundant in temperate seas. It is attached on all types of substrates such as algae or seagrass vegetation.
The presence of several *Quinqueloculina*'s in the lowermost part of the section indicates a nearshore environment with a salinity higher than 30%.
Cancris occurs on the shelf of normal marine seas in a subtropical climate.
Bifarina survives on an inner shelf. As the sea depth increases, *Bifarina selseyensis* disappears in the upper levels.
Eponides prefers a continental shelf of a normal marine sea with cold to temperate waters.
Nonion occurs on the shelf of normal to hyposaline seas in different temperature conditions, but with oxygen-rich waters.
Nonionella is a normal marine shelf genus in temperate to tropical seas.
Small smooth species of *Bolivina* prefer an inner shelf environment with normal salinity (32-36%).
The appearance of *Spiroplectammina* in the upper part of the interval indicates a deepening of the sea.

Faunule 2.

Several taxa from faunule 1 still occur and often even higher frequencies. Individuals of *Cancris, Eponides, Cibicides, Nonion, Nonionella* and *Bolivina (B. anglica)* still survive in this environment. *Asterigerina* however disappeared nearly completely.
The appearance of some new taxa however indicates an increasing depth.
Striate *Bolivina*'s *(B. cookei)* prefer a central to outer shelf milieu.
The occurrence of *Karreriella, Spiroplectammina, Lenticulina* and *Uvigerina*

also suggests a greater depth of the sea in normal marine conditions.
Guttulina and *Globulina* prefer a shelf of a normal sea in a temperate to tropical climate.
Bulimina lives in a wide depth range, from nearshore to bathyal, in a normal marine environment.
Elphidium normally dominates at an inner shelf depth with rather high salinities (35-50%) and in a oxygen-rich water.

11. CONCLUSIONS.

The nearshore facies at the beginning of the Wemmel transgression passed to an inner shelf environment. The normal salinity was fairly constant and the sedimentation took place in a subtropical- tropical climate. The sea bottom however was rather unstable. The water was oxygen-rich and algae or seagrass were favoured.
A second impulse in the transgression was accompanied by strong currents , which explains the cross bedding. The sea bottom became more stable with increasing depth. The sediments were finally deposited in a central to outer shelf environment in a subtropical to tropical climate.
The salinity of the water remained normal (33-37%).

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Quantitative distribution and paleoecology of benthonic foraminifera in the Asse and Kallo Formation at Assenede (Belgium).

H.J.F., HOOYBERGHS

CONTENTS.

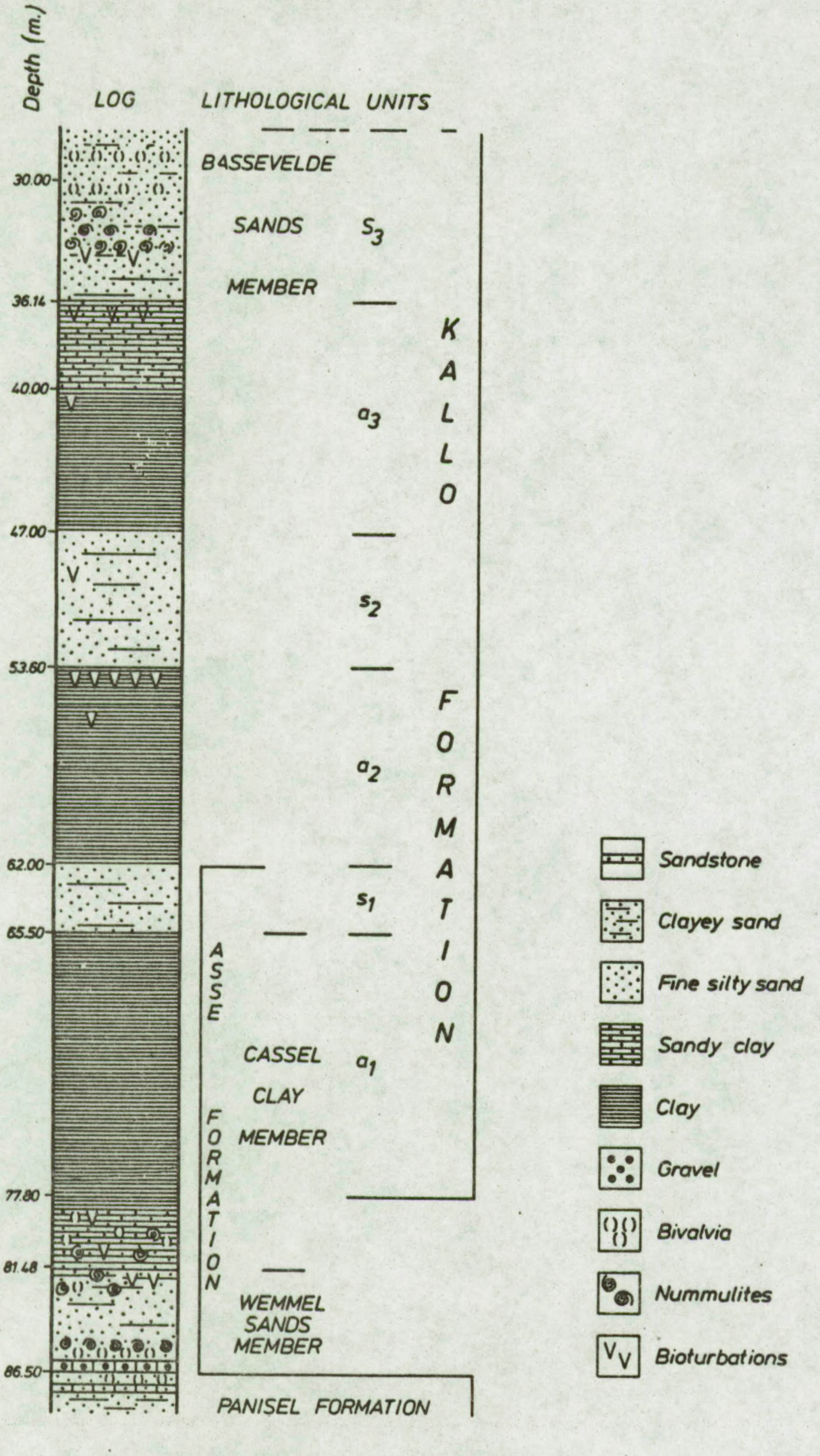

Fig. 1 : Lithological subdivision in the Assenede well.

1. ABSTRACT.

The benthonic foraminiferal populations in the Eocene Asse Formation and Kallo Formation have been studied in a borehole at Assenede. Quantitative countings of up to 100 individuals per sample have been made. To interpret the faunal assemblages paleoecologically, we successively used the following methods : quantitative distributions,triangular plot of suborders, similarities, Fisher α index; dominance index, percentage dominance and paleoecological significance of the occurring taxa.

2. INTRODUCTION.

The Asse Formation and the Kallo Formation have been sampled in a well at Assenede. The well description is held in the archives of the Belgian Geological Survey (K.B. Zelzate 25E-123Id - codenr. DB.43002-14.2, Peilput 101, Assenede).
The samples were washed on a 0.0074mm sieve. Since different samples yielded only a small number of benthonic foraminifera, we were obliged to use the CCL_4 method to concentrate the foraminifera. Countings of up to maximum 100 individuals have been made in the different samples. For a full systematic description of the taxa, we refer to KAASSCHIETER (1961).

3. LITHOLOGICAL DESCRIPTION OF THE SECTION STUDIED.

Two lithological units have been sampled in the Assenede well : the Asse Formation and the Kallo Formation (Fig.1.).

1) Asse Formation. (KAASSCHIETER, 1961)

A thin petrified gravel bed occurs at the base of the Wemmel Sands Member which is developed between 86.50 and 81.48m . Higher up, the deposit contains fine, slightly clayey, silty grey-green sands.
Bivalvia and *Nummulites* have been observed in both the lower and the upper part of the Wemmel Sands. Especially the upper part is distinctly glauco-

SAMPLES	TAXA	Textularia agglutinans	Triloculina angularis	Globulina gibba	Guttulina irregularis	Guttulina lactea	Guttulina problema	Guttulina pulchella	Pyrulina thouini	Bolivina anglica	Rotalia audouini	Elphidium laeve	Elphidium subnodosum	Bifarina selseyensis	Cibicides proprius acutimargo	Cibicides proprius proprius	Cibicides tenellus	Nonion affine	Nonion scaphum	Nonionella wemmelensis	Hanzawaia boueana	Spiroloculina bicarinata	Globulina gravida	Eponides schreibersi	Quinqueloculina ludwigi	Bulimina parisiensis	Gyroidina octocamerata	Lamarckina cristellaroides
s_3	31,90	5				2	1			1			2		3	36	7	11							2			
	32,40			1	1	1							2		4	37	2	13							4		1	
	32,90	3		8		4	2	2				2	3		3	36		13	2								2	
a_3	36,40					3	1						1			2					4							1
	37,45 - 37,50			1		2							1		3						2						1	
	38,30 - 38,40											1	2		4	2					4						1	
	39,40												1			1	1										1	
	40,30 - 40,40														1						1							
	41,50 - 41,60												1		1						1							
	42,65 - 42,80			1											1													
	43,60																											
s_2	47,60																	1						1	1			
	52,30 - 52,40		1	3	1	4									1													
a_2	58,35 - 58,45	2		2		3									1						6			2	6			
	60,60 60,75		1																					1	1			
s_1	62,55 - 62,65										1					1					1							
a_1	69,55 - 69,70														1													
CASSEL CLAY	80,25 - 80,30	12				2				10	2	1				19		3		5	1			1	1			
	80,90 - 80,95	4		1		7				4					2	8	2	4	3	6				1	3			
	81,15 - 81,20	6				3				7	1	1			1	2	4	7	5	1					1	2		2
WEMMEL SANDS	81,90	9	1	2		12			1	3		4			3	5			4		1		1	2	4	3		2
	82,30 - 82,40	5	1	2		4			2	3	2				1	5	6	4							7			6
	82,65 - 82,70	10	2	1		9			9			1			1	10		1	3				1		1			
	82,95	35	3	1	2	7	1				1				3	3		1	3	6			2	1	5			
	83,30 - 83,40	22	1	8		19					2					3	2	3	2	7					7	1		4
	83,80 83,85	15			1					15	1					2	6	13		2	1				6			3
	84,35 - 84,40	10		1	2	1										2		1	3		1		1		4			1
	84,45	20		2		21	1				3	1			1	11	2	2	8	6					2	1		
	84,50	11		4		4			3	2	3	2		3	2	3	4	3	2	1		2			6			15
	85,60 - 85,65	12				5				17	1	7		8	2	12	10	2		4			1		7	1		
	85,90 - 86	10			3	7				3		13		7	6	8	2	5	3		2		1		3	2		
	86,50	12		4	3	5			1	1'		1			3	4		1	1	2	2				1	5	1	1

Table 1 : Quantitative distribution of benthonic foraminifera.

SAMPLES \ TAXA		*Bolivina carinata*	*Bolivina crenulata*	*Reusella terquemi*	*Uvigerina farinosa*	*Trifarina muralis*	*Discorbis quadrata*	*Eponides toulmini*	*Alabamina wolterstorffi*	*Karreriella siphonella*	*Quinqueloculina carinata*	*Lagena striata*	*Cibicides dutemplei*	*Cibicides pygmeus*	*Spiroloculina tricarinata* var. *belgica*	*Quinqueloculina seminula*	*Dentalina elegans*	*Lenticulina* sp.	*Cancris subconicus*	*Cibicides carinatus*	*Spiroplectammina carinata* var. *deperdita*	*Spiroloculina canaliculata*	*Triloculina trigonula*	*Cancris auriculus* var. *primitivus*	*Anomalina acuta*	*Entosolenia orbignyana*	*Buliminella* cf. *B. pulchra*	*Trifarina wilcoxensis*
s_3	31,90									2		1	1	8					1		1			1	2			
	32,40													7					3		14							
	32,90	1												3				1			2							
a_3	36,40																	1										
	37,45-37,50												1															
	38,30-38,40																											
	39,40																											
	40,30-40,40																											
	41,50-41,60																											
	42,65-42,80										1					1												
	43,60																											
s_2	47,60										1													1				
	52,30-52,40															2												
a_2	58,35-58,45										11				1	3						1		3				
	60,60 60,75																					1						
s_1	62,55-62,65																											
CASSEL CLAY a_1	69,55-69,70																											
CASSEL CLAY	80,25-80,30						2		13	3	2			5			1		4		9					4		
	80,90-80,95	4			1		3	1	7	8			1	3	1				6		4	2			1	6	1	4
	81,15-81,20	14		2	4	5	4	2	11										1					2		3	3	2
WEMMEL SANDS	81,90		1	2	3	2	2			1				1		1			1		2	1				7	2	
	82,30-82,40			2	1					3	2			2			2				3	2	1			5	1	24
	82,65-82,70	3				9	5	4		2	1			2		2				1	8	2		2		2	1	6
	82,95	1	1			3	1			3	1					1			6		1		4			2		
	83,30-83,40				1					1	2					2			7				2			,		
	83,80 83,85			1	1		2			2			5	7							3			1		6	1	3
	84,35-84,40															1			5		1	4	1	1	1			
	84,45				1	2							1	1				2	12									
	84,50			2		1				2		1	1		2	3	1	1	2	1								
	85,60-85,65	1	4		1	3	2		1	1	1	1	1	2														
	85,90-86	3	2	2	1	6	3	2	2																			
	86,50																											

Table 1 : Quantitative distribution of benthonic foraminifera.

Unit	SAMPLES / TAXA	Angulogerina abbreviata var. tubulifera	Quinqueloculina bicarinata	Glandulina laevigata	Quinqueloculina costata	Articulina flandrica	Anomalina acuta anomalinoides	Dentalina sp. D. ewaldi	Lagena hexagona	Bolivina cookei	Asterigerina sp.	Cibicides westi	Reusella limbata	Total number of individuals
s_3	31,90									12			1	100
	32,40									9				100
	32,90									12	1			100
a_3	36,40													13
	37,45 - 37,50											1		12
	38,30 - 38,40											3		17
	39,40													4
	40,30 - 40,40													2
	41,50 - 41,60													3
	42,65 - 42,80											1		5
	43,60											1		1
s_2	47,60											1		6
	52,30 - 52,40											1		13
a_2	58,35 - 58,45													41
	60,60 60,75													4
s_1	62,55 - 62,65													3
CASSEL CLAY a_1	69,55 - 69,70													1
CASSEL CLAY	80,25 - 80,30													100
	80,90 - 80,95													98
	81,15 - 81,20			1							3			100
WEMMEL SANDS	81,90		1	1				2	1	1				89
	82,30 - 82,40					2	2							100
	82,65 - 82,70													99
	82,95				2									100
	83,30 - 83,40		3	1										100
	83,80 83,85	1												100
	84,35 - 84,40													41
	84,45													100
	84,50													87
	85,60 - 85,65													100
	85,90 - 86													96
	86,50													48

Table 1 : Quantitative distribution of benthonic foraminifera.

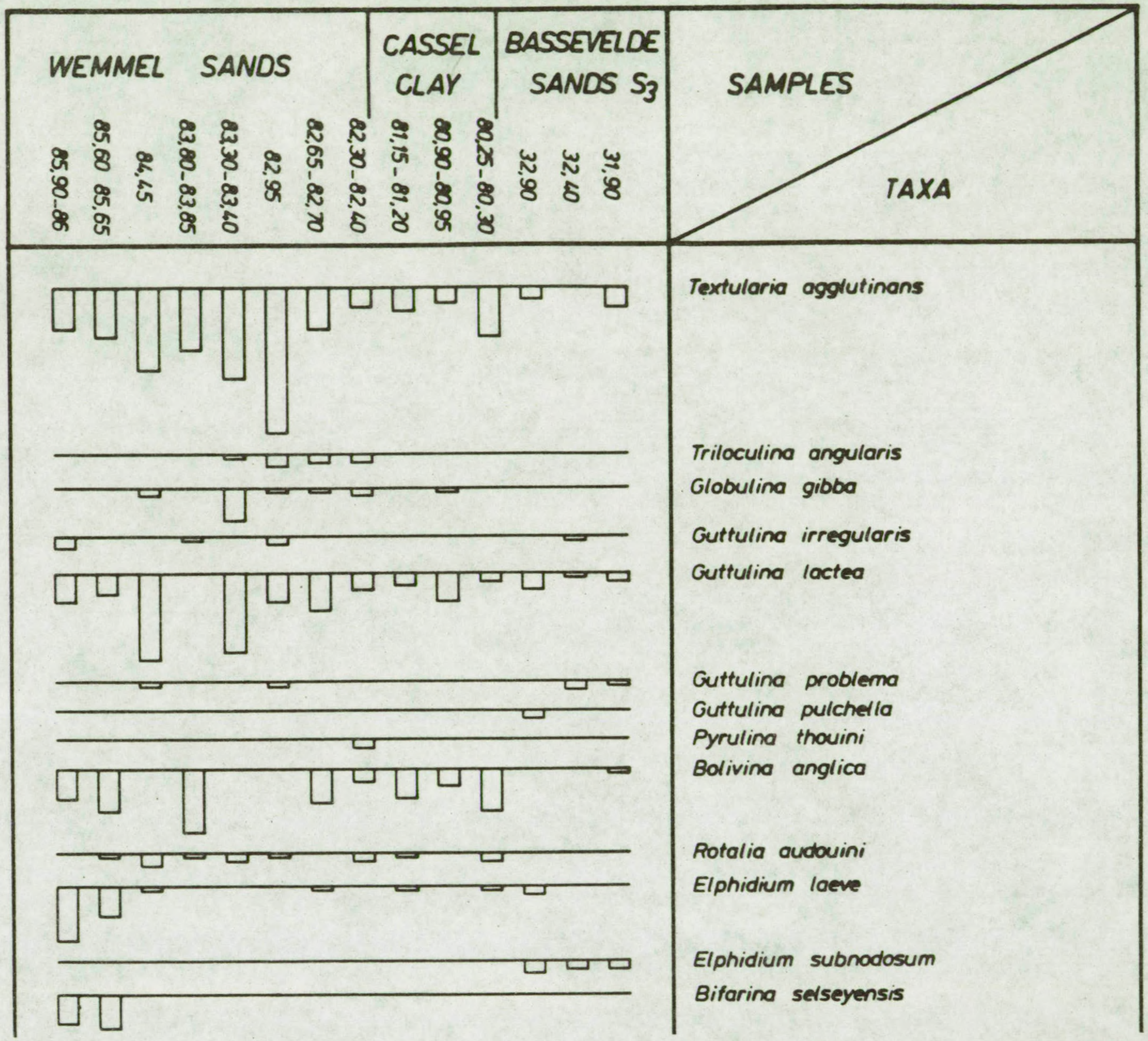

Table 2 : Relative abundance of benthonic foraminifera.

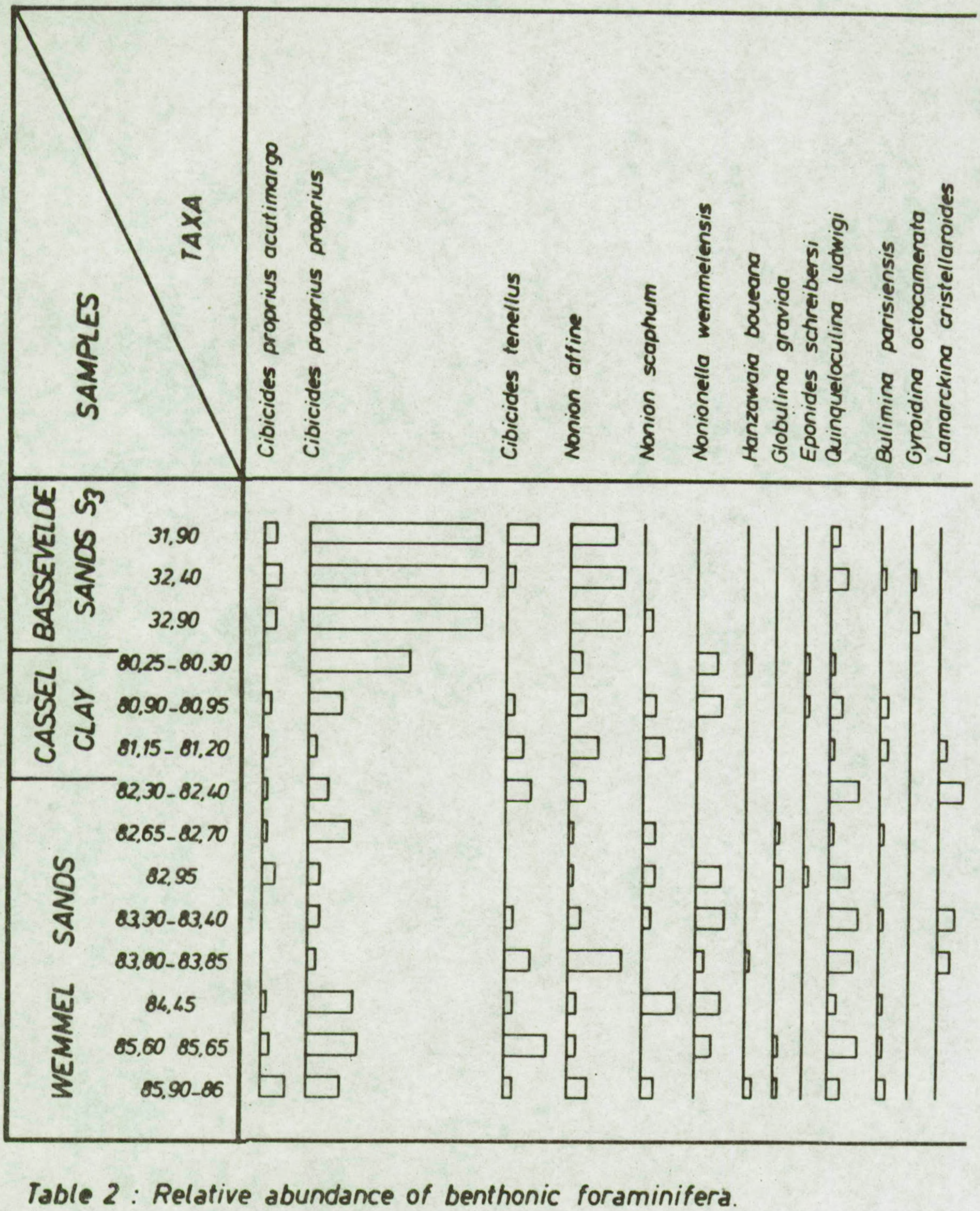

Table 2 : Relative abundance of benthonic foraminifera.

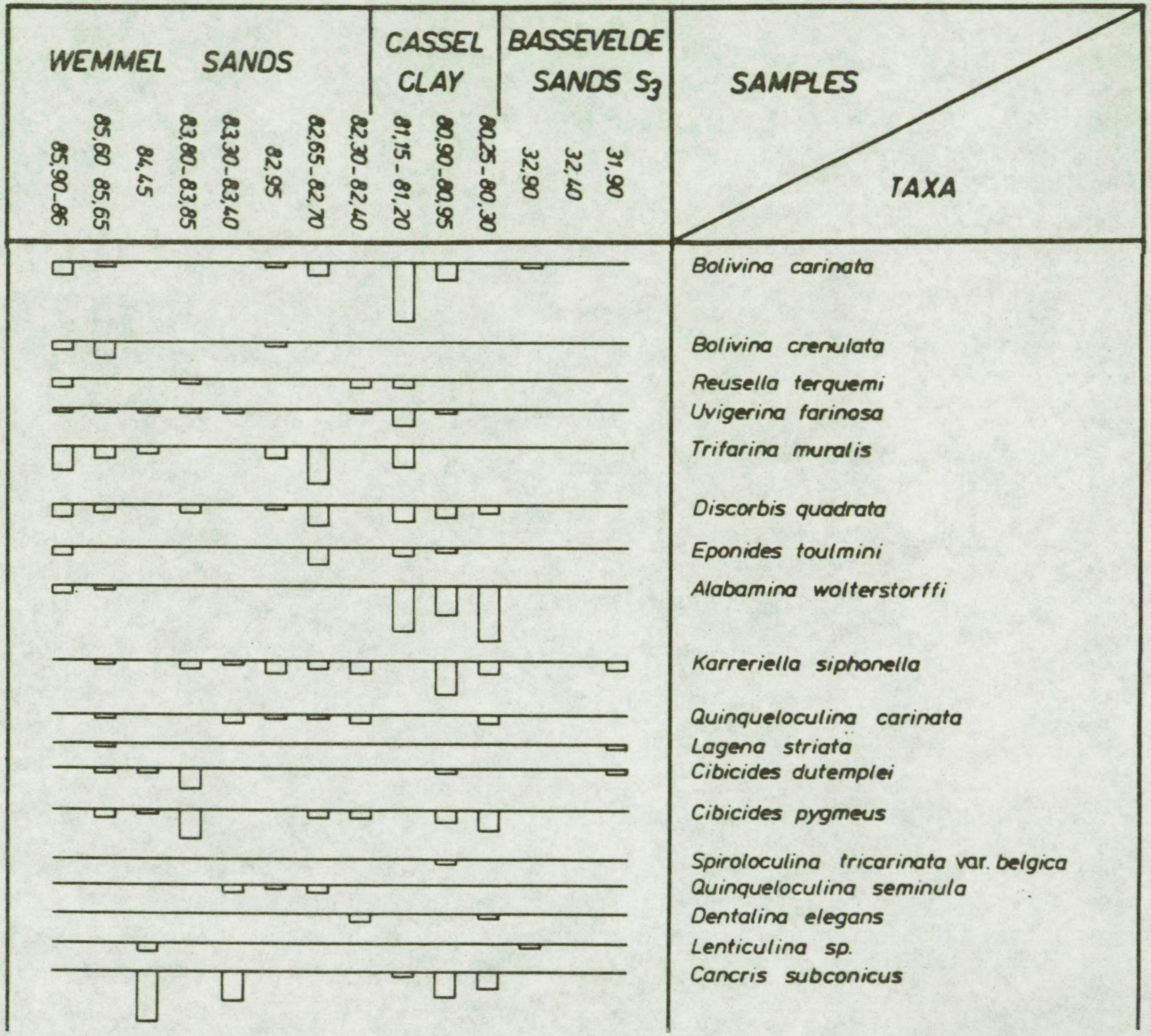

Table 2 : Relative abundance of benthonic foraminifera.

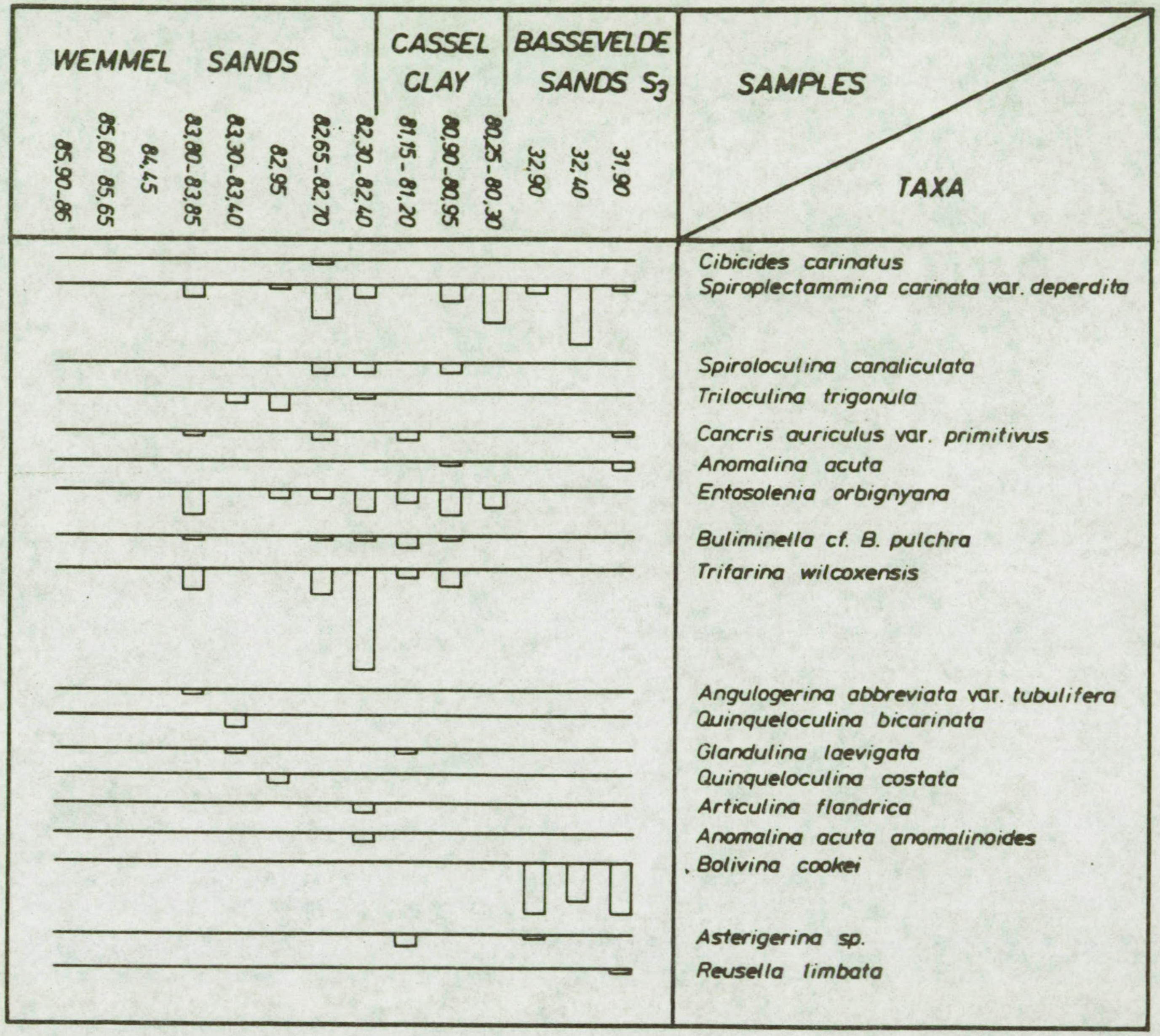

Table 2 : Relative abundance of benthonic foraminifera.

niferous and bioturbated. The clay percentage increases upwards.
The Wemmel Sands are covered by a very glauconiferous clayey level (-81.48 and -77.80m) which is also bioturbated and which yields Bivalvia and *Nummulites*. It constitutes the basal layer of the Cassel Clay Member of the Asse Formation (DELATTRE et al., 1973).

2. Kallo Formation. (GULINCK, 1969)

The Kallo Formation represents a marine cyclic sedimentation with alternating clay layers ans silty sands. The different beds have been numbered by GULINCK (1969) as a_1, s_1, a_2, s_2, a_3, and s_3.

s_3 : glauconiferous, micaceous sands with *Nummulites* and Bivalvia and slightly bioturbated. Those sands are know as the Bassevelde Sands Member.

a_3 : clay bed of which especially the upper part becomes very sandy and micaceous. It is bioturbated at the top. Pyrite has been observed in this part.

s_2 : gray-green to dark gray clayey fine sands.

a_2 : gray-green silty clay with pyrite.

s_1 : gray-green silty and clayey sands.

a_1 : gray-green clay with pyrite. This can be correlated with the Cassel Clay Member of the Asse Formation.

4. DISTRIBUTION OF BENTHONIC FORAMINIFERA IN THE ASSENEDE WELL.

Table 1 shows the quantitative distribution of benthonic foraminifera to a maximum of 100 individuals. The relative abundance of the benthonic foraminifera in samples with 100 individuals is given in table 2. In this table, we can distinguish three different faunules which corresponds respectively to the Wemmel Sands, the Cassel Clay and the Bassevelde Sands.

1) Faunule 1 (Wemmel Sands).

The agglutinated *Textularia agglutinans* becomes a very important

component of the populations. Its frequency varies between 5 and 35%.
A few other agglutinated species occur in part of this interval : *Karreriella siphonella* (0-3%) and *Spiroplectammina carinata* var. *deperdita* (0-8%).
Different porcelaneous species appear in at least part of the section : *Quinqueloculina ludwigi* (1-7%), *Triloculina angularis* (0-3%), *Quinqueloculina carinata* (0-2%), *Quinqueloculina seminulum* (0-2%), *Spiroloculina canaliculata* (0-8%) and *Triloculina trigonula* (0-4%).
The populations contain several hyalin calcareous foraminifera. An important genus is *Cibicides : Cibicides proprius proprius* (2-12%), *Cibicides proprius acutimargo* (0-6%), *Cibicides tenellus* (0-10%), *Cibicides dutenplei* (0-5%) and *Cibicides pygmeus* (0-7%).
Some other taxa become frequent in part of the interval : *Globulina gibba* (0-8%), *Guttulina lactea* (0-21%), *Bolivina anglica* (0-15%), *Elphidium laeve* (0-13%), *Bifarina selseyensis* (0-8%), *Nonion affine* (1-13%), *Nonion scaphum* (0-8%), *Nonionella wemmelensis* (0-7%), *Trifarina muralis* (0-6%), *Cancris subconicus* (0-12%), *Entosolenia orbignyana* (0-6%) and *Trifarina wilcoxensis* (0-24%).
Other hyalin calcareous species occurs regularly but less frequently : *Rotalia audouini* (0-3%), *Bulimina parisiensis* (0-2%), *Lamarckina cristellaroides* (0-4%), *Bolivina carinata* (0-3%), *Bolivina crenulata* (0-4%), *Reusella terquemi* (0-2%), *Uvigerina farinosa* (0-1%), *Discorbis quadrata* (0-5%), *Eponides toulmini* (0-4%), *Alabamina wolterstorfi* (0-2%), *Cancris auriculus* var. *primitivus* (0-2%) and *Bulininella* sp. cf. *B. pulchra* (0-1%).

2) Faunule 2 (Cassel Clay).

This faunule is characterized by the sudden frequent appearrance of *Alabamina wolterstorfi* (7-11%).
Agglutinated species still occur commonly : *Textularia agglutinans* (4-12%), *Karreriella siphonella* (0-8%) and *Spiroplectammina carinata* var. *deperdita* (0-9%).
Cibicides is well represented in the populations : *Cibicides proprius acutimargo* (0-2%), *Cibicides tenellus* (0-4%), *Cibicides pygmeus* (3-5%) and especially *Cibicides proprius proprius* (2-19%), which becomes abundant at the top of this interval.

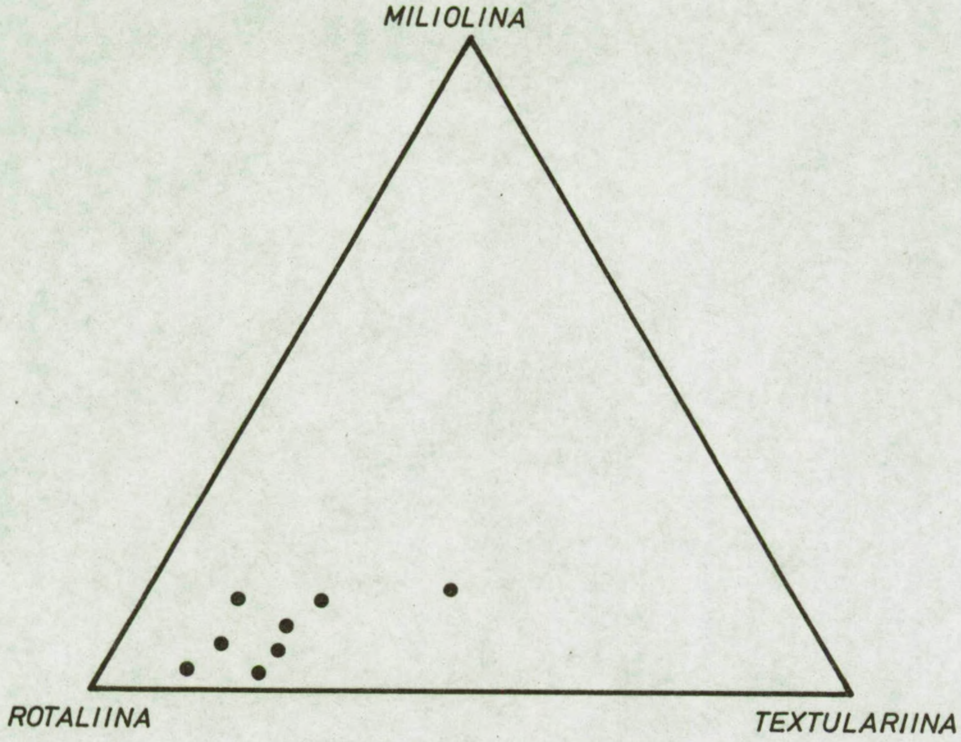

Fig. 2 : Triangular plot of suborders in faunule 1.

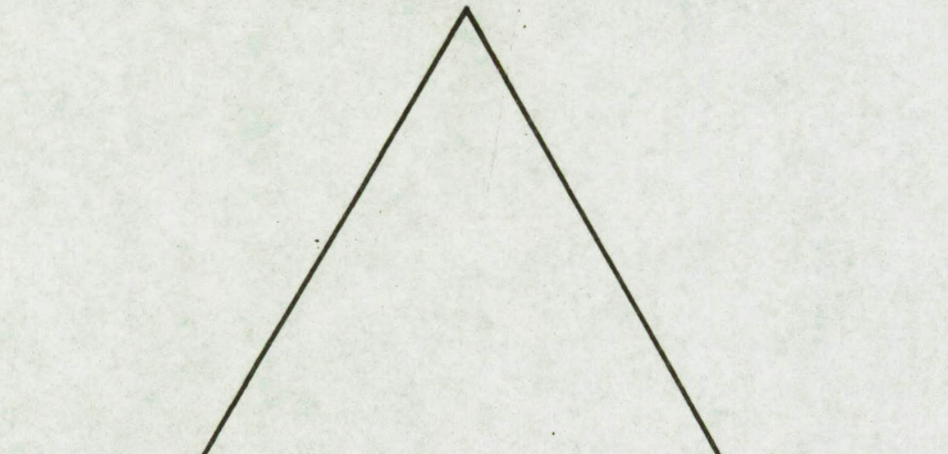

Fig. 3 : Triangular plot of suborders in faunule 2.

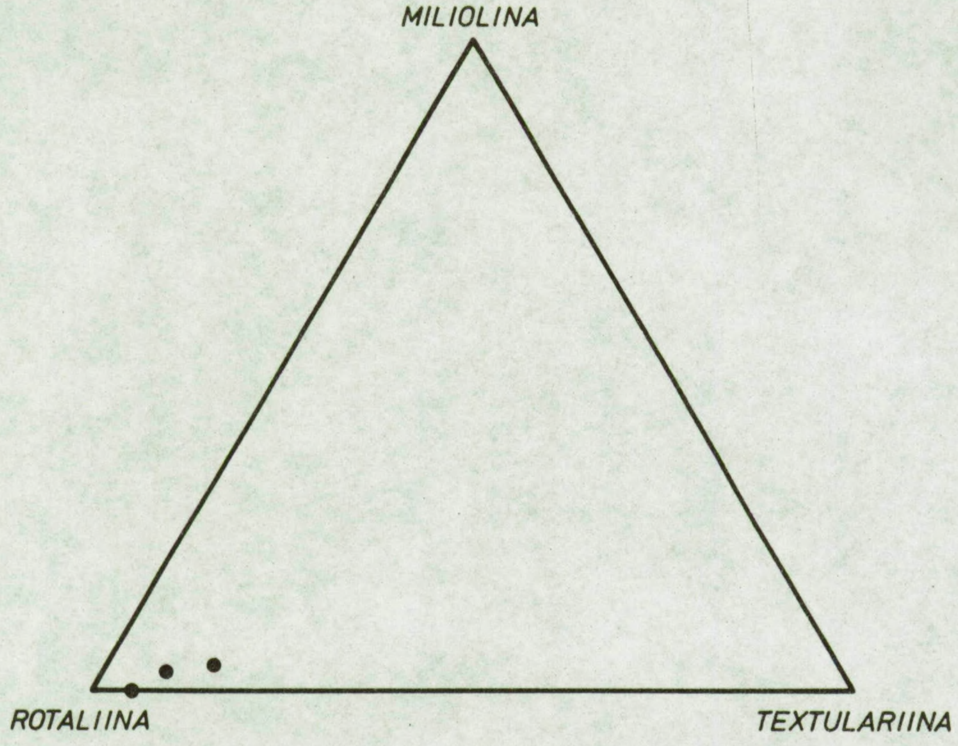

Fig. 4 : Triangular plot of suborders in faunule 3.

The porcelaneous taxa are represented by *Quinqueloculina ludwigi* (1-3%), *Quinqueloculina carinata* (0-2%), *Spiroloculina tricarinata* var. *belgica* (0-1%) and *Spiroloculina canaliculata* (0-2%).
Several hyalin calcareous species occur regularly in this interval : *Guttulina lactea* (2-7%), *Bolivina anglica* (4-10%), *Nonion affine* (3-7%), *Nonionella wemmelensis* (1-6%), *Discorbis quadrata* (2-4%), *Cancris subconicus* (1-6%) and *Entosolenia orbignyana* (3-6%).
Some other hyalin calcareous individuals appear in part of the Cassel Clay : *Rotalia audouini* (0-2%), *Elphidium laeve* (0-1%), *Nonion scaphum* (0-5%), *Bolivina carinata* (0-14%), *Uvigerina farinosa* (0-4%), *Trifarina muralis* (0-5%), *Eponides toulmini* (0-2%), *Buliminella* sp. cf. *B pulchra* (0-3%) and *Trifarina wilcoxensis* (0-4%).

3) Faunule 3 (Bassevelde Sands).

Faunule 3 shows the appearrance of several *Bolivina cookei* specimens (9-12%). A few other taxa occur more frequently than before. Especially the frequency of *Cibicides proprius proprius* (36-37%) increases distinctly. *Nonion affine* (11-13%) and *Spiroplectammina carinata* var. *deperdita* (1-14%) become important components of the assemblages. *Elphidium laeve* (0-2%) is replaced by *Elphidium subnodosum* (2-3%).
The agglutinated *Textularia agglutinans* occurs less frequently (0-5%). Porcelaneous taxa become less characteristic elements. The frequency of *Quinqueloculina ludwigi* varies from 0 to 4%.
A few hyalin calcareous species are significantly present in(part of) the interval : *Globulina gibba* (0-8%), *Guttulina lactea* (1-4%), *Guttulina problema* (0-2%), *Cibicides proprius acutimargo* (3-4%), *Cibicides tenellus* (0-7%), *Cibicides pygmeus* (3-8%), *Gyroidina octocamerata* (0-2%) and *Cancris subconicus* (0-3%).

5. TRIANGULAR PLOT OF SUBORDERS.

The three suborders of benthonic foraminifera are plotted in the triangular diagrams shown in figs.2,3 and 4. MURRAY (1973) marks out the fields for the different possible environments.

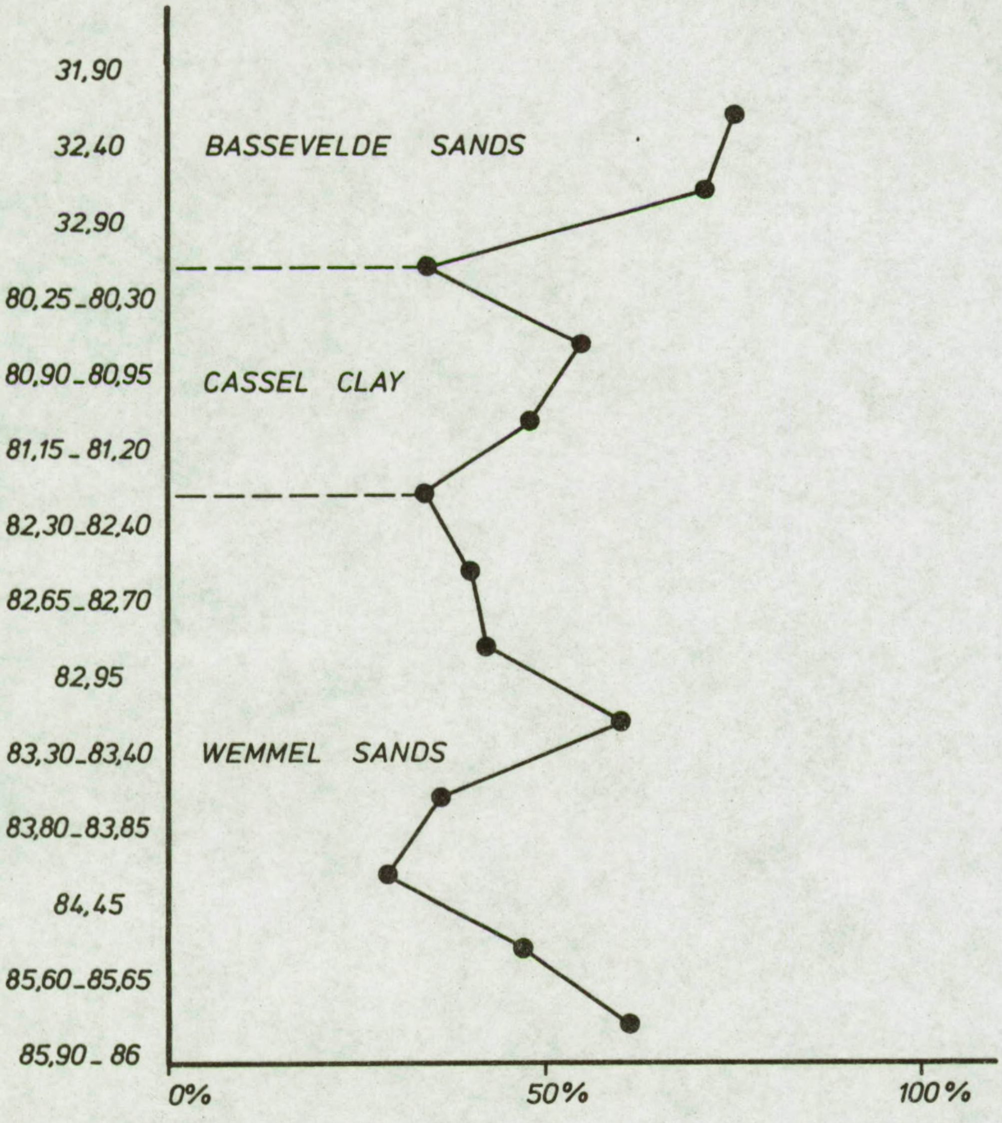

Fig. 5 : Similarity index between the successive samples.

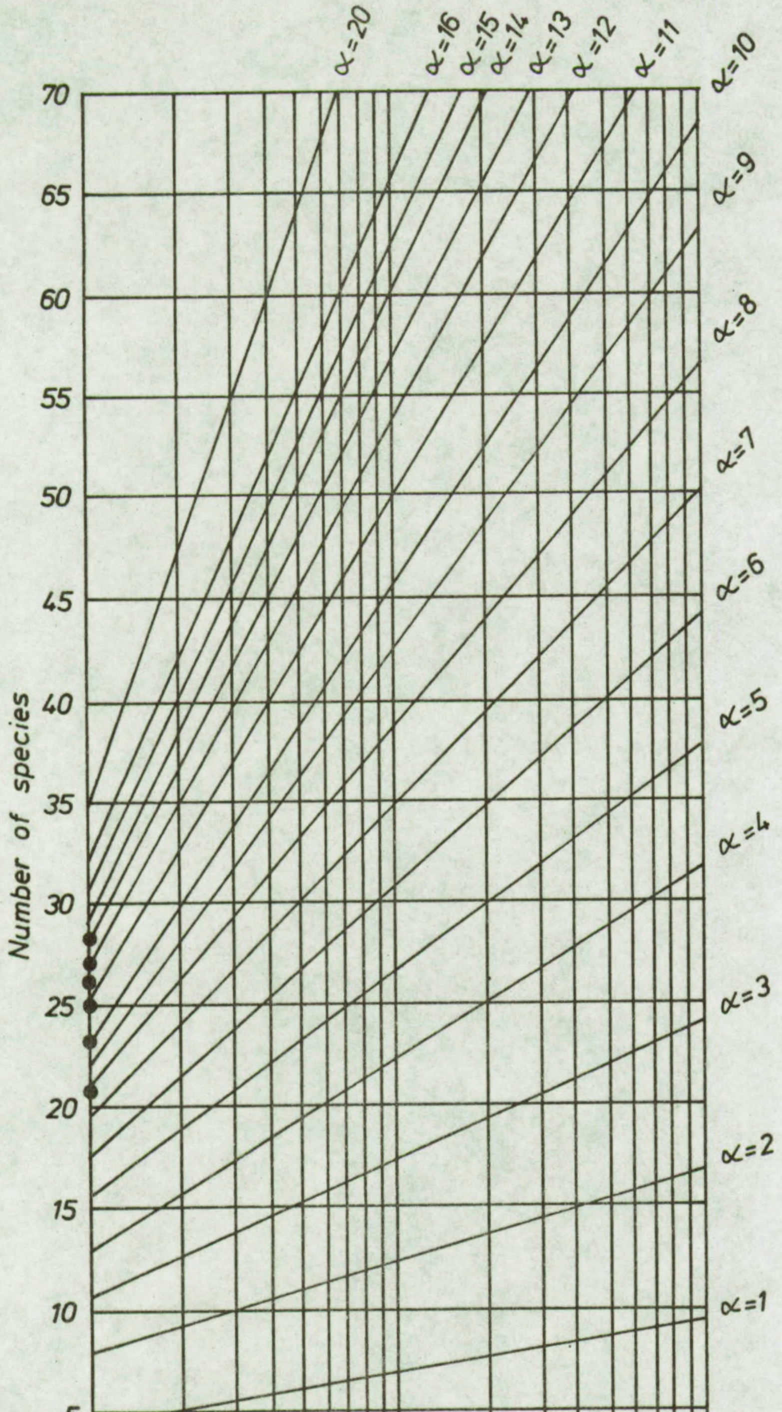

Fig.6 : Fisher α index in faunule 1.

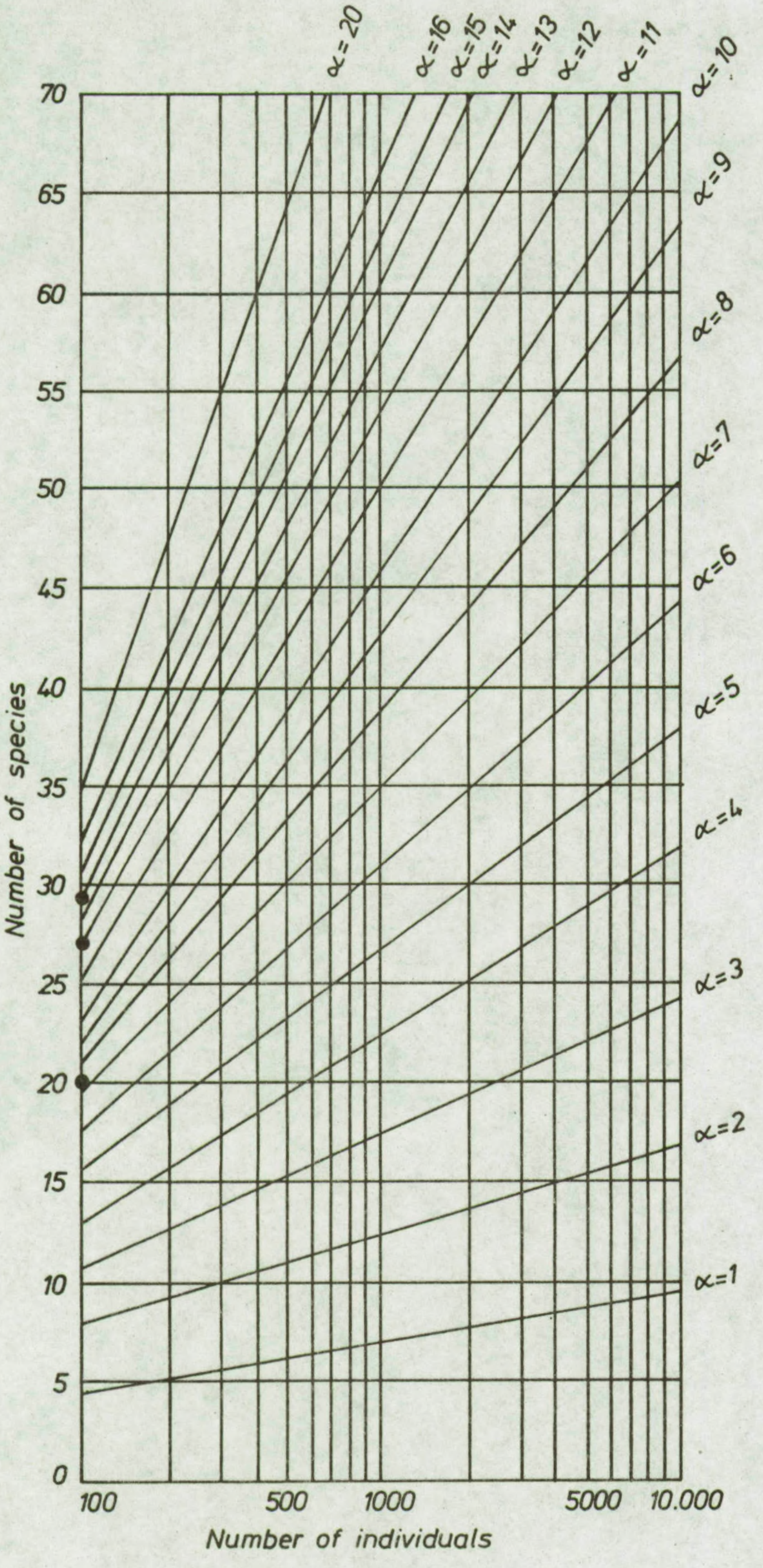

Fig. 7: Fisher α index in faunule 2.

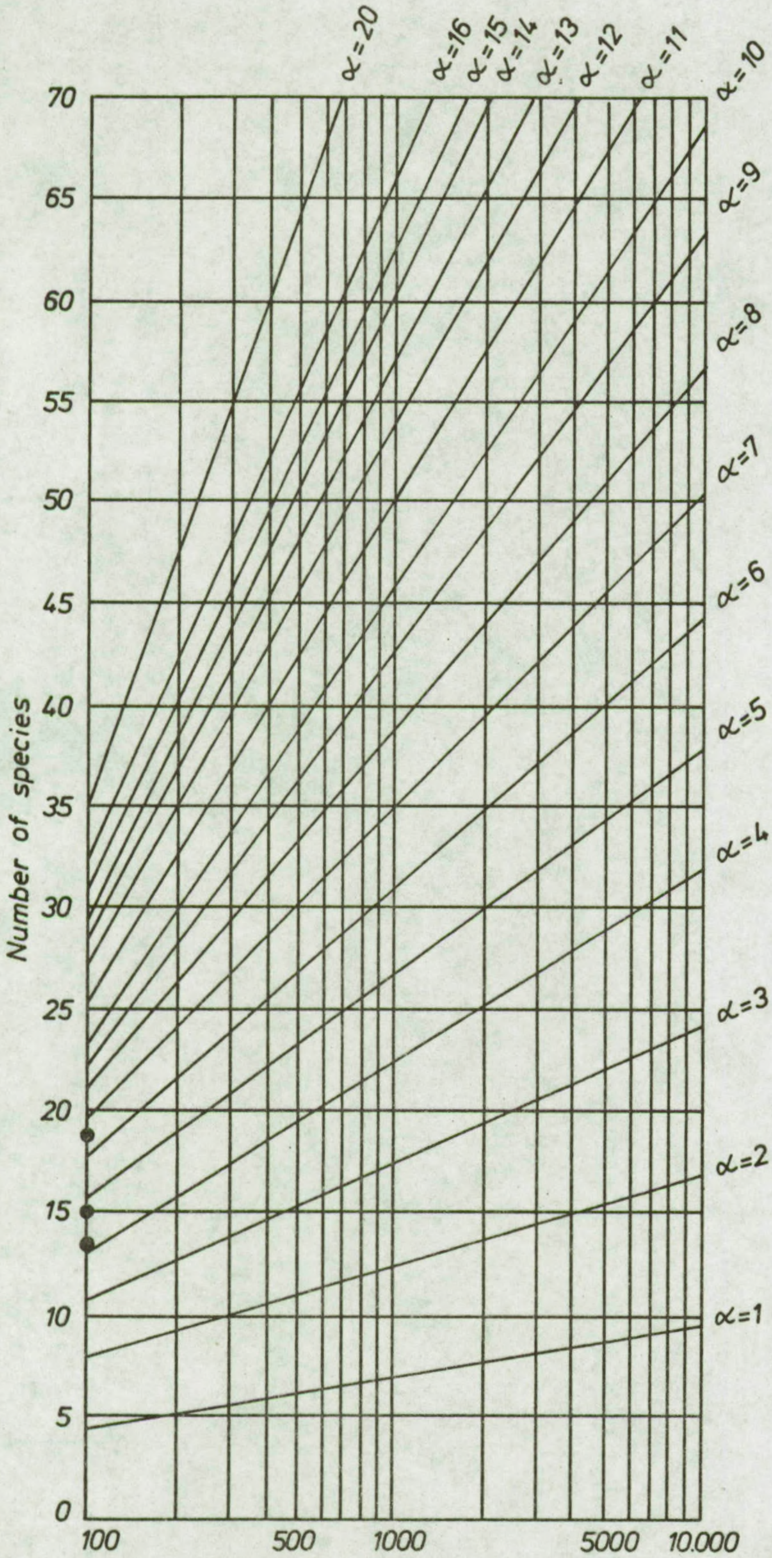

Fig.8: Fisher α index in faunule 3.

According to this interpretation, the following environments are possible for the different faunules.
Faunule 1 can occur in hypersaline or normal marine marshes, hyposaline lagoons or on the continental shelf.
Faunule 2 can survive in hypersaline or normal marine marshes, hyposaline or hypersaline lagoons and on the continental shelf.
Faunule 3 is typical for hypersaline marshes and lagoons, normal marine marshes, hyposaline marshes and lagoons and the continental shelf.

6. SIMILARITIES (SANDERS, 1960).

The similarity between the successive samples in the section studied is given in fig.5.
Within the Wemmel Sands, this index varies between 29 and 61. The lower values are explained by the aberration in the frequencies of taxa as *Guttulina lactea, Bolivina anglica, Nonion affine* and *Cancris subconicus* in sample 83.80-83.85. This association could be described as a subfaunule within the Wemmel Sands.
The transition from the Wemmel Sands to the Cassel Clay is marked by a low similarity index (34%). Within the Cassel Clay, the values vary between 48 and 55%. The generally low similarity index in the Wemmel Sands and Cassel Clay reflects the rather different populations within this units.
A low similarity index of 34% marks the transition from the Cassel Clay to the Bassevelde Sands. Within the Bassevelde Sands, the similarity index is distinctly higher than in the previous deposits (71-75%), which indicates more homogeneous populations in this member.

7. DIVERSITY INDEX OR FISHER α INDEX (FISHER, CORBETT & WILLIAMS, 1943).

The relationship between the number of individuals and the number of species in the populations of the three faunules is represented in figs. 6,7 and 8. According to the interpretations of the different environments corresponding to the various α values by WRIGHT & MURRAY (1972) and MURRAY (1973), the following conditions for the three faunules are possible.

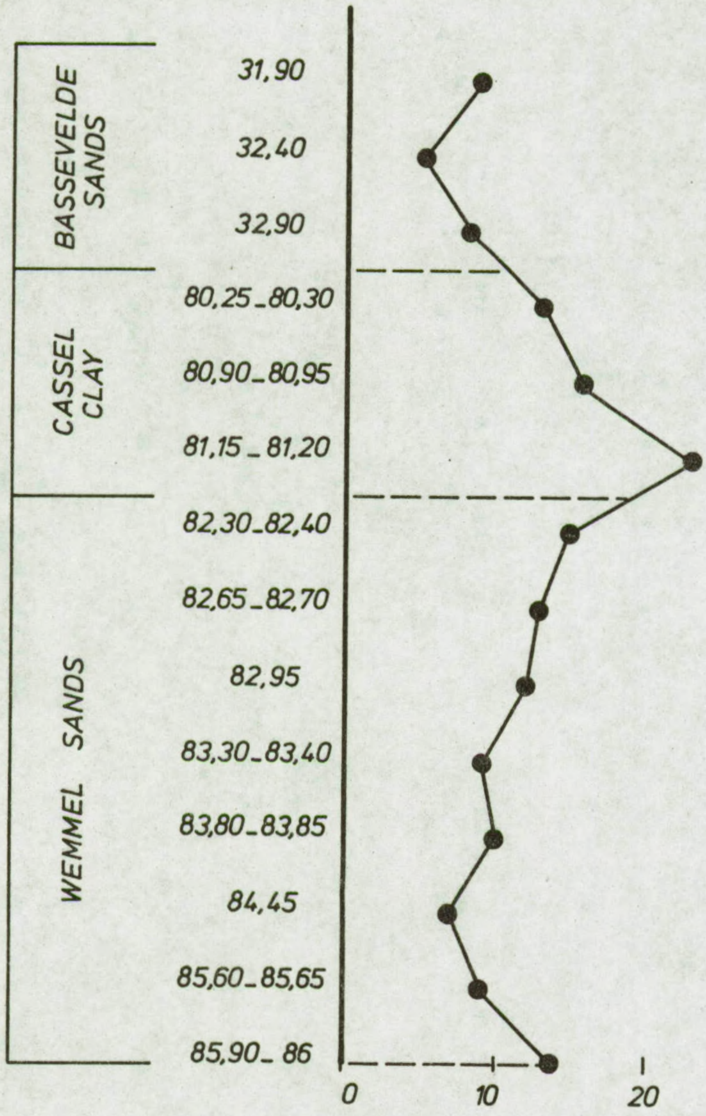

Fig. 9 : Dominance index.

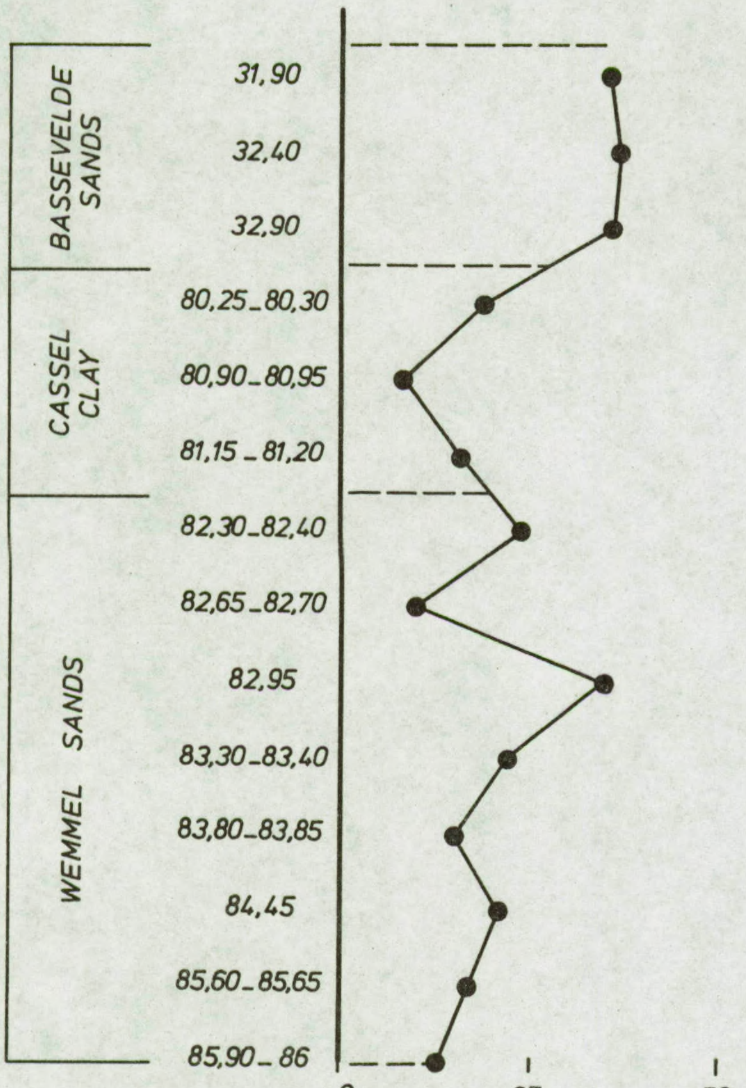

Fig. 10 : Percentage dominance.

In faunule 1, the Fisher α index varies between 7.5 and 13.
Faunule 2 gives α values between 7 and 14. These populations survive in shelf seas of normal salinity or in normal marine lagoons.
The diversity index is distinctly lower in faunule 3. It varies between 4 and 6.5. These associations occur in shelf seas of normal salinity or in hyposaline and nearshore shelf seas, in normal marine lagoons, in hyposaline and hypersaline lagoons and in hypersaline marshes.

8. DOMINANCE INDEX (WRIGHT, 1972).

Fig.9 represents the number of species in 80% of the populations. Within the Wemmel Sands, the dominance index varies between 7 and 15. Especially in sample 84.45, the index is rather low (7). The stability of the sea bottom probably changed during the deposition of the Wemmel Sands. An important increase of the dominance index in sample 81.15 - 81.20 (18) markes the transition to the Cassel Clay. The index however decreases quickly higher up in this unit (13). Roughly speaking, the values become higher in the Cassel Clay than in the Wemmel Sands. The Cassel Clay was deposited in a more stable environment. The dominance index is lowest in the Bassevelde Sands (5-9), which should suggest a more marginal environment.

9. PERCENTAGE DOMINANCE (WALTON, 1964).

The percentages of the most abundant species in the different samples are given in fig.10.
In the Wemmel Sands, these percentages vary distinctly. The values lie between 10 and 35. It suggest an environment with changing stability of the sea bottom.
The percentage dominance becomes lower in the Cassel Clay. Here, the values vary between 8 and 19. The sea bottom became more stable during deposition of this Cassel Clay.
The Bassevelde Sands are characterized by high and more constant values of the percentage dominance (36-37). These high values could indicate

a deposition in a shallower sea, in which however this deposition took place under stable conditions.

10. PALEOECOLOGICAL SIGNIFICANCE OF THE OCCURRING TAXA.

Different authors supply us information on the (paleo-) ecological significance of the occurring taxa : PHLEGER (1960), BANDY (1960, 1964), WALTON (1964), WRIGHT & MURRAY (1972), MURRAY (1973), WRIGHT (1972-1973), MURRAY & WRIGHT (1974), BOLTOVSKOY & WRIGHT (1976) and GERITS, HOOYBERGHS & VOETS (1981).

1) Wemmel Sands.

The agglutinated *Textularia*, which lives on the continental shelf or in the upper bathyal zone, is well represented in the Wemmel Sands. Other agglutinated genera with more complex morphological features as *Spiroplectammina* and *Karreriella* (siphonate aperture) prefer greater depths in the sea (outer shelf to upper bathyal zone). *Karreriella* occurs most abundantly on a muddy sediment.
The porcelaneous *Quinqueloculina* is widespread in shallow shelf conditions with a salinity higher than 30%. *Triloculina* can survive at greather depths in temperature to tropical waters of at least normal marine seas.
Several hyalin calcareous genera occur in this interval.
Guttulina and *Globulina* occur most frequently on a inner shelf. *Globulina* prefers temperate to tropical waters in normal marine seas.
Small smooth species of *Bolivina (B. anglica* and *B. crenulata)* are found in rather shallow shelf conditions.
Rotalia occurs most frequently in a nearshore environment.
The greatest abundance of *Elphidium* is observed on a shallow inner shelf with oxygen-rich waters in which algae are favourable.
Bifarina is a typical inner shelf genus.
Cibicides is currently most abundant in temperate, normal marine seas, where it lives on the shelf or in the bathyal zone in a wide range of salinity. It is attached to all types of substrates.

Nonion prefers an inner shelf zone in hyposaline to normal marine seas with cold to tropical temperatures and with oxygen-rich waters.
Nonionella is an inner shelf to bathyal genus in temperate to tropical seas.
Bulimina occurs most frequently on muddy sediment in a nearshore to bathyal environment with salinities between 32 and 36%.
Uvigerina and *Trifarina* also like a muddy sediment in normal marine seas in an outer shelf to upper bathyal environment.
Discorbis prefers a shallow sea with subtropical to tropical temperature and with a lot of seagrass and algae.
Cancris is found in the central shelf zone of subtropical normal marine seas. *Buliminella* prefers a muddy sediment in a temperate, normal marine shelf to bathyal environment.

2) Cassel Clay.

Several taxa from the Wemmel Sands still occur in the Cassel Clay. The appearance of *Alabamina* however, indicates an increasing depth. This genus prefers an outer shelf to upper bathyal environment. The increase of *Karreriella* also suggest a greather depth of the sea. *Quinqueloculina* occurs less frequently in this conditions and *Elphidium* completely disappeared.

3) Bassevelde Sands.

Genera as *Textularia*, *Spiroplectammina*, *Guttulina*, *Cibicides* and *Nonion* also occurs in the Bassevelde Sands. The most important renewal in the populations is the occurrence of striate *Bolivina*'s (*B. cookei*). This suggest a considerable depth of the sea in which the deposition took place. Nevertheless, *Elphidium* reappears in the assemblages, which indicates the presence of oxygen-rich waters and algae.

11. CONCLUSIONS.

The trangression of the Wemmel sea led to a deposition of fine sands in an inner, later in a central shelf environment. The sea bottom

however was rather unstable. The salinity of the water was at least normal (33%). The temperature increased to subtropical values. The sea water was oxygen-rich and algae were favourable.
The sea depth increased to an outer shelf environment during the deposition of the Cassel Clay. The sea bottom became more stable in this time.
We get little information on the environment of deposition of the middle part of the Kallo Formation, which is explained by the small number of benthonic foraminifera in this part of the formation. The occurrence of several *Miliolina* in sample 58.35 - 58.45 (a_2) however suggest nearshore conditions or a temporary regression of the sea at this time.
The upper part of the Kallo Formation, or the Bassevelde Sands, was deposited on a stable shelf with oxygen-rich waters. Although the dominance index and the percentage dominance suggest more marginal conditions, the presence of *Bolivina cookei* reflects a rather deep sea.

12. ACKNOWLEDGEMENTS.

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