

Size and shape variations of *Discoaster quinqueramus* in the Late Miocene NN11 Zone of offshore Gulf of Guinea region

Suyi Lawrence Fadiya

Department of Geology, Obafemi Awolowo University, Ile-Ife, Nigeria
email: slfadiya@oauife.edu.ng; fadiyalawrence@yahoo.co.uk

ABSTRACT: A detailed study on the distribution and morphology of *Discoaster quinqueramus* carried out within the Late Miocene NN11 zone of three basins (Niger Delta, Benin and Joint Development Zone of Nigeria/Sao Tome and Principe) in the Gulf of Guinea revealed the stratigraphic value of the taxon in terms of age and particularly the subzonal resolutions. This index calcareous nannofossil is widely distributed throughout the Niger Delta and the adjoining basins. The importance as a stratigraphic tool in regional and field-specific studies in the region, was found to be aided by the recognized size and shape variations, as well as the distributional patterns throughout approximately a three million year stratigraphic range. These three distinctive morphotypes - *Discoaster bergonii*, *Discoaster berggrenii* and *Discoaster quinqueramus* were clearly distinguished. They evolved as a medium-sized, 5-rayed, star-shaped form, with about a double distance relationship of the central area to the free ray length (*Discoaster bergonii*). They gradually developed into robust forms with a gradual reduction in the central area, having the free ray length approximately double of the central area (*Discoaster berggrenii*). This was succeeded by forms with further reduction in the central area to the free ray length which sometimes tripled the central area (*Discoaster quinqueramus*) at the upper part of the zone. Knowledge of the size with shape variation, their quantitative relationship as well as the distribution of the morphotypes, have been used to determine their relative positions within the NN11 stratigraphic zone. These criteria enhanced the delineation of three stratigraphically important subzones thus - *Discoaster bergonii* subzone, *Discoaster berggrenii* abundance subzone and *Discoaster quinqueramus* abundance subzone.

KEYWORDS: Calcareous nannofossil, *Discoaster quinqueramus*, *bergonii*, *berggrenii*, Niger Delta.

INTRODUCTION

Discoaster quinqueramus was originally described by Gartner (1969) as an asterolith with five regularly spaced slender rays and sharply bent at tip toward proximal side, having a centre with prominent five-sided knob on proximal side. The species was further described by Young (1998) as a symmetrical 5-rayed discoaster having a central-area, with prominent distal sutural ridges and large proximal boss. The rays are concavo-convex, with rounded tips and a central area width less than free ray length.

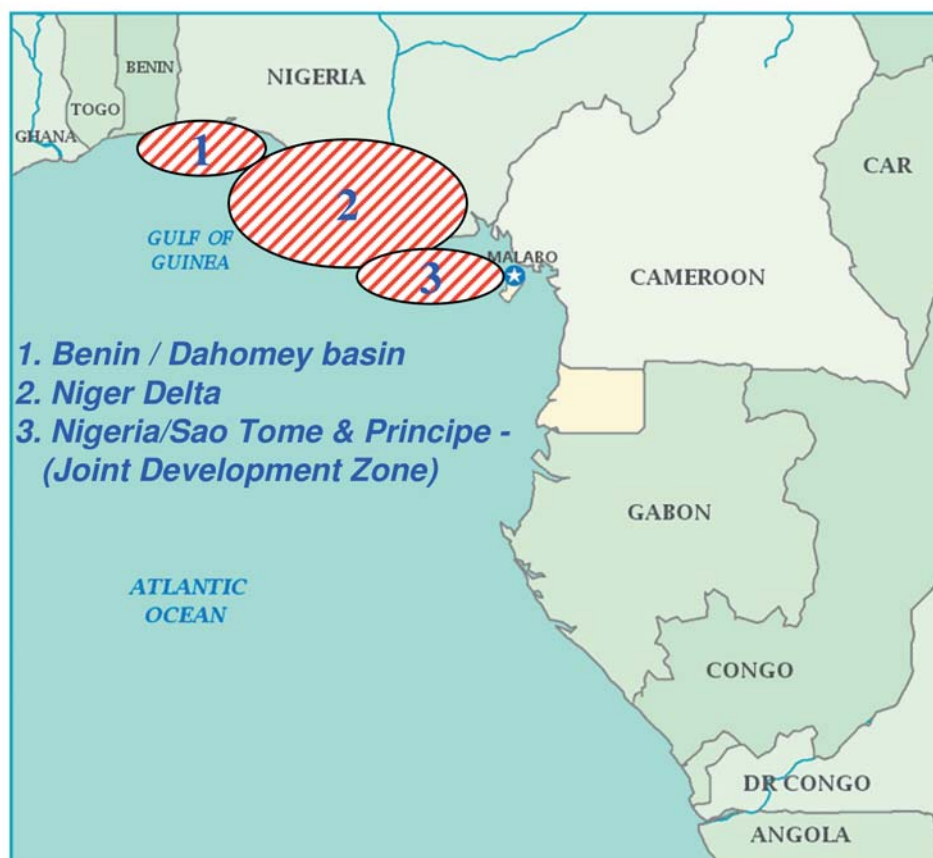
Discoaster berggrenii – the assumed progenitor of *D. quinqueramus* was first described by Bukry (1971) as a symmetric five-rayed asterolith with the free length of the tapering rays approximately equal to the diameter of the central area. The rays are radial and terminate simply. A prominent star shaped knob on the concave side of the asterolith practically fills the central area and thus usually occupies a third of the diameter of the entire asterolith and with an approximate size of 8-13 microns. A further description of the taxon was made in the Nannoware software (BugCam 2k ver. 2004.1.3) as a medium-sized form with a medium-sized central area (1/3 or more of the total diameter). The central area is partially filled by a prominent 5-rayed stellate knob on the concave side, the rays of which are oriented toward the inter-ray areas of the asterolith; the five symmetric arms of the asterolith straight, taper to a point, and vary in length from one specimen to another, but usually don't exceed the width of the central area.

D. bergonii was first described by Knuttel et al. (1989) and later re-described by Young (1998) and compared with *D. quinqueramus* but with a very wide central area (>2x free ray length).

Young (2011) remarked that *D. bergonii*, *D. berggrenii* and *D. quinqueramus* form an anagenetic lineage, with decreasing central area size and increasing free ray length.

The relevance of distinguishing between the three morphotypes for determining position within the early part of zone NN11 has been mentioned by Young (2011). Various discussions of the observed usefulness are ongoing on the nannotaxa website.

Most calcareous nannofossil zones have been found to cover a very short stratigraphic range as a result of their rapid evolutionary trend. Species with approximately three million years (3 Ma) age range might be considered as long ranging except if there are variations in the species (along lineage) that could further aid in the subdivision of the zones by which they were characterized. One of such zone is the *Discoaster quinqueramus* (NN11) zone. Most zonation schemes delineated the NN11 (*Discoaster quinqueramus* zone) as a single zone based on the total range of *Discoaster quinqueramus* (Martini 1971; Okada and Bukry 1980). The zone spanned approximately three million years with the First Occurrence (FO) dated 8.6 Ma and the Last Occurrence (LO) dated 5.6 Ma (Berggren et al. 1995). Okada and Bukry (1980) subdivided the *Discoaster quinqueramus* zone into an upper *Amaurolithus primus* Subzone (CN9b) and a lower *Discoaster berggrenii* Subzone (CN9a). Martini and Muller (1986) relied on the appearance of horse-shoe-shaped, non-birefringent *Amaurolithus* species to divide the NN11 zone into the NN11a and NN11b subzone. However, the NN11 zone in many basins in the Gulf of Guinea region (e.g. Niger Delta, Dahomey and the Nigeria Sao Tome & Principe areas) shows inconsistent occurrence of the species of *Amaurolithus* and other NN11 subzonal markers in use by other workers



TEXT-FIGURE 1
Map showing the Basins in the Gulf of Guinea area where the studied wells were located.

around the world. This led to the employment of various local events to subdivide the NN11 - *Discoaster quinquaramus* zone in the Gulf of Guinea region.

Many reservoirs have been found in the Messinian age in the Niger Delta and precisely within the NN11 zone. The vast oil accumulation within the sediments of this age both in the on-shore and offshore Niger Delta makes a refined stratigraphic subdivision imperative for the sediments of this age. The attendant advantage of such refinement cannot be over-emphasized in the required correlation of thin reservoirs and in wellsite operations involving biostratigraphically controlled horizontal drilling. This paper presents observations made on the size and shape variations on the NN11 nominate taxon in the Niger Delta and adjoining basins, on the basis of which the zone can be further refined for biostratigraphic interpretation.

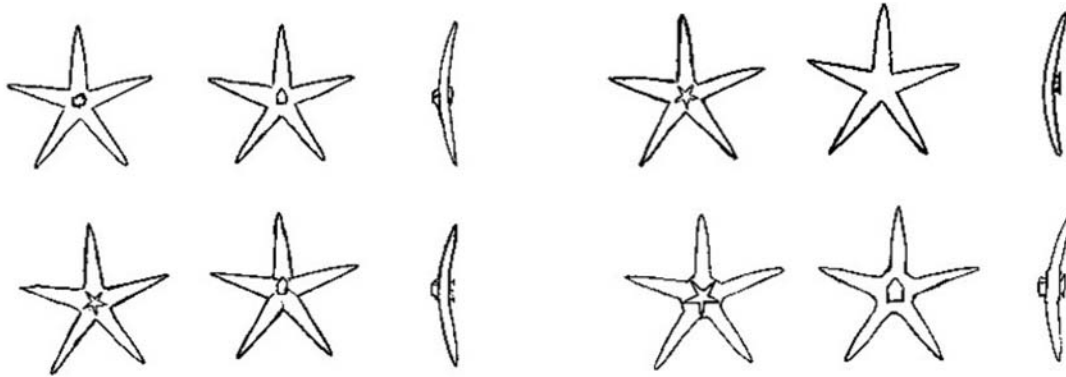
MATERIALS AND METHODS

Observations were made on approximately 30 wells cutting across the onshore and offshore Niger Delta areas, the Joint Development Zones of the Nigeria / Sao Tome & Principe and the Dahomey Basins (text-fig. 1) during routine but different biostratigraphic analyses. The three peri-oceanic basins are very rich in marine microfossils, showing abundant well-preserved calcareous nannofossil distribution across all the ages penetrated by available wells in the basins. This is attributed to the predominantly marine nature of the sediments deposited in

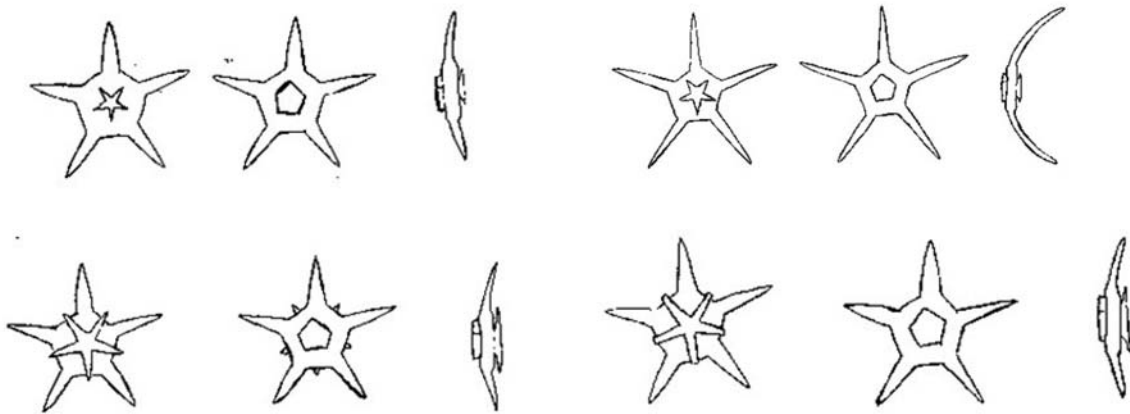
the basins. A striking similarity exists in the nannofossil distribution in the basins with similar taxa distribution and common events. This led to the proposition of a common nannofossil scheme for the region (Fadiya and Salami 2015).

A modified smear slide calcareous nannofossil preparation technique was employed. Approximately 5 grams of the shaly sediment was gently crushed and dispersed in water inside a glass vial. Disaggregation and full dispersion of the sediment was ensured through the aid of a stirring rod. A disposable glass pipette was used to transfer the suspension onto a cover slip (22 x 40mm), dried at about 35–45°C and mounted on a glass slide using the Norland optical adhesive mounting medium (NOA 61). Prepared slides were examined under an Olympus polarizing microscope at X1000 magnification in plain and cross – polarized light. Details of distribution, size and shape variations and associated nannofossils were documented.

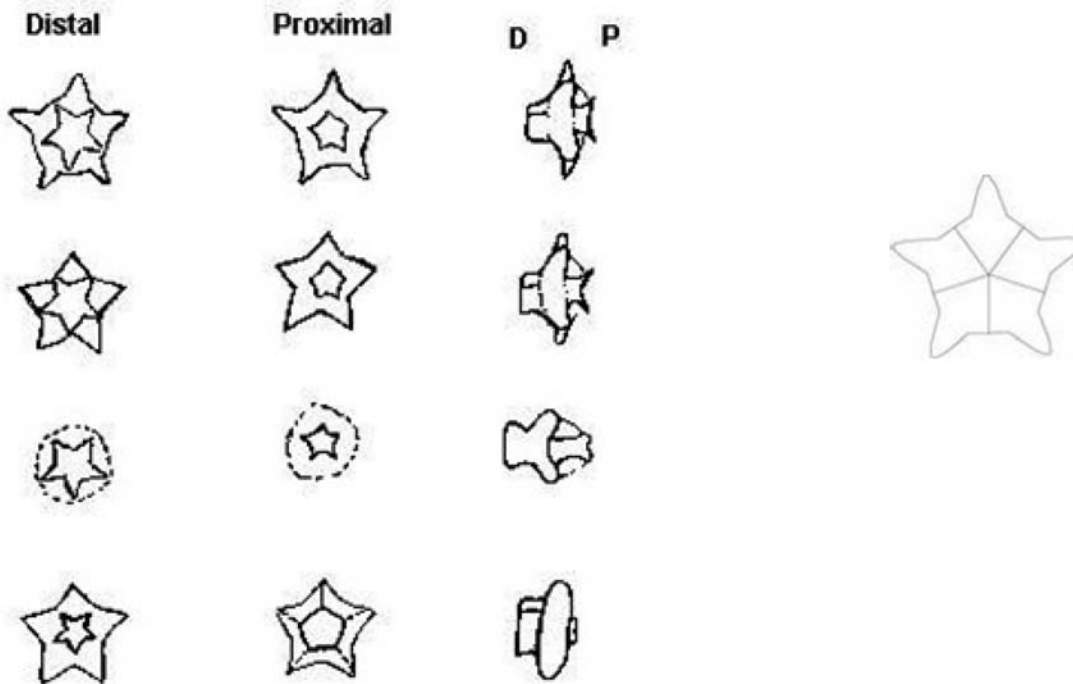
In a Taxonomy Equivalency Project, trading of data of ‘marker taxa’ in the oil and gas industry in the United States was carried out on the *Discoaster quinquaramus* morphotypes, to serve as global reference (Styzen 2013). Different people interpreted the descriptions of the morphotypes differently and there are more useful morphotypes than the names available for them. Members of the Taxonomic Equivalency Project Group were less concerned with how the various morphotypes fit into the three original descriptions with the objective to have more useful taxa (and consequently more horizons) so as not to lump everything



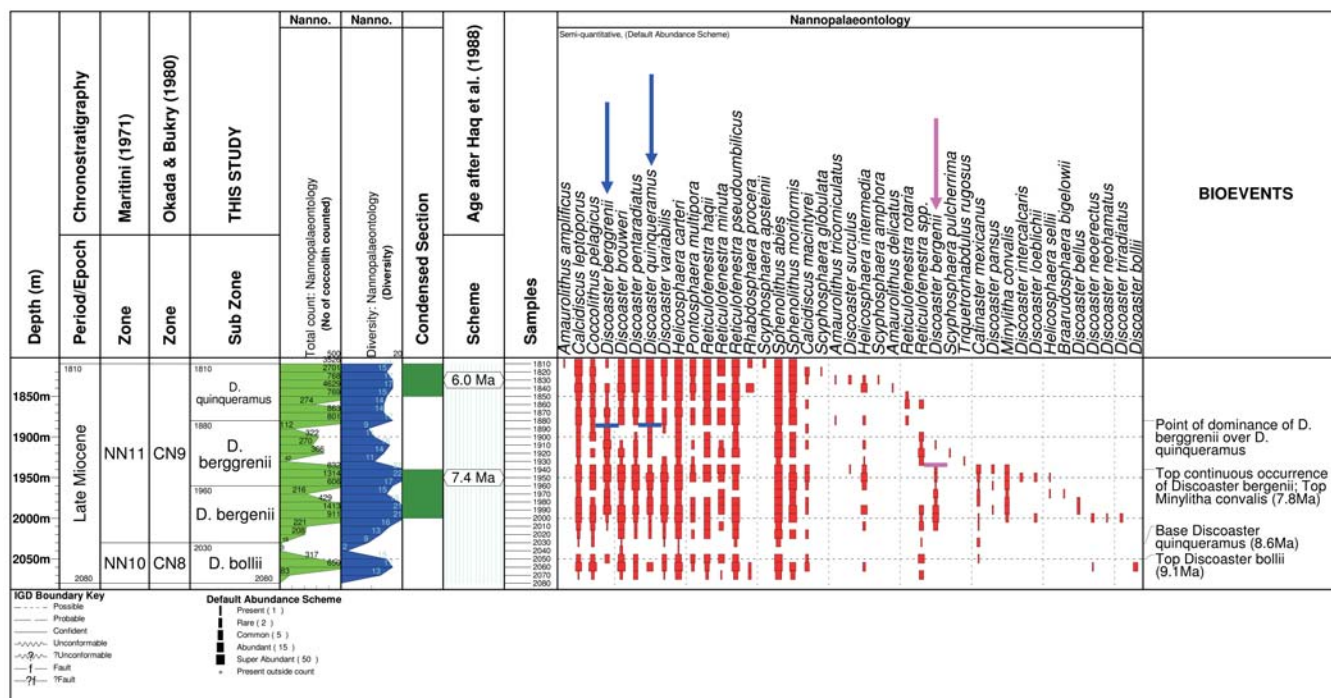
TEXT-FIGURE 2a
Discoaster quinqueramus morphotype.



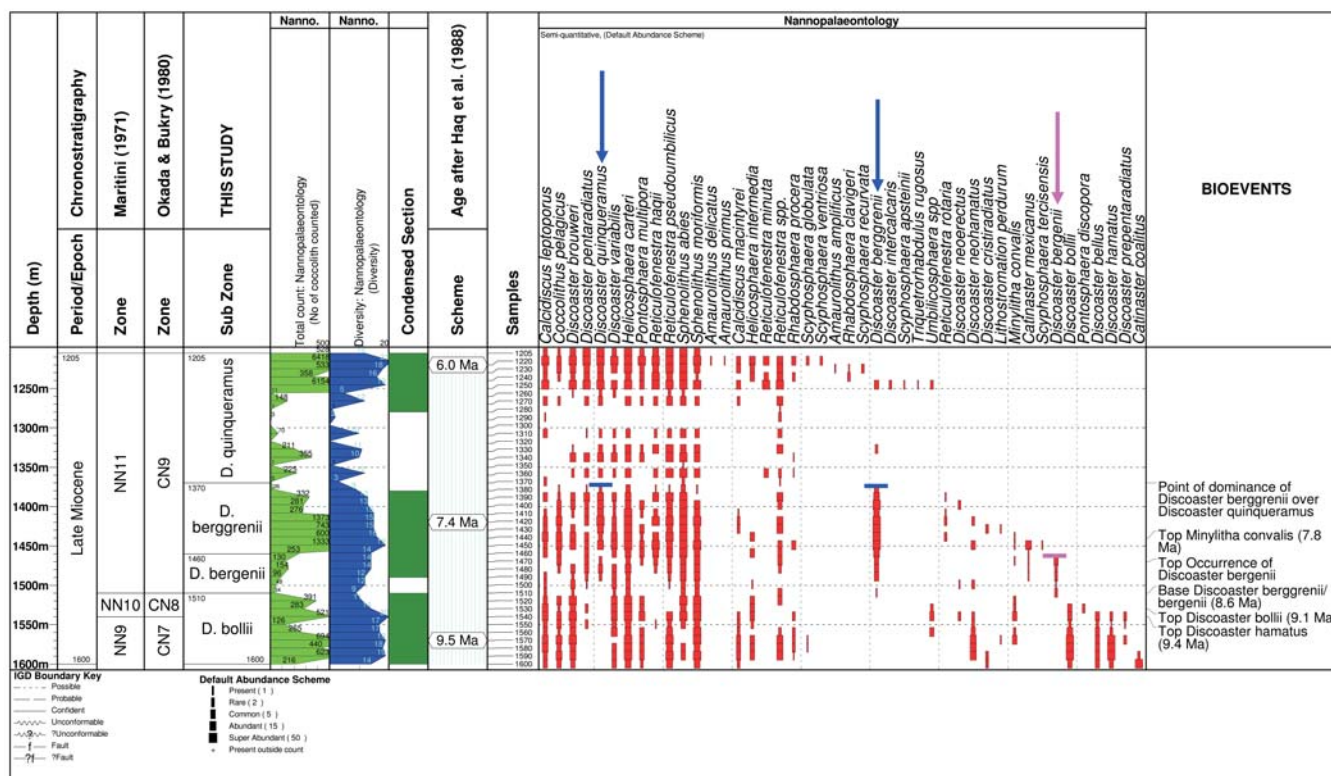
TEXT-FIGURE 2b
Discoaster berggrenii morphotype.



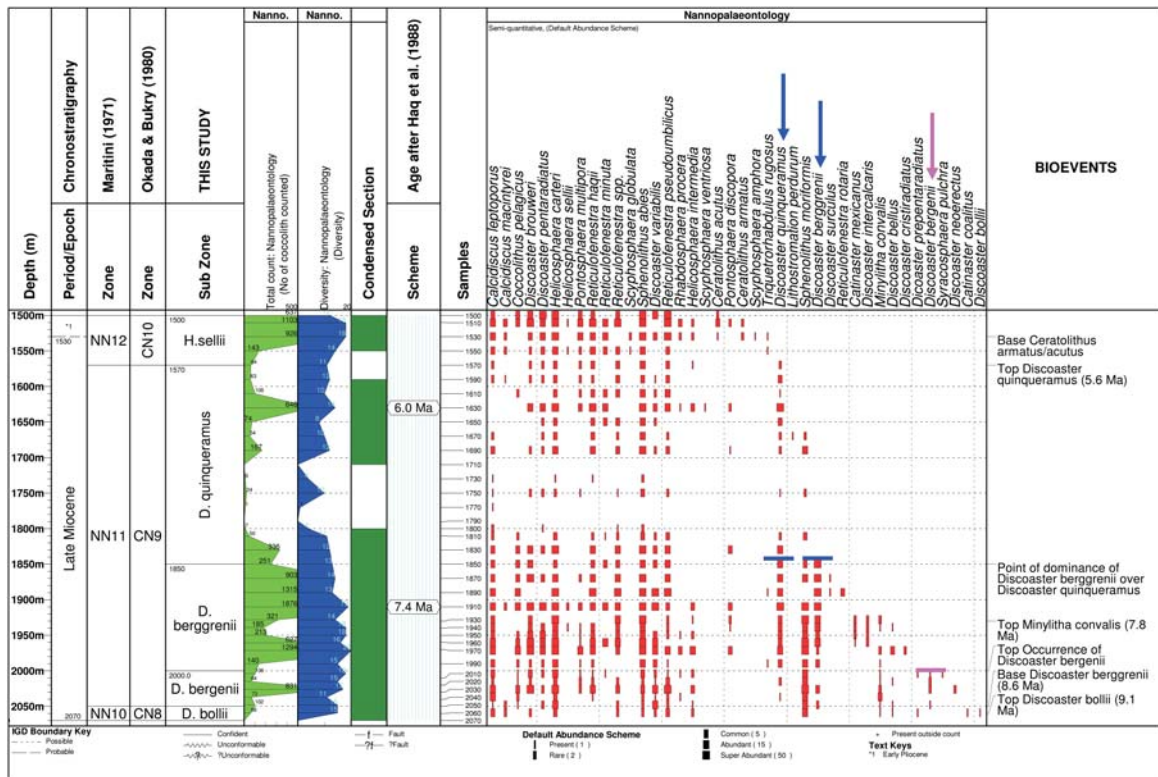
TEXT-FIGURE 2c
Discoaster bergrenii morphotype.
Text-figures 2a-2c: *Discoaster quinqueramus* morphotype sketches (after Styzen 2013).



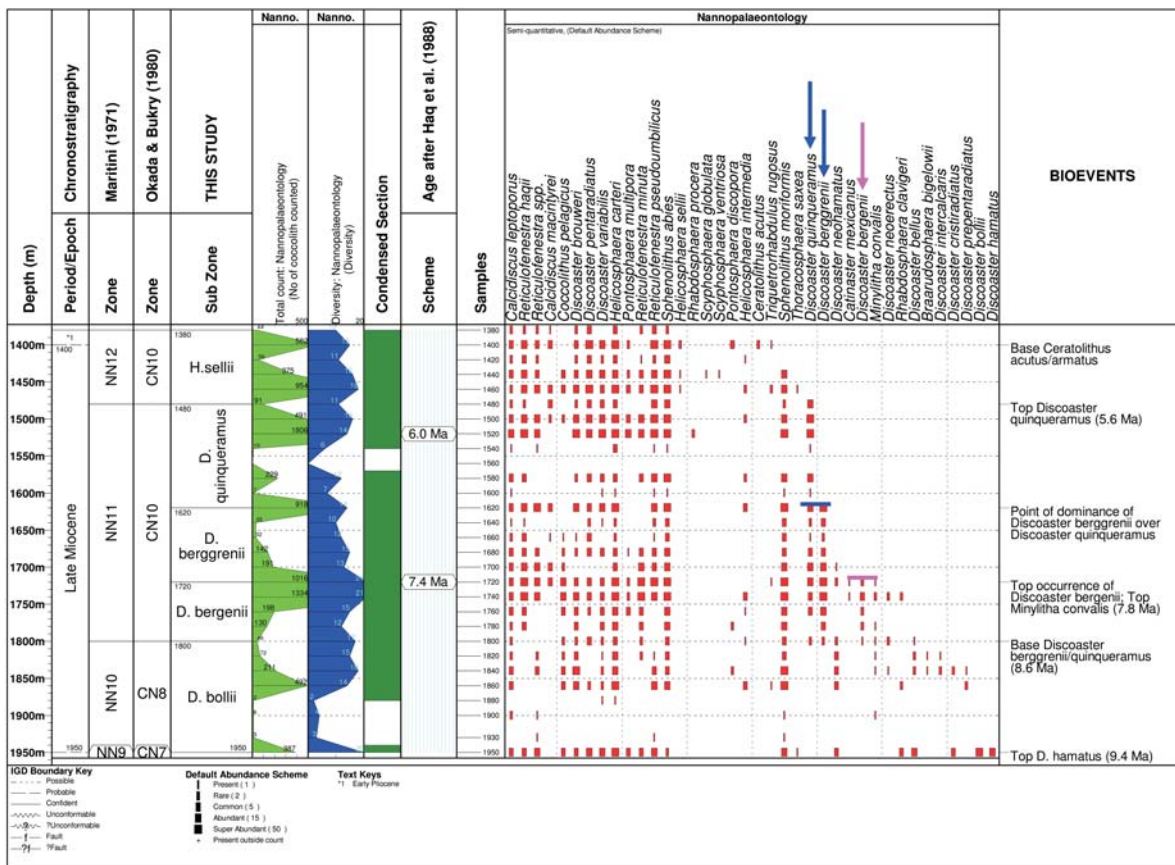
TEXT-FIGURE 3
Nannofossil Distribution of well DQ1 (Niger Delta).



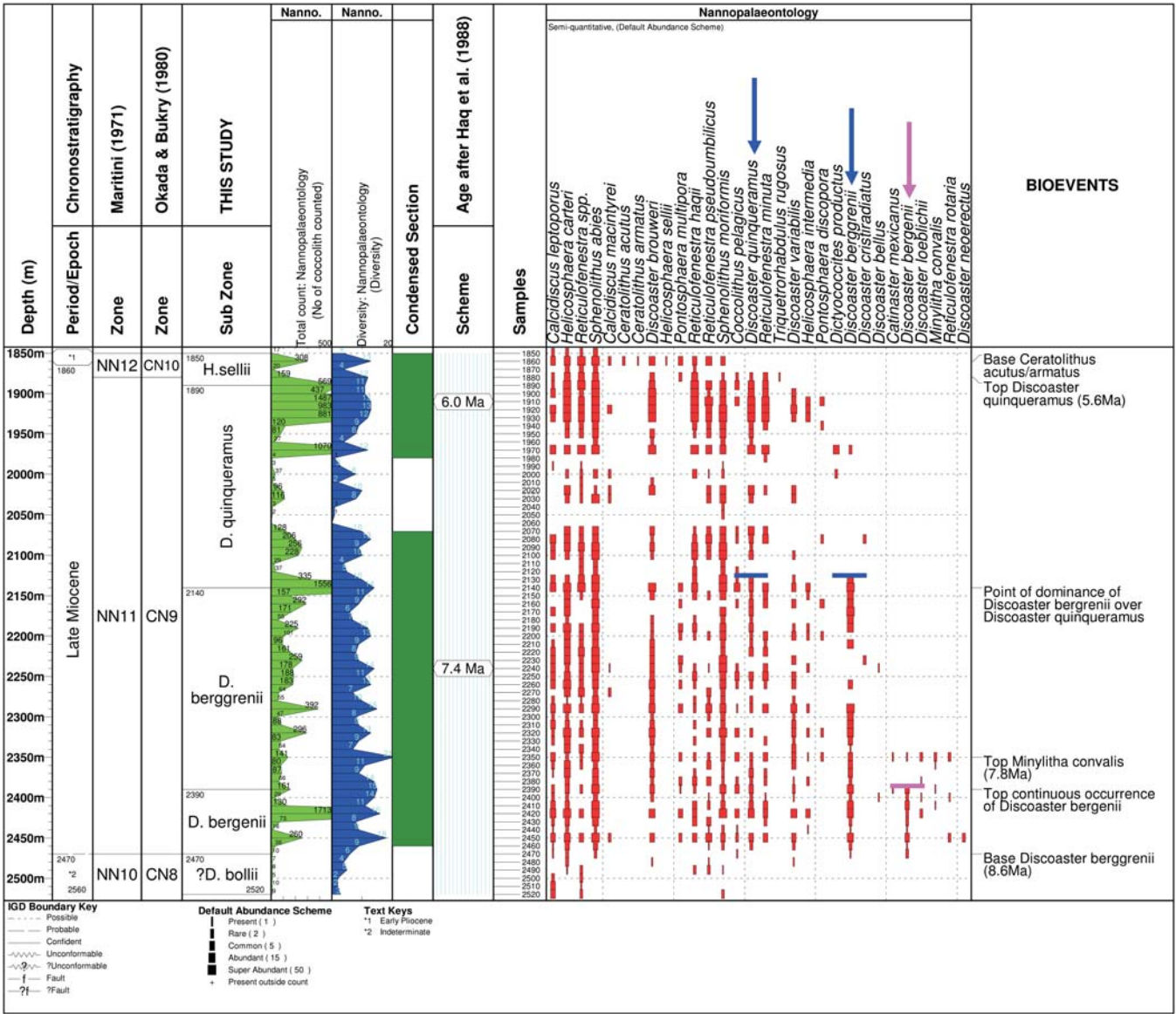
TEXT-FIGURE 4
Nannofossil Distribution of well DQ2 (Niger Delta).



TEXT-FIGURE 5
 Nannofossil Distribution of well DQ3 (Nigeria/Sao Tome and Principe JDZ).



TEXT-FIGURE 6
 Nannofossil Distribution of well DQ4 (Niger Delta).



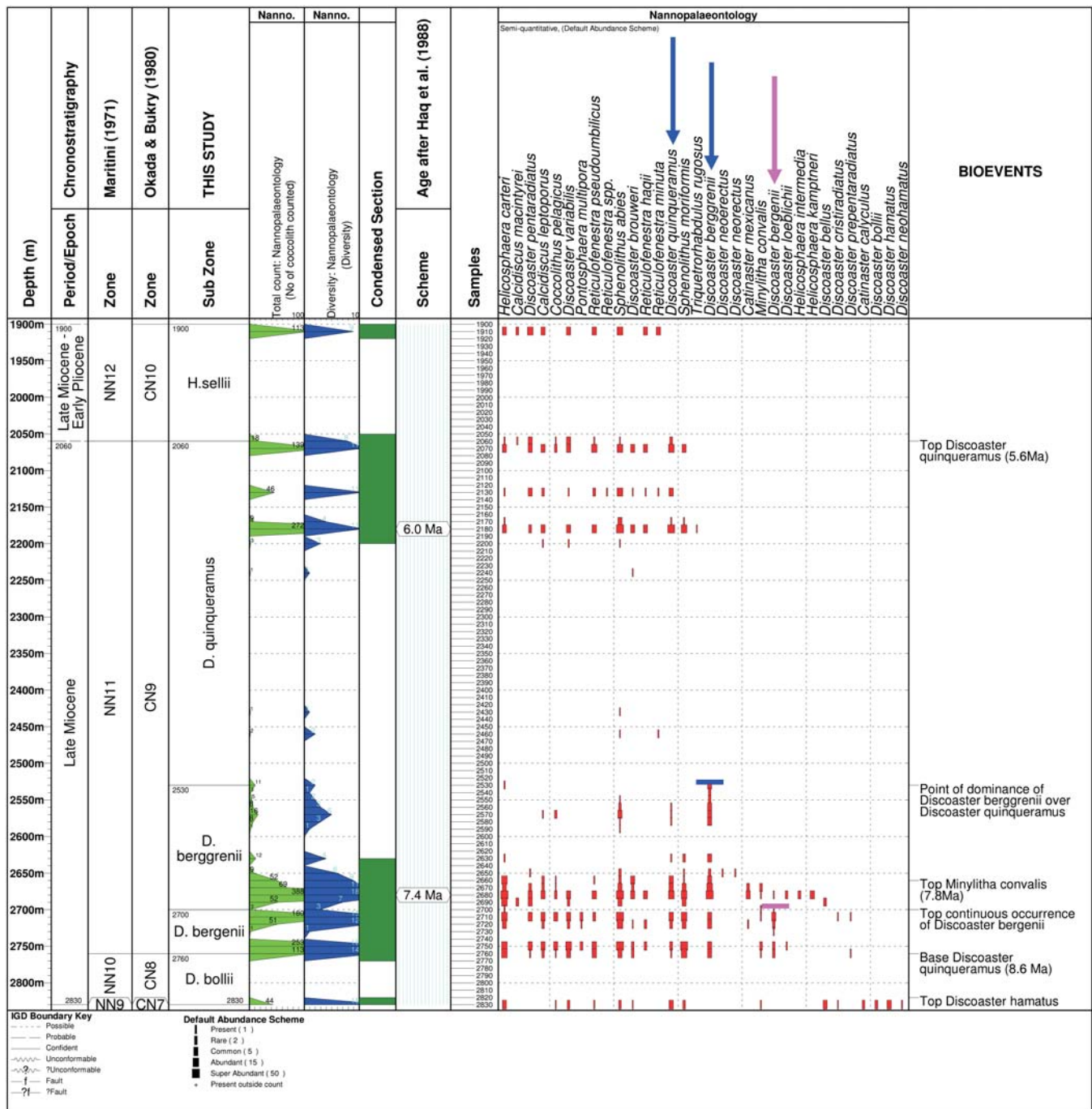
TEXT-FIGURE 7
Nannofossil Distribution chart of well DQ5 (Dahomey Basin).

into the original three species. In contrast to drawing several lines between the groups which would result in having several morphotypes, this work has limited the scope to the three distinctive morphotypes for easy recognition and correlation in the Niger Delta region. The sketches illustrated by Styzen (2013) have been grouped so as to know which shape and sizes are called the different names in this work as there are little variations when compared to the original groupings (text-figs. 2a-c)

RESULTS

Stratigraphic distribution charts displaying the results of the nannofossil analysis of six (6) of the wells studied are as shown in text-figures 3-8. On the basis of the nannofossil distribution, the studied sections were subdivided into zones based on the Martini (1971) zonation scheme. Furthermore, subzones were

erected based on the size and shape variations of the *Discoaster quinqueramus* morphogroups for the NN11 zone while other index taxa were employed for the other subzones penetrated as seen in the Subzone column. The total abundance, as well as species diversity of the calcareous nannofossils recorded in each sample are as shown in the 'Nannopaleontology Total Count' and 'Nannopaleontology Diversity' columns respectively. Intervals with high abundance and diversity of nannofossil occurrence were indicated in the Condensed Section Column. The condensed sections were calibrated with chronostratigraphically important nannofossils and correlated to the Haq et al. (1987) Global Sequence Cycle Charts. The corresponding dated Flooding Surfaces were shown in the Age Column. This was followed by the sample depth versus nannofossil Abundance / Diversity distribution of all the re-



TEXT-FIGURE 8
Nannofossil Distribution chart of well DQ6 (Dahomey Basin).

corded taxa. Dated bioevents and other comments that aided the subdivision of the analyzed section were carefully recorded in the bioevent column.

Intervals 1810–2080 m and 1205–1600 m were studied from DQ1 and DQ2 Wells respectively. The two wells came from the Niger Delta offshore region. The wells sections were characterized by abundant occurrence of *Discoasters* including *Discoaster berggrenii*, *D. quinqueramus*, *D. brouweri*, *D. variabilis* and *D. bergeni*. Other taxa recorded within the studied section

of the two wells include *Reticulofenestra pseudumbilicus*, *Sphenolithus abies*, *Sphenolithus moriformis*, *Minylitha convalis* and *Catinaster mexicanus*. DQ2 well was further characterized by the occurrence of *Discoaster bollii*, *D. hamatus* and *D. prepentaradiatus*. DQ1 well was found to penetrate the Late Miocene NN10 – NN11 zones of Martini (1971) while DQ2 well tested zones NN9–NN11 (text-figs. 3 and 4). Similarly, DQ4 well (Interval 1380 – 1950 m) came from the offshore Niger Delta and was characterized by the same assemblage as we have in DQ1 and DQ2 wells. With the pene-

tration of sequences of a younger zone (NN12). *Ceratolithus acutus* and *Helicosphaera sellii* was recorded in the upper part of the DQ4 well section (text-fig. 6).

Well DQ3 was obtained from the Nigeria/Sao Tome & Principe Joint Development Zone. Nannofossil taxa recorded within the studied section of the well (1500–2020 m) include *Discoaster pentaradiatus*, *D. brouweri*, *D. variabilis*, *D. quinquaramus*, *D. berggrenii*, *Helicosphaera carteri*, *Helicosphaera sellii*, *Reticulofenestra haqii*, *Reticulofenestra pseudumbilicus*, *Sphenolithus abies*, *Sphenolithus moriformis*, *Minylitha convalis*, *Catinaster mexicanus*, *D. bergonii*, *D. bollii* and *D. prepentaradiatus*. The interval covers the NN10 – NN12 zones (text-fig. 5).

Wells DQ5 (Interval 1850–2560 m) and DQ6 (Interval 1900–2830 m) came from the Dahomey Basin. Well DQ5 is characterized by abundant and diverse nannofossil assemblages while DQ6 well has a lower population and less diverse assemblage. However, a close similarity is observed in the taxa distribution behavioural patterns between the two wells. Nannofossils recorded in the two well sections include *Discoaster pentaradiatus*, *D. variabilis*, *D. quinquaramus*, *D. berggrenii*, *Helicosphaera carteri*, *Reticulofenestra pseudumbilicus*, *Sphenolithus abies*, *Sphenolithus moriformis*, *Helicosphaera carteri* and some species of *Reticulofenestra*. Other index nannofossils recorded include *M. convalis*, *D. bergonii*, *Catinaster mexicanus* and *D. bollii*. Well DQ5 with richer assemblage has *Ceratolithus acutus*, *Ceratolithus armatus* and *Helicosphaera sellii* as part of the taxa recorded and penetrates the Late Miocene (NN10) to Early Pliocene (NN12) zones (text-fig. 7). Well DQ6 on the other hand penetrated the Late Miocene NN9 zone (with the presence of *D. hamatus* in the last sample analyzed) to the Late Miocene part of the NN12 zone (text-fig. 8).

Generally, the NN11 zone in almost all the wells studied are characterized by abundant and diverse calcareous nannofossils dominated by *Discoaster quinquaramus* and the variants *Discoaster berggrenii* and *Discoaster bergonii*. The species is characterized by the typical 5 rays. However, some variants can display 3 or 6 rays (Perch-Nielsen 1985; Young 1998).

DISCUSSION

The studied sections encountered the NN9 – NN12 zones of Martini (1971). Zone NN9 was recognized based on the occurrence of the nominate taxon – *Discoaster hamatus* in wells DQ4 and DQ6 (text-figs. 6 and 8). The interval above the LO of

Discoaster hamatus but below the FO of *Discoaster quinquaramus* / *berggrenii* was assigned NN10 as seen in all the wells studied. Both the NN10 and NN11 zones were combined to represent the *Discoaster bollii* subzone in this work. This is due to the abundant occurrence of *Discoaster bollii* within the interval (text-figs. 3-8). The total range of *Discoaster quinquaramus* / *berggrenii* represents the NN 11 zone as observed in all the studied wells. Zone NN12 represents the interval above the LO of *Discoaster quinquaramus* and the youngest of all the zones recognized in this work as we have in wells DQ3, DQ4, DQ5 and DQ6 (text-figs. 5-8). The lower part of the NN12 zone has been designated the *Helicosphaera sellii* subzone based on the conspicuous occurrence of the taxon in this interval.

Observations on the *Discoaster quinquaramus* morphogroups formed the basis on which the N11 has been subdivided into subzones. On the basis of the size and shape variations as well as abundance, three (3) major subzones were delineated within the NN11 zone as follows:

- (a) *Discoaster bergonii* subzone
- (b) *Discoaster berggrenii* subzone
- (c) *Discoaster quinquaramus* subzone

Subzonal Description

Discoaster bergonii subzone

Definition: Interval from the First Occurrence of *Discoaster quinquaramus* / *D. berggrenii* / *D. bergonii* to the Top and/ or Top Occurrence of *Discoaster bergonii*.

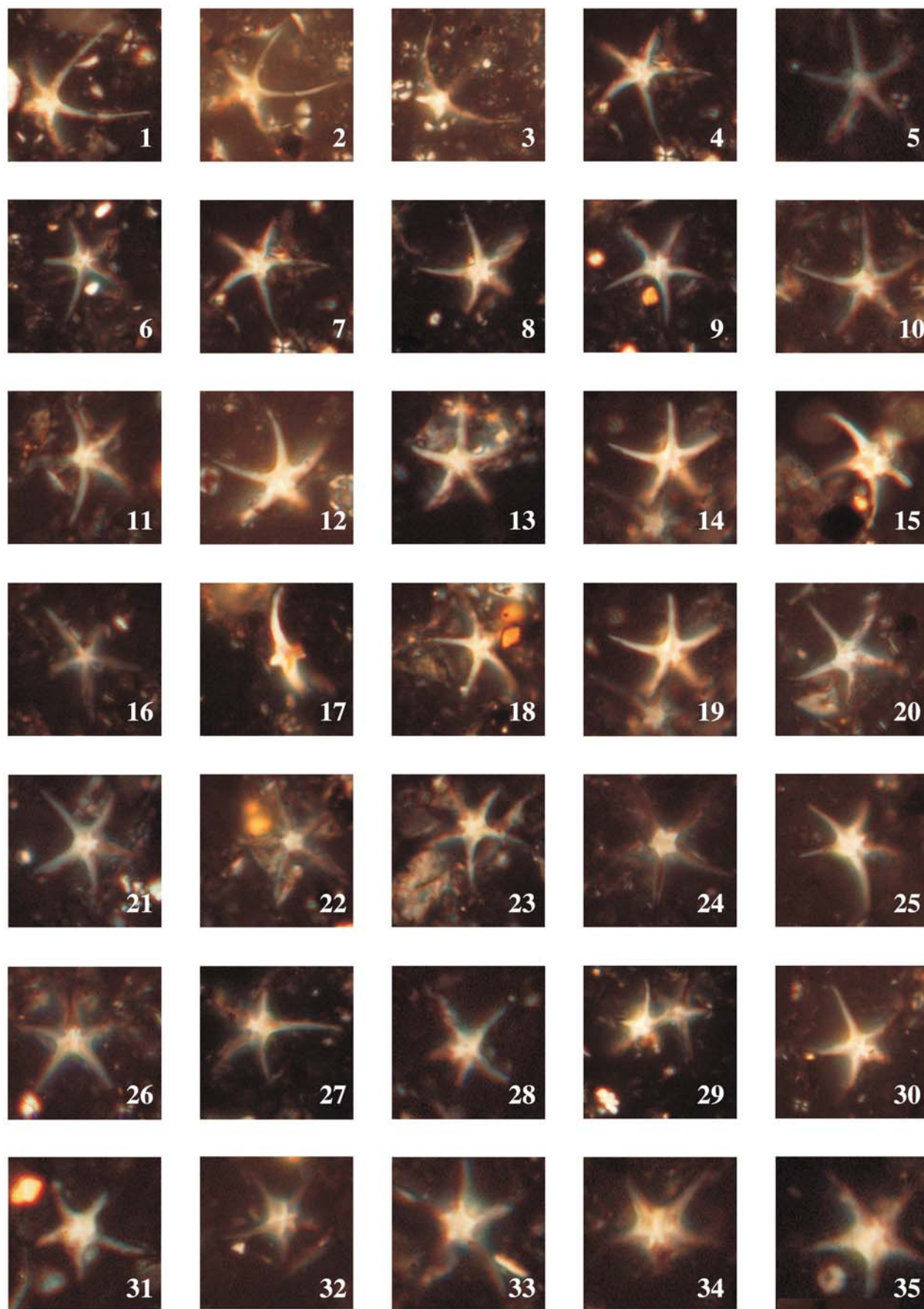
Correlation: This subzone corresponds to the lowermost part of the NN11a subzone of Martini (1971) and the lowermost part of the CN9a subzone of Okada and Bukry (1980).

Description: This is the oldest subzone within the NN11 zone. *Discoaster bergonii* did not typically predominate the two other morphotypes (*Discoaster berggrenii* and *Discoaster quinquaramus*), but occurs in significant numbers than can be seen in the subsequent subzone. The top of the subzone is delineated at the top occurrence of *Discoaster bergonii*. This point is marked at depths 1460 m in DQ2 well, 2000 m in DQ3 well and 1720 m in DQ 4 well (text-figs. 4-6). However, the top continuous occurrence of the taxon is also an effective datum for the top of the subzone as the taxon occurs sporadically near its Last Occurrence as noticed at depths 1960 m in DQ1 well, 2390 m in DQ5 well and 2700 m in DQ6 well (text-figs. 1, 7 and 8). *Discoaster bergonii* provides an excellent index fossil as it rarely extends

PLATE 1

1-30 *Discoaster quinquaramus* morphotype

31-35 *Discoaster berggrenii* morphotype



over and above the upper occurrence of *Discoaster berggrenii* abundance subzone and virtually absent in the uppermost *Discoaster quinquaramus* subzone. The nominate taxon, *Discoaster berggrenii* represents the progenitor of the other two morphotypes. It is typically identified by its medium size and a ray length about half of the central area. In some instances the ray only managed to project beyond the very wide central area. The prominent 5-rayed stellate knob found in the succeeding *Discoaster berggrenii* is less pronounced.

Characteristic index calcareous nannofossil taxa found within this subzone include *Catinaster mexicanus*, *Minylitha convalis*, *Discoaster neohamatus*, *D. intercalaris*, *D. cristiradiatus*, *D. loeblichii*, *D. quinquaramus* and *D. berggrenii*. There appears an overlap between this subzone and the upper *Discoaster berggrenii* abundance subzone based on the distribution of the listed species as some of them have their Last Occurrences extending into the upper subzone. Other nannofossils occurring in high abundance include *Sphenolithus abies*, *Reticulofenestra pseudoumbilicus*, *R. haqii*, *R. minutula*, *S. moriformis* and *Calcidiscus macintyreii*.

***Discoaster berggrenii* abundance subzone**

Definition: Interval from the Top and/or Top Occurrence of *Discoaster berggrenii* to the point of dominance of *Discoaster berggrenii* over *D. quinquaramus*.

Correlation: This subzone corresponds to the middle to upper part of the NN11a subzone of Martini (1971) and the middle to the upper part of the CN9a subzone of Okada and Bukry (1980).

Description: This subzone is easily identified by the preponderance of *Discoaster berggrenii*. The recorded number of *Discoaster berggrenii* supersedes and almost equates the total abundance of all the other *Discoasters* put together in each of the samples analysed within the subzone. This morphotype, is easily distinguished from *Discoaster quinquaramus* by its characteristic 5-rayed prominent stellate knob on both the concave and convex sides. The free end of the rays is approximately equal to the radius of the central area and even sometimes shorter at the lower part of the subzone. Forms with free ray length longer than the diameter of the central area are few and only noticeable in the uppermost part of the subzone before transiting into a region with a dominance of *D. quinquaramus* over *D. berggrenii*. As rightly observed by Perch-Nielsen (1985), the exact break between *D. berggrenii* and *D. quinquaramus* is difficult to determine which resulted in putting the species in synonymy by various authors. However, a combination of the characteristically wide central area, more prominent central knob and thicker arms, helps in differentiating the

two species in the upper part of the subzone. The subzonal boundary is however easier to demarcate as this can easily be placed at the point where the dominance of either of the species is observed along the stratigraphic column as observed at depths 1880 m in DQ1 well, 1370 m in DQ2 well, 1850 m in DQ3 well, 1620 m in DQ4 well, 2140 m in DQ5 well and 2530 m in DQ6 well (text-figs. 3-8). While the number of *Discoaster quinquaramus* recorded within the subzone is appreciable, although not as much as *D. berggrenii*, *D. berggrenii* made only spot occurrences in the lower part, and are barely absent in the upper part of the subzone (text-figs. 3-7). Characteristic nannofossils at the lowermost part of the subzone include *Catinaster mexicanus*, *Minylitha convalis*, *Discoaster neohamatus*, *D. intercalaris*, *D. cristiradiatus* and *D. loeblichii*. This lowermost part of the subzone is easily distinguished from the *Discoaster berggrenii* subzone by the rare occurrence to the absence of *Discoaster berggrenii*.

***Discoaster quinquaramus* abundance subzone**

Definition: Interval from the point of dominance of *Discoaster berggrenii* over *D. quinquaramus* to the Last Occurrence of *Discoaster quinquaramus*

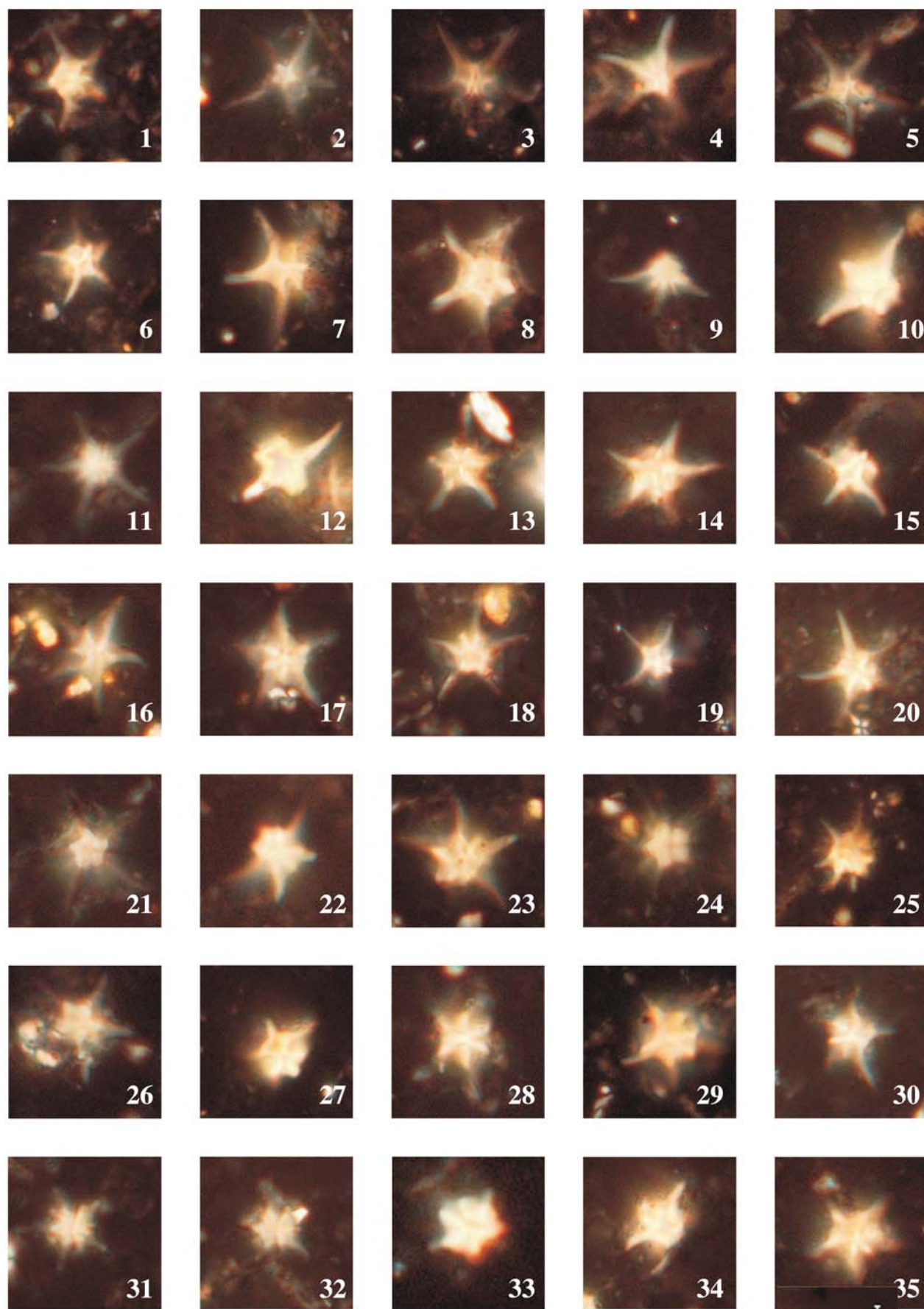
Correlation: This subzone approximates the NN11b subzone of Martini (1971) and the CN9b subzone of Okada and Bukry (1980).

Description: This subzone is characterized by the dominance of *Discoaster quinquaramus* over *Discoaster berggrenii*. Size and shape variation within this subzone is less pronounced as in the *Discoaster berggrenii* subzone. This is because the morphotype have consistently longer rays, which in most cases exceeds a double of the central area. However, the uppermost part of the zone is characterized by forms with very long rays that tripled the diameter of the central area. The *Amaurolithus* group are found scattered within the subzone but not consistently distributed as to be used as subzonal markers. The population of *D. berggrenii* reduces as you move up the stratigraphic column and are very rare in the uppermost part of the subzone as observed in DQ2, DQ3, DQ4 and DQ6 wells (text-figs. 3, 4, 5 and 7). Characteristic nannofossil assemblage co-occurring with *Discoaster quinquaramus* within the subzone include *Discoaster berggrenii*, *Sphenolithus abies*, *Reticulofenestra haqii*, *R. pseudoumbilicus*, *Coccolithus pelagicus*, *Calcidiscus macintyreii* and *Sphenolithus moriformis*. *Helicosphaera carteri*, *Calcidiscus leptoporous* and *Reticulofenestra minuta* occur in very high abundance within the subzone. The *Scyphospaera* group occurs in high abundance and diversity in the upper part of the subzone.

PLATE 2

1-20 *Discoaster berggrenii* morphotype.

21-35 *Discoaster berggrenii* morphotype.



Besides the recognition of the three subzones of the NN11 proposed in this study, the variation in the shape of the *Discoaster quinqueramus* morphotypes is also important. For instance, the specie is small with very short rays near its First Occurrence (base) and gradually becomes robust with a more prominent central knob until it reaches its first acme. This acme is dominated by the *Discoaster berggrenii* morphotype, hence referred to as the '*Discoaster berggrenii* acme' and has been found to be related to the condensed section associated with the 7.4 Ma Maximum Flooding Surface based on the dated top of *Minylitha convalis* (7.8 Ma) and the top of *Catinaster mexicanus* at the lower part of the condensed section (text-figs. 3-8). This is followed by forms with slightly longer rays but with reduced central area which along the stratigraphic column, continued a gradual but progressive extension of the rays beyond the reduced central area. This continued to the second acme – the '*Discoaster quinqueramus* acme event' near the Last Occurrence (top) of the taxon. This has been linked with the condensed section associated with the 6.0 Ma Maximum Flooding Surface of Haq et al. (1988) based on its position just below the dated Last Occurrence (Top) of *Discoaster quinqueramus* (text-figs 5-8). The variation in the sizes and shapes are pictorially shown in the microphotographs in Plates 1-2 from the youngest to the oldest forms. Following the progressive reduction in central area and extension of rays along the stratigraphic column, it is easy to define point of study within the NN11 zone. Consequently, any objective reservoir within the NN11 zone can be properly correlated around the Field, and possibly into adjacent wells across regional faults.

CONCLUSION

A detailed study on the distribution and morphology of the Late Miocene taxon - *Discoaster quinqueramus* shows that a more refined stratigraphic succession can be erected within the NN11 zone. Local nannofossil occurrences have been used to revise and then subdivide the broad NN11 zone into different subzones in North Sea and Gulf of Mexico exploration efforts. The size, shape and the morphology of the nominate taxon are invaluable in subdividing the zone in Niger Delta and the adjoining basins. The ability of a biostratigrapher to identify correctly the three morphotypes – *Discoaster berggrenii*, *D. berggrenii*, and *D. quinqueramus* is a great step to the recognition of the three subzones. The fact that, there are two morphotype abundance-based subzones, makes their delineations easy to pick during regional and field studies. Within the NN11 zone therefore, the condensed section with the dominance of *D. quinqueramus* over the other two morphotypes can be linked to the 6.0 Ma Maximum Flooding Surface. The 7.4 Ma Maximum Flooding Surface on the other hand, has the dominance of *D. berggrenii* over *D. quinqueramus* and *D. berggrenii*.

ACKNOWLEDGMENTS

I am grateful to the Department of Petroleum Resources for providing the materials for this study. Thanks to Statoil Nigeria Limited, Ocean Energy Nigeria Limited, Petroleo Brasileiro Nigeria Limited, Chevron Nigeria Limited, Statoil Nigeria Limited and other Nigerian deepwater operators for permission to use their well information. My sincere appreciation goes to Crystal Age Limited, Professor M. O. Odebo and Mr. Ajibola Oyebamiji for their support and encouragement.

REFERENCES

- BERGGREN, W. A., KENT, D. V., SWISHER, C. C. and AUBRY, M., 1995. A Revised Cenozoic Geochronology and Chronostratigraphy. In: Geochronology Time Scales and Global Stratigraphic Correlation, *Society of Economic Paleontologists and Mineralogists Special Publication*, 54: 129–211.
- BUKRY, D., 1971. *Discoaster* evolutionary trends. *Micropaleontology*, 17: 43–52.
- GARTNER, S., Jr., 1969. Correlation of Neogene planktonic foraminifera and calcareous nannofossil zones. *Transactions-Gulf Coast Association of Geological Societies*, 19: 585–599.
- HAQ, B. U., HARDENBOL, J. and VAIL, P. R., 1988. Mesozoic and Cenozoic chronostratigraphy and cycles of sea level change. In: Wilgus, C. K., Hastings, B. S., Kendall, C. G. St. C., Posamentier, H. W., Ross, C. A. and Van Wagoner, J. C., Eds., Sea level change: an integrated approach. *Society of Economic Paleontologists and Mineralogists Special Publications* 42: 71–108.
- KNUTTEL, S., RUSSELL, M. D. and FIRTH, J. V., 1989. Neogene calcareous nannofossils from Leg 105: Implication for Pleistocene paleoceanographic trends. *Proceedings of the ODP Scientific Results*, 105: 245–262.
- MARTINI, E., 1971. Standard Tertiary and Quaternary Calcareous Nannoplankton Zonation. In: Farinacci, A., Ed., *Proceedings II Planktonic Conference, Roma*: Rome: Edizioni Tecnoscienza, 2: 739–785.
- MARTINI, E. and MULLER, C., 1986. Current Tertiary and Quaternary calcareous nannoplankton stratigraphy and correlations. *Newsletters on Stratigraphy*, 16: 99–112.
- OKADA, H. and BUKRY, D., 1980. Supplementary modification and introduction of code numbers to low latitude coccolith biostratigraphic zonation. *Marine micropaleontology*, 5(2): 321–325.
- STYZEN, M. Comment on *Discoaster musicus*. Nannotax website. 21 Sept 2011. <<http://nannotax.org/content/discoaster-musicus>>
- YOUNG, J. R. 1998. Neogene. In: Bown, P. R., Ed., *Calcareous Nannofossil Biostratigraphy*. Kluwer Academic Publications, 225–265.
- YOUNG, J. R., BOWN, P. R. and LEES, J. A., Editors. Nannotax website. International Nannoplankton Association. 21 Sept 2011. URL: <http://nannotax.org>