

GEOLOGICA ULTRAIECTINA

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No. 134

**APPLICABILITY OF DINOFLAGELLATE CYST STRATIGRAPHY
TO THE ANALYSES OF
PASSIVE AND ACTIVE TECTONIC SETTINGS**



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Photo on cover-page: Sunshine after thunderstorm during fieldwork in SE-France (photo by A.S. Dijkema, 1989)

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**APPLICABILITY OF DINOFLAGELLATE CYST STRATIGRAPHY
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TOEPASSING VAN DINOFLAGELLATEN CYST STRATIGRAFIE
OP DE ANALYSE VAN PASSIEVE EN ACTIEVE TECTONISCHE SETTINGS

(MET EEN SAMENVATTING IN HET NEDERLANDS)

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*... und zum erstenmal überfiel mich
in diesen verzauberten Reisetagen eine
Vorstellung, die mich später immer
wieder einmal besucht und beglückt hat:
daß Geologie Musik der Erde sei.*

Hans Cloos, 1954
Gespräch mit der Erde

This thesis is based on the following papers:

- Chapter 1.1 Wilpshaar, M. and Leereveld, H. (1994) *Review of Palaeobotany and Palynology* **84** (1/2), 121-128.
- Chapter 1.2 Wilpshaar, M. (1995) *Cretaceous Research* **16**, 273-281.
- Chapter 1.3 Wilpshaar, M., Leereveld, H. and Visscher, H. (to be submitted).
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- Chapter 2.2 Wilpshaar, M., Brinkhuis, H., Hoek, R.P., Peeters, F.J.C., De Boer, P.L., Krijgsman, W. and Meulenkamp, J.E. (to be submitted).

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INTRODUCTION

The notion that fluctuating tectonic stress patterns within or between continental plates directly influence the development of a given sedimentary basin is a well-established concept in geotectonics. In recent years it has become increasingly understood that notably the phase of relative compressional stress build-up causes dramatic changes in basin configurations, particularly at basin margins. Detailed assessment of the timing and duration of such phases, and characterisation of the concomitant changes in sedimentary facies distribution patterns (or paleoenvironments) is vital for the better understanding of this process and the various possible underlying mechanisms. Conventionally in Mesozoic and Cenozoic basin analysis notably, the study and interpolation of ammonites and/or calcareous microfossils (planktic and benthic foraminifera, calcareous nannoplankton) play an important role in the generation of chronostratigraphically and paleoenvironmentally significant information. However, these fossil groups are frequently unsuitable for intra-basinal correlations between marginal marine and deeper marine deposits. Meanwhile, notably in hydrocarbon exploration the study and interpretation of dinoflagellate cyst assemblages has become increasingly successful in stratigraphic analysis of Mesozoic and Cenozoic basins throughout the world. Studies on Cenozoic and Recent dinoflagellate cysts published over the last decades stress their sensitivity to environmental changes, and successful application in high resolution stratigraphy (e.g., Wall *et al.*, 1977; papers in Head and Wrenn, 1992; Brinkhuis, 1992; Versteegh, 1995). Moreover, the organic-walled cyst producing dinoflagellates are primarily associated with neritic environments, causing their consistent occurrence in marginal marine settings. In more offshore settings, the dinoflagellate signal increasingly consists of transported elements, thus allowing detailed correlations along onshore-offshore transects.

This thesis therefore concentrates on the assessment of the applicability of this relatively new biostratigraphic tool on the timing and characterisation of periods (inception) of compression. For the purpose of this study compressional phases recognised in two highly contrasting basins were selected, viz. (1) in the Early Cretaceous of the primarily carbonate dominated Dauphinois Basin (SE France), developed in a tectonically passive setting, and (2) in the Oligocene of the mainly siliciclastic-dominated Pindos Foreland Basin (Epirus, NE Greece) which developed in front of the Pindos Thrust.

ORGANIC-WALLED DINOFLAGELLATE CYSTS

Dinoflagellates (division Dinoflagellata) are a group of unicellular organisms (protists) that have a free-swimming motile biflagellate stage in their life-cycle. The dinoflagellates include autotrophs, phagotrophs, symbionts and parasites. They are among the most important groups of phytoplankton today. They are the notorious cause of 'red tides' and paralytic/diaretic shellfish poisoning, resulting from blooms of toxic species. The life cycle of modern dinoflagellates is complex, and includes the formation of organic-walled cysts. The motile (thecate) stage has a low preservation potential, but cysts are frequently composed of resistant organic material similar to sporopollenin, so that organic-walled dinoflagellate cysts are typically encountered in palynological preparations that also contain sporomorphs.

Living dinoflagellates occur in most aquatic environments. Dinoflagellate cysts are, however particularly widespread in marine sediments. Only a few dinoflagellate cysts have been reported from ancient freshwater sediments. The record of unequivocal cysts of fossil dinoflagellates begins in the Late Triassic when they probably developed their characteristic cingular-sulcal (dinokont) biflagellar arrangement (Bujak and Williams, 1981). However, dinoflagellates may have already evolved as a separate group in the Precambrian, with early cysts having an anterior (desmokont) biflagellar arrangement and being indistinguishable from algal cysts of uncertain affinity classified within the group Acritarcha (Fensome *et al.*, 1993).

It has become appreciated that most organic-walled cysts found in sediments represent hypnozygotic benthic resting stages. For the majority of species the cyst appears to function also as dispersal mechanism, often meant to reach the bottom sediments quickly ('sinkers'). Since the subsequent motile stage must be able to reach surface waters also relatively quickly, they are primarily associated with coastal and neritic environments (e.g., Dale, 1983). Only specialists ('floaters') among the organic-walled cyst forming dinoflagellates occur in more offshore (oceanic) settings, like the extant genera *Impagidinium* and *Nematosphaeropsis* (Dale, 1983).

As a result of their rapid evolution and resulting diversification, with species optima in the Upper Jurassic, Upper Cretaceous and Eocene (Bujak and Williams, 1981), qualitative dinoflagellate cyst biostratigraphy has become accepted as an important tool in stratigraphical analysis. In addition, quantitative studies on Recent and fossil dinoflagellate cyst distribution resulted in the recognition of their great potential for detailed paleoenvironmental analysis (e.g., Wall *et al.*, 1977; Edwards, 1992; Edwards and Andrie, 1992; Versteegh, 1995). Applications include the establishment of proxies for changes in relative sea-level, sea surface temperatures and productivity (e.g., Brinkhuis, 1992; Versteegh, 1995).

SYNOPSIS

This thesis concentrates on the applicability of dinoflagellate cyst biostratigraphy on the timing and characterisation of phases of relative compressional stress build-up. For this purpose sedimentary successions in two highly contrasting basins were selected for investigation, viz. (1) the Lower Cretaceous of the Dauphinois Basin (SE France), and (2) the Oligocene of the Pindos Foreland Basin (Epirus, NE Greece). As a result, the thesis is divided in two parts.

Part 1 concentrates on the mainly carbonate-dominated Early Cretaceous Dauphinois Basin. This basin developed on the European (passive) margin of the Piemonte-Ligurian ocean. During the late part of Early Cretaceous large-scale plate reorganisation resulted in a transition from extension to compression. The initial and subsequent indications of increasing compressional stress build-up form the subject of this part of the thesis.

In **Chapter 1.1** the results of a study of the quantitative dinoflagellate cyst distribution in a Valanginian to Lower Cenomanian composite stratigraphic section of the Vocontian Basin, the deeper part of the Dauphinois Basin, are presented. Within the record of dinoflagellate cyst assemblages a distinct basin-wide long-term quantitative change is apparent during the Early Cretaceous reflecting a paleoenvironmental change from inner neritic to outer neritic conditions. This change is considered to reflect a relative rise in sea-level. The overall composition of the dinoflagellate cyst assemblages suggests that the basin never reached a paleodepth of more than a few hundred meters.

Chapter 1.2 shows the basin-wide stratigraphic correlation by means of dinoflagellate cysts between selected intervals from the Barremian carbonate platforms at the northern margin of the Dauphinois Basin (the Vercors Plateau) to the Barremian stratotype in the Vocontian Basin. The dinoflagellate-based age-assessments from the Vercors Plateau markedly contrast with previously established age-interpretations for the sediments from these localities.

This controversy has important implications for the interpretation of the carbonate platform development at the margins of the Dauphinois Basin and is further discussed in **Chapter 1.3**. In this chapter subsidence analysis is performed on the basis of two Lower Cretaceous composite columns from the Dauphinois Basin using all available information, in addition to the newly acquired dinoflagellate-based age-assessments. One of the two columns is derived from the deeper marine Vocontian Basin, the other from a marginal setting (Vercors Area). It is shown that the compressional stress build-up coincides with the onset, progradation and eventual disappearance of extensive carbonate platforms at the margins of the Dauphinois Basin. It is concluded that the onset of carbonate platform formation document

the very first sedimentary response to the changing tectonic regime.

Part 2 focuses on the terrigenous clastic succession of the Pindos Foreland Basin (Epirus, NW Greece) which developed during the late Paleogene in front of the Pindos Thrust. A study of dinoflagellate cysts can assist in the establishment of more detailed age-assessments of the various tectonic phases across the isopic zones.

Since a well-constrained dinoflagellate zonal framework, vital for the detailed assessment of the timing and characterisation of the tectonic phases, was still lacking for the (central) Mediterranean Oligocene, in **Chapter 2.1** a new, well-calibrated relatively high-resolution scheme is presented. The zonation is established on the basis of chronostratigraphically well-constrained sections from central Italy. Special reference is made in this chapter to the Early/Late Oligocene (or Rupelian/Chattian) boundary in the light of the current discussions on the selection of a suitable Rupelian/Chattian Global Boundary Stratotype Section and Point (GSSP). The first occurrence of the dinoflagellate cyst *Distatodinium biffii* may provide a good criterion for recognition of the Rupelian/Chattian boundary.

The zonation scheme presented in Chapter 2.1 is applied to the Pindos Foreland Basin in **Chapter 2.2** in order to construct a tectonostratigraphic frame. The results indicate that (1) the onset of 'flysch' sedimentation in the Pindos Foreland Basin is diachronous, starting not earlier than the earliest Oligocene, and (2) the evolution of the Ionian Zone of the Pindos Foreland Basin into a piggy-back basin occurred during the Late Oligocene. The relatively fast evolution of the Pindos Foreland Basin into a piggy-back basin is in marked contrast with previous reconstructions.

INLEIDING

Wisselende tektonische spanningsvelden in of tussen continentale platen zijn direct van invloed op de ontwikkeling van sedimentaire bekkens. In de afgelopen jaren is vastgesteld dat vooral de fase van compressieve spanningsopbouw belangrijke veranderingen teweeg brengt aan de bekkenrand en in de vorm van een bekken. Nauwkeurige bepaling van het tijdstip en duur van deze periodes van compressieve spanningsopbouw en de karakterisering van de gelijktijdige veranderingen in sedimentaire facies verspreidingspatronen en de hiermee samenhangende veranderingen in paleomilieus zijn essentieel voor een beter begrip van de processen die hier aan ten grondslag liggen. Traditioneel spelen in analyses van Mesozoïsche en Cenozoïsche bekkens de studie en interpolatie van ammonieten en/of kalkige microfossielen (planktonische en benthonische foraminiferen, kalkig nannoplankton) een belangrijke rol in het vergaren van chronostratigrafische en paleomilieu gegevens. Deze fosielgroepen zijn echter vaak niet geschikt voor interne bekken correlaties tussen ondiep en diep mariene afzettingen. Inmiddels is met name in de olie- en gasexploratie de analyse van dinoflagellatencysten met een organische wand succesvol geworden bij stratigrafische interpretatie van Meso- en Cenozoïsche bekkens. Daarnaast benadrukken de resultaten van Cenozoïsch en Recent kwantitatief dinoflagellatencysten onderzoek tevens (1) hun gevoeligheid voor milieuveranderingen en (2) hun succesvolle toepassing voor zeer nauwkeurige stratigrafie (b.v. Wall *et al.*, 1977; artikelen in Head en Wrenn, 1992; Brinkhuis, 1992; Versteegh, 1995). Bovendien zijn dinoflagellaten die een cyste produceren met een organische wand in hoofdzaak geassocieerd met neritische milieus. In meer van de kust gelegen gebieden is het dinoflagellaten signaal in toenemende mate opgebouwd uit getransporteerde elementen, waardoor een nauwkeurige correlatie mogelijk is van ondiep tot diep marien.

Dit proefschrift bespreekt de toetsing van de toepasbaarheid van dinoflagellatencysten voor de tijdsbepaling en beschrijving van periodes van samendrukkende spanningsopbouw.

DINOFLAGELLATENCYSTEN MET EEN ORGANISCHE WAND

Dinoflagellaten zijn een groep van ééncellige organismen, gekarakteriseerd door het bezit van twee flagellen oftewel zweephaartjes. In het algemeen bestaat de levenscyclus uit een vrij-zwemmend en een ruststadium. Er zijn autotrofe, phagotrofe, symbiotische en parasitaire dinoflagellaten. Ze zijn één van de meest belangrijke phytoplankton groepen van dit moment. Een explosieve vermenigvuldiging van giftige soorten (zogenoeten 'red tides', de vloed die het water rood kleurt) kan op grote schaal vis, schelp en schaaldier vergiftigingen veroorzaken. De levenscyclus van moderne dinoflagellaten is complex en omvat o.m. de vorming van cysten met een organische wand. Het vrijzwemmende stadium heeft een laag preservatiepotentieel, maar de cysten zijn vaak opgebouwd uit resistent organisch materiaal dat te vergelijken is met het sporopollenine van sporomorfen. Hierdoor kunnen dinoflagellatencysten met een organische wand tezamen met sporomorfen gevonden worden in palynologische preparaten.

Dinoflagellaten komen voor in de meeste aquatische milieus. Fossiele cysten van dinoflagellaten komen daarentegen in het bijzonder voor in mariene afzettingen. Een klein aantal dinoflagellatencystensoorten is echter ook gevonden in fossiele zoetwater afzettingen. De eerste fossiele dinoflagellatencysten zijn bekend uit de Boven Trias. Dinoflagellaten hebben zich echter waarschijnlijk al sinds het Precambrium als een aparte groep ontwikkeld (Fensome *et al.*, 1993).

De meeste cysten met een organische wand aanwezig in het sediment representeren een zgn. hypnozygotisch bentisch ruststadium. Voor het merendeel van de soorten functioneert de cyst tevens als 'verspreidingsmechanisme', vaak bedoeld om het sediment snel te bereiken (zgn. 'zinkers'). Omdat het daaropvolgende vrij-zwemmende stadium ook het oppervlakte water relatief snel moet kunnen bereiken, zijn dinoflagellaten voornamelijk met kustnabije en neritische milieus geassocieerd (Dale, 1983). Alleen specialisten (zgn. 'drijvers') onder de dinoflagellaten die een cyste met een organische wand produceren, komen voor in oceanische milieus, zoals de recente soorten van de genera *Impagidinium* en *Nematosphaeropsis* (Dale, 1983).

Een resultaat van hun snelle evolutie en daarmee samengaande diversiteit, met soorten maxima in de Boven Jura, het Boven Krijt en het Boven Eoceen (Bujak en Williams, 1981), is het feit dat kwalitatieve dinoflagellatencystenbiostratigrafie een belangrijk gereedschap is geworden bij stratigrafische analyses. Kwantitatieve toepassingen omvatten o.m. het vaststellen van veranderingen in de relatieve zeespiegel, zeeoppervlaktetemperatuur en produktiviteit (b.v. Brinkhuis, 1992; Versteegh, 1995).

SAMENVATTING

Dit proefschrift beschrijft de toepassing van dinoflagellatencystenbiostratigrafie bij de tijdsbepaling en karakterisering van periodes van samendrukkende spanningsopbouw. Voor dit doel zijn de sedimentaire successies in twee zeer verschillende bekken geselecteerd, te weten (1) het Onder Krijt van het Dauphinois Bekken (ZO-Frankrijk), en (2) het Oligoceen van het Pindos Voorland Bekken (Epirus, NW-Griekenland).

Deel 1 behandelt het voornamelijk door kalkige sedimenten gedomineerde Dauphinois Bekken uit het Vroeg Krijt. Dit bekken ontwikkelde zich aan de Europese (passieve) rand van de Piemonte-Ligurische oceaan. Grootchalige plaatreorganisaties resulteerden ten tijde van het laatste Vroeg Krijt in een verandering van een extensief naar een compressief regime. De allereerste en daaropvolgende aanwijzingen van toenemende compressieve spanningsopbouw vormen het onderwerp van dit deel van het proefschrift.

In **Hoofdstuk 1.1** worden de resultaten van een studie van de kwantitatieve dinoflagellatencystendistributie in een Valanginien tot Vroeg Cenomanien samengestelde stratigrafische sectie uit het Vocontische Bekken (het diepere gedeelte van het Dauphinois Bekken) behandeld. In de kwantitatieve dinoflagellatencystenverdeling is een duidelijke lange termijns trend aanwezig. De trend wordt representatief geacht voor het gehele bekken. Deze verandering weerspiegelt een transitie van ondiep neritische naar dieper neritische omstandigheden, gerelateerd aan een relatieve zeespiegelstijging. De algehele samenstelling van de dinoflagellatencystenassociaties suggereert dat het bekken nooit een paleodiepte van meer dan een paar honderd meter heeft bereikt.

Hoofdstuk 1.2 laat een interne bekken correlatie zien met behulp van dinoflagellatencysten tussen geselecteerde intervallen van het Barremien kalkplatform aan de noordzijde van het Dauphinois Bekken (het Vercors Plateau) en het Barremien stratotype in het Vocontische Bekken. De hieruit afgeleide ouderdomsbepalingen van het Vercors Plateau zijn opvallend verschillend van eerdere ouderdomsinterpretaties.

Deze nieuwe dateringen hebben belangrijke consequenties voor de interpretatie van de ontwikkeling van de kalkplatformen aan de randen van het Dauphinois Bekken. In **Hoofdstuk 1.3** wordt daarom een dalingsanalyse uitgevoerd gebaseerd op twee Onder Krijt samengestelde kolommen van het Dauphinois Bekken, waarbij gebruik wordt gemaakt van alle beschikbare informatie. Eén van de twee kolommen is afkomstig van het diepere mariene Vocontische Bekken; de andere van een aan de rand gelegen omgeving (Vercors Plateau). Aangehouden wordt dat de compressieve spanningsopbouw gerelateerd is aan het begin, de progradatie en de uiteindelijke verdwijning van uitgestrekte kalkplatformen aan de randen van

- Inleiding en samenvatting -

het Dauphinois Bekken. Geconcludeerd wordt dat het begin van de kalkplatform-opbouw het eerste sedimentaire 'antwoord' is op het veranderende tektonische regime.

Deel 2 concentreert zich op de terrigeen klastische opeenvolging van het Pindos Voorland Bekken (Epirus, NO-Griekenland), dat zich ontwikkelde ten tijde van het laat Paleogeen aan de voorzijde van de Pindosoverschuiving. De studie van de dinoflagellatencysten is gericht op het verkrijgen van meer nauwkeurige ouderdomsbepalingen voor de verschillende tektonische fasen in de zogenaamde 'isopic' zones oftewel zones van gelijke deformatie.

Een goede dinoflagellatencystenzonering is essentieel voor een nauwkeurige tijdsbepaling en karakterisering van deze tektonische fasen. Omdat een dergelijke zonering nog ontbrak voor het Oligoceen van het (centrale) Middellandsezegebied, wordt in **Hoofdstuk 2.1** een nieuw, goed gecalibreerd en relatief zeer nauwkeurig schema gepresenteerd. Het zoneringsschema is gemaakt aan de hand van chronostratigrafisch goed bekende secties in midden Italië. Speciale aandacht in dit hoofdstuk wordt besteed aan de Onder/Boven Oligoceen (of Rupelien/Chattien) grens in het licht van de recente discussies over de selectie van een geschikt stratotype. Het vroegste voorkomen van de dinoflagellatencyste *Distatodinium biffii* kan gebruikt worden voor de herkenning van het vroegste Chattien.

Het zoneringsschema van Hoofdstuk 2.1 is in **Hoofdstuk 2.2** toegepast op het Pindos Voorland Bekken voor het construeren van een tektonostratigrafisch kader. De resultaten laten zien dat (1) de 'flesch'-sedimentatie in het Pindos Voorland Bekken diachroom is en niet eerder begon dan het vroegste Oligoceen, en (2) de evolutie van de Ionische Zone van het Pindos Voorland Bekken naar een zogeheten 'piggyback basin', oftewel varkensrugbekken, tijdens het Laat Oligoceen plaatsvond. Deze relatief snelle verandering van het Pindos Voorland Bekken in een varkensrugbekken is opmerkelijk verschillend met eerdere reconstructies.

PART 1

APPLICABILITY OF DINOFLAGELLATE CYST STRATIGRAPHY

TO THE ANALYSES OF A PASSIVE MARGIN

DURING A PHASE OF RELATIVE COMPRESSION.

CASE STUDY OF THE EARLY CRETACEOUS DAUPHINOIS BASIN (SE-FRANCE).

CHAPTER 1.1

PALEOENVIRONMENTAL CHANGE IN THE EARLY CRETACEOUS VOCONTIAN BASIN (SE-FRANCE) REFLECTED BY DINOFLAGELLATE CYSTS

ABSTRACT

A Valanginian-Lower Cenomanian composite stratigraphic section of the Vocontian Basin (SE France) has been studied palynologically with emphasis on quantitative dinoflagellate cyst distribution. The overall composition of the dinoflagellate cyst assemblages suggests that the basin never reached a paleodepth of more than a few hundred meters. Within the dinoflagellate cyst assemblages a distinct basin-wide long-term quantitative change is apparent during the Early Cretaceous reflecting a palaeoenvironmental change from inner neritic to neritic conditions. This change is considered to reflect a relative rise in sea-level.

INTRODUCTION

The Early Cretaceous paleogeography of the Western Alps in SE France is inherited from the Liassic rifting phases, creating a roughly triangular basin (Baudrimont and Dubois, 1977; Lemoine *et al.*, 1986; Arnaud, 1988; Fig. 1). This Vocontian Basin (Paquier, 1900) was surrounded by carbonate platforms and developed on the passive European continental margin (Lemoine and Graciansky, 1988). The main sedimentation is characterised by hemipelagic limestone-marl alternations which can be correlated basin wide (Cotillon *et al.*, 1980, Bréheret, 1988). Within the Early Cretaceous succession limestone dominated intervals (e.g. Barremian) and marl dominated intervals (e.g. Aptian-Albian) can be distinguished.

The sediments of the Vocontian Basin are generally interpreted to have been deposited in a deep basin (Paquier, 1900; Killian, 1912). The commonly used name "Fosse Vocontienne" (Vocontian Trough) refers to this presumed deep depositional setting. "This interpretation, conceived at an early date in French geology, has since persisted in all later textbooks. Its justification is slender, as we have no indication whatsoever as to actual depth of sedimentation" (Rutten, 1969; p.276). This persistent and slender justification is still upheld. More recent assessments are in the range of bathyal depths around 1000 to 2000 meters or more (e.g. Ferry, 1978; Cotillon *et al.*, 1984; Cotillon and Rio, 1984; Arnaud, 1988; Ferry and Rubino, 1989; Arnaud-Vanneau and Arnaud, 1990; Jacquin *et al.*, 1991). In contrast, however, based on sedimentological criteria De Boer (1983) interpreted the sediments of the Vocontian Basin to have been deposited in a shallower setting (not more than a few hundred meters).

The classical outcrops in the Vocontian Basin and surrounding carbonate platforms play a prominent role in the establishment of regional sea level variation curves (Ferry and Rubino, 1989; Jacquin *et al.*, 1991), as well as the reconstruction of a global eustatic curve (Haq *et al.*, 1988). However, it should be realised that the extensively documented arguments in favour of the presence of third-order sea level cycles are not accompanied by analyses of the depositional paleoenvironment in the basin.

Changes in physical and chemical features of watermasses are reflected in the distribution patterns of dinoflagellate cysts. Consequently, quantitative analysis of dinoflagellate cyst assemblages may provide information regarding sedimentary paleoenvironments, sea level variations, sea-surface temperature, productivity and salinity (e.g. Wall *et al.*, 1977; Goodman 1979; Harland, 1983; Brinkhuis and Zachariasse, 1988; Brinkhuis 1992). Through the analysis of dinoflagellate cysts, therefore, the present study aims to contribute to a better characterisation of the depositional paleoenvironment, of the Early Cretaceous Vocontian Basin.

- Palaeoenvironmental change: Vocontian Basin -

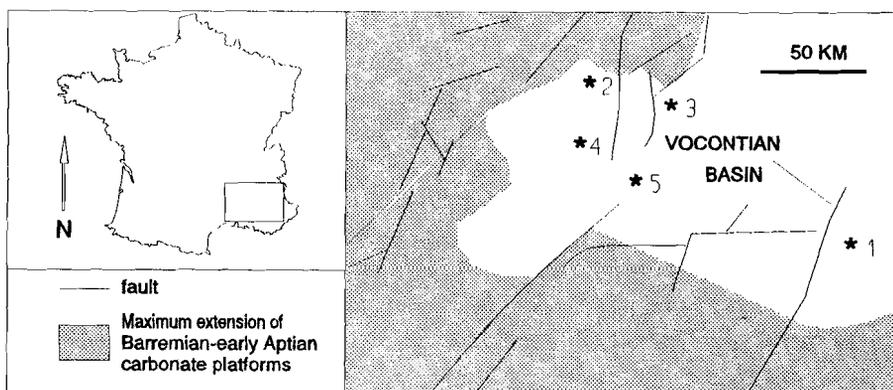


Figure 1: Simplified Early Cretaceous paleogeographical map of southeast France showing the locations of the studied sections: (1) Angles; (2) Chamoloc de Rousset; (3) Serre Chaitieu; (4) Pré-Guittard and (5) Palluel.

MATERIAL

Five sections in the Vocontian Basin (Fig. 1) are combined, creating a composite stratigraphic column of approximately 1250 meters covering the Valanginian to Lower Cenomanian (Fig. 2). A total of 165 samples, regularly distributed throughout the composite section, are analyzed in this study. For reasons of comparison all samples are set in marly intervals. The hemipelagic limestone-marl alternations of the studied sections can be traced basinwide (Cotillon et al, 1980; Bréheret, 1988) and are biostratigraphically well-controlled with ammonites. Definition and subdivision of the stages are adapted from Hoedemaeker and Bulot (1990).

The following sections are studied (Fig. 1):

- The Angles section covering the Valanginian (Busnardo *et al.*, 1979), the Barremian stratotype and the base of the Aptian (Busnardo, 1965).
- The Chamoloc de Rousset section covering the Hauterivian (Arnaud-Vanneau *et al.*, 1987).
- The Serre Chaitieu, Pré-Guittard and Palluel sections from an Aptian to Lower Cenomanian composite stratigraphic column studied by Bréheret (1988).

METHODS

The samples are processed according to palynological standard preparation techniques (briefly: HCl and HF treatment, heavy liquid separation, sieving of residue using a 25 μ m sieve and mounting). They are quantitatively analyzed for their dinoflagellate cyst content. The quantitative analysis included two successive steps: (1) counting of 100 palynomorphs for a characterisation of the entire palynological association; for this purpose five broad palynological categories are recognised, i.e. sporomorphs, acritarchs, determinable dinoflagellate cysts, indeterminate dinoflagellate cysts and inner walls of foraminifers; (2) counting of up to 200 determinable dinoflagellate cysts if possible. The taxonomy of dinoflagellate cysts corresponds to that cited in Lentin and Williams (1989).

Morphologically closely related genera have been selected and combined into stratigraphically long ranging dinoflagellate cyst groups in order to obtain paleoecological information. The following seven dinoflagellate cyst groups are considered and named after a representative genus: (1) the *Muderongia* Group (including *Odontochitina* and *Phoberocysta*), (2) the *Systematophora* Group, (3) the *Cribroperidinium* Group (including *Apteodinium*), (4) the *Circulodinium* Group (including *Aptea*, *Cyclonephelium*, *Cerbia* and *Sentusidinium*), (5) the *Oligosphaeridium* Group (including *Kleithriasphaeridium* and *Hystrichosphaeridium*), (6) the *Spiniferites* Group (including *Achomosphaera*), and (7) the *Pterodinium* Group. All other species are placed in 'Others' (Fig. 2). Representative specimens of the seven dinoflagellate cyst groups are depicted on Plate I.

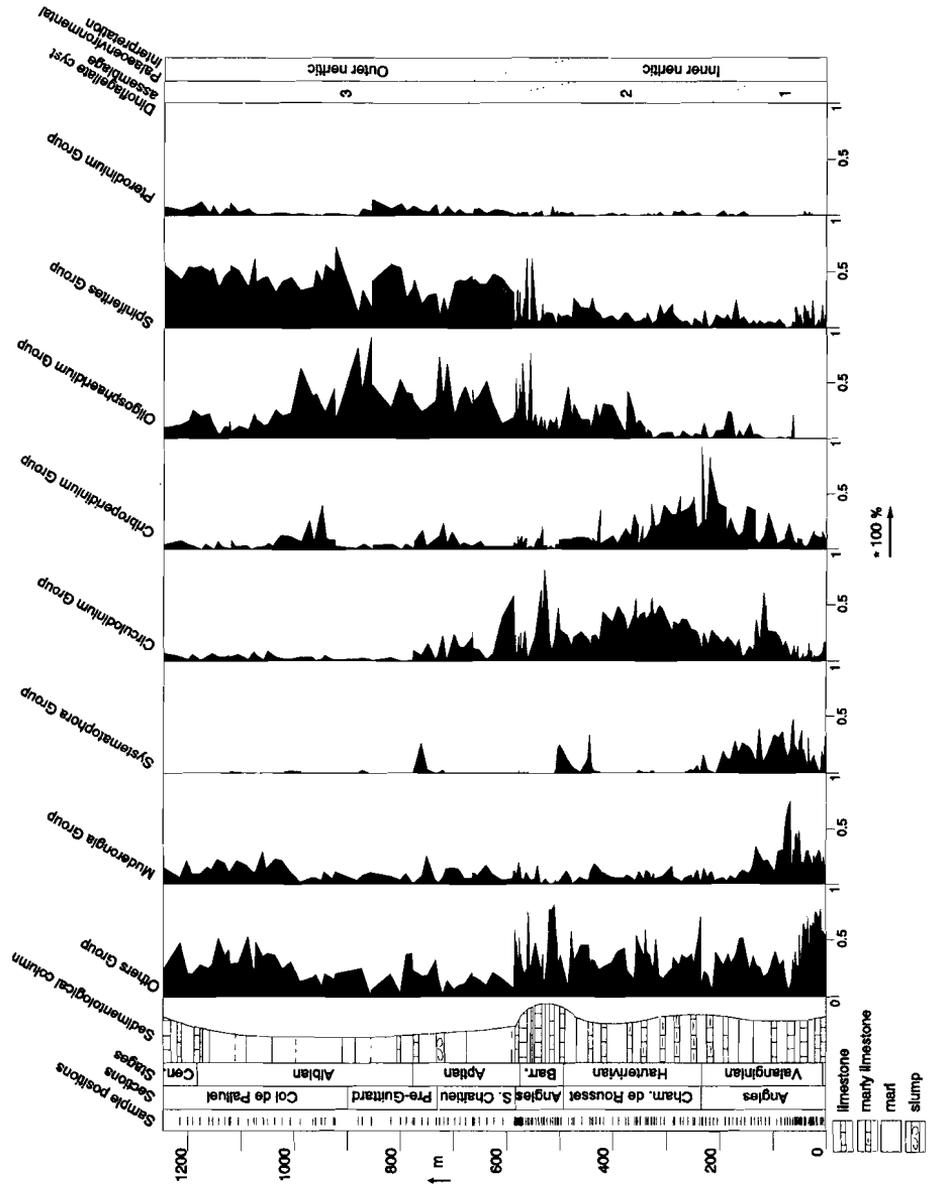
The distribution of these dinoflagellate cyst groups can be related to certain paleoenvironments:

Restricted shallow marine

High abundances of the *Muderongia* Group have been reported in sediments representing varying salinity conditions (e.g., Lister and Batten, 1988).

Figure 2: (next page) Frequency patterns of the seven dinoflagellate cyst groups and the 'Others Group' from 165 samples distributed along the Valanginian-Lower Cenomanian composite section.

- Palaeoenvironmental change: Vocontian Basin -



Inner neritic

High abundances of the *Systematophora*, *Cribroperidinium* and *Circulodinium* Groups are associated with inner neritic environments and restricted marine environments (e.g. May, 1980; Hunt, 1987; Noe-Nygaard *et al.*, 1987; Brinkhuis and Zachariasse, 1988; Lister and Batten, 1988; Omran *et al.*, 1990; Marshall and Batten, 1988).

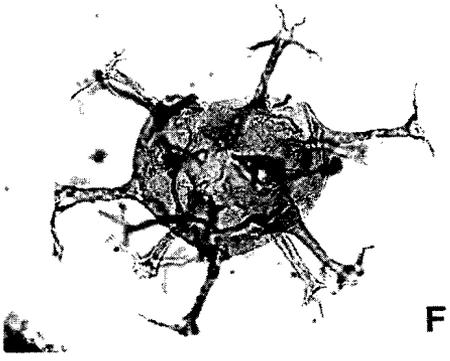
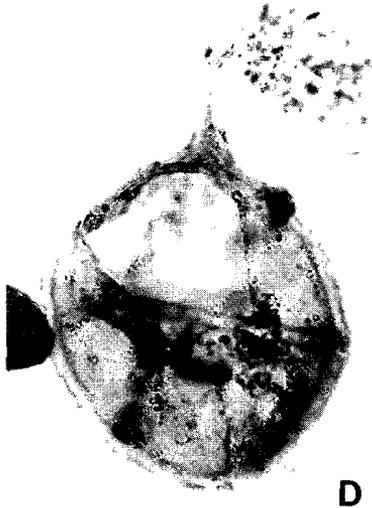
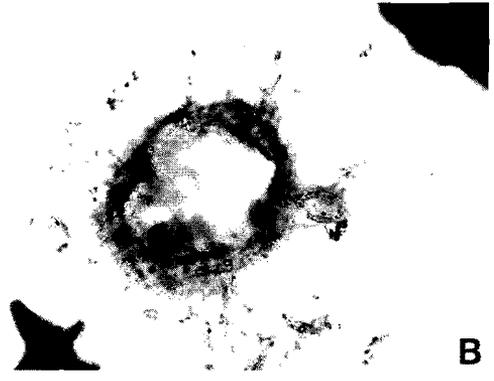
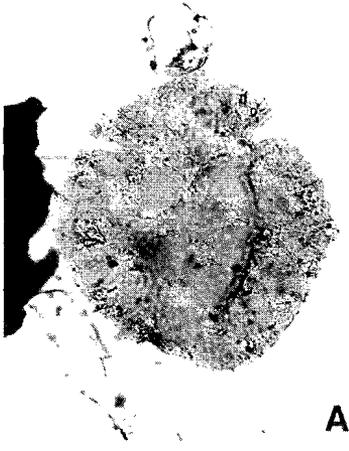
Neritic to outer neritic

The *Oligosphaeridium* Group comprises dinoflagellate cyst types with long processes which are indicative for open marine neritic conditions (e.g., May, 1980; Hunt, 1987; Lister and Batten, 1988; Smelror and Leereveld, 1989). The *Spiniferites* Group has extant representatives which reach their highest abundances in open marine neritic conditions (e.g., Davey and Rogers, 1975; Harland, 1983).

Oceanic

The *Pterodinium* Group is morphologically comparable with extant *Impagidinium spp.* which are typically well represented in oceanic waters (e.g., Wall *et al.*, 1977; Harland, 1983). Accordingly, consistent and frequent occurrences of representatives of this group are considered to reflect influences of oceanic waters.

Plate I: (next page) Representatives of the seven dinoflagellate cyst groups. Every representative is followed by a code denoting the slide, England Finder coordinates and the minimum and maximum dimension. (a) *Circulodinium* Group, CHAM 261, U68/3, 90-100 μm (b) *Systematophora* Group, JGB 1784 II, L44/3, 70-70 μm (c) *Muderongia* Group, AHAP 161 I, H40/3, 40-90 μm . (d) *Cribroperidinium* Group, JGB 2917 II, N41/4;O41/2, 70-120 μm (e) *Pterodinium* Group, AHAP 182 II, L36/1, 45-50 μm . (f) *Oligosphaeridium* Group, AHAP 82 I, J/35, 100-100 μm (g) *Spiniferites* Group, AHAP 151 I, P45/1;2, 40-50 μm . All slides are stored in the collection of the Laboratory of Paleobotany and Palynology of the University of Utrecht, The Netherlands.



RESULTS

The continental ratio of the total palynomorph association (i.e. percentage of sporomorphs) strongly fluctuates between 4% and 80 %, but without any large scale trend. The dominance and diversity curves of dinoflagellate cyst genera show no significant trend, either. The two most dominant genera per sample oscillate between 15 and 70 % of the total counted specimens throughout the studied interval. The number of genera per sample (diversity) fluctuates between 10 and 30.

The frequency patterns of the paleoenvironmentally important dinoflagellate cyst groups are depicted in Fig. 2. It is evident that certain dinoflagellate cyst groups successively dominate in the studied interval. The *Systematophora* Group dominates the Early Valanginian dinoflagellate cyst assemblages (Assemblage 1); this dominance is gradually replaced by dominance of *Cribroperidinium* and *Circulodinium* Groups (Assemblage 2); finally the *Oligosphaeridium* and *Spiniferites* Groups become the dominant components (Assemblage 3). Moreover, in the Aptian-Early Cenomanian the *Pterodinium* Group reaches its highest, although relatively low, frequencies. Note that the *Muderongia* Group is consistently and well represented throughout the whole column although this group attains its highest values in the Early Valanginian part of the sequence.

DISCUSSION

The distinct long-term quantitative compositional change (Fig. 2) may be considered to represent a basinwide signal for the following reasons: (1) The quantitative aspect of dinoflagellate cyst content of the Hauterivian Chamoloc de Rousset (this study) and Vergons sections (Londeix, 1990) is comparable; (2) The character of this large scale trend is not distinctly different from one section to the other. Furthermore, the compositional change of the Cenomanian-Turonian dinoflagellate cyst assemblages of the Vocontian Basin (Courtinat *et al.*, 1991) is an obvious continuation of the trend as recognised in the present study.

In the studied Valanginian-Lower Cenomanian interval, the basal part is dominated by dinoflagellate cyst groups (Assemblage 1 and 2) which are considered characteristic for inner neritic environments; the top part is dominated by dinoflagellate cyst groups (Assemblage 3) which are thought to represent outer neritic environments (see Fig. 2). Hence, if the dinoflagellate cyst assemblages are considered to represent the actual sedimentary environment, a maximum paleodepth of only a few hundred meters must be inferred. Such conditions are in contrast with some reconstructions of the Vocontian Basin during this time (e.g., Cotillon *et al.*, 1984) which imply that bathyal depths (around 1000

- Palaeoenvironmental change: Vocontian Basin -

meters or more) were achieved during this time. However, some sedimentological and palaeontological observations may provide supporting evidence for a less deeper setting. The relatively small width of the Vocontian Basin of approximately 150 km (De Boer, 1983) with bathyal depths in the centre and platform building at the margins implies the existence of a relatively steep slope. This would most probably have caused predominantly mass-transported sediments rather than the characteristic hemipelagic deposits of the Vocontian Basin (De Boer, 1983). Furthermore, the documented extensive progradation of the Barremian-early Aptian platforms towards the centre of the Vocontian Basin (Arnaud-Vanneau *et al.*, 1979; Arnaud-Vanneau and Arnaud, 1990; see also Fig. 1) is not likely to have occurred at bathyal depths (compare e.g., Bossilini, 1984; Eberli and Ginsburg, 1989). Moreover, the occurrence of ostracods with eyes in the Valanginian part of the Angles section can be considered to indicate a depth of less than 600 meters (Busnardo *et al.*, 1979). In addition, the high abundance of ammonites throughout the basin may also point towards sedimentary conditions less than 400 to 500 meters (Lehmann, 1976; Ziegler, 1983).

If a neritic paleoenvironment for the Vocontian Basin is accepted, the basinwide change from inner neritic to outer neritic dinoflagellate cyst assemblages may be considered to reflect an Early Cretaceous rise in sea level. This relative rise corresponds to the Early Cretaceous part of the second order eustatic curve of Haq *et al.* (1988). The slightly elevated Aptian-early Cenomanian abundance of the *Pterodinium* Group can be regarded to represent increasing influence of oceanic watermasses in response to this second order rise in sea level. The consistent and frequent presence of representatives of the *Muderongia* Group is considered to reflect continuous transport of restricted shallow marine material towards the Vocontian Basin.

CONCLUSIONS

The quantitative composition of the Early Cretaceous dinoflagellate cyst assemblages of the Vocontian Basin may be considered to indicate inner neritic to outer neritic paleoenvironments with transported restricted shallow marine material and minor oceanic influences. Consequently, a maximum paleodepth of only a few hundred meters is inferred, considerably less than earlier proposed bathyal depths (e.g. Cotillon *et al.*, 1984). This study shows that there is no evidence to refer to the Vocontian Basin as the Vocontian Trough ("Fosse Vocontienne"). An Early Cretaceous relative rise in sea level is concluded from the basinwide long-term quantitative compositional change in the dinoflagellate cyst assemblage. This relative rise corresponds to the second order eustatic curve of Haq *et al.* (1988).

CHAPTER 1.2

DIRECT STRATIGRAPHIC CORRELATION OF SELECTED INTERVALS IN THE CARBONATE PLATFORM DEVELOPMENT OF THE VERCORS PLATEAU (SE FRANCE) WITH THE BARREMIAN STRATOTYPE BY MEANS OF DINOFLAGELLATE CYSTS

ABSTRACT

Several spot samples from selected intervals in the Barremian-lower Aptian carbonate platform development of the Vercors Plateau (SE-France) at the Pas de Berrieves, the Montagnette and the Archiane valley were examined for their dinoflagellate cyst content. Using qualitative data, a direct correlation with stratigraphic occurrences of dinoflagellate cysts in the Barremian stratotype in the adjacent Vocontian Basin is established. Based on the concurrent presences of the diagnostic species *Pseudoceratium retusum*, *Cerbia tabulata* and *Odontochitina operculata* a late Barremian age for these spot samples has been inferred. This assessment is not in accordance with the previously interpreted early Barremian age for the sediments from these localities. This controversy might be due to lack of ammonite information from the middle part of the Barremian stratotype section and the resulting poorly defined lower-upper Barremian boundary.

INTRODUCTION

A detailed stratigraphy for the Barremian part of the Vercors carbonate platform in SE-France must obviously provide a correlation with the Barremian stratotype which is defined in the adjacent Vocontian Basin (Busnardo, 1965). A major problem for the biostratigraphical correlation between the shallow water setting of the Vercors carbonate platform and the deeper water setting of the Barremian stratotype is the limited overlap in the strongly environmental controlled fossil assemblages such as ammonites and foraminifers.

Occurrences of ammonites, important as being the fossil group defining the Tethyan Cretaceous stages and substages, are extremely rare in carbonate platform settings. Moreover, in more ideal settings as the Vocontian basin the chance to find high abundances of ammonites is little, e.g. for the middle part of the Barremian stratotype no diagnostic ammonites were collected (Busnardo, 1965). The biostratigraphy for the Barremian platform development in the Vercors area is mainly based on benthonic foraminifers (Arnaud, 1981). Their distribution is even more environmentally controlled and therefore not well suited for direct correlation with the Barremian stratotype (compare Magniez-Jannin, 1991 and Arnaud, 1981). The problem of correlation is reflected in controversial stratigraphic interpretations of the Vercors carbonate platform (e.g. Arnaud, 1981; Clavel *et al.*, 1987).

Lately the exposures of the Vercors carbonate platform have been interpreted and correlated by means of sequence stratigraphy with the Barremian stratotype. This approach did not solve the problem for a detailed stratigraphy since (1) the geometric relations from the Vercors carbonate platform towards the Barremian stratotype are not basin wide bed-to-bed exposed, and (2) the sequence stratigraphic interpretations of the carbonate platform development in the Vercors area (see Arnaud-Vanneau and Arnaud, 1990; Jacquín *et al.*, 1991) differ as well as the interpretation of the Barremian stratotype (see Ferry and Rubino, 1989; Jacquín *et al.*, 1993).

Despite the paleoecologically controlled distribution of dinoflagellates, their cysts are dispersed basin wide due to the (1) planktonic as well as benthonic stages in their life cycle and (2) specific hydrodynamic characteristics of dinoflagellate cysts (e.g. Wall *et al.*, 1977). This implies that dinoflagellate cyst assemblages from different sedimentary facies realms can be directly correlated. Direct stratigraphic correlation of the carbonate platform of the Vercors area with the Barremian stratotype by means of dinoflagellate cysts has not been established. The Barremian stratotype has been studied with emphasis on dinoflagellate cyst by Renéville and Raynaud (1981) and Srivastava (1984); the latter also included other Barremian sections of the Vocontian basin. The purpose of the present study is a biostratigraphic correlation of spot samples from the Vercors area with the pelagic Barremian

- Stratigraphic correlation: Vercors Area with Barremian stratotype -

stratotype section by means of dinoflagellate cysts to evaluate the different stratigraphic interpretations of earlier studies.

MATERIAL AND METHODS

In the Vercors area three exposures have been sampled: Pas de Berrieves, Montagnette and the Archiane valley (Figure 1). The spot sample of the Pas de Berrieves is taken from a distinct marly layer of a few meters thick (Figure 2; see Jacquin *et al.*, 1993, figure 5.07). Montagnette 1 is set a hundred meters northwest from the Ranconnet mountain. Montagnette 2 originates from a small valley a few hundred meters south of the top of the Ranconnet (Figure 3; see Arnaud-Vanneau and Arnaud, 1990, figure 9). Three spot samples were taken from the Archiane valley: Archiane 1 and 2 originate from the eastern slope of the valley (Figure 4; see Jacquin *et al.*, 1991, figure 18) and are respectively the base and top sample of the "platform-flank" section described by Everts *et al.* (in press). Archiane A is collected in the northern part of the Archiane valley; this sample is set in a shale layer of a few centimetres thick along a track going north in the valley near the foot of a little mountain called 'Tête du petit Jardin' and just underneath some graffiti text.

A detailed biostratigraphy for the carbonate platform of the Vercors area based on benthonic foraminifers was established by Arnaud (1981). A revised version was presented by Arnaud-Vanneau and Arnaud (1990). Arnaud (1981) defined six stratigraphic members in the early Barremian belonging to one formation, the 'Glandasse bioclastic limestone'. The Vercors samples investigated in the present study originate from this 'Glandasse bioclastic limestone' whereby the position of the Archiane 1 and 2 and Montagnette 1 and 2 correspond with the fifth member (Bi 5 of Arnaud, 1981, see Figure 5). Lately, a specimen of the ammonite *Moutinoceras* has been found at Montagnette (pers. comm. L. Bulot, 1993). Although this ammonite is correlatable with the latest early Barremian ammonite zone, *Caillaudianus* Zone (Hoedemaeker and Company *et al.*, 1993), its latest occurrence corresponds to the earliest late Barremian (Cotillon *et al.*, 1984).

A detailed sequence stratigraphic interpretation of the platform in the Vercors area was established by Jacquin *et al.* (1991) and a revised version was presented in Jacquin *et al.* (1993). They recognised 3 sequences in the lower Barremian (Figure 5). Samples Archiane A, Montagnette 1 and 2 originate from the second sequence. The other samples are interpreted to belong to the third sequence (Figure 5).

The biostratigraphic correlation of the spot samples is primarily based on qualitative dinoflagellate cyst information from the Barremian stratotype. In order to obtain a firm dinoflagellate cyst stratigraphy for correlation, the ranges of important markers were refined

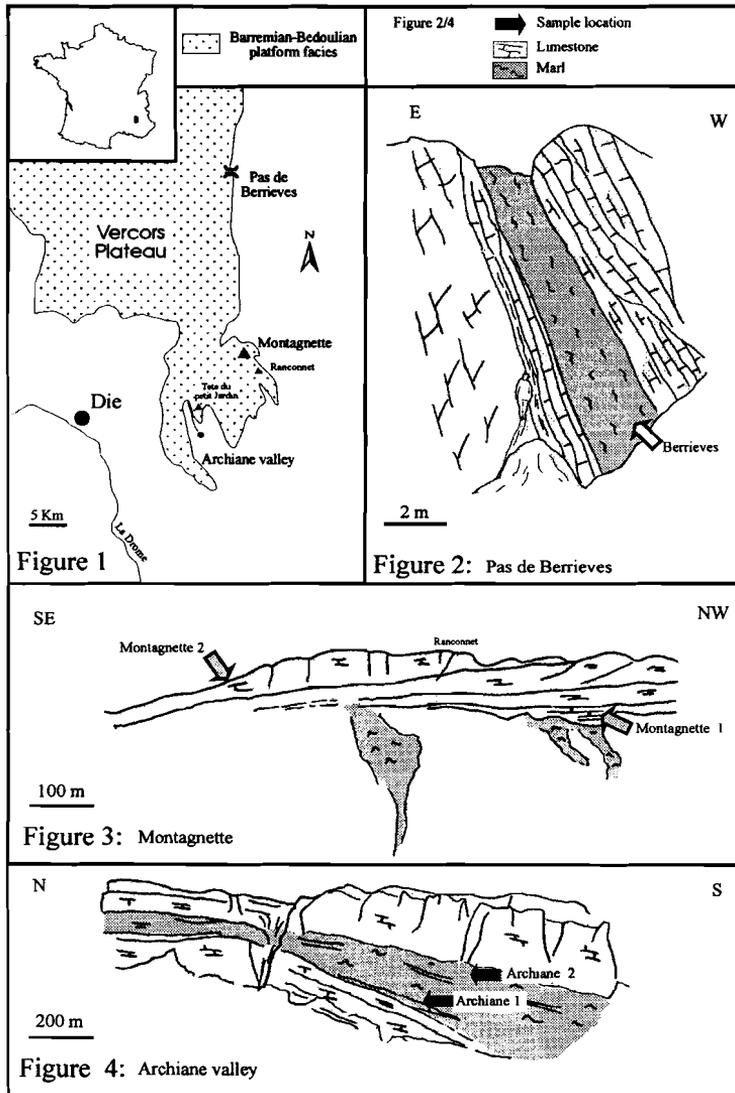
- Chapter 1.2 -

(compare Renéville and Raynaud, 1981, Srivastava). For this purpose the Barremian stratotype section has been sampled bed by bed with a total of about 140 samples. The applied ammonite stratigraphy corresponds with the standard ammonite zonation for the Tethyan realm from Hoedemaeker and Company *et al.* (1993). The ammonite zonation of the Barremian stratotype in Figure 5 is an unpublished revised version after Busnardo (1965; written comm. Ph. J. Hoedemaeker, 1994). It is here stressed that diagnostic ammonites have not been reported from the "mid"-Barremian interval (Figure 5, hatched interval) in the stratotype section and that the lower-upper Barremian boundary has been tentatively placed in bed number 136 (Busnardo, 1965).

The samples were processed according to palynological standard preparation techniques (HCl and HF treatment, heavy liquid separation, sieving of residue using a 25 μ m sieve and mounting). It is beyond the scope of the present paper to focus on quantitative results of the palynological analysis. The spot samples were qualitatively analyzed for their dinoflagellate cyst content and the samples of the Barremian stratotype were examined for their stratigraphically diagnostic dinoflagellate cyst taxa. All slides are stored in the collection of the Laboratory of Paleobotany and Palynology at the Utrecht University.

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- Figure 1: (next page) Location map of the Vercors plateau (after Arnaud, 1981).
Figure 2: (next page) Sketch of the Pas de Berrieves outcrop with sample location indicated.
Figure 3: (next page) Sketch of the Montagnette outcrop with sample location indicated.
Figure 4: (next page) Sketch of the eastern side of the Archiane valley with sample location indicated.

- Stratigraphic correlation: Vercors Area with Barremian stratotype -

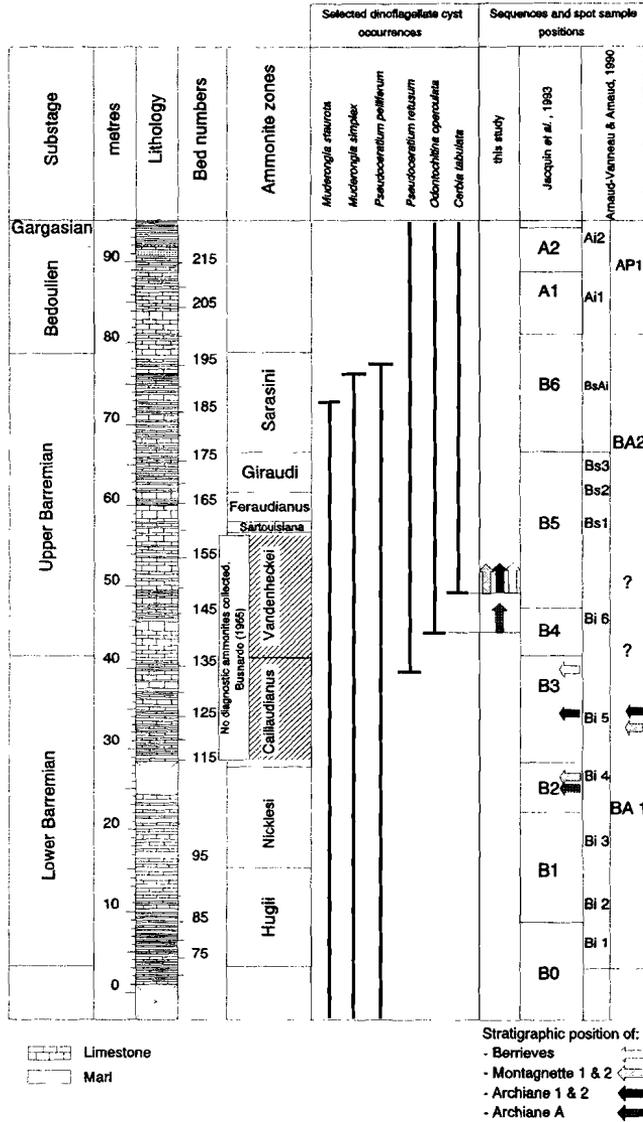


RESULTS AND DISCUSSION

The qualitative results of the analysis of the Vercors samples are presented in Table 1 and are below compared with the refined dinoflagellate cyst stratigraphy of the Barremian stratotype. For citations of the dinoflagellate cyst taxa (Table 1) is referred to Lentin and Williams (1993). After evaluation of the first occurrences (FO) and last occurrences (LO) in the Barremian stratotype, the following six stratigraphic events were identified (Figures 5 and 6). (1) *Cerbia tabulata* has its FO in bed number 149, i.e. several beds lower than reported by Renéville and Raynaud (1981). Although *Cerbia tabulata* is not found below bed 149 in the Barremian stratotype it is reported from uppermost lower Barremian sediments in the Rio Argos section in southern Spain (pers. comm. H. Leereveld, 1993), and from the "mid" Barremian in Speeton, England (Duxbury, 1977) and basal upper Barremian sediments of Great Britain (Costa and Davey, 1992). (2) After critical examination *Odontochitina operculata* has its FO in bed 142; this is higher than the record of Renéville and Raynaud (1981), but coincides with their first high abundance peak of the species. The inception of *O. Operculata* in the 'middle' Barremian is in agreement with the opinion of Duxbury (1980, p. 138). (3) The FO of *Pseudoceratium retusum* has been recorded in bed number 134 of the stratotype (*Aptea polymorpha* in Renéville and Raynaud, 1981, plate 2, figure 12 is here considered to be a representative of *P. retusum*). Srivastava (1984) recorded *P. retusum* from upper Barremian Vocontian basin sediments. (4) The LO of *Muderongia staurota* is found higher in the Barremian stratotype than reported in Renéville and Raynaud (1981). (5) The LO of *M. simplex* is in accordance with the record of Renéville and Raynaud (1981). (6) The LO of *Pseudoceratium pelliferum* is found higher in the Barremian stratotype than reported in Renéville and Raynaud (1981).

Figure 5: (next page) Correlation scheme of the Barremian stratotype section with bed numbers (after Busnardo, 1965), Tethyan ammonite zones (Hoedemaeker and Company *et al.*, 1993) hatched interval indicating interval where no diagnostic ammonites were collected (Busnardo, 1965), selected dinoflagellate cyst ranges, sequences identified by Jacquin *et al.* (1993) and Arnaud-Vanneau and Arnaud (1990) in the Vercors Plateau and indication of the studied intervals of the platform development according to the latter authors and as proposed here.

- Stratigraphic correlation: Vercors Area with Barremian stratotype -



CONCLUSIONS

The stratigraphic occurrences of selected dinoflagellate cyst taxa in the spot samples of the Archiane valley, Montagnette and Pas de Bervieres exposures in the carbonate platform development of the Vercors area can be directly correlated with the pelagic succession in the Barremian stratotype. A fine stratigraphic assessment of the studied intervals of the Vercors Plateau based on dinoflagellate cysts, however, is hampered by lack of detailed ammonite information of the lower-upper Barremian boundary interval for the Barremian stratotype. Correlation of stratigraphic significant dinoflagellate cyst events in SE France (e.g. FO of *Cerbia tabulata*) with those in other areas (e.g. S Spain, Great Britain) suggests the position of the lower-upper Barremian boundary in the stratotype to be placed a little too low by Busnardo (1965). If the position of the lower-upper Barremian boundary is considered in agreement with Busnardo (1965) then the studied intervals of the carbonate platform development of the Vercors area correlate with the upper Barremian. This conclusion is at variance with the early Barremian age inferred in former publications (Arnaud, 1981; Clavel, 1987; Jacquin *et al.*, 1991).

Table I: (next page) Dinoflagellate cyst taxa from five spot samples in the Vercors area.

- Stratigraphic correlation: Vercors Area with Barremian stratotype -

	Berrievae	Montagnette 2	Archiliane 1	Archiliane 2	Archiliane A	Dinoflagellate cyst taxa	References according to Lentini and Williams 1993
1						<i>Batioladinium micropodium</i>	(Elsneck & Cookson, 1960) Brideaux 1975
2	x	x	x	x	x	<i>Calliaosphaeridium asymmetricum</i>	(Deflandre & Courteville, 1939) Davey & Williams 1966b
3	x	x	x	x	x	<i>Cerbia tabulata</i>	(Davey & Verdier, 1974) Below 1981a
4						<i>Chlamydothorea nysii</i>	Cookson & Elsneck 1958
5	x	x	x	x	x	<i>Chlamydothorea spp.</i>	
6						<i>Chytrosphaeridia spp.</i>	
7	x	x	x	x	x	<i>Circulodinium spp.</i>	
8	x	x	x	x	x	<i>Cleistosphaeridium spp.</i>	
9						<i>Cometodinium ?whitei</i>	(Deflandre & Courteville, 1939) Stover & Evtitt 1976; emend. Montell 1991a
10		x				<i>Coronifera albertii</i>	Milloud 1969
11	x	x	x	x	x	<i>Coronifera oceanica</i>	Cookson & Elsneck 1958; emend. May 1980
12	x	x	x	x	x	<i>Cribroperidinium spp.</i>	
13	x	x	x	x	x	<i>Ctenodinium elegantulum</i>	Milloud 1969; emend. Below 1981a
14						<i>Dapsilidinium warrenii</i>	(Habib, 1976) Lentini & Williams 1981
15		x	x			<i>Dingodinium cerviculum</i>	Cookson & Elsneck 1958
16						<i>Endoscrinium bessebae</i>	Below 1981a
17	x					<i>Endoscrinium campanula</i>	(Gocht, 1959) Vozzhennikova 1967
18		x				<i>Florentinia mantelli</i>	(Davey & Williams, 1966b) Davey & Verdier 1973
19	x					<i>Florentinia spp.</i>	
20						<i>Gonyaulocysta cassidata</i>	(Elsneck & Cookson, 1960) Sarjaent 1966b
21						<i>Gonyaulocysta spp.</i>	
22		x				<i>Hystichodinium pulchrum</i>	Deflandre 1935
23	x	x	x	x	x	<i>Hystichosphaerina schirdehoffii</i>	Albert 1961
24						<i>Klokansium polypes</i>	(Cookson & Elsneck, 1962b) Below 1982c
25	x	x	x	x	x	<i>Kleithrasphaeridium spp.</i>	
26						<i>Luxadinium primum</i>	Brideaux & McIntyre 1975
27	x					<i>Muderongia asymmetrica</i>	Brideaux 1977; emend. Montell 1991b
28						<i>Muderongia spp.</i>	
29	x	x	x	x	x	<i>Muderongia neocomica</i>	(Gocht, 1957) Montell 1991b
30	x	x	x	x	x	<i>Muderongia simplex</i>	Albert 1961; emend. Montell 1991b
31	x	x	x	x	x	<i>Muderongia steurota</i>	Sarjaent 1966c; emend. Montell 1991b
32	x	x	x	x	x	<i>Muderongia tomaszowensis</i>	Albert 1961; emend. Montell 1991b
33	x	x	x	x	x	<i>Odontochitina operculata</i>	(O. Wetzel, 1933a) Deflandre & Cookson 1958
34	x	x	x	x	x	<i>Oligosphaeridium complex</i>	(White, 1842) Davey & Williams 1966b
35	x	x	x	x	x	<i>Ovoidinium diversum</i>	Davey 1979b
36	x	x	x	x	x	<i>Pseudoceratium pelliterum</i>	Gocht 1957a; emend. Dörhöfer & Davies, 1980
37	x	x	x	x	x	<i>Pseudoceratium retusum</i>	Brideaux, 1966
38						<i>Pterodinium spp.</i>	
39						<i>Rhynchodiniopsis aptians</i>	Deflandre 1935
40	x	x	x	x	x	<i>Spiniferites spp.</i>	
41	x	x	x	x	x	<i>Subtilisphaera spp.</i>	
42	x	x	x	x	x	<i>Subtilisphaera terrula</i>	(Davey, 1974) Lentini & Williams 1976; emend. Harding 1986a
43						<i>Systematophora complicata</i>	Neale & Sarjaent 1962
44	x					<i>Systematophora silybum</i>	Davey 1979a
45		x	x	x	x	<i>Systematophora spp.</i>	
46	x	x	x	x	x	<i>Tanyosphaeridium isocalamus</i>	(Deflandre & Cookson, 1955) Davey & Williams 1969
47	x	x	x	x	x	<i>Tanyosphaeridium magneticum</i>	Davies 1983
48	x	x	x	x	x	<i>Tanyosphaeridium regulare</i>	Davey & Williams 1966b
49	x					<i>Tanyosphaeridium varicolum</i>	Davey & Williams 1966b
50						<i>Trichodinium castanea</i>	(Deflandre, 1935) Clarke & Verdier 1967
51						<i>Valensielia reticulata</i>	(Davey, 1969a) Courtinat 1989
52	x					<i>Waliodinium krutzschii</i>	(Albert, 1961) Habib 1972

Figure 6: (next page) Diagnostic dinoflagellate cyst species. The species name is followed by the sample location, slide-code and England Finder coordinates, respectively.

(A/B) *Odontochitina operculata*, Archiane A, Aix 7D, T29/4.

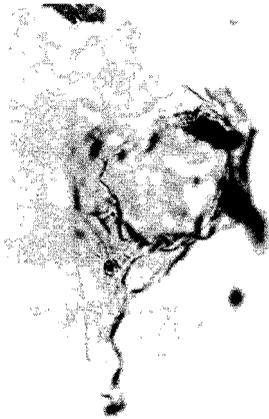
(C) *Pseudoceratium retusum*, Montagnette 1, Aix 41D, X28.

(D/E) *Odontochitina operculata*, Berrieves, Dijon11 Jan2, J26/2.

(F/G) *Pseudoceratium pelliferum*, Archiane A, Aix 7A, H30/4.

(H/I) *Odontochitina operculata*, Berrieves, Aix 46 II, T43/U43.

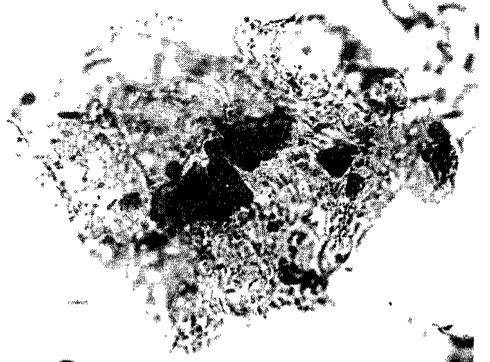
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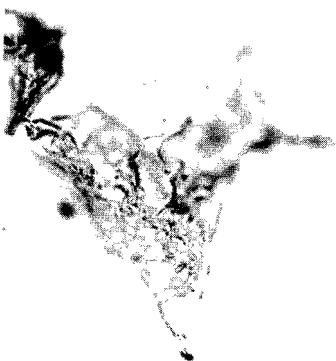
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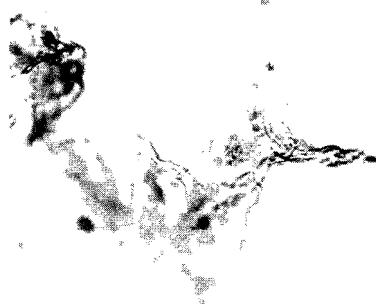
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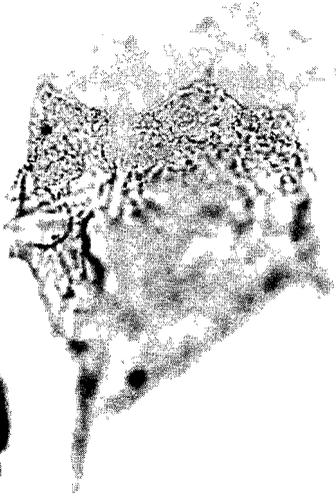
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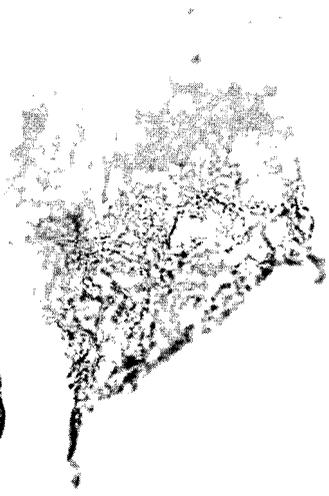
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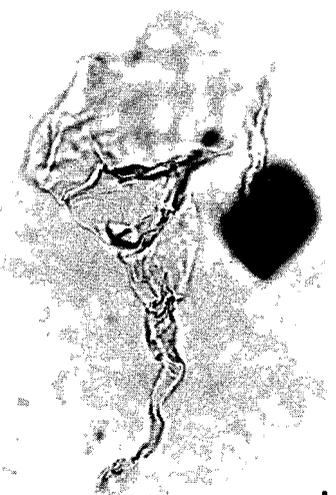
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F



G



I

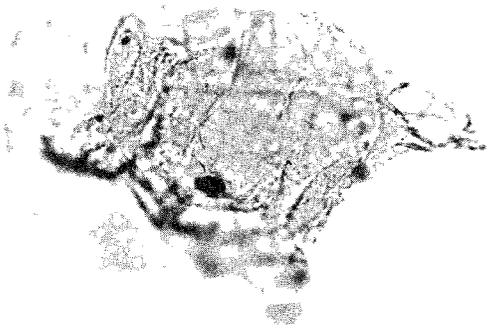
Figure 7: (next page) Diagnostic dinoflagellate cyst species. The species name is followed by the sample location, slide-code and England Finder coordinates respectively. Same scale as Figure 6.

(J/K) *Muderongia simplex*, Archiane A, Aix 7B, V32.

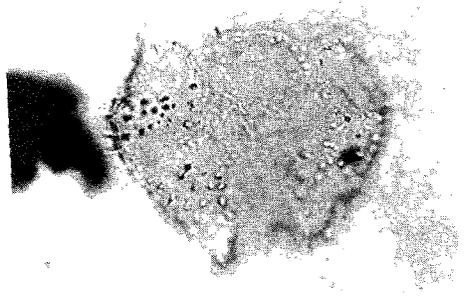
(L/M) *Cerbia tabulata*, Archiane 2, 92D126 II, M45/3.

(N/O) *Pseudoceratium retusum*, Berrieves, Aix 46B, J45/J46.

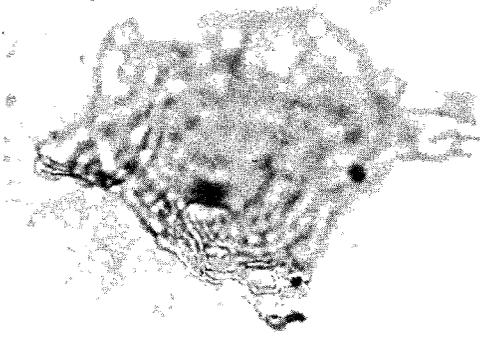
(P/Q) *Cerbia tabulata*, Montagnette 1, Aix 41 A, E42/2.



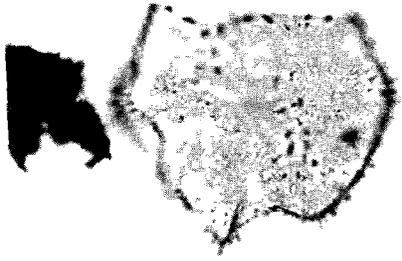
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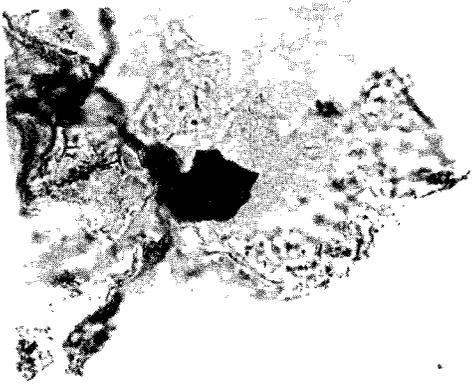
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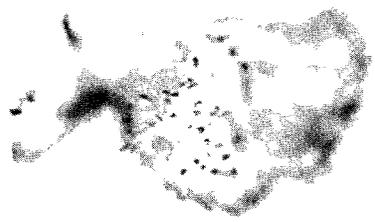
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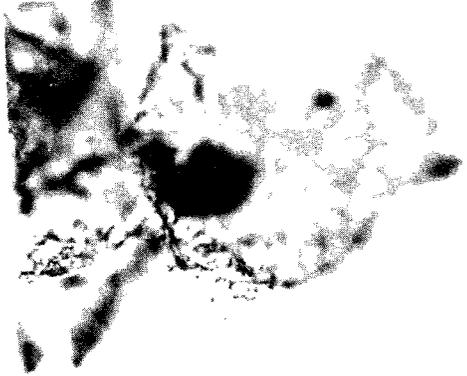
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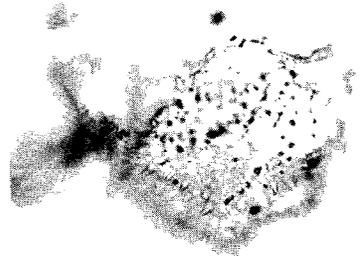
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P



O



Q

CHAPTER 1.3

EARLY CRETACEOUS SEDIMENTARY AND TECTONIC DEVELOPMENT OF THE DAUPHINOIS BASIN (SE-FRANCE)

ABSTRACT

A subsidence analysis is applied to two Valanginian - Albian composite columns of the Dauphinois Basin (SE France); one for the deeper part of the Dauphinois Basin (Vocontian Basin) and one for its marginal setting (Vercors Area). Within the Valanginian - Albian interval, three phases of subsidence can be recognised: (1) a Valanginian-Hauterivian phase characterised by relatively uniform tectonic subsidence patterns; (2) a Barremian - Gargasian phase characterised by profound shifts in subsidence; (3) a Clansayesian - Albian phase characterised by relatively small rates of tectonic subsidence or uplift. The Barremian - Gargasian phase can be further subdivided in three subphases viz. (a) Uplift during the Early Barremian; (b) Subsidence during the Late Barremian to Bedoulian; (c) Virtually no subsidence of the Vercors Area and subsidence of the Vocontian Basin during the Gargasian. This Barremian - Gargasian phase is related to compressional stress build up as a result of the changing tectonic regime of the Piemonte-Ligurian Ocean from extension to compression. As a consequence the Barremian - Gargasian tectonic phase forces the onset, progradation and eventual disappearance of extensive carbonate platforms at the margin of the Dauphinois Basin. It implies that these carbonate platforms document the very first sedimentary response to the changing tectonic regime. Vertical motions induced by such a changing tectonic regime in particular determine the regional sea-level curves established for these carbonate platforms and related basinal facies rather than global sea level changes.

INTRODUCTION

In southeastern France, Jurassic and Early Cretaceous marine sedimentation patterns are largely determined by the development of the Dauphinois Basin, that separates the stable Jura-Bas Dauphiné and Provence Platforms (Fig. 1). Basin formation took place as a response to Early to Middle Jurassic rifting and a subsequent spreading phase that resulted in the opening of the Piemonte-Ligurian oceanic segment of the Mesozoic Tethys (e.g. Baudrimont and Dubois, 1977; Lemoine et al, 1986; Lemoine and Graciansky, 1988), separating the European and Apulian-Adriatic continental plates.

As an isostatic response to crustal thinning, during the Middle and Late Jurassic the European passive margin of the Piemonte-Ligurian oceanic realm subsided rapidly (Roux *et al.*, 1988; Rudkiewicz, 1988), resulting in the individualisation of the Dauphinois Basin. Such a phase of rapid subsidence is generally followed by lower subsidence rates determined by a regional return to thermal equilibrium (McKenzie and Sclater, 1969; McKenzie, 1978; Angevine *et al.*, 1990). In the Dauphinois Basin, the Early Cretaceous sedimentary record has been interpreted to correspond to decreased subsidence (Lemoine et al, 1986). The change in the Aptian from carbonate-dominated sediments to more terrigenous-dominated sediments, as recognised throughout the Piemonte-Ligurian oceanic segment (e.g. Galbiati 1985; Cresta et al, 1989), has been considered to mark the sedimentary response to the subsequent onset of a compressional tectonic regime in the Mediterranean (Van Wamel, 1987; Debelmas, 1989; Hoogerduijn Strating, 1991) related to spreading in the Central Atlantic domain (e.g. Dercourt et al, 1986; Ziegler, 1987). Although this overall scenario of basin evolution may be correct, results of subsidence analysis and sequence stratigraphy of Early Cretaceous carbonate platform successions (e.g. Arnaud, 1988; Arnaud-Vanneau and Arnaud, 1990; Jacquin *et al.*, 1991) along the margin of the Dauphinois Basin strongly indicate that notably the precise timing of the onset of a compressional regime may need reconsideration.

An extensive formation of prograding carbonate platforms took place on the margins of the Dauphinois Basin during Barremian to Early Aptian times (e.g., Arnaud-Vanneau *et al.*, 1979; Cotillon *et al.*, 1984; Masse, 1993). The onset and development of these platforms have been related to a distinctive Early Barremian regression, followed by a prolonged period of sea-level lowstand (e.g. Arnaud-Vanneau and Arnaud, 1990; Jacquin *et al.*, 1991). However, this picture does not correspond to the concept of a global Barremian-Early Aptian sea-level highstand established by Haq *et al.* (1988). In order to explain regional sea-level curves that significantly deviate from the global trend, superimposed effects of regional tectonic activity should be taken into consideration (e.g., Cloetingh, 1988). According to Bosellini (1989) tectonics should even be regarded as the dominant control for Tethyan

carbonate platform developments.

In the Dauphinois Basin, the presence of significant pre-Aptian tectonic activity has been convincingly inferred from unconformities in Early Barremian carbonates (Jacquin *et al.*, 1991), as well as from marked differences in sediment accumulation rates defined as the Barremian crisis (Arnaud, 1988). However, despite these observations and the fact that Arnaud (1988) relates the Barremian crisis to an echo of the beginning of the spreading of the near Atlantic (Boilot *et al.*, 1986), the role of tectonics for the Barremian-Early Aptian carbonate platform development in SE-France has not been emphasised, and no comprehensive model of Early Cretaceous geodynamic evolution has been proposed for the Dauphinois Basin.

An important tool in constructing a geodynamic model is the use of the backstripping method that enables the detection of tectonically driven basement subsidence through time (e.g. Steckler and Watts, 1978; Bond and Kominz, 1984). Backstripping has been applied by Jacquin *et al.* (1991) for the Early Cretaceous carbonates of the Vercors Area, located at the margin of the Dauphinois Basin (Fig. 1). However, to arrive at a conceptual model of regional geodynamic evolution, complementary subsidence analysis of the deeper part of the Dauphinois Basin, the so-called Vocontian Basin, is a prerequisite. In the present paper such an analysis is presented with emphasis on the detection and interpretation of tectonically induced subsidence and sedimentation patterns that may reflect the onset of a compressional regime in SE France.

MATERIAL

Vocontian Basin

The composite Valanginian-Albian column from Wilpshaar and Leereveld (1994) is used as the basis for the subsidence analysis of the deeper part of the Dauphinois Basin, the Vocontian Basin (Fig. 1). Early Cretaceous sediments in the Vocontian Basin consist primarily of pelagic limestone-marl alternations which can be traced basin wide (Cotillon *et al.*, 1980; Bréheret, 1988). Accordingly, the composite column used herein is considered to represent the development of the Vocontian Basin during the Valanginian-Albian. The studied sections of the composite column are biostratigraphically controlled by ammonites (Busnardo, 1965; Moullade, 1966; Busnardo *et al.*, 1979; Delamette *et al.*, 1986; Arnaud, 1981 and Arnaud-Vanneau *et al.*, 1987). Definition and subdivision of the Early Cretaceous stages and substages are adopted from Hoedemaeker and Company *et al.* (1993).

Vercors Area

The development of the southern and northern marginal areas of the Dauphinois Basin is comparable (e.g. Arnaud-Vanneau and Arnaud, 1990; Masse, 1993). For the basin analyses the northern Vercors composite Valanginian-Albian column from Arnaud (1988) is chosen as representative of these marginal areas (Figure 1); the stage and substage indications from Arnaud (1988) are adopted (Table II).

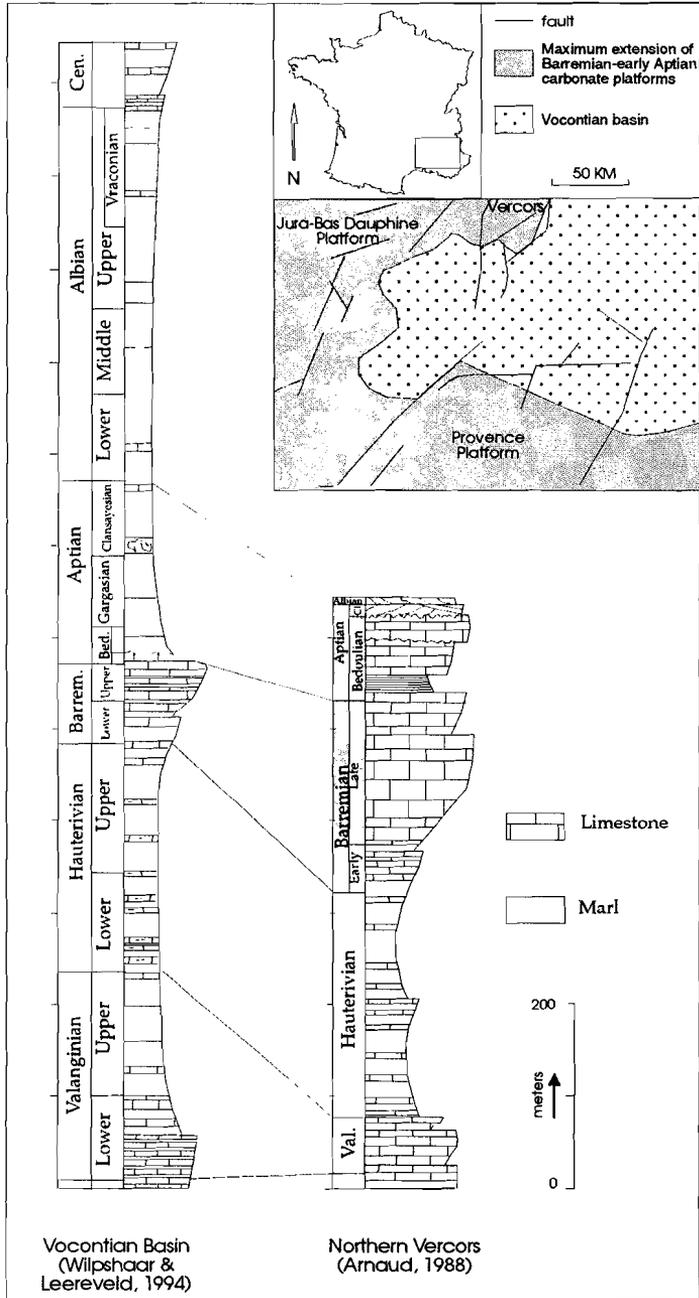
METHODS

In the subsidence analysis of the present study the tectonic component is reconstructed using methods discussed by Steckler and Watts (1978), Sclater and Christie (1980) and Bond and Kominz (1984). Lithostratigraphic units are defined in order to apply a backstripping program. Apart from an early and late subdivision for the Bedoulian of the Vocontian Basin, substage boundaries have been employed to define lithostratigraphic units (Table I and II). Substage boundaries are calibrated against the timescale of Haq *et al.* (1988). Note that the early-late Bedoulian unconformity of the Angles section is correlated with the major sea-level fall at 112 Ma of Haq *et al.* (1988; Table I). For each lithostratigraphic unit a silt, shale and carbonate percentage has been estimated (Table I and II). These percentages are used in order to predict minimum and maximum limits of lithological unloading effects for basement and tectonic subsidence, using porosity-depth relations from Bond and Kominz (1984).

A subsidence diagram corrected for sediment loading only, so-called burial history diagrams, automatically reveals a continuous subsidence pattern which is primarily a reflection of sediment accumulation rates. Subsidence diagrams also corrected for water loading and eustatic sea-level variations, so-called geohistory analysis, describe the absolute tectonic subsidence pattern.

Figure 1. (next page) Simplified geological map of southeast France showing the Dauphinois Basin and maximum extension of Barremian-early Aptian carbonate platforms. Composite column for the deeper part of the Dauphinois Basin, the so-called Vocontian Basin, from Wilpshaar and Leereveld (1994) and a composite column representing the northern Dauphinois Basin's margin of the Vercors Area (after Arnaud, 1988). Used abbreviations for substages: Bed. (Bedoulian); Cl. (Clansayesian).

- Early Cretaceous development of the Dauphinois Basin -

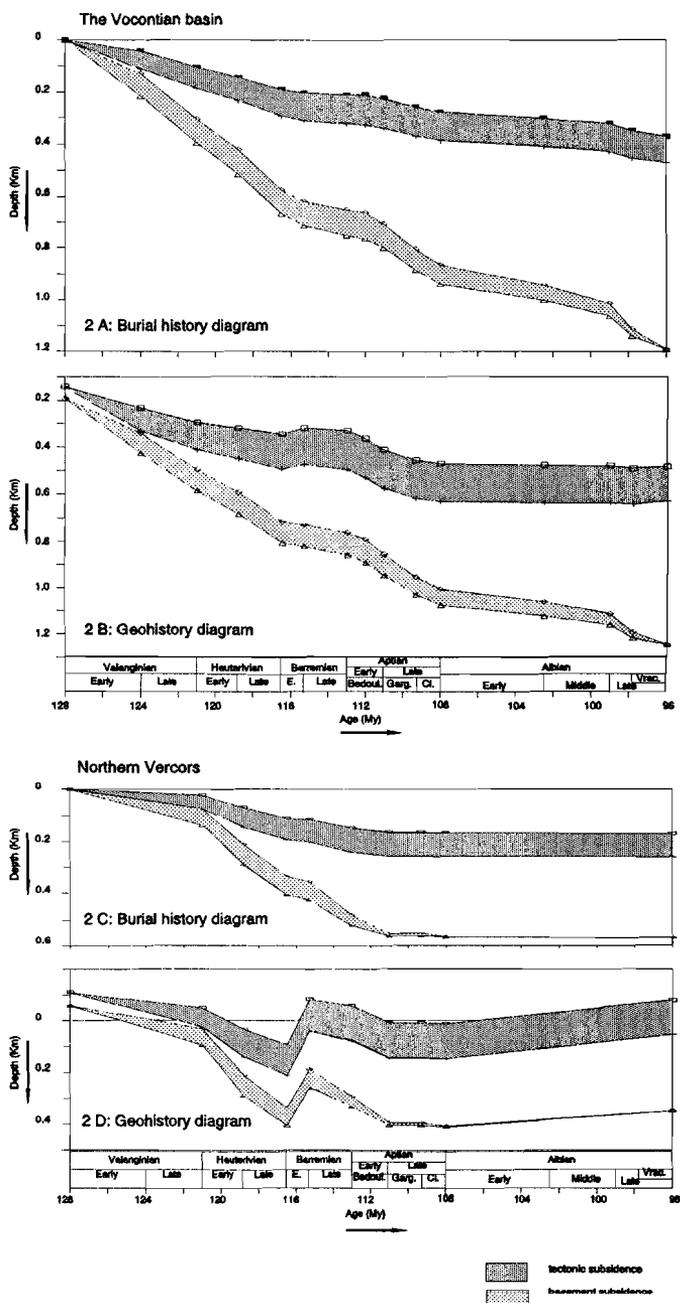


A paleobathymetrical estimate for the Vocontian Basin is inferred from quantitative dinoflagellate cyst distribution patterns from Wilpshaar and Leereveld (1994, Fig. 1); these basin wide patterns indicate a waterdepth of maximally a few hundred meters. This depth estimate contrasts some reconstructions of the Vocontian Basin during this time (e.g., Cotillon *et al.*, 1984) which suggest that bathyal depths (around 1000 meters or more) were achieved. However, some sedimentological and paleontological observations provide supporting evidence for a less deeper setting. The relatively small width of the Vocontian Basin of approximately 150 km with bathyal depths in the centre and platform building at the margins implies the existence of a relatively steep slope. This would most probably have caused predominantly mass-transported sediments rather than the characteristic hemipelagic deposits of the Vocontian Basin (De Boer, 1983). Furthermore, the documented extensive progradation of the Barremian-early Aptian platforms towards the centre of the Dauphinois Basin (Cotillon, 1984; Fig. 1) is not likely to have occurred at bathyal depths (e.g., Bosselini, 1984; Eberli and Ginsburg, 1989). In addition, the high abundance of ammonites throughout the basin may also point towards sedimentary conditions less than a few hundred meters (Lehmann, 1976; Ziegler, 1983). The Vocontian Basin waterdepth used herein (Table I) has been derived from the stratal patterns of the Barremian platform to basin transition in the Vercors Area (Jacquin *et al.*, 1991; figure 12).

For the northern Vercors composite Valanginian-Albian column (Arnaud, 1988) the facies evolution curve of Arnaud (1988) and paleobathymetrical estimates from Jacquin *et al.* (1991, figure 8) are used for information on sea-level variations (Table II). A eustatic component is introduced to elucidate the effect of global sea level changes on a regional scale. For the eustatic component the Haq *et al.* (1988) second order sea-level curve is adopted in order to maintain consistency with the chronostratigraphic data, despite the poor documentation of this curve.

Figure 2. (next page) Subsidence diagrams of the Vocontian Basin and Vercors Area (using backstrip techniques). Figure 2A and 2C show tectonic subsidence corrected for sediment loading only, so-called burial history diagrams. Figure 2B and 2D show tectonic subsidence corrected for sedimentloading, waterloading and eustasy, so-called geohistory diagrams. Used abbreviations for substages: E. (Early); L. (Late); Bedoul. (Bedoulian); Garg. (Gargasian); Cl. (Clansayesian); Vrac. (Vraconian).

- Early Cretaceous development of the Dauphinois Basin -



RESULTS

Burial history diagrams

Three phases of tectonic subsidence may be identified in the burial history diagrams for both the Vocontian Basin and Vercors Area as shown in Figure 2A and Figure 2C:

(I) Vocontian Basin (Fig. 2A):

- 1) A Valanginian-Hauterivian phase characterised by tectonic subsidence averaging 2.1 cm/Kyr.
- 2) A Barremian-Aptian phase subdivided in a Barremian - early Bedoulian subphase with a tectonic subsidence averaging 0.7 cm/Kyr and a late Bedoulian - Aptian subphase with accelerated tectonic subsidence averaging 1.5 cm/Kyr.
- 3) An Albian phase subdivided by a Early Albian - Middle Albian subphase with a tectonic subsidence averaging 0.5 cm/Kyr followed by a Late Albian subphase with a tectonic subsidence averaging 1.6 cm/Kyr.

(II) Vercors Area (Fig. 2C):

- 1) A Valanginian-Hauterivian phase subdivided in a Valanginian subphase with a tectonic subsidence averaging 0.5 cm/Kyr and a Hauterivian phase with accelerated tectonic subsidence averaging 2.3 cm/Kyr.
- 2) A Barremian-Bedoulian phase subdivided in an Early Barremian subphase with tectonic subsidence averaging 0.5 cm/Kyr and a Late Barremian - Bedoulian subphase with increasing tectonic subsidence rates averaging 1.2 cm/Kyr.
- 3) A Late Aptian - Albian phase virtually without tectonic subsidence.

Geohistory diagrams

Again three phases of tectonic subsidence may be identified in the geohistory diagrams for the Vocontian Basin and Vercors Area as shown in Figure 2B and Figure 2D, respectively:

(I) Vocontian Basin (Fig. 2B):

- 1) A Valanginian-Hauterivian phase characterised by a relatively uniform tectonic subsidence pattern.
- 2) A Barremian-Gargasian phase starting with tectonic uplift during the Early Barremian and rapidly increasing tectonic subsidence in the Late Barremian-Bedoulian and Gargasian.
- 3) A Clansayesian to Albian phase characterised by relatively small rates of subsidence or uplift.

- Early Cretaceous development of the Dauphinois Basin -

(II) Vercors Area (Fig. 2D):

- 1) A Valanginian-Hauterivian phase characterised by accelerated tectonic subsidence rates.
- 2) A Barremian-Bedoulian phase starting with tectonic uplift during the Early Barremian and followed by accelerated tectonic subsidence in the Late Barremian-Bedoulian.
- 3) A Late Aptian to Albian phase starting with virtually no tectonic subsidence during the Late Aptian and followed by little tectonic uplift during the Albian.

DISCUSSION

The Valanginian - Bedoulian geohistory pattern of Figure 2D for the Vercors Area is comparable with the one constructed by Jacquin *et al.* (1991, figure 8); the contrasting successive Late Aptian and particularly the Albian subsidence patterns of Jacquin *et al.* (1991) results from the introduction of many times more sediment than 'the several meters of sands.....from the Albian age' as stated by Arnaud (1988).

The geohistory diagrams (Figure 2B and 2D) parallels and accentuates the faint outline of the burial history trends of Figure 2A and 2C. The nature of the identified subsidence trends of the Vocontian Basin and Vercors Area is similar for the Valanginian - Bedoulian; the successive Gargasian - Albian period reflects contrasting subsidence trends. In summary, in the Early Cretaceous of the Dauphinois Basin three subsidence phases can be recognised: (1) a Valanginian-Hauterivian phase characterised by relatively uniform subsidence patterns; (2) a Barremian-Gargasian phase characterised by profound shifts in subsidence; (3) a Clansayesian-Albian phase characterised by relatively small rates of subsidence or uplift (Fig. 2). Within the Barremian-Gargasian phase three successive subphases can be distinguished in the Dauphinois Basin (Fig. 2B and 2D): (2a) Early Barremian uplift for the entire Dauphinois Basin; (2b) Late Barremian-Bedoulian subsidence for the entire Dauphinois Basin; (2c) differentiation of subsidence rates in the Gargasian with subsidence for the Vocontian Basin and virtually no tectonic subsidence for the surrounding carbonate platforms. The sedimentary response to the fluctuations in the Valanginian-Albian subsidence of the Dauphinois Basin are discussed below with special emphasis on the Barremian-Gargasian phase. The relation between tectonic events and sedimentary development are schematically illustrated in five steps (Fig. 3).

(I) Valanginian-Hauterivian subsidence

During the Valanginian-Hauterivian tectonic subsidence patterns in the Dauphinois Basin are relatively uniform. The slightly accelerated Hauterivian tectonic subsidence in the

northern Vercors probably caused drowning of the small Berriasian-Valanginian carbonate platform (Jacquin *et al.*, 1991) positioned at the outermost margin of the Dauphinois Basin (Arnaud-Vanneau and Arnaud, 1991). After this drowning hemipelagic sediments were deposited in the entire Dauphinois Basin (Fig. 3A).

(II) Early Barremian uplift (Fig. 3B)

The relatively rapid tectonic uplift of the Dauphinois Basin during the Early Barremian coincided with the onset and development of extensive carbonate platforms on the margins (e.g. Arnaud-Vanneau and Arnaud, 1990; Jacquin *et al.*, 1991; Masse, 1993). It is here considered that the onset and development of these carbonate platforms could occur at such a large scale because the *initial* paleobathymetry of the Vocontian Basin was only maximally a few hundred meters (Wilpshaar and Leereveld, 1994): as a consequence of the tectonic uplift large relatively shallower areas of the Dauphinois Basin's margin were lifted into the euphotic zone creating ideal shallow marine carbonate platform environments.

(III) Late Barremian-Bedoulian subsidence (Fig. 3C)

During the Late Barremian to Bedoulian the Dauphinois Basin subsided again and the growth of the carbonate platforms could keep up with the subsidence and even prograde towards the Vocontian Basin (e.g. Arnaud-Vanneau and Arnaud, 1990; Masse, 1993). The effect of platform progradation resulted in increased deposition of mass-transported sediments in the Vocontian Basin (Ferry and Flandrin, 1979; Cotillon *et al.*, 1984; Ferry and Rubino, 1989; Fries and Rubino, 1990).

(IV) Gargasian differentiation (Fig. 3D)

During the Gargasian the Vocontian Basin subsided while the Vercors Area displayed virtually no tectonic subsidence. This process created an increased tilting of the area with slope angles allowing mass-transported sediments to be deposited in the basin. Resulting hiatuses are traceable over large areas on these slopes (e.g. Ferry, 1978; Cotillon *et al.*, 1984; Ferry and Rubino, 1989; Fries and Rubino, 1990). Coeval with this tectonic differentiation of the Dauphinois Basin the extensive carbonate platform development at its margins ceased due to platform exposure whereby large incised valleys and major unconformities were formed due to erosion (e.g. Arnaud-Vanneau and Arnaud, 1990). Contemporaneously terrigenous input progressively increased in the Vocontian Basin (e.g.

- Early Cretaceous development of the Dauphinois Basin -

Cotillon, 1984, Breheret, 1994).

(V) Clansayesian-Albian in-fill (Fig. 3E)

During the Clansayesian-Albian the Dauphinois Basin displayed relatively small rates of subsidence or uplift and siliciclastic sedimentation prevailed. Uplift of the margins coincided with increased exposure of terrigenous sources in the hinterland. Because sedimentation exceeded the small rates of subsidence; the terrigenous supply eventually filled up the Vocontian Basin. The terrigenous influx terminated large-scale shallow marine carbonate production, even when the area of these carbonate platforms became flooded again during the 'mid'-Cretaceous sea-level rise (Haq *et al.*, 1988).

The Early Cretaceous Dauphinois Basin was interpreted to correspond to the slower subsidence-driven thermal reequilibrium phase (Lemoine *et al.*, 1986) making it ideal for the establishment of detailed sea level changes to be compared with global sea level curves. However, the present study shows that the first signs of interference with the thermal reequilibrium phase is already documented in the Lower Barremian of the Dauphinois Basin, i.e. the distinct Early Barremian uplift. As a consequence the very first sedimentary response to the changing tectonic regime is reflected in the onset and extensive development of carbonate platforms at the margin of the Dauphinois Basin rather than the change in the Aptian from carbonate dominated sediments to more terrigenous dominated sediments. The Barremian - Gargasian tectonic phase, with the Early Barremian uplift of the entire Dauphinois Basin finally resulting in Gargasian exposure of the margins and subsidence of the basin centre, can be explained by progressive shortening of the wavelength of lithospheric buckling (Cloetingh *et al.*, 1985) superposed on the Early Cretaceous relatively uniform subsidence pattern related to the thermal reequilibrium.

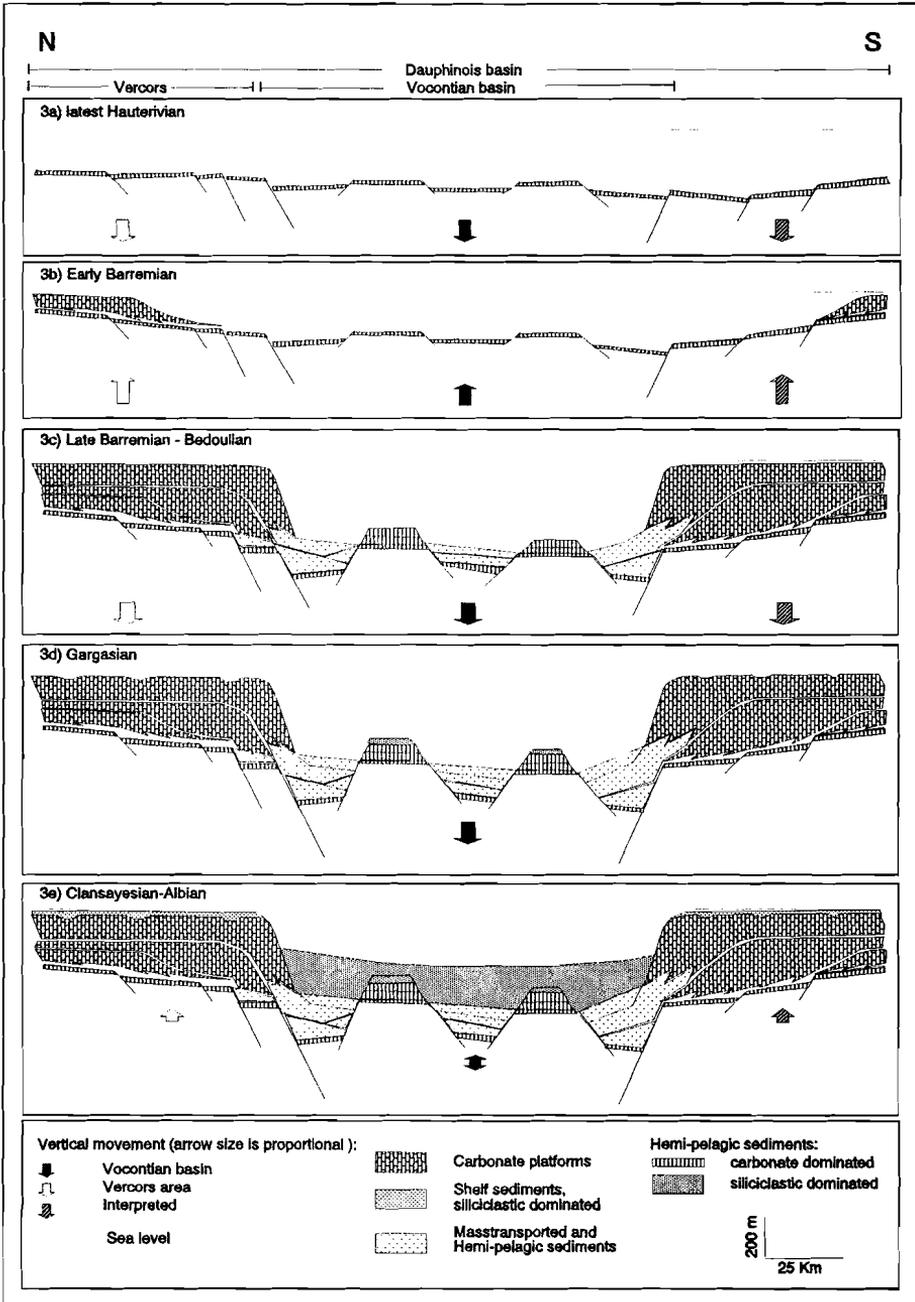
According to Cloetingh (1988) vertical motions, produced by a change from an extensional towards a compressional regime, may cause relative sea-level changes to contrast global sea-level changes. It should be realised that if these carbonate platforms and related basinal facies are used for the establishment of detailed sea-level curves to be compared with global sea-level curves (Ferry and Rubino, 1989; Arnaud-Vanneau and Arnaud, 1990; Jacquin *et al.*, 1991), its tectonic origin may cause variances between the curves.

CONCLUSION

Three subsidence phases are recognised within the Early Cretaceous of the Dauphinois Basin; (1) a Valanginian-Hauterivian phase characterised by relatively uniform subsidence; (2) a Barremian-Gargasian phase characterised by profound shifts in subsidence; (3) a Clansayesian - Albian phase characterised by relatively small rates of tectonic subsidence or uplift. The Barremian-Gargasian tectonic phase, with the Early Barremian uplift of the entire Dauphinois Basin finally resulting in Gargasian exposure of the margins and accelerated subsidence of the basin centre is associated with the changing tectonic regime of the Piemonte-Ligurian ocean from extension towards compression forcing the onset, progradation and disappearance of extensive carbonate platforms at the margin of the Dauphinois Basin. As a consequence, the carbonate platforms document the very first sedimentary response to this changing tectonic regime. Vertical motions induced by such a changing tectonic regime in particular determine the regional sea-level curves established for these carbonate platforms and related basinal facies rather than global sea level changes.

Figure 3. (next page) Simplified diagram illustrating the tectonic scenario during latest Hauterivian-Albian interval. The schematic evolution of the carbonate platforms is modified after Arnaud-Vanneau and Arnaud (1990) and Masse (1993).

- Early Cretaceous development of the Dauphinois Basin -



- Chapter 1.3 -

Table I: Used data set for the composite column of the Vocontian Basin (Wilpshaar and Leereveld, 1994). The columns from left to right represent the defined lithostratigraphic intervals, depth (in meters) and time interval (in My), percentage of silt, shale and carbonate, waterdepth and eustatic signal (Haq *et al.*, 1988).

Stratigraphic unit	Depth (m)	Age (My)	silt %	shale %	carbonate %	waterdepth	eustasy (m)
Vraconian	0 - 110	96.0 - 97.8	0.1	0.7	0.2	300	245
Late Albian	110 - 240	97.8 - 99.0	0.1	0.7	0.2	300	220
Middle Albian	240 - 325	99.0 - 102.5	0.0	0.8	0.2	300	200
Early Albian	325 - 410	102.5 - 108.0	0.0	0.8	0.2	300	180
Clansyasian	410 - 475	108.0-109.25	0.0	0.8	0.2	300	160
Gargasian	474 - 570	109.25-111.0	0.0	0.8	0.2	300	150
late Bedoulian	570 - 610	111.0 -112.0	0.0	0.8	0.2	300	150
early Bedoulian	610 - 622	112.0 -113.0	0.0	0.2	0.8	300	170
Late Barremian	622 - 659	113.0 -115.3	0.0	0.3	0.7	300	190
Early Barremian	659 - 704	115.3 -116.5	0.0	0.5	0.5	300	190
Late Hauterivian	704 - 849	116.5 -118.8	0.0	0.6	0.4	300	160
Early Hauterivian	849 - 950	118.8 -121.0	0.0	0.6	0.4	300	130
Late Valanginian	950 -1129	121.0 -124.0	0.0	0.7	0.3	300	110
Early Valanginian	1129-1190	124.0 -128.0	0.0	0.3	0.7	300	90

Table II: Used data set for the composite column of the Northern Vercors (after Arnaud, 1988). The columns from left to right represent the defined lithostratigraphic intervals, depth (in meters) and time interval (in My), percentage of silt, shale and carbonate, estimated waterdepths and eustatic signal (Haq *et al.*, 1988).

Stratigraphic unit	Depth (m)	Age (My)	sand%	silt %	shale %	carbonate %	waterdepth	eustasy
Albian	0 - 5	96.0 - 108.0	0.9	0.1	0.0	0.0	5	225
Clansyasian	5 - 20	108.0 - 109.25	0.9	0.1	0.0	0.0	5	160
Gargasian	unconformity							
Bedoulian	20 - 102	111.0 - 113.0	0.0	0.0	0.1	0.9	5	160
Late Barremian	102 - 242	113.0 - 115.3	0.0	0.0	0.1	0.9	5	190
Early Barremian	242 - 262	115.3 - 116.5	0.0	0.0	0.1	0.9	25	190
Late Hauterivian	262 - 382	116.5 - 118.8	0.0	0.0	0.5	0.5	150	160
Early Hauterivian	382 - 502	118.8 - 121.0	0.0	0.0	0.5	0.5	150	130
Valanginian	502 - 586	121.0 - 128.0	0.0	0.0	0.1	0.9	50	100

PART 2

APPLICABILITY OF DINOFLAGELLATE CYST STRATIGRAPHY

TO THE ANALYSES OF AN ACTIVE MARGIN

DURING PHASES OF RELATIVE COMPRESSION.

CASE STUDY OF THE OLIGOCENE PINDOS FORELAND BASIN (NW GREECE).

CHAPTER 2.1

A DINOFLAGELLATE CYST ZONATION FOR THE OLIGOCENE OF THE CENTRAL MEDITERRANEAN; With special reference to the Rupelian/Chattian boundary

ABSTRACT

Two new dinoflagellate cyst zones are proposed linking previously established zonal schemes for the Eocene/Oligocene and Oligocene/Miocene transitions in the central Mediterranean. The new *Hystriochokolpoma pusillum* (Hpu) and *Chiropteridium lobospinosum* (Clo) interval zones are based on the Contessa Quarry and Monte Cagnero sections (central Italy), and are correlated to previously established magneto- and biostratigraphical schemes. The Rupelian/Chattian boundary is considered to be correlative to Chron C10n. In central Italy, the most distinct dinoflagellate cyst event associated with this chron is the first occurrence (FO) of *Distatodinium biffii*, marking the base of the *Distatodinium biffii* (Dbi) Zone. Indirect evidence suggests that also in the Chattian type area the FO of *Distatodinium biffii* equates with the base of the Chattian Stage, thus making it an important marker. Other possible markers for the base of the Chattian are the LO of *Areosphaeridium pectiniforme* and the oldest acme of *Chiropteridium* spp. The latter may be related to the major mid-Oligocene sea-level fall (TA/TB Exxon supercycle boundary), also considered to represent the Rupelian/Chattian boundary and previously correlated to Chron C10n. However, in the Contessa Quarry section this dinoflagellate cyst event is associated with the older Chron C11.

INTRODUCTION

Italian sections have come to play a principal role in the quest for Paleogene 'Global Stratotype Sections and Points' (GSSPs). The Massignano section in central Italy and the Lemme section of NW Italy have been accepted as base Oligocene (Odin and Montanari, 1988, 1989) and proposed as base Miocene GSSPs (Steininger *et al.*, 1994; Steininger and Cati, *in press*) respectively. The suitability of the Italian sections seems mainly due to their relatively undisturbed, well-exposed and pelagic nature, which are ideally suited for chronobiostratigraphical research. Furthermore, various central Italian sections are also being evaluated as suitable candidates for the base Chattian (Late Oligocene) GSSP.

Much recent effort has been placed on the establishment of well-calibrated and detailed calcareous plankton biozonations for the Eocene/Oligocene and Oligocene/Miocene transitions in the central Mediterranean area (e.g., papers in Premoli Silva *et al.*, 1988a; Steininger *et al.*, 1994; Steininger and Cati, *in press*). Also new detailed dinoflagellate cyst (dinocyst) zonal schemes have been proposed for Italian sections including the GSSP-sites (Brinkhuis *et al.*, 1992; Brinkhuis and Biffi, 1993; Zevenboom, *in press* a,b,c; Zevenboom *et al.*, 1994). Because dinocysts are particularly well suited for correlations between proximal and distal marine sites (e.g., Brinkhuis, 1994; Wilpshaar, 1995), they are important in correlating the predominantly marginal marine Paleogene stages of NW Europe to the deeper marine settings of the GSSPs (Brinkhuis and Visscher, *in press*). Although various Oligocene dinocyst zonations have been proposed, they are primarily for high and middle latitude sections, where independent magneto- and/or biostratigraphic control is not readily available (see Head and Norris, 1989; Powell, 1992; Brinkhuis and Biffi, 1993). Biffi and Manum (1988) found the zonal schemes established in NW Europe difficult to apply in their study of the relatively complete pelagic sections from central Italy, and proposed a regional zonal scheme for the Oligocene succession. However, also this scheme has a relatively low resolution and poor calibration. Moreover, subsequent studies from the same interval and area have demonstrated that many of the zonal definitions introduced by Biffi and Manum (1988) required revision (Brinkhuis *et al.*, 1992; Brinkhuis and Biffi, 1993). While well-calibrated dinocyst zonal schemes cover the lowermost (Brinkhuis and Biffi, 1993) and uppermost (Brinkhuis *et al.*, 1992) Oligocene successions of the central Mediterranean, no detailed scheme is available for the 'middle' Oligocene. Such a scheme may be particularly useful in correlation of the base Chattian GSSP, and forms the main aim of the present study.

MATERIAL

The Contessa Quarry section (central Italy, Figure 1) was selected for this study because calcareous planktonic and magnetostratigraphical information are available, as well as radiometric datings (Lowrie *et al.*, 1982; Nocchi *et al.*, 1986, 1988a; Premoli-Silva *et al.*, 1988b; Montanari *et al.*, 1991; Bice and Montanari, 1992; Coccioni and Monechi, 1992; Zevenboom *et al.*, 1994; Coccioni *et al.*, 1994). In addition, the Oligocene part of the nearby Monte Cagnero section (Figure 1) was selected for reference purposes.

The Upper Eocene of central Italy is characterised by an alternation of reddish and greenish-grey pelagic limestones of the Scaglia Variegata Formation (Renz, 1936; Baumann, 1970). Near the Eocene/Oligocene boundary, the lithology changes to the exclusively greenish-grey marls characteristic of the Scaglia Cinerea Formation (Renz, 1936; Baumann, 1970; Nocchi *et al.*, 1988a). Just above the Oligocene/Miocene boundary a thin bentonite layer ('Livello Raffaello') is overlain by coarser grained beds of the so-called Bisciario Formation (Montanari *et al.*, 1991; Coccioni *et al.*, 1994).

The Contessa Quarry section

Initially, the Contessa Quarry was thought to contain a complete upper Eocene to lower Miocene section. However, Nocchi *et al.* (1986) and Premoli Silva *et al.* (1988b) showed the Eocene/Oligocene boundary interval to be incomplete in this section, due to small scale faulting. Although the lower part of the succession has been affected by tectonic deformation, Lowrie *et al.* (1982) indicated that no major unconformities are present. Recent studies of the Oligocene/Miocene transition included geochronology, calcareous plankton distributions, magnetostratigraphy and Sr isotope analysis, (Montanari *et al.*, 1991; Coccioni and Monechi, 1992; Bice and Montanari, 1992). Brinkhuis *et al.* (1992) formally defined two dinocyst zones for the Oligocene/Miocene transition of the Contessa Quarry section. Correlation between the proposed Oligocene/Miocene GSSP at Lemme and the Contessa Quarry section (Zevenboom *et al.*, 1994) resulted in further refinement to the interpretation of the magnetostratigraphical succession and recognition of an unconformity at the base of the Bisciario Formation. A summary of the available information on the section and the sample positions are depicted in Figure 2.

The Monte Cagnero section

Parisi *et al.* (1988) gave detailed biostratigraphical descriptions of the lower part of the Monte Cagnero section, which spans the Eocene/Oligocene boundary (Figure 2). For the overlying Oligocene part of the section no additional detailed biostratigraphical data are

currently available. The Oligocene part of the section is developed in the typical Scaglia Cinerea Formation; the overlying Bisciario Formation is not exposed. To provide correlation with the Contessa Quarry section W.J. Zachariasse (University Utrecht) analyzed the planktonic foraminiferal content of selected samples from the Monte Cagnero section. A summary of the available biostratigraphical information of the section and sample locations are shown in Figure 2.

METHODS

The samples were processed using standard palynological techniques. The slides were studied qualitatively and quantitatively following the methodology described by Brinkhuis and Biffi (1993). The dinoflagellate cyst taxonomy follows Lentin and Williams (1993). All material is stored in the collection of the Laboratory of Paleobotany and Palynology, University of Utrecht, The Netherlands. This paper reports on selected, stratigraphically important dinocyst events only.

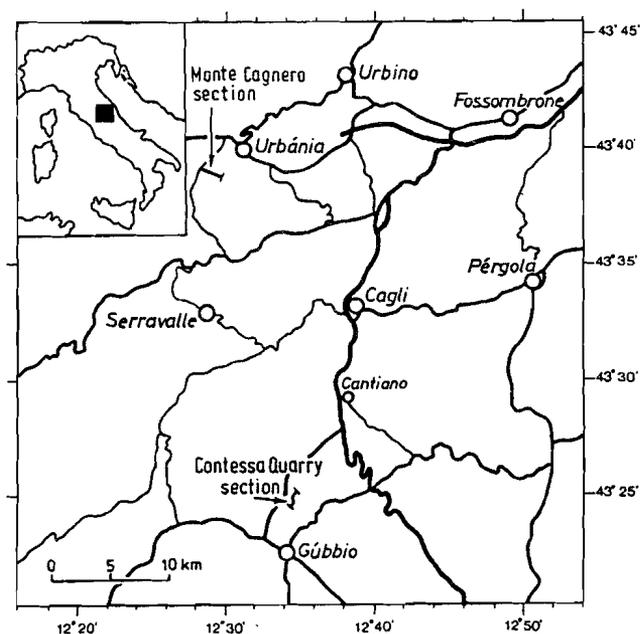


Figure 1 Map of central Italy with the approximate locations of the Contessa Quarry (43° 24', 12° 34') and Monte Cagnero sections (43° 40', 12° 28').

RESULTS

All samples contain rich assemblages of relatively well preserved palynomorphs. In general, samples are dominated by dinoflagellate cysts and bisaccate pollen. Other palynomorphs occur in smaller numbers. About 100 dinoflagellate cyst taxa were recognised. Most assemblages are characterised by relatively high numbers of *Spiniferites* spp., *Operculodinium* spp. and *Systematophora* spp. In some samples, either *Deflandrea* spp. or *Chiropteridium* spp. are dominant. Detailed comparison and literature-based evaluation of the first and last occurrences (FO/LO) of taxa, as well as distinct quantitative events recorded in the two approximately coeval Contessa Quarry and Monte Cagnero sections, led to the recognition of a suite of important stratigraphic events (Figure 2).

A characteristic dinocyst genus of the Oligocene is *Chiropteridium*. The genus has a global distribution, particularly during the late Oligocene. In the present study, four discrete acmes of *Chiropteridium* spp. were recorded in the Monte Cagnero section (Figure 2) but only two in the Contessa Quarry section (Figure 2), most probably correlating with the first and last acme at Monte Cagnero (Figure 2). The missing two acmes at Contessa may be explained by missing section and/or insufficient sample spacing.

Zonation

Two new zones, the *Hystrichokolpoma pusillum* (Hpu) and *Chiropteridium lobospinosum* (Clo) zones, are proposed to connect the earlier established lower and upper Oligocene zonations from Brinkhuis and Biffi (1993) and Brinkhuis *et al.* (1992) respectively. The new zones are interval zones, defined below following the North American Commission on Stratigraphic Nomenclature (1983). All dinocyst zones recognised in the Contessa Quarry and Monte Cagnero sections, together with other biostratigraphical data and magnetic polarity zones are depicted in Figure 2. A summary of all available information, including a compilation of the studies of Brinkhuis *et al.* (1992), Brinkhuis and Biffi (1993), Zevenboom *et al.* (1994) and Zevenboom (*in press*, a) is provided in Figure 3. In addition, stratigraphically important dinoflagellate cysts are depicted in Figure 4. A formal description of the two new dinoflagellate zones and necessary emendations of earlier established zones is given below, in ascending stratigraphical order.

Corrudinium incompositum (Cin) Interval Zone Brinkhuis and Biffi (1993) emend.

Definition. The interval from the LO of *Glaphyrocysta semitecta* to the FO of *Hystrichokolpoma pusillum*.

Calibration. Planktonic foraminifers: upper P18 Zone; nannoplankton: upper NP21 (=CP16B) Zone.

Age. Middle Early Oligocene (Rupelian).

Type section. Monte Cagnero

Thickness. 5m; samples CA108-113 (Figure 2).

Remark. This zone appears to be missing in the Contessa Quarry section, probably due to small-scaled faulting (Figure 2).

Hystriochokolpoma pusillum (Hpu) Interval Zone

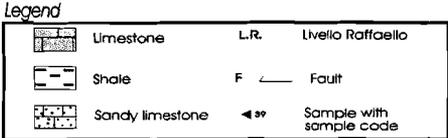
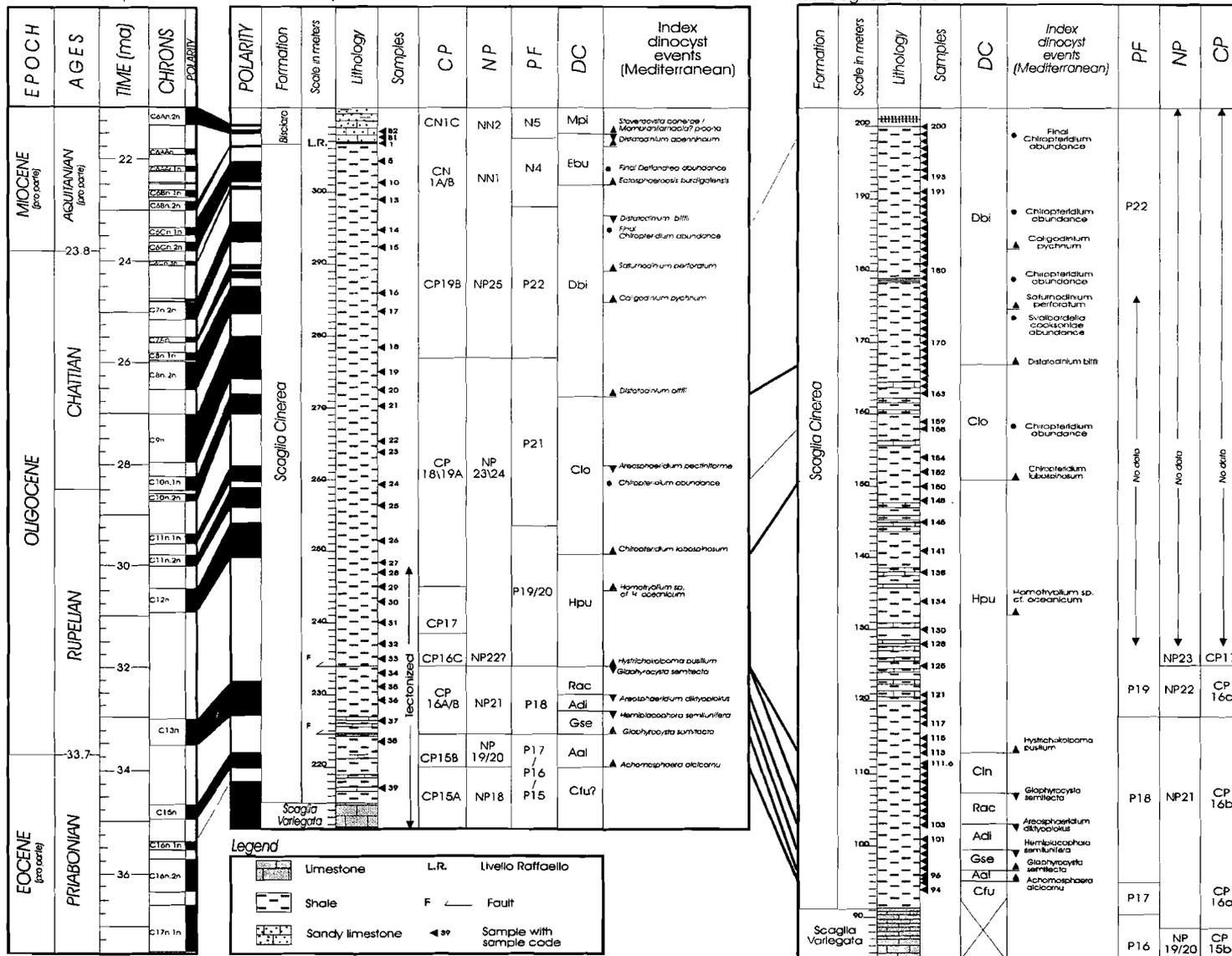
Definition. The interval from the FO of *Hystriochokolpoma pusillum* to the FO of *Chiropteridium lobospinosum*.

Calibration. Planktonic foraminifers: top P18 to top P19/P20 Zones; nannoplankton: top NP21 (CP16B) to lower NP23/24 (= CP18/19A) Zones; upper part of Chron C12r to the lower part of Chron C12n.

Age. Middle Early Oligocene (Rupelian).

Type section. Monte Cagnero for the base; Contessa Quarry for the top

Figure 2. (next page) Schematic representation and correlation of the Contessa Quarry and Monte Cagnero sections, and sample positions. The calcareous plankton and magnetostratigraphical data of the Contessa Quarry section are compiled from Lowrie *et al.* (1982), Nocchi *et al.* (1986), Premoli Silva *et al.* (1988b), Montanari *et al.* (1991), Coccioni and Monechi (1992), Bice and Montanari (1992), and Coccioni *et al.* (1994). Montanari *et al.* (1991) dated the Livello Raffaello as 21.2 ± 0.5 Ma. The magnetostratigraphy of the Contessa section is calibrated against the geomagnetic polarity time scale (GPTS) of Cande and Kent (*in press*). Calcareous plankton data of the lower part of the Monte Cagnero section are from Parisi *et al.* (1988). Additional data on planktonic foraminifers from the upper part of the Monte Cagnero section is by W.J. Zachariasse (written comm., 1994). The dinoflagellate cyst zonation (DC) is according to the present study, combined with Brinkhuis *et al.* (1992), Brinkhuis and Biffi (1993), Zevenboom *et al.* (1994), and Zevenboom (*in press*, a,b,c). The correlations between the sections are based on dinocysts. PF = standard planktonic foraminifer zones (after Blow, 1969, and Nocchi *et al.*, 1988a,b); CP = standard nannoplankton zones (after Okada and Bukry, 1980); NP = standard nannoplankton zones (after Martini, 1971).



Thickness. Monte Cagnero: 37m; samples CA114-150 (Figure 2). Contessa Quarry: 15m; samples CN33-27 (Figure 2).

Remarks. *Homotryblium* sp. cf. *H. oceanicum* of Brinkhuis *et al.* (1992) first occurs in the middle part of this zone.

Chiropteridium lobospinosum (Clo) Interval Zone

Definition. The interval from the FO of the *Chiropteridium lobospinosum* to the FO of *Distatodinium biffii*.

Calibration. Planktonic foraminifers: top P19/20 to upper P21 Zone; nannoplankton: middle-upper NP23/24 (= CP18/19A) Zones; upper part of Chron C12n to mid Chron C10n.

Age. Late Early Oligocene (Rupelian).

Type section. Contessa Quarry.

Thickness. Contessa Quarry: 22m; samples CN26-21 (Figure 2). Monte Cagnero: 16m; samples CA152-167 (Figure 2).

Remarks. *Areosphaeridium pectiniforme* last occurs in the middle part of the zone, close to the oldest acme of *Chiropteridium* spp.

Distatodinium biffii (Dbi) Interval Zone Brinkhuis *et al.* (1992) emend. Zevenboom (*in press*, a) emend.

Definition. The interval from the FO of *Distatodinium biffii* to the FO of *Ectosphaeropsis burdigalensis*. The base of the youngest acme of *Deflandrea* spp. may be used as a confirmatory event for the latter.

Calibration. Planktonic foraminifers: top P21 to top part of zone P22; nannoplankton: upper part of NP23/24 (= CP18/19A) to top NP25 (= CP19B) Zones; magnetic polarity chrono(sub)zones C10n to basal C6Cn.2r (all calibrations for the top of the Dbi Zone are derived from the Lemme section; see Steininger *et al.*, 1994; Zevenboom, *in press*, a).

Age. Late Oligocene (Chattian).

Type section. Contessa Quarry for the base; the Lemme section for the top (see Zevenboom, *in press*, a).

Thickness. Contessa Quarry: 28m; samples CN20-11 (Figure 2). Monte Cagnero: 32m; samples CA168-200; upper part not exposed (Figure 2).

Remarks. Originally defined by Brinkhuis *et al.* (1992) at Contessa Quarry, Zevenboom (*in press*, a) relocated the type section for this zone to the Lemme section (NW Italy, Oligocene/Miocene GSSP-site) in view of better calibrations. However, this is only appropriate for the top of the zone; the base of the zone in the Lemme section is poorly calibrated. We therefore prefer to use the original location of the base at Contessa Quarry as the type section

- *Oligocene dinoflagellate cyst zonation* -

where relatively detailed magnetostratigraphical and calcareous plankton biostratigraphical information are available. We recorded *Distatodinium biffii* from a sample underlying its originally reported FO at Contessa Quarry, thus moving the base of the Dbi Zone to slightly below that indicated in Brinkhuis *et al.* (1992). The top is as defined in the Lemme section, at a horizon just below the base Miocene GSSP, following the recommendations of Zevenboom (*in press*, a).

The Dbi Zone is subdivided into two subzones, viz. the *Hystrichosphaeropsis* sp. cf. *H. obscura* (Hob) Interval Subzone and the *Chiropteridium* (Chi) Abundance Subzone (Brinkhuis *et al.*, 1992).

DISCUSSION

The relative validity of the proposed zonation within the Mediterranean area is difficult to assess in view of the few studies available. However, results of a multidisciplinary study of Paleogene sections in NW Greece (Wilpshaar *et al.*, chapter 2.2), and similar unpublished studies in southern Spain suggest that the zones are reasonably synchronous across the Mediterranean. Correlations to other regions are problematic due to possible migration effects and the low resolution and poor calibrations of the published zonal schemes. More studies with sound calibration need to be carried out before accurate correlations may be made. However, some dinocyst events appear to be reasonably synchronous throughout Europe and have potential for correlation purposes. For example, the FO of *Distatodinium biffii* is used by Gradstein *et al.* (1992) to characterise the base of the Chattian deposits in exploration wells from offshore Norway; it was also reported (as "*Microsphaeridium ancistroides*") by Benedek (1972) from lower Chattian deposits of northwest Germany. Other events which appear to correlate in the Northern Hemisphere Oligocene include (in stratigraphical order) the LOs of *Areosphaeridium diktyoplokus*, *Glaphyrocysta semitecta*, *Corrudinium incompositum*, *Areosphaeridium pectiniforme*, *Distatodinium biffii*, and *Wetzeliella* spp., and the FOs of *Areoligera semicirculata*, *Wetzeliella gochtii*, *Hystrichokolpoma pusillum*, *Chiropteridium lobospinosum* and *Ectosphaeropsis burdigalensis* (compare overviews by e.g., Powell, 1992; Brinkhuis and Biffi, 1993).

Eocene/Oligocene boundary

The Eocene/Oligocene boundary is widely regarded as characterised by the LO of the plankton foraminifera belonging to the Hantkeninidae (see e.g., Beckmann *et al.*, 1981; Poore *et al.*, 1982; Nocchi *et al.*, 1988a,b). The LO of the hantkeninids corresponds to the

planktonic foraminiferal P17/P18 zonal boundary (Nocchi *et al.*, 1988a,b; Premoli Silva *et al.*, 1988b). This event (1) does not coincide with any major event in the calcareous nannoplankton record, it occurs in the middle part of Martini's (1971) NP21 Zone and below Okada and Bukry's (1980) CP16A/CP16B subzonal boundary (Pomerol and Premoli Silva, 1986; papers in Premoli Silva *et al.*, 1988a) and (2) occurs just above the last normal cryptochron (C13r.1n) within Chron C13r (Poore *et al.*, 1982; papers in Premoli Silva *et al.*, 1988a). The Massignano section in central Italy has become accepted as the base Oligocene GSSP using the hantkeninid extinction as the boundary criterion (Odin and Montanari, 1988; Odin and Montanari, 1989). However, Brinkhuis and Visscher (*in press*) recently challenged this decision, based on dinocyst data from the Priabonian type section at Priabona. They showed that the correlative horizon of the LO of the hantkeninids occurs in the middle part of the Priabonian type section. They argued to characterise the base of the Oligocene by the LO of the dinocyst *Areosphaeridium diktyoplokus*. This post-hantkeninid extinction event marks the top of the Priabonian Stage in the type section, is correlative to Chron C13n and to a distinct global $\delta^{18}\text{O}$ spike. However, here we conform to the presently accepted position of the base Oligocene GSSP as characterised by the LO of the hantkeninids at Massignano.

Interpolation between radioisotopic ages suggests that the Massignano-based Eocene/Oligocene boundary has an age of 33.7 +/- 0.5 Ma (Odin and Montanari, 1988).

Figure 3. (next page) Composite diagram of the dinoflagellate cyst zonation with associated biostratigraphical data from central Italy and the third order cycles of Haq *et al.* (1988), plotted according to available magnetostratigraphical calibrations. Magnetostratigraphical calibration of the central Italian succession to the Cande and Kent (*in press*) scale is derived from Figure 2, complemented with available data summarised in Brinkhuis *et al.* (1992), Brinkhuis and Biffi (1993), Steininger *et al.* (1994), Zevenboom *et al.* (1994), and Zevenboom (*in press*, a,b,c). PF = standard planktonic foraminifer zones (after Blow, 1969, and Nocchi *et al.*, 1988a,b); NP = standard nannoplankton zones (after Martini, 1971); CP = standard nannoplankton zones (after Okada and Bukry, 1980); DC = composite dinocyst zonation of this study combined with Brinkhuis *et al.* (1992), Brinkhuis and Biffi (1993), Zevenboom, *et al.* (1994), and Zevenboom (*in press*, a,b,c).

- Oligocene dinoflagellate cyst zonation -

EPOCH	AGES	TIME (ma)	CHRONS	POLARITY	CP	NP	PF	DC	Index dinocyst events (MEDITERRANEAN)	Cycles (3rd order)
MIOCENE <i>(pro parte)</i>	AGUTANIAN <i>(pro parte)</i>	22	C6n.2n	■	CN1C	NN2	N5	Mpi		TB1.5
			C6n.1n	■					▲ <i>Membranilamella? ploana</i> / <i>Stoverocysta conarea</i> ▼ <i>Distatodinium apenninicum</i> ▼ <i>Distatodinium apenninicum</i> ▲ <i>Hystrioholopoma pusillum</i> ● Final <i>Deflandrea</i> abundance	TB1.4
	CHATTIAN	23.8	C6n.2n	■	CN1A/1B	NN1		Ebu	▲ <i>Ectosphaeropsis burgalensis</i>	
			C6n.1n	■					▼ <i>Distatodinium bifidum</i> ● Final <i>Chiropteridium</i> abundance	TB1.3
		24	C7n.2n	■					● <i>Chiropteridium</i> abundance	TB1.2
			C7n.1n	■	CP19B	NP25	P22	Dbl	▲ <i>Collypodinium pychnum</i> ● <i>Chiropteridium</i> abundance	TB1.1
		26	C8n.2n	■					▲ <i>Sakumodinium perforatum</i> ● <i>Svalbardella cooksoniae</i> abundance	TB
		28	C9n	■					▲ <i>Distatodinium bifidum</i>	TA
			C10n.1n	■					▼ <i>Areosphaeridium pectinifera</i> ● <i>Chiropteridium</i> abundance	TA4.5
			C10n.2n	■	CP18/19A	NP23/24	P21	Clo	▲ <i>Chiropteridium labaspinosum</i>	
OLIGOCENE	RUPELIAN	30	C11n.1n	■					▲ <i>Homotryblum cf. sp. H. oceanicum</i>	TA4.4
			C11n.2n	■	CP17	NP22	P19/20	Hpu	▲ <i>Hystrioholopoma pusillum</i>	TA4.3
		32	C12n	■	CP16c				▼ <i>Glyphrocysta semitecta</i> ▲ <i>Watzelella gochillii</i>	TA4.2
					CP16b			P18	▼ <i>Areosphaeridium alkylolotus</i> ▼ <i>Hystrioholopoma seminitera</i> ▲ <i>Glyphrocysta semitecta</i>	TA4.1
		34	C13n	■	CP16a	NP21	P17	Acl	▲ <i>Achomatosphaera alaicornu</i>	
	PRIABONIAN	33.7							▼ <i>Schematophora speciosa</i> ▼ <i>Meliosphaeridium pseudorecurvatum</i>	
			C15n	■	CP15b	NP19/20	P16	Cfu		
			C16n.1n	■					▼ <i>Schematophora speciosa</i> ▼ <i>Meliosphaeridium pseudorecurvatum</i>	
		36	C16n.2n	■	CP15a	NP18	P15	Mps		
			C17n.1n	■						

Rupelian/Chattian boundary

In chronostratigraphical considerations the base of the Chattian Stage at its type-locality at Doberg, near Bünde (NW Germany) is of particular importance. In their detailed evaluation

of the Paleogene stages, Berggren *et al.* (1985) proposed placing the base of the Chattian *sensu lato* within Chron C10n, and the base of the Chattian *sensu stricto* ('Eochattian') within the younger Chron C9r. Furthermore, they associated the Rupelian/Chattian boundary with the LO of the foraminifer *Chiloguembelina* and the NP23/24 boundary, both placed in Chron C10n. This view was subsequently adopted by Cande and Kent (1992), who provided an extrapolated age for the Rupelian/Chattian boundary of 28.5 Ma (mid Chron C10n). In central Italy, the most distinct dinocyst event falling within Chron C10n is the FO of *Distatodinium biffii*, which marks the base of the *Distatodinium biffii* (Dbi) Zone. Other important events occur just below this horizon (FO of abundant *Chiropteridium* spp. and LO of *Areosphaeridium pectiniforme*, correlated to Chron C11n.1r).

Despite problems associated with provincialism and migration effects, dinocysts may be considered important in the base Chattian GSSP research because they are diverse and abundant in the well-calibrated central Italian sections and in the Rupelian and Chattian stratotypes (Benedek, 1975; Chen *et al.*, 1993; Stover and Hardenbol, 1993). Benedek (1972; 1975; 1986) and Benedek and Müller (1974; 1976) described Chattian dinocyst assemblages, including those of the type area, from northwest Germany. From these studies no distinct dinocyst event seem to coincide with the base Chattian. Van Daniels *et al.* (1993, p.86) in their review of correlation between the Rupelian of Belgium and Germany, also stated: "...To define a Rupelian/Chattian boundary by ranges of dinoflagellates or calcareous nannoplankton seems to be difficult...". Nevertheless, some events reported by Benedek may be recognisable in the Italian sections. For example, Benedek (1975) records the LO of *Areosphaeridium pectiniforme* (as *Cleistosphaeridium pectiniforme*) in the basal part of the type Chattian. Furthermore, if the FO of "*Microsphaeridium ancistroides*" as recognised by Benedek (1972) in the "Untere Grafenberger Schichten" (lower Chattian) is interpreted as *Distatodinium biffii* (see discussion in Brinkhuis *et al.*, 1992), the event occurs somewhat above, but close to the Rupelian/Chattian boundary in the type area.

Other clues may be provided by correlation of stratigraphic sequences. The basal part of the type Chattian succession consists of glauconitic sands, interpreted to reflect transgressional deposits, following one of the most severe sea-level falls of Mesozoic and Cenozoic time, according to Haq *et al.* (1988; their TA/TB supercycle boundary). The Lower Oligocene in France and Belgium (*i.e.* the Stampian and Rupelian type sections) is overlain

- *Oligocene dinoflagellate cyst zonation* -

by similar deposits, suggesting that the base Chattian sea-level fall and subsequent transgression was a large-scale event. Haq *et al.* (1988) correlate the corresponding sequence boundary to a horizon within Chron C10n, claiming it reflects the Rupelian/Chattian boundary. Although no marked lithological changes are apparent in the monotonous central Italian Oligocene succession, quantitative shifts in the dinocyst distribution in the uppermost part of the Scaglia Cinerea have been interpreted to reflect sea-level changes at least in part. Brinkhuis *et al.* (1992) related the youngest acme of *Chiropteridium* spp. occurring near the top of the Contessa section, to a sea-level fall associated with the Oligocene/Miocene transition. In the present study four discrete, successive *Chiropteridium* acmes occur in the Upper Oligocene succession (see Figures 2 and 3), the oldest one close to the presumed Rupelian/Chattian boundary. If all four acmes are related to sea-level falls, this would agree with the four third-order sea-level drops in the Upper Oligocene as recognised by Haq *et al.* (1988). If the oldest *Chiropteridium* acme in the Central Italian sequence reflects the 'base Chattian' sequence boundary consequently the Contessa-based dinocyst evidence would imply that this horizon is correlative to a level within Chron C11, rather than Chron C10.

Oligocene/Miocene boundary

Following IUGS-initiated multidisciplinary investigations of various sections worldwide, but particularly around the Mediterranean (papers in Cati *et al.*, 1981; papers in Gelati and Steininger, 1983), the Lemme section (Piedmont Basin, NW Italy) was recently proposed as the base Miocene GSSP site (Steininger *et al.*, 1994; Steininger and Cati, *in press*). The boundary is placed at a horizon 35m from the top of the Lemme section at the base of Chron C6Cn.2n, just below the FO of the planktonic foraminifer *Globorotalia kugleri* (base N4 Zone). At Contessa Quarry, the Dbi Zone could be interpreted to straddle the Oligocene/Miocene boundary, since the FO of *Globorotalia kugleri* is reported from the uppermost part of this zone at this site (Montanari *et al.*, 1991; Brinkhuis *et al.*, 1992; Coccioni and Monechi, 1992; Zevenboom *et al.*, 1994; Coccioni *et al.*, 1994; see Figure 2). Moreover, other available calibrations at Contessa Quarry suggest the top of the Dbi Zone to be equivalent to the basal part of the Early Miocene NN1 (or CN1B) nannoplankton biozone (Coccioni and Monechi, 1992). However, the study of Zevenboom *et al.* (1994) indicated that the first normal polarity interval recorded in the Scaglia Cinerea Formation at Contessa Quarry above Chron C7n represents Chron C6Cn.3n, rather than Chron C6C? as postulated by Bice and Montanari (1992). Thus the FO of *Ectosphaeropsis burdigalensis*, the index-event for recognition of the base of the Ebu Zone, seems to lie within Chron C6Cn.2r at Contessa, as it does in the Lemme section. It hence appears that the index planktonic

foraminifer and calcareous nannoplankton events occur earlier at Contessa than in the Lemme GSSP section.

Interpolation between radioisotopic ages suggests that the Oligocene/Miocene boundary is 23.8 Ma (Cande and Kent, 1992).

CONCLUSIONS

Two new 'middle' Oligocene dinocyst zones are proposed (the *Hystrichokolpoma pusillum* and *Chiropteridium lobospinosum* interval zones) to link previously established dinocyst zonal schemes for the Eocene/Oligocene and Oligocene/Miocene transitions in central and north Italy. The new zones are based on the Contessa Quarry and Monte Cagnero sections (central Italy), and are calibrated against magneto- and biostratigraphical information. Furthermore, the previously established central Mediterranean zonal schemes have been evaluated in terms of recent data on the chronology of the Eocene/Oligocene and Oligocene/Miocene boundaries. Indications are that the resulting composite zonation is applicable throughout the Mediterranean region but awaits further well calibrated studies from various latitudes outside the Mediterranean region.

The Rupelian/Chattian boundary is associated with the LO of the foraminifer *Chiloguembelina* and the calcareous, nannofossil NP23/24 Zone boundary, both considered to be calibrated with Chron C10n (Berggren *et al.*, 1985). In central Italy, the most distinct dinocyst event associated with this chron is the FO of *Distatodinium biffii*, which marks the base of the *Distatodinium biffii* (Dbi) Zone. Other important events such as the FO of abundant *Chiropteridium* spp. and the LO of *Areosphaeridium pectiniforme*, occur just below this horizon but are associated with Chron C11. The above stresses the potential of dinocyst studies in the Rupelian/Chattian GSSP discussions.

The oldest acme of *Chiropteridium* spp. in Italy may reflect the major mid Oligocene sea-level fall as recognised by Haq *et al.* (1988; their TA/TB supercycle boundary). These authors considered the associated sequence boundary to equate to the Rupelian/Chattian boundary and correlated this horizon to Chron C10n. The dinocyst evidence from Contessa Quarry would however place this horizon in the older Chron C11.

- *Oligocene dinoflagellate cyst zonation* -

Figure 4. (next pages) Magnification is 450x for all figures unless stated otherwise. Most specimens have been photographed from Contessa Quarry material (CN), a few specimens have been photographed from other sections in central and NE Italy, derived from the collection of H.B. All taxonomic citations are according to Lentin and Williams (1993). England Finder coordinates between brackets.

Figure 4A next page (a,b) *Glaphyrocysta semitecta* Bujak; Lentin and Williams, 1980; Monte Cagnero CA 107-01 (Q-38/3); (c,d) *Melitasphaeridium pseudorecurvatum* Morgenroth; Bujak *et al.*, 1980; Massignano 7.50-02 (H-46/2); (e,f) *Hemiplacophora semilunifera* Cookson and Eisenack, 1965; Massignano 7.20-01 (P-43/2); (g,h) *Schematophora speciosa* Deflandre and Cookson, 1955; Priabona Pb 05-01 (N-29/3); (i) *Deflandrea* sp. cf. *D. heterophlycta* Deflandre and Cookson, 1955; Priabona Pb 27-01 (V28-4); (j) *Achomosphaera alvicornu* Eisenack; Davey and Williams, 1966; CN 38 (E-40/4); (k) *Areosphaeridium diktyoplokus* Klumpp; Eaton, 1971; Bressana Bs 30-n01 (T-40/2); 250x.

- Oligocene dinoflagellate cyst zonation -

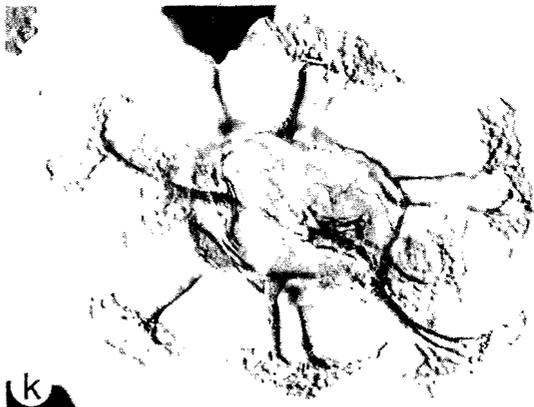
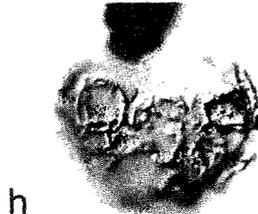
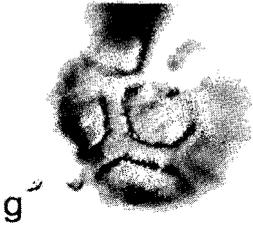
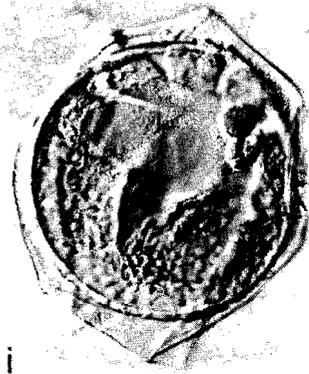
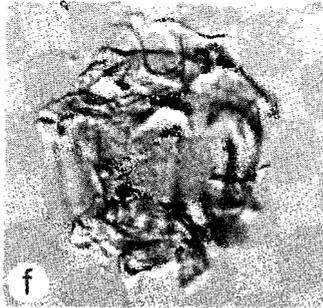
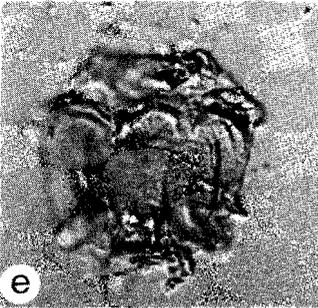
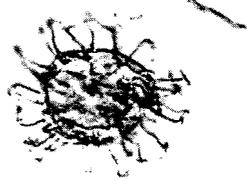
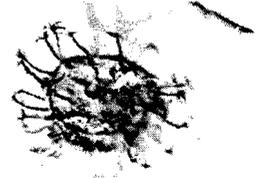
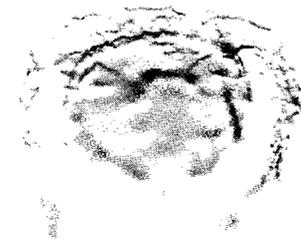
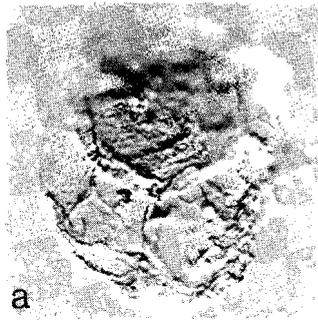


Figure 4B: next page (a,b) *Wetziella gochtii* Costa and Downie, 1976; CN 21 um-01 (T-42/3); 250x; (c) *Homotryblium* sp. cf. *H. oceanicum* Brinkhuis *et al.*, 1992; CN 14-01 (J-34/4); (d,e) *Hystrichokolpoma pusillum* Biffi and Manum, 1988; CN 14-01 (J-20/3); (f,g) *Areosphaeridium pectiniforme* Gerlach; Stover and Evitt, 1978; CN 39-02 (T-28/2); (h) *Chiropteridium lobospinosum*; Gocht; Gocht 1960; CN 14-01 (R-48/4).

- *Oligocene dinoflagellate cyst zonation* -

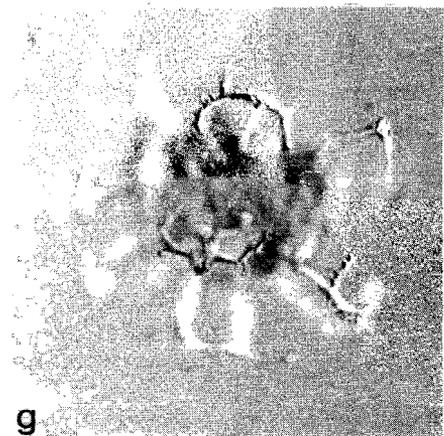
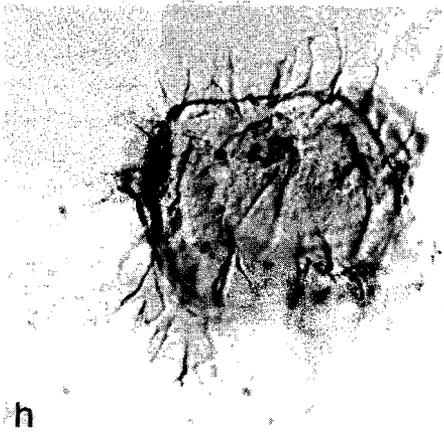
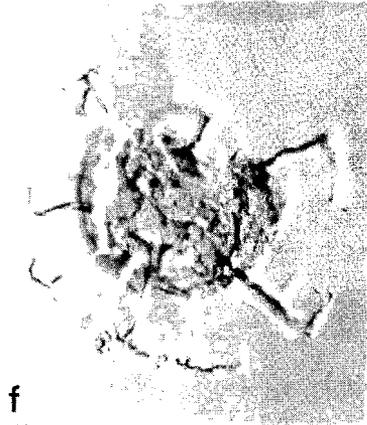
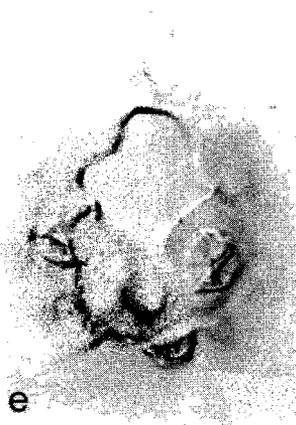
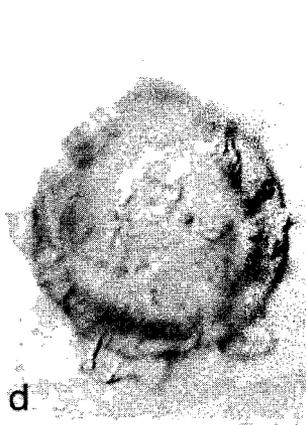
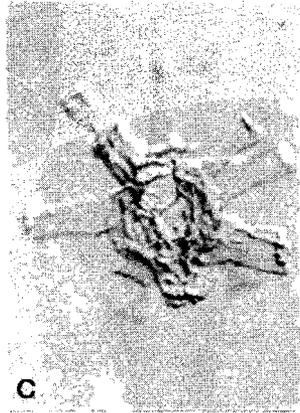
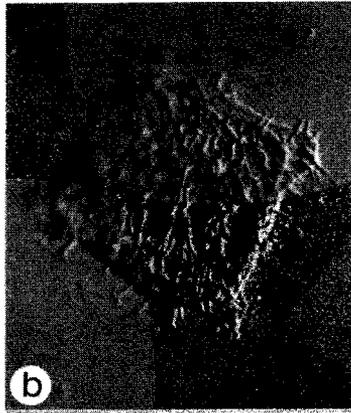
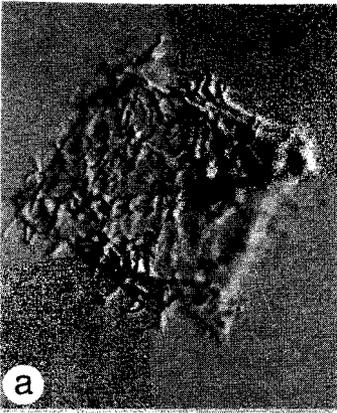
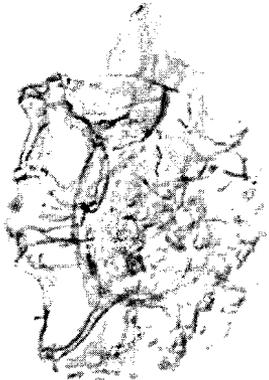
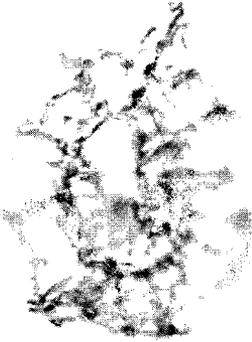


Figure 4C: next page (a) *Ectosphaeropsis burdigalensis* Londeix and Jan du Chêne, 1988; CN 03-02 (S-28/2); (b,c) *Ectosphaeropsis burdigalensis* Londeix and Jan du Chêne, 1988; CN 03-02 (U-45/1); (d/e) *Distatodinium apenninicum* Brinkhuis *et al.*, 1988; CN 01-01 (E38/4); (f,g) *Caligodinium pychnum* Biffi and Manum, 1988; CN 02-01 (T-20/3); (h) *Saturnodinium perforatum* Brinkhuis *et al.* 1992; CN 05-01 (L-18/3); (i) *Distatodinium biffii* Brinkhuis *et al.* 1992; CN 14-01 (G-25/4); holotype

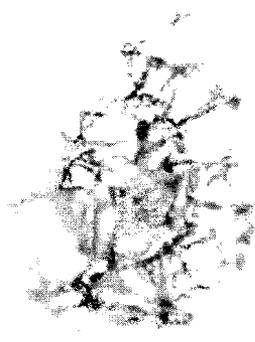
- *Oligocene dinoflagellate cyst zonation* -



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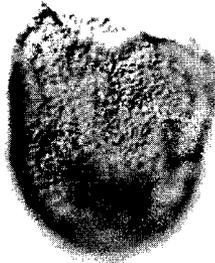
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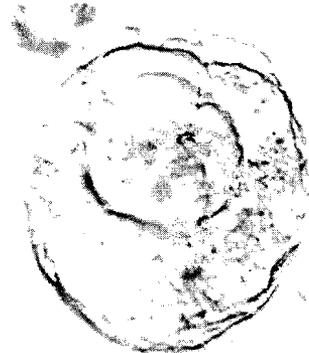
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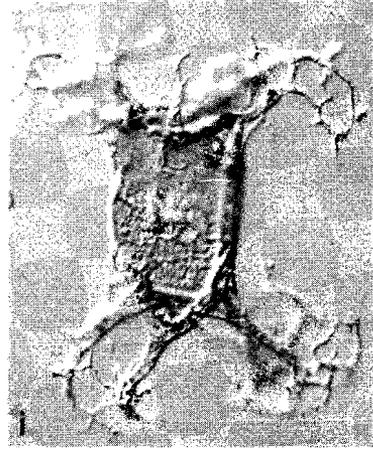
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CHAPTER 2.2

TECTONOSTRATIGRAPHY OF OLIGOCENE SEDIMENTS FROM THE INTERNAL AND MIDDLE IONIAN ZONES (EPIRUS, NW GREECE); CONSEQUENCES FOR THE RECONSTRUCTION OF THE PINDOS FORELAND BASIN EVOLUTION

ABSTRACT

Age assessments of successive stages of the late Eocene - Early Miocene evolution of the Pindos foreland Basin System (Epirus, NW Greece) indicate that 1) the inception of flysch sedimentation was diachronous in different parts of the Ionian Zone and 2) the transformation of the flysch basin into a piggy-back setting took place in late Oligocene time already. Furthermore results of our pilot study on the latest Eocene to Early Miocene successions of the internal and middle Ionian Zones, primarily based on the analysis of dinocyst associations, suggest much higher rates of change in Pindos foreland basin evolution than hitherto assumed. Discrete steps in the evolution of these zones were most probably coeval to changes in sedimentation patterns in the external Ionian Zone. At least some of these changes, in turn, might portray the effects of the development of blind thrusts.

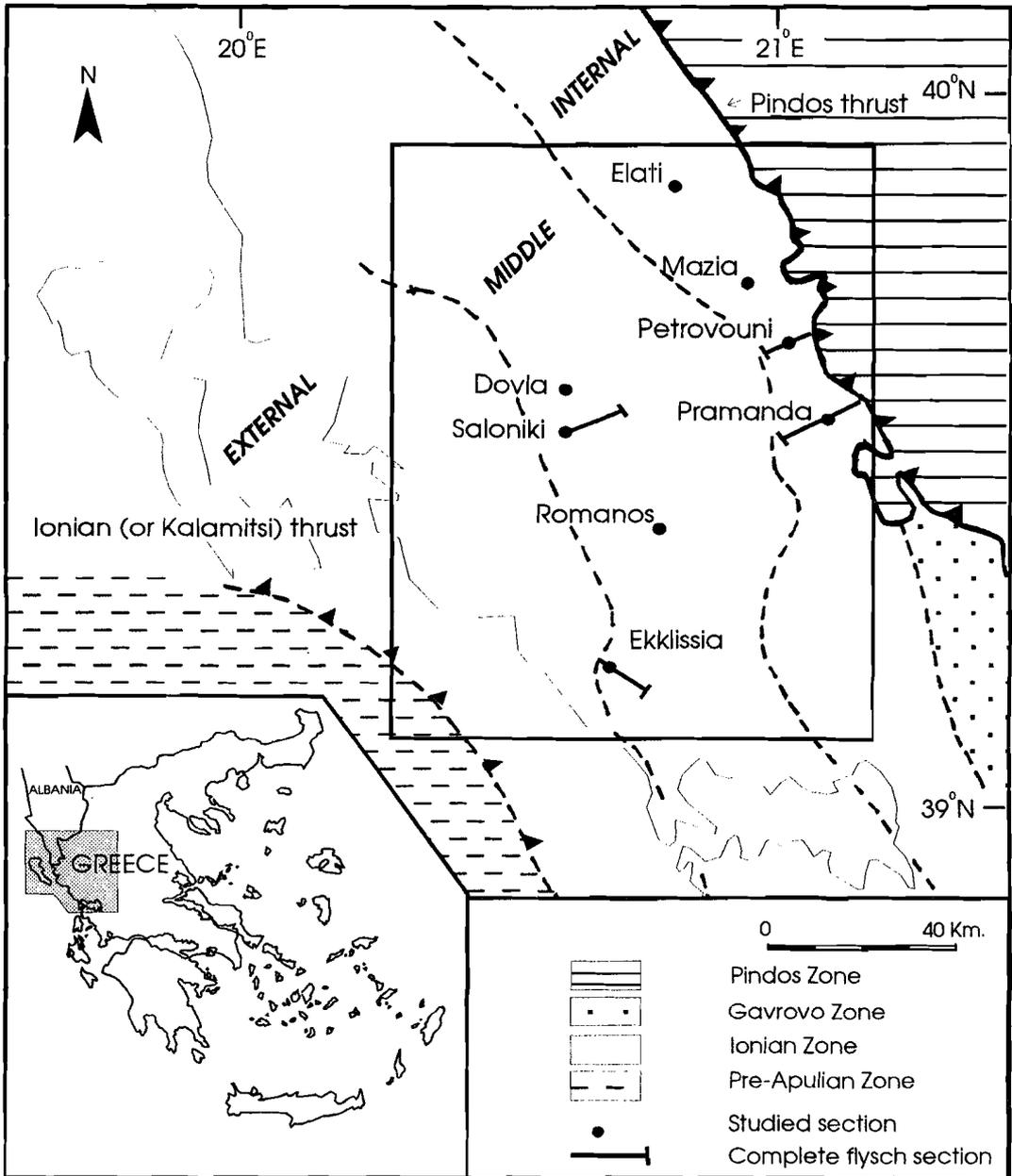
INTRODUCTION

Sedimentary-tectonic models pertinent to the outlines of the evolution of foreland basins (e.g. Allen and Homewood, 1986) are well-established now, but detailed, high-resolution tectonostratigraphic reconstructions of foreland basin development are often impeded by the lack of accurate datings. Such datings, however, are a prerequisite for any attempt to reconstruct in fair detail the temporal and spatial relationships between changes in foreland basin configuration and sedimentation resulting from tectonics and/or glacio-eustasy. As a rule, (relative) age assessments are mainly based on the study of calcareous microfossils (planktonic foraminifera, calcareous nannoplankton), but recently it has been shown (e.g., Brinkhuis *et al.*, 1992; Wilpshaar *et al.*, chapter 2.1; Zevenboom, *in press,a,b,c*; Zevenboom *et al.*, 1994) that dinocyst assemblages can be a powerful tool in Mediterranean biostratigraphy and paleoenvironmental interpretations.

In this (pilot) study we will test the applicability of dinocysts in the reconstruction of the late Eocene to Miocene history of the foreland (sub)basins of the Ionian Zone of the external Hellenides (Epirus, NW Greece). This in order to further constrain the timing and impact of major events described in the literature (e.g. IFP, 1966; de Mulder, 1975; Fleury, 1980; Clews, 1989; Waters, 1994). It will be attempted to date the Ionian sequences in terms of the dinoflagellate zones recently established for the Upper Eocene to Lower Miocene of the central Mediterranean (Brinkhuis *et al.*, 1992; Brinkhuis and Biffi, 1993; Brinkhuis, 1994; Zevenboom *et al.*, 1994; Zevenboom, *in press,a,b,c*) and summarized and extended by Wilpshaar *et al.* (chapter 2.1). These zones have been correlated with the Global Polarity Time Scale (GPTS), in part by first-order correlations, thus allowing their calibration with the numerical time scale. Two sets of samples for magnetostratigraphic analyses were taken from the sequences of the Ionian Zone in order to test the correlations based on the successions of the (northern) Apennines.

Figure 1. (next page) Geological sketch-map of the study area showing the distribution of isopic zones (after IFP, 1966) and locations of the studied sections. Names of the studied sections are derived from nearby villages: Dovla (20°33'E/39°34'N); Ekkliasia (20°37'E/39°12'N); Elati (20°45'E/39°50'N); Mazia (20°57'E/39°41'N); Petrovouni (21°01'E/39°34'N); Pramanda (21°07'E/39°31'N); Romanos (20°42'E/39°23'N); Saloniki (20°34'E/39°32'N). Underlined location names of the studied sections represent, besides the limestone-marl transition at the base, the complete (overlying) flysch sequence. The outlined area is represented in three dimensional thickness block diagrams of Figure 10.

- Pindos Foreland Basin evolution -



GEOLOGICAL BACKGROUND

NW Greece (Fig. 1) is part of the external Hellenides which comprise the Pindos, Ionian and Preapulian (=Paxos) isopic zones (Aubouin, 1959; 1965). The oldest sediments of the external Hellenides consist of Triassic evaporites and evaporitic carbonates (IFP, 1966), which sediments acted as a decollement level during late orogeny (Underhill, 1988). During the Liassic rifting phase (Sengor, 1979) pelagic carbonate sedimentation occurred in a deep furrow defined as the Ionian Zone (Aubouin, 1965). This structure was bounded to the east and west by the carbonate platforms of the Gavrovo and Pre-Apulian Zones, respectively. The Ionian Zone (Fig. 1) is subdivided, from east to west, in the Internal, Middle and External Ionian Zones (I.F.P., 1966). Carbonate sedimentation in the Ionian and Gavrovo Zones prevailed until the end of the Eocene. Around the Eocene-Oligocene transition sedimentation changed into the accumulation of thick terrigenous clastic turbidite successions. These 'flysch' sediments were deposited in a foreland basin that included both the Ionian and Gavrovo Zones and developed in response to the westward advance of the Pindos Thrust belt (Fig. 1). Therefore the flysch sediments in the Gavrovo Zone and in the Internal Ionian Zone are considered one genetic system (e.g. Jenkins, 1972; Alexander *et al.*, 1990). Age estimates of the flysch sediments of the Pindos Foreland Basin vary from late Eocene to Early Miocene (e.g. I.F.P., 1966; B.P., 1971; De Mulder, 1975; Fleury, 1980; Alexander *et al.*, 1990; Leigh, 1991).

The base of the flysch is not disrupted by a major unconformity (I.F.P., 1966; Fleury, 1980; Leigh, 1991; this study) as was suggested by B.P. (1971) and Jenkins (1972). B.P. (1971) proposed an Early to Middle Miocene age for the Pindos foreland basin fill explaining the presence of dominant Oligocene fauna as being the products of large-scale erosion and reworking of older deposits during the Miocene. This age assessment could not be confirmed by later authors (De Mulder, 1975; Fleury, 1980; Alexander *et al.*, 1990; Leigh, 1991; this study). Unfortunately the B.P. (1971) data have been (ab)used in later publications (e.g. Jenkins 1972; Piper, 1978; Clews, 1989). Several authors studied the inception of 'flysch' sedimentation characterised by the transition from limestones via marl into turbiditic sandstones (I.F.P., 1966; De Mulder, 1975; Fleury, 1980; Leigh, 1991). Some dispute on the age of the transition is apparent from these papers. I.F.P. (1966) dated the onset of flysch sedimentation as late Eocene and proposed it to be a synchronous event throughout the Ionian zone. In contrast Fleury (1980) proposed the onset to be diachronous, whereby the oldest flysch sediments contained Early Oligocene foraminifera. De Mulder (1975) dated the lowermost terrigenous clastic beds in the Middle Ionian Zone (Ekkliissia section) as Early Oligocene. Coccolith assemblages from the transitional sediments in the Internal Ionian Zone

- Pindos Foreland Basin evolution -

are in support of an Early Oligocene age (Leigh, 1991).

The age assessments of the basin fill are even more controversial than those of the onset of 'flysch sedimentation', especially when considering the age assessments of the flysch in the Internal Ionian and Gavrovo Zone (Fig. 2). I.F.P. (1966) suggested that a Late Eocene to Early Miocene (Aquitanian) age may be assigned to the basin fill of the Internal Ionian Zone. Fleury (1980) assigned an Oligocene age to the sediments deposited in the Internal Ionian Zone. Leigh (1991), using nannofossil zones also demonstrated that much of the sedimentary sequence in the Internal Ionian Zone is of Oligocene age, specified as CP17 (Early Oligocene) to CP19B (Late Oligocene) following the scheme of Okada and Bukry (1980).

In the External and Middle Ionian Zones the flysch sediments are unconformably (IFP, 1966) overlain by sediments deposited in a more restricted shallow marine so-called piggy-back basin which developed behind the Ionian (or Kalamitsi) Thrust (Clews, 1989; Fig. 1). The flysch sediments in the Internal Ionian and Gavrovo Zones are overthrust by the Pindos Thrust (Fig. 1). This study will mainly concentrate on the development of the flysch sediments in the Ionian Zone.

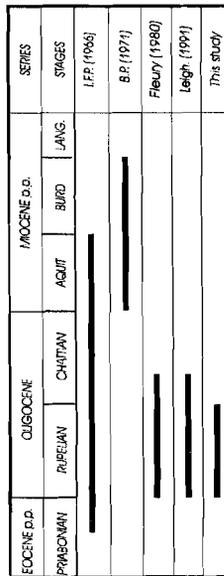


Figure 2. Ages of the Pindos foreland basin deposits of the Internal Ionian Zone from selected literature.

MATERIAL AND METHODS

Eight sections were selected for the analysis and documentation of the flysch sediments of the Ionian Zone: four sections in the Internal Ionian Zone (at Pramanda, Petrovouni, Mazia and Elati, Fig. 1), and four sections in the Middle Ionian Zone (at Saloniki, Ekklissia, Romanos and Dovla, Fig. 1) were palynologically analyzed and sedimentologically characterised. A palynological pilot study of the flysch sediments from the External Ionian Zone of the island of Ithaki revealed barren samples. Palynological samples were processed following standard palynological techniques. The taxonomy of dinoflagellate cysts corresponds to that of Lentin and Williams (1993). All material is stored in the collections of the Laboratory of Paleobotany and Palynology, University of Utrecht, The Netherlands. This paper reports on selected, stratigraphically important dinocyst events. These events allow detailed age assessments using the late Eocene - early Miocene zonal scheme of Wilpshaar *et al.* (submitted, Chapter 2.1 ; fig. 3).

Standard paleomagnetic cores were drilled with an electric drill and a generator as power supply for the 'transitional' intervals at Petrovouni (is Arakthos section, I.F.P., 1966) and Ekklissia (I.F.P., 1966). From the limestones of the lower part of the sections oriented handsamples were taken. All samples were progressively demagnetised, either by applying alternating fields or by stepwise thermal demagnetisation. The natural remanent magnetisation (NRM) was measured on a high-sensitivity 2G Enterprises cryogenic magnetometer, using DC squids.

Figure 3. (next page) Right: Stratigraphic columns with sample positions, important dinocyst occurrences and sub-stage indication of two Internal Ionian sections *viz.*, Pramada and Petrovouni (stratigraphic column after unpublished M.Sc. reports Utrecht University). Left: Stratigraphic columns with sub-stage indication of two Middle Ionian sections *viz.*, Saloniki and Ekklissia. Additional information on sample positions, dinocyst and/or foraminiferal zonation for the Middle Ionian sections are shown in Figure 7 and 8 for the Ekklissia and Saloniki sections, respectively.

- Pindos Foreland Basin evolution -

Internal Ionian zone

Petrovouni

Pramada

Legend

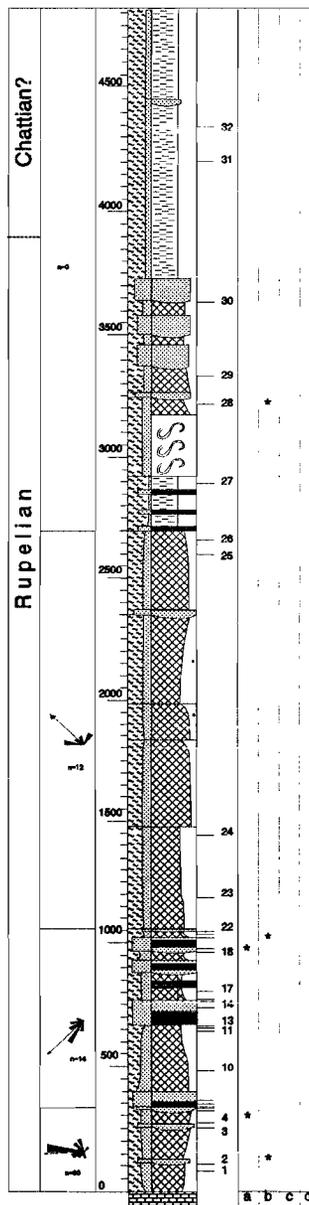
- Marl vs sand percentage
- Channel fill
- Blue-gray marl lithofacies
- Sandy turbidites
- Pebbly mud-grain flows
- Slumped turbiditic facies
- Well sorted sandstone
- Limestone

Diagnostic dinoflagellate cyst:

- a: *W. gochtii*
- b: *A. pectiniforme*
- c: *H. cf. sp.*, *H. oceanicum*
- d: *Chiropteridium*

Unidirectional paleocurrent data.
 n is number of measurements.
 Arrow indicates circular mean.
 Axe length = 10n

Series :
 Aq. : Aquitanian
 Chat. : Chattian

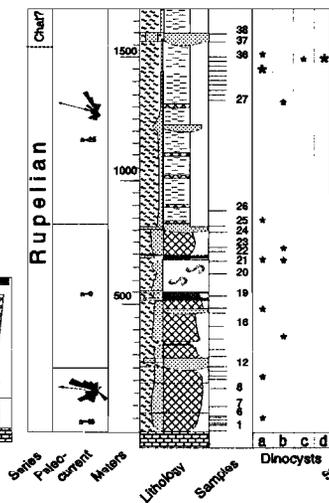
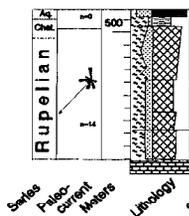
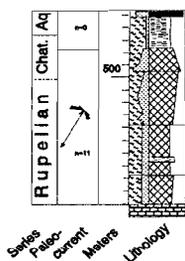


Middle Ionian zone

Petrovouni

Ekklissia (see Fig. 7)

Saloniki (see Fig. 8)



SEDIMENTARY CHARACTERISTICS

The flysch sediments of the Ionian Zone have been extensively described before (e.g. I.F.P., 1966; De Mulder, 1975; Piper *et al.*, 1978; Fleury, 1980; Alexander *et al.*, 1990; Leigh, 1991; Leigh and Hartley, 1992; Schuppers, 1995). The base of the flysch sequence is characterised by a gradual transition from limestones via a marl-dominated interval into sandy turbidites (flysch) mirroring the onset of the Pindos Thrust sheet activity. In general the flysch sequence of the Ionian Zone shows a gradual transition from turbidites with coarse clastic (pebbly mudflow) intercalations in the Internal Ionian Zone (thickness up to 6000m) towards (more distal) finer grained turbidites without coarse terrigenous interbeds (thickness up to 200m) in the External Ionian Zone (I.F.P., 1966). This westward change from proximal to distal lithologies is consistent with paleocurrent data, which indicate (1) axial flow (\pm N-S) and (2) transverse flow (\pm E-W) suggesting an eastern source of these turbidites (Piper *et al.*, 1978; Fleury, 1980; Clews, 1989; Alexander *et al.*, 1990 and this study). This eastern source is reflected by the presence of fragments which originated from sediments of the emerging Pindos Zone and from more internal parts of the Hellenides (Aubouin, 1959).

Internal Ionian Zone

The thickness of the flysch sediments within the Internal Ionian Zone varies from 6000 m (I.F.P., 1966) to 1700 m (Petrovouni section, Fig. 3). These extremes may occur only a few kilometers apart (Fig. 1 and 3; the Petrovouni and Pramanda sections).

In the Internal Ionian sections the limestones below the flysch sequence are mainly bioclastic with mass transport phenomena (e.g. turbiditic limestones, channel fills). A characteristic feature in the marl unit just above the bioclastic limestones but below the first sandy turbidites is a level of up to some 20-30 m, so-called lithographic limestones which is found at many places in the studied part of the Internal Ionian Zone (Fig. 4). The next higher interval is characterised by sandy turbidites (Fig. 3). Moreover, thick units of slumped, massive and chaotic sandstone units occur throughout this interval, mainly in the upper part. The top few hundred meters of the Pramanda and Petrovouni sections (Fig. 3) consist of marls with isolated units of sandstones and/or conglomerates. In general, such sandstone intercalations can be traced laterally over a few kilometers. In contrast, the conglomerates which occur at the top of the sequence can only be correlated over short distances (some hundreds of meters).

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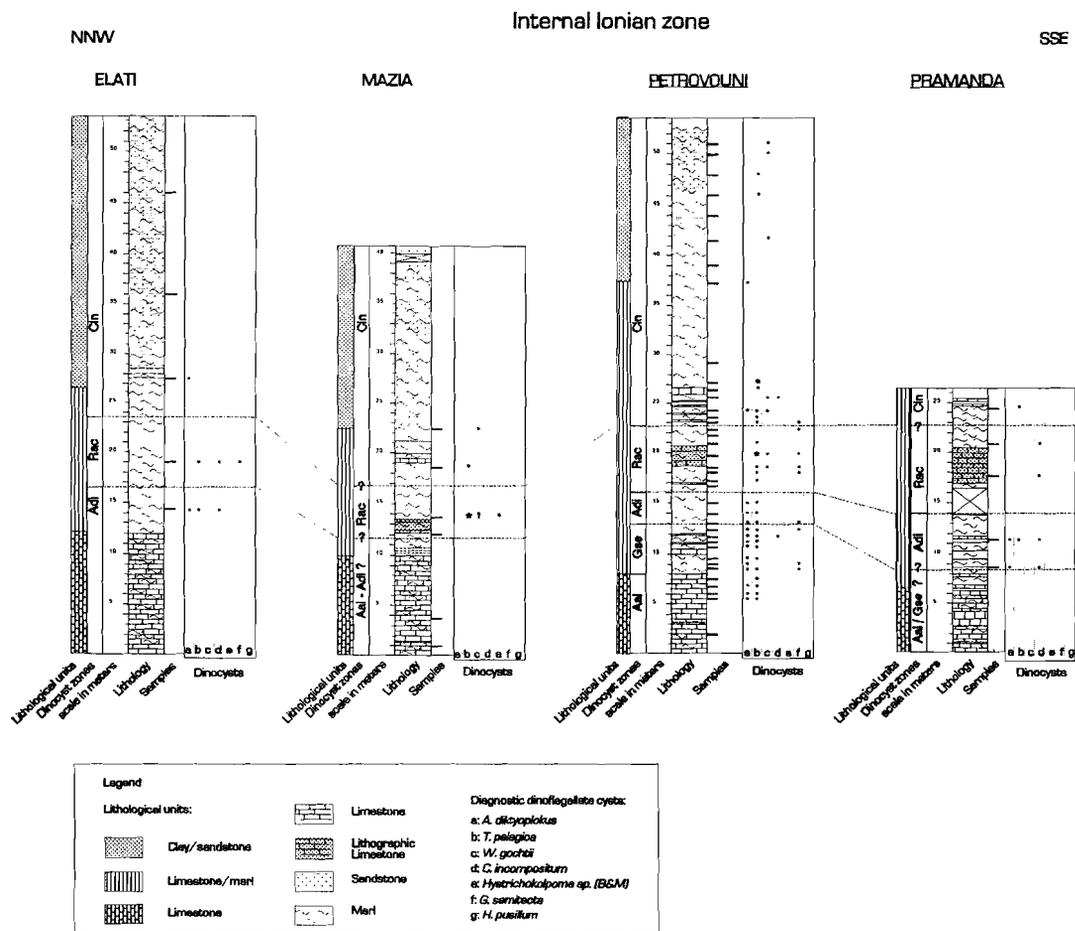


Figure 4. Correlation diagram between four Internal Ionian 'transitional' sections

- Chapter 2.2 -

The flysch sediments exposed in the Internal Ionian and Gavrovo Zones have been interpreted as prograding submarine fan systems by Piper *et al.* (1978). The turbidites at the base of the section in Figure 3 are inferred to represent the most distal parts of this submarine fan system. The subsequent units of slumped, massive and chaotic sandstones are consequently interpreted to originate from the slumping of submarine delta-fan sediments. They must be related to a build-up, and subsequent collapse of deltas and/or to a (tectonically controlled) gradual increase in slope-angle, leading to slope failure. The isolated sandstone bodies in the top few hundred meters of both sections are interpreted as fan lobes formed laterally of the main feeder systems, while the conglomerate bodies are considered to represent proximal feeder-channel deposits (upper-fan deposits). The sediments of the Internal Ionian Zone have been overthrust by the Pindos Thrust, and thus originally deposited younger sediments may now be missing.

Middle Ionian Zone

The flysch sediments exposed at Saloniki and Ekklissia in the Middle Ionian Zone display an almost identical lithology and thickness (Figs. 5, 6). The thickness of the flysch sediments are up to $\pm 1500\text{m}$ (I.F.P., 1966). The lower parts of both sections are characterised by a unit of distal turbidites. The upper part of this unit is characterised by poorly sorted, immature, organic rich sandy turbidites referred to as 'Formation de Radhovizi' by I.F.P. (1966). The upper part of this 'Formation de Radhovizi' is characterised by a more marly interval. Within this marly facies, calciturbidites with eastward directed paleocurrents have been recorded. This is opposite to the dominant westward directed paleocurrents measured within the sandy turbidites. This marly unit is unconformably covered by thick, well-sorted and positively graded sandstone beds.

External Ionian Zone

The thickness of the late Paleogene to early Neogene flysch sequences of the external Ionian Zone exposed on the islands of Kefallinia, Ithaki and Kerkyra (Corfou) does not exceed 200 m (IFP, 1966). As a rule, these sequences are composed of marly beds followed upwards by sandy turbidites. According to De Mulder (1975) the transition from (predominantly) pelagic carbonate into terrigenous mud accumulation took place in the earliest Oligocene. The deposition of relatively fine-grained, sandy turbidites of distal character started around the Oligocene - Miocene transition.

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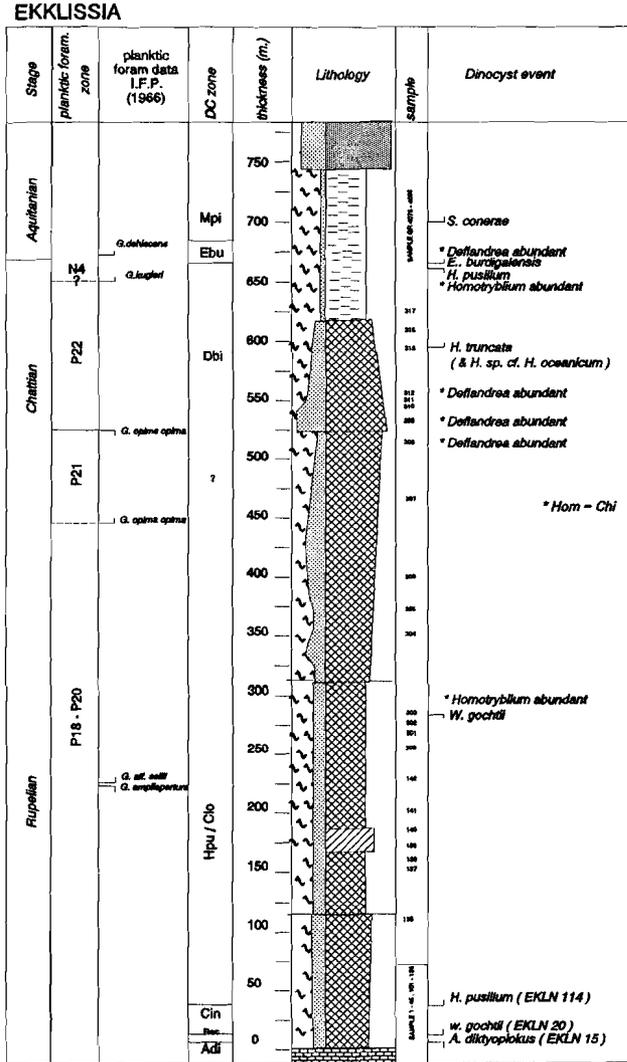


Figure 5. Stratigraphic column with sample positions, foraminiferal zonation (after I.F.P., 1966), dinocyst zonation and substage indication of the Eklissia section.

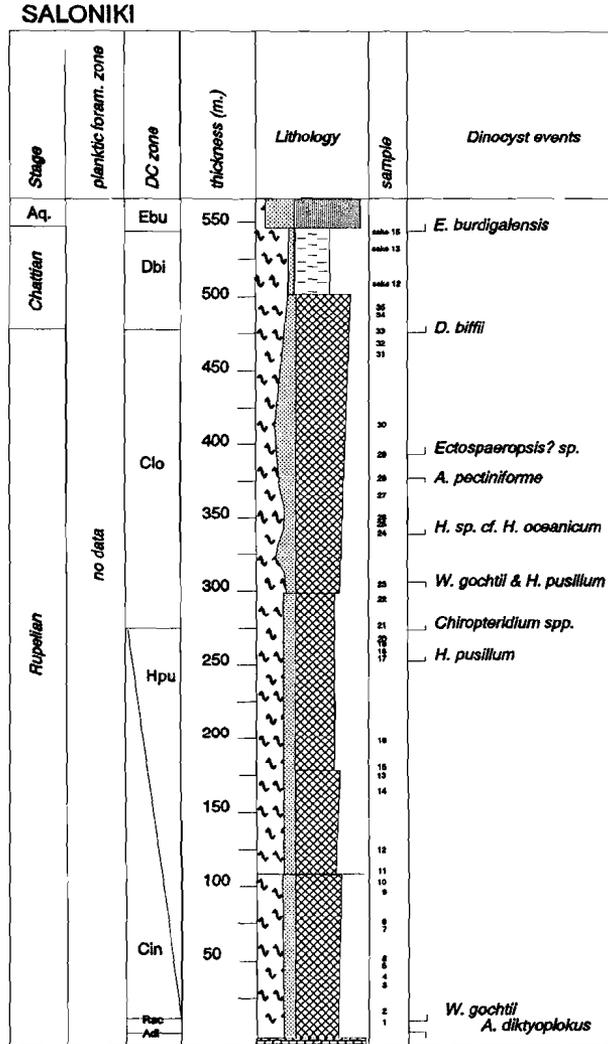


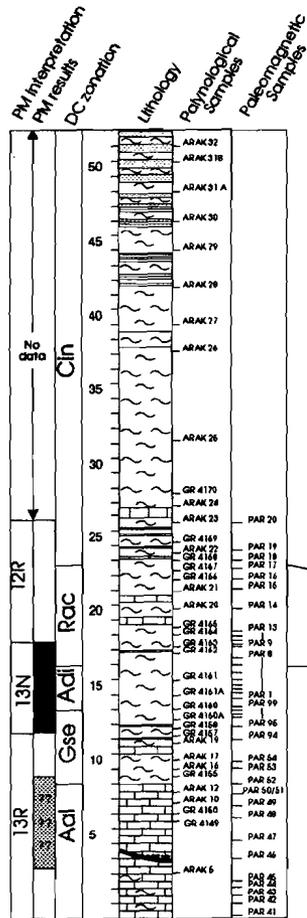
Figure 6. Stratigraphic column with sample positions, dinocyst zonation and substage indication of the Saloniki section.

Superimposed upon the longitudinal infill of terrigenous-clastic turbidites in the (sub)basins of the external Ionian Zone, coarse, ill-sorted carbonate breccias and breccioconglomerates were transported from shoals and emerged areas bordering the flysch (sub)basins (De Mulder, 1975). Such coarse carbonate intercalations of a very proximal character were reported to be most frequent on the island of Ithaki, where they are found in two intervals in the 'Middle to Upper Oligocene' and in the upper Lower Miocene (Burdigalian), respectively. The Oligocene coarse carbonates are intercalated in the lower, marly part of the flysch sequence, those of the Burdigalian in the sandy turbidites. No proximal mass-transported carbonates were observed in the Aquitanian part of the flysch sequence.

MAGNETOSTRATIGRAPHIC ANALYSIS

The demagnetisation diagrams from the transitional interval at Petrovouni (Internal Ionian) and Ekkliissia (Middle Ionian; Figure 7) reveal both normal and reversed components and show that in most samples the characteristic remanent magnetisation (ChRM) is removed between 200 and 570 °C (Figure 8). The ChRM directions show on average a 48° clockwise tectonic rotation for the Arakthos section, which is in good agreement with the results from Horner and Freeman (1983) and Kissel and Laj (1988) who report rotations of 45-50°. This large rotation of the ChRM enables to distinguish between a primary normal direction and a normal overprint. Since there are both normal and reversed directions we take this as additional evidence for a primary origin of the magnetisation. Unfortunately, some samples show such a low intensity that no reliable directions could be determined (e.g., at Ekkliissia below and above a normal polarity interval). The ChRM directions of the Arakthos section record allow for the recognition of a well-defined normal polarity interval, comprising the upper part of the Gse Zone, the whole Adi Zone and the lower part of the Rac Zone (Figure 7). Despite uncertainties, the results from the Ekkliissia section indicate a reversed polarity for the Cin Zone and a normal polarity for the lower part of the Rac Zone (Figure 7). Comparison of the biostratigraphic and magnetostratigraphic results with the scheme of Wilpshaar *et al.*, (Chapter 2.1, figure 3) indicate that the normal polarity interval in both sections may be interpreted to represent subchron C13n. The comparison furthermore confirms that the sections are largely time-equivalent and also indicates that the transition from limestones to terrigenous clastic deposits occurs somewhat earlier at Arakthos than at Ekkliissia (Figure 7).

Arakthos (proximal)



Ekkliisia (distal)

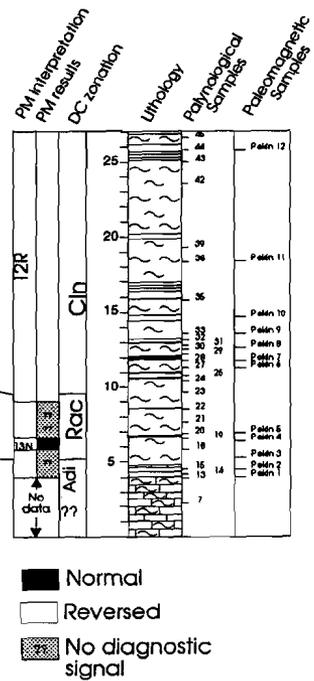


Figure 7. Magnetostratigraphic results at Ekkliisia and Petrovouni (=Arakthos, IFP, 1966).

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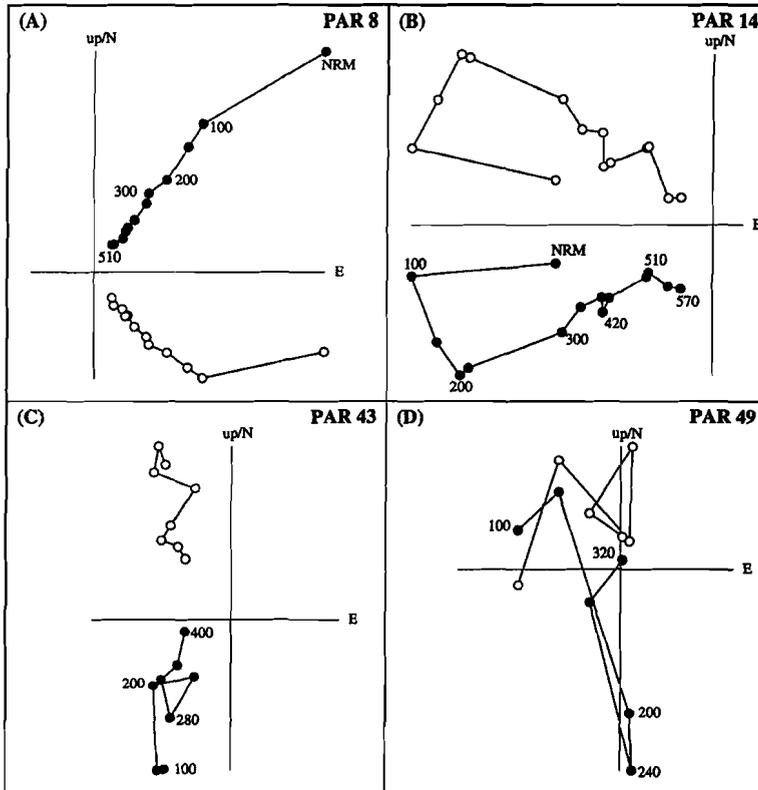


Figure 8. Orthogonal projections of stepwise thermal demagnetisation of selected samples from the Arakthos section. Dots (circles) represent the projection of the ChRM vector end-point on the horizontal (vertical) plane. Values represent temperatures in °C.

PALYNOLOGY AND REEVALUATION OF PREVIOUS AGE ASSESSMENTS

Internal Ionian Zone

The dinoflagellate cyst distribution in the investigated sections shows that the base of the marly unit immediately on top of the bioclastic limestones in the Internal Ionian Zone coincides with the Aal/Gse zonal boundary, which corresponds with the Eocene Oligocene boundary (Fig. 4, Appendix I). The samples from the overlying sandy turbiditic flysch sediments of the Internal Ionian Zone at Pramanda and Petrovouni only yield poorly diversified dinoflagellate cyst assemblages (Appendix II and III). Apparently, the significantly increased sedimentation rates caused a diluted palynological signal. However, the few age-diagnostic taxa indicate that the flysch deposits are of Oligocene age. The co-occurrence of *Homotryblum* cf. sp. *H. oceanicum*, *Chiropteridium* spp. and *Areosphaeridium pectiniforme* in the top part of the Petrovouni section suggests a late Rupelian Age (Clo Zone; Fig. 3). No typical Chattian dinoflagellate cyst taxa (e.g., *Distatodinium biffii*) have been found, neither in the Pramanda nor in the Petrovouni section.

The age assignment of the upper part of the flysch sequence of the internal Ionian Zone is in accordance with datings by Fleury (1980) and Leigh (1991), based on planktonic foraminifera and calcareous nannoplankton, respectively. These findings seem to be in contrast with the Aquitanian Age as proposed by the authors of the IFP (1966). However, this discrepancy may be attributed to the assignment of the planktonic foraminiferal *G.opima opima* Zone to the Aquitanian at the time, which zone is now considered to belong to the Oligocene (see also Stainford *et al.*, 1975, in Fleury, 1980).

Middle Ionian Zone

Deposition of the marly sediments on top of the limestone beds in the Middle Ionian Zone started during the Adi dinoflagellate cyst zone (Fig. 9; Appendix IV). The samples from the flysch sediments of the sections of the Middle Ionian Zone (Figs. 5 and 6; Appendix V and VI) yield somewhat richer and better preserved dinoflagellate cyst assemblages than their counterparts in the Internal Ionian Zone. Age-diagnostic dinoflagellate cysts indicate a Rupelian Age for the lower and middle parts of the analyzed sections (Fig. 5, 6). The upper marl-dominated part of the sections is of Late Oligocene to Early Miocene age. The Oligocene/Miocene transition occurs approx. 75m below the uppermost sandstones at Ekklissia, and some 10m below this unit at Saloniki (Figs. 5, 6).

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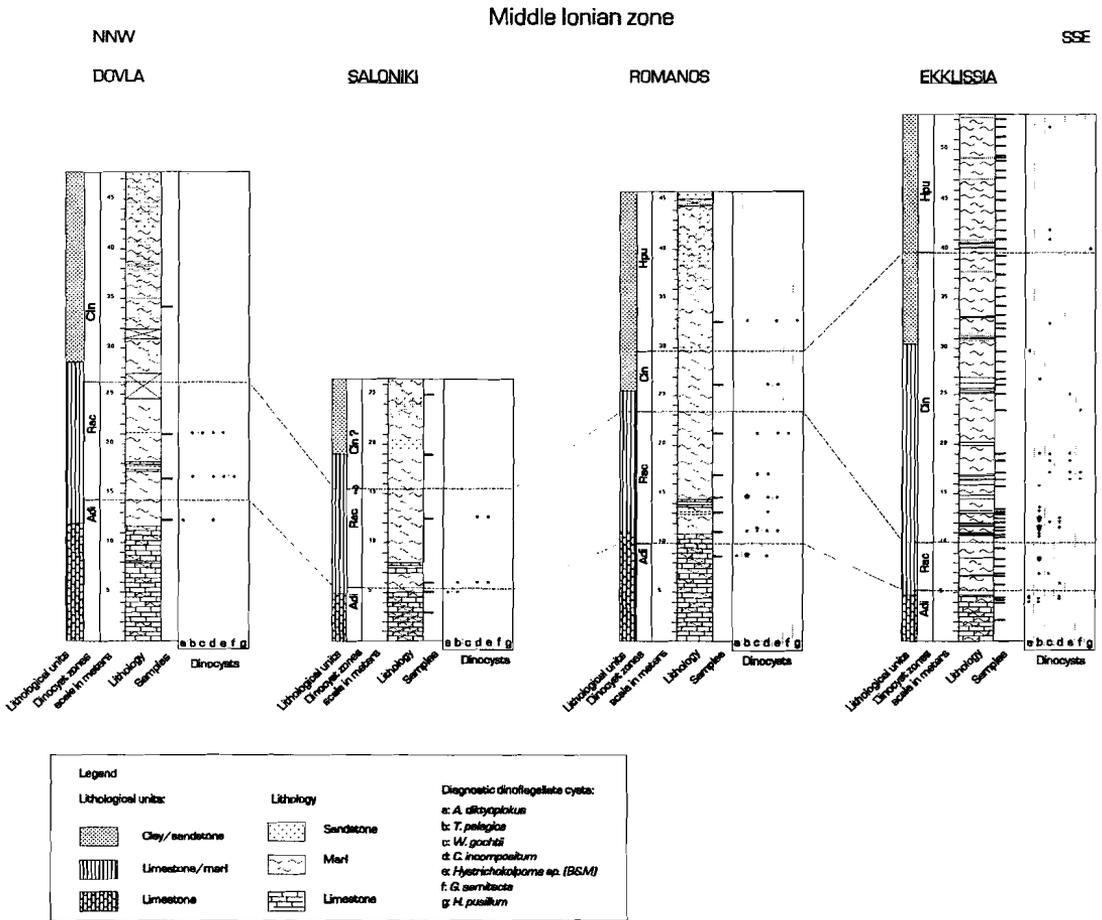


Figure 9. Correlation diagram between four Middle Ionian 'transitional' sections.

If our stratigraphic interpretation of the Ekkliissia section is compared with available planktonic foraminiferal data from I.F.P. (1966) using more recent chronostratigraphic interpretations (e.g. Blow 1969; Stainford *et al.* 1975; Boli and Saunders 1985), then it appears that both the zonations established on the basis of planktonic foraminifera and dinoflagellate cysts confirm a largely Oligocene to Early Miocene age for the Ekkliissia section (Fig. 5).

External Ionian Zone

Unfortunately, no dinoflagellate cysts could be recovered from a set of samples taken from the various units of the latest Eocene to latest Early Miocene sequence of the island of Ithaki. Therefore, we have to rely on the ages of the sedimentary- tectonic units as given by De Mulder (1975). His dating of the inception of sandy turbidite sedimentation at about the Oligocene - Miocene (Chattian - Aquitanian) transition is corroborated by planktonic foraminiferal findings from the succession of the island of Kefallinia (transition *G. mendacis* to *G. kugleri* types, W.J. Zachariasse, pers. comm.).

DISCUSSION

In order to visualize the outlines of latest Eocene to Miocene evolution of basin configurations and accumulation patterns three block diagrams were constructed for the Eocene, the Oligocene and the (Early) Miocene, respectively. These diagrams are based on thickness distributions given by IFP (1966; corrected for newly obtained age assignments) and our own observations. From the diagrams (Figure 10) it can be inferred that the Eocene sequences do not show any pronounced differences in thicknesses between various parts of the Ionian Zone, which suggests fairly smooth bottom topography at the time, i.e. prior to the shift from carbonate to terrigenous clastic sedimentation.

The diagram for the Oligocene (Figure 10b) clearly portrays the effects of the increasing differentiation between the internal, middle and external parts of the Pindos foreland Basin system, in particular with respect to the development of a pronounced foredeep in the internal parts of the system (Internal Ionian Zone) starting at the beginning of the Oligocene. The diagram for the (Early) Miocene shows the net-result of subsequent changes which resulted in the emergence of the Internal Ionian Zone and a depocenter shift towards more external Ionian Zones.

Below, an attempt to reconstruct the tectonostratigraphic history in more detail, based on the combination of our dinoflagellate cyst analyses and relevant literature data is presented.

- Pindos Foreland Basin evolution -

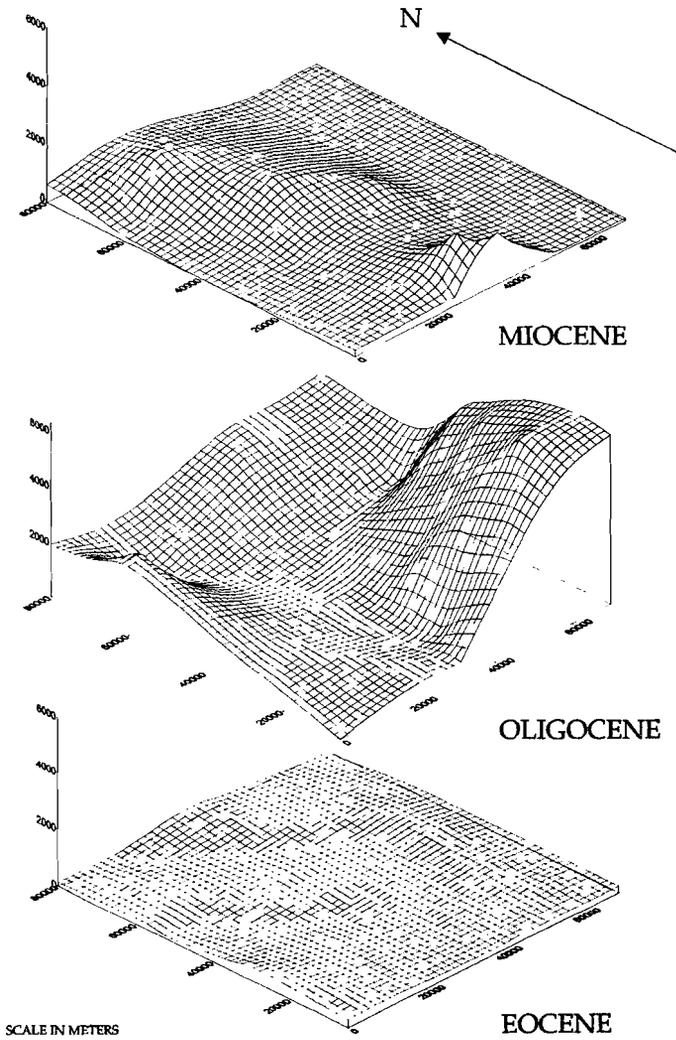


Figure 11 Three dimensional block diagrams for thicknesses of Eocene, Oligocene and Miocene sequences (modified after I.F.P., 1966). Outlined area is that of Figure 1. View direction is towards the northwest with a view angle of 20 degrees.

Latest Eocene - earliest Oligocene (Fig. 11a)

The mass-transported, coarse limestone breccia intercalations of shallow marine origin in the uppermost part of the predominantly pelagic Eocene carbonate sequences witness of the increasing tectonic instability prior to the fundamental change in sedimentation in the Eocene - Oligocene boundary interval. Such intercalations are most frequent in the Internal and Middle Ionian Zones, whereas they are absent in the pelagic carbonate sequence of the External Ionian Zone. Detailed analyses of the dinoflagellate cyst associations across the carbonate - marl transitions in various parts of the foreland basin system clearly indicate that the change in sedimentation occurred in earliest Oligocene time. However, this change seems to have taken place in the Internal Ionian Zone earlier (*i.e.* in the earliest Gse Zone) than in the Middle Ionian Zone (*i.e.* top Adi Zone; see also Figure 7). In a forthcoming paper by Peeters et al. (*in prep.*) it is demonstrated that glacio-eustatic events were superimposed upon the tectonically-induced changes around the Eocene-Oligocene transition.

Our observations on the lowermost, marly parts of the terrigenous clastic sequences suggest the absence of any pronounced submarine relief during the earliest stage of clastic infill of the foreland basin system (see also Figure 10). Sedimentation rates were low, in the order of magnitude of a few cm/Kyr at the maximum. Local intercalations of lithographic limestones in the lowermost part of the flysch successions of the Internal Ionian Zone (Petrovouni, Pramanda, Mazia, see fig. 1) may reflect deposition in small, restricted subbasins, originating from small-scale transverse basement faulting (*cf.* Ricci Lucchi, 1986; Oost and De Boer, 1994; Schuppert, 1995).

Early Oligocene (Fig. 11b)

In the course of the early Oligocene the hitherto rather smooth submarine relief changed into a complex configuration, primarily marked by the development of a rapidly subsiding foredeep in the internal Ionian Zone, where up to 5000 - 6000 meter of sediments accumulated. This change was accompanied by the rapidly increasing supply of relatively coarse clastics and the development of submarine fan systems. The results of our biostratigraphic analyses suggest that accumulation rates (uncorrected for compaction) were locally as high as 100 cm/Kyr in the Internal Ionian Zone. We speculate that the large thickness differences between the successions of the Internal (acting as a sediment trap) and the Middle and External parts of the Ionian Zone may be attributed to the development of a foreland bulge.

- Pindos Foreland Basin evolution -

Great longitudinal (alongstrike) differences in thickness of the turbiditic sequences (see e.g. sections Pramanda and Petrovouni, Figure 3) may have been related to synsedimentary displacements along transverse fault systems, which transverse faulting, in turn, may have been coupled with differential horizontal displacements of (parts of) the advancing thrust sheets.

Late Oligocene (Fig. 11c)

In the Internal part of the Pindos foreland Basin system sedimentation most probably had come to a close at the beginning of Late Oligocene (Chattian) time. The conglomerates of the top part of the flysch sequences in the Internal Ionian Zone are considered proximal feeder channels of the prograding submarine fan system and represent the final stage of infill of the foredeep. Dinoflagellate cyst associations recovered from clays below these channels suggest a (late) Rupelian Age. From these sedimentary and palynological observations we tentatively conclude that the Internal Ionian Zone became emerged in the course of the Late Oligocene, whereas sedimentation continued in the Middle (and External) Ionian Zones, as evidenced by Chattian (and younger) dinoflagellate cyst associations.

Literature data (IFP, 1966; De Mulder, 1975) and our own observations indicate an increasing degree of differentiation between various parts of the Middle and External Ionian Zones from about the Early-Late Oligocene transition onward. This is evidenced by pronounced differences in Late Oligocene to earliest Miocene types of sediment succession both within and between the Middle and External Zones. In this respect the intercalations of mass transported calcareous intercalations (pebbly mudflows and calciturbidites) in the Upper Oligocene sequence of the External Ionian Zone are of particular interest. As demonstrated by De Mulder (1975) these intercalations, composed of mixtures of shallow water detrital limestones and pre-Oligocene components must have been derived from intrabasinal shoals and islands or from the nearby Apulian Platform. In combination with comparable features of mass transport of carbonates of a proximal character elsewhere in the External and Middle Ionian Zones, these observations strongly suggest high tectonic instability in the Middle and External Ionian Zones during the Late Oligocene.

Our interpretations on the tectonostratigraphic evolution of the Pindos Foreland Basin system in Late Oligocene to earliest Miocene time are schematically summarized in Figure 11c. It is assumed that the final stage of infill of the Internal Ionian foredeep was connected to a major phase of thrusting, which resulted in the uplift and emergence of the internal part of the Pindos foreland Basin system in the course of the Late Oligocene. These processes were most likely coupled with the inception and/or accentuation of thrusting in the Middle

and External Ionian Zones. The development of blind thrusts may have resulted in the origin of intra-basinal shoals and/or islands; continuing movements along these thrusts caused the fairly continuous removal of carbonate debris and of pre-Oligocene clasts from the islands and shoals and their subsequent downslope transport in the flysch (sub)basins where longitudinal infill of terrigenous clastics prevailed.

Probably these processes played their major part along the western margin of the External Ionian Zone, i.e. along the transition towards the Preapulian (Paxos) Zone, as suggested by the high numbers, thickness and coarse-grained character of the proximal mass flows on the Ionian islands. It may be postulated that the Ionian (Kalamitsi) Thrust, which at present separates the Preapulian and Ionian Zones started, to act as the major thrust of the mobile fold and thrust belt of the external Hellenides already in the Late Oligocene. This would imply that the (sub)basins of the Middle and External Ionian Zones were transformed into piggy-back basins at the time; in the latter zones no foredeep developed as in the Internal Ionian Zone before.

Early Miocene

As yet no detailed dinoflagellate cyst analyses were performed on the Early Miocene to Middle Miocene sequences. However, literature data suggest that another basin rearrangement occurred at about the Aquitanian - Burdigalian transition, accentuating the already existing piggy-back setting of the Middle and External Ionian Zones. This Burdigalian episode was expressed in Epirus by the accumulation of relatively shallow, positively graded calcareous sandstone sequences in the Botzara syncline (IFP, 1966). On the Ionian island of Ithaki (De Mulder, 1975) the Burdigalian was marked by a renewed episode of high tectonic instability along the western margin of the Ionian Zone, predating a major thrusting event at about the Early to Middle Miocene transition (Cushing, 1985; Meulenkamp and Hilgen, 1986).

Figure 11. (next page) Tectonostratigraphic evolution of the Pindos Foreland Basin during the Oligocene, showing the earliest Oligocene basin configuration (11a), the Early Oligocene foreland basin which developed in front of the Pindos Thrust (11b) and the late Oligocene piggy back basin which developed east of the Kalamitsi Thrust (11c).

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Figure 11A: latest Eocene - earliest Oligocene

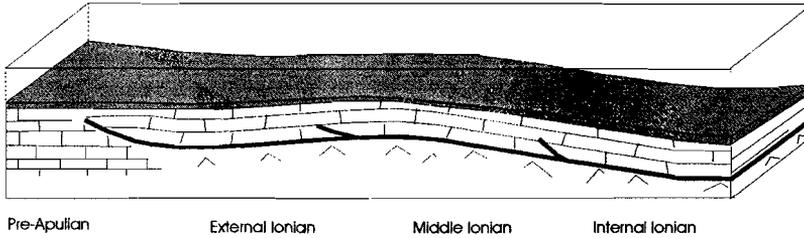


Figure 11B: Early Oligocene

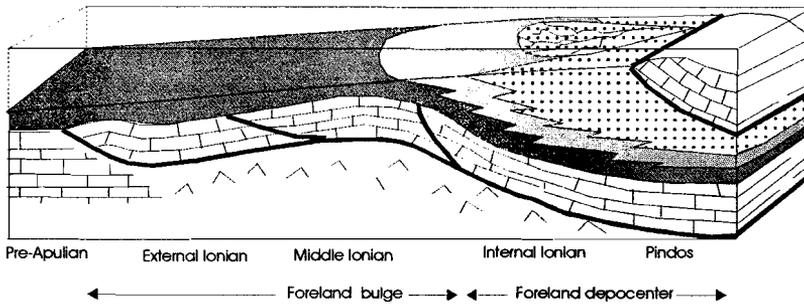
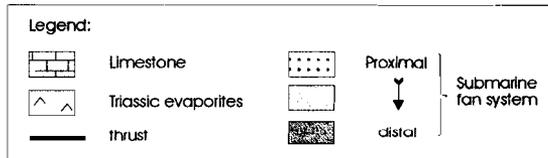
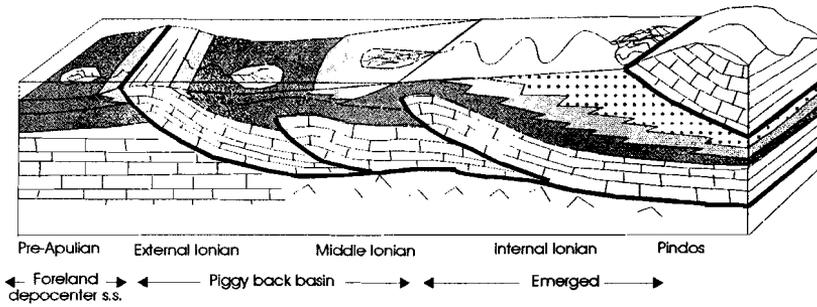


Figure 11C: Late Oligocene



- References -

REFERENCES

- Alexander J., Nichols G.J. and Leigh S., 1990. The origins of marine conglomerates in the Pindus foreland basin, Greece. *Sedimentary Geology* **66**: 243-254.
- Allen, P.A. and Homewood, P. (Eds.), 1986. Foreland Basins. *International Association of Sedimentologists, special publication* **8**.
- Angevine, C.L., Heller, P.L. and Paola, C. 1990. Quantitative sedimentary basin modelling. *American Association of Petroleum Geologists Education Course Note Series*, **32**.
- Arnaud, H. 1981. De la plate-forme urgonienne au bassin vocontien: le Barremo-Bedoulien des Alpes occidentale entre Isere et Buech (Vercors, Méridional, Diois et Devoluy). *Geologie Alpine Memoire Special* **12**, 3 vol., 804pp.
- , 1988. Subsidence in certain domains of southeastern France during the Ligurian Tethys opening and spreading stages. *Bulletin de la Société Géologique de France* **8** (5): 725-732.
- Arnaud-Vanneau A., Arnaud H., 1990. Hauterivian to Lower Aptian carbonate shelf sedimentation and sequence stratigraphy in the Jura and northern Subalpine chains (southeastern France and Swiss Jura). *International Association of Sedimentologists, special publication* **9**: 203-233.
- and Arnaud, H., 1991. Sédimentation et variations relatives du niveau de la mer sur les plates-formes carbonatées du Berriasien-Valanginien inférieur et du Barrémien dans les massifs subalpins septentrionaux et le Jura (Sud-Est de la France). *Bulletin de la Société Géologique de France*, **3**, 535-545.
- , Arnaud H., Charollais J., Conrad M-A., Cotillon P., Ferry S., Masse J-P., Peybernes B., 1979. Paléogéographie des calcaires Urgoniens du sud de la France. *Géobios, Mémoire spécial*, **3**, 363-383.
- , Arnaud H., Adatte T., Argot M., Rumley G. and Thieuloy J.-P. 1987. The Lower Cretaceous from the Jura Platform to the Vocontian basin (Swiss Jura, France), *3 rd International Cretaceous Symposium Tübingen 1987. Field guide excursion D*: 128 pp.
- Aubouin J., 1959. Contribution à l'étude géologique de la Grece septentrionale: les confirm de l'Epire et de la Thessalie. *Annales Geologiques des Pays Helleniques*, **10**, 483 pp., Athens.
- , 1965. Contribution à l'étude géologique de la Grece septentrionale: les confirm de l'Epire et de la Thessalie. Geosynclines: Amsterdam, New York, Elsevier Publishing Company, 335 p..
- Baudrimont A.F. and Dubois P., 1977. Un bassin Mésogéen du domaine péri-alpin: le Sud-Est de la France. *Bulletin des Centres de Recherches Exploration - Production Elf*

- References -

- Acquitaine, Pau 1 (1): 261-308.*
- Baumann, P. 1970. Mikropalaeontologische und stratigrafische Untersuchungen der obereozänen-oligozänen Scaglia in zentralen Apennin Italien. *Eclogae Geologica Helvetica*, **46(2)**, 1133-1211.
- Beckmann, J.P., Bolli, H.M., Perch-Nielsen, K., Proto-Decima, F., Saunders, J.B. and Toumarkine, M. 1981. Major calcareous nannofossil and foraminiferal events between the Middle Eocene and Early Miocene. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **36 (3-4)**, 155-190.
- Benedek, P.N. 1972. Phytoplankton aus dem Mittel- und Ober-Oligozän von Tönesberg (Niederrheingebiet). *Palaeontographica*, **137 Abteilung B**, 1-71.
- , 1975. Phytoplankton from the type Chattian (Upper Oligocene). *Proceedings VIth Congress Regional Commission Mediterranean Neogene Stratigraphy (Bratislava)*, **1**, 43-47.
- , 1986. Ergebnisse der Phytoplankton Untersuchungen aus dem Nordwestdeutschen Tertiär. In: Tobien, H. (ed). *Nordwestdeutschland im Tertiär; Beiträge zur regionalen Geologie der Erde*, Gebr. Bornträger, Berlin-Stuttgart, **18**, 157-185.
- and Müller, C. 1974. Nannoplankton-Phytoplankton-Korrelation im Mittel- und Ober-Oligozän von NW-Deutschland. *Neues Jahrbuch Geologie Paläontologie, Mitteilungen*, **7**, 385-397.
- and Müller, C. 1976. Die Grenze Unter-/Mittel-Oligozän am Doberg bei Bünde/Westfalen. I. Phyto- und Nannoplankton. *Neues Jahrbuch Geologie Paläontologie, Mitteilungen*, **9**, 129-144.
- Berggren, W.A., Kent, D.V. and Flynn, J.J. 1985. Jurassic to Paleogene: Part 2: Paleogene geochronology and chronostratigraphy. In: N.J. Snelling (ed.) *The Chronology of the Geological Record*. Geological Society Memoirs, **10**, 141-189.
- Bice, D.M. and Montanari, A. 1992. Magnetic stratigraphy of the Upper Oligocene-Lower Miocene Scaglia Cinerea and Bisciaro Formations from the Contessa Gorge. In: Montanari, A., Coccioni, R. and Odin, G.S. (eds.) *Interdisciplinary Geological Conference on the Miocene Epoch with emphasis on the Umbria-Marche sequence*. Abstract book, 21-22.
- Biffi, U. and Manum S.B. 1988. Late Eocene-Early Miocene dinoflagellate cyst biostratigraphy from the Marche Region (Central Italy). *Bollettino della Società Palentologica Italiana*, **27 (2)**, 163-212.
- Blow, W.H. 1969. Late Middle Eocene to Recent planktonic foraminiferal biostratigraphy. In: Brönnimann, R. and Renz, N.H. (eds.) *Proceedings of the First International Conference on Planktonic Microfossils, Geneva, 1967*, E.J. Brill, Leiden **1**, 199-421.

- References -

- Bolli, H.M. and Saunders, J.B., 1985. Oligocene to Holocene low latitude planktic foraminifera. In: Bolli, H.M., Saunders, J.B. and Nielsen, P. (Eds.). Plankton stratigraphy. *Cambridge University press*, 155-262.
- Bond, G.C. and Kominz, M.A. 1984. Construction of tectonic subsidence curves for the early Paleozoic miogeocline, southern Canadian Rocky Mountains: Implications for subsidence mechanisms, age of break-up and crustal thinning. *Geological Society of America Bulletin*, **95**, 155-173.
- Bosellini A., 1984. Progradation geometries of carbonate platforms: examples from the Triassic of the Dolomites, northern Italy. *Sedimentology* **31**: 1-24.
- , 1989. Dynamics of tethyan carbonate platforms. In: Crevello, P.D., Wilson, J.L., Sarg, J.F. and Read, J.F. (eds.) *Controls on carbonate platform and basin development*. Society of Economic Paleontologists and Mineralogists Special Publication, **44**, 3-13.
- Bréheret J.G., 1988. Episodes de sédimentation riche en matière organique dans les marnes bleues d'âge Aptien et Albien de la partie pélagique du Bassin Vocontien. *Bulletin de la Société Géologique de France* **2**: 349-356.
- , 1994, The Mid-Cretaceous Organic-Rich Sediments from the Vocontian Zone of the French Southeast Basin, in Mascle, A. (ed.), Hydrocarbon and petroleum geology of France: *Special publication of the European Association of Petroleum Geoscientists* **4**: 295-320.
- Brinkhuis H., 1992. Late Eocene to Early Oligocene dinoflagellate cysts from central and northeast Italy. PhD thesis, Utrecht University, Utrecht, 169 pp.
- , 1994. Late Eocene to Early Oligocene dinoflagellate cysts from the Priabonian type-area (northeast Italy); biostratigraphy and palaeoenvironmental interpretation. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **107**, 121-163.
- , and Zachariasse W.J., 1988. Dinoflagellate cysts, sea level changes and planktonic foraminifera across the Cretaceous-Tertiary boundary at El Haria, northwest Tunisia. *Marine Micropalaeontology* **13**: 153-191.
- , and Biffi, U. 1993. Dinoflagellate cyst stratigraphy of the Eocene/Oligocene transition in central Italy. *Marine Micropalaeontology*, **22**, 131-183.
- , and Visscher, H. *in press*. The upper boundary of the Priabonian Stage; a reappraisal based on dinoflagellate cyst biostratigraphy. In: W.A. Berggren, D.V. Kent and J. Hardenbol (eds.) *Geochronology, Time Scales and Stratigraphic Correlation: Framework for an Historical Geology*. Society of Economic Paleontologists and Mineralogists Special Publication.
- , Powell, A.J. and Zevenboom, D. 1992. High-resolution dinoflagellate cyst

- References -

- stratigraphy of the Oligocene/Miocene transition interval in northwest and central Italy. In: M.J. Head and J.H. Wrenn (eds.) *Neogene and Quaternary Dinoflagellate Cysts and Acritarchs*. American Association of Stratigraphic Palynologists Foundation, Dallas, 219-258.
- British Petroleum Co. Ltd., 1971. The geological results of petroleum exploration in western Greece. Institute for Geology and Subsurface Research (now Institute for Geology and Mining Research), *Special Report 10*. Athens.
- Bujak, J.P. and Williams, G.L., 1981. The evolution of dinoflagellates. *Canadian Journal of Botany*, **59**: 2077-2087.
- Busnardo R., 1965. Le stratotype du Barremien. Lithologie et macrofaune. (in Colloque sur le Crétacé inférieur, Lyon 1963), *Mémoires du Bureau de Recherches Géologique et Minières, Paris*, **34**: 101-116.
- , Thieuloy J. P., Moullade M., 1979. Comité français de stratigraphie les stratotypes français Volume **6**, Hypostratotype Mésogéen de l'étage Valanginien. *Editions du C.N.R.S.*, 139pp.
- Cande, S.C. and Kent D.V. 1992. A New Geomagnetic Polarity Time Scale for the Late Cretaceous and Cenozoic. *Journal of Geophysical Research*, **97**, 13917-13951.
- and Kent D.V. *in press*. Revised calibration of the geomagnetic polarity time scale for the Late Cretaceous and Cenozoic. *Journal of Geophysical Research*.
- Cati, F., Steininger, F.F., Borsetti, A.M. and Gelati, R. (eds) 1981. In search of the Palaeogene/Neogene boundary stratotype. Part 1. Potential boundary stratotype sections in Italy and Greece and a comparison with results from the deep sea. *Giornali di Geologia*, **44** (1-2).
- Chen, Y.Y., Farley, M.B. and McLaughlin, P.P. 1993. Dinoflagellate cycles in the Oligocene Boom Clay (Rupelian) of Belgium: Implication for sequence stratigraphic interpretation in fine-grained sediments. Poster presentation, Vth International Conference on Modern and Fossil Dinoflagellates, Zeist, The Netherlands, 1994, Abstract book, 25.
- Clavel, B., Charollais, J. and Busnardo, R. 1987. Données biostratigraphiques nouvelles sur l'apparition des faciès urgoniens du Jura au Vercors. *Eclogae Geologicae Helveticae* **80**, 59-68.
- Clews J.E., 1989. Structural controls on basin evolution: Neogene to Quaternary of the Ionian Zone, Western Greece. *Journal of the Geological Society*, London **146**: 447-457.
- Cloetingh, S., McQueen, H. and Lambeck, K. 1985. On a tectonic mechanism for regional sealevel variations. *Earth and Planetary Science Letters*, **75**, 157-166.

- References -

- , 1988. Intraplate Stresses: A tectonic cause for third-order cycles in apparent sea level? *Society of Economic Paleontologists and Mineralogists Special Publication*, **42**, 19-29.
- Coccioni, R. and Monechi S. 1992. New biostratigraphic data based on calcareous plankton of the uppermost Oligocene-Lower Miocene of the Contessa section (Gubbio, Italy). In: A. Montanari, R. Coccioni and G.S. Odin (eds). *Interdisciplinary Geological Conference on the Miocene Epoch with emphasis on the Umbria-Marche sequence*, Abstract book, 38-40.
- , Morandi, N. and Tateo, F. 1994. The Livello Raffaello (early Miocene) in the Umbria-Marche Apennines, Italy: stratigraphy, paleontology, mineralogy and geochemistry. *Giornale di Geologia*, serie 3a, **56(1)**: 55-78.
- Costa, L.I. and Davey, R.J. 1992. Dinoflagellat cysts of the Cretaceous System. In *A Stratigraphic Index of Dinoflagellate Cysts* (ed. A.J. Powell), Chapman and Hall, London, 99-154.
- Cotillon P., Ferry S., Gaillard C., Jautée É, Latreille G. and Rio M., 1980. Fluctuation des paramètres du milieu marin dans le domaine Vocontien (France Sud-Est) au Crétacé inférieur: mise en évidence par l'étude des formations marno-calcaires alternantes. *Bulletin de la Société Géologique de France* (7), **t.XXII**, 5: 735-744.
- and Rio M., 1984. Cyclic sedimentation in the Cretaceous of Deep Sea Drilling Project sites 535 and 540 (Gulf of Mexico), 534 (central Atlantic) and in the Vocontian basin (France). *Initial Reports of the Deep Sea Drilling Project* (volume **LXXVII**): 339-376.
- , Arnaud-Vanneau, A., Arnaud, H., Boisseau, T., Busnardo, R., Charollais, J., Clavel, B., Combemorel, R., Conrad, M.A., Darsac, C., Demay, J.L., Ferry, S., Jardine, S., Le Hegarat, G., Magniez-Jannin, F., Manivit, H., Masse, J.P., Medioni, R., Moullade, M., Oertli, H.J., Peybernes, B., Raynaud, J.F., Renéville de, P., Salvini, G., Sornay, J., Steinhäuser, N., Thieuloy, J.P., Tronchetti, G. and Vieban, F. 1984. Crétacé Inférieur. *Mémoires du Bureau de Recherches Géologique et Minières* **126**, 287-338.
- Courtinat B, Crumière J.P., Méon H. and Schaaf A., 1991. Les associations de kystes de dinoflagellés du Cénomanién-Turonien de Vergons (Bassin Vocontien France). *Geobios* **24**, fasc. 6: 649-666.
- Cresta, S., Monechi, S. and Parisi, G. 1989. Mesozoic-Cenozoic stratigraphy in the Umbria-Marche area. Geological field trips in the Umbria-Marche Apennines (Italy). *Memorie descrittive della carta geologica d'Italia*, **39**.
- Cushing, E.M., 1985. Evolution structurale de la marge nord ouest Hellenique dans l'île de

- References -

- Levkas et ses environs (Grece nord-occidentale). Unpublished Ph.D. thesis, Universite de Paris-Sud (XI), Centre d'Orsay.
- Dale, B., 1983. Dinoflagellate resting cysts: "benthic plankton". In: Fryxell, G.A. (ed.), *Survival Strategies of the Algae*. Cambridge, Cambridge University Press: 69-136.
- Davey, R.J. and Rogers J., 1975. Palynomorph distribution in recent offshore sediments along two traverses off South-West Africa. *Marine Geology* **18**: 213-225.
- Debelmas J., 1989. One some key features of the evolution of the western Alps. In: A.M.C. Şengör (ed.) *Tectonic Evolution of the Tethyan Region*. Kluwer Academic Press, 23-42.
- De Boer P., 1983. Aspects of Middle Cretaceous pelagic sedimentation in southern Europe. *Geologica Ultraiectina* **31**, 112pp.
- Delamette, M., Caron, M. and Bréheret, J.G. 1986. Essai d'interprétation génétique des faciès euxiniques de l' Eo-Albien du bassin vocontien (SE France) sur la base de données macro- et microfauniques. *Comptes Rendus de l'Académie des Sciences*, **302**, 1085-1090.
- De Mulder, E.F.J. 1975. Microfauna and sedimentary-tectonic history of the Oligo-Miocene of the Ionian islands and western Epirus (Greece). *Utrecht Micropaleontological Bulletins* **13**: 127 pp.
- Dercourt, J., Zonenshain, L.P., Ricou, L.E., Kazmin, V.G., Le Pichon, X, Knipper, A.L., Grandjacquet, C., Sbertshikov, I.M., Geysant, J., Lepvrier, C., Pechersky, D.H., Boulin, J., Sibuet, J.C., Savostin, L.A., Sorokthin, O., Westphal, M., Bazhenov, M.L., Lauer, J.P. and Biju-Duval, B. 1986. Geological evolution of the Tethys Belt from the Atlantic to the Pamirs since the Lias. *Tectonophysics*, **123**, 241-315.
- Duxbury, S. 1977. A palynostratigraphic of the Berriasian to Barremian of the Speeton Clay of Speeton, England. *Palaeontographica Abteilung B* **160**, 17-67.
- , 1980. Barremian phytoplankton from Speeton, East Yorkshire. *Palaeontographica Abteilung B* **173**, 107-146.
- Eberli G.P. and Ginsburg R.N., 1989. Cenozoic progradation of northwestern great Bahama bank, a record of lateral platform growth and sea-level fluctuations. *Society of Economic Paleontologists and Mineralogists Special Publication* **44**: 339-351.
- Edwards, L.E., 1992. New semiquantative (paleo)temperature estimates using dinoflagellate cysts, an example from the north Atlantic Ocean. In: M.J. Head and L.H. Wrenn (editors), Neogene and Quarternary Dinoflagellate Cysts and Acritarchs. *American Association of Stratigraphic Palynologists Foundation*, Dallas: 69-87.
- and Andrie, A.S., 1992. Distribution of selected dinoflagellate cysts in modern marine sediments. In: M.J. Head and L.H. Wrenn (editors), Neogene and Quarternary

- References -

- Dinoflagellate Cysts and Acritarchs. *American Association of Stratigraphic Palynologists Foundation*, Dallas: 259-274.
- Everts, A.J.W., Stafleu, J., Schlager, Fouke, B.W. and Zwart, E.W., (in press). Stratal Patterns, Sediment Composition and Sequence Stratigraphy at the margin of the Vercors platform (Lower Cretaceous, SE France). *Journal of Sedimentary Research*, February 1995.
- Fensome, R.A., Taylor, F.J.R., Norris, G., Sarjaent, W.A.S., Wharton, D.I. and Williams, G.L., 1993. A classification of living and fossil dinoflagellates. *Micropaleontology special publication 7*: 351pp.
- Ferry S., 1978. Les "Calcaires à débris" Barrèmo-Aptiens de la Drôme Vocontienne (France S-E): des cônes d' épandage bioclastique en eau profonde. *Documents des laboratoires de Géologie de la Faculté des Sciences de Lyon*, 4: 273-303.
- and Rubino J.L., 1989. Mesozoic eustacy record on western Tethyan margins, excursion guide. *Publication Association Sedimentology Français* 12, 140 pp.
- Fleury, J.J. 1980. Les zones de Gavrovo-Tripolitza et du Pinde-Olonos (Grèce continentale et Péloponnèse du Nord). Evolution d'une plate-forme et d'un bassin dans leur cadre alpin. *Société Géologique du Nord* 4.
- Fries, G. and Rubino, J.L. 1990. Testing the application of sequence stratigraphy to Aptian deposits in Southeast France. In R.N. Ginsburg and B.Beaudoin (eds.), *Cretaceous Resources, Events and Rhythms*, Kluwer Academic Publishers, the Netherlands, 47-62.
- Galbiati, B. 1985. L'unita del Bracco e il suo ruolo nella paleogeografia liguride cretacea. *Atti dell Istituto Geologico della Univesita di Pavia*, 30, 316-336.
- Gelati, R. and Steininger, F.F. (eds) 1983. In search of the Paleogene/Neogene stratotype, Part 2: Potential boundary stratotype sections in Italy and Spain and comparison with results from the deep sea and the environmental changes. *Rivista italiana di paleontologia e stratigrafia*, 89 (4), 451-564.
- Goodman D.K., 1979. Dinoflagellate "communities" from the Lower Eocene Nanjemoy Formation of Maryland U.S.A.. *Palynology* 3: 169-190.
- Gradstein, F.M., Kristiansen, I.L., Loemo, L. and Kaminski, M.A. 1992. Cenozoic foraminiferal and dinoflagellate cyst biostratigraphy of the central North Sea. *Micropaleontology*, 38 (2), 101-137.
- Hardenbol, R. 1968. The Priabonian type section (a preliminary note). *Mémoires du Bureau de Recherches Géologique et Minières*, 58, 629-635.
- Harland R., 1983. Dinoflagellate cysts in bottom sediments from the north Atlantic Ocean and adjacent seas. *Palaeontology* 26 (2): 321-387.
- Haq, B.U., Hardenbol, J. and Vail, P.R., et al. (Editors) 1988. Mesozoic and Cenozoic

- References -

- chronostratigraphy and cycles of sea-level change. In: Wilgus, C. K., Hastings, B. S., *et al.* (eds) *Sea-level Changes; An Integrated Approach*. Society of Economic Paleontologists and Mineralogists Special Publication, **42**, 71-108.
- Head, M.J. and Norris, G. 1989. Palynology and dinocyst stratigraphy of the Eocene and Oligocene in ODP-Leg 105, Hole 647A, Labrador Sea. In: Srivastava, S. P., Arthur, M., Clement, B. *et al.* (eds.) Proceedings ODP, Scientific Results, 105: College Station, Texas (Ocean Drilling Program), 515-550.
- and Wrenn, J.H. (eds.), 1992. Neogene and Quaternary Dinoflagellate Cysts and Acritarchs. *American Association of Stratigraphic Palynologists* Foundation, Dallas, 438 p.
- Hoedemaeker P.J. and Bulot L. (Editors), 1990. Preliminary Ammonite zonation for the Lower Cretaceous of the Mediterranean region. *Geologie Alpine* **66**: 123-127.
- and Company, M. *et al.*, 1993. Ammonite zonation for the Lower Cretaceous of the Mediterranean region; basis for the stratigraphic correlations within IGCP-Project 262. *Revista Española de Paleontología* **8**, 117-120.
- Hoogerduijn Strating, E.H. 1991. The evolution of the Piemonte-Ligurian ocean. A structural study of ophiolite complexes in Liguria (NW Italy). *Geologica Ultraiectina*, **74**.
- Horner F. and Freeman R., 1983. Palaeomagnetic evidence from pelagic limestones for clockwise rotation of the Ionian Zone, western Greece. *Tectonophysics*, **98**, 11-27.
- Hunt, C.O., 1987. Dinoflagellate cyst and acritarch assemblages in shallow-marine and marginal-marine carbonates; the Portland Sand, Portland Stone, and Purbeck Formations (Upper Jurassic-Lower Cretaceous) of southern England and northern France. In: M.B. Hart (Ed.) *Micropalaeontology of carbonate environments*, Ellis Horwood Ltd, Chichester, U.K., pp. 209-225.
- Institute Français du Pétrole, 1966. Etude géologique de l'Épire (Grèce Nord-Occidentale). Publications Société des Editions Technip et Institut Français du Pétrole, Paris.
- Jacquin T., Arnaud-Vanneau A., Arnaud H., Ravenne C. and Vail P.R., 1991. Systems tracts and depositional sequences in a carbonate setting: a study of continuous outcrops from platform to basin at the scale of seismic lines. *Marine and Petroleum Geology*, **8**: 122-139.
- , Schlager, W., Stafleu, J. and Everts, A.J.W. 1993. *Vercors, France: Sequence Stratigraphy of an Early Cretaceous Carbonate Platform*. Field trip in conjunction with 1993 AAPG International Conference and Exhibition, The Hague, October 1993. Unpublished 163 pp.
- Jenkins D.A.L., 1972. Structural development of Western Greece. *American Association of Petroleum Geologists Bulletin* **56** (1), 128-149.

- References -

- Joseph, P., Beaudoin, B., Fries, G. and Parise, O. 1989. Submarine valleys evidence Lower Cretaceous tilted block activity in the Vocontian Basin (SE-France). *Comptes Rendus de l'Académie des Sciences*, **309**, 1031-1038.
- Kahle H.G., Müller M.V., Mueller S. and Veis, G., 1993. The Kephallonia transform fault and the rotation of the Apulian Platform: evidence from satellite geodesy. *Geophysical Research Letter*, **20** (8), 651-654.
- Killian W., 1912. Sur une carte de la répartition du "facies urgonien" dans le Sud-Est de la France. *C. R. Assoc. fr. Avanc. Sci. Paris.*: 361-365.
- Kissel C. and Laj C., 1988. The Tertiary geodynamical evolution of the Aegean arc: a paleomagnetic reconstruction. *Tectonophysics*, **146**, 183-201.
- Lehmann U., 1976. Ammoniten ihr Leben und ihre Umwelt. Ferdinand Enke Verlag Stuttgart, 171 pp.
- Leigh S.P., 1991. The sedimentary evolution of the Pindos Foreland Basin Western Greece. University of Wales, Unpublished PhD thesis.
- and Hartley, A.J., 1992. Mega-debris flow deposits from the Oligo-Miocene Pindos foreland basin, western mainland Greece: implications for transport mechanisms in ancient deep marine basins. *Sedimentology* **93**, p. 1003-1012.
- Lemoine M. and Graciansky, P. Ch. (1988). Histoire d'une marge continentale passive: les Alpes Occidentales au Mésozoïque. *Bulletin de la Société Géologique de France* **8**, t. IV, Vol. 4: 597-600.
- , Bas T., Arnaud-Vanneau A., Arnaud H., Dumont T., Gidon M., Bourbon M., Graciansky P.-C., Rudkiewicz J.-L., Megard-Galli J. and Tricart P., 1986. The continental margin of the Mesozoic Tethys in the Western Alps. *Marine and Petroleum Geology*, **3**: 179-199.
- Lentin, J.K., and Williams, G.L. 1993. Fossil dinoflagellates: index to genera and species 1993 Edition. *American Association of Stratigraphic Palynologists Foundation, Contribution Series*, **28**.
- Lister J.K. and Batten D.J., 1988. Stratigraphic and palaeoenvironmental distribution of Early Cretaceous dinoflagellate cysts in the Hurlands Farm Borehole, West Sussex, England. *Palaeontographica Abt. B*, **210** (1-3): 9-89.
- Londeix L., 1990. La distribution des kystes de dinoflagellés dans les sédiments hémipélagiques (Ardèche) et pélagiques (Arc de Castellane, S.E. de la France) en domaine Vocontien, du Valanginien terminal au Barrémien inférieur - Biostratigraphie et relations avec la stratigraphie séquentielle. Thèse Université de Bordeaux I, 478 pp (Unpublished).
- Lowrie, W., Alvarez, W., Napoleone, G., Perch-Nielsen, K., Premoli-Silva, I. and

- References -

- Toumarkine, M. 1982. Paleogene magnetic stratigraphy in Umbrian pelagic carbonate rocks: The Contessa sections, Gubbio. *Geological Society of America Bulletin*, **93**, 414-432.
- Magniez-Jannin, F. 1991. Renouvellements de foraminifères et séquences de dépôt dans le Crétacé inférieur du Bassin vocontien (SE de la France). *Bulletin de la Société Géologique de France* **162**, 887-895.
- Marshall K.L. and Batten D.J., 1988. Dinoflagellate cyst associations in Cenomanian-Turonian "black shale" sequences of northern Europe. *Review of Palaeobotany and Palynology*, **54**: 85-103.
- Martini, E. 1971. Standard Tertiary and Quaternary calcareous nannoplankton zonation. In: Farinacci, A. (ed.) *Proceedings of the 2nd Planktonic Conference, Roma, 1970*, 739-785.
- Masse, J.P. 1993. Valanginian-Early Aptian Carbonate Platforms from Provence, Southeastern France. In: Simo, J.A.T., Scott, R.W. and Masse, J.P. (eds) *Cretaceous Carbonate Platforms*. American Association of Petroleum Geologists Memoir, **56**, 363-374.
- May F.E., 1980. Dinoflagellate cysts of the Gymnodiaceae, Peridiniaceae and Gonyaulacaceae from the Upper Cretaceous Monmoth Group, Atlantic Highlands, New Jersey. *Palaeontographica Abt. B*, **172**: 10-116.
- McKenzie, D. 1978. Some remarks on the development of sedimentary basins. *Earth and Planetary Science Letters*, **40**, 25-32.
- and Sclater, J.G. 1969. Heat flow in the Pacific and sea-floor spreading. *Bulletin of Volcanology*, **33**, 101-118.
- Meulenkamp, J.E. and F.J. Hilgen, 1986. Event stratigraphy, basin evolution and tectonics of the Hellenic and Calabro-Sicilian arcs. In: F.C. Wezel (ed.) *The origin of Arcs*. Elsevier, Amsterdam: 327-350.
- Montanari, A., Deino, A., Coccioni, R., Langenheim, V.E., Capo, R. and Monechi, S. 1991. Geochronology, Sr Isotope analysis, magnetostratigraphy, and plankton stratigraphy across the Oligocene-Miocene boundary in the Contessa section (Gubbio, Italy). *Newsletters on Stratigraphy*, **23** (3), 151-180.
- Moullade, M. 1966. Étude stratigraphique et micropaléontologique du Crétacé Inférieur de la fosse "Vocontienne". *Documents des laboratoires de Géologie de la Faculté des Sciences de Lyon*, **15**.
- Nocchi, M., Parisi, G., Monaco, P., Monechi, S., Madile, M., Napoleone, G., Ripepe, M., Orlando, M., Premoli Silva, I. and Bice, D. 1986. The Eocene-Oligocene boundary in the Umbrian pelagic sequences (Italy). In: Pomerol, C., and Premoli Silva, I. (eds.)

- References -

- Terminal Eocene Events*. Developments in Palaeontology and Stratigraphy. (Elsevier), **9**, 25-40.
- , Parisi, G., Monaco, P., Monechi, S. and Madile, M., 1988a. Eocene and Early Oligocene micropaleontology and paleoenvironments in SE Umbria, Italy. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **67**, 181-244.
- , Monechi, S., Coccioni, R., Madile, M., Monaco, P., Orlando, M., Parisi, G. and Premoli Silva, I. 1988b. The extinction of *Haukeninidae* as a marker for recognizing the Eocene-Oligocene boundary: a proposal. In: Premoli Silva, I., Coccioni, R. and Montanari, A., (eds) *The Eocene-Oligocene Boundary in the Marche-Umbria Basin (Italy)*. International Union of Geological Sciences Commission on Stratigraphy, International Subcommittee on Paleogene Stratigraphy Report, Ancona, Italy, 249-252.
- Noe-Nygaard, N., Surlyk, F. and Piasecki, S., 1987. Bivalve mass mortality caused by toxic dinoflagellate blooms in a Berriasian-Valanginian lagoon, Bornholm, Denmark. *Palaios*, **2**: 263-273.
- North American Commission on Stratigraphic Nomenclature, 1983. North American stratigraphic code. *American Association of Petroleum Geologist bulletin*, **67** (5), 841-875.
- Odin, G.S. and Montanari, A. 1988. The Eocene-Oligocene boundary at Massignano (Ancona, Italy): a potential boundary stratotype. In: Premoli Silva, I., Coccioni, R. and Montanari, A., (eds) *The Eocene-Oligocene Boundary in the Marche-Umbria Basin (Italy)*. International Union of Geological Sciences Commission on Stratigraphy; International Subcommittee on Paleogene Stratigraphy Report (Ancona, Italy, 1988), 253-263.
- , and Montanari, A. 1989. Age radiométrique et stratotype de la limite Éocène-Oligocène. *Comptes Rendus de l'Académie des Sciences, Paris*, **309**, série II, 1939-1945.
- Okada, H. and Bukry, D. 1980. Supplementary modification and introduction of code numbers to the low latitude coccolith biostratigraphy zonation. *Marine Micropaleontology*, **5** (3), 321-324.
- Omran A.M., Soliman H.A. and Mahmoud M.S., 1990. Early Cretaceous palynology of three boreholes from northern Western Desert (Egypt). *Review of Palaeobotany and Palynology*, **66**: 293-312.
- Oost, A.P. and De Boer, P.L., (in press). Tectonic and climatic setting of lithographic limestone basins. *Geobios* **16**.
- Paquier V., 1900. Recherches géologiques dans le Diois et les Baronnies orientales. Thèse

- References -

- Grenoble, 402p (Unpublished).
- Parisi, G., Guerrera, F., Madile, M., Magnoni, G., Monaco, P., Monechi, S. and Nocchi, M. 1988. Middle Eocene to Early Oligocene calcareous nannofossil and foraminiferal biostratigraphy in the Monte Cagnero section, Piobbico (Italy). *In: Premoli Silva, I., Coccioni, R. and Montanari, A. (eds) The Eocene-Oligocene Boundary in the Marche-Umbria Basin (Italy)*. International Union of Geological Sciences Commission on Stratigraphy; International Subcommission on Paleogene Stratigraphy Report (Ancona, Italy, 1988), 119-135.
- Peeters, F.J.C., Hoek, R.P., Brinkhuis, H., Wilpshaar, M., Meulenkamp, J.E. and Krijgsman, W., *in prep.* Dinoflagellate cysts, glacio-eustacy and tectonics; a case study from the Eocene-Oligocene transition of the Pindos Foreland Basin (NW Greece).
- Piper, D.J.W., Panagos A.G. and Pe, G.G., 1978. Conglomeratic Miocene flysch, western Greece. *Journal of Sedimentary Petrology* **48** (1), p. 117-126.
- Pomerol, C. and Premoli Silva, I. 1986. The Eocene-Oligocene transition: events and boundary. *In: Pomerol, C. and Premoli Silva, I. (eds) Terminal Eocene Events. Developments in Palaeontology and Stratigraphy*. (Elsevier), **9**, 1-24.
- Poore, R.Z., Tauxe, L., Percival, S.F. and LaBrecque, J.L. 1982. Late-Eocene-Oligocene magnetostratigraphy and biostratigraphy at South Atlantic DSDP Site 522. *Geology*, **10**, 508-511.
- Powell, A.J. 1992. Dinoflagellate cysts of the Tertiary System. *In: A.J. Powell (ed.) A Stratigraphic Index of Dinoflagellate Cysts*. British Micropaleontological Society Publication Series, Chapman and Hall, London, 155-251.
- Premoli Silva, I., Coccioni, R. and Montanari, A. (eds) 1988a. *The Eocene-Oligocene Boundary in the Marche-Umbria Basin (Italy)*. International Union of Geological Sciences Commission on Stratigraphy; International Subcommission on Paleogene Stratigraphy Report (Ancona, Italy, 1988), 268pp.
- , Orlando, M., Monechi, S., Madile, M., Napoleone, G. and Ripepe, M. 1988b. Calcareous plankton biostratigraphy and magnetostratigraphy at the Eocene-Oligocene transition in the Gubbio area. *In: Premoli Silva, I., Coccioni, R. and Montanari, A. (eds) The Eocene-Oligocene Boundary in the Marche-Umbria Basin (Italy)*. International Union of Geological Sciences Commission on Stratigraphy; International Subcommission on Paleogene Stratigraphy Report (Ancona, Italy, 1988), 137-161.
- Renéville, P. de and Raynaud, J.F. 1981. Palynologie du stratotype du Barremien. *Bulletin des centres de Recherches Exploration-Production Elf Aquitaine* **5**, 1-29.
- Renz, O. 1936. Stratigrafische und mikropalaeontologische Untersuchungen der Scaglia

- References -

- (Obere Kreide-Tertiär) in zentralen Apennin. *Eclogae Geologicae Helvetica*, **29** (1), 1-149.
- Ricci Lucchi F., 1986. The Oligocene to Recent foreland basins of the northern Apennines. *Special Publications international Association of Sedimentologists* **8**, 105-139.
- Roux, M., Bourseu, J.P., Bas, T., Dumont, T., Graciansky, P.Ch., Lemoine, M. and Rudkiewicz, J.L. 1988. Bathymetric evolution of the Tethyan margin in the western Alps (data from stalked crinoids): a reappraisal of eustatism problems during the Jurassic. *Bulletin de la Société Géologique de France*, **8**, 633-641.
- Rudkiewicz, J.L. 1988. Quantitative subsidence and thermal structure of the European continental margin of Tethys during early and middle Jurassic in the western Alps (Grenoble-Briançon transect). *Bulletin de la Société Géologique de France*, **8**, 623-632.
- Rutten M.G., 1969. The geology of Western Europe. Elsevier, 520 pp.
- Schuppers, J.D., 1995. Characterization of Deep-Marine Clastic Sediments from Foreland Basins. Outcrop-derived concepts for exploration, production and reservoir modelling. PhD thesis, Delft University of Technology, The Netherlands, 272 p.
- Sclater, J.G. and Christie, P.A.F. 1980. Continental stretching: an explanation for the post-Mid-Cretaceous subsidence of the central North Sea basin. *Journal of Geophysical Research*, **85**, 3711-3739.
- Senogor A.M.C., 1979. Mid-Mesozoic closure of Permo-Triassic Tethys and its implications. *Nature*, **279**, 590-593.
- Smelror M. and Leereveld H., 1989. Dinoflagellate and acritarch assemblages from the Late Bathonian to Early Oxfordian of Montagne Crussol, Rhône valley, southern France. *Palynology*, **13**: 121-141.
- Srivastava, S.K. 1984. Barremian dinoflagellate cysts from southeastern France. *Cahiers de Micropaléontologie* **2**, 90 pp.
- Stainforth, R.M., Lamb J.L., Luterbacher H., Beard J.H. and Jeffords R.M., 1975. Cenozoic planktonic foraminiferal zonation and characteristics of index forms. University Kansas paleontological Contributions, 62 (1-2).
- Steckler, M.S. and Watts, A.B. 1978. Subsidence of the Atlantic-type continental margin off New York. *Earth and Planetary Science Letters*, **41**, 1-13.
- Steininger, F.F., Aubry, M.P., Biolzi, M., Borsetti, A.M., Cati, F., Corfield, R., Gelati, R., Iaccarino, S., Napoleone, C., Rögl, F., Roetzel, R., Spezzaferri, S., Tateo, F., Villa, G. and Zeebe, D. 1994. Proposal for the Global Stratotype Section and Point (GSSP) for the base of the Neogene (The Paleogene/Neogene Boundary). *K. Kumpfner, Vienna, Austria*, 41.

- References -

- and Cati, F., (eds.), *in press*. *In search of the Palaeogene/Neogene Boundary Part III, The Palaeogene/Neogene Boundary and its Global Boundary Stratotype section and Point at meter 35 in the Lemme-Carrosio Section at Carrosio, "Casa Carizziani", Piedmont Basin, Province of Alessandria, Italy. IUGS Commission on Stratigraphy, Subcommission on Neogene Stratigraphy, Working Group on the Palaeogene/Neogene Boundary Report*. Special Issue *Giornale di Geologia*.
- Stover, L.E. and Hardenbol, J. 1993. Dinoflagellates and depositional sequences in the Lower Oligocene (Rupelian) Boom Clay Formation, Belgium. *Bulletin de la Société belge de Géologie*, **102** (1-2), 5-77.
- Underhill, J.R., 1989. Late Cenozoic deformation of the Hellenide foreland, western Greece. *Geological Society of America Bulletin*, **101**, 613-634.
- Van Daniels, C.H., Gramann, F. and Köthe, A. 1993. The Oligocene "Septarienton" of Lower Saxony. Biostratigraphy of an equivalent of the Boom Formation of Belgium, with special considerations to its upper and lower boundaries. *Bulletin van de Belgische Vereniging voor Geologie*, **102** (1-2), 79-89.
- Van Wamel, W.A. 1987. On the tectonics of the Ligurian Apennines (northern Italy). *Tectonophysics*, **142**, 87-98.
- Versteegh, G.J.M., 1995. Palaeoenvironmental changes in the Mediterranean and North Atlantic in relation to the onset of northern hemisphere glaciations (2.5 Ma B.P.). A palynological approach. PhD-thesis University Utrecht: 134pp.
- Wall D., Dale B., Lohmann G.P. and Smith W.K., 1977. The environmental and climatic distribution of dinoflagellate cysts in modern marine sediments from regions in the north and south Atlantic oceans and adjacent seas. *Marine Micropalaeontology* **2**: 121-200.
- Waters, D.W., 1994. The tectonic evolution of Epirus, Northwest Greece. PhD-thesis University of Cambridge (U.K.) unpublished.
- Wilpshaar, M., 1995. Direct stratigraphic correlation of selected intervals in the carbonate platform development of the Vercors area (SE-France) with the Barremian stratotype by means of dinoflagellate cysts. *Cretaceous Research*, **16**, 273-281.
- and Leereveld, H. 1995. Palaeoenvironmental change in the Early Cretaceous Vocontian Basin (SE France) reflected by dinoflagellate cysts. *Review of Palaeobotany and Palynology*, 121-128.
- , Santarelli, A., Brinkhuis, H. and Visscher, H., submitted. A dinoflagellate cyst zonation for the Oligocene of the Central Mediterranean. With special reference to the Rupelian/Chattian boundary. *Journal of the Geological Society*.
- Zevenboom, D., *in press*, a. Late Oligocene-Miocene dinoflagellate cysts from the Lemme

- References -

- section (NW Italy): biostratigraphy and palaeoenvironmental interpretations. In: Steininger, F.F. and Cati, F., (eds), *in press*. *In search of the Palaeogene/Neogene Boundary Part III, The Palaeogene/Neogene Boundary and its Global Boundary Stratotype section and Point at meter 35 in the Lemme-Carrosio Section at Carrosio, "Casa Carizziani", Piedmont Basin, Province of Alessandria, Italy. IUGS Commission on Stratigraphy, Subcommittee on Neogene Stratigraphy, Working Group on the Palaeogene/Neogene Boundary Report*. *Giornale di Geologia Special Issue*.
- , *in press*, b. Late Oligocene-Miocene dinoflagellate cysts from the Contessa sections. In: Montanari, A., Odin, G.S., and Coccioni, R. (eds) *Miocene Integrated Stratigraphy Sequence*.
- , *in press*, c. Late Oligocene-Miocene dinoflagellate cysts from the Santa Croce di Arcevia section. In: Montanari, A., Odin, G.S., and Coccioni, R. (eds) *Miocene Integrated Stratigraphy Sequence*.
- , Brinkhuis, H. and Visscher, H., 1994. Dinoflagellate cysts palaeoenvironmental analysis of the Oligocene/Miocene transition in Northwest and central Italy. *Giornale di Geologia, serie 3a*, **56** (1), 155-169.
- Ziegler B., 1983. Einführung in die Paläobiologie Teil 2. Spezielle Paläontologie, Protisten, Spongien und Coelenteraten, Mollusken. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, 409 pp.
- , 1987. Evolution of the Arctic-North Atlantic and the Western Tethys. *American Association of Petroleum Geologists Memoires*, **43**.

- *Appendix* -

Appendix I: (next pages) Quantative palynological analysis of the basal Petrovouni (=Arakthos) section.

- *Appendix* -

Appendix II: (next page) Semi-quantitative palynological analysis of the Petrovouni section. 10 = frequent; 5 = common; 1 = present

- *Appendix* -

Appendix III: (next page) Semi-quantitative palynological analysis of the Pramada section. 10 = frequent; 5 = common; 1 = present

- *Appendix* -

Appendix IV: (next pages) Quantitative palynological analysis of the basal Ekklissia section.

- *Appendix* -

Appendix V: (next page) Semi-quantitative palynological analysis of the Ekklissia section. 10 = frequent; 5 = common; 1 = present

- *Appendix* -

Appendix VI: (next pages) Semi-quantitative palynological analysis of the Saloniki section. 10 = frequent; 5 = common; 1 = present

	Zone	
	Samples	Depth
	SALO 35A	-10.0
	SALO 34	-12.0
	SALO 33	-23.0
	SALO 32	-23.0
	SALO 31	-23.0
	SALO 30	-29.0
	SALO 29	-110.0
	SALO 28	-120.0
	SALO 27	-130.0
	SALO 26	-145.0
	SALO 25	-150.0
	SALO 24	-160.0
	SALO 23	-195.0
	SALO 22	-210.0
	SALO 21	-225.0
	SALO 20	-235.0
	SALO 19	-245.0
	SALO 18	-250.0
	SALO 17	-295.0
	SALO 16	-305.0
	SALO 15	-320.0
	SALO 14	-320.0
	SALO 13	-375.0
	SALO 12	-390.0
	SALO 11	-400.0
	SALO 10	-410.0
	SALO 09	-410.0
	SALO 08	-425.0
	SALO 07	-435.0
	SALO 06	-435.0
	SALO 05	-460.0
	SALO 04	-465.0
	SALO 03	-475.0
	SALO 02	-485.0
	SALO 01	-500.0
<i>S. chlamydophora</i>		38
<i>A. ramulifera</i>		39
<i>H. cinctum</i>		40
<i>N. labyrinthea</i>		41
<i>P. golzowense</i>		42
<i>Hystrichokolpoma</i> sp. B&M		43
<i>G. semitecta</i>		44
<i>Paralecaniella</i> sp.		45
<i>Cordosphaeridium?</i> sp.		46
<i>Adnatosphaeridium?</i> sp.		47
<i>H. pusilla</i>		48
<i>D. cf. ellipticum</i>		49
<i>H. floripes</i>		50
<i>D. paradoxum</i>		51
<i>Lingulodinium</i> sp.		52
<i>R. actinocoronata</i>		53
<i>I. velorum</i>		54
<i>W. symmetrica</i>		55
<i>L. machaerophorum</i>		56
<i>Chiropteridium</i> spp.		57
<i>H. leptalea</i>		58
<i>D. pastiejsii</i>		59
<i>S. nephroides</i>		60
<i>H. vallum</i>		61
<i>Cannosphaeropsis</i> sp.		62
<i>H. sp. cf. H. oceanicum</i>		63
<i>Lejeunecysta</i> spp.		64
<i>H. aculeatum</i>		65
<i>L. pycnospinosum</i>		66
" <i>Impagidinium Damassa</i> "		67
<i>Ectosphaeropsis?</i> sp.		68
<i>Spiniferites?</i> sp.		69
<i>G. inflata</i>		70
<i>H. rigaudiae</i>		71
<i>H. campanula</i>		72
<i>I. aculeatum</i>		73
<i>S. membranaceus</i>		74
<i>D. bifidii</i>		75

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