The Karumba Basin, northeastern Australia and southern New Guinea

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The Karumba Basin in its present form coincides areally with the Gulf of Carpentaria and the river systems draining into it.

The Basin is mainly of Cainozoic age, epi-cratonic, and superimposed on the Mesozoic Carpentaria Basin of the Trans-Australian Platform Cover. The development of the Karumba Basin related to the separation of Australia from Antarctica, and to subsequent plate margin events in New Guinea, in contrast to the evolution of the Carpentaria Basin which probably correlated with plate convergence to the east.

The structural basin contains four main sets of deposits, each primarily resulting from an uplift episode. The oldest set, the Bulimba Formation, is probably of late Cretaceous-Paleocene age; the next, the Wyaaba Beds and equivalents, is Miocene to early Pliocene; the third, the Yam Creek Beds and equivalents, is of Pliocene age; the youngest began accumulating in the late Pliocene and is still being deposited. The total thickness of the four sets is about 400 m; they occupy a relatively small part of the present Karumba structural Basin.

This paper proposes and describes the mainly Cainozoic Karumba Basin, accenting it as a tectonic entity. The Karumba Basin is named after Karumba township at the head of the Gulf of Carpentaria; the Basin as it is now coincides with the Gulf of Carpentaria and the river systems draining into it. In the past the rocks and sediments of the Basin have been regarded as being part of the Carpentaria Basin, or as surficial deposits.

Differentiation of the Karumba Basin from the Carpentaria Basin could be based on the regional unconformity between them, and on lithological differences. However, basins cannot be completely defined by their structures and stratigraphies, and ultimately need to be specified according to their origins. Thus recognition of separate Karumba and Carpentaria Basins will be more acceptable if the unconformity and lithologies can be related to distinctive stages of crustal history. The author considers that the evidence given in this paper suggests that the Karumba Basin was consequent on the separation of Australia from Antarctica, an event which ended the development of the Carpentaria Basin.

The history of development of the Karumba Basin thus differentiated provides a uniformitarian and actualistic model with which the evolution of older basins can be compared. However, the Gulf of Carpentaria, which covers most of the Basin, provides an expensive obstacle to investigation, and nearly all the facts about the Basin's rocks come from onshore; between the Gulf and the Arafura Sea the only information about the basin's margins is bathymetry, and a little geophysical evidence which suggests that thin Cainozoic deposits may occur there (cf. Jongsma, 1974).

In what follows the term sedimentary basin will broadly mean the structural entity in which the sedimentary fill is platform cover, and in which most provenance areas to the fill occur.

Late Cretaceous-Early Tertiary: inception of the Basin

The most direct evidence for distinguishing the Karumba Basin from the underlying Carpentaria Basin comes from the Bulimba Formation and the stratigraphic relations it displays (Smart *et al.*, 1972). The Bulimba Formation is present in Cape York Peninsula, and extends under the adjacent part of the Gulf of Carpentaria (Fig. 1; Zwigulis, 1971; Smart, in prep.a).

The continental clayey quartzose sandstone and sandy claystone of the Bulimba Formation rest unconformably mainly on early Cretaceous marine mudstone and labile sandstone of the Rolling Downs Group of the Carpentaria Basin, and to a lesser extent on older rocks of the Basin and of the Georgetown, Yambo and Coen Inliers (Smart, ibid; Smart & Bain, in prep.). The greatest known thickness of the Bulimba Formation is approximately 139 m in BMR Holroyd 1 (Gibson *et al.*, 1974).

That the unit is more than just an alluvial depositional wedge consequent solely on an eustatic regression of the sea from the Carpentaria Basin is shown by 'piano-key' block faulting and associated broad folding along the northern flanks of the Georgetown Inlier. These tectonic movements occurred after Jurassic and early Cretaceous rocks consolidated and before deposition of the Bulimba Formation (Smart & Bain, ibid). The tectonic origin of the unconformity separating the Bulimba Formation from the various early Cretaceous units it overlies is a prime reason for differentiating the Karumba Basin from the Carpentaria Basin; lithological differences and the depositional hiatus are almost as important, but not critical.

Tectonism probably affected most of the eastern margin of the Karumba Basin at this time. Uplift seems necessary before a granitic provenance for the Bulimba Formation could be exhumed from below Carpentaria Basin rocks to provide what was originally arkosic detritus for the unit (Smart, in prep. a), which, apparently also as a result of uplift, in part consists of valley-fill deposits on the flanks of the present Great Dividing Range and Georgetown Inlier.

There is no evidence that the formation accumulated in a downwarp, although some sagging occurred just north of the Euroka Arch (Fig. 1) after early Cretaceous deposition ceased.

The unfossiliferous Bulimba Formation was deposited between early Cretaceous and Miocene times (see discussion on Wyaaba Beds below). The lateritized Aurukun Surface on the formation appears to correlate with an unnamed surface to the south in the Eromanga Basin which was lateritized in Paleocene times (B. R. Senior, pers. comm.; Table 1). The Bulimba Formation is therefore probably of late Cretaceous-early Paleocene age. As corroborative evidence, the uplift with which the formation was associated can be correlated with emergence of adjacent areas to the north in New Guinea between Cenomanian and Miocene times (Dow, in prep.; APC, 1961).

Cessation of deposition of the Bulimba Formation may have occurred more or less simultaneously with, and as a re-

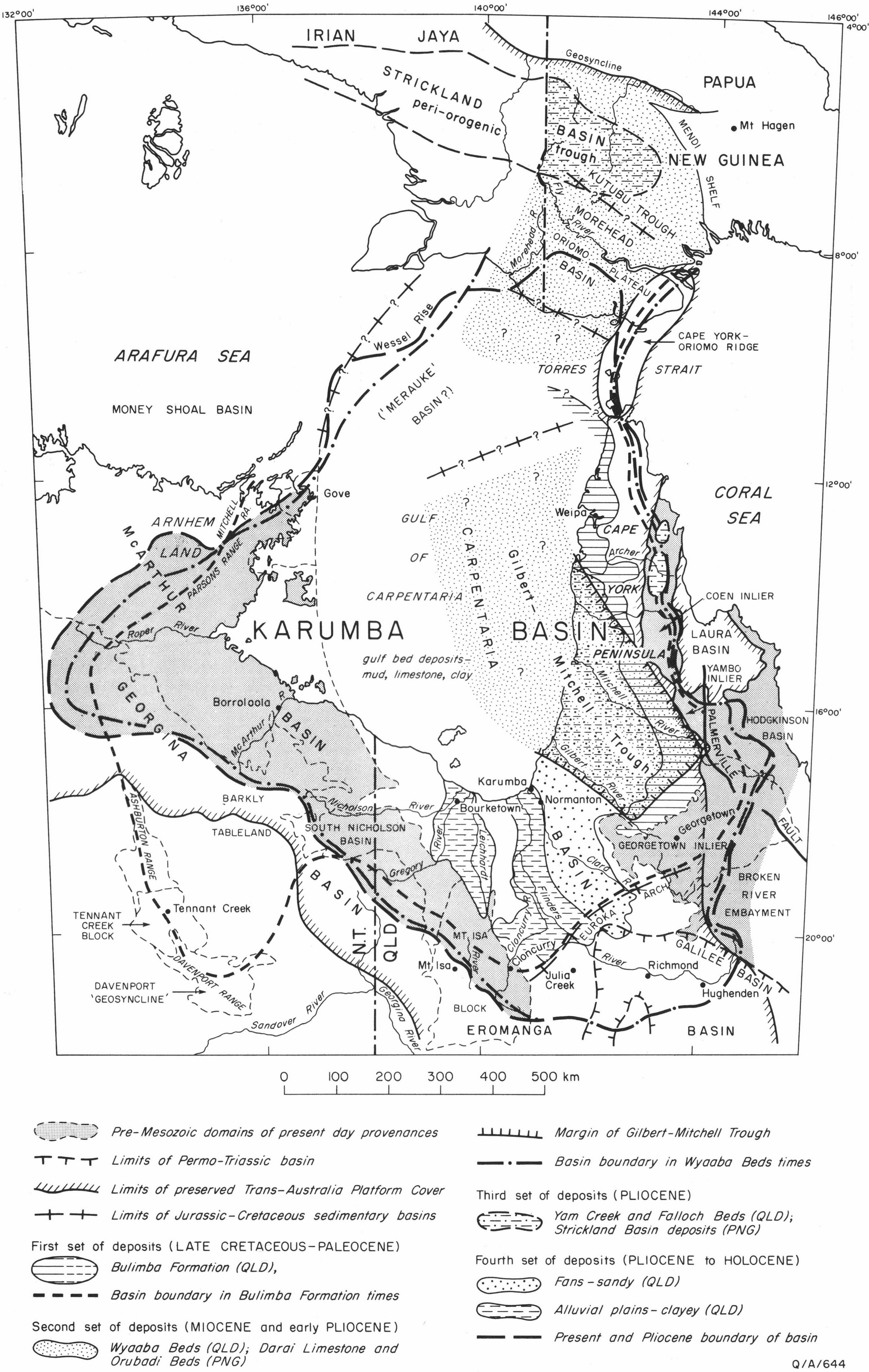

Figure 1. Simplified geology of the Karumba Basin.

sult of, lowering of relief and altitude in provenance areas. Such a terminal state would favour lateritization. This appears to have been the situation in northern Cape York Peninsula, where laterite associated with the Aurukun Surface, preserved as mesa-top peneplain remnants (author, work in progress), occurs on both the Bulimba Formation and the immediately adjacent rocks of Jurassic-Cretaceous age from which it was derived, but not on younger rocks.

The Aurukun Surface is equivalent to Hays' (1967) Tennant Creek Surface (author, work in progress), which was present in southwestern provenance areas of the Bulimba Formation. The bauxite at Gove in eastern Arnhem Land is also an indicator of a contemporaneous surface. In due course parts of these surfaces became provenance areas within the Karumba Basin and were eroded, providing detritus for subsequent basin units.

The late Cretaceous-early Tertiary emerged area in New Guinea is taken to be the northern structural margin of the Karumba Basin at that time. An ancestral Great Dividing Range formed the eastern structural margin. West and south of the present Gulf of Carpentaria equivalents of the Bulimba Formation have not been preserved, and much of this area was probably a provenance for, and in part within, the Basin; the margins of the sedimentary basin there at that time would have been watersheds in the vicinity of the present Parsons and Mitchell Ranges further west of Arnhem Land, the Davenport Range-Tennant Creek-Ashburton Range area in the southwest, and the Mount Isa Block and Euroka Arch in the south (Fig. 1).

Overall, it is proposed that inception of the Karumba Basin occurred in late Cretaceous times as a result of uplifts in New Guinea and Cape York Peninsula. This tectonism is thought to broadly reflect the breaking apart of Australia and Antarctica (Table 1; Falvey, 1971; Boeuf & Doust, 1975). Consequent sedimentation making up the first set of Basin deposits terminated when uplift relief was reduced by erosion. Lateritization completed the initial history of the Karumba Basin.

Late Tertiary: Development of the Basin

Faulting and warping disrupted the lateritized Aurukun Surface (Table 1; Doutch *et al.*, 1973), setting the scene for accumulation of the second set of Karumba Basin deposits, the Wyaaba Beds and their equivalents (Smart *et al.*, 1972; Powell *et al.*, in press), which consist mainly of clayey quartzose sand and sandstone; they are not unlike the Bulimba Formation.

In particular the Gilbert-Mitchell Trough came into existence as the eastern part of the basin (Fig. 1). The downwarping of this trough probably complemented renewed uplifts of the basin margin, which gave rise to a new version of the ancestral Great Dividing Range to the east — especially in the vicinity of the Palmerville Fault (cf. de Keyser & Lucas, 1965, and Willmott *et al.*, 1973 on extent and movements of the fault). The uplifted areas became a new provenance supplying Basin deposits.

The Bulimba Formation, topped by remnants of the Aurukun Surface, forms the basement of the Trough. The contents of the trough may account for the greater part of the 300 m of Cainozoic sediments beneath the Gulf of Carpentaria (Pinchin, 1973); onshore in the southwest of Cape York Peninsula they are represented mainly by the Wyaaba Beds. Again, as in the case of the Bulimba Formation, there is the possibility that slowing down and then the cessation of deposition went hand in hand with a lowering of relief in the provenance areas — and in this instance demonstrably with a reduction in the actual area of provenance. Similarly the culminating event was widespread deep weathering. This time it resulted in the development of patchy silcrete and silicification of the terminal, combined erosional-depositional, Strathgordon Surface, the pediplain part of which resulted from the destruction of the Aurukun Surface by scarp retreat (Grimes & Doutch, in prep.; cf. Doutch *et al.*, 1973). The Aurukun Surface was reduced to a dissected plateau and mesa-top remnants.

The Wyaaba Beds are partly marine, containing fossils with a Pliocene age range (Palmieri, 1973); the pediplain part of the Strathgordon Surface in basalt areas west of Townsville appears to be of early Pliocene age (Grimes & Doutch, ibid). As a result the onshore Wyaaba Beds are considered likely to be of an early Pliocene age, if not older.

In parts of the Gilbert-Mitchell Trough presently under the Gulf of Carpentaria older strata of the Basin's second set of deposits may well occur. This possibility is enhanced by the occurrence, conformably under late Miocene to early Pliocene Orubadi Beds (Bain & Mackenzie, 1974; Dow, in prep.), of 1000 m or more of Darai Limestone that accumulated on the Australian Platform in southern New Guinea during nearly all of Miocene times (Table 1; of APC, 1961, and Willmott, 1972). Both New Guinea units appear to continue southwards into the Karumba Basin, and possibly reflect a northern extension of the Gilbert-Mitchell Trough, representing a northern facies equivalent of the Wyaaba Beds.

These postulated relationships raise the possibility that the marine deposition marked the beginnings of the Gulf of Carpentaria, and thus of the consequent base level regime controlling erosion and deposition in the Karumba Basin ever since. Marine conditions may in part have resulted from transgression following the glacial-eustatic sea level low of early and mid Oligocene times postulated by Kennett *et al.* (1972).

Thus uplift of the ancestral Great Dividing Range, sinking of the Gilbert-Mitchell Trough and the New Guinea part of the Australian Platform, and dislocation of the Aurukun Surface seem on the available stratigraphic evidence to have begun in Eocene to early Miocene times; this tectonism can be associated with the Oligocene orogenic event in New Guinea reported by Dow (in prep.). Downwarping continued during the Miocene deposition of the Darai Limestone, Orubadi Beds and Wyaaba Beds. The early Pliocene silicification (Table 1) suggests that deposition had ceased by then; tectonism may have died down somewhat earlier.

In the north it is impossible to localize the Karumba Basin boundary of the times. But in the east, the sedimentary and structural margin of the Basin was the contemporary version of the Great Dividing Range. The margin of the sedimentary basin was probably pushed westwards and southwards (Fig. 1) by pediplanation concurrent with that which produced the Strathgordon Surface.

The southwestern margin was in the lateritized Cretaceous rocks of the Tennant Creek Surface. This surface has been cut into by pediplanation which advanced simultaneously from the northeast and southwest, and shaped the first watershed between the Karumba Basin and the Barkly Tableland. There is no evidence of tectonism disturbing this area during this event or since (author, work in progress). The maximum elevation of the Cretaceous rocks of this watershed is presently about 300 m, and uplift of these rocks seems more likely than that eustatic regression of the sea stranded sediments at this altitude. Such an uplift, the Pine Creek Upwarp postulated by Hays (1967), would have had to occur before pediplanation produced the watershed and the Wave Hill Surface below it (Hays, ibid); thus uplift could well have taken place at the same time as the Aurukun Surface was dislocated further

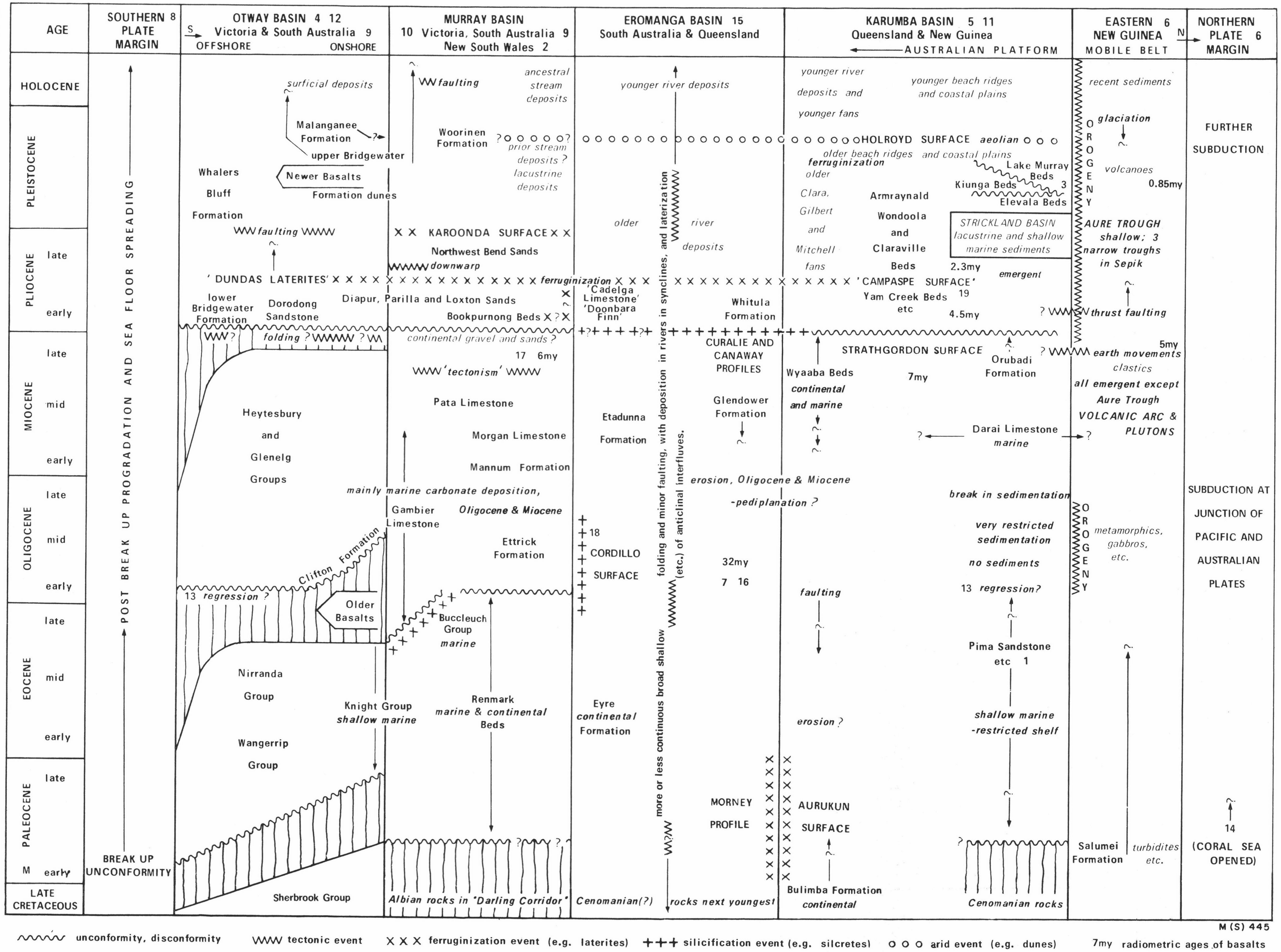

Table 1.
Possible Cainozoic correlations 1. Bain & MacKenzie, 1974; 2. Bembrick, 1974; 3. Blake, 1971; 4. Boeuf & Doust, 1975; 5. Work in progress by the author; 6. Dow, in prep.; 7. Exon et al., 1970; 8. Falvey, 1974; 9. Firman, 1973; 10. Gill, 1973; 11. Grimes & Doutch, in prep.; 12. Kenley, 1971; 13. Kennett *et al.*, 1972; 14. Mutter, 1975; 15. B. R. Senior, pers. comm.; 16. Webb & McDougall, 1967; 17. P. Wellman, pers. comm.; 18. Wopfner *et al.*, 1974; 19. Wyatt & Webb, 1970.

east, i.e. Oligocene, and for the same reason: namely the collision of the Australian and Pacific plates, which resulted in the Oligocene orogeny in New Guinea (Table 1; Dow, in prep.). Furthermore, the Wave Hill surface pediplanation which cut into the upwarped Tennant Creek Surface can be looked on as an event closely related to the destruction of the Aurukun Surface by the developing Strathgordon Surface. As an important side issue here, the Barkly Tableland thus had its inception by isolation from the Karumba Basin by the upwarp; The Davenport Range-Tennant Creek-Ashburton Range source area for the Bulimba Formation became a Tableland provenance thereafter. So the Pine Creek Upwarp is proposed to have been the structural margin of the Karumba Basin in the southwest during deposition of the Wyaaba Beds, and was in much the same place as the present Gulf of Carpentaria watershed.

In summary, late Tertiary development of the Karumba Basin began with uplift along the eastern and southwestern margins and a downwarp in the east. These movements were probably related to the Oligocene orogeny in New Guinea, attributed to a collision of the Australian and Pacific Plates. In a repetition of the Basin's initial history, the second set of deposits was consequent on these uplifts, and similarly, deposition and erosion gave way to deep weathering after relief could be reduced no more. This phase of Karumba Basin history ended with patchy silicification of the Strathgordon Surface.

Pliocene: Modern Basin beginnings

During Pliocene times the two continuing and probably related events that dominated development of the Karumba Basin were the beginning of orogeny in New Guinea and uplifts and associated volcanism in the ancestral Great Dividing Range.

Basalt 7 million years old in the McBride Basalt Province west of Townsville (Griffin & McDougall, 1975) probably indicates the beginning of the end for the Strathgordon and Wave Hill Surfaces. Basalt 4.5 million years old in the Nulla Basalt Province (Wyatt & Webb, 1970) just southeast of the McBride province, occurs in valleys of, or eroded into, the Strathgordon and Aurukun Surfaces (author, work in progress); basalts, apparently also about 4 million years old, of the Chudleigh Park Basalt Province west of the Nulla province, were erupted after an uplift (Doutch *et al.*, 1970) which dislocated the Strathgordon Surface.

Subsequently the Strathgordon and Wave Hill Surfaces represented by the lateritized 'coastal plain' of Dunn (1963), Plumb & Paine (1964), and others.

In the island of New Guinea orogeny has been raising the central highlands during Pliocene times and since (Visser & Hermes, 1962; Dow, in prep.). South of the rising highlands there was a complementary sinking in the Pliocene of a 'peri-orogenic' trough (Visser & Hermes, ibid.) of which the 'Strickland Basin' (APC, 1961; Fig. 1) is the eastern part (GSA, 1971). This 'basin' is a 3000 metre downwarp of the margin of the Australian Platform and is separated from the Karumba Basin by an east-west upwarp south of the Fly River (Blake, 1971). This upwarp closed the Karumba Basin structurally.

At the end of the third phase of development of the Karumba Basin its margin had altered substantially only in the north, the uplifts in the east hardly affecting the Great Dividing Range watershed; elsewhere Campaspe Surface erosion left a selvedge of Wave Hill and Strathgordon Surfaces piedmont to the remnants of the Tennant Creek and Aurukun Surfaces. The Basin's third set of sediments are the least of the four by volume and area, and are restricted to the south and east of it.

Pliocene-Holocene: latest Basin history

From Pliocene times onwards the northern and southeastern parts of the Karumba Basin continued to be sporadically subject to tectonic disturbance. However, there is little or no evidence of tectonism elsewhere in the basin, and in general the basin margins are watersheds inherited from the Campaspe Surface which have since been modified by headward erosion.

To the southeast, in the eastern part of the Georgetown Inlier, the basaltic volcanism initially associated with uplift in the Chudleigh Park area continued until about 50 000 years ago (Wyatt & Webb, 1970; Griffin & McDougall, 1975; Grimes & Doutch, in prep.). Complementary to this uplift there was dislocation of the Campaspe Surface around the margins of the Gilbert-Mitchell Trough (Grimes & Doutch, op. cit) which could be interpreted to indicate a further slight sinking of the Trough. However, onshore in the Trough, Pliocene to Holocene sandy and clayey delta-like fan deposits of the Gilbert, Mitchell and smaller rivers are probably only of the order of 50 m thick (Powell *et al.*, in press), and uplift of the Campaspe Surface and later prograding of the fans are as likely as sinking of the Trough.

The fan units, together with the sediments below the

the author will define more fully in due course. The event affected older inner beach ridges which are probably between 100 000 to 120 000 years old, but not younger, outer, ridges containing shells giving C^{14} dates of 6440 yrs. BP and less (Smart, in prep. b; Rhodes, pers. comm.; Australian National University, Sydney University and University of N.S.W. laboratory datings). This event may well correlate with the last glacial maximum and corresponding sea level minimum circa 20 000 years ago (cf. Mabbutt, 1967, on the 'great Australian Arid Period'), at which time the Gulf of Carpentaria was dry (Smart, in prep. b).

Increased rainfall after the desiccation event rejuvenated drainage, initiating the last two episodes of erosion and deposition — although some valleys choked during this event have not yet been incised. The increase probably occurred about 11 000 years ago (Kershaw, 1975). The first of the depositional episodes probably began when rainfall increased and terminated when sea level reached a probable maximum 7000 years ago (Smart, in prep. b); the second corresponds with sea level fall since.

South of the Gilbert-Mitchell Trough the fan of the Clara River, which shared the history just outlined, interfingers with the deposits below the 'black soil' plains of the Flinders and Cloncurry Rivers. Grimes (pers. comm.) and the author find it difficult to correlate fan episodes with the history of these two rivers and their deposits, or to the history of the Leichhardt River deposits further west.

Elsewhere in the Karumba Basin, except in New Guinea, erosion predominated in Pliocene to Holocene times. The Holroyd Surface is conspicuous as sand sheets in most areas and as dunes south of the Gulf, and is ubiquitously represented by choked drainage that is now being rejuvenated (author, work in progress).

The little that is known of the offshore equivalents of fan deposits was first outlined by Smart (in prep. a). The sediments consist of thin Pleistocene marine calcareous clay and limestone and late Pleistocene and Holocene sandy shelly muds; the two units overlie the Wyaaba Beds (and/or contemporary sediments) and equivalents of the older fans below the Gulf of Carpentaria.

Phipps (1970) reported C^{14} dates and environmental interpretations from samples collected from the bed of the Gulf by piston coring. His oldest deposits he considered to be of non-marine origin, and they are more than 19 600 years old. Smart (in prep. a) correlated them with his calcareous clay unit. Phipps recognized another non-marine interval which began about 16 600 years ago, and a youngest one which occurred between about 10 000 and 6 500 years B.P.; he considered that these alternations were the result of uplift of the Gulf bed keeping pace with rising sea level. There are no features on shore which support these interpretations.

Smart (in prep. b) has re-examined Phipp's information together with that of Bates *et al.* (1970), Zwigulis (1971) and Gunn (1972). He considered that the older unit was calcreted during an arid period between 35 000 and 11 000 years ago, when the sea had departed from the area of the Gulf. The younger unit was deposited during the subsequent transgression, which reached the Gulf about 11 000 years ago. It is probably more than a coincidence that this is about the time when rainfall began to increase.

In southern Papua New Guinea, Karumba Basin beds correlating with fan deposits are difficult to recognize. Blake (1971) describes Pliocene(?) to Holocene deposits whose stratigraphic inter-relationships are not fully worked out, but which probably belong to the Karumba Basin; Table 1 follows Blake (ibid). Most of them were affected by uplift, one physiographic expression of which is the Oriomo Plateau between the Fly River and the south coast. The Oriomo Plateau is the present northern structural and provenance margin of the Karumba Basin.

Thus the latest phase of the development of the Karumba Basin is related to tectono-magmatic events modifying the Georgetown Inlier which correlate with orogeny in New Guinea. The Basin's fourth, Pliocene-Holocene, deposits are restricted to the Gilbert-Mitchell Trough and to the alluvial plains country in Queensland south of the Gulf of Carpentaria.

Correlation

Table 1 proposes tentative correlations for Cainozoic epicratonic events in eastern Australia. It is no more than a working hypothesis to be tested by more dating. It was constructed by considering events in sequence rather than in isolation, which should enhance the probability that the correlations proposed are sound: e.g., overall the fabrics of Cainozoic tectonism and climatic changes in the Karumba and Eromanga Basins appear similar, and many events are therefore postulated to be penecontemporaneous (of course, the consequences of these events in each basin may differ morphologically). Thus the downwarping that initiated the Gulf of Carpentaria after Aurukun Surface lateritization and before Strathgordon Surface silicification is correlated witht the broad shallow folding that occurred between lateritization and silicification in the Eromanga Basin; this framework then provides a basis for correlating consequent erosion and deposition — e.g., for 'correlating' the Wyaaba Beds with the Glendower Formation — and for a better understanding of crustal evolution.

The overall simplicity and broad uniformity of the Cainozoic evolution of eastern Australia suggested by Table 1 indicates the degree of stability the craton has acquired since Tasman Geosyncline mobility ceased, and the quality of the craton's resistance to plate collision in New Guinea.

Somewhat surprising, considering the Australian continent's dimensions and its northwards drift during the Cainozoic, is the uniformity of the response of the eastern half of it to changes in climate. Ferruginization, including lateritization, in both early Tertiary and Pliocene times was widespread (Table 1), and so, it is beginning to be shown, were the results of the silicification event in early Pliocene times. A general similarity and contemporaneity of response to both climate and tectonism is shown by the histories of the Clara, Gilbert and Mitchell Fans of the Karumba Basin and the Riverine Plains of the Murray Basin (author, work in progress). The arid Holroyd Surface occurs not only in most of eastern Australia but also in a large part of the rest of it: the author has made spot checks of maps, air photographs, Landsat 1 imagery, and from the air. Thus, the climatic history of the Karumba Basin was not unique to it.

Resources

Cainozoic erosion of provenance areas within the structural basin during its development exposed much of the mineral resources of the Cloncurry-Mount Isa areas (Fig. 1; Plumb & Derrick, in press) and parts of the Coen, Yambo and Georgetown Inliers (Fig. 1; Oversby *et al.*, in press), and led to concurrent deposition of alluvials such as gold and tin at Croydon (Doutch, in prep.), the gold deposits of the Palmer River, and gold at Wenlock (Whitaker & Gibson, in prep.). More detrital concentrations probably remain to be discovered.

Pliocene deep weathering of Paleocene (?) laterites of Aurukun Surface plateau and mesa tops culminated in bauxites at Gove (Dunn, 1965; Grubb, 1970) and Weipa (Evans, 1959; Plumb & Gostin, 1973, Smart, in prep. a).

The sediments of the Karumba Basin are not known to contain currently useful mineral reserves at the moment. The known gold and tin alluvials are worked out or uneconomic. Sub-economic heavy mineral beach sands occur south of Weipa (Miller, 1957). Salt could be produced in some coastal areas. Hydrocarbon accumulation in the basin deposits is highly unlikely (Doutch, in press).

Groundwater, some of it highly saline, occurs in discontinuous aquifers in all three sets of Karumba Basin deposits (see e.g. Warner, 1968; Grimes, 1972; Pettifer *et al.*, in prep.). Potable water for the inhabitants of Weipa and Aurukun is obtained from the Bulimba Formation, and for Edward River from the Wyaaba Beds, these settlements being on tidal inlets. Some Bulimba Formation water is used for processing bauxite at Weipa. Pastoralists use some groundwater for stock during the dry season.

Synthesis, discussion and conclusions

Structurally the Karumba Basin is seen as one element of the response of the eastern half of the wholly cratonic continent of Australia to separation from Antarctica and collision with the Pacific Plate during Cainozoic times. The basin developed its present form more from uplift of its margins than from downwarping of its interior, although the Gilbert-Mitchell Trough is an important feature (Fig. 1). Tectonism occurred much more frequently and strongly in the eastern than the western half, and practically all the sediments are also in the east. This suggests relative stability of older cratonic basement blocks in the west with respect to younger ones in the east (cf. GSA, 1971).

The continental clayey sands, sandstones and silts of the Karumba Basin contrast with the underlying marine mudstones and labile sandstones of the Carpentaria Basin, and the sediments of the two basins are separated by an unconformity reflecting a hiatus in late Cretaceous deposition. Sedimentation episodes in the Karumba Basin were initiated by the tectonism responsible for its structure, but arid climates dominate most of the histories of the deposits. Areas between the limits of deposition in the Karumba Basin and the structural margins of the basin were practically the only provenance sources for its deposits.

Erosion in the source areas exposed the mineral resources of the Mount Isa-Cloncurry and McArthur River areas and parts of the Coen, Yambo and Georgetown Inliers, while deep weathering culminated in bauxites at Gove and Weipa. The Basin contains negligible mineral and energy resources of current value.

Tectonically, the Karumba Basin could be regarded as being the youngest part of the Trans-Australian Platform Cover in the sense of the Tectonic Map of Australia and New Guinea, 1971 (GSA, 1971). In the legend of this map the Cover is tied conceptually to the cratonization of the Tasman Geosyncline. More realistically, the three elements of this cover in eastern Australia — the Permo-Triassic, Jurassic-Cretaceous and essentially Cainozoic basins — can be said to reflect three different events in Australia's crustal history. This is an aspect of the Cover which is basic to recognition of the Karumba Basin, and of similar features elsewhere, as a specific and distinctive tectonic entity rather than merely as a collection of surficial deposits.

In the Trans-Australian Platform Cover the Permo-Triassic Cooper and Galilee Basins and equivalents (GSA, op. cit) were hinterland epi-cratonic responses to the Hunter-Bowen tectonic event (cf. Scheibner, 1974). The overlying Jurassic—early Cretaceous Eromanga and Carpentaria Basins were probably the result of mild crustal warping possibly associated with further plate convergence to the east (Veevers & Evans, 1973); this occurred before late Cretaceous rifting which presaged the separation of Australia from Antarctica (Falvey. 1974). The Karumba Basin began forming over the Carpentaria Basin at the time of this split, and developed further during a period of plate margin events in New Guinea. It is probably better not to include the Karumba Basin in the Trans-Australian Platform Cover because of this history; somewhat similar reasoning is inherent in the depiction on the Tectonic map of Australia and New Guinea of the Trans-Australian Platform Cover overlapping older platform covers (GSA, op. cit).

A change in the environment of the Australian Craton between Mesozoic and Cainozoic times seems also to be reflected in the change from submergent to something like emergent-oscillatory epeirogenic conditions in the sense of Sloss & Speed (1974). In Australia both regimes were less energetic than the North American prototypes, while the types of consequent deposits these authors' definitions require are not present in the Carpentaria and Karumba Basins. However, what the deposits in these basins should be according to Sloss & Speed is not as important as that they should differ, which is the case.

Sloss & Speed (op. cit) inferred from their evidence that vertical movements of continental lithospheres relate to the behaviour of oceanic lithospheres. Their conclusion that submergent conditions on the craton correlate with active orogeny or plate convergence raises the question of what the plate margins around Australia were in Carpentaria Basin times — late Jurassic and early Cretaceous — and what their manifestations were. Relatively minor early Cretaceous plutonism and north-trending folding, of late Hunter-Bowen Orogeny affinities perhaps, represent the most vigorous tectonism on the periphery of the Australian continent, or within it for that matter, during those times (GSA, 1971; cf. Dickins & Malone, 1973). The area affected lies east of the Eromanga Basin, the southern and adjacent analogue of the Carpentaria Basin, suggesting a plate margin still further to the east; the relatively minor, if widespread, Jurassic-Cretaceous downwarping and submergence of these two basins was of much the same order of magnitude as the contemporaneous 'orogeny'.

Sloss and Speed's correlation of oscillatory cratonic behaviour with convergence of oceanic and continental plates at distances relatively remote from cratonic margins does not give quite the same picture as that which the Karumba Basin gives of an epicratonic hinterland adjacent to craton margin collision areas in New Guinea. Therefore it may be better to consider the Karumba Basin as being the result of sporadic rather than oscillatory emergence; sporadic emergence could be defined by generalizing the history of movements and kinds of sedimentation marking the development of the Karumba Basin (albeit the Basin is probably still developing). As already shown, these details differ from those of the preceding Carpentaria Basin.

Johnson (1971) demonstrated that orogeny, epeirogeny and eustacy worked in concert in the Phanerozoic in North America — his 'Antler Effect' — in which orogeny and the maximum spread of epeirogenic seas coincide. This idea once again raises the question of a linked orogeny during the Aptian maximum of marine transgression in the Carpentaria and Eromanga Basins, and the answer is the one already given above; the idea also embraces the relationship between the Gulf of Carpentaria and the Pliocene—Holocene orogeny in New Guinea. These two transgressions, then, represented two separate occurrences of the Antler Effect.

Both Sloss and Speed, and Johnson, used the term Sequence: the former correlated a Sequence with each emergent or submergent state of the craton, while the latter described Sequences as major onlap-offlap cycles. The Carpentaria and Karumba Basin successions would seem to be two such Sequences, Aptian-Albian and Miocene-Holocene times being periods of transgression and onlap.

The author neither accepts nor rejects the use of the term Sequence in this context, and is awaiting the outcome of the debate on unconformity-bounded stratigraphic units which began in Circulars 45 and 46 of the International Subcommission of Stratigraphic Classification of the IUGS Commission on Stratigraphy.

Sequences can represent the Tectonic Stages of Doutch (1974) and Schiebner (1974). Their Stages depend on regional unconformities as domain boundaries to more or less conformable successions each with its own structural style. Stages, however, can consist of successions of the order of Sequences on the one hand, or sets (as in the Karumba Basin) on the other, depending in part on assessment of deformation relations between them and with crustal movements elsewhere. Whether the Karumba Basin consists of one or three tectonic Stages is not clear yet, but that the Carpentaria Basin stands on its own as a distinct Tectonic Stage seems undeniable.

The term 'Synthem' has been discussed in the ISSC Circulars mentioned above, and has been proposed formally and used by Chang (1975, a, b, c) for Korean unconformity-bounded successions very like Tectonic Stages. It appears that the Carpentaria Basin constitutes such a Synthem, and the Karumba Basin another, its sets being Chang's 'Interthems'.

These various approaches to the analysis of epeirogeny when taken together emphasize the contrasts between the Carpentaria and Karumba Basins and provide the most fundamental criteria so far available for recognizing and differentiating between sedimentary basins and also between platform covers. They are sufficient for differentiating the Eromanga Basin from the underlying Galilee and Cooper Basins, for example. Recognition of the Karumba Basin also makes the terms Cainozoic and Mesozoic more meaningful for the Australian continent and plate.

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References

APC (Australasia Petroleum Co Pty), 1961 — Geological results of petroleum exploration in western Papua 1937-1961. *Journal of the Geological Society of Australia,* **8** (1), 105.

BAIN, J. H. C., & MACKENZIE, D. E., 1974—Karimui, PNG—1:250 000 Geological Series. *Bureau of Mineral Resources, Australia—Explanatory Notes* **SB/55-9.**

BATES, T. E., SMITH, J. W., & TILLMAN, L. R. JUN, 1971 — Gulf of Carpentaria Bauxite project, A. T. P. 796 M. *Report to Canadian Superior Mining (Aust.) Pty Ltd and Ocean Resources N. L.* (unpublished).

BEMBRICK, C. S., 1974—Murray Basin *in* N. L. Markham & H. Basden (Editors). THE MINERAL DEPOSITS OF NEW SOUTH WALES. *Geological Survey of NSW.* 555-568.

BLAKE, D. H., 1971—Geology and Geomorphology of the Morehead-Kiuanga Area *in* Land Resources of the Morehead-Kiunga Area, Territory of Papua and New Guinea. *Commonwealth Scientific and Industrial Research Organization,* **29,** 56-68.

BOEUF, M. G., & DOUST, H., 1975 — Structure and Development of the Southern Margin of Australia. *Australian Petroleum Exploration Association Journal* **15**(1), 33-43.

CHANG, K. H., 1975a — Cretaceous Stratigraphy of Southeast Korea. *Journal of the Geological Society of Korea* **11**(1), 1-23.

CHANG, K. H., 1975b — General Stratigraphy of Korea. *Journal of the Korean Institute of Mining Geology* **8**(2), 73-88.

CHANG, K. H., 1975c—Unconformity-bounded stratigraphic units. *Geological Society of America Bulletin* **86,** 1544-1552.

DE KEYSER, F., & LUCAS, K. G., 1968 — Geology of the Hodgkinson and Laura Basins, North Queensland. *Bureau of Mineral Resources, Australia — Bulletin* **84.**

DICKINS, J. M., & MALONE, E. J., 1973 — Geology of the Bowen Basin, Queensland. *Bureau of Mineral Resources, Australia — Bulletin* **130.**

DOUTCH, H. F., 1974 — Legend Recommendations, Tectonic Map of Asia and the Far East. *Bulletin of the Commission for the Geological Map of the World,* **15,** 20-49

DOUTCH, H. F., in press — Carpentaria Basin; *in* Knight, C. J. (Editor): ECONOMIC GEOLOGY OF AUSTRALIA AND PAPUA NEW GUINEA. *Australian Institute of Mining and Metallurgy,* Melbourne.

DOUTCH, H. F., in prep. — Croydon, Queensland — 1:250 000 Geological Series. *Bureau of Mineral Resources, Australia — Explanatory Notes* **SE/54-11.**

DOUTCH, H. F., INGRAM, J. A., SMART, J., & GRIMES, K. G., 1970 — Progress report on the geology of the Southern Carpentaria Basin. *Bureau of Mineral Resources, Australia — Record* 1970/39 (unpublished).

DOUTCH, H. F., SMART, J., GRIMES, K. G., GIBSON, D. L., & POWELL, B. S., 1973—Progress report on the geology of the Carpentaria Basin in Cape York Peninsula, 1972. *Bureau of Mineral Resources, Australia: Record* 1973/187 (unpublished).

DOW, D. B., in prep. — A geological synthesis of Papua New Guinea. *Bureau of Mineral Resources, Australia — Bulletin.*

DUNN, P. G., 1965 — Bauxite deposits of Gove Peninsula, Arnhem Land; *in* McAndrew, J., (Editor), GEOLOGY OF AUSTRALIAN ORE DEPOSITS (2nd Edition). *Eighth Commonwealth Mining and Metallurgical Congress,* 1, 216-8.

DUNN, P. R., 1963—Urapunga, N.T.—1:250 000 Geological Series —*Bureau of Mineral Resources, Australia—Explanatory Notes* **SD/53-10.**

EVANS, H. J., 1959 — The geology and exploration of the Cape York Peninsula Bauxite Deposits in Northern Queensland. *Queensland Government Mining Journal* **60,** 679-88.

EXON, N. F., LANGFORD-SMITH, T., & MCDOUGALL, I., 1970—The age and geomorphic correlations of deep-weathering profiles, silcrete and basalt in the Roma-Amby region, Queensland. *Journal of the Geological Society of Australia* **17**(1), 21-30.

FALVEY, D. A., 1974—Continental Margin Development and Plate Tectonic Theory. *Australian Petroleum Exploration Association Journal,* **14**(1), 95-106.

FIRMAN, J., 1973 — Regional Stratigraphy of Surficial Deposits in the Murray Basin and Gambier Embayment. *Geological Survey of South Australia — Report of investigations* **39.**

GIBSON, D. L., POWELL, B. S., & SMART, J., 1974 — Shallow stratigraphic drilling, northern Cape York Peninsula, 1973. *Bureau of Mineral Resources, Australia—Record.* 1974/76 (unpublished).

GILL, E. D., 1973 — Geology and geomorphology of the Murray River region between Mildura and Renmark, Australia. *Memoirs of the National Museum of Victoria* **39.**

GRIFFIN, T. J., & MCDOUGALL, I., 1975 — Geochronology of the Cainozoic McBride Volcanic Province, Northern Queensland. *Journal of the Geological Society of Australia,* **22**(4). 387-96.

GRIMES, K. G., 1972 — A shallow artesian aquifer in the Tertiary deposits of southern Cape York Peninsula. *Queensland Government Mining Journal* **73,** 247-9.

GRIMES, K. G., 1974 — Mesozoic and Cainozoic geology of the Lawn Hill, Westmoreland, Mornington and Cape van Diemen 1:250 000 Sheet areas, Queensland. *Bureau of Mineral Resources, Australia—Record* 1974/106 (unpublished).

GRIMES, K. G., & DOUTCH, H. F., in prep. — Late Cainozoic fluvial deposits from the Carpentaria Plains, North Queensland. *Geological Survey of Queensland Report.*

GRUBB, P. L. C., 1970 — Mineralogy, geochemistry, and genesis of the bauxite deposits on the Gove and Mitchell Plateaux, Northern Australia. *Mineralium Deposita,* **5,** 248-72.

GSA, 1971 — Geological Society of Australia, 1971 — Tectonic Map of Australia and New Guinea 1:5 000 000 Sydney.

GUNN, M. D., 1972 — Final exploration report on ATP 923M, Port Musgrave. *Broken Hill Pty Ltd* (unpublished).

HAYS, J., 1967 — Land surfaces and laterites in the north of the Northern Territory; *in* Jennings, J. N., & Mabbutt, J. A. (Editors): LANDFORM STUDIES FROM AUSTRALIA AND NEW GUINEA. *Canberra, Australian National University Press,* 182-210.

JOHNSON, J. G., 1971 — Timing and Coordination of Orogenic, Epeirogenic, and Eustatic Events. *Geological Society of America — Bulletin* **82,** 3263-98.

JONGSMA, D., 1974 — Marine Geology of the Arafura Sea. *Bureau of Mineral Resources, Australia — Bulletin* **157.**

KENLEY, P. R., 1971—Cainozoic Geology of the Eastern Part of the Gambier Embayment, Southwestern Victoria; *in* Wopfner, H., & Douglas, J. G. (Editors) — The Otway Basin of Southeastern Australia. *Special Bulletin of the Geological Surveys of South Australia and Victoria,* 89-153.

KENNETT, J. P., BURNS, R. E., ANDREWS, J. E., CHURKIN, M. JUN., DAVIES, T. A., DUMITRICA, P., EDWARDS, A. R., GALEHOUSE, J. S., PACKHAM, G. H., & VAN DER LINGEN, G. J., 1972 — Australian-Antarctic Continental Drift, Palaeocirculation Changes and Oligocene Deep-Sea Erosion. *Nature Physical Science* **239,** 51-5.

KERSHAW, A. P., 1975 — Late Quaternary Vegetation and Climate in Northeastern Australia; *in* Suggate, R. P., & Creswell, M. M. (Editors) — QUATERNARY STUDIES *Royal Society of New Zealand,* 181-187.

MABBUTT, J. A., 1967 — Denudation Chronology in Central Australia; *in* Jennings, J. N., & Mabbutt, J. A. (Editors) — LANDFORM STUDIES FROM AUSTRALIA AND NEW GUINEA. *Canberra, Australian National University Press,* 144-181.

MILLER, P. G., 1957 — Beach sand reconnaissance west coast of Cape York Peninsula ATP 37M. *Enterprise Exploration Co. Pty Ltd* (unpublished).

MUTTER, J. C., 1975 — Basin evolution and marginal plateau subsidence in the Coral Sea. *Australian Society of Exploration Geophysicists — Bulletin* **6**(2/3), 35-7.

OVERSBY, B. S., PALFREYMAN, W. D., BLACK, L. P., COOPER, J. A., & BAIN, J. H. C., in press — Regional geology of Georgetown, Yambo and Coen Inliers; *in* Knight, C. J. (Editor) — ECONOMIC GEOLOGY OF AUSTRALIA AND PAPUA NEW GUINEA. *Australian Institute of Mining and Metallurgy.* Melbourne.

PALMIERI, V., 1973 — Micropalaeontological analysis of samples from Beefwood No. 1 bore, IWSC license No. 38472, Rutland Plains 1:250 000 Sheet area; *in* H. F. Doutch, J. Smart, K. G. Grimes, D. L. Gibson & B. S. Powell: Progress Report on the Geology of the Carpentaria Basin in Cape York Peninsula. *Bureau of Mineral Resources, Australia — Record* 1973/187 (unpublished).

PETTIFER, G., SMART, J., HORSFALL, M. C., MCDOWELL, M. I., & GIBSON, D. L., 1976—Cape York Peninsula geophysical and geological ground-water investigation, 1974. *Bureau of Mineral Resources, Australia—Record* 1976/3 (unpublished).

PHIPPS, C. V. G., 1970 — Dating of eustatic events from cores taken in the Gulf of Carpentaria, and samples from the NSW continental shelf. *Australian Journal of Science,* **32**(8), 329-30.

PINCHIN, J., 1973—A geophysical review of the Carpentaria, Laura and Olive River Basins. *Bureau of Mineral Resources, Australia — Record* 1973/132 (unpublished).

PLUMB, K. A., & DERRICK, G. M., in press — Geology of the Proterozoic rocks of Northern Australia; *in* Knight, C. J. (Editor): ECONOMIC GEOLOGY OF AUSTRALIA AND PAPUA NEW GUINEA. *Australian Institute of Mining and Metallurgy,* Melbourne.

PLUMB, K. A., & GOSTIN, V. A., 1973 — Origin of Australian bauxite deposits. *Bureau of Mineral Resources, Australia—Record* 1973/156 (unpublished).

PLUMB, K. A., & PAINE, A. G. L., 1964 — Mt Young, N.T. 1:250 000 Geological Series. *Bureau of Mineral Resources, Australia—Explanatory Notes* **SD/53-15.**

POWELL, B. S., GIBSON, D. L., SMART, J., GRIMES, K. G., & DOUTCH, H. F., in press—New and revised stratigraphic nomenclature, Cape York Peninsula. *Queensland Government Mining Journal.*

SCHEIBNER, E., 1974 — An outline of the Tectonic Development of New South Wales with special reference to Mineralization; *in* Markham, N. L. & Basden, H., (Editors): THE MINERAL DEPOSITS OF NEW SOUTH WALES. *Geological Survey of NSW,* 3-39.

SLOSS, L. L., & SPEED, R. C., 1974 — Relationships of cratonic and continental-margin tectonic episodes. *Society of Economic Palaeontologists and Mineralogists — Special Publication* **22,** 98-119.

SMART, J., GRIMES, K. G., & DOUTCH, H. F., 1972 — New and revised stratigraphic names, Carpentaria Basin. *Queensland Government Mining Journal* **73,** 190-201.

SMART, J., in prep. a — Weipa, Qld — 1:250 000 Geological Series. *Bureau of Mineral Resources, Australia — Explanatory Notes* **SD/54-3.**

SMART, J., in prep. b—Late Pleistocene sea level changes in the Gulf of Carpentaria.

SMART, J., & BAIN, J. H. C., in prep. — Red River, Qld — 1:250 000 Geological Series. *Bureau of Mineral Resources, Australia — Explanatory Notes* **SE/54-8.**

TAYLOR, L. W. H., 1975 — Depositional and tectonic patterns in the western Coral Sea. *Australian Society of Exploration Geophysicists — Bulletin* **6** (2/3), 33-5.

VEEVERS, J. J., & EVANS, P. R., 1975 — Late Palaeozoic and Mesozoic History of Australia; *in* Campbell, K. S. W. (Editor): GONDWANA GEOLOGY. 3RD GONDWANA SYMPOSIUM. *Canberra, Australian National University Press* 579-607.

VINE, R. R., & PAINE, A. G. L., 1974 — Hughenden, Qld — 1:250 000 Geological Series. *Bureau of Mineral Resources, Australia — Explanatory Notes* **SF/55-1.**

VISSER, W. A., & HERMES, J. J., 1962 — Geological results on the exploration for oil in Netherlands New Guinea. *Staatsdrukkerij en Vitgeverijbedrijf.*

WARNER, K. R., 1968 — Gilbert-Staaten Rivers groundwater investigations. *Geological Survey of Queensland — Report* **24.**

WEBB, A. W., & MCDOUGALL, I., 1967 — A comparison of mineral and whole rock potassium-argon ages of Tertiary volcanics from central Queensland, Australia. *Earth and Planetary Science Letters* **3,** 41-7.

WHITAKER, W. G., & GIBSON, D. L., in prep.—Coen, Queensland—1:250 000 Geological Series. *Bureau of Mineral Resources, Australia—Explanatory Notes* **SD/54-8.**

WHITAKER, W. G. & POWELL, B. S., in prep.—Cape Weymouth, Qld.—1:250 000 Geological Series. *Bureau of Mineral Resources, Australia—Explanatory Notes* **SD/54-4.**

WILLMOTT, W. E., 1972 — Daru-Maer, Papua and Qld — 1:250 000 Geological Series. *Bureau of Mineral Resources, Australia — Explanatory Notes* **SC/54-8** and **SC/55-5.**

WILLMOTT, W. F., WHITAKER, W. G., PALFREYMAN, W. D., & TRAIL, D. S., 1973—Igneous and Metamorphic rocks of Cape York Peninsula and Torres Strait. *Bureau of Mineral Resources, Australia — Bulletin* **135.**

WOPFNER, H., CALLEN, R., & HARRIS, W. K., 1974 — The Lower Tertiary Eyre Formation of the Southwestern Great Artesian Basin. *Journal of the Geological Society of Australia* **21**(1), 17-51.

WYATT, D. H., 1968 — Townsville, Qld — 1:250 000 Geological Series. *Bureau of Mineral Resources, Australia — Explanatory Notes* **SE/55-14.**

WYATT, D. H., & WEBB, A. W., 1970 — Potassium-argon Ages of some Northern Queensland Basalts and an interpretation of Late Cainozoic History. *Journal of the Geological Society of Australia* **17**(1), 39-51.

ZWIGULIS, M., 1971 — Exploration Report Gulf of Carpentaria Bauxite Project A.P. 796M. Drilling programme August 1971. *Unpublished Report, Geological Survey of Queensland Library* CR 3793.