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Neogene calcareous nannofossils from the Nam Con Son Basin, offshore Vietnam

Nguyen Thi Tham, Nguyen Van Su*
Vietnam Petroleum Institute, Lot E2b-5, D1 Street, Saigon Hi-Tech Park, Tan Phu Ward, District 9, Ho Chi Minh City, Vietnam; *sunv@vpi.pvn.vn

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Abstract Calcareous nannofossils have been studied from the post-rift stage (Neogene) in the Nam Con Son Basin, offshore Vietnam. Ditch cuttings and core samples were collected from 60 wells and were processed according to the standard sample preparation technique. A total 18 calcareous nannofossil events were identified. These bioevents were used to establish a biozonation, to determine the geological age and produce stratigraphic correlations in the area. The following calcareous nannofossil zones were identified relative to geologic formations: the Dua Formation spans NN2-NN4, the Thong-Mang Cau Formation spans NN5-NN7, the Nam Con Son Formation spans NN9-NN11, and the Bien Dong Formation includes NN12-NN18. The calcareous nannofossil assemblages are characterized by a low abundance and poor diversity in the Dua Formation, with slight increases in total species counts in the overlying Thong-Mang Cau Formation. Nannofossils are very abundant and richly diverse in the Nam Con Son Formation, but the assemblages then gradually decrease upward in both total abundance and species richness in the Bien Dong Formation.

Keywords Calcareous nannofossils, Vietnam, Nam Con Son Basin, biostratigraphy, Neogene

1. Introduction

The Nam Con Son Basin is situated within 6.00°–9.75°N and 106.00°–109.50°E, an area of c. 150,000km^2, and belongs to the south-eastern Vietnam continental shelf. It is bordered by the Con Son swell in the north-west, the Khorat-Natuna swell in the west and south-west, the Tu Chinh Vung May Basin in the east, and the Phu Khanh Basin in the north-east (Giao & Tin, 2005) (Figure 1).

More than 60 wells were analyzed for calcareous nannofossils in the Nam Con Son Basin. For most wells, the nannofossil assemblages are relatively abundant and diverse and, hence, are a useful biostratigraphic tool for determining the geological age, establishing a biostratigraphic framework and performing well correlations in this region. This paper aims to summarize the calcareous nannofossil assemblages and apply a standard nannofossil zonation to better understand the regional stratigraphy in the Nam Con Son Basin.

2. Regional geology

The tectonic history of the Nam Con Son Basin can be divided into three stages: i) Pre-rift stage (Paleocene-Eocene); ii) Syn-rift stage (Oligocene); iii) Post-rift stage (Early Miocene-Quaternary) (Giao & Tin, 2005). A total of six major formations are recognized in the Nam Con Son Basin (Giao & Tin, 1990; Tin & Ty, 1995; Thanh & Khuc, 2006) as shown in Figure 2. From the oldest to the youngest, these formations are described as follows:

1) Pre-Tertiary basement is heterogeneous, composes of fractured, weathered igneous (quartz diorite, granodiorite) and metamorphic rocks.
2) The Cau Fm (Formation) (Oligocene) can be divided into three main parts. The lower part includes light grey, brownish-grey or reddish-brown, fine- to coarse-grained sandstone, intercalated with several beds of silty clay. The middle part is characterized by the predominance of fine-grained sediments, including thick beds of ash-grey, dark-grey or black-grey clay, intercalated with some light to dark-grey siltstones and fine to coarse sandstone. The upper part consists of an intercalation of ash-grey and light grey, fine- to medium-grained sandstone.
3) The Dua Fm (lower Miocene) unconformably overlies the Cau Fm. It consists mainly of light grey to greenish-grey sandstone and siltstone, carbonate-bearing claystone, carbonaceous shale and thin interbeds of coal. Locally there are interbeds of limestone.
4) The Thong-Mang Cau Fm (middle Miocene) is dominantly clastics interbedded with biogenic carbonates. The lower part of the formation is composed of quartz sandstones and calcareous sandstones, interbedded with clays and siltstones. The upper part includes three significant carbonate intervals. These carbonates are light grey to whitish-grey, though locally reddish brown, and are intercalated with friable siltstones and fine-grained sandstones.
5) The Nam Con Son Fm (upper Miocene) unconformably overlays the Thong-Mang Cau Fm. The lower part is characterized by clastics, including siliciclastic clay, calcareous clay and grey sandstones. The upper part mainly consists of whitish-grey carbonates and quartz sandstones.
6) The Bien Dong Formation (Pliocene-Quaternary) is widespread in the basin and has great thickness, especially in the eastern part of the basin. The formation is predominantly fine-grained clastics and can be subdivided into two parts: The lower part is Pliocene in age,

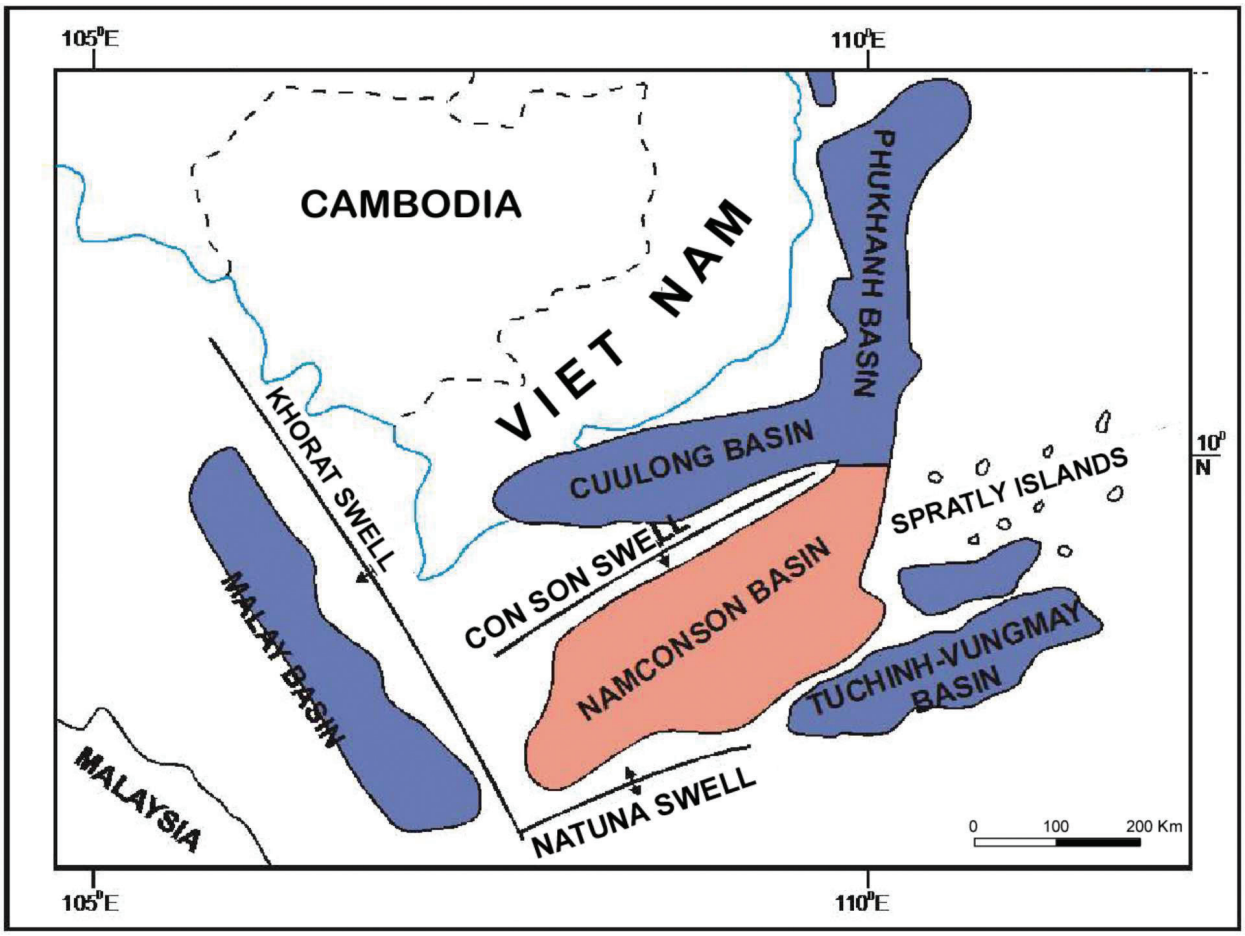

Figure 1: Location map of the Nam Con Son Basin, offshore Vietnam

consisting of siltstones, friable claystones and grey calcareous clays, intercalated with white or light yellow quartz sandstone, rich in carbonate and containing glauconite; The upper part is Quaternary in age, includes mainly quartz sand in the lower section, gradually changing to silty clay in the middle section and to quartz sand containing shell fragments in the top section.

3. Materials and methods

Materials used for this study were mainly ditch cuttings and core samples. These samples were collected from 60 wells throughout the Nam Con Son Basin.

Smear slides were prepared following the standard methods of sample preparation for quantitative analysis (Bown, 1998), because it is rapid, simple, inexpensive and efficient. A small portion of sediment was scraped onto a glass coverslip. A few drops of distilled water were added to make a thick sediment suspension using a flat-sided toothpick. The suspension was smeared thinly across the surface of the coverslip with a toothpick, and dried on a hot-plate for few minutes at a temperature of about 60–70°C. The coverslips were then affixed (smear-side down) to a labelled microscope slide using a few drops of an optical mounting medium.

All slides were analyzed for calcareous nannofossils using a Zeiss Axio Imager A2 polarized light microscope at 400x magnification, to quickly scan for samples containing nannofossil recovery. Systematic identification of nannofossils was made using the taxonomy of Young (1998) and Nannotax3. References for systematic paleontology follow those cited in Perch-Nielsen (1985), Bown (1998) or Nannotax3.

The nannofossil abundance and diversity were estimated by counting all species within 600 FOV (fields of view) of the thin section, particularly to identify rare species with key biostratigraphic value. Smear slides were examined at 1000x magnification to investigate the smallest species and for photographic documentation.

4. Results

Calcareous nannofossil recovery from this study, moving stratigraphically upwards, shows a low abundance and poor diversity in the Dua Fm, a slight increase in the Thong-Mang Cau Fm, very high abundance and diversity in the Nam Con Son Fm, and then gradually decreases in the Bien Dong Fm. A total of 12 calcareous nannofossils zones, either individual or combined, (NN2 – NN18) were identified following the standard zonation scheme of Martini (1971) with additional

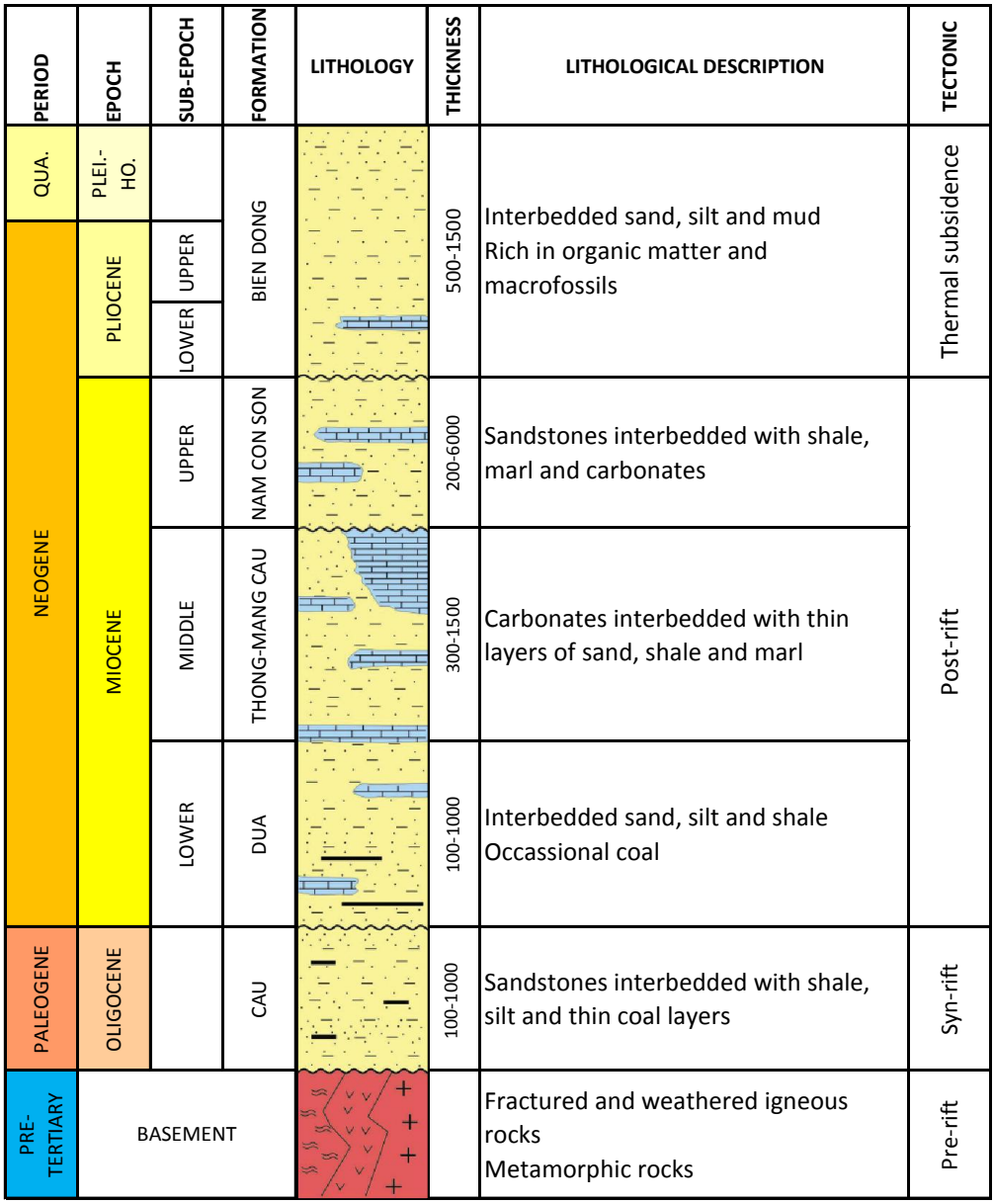

Figure 2: Stratigraphy of the Nam Con Son Basin (modified from Giao & Tin, 2005). Thickness in meters. Qua. = Quaternary; Plei. = Pleistocene; Ho. = Holocene

events (e.g. *Sphenolithus disbelemnos*) from Young, 1998, and is illustrated in Figure 3. Based on the integration between nannofossil biostratigraphy and proprietary chronostratigraphic data, the succession in the Nam Con Son Basin is summarized as follows:

4.1 Dua Formation

Thickness: 100–1000m
Nannofossil zones: NN2–NN4
Age: early Miocene

The Dua Fm (Figure 4) shows a low abundance and species richness of calcareous nannofossils. This assemblage is characterized by the presence of *Calcidiscus leptoporus, Coccolithus pelagicus, Cyclicargolithus floridanus, Discoaster deflandrei, Helicosphaera ampliaperta, H. carteri, H. intermedia, Pontosphaera japonica, Reticulofenestra minuta, R. haqii, R. pseudoumbilicus* (5–7μm), *Sphenolithus belemnos, S. heteromorphus,* and *S. moriformis*. Additional species are very rare or sporadic throughout the examined wells.

The lower Dua Fm is assigned to nannofossil zones NN2 and NN3 based on the presence of *Sphenolithus disbelemnos, S. belemnos* and *H. ampliaperta*, as well as the absence of *S. heteromorphus*. Zone NN2 was defined by Martini (1971) as the base of *Discoaster druggi* to the top of *Triquetrorhabdulus carinatus*; however, these events were not recognized in most wells in the basin. Thus, the base of *S. disbelemnos* and the base of *S. belemnos* are used as secondary events for

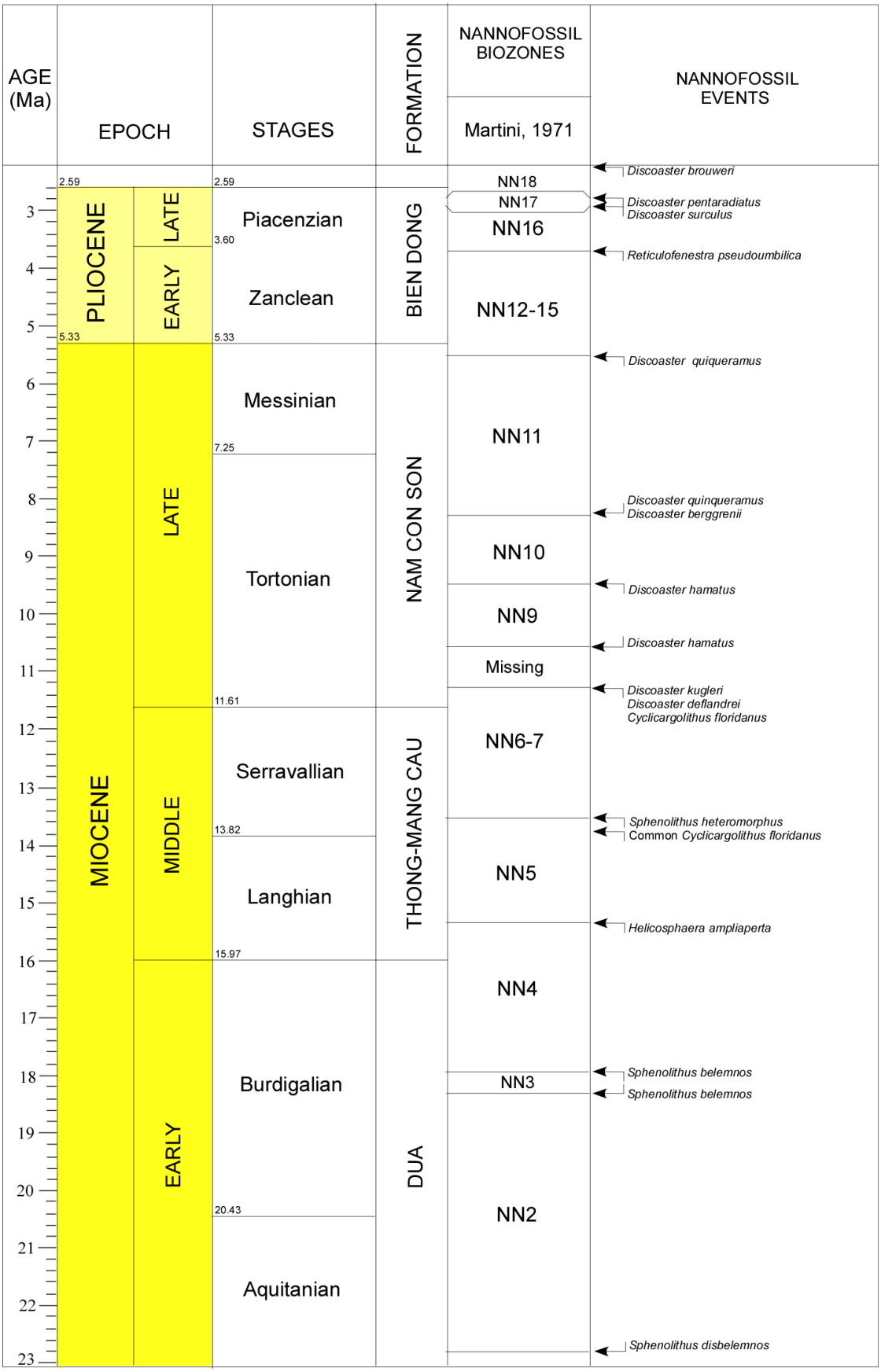

Figure 3: Neogene-Quaternary biochronostratigraphic framework in the Nam Con Son basin, offshore Vietnam. Modified from TimeScale Creator v.6.3

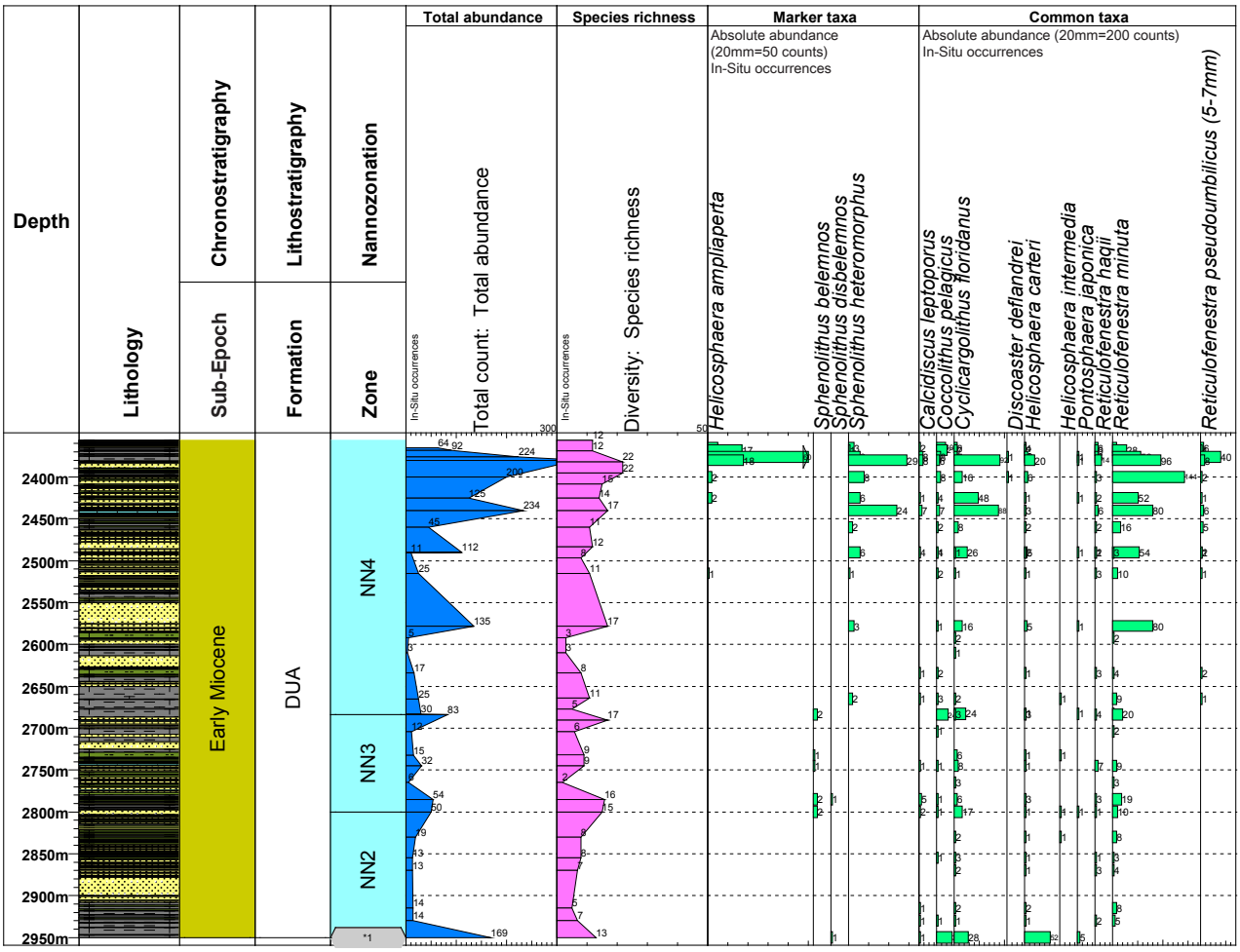

Figure 4: Example of nannofossil abundance, species richness and stratigraphic ranges for the Dua Formation

determining the base and top of this zone, respectively (See Young, 1998). Zone NN3 is limited to the short stratigraphic range of *S. belemnos* and contains a calcareous nannofossil assemblage similar to zone NN2, with the addition of the key biostratigraphic marker, *S. belemnos*.

The upper Dua Fm is assigned to nannofossil zone NN4 based on the absence of *S. belemnos* and the presence of *S. heteromorphus* and *H. ampliaperta.* In this interval, the calcareous nannofossil recovery shows a slight increase in the total abundance and species richness. This is mainly due to the common presence of *S. heteromorphus* and the increases of *R. minuta, R. pseudoumbilicus* (5–7*μm*) and *Cy. floridanus.*

4.2 Thong-Mang Cau Formation

Thickness: 300–1500m
Nannofossil zones: NN5–NN7
Age: middle Miocene

The Thong-Mang Cau Fm (Figure 5) shows an increase in abundance and species richness when compared to the underlying Dua Fm. In addition, it shows a gradual increase in the total abundance and a slight increase in the species richness of calcareous nannofossils upwards through the formation. The observed assemblage is common in the lower part, becoming relatively abundant in the upper part of this formation. This change is mainly linked to the increase of total species counts of *Sphenolithus abies, R. minuta* and *R. pseudoumbilicus.* Additional common species recorded in the formation include *Ca. leptoporus, C. pelagicus, Cy. floridanus, Coronocyclus nitescens, Discoaster exilis, D. deflandrei, H. carteri, H. intermedia* and *S. moriformis*.

The lower Thong-Mang Cau Fm is assigned to nannofossil zone NN5 based on the presence of *S. heteromorphus* and the absence of *H. ampliaperta*. The calcareous nannofossil assemblage shows a slight overall increase in total abundance in comparison with the Dua Fm. The top of this lower interval can be correlated with the top of common *Cy. floridanus*. Additionally, the lower Thong-Mang Cau Fm also contains an acme of *S. heteromorphus* in the uppermost part (See Figure 5).

The upper Thong-Mang Cau Fm is assigned to a combined nannofossil zone NN6-7 based on the absence of *S. heteromorphus* and the presence of *Cy. floridanus*, *Discoaster kugleri*, and *D. deflandrei*. Zones NN6 and NN7 are usually combined in most wells in this basin due to the rare and the sporadic presence of *D. kugleri.* The top of *Cy. floridanus*

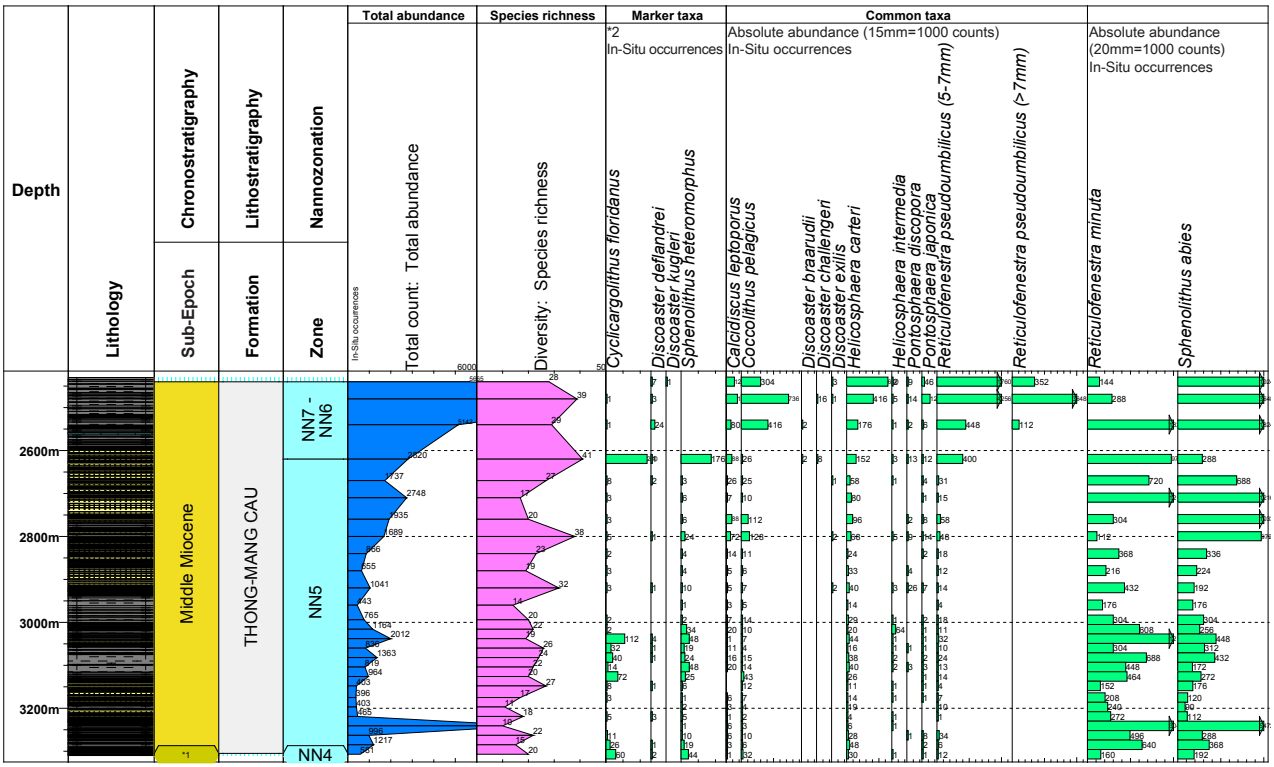

Figure 5: Example of nannofossil abundance, species richness and stratigraphic ranges for the Thong-Mang Cau Formation

and *D. deflandrei* are used as secondary data for determining the top of this combined zone when *D. kugleri* is absent. The calcareous nannofossil assemblage becomes consistently more abundant in this part of the formation.

4.3 Nam Con Son Formation

Thickness: 200–600m
Nannofossil zones: NN9–NN11
Age: late Miocene

The boundary between the Thong-Mang Cau Fm and the Nam Con Son Fm is marked by a sharp change in the calcareous nannofossil assemblage, recorded as a significant increase in the total abundance and diversity of calcareous nannofossils in the Nam Con Son Fm (Figure 6). This assemblage is mainly dominated by *Ca. leptoporus, C. pelagicus,* several species of the genus *Discoaster, Pontosphaera discopora P. japonica, H. carteri, R. minuta, R. haqii* and *S. abies.* Of these, *R. minuta* and *S. abies* occur very abundantly, while other species are rare to common.

The lower Nam Con Son Fm is assigned to nannofossil zones NN9 and NN10 based on the rare and sporadic presence of *Discoaster hamatus* and the absences of *D. quinqueramus* and *D. berggrenii*. However, these two zones were only recorded in some wells in the central portion of the basin. In the other parts of basin, these zones are often missing. This may be caused by a major erosional unconformity developed in the Late Miocene (Giao & Tin, 2005).

The upper Nam Con Son Fm is assigned to nannofossil zone NN11, which is defined by the stratigraphic range of *D. quinqueramus*, supported by the presence of *D. berggrenii*. These species are common to abundant and widely distributed throughout the basin, therefore, the NN11 zone can be determined more precisely than zones NN9-NN10 (See Figure 6). This interval is also characterized by the expansion of the genus *Discoaster* and the temporary reduction in *R. pseudoumbilicus*. *Reticulofenestra minuta* and *S. abies* become most abundant when compared with the other zones in this region.

4.4 Bien Dong Formation

Thickness: 500–1500m
Nannofossil zones: NN12–NN18
Age: Pliocene

The calcareous nannofossil recovery in the Bien Dong Fm is still relatively abundant and diverse, but shows an upward decrease in total abundance and species richness (Figure 7). The calcareous nannofossil assemblage is characterized by the presence of *Ca. leptoporus, C. pelagicus, Ceratolithus cristatus, C. telesmus, Discoaster brouweri, D. pentaradiatus, D. surculus, D. variabilis, H. carteri, P. japonica, Scyphosphaera apsteinii, S. globulata, S. intermedia, S. pulcherrima, R. minuta, R. minutula, R. pseudoumbilicus* and *S. abies*. Of these taxa, *R. minuta* and *S. abies* again are the most abundant.

The lower Pliocene Bien Dong Fm is assigned to nannofossil zones NN12 to NN15 by the presence of *R. pseudoumbilicus*, *S. abies* and *Discoaster asymmetricus*, as well as and the absence of *D. quinqueramus* and *D. berggrenii*. The calcareous nannofossil assemblage shows a gradual decrease

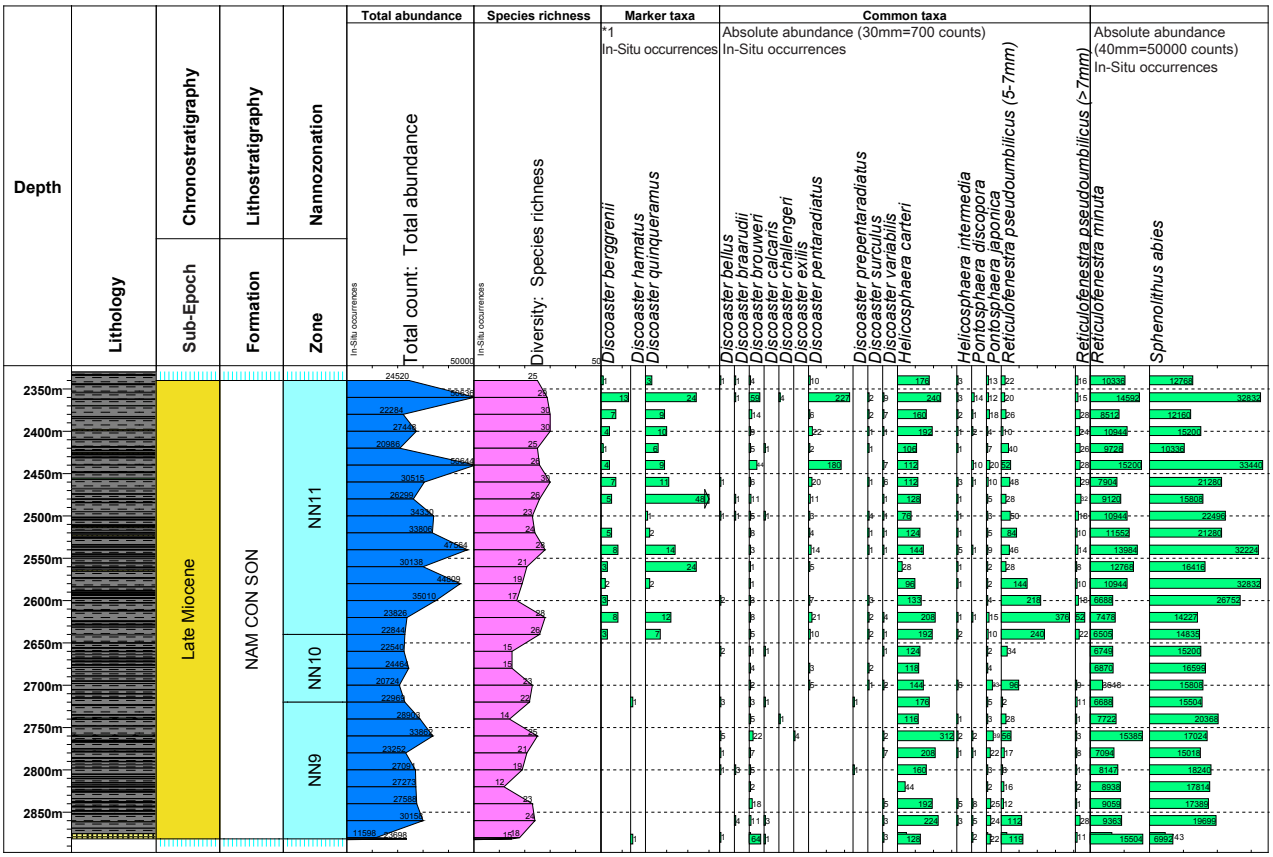

Figure 6: Example of nannofossil abundance, species richness and stratigraphic ranges for the Nam Con Son Formation

in total abundance from the base to top of this section. The nannofossil assemblage, however, still shows relatively high abundance and species richness. The zonal markers for division of zones NN12 to NN15, including *Ceratolithus rugosus* and *Amaurolithus tricorniculatus*, are very rare and sporadic and, hence, these zones are usually combined in most wells within the basin. The base of this zone is marked by the last occurrence of *D. quinqueramus,* while the top of this combined zone is marked by the top of *R. pseudoumbilicus*.

The upper Pliocene Bien Dong Fm is assigned to nannofossil zones NN16 through NN18, based on the last occurence of *Discoaster surculus*, *D. pentaradiatus* and *D. brouweri*, respectively, as well as the absence of *R. pseudoumbilicus* and *S. abies*. At the base of this upper interval (base of zone NN16), the calcareous nannofossil assemblage sharply decreases in total abundance, but the species richness is relatively similar to that found in the lower part (NN12-15). This is linked to the absence of *R. pseudoumbilicus* and *S. abies* as well as the significant decrease of *R. minuta*. The calcareous nannofossil assemblage continues to show a significant decrease in total abundance through zones NN17 and NN18, decreasing from fairly common to relatively rare (Figure 7).

Discussion and Conclusion

From this investigation, a Neogene biostratigraphic framework for this study region was established and is illustrated in Figure 3. This framework suggests the nannozonation and zonal marker taxa which can be reliably applied in the Nam Con Son Basin.

The Neogene calcareous nannofossil assemblages show variations in both abundance and diversity through the formations of the Nam Con Son Basin. The assemblage is characterized by a low abundance and poor species richness in the Dua Fm, with a slight increase in total species count in the overlying Thong-Mang Cau Fm. Calcareous nannofossils are very abundant and richly diverse in the Nam Con Son Fm, with the assemblage then gradually decreasing in both total abundance and species richness in the Bien Dong Fm.

A total of 12 individual and combined nannofossil zones were identified in this study following the standard zonation scheme of Martini (1971), with secondary events derived from Young (1998): the lower Miocene Dua Fm spans NN2-NN4, the mid-Miocene Thong-Mang Cau Fm spans NN5-NN7, the Nam Con Son Fm spans the upper Miocene zones NN9-NN11, and the Pliocene Bien Dong Fm includes zones NN12-NN18. An unconformity between the Thong-Mang Cau and Nam Con Son Fms can be suggested due to the change in the calcareous nannofossil assemblage, also supported by the work of Morley *et al*. (2011). This unconformity is recognized particularly by the absence of calcareous

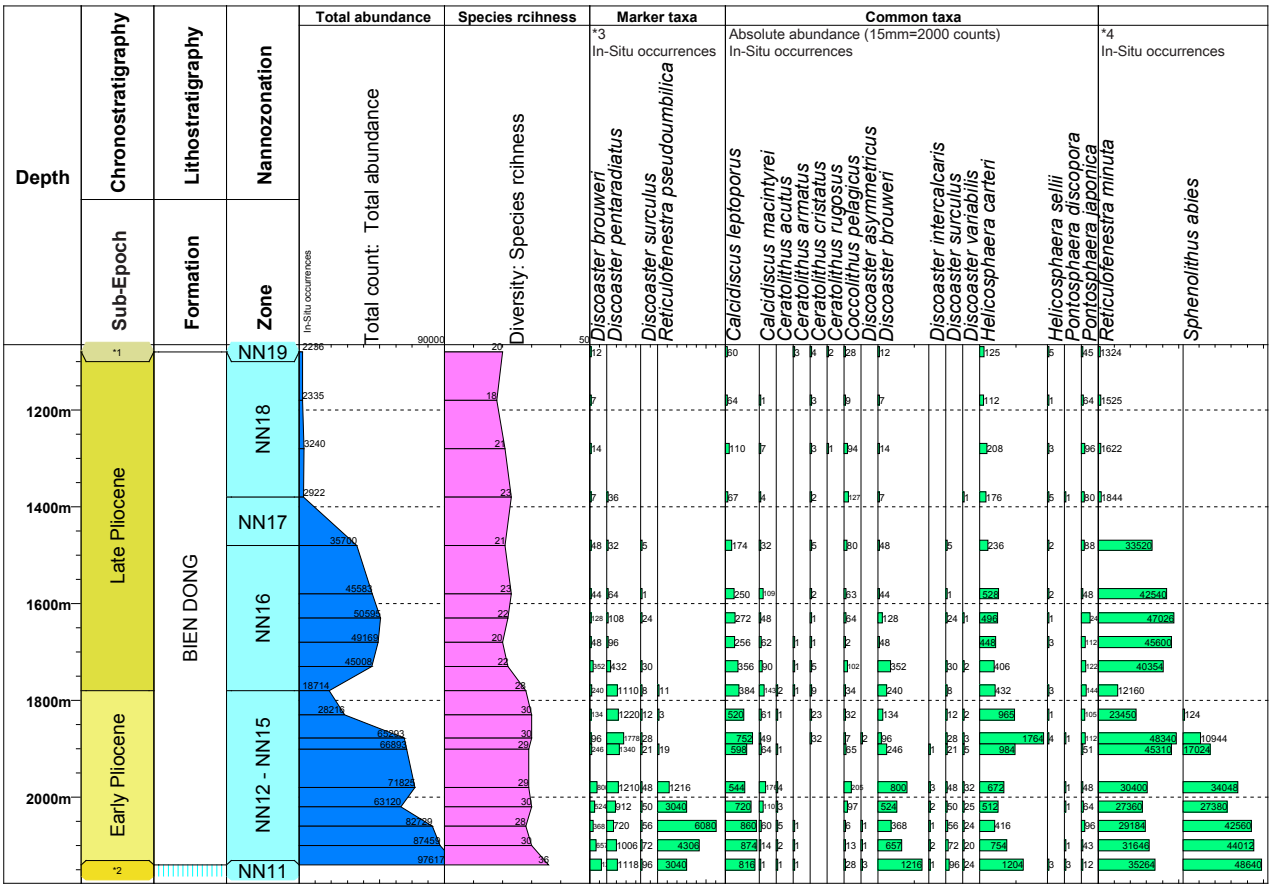

Figure 7: Example of nannofossil abundance, species richness and stratigraphic ranges for the Bien Dong Formation

nannofossil zones NN8, but also NN9 and NN10 locally in many wells throughout the basin.

The paleoenvironmental evolution in the Nam Con Son Basin can be inferred based on the distribution of calcareous nannofossils. Sediments in the Dua Fm represent shallow marine deposits due to the rare abundance and poor diversity of calcareous nannofossils, as well as the presence of transported terrestrial (coal) sediments. The overlying Thong-Mang Cau Fm reflects an increase in marine influence across the basin, with a slight increase in total abundance and species richness, as well as increases in the distribution of carbonates in this formation. A deeper marine environment is indicated in the more fine-grained Nam Con Son Fm, due to the significant increase of the calcareous nannofossil assemblages, with respect to both abundance and species richness. A shallower marine deposit is shown in the Bien Dong Fm relative to the preceding formation, linked to the progradation of the proto-Mekong delta system, and shown as an increase in marine macrofossil content concurrent with a decrease in nannofossil abundance and species richness.

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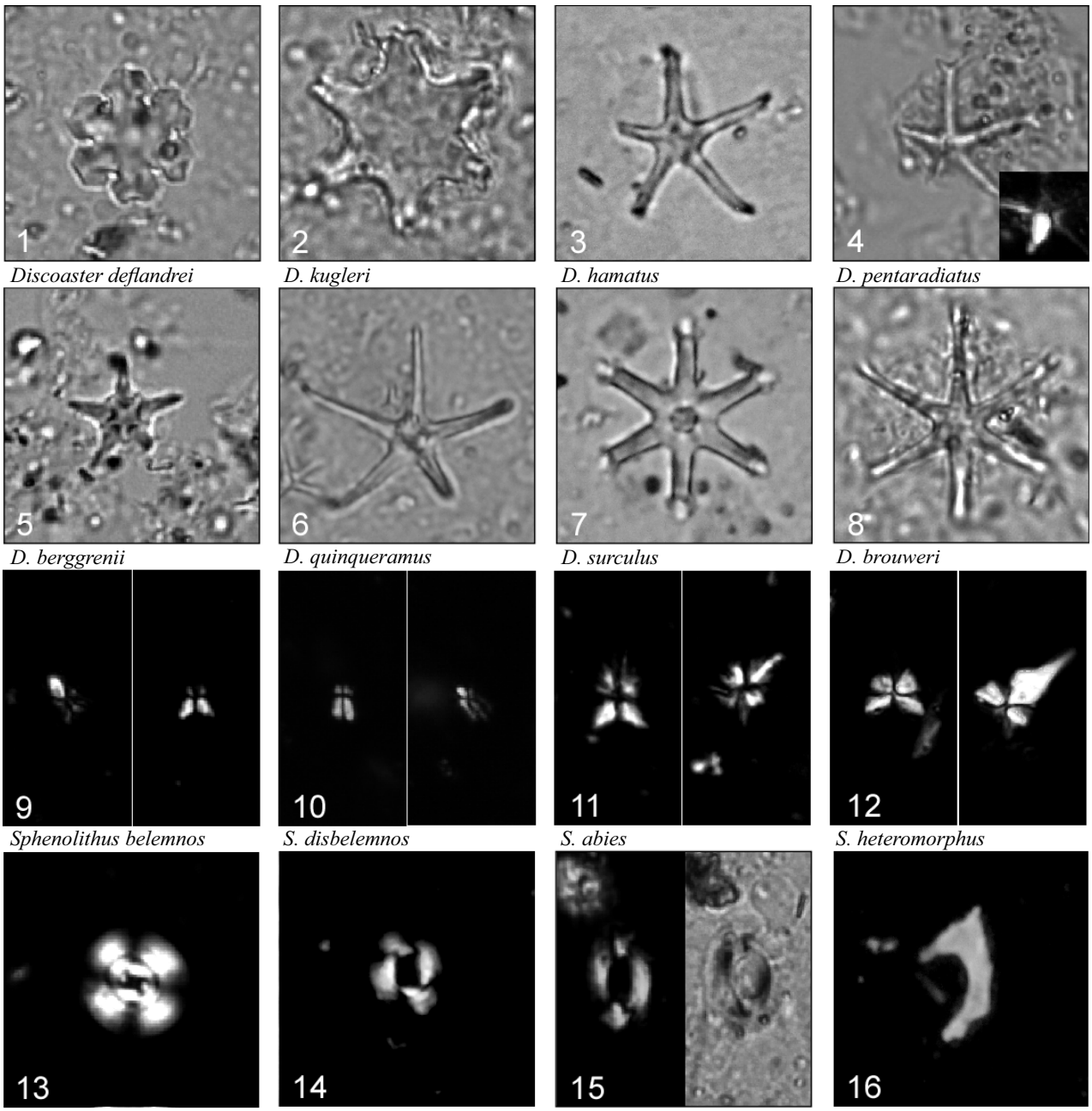
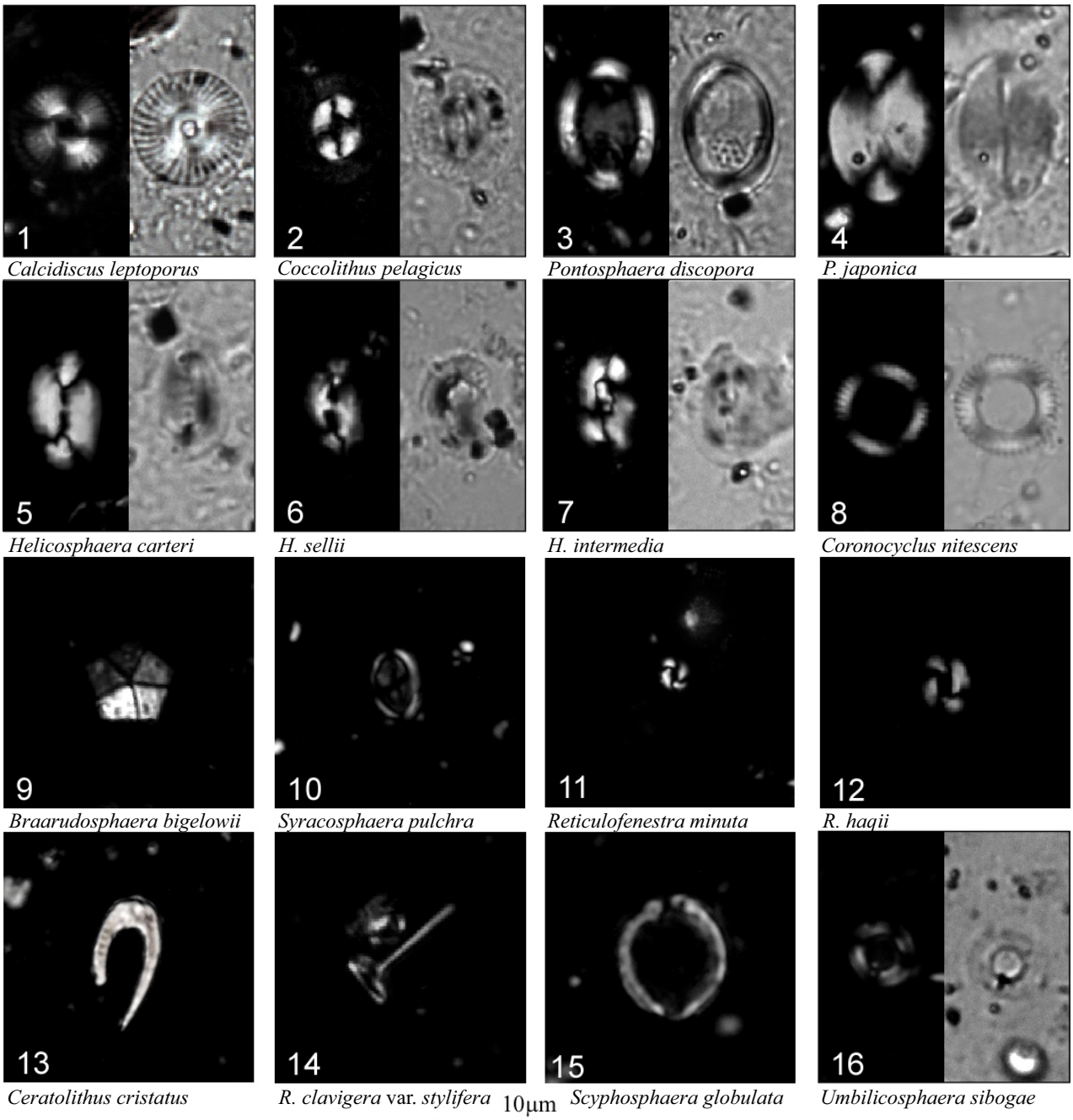
Plate 1



1. NN6-7, Thong-Mang Cau Fm; **2.** NN6-7, Thong-Mang Cau Fm; **3.** NN9, Nam Con Son Fm; **4.** NN17, Bien Dong Fm; **5.** NN11, Nam Con Son Fm; **6.** NN11, Nam Con Son Fm; **7.** NN16, Bien Dong Fm; **8.** NN18, Bien Dong Fm; **9.** NN3, Dua Fm; **10.** NN3, Dua Fm; **11.** NN15, Bien Dong Fm; **12.** NN5, Thong-Mang Cau Fm; **13.** NN6-7, Thong-Mang Cau Fm; **14.** NN15, Bien Dong Fm; **15.** NN4, Dua Fm; **16.** NN12-15, Bien Dong Fm

Plate 2



1. NN5, Thong-Mang Cau Fm; **2.** NN11, Nam Con Son Fm; **3.** NN11, Nam Con Son Fm; **4.** NN4, Dua Fm; **5.** NN12-15, Bien Dong Fm; **6.** NN18, Bien Dong Fm; **7**. NN5, Thong-Mang Cau Fm; **8.** NN5, Thong-Mang Cau Fm; **9.** NN11, Nam Con Son Fm; **10.** NN18, Bien Dong Fm; **11.** NN11, Nam Con Son Fm; **12.** NN10, Nam Con Son Fm; **13.** NN17, Bien Dong Fm; **14.** NN11, Nam Con Son Fm; **15.** NN18, Bien Dong Fm; **16.** NN18, Bien Dong Fm