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PALEONTOLOGICAL AND GEOCHEMICAL ANALYSIS OF THREE LAMINATED SEDIMENTARY UNITS OF LATE PLIOCENE–EARLY PLEISTOCENE AGE FROM THE MONTE SAN NICOLA SECTION IN SICILY

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Key–words: Micropaleontology, Geochemistry, Paleoecology, Laminated Sedimentary Units, Upper Pliocene–Lower Pleistocene, Southern Sicily.

Riassunto. Lo studio micropaleontologico e geochimico di 3 distinti intervalli laminati affioranti nella sezione di Monte San Nicola (Gela, Sicilia) e riferibili rispettivamente alla parte alta della biozona M Pl 5 (G–1), alla parte intermedia della biozona M Pl 6 (G–2) e alla base della biozona a *Globigerina cariacoensis* (G–3) ha permesso di ricostruire le prevalenti condizioni delle acque superficiali e di fondo durante la loro deposizione. I tre intervalli laminitici sono costantemente privi di associazione a Foraminiferi bentonici, che sono invece ben rappresentati nelle marne sottostanti e soprastanti. Nei livelli marnosi immediatamente a contatto al di sotto e al di sopra delle laminiti sono presenti associazioni a Foraminiferi bentonici fortemente impoverite, caratterizzate dalla prevalenza di specie che chiaramente indicano un paleoambiente scarsamente ossigenato; la totale assenza di individui bentonici nelle laminiti suggerisce che tali condizioni anossiche persistettero durante la loro deposizone. L'associazione a Foraminiferi planctonici nei due intervalli laminitici pliocenici indica acque superficiali calde, mentre l'associazione presente nell'intervallo attribuibile al Pleistocene basale indica acque superficiali temperato–fredde durante la deposizione di questo intervallo. In tutti e tre gli intervalli laminati un rimarchevole aumento di individui di *Neogloboquadrina dutertrei* evidenzia una riduzione di salinità delle acque superficiali. Ampie diminuzioni nel $\delta^{18}O$ nei Foraminiferi planctonici suggerisce pure una ridotta salinità delle acque superficiali in corrispondenza delle laminiti.

Sulla base di tali risultati si può concludere che i tre intervalli laminati si depositarono durante periodi di ridotta salinità superficiale, molto probabilmente imputabile ad un aumento di apporti continentali. La diminuzione di salinità superficiale diede origine ad una stratificazione delle acque superficiali, che alla fine portò ad un impoverimento nella ossigenazione al fondo. Benchè sia stato possibile riconoscere un aumento di Carbonio organico nelle laminiti rispetto alle marne, i suoi valori restano molto bassi, tali da non permettere di attribuire tali sedimenti a sapropels o sedimenti sapropelitici. Il basso valore del contenuto in Carbonio organico nei tre intervalli laminitici suggerisce che non ci fu un apprezzabile aumento di produttività biologica nelle acque superficiali durante la loro deposizione.

Abstract. A micropaleontological and geochemical study of three Upper Pliocene–Lower Pleistocene laminated units from the Monte San Nicola section in southern Sicily was carried out in order to determine prevailing surface and bottom water conditions during their deposition. Although all three laminites are devoid of benthic foraminifera, the benthic assemblages present in the marls immediately below and above the laminites are diagnostic of oxygen–depleted bottom waters and suggest that anoxic

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conditions persisted during laminite deposition. The planktonic foraminifera present in the two Upper Pliocene laminites (G–1 and G–2) are indicative of warm surface waters, while the assemblage found in the Lower Pleistocene laminite (G–3) reflects cool surface waters during laminite formation. For all three layers, relatively high abundance of *Neogloboquadrina dutertrei* point to reduced surface water salinities. Large depletions in the $\delta^{18}O$ of planktonic foraminifera from the laminites also suggest reduced surface salinities.

Based on these results it is concluded that these laminites were formed during periods of reduced surface water salinity, mostly likely due to enhanced continental run–off. The lowering of surface salinities resulted in a stratification of the water column, which eventually led to oxygen–depletion of bottom waters. Although there is an increase in the organic content of the laminites relative to the surroundings marls, it would appear that preferential preservation of organic matter in poorly oxygenated bottom waters can most easely account for the observed increase.

Introduction.

Organic carbon–rich sediments called sapropels are a common feature in the eastern Mediterranean Middle Miocene–Pleistocene deep–sea record (Olausson, 1961; Cita & Ryan, 1979; Cita & Grignani, 1982; Thunell et al., 1984). Deep sea sapropels have not been recovered from the time interval corresponding to the *Sphaeroidinellopsis subdehiscens* (M Pl 4) foraminiferal biozone (from about 3.6 to about 3.0 MA). This was probably a period of invigorated bottom circulation and better ventilation of the deep eastern Mediterranean. Upper Miocene laminated sediments have been identified in several land sections in Sicily (for instance, the Tripoli sequence at the base of the Messinian Gessoso–solfifera formation). Recently anoxic laminated black sediments from the lower part of the Late Pliocene (basal part of M P1 5 biozone of Cita, 1975) were described by Gudjonsson & van der Zwaan (1985) in the Capo Rossello area.

Organic carbon–rich sediments accumulate in three different settings. According to Demaison & Moore (1980) these can be classified as: 1) silled basins with anoxic bottom conditions induced by density stratification of the water column; 2) open ocean continental margins impinged upon by mid–depth oxygen minimum zones; and 3) upwelling regions with oxygen–depleted bottom–waters produced by high biological productivity. Extensive geochemical (Kullemberg, 1952; Nesteroff, 1973), sedimentological (McCoy, 1974; Maldonado & Stanley, 1976b, 1977, 1979), stable isotope (Vergnaud–Grazzini, 1975; Williams, Thunell & Kennett, 1978; Thunell & Williams, 1982) and paleontological (Cita, Vergnaud–Grazzini, Robert et al., 1977; Thunell, Williams & Cita, 1983; Williams & Thunell, 1979) studies on Late Pleistocene sapropels, tend to support Olausson's (1961) hypothesis: sapropels are deposited in a silled basin with anoxic bottom conditions produced by density stratification due to a low salinity surface layer. Two potential source of fresh water for this low salinity surface layer are the Black Sea (Ryan, 1972; Cita et al., 1977; Thunell & Lohmann, 1979; Stanley & Blanpied, 1980; inter alios) and the Nile River region (Rognon & Williams, 1977; Street & Groove, 1979; Adamson, Gasse, Street &

Williams, 1980; Rossignol–Strick, Nesteroff, Olive & Vergnaud–Grazzini, 1982; Rossignol–Strick, 1983). Recently Gudjonsson & van der Zwaan (1985) proposed that European river water was the most likely source during the Early and lower Late Pliocene Sicilian laminite deposition. Nevertheless, more complex mechanism(s) of sapropels formation during Pliocene–Pleistocene time, not related only to fresh water run–off, seems to emerge from recent studies (Meulenkamp et al., 1979; Thunell et al., 1984; Calvert, 1983).

Several studies have dealt with benthic foraminifera from around sapropel levels. Most of them have only considered Late Pleistocene sapropels (Cita & Podenzani, 1980; Mullineaux & Lohmann, 1981; Vismara Schilling, 1984), while the recent paper by Katz & Thunell (1984) examines the response of benthic foraminifera to Middle Miocene–Early Pliocene stagnations and sapropel formation in the Eastern Mediterranean.

In this study benthic and planktonic foraminifera and geochemical changes associated with three discrete laminite–bearing sequences of upper Late Pliocene and Early Pleistocene age are discussed in order to provide us with further insight into the mechanism(s) responsible for the formation of laminated sediments of this age.

Material source.

Samples come from three segments of the Monte S. Nicola section, outcropping in the South–eastern Sicily, about 8 kilometers north of Gela (Fig. 1).

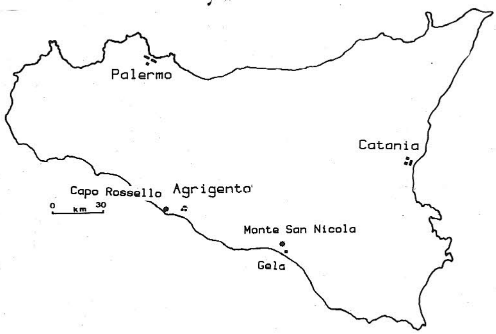

Fig. 1 — Index map of the Monte San Nicola section.

This continuous, well exposed, undisturbed section, represented by about 170 meters of sediments, covers an interval between the topmost part of the Lower Pliocene and the lower part of the Santernian (Lower Pleistocene) (from uppermost part of M Pl 3 to the lower part of *Gl. cariacoensis* foraminiferal biozones; from the upper part of *R. pseudoumbilica* to the lower part of the *C. macyntyrei* nannofossil biozones) (Fig. 2). In terms of absolute age, it covers a time–interval from about 3.6 MA to about 1.6 MA (Rio, Sprovieri & Raffi, 1984). The lowermost part of the section (about 32 meters) is represented by

«Trubi» marls, followed upwards by the grey marl of the Monte Narbone Formation. The transition between the two lithotypes is characterized by about 8 meters of brownish, laminated, manganese–rich sediments. In the uppermost part of the section two sandy levels of turbiditic origin are present. In the middle and upper part of the Monte Narbone Formation three discrete laminated intervals have been identified (Fig. 3). They are always finely laminated and brown–reddish in color. Sediments below and above these intervals are grey, non–laminated marls.

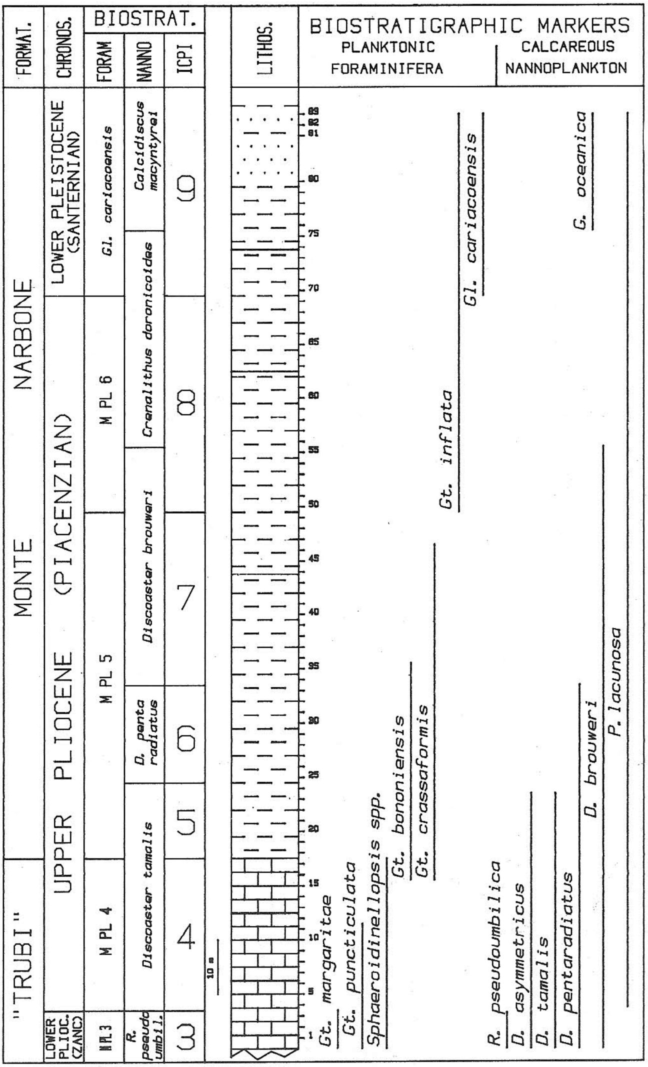

Fig. 2 – Calcareous plankton biostratigraphy and range of selected species in the Monte San Nicola section.

Benthic and planktonic foraminifera are very abundant and generally well preserved in this section. Reworking is absent, but rare displaced forms are occasionally present in the upper part of the section. Based on the benthic foraminifera (Sprovieri, in progress) and Ostracoda (Bonaduce & Sprovieri, 1984) the paleobathymetry of the section has been estimated at around 800–1000 meters in depth.

Samples have been collected at 25 cm intervals from below, within and above each of laminites. At the sharp bottom and top contacts samples have been collected at 5 cm intervals. The mean sedimentation rate in the part of

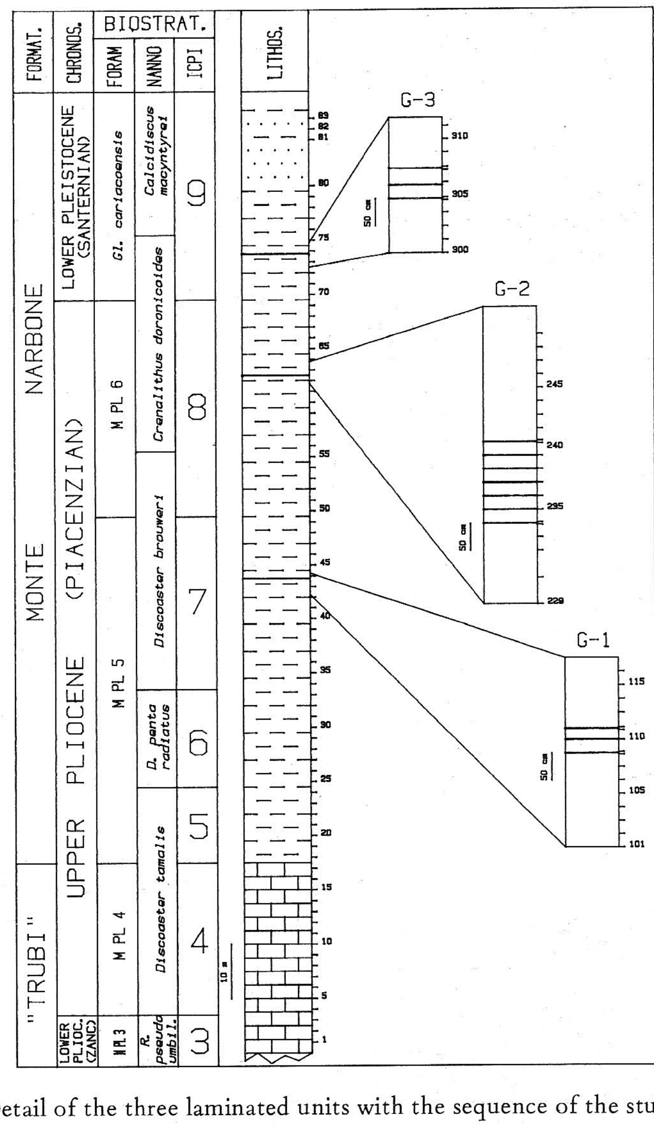

Fig. 3 – Detail of the three laminated units with the sequence of the studied samples.

the section containing the three laminated intervals is about 10 cm/1000 years. Samples have therefore been collected at an average time interval of about 2,500 years.

Methods and general results.

Foraminifera.

For each sample 100 grams of dried sediment have been disaggregated in hydrogen peroxide, washed on a 63 micron sieve and dried. The residue was used to determine the presence of all benthic and planktonic foraminiferal species and relative range charts. Individual species abundances have been obtained from fractions greater than 125 microns, previously split into aliquots containing 300 or more benthic and planktonic forms. Individuals were originally identified at species level and considered as such; for paleoecological and computer analyses only species or groups of species present in abundances greater than 2% in at least one sample were considered. These groups were established by lumping together species which seem to have positive correlations or which have similar ecological preference.

The different planktonic groups, in which the entitling species represents the most abundant form, are as follow:

1) *Globigerinoides ruber: Gld. elongatus* and very rare *Gld. obliquus, Gld. quadrilobatus* and *Gld. sacculifer* are included.
2) *Globorotalia inflata: Gt. oscitans* is included.
3) *Globigerina bulloides:* rare *Gl. apertura, Gl. bulbosa* and *Gl. praecalida* are included.
4) *Globigerina quinqueloba: Gl. egelida* is included.
5) *Orbulina universa: Orbulina suturalis* is included.
6) *Neogloboquadrina dutertrei:* only specimens of this species are here included.
7) *Globigerinita glutinata:* only specimens of this species are here included.

Benthic foraminiferal grouping are as follows:

1) *Bolivina dilatata: B. catanensis* and *B. alata* are included.
2) *Bolivina albatrossi: B. spinescens* and *B. subspinescens* are included.
3) *Bulimina lappa* or *Bulimina inflata:* all *Bulimina* species are included.
4) *Cassidulina carinata: C. crassa, Globobulimina subglobosa, G. oblonga, Cassidulinoides bradyi, Ehrembergina trigona* are included.
5) *Chilostomella oolina: Chilostomella mediterranensis* and *Chilostomella ovoidea* are included.
6) *Cibicidoides pachyderma: C. ungerianus,* and *C. robertsonianus* are included.
7) *Fursenkoina tenuis:* only specimens belonging to this species are included.
8) *Globobulimina affinis: G. pyrula, G. subspinescens* and *Praeglobobulimina pupoides* are included.
9) *Gyroidinoides neosoldanii:* rare *G. altiformis, G. delicata, G. umbonatus* and *Gyroidina soldanii* are included.
10) Agglutinants: *Bigenerina nodosaria, Eggerella bradyi, Karreriella bradyi, Martinottiella communis, Spiroplectammina wrighti* and *Textularia* spp. are included.
11) *Hoeglundina elegans:* only specimens belonging to this species are included.

12) *Melonis padanum: M. soldanii* is included.
13) *Miliolidae: Spiroloculina* spp., *Pyrgo* spp. and rare *Quinqueloculina* spp. and *Triloculina* spp. are included.
14) *Pullenia bulloides:* all *Pullenia* species are included.
15) *Sigmoilopsis schlumbergeri:* only specimens belonging to this species are included.
16) *Sphaeroidina bulloides:* only specimens belonging to this species are included.
17) *Uvigerina canariensis:* all spinose Uvigerinas are included.
18) *Uvigerina peregrina:* all costate Uvigerinas are included; *Hopkinsina bononiensis*, if not distinguished, is included here.
19) *Nodosariidae.*
20) *Hanzawaia rodhiensis:* only specimens belonging to this species are included.
21) *Oridorsalis stellatus:* only specimens belonging to this species are included.
22) *Valvulineria complanata:* all *Valvulineria* species are included, if distinguished.
23) *Miscellanea: Anomalinoides ornata, Cancris* spp., *Planulina ariminensis, Pleurostomella alternans, Siphonina reticulata, Stainforthia complanata, Stilostomella* spp., *Valvulineria* spp. (if not distinguished) are included here. All the species of this group are generally rare.

Each of the foraminiferal groupings is considered to have specific ecological implications. For the planktonic foraminiferal assemblages, group 1 (*Gld. ruber*) is considered to be indicative of warm water conditions (Bé & Tolderlund, 1971; Bé, 1977; Thunell, 1979), while group 3 (*Gl. bulloides*), group 2 (*Gt. inflata*), group 4 (*Gl. quinqueloba*) and *Gl. pachyderma* are considered indicative of cool to cold water conditions (Bé & Tolderlund, 1971; Bé, 1977; Thunell, 1979); *Neogloboquadrina dutertrei* is considered a warm to transitional species, indicative of low salinity conditions (Bé & Tolderlund, 1971; Ruddimann, 1971). Group 5 (*O. universa*) and *Globigerinita glutinata* are ubiquitous species not indicative of any particular climatic conditions.

Some of the benthic foraminiferal groupings dominate the assemblage and are characteristic of specific environmental conditions. According to their recent biogeographic distribution in both the Mediterranean region (Parker, 1958; Blanc–Vernet, 1969; Mullineaux & Lohmann, 1981; van der Zwaan, 1982; Katz & Thunell, 1984) and in the open oceans (Phleger & Soutar, 1973; Douglass & Woodruff, 1981; Streeter, 1972; Streeter & Shackleton, 1979; among others) the benthic groupings are interpreted as follow. Group 1 (*Bolivina dilatata*) and group 18 (*U. peregrina*) together with *Valvulineria complanata* are considered indicative of low oxygen bottom conditions; group 8 (*Globobulimina affinis*) together with group 5 (*Chilostomella oolina*) and *Fursenkoina tenuis* are indicative of extremely low oxygen bottom conditions; group 6 (*C. pachyderma*) is indicative of open marine conditions.

Marls below and above the laminites always contain a rich benthic fauna (Fig. 4, 10, 15). Within the laminated intervals very few species and specimens of deep–dwelling benthic foraminifera are present, and all are smaller than 125 microns in size. Due to the presence of clearly displaced, shallow water *Ammo-*

nia spp. and *Elphidium* spp., it cannot be ruled out that the deep water species are present in the laminites as also displaced forms. Planktonic foraminifera are always abundant, generally comprising more than 60% of the foraminiferal fauna; the greatest values are within the laminites and in the marly intervals immediately below and above the laminites. Residues greater than 63 microns in size are always very poor and decrease in the laminated intervals, with values lower than 2% : only in segment G–1 are the laminite residues greater than the residues of the underlying marls. Large translucent gypsum crystals are consistently present in all of the laminite samples; it is rare or absent in the marls. Pteropods, present as pyritized molds, are rare in the «normal» sediments, but frequent in the G–1 and G–3 laminites. Echinoids remains are totally absent from anoxic sediments.

Varimax Q–mode factor analysis (Davis, 1973) has been carried out on the benthic and planktonic foraminiferal data in order to reduce the large number of species to a few ecologically meaningful factors. Samples coming from the laminites, which are totally devoid of benthic foraminifera in the greater than 125 micron fraction, have not been considered in the statistical analysis of the benthic foraminifera.

Geochemical analysis.

A portion of each sample was analyzed for total organic carbon content and carbonate content. For the organic carbon measurements, the sediment was crushed and then reacted at room temperature with 15 ml of 1 M H_3 PO_4 to remove $CaCO_3$ (Froelich, 1980). The residue was then concentrated on glass fiber filters using distilled water and a millipore filter system. After drying at 50°C for 24 hours, each sample was analyzed on a Hewlett Packard carbon/nitrogen analyzer. The average standard deviation of the analyses is ± 0.02%.

Carbonate content was determined using a gasometric method similar to that described in Jones and Kaiteris (1983). Replicate analyses indicate a precision of ± 1.2%. The organic carbon and carbonate content data are given in Tab. 1.

All stable isotopic work was performed following the methods outlined in Williams et al. (1977). Specimens of *Globigerinoides ruber* were used in the analyses. The foraminifera were rosted under vacuum at 380°C for 1 hour and then dissolved in purified H_3 PO_4 at 50°C. The resultant CO_2 was purified of water vapor and analyzed on a VG Micromass 602D isotope ratio mass spectrometer. The isotope difference between the sample CO_2 and that of the PDB standard are reported in δ notation as the per mil (0/00) enrichment or depletion of the heavy isotope relative to the standard. The stable isotope data are given in Tab. 1.

Tab. 1 – Geochemical data of the three Monte San Nicola laminites.

UNITS	% $CaCO_3$	% Org. C	‰ $\delta^{18}O$	‰ $\delta^{13}C$
G–3				
311	26.4			
310	26.9	0.22	1.15	0.56
309	30.8			
308	13.1	0.27	−1.90	−0.92
307	10.4	0.10	−0.44	0.28
306	10.5	0.16	0.36	0.65
305	10.6	0.17	−0.23	0.61
304	11.4	0.15	−1.04	0.35
303	16.2			
302	19.9	0.18	0.08	−0.43
301	20.2			
300	23.1	0.24	0.16	0.17
G–2				
249	21.3		0.59	1.24
248	23.1			
247	26.3		0.72	1.38
246	28.0			
245	25.0		0.14	1.70
244	21.6			
243	20.5	0.00	−2.68	−0.72
242	17.2			
241	14.6	0.20	−0.88	0.31
240	14.1	0.37	−0.62	1.24
239	13.4	0.18		
238	13.4	0.23	−0.17	0.52
237	12.8	0.24		
236	12.5	0.25	−1.75	1.16
235	11.9	0.24		
234	12.4	0.21	−2.15	1.32
233	8.7	0.00	−1.10	0.90
232	16.4			
231	19.5	0.00	0.39	0.85
230	24.3			
229	25.7	0.05	0.23	1.02
G–1				
116	41.2			
115	42.5	0.20		
114	41.3			
113	42.8	0.22	0.34	1.55
112	29.3	0.31	0.22	−0.20
111	22.0	0.26		
110	18.0	0.16	−0.11	−0.56
109	19.0	0.15	−3.56	−1.26
108	18.2	0.21	−2.25	−0.89
107	18.4			
106	16.7			
105	25.2	0.20	0.46	0.56
104	22.3			
103	14.6		0.04	0.31
102	15.8			
101	30.1			

Results and discussion

Segment G–1.

General information.

A set of 16 samples have been collected from a 3.2 meter thick interval; a 50 cm thick, well laminated brownish unit is present in the middle of this interval. The segment belongs to the upper part of M Pl 5 foraminiferal zone, just between the *Gt. bononiensis* L.O. and the *Gt. crassaformis* L.O., and a few meters below the *Gt. inflata* F.O. In terms of calcareous nannoplankton biostratigraphy, it belongs to the middle part of the *D. brouweri* biozone (Fig. 3). According to Rio et al. (1984) absolute age is about 2.15 MA. The number of species, percent of residues greater than 63 micron, percent of planktonic foraminifera, presence of gypsum, pteropods and echinoid remains per sample are illustrated in Fig. 4.

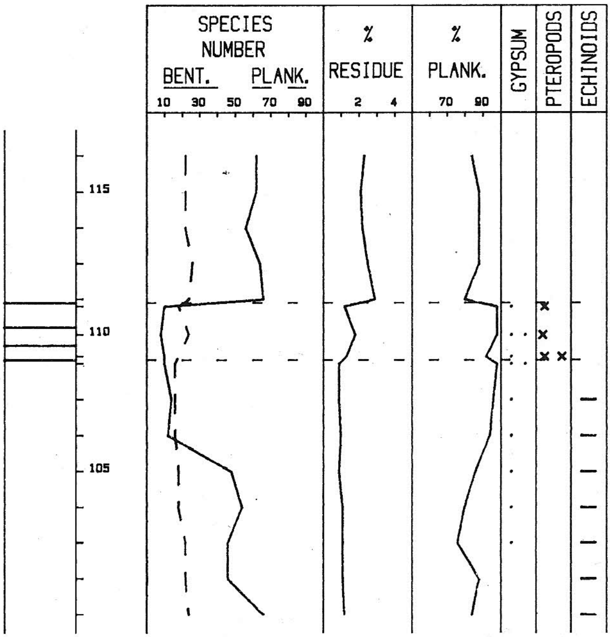

Fig. 4 — Unit 1. Main general features of the residues and of the faunistic assemblage.

Foraminifera.

A total of 123 benthic and 33 planktonic foraminiferal species were identified from the generally well preserved assemblages. Abundance variations of the benthic and planktonic species are illustrated in Fig. 5 and 6. Apart from a

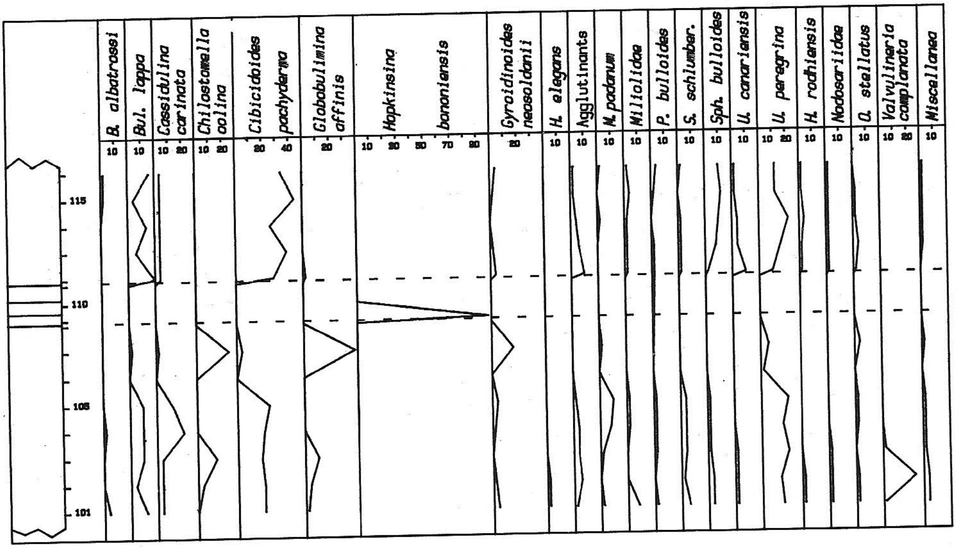

Fig. 5 – Unit 1. Abundance variation in the benthic foraminiferal groupings.

sharp peak in *Hopkinsina bononiensis* at the base of the laminite, a species generally not recorded from anoxic bottom sediments, all other species disappear within the laminated interval. *Chilostomella oolina, Globobulimina affinis* and *Gyroidinoides neosoldanii* peak in sample 107, 25 cm below the base of the laminite, where they combine to account for about 100% of the benthic assemblage. All other species indicative of open marine bottom conditions are absent or extremely rare in sample 106. In sample 103 an increase in *Chilostomella oolina* and *Globobulimina affinis*, preceeded in sample 102 by a sharp increase in *Valvulineria complanata* and followed by an increase in *Cassidulina carinata* (both indicative of moderate to low oxygen bottom conditions) would seem to indicate the gradual development of anoxic bottom conditions. However this level is not followed by the deposition of laminated sediments.Instead, a normal marine benthic assemblage is reestablished, indicating that fully anoxic conditions were never developed. The top of the laminite is rapidly followed by the reestablishment of open marine bottom conditions, as indicated by the presence of a diversified benthic assemblage (Fig. 5), yielding open marine species (*Cibicidoides pachyderma, Sphaeroidina bulloides*, Agglutinants, among others), whereas species indicative of an anaerobic environment are practically absent.

The planktonic assemblages provide a clear indication of the surface water conditions during this time interval. Climatic fluctuations are well documented by the inverse oscillations of warm (*Gld. ruber*) and cold (*Gl. pachyderma, Gl. quinqueloba*) species abundances. A cycle with a short warm–temperate inter-

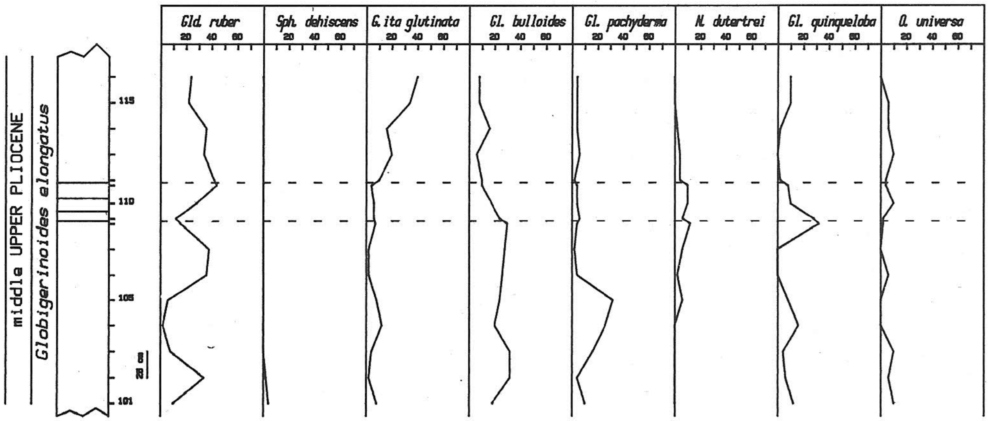

Fig. 6 — Unit 1. Abundance variations in the planktonic foraminiferal groupings.

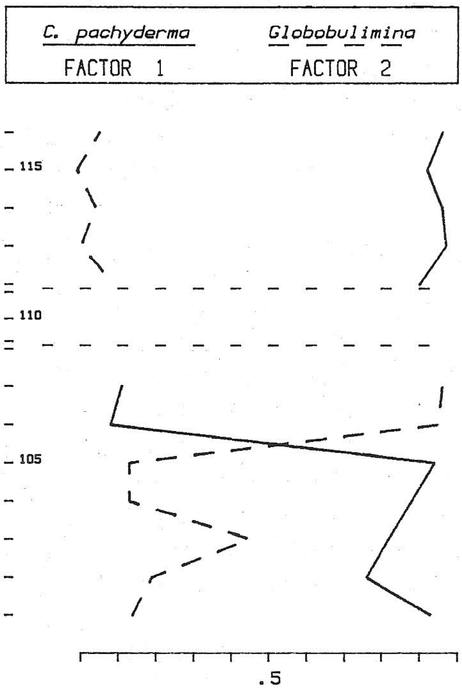

Fig. 7 — Unit 1. Plot of the Q–mode Factor analysis results of the benthic foraminiferal abundance data.

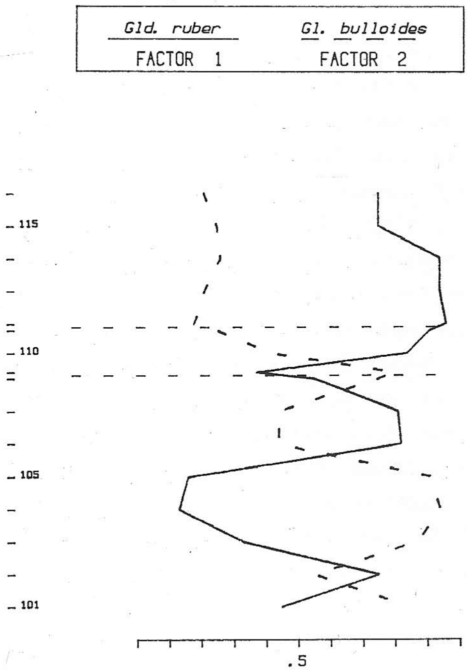

Fig. 8 — Unit 1. Plot of the Q–mode Factor analysis results of the planktonic foraminiferal abundance data.

val followed upwards by a cold episode (samples 104–105) is associated with the above mentioned brief establishment of moderate anoxic bottom conditions. Another short warm to cold climatic oscillation precedes the onset of laminite deposition. Within the laminated interval a clear warming trend is detectable, followed by stable warm–temperate conditions in the upper marls. The abundance of *Neogloboquadrina dutertrei* increases slightly in the laminated interval, but only reaches values of about 10% . This may indicate that surface water salinities were not greatly reduced during the deposition of this particular laminite.

The result of a Q–mode factor analysis of the benthic and planktonic abundance data (Fig. 7, 8; Tab. 2, 3) support the above interpretations. Factor 1 (warm) and Factor 2 (cold) for the planktonic data are inversely related and clearly demonstrate the warming trend within the laminite. Factor 1 (normal marine) and Factor 2 (low oxygen conditions) from the benthic data analysis also vary inversely. Factor 2 is very high just below the base of the laminated interval. A relatively small increase in Factor 2 in sample 103 reflects the brief moderately anoxic bottom conditions. The high values of Factor 1 at the base of the upper marls testifies to the rapid reestablishment of open marine conditions. Factor 3, not plotted in Fig. 7, is dominated by *Hopkinsina bononiensis* (Tab. 2); it peaks in sample 109, at the base of the laminated interval, and is essentially absent in all the other samples. The presence of *Hopkinsina bononiensis* (Fig. 5) at the base of the laminite is here interpreted as an indication of extremely anoxic bottom conditions.

Geochemical analysis.

The organic carbon, carbonate and stable isotopic data for segment G–1 are presented in Fig. 9. The organic carbon content of the marls above and below the laminite is approximately 0.2%. Within the laminite, organic carbon content initially decreases to about 0.16%, and then increases to maximum values of 0.3% at the top of the laminite. Despite this slight increase in organic carbon content in the upper part of the laminite, this unit can certainly not be considered a sapropel (sapropels must contain at least 2% organic carbon).

The carbonate content of the interval below the G–1 laminite is somewhat variable, fluctuating between 15–25% (Fig. 9). Within the laminite, carbonate values are fairly uniform (20%), and then increase significantly above the laminite to greater than 40%. It is difficult to determine if the differences in carbonate content between the laminated sediments and the marls is due to preservation, productivity or dilution by non–calcareous material.

The oxygen isotope record of *Globigerinoides ruber* shows a large depletion (4.0‰) in $\delta^{18}O$ from the underlying marls to the lower part of the laminite, followed by a rapid enrichment in $\delta^{18}O$ in the upper part of the laminite

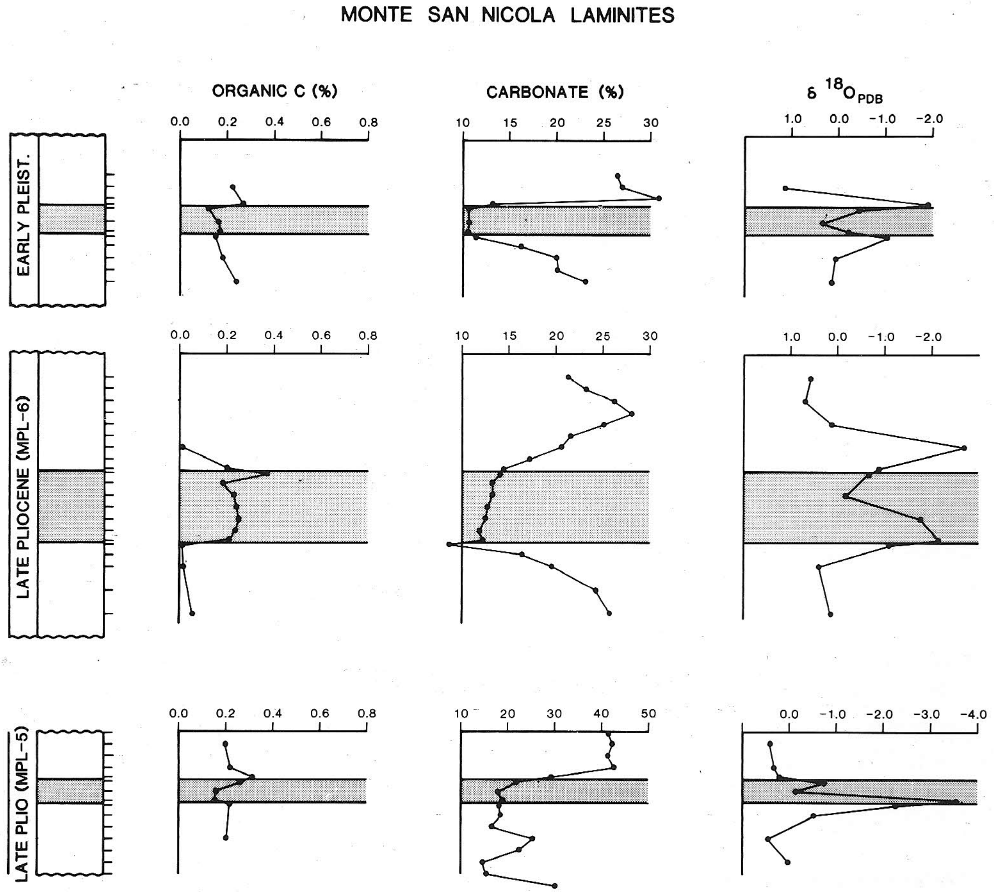

Fig. 9 – Change in organic carbon content, carbonate content and oxygen isotopic composition of the planktonic foraminifera *Globigerinoides obliquus* across the three Monte San Nicola laminites. The laminated units are indicated by stipled pattern.

(Fig. 9). The marls above the laminite have $\delta^{18}0$ values similar to those from below the laminite.

The organic carbon, carbonate and oxygen isotope results, when considered together with the foraminiferal data, support the idea that the G–1 laminite was deposited in oxygen–depleted bottom water. However, the relatively low organic carbon content of the laminated unit suggests that there was no significant increase in surface productivity associated with the deposition of this particular laminite. The very large $\delta^{18}0$ depletion at the base of the laminite is indicative of reduced surface salinities, and may be due to a sudden increase in fresh water run–off. The low carbonate content of the laminite is most likely due to dilution by materials carried in with the increased run–off. In addition,

Tab. 2 – Unit 1. Q–mode Factor analysis results of the benthic foraminiferal abundance data.

	EIGENVALUES	% OF TRACE	CUMULATIVE % OF TRACE
1	8.5340	65.6458	65.6458
2	1.9112	14.7015	80.3473
3	1.0000	7.6926	88.0399
4	.4776	3.6739	91.7138
5	.3966	3.0509	94.7647
6	.2223	1.7103	96.4750
7	.2018	1.5526	98.0276
8	.1145	.8811	98.9087
9	.0597	.4592	99.3678
10	.0377	.2901	99.6579
11	.0266	.2043	99.8622
12	.0156	.1199	99.9821
13	.0023	.0179	100.0000

	ROTATED FACTOR MATRIX			COMMUNALITY
	Factor 1	Factor 2	Factor 3	
116	.9649	.0467	.0016	.933123
115	.9259	–.0134	–.0015	.857508
114	.9685	.0431	.0006	.939917
113	.9678	.0035	–.0012	.936728
112	.9082	.0957	.0099	.834164
109	.0020	.0025	1.0000	.999972
107	.1152	.9639	.0012	.942429
106	.0816	.9555	.0019	.919627
105	.9426	.1291	.0011	.905247
104	.8824	.1282	.0011	.795043
103	.8217	.4539	.0008	.881252
102	.7588	.1949	–.0018	.613708
101	.9307	.1421	.0023	.886461

	VARIMAX FACTOR SCORES		
	Factor 1	Factor 2	Factor 3
Bolivina dilatata	1.4066	.8194	.9452
Bulimina lappa	11.3396	4.5352	.5956
Cassidulina carinata	6.4133	3.5173	–.0222
Chilostomella oolina	–1.5843	26.0171	–.0831
Cibicidoides pachyderma	30.9516	–3.9494	–.0980
Globobulimina affinis	–2.3512	32.0391	.3843
Hopkinsina bononiensis	–.0920	–.1452	97.1550
Gyroidinoides neosoldanii	–.0627	22.1724	–.0263
Hoeglundina elegans	.8043	–.0410	–.0008
Agglutinanti	3.7305	.0534	.4314
Melonis padanum	2.7224	1.1018	.4583
Miliolidi	2.7112	–.6362	.0117
Pullenia bulloides	2.0910	–.2205	.0065
Sigmoilopsis schlumbergeri	2.5652	.2675	–.0091
Sphaeroidina bulloides	6.4660	–2.0997	–.0570
Uvigerina canariensis	3.1058	–.5269	.0566
Uvigerina peregrina	17.3567	3.7367	–.0950
Hanzawaia rodhiensis	1.5599	–.4425	.0019
Nodosariidae	2.2401	–.1832	–.0022
Oridorsalis stellatus	1.6298	1.0872	–.0107
Valvulineria complanata	2.8841	1.2220	–.0851
Miscellanea	1.9293	.5602	–.0165

Tab. 3 – Unit 1. Q–mode Factor analysis results of the planktonic foraminiferal abundance data.

	EIGENVALUES	% OF TRACE	CUMULATIVE % OF TRACE
1	11.3912	71.1950	71.1950
2	2.2613	14.1330	85.3280
3	1.2596	7.8722	93.2002
4	.4487	2.8042	96.0045
5	.3031	1.8943	97.8987
6	.1937	1.2105	99.1092
7	.0930	.5815	99.6907
8	.0224	.1399	99.8306
9	.0193	.1203	99.9509
10	.0052	.0325	99.9835
11	.0020	.0122	99.9957
12	.0005	.0029	99.9986
13	.0002	.0014	100.0000

	ROTATED FACTOR MATRIX		COMMUNALITY
	Factor 1	Factor 2	
116	.7524	.2180	.613588
115	.7557	.2495	.633358
114	.9406	.3131	.982758
113	.9398	.2174	.930536
112	.9653	.1785	.963647
111	.9137	.2505	.897576
110	.8395	.4225	.883240
109	.3738	.7966	.774278
108	.5511	.7475	.862502
107	.8159	.4283	.849223
106	.8207	.4435	.870338
105	.1581	.9120	.856696
104	.1352	.9352	.892877
103	.3362	.8767	.881542
102	.7547	.5481	.869958
101	.4555	.8264	.890361

	VARIMAX FACTOR SCORES	
	Factor 1	Factor 2
Globigerinoides ruber	41.2881	−4.7300
Globigerinita glutinata	14.8799	1.4039
Globigerina bulloides	7.2569	27.4405
Globigerina pachyderma	−4.0299	20.3320
Neogloboquadrina dutertrei	3.4534	3.4252
Globigerina quinqueloba	−.5314	14.1079
Orbulina universa	5.1456	2.8308
Hastigerina siphonifera	.5553	.3196
Globorotalia scitula	−.3986	1.3535
Globorotalia crassaformis	1.2328	−.3915
Sphaeroidinella dehiscens	−.0913	.9150
Globigerina falconensis	1.9486	.4721
Globorotalia planispira	2.0255	−1.1390

the low carbonate content may be at least partially attributable to dissolution. Schrader et al. (1981) have shown that carbonate dissolution may actually be enhanced within anoxic bottom waters.

Segment G–2.

General information.

Twenty–one samples have been collected from a 5 meter thick segment, which contains a 150 centimeter thick, brown, well–laminated interval. This segment belongs to the middle part of M Pl 6 foraminiferal biozone and to the *C. doronicoides* nannofossil zone. According to Rio et al. (1984) this section has an absolute age of about 1.8 MA. The number of species, percent of residue greater than 63 microns, percent of planktonic foraminifera, and presence of gypsum, pteropods and echinoid remains per sample are illustrated in Fig. 10.

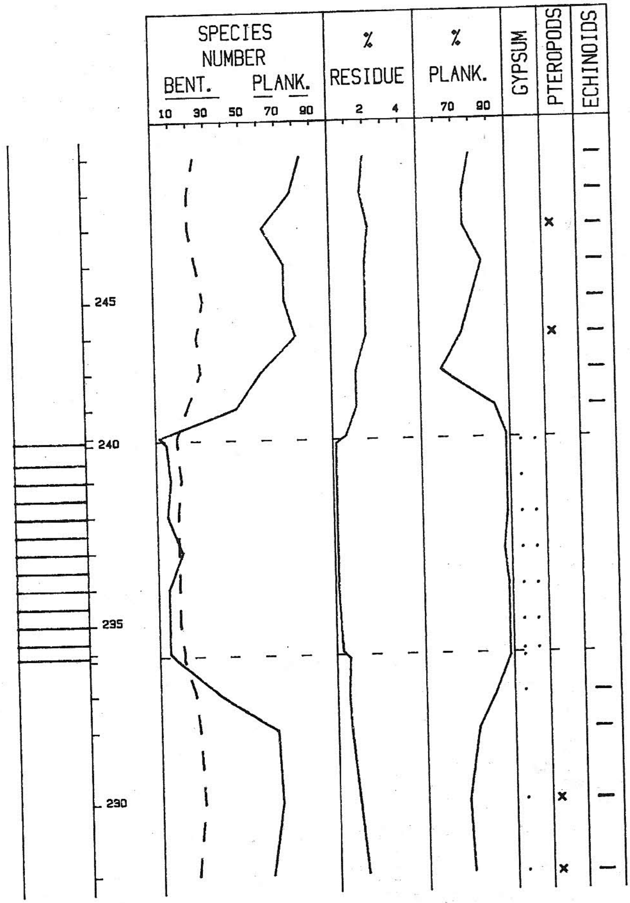

Fig. 10 – Unit 2. Main general features of the residues and of the faunistic assemblage.

Foraminifera.

A total of 139 benthic and 33 planktonic species were identified from the generally well preserved assemblages. Only in sample 233, just below the laminite interval, is the foraminiferal assemblage badly preserved, with specimens represented by pyritized molds and corroded tests. Variations in the abundance of benthic and planktonic species are illustrated in Fig. 11 and 12. *Bolivina di-*

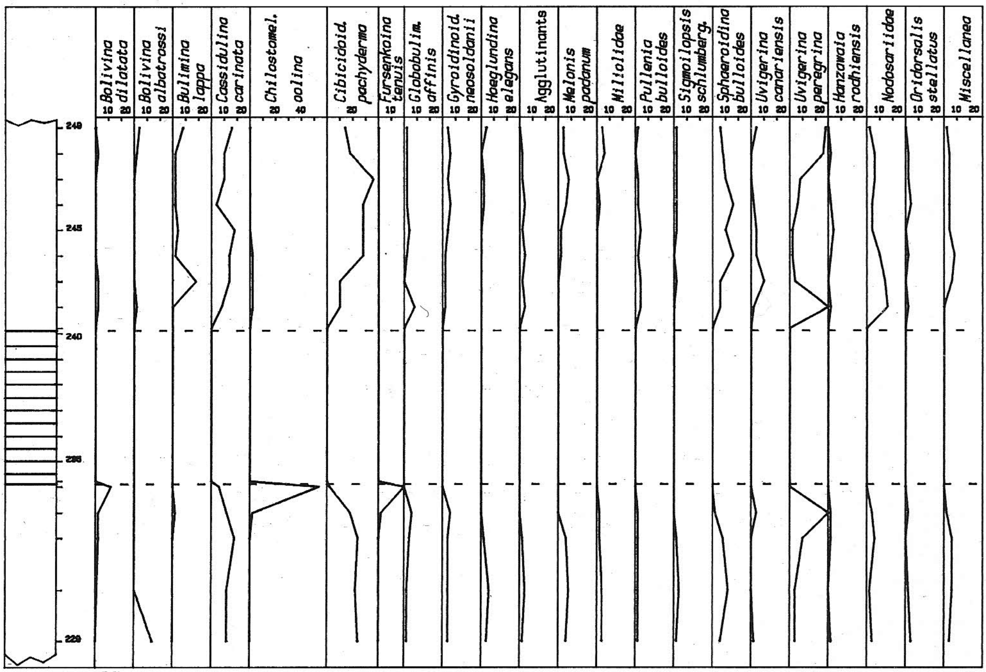

Fig. 11 — Unit 2. Abundance variations in the benthic foraminiferal groupings.

latata, Chilostomella oolina, Fursenkoina tenuis and *Cassidulina carinata* (rare) constitute nearly all of the benthic assemblage just below the base of the laminite (sample 233). The first three of these species have peak abundance in this sample, indicating a strongly reduced bottom environment. It is preceded by a significant increase in *Uvigerina* spp. and by a smaller increase in *Globobulimina affinis* and *Gyroidinoides neosoldanii* in sample 232, indicating less severe anoxic bottom conditions. Species which are indicative of normal marine conditions are practically absent from this laminated interval, but are well represented in the underlying marls. Within the laminite, benthic species are totally absent in the greater than 125 micron fraction. Above the laminite, the first sample (241) is still devoid of a benthic assemblage, indicating the persistence of anoxic conditions. A less severe, but still not well—oxygenated environment can be inferred for sample 242, in which *Globobulimina affinis* and *Uvigerina* *peregrina* are abundant. This assemblage is more diversified, including species indicative of quite normal conditions (*Nodosariidae, Cibicidoides* spp., *Sphaeroidina bulloides*, among others). A rich benthic assemblage with several different species is present above the laminite, reflecting the reestablishment of open marine conditions.

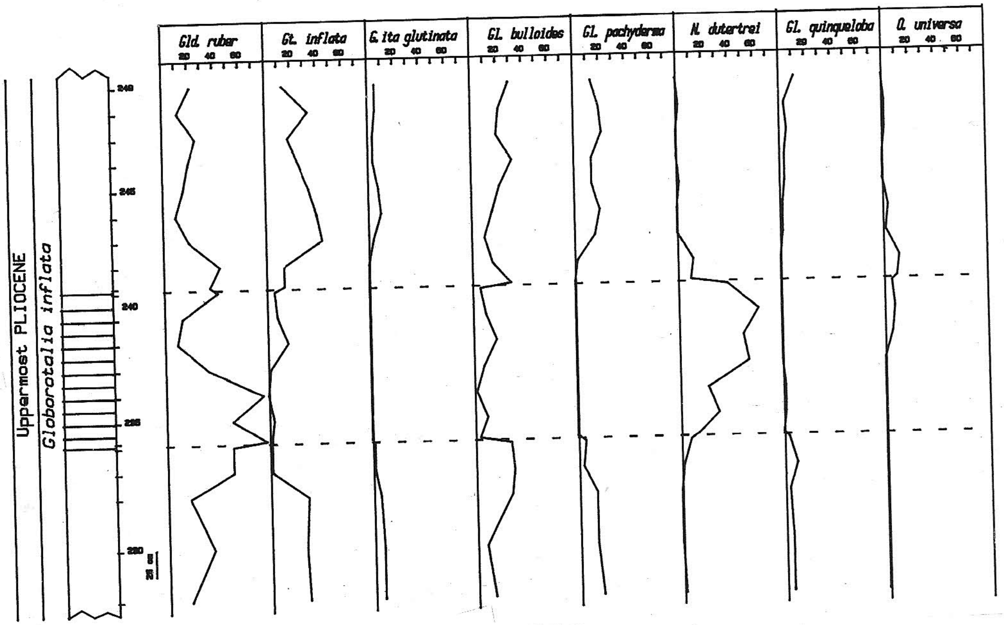

Fig. 12 – Unit 2. Abundance variations in the planktonic foraminiferal groupings.

For the planktonic species, an increase in *Gld. ruber*, decrease in *Gt. inflata* and *Gl. bulloides*, and the disappearance of *Gl. pachyderma* and *Gl. quinqueloba* at the base of the laminated interval indicate a warming, followed by a cool episode and another warming trend. *Gld. ruber* greatly decreases, and the «cold» species increase in the upper marls, where only small climatic fluctuations are detectable. *Neogloboquadrina dutertrei* increases dramatically within the laminite and is rare or absent in the marls below and above. The high abundances of this species are indicative of lowered surface salinities during laminite deposition.

Q–mode factor analysis of the planktonic abundance data clearly defines three factors (Fig. 13; Tab. 4). Factor 1 (cold) has low values within the laminite, and substantially higher values in the marls below and above. Factor 2 (warm) has its highest values at the base of the laminite, with a smaller peak at the base of the upper marls. Factor 3 (low salinity) has very low values in the lower and upper marls, and strongly increases within laminite.

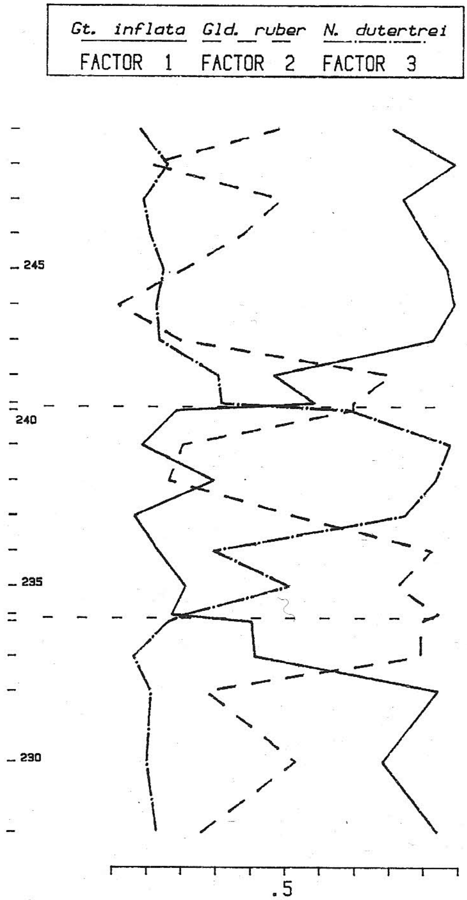

Fig. 13 — Unit 2. Plot of the Q—mode Factor analysis results of the planktonic foraminiferal abundance data.

From the Q—mode factor analysis of the benthic data three factors emerge (Fig. 14; Tab. 5). Factor 1 (normal marine environment) has its highest values in levels relatively far from the laminite, drops to zero in the two samples just below and above the laminite. Factor 3 (severe anoxic conditions) is generally low in the marls and peaks in sample 233, just below the base of the laminites. Factor 2, interpreted as indicative of less severe anoxic conditions, is dominated by *Uvigerina peregrina.* The highest values of Factor 3 occur in levels near the laminites. This Factor gradually increases from the bottom of the segment untill it peaks in sample 232; in sample 233 it drops to zero, and is replaced by Factor 2. This clearly indicates a rapid transition from a moderate to a severe anoxic bottom environment. Factor 3 increases again in sample 242, 30 centimeters above the top of laminite, again indicating the persistence of moderately low oxygen conditions. Factor 3 then decreases in coincidence with the reestablishment of an open marine benthic assemblage (high values of Factor 1).

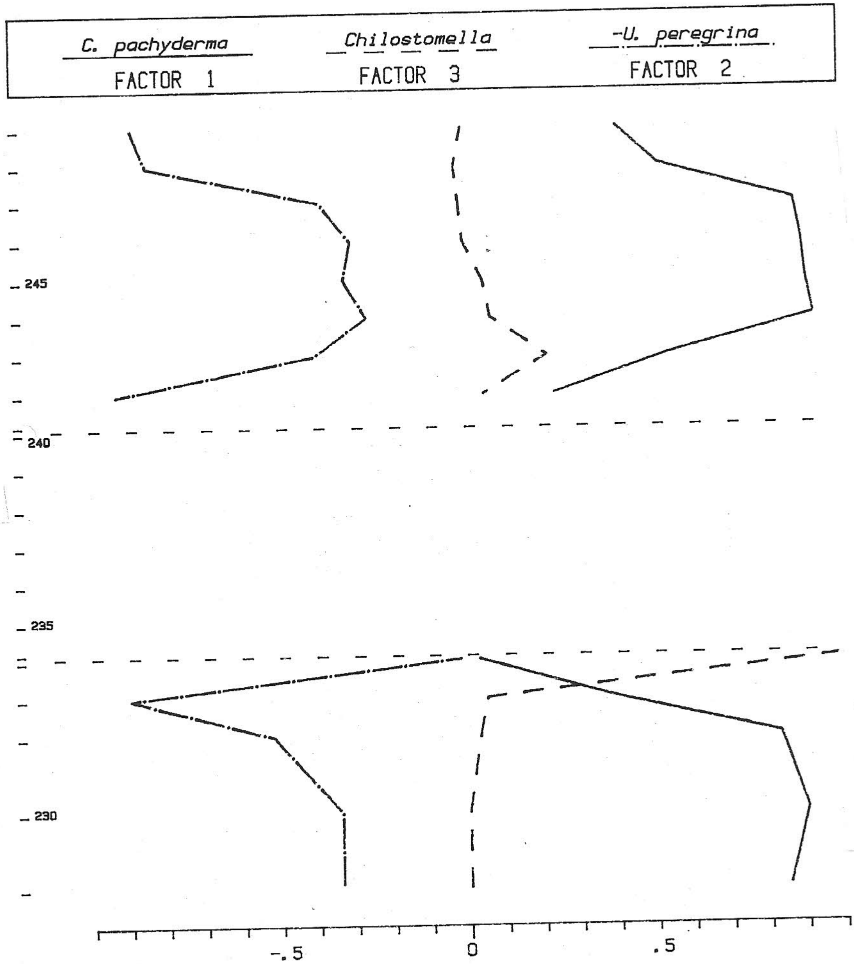

Fig. 14 — Unit 2. Plot of the Q—mode Factor analysis results of the benthic foraminiferal abundance data.

Geochemical analysis.

The organic carbon, carbonate and stable isotope data for segment G—2 are illustrated in Fig. 9. The organic carbon content displays a very distinct pattern, with values in the laminite (0.2—0.4%) being noticeably higher than the marls (0.0—0.05%). As with G—1, the carbon content of the G—2 laminite is too low for this unit to be classified as a sapropel. The increase in organic carbon within the G—2 laminite is most likely due to enhanced preservation within oxygen—depleted bottom waters. The absolute values (~ 0.25%) are not that high that a major increase in productivity need be invoked.

The carbonate content of segment G—2 also displays a very striking pattern (Fig. 9). There is a systematic decrease in the carbonate content of the

Tab. 4 – Unit 2. Q–mode Factor analysis results of the planktonic foraminiferal abundance data.

	EIGENVALUES	% OF TRACE	CUMULATIVE % OF TRACE
1	14.2224	67.7257	67.7257
2	4.0561	19.3146	87.0403
3	1.7768	8.4611	95.5014
4	.6541	3.1148	98.6162
5	.1883	.8968	99.5130
6	.0564	.2687	99.7817
7	.0347	.1652	99.9469
8	.0112	.0531	100.0000

	ROTATED FACTOR MATRIX			COMMUNALITY
	Factor 1	Factor 2	Factor 3	
249	.7981	.4661	.0790	.860575
248	.9804	.1054	.1542	.996033
247	.8374	.4768	.0809	.935179
246	.8929	.3674	.1035	.943004
245	.9630	.2010	.1427	.988096
244	.9764	.0136	.1232	.968732
243	.9177	.1872	.1297	.893999
242	.4617	.8046	.3024	.951920
241	.5772	.6877	.3132	.904186
240	.1795	.6935	.6874	.985720
239	.0809	.2023	.9719	.992101
238	.2879	.1656	.9340	.982681
237	.0558	.5195	.8449	.986864
236	.1285	.9225	.2957	.954893
235	.2091	.8251	.5142	.988919
234	.1699	.9408	.2092	.957703
233	.3990	.8821	.1646	.964490
232	.4095	.8792	.0671	.945134
231	.9452	.2724	.1128	.980415
230	.7853	.5322	.1042	.910735
229	.9362	.2626	.1356	.963843

	VARIMAX FACTOR SCORES		
	Factor 1	Factor 2	Factor 3
Globigerinoides ruber	.3507	64.2454	1.0146
Globorotalia inflata	35.6026	–11.5326	9.1307
Globigerinita glutinata	7.3253	–1.6490	–.7881
Globigerina bulloides	20.1915	9.9382	3.7567
Globigerina pachyderma	18.9332	3.4457	–2.4192
Neogloboquadrina dutertrei	–8.1649	1.5982	59.7847
Globigerina quinqueloba	4.9204	2.8303	–2.6876
Orbulina universa	1.4826	.3491	5.6638

Tab. 5 – Unit 2. Q–mode Factor analysis results of the benthic foraminiferal abundance data.

	EIGENVALUES	% OF TRACE	CUMULATIVE % OF TRACE
1	9.2966	71.5125	71.5125
2	1.4148	10.8831	82.3956
3	1.0113	7.7792	90.1748
4	.6285	4.8346	95.0095
5	.2195	1.6882	96.6977
6	.1596	1.2273	97.9250
7	.1138	.8754	98.8004
8	.0772	.5940	99.3944
9	.0399	.3070	99.7014
10	.0240	.1845	99.8859
11	.0078	.0596	99.9455
12	.0054	.0417	99.9872
13	.0017	.0128	100.0000

	ROTATED FACTOR MATRIX Factor 1	Factor 2	Factor 3	COMMUNALITY
249	.4096	–.8817	.0069	.945244
248	.5207	–.8359	–.0188	.970164
247	.8895	–.3847	–.0112	.939376
246	.9079	–.3058	–.0062	.917811
245	.9163	–.3209	.0542	.945486
244	.9287	–.2642	.0672	.936860
243	.5423	–.4057	.2192	.506781
242	.2369	–.9260	.0543	.916460
233	.0279	–.0359	.9844	.971035
232	.3918	–.8970	.0499	.960723
231	.8280	–.5114	.0328	.948229
230	.9036	–.3413	.0019	.932929
229	.8470	–.3379	–.0044	.831631

	VARIMAX FACTOR SCORES Factor 1	Factor 2	Factor 3
Bolivina dilatata	–.7140	–1.5540	12.4388
Bolivina albatrossi	1.6102	–1.0851	–.6898
Bulimina lappa	2.1578	–2.6075	4.1006
Cassidulina carinata	11.1693	–8.1530	6.7521
Chilostomella oolina	–1.1873	.6114	53.3245
Cibicidoides pachyderma	28.6290	–4.2114	–.9851
Fursenkoina tenuis	–.7526	.1080	23.5887
Globobulimina affinis	.4344	–4.9802	–.1372
Gyroidinoides neosoldanii	2.9246	–3.6642	–.5567
Hoeglundina elegans	2.9271	.4217	–.6723
Agglutinanti	3.0515	–.7511	.1020
Melonis padanum	6.0578	.1362	–1.2936
Miliolidi	1.4338	–2.2470	–.9373
Pullenia bulloides	2.2577	–1.0813	.6740
Sigmoilopsis schlumbergeri	2.2857	–.2012	–.1724
Sphaeroidina bulloides	12.4925	.0076	–.4035
Uvigerina canariensis	1.9572	–1.6645	1.7019
Uvigerina peregrina	–8.1218	–35.0518	–2.2036
Hanzawaia rodhiensis	1.3323	–1.1401	.0243
Nodosariidae	2.9149	–7.0748	2.2857
Oridorsalis stellatus	1.9809	–.8699	–.3758
Miscellanea	6.1153	.1780	.5799

lower marls from 25% to less than 10% at the base of the laminite. As pointed out above, there is also very poor foraminiferal preservation in the sample immediately below the laminite. Carbonate content is uniformly low within the laminite (less than 15%), and then steadily increases to greater than 25% in the overlying marls.

There is about a 2.5‰ depletion in the $\delta^{18}O$ of *Globigerinoides ruber* from the lower marl to the lower part of the laminite, followed by a 2.0‰ enrichment within the laminite. Immediately above the laminite there is a 2‰ depletion, followed by a 3‰ enrichment. These large and sudden changes in $\delta^{18}O$ are a clear indication of significant changes in surface water conditions at this time. Most likely, these large depletions and enrichments are a complex mixture of changes in surface water temperatures and salinities.

The depletion at the base of the G–2 laminite is similar to what occurs in the G–1 laminite (Fig. 9). As discussed above, the planktonic foraminiferal fauna indicates a warming in the lower part of the G–2 laminite (Fig. 12, 13), and this may be responsible for at least part of the $\delta^{18}O$ depletion. Similarly, as the $\delta^{18}O$ values become enriched within the G–2 laminite, the planktonic fauna indicates a cooling (increase of *Globorotalia inflata*). In addition, the overall high abundances of *Neogloboquadrina dutertrei* within the G–2 laminite suggest reduced surface salinities. It would therefore seem that during the deposition of the G–2 laminite surface waters were initially warm with a reduced salinity, but then cooled during the later stage of laminite deposition.

Segment G–3.

General information.

Twelve samples have been collected from a 2.25 meter thick interval; a

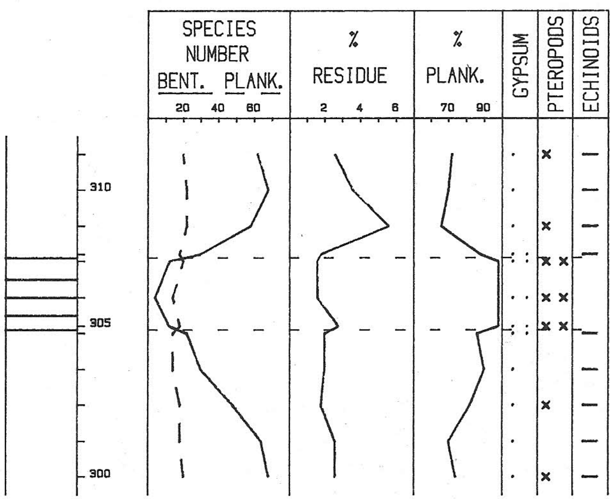

Fig. 15 – Unit 3. Main general features of the residues and of the faunistic assemblage.

50 centimeter thick, brownish, well laminated unit is present in the middle of this interval. The segment belongs to the lower part of the *Gl. cariacoensis* foraminiferal biozone and the uppermost part of the *C. doronicoides* nannofossil biozone, just below the *Gephyrocapsa oceanica* F.O. According to Rio et al. (1984) the mean absolute age of this segment is about 1.63 MA. Number of species, percent of residue greater than 63 micron, percent of planktonic foraminifera, and presence of gypsum, pteropods and echinoids remains per sample are illustrated in Fig. 15.

Foraminifera.

A total of 106 species of benthic and 30 species of planktonic foraminifera were identified from the generally well preserved assemblages. Only in sample 304 are specimens badly preserved. Variations in the abundance of benthic and planktonic species are illustrated in Fig. 16 and 17. *Globobulimina*

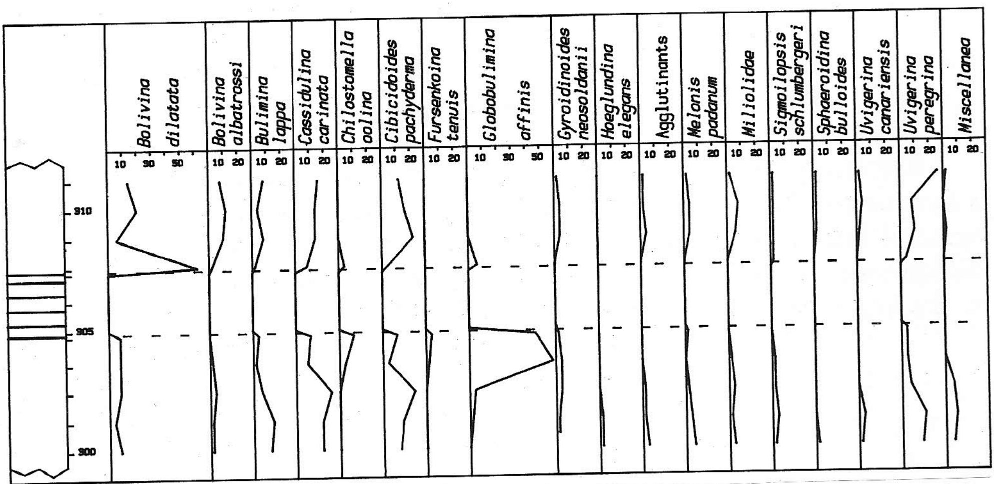

Fig. 16 – Unit 3. Abundance variations in the benthic foraminiferal groupings.

affinis, *Chilostomella oolina* and *Fursenkoina tenuis* strongly increase just below the base of the laminite, while *Bolivina dilatata, Cassidulina carinata, Gyroidinoides neosoldanii* and *Uvigerina peregrina* are also present in low abundances, but in generally decreasing trends. *Cibicidoides pachyderma* (about 15%) is still present at the top of the lower marls. All other species indicative of normal conditions are practically absent. A moderately oxygen–depleted bottom environment can therefore be inferred for this level close to the base of the laminite. Within the laminite interval benthic species are totally absent in the greater than 125 micron fraction. The base of the upper marls is characterized by a peak in *Bolivina dilatata* and *Cassidulina carinata. Chilostomella oolina, Globobulimina affinis* and *Uvigerina peregrina* are also present at this level but in lower numbers. This assemblage is clearly indicative of the persistence of moderately anoxic bottom conditions. A more normal marine assemblage is present in sample 309, about 30 centimeters above the top of the laminite. At this level *Bolivina dilatata* strongly decreases, and *Chilostomella oolina* and *Globobulimina affinis* drop to zero.

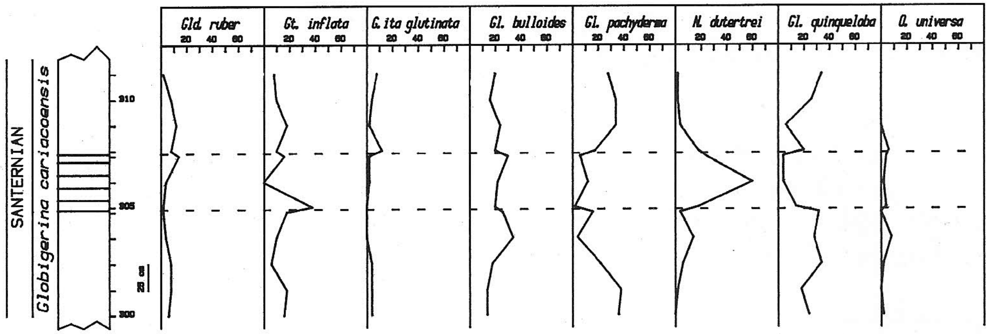

Fig. 17 — Unit 3. Abundance variations in the planktonic foraminiferal groupings.

Regarding the planktonic foraminifera, *Gld. ruber* is never very abundant: it increases within the laminite interval, but is always less than 20%. *Gt. inflata* increases briefly at the base of the laminated interval but then decreases within the laminite. *Gl. bulloides, Gl. pachyderma* and *Gl. quinqueloba* are abundant in the lower marls and decrease within laminite.

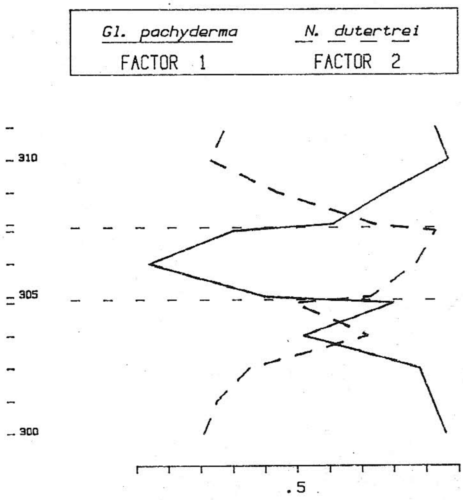

Fig. 18 — Unit 3. Plot of the Q—mode Factor analysis results of the planktonic foraminiferal abundance data.

Q–mode factor analysis of the planktonic abundance data defines 2 factors (Fig. 18; Tab. 6); Factor 1 (cold) has high values in the lower and upper marls, and decreases within laminite. Factor 2 (low salinity) increases in the upper part of laminite and is present in uniformely low values in the marls, indicating a sharp surface salinity decrease during laminite deposition.

From the Q–mode factor analysis of the benthic data three factors emerge (Fig. 19; Tab. 7). Factor 1 (normal marine conditions) is highest in the levels

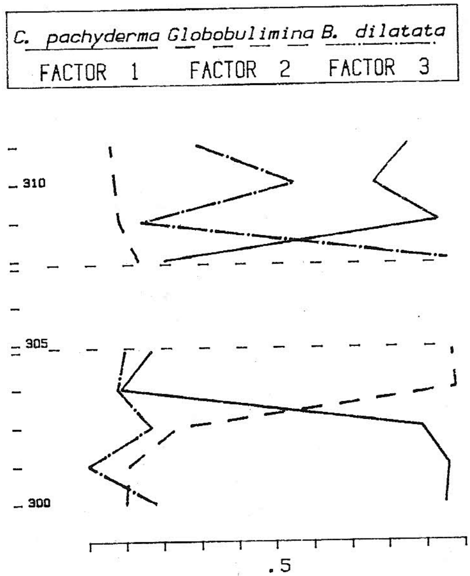

Fig. 19 – Unit 3. Plot of the Q–mode Factor analysis results of the benthic foraminiferal abundance data.

quite far from laminites, with very low values below and just above the boundaries of the laminites. Factor 2 (severe anoxic conditions) is generally very low, but peaks in the two samples just below the base of the laminite. Factor 3 (moderate anoxic conditions) is also generally low, but peaks in sample 308, just above the top of the laminite. It rapidly decreases in the following sample (309) where a well diversified benthic assemblage with several species indicative of a normal marine environment are present. A moderate increase in Factor 3 (and a corresponding decrease in Factor 1) in sample 310 indicates the brief development of oxygen–deficient bottom conditions.

Geochemical analysis.

The organic carbon, carbonate and stable isotope data for segment G–3 are illustrated in Fig. 9. There is no increase in organic carbon content of the laminated unit in this segment. In fact, the marls tend to have slightly higher carbon content.

Tab. 6 – Unit 3. Q–mode Factor analysis results of the planktonic foraminiferal abundance data.

	EIGENVALUES	% OF TRACE	CUMULATIVE % OF TRACE
1	8.8884	74.0703	74.0703
2	1.6490	13.7420	87.8122
3	.6641	5.5339	93.3461
4	.4823	4.0191	97.3652
5	.2051	1.7088	99.0741
6	.0639	.5329	99.6069
7	.0417	.3472	99.9541
8	.0055	.0459	100.0000

	ROTATED FACTOR MATRIX		COMMUNALITY
	Factor 1	Factor 2	
311	.9297	.2803	.942835
310	.9676	.2271	.987834
309	.7829	.4360	.803030
308	.6091	.7371	.914333
307	.2973	.9296	.952608
306	.0409	.8727	.763319
305	.4009	.7348	.700746
304	.8039	.4917	.888117
303	.5217	.7165	.785506
302	.8826	.3518	.902643
301	.9250	.2538	.920038
300	.9651	.2124	.976463

	VARIMAX FACTOR SCORES	
	Factor 1	Factor 2
Globigerinoides ruber	4.1588	7.3969
Globorotalia inflata	10.7458	12.5136
Globigerinita glutinata	4.0024	1.3012
Globigerina bulloides	10.6608	29.0980
Globigerina pachyderma	33.4923	−4.5266
Neogloboquadrina dutertrei	−12.6568	39.6624
Globigerina quinqueloba	27.3177	1.1622
Orbulina universa	.0625	5.1037

Tab. 7 – Unit 3. Q–mode Factor analysis results of the benthic foraminiferal abundance data.

	EIGENVALUES	% OF TRACE	CUMULATIVE % OF TRACE
1	5.7384	63.7596	63.7596
2	1.7757	19.7304	83.4899
3	.9187	10.2080	93.6979
4	.3373	3.7474	97.4453
5	.1263	1.4031	98.8484
6	.0552	.6134	99.4618
7	.0231	.2572	99.7190
8	.0150	.1667	99.8857
9	.0103	.1143	100.0000

	ROTATED FACTOR MATRIX			COMMUNALITY
	Factor 1	Factor 2	Factor 3	
311	.8658	.0768	.3049	.848447
310	.7701	.0887	.5661	.921435
309	.9385	.0903	.1526	.912262
308	.2129	.1441	.9569	.981848
304	.1713	.9747	.1058	.990572
303	.0944	.9858	.0835	.987650
302	.8971	.2451	.1722	.894472
301	.9648	.1105	.0057	.943165
300	.9530	.1027	.1847	.952961

	VARIMAX FACTOR SCORES		
	Factor 1	Factor 2	Factor 3
Bolivina dilatata	–3.4551	3.1439	59.1477
Bolivina albatrossi	5.7445	–.6115	3.5392
Bulimina inflata	10.2236	1.0031	–2.3835
Cassidulina carinata	18.2731	6.9410	2.3057
Chilostomella oolina	–1.4253	6.9028	2.6560
Cibicidoides pachyderma	17.2934	4.0921	.5755
Fursenkoina tenuis	–.3629	2.6380	.3607
Globobulimina affinis	–5.6461	54.0225	–1.1927
Gyroidinoides neosoldanii	2.5144	3.1203	.4914
Hoeglundina elegans	1.1128	–.0231	–.8342
Agglutinanti	2.8125	–.4467	–.4983
Melonis padanum	4.4929	.2257	.1131
Miliolidi	3.9922	.5283	.5322
Sigmoilopsis schlumbergeri	1.9313	.2713	.7515
Sphaeroidina bulloides	1.2869	–.0703	.5271
Uvigerina canariensis	2.4840	–.5227	.4210
Uvigerina peregrina	14.9151	1.1086	.3904
Miscellanea	5.1464	–.1803	–2.3592

The marls and the laminites have vastly different carbonate content. The laminite is uniformly low at about 10% carbonate, while the marls contain as much as 25–30% carbonate. This pattern is very similar to what was found in segment G–2. Planktonic foraminiferal preservation is bad immediately below the laminite and dissolution may be at least partially responsible for the low carbonate content of the laminite. In addition, all three of the laminites are essentially devoid of benthic foraminifera, and this loss of foraminiferal calcite may also play a significant role in reducing the overall carbonate content in the laminites.

The oxygen isotopic record of *Globigerinoides ruber* in segment G–3 is very similar to that for segment G–2. Specifically, there is a large depletion in $\delta^{18}O$ at the base of the laminite, followed by an enrichment within the laminite, and ending with a rapid depletion/enrichment cycle in the overlying marl (Fig. 9). This is again interpreted as reflecting rapid changes in both surface water temperatures and salinities. The planktonic foraminiferal fauna (Fig. 17) indicates that surface waters were cool during the early and middle stage of laminite formation (high abundance of *Globorotalia inflata* and then *Globigerina pachyderma*), but then warmed during the late stage of laminite deposition (increase in *Globigerinoides ruber*).

Conclusions

The low organic content (less than 0.5%) of the three laminated intervals indicates that they are not sapropels or sapropelitic sediments. Nevertheless certain faunistic and geochemical trends across them can be directly compared with similar changes associated with sapropels. Anoxic bottom conditions always develop immediately before the onset of laminite deposition. At this time the benthic fauna is dominated by the *Fursenkoina tenuis, Globobulimina affinis* and *Chilostomella oolina* groups. The transition from open marine to these severe anoxic conditions is always gradual. The transitional assemblage is characterized by the predominance of *Uvigerina peregrina, Cassidulina carinata* and *Bolivina dilatata.* Laminated intervals are always devoid of benthic foraminifera in the greater than 125 micron fraction. A few species, represented by rare specimens, are sometimes present in the smaller than 125 micron fraction, but they may be displaced, since they include specimens of the shallow water *Ammonia* spp. and *Elphidium* spp. Only in sample 109, from the base of the G–1 laminated interval, is there an authocthonous benthic assemblage. It is represented exclusively by well preserved specimens of *Hopkinsina bononiensis*, a species not previously associated with oxygen depleted condition. The transition from anoxic to normal marine conditions above the laminites is generally rapid, characterized by a transitional assemblage indicative of moderately anoxic conditions (*Bolivina dilatata, Cassidulina carinata, Uvigerina peregrina*). In the grey marls, the benthic assemblage is always very diverse and abundant.

The planktonic foraminifera clearly indicate changing surface water conditions associate with laminite deposition. In segments G–1 and G–2 laminite deposition is associated with a surface water warming, while the G–3 laminite occurs during a relative cooling. Within the laminated units, relatively high abundance of *N. dutertrei* are indicative of a low salinity surface layer. This is particularly clear in segments G–2 and G–3, but less evident for segment G–1.

The low organic carbon content of all three laminites suggests that there was no appreciable increase in surface productivity during their deposition. The low carbonate content of the laminites is probably due to three factors: 1) dissolution, 2) dilution by noncalcareous material, and 3) the total absence of benthic foraminifera. The later of these being a clear indication of the oxygen–depleted nature of the bottom waters during laminite formation.

The large oxygen isotopic changes in the planktonic foraminifera *Globigerinoides ruber* across each of the laminated units reveal a complex pattern of changing surface water temperatures and salinities. Large $\delta^{18}0$ depletions occur across the base of all three laminites. Based on the magnitude of these depletions (up to 4.0‰), it is concluded that the onset of laminite deposition was associated with both a warming and a reduction in surface water salinities. The reduced salinities were most likely due to enhanced continental run–off, and resulted in stratification of the water column. Within each of the laminites there is a sudden enrichment in $\delta^{18}0$. In light of the planktonic faunal results, it would appear that this enrichment is due to a cooling of surface waters.

Three stratigraphically equivalent laminite–bearing intervals have been identified in a corresponding sequence from the Capo Rossello section, outcropping along the southern coast of Sicily about 150 kilometers west of Monte S. Nicola.

Within the eastern Mediterranean basin, no anoxic sediments of Late Pleistocene age have been identified in cores from the Strait of Sicily (Maldonado & Stanley, 1979). Likewise, Pliocene–Early Pleistocene sapropels or laminites recovered from DSDP Sites (Leg 13 and 42A) are also well to the east of the Strait of Sicily (Kidd et al., 1978; Thunell et al., 1984). The identification of laminated, anoxic sediments in Pliocene–Lower Pleistocene bathyal land–sections from Sicily indicates that oxygen–depleted bottom conditions periodically extended to the extreme western border of the eastern basin, well within the Strait of Sicily. In addition, the bathymetry of this segment has been estimated at about 500–400 meters depth (Sprovieri, 1978). Therefore it is suggested that oxygen–deficient conditions, at least during this time interval, extended throughout the greatest part of the water column.

BIBLIOGRAPHY

Adamson D.A., Gasse F., Street F.A. & Williams M.A.J. (1980) - Late Quaternary history of the Nile. *Nature*, v. 288, pp. 50–55, London.

Bé A.W.H. (1977) - An ecological, zoogeographic and taxonomic review of Recent planktonic foraminifera. In Ramsey A.T S. (Ed.) - *Oceanic Micropaleont.*, 1, Ac. Press, London, pp. 1–100, London.

Bé A.W.H. & Tolderlund D.S. (1971) - Distribution and ecology of living planktonic foraminifera in surface waters of the Atlantic and Indian Oceans. In Funnell B.M. & Riedel W. R. (Eds.) - *The Micropaleontology of Oceans*, Cambridge University Press, pp. 105–149, London.

Berry W.B.N. & Wilde P. (1978) - Progressive ventilation of the ocean: an explanation for the distribution of lower Paleozoic black shale. *Am. Journ. Sc.*, v. 278, pp. 257–275, New Haven.

Blanc–Vernet L. (1969) - Contribution à l'étude des foraminifères de Méditerranée. *Rec. Trav. Stat. Mar. Endoume*, v. 64–48, 281 pp., Marseille.

Bonaduce G. & Sprovieri R. (1984) - The appearance of *Cytheropteron testudo* Sars (Crustacea: Ostracoda) is a Pliocene event. Evidences from a Sicilian sequence (Italy). *Boll. Soc. Paleont. Ital.*, v. 23, n. 1, pp. 131–136, Modena.

Calvert S.E. (1983) - Geochemistry of Pleistocene sapropels and associated sediments from the eastern Mediterranean. *Ocean. Acta*, v. 6, pp. 255–267, Montreuil.

Cita M.B. (1975) - Studi sul Pliocene e sugli strati di passaggio dal Miocene al Pliocene. VIII. Planktonic foraminiferal biozonation of the Mediterranean Pliocene deep–sea record. A revision. *Riv. Ital. Paleont. Strat.*, v. 81, n. 4, pp. 527–544, Milano.

Cita M.B. & Grignani D. (1982) - Nature and origin of late Neogene Mediterranean sapropels. In Schlanger S.O. & Cita M.B. (Eds.) - Nature and Origin of Cretaceous Carbon–rich Facies. *Academy Press*, New York, pp. 165–196, New York.

Cita M.B. & Podenzani M. (1980) - Destructive Effects of Oxygen starvation and Asl Falls on Benthic Life: a Pilot study. *Quat. Res.*, v. 13, pp. 230–241, London.

Cita M.B. & Ryan W.B.F. (1973) - Time scale and general synthesis. In Ryan W.B.F. et al. - *Init. Rep. DSDP*, v. 13, pp. 1405–1415, Washington.

Cita M.B. & Ryan W.B.F. (1979) - Late Neogene environmental evolution. In von Rad U. et al. - *Init. Rep. DSDP*, v. 47, pp. 447–459, Washington.

Cita M.B., Vergnaud–Grazzini C., Robert C. et al. (1977) - Paleoclimatic record of a long deep sea core from the Eastern Mediterranean. *Quat. Res.*, v. 8, pp. 205–235, London.

Davis J.C. (1973) - Statistics and Data Analysis in Geology. V. of 550 pp., John Wiley & Sons, Inc., London.

Demaison G.J. & Moore G.T. (1980) - Anoxic environments and oil source bed genesis. *Am. Ass. Petr. Geol. Bull.*, v. 64, pp. 1179–1209, Tulsa.

Douglass R. & Woodruff F. (1981) - Deep Sea benthic foraminifera. In Emiliani C. (Ed.) - The Oceanic Lithosphere: The Sea, v. 7, pp. 1233–1327, Washington.

Froelich P.N. (1980) - Analysis of organic carbon in marine sediments. *Limn. Oceanogr.*, v. 25, pp. 564–572, New York.

Gudjonsson L. & van der Zwaan G.J. (1985) - Anoxic events in the Pliocene Mediterranean: stable isotope evidence of run–off. *Proc. Kon. Ned. Ak. Wet.*, v. 88, pp. 69–82, Amsterdam.

Jenkyns H.C. (1980) - Cretaceous anoxic events: from continents to oceans. *Journ. Geol. Soc. London*, v. 137, pp. 171–188, London.

Jones G.A. & Kaiteris P. (1983) - A vacuum–gasometric technique for rapid and precise analysis of calcium carbonate in sediments. *Journ. Sedim. Petrol.*, v. 53, pp. 655–660, London.

Katz M.E. & Thunell R.C. (1984) - Benthic foraminiferal biofacies associated with middle Miocene to Early Pliocene oxygen–deficient conditions in the Eastern Mediterranean. *Journ. For. Res.*, v. 14, pp. 187–202, Washington.

Kidd R.B., Cita M.B. & Ryan W.B.F. (1978) - Stratigraphy of Eastern Mediterranean sapropel sequences recovered during Leg 42A and their paleoenvironmental significance. In Hsu K. J. et al. - *Init. Rep. DSDP*, v. 42, pp. 421–443, Washington.

Kullemberg B. (1952) - On the salinity of the water contained in marine sediments. *Med. Oceanogr. Inst. Goteborg*, v. 21, pp. 1–38, Goteborg.

Leggett J.K., McKerrow W.S., Cocks L.R.M. & Rickards R.B. (1981) - Periodicity in the early Paleozoic marine realm. *Journ. Geol. Soc. London*, v. 138, pp. 167–176, London.

Maldonado A. & Stanley D.J. (1976 a) - The Nile Cone: submarine fan development by cyclic sedimentation. *Mar. Geol.*, v. 20, pp. 27–40, Amsterdam.

Maldonado A. & Stanley D.J. (1976 b) - Late Quaternary sedimentation and stratigraphy in the Strait of Sicily. *Smith. Contr. Earth Sci.*, v. 16, pp. 1–73, Washington.

Maldonado A. & Stanley D.J. (1977) - Lithofacies as a function of depth in the Strait of Sicily. *Geology*, v. 5, pp. 111–117, Boulder.

Maldonado A. & Stanley D.J. (1979) - Depositional patterns and Late Quaternary evolution of two Mediterranean submarine fans: a comparison. *Mar. Geol.*, v. 31, pp. 215–250, Amsterdam.

McCoy F.W. (1974) - Late Quaternary sedimentation in the Eastern Mediterranean Sea. V. of 132 pp., *Ph. D. Thesis, Harvard Univ., Cambridge, Mass.* (unpublished).

Meulenkamp J.E., Driever B.W.M., Jonkers H.A., Spaak P., Zachariasse W.J. & van der Zwaan G.J. (1979) - Late Miocene–Pliocene climatic fluctuation and marine «cyclic» sedimentation pattern . *Ann. Géol. Pays Hellén.*, Hors Série II, pp. 831–842, Athens.

Mullineaux L.S. & Lohmann G.P. (1981) - Late Quaternary stagnation and recirculation of the eastern Mediterranean: changes in the deep water recorded by fossil benthic foraminifera. *Journ. For. Res.*, v. 11, pp. 20–39, Washington.

Nesteroff W.D. (1973) - Petrography and mineralogy of sapropels. In Ryan W.B.F. et al. - *Init. Rep. DSDP*, v. 13, pp. 713–720, Washington.

Olausson E. (1961) - Studies of deep–sea cores. *Rep. Swed. Deep Sea Exped.*, 1947–1948, v. 8, pp. 353–391, Goteborg.

Parker F.L. (1958) - Eastern Mediterranean Foraminifera. *Rep. Swed. Deep Sea Exped.*, 1947–48, v. 8, pp. 217–283, Goteborg.

Phleger F.B. & Soutar A. (1973) - Production of benthic foraminifera in three east Pacific oxygen minima. *Micropaleont.*, v. 19, pp. 110–115, New York.

Rio D., Sprovieri R. & Raffi I. (1984) - Calcareous Plankton Biostratigraphy and Biochronology of the Pliocene–Lower Pleistocene succession of the Capo Rossello area (Sicily). *Mar. Micropaleont.*, v. 9, pp. 135–180, New York.

Rognon P. & Williams M.A.J. (1977) - Late Quaternary climatic changes in Australia and North Africa: a preliminary interpretation. *Palaeogeogr., Palaeoclimat., Palaeoecol.*, v. 21, pp. 285–327, Amsterdam.

Rossignol–Strick M. (1983) - African monssons, an immediate climatic response to orbital insolation. *Nature*, v. 304, pp. 46–49, London.

Rossignol–Strick M., Nesteroff W., Olive P. & Vergnaud–Grazzini C. (1982) - After the deluge: Mediterranean stagnation and sapropel formation. *Nature*, v. 295, pp. 105–110, London.

Ruddimann W.F. (1971) - Pleistocene sedimentation in the equatorial Atlantic — stratigraphy and faunal paleoclimatology. *Geol. Soc. Am. Bull.*, v. 82, pp. 283—302, Boulder.

Ryan W.B.F. (1972) - Stratigraphy of Late Quaternary sediments in the eastern Mediterranean. In Stanley D.J. (Ed.) - *The Mediterranean Sea: a Natural Sedimentation Laboratory*, pp. 149—169, Dowden, Hutch. and Ross, Stroudsberg.

Ryan W.B.F. & Cita M.B. (1977) - Ignorance concerning episodes of ocean—wide stagnation. *Mar. Geol.*, v. 23, pp. 197—215, Amsterdam.

Schrader H. & Matherne A. (1981) - Sapropel formation in the eastern Mediterranean Sea: Evidence from preserved opal assemblages. *Micropaleont.*, v. 27, pp. 191—203, New York.

Sprovieri R. (1978) - I Foraminiferi benthonici della sezione plio—pleistocenica di Capo Rossello (Agrigento, Sicilia). *Boll. Soc. Paleont. Ital.*, v. 17, n. 1, pp. 68—97, Modena.

Stanley D.J. & Blanpied C. (1980) - Late Quaternary water exchange between the eastern Mediterranean and the Black Sea. *Nature*, v. 285, pp. 537—541, London.

Street F.A. & Grove A.T. (1979) - Global maps of lake—level fluctuations since 30,000 yr. B.P. *Quat. Res.*, v. 12, pp. 83—118, London.

Streeter S.S. (1972) - Living benthonic foraminifera of the Gulf of California, a factor analysis of Phleger's (1964) data. *Micropaleont.*, v. 18, pp. 64—73, New York.

Streeter S.S. & Shackleton N.J. (1979) - Paleocirculation of the deep North Atlantic: 150,000 -yr record of benthic foraminifera and Oxygen—18. *Science*, v. 203, pp. 168—171, Washington.

Thunell R.C. (1979) - Climatic evolution of the Mediterranean Sea during the last 5.0 million years. *Sed. Geol.*, v. 23, pp. 67—79, Amsterdam.

Thunell R.C. & Lohmann G.P. (1979) - Planktonic foraminiferal faunas associated with Eastern Mediterranean Quaternary stagnation. *Quat. Res.*, v.11, pp. 353—379, London.

Thunell R.C. & Williams D.F. (1982) - Paleoceanographic events associated with Termination II in the Eastern Mediterranean. *Oceanol. Acta*, v. 5, pp. 229—233, Montreuil.

Thunell R.C., Williams D.F. & Belyea P.R. (1984) - Anoxic events in the Mediterranean sea in relation to the evolution of Late Neogene climates. *Mar. Geol.*, v. 59, pp. 105—134, Amsterdam.

Thunell R.C., Williams D.F. & Cita M.B. (1983) - Glacial anoxia in the eastern Mediterranean. *Journ. For. Res.*, v. 13, pp. 283—290, Washington.

Van der Zwaan G.J. (1982) - Paleoecology of Late Miocene Mediterranean foraminifera. *Utrecht Micropal. Bull.*, v. 25, 201 pp., Utrecht.

Van Straaten L.M.J.V. (1972) - Holocene Stage of Oxygen Depletion in Deep Water of the Adriatic Sea. In Stanley D.J. (Ed.) - *The Mediterranean Sea*, pp. 631—649, Strasbourg.

Vergnaud—Grazzini C. (1975) - 180 changes in foraminifera carbonates during the last 10^5 years in the Mediterranean Sea. *Science*, v. 190, pp. 272—274, New York.

Vismara Schilling A. (1984) - Holocene stagnation event in the Eastern Mediterranean. Evidence from deep—sea benthic Foraminifera in the Calabrian and western Mediterranean ridges. *Int. Symp. Benthic For.* (Pau, 1983), pp. 585—596, Pau.

Williams D.F., Sommer M.A. & Bender M.L. (1977) - Carbon isotopic composition of Recent planktonic foraminifera of the Indian Ocean. *Earth Planet. Sci. Lett.*, v. 36, pp. 391—403, Amsterdam.

Williams D.F. & Thunell R.C. (1979) - Faunal and oxygen isotopic evidence for surface water salinity changes during sapropel formation in the eastern mediterranean Sea. *Sed. Geol.*, v. 23, pp. 81—93, Amsterdam.

Williams D.F., Thunell R.C. & Kennett J.P. (1978) - Periodic fresh water flooding and stagnation of the eastern Mediterranean Sea during the Late Quaternary. *Science*, v. 201, pp. 252—245, New York.

Recensioni

PUBBLICAZIONI DI CARATTERE GENERALE

Vasishat R.N. (1985) – **Antecedents of Early Man in Northwestern India.** V. di XXXII + 230 pp., 36 tav., Inter–Indian Publications, New Delhi, India.

I ritrovamenti dei primati antropoidi *Sivapithecus*, *Ramapithecus* e *Gigantopithecus* hanno attratto l'interesse di primatologi e antropologi e alimentato la speranza di rintracciare nel subcontinente indiano le possibili origini della linea evolutiva dell'uomo. Sviluppi recenti delle ricerche paleontologiche in Asia e in Africa e di studi biochimici sui primati viventi hanno inferto un duro colpo a queste idee: mentre *Gigantopithecus* rappresenta una linea evolutiva fortemente specializzata, estinta nel Neogene, *Sivapithecus* – di cui *Ramapithecus* è oggi considerato un sinonimo – è imparentato con l'Orango (*Pongo*), e solo più lontanamente con i grandi primati africani *Pan, Gorilla* e con l'uomo.

Tuttavia le speranze di trovare anche in India antenati più o meno lontani dell'uomo non sono per questo tramontate, come è apertamente dichiarato nella prefazione del libro. Vana o giusta che sia, questa speranza ha dato i suoi frutti e ancora spinge i ricercatori a indagare sulle faune che si sono succedute nella fascia subhimalayana nel corso del Neogene e del Quaternario, a ricostruire attraverso l'analisi delle associazioni faunistiche le variazioni del clima e del paesaggio, a ricostruire per quanto possibile nei dettagli l'ambiente in cui si sono sviluppate le prime culture umane, la cui presenza è in ogni caso documentata in India a partire dal Paleolitico arcaico.

Questo tema è affrontato nel libro partendo dall'analisi di dettaglio della serie fossilifera di Haritalyangar, distretto di Bilaspur nello Stato di Himachal Pradesh, in un'area compresa tra il fiume Sutlej a E e il suo affluente Beas a W. La serie si estende dal Miocene inferiore al Pliocene, ma gli strati riccamente fossiliferi sono compresi tra il Miocene medio e superiore. La fauna, raccolta per la maggior parte dall'autore, comprende tre specie di primati, nove di roditori, un dinoterio, tre perissodattili e tre artiodattili. Di ciascuna specie è documentata l'esatta distribuzione stratigrafica. Di particolare interesse nella fauna risultano i primati, tra cui l'antropoide *Gigantopithecus giganteus*, un loriside e il primitivo *Palaeotupaia sivalicus*, il più antico rappresentante della sottofamiglia *Tupaiinae*.

Il libro è preceduto da un dettagliato capitolo storico e chiude con un'analisi paleoecologica basata su dati faunistici, floristici e geologici. La bibliografia, di 678 titoli, molti dei quali di autori indiani, documenta l'interesse dei ricercatori nelle faune indiane e l'attività delle Università e del Servizio Geologico dell'India. 36 tavole di fotografie di fossili e località fossilifere, schizzi geologici e tabelle completano l'opera.

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