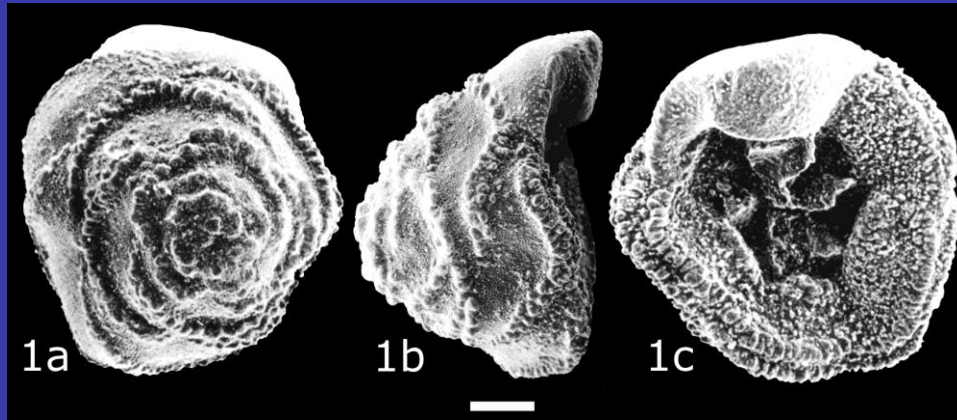# EGU - General Assembly 2014

Jan Baptiste Lamarck Medal
Vienna, 28 April 2014

Contusotruncana contusa

The long way of planktonic Foraminifera from Biostratigraphy to Paleoceanography

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Importance of Foraminifera in Stratigraphy

Even though the stratigraphic importance of microfossils was recognized since the 19° century, the use of foraminifera in stratigraphy was strictly related to the needs of petroleum exploration that increased remarkably after the Great War and accelerated furthermore after World War II.

PlanktonicForaminifera are known since the mid-Jurassic, however, they become stratigraphically important only since the Early Cretaceous.

The first studies dedicated to planktonicForaminifera started toappear around 1940s. Among the stratigraphic pioneer works we can mention Gandolfi (1942, Aptian-Turonian, Breggia section), Bolli (1945, Cretaceous of Helveticum in thin section), Cita (1948-50, Cretaceous-Eocene, L. Garda), Cushman and co-authors (1942-45, Cretaceous to Eocene, USA & Trinidad) that showed for the first time their rapid evolution usable for precise dating. However, the first biostratigraphic schemes, based on appearance/disappearance of specifictaxa and on distributionof the numerous planktonicspecies (and genera) recognized, are dated to 1953 (Subbotina, Southern USSR) for the Paleocene to Eocene/Oligocene boundary, and to 1957(Bolli, Trinidad & Caribbean) for the Upper Cretaceous to Miocene interval.

Investigations on stratotypes

In late 1950s and 1960s a lot of efforts have been dedicated to establishing the relative time relationships of stratigraphic successions represented in the numerous regional stratotypes, formally defined at their base, from Europe to New Zealand. As the identifications of most of them were based on poorly age diagnostic, facies-controlled macrofossils, the scientific community undertook systematically intense investigations of stratotype's planktonic foraminiferal contents, aimed to provide a chronostratigraphic framework applicable at least at supraregional scale.

Even though these studies on planktonic Foraminifera were fundamental for clarifying the relative time relationships of some stratotypes defined in the numerous European Basins (i.e. Helvetian), the applicability of Trinidad zonation turned out to be difficult for the absence of several marker species preventing, as a consequence, to precisely attribute Trinidad zones to the official stages.
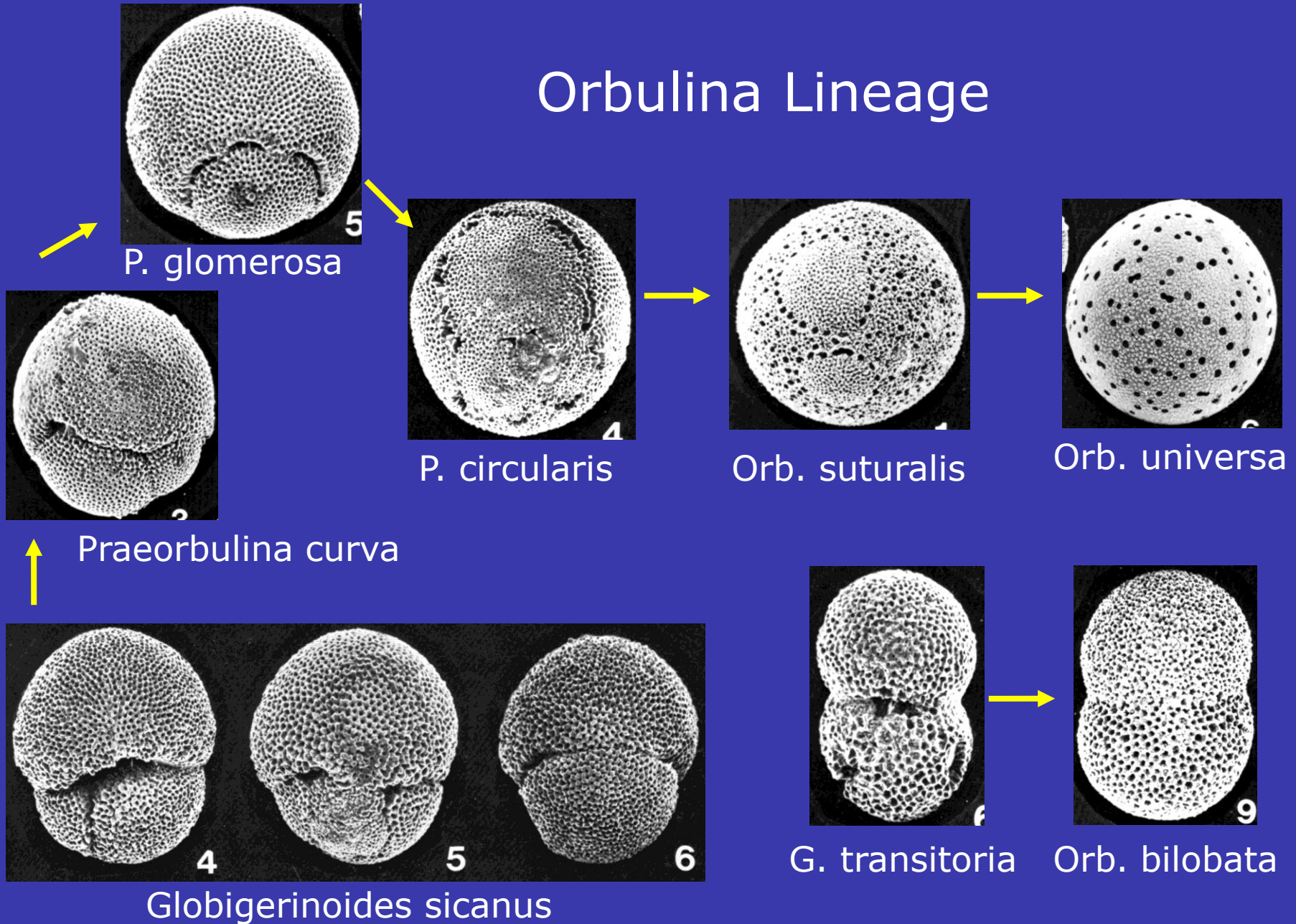
The case of Mediterranean Miocene

Emblematic is the case of the Langhian stratotype (Piemont Tertiary Basin), my thesis subject: even though the planktonic foraminiferal content of the hemipelagic "Pteropod Marls" was abundant, the correlation with the Trinidad zonation could rely only on the evolution of the *Globigerinoides-Praeorbulina-Orbulina* lineage (Blow, 1956), as most of the Early to Middle Miocene marker species were missing.

As the studies progressed and were extended up to the Upper Miocene stages (Serravallian, Tortonian to Messinian), the correlations with the tropical zonation were even more difficult in particular for the absence of most taxa of the *Globorotalia fohsi* lineage, only *G. peripheroronda* wasrecorded, and of *Globorotalia tumida* whose lineage was truncated by the Messinian Salinity Crisis.
The lack of the more evolute taxa of these two lineages prevented to apply the tropical zonation to the Mediterranean successions, for which a new zonation was proposed that has only few tie-points to be used for correlation.
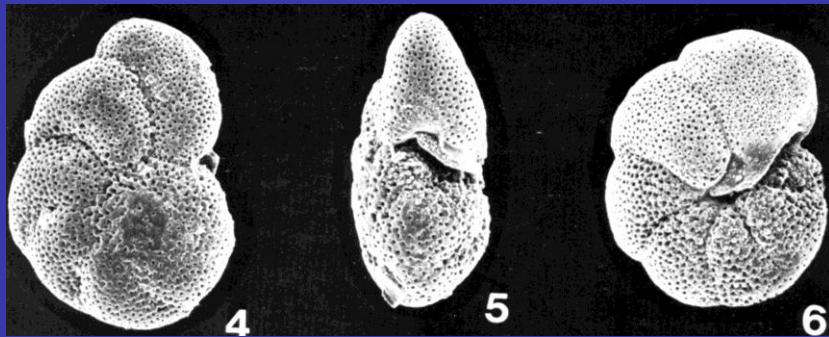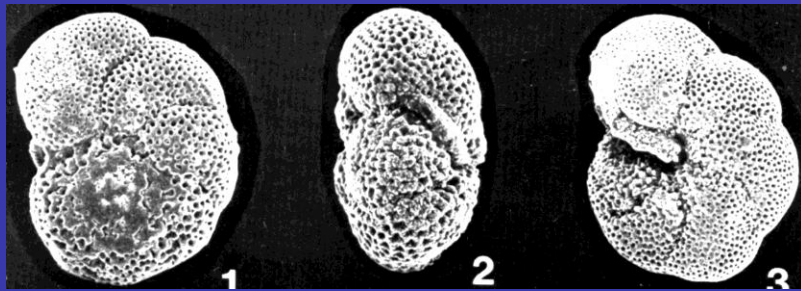
Middle Miocene

Orbulina Lineage

P. glomerosa

Praeorbulina curva

P. circularis

Orb. suturalis

Orb. universa

Globigerinoides sicanus

G. transitoria

Orb. bilobata

Fohsella Lineage

Middle Miocene

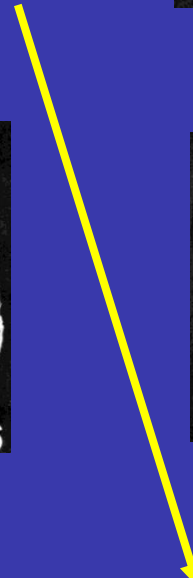G. praefohsi

G. robusta

G. peripheroacuta

G. lobata

Globorotalia peripheroronda
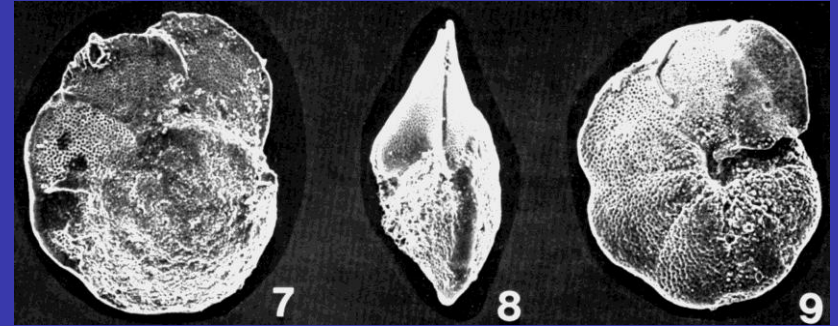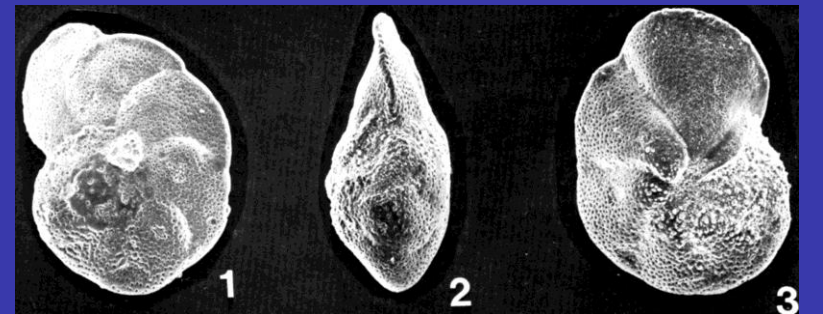
G. fohsi

Paleocene to Eocene of the Gubbio section

Contemporaneously, Bolli's tropical zonation was tested in the Paleocene-Eocene time interval, first on the Paleocene succession exposed at Paderno d'Adda (Bolli & Cita, 1960), then on the pelagic sediments of the Umbria Scaglia Formation at Gubbio, previously roughly dated by O. Renz (1936, PhD thesis) to the Cretaceous and Paleogene using planktonic Foraminifera identified in thin section.

The rather dense sampling of the entire Scaglia from Aptian to Upper Eocene of the Bottaccione section and the very high resolution sampling across the Cretaceous/Paleogene (K/Pg) boundary allowed to complete Bolli's zonation at the base of the Paleocene and at the Paleocene/Eocene boundary, respectively.

Three new zones have been introduced by Luterbacher (1964) and Luterbacher & Premoli Silva (1964):

the *eugubina* Zone at the base followed by the *pseudobulloides/ daubjergensis* Zone in the lower Paleocene and the *aequa*(= *edgari*) Zone at the top of the Paleocene.
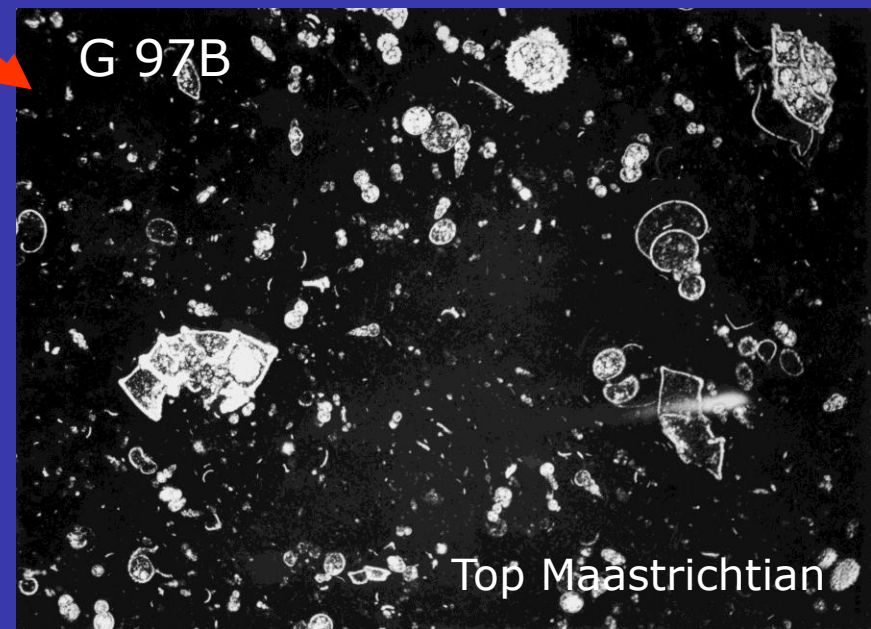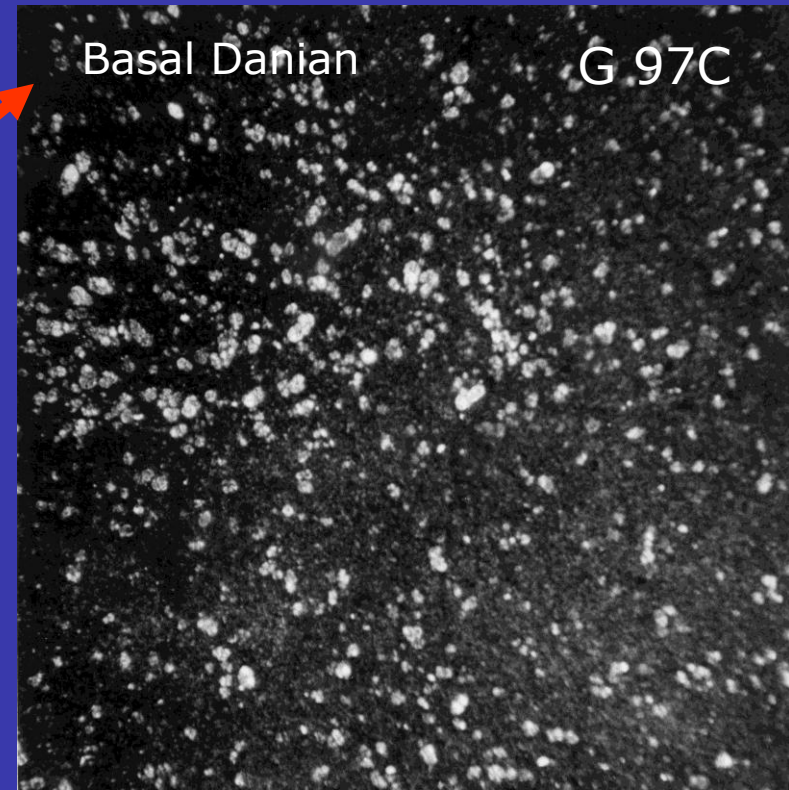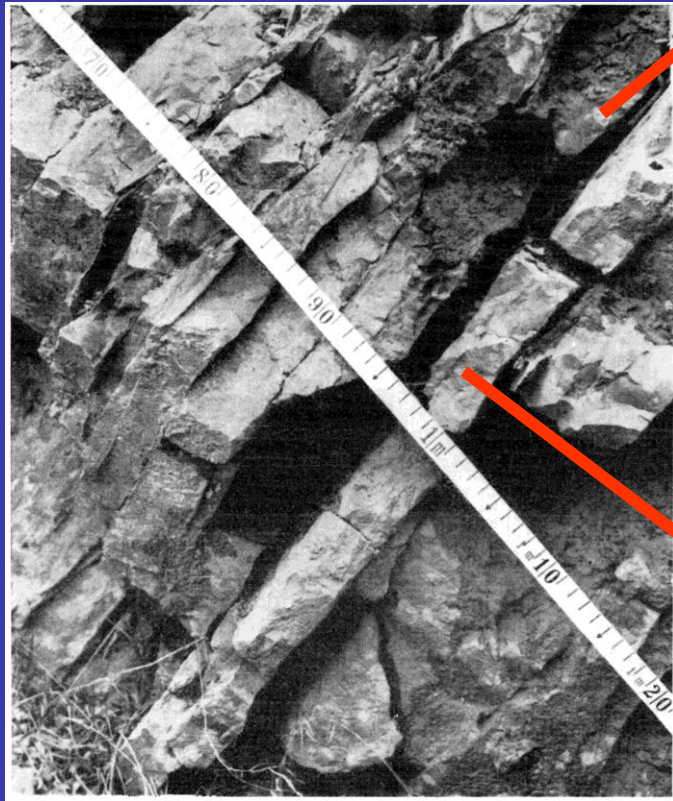
The Cretaceous/Paleocene boundary at Gubbio

Maastrichtian (bleached) and Danian (dark red) are separated by 1 cm-thick, clayey green & red layer, barren and devoid of CaCO3, but it contains the Iridium spike

Danian

Maastrichtian

# The Cretaceous/Paleocene boundary at Gubbio

Basal Danian — G 97C

G 97B — Top Maastrichtian

The change of planktonic fauna below and above the boundary is stricking - visible with just a hand lens - and it was even more drastic than what was known at that time (Luterbacher & Premoli Silva 1964)
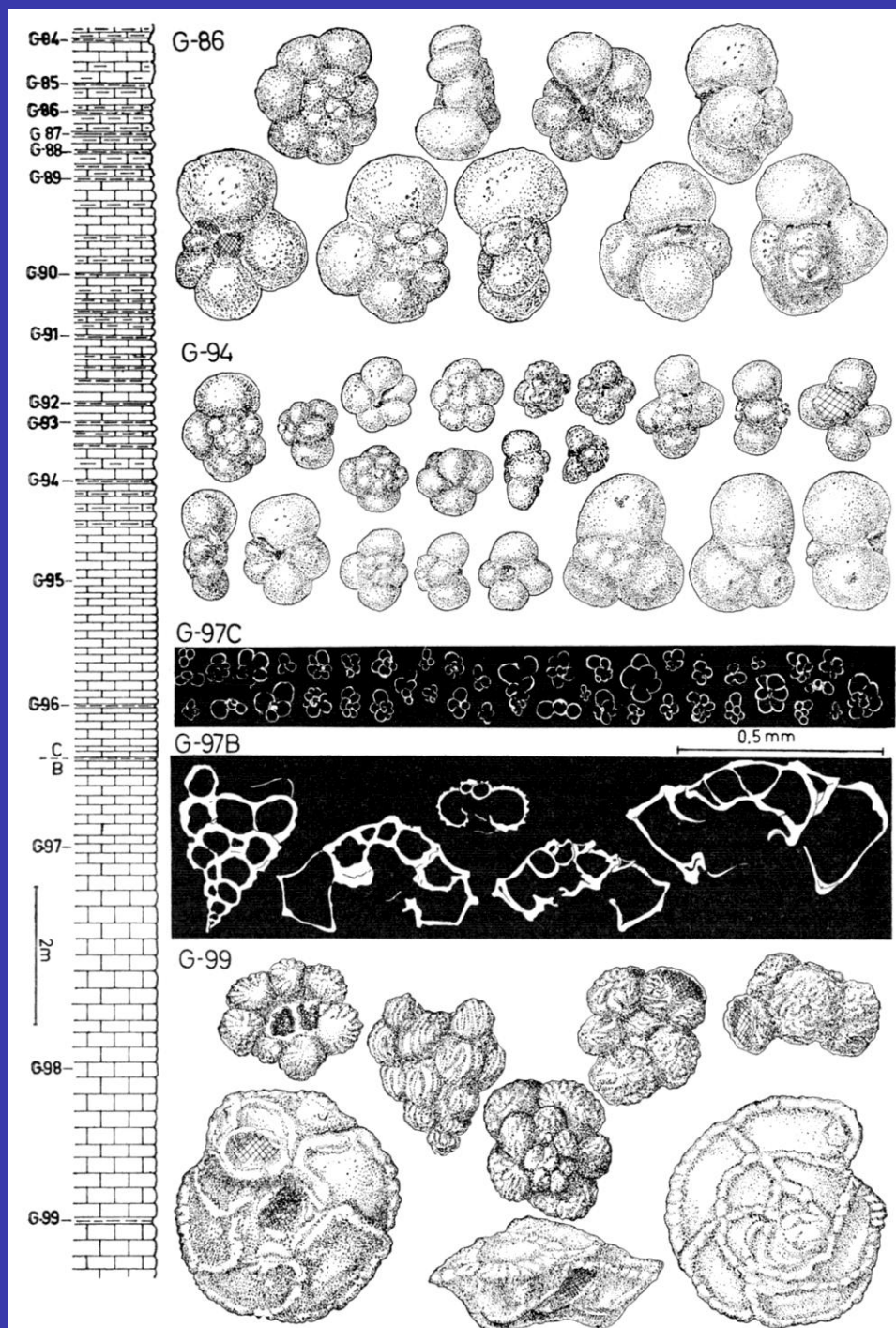
The Cretaceous/Paleocene boundary at Gubbio

The minute basal fauna evolves gradually giving rise to new genera and species of progressively larger sizes.
The *eugubina* Zone was recovered in numerous localites from the Umbria-Marche area and in few from Southern Alps (Luterbacher & Premoli Silva 1964). Its absence indicates a gap in the succession like in Trinidad.
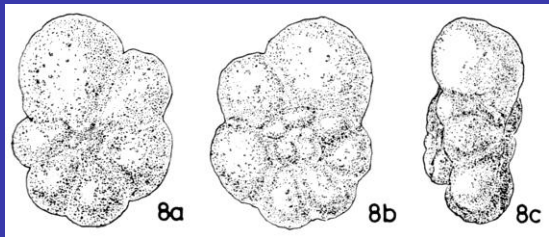
P. eugubina Holotype
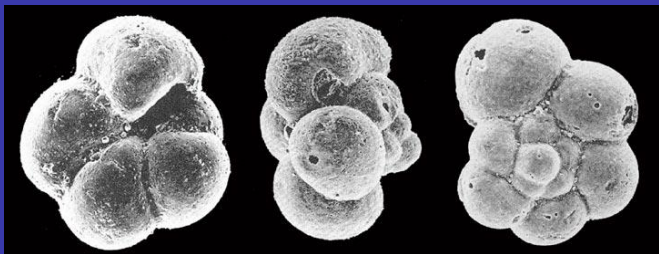
Paleocene Atlas, Pl. 66

TRINIDAD Bolli 1957	CENTRAL APENNINES Luterbacher 1964	CENTRAL PART OF NORTHERN CAUCASUS			
		Subbotina 1953		Strat.Commission USSR 1963	Alimarina 1963
H. aragonensis		A. crassaformis		A. crassaformis	A. crassaformis
G. palmerae	G. bullbrooki	zone of conical Globorotaliids		G. aragonensis	group of T. aragonensis / T. caucasica
	?— —?— —?—				
G. aragonensis	G. aragonensis				
	—?— —?—				
G. formosa formosa	G. formosa formosa / G. subbotinae		G. marginodentata	G. subbotinae	group of A. subsphaerica & group of A. aequa	G. marginodentata
	—?— —?—		—?— —?—	—?— —?—		—?— —?—
G. rex	G. aequa	zone of flattened Globorotaliids		G. aequa		G. aequa & G. wilcoxensis
— — — gap? — — —				—?— —?—		
G. velascoensis	G. velascoensis		G. crassata & A. intermedia	A. acarinata		—?— —?—
				—?— —?—	—?—	A. aff. subsphaerica
G. pseudomenardii	G. pseudomenardii			A. subsphaerica		—?— —?—
				—?— —?—	group of A. angulata	G. (?) kolchidica rounded A. tadjikistanensis
				A. tadjikistanensis djanensis		A. conicotruncata
G. pusilla pusilla	G. pusilla pusilla	—?—	—?— —?—	A. conicotruncata		A. angulata
		zone of rotaloid Globorotaliids	Gg. inconstans	A. angulata		A. praecursoria
G. uncinata	G. uncinata		—?— —?—		group of A. inconstans	A. indolensis
			Gg. trivialis			
		—?—	—?— —?—			
G. trinidadensis	G. trinidadensis					reticulate Globigerina
					group of G. pseudobulloides	
(Rzehakina epigona)	G. pseudobulloides / Gg. daubjergensis					"Eoglobigerina"
	Gg. eugubina				—?—	?— —?—

Luterbacher (1964) provided the first order correlation between Trinidad and Gubbio zonations as well as the first correlation with the zonal schemes applied to Northern Caucasus by scientists of former USSR. Some marker taxa from the USSR zonations have been incorporated in the most recent tropical zonal schemes (i.e. Berggren et al. 1995)

The birth of magnetostatigraphy

In the early '70s the inversion of the Earth magnetic field was suggested as one of the possible causes of the mass extinction of planktonic Foraminifera at the end of the Cretaceous.

In spring 1973 Al Fischer and my self, and independently G. Napoleone one week later, closely cored across the K/Pg boundary at Gubbio for paleomagnetic analysis.

Both sets, oriented with different methods, were measured by Napoleone at Princeton.

It was recognized
First, the pelagic sediments of the Scaglia registered good, even weak,magnetic signals.

Second, the Scaglia pelagic limestones carried a record of the reversals of the magnetic field correletable with the oceanic magnetic anomalies.

Third, the K/Pg boundary was falling within the magnetic reversal C29r, in agreement with Sclater et al. (1973, Indian Ocean), and not in C26r as plotted in Heirtzler et al. 1968 scale.

Gubbio

Premoli Silva et al. 1974
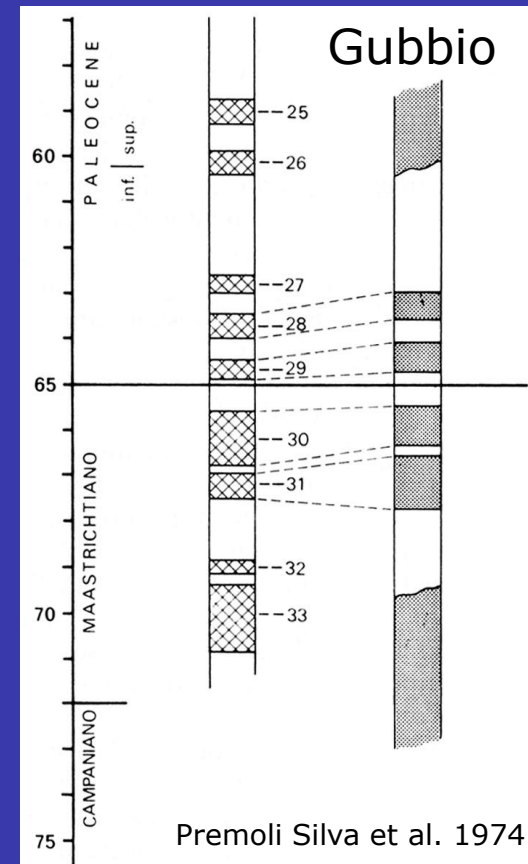
After these positive results, paleomagnetic analyses were extended from the Upper Cretaceous up to Paleocene. The initial group was joined by Alvarez, Arthur, Lowrie and Roggenthen, co-authors of the 5 basic papers published in 1977 (GSA Bulletin).

Oceanic Magnetic Anomalies

Lowrie & Alvarez 1977
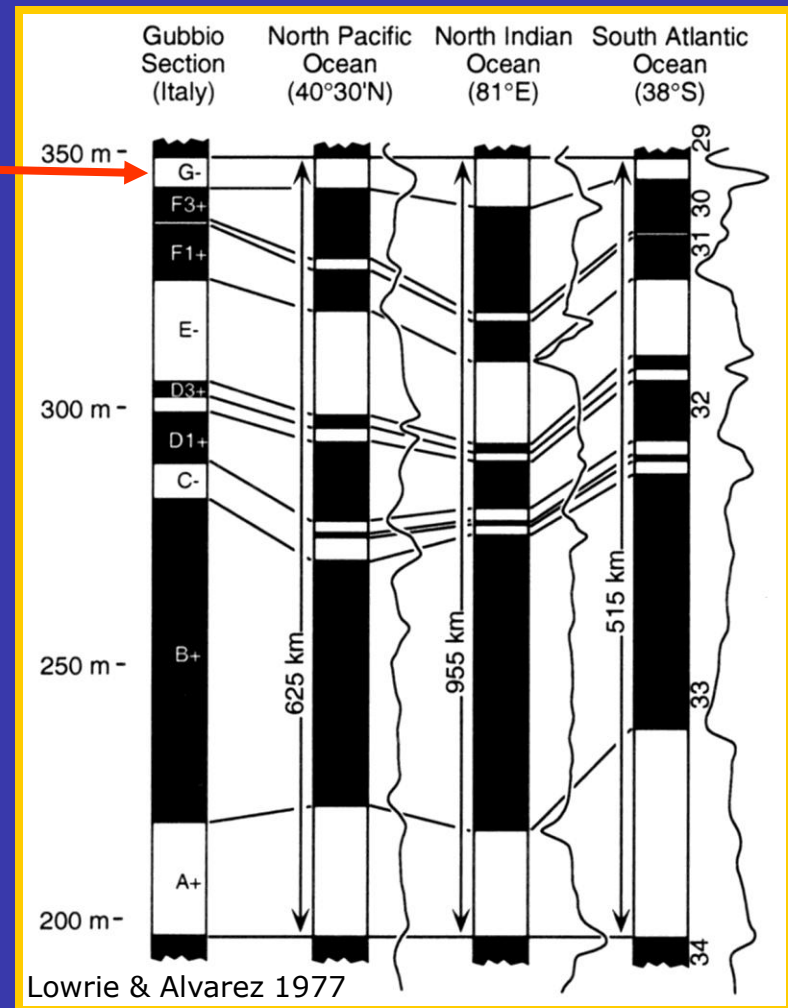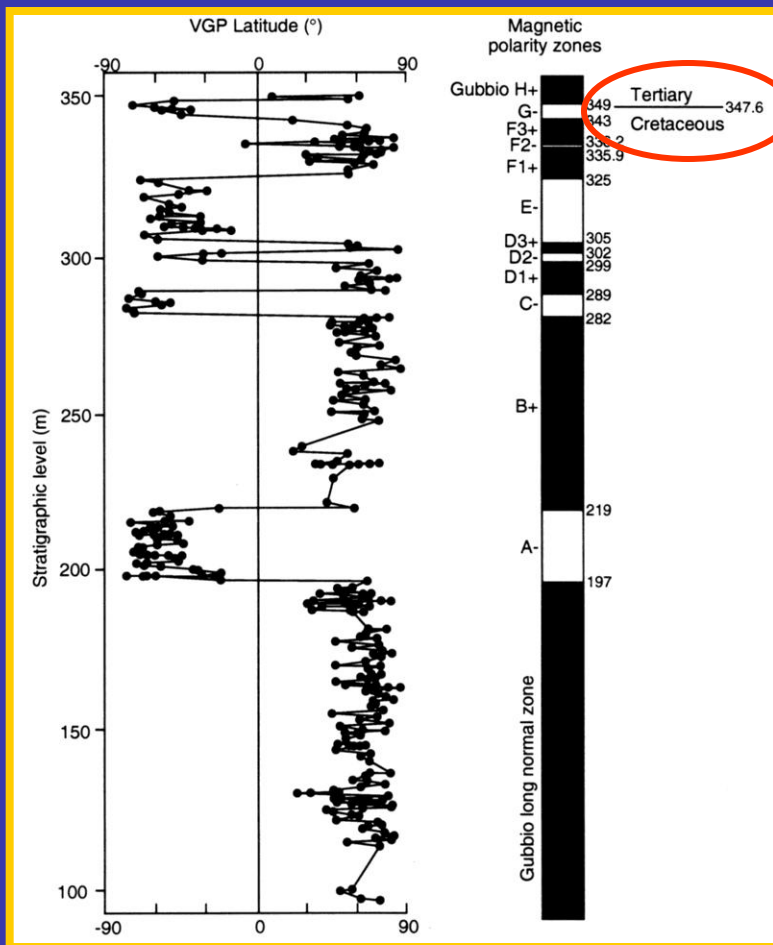
First integrated stratigraphy

The abundant planktonic foraminiferal content made it possible to date the magnetic reversals from 80 to 50 Ma, and subsequent studies of related pelagic sediments allowed the micropaleontological calibration (including also calcareous nannofossils) of more than 100 Myr of geomagnetic polarity stratigraphy, from ca. 137 (Early Cretaceous) to ca. 23 Ma (end of the Paleogene).

Lowrie et al. in 1982 presented the new GPTS for the whole Paleogene, merging the data from Gubbio with those from the close-by Contessa sections, that can be seen as the first integrated bio-magnetostratigraphy.

New GPTS of Paleogene

Lowrie et al. 1982

PALEOGENE GEOMAGNETIC POLARITY
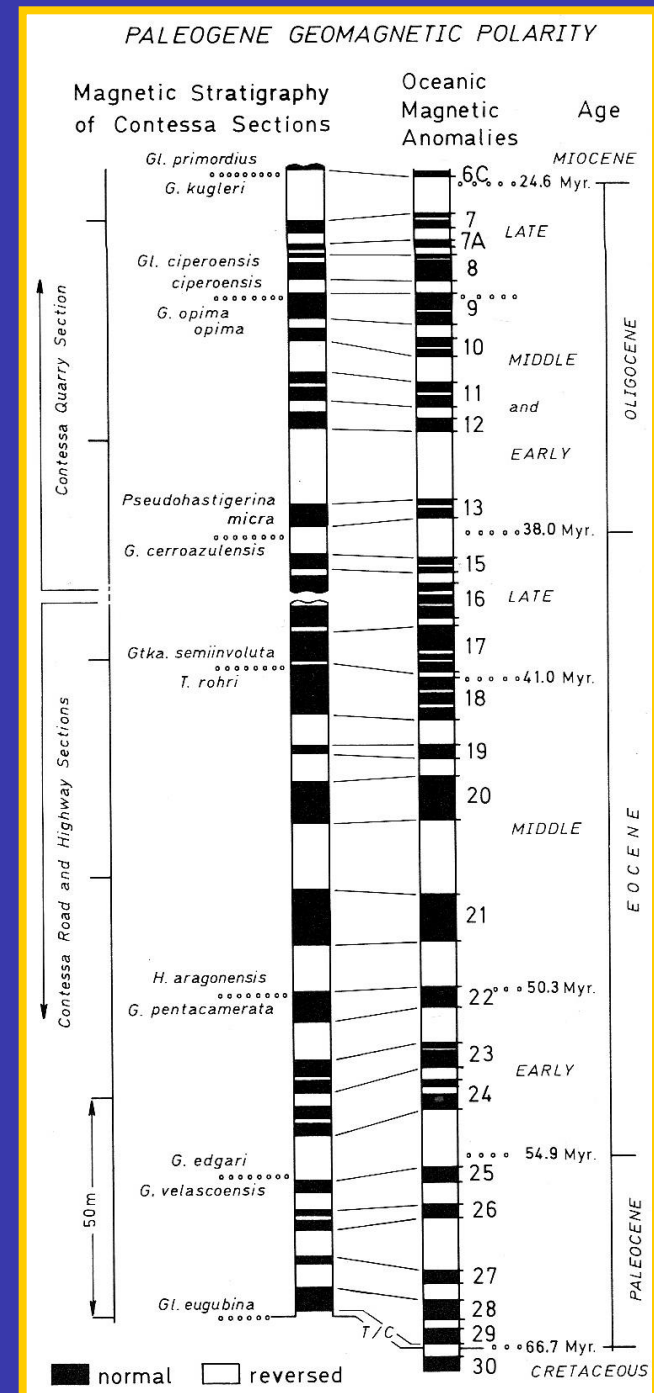
Updated integrated stratigraphy

In the '60s numerous planktonic foraminiferal local schemes have been generated from different basins and settings spanning the interval from Upper Cretaceous to Recent. Even though these biostratigraphic schemes were regarded as global within broad latitudinal belts, some degree of provincialism was also recognized in different ocean basins, the Mediterranean, and areas of upwelling. The state of the art for the Cretaceous and Paleocene-Eocene was first summarized by Caron and Toumarkine & Luterbacher in 1985, respectively (Plankton Stratigraphy).

Since 1985 the tropical/subtropical integrated zonation has been further refined, and partly modified, and rather recently could be precisely correlated to the Upper Cretaceous through Paleogene zonal schemes from southern Ocean-Austral realm through magnetostratigraphy (Huber, 1992; Petrizzo, 2000; Huber & Quillivéré, 2005). The updating process is still underway also including implementation of bio-magnetochronology calibration (see Poster on new Gubbio Cretaceous data).

Correlation of Cretaceous Zones across latitudes in the Atlantic realm

(Caron 1985)

Here the tropical zonation, extended down to the Hauterivian, incorporates data from the Tethys provided by Moullade (1966), Longoria (1974), and Sigal (1977) and from DSDP sites. To note that faunas at high latitudes are much less diversified.

Maastrichtian record at Maud Rise (Huber 1990)

Ge. havanensis, Ab. mayaroensis, Ab. intermedius, Gr. subcircumnodifer (from left to right)

Comparison of zonal schemes from Tethys, Transitional (NW Australia) and Austral Provinces (Huber 1990; calcareous nannofossils by Wind & Wise 1983)

		Bolli (1957a,b,1966), Premoli Silva & Bolli (1973), this volume	Krasheninnikov (1965, 1969)		Hillebrandt (1974)	Blow, 1969 Berggren & van Couvering (1974)		Blow (1979)	
EOCENE	Late	T. cerroazulensis s. l.	G. corpulenta		G. cerroazulensis	P 17	G. gortanii/G. centralis	P 17	G. g. gortanii/G. (T.) centralis
						P 16	C. inflata	P 16	C. inflata
		G. semiinvoluta			G. semiinvoluta	P 15	G. mexicana	P 15	P. semiinvolutus
	Middle	T. rohri	T. rohri		T. rohri	P 14	T. rohri - G. howei	P 14	G. (M.) sp. spinulosa
		O. beckmanni	H. alabamensis		O. beckmanni	P 13	O. beckmanni	P 13	G. beckmanni
		M. lehneri	A. rotundimarginata		G. lehneri	P 12	G. lehneri	P 12	G. (M.) lehneri
		G. s. subconglobata	A. bullbrooki	G. kugleri	G. s. subconglobata	P 11	G. kugleri	P 11	G. kugleri/S. frontosa boweri
		H. nuttalli		H. aragonensis	H. aragonensis	P 10	H. aragonensis	P 10	S. f. frontosa/G. (T.) pseudomayeri
	Early	A. pentacamerata	G. aragonensis	A. pentacamerata	G. caucasica	P 9	A. densa	P 9	G. (A.) aspensis/G. lozanoi prolata
					G. palmerae				
		M. aragonensis		G. aragonensis	G. aragonensis	P 8	G. aragonensis	P 8 b	G. (M.) aragonensis/G. (M.) formosa
		M. formosa formosa	G. subbotinae	G. marginodentata	G. formosa/A. angulosa	P 7	G. formosa	a	G. (M.) formosa/G. (M.) lensiformis
		M. subbotinae			G. lensiformis	P 6 b	G. subbotinae/P. wilcoxensis	P 7	G. (A.) wilcoxensis berggreni
		M. edgari		G. subbotinae	G. marginodentata/G. subbotinae				
PALEOCENE	Late	M. velascoensis	G. velascoensis	G. velascoensis	G. velascoensis	P 6 a	G. velascoensis/G. subbotinae	P 6	G. (M.) s. subbotinae/G. (M.) velascoensis acuta
						P 5	G. velascoensis	P 5	M. s. soldadoensis/G. (M.) velascoensis pasionensis
		P. pseudomenardii		G. pseudomenardii	G. pseudomenardii	P 4	G. pseudomenardii	P 4	G. (G.) pseudomenardii
	Middle	P. pusilla pusilla	G. angulata	G. conicotruncata	G. pusilla	P 3	G. pusilla/G. angulata	P 3	G. (M.) a. angulata
		M. angulata		G. angulata	G. angulata				
		M. uncinata	A. uncinata		G. inconstans/G. uncinata	P 2	G. uncinata/G. spiralis	P 2	G. (A.) p. praecursoria
	Early	M. trinidadensis	G. triloculinoides/ G. pseudobulloides		G. trinidadensis	P 1 d	G. compressa/G. inconstans/ G. trinidadensis	P 1 b	G. (T.) c. compressa/E. eobulloides simplissima
		M. pseudobulloides				c	G. pseudobulloides	a	G. (T.) pseudobulloides/G. (T.) archaeocompressa
			E. eobulloides		G. edita	b	G. triloculinoides		
						a	G. eobulloides	Pα	G. (T.) longiapertura
		G. eugubina				M 18			R. hexacamerata

Correlation of major Paleocene and Eocene zonal schemes
(Toumarkine & Luterbacher 1985)

Correlation between Paleocene tropical integrated stratigraphy and planktonic foraminiferal zonation for Austral Province (Huber & Quillivéré 2005)

Correlation between Eocene tropical integrated stratigraphy and planktonic foraminiferal zonation for Austral Province (Huber & Quillivéré 2005)

Correlation between Oligocene tropical integrated stratigraphy and planktonic foraminiferal zonation for Austral Province (Huber & Quillivéré 2005)

Paleoceanographic Reconstructions

Paleoceanography could develop thanks to the recovery, since 1968, of several thousand of cores from over 1000 holes drilled in all oceans by the DSDP, ODP and IODP projects

The study of this practically continuous record of pelagic sediments, mainly unconsolidated, from all latitudes, especially from Upper Cretaceous to Holocene, 1) allowed to refine planktonic foraminiferal biostratigraphy, along with other fossil groups, at high, sometimes very high, resolution, and 2) for the better preservation of the organisms facilitate the identification and updating their taxonomy.

For the Paleogene and Cretaceous reconstructions we started from the assumption that these extinct organisms lived in the water column like their modern counterpart and were controlled by similar environmental factors (water temperature, water-mass structure, amount of nutrients, stability/instability of oceanographic conditions)

Modern planktonic Foraminifera

* Planktonic Foraminifera, inhabiting the "mixed" layer today, characteristically decrease in number from the tropics toward the high latitudes and, in general, are absent in polar waters. The decrease in species richness from tropics to high latitudes is reflected in the planktonic foraminiferal assemblages which progressively loose the less tolerant species (*k*-selected strategists), characterized by complex morphologies, and become dominated by the most tolerant, cosmopolitan and opportunistic taxa, characterized by small-sized, simple morphologies.

* Similar patterns characterize intensifying upwelling regimes. Diversity decreases with increasingly less stable conditions in the upper water column. As a consequence, stratification decreases or disappears in these areas as do the ecological niches. When conditions are extreme, the assemblages are dominated by a single species: *Globigerina bulloides* in the meridional upwelling areas (Kroon & Ganssen, 1988) and *Neogloboquadrina pachyderma* in the Polar bioprovinces.

In the geologic past

Planktonic Foraminifera, recorded since the Middle Jurassic, underwent 3 main radiations. Two of them occurred in the Early Cretaceous, in the earliest Valanginian and earliest Albian, respectively, while the third one coincides with the earliest Paleocene.

Each radiation is characterized by a progressive increase in diversity at a genus and species levels associated with increasing overall size and shell complexity, and is truncated by a major extinction event. Within each evolutionary trend there are subtle to marked replacements of the old taxa that become extinct by originations of new ones.

Major Evolutionary Trends

*Primitive forms are of small size (< 75 μm), with globular chambers and globigeriniform coiling

* Simple morphotypes increase only slightly in size (max 200/250 microns)

* Some simple morphotypes give rise to forms with planispiral coiling mode that increase mainly moderately in size

* Some simple morphotypes give rise to forms with globorotaliiform coiling and various types of ornamentations, that may increase markedly in size

* Peripheral profile modifies from rounded (subspherical chambers), to subangular, subacute, angular, to keeled

Paleogene of the Atlantic Ocean

Based on the knowledge acquired on modern taxa, we looked at the changes in morphological characters *vs* assemblage composition through time and latitudes.

The firststudies, rigorously quantitative per size fractions (>40, >150, >250 μm), have been conducted in the '70 on the Paleogene of the Atlantic Ocean, the interval with the best latitudinal coverageat that time. From the areal distribution and variations in assemblage composition through time we identified the biogeographic indices, then the paleoclimatic ones, from which we reconstructed the paleoceanographic evolution

DSDP and ODP Sites, commercial wells, piston cores, and land sections studied for the Paleocene to Oligocene interval in he Atlantic Ocean

Paleocene assemblages comprise a number of new morphologies displaying new wall textures & ornamentation, unknown in the Cretaceous, some of which are still present in modern taxa.

Premoli Silva & Boersma 1988

Muricate - nonspinose

Acarinina angulosa

Morozovella velascoensis

Spinose cancellate

Subbotina triloculinoides
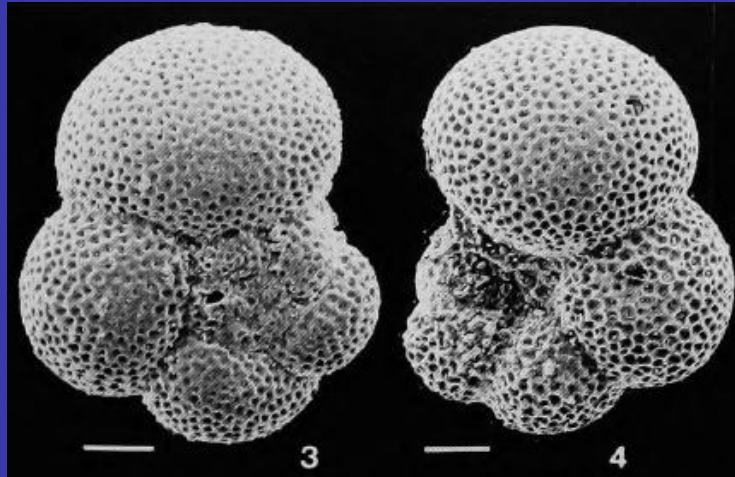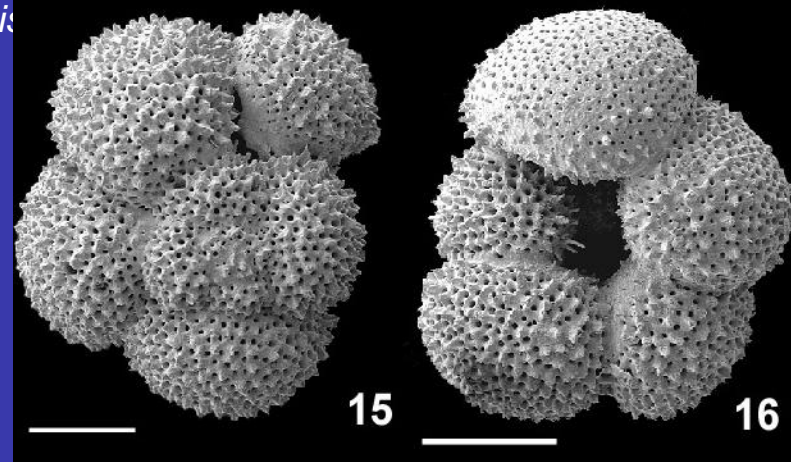
Parasubbotina pseudobulloides

Smooth nonspinose
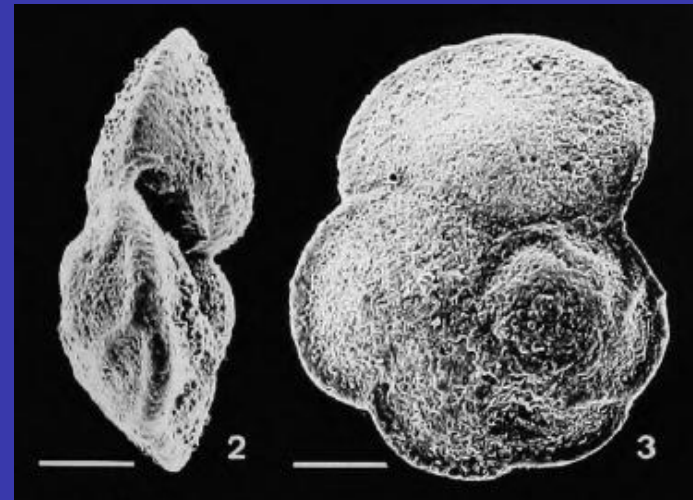
Globanomalina pseudomenardii

Wall textures

Paleogene Principal Component Analysis Data
65 to 38 Ma (Haq et al. 1977)
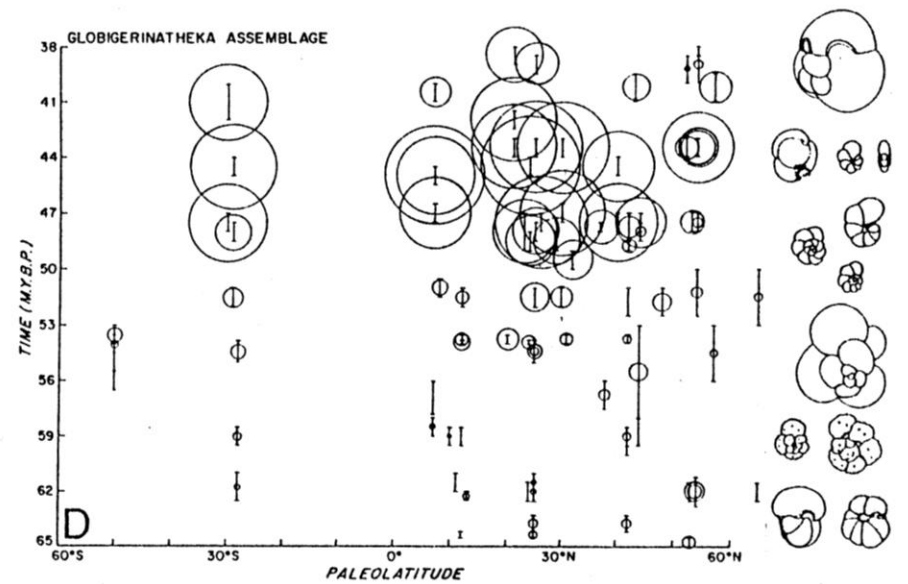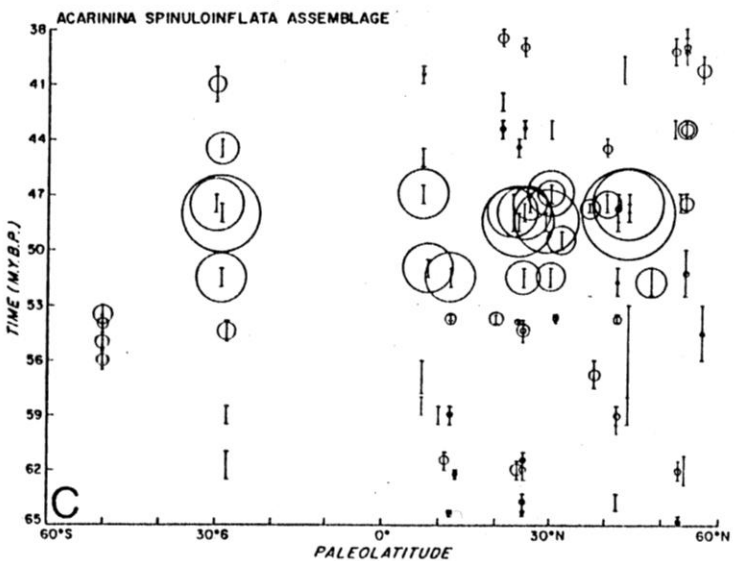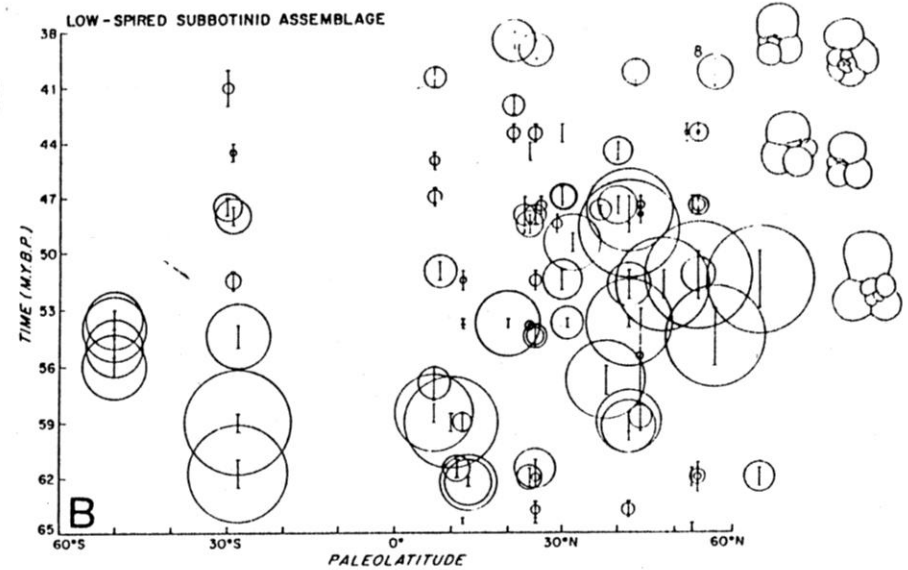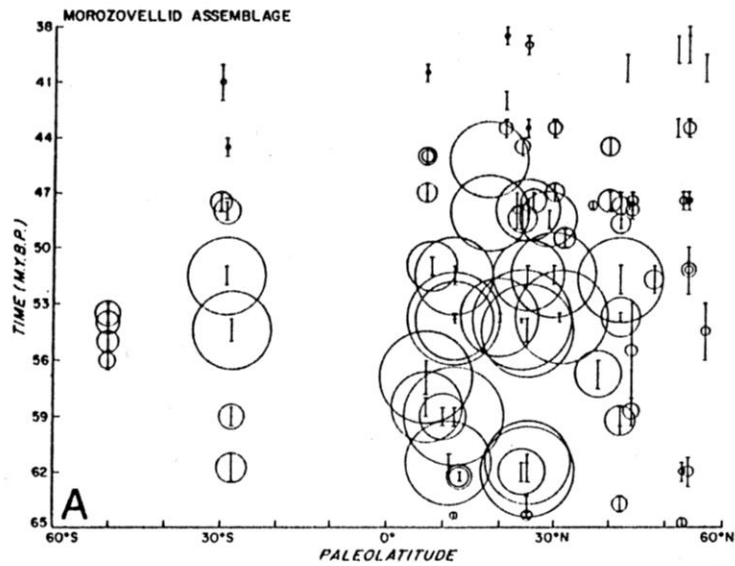
Synthesis of migration patterns of calcareous plankton during the Paleogene in the Atlantic Ocean.

2° Paleo-oceanographic Conference, Edinburgh 1976

NANNOFLORAL MIGRATIONS

COOLING
WARMING

FORAMINIFERAL MIGRATIONS

COOLING
WARMING

TIME (Ma)
PALEOLATITUDE

>20% PALEOCENE HIGH-LATITUDE NANNO ASSEMBLAGE
>15% EOCENE HIGH LATITUDE NANNO ASSEMBLAGE
>30% EOCENE LOW-LATITUDE NANNO ASSEMBLAGES
>20% OLIGOCENE HIGH-LATITUDE NANNO ASSEMBLAGES
>15% OLIGOCENE LOW-LATITUDE NANNO ASSEMBLAGE
>50% PALEOCENE-MID. EOCENE MID-LAT. L.SP. SUB. ASSEMBLAGE
>40% PALEOCENE-MID EOCENE LOW-LAT. MOROZOVELLID ASSEMBLAGE
>25% MID.EOCENE-OLIGOCENE HIGH-LATITUDE GLOBIGERINID ASSEMBLAGE
>30% OLIGOCENE LOW-LATITUDE GLOBOQUADRINID ASSEMBLAGE

Haq et al. 1977

Planktonic Foraminifera per latitude during the Eocene (Premoli Silva & Boersma 1988)

Cambridge 1989

E. Vincent A. Boersma E. Thomas Isabella P. Hallock
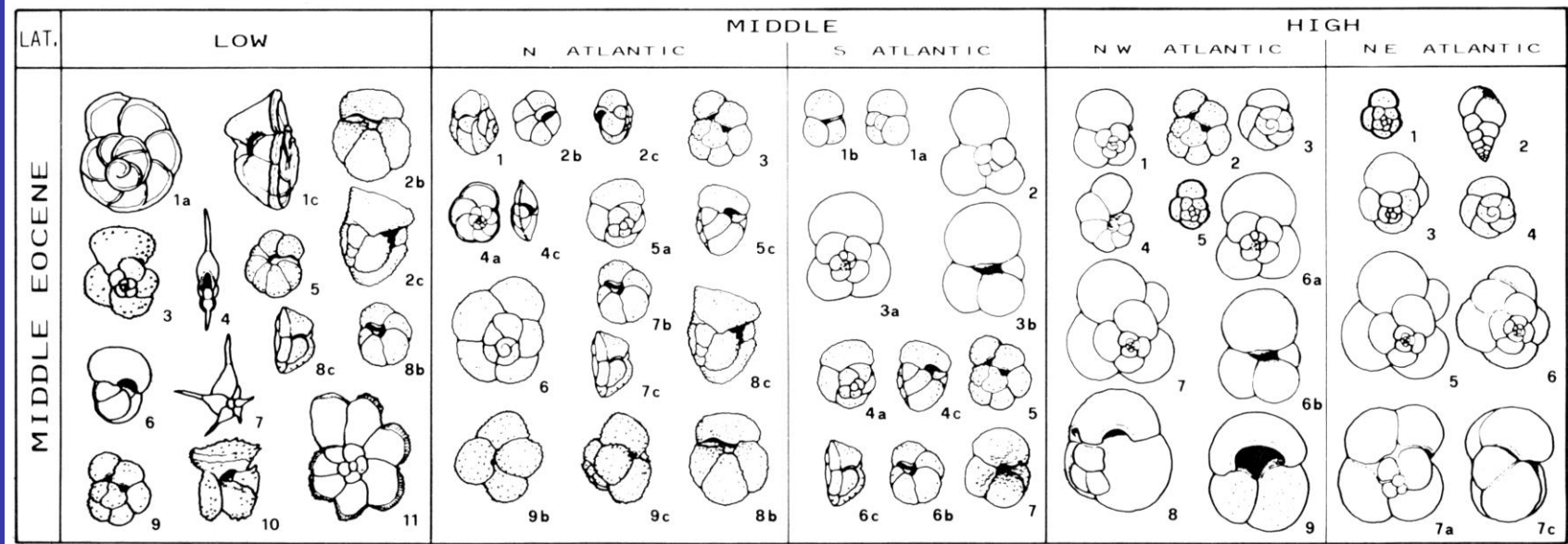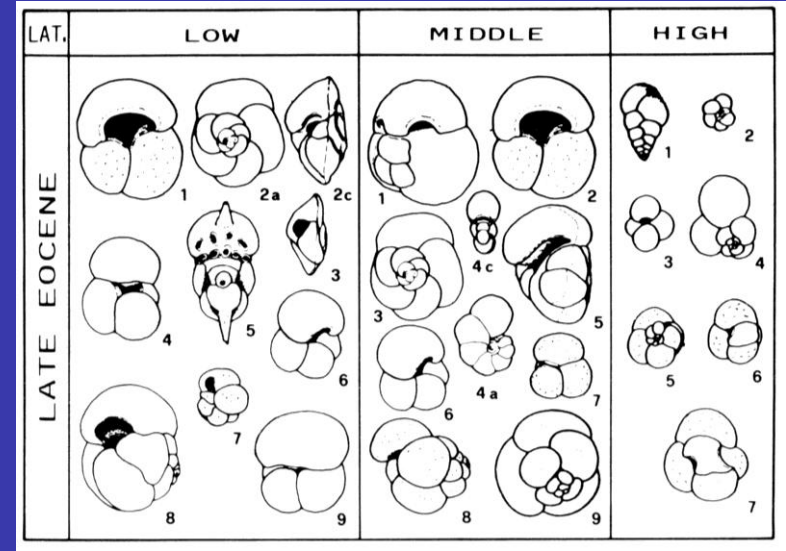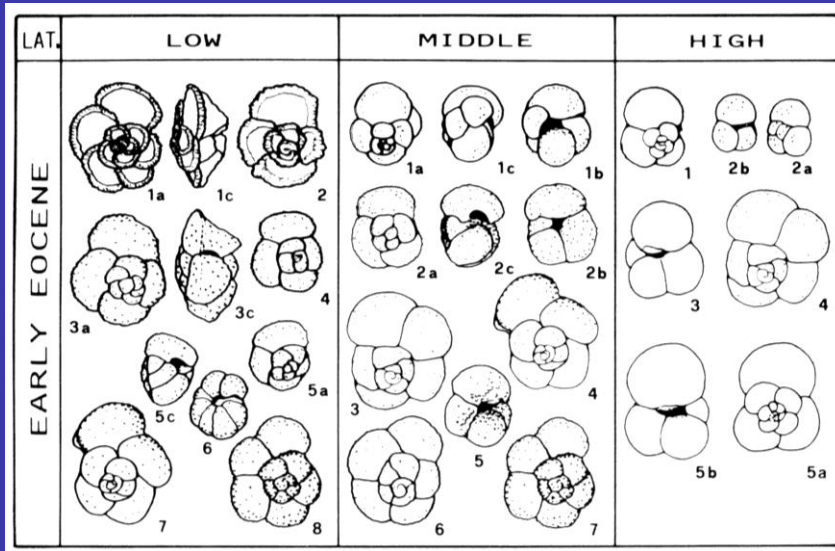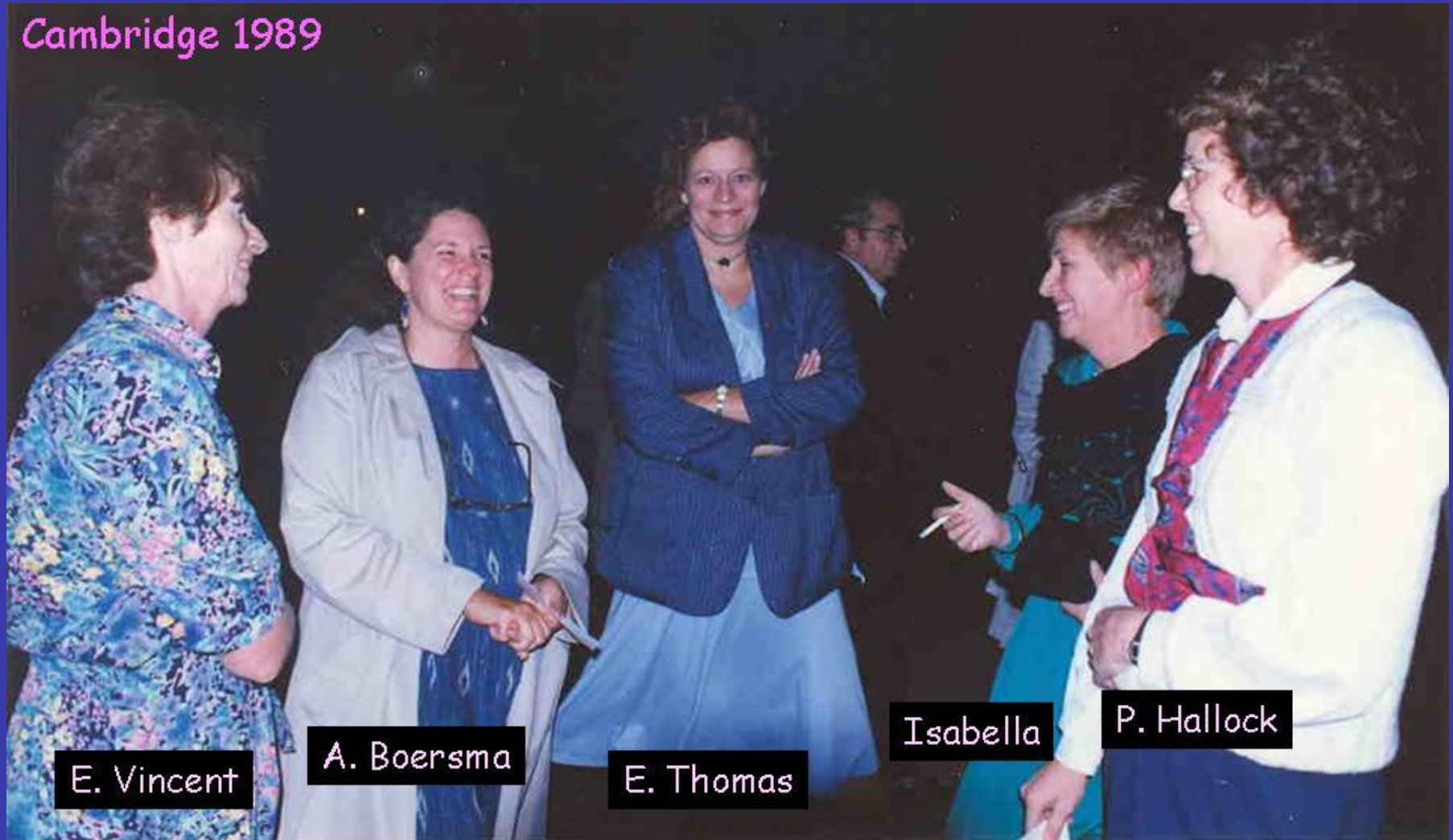
The Ocean of the Paleogene Symposium, at the 3° Paleoceanographic Conference

In terms of climatic evolution,

* the Paleocene is a period of climate increasingly warmer as suggested by the rapid evolution of the *k*-strategists (= muricate taxa)

* the Thermal Maximum occurs across the Paleocene/Eocene boundary as indicated by the maximum diversity within the *k*-strategists

* after the Early Eocene Climatic Optimum the temperature gradually decreases and the climate becomes less uniform; some proto-bioprovinces started to differentiate especially in the southern Hemisphere

based on benthos

Zachos et al. 2001
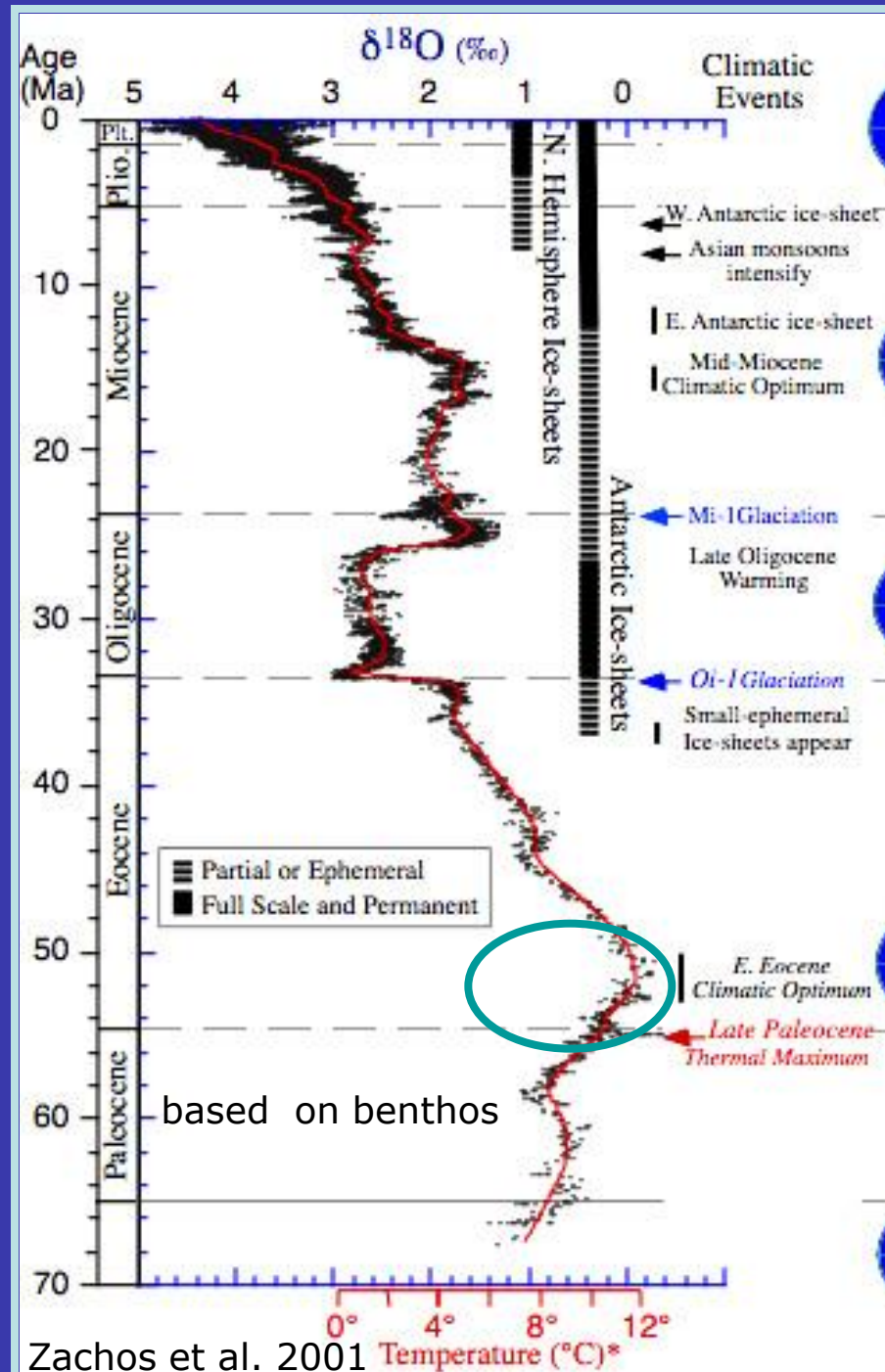
In terms of climatic evolution,

In the middle Eocene new intermediate taxa gradually appear and subordinately some *r*-strategists along with few *k*-strategists (muricates) resulting in the maximum diversity of the whole Cenozoic (> 50 species).

At the end of the Middle Eocene there is a drastic change within the assemblages: most of the *k*-strategists become extinct whereas the *r*-strategists or *r*-intermediates proliferate

The Eocene/Oligocene boundary coincides with the definitive extinction of the survived *k*-strategists.

Zachos et al. 2001
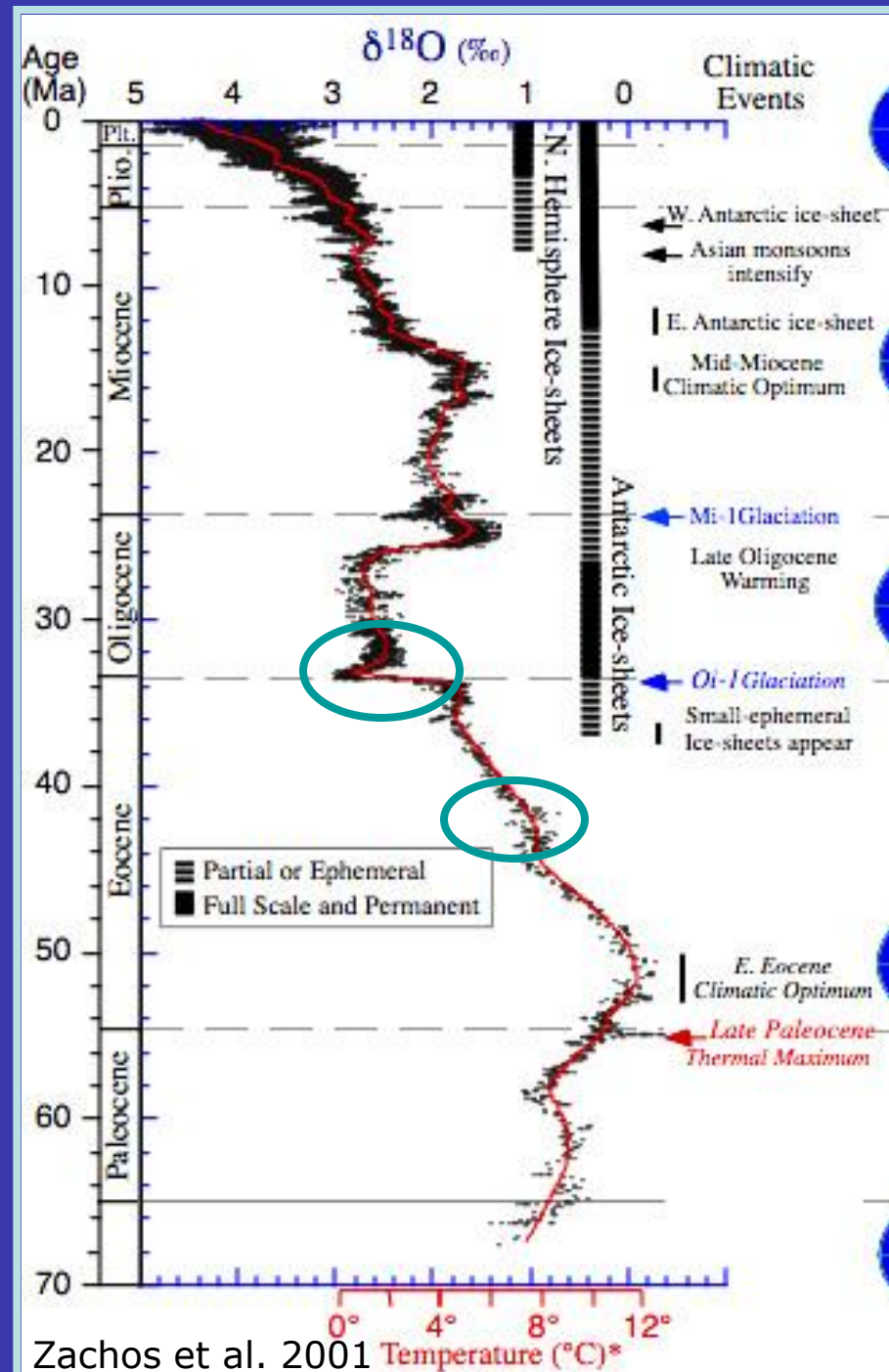
Cretaceous Reconstructions

The climate during the Cretaceous, a time interval ca 75 Myr long, has been globally warm, though not uniform, with temperature (T°) gradients from surface to ocean floor, thus from low to high latitudes, much less contrasted than in modern oceans.

Preliminary paleoceanographic reconstructions were based on Albian to Maastrichtian planktonic foraminiferal evolution from the remarkably continuous pelagic successions from central Italy (Wonders 1980; Premoli Silva & Sliter 1995). The record was subsequently extended in 1999 to the lower Valanginian (= 1° radiation) by incorporating the paleontological results from the Rio Argos (SE Spain; Coccioni & Premoli Silva 1994) and Gorgo a Cerbara (c. Italy; Coccioni et al. 1992; Cecca et al. 1994) sections.

The deep-sea record (DSDP, ODP) for the Cretaceous is much more limited and discontinuous than in the Paleogene. However, some ODP campaigns provided a discrete latitudinal coverage from the Antarctic margins to the northern high middle-latitudes (Hart 1980; Huber 1990, 1991; Leckie 1990; Haig 1992; Wonders 1992; Petrizzo 2000, 2001).

Upper Cretaceous Bio- Magnetostratigraphy of the Bottaccione section

Premoli Silva & Sliter 1995
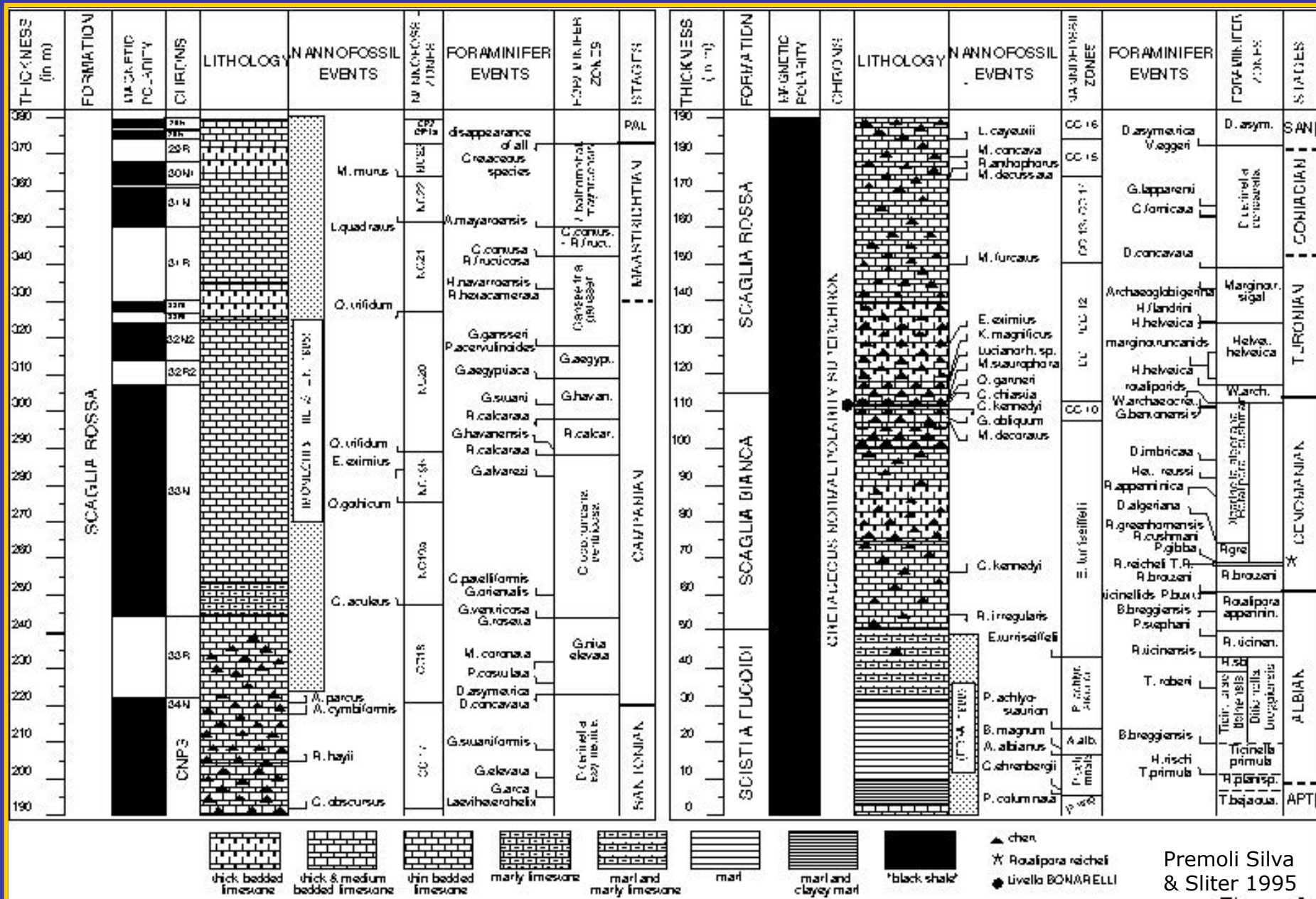
With Bill Sliter at Ristorante Bottaccione relaxing during sampling

Cretaceous Reconstructions

During the two important Cretaceous radiations (earliest Valanginian & earliest Albian) planktonic foraminifera overall increase remarkably in size and acquire very characteristic morphologies much more complex than in the Paleogene, especially in the second radiation.

As for the Paleogene, we looked first at the morphological evolution, then from the areal distribution and variations in assemblage composition through time and latitudes we identified the biogeographic and paleoclimatic indices, from which we reconstructed the paleo-oceanographic evolution.
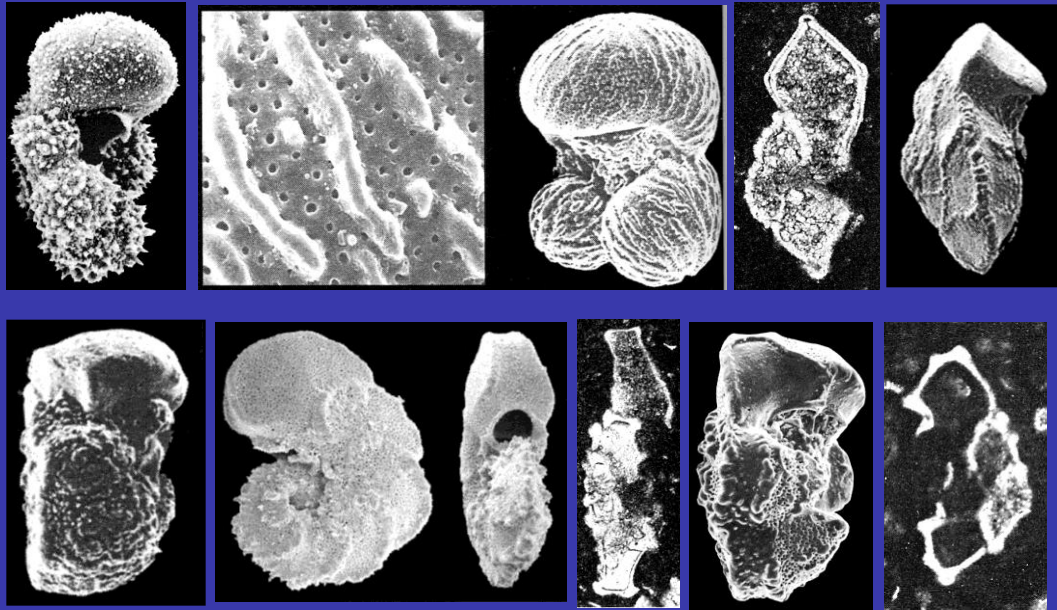
Examples of characteristic ornamentations (pustules, costellae, single and double keels)

Species Richness

Both Cretaceous Radiations initiate with few tiny species. Maximum diversity is reached in the lower upper Aptian and in lower Maastrichtian, respectively.

Planktonic Foraminifera evolved rapidly in some intervals, slower in others, allowing in any way to reconstruct a biostratigraphic scale at rather high resolution especially at low latitudes.

Premoli Silva & Sliter, 1999

Species richness
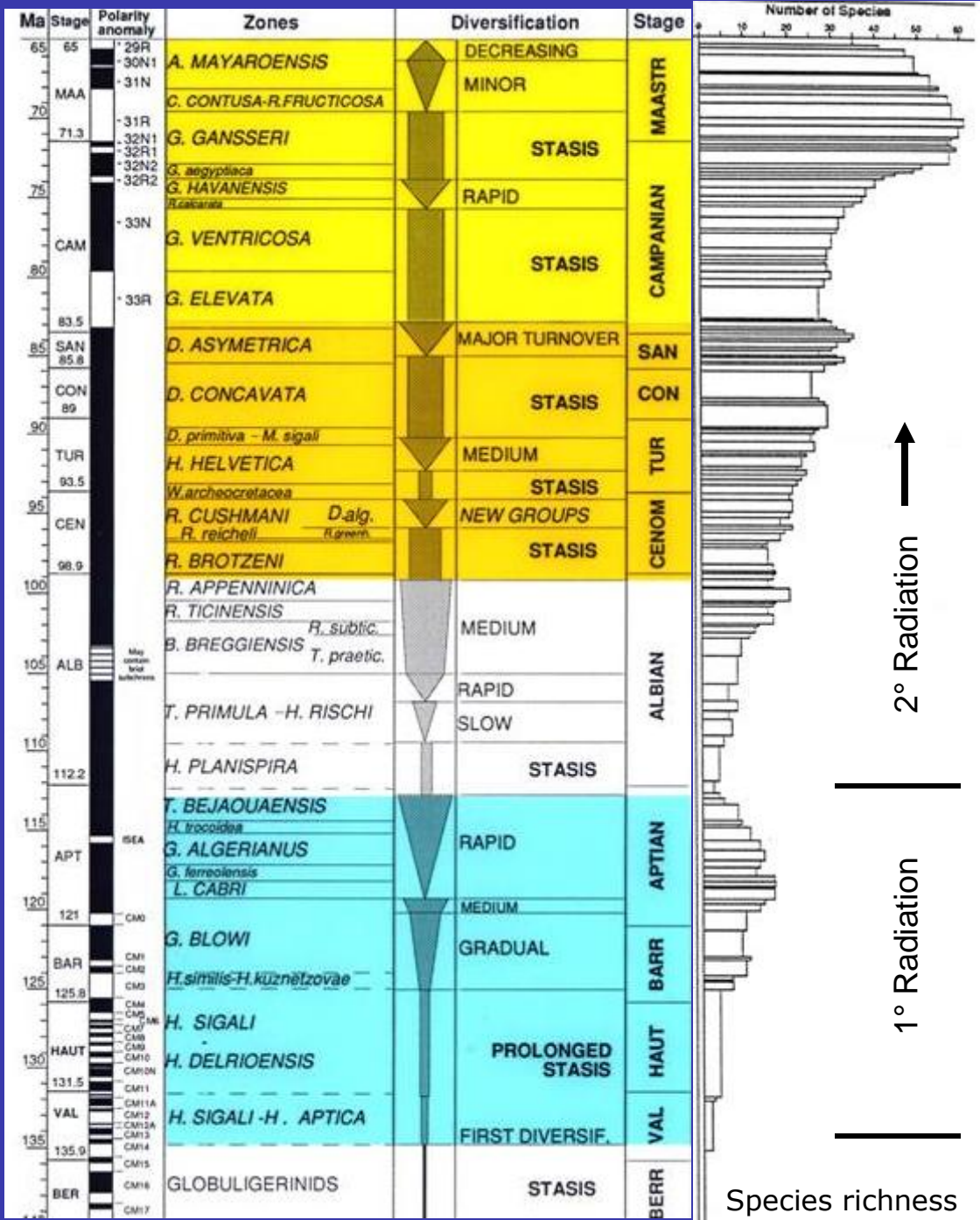
The Aptian/Albian boundary

Planktonic foraminiferal assemblage marking the initiation of the 2nd Radiation (Aptian/Albian) is composed of tiny primitive morphotypes.

The wall is changing from finely perforate and possessing perforation cones in the Aptian to microperforate and smooth then normally perforate and muricate in the Albian (Huber & Leckie 2011; Petrizzo et al. 2012).

Smooth & microperforate
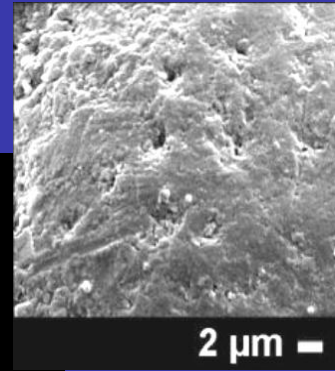
Early Albian
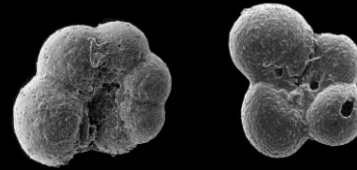
Late Aptian
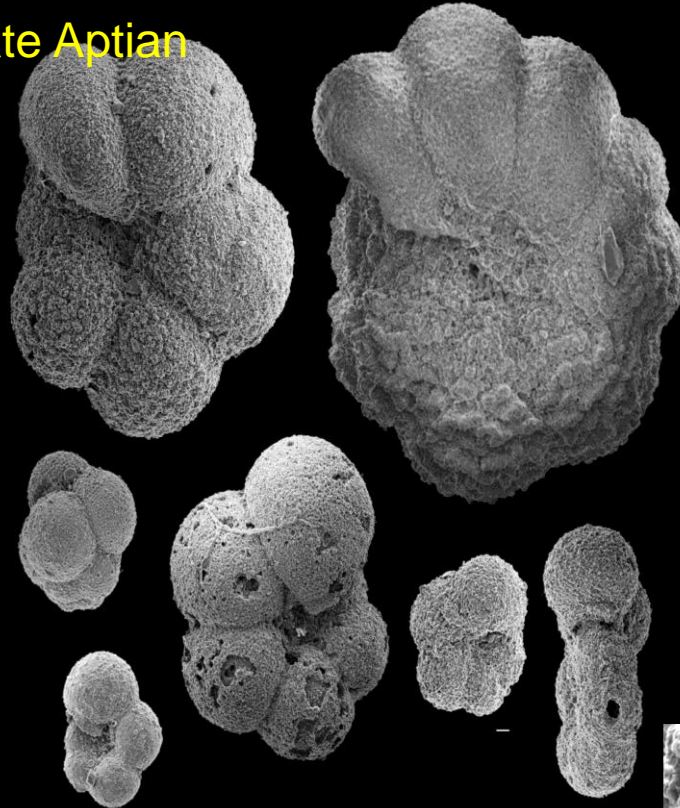
Perforation cones
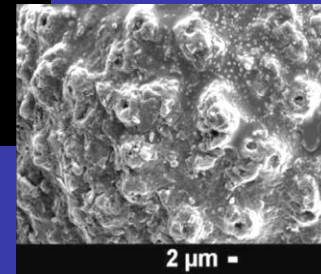
Courtesy of Petrizzo 2014

Abundance and distribution of genera based on life-strategy during the Cretaceous

To note that the true k-strategists appear only in the Late Albian

r-k strategists

K-mode specialists

r/K-mode intermediate forms

r-strategists <-----------> k-strategists
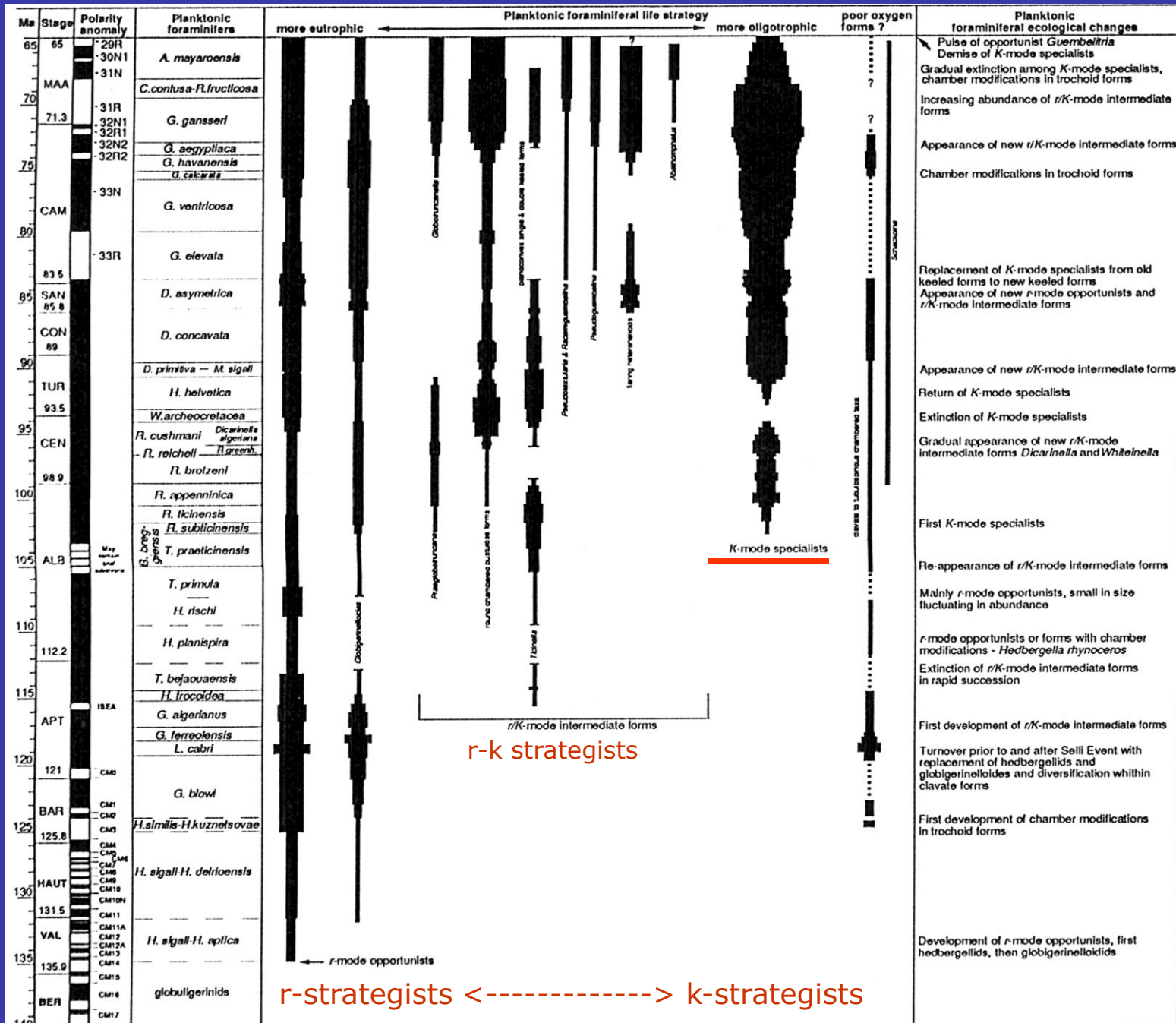
Spatial distribution and abundance

*Diversity decreases from tropics to high latitudes

*Small-sized, opportunistic taxa (*r*-strategists) are ubiquitous including in upwelling areas

*Species disappearing toward the high latitudes are the larger-sized, more-ornamented *k*-strategists

*The occurrence of *k*-strategists at higher latitudes indicates the expansion of warmer conditions at a given time

*Intermediate morphotypes occupy intermediate habitats, with the most ornamented ones closer to the tropics and viceversa

*From $\delta^{18}O$ values it is proved that Cretaceous planktonic Foraminifera lived at different depths within the water column

Cretaceous Cyclostratigraphy

Gilbert in 1895 suggested that rhythmical repetition of patterns in the sequences of strata correspond to orbital variations and could provide a chronology of Earth history.
In early '80s it was demonstrated that limestone-shale couplets represented the sedimentary expression of the Earth's precession (19-23 kyr), while their grouping into bundles records the orbital eccentricity cycle (100 kyr) (i.e. Schwarzacher & Fischer 1982; de Boer 1982).

Mid-Cretaceous sediments of the Umbria-Marche basin show picturesque chromatic variations which appear rhythmic at first sight.

Drilling the Piobbico core, April 1982

Cretaceous Cyclostratigraphy

In order to pursue studies of rhythmicity in more detail, a core, 84-m long, was cut near Piobbico through the Aptian-Albian Fucoid Marls in 1982. The entire core was photographed, logged for lithology and chromatic variations, dated by calcareous plankton (nannos & forams) at 1-cm scale using a continuous set of acetate peels (Erba 1986, 1988; Tornaghi et al. 1989).

A pilot study was conducted on 8-m long core segment in the Albian: rhythmicity in color variations and CaCO3 content resolved the Milankovitch frequencies of 18 to 23 kyr precessional cycles, that could be grouped in bundles (100 kyr) and superbundles (405 kyr) (Herbert & Fischer 1986).
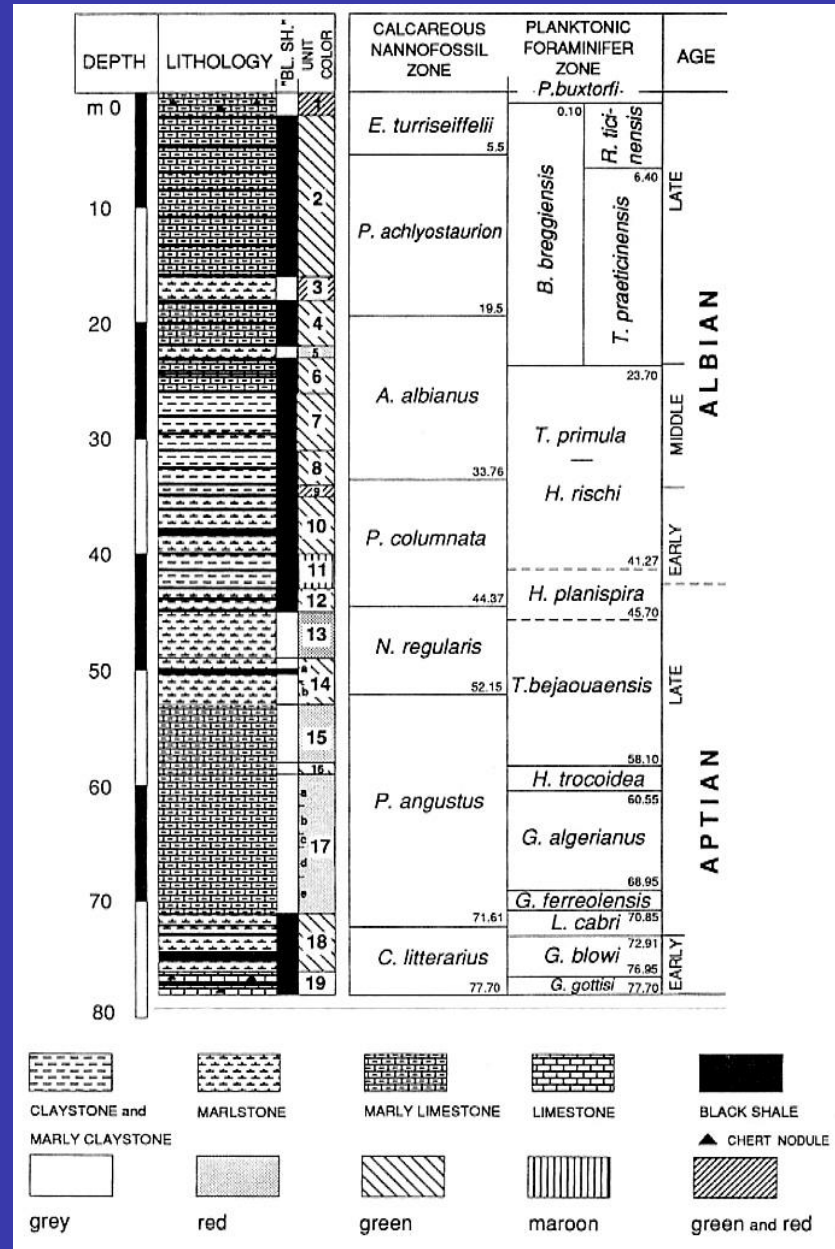
Piobbico core Log
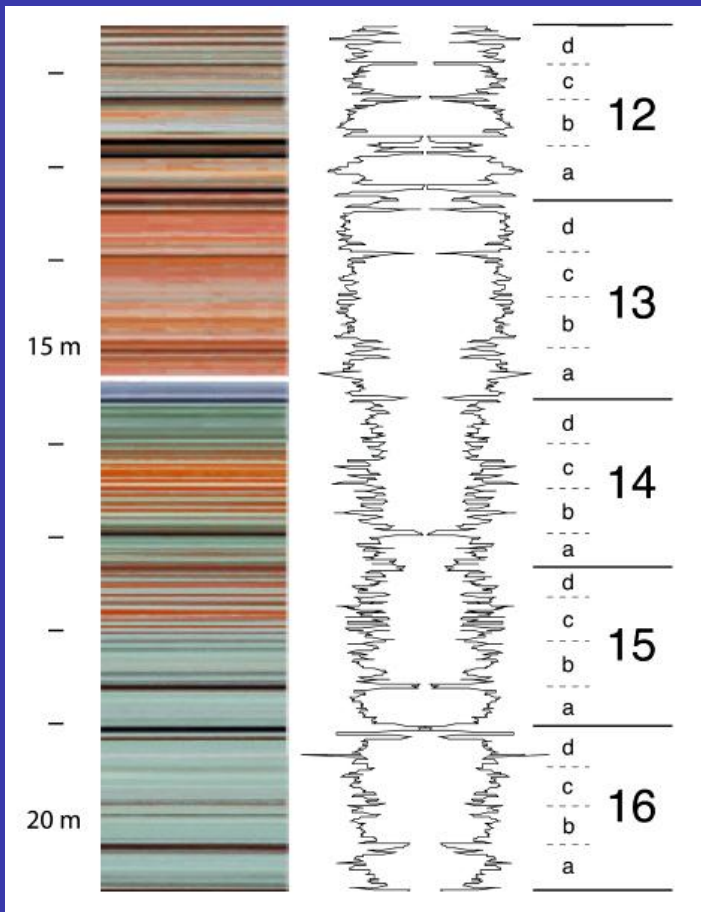
Grippo et al. 2004

Bill Sliter, me, Giovanni Napoleone, John Tarduno & Tim Herbert checking on outcrop the 8-m long rhythmic segment of the Piobbico Core, Albian Fucoid Marls at Le Brecce.

Lisa Pratt

Tim Herbert

me

Giov. Napo-leone

Elisabetta Erba

& Al Fischer

Piobbico Core Team, 1982

Surprisingly, the distribution of planktonic Foraminifera through the pilot segment at 1-cm scale did not reveal any relationship either in abundance of specimens or rhythmicity in faunal composition to the CaCO3 cyclicity.
A new investigation at 1-mm scale was conducted using photomicrographs of the acetate peels. Foraminiferal distribution at 1-mm scale resolves the Milankovitch frequencies of 41 kyr and 18 to 23 kyr, equated with obliquity and precessional cycles. But foraminiferal abundance is not in phase with carbonate content, which was largely controlled by calcareous nannofossils, but peaked at intermediate carbonate values (Premoli Silva et al. 1989). Based on the five long eccentricity cycles recognized the pilot segment represents in time ca 2 Myr.

Conclusions

* Major and minor changes in the evolution of Cretaceous planktonic Foraminifera correspond to coeval changes in the hydrosphere

* Increases in diversity, size and morphological complexity through time identify an increasing number of trophic niches within the mixed layer and the onset of at least a weak thermocline

* The early planktonic foraminiferal assemblages comprise only small-sized opportunistic taxa, *r/k* intermediate taxa start to evolve in the Aptian, while specialized,morphological complex keeled taxa evolve in the late Albian and persist although with different genera until the end of the Cretaceous

* These general evolutionary patterns are interrupted by one major event at the Aptian/Albian boundary (faunal extinction), one minor one at the C/T boundary (rotaliporid extinction) and a major turnover in the Santonian, all events that parallel paleoenvironmental changes

Conclusions

* Throughout the Cretaceous water masses were more uniform than today even during the coolest interval of the Early Cretaceous and water temperatures through the water column were overall much higher than in modern oceans.

* Highest surface water T° are recorded in the latest Albian and across the C/T boundary, equated to the peak of the "greenhouse" world. The remain of the Late Cretaceous is characterized by a progressive cooling accompanied by increasing seasonal climatic contrast that resulted on the onset of bioprovinces in Campanian-Maastrichtian time.

* If the onset of bioprovinces resulted in an ocean's structure very similar to the present, however, the still low thermal equator-to-pole gradient and the overall higher T° of the water masses indicate the absence of a cold, deep-water source in Cretaceous polar region as well as of a true polar bioprovince being planktonic foraminiferal assemblages much richer in species than the modern, almost monospecific one.

Conclusions

* Similarly to the Cretaceous Paleogene water masses were more uniform than today even when water temperature started to decrease in late Early Eocene, as water temperatures through the water column were overall much higher than in modern oceans.

* The abundance and great diversity among the complex *k*-strategists suggest that the Cretaceous, especially the Late Cretaceous, and mid Paleocene-Middle Eocene interval overall were characterized by a warm, equable climate.

* The strong decrease, then extinction of *k*-strategists from the Middle/Late Eocene boundary indicate a climate deterioration. However, even in the coldest intervals of the Oligocene the diversity at high latitudes was high compared to the almost monospecific assemblage recorded since the mid-late Miocene.
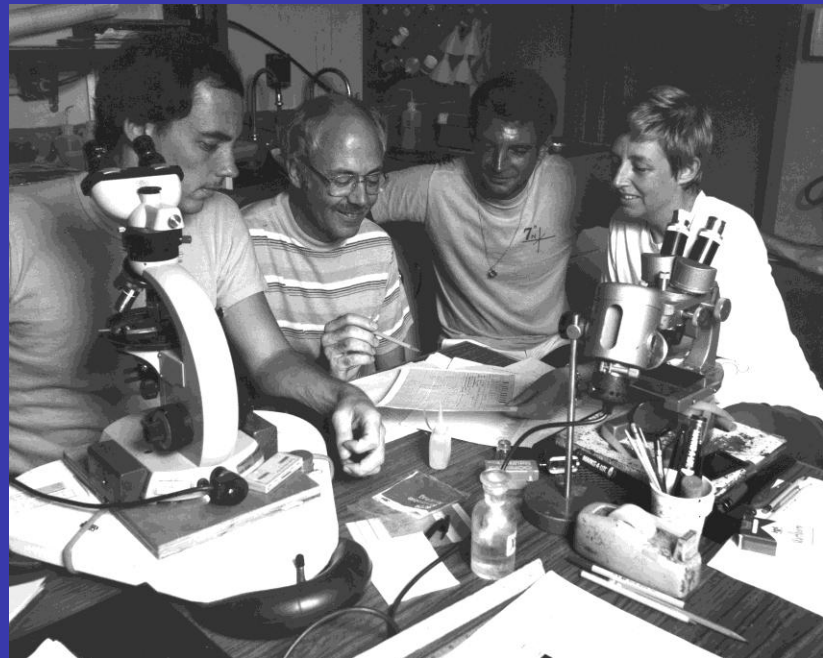
JOIDES Resolution ODP Leg 198, Shatsky Rise, NW Pacific, September 2001

Jim Zachos & me

Hans Bolli & me looking at the drill-bit damaged during reentry, GLOMAR Challenger DSDP Leg 15, Caribbean, January 1970

Paleontologists in action (Jim Bergen, Bill Sliter, André Schaaf & me), GLOMAR Challenger DSDP Leg 89, western Pacific, October 1982

Lastly,

I would like to warmly thank the many friends and colleagues who have accompanied me in this long scientific adventure, especially Maria Bianca Cita, my mentor, HansPeter Luterbacher, Walter Alvarez, Mike Arthur, Bill Berggren, Anne Boersma, Hans Bolli, Tim Bralower, Michèle Caron, Rodolfo Coccioni, Al Fischer, Simone Galeotti, Pamela Hallock, Bilal Haq, Tim Herbert, Brian Huber, Mark Leckie, Pat Lohman, Bill Lowrie, Simonetta Monechi, Giovanni Napoleone, Lisa Pratt, Maurizio Ripepe, Sy Schlanger, Nick Shackleton, Bill Sliter, Dave Watkins, and last, not least, my closest friends & collaborators from Milan University Elisabetta Erba, Maria Rose Petrizzo, Milly Tornaghi and Davide Verga.

Thanks you
for
your attention