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PALAEOECOLOGY AND PALAEOGEOGRAPHY OF CRETACEOUS DEPOSITS OF THE GREAT ARTESIAN BASIN (AUSTRALIA)

By VIERA SCHEIBNEROVÁ

(*Manuscript dated May* 1970)

ABSTRACT

Some ideas about the palaeoecology and palaeogeography of the marine Cretaceous sediments of the Great Artesian Basin, based on analysis of foraminiferal assemblages, are presented. The author takes into consideration the variety of species, the general character of the benthos (both agglutinated and calcareous), and the presence or absence and the character of planktonic species, and correlates these phenomena with other similar areas. The existence of climatic zonation during Cretaceous time is accepted, and the existence and development of world-wide distribution of planktonic foraminifera in the Cretaceous is discussed, as well as foraminiferal zonation depending on temperature differences due to palaeolatitudes. On the basis of microfaunal assemblages the environment of the Great Artesian Basin sedimentary area during part of the Cretaceous (Aptian–Albian–Lower Cenomanian) is classified as marine, shallow, and cold in comparison with the Tethyan areas; as such it is compared with the West Siberian Artesian Basin sedimentary area and also with Cretaceous epicontinental deposits of North America, northern Europe, South America, and South Africa. The author distinguishes the Austral biogeoprovince of the Southern Hemisphere as being equivalent to the Boreal biogeoprovince of the Northern Hemisphere. The Great Artesian Basin is regarded as the type area of the Austral biogeoprovince.

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INTRODUCTION

In recent years much information has accumulated regarding the character, composition, and environmental and evolutionary relationships of both benthonic and planktonic foraminifera in geological time. At the present time the marine environment in low latitudes is relatively stable and a biostratigraphic zonation has been formulated. However, in latitudes in excess of 40° N. or S. distribution of planktonic foraminifera is markedly different from that in low latitudes. To a great extent it is possible to observe similar conditions during the Cretaceous and Tertiary although, on the other hand, there is evidence (such as palaeotemperature measurements) of quantitative and qualitative differences which prevent the application of Recent conditions to those in past geological times. As far as the Cretaceous is concerned, a comprehensive analysis of Cretaceous planktonic foraminiferal zonation was published by Bandy (1967). He discussed different factors affecting the distribution of Cretaceous planktonic foraminifera such as latitude, bathymetry, salinity, relationships to water masses and currents, structure, and environment and life cycle. However, Bandy (op. cit.) considered only Tethyan, i.e., warm (tropical) forms of planktonic foraminifera.

Comparatively little information on bethonic foraminifera during the Cretaceous is available, although some local analyses of Cretaceous benthonic assemblages and environments have appeared.

In Cretaceous sequences from the Albian (or Aptian) onwards, the most characteristic planktonic foraminifera are globotruncanids or keeled forms. Their distribution coincides with that of the marine Cretaceous within tropical Tethyan areas. Both the lower and upper boundaries of their occurrence are progressively restricted polewards, with localized appearances due to specific oceanographic conditions such as warm currents.

Although tropical Cretaceous assemblages of planktonic foraminifera are now well known, it is not possible to say the same for temperate and cold-water (otherwise Boreal and Austral) assemblages. Tropical Cretaceous marine depositional areas correspond with the Tethyan and adjacent areas which were circumglobal and were distributed within low latitudes in the Northern as well as the Southern Hemisphere, crossing the equator. To both the north and south of the tropical Tethys were temperate or transitional, and cold or polar seas with or without direct connection with the Tethys. Although the temperature differences between these areas might have not been very large, ecological conditions in these depositional areas were still influenced by latitude-controlled temperatures.

Reconstruction of the palaeoecology and palaeogeography of the sedimentary basins to the north and south of the Tethys has led to the generally accepted belief that a certain climatic zonation, depending on latitudes and local oceanographic régime existed also in the Cretaceous. Published palaeotemperature measurements indicate that during the Cretaceous the polar ice caps did not exist and in general the minimum temperatures were much higher than in Recent time. The lowest palaeotemperatures based on belemnites showed values between 12° and 16° C (Dorman and Gill, 1959; Lowenstam and Epstein, 1954; Bowen, 1961a, b, c).

In Recent seas, temperate (subarctic and subantarctic) and cold (arctic and antarctic) waters are characterized by much less variety of planktonic species. In the Northern Hemisphere three species are characteristic: *Globigerina pachyderma* (Ehrenberg), *Globigerina quinqueloba* Natland and *Globigerina bulloides* (d'Orbigny) (Bé and Hamlin, 1967) and in the Southern Hemisphere *Globigerina pachyderma* (Ehrenberg), *Globigerinita uvula* (Ehrenberg) and the very rare *Globigerina bulloides* (d' Orbigny) (Boltovskoy, 1969). In the high antarctic zone (more than 60° S.) only *Globigerina pachyderma* is represented. There are many indications that an analogous situation might have existed also in the Cretaceous. However, the role of *Globigerina pachyderma* was played by globigerine-shaped planktonic forms, the most important of which are *Hedbergella infracretacea* (Glaessner) and *Hedbergella washitensis* (Carsey) or *Hedbergella planispira* (Tappan) in upper part of the Lower and lower part of the Upper Cretaceous, and *Hedbergella trocoidea* (Gandolfi) or *Hedbergella amabilis* Loeblich & Tappan (if they are not conspecific) in the Upper Cretaceous as far as the Southern Hemisphere is concerned.

Marine sequences of the Boreal Upper Cretaceous in the Northern Hemisphere, on which an excellent paper by Douglas and Rankin (1969) appeared recently, are characterized by the occurrence of *Whiteinella*, *Hedbergella*, *Archaeoglobigerina*, *Globigerinelloides* (globigerine-shaped forms) and the group of *Globotruncana marginata* (Reuss) and *Heterohelix*. In general, the taxonomic position of these globigerine-shaped forms as well as their stratigraphy needs revision based on comparison and study of type materials. However, the areas dealt with in the publication mentioned represent rather a Transitional zone between the Tethyan and Boreal; in the true Boreal (cold) deposits in very high latitudes only *Globigerina* (*Hedbergella*) of unusually small size occur.

In general, we can suggest that benthonic (both agglutinated and calcareous) foraminifera have been less sensitive than plankton to temperature change in connection with the change of latitude, or they lived in depths where temperature gradient was more or less constant and not influenced by the latitudinal or seasonal temperature changes. There are several cosmopolitan forms enabling interregional correlations, stratigraphical determinations and reconstruction of ways of migration. However, the knowledge of these forms is more advanced for the Upper Cretaceous than the Lower Cretaceous, and for the Northern rather than the Southern Hemisphere. The purpose of this paper is to give some information on Aptian, Albian, and Cenomanian benthonic (both agglutinated and calcareous forms) in the Southern Hemisphere, the prominent part of which is represented in the Australian Cretaceous, especially in the Great Artesian Basin. Microfaunal assemblages of the Great Artesian Basin represent an Austral (anti-Boreal) biogeoprovince* and are compared with similar assemblages in other areas with similar climatic conditions and similar marine environments in both the Southern and Northern Hemispheres.

Distribution of Cretaceous Deposits in Australia

Cretaceous deposits in Australia cover over approximately one-third of the present land masses (Brown, Campbell, and Crook, 1968) (figure 1). They belong to two different biogeoprovinces:

1. The western, northwestern, and northern margins of the Australian continent where marine Cretaceous deposits range from Lower (or upper part of Lower) to Upper Cretaceous with a mild unconformity after the Turonian and after the Maastrichtian, and the character of Upper Cretaceous micro- and macrofauna show strong Tethyan influence. They are deposited in warm (subtropical under the influence of a warm current) epicontinental basins such as the Carnarvon and Perth Basins, and the area of Bathurst Island and the Naturaliste Plateau, as shown by foraminiferal fauna containing typical Tethyan elements, mainly globotruncanids (Edgell, 1954, 1957, 1962; Belford, 1958; Belford and Scheibnerová, 1971; Burckle, Saito, and Ewing, 1967). According to data based on palaeomagnetic study (Irving, 1964) the areas of the Carnarvon and Perth Basins lay between 60° and 50° S. and of Bathurst Island between 30° and 40° S. latitudes. The presence of foraminiferal assemblages characteristic of tropical and subtropical Tethyan elements in these quite high latitudes may serve as evidence of the existence of a warm current during the Cretaceous along what is now the western margin of the Australian continent.

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* Because zoogeographic provinces of the Recent are difficult to follow in the geological past, especially in the Mesozoic, as several Recent marine environments were in the early stage of development, I suggest the use of the term biogeoprovince for bioprovinces of the geological past.

2. By far most extensive part of the Cretaceous sediments on the Australian continent is largely distributed in central, northern, eastern, and southern Australia. The stratigraphical extent of the marine Cretaceous strata here comprise mostly Aptian and Albian and to a lesser extent Cenomanian. Basal Cretaceous (pre-Aptian) and Upper Cretaceous (post-Cenomanian) strata are mostly non-marine (fluviatile, lacustrine, and terrestrial). Such conditions

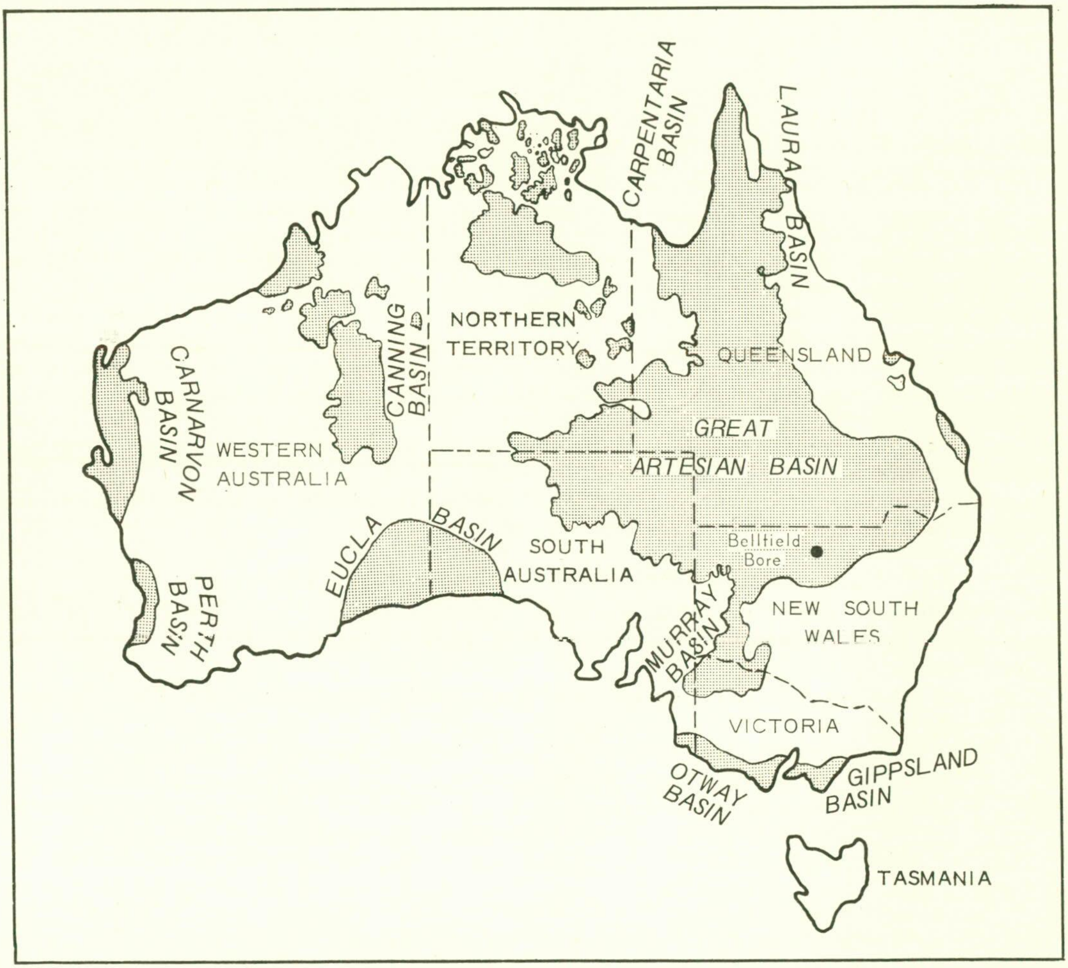


Figure 1. Distribution of Cretaceous deposits in Australia

occurred in the Great Artesian Basin and adjacent smaller basins, which were probably connected intermittently. Marine sediments of the Upper Cretaceous (from Cenomanian to Senonian or Turonian up to Senonian) are known from the Otway Basin in southern Victoria. Microfaunas of these deposits were studied by Taylor (1964).

Stratigraphical Interpretation of Marine Cretaceous Sequences of the Great Artesian Basin

The Great Artesian Basin covers an inland area of about 1·2 million km^2 (463,000 square miles) in Queensland, the Northern Territory, South Australia, and New South Wales, and is subdivided by pre-Mesozoic basement ridges into a number of minor sub-basins. Mesozoic sediments in the Eromanga and Surat Basins reach about 2,500 m in thickness while over the ridges they reach only about 1,000 m (such as at Longreach) (see Geological Notes, Tectonic Map of Australia, 1962), these sequences being only gently folded. The basement for the Great Artesian Basin is provided by the Australian cratogen in the west and by elements of the Tasman fold belt and its early Mesozoic cover in the east and south.

It is possible to date the existence of the Great Artesian Basin as a sedimentary epiplatform basin from as early as the Jurassic, represented by terrestrial development, and mainly during the Cretaceous, represented by marine development. During the Tertiary the area of the Great Artesian Basin was covered by drainage systems, the largest being that of Lake Eyre.

The Great Artesian Basin represents tectonically the epi-Tasman platform cover. During the Cretaceous it was probably a semi-enclosed sea (according to the term as defined by Menard, 1967, and Hedberg, 1970) of definitely epicontinental character, like the North Sea or Hudson Bay today.

Morphologically, the Great Artesian Basin is mostly represented by the Central Eastern Lowlands (David, 1950). This area has been consistently of a low altitude since Palaeozoic time and has been occupied at intervals by the sea. During the Tertiary it lagged notably behind the rest of the continent and at the present day most of it has altitudes less than 250 m (800 feet). The continuity of the lowland is interrupted by low barriers: the east–west bulge forming the eastern boundary of the Lake Eyre drainage system, the constriction between the Cobar projection and the Far West Uplands in New South Wales, and the broad Mallee Ridge in the region of the lower Murray. Hydrologically, the area of the Great Artesian Basin belongs to the following drainage systems: coastal, Lake Eyre, and Murray-Darling.

The rivers are slow, active practically only in rainy periods. Their channels are shallow and in times of flood the waters spread to a vast extent over the alluvial plains. Several lakes are of varying size and origin. They are mostly only periodically or intermittently filled and for many dryness is a normal and dominant condition.

With respect to the geological structure and development during the Cretaceous it is possible to compare the Great Artesian Basin with other analogous basins such as the West Siberian Artesian Basin which also represents an epi-Palaeozoic platform cover. Morphologically it is represented by the West Siberian Lowlands and covers a vast inland area of 2·5 million km^2. It is underlain by a Palaeozoic cratogen-platform to the east and by the Palaeozoic fold belt to the west. The West Siberian Lowlands represent a very flat, slightly declined area to the north, depressed in its central part with average heights of between 150 and 200 m. Slow-flowing rivers frequently change course and aggrade sediment. There are several lakes, some salty due to the dry continental climate.

During the Cretaceous a comparatively cold climate predominated in both areas. Palaeolatitudes of the Great Artesian Basin were between 50° and 70° S. and those of the West Siberian Artesian Basin between 50° and 80° N. In both areas the Cretaceous seas were of the semi-enclosed epicontinental type and yielded very similar microfaunas of a Boreal character, several species being identical.

Historical Review

The marine Cretaceous sequences of the Great Artesian Basin and adjacent smaller basins have yielded quite numerous macrofossils comprising mainly Ammonoidea, Lamellibranchiata, Belemnoidea, Brachiopoda, and Nautiloidea as the most important groups. A review of stratigraphy based on macropalaeontological investigations was published by Ludbrook (1966). A chart correlating the Cretaceous sequences of Australia was prepared by Skwarko (1969).

In general, the marine Cretaceous strata of the Great Artesian Basin and adjacent smaller basins occupy the Aptian to Lower Cenomanian interval. Foraminiferal assemblages found in the Great Artesian Basin were classified by Crespin (1956) who distinguished three characteristic zones:

1. The uppermost zone in which arenaceous species have been recognized. No forms were regarded as predominant enough to be of zonal value.
2. A middle zone or zone with *Valvulineria parvula* often associated with *Anomalina mawsoni*, and with scarce Lagenidae.
3. A basal zone or zone with *Haplophragmoides chapmani*, *Spiroplectammina cushmani*, and *Trochammina raggatti*, and some Lagenidae present.

None of these zones was regarded as stratigraphically significant.

Ludbrook (1966) distinguished four foraminiferal zones and mentioned the endemic nature of the faunas. These zones were also stratigraphically evaluated.

1. Zone of *Trochammina raggatti–Textularia anacooraensis*—Lower Aptian.
2. Zone of *Hergottella jonesi*—Upper Aptian.
3. Zone of *Verneuilina howchini–Trochammina flosculus*—Upper Aptian to Upper Albian.
4. Zone of *Neobulimina australiana*—Upper Albian.

On the whole more than a hundred species of both agglutinated and calcareous foraminifera have been described in the Cretaceous sequences of the Great Artesian Basin. Crespin (1956) listed 101 species representing 57 genera. Approximately one-half of this number were agglutinated forms (according to Ludbrook's (1966) data only one-third).

Cretaceous Section in Bore DM Bellfield 1 and 1a

The Cretaceous profile of the Great Artesian Basin was studied from material from the borehole at Wallon (near Moree in northern New South Wales) and borehole DM Bellfield 1 and 1a (at Bourke, northern New South Wales). The author also had an opportunity to see rich material studied by D. J. Belford, I. Crespin, and G. Terpstra from other boreholes in different parts of the Great Artesian Basin.

The most important profile studied from the marine Cretaceous of the Great Artesian Basin is based on bore DM Bellfield 1 and 1a, and is about 1,100 feet (335 m) long. More than 500 samples were taken from this sequence, more than 300 of which contained microfossils. The microfauna was composed predominantly of foraminifera, both agglutinated and calcareous, fewer ostracodes and other microscopic organic remains. In general, the composition of foraminiferal assemblages was very similar to that found and described by other authors studying the Cretaceous strata of the Great Artesian Basin (Crespin, 1944, 1956, 1963; Ludbrook, 1966). After a preliminary revision in an attempt to avoid some junior synonyms, the author of this paper determined ninety species, half of which were agglutinated forms.

From charts 1–3 it may be seen that the lowest parts of the Cretaceous section of bore DM Bellfield 1 and 1a are rich in foraminiferal assemblages containing agglutinated and calcareous benthos. Especially characteristic and numerous are *Psammopshaera scruposa*

(Berthelin), *Saccammina alexanderi* (Loeblich & Tappan), *Reophax* cf. *deckeri* Tappan, *Haplophragmoides gigas* Cushman, *Textularia anacooraensis* Crespin, *Pseudobolivina variana* (Eicher), *Trochammina raggatti* Crespin, *T. minuta* Crespin, *Nodosaria* cf. *orthopleura* Reuss, *Dentalina hamiltonensis* Ludbrook, *Lenticulina australiensis* Crespin, *L.* cf. *cretacea* (Cushman), *L. dalhousiensis* Ludbrook, *L. harpa* (Reuss), *Marginulina curvatura* Cushman (the last two species being long ranging), *Marginulina* cf. *plummerae* Cushman, *M.* cf. *australiensis* Crespin, *Globulina lacrima* (Reuss), *Pyrulina* sp. (two last species being long ranging). The top of the vertical distribution of this group of species, mostly long ranging and very rarely restricted to a short interval, is marked by *Quinqueloculina* sp. occurring at 610 feet (186 m) depth.

Around a depth of 500 feet (152 m) a second group of species starts to occur comprising *Trochammina* cf. *wetteri* Stelck & Wall, *Haplophragmoides topagorukensis* Tappan, *Marginulinopsis collinsi* Stelck & Wall, *Discorbis* sp. 2, *Haplophragmoides* cf. *lapillosus* Ludbrook, *H.* cf. *platus* Loeblich, *H.* cf. *gigas* Cushman, *Cribrostomoides* sp., *Bigenerina loeblichae* Crespin, *Lenticulina cephalotes* (Reuss), *L. warregoensis* Crespin, *Ammobaculites irregulariformis* Berthelin, *A. fisheri* Crespin, *A.* cf. *junceus* Cushman, *A.* cf. *erectus* Crespin, *Ammobaculoides romaensis* Crespin, *Ammomarginulina peterella* Eicher, "*Hergottella*" *jonesi* (Chapman,) *Valvulineria gracillima* Dam, *Cibicides* sp., *Epistomina australiensis* Crespin, *Pseudolamarckina* sp. (=*Lamarckina lamplughi* (Sherlock) of Bukalova, 1960).

At a depth of 347 feet (105·8 m) occurs a very characteristic assemblage containing *Discorbis* sp. 1 (= *Discorbis* sp. 5 of Hamaoui, 1965), *Lenticulina cephalotes* (Reuss), *L. excentrica* (Cornuel) and first specimens of Anomalinid indet. n. gen. n. sp.

From 347 feet (105·8 m) upwards the following species occur: *Textularia* sp. (similar to *Textularia anceps* Reuss of Taylor, 1964), *Ammodiscus cretaceus* Reuss, *Haplophragmoides* cf. *gigas* Cushman, *Ammobaculite fisheri* Crespin, *Ammobaculoides romaensis* Crespin, *Haplophragmoides* cf. *lapillosus* Ludbrook, *Trochammina wetteri* Stelck & Wall, *Lenticulina compressa* (d'Orbigny), *Nodosaria* cf. *orthopleura* Reuss, *Dentalina guttifera* d'Orbigny, *Lenticulina bononiensis* (Berthelin), *Marginulinopsis subcretacea* Crespin, *Pyrulina* sp. *Lingulogavelinella frankei* (Bykova), Anomalinid indet. n. gen. n. sp., *Valvulineria parvula* (Crespin) (first specimens of *V. parvula* occurring at 440 feet (134 m) and becoming abundant from 220 feet (67 m) upwards), *Haplophragmoides topagorukensis* Tappan, *Ammomarginulina peterella* Eicher, *Verneuilina howchini* Crespin, *Trochammina* sp., *Verneuilinoides crespinae* Ludbrook, *Uvigerinammina* sp. (occurring at 270 feet (82 m) depth only).

From the above description of the succession of foraminiferal species in the profile studied it is clear that only about one-quarter of the species occur throughout. The occurrence of most of the species is quite restricted and there are also species occurring only within a very short time interval. It is necessary to emphasize that this is valid for both agglutinated as well as calcareous forms. A glance at chart 1 shows that the distribution of foraminifera is somewhat irregular and that there are at least two maximum and two minimum occurrences of foraminifera. However, this observation might have been due to irregular sampling rather than unsuitable lithology, although the richest associations come from sandy shales.

For the present study we shall pay more attention to a few species which showed themselves as good zone markers.

The lowest and oldest parts of the Cretaceous section of the Great Artesian Basin are characterized by the agglutinated form described by Crespin (1953) as *Textularia anacooraensis*, and used by Ludbrook (1966) as a zone marker. This species occurs within the depth interval 1,024 feet to 670 feet (312 to 204 m). Other distinct agglutinated forms, *Trochammina raggatti* Crespin and *Trochammina minuta* Crespin have a similar, slightly shorter range. These were also chosen as zone species by Ludbrook (1966). The author of the present study distinguishes the zone of *Textularia anacooraensis* (Aptian in age) comprising the subzones of *Trochammina raggatti* (Lower Aptian) and of *Trochammina minuta* (Upper Aptian).

In a rather short time interval within a second group of species with limited vertical range in the Cretaceous section of the Great Artesian Basin, there occurs the calcareous form determined here as *Pseudolamarckina* sp. It seems identical with the form figured by Bukalova (1960a) and named as *Lamarckina lamplughi* (Sherlock). This species occurs between 550 and 439 feet (167·6 and 133·8 m) and is regarded as a subzone marker for the Lower Albian. The Upper Albian is characterized by the subzone of discorbids. The zone of *Ammobaculoides romaensis* covers the whole Albian. At depths of 560 feet (170·7 m) and 437 feet (133·2 m) occurs *Marginulinopsis collinsi* Mellon & Wall which was used in the Boreal Cretaceous sequence of Alberta (Canada) by Wall (1967a) as a zone marker for the Lower–Middle Albian.

The Cenomanian section of the Cretaceous profile of the Great Artesian Basin is characterized by the occurrence of *Lingulogavelinella frankei* (Bykova) and *Valvulineria parvula* (Crespin). Neither the upper boundary nor a more detailed division of the Cenomanian strata has been defined, as it probably changes from place to place depending on the extent of marine sedimentation. The uppermost part of the Cretaceous section is characterized by *Verneuilinoides kansasensis* Loeblich & Tappan and probably corresponds to the zone of *Verneuilinoides kansasensis* of the Boreal Cretaceous (Cenomanian) of Alberta, Canada (Wall, 1967a).

Another important species occurring in the uppermost parts of the marine Cretaceous section of the Great Artesian Basin is a species probably identical with that determined by Taylor (1964) as *Textularia anceps* (Reuss), detailed analysis of which is a matter for further study.

The occurrence and both vertical and areal distribution of some other forms such as *Neobulimina*, *Spiroplectammina*, *Anomalinoides*, *Gyroidina*, and several species of *Valvulineria* remain open questions. Most of these genera were recorded in the American Boreal Cretaceous as being long ranging. However, it seems that most of these forms are restricted areally rather than vertically in the Great Artesian Basin. They occur in the more northerly parts of the Great Artesian Basin together with *Globigerina infracretacea* (Glaessner) and similar planktonic forms, i.e., in nearer to open sea conditions. However, the purpose of this paper is to give only an outline of the stratigraphy and composition of foraminiferal assemblages of the Great Artesian Basin and further study is in progress.

Besides quite rich foraminiferal assemblages, numerous ostracodes occur in the marine Cretaceous strata of the Great Artesian Basin. In both generic and specific character they are very similar to those described from the marine Cretaceous sequences of the West Siberian Artesian Basin. They are also very close to the ostracodal assemblages described from the Boreal type Sutterby Marls (Upper Aptian) of South Lincolnshire in England by Kaye and Baker (1965). Ostracodes of the Great Artesian Basin are a matter for further study.

PALAEOECOLOGY AND PALAEOGEOGRAPHY OF THE MARINE CRETACEOUS SEQUENCES OF THE GREAT ARTESIAN BASIN

Historical Review

As was briefly mentioned, marine Cretaceous strata of the Great Artesian Basin can be dated from as early as the Aptian, or according to recent study by Wopfner, Freytag, and Heath (1970) from as early as the Neocomian (Valanginian or Hauterivian) in the western Great Artesian Basin. Marine conditions persisted in the Albian and Lower Cenomanian. Negative micropalaeontological evidence suggests that strata older than Aptian and younger than Lower Cenomanian are probably non-marine—mostly brackish, lacustrine or freshwater and terrestrial. Rocks of these ages are lithologically very similar to those of the Boreal Wealden.

Micropalaeontologists who studied marine Cretaceous foraminifera in Australia (Crespin, 1944, 1953, 1956, 1963; Ludbrook, 1966; Taylor, 1964) regarded predominating agglutinated foraminifera as showing shallow and occasionally brackish-water conditions.

Crespin (1963) emphasized the close similarity of depositional environments of the Great Artesian Basin and those found in the Lower Cretaceous of northern Alaska, central and western Canada, and parts of the United States. She regarded them as fitting into the three divisions given by Tappan (1960):

1. Inner sublittoral environment.
2. Outer sublittoral environment.
3. Open sea environment.

1. The inner sublittoral environment was indicated by the predominance of agglutinated foraminifera (equivalent of Roma and lower part of Wilgunya Formations). This environment is characterized by high turbidity and considerable turbulence with low salinity resulting in a scarcity of calcareous foraminifera. Macrofossils associated with these arenaceous assemblages include cephalopods and pelecypods. The microfauna was described as typical of turbidity facies with families Rhizamminidae, Reophacidae, Ammodiscidae, Lituolidae, Textulariidae, Verneuilinidae, and Valvulinidae. Similar conditions have been claimed for the Aptian Muderong Shale in the Carnarvon Basin of Western Australia.
2. Outer sublittoral environment. In some subsurface sections throughout the Great Artesian Basin, in certain beds equivalent to the Roma and the lower part of the Wilgunya Formations, the foraminiferal associations are more diversified, calcareous and arenaceous forms being almost equally abundant. Such a situation occurred in bores in the northern, southern, and southwestern portions of the basin. There were indications of decreasing turbidity and increasing salinity in the presence of calcareous forms belonging to Nodosariidae, Buliminidae, Virgulinidae, and some Rotaliidea.
3. Open sea environment. A striking change in environment is noticeable in the faunas overlying the Tambo Formation and the upper part of the Wilgunya Formation. The change to open sea conditions has brought about a considerable lessening of turbidity and increase in salinity. Megafossils are represented by ammonites, inocerami, and fish bone fragments. In the Toolebuc Limestone Member of the Wilgunya Formation and its equivalents in northern and southwestern Queensland the foraminiferal assemblages are dominated entirely by minute tests of the planktonic genus *Globigerina*. According to Crespin (op. cit.) this open sea environment trends northwards from localities in the Boulia area to the northern margin of the Great Artesian Basin. Along the southern and eastern edge of the Gulf of Carpentaria this influx of globigerinid forms is characteristic of horizons in some of the bores of this region.

Ludbrook (1966) classified palaeoecological conditions in the Cretaceous depositional environment of the Great Artesian Basin in a similar way, suggesting agglutinated assemblages as possibly indicating conditions of low salinity. She mentioned oxygen isotope palaeotemperature measurements by Dorman and Gill (1959) of six belemnites which gave readings of 13·8° and 15° C. She deduced from this that because the depth of water in which the belemnites were deposited may have exceeded 100 fathoms (183 m), the climatic conditions were warm from at least the Upper Aptian to the Upper Albian. Calcareous foraminifera (*Anomalinoides*, *Praebulimina*, and Nodosariidae) indicated deposition off shore in depths from 150 to 600 fathoms (274 to 1,098 m) over most of the area represented by the Aptian part of the Marree Formation today.

According to Ludbrook (1966) the end of the Aptian is characterized again by arenaceous foraminifera (*Bigenerina*, *Verneuilinoides*, *Ammodiscus*, *Hyperammina*, and *Saccammina*) in sandy and calcareous interbedded strata with worm burrows, *Lingula*, fish bones, fish teeth, scales, and occasional Radiolaria and holothurian sclerites. They were interpreted by Ludbrook (op. cit.) as still belonging to the offshore environment with limited access to the open sea. In the Upper Albian, planktonic foraminifera occur with ammonites and inocerami, occasional fish scales and fish bones, and give evidence of a fairly shallow open sea since they occur in association with both calcareous and agglutinated forms and in highly carbonaceous, pyritic, and glauconitic mudstone. Their sporadic occurrence indicates deposition by currents or as a result of drifting. Conditions of sedimentation at this time (Upper Albian) were described as stagnant and the abundance of the megaspore *Arcellites* was regarded as suggesting that even brackish conditions such as marine swamps and freshwater lagoons could have existed.

The close of sedimentation of the Marree Formation was marked by the disappearance of the ammonites, inocerami, *Aucellina* and calcareous foraminifera such as *Neobulimina australiana*. A few tolerant species such as *Haplophragmoides chapmani* and *Verneuilina crespinae* survived into the Cenomanian Blanchewater Formation during which marine influence ceased.

An interesting study of foraminifera of the western Victorian Cretaceous sediments was done by Taylor (1964) who stated a Turonian--Upper Senonian age for the marine fossiliferous sequences.

According to Taylor (op. cit.) the "higher calcareous foraminiferal assemblages" are Senonian and probably no younger than Santonian. Assemblages of agglutinated species were observed alternating with calcareous assemblages. There is no palaeontological, lithological, or structural evidence of a discontinuity of sedimentation which would indicate a depositional break between the Turonian and Santonian. During the end of the Santonian there was a marine regression though non-marine sedimentation appears to have been continuous until the marine transgression in the Paleocene.

Taylor's (op. cit.) notes on the palaeoecology of the studied marine Upper Cretaceous assemblages were very interesting. He has seen the major palaeoecological character in the alternation of arenaceous, mixed arenaceous and calcareous, and calcareous species. This alternation and especially the appearance of "waves" of calcareous species were explained by Taylor (op. cit.) as the result of changing water salinity leading to brackish conditions resulting in an anaerobic benthonic environment.

Taylor (op. cit, p. 553) pointed out the absence of *Globotruncana* and other planktonic foraminifera of "world wide distribution" in Turonian and Senonian sediments of the Otway Basin. He concluded that a definite latitudinal oceanic distribution of *Globotruncana* would imply a distribution influenced by latitudinal temperature variation if the analogy with the present day was correct. He mentioned also the lack of *Globotruncana* in Cretaceous deposits of northern Alaska and northern Alberta. Therefore, the Victorian fauna "could well have been a cold water fauna by reasons of the above arguments and because of the predominance of arenaceous forms".

Comprehensive notes on palaeoclimatic conditions in the area of the Great Artesian Basin were made by Whitehouse (1953 and mainly 1954), who based his opinion about the cold character of the Lower Cretaceous marine environment on the presence of "glacial erratics" in the "Roma beds" in New South Wales and South Australia, mineralogical characteristics (the mass occurrence of feldspars, chiefly microcline), and the character of fauna. Whitehouse (1954, p. 11) has written: "Furthermore the Roma faunas have little in common with the warmer (Tethyan and near-Tethyan) faunas of the time. They contain no phylloceratid, Lytoceratid, hoplitid, or pseudoceratitic ammonites, hibolitid belemnites, reef coral faunas, rudistic lamellibranches, nerineid gastropods, or large foraminifera. Instead, their faunas are most closely akin to those similarly depleted faunas remote from the Tethys—Patagonia, Spitzbergen, and Greenland. There is similar evidence for the Tambo Group."

David (1950, pp. 500–502 and 515) also interpreted the climate of epicontinental seas and lakes of Australia during Lower Cretaceous time as cold. If from among reasons showing the cold climate we exclude the misinterpretation of the "glacial erratics and boulders" (a comprehensive discussion of these was given by Wopfner, Freytag, and Heath, 1970, pp. 408–410), the most interesting are those showing affinities of marine invertebrates with cold-water faunas in other parts of the world. He showed that the ammonite faunas of Roma bear no resemblance to those of southern France, Colombia, and Africa of the same age, but are very similar to those of the northern Caucasus, Simbrisk, Spitzbergen, and Patagonia. For instance, the Roma and Upper Gargasian of Patagonia contain the same forms of *Maccoyella*, *Aioloceras* and *Sanmartinoceras*. *Australiceras* was found in Holland, Western Germany, and the northern Caucasus, but is abundant only in the U.S.S.R. (Simbrisk) and eastern Australia. The Tropaeum zone was found in many areas but the two chief Roma species are known only from Queensland and Spitzbergen. David (1950) mentioned also the faunal affinities with South African Uitenhage Beds and England.

Recently, Wopfner, Freytag, and Heath (1970) studied the basal Jurassic–Cretaceous rocks of the western part of the Great Artesian Basin. They based their discussion of the environment and palaeoecology of these sequences mainly on the analysis of lithology and flora and partly on oxygen isotope measurements by Dorman and Gill (1959). They interpreted the basal sedimentary rocks of this area as recording the change from continental (freshwater, terrestrial) regime in late Jurassic time to the epicontinental marine environment of the early Cretaceous. Marine conditions were described as shallow-water, marginal marine with several specialized environments including brackish ones. The marine transgression was suggested as early as in the Neocomian, perhaps in the Valanginian or Hauterivian. The climate was interpreted as moist, warm subtropical on the basis of some fossil plants.

Doubtless, the most important information on the character of the macrofaunas of the Great Artesian Basin is that given by Day (1969), who made a stratigraphic correlation and ecological and climatic evaluation based mainly on ammonites and other molluscs. He showed that, although there are still several problems in interregional correlations, it is possible to regard the Roma and Tambo (Aptian and Albian) faunas as provincial temperate or cool temperate equivalents of Northern Hemisphere Boreal faunas.

His palaeoclimatic and palaeoecological results are very perceptive and show not only that the climate might have been cool temperate, but he also noticed the climatic zonation within the Great Artesian Basin, namely that in the pre-Roma (Neocomian-early Aptian) sequences a northern, warmer water assemblage may be differentiated from southern, cooler ones.

Palaeoecological Evaluation of Microfaunas of the Marine Cretaceous Sequences of the Great Artesian Basin

Specific determinations of foraminiferal assemblages in the marine Cretaceous sequences of the Great Artesian Basin by the present author are in general similar to those given by Crespin (1956, 1963) or Ludbrook (1966). All data show very obvious alternation of agglutinated, mixed agglutinated and calcareous, and of calcareous assemblages. There are also some similarities in general stratigraphical evaluation of the extent of marine strata ranging from the Aptian to Cenomanian (Ludbrook (op. cit.) admitted a Lower? Cenomanian age for the uppermost part of the marine sequence of the Great Artesian Basin in South Australia). Differences, however, appear in details of stratigraphical, palaeoecological, and palaeogeographical conclusions.

Marine Cretaceous deposits of the Great Artesian Basin contain several agglutinated and calcareous forms, many of them occurring in other Cretaceous deposits of the same age, especially in the Boreal Cretaceous sequences of the Northern Hemisphere. There are also striking similarities between microfaunas of the Great Artesian Basin and the southern continents (South America—Magellan Geosyncline, South Africa—Uitenhage Formation). Some of the species proved to be very good index fossils and zone markers. They include especially *Textularia anacooraensis* Crespin, *Trochammina raggatti* Crespin, *T. minuta* Crespin, *Marginulinopsis collinsi* Stelck & Wall, *Pseudolamarckina* sp., *Ammobaculoides romaensis* Crespin, a group of discorbids, *Valvulineria parvula* (Crespin), *Lingulogavelinella frankei* (Bykova), *Verneuilinoides kansasensis* Loeblich & Tappan, *Textularia* cf. *anceps* (Reuss) (probably *Textularia foeda* of Vasilenko, 1961) and some other forms which are a matter of further detailed taxonomical study. Most of these species are cosmopolitan forms with a short range enabling wide stratigraphical and palaeoecological correlations.

From among the reasons for this similarity, the homeomorphy is suggested to be the least important factor, and that of migration the most important one. The reasons for this interpretation are:

1. The comparatively small temperature differences during the Lower Cretaceous in general allowing the existence of a greater number of cosmopolitan species.
2. The general configuration of land and seas. The distribution of land and seas was predominantly latitudinal and the most important tropical sea body—Tethys—was equatorial and nearly circumglobal. As the differentiation of Gondwana and Laurasia was only in the initial stages, widespread migration within water bodies of the same latitudes was common due to their proximity. There were either no physical and mechanical barriers, such as temperature differences and the configuration of continents, preventing migration as in the Recent, or they were much more limited than in Recent time.

Until now the study of Cretaceous benthonic forms has been much less advanced than the study of Upper Cretaceous planktonic species, and the latter has been much more advanced in the Tethyan area than in areas north and especially south of the Tethys. However, neither the Lower nor the Upper Cretaceous in the Southern Hemisphere, with certain exceptions in Australia and New Zealand, has been systematically studied. This was probably the main reason why Hornibrook (1953, 1958, 1962, 1969) in New Zealand and Ludbrook (1966) in Australia still regarded marine Cretaceous microfaunas as endemic, although Crespin (1956, 1963) has compared them partly with similar microfaunas of Alaska, Canada, and some parts of the United States.

The study by the present author and the consequent preliminary revision of species occurring in the Great Artesian Basin show that most of the species also occur in other areas of Cretaceous deposits. Striking similarities appear especially if we compare forms occurring in Alaska, some parts of Canada and the United States, the West Siberian Lowlands and Mangyshlak, and part of northern Europe (namely northwestern Germany, Holland, northern Poland, the Russian Platform, and some parts of Scandinavia). The concept of endemic character, however, might have been supported also by the circumstance that some of the Lower Cretaceous and a few Upper Cretaceous forms were described first in Australia or New Zealand and only later in other parts of the world, typical instances being that of the genus *Aragonia* Finlay, some species of *Bolivinoides*, and many Lower Cretaceous forms, and also by the fact that authors studying Cretaceous foraminifera in different parts of the world did not correlate these and used new specific names for the same species with little or no revision based on comparison.

The marine Cretaceous environment of New Zealand undoubtedly requires special attention. Finlay (1939a, b, c; 1947) in his works on the New Zealand foraminifera gave a clear picture of their cold-water character. As early as in 1940 he indicated the similarity between the South American Burdwood Bank uppermost Cretaceous and the New Zealand Piripauan-Teurian microfauna and indicated that they are almost identical down to species. He also noticed that these faunas do not resemble those of the Western Australian Gingin Chalk, but are close to coeval faunas from Central and South America. As mentioned also by Hornibrook (1953), Glaessner (1945) noted that the occurrence of arenaceous assemblages (containing *Ammobaculites*, *Ammomarginulina*, *Bathysiphon*, *Ammodiscus*, *Cyclammina*, *Haplophragmoides*, *Bolivinopsis*, etc.) in New Zealand and elsewhere, with the exception of some anomalous occurrences, appears to indicate a cold-water period in New Zealand. However, Hornibrook (op. cit.) concluded that "Although it seems possible that the Danian was a cold period in New Zealand, the chocolate-coloured, sulphurous nature of the deposits suggests that unusual environmental conditions rather than cool seas may have been the cause of these peculiar assemblages". However, the cold-water (Austral) character of some New Zealand foraminiferal assemblages is quite obvious from further comments of Hornibrook (op. cit., p. 436): "The complete absence of large Foraminifera and the rarity of *Globotruncana* which became rock-forming at this time in the Indo-Pacific Region (Glaessner, 1942, p. 52) [Glaessner, 1943, p. 52], strongly suggest that a temperate marine climate excluded from New Zealand many of the forms that characterize Tethyan and Indo-Pacific upper Cretaceous assemblages". He described the earliest Cretaceous microfaunas (Albian-Clarentian) as assemblages in which "*Karrerulina*, *Recurvoides*, *Ammobaculites*, *Pseudoclavulina*, *Quinqueloculina*, *Ramulina*, *Bolivina*, *Nodosarella*, *Allomorphina* and Lagenidae make their first local appearance together with rare *Globotruncana*. The Upper Cretaceous species *Globigerina cretacea* d'Orb. and *Globigerinella aspera* (Ehren.) are common."

A very interesting paper on the Lower Cretaceous (Clarentian) foraminifera of New Zealand was published by Stoneley (1962). Stoneley described several new species of the genera *Ammobaculites*, *Spiroplectinnata*, *Karreriella*, *Trochammina*, *Gyroidina*, *Gyroidinoides*, *Gavelinella*, *Eponidopsis*, *Epistomina*, *Praeglobotruncana ?*, *Anomalina*, and *Anomalinoides*. A revision of this material is necessary.

The most modern study of the New Zealand Cretaceous foraminifera was done by Webb (1966) who has written that the New Zealand Late Cretaceous microfauna was dominated by cosmopolitan elements, i.e., species common to both the Boreal and Tethyan realms, and the endemic taxa were almost completely unknown. The restriction in latitudinal distribution of *Globotruncana* was taken to indicate a southward cooling of the open ocean environment. The total absence of larger foraminifera and reef organisms in the shallower water facies was suggested by Webb (op. cit.) as evidence "that in the Late Cretaceous New Zealand lay outside the mainstream of tropical ocean circulation in a temperate marine environment similar to that which exists in the same latitudes today".

The present author had an opportunity to see the Cretaceous assemblages from New Zealand. In New Zealand two biogeoprovinces are represented during the Cretaceous—the Austral (cold water) and the biogeoprovince with some Tethyan elements shown in data by Webb (included in the report by Hornibrook, 1969) indicating the presence of globotruncanids.

On the other hand, Cretaceous microfaunas of the Great Artesian Basin show striking similarities with those occurring in the Cretaceous strata of the southern continents of South America and South Africa. However, only limited information is available on these microfaunas. There have been some studies on ostracodes (Dingle, 1969a, b) from the marine Neocomian and Upper Cretaceous from the South African Uitenhage Basin and

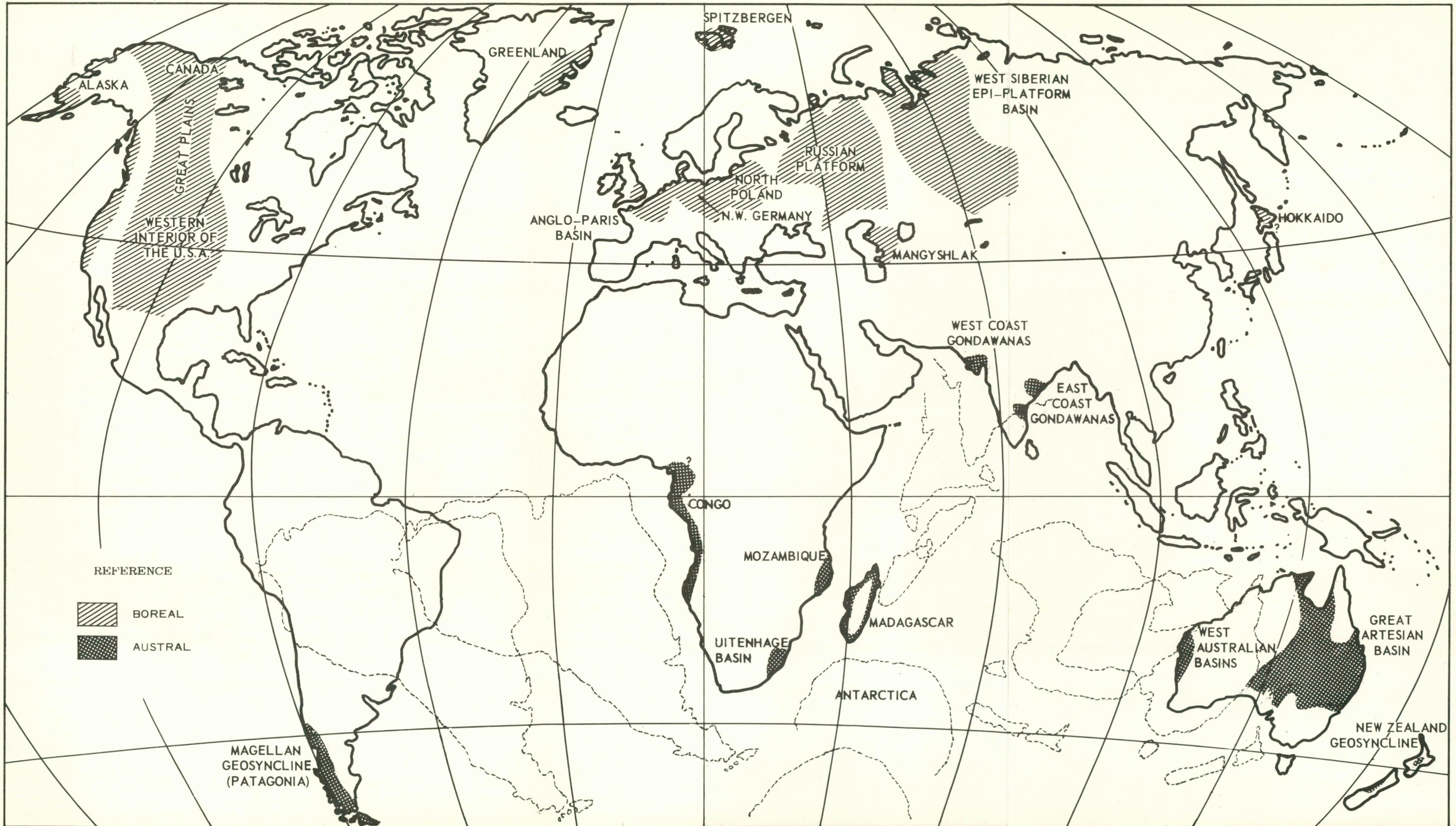
Umzamba Beds, Pondoland. The common feature of Cretaceous deposits of the studied area and those of southern continents such as the Magellan Geosyncline of South America and the Uitenhage Basin of South Africa is lack of globotruncanids, which are also missing from the deposits of the West Siberian Lowlands, Alaska, and some parts of Canada and the United States.

From the palaeogeographical point of view, areas with similar or identical microfaunal assemblages occur more or less symmetrically to the north and south of the Tethys. Climatic conditions in these areas were characterized by lower temperatures, although in general the differences in temperatures during the Cretaceous were not as large as they are now. It is generally accepted that during the Cretaceous the polar ice caps did not exist (a very interesting explanation of this was recently published by Crowell and Frakes, 1970). The lowest palaeotemperatures obtained on the basis of oxygen isotope measurements of belemnites are around 12·2° C, the highest around 25–30° C. The variation of temperatures in Recent seas ranges from 0° (in winter) to about 28° C. Therefore, the difference between maximum and minimum temperatures of 60° C postulated by Bowen (1961c) for the Recent is misleading; he apparently compared the temperature difference of 60° C valid for the atmosphere above equatorial areas and that above the polar areas with that of the marine environments where the belemnites lived. The temperature difference in the Recent hydrosphere is only about 28° C, i.e., much closer to that in the Cretaceous (13–18° C), and is in clearer agreement with the quite analogous character of microassemblages in Recent cold-water marine environments and those of the Cretaceous boreal and austral environments. The difference in temperatures was apparently sufficient for faunistic zonation, and it is well known that temperature is the main factor controlling the distribution of foraminifera (Glaessner 1945, Pokorný 1960, and others).

The author of this paper suggests the following principal climatic zones in the Cretaceous:

1. A tropical equatorial zone corresponding to the distribution of the Tethys (Tethyan Ocean) within the latitudes 0° and approximately 30° N. and S. characterized by diversified globotruncanid plankton with less prominent benthos.
2. Boreal and Austral zones between approximately 50° and 90° N. and S. latitudes characterized by predominating agglutinated foraminifera in benthos and absence of globotruncanids, with plankton being represented mainly by simple globigerine-shaped forms.
3. Transitional zones between approximately 30° and 50° N. and S. latitudes occupying epicontinental marginal seas of the Tethys and characterized by rich assemblages of calcareous benthos and much less variety of planktonic species with a prominent group of *Globotruncana marginata* (Reuss) (*Globotruncana marginata* microfacies).

The widest zones are formed by the Boreal and Austral biogeoprovinces distributed approximately between 50° and 90° N. and S. latitudes. They are represented characteristically by wide epicontinental flooding over Palaeozoic cratogens and partly by the geosynclinal sedimentary basins in South America (Magellan Geosyncline) and New Zealand. The epicontinental seas were typically represented by semi-enclosed shallow marine basins. Frequent brackish or even freshwater or terrestrial periods are quite characteristic. The Boreal and Austral marine environments are characterized by the dominant agglutinated benthos which often reaches larger dimensions, and the presence of some calcareous forms with thin, small, and smooth shells. Planktonic species are often very tiny and represented by simple "globigerine-shaped" forms representing a few taxa only.


SPITZBERGEN
GREENLAND
CANADA
ALASKA
GREAT PLAINS
WESTERN INTERIOR OF THE U.S.A.
WEST SIBERIAN EPI-PLATFORM BASIN
RUSSIAN PLATFORM
NORTH POLAND
N.W. GERMANY
ANGLO-PARIS BASIN
MANGYSHLAK
HOKKAIDO
WEST COAST GONDAWANAS
EAST COAST GONDAWANAS
CONGO
MOZAMBIQUE
MADAGASCAR
UITENHAGE BASIN
ANTARCTICA
WEST AUSTRALIAN BASINS
GREAT ARTESIAN BASIN
NEW ZEALAND GEOSYNCLINE
MAGELLAN GEOSYNCLINE (PATAGONIA)
REFERENCE
BOREAL
AUSTRAL

The Boreal biogeoprovince of the Northern Hemisphere is well known now and several microfaunas have been studied in detail. However, much less is known about microfaunas of the Austral biogeoprovince, which has not been distinguished until now. Furthermore, we shall deal with the marine Cretaceous sequences of the Great Artesian Basin as the type area of the Austral biogeoprovince, equivalent to the Boreal biogeoprovince of the Northern Hemisphere (figure 2).

In connection with the distinguishing of the Austral biogeoprovince and the enlargement of the Boreal biogeoprovince, it will be necessary to reconsider the validity of the Indo-Pacific bioprovince as postulated until now.

The Austral, cold-water character of the Cretaceous environment of the Great Artesian Basin is confirmed also by the character of the macrofauna in which reef corals are completely missing. For more about the cold-water affinities of the Australian macrofauna see pages 14–15. The microfaunas are of the following nature: agglutinated species which sometimes form a dominant part of the assemblages and are often large, and plankton represented by a very few globigerine-shaped forms, which are often extremely small. The calcareous benthos is also often very small, thin-walled, fragile, and smooth, or only very simply ornamented. The generic and, in many cases also, specific composition of these microfaunas is identical with those found in the Boreal Cretaceous of North America, in Alaska and the western interior of Canada and the United States; in the West Siberian Lowlands and Mangyshlak of northern Asia; and in part of northern Europe (northwestern Germany, northern Poland and the Russian Platform as well as some parts of Scandinavia). However, most of the authors, especially those working with the North American material, explained these features of the microfauna as being due to unfavourable conditions caused by turbidity and low salinity. Only very few (Vasilenko, 1961; Baryshnikova, 1959; Bulatova, Gorbovec, Kiselman, and Ushakova, 1969; Todd and Low, 1964; partly Taylor, 1964, and recently also Wall, 1967a), noticing the variety of microfaunas contradicting observations on both Recent and some fossil brackish faunas, tended to explain the character of the particular microfauna as being due to cold climatic conditions. In some areas they even observed changes in the character of foraminiferal associations when the climatic conditions changed in connection with transgression and influence either from the south (from the areas with Tethyan influence) or from the north (from the areas with Boreal influence) (Vasilenko, 1961).

In general, the Cretaceous sea of the Great Artesian Basin corresponds well with the definition of a semi-enclosed epicontinental sea by Menard (1967) and Hedberg (1970). It was mostly shallow, rarely more than 300 m in depth, although local greater depths ranging around a thousand metres should be admitted. The maximum extent of flooding was in the Aptian and Lower Albian, with occasional periods of slowing of the rate of sedimentation as shown by the very frequent occurrence of "glauconite"—green pellets of different illitic minerals (montmorillonite predominating as shown by X-ray analyses) with an admixture of glauconite, chlorite, etc.

Crespin (1956, 1963) and Ludbrook (1966) as well as Taylor (1964) often suggested an occasional sub-saline to brackish character for the Cretaceous assemblages of the Great Artesian Basin, especially for those with dominant agglutinated forms. However, the mere predominance of agglutinated forms is not sufficient to prove the brackish environment. In Recent brackish environments a limited number of taxa and large number of individuals are characteristic. On the other hand, in the Great Artesian Basin, more than a hundred species were described, most of the taxa being represented by only a few specimens. Thus, the variety of species and especially the presence of Globigerinacea, Nodosariidae, Radiolaria and several other calcareous groups, occurring in small numbers but mostly throughout the Cretaceous strata, and also the presence of ammonites and other typically marine macrofaunas, seriously contradicts the postulated sub-salinity of the Cretaceous environment yielding the microfaunas in question.

The alternation of agglutinated, mixed agglutinated and calcareous, and calcareous assemblages cannot be explained by one factor only. It was probably caused by changing lithological character of the bottom (the richest mixed assemblages are from the sandy shales), seasonal changes of the nutrient content, and slight seasonal changes of salinity (such as observed in some Recent cold shallow seas) as the most prominent reasons.

In palaeoecological studies of the Great Artesian Basin special attention should be paid to radiolarians. Already preliminary studies show that radiolarians occurring in the Great Artesian Basin belong to types recorded from environments characterized by low temperatures in other areas. They are represented mainly by simple globular and lens-like shapes with the genus *Dictyomitra* prominent and as such are very close to those described from the Boreal Cretaceous sequences of the Northern Hemisphere (Tappan, 1962, and others).

Although we cannot directly compare Cretaceous or any other fossil assemblages with Recent ones as several of the fossil species have not survived, the striking similarity can be seen if we compare the general character of fossil and Recent associations living in a similar environment, in our case in semi-enclosed shallow arctic seas (as for instance that of the Chukchi Sea studied by Cooper, 1964, or the Canadian and Greenland arctic studied by Phleger, 1952, and many other instances): predominance of agglutinated forms very characteristically reaching larger sizes; small size and decalcification of calcareous forms composed characteristically of Rotaliidea (genera *Anomalinoides*, *Discorbis*, *Rosalina*, *Anomalina*, *Valvulineria*, and related groups), Nodosariidae and Polymorphinidae; and plankton represented by only a few species of globigerine-shaped forms. Very similar comparisons and conclusions were made also by Baryshnikova (1959), Bulatova, Gorbovec, Kiselman, and Ushakova (1969, p. 132), Todd and Low (1964) and others.

Warm-water elements in both agglutinated and calcareous faunas such as *Coskinolina*, *Cuneolina*, *Pseudocyclammina*, *Choffatella*, *Orbitolina*, etc., were observed neither in the Great Artesian Basin, nor in the other Boreal and Austral areas. However, the most distinct difference is in the character of plankton of which such typically Tethyan genera as *Ticinella*, *Planomalina*, *Praeglobotruncana*, *Biglobigerinella*, *Schackoina*, *Hastigerinella*, *Globotruncana*, or *Rotalipora* have not been found.

Palaeotemperature Measurements in Australia

Oxygen isotope palaeotemperature measurements on belemnites are very interesting and provide valuable information on the palaeoclimate of the Australian continent during the Cretaceous. Lowenstam and Epstein (1954) used belemnites from the Hughenden district in Queensland for their palaeotemperature studies and obtained values of 15·2° and 16·6° C. Dorman and Gill (1959) obtained values of 13·8° and 15° C from rostra of three Aptian belemnites from the Great Artesian Basin. Bowen (1961a, c) presented very different figures, which is, however, in agreement with the fact that he studied palaeotemperatures on several specimens of belemnites coming from very distant areas in Australia. In Western Australia, specimens were derived from strata of the Alinga Formation of Albian to

Turonian age in the Carnarvon Basin. Thirteen specimens came from the Murchison River area, eight of these being from cliffs west of Murchison House station and giving temperatures ranging from 17·7° C to 26·1° C, the average temperature being 20·6° C. Four additional specimens from uncertain strata from Junnawa Hill in the lower Murchison River area have an average temperature of 19·8° C. Two specimens collected from the Gearle Siltstone of Albian to Turonian age in the Giralia area have very different results of 20·3° and 30·1° C. As was mentioned above, this area of Cretaceous deposits represents an epicontinental sea influenced probably by a warm current and connected to the open sea with a resulting strong Tethyan influence in its faunas.

In this connection, extremely interesting data on Western Australian Lower Cretaceous microfaunas with prominent agglutinated forms are given by Belford (1958) showing that they contain species similar to those of the Great Artesian Basin. The author of this study had an opportunity to see these assemblages and came to the conclusion that it is possible to see the connection between some quite low palaeotemperatures (17·7° C) as mentioned above and the occurrence of these, mainly agglutinated, foraminiferal assemblages. They also indicate the lower boundary of the existence and action of the warm current in Western Australia during the Upper Cretaceous, most probably in the upper part of the Cenomanian.

Bowen (1961c) also studied some specimens from the Great Artesian Basin. Six belemnites were obtained from the Albian of South Australia at Fossil Creek, 35 miles (56 km) from Oodnadatta and gave a temperature of 21·9° C. On the basis of this Bowen (op. cit.) criticized Lowenstam and Epstein's (1954) data of 15·2° and 16·6° C which were, however, based on material coming from Queensland 1,000 miles (1,600 km) from Oodnadatta. Also, Dorman and Gill (1959) gave readings for specimens derived from the Aptian Lake Eyre area, close to Oodnadatta and ranging from 12·2° to 16·6° C. Bowen (1961c) regarded this difference as either an error by Lowenstam and Epstein (1954) or as a record of seasonal temperature changes. Another explanation is possible, namely either that this sole different palaeotemperature measurement was incorrect or that climatic zones ran across the Australian continent from south-southeast to north-northwest during the Cretaceous. The "coldest" area in such a case was in the southeastern part of Australia (and consequently of the Great Artesian Basin) and temperatures were increasing in a northwesterly direction. That such conditions might have existed can be proved on the basis of microfaunal assemblages which are definitely of the cold-water, Austral (equivalent to Boreal) type in most parts of the Great Artesian Basin during the Lower and lower part of the Upper Cretaceous and in the Otway Basin of Victoria during the Upper Cretaceous. On the other hand, microfaunas of the epicontinental marine basins in Western Australia and part of the northern margin of the Australian continent in the Carnarvon and Perth Basins, Bathurst Island and Naturaliste Plateau areas are characterized by extremely rich assemblages of globotruncanids, forming typical Tethyan elements.

However, it is necessary to take into consideration that the palaeotemperatures obtained on the basis of freely swimming forms as are belemnites, may be misleading when applied to the bottom environments represented by our assemblages in question. The bottom assemblages might have lived in a much colder environment, especially those of higher latitudes where the bottom waters might have been cooled by cold currents approaching from the neighbouring polar areas.

Palaeolatitudes of Australia during the Cretaceous

According to palaeomagnetic studies by several authors, but especially those by Irving (1964), Australia was on the whole within high latitudes during the Cretaceous. The area of the Great Artesian Basin and also that of the Otway Basin lay between 50° and 80° S.

A SHORT REVIEW OF FORAMINIFERAL ASSEMBLAGES IN SOME MARINE BOREAL, TRANSITIONAL, AND AUSTRAL CRETACEOUS BIOGEOPROVINCES*

Asia

West Siberian (epi-Hercynian) Platform

The West Siberian Platform is formed by the artesian basin representing a vast area of 2·5 million km² in the Asiatic part of the U.S.S.R. Orographically it is formed by the West Siberian Lowlands. It is bordered by the Ural Mountains in the west, the Yenisei River valley in the east, the Karskoe Sea in the north and the Central Kazakhstan Mountains and the Altai System in the south. The basement for the West Siberian Lowlands is provided by the Precambrian platform and Precambrian and Palaeozoic complexes consolidated during the Baikalian and Caledonian, and Hercynian Orogenies. Above the basement occur Mesozoic and Cainozoic sequences which are only gently folded. Triassic and Jurassic are represented by a complex of partly coal-bearing terrestrial and marine deposits. Cretaceous sequences are of both terrestrial and marine origin. In contrast to the Great Artesian Basin, the Upper Cretaceous and Tertiary also belong to the marine facies.

Cretaceous and Tertiary microfaunas of the West Siberian Lowlands were studied by several authors, mostly in boreholes searching for oil and water.

Subbotina *et al.* (1964) described the following zones from the marine Albian strata of the West Siberian Lowlands:

1. Lower zone with *Hyperammina*, *Haplophragmoides*, *Ammomarginulina*, *Globulina*, *Rectoglandulina: Ammobaculites fragmentarius* zone (Lower Albian).
2. Middle zone of *Verneuilinoides borealis* with species of the genera *Hippocrepina*, *Reophax*, *Haplophragmoides*, *Saccammina*, *Thurammina*, *Crithionina*, *Hyperammina*, *Agathammina*, *Miliammina*, *Uvigerinammina*, *Discorbis*, and *Guttulina*.
3. Upper zone called the zone of small miliamminas and saccamminas, and containing the genera *Hyperammina*, *Verneuilinoides*, *Haplophragmoides* and ammonites in accompanying macrofaunas.

Aptian strata of the area studied by Subbotina *et al.* (op. cit.) are of continental origin.

Another author studying Cretaceous microfaunal assemblages of the West Siberian Lowlands was Bulatova (1969a) who studied the Turonian up to Santonian association in the Taza River and the Transpolar Research Areas. She noticed a common feature of the agglutinated assemblages, i.e., a yellow-brown or whitish colour which is also characteristic of the Great Artesian Basin and was marked by the present author as "gold-fish red colour". In the studied section, Bulatova (op. cit.) determined genera *Astrorhiza*, *Rhizammina*, *Psammosphaera*, *Saccammina*, *Hippocrepinella*, *Leptodermella*, *Thurammina*, *Thuramminoides*, *Crithionina*, *Hyperammina*, *Hyperamminoides*, *Reophax*, *Glomospirella*, *Lituotuba*, *Haplophragmoides*, *Recurvoides*, *Thalmannammina*, *Placopsilina*, *Trochamminoides*, *Lituola*, *Ammobaculites*, *Haplophragmium*, *Ammomarginulina*, *Flabellammina*, *Miliammina*, *Spiroplectammina*, *Textularia*, *Bimonilina*, *Verneuilinoides*, *Gaudryina*, *Gaudryinella*, *Pseudoclavulina*, *Martinotiella*, *Quinqueloculina*, *Nodosaria*, *Globulina*, *Polymorphina*, *Frondicularia*, *Gyroidina*, *Discorbis*, *Valvulineria*, *Anomalina*, *Gyroidinoides*, *Eponides*, *Eoeponidella*, *Epistomina*, *Brotzenia*, *Reinholdella*, *Anomalinoides*, *Cibicides*, *Nonionella*, *Globigerina*, *Hedbergella*, *Globorotaloides*, *Praebulimina*, *Bulimina*, *Neobulimina*, *Bolivinam*, *Gümbelina*, and *Gyromorphina*. Several species were identical with those described from North America (Alaska, western interior of Canada and the United States) and northern Europe.

* All taxa are quoted as in the original publications of the respective authors.

The same author described the Aptian-Albian sequences (Koshai and Vikulov Formations) of the West Siberian Lowlands. She described several species of agglutinated and calcareous forms of the genera *Haplophragmoides*, *Hyperammina*, *Verneuilinoides*, *Trochammina*, *Ammobaculites*, *Dentalina*, *Lenticulina*, *Eponides*, *Conorboides*, *Gavelinella*, *Valvulineria*, *Praebulimina*, *Globorotalites*, *Anomalina*, many of the species described being identical with those described in North America and northern Europe. Planktonics were represented by *Hedbergella*, the same species as those described in North America, especially in Alaska. They are very small, and yellow in colour.

Complexes of arenaceous foraminifera with many identical species as described from other Boreal areas were also found by Tairov (1959) in the Aptian–Albian sequences of northeastern Azerbaidzhan. He stated that:

1. The Lower Cretaceous microfauna differs from the Jurassic by the presence of numerous agglutinated forms and the disappearance of some calcareous forms.
2. The Aptian and Albian of the northern Kobystan and pri-Caspian region of the northeastern Azerbaidzhan contain a rich characteristic foraminiferal fauna composed of agglutinated and calcareous forms of the families Astrorhizidae, Rhizamminidae, Hyperamminidae, Reophacidae, Ammodiscidae, Lituolidae, Trochamminidae, Verneuilinidae, Globigerinidae, Lagenidae, Anomalinidae, Ellipsoidinidae, Polymorphinidae, Buliminidae, Rotaliidae, and Epistominidae.

In dividing the Aptian into two substages, according to Tairov (op. cit.) the major role was played by Ammodiscidae, Trochamminidae, Lituolidae, Textulariidae, Globigerinidae, Buliminidae, Rotaliidae, Astrorhizidae, Rhizamminidae, Miliolidae, etc.

3. Albian sequences are characterized by Rhizamminidae, Hyperamminidae, Reophacidae, Ammodiscidae, Lituolidae, Verneuilinidae, Valvulinidae, Textulariidae, Placopsilinidae, Rotaliidae, Ellipsoidinidae, and Polymorphinidae.
4. Very rich radiolarian assemblages with species of spherical and discoidal forms of various sizes appeared in the Upper Albian.
5. The study of the horizontal distribution of long-ranging forms is also very important as they might indicate lithological and palaeoecological changes.
6. The number of agglutinated forms in the Aptian is much higher than in the Barremian, where Lagenidae predominate. These are replaced by agglutinated and some calcareous forms such as Rotaliidae and Globigerinidae.

Mangyshlak Peninsula

Extremely interesting and comprehensive information on the character of epicontinental Cretaceous strata of Central Asia is given by Vasilenko (1961) who studied the Cretaceous sequences of the Mangyshlak Peninsula.

The Cretaceous section of the Mangyshlak area is quite complete. Marine sequences of the Cenomanian and Lower Turonian are characterized by sandy and clayey deposits, while those of the Upper Turonian and the whole Senonian up to the Danian are represented by marls and chalk. Vasilenko (op. cit.) analysed the differences in lithology and the character of foraminiferal microfauna and concluded that while the Upper Turonian–Campanian strata show the Tethyan influence, the Cenomanian–Lower Turonian have a pronounced Boreal character. The Boreal microfauna is composed in general of forms of small dimensions, thin and fragile shells, and yellowish-grey colour. In other cases, such as in Lower Turonian sandy deposits with *Neobulimina numerosa* Vassoevich, he often observed anomalies of the test form of *Rugoglobigerina hoelzli*. He concluded that these changes are a reflection of changed hydrochemical conditions principally in connection with a shallowing and cooling process. Characteristic calcareous genera are *Valvulineria*, *Gyroidina*, *Anomalina*, and *Cibicides*.

The Upper Cretaceous of the Mangyshlak area is again characterized by an increase of temperature and the consequent appearance of Tethyan elements—mainly globotruncanids showing affinities to the typical *Globotruncana marginata* group assemblages of the Transitional zone.

In general, during the marine history of the Mangyshlak Basin, the Boreal influence was stronger than the Tethyan and the foraminiferal complexes are very similar to those of western Europe. Temperature changes are also very similar to those observed in western Europe, i.e., increasing temperatures during the Upper Cretaceous and a general decrease after the Campanian.

Japan

The author considers that some interesting occurrences of probably Boreal–type Cretaceous sediments and microfaunas in Japan should be mentioned. As early as in 1962 Takayanagi and Iwamoto described an assemblage of "planktonic" foraminifera from the Middle Yezo Group of the Ikushumbetsu and Miruto areas represented by *Hedbergella trocoidea* (Gandolfi), *H. delrioensis* (Carsey), *H. washitensis* (Carsey) and *Biticinella? breggiensis* (Gandolfi). The last-mentioned species requires more attention because it resembles strongly a form occurring in the Great Artesian Basin. It is described in this paper as Anomalinid indet. n. gen. n. sp. and it represents a biumbilicate, asymmetrically planispiral anomalinid form being prepared for publication. The general composition of the assemblage where *Rotalipora* and *Ticinella* are completely missing (Takayanagi and Iwamoto, 1962, p. 187) as well as lithology (shale interbedded with sandstone) suggest the Boreal character of the sequence studied by the abovementioned authors.

Indian Peninsula

Lower and Upper Cretaceous deposits occur in several sedimentary basins of different tectonic origin on the Indian Peninsula. The extent of marine Cretaceous sedimentation varies.

The most complete profile of the Cretaceous marine sequence is preserved in the Cauvery Basin. The Cauvery Basin is an intracratonic graben situated between the Indian Peninsular Shield and the Ceylon Massif. It is a coastal sedimentary basin south of Madras and contains an almost complete Meso–Cainozoic succession beginning from early Cretaceous. The general succession developed near the Tiruchirapalli (former Trichinopoly) area has been subdivided into Upper Gondwana (Upper Jurassic–Lower Cretaceous), Uttatur Formation (Cenomanian–Lower Turonian), Trichinopoly Formation (Turonian–Lower Senonian), Ariyalur Formation (Senonian–Campanian–Maastrichtian), Ninyur Formation (Danian), and Cuddalore Sandstone (Mio–Pliocene) (see Datta, Banerji, and Soodan; 1969, Sastri and Bhandari, 1969).

Lower Cretaceous microfaunas of this basin show affinities to those of the Great Artesian Basin (foraminifera from the "Utatur Stage" were studied by Sastry and Sastri, 1966). The Upper Cretaceous foraminifera from the Cauvery Basin were studied by Raju and Guha (1969) and others, and are composed of typical Tethyan elements, mainly globotruncanids.

Similar Upper Cretaceous microfaunas were described also from Rajastan, the West Bengal Shelf, and other places (see Datta, Banerji, and Soodan, 1969).

Bhalla (1968, 1969a, b) described quite rich assemblages of purely agglutinated foraminifera from the Gondwana System (Raghavapuram Shales), East Coast Gondwanas in India. The microfauna (Bhalla, 1969a) consisted of fifteen species of the genera *Saccammina*, *?Ammopemphix*, *Ammodiscus*, *Haplophragmoides* (predominating), and *Ammobaculites* (very rich). He regarded this assemblage as being composed of well-known cosmopolitan forms and compared it especially with those of the Great Artesian Basin. He supported the views expressed by Ahmad (1961) that the East Coast Gondwanas of India, including the Raghavapuram area, was connected with the Great Artesian Basin of Australia by a mixed environment during the Lower Cretaceous.

Another intercalation of marine beds within the freshwater sequence of the Gondwanas are the Bubavada Beds described by Bhalla (1969b). These are rich in megafossils, but quite poor in microfossils. The microfauna is composed of *Dentalina* sp., *?Bathysiphon*, *Lenticulina*, *Frondicularia*, and *Pseudopolymorphina*. On the basis of ammonites he determined the age of these beds as Lower Cretaceous (Neocomian). He interpreted the environment of these beds as "rather tranquil, open marine basin near the shore line".

The same author in 1968 published some ideas on the palaeoecology of the Raghavapuram Shales. He was apparently confused by the predominance of agglutinated forms in foraminiferal faunas and regarded them as indicating a shallow, brackish-water environment. He explained the presence of ammonites in the Raghavapuram Shales by a sporadic connection with open sea. After the regression of the sea the basin gradually became land-locked and the salinity of the water body also decreased mainly due to intake of fresh water from the adjacent land area, resulting in the development of marshy conditions. Later (1969b) Bhalla discussed the occurrence of glauconitic mudstone at a place where the arenaceous foraminifera appear for the first time. He deduced that the appearance of glauconite (not allochthonous) is in accordance with the development of "restricted basin conditions" (land-locked basin). Although Bhalla (op. cit.) did not write further about brackish-water conditions in connection with the glauconitic mudstone, he also did not mention that most glauconitic sediments originate in marine conditions and show the slow down of sedimentation, as is also indicated by the character of the microfauna of the Raghavapuram Shales which contains marine elements.

From the palaeoecological and palaeogeographical point of view the Cretaceous deposits of the Indian Peninsula pose a very interesting problem. Bowen (1961b) has obtained temperature readings of 18·5° C from Jurassic specimens which were substancially lower than the Cretaceous readings. Bowen (op. cit.) interpreted this as indicating that India might have undergone a migratory movement from a position south of Tethys to a position north of it during the late Mesozoic. If this is correct, then it could explain the Austral affinities of the Lower Cretaceous foraminiferal assemblages and the Tethyan character of those of the Upper Cretaceous.

Europe

North of the tropical area of the Tethys covering the southern parts of Europe (Tethys Geosyncline) was the area of vast epicontinental seas covering northern France, southern England (Anglo-Paris Basin), northwestern Germany, Holland, Denmark, some parts of Sweden (Scania), northern Bohemia, northern Poland, and the Russian Platform. These areas have an analogous geological history, i.e., the Cretaceous sea transgressed on to the Hercynian cratogens in the form of shallow, intermittently connected, semi-enclosed epicontinental seas, and consequently with similar ecological conditions. Lower Cretaceous strata are characterized by lacustrine, brackish or freshwater facies (Wealden), and marine transgression is widespread in the Cenomanian, with only a few exceptions of different vertical extension in different areas (for instance, the marine Boreal Lower Cretaceous—the Valendis of northwestern Germany or the Polish Lowlands, or the Gault in western Europe). Microfaunas of these Cretaceous seas contain both Boreal and some Tethyan elements and form two biogeoprovinces: a Transitional biogeoprovince, or Middle European bioprovince of Neumayr (1872), meridional bioprovince of Pożaryska (1965); and a Boreal biogeoprovince. They are composed of several species similar to those occurring in the Tethyan area and to a varying extent some Boreal elements also occur here. The microfaunas of these biogeoprovinces were studied in detail by several authors: Bartenstein (1959, 1962a, b), Bartenstein and Bettenstaedt (1962), Bartenstein, Bettenstaedt, and Bolli (1957, 1966), Bartenstein and Brand (1951), Baryshnikova (1959), Beckmann and Koch (1964), Beissel (1891), Bettenstaedt, and Wicher (1955), Brotzen (1935, 1936, 1945), Bukalova (1960a, b), ten Dam (1948), Franke (1928), Hiltermann (1949–1966), Hiltermann and Koch (1950, 1962), Hofker (1960 and several others), Jírová (1956, 1958), Štemproková-Jírová (1963a, b, 1967a, b), Marie (1936, 1941), Marsson (1878), Meijer (1959), Moorkens (1967), Morosova (1948), Oertli (1958), Olbertz (1942), Orbigny (1840), Perner (1892), Pożaryska (1952, 1954, 1957, 1965, 1967), Pożaryska and Szczechura (1968), Pożaryski (1967), Pożaryski and Witwicka (1956), Reuss (1845–1846), Roemer (1842), Sztejn (1957, 1967), Voloshina (1961), Wedekind (1938, 1940), Wicher (1943, 1953) and several others.

It is not the purpose of this study to give a detailed review of the results of comprehensive and detailed studies of the authors mentioned. For the present study we shall deal with the general character of epicontinental European microfaunas, especially with their ecological affinities with the Boreal Cretaceous assemblages.

The Transitional epicontinental (Middle European, Meridional) biogeoprovince is different from the Tethyan area, but there are also some essential differences from the Boreal biogeoprovince. It differs from the Tethyan biogeoprovince in a smaller variety of planktonics (globotruncanids). A globotruncanid assemblage does occur, but it is represented by a specific group of *Globotruncana marginata* (Reuss) (*Globotruncana linneiana–Globotruncana marginata* group according to Jírová (1956)—see also Glaessner (1937). We cannot observe that variety of species as is characteristic for the Tethyan assemblages. There are very characteristic calcareous benthoic forms, containing some Boreal elements as well (especially some species of *Lingulogavelinella*, *Discorbis*, *Cibicides*, *Stensioeina*, *Tappanina*, *Eouvigerina*, *Valvulineria*, *Gyroidina*, *Anomalina*, etc.) many of them being extremely valuable cosmopolitan index markers (see especially Bettenstaedt and Wicher 1955, and many others) both in Lower and Upper Cretaceous, though more frequently in the latter (species of the genera *Bolivinoides*, *Aragonia*, *Neoflabellina*, etc.).

The Boreal biogeoprovince is well represented in northwestern Germany, the Polish Lowlands (Tomaszów Mazowiecki and other areas) and northern parts of the Russian Platform.

However, the boundary between the Transitional and Boreal biogeoprovinces in Europe varied in time and space with the progressive rise in ocean temperatures from the Cenomanian and these reached a peak in the Coniacian–Santonian with a general decline in the Maastrichtian (Lowenstam and Epstein, 1954). This may explain the occurrence of some Tethyan elements (globotruncanids) in latitudes as high as those of Belgium and Sweden (Scania). Wicher (1953) related the spread of the Mediterranean species into the Boreal realm to a warm-current shift perhaps involving the Gulf Stream.

It is generally accepted that there is no clear-cut evidence for latitudinal changes to explain higher temperatures and the northward shift of the subtropical climate in Europe during the Cretaceous (Lowenstam and Epstein, 1954; Bowen, 1961b.) However, there is micropalaeontological and palaeotemperature evidence for higher temperatures during the Upper Cretaceous (with the acme in the Coniacian). The higher temperatures can be explained by postulating the existence of a warm current which could have influenced the occurrence of the Tethyan elements in higher latitudes. The end of its influence can be correlated with important changes in the configuration of the Tethyan Ocean because of tectonic development connected with the Alpine–Carpathian Orogeny.

North America

Cretaceous deposits of North America yield foraminiferal faunas which are very similar in character to and contain many species close to or identical with those of the Great Artesian Basin. These Cretaceous strata belong to different geological-tectonic units in connection with the Nevadan Orogeny. West of the Cordillera, the marginal seas were distributed along the Pacific Coast, while east of the Cordillera the Cretaceous is widespread in the form of epiplatform seas which were intermittently connected. Because these epicontinental seas were distributed in a submeridional direction they comprise different climatic zones which are reflected in the character of their faunas. Geographically these vast areas form a Great Plains region. In the northern parts of the North American continent an arctic influence is typical and microfaunas have a Boreal character, while southwards, close to the Mediterranean province, tropical Tethyan elements, especially globotruncanids, occur. The area of North America with a cold, Boreal climate characterized by Boreal faunal elements lay between 50° and 90° N. palaeolatitudes.

Alaska

Tappan (1951, 1957, and especially 1960) in comprehensive studies described microfaunas coming from various Cretaceous strata in northern Alaska and bearing a clear Boreal, cold-water character, although not characterized as such. Tappan (op. cit.) described nearly 200 species of the genera *Bathysiphon*, *Glomospira*, *Glomospirella*, *Ammodiscus*, *Reophax*, *Haplophragmoides*, *Textularia*, *Siphotextularia*, *Marginulinopsis*, *Marginulina*, *Rectoglandulina*, *Lingulina*, *Nodosaria*, *Dentalina*, *Vaginulina*, *Astacolus*, *Vaginulinopsis*, *Citharina*, *Frondicularia*, *Oolina*, *Palaeopolymorphina*, *Pyrulinoides*, *Globulina*, *Neobulimina*, *Pallaimorphina*, *Globorotalites*, *Eponides*, *Conorboides*, *Conorbina*, *Valvulineria*, *Gavelinella*, *Heterohelix*, *Hedbergella*, *Anomalinoides*, and *Quinqueloculina*.

Discussing the depositional environment of the Cretaceous sediments of the Arctic Slope of northern Alaska, Tappan (1960) characterized the foraminiferal assemblages as different from those of "most normal Cretaceous depositional environments". According to Tappan (op. cit.) the foraminiferal generic composition was influenced by intertonguing marine and non-marine strata as a result of fluctuation of sea level, and the faunal and lithological facies followed these fluctuations across time lines. The absence of planktonic foraminifera in Alaskan strata was regarded as probably due to offshore currents. It was suggested that the barrier to migration of both benthos and plankton was physical, not because of currents. Several environments were described, such as: fluviatile, containing no fauna; coastal facies, both supralittoral and littoral, with megafossils limited to freshwater pelecypods such as *Unio* and charophyte oogonia; and intertidal littoral zone including the area of tidal pools and brackish water bearing a few tolerant species which may locally become relatively abundant (*Verneuilinoides borealis* Tappan, *Uvigerinammina manitobensis* (Wickenden), *Gaudryina canadensis* Cushman, *Miliammina manitobensis* Wickenden, *Saccammina lathrami* Tappan, in other places replaced by *Gaudryina irenensis* Stelck & Wall, *Trochammina ribstonensis rutherfordi* Stelck & Wall, or *T. rainwateri* Cushman & Applin).

Offshore facies–inner sublittoral environment: Throughout much of the Cretaceous in northern Alaska this environment was characterized by Tappan (op. cit.) by high turbidity and turbulence, probably with a strong current flowing from the land. The families characteristic of this environment include Rhizamminidae, Reophacidae, Ammodiscidae, Lituolidae, Textulariidae, Verneuilinidae, and Valvulinidae. Calcareous foraminifera as well as Radiolaria were described as rare or absent in the strata of this facies in Alaska.

Offshore facies–outer sublittoral environment: Turbidity and turbulence were less pronounced in this type of environment, and deposition was less rapid. The foraminiferal fauna was more diversified and contained both agglutinated and calcareous forms. Families Nodosariidae, Buliminidae, Virgulinidae, and rotaliid forms are well represented.

Offshore facies--open sea environment: This environment was characterized by Tappan (op. cit.) as including ammonites, inocerami, fish scales, and fishbone fragments, and she mentioned that it was not necessarily indicative of deep water. In the foraminiferal fauna simple forms of *Heterohelix* and *Hedbergella* occur.

Microfaunas described by Bergquist (1961) from the Upper Cretaceous Matanuska Formation (Squaw Creek–Nelchina River area) of southern Alaska are of a similar character, i.e., cold water, Boreal.

Canada (*British Columbia and Alberta*)

The Cretaceous microfaunas of Canada are characterized by genera and species very similar to and in many cases identical with, those occurring in the Great Artesian Basin. However, they are very close to microfaunas described from the West Siberian Lowlands and other typical Boreal areas.

As early as 1947 Nauss described in the Vermilion area of east-central Alberta in the Lea Park and Lloydminster Shales (Upper Cretaceous) the following genera: *Ammobaculites*, *Loxostomum*, *Miliammina*, *Neobulimina*, *Planulina*, *Tritaxia*, *Trochammina*, *Verneuilina*, *Lamarckina*, *Quinqueloculina*, *Bulimina*, *Gyroidina*, *Lagena*, *Nonionella*, *Textularia*, *Ammodiscus*, *Anomalina*, *Bathysiphon*, *Bolivina*, *Dentalina*, and *Dictyomitra* (Radiolaria). However, Nauss (op. cit.) did not make any ecological conclusions.

Later, several comprehensive works by Wall (1960, 1967a, b), Wall and Germundson (1961, 1963), Mellon, Wall, and Stelck (1963), and Mellon and Wall (1963) appeared dealing with the Cretaceous biostratigraphy of various sequences of Canada, mainly those outcropping in the territory of Alberta and British Columbia. Wall in his earlier works tended to interpret agglutinated assemblages as reflecting a non-marine environment, but later (1967b) he stated that the Boreal flooding of the Lower–Middle Albian is reflected by a normal neritic assemblage, the *Marginulina collinsi* fauna, a shallow epicontinental sea being postulated for the late Albian due to the presence of the exclusively agglutinated *Miliammina manitobensis* fauna.

The appearance of pelagic microfauna with *Hedbergella loetterlei* in the Lower Turonian is understood as reflecting open marine conditions and a connection with the late Greenhorn seaway of the Great Plains region. The generic composition of the Lower–Middle Albian was: *Ammodiscus*, *Haplophragmoides*, *Verneuilina*, *Lenticulina*, *Marginulinopsis*, *Saracenaria*, *Vaginulina*, *Discorbis*, *Valvulineria*, and *Quadrimorphina* indicating the middle and outer part of the neritic zone where the water was quiet and of normal salinity.

Dominance of agglutinated forms was regarded as suggesting an environment nearer the shore—close to the southern margin of this Boreal flooding.

The late Albian is represented in the Canadian part of the Great Plains by the basal *Haplophragmoides gigas* fauna.

The Upper Cretaceous environment of the Smoky River area of Alberta was explained by Wall (1960), on the basis of almost exclusively arenaceous assemblages of foraminifera, as indicating a quite shallow, probably cold-water environment in the Upper Kaskapau Shale. Further lowering of the sea depth just prior to the deposition of the Bad Heart Sandstone is suggested by the presence, for a short time interval below this, of coarse-grained representatives of *Involutina*, *Haplophragmoides*, and *Reophax*. After the deposition of the Bad Heart Sandstone the water probably deepened somewhat, although remaining relatively shallow, as revealed by the assemblage of finely arenaceous species in the lower part of the Puskwaskau Shale.

The occurrence of the pelagic microfauna of *Guembelina* and *Globigerina* to the virtual exclusion of arenaceous foraminifera was regarded as indicative of further deepening and of a connection with the vast interior seaway to the south and east.

Analysing the microfaunas occurring in the Cretaceous section of the Rocky Mountain Foothills area in Alberta, Wall (1967b) explained the entirely agglutinated character of microfaunas of the Sunkay Member (Cenomanian) as indicating a shallow, cool, somewhat turbid environment of perhaps subnormal salinity.

Western interior of the United States (*Iowa*, *Dakota*, *Montana*, *Kansas*, *Texas*, *New Mexico*, *Wyoming*, *Colorado*)

Cretaceous strata of the western interior of the United States bearing microfaunas similar to those of the Great Artesian Basin and to those of the typical Boreal and Transitional areas belong to the epiplatform cover type. Palaeolatitudes of this sedimentary area during the Cretaceous were between 40° and 50° N. In the north typical Boreal elements occur in the micro-assemblages, while toward the south some Tethyan elements start to occur, mainly *Rotalipora* in the Cenomanian. Cretaceous stratigraphy is based on ammonites (see Cobban and Reeside, 1962).

One of the first important studies of foraminifera from the Boreal Cretaceous of the western interior of the United States is that by Morrow (1934). Morrow wrote: "Most of these samples yielded only the very common species of *Gümbelina* and *Globigerina*. This fact has undoubtedly tended to discourage microscopic study in this region even though there was apparently no good explanation of this paucity of species". In fact his assemblages are characteristic of a Transitional zone between a cold one in the north with Boreal, and a warm one in the south with Tethyan, elements. He found in his assemblages very characteristic elements of a cold Boreal environment such as the genera *Lenticulina*, *Dentalina*, *Nodosaria*, *Vaginulina*, *Frondicularia*, *Guembelina*, *Eouvigerina*, "*Hantkenina*", *Bulimina*, *Bolivina*, *Pleurostomella*, *Nodosarella*, *Valvulineria*, *Gyroidina*, *Anomalina* (*bentonensis*), *Planulina*, *Globigerina*, and, on the other hand, *Hastigerinella* and *Rotalipora* (*Globorotalia cushmani*, *G. multiloculata*, *G. greenhornensis*). Some of these forms are represented by species occurring also in the Great Artesian Basin.

Skolnick (1958) described fifteen species of arenaceous foraminifera from the Lower Cretaceous of the Black Hills (Lower–Middle Albian) represented by the genera *Ammobaculites*, *Ammobaculoides*, *Trochammina*, and *Haplophragmoides*. He interpreted the Black Hills Formation as showing a near-shore, brackish, shallow-water environment of lagoonal character. However, at the same time, he mentioned that Lower Cretaceous ammonites have been reported in the Mowry Shale of the western flanks of the Black Hills and from the Mowry equivalents of Colorado, Montana, and Wyoming. Skolnick (op. cit.) concluded that the microfauna from the shales of the Black Hills was similar to the assemblages of the Walnut, Kiowa, and Kiamichi Formations of Lower–Middle Albian age. In a palaeoecological evaluation he agreed with the opinion that temperature and depth were the most important controlling factors in the distribution of foraminifera. However, he also agreed with other authors that salinity is another important controlling factor. He concluded that the completely arenaceous character of the Black Hills assemblages, the generic dominance of *Ammobaculites*, and the extreme rarity of megafauna indicate a rigorous environment during deposition of these lithic units, an environment such as that occurring today in lagoonal areas along the Gulf Coast of Mississippi and Alabama.

Recently a very interesting paper appeared on the petrology of the Mowry Shale of Wyoming by Davis (1970). On the basis of mineralogical and petrographical analysis, Davis interpreted the Mowry Shale as originating in the Boreal reducing environment with not extreme water depth precluding deep basin currents. Mineral composition of the Mowry Shale was as follows: 50 per cent quartz, 5 per cent feldspar, and 2 per cent organic carbon. The rest of the rock was composed of clay minerals, predominantly mixed layer types, and minor zeolites. The lower part of the Mowry Shale contained kaolinite and the upper Mowry was enriched in montmorillonite. On the mineral distribution pattern Davis concluded that the Mowry Shale was a transgressive clastic unit similar to other Cretaceous fine-grained deposits in the Rocky Mountains. Excess silica and organic carbon was believed as derived from tests of Radiolaria and other planktonic organisms that proliferated in the upper zones of a restricted arm of the Boreal seaway. Radiolarian bloom was promoted by a continuous supply of silica to the seaway from the western margin. Deposition of Mowry Shale ceased when the Boreal seaway became connected to the Gulf Sea.

Young (1951) described thirty-four species (seventeen genera) from the Niobrara Formation, Greenhorn Limestone, Eagle Ford Formation, and the Frontier Formation of southern Montana. The microfauna described in his paper was from the "Vascoceras Beds". Only a poor microfauna composed of *Reophax*, *Dorothia*, *Clavulinoides*, *Marginulinopsis*, *Planularia*, and *Nodosaria* was found. Young (op. cit.) concluded from this that the sea bottom was either too muddy for benthonic organisms, or that the water was brackish. However, the presence of several genera of Mollusca in concretions in the Upper Frontier of southern Montana indicates that the water conditions during that time did not inhibit marine life. In places such as the Vascoceras Beds (unit 3), numerous foraminifera occur and Young deduced from this that sedimentation was sufficiently slow to allow the development of a benthonic faunule. The absence of remains of planktonic forms such as *Globigerina* might have been due to their later destruction by acid groundwaters.

The character of the microfauna (Lagenidae), the presence of ammonites and also the palaeolatitudes show, however, the rather cool temperatures of the environment studied by Young (op. cit.).

Bolin (1956), describing Upper Cretaceous microfossils of Minnesota, deduced from the character of the microfauna, which, in the lower part of the section studied, corresponding to Cenomanian, was dominated by arenaceous genera, that the fauna belonged to a very near-shore probably cold brackish-water environment. He admitted that it was difficult to interpret the ecology of a microfaunal assemblage dominated by planktonic forms such as several species of *Guembelina* and *Globigerina* accompanied by *Neobulimina*, *Planulina*, *Loxostomum*, and *Anomalina* (see Bolin, p. 282) of much smaller size than the average for these species. He also mentioned a few species of radiolarians—genera *Dictyocephalus* and *Dictyomitra*. The microfauna shows striking similarity with that of the Great Artesian Basin, the West Siberian Lowlands and other Boreal areas.

Loeblich and Tappan (1949) studied the foraminiferal assemblages of the Walnut Formation (Walnut Clay, Fredericksburg Group) in Texas and Oklahoma. They described forty-seven species and classified them as being dominated by arenaceous foraminifera, with the family Lituolidae being the most abundant (thirteen representatives). Several of them were of robust size and most abundant (*Buccicrenata* and *Lituola*). The Lagenidae were next in number of representatives. They determined the following genera: *Ammodiscus*, *Trochamminoides*, *Haplophragmoides*, *Ammomarginulina*, *Ammobaculites*, *Ammobaculoides*, *Buccicrenata*, *Lituola*, *Spiroplectammina*, *Textularia*, *Verneuilinoides*, *Quinqueloculina*, *Trochammina*, *Lenticulina*, *Marginulina*, *Dentalina*, *Nodosaria*, *Lingulina*, *Citharina*, *Quadrimorphina*, *Guttulina*, *Pseudoglandulina*, *Turrispirillina*, *Patellina*, *Conorbina*, *Discorbis*, and *Globigerina*. The whole faunule strikingly resembles those occurring in the Great Artesian Basin. The macrofauna of these shales contains *Exogyra*, *Gryphaea*, fragments of Mollusca, echinoids, holothurians, and ophiuroid remains.

Eicher (1960, 1965, 1966, 1967, 1969a, b) studied the foraminifera and biostratigraphy of Boreal and Transitional Cretaceous deposits in the United States, especially the Graneros Shale of Colorado and Kansas. In 1960 he determined the following genera: *Saccammina*, *Ammodiscus*, *Reophax*, *Miliammina*, *Spirolocammina*, *Trochamminoides*, *Haplophragmoides*, *Ammobaculites*, *Ammobaculoides*, *Textularia*, *Pseudobolivina*, *Trochammina*, *Verneuilina*, *Verneuilinoides*, *Gaudryina*, *Lenticulina*, *Praebulimina*, *Valvulineria*, *Heterphelix*, *Globigerinelloides* (*bentonensis*), *Hedbergella*, *Praeglobotruncana*, and *Rotalipora*. However, *Praeglobotruncana* and *Rotalipora* occur only exceptionally in the Rock Canyon, and in the lower part of the Graneros Shale only single *Rotalipora* specimens (*R. greenhornensis*) occur. They apparently represent a marginal part of the Boreal Cretaceous environment of North America.

Later (1965) Eicher studied the foraminifera and biostratigraphy of the Graneros Shale and equivalent strata. He described twenty-three predominating arenaceous and eleven common calcareous species. According to Eicher (1965) the Graneros Shales were deposited in a broadening interior seaway which joined both the Boreal and Gulf Coastal Seas at the beginning of late Cretaceous time. The Graneros Shale occurs in southern and northern Colorado, Kansas, and Wyoming.

In regard to palaeoecology of this area, Eicher compared the microfauna dominated by agglutinantia with that of the Cretaceous Thermopolis, Skull Creek, Kiowa, and Shall Creek Shales in the western interior of the United States and the upper McMurray and lower Kaskapau Formations of western Canada. As well as Loeblich and Tappan (1949), Stelck and Wall (1955), Mellon and Wall (1963), Skolnick (1958), and Eicher (1960) he concluded that such assemblages of foraminifera are characteristic of beds deposited in waters of less than normal marine salinity. These conclusions were based chiefly on the pattern of distribution of modern foraminifera in which the highest proportion of arenaceous foraminifera is usually found in environments where salinity is somewhat lower than that of the open ocean (Eicher, 1965). Analysing the palaeoecology of the Graneros Shale Eicher (1965) quoted Stainforth (1952) who has concluded that waters of certain turbidity were responsible for the dominating arenaceous foraminiferal faunas: "Low salinity, of course, goes hand in hand with excessively turbid water in an inland seaway. Runoff which is adequate to maintain brackish conditions might simultaneously supply a lot of fine suspended material. However, the Graneros Shale did not accumulate rapidly relative to other Cretaceous shale units in the western interior which do contain abundant calcareous foraminifera". According to Eicher (1965) the Graneros Sea was a large elongate sea extending from Alaska to the Gulf Coast. It was connected at both ends with the open sea, but may not have been very deep, especially at first. If the inflow of fresh water exceeded evaporation from the sea, brackish conditions would have been maintained. The sporadic occurrence of planktonic foraminifera in the Graneros and its equivalents indicates that they did not continuously inhabit the interior seaway. The planktonic habit became temporarily common only when favourable currents brought them in from the open ocean to the south; but once in, they did not survive and proliferate. However, the presence of tintinnids in the Graneros Shale and its equivalents was unexpected as nearly all recorded fossil tintinnids are from open marine, pelagic strata, although Recent tintinnids also live in brackish environments (Eicher, 1965).

Similar palaeoecological conclusions were made by Eicher (1966) also for the Belle Fourche Shale and its equivalents in Wyoming and Montana.

South America

According to Harrington (1962), during the Middle Cretaceous there was a marked marine flooding in the northern Andean Basin. Marine Aptian to Cenomanian beds are known in Trinidad, eastern and western Venezuela, the Eastern Cordillera of Colombia, and the middle and upper Magdalena Valley. Some marine sequences with Aptian ammonites were recorded from the Central Cordillera of Colombia. The marine transgression was especially marked along the southern half of the Venezuelan-Peruvian Basin, where the sea flooded areas of eastern Equador and Peru. The Middle Cretaceous is also represented in the Central Cordillera of Bolivia. During the Middle Cretaceous, the marine advance was registered in the northern half of the Chilean Basin. Marine Aptian-Albian beds are known in southwestern Peru and in northern Chile.

In the Patagonian Basin marine sedimentation continued uninterruptedly from the Neocomian into the Middle Cretaceous reaching the maximum in the Albian. It contains fauna, according to Harrington (1962), markedly different from that of the Venezuelan-Peruvian Trough.

In the extra-Andean regions, continental accumulation ceased in the intercratonic basins of Brazil, but in the coastal strip of northern Brazil marine and brackish-water sedimentation continued without interruption.

Except for the microfaunas of the northern part of South America, such as Trinidad and Venezuela studied in detail by Brönnimann (1952), Bermúdez (1952), Bartenstein, Bettenstaedt and Bolli (1957, 1966), Bolli (1951, 1957a, b, 1959), Bolli, Loeblich, and Tappan (1957) and typically representing the Tethyan biogeoprovince, there is not much known about the nature of marine Cretaceous sediments in other parts of South America. In a paper by Stone (1949) new foraminifera from northwestern Peru were described, and in the mentioned paper we can also find some general information on the Upper Cretaceous. In notes on the new genus *Sporobuliminella* there are interesting comments on the assemblage composed of "rich fauna consisting of *Lingulina taylorana* Cushman, *Siphogenerinoides clarki* Cushman and Campbell, *Neobulimina canadensis* Cushman and Wickenden and many other typical Upper Cretaceous forms" and at its type locality *Sporobulimina perforata* is associated with *Siphogenerinoides bermudezi* Stone, *S. reticulata* Stone, *Bolivina explicata* Cushman and Hendling and "other typical Cretaceous forms". However, there are no specific data about the character of this microfauna, but no globotruncanids were mentioned.

Quite a comprehensive study of Cretaceous deposits in Chile was done by Cecioni (1957), who studied the flysch and molasse formations of the Magellan province (departamento Ultima Esperanza). On the basis of faunal analysis, with typical warm-water animals such as rudists, Caprinidae, Nerineidae, and Olividae missing, and some lithological criteria such as the absence of red beds in Patagonia, Cecioni (op. cit.) concluded that the climate during the Cretaceous was cold. "The geographic distribution of the Cretaceous faunas was more probably controlled by the climate and not by eventual geographic barriers, because the Cretaceous Magellan Trough was in contact with North America and Peru, with India through the Mozambique Channel . . . The glacial control theory of the deposition of the Lago Soffa Conglomerate has the virtue of co-ordinating all the data observed."

According to Cecioni (1957) in the molasse the fauna which indicates a littoral environment contained *Plesiosaurus* and was regarded as indicative of increasing temperature.

Interesting information on the character of microfaunas in Chile is given by Martínez-Pardo (1965) who recorded the occurrence of *Bolivinoides draco dorreeni* Finlay in the Magellan Basin. In his quite comprehensive palaeoecologic and palaeogeographic remarks, Martínez-Pardo (op. cit.) reviewed data by other authors studying Cretaceous fossils in South America, who, according to the mentioned author "traditionally" regarded the Cretaceous of Patagonia as being cold. He concluded, on the basis of the occurrence of *Bolivinoides draco dorreeni* in the Upper Cretaceous sediments of the Magellan Basin, which occurs in the Boreal as well as Tethyan areas and, quoting Hofker (1958) who published that this species was confined to the Tethyan area only, that the tropical or warm-water faunas occurred at comparatively high latitudes during the Cretaceous and early Tertiary. He did not analyse the fact that in the Magellan Basin there is a lack of the genus *Globotruncana.*

He thought that the Magellan Basin represented "an enlargement of the climatic conditions prevailing in the Indo-Pacific region which reached southward and should have had its origin in a general world-wide increase of temperature toward the end of Maastrichtian time".

Herm (1966) gives the most important information on the palaeogeography of the Magellan Basin. The microfaunas he described from South America show striking similarities to those of the Australian and especially the New Zealand Lower and Upper Cretaceous and are in full agreement with the present author's observations and conclusions.

South Africa

The characteristic Austral Cretaceous strata of South Africa are represented by sediments of the Uitenhage Basin and associated basins. Lower Cretaceous marine strata were regarded as Neocomian in age on the basis of ammonites. Ostracodes coming from the Uitenhage Group were recently studied by Dingle (1969a, b), and are confined to the coastal areas in the east and southeast. The thickest sequence with extensive outcrops occurs in the southern part of Cape Province, where a series of intermontane basins are preserved between the east–west folded Cape sequence. The largest and best known of these is the Uitenhage Basin. It is an irregular elongate basin invaded by the sea from the southeast. Sediments of this basin are terrestrial, fluviatile, and estuarine ("Wealden facies" series), with marine intercalations forming the Sundays River Formation. This formation becomes markedly thicker to the south and the deepest part of the Uitenhage Basin possibly lies off-shore on the present-day continental shelf, where a complete marine Cretaceous succession can be expected (Dingle, 1969a). Marine fossils occur throughout the formation, and ammonites, while not common, are well represented. After the Lower Cretaceous (Neocomian) sedimentation the southeastern and eastern parts of the South African continental margin were subjected to strong movements and erosion resulting in the isolation of small tectonic outliers of Neocomian strata at Ungasana River and Embotyi, and further south in the deep Uitenhage and associated basins. Sedimentation commenced again in the Aptian and the marine transgression progressed southwards throughout the Upper Cretaceous. Dingle (1969a) described one new genus, one new subgenus, and eight new species from the Sundays River Formation.

Of great palaeoecological value is negative information on the planktonic foraminifera, particularly globotruncanids in the Uitenhage Group in South Africa, given by Dingle (1969a).

Analogous Cretaceous sequences are known also from Mozambique where palaeotemperature measurements on some belemnites (see Bowen, 1961b) provided unusually low temperatures at a time when in Europe a climatic maximum was approaching. According to Bowen (op. cit.) it appeared possible that the poles were located somewhere in the regions now occupied by the Bering Sea in the north and South Africa in the south. The equator, which is known to have been situated in the southern United States and southern Europe, is consistent with this interpretation. There is some evidence that the pole position and that of the equator were much the same throughout the Mesozoic (Bowen, op. cit.).

CONCLUSIONS

The author of this paper distinguishes the following foraminiferal zones and subzones in the Great Artesian Basin representing the time span from the Lower Aptian to Lower Cenomanian in marine development:

1. Zone of *Textularia anacooraensis*—covering the whole Aptian
    - subzone of *Trochammina raggatti*—Lower Aptian
    - subzone of *Trochammina minuta*—Upper Aptian

2. Zone of *Ammobaculoides romaensis*—covering the whole Albian
   subzone of *Pseudolamarckina* sp.—Lower Albian
   subzone of discorbids—Upper Albian
3. Zone of *Lingulogavelinella frankei* and *Valvulineria parvula*—Lower Cenomanian

Until now there has been some confusion concerning the specific character of microfaunas and their ecology in the marine Cretaceous sequences of the Great Artesian Basin.

1. The foraminiferal assemblages were regarded (Ludbrook, 1966; partly Crespin, 1956, 1963) as endemic and unique in their habit, although Crespin partly mentioned their similarity with those occurring in the Lower Cretaceous of Alaska, Canada, and some parts of the United States.
2. There was a tendency to explain some features of the Cretaceous assemblages of the Great Artesian Basin, e.g., predominance of agglutinated forms and the presence of only some groups of calcareous forms as well as low frequency, small dimensions, and simplicity of planktonics, as evidence of the brackish nature of the environment in the Great Artesian Basin during the Lower Cretaceous at least intermittently.
3. The environment was regarded as having been shallow, turbid, and warm because confusion caused by comparatively high palaeotemperatures based on belemnites and ranging from 13·8° to 15·0° C (see Ludbrook, 1966, p. 25; see also recent publication by Wopfner, Freytag, and Heath, 1970).

However, the results of studies by the present author show that there are striking similarities between the Boreal microfaunas, both foraminiferal and ostracodal, of the Northern Hemisphere and those of the Great Artesian Basin. The present author interprets the marine Cretaceous environment of the Great Artesian Basin as well as that of the Upper Cretaceous Otway Basin (see also Taylor, 1964) as an Austral (anti-Boreal) equivalent in the Southern Hemisphere of the Boreal environments of the Northern Hemisphere.

During the Cretaceous (upper part of the Lower and the Upper) south and north of the tropical Tethys which was circumglobal and modified by local oceanographic and climatic conditions, areas of vast epicontinental flooding were distributed. They belong to two categories:

1. Epiplatform sedimentary covers—forming the essential part of the Boreal and Austral marine flooding and very often having the character of semi-enclosed seas.
2. Geosynclinal sedimentary basins—comprising only a small part of Boreal and Austral Cretaceous sedimentation areas, such as the Magellan Geosyncline in South America and the Northern Trough and the East Coast Geosyncline in New Zealand.

In climatic sense, these areas comprise Boreal and Austral zones.

The author of this paper distinguishes the following biogeoprovinces during the Cretaceous:

1. Tethyan, tropical, equatorial, coinciding with the distribution of the Tethyan Ocean and adjacent areas of epicontinental marginal seas.
2. Boreal (cold) biogeoprovince in the Northern Hemisphere between 50° and 90° N. palaeolatitudes with an equivalent Austral (cold) biogeoprovince in the Southern Hemisphere between 50° and 90° S. palaeolatitudes. These biogeoprovinces have analogous microassociations, both foraminiferal and ostracodal, with

several similar or identical species. The faunal composition is strikingly similar within these biogeoprovinces, but there are striking similarities also between the Boreal and Austral biogeoprovinces. Apparently there existed intensive migration of species along isotherms, most probably via the Pacific Ocean, although there seem to be some species confined to the Austral or Boreal regions only.

3. Transitional biogeoprovince comprising regions between the 30° and 50° N. and S. palaeolatitudes with several Boreal elements in fauna, but also some Tethyan faunistic elements, especially globotruncanids. Their variety of species, however, is much less than in the Tethyan area and the *Globotruncana marginata* microfacies is very characteristic.

Cretaceous microfaunas of New Zealand, which until now were regarded as strongly endemic (Hornibrook, 1953, 1958), require special attention. Some of these microfaunas show clear Austral affinities and, on the other hand, especially those of the Upper Cretaceous, contain also some tropical Tethyan elements—globotruncanids and show a transitional character.

In connection with the distinguishing of the Austral biogeoprovince it will be necessary to reconsider the validity of the Indo-Pacific bioprovince during the Cretaceous.

Cretaceous sequences in Australia cover more than a third of the present land masses. They belong to two biogeoprovinces:

1. A biogeoprovince with Tethyan influence in the western, northwestern, and part of the northern margins of the Australian continent, where marine Cretaceous deposits range from Lower (or upper part of Lower) to Upper Cretaceous and their microfaunas show a strong Tethyan influence. The latter ones were deposited in warm (subtropical, warm currents influenced) epicontinental basins such as the Carnarvon and Perth Basins, and the Bathurst Island area, etc., as shown by foraminiferal faunas containing typical Tethyan globotruncanids. Palaeotemperatures based on belemnites from the Albian, or Cenomanian, according to Bowen (1961b) gave a value of 17·5° C and those based on Turonian and younger material values over 20° C, one value being over 30° C in the Giralia area. This fact, and also the fact that microfaunas of the Lower Cretaceous of this area have a similar character to those occurring in the Great Artesian Basin (Belford, 1958), may serve as evidence of the existence of a warm current along the northern and western margins of Australia starting with Upper Cenomanian and Lower Turonian time. However, these data are extremely interesting also from the point of view of continental drift. Comparatively high palaeolatitudes in this area (according to Irving, 1964, the Carnarvon and Perth Basins area was situated between 50° and 60° S. and Bathurst Island between 30° and 40° S. during the Cretaceous) are in agreement with this idea.

2. A second, much more extensive area of epicontinental Cretaceous sedimentation on the Australian continent, was widely distributed over its central, northern, eastern, and southern sections. The marine sequences here are mostly restricted to the Aptian, Albian, and Cenomanian. Basal Cretaceous (pre-Aptian) and Upper Cretaceous (post-Cenomanian) strata are mostly non-marine (fluviatile, lacustrine, and terrestrial). These conditions were usual in the Great Artesian Basin and to a lesser extent in the adjacent smaller basins which were probably connected with it from time to time. The only marine development of the Upper Cretaceous (Turonian up to Maastrichtian) is known from the Otway Basin in Victoria and foraminiferal assemblages were studied by Taylor (1964).

The Great Artesian Basin covers an inland area of about 1·2 million km² (463,000 square miles) in Queensland, the Northern Territory, South Australia, and New South Wales, and is subdivided by pre-Mesozoic basement ridges into a few minor sub-basins. Sequences in these sub-basins reach up to 2,500 m (8,200 feet) in thickness and are gently folded. The basement for the Great Artesian Basin is provided by the Australian cratogen in the western part and by elements of the Palaeozoic Tasman fold belt and its early Mesozoic cover in the eastern part.

Although the Great Artesian Basin is smaller, it is possible to compare it with such vast artesian basins as the West Siberian Artesian Basin which covers an inland area of 2·5 million km². It represents also an epi-Palaeozoic platform cover. The extent of the marine deposition (with a few terrestrial episodes) covers the time of Jurassic-Cretaceous and Tertiary. This basin has an analogous geological development, although the extent of the marine flooding, having the character of a semi-enclosed sea, was much larger and comprises also the Upper Cretaceous and large part of the Tertiary. Marine Cretaceous sequences of the West Siberian Artesian Basin or the West Siberian epi-Hercynian Platform contain very similar microassemblages to those of the Great Artesian Basin.

The Great Artesian Basin was developed as an epi-Palaeozoic platform cover and during the Jurassic terrestrial, and during the Cretaceous terrestrial and marine, developments existed. The Cretaceous flooding represented a semi-enclosed sea (as defined by Menard, 1967, and Hedberg, 1970) with definite epicontinental character. The sea was mostly shallow (up to 300 m, with local depths of more than 1,000 m), cold (in comparison with the Tethyan area) and most probably of normal or close to normal salinity.

Microassociations of the marine Cretaceous strata of the Great Artesian Basin have characteristic features similar to those occurring in some Recent (especially semi-enclosed) arctic shallow seas (see Phleger, 1952; Cooper, 1964, and others). Although most of the Cretaceous species have not survived, the general composition and character of agglutinated and calcareous benthos, as well as planktonics, are strikingly similar.

On the other hand, Cretaceous marine microassemblages of the Great Artesian Basin are analogous, in many cases identical, with those of the "classical" Boreal areas of the Northern Hemisphere such as the West Siberian Lowlands, the North American epiplatform Boreal Cretaceous, and part of northern Europe. Planktonics are represented by only a few species of simple globigerine-shaped forms and *Heterohelix* in the Upper Cretaceous.

Agglutinated forms tend to dominate assemblages and often reach larger dimensions than those occurring in warm environments. They are represented principally by certain species of the genera *Hyperammina*, *Psammosphaera*, *Saccammina*, *Pelosina*, *Ammodiscus*, *Reophax*, *Haplophragmoides*, *Trochamminoides*, *Trochammina*, *Ammobaculites*, *Ammobaculoides*, *Verneuilina*, *Verneuilinoides*, and *Uvigerinammina*.

Calcareous benthos makes a second important part of these assemblages characterized mainly by certain species of the genera *Nodosaria*, *Dentalina*, *Lagena*, *Lenticulina*, *Marginulina*, *Marginulinopsis*, *Globulina*, *Pyrulina*, *Neobulimina*, *Praebulimina*, *Discorbis*, *Lingulogavelinella*, *Pseudolamarckina*, *Valvulineria*, *Cibicides*, and *Epistomina*. Their shells are often of unusually small dimensions, smooth or only very simply ornamented and thin. Decalcification phenomena are quite frequent.

The marine character of these associations is denoted not only by the presence and taxonomic variety of such families as Globigerinidae, Nodosariidae as well as Radiolaria, but also by the presence of Ammonoidea, ophiuroid ossicles and other exclusively marine animals in the accompanying macrofauna.

The microfaunal assemblages (both foraminiferal and ostracodal) are not endemic but contain several cosmopolitan forms characteristically occurring in other areas with similar palaeoecological conditions. Their number will increase after necessary revision and correlation studies. Authors working in different parts of the world with Boreal microfaunas often used new specific names for the same species over vast areas. The similarity of the assemblages of the marine Cretaceous strata of the Great Artesian Basin to those of the West Siberian Lowlands, North American Boreal Cretaceous, and part of northern Europe is striking and the present author suggests as the most logical explanation of these affinities the analogous environmental conditions—cold water and the epicontinental, semi-enclosed character of the sedimentary basins.

The suggestion of cold Boreal and analogous cold Austral biogeoprovinces during the Cretaceous is supported by palaeomagnetic and palaeotemperature studies. According to Irving (1964) the Australian continent was at very high latitudes on the whole, and the area of the Great Artesian Basin and also that of the Otway Basin lay between 50° and 70° S. For comparison, the palaeolatitudes of the West Siberian Lowland during the Cretaceous lay between 50° and 80° N. and those of the North American Boreal Cretaceous between 50° and 80° N.

Palaeotemperatures given by Lowenstam and Epstein (1954), Dorman and Gill (1959), and Bowen (1961c) for the Great Artesian Basin are values between 12·2° and 16·6° C with the exception of a measurement of a sample from around Oodnadatta, which was 21·9° C according to Bowen (1961c). Although the value of the palaeotemperature measurements is probably rather comparative than absolute, they show a possible Cretaceous climatic zonation for the Australian continent during the Cretaceous from south-southeast (cold Austral) to north-northwest (warm, under the influence of a warm current along what is now the northern and western margins of the land mass) with a Transitional zone. The trend of these zones accords well with the palaeolatitudes proposed by Irving (1964, figure 9.16, p. 199).

As already mentioned, the microassemblages of the Great Artesian Basin are markedly similar (also on specific level) in character to the Boreal faunas of the Northern Hemisphere. On the other hand, the microfaunas of the Great Artesian Basin are strikingly similar to those occurring in the South African marine Cretaceous assemblages. The foraminiferal faunas from southern continents have not been studied in detail, but have in common at least an absence of diversified globotruncanids (Dingle, 1969a, p. 161; Martínez-Pardo, 1965; Stone, 1949: Taylor, 1964). These assemblages appear to represent an Austral (anti-Boreal) faunal biogeoprovince of the Southern Hemisphere equivalent to the Boreal biogeoprovince of the Northern Hemisphere.

Results of the study of macrofaunas of the Great Artesian Basin accord very well with the author's results of the study of foraminifera. As early as in the thirties Whitehouse and in the fifties David recognized the affinities of the macrofauna (especially ammonites) of the Great Artesian Basin with the Boreal assemblages and defined their cold-water character. Recently Day (1969) contributed considerably to the definition of the environment of the Great Artesian Basin during the Cretaceous and interpreted the macrofaunas (mainly ammonites) as being temperate or cool temperate, equivalent to some Boreal assemblages of the Northern Hemisphere.

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ADDENDUM

After the manuscript of this paper was submitted for publication, the author visited Professor Dr M. F. Glaessner and Dr M. Wade (Adelaide University), and Dr B. McGowran and Dr N. H. Ludbrook (Department of Mines, Geological Survey of South Australia, Adelaide) and had interesting discussions, as well as seeing collections of foraminifera housed in the Adelaide University and the Geological Survey of South Australia. The author further had the opportunity of visiting New Zealand Cretaceous and Tertiary sequences, of seeing the extensive collections of the Geological Survey of New Zealand, and of benefiting from discussions with Dr N. de B. Hornibrook, Dr Jenkins, Dr Speden, Dr Stevens, and Dr P. N. Webb. Many suggestions in this manuscript were confirmed, especially on the identity of Cretaceous foraminiferal species occurring in Australia and New Zealand, such as *Lingulogavelinella frankei* (Nykova), *Gavelinella parvula* (Crespin), and discorbids which are regarded as good index markers. The author had also an opportunity to see material described by Stoneley (1962) which is a matter of revision by P. N. Webb.

During the publication of this paper a note on the species mentioned in this paper as Anomalinid indet. n. gen. n. sp. (p. 11) was submitted for publication in the *Contributions from the Cushman Foundation for Foraminiferal Research* and named *Bilingulogavelinella australoborealis* n. gen. n. sp.

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Chart 2. Tentative stratigraphic value of foraminifera in borehole DM Bellfield 1 and 1a.

Chart 3. Relative abundance of foraminiferal families in borehole DM Bellfield 1 and 1a.


C R E T A C E O U S
L O W E R
A P T I A N
A L B I A N
VRACONIAN
UPPER CENOMANIAN
R O L L I N G D O W N S G R O U P
CHRONOSTRATIGRAPHIC UNITS
LITHOSTRATIGRAPHIC UNITS
LITHOLOGY
METRES
FEET
SCALE
FIELD SAMPLES (footages)
POSITIVE SAMPLES
CLAUCONITE
ASTRORHIZIDAE
SACCAMMINIDAE
AMMODISCIDAE
HORMOSINIDAE
LITUOLIDAE
TEXTULARIIDAE
TROCHAMMINIDAE
ATAXOPHRAGMIIDAE
MILIOLIDAE
NODOSARIIDAE
POLYMORPHINIDAE
DISCORBIDAE
ANOMALINIDAE
CERATOBULIMINIDAE
RADIOLARIA
OSTRACODA
RELATIVE ABUNDANCE OF FORAMINIFERAL FAMILIES
OTHER MICROFOSSILS
REFERENCE
50%
0%
THIS WIDTH INDICATES PERCENT - RELATIVE ABUNDANCE OF FORAMINIFERA
SHALE
SILTSTONE
CLAYSTONE
SANDSTONE


CRETACEOUS
LOWER
APTIAN
ALBIAN
VRACONIAN
UPPER CENOMANIAN
CHRONOSTRATIGRAPHIC UNITS
ROLLING DOWNS GROUP
LITHOSTRATIGRAPHIC UNITS
LITHOLOGY
METRES
FEET
SCALE
FIELD SAMPLES (footages)
POSITIVE SAMPLES
TEXTULARIA ANACOORAENSIS
AMMOBACULOIDES ROMAENSIS
VERNEUILINOIDES KANSASENSIS
LINGULOGAVELINELLA FRANKEI
FORAMINIFERAL ZONES
Hyperammina gaultina
Psammosphaera scruposa
Saccammina alexanderi
Saccammina sp.
Reophax deckeri
Pyrulina exserta
Textularia anacooraensis
Pseudobolivina variana
Trochammina raggatti
Dentalina hamiltonensis
Lenticulina cephalotes
L. australiensis
L. cf. cretacea
L. dalhousiensis
L. harpa
Marginulinopsis cf. loeblichae
Globulina lacrima
Pyrulina cylindroides
Marginulina cf. texasensis
Marginulinopsis cf. australiensis
Haplophragmoides excavatus
H. cf. arenatus
Ammobaculites irregulariformis
A. junceus
Trochammina cf. apricaria
Ammobaculoides romaensis
Ammomarginulina peterella
Bigenerina loeblichae
Trochammina minuta
T. cf. rainwateri
T. cf. minuta
Ammobaculites cf. minima
Nodosaria regularis
Quinqueloculina sp.
Dentalina communis
D. santoodnae
Lagena apiculata
Lenticulina warregoensis
Lenticulina sp. 1
Marginulina curvatura
Haplophragmoides wilgunyaensis
Marginulinopsis collinsi
Haplophragmoides gigas
Discorbis sp. 1 (=D. sp. 5:Hamaoui 1965)
Discorbis sp. 2
Gen. indet. nov. gen. nov. sp.
Discorbis sp. 3
Valvulineria gracillima
"Hergottella" jonesi
Cibicides sp.
Epistomina australiensis
Pelosina lagenoides
Ammodiscus cretaceus
Haplophragmoides eggeri
Lingulina cf. malamila
Pseudolamarckina nov. sp.
H. topagorukensis
H. cf. collyra
H. cf. nonioninoides
Haplophragmoides sp. 1
Cribrostomoides sp.
Dentalina cf. nana
Reophax sp. 1 (Crespin 1963)
Ammobaculites fisheri
A. erectus
Textularia sp. 1
Textularia sp. 2
Trochammina wetteri
T. cf. triformis
Trochammina sp. 1
Trochammina sp. 2
Verneuilina howchini
Verneuilinoides kansasensis
V. crespinae
Uvigerinammina sp.
Nodosaria cf. orthopleura
Dentalina guttifera
Lenticulina bononiensis
L. triangularis
L. excentrica
L. grata
L. compressa
Lenticulina sp. 2
L. cf. acuta
Marginulinopsis subcretacea
Pyrulina sp.
Lingulogavelinella frankei
Pseudopatellinella howchini
Valvulineria parvula
REFERENCE
LESS THAN 2 SPECIMENS
MORE THAN 2 AND LESS THAN 10 SPECIMENS
MORE THAN 10 SPECIMENS
SHALE
SILTSTONE – MUDSTONE
CLAYSTONE
SANDSTONE
EXPECTED OCCURRENCE OF SPECIMENS


CRETACEOUS
LOWER
APTIAN
ALBIAN
VRACONIAN
UPPER
CENOMANIAN
CHRONOSTRATIGRAPHIC UNITS
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PSEUDOLAMARCKINA
DISCORBIDS
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RADIOLARIAN HORIZONS
Hyperammina gaultina
Psammosphaera scruposa
Saccammina alexanderi
Saccammina sp.
Pelosina lagenoides
Ammodiscus cretaceus
Reophax deckeri
Reophax sp. (=R. sp. A:Crespin 1963)
Haplophragmoides cf. eggeri
H. cf. lapillosus
H. cf. platus
H. topagorukensis
H. wilgunyaensis
H. cf. collyra
H. cf. nonioninoides
H. excavatus
H. gigas
H. cf. arenatus
Haplophragmoides sp. 1
Cribrostomoides sp.
Trochamminoides cf. apricaria
Ammobaculites irregulariformis
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