

INTRODUCTION AND SUMMARY

1.1 The mid-Cretaceous

The mid-Cretaceous “greenhouse” state of the Earth, during which time major changes in biogeochemical cycling, climate and evolution occurred (e.g. Hay, 1995; Erbacher et al., 1996; Mutterlose, 1998; Premoli Silva and Sliter, 1999), is thought to have been initiated by increased oceanic-crust production (e.g. at the Kerguelen, Ontong Java, and Caribbean plateaus; Larson, 1991; Larson and Erba, 1999), possibly in combination with sudden releases of methane at times (Hesselbo et al., 2000; Weissert, 2000; Jahren et al., 2001). This resulted in increased atmospheric CO₂ concentrations, with levels being at least four times higher than today’s (e.g. Berner, 1991), as well as a rise in global sea level (see in Haq et al., 1988; Hardenbol et al., 1998). With the continuing increase in global atmospheric CO₂ at present, the concern for future environmental change makes the causes and effects of the Cretaceous warming focus of many studies and modelling exercises.

That these mid-Cretaceous greenhouse conditions were not continuously on the rise but alternated in the Barremian-Albian (~127-99 Ma) with short-term cooler periods, is indicated by the presence of dropstones (ice-rafted debris) and glendonites (pseudomorphs of ikaite, calcium carbonate unstable at temperatures above 0°C; e.g. Kemper, 1987; Frakes and Francis, 1990). The cooler conditions can also be inferred from shifts in the distribution patterns of latitudinal determined faunal and floral provinces, which can roughly be divided into different realms (Figure 1): the Arctic, Boreal (northern, high-latitude temperate zone), the Tethyan (low-latitude tropical-subtropical zone), and the Austral (southern, high-latitude temperate zone), and the Antarctic.

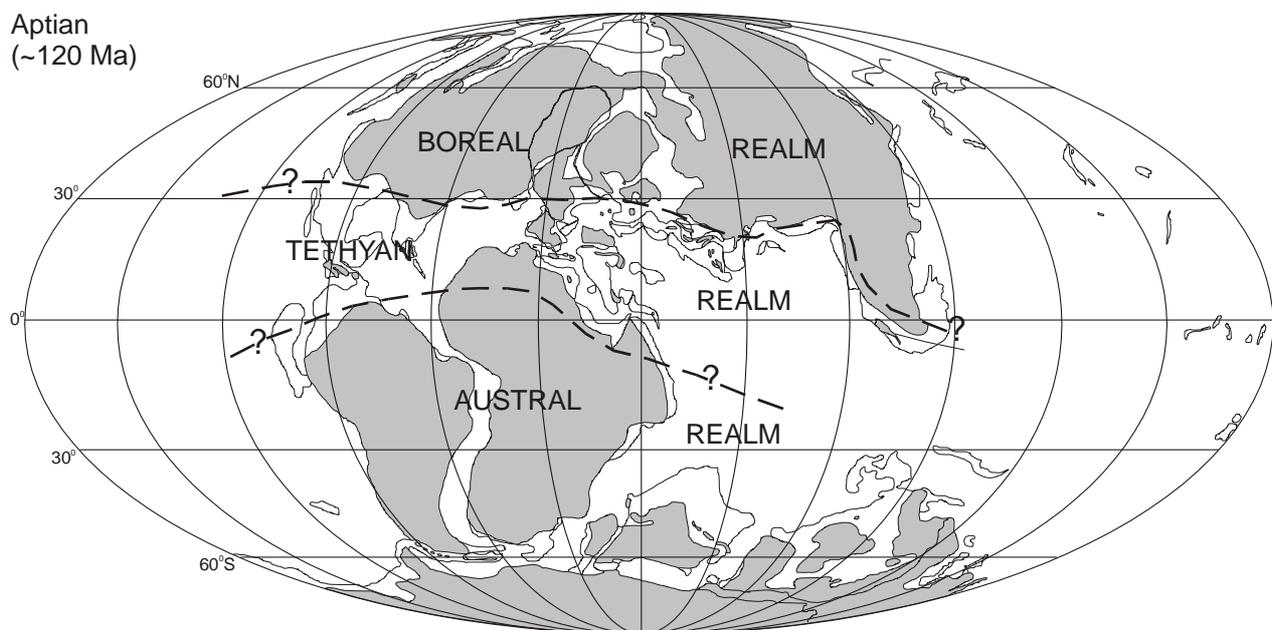


Figure 1. Approximate positions of floral and faunal province boundaries between the Boreal, Tethyan and Austral realms.

EARLY CRETACEOUS				
Age	Stage	Substages	Boreal ammonite zones	
	ALBIAN	U	<i>S. (S.) dispar</i>	
			<i>M. inflatum</i>	
			<i>E. lautus</i>	
		M	<i>E. lorincatus</i>	
			<i>H. dentatus</i>	
			<i>D. mammilatum</i>	
		L	<i>L. tardefurcata</i>	
			U	<i>H. jacobi</i>
				M
	<i>E. martinioides</i>			
	L	<i>T. bowerbanki</i>		
		<i>D. deshayesi</i>		
		<i>D. forbesi</i>		
		<i>P. fissicostatus</i>		
		BARREMIAN	U	<i>P. bidentatum</i>
				<i>S. stolleyi</i>
	<i>S. pingue/"A." innexum</i>			
	L	<i>P. denckmanni</i>		
<i>P. elegans</i>				
<i>"H." fissicostatum</i>				
<i>"H." rarocinctum</i>				
<i>S. variabilis</i>				

Stage	Substages	Tethyan ammonite zones	
ALBIAN	U	<i>S. (S.) dispar</i>	
		<i>M. inflatum</i>	
		<i>E. lautus</i>	
	M	<i>E. lorincatus</i>	
		<i>H. dentatus</i>	
		<i>D. mammilatum</i>	
	L	<i>L. tardefurcata</i>	
		U	<i>H. jacobi</i>
			<i>A. nolani</i>
M	<i>P. melchioris</i>		
	<i>E. subnodosocostatum</i>		
L	<i>D. furcata</i>		
	<i>D. deshayesi</i>		
	<i>D. weissii</i>		
	<i>D. tuarkyricus</i>		
	BARREMIAN	U	<i>P. waagenoides</i>
			<i>M. sarasini</i>
<i>I. giraudi</i>			
L	<i>H. feraudianus</i>		
	<i>H. sartousiana</i>		
	<i>A. vandenheckii</i>		
	<i>H. caillaudianus</i>		
	<i>S. nicklesi</i>		
<i>S. hugii</i>			

Australian dinocyst zonation		
Stage	Super zone	Zone
ALBIAN	HETERO-SPHAERIDIUM	<i>Xenascus asperatus</i>
		<i>Pseudoceratium ludbrookiae</i> (now <i>Encoceratium ludbrookiae</i>)
		<i>Canninginopsis denticulata</i>
		<i>Muderongia tetracantha</i>
APTIAN	MUDERONGIA	<i>Diconodinium davidii</i>
		<i>Odontochitina operculata</i>
		<i>Ascodinium cinctum</i> (now <i>Ovoidinium cinctum</i>)
		<i>Muderongia australis</i>
		<i>Muderongia testudinaria</i>
BARREMIAN		

Figure 2. The biostratigraphic framework for the Boreal (left) and Tethyan (middle) realms based on ammonites (adapted from Leereveld, 1995, and Hoedemaeker and Rawson, 2000), and the Australian dinocyst zonation scheme (on the right) for the mid-Cretaceous (Helby et al., 1987).

Traditionally Cretaceous chronostratigraphy is based on ammonites (Figure 2). Unfortunately, the existence of strong faunal and floral latitudinal contrasts in the mid-Cretaceous inhibited direct biostratigraphic correlation and thus calibration of Australian sequences (they lack stratigraphically diagnostic ammonites) until now.

More than a decade ago a comprehensive dinoflagellate zonation was established for stratigraphic correlation of a wide variety of Jurassic-Cretaceous marine sections in Australia (Helby et al., 1987; Figure 2). Since then the zonal scheme is extensively applied and it has proven its value as a solid tool for pan-Australian biostratigraphic correlations, but in addition to the limited potential for cross-hemisphere correlation, only a very few levels of this zonation scheme could be calibrated to the stratigraphic standard of Stages and Substages.

In recent years the advances in the knowledge on organic walled dinoflagellate cysts (dinocysts) have proven to offer a potential biostratigraphic tool to correlate widely separated shallow marine sections (e.g. Prauss, 1993; Hoedemaeker and Leereveld, 1995; Leereveld, 1997; Torricelli, 2000).

In addition to its value in biostratigraphy, dinocyst analysis can be applied for (palaeo-) environmental evaluation. Because dinoflagellate distribution patterns are controlled by

environmental conditions (for example by sea-surface temperature, nutrient supply, salinity, and light penetration), in fossil dinocyst studies the quantitative composition of selected groups may be used for (palaeo-)environmental reconstructions (e.g. Wall et al., 1977; Davey, 1979; Lister and Batten, 1988; Smelror and Leereveld, 1989; Brinkhuis, 1994; Zevenboom et al., 1994; Leereveld, 1995).

During the periods of global warming in the mid-Cretaceous, the equator-to-pole temperature gradient decreased (Barron, 1983; Huber et al., 1995), leading to sluggish oceanic conditions and diminished deep-water formation hampering oxygenation of the water column, causing the oxygen minimum zone to expand. These changes led to deposition of conspicuous organic-rich layers in deep marine settings, also referred to as Oceanic Anoxic Events (OAEs; Schlanger and Jenkyns, 1976; Jenkyns, 1980). These OAEs correspond to excursions in the carbon isotope ($\delta^{13}\text{C}$) record (Figure 3) and in the total amount of organic carbon stored (e.g. Menegatti et al., 1998; Bralower et al., 1999; Leckie et al., 2002). Several authors recognized intervals in the $\delta^{13}\text{C}_{\text{org}}$ records showing changes in a same pattern and with a comparable magnitude in sequences from different areas and defined these characteristic intervals as carbon isotope segments (e.g. Menegatti et al., 1998; Bralower et al., 1999).

In European sections, e.g., Erba et al. (1999) and Wissler et al. (2002) have shown that the events in the $\delta^{13}\text{C}_{\text{org}}$ records correspond to distinct biostratigraphic events (nannofossils and foraminifera). In the present study is explored if a similar correspondence can be inferred for dinocyst and organic carbon isotope stratigraphy in Australian and European sections. If so, this combination would provide a strong stratigraphic tool for the assessment of the position of mid-Cretaceous Stage and Substage boundaries in Australia. The focus of the present study is therefore: the geochemistry and palynology of mid-Cretaceous marine sediment sequences from several locations in Australia and their relation to a standard, ammonite calibrated Tethyan sequence, which could then enable further comparisons between sections from these different regions. Consequently resulting in: 1) definition of a high-resolution biostratigraphical framework based on palynology, 2) comparison and correlation of $\delta^{13}\text{C}_{\text{org}}$ isotope records between different realms, 3) characterization of the nature and extent of the global palaeoenvironmental and -climatic changes.

1.2 Scope and outline of the thesis

With the aim set for this study, the European sequence chosen as reference for global correlation is the Barremian type section at Angles, SE France (Birkelund et al., 1984). Various studies on this section, which contains a Barremian-Aptian transition interval, have already described its ammonite stratigraphy (Delanoy, 1995), $\delta^{13}\text{C}$ isotope stratigraphy (Wissler et al., 2002), and dinocyst content (e.g. De Renéville and Raynaud, 1981; Srivastava, 1984; Wilpshaar, 1995). A corresponding stratigraphic interval was sampled at Deep Sea Drilling Project (DSDP) site 263 located on the NW Australian continental margin. To test the established bio-stratigraphic framework for Australia, further drillholes were chosen from two other depositional basins, i.e., from the Carpentaria Basin the Bureau of Mineral Resources (BMR) Mossman-1 core, and from the Eromanga Basin: Geological Survey of Queensland (GSQ) Hughenden-7, GSQ Manuka-1, and GSQ Eromanga-1, drillcores.

In Chapter 2 the direct correlation between an Australian Barremian-Aptian marine section with European ammonite controlled standard successions, based on corresponding stratigraphic events in the compositional development of the dinoflagellate assemblages is presented. It outlines the correlation between the Barremian-Aptian part of DSDP site 263 in NW Australia, and the equivalent interval in the Barremian stratotype section at Angles, SE France. The correlation provides a suit of nine dinoflagellate cyst (dinocyst) index events, which are useful for cross-

hemisphere comparisons. These dinocyst events further enable age-assessment for the Australian dinocyst zonation scheme traditionally used for Austral biostratigraphic correlation. Palaeoenvironmental evaluation of the dinoflagellate cyst assemblages in DSDP site 263 indicates that the NW Australian margin was affected by cool water-currents during the Barremian-Aptian.

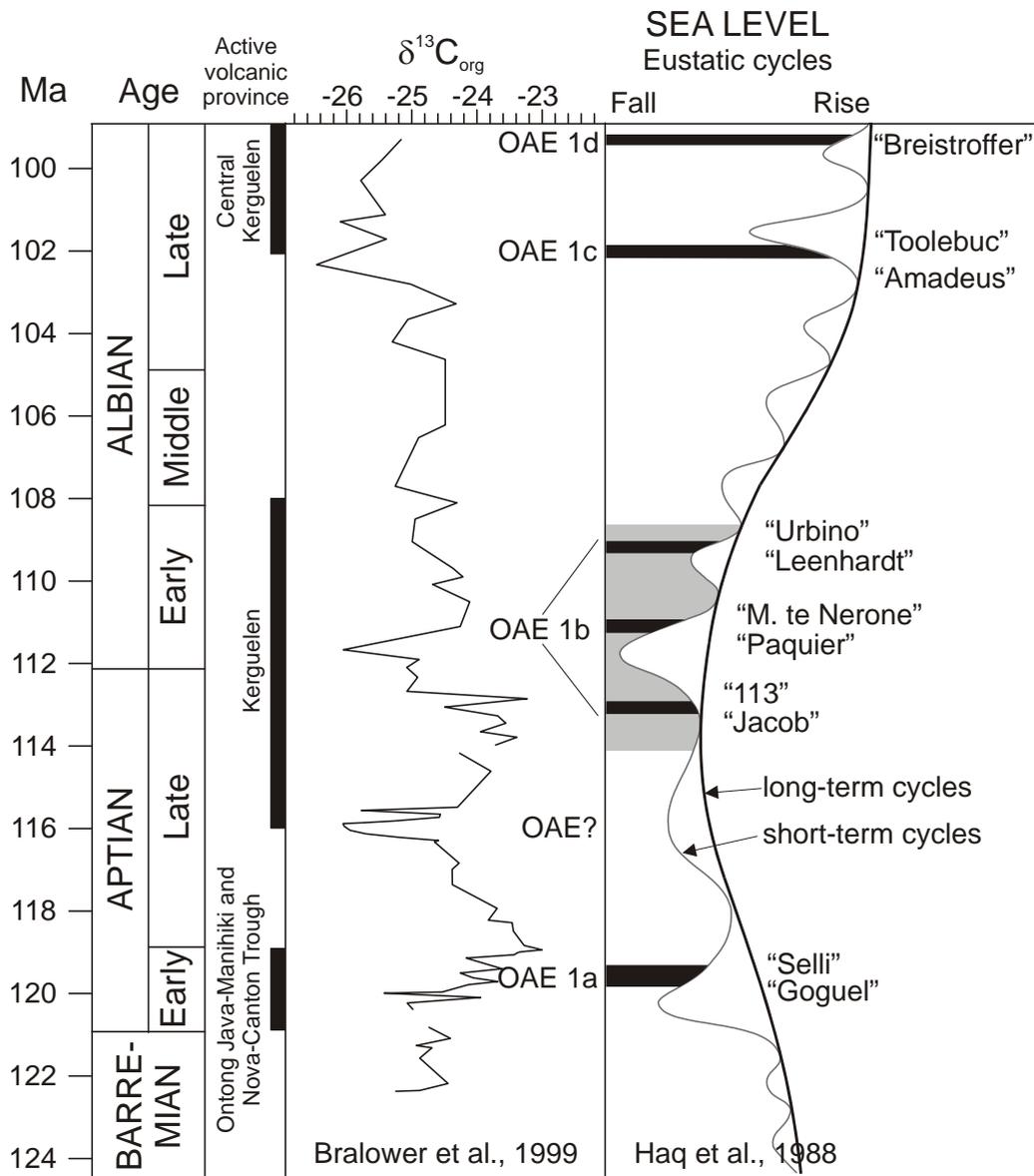


Figure 3. The mid-Cretaceous record of major black shales and oceanic anoxic events, related to volcanic provinces (adapted from Leckie et al., 2002). The carbon isotope record is from Bralower et al. (1999), and the sea-level curve from Haq et al. (1988), i.e., short-term seal-level changes are shown as the solid dark grey line, and the long term as the solid black line (from Leckie et al., 2002).

In Chapter 3 the established timeframe from chapter 2 is applied to BMR Mossman-1 located in northeastern Australia. Comparison of the palynostratigraphic framework, elaborated with $\delta^{13}\text{C}_{\text{org}}$ data, with time equivalent Tethyan and Atlantic records shows identical bio- and geochemical stratigraphic changes and reveals an interval in BMR Mossman-1, which most likely corresponds to oceanic anoxic event (OAE) 1a.

Palaeoenvironmental reconstructions are based on groups distinguished within the dinocyst and spore/pollen assemblages. These groups indicate warmer and wetter conditions prior to OAE

1a changing to cooler and drier conditions starting at the onset of OAE 1a. The $\delta^{13}\text{C}_{\text{org}}$ results add new detail to global stratigraphic changes in Barremian-Aptian carbon isotope records and confirm the assumption that OAE 1a was of global extent.

In comparison with the global sea-level chart of Hardenbol et al. (1998), the changes in palynology, carbon isotope stratigraphy, and lithology allow identification of variations within a third order cycle.

In Chapter 4 the dinoflagellate cyst zonation as presented in chapter 2 and 3 is further tested by applying it to three cores from the Eromanga Basin in eastern Australia; GSQ Hughenden-7, GSQ Manuka-1, and GSQ Eromanga-1, respectively.

The dinocyst events combined with the $\delta^{13}\text{C}_{\text{org}}$ records inferred an Early Aptian to Albian age for the studied sections. The changes in palynology, isotope stratigraphy and lithology are deduced to reflect third order sea-level fluctuations.

Comparison of the data with the BMR Mossman-1 core from the Carpentaria Basin reveals that the start of the mid-Cretaceous marine incursion into the Eromanga Basin is related with the earliest Aptian sea-level rise. Further comparison with time-equivalent Tethyan records shows that the Toolebuc Formation relates to OAE 1c and correlates with the inflexion point of a relative maximum sea-level fall in the earliest Late Albian.

The same palaeoenvironmental groups as in the previous chapter have been used, they indicate cooler and drier conditions at the onset, changing to warmer and more humid conditions within the upper part of the Toolebuc Formation.

In Chapter 5 comparison of Barremian to Albian sequences from the three Early Cretaceous depositional basins in Australia show similar variations within the $\delta^{13}\text{C}_{\text{org}}$ stratigraphy as in time-equivalent Atlantic and Pacific sequences. The observed excursions in the isotope records from the European and Australian sequences can be correlated by biostratigraphic events. For the Barremian-Albian time interval eleven successive dinocyst events prove to be useful for global comparisons. Correlation of the selected results reveals similar patterns and responses in the $\delta^{13}\text{C}_{\text{org}}$ records for the Tethyan, Boreal and Austral realms, and that two periods of oceanic anoxic events, representing OAE 1a and 1c, can be recognized in Australia as well. Furthermore, it enabled recognition of mid-Cretaceous stage and substage boundaries in Australia, and as such provides age assessment for the Australian dinocyst zonation scheme.

The similar patterns in the carbon isotope records, and the response of the palynological assemblages from Australia and other areas to palaeoenvironmental and climatic changes during the mid-Cretaceous indicate that OAE 1a and 1c were of global extent. The first anoxic event lies within the transgressive systems tract of cycle T13, and the latter correlates to the inflexion point of the regressive R14 and following transgressive systems tract of cycle T15, indicating that the underlying driving forces for the various OAEs differ.

N.B. The chapters of this thesis have been/will be submitted as separate papers to scientific journals. Consequently, some repetition could not be avoided.