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LITHOSTRATIGRAPHY AND PLANKTONIC FORAMINIFERAL BIOSTRATIGRAPHY OF THE APTIAN-ALBIAN "SCISTI A FUCOIDI" IN THE PIOBBICO CORE, MARCHE, ITALY: BACKGROUND FOR CYCLOSTRATIGRAPHY

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Key-words: Piobbico core, Scisti a Fucoidi, Marche, Italy, Aptian-Albian, Lithostratigraphy, Planktonic foraminifera, Paleoenvironmental remarks.

Riassunto. La formazione degli Scisti a Fucoidi, affiorante estesamente nel Bacino Umbro-Marchigiano, è caratterizzata da una successione pelagica depostasi ciclicamente durante l'intervallo Aptiano-Albiano. I litotipi dominanti sono marne e marne calcaree, cui si intercalano calcari marnosi, argille calcaree ed argille. Carattere peculiare di questa formazione sono le variazioni cromatiche, con colori dal grigio chiaro, al grigio, al verde oliva, al rosso, al marrone scuro, al nero. Livelli neri, denominati "black shales", contenenti sostanza organica in diverse percentuali, sono frequenti soprattutto nella parte centrale degli Scisti a Fucoidi, e sovente sono modulati ciclicamente. Sulla base dei colori e della loro alternanza, e della presenza di "black shales" sono state distinte negli Scisti a Fucoidi 18 unità, riconoscibili arealmente alla scala del bacino, comprese tra la sottostante Maiolica (Aptiano basale) e la sovrastante Scaglia Bianca (Albiano sommitale). Al fine di studiare in modo dettagliato sia le apparenti ciclicità deposizionali, sia i passaggi tra cromie diverse per individuarne il significato specifico, l'intero spessore degli Scisti a Fucoidi è stato perforato nel Pozzo Piobbico, nei pressi della città omonima, in carotaggio continuo. Il recupero è stato del 98% per uno spessore di circa 84 m (=77,70 m in spessore reale).

Le carote sono state principalmente studiate mediante "peels" (acetate peels), che hanno permesso di ricostruire un record continuo del contenuto fossilifero di dimensioni >40 μm. In particolare, l'analisi biostratigrafica sui Foraminiferi planctonici ha permesso di individuare: a) tutte le biozone conosciute dalla Zona a *Globigerinelloides duboisi/G. gottisi* dell'Aptiano inferiore alla base della Zona a *Planomalina buxtorfi* (Albiano sommitale) cui è attribuibile la base della sovrastante Scaglia Bianca; b) più di 30 bioeventi concentrati soprattutto nell'Aptiano superiore e nell'Albiano superiore. Inoltre, sui peels ha potuto essere stimata la densità per unità di superficie sia dei Foraminiferi planctonici che dei Radiolari.

La litologia, i colori, il contenuto in carbonato di calcio e l'abbondanza in Foraminiferi planctonici e Radiolari sono stati inseriti usando il Programma Stratabase in un calcolatore Macintosh per poter essere confrontati, indi elaborati al fine di provare le ciclicità deposizionali. In particolare, la distribuzione discontinua dei Foraminiferi planctonici da livello a livello è stata interpretata come dovuta a diagenesi nella porzione aptiana, a dissoluzione primaria nella porzione intermedia, la più ricca in "black shales", indi all'alternanza di condizioni ambientali stabili e mescolamento interessanti la colonna d'acqua per la porzione albiana superiore (Zona a *Biticinella breggiensis*), alternanza riconducibile alle frequenze orbitali.

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Abstract. The Aptian-Albian Scisti a Fucoidi Formation, cropping out widely in the Umbrian-Marchean Basin (Italy), consists of a varicolored pelagic sequence of thinly interbedded red and green marlstones and calcareous marlstones, dark gray to black Corg-rich calcareous shales, and light green-gray marly limestones and limestones. The variable colored lithotypes appear to be rhythmically deposited. In order to investigate in detail such rhythmicity and the mechanism leading to the accumulation of Corg-rich sediments, a core, the Piobbico core, was specifically cut through the Scisti a Fucoidi.

On the basis of dominant color alternation, presence of Corg-rich black shales, and calcium carbonate content, this formation is subdivided into 18 lithologic units, that are recognizable on a regional scale.

Biostratigraphically, the core represents the interval from the planktonic foraminiferal *Globigerinelloides duboisi/G. gottisi* Zone (Early Aptian) to the base of the *Planomalina buxtorfi* Zone (Late Albian). More than 30 planktonic foraminiferal bioevents were identified.

Lithology, colors, calcium carbonate content, and estimated abundance of planktonic foraminifera and radiolarians were stored in specific files according to the Stratabase Program (specifically written and designed). This allowed further processing (Fast Fourier Transform function) to test the possible cyclic deposition of the Scisti a Fucoidi.

Planktonic foraminiferal abundance varies from layer to layer. The variance is interpreted as due 1) to diagenesis in the Aptian interval, 2) to primary dissolution at the sediment-water interface in the middle darker portion of the core, and 3) to the alternation of stable to unstable conditions of the upper water column in the Late Albian, apparently in accord with orbital variations.

Introduction.

The Umbrian-Marchean sequence of the central Italian Apennines consists of a continuous succession of pelagic to hemipelagic sediments extending from Jurassic through the Paleogene. This sequence is become a reference section for global biostratigraphy and magnetostratigraphy of Late Cretaceous through Paleogene, especially across the Cretaceous-Paleocene boundary (e.g. Renz, 1936; Alvarez et al., 1977; Arthur & Fischer, 1977; Premoli Silva, 1977; Premoli Silva et al., 1977; Wonders, 1979; Lowrie et al., 1980; Monechi, 1981; Arthur & Premoli Silva, 1982; de Boer, 1982; Cirilli et al., 1984; Lowrie & Alvarez, 1984; Lowrie & Channell, 1984; Bralower, 1987; Coccioni et al., 1987, 1989; Alvarez & Montanari, 1988).

Within the Umbrian-Marchean sequence, the Aptian-Albian Scisti a Fucoidi Formation represents a more shaly, varicolored interval consisting of thinly interbedded red and green marlstones and calcareous mudstones, dark gray to black calcareous shales, and light green-gray marly limestones and limestones. This formation, cropping out widely in the Umbrian-Marchean Basin, attracted the attention of several scientists for its potential clues to the accumulation of organic-carbon-rich sediments in an open marine environment at that time (Schlanger & Jenkyns, 1976). During the first phase of investigation, mainly focused on Corg-rich black shales interbedded within the Scisti a Fucoidi, it first was noticed that the Scisti a Fucoidi (Fucoid Marls) appeared to be rhythmically deposited (de Boer, 1982; Schwarzacher & Fischer, 1982; de Boer & Wonders, 1984; Fischer et al., 1985; Fischer & Herbert, 1988, i. e.).

In order to investigate the characteristic and the origin of these rhythmically deposited pelagic sediments as well as the mechanisms responsible for the accumulation and preservation of the organic matter, a continuous 84 meter section of core was drilled through the Scisti a Fucoidi at Piobbico (prov. Pesaro-Urbino, Marche region, Italy). Lithostratigraphy, sedimentary structures, biostratigraphy and paleontology, organic and inorganic geochemistry, and remanent magnetism of the core are being studied by a consortium of Italian and American scientists (Premoli Silva et al., 1983; Fischer et al., 1985; Erba, 1986; Herbert & Fischer, 1986; Herbert et al., 1986; Pratt & King, 1986; Herbert, 1987; Erba, 1988; Fischer & Herbert, 1988; Premoli Silva et al., 1989). Preliminary results of this combined effort on the Piobbico core, correlated to outcrops, were presented at the first Meeting on Cyclostratigraphy within the CRER Program in Perugia, September 1988 (Fischer, 1988; Fischer & Herbert, 1988; Premoli Silva & Erba, 1988).

The present paper deals with the description of the entire Piobbico core including detailed lithostratigraphy at macro- and microscopical scale, light transparency's estimate of the variously colored lithotypes, biostratigraphy based on planktonic foraminifera also correlated to that based on calcareous nannofossils (Erba, 1988), distribution and abundance of organisms larger than 40 μm, and finally, evolutionary, diagenetic and paleoenvironmental interpretations. The data set collected will provide the framework for the recognition of cycles, the final aim of our research.

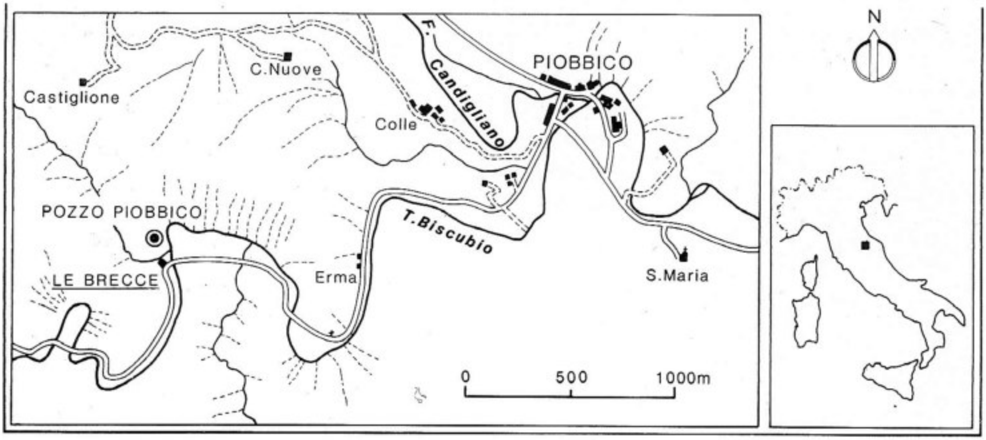


Fig. 1 - Location of the Piobbico drill site (Marche, Italy).

Location of the drill site and drilling operations.

The Piobbico core was drilled at "Le Brecce", located 3 km west of the town of Piobbico (Marche, Italy), at km 33 of the Apecchiese State Road No. 257, on the left hydrographic side of Torrente Biscubio, beneath the more than 100 m high wall of Scaglia Bianca, the base of which crops out a few meters adjacent to the hole site (Fig. 1).

Continuous coring started at -5.80 m below ground surface where the uppermost *in situ* rock was recovered. The core penetrated the entire Scisti a Fucoidi including the upper transition to the Scaglia Bianca and the lower transition to the Maiolica. The total length of the core is 84 m with 98.8% recovery. Taking into account the mean bedding dip of 23°, the correct thickness of the drilled section is 77.70 m. Strata strike at 297°.

Lithologies were logged and color slide photographs taken, as each core section was recovered, by E. Erba, L. Pratt and B. Quadrio. Sections were wrapped first in aluminum foil, then in thin plastic wrap and stored in PVC plastic liners to prevent contamination and loss of moisture. Fragments from the few fractured portions were collected in plastic bags.

Drilling operations were performed by the Technical Staff of the CNR of Padova with the Atlas Copco D750 drilling equipment mounted on a truck. Coring was done with diamond bits and double NT2 core barrels. 101 mm cores were cut till -47.70 m, 86 mm cores from -47.70 m to -82.90 m, and 56 mm cores from -82.90 m to the bottom at -89.20 m.

Methodology.

Core Preparation.

The core was split by diamond saw into a working half and archive half.

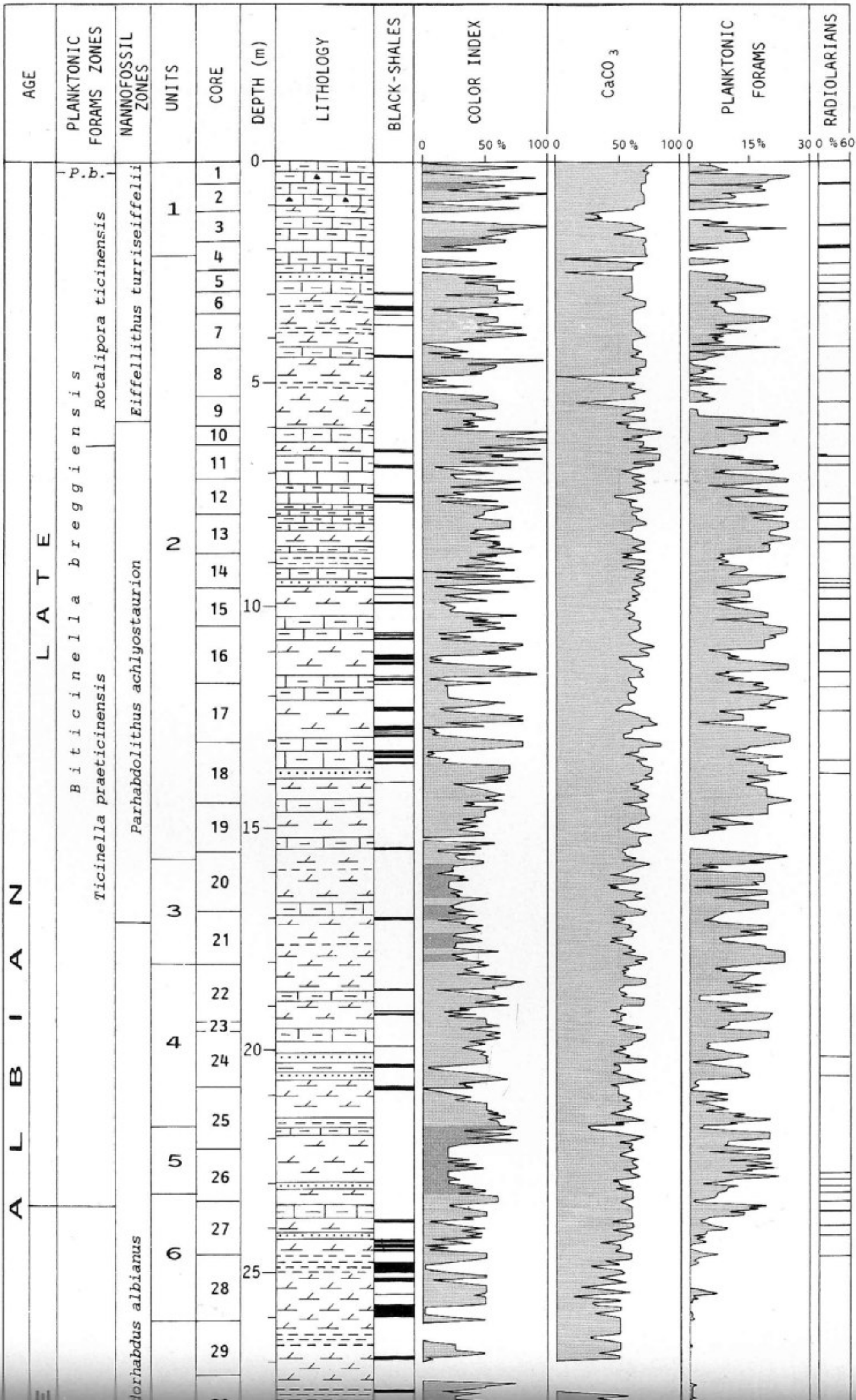
Special care was taken to avoid contamination of the organic matter and the other geochemical characters of the sediments. For this purpose three special holders, 30 cm long and of different diameters according to the core size, were constructed from a mixture of epoxy and quartz sand with a lining of fiberglass. The holders were longitudinally split and the halves kept four millimeters apart by a metal holder fixed to both parts of the core-holders with screws in order to leave enough space for sawing them through the middle.

The archive half of the core was mounted in epoxy and quartz sand to prevent breackage, leaving the cut surface free. A full set of 35 mm ektachrome diapositives scaled and color-monitored wet surface of the archive half. Prints were mounted in an atlas for further observation.

The archive portion was also used for preparing acetate peels. The surfaces were first polished, then etched with HCl. HCl concentration and duration of immersion changed according to a given type of peel: 1‰ per 30" for sedimentary structures, and 1‰ per 2'-3' for fossil records. After immersion in HCl solutions, the surfaces were washed under running water. Once dried, the surfaces were flooded with acetone and immediately covered with acetate film, evenly pressed in order to adhere smoothly to the surface. After several hours of drying the acetate films were peeled off. Five sets of acetate peels were made. During peel preparation calcium sulphate crystallites neoformed on core surfaces as artifacts due to exposure to fresh air (see below for explanation).

The consolidated portions were also used for paleomagnetic sampling.

Specific samples from fractured and dissolved portions and/or close to critical zonal boundaries were washed to obtain isolated fossils. These samples were first soaked in a H_2O_2 solution for two days, then reprocessed with Désogène, a tensio-active chemi-


AGE
PLANKTONIC FORAMS ZONES
NANNOFOSSIL ZONES
UNITS
CORE
DEPTH (m)
LITHOLOGY
BLACK-SHALES
COLOR INDEX
CaCO3
PLANKTONIC FORAMS
RADIOLARIANS
0 50 % 100
0 50 % 100
0 15% 30
0 % 60
A L B I A N
L A T E
P.b.
Biticinella breggiensis
Rotalipora ticinensis
Ticinella praeticinensis
Eiffellithus turriseiffelii
Parhabdolithus achlyostaurion
Axopodorhabdus albianus
1
2
3
4
5
6
0
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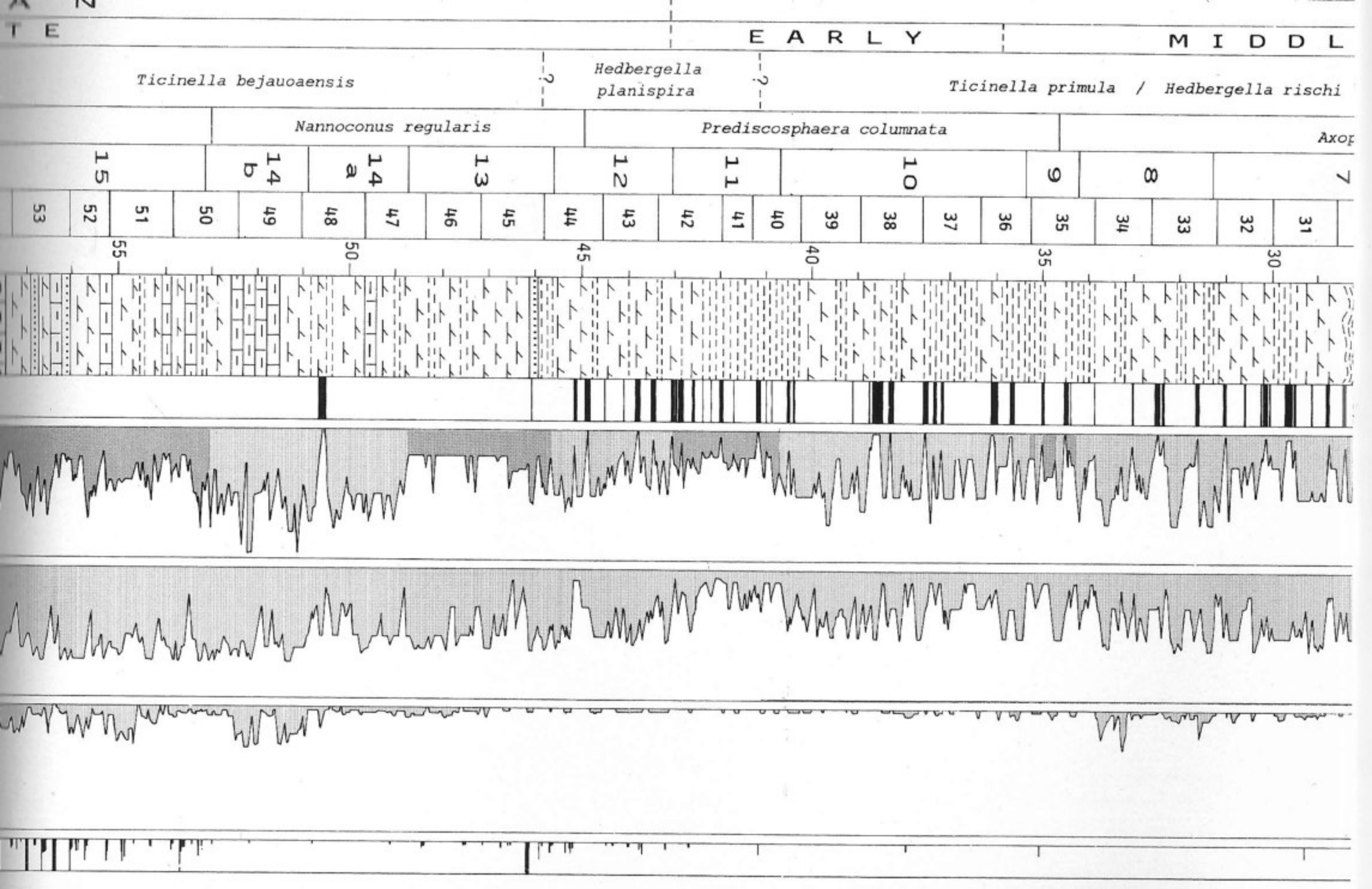

T E
E A R L Y
M I D D L
Ticinella bejauoaensis
?
Hedbergella
planispira
?
Ticinella primula / Hedbergella rischi
Nannoconus regularis
Prediscosphaera columnata
Axop
15
14 b
14 a
13
12
11
10
9
8
7
53
52
51
50
49
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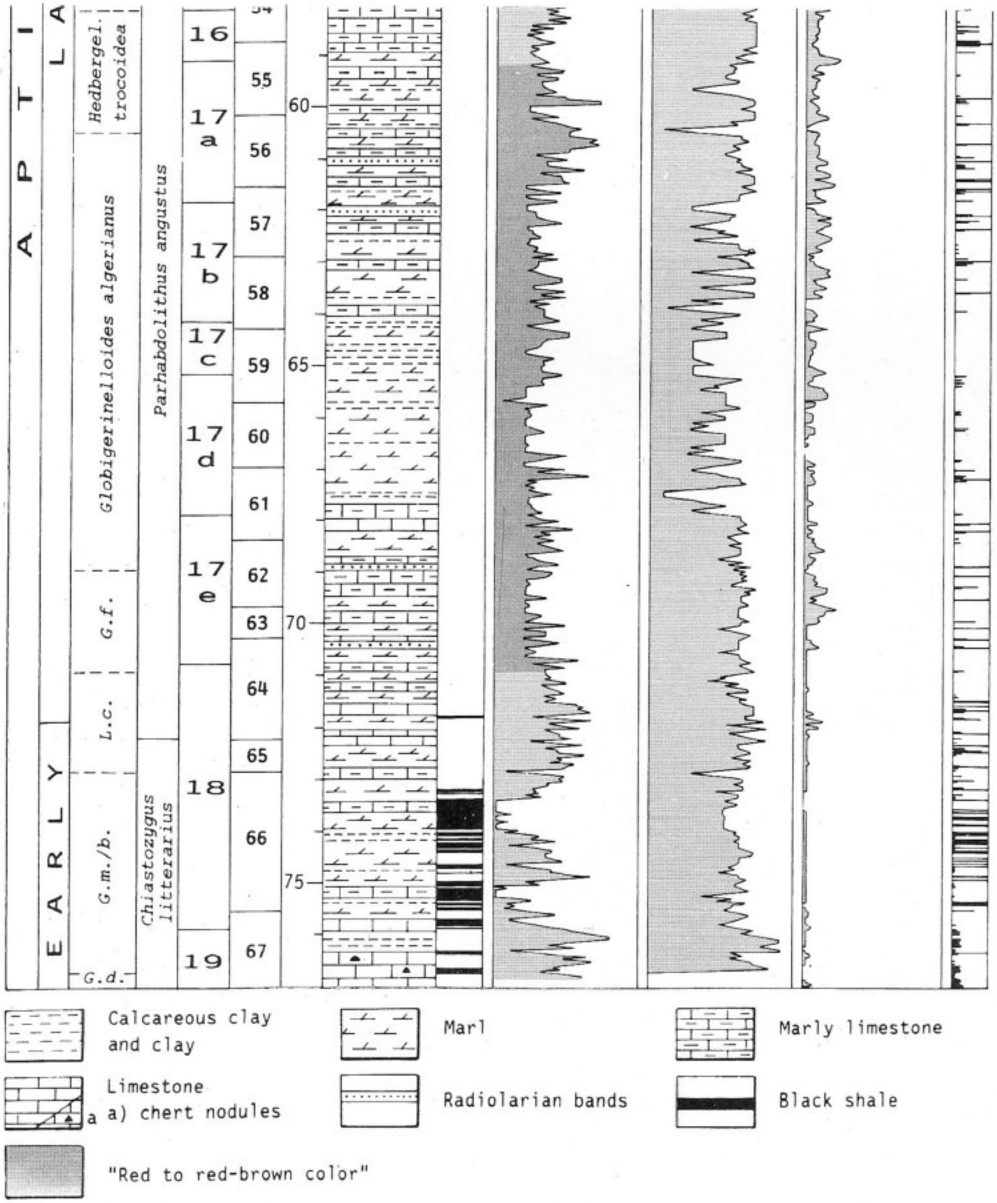

Fig. 2 - Log of the Piobbico core with lithology, black-shale layers, smoothed curves of Color Index, $CaCO_3$, and planktonic foraminifera, and radiolarian percentages, plotted against calcareous nannofossil and planktonic foraminiferal biostratigraphy and ages. Planktonic foraminiferal zones: *G.d.* = *Globigerinelloides duboisi/G. gottisi* Zone; *G. m./ b.* = *Globigerinelloides maridalensis / G. blowi* Zone; *L.c.* = *Leupoldina cabri* Zone; *G.f.* = *Globigerinelloides ferreolensis* Zone. Missing vertical line in Color Index, $CaCO_3$, and planktonic foraminifera tracks = no or poor recovery. Calcareous nannofossil biostratigraphy after Erba (1988).

cal product of the Ciba-Geigy Company. Disaggregated residues were washed under running water through sieves with 270 μm, 150 μm, and 40 μm meshes. Identification of microfossils was performed for all the three fractions with a stereomicroscope.

Both the archive and working halves of the entire core are deposited at the Department of Earth Sciences, Section of Geology-Paleontology, University of Milan.

Peel Analysis.

Acetate peels of the second type described above were analyzed for fossil content by transmitted light microscopy, basically with the same technique used for studying thin sections. The first advantage of using peels is that the record is practically continuous and, secondly, the surface available is constrained only by core size. Moreover, the mineralogical composition of the single fossils or grains is still recognizable in some cases even under crossed nicols.

The fossil groups observed belong to planktonic and benthic foraminifera, radiolarians, fish debris, calcispheres, and fragments of megafossils. Presence of bioturbation and especially "Fucoidi", the local name for *Chondrites*, were also recorded as well as occurrence of pyrite nodules.

For estimating fossil abundance, peels were observed on a graduate screen with 1 cm^2 field mounted on a light microscope. Counts of the recognized fossil forms were compared with Bacelle-Bosellini diagrams and converted to percentages (Bacelle & Bosellini, 1965). As abundance estimates that resulted from the counts and from the standard % diagrams were consistently similar, most of fossil abundances from the core were estimated directly by comparing the peel content to the standard diagrams.

Lithologic description.

The Scisti a Fucoidi Formation, located stratigraphically between the Scaglia Bianca Formation (above) and the Maiolica Formation (below) (Fig. 2), is subdivided macroscopically into 18 lithological units based on: a) dominant color alternation, b) presence of black shales, and c) calcium carbonate percentage (Erba, 1986; Premoli Silva et al., 1989). The underlying Maiolica is equated with Unit 19. Visual description of individual units is complemented by microscopic analyses of acetate peels and of washed residues mainly from fractured intervals. Mean values of carbonate content and fossil abundance per each unit or subunit are weighted means.

Figure 2 shows a simplified lithologic log, the occurrence of black shales, the smoothed curves of color index, calcium carbonate and planktonic foraminifera obtained from smoothing function applied to % histograms (see below for explanation), and radiolarian %, plotted against depth in meter, units, and nannofossil and planktonic foraminiferal biostratigraphy. The final scale used in Figure 2 lumped any feature thinner and/or closer than 2 cm. Moreover, smoothing processing smoothed highs and lows in the reported % curves, so the real single values cannot be detected.

From stratigraphic top to bottom the sequence is as follows:

UNIT 1: Thickness = 2.18 m (0 m-2.18 m); $CaCO_3$: 62% to 75% (mean = 70%).

Marly limestones, predominantly gray-green in color, 1-5 cm thick with interbedded 5 cm thick varicolored gray and pink marls and 3 cm thick subordinate white-gray limestones. A single 2 cm thick very dark gray, marly clayey layer is present. Abundant 1-2 cm thick, white-gray chert lenses are observed. Four recrystallized and poorly preserved radiolarian horizons (50% radiolarians) are present. Indistinct gray bioturbations are widespread.

Planktonic foraminiferal abundances vary from 1% to 25% (mean = 10%). Highest values are associated with elevated calcium carbonate concentrations and minimum foraminiferal abundance values correspond to the radiolarian bands.

Planktonic foraminiferal faunas are well preserved and consist predominantly of medium to small sized forms (see section in taxonomy), frequently oriented parallel to the bedding plane. Scattered throughout the section are rare larger sized benthic foraminifera.

UNIT 2: Thickness = 13.53 m (2.18 m to 15.71 m). $CaCO_3$: 42% to 85% (mean = 65%).

Marls and marly limestones, gray-green to white-gray in color, 3-18 cm thick, with rare 2-3 cm thick white limestones. Frequently interbedded, 1-9 cm thick, dark gray-black clayey marls (black shales, N=40). Frequent radiolarian bands (N=21) approximately equispaced from the top of this unit to 13.43 m (Plate 15, fig. 1). From 13.52 m to the base of this unit, both the black shales and radiolarian bands decrease in frequency and interval spacing. Bioturbated horizons are common and *Chondrites* are clearly observed within or juxtaposed and below the black shale layers.

Planktonic foraminiferal abundances vary from 1% to 25% (mean = 10%) in the upper portion (2.18 m to 5.70 m) grading to ±15% in the lower portion of this unit (Pl. 11, fig. 1-4). Planktonic foraminifera are moderately well preserved and mainly consist of small to medium sized forms. Medium to larger sized specimens are occasionally concentrated in millimeter thick lenses and/or layers.

Black-shale horizons contain an abundance of diverse planktonic foraminifera (Pl. 11, fig. 1), which decrease abruptly in percentage at the shale boundaries (Pl. 12, fig. 1). Within the black shales, planktonic foraminifera are poorly preserved and mainly oriented parallel to the bedding plane (Pl. 12, fig. 2). Thin calcitized lenses, whose boundaries occasionally coalesce, are commonly preserved adjacent to black shale limits. They probably originated from the dissolution of planktonic calcitic tests followed by precipitation of carbonate. Chambers of planktonic foraminifera are sometimes still visible.

Radiolarian bands contain specimens up to 50%, which are generally poorly preserved and strongly recrystallized. Agglutinated and calcitic benthic foraminifera are scattered throughout.

UNIT 3: Thickness: 2.35 m (15.71 m to 18.06 m). $CaCO_3$: 52% to 71.5% (mean = 60%).

Marls brown-red in color and 2-20 cm thick, alternating with marly limestones, gray-green in color and 1-5 cm thick. This unit contains two, 3 cm thick, clayey marls (black shales). Radiolarian horizons are absent. *Chondrites* are present directly below the black shales.

Planktonic foraminiferal abundances vary from 1% to 25% (mean = 10%). Planktonic foraminiferal faunas are similar to those in Unit 2 in that moderately well preserved, medium to small sized specimens, oriented parallel to bedding planes, dominate with larger sized specimens concentrated in millimeter thick layers and lenses.

The black-shale horizons are distinctly laminated and contain predominantly small sized planktonic foraminifera up to 5% in the medial portion, decreasing in abundance in both the upper and lower portions of the horizon.

Radiolarians and benthic foraminifera are rare and scattered randomly throughout the unit.

UNIT 4: Thickness: 3.76 m (18.06 m to 21.82 m). $CaCO_3$: 28.6% to 71.5% (mean = 58%).

Marls, gray-green to light gray in color and 3-25 cm thick, alternating with subordinate marly limestones, light-gray in color, 2-10 cm thick. Carbonate rich black-shale layers, 1-6 cm thick, occur more frequently (N=8) than in Unit 3. Dark-gray bioturbations are abundant, whereas *Chondrites* are concentrated both stratigraphically below and above the black-shale layers. Radiolarian layers are lacking.

Planktonic foraminiferal abundances vary rhythmically from 1% to 25%. Higher percentages (10%) of the more normal sized planktonic foraminifera occur in the upper two meters of the unit and are characteristically oriented parallel to the bedding plane. Lower foraminiferal abundances (2.5-5%) occur, still rhythmically preserved, in the lower portion of the unit and are characterized by the smaller sized planktonic forms.

Benthic foraminifera are rare to sparse and of larger size; radiolarians are very rare and sparse.

Thinly laminated, black-shale horizons contain up 20-25% of planktonic foraminifera of predominantly small to medium size, partially oriented parallel to the bedding plane. Radiolarians and benthic foraminifera are very rare within these black-shale horizons. Millimeter thick, crenulated calcitic laminae are abundant. The black-shale layer at 20.80-20.89 m is characterized by numerous undulated thin calcitic laminae. Small-sized and poorly preserved planktonic foraminifera are rare with a maximum abundance of 2.5%. This layer is additionally characterized by sparse benthic foraminifera, an apparent absence of radiolarians, and questionable rare calcispherulids.

UNIT 5: Thickness: 1.39 m (21.82 m to 23.21 m). $CaCO_3$: 52% to 71.5% (mean = 62%).

Marls, predominantly brown-red, slightly bioturbated, with subordinate interbedded white-gray marly limestones. Black-shale layers are absent, radiolarian horizons are rare.

Planktonic foraminiferal abundances range from less than 1% to 25% (mean = 10-12%). When planktonic foraminifera are abundant, they are well preserved and characterized by normal size ranges yet, when scarse, they are of small size and typically oriented parallel to the bedding plane. Planktonic foraminiferal faunas vary considerably within this unit. Benthic foraminifera are sparse. Poorly preserved radiolarians occur in distinct horizons in the lowermost portion associated with a few planktonic foraminifera.

UNIT 6: Thickness: 2.88 m (23.21 m to 26.09 m). $CaCO_3$: 8.9% to 62% (mean = 50%).

Marls and marly limestones, gray-green to white-gray in the upper portion grading to predominantly olive-green marls in the lower portion. 2 to 3-4 centimeter thick black-shale layers are frequently interbedded, poor to moderately rich in calcium carbonate. Radiolarian bands, approximately equispaced, occur solely in the upper part of the unit (to 24.60 m). *Chondrites* are frequent and preserved adjacent to the black-shale layers.

The upper 50 cm of this unit (to 23.80 m) is characterized by abundant, normal sized, moderately preserved planktonic foraminifera (max. of 20%) to very rare (<1%) in a few layers. Foraminiferal abundances vary from <1% to 5-7.5%, grading in decreasing abundances to <1%; very rare layers contain mainly planktonic foraminifera with abundances up to 7.5%. Planktonic foraminifera, when rare, are poorly preserved, characterized by smaller sizes, and are associated with thin calcitic laminae. Benthic foraminifera are very rare and sparse. Radiolarian layers are commonly preserved in the upper portion of this unit. Radiolarians are often recrystallized and associated with a few planktonic foraminifera.

Black-shale layers yielded common planktonic foraminifera (up to 5%) in the middle portion, and are decreasing to <1% upwards and downwards. Planktonic foraminifera in these shales are small in size, poorly preserved, frequently deformed and oriented parallel to the bedding plane. Undulating calcitic laminae and lenses are very abundant, particularly adjacent to both upper and lower boundaries. These calcitic laminae clearly are derived from dissolution/reprecipitation of planktonic foraminiferal tests. Between 25 m and 26 m (core 28) within black-shale layers, laminated intervals of abundant calcitic laminae alternate with thin, nonlaminated horizons. Identifiable planktonic foraminifera are rare (1% max.) and poorly preserved.

UNIT 7: Thickness: 5.17 m (26.09 m to 31.26 m). $CaCO_3$: 8.9% to 62% (mean = 40%).

Marls gray-green, frequently interbedded with olive-green to dark-gray marly clays and clays. Abundant, carbonate deficient, black-shale layers are preserved. Radiolarian bands are absent in this unit. Black bioturbated and *Chondrites* horizons are abundant.

Between 27.42 m and 27.74 m a few folded layers, of probably tectonic origin, are associated with common calcitic lenses.

Planktonic foraminifera are very rare to few, small-sized, and poorly preserved. A slight increase in abundance (up to 5%) was noted in the lower part of this unit. Washed residues yielded very poor faunas including rare benthic foraminifera.

At 29.25 m, a 1 cm thick, single layer contains about 10% radiolarians and 1% planktonic foraminifera.

Laminated black-shale layers are abundant and commonly contain calcitic laminae which occasionally coalesce. Rare, poorly preserved benthic and planktonic (1% max.) foraminifera occur. Radiolarians are not visible.

UNIT 8: Thickness: 2.95 m (31.26 m to 34.21 m). $CaCO_3$: 8.9% to 62% (mean = 35%).

Marly clays and marls, gray-green to white-gray, and subordinate calcareous marls. Rare to frequent, centimeter thick, poor to medium rich in carbonate, black-shale layers are interbedded. Radiolarian bands are absent. Bioturbated horizons are less abundant than in the preceding Unit 7. *Chondrites* are abundantly concentrate adjacent to the black-shale beds.

Planktonic foraminiferal abundances vary from <1% to 15% with the tendency towards low concentrations. Highest planktonic foraminiferal concentration occurs between 33.05 m and 33.65 m where they display normal size ranges and better preservation. Planktonic foraminifera are mostly small sized and poorly preserved. Benthic foraminifera are rare. Radiolarians are rare and sparse except at 32.68 m where few and large specimens are recorded.

Interbedded black-shale intervals are characterized by abundant, closely spaced calcitic laminae, probably derived from dissolution/reprecipitation of planktonic foraminiferal tests. Planktonic foraminifera are small to medium in size and poorly preserved. Radiolarians are sparse and benthic foraminifera absent.

UNIT 9: Thickness: 1.11 m (34.21 m to 35.32 m). $CaCO_3$: 8.9% to 51.2% (mean = 25%).

Gray-green, occasionally variegated gray-brown, clayey marls and marls with alternating brown, rarely green varicolored, clays. A single homogeneous, millimeter thick, green-turquoise lamina parallel to bedding occurs at 34.75 m. Three, 3-5 centimeter thick, carbonate-poor, black-shale layers are recorded. *Chondrites* are concentrated below these black-shale horizon. A single, thin (1cm thick) radiolarian level also occurs.

Planktonic foraminifera vary in abundances from absent, a low of <1% to a high of 5%. Such faunas are depauperate with only small, indistinct specimens preserved except in a millimeter thick bed (not plotted) which yielded mostly small specimens (10%). Benthic foraminifera are rare.

A single horizon passing laterally to small lenses yielded large sized radiolarians (10%). Black-shale layers contain interbedded calcitic laminae. Planktonic foraminifera are rarely preserved. Abundant calcium sulfate crystallite artifacts obscure the matrix (see above).

UNIT 10: Thickness: 5.34 m (35.32 m to 40.66 m). $CaCO_3$: 8.9% to 51.2% (mean = 30%).

Gray-greenish to white gray marls with very rare white-gray calcareous marls. Clays and marly clays predominate from 36 m to 37 m. Frequent black-shale beds, ranging in thickness from 1 cm to 24 cm, are poor-to medium-rich in carbonate. The thickest (24 cm thick) black-shale layer of the entire sequence described in this paper occurs at 38.46-38.70 m in this unit. This black-shale is significantly enriched in calcium carbonate (Pl. 13, fig. 1).

Chondrites are abundantly preserved adjacent to the black-shale beds. At 35.93 m, a millimeter thick, green-turquoise layer occurs; a few pyrite nodules were recovered at 39.13 m. Six radiolarian bands were recognized, although they appear to yield less abundant radiolarians than in the upper units. Bioturbated horizons are widespread throughout this unit.

Planktonic foraminiferal faunas are characterized by limited diversity, small size, poor preservation, and vary in abundance from absent to a maximum of 2.5%. A more diversified, normal-sized planktonic foraminiferal faunas occur in a few, very thin laminae (not plotted). Calcitic laminae are present in almost all the lithotypes. Benthic foraminifera are rare and sparse.

Radiolarians are generally poorly preserved and range in abundance from <1% to a maximum of 5% except at 38.25 m where an abundance of 10% was documented.

Black-shale layers are rich in calcitic laminae with the matrix largely obscured by abundant artifacts of calcium sulfate crystallites. The thickest black-shale layer at 38.46-38.70 m contains strongly recrystallized calcitic laminae that alternate with thinner, less recrystallized laminae of similar composition (Pl. 13, fig. 1). The calcite laminae adjacent to the bed boundaries have few planktonic foraminiferal chambers preserved (Pl. 13, fig. 2). Recognizable planktonic foraminifera do not exceed 1-2%. A single radiolarian specimen is pyritized.

UNIT 11: Thickness: 2.36 m (40.66 m to 43.02 m). $CaCO_3$: 2.8% to 50% (mean = 17%).

Clays and marly clays, rarely marls, predominantly dark-brown in color, occasionally varicolored to gray-green. Black-shale layers, which are carbonate deficient, are abundant (No=13) and display rhythmicity. Two radiolarian beds were identified, however, radiolarian abundance is poor. Although *Chondrites* are widespread throughout this unit, they cluster adjacent to the black-shale layers.

Planktonic foraminifera range in abundance from absent to a maximum of 2.5%. They typically are poorly preserved and small in size. Planktonic foraminifera are not visible in most of this unit except in a single, 4 millimeter thick bed at 41.08 m which contains a normal-sized planktonic forms (up to about 2.5%) and some benthic foraminifera.

Poorly preserved radiolarians are rare (2%) except in one horizon at 41.10 m with 10% radiolarians. Benthic foraminifera are rare except in one horizon at 40.75 m where they are concentrated in lenses. Benthic foraminifera are occasionally pyritized. Calcium sulfate crystallite artifacts are abundant throughout, masking the lithologic facies. Black-shale layers are characterized by calcite laminae and rare ghosts of planktonic foraminifera.

UNIT 12: Thickness: 2.55 m (43.02 m to 45.57 m). $CaCO_3$: 8.9% to 62 % (mean = 40%).

Marls, rarely calcareous marls, predominantly gray-green in color, rarely varicolored or with gray-brown thin layers. In the lower 0.05 m of the unit (45.35-45.40 m) gray-white green calcareous marls are additionally present. Black-shale beds are relatively rich in carbonate. Radiolarian bands are frequent. *Chondrites* and *Zoophycos*, occasionally several centimeter large, are abundant throughout.

Planktonic foraminifera range from very rare to 2.5% in a few layers. This fauna is poorly preserved, and the species are frequently unrecognizable, occasionally pyritized, and always small in size. Radiolarians occur in few layers, are generally scattered except in the middle portion of a single layer (at 45.34 m) where they are up to 10% and fairly well preserved. Rare to few, large-sized benthic foraminifera are scattered throughout.

At 44.81-44.91 m a black-shale bed contains few sparse calcitic laminae, very rare planktonic foraminifera and one benthic foraminifer. This black-shale layer is homogeneous at the basal contact with the calcareous marls and is covered by common calcium sulphate crystallite artifacts at its stratigraphic top. The black-shale layer at 45.10-45.15 m is very similar to the black shale described above, but differs in that it contains more frequent benthic foraminifera and few radiolarians.

UNIT 13: Thickness: 3.19 m (45.57 m to 48.76 m). $CaCO_3$: 8.9% to 62% (mean = 48%).

Marls, rarely calcareous marls, dark-red to gray-red in color with some gray-green areas. Clayey horizons are very rare, and black-shale beds are absent. Radiolarian bands (N=3) are rare as are *Chondrites*, which are confined to the upper portion of this unit.

Planktonic foraminiferal abundances vary from <1% to 2.5-3%. However, planktonic foraminifera are constantly present particularly in the lower portion of this unit. They are poorly preserved and small in size with only rare, normal-sized specimens. No correlation between the occurrence of planktonic foraminifera and color variations was observed. Large-sized benthic foraminifera are scattered throughout. Radiolarians are poorly preserved, generally sparse, but they may attain concentrations of up to 7.5% in some beds. Radiolarians appear to occur in larger abundances in some red layers and are less common in some gray lithotypes.

UNIT 14: Thickness: 4.38 m (48.76 m to 53.14 m). $CaCO_3$: (a) 8.9% to 71.5% (mean = 48%); (b) 28.6% to 71.5% (mean = 60%)

Marls, gray-green to very light-gray in color with interbedded dark olive-gray marly clays and clays that dominate the upper portion (a) (to 50.90 m). In the lower portion (b) marls alternate with marly limestones, similarly colored as lithologies in (a), yet only two thin layers are marly clays. A single >10 cm thick, laminated black-shale bed occurs in this unit. Radiolarian bands are very rare and contain few specimens. Dark-gray bioturbations and *Chondrites* are frequent in the more calcareous-rich layers.

In the upper portion (a) of the unit planktonic foraminiferal abundances range from absent to a maximum of 2.5%, are generally represented by small-sized individuals and are poorly preserved. Any relationship with specific colored lithotypes is lacking. Radiolarian abundances vary from sparse to a maximum of 2%.

The second thickest black-shale layer (>10 cm thick) of the core occurs at 50.50-50.65 m. It is laminated similarly to that described from Unit 10. However, this black-shale layer contains more abundant, recognizable planktonic foraminifera, particularly in the upper portion where calcitic laminae are more largely spaced and less abundant than in the lower portion. The basal portion of the black-shale bed is characterized by coalescing, tightly spaced calcite lenses and laminae. Recognizable planktonic foraminifera within this calcite-rich portion are rare. Planktonic foraminiferal abundances attain a maximum of 7.5% which consists of both small- and large-sized individuals. Radiolarians are rare, and phosphatic fragments are few to common.

The lower part (b) of this unit shows an increase in carbonate content and more abundant (<1% to 12.5%) planktonic foraminifera (Pl. 15, fig. 3). Richer levels are more frequent than in subunit (a) although planktonic foraminiferal abundances again decrease at the bottom of this unit. Planktonic foraminiferal faunas are well diversified, of normal size, frequently fairly well preserved and occasionally concentrated in thin beds. There is considerably bed to bed variation in the abundance of small-sized individuals. Benthic foraminifera are few and scattered throughout. Radiolarians vary in abundance from rare to a maximum of 2%.

UNIT 15: Thickness: 5.05 m (53.14 m to 58.19 m). $CaCO_3$: 8.9% to 71.5% (mean = 58%).

Calcareous marls and marly limestones, red to dark red in color with occasional green-gray areas and subordinate green-gray marls with localized redder regions. Clayey and marly clayey beds are rare, and black-shale horizons are absent. Visible radiolarian bands are numerous (N=7) evenly spaced, and range from 0.5 cm to 1.5 cm in thickness. Bioturbations are black and *Chondrites* are common.

Planktonic foraminiferal abundances vary from 1% to 20%. Greater concentrations of the foraminiferal faunas (20%) occur in rare 1 cm thick beds where planktonic faunas consist of normal-sized forms. Planktonic foraminifera are scarse in the upper portion of this unit but grade to increasing, even fluctuating, abundances downcore (Pl. 15, fig. 4). Preservation is typically fair to poor. Correlation between planktonic foraminifera and specific lithologic colors is lacking.

Radiolarian horizons are more numerous than those visible and contain up to 30% of very poorly preserved specimens. In these radiolarian layers planktonic foraminifera occasionally occur in relative abundance (2.5-5%). Within a given bed, radiolarian abundance increases gradually from 1-2% at the boundaries, to a maximum concentration in the middle portion of the bed, which may be silicified. Radiolarians display preferential preservation in the gray and green calcareous marls, whereas the red, more oxidized, marls are barren. Benthic foraminifera are scattered throughout the unit.

UNIT 16: Thickness: 0.91 m (58.19 m to 59.10 m). $CaCO_3$: 51.2% to 71.5% (mean = 65%).

Marly limestones, dominantly green-gray in color with dark-red areas and bands, that range in thickness from 2 to 6 cm. These marly limestones are interbedded with red to dark-brown marly limestones and calcareous marls, intercalated with 2 to 5 cm thick, green-gray bands. Radiolarian beds are common and evenly spaced throughout. The unit is highly bioturbated. Black-shale layers are absent.

Planktonic foraminiferal abundances vary from 1% to 7.5% (mean = 3%). These faunas are similar to those of Unit 15 in that they are poorly preserved and tend to cluster in the small to medium size range. Highest abundance percentages were observed in thin lenses. Planktonic foraminifera lack correlation with specific lithotypes.

Radiolarian horizons contain up to 20% in the mid bed portions, whereas radiolarians decrease in abundance at the boundaries. They are always poorly preserved and generally occur in the gray or green-gray marly limestone horizons and are absent in the more reduced red-brown marls.

UNIT 17: Thickness: 11.55 m (59.10 m to 70.65 m). $CaCO_3$: a) 8.9% to 71.5% (mean = 55%); b) 8.9% to 71.5% (mean = 48%); c) 28.6% to 51.2% (mean = 30%); d) 8.9% to 71.5% (mean = 40%); e) 51.2% to 71.5% (mean = 63%).

Based on carbonate mean %, this unit is subdivided into five subunits:

a) calcareous marls and marly limestones, with subordinate marls and very rare marly clayey beds (59.10 m - 61.80 m);

b) closely spaced alternating horizons of marly limestones, marls, and clayey marls with a single clayey level (61.80 m - 64.10 m);

c) marly clays with subordinate marls (64.10 m - 65.10 m);

d) marls with subordinate marly limestones and marly clays. Very rare clayey horizons (65.10 m - 67.80 m);

e) calcareous marls with subordinate marls and marly limestones (67.80 m - 70.65 m).

The dominant lithotypes are dark-red and dark-brown in color with occasional green-gray areas, whereas white-gray marly limestones separated by one cm to 3 cm thick, green-gray levels are subordinate. Green-gray beds occur more frequently in the lower portion of this unit. Radiolarian beds are numerous. Bioturbations infilled with black marl are widespread throughout the whole unit, yet black-shale beds are absent.

Planktonic foraminiferal abundances vary from 0.5% to 5% (mean = 2%) (Pl. 14, fig. 1-3). The mean value is the averaged weighted mean from the following four intervals:

a') 59.10 m to 63.70 m = 2.4%;

b') 63.70 m to 65.65 m = 2.2%;

c') 65.65 m to 68.00 m = 1.5%;

d') 68.00 m to 70.65 m = 2.0%.

The mean values of these four intervals are not correlative to the five subunits based on calcium carbonate content. The lowest planktonic foraminiferal abundance does not occur in subunit (c) which is the poorest in carbonate, but rather in subunit (d). At the base of this unit, planktonic foraminifera become significantly rarer in abundance (<1%) with only a few beds containing up to 5% of planktonic tests. Planktonic foraminifera are almost exclusively small in size, poorly preserved and more densely cluster in some lenses. Their abundance does not correlate with any specific lithotype.

Radiolarian beds are numerous with an increased abundance in the middle of each bed, grading to lower concentrations on both upper and lower margins of the bed (Pl. 15, fig. 2). Radiolarians are predominantly recrystallized and oriented parallel to the bedding plane. Highest percentages occur within gray and green-gray marly limestones, very rarely in the red oxidized marls.

Benthic foraminifera are rare and scattered throughout the unit.

UNIT 18: Thickness: 5.18 m (70.65 m to 75.83 m). $CaCO_3$: 28.6% to 85% (mean = 60%).

Light green-gray calcareous marls, marly limestones with subordinate limestones, interbedded dark olive-gray marly clays and frequent (N=17), thick black-shale beds. Black-shale layers, preserved specifically in the lower portion of this unit, range in thickness from 1-2 cm to >15 cm, and are enriched in calcium carbonate. Radiolarian bands are also numerous (N=15) and almost equispaced. At 72.28 m, 73.86 m, and at 74.27 m pyrite nodules >2 centimeter in diameter are recorded (Pl.14, fig. 4).

Bioturbations, in which black marls are preserved, are numerous and *Chondrites* are additionally abundant, particularly when adjacent to the black-shale horizons.

This unit, comprising the "Livello Selli" described by Coccioni et al. (1987), is enriched with fish remains at 73.47-73.68 m.

Planktonic foraminiferal abundance decreases drastically (1%) as in the lowermost portion of the overlying unit. Planktonic foraminiferal faunas consist of small individuals, generally poorly preserved.

Recrystallized radiolarians are abundant, either as single specimens scattered throughout or as radiolarian bands. The highest concentration of radiolarians occurs in the mid bed position.

Black-shale beds are devoid of visible planktonic foraminifera. These black shales contain thin calcitic laminae with rare to few radiolarians, occasionally of larger size. In the upper part, 73.47-73.68 m, abundant fish remains and phosphatic pellets provide the identification of the black interval of the "Livello Selli" (Coccioni et al., 1987).

UNIT 19: Thickness: cored portion = 1.87 m (75.83 m to 77.70 m). $CaCO_3$: 85%.

Green-gray to very light gray limestones frequently intercalated with thin, black marly layers and carbonate rich black-shale beds, 2 to 3 cm thick. Dark-gray bioturbated zones are extremely abundant throughout this unit. *Chondrites*, small in size, are rare.

This unit belongs to the top of the Maiolica, which underlies the Scisti a Fucoidi Formation.

The planktonic foraminiferal faunas are typically small-sized and recrystallized. Abundances vary from <1% to 2.5%. Benthic foraminifera are rare. Radiolarians, scattered and occasionally oriented parallel to bedding, are numerous (up to 7.5%). A single black chert nodule, located within the light gray limestones, contains abundant radiolarians. Very rare planktonic foraminifera and numerous thin, elongated calcitic lenses occur within associated black-shale beds.

Biostratigraphy.

Planktonic foraminifera, although unevenly distributed as described above, provide an almost continuous biostratigraphic record throughout the core. Most of the important bioevents known from lower latitude regions were recognized allowing us to apply the standard zonal scheme (Longoria, 1974; Premoli Silva et al., 1977; Sigal, 1977; Arthur & Premoli Silva, 1982; Caron, 1985; Erba & Quadrio, 1987, i.e.). Biostratigraphic data was based mainly on the identification of taxa from the acetate peels. For problem areas where zonal boundaries could not be identified with certainty, such as across the Aptian-Albian boundary, washed residues (>40 μm) were specifically prepared and studied. Planktonic foraminiferal distribution is reported in Fig. 3.

The biozones recognized are (from bottom to top) (Fig. 2 and 3):

Globigerinelloides duboisi/G. gottisi Zone (76.95 m to the bottom = 77.70 m)

= Interval from the first occurrence (FO) of the nominal species to the FO of *Globigerinelloides maridalensis* and *G. blowi.*

Remarks. The zonal markers are already present in the lowermost sample. Thus, the base of the zone lies in the underlying uncored interval belonging to the Maiolica Formation.

Planktonic foraminiferal fauna in this interval consists of rare, small-sized species such as *Hedbergella sigali, H. similis, H.* cf. *occulta,* and *Globigerinelloides gottisi.*

Globigerinelloides maridalensis/G. blowi Zone (72.91 m to 76.95 m)

= Interval from the FO of the nominal species to the FO of *Leupoldina cabri.*

Remarks. The lower boundary is placed at the appearance of *G. maridalensis,* while *G. blowi* is first recorded just below the top of the zone. The rare specimens recorded in this interval commonly belong to small-sized *Globigerinelloides duboisi, Hedbergella similis, H. bollii, H. sigali, H. occulta,* and *Gubkinella graysonensis.* Moreover, some layers, particularly the black shales, are devoid of planktonic foraminifera, whereas in other horizons only very rare hedbergellids are recognized.

Leupoldina cabri Zone (70.85 m to 72.91 m)

= Total range zone.

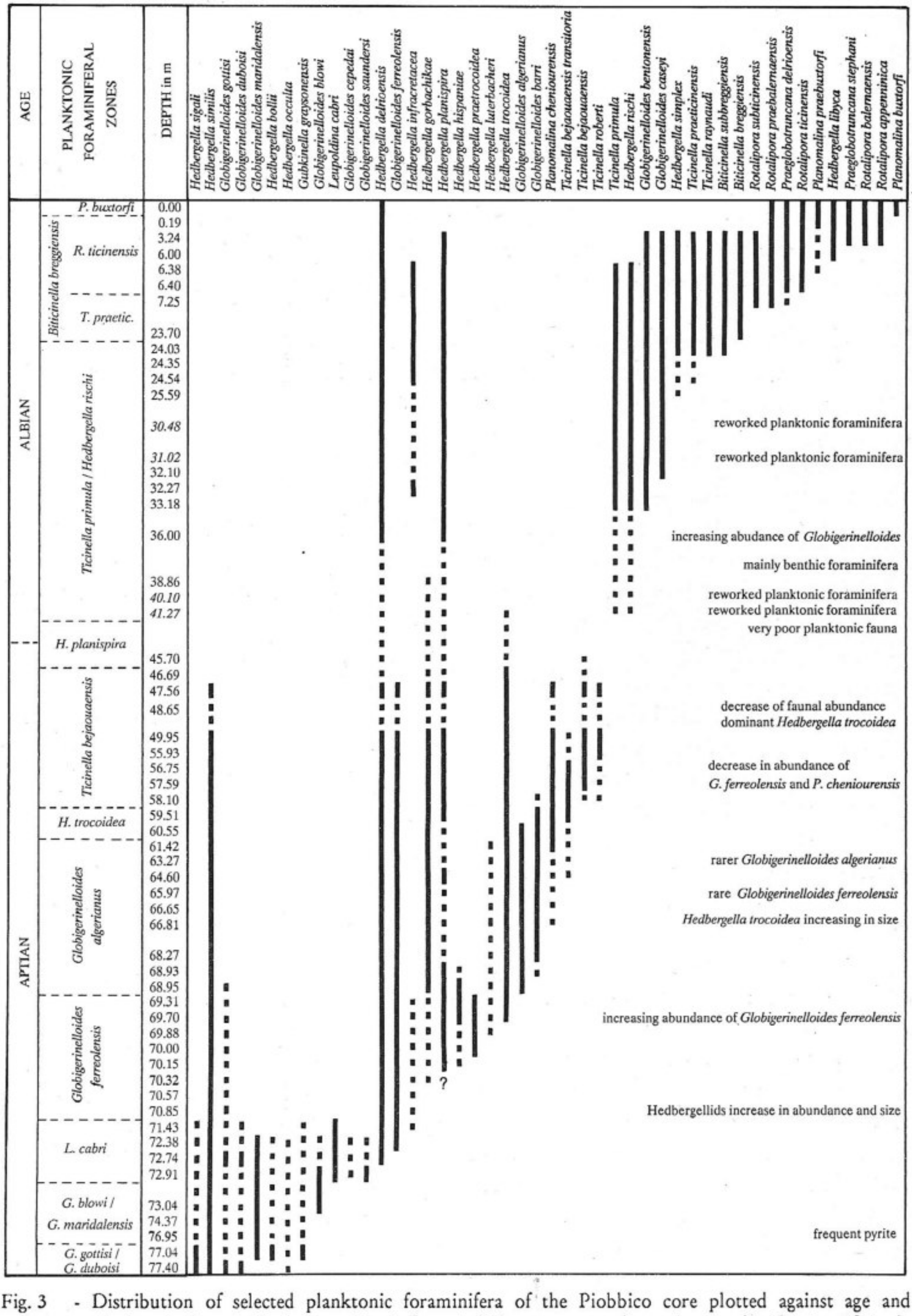

Fig. 3 - Distribution of selected planktonic foraminifera of the Piobbico core plotted against age and planktonic foraminiferal zones. Dashed vertical lines represent discontinuous distribution of single taxa. Numbers in italics = washed samples.

Remarks. The zonal marker was identified in both acetate peels and washed residues, but it is always rare. Planktonic foraminiferal faunas are slightly more abundant and consistently present than in the previous zones. Moreover, the average sizes of the specimens increase as well as the species diversity. Beside the zonal marker, *Globigerinelloides blowi, G. maridalensis, G. saundersi, Hedbergella occulta, H. similis, H. sigali,* and *Gubkinella graysonensis* are commonly recorded. Small-sized *Hedbergella delrioensis* first occurs in the lower part of the interval, whereas the first, but small-sized, representatives of *Globigerinelloides ferreolensis* appear in the upper portion of the zone.

Globigerinelloides ferreolensis Zone (68.95 m to 70.85 m)
= Interval from the LO (last occurrence) of *Leupoldina cabri* to the FO of *Globigerinelloides algerianus.*

Remarks. The trend to increasing size and diversity among planktonic foraminiferal assemblages, already noticed in the previous zone, becomes more pronounced in this interval. The bulk of the assemblages contain the same species from the previous zones, which increase both in abundance and overall size with thicker walls. Among the species appearing in this interval are *Hedbergella infracretacea* and *H.* cf. *hispaniae* (possibly ancestral to *H. gorbachikae*) at the base of the zone, *H. praetrocoidea* in the middle portion followed slightly higher by rare *H. trocoidea.* At the very top of the zone rare transitional forms between *Globigerinelloides ferreolensis* and *G. algerianus* along with *Hedbergella* cf. *luterbacheri* are also observed. *Globigerinelloides gottisi* disappears at the end of the *G. ferreolensis* Zone.

Occasionally, some layers attributed to this zone may contain small-sized and impoverished assemblages.

Globigerinelloides algerianus Zone (60.55 m to 68.95 m)
= Total range zone.

Remarks. This zone is characterized by an almost constant presence of the index species which reaches its acme around 63-64 m (Pl. 14, fig. 1), then decreases gradually upwards. Just before its extinction, *G. algerianus* is represented by smaller-sized individuals similar to those at the beginning of its range.

In this zone planktonic foraminiferal assemblages are generally abundant and higher in diversity in respect to the underlying zone. Beside the species already present in the *G. ferreolensis* Zone except for *Globigerinelloides gottisi*, we record the appearance of *Hedbergella planispira*, followed by that of *Globigerinelloides barri* and *Hedbergella gorbachikae*, all in the lower portion. Between 66 m and 65 m *Hedbergella trocoidea* becomes dominant and increases in size (Pl. 14, fig. 1, 3). The pinched, slightly keeled descendant of *G. algerianus, Planomalina cheniourensis*, overlaps with its ancestor in the last levels attributed to this zone. Transitional forms slightly preceded the FO of *P. cheniourensis* and may persist together with typical specimens of both taxa (Pl. 14, fig. 2). Rare forms attributed to *Ticinella bejaouaensis transitoria* occur discontinuously in the middle of the *G. algerianus* Zone (at 64.60 m).

Occasionally, some layers attributed to this zone yielded planktonic faunas impoverished of small hedbergellids or devoid of planktonic foraminifera.

Hedbergella trocoidea Zone (58.10 m to 60.55 m)

= Interval from the LO of *Globigerinelloides algerianus* to the FO of *Ticinella bejaouaensis.*

Remarks. The assemblage is dominated by large-sized *Hedbergella trocoidea* associated to common *H. gorbachikae, H. delrioensis*, rare *H. luterbacheri*, and common *Globigerinelloides ferreolensis. Globigerinelloides barri* and *Planomalina cheniourensis* occur discontinuously, but when present are represented by a few individuals. *Ticinella bejaouaensis transitoria* reappears in the middle portion of the zone, although in very low abundance.

Ticinella bejaouaensis Zone (45.70 m to 58.10 m)

= Total range zone.

Remarks. Planktonic foraminiferal abundances, varying considerably within this zone, allow us to recognize three different intervals; a lower interval (up to about 51 m) which is mainly characterized by abundant, well diversified and moderately preserved foraminifera (Pl. 15, fig. 3,4); a middle interval (from about 51 m to about 47 m) in which planktonic foraminifera occur continuously but in low numbers; and an upper interval (from about 47 m to 45.70 m) in which layers yielding planktonic foraminifera are rare and, when present, are dramatically impoverished and poorly preserved.

The rich planktonic foraminiferal assemblages from the lower interval consist of abundant *Hedbergella trocoidea* associated to common *H. gorbachikae, H. delrioensis* and other small hedbergellids, *Planomalina cheniourensis,* and *Globigerinelloides ferreolensis.* The zonal marker, rare only at the beginning of its range, is common throughout this interval. Around 55.50 m *Ticinella roberti* becomes a constant component of the faunas, while *Globigerinelloides ferreolensis* decreases in abundance and size. *Planomalina cheniourensis* becomes rare around 54 m, then occurs randomly. In the uppermost part of this interval some layers occasionally contain very poor faunas. The middle interval yields the same planktonic faunas as the lower one except that planktonic individuals are much less common.

In the upper interval, planktonic foraminifera are very rare and confined to few layers, in which *Hedbergella planispira, H. trocoidea,* and *H. delrioensis* are the only species present, frequently each alone, and of small size. In the other layers they are absent or they have been dissolved and contribute to the formation of calcitic laminae, at the edge of which some chambers are still visible.

Hedbergella planispira Zone (41.27 m to 45.70 m)
= Interval from the LO of *Ticinella bejaouaensis* to the FO of *Ticinella primula* and *Hedbergella rischi*.

Remarks. This zone may be a stratigraphic artifact due to intense dissolution at the sediment/water interface (Erba, 1986; Premoli Silva et al., 1989). In fact, both boundaries of this zone are very uncertain due to the paucity of planktonic foraminifera. The lower boundary is placed above the last local occurrence of *Ticinella bejaouaensis*, whereas the upper boundary is drawn just below the appearance of positively identified *Ticinella primula* and *Hedbergella rischi*, the zonal markers of the following zone.

In this zone, layers devoid of planktonic foraminifera are numerous. In the few remaining layers, planktonic foraminifera commonly are represented by a single species, rarely more than one species. All are very small in size and poorly to very poorly preserved. The recurrent species are *Hedbergella planispira, H. delrioensis, H. gorbachikae*,and rarely *H. trocoidea*.

According to correlation with the ammonite zonation via calcareous nannofossils (Erba, 1988), the *Hedbergella planispira* Zone straddles the Aptian-Albian boundary.

Ticinella primula/Hedbergella rischi Zone (23.70 m to 41.27 m)
= Interval from the FO of the nominal taxa to the FO of *Biticinella breggiensis*.

Remarks. In this zone planktonic foraminifera are still very rare or absent except for a few levels in which they are moderately common (see Fig. 2). Layers devoid of planktonic foraminifera alternate apparently with some cyclicity with those yielding a few planktonics, however, such cycles are not yet proved to represent any specific frequency.

The species occurring with some continuity are *Ticinella primula, Hedbergella rischi*, the two index species, *H. delrioensis*, and *H. planispira*. Rare very small specimens might belong to the genus *Globigerinelloides*, whose representatives become slightly more common around 31 m, and increase in abundance around 28 m. From that level upcore *Globigerinelloides bentonensis* becomes a constant component of the planktonic faunas.

A few horizons, each one millimeter thick, occurring at 41.27 m, 40.10 m, 31.02 m, and 30.48 m represent an exception to the overall paucity of fauna. Acetate peels and washed residues of the first two layers yielded scarse, but diversified, planktonic foraminiferal faunas containing very rare, poorly preserved specimens attributable to *Ticinella primula* along with normal-sized *Ticinella bejaouaensis, T. roberti, Hedbergella trocoidea* associated with *Globigerinelloides algerianus* and *Planomalina cheniourensis*. In the upper two levels, again, some doubious *Planomalina cheniourensis* and/or *Globigerinelloides algerianus* seem to be present. Such anomalous assemblages imply redeposition and a partial reworking at least for the latter two taxa. *T. primula* and the other large ornamented taxa could be redeposited, but not mixed. Confirmation of an overlap of *Ti-*

cinella primula and *T. bejaouaensis*, even for a short interval, would result in the elimination of the intermediate, poorly defined, *Hedbergella planispira* Zone as suggested by Caron (1985).

A few new species that appear successively towards the top of the zone include *Ticinella praeticinensis, T. raynaudi, Hedbergella simplex*, and finally a few forms transitional to *Biticinella breggiensis*, referred to *Biticinella subbreggiensis. Hedbergella infracretacea* is randomly distributed throughout this zone, but becomes more common towards the top of the zone.

Biticinella breggiensis Zone (0.00 m to 23.70 m)

= Interval from the FO of the zonal marker to the FO of *Planomalina buxtorfi.*

This zone is subdivided in two subzones according to the following definitions:

Ticinella praeticinensis Subzone (6.40 m to 23.70 m)

= Interval from the FO of *Biticinella breggiensis* to the FO of *Rotalipora ticinensis.*

Remarks. This subzone is characterized by planktonic foraminiferal assemblages that rhythmically alternate in abundance (between abundant and poor) (Pl. 11, fig. 2-4). Fluctuations in abundance are cyclic from 10 m to 20 m (see below). The most common component of the rich faunas are *Biticinella breggiensis* associated in the lower portion with the transitional form *Biticinella subbreggiensis*, and *Ticinella praeticinensis, T. primula, T. raynaudi, Hedbergella rischi, H. delrioensis, H. planispira, Globigerinelloides bentonensis*, and *G. caseyi*. Towards the top of the subzone, around 8 m, a major biostratigraphic event is recorded with the appearance of the rotaliporids including *Rotalipora praebalernaensis* and *R. subticinensis*, and of the praeglobotruncanids, specifically *Praeglobotruncana delrioensis.*

The components of the variously impoverished faunas are mainly small hedbergellids including *H. planispira* and *H. delrioensis*, and much rarer, small *Globigerinelloides*. Faunas consisting of small- to medium-sized forms and lacking only the larger ornamented species can also occur.

Rotalipora ticinensis Subzone (0.00 m to 6.40 m)

= Interval from the FO of the zonal marker to the FO of *Planomalina buxtorfi.*

Remarks. Planktonic foraminifera in this subzone are always abundant. The large negative fluctuations reported in Fig. 2 are due to the lack of peels in the upper portion of the core. Cores in this portion were frequently broken preventing peel preparation. Washed residues from the broken portions provided semiquantitative abundance estimates of isolated specimens, which could not be compared with those from analysis of the peels.

Planktonic foraminiferal assemblages are very similar to those from the underlying subzone except they are more abundant and constantly present. The most common species are large-sized *Biticinella breggiensis, Rotalipora ticinensis* (the zonal marker), *R. subticinensis, R. praebalernaensis, Ticinella primula, T. raynaudi, T. praeticinensis*, and *Praeglobotruncana delrioensis* in addition to the small hedbergellids. In the upper portion of the subzone *Rotalipora balernaensis, Praeglobotruncana stephani*, and *Hedbergella libyca* made their first appearance, and the topmost layers yield a few *Planomalina praebuxtorfi.*

Planomalina buxtorfi Zone

= Interval from the FO of the zonal marker to the FO of *Rotalipora brotzeni.*

Remarks. The zonal marker, *Planomalina buxtorfi*, is recorded in the first layer *in situ* encountered just below the 5.50 m thick, heterogeneous cover at the beginning of the drilling operation. The planktonic fauna of this 10 cm thick, white limestone is rich, abundant and very similar to that described from the top of the underlying zone except for the occurrence of the new marker. This zone is known to occur in its entirety in the nearby outcrops belonging to the Scaglia Bianca.

Benthic Foraminifera.

In the Piobbico core, benthic foraminifera are always present, but scattered throughout, except in some of the black-shale layers which are devoid of them, or in one layer at 40.75 m where they are concentrated in lenses. Species could not generally be identified in peels and benthic foraminifera occur too randomly for estimating a significant plankton/benthos (P/B) ratio. In a general way, we can state that benthic foraminifera are more common where planktonic foraminifera decrease in abundance and vice versa. In washed residues benthic foraminifera, although always present, are a minor component of the total foraminiferal faunas (<1% to 5%) in the lower and upper portion of the core. In the middle portion benthic foraminifera frequently are the only foraminifera present.

Although benthic foraminifera are almost always present, species diversity varies from layer to layer, occasionally only one taxon can be observed in a peel 20 cm long. Taking that into account, benthic faunas are very monotonous throughout the core, and are mainly composed of the same taxa. Among the calcareous benthics, the most common forms include *Gyroidinoides nitidus*, the most ubiquitous species that is also very common in some layers (at 46.90 m, 25.60 m, and 20.20 m), the lagenids (including common *Lenticulina, Dentalina*, rarer *Nodosaria*, and occasionally *Marginulina* or *Lagena*), and *Gavelinella. Praebulimina* occurs very rarely, randomly in the Early Aptian and in a single layer in the Late Aptian *Hedbergella trocoidea* Zone. At the base of the *Globigerinelloides algerianus* Zone the genus *Osangularia* first appears. The distribution of latter taxon is random throughout and it never becomes a constant or important component of the benthic faunas. Rare possible *Sigmoilina* were observed in two layers belonging to the *Globigerinelloides algerianus* Zone, while single specimens of *Guttulina* and *Spirillina* are recorded from about 50 m to 48.20 m within the *Ticinella bejaouaensis* Zone. Around 50 m and for a short interval up to 48.63 m rare *Conorotalites* and *Globorotalites* were found. Rare *Pleurostomella* are recorded randomly from 47.75 m in the upper part of the *Ticinella bejaouaensis* Zone upwards. Finally, *Neobulimina*, unidentified rotaliids, and a possible *Aragonia* occur in single horizons at 24.55 m, 20.20 m, and 19.90 m, respectively.

The first agglutinated benthic foraminifera are recorded from the *Leupoldina cabri* Zone. Among them the most common taxa belong to the finely textured genera *Dorothia* and *Gaudryina* that range, although discontinuously, to the top of the core. They are the only benthic component of the faunas in a layer, 45 cm thick at 59.96-59.51 m within the Late Aptian *Hedbergella trocoidea* Zone. Much more random and rare are the genera *Tritaxia* and *Haplophragmoides*, while *Spiroplectammina* is randomly present from 48 m up to 35.60 m, an interval that spans the late *Ticinella bejaouaensis* Zone through the mid- *Ticinella primula/Hedbergella rischi* Zone. It is worth mentioning that in the interval from about 39 m up to 24 m, agglutinated benthic foraminifera frequently possess walls rich in pyrite if not totally pyritized. This interval overlaps the lithologic units characterized by the largest concentration of black-shale layers.

From 46.10 m to 40.75 m benthic foraminifera could not be observed because of the very poor quality of the peels. This interval, mainly attributed to the *Hedbergella planispira* Zone and straddling the Aptian-Albian boundary, was studied in nearby outcrops (Arthur & Premoli Silva, 1982; Coccioni et al., 1989). There, benthic faunas, although very poor, contain a few simple agglutinated forms such as *Rhizammina*, *Bathysiphon*, and *Haplophragmoides* in the less carbonate-rich layers, whereas *Gyroidinoides nitidus*, and rare *Gavelinella* and lagenids occur in association with the very rare planktonic forms.

Biostratigraphically, the only important events are the FO of *Neobulimina* which is a Late Albian event and seems to be synchronous (see also Sliter & Premoli Silva, 1984) and, if confirmed, the FO of a possible *Aragonia*.

Benthic foraminifera are more interesting for their paleoecologic significance. The assemblage would suggest a middle to lower bathyal environment, although the bathyal zone was poorly differenciated by the Aptian-Albian time (Sliter, 1977). This interpretation could be confirmed by the occurrence of rare individuals resembling to *Aragonia*, a lower bathyal indicator. The abundance of simple agglutinated forms in the middle portion, where dissolution is higher (Erba, 1986) and black shales are common, could be interpreted as the signal of poorly-oxygenated environment (see Decker & Roegl, 1986; Magniez-Jannin & Jacquin, 1988, i.e.). The appearance of *Neobulimina* could suggest that an oxygen-minimum zone might begin to differentiate within the bathyal range; it would be the first and oldest attempt of stratification of the water masses similar to that in the modern ocean (Sliter & Premoli Silva, 1985).

Other Organisms.

Besides foraminifera and radiolarians, other organisms are very rare in the Scisti a Fucoidi cored at Piobbico. Some aptychi occur in the *Hedbergella trocoidea* Zone and at the base of the *Ticinella bejaouaensis* Zone in the Late Aptian. *Inoceramus* prisms are recorded from three layers belonging to the Middle and Late Albian *Ticinella primula/Hedbergella rischi* and *Biticinella breggiensis* Zones (at 32.30 m, 20.40 m, and 15.50 m, respectively). A possible ammonite mold is recorded at 30.85 m within the Middle Albian *Ticinella primula/Hedbergella rischi* Zone. Very rare ostracods were identified randomly throughout the core.

Database.

The large data set collected from the Piobbico core required for easily handling the development of a computer database. For this purpose, a specific program STRATABASE was written and designed for the Macintosh personal computer by Ripepe (1988). This program allowed us to store and process all the collected data and to retrieve them in a graphic form. The data were stored with a sampling rate of 1 cm for the entire 84 m core, without dip correction.

Storage of data.

The lithological characteristics and fossil content were stored in specific files organized in a branch-type of structure with groups including several subgroups or members.

The principal groups considered in this paper are: 1) lithology, 2) colors, 3) geochemistry, and 4) organisms.

1) Lithology was stored using different patterns for the main lithotypes, which include limestone, marly limestone, marl, calcareous clay and clay, and radiolarian horizon. The graphic plot at 1:50 scale was utilized as a base for drafting the lithology in Fig. 2.

2) Colors. 14 colors, from white to black, were identified throughout the core using a core field description and color photographs according to the Monsel color chart. Each color was represented by a different pattern. This extremely detailed plot was unreproducible at any scale acceptable for publication, and particularly the color patterns could not be processed and compared with the other data. Consequently, color patterns were transformed into light transparency percentages. Black was equated to one and white to 100. All the other colors between those two extremes were given values in decreasing percentage from light gray to brown. 50% light transparency was given to green-gray and olive-gray colors (Fig. 4).

Cromatic scale		
Main color	**patterns**	**values**
White		100
Light Grey		80
Light Olive Grey		70
Grey		60
Green Grey		50
Olive Grey		50
Reddish Grey		45
Red		40
Greenish Brown		35
Reddish Brown		30
Dark Olive Grey		25
Brown		20
Dark Grey		20
Black		1

Fig. 4 - Color patterns and percentage values of light transparency used for constructing the smoothed Color Index curve of Fig. 2.

3) Geochemistry. In the Geochemistry group only the carbonate content was plotted. Most data were provided by Herbert (1987) at a sampling rate of every 2.5 cm except from two intervals (10 m to 20 m, Units 2 *partim*, 3, and 4 *partim*; and 40 m to 45 m, Units 11 and 12) where analyses were performed at a closer spacing, occasionally less than 1 cm. Some carbonate analyses from the broken portions, particularly in the upper portion of the core, were also added in order to obtain a more complete record.

4) Organisms. Among the organisms only two fossil groups, planktonic foraminifera and radiolarians, were sufficiently abundant to provide significant data. They were plotted as discrete members. All the other fossil groups such as benthic foraminifera, fragments of megafossils or fish debris were too random and rare to justify storage and were reported only in the peel and biostratigraphic descriptions.

a) Planktonic foraminiferal abundances were stored at a sampling rate of 1 cm for the entire 84 meters. Because of the extremely low abundances, particularly in the middle portion of the core, planktonic foraminifera were stored and plotted at a larger (1/2) scale with respect to carbonate content. This scale allowed the illustration of even the smallest abundance fluctuations.

b) Radiolarians, contrary to planktonic foraminifera, occurred throughout the core in discrete layers occasionally with percentages as high as >50%. In several units radiolarians were apparently absent (see below for explanation).

For both members, the graphic output is a histogram that is almost continuous for the planktonic foraminifera and similar to the carbonate content, and markedly discontinuous for the radiolarians.

Processing of data.

The main processing functions used for the Piobbico core are: a) smoothing process, which quickly computes the smoothing function using a weight-average-like algorithm, but without preserving the real amplitude; b) trend analysis, which eliminates a trend from the considered function (Davis, 1973). This is important when one wants to analyze the frequency content; and c) Fast Fourier Transform, which computes the frequency spectrum using the classic Cooley & Tukey (1965) algorithm. At known and uniform sedimentation rates, the program will display the spectral amplitude values of stratigraphic variations versus time.

In order to obtain the final log in Fig. 2, the original stored histograms of color/light transparency, calcium carbonate, and planktonic foraminifera percentages were processed via equispacing and smoothing functions, while radiolarians are reported as histograms without any processing. The resultant smoothed curves of the aforementioned members were first corrected for the average dip of 23° and then stored in real thickness, equated to 77.70 meters.

Fast Fourier analysis was performed only in particular intervals. It will be the purpose of a further paper.

Log description.

Processing of all the data yielded a continuous log (Fig. 2). Beside the lithology plotted against the identified units and subunits, and the biostratigraphy, Fig. 2 shows the occurrence of black shales and radiolarian bearing-horizons (plotted as radiolarian percentages), along with smoothed curves for light transparency, calcium carbonate content, and planktonic foraminiferal abundance. As seen in Fig. 2, the data plots are nonhomogeneous and several trends are apparent.

a) Black-shale Occurrence.

Black shales are particularly frequent in the interval between 10 m to 15 m, then from 24 m to 45 m and at the bottom of the core. The prominent black shales are at 38.5 m (more than 20 cm thick) and at around 50.5 m (about 10 cm thick). Following a thick interval in which black shales are absent, the transition to the underlying Maiolica is marked by several thick black shales which correspond to the Livello Selli (Coccioni et al., 1987).

b) Color Index.

The Color Index curve shows that lower percentages of light transparency, which correspond mainly to the darker colors (brown, red-brown, red, and dark green) associated with frequent black-shales, occur in the middle portion of the core, whereas higher percentages (lighter colors) are more frequent in the upper portion, particularly near the transition to the overlying Scaglia Bianca. It is also in the upper portion of the curve that the maximum excursions were observed. They usually correspond to higher frequencies of black-shale layers which are bounded by light lithotypes, as from 10 m to 15 m.

c) Distribution of organisms.

For the planktonic foraminifera we can clearly distinguish four major intervals:

- an upper portion, down to about 25 m where the abundances fluctuate with mean values up to 15%. In a general way, planktonic foraminifera are always present and frequently abundant;

- a second interval, from 25 m to about 50 m, where planktonic foraminifera are rare or frequently absent;

- a third interval, from 50 m to 71 m, where planktonic foraminifera are again present, but they never reach the high values of the upper portion;

- finally, in the bottom interval planktonic foraminifera are always present but are very rare. In this case we are dealing with the combination of several factors: a) evolution, they are at the beginning of their range and in general are rare; b) they are diluted within abundant radiolarians; and c) some of them were probably removed by dissolution and/or diagenesis being small in size and having thin walls.

Radiolarians are distributed unevenly throughout the core. As with planktonic foraminifera, different characteristic intervals can be identified. In the upper portion, down to 13 m, radiolarians occur apparently with some cyclicity and they are in general associated with discrete cherty layers also visible in the core and in outcrop.

Then, in the middle portion, from 13 m to 53 m, radiolarians are in general absent or very poorly represented. In several cases they appear like ghosts or are pyritized. The peel technique is not the best for detecting radiolarians specifically in the more clayey lithotypes. From 53 m down to the bottom of the core, radiolarians show the maximum abundance either as discrete layers or as a number of layers with the greatest concentration around the Livello Selli. Cherty horizons, however, are missing.

d) Calcium Carbonate content.

The calcium carbonate content allows us to identify an intermediate interval, from 31 m to 44 m, where the calcium carbonate percentage is lower than in the upper and lower portions of the core. Roughly, this carbonate-poor interval corresponds to the greatest low in planktonic foraminiferal abundance and to the darker, more shaly units. Moreover, the latter interval is also characterized by the maximum excursions in carbonate content.

Correlations.

The described log and associated curves of Fig. 2 form the base for further studies of the core itself and for outcrops, to which other parameters and features may be compared and/or correlated.

A first correlation was already attempted with coeval outcropping sequences of the Umbrian-Marchean Basin, especially on the basis of the principal identified units and the lithological and chromatic variations. Besides the Erma section, which crops out close to the drilling location (Fischer & Herbert, 1988), other sections, such as Gorgo a Cerbara, Moria, and Monte Petrano sections, have been visually, even partially, correlated to the Piobbico core by A.G. Fischer, as reported by Premoli Silva and Erba (1988). Moreover, a more comprehensive correlation was made possible with the Poggio le Guaine section, studied in detail by Coccioni et al. (1989). There, beside the perfect match on the lithologic characteristics, the carbonate and organism distributions display a consistent correlation with the corresponding Piobbico's curves. Moreover, the study of the Poggio le Guaine section provided a better record of the middle dissolved portion of the Piobbico sequence. In particular, the washing technique used in this exposed section allows us to improve the record of the radiolarians and benthic foraminifera. In fact, radiolarians are not only present but also abundant (up to 50% of the total residues) in the interval corresponding from the top of Unit 12 through Unit 7 of the Piobbico core where they apparently were missing. It is worth mentioning that radiolarians are poorly preserved and frequently pyritized. Coccioni et al. (1989) also estimated the abundance of benthic foraminifera throughout the entire section, not possible in our peel analysis. Plots of Coccioni et al.'s fig. 2 show that benthic foraminifera become abundant in the interval characterized by rare planktonics specifically in the middle portion as do the radiolarians, whereas they are rare where planktonic foraminifera are more frequent. This negative correlation is clearly visible either at large or small scale.

Evolution, diagenesis, and paleoenvironmental remarks.

The interval represented by the Scisti a Fucoidi contains the first radiation of planktonic foraminifera. Although they are recorded in the Barremian, they diversified only by Early Aptian time and bloom later in the Late Aptian. The increase in diversity is accompanied by an increase, slow at the beginning then the much faster, in the overall size of individuals within a single species, such as *Hedbergella delrioensis*, as well as with the appearance of larger species. This trend, well known from other areas as recently described in detail by Leckie (1987), is recorded in Units 18 through 14 of the Piobbico core. The decrease in planktonic foraminiferal abundance beginning at the bottom of Unit 14a also coincides with a decrease in species diversity and elimination of the most ornamented forms. In term of evolution, this event appears to be a step back. In fact, planktonic foraminifera slowly reappear in Unit 8 up to Unit 6, but only in the middle of the latter unit do planktonic foraminifera display higher abundances, increased diversity and renewed enrichment of the overall faunas in medium-sized individuals and species.

A comparison of planktonic faunal distributions between the Late Aptian and Middle to Late Albian intervals reveals that a) planktonic foraminiferal abundances vary from layer to layer (see above), and b) the recorded foraminiferal assemblages display a marked difference in species composition in the presence of similar carbonate content and independently of the occurrence or absence of radiolarians. In particular, the dominantly red and green units without black shales of Late Aptian age yield planktonic faunas rich in large-sized, thick-walled ornamented forms (Pl. 16, fig. 2), whereas at higher carbonate content in the Late Albian portion, planktonic foraminiferal faunas consist of rare small-sized, thin-walled individuals (Pl. 16, fig. 1). Such a marked difference between the two assemblages could not be related to evolution, because large and thick-walled individuals of Late Albian age are preserved in the less carbonate-rich black shale layers.

It is worth mentioning that, as it will be discussed below, there is no evidence of major changes in paleobathymetry of the basin during the two aforementioned intervals. Consequently, the observed differences in faunal composition must be explained by other factors such as differential preservation due to dissolution and/or diagenesis, different degree of oxygenation of the water column, or changes in paleoenvironmental parameters, etc.

In order to solve such a puzzle, calcareous nannofossil characteristics and carbonate content fluctuations have been compared with the planktonic foraminiferal record. In addition, benthic foraminiferal assemblages and their distribution throughout the sequence were also analyzed.

According to the calcareous nannofossil record, the Piobbico sequence can be split into three intervals, each of them characterized by different indices. Erba (1986; in prep.) recognized that 1) the dominantly red and green portion of Late Aptian age is marked by a high content of micarbs (microcrystallites due to the destruction of either calcareous nannofossils or planktonic foraminifera), medium nannofloral diversity, and high abundance of the very solution-resistant *Watznaueria*; 2) the darker latest Aptian to Early Albian portion contains the poorest nannofloras dominated by *Watznaueria* in the absence of micarbs; and finally 3) the alternating lighter and dark lithologic portion of Late Albian age yielded highly diversified nannofloras with *Watznaueria* and micarbs in larger amount in layers with higher carbonate content (see also Premoli Silva et al., 1989). Erba (1986) interpreted that the lowest portion was strongly affected by diagenesis, the poor fossil content of the second segment is the result of a strong primary dissolution at the sediment/water interface, and the topmost interval is the sedimentary expression of fluctuations in calcium carbonate flux with higher nannofloral diversity associated with higher calcium carbonate flux and stronger diagenesis. In the latter interval, moreover, layers with higher carbonate content also yield a nannofloral assemblage indicative of highly-fertile surface waters.

As described, it appears that small-sized, thin-walled planktonic foraminifera are absent in layers where diagenesis is more pronounced. That means that the small hedbergellids are among the major contributors to micarbs. If diagenesis can account for the absence of small-sized forms in the presence of the ornamented ones in the Late Aptian, then diagenesis alone cannot explain the scarcity of planktonic foraminifera in the carbonate-rich layers of the Late Albian interval. A possible interpretation of such phenomenon could reside in the original faunal composition. In the pre-Neogene ocean, the most ornamented, larger-sized planktonic foraminifera proliferated at lower latitudes and during times of warmer climate, well stratified water masses, and weaker thermal gradients (Boersma & Premoli Silva, 1983; Leckie, 1987; Premoli Silva & Boersma, 1988, i.e.). Past upwelling or highly mixed waters, similar to modern upwelling areas or cooler waters, were possibly inhabited by depauperated faunas, in general enriched in the most tolerant or cosmopolitan species (eurytopic *sensu* Leckie, 1987). During the Albian small-sized, thin-walled hedbergellids were cosmopolitan and are expected to proliferate in unstable environments (Tappan, 1962; Sliter, 1971; Hart & Ball, 1986; Leckie, 1987). If this interpretation is correct then the paucity of planktonic foraminifera, generally represented by small hedbergellids, may be related to the characteristics of an unstable environment and thus represent a primary signal further modified by diagenesis. According to Herbert (1987), the carbonate-rich layers represent intervals of high carbonate productivity in higher-fertility waters, as corroborate by the occurrence of calcareous nannofossil fertility Index (Erba, 1986; in prep.; Premoli Silva et al., 1989). On the other hand, well diversified faunas including also the larger-sized, well-ornamented forms such as the ticinellids, *Biticinella breggiensis*, etc., should occur in the carbonate-poor layers. In the case of the Piobbico core, the latter are represented by black-shales which, in fact, yield more complete and abundant faunas, implying also that the black-shales in this portion are the sedimentary expression of a more stable environment. This interpretation is in agreement with that suggested by Weissert et al. (1979) for the black-shale-limestone cycles in the uppermost Maiolica from the Southern Alps (see also Weissert, 1989). These authors related black-shale deposition to periods of a stable, stratified anoxic environment, whereas limestones are the sedimentary expression of a more oxygenated, overturning water mass.

Oxidation State.

Oxidation state on the sea floor of the Umbrian-Marchean Basin was primarily responsible for controlling the degree of bioturbation and for the diagenetic fixing of iron. Changes in oxidation state during the deposition of the Scisti a Fucoidi are reflected in sediment coloration. These are influenced by the retention of organic carbon and by the presence or absence of diagenetic pyrite or hematite. The state of iron is presumably dependent on original organic content and, to a smaller degree, on the sedimentation rate

(Arthur & Fischer, 1977). Within the Scisti a Fucoidi, however, the spectacular changes in coloration as described above are not correlated yet to the state of iron in a systematic way. On the basis of colors we can infer that red units have higher iron-oxide content than darker units. Darker units of the middle portion of the core do contain higher organic carbon and pyrite is more abundant. Occurrence of sulfides is expected in such units, and was found in some exposed sequences from the Umbrian-Marchean Basin (Arthur & Premoli Silva, 1982; Coccioni et al., 1989; and personal observations). The few analyses from the Piobbico core are confined to the 10-15 m interval and are semi-quantitative elemental analyses. There, sulfur is rare and not significant even in the black-shale layers. Nevertheless, we suspect that sulfides were comparatively common from 25 m to 45 m in the darker, medium dissolved portion of the core and from 59 m to 71 m. This hypothesis is supported by the occurrence, even discontinuous, of frequently abundant acicular crystallites of dehydrated calcium sulfate of neoformation on the acetate peels of Units 6 through 12 from the interval exhibiting numerous black-shale layers, and of most of Unit 17. We believe that these sulfate crystallites, with their typical radial arrangement (Pl. 14, fig. 2), formed by oxidation of sulfides in the presence of calcium carbonate when the core was exposed to fresh air (Olausson, 1961). They are common in the Pleistocene sapropels from Eastern Mediterranean.

Conclusions.

Detailed analysis of the Scisti a Fucoidi recovered in the Piobbico core suggests that this formation registered marked changes in paleoenvironmental conditions which affected water masses during the Aptian-Albian interval at least in the Umbrian-Marchean Basin. The overall trend derived from planktonic and benthic foraminifera, radiolarians, calcium carbonate content, color distribution, and occurrence or absence of black-shales shows:

a) in the Early Aptian, corresponding to Units 19 and 18, the alternating black and lighter sediments testify to rapid changes in the oxygenation state from anoxia to more oxygenated conditions with strong primary dissolution in some of the black-shale horizons;

b) most of the Late Aptian was a time during which more oxidized sediments were deposited. Such sediments, mainly red in color, apparently resulted from increased oxygenation in the water masses, but they are also affected by stronger diagenetic processes, which may be responsible for the enrichment in iron-oxides. The fact that planktonic foraminifera rapidly evolved and diversified during this time would suggest that the overturn of the water masses was not pronounced. Consequently, any increase in oxygenation, if present, affected more the deeper rather than the shallower part of the water column. The occurrence of *Praebulimina* whose modern analogues are characteristic of poorly oxygenated waters, would agree with a possible, although weak, stratification of the water column, which provided a relatively stable niche for the proliferation of planktonic foraminifera;

c) by latest Aptian through early Middle Albian, oxygenation became very low possibly throughout the entire water column and the bottom of the basin experienced several periods of anoxia. In such conditions, stratification of the water column is expected strongly enhanced, thus planktonic foraminiferal faunas should have been abundant and well diversified. Conversely, planktonic foraminifera recorded in this time period are rare, poorly diversified and poorly preserved. Calcareous nannoflora suggest that strong dissolution at the sediment/water interface affected sediment deposition at this time. Therefore, planktonic foraminifera could also have been removed by dissolution. This hypothesis, however, does not explain why several planktonic foraminiferal species and genera became extinct and why only a few opportunistic species (eurytopic *sensu* Leckie, 1987) survived, an environmental change which apparently was not registered by the calcareous nannofossils. Further studies are needed to clarify these contradictory interpretations;

d) by the late Middle Albian black-shale horizons begin to rarefy, whereas lighter colored, occasionally red, lithotypes reappear, carbonate content increases on average, and planktonic foraminifera exhibited a new radiation. These new features are not constant, but alternate rhythmically with those from the previous interval throughout the remainder of the core except in the topmost portion of Late Albian age. Detailed studies of a part of this interval proved that poor to rich carbonate sediment alternations are cyclic according to orbital forcing (Herbert & Fischer, 1986). From a paleoenvironmental point of view, carbonate-poor sediments are the sedimentary expression of periods of low primary carbonate flux, stable environment responsible for proliferation of planktonic foraminifera as well as the accumulation of organic matter, whereas carbonate-rich sediments are the response to an increase in primary carbonate flux, a stronger mixing and more oxygenated waters. The less stable environment, however, caused a selection among planktonic foraminifera toward opportunistic species that were easely removed by diagenesis. This trend continued for most of the Late Albian, when carbonate content, lighter colored lithotypes, and abundant planktonic foraminifera no longer fluctuate.

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List of Identified Species*.

Biticinella breggiensis (Gandolfi, 1942). Luterbacher & Premoli Silva, 1962, p. 272, pl. 23, fig. 2-4; Longoria, 1974, p. 95, pl. 25, fig. 7, 14-16.

Biticinella subbreggiensis Sigal, 1966. Sigal, 1966, p. 193, pl. 1, fig. 1-7; pl. 2, fig. 2.

Globigerinelloides algerianus Cushman & Ten Dam, 1948. Longoria, 1974, p. 77, pl. 6, fig. 1-18.

Globigerinelloides barri (Bolli, Loeblich & Tappan, 1957). Longoria, 1974, p. 80, pl. 4, fig. 1-3, 8, 14; pl. 5, fig. 9-16; pl. 27, fig. 19.

Globigerinelloides bentonensis (Morrow, 1934). Caron, 1985, p. 47, pl. 29, fig. 8, 9.

Globigerinelloides blowi (Bolli, 1959). Longoria, 1974, p. 82, pl. 4, fig. 4, 7, 11-13.

Globigerinelloides caseyi (Bolli, Loeblich & Tappan, 1957). Pessagno, 1967, p. 276, pl. 49, fig. 2-5.

Globigerinelloides duboisi (Chevalier, 1961). Longoria, 1974, p. 83, pl. 4, fig. 15, 16; pl. 11, fig. 12, 13.

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PLATE 11

Fig. 1 - Piobbico core, Unit 2 (11.06-11.08 m). Small-sized planktonic foraminiferal assemblage from a black-shale layer; x 10.

Fig. 2 - Piobbico core, Unit 2 (12.22-12.23 m). Abundant planktonic foraminifera of the *Biticinella breggiensis* Zone from a gray layer; x 20.

Fig. 3 - Piobbico core, Unit 2 (12.28-12.29 m). Example of change in planktonic foraminiferal abundance within a layer of apparently uniform lithology; x 10.

Fig. 4 - Piobbico core, Unit 2 (12.65-12.67 m). Same as fig. 3; x 10.

PLATE 12

Fig. 1 - Piobbico core, Unit 2 (6.85-6.86 m). Frequent planktonic foraminifera, oriented parallel to the bedding plane, from a black-shale layer; x 20.

Fig. 2 - Piobbico core, Unit 2 (11.14-11.15 m). Example of black shale boundary. Note the abrupt increase in planktonic foraminiferal abundance in the black shale (upper part); x 10.

PLATE 13

Fig. 1 - Piobbico core, Unit 10 (38.56-38.58 m). Coarsely laminated black shale. Note the abundance of calcitic laminae frequently coalescing to form thicker laminae alternating with organic-rich darker layers; x 10.

Fig. 2 - Detail of fig. 1 showing that calcitic lenses are coalescing. Rare planktonic foraminifera are still visible; x 40.

PLATE 14

Fig. 1 - Piobbico core, Unit 17 c (64.18-64.38 m). *Globigerinelloides algerianus* Zone. Note two specimens of *G. algerianus* and possibly *Hedbergella trocoidea*; x 30.

Fig. 2 - Piobbico core, Unit 17c (64.18-64.38 m). The large specimen represents the transition from *G. algerianus* to *Planomalina cheniourensis*. Note the radiate microcrystallites of calcium sulfate (artifacts) in the background; x 40.

Fig. 3 - Piobbico core, Unit 17c (65.31-65.53 m). Faunal assemblage of the *G. algerianus* Zone. The large specimen is belonging to *Hedbergella trocoidea*. Note that small-sized planktonic foraminifera are much rarer than in fig. 1 and 2; x 30.

Fig. 4 - Piobbico core, Unit 18 (74.27-74.28 m). Pyrite nodules; x 8.

PLATE 15

Fig. 1 - Piobbico core, Unit 2 (11.02-11.03 m). Core of a band rich in moderately well preserved radiolarians; x 40.

Fig. 2 - Piobbico core, Unit 17b (62.29-62.30 m). Boundary between a radiolarian-rich band and the underlying poorly fossiliferous marlstone; x 10.

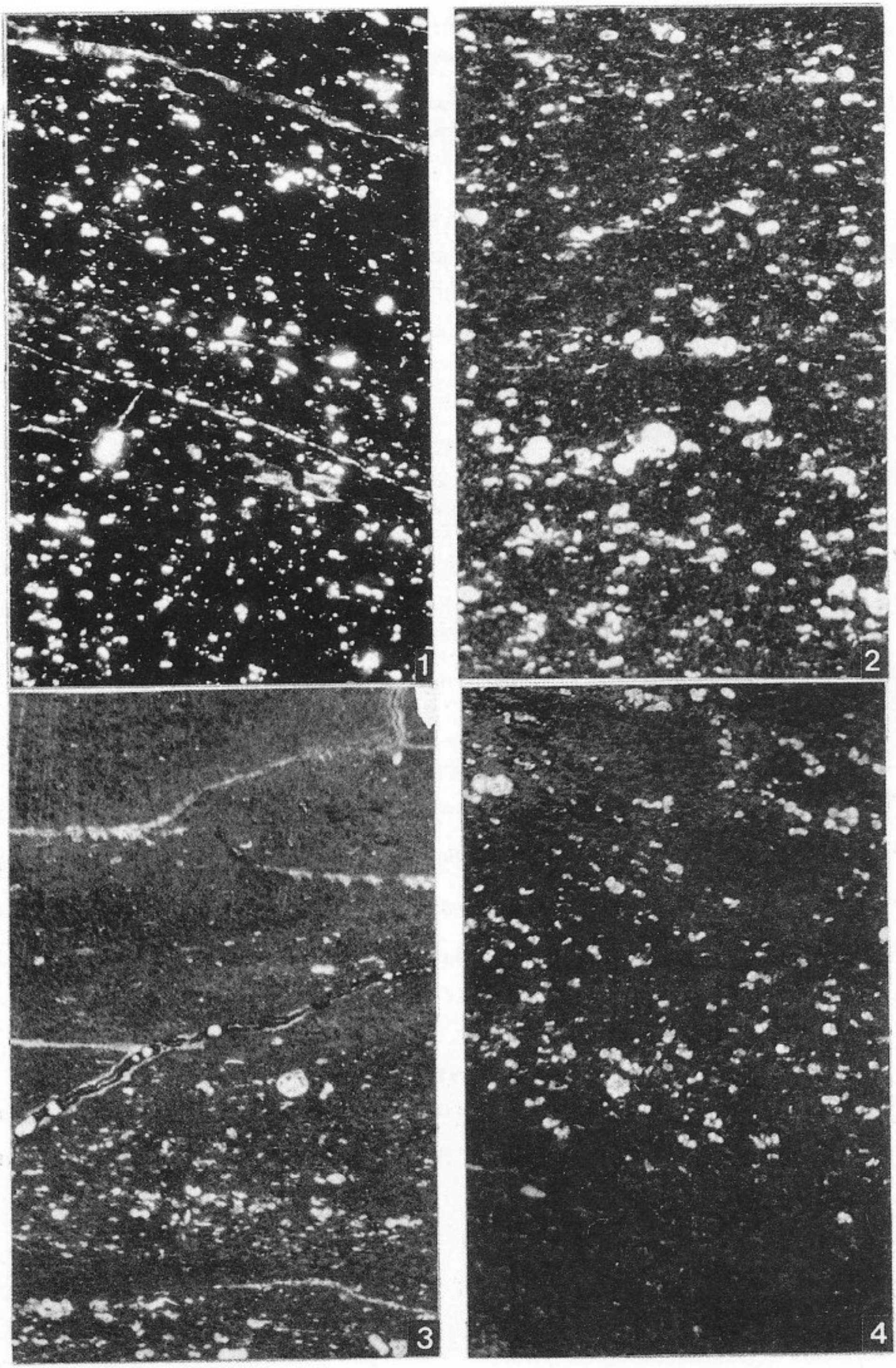
Fig. 3 - Piobbico core, Unit 14b (52.13-52.36 m). *Ticinella bejaouaensis* Zone. Small-sized planktonic foraminifera are scarse; x 15.

Fig. 4 - Piobbico core, Unit 15 (55.93-56.11 m). *Ticinella bejaouaensis* Zone. Note the paucity of small-sized specimens, much rarer than in fig. 3; x 11.

PLATE 16

Fig. 1 - Piobbico core, Unit 2 (12.56-12.57 m). In carbonate-rich layers planktonic foraminifera are scarse and minute in size; x 10.

Fig. 2 - Piobbico core, Unit 17b (62.81-62.82 m). The paucity of planktonic foraminifera is interpreted as the effect of diagenesis; x 10.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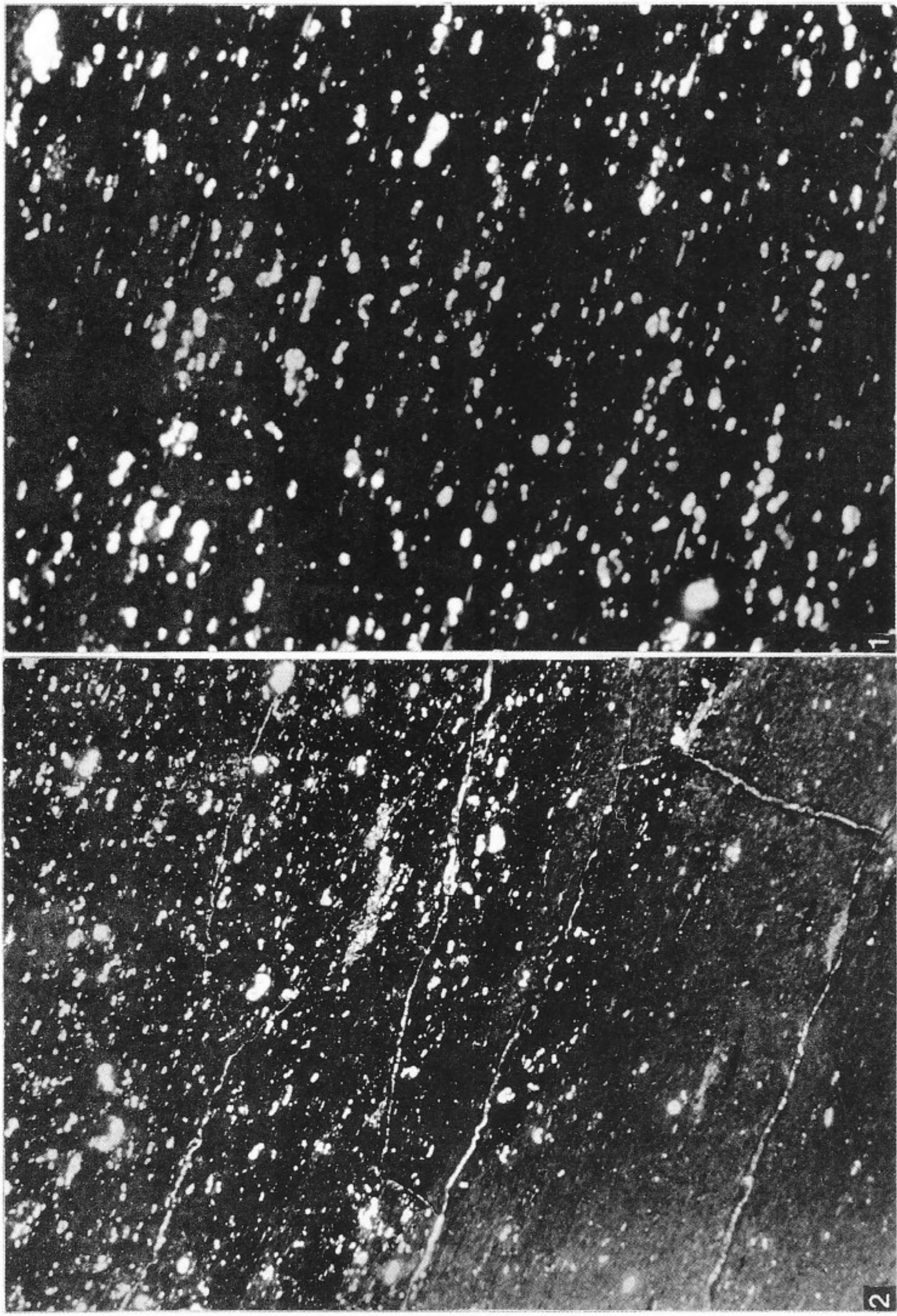

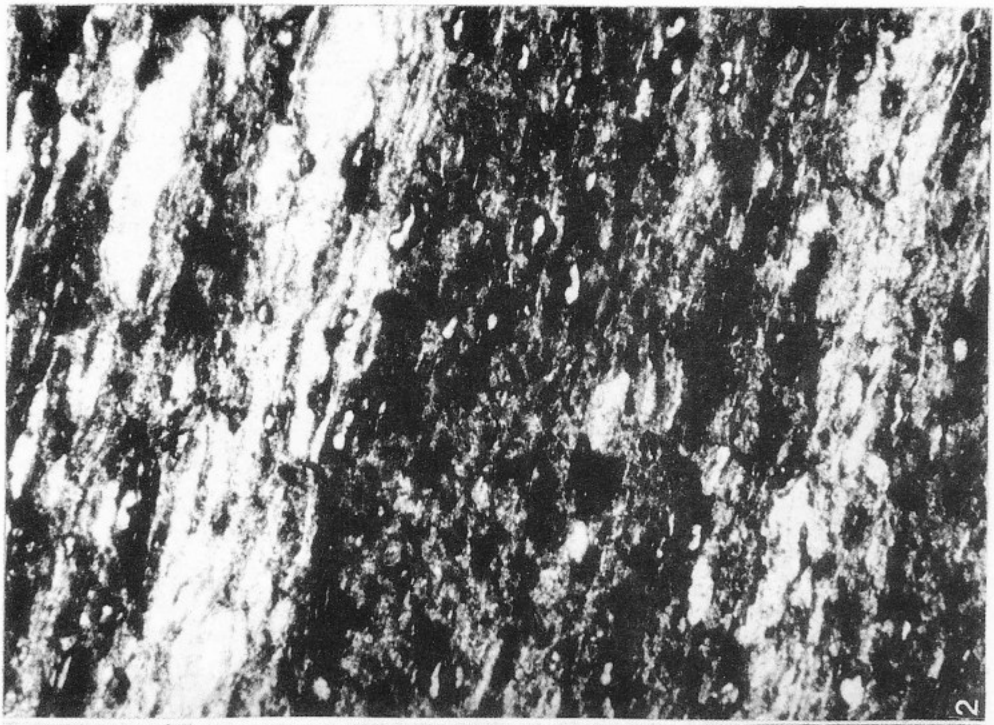

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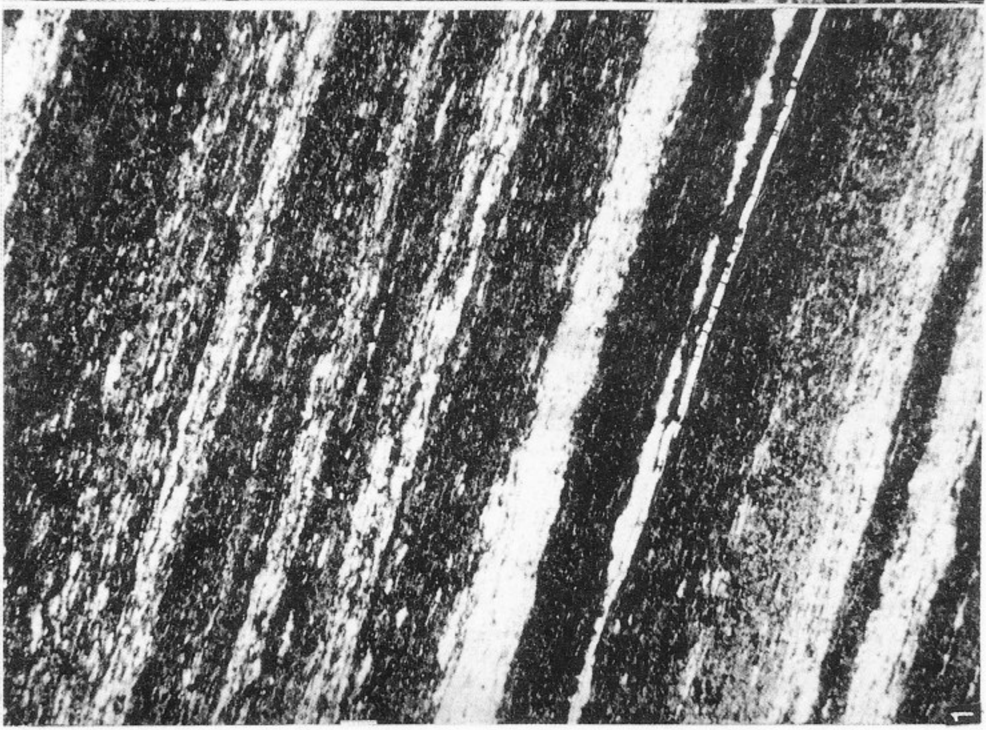

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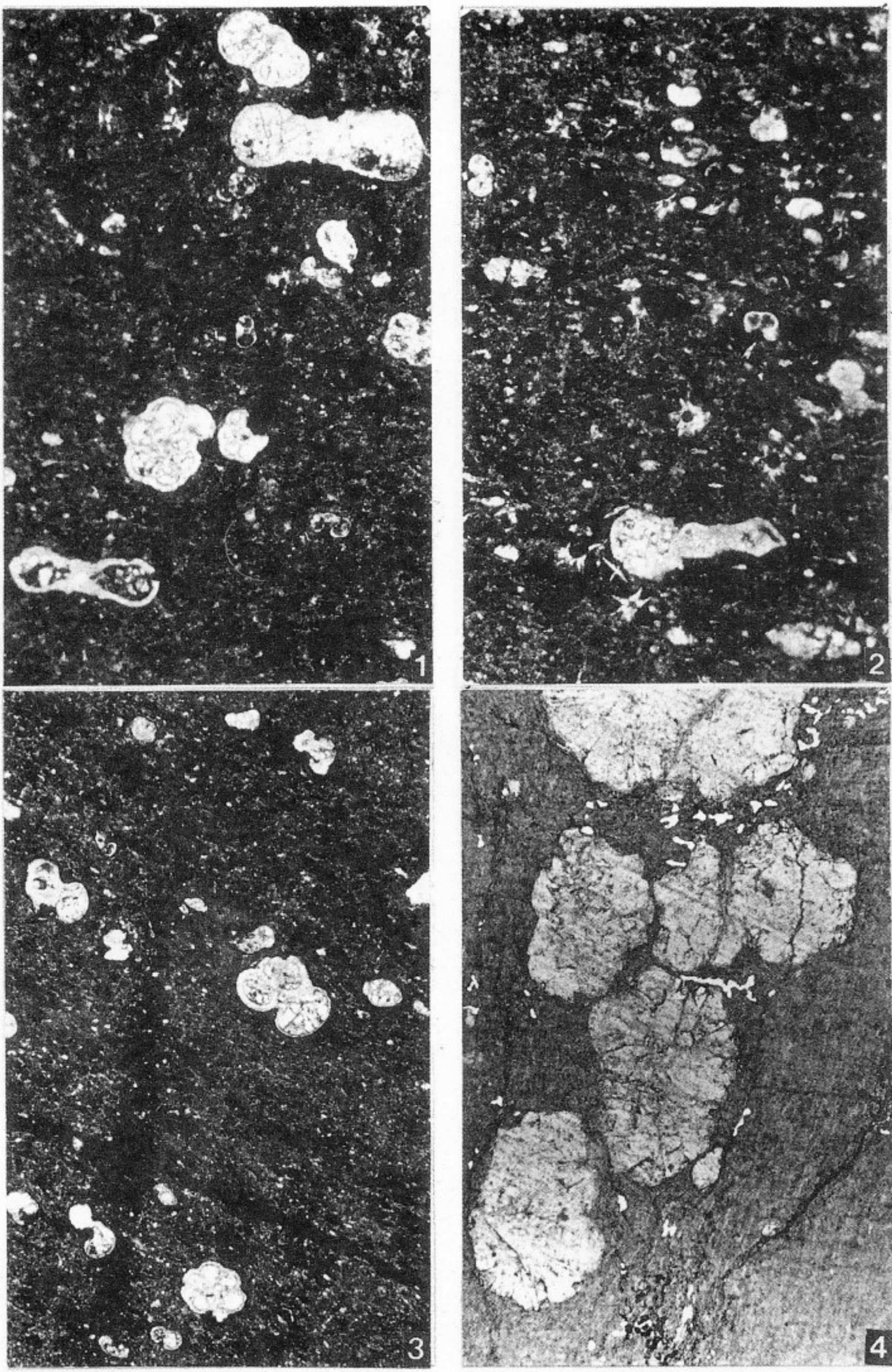
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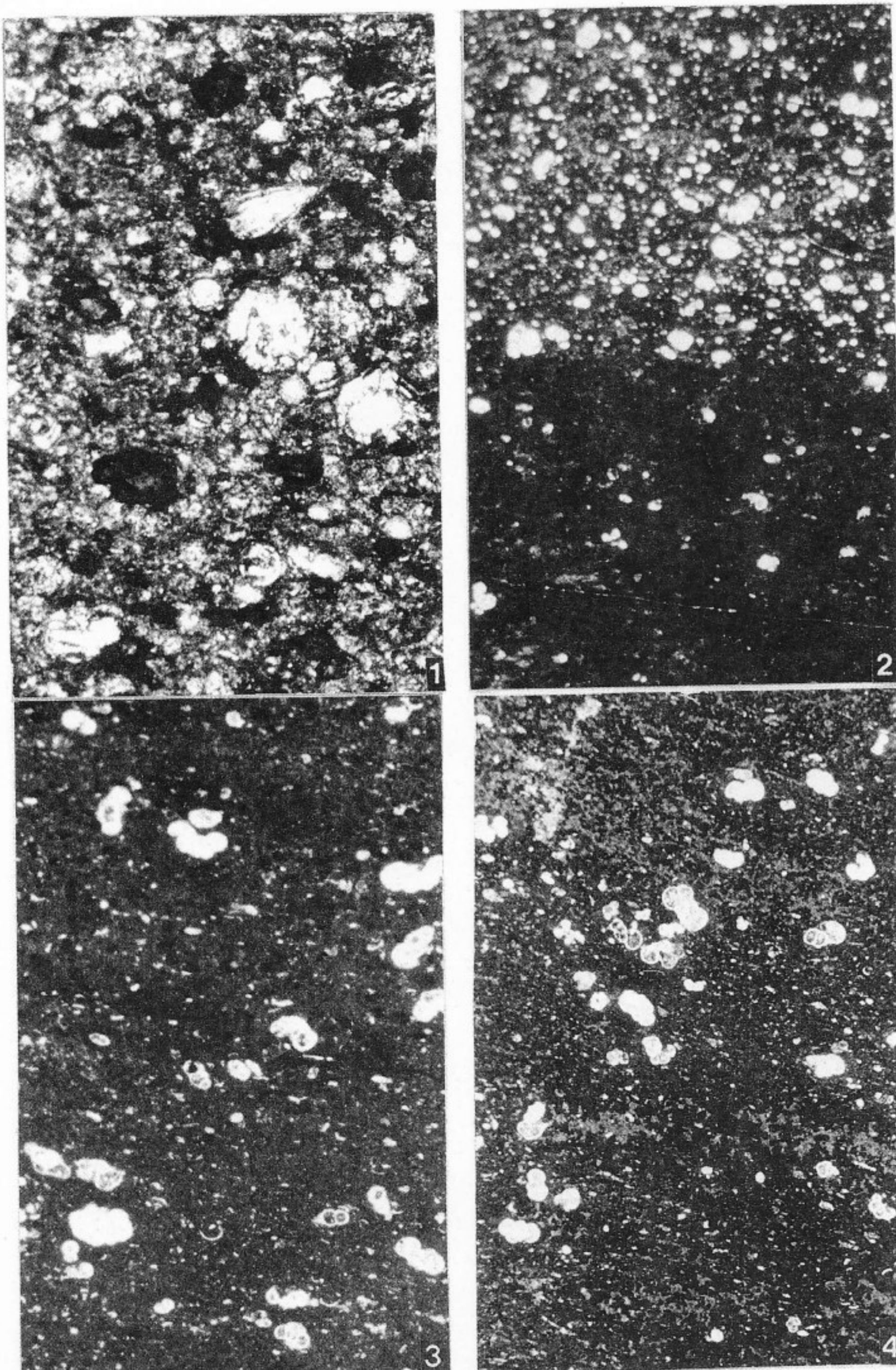
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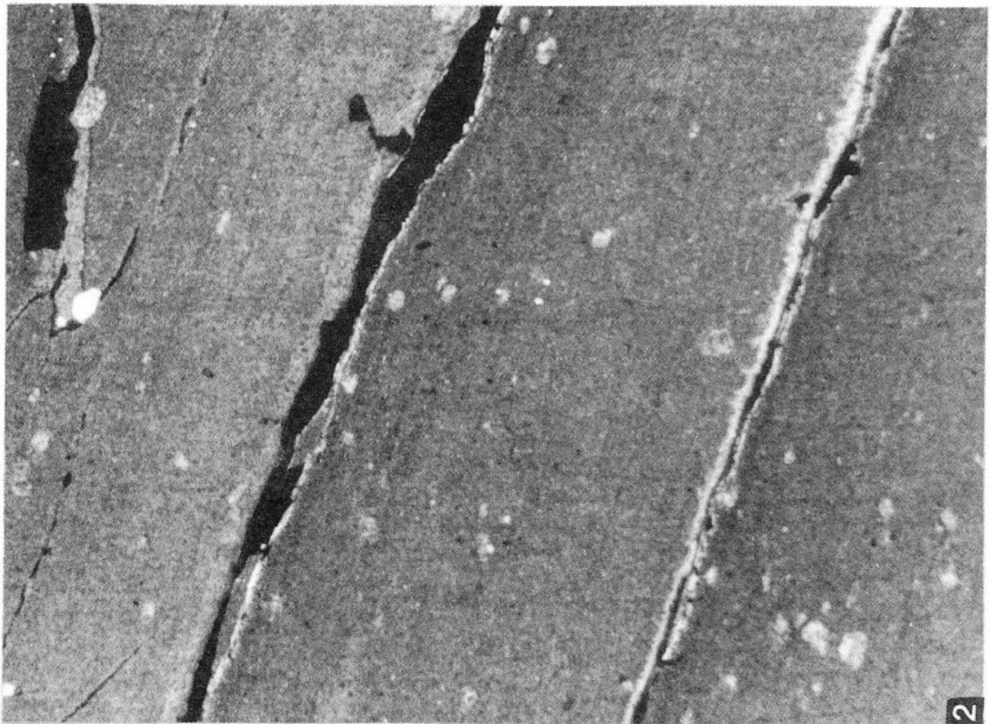
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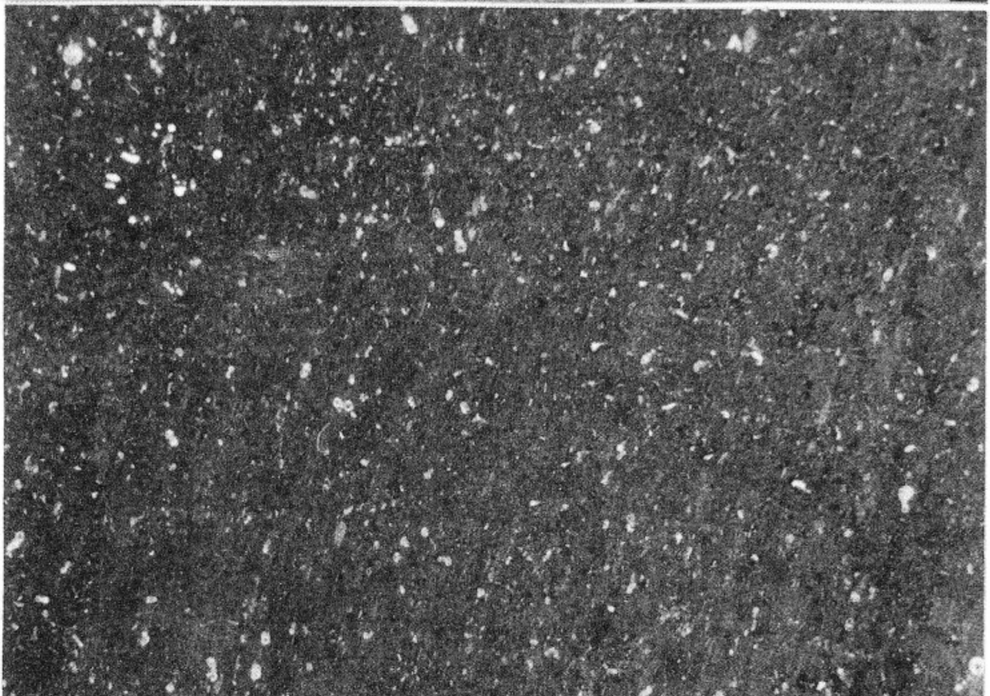
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