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REVIEW OF CALCAREOUS NANNOFOSSIL BIOSTRATIGRAPHY AND CORRELATION ACROSS THE JURASSIC- CRETACEOUS BOUNDARY

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Key words: Calcareous nannofossils, Upper Jurassic, Lower Cretaceous, boundary, biostratigraphy, correlation, provincialism, preservation.

ABSTRACT

While receiving less attention than many other stratigraphic boundaries the Upper Jurassic-Lower Cretaceous interval is nevertheless of great interest in terms of both stratigraphy and palaeontology. The stratigraphy, biostratigraphy and correlation of the boundary interval will be reviewed. The boundary in-

terval represents a particularly important period for calcareous nannofossils. The potential for a refined nannofossil biostratigraphy has been well illustrated in recent studies by ROTH (1983), COOPER (1985), and BRALOWER *et al.*, (1989). These biostratigraphical refinements reflect an important evolutionary episode which was initiated in the Tithonian and continued into the Berriasian. The evolutionary radiation also coincided with the first occurrence of pelagic carbonates whose origin is attributed to nannofossils. Despite these favourable factors of increased diversity and abundance, biostratigraphy across this interval remains difficult due to the problems of preservation and provincialism. The application of nannofossil biostratigraphy will be discussed and illustrated with reference to DSDP Sites 534 and 261, and onshore sections from Turkey.

RIASSUNTO

L'intervallo Giurassico superiore - Cretaceo inferiore, benché risulti relativamente poco studiato, è di notevole interesse sia dal punto di vista stratigrafico che paleontologico. Questo lavoro espone una rassegna della stratigrafia, biostratigrafia e correlazione dell'intervallo intorno al limite Giurassico - Cretaceo, che risulta particolarmente significativo per i nannofossili calcarei. La potenzialità di risoluzione offerta dalla biostratigrafia a nannofossili è stata ben illustrata in studi recenti di ROTH (1983), COOPER (1985) e BRALOWER *et al.* (1989). Tale risoluzione biostratigrafica è il risultato di un importante episodio evolutivo iniziato nel Tithoniano e proseguito nel Berriasiano. La radiazione

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evolutiva concide anche con la prima comparsa di carbonati pelagici la cui origine viene attribuita ai nannofossili calcarei. Nonostante i fattori favorevoli dell'aumento della diversità e dell'abbondanza, la biostratigrafia di questo intervallo permane difficile per problemi di preservazione e provincialismo. Viene discussa ed illustrata l'applicazione della biostratigrafia a nannofossili facendo riferimento ai Sites DSDP 534 e 261, ed a sezioni della Turchia.

INTRODUCTION

The definition and geological implications of major stratigraphical boundaries have been the subject of intensive investigations within the past few decades. The Cretaceous/Tertiary boundary has provided the focus for much attention due to the dramatic fossil extinctions and the supposed causal extraterrestrial intervention. While the Jurassic-Cretaceous boundary is far less dramatic in terms of biotic changes, its stratigraphical definition and recognition worldwide is problematic and under constant revision. This paper will review the chronostratigraphy and highlight the increasing level of biostratigraphical resolution provided by calcareous nannofossils.

STRATIGRAPHICAL FRAMEWORK

The time interval considered in this paper spans the Early Kimmeridgian (156Ma) to Late Barremian (119 Ma) (KENT and GRADSTEIN, 1985). The period is characterised by strong provincialism in almost all fossil groups with a clear-

ly delineated high-latitude Boreal realm and a low-latitude Tethyan realm. In addition there are sharp facies changes, particularly across the European area, where many of the stratigraphical definitions were originally formulated. The problems associated with faunal provincialism and facies differentiation have led to the development of at least three stratigraphical systems for this interval, each with its own nomenclature (Fig. 1). The boundary is drawn between the Tithonian and Berriasian in the Tethyan realm, the Volgian and Ryazanian in the Boreal realm (marine facies), and the Portlandian (marine and non-marine) and Ryazanian (marine) in the Boreal realm of Britain.

BIOSTRATIGRAPHICAL FRAMEWORK

A. AMMONITES

Amongst all the fossils of the Jurassic-Cretaceous interval the nekto-planktonic ammonites have traditionally formed the basis of a standard and high resolution biostratigraphy. For the interval considered here there are 43 Boreal ammonite zones, many representing a time period of one million years or less. While this is a very refined biostratigraphical division within a biogeographical area, it is when inter-regional correlations are attempted that problems are encountered. The Late Jurassic and Early Cretaceous ammonites display marked provincialism, with Tethyan faunas dominated by the family Berriassellidae and Boreal faunas by the family Craspeditidae. The faunas are almost entirely endemic and thus correlation between the two realms is problematic (ZEISS, 1983). Across the boundary itself there is no major event in ammonite evolutionary history.

B. OTHER FOSSIL GROUPS

1. *Calpionellids*

An abundant group of pelagic, marine protozoan microplankton restricted in stratigraphic range to the Late Tithonian-Early Valanginian and in geographic distribution to the Tethyan Realm. Together with ammonites they form the standard biostratigraphic zonation in the Tethyan realm for the boundary interval. Nine zones are present in the latest Tithonian-Early Valanginian interval (e.g. REMANE in BOLLI *et al.* 1985; AL-RIFA'IY and LEMONE, 1987).

2. *Radiolaria*

Zonation schemes have been developed by PES-

TIME SCALE M.Y.				TETHYAN	BOREAL	
	1	2	3		ENGLAND	RUSSIAN PLATFORM
115	119	119		APTIAN	APTIAN	APTIAN
121	125	124		BARREMIAN	BARREMIAN	BARREMIAN
				HAUTERIVIAN	HAUTERIVIAN	HAUTERIVIAN
126	131	131		VALANGINIAN	VALANGINIAN	VALANGINIAN
131	138	138		BERRIASIAN	RYAZANIAN	RYAZANIAN
135	144	144		TITHONIAN	PORTLANDIAN	VOLGIAN
141	150	152		KIMMERIDGIAN	KIMMERIDGIAN	KIMMERIDGIAN
143	156	156		OXFORDIAN	OXFORDIAN	OXFORDIAN

FIG. 1 - Nomenclature and correlation of stages in the Upper Jurassic-Lower Cretaceous interval. Age determinations from 1. VAN HINTE, 1976a,b; 2. HARLAND *et al.* 1982; 3. KENT and GRADSTEIN, 1985.

SAGNO (1977a, b), PESSAGNO *et al.* (1987), BAUMGARTNER (1987), and MATSUOKA and YAO (1986). BAUMGARTNER (1987) presents 5 zones, based on unitary association analysis, for the Kimmeridgian to Hauterivian interval in the Tethyan area.

3. Foraminifera

Although the ancestral forms of planktonic foraminifera are thought to have appeared in Bajocian time or earlier they are generally rare and biostratigraphically undiagnostic until the late Hauterivian/Barremian (*e.g.* CARON in BOLLI *et al.* 1985; STAM 1986). Calcareous and arenaceous benthic foraminifera have been used to develop zonation schemes by ASCOLI *et al.* (1984), with three calcareous benthic and three arenaceous benthic zones given for the Kimmeridgian to Valanginian interval.

4. Dinoflagellates

Biostratigraphic zonations have been proposed for the Late Jurassic-Early Cretaceous interval, for example, HABIB and DRUGG (1983), WOOLLAM and RIDING (1983), and HELBY *et al.* (1987). The most complete and refined scheme is that of HELBY *et al.* (1987) developed in the Australian area which proposes 15 zones for the Kimmeridgian to Barremian interval.

5. Ostracods

Ostracods have been successfully used as zonal fossils in non-marine sequences, *e.g.* ANDERSON (1985). In marine sequences ASCOLI *et al.* (1984) have zoned and correlated sediments of the Atlantic margin of North America (three zones).

C. MAGNETOSTRATIGRAPHY

The development of a magnetic polarity time scale for the Jurassic-Cretaceous boundary interval has progressed considerably in recent years, for example, OGG and STEINER, 1989. Polarity chrons M25 to M1 have been recognised in the Kimmeridgian to Barremian interval and correlated to ammonite, calpionellid, nannofossil, dinoflagellate, and radiolarian zonations and datum levels. Despite the great potential for correlation using magnetostratigraphy, problems do arise, for example, the recognition of polarity zones may be hindered by re- or de-magnetization of rocks, and/or correlation with the magnetic time scale may prove difficult due to an insufficient number of polarity intervals or omissions of polarity intervals due to hiatuses and/or low sedimentation rates. In addition, there have not yet been successful magnetostratigraphic studies in the Boreal area.

D. CALCAREOUS NANNOFOSSILS

a. Introduction

The biostratigraphic utility of calcareous nannofossils has been proven through the development of high-resolution zonation schemes for much of the late Mesozoic to Recent time interval. In the last decade a great deal of research has concentrated upon the origins and early history of the group (Triassic to Early Cretaceous), for example, ROTH (1983), BOWN (1987), BRALOWER *et al.* (1989), COOPER (1989), and CRUX (1989). The increasing amount of data and improved understanding of calcareous nannofossils in this time interval has resulted in more refined biostratigraphic schemes for the Jurassic and Cretaceous and their use in the critical boundary interval is the principal subject of the next sections of this paper.

b. Previous work

Upper Jurassic and Lower Cretaceous nannofossil biostratigraphic schemes in the Boreal realm include STRADNER (1963), BARNARD and HAY (1974), LORD (1982), MEDD (1982), LORD *et al.* (1987), JAKUBOWSKI (1987), BOWN *et al.* (1988), and CRUX (1989). In the Tethyan realm zonation schemes have been developed from land sections together with marine sequences from the Western Atlantic and include THIERSTEIN (1971, 1973), WORSLEY (1971), WILCOXON (1972), SISINGH (1977), DERES and ACHERITEGUY (1980), ROTH *et al.* (1983), COOPER (1985), MANIVIT *et al.* (1986), ERBA and QUADRIO (1987), and BRALOWER *et al.* (1989).

c. Nannofloral succession

The Late Jurassic-Early Cretaceous interval represented a particularly significant stage in the development of calcareous nannofossils in terms of both diversity (evolutionary development) and abundance (productivity).

Calcareous nannofossils first appeared in the Late Triassic and suffered a relatively major extinction event at the Triassic/Jurassic boundary (BOWN and LORD, 1990). Recovery was immediate in the Early Jurassic, which saw an important period of evolutionary diversification. First discolith, then placolith coccolith lineages became established and nine major family groups were present by the latest Toarcian (BOWN, 1987). The Mid Jurassic was a time of more gradual increase in species numbers and nannofloras were dominated by coccoliths of the genus *Watznaueria*. The first two stages of the Late Jurassic (Oxfordian and Kimmeridgian) saw a decline in diversity,

and assemblages were characterised by high abundances, low diversities, and the dominance of *Watznaueria* spp.. Extinction of Early and Mid Jurassic taxa continued into the Tithonian but became masked as a second Jurassic radiation began. Speciation was particularly evident in the coccolith lineage Retecapsaceae, but the radiation was characterised by the cryptogenic appearance of new nannolith groups, for example, *Nannoconus*, *Conusphaera*, *Polycostella*, and *Braarudosphaera*. Diversity rose from 29 species in the Kimmeridgian to 60 species in the late Tithonian and the radiation continued without a break into the Berriasian (BOWN *et al.*, this volume). Increase was rapid through the Berriasian and many of the Jurassic lineages which had suffered extinctions in the Late Jurassic were re-established at this time, e.g. Podorhabdaceae, Stephanolithiaceae. New coccolith families also appeared including Rhagodicaceae and Eiffellithaceae. The rate of evolutionary increase dropped back down to background levels in the remainder of the Early Cretaceous (BOWN *et al.*, this volume).

Initiation of the Late Jurassic radiation coincided with the first occurrence of significant and persistent thicknesses of biogenic pelagic carbonate which can be solely attributed to the presence of calcareous nannofossils. The onset of nannofossil carbonate sedimentation is thought to reflect an increase in nannoplankton productivity, particularly attributable to the successful rise of the new nannolith groups *Nannoconus* and *Conusphaera*. This may also have coincided with, and/or contributed to, increasingly favourable conditions for the deposition and preservation of calcite in the deep sea, i.e. lowering of the CCD.

d. Nannofloral provincialism

The recognition of strongly developed biogeographic provinces in Late Jurassic-Early Cretaceous nannofloral distribution has been discussed by THIERSTEIN (1976), TAYLOR (1978), COOPER (1989), and CRUX (1989). Like many other micro- and macro-fossil groups at this time, nannofloral distribution clearly delineates a low-latitude Tethyan realm and a high-latitude Boreal realm. It is likely that a southern high-latitude, Austral realm, also existed. Provincialism was at its most extreme around the boundary interval itself.

The Tethyan nannofloras are distinguished by the presence of endemic taxa. The nannolith groups *Nannoconus* and *Conusphaera* in the Tithonian, and coccolith species such as *Crucialipsis cuvillieri*, *Speetonia colligata*, *Calcicalathina oblongata*, and *Tubodiscus vereneae* in the Early

Cretaceous, particularly characterise the Tethyan assemblages. The presence of some of these "Tethyan" taxa in Boreal areas during the Early Cretaceous has been attributed to the influence of (warmer) Tethyan water masses during times of transgression (CRUX, 1989; MUTTERLOSE, 1989), but may also be due to broader ecological tolerance. It is also likely that some Tethyan forms which were moved into the Boreal area became established there and diversified, e.g. *Nannoconus abundans*, *Nannoconus borealis*, and *Conusphaera rothii*. There are also a number of endemic Boreal taxa, including *Sollasites arcuatus*, *Micrantholithus speetonensis*, *Crucibiscutum salebrosum*, and *Tegulalithus septentrionalis*.

The cause of such biogeographic differentiation may have been latitudinal or current-controlled temperature differences, together with variation in water depth, and the overall stability of environmental conditions. The Tethyan region has been associated with warmer, deeper and more stable marine conditions, and the proto-North Atlantic is likely to have had similar characteristics. The influence of cold Boreal Arctic Ocean currents/transgression has also been postulated by CRUX (1989).

e. Zonal schemes

It is evident that a universal nannofossil zonation scheme for the Upper Jurassic-Lower Cretaceous is inappropriate due to the effects of provinciality (endemism and differing stratigraphic ranges). It is far more realistic to apply a number of regional schemes which may ideally include a number of common datum levels. The zonations of BOWN *et al.* (1988) and CRUX (1989) in the Boreal realm, and ROTH *et al.* (1983) and BRALOWER *et al.* (1989) in the Tethyan realm, provide good reference schemes for this time interval (Fig. 2). These studies represent considerable refinement of nannofossil biostratigraphy for this interval and reflect and build upon the increasing amount of published material available, enhanced particularly in the Tethyan area by recently drilled DSDP sequences. BRALOWER *et al.* (1989), for example, propose 6 zones, 11 subzones, and 38 biohorizons for the Upper Oxfordian to mid Valanginian interval. This paper is also effective in tying nannofossil biostratigraphy to the geomagnetic polarity time scale (Fig. 3).

The marker species and other datum levels utilised by the zonation schemes cited are listed below. The Boreal (B) or Tethyan (T) nature of the species is indicated in the right hand column. A question mark is given if the presence of the

AUTHOR(S) STAGE		BOREAL	TETHYAN				
		CRUX, 1989 BOWN ET AL. 1988	ROTH; ROTH ET AL. 1983		BRALOWER, 1987; BRALOWER ET AL., 1989		
BARREMIAN		Z. sisyphus	Watznaueria oblonga		N. steinmannii		
		C. conicus					
		N. abundans					
		C. inaequalis					
HAUTERIVIAN		S. comptus	Cruciellipsid cuvieri		C. oblongata L. bollii Lithastrinus sp. C. cuvieri L. bollii		
		T. septentrionalis					
		C. margerelii					
		C. silvaradion					
		E. antiquus					
VALANGINIAN		T. striatum	Tubodiscus verenae		C. oblongata	T. verenae	
		M. speetonensis					
BERRI- ASIAN	RYAZ- ANIAN	unnamed	Reticapsa neocomiana		C. angustiforata	P. fenestrata A. infractetacea	
		S. arcuatus					
		P. fletcheri					
		Nannoconus sp.					
TITH- ONIAN	VOLG- IAN		Nannoconus colomii		M. chiastius	N. stein. minor R. laffittei U. gran. granulosa H. noelae	
		S. atmetros	Conusphaera mexicana				Polycostella beckmannii
		S. helotatus					H. cuvieri
KIMMERIDGIAN		H. cuvieri	Vagalapilla stradneri		V. stradneri	P. embergeri	

FIG. 2 - Correlation of calcareous nannofossil zonation schemes for the Upper Jurassic-Lower Cretaceous interval.

species is uncertain; an asterisk indicates that a datum level has not been firmly established in that area. Underlined species have been used in previous zonation schemes.

F.O. <i>S. helotatus</i>	L. Kimmeridgian	B
F.O. <i>Z. embergeri</i>	U. Kimmeridgian	B/T
F.O. <i>S. atmetros</i>	M. Volgian	B
F.O. <i>C. mexicana</i>		
minor	L. Tithonian	T
L.O. <i>S. bigotii</i>	M. Volgian/L. Tithonian	B/T
F.O. <i>C. mexicana</i>		
mexicana	L. Tithonian	T
F.O. <i>M. chiastius</i>	U. Tithonian	T/B*
F.O. <i>U. granulosa</i>	U. Tithonian	T
F.O. <i>R. laffitei</i>	U. Tithonian	T/B*
F.O. <i>N. steinmannii</i>		
minor	L. Berriasian	T
F.O. <i>N. steinmannii</i>		
steinmannii	L. Berriasian	T/B*
F.O. <i>R. angustiforata</i>	Berriasian/U. Ryazanian	T/B
F.O. <i>Nannoconus</i>		
sp. discs	U. Ryazanian	B/?T
F.O. <i>S. arcuatus</i>	U. Ryazanian	B/?T

F.O. <i>P. fenestrata</i>	U. Berriasian	T/B*
F.O. <i>C. oblongata</i>	L. Valanginian	T/B*
F.O. <i>M. speetonensis</i>	L. Valanginian	B
F.O. <i>T. striatum</i>	U. Valanginian	B

As indicated above, many of the marker species have been used in earlier schemes and have clearly defined taxonomic characters. A number of species, however, are less well constrained taxonomically and caution should be exercised when using *Z. embergeri*, *N. steinmannii*, *N. colomii*, *R. angustiforata* (taxonomy of the reticapsid group during this interval is particularly problematic), and *T. verena*.

Marker species which occur in both floral provinces and which have first or last occurrence datums that appear to be synchronous are rare but include *Z. embergeri*, *S. bigotii*, *R. angustiforata*, and also possibly *P. fenestrata*. These species should prove particularly useful when correlating between Boreal and Tethyan sequences. Many datum levels occurring in the boundary interval in the Tethyan realm have yet to be firmly estab-

SYSTEM	STAGE	MAGNETIC POLARITY SEQUENCE	CALCAREOUS NANNOFOSSIL ZONATION	CALPIONELLID ZONATION	RAD. ZON.	DINOFLAGELLATE ZONATION	TETHYAN AMMONITE ZONATION	STAGE
CRETACEOUS	VAL.	CM14n	C. oblongata	R. wisei	Calpionellites (F)	E. torynum	K. roubaudiana	VAL.
		CM14			Lo. hungarica (D3)	B. reticulatum		
	BERRIASIAN	CM15n		P. fenestrata	Cs. oblonga (D2)		B. callisto	BERRIASIAN
		CM15			Cs. simplex (D1)	D. lobispinosum	P. picteti	
		CM16n	C. angustiforata	A. infra-cretacea		C. delicata	M. paramimounum	
		CM16			C. elliptica (C)		D. dalmasi	
		CM17n				K. wisemaniae	privasensis	
		CM17	N. steinmannii steinmannii				T. subalpina	
		CM18n		N. steinmannii minor	C. alpina (B)		P. grandis	
		CM18					B. jacobi	
		CM19n	M. chiastius	R. laffittei		P. iehiense		
		CM19		U. gran. gran.	Crassicolaria (A)	D. jurassicum	Durangites	
		CM20n		H. noelae			P. transitorius	
		CM20			Chitinoidea	O. montgomeryi	Simplisphinctes	
		CM21n	C. mexicana	P. beckmannii			B. peroni	
		CM21		H. cuvillieri		C. perforans		
JURASSIC	K	CM22n	V. stradneri	P. embergeri		D. swanense		K

FIG. 3 - Integrated correlation of chrono-, magneto- and biostratigraphy for the Upper Jurassic-Lower Cretaceous interval. After BRALOWER *et al.* 1989 (Fig. 14) and including the nannofossil zonation of BRALOWER *et al.* 1989; calpionellid zonation of REMANE, 1985; radiolarian zonation of BAUMGARTNER, 1987; and dinoflagellate zonation of HELBY *et al.* 1987.

lished in the Boreal area due to the lack of marine sequences in northern Europe at this time.

f. Application of nannofossil biostratigraphy in the Jurassic/Cretaceous boundary interval

While it is clear that great advances have been made in the field of nannofossil biostratigraphy for this stratigraphic interval, there still remain a number of problems, already alluded to above, which may hinder its application. These problems of floral/faunal provincialism and fossil preservation are particularly acute at this time and not exclusive to the study of nannofossils. Provincialism is recognised by discrepancies in species ranges and the development of endemism. The Tithonian-Berriasian evolutionary radiation appears to have been geographically centred in the Mediterranean-Tethys area and many new taxa remained in the region of origin or were not

present elsewhere until considerably later. This distribution pattern has allowed for refined biostratigraphical division in the Tethyan province but requires a different set of criteria for applications elsewhere. The problem of nannofossil preservation is felt in both the floral provinces. In northern Europe, during the latest Jurassic, a regression event rendered much of the shelf area unfavourable for the presence and/or preservation of nannofossils. The Portlandian-Lower Ryazanian sequences in Britain and Upper Volgian-Lower Ryazanian sequences in Russia are largely represented in non-marine or transitional facies. No published data are available from Boreal sequences where the boundary is preserved in marine sediments, *e.g.* North Sea. In the southern, Tethyan area, the development of massive carbonate sequences, *e.g.* Maiolica facies, is equally detrimental to nannofossil preservation. Oceanic sites, *e.g.* DSDP Sites 534 and 391 in the Western

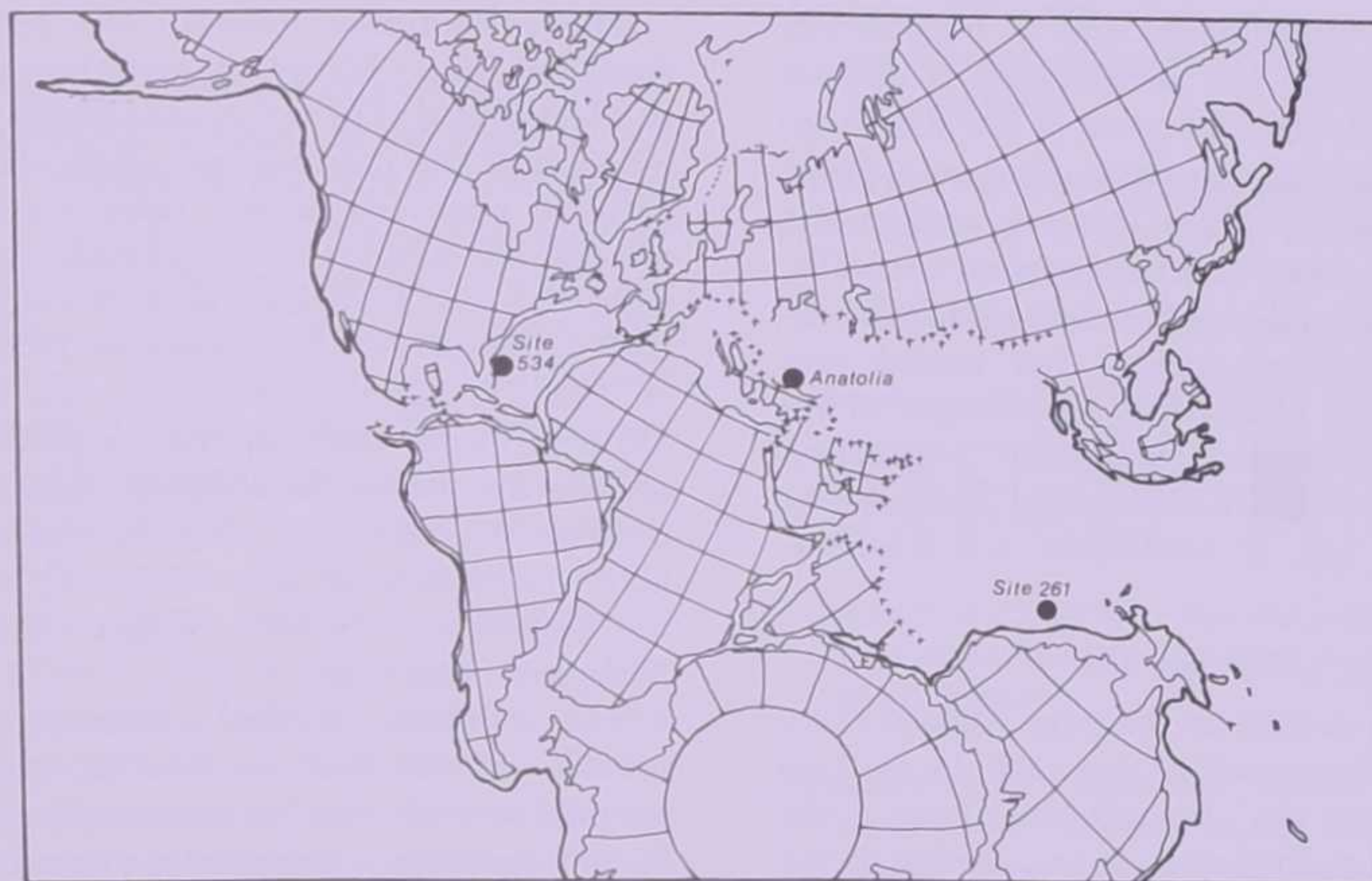


FIG. 4 - Location of sections.

North Atlantic, have yielded better states of preservation but even there the abundance of carbonate and length of burial have caused some preservational deterioration. Three sections/areas will be briefly discussed below to illustrate these problems (Fig. 4).

Western North Atlantic ("Tethyan"), DSDP Site 534A

Site 534A cored a continuous sequence from Callovian through Maastrichtian and includes a complete section across the Jurassic/Cretaceous boundary interval. The nannofossils were initially studied by ROTH (1983) and ROTH *et al.* (1983), and subsequently by COOPER (1985), BRALOWER *et al.* (1989), and the present authors. The lithologies through the boundary sequence comprise alternating claystone, marl, and limestone, and nannofossil preservation is moderate to good throughout. This section provides the finest and most complete record yet of nannofloral succession for the Tithonian to Berriasian interval.

The nannofloral succession in Site 534A includes all the "Tethyan" bioevents listed in section (e). The evolutionary development of the nannoconid group from small forms, such as, *N. compressus*, *N. infans*; the transition from *C. mexicana minor* to *C. mexicana mexicana*; and the evolutionary proliferation within the Retecapsaceae (=Cretarhabdaceae) are all well represented.

The Tethyan affinities and preservational attributes of this section have preserved a greater

proportion of the nannoflora than is usually observed for this time. This has led to a far greater understanding of the evolutionary radiation which occurred during the Tithonian and Berriasian. The concurrence of this period of rapid evolutionary increase with the boundary interval has allowed the development of a refined biostratigraphic scheme, *e.g.* BRALOWER *et al.* (1989). While many of the biostratigraphic events can also be recognised in other oceanic sequences, *e.g.* DSDP Site 391, and less successfully in land sections, *e.g.* Fiume Bosso (BRALOWER *et al.* 1989), preservational deterioration often precludes such biostratigraphic precision (see next section).

Mediterranean-Tethys section

Publications by AITA and OKADA (1986); MANIVIT *et al.* (1986); and ERBA and QUADRIO (1987) illustrate the difficulties encountered when studying nannofossils from the boundary interval in typically Tethyan lithologies dominated by micritic limestones, *e.g.* Maiolica and equivalents. The diagenesis of such lithologies invariably entails varying degrees of alteration of the original fabric, often rendering the freeing of nannofossils from the rock difficult or destroying them completely. Generally, nannofossil assemblages are poorly preserved and of low diversity, dominated by the most abundant and solution resistant taxa, such as, *Nannoconus* spp. and *Watznaueria* spp.. Other coccolith marker species may be very rare or absent. Thin sections may reveal rock-forming

quantities of nannofossils, such as nannoconids and conusphaerids, but identification is difficult by this method. The application of statistical biostratigraphic methods in these cases may prove useful, e.g. COOPER (1985). Our examination of a number of sections from northwest Anatolia, Turkey in the Sogukcam Limestone (Maiolica equivalent, Tithonian-L.Aptian) has yielded very high abundance nannofossil assemblages, as revealed by thin sections, but smear preparation yield only low diversity assemblages dominated by *Watznaueria* spp., *Z. embergeri*, and braarudospherids.

Eastern Tethys, DSDP Site 261

Site 261 is situated on the Argo Abyssal Plain, off the northwest shelf of Australia. In the Late Jurassic the area was a juvenile ocean basin to the south of the major Tethys Ocean. Dating of the lower portion of the section was entirely based upon nannofossils (PROTO DECIMA, 1974), all other microfossil groups yielding undiagnostic or ambiguous results (VEEVERS, HEIRTZLER *et al.*, 1974).

The nannofossils indicate the section ranges from the Upper Kimmeridgian/Lower Tithonian to Hauterivian (Fig. 5). Nannofossils are present throughout the interval but preservation is moderate to poor and barren intervals do occur. A nannofloral succession comparable with that observed in the European area is recognised, e.g. LAD *S. bigotii*, FAD *Z. embergeri*, FAD *C. cuvillieri*, FAD *T. verenae*, however, characteristically Tethyan forms, such as, *Nannoconus* and *Conusphaera* are absent. In addition, assemblage composition is unlike that seen elsewhere with very high abundances of *W. manivitae*, occurring in the Tithonian. Diversity is low compared with Tethyan assemblages.

The reliability of the well-known European marker species has yet to be independently checked in areas such as eastern Tethys. Nannofloral successions appear to be comparable despite some assemblage composition differences which may simply reflect further provincialism in a southern, Austral realm (see DUMOULIN and BOWN, in press; BAUMGARTNER *et al.*, in press).

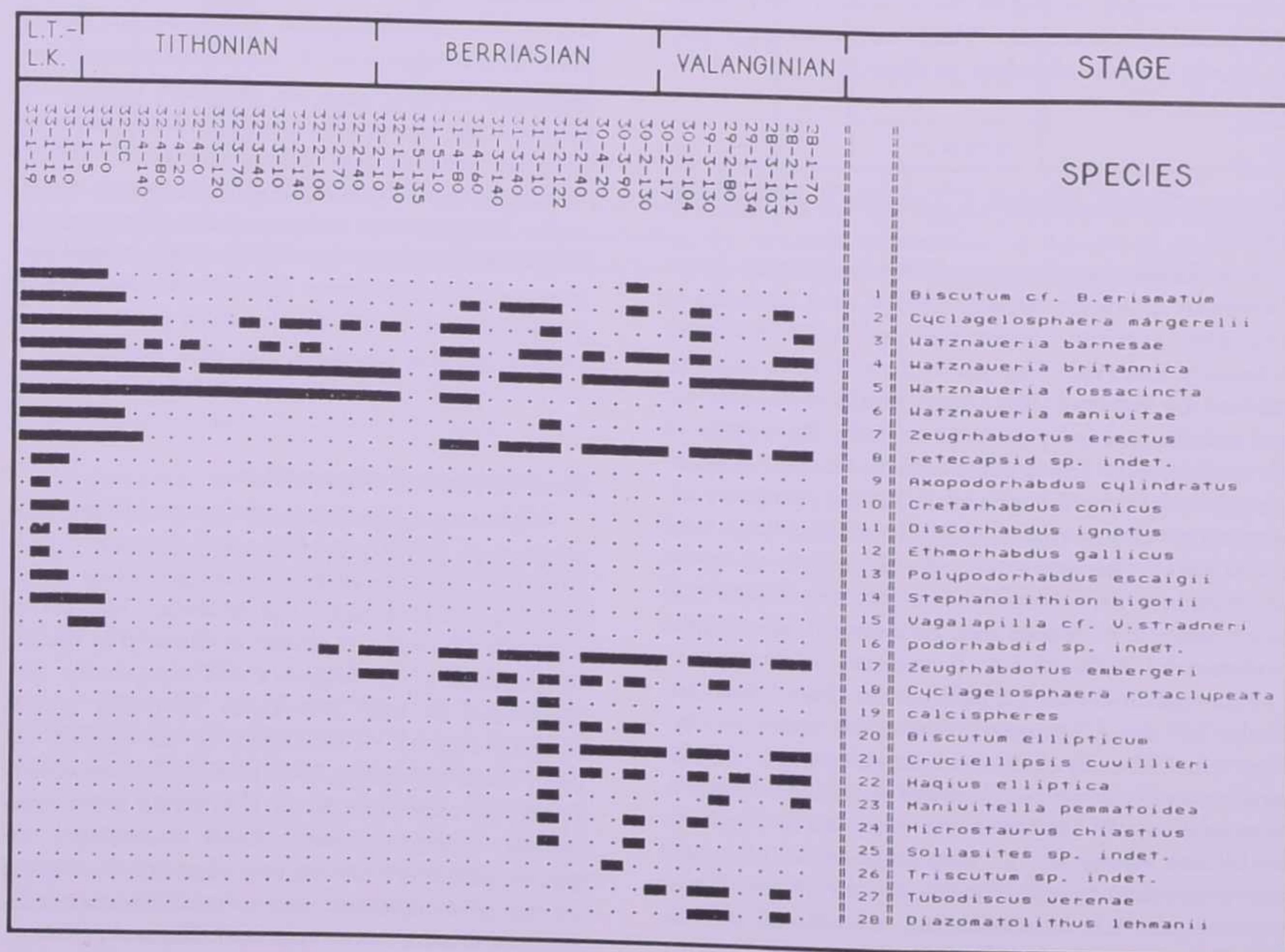


FIG. 5 - Stratigraphic distribution of calcareous nannofossils from DSDP Leg 27, Site 261 - Argo Abyssal Plain, off northwest Australia. LT.-L.K. stands for: Lower Tithonian - Late Kimmeridgian.

CONCLUSIONS

The last decade has seen a great increase in the amount of research devoted to the study of calcareous nannofossils in the Jurassic and Lower Cretaceous. This has allowed the development of high-resolution calcareous nannofossil biostratigraphical zonation schemes which are comparable with or improve upon the more well-established micro- and macro-fossil groups. The recognition of well-defined biogeographical realms in the distribution of nannofossils at this time has necessitated the establishment of separate schemes for the Boreal and Tethyan areas but common datum levels are present and assist correlation. The presence of regressive facies in northern Europe and micritic carbonates in Mediterranean-Tethys may hinder application of the biostratigraphic schemes in certain stratigraphic intervals due to the absence, difficulty of extraction, or dissolution of nannofossils.

Nannofloral successions, particularly around the boundary itself are best developed in oceanic sequences in the western North Atlantic. Away from the European/Atlantic area, little information is available. The one section from eastern Tethys includes familiar nannofossil datum levels together with assemblage features different to those of the Boreal and Tethyan areas, suggesting the existence of a separate Austral nannofloral province.

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REFERENCES

- AITA Y. and OKADA H., 1986 - *Radiolarians and calcareous nannofossils from the uppermost Jurassic and Lower Cretaceous strata of Japan and Tethyan regions*. Micropaleontology, v. 32, pp. 97-128, New York.
- AL-RIFA'IY I.A. and LEMONE D., 1987 - *Calpionellids and the Late Jurassic and Early Cretaceous stratigraphy of Kuwait and the Gulf Region*. Mar. Micropaleontology, v. 12, pp. 383-388, Amsterdam.
- ANDERSON F.W., 1985 - *Ostracod faunas in the Purbeck and Wealden of England*. J. Micropal., v. 4 (2), pp. 1-67, Blackpool.
- ASCOLI P., POAG C.W. and REMANE J., 1984 - *Microfossil zonation across the Jurassic-Cretaceous boundary on the Atlantic Margin of North America*. Geol. Ass. Canada, Special Paper 27, pp. 31-48, Ottawa.
- BARNARD T. and HAY W.W., 1974 - *On Jurassic coccoliths: a tentative zonation of the Jurassic of Southern England and North France*. Ecl. Geol. Helv., v. 67, pp. 563-585, Basel.
- BAUMGARTNER P.O., 1987 - *Age and genesis of Tethyan Jurassic radiolarites*. Ecl. Geol. Helv., v. 80, pp. 831-879, Basel.
- BAUMGARTNER P.O., BOWN P.R., MARCOUX J., HAIG D., KAMINSKI M., MC MINN A., and MUTTERLOSE J., in press - *Early Cretaceous oceanographic and biogeographic synthesis of Leg 123 (off NW Australia)*. Proc. ODP. Sci. Results, v. 123, College Station.
- BOWN P.R., 1987 - *Taxonomy, biostratigraphy and evolution of late Triassic-early Jurassic calcareous nannofossils*. Special Papers in Palaeontology, v. 38, pp. 1-118, Oxford.
- BOWN P.R., COOPER M.K.E. and LORD A.R., 1988 - *A calcareous nannofossil biozonation scheme for the Early to Mid Mesozoic*. Newsletters on Stratigraphy, v. 20 (2), pp. 91-114, Berlin-Stuttgart.
- BOWN P.R. and LORD A.R., 1990 - *The occurrence of calcareous nannofossils in the Triassic/Jurassic boundary interval*. Proceedings of the Triassic/Jurassic Boundary Working Group, Lyon 1988.
- BRALOWER T.J., 1986 - *Part A. An integrated Mesozoic timescale. Part B. Studies of Cretaceous black shales*. University of California, Ph.D. thesis, 425 pp., San Diego.
- BRALOWER T.J., MONECHI S. and THIERSTEIN H.R., 1989 - *Calcareous nannofossil zonation of the Jurassic-Cretaceous boundary interval and correlation with the geomagnetic polarity timescale*. Mar. Micropal., v. 14, pp. 153-235, Amsterdam.
- CARON M., 1985 - *Cretaceous planktonic foraminifera*. In H.M. BOLLI, J.B. SAUNDERS and K. PERCH-NIELSEN (eds.), Plankton Stratigraphy, pp. 17-86, Cambridge.
- COOPER M.K.E., 1984 (1985) - *Nannofossils across the Jurassic-Cretaceous boundary in the Tethyan Realm*. In O. MICHELSEN and A. ZEISS (eds.), Proceedings of the International Symposium on Jurassic Stratigraphy, v. 2, pp. 429-443, Copenhagen.

- COOPER M.K.E., 1989 - *Nannofossil provincialism in the Late Jurassic-Early Cretaceous (Kimmeridgian to Valanginian) period*. In J.A. CRUX and S.E. VAN HECK (eds.), *Nannofossils and their applications*, pp. 223-246, Ellis Horwood, Chichester.
- CRUX J.A., 1989 - *Biostratigraphy and paleogeographical applications of Lower Cretaceous nannofossils from north-western Europe*. In J.A. CRUX and S.E. VAN HECK (eds.), *Nannofossils and their applications*, pp. 143-211, Ellis Horwood, Chichester.
- DERES F. et ACHERITEGUY J., 1980 - *Biostratigraphie des Nannoconides*. Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine, v. 4, pp. 1-53, Pau.
- DUMOULIN J.A. and BOWN P.R., in press - *Depositional History, Nannofossil Biostratigraphy and Correlation of Argo Abyssal Plain Sites 765 and 261*. Proc. ODP. Sci. Results, v. 123, College Station.
- ERBA E. e QUADRIO B., 1987 - *Biostratigrafia a Nannofossili calcarei, Calpionellidi e Foraminiferi planctonici della Maiolica (Titoniano superiore-Aptiano) nelle Prealpi Bresciane (Italia settentrionale)*. Riv. Ital. Paleont. Strat., v. 93, pp. 3-108, Milano.
- HABIB D. and DRUGG W.S., 1983 - *Dinoflagellate age of Middle Jurassic-Early Cretaceous sediments in the Blake Bahama Basin*. Initial Reports D.S.D.P., v. 76, pp. 623-639, Washington.
- HARLAND W.B., COX A.V., LLEWELLYN P.G., PICKTOM C.A.G., SMITH A.G. and WALTERS R., 1982 - *A geologic time scale*. Cambridge Univ. Press, 128 pp., Cambridge.
- HELBY R., MORGAN R. and PARTRIDGE A.D., 1987 - *A palynological zonation of the Australian Mesozoic*. In P.A. JELL (ed.), *Studies in Australian palynology*, Association of Australasian Palaeontologists, pp. 1-94, Sydney.
- JAKUBOWSKI M., 1987 - *A proposed Lower Cretaceous calcareous nannofossil zonation scheme for the Moray Firth area of the North Sea*. Abh. Geol. B.A. v. 39, pp. 99-119, Wien.
- KENT D.V. and GRADSTEIN F.M., 1985 - *A Cretaceous and Jurassic geochronology*. Geol. Soc. Am. Bull., v. 96, pp. 1419-1427, Boulder.
- LORD A.R., 1982 - *A stratigraphical index of calcareous nannofossils*. British Micropaleontological Society Series, 192 pp., Ellis Horwood, Chichester.
- LORD A.R., COOPER M.K.E., CORBETT P.W.M., FULLER N.G., RAWSON P.F. and REES A.J.J., 1987 - *Microbiostratigraphy of the Volgian Stage (Upper Jurassic), Volga River, USSR*. N. Jb. Geol. Palaeont. Mh., v. 10, pp. 577-605, Stuttgart.
- MANIVIT H., AZEMA J., GALBRUN B. and DE WEVER P., 1986 - *Biostratigraphic study of calpionellids and nannofossils in the Tethyan Realm (Spain, Sicily, SE France) in Late Jurassic and Berriasian time: A correlation with magnetostratigraphic results*. Acta Geologica Hungarica, v. 29 (1-2), pp. 105-123, Budapest.
- MATSUOKA A. and YAO A., 1986 - *A newly proposed radiolarian zonation for the Jurassic of Japan*. Mar. Micropal., v. 11, pp. 91-105, Amsterdam.
- MEDD A.W., 1982 - *Nannofossil zonation of the English Middle and Upper Jurassic*. Mar. Micropal., v. 7, pp. 73-95, Amsterdam.
- MUTTERLOSE J., 1989 - *Temperature-controlled migration of calcareous nannofossils in the north-west European Aptian*. In J.A. CRUX and S.E. VAN HECK (Eds.), *Nannofossils and their Applications*, pp. 122-142, Chichester.
- OGG J.G. and STEINER M.B., 1989 - *Late Jurassic and Early Cretaceous Magnetic Polarity Time Scale*. Proceedings of the International Symposium on Jurassic Stratigraphy, Lisbon 1986.
- ORBIGNY (D') A., 1850 - *Prodrome de Paléontologie stratigraphique universelle des animaux mollusques et rayonnés*. Masson, v. 1, 394 pp., Paris.
- PESSAGNO E.A., JR., 1977a - *Upper Jurassic Radiolaria and radiolarian biostratigraphy of the California Coast Ranges*. Micropaleontology, v. 23, pp. 56-113, New York.
- PESSAGNO E.A. JR., 1977b - *Lower Cretaceous radiolarian biostratigraphy of the Great Valley Sequence and Franciscan Complex, California Coast Ranges*. Cushman Found. For. Res. Spec. Publ., v. 15, pp. 1-87, Washington.
- PESSAGNO E.A. JR., LONGORIA J.F., MACLEOD N. and SIX W.M., 1987 - *Studies of North American Jurassic Radiolaria: Part 1. Upper Jurassic (Kimmeridgian-upper Tithonian) Pantanelliidae from the Taman Formation, east-central Mexico; Tectonostratigraphic, chronostratigraphic and phylogenetic implications*. Cushman Found. For. Res. Spec. Publ., v. 23, pp. 1-51, Washington.
- PROTO DECIMA F., 1974 - *Leg 27 calcareous nannoplankton*. In J.J. VEEVERS, J.R. HEIRTZLER et al., Init. Repts. DSDP, v. 27, pp. 589-622, (U.S. Govt. Printing Office) Washington.
- REMANE J., 1985 - *Calpionellids*. In H.M. BOLLI, J.B. SAUNDERS and K. PERCH-NIELSEN (eds.), *Plankton Stratigraphy*, pp. 555-572, Cambridge.
- ROTH P.H., 1983 - *Jurassic and Lower Cretaceous calcareous nannofossils in the Western North Atlantic (Site 534): Biostratigraphy, preservation, and some observations on biogeography and paleoceanography*. Initial Reports D.S.D.P., v. 75, pp. 587-621, Washington.

- ROTH P.H., 1986 - *Mesozoic palaeoceanography of the North Atlantic and Tethys oceans*. In C.P. SUMMERHAYES and N.J. SHACKLETON (eds.), *North Atlantic Palaeoceanography*, Geological Society, Special publication, v. 21, pp. 299-320, Blackwell, Oxford.
- ROTH P.H., MEDD A.W. and WATKINS D.K., 1983 - *Jurassic calcareous nannofossil zonation, an overview with new evidence from Deep Sea Drilling Project Site 534A*. Initial Reports D.S.D.P., v. 76, pp. 573-579, Washington.
- SISSINGH W., 1977 - *Biostratigraphy of Cretaceous calcareous nannoplankton*. Geol. Mijnbouw, v. 56 (1), pp. 37-65, Voorschoten, Netherlands.
- STAM B., 1986 - *Quantitative analysis of Middle and Late Jurassic Foraminifera from Portugal and its implications for the Grand Banks of Newfoundland*. Utrecht Micropal. Bull., v. 34, pp. 168, Utrecht.
- STRADNER H., 1963 - *New contributions to Mesozoic stratigraphy by means of nannofossils*. Proc. 6th World Petroleum Congress, Sect. 1, pp. 167-182, Frankfurt.
- TAYLOR R.J., 1978 - *The distribution of calcareous nannofossils in the Speeton Clay (Lower Cretaceous) of Yorkshire*. Proceedings of the Yorkshire Geological Society, v. 42 (2), pp. 195-209, Bradford.
- THIERSTEIN H.R., 1971 - *Tentative Lower Cretaceous calcareous nannoplankton zonation*. Ecl. Geol. Helv., v. 64, pp. 459-488, Basel.
- THIERSTEIN H.R., 1973 - *Lower Cretaceous calcareous nannoplankton biostratigraphy*. Abh. Geol. Bundesanstalt, v. 29, pp. 1-52, Wien.
- THIERSTEIN H.R., 1976 - *Mesozoic calcareous nannoplankton biostratigraphy of marine sediments*. Mar. Micropal. v. 1, pp. 325-362, Amsterdam.
- VAN HINTE J.E., 1976a - *A Cretaceous time scale*, Am. Assoc. Pet. Geol. Bull., v. 60, pp. 498-516, Tulsa.
- VAN HINTE J.E., 1976b - *A Jurassic time scale*. Am. Assoc. Pet. Geol. Bull., v. 60, pp. 487-497, Tulsa.
- VEEVERS J.J., HEIRTZLER J.R., et al., 1974. - *Init. Repts. DSDP*, v. 27, 1060 pp. (U.S. Govt. Printing Office), Washington.
- WILCOXON J.A., 1972 - *Upper Jurassic-Lower Cretaceous calcareous nannoplankton from the Western North Atlantic Basin*. Init. Repts. DSDP, v. 11, pp. 427-457, Washington.
- WOOLAM R. and RIDING J.B., 1983 - *Dinoflagellate cyst zonation of the English Jurassic*. Rep. Inst. Geol. Sci. v. 83 (2), 42pp., London.
- WORSLEY T.R., 1971 - *Calcareous nannofossil zonation of Upper Jurassic and Lower Cretaceous sediments from the western Atlantic*. Proc. 2nd Plank. conf. v. 2, pp. 1301-1321, Roma.
- ZEISS A., 1983 - *Zur Frage der Äquivalenz der Stufen Tithon/Berrias/Portland in Eurasien und Amerika. Ein Beitrag zur Klärung der Weltweiten Korrelation der Jura/Kreide Grenzschiechten im Marinen Bereich*. Zitteliana, v. 10, pp. 427-428, München.

