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STRATIGRAPHY AND MICROPALAEONTOLOGY OF THE UPPER CRETACEOUS OF WESTERN AUSTRALIA

by

D.J. BELFORD

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ABSTRACT

The distribution, relationships and stratigraphical significance of the microfaunas (mainly foraminifera) in the Upper Cretaceous deposits of Western Australia are discussed, and palaeogeography and palaeoecology considered.

Formations deposited during the Cenomanian-Turonian are the Gearle Siltstone and Alinga Greensand and perhaps the Molecap Greensand. Among the foraminifera recorded are the stratigraphically restricted planktonic forms *Globotruncana (Praeglobotruncana) stephani* subspp. and *G. helvetica.*

The lower part of the Toolonga Calcilutite and the Gingin Chalk were deposited during the Santonian. These formations contain the crinoid genera *Marsupites* and *Uintacrinus*, several species of *Globotruncana* and *Neoflabellina* and *Bolivinoides strigillata strigillata*. Santonian beds are known in subsurface section as far north as the area of the Warroora Anticline.

The Toolonga Calcilutite extends up into the lower Campanian and *Globotruncana arca* appears in the fauna. The occurrence of Campanian beds in the Perth Basin cannot be proved; most of the Poison Hill Greensand may be of this age. On foraminiferal evidence deposition of the Korojon Calcarenite began during the Campanian. Important species identified are *Globotruncana arca*, *Cibicides voltzianus* and *Bolivina incrassata.*

The upper beds of the Korojon Calcarenite and the Miria Marl are of Maestrichtian age. The Miria Marl contains the species *Globotruncana stuarti*, *G. citae* and *G. contusa*. The upper beds of the Poison Hill Greensand may range into the Maestrichtian.

INTRODUCTION

This paper reviews the present knowledge of the distribution and relationships of the Upper Cretaceous foraminifera of Western Australia; their stratigraphical and Palaeogeographical significance is also considered. Much of the information presented here has been obtained from samples forwarded by West Australian Petroleum Pty. Ltd., and permission from the Company to use this information is gratefully acknowledged.

Upper Cretaceous microfaunas were first recorded from Western Australia almost 50 years ago, but knowledge of their distribution and relationships was very incomplete until detailed field work was begun in the Carnarvon Basin by geologists of the Bureau of Mineral Resources in 1948. Surface samples collected in the Carnarvon Basin by geologists of the Bureau since that time have been examined for microfossils; examination of surface and sub-surface samples collected by West Australian Petroleum Pty. Ltd. during the search for oil in Western Australia has also greatly increased knowledge of the micro-faunas. Investigations have, up to the present, been carried out mainly in the area of the Carnarvon Basin, and the foraminifera have enabled correlations to be made with areas outside Australia.

OUTLINE OF GEOLOGY

In Western Australia, Upper Cretaceous marine sediments are known only in the Carnarvon Basin, which extends from Onslow in the north to the Murchison River in the south, and in the Perth Basin, near Gingin and Dandaragan. The most northerly outcrop in the Carnarvon Basin is on the Giralia Anticline; the geology of this area is given by Condon, Johnstone, Prichard and Johnstone (1956); the Upper Cretaceous sequence includes siltstone, calcarenite and marl, with unconformities in the section. The same sequence was penetrated in bores drilled by West Australian Petroleum Pty. Ltd. on the Cape Range and Rough Range structures, where Upper Cretaceous beds are covered by Tertiary and younger deposits. Upper Cretaceous deposits are also recorded from water bores near Carnarvon, notably the Brickhouse Station Water Bores No.1 and No.4 and the Pelican Hill Bore.

Upper Cretaceous beds crop out in the lower Murchison River and Shark Bay areas. Clarke and Teichert (1948) investigated the Murchison River area; geologists of the Bureau of Mineral Resources and West Australian Petroleum Pty. Ltd. re-examined this area, and also examined the Shark Bay area in 1954, (Johnstone, Condon and Playford, in press). In the Murchison River area the sequence is similar to that of the Giralia Anticline, but is much thinner, and without definite field evidence for disconformities. In the Shark Bay area, only calcilutite crops out; there is little doubt that these outcrops and those of the Murchison River area are continuous beneath a thin cover of sand and travertine. Upper Cretaceous beds occur in quarries between the two outcrop areas, and are also known from numerous water bores, in which the same sequence and lithology have been observed.

In the Perth Basin, the best known sequence is at Gingin (Teichert, 1947; Fairbridge, 1953). The lowermost unit exposed is a glauconitic sandstone, named by Fairbridge the Molecap Greensand; overlying this is the Gingin Chalk, slightly glauconitic at the base and top, and above this another glauconitic sandstone, named by Fairbridge the Poison Hill Greensand. In this section also there is no direct evidence of disconformities. The same sequence occurs at Dandaragan, except that the Molecap Greensand contains two phosphate beds; the beds in these two outcrop areas are probably continuous beneath a thin surface cover.

A deep bore at Pearce Aerodrome, and other bores in the Perth metropolitan area, passed through unfossiliferous glauconitic sandstones, which lithologically have been correlated with the sandstones of the

Gingin sequence (Fairbridge, 1953). No equivalent of the Gingin Chalk was observed in these bores.

PREVIOUS WORK

The Upper Cretaceous microfaunas of Western Australia have been investigated by several workers; the first was Howchin, who in 1907 published a brief description of 37 species from the Gingin Chalk. A chart showing the range of these species as known at that time was published by Glauert in 1910. Chapman (1917) published a more comprehensive paper on the fauna of the same formation, recording and figuring 134 species and varieties of foraminifera, and 20 species and varieties of ostracoda. Chapman and Crespin (in Raggatt, 1936), and Crespin (1938) gave lists of foraminiferal species identified from samples collected in the Giralia-Cardabia area, and commented on the age of the formations. Edgell (1952 and 1954) examined the fauna of the beds of the Giralia Anticline. More recently, the writer (Belford, 1954) has examined outcrop and subsurface samples from the Murchison River and Shark Bay areas, and also samples of the Gingin Chalk. In addition, samples from several bores in the coastal part of the Carnarvon Basin have been examined by Miss Crespin and the writer for West Australian Petroleum Ltd. (see references). B.E. Balme (1956) has found spores of possible Upper Cretaceous age in samples from water bores in the Perth Basin.

In all investigations of the Upper Cretaceous microfaunas of Western Australia, the foraminifera have received more attention than other groups. Ostracoda and radiolaria are often abundant and well preserved, but little work has been done on them.

STRATIGRAPHY.

Following the standard division of the Cretaceous system (see Muller and Schenck, 1943), the boundary between the Lower and Upper Cretaceous in Western Australia is placed between the Albian and Cenomanian stages. Established European stage names have been used in sub-dividing the Upper Cretaceous beds of Western Australia, in preference to introducing local names as has been done in other areas, for example the Gulf

Coast of the United States of America. The succession of Upper Cretaceous smaller foraminifera established in other parts of the world enable fairly exact stratigraphical determinations and inter-regional correlations to be made. The Upper Cretaceous foraminiferal fauna of Western Australia has affinites with those of Europe and America; numerous publications have been consulted during examination of the various foraminiferal assemblages, but in the text only those references relevant to some particular point are given.

The ages of the beds as determined from an examination of the foraminifera do not in all cases agree with those resulting from a study of macro-fossils. Different workers who have examined the macro-fossils are also not always in agreement; this position is similar to that recently reported by Reiss (1956) from the Upper Cretaceous of Israel.

CENOMANIAN-TURONIAN

These two stages are treated together, as the assemblages examined by the writer do not give sufficient evidence to enable a boundary to be drawn between them.

Sedimentation was continuous from the Lower Cretaceous into the Upper Cretaceous, and at the beginning of Upper Cretaceous time the Gearle Siltstone was being deposited in the northern part of the Carnarvon Basin. In outcrop at the type locality, this formation has a thickness of 535 feet (Condon et al. 1956); at other places, lack of reliable dips and poor outcrop make measurement of the thickness difficult. Foraminifera are rare in outcrop samples, and arenaceous forms are dominant. Species recorded are Ammobaculites fisheri Crespin, Ammodiscus cf. cretaceus (Reuss) Trochamminoides cf. coronus Loeblich and Tappan, Gaudryinella cf. irregularis Tappan, Marssonella oxycona (Reuss), Textularia cf. washitensis Carsey, Haplophragmoides sp. and Pelosina sp. Radiolaria are common throughout, with one band of abundant and well preserved specimens towards the top of the formation. Forms identified are Dictyomitra australis Hinde, Lithocampe fusiformis Hinde, Lithocyclia exilis Hinde, Cenosphaera spp. Spongodiscus sp., Saturnalis sp., Rhopalodictyum sp., Spongoprunum sp., Stylosphaera sp., Staurosphaera sp., Spongotripus sp. and Diacanthocapsa sp. This assemblage contains species described by Hinde (1893) from Fanny Bay, Port Darwin, but is much richer.

The foraminiferal assemblage recorded by Edgell (1952) and by Condon et al. (1955) as from the top of the Gearle Siltstone is now known to be incorrectly placed. The sample in which this assemblage occurred was thought to be from the Gearle Siltstone, but it was later recognised to belong in the Korojon Calcarenite. It was this sample which caused Edgell to regard the upper beds of the Gearle Siltstone as Senonian (Campanian) in age.

Subsurface sections of the Gearle Siltstone penetrated by bores on the Rough Range Structure are much thicker than any known from outcrop. A core taken in the lower part of this formation contained an assemblage of foraminifera not known from outcrop samples. Species recorded are Ammobaculites cf. fisheri Crespin, Ammodiscus cf. milletianus Chapman, Bigenerina cf. wintoni Loeblich and Tappan, Globotruncana (Praeglobotruncana) delrioensis (Plummer) Spiroplectammina cushmani Crespin, S. edgelli Crespin, Trochammina minuta Crespin, T. cf. depressa Lozo, Pelosina lagenoides Crespin, Tristix excavata (Reuss) and T. sp. A number of these species have been described from lower Cretaceous deposits in the Great Artesian Basin (Crespin, 1953). Globotruncana (Praeglobotruncana) delrioensis, Bigenerina wintoni and Tristix excavata occur in Texas in the Washita Group, and Trochammina depressa in the Fredicksburg Group (Frizzell, 1954). These beds, according to Schuchert (1943) are of middle to upper Comanchean age, that is, middle Albian to lower Cenomanian, the ages being based on ammonites. The first three species mentioned do not occur below the Upper Albian, and G. (P.) delrioensis seems to be more characteristic of the lower Cenomanian.

Against this, Lozo (no date given) recorded G. (P.) delrioensis from subsurface samples from the Washita Group in Texas, and placed this group in the Lower Cretaceous. The assemblage from the Gearle Siltstone is recorded here, as it may be of basal upper Cretaceous age. On this evidence of either Upper Albian or lower Cenomanian age for beds of the Gearle Siltstone well above the base of the formation in subsurface sections, it is not possible to accept the suggested upper Albian or Cenomanian age for the underlying Windalia Radiolarite (Edgell, 1952). This formation is at least lower Albian in age, and may even be of Aptian age. It is of interest to note that ammonites of the family Aconeceratidae, an Aptian-Albian group, have been found in the Windalia Radiolarite; the age has been given as Cenomanian because of the occurrence of species of the family Acanthoceratidae in the formation (Brunnschweiler, in Condon et.al.1956).

Cores taken on the Rough Range Structure from the upper beds of the Gearle Siltstone also contain assemblages not known from outcrop. One core contained abundant specimens of Globotruncana (Praeglobotruncana) stephani stephani (Gandolfi), G.(P) stephani (Gandolfi) turbinata (Reichel), and very rare G. helvetica Bolli. The species Globotruncana stephani was made the subgenotype of the subgenus Rotundina Subbotina, 1953 (see Kupper, 1955). Later Kupper (1956) compared this species with the subgenotype of the subgenus Praeglobotruncana Bermudez, 1952, G.(P.) delrioensis (Plummer), and found them to be identical. Benthonic forms were rare in this core; species recorded are Anomalina cf. petita Carsey, Gaudryina cushmani Tappan, Spiroplectammina cf. nuda Lalicker, Marssonella oxycona (Reuss) and Trochammina sp.

Kupper (1956) states that the distribution of G.(P.) stephani stephani is generally given as Cenomanian, and that in the upper Cenomanian it is replaced by the sub-species turbinata; he further states that the association of the two subspecies has not been recorded. Later (1956) the same author states that although the absolute range of the subspecies turbinata is Cenomanian-lower Turonian, it is most abundant in the upper Cenomanian. A chart with this paper shows both subspecies restricted to the Cenomanian. Hagn and Zeil (1954), who quote Mornod (1949), state (p.34) that the distribution of the two forms is the same, with the subsepcies turbinata appearing a little later in the section. They also (p.17) record the association of the two subspecies.

From the known stratigraphical range of the planktonic forms present, and the absence of any planktonic species known only from beds younger than Cenomanian, the assemblage from the upper part of the Gearle Siltstone is regarded as upper Cenomanian in age. This assemblage has been found only once, and was the first record of definite and stratigraphically restricted Upper Cretaceous foraminiferal species from the Gearle Siltstone.

Other equally important samples from the upper beds of the Gearle Siltstone, also taken in bores on the Rough Range structure, contain a fauna which shows that deposition of this formation continued into the lower Turonian. These cores contain representatives of the Globotruncana lapparenti group, mainly G. lapparenti Brotzen tricarinata (Quereau), Globigerina cretacea d'Orbigny, Globigerinella aspera (Ehrenberg), Hastigerinella sp. (cf. subcretacea Carsey), Anomalina cf. petita Carsey, Ammodiscus cf. cretaceus (Reuss), and also the forms Bigenerina cf. compressiuscula Chapman, Clavulinoides cf. trilaterus (Cushman) Stensioina sp., Valvulineria sp. and Anomalinoides spp. which previously have been known only in outcrop, from beds of Santonian age. One core also contained rare, small specimens of Globotruncana (Praeglobotruncana) stephani stephani. Published work, (Hamilton, 1953; Hagn and Zeil, 1954; Bolli, 1951; Kupper, 1956), indicates that most of the planktonic species in these cores are not known to occur below the Turonian, while G. (P.) stephani stephani is not known above the lower Turonian. This assemblage is therefore regarded as lower Turonian in age. Spores have been recorded from this horizon by Cookson (1956) who regarded it as possibly Turonian in age.

The relationship between the outcrop and subsurface sections of the Gearle Siltstone in the area of the Giralia and Rough Range Anticlines is not known. The fact that the Upper Cretaceous planktonic foraminifera occurring in the upper beds in subsurface sections have never been recorded from outcrop suggests that the outcrop represents the lower part of this formation. This would agree with the field evidence of disconformity recorded by Condon et al. (1956) at the top of the Gearle Siltstone. Similar assemblages of arenaceous foraminifera occur both in outcrop and in the lower beds of subsurface sections. If this correlation is correct, it is probable that the outcrop beds of the Gearle Siltstone are of

Lower and not Upper Cretaceous age. The problems of the exact position of the Lower Cretaceous-Upper Cretaceous boundary and the Cenomanian-Turonian boundary, have not been solved. A boundary could be drawn between the Cenomanian and Turonian in this area if the vertical ranges of the planktonic species were accurately known. As they have not been recorded from outcrop in the Gearle Siltstone and present subsurface information in insufficient, this is not yet possible.

Other subsurface sections of the Gearle siltstone, or of formations equivalent to the Gearle Siltstone, are known from bores in the Shark Bay area, the Pelican Hill and Brickhouse Bores near Carnarvon, and the Onslow Bore. Arenaceous foraminifera are dominant in samples from all these bores.

In the Murchison River section, the Alinga Greensand is probably to be placed in the Cenomanian-Turonian. Thicknesses of beds are greatly reduced in comparison with outcrops on the Giralia Anticline, and the foraminiferal faunas of the Gearle Siltstone are absent. Rare, poorly preserved radiolaria have been found, and also fish teeth. Belemnites occur in both the Alinga Greensand and the Gearle Siltstone, and form the main basis for a comparison between the two formations.

The Thirindine Radiolarite, underlying the Alinga Greensand, contains very rare Ammodiscus sp., Pelosina lagenoides, Haplophragmoides sp. and abundant poorly preserved radiolaria, (Dictyomitra australis, Cenosphaera spp.). This formation is probably to be correlated with the Windalia Radiolarite, of Lower Cretaceous age.

The Molecap Greensand of the Gingin sequence may also have been deposited during this interval. There is no field evidence of any break in deposition between this formation and the overlying Gingin Chalk; Teichert (1947) regarded the contact as gradational and conformable, and placed the Molecap Greensand in the Santonian. No microfossils are known from the formation; the only fossils found are plesiosaur and fish bones, fossil wood and a belemnite, (?Dimitobelus). Lithologically, the Molecap Greensand is similar to the Alinga Greensand, and as both formations also have a similar fossil content, it is here suggested that they are approimate time equivalents. If this interpretation is correct, there is a time break between the Molecap Greensand and the overlying Gingin Chalk; some support is given to this suggestion by the absence of belemnites from formations above both the Gearle Siltstone and the Alinga Greensand.

During the Cenomanian and lower Turonian, deposition occurred throughout much of the Carnarvon Basin. The greatest thickness of beds was deposited in the northern part of the basin, in the area of the present Rough Range and Cape Range structures. In the Murchison River area, the thickness is very small; either of two reasons may account for this:-

(1) Disconformities are present in the section, but cannot be detected by field observation (except perhaps by abrupt changes in lithology).

(2) This was an area of continuous but very slow deposition.

An indication of the depositional environment may be obtained from a consideration of the faunal and mineral content of the beds. Lowman (1949) showed that assemblages dominated by _Haplophragmoides_ and _Trochammina_ are characteristic of brackish water marshes, or of marine environments with a low oxygen content, and states (p. 1957) "_Haplophragmoides_, _Trochammina_, and their associates tolerate bottom conditions that the normal assemblages do not tolerate". Arenaceous foraminifera also seem to be more characteristic of cold water conditions, (Glaessner, 1945, p.100).

The mineral glauconite is common in the deposits of this interval in the Murchison River and Gingin sequences, but is rare in the Giralia Anticline. Cloud (1955) reviewing the literature dealing with the occurrences of this mineral gave many factors controlling its formation; amongst these are:- (a) at least slightly reducing conditions (i.e. a low oxygen content); (b) marine waters of normal salinity; (c) formed mainly in the neritic zone; (d) not favoured by markedly warm waters; (e) slow rate of detrital influx.

Considering all these factors, it seems probable that the beds of the Murchison River and Gingin sequences were deposited in a near-shore environment, with a low hinterland giving very slow accumulation, and in a reducing environment too extreme to allow the development of a large benthonic fauna. With this interpretation it is unnecessary to postulate disconformities to explain the small thickness of beds deposited. In the area of the present Rough Range and Cape Range structures, which was the main depositional area of the basin at this time, conditions were at first unfavourable to benthonic life, and the assemblages were dominated by planktonic forms. Later, conditions improved, probably to deep, open clear water, allowing a more varied fauna to exist.

After the deposition of the beds discussed above, and probably in lower Turonian time, a general regression began from the Carnarvon Basin, and possibly also the Perth Basin. Deposition was resumed in the Perth Basin and the southern part of the Carnarvon Basin in middle Senonian time.

SENONIAN

(a) Santonian

The only known outcrops of beds of this age are in the Perth Basin, near Gingin and Dandaragan, (Gingin Chalk), and in the lower Murchison River area in the Carnarvon Basin, where the Toolonga Calcilutite was deposited. It should be noted here that the Toolonga Calcilutite as now defined, (Johnstone, Condon and Playford, in press), includes the Toolonga Chalk and Second Gully Shale of Clarke and Teichert (1948). The formation as defined ranges in age from Santonian to Campanian. The age of the lower part of the formation is determined as Santonian by the occurrence in it of plates of the crinoid genera Marsupites and Uintacrinus, which enable a correlation with the Marsupites zone of the standard Cretaceous System (see e.g. Muller and Schenck, 1943). This correlation was first given by Withers (1924) when he recorded the genus Uintacrinus in the Gingin Chalk, and then again in 1926, when the genus Marsupites was found.

Foraminiferal assemblages of the Gingin Chalk and the Toolonga Calcilutite are very similar. The change from the underlying beds is very abrupt; calcareous species predominate, but some large arenaceous species which are not known to occur above the Santonian are also present. These species are Bigenerina compressiuscula Chapman, Goesella chapmani Cushman, and Clavulinoides cf. trilaterus (Cushman). Other arenaceous species are Dorothia cf. bulletta (Carsey), Verneuilina parri Cushman, Marssonella oxycona (Reuss) and Spiroplectammina laevis (Roemer) var. cretosa Cushman, all of which range throughout the Santonian beds. Gaudryina cf. laevigata Franke occurs rarely. Globigerinidae and Globorotalidae are abundant. Species of Globotruncana recorded are G. lapparenti lapparenti Brotzen, G. lapparenti Brotzen tricarinata (Quereau), G. lapparenti Brotzen bulloides Vogler, G. marginata (Reuss), G. ventricosa White, G. aff. concavata (Brotzen) and G. globigerinoides Brotzen (very rare at base of interval only). Globigerina cretacea d'Orbigny and Globigerinella aspera (Ehrenberg) are abundant. Bolivinoides strigillata strigillata (Chapman) is common in the Gingin Chalk, and has been found at several localities in the Murchison River area. Species of Neoflabellina are common; N. praerugosa Hiltermann, N. ovalis Wedekind, N. cf. deltoidea Wedekind, and N. interpunctata gibbera Wedekind (found only in the Murchison River Section). Buliminidae are rare and are represented only by Bulimina reussi Morrow and B. parva Franke. Several species of Frondicularia have been identified such as F. mucronata Reuss, F. teuria Finlay, F. goldfussi Reuss, F. planifolium Chapman, F. archiaciana Reuss. Other lagenid genera such as Robulus, Lenticulina, Marginulina, Saracenaria, Vaginulina, Dentalina and Nodosaria are well represented. Cibicides excavata Brotzen, Anomalina cf. rubiginosa Cushman, Cibicidoides sp., Valvulineria allomorphinoides (Reuss), Bouvigerina aculeata (Marsson), Pullenia reussi Cushman and Todd, Stensioina sp. nov., Osangularia sp. nov. and Anomalinoides spp. also occur (the last three not known above the Santonian).

Bores in the Carnarvon Basin have extended the previously known area of occurrence of beds of Santonian age. Beds of this age have been penetrated in bores on the Grierson, Cape Cuvier and Warroora Anticlines, in the Brickhouse Bores and Pelican Hill Bore, both near Carnarvon, and in the Peron Peninuula No. 2 Bore. The area of the Warroora Anticline is at present the farthest north that beds of Santonian age have been recognised. The foraminifera from these beds are similar to those from outcrop; they include the large arenaceous species, and also species of Neoflabellina, Bolivinoides strigillata strigillata, and Osangularia sp. nov.

Ostracoda are abundant and well preserved in the Santonian and younger beds. Genera identified are Cytherelloidea, Bairdia, Cythereis, Acanthocythere, Cytheridea, Paracypris, Brachycythere and Loxoconcha.

In the Giralia Anticline, although the Korojon Calcarenite has been placed in the Santonian on macro-fossil evidence, no evidence of Santonian age is found in the foraminiferal assemblages.

(b) Campanian.

In the Gingin sequence, the Poison Hill Greensand overlies the Gingin Chalk; no fossils have been found in this formation, and it is not possible to give any definite statement as to its age. Lithologically, the Poison Hill Greensand may be compared with the Boongerooda Greensand of the Carnarvon Basin; this formation is regarded as Palaeocene in age (Condon et al. 1956). Teichert (1947) placed the Poison Hill Greensand in the Campanian, and it is possible that most of the formation is of this age, although the upper beds may extend into the Maestrichtian, or even higher.

In the Murchison River area the depositional environment was unchanged, and the deposition of a calcilutite continued. Lithologically similar deposits of this age also crop out in the Shark Bay area, near the Hamelin Telegraph Station, and on Yaringa North Station. Transgression occurred in the area of the Giralia Anticline during Campanian time, and the Korojon Calcarenite was deposited disconformably on the Gearle Siltstone.

A distinct faunal change occurs in the upper beds of the Toolonga Calcilutite, although several species continue from the underlying Santonian beds. The large arenaceous species of the Santonian are not present; of the Lagenidae, Robulus and Lenticulina are still abundant, but species of Nodosaria, Dentalina and Frondicularia occur rarely. Globotruncana arca appears, in addition to the species of Globotruncana given above for the Santonian. Spiroplectammina grzybowskii Frizzell and Palmula cf. pilulata Cushman occur for the first time in this section. Bolivinoides strigillata strigillata has been found at one locality at the base of the interval, in association with Globotruncana arca. Small papillate species of Neoflabellina, possibly referable to N. rugosa sub-spp., occur very rarely, and also N.sp.aff.praereticulata Hilterman. Globorotalites conicus (Carsey) occurs commonly. Species ranging upward from the Santonian are Marssonella oxycona, Dorothia cf. bulletta, Verneuilina parri, Valvulineria allomorphinoides, Eouvigerina aculeata, Anomalina cf. rubiginosa, and Cibicides excavata.

The beds of the Shark Bay area contain all the species recorded from the Campanian of the Murchison River section, with the exception that Bolivinoides strigillata strigillata has not been found.

In the Korojon Calcarenite of the Giralia Anticline, Globotruncana arca (typical form) occurs throughout. Other species of Globotruncana identified are G.lapparenti lapparenti, G.lapparenti tricarinata, G.ventricosa, and G.marginata. Other characteristic upper Senonian species also ranging throughout the formation are Cibicides voltzianus (d'Orbigny) and Bolivina incrassata Reuss. Areanceous species occurring throughout are Spiroplectammina grzybowskii, S.laevis var.cretosa, Gaudryina laevigata, G.rugosa d'Orbigny, Verneuilina parri and Marssonella oxycona. Lagenidae are abundant; species of Frondicularia recorded are F.archiaciana, F.goldfussi, F.teuria and F.inversa. Palmula cf. pilulata occurs rarely. Bolivinoides decorata (Jones) cf. delicatula Cushman has been recorded towards the base of the formation in the Brickhouse Bore, and B.decorata australis Edgell from the upper beds in outcrop (Edgell, 1954). Neoflabellina praereticulata Hilterman is recorded from subsurface samples on the Rough Range Structure, and N.numismalis Wedekind occurs in outcrop. Stensioina pommerana Brotzen and S.sp.occur frequently throughout.

The Korojon Calcarenite is regarded by the writer, and also by Edgell (1952)as mainly Campanian, with the upper-most beds extending into the Maestrichtian. In Condon (1954) the age is given as Santonian, and in Condon et.al. (1956) as "Santonian, but perhaps also early Campanian"; this age is repeated by Glenister, Miller and Furnish (1955, p.494). The Santonian-early Campanian age is based on cephalopoda found in the formation, and identified by R.O. Brunnschweiler. In the writer's opinion, the absence of the crinoid genera Marsupites and Uintacrinus, the absence of typical Santonian foraminifera, and the occurrence of Upper Senonian forms such as Globotruncana arca, Bolivina incrassata, Cibicides voltzianus and Neoflabellina numismalis leave no doubt as to the Campanian age of the Korojon Calcarenite.

Subsurface information has enlarged the area over which beds of Campanian age are known to occur. All bores on the Rough Range structure, on the Grierson, Warroora, and Cape Cuvier Anticlines, Dirk Hartog Island and Peron Peninsula and also the Onslow Bore have passed through beds of Campanian age. The typical assemblage of the Korojon Calcarenite has been found in all these bores. The assemblage of the upper beds of the Toolonga Calcilutite occurs in samples from the Pelican Hill Bore.

Two biotopes may be recognised in the Campanian of the Carnarvon Basin; one is typified by the assemblage occurring in the beds of the Murchison River area and the other by the assemblage of the Korojon Calcarenite. The two assemblages have some species in common, but they are easily distinguished by the species ~~common~~ restricted to one or the other. Bolivina incrassata, Cibidides voltzianus, Globotruncana arca (typical form) Bolivinoides decorata cf. delicatula, B.decorata australis, Stensioina pommerana, and Neoflabellina numismalis occur in the Korojon Calcarenite, but not in the Toolonga Calcilutite. Bolivinoides strigillata strigillata and Neoflabellina sp.aff. praereticulata are known only from the Toolonga Calcilutite.

The faunal assemblage of the Korojon Calcarenite may be traced from the outcrop area on the Giralia Anticline southward to subsurface sections on Dirk Hartog Island and Peron Peninsula, a distance of some 230 miles. The assemblage of the Toolonga Calcilutite is known over much the same distance from outcrop in the lower Murchison River area to subsurface sections near Carnarvon. The uniformity of the faunas over such an area suggests that the Campanian beds of Western Australia were deposited in a shallow epicontinental sea, as on other continents; in these the faunas are known to have been remarkably uniform over wide areas.

The relationship of the two biotopes of Campanian age is important for both stratigraphy and palaeogeography. Some indication of the ages of the biotopes may be obtained by considering the known vertical range of species common to the Upper Cretaceous of Australia and other parts of the world. Tables have been published showing the vertical distribution of some of these species in Europe. Hiltermann (1953) indicates in Tables 3 and 4 that Bolivina incrassata and Neoflabellina numismalis are more characteristic of upper Campanian and Maestrichtian beds in north-west Germany. Cushman (1946) records B.incrassata from beds of Taylor and Navarro age, that is Campanian and Maestrichtian. In north-west Germany Stensioina pommerana occurs rarely at the top of the lower Campanian, but is more characteristic of the upper Campanian and lower Maestrichtian. Pozaryska (1954) shows this species occurring in the uppermost Campanian and lower Maestrichtian of Poland. Little significance can be attached at present to the record of Bolivinoides decorata cf.delicatula from the upper Cretaceous of Australia. According to Hiltermann and Koch (1950) and Hiltermann (1953), B.decorata delicatula does not occur below the upper Campanian in north-west Germany. However, the form referred to this species by Hiltermann and Koch has been placed by Reiss (1954) in B.regularis sp.nov. The form recorded by Edgell (1954) from the Upper Cretaceous of Western Australia is stated to be similar to specimens from the upper part of the lower Campanian and the basal upper Campanian of north-west Germany, and it has been suggested that they are primitive forms of B.decorata delicatula (Hiltermann, personal communication to Edgell). The taxonomic position of the Australian forms is uncertain; Edgell notes that they are not nearly so highly ornamented as forms referred to this subspecies by Hiltermann and Koch. They are possibly to be included in the group of poorly ornamented Bolivinoides, such as B.praecursor and B.laevigata; specimens are very rare in the Upper Cretaceous of Western Australia and none are available for examination. The most important point is the stratigraphical position of similar forms in the Upper Cretaceous of north-west Germany. Pozaryska (1954) recorded this species from the Upper Cretaceous of Poland, and showed its range as upper Santonian to

Maestrichtian. From her figure (p.56, fig.7) it is obvious that the Polish specimens, or at least those conspecific with the specimens figured, cannot be referred to this species. The species Bolivinoides strigillata strigillata, which occurs in the Toolonga Calcilutite, is not known to range above the lower Campanian.

In some bores both biotopes have been penetrated, and this has given further evidence of the relationship between them. In the Brickhouse Station No.1 Water Bore and the Pelican Hill Bore, both near Carnarvon, Campanian assemblages occur underlying the fauna of the Korojon Calcarenite, and agreeing very closely with the fauna of the Murchison River section. The Santonian-Campanian beds in these bores are almost 1,000 feet thick. Isolated cores from other bores also contain a fauna of Campanian age, with the characteristic upper Senonian species of the Korojon Calcarenite being absent.

The available evidence is sufficient to indicate that these two biotopes contain successive fossil faunas, and are not laterally equivalent. From the known distribution of some species in other areas, the Korojon Calcarenite is regarded as most probably upper Campanian in age, and the upper beds of the Toolonga Calcilutite as lower Campanian. Although the differences between the two biotopes are distinct in outcrop samples, it is probable that the change from one to the other is gradual. The thickness of the Campanian beds in subsurface section indicates that a large part of the section, over which the change could be traced, is not exposed; this gap in outcrop extends from the top of the Toolonga Calcilutite to the base of the Korojon Calcarenite. The nature of the contact between the two biotopes would be known only if a complete subsurface section were available from those parts of the basin where deposition was continuous through the Upper Cretaceous.

The interpretation of the palaeogeography of this area during the Campanian is shown in figures 5 and 6. During the lower Campanian, deposition occurred in the basin only along a narrow coastal strip from north of Carnarvon to south of the Murchison River. In the Perth Basin, positive evidence of deposition during lower Campanian time is lacking.

In the Murchison River and Shark Bay areas, there is no evidence of the deposition of beds younger than the lower Campanian, but as the top of the Toolonga Calcilutite throughout its outcrop area is an erosional surface, it is possible that beds of upper Campanian age have been removed. On Yaringa North Station, beds of Eocene age overlie the Toolonga Calcilutite and all that can be definitely stated is that regression and erosion occurred at some time between the lower Campanian and the Eocene. This regression may have begun at the beginning of Upper Campanian time, together with the transgression in the north over the area of the present Giralia Anticline. The suggested upper Campanian shoreline is drawn along the known limits of beds of this age; further information, particularly in the Murchison River and Shark Bay areas, may make it necessary to move this shoreline to the east.

MAESTRICHTIAN

No outcrops of this age are known from the Murchison River or Shark Bay areas. In the Giralia Anticline, deposition of the Korojon Calcarenite continued; Edgell (1952) considered the uppermost beds of this formation to be Maestrichtian in age, and I also am of this opinion. The Maestrichtian age is based on such species as Bolivinoides draco draco (Marsson), Neoflabellina reticulata (Reuss), Bolivinoides decorata (Jones) gigantea Hiltermann and Koch and Pseudotextularia varians Rzehak. The Maestrichtian species of Globotruncana which occur in the overlying Miria Marl have not been found in the Korojon Calcarenite. The species Neoflabellina reticulata has been regarded as an index fossil for Maestrichtian age (Reiss, 1952: Pozaryska, 1954). Hiltermann (1953) showed this species occurring in the uppermost Campanian of north-west Germany, but has since (1956) modified his Table 5 to show it restricted to the Maestrichtian. Cushman (1946) records the species from the upper part of the Taylor marl, and from beds of Navarro age, that is, upper Campanian and Maestrichtian. Bolivinoides draco draco was also recorded by Hiltermann (1953) from the uppermost Campanian, but is now (1956) restricted to the Maestrichtian; it does not occur below the Maestrichtian of Poland. B.decorata gigantea and Pseudotextularia varians are not known to occur in beds older than Maestrichtian.

Following the deposition of the Korojon Calcarenite, there was a withdrawal of the sea, probably in lower Maestrichtian time, and this was followed by an erosional interval. The sea then returned to the area, and the Miria Marl was deposited disconformably on the Korojon Calcarenite; the area of the present Giralia Anticline, is the only known area of outcrop of deposits of this transgression. Condon et.al. (1956 p.68) consider this disconformity to represent non-deposition in lower and middle Campanian times, on macro-fossil evidence.

In addition to the Maestrichtian species occurring in the Korojon Calcarenite, the Miria Marl contains Globotruncana stuarti (de Lapparent), G.citae Bolli, G.contusa (Cushman), G.caliciformis (de Lapparent) and Coleites sp. Species ranging upward from the Campanian are Bolivina incrassata, Cibicides voltzianus and Globotruncana arca.

Beds of Maestrichtian age, lithologically similar to the uppermost beds of the Korojon Calcarenite, and containing the same fauna, have been penetrated in bores on Cape Cuvier Anticline, Dirk Hartog Island, Peron Peninsula and in the Pelican Hill Bore, near Carnarvon.

On macro-fossil evidence, Spath (1940) regarded the Miria Marl as lower Maestrichtian in age, with possibly some late Campanian. Brunnschweiler (in Condon et.al., 1956) recognised two successive, partly overlapping assemblages, one upper Campanian and the other lower Maestrichtian.

The suggested shore lines for both periods of deposition in the Maestrichtian are shown in figures 7 and 8. Deposition in the Perth Basin again cannot be demonstrated.

It is difficult to reach any reliable conclusions on the ecology of the Santonian, Campanian and Maestrichtian assembalges. There was evidently a strong open water influence, and from the work of Lowman (1949), the frequent abundance of rotaliid species may indicate the middle neritic zone as the environment of deposition. The necessary quantitive work to determine the proportion of planktonic species has not been done but as Bandy (1951) has pointed out, the distribution of these forms could be affected by currents, and therefore be of little significance.

CONCLUSION

The interpretations given above, based on present knowledge of the foraminiferal faunas, may have to be revised in the future, particularly as a result of further subsurface investigations. Much work remains to be done on the Upper Cretaceous micro-faunas of Western Australia, particularly in the description and figuring of the faunas, and in determining more accurately the range of significant species. When this is done it will be possible to zone the beds more closely and to make more exact correlations, and the value of the foraminifera to the stratigraphy of Western Australia will be greatly increased.

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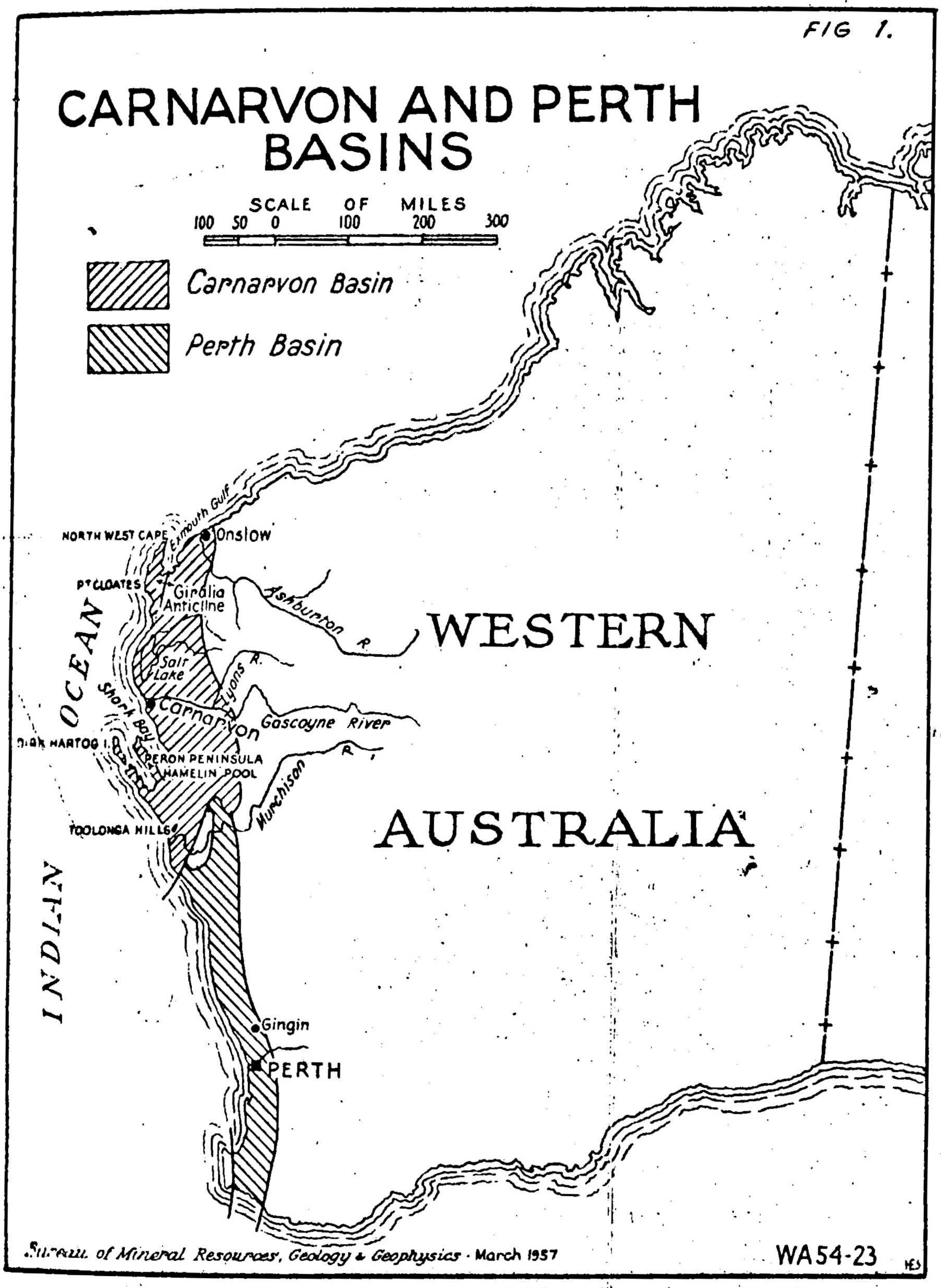
FIG 1.



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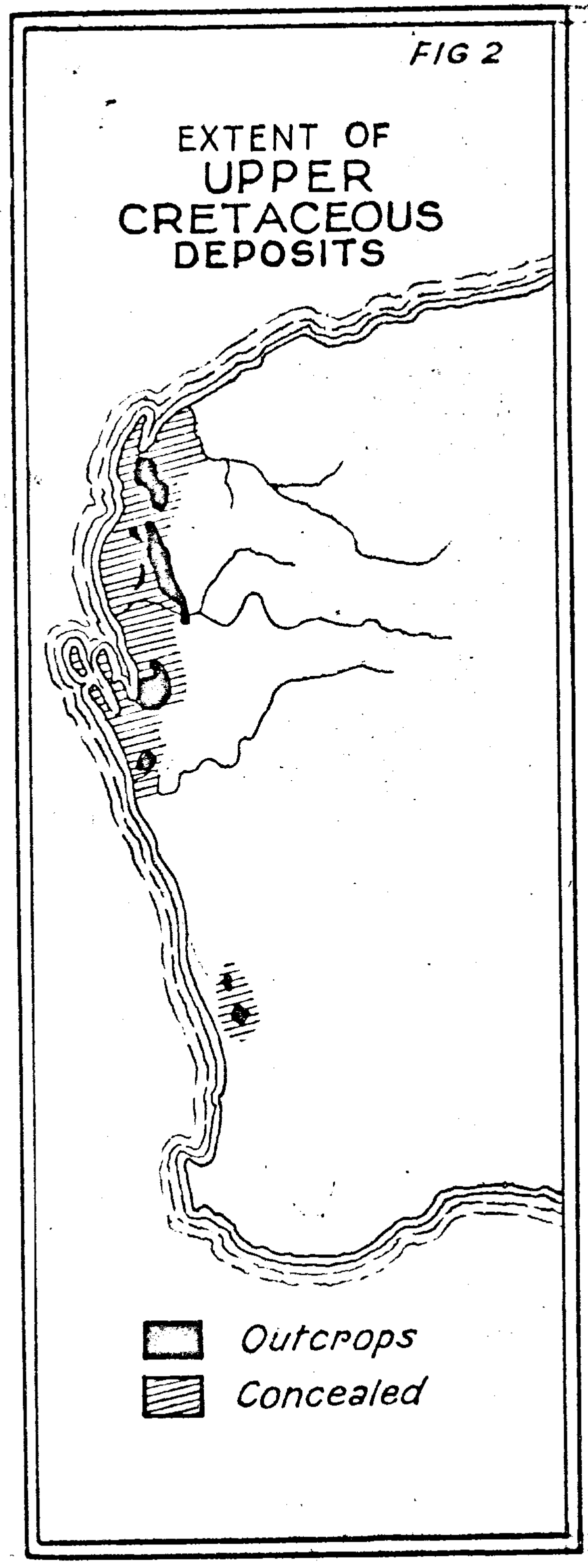
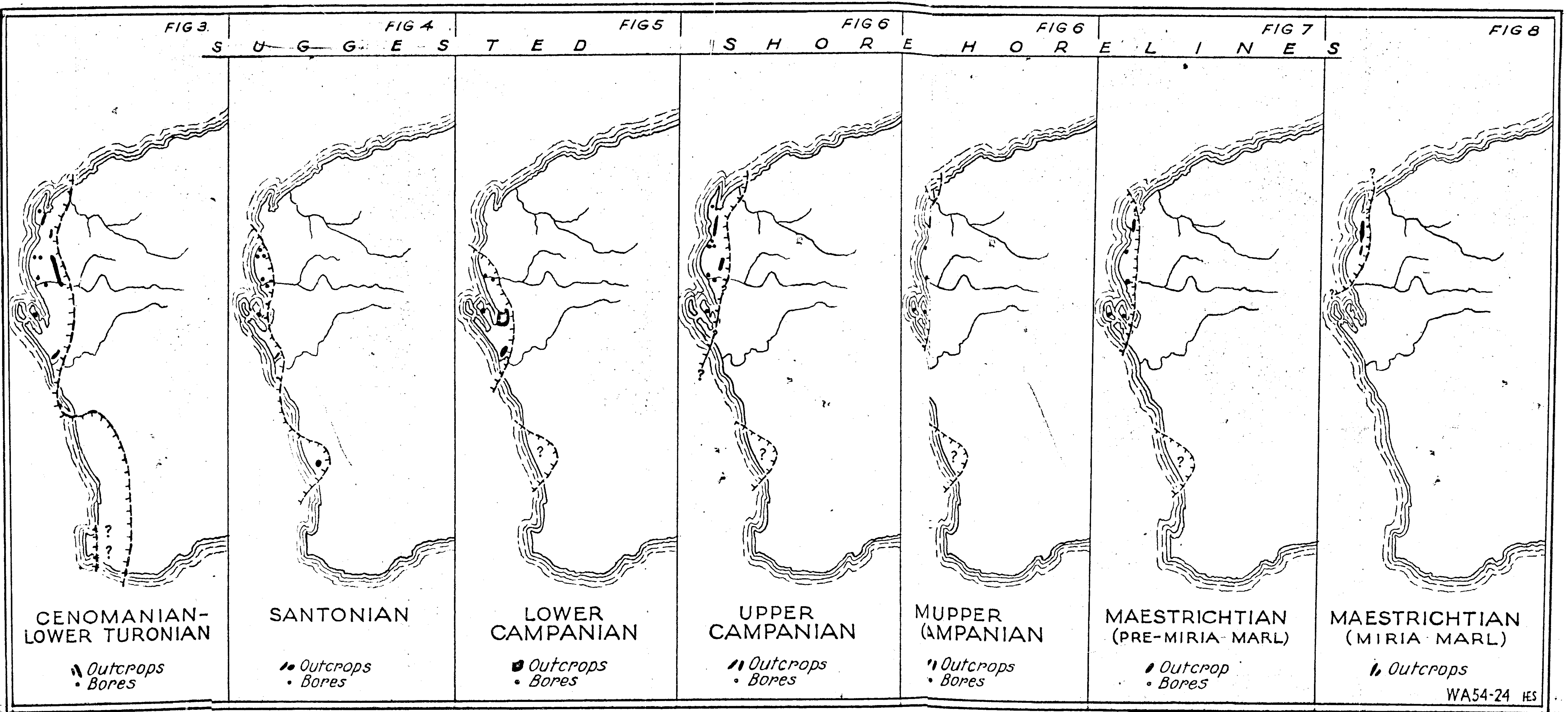


FIG 2
EXTENT OF
UPPER
CRETACEOUS
DEPOSITS
Outcrops
Concealed


S U G G E S T E D S H O R E L I N E S
FIG 3
CENOMANIAN-
LOWER TURONIAN
Outcrops
Bores
FIG 4
SANTONIAN
Outcrops
Bores
FIG 5
LOWER
CAMPANIAN
Outcrops
Bores
FIG 6
UPPER
CAMPANIAN
Outcrops
Bores
FIG 6
MUPPER
(AMPANIAN
Outcrops
Bores
FIG 7
MAESTRICHTIAN
(PRE-MIRIA MARL)
Outcrop
Bores
FIG 8
MAESTRICHTIAN
(MIRIA MARL)
Outcrops
WA54-24 HES

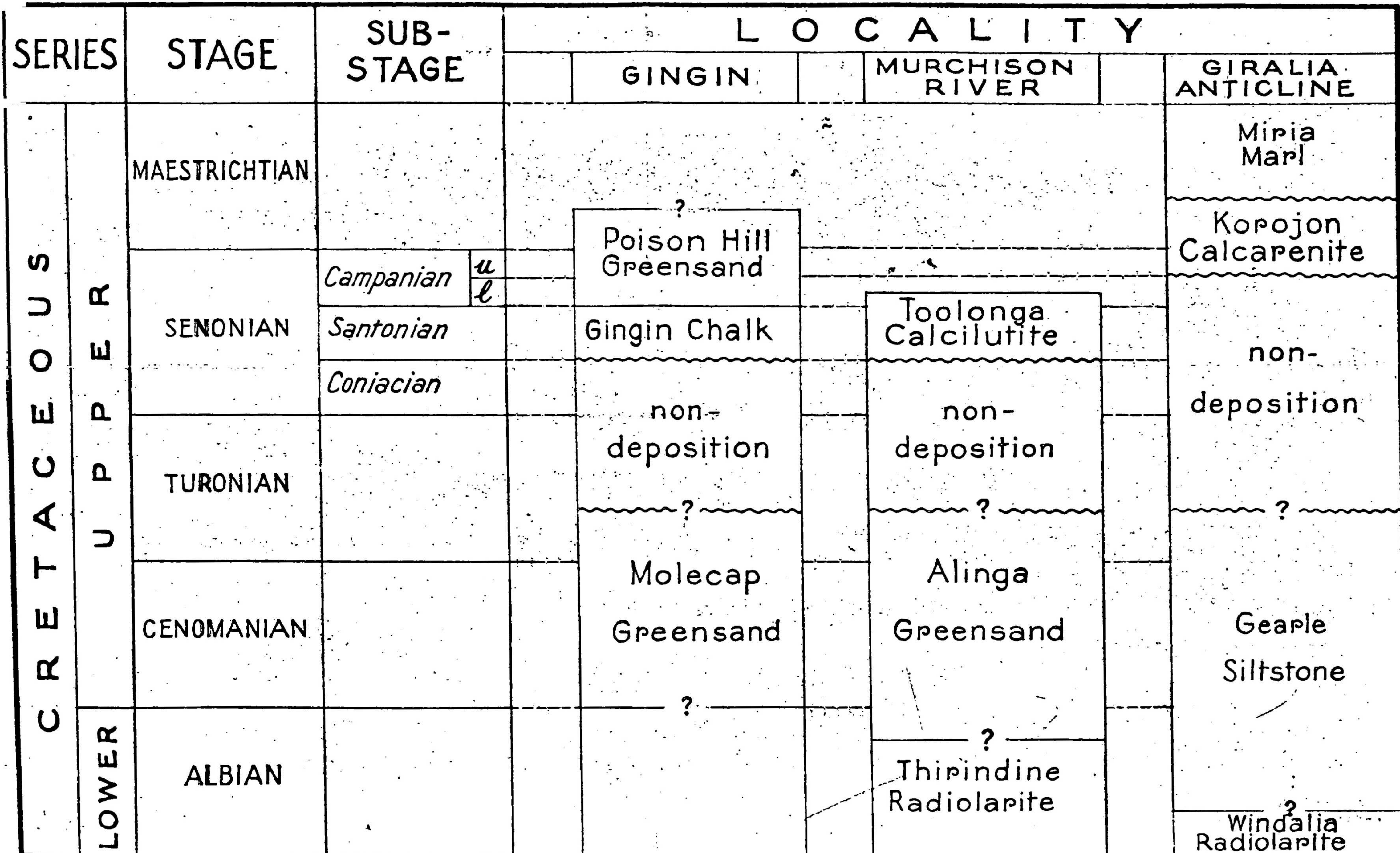


Fig 9. SUGGESTED TIME-RANGE OF UPPER CRETACEOUS FORMATIONS IN WESTERN AUSTRALIA

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