

# UPPER ZANCLEAN SILICOFLAGELLATES FROM MILOS ISLAND (CYCLADES, GREECE)

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**Abstract:** A calcareous and siliceous assemblage of phytoplankton from diatomaceous, laminated marls of the Frago section, at the southern part of Milos Island, was studied. It contains principally calcareous nannofossils and silicoflagellates. The calcareous nannofossil association belongs to subzone CN11b (*Discoaster assymetricus*) from the Upper Zanclean (*sensu* Okada & Bukry, 1980), whereas the silicoflagellates correspond, more or less, to the upper part of the *Dictyocha extensa* Interval Zone (*sensu* McCartney et al., 1995). *Dictyocha arbutusensis* (Bukry, 1982) *cycladica* n. subsp. and *Dictyocha*(?) sp. were found and are described from the silicoflagellates of the Frago section. The percentage variation of the silicoflagellate species reflects the deposition of the sequence in subtropical to tropical conditions.

### Introduction

The island of Milos belongs to the southern part of the active Cyclades volcanic arc (Figure 1A), which extends from Soussaki (adjacent to the Isthmus of Corinth) up to Nissyros and Giali, through Aegina, Methana, Poros, Milos and Santorini islands (Fytikas et al., 1976). Numerous scientists have studied the geology of Milos since the last century. Sauvage (1846) compiled a geological map of the island. Philippson (1897) published the first synthetic work on the geology of the Cyclades. The significant work of Sonder (1925) relates to the volcanic rocks. Liatsikas (1949) studied the important minerals and rocks of the island. Angelier et al. (1977), Fytikas (1977a), Jacobshagen (1986) and Pe-Piper & Piper (1989) studied the geology of Milos with respect to the evolution of the Hellenides. A detailed geological map of the island (at 1:25 000 scale) was compiled by Fytikas (1977b). Neogene carbonate deposits transgressively overlie the Upper Cretaceous-Palaeogene metamorphic basement. Volcanic deposits are the dominant lithology of the island. This volcanic activity has lead to the development of hydrothermal fields and fumeroles at Chora and Adamas (Fytikas, 1977a), related to the increased geothermal gradients. Frydas (1994a) studied the

stratigraphy and palaeoecology of Lower Pleistocene silicoflagellate and diatom assemblages near Adamas. Bellas & Frydas (1994), in a preliminary report, described the Neogene deposits of the Tsouvala and Frago sections in southern Milos. They assigned to the calcareous nannofossil assemblage of the former section a Messinian age.

The subject of this paper is a stratigraphical study of Neogene deposits from the Frago section, using calcareous nannofossils in conjunction with silicoflagellates.

### Lithostratigraphy

The sequence outcrops along the southern coast of Milos Island. It comprises approximately 8m of sediment above present sea-level and is located on the Frago Peninsula, between the cape Mesa Akrotiraki and the Pounta Peninsula (Figure 1B). Three coarsening-upwards sedimentation cycles can be distinguished in the section (Figure 2). The beds of the section dip S-SE at an angle of 5-15°. The basal

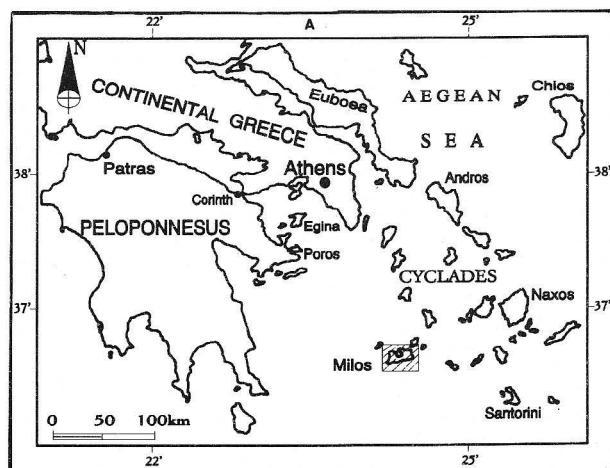


Fig. 1A: Map showing the island of Milos among the Cyclades group in the southern part of the volcanic arc of the Aegean Sea.

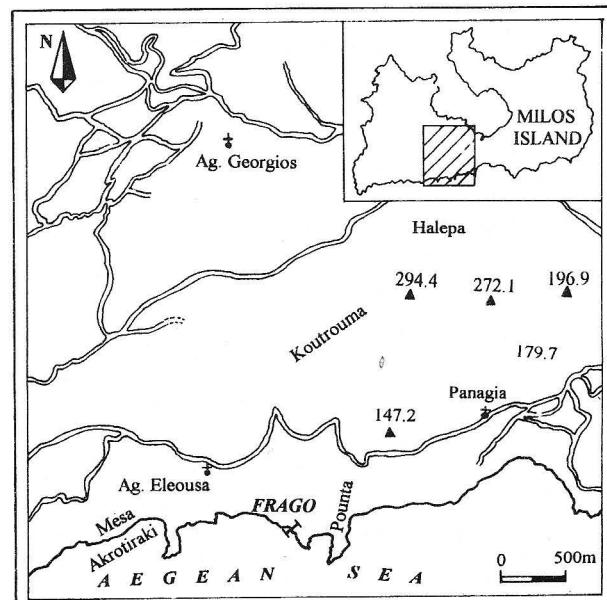


Fig. 1B: Location of the Frago section on the island of Milos, Greece.

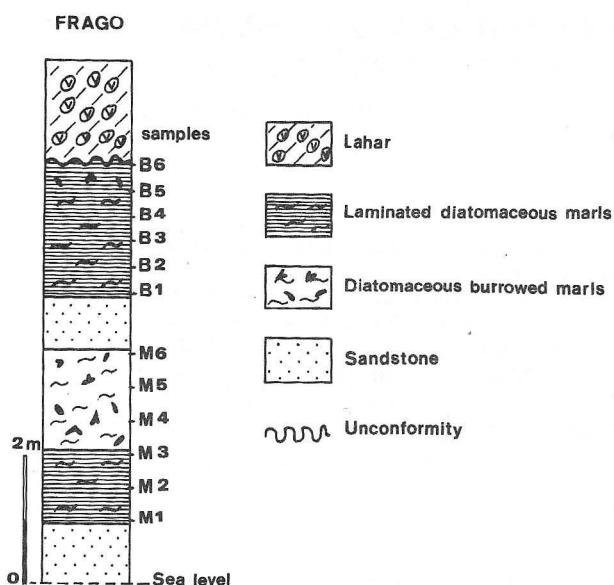


Fig. 2: Lithostratigraphy of the Frago section.

part consists of a sandstone bank which probably represents the uppermost part of an incomplete sedimentation cycle. This is overlain by light green to yellowish, medium-cemented, laminated marls which pass upwards through yellowish, sandy marls with burrows and iron oxides, to medium-grained, light green, slightly cemented sandstone. White in colour, stratigraphically important diatomaceous layers are also interbedded in the second complete sedimentation cycle. Moderately laminated, white to yellowish diatomaceous marls overlay the complete cycle. The upwardly-increasing percentage of sand, heavily burrowed traces, and an internally, almost-destroyed structure due to the bioturbation, are indications of water shallowing during the deposition of these diatomites. The sandstone,

which probably covered them as part of a third sedimentation cycle, has been removed by erosional processes which followed another regressive event.

Finally, at the top of the section, an approximately 1.5m thick, green-coloured volcanic deposit ('lahar' after Fytikas, 1977b) unconformably overlies the older sequence. Recent studies consider lahar to be the result of one or more discrete processes, rather than a single depositional product (Fisher & Smith, 1991).

### Biostratigraphy

The studies of Deflandre (1950), Stradner (1961), Stradner & Bachmann (1978), Bukry (1981, 1982), Bukry & Foster (1973), Dumitrica (1973), Perch-Nielsen (1985a, b) and Frydas (1990, 1991, 1993) were used for the identification of the various calcareous and siliceous phytoplankton species. The most characteristic species are shown in Plate 1. Table 1 shows the stratigraphical distribution of the calcareous and siliceous nannofloras along the studied section.

Calcareous nannofossils, as well as some silicoflagellate species (samples M1 to M6), were recovered from the laminated, marly diatomites of the lower part of the Frago section. According to the common presence of *Discoaster asymmetricus*, *Discoaster tamalis* and *Reticulofenestra pseudoumbilica*, the rich calcareous nannoplankton association (Table 1) is assigned to NN14-15B (Lower Pliocene) *sensu* Driever (1988), which corresponds to CN11b of Okada & Bukry (1980) and to the upper part of NN15 (Martini, 1971).

The diatomites of the upper part of the Frago section (samples B1-B6) yielded silicoflagellates and diatoms of higher abundance compared to the underlying, lower part, while the occurrence of calcareous nannoplankton decreased towards the top. In this upper part, *Reticulofenestra pseudoumbilica* is absent, whereas *Discoaster*

Frage-section, Milos Island												Table 1	Nannofossils are indicated as percents (%)
M						B							
1	2	3	4	5	6	1	2	3	4	5	6		
Uppermost Zanclean													
<i>Discoaster asymmetricus</i> Subzone													
6	9	4	8	5	7				4	6		Age	
11	3	14	5	9	2	6	7					Calcareous nannofossils	
9	7	10	12	9	6			3	2			<i>Calcidiscus leptoporus</i> (MURRAY & BLACKMAN)	
7	10	12	9			3						<i>C. macintyreai</i> (BUKRY & BRAMLETTE)	
9	8	4				5						<i>Coccolithus pelagicus</i> (WALLICH)	
17	7	6	10	6	8			2				<i>Discoaster asymmetricus</i> GARTNER	
				6	4							<i>D. brouweri</i> TAN SIN HOK	
4	3											<i>D. pentaradiatus</i> TAN SIN HOK	
6	4	7	10	7	5							<i>D. surculus</i> MARTINI & BRAMLETTE	
12	11	12	10	7	5							<i>D. tamalis</i> KAMPTNER	
4	6		4		3							<i>D. triradiatus</i> TAN SIN HOK	
1		2										<i>D. variabilis</i> MARTINI & BRAMLETTE	
						11		16				<i>Helicosphaera carteri</i> (WALLICH)	
						12	14					<i>Pseudoemiliania lacunosa</i> (KAMPTNER)	
7	8	12	10	12	13	34	48	39	22	48	46	<i>Reticulofenestra pseudoumbilicata</i> (GARTNER)	
5						4	7	8	5			<i>Scyphosphaera</i> sp.	
									4	7		<i>Dictyocho</i> (?) sp.	
									6			<i>D. arbutusensis</i> (BUKRY) <i>cycladica</i> n. subsp.	
2						2	5	4	8			<i>D. brevispina brevispina</i> (LEMMERMANN)	
4	8	5	7			16	21	23	13	25	28	<i>D. extensa extensa</i> (LOCKER)	
5	6	11	14	20	10	23	19	22	20	10	17	<i>D. messanensis aspinosa</i> (BUKRY) LOCKER & MARTINI	
100	100	100	100	100	100	100	100	100	100	100	100	<i>D. cf. perlensis perlensis</i> (FRENGUELLI)	
												<i>Distephanus boliviensis boliviensis</i> (FRENGUELLI)	
												<i>Ds. speculum minutus</i> (BACHMANN)	
												<i>Ds. speculum speculum</i> (EHRENBERG)	
												<i>Mesocena circulus</i> (EHRENBERG)	

*tamalis* is scarcely present. In our material, the silicoflagellate association corresponds to the upper part of the *Dictyocha fibula* Zone (Bukry, 1981) and, more or less, to the upper part of the *Dictyocha extensa* Interval Zone of the eastern equatorial Pacific (McCartney *et al.*, 1995).

The above-mentioned *Dictyocha extensa* Interval Zone is not congruent to the *Mesocena circulus* Zone of Martini & Müller (1976, DSDP Leg 38) and Perch-Nielsen (1985b), which really represents the *Paramesocena apiculata/Paramesocena circulus apiculata* Zone. Locker & Martini (1986, DSDP Leg 90) have introduced a *Paramesocena circulus* Zone for Lower to Upper Pliocene sediments of the southwestern Pacific Ocean. This zone lies above the uppermost Miocene-Lower Pliocene *Neonavicularopsis neonautica neonautica* Zone (Locker & Martini, 1986).

Common to abundant silicoflagellates are: *Dictyocha extensa extensa*, *Distephanus speculum speculum* and *Mesocena circulus*, the latter constituting more than 20% in the studied samples. In smaller amounts are also to be found: *Dictyocha* (?) sp., *Dictyocha arbutusensis cycladica* n. subsp., *Dictyocha brevispina brevispina*, *Dictyocha* cf. *D. perlaevis perlaevis* and *Dictyocha messanensis aspinosa*, while *Distephanus boliviensis boliviensis* and *Distephanus speculum minutus* are rare. Most of the silicoflagellate species encountered in the present study have been reviewed in detail (Frydas, 1990, 1991, 1993). Silicoflagellate taxonomy is fully given in these works. Therefore, full synonymies are not presented here. One new subspecies of the genus *Dictyocha*, as well as a *Dictyocha*(?) species of late Early Pliocene samples from the Frago section, were determined and are described here.

### Systematic descriptions

#### Order Silicoflagellata Borgert, 1891

#### Family Dictyochaceae Lemmermann, 1901

#### Genus *DICTYOWHA* Ehrenberg, 1840

*Dictyocha arbutusensis* (Bukry, 1982) *cycladica* n. subsp.

Plate 1, Figures 1, 2

**Derivation of name:** 'Cyclades' = group of islands in the Aegean Sea to which the island of Milos belongs.

**Holotype:** Plate 1, Fig. 1; sample M5.

**Paratype:** Plate 1; Fig. 2, sample M6, from type locality.

**Type locality:** Frago section, samples M5, M6 (290-340cm above sea-level), Milos Island, central Aegean Sea.

**Type horizon:** Lower Pliocene (Zanclean), Subzone CN11b (*Discoaster asymmetricus*) (or upper NN15).

**Diagnosis:** Elongated basal ring with two short radial spines and a very short apical bar.

**Description:** *Dictyocha arbutusensis cycladica* n. subsp.

has an elongated to elliptical ring lacking minor-axis spines, and a very short apical bar. Two short, radial spines are aligned at the major axis of the elongated basal ring. The basal-ring bars show a distinctly rounded to half-circular form in the part on the ring where the lateral bars instate. The maximum from inner diameter ranges from 39 to 52 $\mu$ m (holotype = 49.3 $\mu$ m). The length/width (L/W) ratio from inner diameter ranges from 1.7 to 2.5.

**Discussion:** *Dictyocha arbutusensis cycladica* n. subsp. is distinguished from *Dictyocha arbutusensis* (Bukry, 1982) by the distinctly more semi-circular, rounded basal bars in the part of the ring where these are joined with the oblique lateral bars; by the obliquely-oriented apical bars; by the very short, radial spines; and by its generally smaller size and less broad outline. *Dictyocha arbutusensis* (Bukry, 1982) has a maximum inner diameter from 45 to 65 $\mu$ m, and a L/W ratio from 2.8 to 3.4.

**Age:** *Dictyocha arbutusensis cycladica* n. subsp. first appears in the Frago section at the stratigraphical level of Subzone CN11b (*Discoaster asymmetricus*) in the Lower Pliocene (Zanclean). *Dictyocha arbutusensis* (Bukry, 1982) occurs in low frequencies in the Upper Pliocene in the eastern equatorial Pacific. Its stratigraphical range is not yet exactly established.

**Occurrence:** *Dictyocha arbutusensis cycladica* n. subsp. is a common species in Zanclean samples M5 and M6 (290-340cm above sea-level) in the Frago section. Other common species in these samples are: *Dictyocha extensa extensa*, *Dictyocha messanensis aspinosa*, *Distephanus speculum minutus*, *Distephanus speculum speculum* and *Mesocena circulus*.

*Dictyocha*(?) sp.

Plate 1, Figures 3, 4

**Holotype:** Plate 1, Fig. 3; sample B1.

**Paratype:** Plate 1, Fig. 4; sample B4, from type locality.

**Type locality:** Frago section, samples B1 and B4 (470cm and 570cm above sea-level, respectively).

**Type horizon:** Lower Pliocene (Zanclean), Subzone CN11b (*Discoaster asymmetricus*) (or upper NN15).

**Diagnosis:** Subparallel basal ring with two short spines and a convex apical bar.

**Description:** *Dictyocha*(?) sp. has a subparallel to slightly oblong basal ring with only two short spines aligned at the major axis of the elongated ring. A slightly convex apical bar connects the subparallel sides of the ring along the minor axis. The maximum from inner diameter ranges from 42 to 62 $\mu$ m (holotype = 51.3 $\mu$ m). The L/W (length/width) ratio from the inner diameter ranges from 2.1 to 2.6.

**Discussion:** *Dictyocha*(?) sp. is distinguished from *Dictyocha neonautica* (Bukry, 1981), from the Upper

Miocene of the Carnegie Ridge, Pacific Ocean, DSDP 157-38-CC (343m) and the Panama Basin, by its essentially smaller size. *Dictyocha neonautica* (Bukry, 1981) has a maximum inner diameter of 70-90 µm.

**Age:** *Dictyocha neonautica* defines the homonymous subzone (Bukry, 1981) which is equivalent to the lower part of the silicoflagellate *Dictyocha fibula* Zone (Upper Miocene). On the island of Crete, *Dictyocha* cf. *D. neonautica* (*sensu* Bukry, 1981) has been established as the marker for an acme-subzone in the Lower Piacentian in the Marathiti, Aghios Vlassios (Frydas, 1990, 1996) and Gournes (Frydas, 1994b) sections of the Heraklion Province, and also in the Stavromenos section (Frydas & Keupp, 1992) of the Rethymnon Province.

**Occurrence:** *Dictyocha*(?) sp. is a common species in Upper Zanclean samples B1 and B4 in the Frago section. Its stratigraphical range is not yet exactly known. Other common species in these samples are: *Dictyocha extensa extensa*, *Dictyocha brevispina brevispina*, *Dictyocha* cf. *D. perlaevis perlaevis*, *Dictyocha messanensis aspinosa*, *Distephanus boliviensis boliviensis*, *Distephanus speculum minutus*, *Distephanus speculum speculum* and *Mesocena circulus*.

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## PLATE 1

Figs 1-17: Silicoflagellates. Figs 1-6, 12, 14 and 15-17 magnified x850 approximately; Figs 7-11 and 13 magnified x950 approximately. Figs 18-24: Calcareous nannofossils. All specimens magnified 1400x approximately. Holotypes are stored in the Dept. of Geology, University of Patras.

**Figs 1, 2:** *Dictyocha arbutusensis* (Bukry) *cycladica* n.subsp..

**Fig.1:** Holotype, sample M5.

**Fig.2:** Paratype, sample M6.

**Figs 3, 4:** *Dictyocha*(?) sp..

**Fig.3:** Holotype, sample B1.

**Fig.4:** Paratype, sample B4.

**Figs 5, 6:** *Dictyocha brevispina brevispina* (Lemmermann).

**Fig.5:** Sample M6.

**Fig.6:** Sample B4.

**Figs 7-9:** *Dictyocha extensa extensa* (Locker) Locker & Martini.

**Figs 7, 9:** Sample B4.

**Fig.8:** Sample M6.

**Figs 10, 11:** *Dictyocha messanensis aspinosa* (Bukry) Locker & Martini.

**Fig.10:** Sample M6.

**Fig.11:** Sample B4.

**Fig.12:** *Distephanus boliviensis boliviensis* (Frenguelli). Sample B4.

**Fig.13:** *Distephanus speculum minutus* (Bachmann). Sample M6.

**Fig.14:** *Distephanus speculum speculum* (Ehrenberg). Sample B4.

**Figs 15-17:** *Mesocena circulus* (Ehrenberg) [syn: *Paradictyocha circulus* (Ehrenberg) Dumitrica].

**Fig.15:** Sample B4.

**Fig.16:** Sample M5.

**Fig.17:** Sample M6.

**Figs 18-19:** *Discoaster asymmetricus* Gartner.

**Fig.18:** Sample M1.

**Fig.19:** Sample M6.

**Fig.20:** *Discoaster brouweri* Tan Sin Hok. Sample M6.

**Fig.21:** *Discoaster surculus* Martini & Bramlette. Sample M6.

**Fig.22:** *Discoaster variabilis* Martini & Bramlette. Sample M6.

**Fig.23:** *Discoaster tamalis* Kamptner. Sample M6.

**Fig.24:** *Discoaster triradiatus* Tan Sin Hok. Sample M6.

PLATE 1

