SHORT-TERM DISAPPEARANCE OF *GEPHYROCAPSA* (COCCOLITHOPHORALES) RELATED TO KOS-NISYROS-YALI SUBVOLCANIC CHAMBER MAGMATIC EVENTS?

BELLAS[1,2], S.M., SEYMOUR[1,3], ST. & FRYDAS[1], D.

ABSTRACT

The gravity core NS-3 of late Quaternary to Recent sea sediments recovered between Kos and Nisyros islands, has been investigated for its calcareous nannoplankton content. *Emiliania huxleyi* dominated the assemblages, whilst a marked paucity of gephyrocapsids is observed from the base of the core, dated by AMS at 22,900±150 yr BP and lasted until the sapropel S1 approximately. This time interval spans most of the last Glacial period. The rest coccolithophorae species identified so far can not tolerate very low temperatures. In addition, absence of *Coccolithus pelagicus*, a cold-water indicator, clearly support the argument of a rather warm than cool depositional environment. South of Kos an underlying active magma chamber is present. This area has been depicted among the most volcanically active of the Quaternary Aegean Arc. There exist numerous submarine vents, the largest being the Nisyros and Yali volcanoes, erupted in a Plinian fashion. It is expected that they have affected the physicochemical parameters of the overlying sea-water column. The question if such an effect in physicochemical conditions of the environment could be reflected in the apparent decimation of the *Gephyrocapsa* population, is addressed here.

KEY WORDS: Calcareous nannofossils, *Gephyrocapsa*, paleoecology, decimation, deglaciation, magmatic events, hydrothermal exhalations, Kos, Nisyros, Yali.

INTRODUCTION

Calcareous nannoplankton consists of various marine algae, which have a restricted depth habitat. Since they are photosynthetic, they exist only in the photic zone of the seas. As a result calcareous nannofossils, their remains, are considered not only a useful biostratigraphic tool, but they are also ideal candidates for paleotemperature estimation of the surface waters, paleoecology and paleonutrient studies (STEINMETZ & ANDERSON, 1983/84; ROTH, 1994).

Oceanic microflora in general, has been used in many interdisciplinary paleoecological studies but rarely in connection with volcanological investigations. An overview of the intense volcanic activity and its evolution in Greece related to the Tertiary to Quaternary age Aegean Arc has been presented by Fytikas et al. (1984). Thera and Nisyros are considered the two most active and hazardous volcanoes in the Aegean. Both may explode in a particularly catastrophic i.e. Plinian fashion. Such were the big eruptions of Thera at ~3300yr BP (Eastwood et al., 2002), ca. 12000yr BP and 18000yr BP, and of Nisyros and Yali, in its proximity, at ca. 31000 to 36000yr BP. As early as in 1984 Papadopoulos has depicted from geophysical data the presence of an active magma chamber located between Kos and Nisyros. Since then, other studies have followed on the detection of submarine volcanoes in the Kos-Nisyros area (NOMIKOU & PAPANIKOLAOU, 1999).

A systematic submarine survey of the area located between Nisyros and Kos, which was carried out with the R/V Aegaio in 1998, proved the prolongation of the high tectonic and volcanic activity into the sea (Papanikolaou et al., 1998a, 1998b). During this cruise, several gravity cores were collected and among them the presently studied NS-3. This core was taken at a water depth of 490m and presents a recovery of 98%. Due to its excellent state of preservation and high degree of recovery, core NS-3 is considered representative for the sedimentary development of the basins situated between Nisyros and Kos islands and will be paleoecologically studied in detail.

The present study aims firstly, to the biostratigraphical assignment of the NS-3 core sediments, secondly it is a first attempt to establish assemblage intervals relative to the development of the paleoenvironment and further, it addresses the question in how far an unterlying, relatively shallow magma chamber and its products, could have affect the calcareous nannoplankton due to alteration of the physicochemical parameters of the overlying sea-water column.

---

[1] Geology Dept., Lab. of Paleontology, Patras Univ., GR-26500 Patras, drbellas@zedat.fu-berlin.de

[2] Environmental Studies Dept., (former "Xenia" Building), Aegean Univ., GR-81100 Lesvos, sbellas@aegean.gr

[3] Geology Department, Ottawa University & Chemistry Department, Concordia University, Canada

LITHOLOGY OF CORE NISYROS 3 (NS-3)

Core NS-3 (fig. 1)was studied due to its excellent state of preservation and 98% recovery degree. It has a total length of 330cm. Lithologically, its sediments almost completely consist of light olive grey to olive grey silt to mud. The upper 20cm are oxidized due to contact with the sea-bottom water. The silty-muddy lithological continuity of the core is interrupted by five significant events (I-V), which are represented by five lithological units from top to bottom: **I**) a sandy layer at 40cm depth, **II**) an ash-layer from 57 to 68cm with light grey to whitish colour, which displays grain size from sand to silt and is rich in clear glass shards, **III**) the latter overlies sapropel S1, which in core NS-3 consists of an upper and a lower part. The upper part occurs at 91 to 103cm (15cm in thickness). The lower part occurs at 104 to 123cm being 18cm thick. Near its base small balls have been observed and the contact towards normal sedimentation conditions is a gradual one. **IV**) At 200cm depth, sediment colour becomes yellowish and develops a hard, muddy texture. At 236cm the soft olive grey sediments reappears. The 36cm of this yellowish, hard, muddy sediments appears to have small angular debris. The interpretation of its origin is discussed further below. **V**) From 306cm down to the base of core NS-3 at 330cm, a dark olive grey layer occurs, dominated by tephra. The tephra consists of light grey to whitish grey pumice in the size of lapilli embedded in a shard-rich matrix. Shards consist of glass and pumice. Larger vacuoles in the pumice (Plate 1) are filled by authigenic minerals. The glass shards are of sand to silt size, have a fluidal shape with many intersections and pipe vacuoles (Plate 1) indicative of a Plinian origin. AMS dating of this tephra gave an age of 22900±150 yr BP (Papanikolaou pers.comm., 2001; Bellas et al., 2001).

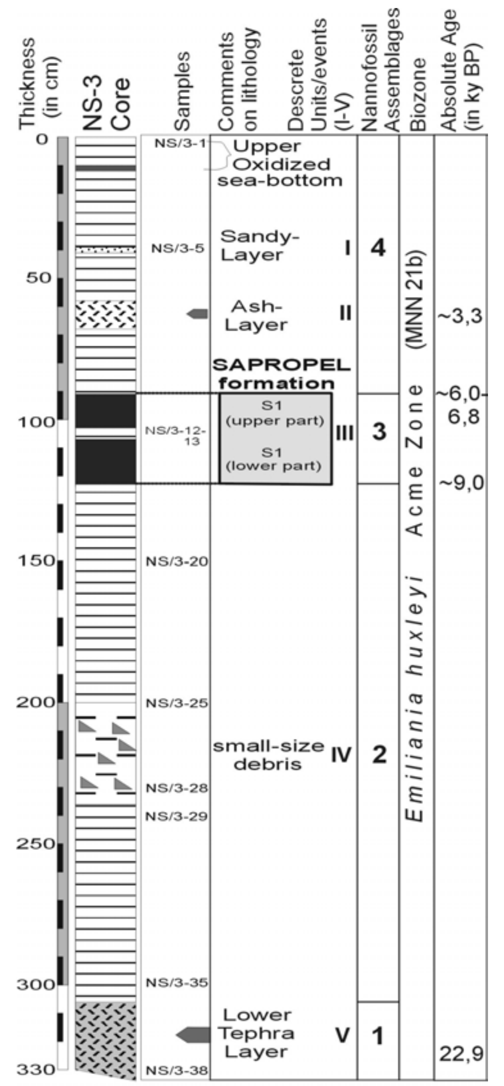


Fig.1: Lithology, biostratigraphy, age and assemblage-zones of NS-3 core, Aegean

BASINAL CONDITIONS AFFECTED BY HYDROTHERMAL VENTING

The near shore coastal regions of Kos were among the sites of hydrothermal venting selected for study in the Aegean Hydrothermal Fluxes and Biological Production Project. The aims of this project were to estimate the fluxes of fluids, chemicals, heat and bacterial from hydrothermal venting (Dando et al., 2000).

Mixing of hydrothermal reservoir waters with sea-water and vapour condensates results in H_2O compositions ranging from nearly sea-water with slightly reduced pH to higher or lower salinity fluids with a pH as low as 3 and with large enrichments in heavy and trace metals. An earlier study by Varnavas & Cronan (1991) has shown that both, waters and sediments in two submarine hydrothermal fields off the coasts of Kos and Yali, were enriched in Fe, Mn and Zn, with As, Mo and V, enriched in the sediments only. The dry gas phase in these exhalations was mainly CO_2, but with significant amounts of H_2S, CH_4 and H_2.

SELECTED CALCAREOUS NANNOFOSSILS PALEOECOLOGICAL RANGES AND LIMITS

The gephyrocapsids have been widely and variously, though partly controversially, utilized as paleotemperature and generally paleoceanographic proxies. *Gephyrocapsa oceanica* particularly, due to its relatively large size has been studied in great detail (Bollmann, 1997 and references therein). It is considered to be an eurythermal taxon living in the range of 12 to 31°C. In the Recent waters of western North Atlantic, *G. oceanica* shows its optimum temperature range usually above 12°C (Okada & McIntyre, 1979). In surface sediments of North Pacific this taxon dominates assemblages of warm and moderately nutrient-rich waters (Roth & Coulbourn, 1982). In the Mediterranean, this species is related with low salinity surface waters (KNAPPERTSBUSCH, 1993), though ROTH (1994) suggested that it may tolerate higher salinities in the range of 45-51‰. In the present Mediterranean Sea, *G. oceanica* occurs abundantly together with *Emiliania huxleyi* (WINTER et al., 1994). The tolerance of *G. ericsonii*, a small in size species of the same genus, ranges between 12 to 27°C and presents its maximum abundance between 13 and 22°C.

Coccolithus pelagicus, is generally considered to be a "cool-water" indicator since the late Pleistocene (MCINTYRE, 1967; MORLOTTI & RAFFI, 1981, FLORES et al., 1997). It prefers high nutrient concentrations (ROTH, 1994). In our samples *C. pelagicus* is practically absent, thus pointing to relative warm-water and oligotrophic conditions.

CALCAREOUS NANNOPLANKTON

Calcareous nannofossils from the NS3 core have been studied in very detail both in the SEM (Plate 2) and under normal polarizing light (LM). According to the high abundance (>20% in the total assemblage) of *E. huxleyi*, the whole core is biostratigraphically placed in the *Emiliania huxleyi* Acme Zone (coded MNN 21b) of RIO et al. (1990). Concerning the paleoecology, several of the recorded nannofossils are present in the Mediterranean Sea today, thus, providing us with a good paleoenvironmental proxy tool. Most assemblages of the NS-3 core show moderate paleodiversity patterns of twenty to thirty species, probably related to the oligotrophic character of the eastern Mediterranean (BELLAS et al., 2001), but major differences were recorded in particular calcareous nannofossil associations. These may concern on 1) the constitution of each assemblage, 2) the diversity of species in the assemblages at selected levels of the core and 3) variations in the abundances of various nannoflora species among the studied samples. It was possible to recognize four assemblages (1-4 in Figure 1) following below from bottom to top:

Tephra layer samples (Assemblage 1, interval within event V)

A typical calcareous nannofossils assemblage of the bottom core samples within the so-called Lower Ash-layer (BELLAS et al., 2001) mainly consists of *E. huxleyi*. *Helicosphaera carteri*, *Rhabdosphaera* sp. and overgrown *Syracosphaera pulchra* are subordinate species and occur in very rare abundances or they are simply present. Alteration of the *E. huxleyi* coccoliths is very obvious, probably due to the tephra input. Gephyrocapsids are absent from this assemblage.

Samples between the tephra layer and Sapropel S1 (Assemblage 2, event IV)

In the samples located directly above the tephra, *E. huxleyi* dominates again the assemblage, but *Sy. pulchra* is also found in low abundances. Five other species consist the rest nannoflora, among them a holococcolith: *Calcidiscus leptoporus*, *Holodiscolithus macroporus* (holococcolith), *Oolithotus fragilis*, *Rhabdosphaera clavigera*, *Syracosphaera mediterranea*. Ascidian spicules are also present in these samples. It is very surprisingly the absence of *G. oceanica* and generally of nannofossils of this taxon, which normally represents in similar age sediments almost the half or more of the total association.

In the next samples up to the S1, *H. carteri* abundance increases, though heavily affected by alteration. *E. huxleyi* remains the dominant species and *Sy. mediterranea* and *Sy. pulchra* continue upwards in low abundance. Very rare and small representatives of the gephyrocapsids occur sporadically, as well as few globigerinids planktonic foraminifera (Plate 1f). Recovering of the calcareous nannofossil assemblage above the tephra layer seems to have occurred very fast, with the exception of gephyrocapsids.

Sapropel S1 (Assemblage 3, within event III)

The calcareous nannofossil assemblage of the sapropel S1 in the western Ionian Sea, are generally of low total abundance and preservation (NEGRI et al, 1999). Our present data from the Aegean Sea confirm and extend these observations to the eastern Mediterranean Sea as well. With the exception of *E. huxleyi* which is few to common, *H. carteri*, *Rh. clavigera*, *Scapholithus fossilis* and *Umbilicosphaera sibogae* are all present in rare to few fluctuating frequencies. Gephyrocapsids are usually small in size and rare.

Samples above Sapropel S1 to Present (Assemblage 4, interval between event III and sea-bottom)

This assemblage generally consists of calcareous nannofossils still living today and is representative of the present diversity. *E. huxleyi* is the dominant species (usually >20% of the whole nannoflora). Twenty to thirty species have been identified in this stratigraphic interval of the core. Among them, *C. leptoporus* is common, while *Helicosphaera hyalina*, *H. wallichii*, *Pontosphaera* *discopora, Rh. clavigera*, *Syracosphaera histrica* and *Sy. lamina* are few. Other subordinate species include the *Discosphaera tubifera*, various Gephyrocapsids, Pontosphaerids, *S. fossilis*, *Scyphosphaera apsteinii*, Thoracosphaerids, Umbilicosphaerids and very rare and sporadic *Florisphaera profunda*, a species usually found in the western and central Mediterranean Sea in high abundances. At the uppermost layers moderate alteration exists, due to oxidation of the sediments, coming in direct contact with the sea-water.

DISCUSSION-CONCLUSIONS

Calcareous nannofossil Assemblage 1 occurs at 306 to 330cm of NS-3, in a tephra of ash to lapilli size pumice of rhyolitic, calc-alcaline composition (Seymour unpublished data). The AMS age of this tephra is 22900±150yr BP (D. Papanikolaou pers. com. 2001). Nisyros has exploded at 31000 and 36000 yr BP (Hardiman, 1996) resulting in deposits of rhyodacitic bulk composition (Seymour & Vlasopoulos, 1992). The Plinian tephra of the volcano of Yali was deposited ca. 31000yrs BP (Keller et al., 1978) and has rhyolitic bulk composition (Seymour, 1996). Despite the apparent discrepancy between the AMS age from the tephra of the NS-3 core, and the ages reported for the most recent Plinian events for Nisyros and Yali, we correlate the NS-3 tephra due to its rhyolithic composition with the Yali event.

From the studies of Papadopoulos (1984) and Nomikou & Papanikolaou (1999), as well as from earlier volcanological observations (Di Paola, 1974) it becomes apparent that the area between Nisyros and Kos overlies an active and rather extensive subvolcanic magma chamber. From the studies of Dando et al. (2000) and Varnavas & Kronan (1991) in submarine basins between Nisyros and Kos, it is apparent that hot hydrothermal exhalations (350-100°C) are actively mixing with sea-water, resulting in the lowering of its pH, altering its salinity and charging it with trace elements like Fe, Mn and Zn and dry gas components such as CO_2, H_2S, CH_4 and H_2.

Since the effect of temperature exceeds the effect of trace element dissolution on the density of the brines, these will rise in the water basin and will mix with normal sea-water. Mixing will be more effective when the water level in the basin is considerably lowered, as for example it probably was in the Last Glacial Maximum that has ended at 16 to 18 kys BP approximately. NS-3 core was obtained from a depth of 490m. We venture to say that during the LGM this depth was decreased down to ca. 370m.

It has been suggested that total abundances of *Gephyrocapsa* consistently decreased from the Late Glacial period to the Holocene (Wei et al., 1997). *G. oceanica* particularly, is usually present in great abundance during warm periods or generally interglacials. Therefore, high *Gephyrocapsa* abundances had to be expected in the lower part of the studied core, directly below the sapropel S1 down to the tephra layer. As it was mentioned above, *G. oceanica* is an eurythermic organism living in the range of 12 to 31°C and would tolerate salinities of 41 to 51^{0}/00, although it would prefer a salinity of less than 38^{0}/00. Temperature fluctuations were not probably that extreme to cause the decimation of *Gephyrocapsa* in NS-3 calcareous nannofossil Assemblages 1 to 3, since the "cool" water indicator *C. pelagicus* is absent and the other calcareous nannofossils are present in the aforesaid assemblages.

In Assemblage 1 which occurs in the lower NS-3 tephra of the 31000 yr BP explosion of Yali, the turbidity caused by the lapilli and ash-size airfall in the basin has decimated all, but the most resilient calcareous nannofossil species. The most abundant of this, *E. huxleyi*, is reported to display high tolerance in water turbidity (Wei et al., 1997).

However, additional arguments have to be presented for the paucity of gephyrocapsids where one would not expect extreme water turbidity volcanically induced. Some significant turbidity would have probably been caused by the high amounts of terrigenous material introduced into the basin during the deglaciation period, when melting of ice to the north, eroded and transported such material from the surrounding landmass into the basin. This may also be supported by the absence of *F. profunda*, a nannofossil which prefers clear water (Wei et al., 1997). The sedimentation interval which has lasted approximately 6500 yrs, from the beginning of Termination 1A (ca. 15000 yr BP) to the end of Termination 1B (ca. 8500 yr BP), was characterized by a warm event (from ~13300 to ~10000 yr BP). The knobby sediment from 200 to 236cm in NS-3 core may probably be related to the deglaciation, postdating the previous warm event. Additional transient events adding ash in the Kos-Nisyros basin would be the two Plinian eruptions of Thera volcano at ca. 18000 and 12000 yr BP respectively (Federman & Carey, 1980; Pichler & friedrich, 1976).

Even if not corroborated by rigorous quantitative arguments, it is probably safe to propose here, that the paucity of gephyrocapsids in Assemblage 2 of NS-3 was caused by a combination of terrigenous postglacial erosion and transient volcanically-induced turbidity with mixing of the lowered basinal waters with volcanic exhalations which had effects, however transient and local, on the pH, salinity and water poisoning with dissolved trace elements.

AKNOWLEDGEMENTS

Prof. D. Papanikolaou (National & Kapodistrian Univ. of Athens and General Secr. for Civil Protection) is warmly thanked for giving the permission (as former Director of NCMR) to S. Bellas for sampling-studying gravity cores obtained by the R/V Aegaio from the E. Aegean Sea. Drs. V. Lykousis, D. Sakellariou and G. Rousakis (all NCMR) provided useful geological information and made easier sampling while in NCMR. SEM facilities were kindly supplied by Prof. H. Keupp (Inst. of Geosciences, Paleont. Div., FU-Berlin). IKY has financially supported one year Postdoc. Research of S.Bellas and is from this position faithfully aknowledged.

REFERENCES

[1]Bellas, S.M., Lykousis, V., Sakellariou, D., Nomikou, P., Frydas, D. & Papanikolaou, D. (2001): Palaeoenvironmental conditions prevailed during the Upper Pleistocene to Recent development of the submarine basins surrounding the Nisyros Island, Aegean Volcanic Arc, eastern Mediterranean: First results based on micropalaeontology of the NS-3 core.- In: Roth, S. & Rueggeberg, A. (Eds.), 2001 MARGINS Meeting, Program & Absts., *Schrift. der DGG*, **14**: 22; Kiel.

[2]Bollmann, J. (1997): Morphology and biogeography of Gephyrocapsa coccoliths in Holocene sediments.- *Mar. Micropaleontol.*, **29**: 319-350.

[3]Dando, P.R. et 24 al. (2000): Hydrothermal studies in the Aegean Sea.- *Physics and Chemistry of the Earth, Part B: Oceans and Atmosphere*, **25**(1): 1-8.

[4]Di Paola, G.M. (1974): Volcanology and petrology of Nisyros island (Dodecanese, Greece).- *Bull. Volcanol.*, **38**: 944-987.

[5]Eastwood, W.J., Tibby, J., Roberts, N., Birks, H.J.B. & Lamb, H.F. (2002): The environmental impact of the Minoan eruption of Santorini (Thera): statistical analysis of palaeoecological data from Gölhisar, southwest Turkey.- *The Holocene*, **12**: 431-444.

[6]Federman, A.N. & Carey, S.N. (1980): Electron microprobe correlation of tephra layers from eastern Mediterranean abyssal sediments and the Island of Santorini.- *Quaternary Research*, **13**: 160-171.

[7]Flores, J.A., Sierro, F.J., Francés, G., Vázquez, A., Zamarreño, I. (1997): The last 100,000 years in the western Mediterranean: sea surface water and frontal dynamics as revealed by coccolithophores.- *Mar. Micropal.*, **29**: 351-366.

[8]Fytikas, M., Innocenti, F., Manetti, P., Mazzouli, R., Peccerillo, A. & Villari, L. (1984): Tertiary to Quaternary evolution of volcanism in the Aegean region.- In: Dixon, J.E. and Robertson, A.H.F. (Eds.), "The Geological Evolution of the Eastern Mediterranean", pp. 687-699; Blackwell, Oxford.

[9]Hardiman, J.C. (1996): Volcanology and dating of the caldera phase eruptions on Nisyros volcano, Greece.- In: Barberi, F., Casale, R. & Fantechi, R. (Eds.), Course Proceedings "*The mitigation of volcanic hazards*", Vulcano, Italy, 12-18.06.1994, pp. 519-522; ECSC-EC-EAEC, Brussels, Luxemburg.

[10]Keller, J., Ryan, W.B.F., Ninkovich, D. & Altherr, R. (1978): Explosive volcanic activity in the Mediterranean over the past 200,000 yrs as recorded in deep-sea sediments.- *Bull. Geol. Soc. Amer.*, **89**: 591-604.

[11]Knappertsbusch, M. (1993): Geographic distribution of living and Holocene coccolithophores in the Mediterranean Sea.- *Mar. Micropaleontol.*, **21**: 219-247.

[12]McIntyre, A. (1967): Coccoliths as Paleoclimatic indicators of Pleistocene Glaciation.- *Science*, **158**: 1314-1317.

[13]Morlotti, E. & Raffi, I. (1981): Climatic fluctuations in the Tyrrhenian Sea (cores BS 77-15 and BS 78-13).- In: Wezel, F.C. (ed.), "Sedimentary basins of Mediterranean margins", pp. 163-172; Bologna.

[14]Negri, A., Capodonti, L. and Keller, J., 1999. Calcareous nannofossils, planktonic foraminifera and oxygen isotopes in the late Quaternary sapropels of the Ionian Sea.- *Mar. Geology*, **157** : 89-103.

[15]Nomikou, P. & Papanikolaou, D. (1999) : 2. Detection of submarine volcanoes in the Kos-Nisyros area.- *Newsletter of the European Centre on Prevention and Forecasting of Earthquakes*, **3**: 12-14.

[16]Okada, H. & McIntyre, A. (1979): Seasonal distribution of modern coccolithophores in the western North Atlantic Ocean.- *Marine Biol.*, **54**: 319-328.

[17]Papadopoulos, G.A. (1984): Seismic properties in the eastern part of the south Aegean volcanic arc.- *Bull. Volcanol.*, **47**: 143-152.

[18]Papanikolaou, D.J., Lekkas, E., Sakellariou, D. & Nomikou, P. (1998a): 2. The Nisyros Volcano (Progress Report of Research Project).- *Newsletter of the European Centre on Prevention and Forecasting of Earthquakes*, **2**: 13-14.

[19]Papanikolaou, D.J., Nomikou, P., Lykousis, V. (1998b): 6. Submarine Reconnaisance (Progress Report of Research Project).- *Newsletter of the European Centre on Prevention and Forecasting of Earthquakes*, **2**: 23-26.

[20]Pichler, H. & Friedrich, W. (1976): Radiocarbon dates of Santorini volcanics.- *Nature*, **262**: 373-374.

[21]Rio, D., Raffi, I. and Villa, G., 1990. Plio-Pleistocene calcareous nannofossil distributions patterns in the western Mediterranean. In: K.A. Kastens, J. Mascle, et al., *Proc. ODP, Sci. Results*, **107**: 513-533.

[22]Roth, P.H. (1994): Distribution of coccoliths in oceanic sediments.- In: Winter, A. & Siesser, W.G. (Eds.), "Coccolithophores", pp. 199-218; Cambridge Univ. Press/New York.

[23]Roth, P.H. & Coulbourn, W.T. (1982): Floral and solution patterns of coccoliths in surface sediments of the North Pacific.- *Mar. Micropaleontol.*, **7**: 1-52.

[24]Seymour, K.St. & Vlassopoulos, D. (1992): Magma mixing at Nisyros volcano, as inferred from incompatible trace-element systematics.- *Journal of Volcanol. and Geothermal Research*, **50**: 273-299.

[25]Seymour, K.St. (1996): Geochemistry of the Yali volcano rhyolites and their relationship to the volcanic products of Nisyros, Aegean Volcanic Arc.- *N. Jb. Miner. Mh.*, **1996** (2): 57-72.

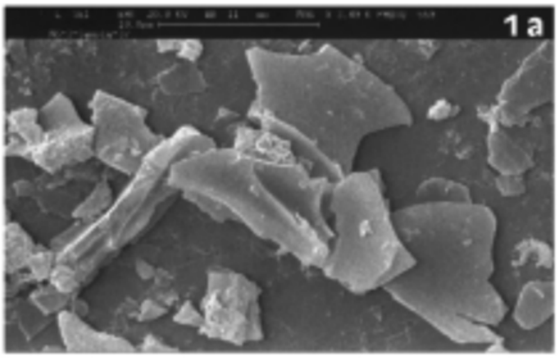
[26]Steinmetz, J.C, & Anderson, T.F. (1983/84): The significance of isotopic and paleontologic results on Quaternary calcareous nannofossils assemblages from Caribbean Core P6304-4.- *Marine Micropaleontology*, **8**: 403-424.

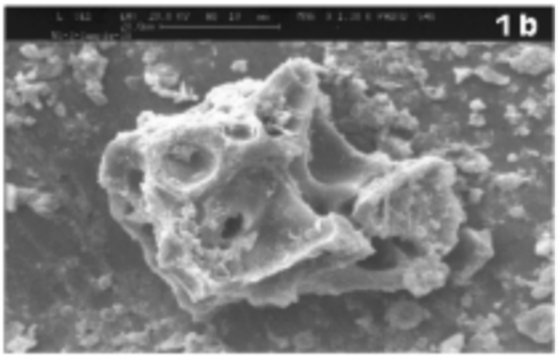
[27]Varnavas, S.P. & Kronan, D.S. (1991): Hydrothermal metallogenic processes off the islands of Nisiros and Kos in the Hellenic Volcanic Arc.- *Mar. Geology*, **99**: 109-133.

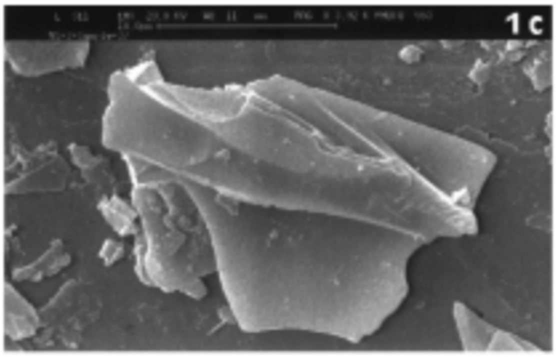
[28]Wei, K.-Y., Yang, T.-N., Huang, C.-Y. (1997): Glacial-Holocene calcareous nannofossils and paleoceanography in the northern South China Sea.- *Mar. Micropaleontol.*, **32**: 95-114.

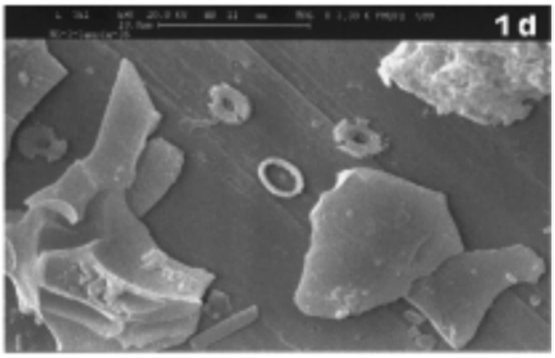
[29]Winter, A., Jordan, R.W. & Roth, P.H. (1994): Biogeography of living coccolithophores in ocean waters.- In: Winter, A. & Siesser, W.G. (Eds.), "Coccolithophores", pp. 161-167; Cambridge University Press/New York.

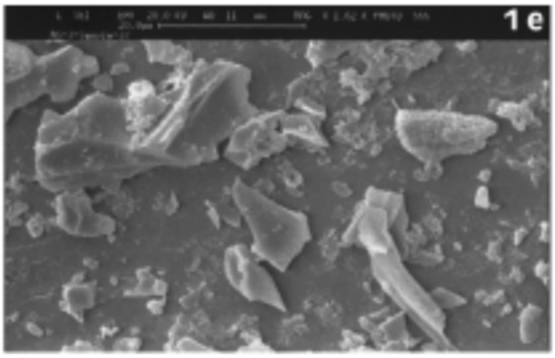
PLATE 1

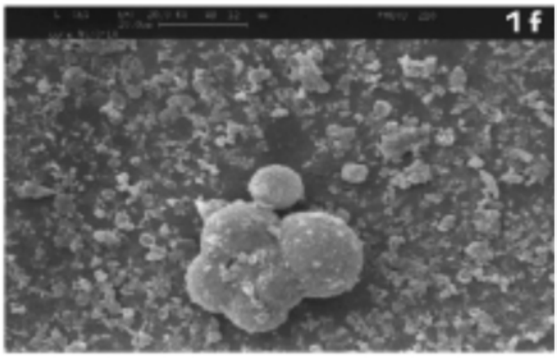








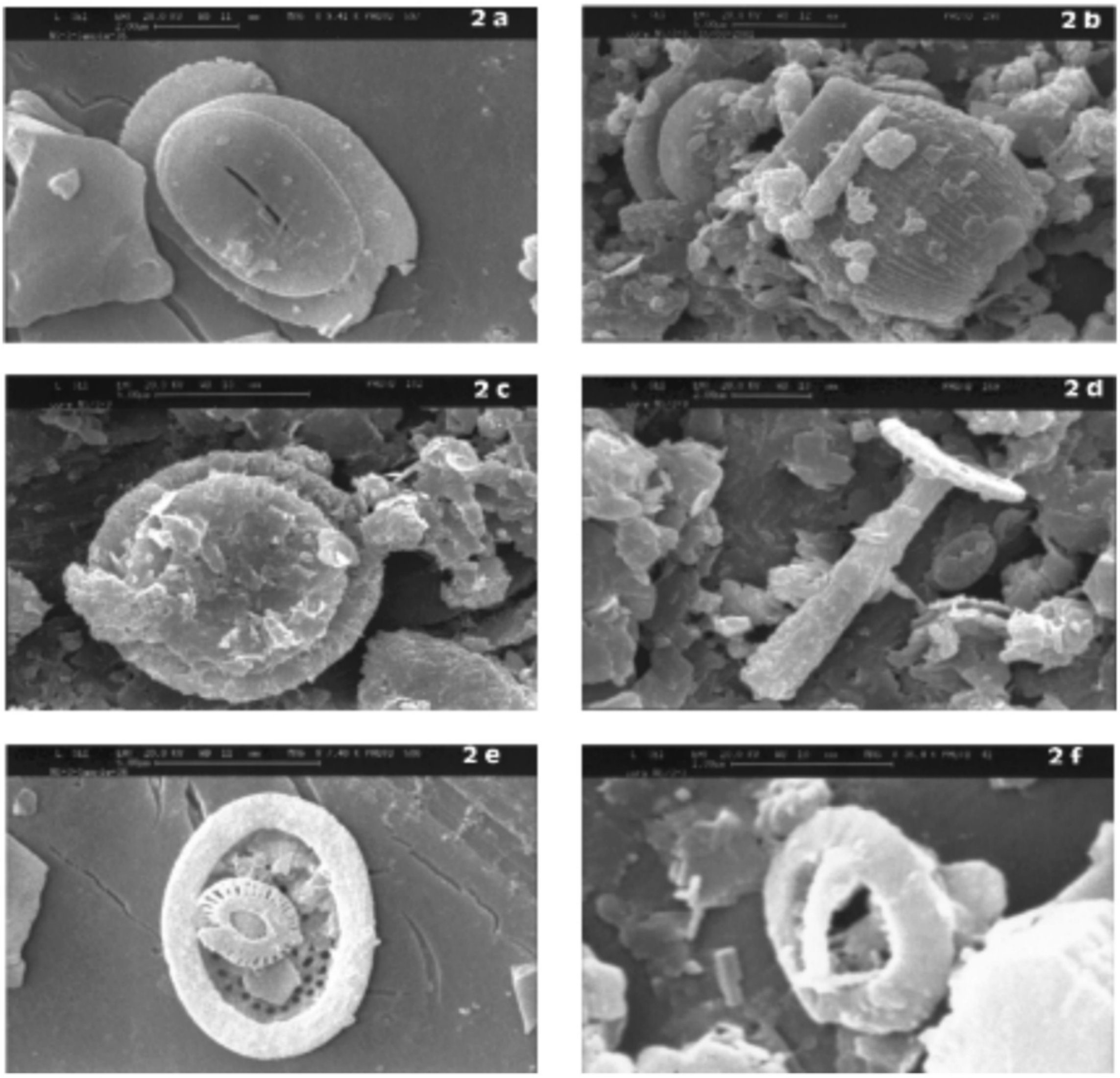




SEM photos (1a to 1e) are from the lower tephra layer of core NS-3 (fig.1), coexisting with assemblage 1 (see text and fig. 1). 1f refers to calcareous nannofossil assemblage 2 in the text (and fig. 1).

1a. Platy, delicate, felsic glass shards with fluidal textures, Y intersections and pipe, elongate vesicules. Many are overgrown by authigenic minerals. White bar in black border is 10 microns.
1b. Felsic pumice shard displaying extreme vesiculation. It is strongly overgrown by authigenic minerals. Size bar is 20 microns.
1c. Y-shaped, glass shard appears in pristine condition. Felsic shards with this morphology characterize intensely explosive i.e. Plinian eruptions. Nisyros and Yali have exploded in the recent past in a Plinian fashion. Size bar is 10 microns.
1d. Platy, Y-shaped felsic shards and coccoliths of *Emiliania huxleyi* and *Syracosphaera* sp. Size bar is 10 microns.
1e. Y- and fluidal-shaped shards with pumice fragments in a background of coccoliths. Size bar is 10 microns.
1f. Planktonic foraminiger (*Globigerina* sp.) in a background of coccoliths (assemblage 2 in fig. 1 and in the text). Size bar equals 20 microns.

PLATE 2



SEM microphotos of typical calcareous nannofossils from the assemblages established for the NS-3 core. For scale note the white bar in the top black border.

2a. *Helicosphaera carteri* and glass shard to the left. It appears in a very good state of preservation. It refers to assemblage 2 in fig. 1 and in the text. Bar equals 2 microns.

2b. *Scyphosphaera apsteinii*, side view. It appears in a good state of preservation. It refers to assemblage 4 in fig. 1 and in the text. Bar equals 5 microns.

2c. *Calcidiscus leptoporus*. Proximal view of alterated coccolith located directly above the lower tephra layer. It refers to assemblage 2 in fig. 1 and in the text. Bar equals 2 microns.

2d. Moderately overgrown coccolith of *Rhabdosphaera clavigera* from the sapropel layer S1. It refers to assemblage 3 in fig. 1 and in the text. Bar equals 2 microns.

2e. Note the size difference between *Pontosphaera discopora* and *Emiliania huxleyi*. Both are well preserved. Bar equals 5 microns.

2f. *Gephyrocapsa* Oligotroph (after BOLLMANN, 1997). Small coccolith, moderately preserved. It refers to assemblage 4 in fig. 1 and in the text. Bar equals 1 micron.