Discoaster zonation of the Miocene of the Kutei Basin, East Kalimantan, Indonesia (Mahakam Delta Offshore).

Bernard LAMBERT[1]

Cécile LAPORTE-GALAA[2]

Abstract: Thirteen time-stratigraphic associations of the nannofossil *Discoaster* have been defined and used in the Miocene Kutei Basin of eastern Borneo to establish a regional stratigraphic framework. The methodology used is discussed and the fossils employed are figured and annotated. Their aid in resolving the timing, stages and details of delta construction is presented graphically.

Key Words: Borneo; delta; *Discoaster*; Kutei; Mahakam; Miocene; nannoflora; nannofossil; Neogene; stratigraphy; zonation.

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Résumé : Distribution chronostratigraphique des représentants du genre *Discoaster* au Miocène dans le bassin de Kutei (delta de la Mahakam, Est de l'île de Kalimantan, Indonésie).- Treize associations chronostratigraphiques basées sur les espèces du genre *Discoaster* ont été définies et utilisées pour le Miocène du basin de Kutei (Est de Bornéo) pour établir un cadre chronostratigraphique régional. La méthodologie utilisée et les nannofossiles utilisés sont figurés et discutés. L'aide apportée par les Discoasters pour comprendre la mise en place des différents systèmes deltaïques est présentée.

Sommaire : Le basin de Kutei est reconnu comme une province pétrolière depuis les premières découvertes à terre à la fin du 19éme siècle. De 1970 à 1985 le cadre chronostratigraphique régional n'a pu être précisé faute d'avoir des marqueurs paléontologiques fiables. La prédominance des faciès deltaïques excluant les formes planctoniques au profit de fossiles benthiques de large extension chronostratigraphique.

A la fin des années 1980, Total utilise les nannofossiles calcaires. Une méthodologie adaptée aux facies détritiques peu favorable à la préservation des éléments planctoniques et au matériel disponible (déblais de forage) été mise en œuvre.

Les premières investigations avaient révélé la présence de représentants du genre *Discoaster* dans les argiles de prodelta parfois localisées loin en arrière de la rupture de pente correspondant à de faibles profondeurs d'eau. Ils étaient souvent les seuls représentants de la nannoflore calcaire et dans la plupart des cas dispersés dans un abondant matériel détritique (silts, matière organique, *etc*.).

Treize intervalles chronostratigraphiques ont pu être reconnus et sont décrits dans ce mémoire. Ils couvrent la presque totalité du Miocène à l'exception de la partie basale (Aquitanien) non rencontrée. Une comparaison avec les zonations classiquement utilisée (MARTINI, BUKRY) est présentée. L'utilisation de ces différents intervalles a permis d'établir un cadre chronostratigraphique régional fiable en corrélant un grand nombre de puits largement disséminés dans le bassin de Kutei.

Mots-Clefs : Bornéo ; delta ; *Discoaster* ; Kutei ; Mahakam ; Miocène ; Nannofossiles ; Néogène ; stratigraphie ; zonation.

Sari: Pembagian daerah *Discoaster* pada lapisan Miocene dari Cekungan Kutei (Mahakam, Delta Offshore).- Tiga belas assosiasi waktu stratigrafi dari fosil nanno *Discoaster* telah didefinisikan dan digunakan pada lapisan Miosen di cekungan Kutei Kalimantan Timur untuk menetapkan kerangka stratigrafi regional. Metoda yang diterapkan akan didiskusikan dan fosil yang digunakan akan digambarkan dan dicatat. Penggunannya dalam mengatasi masalah waktu (time), masa (stage) dan konstruksi rinci dari delta di presentasikan secara grafik.

Ringkasan: Cekungan Kutei sudah dikenal sebagai daerah yang kaya minyak bumi semenjak penemuan minyak pertama didaratan pada akhir abad ke-19. Selama 15 tahunan (1970-1985) suatu kerangka stratigrafi regional yang lengkap untuk lapisan Neogen di cekungan Kutei belum bisa ditetapkan karena kurangnya marker fauna yang bisa dipercaya. Kekurangan ini disebabkan oleh jarangnya foraminifera plankton pada facies yang didominasi oleh delta dan ketidak hadiran bentuk bentonik yang luas dengan nilai stratigrafi yang berarti.

Pada akhir tahun 80an Total mencoba menggunakan fosil nanno kapuran untuk mengatasi masalah ini. Metoda baru dikembangkan untuk memperhitungkan karakteristik penghalang pada sedimen didaerah tsb: lempung, lanau dan pasir; dan kualitas dari material yang tersedia untuk studi: utamanya, "cutting".

Penyelidikan pertama menemukan fosil nanno dari genus *Discoaster* pada lempung berfacies "prodelta", umumnya berada jauh kearah laut dari batas paparan. Mereka mewakili secara unique dari plankton nanno kapuran yang ditemukan. Kehadirannya bersifat sporadis dan contoh ini jarang yang menyebar dalam jumlah yang banyak pada detritus halus.

[1] *Total, DGEP/GSR/PN, Tour Coupole, 2 Place de Coupole, La Défense 6 - Cédex 4, 92078 Paris La Défense (France)*
Bernard.Lambert@Total.com

[2] *Total, DGEP/GSR/TG, Centre Scientifique et technique, Avenue Larribau, 64018 Pau cedex (France)* *Cecile.Laporte@Total.com*

Sekalipun demikian, 13 assosiasi waktu stratigrafi terpisah telah dapat dikenal, didefinisikan dan dideskripsikan. Mereka mewakili semua lapisan, kecuali lapisan terbawah Miosen yang tidak ditembus oleh sumur pada daerah tsb. Hubungannya dengan zonasi fosil nanno yang diangap sebagai "Standard" (MARTINI, BUKRY) telah ditunjukkan. Kegunaannya sebagai fasilitasi penentuan hubungan umur dan memungkinkan untuk korelasi sumur-sumur yang tersebar secara luas di cekungan Kutei.

Kata-Kata kunci: Borneo; delta; *Discoaster*; Kutei; Mahakam; Miocene; nannoflora; nannofossil; Neogene; stratigraphy; zonation.

Introduction

The Kutei basin has been known as a prolific petroleum province since the first discoveries onshore at the end of the 19th century. For some fifteen years (1970-1985) a comprehensive regional stratigraphic framework for the Neogene sequence of the Kutei basin could not be established because of a lack of reliable faunal markers. The deficiency was caused by a scarcity of planktonic foraminifera in the predominant delta facies and the absence of large benthonic forms with significant stratigraphic value.

In the final years of the "eighties" Total attempted the use of calcareous nannofossils to resolve this problem. A new methodology was developed to take into account the obstructive characteristics of the sediments in the region: deltaic clays, silts and sands; and the quality of the materials available for study: for the most part, "cuttings".

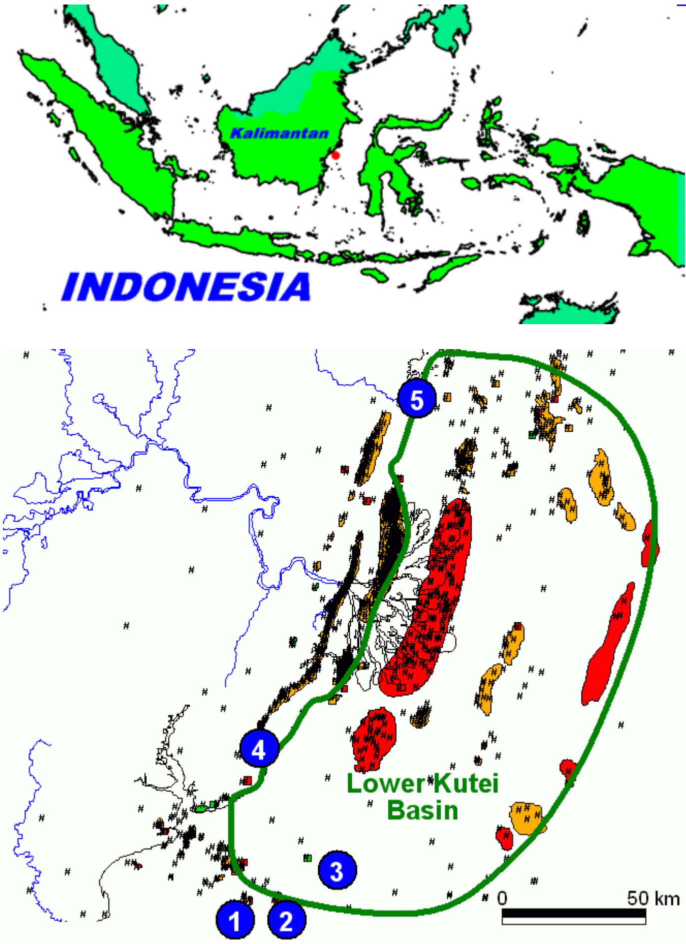


Figure 1: Location map of the area studied, in red main gas fields, in orange other oil and gas fields.. The circled numbers show the location of the reference wells.

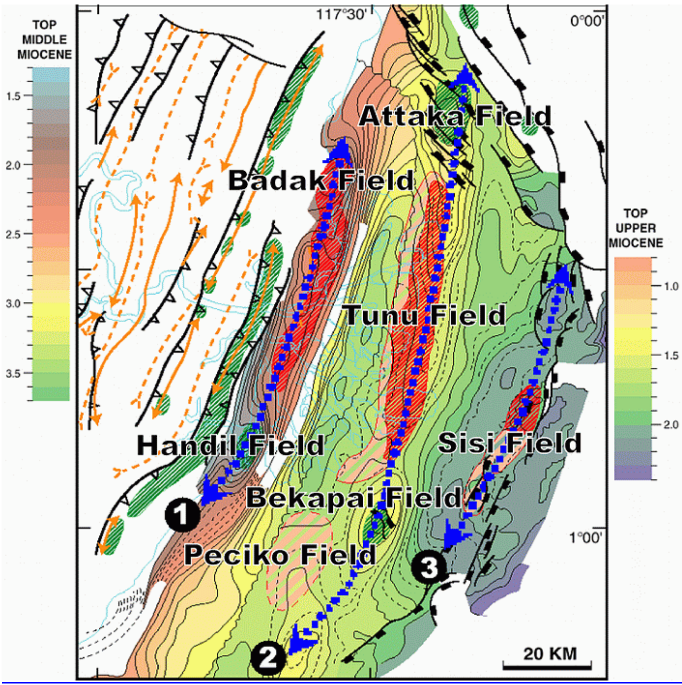


Figure 2: Mahakam Delta, simplified structural map at the so-called MF9 marker (Middle Miocene). Location of the main structural axes and the two giant gas fields (Tunu and Peciko): 1- Internal axis; 2- Median axis; 3- External axis (modified from GROSJEAN *et alii*, 1994).

The first investigations found nannofossils of the genus *Discoaster* in the shales of the "prodelta" facies, commonly far seaward of the shelf edge. They were and are the unique representatives of calcareous nannoplankton encountered. Their presence is sporadic and specimens are always sparsely dispersed in a huge amount of fine detritus.

Nevertheless, thirteen discrete time-stratigraphic associations have been recognized, defined, and described. They represent all but the lowermost stage of the Miocene, which was not reached by wells in the area. Their relationships to the nannofossil zonation considered "Standard" (MARTINI, BUKRY) are indicated. Their use facilitated the determination of age relationships and permitted the correlation of a number of wells scattered widely in the Kutei basin.

Regional Setting

The Tertiary Kutei Basin is in the eastern part of the island of Borneo in the Indonesian state of Kalimantan. It occupies more than 45,000 km^2 onshore and offshore. The Mahakam delta, the seaward extension of the basin, is often referred to as the "Lower Kutei" Basin (Fig. 1). There, sedimentation was continuous throughout the Neogene, whereas in

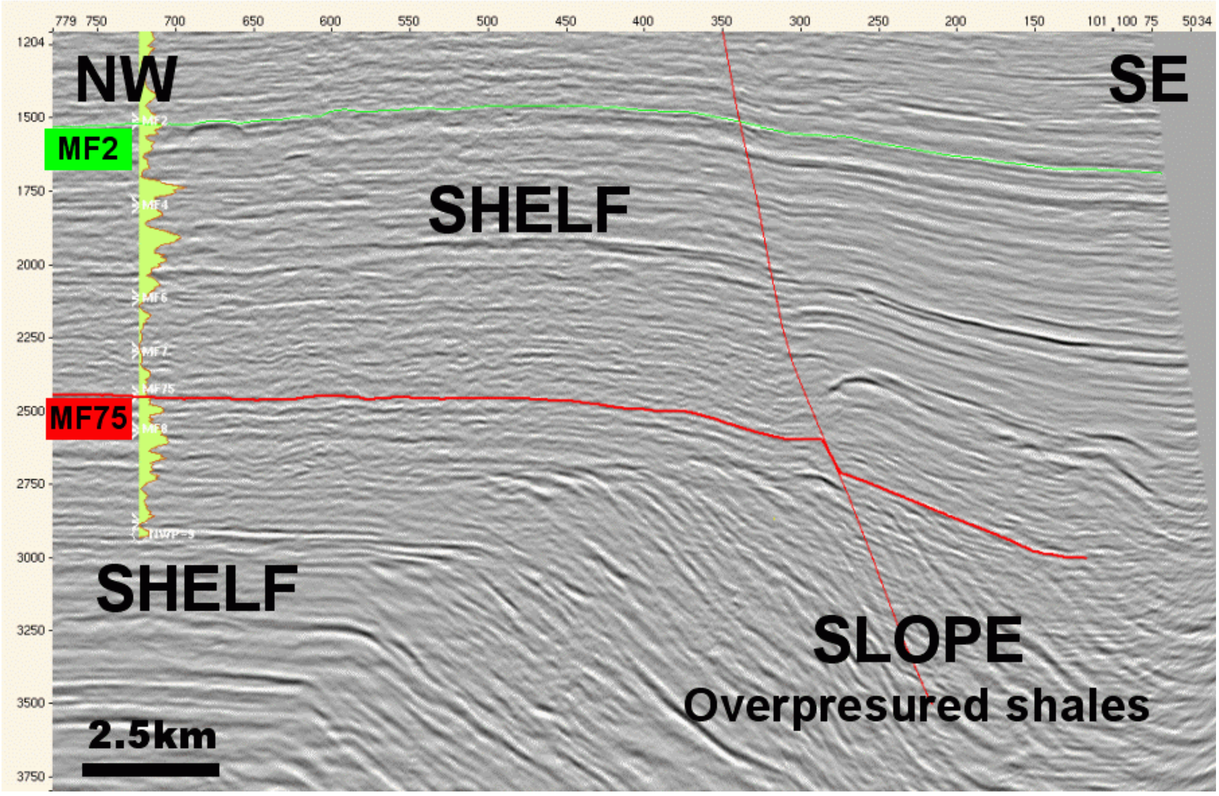
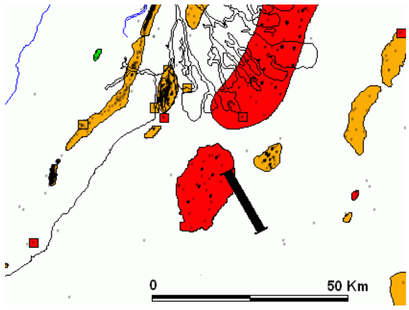


Figure 3 (a): Mahakam Delta, Peciko field area: location of a seismic dip line showing overall deltaic progradation, the shelf, the shelf break and overpressured slope facies. The main seismic markers are related to the main flooding events (two of them are demarcated, MF2 and MF75).



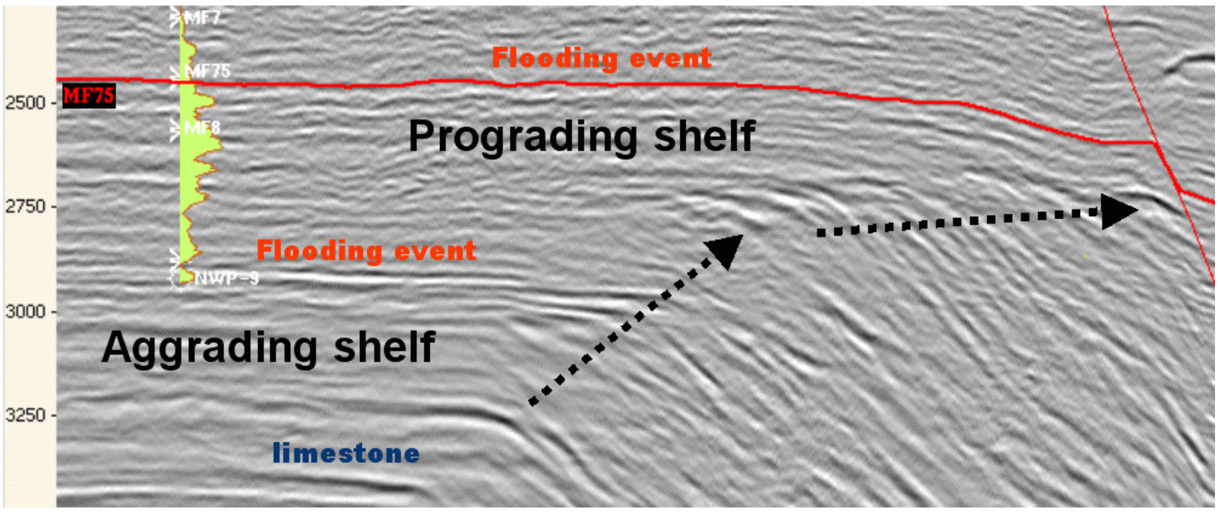


Figure 3 (b): Detail of the previous line showing the transition between an aggrading and a prograding interval. In the aggrading interval corresponding to a low influx of terrigenous sediment (see Fig. 4) transgressive limestones are widespread on the shelf (strong reflections visible on the line). In the prograding interval the transgressive limestones have disappeared (no strong reflections).

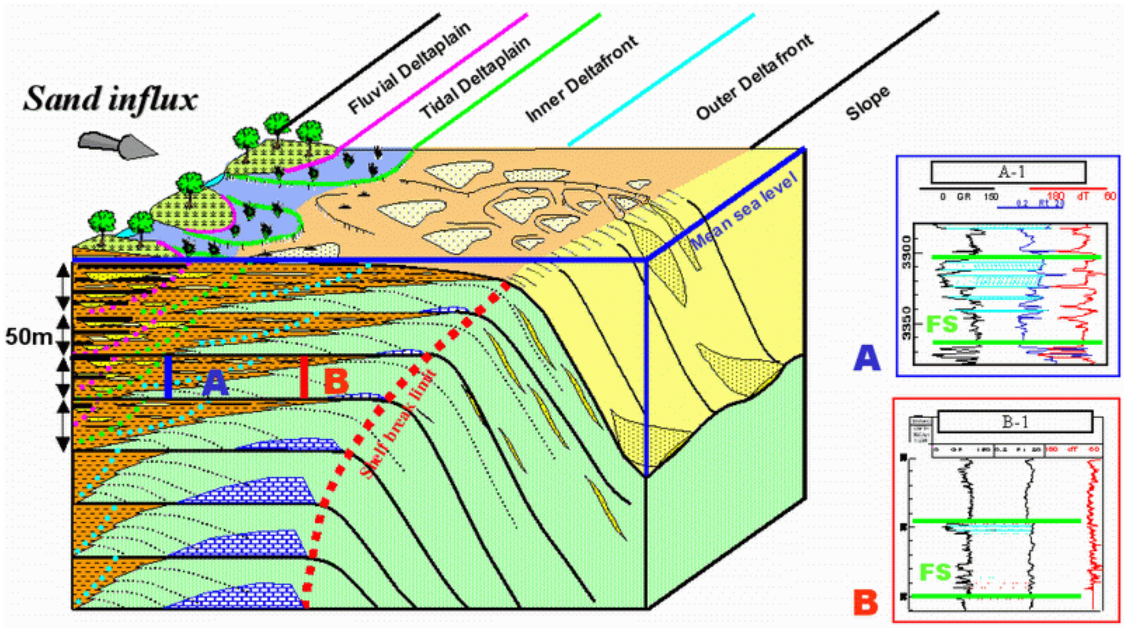


Figure 4: Geological interpretation of the seismic observations. The average thickness of a single deltaic unit is relatively constant (50 m) and corresponds to the pulses of regional subsidence. If the influx of sediment is heavy the deltaic unit will be strongly prograding and the shelf will be mainly sand prone (clays will be carried seaward to construct the slope). If the influx of sediment is relatively low, deltaic units will be aggradational and the shelf will be shale prone (most of the sediment will remain on the shelf). The geological interpretation of facies from electric logs: "A" and "B" of a single deltaic cycle shows graphically the marked change in sand content seaward and that the expression of the basal transgressive event (flooding surface) is not the same in a proximal and in a more distal location.

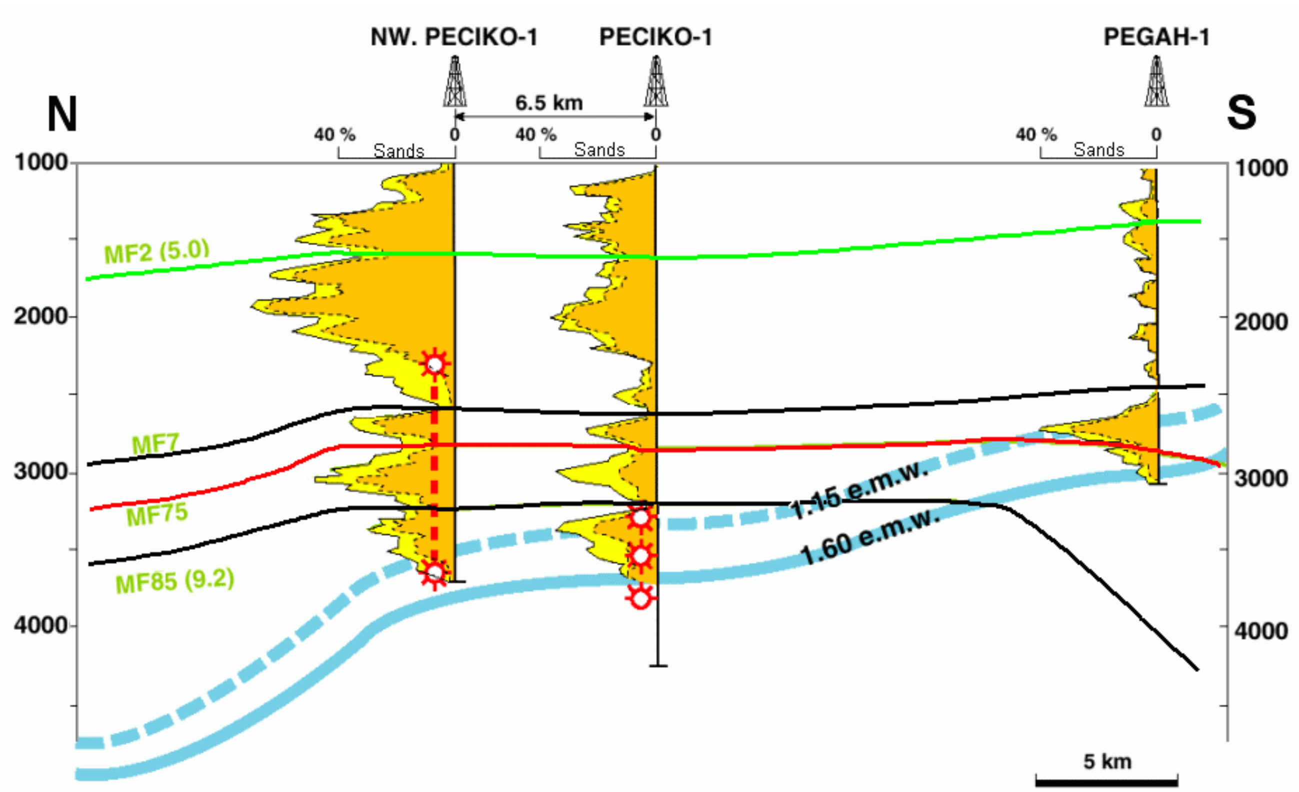


Figure 5: Mahakam Delta, Peciko field area, geological characterization of the flooding events. Using the moving averages method (quantitative sand distribution) flooding events could be distinguished and correlated from well to well. The MF2 and MF75 markers previously identified on the seismic line are shown in green and red.
Legend:
MF (5.0): flooding surfaces (age in MY)
emw: density (equivalent mud weight)
40%: sand content, moving averages

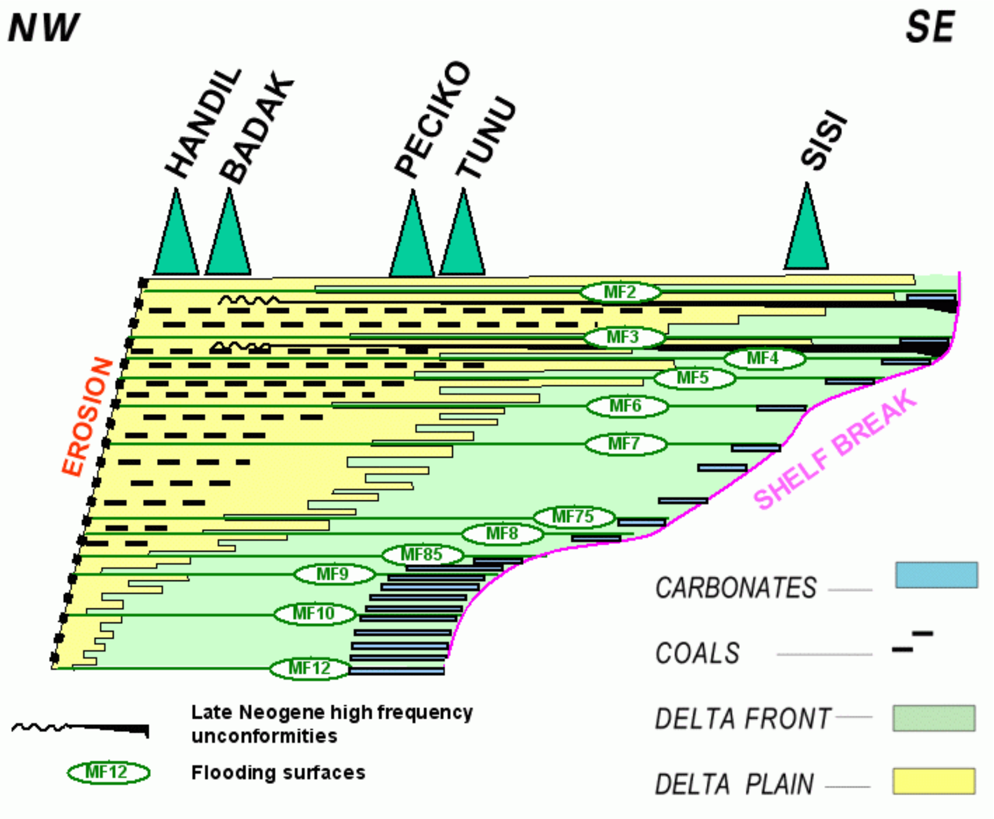


Figure 6: Mahakam Delta, Upper Miocene deltaic stacking pattern with the main flooding events detected seismically and in wells numbered in green.

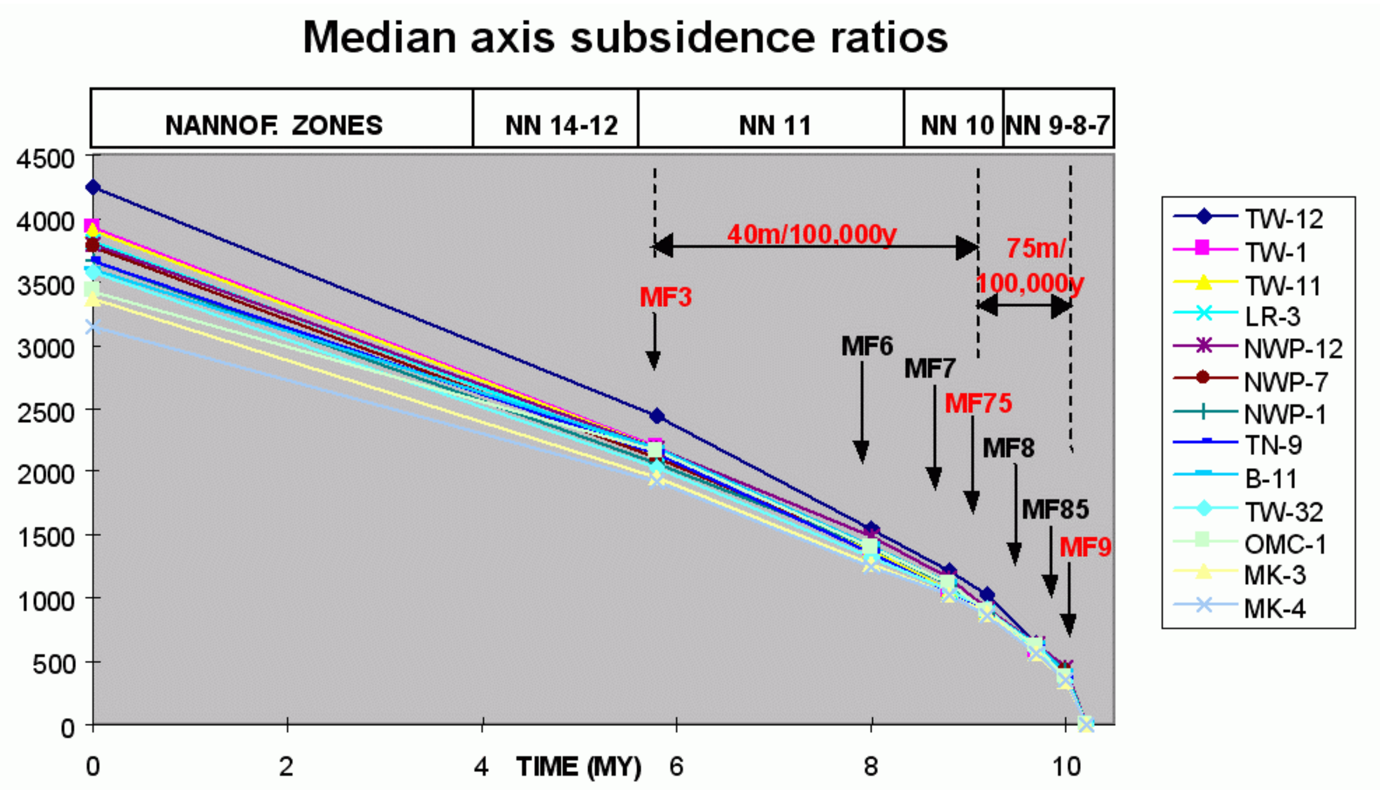


Figure 7: Mahakam Delta, Tunu and Peciko areas, Offshore Mahakam Area, subsidence rate of Median axis. The chronostratigraphic calibration is based on calcareous nannoplankton identified in the shales associated with flooding surfaces.

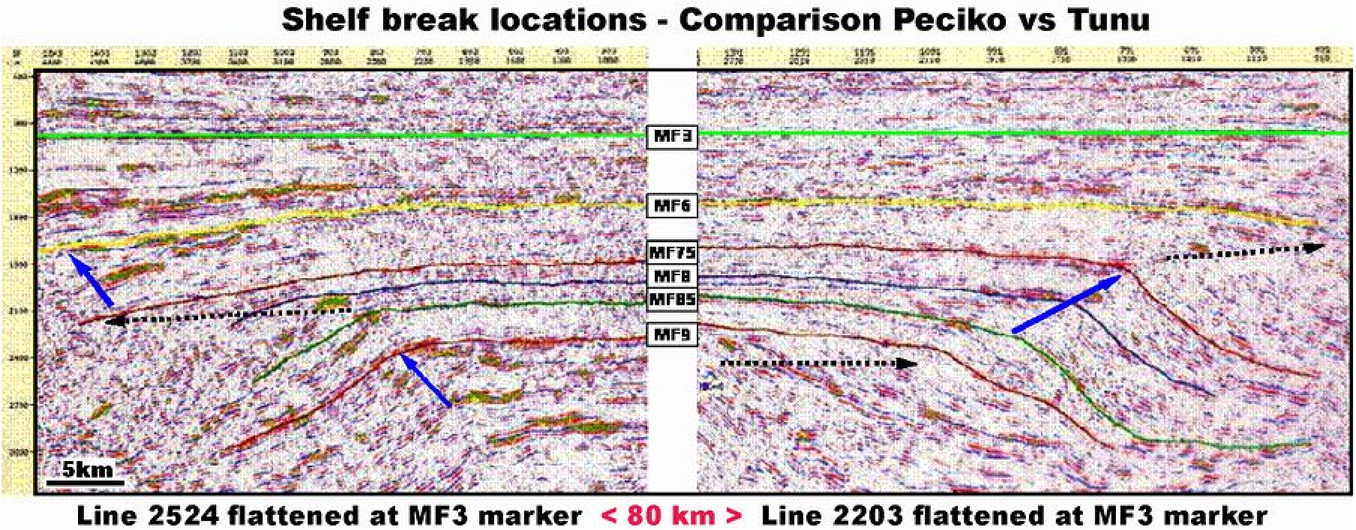


Figure 8: Mahakam Delta, evolution of shelf break through time, comparison of the areas north and south of the Tunu field showing the huge differences in the aggradation / progradation pattern between north and south (after LAMBERT *et alii*, 2004). These differences are related to the changes in the rate of sedimentary influx through time.

the onshore portion only strata of lower Neogene age are present because of uplift late in Miocene times. This tectonic activity resulted in the development of three structural axes offshore, oriented slightly east of north (Fig. 2). They are the sites of the main oil and gas fields of the Kutei basin. The Median axis houses the giant Peciko and Tunu gas fields (LAMBERT *et alii*, 2004). Trapping mechanisms are both structural and stratigraphic and are enhanced by overpressured slope shales.

Sedimentation

Overall, the sedimentary sequence of the Mahakam delta Basin consists of very thick, generally regressive clastics deposited without interruption from earliest Miocene times to the Present by the Mahakam river in its center. Their thickness totals more than 10 km. Consequently, the lithology is monotonously repetitive, a superposition of deltaic cycles clearly visible on seismic sections (Fig. 3). Progradation was interrupted at regular intervals, for short periods of aggradation are intercalated in longer periods of strong progradation (Fig. 3). The average thickness of a cycle ranges between 30 and 50 meters, and appears to correspond to the length of the average step of regional subsidence.

In each cycle, the normal sequence of facies (Prodelta, Deltafront and Deltaplain) are present (LAMBERT, 2003). Their lithology includes shales (Prodelta and Deltafront), sands (Deltafront and Deltaplain), and coal (Deltaplain). In more distal locations on the shelf, limestones and marine shales exist, but are always strongly affected by deltaic influx, and, of course, are confined to the base of the deltaic cycle in its initial transgressive phase.

One deltaic cycle represents the progressive replacement of a column of water 30 to 50 meters deep. In general the replacement consisted mainly of clay (80 per cent) and sand (20 per cent). When deposition was relatively slow, most of these clastics remained on the shelf (aggradation: shelf shale prone, Fig. 4).

When deposition was more rapid and more abundant, most sediment deposited on the slope was clay while sand remained trapped on the shelf (Progradation: Shelf sand prone, Fig. 4). The clays built the shelf outward. In any case, the deltaic cycle begins with a deposit of fine-grained clay produced by landward flooding. Identifying these more marine intercalations is important because they are sites where nannofossils may be present. During the "eighties" an important side-wall coring program was launched to identify these potential regional datums of maximum flooding surfaces. The moving average method was widely used to help locate them. It is based on a quantification of sand content. The average "Net to Gross" is first determined for a 50 meter interval. Then the same calculation is made for another 50 meter interval but "slid" from the previous interval by 10 meters. Thus a curve is obtained, useful in defining a subregional "shale" event (Fig. 5). In the Neogene sequence of the Kutei Basin some 20 of these regional flooding events have been detected (Fig. 6).

Most of them have been dated using Discoasters (Fig. 7), including some far landward of the shelf break. Combining this direct chronostratigraphic dating with electrofacies correlations permitted the construction of a detailed history of subsidence in the Mahakam delta sub-Basin (Median axis, Fig. 7). However, no correlation with presumed third order cycles of sea level change could be seen. Consequently, the large number of regional flooding events is probably caused by rapid and repeated subsidence, for it is most difficult to link any one of these events to the

Vail *et alii* chart.

Progradation and aggradation and their relative duration in time have been mentioned, but another point of interest is the rapid change of the stacking pattern from place to place in a given interval of time. This phenomenon is probably controlled by changes in the direction from which deposition took place. Fig. 8 shows the change in the pattern of progradation–aggradation on the Median axis, some 80 km long. This effect is important for it regulates the characteristics of the shelf sediments. For example, in the south (Peciko area) the interval MF 75/MF 85 has a large amount of progradation. In the north progradation is much less evident. Consequently, the strata will be sand prone in the south because flooding duration was reduced, whereas the northern portion with well-developed flooding cycles is shale prone. Therefore it is difficult to establish a hierarchy among the several flooding events in the Mahakam delta region, and as mentioned, to identify the effects of changes in sea level.

Development of Nannoplankton Biostratigraphy

Historical

As the usual chronostratigraphic markers (foraminifera, spores and pollen) are rare or absent in most of the Kutei Basin, for many years it was not possible to set up a comprehensive, integrated, stratigraphic model for the whole of the basin. At the beginning of the "eighties" nannofossils were used successfully by C. MULLER to make stratigraphical correlations in a few selected wells. These initial satisfactory results caused Total at the end of that decade to begin a complete regional synthesis. To do this, exchanges of well data were negotiated with other operators in the area (Vico and Unocal). These initial efforts ended finally in a complete review of 70 wells. All of the rare slope facies information was studied first, then all significant thicknesses of shale on the shelf were sampled and studied (side-wall cores and cuttings). A large number of thin beds of shale clearly identified by benthic foraminifera and electric logs as typical of a prodelta facies contained scattered and generally poorly preserved nannofossils, predominantly specimens of *Discoaster*. This finding focused attention on the unique potential of *Discoaster*. But the question immediately arose: How do we make full use of the sparse and often poorly preserved populations of Discoasters, commonly less than 50 specimens per sample?

Methodology

No commonly used conventional methods would be really efficient or satisfactory in collecting and concentrating the fossils from this type of clastic, scantily fossiliferous sediments. The material available was mainly cuttings, with some side-wall cores and occasional conventional cores. Each level selected, (spacing 10 meters) was soft-washed with water (for water-based mud), or with gasoline (for oil-based mud). Under a binocular microscope the lithologies were described and cuttings selected in accordance with electric log indications of rock type. Doubtful cuttings and cavings were removed, leaving a selection of the principal, presumably valid lithologies. Some 10 to 20 cutting chips were usually chosen (occasionally up to 50), crushed, and mounted with Canada balsam on a smear slide.

For a quantitative evaluation only specimens of the genus *Discoaster* were counted. A minimum of 30 specimens was considered an adequate representation for a chronostratigraphic determination based on both identity and relative abundance. For that reason the number of smear slides prepared for each sample was increased until the 30 specimens were obtained (in one single slide). All of them were photographed. In the sparsest intervals sometimes more than 50 smear slides had to be made in order to get the required 30 in one individual slide. For side-wall and conventional cores the results of several slides from the same piece or fragment were added together. Unfortunately sometimes the specified 30 specimens are not obtained. However it seems possible with around 20 specimens to determine the corresponding association (see Pl. 8 for instance).

Discoaster Associations and Chronostratigraphy

To improve the reliability of the chronostratigraphic significance of sparse populations of Discoasters the following procedure was followed:

First, a general chronostratigraphic chart using commonly accepted criteria was established, using mainly Discoasters, but including other calcareous nannofossils. The chart adopted the nomenclature of the classical zone markers (MARTINI NN). To construct the chart, wells in the most distal locations (slope facies) were sampled, their nannoflora identified and studied in detail.

This work was then added to with data from more landward wells. The result: a comprehensive survey of the distribution of the calcareous nannoflora of the Kutei basin keyed to the standard zonation proposed by MARTINI and used by C. MULLER in her pioneer work. Helpful more recent modifications of this standard zonation were included (BUKRY, 1973; PERCH-NIELSEN, 1985; THEODORIDIS, 1984).

Most commonly, Discoasters are the only nannofossils present in the sediments.

Consequently, their identification, associations and frequency are the bases of the chart: a statistical approach using the relative abundance of the several species as a means of establishing a chronologic succession.

In the Miocene strata involved (Aquitanian not reached), 13 discrete associations are recognized based on the presence and relative abundance of index species. In the more landward wells where less than 50 specimens per slide occur and no other fossils are present, relative abundance is the most useful means of determining age accurately.

Preservation

Generally speaking, in deltaic environments (including the slope facies) the integrity of the individual specimen is vital to reliable identification. In lithologies rich in organic matter and lacking carbonates, overgrowth does not occur. On the other hand, specimens are often damaged and incomplete. Elongate slender forms are particularly susceptible, as their delicate arms are seen to lack terminal portions critical to their identification. However, some specimens from more marly (seaward) localities do exhibit calcitic overgrowths and some of them have been illustrated (Pl. 8). In order to preserve homogeneity, all specimens shown in this study are from the same facies, *i.e.* the upper slope.

Standard Zonation

Here is a review of the two well-known nannofossil zonations (BUKRY, 1973; MARTINI, 1971) used by biostratigraphers working with Tertiary Nannofossils; some of the modifications proposed by THEODORIDIS in 1984 have been added. With the exception of the original definitions of zones that include all calcareous nannofossils, the following discussion is confined to the zones and subzones defined by their content of *Discoaster* species as indicated by their author. A compilation is given in Fig. 9.

MARTINI (1971)

NN1: *Triquetrorhabdulus carinatus* zone
Interval from the last occurrence of *Helicosphaera recta* to the first occurrence of *Discoaster druggii*. This interval has not been reached in the Mahakam Delta sub-basin.

NN2: *Discoaster druggii* Zone
In the Neogene sequence of the Kutei basin, the first *Discoaster* used for chronostratigraphic purposes is *Discoaster druggii* (BRAMLETTE et WILCOXON 1967b). The first occurrence of this marker is the main criterion for the NN2 zone (first occurrence of *D. druggii* plus last occurrence of *Triquetrorhabdulus carinatus*). Neither of these two markers has been observed in the area of interest probably due to the fact that no strata of the lowermost Miocene have been reached in the offshore Kutei basin.

NN3: *Sphenolithus belemnos* Zone
Interval from the last occurrence of *Triquetrorhabdulus carinatus* to the last occurrence of *Sphenolithus belemnos*. MARTINI indicates the appearance of *S. heteromorphus* in the upper part of the NN3 zone. It is the oldest stratigraphic entity found in the Mahakam delta sub-basin.

NN4: *Helicosphaera ampliaperta* Zone
Interval from the last occurrence of *Sphenolithus belemnos* to the last occurrence of *Helicosphaera ampliaperta* MARTINI indicated the appearance of *Discoaster variabilis* in the upper part of the NN4 zone. In the Kutei basin *Helicosphaera ampliaperta* is not present.

NN5: *Sphenolithus heteromorphus* Zone
Interval from the last occurrence of *Helicosphaera ampliaperta* to the last occurrence of *Sphenolithus heteromorphus*, a well known common marker. MARTINI indicated among the common species: *Discoaster variabilis*, *D. exilis*, *D. nephados*, *D. trinidadensis*, last occurrence of *D. druggii* and first occurrence of *D. brouweri*. In the Kutei basin *D. nephados* and *D. druggii* have never been observed and *D. trinidadensis* is considered to be a morphotype of *D. deflandrei*.

NN6: *Discoaster exilis* Zone
Interval between the last occurrence of *Sphenolithus heteromorphus* and the first occurrence of *Discoaster kugleri*. Common species: *D. exilis*, *D. trinidadensis* and *D. nephados*. In the Kutei basin *D. kugleri* has never been identified.

NN7: *Discoaster kugleri* Zone
Interval from the first occurrence of *Discoaster kugleri* to the first occurrence of *Catinaster coalitus*. Common species: those listed for zone NN6 plus *Discoaster kugleri*. *D. trinidadensis* has its last occurrence and *D. challengeri* and *D. pseudovariabilis* have their first occurrence in zone NN7.

NN8: *Catinaster coalitus* Zone
Interval from the first appearance of *Catinaster coalitus* to the first occurrence of *Discoaster hamatus*. Common species: those listed for zone NN7 plus *Catinaster coalitus*. The first occurrence of *Discoaster calcaris* is in the uppermost part of the *Catinaster coalitus zone*.

Figure 9: Distribution chart of Miocene Discoasters, and a comparison relating it to the two main standard zonations (MARTINI and BUKRY) and THEODORIDIS / Kutei basin. ▶


Martini
Bukry
Theodoridis
Kutei basin
D. deflandrei
D. druggi
D. lidzi
D. aulakos
D. protoexilis
D. formosus
D. variabilis
D.challengeri
D.exilis
D. nephados
D. trinidadensis
D. signus
D. musicus
D. subsurculus
D. brouweri
D. kugleri
D. braarudi
D. pseudovariabilis
C. coalitus
D. bolli
D. pansus
D. hamatus
D. calcaris
D. prepentaradiatus
D. neohamatus
D. pentaradiatus
D. bellus
D. asymetricus
D. misconceptus
D. intercalaris
D. loeblichi
N. neorectus
D. perclarus
D. berggrenii
D. quinqueramus
D. surculus
D. icarus
Martini
Bukry
Theodoridis
Kutei Basin
NN 11
b
a
NN 10
NN 9
NN 8
NN 7
NN 6
NN 5
NN 4
NN 3
NN 2
NN 1
CN 9
b
a
CN 8
b
a
CN 7
CN 6
CN 5
b
a
CN 4
CN 3
CN 2
CN 1
c
b
a
C. leptoporus
R. rotaria
A. primus
C. pelagicus
M. convallis
E. calcaris
E. exilis
S. heteromorphus
H. ampliaperta
T. milowii
T. carinatus
A 13
A 12
A 11
A 10
A 9
A 8
A 7
A 6
A 5
A 4
A 3
A 2
A 1
?
Martini references
Kutei basin events

NN9: *Discoaster hamatus* Zone

Interval from the first to the last occurrence of *Discoaster hamatus*. Common species: *D. hamatus*, *D. variabilis*, *D. challengeri* and *D. calcaris*. *D. exilis* seems to have its last occurrence, *D. neohamatus* and *D. pentaradiatus* their first occurrence in the lower part of the *D. hamatus* zone. *D. pseudovariabilis* has its last occurrence and *D. bollii* its first occurrence in the upper part of the NN9 zone.

NN10: *Discoaster calcaris* Zone

Interval from the last occurrence of *Discoaster hamatus* to the first occurrence of *D. quinqueramus*. Common species: those listed for the NN10 zone less *D. hamatus*. *D. bollii* has its last occurrence in the lower part of the *D. calcaris* zone.

NN11: *Discoaster quinqueramus* Zone

Interval from the first to the last occurrence of *Discoaster quinqueramus*. Common species: *D. quinqueramus*, *D. variabilis*, *D. challengeri*, *D. brouweri* and *D. pentaradiatus*. *D. calcaris* and *D. neohamatus* have their last occurrence. Rare specimens of *D. surculus* occur throughout zone NN11.

In 1986 MARTINI and MULLER proposed a revised version of the original standard zonation. In that text no change is proposed for the Neogene except the introduction of a subdivision in the NN11 zone based on the first occurrence of *Amaurolithus delicatus*. But in the detailed chart they provide, some changes to the original zonation are noted:

- the last occurrence of *Discoaster deflandrei* is in the lower part of the NN6 zone,
- *D. icarus* is restricted to the upper part of the NN11 zone.

D. icarus has never been found in our samples.

BUKRY (1971b, 1973),

LOW LATITUDE COCCOLITH BIOSTRATIGRAPHIC ZONATION

BUKRY introduces in this zonation the concept of "acme zone" corresponding to the interval of time in which a given species is most abundant.

In 1980 in association with OKADA, BUKRY proposed a revision of his initial zonation and introduced a code number.

A comparison between the two classical standard zonations is provided by MARTINI and MULLER in 1986.

***Triquetrorhabdulus carinatus* Zone (CN1 = NN1+2)**

<u>*Cycligargolithus abisectus* Subzone (CN1a)</u>

Interval from the last occurrence of *Sphenolithus ciperoensis* to the last occurrence of *Cyclicargolithus abisectus*. Common species: *Discoaster deflandrei*.

<u>*Discoaster deflandrei* Subzone (CN1b)</u>

From the last occurrence of *Cyclicargolithus floridanus* to the first occurrence of *Discoaster druggii*. Abundance of *D. deflandrei*.

<u>*Discoaster druggii* subzone (CN1c)</u>

From the first occurrence of *Discoaster druggii* to the first occurrence of *Sphenolithus belemnos*. Common species: *D. deflandrei*, *D. lidzi*, *D. druggii*, *D.* sp. and *D. variabilis*.

D. lidzi has never been observed here by this author. This form is relatively close to *D. nephados* (both described originally by HAY, 1967).

***Sphenolithus belemnos* Zone (CN2 = NN3)**

From the first to the last occurrence of *Sphenolithus belemnos* and to the first occurrence of *S. heteromorphus*. Common species: *Discoaster aulakos* and *D. deflandrei*

D. aulakos originally described by GARTNER, 1967, obviously is a specimen overgrown by calcite.

***Helicosphera ampliaperta* Zone (CN3 = NN4)**

From the last occurrence of *Sphenolithus belemnos*, the first occurrence of *S. heteromorphus* to the end of the acme zone of *Discoaster deflandrei* and to the last occurrence of *Helicosphera ampliaperta*. Reduction of the dominance of *Discoaster deflandrei* in favour of long-rayed Discoasters such as *D. exilis*, *D. signus* and *D. variabilis*.

***Sphenolithus heteromorphus* Zone (CN4 = NN5)**

From the last occurrence of *Discoaster deflandrei* and *Helicosphaera ampliaperta* to the last occurrence of *Sphenolithus heteromorphus*. Decrease of the short-rayed *Discoaster* (*deflandrei*), presence of *D. exilis*, *D. moorei*, *D. signus* and *D. variabilis*.

We consider *D. moorei* as a pentaradiate form of *D. exilis*.

***Discoaster exilis* Zone (CN5 = NN6+7)**

<u>*Coccolithus miopelagicus* Subzone (CN5a =NN6)</u>

From the last occurrence of *Sphenolithus heteromorphus* to the first occurrence of *Discoaster kugleri*. Common species: *D. exilis*, *D. variabilis*, *D. aulakos*, *D. deflandrei*, *D. braarudii*, *D. moorei* and *D. signus*.

<u>*Discoaster kugleri* Subzone (CN5b = NN7)</u>

From the first to the last occurrence of *Discoaster kugleri* to the first occurrence of *Catinaster coalitus*. Common species: *Discoaster aulakos*, *D. bollii*, *D. braarudi*, *D. challengeri*, *D. kugleri* and *D. variabilis*.

D. braarudii has never really been observed in our samples. Various planar 6-rayed asteroliths have been found often without any satisfactory specific name to propose for them.

***Catinaster coalitus* Zone (CN6 = NN8)**

From the first occurrence of *Catinaster coalitus* to the first occurrence of *Discoaster hamatus*. Common species: *Catinaster coalitus*, *Discoaster bollii*, *D. braarudii*, *D. challengeri*, *D. exilis*, *D. pseudovariabilis* and *D. variabilis*.

***Discoaster hamatus* Zone (CN7 = NN9)**

From the first to the last occurrence of *Discoaster hamatus*. Common species: *Catinaster coalitus*, *Discoaster hamatus*, *D. bellus*, *D. bollii*, *D. braarudii*, *D. brouweri* (rare), *D. calcaris*, *D. neohamatus*, *D. prepentaradiatus* and *D. pseudovariabilis.*

D. bellus has not been found / used, we consider this species as a pentaradiate asterolith overgrown by calcite.

***Discoaster neohamatus* Zone (CN8 = NN10)**

<u>*Discoaster bellus* Subzone (CN8a)</u>

From the last occurrence of *Discoaster hamatus* to the first occurrence of *D. neorectus.* Common species: *Catinaster coalitus*, *Discoaster asymmetricus* (rare, possibly a variant of *D. bellus*), *D. bellus*, *D. bollii*, *D. brouweri*, *D. intercalaris* (rare), *D. loeblichii*, *D. neohamatus*, *D. pentaradiatus*, *D. perclarus*, *D. prepentaradiatus*, *D. pseudovariabilis* and *D. variabilis*.

<u>*Discoaster neorectus* Subzone (CN8b)</u>

From the first to the last occurrence of *Discoaster neorectus* to the first occurrence of *D. berggrenii.* Common species: *D. asymmetricus*, *D. bellus*, *D. brouweri*, *D. challengeri*, *D. intercalaris*, *D. loeblichii*, *D. neohamatus*, *D. neorectus*, *D. pentaradiatus* (rare), *D. perclarus*, *D. quinqueramus* (transitional form from *D. bellus*) and *D. variabilis*.

We follow THEODORIDIS and consider *D. neohamatus* as a form of *D. calcaris* / *neorectus* ovegrown by calcite. *D. loeblichii* has never been observed; generally speaking bifurcated asteroliths remain very rare in the uppermost part of the Miocene of the Kutei basin.

***Discoaster quinqueramus* Zone (CN9 = NN11)**

<u>*Discoaster berggrenii* Subzone (CN9a = NN11a)</u>

From the last occurrence of *Discoaster neorectus* / first occurrence of *D. berggrenii* to the first occurrence of *Ceratolithus primus*. Common species: *Discoaster asymmetricus* (rare), *D. berggrenii*, *D. brouweri*, *D. challengeri*, *D. intercalaris*, *D. pentaradiatus*, *D. quinqueramus*, *D. surculus* and *D. variabilis*.

<u>*Ceratolithus primus* Subzone (CN9b = NN11b)</u>

From the last occurrence of *Ceratolithus primus* to the last occurrence of *Discoaster quinqueramus*. Common species: *D. asymmetricus* (rare), *D. berggrenii*, *D. brouweri*, *D. challengeri*, *D. intercalaris*, *D. pentaradiatus*, *D. quinqueramus*, *D. surculus* and *D. variabilis*.

THEODORIDIS (1984)

In 1984, THEODORIDIS, in his work devoted to the biozonation of the Miocene, proposed some interesting modifications, some of them based on accurate *Discoaster* species descriptions. Most of these observations have been confirmed in our Indonesian material. However, following AUBRY (1984) and PERCH-NIELSEN (1985) we consider the distinction between *Helio-Discoaster* and *Eu-Discoaster* unnecessary so we use only the name *Discoaster*. Below we maintain the name *Eudiscoaster* only in the author's original designation of the zone or subzone.

***Triquetrorabdulus carinatus* Zone (NN1 - NN2 zones)**

From the end of the acme of *Reticulofenestra abisecta* to the first occurrence of *Geminilithella rotula*.

<u>*Eu-discoaster deflandrei* Subzone</u>

End of the acme of *Reticulofenestra abisecta* and the first occurrence of *Discoaster druggii*, presence of *D. deflandrei* in the nannofossils assemblages.

<u>*Eu-discoaster druggii* Subzone</u>

First occurrence of *Discoaster druggii* to the first occurrence of *Helicosphaera ampliaperta*, presence of *Discoaster deflandrei*.

<u>*Helicosphaera vedderi* Subzone</u>

From the first occurrence of *Helicosphaera ampliaperta* to the first occurrence of *Geminilithella rotula*. Presence of *Discoaster deflandrei* and *D. druggii*.

***Triquetrorhabdulus milowi* Zone (upper NN2 - NN3)**

First occurrence of *Geminilithella rotula* to the first occurrence of *Sphenolithus heteromorphus.*

<u>*Triquetrorhabdulus martinii* Subzone</u>

First occurrence of *Geminilithella rotula* to the last occurrence of *Triquetrorhabdulus carinatus*. *Discoaster deflandrei* and *D. druggii* are present in the assemblages.

<u>*Sphenolithus belemnos* Subzone</u>

From the last occurrence of *Triquetrorhabdulus carinatus* and/or the first occurrence of *Sphenolithus belemnos* to the first occurrence of *S. heteromorphus*. *Discoaster druggii* and *D. deflandrei* are present in the assemblages.

***Helicosphaera ampliaperta* Zone (lower NN4)**

From the first occurrence of *Sphenolithus heteromorphus* to the first occurrence of *Discoaster exilis*. *D. deflandrei* and *D. protoexilis* are present in the association.

***Sphenolithus heteromorphus* Zone (upper NN4 – NN5)**

First occurrence of *Discoaster exilis* to the last occurrence of *Sphenolithus heteromorphus.*

Helicosphaera obliqua Subzone (upper NN4): Interval from the first occurrence of *Discoaster exilis* to the first occurrence of *D. signus.* Common species: *D. deflandrei* and *D. exilis.*

Eu-discoaster signus Subzone (upper NN4): Interval from the first occurrence of *Discoaster signus* to the last occurrence of *Helicosphaera ampliaperta.* Common species: *Discoaster deflandrei*, *D. exilis*, *D. musicus* and *D. signus*.

Helicosphaera perch-nielseniae Subzone (lower NN5): Interval from the last occurrence of *Helicosphaera ampliaperta* to the last occurrence of *Helicosphaera perch-nielseniae*. Last occurrence of *Discoaster signus*.

Helicosphera waltrans Subzone (middle NN5): Interval from the last occurrence of *Helicosphaera perch-nielseniae* to the last occurrence of *Helicosphaera waltrans*. Common species: *Discoaster deflandrei*, *D. exilis*, *D. musicus*, *D. signus* and *D. variabilis*.

Eu-discoaster musicus Subzone (upper NN5): Interval from the last occurrence of *Helicosphaera waltrans* to the last occurrence of *Sphenolithus heteromorphus*.

***Eu-discoaster exilis* Zone (lower NN6 - NN8)**

Interval from the last occurrence of *Sphenolithus heteromorphus* to the first occurrence of *Discoaster calcaris* / *D. bellus*.

Helicosphaera walbersdorfensis Subzone (lower NN6): Interval from the last occurrence of *Sphenolithus heteromorphus* to the first occurrence of *Helicosphaera orientalis* and/or the first occurrence of *Syracosphaera fragilis*. Common species: *Discoaster deflandrei*, *D. exilis*, *D. subsurculus* and *D. variabilis*.

Helicosphaera orientalis Subzone (part of NN6): Interval from the first occurrence of *Helicosphaera orientalis* ond/or the first occurrence of *Syracosphaera fragilis* to the first occurrence of *Helicosphaera stalis*. Common species: *Discoaster deflandrei*, *D. exilis*, *D. subsurculus* and *D. variabilis*.

Helicosphara intermedia Subzone (upper NN6): Interval from the first occurrence of *Helicosphaera stalis* to the last occurrence of *Reticulofenestra floridana* and/or the first occurrence of *Discoaster kugleri*. Common species: *D. bollii*, *D. deflandrei*, *D. exilis*, *D. subsurculus* and *D. variabilis*.

Eu-discoaster kugleri Subzone (NN7): Interval from the first occurrence of *Discoaster kugleri* and the last occurrence of *Reticulofenestra floridana* to the last occurrence of *Discoaster kugleri* and/or the first occurrence of *Catinaster coalitus*. Common species: *Discoaster bollii*, *D. deflandrei*, *D. exilis*, *D. micros*, *D. pansus*, *D. subsurculus* and *D. variabilis*.

Eu-discoaster bollii Subzone (lower NN8): Interval from the last occurrence of *Discoaster kugleri* and/or the last occurrence of *Helicosphaera walbersdorfensis* and/or the first occurrence of *Catinaster coalitus* to the first occurrence of *Discoaster calcaris* and / or the first occurrence of *D. bellus*. Common species: *Catinaster coalitus*, *Discoaster bollii*, *D. deflandrei*, *D. exilis*, *D. pansus*, *D. pseudovariabilis* and *D. variabilis*.

***Eu-discoaster calcaris* Zone (upper NN8 - lower NN9)**

Interval from the first occurrence of *Discoaster calcaris* / *D. bellus* to the first occurrence of *Minylitha convallis*.

Eu-discoaster bellus Subzone (upper NN8): Interval from the first occurrence of *Discoaster calcaris* / *D. bellus* to the first occurrence of *D. hamatus*. Common species: *Catinaster coalitus*, *Discoaster bellus*, *D. bollii*, *D. calcaris*, *D. deflandrei*, *D. exilis*, *D. pansus*, *D. pseudovariabilis* and *D. variabilis*.

Eu-discoaster hamatus Subzone (lower NN9): Interval from the first occurrence of *Discoaster hamatus* to the first occurrence of *Minylitha convallis*. Common species: *Catinaster coalitus*, *Discoaster bellus*, *D. bollii*, *D. calcaris*, *D. deflandrei*, *D. exilis*, *D. hamatus*, *D. pansus*, *D. pseudovariabilis* and *D. variabilis*.

***Minylitha convallis* Zone (upper NN9 - lower NN11)**

Total range of *Minylitha convallis.*

Eu-discoaster pseudovariabilis Subzone (upper NN9): Interval from the first occurrence of *Minylitha convallis* to the last occurrence of *Discoaster hamatus*. Common species: *Catinaster calyculus*, *C. coalitus*, *Discoaster bellus*, *D. bollii*, *D. brouweri*, *D. calcaris*, *D. deflandrei* (rare), *D. exilis* (rare), *D. giganteus*, *D. hamatus*, *D. pansus*, *D. pentaradiatus*, *D. pseudovariabilis* and *D. variabilis*.

Eu-discoaster pentaradiatus Subzone (lower NN10): Interval from the last occurrence of *Discoaster hamatus* to the last occurrence of *D. pentaradiatus* and / or the first occurrence of *D. misconceptus*. Common species: *Catinaster coalitus*, *Discoaster bellus*, *D. brouweri*, *D. calcaris* (sporadic), *D. giganteus*, *D. loeblichii*, *D. neorectus*, *D. pansus*, *D. pentaradiatus*, *D. pseudovariabilis*, *D. surculus* and *D. variabilis*.

Geminithella rotula Subzone (upper NN10 - lower NN11): Interval from the last occurrence of *Discoaster pentaradiatus* and / or the first occurrence of *D. misconceptus* to the last occurrence of *Minylitha convallis*. Common species: *Discoaster bellus*, *D. brouweri*, *D. calcaris* (sporadic), *D. giganteus*, *D. loeblichii*, *D. misconceptus*, *D. neorectus*, *D. pansus*, *D. pseudovariabilis*, *D. quinqueramus*, *D. surculus* and *D. variabilis*.

***Coccolithus pelagicus* Zone (part of NN11)**

Interval from the last occurrence of *Minylitha convallis* to the first occurrence of the genus *Amaurolithus*. Common species: *Discoaster bellus*, *D. brouweri*, *D. misconceptus*, *D. pansus*, *D. quinqueramus*, *D. surculus* and *D. variabilis*.

***Amaurolithus primus* Zone (part of NN11)**

Interval from the first occurrence of species of *Amaurolithus* to the first occurrence of *Reticulofenestra rotaria*. Common species: *Discoaster bellus*, *D. brouweri*, *D. misconceptus*, *D. pansus*, *D. quinqueramus*, *D. surculus* and *D. variabilis*.

***Reticulofenestra rotaria* Zone (part of NN11)**

Range defined by the range of *Reticulofenestra rotaria*. Common species: *Discoaster bellus*, *D. brouweri*, *D. misconceptus*, *D. pansus*, *D. quinqueramus*, *D. surculus* and *D. variabilis*.

***Calcidiscus leptoporus* Zone (upper NN11 – lower NN12)**

Interval from the last occurrence of *Reticulofenestra rotaria* to the first occurrence of *Ceratolithus rugosus*.

Calcidiscus leptoporus Subzone A (NN11 upper): Interval from the last occurrence of *Reticulofenestra rotaria* to the last occurrence of *Discoaster quinqueramus* and / or the first occurrence of *Ceratolitus acutus* and / or the last occurrence of *Triquetrorhabdulus rugosus*. Common species: *Discoaster bellus*, *D. brouweri*, *D. misconceptus*, *D. pansus*, *D. quinqueramus*, *D. surculus* and *D. variabilis*.

Description of Outer Kutei Basin Zonations

Association 1 (Pls. 1-2, Figs. 10-11)

Age: Lower Miocene.

NN reference: Zones NN3, NN4, NN5.

Type level: Well-1, 2265 m (*Sphenolithus belemnos*, NN3) + Well-4, 3660 m (*S. heteromorphus*, NN4/5).

Description: 40% of the *Discoaster* population are specimens of *D. deflandrei* Bramlette et Sullivan 1963. 40% of the population are specimens referred to *D. protoexilis* Theodoridis 1984. The remaining 20% are pentaradiate forms probably *D. protoexilis*.

Taxonomic comment: We do not follow Theodoridis in the use of the concept of *Helio-Discoaster* and *Eu-Discoaster* (see previous discussion).

Discoaster protoexilis: The specimens observed in the Kutei basin are similar to the specimens described by Theodoridis:

- proximal and distal knob,
- distal knob surrounded by depression,
- relatively short, slender, bifurcate arms (acute angle between bifurcations).

Generally small asterolith, size between 5 and 15 µm.

The pentaradiate forms have been referred to *D. protoexilis* because of the presence on the distal side of depressions around the distal knob. These depressions do not exist in *D. deflandrei*.

Discoaster deflandrei:

- short and thick arms (very little space between the arms),
- distal knob,
- bifurcated arm with branches also bifurcate ("double bifurcation").

As explained by Theodoridis, although the typical forms of the index species *D. deflandrei* and *D. protoexilis* can be easily recognized, intermediate forms are common especially when the overall poor state of preservation of the specimens is taken into account and in particular when the central area is not clearly visible. On the distal part a sometimes well developed knob is present, and on the flat proximal side it is possible to see sutures between the arms (as illustrated by Stradner and Allram, Pl. 1, fig. 3; Pl. 3, figs. 1-2). In the same paper these authors present good SEM illustrations of the proximal and distal sides of typical *D. deflandrei*. In these illustrations no depression exists on the distal side of *D. deflandrei*.

Chronostratigraphic comment: In the Kutei basin area the classical marker *Helicosphaera ampliaperta* has never been encountered. For this reason it is not possible to delimit the NN3-NN4 and NN4-NN5 boundaries. Based strictly on the presence of index species of *Sphenolithus* this association is placed in the NN2-3 / 4-5 zones (presence of *S. belemnos* in Well-1, 2265 m and *S. heteromorphus* in Well-4, 3660 m). Theodoridis indicates that *Discoaster protoexilis* appears in his *Helicosphaera ampliaperta* zone (among with *Sphenolithus heteromorphus* and *S. belemnos*. This zone is the equivalent of the upper part of Martini's NN3 zone). In the Mahakam area, the oldest sample studied in Maruat-1, 2265 m contained only *S. belemnos*, so the first occurrence of *Discoaster protoexilis* must be in the NN3 zone below the first appearance of *Sphenolithus heteromorphus*. The absence of long, bifurcate, rayed *Discoaster* (*D. variabilis* / *challengeri*) allows us to restrict this association to the lower part of NN4 (MARTINI, 1971). It accords with the position of the *Helicosphaera ampliaperta* zone of THEODORIDIS (last occurrence of *Discoaster protoexilis*) if its *D. exilis* (illustrated by forms with large bifurcated arms) corresponds pro parte to our *D. variabilis* / *challengeri* group.

Proposed range of association 1: NN3 - lower NN4

Association 2 (Pls. 3-4, Figs. 12-13)

Age: Lower Miocene.

NN reference: Zones NN4-5.

Type levels: Well-4, 3355 m and 3051 m.

Description: 30% of the population is *Discoaster deflandrei.* 70% of the population is "slender" asteroliths comprised of:

- *D. protoexilis* (50%),
- *D. variabilis* / *challengeri* (20%) occur first in this level.

Taxonomic comment: In this interval a more diversified association appears including relatively larger specimens with slender bifurcate arms. They are related to the species *D. variabilis* and *D. challengeri* (Any one asterolith is very much like its neighbour). From the association found in Well-4, 3355 m to the association present in Well-4, 3051 m the average size increases slightly (from 10 to 15 µm).

All the small specimens (less than 10 µm) are referred to *D. protoexilis*. Their number decreases through time and in the latest sample (Well-4, 3051 m) they have all disappeared.

Discoaster variabilis / D. challengeri: These index species constitute the two poles of a population composed of various morphotypes with numerous intermediate forms as explained by MARTINI and BRAMLETTE 1963 in their original description of *D. variabilis*.

Chronostratigraphic comment: The presence of *Sphenolithus heteromorphus* indicates a range from NN4 to NN5. For THEODORIDIS, *Discoaster protoexilis* disappears before the last occurrence of *Helicosphaera ampliaperta* (NN4 lower). But the distinction between lower and upper NN4 equivalents based on the first appearance of *Discoaster exilis* is not obvious in our material. The presence of about 20% of Discoasters belonging to the long rayed *D. variabilis* / *challengeri* group suggests (following MARTINI) that Association 2 is probably situated in the NN4 upper - NN5 zones. This is in agreement with BUKRY who indicates a decrease of *D. deflandrei* during CN3 (NN4).

Proposed range of association 2: upper NN4 – NN5.

Association 3 (Pl. 5, Fig. 14)

Age: Middle Miocene.

NN reference: NN6-7 zones.

Type level: Well-5, 3660 m.

Description: 10% *Discoaster deflandrei*, 50% *D. variabilis* / *D. challengeri*, 40% *D. brouweri*.

Taxonomic comment: Appearance of large slender non-bifurcate specimens of *Discoaster*. We have assigned these large elongated non-bifurcated forms to *D. brouweri*. The arms of the specimens are slightly bent. In many cases, the arms of these delicate forms are broken and it is difficult to determine whether or not some of them are Discoasters with broken bifurcated branches. Appearance of small massive forms very similar to *D. adamanteus* BRAMLETTE et SULLIVAN 1967.

Chronostratigraphic comment: Following MARTINI and MULLER 1986, the last occurrence of *D. deflandrei* allows us to place this association in the NN6 zone. Unfortunately in the Kutei basin the zonal marker *D. kugleri* has never been found and for this reason, in company reports this association is often assigned the overall NN6 - NN7 interval (from last occurrence of *Sphenolithus heteromorphus* to the first occurrence of *Catinaster coalitus*).

Proposed range of association 3: lower NN6.

Association 4 (Pls. 6-7, Fig. 15)

Age: Middle Miocene.

NN reference: NN 6-7 zones.

Type levels: Well-1, 1403 m, Well-5, 2502 m.

Description: 45% *Discoaster exilis,* 45% *D. variabilis* / *D. challengeri*, 10% non-bifurcate specimens.

Taxonomic comment: We have referred to *D. exilis* all asteroliths which satisfy the original description proposed by MARTINI and BRAMLETTE :

- small knob, normally stellate,
- long and slender rays,
- end of each ray slightly bifurcate.

As noted in the previous association, the specimens observed are large (up to 20 µm)

D. adamanteus BRAMLETTE et WILCOXON 1967: First appearance of typical specimens of this small species, always sporadic in the samples

D. sp. aff. *formosus:* Appearance of asteroliths with six simple arms and a prominent star shaped central knob (Pl. 6, fig. 26; Pl. 7, figs. 6-10).

Pl. 6, fig. 16 may be a broken specimen of *D. exilis* (to be compared with Pl. 6, figs. 2-3). The central area is hexagonal with a stellate central knob. If these specimens are really unbifurcated they are close to *D. archipelagoensis* described by SINGH and VIMAL 1976.

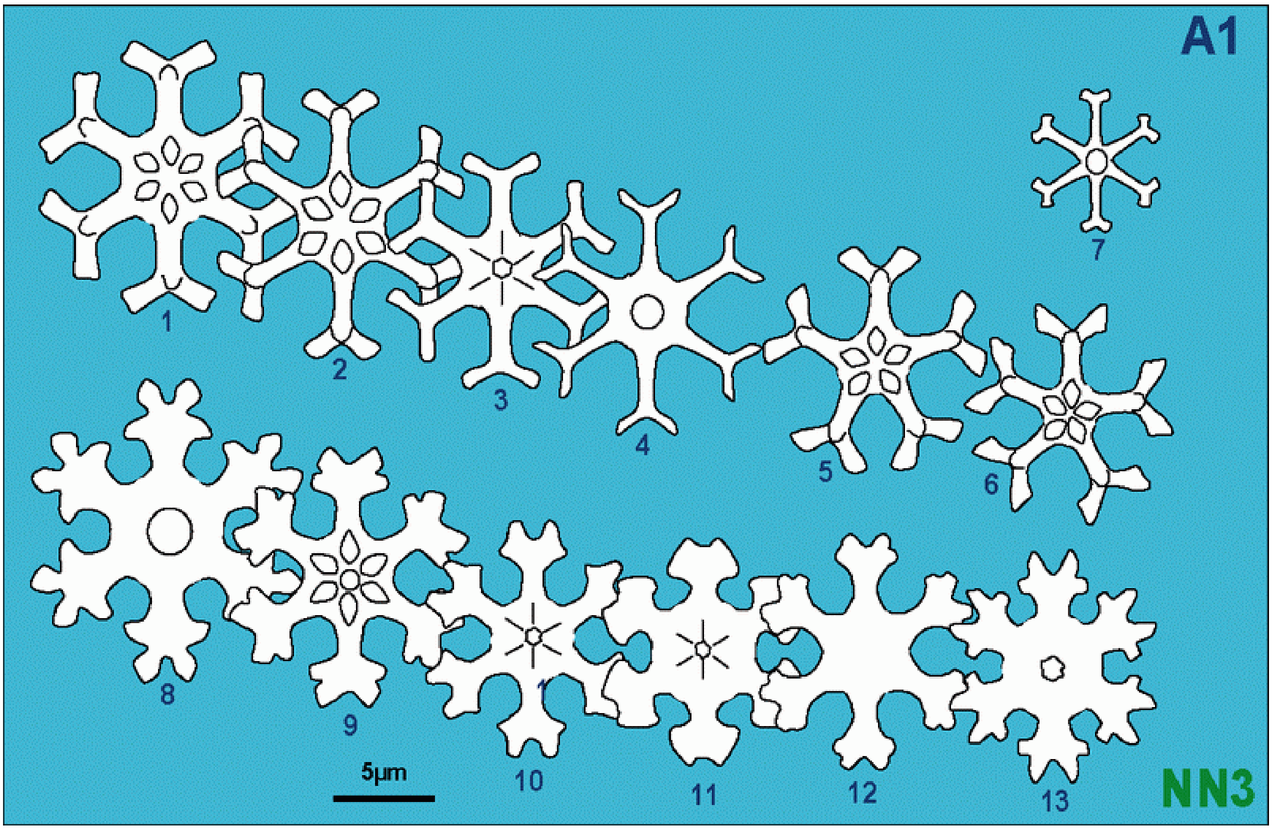


Figure 10: Well-1, 2265 m, association 1, NN 3. 1-5 & 7: *Discoaster protoexilis* (5-6: pentaradiate forms, 7: small form with a reduced central area, see Pl. 1, figs. 23 & 25), 8-13: *D. deflandrei*.

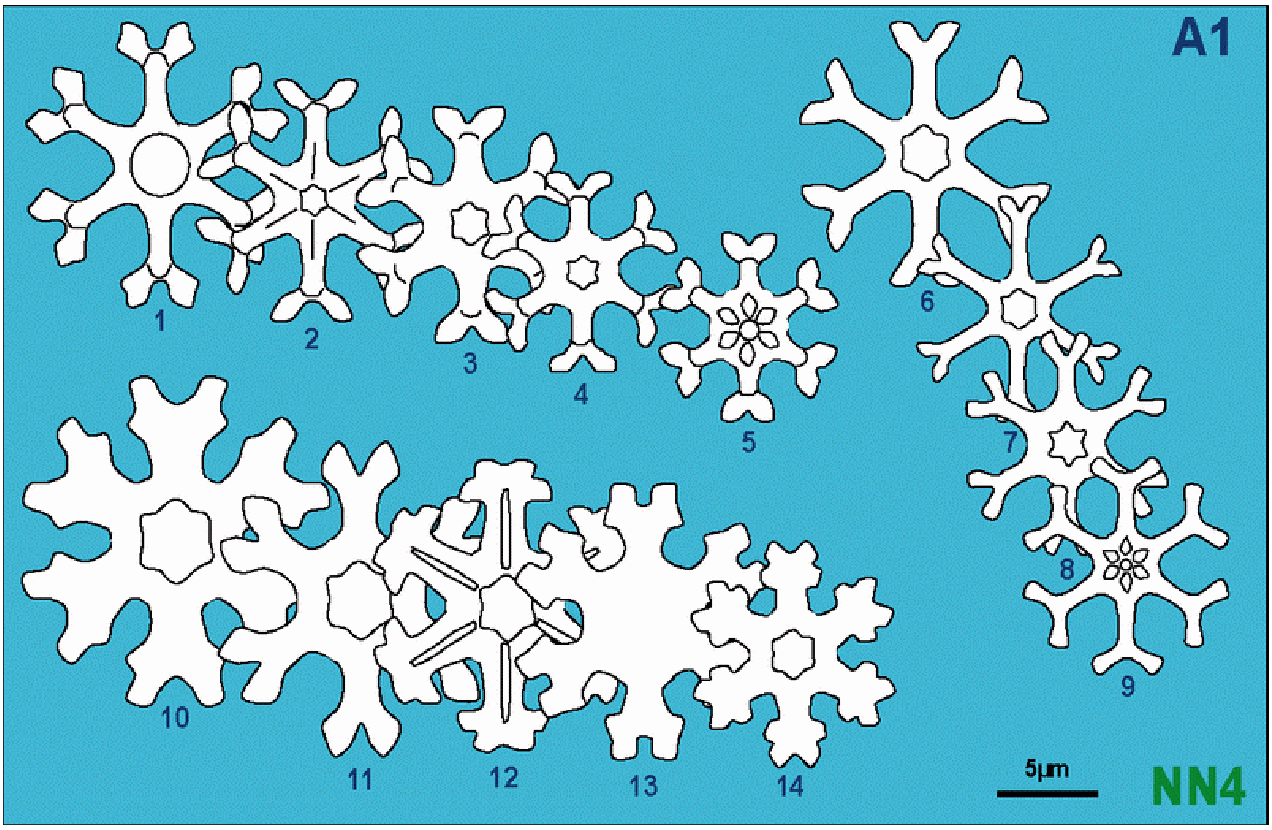


Figure 11: Well-4, 3660 m, association 1, NN 4. 1-5: *Discoaster protoexilis sensu stricto*, 6-9: *D. protoexilis* with reduced central area, 10-14: *D. deflandrei*.

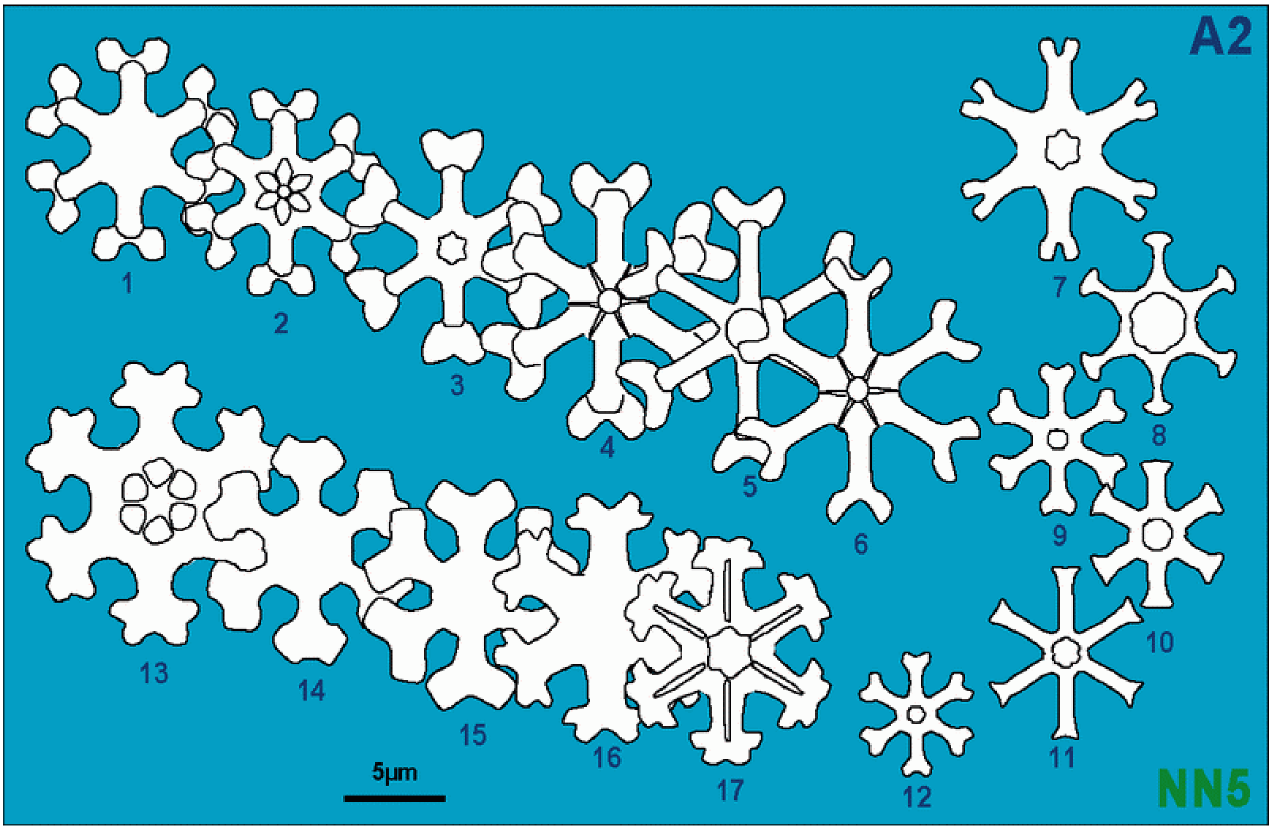


Figure 12: Well-4, 3355 m, association 2, NN 5. 1-6: *Discoaster variabilis* / *challengeri*, 7-12: *D. protoexilis* "group", 13-7: *D. deflandrei*.

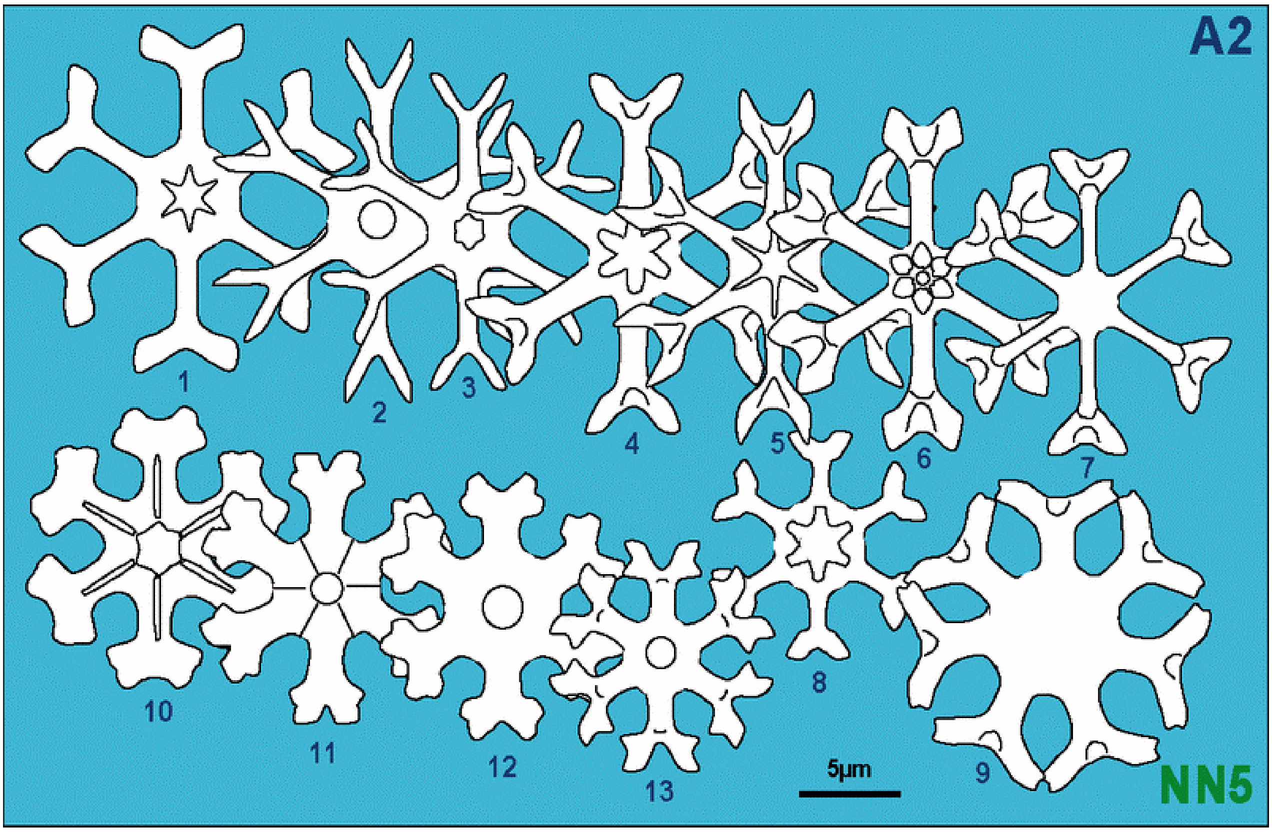


Figure 13: Well-4, 3051 m, association 2, NN5. 1-9: *Discoaster variabilis* / *challengeri*, 10-13: *D. deflandrei*.

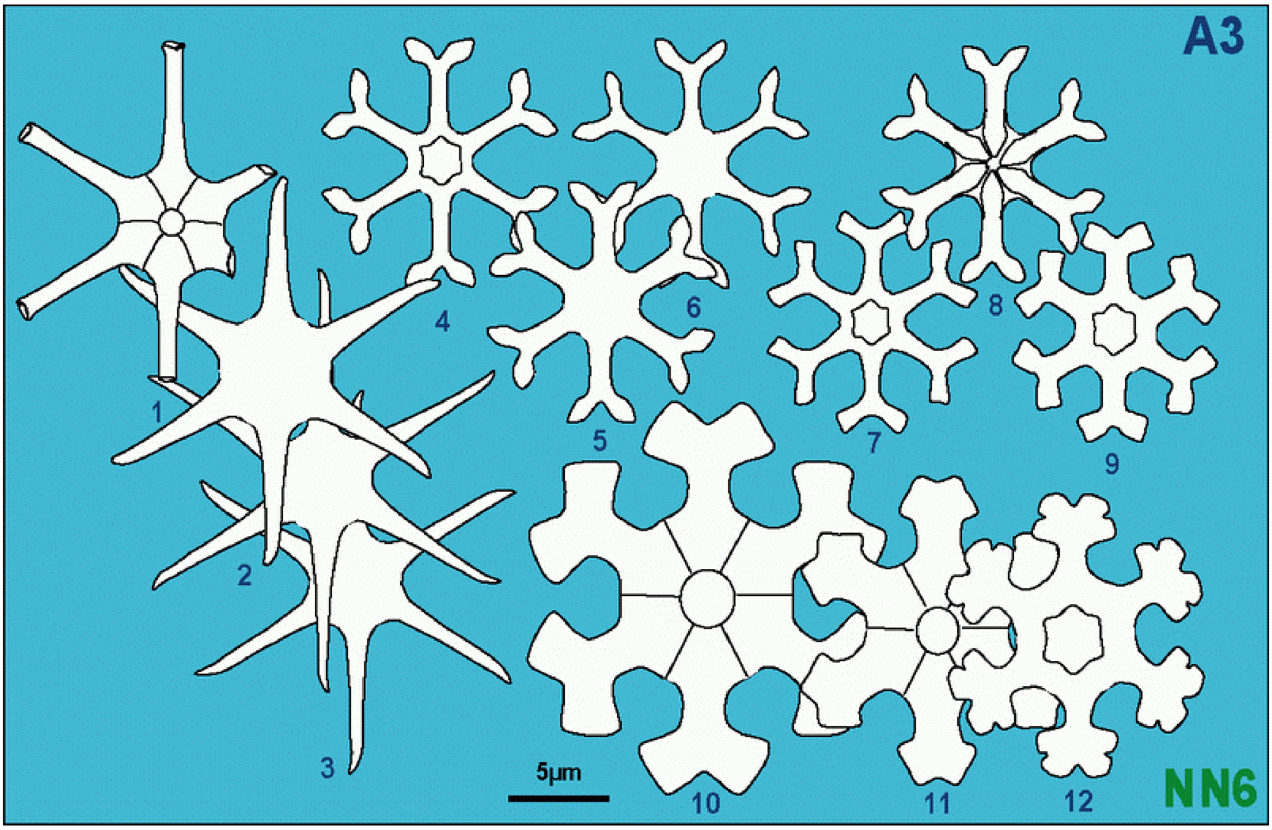


Figure 14: Well-5, 3660 m, association 3, NN6. 1-3: *Discoaster brouweri*, 4-9: *D. variabilis* / *challengeri*, 10-12: *D. deflandrei*.

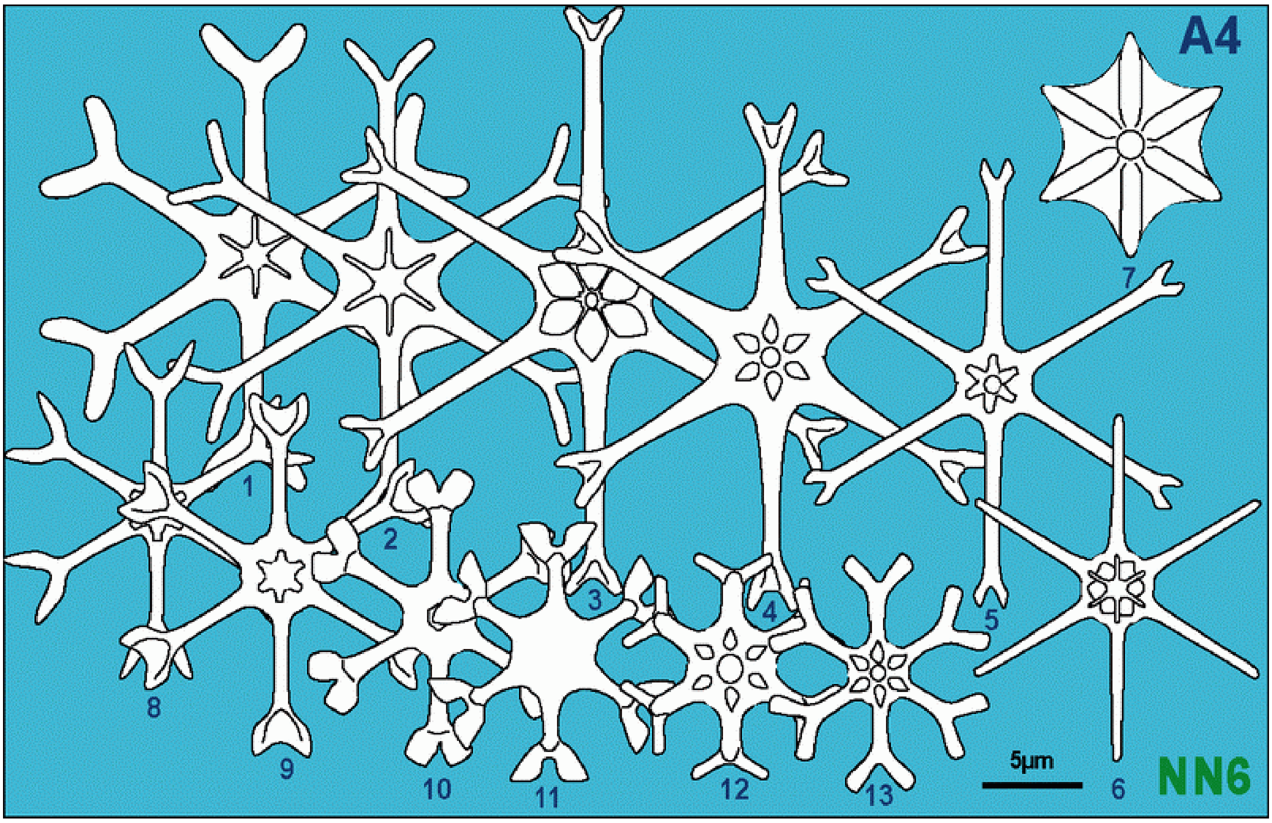


Figure 15: Well-1, 1403 m, association 4, NN6. 1-5: *Discoaster exilis*, 6: *D. brouweri*, 7: *D. adamanteus*, 8-13: *D. variabilis*.

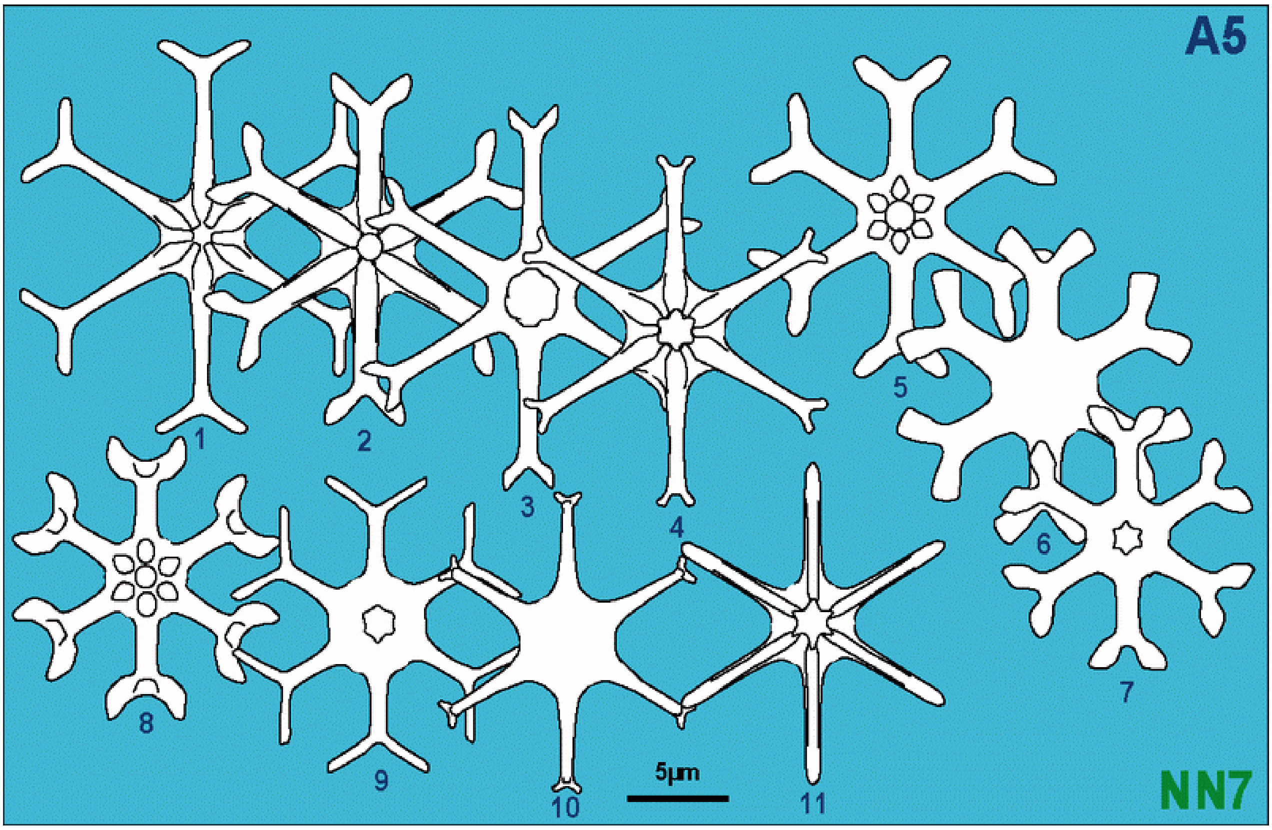


Figure 16: Well-5, 2502 m, association 5, NN7. 1-10: *Discoaster variabilis* / *exilis*, 11: *D. brouweri*.

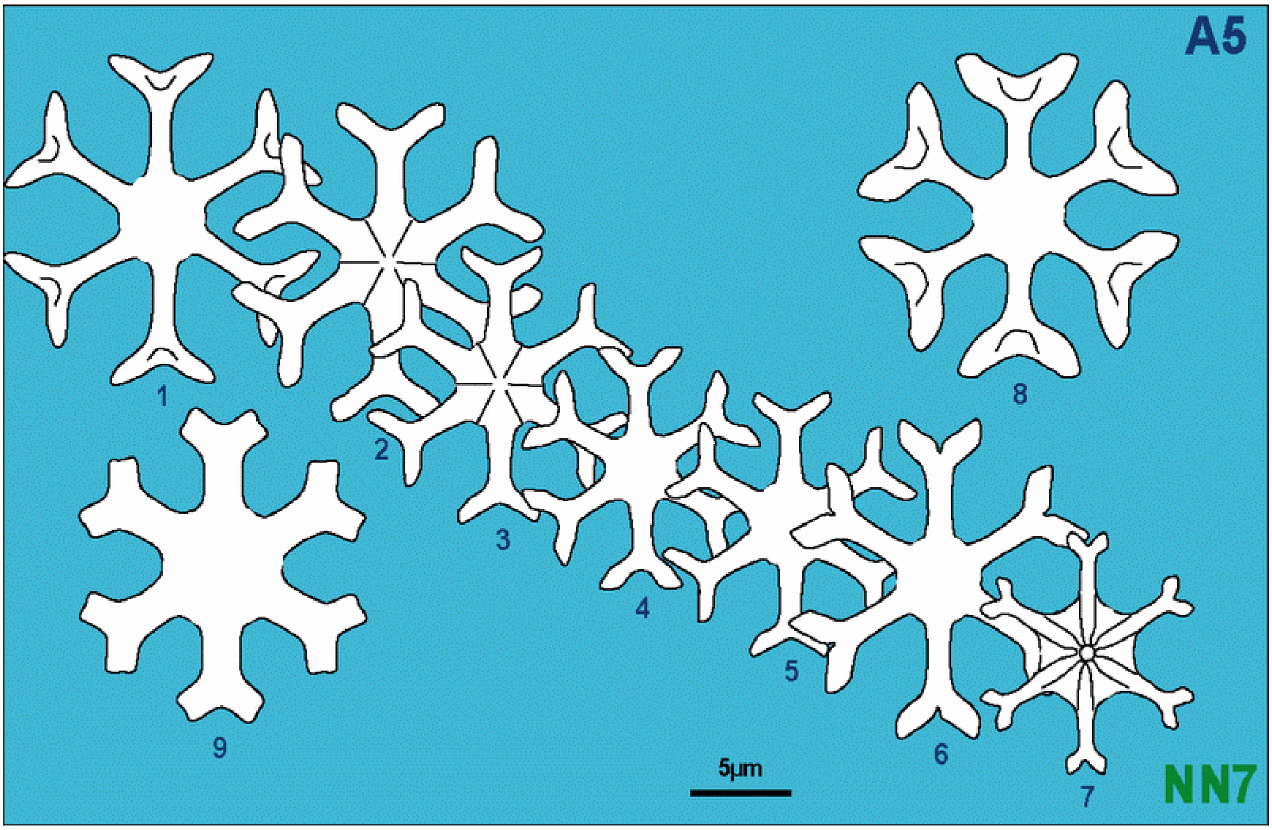


Figure 17: Well-2, 3398 m, association 5, NN7. 1-9: *Discoaster variabilis*.

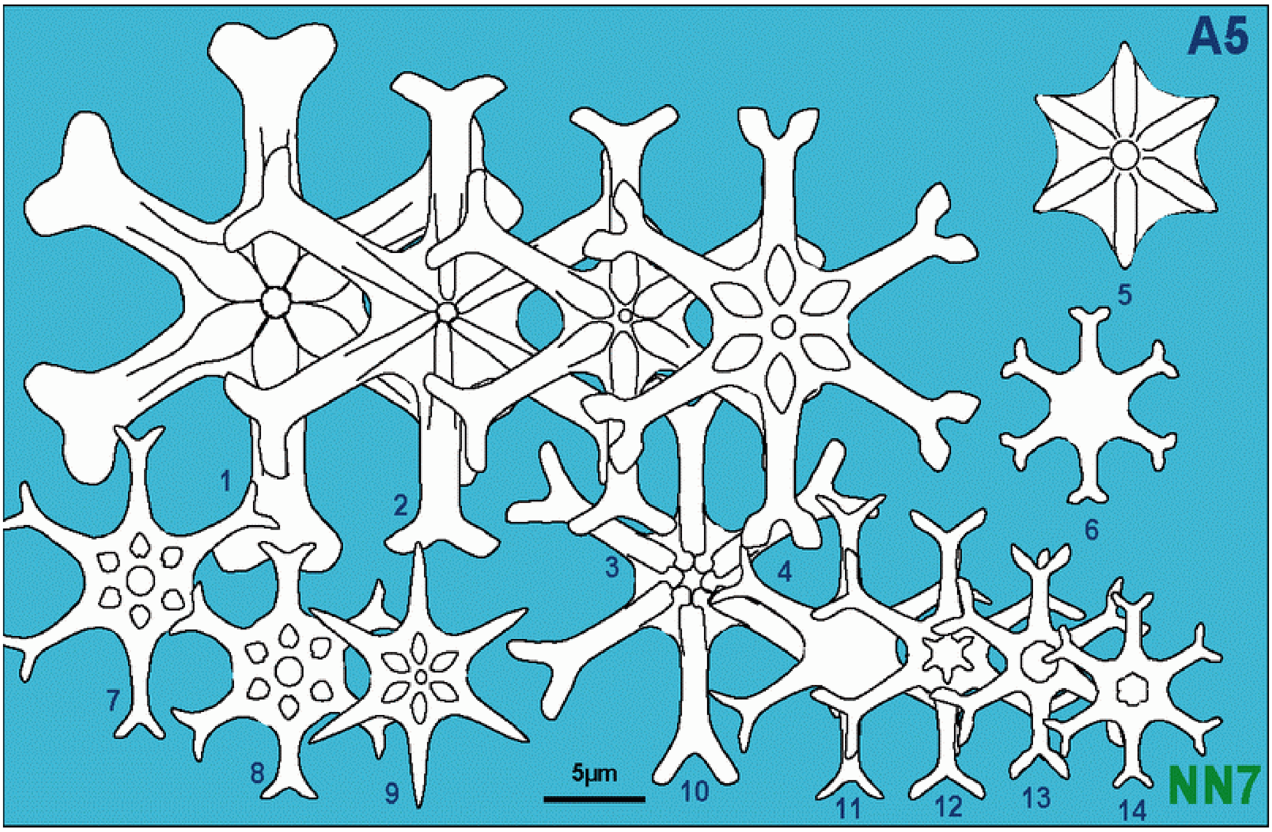


Figure 18: Well-2, 2821 m, association 5, NN7. 1-4, 6-8, 10-14: *Discoaster variabilis* group, 5: *D. adamanteus*, 9: *D.* sp.

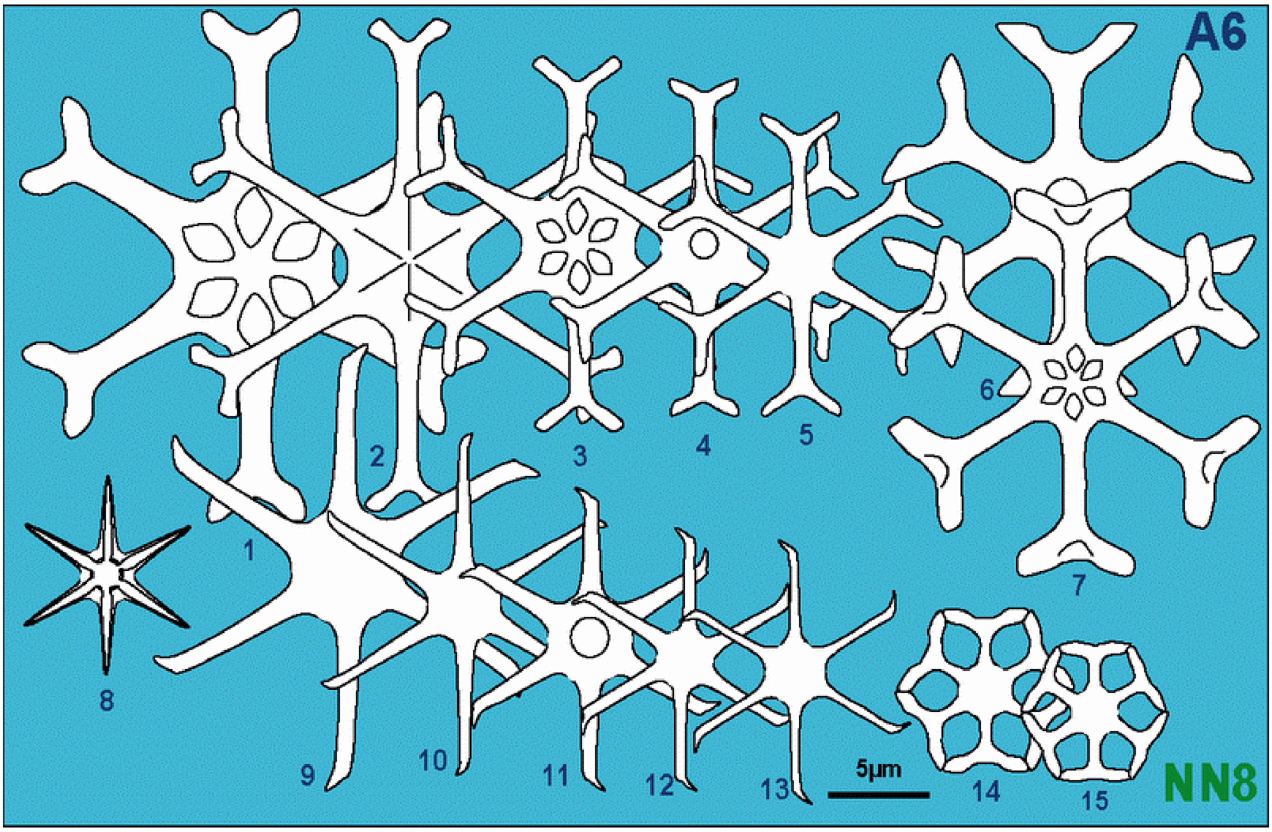


Figure 19: Well-2, 2747 m, association 6, NN8. 1-7: *Discoaster variabilis* / *exilis* group, 8: *D.* sp., 9-13: *D. brouweri*, 14-15: *Catinaster coalitus*.

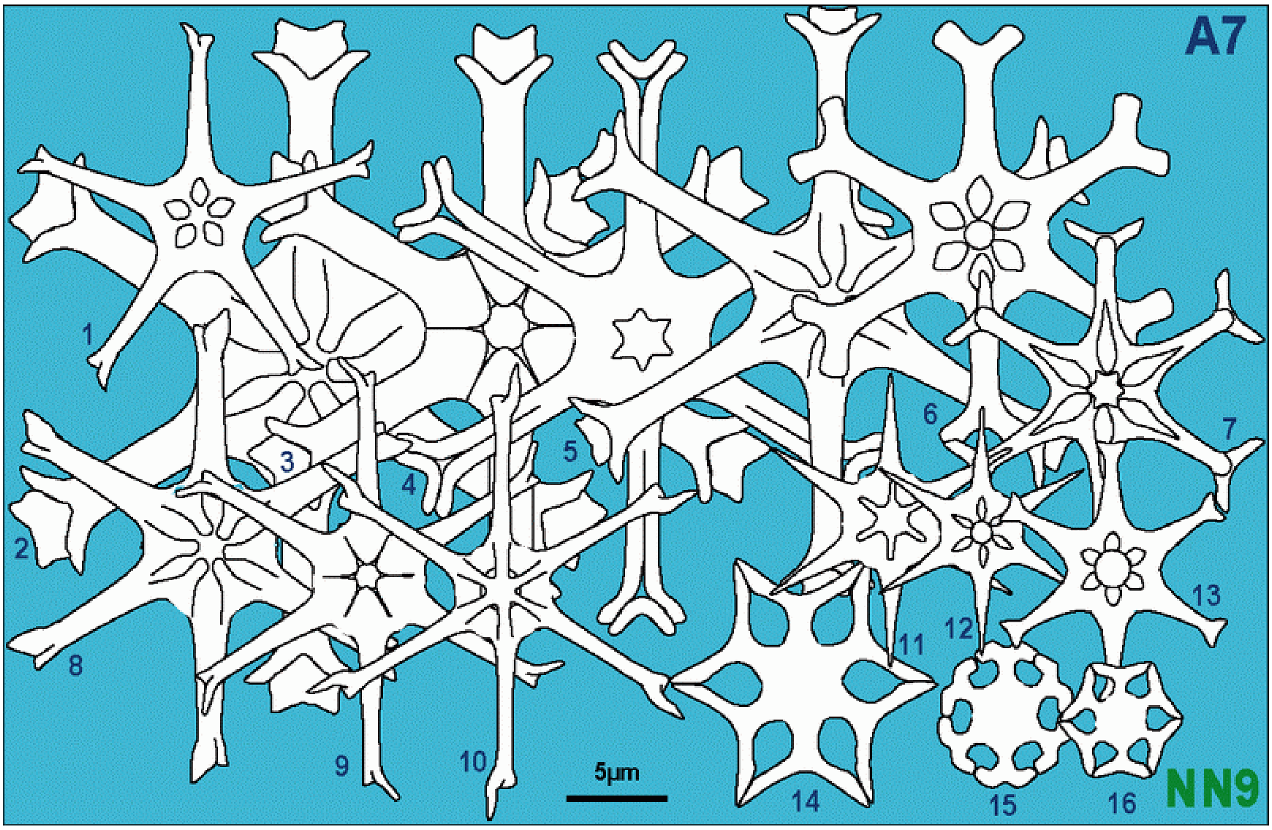


Figure 20: Well-3, 2980 m, association 7, (lower) NN9. 1: *Discoaster hamatus*, 2-5: *D. pseudovariabilis*, 6-7: *D. variabilis*, 8-10: *D. calcaris*, 11-12: *D.* sp., 13: *D. bollii*, 14-16: *Catinaster coalitus*.

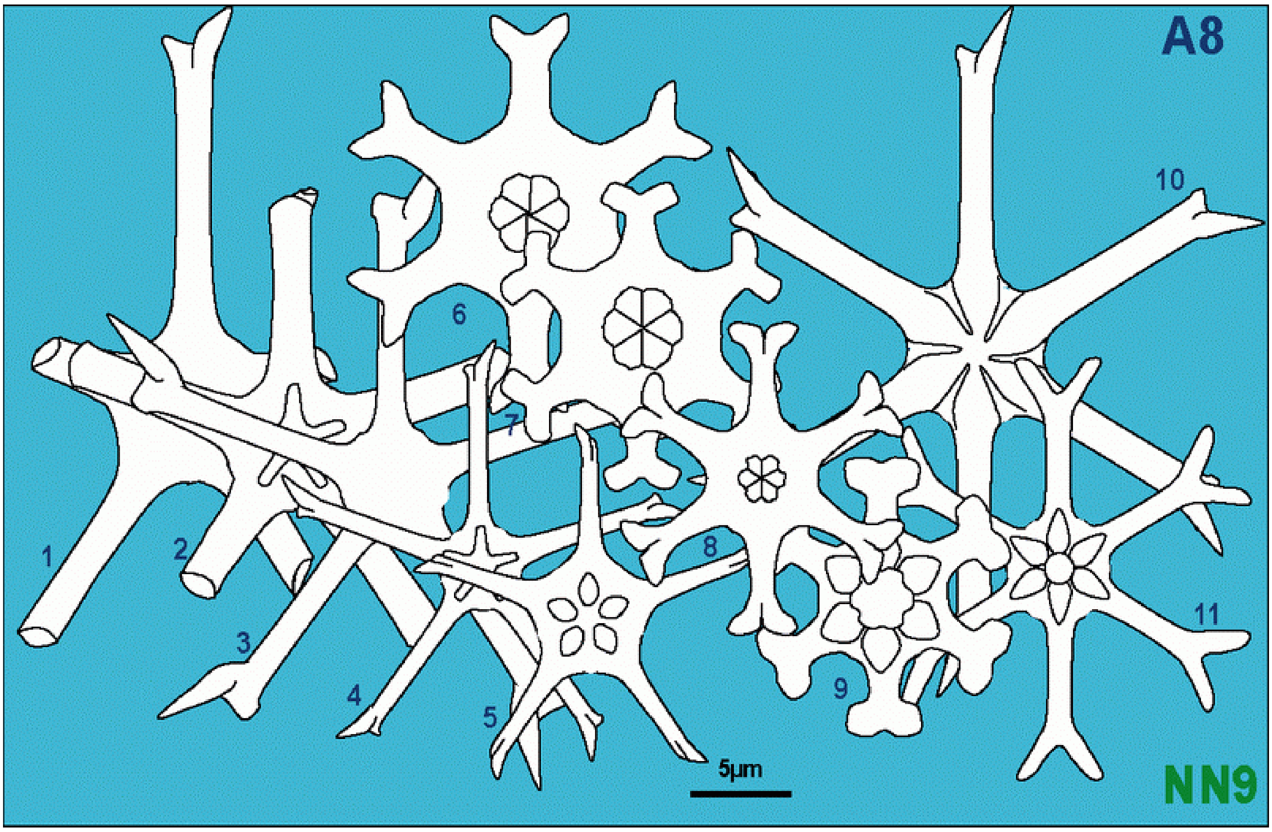


Figure 21: Well-3, 2550 m, association 8, (upper) NN9. 1-5: *Discoaster hamatus*, 6-9: *D. bollii*, 10: *D. calcaris*, 12: *D. variabilis*.

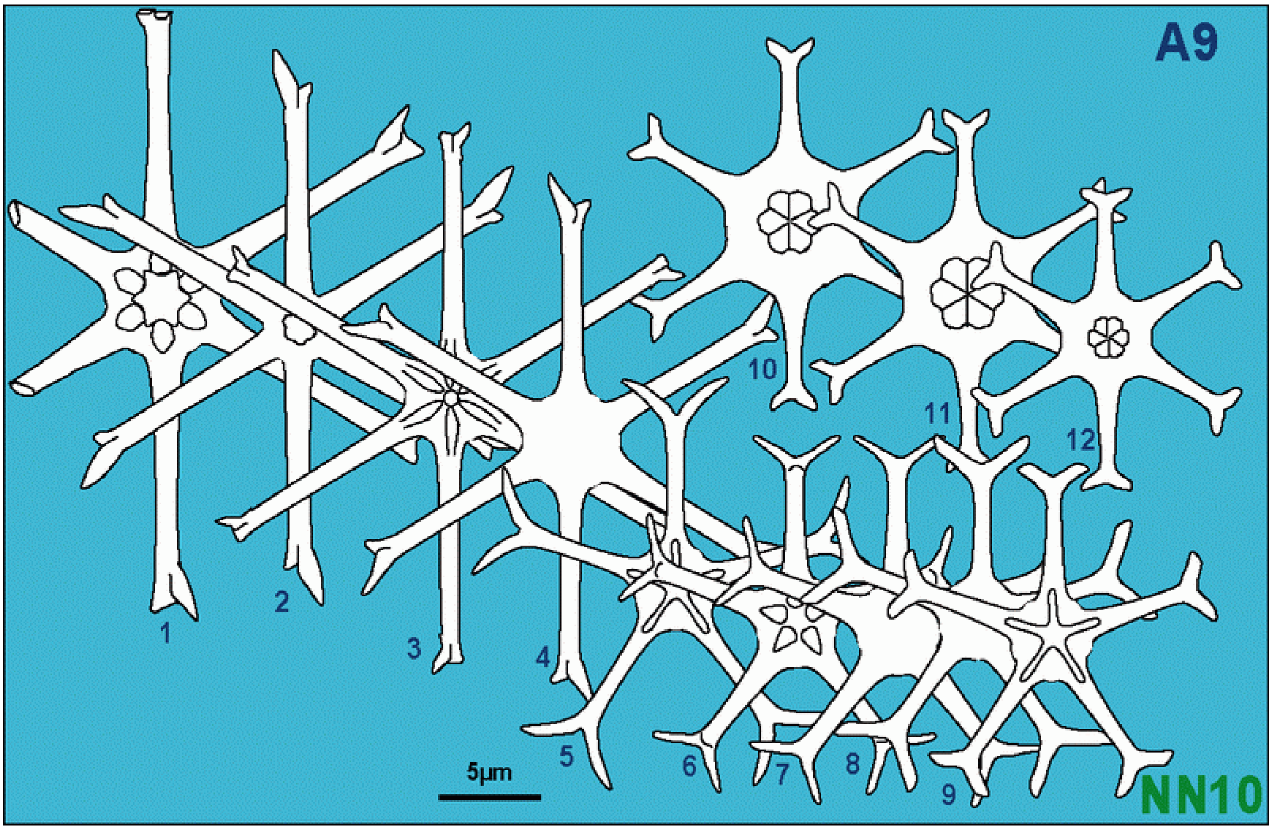


Figure 22: Well-3, 2320 m, association 9, (lower) NN10. 1-4: *Discoaster calcaris*, 5-9: *D. pentaradiatus*, 10-12: *D. bollii*.

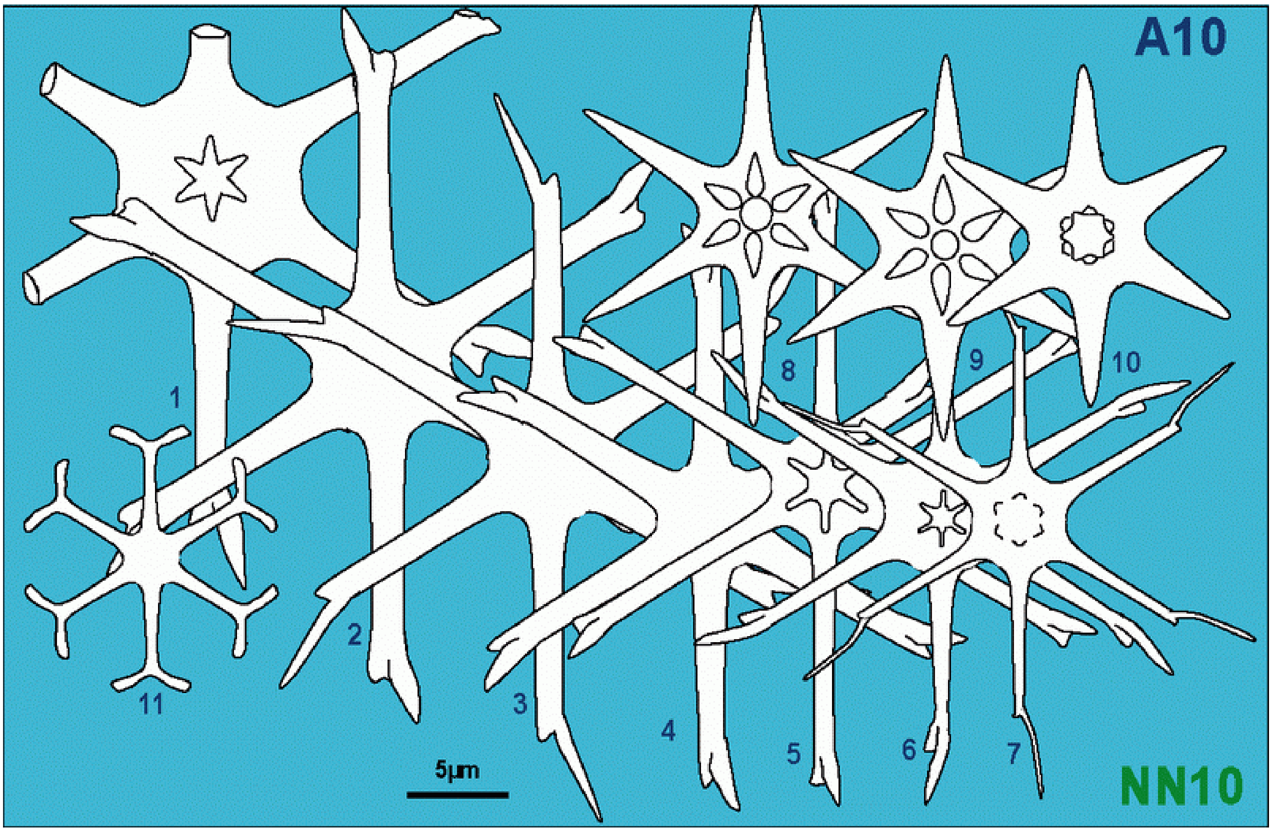


Figure 23: Well-3, 2160 m, association 10, (upper) NN10. 1-2: *Discoaster calcaris*, 3-7: *D. neorectus*, 8-10: *D. intercalaris*, 11: *D.* sp.

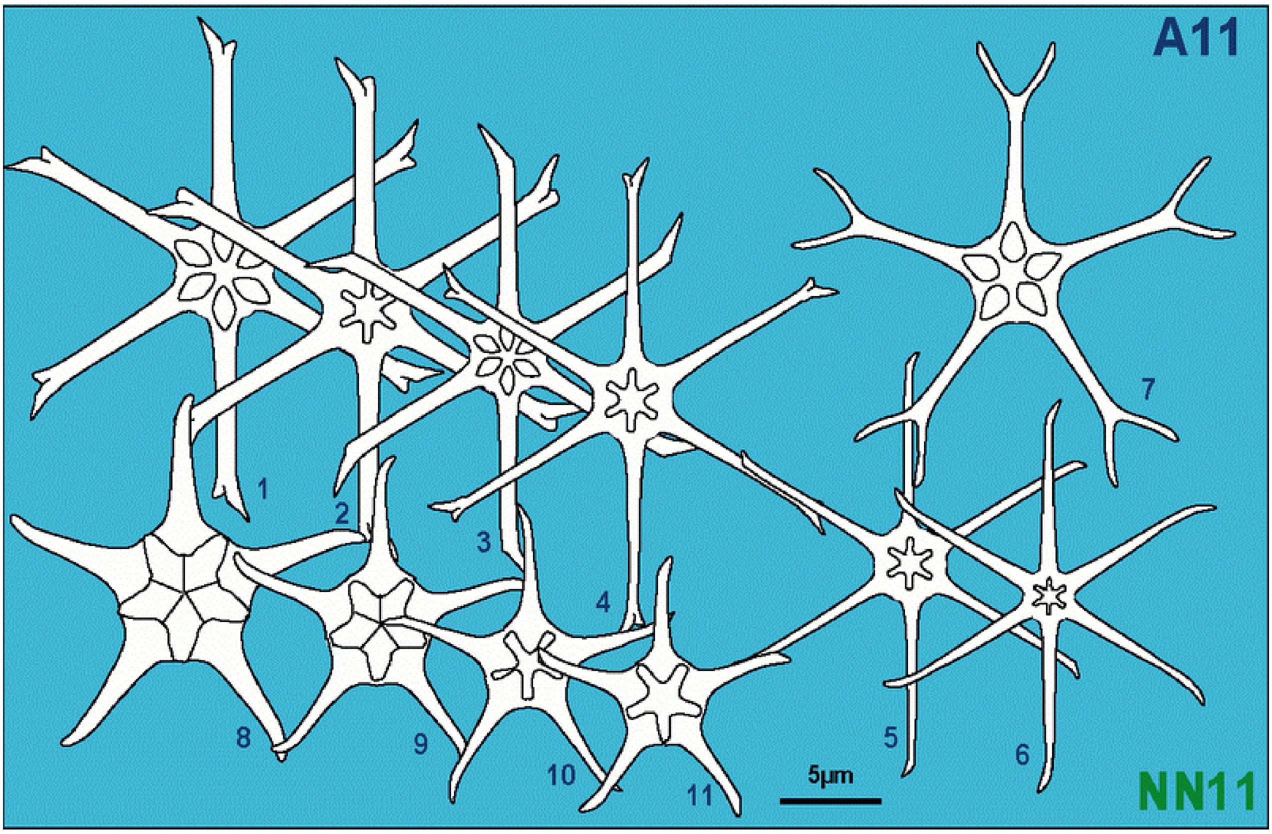


Figure 24: Well-3, 2040 m, association 11, (lower) NN11. 1-6: *Discoaster neorectus*, 7: *D. misconceptus*, 8-11: *D. berggrenii*.

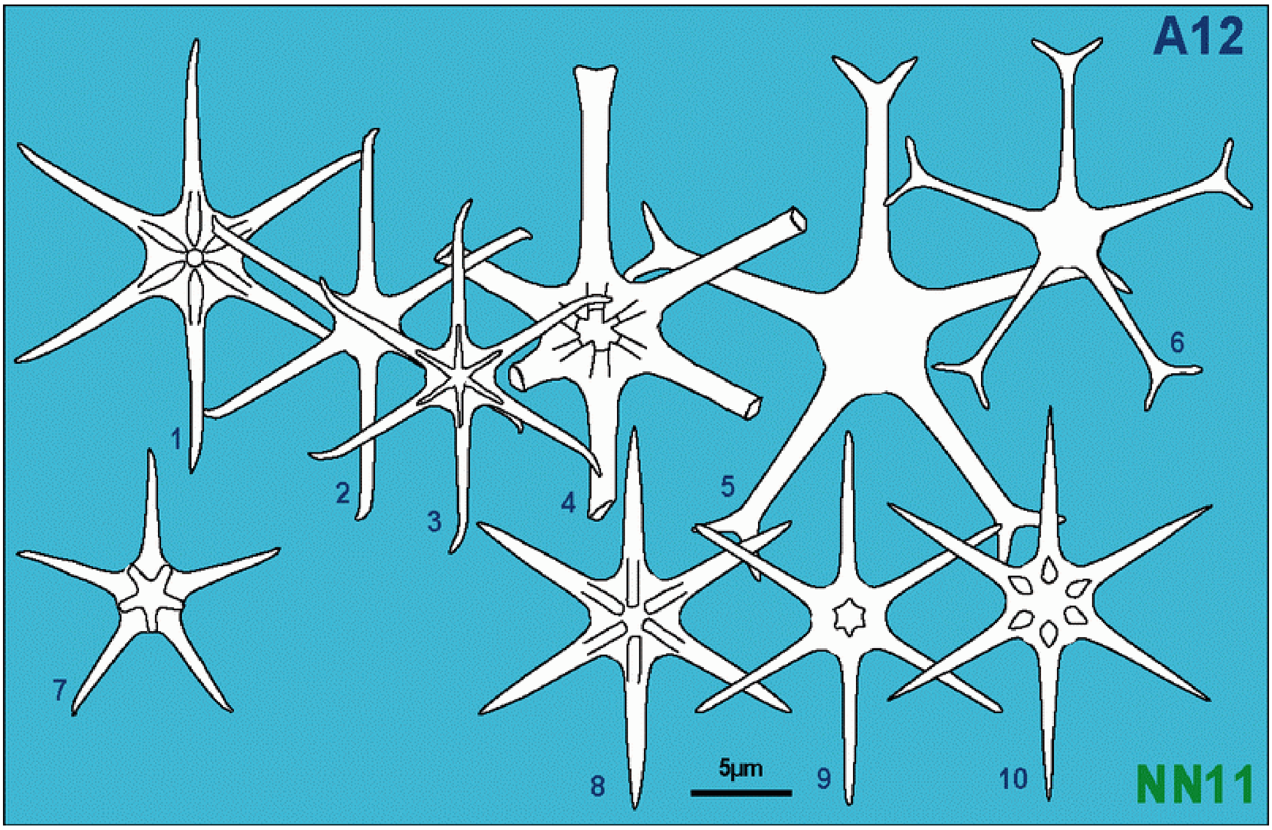


Figure 25: Well-3, 1960 m, association 12, NN11. 1-3: *Discoaster neorectus*, 4: *D.* sp., 5-6: *D. misconceptus*, 7: *D. quinqueramus*, 8-10: *D. brouweri*.

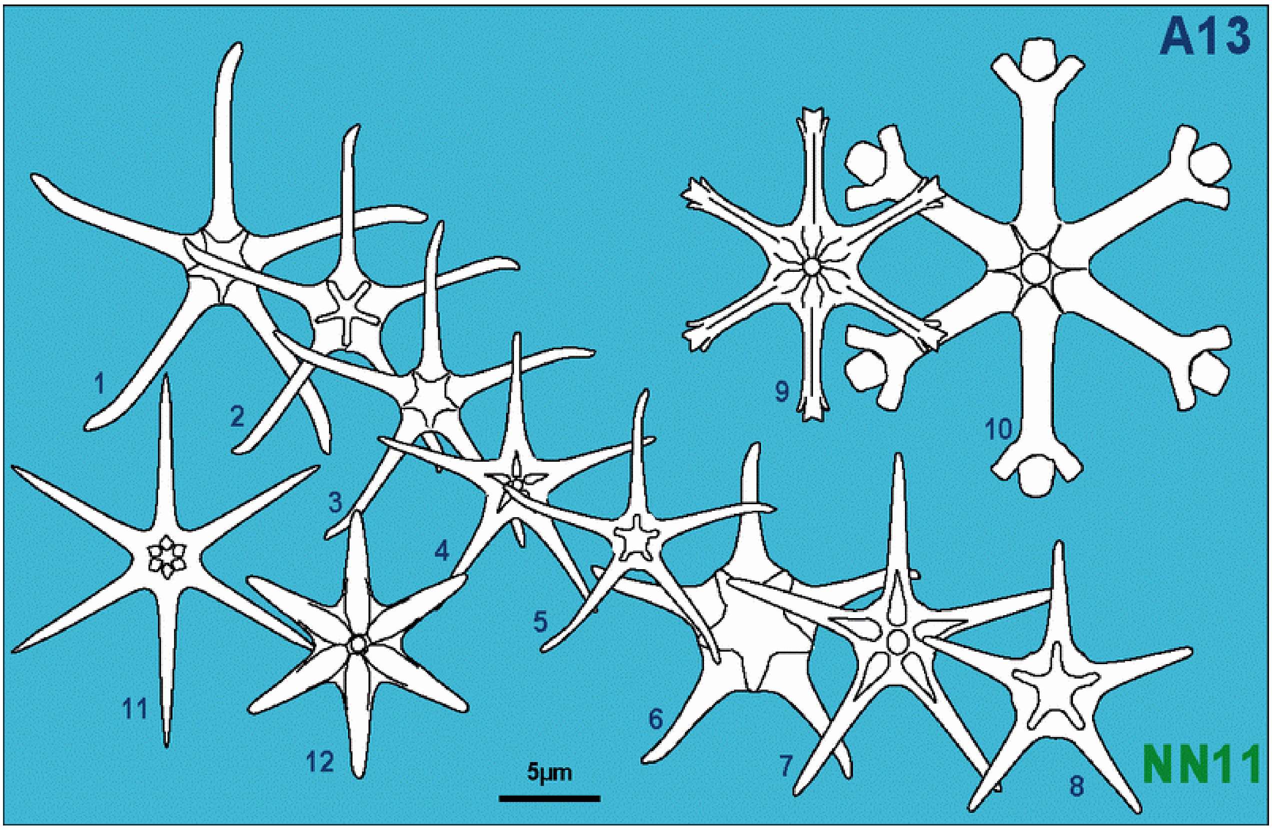


Figure 26: Well-3, 1420, association 13, (upper) NN11. 1-5: *Discoaster quinqueramus*, 6-8: *D. berggrenii*, 9-10: *D. surculus*, 11: *D. brouweri*, 12: *D.* sp.

D. sp. aff. *signus*, some specimens are close to *D. signus* BUKRY 1971a (Pl. 6, figs. 11-12, to be compared with BUKRY 1971a, Pl. 3, fig. 34). The central area is extremely reduced and the slender arms are bifurcate. These bifurcations seem to be smaller in our material than in the type specimens (broken?).

D. sp. aff. *tuberis* FILEWICKZ 1985 (Pl. 7, figs. 1-4) illustrate asteroliths with six simple arms and a very large prominent central knob. In the type species the arms are clearly bifurcate. We do not follow THEODORIDIS who places asteroliths with bifurcate arms and a prominent central knob in the species *D. musicus*. It is difficult to reconcile the illustrations provided by THEODORIDIS (1984: Pl. 33, figs. 14-17; Pl. 34, figs. 1-6) with the original illustrations (BUKRY, 1971: Pl. 3, figs. 3-4).

Chronostratigraphic comment: This association in similar to the previous one but differs in the high percentage of large, elongate *D. exilis* specimens. *D. formosus* is reported by MARTINI and WORSLEY as restricted to the *Sphenolithus heteromorphus* zone. The specimens *Discoaster* aff. *formosus* are slightly younger. *D. deflandrei* has disappeared. As *D. kuglerii* is absent, NN6 cannot be segregated from NN7. But the change in the ratios of *D. exilis* and *D. variabilis* suggests that Association 4 represents only the NN6 zone.

Proposed range of association 4: NN6.

Association 5 (Pls. 8-9, Figs. 16-18)

Age: Middle Miocene.

NN reference: NN6-7 zones.

Type levels: Well-2, 2821 m and 3398 m.

Description: 90% of the population is *Discoaster variabilis* and *D. challengeri*.

Taxonomic comment: The upper levels of this interval are characterized by the presence of big asteroliths (up to 20 µm).

Chronostratigraphic comment: Probably restricted to the NN7 zone due to the presence of numerous bifurcate species (*D. variabilis / challengeri*). This characteristic is shared with the next interval (NN8, *Catinaster coalitus*, see hereafter).

Proposed range of association 5: NN 7.

Association 6 (Pl. 10, Fig. 19)

Age: Upper Miocene.

NN reference: NN8 zone.

Type level: Well-2, 2747 m.

Description: 20% of the population is *Catinaster coalitus* which has its first occurrence in this association; 30% of the distribution is large *Discoaster variabilis*; 30% of the population is *D. brouweri* (small forms).

Taxonomic comment: This association is characterized by the presence of asteroliths with long, slender arm without clear bifurcations. The end of the arm is curved. Due to relatively poor preservation it is often difficult to distinguish between a simple curve, for instance *D. brouweri rutellus* GARTNER, and

D. calcaris GARTNER in which the end of the arm turn sharply in one direction, bifurcating asymmetrically. GARTNER reports the two in the same stratigraphic interval (Lengua Formation, Trinidad).

Chronostratigraphic comment: This association is undoubtedly in the NN8 zone because of the appearance the zonal marker *Catinaster coalitus*.

Proposed range of association 6: NN8.

Association 7 (Pl. 11, Fig. 20)

Age: Upper Miocene.

NN reference: NN 9 zone.

Type level: Well-3, 2980 m.

Description: 30% *Catinaster coalitus*; 20% *Discoaster pseudovariabilis*; 20% *D. variabilis* (large forms with simple bifurcation); 20% *D. calcaris*; *D. hamatus* (sporadic).

Taxonomic comment: *D. pseudovariabilis* MARTINI et WORSLEY was found only in this association. Large asteroliths (up to 25 µm):

- bifurcate arms,
- between the bifurcations a tongue-like extension projects,
- small stem-shaped knob.

Typical *D. calcaris*, with a long asymmetrical spine, occurs for the first time.

Chronostratigraphic comment: The appearance of the zonal marker *D. hamatus* confirms the placement of this association in the NN9 zone. In the Kutei basin, *D. pseudovariabilis* seems to be restricted to the lower part of the NN9 zone (MARTINI and WORSLEY give NN8 through 9 zones as its full range.

First occurrence of typical *D. calcaris*.

Last occurrence of large *D. variabilis*.

The presence of *D. hamatus* and *Catinaster coalitus* suggests a lower NN9.

Proposed range of association 7: lower NN9.

Association 8 (Pl. 12, Fig. 21)

Age: Upper Miocene.

NN reference: NN 9 zone.

Type level: Well-3, 2550 m.

Description: 70% *Discoaster hamatus*, 20% *D. bollii*, 10% *D. calcaris*.

Taxonomic comment: Dramatic decrease of the bifurcate forms (*D. variabilis*). After this interval bifurcate specimens occur only sporadically in the samples.

Chronostratigraphic comment: This association is characterized by the acme of *D. hamatus*. *D. bollii* (slender forms) appears in this association. *Catinaster coalitus* is no longer present.

The contrast between the lower and the upper part of the NN9 is significant and it is easy to determine even from a restricted number of specimens.

Proposed range of association 8: upper NN9.

Association 9 (Pl. 13, Fig. 22)

Age: Upper Miocene.

NN reference: NN 10 - CN8a zone

Type level: Well-3, 2320 m

Description: 40% *Discoaster pentaradiatus* (*sensu* THEODORIDIS 1984), 20% *D. bollii*, 30% *D. calcaris*.

Taxonomic comment: *D. pentaradiatus sensu* THEODORIDIS (*D. quintatus sensu* DRIEVER, see this author for further details). The specimens of this pentaradiate asterolith observed in the Kutei basin correspond to those described by THEODORIDIS:

- pentaradiate form,
- arms short and flat, bifurcate,
- branches of the bifurcation relatively long (when well preserved!),
- on proximal side, low and stellate central knob,
- no birefringence exhibit by these asteroliths (this point is crucial to the distinction of *D. pentaradiatus sensu* THEODORIDIS from *D. misconceptus* THEODORIDIS.

Chronostratigraphic comment: The absence of both *D. hamatus* (NN9) and *D. quinqueramus* / *berggrenii* (NN11) proves an NN10 age for this association. The restriction of *D. pentaradiatus* (*sensu* THEODORIDIS) to the lower part of the NN10 zone accords with the restricted distribution proposed by THEODORIDIS (*Eu-discoaster pentaradiatus* Subzone) and supports the subdivision of NN10.

Proposed range of association 9: lower NN10.

Association 10 (Pl. 14, Fig. 23)

Age: Upper Miocene.

NN reference: NN10 – CN8b zone.

Type level: Well-3, 2160 m.

D**escription:** 80% *Discoaster calcaris* / *D. neorectus*, 15% *D. intercalaris*.

Taxonomic comment: Acme zone of *D. calcaris* / *D. neorectus*.

Presence of *D. intercalaris* BUKRY 1971b, typical stellate asterolith with:

- large central area,
- central stem,
- arms clearly tapering, terminating in a single rounded point.

D. perclarus, some delicate, slender, bifurcate asteroliths occur sporadically in this interval (Pl. 14, fig. 26). The presence of this small species in the NN10 / CN8 is in agreement with its range as proposed by BUKRY, but the number of specimens seen in the Kutei basin are too few for a valid assessment of the true range of this taxon.

Chronostratigraphic comment: *D. intercalaris* seems to be restricted to the upper part of the NN10 zone. It has never been found with the NN11 zonal marker (*D. berggrenii*) as reported by PERCH-NIELSEN 1985.

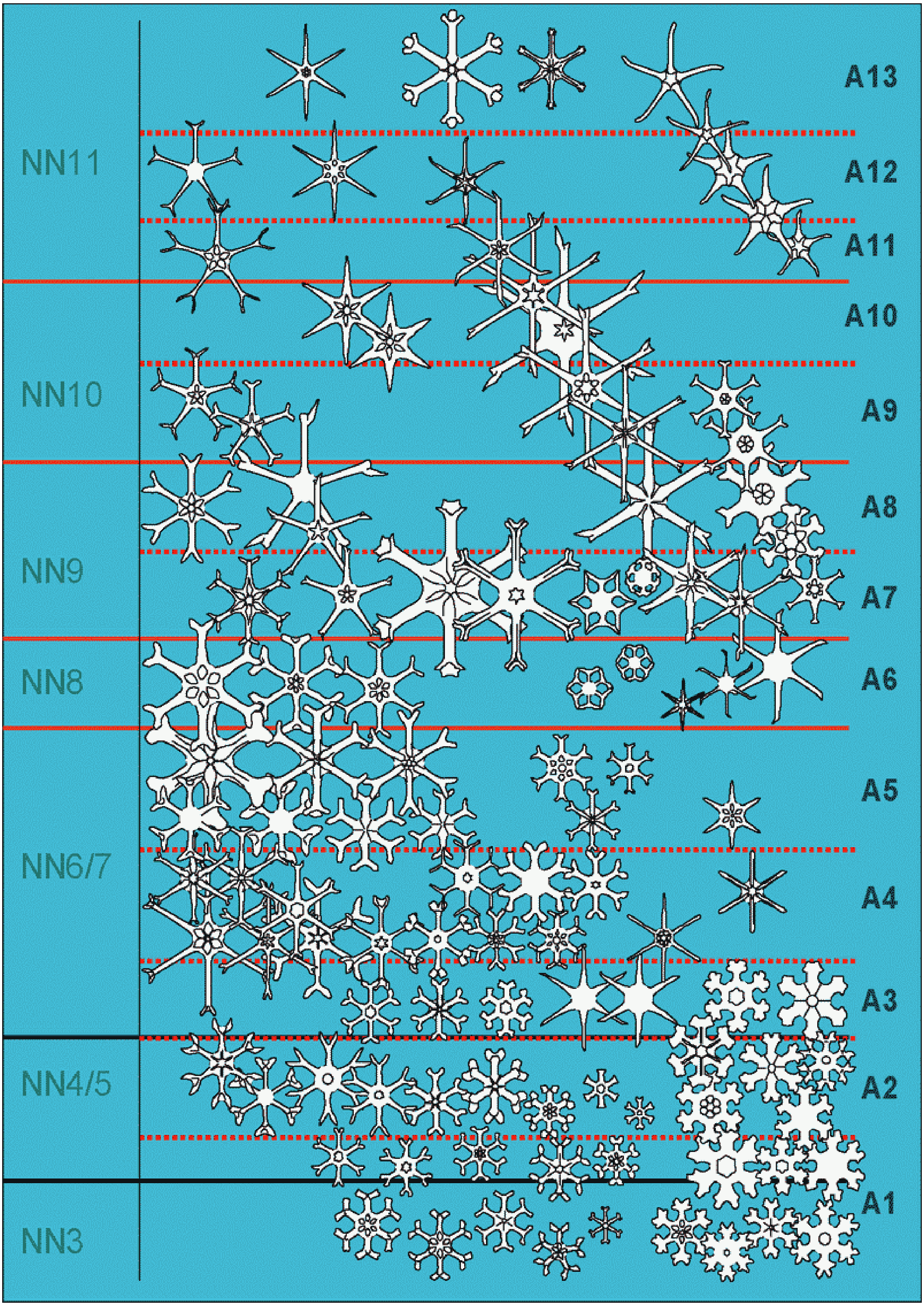


Figure 27: Mahakam area, general distribution of species of *Discoaster*.

As in the NN9 zone, a marked difference exists between the lower and the upper levels of NN10. Even based on only a few specimens it is relatively easy to distinguish them. The subdivision proposed here corresponds to that proposed by BUKRY to divide CN8 (a&b), a separation based on the first occurrence of *D. neorectus*.

Proposed range of association 10: upper NN10.

Association 11 (Pl. 15, Fig. 24)

Age: Upper Miocene.

NN reference: NN 11 zone.

Type level: Well-3, 2040 m.

Description: 60% *Discoaster calcaris* / *D. neorectus*, 30% *D. berggrenii*, 10% *D. misconceptus* THEODORIDIS.

Taxonomic comment: *D. misconceptus* THEODORIDIS 1984 is a pentaradiate asterolith characterised by:

- relatively small central area,
- long and slender arms,
- low central knob,
- bifurcate arms with long and pointed extremities,
- slightly birefringent with extinction bands along the suture of the central area (this criterion distinguished this asteroliths from all other pentaradiate Discoasters).

D. berggrenii: THEODORIDIS proposed that *D. berggrenii* is a morphotype of *D. quinqueramus*. He also indicated that the number of more elongated specimens (*D. quinqueramus*) increased with time (upper NN11) but that the two share a common stratigraphic range (NN11). In the Kutei basin the lower part of NN11 is characterized by the presence of massive specimens of *D. berggrenii* with no elongated asteroliths present, but we do not know if in a more fossiliferous time equivalent stratum we will not find some elongate specimens corresponding to *D. quinqueramus*. However we maintain that the two species are distinct because we see a clear quantitative evolution during the uppermost Miocene and that based partly on this evolution we can subdivide NN11 into several subzones.

Chronostratigraphic comment: *D. misconceptus* appears in the NN11 zone in the Kutei basin and this appearance is in agreement with the first appearance proposed for it by THEODORIDIS.

D. berggrenii also appears for the first time in this zone (CNN9 / NN11).

Proposed range of association 11: lower NN11.

Association 12 (Pl. 16, Fig. 25)

Age: uppermost Miocene.

NN reference: NN 11 zone.

Type level: Well-3, 1960 m.

Description: 40% *Discoaster brouweri*, 50% *D. berggrenii / quinqueramus*, 10% *D. misconceptus*.

Taxonomic comment: The 6-rayed specimens are almost entirely single armed *D. brouweri*. The pentaradiate forms are a mix of *D. misconceptus* (easily recognizable under cross polarized light) typical *D. berggrenii* and *D. quinqueramus* (first occurrence of this slender pentaradiate form). *D. berggrenii* and *D. quinqueramus* represent two poles of a same population with all possible transitional forms between them. Probably the two coccoliths belong to the same biological species. However due to the clear quantitative evolution observed we have to maintain two distinct typological species. It is frequent to observe distinct morphotypes on the same coccolithophoraceae cell in other species.

Chronostratigraphical comment: Transitional interval between a lower NN11 / CN9 clearly identified by the appearance of *D. berggrenii* and an upper NN11 / CN9 with *D. berggrenii / quinqueramus* and *D. surculus*.

Proposed range of association 12: "middle" NN11.

Association 13 (Pl. 17, Fig. 26)

Age: uppermost Miocene.

NN reference: NN11 zone.

Type level: Well-3, 1420 m.

Description: 80% *D. quinqueramus / berggrenii*, 20% *D. surculus*.

Taxonomic comment: Appearance of *D. surculus*, with typical forms, "stellate knob, small ridges, slender rays clearly trifurcated with the central spine extending beyond and downward from the outer pair" (MARTINI and BRAMLETTE 1963).

With the exception of *D. surculus* we note a true collapse of 6-rayed Discoasters (80% of the population is 5-rayed).

Chronostratigraphic comment: Both MARTINI and BUKRY indicate the first occurrence of *D. surculus* in their NN11/CN9 zone(s) (uppermost Miocene). In the Kutei basin the first significant occurrence of this species has a clear relationship with the upper portion of the NN11/CN9 zone. These taxa together (*D. surculus* and *D. berggrenii /quinqueramus*) are characteristic of the upper part of the NN11/CN9 zone(s).

From a quantitative point of view, as is the case in the two previous zones (NN9 and 10) there is a marked distinction between the lower and upper portions of NN11, supplemented by the quasi-extinction of 6-rayed asteroliths in the upper part of the zone.

Proposed range of association 13: upper NN11.

Distribution chart (Fig. 9 & 27)

A general correspondence exists between the associations in the Kutei basin described in this work and the MARTINI standard zonation. It is illustrated in Fig. 27. Its correspondence with the BUKRY and THEODORIDIS zonations is illustrated by Fig. 9.

It is important to keep in mind that in the Kutei basin, two important factors strongly influenced our perception of the distribution of *Discoaster* specimens in the sediments:

- the rapid rate of sedimentation,
- the stroboscopic effect resulting from the fact that the fossilliferous intervals are separated by very long barren intervals of fluvial-deltaic deposition.

The conjunction of these two factors enhances the contrast between the adjacent associations observed in the sediments. Each fossiliferous association must represent only a short chronostratigraphic interval.

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Taxonomic appendix

Discoaster species in alphabetical order of species names

Discoaster adamanteus BRAMLETTE et WILCOXON 1967a
Discoaster archipelagoensis SINGH et VIMAL 1976
Discoaster aulakos GARTNER 1967
Discoaster bellus BUKRY et PERCIVAL 1971
Discoaster berggrenii BUKRY 1971a
Discoaster braarudi BUKRY 1971a
Discoaster bollii MARTINI et BRAMLETTE 1963
Discoaster brouweri TAN SIN HOK 1927
Discoaster calcaris GARTNER 1967
Discoaster calculosus BUKRY 1971a
Catinaster calyculus MARTINI et BRAMLETTE 1963
Discoaster challengeri BRAMLETTE et RIEDEL 1954
Catinaster coalitus MARTINI et BRAMLETTE 1963
Discoaster deflandrei BRAMLETTE et RIEDEL 1954
Discoaster druggii BRAMLETTE et WILCOXON 1967b
Discoaster exilis MARTINI et BRAMLETTE 1963
Discoaster formosus MARTINI et WORSLEY 1971
Discoaster hamatus MARTINI et BRAMLETTE 1963
Discoaster intercalaris BUKRY 1971b
Discoaster kugleri MARTINI et BRAMLETTE 1963
Discoaster lidzi HAY 1967
Discoaster loeblichii BUKRY 1971b
Discoaster misconceptus THEODORIDIS 1984
Discoaster moorei BUKRY 1971a
Discoaster musicus STRADNER 1959
Discoaster neohamatus BUKRY et BRAMLETTE 1969
Discoaster nephados HAY 1967
Discoaster neorectus BUKRY 1971b
Discoaster pansus BUKRY 1971b
Discoaster pentaradiatus TAN SIN HOK 1927, emend THEODORIDIS 1984
Discoaster perclarus HAY 1967
Discoaster prepentaradiatus BUKRY et PERCIVAL 1971
Discoaster protoexilis THEODORIDIS 1984
Discoaster pseudovariabilis MARTINI et WORSLEY 1971
Discoaster quinqueramus GARTNER 1969
Discoaster signus BUKRY 1971a
Discoaster subsurculus GARTNER 1967
Discoaster surculus MARTINI et BRAMLETTE 1963
Discoaster trinidadensis HAY 1967
Discoaster tuberis FILEWICZ 1985
Discoaster variabilis MARTINI et BRAMLETTE 1963

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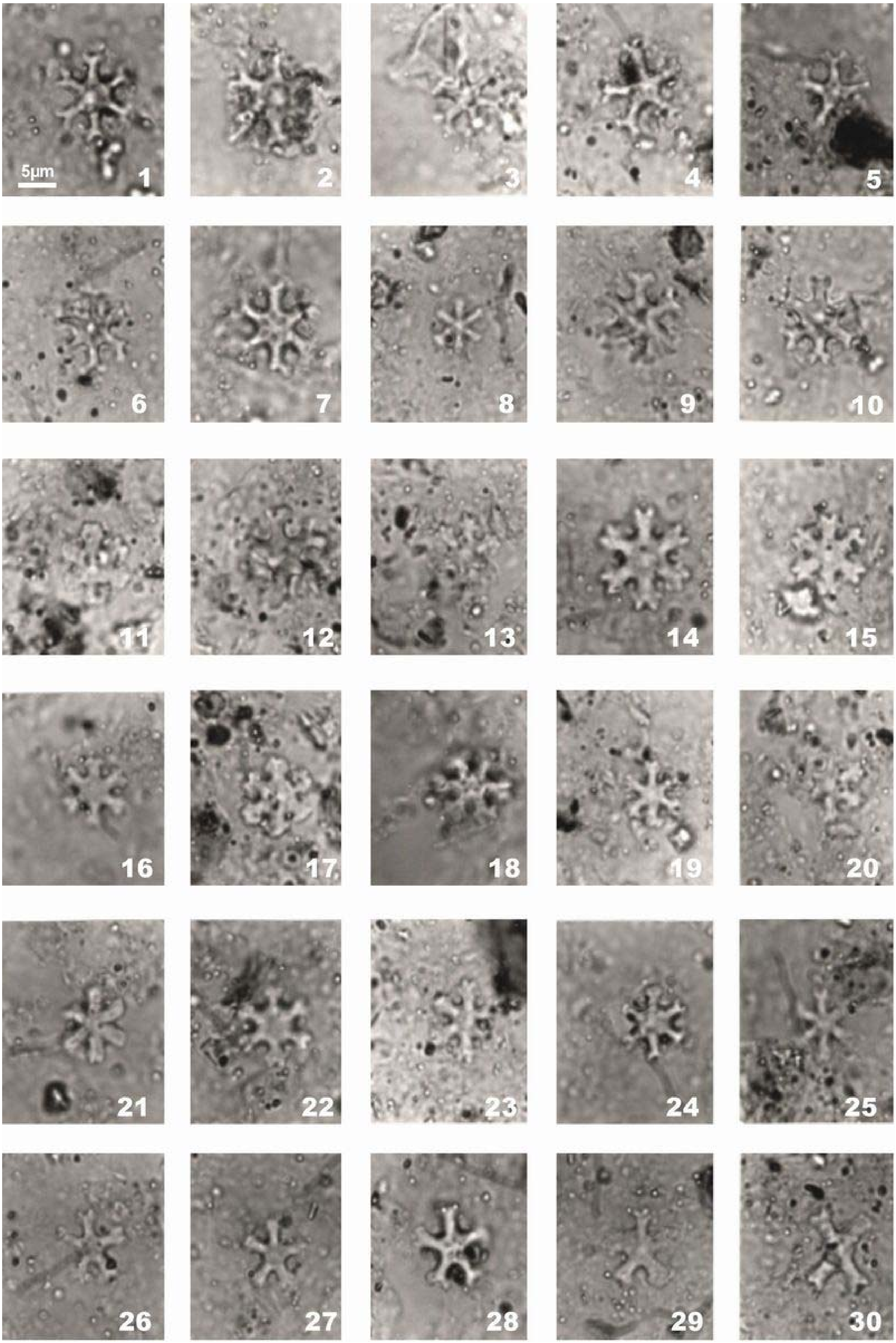
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Plate 1: Association 1 (NN3).
Type level: Well-1, 2265 m.
Figs. 1-3, 6-9, 12, 24-25, 27: *Discoaster protoexilis* Theodoridis 1984, 6-rayed forms.
On the proximal side of the asterolith the knob is clearly visible (figs. 1-2, 6) and the elliptical depressions around a limited little knob on the distal side associated with median ridges (fig. 7). Most of them are relatively small (less than 10 µm). Note in figs. 23 and 25 a clear reduction of the central area foreshadowing *D. variabilis* / *challengeri* ?).
Figs. 4-5, 26-30: *D. protoexilis*, pentaradiate forms.
Figs. 10, 18-19: Intermediate form between *D. protoexilis* and *D. deflandrei* Bramlette et Riedel 1954.
When the terminal branches of the arms are also bifurcate it is difficult to separate these forms from the most slender specimens of *D. deflandrei*. Note in fig. 18 the presence of depressions in this distal side. This characteristic is typical of *D. protoexilis* but not of *D. deflandrei.*
Figs. 11, 13-17, 20, 22-23, 26: *D. deflandrei* Bramlette et Riedel 1954.
Note the variation in size (small forms, fig. 13, large form, fig. 14) and in morphology (massive specimen, fig. 17 and more "slender" specimens, fig. 14).

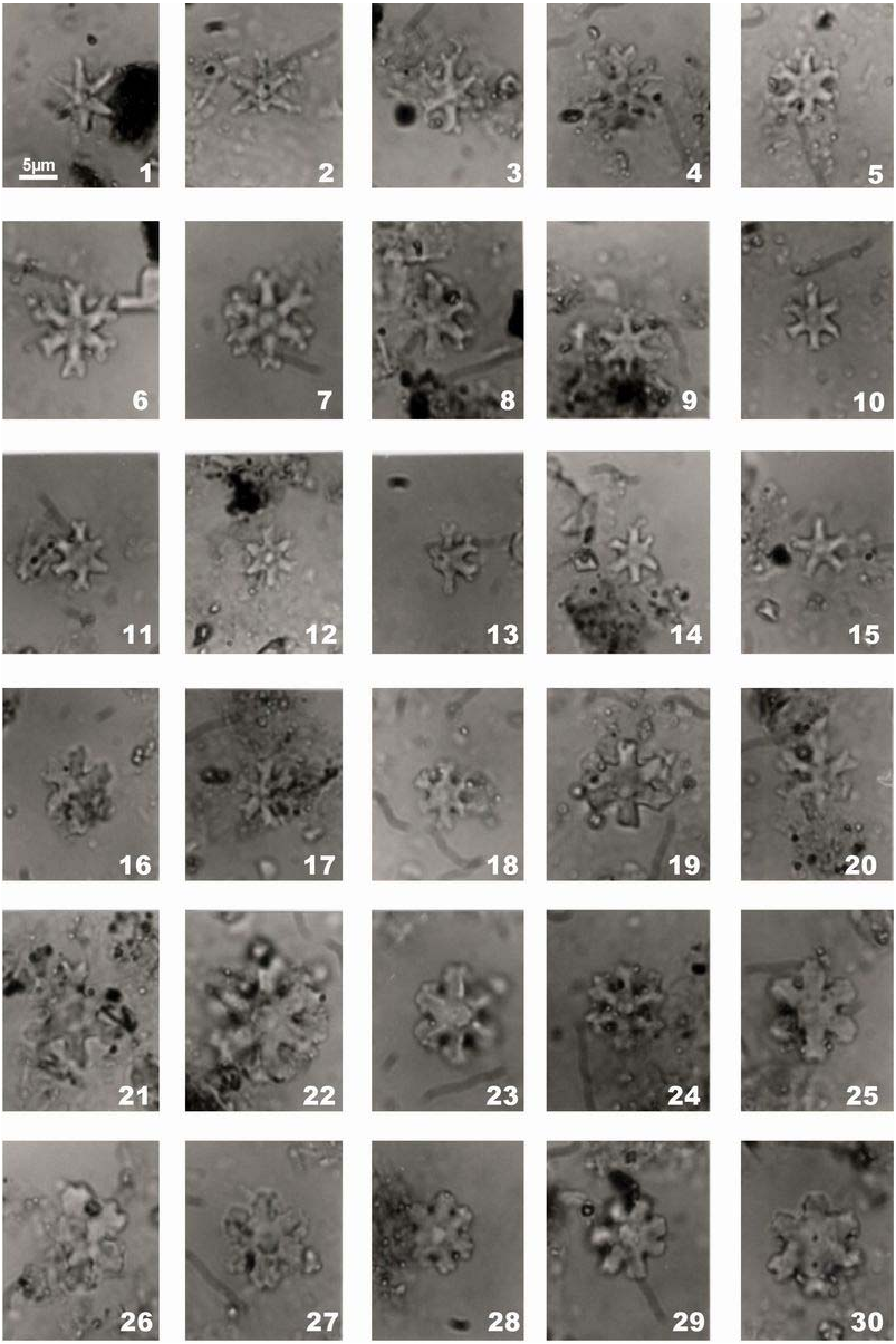
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Plate 2: Association 1 (NN 4).
Type level: Well-4, 3360 m.
Figs. 1-20: *Discoaster protoexilis* THEODORIDIS 1984.
The number of specimens increases (60% of the association). Forms of moderate size are always present (less than 10 µm).
A change in the size of the central area observed sporadically in the previous association (and shown on the plate) is confirmed, and the relative number of specimens exhibiting it increases (as compared to the previous plate). We note that the reduction of this central area (figs. 2, 6-7, for example) is associated with a well developed central knob that occupies the whole area.
Figs. 20-29: *D. deflandrei* BRAMLETTE et RIEDEL 1954. Note in figs. 22 & 23, the presence of prominent knob associated with well-defined ridges (proximal view). This variant was illustrated by MULLER 1974 (Leg 25, Pl. 7, fig. 3) reported from the NN5 zone.
Fig. 30: *D. calculosus* BUKRY 1971a. "Compact form with short free length of the broad bifurcated tap, lack of any prominent central knob" (BUKRY 1971a). Specimens have been observed only rarely in our material.

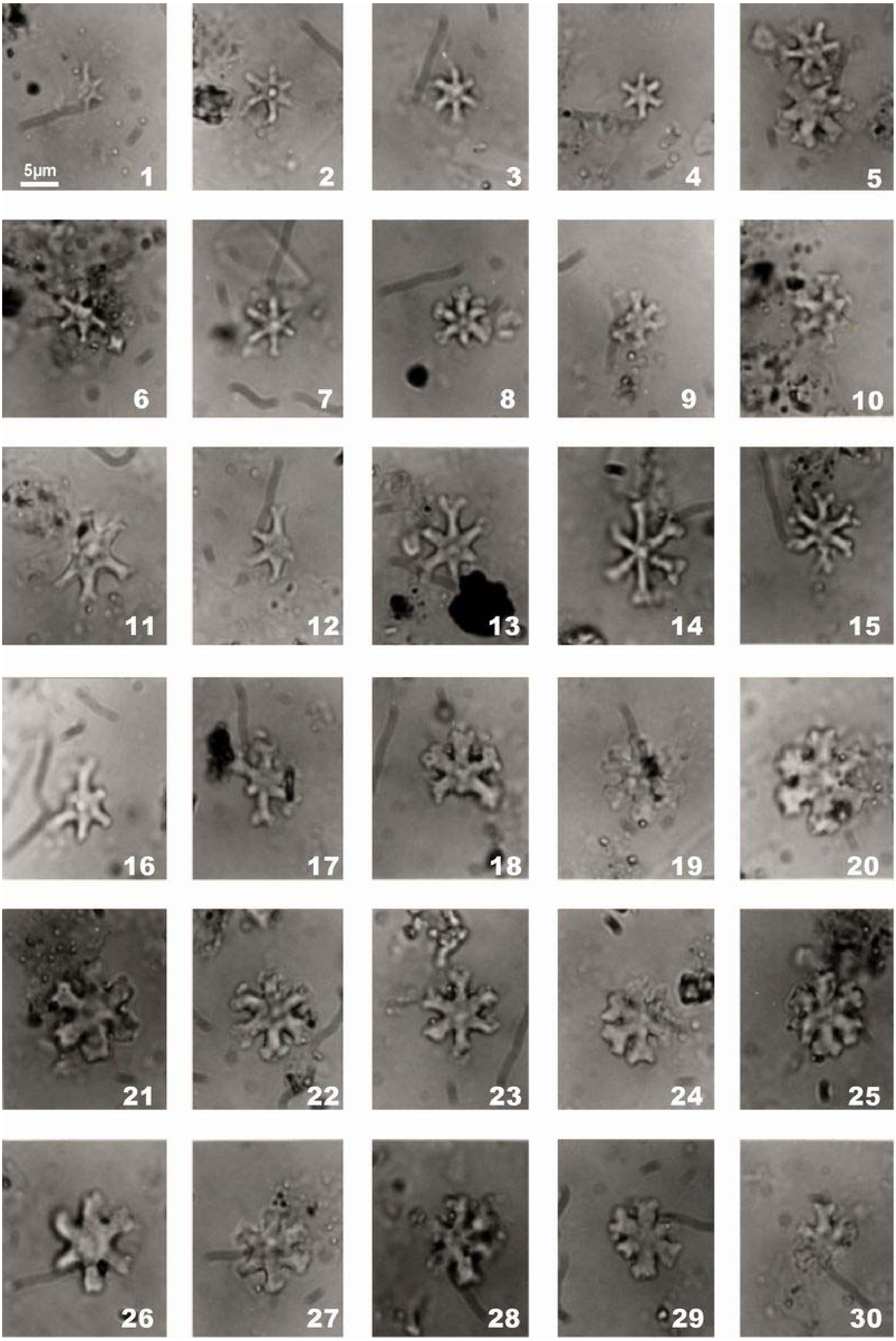
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Plate 3: Association 2 (NN5).
Type level: Well-4, 3355 m.
Figs. 1-10, 18, 22-23: *Discoaster protoexilis* THEODORIDIS 1984. Note the very small size of the specimens and the great variability in their morphology (see fig. 8).
Figs. 11-17: *D. variabilis* MARTINI et BRAMLETTE 1963 / *challengeri* BRAMLETTE et RIEDEL 1954 group? Appearance of relatively small forms with slender bifurcate arms. The central area varies greatly in size, so it is very difficult to differentiate the two species. A more or less heterogeneous population of asteroliths ranging from specimens with a relatively large central area (*variabilis* type) to specimens with a very small central area (*challengeri* type). Size is not stable: forms from very small (5 µm) to moderate in size (10 µm). Most of the small forms retain some "ancestral" aspects of *D. protoexilis*.
Figs. 18-21, 24-30: *D. deflandrei* BRAMLETTE et RIEDEL 1954. The relative poor preservation of the specimens does not permit a distinction among forms transitional between *D. protoexilis* (overgrowth) and *D. deflandrei*.

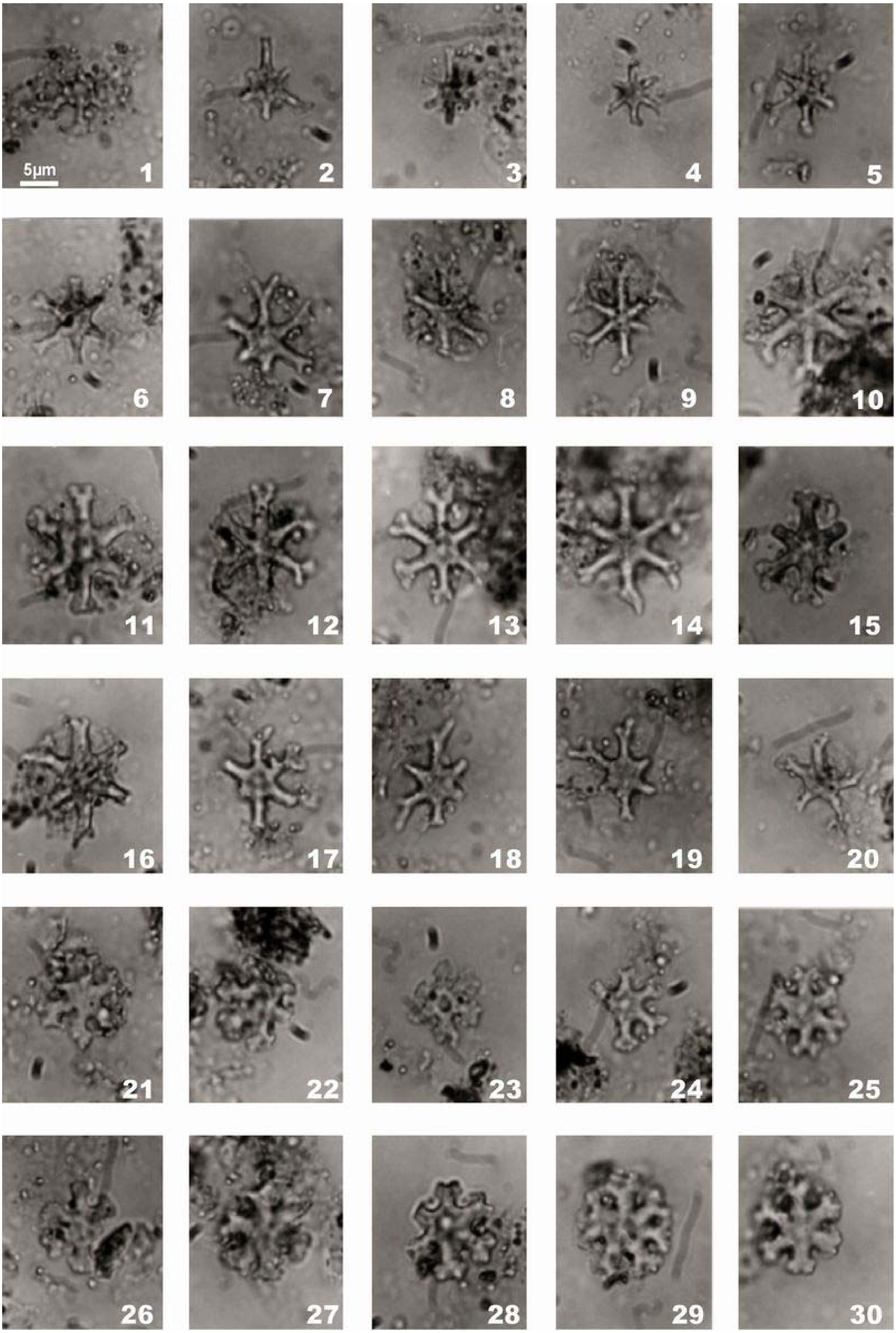
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Plate 4: Association 2 (NN5).
Type level: Well-4, 3051 m.
Figs. 1-20, 29: *Discoaster variabilis* MARTINI et BRAMLETTE 1963 / *challengeri* BRAMLETTE et RIEDEL 1954. The average size of the specimens increases (up to 15 µm), probably because of the disappearance of the smallest asteroliths. As in the previous level, the size of the central area ranges widely: from narrow to broad. The bifurcations are also variable from acute angles (figs. 11-12) to obtuse angles (figs. 9-10), and from short ends (figs. 11-12) to long ends (figs. 7, 14). Some specimens have more than six rays (fig. 29).
Figs. 21-28, 30: *D. deflandrei* BRAMLETTE et RIEDEL 1954.

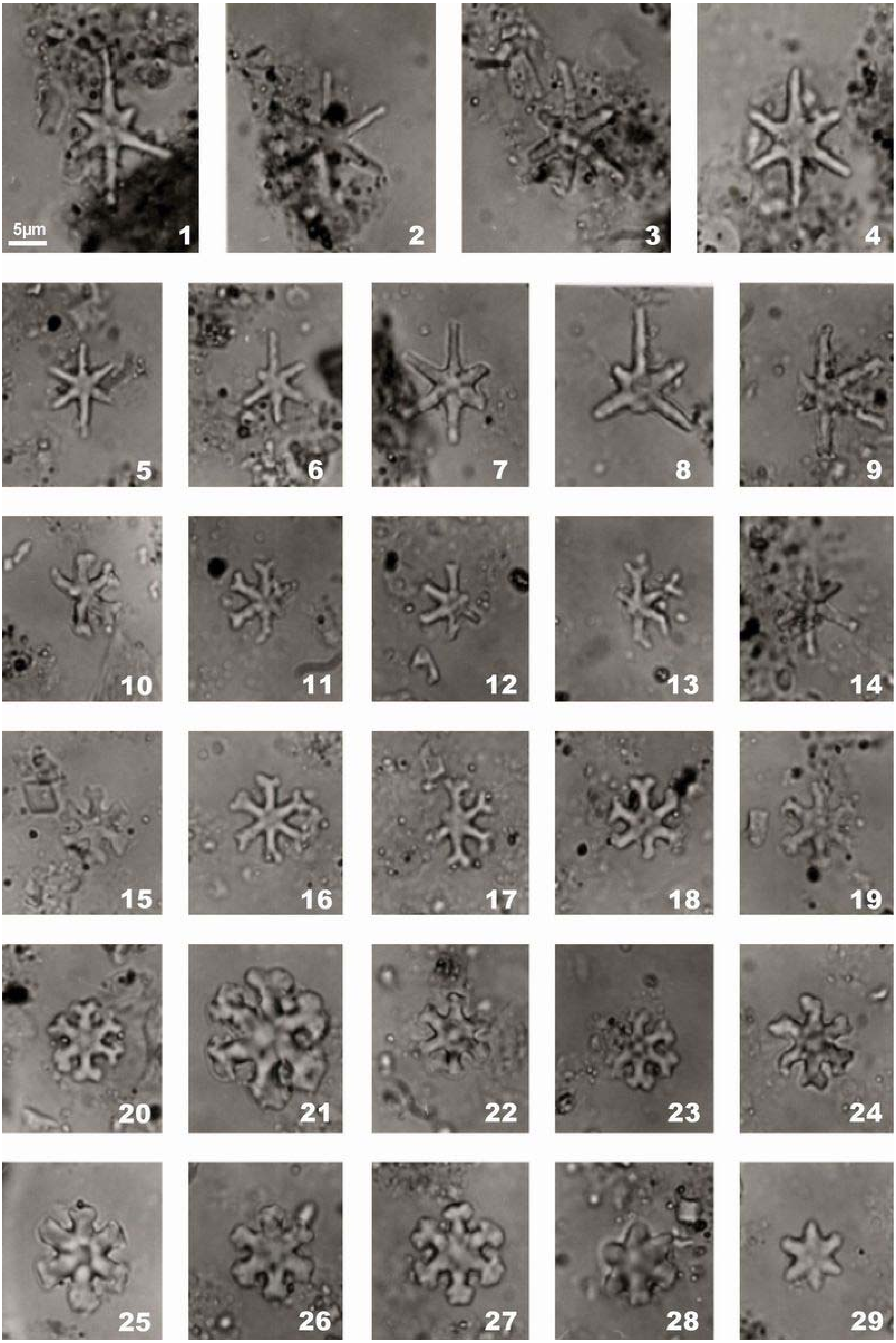
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Plate 5: Association 3 (NN6).
Type level: Well-5, 3660 m, limy sample, specimen with slight calcitic overgrowths.
Figs. 1-9, 14: *Discoaster brouweri* TAN SIN HOK 1927. This association is characterized by the first occurrence of slender non–bifurcate *Discoaster*.
Figs. 10-13, 15-19: *D. variabilis* group.
Figs. 20-28: Forms intermediate between *D. variabilis* and *D. deflandrei*. Massive small forms with short arms and the ends of the bifurcations proximate.
Fig. 29: *D.* sp. cf. *adamanteus*.
This plate demonstrates the effects of a more calcareous milieu by the existence of forms with minor calcitic overgrowths. The general morphology and size are preserved but the details are obscured.

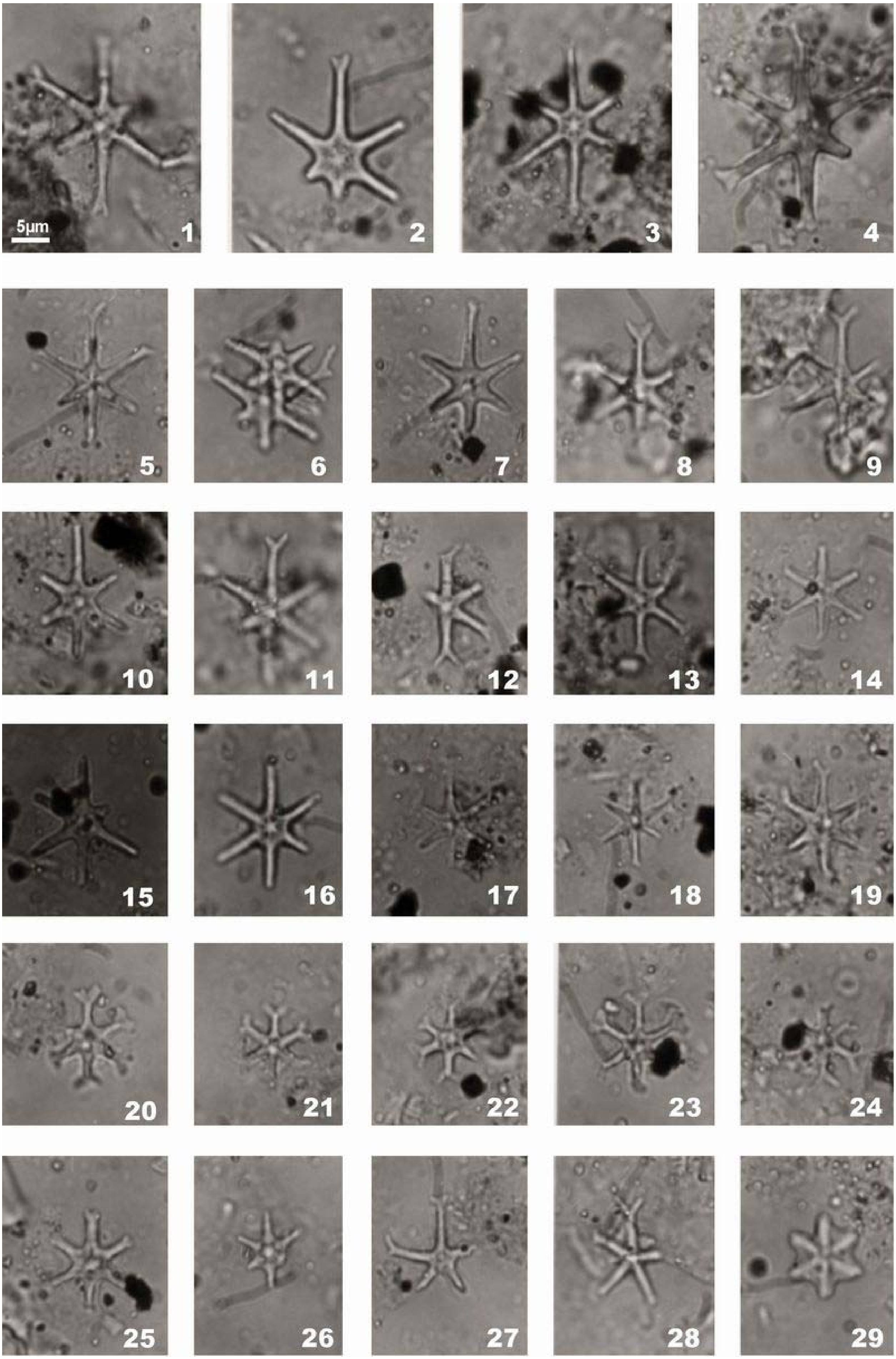
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Plate 6: Association 4 (NN6).
Type level: Well-1, 1403 m.
Figs. 1-4, 19, 19: *Discoaster exilis*. Large specimens (up to 25 µm) with a more or less well developed central area, long slender arms, weakly bifurcate.
Figs. 5-9: *D.* sp. aff. *exilis*. Close to the type specimens but differ in that the bifurcations are longer. Sometimes a web is visible between the ends of the bifurcation (fig. 8).
Figs. 13-14: *D.* sp. cf. *exilis*. Broken specimens.
Figs. 11-12: *D.* sp. aff. *signus* Bukry 1971a. Small central area close to the type, but without the prominent central knob. The bifurcations seem to be shorter.
Figs. 15-17: *D. brouweri* (?), fig. 16 could be a broken specimen of *D. exilis* or a form close to *D. archipelagoensis* Singh et Vimal.
Figs. 20-25: *D. variabilis* (small forms). The ends of the bifurcations are flat with a web between them. Always, some of them are very similar to *D. protoexilis* (fig. 22).
Fig. 26: *D.* aff. *formosus* Martini et Worsley. Small (less than 10 µm) in comparison to the type species described by Martini et Worsley. Knob always present.
Fig. 27-28: pentaradiate forms (*D. exilis* / aff. *signus* variant).
Fig. 29: *D. adamanteus.*

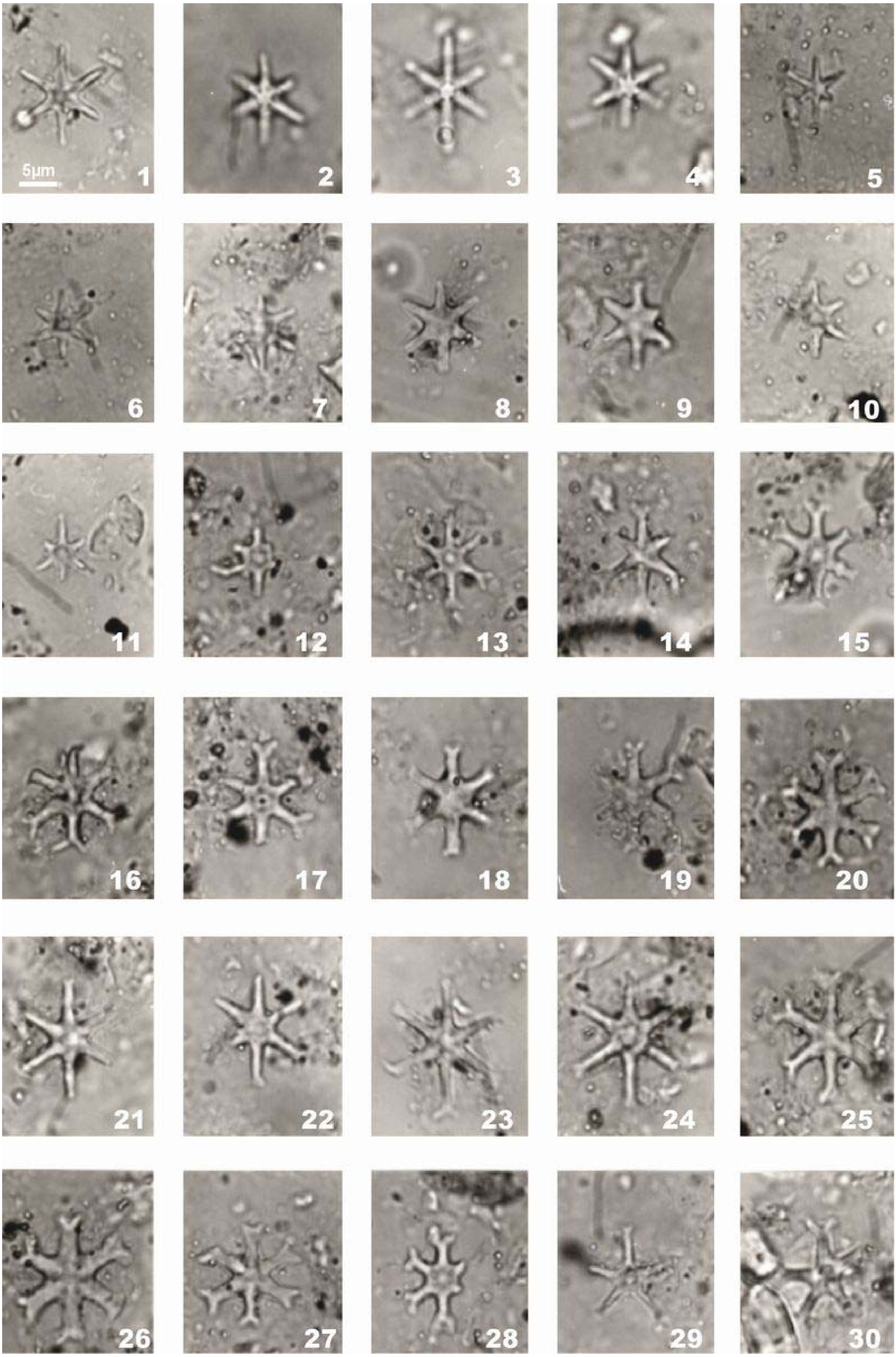
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Plate 7: Association 5 (NN7).
Type level: Well-5, 2502 m.
Figs. 1-4: *Discoaster* sp. aff. *tuberis* FILEWICZ 1985. All the specimens seen do not have a clear bifurcation at the ends of the arms.
Figs. 6-10: *D.* aff. *formosus* MARTINI et WORSLEY. Sometimes it is difficult to discriminate between specimens of this species and broken specimens of *D. variabilis*. Small, with a well–developed star–shaped central knob and ridges extending from the knob to the rays.
Figs. 11-20, 25-30: *D. variabilis* MARTINI et BRAMLETTE.
Figs. 21-24: *D. exilis.*
Figs. 29-30: pentaradiate forms (*exilis*, *variabilis*).

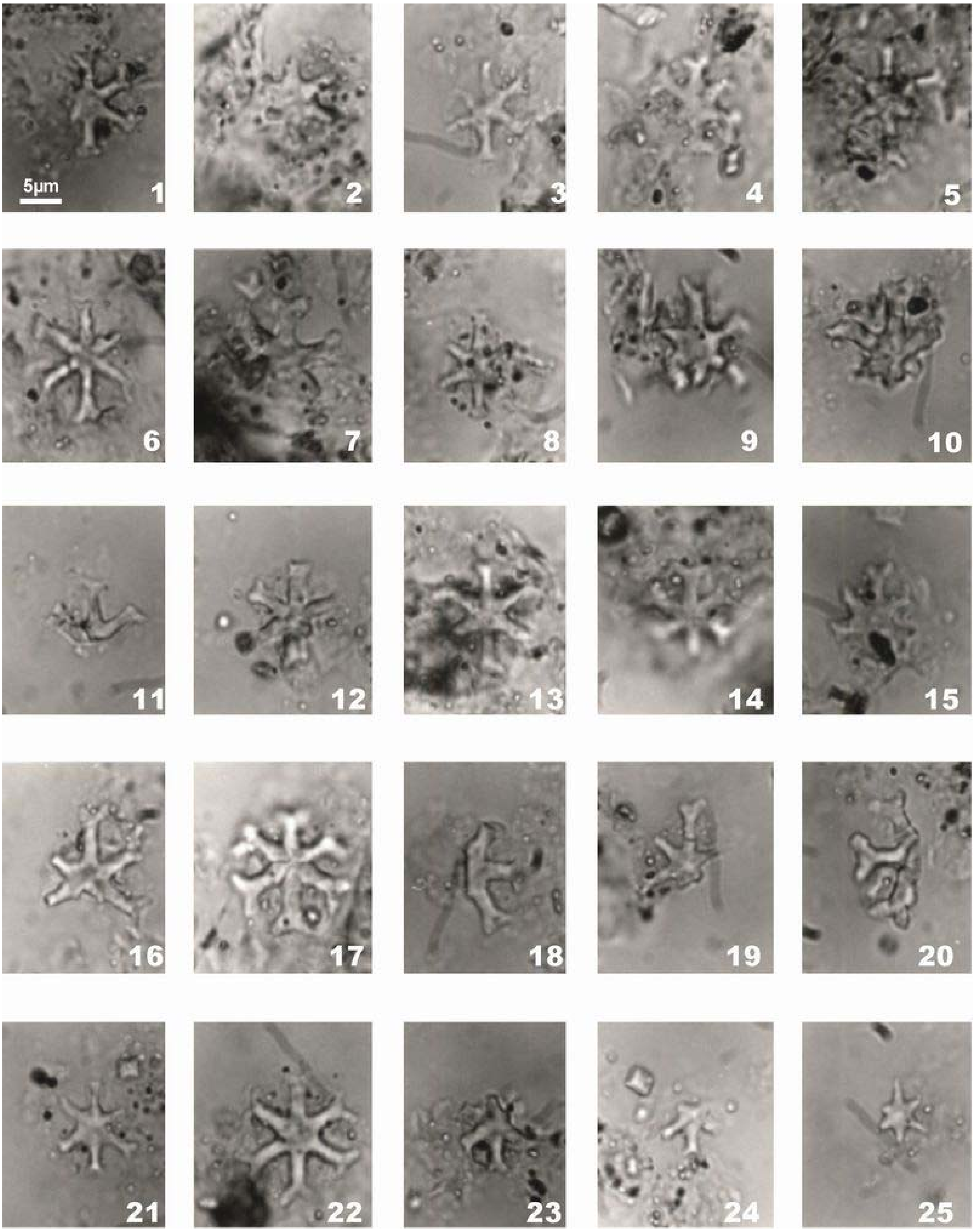
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Plate 8: Association 5 (NN7).
Type level: Well-2, 3398 m.
Figs. 1-25: *Discoaster variabilis* group.
Illustration of a typical poorly preserved association with but few specimens of *Discoaster*.
Only 25 specimens were obtained but all of them are assignable to the *D. variabilis* group.

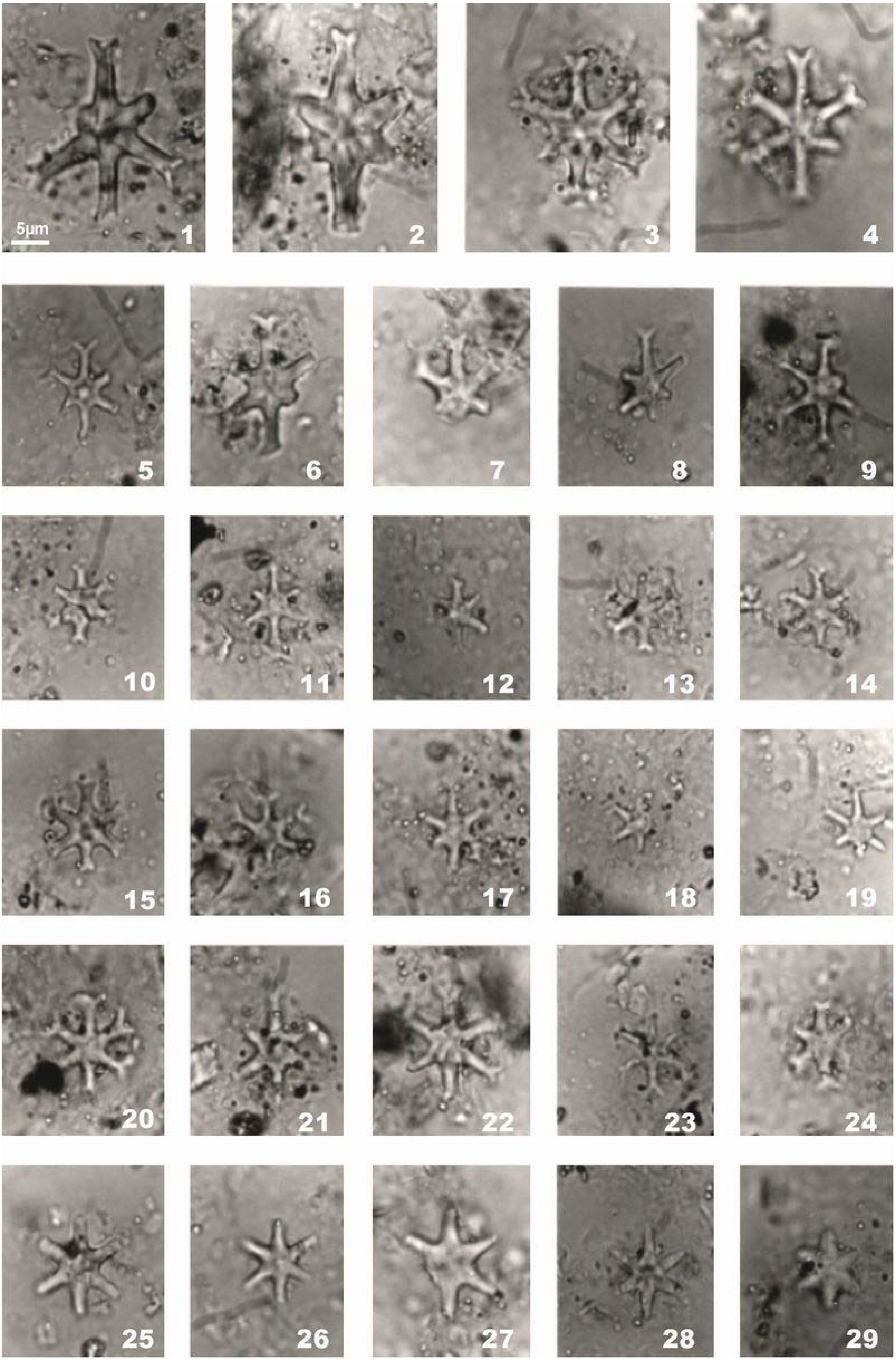
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Plate 9: Association 5 (NN7).
Type level: Well-2, 2821 m.
Figs. 1-4: *Discoaster variabilis* group. Large specimens appear (up to 30 μm).
Figs. 5-24: *D. variabilis* group (including form with weak bifurcations approaching *D. exilis*).
Figs. 25-26: *D.* sp. aff. *formosus*.
Figs. 27-28: *D.* sp.
Fig. 29: *D. adamanteus.*

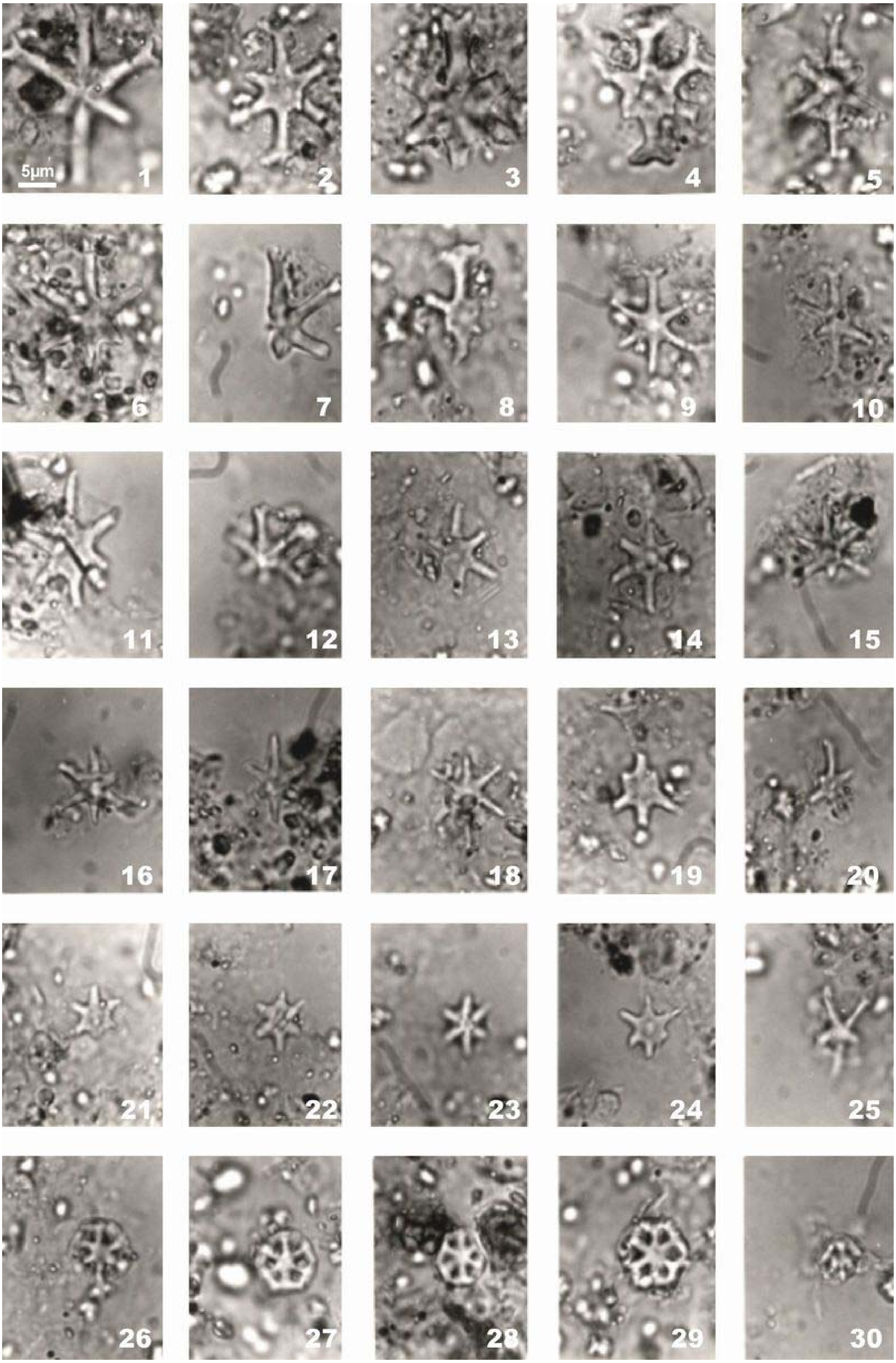
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Plate 10: Association 6 (NN8).
Type level: Well-2, 2747 m.
Figs. 1-4, 8-10: *Discoaster variabilis* group, large forms (up to 25µm). Some of them with large bifurcations could be related to *D. pansus* (fig. 4). But these specimens are always rare and occur only where *D. variabilis* is abundant.
Figs. 5-7, 12: *D. exilis* MARTINI et BRAMLETTE.
Figs. 14, 15, 20: *D. brouweri* TAN SIN HOK (*sensu* MARTINI et BRAMLETTE 1963).
Figs. 13, 16-18: *D.* sp. cf. *brouweri.*
Figs. 21-22, 24: *D.* sp.
Fig. 23: *D.* sp. aff. *tuberis* FILEWICZ.
Fig. 25: *D.* sp. pentaradiate form.
Figs. 26-30: *Catinaster coalitus* MARTINI et BRAMLETTE.

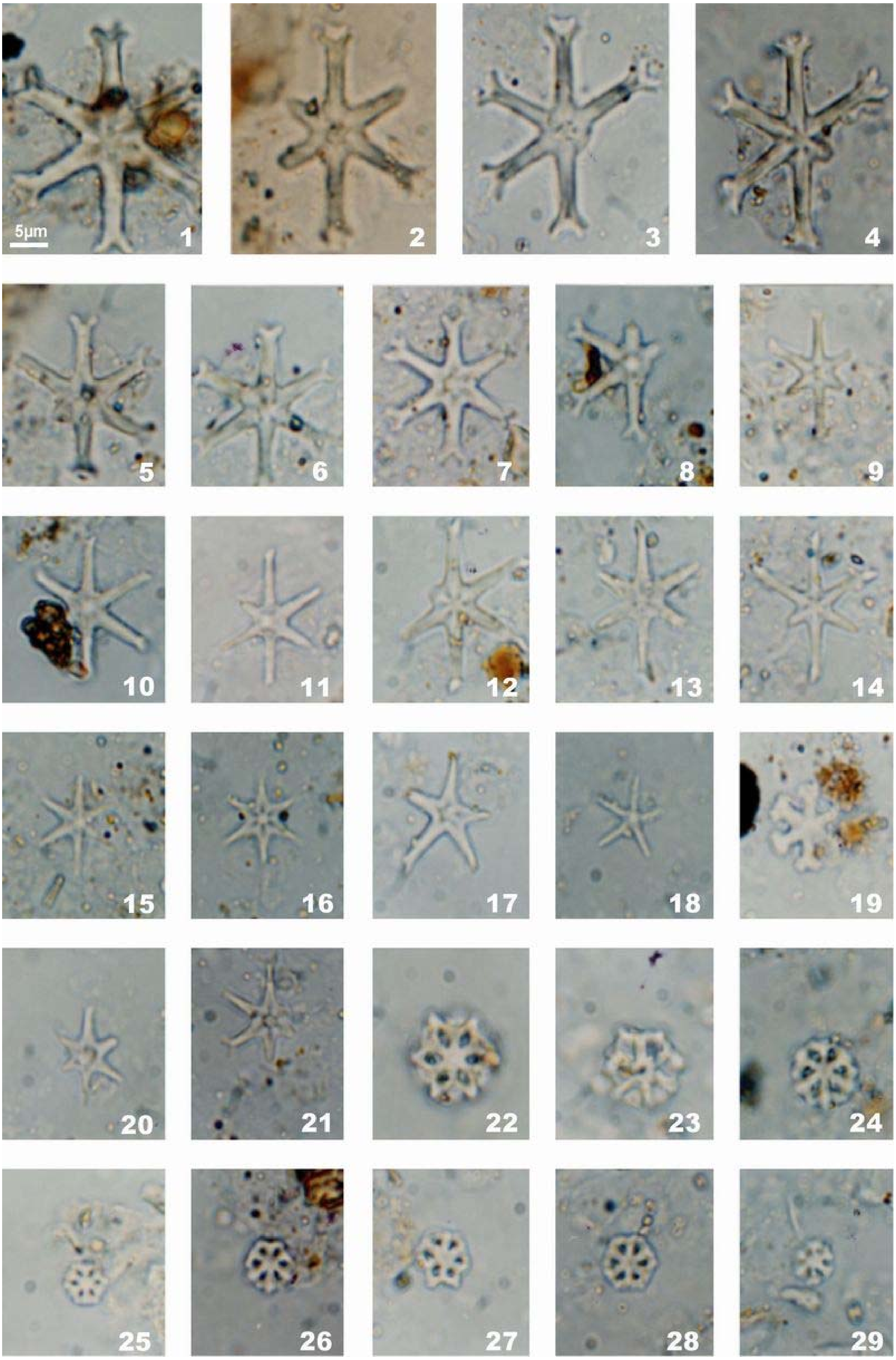
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Plate 11: Association 7 (NN9 lower).
Type level: Well-3, 2980 m.
Figs. 1-4: *Discoaster pseudovariabilis* MARTINI et WORSLEY. Huge specimens (up to 25/30 µm) with the typical trifurcation (with two dent-like tips) described by MARTINI et WORSLEY.
Figs. 5-8: *D. variabilis* MARTINI et BRAMLETTE.
Figs. 10-14: *D. calcaris* GARTNER.
Figs. 15-16: *D.* sp.
Figs. 17-18: *D. hamatus* MARTINI et BRAMLETTE.
Fig. 19: *D.* sp.
Figs. 20-21: *D. bollii* MARTINI et BRAMLETTE. "Primitive" slender forms with a relatively small central knob.
Fig. 22: *Catinaster* aff. *coalitus* MARTINI et BRAMLETTE (*sensu* MARTINI and BRAMLETTE, large specimens).
Figs. 23-29: *C. coalitus* MARTINI et BRAMLETTE.

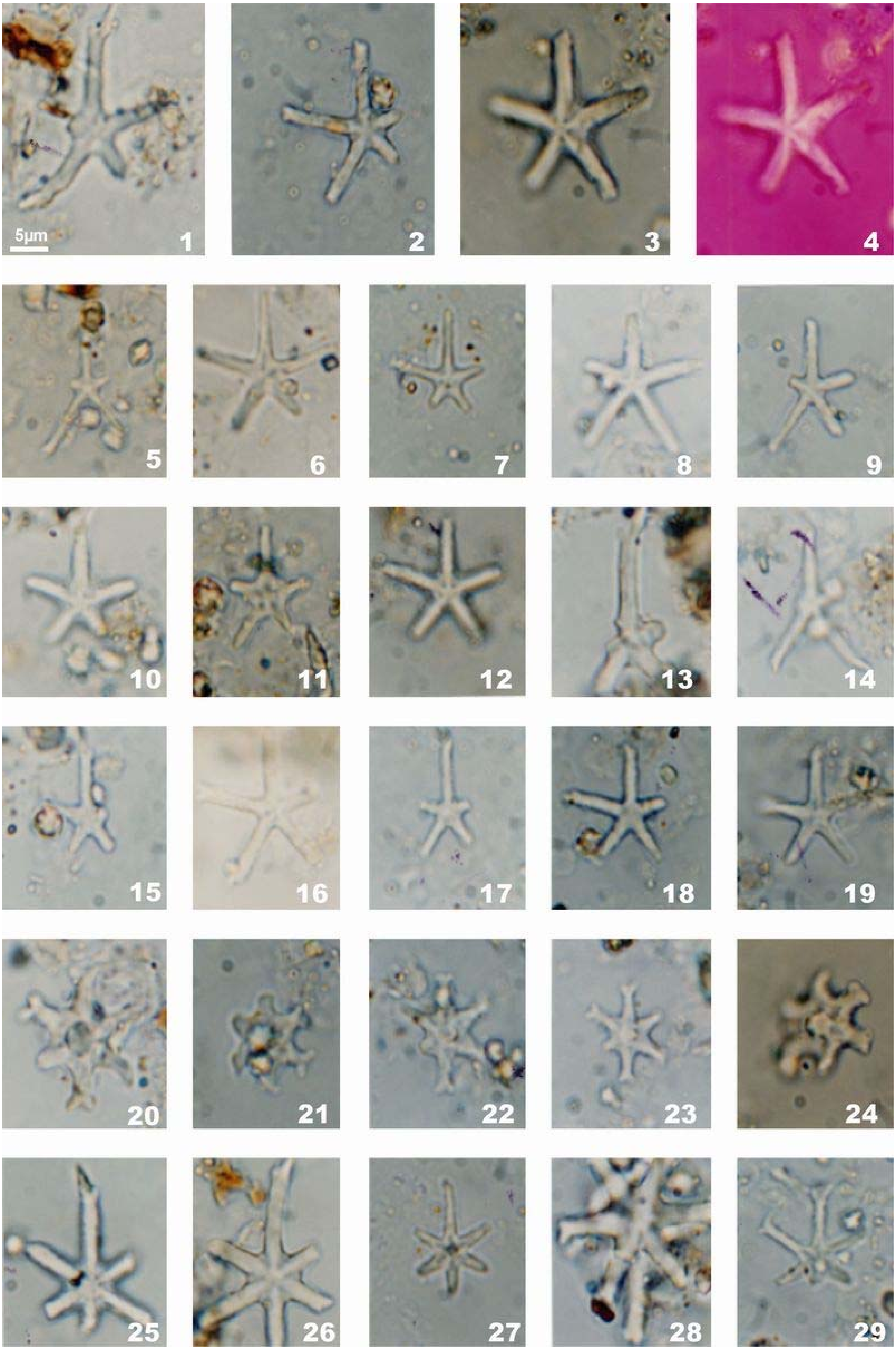
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Plate 12: Association 8 (NN9 upper).
Type level: Well-3, 2550 m.
Figs. 1-19: *Discoaster hamatus* MARTINI et BRAMLETTE.
Figs. 20-24: *D. bollii* MARTINI et BRAMLETTE.
Figs. 25-27: *D. calcaris* GARTNER.
Figs. 28-29: *D. variabilis* / *exilis*.

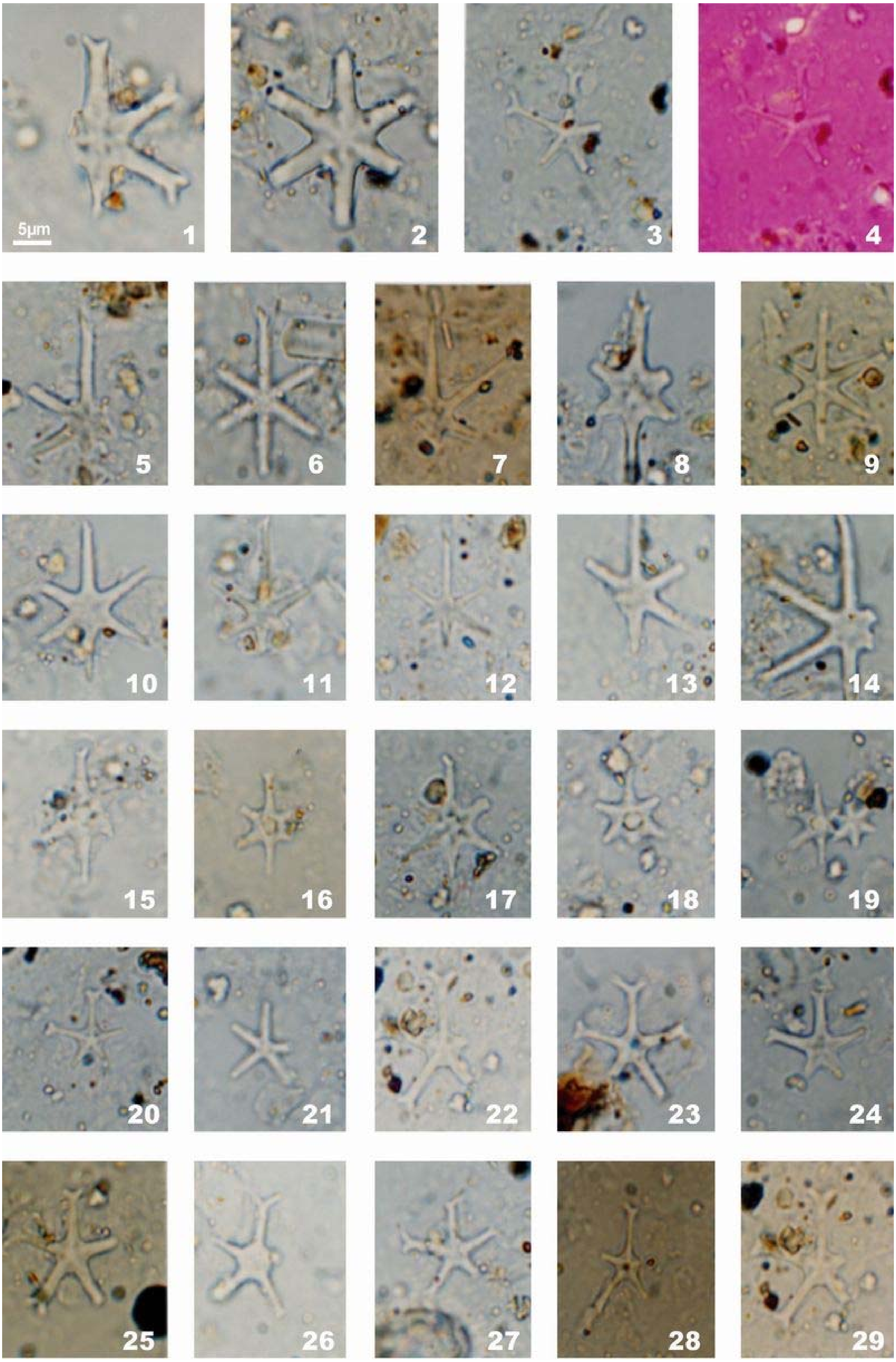
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Plate 13: Association 9 (NN10 lower).
Type level: Well-3, 2320 m.
Figs. 1-2: *Discoaster variabilis* MARTINI et BRAMLETTE.
Figs. 3-4, 20-29: *D. pentaradiatus* TAN SIN HOK (*sensu* THEODORIDIS 1984).
Figs. 5-14: *D. calcaris* GARTNER.
Figs. 15-19: *D. bollii* MARTINI et BRAMLETTE.

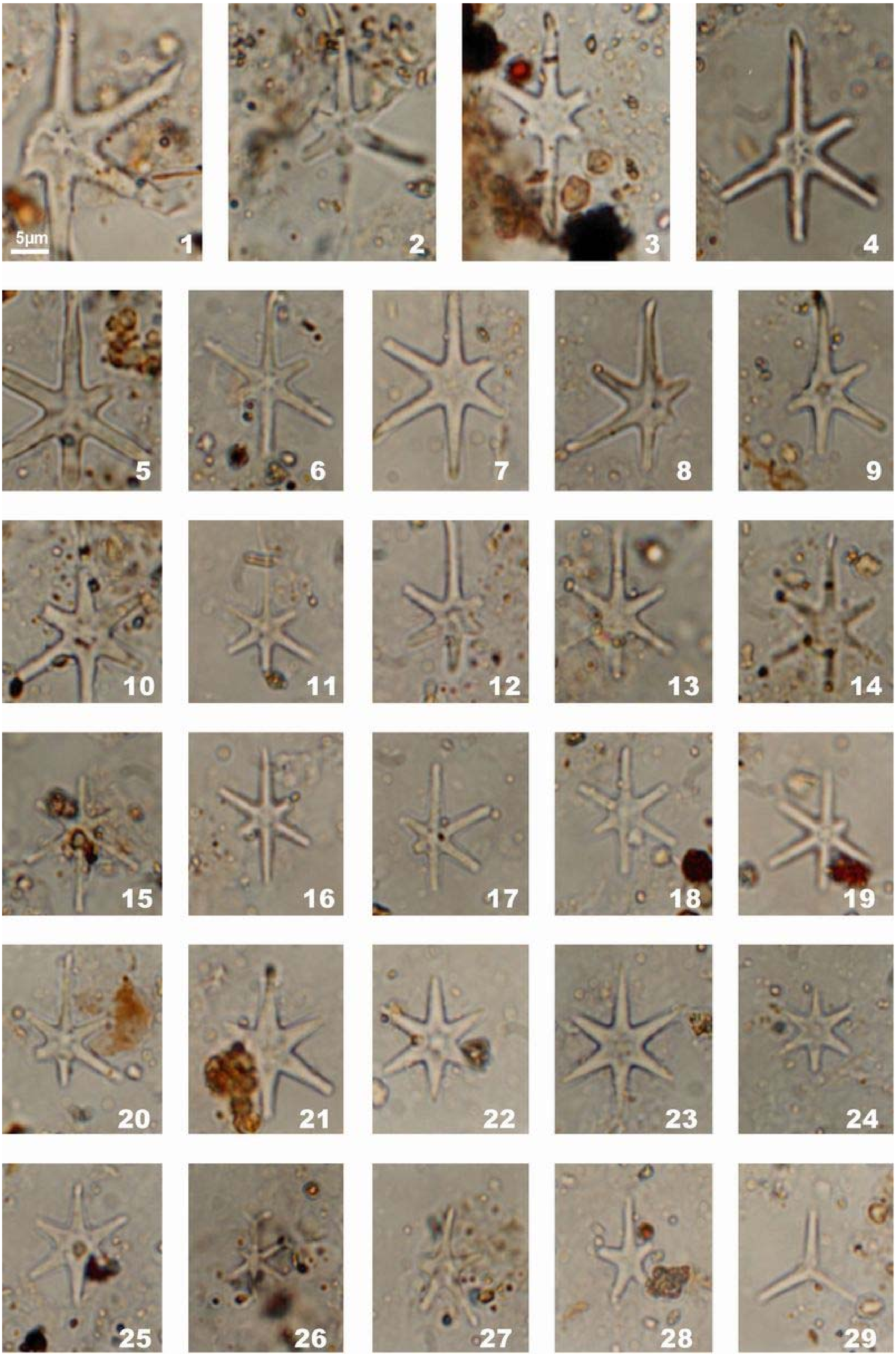
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Plate 14: Association 10 (NN10 upper).
Type level: Well-3, 2160 m.
Figs. 1-2: *Discoaster calcaris* GARTNER.
Figs. 3-14: *D. neorectus* BUKRY.
Figs. 15-20: *D. brouweri* TAN SIN HOK or broken *D. neorectus*?
Figs. 21-25: *D. intercalaris* BUKRY.
Fig. 26: *D.* sp.
Figs. 27-28: pentaradiate forms (*D. calcaris* / *neorectus*?).
Fig. 29: triradiate form.

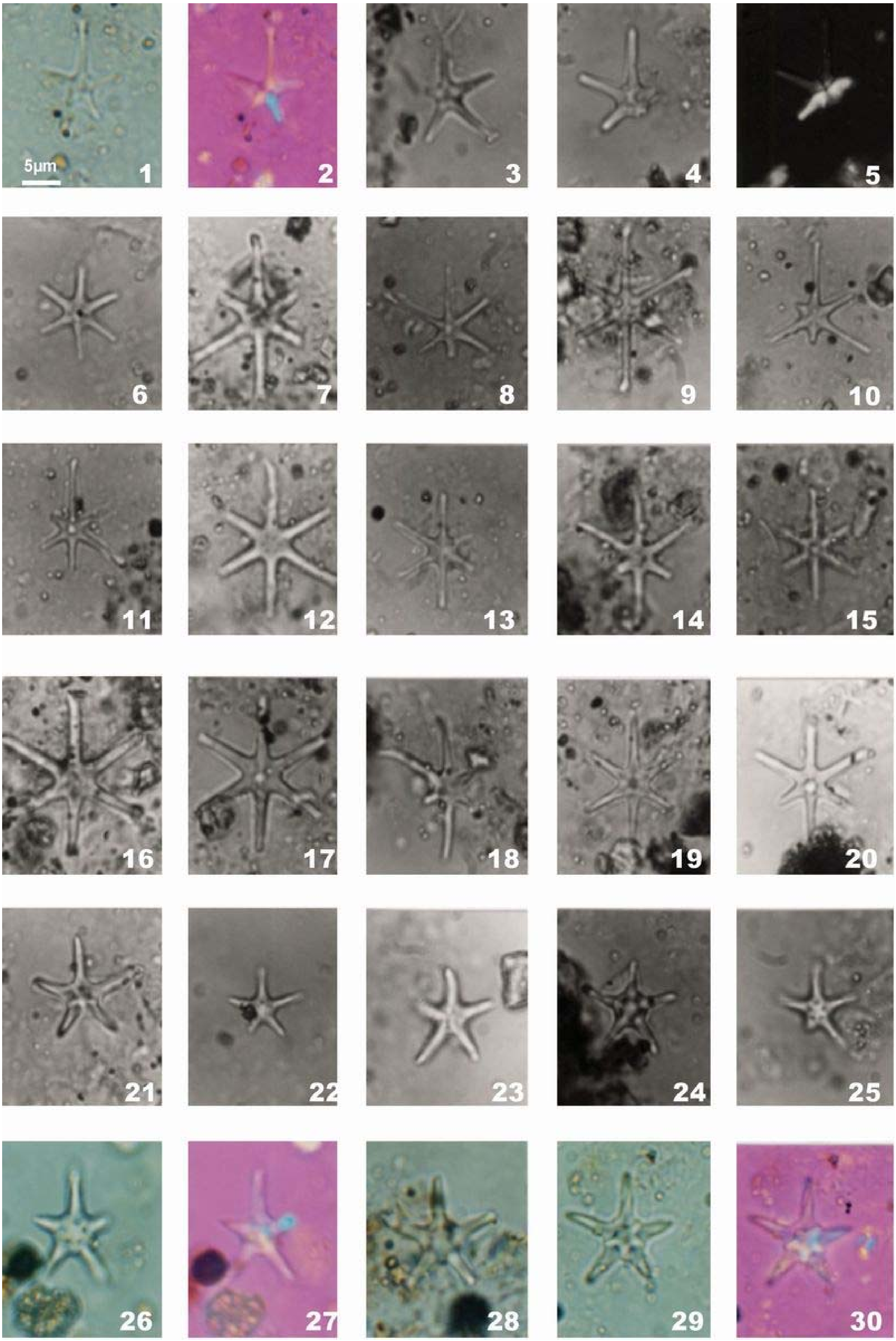
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Plate 15: Association 11 (NN11 lower).
Type level: Well-3, 2040 m.
Figs. 1-5: *Discoaster misconceptus* THEODORIDIS.
Figs. 6, 19-20: *D. brouweri* ?
Figs. 7-18: *D. neorectus* BUKRY.
Figs. 21-30: *D. berggrenii* BUKRY.

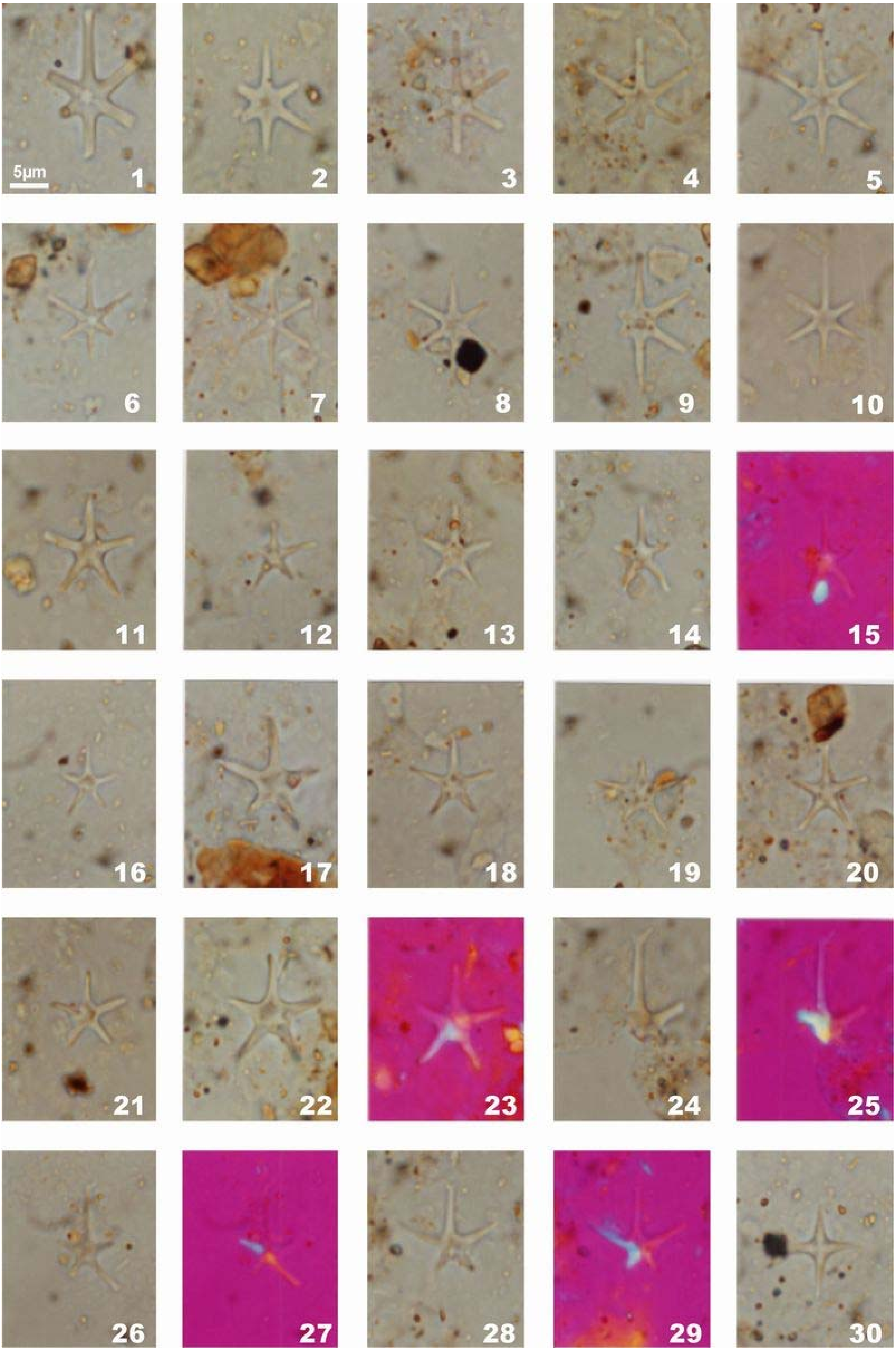
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Plate 16: Association 12 (NN11 "middle").
Type level: Well-3, 1960 m.
Fig. 1: *Discoaster* sp.
Figs. 2-10: *D. brouweri* TAN SIN HOK (fig. 6: *D. neorectus* ?).
Figs. 11-23: mixed *D. berggrenii* and *D. quinqueramus* GARTNER.
Figs. 24-29: *D. misconceptus* THEODORIDIS.
Fig. 30: quadriradiate form.

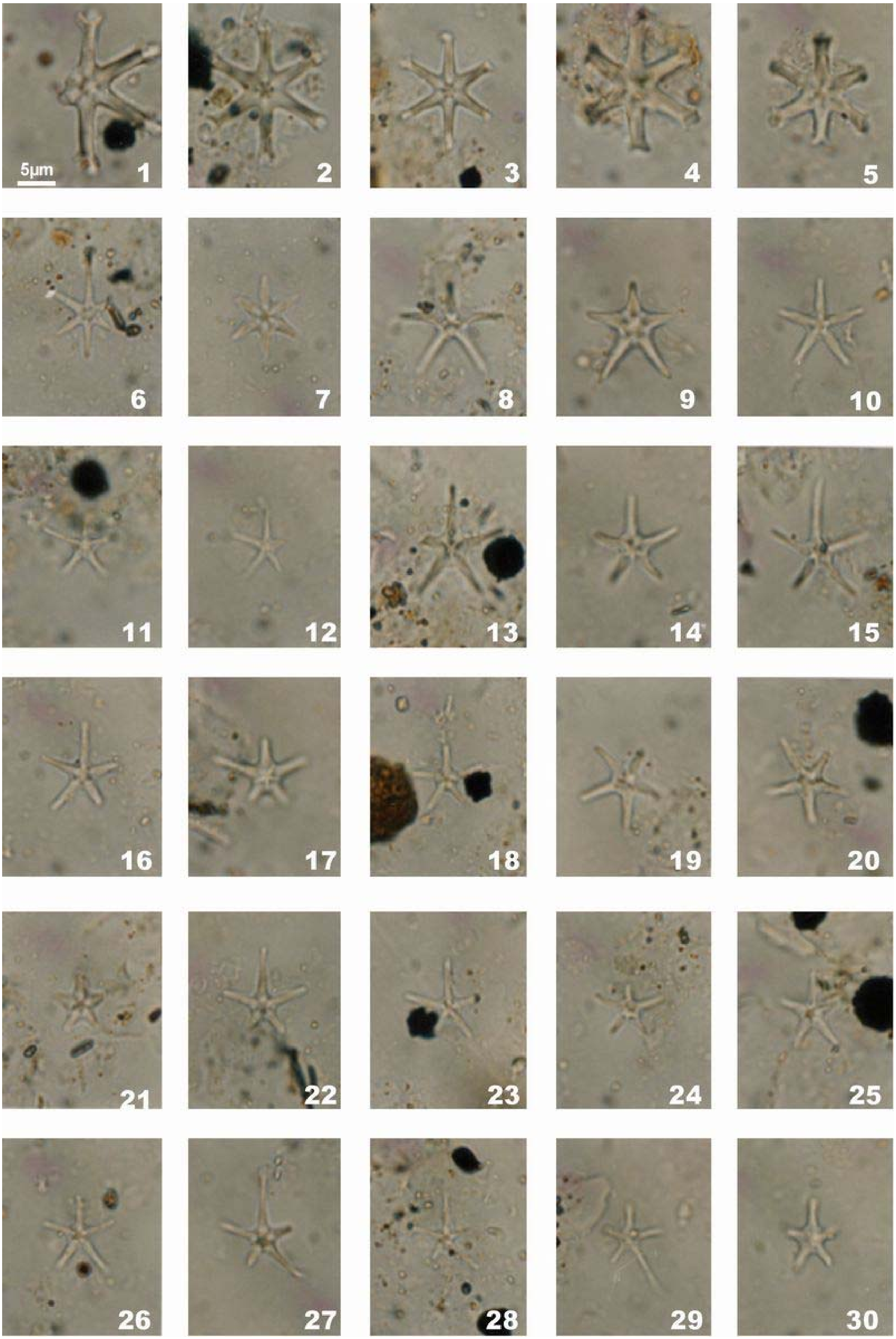
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Plate 17: Association 13 (NN11 upper).
Type level: Well-3, 1420 m.
Figs. 1-3: *Discoaster surculus* MARTINI et BRAMLETTE, typical forms.
Figs. 4-5: *D.* sp. aff. *surculus*, similar to figs. 1–3 but the trifurcation is not clearly visible and the central spine appears to be missing.
Fig. 6: *D. brouweri* TAN SIN HOK.
Fig. 7: *D.* sp.
Figs. 8-9, 14, 19-20, 30: *D. berggrenii* BUKRY.
Figs. 10, 12: *D. quinqueramus* GARTNER.
Figs. 11, 13, 15-16, 18, 26-29: forms intermediate between *D. quinqueramus* and *D. berggrenii*.