

Eocene nannofossil biostratigraphy of the mid-Waipara River section, Canterbury Basin, New Zealand

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Abstract Samples collected from the middle reaches of the Waipara River, northern Canterbury Basin, New Zealand, provide a detailed record of calcareous nannofossil assemblages from lower Eocene to uppermost middle Eocene sediments of this southwestern Pacific, mid-paleolatitude region (~52°S). Biostratigraphic analysis indicates an almost complete section spanning nannofossil Zones NP10 to NP16 (Ypresian to Bartonian Stages), with a hiatus that encompasses all of NP15 (Lutetian Stage) and likely portions of upper NP14 and lower NP16. There is also evidence for an unconformity that includes part of upper NP10 and lower NP11, which is also found in other New Zealand sections. This paper documents the biostratigraphy and calcareous nannofossil assemblages of the mid-Waipara River section.

Keywords calcareous nannofossils, biostratigraphy, early-middle Eocene, mid-Waipara River, southwest Pacific, New Zealand

1. Introduction

The mid-Waipara River section, located in the northern Canterbury Basin, New Zealand (Figure 1), is recognised as an important record of climatic change in the New Zealand region from the early to middle Eocene (Hollis *et al.*, 2009; Hollis *et al.*, 2012). Recent studies by Dallanave *et al.* (2014; 2016) provide a new integrated magneto-biostratigraphic chronology for this Eocene interval (~51–47 Ma) of the mid-Waipara section. The biostratigraphy was based on foraminiferal, calcareous nannofossil and dinoflagellate cyst analyses of new samples collected at the same levels as mini-cores used for paleomagnetic analysis, and spans the Ypresian to Lutetian Stages (New Zealand Waipawan, Mangaorapan, Heretaungan and lowermost Bortonian Stages). Key nannofossil events from mid-Waipara were reported in Dallanave *et al.* (2016) and here we provide a more detailed description of the calcareous nannofossil assemblages, together with NP zonal assignments and notes on systematic paleontology. In future work, the nannofossil data will be correlated with other biostratigraphic and climate proxy data from earlier studies (Hollis *et al.*, 2009; Hollis *et al.*, 2012) and on-going TEX₈₆ work. This will better elucidate climatic changes across the early–middle Eocene in the New Zealand region, particularly during climatic events such as the Early Eocene Climatic Optimum (EECO).

2. Geological setting

The mid-Waipara River section is located along the middle part of the Waipara River, northern Canterbury Basin (Figure 1). During the early Eocene the New Zealand landmass was positioned ~10–15° further south than its current location (Seton *et al.*, 2012), with the mid-Waipara River

section located at a paleolatitude of ~52°S (Figure 2). At that time extensive transgressive sediment deposition occurred along the passive margin of New Zealand (Ballance, 1993; King *et al.*, 1999). Previous work by Morgans *et al.* (2005) integrated samples from mid-Waipara River into a series of separate composite sections, spanning the Upper Cretaceous to middle Eocene. This study focuses on sediments of the Ashley Mudstone (grid reference NZMS260 M34/7831 9486 to M34/7848 9469; New Zealand Map Series 260 topomap M34, 1:50,000, Edition 1, 1991), a calcareous mudstone deposited in upper bathyal depths in the early to middle Eocene (Morgans *et al.*, 2005; Hollis *et al.*, 2012).

The Ashley Mudstone was first described by Mason (1941) and the formation definition was later revised by Browne & Field (1985). At mid-Waipara, basal Ashley Mudstone is separated from the underlying Paleocene strata (Waipara Greensand) by a sharp and unconformable contact. Hollis *et al.* (2012) identified the Paleocene–Eocene Thermal Maximum (PETM) in the basal Ashley Mudstone by a negative δ¹³C excursion (measured from bulk organic carbon) and dinoflagellate assemblages. This interval is overlain by a 50–75 m thick section of Ashley Mudstone that extends from lower to middle Eocene (New Zealand Waipawan to Bortonian Stages) and spans the New Zealand Mangaorapan/Heretaungan Stage boundary (Hollis *et al.*, 2012). This encompasses a time interval of 16 million years (56–40 Ma) based on the recently recalibrated New Zealand Geological Time Scale (Raine *et al.*, 2015). The Amuri Limestone of late Eocene–Oligocene age conformably overlies the Ashley Mudstone (Morgans *et al.*, 2005).



Figure 1: Map showing the present-day location of the mid-Waipara River section, Canterbury Basin, New Zealand

3. Materials and methods

This study utilises 27 samples collected in 2012 from a ~66m succession of Ashley Mudstone and seven samples collected in 2007 from above the PETM interval in the basal Ashley Mudstone (Figure 3). The two sample sets were correlated using foraminifera, dinocyst and nannofossil bioevents to produce a composite section (Figure 4). Calcareous nannofossil smear slides were made directly from unprocessed samples using standard techniques (Bown & Young, 1998). In some cases, samples contained a large amount of coarse material and strewn slides were prepared. Slides were analysed using an Olympus BX53 microscope at 1000 \times magnification in plane-transmitted light (PL), cross-polarised light (XPL) and phase-contrast (PC) light. Counts of 200 specimens were made along random traverses of each slide, followed by a further 20 minutes of scanning to identify rare species not recorded in the initial count. Relative species abundances were estimated using the scale: V = very abundant (>50%); A = abundant (20–50%); C = common (5–20%); F = few (1–5%); R = rare (<1%); P = present (noted in the second scan). Taxonomic concepts for species follow those of Perch-Nielsen (1985) and Bown (1998, 2005). Results are correlated to the biostratigraphic zonation scheme of Martini (1971), with subzones as defined by Aubry (1991) and absolute ages for events from Gradstein *et al.* (2012). Comparison with the biozonation scheme of Agnini *et al.* (2014) is included in the discussion section. Zonal boundaries are positioned at the midpoint between consecutive samples in which the FO or LO of key taxa are observed.

4. Results

Nannofossil analysis indicates that the sampled section spans the lower Eocene to uppermost middle Eocene

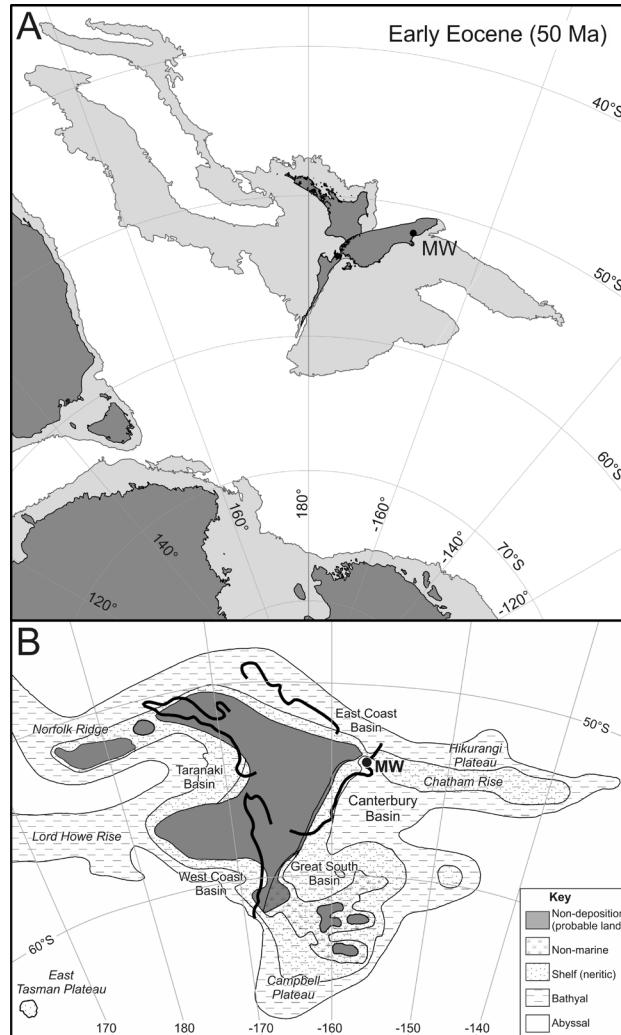


Figure 2: Location of the mid-Waipara River section in the early Eocene. (A) Tectonic reconstruction of the southwest Pacific (based on Seton *et al.*, 2012). (B) Paleogeographic reconstruction of the New Zealand region (after King *et al.*, 1999; modified from Hollis *et al.*, 2012). MW = mid-Waipara River section

(Nannofossil Zone NP10 to NP16/17; New Zealand Waipawan to Bortonian Stages), with a hiatus/unconformity in the lower middle Eocene (NP15, New Zealand Porangan Stage), as outlined below (Table 1; Figure 4). Nannofossils are common to abundant throughout the studied interval. Preservation of nannofossils is variable throughout the section but is generally moderate and worsens in the upper middle Eocene (New Zealand Heretaungan Stage). The distribution of taxa is shown in Table 2, with the key biostratigraphic results outlined below.

4.1 *Tribrachiatus contortus* Zone (NP10)

Interval: -15.25m (base of studied section) to -9.91m (3 samples)

Thickness: 5.34m

The first occurrence (FO) of *Rhomboaster bramlettei* marks the base of Zone NP10 (Martini, 1971). This taxon is

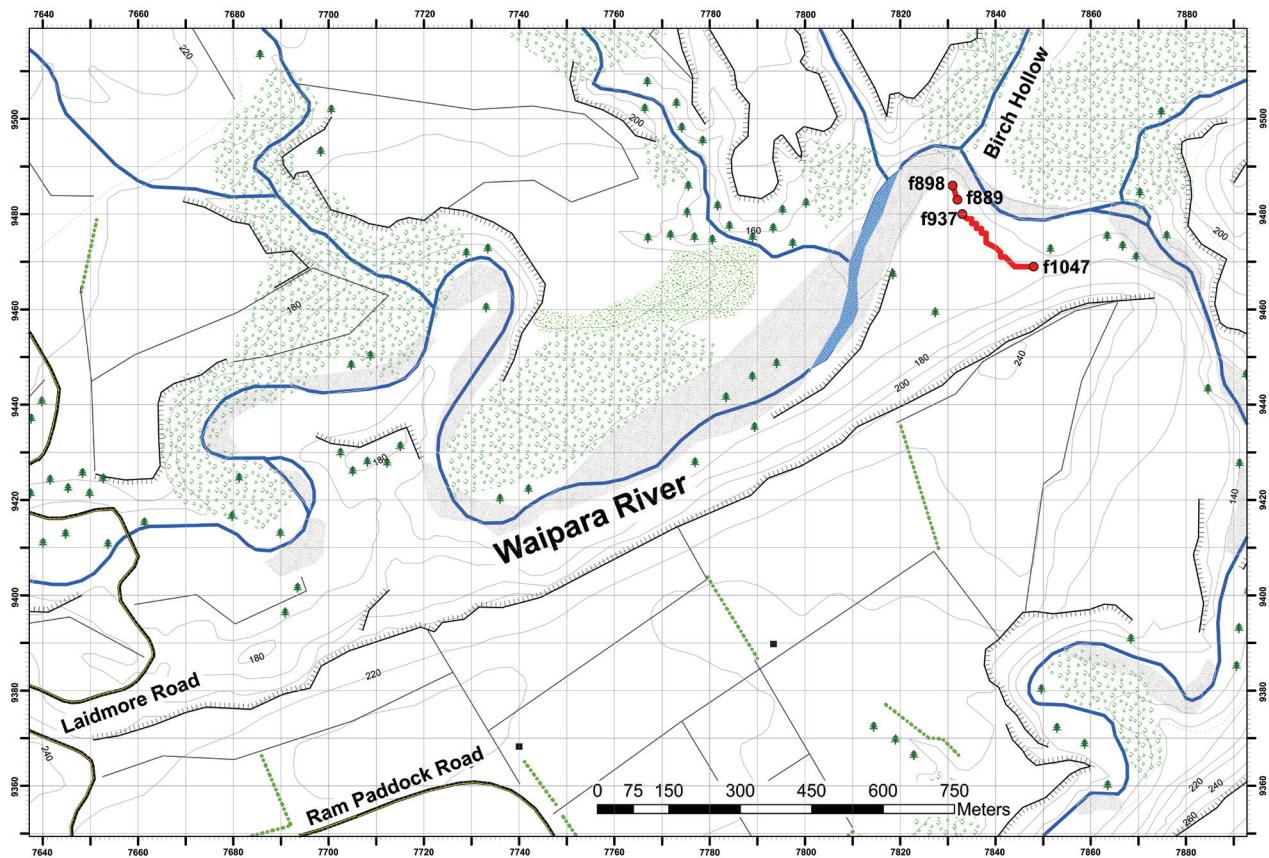


Figure 3: Map of the mid-Waipara River section showing the location of the sections sampled in 2012 (f937–f1047) and 2007 (f898–f889)

Bioevent	NP Zone (base)	CNE Zone (base)	Sample ID	Stratigraphic position	Next sample lower (B) or higher (T)	Stratigraphic position	Zonal Boundary Placement (midpoint)
B <i>Reticulofenestra umbilicus</i>		CNE13	M34/f1043	62.26	M34/f1039	58.55	60.41
T <i>Discoaster lodoensis</i>		CNE7	M34/f1019	40.76	M34/f1023	43.00	41.88
T <i>Tribrachiatus orthostylus</i>	NP13	CNE5	M34/f0959	11.13	M34/f0963	12.55	11.84
B <i>Discoaster lodoensis</i>	NP12	CNE4	M34/f0891	-2.87	M34/f0892	-3.99	-3.43
B <i>Sphenolithus radians</i> ¹	NP11		M34/f0894	-6.61	M34/f0895	-13.20	-9.91
B <i>Tribrachiatus orthostylus</i>		CNE3	M34/f0894	-6.61	M34/f0895	-13.20	-9.91
B <i>Rhomboaster bramlettei</i> ²	(in) NP10		M34/f0898	-15.25			

¹ Secondary marker for base of Zone NP11

² Base of studied section

Table 1: Summary of key bioevents identified at the mid-Waipara River section

observed at mid-Waipara in sample M34/f0898 (-15.25m), which indicates that the base of the studied section is within Zone NP10. The last occurrence (LO) of *Fasciculithus* has been reported as late NP9–early NP10 (Raffi *et al.*, 2005); therefore, the presence of *Rhomboaster* and *Fasciculithus* taxa in samples M34/f0898 (-15.25m) to M34/f0896 (-13.2m) confines this interval to Zone NP10. The assemblage is dominated by *Toweius callosus* with common *Coccolithus pelagicus*. Other taxa characteristic of this zone include few to rare *Discoaster lenticularis*, *Toweius eminens*, *T. pertusus*, *T. serotinus* and *T. tovae*. *Discoaster multiradiatus* and *D. salisburgensis* are common in the lowermost sample examined but are rarer towards the top of this interval.

4.2 *Discoaster binodosus* Zone (NP11)

Interval: -9.91 to -3.43m (2 samples)

Thickness: 6.48m

The base of Zone NP11 is defined by the last occurrence of *Tribrachiatus contortus* (Martini, 1971); however, this species is absent from the studied section. This is consistent with previous studies that document the *Rhomboaster* lineage as incomplete or absent in the New Zealand region (Edwards, 1971; Hollis *et al.*, 2015). Instead, we use the FO of *Sphenolithus radians*, which can be used as a secondary marker to define the base of Zone NP11 (Backman, 1986). At mid-Waipara, the FO of *S. radians* is found in sample M34/f0894 (-6.61m) and the base of Zone NP11 is placed at -9.91m, the midpoint

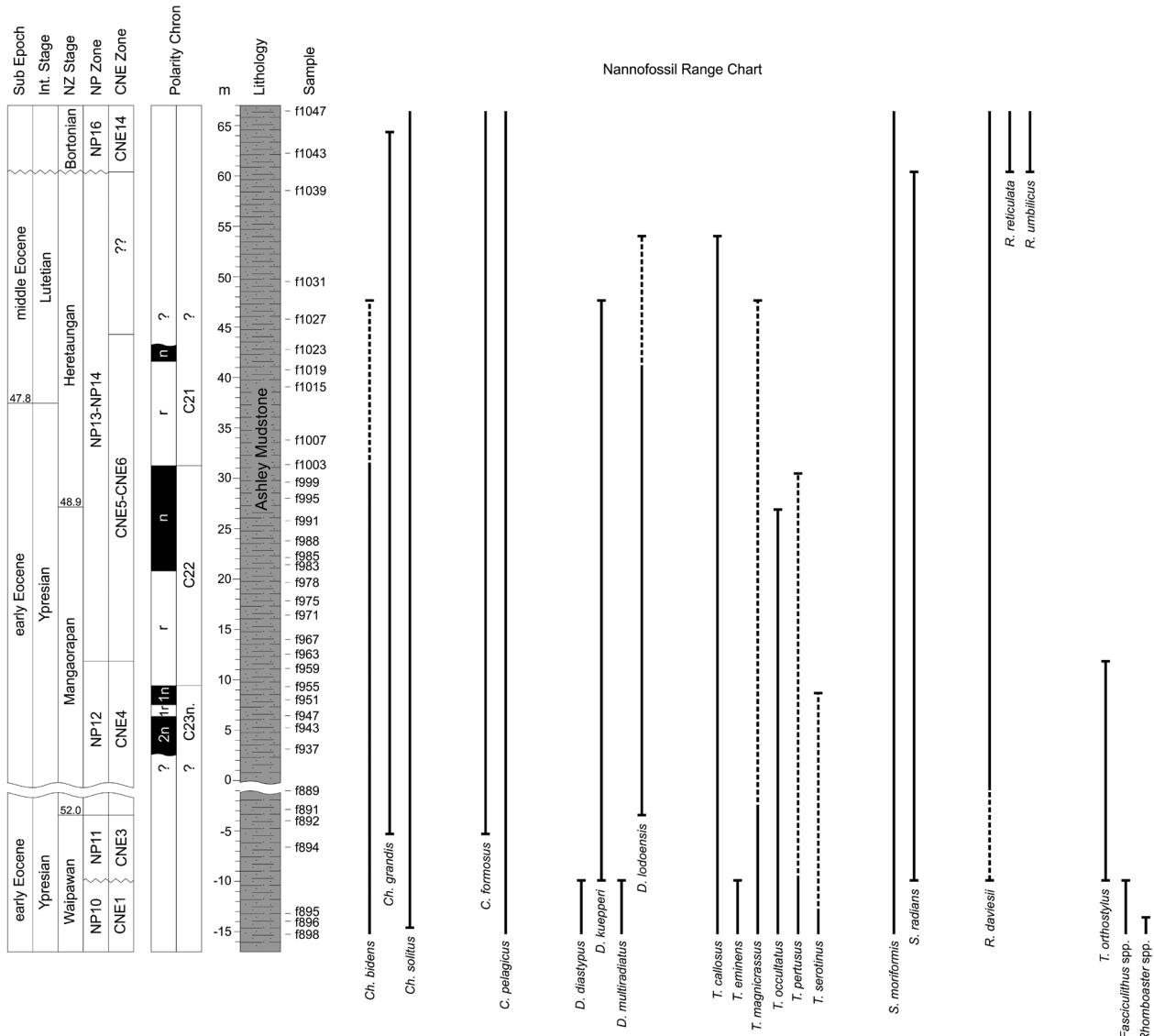


Figure 4: Stratigraphic section at mid-Waipara River, showing the distribution of key taxa through the section. Magnetostratigraphy and correlation to international and New Zealand (NZ) Stages is based on Dallanave *et al.*, (2016). Solid vertical lines indicate consistent occurrence, dashed vertical lines indicate intermittent occurrence and solid horizontal lines indicate limits of stratigraphic range. NP and CNE zonal boundaries are drawn at the midpoint between samples

between this sample (-6.61m) and the next deeper sample examined (-13.20m). Samples M34/f0894 (-6.61m) to M34/f0892 (-3.99m) are assigned to Zone NP11. The FO of *Tribrachiatus orthostylus*, which occurs in the upper part of Zone NP10, is found with *S. radians* at mid-Waipara, which provides evidence that the upper part of Zone NP10 is missing or not sampled. Sediments of this zone are dominated by abundant *C. pelagicus* and *T. callosus*, with few *Chiasmolithus bidens*, *Discoaster barbadiensis*, *D. kuepperi*, *Sphenolithus anarhopus*, *S. editus*, *S. moriformis* and *T. orthostylus*. Rare taxa include *Calcidiscus pacificanus*, *Cyclicargolithus parvus*, *Discoaster binodosus*, *Girgisia gammation*, *Lophodolithus nascens*, *Neochiastozygus imbriei* and *Reticulofenestra* spp.

4.3 *Tribrachiatus orthostylus* Zone (NP12)

Interval: -3.43 to 11.84m (8 samples)

Thickness: 15.27m

The FO of *Discoaster lodoensis* is used to mark the base of Zone NP12 (Martini, 1971), and is observed in sample M34/f0891 (-2.87m) in the mid-Waipara section. The base of Zone NP12 is placed at the midpoint between -3.99 and -2.87m (-3.43m), with samples from M34/f0891 (-2.87m) to M34/f0959 (11.13m) assigned to this zone. The assemblage is characterised by abundant *C. pelagicus* and *Toweius occultatus*, with common *D. kuepperi* and *Reticulofenestra samodurovii*. *Toweius callosus* is abundant in the lower part of Zone NP12 but becomes less so towards the top of the zone. Less common taxa include *Blackites* spp., *Chiasmolithus grandis*, *C. solitus*, *Coccolithus formosus*,

G. gammation, *Helicosphaera seminulum*, *Markalius inversus*, *Neococcolithes dubius*, *N. minutus*, *Orthozygus occultus*, *Pontosphaera exilis*, *P. pulchra*, *Reticulofenestra daviesii*, *R. dictyoda*, *R. minuta*, *R. producta*, *S. moriformis*, *S. radians*, *T. orthostylus* and *Zygrhablithus bijugatus bijugatus*.

4.4 *Discoaster lodoensis* Zone (NP13) and *Discoaster sublodoensis* Zone (NP14)

Interval: 11.84 to 60.41m (19 samples)

Thickness: 48.57m

The LO of *T. orthostylus* defines the base of Zone NP13 (Martini, 1971). The LO of *T. orthostylus* is observed in sample M34/f0959 (11.13m) at mid-Waipara and the base of Zone NP13 is placed at the midpoint between 11.13 and 12.55m. The FO of *Discoaster sublodoensis* is used to mark the base of Zone NP14; however, *D. sublodoensis* is very rare in the New Zealand region (Edwards, 1971; Edwards & Perch-Nielson, 1975) making it difficult to confidently define the NP13/NP14 boundary at mid-Waipara. Therefore, samples M34/f0963 (12.55m) to M34/f1039 (58.55m) are placed in a combined NP13–NP14 zone. Sediments of these zones contain abundant *C. pelagicus*, with common *R. dictyoda* and *R. samodurovii*. *Reticulofenestra wadeae* first occurs near the base of this combined zone and is present in few to common numbers throughout the rest of the samples assigned to this zone. *Discoaster kuepperi*, *T. callosus* and *T. occultatus* are generally more common in the lower part of the zone, with decreased abundances in the upper part. *Discoaster elegans* first occurs toward the top of this combined zone in rare numbers.

4.5 *Nannotetra fulgens* Zone (NP15)

Interval: absent

The FO of *Nannotetra fulgens* is used to mark the base of NP15 (Martini, 1971). The absence of this taxon, along with the absence of *Chiasmolithus gigas*, which defines the base of Subzone NP15b (Aubry, 1991), suggests that some, if not all, of Zone NP15 is missing at the mid-Waipara section. This zone encompasses the New Zealand Porangan Stage, which is commonly absent in the New Zealand region (Field *et al.*, 1989; King *et al.*, 1999; Hines *et al.*, 2013).

4.6 *Discoaster tanii nodifer* Zone (NP16)

Interval: 60.41 to 66.45m (top of studied section; 2 samples)

Thickness: 6.04m

The LO of *Blackites gladius* marks the base of Zone NP16 (Martini, 1971); however, this taxon is rarely found (Gradstein *et al.*, 2012) and, therefore, the LO of *Nannotetra alata/fulgens* is used instead (Backman, 1986; Expedition 320/321 Scientists, 2010). As this taxon is absent from mid-Waipara, we cannot identify the base of the zone. Instead, the presence of *Reticulofenestra umbilicus* (>14µm) and *Reticulofenestra reticulata* in samples M34/f1043 (62.26m) to M34/f1047 (66.45m) places them within Zone NP16. The FO of both of these taxa is observed in sample M34/f10403 (62.26m)

and suggests that the lower part of NP16 is missing at mid-Waipara given that they are both reasonably abundant in the lowermost sample in which they occur and *R. reticulata* evolved at least several hundred thousand years after *R. umbilicus* (Gradstein *et al.*, 2012; Agnini *et al.*, 2014). This zone is dominated by common to abundant *C. pelagicus* and common *Reticulofenestra* taxa. Other taxa characteristic of this zone include *Chiasmolithus expansus* and *Discoaster saipanensis*.

5. Discussion

5.1 Correlation with CNE zones

The biozonation scheme of Agnini *et al.* (2014) was developed for use at low to middle latitudes; however, it has recently been applied to a high latitude section in the southwest Pacific (Dallanave *et al.*, 2015). At mid-Waipara this biozonation scheme is difficult to apply continuously throughout the studied section because of the absence of key taxa. Here we summarise the CNE biozones recognised at mid-Waipara and correlate these with the biostratigraphic framework outlined in the results section.

The base of Zone CNE1 is marked by the LO of the *Fasciculithus richardii* group, with the first appearance of *Rhomboaster* spp. occurring just a short time later (Agnini *et al.*, 2014), making the base of CNE1 nearly equivalent to the base of NP10. The base of Zone CNE2 is defined by the top of *Fasciculithus tympaniformis*, which Agnini *et al.* (2014) indicate is the last member of *Fasciculithus* to go extinct, and this event correlates to lower Zone NP10. At mid-Waipara, the top of *Fasciculithus* occurs in the sample at -13.20m, suggesting that the entire Zone NP10 interval correlates with Zone CNE1 (Figure 4).

Zone CNE3 extends from base *T. orthostylus* to base common *D. lodoensis*, corresponding with upper Zone NP10 and Zone NP11. At mid-Waipara, the FO of *T. orthostylus* is found together with *S. radians*, which we use as a secondary marker for the base of Zone NP11, in sample M34/f0894 (-6.61m). Thus, the base of Zone CNE3 occurs in the same position as the base of Zone NP11 (Figure 4). This provides further evidence of an unconformity between Zones NP10 and NP11, with possibly all of Zone CNE2 and part of CNE3 missing. However, it should also be noted that a large sampling gap of ~6.60m occurs between these samples (Figure 4).

The base of common *D. lodoensis* defines the base of Zone CNE4, whereas the base of *D. lodoensis* marks the base of Zone NP12. At mid-Waipara, these events are defined together in sample M34/f0891 (-2.87m), with the zonal boundaries placed at the midpoint between -3.99m and -2.87m. The top of *T. orthostylus* defines the base of Zones CNE5 and NP13. The last occurrence of *T. orthostylus* is found in the sample at 11.13m and so the base of Zones CNE5/NP13 is defined at the midpoint between 11.13m and 12.55m. Thus, the interval between -3.43 and 11.84m is assigned to Zones CNE4/NP12 (Figure 4).

Zone CNE6 is defined as the interval from the base of common 5-rayed *D. sublodoensis* to the top of *D. lodoensis* and correlates to the lower part of Zone NP14. Since *D. sublodoensis* is rare in the New Zealand region (Edwards, 1971; Edwards & Perch-Nielson, 1975), the base of CNE6 cannot be identified at mid-Waipara. The last occurrence of *D. lodoensis* defines the base of Zone CNE7 and is found in the sample at 40.76m, with the zonal boundary placed at the midpoint between 40.76m and 43.00m. Since the base of Zone CNE6 cannot be identified, the interval from the top of *T. orthostylus* to the top of *D. lodoensis* is assigned to combined Zones CNE5–6. This interval is equivalent to most of the combined NP13–14 interval (Figure 4).

The markers for the bases of Zones CNE8 (base *N. cristata*), CNE9 (base *Nannotetraina alata* group), CNE10 (base *C. gigas*), CNE11 (base common *Sphenolithus cuniculus*) and CNE12 (top *C. gigas*) are absent at mid-Waipara and therefore these zones cannot be defined. These taxa occur in the New Zealand region but are generally not very abundant (e.g., *Nannotetraina*, [Edwards & Perch-Nielson, 1975; Hines *et al.*, 2013]; *C. gigas*, [Martini, 1986]). Thus, samples M34/f1023, f1027, f1031 and f1039 either cannot be assigned to a CNE zone or must be assigned to combined Zones CNE7–12 (Figure 4). These zones correspond to part of NP14, all of NP15, and the lower part of NP16. Given that the local Porangan Stage (which includes most of NP15 or CNE10–11) is commonly absent in the New Zealand region (Field *et al.*, 1989; King *et al.*, 1999; Hines *et al.*, 2013), it is likely that a hiatus that encompasses at least those zones (and the total range of *C. gigas*) is present in the section.

Reticulofenestra umbilica and *R. reticulata* occur together in sample M34/f1043 (62.26m). The former marks the base of Zone CNE13 and the latter the base of CNE14, indicating that CNE13 is missing or occurs within the 3.71m sampling gap. This interval correlates to part of lower Zone NP16.

5.2 Nannofossil bioevents in the southwest Pacific

5.2.1 FO *Sphenolithus radians*

In Gradstein *et al.* (2012), the FO of *S. radians* is dated to 54.17Ma, equivalent to the top of *T. contortus*, which marks the base of Zone NP11. Previous workers have suggested that the base of *S. radians* can be used to approximate the base of NP11 (Backman, 1986) and this event appears to be reliable in the New Zealand region. In addition to the mid-Waipara section, it is useful at DSDP Site 277 (Hollis *et al.*, 2015). Since *T. contortus* is rare or absent in this region (e.g., Edwards, 1971), whereas *S. radians* is common, the latter is very biostratigraphically useful.

5.2.2 FO *Girgisia gammation*

Agnini *et al.*, (2014) place the FO of *G. gammation* within Zone CNE3, slightly older than the base of common *D. lodoensis* (CNE3/CNE4 boundary). At mid-Waipara,

the FO of *G. gammation* occurs at the CNE2/CNE3 (NP10/ NP11) boundary and, given the sampling gap discussed previously, it is possible that it extends even lower in the section. This is supported by other observations from the southwest Pacific where it is found to occur sporadically in sediment assigned to Zone NP9 (Kulhanek *et al.*, 2015).

5.2.3 *Toweius/Reticulofenestra* turnover event

The abundance turnover between *Toweius* and *Reticulofenestra* in the early Eocene has been well documented in the Mediterranean (Agnini *et al.*, 2006) and the eastern Indian Ocean (Shamrock & Watkins, 2012). Agnini *et al.* (2014) describe this event as occurring in three phases across upper Zone CNE4 (NP12) to lower Zone CNE5 (NP13). This event follows a similar pattern at mid-Waipara with slight differences in the FO of *Reticulofenestra* and LO of *Toweius*. Agnini *et al.* (2014) indicate that the FO of *Reticulofenestra* occurs within Zone CNE4 (NP12) in low and mid-latitudes. However, *Reticulofenestra* is known to evolve earlier in the high southern latitudes (Schneider *et al.*, 2011) and data from the New Zealand region support this observation. Data from this study show that at least three species of *Reticulofenestra* first occur within Zone NP11 (Zone CNE3). This older FO of the *Reticulofenestra* group is also documented at DSDP Site 277, Campbell Plateau (Hollis *et al.*, 2015). The extinction of *Toweius* is reported to occur in Zone NP13 (Zone CNE5) (Agnini *et al.*, 2006; Agnini *et al.*, 2014); however, at mid-Waipara *Toweius* ranges well up into the combined NP13–14 zone (CNE5–6). This extended range of *Toweius* is also observed in the Tora section, Southwest Wairarapa, New Zealand (Hines *et al.*, 2013).

5.2.4 *Blackites*

At mid-Waipara, *Blackites* specimens are difficult to identify to species level and many of the counts of this genus are based on the observation of undifferentiated bases. This is consistent with previous studies in the New Zealand region where this genus occurs sporadically or in rare numbers. *Blackites* is observed very sporadically at DSDP Site 277 in mid- to upper NP11 (Hollis *et al.*, 2015), is absent from NP10 at Toi Flat, East Coast Basin (Kulhanek *et al.*, 2015) and is present in rare to few numbers at Tora, southeast Wairarapa (Hines *et al.*, 2013). In addition, Edwards & Perch-Nielsen (1975) report the continuous observation of *Rhabdolithus* sp. (=*Blackites*) in rare to few numbers through mid- to upper Eocene at DSDP Site 277.

5.2.5 *Ellipsolithus*

Ellipsolithus is observed through Zones NP10–11 in the southeastern Atlantic (Agnini *et al.*, 2007) and southeastern Maryland, USA (Self-Trail, 2011) in common to frequent numbers. At mid-Waipara this genus occurs rarely and sporadically, an observation that is consistent with other New Zealand sections. *Ellipsolithus* is consistently present at

DSDP Site 277 in rare numbers into NP11 (Hollis *et al.*, 2015), is very sporadic and rare at Tora (Hines *et al.*, 2013), and present in few numbers through NP10 at Toi Flat (Kulhanek *et al.*, 2015).

6. Conclusions

We examined the nannofossil assemblages in samples collected from ~85m of Ashley Mudstone exposed in the mid-Waipara River, northern Canterbury Basin, New Zealand. The studied section spans Zones NP10 to NP16 (lower to middle Eocene), with two hiatuses. The first encompasses upper NP10 to lowermost NP11 (equivalent to all of CNE2 and part of CNE3). The second includes at least NP15, and likely the upper part of NP14 and lowermost NP16. The FO of *S. radians* proves to be a reliable marker for the base of Zone NP11, as suggested by previous workers. Given the sporadic occurrence of *T. contortus* in the southwest Pacific, the common abundance of *S. radians* provides an extremely useful biostratigraphic marker for this region.

Several nannofossil bioevents in the southwest Pacific differ from those observed at lower latitude sites. The *Toweius/Reticulofenestra* turnover event documented in the Mediterranean and eastern Indian Ocean (Agnini *et al.*, 2006; Shamrock & Watkins, 2012) is recognised in the mid-Waipara section; however, the FO of *Reticulofenestra* occurs much earlier (NP11) and the LO of *Toweius* occurs much later (NP13–14) than is observed at the lower latitude sites. In addition, taxa that are well represented in low latitude sections (e.g. *Blackites*, *Ellipsolithus*) appear more sporadically or in rarer numbers at mid-Waipara and this is consistent with observations from other sites in the New Zealand region.

7. Systematic Paleontology

Full references for taxa can be found in Perch-Nielsen (1985) and Bown (1998, 2005).

7.1 Placolith coccoliths

Order ISOCHRYSIDALES Pascher, 1910

Family PRINSIACEAE Hay & Mohler, 1967 emend.
Young & Bown, 1997

Girgisia gammation (Bramlette & Sullivan, 1961)

Varol, 1989

Pl.1, figs 28–30

Toweius callosus Perch-Nielsen, 1971

Pl.1, figs 1–4

Remarks: In the lower part of the section, outer shields appear to have been lost and only the bright central tube remains.

Toweius eminens (Bramlette & Sullivan, 1961)

Gartner, 1971

Pl.1, figs 5–7

Toweius? magnicrassus (Bukry, 1971) Romein, 1979

Pl.1, figs 8–11

Remarks: This species is fairly consistently present in low numbers through NP10 to NP12 at mid-Waipara, a range that is similar to that seen at South Dover Bridge, Maryland, USA (Self-Trail, 2011).

Toweius occultatus (Locker, 1967)

Perch-Nielsen, 1971

Pl.1, figs 12–14

Toweius pertusus (Sullivan, 1965) Romein, 1979

Pl.1, figs 15–16

Toweius rotundus Perch-Nielsen in Perch-Nielsen *et al.*,

1978

Pl.1, figs 17–18

Toweius serotinus Bybell & Self-Trail, 1995

Pl.1, figs 19–20

Toweius tovae Perch-Nielsen, 1971

Pl.1, figs 21–23

Toweius sp. 1

Pl.1, fig. 24

Remarks: Medium, subcircular placolith with a bright central area spanned by a visible net. Possible variation of *Toweius* sp. 1 of Bown (2005).

Toweius sp. 2

Pl.1, figs 25–27

Remarks: Small to medium, elliptical to subcircular placoliths with a wide central area spanned by a visible plate. Similar to *Toweius* sp. 2 of Bown (2005).

Family NOELAERHABDACEAE Jerkovic, 1970
emend. Young & Bown, 1997

Cyclicargolithus floridanus (Roth & Hay in Hay *et al.*, 1967) Bukry, 1971
Pl.3, figs 1–2

Cyclicargolithus luminis (Sullivan, 1965) Bukry, 1971
Pl.3, fig. 3

Cyclicargolithus parvus Shamrock & Watkins, 2012
Pl.3, figs 4–5

Reticulofenestra bisecta (Hay *et al.*, 1966) Roth, 1970
Pl.2, figs 5–7

Reticulofenestra circus de Kaenel & Villa, 1996
Pl.2, figs 17–18

Remarks: Medium to large, subcircular reticulofenestrids with narrow central area. **Differentiation:** Similar to *Reticulofenestra wadeae* Bown 2005 but the central area is narrower.

Reticulofenestra clatrata Müller, 1970

Pl.2, figs 21–22

Reticulofenestra daviesii (Haq, 1968) Haq, 1971
Pl.2, figs 23–24

Reticulofenestra dictyoda (Deflandre in Deflandre & Fert, 1954) Stradner in Stradner & Edwards, 1968
Pl.2, fig. 14

Remarks: Described by some workers as elliptical with an open central area. Name used here for small to very large (3–14 µm) elliptical reticulofenestrids with a narrow central region.

- Reticulofenestra filewiczii* (Wise & Wiegand in Wise, 1983) Dunkley Jones *et al.*, 2009
Pl.2, figs 25–26
- Reticulofenestra hampdenensis* Edwards, 1973
Pl.2, figs 19–20
- Reticulofenestra lockeri* Müller, 1970
Pl.2, figs 27–28
- Reticulofenestra minuta* Roth, 1970
Pl.2, figs 8–9
- Reticulofenestra producta* (Kamptner, 1963)
Backman, 1980
Pl.2, figs 1–2
- Reticulofenestra reticulata* (Gartner & Smith, 1967)
Roth & Thierstein, 1972
Pl.2, figs 29–30
- Reticulofenestra samodurovii* (Hay *et al.* 1966)
Roth, 1970
Pl.2, figs 10–11
- Reticulofenestra scrippsae* Bukry & Percival, 1971
Pl.2, figs 3–4
- Reticulofenestra umbilicus* (Levin, 1965) Martini & Ritkowski, 1968
Pl.2, figs 12–13
- Reticulofenestra wadeae* Bown, 2005
Pl.2, figs 15–16

Order COCCOSPHAERALES Haeckel, 1894 emend.

Young & Bown, 1997

Family COCOLITHACEAE Poche, 1913 emend.
Young & Bown, 1997

- Campylosphaera dela* (Bramlette & Sullivan, 1961)
Hay & Mohler, 1967
Pl.3, fig. 6

- Chiasmolithus bidens* (Bramlette & Sullivan, 1961)
Hay & Mohler, 1967
Pl.3, figs 7–8

- Chiasmolithus californicus* (Bramlette & Sullivan, 1961)
Hay & Mohler, 1967
Pl.3, figs 9–10

- Chiasmolithus expansus* (Bramlette & Sullivan, 1961)
Gartner, 1970
Pl.3, fig. 11

- Chiasmolithus grandis* Bramlette & Riedel, 1954
Pl.3, figs 12–14

- Chiasmolithus mediuss* Perch-Nielsen, 1971
Pl.3, figs 15–16

- Chiasmolithus modestus* Perch-Nielsen, 1971
Pl.3, figs 17–18

- Chiasmolithus nitidus* Perch-Nielsen, 1971
Pl.3, figs 19–21

Chiasmolithus solitus (Bramlette & Sullivan, 1961)

Locker, 1968

Pl.3, figs 22–23

Clausicoccus fenestratus (Deflandre & Fert, 1954)

Prins, 1979

Pl.3, figs 24–25

Clausicoccus subdistichus (Roth & Hay in Hay *et al.*, 1967) Prins, 1979

Pl.3, figs 26–27

Clausicoccus vanheckiae (Perch-Nielsen, 1986)

de Kaenel & Villa, 1996

Pl.3, figs 28–29

Coccolithus foraminis Bown, 2005

Pl.4, figs 1–2

Remarks: Bown (2005) reported *C. foraminis* from Zone NP10 in Tanzania. Here we document an expanded stratigraphic range, with the taxon present in rare numbers in a single sample assigned to Zone NP12. It is more consistently present in rare to few numbers in Zones NP13–14 and NP16.

Coccolithus formosus (Kamptner, 1963) Wise, 1973

Pl.4, figs 3–4

Coccolithus latus Bown, 2005

Pl.4, figs 5–6

Coccolithus pelagicus (Wallich, 1977) Schiller, 1930

Pl.4, figs 7–8

Family CALCIDISCACEAE Young & Bown, 1997

Calcidiscus bicircus Bown, 2005

Pl.4, figs 9–13

Remarks: Medium to large (6–9 µm) subcircular placolith with a non-birefringent distal shield and a narrow to closed central region. There is a great deal of variation seen in the central region across specimens, but generally they show a narrow, bright tube cycle.

Calcidiscus pacificanus (Bukry, 1971) Varol, 1989

Pl.4, figs 14–16

Remarks: Medium to large (6–9 µm) subcircular placolith with a closed centre.

Calcidiscus protoannulus (Gartner, 1971) Loeblich &

Tappan, 1978

Pl.4, figs 17–18

Remarks: Young & Bown (2014) recombined this taxon with *Umbilicosphaera*, proposing that Paleogene species with clearly open central areas be placed in this genus, whereas those with closed central areas be assigned to *Calcidiscus*. They added that those with narrow central openings may be ambiguous and proposed a criterion of a central area opening >25% of the distal shield diameter to distinguish *Umbilicosphaera* from *Calcidiscus*. Given that they indicated that this division is artificial and additional work needs to be done, we retain *Calcidiscus* as the genus at this time.

Coronocyclus bramlettei (Hay & Towe, 1962)
Bown, 2005
Pl.4, figs 19–21

7.1.1 Placolith coccoliths incertae sedis

- Ellipsolithus bollii* Perch-Nielsen, 1977
Pl.4, fig 22–23
- Ellipsolithus distichus* (Bramlette & Sullivan, 1961)
Sullivan, 1964
Pl.4, figs 24–25
- Markalius apertus* Perch-Nielsen, 1979
Pl.4, figs 26–27
- Markalius inversus* (Deflandre in Deflandre & Fert, 1954)
Bramlette & Martini, 1964
Pl.4, figs 28–30
- Tetralithoides symeonidesii* Theodoridis, 1984
Pl.5, figs 1–2

7.2 Murolith coccoliths

7.2.1 Mesozoic survivor muroliths

Order EIFFELLITHALES Rood *et al.*, 1971
Family CHIASTOZYGACEAE Rood *et al.*, 1973

Jakubowskia leoniae Varol, 1989
Pl.5, figs 3–5

7.2.2 Cenozoic muroliths

Order ZYGODISCALES Young & Bown, 1997
Family HELICOSPHAERACEAE Black, 1971

Helicosphaera bramlettei (Muller, 1970) Jafar & Martini,
1975
Pl.5, figs 6–7

Helicosphaera seminulum Bramlette & Sullivan, 1961
Pl.5, figs 8–10

Remarks: This taxon is continuously present from NP12 to upper NP13/14 at mid-Waipara. This is consistent with observations from the South Dover Bridge Core, Maryland, USA (Self-Trail, 2011) where it also makes its first appearance in NP12. Further work needs to be done to determine if this taxon may be biostratigraphically useful.

Family PONTOSPHAERACEAE Lemmermann, 1908

Genus *Pontosphaera* Lohmann, 1902

Used to classify all pontosphaerid coccoliths, including species that are classified as *Transversopontis* by some authors.

Pontosphaera distincta (Bramlette & Sullivan, 1961)
Roth & Thierstein, 1972
Pl.5, figs 11–12

- Pontosphaera duocava* (Bramlette & Sullivan, 1961)
Romein, 1979
Pl.5, figs 13–14
- Pontosphaera exilis* (Bramlette & Sullivan, 1961)
Pl.5, figs 15–17
- Pontosphaera pax* Stradner & Seifert, 1980
- Pontosphaera pectinata* (Bramlette & Sullivan, 1961)
Sherwood 1974
Pl.5, figs 18–19
- Pontosphaera plana* (Bramlette & Sullivan, 1961) Haq,
1971
Pl.5, figs 20–21
- Pontosphaera pulcheroides* (Sullivan, 1964) Romein,
1979
Pl.5, figs 22–23
- Pontosphaera pulchra* (Deflandre in Deflandre & Fert,
1954) Romein, 1979
Pl.5, figs 24–25
- Pontosphaera punctosa* (Bramlette & Sullivan, 1961)
Perch-Nielsen, 1984
Pl.5, fig. 26
- Pontosphaera versa* (Bramlette & Sullivan, 1961)
Sherwood, 1974
Pl.5, figs 27–29
- Pontosphaera* sp.
Pl.5, fig. 30

Family ZYGODISCACEAE Hay & Mohler, 1967

Lophodolithus nascens Bramlette & Sullivan,
1961
Pl.6, figs 1–3

Neochiastozygus distentus (Bramlette & Sullivan, 1961)
Perch-Nielsen, 1971
Pl.6, fig. 4

Neochiastozygus imbriei Haq & Lohmann, 1975
Pl.6, figs 5–7

Neococcilithes dubius (Deflandre in Deflandre & Fert,
1954) Black, 1967
Pl.6, figs 8–10

Neococcilithes minutus (Perch-Nielsen, 1967)
Perch-Nielsen, 1971
Pl.6, figs 11–13

Neococcilithes protonus (Bramlette & Sullivan, 1961)
Black, 1967
Pl.6, figs 14–16

7.3 Holococciliths

Family CALYPTROSPHAERACEAE Boudreux &
Hay, 1967

Orthozygus occultus Dunkley Jones *et al.*, 2009
Pl.6, figs 17–22

Remarks: Dunkley Jones *et al.* (2009) described this taxon from the upper Eocene (NP18–20) of Tanzania. This

taxon is found in much older sediment at mid-Waipara (NP12) than previously reported.

S. cf. Semihololithus biskayae Perch-Nielsen, 1971
Pl.6, fig. 23

Zygrhablithus bijugatus bijugatus (Deflandre in Deflandre & Fert, 1954) Deflandre, 1959
Pl.6, figs 24–27

Zygrhablithus bijugatus cornutus Bown, 2005

7.4 Nannoliths

Family BRAARUDOSPHAERACEAE Deflandre, 1947

Micrantholithus lateralis Sullivan, 1965
Pl.6, figs 28–30

Family DISCOASTERACEAE Tan, 1927

Discoaster barbadiensis Tan, 1927
Pl.7, figs 1–6

Discoaster binodosus Martini, 1958
Pl.7, figs 7–10

Discoaster cruciformis Martini, 1958
Pl.7, figs 11–12

Discoaster diastypus Bramlette & Sullivan, 1961
Pl.7, figs 13–16

Remarks: Used here for medium to large rosette-shaped discoasters with prominent bosses on both sides and short rays that typically curve.

Discoaster distinctus Martini, 1958
Pl.7, figs 17–20

Discoaster elegans Bramlette & Sullivan, 1961
Pl. 8, figs 1–4

Remarks: Present in rare abundances in the upper part of the combined NP13–14 interval and in the lowermost NP16 sample. *D. elegans* is easily distinguished from *D. barbadiensis* by the presence of concentric lines.

Discoaster kuepperi Stradner, 1959
Pl.8, figs 5–8

Discoaster lenticularis Bramlette & Sullivan, 1961
Pl.8, figs 9–12

Discoaster lodoensis Bramlette & Riedel, 1954
Pl.8, figs 13–20

Discoaster mediosus Bramlette & Sullivan, 1961
Pl.9, figs 1–8

Remarks: Discoaster species with 8–10 arms with rounded to pointed tips. Bown (2005) differentiates *D. mediosus* from *D. binodosus* based on the number of arms; however, we do not make that distinction. Instead, we differentiate between the two species based on the presence or absence of prominent lateral nodes.

Discoaster multiradiatus Bramlette & Riedel, 1954
Pl.9, figs 9–12

Discoaster nodifer (Bramlette & Riedel, 1954) Bukry, 1973
Pl.9, figs 13–16

Discoaster saipanensis Bramlette & Riedel, 1954
Pl.9, figs 17–20

Remarks: Perch-Nielsen (1985) indicated sporadic occurrences of this species in NP15, with it more consistently present in NP16. More recently this taxon has been reported from upper NP14 (Self-Trail, 2011). The absence of this taxon at mid-Waipara below the NP16 section may be due to part of Zone NP14 and NP15 being missing.

Discoaster salisburgensis Stradner, 1961

Pl.10, figs 1–4

Discoaster septemradiatus (Klumpp, 1953) Martini 1958
Pl.10, figs 5–8

Discoaster splendidus Martini, 1960
Pl.10, figs 9–10

Discoaster sublodoensis? Bramlette & Sullivan, 1961

Discoaster tanii Bramlette & Riedel, 1954
Pl.10, figs 11–14

Discoaster wemmelensis Achuthan & Stradner, 1969
Pl.10, figs 15–20

Family FASCICULITHACEAE Hay & Mohler, 1967

Fasciculithus bobii Perch-Nielsen, 1971
Pl.11, fig. 1

Fasciculithus involutus Bramlette & Sullivan, 1961
Pl.11, figs 2–5

Fasciculithus thomasii Perch-Nielsen, 1971
Pl.11, fig. 6

Fasciculithus tympaniformis Hay & Mohler in Hay et al., 1967
Pl.11, figs 7–8

Family RHOMBOASTERACEAE Bown, 2005

Rhomboaster bramlettei (Brönnimann & Stradner, 1960)
Bybell & Self-Trail, 1995

Pl.11, figs 9–13

Rhomboaster cuspis Bramlette & Sullivan, 1961
Pl.11, figs 14–17

Tribrachiatus orthostylus Shamrai, 1963
Pl.11, figs 18–19

Tribrachiatus morphotype A
Pl.11, fig. 20

Remarks: Nannolith with two strongly curved arms of equal length and a third, shorter arm that extends perpendicular to the other arms. Generally shows higher order birefringence than *T. orthostylus*.

Tribrachiatus morphotype B
Pl.11, figs 21–22

Remarks: Nannolith with two arms of equal length that are flattened on upper and lower sides and a third short arm. Well preserved specimens exhibit claw-like structures

at the tips of the longer arms. A “vault” is noticeable on the underside of the nannolith.

Family SPHENOLITHACEAE Deflandre, 1952

- Sphenolithus anarrhopus* Bukry & Bramlette, 1969
- Sphenolithus editus* Perch-Nielsen in Perch-Nielsen *et al.*, 1978
Pl.11, figs 23–24
- Sphenolithus moriformis* (Brönnimann & Stradner, 1960)
Bramlette & Wilcoxon, 1967
Pl.11, figs 25–26
- Sphenolithus radians* Deflandre in Grassé, 1952
Pl.11, figs 27–28
- Sphenolithus spiniger* Bukry, 1971
Pl.11, figs 29–30

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Plate 1
Prinsiaceae: *Toweius*, *Grgisia*

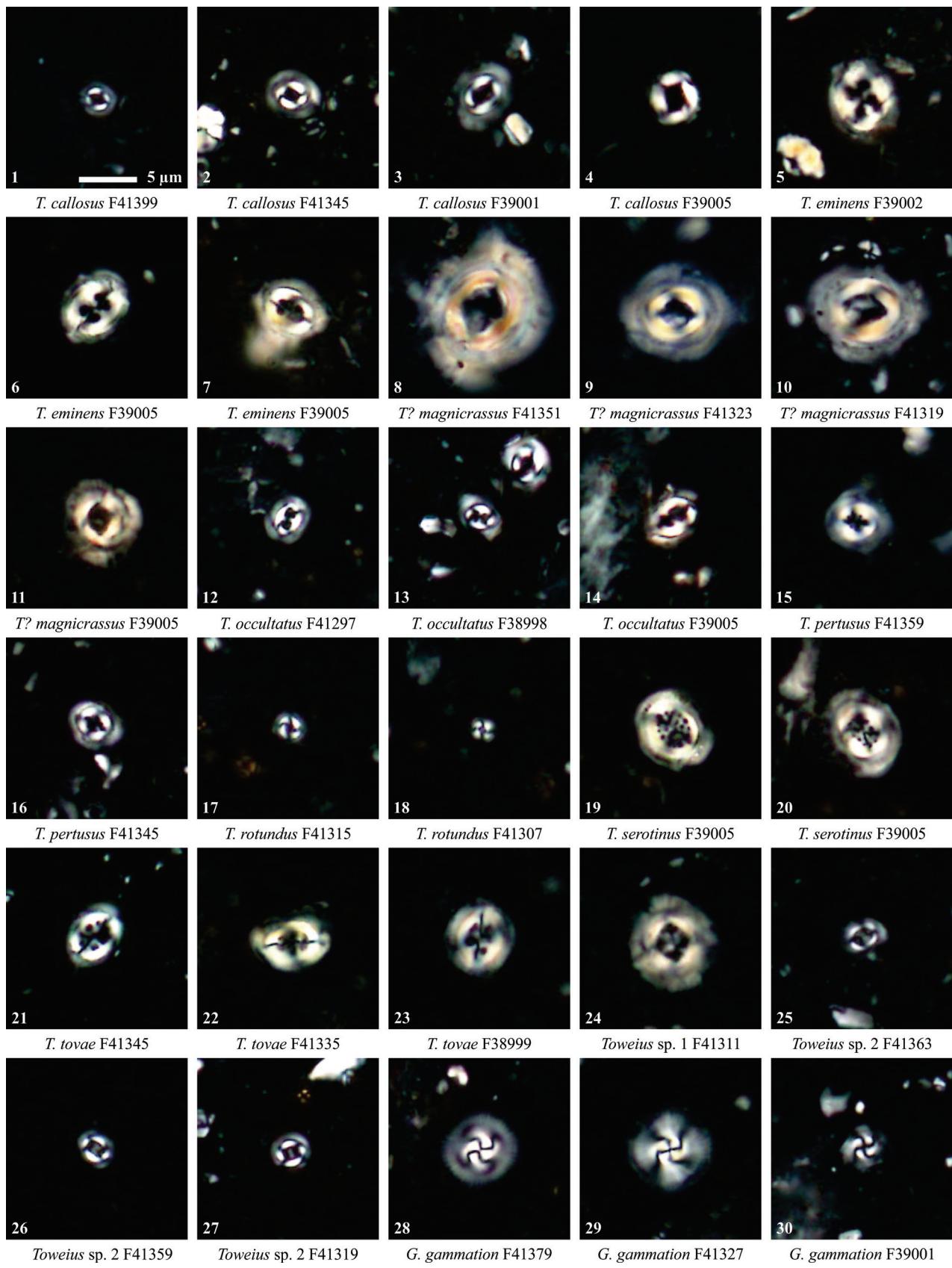


Plate 2
Noelaerhabdaceae: *Reticulofenestra*

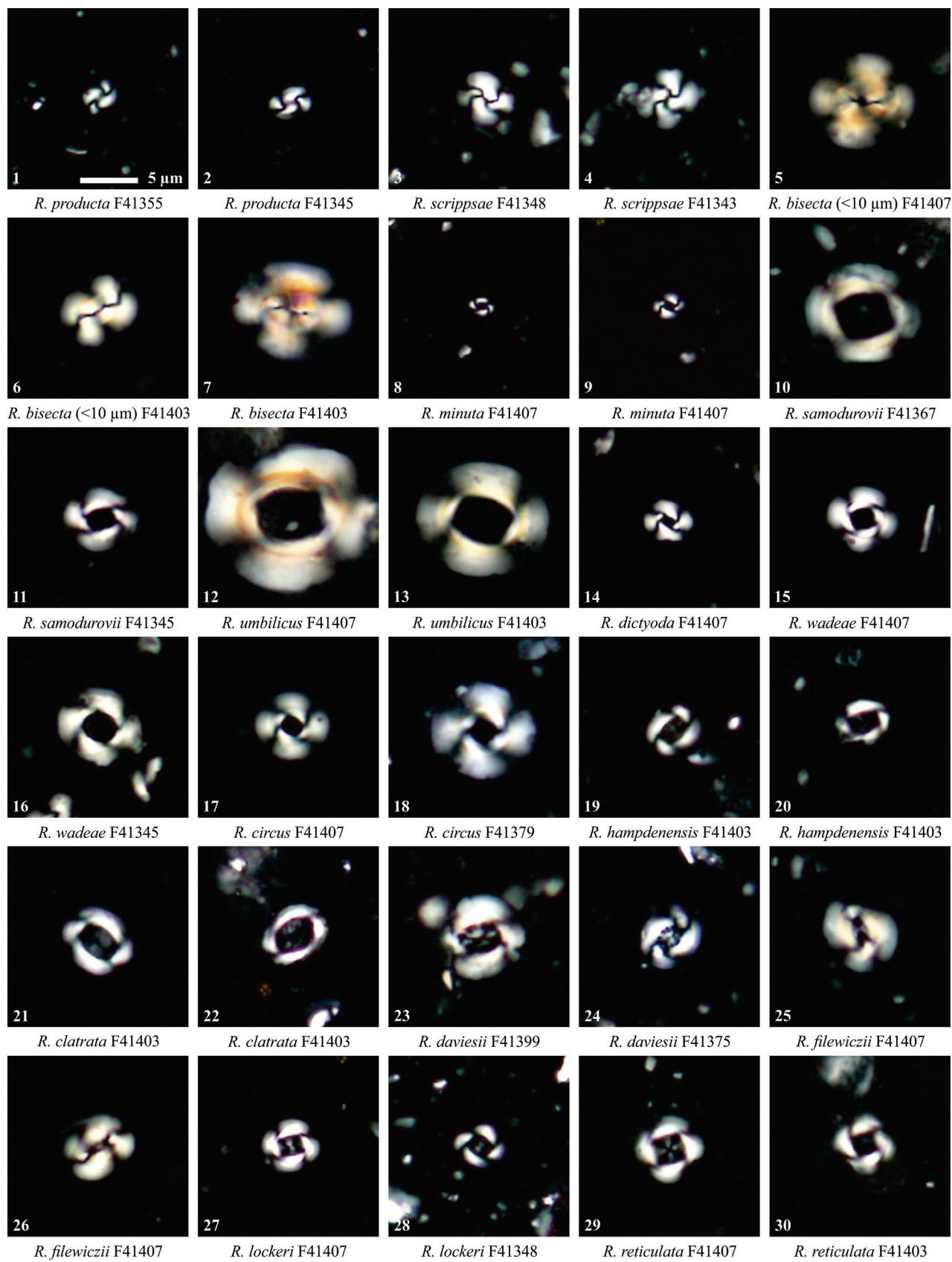


Plate 3
Noelaerhabdaceae: *Cyclcargolithus*; Coccolithaceae:
Campylosphaera*, *Chiasmolithus*, *Clausicoccus

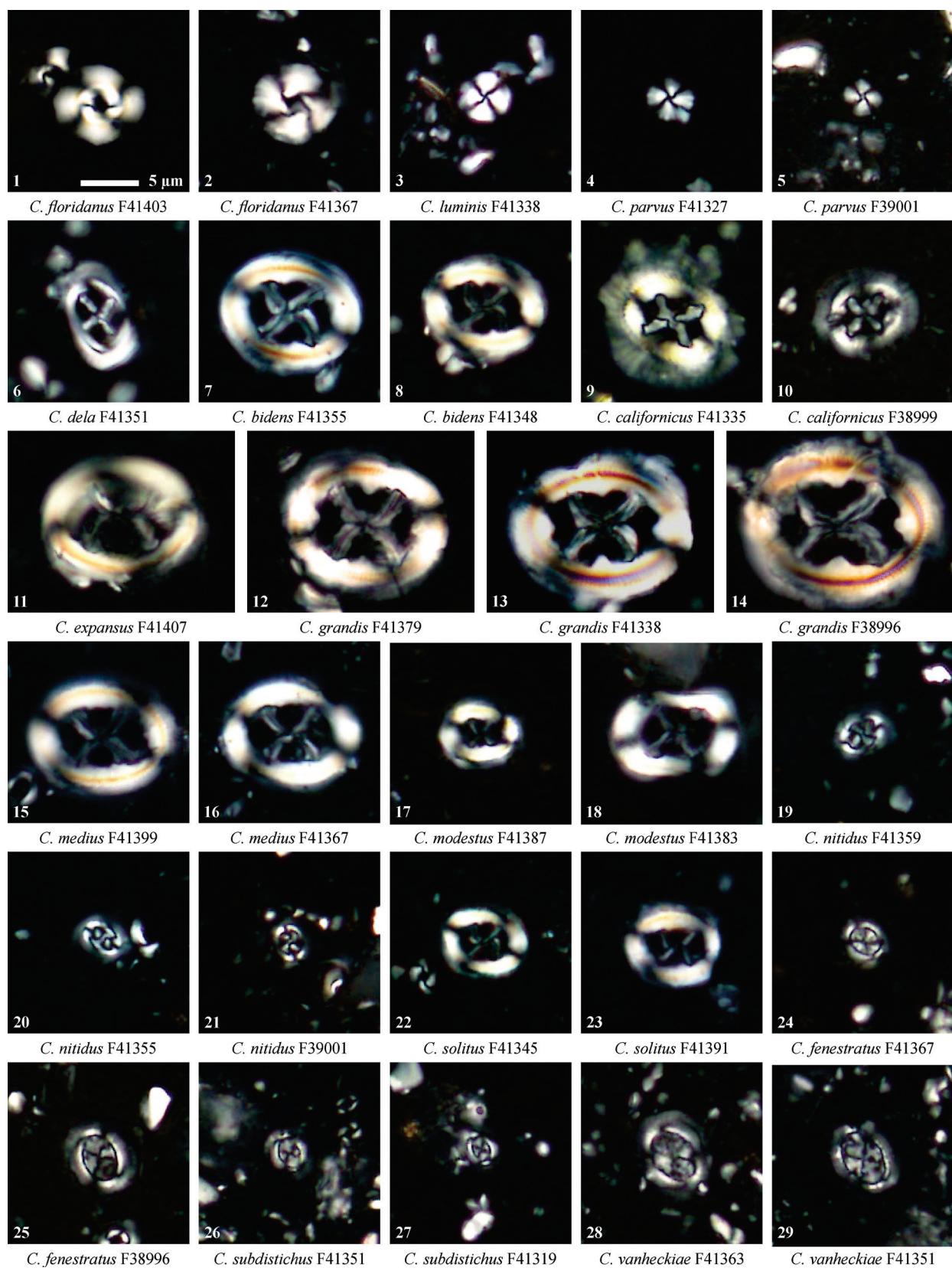


Plate 4

**Coccolithaceae: *Coccolithus*; Calcidiscaceae: *Calcidiscus*,
Coronocyclus; Incertae sedis placoliths: *Ellipsolithus*, *Markalius***

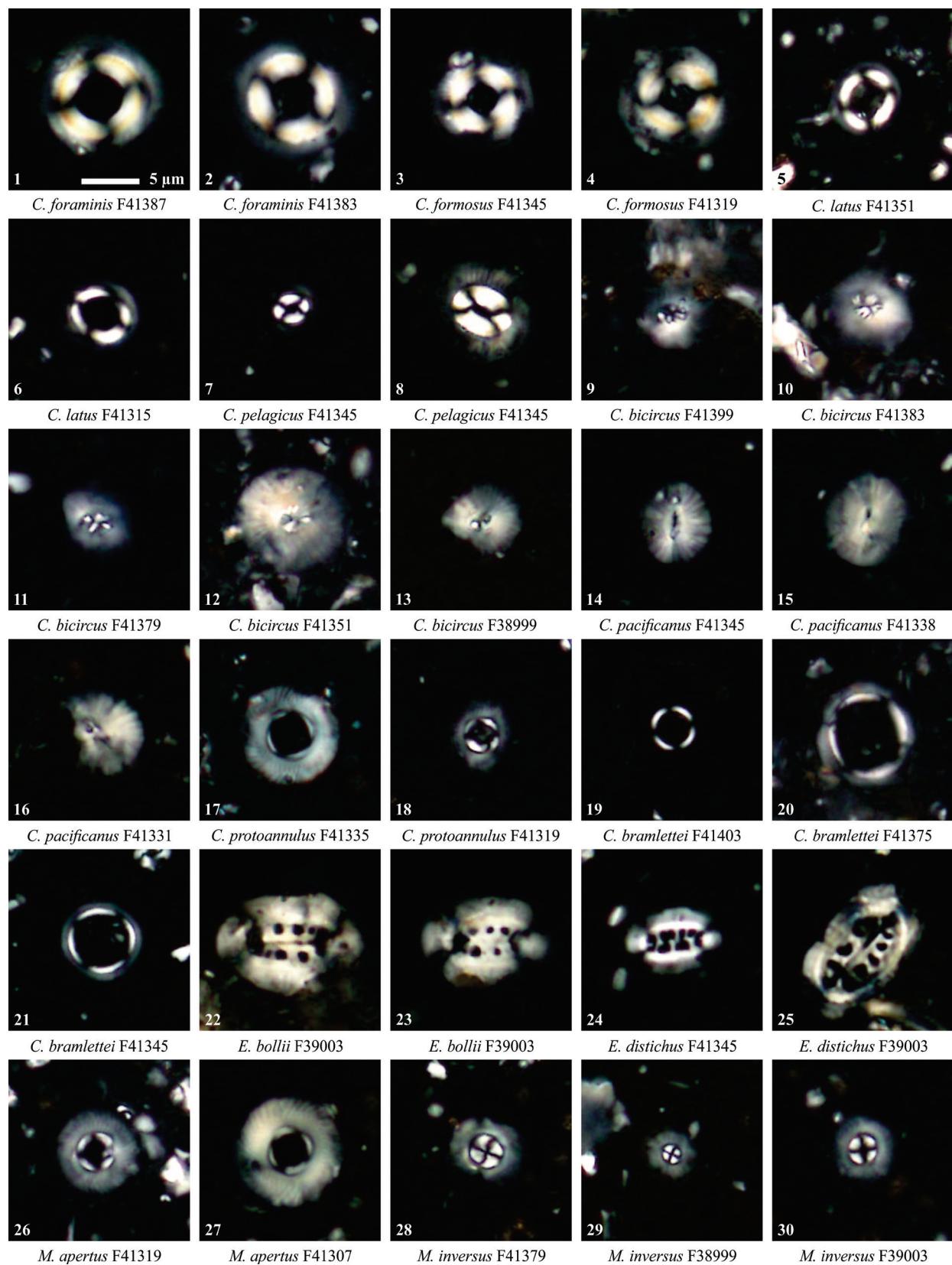


Plate 5

***Incertae sedis placoliths: Tetralithoides; Chiastozygaceae:
Jakubowskia; Helicosphaeraceae: Helicosphaera; Pontosphaeraceae:
Pontosphaera***

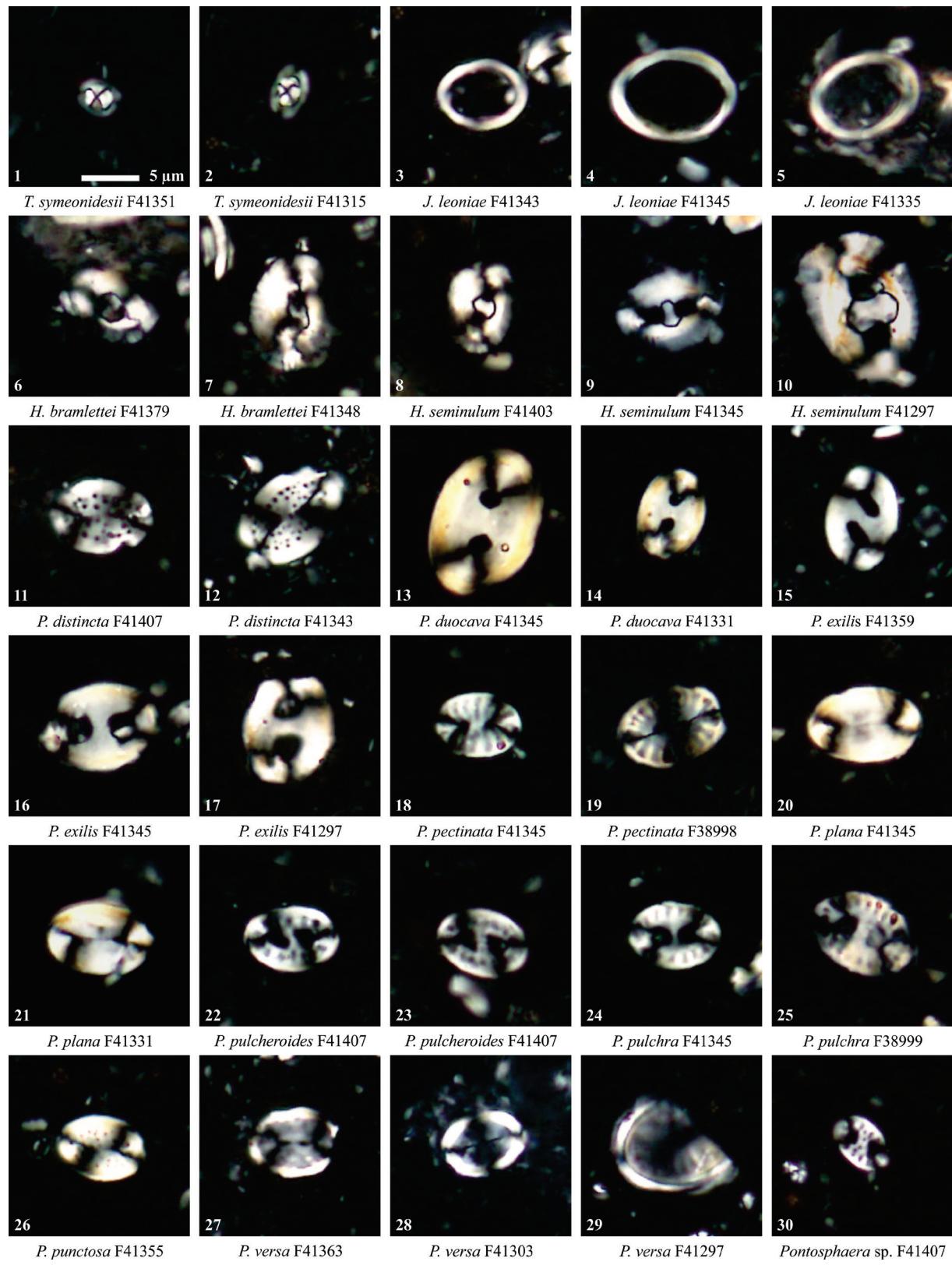


Plate 6

Zygodiscaceae: *Lophodolithus*, *Neochiastozygus*, *Neococcocoliths*;
Holococcocoliths: *Orthozygus*, *Semihololithus*, *Zygrhablithus*;
Nannoliths: *Braarudosphaeraceae*

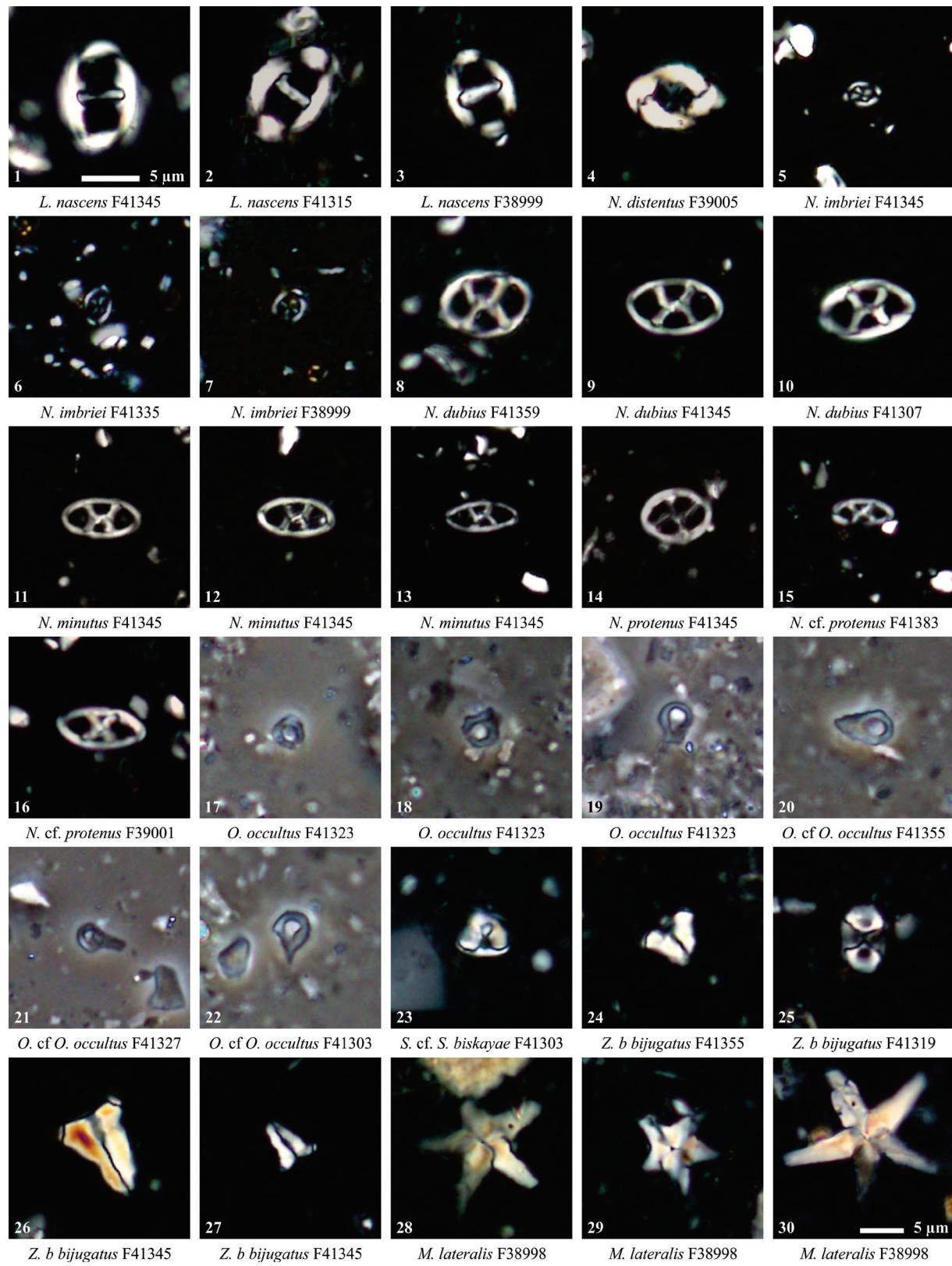


Plate 7

Nannoliths: Discoasteraceae

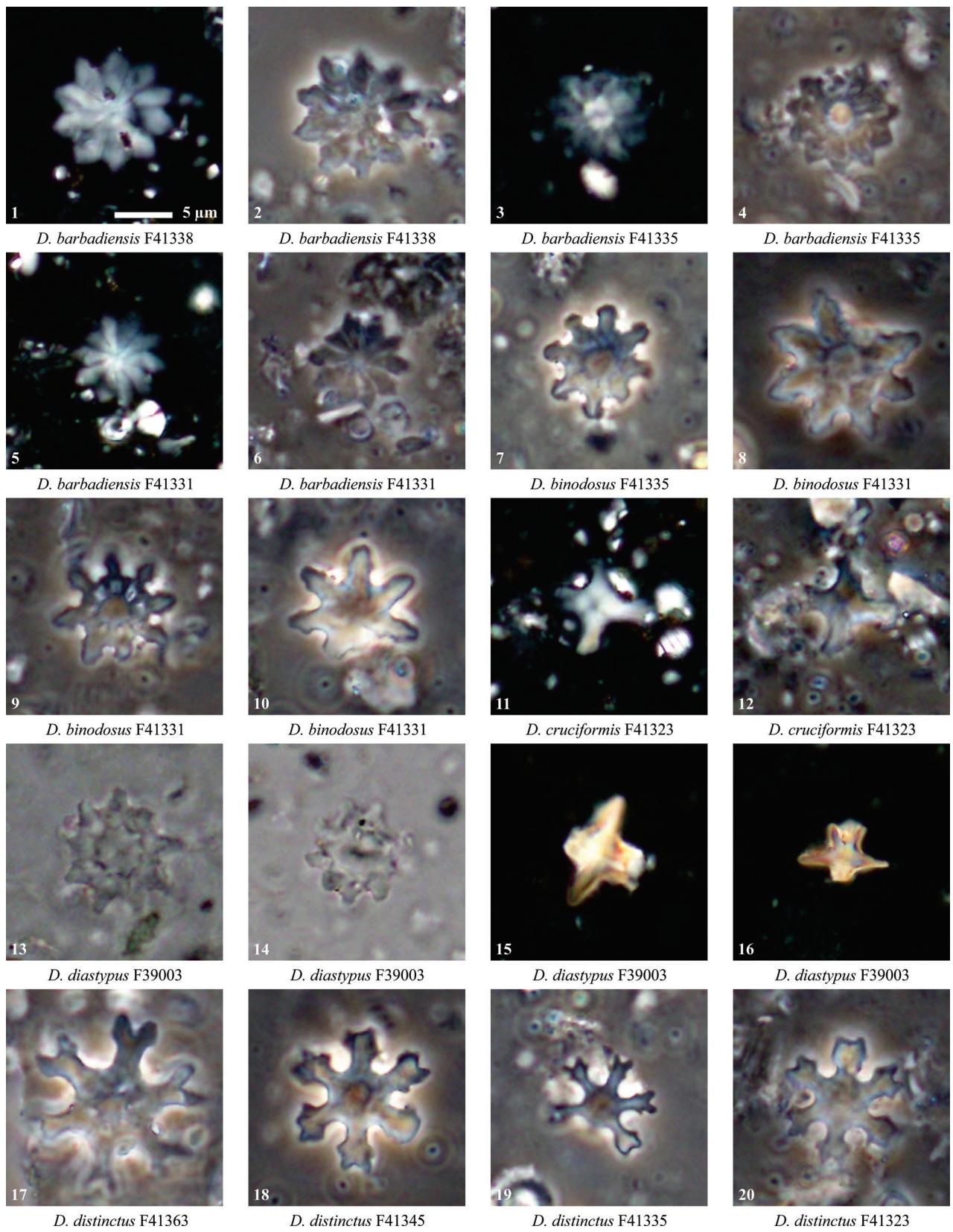


Plate 8

Nannoliths: Discoasteraceae

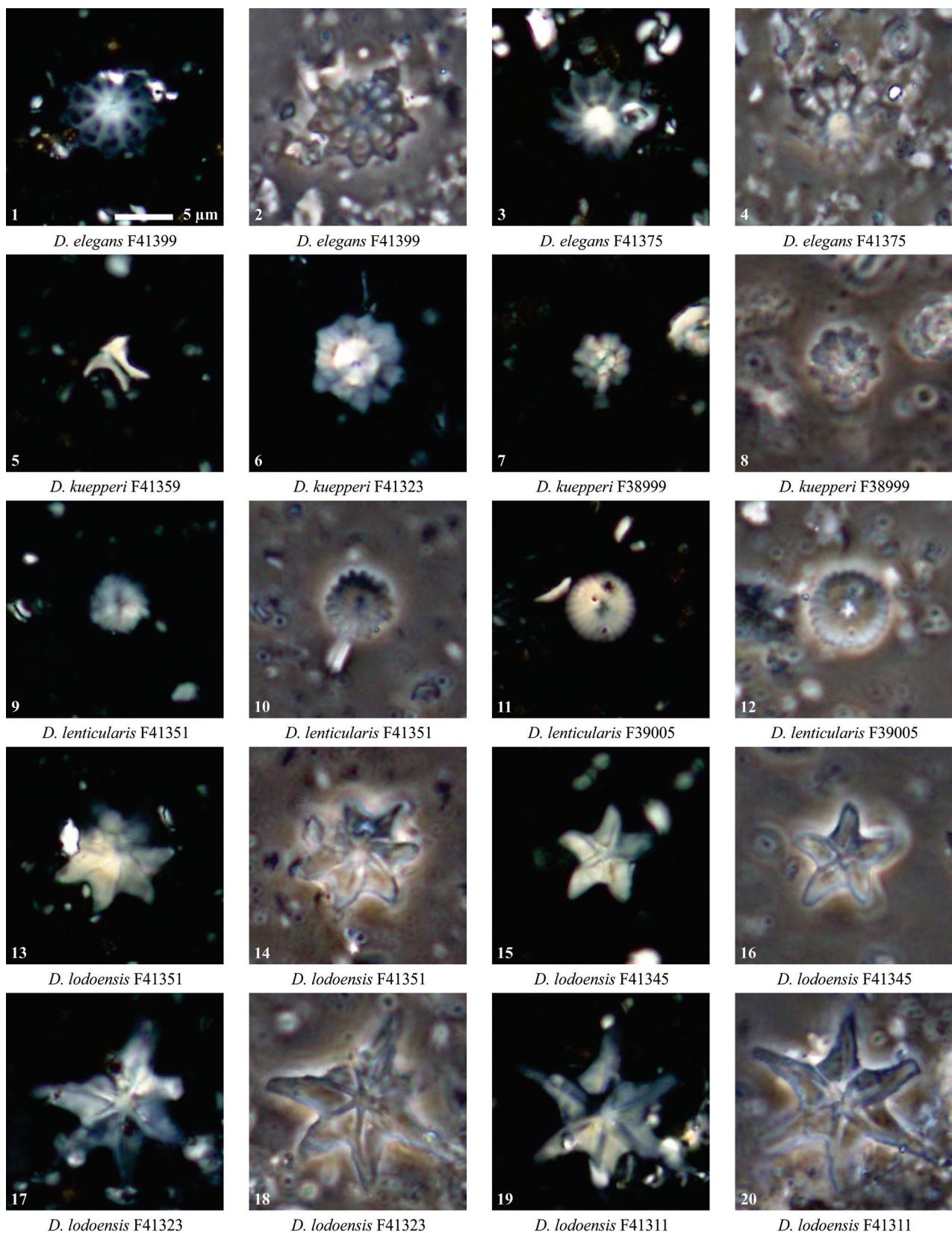


Plate 9

Nannoliths: Discoasteraceae

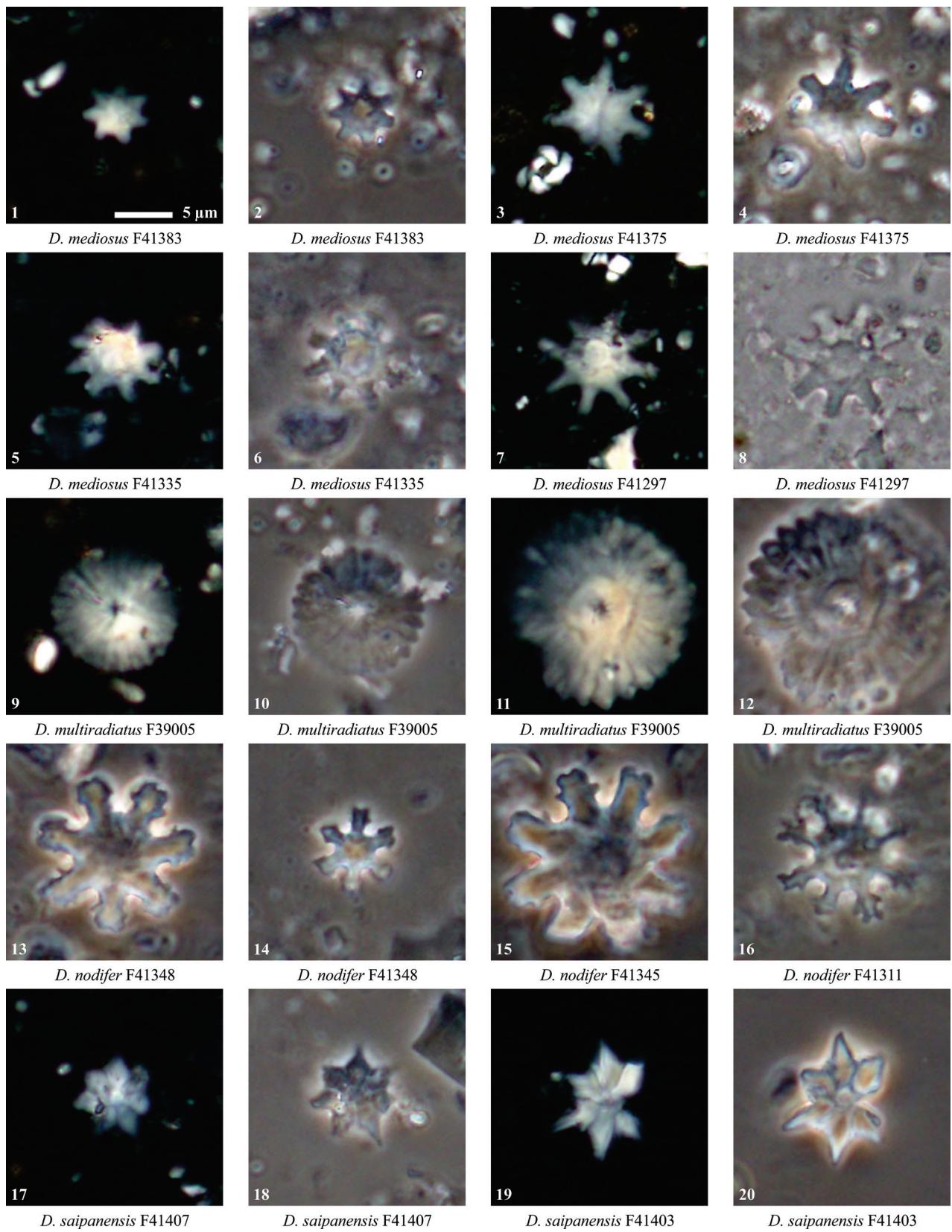


Plate 10
Nannoliths: Discoasteraceae

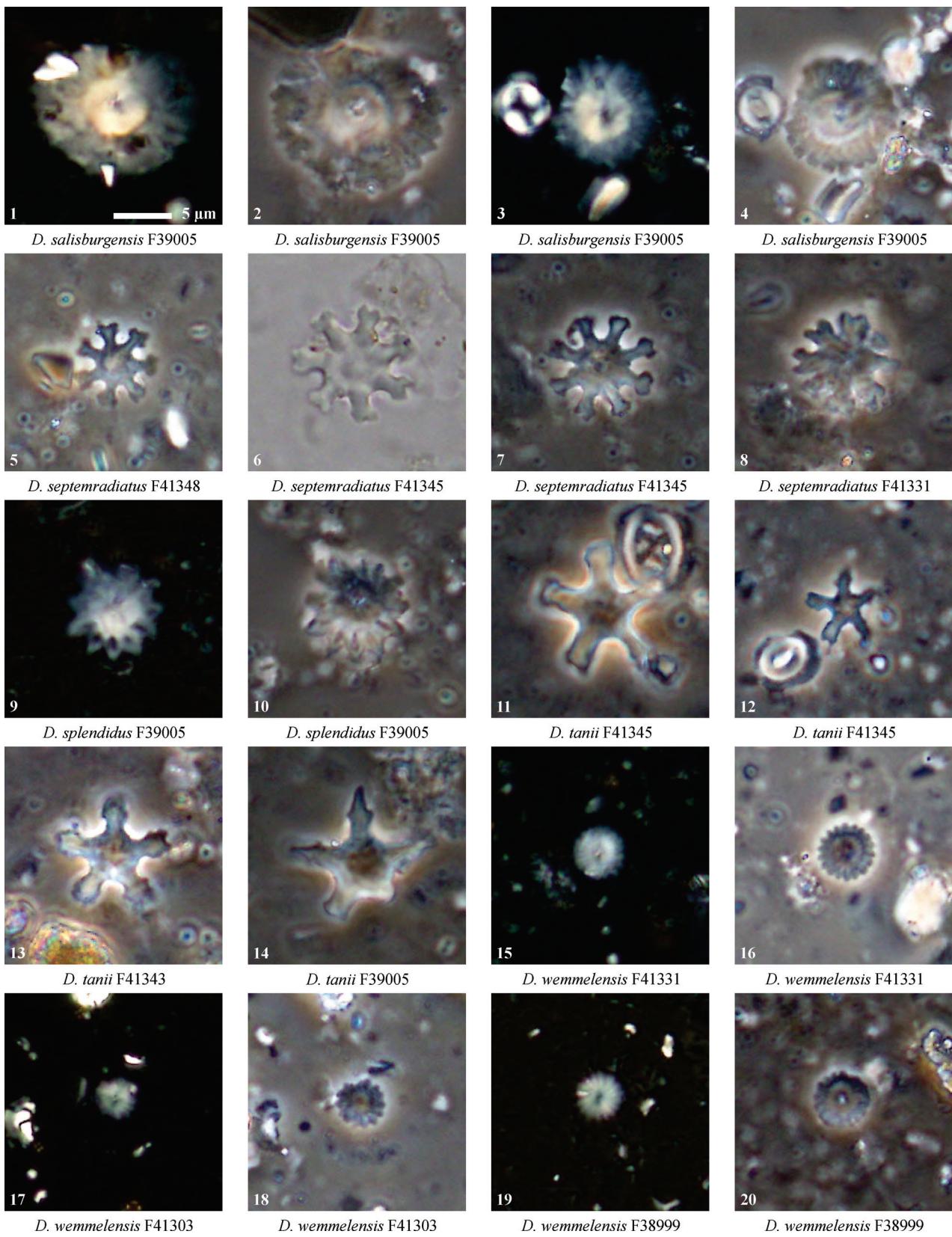


Plate 11

Nannoliths: *Fasciculithaceae*, *Rhomboasteraceae*, *Sphenolithaceae*

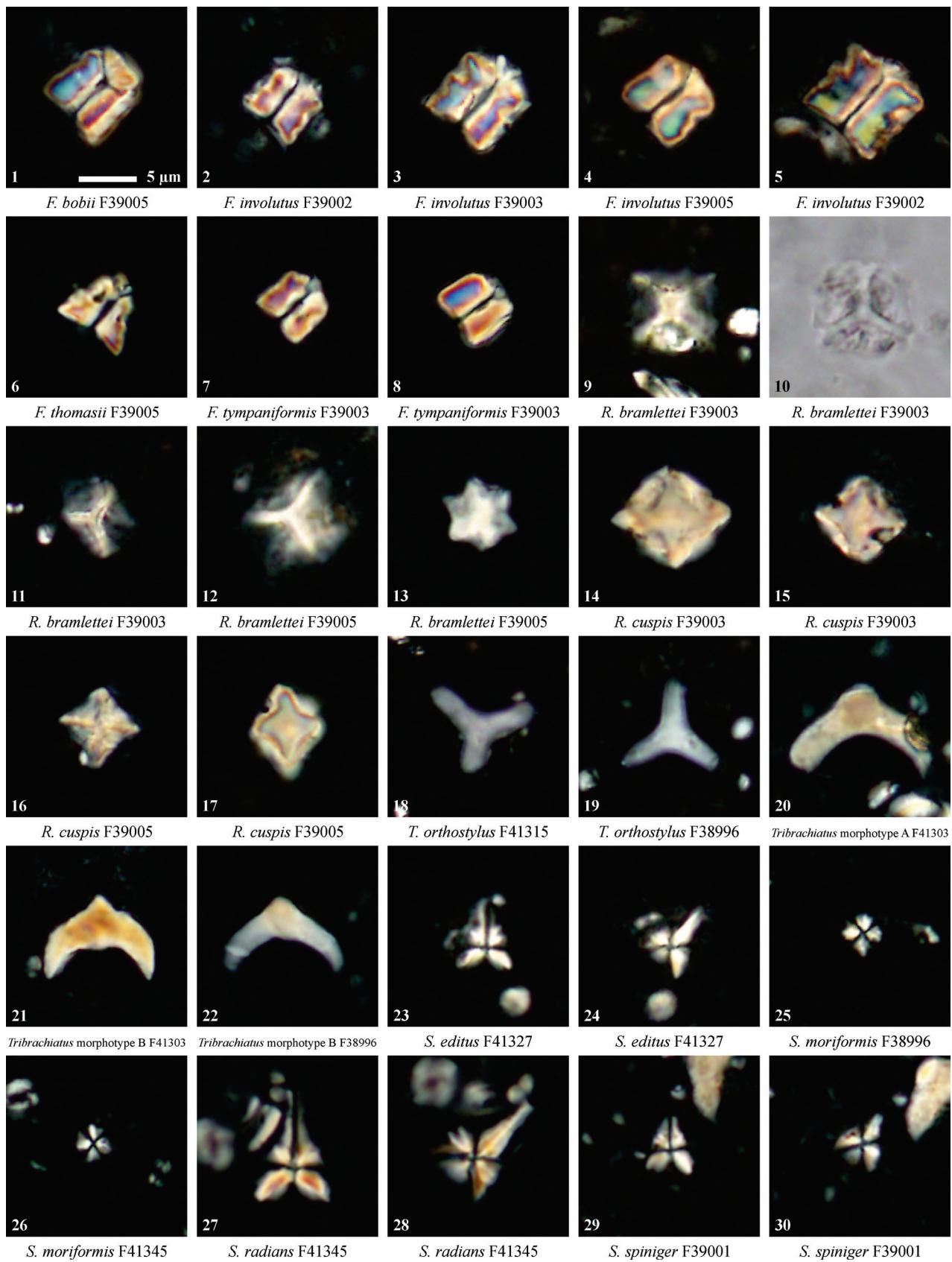


Table 2: Calcareous nannofossil occurrences in the mid-Waipara River Section, Canterbury Basin, New Zealand. Species abundance: V, very abundant or 50–100% of total count; A, abundant or 20–50%; C, common or 5–20%; F, few or 1–5%; R, rare or < 1%. Preservation: G, good; M, moderate; P, poor. Other symbols: r, reworked specimen; f, fragments; ?, questionable occurrence

Formation	Ashley Mudstone	Zone (Martin, 1971)	Stratigraphic position (m)	Sample No.	Preservation	
NP11			-3.99	M34f0832	M -	
NP10			-6.61	M34f0834	M -	
NP10			-13.20	M34f0835	P R -	
NP10			-13.95	M34f0836	M R -	
NP10			-15.25	M34f0838	P C -	
NP12			11.13	M34f0939	M-G -	
NP12			9.33	M34f0935	M-G -	
NP12			8.02	M34f0931	M R -	
NP12			6.44	M34f0947	G -	
NP12			5.23	M34f0943	G -	
NP12			3.13	M34f0937	M -	
NP12			-1.00	M34f0839	G -	
NP12			-2.87	M34f0891	G -	
NP13-14			66.45	M34f1047	M -	
NP13-14			62.26	M34f1033	M -	
NP13-14			58.55	M34f1039	P -	
NP13-14			49.52	M34f1031	P -	
NP13-14			45.78	M34f1027	P -	
NP13-14			42.78	M34f1023	P -	
NP13-14			40.76	M34f1019	P -	
NP13-14			39.16	M34f1015	M-P -	
NP13-14			33.79	M34f1007	M -	
NP13-14			31.35	M34f1003	M -	
NP13-14			29.61	M34f0998	M-G -	
NP13-14			28.00	M34f0995	G -	
NP13-14			25.79	M34f0991	M-G -	
NP13-14			23.79	M34f0988	G -	
NP13-14			22.14	M34f0985	G+ -	
NP13-14			21.43	M34f0983	G -	
NP13-14			19.67	M34f0978	M-G -	
NP13-14			17.83	M34f0975	G -	
NP13-14			16.43	M34f0971	G -	
NP13-14			14.01	M34f0957	M-G -	
NP13-14			12.55	M34f0963	M-G -	
NP13-14			11.13	M34f0959	M-G -	
NP13-14			9.33	M34f0955	M-G -	
NP13-14			8.02	M34f0951	M R -	
NP13-14			6.44	M34f0947	G -	
NP13-14			5.23	M34f0943	G -	
NP13-14			3.13	M34f0937	M -	
NP13-14			-1.00	M34f0839	G -	
NP13-14			-2.87	M34f0891	G -	
NP13-14			-3.99	M34f0832	M -	
NP13-14			-6.61	M34f0834	M -	
NP13-14			-13.20	M34f0835	P R -	
NP13-14			-13.95	M34f0836	M R -	
NP13-14			-15.25	M34f0838	P C -	
						Portosphaera distincta
						Orthocygus occultus
						Neococcolithes spp.
						Neococcolithes protenuis
						Neococcolithes minutus
						Neococcolithes dubius
						Neochastozygus imbricari
						Neochastozygus distensus
						Micrantholithus spp.
						Micrantholithus lateralis
						Markalius inversus
						Markalius apertus
						Lophodollithus spp.
						Lophodollithus nascentis
						Jakubowska leoninae
						Helicosphaera spp.
						Helicosphaera seminulum
						Helicosphaera bramleteri
						Griphisa gamma
						Fascicilliatus (tip view)
						Fascicilliatus tympaformis
						Fascicilliatus thomasi
						Fascicilliatus involutus
						Fascicilliatus bobi
						Ellipsolithus distichus
						Ellipsolithus bolli
						Discocaster spp.
						Discocaster (rosette)
						Discocaster spp. (T+ray)
						Discocaster spp. (5 ray)
						Discocaster spp. (6 ray)
						Discocaster tenui
						Discocaster subloboidensis
						Discocaster splendens
						Discocaster salisburyensis
						Discocaster sepmaradiata
						Discocaster saipanensis
						Discocaster nodifer
						Discocaster multiradiatus

Table 2: Continued

Table 2: Continued

Formation	Zone (Martin, 1971)	Stratigraphic position (m)	Sample No.	Preservation	
Ashley Mudstone	NP13-14				
	NP16		M34/1047	M	
		66.45	M34/1043	M	
		62.26	M34/1039	P-	
		58.55	M34/1031	P-	
		49.52	M34/1027	P R	
		45.78	M34/1023	P	
		42.78	M34/1019	P R	
		40.76	M34/1015	M P	
		39.16	M34/1007	M	
		33.79	M34/1003	M G	
		31.35	M34/10991	M G R	
		29.61	M34/10988	G R	
		28.00	M34/10995	G+	
		25.79	M34/10991	G R F	
		23.79	M34/10985	G R R	
		22.14	M34/10983	G R R	
		21.43	M34/10978	M G R	
		19.67	M34/10975	G F	
		17.83	M34/10971	G F	
		16.43	M34/10967	M G R C	
		14.01	M34/10963	M G R C	
		12.55	M34/10959	M G R A	
		11.13	M34/10955	M G A R	
		9.33	M34/10951	M R A	
		8.02	M34/10947	G A	
		6.44	M34/10943	G A	
		5.23	M34/10937	M A R	
		3.13	M34/10989	G -	
		-1.00	M34/10991	G R	
		-2.87	M34/10892	M F R	
		-3.99	M34/10894	M R	
		-6.61	M34/10895	P R	
		-13.20	M34/10896	M R F	
		-13.95	M34/10898	P F	
		-15.25		R F	

Table 2: Continued

Mid-Waipara River Section

Formation	NP Zone (Martini, 1971)	Stratigraphic position (m)	Sample no.	F number
Ashley Mudstone	NP16-17	66.45	M34/f1047	F41407
		62.26	M34/f1043	F41403
	NP13-14	58.55	M34/f1039	F41399
		49.52	M34/f1031	F41391
		45.78	M34/f1027	F41387
		42.78	M34/f1023	F41383
		40.76	M34/f1019	F41379
		39.16	M34/f1015	F41375
		33.79	M34/f1007	F41367
		31.35	M34/f1003	F41363
		29.61	M34/f0999	F41359
		28.00	M34/f0995	F41355
		25.79	M34/f0991	F41351
		23.79	M34/f0988	F41348
		22.14	M34/f0985	F41345
		21.43	M34/f0983	F41343
		19.67	M34/f0978	F41338
		17.83	M34/f0975	F41335
		16.43	M34/f0971	F41331
		14.01	M34/f0967	F41327
		12.55	M34/f0963	F41323
NP12	NP12	11.13	M34/f0959	F41319
		9.33	M34/f0955	F41315
		8.02	M34/f0951	F41311
		6.44	M34/f0947	F41307
		5.23	M34/f0943	F41303
		3.13	M34/f0937	F41297
		-1.00	M34/f0889	F38996
NP11	NP11	-2.87	M34/f0891	F38998
		-3.99	M34/f0892	F38999
		-6.61	M34/f0894	F39001
NP10	NP10	-13.20	M34/f0895	F39002
		-13.95	M34/f0896	F39003
		-15.25	M34/f0898	F39005

Addendum - table of sample numbers

Different sample numbers were used in the field and for subsequent curation. The curation numbers are used on the plates but the field numbers are used on the log. This table provides the correlation between the two.