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CALCAREOUS AND SILICEOUS PHYTOPLANKTON STRATIGRAPHY FROM NEOGENE DEPOSITS OF MILOS ISLAND (CYCLADES, GREECE)

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ABSTRACT

An important calcareous and siliceous phytoplankton assemblage containing mainly Ceratolithaceae, Coccolithaceae, Discoasteraceae, Helicosphaeraceae, and Silicoflagellates was studied from sandy marls and finely laminated diatomaceous marls of two sections at the southern part of Milos island (Greece). The calcareous nannofossil association from the Tsouvala section, belongs to the upper part of the *Discoaster quinqueramus* biozone (NN11b) of Messinian age. In the Frago section the association of the calcareous Nannoplankton has been placed in the CN11b subzone (*Discoaster asymmetricus*), whereas the Silicoflagellates belong to the new proposed *Mesocena circulus* subzone placed at the top of the Tabianian Stage. The percentage variation of the Silicoflagellates species reflects the deposition of the succession during subtropical to tropical conditions.

ΣΥΝΟΨΗ

Από τις τομές Τσουβάλα και Φράγκο στο νότιο τμήμα της Μήλου, που δομούνται από αμμούχες μάργες και από λαμινοειδείς μαργαϊκούς Διατομίτες, βρέθηκε και προσδιορίστηκε για πρώτη φορά μία σημαντική συνάθροιση ασβεστολιθικού και πυριτικού φυτοπλαγκτού που περιέχει κυρίως Ceratolithaceae, Coccolithaceae, Discoasteraceae, helicosphaeraceae και πυριτικά Μαστιγοφόρα. Τα σβεστολιθικά ναννοαπολιθώματα της τομής Τσουβάλα ανήκουν στο ανώτερο τμήμα της βιοζώνης *Discoaster quinqueramus* (NN11b) του Μεσσηνίου. Από την τομή Φράγκο, τα μεν ασβεστολιθικά ναννοαπολιθώματα τοποθετούνται στην υποβιοζώνη *Discoaster asymmetricus* (CN11b), ενώ τα πυριτικά Μαστιγοφόρα ανήκουν στη νέα προταθείσα υποβιοζώνη Mesocena circulus του Ανωτάτου Ζανκλίου. Η ποσοστιαία αναλογία των ειδών των πυριτικών Μαστιγοφόρων, αντανακλά συνθήκες απόθεσης υπό εύκρατο έως τροπικό περιβάλλον.

1. INTRODUCTION

The island of Milos belongs to the volcanic island group which form the southern part of the active Cyclades volcanic arc (fig. 1), extending from Soussaki (adjacent to Corinth Isthmos) up to Nissyros and Giali, through Egina, Methana, Poros, Milos and Santorini islands (FYTIKAS et al., 1976) .

ANGELIER et al. (1977), FYTIKAS (1977a), JACOBSHAGEN (1986), and PE-PIPER & PIPER (1989) described the geological and tectonical pattern of Milos through the development of the Hellenides. A detailed geological map of the

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island in a scale of 1:25,000 was compiled by FYTIKAS (1977b). According to the above researchers, Neogene carbonate deposits are transgressively overlying the Upper Cretaceous - Paleogene metamorphic basement.

Since then, volcanic deposits dominate the island lithology. The intense volcanic activity led to the development of the hydrothermal fields and fumaroles, which are directly connected with the continuous increasing geothermal gradient in the localities of Chora (or Plaka) and Adamas (FYTIKAS, 1977a).

KOSTAKIS (1983) studied the electric conductivity of the Milos Obsidian between 250° and 600° C, whereas WIEDENBEIN (1988) in his doctoral thesis presents the Quaternary geological development of the island. Recently, the thesis of KRONABEL (1989) and MAVRONYCHI (1990) deal with the Geology, Archaeometry of Obsidian ores and the Mineralogy of the Kaolinite and Bentonit respectively, whereas FRYDAS (1994a) studies the stratigraphy and palaeoecology of Lower Pleistocene Silicoflagellate and Diatom assemblages from an outcrop nearby Adamas.

The aim of this paper is the detailed biostratigraphical study of the Neogene deposits of Milos, from two sections, Tsouvala and Frago (fig. 2), using calcareous Nannoplankton in combination with Silicoflagellate assemblages.

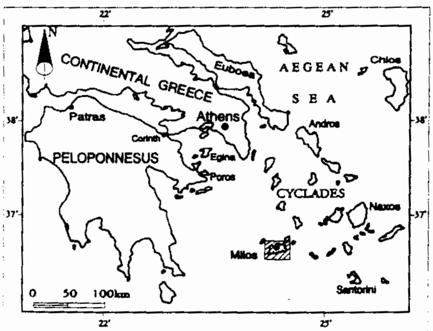

Fig.1: Location map showing the island of Milos among the Cyclades group in the southern part of the volcanic arc of Aegean Sea, Greece.

Εικ. 1: Το νησί των Κυκλάδων Μήλος, στο νότιο τμήμα του ηφαιστειακού τόχου του Αιγαίου Πελάγους.

2. LITHOSTRATIGRAPHY

2.a. Tsouvala section (fig. 2)

This section is located in Tsouvala area, southern-middle Milos and comprises approximately eighteen meters in thickness. It outcrops as a small hill resting on light grey in colour, Miocenic limestones. The contact is not exposed, due to alluvial deposits. The latter reefal limestones resemble those of the Lower Messinian age on Crete island (MEULENKAMP, 1985).

Thin-bedded horizontal marls arranged in four big and fourteen smaller rythmically shallowing upwards cycles, dominate the sections' sediments. Each cycle starts with yellowish to light brown in colour sandy marl layers, which grade upwards to dark brown laminated sandy marls with plant remains. The sequence is overlain by a capping consisted of medium to fine grained sandstone, which represents extremely shallowing conditions.

The uppermost part of the section (three meters in thickness), consists of poorly cemented, light grey to white volcanic rocks (Ignimbrites, after FYTIKAS; 1977b), which unconformably overlying the prementioned sandstone bank. This unconformity indicates a regression with contemporaneous erosional features, although the sections' beds preserved their initial horizontal position.

2.b. Frago section (fig. 2)

The succession outcrops on the southern coast of Milos island. It comprises approximately eight meters in thickness, starting from the present sea-level and is located on the homonymous Frago penninsula, between the Cape Mesa

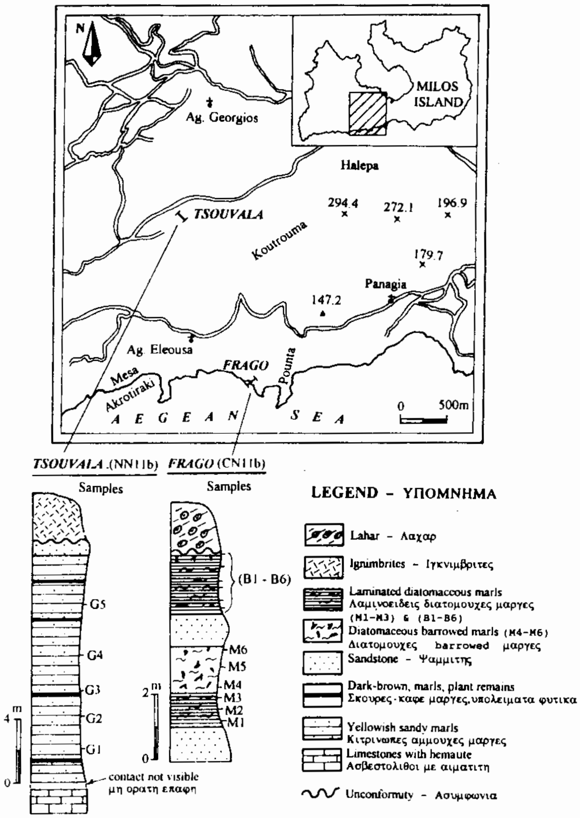

Fig.2: The Tsouvala and Frago studied sections on Milos island Lithostratigraphy and location.

Εικ. 2: Οι τομές Τσουβάλα και Φράγκο που μελετήθηκαν στο νησί Μήλος. Τοποθεσία και λιθοστρωματογραφία τους.

Akrotiraki and the Pounta penninsula. The beds of the section dip S.SE. at an angle of 5-15°.

Three coarsening upwards sedimentation cycles can be distinguished in the section, of which only one, in the middle, is considered complete. It consists of light green to yellowish, medium cemented, laminated marls which pass upwards via yellowish sandy marls with barrows and iron oxides, to medium grained, light green, slightly cemented sandstone. White in colour stratigraphically important diatomaceous layers are also interbedded. A sandstone bank underlying the complete previous succession, represents the uppermost part of another not visible depositional cycle. Fairly laminated in the lower part, diatomaceous, white to yellowish marls overlie the complete cycle. Increasing upwards sand content, heavily barrowed imprints and an internally almost destroyed structure due to the bioturbation, are indications of the water shallowing during the deposition of these diatomites. The sandstone which probably covered them as a consequence of a third sedimentation regressional cycle, has been either removed by erosional processes, or most probably, it was never developed, and interrupted by the volcanic deposition which followed a new eruption.

At the top of the section, the one and a half meters green in colour volcanic deposits (Lahar; after FYTIKAS, 1977b) follow after an unconformity. The thickness of these deposits increases towards the southern penninsula edge, to the sea, whereby they entirely dominate due to normal, antithetical faulting of the studied section area. Recent studies consider the Lahar as an event which can be refered to one or more discrete processes, but it is not refered to a deposit (FISHER & SMITH, 1991).

3. BIOSTRATIGRAPHY

For the identification of the various calcareous and siliceous phytoplankton species the studies of DEFLANDRE (1950), STRADNER (1961), STRADNER & BACHMANN (1978), LOEBLICH et al. (1968), BUKRY (1981, 1982), BUKRY & FOSTER (1973) and FRYDAS (1990, 1991 & 1993) were taken into account. The most characteristic species are given in plate 1. Table 1 demonstrates the stratigraphical distribution of the calcareous and siliceous nannoflora along the studied

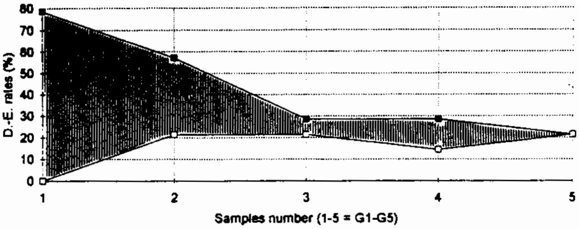

Fig.3: Diversities (D, closed squares) - Extinctions (E, opened squares) calcareous Nannoplankton rates plotting, showing the negative overall trend of the former in contrast to the rather positive trend of the latter. Shadowed area represents the differences between the variants. Section Tsouvala, from base (sample G1) to the top (sample G5).

Εικ. 3: Διάγραμμα των ρυθμών ποικιλότητας (D, σκούρα τετράγωνα), - Εξαφάνισης (E, λευκά τετράγωνα) του ασβεστολιθικού Ναννοπλαγκτού από την τομή Τσουβάλα. Παρατηρούμε την αρνητική τάση της ποικιλότητας των ειδών σε αντίθεση με τη σχετική τάση της εξαφάνισής τους. Η γραμμοσκιασμένη περιοχή αντιπροσωπεύει την εξέλιξη της διαφοράς των δύο μεταβλητών από τη βάση (δείγμα G1) προς την κορυφή (δείγμα G5) της τομής.

sections, according to PERCH-NIELSEN (1985a, b) Taxonomy.

The association of calcareous nannofossils of the Tsouvala section (tab. 1) is characterized by the common presence of the key Taxa *Amaurolithus delicatus* (common) and *Discoaster quinqueramus* (rare), which delimited the upper part of the biozone *D. quinqueramus* (NN11b). The presence of *A. delicatus* at 6.2 m.y. ago (Messinian), has been used by MARTINI & MάLLER (1986) to subdivide the long interval of the NN11 biozone in two subzones 11a and 11b. Diversities/Extinction diagram of the calcareous nannoflora, shows the differences in the rates of the evolution along the studied section (fig. 3, shadowed area). It is worth noticing the negative overall diversification trend, which by the top, is found in ballance with the positive extinction trend. The total nannoflora diversity value of Tsouvala section is low 23.33%, compared with the maximum calcareous nannoplankton diversity computed after BOWN et al., (1992) for the studied interval of time.

Calcareous nannofossils as well as Silicoflagellate and Diatom nannofloras (samples M1 to M6), have been recovered from the laminated, marly diatomites of the lower part of Frago section. According to the common presence of *Discoaster asymmetricus*, *D. tamalis* and *Reticulofenestra pseudoumbilicus*, the rich calcareous Nannoplankton association (tab. 1) is assigned to the uppermost Tabianian NN14-15B subzone (sensu DRIEVER 1988), which corresponds to the CN11b subzone of OKADA & BUKRY (1980) or to the upper part of the NN15 (MARTINI & MÜLLER, 1986) zone.

The diatomites of the upper part of Frago section (samples B1-B6) yielded Silicoflagellates and Diatoms in higher abundances than the underlying ones (see fig. 4 diversities correlation diagram); Sporadic occurrences of calcareous Nannoplankton which gradually disappeared towards the top (fig. 4; sample B6) were also recorded. In this upper part the *R. pseudoumbilicus* is absent, whereas *D. tamalis* is scarcely represented. Along this section the total diversity of the calcareous nannoplankton reaches a value of 29.16%, although it still remains low compared with the global one refered by BOWN et al., (1992).

Mesocena circulus species is prominent throughout the Frago section. Its acme in the biostratigraphical distribution, allows us the proposion herein of a new subzone, named *Mesocena circulus*, which corresponds to the upper part of the uppermost Tabianian *Dictyocha fibula* zone (sensu BUKRY, 1981).

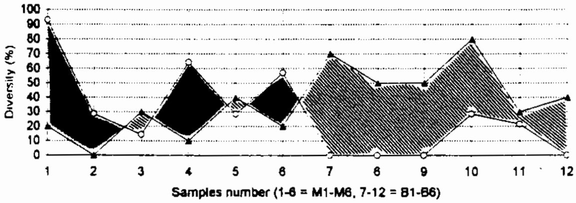

Fig. 4: Calcareous (opened circles) - siliceous (closed triangles) phyto-plankton diversities rates correlation diagram recorded along Frago section. Note the oscillations of diversities in the lower part (samples M1-M6) of the section with higher rates of calcareous Nannoplankton, whereas in the upper part (samples B1-B6) the Silicoflagellates almost entirely dominate.

Εικ. 4: Συγκριτικό διάγραμμα των ρυθμών ποικιλότητας μεταξύ ασβεστιτικού (λευκοί κύκλοι) και πυριτικού (σκούρα τετράγωνα) φυτοπλαγκτού κατά μήκος της τομής Φράγκο. Στο κατώτερο τμήμα της (δείγματα M1 - M6) όπου κυριαρχούν υψηλότεροι ρυθμοί (εξέλιξης) της ποικιλότητας του ασβεστολιθικού Ναννοπλαγκτού παρατηρούμε πολλές διακυμάνσεις (στικτή περιοχή), ενώ στο ανώτερο τμήμα τα πυριτικά Μαστιγοφόρα επικρατούν σχεδόν ολοκληρωτικά (πλάγια διαγράμμιση).

According to the range of its acme, the *Dictyocha neonautica* appearance in the Upper Miocene of the Pacific ocean defines the homonymous subzone (BUKRY, 1981), which is equivalent to the lower part of the *D. fibula* zone for the Silicoflagellates. According to BUKRY (1981) and PERCH-NIELSEN (1985b), the upper part of the prementioned zone is defined by the *Dictyocha aspera aspera* subzone which corresponds to the stratigraphical interval between the last occurrence of *D. neonautica* and the first occurrence of *Dictyocha stapedia stapedia*. In Crete island the *D. neonautica* subzone has been identified in the Lower Piacentian of the Marathitis, Agios Vlassios (FRYDAS, 1990), and Gournes (FRYDAS, 1994b) sections of Iraklion Province, as well as in the section Stavromenos, Rethymnon Province (FRYDAS & KEUPP, 1992). A form of *Dictyocha arbutusensis* originaly described from eastern equatorial Pacific Upper Pliocene in age DSDP cores, where it observed in low frequency (BUKRY, 1982), is also identified in Frago section.

Dictyocha fibula **Zone**

Subzone *Mesocena circulus* **n. subzone**

Definition: Subzone corresponding to the uppermost interval of the *Dictyocha fibula* Zone (sensu BUKRY, 1981 - Silicoflagellate Zonation for Tropical / Subtropical regions), according to the great abundance and acme of the *Mesocena circulus* species (pl. 1, figs. 24; 25).

Type section: The laminated, marly diatomites of Frago section, Milos island, Greece (Fig.1, samples M1, M3, M5, M6, B1 - B6).

Age: Uppermost Tabianian (for correlation based on calcareous Nannoplankton zones see tab. 1).

Association: Common to abundant presence of the Silicoflagellates species *Dictyocha fibula*, *Distephanus speculum speculum* and *Mesocena circulus*; while the latter predominates with a frequency of more than 20%. *Dictyocha* cf. *arbutusensis*, *D. brevispina brevispina*, *D. neonautica* and *D. stapedia aspinosa* are also encountered in low percentages, while *Cannopilus major* and *Distephanus boliviensis boliviensis* occur sparsely.

Remarks: A sample from the type Tabianian yielded *M. circulus*, which was encountered in a typical assemblage of the *Dictyocha fibula* zone (SANFILIPPO et al., 1973). Sporadic *Mesocena (Paradictyocha) circulus* species was found to constitute a minor fraction of the siliceous assemblage of DSDP Leg 42A, Site 378, cores 5,8 (south of Santorini island, STRADNER & BACHMANN, 1978)

TABLE 1

Distribution and Appendix of the nannofossils recovered from the Tsouvala and Frago sections on Milos island

Studied sections	TSOUVALA					FRAGO											
Sample number	G1	G2	G3	G4	G5	M1	M2	M3	M4	M5	M6	B1	B2	B3	B4	B5	B6
Age	Messinian					Uppermost Zanclean											
Calcareous nannofossils	NN11b(CN9b)					Top of NN15 (CN11b)											
Amaurolithus delicatus GARTNER & BUKRY, 1975 (pl. 1, figs. 1,2)	●	●															
Calcidiscus leptoporus (MURRAY & BLACKMAN, 1898) (pl. 1, fig. 7)	●		●		●	●				●					●	●	
C. macintyrei (BUKRY & BRAMLETTE, 1969)	●	●	●		●	●				●	●				●	●	
Coccolithus pelagicus (WALLICH, 1877)		●		●		●	●	●		●							
Discoaster asymmetricus GARTNER, 1969 (pl. 1, figs. 3,4)						●		●	●		●						
D. cf. bollii (MARTINI & BRAMLETTE, 1963) (pl. 1, fig. 6)	●																
D. brouweri TAN, 1927 (pl. 1, fig. 5)						●			●		●				●	●	
D. deflandrei BRAMLETTE & RIEDEL, 1954 (pl. 1, fig. 12)		●	●														
D. intercalaris BUKRY, 1971 (pl. 1, fig. 13)	●	●															
D. pansus (BUKRY & PERCIVAL, 1971) (pl. 1, fig. 11)		●															
D. pentaradiatus TAN, 1927 (pl. 1, fig. 14)						●	●		●		●						
D. quinqueramus GARTNER, 1969 (pl. 1, fig. 15)	●		●														
D. surculus MARTINI & BRAMLETTE, 1963 (pl. 1, fig. 16)									●		●						
D. tamalis KAMPTNER, 1967 (pl. 1, fig. 17)						●	●		●						●		
D. triradiatus TAN, 1927						●											
D. variabilis MARTINI & BRAMLETTE, 1963	●	●		●	●												
Helicosphaera carteri (WALLICH, 1877)	●			●		●	●		●	●	●						
H. sellii BUKRY & BRAMLETTE, 1969						●					●						
Pontosphaera multipora (KAMPTNER, 1948)	●																
Pseudoemiliania lacunosa (KAMPTNER, 1963) (pl. 1, fig. 8)						●			●		●						
Reticulofenestra pseudoumbilicus (GARTNER, 1967) (pl. 1, fig. 9)	●					●			●								
Scyphosphaera sp.						●			●								
Sphenolithus abies DEFLANDRE, in DEFLANDRE & FERT (1954) (pl. 1, fig. 10)	●	●		●													
Silicoflagellates						*Mesocena circulus* n. subzone											
Cannopilus major (FRENGUELLI, 1951)															●		
Dictyocha cf. arbutusensis BUKRY, 1982 (pl. 1, figs. 27,28)										●	●						
D. brevispina brevispina (LEMMERMANN, 1901) (pl. 1, fig. 21)														●	●		●
D. fibula EHRENBERG, 1839 (pl. 1, fig. 22)						●		●	●	●		●	●	●	●	●	●
D. neonautica BUKRY, 1981 (pl. 1, figs. 18,29)												●			●		
D. stapedia aspinosa BUKRY, 1976 (pl. 1, fig. 23)											●	●	●		●		
Distephanus boliviensis boliviensis (FRENGUELLI, 1940) (pl. 1, fig. 19)												●			●		
Ds. speculum minutus (BACHMANN, 1967) (pl. 1, fig. 20)												●	●	●			
Ds. speculum speculum (EHRENBERG, 1839) (pl. 1, fig. 26)								●		●		●	●	●	●	●	●
Mesocena circulus (EHRENBERG, 1840) (pl. 1, figs. 24,25)						●		●		●	●	●	●	●	●	●	●

Περιεχομενα ναννοαπολιθωματα και η κατανομη τους στις τομες Φραγκο και Τσουβαλα

with a late Pliocene age assigned to it. Pliocenic occurrences of this species from Crete island have been also reported by FRYDAS (1986), ALMEKINDERS (1987), FRYDAS (1989, 1990, 1993, 1994b), and FRYDAS & KEUPP (1992), but such an acme recorded in Frago section has never been observed in the Mediterranean before.

4. CONCLUSIONS

Coexistence of *Amaurolithus delicatus* together with *Discoaster quinqueramus* characterizes the Messinian Stage on Milos island, Tsouvala section. The rich nannoflora of Frago section with a calcareous Nannoplankton association of *Discoaster asymmetricus*, *D. surculus*, *D. tamalis* and *Reticulofenestra pseudoumbilicus* is assigned to the uppermost Tabianian. *Mesocena circulus* dominates the Silicoflagellates. Subsequently we propose herein a new subzone *M. circulus,* which at least presents local (Aegean Sea) interest. The diachronous species *Dictyocha neonautica* which on Crete island occurred in Pliocene has been identified. *Dictyocha arbutusensis* known from the Upper Miocene of the Pacific ocean (BUKRY, 1982), is for the first time on Milos and generally in the Mediterranean identified. The latter two species as well as the whole Silicoflagellate association denotes tropical to temperate climate (warm waters). The calcareous and siliceous phytoplankton coexistence is probably the result of the ideally ballanced conditions in water chemistry pattern (between acid and alcalic environment), which favoured the development of both nannoflora group.

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PLATE 1

Magnification : Calcareous nannofossils x900, Silicoflagellates x450
Μεγέθυνση - Ασβεστολιθικό Ναννοπλαγκτό x900, πυριτικά Μαστιγοφόρα x450

Fig. 1, 2 *Amaurolithus delicatus* GARTNER & BUKRY, 1975.
Samples G1, G2; Tsouvala section.

Fig. 3, 4 *Discoaster asymmetricus* GARTNER, 1969.
Samples M1, M3, M4, M6; Frago section.

Fig. 5 *Discoaster brouweri* TAN, 1927.
Samples M1, M4, M6, B4, B5; Frago section.

Fig. 6 *Discoaster cf. bollii* MARTINI & BRAMLETTE, 1963.
Sample G1; Tsouvala section.

Fig. 7: *Calcidiscus leptoporus* (MURRAY & BLACKMAN, 1898).
Samples G1, G3, G5; Tsouvala section, M1, M5, B4, B5; Frago section.

Fig. 8: *Pseudoemiliania lacunosa* (KAMPTNER, 1963).
Samples M1, M4, M6; Frago section.

Fig. 9: *Reticulofenestra pseudoumbilicus* (GARTNER, 1967).
Samples G1; Tsouvala section, M1, M4; Frago section.

Fig. 10: *Sphenolithus abies* DEFLANDRE in DEFLANDRE & FERT,1954.
Samples G1, G2, G4; Tsouvala section.

Fig. 11: *Discoaster pansus* (BUKRY & PERCIVAL, 1971).
Sample G2; Tsouvala section.

Fig. 12: *Discoaster deflandrei* BRAMLETTE & RIEDEL, 1954.
Samples G2, G3; Tsouvala section.

Fig. 13: *Discoaster intercalaris* BUKRY, 1971.
Samples G1, G2; Tsouvla section.

Fig. 14: *Discoaster pentaradiatus* TAN, 1927.
Samples M1, M2, M4, M6; Frago section.

Fig. 15: *Discoaster quinqueramus* GARTNER, 1969.
Samples G1, G3; Tsouvala section.

Fig. 16: *Discoaster surculus* MARTINI & BRAMLETTE, 1963.
Samples M4, M6; Frago section.

Fig. 17: *Discoaster tamalis* KAMPTNER, 1967.
Samples M1, M2, M4, B4; Frago section.

Fig. 18,29: *Dictyocha neonautica* BUKRY, 1981.
Samples B1, B4; Frago section.

Fig. 19: *Distephanus boliviensis boliviensis* (FRENGUELLI, 1940).
Sample B1, B4; Frago section.

Fig. 20: *Distephanus speculum minutus* (BACHMANN, 1967).
Samples B1 - B3; Frago section.

Fig. 21: *Dictyocha brevispina brevispina* (LEMMERMANN, 1901).
Samples B3, B4, B6; Frago section.

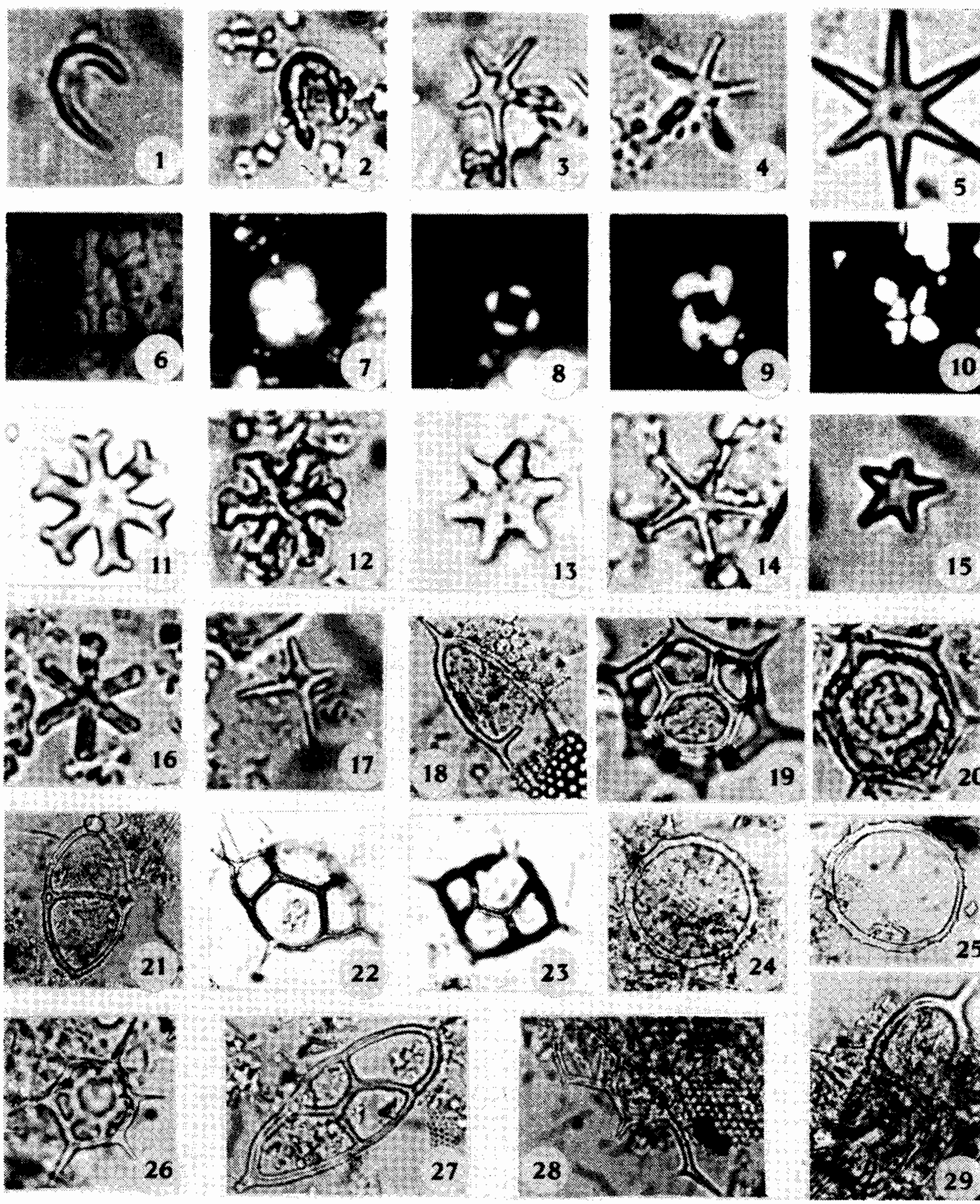
Fig. 22: *Dictyocha fibula* EHRENBERG, 1839.
Samples M1, M3 - M5, B1 - B6; Frago section.

Fig. 23: *Dictyocha stapedia aspinosa* BUKRY, 1976.
Samples M6, B1, B2, B4; Frago section.

Fig. 24,25: *Mesocena circulus* (EHRENBERG, 1840).
Samples M1, M3, M5, M6, B1 - B6; Frago section.

Fig. 26: *Distephanus speculum speculum* (EHRENBERG, 1839).
Samples M3, M5, B1 - B6; Frago section.

Fig. 27,28: *Dictyocha cf. arbutusensis* BUKRY, 1982.
Samples M5, M6; Frago section.



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