| Πρακτικά | 6ου Συνεδρίου | | Μάϊος 1992 |
|---|---|---|---|
| Δελτ. Ελλ. Γεωλ. Εταιρ. | Τομ. XXVIII/3 | σελ. 99-115 | Αθήνα 1993 |
| Bull. Geol. Soc. Greece | Vol. | pag. | Athens |


# SANTORINI, PART OF THE HELLENIC ARC: AGE OF THE EARLIEST VOLCANISM DOCUMENTED BY FORAMINIFERA


M.SEIDENKRANTZ*, W.L.FRIEDRICH*



## ABSTRACT

Volcanic dacitic tuffs are interbedded with fossil bearing marine deposits at several places on the Akrotiri Peninsula on the island of Thera, Santorini (Greece). Palaeontological data from these deposits facilitate dating of the earliest volcanism in the region.

Two different marine environments can be documented:

1) A littoral to inner neritic palaeoenvironment (water depth: 0-25 m) with mainly benthic foraminifera was encountered at Mt. Archangelos and Mt. Loumaravi. This observation is supported by the occurrence of beach gravels of volcanic origin in the fossiliferous deposits at Mt. Archangelos.

2) An upper epibathyal environment (water depth exceeding 100 m) dominated by planktic foraminifera is documented on the caldera wall of Cape Loumaravi. These foraminifera are registered in lenses of marine marl interbedded in the volcanic tuffs.

The analysis of foraminifera from the Archangelos-Loumaravi area combined with absolute dates on volcanic material from the Akrotiri Peninsula, show that the marine deposits have an age of maximum 2.0 Ma and minimum 1.6 Ma. The beginning of the volcanism on Santorini predates the marine deposits of the Akrotiri area. Our data, thus, indicate that volcanism on Santorini was initiated during the Pliocene or even earlier.


## INTRODUCTION

The islands of Santorini, Greece, are situated in the central part of the Hellenic Island Arc (Fig. 1). This arc of volcanic islands is generated by the collision of the African and Eurasian lithospheric plates. According to calculations of the collision rate and to radiometric data volcanism in the island arc must have been initiated during the Pliocene (BARBERI et al. 1974; FERRARA et al., 1980; FYTIKAS et al. 1986/1987). Santorini is the only active volcano in the Hellenic Arc today.

Santorini consists of volcanic products draped over a pre-volcanic island complex of Mesozoic and Early Cainozoic semimetamorphic sediments, the Mt. Profitis Elias Complex. The earliest volcanism and the doming connected to this created a volcanic island in the area of the present Akrotiri Peninsula, only a few kilometres to the west of the old non volcanic island complex (Fig. 2). The volcanic products are interbedded with deposits of marine origin on the Akrotiri Peninsula. These marine relicts are documented from several localities (Fig. 3).


Department of Earth Sciences, University of Aarhus, DK-8000 Århus C (Denmark)

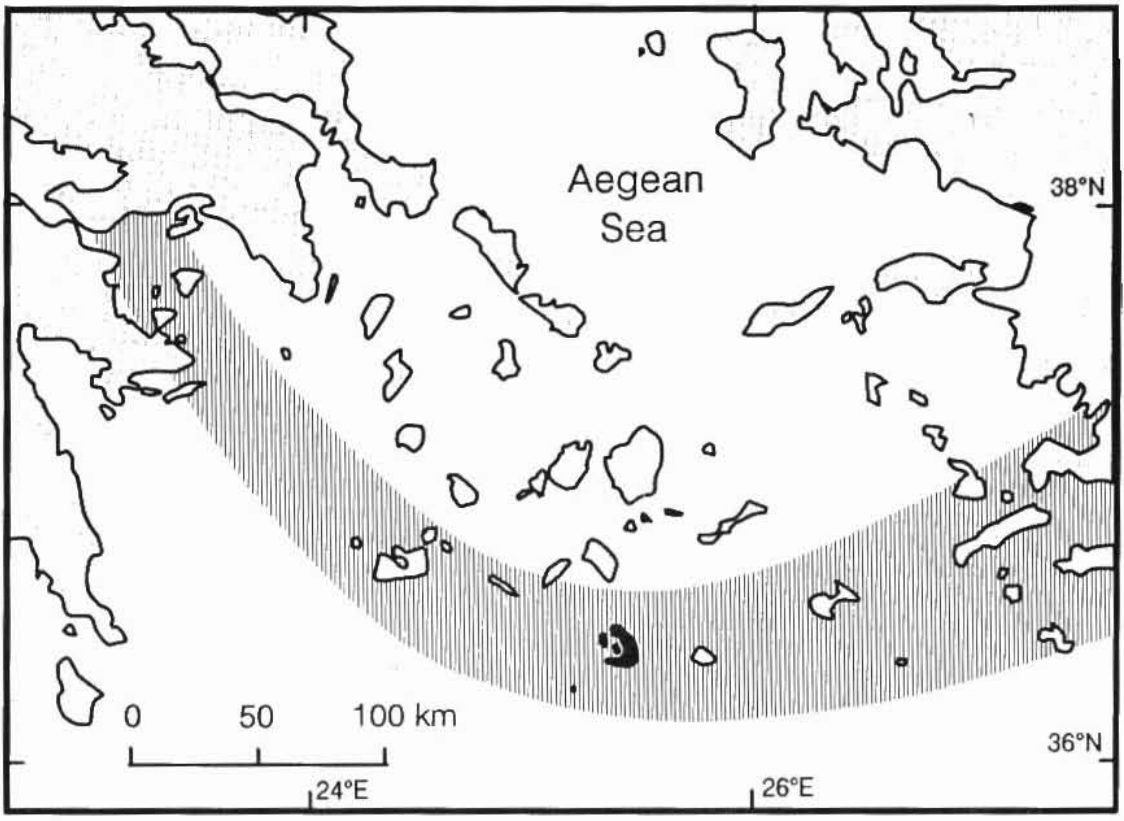


Fig. 1. Map of the Hellenic Arc in the Aegean Sea. Santorini (dark) is at present the only active volcano in this island arc.

At the lighthouse (Fanari), on the easternmost point of the Akrotiri Peninsula, the marine deposits are reddish in colour and seem to consist almost exclusively of spicules of silicious sponges (K. Pauluskova, pers. comm., 1987) (Figs. 3, 4). They are overlain by brecciated pillow lava.

The Archangelos - Loumaravi Complex consists of white dacitic tuffs ($A_1$-Tuffs of PICHLER and KUSSMAUL, 1980) containing marine faunas of invertebrate macrofossils and foraminifera. The faunas were discovered by A. Stübel and mentioned as early as in 1871 by VON FRITSCH and in 1879 by FOUQUÉ. They both allocated a Late Pliocene age for the tuffs. More recently this chronostratigraphical interpretation has been supported by SAUVAGE and JARRIGE (1978) on the basis of palynomorphs from the Akrotiri Peninsula.

The fossiliferous tuffs and sediments on the Akrotiri Peninsula are considered to be raised by updoming during the earliest volcanism on Santorini (e.g. VON FRITSCH, 1871; PICHLER and KUSSMAUL, 1972). Hence, the faunas give a unique possibility to date this volcanic updoming. Furthermore, the palaeoecology indicated by the faunas may contribute to the understanding of the palaeogeography during the deposition of the marine sediments. Thus, the present data give additional informations about the earliest history of the Hellenic Arc.

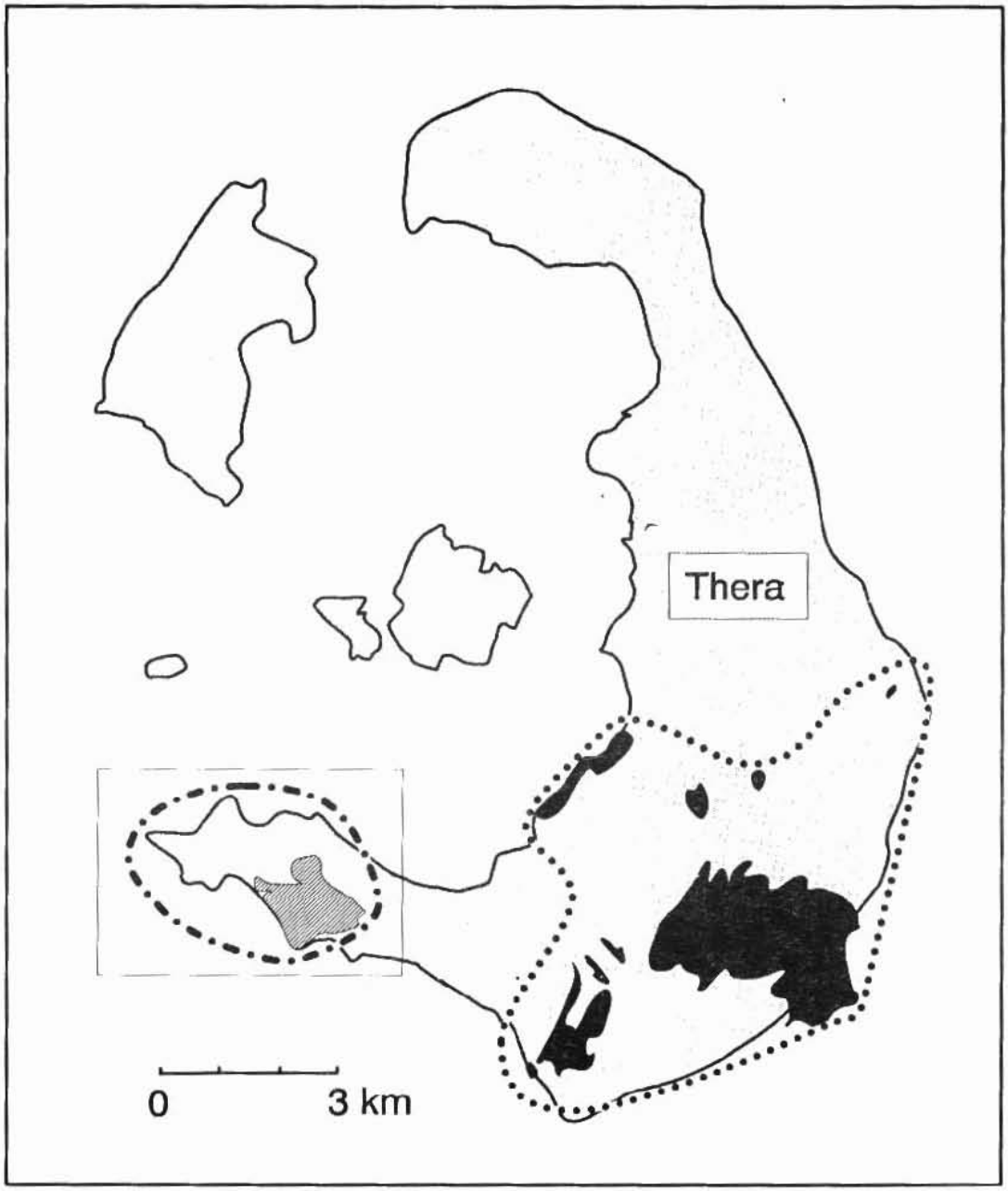


Fig. 2. Map of Santorini illustrating the present relicts of the two islands, which existed after the doming process on the Akrotiri Peninsula. Black: the non volcanic Mt. Profitis Elias Complex. Hatched: the volcanic Archangelos-Loumaravi Complex (after PICHLER and KUSSMAUL, 1980). The dotted line marks the presumed extension of the Mt. Profitis Elias Island Complex and the dot-and-dash line shows the presumed extension of the Archangelos-Loumaravi Island Complex.

Fig. 3. Fossil sponge reef overlain by brecciated lava near the lighthouse Fanari at the easternmost end of the Akrotiri Peninsula.

## MATERIAL AND METHODS

The foraminiferal content of the material was analyzed by the first author. A total of 119 samples (50-250 g each) from the Akrotiri Peninsula have been analyzed for their foraminiferal content. The samples were disintegrated by crushing with a hydraulic press before preparation using standard techniques. All specimens present in the 0.1-1.0 mm fraction were counted. The specimens were generally badly preserved and were often only present as casts. Due to bad preservation, it was not always possible to distinguish between Globigerinoides conglubatus and G. ruber, and these species have, therefore, not been counted separately.

Two samples from the reddish marine sediment at the lighthouse (Fanari, Figs. 3, 4) were analyzed, but they contained only sponge spicules. Of the remaining 117 samples only 21 samples contained foraminifera. Six of these had less than 10 specimens. Other fossil groups found were: algae, bivalves, bryozoans, crinoids, gastropods, ostracods, and sponge spicules.

The analysis of the foraminiferal faunas allowed distinction between 3 different faunal types from 4 localities (Fig. 4). The composition of each of these assemblages is listed in appendices A to C and the relative frequencies of different faunal elements are visualized in Figs. 5a, b.

## FORAMINIFERAL FAUNAS AND PALAEOECOLOGY

### Archangelos and Loumaravi area

The areas of Mt. Archangelos and Mt. Loumaravi are more or less uniformly covered by white, dacitic tuffs (VON FRITSCH, 1871; $A_1$-Tuffs of PICHLER and KUSSMAUL, 1980). Despite the great number of samples analyzed from the area marine fossils were only found in the tuffs at three small localities. These localities are:

1) Archangelos (Figs. 4, 6): A small outcrop of light grey sediments about 50 m from the church at Mt. Archangelos.

2) Akrotiri I (Fig. 4): A 1-2 $m^2$ outcrop found in the sidewall of a footpath in the easternmost part of the village Akrotiri.

3) Akrotiri II (Fig. 4): 1 $m^2$ of fossiliferous deposits from the eastern slope of Mt. Loumaravi, south of the village Akrotiri.

The foraminiferal faunas from Archangelos and Akrotiri I do not display noticeable differences and will, therefore, be presented together here. However, the fauna from Akrotiri II, is somewhat different and will be treated separately.

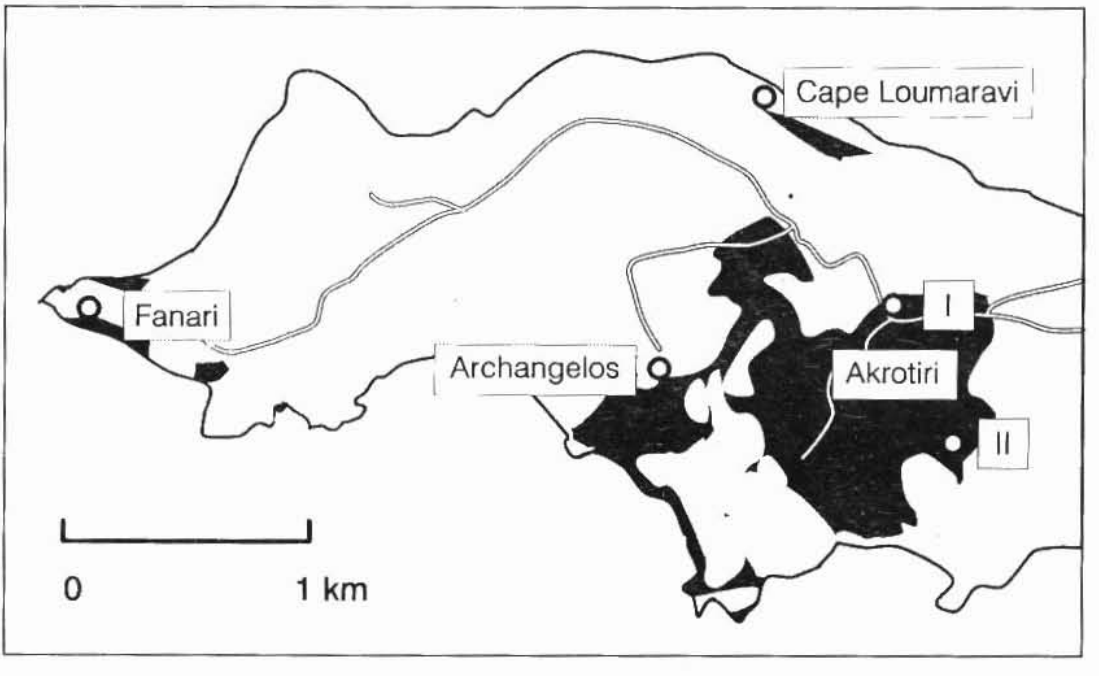


Fig. 4. Localities on the Akrotiri Peninsula: Fanari (lighthouse), Archangelos, Akrotiri I, Akrotiri II and Cape Loumaravi. $A_1$-Tuffs are illustrated by dark shading (Simplified after geological map by PICHLER and KUSSMAUL, 1980).

**Archangelos and Akrotiri I.** The foraminiferal assemblage (see Appendix A, Fig. 8) from Archangelos and Akrotiri I (Fig. 4) is dominated by benthic foraminifera and is characterized by Ammonia beccarii s.l., Elphidium spp., Cibicides lobatulus, Neoconcorbina millettii, Quinqueloculina spp., Asterigerinata mamilla, and Melonis barleeanus. Noteworthy also is the occurrence of the planktic species Globorotalia inflata.

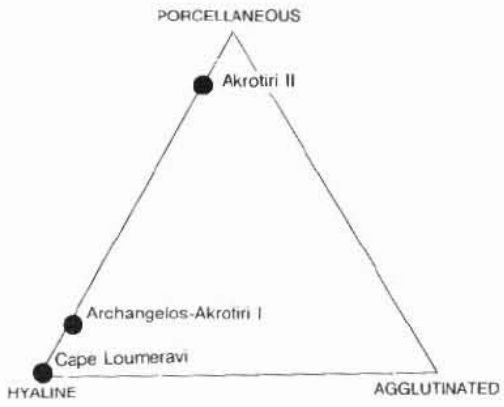


Fig. 5a. Composition of the benthic fauna grouped according to wall structure (porcellaneous, hyaline, and agglutinated).

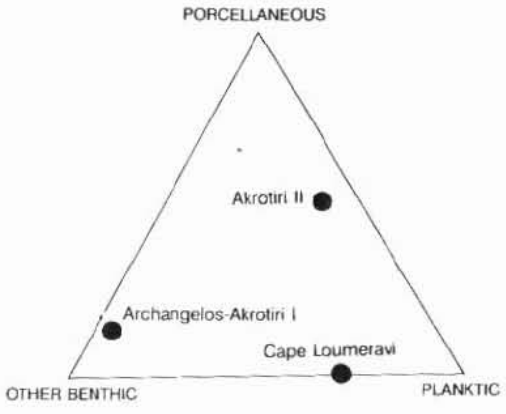


Fig. 5b. Composition of the total foraminiferal fauna (benthic and planktic) classified into porcellaneous, other benthic, and planktic groups.

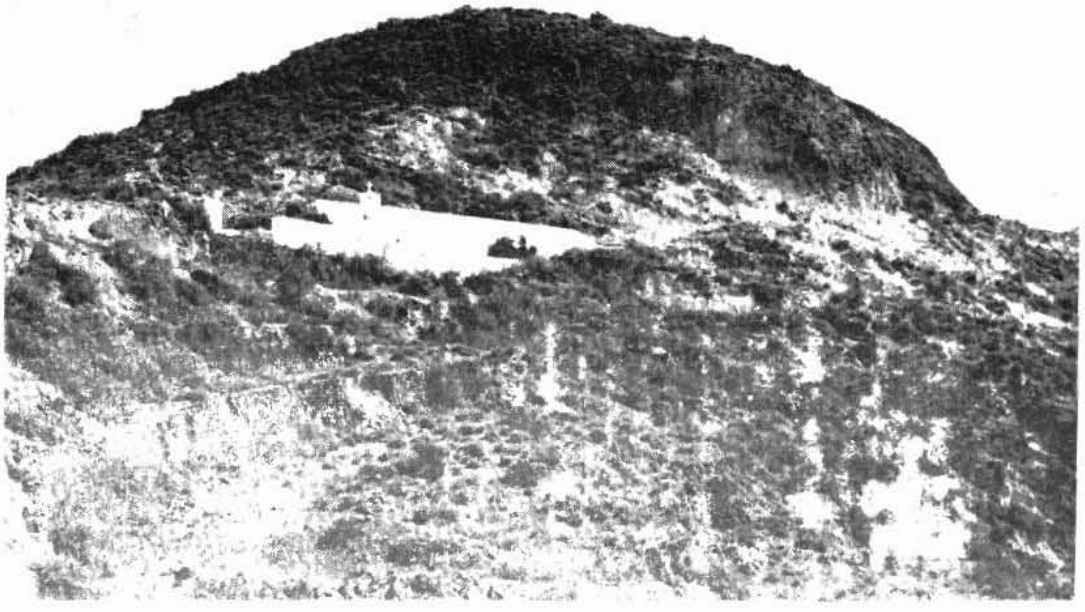

Fig. 6. The updomed hill of Mt. Archangelos.

The Elphidium species (e.g. E. crispum, E. macellum), are all flat, acute to carinate, epifaunal forms, which are characteristic of inner neritic and littoral environments (MURRAY, 1991). The majority of the other benthic foraminifera are also epifaunal, littoral to inner neritic species, which are mainly restricted to areas with sandy substrate or seaweed (PARKER, 1958; MURRAY, 1970, 1991; WRIGHT, 1978; JORISSEN, 1987). Furthermore, most of the specimens of A. beccarii belong to the tidal to near shore variety sobrina (TODD and BRONNIMANN, 1957, = Streblus beccarii, var. sobrina; SEIBOLD, 1971, = Ammonia sobrina). The composition of the benthic fauna, combined with the occurrence of only 4.6% planktic foraminifera indicates near-shore conditions. This interpretation is supported by the occurrence of rounded volcanic pebbles interbedded in the tuffs at the Archangelos locality (Figs. 6, 7). These pebbles are assumed to be beach gravel deposits.

Fig. 7. Rounded pebbles of volcanic origin interbedded in the tuffs at Mt. Archangelos (photo K.L. Knudsen).

Figure 3

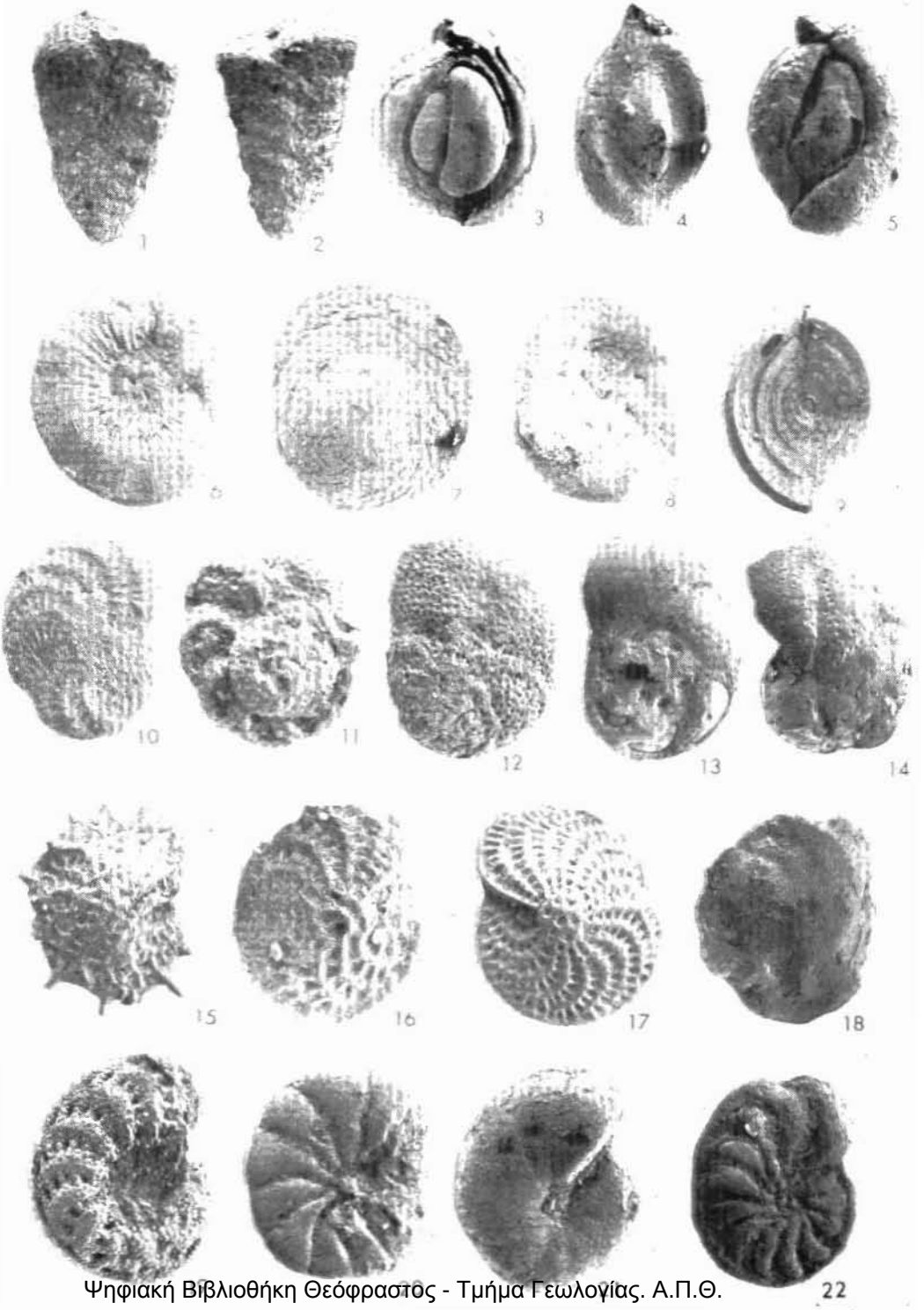

Fig. 8. The foraminiferal fauna from the localities Archangelos, Akrotiri I and Akrotiri II (Scanning Electron Microscope photographs): 1 Textularia pseudogramen, x 60. 2 Textularia pseudorugosa, x 25. 3 Miliolinella subrotunda, x 90. 4 Triloculina inflata, 60. 5 Quinqueloculina vulgaris, x 40. 6-7 Neoconcorbina millettii, x 80. 8 Asterigerinata mamilla, x 110. 9 Spiroloculina excavata, x 45. 10 Elphidium fichtellianum, x 60. 11 Rosalina aff. R. macropora, x 40. 12 Rosalina bradyi, x 95. 13 Stomatorbina concentrica, x 45. 14 Cibicides lobatulus, x 60. 15 Elphidium aculeatum, x 65. 16 Elphidium macellum, x 70. 17 Elphidium crispum, x 45. 18 Cassidulina laevigata, x 85. 19 Elphidium complanatum, var. tyrrhenianum, x 75. 20 Ammonia beccarii, var. sobrina, x 50. 21 Melonis barleeanus, x 75. 22 Nonion limbum, x 80.

Akrotiri II. The foraminiferal fauna (Appendix B) on the eastern slope of Mt. Loumaravi (Fig. 4) consists mainly of porcellaneous shelled species (e.g. Quinqueloculina, Triloculina, and Pyrgo), which comprise 83 % of the benthic fauna (Fig. 5a). This assemblage might represent a hypersaline, near-coastal environment (MURRAY, 1966, 1991), but the presence of 40 % plankic foraminifera such as Orbulina universa and Globorotalia inflata points to more open water conditions at a greater distance from the coast than indicated by the assemblages from the localities Archangelos and Akrotiri I.

### Cape Loumaravi

A major part of the caldera wall east of Cape Loumaravi (Fig. 4) is characterized by the white, dacitic tuffs, which were formed by the same updoming as registered at Mt. Archangelos and Mt. Loumaravi ($A_1$-Tuff, PICHLER and KUSSMAUL, 1980). However, during field work in 1989 marine faunas were only observed in a small outcrop at Cape Loumaravi, about 10 m above present sea level (Cape Loumaravi, Fig. 9). The marine fossils were confined to lenses, which were only a few decimetres in thickness. They consist of light brown and light grey marl.

The grey sediment displayed a higher concentration of foraminiferal specimens and a more diverse fauna than the light brown marl, but no general differences in the species distribution could be registered. The foraminifera will, therefore, be treated as a single assemblage here.

The fauna (Appendix C, Fig. 10) is dominated by planktic foraminifera which comprise 68 % of the total fauna (Fig. 5b). The benthic assemblage is characterized by Uvigerina mediterranea, Melonis barleeanus, Anomalinoides ornatus, Gyroidina soldanii, Cibicidoides pachydermus, Chilostomella mediterranensis, and Sphaeroidina bulloides. The planktic assemblage is characterized by Orbulina universa, Globigerinoides conglubatus, G. ruber, Globorotalia inflata, and dextral Neogloboquadrina pachyderma.

The high frequency of planktic specimens infers an open marine environment, and comparison with similar benthic assemblages from the Mediterranean (PARKER, 1958; WRIGHT, 1978) indicates that the sediments were deposited in an upper epibathyal environment (water depth exceeding 100 m). The presence of shallow water species such as Elphidium spp. is regarded as a result of down slope transportation of the foraminiferal tests.

## BIOSTRATIGRAPHICAL INTERPRETATION OF THE FOSSILIFEROUS SEDIMENTS

The three foraminiferal assemblage types show sufficient similarities to conclude that the sediments from the examined areas were deposited at approximately the same time.

Fig. 9. The caldera wall with the fossil locality at Cape Loumaravi.

The occurrence of abundant Globorotalia inflata in all three assemblages indicates correlation to the Globorotalia inflata Interval Zone of CITA (1973, 1975). As the immigration of G. inflata to the Mediterranean has been estimated to 1.99 Ma (RIO et al., 1991) this demonstrates a well defined maximum age of about 2 Ma for the marine deposits at Akrotiri.

The last appearance datum of Globigerinoides obliquus extremus Bolli and first appearances of Globorotalia truncatulinoides (d'Orbigny) and Hyalinea balthica have traditionally been used in establishing the Plio-Pleistocene boundary in the Mediterranean (CITA, 1973, 1975; BIZON and MULLER, 1978; BREMER et al., 1980; AGUIRRE and PASINI, 1985). However, according to CITA (1975) G. obliquus extremus occurs only abundantly prior to the first appearance datum of Globorotalia inflata, the species G. truncatulinoides is rare in sediments from the Eastern Mediterranean (THUNELL, 1978, 1979), and H. balthica has been recorded in the Pliocene (BIZON et al., 1978; BREMER et al., 1980; HERMELIN, 1991) as well as in the Pleistocene. G. obliquus extremus and G. truncatulinoides are both absent in the present samples, but a single specimen of H. balthica (Appendix C) was recorded in the Akrotiri material. Due to the relatively poor faunas in this study these observations can, however, not be used to determine a more exact age for the deposits.

On the basis of the palaeontological data it can, therefore, only be concluded that the age of the fossiliferous sediments from the Akrotiri [illegible]

Fig. 10. The foraminiferal fauna from the locality Cape Loumaravi (Scanning Electron Microscope photographs): 1-2 Anomalinoides ornatus, 1 x 50, 2 x 60. 3 Chilostomella mediterranensis, x 50. 4 Melonis barleeanus, x 85. 5-7 Cibicidoides pachydermus, 5, 6 x 65, 7 x 70. 8 Sphaeroidina bulloides, x 110. 9-10 Gyroidina soldanii, x 80. 11 Trifarina angulosa, x 80. 12 Uvigerina mediterranea, x 75. 13 Hyalinea balthica, x 100. 14-15 Globorotalia inflata, 14 x 110, 15 x 100. 16 Orbulina universa, x 95. 17 Globigerinoides ruber, x 105. 18-19 Neogloboquadrina pachyderma, 18 x 160, 19 x 135. 20 Turborotalita quinqueloba, x 180. 21 Globigerinoides conglubatus, x 120.

## AGE OF THE EARLIEST VOLCANISM ON SANTORINI

The landscape of the Akrotiri Peninsula, Santorini, is characterized by a number of hills of which Mt. Archangelos (162 m) and Mt. Loumaravi (210 m) are the most prominent. These hills are interpreted as domes formed due to rising of magma (PICHLER and KUSSMAUL, 1972). The Akrotiri Peninsula presumably displays the transition from submarine to subaerial volcanic activity in the Santorini volcanic group. Thus, the origin of these domes may be compared to the doming process, which occurred on May 23rd 1707 A.D. during the eruption west of Mikra Kameni in the Santorini caldera. Here a white island suddenly appeared and still living sea animals were observed on its surface (ROSS, 1840).

Assuming that the fossiliferous marine sediments from the Akrotiri Peninsula were formed prior to the updoming, the palaeontological dating of these sediments gives a maximum age for the volcanic doming process. On the other hand the existence of rounded volcanic pepples in the sediments testifies to the fact that volcanism had already occurred before the deposition the fossiliferous layers.

The following sequence of events can be established:

1) Volcanic activity, probably submarine, producing the material from which the rounded pebbles had their origin.

2) Synchronous sedimentation of dacitic tuffs, foraminifera, and rounded pebbles (beach gravel) in a marine environment.

3) Uplifting of these marine sediments to more than 100 m above sea level due to volcanic doming.

According to the general stratigraphy of the peninsula (PICHLER and KUSSMAUL, 1980) the $A_1$-Tuff-Series is the oldest volcanic sequence in this area. Hence, we consider that the absolute dates from the Akrotiri Peninsula (FERRARA et al., 1980) obtained from effusive volcanic products are younger than the $A_1$-Tuffs containing the fossiliferous sediments. These radiometric dates indicate a minimum age for the deposition of the fossil-bearing sediments from the Akrotiri-Loumaravi Complex. Therefore, it can be concluded that the age of the fossiliferous sediment must be between c. 1.6 Ma and 2.0 Ma. According to the present definition of the Plio-Pleistocene boundary just above the palaeomagnetic Olduvai Subchron (c. 1.6 Ma) (TAUXE et al., 1983; AGUIRRE and PASINI, 1985) the marine sediments from the Akrotiri Peninsula can be referred to the Uppermost Pliocene.

The age of the earliest volcanism on Santorini can be deduced from the fact that the dated faunas are younger than the rounded volcanic pebbles. Hence, we conclude that the earliest volcanism occurred in the Pliocene or earlier, an age which coincides with dates obtained for the earliest volcanism elsewhere in the Hellenic Arc (FERRARA et al., 1980; FYTIKAS et al., 1986/1987).

## CONCLUSION

Several localities on the Akrotiri Peninsula containing marine fossils document the existence of marine deposits, which were formed at water depths ranging between 100 metres and several hundred metres

(littoral to upper epibathyal environment).

On the basis of the present palaeontological data and the absolute dates of FERRARA et al. (1980) it can be concluded that the marine sediments and tuffs belong to the uppermost Pliocene, between c. 2.0 Ma and 1.6 Ma. Furthermore, it is concluded that the initiation of volcanic activity on the Akrotiri Peninsula occurred during the Pliocene or earlier. According to our present knowledge this was the earliest volcanism on Santorini. This result is in accordance with dates of early volcanic activity elsewhere in the Hellenic Arc.

The existence of fossil bearing tuffs and sediments, which were deposited nearly simultaneously, but at different water depths, may be explained in two different ways:

1) a palaeo-relief existed prior to the updoming, or

2) a palaeo-relief was formed during the updoming. In the latter case the updoming occurred very slowly allowing deposition of marine sediments at different water depth during its early stages.


## ACKNOWLEDGEMENTS

Our sincere thanks to the Carlberg Foundation (WLF) and the Danish Natural Science Research Council (MSS) who funded this study. We are grateful to Karen Luise Knudsen and David N. Penney for critically reading the manuscript and to Svend Meldgaard Christiansen for the laboratory processing and photographs. We would also like to thank Ulrike Eriksen, Lotte Melchior Larsen, and Asger Ken Pedersen for assistance during the field work.


## REFERENCES


AGUIRRE, E. and PASINI, G. (1985). The Pliocene-Pleistocene Boundary. Episodes 8 (2), 116-120.

BIZON, G., CITA M. B., WRIGHT, R., and MÜLLER, C. (1978). DSDP leg 42A biostratigraphic range charts. IN: Kidd, R.B. and Worstell, P.J. (eds.), Init. Rep. DSDP, 42, 1095-1138.

BIZON, G. and MULLER, C. (1978). Remarks on the determination of the Pliocene/Pleistocene boundary in the Mediterranean. IN: Kidd, R. B. and Worstell, P. J., (eds.), Init. Rep. DSDP, 42, 847-853.

BREMER, M. L., BRISKIN, M., and BERGGREN, W. A. (1980). Quantitative paleobathymetry and paleoecology of the Late Pliocene-Early Pleistocene foraminifera of Le Castella (Calabria, Italy). J. foramin. Res. 10 (1), 1-30.

CITA, M. B. (1973). Pliocene biostratigraphy and chronostratigraphy. In: Ryan, W.B., Hsü, K.J., et al., Init. Rep. DSDP, 13, 1343-1399.

CITA, M. B. (1975). Planktonic foraminiferal biozonation of the Mediterranean Pliocene deep sea record. A revision. Riv. Ital. Paleontol., 81 (4), 527-544.

FERRARA, G., FYTIKAS, M., GIULIANA, O., and MARINELLI, G.(1980). Age of the Formation of the Aegean Active Volcanic Arc. In: Doumas, C. G. (ed.), Thera and the Aegean World II. Thera and the Aegean World, London, 37-41.

FOUQUE, F. (1879). Santorin et ses Éruptions. Masson & Cie, Paris, 440 pp.

FYTIKAS, M., INNOCENTI, F., KOLIOS, N., MANETTI, P., MAZZUOLI, R. (1987/1988). The Plio-Quaternary Volcanism of Saronikos Area (Western Part of the Active Aegean Volcanic Arc). Ann. Géol. Pays Hellén., ser. 1, 33 (2), 23-45.

HERMELIN, J. O. R. (1991). Hyalinea balthica (Schroeter) in Lower Pliocene sediments of the Northwest Arabian Sea. J. foramin. Res., 21 (3), 244-251.

JORISSEN, F. J. (1987). The distribution of benthic foraminifera in the Adriatic Sea. Utrecht Micropaleontological Bulletins, 37, 174 pp.

MURRAY, J. W. (1966). The Foraminiferida of the Persian Gulf. 4. Khor al Bazam. Palaeogeogr., Palaeoclimatol., Palaeoecol., 2, 153-169.
MURRAY, J. W. (1970). The Foraminiferida of the Persian Gulf. 6. Living forms in the Abu Dhabi Region. J. nat. Hist., 4, 55-67.
MURRAY, J. W. (1991). Ecology and Palaeoecology of Benthic Foraminifera. Longman Scientific & Technical, Harlow, Essex, 397 pp.
PARKER, F. L. (1958). Eastern Mediterranean Foraminifera. Report of the Swedish Deep-Sea Expedition, vol. VIII, Sediment cores from the Mediterranean Sea and the Red Sea., 4, 217-283.
PICHLER, H. and KUSSMAUL, S. 1972. The Calc-Alcaline Volcanic Rocks of the Santorini Group (Aegean Sea, Greece). N. Jb. Miner. Abh., 116, 268-307.
PICHLER, H. and KUSSMAUL, S. (1980). Geological map of Santorini. In: Doumas, C. G. (ed.), Thera and the Aegean World II. Thera and the Aegean World, London.
RIO, D., SPROVIERI, R., and THUNNE, R. (1991). Pliocene-lower Pleistocene chronostratigraphy: A re-evaluation of Mediterranean type section. Bull. Geol. Soc. Am., 103: 1049-1058.
ROSS, D. L. (1840). Reisen auf den griechischen Inseln des agaischen Meeres. Stuttgart and Tubingen, 182 pp.
SAUVAGE, J. and JARRIGE, J.-J. (1978). Sur l'age des stades initiaux de l'activite volcanique dans l'ile de Thira (Grèce): Etudes palynologiques. C. R. Acad. Sc. Paris, ser D, 286, 929-931.
SEIBOLD, I. (1971). Ammonia Brünnich (Foram.) und verwandte Arten aus dem Indischen Ozean (Malabar-Küste, SW-Indien). Paläontol. Z., 45 (1/2), 41-52.
TAUXE, L., OPDYKE, N. D., PASINI, G., and ELMI, C. (1983). Age of the Pliocene-Pleistocene Boundary in the Vrica section, southern Italy. Nature, 304, 125-129.
THUNELL, R. C. (1978). Distribution of recent planktonic foraminifera in surface sediments of the Mediterranean Sea. Mar. Micropaleontol., 3, 147-173.
THUNNEL, R. C. (1979). Quantitative biostratigraphy and paleoclimatology of late Neogene deep sea drilled sequences from the Mediterranean. Ann. Géol. Pays Hellén. Hors sér., fasc. III: 1215-1223.
TODD, R., and BRONNIMANN, P. (1957). Recent foraminifera and thecamoebina from eastern Gulf of Paria. Spec. Publ. Cushman Found. Foram. Res., 3, 1-43.
VON FRITSCH, K. (1871). Geologische Beschreibung des Ringgebirges von Santorin. Zeitschrift der Deutschen geologischen Gesellschaft, 23, 125-209, Berlin.
WRIGHT, R. (1978). Neogene paleobathymetry of the Mediterranean based on benthic foraminifers from DSDP leg 42A. IN: Kidd, R. B. and Worstell, P. J., (eds.), Init. Rep. DSDP, 42, 837-846.

## APPENDIX A: FORAMINIFERAL ASSEMBLAGE FROM ARCHANGELOS AND AKROTIRI I

| BENTHIC FORAMINIFERA | % |
|---|---|
| *Ammonia beccarii* s.s. (Linné, 1758 = *Nautilus beccarii*) | 1.0 |
| *Ammonia beccarii*, var. *sobrina* (Shupack, 1934 = *Rotalia beccarii*, var. *sobrina*) | 17.7 |
| *Anomalinoides ornatus* (Costa, 1850 = *Nonionina ornata*) | 0.8 |
| *Asterigerinata mamilla* (Williamson, 1858 = *Rotalia mamilla*) | 4.6 |
| *Asterigerinata planorbis* (d'Orbigny, 1846 = *Asterigina planorbis*) | 0.1 |
| *Biloculinella depressa* (d'Orbigny, 1826 = *Biloculina depressa*) | 0.1 |
| *Bulimina gibba* Fornasini, 1902 | 0.2 |
| *Cancris auriculus* (Fichtel and Moll, 1798 = *Nautilus auricula*) | 0.1 |
| *Cassidulina laevigata* d'Orbigny, 1826 | 1.8 |
| *Cassidulina obtusa* Williamson, 1858 | 0.5 |
| *Cibicides lobatulus* (Walker and Jacob, 1798 = *Nautilus lobatulus*) | 11.9 |
| *Cibicides refulgens* Montfort, 1808 | 0.5 |
| *Discorbinella* sp. | 0.1 |
| *Elphidium aculeatum* (d'Orbigny, 1846 = *Polystomella aculeata*) | 0.7 |
| *Elphidium advenum* (Cushman, 1922 = *Polystomella advena*) | 0.4 |
| *Elphidium articulatum* (d'Orbigny, 1839 = *Polystomella articulatum*) | 0.2 |
| *Elphidium complanatum* (d'Orbigny, 1839 = *Polystomella complanata*) | 1.2 |
| *Elphidium complanatum*, var. *tyrrhenianum* Accordi, 1951 | 0.6 |
| *Elphidium crispum* (Linné, 1758 = *Nautilus crispum*) | 5.0 |
| *Elphidium fichtellianum* (d'Orbigny, 1846 = *Polystomella fichtelliana*) | 2.2 |
| *Elphidium macellum* (Fichtel and Moll, 1798 = *Nautilus macellus*) | 3.6 |
| *Elphidium* sp. | 0.1 |
| *Eponides turgidus* Phleger and Parker, 1951 | 0.1 |
| *Fissurina* sp. | 0.1 |
| *Gavelinopsis praegeri* (Heron-Allen and Earland, 1913 = *Discorbina praegeri*) | 0.1 |
| *Globocassidulina subglobosa* (Brady, 1881 = *Cassidulina subglobosa*) | 1.9 |
| *Globulina gibba* d'Orbigny, 1826 | 0.5 |
| *Guttulina* sp. | 0.5 |
| *Gyroidina soldanii* d'Orbigny, 1826 | 0.2 |
| *Heterolepa pseudoungeriana* (Cushman, 1922 = *Truncatulina pseudoungeriana*) | 2.9 |
| *Heterolepa ungeriana* (d'Orbigny, 1846 = *Rotalia ungeriana*) | 0.4 |
| *Laryngosigma lactea* (Walker and Jacob, 1798 = *Serpula lactea*) | 0.5 |
| *Melonis barleeanus* (Williamson, 1858 = *Nonionina barleeana*) | 4.3 |
| *Miliolinella* cf. *M. fichteliana* (d'Orbigny, 1839 = *Triloculina fichteliana*) | 0.1 |
| *Miliolinella subrotunda* (Montagu, 1803 = *Vermiculum subrotundum*) | 2.5 |
| *Neoconcorbina millettii* (Wright, 1910 = *Discorbis millettii*) | 6.4 |
| *Nonion limbum* (d'Orbigny, 1826 = *Nonionina limba*) | 2.4 |
| *Osangularia culter* (Parker and Jones, 1865 = *Planorbulina culter*) | 1.0 |
| *Paromalina bilateralis* Loeblich and Tappan, 1957 | 0.1 |
| *Patellina corrugata* Williamson, 1858 | 0.1 |
| *Planorbulina mediterranensis* d'Orbigny, 1826 | 0.2 |
| *Planulina ariminensis* d'Orbigny, 1826 | 1.1 |
| *Pyrgo tubulosa* (Costa, 1856 = *Biloculina tubulosa*) | 0.2 |
| *Pyrgo elongata* (d'Orbigny, 1826 = *Biloculina elongata*) | 0.2 |
| *Quinqueloculina lamarchiana* d'Orbigny, 1839 | 0.2 |
| *Quinqueloculina lata* Terquem, 1876 | 0.2 |
| *Quinqueloculina longirostra* d'Orbigny, 1826 | 0.1 |
| *Quinqueloculina oblonga* (Montagu, 1803 = *Vermiculum oblongum*) | 0.7 |
| *Quinqueloculina padana* Perconig, 1954 | 0.1 |
| *Quinqueloculina seminulum* s.l. (Linné, 1758 = *Serpula seminulum*) | 6.3 |
| *Quinqueloculina venusta* Karrer, 1868 | 0.1 |
| *Quinqueloculina vulgaris* d'Orbigny, 1826 | 1.2 |
| *Rosalina bradyi* (Cushman, 1915 = *Discorbis globularis*, var. *bradyi*) | 0.1 |
| *Rosalina* cf. *R. bradyi* (Cushman, 1915 = *Discorbis globularis*, var. *bradyi*) | 0.7 |
| *Rosalina carnivora* Todd, 1965 | 0.1 |
| *Rosalina concinna* d'Orbigny, 1826 | 0.2 |
| *Rosalina globularis* d'Orbigny, 1826 | 1.0 |
| *Rosalina* aff. *R. macropora* (Hofker, 1951 = *Discopulvinulina macropora*) | 2.3 |

*Sigmomorphina semitecta* (Reuss, 1867 = *Polymorphina semitecta*)
*Spiroloculina depressa* d'Orbigny, 1826
*Spiroloculina excavata* d'Orbigny, 1846
*Stomatorbina concentrica* (Parker and Jones, 1864 = *Pulvinulina concentrica*)
*Textularia candeiana* d'Orbigny, 1839
*Textularia pseudogramen* Chapman and Parr, 1937
*Textularia pseudorugosa* Lacroix, 1931
*Trifarina angulosa* (Williamson, 1858 = *Uvigerina angulosa*)
*Triloculina inflata* d'Orbigny, 1826
*Triloculina oblonga* (Montagu, 1803 = *Vermiculum oblongum*)
*Triloculina trigonula* (Lamarck, 1804 = *Miliolites trigonula*)
*Uvigerina flintii* Cushman, 1923
*Valvulineria complanata* (d'Orbigny, 1846 = *Rosalina complanata*)
Other Miliolidae
Indeterminata
MATERIAL: 831 benthic specimens.

PLANKTIC FORAMINIFERA

*Orbulina universa* d'Orbigny, 1839
*Neogloboquadrina pachyderma* (Ehrenberg, 1861 = *Aristerospira pachyderma*)
*Globigerinoides conglubatus* (Brady, 1879 = *Globigerina conglubata*) }
*Globigerinoides ruber* (d'Orbigny, 1839 = *Globigerina ruber*) }
*Globigerinella siphonifera* (d'Orbigny, 1839 = *Globigerina siphonifera*)
*Globorotalia inflata* (d'Orbigny, 1839 = *Globigerina inflata*)
MATERIAL: 40 planktic specimens.

## APPENDIX B: FORAMINIFERAL ASSEMBLAGE FROM AKROTIRI II

BENTHIC FORAMINIFERA

*Ammonia beccarii* s.l. (Linné, 1758 = *Nautilus beccarii*)
*Asterigerinata planorbis* (d'Orbigny, 1846 = *Asterigina planorbis*)
*Cassidulina laevigata* d'Orbigny, 1826
*Cibicides lobatulus* (Walker and Jacob, 1798 = *Nautilus lobatulus*)
*Nummoloculina contraria* (d'Orbigny, 1846 = *Biloculina contraria*)
*Pyrgo comata* (Brady, 1881 = *Biloculina comata*)
*Pyrgo elongata* (d'Orbigny, 1826 = *Biloculina elongata*)
*Pyrgo tubulosa* (Costa, 1856 = *Biloculina tubulosa*)
*Quinqueloculina lamarchina* d'Orbigny, 1839
*Quinqueloculina lata* Terquem, 1876
*Quinqueloculina padana* Perconig, 1954
*Quinqueloculina seminulum* (Linné, 1758 = *Serpula seminulum*)
*Quinqueloculina vulgaris* d'Orbigny, 1846
*Sphaeroidina bulloides* d'Orbigny, 1826
*Triloculina inflata* d'Orbigny, 1826
MATERIAL: 37 benthic specimens.

PLANKTIC FORAMINIFERA
*Globorotalia inflata* (d'Orbigny, 1839 = *Globigerina inflata*)
*Globigerinella siphonifera* (d'Orbigny, 1839 = *Globigerina siphonifera*)
*Globigerinoides conglubatus* (Brady, 1879 = *Globigerina conglubata*)
*Orbulina universa* d'Orbigny, 1839
Indeterminata
MATERIAL: 25 planktic specimens.

## APPENDIX C: FORAMINIFERAL ASSEMBLAGE CAPE LOUMARAVI

| BENTHIC FORAMINIFERA | % |
|---|---|
| *Ammonia beccarii*, var. *sobrina* (Shupack, 1934 = *Rotalia beccarii*, var. *sobrina*) | 0.4 |
| *Anomalinoides ornatus* (Costa, 1850 = *Nonionina ornata*) | 13.8 |
| *Bolivina pseudoplicata* Heron-Allen and Earland, 1930 | 0.2 |
| *Bulimina aculeata* d'Orbigny, 1826 | 0.2 |
| *Cassidulina crassa* d'Orbigny, 1839 | 0.4 |
| *Cassidulina laevigata* d'Orbigny, 1826 | 0.2 |
| *Chilostomella mediterranensis* Cushman and Todd, 1949 | 3.5 |
| *Cibicides fletcheri* Galloway and Wissler, 1927 | 0.2 |
| *Cibicides lobatulus* (Walker and Jacob, 1798 = *Nautilus lobatulus*) | 0.9 |
| *Cibicidoides pachydermus* (Rzehak, 1953 = *Truncatulina pachyderma*) | 12.2 |
| *? Discorbis* sp. | 1.4 |
| *Eggerella bradyi* (Cushman, 1911 = *Verneilina bradyi*) | 0.4 |
| *Elphidium complanatum* (d'Orbigny, 1839 = *Polystomella complanata*) | 1.3 |
| *Elphidium complanatum*, var. *tyrrhenianum* Accordi, 1951 | 0.2 |
| *Elphidium macellum* (Fichtel and Moll, 1798 = *Nautilus macellus*) | 0.2 |
| *Epistominella* sp. | 0.2 |
| *Fissurina orbignyana* Seguenza, 1826 | 0.2 |
| *Globocassidulina subglobosa* (Bradyi, 1881 = *Cassidulina subglobosa*) | 1.7 |
| *Gyroidina neosoldanii* Brotzen, 1936 | 0.9 |
| *Gyroidina soldanii* d'Orbigny, 1826 | 12.7 |
| *Hyalinea balthica* (Schroeter, 1783 = *Nautilus balthicus*) | 0.2 |
| *Kareriella bradyi* (Cushman, 1911 = *Gaudryina bradyi*) | 0.2 |
| *Lenticulina orbicularis* (d'Orbigny, 1826 = *Robulina orbicularis*) | 0.2 |
| *Lenticulina thalmanni* (Hessland, 1943 = *Robulus thalmanni*) | 0.2 |
| *Loxostomoides* sp. | 0.2 |
| *Martinotinella* sp. | 0.2 |
| *Melonis barleeanus* (Williamson, 1858 = *Nonionina barleeana*) | 17.5 |
| *Nonion faba* (Fichtel and Moll, 1798 = *Nautilus faba*) (*N. asterizans* of others) | 0.4 |
| *Nonion limbum* (d'Orbigny, 1826 = *Nonionina limba*) | 2.6 |
| *Oridorsalis stellatus* (Silvestri, 1898 = *Truncatulina tenera* ?, var. *stellata*) | 0.4 |
| *Pyrgo elongata* (d'Orbigny, 1826 = *Biloculina elongata*) | 0.2 |
| *Rosalina* cf. *R. bradyi* (Cushman, 1915 = *Discorbis globularis*, var. *bradyi*) | 0.2 |
| *Sphaeroidina bulloides* d'Orbigny, 1826 | 0.2 |
| *Stomatorbina concentrica* (Parker and Jones, 1864 = *Pulvinulina concentrica*) | 1.3 |
| *Trifarina angulosa* (Williamson, 1858 = *Uvigerina angulosa*) | 0.2 |
| *Uvigerina flintii* Cushman, 1923 | 0.4 |
| *Uvigerina mediterranea* Hofker, 1932 | 1.1 |
| *Uvigerina peregrina* Cushman, 1923 | 21.5 |
| *Uvigerina proscidea* Schwager, 1866 | 0.7 |
| *Valvulineria complanata* (d'Orbigny, 1846 = *Rosalina complanata*) | 0.2 |
| Indeterminata | 0.6 |
| MATERIAL: 543 benthic specimens | 0.7 |

| PLANKTIC FORAMINIFERA | % |
|---|---|
| *Globigerina bulloides* d'Orbigny, 1826 | 1.0 |
| *Globigerinoides conglubatus* (Brady, 1879 = *Globigerina conglubata*) | 31.4 |
| *Globigerinoides ruber* (d'Orbigny, 1839 = *Globigerina ruber*) | |
| *Globorotalia crassaformis* (Galloway and Wissler, 1927 = *Globigerina crassaformis*) | 0.1 |
| *Globorotalia inflata* (d'Orbigny, 1839 = *Globigerina inflata*) | 23.4 |
| *Globorotalia scitula* (Brady, 1882 = *Pulvinulina scitula*) | 0.2 |
| *Neogloboquadrina dutertrei* (d'Orbigny, 1839 = *Globigerina dutertrei*) | 0.3 |
| *Neogloboquadrina pachyderma* (Ehrenberg, 1861 = *Aristerospira pachyderma*) | 7.4 |
| *Orbulina universa* d'Orbigny, 1839 | 33.8 |
| *Sphaeroidinella dehiscens* (Parker and Jones, 1865 = *Sphaeroidina dehiscens*) | 0.1 |
| *Turborotalita quinqueloba* (Natland, 1938 = *Globigerina quinqueloba*) | 0.9 |
| Inderteminata | 1.4 |
| MATERIAL: 1203 planktic specimens | |