# TIMESCALES 9

## CALIBRATION AND DEVELOPMENT



AGSO
AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

# CRETACEOUS

| |
|---|
| Cainozoic |
| 65 |
| **Cretaceous** |
| 141 |
| Jurassic |
| 205 |
| Triassic |
| 251 |
| Permian |
| 298 |
| Carboniferous |
| 354 |
| Devonian |
| 410 |
| Silurian |
| 434 |
| Ordovician |
| 490 |
| Cambrian |
| 545 |



RECORD 1995/38

NATIONAL GEOSCIENCE INFRASTRUCTURE AND RESEARCH PROGRAM
GEOLOGICAL SURVEY ORGANISATION

AGSO RECORD 1995/38

# TIMESCALES

## 9. CRETACEOUS

AUSTRALIAN PHANEROZOIC TIMESCALES
BIOSTRATIGRAPHIC CHARTS AND EXPLANATORY NOTES
SECOND SERIES

by

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## FOREWORD

This second series of Timescales Calibration and Development Correlation Charts and Explanatory Notes revises that originally entitled Australian Phanerozoic Timescales which was published as Bureau of Mineral Resources Records 1989/31-40. That series was prepared to provide a firm chronological base for the AMIRA (Australian Mineral Industry Research Association) sponsored *Palaeogeographic Atlas of Australia* and APIRA (Australian Petroleum Industry Research Association) funded *Phanerozoic History of Australia.*

The Correlation Charts and Explanatory Notes for each system have formed the basis for the development of a composite Australian Geological Survey Organisation (AGSO) Phanerozoic Timescale Chart and a condensed single volume summary. The summary chart and single volume together provide ready access to the ages of most Phanerozoic chronostratigraphic subdivisions in Australia. The Correlation Charts and Explanatory Notes also provide the specialist biostratigrapher with the data to understand the basis for the ages estimated. It is anticipated that both charts and notes will be updated at regular intervals, as and when significant bodies of new information become available.

The revised charts have been compiled mostly by palaeontologists of the Timescales Calibration and Development Project from data published in the specialist literature, as well as unpublished information from on-going biostratigraphical research. As previously, the charts integrate zonal schemes using different groups of key fossils with isotopic and magnetostratigraphic data, and where possible related to sea level curves. Recent geochronological numbers generated by SHRIMP (Sensitive High-Mass Resolution Ion Microprobe) technology have been responsible for significant revision of the timescale applied to some systems, notably the Cambrian, Ordovician, Carboniferous and Permian. Similarly, the definition of the base of the Cambrian by the International Union of Geological Sciences, Commission on Stratigraphy, at a level approximately 545 my old has led to a shortening of the Phanerozoic timescale by some 25 my. Such changes are represented in the new cover design for the Timescales Calibration and Development charts that depicts the geochronological time scale currently used in AGSO.

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CONTENTS

# ABSTRACT

Sedimentary sequences of Cretaceous age have been described from all major continents including Australia. To establish a globally applicable time framework for those sequences the most important fields of study to date have been palaeontology, radiometry, and magnetostratigraphy. Another study object, eustasy, provides a promising additional avenue for dating depositional events in Australian basins. The chief evidence regarding those disciplines in the Tethyan Realm is briefly summarised, to present an integrated geochronology with which the Cretaceous of Australia may be correlated.

During the Cretaceous the Australian Plate remained fairly constant with regard to the South Pole. As it gradually broke loose from the other Gondwana continents its present northwestern margin moved from 50° to 40° south. New sea floor had been forming in the north and northwest already during the Jurassic, and separation (from greater India?) started during the Valanginian-Barremian. Initial separation between Australia and Antarctica, with inundation of existing rift valleys, started in the Turonian. Sea floor spreading along the eastern margin slowly separated Australia from Lord Howe Rise and New Zealand, starting in about Santonian times.

The Australian Cretaceous fossil record includes vertebrate faunas (fishes, reptiles, birds, mammals), invertebrate faunas (a variety of macro- and microfaunal groups), and floras (plants, spores, pollen, marine microphytoplankton, nannofossils). This record is compiled from 23 onshore, coastal, and offshore sedimentary basins. It can be correlated in a broad sense with the European Tethys, despite a tendency towards progressive endemism as the fragments of ancient Gondwana drifted apart.

Magnetostratigraphy has rapidly developed to become a major chronostratigraphic tool, and research in this field is under way in the Cretaceous of Australia. Radiometry has provided valuable data for Australian hardrock geology, and successful attempts have been made to obtain radiometric (K-Ar, fission track) ages on fossiliferous sedimentary formations in eastern Australia. Eustatic influences have been detected in several sedimentary basins, and are being studied further as a possible aid towards dating nonmarine strata sequences.

| Cretaceous Stage | upper Stage limit Ma | chron | magnetostratigraphic evidence |
|---|---|---|---|
| MAASTRICHTIAN | 65 (top *B. casimirovensis*) | 92R | Gubbio[1] |
| CAMPANIAN | 73 (top *B. polyplocum*) | 33N | Gubbio[1,2] |
| SANTONIAN | 83 (top *syrtale*) | 34N | Gubbio[1] |
| CONIACIAN | 87 (top *serratomarginatus*) | CQZ | Gubbio[1] |
| TURONIAN | 89 (top *deveriai*) | CQZ | Gubbio[1] |
| CENOMANIAN | 91 (top *juddi*) | CQZ | Gubbio[1] |
| ALBIAN | 97.5 (top *perinflatum*) | CQZ | Moria[3] |
| APTIAN | 108 (top *nodocostatum/ bigoureti*) | CQZ | Poggio[3], le Guaine[3] |
| BARREMIAN | 115 (top *seranonis*) | M0 | Valdorbia[3,4,5] |
| HAUTERIVIAN | 123 (top *angulicostata*) | M7N | Gorgo a Cerbaria Presale[9] |
| VALANGINIAN | 130 (top *callidiscus*) | M10N | Cismon[9] |
| BERRIASIAN | 135 (top *boissieri*) | M14 | Caprolo[8], Xausa[8] |
| (JURASSIC/Tithonian) | 141 (base *grandis*) | M18 | Bosso[7], Foza[7] |
| | 142 (base *jacobi*) | M19N | Carcabuey[6], Foza[6,7,8], Xausa[6,7,8] |

1. Alvarez & others (1977)
2. Lowrie & Alvarez (1981)
3. Lowrie & others (1980)
4. Lowrie & Alvarez (1984)
5. Lowrie & Ogg (1986)
6. Ogg & others (1984)
7. Ogg & Lowrie (1986)
8. Channell & others (1987)
9. Bralower (1987)

**Figure 1:** Isotopic ages of Cretaceous Stage boundaries and their magnetostratigraphic correlations (for details see text)

## INTRODUCTION

During the last decades, significant advances in biostratigraphy and chronostratigraphy have led to a series of proposals towards improving the standard Cretaceous time scale. This paper takes account of the most recent proposals, and updates Burger (1990) and the Cretaceous chapter in Young & Laurie (in press). It summarises chronostratigraphic scales and standard biostratigraphic schemes, against which the record of the Australian Cretaceous may be fitted (see Fig. 1). The data are presented as follows:

A. Selected **palaeontological** records from key regions in Gondwana and Laurasia are summarised in the text and set out in Table I as columns against the Cretaceous Stages. Tethyan and Boreal ammonite records from Europe are given in columns 3-4, and ammonite sequences from other regions in columns 5-8. Selected microfaunal and microfloral biostratigraphic schemes are set out in columns 9-20. Columns on single subjects bear identical numbers in Table IA (Berriasian-Aptian) and Table IB (Albian-Maastrichtian).

B. **Absolute ages** here accepted for the Cretaceous Stage boundaries are given in Figure 1 and set out in Table I column 1.

C. The standard global **magnetostratigraphic** record for the Cretaceous is set out in Table I column 1.

D. Cretaceous global **sealevel movements** have been logged and described by Cooper (1977), Vail & Todd (1981), Haq & others (1987), and other workers. The effect of eustasy on the depositional history of several Australian basins is briefly reviewed, and set out in Figure 5.

E. The section **Cretaceous of Australia** is an update of Burger (1990) and Bradshaw & Yeung (1992). The records of the most important groups of fossils are given in Table I columns 21-37.

## THE STANDARD CRETACEOUS TIME SCALE

The Cretaceous Period succeeds the Jurassic Period, and is followed by the Cainozoic Era. The Cretaceous System was first referred to as such (*terrain Crétacé*) in 1822 by d'Omalius d'Halloy, during his observations in France, Belgium, and the Netherlands. D'Orbigny studied the marine fossil record, and he was the first to recognise *étages*, each with its own peculiar fauna. They form the backbone of the present subdivision of the Cretaceous into 12 Stages. Each Stage is defined by zonal sequences (primarily of ammonites) described chiefly from marine epicontinental environments of the western Tethyan Realm in France, the Netherlands, and Switzerland (Fig. 1).

This chapter briefly reviews the most recent ideas concerning Tethyan and global standards in the fields of biostratigraphy, chronostratigraphy, and magnetostratigraphy. They provide the mutual verification required for establishing an internally consistent geochronology, which may serve as a standard for the Cretaceous of Australia. Limited space prevents any but the briefest review of earlier studies, but they are acknowledged in publications referred to here.

## THE AMMONITE RECORD

As in the Jurassic, ammonites have been used to subdivide the marine Cretaceous in many regions of the earth. However, an overall shallowing of the Cretaceous seas sharpened the contrasts between Tethyan, Boreal, and Pacific provinces and led to progressive endemism and impoverishment (even disappearance) of ammonite faunas. This is reflected in the record and complicates worldwide correlations. The following summary indicates the ephemeral character of the sea-lanes which connected various key regions during the Cretaceous, and the problems arising from attempts to relate the Australian ammonite record with the Tethyan biostratigraphy.

There is at present no uniform ammonite biostratigraphy for the Cretaceous of the Mediterranean Province, which encompasses much of western Europe, North Africa, and the Middle East. The zonal scheme which has been proposed as a standard for the Tethyan Cretaceous has been described from western Europe (see Table I columns 3, 4), and is a compromise based on Birkelund & others (1984), Robaszynski (1984), and Kennedy (1984a,b, 1986, 1987).

Type areas of individual Cretaceous Stages were initially established in western Europe. Many stratotype boundaries reflect geological events, and are frequently gaps in the record. This has convinced geoscientists of the need for more detailed definitions of Stage boundaries, if needed outside the former type areas, based on ammonites and where desirable also on evidence from bivalve molluscs, foraminifera, calpionellids, nannofossils, and palynomorphs.

Proposals to achieve this were presented at the 1963 Colloque sur le Crétacé Inférieur, the 1973 Colloque sur la limite Jurassique-Crétacé, the 1983 Symposium on Cretaceous Stage boundaries, organised by the IUGS Subcommission on Cretaceous Stratigraphy, and by Cavelier & Roger (1980). At this time several Stage boundaries have not yet been formally established, as ammonite records need to be verified and proposals for alternative type boundaries evaluated.

## Jurassic-Cretaceous boundary

A satisfactory palaeontological definition for the J-K boundary has never been agreed upon, as provincialism in ammonite ecology following the great latest Jurassic marine regression in Europe has fueled continuous debates on time relationships between regional Boreal and Tethyan Stages, such as the Portlandian, Tithonian, Berriasian, Volgian, and Ryazanian (Fig. 2).

At the 1963 Colloque sur le Crétacé Inférieur a recommendation was made to recognise the Berriasian as a separate Stage. This recommendation was confirmed by the Mediterranean Mesozoic Committee in Cassis, France (1964). The accepted J-K boundary in the Tethyan biostratigraphy, i.e. the base of the Berriasian, as being the base

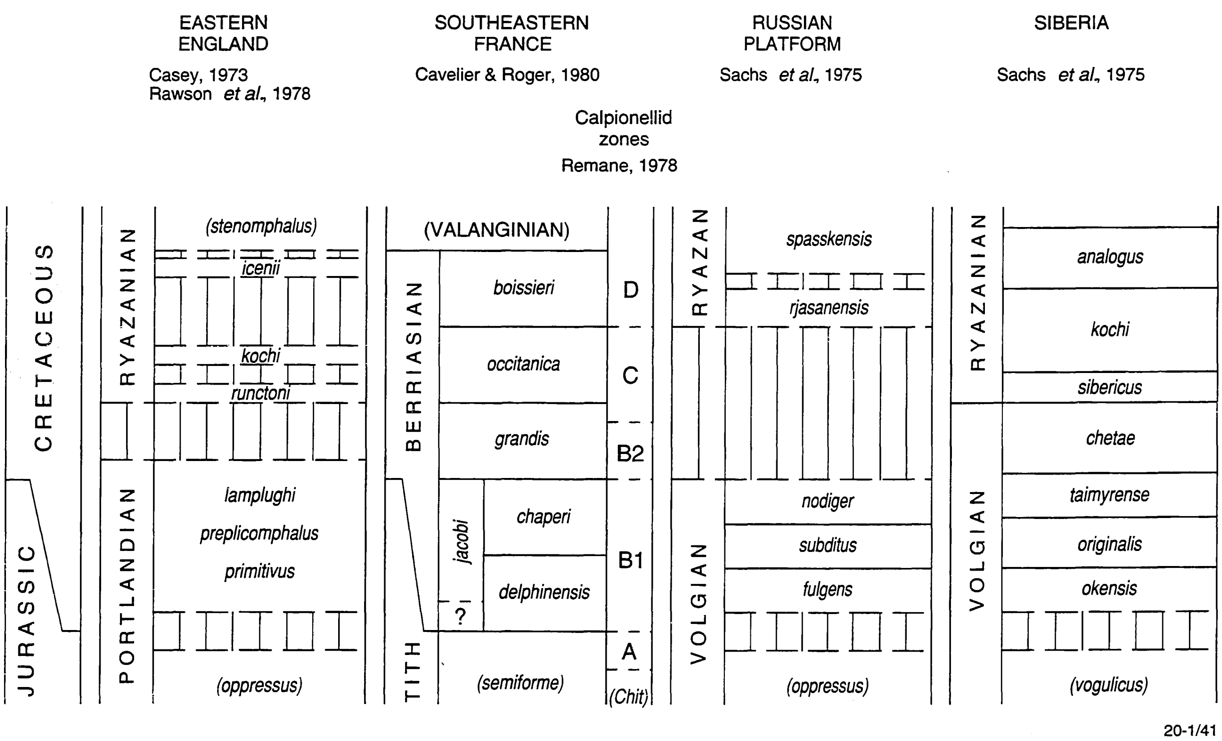



Figure 2: Correlation of basal Cretaceous ammonite zones in England, France, Russia, and Siberia

of the GRANDIS zone was upheld by Le Hégarat (Cavelier & Roger, 1980, p. 96), but more recently has been questioned, chiefly because the original stratotype of the Berriasian in southeastern France (Busnardo & others, 1965) contains few ammonites in its basal interval, and its exact relationship with the preceding Tithonian (which has not been formally defined) is not yet certain.

At the Colloque sur la limite Jurassique-Crétacé (1973) the desirability of adopting the GRANDIS-JACOBI zonal interval as the lowermost Cretaceous ammonite zone in the Tethyan Realm was seriously considered as presenting the least disruptive alternative to the present J-K boundary (Yegoyan, 1975). The new boundary is recognised in southern Spain (Enay & Geyssant, 1975). It would probably require a revised definition for the Tithonian from that proposed by Zeiss (1974), but unlike the base of the GRANDIS zone it has an equivalent in the Boreal Realm of Russia. It coincides with the base of the *Calpionella alpina* zone (calpionellid zone B of Remane, 1978), which has been widely observed in regions where the standard ammonite succession is not recognised, such as in Spain (Allemann & others, 1975; Ogg & others, 1984), Italy (Ogg & Lowrie, 1986), and North Africa (Memmi & Salaj, 1975).

## Early Cretaceous

The present standard ammonite biostratigraphy for the Boreal and Tethyan Early Cretaceous (Table I column 3) follows that compiled by Van Hinte (1978) and Kennedy & Odin (1982). The positions of various Stage boundaries has been discussed in Cavelier & Roger (1980) and Birkelund & others (1984).

No comparable ammonite succession has been developed for the Early Cretaceous of North America, where marine deposition was spasmodic; faunas are impoverished and contain few ammonites. Marine biostratigraphies for various regions are based largely on bivalve molluscs (*Inoceramus*, *Buchia*, *Meleagrinella*) and foraminifera (Jeletzky, 1971, 1973; Chamney, 1973; Stott, 1975). The Albian hoplitid-dominated fauna from Europe spread as far west as Greenland, but is not recognised in the North American Interior, where a more or less continuous ammonite record begins with an endemic gastroplinitid fauna. Owen (1973) regarded that fauna as chiefly late Albian, because one of its components, *G. cantianus*, also occurs in the INFLATUM zone in the U.K.

## Late Cretaceous

The standard Tethyan ammonite zonation for northwestern Europe has been reviewed by Cavelier & Roger (1980), Kennedy & Odin (1982), and Kennedy (1984a,b, 1986). Positions of Stage boundaries in the zonal scheme, and possible alternatives, have been discussed by Birkelund & others (1984). Ammonite occurrences are less frequent than in the Early Cretaceous; individual zones are much broader, and the Maastrichtian is usually subdivided by the much more common belemnites (Table IB column 3).

The Late Cretaceous ammonite sequence of the North American Interior (Table IB column 5) is derived from Obradovich & Cobban (1975), Stelck (1975), Stott (1975), and Caldwell & North (1984). The position of the Campanian-Maastrichtian boundary is still uncertain. *H. nicolletti* has been found in the early Maastrichtian *B. cimbricata* zone in Germany, and Obradovich & Cobban (1975) referred to indirect evidence suggesting an earliest Maastrichtian age for the *B. reesidei* zone. However, the authors also pointed out that evidence from planktonic foraminifera suggests that the base of the Maastrichtian may fall below the STEVENSONI zone in the western Gulf Coast, or near the *B. scotti* zone in New Jersey.

## Cretaceous-Tertiary boundary

The K-T boundary in Europe is generally taken to lie at the Maastrichtian-Danian boundary contact, although several geo-scientists would prefer the Danian to be included in the Cretaceous (Berggren & others, 1985). The former type sequences of the Maastrichtian and Danian were defined respectively in Limburg (The Netherlands) and Stevns Klint (Denmark). The boundary type has been established at Stevns Klint.

The base of the Danian in the sense of Hardenbol & Berggren (1978) thus lies between the *Abathomphalus mayaroensis* and *Globigerina eugubina* foraminiferal zones.

In North America the sediments deposited in the Western Interior sea contain rich ammonite faunas. U.S. and Canadian biostratigraphers have developed a zonal scheme which - despite its endemic character - can be broadly correlated with Europe. It is given in Table I column 5, as it makes a substantial contribution to Cretaceous geochronology.

The Western Interior sea gradually withdrew to the south; in Canada the ammonite record ends with the GRANDIS zone, and in the U.S.A. with the CHEYENNENSIS zone, both zones being dated as early Maastrichtian (Obradovich & Cobban, 1975). The K-T boundary thus lies within sequences of largely nonmarine strata, and they have been studied in almost a dozen sedimentary basins in the Western Interior. The northern U.S.A. may serve as an example of the problems met in connection with that boundary.

In Montana and Wyoming, deltaic and lagoonal deposits of the Fox Hill Formation containing oysters and other bivalves of Maastrichtian age (Feldmann & Palubniak, 1975) interfinger with coastal lowland and alluvial plain deposits of the Hell Creek Formation, which includes a diverse reptilian fauna (Russell, 1975; Lehman, 1987). This classic *Triceratops* fauna has been (partly or wholly) correlated with the late Maastrichtian *B. junior* and *B. casimirovensis* zones in Europe (Lanphere & Jones, 1975).

The demise of that fauna has traditionally been accepted as marking the K-T boundary. Sloan & others (1986) recovered dinosaur remains, together with Palaeocene mammals, from beds above the basal Tertiary «Z-Coal» overlying the Hell Creek Formation in Montana, but Argast & others (1987) doubted if those remains were in situ occurrences. Magnetostratigraphic data (to be evaluated) seem to add to a growing body of evidence which leads several geoscientists to believe that the dinosaur extinction level in North America may be a diachronous event (see Channell, 1982; Officer & Drake, 1983).

Palynologists are aware that correlations based on spores-pollen and on vertebrates may not yield parallel results (see Berggren & others, 1985). Brown (1962) suggested that the K-T boundary be drawn at the base of the stratigraphically lowest persistent lignite horizon overlying the highest occurrence of dinosaurs. North American palynologists have generally followed Brown's definition, as specific changes occur in the palynological record near the base of certain coaly horizons overlying the Hell Creek Formation, as well as in other areas of the Western Interior (Tschudy & Tschudy, 1986). However, it has not yet been established beyond doubt that those changes are isochronous events.

Palynological changes such as have been described from North America have not been observed in Europe, and we must conclude that the correlative of the K-T boundary in Europe has not yet been accurately pinpointed in North America.

**Ammonite records outside Europe**

L a u r a s i a : There were frequent interchanges between Boreal and Tethyan faunas of Laurasia (Rawson, 1973; Donze, 1973; Owen, 1973), and these facilitate correlations (based on crioceratitid ammonites) between North America and Eurasia. In North America, marine sequences in the Gulf region are biostratigraphically subdivided in part on ammonites, and in part on bivalve molluscs.

The Boreal Realm in Eurasia presents a more varied and less coherent picture. Despite periodic influxes of Tethyan marine faunal elements (Rawson, 1973) - which are best displayed in Germany (Kemper, 1973a,b), England (Casey, 1973), and other western European regions - ammonites, belemnites, and bivalve molluscs of strongly endemic character have been used as biostratigraphic indicators in all major Boreal provinces (Russian Platform, northern Urals, northern and eastern Siberia). Several biogeographic provinces have been described from China, and Yang (1986) outlined several ammonoid and bivalve associations. Apparently the detailed ammonite biostratigraphy developed for Japan (kindly communicated by prof. T. Matsumoto, Table I column 6) has not been identified in China, suggesting western limits of the Pacific

Realm on the East Asian mainland.

G o n d w a n a : Sea-lanes existed between Laurasia and Gondwana, and although they permitted faunal interchanges the record from Gondwana suggests that they were tenuous at best. The Cretaceous of western South America is dominated by the Andean Trough and Magellanean Geosyncline; the record of ammonites is incomplete and endemic but indicates Mediterranean Tethyan influences (Wiedmann, 1980). Towards the east (Brazil, Argentina) marine Albian to Maastrichtian sediments occur in coastal basins and the eastern continental shelf. In the southern regions of the continent (see Riccardi, 1988), Early Cretaceous ammonite faunas of the Austral Basin in Patagonia show Boreal, South African, and Caucasian influences, and Late Cretaceous faunas indicate Indo-Pacific affinities. Farther north, Early Cretaceous ammonites from the Andean Basin include Himalayan and Mediterranean elements.

In Africa the record of marine Lower Cretaceous strata is fragmentary. Marine Upper Cretaceous strata have been mapped in some detail in several countries but detailed ammonite schemes have been published only from Morocco (Wiedmann & others, 1982; Table I column 7). In both West and South Africa, where near-complete Cretaceous sedimentary sequences occur in coastal and offshore regions, microfaunas provide the main time framework, and some ammonite control exists in the Algoa Basin and Zululand. A shallow sea along the African east coast connected the region with the main Tethys Ocean at least from the Late Jurassic onwards, but the fossil record has no overriding Tethyan character.

In India the Cretaceous is nowhere fully preserved, and the most complete marine sequences overlying Lower Cretaceous «Upper Gondwana» strata (frequently in unconformable contact) have been described from the Cauvery, Palar, Godavari-Krishna, and Mahanadi Basins at the east coast (Sastri & others, 1974). Ammonite biostratigraphies have been developed for the middle and Late Cretaceous of the eastern and northwestern subcontinent (Table I column 8).

The Cretaceous marine record of New Zealand covers only the Aptian to Maastrichtian; the oldest Cretaceous history has been partly obliterated by the Late Mesozoic Rangitata Orogeny. Stages are defined by ammonites and bivalve molluscs (*Aucellina, Inoceramus, Maccoyella*). New Zealand and Australia were then much closer to each other and to Antarctica than they are today, but few parallel faunal developments have been found from the two regions. The positions of several Stages are still under consideration, but correlation with the standard Cretaceous is gradually being refined (Raine, *in* Edwards & others, 1989).

## ABSOLUTE TIME

Isotopic ages of Cretaceous Stage boundaries, which form the basis of the Cretaceous time scale, have been calculated from K-Ar, Ar-Ar, and Sb-Sr age determinations on glauconites from Europe and the USSR, and biotites and sanidines from volcanic ashes in North America (Table I columns 1, 2).

There are generally accepted istopic dates only for a few Cretaceous Stage boundaries. Ages extrapolated for the Late Cretaceous boundaries by Harland & others (1982, 1989), Snelling (1985), and Odin & Odin (1990) diverge not more than 2 Ma. The Mesozoic time scale of Gradstein, Ogg, & others (see AAPG Annual Convention 1993) was not available to this author at the time of publication. Values for the Early Cretaceous boundaries given in various published timescales deviate much more, and they move up and down continually as new isotopic data are released. The author has tried to find a compromise by adopting the timescale of Harland & others (1982) for the Late Cretaceous, and that of Haq & Van Eysinga (1987) for the Early Cretaceous, slightly modified to accept 141 Ma for the J-K boundary, as has been accepted by Bralower & others (1990).

## GEOMAGNETIC REVERSALS

Since the early nineteen sixties, recurrent reversals of the earth's dipole magnetic field have been logged in Cainozoic, Mesozoic, and Upper Palaeozoic magmatic and sedimentary rock sequences, both on the ocean floor and on land. Those reversals most probably originated from internal, not extra-terrestrial causes (Merrill & McFadden, 1988).

Standardisation of the sequence of logged Cretaceous reversals is primarily the result of studies of geomagnetic lineations from rift zones in the Pacific (south of Hawaii) and the Atlantic Oceans. Heirtzler & others (1968) compiled a standard reversal diagram for the Cainozoic and Late Cretaceous, including anomalies 0 to 34. Helsley & Steiner (1969) first recognised a long interval of normal polarity in Cretaceous volcanics of North America; it is known as the Cretaceous Quiet Zone and extends between anomalies 34 and M0. Larson & Hilde (1975) and Vogt & Einwich (1979) set up a standard reversal diagram for the Late Jurassic and Early Cretaceous - known as the Keithley sequence - which includes Cretaceous anomalies M0 to M18 (Table 1 column 1). The numbering code of Couillard & Irving (1975), although perhaps more logical, was not followed by those authors.

## INTEGRATION OF DATA

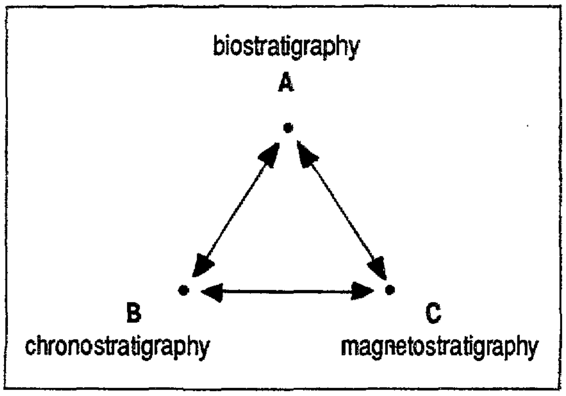
The integration of magnetostratigaphy with independent evidence from fossils and radiometry enables geoscientists to confirm the reliability of their data with enhanced confidence. At the present time however, a high degree of internal consistency cannot be expected from such integration, in view of inherent uncertainties within each discipline (rate of sea floor spreading, isotopic decay constants, biostratigraphic resolution). The following correlations show the possibilities and limits of this approach towards the Cretaceous (see following diagram).

### Correlation A - B

This correlation links the fossil record to radiometric data, and is summarised in the section ABSOLUTE TIME. Biostratigraphic control of isotopic ages is often very high, as many source rocks (glauconies, benthonites) are associated with zonal index ammonites.

### Correlation C - A

This correlation aims at linking individual geomagnetic anomalies with the Cretaceous Stages. Very few such links have been obtained from the seafloor, but pioneering work on Neogene volcanics in several parts of the world during the nineteen sixties showed that geomagnetic reversal patterns can be recognised in suitable land-based sequences (Helsley & Steiner, 1969; Alvarez & others, 1977).




The advantage of easy accessibility was demonstrated by a multidisciplinary study of Palaeogene and Late Cretaceous pelagic limestones near Gubbio (central Italy). Those limestones are associated with a sequence of magnetic reversals, of which the oldest could be correlated with ocean floor anomalies 29 to 34 and with part of the Cretaceous Quiet Zone. On the evidence of planktonic foraminifera, calpionellids, and nannofossils that sequence of reversals could be dated as Maastrichtian to Cenomanian (Alvarez & others, 1977; Lowrie & Alvarez, 1981).

Subsequent studies have linked magnetic reversal sequences measured from Lower Cretaceous pelagic limestones in central and northern Italy and southern Spain with ocean floor anomalies M0-M19 (Lowrie & others, 1980; Ogg & others, 1984, 1988; Galbrun, 1985; Ogg & Lowrie, 1986; Channell & Grandesso, 1987; Channell & others, 1987; Bralower, 1987).

The C-A correlations thus established for the Early and Late Cretaceous are set out in Table I columns 1, 2, and given in Figure 1.

## Correlation C - B

This correlation aims at providing true ages for geomagnetic anomalies, but it is still in the early stages of progress. Usually, ocean floor reversals are dated by extrapolating between isotopically dated magnetic polarity intervals, taking into account rates of sea floor spreading calculated for individual rift zones. This is in principle the most accurate method, provided that sea floor spreading remained constant over a long period.

Radiometric ages so far obtained from the ocean floor are few and spaced widely apart in time. On isotopically dated Early Tertiary and Late Cretaceous anomalies, Tarling & Mitchell (1976), Lowrie & Alvarez (1981), Harland & others (1982, 1989), Berggren & others (1985), and other workers have calculated closely matching ages for Late Cretaceous anomalies 29 to 34. Ages for the Maastrichtian to Aptian reversals adopted here are those of Harland & others (1982).

At present no generally accepted ages have been published for the Early Cretaceous ocean floor anomalies. Values calibrated by Larson & Hilde (1975), Vogt & Einwich (1979), Harland & others (1982), and Lowrie & Ogg (1986) have resulted in 21 to 29 million years duration for the Neocomian. Those uncertainties required this author to match the sequence including M0 to M18 against a pre-existing time scale (a step which in fact expresses correlation B-C). Although unavoidable at this time, so as not to violate known correlations A-C and A-B, this procedure perpetuates the very imperfections of those correlations which it is supposed to correct. The author therefore does not impute ages for anomalies M0 to M18; and Table I columns 1 and 2 cannot pretend to be more than a state-of-affairs presentation for the end of this century.

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# THE RECORD OF MICROFOSSILS

## FAUNAS

Micropalaeontological research plays an increasingly important role in world-wide correlations, aided by the huge influx of data from the subsurface, and from the continental shelves and ocean floors, provided by scientific and commercial drilling programs. Foraminiferal biostratigraphies (Bolli 1966; Sigal 1977; Van Hinte 1978; Pflaumann & Cepek 1982; Caron, 1985) have been published for the Cretaceous in the Atlantic and Mediterranean regions (Table I columns 9,10). They have been applied in other parts of the world, but at present no global standard biostratigraphy has been formally agreed upon. No calpionellid biostratigraphy has been developed for the entire Cretaceous (Remane 1978), and this group is not discussed except where useful for indicating correlation of other fossil sequences.

## FLORAS

### Calcareous nannofossils *(Text and Table I columns 11-14 contributed by S. Shafik)*

Nannofossil biostratigraphies have been devised for the Early Cretaceous of high-latitude regions (e.g. NW European zones of Crux, 1989; Table IA column 24) and mid- to low-latitude regions (e.g. Blake-Bahama Basin zones of Roth, 1983; Table I column 24). Neither scheme could be used on material from the Rowley Terrace. However, the Albian high-latitude zonation of Wise & Wind (1977; incorporated in Table I column 24) could be successfully applied in north-eastern and northwest Australia (Shafik, 1985, 1992, unpublished data).

Various events in the nannofossil biostratigraphies of Table I columns 11-14 and 26-28 are coded as follows: **FO, FAD** indicate earliest appearances (bases of stratigraphic ranges, evolutionary appearances, lowest regular occurrences); **LO, LAD** express last appearances (tops of stratigraphic ranges, exits, extinctions, highest regular and common to abundant occurrences - tops of acme occurrences, or re-entries).

### Palynomorphs

Palynology today covers a very wide range of palaeoenvironments. Sediments of flood plain, fluvial/lacustrine, deltaic to lagoonal, littoral, and marine (epineritic to continental shelf) origins produce a wealth of plant fossils, of which spores, pollen grains, and dinoflagellate cysts are the most significant for biostratigraphy.

S p o r e s & p o l l e n : The study of spores and pollen has outlined broad floral provinces in the Northern Hemisphere, frequently indicating palaeolatitudinal (e.g. climatic) control, especially during the Early Cretaceous. During the Late Cretaceous Europe and European Russia were part of the Normapolles Province, and Siberia part of the *Aquilapollenites* Province. Recent studies have covered various aspects of Cretaceous phytogeography and biostratigraphy in China (Sun, 1980; Song & others, 1983). Broadly parallel palynofloral developments have been observed near the J-K boundary in southern England and on the Russian Platform (Bolchovitina, 1973), but so far correlation between continents has met with limited success, and no biostratigraphies are given in Table I.

The spore and pollen records of Australia and New Zealand reveal broad similarities, but still cannot be readily compared (Raine, 1984).

D i n o f l a g e l l a t e s : The study of marine dinoflagellate cysts has enabled much wider correlations to be made, due to the floating life-style of the organisms involved. A very comprehensive summary including various proposed biostratigraphic schemes was written by Williams & Bujak (1985). Table I columns 15-20 set out some of the most recently published schemes for the Tethyan and the Boreal Realms.

Boreal assemblages recorded from Canada and northern Europe reflect phytoplankton provincialism, especially during the Early Cretaceous (Pocock, 1976, 1980). Parallel developments also occur; the *P. neocomica* zone approximately marks the J-K boundary in areas from Eastern Canada to the Moscow Platform. In the Moscow Basin that zone is dated Ryazanian (Fisher & Riley, 1980), and in eastern offshore Canada Berriasian to Valanginian (Bujak & Williams, 1978).

The European and Mediterranean Tethyan record has been analysed in part by Habib & Drugg (1983; see also Ogg, 1994). They proposed a zonal scheme for the (late) Berriasian-Aptian in France, and recognised a virtually identical sequence in the northwest Atlantic. Few of those elements are found in Davey's (1979, 1982) mixed Tethyan-Boreal biostratigraphy for the Early Cretaceous of northwestern Europe, in which the base of his *G. villosa* zone coincides with the base of the JACOBI ammonite zone.

Marine sediments of Cretaceous age are rare in China, and the published record is still very fragmentary and localised. Broad biostratigraphic schemes have been proposed for the Neocomian in the east (Yu, 1982) and the Late Cretaceous in the west (Yu & Zhang, 1980). In New Zealand, the dinoflagellate biostratigraphy for the Korangan-Haumurian (late Aptian-Maastrichtian) has been summarised by Wilson (1984).

Comparisons of Australian Cretaceous sequences with western Europe have yielded some results (Morgan, 1980a; Burger, 1982; Helby & others, 1987), and it is possible that these and other parallel sequential developments (see Williams & Bujak, 1985) may eventually for the basis for an integrated Tethyan record for the Cretaceous.

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## EUSTASY

During the last hundred years a growing body of evidence has demonstrated the existence of synchronous rises and falls of the sealevel in several continents during the Phanerozoic. Several mechanisms have been proposed to explain those eustatic movements. Those with most likely noticeable impact during the Cretaceous would have been changes in the volume of oceanic basins, specifically by recurrent uplifts and subsidence of oceanic ridges, and changes in the rate of sea floor spreading. Changes in volume of land ice or in mean temperature of oceans would have been minor or non-existent, at least during the Cretaceous (see Hallam, 1977, 1984b; Donovan & Jones, 1979). Changes in the configuration of the globe also fall outside the scope of this paper, as they would result in infinitely slower eustatic movements.

The combined effect of those mechanisms on the Cretaceous fossil and environmental records of five continents was first investigated by Cooper (1977) and Pitman (1978). Cooper summarised relevant data into a curve of rises and falls of sealevel relative to the margins of the ancient Gondwana and Laurasia continents.

The earliest attempts to use seismically profiled truncation of strata sequences (primarily in the north Atlantic), as a means of retracing world-wide sealevel movements during the Mesozoic and Cainozoic was made by Vail and his collaborators. They published sealevel curves representing 'relative changes of coastal onlap' (Vail & others, 1977a, emended by Vail & Todd, 1981). However, their curves lack detail with regard to the Cretaceous.

A broader-based study was set up by Haq & others (1987), who integrated seismic and sequence stratigraphic data from continental margins elsewhere, to create depositional models for the reconstruction of a detailed Mesozoic and Cainozoic coastal onlap curve. The underlying premise that primary seismic reflectors are time-concordant is plausible (Vail & others, 1977b) but has not yet been backed by published evidence, and seismic results need to be checked against other methods (Hallam, 1977).

There is evidence from both fossil and sedimentological records for recurrent marine transgressions and regressions in several Australian sedimentary basins during the Cretaceous. Their relationships to worldwide sealevel movements are discussed below.

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## THE CRETACEOUS OF AUSTRALIA

### INTRODUCTION

The earliest geological and palaeontological observations of this continent date from the late eighteenth century, made by explorers, chance visitors, prospectors, and local laymen with geological interest, many trekking the country on horseback. The earliest known geological observations of the Cretaceous stem from the earliest settlement of Europeans in Victoria in the nineteenth century, and are tied with names like Sturt, Mitchell, Strzelecki, Hobson, and Jukes, who made repeated exploratory treks through eastern Victoria (Darragh, 1976).

The mining of economically valuable minerals (gold, coal, copper) led to the institution of State Geological and Mining Departments in Victoria, New South Wales, and Queensland. They appointed government geologists and palaeontologists, who were charged with organising and planning mining acitivities and mapping the country. At the beginning of the twentieth century geological and palaeontological research had been placed on a proper organisational and legislative footing in each of the states and territories.

Geological exploration in Western Australia started near the end of last century. Much of it was done by A. Gibb Maitland, who, as government geologist, reported on Cretaceous strata in the first comprehensive publication on the state's geology. He reported the presence of artesian water in the Eucla Basin. Subsequent studies by C. Teichert offered more detailed stratigraphic and palaeontological accounts of several Western Australian basins.

The discovery of coal along the east coast of Queensland stimulated palaeobotanical research (W.H. Rands, T.W.E. David, A.B. Walkom). With the influx of immigrants into rural Queensland and the discovery of subterranean (artesian) water, exploration of the vast expanses of the Great Australian or Great Artesian Basin in Queensland and South Australia (by H.Y.L. Brown, R.L. Jack, and others) started in earnest around the turn of the century (Sprigg, 1986).

W.B. Clarke, F. McCoy, C. Moore, and R. Etheridge Jnr. first described marine Cretaceous faunas from the Great Australian Basin (Day, 1969). Whitehouse (1926) first attempted to correlate what was known of marine Cretaceous deposits of Australia. Cape York Peninsula was first explored early last century by L. Leichhardt, A.C. Gregory, and R.L. Jack. Oil exploration at Weipa, Wyaaba, and Karumba, and geophysical surveys have begun to fill in the peninsula's geological map after World War 2 (Smart & others, 1980).

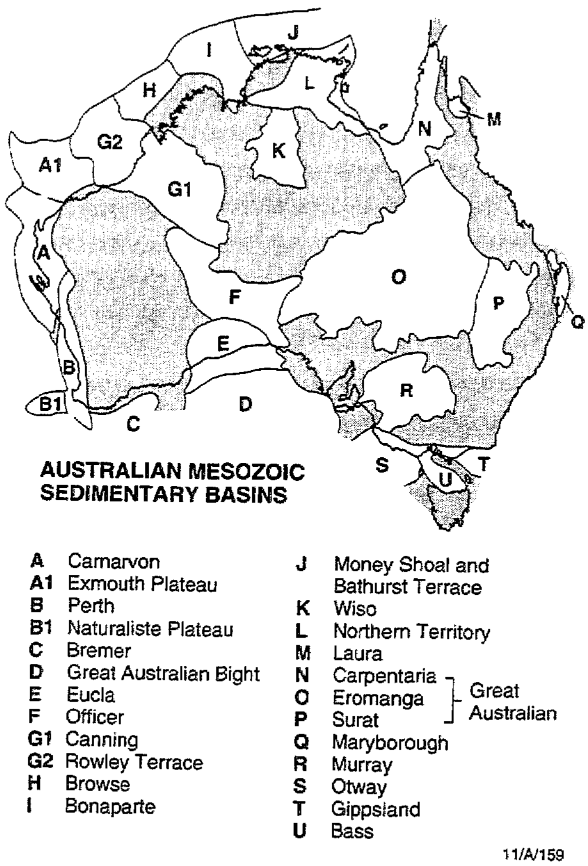


**Figure 3:** Australian sedimentary basins containing Cretaceous strata (slightly modified after Frakes & others, 1987, Fig. 1)

In 1946 the Federal Government instituted the Bureau of Mineral Resources, Geology and Geophysics (BMR). Housed initially in Melbourne, and later in Canberra, A.C.T., the BMR expanded into the largest earth science research institute of Australia. In 1991 it was renamed as the Australian Geological Survey Organisation (AGSO). The organisation acts as the federal repository of geological documentation, and expands and integrates our knowledge of the geology of the Australian plate. Geological and geophysical activity was speeded up when aerial photographs and four-wheel drive vehicles became available. Systematic mapping of sedimentary basins, frequently in joint projects with State Geological Surveys, started in Western Australia, Queensland, and Northern Territory.

The Government also stimulated closer relationships with the petroleum industry by means of the first Petroleum Search Subsidy Act of 1957, which made federal subsidies available for explorarion projects. Those projects furnished essential data for in-depth stratigraphic and palaeontological research of many sedimentary basins. Starting in the nineteen sixties, increased search for oil and natural gas led to intensive offshore seismic exploration and onshore drilling by SHELL, ESSO, WAPET, WOODSIDE, ATLANTIC RICHFIELD, ELF-AQUITAINE, BURMAH OIL, and other companies. Their activities have greatly expanded the known blanket of Cretaceous sediments, particularly in the southern, western, and northwestern offshore regions of Australia.

Cretaceous strata of the Murray Basin were first dated in Victoria (Kenley, 1954) and South Australia (Ludbrook, 1961). Commercial drilling since 1964 has disclosed the presence of Cretaceous sediments also underneath the Tertiary of the Murray, Eucla, and Bass Basins.

## THE RECORD OF DEPOSITION

The Cretaceous geological history of Australia - including plate tectonics, stratigraphy, palaeontology, and palaeoenvironments of 23 onshore, coastal, and offshore sedimentary basins - has been reviewed by Frakes & others (1987), Dettmann & others (1992), and Bradshaw & others (in press).

During the Cretaceous the Australian Plate was part of marine orthogeosynclinal developments taking place in the Himalayan Province of the eastern Tethys region (Brinkmann 1959), or the Austral Province of the Indo-Pacific region (Kauffman, 1979). Australia moved comparatively little with regard to the South Pole, its northern rim shifting from 50° to 40° palaeolatitude as it gradually separated from the other Gondwana continents (Barron & others, 1981). Initial rifting with Antarctica occurred already

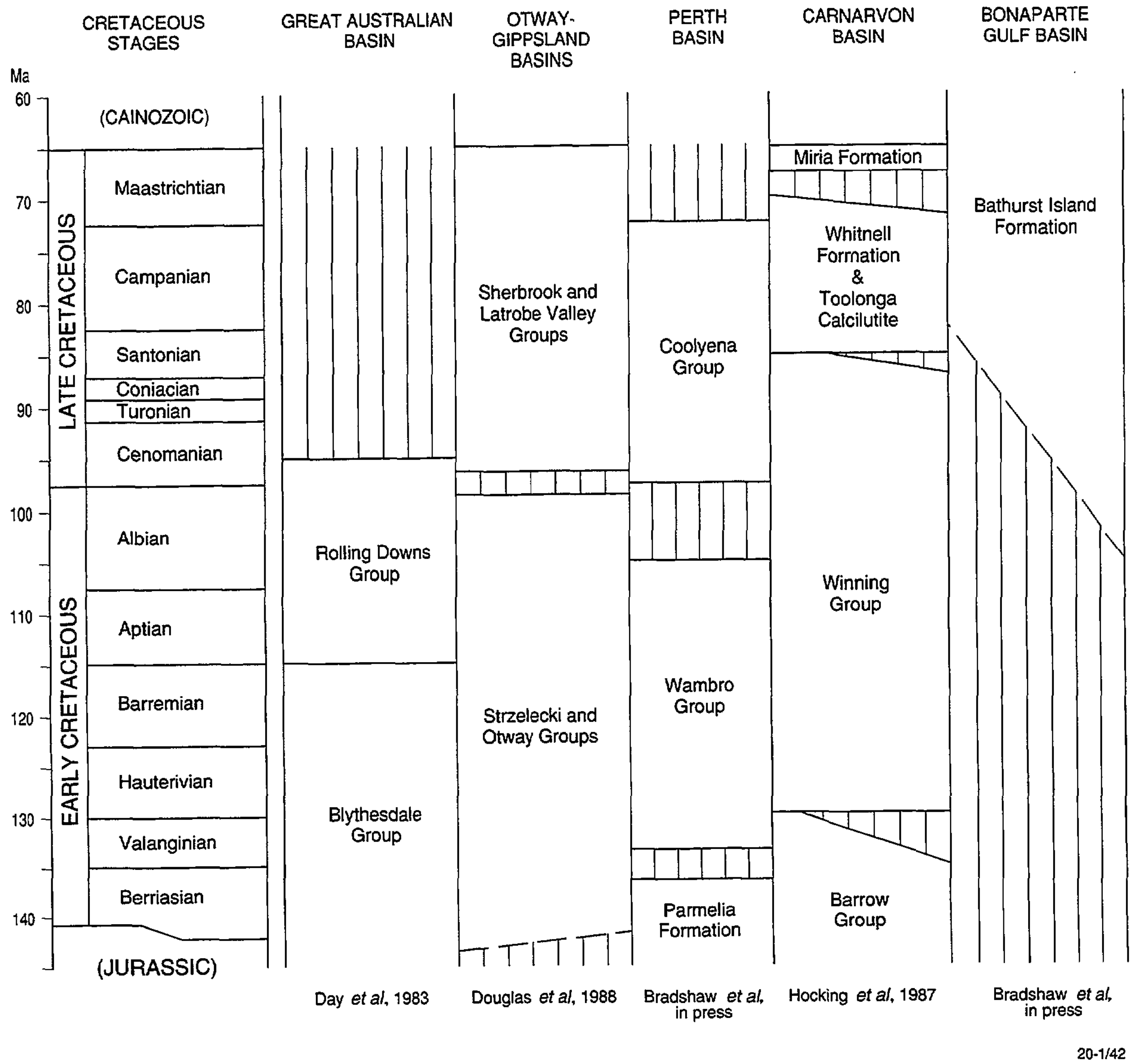


Figure 4: Prominent Cretaceous lithostratigraphic sequences in Australia

before the Cretaceous (Johnstone & others, 1973); the sea penetrated into the rift valleys as from latest Albian, and inundated them during the Turonian. In the northwest, the greater Indian Plate separated during the Valanginian-Barremian as new seafloor was forming (Buffler, 1994; Exon & Colwell, 1994). In the east, New Zealand and the Lord Howe Rise slowly separated during the Santonian (Laird, 1981; Johnson & Veevers, 1984).

Large parts of Australia remained above sealevel, although shallow epicontinental seas repeatedly covered the western and north-eastern regions during Early and Middle Cretaceous phases of global high sealevel. During the Late Cretaceous the widening ocean basins were filled by retreating seas as the Indian, Australian, and Antarctic Plates separated (Frakes & others, 1987; Veevers, 1988; Bradshaw & others, 1988). By Turonian times most of the Australian plate was permanently above sealevel, and marine developments are known almost exclusively from offshore and coastal basins at the western and southern margins (Figs 3, 4).

## THE FOSSIL RECORD

The above summary explains why the

marine Cretaceous faunal and floral records in eastern Australia remain incomplete. However, drilling by petroleum exploration companies, the Bureau of Mineral Resources in Canberra, and various State Geological Surveys since the nineteen fifties, enabled micropalaeontology and palynology to fill many biostratigraphic gaps. Palynology now provides a continuous standard biostratigraphic record for the Australian Cretaceous.

Cretaceous faunas, although more or less endemic, indicate Antarctic influences, and certain affinities with other Gondwana continents. Australian palaeontologists have therefore traditionally related the fossil record to the standard European Tethyan Cretaceous geochronology. Cretaceous floras include endemic elements, but also indicate affinities with New Zealand, Antarctica, the southern Atlantic, and East Asia.

**Faunas**

Vertebrates (Table I column 37): The record is poor and too episodic for biostratigraphic synthesis. *Fishes* are well represented in the late Albian Toolebuc Formation, Great Australian Basin, and in the Aptian Koonwarra Beds, Gippsland Basin (Long, 1991; A. Kemp, 1991; N.R. Kemp, 1991). *Reptiles* are well represented in the Late Neocomian to Albian fauna in Victoria, and in the Toolebuc and early-middle Albian Lightning Ridge faunas (Molnar, 1991). *Birds* are known only from isolated feathers (Koonwarra Beds) and some skeletal fragments in the late Albian of the Great Australian Basin (Vickers-Rich, 1991). *Amphibians* have now been reported from the Early Cretaceous of the Gippsland Basin (Warren, 1991). The first known Mesozoic *mammal* from Australia (jaw and teeth of a monotreme) has recently been discovered in the Lightning Ridge fauna (Rich, 1991).

Invertebrates: This record is much more extensive. *Foraminifera* have been most actively studied, but data have been published also on other *protists* (radiolaria), *brachiopods*, *molluscs* (ammonites, belemnites, bivalves, gastropods), *crustacea* (crabs, ostracods), *spiders*, *insects*, *otoliths*, and many other fossil taxa (see Quilty, 1975). The foraminifera, bivalves, and ammonites indicate various degrees of provincialism, which may indicate climatic control, as well as increasing isolation of Australia during the break-up of ancient Gondwana.

Foraminifera (Table I columns 23-25): Benthonic and planktonic foraminifera have made successful biostratigraphic contributions to basin studies, especially for the mid-Cretaceous of northeastern Australia (Crespin, 1963; Ludbrook, 1966; Scheibnerova, 1976; Haig, 1979) and the Middle and Late Cretaceous of the North West Shelf (Wright & Apthorpe, 1976; Apthorpe, 1979; Quilty, 1984, and many unpublished reports). Belford (1958, 1960) and Quilty (1978) described Late Cretaceous agglutinated and calcareous foraminifera from the Perth and Carnarvon Basins. The Late Cretaceous sequence of agglutinated-calcareous foraminifera in the Otway Basin has been described by Taylor (1964) and Ludbrook (1971).

Ammonites (Table I columns 21, 22): Cretaceous ammonites have been described and reported from the Great Australian Basin (Whitehouse, 1955; Reyment, 1964; Day, 1969, 1974; McNamara, 1978, 1980, 1985; Skwarko, 1981), and from northern and Western Australia (Spath, 1940; Brunnschweiler, 1959, 1966; Wright, 1963; Skwarko, 1966, 1983; Henderson & McNamara, 1985; Henderson, 1990; Henderson & others, 1992). Only the Bathurst Island and some of the Western Australian Maastrichtian faunas have been directly correlated with the standard Tethyan ammonite succession; the Great Australian Basin fauna is more endemic, although it shares certain elements with other Tethyan regions (Day, 1969).

Additional studies of local character and from before World War 2, not mentioned here, are referred to in the abovementioned papers. At present an ammonite biostratigraphy has been publidshed only for the Great Australian Basin (Table I column 22).

**Floras**

Land plants (Table I column 36):

These fossils are best known from eastern Australia. Records of the Neocomian to Cenomanian from the Great Australian Basin are fragmented and include chiefly poorly preserved leaf and wood impressions and (locally abundant) silicified wood (Gould, 1975). The much richer vegetation preserved in the Otway/Gippsland Basins (Victoria) has been taxonomically and biostratigraphically studied by Douglas (1969, 1973), Cantrill & Webb (1987), Douglas & others (1988), and Taylor & Hickey (1990). Plant remains also occur near the J-K boundary in Tasmania (Tidwell & others, 1989).

Calcareous nannofossils *(Text and Table II columns 26-28 contributed by S. Shafik)*: Cretaceous calcareous nannofossils from several basins marginal to West Australia and from the epeiric Eromanga Basin were studied by Shafik (1978, 1985, 1990a, 1994; *in* Colwell, Graham & others, 1990). Early Cretaceous assemblages were recorded from the Rowley Terrace in the offshore Canning Basin, and Late Cretaceous assemblages from the Carnarvon and Perth Basins. In onshore sections of the Carnarvon Basin calcareous nannofossils first appear in the late Turonian, and Albian nannofossils were recorded from the Carnarvon Terrace. In the western Great Australian Bight Basin, the only known calcareous nannofossils are Maastrichtian in age (Shafik 1990b). In the Eromanga Basin Albian nannofossil assemblages are mostly diversified, although often dominated by only a few species.

So far no standard nannofossil zonation has been formally proposed for the Cretaceous of the Australian region. None of the published zonations can be applied singularly in the western margin of Australia (Bralower & Siesser, 1992; Bown, 1992; Shafik, 1978, 1994), but reliable biostratigraphic events based on widely distributed (cosmopolitan) species have been identified in most areas. Shafik (1990a) identified a set of Turonian-Coniacian/early Santonian events in the Carnarvon Basin, and a set of late Coniacian/early Santonian-Campanian events in the Carnarvon Basin and Perth Basins (Table IB, column 26).

Cretaceous sections offshore North West Australia and along the continent's western and southwestern margins were drilled in several DSDP and ODP sites. The most complete nannofossil information came from sites on the Exmouth Plateau and in the adjacent abyssal plains. Sites drilled in the Cuvier and Perth Abyssal Plains and on the Naturaliste Plateau showed that Albian sediments bearing nannofossils are widespread offshore along the Australian western margin.

Dumoulin & Bown (1992) dated the late Jurassic-Early Cretaceous of sites 261 and 765 without assigning it to any particular zones (or subzones). Mutterlose (1992) pointed out ten events in the Berriasian-Albian of sites 765 & 766. Bralower & Siesser (1992) discussed sites 761, 762, and 763, where it is difficult to apply Sissingh's (1977) zonation (Table I column 12). Following the approach made earlier by Shafik (1990a) they described a set of biostratigraphic events instead (Table I column 28). Thierstein (1974) described seven informal zones for the Albian-Santonian of the Naturaliste Plateau (Table IB column 27).

Shafik (1990a, 1993) described several «Nannoprovinces» for the Cretaceous of the Australian region, in particular for the Albian and late Senonian. The association of several (rare) Tethyan species with abundant Austral/Boreal species in the Neocomian of North West Australia (Exmouth Plateau-Rowley Terrace-Swan Canyon-Argo Abyssal Plain) suggests the inflow of warmer water into the generally cool surface water regime of the juvenile ocean being formed northwest of Australia: a connection with the Tethys to the north opened during the Valanginian, but later this connection was not evident; nannoprovinces developed particularly during the Albian and late Senonian (Shafik, 1993, 1994).

The co-occurrence of Albian cool- and warm-water species along the western margin of the continent indicated the *Extratropical Nannoprovince* (Carnarvon Terrace, Perth Abyssal Plain, Naturaliste Plateau, most of Papuan Basin, PNG). At the same time the *Austral Nannoprovince* was evidenced in the Eromanga Basin (northeastern Australia). During the late Campanian-Maastrichtian two nannoprovinces existed along the western margin; the *Austral Nannoprovince*, indicated by abundant cool-water species and lack of warm-water species (Perth Basin, Great Australian Bight), and the *Extratropical Nannoprovince*, indicated by a mixture of cool- and warm-water species (Carnarvon Basin, northern Australia). The *Tropical Nannoprovince*, indicated by abundant warm-water species, extended over most of Papua New Guinea.

S p o r e s & p o l l e n (Table I columns 34, 35): As compared with the Jurassic, the Cretaceous flora included a large number of ferns and bryophytes and a reduced fraction of gymnosperms. The pollen record indicates that the angiosperms probably first appeared in the late Neocomian to early Aptian, and they became the dominant component of the uppermost Cretaceous vegetation.

The study of spores and pollen grains has been the prime instrument in integrating Australian marine and nonmarine bio- and lithorecords, thus enabling marine faunal and microfloral evidence to be applied to the continental facies record. Together with the megafloral record, it has also furnished strong evidence of active interchange of vegetations with adjoining Gondwana continents, and with eastern Laurasia, at least during the Early Cretaceous (Dettmann, 1981).

Early biostratigraphic schemes for the Cretaceous of eastern Australia (Dettmann, 1963; Evans, 1966) have culminated in the scheme of Dettmann & Playford (1969). A slightly modified version of that scheme was published by Helby & others (1987). Biostratigraphies for the Perth and Carnarvon Basins in Western Australia (Balme, 1957, 1964; Backhouse, 1978, 1988) cover only the Early Cretaceous, due to the poor spore-pollen record of the marine Upper Cretaceous strata sequences. At present comparison with the eastern Australian schemes is difficult, since zonal diagnostic fossils are recorded from slightly different time spans.

The biostratigraphy of Table I column 35C is primarily the result of decades of study of hundreds of boreholes drilled in the Otway-Gippsland, Great Artesian, and Laura Basins (Burger, 1973, 1982; Dettmann, 1986; Dettmann & Douglas, 1988).

The Late Cretaceous zones of that scheme have been dated on evidence of foraminifera (Taylor, 1964; Ludbrook, 1971) and dinoflagellates (Evans, 1966; Helby & others, 1987) from the Otway and Bass Basins. The Aptian and Albian zones, described from the Great Australian Basin, have been dated on their association with ammonites (Day, 1969, 1974), foraminifera (Playford & others, 1975; Haig, 1979), and dinoflagellates (Evans, 1966; Dettmann & Playford, 1969; Morgan, 1980a; Burger, 1980, 1986). The Neocomian zones have been dated on their association with invertebrates and dinoflagellates in the Great Australian and Papuan Basins, and also on considerations such as intercontinental spore correlation and estimated rates of floral migration (Dettmann, 1963, 1986; Dettmann & Playford, 1969; Burger, 1973, 1982, 1986, 1989; Helby & others, 1987).

Indirect evidence of eustasy in the the Great Australian Basin has also given certain clues as to ages of spore and pollen zones (see below).

D i n o f l a g e l l a t e s (Table I columns 29-32): Isabel Cookson and collaborators established a systematic and descriptive foundation with their early studies on the marine Jurassic and Cretaceous microphytoplankton in Australia and Papua New Guinea (see Deflandre & Cookson, 1955; Cookson, 1956, 1965; Cookson & Eisenack, 1958, 1960a,b, 1961, 1962, 1970; Eisenack & Cookson, 1960; and many other papers).

Initial biostratigraphic synthesis of records from the Perth and Eucla Basins (Edgell, 1964; Ingram, 1968), and from the Great Australian and Otway Basins (Evans, 1966) was refined by later studies from Western Australia (Backhouse, 1978, 1987, 1988; Wiseman, 1979; McMinn, 1988; and others), and from northeastern and central Australia (Morgan, 1980a; Burger, 1982, and other studies).

Helby & others (1987) proposed the first comprehensive pan-Australian zonation for the Cretaceous, based on data from onshore and offshore boreholes drilled in Australia and Papua New Guinea. Lingering problems regarding species ranges of dinoflagellates in the Late Cretaceous of Western Australia are probably to be attributed to condensed and poorly sampled intervals, and reworking (B.S. Ingram, pers. comm., June 1989).

Several recent biostratigraphies, and ranges of selected species, are set out against the standard Cretaceous chronology, such as they are given by their authors. Slightly modified ages of certain Early Cretaceous zones are proposed below, and are shown in Table IA column 33 (see also Burger, 1990).

**Ages of dinoflagellate zones**

A comparison of age determinations of Early Cretaceous dinocyst zones in Western and northern Australia by various authors disclose certain disagreements. The modified ages and correlations here proposed for the basal Cretaceous zonal units are based on the following considerations:

A. Helby & others (1987) placed the Jurassic-Cretaceous boundary within their *Pseudoceratium iehiense* zone. Data from the Papuan Basin (Davey, 1987) and fresh evidence from the North West Shelf (see (Burger, in press) indicates that that boundary falls most probably within their *Kalyptea wisemaniae* zone.

B. According to Backhouse (pers. comm., June 1989) Control Point CP1 of Wiseman (1979) in the Carnarvon Basin is not older than the *Kaiwaradinium scrutillinum* zone in the Perth Basin. Backhouse (1987, 1988) regarded the lower limit of that zone to be of Valanginian age.

C. The lower limits of the *Phoberocysta lowryi* and *Phoberocysta burgeri* zones, and Wiseman's (1979) Control Point CP2, are intercorrelated on the first appearance of *Muderongia testudinaria*, and this approximately agrees with Helby & others (1987). *M. testudinaria* was first described from northern Queensland, where it occurs with several dinoflagellate species which in the Tethyan north Atlantic are not known prior to the Hauterivian (Burger, 1982). The range of *M. testudinaria* in Australia is therefore assumed not to extend significantly below the Hauterivian.

D. Helby & others (1987) correlated the lower limit of the *Batioladinium jaegeri* zone of Backhouse (1987) with that of their *Muderongia australis* zone, based on the youngest occurrence of *Canningia reticulata*, *Muderongia testudinaria*, and *Phoberocysta burgeri*. However, first appearances of certain other species given by those authors for that part of the sequence also suggest that the *B. jaegeri* zone may correspond approximately in time with the *M. testudinaria* zone.

E. *Odontochitina operculata* and *Ovoidinium cinctum* first appear in the upper part of the *Fromea monilifera* zone in the Perth Basin (Backhouse, 1987; pers. comm., June 1989), and in the *Muderongia australis* zone (Helby & others, 1987). The authors agree that the two zones are Barremian to early Aptian. *O. operculata* first appears in the late Hauterivian of the Western Tethys (Ogg, 1994), and presumably also in northern Australia (Burger, 1982; Helby & others, 1987). This author thus places the Hauterivian-Barremian boundary within the basal intervals of the *M. australis* and *F. monilifera* zones.

**RADIOMETRIC AGES**

A large number of isotopic (K-Ar, Rb-Sr) age analyses have been made on Cretaceous crystalline intrusives and lavas, especially from eastern Queensland, and on lavas from Tasmania (Sutherland & Corbett, 1974; Day & others, 1983). The Bunbury Basalt - a tholeiitic basalt in the Perth Basin - is linked with the *Biretisporites eneabbaensis* spore-pollen zone. It yielded K-Ar ages of 105-88 Ma, which are regarded as unreliable (McDougall & Wellmann, 1976; Backhouse, 1988).

So far, no reliable isotopic ages have been obtained from the sedimentological record of northeastern Australia. Glauconites associated with the *Crybelosporites striatus* and the *Cyclosporites hughesii* spore-pollen zones from the Wallumbilla Formation (Eromanga Basin, New South Wales) yielded preliminary K-Ar ages of 101.2 to 97.9 Ma and 96.6 Ma respectively, and they were rightly

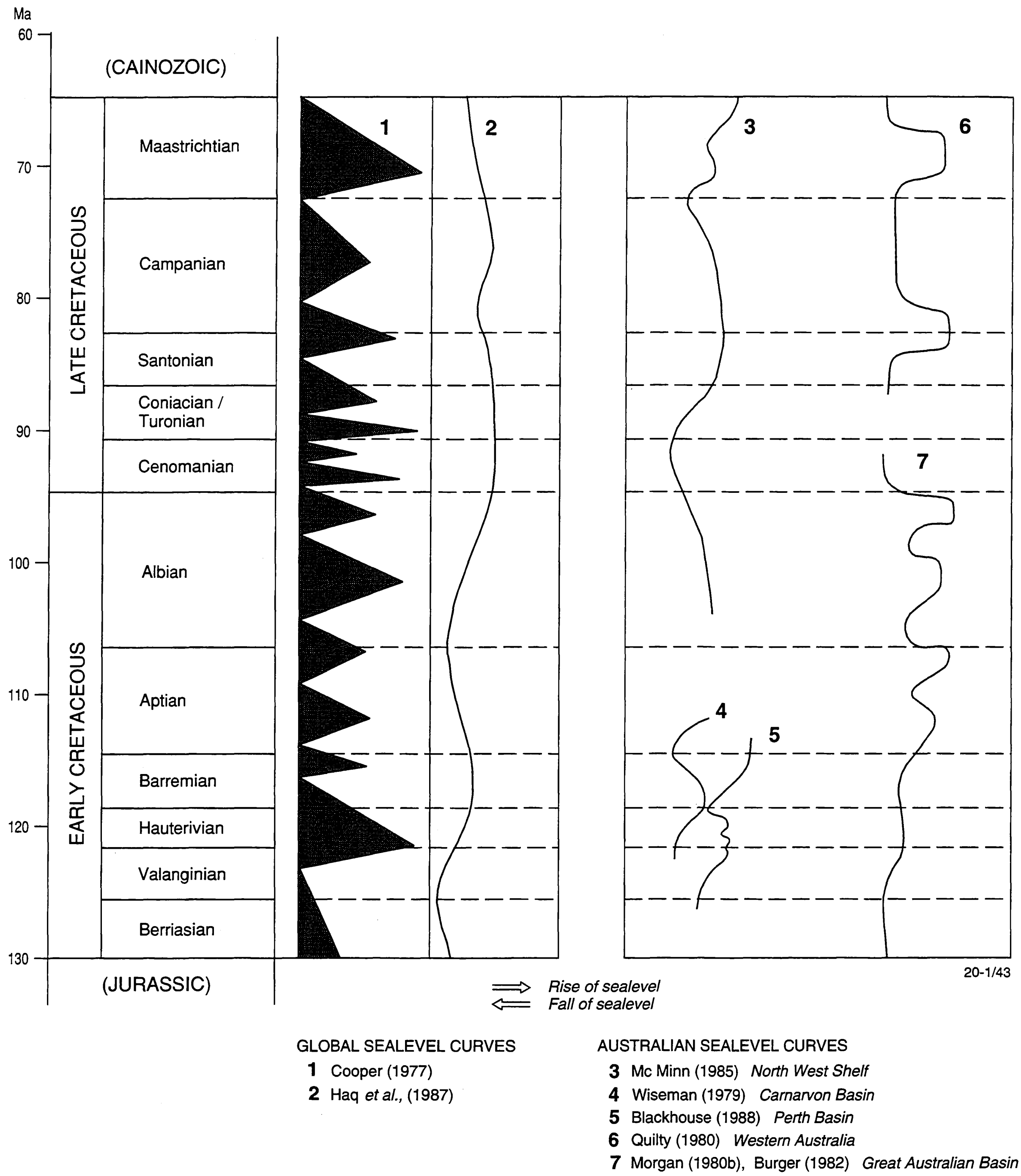


Figure 5: Eustatic sealevel movements, and sealevel movements registered in Australian sedimentary basins (for details see text)

suspected as too young (Byrnes & others, 1975). Fission track dates of 103-126 Ma have been obtained from the largely non-marine Otway Group in the Otway Basin (Gleadow & Duddy, 1981). That sequence is dated Neocomian to Albian on palynological and palaeobotanical evidence (Dettmann & Douglas, 1988; Wagstaff & McEwen-Mason, 1989).

## EUSTASY

Australian geologists have found direct and indirect evidence of Cretaceous sealevel movements in the Perth Basin (Backhouse, 1988), Carnarvon Basin (Wiseman, 1979), Surat Basin (Exon & Burger, 1981), Eromanga and Carpentaria Basins (Burger, 1982, 1986, 1988), and in the Late Cretaceous of Western Australia (Quilty, 1980; McMinn, 1985). Briefly, this evidence relates either to periodic disappearance (or in part statistically established impoverishment) of marine invertebrate faunas and/or dinoflagellate floras.

Various Australian sealevel curves are shown in Figure 5, as drawn by individual authors. Evidently a number of peaks and troughs are of local origin, but certain sealevel movements are synchronous with the global curves and appear to be of eustatic origin. They warrant more attention, in view of their potential value for correlating and dating sedimentary sequences.

Morgan (1980b) made the only attempt so far to integrate Aptian-Albian fossil records (in part complemented by lithorecords) into a pan-Australian Cretaceous sealevel curve. It yielded good results for certain sedimentary basins because, on the whole, there was very little structural activity to mask the effects of sealevel movements on depositional events. Quilty (1980) observed 2 Late Cretaceous sedimentary cycles in various Western Australian basins. They are bounded by widespread unconformities, which he attributed to recurrent eustatic falls of sealevel.

Exon & Burger (1981) and Burger (1986) logged a series of 5 widespread cycles in the Jurassic and Neocomian nonmarine sequence of the Great Australian Basin. Each cycle consists of a lower fluvial sandstone and an overlying lacustrine mudstone/siltstone. The sandstone indicates rapid drainage with a fall of the regional base level of erosion, and the overlying argillaceous sequences (with occasional coal and benthonite, and common acritarchs) indicate times of sluggish drainage during a rising base level of erosion.

Exon & Burger (1981) reviewed several possible causes for this phenomenon. They rejected local hot spots, periodic changes (i.e. precipitation) of the climate, and recurrent uplifts of the eastern Australian craton rim, and concluded global sealevel movements to be the most likely alternative cause of the rising and falling erosion level in the basin. They linked the Jurassic and Neocomian cycles with the eustatic curves of Vail & others (1977a) and Cooper (1977).

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## CRETACEOUS ( ALBIAN - MAASTRICHTIAN )


## CRETACEOUS ( BERRIASIAN - APTIAN )