QUANTITATIVE ANALYSIS OF NEOGENE FORAMINIFERA IN THE CENTRAL NIGER DELTA

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Abstract

A ranking and scaling (RASC) computer programme for zonation and normality testing of paleontological events was employed to identify assemblages of foraminifer a species in the sections studied. The emphasis is on ease of zonal recognition and reliability in correlation. A fourfold interval zonation of benthonic and some planktonic foraminifera were established. Two distinct temporal (Miocene, Pliocene) and four depositional environments (deltaic, lagoonal, shallow marine, and marine) are recognizable. A few benthonic foraminifera appear to have biostratigraphic significance. *Bulimina elegans* is present in the early Miocene, *Cyclammina cancellata* in the middle to late Miocene, while *Brizalina beyrichi* and *Bolivina variablilis* are restricted to the late Miocene in the studied samples. These thus apparently constitute benthic foraminiferal biozones. However, these distributions may have been environmentally controlled and may therefore be ***teil*** zones. The presence and abundance of neritic fauna with lignitic materials indicate alternating shallow marine and non-marine depositional conditions in the parts of the Niger Delta where these strata were sedimented.

1. Introduction

The foraminiferal faunas of the Central Niger Delta contain low numbers of specimens and species, most especially the planktonic forms, because of their deposition under deltaic conditions (Ojo, 1997). Hence, a detailed zonation is often impossible. To solve this problem, in part, a quantitative ranking and scaling of biostratigraphic events based data from seven wells was employed.

This method of Ranking and Scaling (RASC) can process a complex and noisy stratigraphic record in an objective manner (Agterberg and Nel, 1982a,b). Ranking is a pair wise comparison technique that tries to determine the most likely sequence of biostratigraphic sections. Scaling determines the spacing of these events in relative time, using the frequency crossover in relative position of the events in the wells. The relative position of the events in the final ranked and scaled optimum is essentially an average of all the relative positions encountered. The RASC zonation is not vulnerable to outliers in the original data, because tests on the stratigraphic normality of the individual (well) record, relative to the calculated standard reveal where the outliers are. Also, the paleoenvironmental aspects of species, which are often ignored in biostratigraphic classification is important in any biostratigraphic study. The paleoenvironmental history of the Neogene Central Niger Delta is less well studied than that of the West and Northwest Niger Delta using quantitative methods.

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Gibson & Buzas (1973) and (Ingle, 1980) used quantitative data to assess paleoenvironments of foraminifera from eastern margin of North America and Ventura Basin respectively. Many other workers have used quantitative methods to assess paleoenvironment. These include among others, Bandy & Arnal (1960), Mello & Buzas (1967) and Lagoe and Thompson (1988).

In Niger Delta basin, only a few published quantitative paleoenvironmental studies are available and these include the works of Adegoke et al (1976) and Petters (1982). This study quantifies the planktonic and benthonic foraminifera of the Central Niger Delta. It also interprets depositional paleoenvironments by comparison of fossil fauna with present day foraminifera distributions associated with specific environments of the Gulf of Guinea coast.

2. Objectives

The primary objective of this paper is to briefly describe the biostratigraphy of the Central Niger Delta basin form a quantitative point of view and to interpret the environments of deposition. Some specific objectives include:

i. Brief description of the quantitative methods of analysis of biozones and depositional environments of the Neogene times and

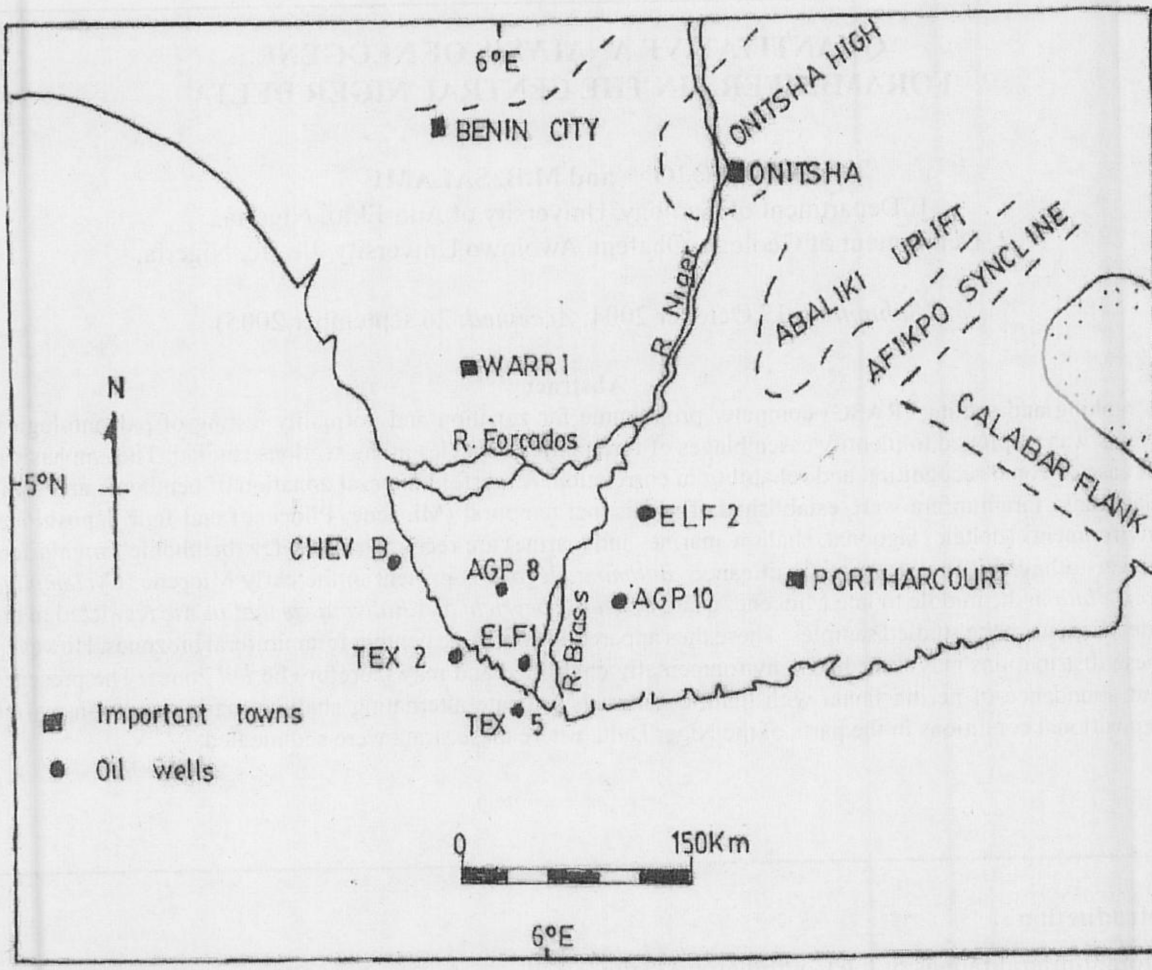

Fig. 1: Map of the Niger Delta showimg location of wells studied

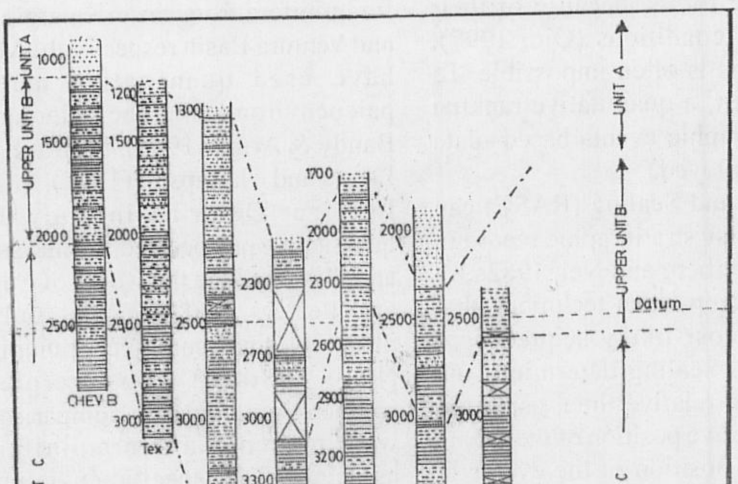

Fig. 2: Location and lithology of studied wells

ii. Detailed documentation of faunal records, precise zonation, and paleoenvironmental interpretation.

3. Methods of Study

Ditch-cutting samples were disaggregated and washed clean of all silt and clay size materials (<63μm). From each sample, foraminifera were picked and identified. Computer methods were used for the recording and displaying of biostratigraphic data and also for the paleoecologic interpretation of picked foraminifera. The computer softwares used for this study are:

(i) The Ranking and Scaling (RASC 12) version 12 and the Data List (DATLST) by Agterberg *et al.* (1989), and

(ii) Multivariate statistical package (MVSP) by Kovach (1990) for the paleoecologic analysis.

The combination of lithofacies and biofacies was used to infer the environments of deposition within the study area. Interpretations made in this study also utilize the investigations of depositional processes and products in the Gulf of Guinea by Oomkens (1974), Adegoke (1976), Salami (1982), Petters (1982), and Tiamuyu (1989).

(a) Study Area

Seven exploratory wells were studied for the purpose of biostratigraphic and paleoenvironmental interpretation from three of the seven depo-belts of the Niger Delta basin. The wells (Fig.1) are located as follows:

ELF-2 well OML58; ELF-1 well OML 59; TEX- 5 well OML86; TEX-2 well OML 86; AGP-1 well OML 63; AGP-8 well OML 63 and CHEV- B well OML 90.

(b) Lithostratigraphy

The lithostratigraphic units presented here are based on the studies of ditch-cutting samples using the unaided eye, hand lens and binocular microscope. In all, 940 samples were studied. Visual observations of these cuttings were done in an attempt to ascertain at each depth, the colour, fissility, hardness of shale, sand/ shale ratio, identifiable minerals and textural characteristics of the sandstones.

Three informal lithostratigraphic units A, B and C have been recognized and described.

(i) Unit A

This lithostratigraphic unit is the uppermost unit, and it is recognized in all the wells studied. Unit A is predominantly sandy, incorporating sandstones, gravelly sandstones and silty sandstones. Occasionally, shaly materials are found which are volumetrically insignificant at the upper level but become more frequently encountered at lower levels. The sandstones, which consist mainly of quartz, are found to range from well sorted to poorly sorted. Some of the quartz grains are rounded to sub-angular, whilst some are pebble-sized. Also found within this unit are broken shells lignite materials and specks of mica flakes (which are restricted to samples within the thin shale intercalations).

The sands and sandstones are white to yellowish brown, when viewed under the binocular stero-microscope. The grain diameters vary from 1.00 mm to 2.00 mm. The observed quartz grains can be grouped into transparent, grayish white, pink and smoky colouration.

This unit cannot be dated accurately because of the rarity of its foraminifera content. However, sparse and uneven recovery of ostracodes, belonging to the genus *Cytherella* (Jones), tentatively dates this unit Eocene-Recent.

The presence of broken shells of micro gastropods, and bivalves and ostracodes carapaces points to a shallow and turbulent depositional environment. This unit is similar to the Benin Formation of Short and Stauble(1967), Avbovbo(1978) and Whiteman (1982).

(ii) Unit B

This unit underlies unit A. The boundary between the two units is herein arbitrarily placed at the section where quartz sand grains grade from coarse to fine and the resistivity value becomes very high.

Unit B consists of alternations of sands, silty sandstones and shale. Numerous off lap rhythms occur. The sandstones are from coarse to fine grained .The slightly consolidated sands have a predominantly calcareous matrix but most are unconsolidated. The sandstones are poorly sorted, except where there is a gradual grading into the shaly beds. Lignitic materials, shell fragments and plant remains are common within the unit.

Unit B differs from the overlying unit A in the following ways:

(i) Feldspathic grains are fewer and smaller in size in the samples of unit B

(ii) The percentage of the yellowish-brown quartz is lower in most samples (about 0-2%) of unit B

(iii) There is a steady increase in shaliness with depth in unit B

This unit range from Miocene to Pliocene based on the microfauna recovered from the sections studied. The age-indicative foraminifera recovered within the unit include *Globigerinoides primordius, G. immaturus, G trilobus, G extremus, Globoratalia mayeri, G. acostaensis* and *G. tumida.*

The paleobathymetric analysis shows that the unit must have been deposited in environments ranging from inner neritic to continental slope. This is based on the presence of characteristic neritic fauna such as *Bolivina, Cassidulina* and *Cibicidoides* (see Gupta *et al.*, 1981) and the lignitic materials, indicating alternation of shallow marine and non-marine conditions during deposition. The abundant neritic fauna of this unit include *Ammonia, Trochammina, Quinqueloculina* and *Bolivina*.

Unit B is similar to Agbada Formation of Short and Stauble (opcit).

(iii) Unit C

Unit C underlies B but the two units actually grade into one another; hence, fixing a boundary between the two units is not easily achieved. The unit is predominantly shaly with occasional layers of sandstones, silty sandstones and silty shales. The intercalated units are in most cases not as thick as the shale. Generally, sandstones decrease in thickness towards the base of the unit while shaliness increases downwards. The shale varies from light to dark grey. A lot of organic materials are pyritized nodules, which are presumed to be responsible for the light to dark greyish coloration found in this unit. In addition, mica flakes, whose sizes are much smaller than what are obtainable in units A and B, occur. The mica flakes, which are silt sizes are believed to have been winnowed out of high-energy environments and carried in suspension to where lower turbulence, prevailed (Pomeranchblum, 1996; Adegoke and Stanley, 1972). It is therefore concluded that unit C was deposited in a low energy environment.

The age of Unit C is put at Upper Oligocene/ Lower Miocene- Recent. The unit is relatively richer in planktonic species than the remaining two units. Some of the very well preserved species include those of *Globigerina, Globigerinoides, Globoquadrina, Globorotalia* and *Orbulina*.

The paledepth of this unit is estimated to range from the middle neritic to upper bathyal zone. This is because of the abundance of benthonic species of *Uvigerina, Epistominella, Eponides, Nodosaria, Bulimina, Cyclammina* and *Nonionella* and some planktonics. Unit C is characteristically similar to the lower Agbada Formation and the uppermost section of Akata Formation of the Niger Delta (Short & Stauble, 1967; Avbovbo, 1978 and Whiteman, 1982).

(c) Biostratigraphy and Age

Data Analysis

The database for the analysis performed with the RASC computer programme comprises the observed sequence of Neogene foraminiferal events from seven exploratory wells, drilled in the Central Niger Delta. A total of 189 foraminiferal events were used for the stratigraphic analysis. Each event is given a unique code number, which is recorded in a dictionary. The inputs consist of the observed sequence of (coded) events accompanied by the dictionary. Simultaneous events are connected by hyphens, which means the computer read those as occurring in the same samples.

The events consist of the highest or first stratigraphic occurrence of fossil forminifera, and or single occurrences. In a subjective approach, stratigraphically isolated occurrences might be considered respectively as due to contamination or reworking and consequently ignored. The data used in this study is not subjected to such bias.

4. Results

After several runs of the RASC program under varying Kc/ Mc conditions, the optimum sequence obtained 4/3, Kc/ Mc conditions were chosen, as the basis for further evaluation of the 189 events entered. Only 28 satisfy these conditions. Figure 3 shows the histograms that display the interfossil distance between the ranked taxa.

Four zones based on planktonic and benthonic foraminiferal species were established. These zones have been compared with the zonations of Ogbe (1982) and Petters (1982). The associated planktonic species are used in determining the ages of the strata in Central Niger Delta. The four interval zones recognized from older to younger, are:

(i) *Textularia laminata Zone:*

Age: Upper Oligocene/ Early Miocene (N3-N5)

Taxa: *Haplohragmoides reticularis, Globigerinoides immaturus, Globorotalia obesa, Alveolophragmium* sp, *Globoquadrina altispira, Bulimina pupoides* and *Cibicides pseudoungerianus.*

Bulimina pupoides was originally described form the Tertiary of the Vienna basin. It is a species, which have been documented in other parts of the world and found to be common in the *Uvigerinella sparsicostata* zone of Agua Salada group of Venezuela; which has been dated Oligocene-Miocene. (The presence of other planktonic species: *Globigerinoides immarturus,* whose stratigraphic range is N5 to Recent, and the *Globorotalia obesa* with a range from P22 to Recent, puts the range of this zone at Upper Oligocene/ Early Miocene).

This zone corresponds to Ogbe's (1982) *Megastomella africana* zone and Petters' (1982) *Hanzawaia mantaensis/ Cibicides coloumbianus* zone.

The zone is recognized in AGP- 10 well at a depth range from 2460 m to 4120 m; in ELF-1 well 3200 m to 3500 m, in AGP-8 well 2420 m to 3340 m and in TEX-5 well 3700 m to 4340 m. The top of this zone is defined by the quantitative top and last appearance of *Cibicides pseudoungerianus*. It is also defined by the first occurrence of *Globigerinoides sacculifera.*

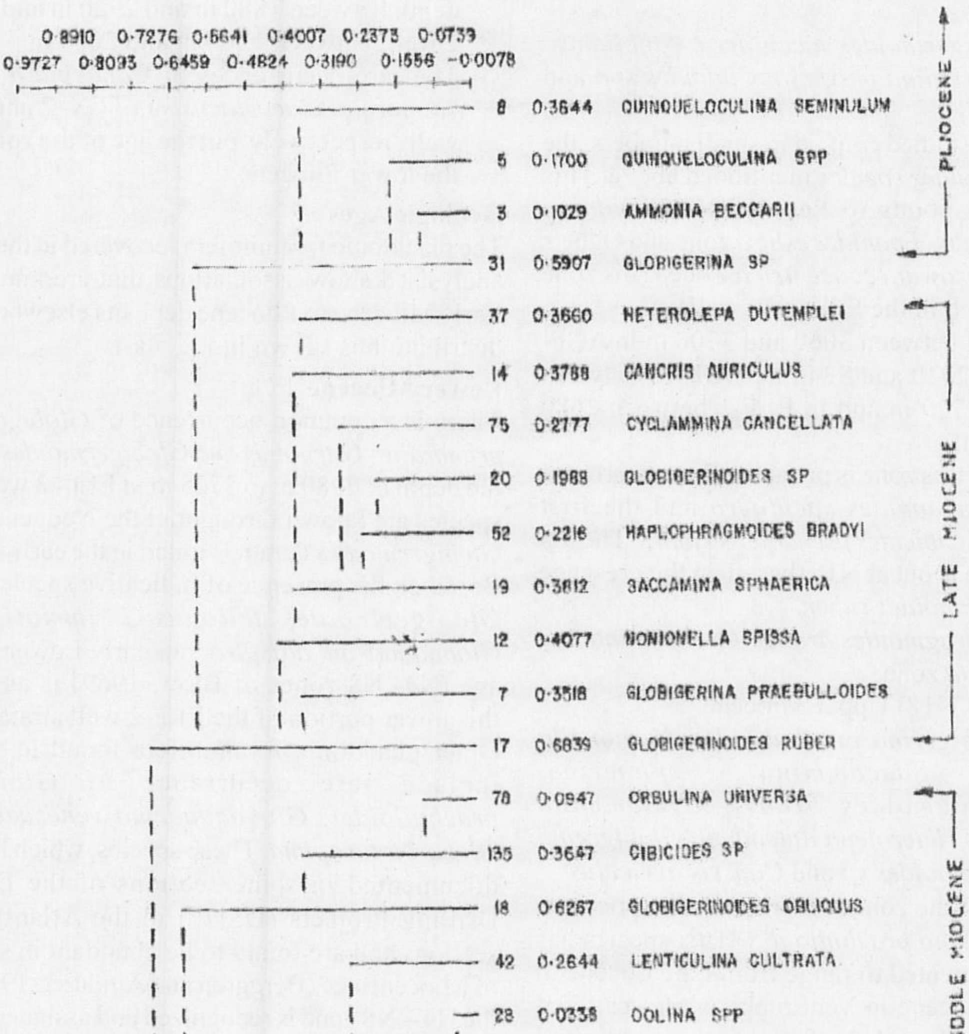

Fig. 3: Informal biostratigraphic zones/Ages of Foraminifera species established in the studied wells

(ii) *Lenticulina cultrata* Zone.

Age: (N6-N14) Early Miocene- Middle Miocene.

Taxa: *Globigerinoides sacculifera, G. obliquus, G. ruber Orbulina universa, Cibicides spp* and *Oolina spp.*

Most wells studied contain in small numbers, the *Globigerinoides species* mentioned above. This zone corresponds to Petters (1982) *Nonion ecuadoranium/ Eponides eshira* zone and Ogbe's (1982) *Hanzawaia concentrica* Zone. This zone is recognized in the following wells:

ELF-2 well between 3060 and 3700 m in AGP-8 between 2420 and 3340 m, AGP-10 between 3100 and 3720 m and in ELF-1 between 2680 and 3480 m.

The base of this zone is put at the first occurrence of *Globigerionoides saculifera* and the first common of *Cibicides pseudoungerianus.* The top of this zone is put at N15, based on the presence of *Globigerinoides ruber*.

(iii) *Haplophragmoides bradyi/ Cyclammina cancellata* zone.

Age: (N15- N18) Upper Miocene.

Taxa: *Globigerina praebulloides, Nonionella spissa, Saccammina sphaerica, Haplophragmoides bradyi, Cyclammina cancellata, Heterolepa dutemplei, Globigerina* sp.,*Globigeinoides sp* and *Cancris auriculus.*

The base of the zone is marked by the presence of *Globigerina praebulloides.* This species has been documented to range from Late Eocene to Middle Miocene in Venezuela, while scattered occurrences have been found in the middle and Late Miocene Deep Sea Drilling Projects (DSDP) sequences.

This zone is equivalent to the *Pseudonodosaria paucicostata, Spiroloculina tenuis* of Petters (1982) and *Spiroloculina* and the Arenaceous species zone of Ogbe (1982). *Haplophragmoides bradyi* is reported to have a common occurrence in the Late Miocene to Pliocene of the Niger Delta (Petters, 1982). *Cyclammina cancellata* is documented to be in the Middle Oligocene-Miocene deep- water facies in the Niger Delta (Petters, *op. cit*).

This zone is recognized in the following wells and at the stated intervals: CHEV- B: 1200 m to 1800 m, TEX- 2: 1200 m to 2760 m, TEX- 5: 1950 m to 3980 m and ELF- 1 2680 m to 35000 m

(iv) *Quinqueloculina seminulum* Zone.

Age: (N19- Recent) Pliocene- Recent

Taxa: *Ammonia beccarii, Quinqueloculina* sp and *Globeriberina* sp.

This Zone is equivalent to the *Epistominella vitrea* zone of Petters (1982) and the *Textularia mexicana* zone of Ogbe (1982). It is recognized in the following wells, in CHEV- B, between the depths of 1200 m and 1900 m, TEX-5 well at a depth between 1880 m and 2920 m and in TEX-2 well, between 1260 m and 2080 m.

The rare occurrences of C*andeina nitida* and *Globorotalia acostaensis* in TEX- 2 and TEX- 5 wells respectively, put the age of the zone within the lower Pliocene.

Geologic Ages

The planktonic foraminifera recovered in the samples analysised show associations that are known from Early Miocene to Pliocene deposits elsewhere. Their distribution is shown in Fig. 4a-f.

Lower Miocene

There is a common occurrence of *Globigerinoides primordius, G. trilobus and Globigerinoides sp*. From the depth of 2980 m to 3725 m in ELF- 2 well. These species are known throughout the Neogene, but the *Globigerinoides* datum is found in the early Miocene. Based on the presence of indicative species such as *Globigerinoides trilobus,G. immatirus* and *Globoquadrina altispira* , an early Lower Miocene age (N4- N8 zones of Blow, 1969) is assigned to this lower portion of the ELF-2 well strata.

Other planktonic foraminifera found in this zone include rare occurrence of *Globigerina praebulloides, Globoquadrina venezuelana* and *Globorotalia opima.* These species, which have been documented in some sections of the Deep Sea Drilling Projects (DSDP) in the Atlantic Ocean sections and are found to be abundant in sediments of Miocene age (Berggren and Amdurer, 1985). Thus the N4 – N8 zone is recognized and assigned to lower section of ELF –2 well zone from a depth of 2980 m to 3735 m and in TEX- 5 well from a depth of 3700 m to 4300 m.

Middle Miocene

A faunal association of *Globorotalia/ Orbulina suturalis* is hereby recognized in the Central Niger Delta. This association is based on the various *Globigerinoides tribolus* variants together with *Orbulina suturalis, O. universa* and *Globorotalia* sp which are found to characterize samples of the wells studied.

Orbulina universa commonly occurs in the depth ranges indicated in the wells below: 2550 m- 3650m in TEX- 5 well, 2328 m- 2750 m in CHEV- B well and 3445 m- 3495 m in ELF- 1 well.

This species is indicative of a middle Miocene age. The *Orbulina* species datum plane is known to span the N8/N9 zones of Blow (1969). Additional evidence of a Miocene age is provided by the presence of the species of *Globorotalia mayeri* at the depths of 3445 m, in ELF-1-well and 2382m in CHEV – B well. *Globorotalia pseudo-obesa*: is also found at a depth of 3480 m in ELF-1-well, thus confirming the recognition of N14 zone of Blow

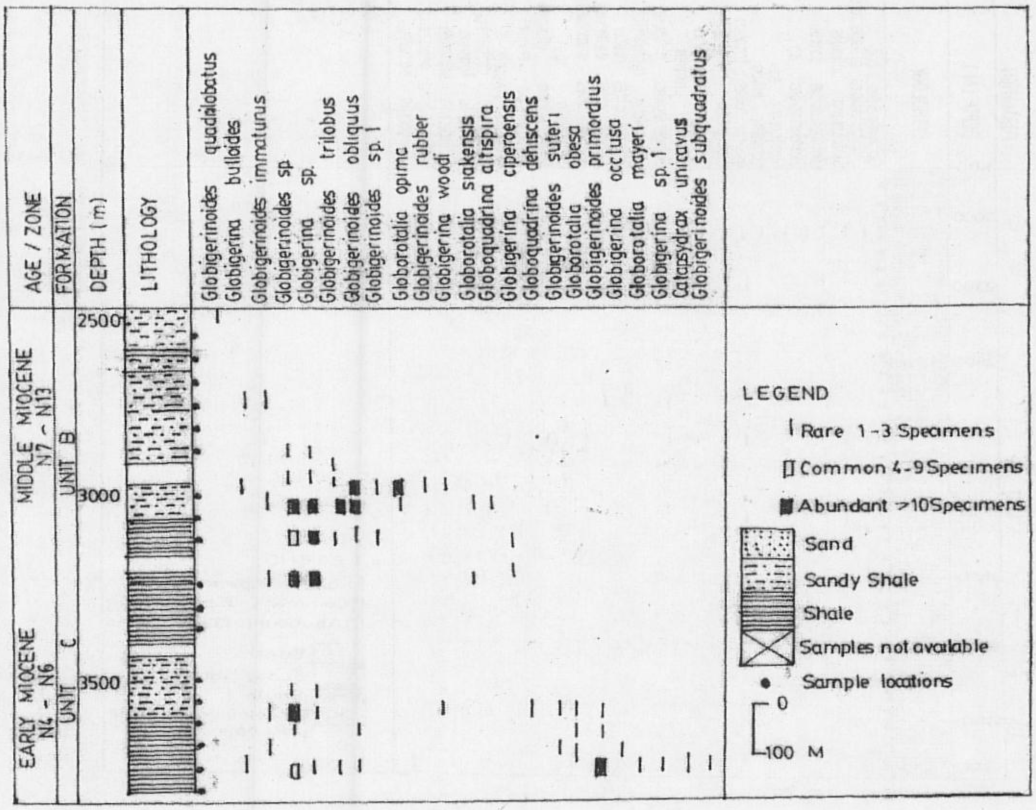

Fig. 4a: Distribution of Planktonic Foraminifera in ELF-2 well

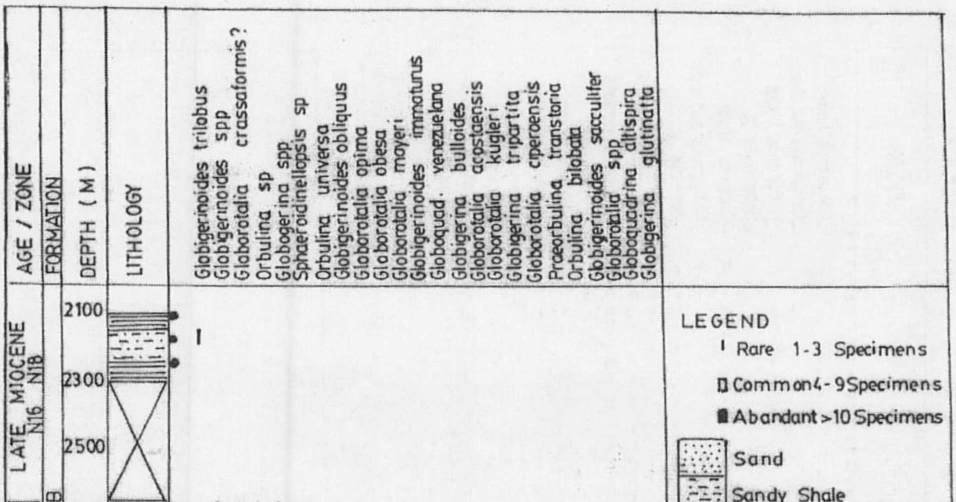

Fig. 4b: Distribution of Planktonic foraminifera in ELf-1 well.

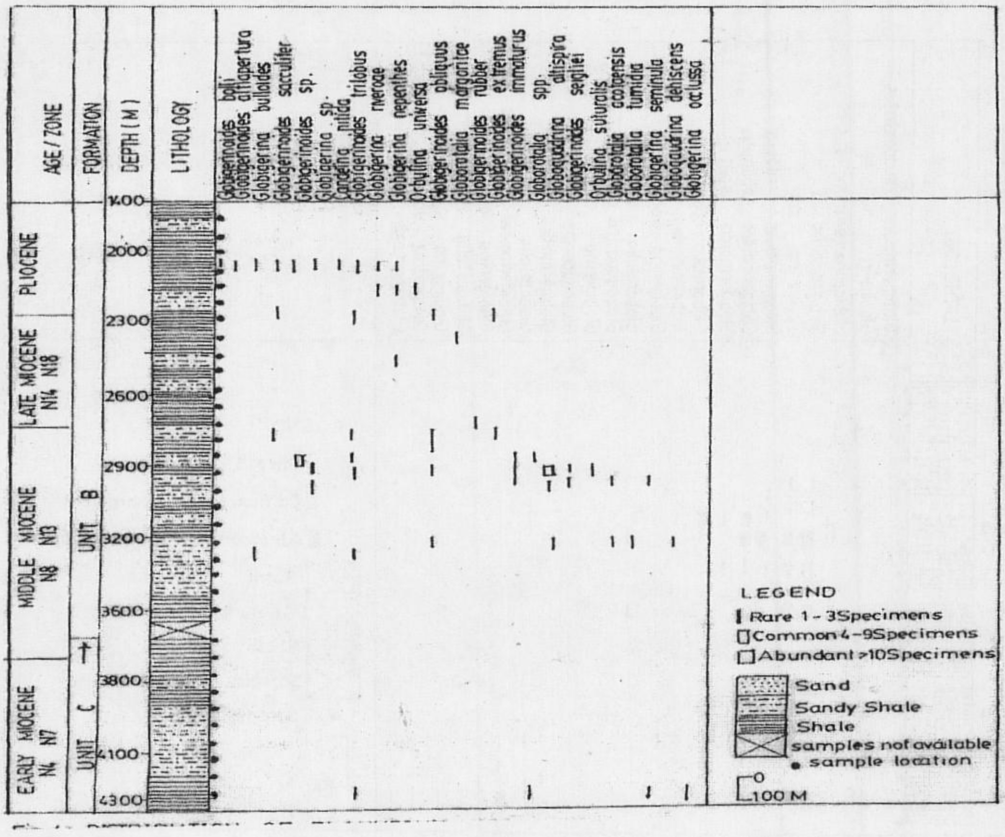

Fig. 4c: Distribution of Planktonic Foraminifera in TEX-5 well

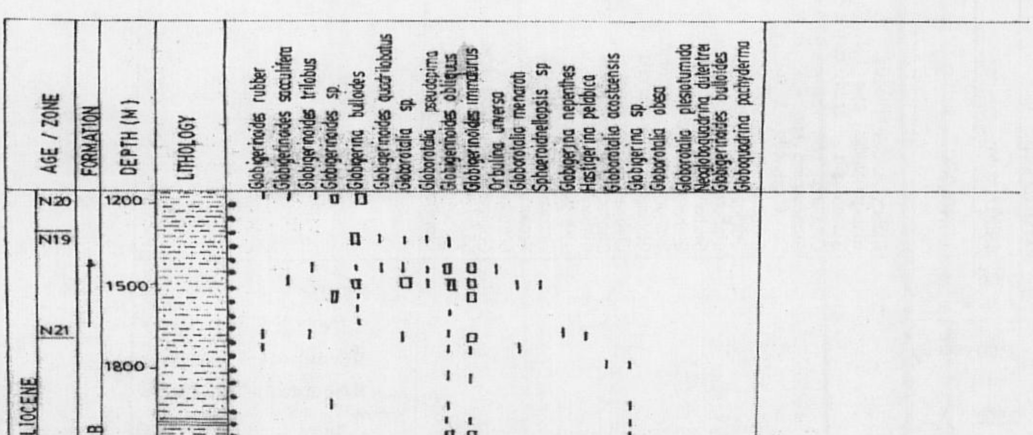

Fig. 4d: Distribution of Planktonic Foraminifera in TEX-2 well

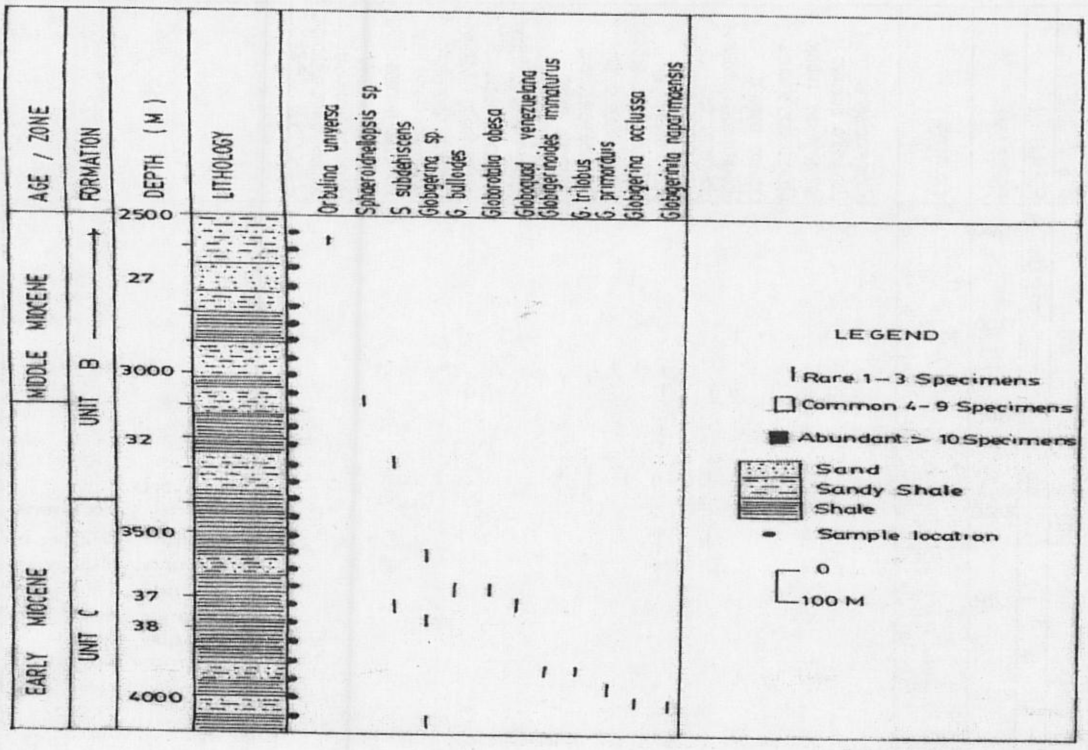

Fig. 4e: Distribution of Planktonic Foraminifera in AGP 10 well

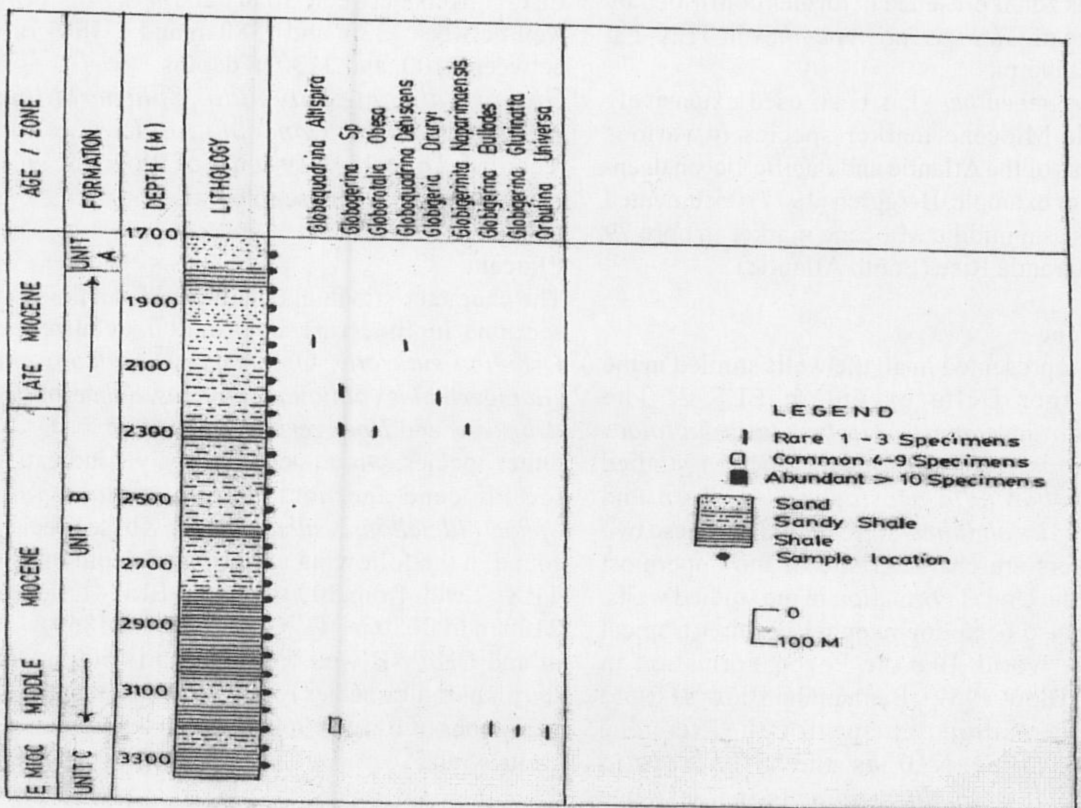

Fig.4f: Distribution of Planktonic Foraminifera in AGP-8 well

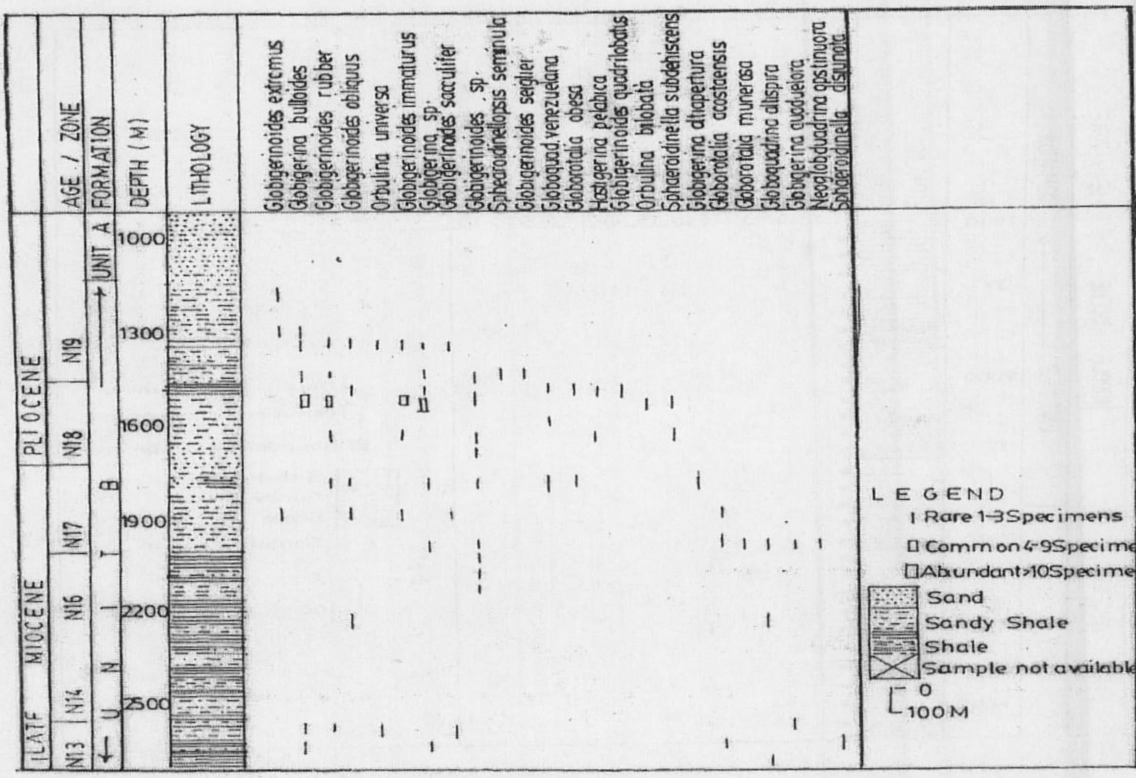

Fig. 4g: Distribution of Planktonic Foraminifera in CHEV-B well

(1969). This zonal presence is further confirmed by the presence of *Globigerina nepenthes* in TEX-2 at a depth of 2505 m.

Globigerina nepenthes has been used extensively as a middle Miocene marker species in various tropical areas of the Atlantic and Pacific Ocean deep-sea cores. For example, Berggren (1977) documented this species as a middle Miocene marker in core 79 of the Rio Grande Rise (South Atlantic).

Late Miocene

This age is represented in all the wells studied in the Central Niger Delta except in ELF–2. The *Globorotalia acostaensis/ Globorotalia bulloides* partial zone is recognized in the section studied because *Globorotalia acostaensis, G obesa* and *Globigerinoides obiliquus* were recorded. These two zonal markers are characteristic of the uppermost member of the Unit C Formation in the studied wells. They have also been documented in other tropical parts of the world, like the Pozon Formation in Venezuela (Blow, 1959). Banner and Blow's (1965) planktonic zonation scheme for the Neogene proposed a zone N16 as the *Globorotalia acostaensis/ Globorotalia merotumida* partial range zone. However, *G. merotumida* was not identified in the present study. Rather, *Globigerinoides extremus, Globorotalia nepenthes* and *Orbulina universa* occur regularly in TEX-5 well between 1887 and 2505 m, ELF- 1 well between 3050 and 3425 m, TEX- 2 well between 1330 and 1380 m and CHEV- B well between 2100 and 2130 m depths.

Globorotalia plesiotumida, Sphraeroidinella subdehiscens and *Candeina nitida* were rarely recorded. The N15- N19 zones of Blow (*op. cit.*) are recognized within these intervals.

Pliocene

The characteristic fauna recovered from the studied sections include rare but regular occurrence of *Orbulina suturalis,* O.*universa, Candeina nitida, Globigerinoides obliquus extremus, Sphaeroidinella dehiscens* and *Hastigerina siphonifera.*

Other species, which occur rarely, yet indicative of the Pliocene age, include *Globorotalia tumida Sphaeroidinellopsis subdehiscens.* These species are found in the following at the stated depth intervals: TEX- 2 well from 300 to 400 m, ELF –1 well from 2180 m to 3050 m, TEX- 5 well from 1869 to 1887 m and CHEV-B well from 1374 to 1509 m. Thus, the planktonic species recovered show that the N19-N21 zones of Blow (1969) occur in the Central Niger Delta strata.

Quantitative Paleoecology

This section focuses on the quantitative paleoecological investigation of the recovered foraminaferal species. It aims at providing an insight into the composition of the faunal communities. Multivariate analytical methods were used to decipher possible correlation between depositional environment and faunal composition.

Cluster Analysis

Cluster analysis of the data was performed using the unweighted pair groups method arithmetric average (UPGMA) of Pielou (1969, 1984). This method is one of the most commonly used forms of average linkage clustering, as it generally gives the most reliable summation of the similarities or dissimilarities of the input data (Sneath & Sokal, 1973). This clustering was performed on a matrix of similarities using the Spearman Rank order coefficient (Sokal & Rholf, 1981). This coefficient takes into consideration only rank order of the abundances of objects.

Results

The dendrogram of Fig. 6- 1 can be divided into four groups of samples. These groups were chosen on the basis of distinctness of the cluster in the dendrogram and apparent major patterns in the data matrix. The selection is based on the fact that clusters are considered as entities without special reference to the vertical or to a horizontal line drawn arbitrarily on the dendrogram. This is necessary in order to keep the discussion relatively concise since the dendrograms offer many interpretations of when and where clusters start and stop.

According to Mello and Buzas (1968), the selection at which the dendrogram reflect meanifully relations between samples (or species) presupposes that such meanifully relations exist over the sampled area and that the data are good enough to reflect them. Hence, natural discontinuities in the dendrogram more of less objectively define groups of samples or species as belonging together. However, other criteria, such as a requisite number of clusters or the closest match of clusters to other criteria may be used for the subdivision. There is no compelling reason to use a level of demarcation in this biofacies analysis.

Each of the sample clusters is characterized by one or more dominant taxa that along with other sub-dominant taxa form the basis for the four clusters.

In the sample dendrogram, two of the clusters (1A and 2A) are small, containing 7 and 8 samples respectively with distinct assemblages. Group 1B contains samples from lower delta plain- delta slope facies, because they are characterized by containing the arenaceous foraminifera like *Valvulina flexilis, Textularia laminata, Ammobaculites strathearnensis* and *Cyclammina cancellata* and some calcareous forms like *Bolivina doniezi* and *Bulimina* sp.

Group 2A cluster contains the same suite of the dominant taxa constituted by *Uvigerina eponides* and *Magastomella africana.* The cluster contains a lot of planktonic species too and is therefore inferred to be of pro- deltaic facies.

Group 2B contains samples from the marginal marine facies. The characteristic species of the samples include *Ammonia beccarii, Quinqueloculina lata, Triloculina trigonula, Marginulina planata, Florilus boueanum* and *Nonion* spp.

Group 1A includes most of the samples from AGP – 10 well and is characterized by different co-dominant taxa, including *Cyclammina cancellata, Bolivina doniezi, Uvigerina* sp, Valvulina *flexilis, Melonis pompiloides* and *Lenticulina costata*. This cluster belongs to the continental slope environment.

The dendrogram (Fig. 6-2) can also be divided into four groups of species. The first major cluster extends from sp. 39 (*Bolivina pseudoplicata*) through sp. 15 (*Brizalina aenariensis).*

The second cluster begins with sp. 30 (*Spiroplectammina wrightii*) through sp. 22 (*Pullenia bulloides*) and ends with sp.7 (*Lenticulina costata*), the group being quite heterogeneous.The third group of cluster containing six species with sp. 38 (Bulimina sp.) and ends with sp.1 (*Globorotalia scitula*). The cluster contains mostly marine fauna.The fourth cluster contains 12 species starting with sp.17 (*Cibicides pseudoungerianus*) to sp.1(*Nonionella* sp.). This cluster contains heterogeneous species most of which are known to be characteristic of near shore environments e.g. sp. 13 (*Amphistegina lessonii*), sp. 10 (*Florilus boueanum*), sp. 6 (*Quinqueloculina lata*), sp.4 (*Triloculina tricarinata*) and sp. 16 (*Nonion costiferum*).

The results of the cluster analysis are presented in a combination diagram (Fig.6- 3), which shows the diagram for both the analyses of species and samples. The data matrix is displayed between the two dendrograms so that the structure in the original data can be seen along with the dendrograms. Figure 6- 3 thus allows evaluation of the inherent structure of the data as well as readily seeing which sample or species are most important in each cluster. Fig. 6- 3 can be divided into four groups of samples (1A, 1B, 2A and 2B) and four groups of taxa (A to D). These groups were chosen and identified based on the distinctness of the cluster in the dendrogram and the apparent major patterns in the data matrix. Each of the samples with clusters can be characterized by one or more dominant taxa, along with other sub-dominant taxa, to form the basis for the four taxa clusters.

In the sample dendrogram, group 1A contains mainly AGP- 8 well, which are characterized by *Brizalina paralica* and *B. doniezi* typical of deltaic environment. Group 2A, another small group, contains marine samples from ELF- 2 well and are characterized by *Uvigerina* spp., *Eponides eshira* and *Bulimina* sp.

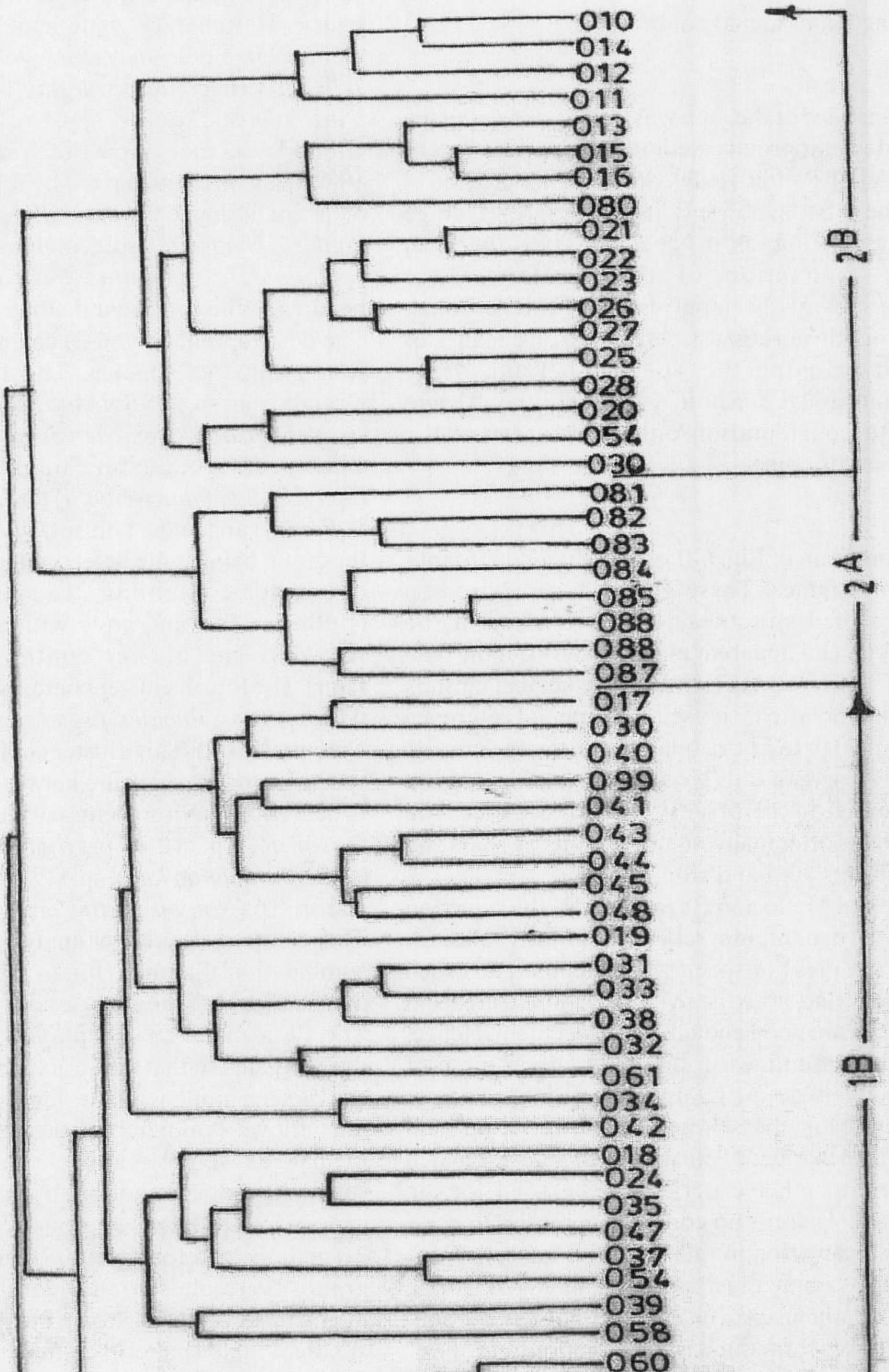

Fig. 6-1: Q-mode cluster analysis

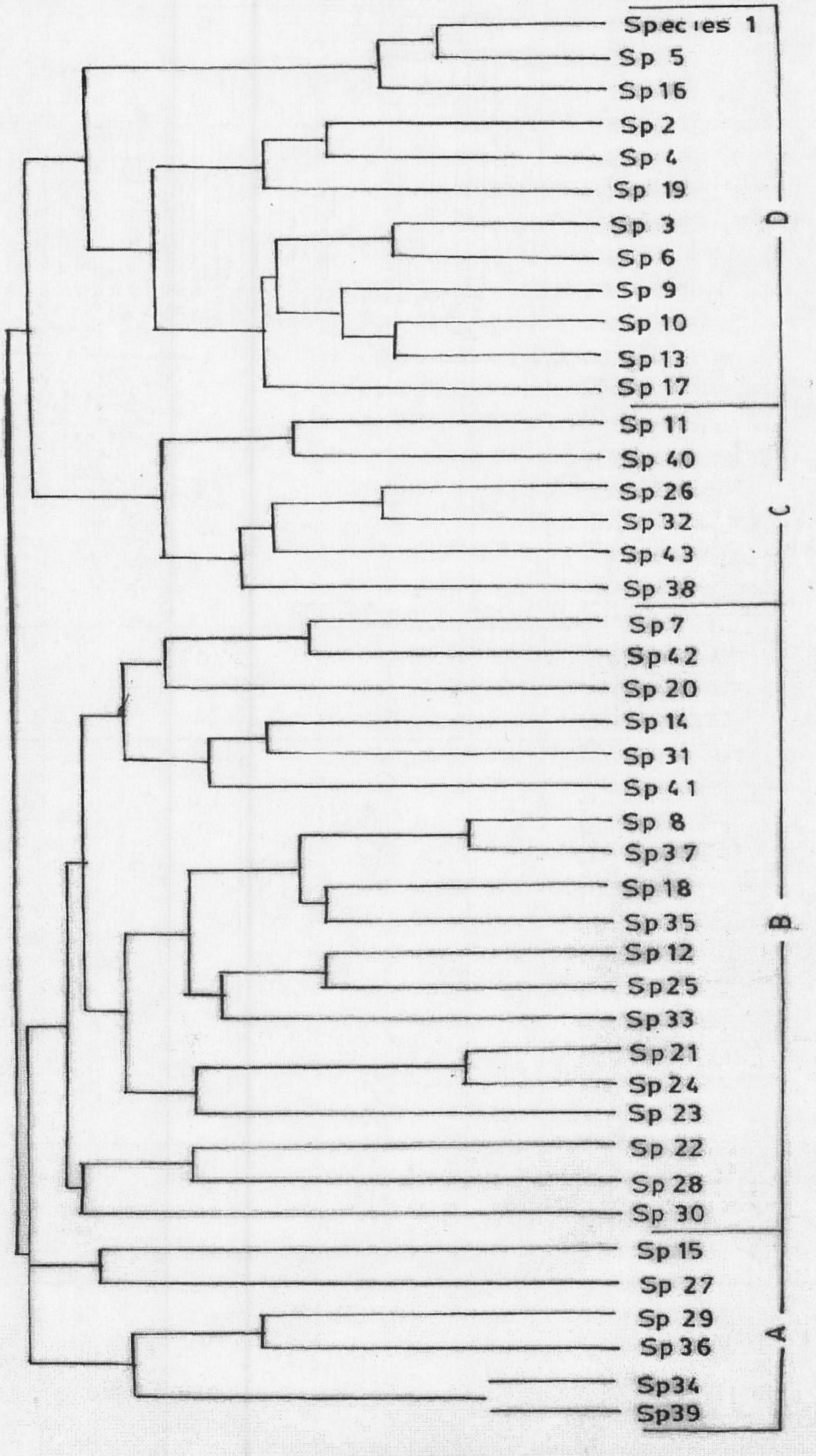

Fig. 6-2: R-moe cluster analysis

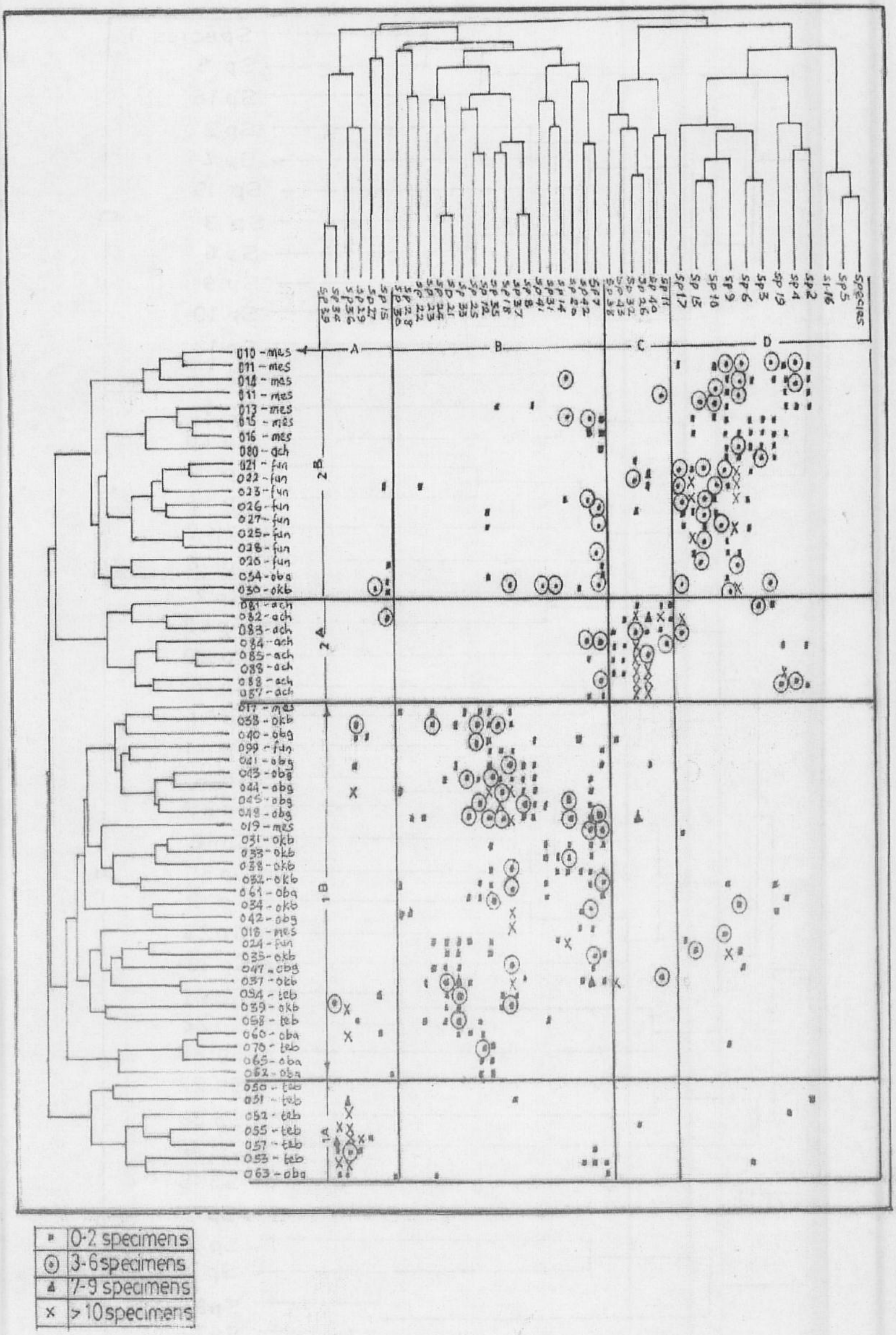

Fig 6-3: Dendogram for UPGMA cluster analysis of taxa (top) and samples (side) using Spearman's rank-order correlation

Group 2B contains three dominant taxa: *Quinqueloculina* spp., *Ammonia beccarii* (which can tolerate a wide range of environment from brackish to shallow marine) and *Amphistegina lesonii,* are characteristic of marginal- marine environments.

Group 1B is the largest of the four groups, containing arenaceous forms as the dominant taxa: *Cyclammina cancellata, Haplophragmoides bradyi, Textularia laminata, Eggerella bradyi, Textularia niloticum* and *Recurvoides contortus*.

Ordination

The ordination technique arranges sample points in space on the bases of their faunal similarity (measured by the Dice-coefficient). Samples containing similar faunas plot close together, different ones farther apart.

A plot of cluster groups on the ordination model (fig. 6-4) shows that they fall into discrete areas. To interprete the ordination model, the occurrence / abundance of environmentally significant species are used. Recognisable trends in these plots were used as a guide in interpreting the model's paleoenvironmental significances.

Interpretation of Biofacies and Biotopes

Correspondence Analysis is an ordination method, which shows results that are similar to those of cluster analysis. The correspondence analysis of the taxa (Fig. 6-5) shows that the groups identified in the cluster analysis can be recognized in the ordination plot.

If different environment are characterized by different taxa, the axes of the ordination plot should correlate with these environmental gradients. In this plot, the first axis reflects the marginal marine gradient samples in this study. The fossils identified in the cluster analysis as occurring most commonly in the marine samples are placed at the positive end of the first axis. By contrast, the benthonic foraminifera, which are restricted to (brackish) deltaic environment are at the negative end.

The samples ordination of Fig. 6- 5 also shows that most samples from the marine shale facies are clustered at the positive end of the first axis. Such significant biotope samples include those from ELF-2 well, which corresponds to a Group 2A of cluster analysis and are known to contain common to abundant faunas of Uvigerina peregrina, U. mantaensis and Eponides eshira. These species are charcteristic of Outer Neritic/ Upper bathyal environment, (Adegoke *et al*., 1976, Salami 1982). The other group (2B) contains samples, which are heterogeneous but dominated by those from offshore wells in the study area. These samples comprise one sample each from TEX-5, AGP-10 and ELF-2 wells. This is dominated by inner neritic to outer neritic species like *Ammonia beccarii, Florilus boueanum, Amphistegina lessonii, Lenticulina costata* and *Nonion ecuadoranium*.

The negative end of the first axis is characterized by samples, which can be grouped into discrete areas. Group 1A, which is dominated by samples from AGP-8 well, is characterized by *Bolivina* species while Group 1B is a large heterogeneous group of samples from CHEV-B, TEX-5, TEX-2, ELF-1, AGP-8 and AGP-10 wells. All the samples contain common to abundant arenaceous foraminifera like *Cyclammina cancellata, haplophragmoides* sp. *Textularia* spp and *Ammobaculities strathearnenses.* This group is inferred to be heterogeneous comprising of taxa of benthonic foraminifera, which are characteristic of environment ranging from Deltaic (brackish) through neritic to bathyal environments. For example, *Haplophragmoides, sp. Textularia* and *Ammobaculites* species characteristise indigenous lagoonal biofacies of Adegoke et al. (1976), while *Cyclammina cancellata* is known to range from turbid waters with low oxygen content through upper slope environment to bathyal environments. The sample groups occupying the left hand side of axis 1 (i.e. Groups 1A and 1B) are characteristic of environments where deposition rate is high.

An additional method of interpretation employed was to check environmentally significant variables that were not included in the original analysis. This was achieved by counting the occurrence of planktonic foraminifera species present in many of the samples, which were not included in the original cluster or ordination analysis. A plot of their abundance on the ordination model shows that they are more abundant in the samples of group 2A, which is thought to represent deeper water. They become rare with decreasing water depths in Group2B andGroup1B- a relationship seen in, modern basins (Adegoke et al. 1971; Van Marle, 1988, 1989).

These and other environmentally significant species not plotted, lead to the following interpretation of the original sample cluster groups.

(i) Sample group 1A represents deposition of unusual assemblages with restricted distributions.
(ii) Sample group 1B represents deposition of an indigenous lagoonal environment.
(iii) Sample group 2A represents deposition at outer neritic/ Upper bathyal environment.
(iv) Sample group 2B represents mixed lagoonal biofacies and near shore turbulent zone biofacies.

The second axis of the plots seems to be dominated by outlying taxa and samples with restricted and unusual assemblages.

Discussion

With reference to the dendrogram for U.P.G.M.A cluster analysis(fig 6-3), the distribution of the

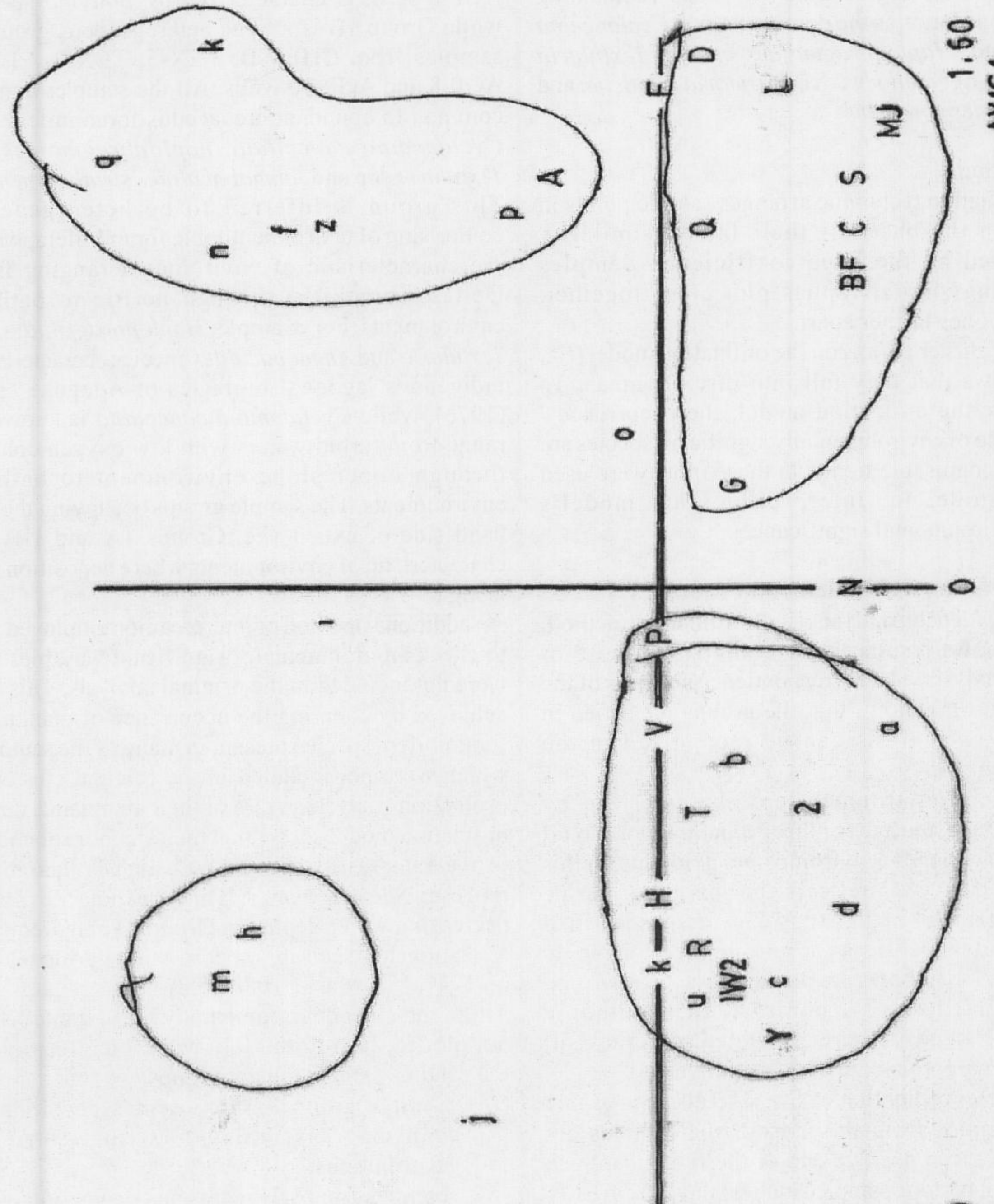

Fig 6-4: R-mode analysis: C.A

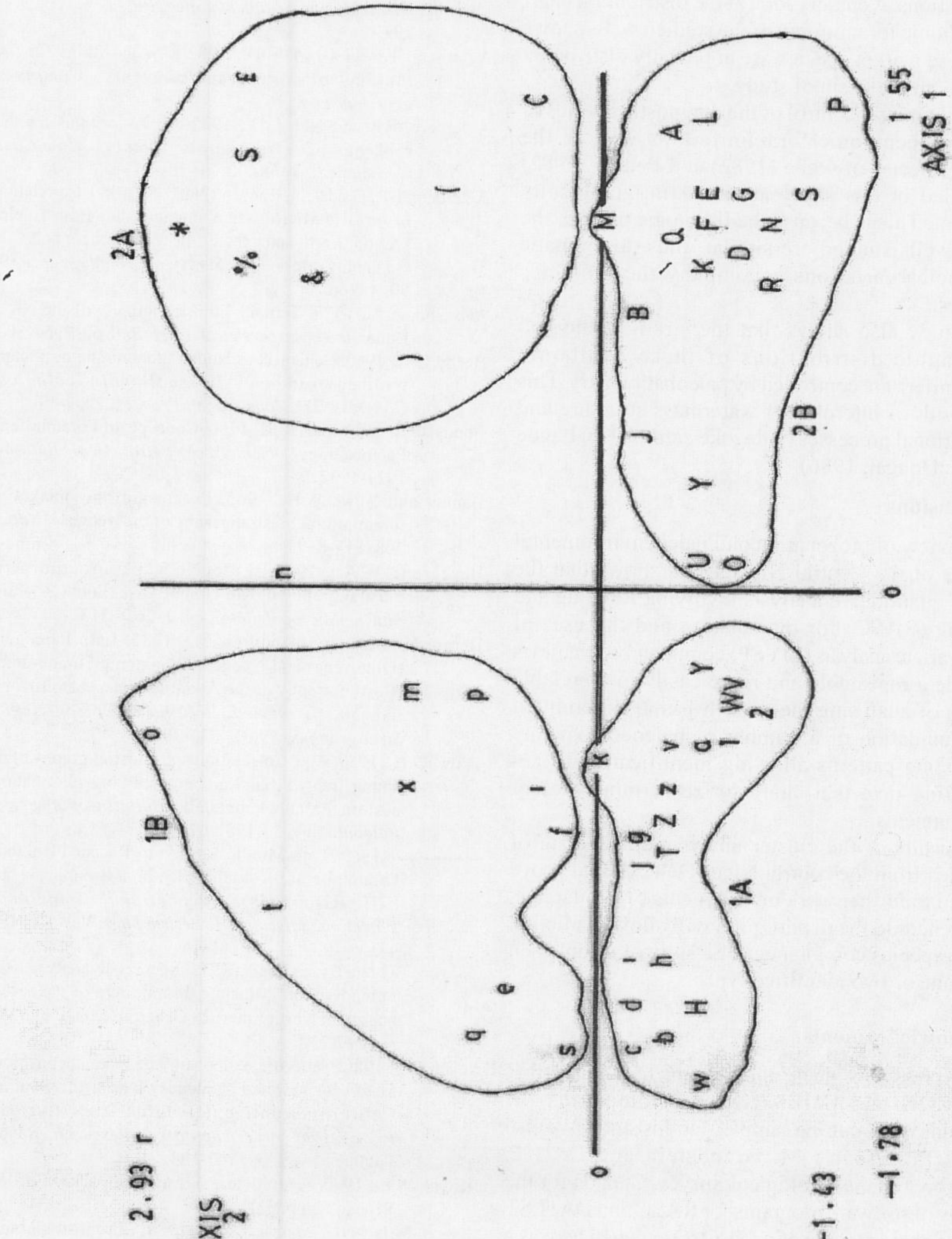

Fig 6-4: Q-mode analysis: C.A

benthonic marker species within the established paleoenvironmental framework illustrates some of the problems encountered with benthonic biozonations. A cursory look at the distribution chart of benthonic foraminifera of the studied wells shows that these marker species are not evenly distributed throughout the basin of study.

The bathymetric control of the diagnostic species of Neogene benthonic foraminifera as well as the marker species of Ogbe (1982) and Petters (1982) identified in this study are not stratigraphically apparent. This is because the lithologic units of the seven wells studied are similar, thus no dramatic lithofacies variations accompany the biofacies changes.

This study also shows that the stratigraphic and geographic distributions of these benthonic foraminifera are controlled by paleobathymetry. This is a result of interplay of watermass structure and depositional processes (Adegoke *et al.*, 1976; Lagoe and McDougal, 1986).

Conclusions

The review of biozonation and paleoenvironmental studies of the Central Niger Delta shows that the use of quantitative analysis involving Ranking and Scaling (RASC) for biozonation and the use of multivariate analysis (MVSP) computer programmes provide a repeatable and more easily interpretable means of analysing the data. It has also permitted the elucidation of a number of paleoecologically interesting patterns allowing identification of co-occurring taxa that characterize certain types of environments.

The results of the cluster analysis on the data of samples from the central Niger Delta should prove helpful to further work on sediments of similar age. References to the dendrogram will allow prediction of the species complement of a suite of samples on only one or two identified types.

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