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Papers by BMR authors

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The Phanerozoic Sedimentary Basins of Australia and their tectonic implications

by

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Introduction

Most Phanerozoic sedimentary basins in Australia (Fig. 1) are platform cover and have been depicted on the 1:5 000 000-scale Tectonic Map of Australia and New Guinea 1971 (GSA, 1971) as 'Trans-Australian Platform Cover' and transitional predecessors, and as the younger part of the 'Central Australian Platform Cover'. When organized as Platform Covers the basins provide a first step towards identifying and formally naming the cratons they succeeded to, and to recognizing the tectonic origins of some of the structures controlling basin development. For an explanation of these concepts, and for many others referred to in this paper the sender is referred to the 1971 Tectonic Map of Australia.

But before discussing Australia's Phanerozoic sedimentary basins as formally named platform covers we examine them in three assemblages, younger internal (intracratonic) basins, older internal (intracratonic) basins, and marginal basins (Fig. 2; cf. Cameron, 1967). New stratigraphic charts by Mayne (in press) are of considerable background value for this discussion.

The younger internal basins are discussed first because they provide something of a uniformitarian model for a better understanding of the development and nomenclature of the older internal basins. They mostly overlie the Eastern Australian Orogenic Province (Tasman Fold Belt System of Scheibner (1973) or 'Tasman Geosyncline') but some overlapped westwards over Precambrian cratons (Fig. 2). With one exception mentioned in due course, the oldest of these basins began developing in early Devonian times; the basins came into existence at one time or another during and after the Fold Belt System's younger 'geosynclinal' and orogenic activity.

The older internal basins do not extend beyond the Precambrian cratons. Some (most?) of them originated in late Proterozoic times and contain Adelaidean System rocks. Some Phanerozoic episodes of sedimentation and deformation seem to be related to similar events in the adjacent Tasman Fold Belt System.

The marginal basins peripheral to the Australian continent had their origins in the Permian in the west, and in the Jurassic in the south. They are pericratonic and can be said to have resulted from the splitting up of Gondwanaland (cf. Veevers & Evans, 1975; Branson, this Symposium), but from a fixist point of view (e.g. Meyerhoff & Meyerhoff, 1972) it would be just as valid to classify them as marginal. Most tend to cut across previous structural trends (cf. Wellman, 1976; BMR 1:5 000 000 Gravity Map of Australia (BMR, 1976)); in particular around northwestern Australia they are superimposed athwart older internal basins.

In using plate tectonics to interpret Australia's marginal basins we raise the problem of the consistent application of plate-tectonic theories to the origins of its internal basins. This can be done with only mixed success.

A comprehensive introduction to Australia's sedimentary basins is available in the BMR 'Records' Series (BMR, 1974). Petroleum geology is described in a recent monograph published by the Australasian Institute of Mining and Metallurgy (Leslie, et. al., Eds, 1976).

Younger Internal Basins

The development of Australia's younger internal basins (Fig. 2) began in early Devonian times and is still in progress. The sequence of development seems to be closely related both to increasing cratonization of parts of the Tasman Fold Belt System, and to contemporaneous tectonic activity in adjacent younger parts of the Belt to the east (see time/space diagram in Figure 3). The pattern of development is one which appears to apply in some respects to the older internal basins, and to the evolution of platform cover in many parts of the world; Figures 3 and 4 show those younger internal basins which best illustrate this pattern of development.

The oldest set of basins are the Adavale and Darling Basins. In both, an unconformity separates early and late Devonian deposits. The early Devonian rocks are predominantly detrital and non-marine in the west and centre, and marine in the east; the marine sequence includes limestone, dolomite, and salt in the Adavale Basin and sandstone and shale in the Darling Basin. The late Devonian rocks are fluviatile red clastics. Sedimentation in the Darling Basin may have continued into the early Carboniferous. A small gas field has been proved in the Adavale Basin.

The mid-Devonian unconformity probably reflects the Tabberabberan Orogeny in adjacent parts of the Tasman Fold Belt System. In the late Carboniferous the Kanimblan Orogeny resulted in block faulting of the Adavale Basin (Fig. 4), associated with a northeast-trending series of anticlines and horsts and small salt diapirs, and in faulting and broad folding of the Darling Basin.

In the Drummond Basin, deposition was mainly in the early Carboniferous, but began in late Devonian times after elevation of the adjacent Anakie High (by the mid-Devonian Tabberabberan Orogeny?). Predominantly fluviatile and lacustrine conglomerates, sandstones, and shales and minor limestones and acid tuffs were deposited; the volcanoes were probably on the Anakie High. Mild syndepositional warping and folding occurred, with concomitant faulting, but the main deformation of the basin took place during the Kanimblan Orogeny, when volcanism and granite intrusion occurred marginal to some parts of the basin (GSA, 1971).

The Drummond, Adavale, and Darling Basins can be considered as representing both the beginnings of platform cover on the Tasman Fold Belt System and the end of 'orogenic' transformation of the Belt thereabouts into a craton. They are therefore thought of as 'transitional' basins (GSA, 1971; Doutch, 1972; cf. Scheibner, 1973). They have important counterparts in some of the older internal basins (see below). Most of their rocks are continental, none were metamorphosed, and the culmination of the only deformation of all three was during the Kanimblan Orogeny. Their structures could as well be due to vertical as to compressional tectonics. In the Darling and Drummond Basins, sediments are molasse-like; folds are parallel, up to two kilometres in amplitude and wavelength, commonly ten kilometres long, and tend to brittle fracture; contemporaneous igneous activity was mainly peripheral, and more vigorous to the east, towards the developing New England Fold Belt.

Other transitional 'basins' of this age are the Burdekin Basin and part of the Broken River Embayment in Queensland, the late Devonian cauldron complexes in Victoria, and the Bancannia Trough in New South Wales. The Bancannia Trough (Fig. 3) also contains Ordovician rocks transitional from the Kanmantoo Fold Belt, the oldest part of the Tasman Fold Belt System (Scheibner, 1973).

The next set of younger internal basins to develop were the Permian Pedirka and Arckaringa Basins, the Permo-Triassic Cooper and Galilee Basins, and the Bowen and Sydney Basins. The Pedirka, Arckaringa, Cooper, and Galilee Basins are intracratonic and the last two partly overlie transitional basins. The Bowen and Sydney Basins formed as foredeeps to the New England Fold Belt orogen flanking them to the east. The Pedirka, Arckaringa, and Cooper Basins also overlap the Precambrian Craton and part of its platform cover, namely the older internal Warburton and Amadeus Basins. The Cooper, Galilee, Bowen and Sydney Basins still form one large composite basin which joins the 'geosynclinal' Yarrol Basin (Fig. 3).

Permian sediments in the Arckaringa and Pedirka Basins and Permo-Triassic sequences in the Cooper and Galilee Basins are mainly non-marine clastics, including coal, which were deposited in fluviatile, lacustrine and flood plain environments. Glacigene sediments occur at the base of the successions in each basin, and in the Galilee Basin some tuffaceous material as well. In the Cooper and Galilee Basins folds and faults developed during sedimentation.

The Pedirka and Arckaringa Basins are less deformed than the Cooper and Galilee Basins, perhaps because of the location of the former on the Precambrian craton. Deformation of the Cooper and Galilee Basins reflects phases of the Hunter-Bowen Orogeny, that affected the adjacent Bowen Basin and the New England Fold Belt. Day et al. (1974) discuss this in more detail.

In the Bowen and Sydney foredeep basins, glacigene sediments also occur at the base of the early Permian successions, which include shallow marine, coastal, and deltaic sediments. Thick coal measures characterize the late Permian. Volcanogenic detritus is common throughout. In the Triassic, non-marine red beds and lithic and quartzose sandstone were laid down, these sequences being thicker in the Bowen Basin than in the Sydney Basin.

The Hunter-Bowen Orogeny of the adjacent New England Fold Belt deformed both basins (Day et al., 1974). Uplift, folding, and faulting occurred along the northeastern margin of the Sydney Basin in late Permian and early Triassic times. In the late Triassic the Bowen Basin was gently to isoclinally folded, and strata along its eastern margin were overturned; décollement may have accompanied the folding.

Permian platform cover sediments are also preserved beneath the Murray and Eucla Basins (Figs. 1, 3); Triassic sediments including coal occur in the Tasmania Basin. Thin Permo-Triassic spreads are present in many older internal basins.

Gas and oil in the Cooper Basin and coal in the Bowen, Sydney, and Galilee Basins are major economic resources.

The third set of younger internal basins are the Jurassic-Cretaceous intracratonic complex of the Carpentaria, Eromanga, and Surat Basins. They conceal most of the Devono-Carboniferous and Permo-Triassic basins of the first two sets, and overlap on to the Precambrian Craton to the west; in particular the Eromanga Basin overlaps the platform cover of the older internal Arrowie, Warburton, Amadeus, and Georgina Basins. To the north the Carpentaria Basin lies on Precambrian basement and is continuous with the Morehead Basin and New Guinea, which apparently adjoined a 'geosyncline'. To the east the basin complex is joined to the small Laura and Clarence-Moreton Basins.

Sedimentation in most of these basins was dominantly continental during the Jurassic, with local development of coal swamps. In early Cretaceous times a widespread marine transgression resulted in shallow marine clastics and minor limestone; the transgression occurred over most parts of the continent, and may have been mainly eustatic. The sea had retreated by mid-Cretaceous times.

The Eromanga and Surat Basins are very gently folded. Some folding is due to compaction over older structures, some to structural growth during deposition, and some to movements of late Cretaceous or Tertiary age. Further east the isolated marginal(?) Jurassic-Cretaceous Maryborough Basin (a successor to the Triassic transitional Esk Rift - Figs. 1, 2, 4) was more intensely folded, and a 'Maryborough Orogeny' used to be invoked. The Lord Howe Rise and Dampier Ridge to the east of the Australian continent may yield a better picture of this tectonic episode in due course; the Maryborough Basin may have been a foredeep basin.

In the Carpentaria, Eromanga, and Surat Basins coal, oil, gas, manganese, and artesian water are all commercially exploited, and reserves of oil shale have been established.

A fourth set of younger internal basins can be proposed, of Cainozoic age (Fig. 5). Thin continental sediments accumulated in the Karumba Basin overlying the Carpentaria Basin (Doutch, 1976b), and in small basins and synclines deforming the Eromanga Basin (GSA, 1971); Cainozoic deformation of part of the Eromanga Basin is controlled by structures which originated during Cooper Basin growth. To the south, in the Murray and Eucla Basins, some marine carbonates were laid down as well.

Present day seismicity (Fig. 5) suggests that only a few basin margins are currently active. Doutch (1976b) pointed out that these intracratonic structural developments took place during the drifting of Australia away from Antarctica and subsequent plate margin collisions to the north; the development of the Otway Basin, treated below as a type marginal basin, is part of this story, and the ages of eastern Australian basalts support a northerly drift.

To be consistent, plate tectonics, if used to explain the development of Cainozoic basins, should be applied in any similar attempt to interpret the evolution of the preceding younger internal basins. To start with, Scheibner (1973) suggested a relationship between the transitional basins and subduction to the east in the region of the New England Fold Belt. The general north-south trend of transitional basin structures is in harmony both with this proposition and with the controlling structural grain of the underlying Tasman Fold Belt System. Next one has to propose, for the period during which the Permo-Triassic basins developed, a new episode of plate interaction that began at the eastern Australian plate margin after the Kanimblan Orogeny (cf. Scheibner, 1973). The Bowen-Sydney foredeep basins, and the New England Fold Belt to which they are related, are features which favour such a proposition; all are parallel to the structural grain of the Tasman Fold Belt System. The four intracratonic basins, however, have gross northwest and northeast trends athwart the Belt, and while this may result from the same stresses that brought about the foredeeps, stresses related to concurrent inception of the oceanic Wharton Basin off northwestern Australia may be of some importance with respect to plate movements as a whole and the reactions of a non-homogeneous crust (cf. Branson, this Symposium).

For consistency, one should also try to identify a plate-margin correlative for the Jurassic-Cretaceous basins also. These basins have no characteristic structural trend of their own; they appear to inherit, and to be controlled by, pre-existing structures. The position of the plate margin east of Australia during this period is difficult to place, although off western Australia both the Wharton Basin and Ninetyeast Ridge spreading centres suggest that the Australian-Antarctic plate was drifting towards the east until the Cainozoic, when Australia split from Antarctica.

When considering the younger internal basins formally as platform cover it is possibly desirable to restrict the term Trans-Australian Platform Cover, if used in a genetic sense, to sediments that accumulated on the cratons of the continent during its easterly drift, and apply a new formal cover name to Cainozoic sediments associated with northerly drift. The implications of this suggestion for the concepts of Sequence (Johnson, 1971; Sloss & Speed, 1974), Synthem (Chang, 1975), and Tectonic Stage (Doutch, 1974, 1976a & b), need exploring.

Older Internal Basins

The older Phanerozoic internal basins of Australia (Figs. 1, 2) can be divided into two groups: one lies centrally in the continent; the other consists of basins cut across by the western coastline of Australia.

The central group commonly contains late Proterozoic 'Adelaidean System' rocks, which in the south were preceded by acid volcanism and plutonism attributed to a transitional 'basin' event (GSA, 1971; Doutch, 1972; Plumb, this Symposium). This transitional tectonism was related to the cratonization of the Central Australian Orogenic Province, and the succeeding Central Australian Platform Cover - which includes the older internal basins - can be said to overlap the older Northern Australian Orogenic Province and in places its platform cover (GSA, 1971).

Proterozoic and Palaeozoic sequences of the central group of older internal basins are separated by an unconformity in some places but by no means everywhere. The southern basins of the group are deeper than the northern (Fig. 6), perhaps reflecting younger less stable basement in the south, i.e., the younger craton.

The southern basins of the group include the Amadeus, Ngalia, Warburton, Arrowie, and Officer Basins. Early Cambrian basalts occur in the Officer Basin, but in general the Cambrian sequence in these basins changes from clastics in the southwest to carbonates in the northeast, and the Ordovician is characterized by interbedded sandstone, siltstone and shale; rocks of both ages are mainly marine. There is a hiatus in the Silurian. Devonian to Carboniferous(?) rocks are syntectonic continental sandstones and rudites with a marine influence strongest in the west (cf. early Devonian sequences of the transitional basins of the 'Younger Internal Basins'). Resources of gas and oil have been proved in the Cambro-Ordovician sequences of the Amadeus Basin.

The northern basins of the group consist of the Georgina, Wiso, and Daly River Basins, and also the Arafura Basin further north about which little is known. In contrast to the southern group, Adelaidean rocks are patchily distributed, and Palaeozoic basin history began with thin plateau basalts extruded in early Cambrian times in the northern part of the area. The early mid-Cambrian sequences of the northern basins are dominated by shallow-water marine carbonates; in the Georgina Basin these include most of Australia's resources of phosphate rock. In later mid-Cambrian times the sea retreated to the north and south where shallow-water conditions persisted until the middle of the Ordovician, with a gradual change from carbonate to sandstone and siltstone. Uplift and erosion occurred during the Silurian. Late Silurian(?) and Devonian rocks are present only in the south of the Georgina Basin.

From the end of the Precambrian until the Carboniferous the Amadeus, Ngalia, and northern basins may have been one large basin (Fig. 6).

The basalts imply that the tectonic regime in the Officer Basin and the northern basins in early Cambrian times differed markedly from that of the region between them; movements of the Musgrave Block (Fig. 6) penecontemporaneous with the volcanism include overthrusting to the north along the southern margins of the Amadeus Basin 600 million years ago (Petermann Ranges Orogeny; Forman & Shaw, 1973), with consequent local molasse-like sedimentation in it.

In Silurian times, broad upwarps seem to have affected the centre of the continent, e.g. the Rodingan Movement of the Amadeus Basin.

In the Carboniferous, the Alice Springs Orogeny, which seems to have been an equivalent of the Kanimblan Orogeny, brought about the major fold deformation of the basins. Folding of this age is pronounced in some of the southern basins, but in the north it is weak and restricted to the southern margin of the Georgina Basin.

In general, late Devonian-Carboniferous sedimentation was very like the sedimentation which took place during the interval between the Tabberabberan and Kanimblan Orogenies in the transitional basins of the 'Younger Internal Basins', and the style of Carboniferous deformation was also similar. Important differences were the southerly overthrusting along the northern margins of the Amadeus and Ngalia Basins, and contrasting fold trends - northerly in the transitional younger internal basins and westerly and northwesterly in the older internal basins. It is suggested, therefore, that the older, more stable, parts of the continent (Gondwanaland?) did not - and could not? - react to the Carboniferous tectonic event in the same way as the younger, less stable, Tasman Fold Belt region.

The Alice Springs Orogeny was, on the face of it, essentially a Carboniferous uplift which most affected the southern basins and their underlying craton, the result being the raising and eventual exposure of the Arunta Block and the separation of the Amadeus, Ngalia, and northern basins from each other (cf. Plumb, this Symposium). The folding in the basins was a consequence of the uplift.

However, the Officer, Amadeus, and Ngalia Basins and the southern part of the Wiso Basin are also associated with Australia's greatest negative Bouguer anomalies (BMR Gravity Map of Australia, 1976). These anomalies, and also the development of the basins, have been explained in terms of compressive buckling leading to granite anatexis in downwarps (Anfiloff & Shaw, 1973), and by postulating intracratonic plate movements (Forman & Shaw, 1973).

Although plate movements to account for the Petermann Ranges Orogeny could be related to the beginnings of the Tasman Fold Belt System in the east and to a possible 'geosyncline' north of the Arafura Basin (cf. Visser & Hermes, 1962), and the Alice Springs Orogeny can be associated with the Kanimblan Orogeny and the plate-margin events of the Fold Belt System, it is difficult to reconcile the north-south compressions implied for the Precambrian cratons with contemporaneous east-west compressions in the Belt. This point is discussed further below.

By comparison with the younger internal basins, the sequence and pattern of development of the central set of older internal basins is one in which stability was essentially achieved in late Proterozoic times after transitional beginnings, and the Petermann Ranges and Alice Springs Orogenies being almost accidentially superimposed on the area.

The western group of older internal basins consists of the Bonaparte Gulf, Canning, Carnarvon, and Perth Basins. They do not appear to be associated with late Proterozoic forerunners as is typical for the central group, and their relationships with their basements are more conjectural than for many other basins.

Their pre-Permian stratigraphy (pre-late Carboniferous in places) reflects two marine transgressive and regressive cycles. The first transgression began in the north in mid-Cambrian times, and extended into the Canning Basin in the Ordovician and the Carnarvon Basin in the Silurian; it apparently did not reach as far south as the Perth Basin, in which probable Silurian continental red sandstones are the only known pre-Permian sediments. The first cycle is notable for late Silurian to early Devonian evaporites and red beds and the second for late Devonian and early Carboniferous reef complexes and deeper water equivalents associated with northwest-trending rifts, the Petrel Graben in the Bonaparte Gulf Basin (Fig. 7) and the Fitzroy Graben in the northern Canning Basin.

The late Carboniferous to early Cretaceous rocks that are usually regarded as belonging to these four basins reflect to varying degrees their development in a tensional tectonic regime interpreted as the rifting phase that led up to the separation of the 'Indian' and Australian parts of Gondwanaland (Veevers & Evans, 1975). However, the rock complexes that were initiated with the rifting phase of this episode, and which are still developing along the western margin of the continent, belong to the marginal basins discussed below rather than to the western group of older internal basins (Figs 7, 10). Separation began in the north in the Jurassic, and in the south during the Cretaceous.

Palaeozoic tectonism affecting the internal basins

Although the stratigraphic and structural differences between the central and western groups of older internal basins tend to support such a distinction, this distinction is less important than the recognition of tectonic domains related to the basins' basements and deformational histories.

The Bonaparte Gulf, Arafura, Daly River, Georgina, and Wiso Basins all overlie a basement of the North Australian Orogenic Province, and for the most part are little deformed.

The Ngalia, Amadeus, Warburton, Officer, and Arrowie Basins overlie the Central Australian Orogenic Province (Plumb, this Symposium), and were affected by three crustal movements. The Carnarvon and Perth Basins probably also overlie this Province, but they are almost undeformed except for modifications by developing marginal basins (q.v.).

The basement of the Canning Basin is largely unknown, although the basin appears to straddle the boundary between the Northern and Central Australian Orogenic Provinces.

The main deformation of the Canning Basin is the northwest trending Fitzroy Graben (Fig. 1). The graben's later development in Tabberabberan-Kanimblan times correlates with northwest-trending deformations and with syntectonic sedimentation in the Bonaparte Gulf Basin (Petrel Graben), southern Georgina, Ngalia, Amadeus, and Warburton Basins. All these basins lie in a northwest-trending zone (Fig. 8) which includes most of, but which is at an angle to, the boundary between the North and Central Australian Orogenic Provinces; the two graben-modified basins of the zone more or less overlie the older craton, i.e. the Northern Province.

In plate-tectonic terms, the Palaeozoic rifts in the Bonaparte Gulf and Canning Basins could be thought of as precursors of continental splits and northeasterly or southwesterly drifting, which did not seem to occur before easterly drift began in the Jurassic. However, tensions in the continent related to northeast-southwest stresses during development of the Tasman Fold Belt System are as hard to allow for as north-south compressions (see above); it is simpler to contemplate Tabberabberan-Kanimblan events in the Tasman Fold Belt System harmonizing with Older Internal Basin deformation events that are related to movements below these basins along the boundary between the Northern and Central Australian Orogenic Provinces. The Silurian (e.g. Rodingan) 'uplift' was possibly the beginning of this episode, and post-Carboniferous rifting the start of the succeeding one (see below).

It would seem that some older event was responsible for the origins of major low gravity anomalies of central Australia.

Marginal Basins

As the marginal basins are the subject of Branson's paper in this Symposium, we confine our discussion to a generalized outline of their tectonic history.

To the south of the continent, the Eucla Basin, Great Australian Bight Basin, and Otway Basin are the largest of those that originated when Australia broke from Antarctica and subsequently drifted to the north in the Cainozoic. Jurassic intrusives and extrusives apparently mark the tensional beginnings of the split. Falvey's concepts of offshore basin development (1974) as applied to the Otway Basin by Boeuf & Doust (1975) would appear to explain the evolution of all Australian basins marginal to ocean-floor spreading centres. Figure 9 shows our version of the Otway Basin model in a generalized fashion.

The oldest marginal basins (e.g., Browse Basin), lie off northwestern Australia and are a consequence of the development of the adjacent oceanic Wharton Basin. Figure 10 shows our application of the Otway Basin model of Figure 9 to the marginal basin that modified the Bonaparte Gulf Basin. Off southwestern Australia, Permian to Holocene sequences and structural features usually regarded as being parts of the Perth and Carnarvon Basins can be said to be characteristic of marginal basins, in this case associated with easterly drift of the Australian continent along the Wallaby-Perth Transform (Johnstone et al., 1973), away from the Ninetyeast Ridge beneath the Indian Ocean.

The paucity of marginal basins off eastern Australia seems due to plate-margin complexities related to eastwards migration of subduction zones and the opening of the Tasman Sea. The Maryborough Basin is one such feature, and we have already suggested that it may have been originally a foredeep basin; the nearby Capricorn Basin is attributed by Branson (this Symposium) to tensional splays at the northern end of the Tasman Sea. It also points up the difference between marginal basins formed where continents break up, such as those to the south and west of the continent, and those formed near subducting plate margins, as in New Guinea (Fig. 2); the latter end up being incorporated in fold belts, while the former could apparently be terminated only by new transforms or subduction zones.

Australia's greatest oil and gas resources occur in the Carnarvon and Gippsland Basins, which are break-up marginal basins.

In any revision of the concept of the Trans-Australian Platform Cover, for instance modifications based on genesis as suggested above in discussing the younger internal basins, the relevance of marginal basins to this platform Cover must also be considered. They should probably be treated as a unique tectonic entity developing contemporaneously with platform cover and fold belts.

Mesozoic and Cainozoic tectonics affecting Australia's sedimentary basins

In this paper we have been considering the evolution of the Australian continent during the Phanerozoic, using sedimentary basins as a starting point. In terms of plate-tectonic concepts the following historical picture can be visualized based on Permian to Holocene rifting and drifting.

If Australia's western and southern marginal basins are the response of the trailing edge of the continent to drift while at the same time basins were forming in 'geosynclinal' settings associated with subduction zones along the continent's leading edge, then contemporary intracontinental (internal, intracratonic) basins are directly or indirectly, also a response to drift. The foredeep Bowen and Sydney Basins, and perhaps other deeper and narrower basins together seem to be a compressional response, whereas broader shallower features such as the Eromanga Basin, with its normal faults and thinning of drape folds, appear to require a dilatational component.

As the continent drifts, not only its leading and trailing edges are modified but its sides should be disturbed also. Features such as the Exmouth and Queensland Plateaux (Branson, this Symposium) may have Cainozoic structural components so generated. Similar pre-Cainozoic features may be recognizable in New Guinea.

This history does not relate the development of the basins to the evolution of the Tasman Fold Belt System; for interpretations which consider the development of the basins as part of the history of the Belt, see Scheibner (1973).

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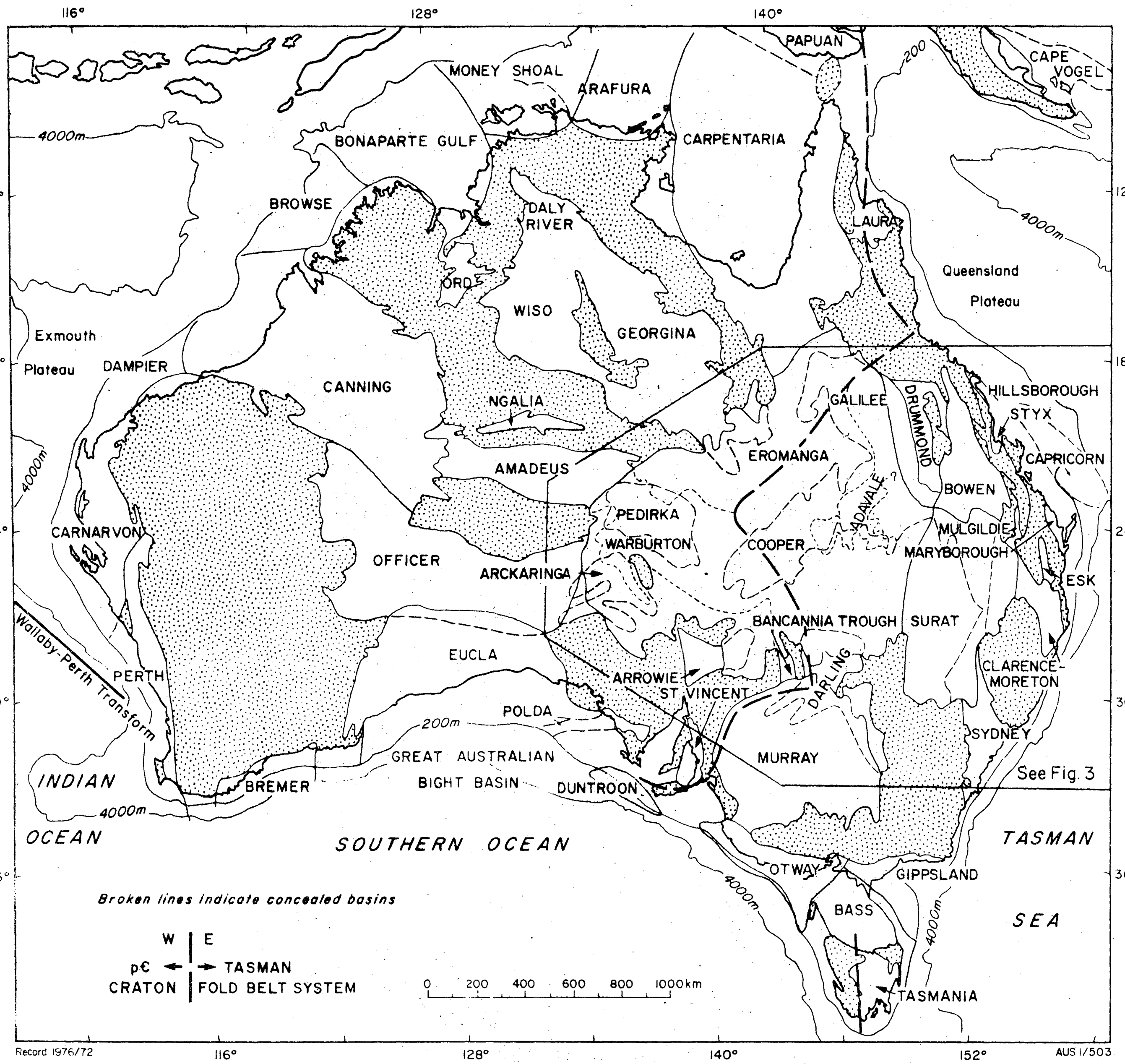

Fig. 1 Phanerozoic Sedimentary Basins of Australia

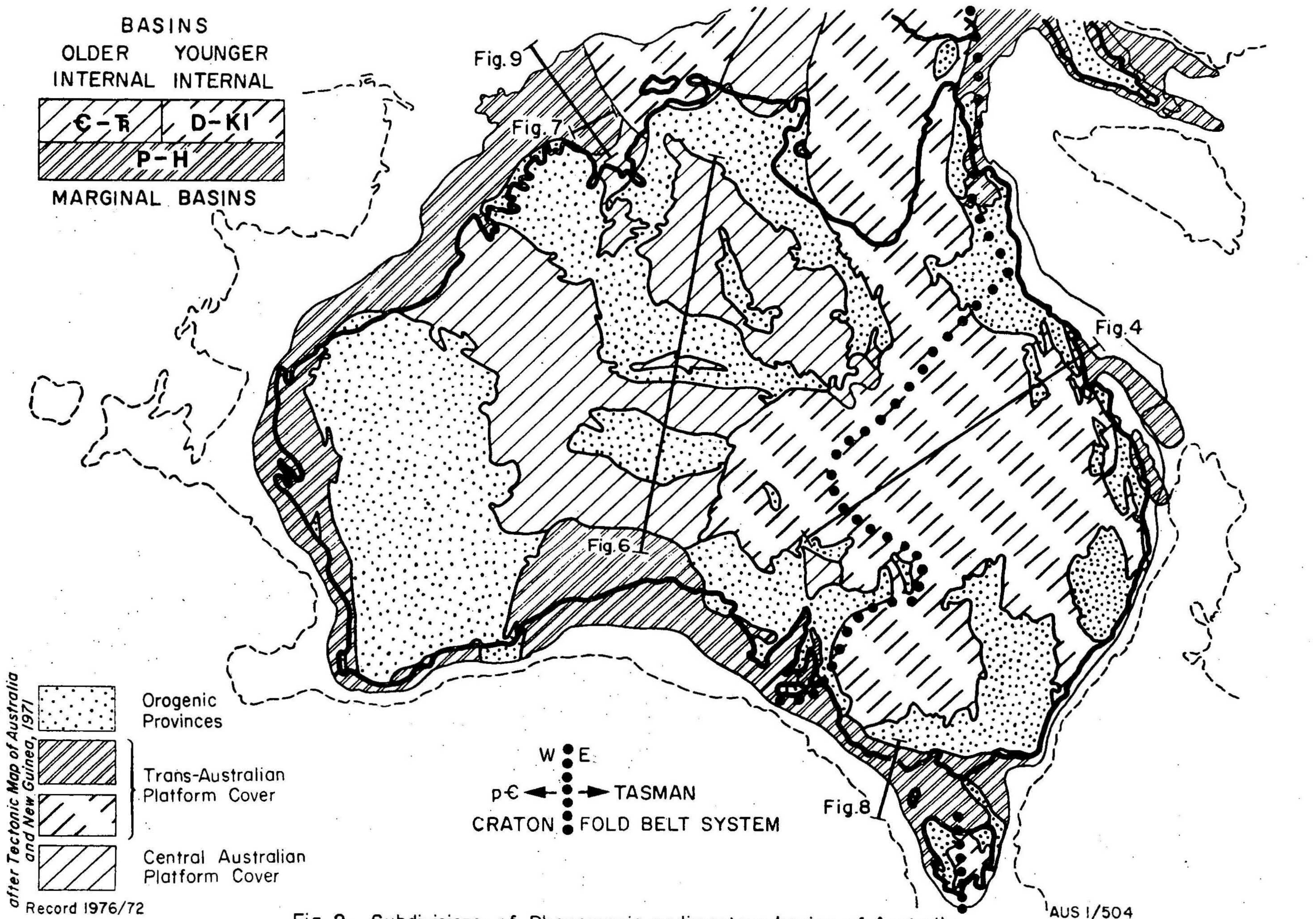

Fig. 2 Subdivisions of Phanerozoic sedimentary basins of Australia

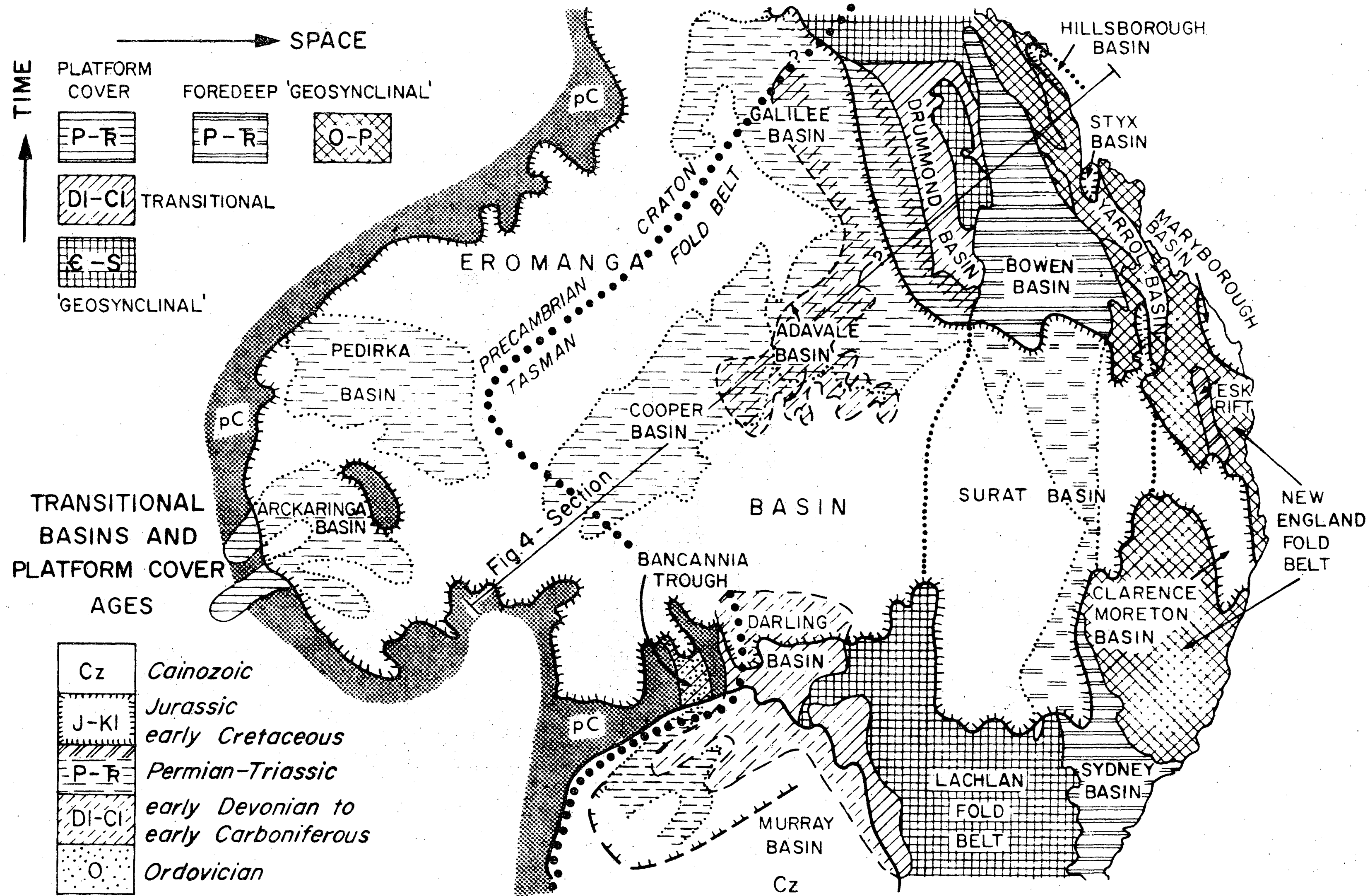

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Fig.3 Representative younger internal basins

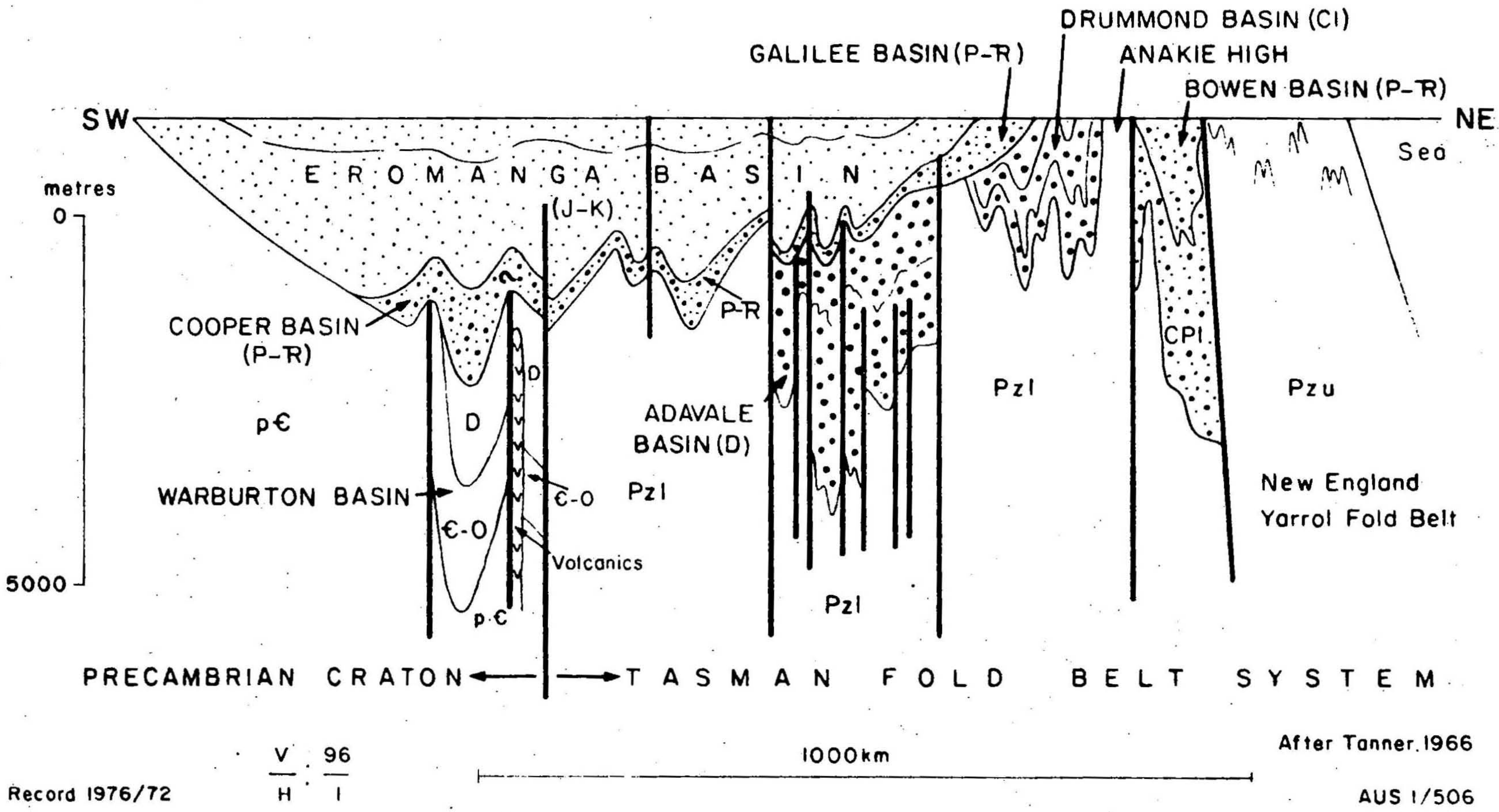

Fig. 4 Section across representative younger internal basins

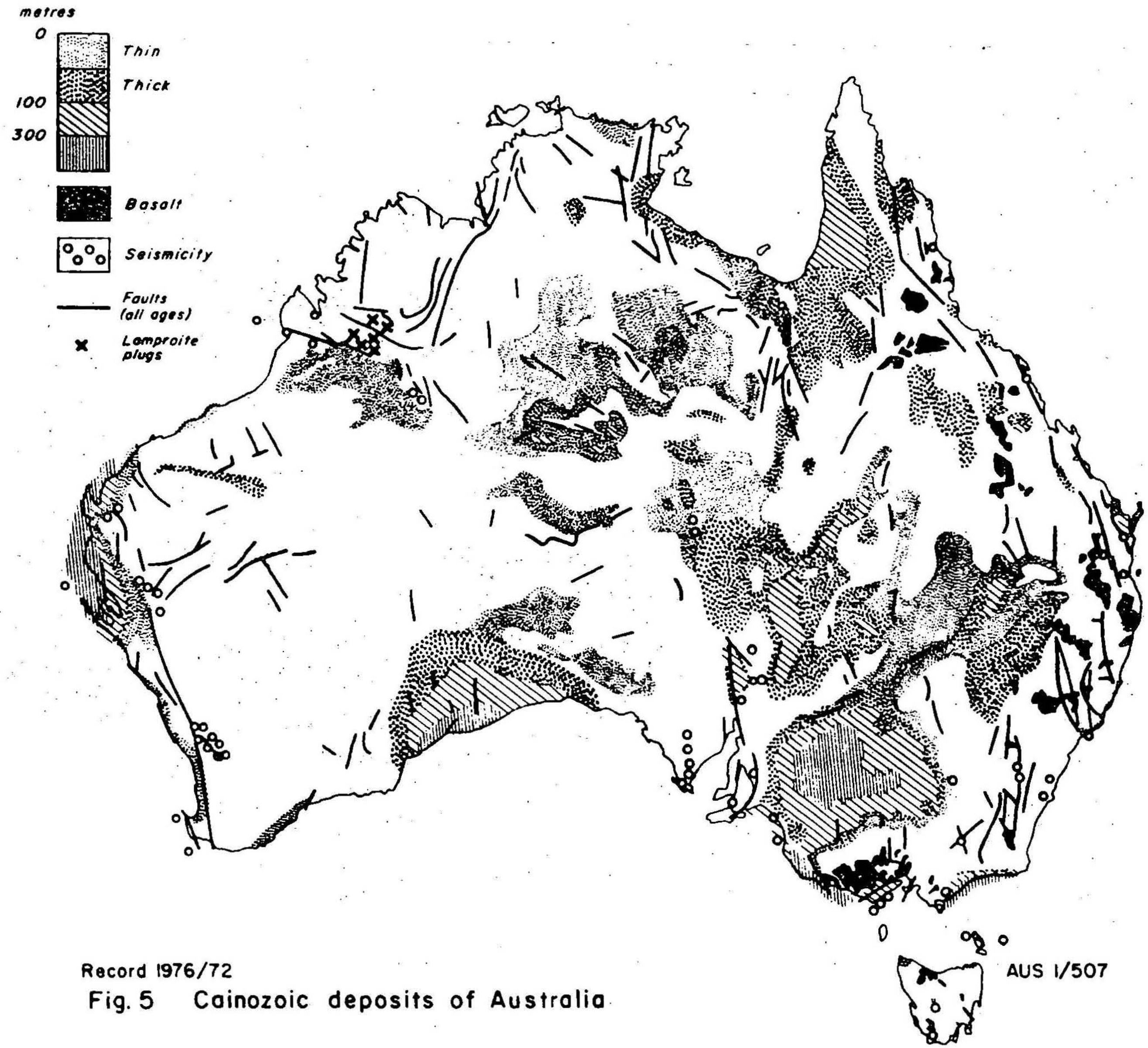

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Fig. 5 Cainozoic deposits of Australia

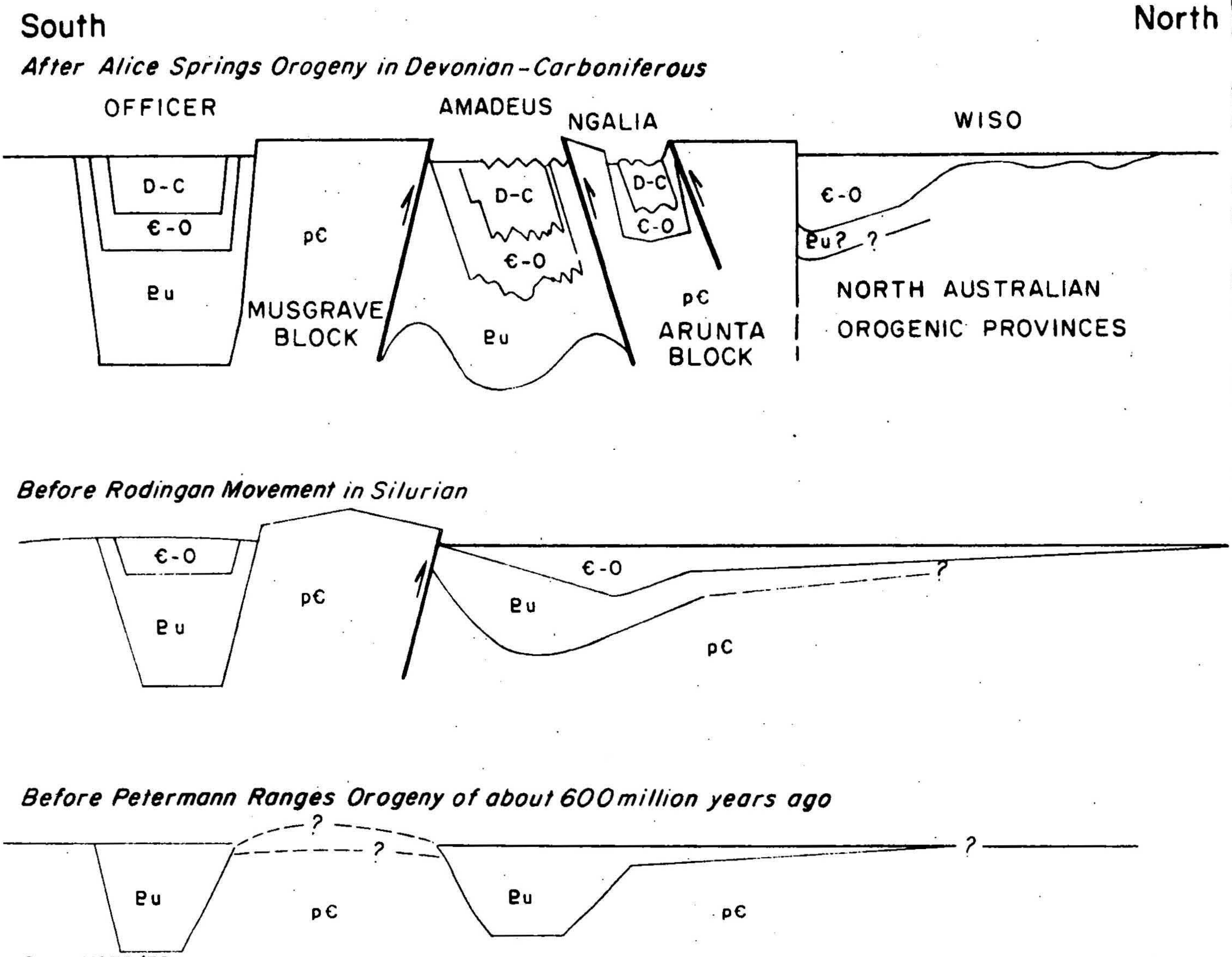

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Fig. 6 Evolution of central group of older internal basins. *Diagrammatic only*

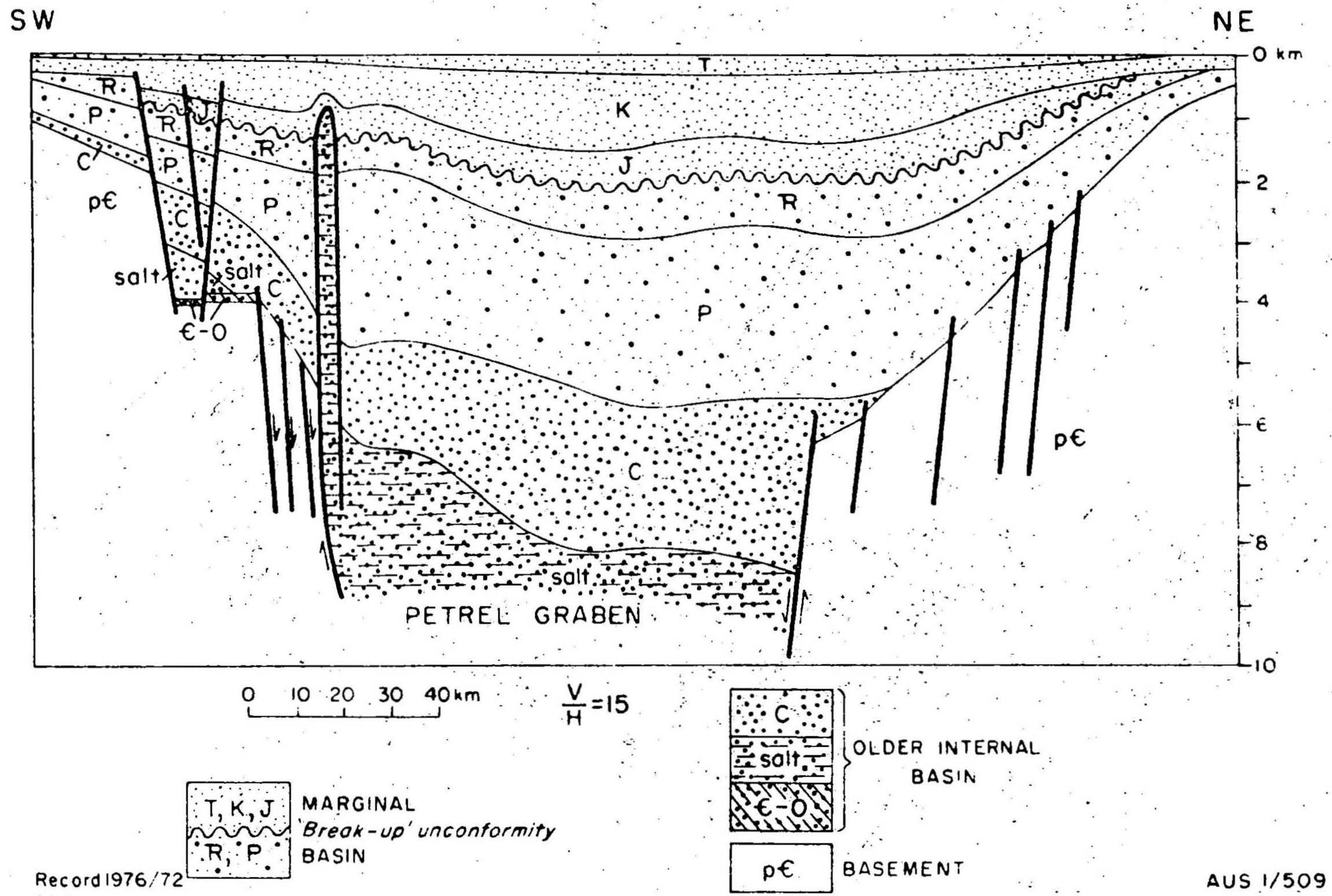

Fig.7 Bonaparte Gulf Basin (after Edgerly and Crist, 1974)

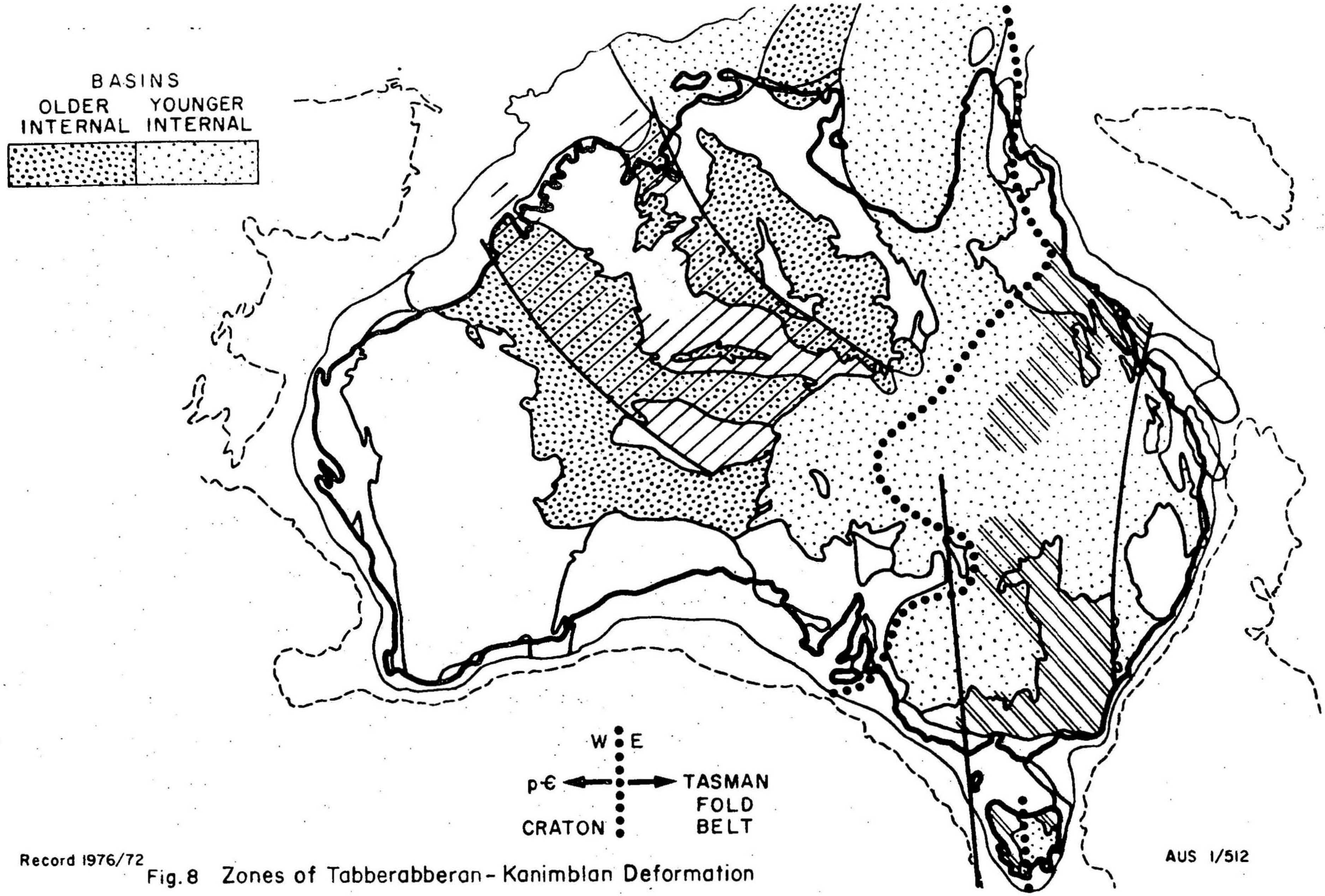

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Fig. 8 Zones of Tabberabberan - Kanimblan Deformation

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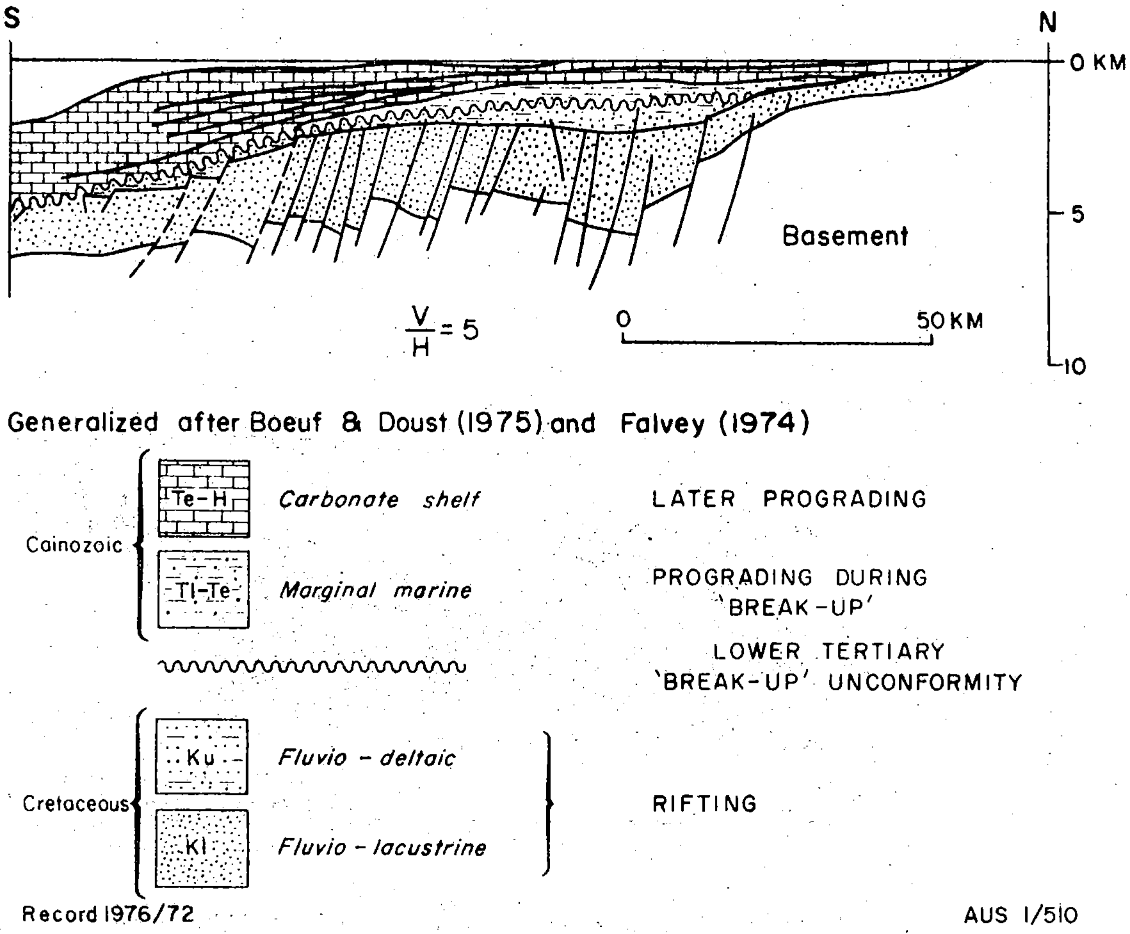

Fig. 9 Otway Basin : Type Marginal Basin

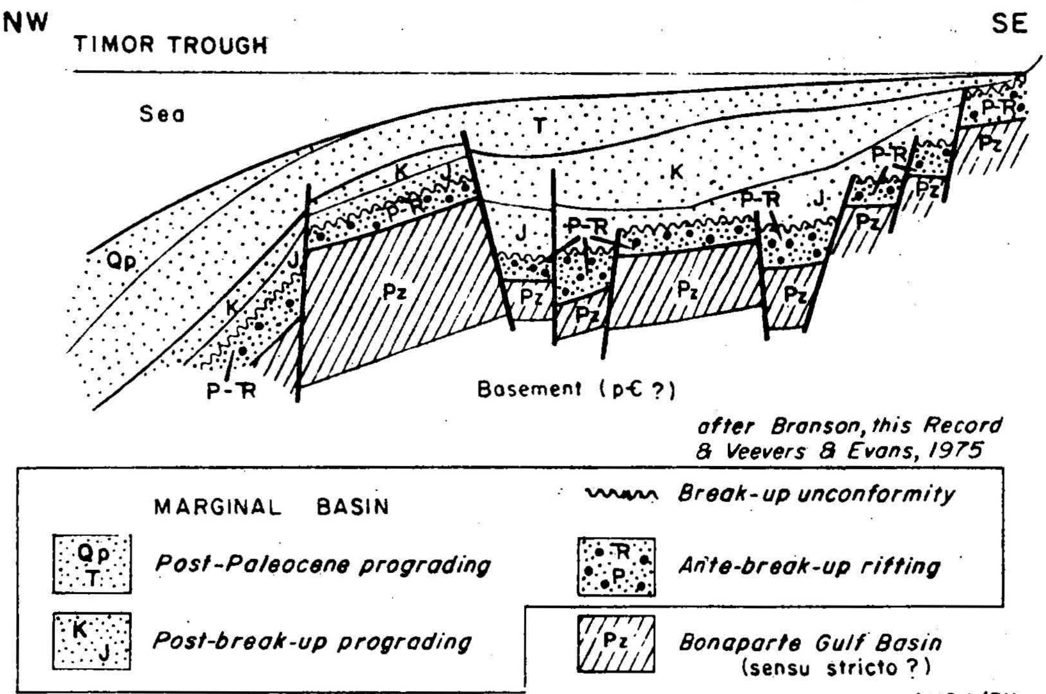

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Fig. 10 Marginal basin above Bonaparte Gulf Basin
(diagrammatic only)

Symposium 103.3 - The structure of Australia and variations in tectonic style. 25th International Geological Congress, Sydney 1976

The Australian Continental Slope and Shelf

by

John C. Branson

ABSTRACT

Evidence for five major ocean-basin spreading events, an ocean-bottom current effect, and tectonism on Australia's northern margin can be identified within sedimentary sequences and basins in the Australian continental slope and shelf. It is possible to recognize seven major stages in the tectonic evolution of the margin: Middle to Upper Jurassic, middle Lower and middle Upper Cretaceous, late Upper Cretaceous to Paleocene, Lower Paleocene to Lower Eocene, Eocene to Oligocene, Miocene, and Plio-Pleistocene to Holocene.

Northwestern, western, and southern continental margins can be explained by Falvey's Atlantic-type model. They have rift-valley sedimentary sequences, although ages of valley-fill and of continental margin collapse vary from place to place. The eastern and northeastern margins do not contain extensive recognizable rift-valley sequences except for tensional splays in the Tasman Sea. The tectonism of the northern margin is mainly recorded on land in Irian Jaya, Timor, and Papua New Guinea where compressive tectonic events have occurred at plate margins.

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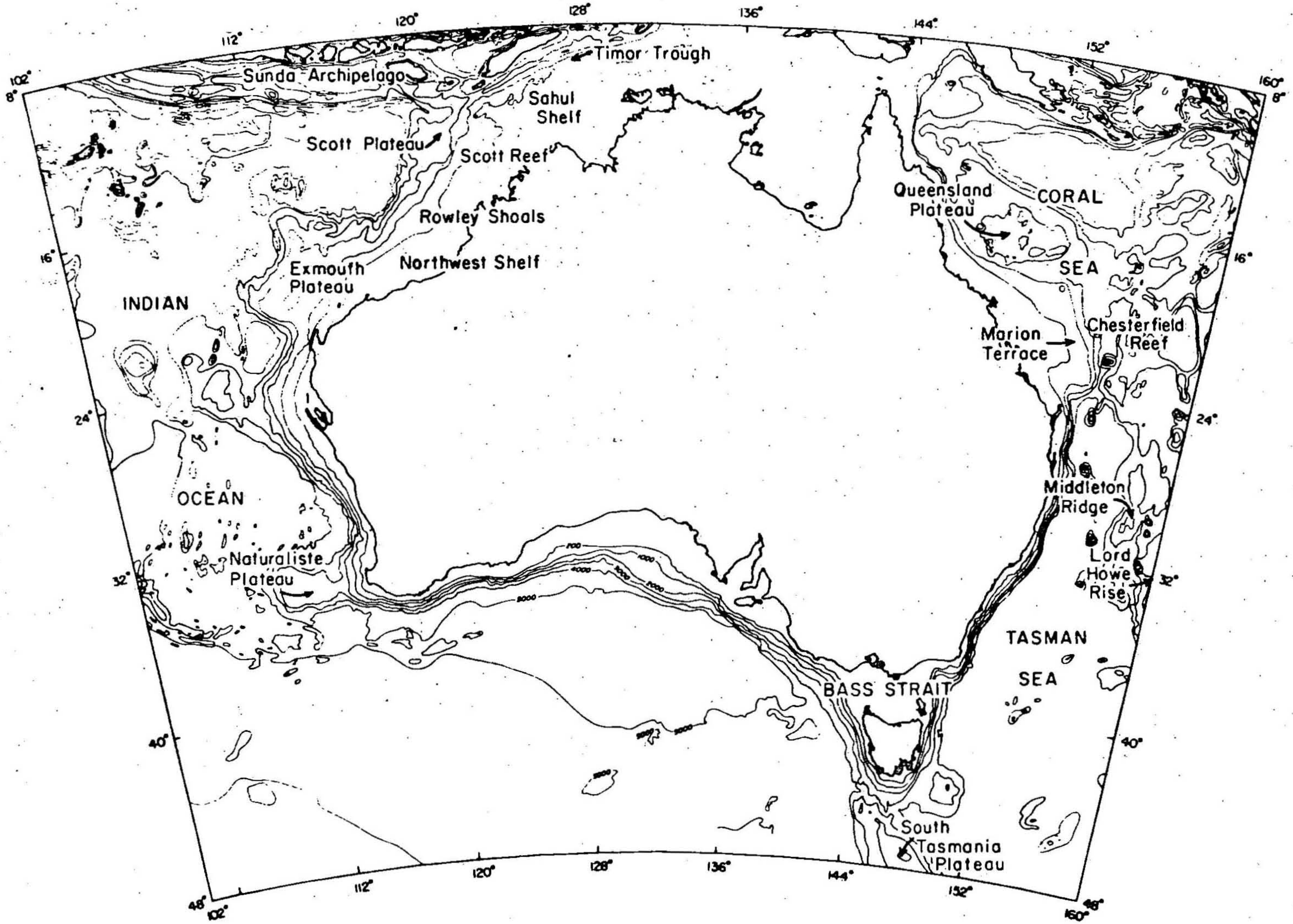

BATHYMETRIC FEATURES

FIG. 1

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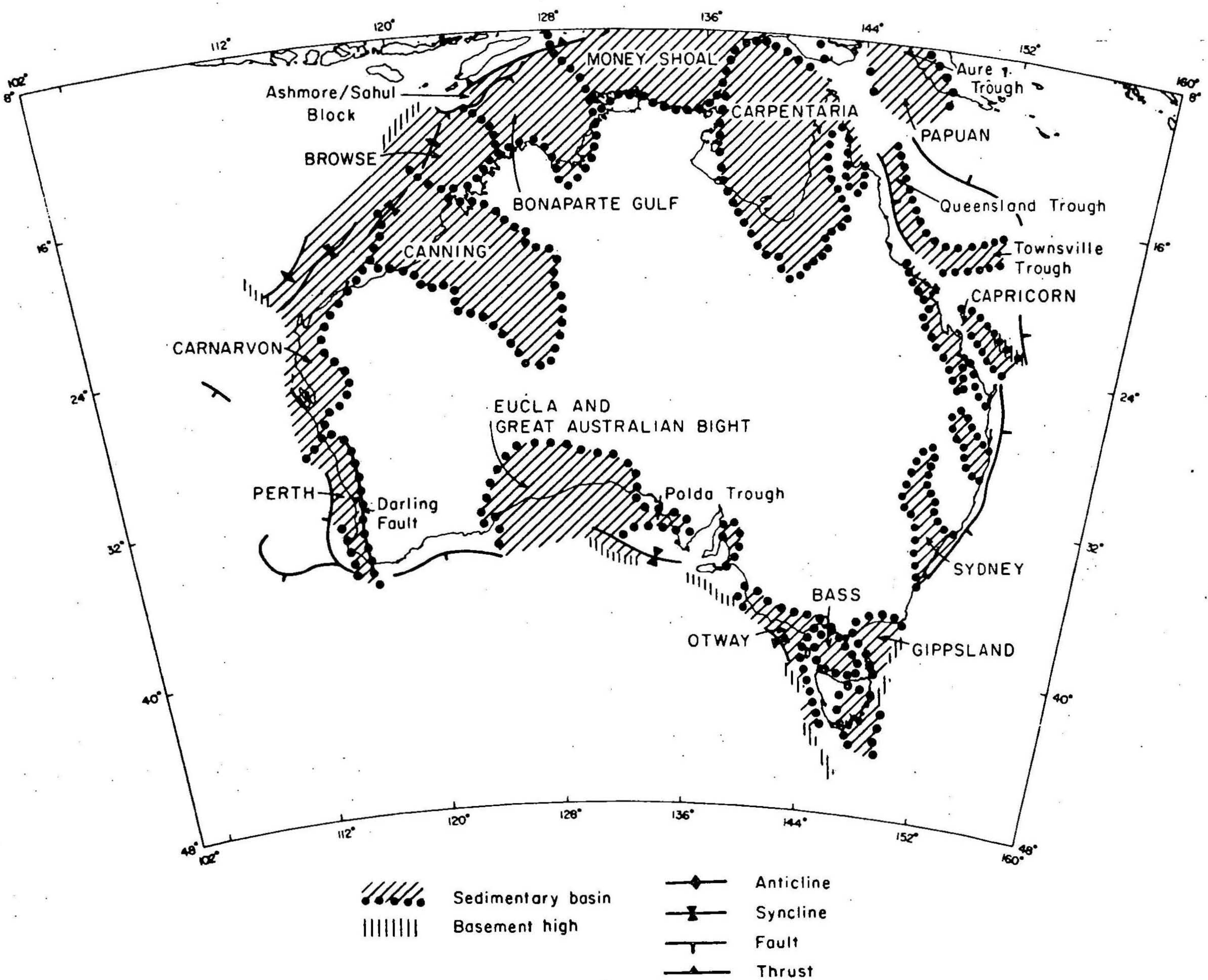

FIG. 2

SEDIMENTARY BASINS

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INTRODUCTION

This paper contains brief descriptions of sedimentary basins on the continental slope and shelf, based on the recognition of seven major stages in the tectonic evolution of the margin.

Eighteen Deep Sea Drilling Project (DSDP) sites have been located in the Australian region since 1970. These, together with an extensive geophysical survey of the continental slope and shelf, reconnaissance geophysical survey lines across the adjacent ocean basins, and sedimentary basin reviews, all contribute to a recent advance in the study of the structure of the Australian margin.

Ocean basins and continental shelves were studied before the regions of the continental slope and rise which join them. As workers in the petroleum industry assessed data from private company and government surveys, a more detailed knowledge of the mode of formation and structure of marginal basins has emerged. The Exmouth Plateau (Fig. 1) is under study in BMR (Willcox & Exon, 1976) and more detail is being added by BMR and Shell (Boeuf & Doust, 1975) to knowledge of structures under the Great Australian Bight. U.S.N.S. Eltanin results across the South Tasmania Plateau are being investigated by Flinders University and several studies of the Tasman and Coral Sea Regions are being undertaken by workers in Sydney. All these studies are contributing to current thinking on the setting of the Australian continent.

Fourteen major sedimentary basins (Fig. 2) are known to extend beneath the continental shelves and continental slopes. The Money Shoal, Bonaparte Gulf, Browse, Carpentaria, Great Australian Bight, Bass, and Capricorn Basins lie almost wholly beneath the continental shelf and slope, and their structures and sedimentary histories have been studied by offshore explorations wells and marine seismic reflection surveys. The remaining sedimentary basins, the Sydney, Gippsland, Otway, Eucla, Perth, Carnarvon, and Canning, retain some of the history and tectonic character of their onshore parts, but structures and sedimentation are modified by the adjacent ocean basin history.

This discussion summarises review papers and recent studies of the Australian continental slope and adjacent oceans. In the north and northwest Audley-Charles (1968) reviews the Timor Region, Laws & Kraus (1974) the Bonaparte Gulf, and Balke, Page, Harrison, & Roussopoulos (1973) the Money Shoal Basin. Brown, Pieters, & Robinson (1975) and Tallis (1975) discuss the development of the Gulf of Papua, and Pinchin (1973) and Doutch (1976) discuss the geophysical coverage and geology of the Carpentaria Basin.

There are no review papers that cover sedimentary basins and ocean basin histories of the Coral Sea and the Tasman Sea. Veevers & Evans (1973) describe the sedimentary and magmatic events for this region as part of a description of the Australian and worldwide setting of the Cretaceous. Hayes & Ringis (1973), and Molnar, Atwater, Mammerickx & Smith (1975), describe the Tasman Basin and its regional setting. In the Coral Sea, the most general descriptions of the continental slope and ocean basins are by Falvey (1974) and Mutter (1975).

The southern margin is reviewed by Boeuf & Doust (1975) as a westward extension of Bass Strait reviews by Weeks & Hopkins (1967), James & Evans (1971), Hocking (1972), and Robinson (1974). The tectonics of the adjacent Southern Ocean are described by Molnar et al. (1975), updating earlier ideas of Griffiths (1971) and Weissel & Hayes (1972).

Veevers & Johnstone (1974) describe ocean drilling and shelf sedimentary basins in Western Australia in a broad review paper. There are more detailed papers on the Perth Basin and southwest by Jones & Pearson (1972) and Johnstone, Lowry, & Quilty (1973), and on the Indian Ocean region by McKenzie & Sclater (1971). The offshore part of the northern Carnarvon Basin is reviewed by Kaye, Edmonds, & Challinor (1972), and the offshore and onshore parts by Thomas & Smith (1974). The Browse Basin is reviewed by Halse & Hayes (1971), the Rowley Sub-basin of the Canning Basin by Challinor (1970), and three northern basins by Williams, Forman, & Hawkins (1974) and Powell (1976).

GENERAL DESCRIPTION OF SEDIMENTARY BASINS

A general clockwise description of the 14 sedimentary basins follows.

Northern margin

The Bonaparte Gulf and Money Shoal Basins on the northern margin of Australia connect with the Timor Trough. The Carpentaria Basin farther east has ill-defined boundaries with offshore basins in New Guinea and with the Money Shoal Basin, and overlies mainly Precambrian rocks.

The northern part of the Bonaparte Gulf Basin underlies the southern slope of the Timor Trough. This slope contains a thick Tertiary sequence of 6000 m of carbonate rocks. DSDP results show that shallow-marine Pliocene rocks were depressed by later tectonic events or Pleistocene sediment loads to 2000 m below present sea level. Both the Mesozoic and the Cainozoic sediments are typical of those expected on a continental shelf which has been subjected to periodic innudation by the sea. Fluvial and deltaic sediments are common near depositional margins. The Bonaparte Gulf Basin commenced as a graben in Palaeozoic times but fault structures die out in the Permian and the basin became saucer shaped. Lower Palaeozoic salt deposits gave rise to piercement structures in response to later sedimentary loading and faulting.

Mesozoic and Cainozoic basin axes and the directions of depositional margins were controlled by northeasterly-trending fractures which developed during Indian Ocean spreading. These depositional axes and basin margins were also affected by rejuvinated Palaeozoic northwesterly trends. The resultant Mesozoic basin has a northeast-trending central axis which bifurcates around the Ashmore-Sahul Block.

The Money Shoal Basin contains a deformed Tertiary carbonate sequence on the southern slope of the Timor Trough, as does the Bonaparte Gulf Basin. The sequence was deformed in Plio-Pleistocene times. A fracture zone or hinge with a north-northeasterly strike, separates a western region where Mesozoic and Cainozoic rocks are 6000 m thick from an easterly region where they are only 4500 m thick. The difference in thickness is almost entirely in the Mesozoic part of the section. Sediments in the western region were probably deposited in deep-water marine conditions, whereas sediments in the east are mainly paralic and fluviatile.

A pre-Mesozoic graben which trends northwest is present in the eastern portion of the Money Shoal Basin. This trend direction parallels the depositional limits of the Palaeozoic sequences and is the principal direction of Palaeozoic faults in the adjoining Bonaparte Gulf Basin.

The epicratonic Carpentaria Basin farther east contains no distinctive hinge zones. Minor pockets of Permian(?) rocks, some thin Jurassic sequences, 800 m of Lower and Upper Cretaceous marine and fluvial rocks and up to 200 m of Cainozoic non-marine clastics reach a maximum thickness of about 1200 m at the basin centre.

Northeastern margin

To the northeast of Australia the Papuan Basin opens southeastwards into the Coral Sea. Off the Queensland coast the Queensland Plateau flanks the deep ocean regions of the Coral Sea. At the southern and western margins of the Queensland Plateau two bathymetric troughs (Queensland and Townsville Troughs) coincide with Cainozoic sedimentary basins.

In Irian Jaya (Visser & Hermes, 1962) and in the Papuan Basin, little is known of the sedimentary and tectonic history of the Cambrian, Silurian, and Devonian. There is no evidence of pre-Cretaceous folding. The pre-Cretaceous sediments are evidence of a tectonically stable province whose provenance was constant throughout the Palaeozoic and probably in the south. There is no evidence of a Melanesian continent to the north.

Facies distribution suggests that Jurassic-Cretaceous sediments were deposited from a mainly southern source onto a shelf which opened towards the Pacific.

Early Tertiary facies distribution shows the same pattern as in the earlier rocks, although the sediments are mainly calcareous rather than clastic. The sediments were deposited over large areas, some being derived from barrier and platform reefs. Sediments became more characteristic of open-marine environments towards the north.

The northern continental slope was deformed in the mid to late Miocene. Basins formed to the north and south of the central Irian Jaya region.

The main uplift of the central ranges took place from the late Miocene to the Pleistocene. Adjacent troughs were filled and subsided to the north and south of the range. Stable shelves and basins to the south merged in time into a single asymmetric trough with a steeply dipping northern side.

Paleocene to Eocene sea-floor spreading, which gave rise to the Coral Sea Basin, also created an unstable region in the eastern part of the Papuan Basin that was later deformed by very recent movements from the east. These movements affected Pliocene and Pleistocene sediments and caused mud diapirs and long-wave-length flexures. Their effects die out westwards towards the shelf and stable craton.

Intrusive masses in the axis of the uplift may contain mantle material near thrusts and faults. Earthquake activity and limited vulcanism occur within the central region today, but the present-day subduction zone is not uniquely determined.

The Queensland Plateau appears to have formed part of the Tasman Geosyncline until the Mesozoic when it began to subside after grabens had formed along its southern and western margins coinciding with the Queensland and Townsville Troughs (Falvey, 1974). Opening of the Coral Sea ocean floor to the northeast of the plateau during the Paleocene to Eocene may have post-dated formation of the grabens, (Falvey, 1974) but there appears to have been a major infilling and subsidence of these grabens during the Miocene (Mutter, 1975). Many unconformities within the thin superficial cover of the plateau indicate current scour and possible emergence of the upper surface since the Eocene; a general development of about 500 m of pelagic material thickens to 1000 m on the northern slopes. Reep growth on the shallow Miocene surface kept pace with the rate of subsidence of the plateau as evidenced by the existence of modern reefs on the plateau.

Eastern Margin

This region of continental margin between the Southern Coral Sea and the Southern Ocean is flanked by a variety of oceanic features. Spreading of the Tasman Sea floor during a 15-million-year period in the Upper Cretaceous and Paleocene separated the New South Wales coast from the Lord Howe Rise. Limited subduction of the western margin of the sea floor was concurrent with the last phases of spreading. Pre-existing sedimentary basins like the Sydney Basin were split, and tensional splays at the northern end of the Tasman Sea and in Bass Strait formed the new Mesozoic and Cainozoic Capricorn and Gippsland Basins.

The Marion Terrace abuts the continental shelf between the ocean basins of the Coral Sea and Tasman Sea. A trough to its east formed as a result of spreading in the Upper Cretaceous (Taylor, 1975). Oceanic floor development is unknown but a number of regions appear to contain faulted and subsided continental blocks as well as oceanic floor. Thicknesses of Cainozoic and Upper Cretaceous rocks on the Marion Terrace range from about 500 m near the shelf to over 1000 m on the continental slope. These sediments are probably marls; reefs have developed on the terraces northern margin.

The region to the east of the Marion Terrace is the most complex part of the Australian Continental margin: it is made up of two meridional lines of guyots, together with subsided continental blocks. The largest continental block underlies the Chesterfield Reef at the northern end of the Lord Howe Rise. The southern margin of the Marion Terrace is on line with the southern margin of the Chesterfield Reef, which has suggested to a number of workers that the northern Tasman Sea is bounded by a transform fault.

The Capricorn Basin contains 3000 m of Mesozoic and Cainozoic sediments bounded by normal faults within the southern Marion Terrace. Mesozoic sequences comprise 400 m of Upper Jurassic conglomerates and volcanics and 900 m of Upper Cretaceous non-marine to shallow-marine sediments. The Cainozoic sequences contain 600 m of shallow-marine and deltaic deposits of Lower Tertiary age and 1200 m of Miocene to Holocene marls. Barrier reefs have developed on unconformities in the Miocene to Holocene section at the northern end of the terrace, near the Townsville Trough (J.C. Mutter, pers. comm.).

Over the continental slope bordering the Tasman Sea, prograded Tertiary sediments lie on Palaeozoic sedimentary and metamorphic rocks. The Permian-Triassic Sydney Basin and smaller sedimentary basins to the north are elongated troughs with trends parallel to the grain of the Tasman Geosyncline. On the continental slope the Sydney Basin sediments were split apart by west-southwest seafloor spreading at the Pacific margin between the late Upper Cretaceous and the Lower Eocene; presumably the missing section will be found at a lower latitude in the Lord Howe Rise. Permian marine rocks up to 3800 m thick contain volcanic detritus. Over these rocks lie 1200 m of deltaic and tidal-flat deposits of the Lower and Middle Triassic. These sediments have been intruded at least four times by hypabyssal rocks.

The Gippsland Basin (Cretaceous-Tertiary) contains features similar to the Otway and Bass Basins. The central graben contains 3000 m of rapidly dumped Lower Cretaceous greywacke and minor volcanics. Basic volcanics are recorded in the unconformably overlying transgressive rocks which range in age from Upper Cretaceous to Eocene. This section consists of 5000 m of deltaic rocks, deeply channelled in the east. A regressive marine sequence 1500 m thick followed: Oligocene deposits grade eastwards to Miocene marls and limestones. Prograded Miocene to Holocene sediments have a similar form to the sediments on the shelf farther north.

Within the Tasman Sea ocean basin two major areas near the continental slope contain sediments which were transported to abyssal depths down a series of continental-slope canyons. Near Brisbane, an elongate region of sediment 1500 m thick lies parallel to the slope. This sediment forms a broad mound between the slope and a series of guyots. Near Bass Strait, the Bass Canyons open onto a trough of sediment 2000 m thick. The upper surface of this trough forms the continental rise and abyssal plain. Sediment ages are unknown but a prominent seismic horizon in the lower third of these sediments is thought to be the Eocene-Oligocene unconformity (discussed below).

Southern margin

Spreading commenced in the Paleocene about a pole of rotation in the western Southern Ocean. This spreading continues to the present day. Shelf and slope sedimentary basins indicate that marine incursions occurred in the Great Australian Bight in the Upper Cretaceous. Deighton, Falvey, & Taylor, (1976) consider these to be the result of marine ingressions across the continent from the north. Rift-valley sediments with fluvial characteristics are prominent in the Bass Strait region.

Bordering the Southern Ocean, south of Australia are the Bass, Otway, Eucla, and Great Australian Bight Basins.

The Otway and Bass Basins contain features similar to those in the Gippsland Basin to the east. They are essentially grabens filled with Upper Jurassic to Cretaceous terrigenous and detrital material up to 3000 m thick. Some of this material is recognisably volcanic in origin and typical of classical rift-valley systems. The Bass Basin has only minor graben structures affecting the Upper Cretaceous and Lower Tertiary. It continued as an epicratonic basin with limited marine influence until the Middle Eocene. In the Upper Eocene the silled basin had a northern entrance to the sea. Marine deposition gradually extended over the basin, replacing fluvial deposits, until the entire basin received marine deposits in the Oligocene. Intrusive and extrusive igneous activity continued throughout the Tertiary.

Along the western Tasmanian section of the coast, the southern Otway basin has taphrogenic form in the present continental margin. Thin Cretaceous sediments are preserved in fault blocks within Palaeozoic/Proterozoic basement. In the main Otway Basin farther west, near the South Australian border, a Jurassic trough is preserved over the Tasman Geosyncline onshore, and Lower and Upper Cretaceous paralic sediments offshore were derived from southern as well as northern sources. Paleocene sediments form the first member of the Tertiary marine sequence. The marine conditions advanced from the west during the Paleocene and had extended throughout the basin by the Eocene. Prograded sediments were deposited over an extending shelf edge.

West of the Otway Basin, smaller basins in the slope edge merge into an extensive basin underlying the continental slope known as the Great Australian Bight Basin. Sediments in the Bight Basin suggest that major marine incursions occurred in the Upper Cretaceous, which is earlier than ages determined for sea-floor-spreading anomalies in the open ocean and slope margin (Weissel & Hayes, 1971). Spreading probably commenced in the Paleocene. On the continental slope a 10 000-m-thick Upper Cretaceous basin is contained behind a marginal dam. On the shelf there is an east-west graben, the Polda Trough containing Jurassic and Lower Cretaceous fill. Farther north the Denman Basin beneath the Tertiary cover contains about 1500 m of Permian and older sediments. A dendritic drainage channel system farther west on the slope also contains Permian and possibly Upper Cretaceous; these channels may be the result of Permian glacial action. A Middle Eocene marine transgression over the shield overstepped older Tertiary deposits and laid down thin calcareous sediments in the Eucla Basin. Prograding of the carbonates at the shelf edge continues to the present day.

The continental slope between the Great Australian Bight Basin and the southwestern corner of the continent contains isolated pockets of sediments of Tertiary age. These pockets are relatively minor and probably contain Eocene rocks deposited during the same marine transgression recorded farther east.

Western margin

A landmass to the west of Australia's western margin, possibly India, is postulated as containing missing sections of the extensive rift-valley formations near Perth and Carnarvon. The Naturaliste Plateau and possibly Broken Ridge farther west appear to be continental fragments. Rift-valley sequences on the shelf formed in the mid-Lower Cretaceous on top of the pre-existing Perth and Carnarvon Basins which are also fault-bounded. Breakup of this rift-valley sequence probably commenced in the mid-Upper Cretaceous.

The Perth Basin is filled by mainly continental deposits although occasional marine incursions occurred during the Palaeozoic rifting of the western margin. Sedimentation commenced in a graben north of Perth in Ordovician and Silurian times. Then followed a long period of nondeposition until the Lower Permian. Widespread deposition in the Triassic and Jurassic reached a maximum north of Perth. A classical Atlantic-type margin formed prior to spreading in the Indian Ocean in Lower Cretaceous times on the site of a pre-existing graben. Offshore a major break in sedimentation occurred in the Neocomian, by which time up to 6000 m of sediments had been deposited in the shelf basin. 1800 m of Tertiary and Upper Cretaceous sediments (mainly Tertiary in the north) overlie the Neocomian unconformity.

The Darling Fault played an important role in Permian and Lower Triassic times and its rejuvenation in the Upper Triassic resulted in rapid basin subsidence until the Neocomian. Movements on other faults caused the collapse of the central part of the offshore region; the effects of this are reflected in the seafloor topography off Perth.

On the Naturaliste Plateau, drilling into the general 500-m-thick pelagic sedimentary cover shows three unconformities - Neocomian, Albian, and Cretaceous-Tertiary - which appear to extend over the whole plateau. Seismic sections show at least 500 m of sediment below the Neocomian unconformity in two separate basins on the plateau.

Northwestern margin

Most of the ocean floor between the North West Shelf and the Sunda Archipelago formed in the Upper Jurassic. A pole of rotation for this opening has been postulated north-east of Timor, though the evidence is poor. Marginal plateaus and irregular oceanic rises border the ocean floor. Rift valleys of late Upper Triassic to Upper Jurassic age lie in the shelf and slope regions. Within these rifts, sources of marine and deltaic deposits of pre-Lower Cretaceous age lay to the west as well as to the east. This section of the continental margin subsided more slowly than any other part of the Australian continental margin. Bordering this region of ocean are the northern Carnarvon, western Canning, and Browse Basins.

On the shelf and onshore the Carnarvon Basin formed on an epicratonic or pericratonic site. A series of rifts was fully developed during the Jurassic; spreading of the ocean floor became almost coincident with rifting (Powell, 1976). Within the basin, Palaeozoic terrestrial sedimentation in the south gave way to a marine environment in the north. In the offshore region a series of horst blocks bounded Jurassic sedimentary troughs. These continued to be restricted deltaic regions into the Neocomian. A widespread marine transgression in the Lower Cretaceous covered all of the block-faulted Palaeozoic and older Mesozoic sediments. Generally the marine influence, which was associated with a low level of influx of detrital material, resulted in the high carbonate content of the Upper Cretaceous and Tertiary. Prograding carbonates built out along the newly formed shelf edge.

General unconformities that occur on the Exmouth Plateau reflect the sedimentation and tectonism of the shelf, particularly in the offshore Carnarvon Basin.

The Canning and Browse Basins on the continental shelf show similar histories of deltaic and shallow-marine deposition into depocentres within the present shelf during Triassic and Jurassic times. Opening of the older section of the Indian Ocean in the Middle to Late Jurassic resulted in erosion of previous elevated surfaces and a gradual westward migration of the depocentres during the Cretaceous and Tertiary. The areas between Rowley Shoals and the shelf edge in the Canning Basin, and Scott Reef and the shelf edge in the Browse Basin received maximum Tertiary deposits.

Marine Jurassic sequences are rarely detected in drill holes as the sediments are traced north in the continental shelf and slope. The Jurassic sequence contains volcanics on the shelf near the Scott Plateau.

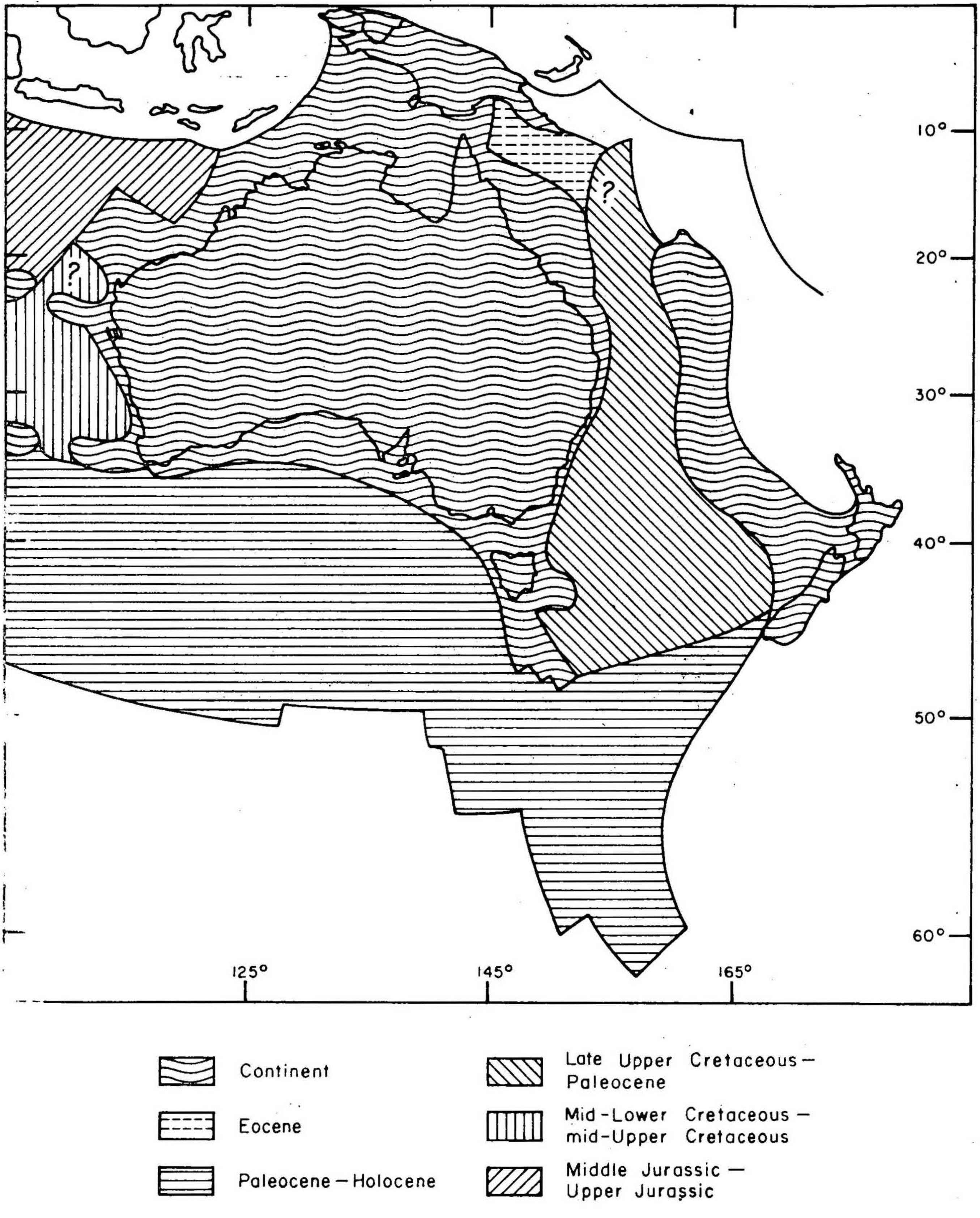
TECTONIC SETTING

Within the large number of marginal sedimentary basins which developed from the Mesozoic to the present, there occur widespread depositional breaks, deformations, and fault patterns. It is possible to recognize seven major stages in the tectonic evolution of the margin: Middle to Upper Jurassic, middle Lower to middle Upper Cretaceous, late Upper Cretaceous to Paleocene, Lower Paleocene to Lower Eocene, Eocene to Oligocene, Miocene, and Plio-Pleistocene to Holocene. Four of these periods are times of opening of the adjacent sea floor during the Gondwana break-up and Pacific margin formation (Fig. 3), one was the time of an extensive hiatus in deposition caused by variations in water-bottom currents, and two periods are associated with plate collisions to the north of Australia.

Middle Jurassic to Upper Jurassic

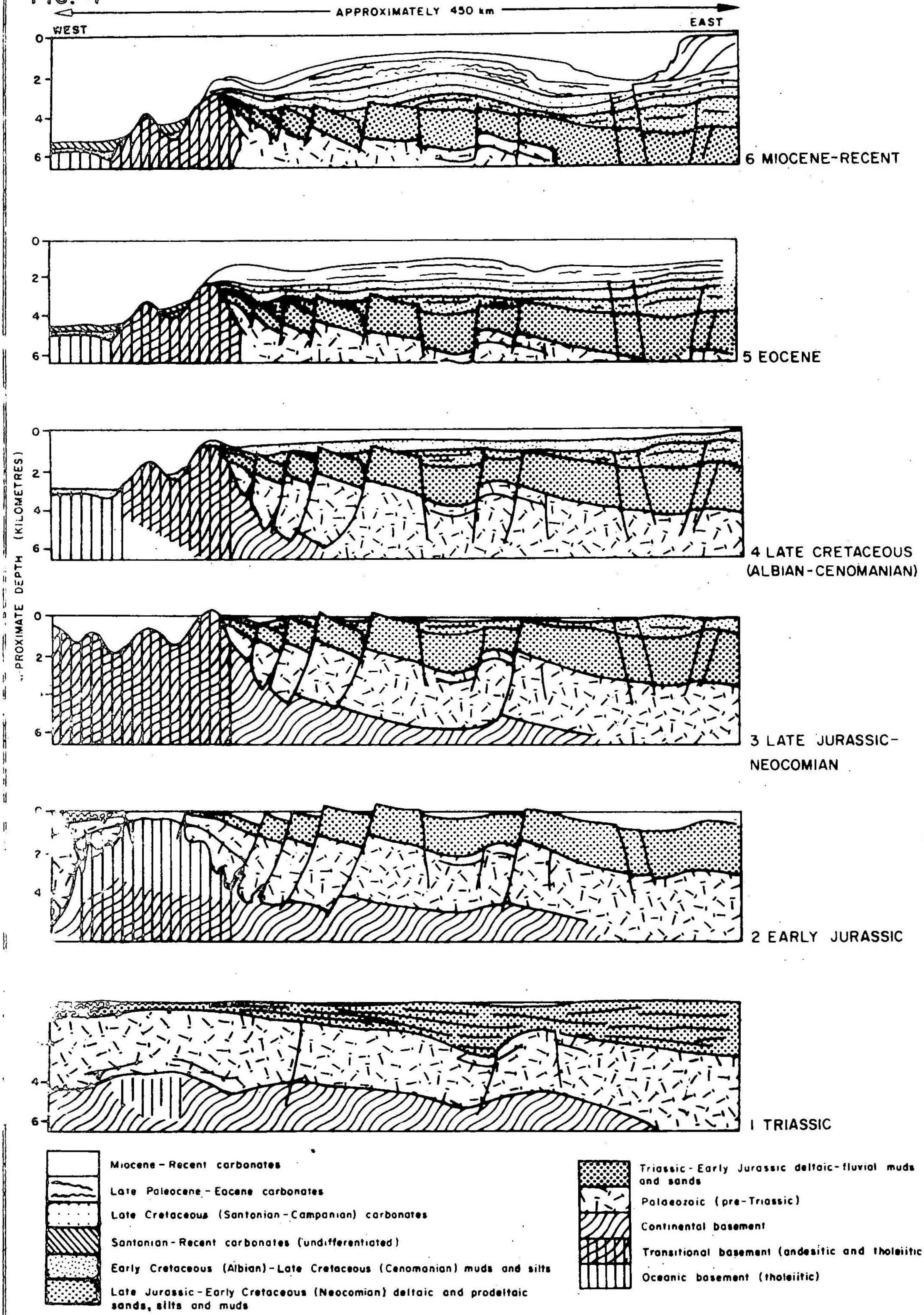
DSDP drilling indicates that spreading occurred between the Sunda Archipelago and the North West Shelf in the Middle and Upper Jurassic (Fig. 4). Middle to Upper Jurassic sediments on the continental shelf were restricted marine sediments. On the Exmouth Plateau was a prograding deltaic sequence. On elevated regions like the Rankin Platform, and at the outer edge of the Browse Basin, the Jurassic is absent. Near the northern Browse Basin margin, Jurassic rocks contain volcanic material, whereas the sequence becomes more uniformly paralic and deltaic northwards onto the Sahul Shelf. In the Bonaparte Gulf and Money Shoal Basins rocks contain similar lithologies and style of bedding to those in the Lower Cretaceous and Upper Jurassic. Uplift of these basins was reflected by thin sequences at basin margins. At the depositional centres sediment was laid down alomst continuously until Lower Cretaceous times.

FIG. 3



MAJOR SEA-FLOOR SPREADING REGIONS AND PERIODS
(after Warris, 1973)

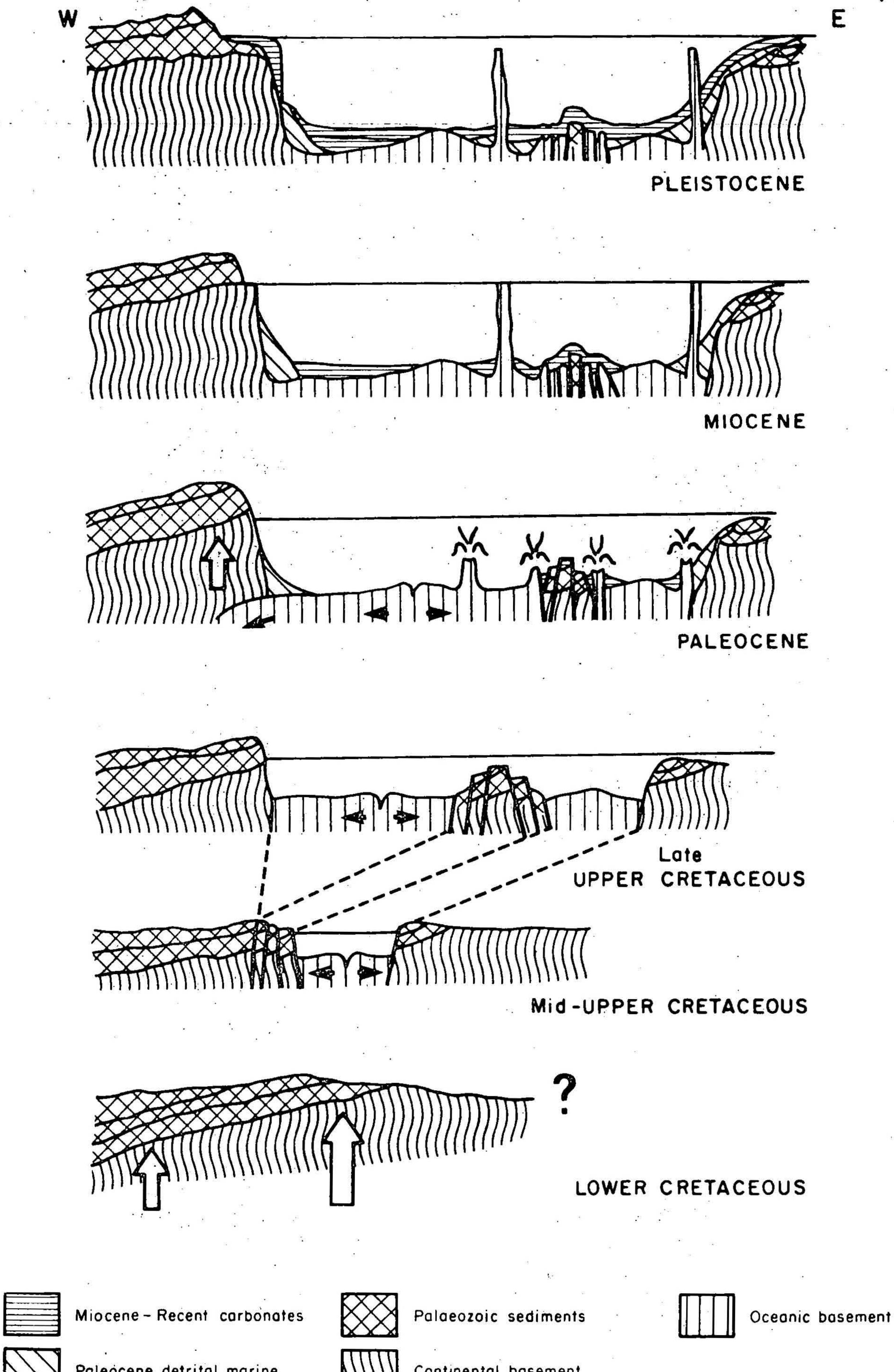
FIG. 4



NORTHWESTERN MARGIN DEVELOPMENT
(from Willcox and Exon, 1976)

Record No. 1976/72 WA/B8-100-1A

FIG. 5



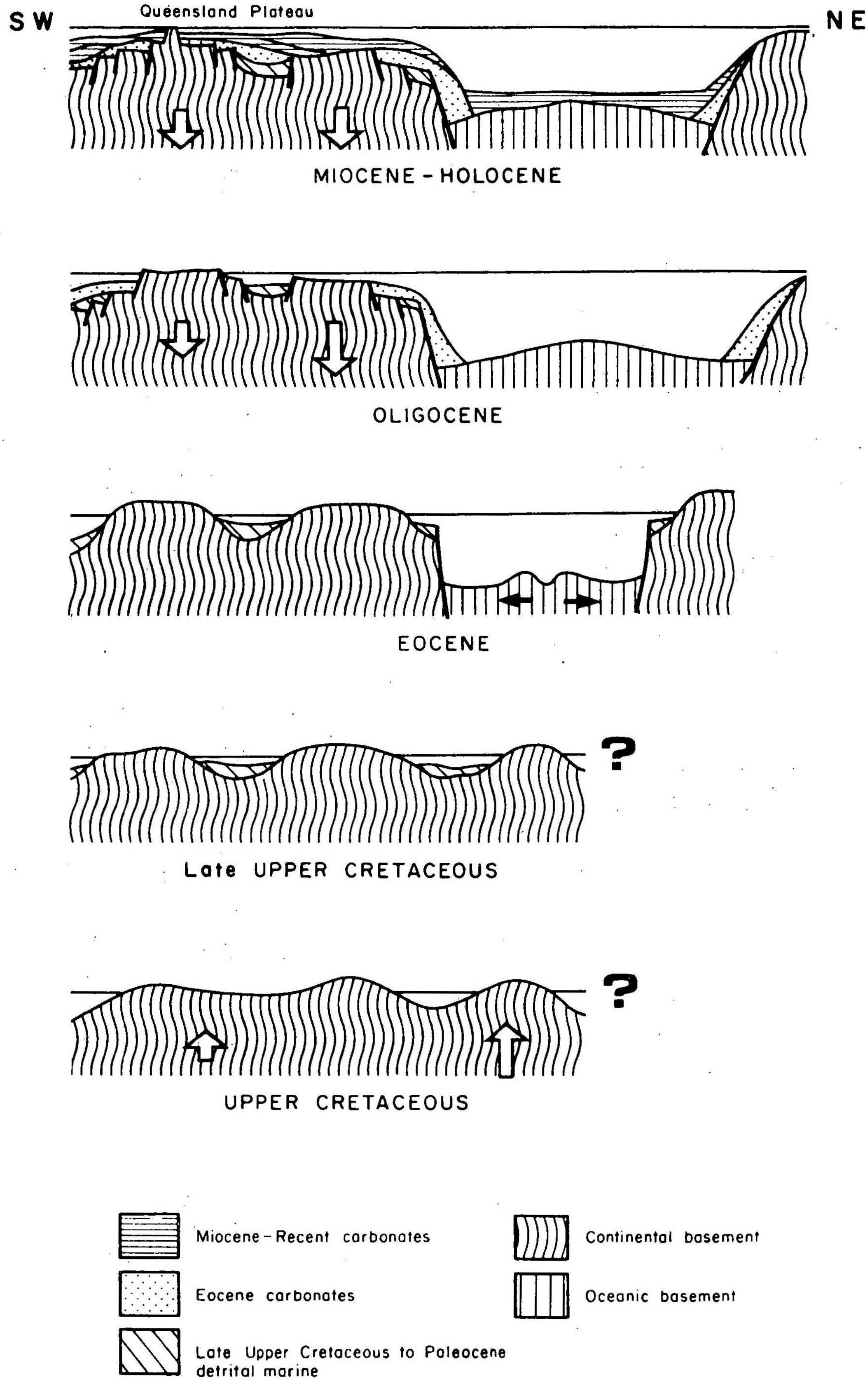
EASTERN MARGIN DEVELOPMENT

(after Hayes and Ringis, 1973)

Record No. 1976/72

A/B8-170A

FIG. 6



NORTHEASTERN MARGIN DEVELOPMENT
(after Mutter, 1975)

Mid-Lower Cretaceous to mid-Upper Cretaceous

The separation of a landmass west of Australia from the western margin is postulated to have commenced in the mid-Lower Cretaceous from structural evidence in the Perth and Carnarvon Basins. Neocomian unconformities are widespread both on the shelf and on the Naturaliste Plateau, and their ages as deduced from seismic evidence correlate with dates of the basaltic sea floor at the DSDP sites. By Albian times there was a complete marine transgression in the Perth and Carnarvon Basins. There was a change in depositional style and graben subsidence ceased; conditions became quiescent and marine carbonate deposition became widespread.

Late Upper Cretaceous to Paleocene

Spreading of the Tasman Sea floor occupied about 15 million years in the late Upper Cretaceous and Paleocene (Fig. 5). The Lord Howe Rise in the east moved away from the eastern Australian margin along a northeast-trending spreading centre. Limited subduction of this newly-formed ocean floor may have occurred in the north of the Tasman Basin (Hayes & Ringis, 1973). Two centres of spreading developed. The eastern centre died out to leave the Middleton (Dampier) Ridge separated from the Lord Howe Rise; the western centre continued to form the main Tasman Basin.

No rift-valley sequences are recognized except in Bass Strait and at the northern limit of the Tasman Sea where tensional splays were formed and accumulated Upper Cretaceous and Cainozoic fill. Pre-existing sedimentary basins, like the Sydney Basin, overlying the Tasman Geosyncline were broken apart.

Paleocene to Lower Eocene

Two ocean basins formed during the Paleocene and Lower Eocene, one in the Coral Sea and the other between Australia and Antarctica.

In the northeast, the Coral Sea was formed during the Eocene by rapid spreading of the sea floor between the Queensland Plateau and the Papuan Peninsula (Fig. 6). Stresses in the northeast of the Coral Sea region are considered to have weakened the crust beneath the Papuan Basin, leading to the development of the Aure Trough and its offshore extension. This site attracted the greatest thickness of the ensuing Tertiary clastic sediment that was derived from the uplifted central regions.

In the southern part of the continent, deposition in the Bass, Otway, and Great Australian Bight Basins became increasingly marine during the Upper Cretaceous and Paleocene and was fully marine by the Eocene (Fig. 7). This marine influence extended from the west and did not greatly affect the Bass Basin, until the Middle Eocene.

Late Upper Eocene to Oligocene

DSDP drilling on the open ocean floor and on plateau and rise regions around Australia records a break of about 15 million years in marine sedimentation during the late Upper Eocene to Oligocene, particularly along the eastern coast. This lack of deposition is attributed to scouring by circum-continental currents rather than to tectonism, although New Guinea was affected by a major tectonic event during the period. Even south of Australia, where only a narrow gulf existed between Australia and Antarctica, there is a major erosional break in the sedimentary section. The Indian Ocean was probably cut off from the Tasman Sea by the South Tasmania Plateau (just as the Sinai forms a barrier between the Mediterranean Sea and Indian Ocean today); hence circumpolar currents swept the whole northeast, north, and east margins.

Miocene

Sedimentary basins resulting from Miocene movements are mainly confined to Irian Jaya and New Guinea. There is also evidence for Miocene subsidence around the margins of the Queensland Plateau (Fig. 6) and elsewhere around the northern continental shelves where prograded carbonates were deposited during a marine transgression after a widespread break in deposition.

The principal uplift of the central region of Irian Jaya occurred in the Miocene, filling adjacent troughs with sediment; the trough profiles were similar to the asymmetric form of the Timor Trough (Fig. 8), the northern limb being the more steeply dipping.

On the North West Shelf, Miocene carbonates were deposited during a marine transgression after a widespread erosional break. Extensive reefs developed on the erosion surface near the position of the present shelf edge. Marginal subsidence and influx of silt from the shelf and continent are considered to have overwhelmed these reefs; few modern reefs remain in the area.

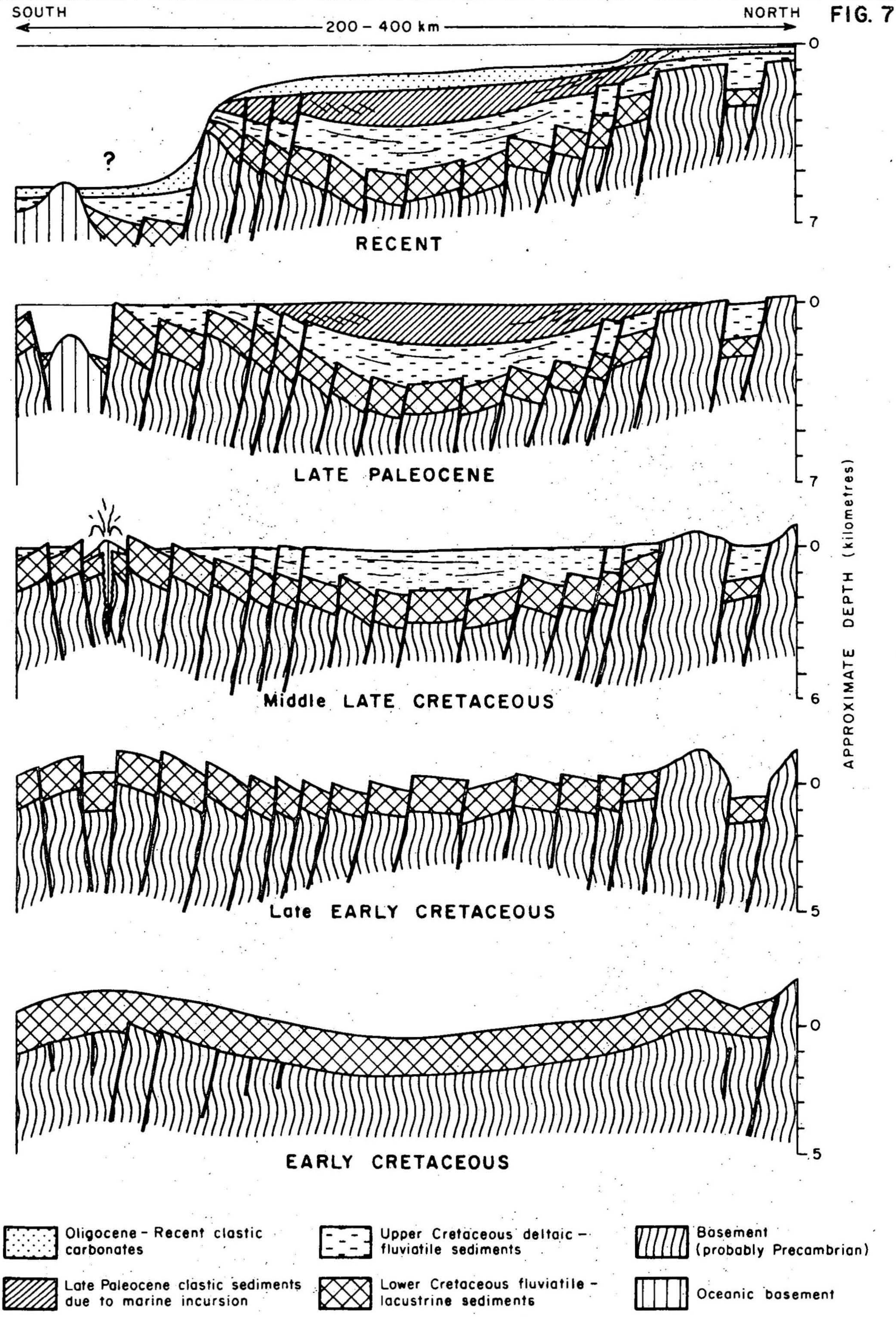


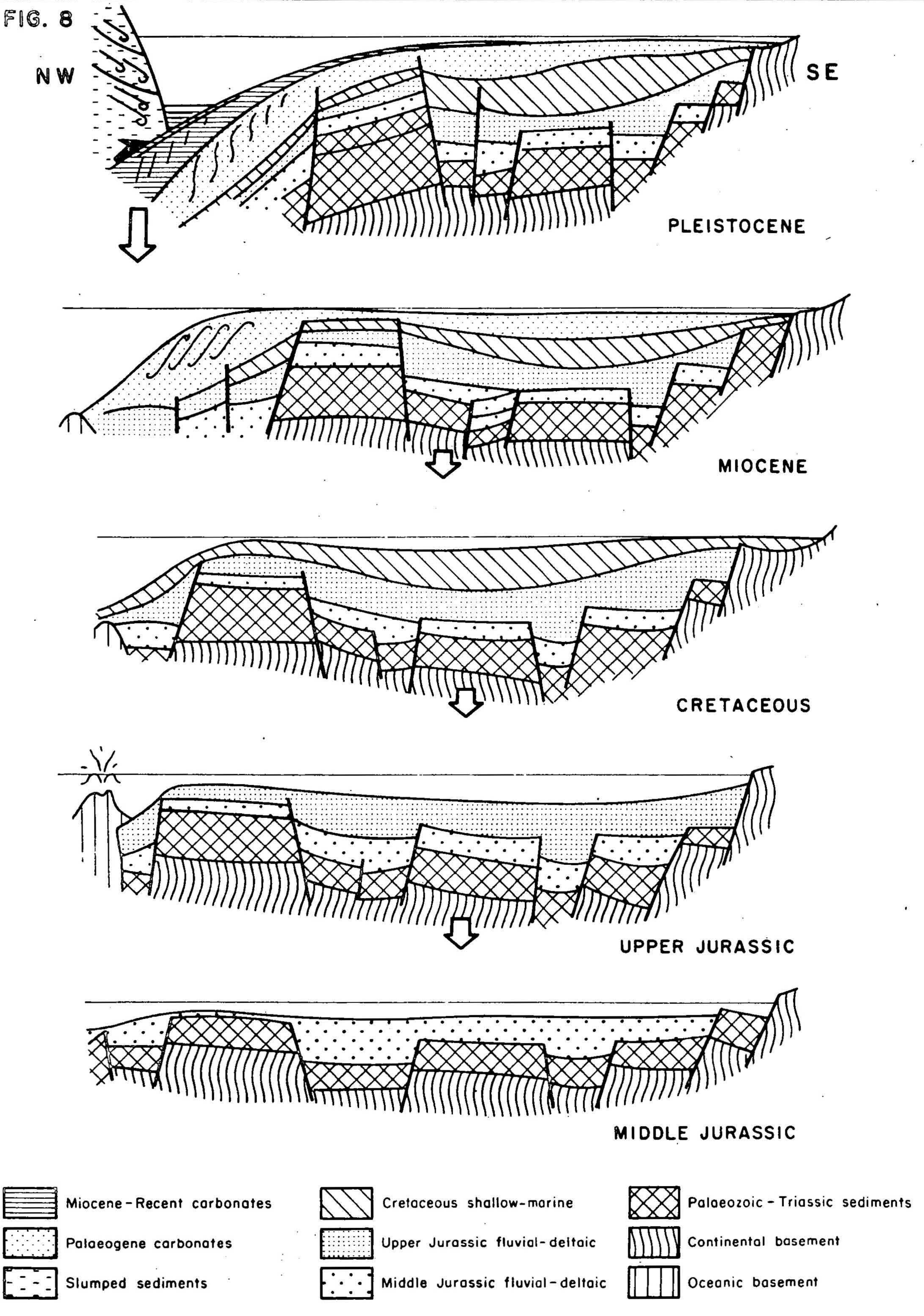
FIG. 7

SOUTHERN MARGIN DEVELOPMENT
(after Willcox, 1974)

Record No. 1976/72

A/B8-169A

FIG. 8



NORTHERN MARGIN DEVELOPMENT

Record No. 1976/72

A/B8-167A

The upper surface of the Queensland Plateau contains a number of coral reefs which probably date from the Lower Miocene. Most of these reefs managed to grow sufficiently rapidly to keep pace with subsidence of the Queensland Plateau. This platform surface was probably protected from major sediment influxes from land by the newly developed Queensland and Townsville Troughs which developed between the plateau and the continent (Mutter, 1975).

Various reef facies developed on the Marion Terrace and adjacent continental shelf (J.C. Mutter, pers. comm.). The major Miocene reefs did not survive the subsidence of the terrace except for those in a small area at the main Marion Reef, and the Great Barrier Reef on the present continental shelf.

Plio-Pleistocene to Holocene

On the southern side of the Timor Trough (Fig. 8), DSDP drilling penetrated deformed Plio-Pleistocene sediments at the base of the continental slope. The slope is convex and contains bedding sub-parallel to the sea floor. The sediments were shown to be shallow-marine carbonates, overlain in the trough base by oozes deposited by turbidity currents. The convex slope is faulted where basement highs in the Bonaparte and Money Shoal basins cross the line of the Timor Trough structure. Possible overthrusting from the north is indicated in some areas, where the trough overlies north-dipping structures characteristic of the southern flank. Present-day motions along the Asian-Australian Plate boundary appear to be farther north in the Inner Banda Arc and northern Timor.

At the eastern side of the Papuan Basin in the Gulf of Papua and north of the Queensland Plateau, a major Pleistocene-Pliocene clastic fill was compressed by westward movement of the Papuan Peninsula area, creating long-wavelength flexures which die out westwards against the Palaeogene and Mesozoic rocks of the pre-Upper Tertiary continental slope of Australia.

Subduction between the Pacific Plate and the Australian Plate continues to the present day in Irian Jaya, but the exact position of the subduction line is uncertain. Earthquakes and limited vulcanism provide evidence of subduction of the Australian Plate beneath the Pacific Plate.

CONCLUSIONS

The northwestern, western, and southern continental margins are of the Atlantic type, characterized by rift-valley sequences. The ages of the rift-valley fill and the type of sediment they contain varing from place to place.

The eastern and northeastern margins do not contain extensive recognisable rift valleys except for tensional splays in the Tasman Sea. The Sydney Basin was split by sea-floor spreading movements and troughs formed on two sides of the Queensland Plateau.

The tectonics of the northern margin are recorded in the geology of Irian Jaya and Papua New Guinea. The Timor Trough results from a late-tectonic phase associated with the collision of the Australian and Asian Plates. Active collision tectonism is now taking place north of Timor. Other complex plate motions are reflected in eastern New Guinea and the Bismarck Sea. The first plate collisions recognized in the northern margin were Miocene in age, when the Pacific Plate overthrust the Australian Plate. The Asian Plate and Australian Plate first collided in Plio-Pleistocene times.

A circum-Australian/Antarctica current in the Eocene and Oligocene is thought to have prevented deposition in the Tasman Sea and adjacent slope and ocean rises. Final separation of the Antarctic continent from the South Tasmania Plateau occurred in the mid-Oligocene when new circulation patterns were established and deposition was resumed within the Tasman Sea.

Within the sedimentary basins on the Australian shelf and slope, the Mesozoic and early Cainozoic rocks grade from a general Mesozoic fluvial and terrestrial suite containing some basic volcanics, to deltaic and marine sequences in the late Cainozoic. An almost continuous belt of sedimentary basins formed along the western and southern margins during the Tertiary. The northeast margin received sedimentary cover after the Oligocene, whereas shelf deposition on the eastern coast is generally post-Miocene.

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Symposium 103.3 - The structure of Australia and variations in tectonic style. 25th International Geological Congress, Sydney, 1976

The Precambrian shields and platforms of northern Australia

by

K.A. Plumb

Abstract

The structure and tectonic style of Australia, to the north of the Musgrave Block and the southern Canning Basin, and to the west of the Tasman Fold Belt System, are summarized.

Northern Australia is largely occupied or underlain by the early Proterozoic North Australian Orogenic Province, which is bounded by younger mid-Proterozoic mobile belts of the Central Australian Orogenic Province along the eastern and southern margins. In the north, a basement of the Archaean West Australian Orogenic Province underlies the North Australian Orogenic Province. The strata of the North Australian Platform Cover were deposited on the North Australian Orogenic Province and were mildly to moderately deformed at the time when the mid-Proterozoic mobile belts were active. The late Proterozoic and Palaeozoic Central Australian Platform Cover developed over both the North and Central Australian Orogenic Provinces. Finally, the Mesozoic-Cainozoic Trans-Australian Platform Cover transgressed most of the region.

The tectonic evolution of northern Australia is clearly related to the times of cratonization of its basements. A uniform pattern of major fractures and lineaments, trending roughly northwest and north-northwest to north-northeast, was established throughout the region very early in its history. The subsequent evolution resulted from repeated reactivation of these lineaments.

Most of the structure can be explained by a simple model in which a central block, between the Kimberleys and Mount Isa, was displaced northwards relative to the blocks on either side, and zones of thrusting and folding developed where the cover was crumpled against east-west-trending rigid blocks.

INTRODUCTION

This paper summarizes the structure and tectonic style of Australia, to the north of the Musgrave Block and southern Canning Basin, and to the west of the Tasman Fold Belt System (Fig. 1). The region is entirely underlain by a Precambrian basement, but the extensive Phanerozoic covers must also be considered in order to interpret the nature of the Precambrian below.

This paper is only a preliminary draft, and will be revised before publication. Only recent references, which update data from the selected bibliography listed at the end of this paper, are quoted in the text. The regional geology of most of the area has been synthesized by Plumb & Derrick, (1975); summaries of the remaining areas are provided by Blake & Hodgson (1975); Crohn (1975); Oversby et al. (1975); Shaw & Stewart (1975); Smart et al. (1975); and Thomson (1975) in the same volume. BMR Bulletins and Reports provide the major descriptions of most areas.

REGIONAL TECTONIC UNITS

The major tectonic units, classified according to the concepts used to prepare the Tectonic Map of Australia and New Guinea (GSA, 1971), are shown in Figure 1, and their ages are summarized in Figure 2. Most units are defined in Plumb & Derrick (1975), but more recent data are available for the ages of some of them.

Northern Australia is underlain by the early Proterozoic North Australian Orogenic Province, which is bounded by younger mid-Proterozoic mobile belts along its eastern and southern margins - the Mount Isa Orogenic Domain, the Georgetown and Coen Inliers, and the Arunta Block - which are assigned to the Central Australian Orogenic Province. In the north, basement rocks belonging to the Archaean West Australian Orogenic Province - the Rum Jungle and Nanambu Complexes - underlie the North Australian Orogenic Province, but the full extent of Archaean basement is unknown. The Mount Isa Orogenic Domain and the Georgetown and Coen Inliers are bounded to the east by the Phanerozoic Tasman Fold Belt System.

The Georgetown and Coen Inliers were remetamorphosed during Tasman deformation, and their relationships to the domains farther to the west are obscured by younger platform covers. The Arunta Block is a metamorphic belt derived from the repeated reworking of North Australian Orogenic Province rocks, but the Mount Isa Orogenic Domain consists of a new sedimentary succession which was deposited on a basement of North Australian Orogenic Province rocks, and then intensely deformed at the same time as the strata of the adjacent mid-Proterozoic North Australian Platform Cover were being deposited on the cratonized North Australian Orogenic Province to the west, and then mildly to moderately deformed.

Late Proterozoic and Palaeozoic platform covers, parts of the Central Australian Platform Cover, then developed over both the North and Central Australian Orogenic Provinces. Later still, the Mesozoic-Cainozoic Trans-Australian Platform Cover transgressed over the Tasman Fold Belt System and over the older domains farther to the west.

REGIONAL STRUCTURE

Figure 3 shows the major structures in rocks of all ages, from Proterozoic to Tertiary.

A uniform pattern of structures trends roughly northwest and north-northwest to north-northeast throughout the area of North Australian Orogenic Province basement, but these trends change slightly in the Arunta and Musgrave Blocks and in the Tasman Fold Belt System. Mobile zones such as the Halls Creek, Fitzmaurice, and King Leopold Mobile Zones, the Batten Trough, the Mount Isa Orogenic Domain, and the Arunta-Musgrave Block (Fig. 1), are clearly defined. Some of these belts (e.g., Halls Creek Mobile Zone) have separated areas of markedly different histories for very long periods of time. Detailed stratigraphic and structural analysis of local areas (e.g., Kimberley region) shows how their tectonic development through long periods of time was controlled by the repeated reactivation of major structures. I consider that a fundamental basement fracture pattern was established throughout North Australia, by at least the end of the early Proterozoic, and that the subsequent tectonic development of the region resulted from the repeated reactivation of major lineaments. The geometric regularity of the pattern suggests that it originated in a uniform crust; it is possible that this was an Archaean crust underlying the whole region.

The north-northwest to north-northeast-trending structures include many fundamental strike-slip faults and their associated oblique folds and reverse faults; those in the west (Halls Creek Mobile Zone) are left-lateral shears, and those in the east (Batten Trough and Mount Isa Orogenic Domain) are right-lateral. The northwest-trending faults commonly show left-lateral strike-slip displacements; these could be interpreted as part of a conjugate set with the right-lateral north-trending faults, but not with the left-lateral north-trending faults. I consider that these inconsistencies can be accommodated by appealing to a process of independent horizontal displacements of major crustal blocks, rather than the operation of a uniform compressive stress field.

The west to west-northwest-trending faults are commonly thrusts or reverse faults (e.g., large nappes in Central Australia). The relationship between northerly-trending strike-slip faults and west-trending folds and thrusts is well demonstrated by the intersecting Halls Creek and King Leopold Mobile Zones, and by the zone of reverse faults perpendicular to the Batten Trough.

A simple interpretation is that the central block of northern Australia, between the Kimberleys and Mount Isa, moved northwards relative to the blocks either side, and locally the displacements were absorbed by crumpling against rigid blocks. The Arunta and Musgrave Blocks may represent the extreme product of such crumpling - metamorphic ages in the Arunta and Musgrave Blocks correlate quite well with horizontal movements along the Halls Creek Mobile Zone. The significance of the northwest-trending left-lateral shears is more obscure; recourse to east-west horizontal movements is needed to explain these.

OROGENIC DOMAINS

Figure 4 schematically summarizes the ages and structural trends of the orogenic domains; the metamorphic facies are shown in Figure 5. Regional gravity trends (Fig. 4) (after Wellman, 1976) are used as evidence of the possible distribution of the domains beneath platform covers; aeromagnetic coverage is incomplete, but where available supports the gravity trends.

West Australian Orogenic Province

The Rum Jungle and Nanambu Complexes contain complexly deformed gneisses, migmatites, and granites which were metamorphosed about 2500 m.y. ago. They form basement to the Pine Creek Geosyncline, and were later emplaced as mantled gneiss domes.

North Australian Orogenic Province

Tectonic Style: All the domains of the early Proterozoic North Australian Orogenic Province have similar tectonic styles and ages. Most went through a complete history of geosynclinal sedimentation, deformation, metamorphism, and transitional tectonism (post-tectonic granites and acid volcanics) within time spans of about 250 m.y. (Fig. 2).

The sediments are predominantly quartz-rich greywackes and siltstones (turbidites) and minor carbonates; volcanic rocks are generally subordinate. Basic sills were commonly emplaced at the end of sedimentation, either just before or during folding. The strata are invariably tightly to isoclinally folded, slaty cleavage or schistosity is ubiquitous, and superposed folding, in places over several periods, is common. The metamorphic grade is mostly greenschist facies, but has risen to amphibolite and low-granulite facies locally; migmatites are common in high-grade terrains. Metamorphism is mostly of the low pressure-intermediate facies series, and cordierite-garnet, and in places andalusite, are common in the high-grade terrains.

Strike-slip faults associated with the northerly-trending fundamental faults of the Halls Creek Mobile Zone (Fig. 1) accompanied deformation and metamorphism of the Halls Creek Province. Shearing and cataclasis in the Mirarrimina Complex, before development of the North Australian Platform Cover, accompanied strike-slip displacements on the northerly-trending faults which later bounded the northern Battan Trough. Substantial movements occurred on northwest-trending, probable strike-slip faults in the Pine Creek Geosyncline before development of the North Australian Platform Cover.

The high-grade metamorphic terrains of the Halls Creek Province appear to be confined to the zones of later reactivation - the Halls Creek and King Leopold Mobile Zones (Fig. 1). The high-grade terrain of the Pine Creek Geosyncline surrounds the mantled gneiss domes of the Nanambu Complex. Scattered inliers in the Arnhem Block cannot be related to any definite structural zones, except for the northerly-trending inlier just described (Mirarrmina Complex), which crops out between major faults of the later-formed Batten Trough (Fig. 1).

<u>Age</u>: Two ages of orogenic domains can be distinguished in the North Australian Orogenic Province (Figs. 2, 4): the older domains were metamorphosed 2000-1950 m.y. ago, and this event was succeeded by transitional tectonism between 1950 and 1850 m.y. ago; the younger domains were metamorphosed 1850-1800 m.y. ago, and succeeded by transitional tectonism between 1800 and 1700 m.y. ago.

<u>Older Domains</u>: The typical older domain is the <u>Halls Creek Province</u>, where thick turbidites and basic to minor acid volcanics of the Halls Creek Group were deposited after about 2200 m.y. (Page, 1976), intruded by basic rocks of the 'older' Lamboo Complex, and then multiply folded and metamorphosed, culminating in the 1960 m.y.-old Tickalara Metamorphics and the cogenetic Mable Downs Granodiorite; metamorphic grades range from greenschist to low-granulite facies. The subsequent transitional tectonism is represented by the 'late' Lamboo Complex - the acid Whitewater Volcanics and cogenetic high-level granites such as the 1875-1855 m.y.-old Bow River Granite. Outcrops of the Halls Creek Province are confined to inliers within the Halls Creek and King Leopold Mobile Zones (Fig. 1); the mobile zones are interpreted as the loci of the most intense metamorphism and igneous activity (Plumb & Gemuts, 1976). The Halls Creek Group itself probably extended beyond the limits of the mobile zones, although Gellatly (1971) speculated that the group was deposited only in

the mobile zones, adjacent to a postulated Archaean craton beneath the Kimberley Basin (Fig. 1). Gravity anomalies indicate that high-grade metamorphic rocks continue beneath the Fitzroy Graben (Fig. 1), to the south of the outcrop of the King Leopold Mobile Zone. The existence of a northern extension of the Halls Creek Mobile Zone is problematical: traditionally it has been considered to continue through the Fitzmaurice Mobile Zone (Fig. 1), but recent offshore structural data (Fig. 3) and gravity trends (Fig. 4), suggest that it may, on the other hand, underlie the Bonaparte Gulf Basin. This is consistent with the fact that the fault (Cockatoo Fault) which links the northeast edge of the Bonaparte Gulf Basin with the Halls Creek Fault is a major strike-slip fault, whereas the fault which marks the eastern edge of the Fitzmaurice Mobile Zone is a thrust, and passes, farther to the north, into a fault (Giants Reef Fault) which has a strike-slip displacement opposite to that of the Halls Creek Mobile Zone.

In the Arnhem Block, pelitic rocks were metamorphosed to high-amphibolite and low-granulite facies about 1945 m.y. ago, but the depositional age of the sediments is unknown. Archaean basement in the Nanambu Complex was reworked about 2000 m.y. ago. 2000 m.y.-old gneisses (L.P. Black, pers. comm., 1976) form basement beneath the Warramunga Group of the Tennant Creek Block. The oldest metamorphosed sequence in the Arunta Block is correlated with the Halls Creek Group. The Kalkadoon Granite and Leichhardt Metamorphics of the Kalkadoon-Leichhardt Block are similar in style and age to the transitional domains of the Halls Creek Province. These older domains are widespread, and perhaps underlie the whole of the North Australian Orogenic Province.

Younger Domains: The younger domains unconformably overlie the older domains (Fig. 2), and are more restricted in their distribution (Fig. 4) - they occur only to the east of the Halls Creek Mobile Zone. They apparently form belts lying between and above older domains, but their overall distribution is obscured by younger platform covers. Gravity trends allow some domains to be linked (e.g., Murphy Tectonic Ridge - Tennant Creek Block - Arunta Block - The Granites-Tanami Block), and the Pine Creek Geosyncline can probably be extended far to the east of its present area of outcrop, but, generally speaking it is not possible to distinguish, by gravity, possible Archaean basement, the 2000 m.y. basement, and the 1800 m.y. basement. The older domains commonly reach higher grades of metamorphism than the younger domains (Fig. 5) and, at least locally in the Halls Creek Province, contain more volcanics.

The typical younger domain is the Pine Creek Geosyncline, where greywackes, siltstones, carbonate rocks, and very subordinate volcanics were deposited after 2000 m.y., intruded by dolerite sills, and then intensely deformed and metamorphosed, locally up to amphibolite facies, about 1850-1800 m.y. ago (Page, 1974). Transitional tectonism followed with the emplacement of discordant granites (e.g., Cullen Granite) and the Edith River Volcanics about 1800-1750 m.y. ago, and sills of the 1720 m.y.-old Oenpelli Dolerite (Page, 1974). Inliers of rocks similar to those in the high-grade terrains and in the transitional domain of the northeast Pine Creek Geosyncline continue eastwards into the Arnhem Block.

A sequence - the Warramunga Group - of similar age to that of the Pine Creek Geosyncline, but with more abundant volcanics, makes up the Tennant Creek Block; it is succeeded by the transitional Hatches Creek Group and 1800-1700 m.y. granites in the Davenport Geosyncline. Both the Warramunga and Hatches Creek Groups can be traced into the Arunta Block, and the Warramunga Group can then be traced into the Tanami Complex of The Granites-Tanami Block. The Tanami Complex is followed by transitional acid volcanics of the 1800 m.y.-old Mount Winnecke Formation and various 1800-1720 m.y.-old granites (Page, Blake, & Mahon, 1976). In the Murphy Tectonic Ridge, an early, possibly syntectonic phase of the Nicholson Granite Complex was emplaced into the Murphy Metamorphics about 1860 m.y. ago, and post-tectonic transitional phases of the granite were emplaced with the cogenetic Cliffdale Volcanics 1770 m.y. ago. The Argylla Formation of the Kalkadoon-Leichhardt Block contains acid volcanics of similar age and type to the Cliffdale Volcanics.

Central Australian Orogenic Province

The domains of the Central Australian Orogenic Province fall into two groups. The Arunta Block is a belt of recurring metamorphism superposed on rocks of the North Australian Orogenic Province (Fig. 2), and it is clearly related in space and time to the main Central Australian Orogenic Province to the south. In comparison, the Mount Isa Orogenic Domain and the Coen and Georgetown Inliers represent new depositional belts accreted on to the eastern edge of the North Australian Orogenic Province (Fig. 2).

Three unconformable deformed sequences, equivalent to the Halls Creek, Warramunga, and Hatches Creek Groups, can be traced from the North Australian Orogenic Province into the metamorphosed rocks of the Arunta Block. All three groups were metamorphosed between 1800 and 1700 m.y. ago to granulite facies and then to amphibolite facies, in a belt occupying the southern half of the block; cordierite is again common in the high-grade terrains. Further metamorphism and granite-intrusion took place locally up to about 1600 m.y. ago, and again about 1400 m.y. ago; about 1050 m.y. ago an intense migmatization event was superimposed on the rocks at the southern margin of the block. Metamorphic events similar to these have been recorded in the Musgrave Block to the south, but the depositional ages of the rocks in this block are not accurately known. Uniform gravity trends beneath the Amadeus Basin allow the Arunta and Musgrave Blocks to be joined. At the close of the Proterozoic, an intra-continental deformation event - the Petermann Ranges Orogeny - uplifted the Musgrave Block and thrust it to the north, over the platform cover of the southwestern Amadeus Basin, as large nappes. During the Late Devonian-Early Carboniferous a similar episode of thrust and nappe formation - the Alice Springs Orogeny - uplifted the Arunta Block, and thrust it to the south, over the northeast Amadeus and Ngalia Basins; metamorphic retrogression in extensive linear belts accompanied this later thrusting, and the structures can be traced by gravity to the southeast, where they truncate the 1000-m.y. and older structures of the concealed Arunta-Musgrave Blocks. To the west, the gravity trends of the Arunta Block are truncated by a zone of north-trending structures; the nature of the basement beneath most of the Canning Basin is uncertain.

In the Georgetown and Coen Inliers, schists, gneisses, migmatites, and metavolcanics were metamorphosed, and granites emplaced, about 1500 m.y. ago (L.P. Black, pers. comm., 1976; Cooper et al., 1975). The metamorphics again belong to the low pressure-intermediate facies series. Pre-folding dolerite dykes were emplaced into the Coen Inlier more than 1800 m.y. ago (Cooper et al., 1975), suggesting that the sediments in the inlier are very much older than their age of metamorphism. The 1470-m.y. acid Croydon Volcanics (L.P. Black, pers. comm., 1976) of the Georgetown Inlier are interpreted as transitional tectonism. The complicated structural pattern of the inliers can be clearly followed beneath the younger covers by gravity trends. During the Early to Middle Devonian, widespread metamorphism related to the adjacent Tasman Fold Belt System was superimposed on the inliers, and obscured most of their earlier history. Granites and acid volcanics were emplaced during the Permo-Carboniferous.

The Mount Isa Orogenic Domain contains Eastern and Western 'Geosynclines', separated by a basement welt of the Kalkadoon-Leichhardt Block - an inlier of the North Australian Orogenic Province. The basement is overlain by a quartz arenite/basic volcanic suite up to 15 km thick (Haslingden Group and equivalents), which is followed by a carbonate sequence up to 5 km thick (Mount Isa Group and equivalents); the entire sequence is contemporaneous (1700-1450 m.y.) with similar successions in the adjacent McArthur Basin of the North Australian Platform Cover; the sequences of the Mount Isa Orogenic Domain are lithologically similar to their platform-cover equivalents, but are much thicker and contain a much greater volume of volcanics. The volcanics in the Western 'Geosyncline' geochemically resemble continental tholeiites, but those of the Eastern 'Geosyncline' become progressively more oceanic in character to the east (Glikson et al., 1976). Several phases of basic dykes and sills intruded the Mount Isa Orogenic Domain, and between 1450 and 1400 m.y. ago the area was deformed, metamorphosed, and intruded by granites. Much of the deformation was in response to strike-slip faulting along fundamental faults which had been active throughout sedimentation. Metamorphism up to amphibolite facies, of the low pressure-intermediate facies series, was most intense in the east. Alternating belts of granitic and basic rocks show up as readily identifiable gravity anomalies: the Mount Isa Orogenic Domain can be projected southeastwards to the edge of the Tasman Fold Belt System, and northwards along the eastern side of the Gulf of Carpentaria where it clearly truncates older trends of the North Australian Orogenic Province and Georgetown and Coen Inliers.

PLATFORM COVERS

Mid-Proterozoic Platform Covers

While intense tectonism was taking place in the Central Australian Orogenic Province, the North Australian Platform Cover (Fig. 6) was being deposited on top of the cratonized North Australian Orogenic Province (Fig. 2).

The oldest basin is the Kimberley Basin. 5 km of quartz-rich arenites, lutites, minor carbonates, and abundant flood basalts were deposited on top of the Halls Creek Province, at the same time as the younger domains of the North Australian Orogenic Province were being deformed to the east of the Halls Creek Mobile Zone. All of the basin was then intruded by vast 1800 m.y.-old dolerite-granophyre sills (Hart Dolerite), totalling up to 3 km thick. Most of the Halls Creek Mobile Zone (Fig. 1) was a structural high during sedimentation, but local troughs and onlap of sediments occurred on it; at the same time, the Red Rock Beds were deposited immediately to the east of the mobile zone. Most of the basin is only mildly deformed; deformation increases suddenly adjacent to and within the Halls Creek and King Leopold Mobile Zones (Fig. 1). Deformation was controlled by strike-slip faulting along the Halls Creek Mobile Zone, alternating with overfolding and thrusting across the King Leopold Mobile Zone; rocks from the basin succession were locally metamorphosed to up to amphibolite facies at the north-western end of the King Leopold Mobile Zone at the end of the Proterozoic.

Following the transitional tectonism and cratonization of the younger domains of the North Australian Orogenic Province, the major elements of the North Australian Platform Cover - the McArthur, South Nicholson, and Birrindudu Basins and the Lawn Hill Platform - developed penecontemporaneously over the region to the east of the Halls Creek Mobile Zone. A number of distinct tectonic elements are recognized within the McArthur Basin (Fig. 6). A very much thicker succession (up to 12 km) was deposited in the 50-60 km wide northerly-trending fault-bounded Batten Trough than on the adjoining stable shelves. The Mount Callanan and Edith Falls Basins and the Waterhouse Syncline are marginal downwarps in which abruptly-thickened sequences of basal arenites were deposited. In the southeast the basin succession thins abruptly on to the Murphy Tectonic Ridge. A very thin succession overlies the Urapunga Tectonic Ridge, which separates the western stable shelves of the basin, and, if extrapolated eastwards beneath widespread soil cover, may also bisect the Batten Trough. Throughout their histories, the Murphy Tectonic Ridge separated the McArthur Basin from the Lawn Hill Platform and South Nicholson Basin, and the thickness of sediment on the Lawn Hill Platform increased towards the Mount Isa Orogenic Domain.

Very similar successions were deposited penecontemporaneously in the McArthur Basin, Lawn Hill Platform, and Mount Isa Orogenic Domain. Three major units are recognized. The Tawallah Group and equivalents (equivalent to the Haslingden Group), comprising quartz-rich arenites, flood basalts, and subordinate carbonates and lutites, is up to 6 km thick in the Batten Trough. These are overlain, commonly with a minor unconformity, by a dominantly carbonate sequence, the McArthur Group and equivalents (equivalent to the Mount Isa Group), which is up to 5.5 km thick in the Batten Trough. After the Mount Isa Orogenic Domain and the adjacent Lawn Hill Platform were deformed, the depositional axes on the adjacent platform shifted, and an unconformably overlying sequence of alternating quartz arenites and micaceous lutites was deposited: the Roper and Malay Road Groups of the McArthur Basin are up to 5 km thick to the west of the Batten Trough, and the South Nicholson Group is up to 6 km thick in the South Nicholson Basin. Deposition ceased when dolerite sills were emplaced in the northwest of the McArthur Basin, and the platform covers were then mildly to moderately deformed. Deformation was mainly in response to complex block faulting on pre-existing basement faults, and was most intense along the Batten Trough and the Urapunga Tectonic Ridge. The Batten Trough was uplifted as a horst, which appears to be a unique phenomenon amongst grabens within platforms. Apparent movements are dominated by vertical displacements of up to 7.5 km, but detailed analysis reveals an overall control by right-lateral horizontal displacements along the faults parallel to the Batten Trough, and by left-lateral horizontal displacements on northwest-trending faults; reverse faulting occurred along the westerly-trending Urapunga Tectonic Ridge.

The quantity of basalt increases towards the Mount Isa Orogenic Domain, but basalt is far less abundant in the Batten Trough than on the adjoining stable shelves, and is absent altogether from the northern part of the Batten Trough. Clearly the major syndepositional faults which bound the Batten Trough could not have provided conduits for the basaltic magma, as is commonly assumed; the basalt seems to be more related to basement highs within shelf areas, such as the Murphy Tectonic Ridge.

The Birrindudu Basin also contains a sequence (Birrindudu Group) of quartz-rich arenites overlain by carbonates, but basalts are absent; the sequence ranges in thickness up to 6 km. Probable equivalents present to the north of the Tennant Creek Block (Tomkinson Creek Beds) may be up to 15 km thick (Randal & Brown, 1969), but the form of the structure in which they were deposited is not known. The Birrindudu Group has been deformed into broad domes and basins, controlled by superposed folding parallel to the nearby Halls Creek Mobile Zone and to the King Leopold Mobile Zone and Arunta Block (Fig. 1).

Late Proterozoic and Phanerozoic Platform Covers

Following the final deformation of the North Australian Platform Cover and the cratonization of the Central Australian Orogenic Province, a new set of late Proterozoic-Palaeozoic sedimentary basins - the Central Australian Platform Cover - covered northern Australia (Figs 3, 7). A still younger set of basins, belonging to the Trans-Australian Platform Cover, transgressed the region during the Mesozoic.

Central Australian Platform Cover: The tectonic style of these covers can be directly related to their basements. The covers overlying the North Australian Orogenic Province have relatively thin sequences (e.g., 3500 m, Victoria River Basin; 2000 m, Ord Basin; 1000 m, Daly River Basin; 350 m, Wiso Basin; 300 m, northern Georgina Basin), and the strata have remained flat-lying and almost undeformed. The youngest metamorphic belts of the Central Australian Orogenic Province are overlain by down-warped belts containing thick successions (e.g., 9000 m, Amadeus Basin; 9000 m, southern Canning Basin), and grabens overlie the older King Leopold (17000 m, Fitzroy Graben) and Halls Creek (17000 m, Bonaparte Gulf Basin) Mobile Zones. Compared to the mid-Proterozoic Batten Trough, these younger downwarps and grabens have remained depressed and mildly deformed, except where the Amadeus and Ngalia Basins were affected by the Petermann Ranges and Alice Springs Orogenies.

The first late Proterozoic basin of the Central Australian Platform Cover in northern Australia - the 1200-900 m.y.-old Victoria River Basin - developed on the stable Sturt Block while the last deformations of the Central Australian Orogenic Province were still taking place. 3500 m of quartz-rich arenites, lutites, and carbonates passed westwards into a very much thicker sequence (9000 m) of arenites and lutites deposited in the adjacent Halls Creek (Carr Boyd Group) and Fitzmaurice (Fitzmaurice Group) Mobile Zones. The rocks of the mobile zone were subsequently mildly to intensely deformed.

After cratonization, the Arunta and Musgrave Blocks were overlain by thick sequences of Adelaidean quartz-rich arenites, carbonates, and lutites in the Amadeus and Ngalia Basins, but it was not until later that late Adelaidean glacial successions transgressed from the Arunta Block on to the North Australian Orogenic Province, beneath the Georgina Basin in the southeast, and into the East Kimberley and Victoria River regions in the northwest. Thrusting, nappe formation, and folding (Petermann Ranges Orogeny) affected the southwestern Amadeus Basin, but sedimentation continued without a break into the Palaeozoic in the northern Amadeus Basin. Farther north there is a mild, but consistent unconformity between the Adelaidean and Palaeozoic sequences, as sedimentation transgressed over a large part of the North Australian Orogenic Province.

Terrigenous and carbonate sedimentation continued, with some breaks, throughout the Palaeozoic in the deep basins - Amadeus, Ngalia, Canning, and Bonaparte Gulf Basins, and Fitzroy Graben - but only Cambro-Ordovician carbonates accumulated in the stable Ord, Daly River, Wiso, and Georgina Basins. An increase in area occupied by platform-covers, which took place during the early Palaeozoic, was accompanied by the widespread extrusion of Early Cambrian flood basalts (Antrim Plateau Volcanics) up to 1000 m thick, beneath the Ord and Wiso Basins, and parts of the Georgina and Bonaparte Gulf Basins; subsidence of the Bonaparte Gulf Basin commenced at the same time. The trough in the southern Canning Basin is an early to middle Palaeozoic feature, of similar age to the Amadeus Basin, but the two troughs are now separated by a north-trending ridge. Deposition ceased in the Amadeus and Ngalia Basins with Late Devonian to Early Carboniferous uplift of the Arunta Block and the associated thrusting, nappe formation, and folding - the Alice Springs Orogeny - and with the filling of syntectonic troughs with molasse in the Amadeus, Ngalia, and southern Georgina Basins. Deep subsidence of the Fitzroy Graben began at this time, and faulting was also active around the Bonaparte Gulf Basin; subsidence of these grabens continued during the Permo-Triassic. All of the Devono-Carboniferous sediments in northern Australia have syntectonic molasse-like characteristics. Deposition in the Arafura Basin commenced in the Early Cambrian, and is presumed to have continued through most of the Palaeozoic; Silurian fossils have been found; a thick succession accumulated in a northwesterly-trending graben, but it cannot be directly related to any known older feature.

Trans-Australian Platform Cover; The onshore part of northern Australia had become extremely stable by the Mesozoic. A Jurassic-Early Cretaceous marine transgression deposited a veneer of sediments over most of the area to the north of a line joining the southeastern Georgina Basin with the northern Victoria River Basin. Thicker sequences (up to 2000 m) accumulated on the eastern edge of the North Australian Block in the Eromanga and Carpentaria Basins.

Thick sequences in the offshore Bonaparte Gulf and Browse Basins are related to the breakup of Gondwanaland. Up to 3000 m of Jurassic-Early Cretaceous terrigenous sediments accumulated in rifts, and these were followed by up to 3000 m of Tertiary carbonates deposited on the collapsing continental shelf. The rifts, which originated during sea-floor spreading, conform with the regional structural pattern of northern Australia, indicating that they were inherited from Precambrian lineaments.

CONCLUDING REMARKS

The tectonic evolution of northern Australia is clearly related to the cratonization of its basement. Early Proterozoic orogenic domains were initially distributed right across the region. A central craton - the North Australian Orogenic Province - became stable by the early mid-Proterozoic while mobile belts surrounding it (Central Australian Orogenic Province) continued to be reactivated until they, too, were cratonized during the Late Proterozoic. Similar time relationships can be seen in the overlying platform covers: thick unstable platform covers (North Australian Platform Cover) developed over the central craton while the marginal belts were still active, and they were then covered by thin stable covers (Central Australian Platform Cover) at the same time that thick unstable covers (also Central Australian Platform Cover) were developing above the younger marginal mobile belts. Finally, the covers (Trans-Australian Platform Cover) over these mobile belts also became stable and the youngest thick covers are confined to the continental margins.

A uniform pattern of major fractures and lineaments, which developed throughout the region very early in its history, has controlled the subsequent tectonic evolution of the region, by repeated reactivation of the lineaments. Mobile belts and lineaments in the basement repeatedly controlled the localization of the thick sequences and deformation of later platform covers.

Although vertical displacements are apparent, the structural evolution of much of the region can be related to horizontal displacements along major lineaments. Most of the structure can be explained by a simple model in which a central zone, between the Kimberleys and Mount Isa, was displaced northwards relative to the blocks on either side, and zones of thrusting and folding developed where the cover was crumpled against east-west-trending rigid blocks during northward transport.

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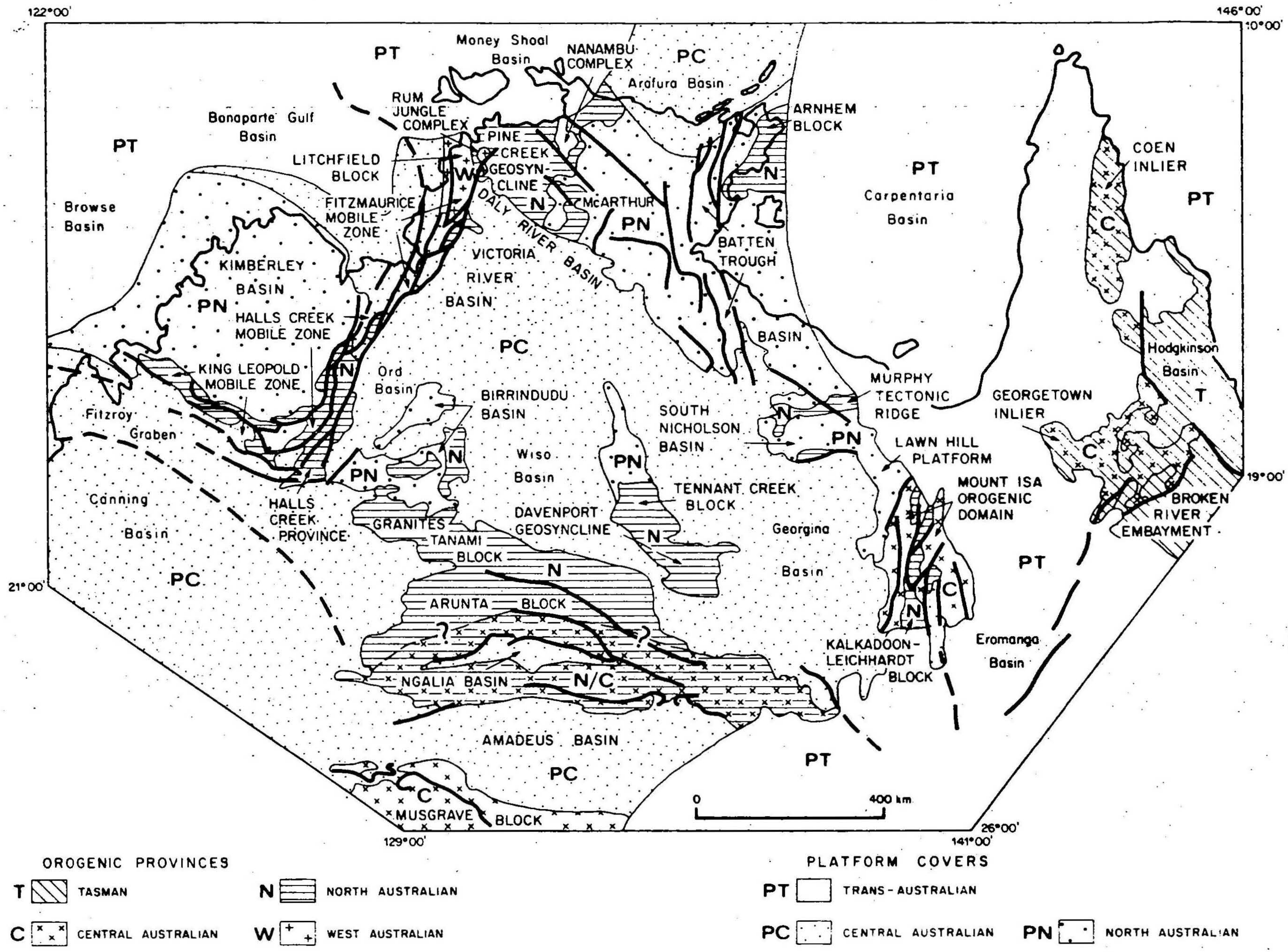

Record 1976/72

Fig. 1 Principal tectonic elements

AUS 4/28

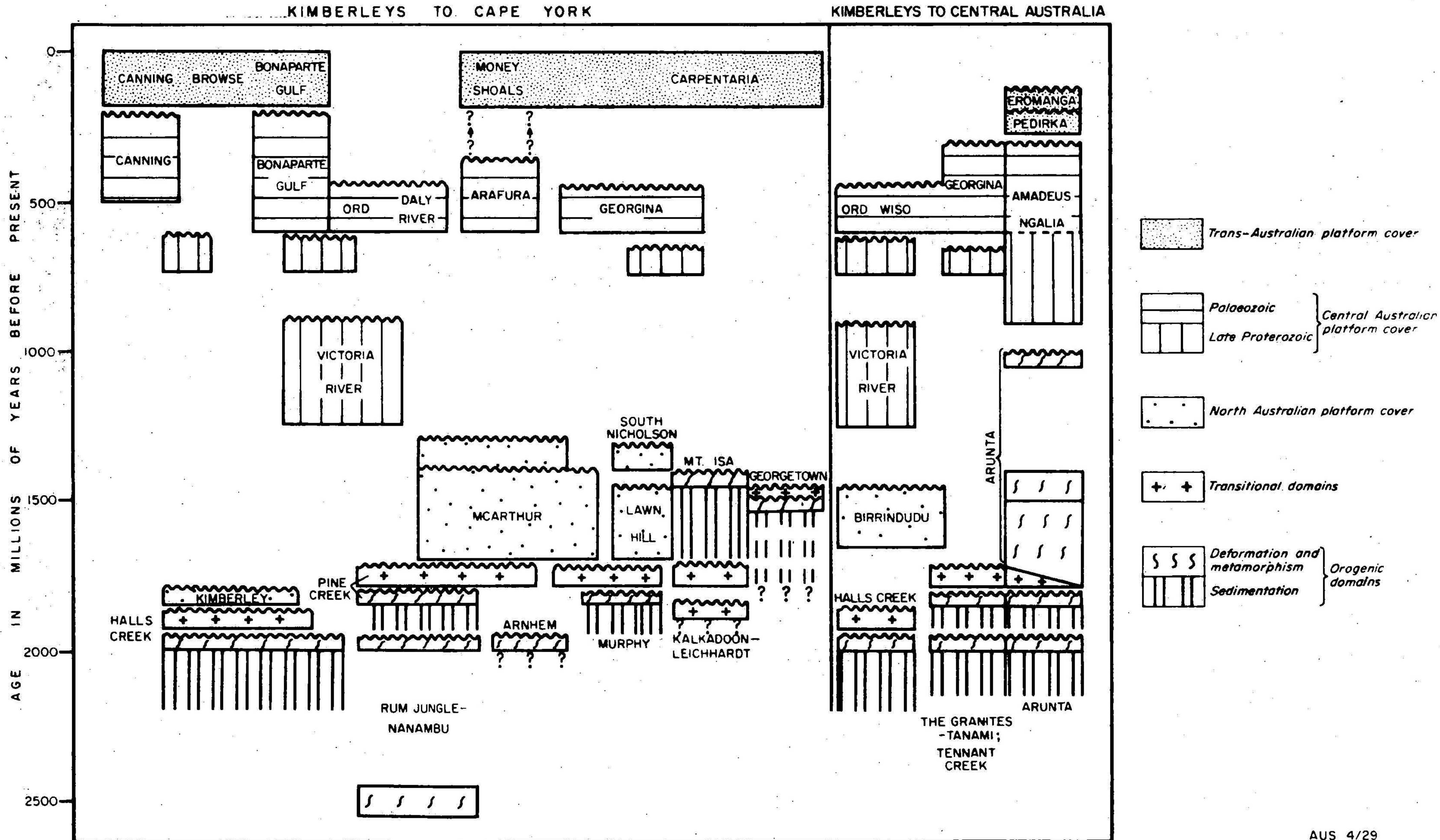

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Fig. 2 Diagrammatic relationship of tectonic units

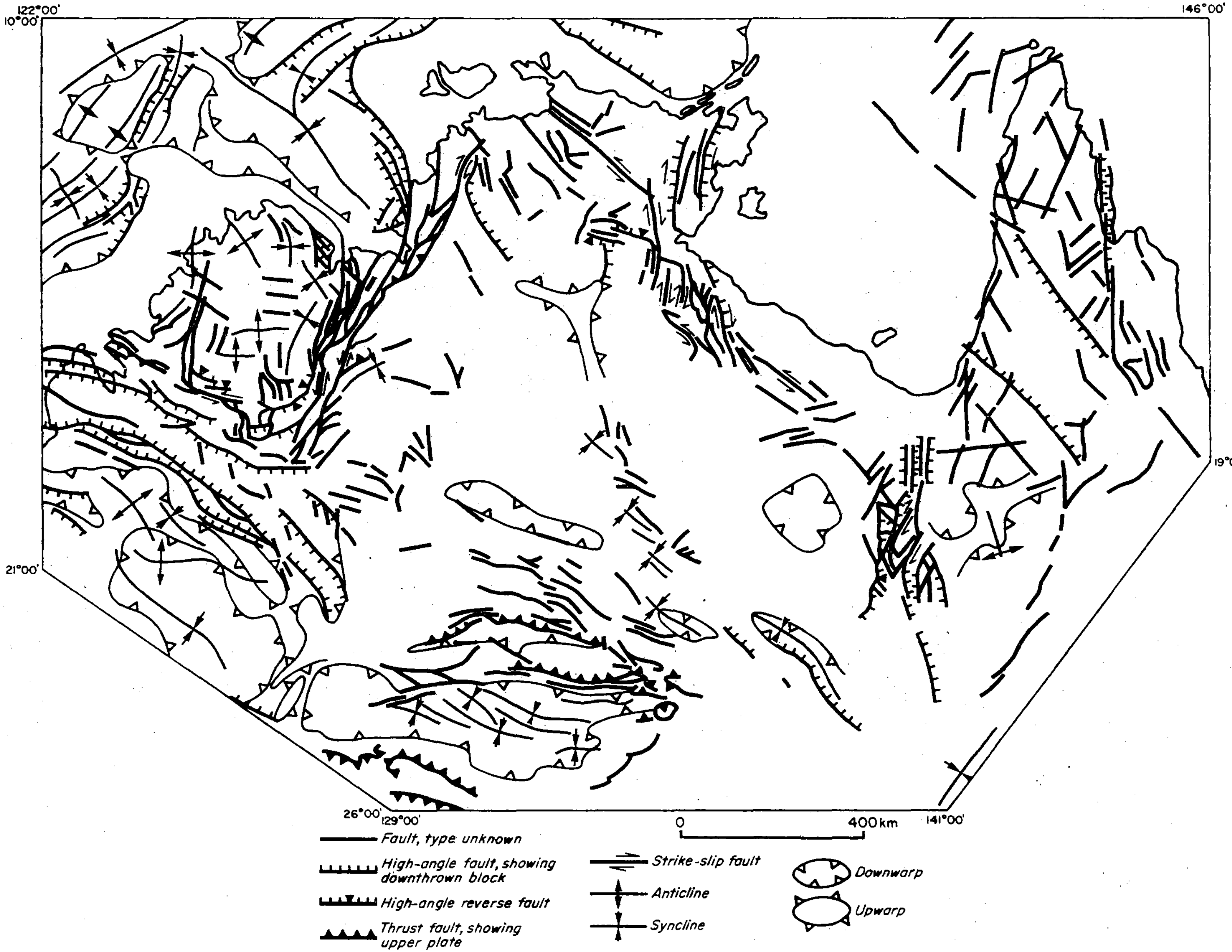

Fig.3 Structural sketch map

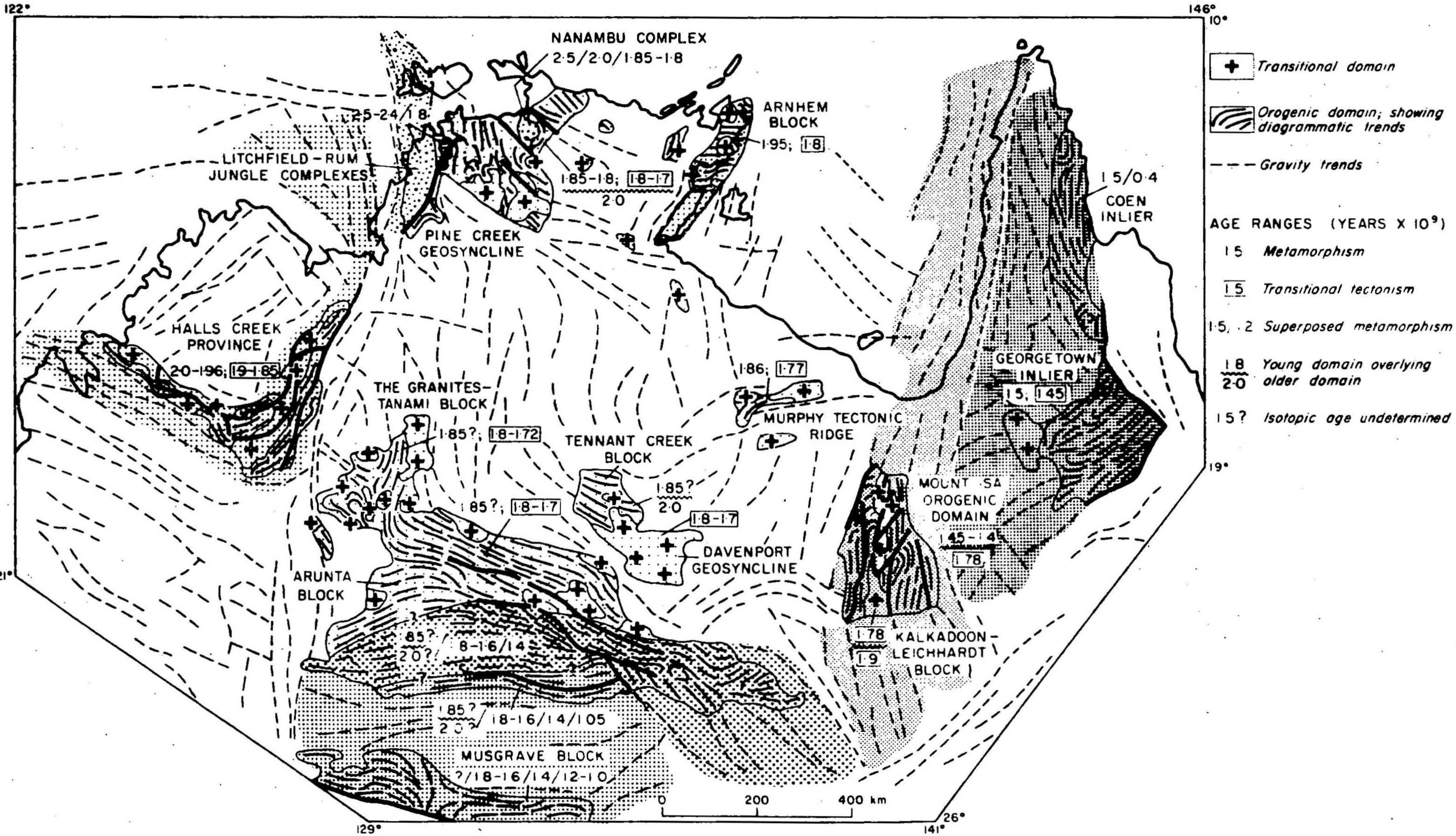

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Fig. 4 Orogenic domains

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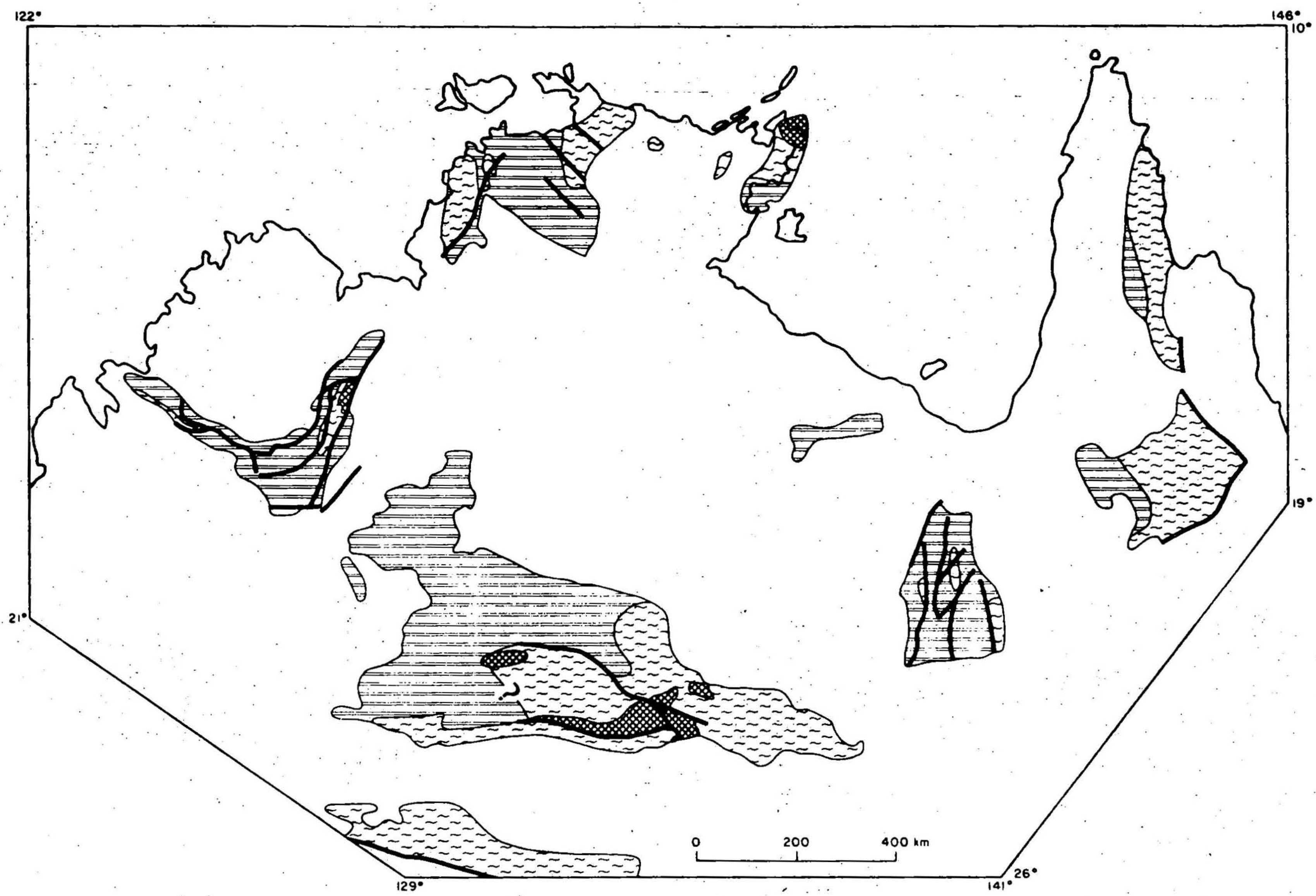

Granulite facies — Amphibolite facies — Greenschist facies or lower

Record 1976/72

Fig. 5 Metamorphic facies

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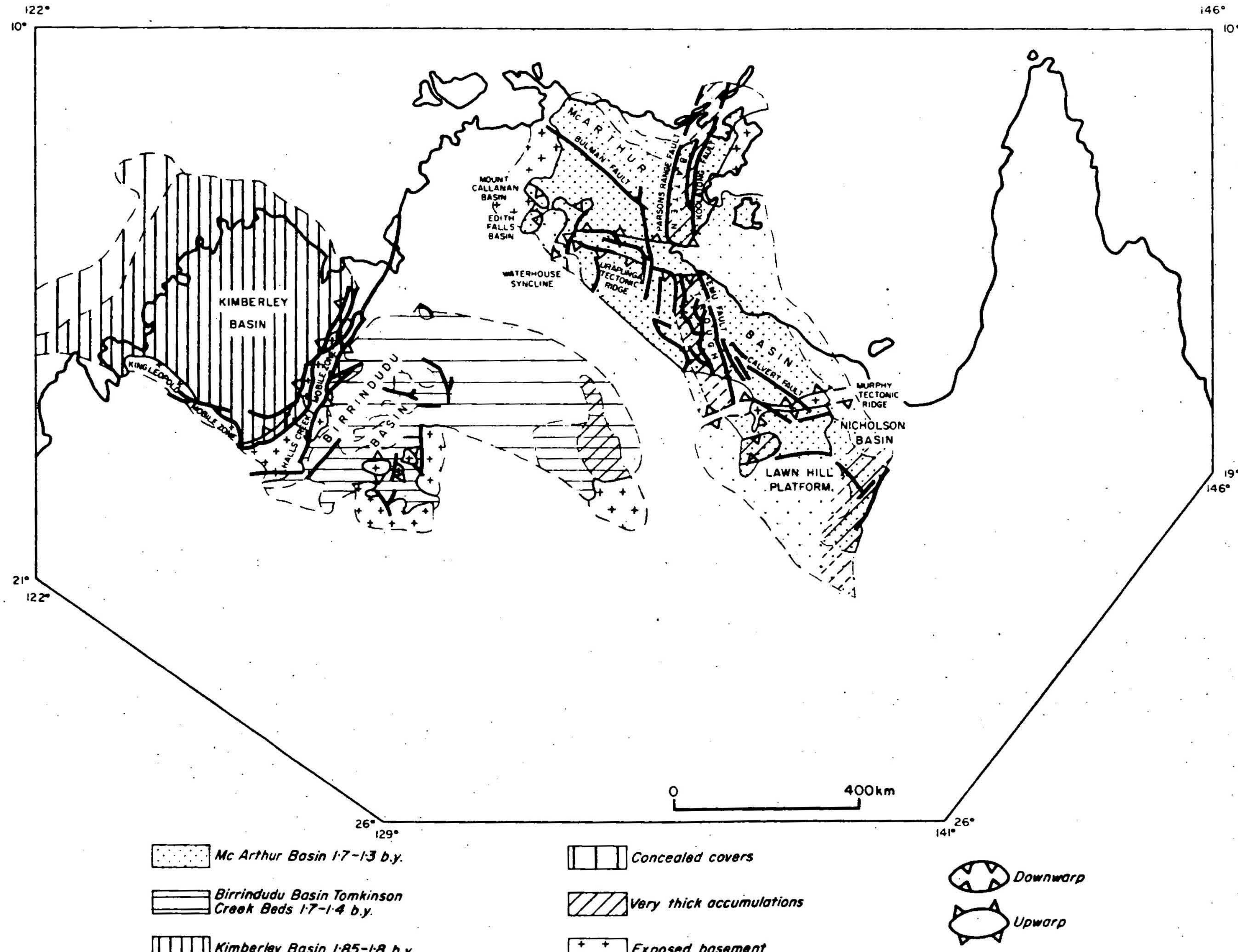

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Fig. 6 Mid-Proterozoic platform covers

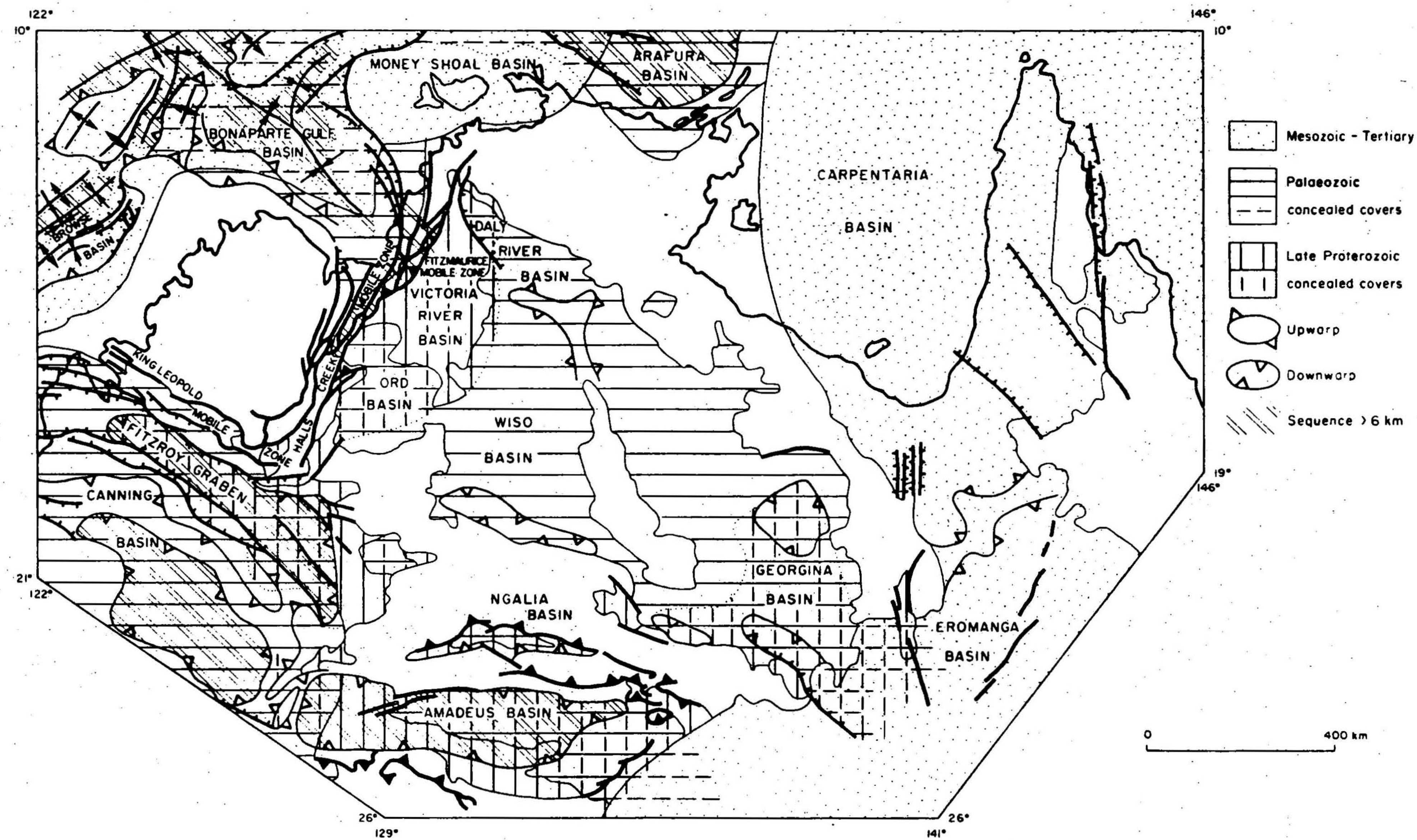

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Fig. 7 Late Proterozoic and Phanerozoic platform covers

Symposium 103.3 - The structure of Australia and variations in tectonic style. 25th International Geological Congress, Sydney, 1976

The Tectonic Evolution of Australia

by

K.A. Plumb

Abstract

15 palaeotectonic maps have been derived from the Tectonic Map of Australia and New Guinea, 1971, to illustrate the progressive development of the Australian continent from the Archaean to the present.

The Archaean Pilbara and Yilgarn Blocks are the oldest cratons in Australia. The early Proterozoic North Australian Block has formed a single craton for over 1700 m.y.; new geosynclines - the Northeast Mobile Belts - accreted onto its eastern edge during the mid-Proterozoic. The Gawler Block was cratonized by about 1450 m.y. Linear metamorphic belts - the Central Australian Mobile Belts - continued to be reactivated, between and surrounding the older cratons, until about 1000 m.y. ago. During the Palaeozoic the Tasman Fold Belt progressively accreted, from west to east, onto the Precambrian Craton. The New Guinea Fold Belt accreted onto the northern edge of the continent during the Mesozoic-Tertiary. Platform covers developed in turn, as the blocks were cratonized.

Much of the tectonic development of the continent resulted from repeated reactivation of ancient lineaments and mobile zones.

The same systems of tectonic analysis and classification may be applied to both the Precambrian and Phanerozoic tectonic units.

INTRODUCTION

15 palaeotectonic maps have been derived from the Tectonic Map of Australia and New Guinea, 1971, to illustrate the progressive development of the Australian continent from the Archaean to the present. They are based on a series first presented by the author in 1972, but have been completely revised to incorporate new data.

Areas on the map are objectively classified into tectonic regimes on the basis of simple lithological and structural criteria, which are independent of hypotheses regarding tectonic processes or the origins of the units. All units are shown in their present positions; relationships of Australia to other continents are not considered, nor are attempts made to reconstruct ancient plate movements.

Legend and Definitions

Following the classification used on the Tectonic Map of Australia and New Guinea, 1971, areas are classified into Orogenic Domains, Transitional Domains, Cratons, and Platform Covers (Fig. 1).

Orogenic Domains are zones of intense tectonism which involve the development and deformation of orthogeosynclines or the development of metamorphic and igneous complexes prior to cratonization. They are characterized by thick flysch-like sequences in extensive linear troughs, abundant and varied volcanic and plutonic rocks, and intense deformation and widespread metamorphism (of the fill). The orogenic domains are subdivided into three types: Orogenic Belts are those belts which, during the time span covered by a particular map, passed through the full cycle of sedimentation (geosynclinal stage) and major deformation and metamorphism (orogenic stage). Geosynclines are those areas which were passing through the geosynclinal stage of orogenic domains, but were not intensely deformed until later. Metamorphic Belts include high-grade metamorphic complexes whose pre-metamorphic history is unknown, as well as reworked belts superimposed on clearly distinguishable older orogenic domains.

Transitional Domains are zones of late to post-orogenic tectonism associated with the last stages of cratonization; they are transitional in time, place, and style between orogenic and cratonic tectonism. They are characterized by downwarps, cauldron subsidences, rifts, molasse-like sediments, abundant acid volcanic and plutonic rocks, moderate deformation, and rare metamorphism (of their fill).

Cratons, as used here, are stable blocks - either shields or ancient platforms - on which no platform-cover sediments were deposited during the time span of the particular map.

Platform Covers are terrains where platform-cover sediments were deposited on the cratons during the time span covered by a particular map. They are characterized by widespread, generally thin sequences of shallow-water and continental sediments, rare small plutons, basalt sheets, and mild deformation. They can include narrow mobile zones where sediment thickness or deformation or both increases. Areas of thick cover (greater than about 3 km) and areas of relatively intense deformation are distinguished.

Full screens are used only on maps for those areas where the tectonic units actually crop out or where platform covers are well known from drilling or seismic data. Units are extrapolated beneath cover either as concealed units which can be confidently extrapolated, or as inferred units for whose presence conclusive evidence is lacking.

For localities referred to in these notes the reader is referred to the Tectonic Map of Australia and New Guinea, 1971.

Acknowledgements

These maps are derived from the data and principles used in the compilation of the Tectonic Map of Australia and New Guinea, 1971, but the author alone is responsible for syntheses and interpretations extending beyond those of the tectonic map. The contributions of the other members of the Tectonic Map Committee to the tectonic map is acknowledged.

This paper is a preliminary draft only, and is subject to revision before final publication. No references are quoted. Many of the data on which the post-1972 revisions are based are still unpublished.

THE MAPS

Pre-2300 m.y. (Fig. 2)

This period covers the classic Archaean development of initial continental crust: greenstone belts lie between more extensive granite and gneiss terrains in the Yilgarn and Pilbara Blocks of Western Australia. The Pilbara Block developed about 3000 m.y. ago, but two distinct ages are recognized in the Yilgarn Block: the southwestern part, where metamorphism is more intense, is similar in age to the Pilbara Block, but the extensive greenstone belts of the Eastern Goldfields developed 2750-2650 m.y. ago. The Pilbara and Yilgarn Blocks have remained as cratons since 2300 m.y. ago.

Small inliers of gneiss and granite about 2550 m.y. old, in the Rum Jungle and Nanambu Complexes, are part of the basement beneath the Pine Creek Geosyncline of northern Australia. An Archaean craton has been postulated beneath the Kimberley Basin, but remains controversial. It is generally accepted that the Gawler Block of South Australia is underlain by Archaean basement.

From wide distribution of these scattered outcrops, and from considerations of the style of its subsequent tectonic development, it is possible that most, if not all, of the Australian Precambrian Craton is underlain by Archaean continental crust.

2300-1950 m.y. (Fig. 3)

This is the period of initiation of the North Australian Orogenic Province, and of the development of the oldest platform cover - West Australian Platform Cover - in Australia.

Although controversial, I favour the interpretation that the Nabberu Basin, which overlies the northern Yilgarn Block, correlates with the Hamersley Basin which overlies the Pilbara Block. Both basins are characterized by abundant banded iron formations, and the Hamersley Basin by extensive initial basic volcanics. These platform covers pass laterally into the intracontinental geosyncline of the Gascoyne and Paterson Blocks. It is commonly considered that the sedimentary successions of the Gawler Block (including the ironstones of the Middleback Ranges) and of the adjoining Musgrave Block (both elements of the Central Australian Orogenic Province) were deposited at this time.

In northern Australia, sedimentation and volcanism commenced after about 2200 m.y. in the Halls Creek Province, and the rocks were metamorphosed (Tickalara metamorphism) about 1960 m.y. ago. High-grade metamorphic rocks of similar age are also known from Arnhem Land and from basement beneath the Pine Creek Geosyncline and the Tennant Creek Block, and the oldest succession of the Arunta Block is correlated with the Halls Creek Province. It appears that this metamorphic event spread right across northern Australia as far as Mount Isa.

1950-1800 m.y. (Fig. 4)

This is the time of development of the Pine Creek Geosyncline in northern Australia and of rocks of similar age in The Granites-Tanami Block, Tennant Creek Block, Murphy Tectonic Ridge, and Arunta Block in central Australia: sedimentation and minor volcanism began 2000 m.y. ago, and then deformation and metamorphism followed 1850-1800 m.y. ago. The interconnections between these inliers are now concealed by younger covers.

To the west of the Halls Creek Fault, the Halls Creek Province was cratonized during transitional tectonism (e.g., Whitewater Volcanics and Bow River Granite) by about 1850 m.y. ago. The first unit of the North Australian Platform Cover (Kimberley Basin), characterized, like the Hamersley Basin, by widespread initial basic volcanics, was deposited and then intruded by the vast 1800-m.y.-old Hart Dolerite.

In the Mount Isa region, the Kalkadoon Granite and Leichhardt Metamorphics are correlated with the transitional domain of the Halls Creek Province. In northeastern Queensland, 1800 m.y.-old dolerites intruding the succession suggest that deposition took place at this time in the Coen and Georgetown Inliers.

In southern Australia, the cratons of the Yilgarn and Pilbara Blocks expanded, and a metamorphic event has been noted along the northwestern edge of the Yilgarn Block. Deposition continued between these cratons in the Gascoyne Block, and possibly extended as a linear belt into the Musgrave Block farther east. To the southeast, high-grade metamorphism commenced in the Gawler Block.

<u>1800-1700 m.y. (Fig. 5)</u>

This is the time of transitional tectonism in the Pine Creek Geosyncline and related domains, thus completing the cratonization of the North Australian Orogenic Province. Intense tectonism became widespread in central and southern Australia during this interval - the first major deformation of the Central Australian Orogenic Province. In the northwest, the Kimberley Block became a craton, with faulting taking place along its margin in the Halls Creek Mobile Zone.

Two episodes of high-grade metamorphism reworked the rocks of the Arunta Block; metamorphism of this age is the oldest so far identified within the Musgrave Block, and the Gascoyne Block and Paterson Province were metamorphosed and intruded by granites; all form part of a vast east-west mobile belt through central Australia which, from gravity evidence, probably extends north of the Pilbara Block as well.

Farther south, the main high-grade metamorphism of the Gawler and Willyama Blocks took place; northeasterly trends suggest that this mobile belt was possibly distinct from that of central Australia. This southern belt may have extended westwards as far as the edge of the Yilgarn Block.

1700-1400 m.y. (Fig. 6)

Most of northern and western Australia was now a craton, and the main development of the North Australian Platform Cover took place - the McArthur and Birrindudu Basins and the Lawn Hill Platform. The platform cover was again characterized by widespread initial basic volcanics and by thick successions in areas such as the Batten Trough and Lawn Hill Platform. Along the eastern margin of the platform, similar but much thicker sedimentary and volcanic sequences were deposited penecontemporaneously in the Mount Isa Orogenic Domain, and these were then intensely deformed, metamorphosed, and intruded by granites about 1450-1400 m.y. ago. Farther east, the Georgetown and Coen Inliers were metamorphosed about 1500 m.y. ago, and then acid volcanics, representing transitional tectonism, were extruded about 1470 m.y. ago.

In the west, sediments of probable platform-cover type were deposited on the Paterson Province, and were possibly continuous with small inliers along the southern edge of the Hamersley Basin.

Intense metamorphic activity, principally along northeasterly-trending zones, continued in southern and central Australia. Metamorphism and granite emplacement occurred at intervals throughout this time in a northeasterly-trending belt extending from the Albany-Fraser Province, through the Musgrave Block, to the southern part of the Arunta Block. Farther east, in the Gawler and Willyama Blocks, orogenic tectonism slowly waned, and the block finally became cratonized during transitional tectonism (e.g., Gawler Range Volcanics) about 1550-1450 m.y. ago.

1400-1250 m.y. (Fig. 7)

Following deformation of the Mount Isa Orogenic Domain, the craton expanded. Sedimentation forming part of the North Australian Platform Cover contracted to local areas in the McArthur and South Nicholson Basins, and terminated, about 1300 m.y. ago, when dolerite sills were emplaced locally.

The first representative (Roopeena Volcanics) of the Central Australian Platform Cover was deposited along the eastern edge of the now cratonized Gawler Block, but I consider that the belt underlying the eventual Adelaide Geosyncline was still in a pre-cratonic stage.

High-grade metamorphism continued intermittently, but particularly about 1350 m.y. ago, in a restricted northeast-trending belt between the Yilgarn and Gawler Blocks, through parts of the Albany-Fraser Province, Musgrave Block, and southern Arunta Block.

Local platform covers along the western edge of the Yilgarn Block may have passed into a geosyncline farther west.

1250-900 m.y. (Fig. 8)

This period produced the final cratonization of the Central Australian Orogenic Province, and is distinguished by the restriction of intense tectonism to narrow belts of metamorphism, migmatization, and granite emplacement between or surrounding major cratons: 1200-1050 m.y. Albany-Fraser Province; 1100-1200 m.y. Musgrave Block; 1050 m.y. Arunta Block; 1050-900 m.y. Mount Painter Block, Houghton Inlier; 1050 m.y. Northhampton Block; more than 800 m.y. Western Tasmania. Gravity results suggest a continuation of Musgrave Block structures along the northeastern edge of the Pilbara Block.

About 1050 m.y. ago large east-west thrust faults, along which large layered mafic-ultramafic intrusions (Giles Complex) were emplaced, developed in the Musgrave Block, granites and acid volcanics were emplaced in cauldron-subsidence areas, and extensive bimodal volcanics were extruded: this is interpreted as transitional tectonism at the close of the formation of the Central Australian Orogenic Province.

These events were accompanied by the development of new elements of the Central Australian Platform Cover on ancient cratons. Thick sequences, including 1100 m.y.-old acid volcanics, were deposited in the Bangemall Basin above the central zone of the Gascoyne Block, and deposition ended with the emplacement of dolerite sills, followed by moderately intense folding. In northern Australia, the 1200-900 m.y.-old Victoria River Basin developed on the stable Sturt Block and passed westwards into very much thicker sequences in the Halls Creek and Fitzmaurice Mobile Zones; the mobile zones were then moderately to intensely deformed.

900 m.y. - Early Cambrian (Fig. 9)

This period was distinguished by its lack of intense tectonism; the Australian Precambrian Craton had taken its final form. The major Precambrian development of the Central Australian Platform Cover took place, and I consider that this period encompasses the whole of the type-Adelaidean succession in South Australia.

The main development of platform cover (Adelaide Geosyncline; Officer, Amadeus, and Ngalia Basins) took place on top of the Central Australian Orogenic Province, and very thick accumulations were localized over the most recently cratonized mobile belts. Basic volcanics (Wooltana Volcanics) were important locally. During the latter stages, comparatively thin successions extended northwards onto the North Australian Orogenic Province: late Proterozoic glacial successions extended almost continuously from Tasmania to the Kimberleys.

At the close of the Proterozoic an exceptional intra-continental event in central Australia - the Petermann Ranges Orogeny - produced large thrusts and nappes and metamorphism. At about the same time metamorphism, intense folding, and thrusting affected platform covers in the King Leopold Mobile Zone. Younger cover obscures any possible connections between the products of these two events beneath the Canning Basin.

A granulite metamorphism about 650 m.y. old has been registered in the Naturaliste Block on the southwest corner of Western Australia.

Early Cambrian - Middle Ordovician (Fig. 10)

This period marks the first recognized events of the Tasman Fold Belt System of eastern Australia, although many authors consider that Precambrian rocks may underlie parts of it. These events were accompanied by a lateral expansion of the Central Australian Platform Cover over the adjoining craton.

Cambrian rocks in the northeast-trending Kanmantoo Fold Belt of South Australia and western New South Wales, and the adjoining Adelaidean and Cambrian platform cover of the Adelaide Geosyncline, were intensely deformed by the Cambro-Ordovician Delamerian Orogeny; a block of rocks of similar age in central New South Wales (Girilambone Beds) may originally have been farther to the west, and may have been displaced eastwards during later plate movements. Rocks deformed at this time in the Lolworth-Ravenswood Block, Anakie High, and western Queensland (bore cores only) define a northeast-trending early phase of the Thomson Fold Belt in Queensland. The connection, if any, between the Thomson and Kanmantoo Fold Belts is concealed; perhaps they originally formed a single belt which has since been split by a major shear.

Cambro-Ordovician sediments and basic volcanics extended far to the east of these fold belts in New South Wales and Victoria, but they were apparently not deformed until much later. In western Tasmania, a succession of volcanics, sediments, and serpentinites accumulated in the Dundas Trough between older Precambrian blocks. A transitional domain developed during the Middle Ordovician in the Gnalta Province of western New South Wales.

Many of the platform cover successions show only slight or no unconformity between the Cambrian and the Adelaidean. Thick deposits were still confined to the older mobile belts in central

Australia, but the axes of the troughs shifted to the northeast following the uplift and exposure of the Musgrave Block by the Petermann Ranges Orogeny. The expansion of thin, mostly undeformed covers across the North Australian Block - the Georgina, Daly River, Wiso, Ord, and Bonaparte Gulf Basins - was accompanied by early Cambrian flood basalts (Antrim Plateau Volcanics). The Arafura Basin, in which deposition commenced in the early Cambrian, probably extended across the Arafura Sea, and joined with similar sediments in the subsurface of Irian Jaya. Sparse drill-hole information suggests that rocks similar to those of the Georgina Basin may underlie much of the Gulf of Carpentaria.

Late Ordovician - Middle Devonian (Fig. 11)

This was the time of development of the Lachlan Fold Belt in New South Wales, Victoria, and Tasmania, and of the main stage of the Thomson Belt in Queensland. A complex series of arches, troughs, volcanic arcs, etc., commonly interpreted nowadays according to plate tectonic models, have been outlined by several authors. A number of orogenies (e.g., Benambran-Quidongian, Bowning, Tabberabberan) have been recognized from the late Ordovician onwards, culminating with the Middle Devonian Tabberabberan Orogeny, and the region was progressively stabilized from west to east.

Penecontemporaneous geosynclinal sedimentation continued farther east in the Hodgkinson Fold Belt of north Queensland and in the New England Fold Belt of New South Wales and Queensland, but these belts apparently remained essentially undeformed. To the west of the Hodgkinson Fold Belt, the Precambrian rocks of the Georgetown and Coen Inliers were metamorphosed during the Middle Devonian. Silurian rocks are known from the Vogelkop Peninsula of Irian Jaya, but the exact time of their deformation, sometime before the Permian, is unknown.

During this complex activity in eastern Australia surprisingly little happened in the craton to the west. A relatively narrow belt of platform-cover troughs continued through central Australia, a deep fault-bounded trough developed in the Carnarvon Basin of Western Australia, and contemporaneous sediments are known from both the Arafura Basin and Irian Jaya.

Late Devonian - End Carboniferous (Fig. 12)

The Late Devonian-Early Carboniferous encompasses the transitional stage and final cratonization of the Lachlan and Thomson Fold Belts, typified by the Lambian sequences of central New South Wales and the sequences in the Drummond and Burdekin Basins of Queensland, viz., molasse-type sediments, acid volcanics, and associated high-level granites.

At the same time the Hodgkinson Basin was intensely deformed and metamorphosed, and this activity was followed, during the late Carboniferous and earliest Permian, by transitional tectonism when acid volcanic and granite cauldron-subsidence structures extended well to the west into the Precambrian craton of north Queensland. The northern extension of the Hodgkinson Fold Belt is obscure, but it is possible that the rocks on Vogelkop were deformed some time during the Devono-Carboniferous.

Many authors recognize a calc-alkaline volcanic arc through eastern Queensland and New South Wales throughout the late Devonian and Carboniferous, at the boundary between the New England Fold Belt and the Lachlan and Thomson Fold Belts. Deposition continued to the east of this arc, apparently without appreciable deformation (Permian deformation is the oldest deformation now positively recognized by most workers in the intensely deformed rocks along the east coast).

The Devono-Carboniferous was a period of rather intense activity in narrow belts within the Precambrian craton. A new period of intracontinental thrusting, nappe formation, and metamorphism (Alice Springs Orogeny) uplifted the Arunta Block of central Australia, and deposited thick molasse-type sediments in the adjoining Amadeus and Ngalia Basins. An extremely thick succession was deposited in the newly formed Fitzroy Graben which probably developed above part of the old King Leopold Mobile Zone; the fault-bounded Bonaparte Gulf Basin took on a definite form at this time, probably above the extension of the Halls Creek Mobile Zone; similar deposits accumulated in the Carnarvon, Officer, and Warburton Basins. All of these deposits are noted for having molasse-like characteristics.

Permian - Triassic (Fig. 13)

The Australian Craton had now greatly increased in area, and intense tectonism on the mainland was confined to the New England Fold Belt in the extreme east. The belt was intensely deformed and locally metamorphosed during the Permian (Hunter-Bowen Orogeny), and emplacement of ultramafic rocks took place along major thrusts. During the Triassic, acid to intermediate volcanics, high-level granites, molasse sediments, and rift structures (e.g., Esk Rift) within the New England Fold Belt represent the transitional tectonic stage and final cratonization of the Australian continent. Granitic basement of Permian age is known from the Kubor Block of New Guinea, and Triassic sediments and arc-trench volcanics to the north of the Kubor Block are the oldest known rocks of the New Guinea Orogenic Province.

At the same time as the New England Fold Belt was being folded and uplifted, a linear downwarp (foredeep) - the Sydney and Bowen Basins - developed along the edge of the adjacent craton, and the edge of the foredeep was itself deformed as the New England Fold Belt was thrust outward onto it. Volcanics attributed to the closing stage of the activity of the Devono-Carboniferous volcanic arc are abundant in the lower parts of the foredeep sequence.

The Permian-Triassic was again a period of major platform cover expansion - the first phase of the Trans Australian Platform Cover - over both the cratonized part of the Tasman Fold Belt System and over the Precambrian Craton. Numerous basins are represented: Galilee, Cooper, Murray, Arckaringa, Pedirka, Canning, Officer, Bonaparte Gulf, and unnamed basins in Irian Jaya. The Fitzroy Graben continued as a prominent feature of northwestern Australia, and associated rifts, cratons, and horsts along the west coast - Perth, Carnarvon, offshore-Canning, Browse, and offshore Bonaparte Gulf Basins - heralded the first movements associated with the eventual break-up of Gondwanaland.

Jurassic - Early Cretaceous (Fig. 14)

This period of comparatively gentle tectonic activity was marked by the transgression of thin platform covers over wide areas of the Australian continent: e.g., Eromanga, Clarence-Moreton, Murray, Carpentaria, Eucla, and Canning Basins, and southern Papua New Guinea and Irian Jaya. Thick deposits are confined to marginal zones of the present-day continent. Rifting associated with the breakup of Gondwanaland continued along the west coast in the offshore Money Shoals, Bonaparte Gulf, Browse, Canning, Carnarvon, and Perth Basins, and rifting also began along the southern coast in the Gippsland, Otway, Duntroon, and Great Australian Bight Basins. Structural highs along the present-day seaward edges of the rifts, and submerged continental blocks overlain by similar sediments farther west (e.g., Naturaliste and Exmouth Plateaus), are parts of the more extensive Gondwanaland continent.

Calc-alkaline volcanics were extruded in the Maryborough and associated basins along the east coast, and small granite bodies intruded parts of the adjacent Palaeozoic Bowen Basin and Connors Arch. Alkali gabbro-syenites intruded parts of south-eastern Australia, and extensive dolerite-granophyre sills were emplaced in Tasmania. Basalts occur south of Perth and alkali basalts are known from the Ashmore Block of the Northwest Shelf.

Along the northern edge of the continent, geosynclinal sedimentation and arc-trench volcanism continued in the New Guinea Orogenic Province.

Late Cretaceous - Oligocene (Fig. 15)

Geosynclinal sedimentation and arc-trench volcanism continued in Papua New Guinea and Irian Jaya, and finally culminated with the deformation and metamorphism of the Highlands Orogenic Domain during the Oligocene. Paired metamorphic belts with glaucophane schists are recognized, and extensive bodies of ultramafic rocks and ophiolites (e.g., Papuan Ultramafic Belt), commonly interpreted as part of the upper mantle and oceanic crust, were emplaced along major faults. The Aure Trough and Coral Sea Basin opened by rotation of the Owen Stanley Metamorphic Belt away from the continent, and the Papuan Ultramafic Belt was emplaced.

The continent now became even more stable; almost all sedimentation was confined to the margin. As the continent drifted away from the rest of Gondwanaland, the marginal basins took the form of collapsed continental margins rather than rifts. Alkali basalts and trachytes were extruded over wide areas of eastern continental Australia.

Miocene - Recent (Fig. 16)

The continent now assumed its present-day form. Apart from the embayment occupied by the Murray Basin and small downwarps filled with terrestrial sediments, platform-cover sedimentation continued to be confined to the collapsed margins of the continent, and the successions are generally much thinner than those deposited in the previous periods; carbonate rocks are common. The Eastern Highlands of Australia were uplifted, and more alkali basalts were extruded.

In Papua New Guinea and Irian Jaya, the Highlands Orogenic Domain and the edge of the adjoining platform were faulted and uplifted during the Late Miocene and Pliocene, and numerous thrust sheets slid southwards across the platform under the influence of gravity. A foredeep developed to the south, and was itself eventually deformed as the uplift continued along its northern edge. The Aure Trough and Coral Sea Basin continued to subside, and were deformed by continuous syndepositional thrusting and folding; later, the northern parts of the trough were uplifted in sympathy with movement in the adjoining highlands.

To the north of the highlands, a volcanic arc-trench complex developed, and geosynclinal sedimentation continued in the North New Guinea Orogenic Domain during the Miocene. Deformation and uplift of much of this domain commenced later, and is still continuing; sedimentation is now restricted to intermontane troughs. At present a new volcanic arc - the South Bismarck Volcanic Arc - is active along the north coast of New Britain and New Guinea, and deposition is presumably occurring in the Bismarck and Solomon Seas, under the influence of a complex pattern of plate movements. Quaternary potassic shield volcanoes are scattered through the cratonized parts of Papua New Guinea.

DISCUSSION

From the preceding synthesis it is possible to divide Australia and New Guinea into major crustal blocks (Fig. 17), each of which has its own distinctive history, tectonic style, and age, and each represents a significant stage in the evolution of the Australian continent. These blocks closely correspond to the major Orogenic Provinces of the Tectonic Map of Australia and New Guinea, 1971.

The Pilbara and Yilgarn Blocks are the main areas of the Archaean West Australian Orogenic Province, and represent the period of initial crustal differentiation and craton development; they are the oldest and probably most stable cratons in Australia.

The early Proterozoic North Australian Block, corresponding to the North Australian Orogenic Province of the tectonic map, is a single uniform crustal block which has remained relatively stable for over 1700 m.y. Its various constituent orogenic domains all underwent very similar and widespread, comparatively rapid, concurrent cycles of geosynclinal fill and deformation, followed by transitional acid volcanism and granite intrusion, and later by platform-cover sedimentation. Many of the orogenic domains are probably continuous in the subsurface. The geosynclinal fill is relatively quartz-rich, and it is possible that much of the block is underlain by an Archaean basement. After deposition of the mid-Proterozoic North Australian Platform Cover, the block remained very stable; subsequent elements of the Central Australian Platform Cover are thin and undeformed, except where they overlie long-lived ancient mobile belts.

The Northeast Mobile Belts developed adjacent to, and concurrently with, the North Australian Orogenic Province and Platform Cover, and, although they were not cratonized until the mid-Proterozoic, they are probably now best related to the North Australian Block rather than to the Central Australian Orogenic Province.

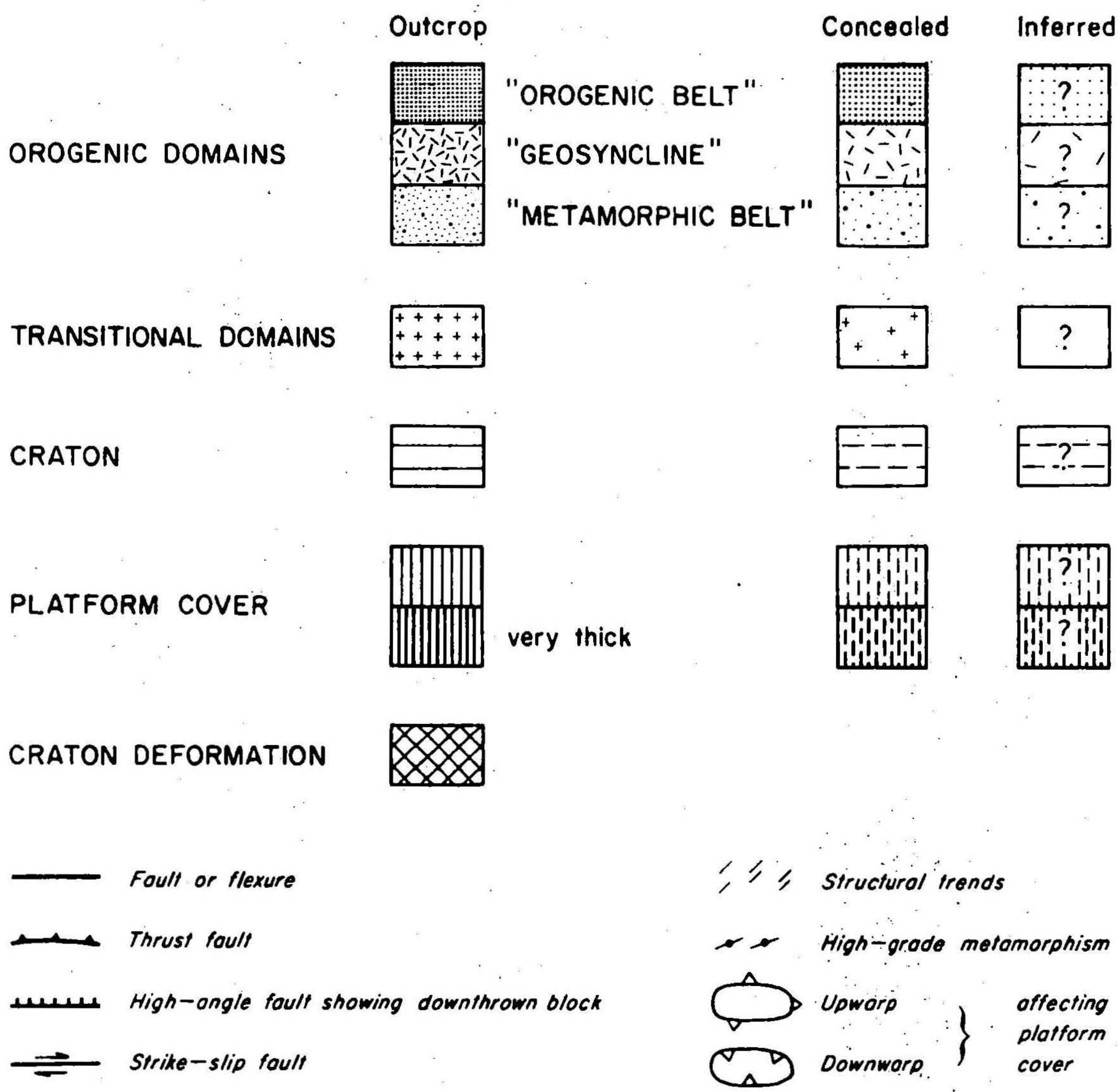
The mid-Proterozoic Central Australian Orogenic Province is characterized by intracontinental mobile belts, which show long histories of repeated high-grade metamorphism, plutonism, and reworking of older crust. The history of most of the province can be traced back to the early Proterozoic, but some elements were not finally cratonized until about 900 m.y. ago, after which the Australian Precambrian Craton assumed its final form. Two main elements of the province can be recognized.

Activity within the Gawler Block decreased considerably after about 1700 m.y., and the block was cratonized by about 1450 m.y. ago. It then formed a stable unit, together with the older blocks just described. Around and between these the linear Central Australian Mobile Belts continued to be deformed and reactivated. The mobile belts progressively decreased in extent as cratonization proceeded. The evidence so far available suggests that the cratonic blocks remained in roughly their present relative positions throughout, and the metamorphic and plutonic activity took place by some undetermined intracontinental process. The main parts of the Central Australian Platform Cover developed above the Central Australian Mobile Belts, where considerable thicknesses of sediment accumulated, and some belts remained as zones of moderately intense activity until the late Palaeozoic.

Crustal development during the Proterozoic apparently took place without major plate movements. The initial intense tectonism took place over very wide areas (initial thin crust?), and was then gradually restricted to narrow linear belts as polygonal blocks progressively cratonized outwards (by crustal thickening?). In comparison, the Palaeozoic Tasman Fold Belt System and the Mesozoic-Tertiary New Guinea Fold Belt are marginal to the Precambrian Craton, and they show progressive accretion from west to east or from south to north, respectively, by processes which may be interpreted by plate tectonic theory; many problems of detail still remain. The Vogelkop Block may represent a fragment of the Tasman Fold Belt System, displaced during the development of the New Guinea Fold Belt.

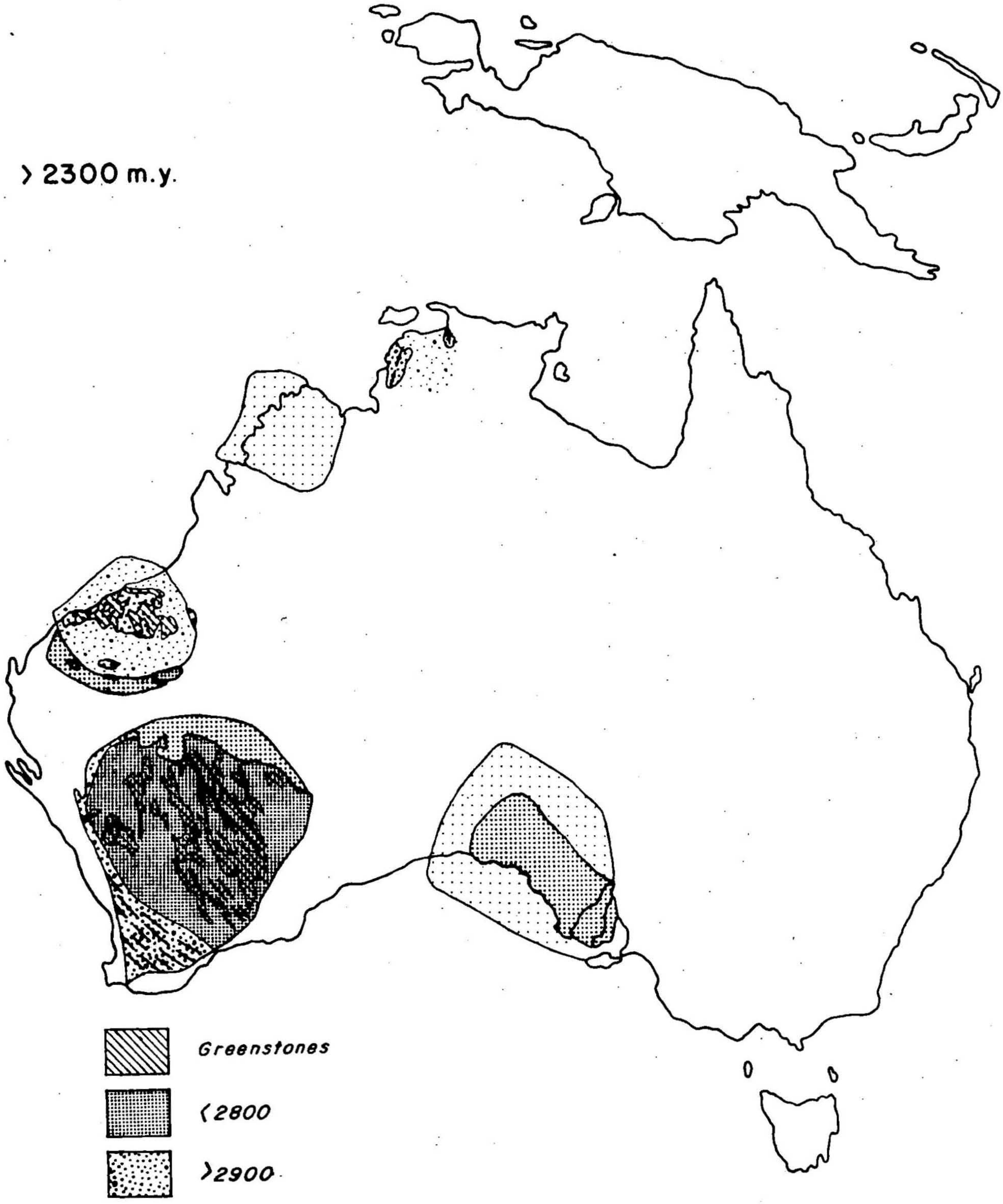
Much of the development of the continent, particularly of the Precambrian Craton, was controlled by fragmentation of the crust by major lineaments and by the repeated reactivation of mobile zones along them. The maps show that repeated reactivation of major lineaments took place over extremely long periods of time.

Although I have pointed out significant differences between the nature of the tectonic processes which operated during the Precambrian and the Phanerozoic in Australia, even more significant parallels exist. The same system of tectonic analysis and classification may be applied to both groups of rocks. The fundamental tectonic cycle which is basic to the concept of the Tectonic Map of Australia and New Guinea, 1971 - a vertical progression through time from geosynclinal deposition and orgenesis (orogenic domains), through transitional tectonism to cratonization, and then the deposition of platform cover - can be equally applied throughout the area covered by the map. Furthermore, it is commonly possible to subdivide the platform covers into an early relatively unstable phase which immediately succeeded the cratonization of the underlying orogenic domain, and a later stable phase related in time to, but more stable than, new platform covers developed elsewhere above new orogenic domains.



AUS 4/35

Fig.1 Legend



Record 1976/72

Fig 2

AUS4/36

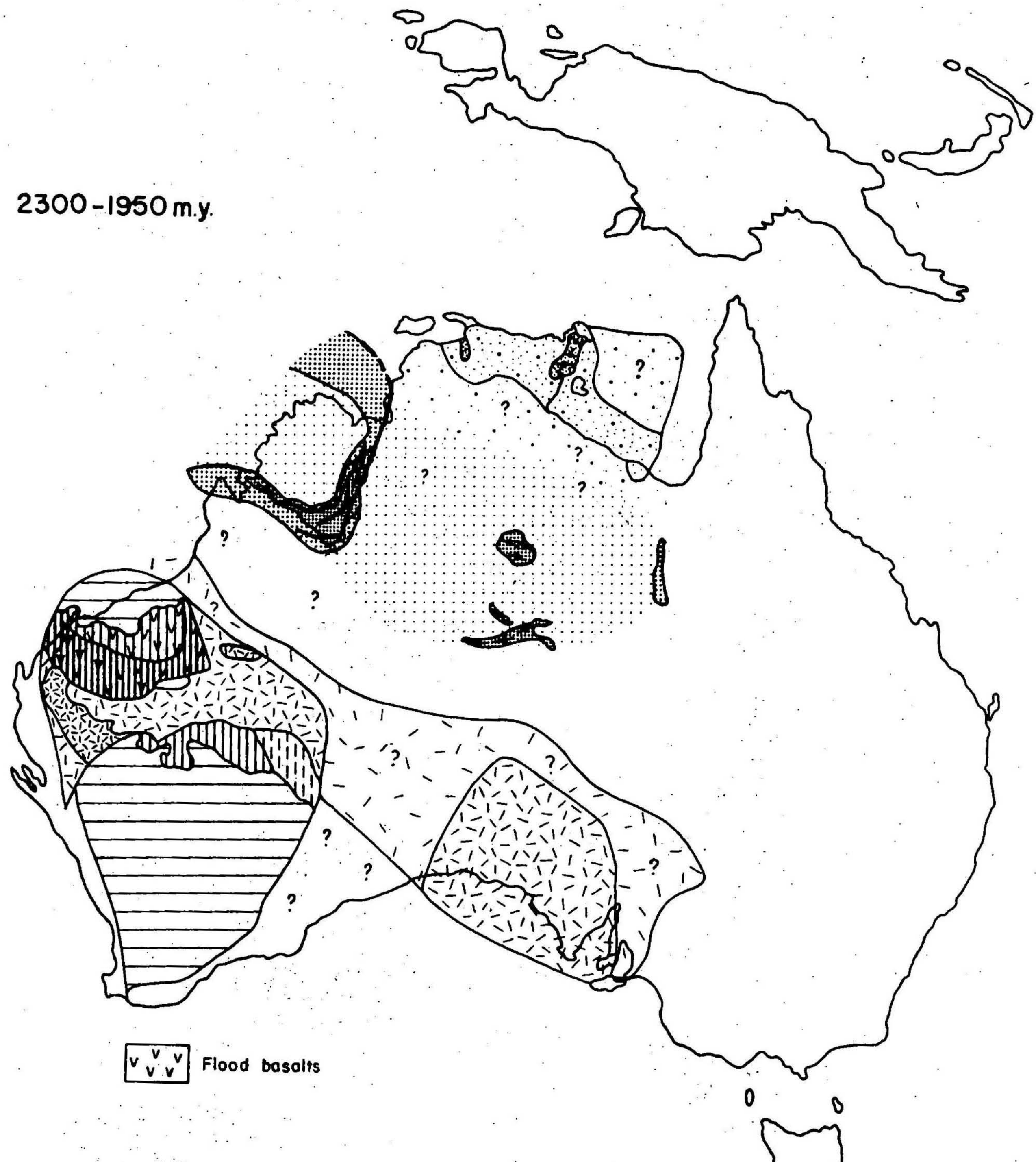


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Fig. 3

AUS 4/37

1950-1800 m.y.

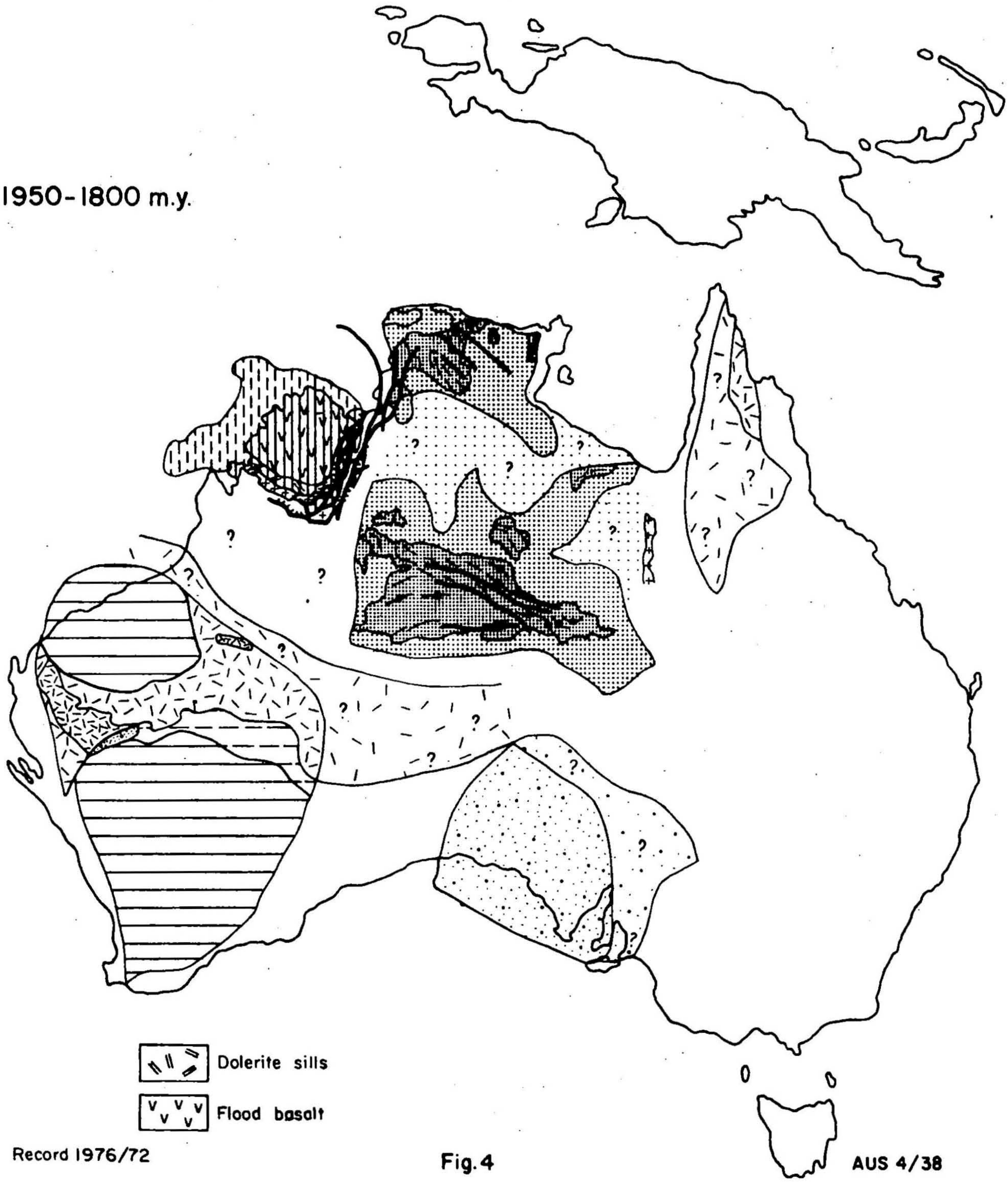

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Fig. 4

AUS 4/38

1800-1700 m.y.

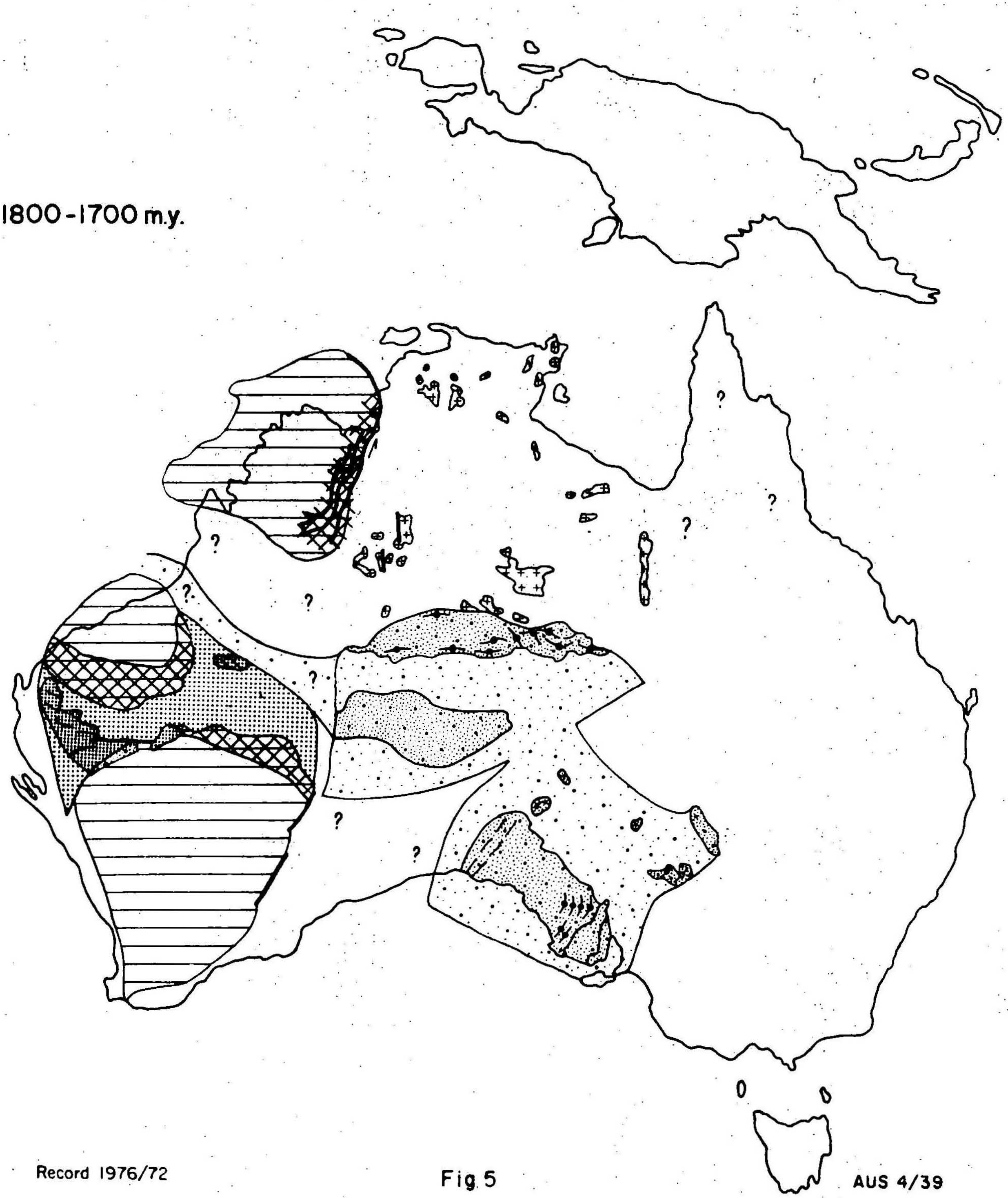

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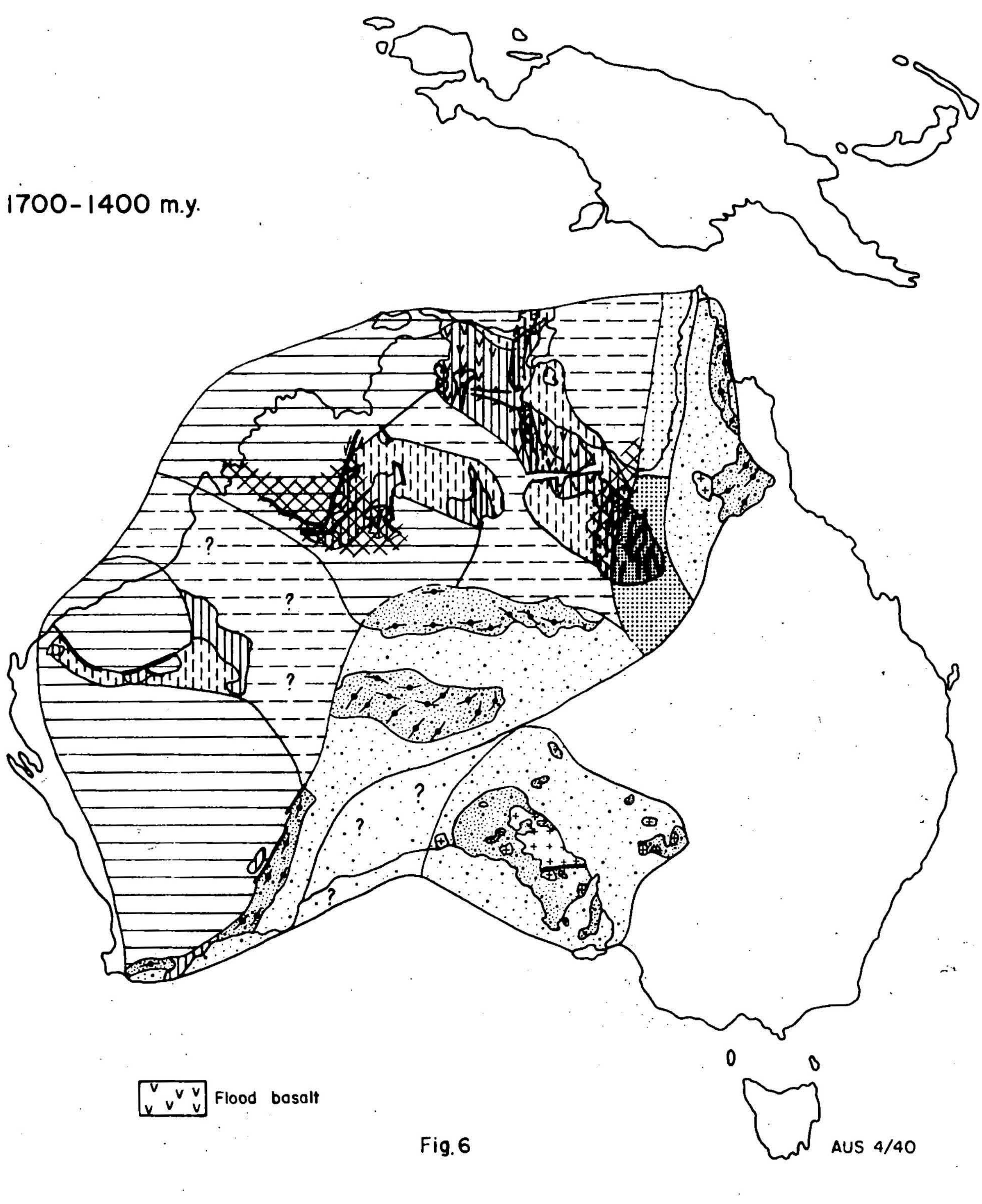
Fig. 5

AUS 4/39

1700-1400 m.y.



v v v v v v Flood basalt

Fig. 6

AUS 4/40

1400-1250 m.y.

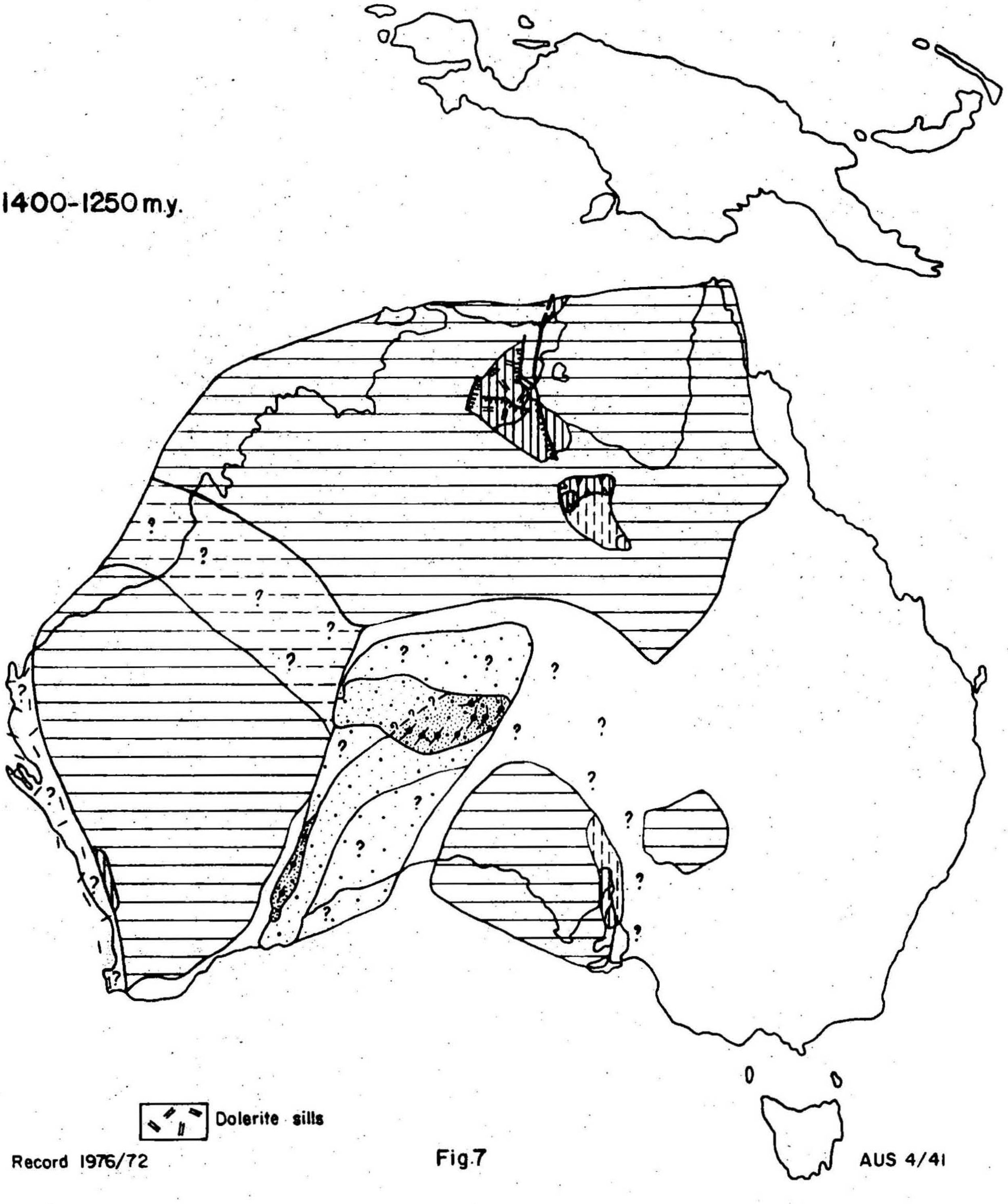


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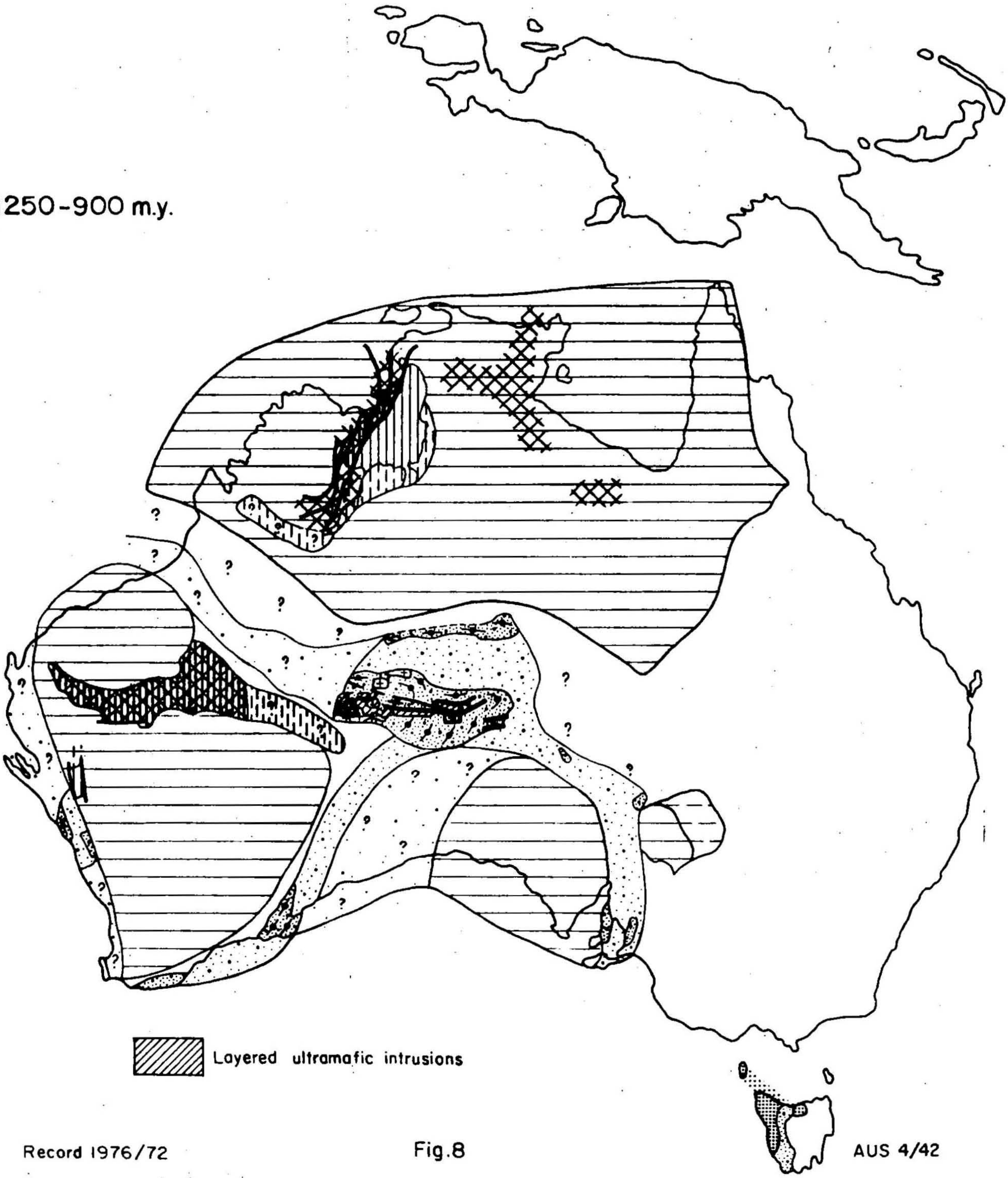
Fig.7

AUS 4/41

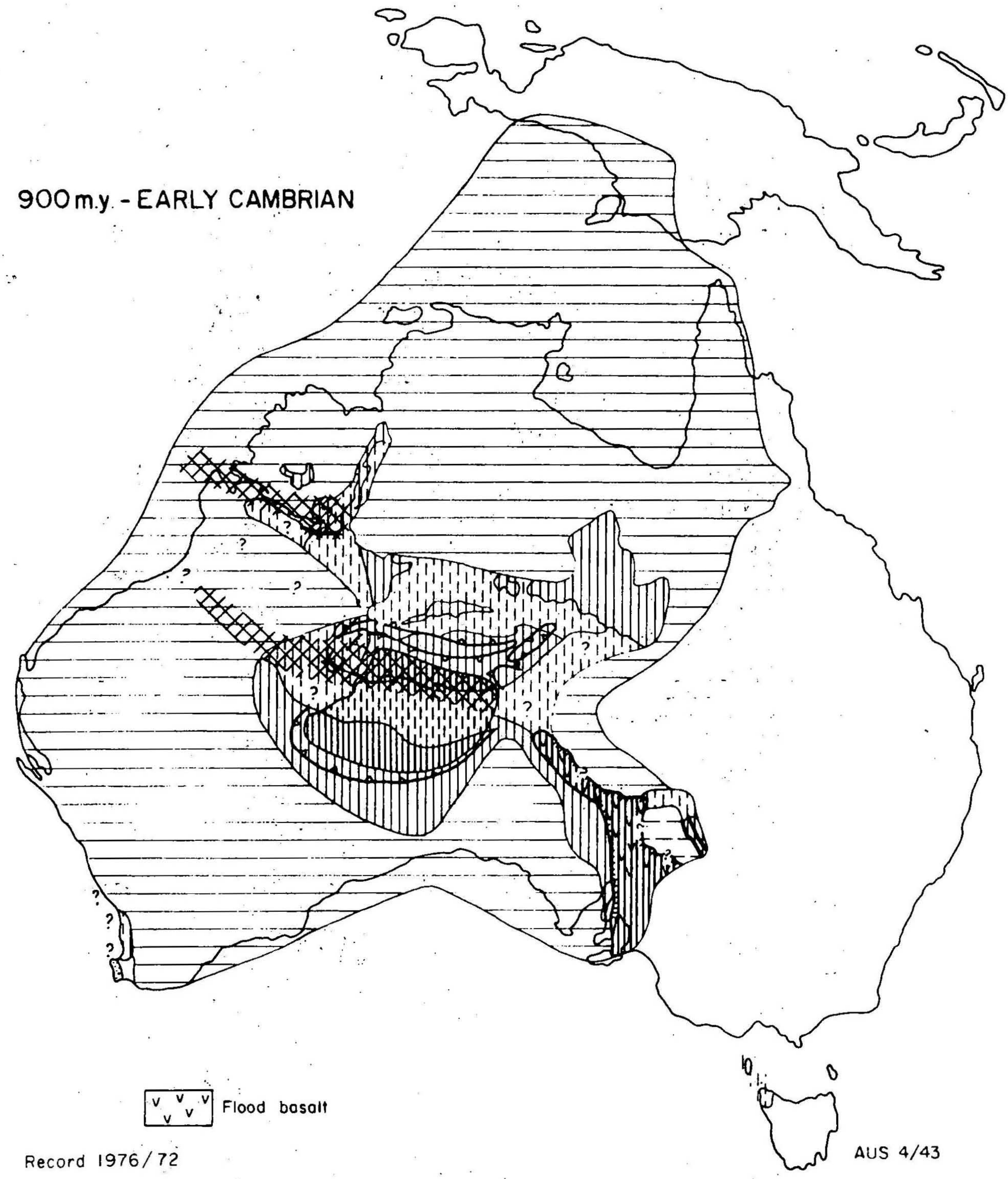
1250-900 m.y.



Record 1976/72

Fig.8

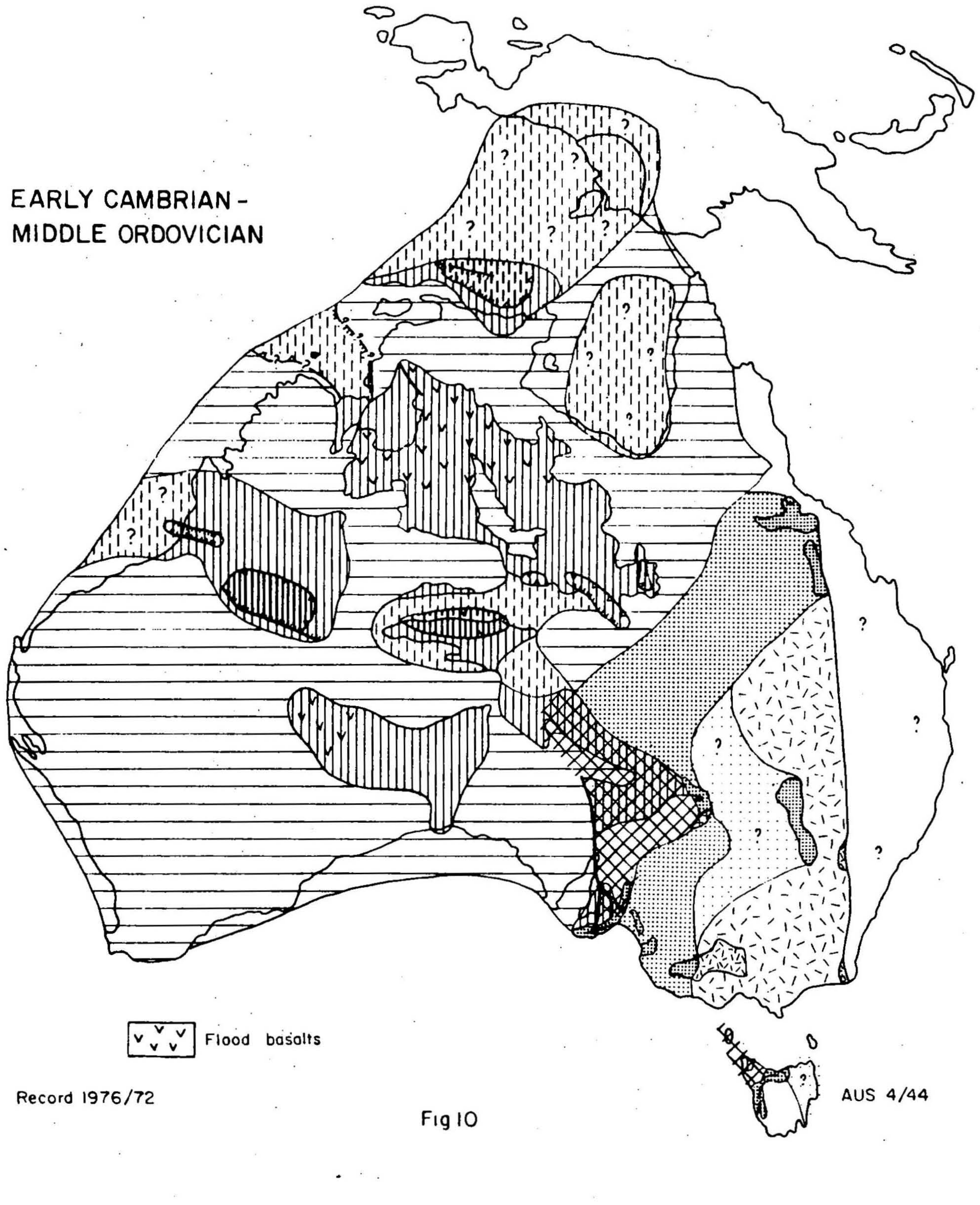
AUS 4/42



Record 1976/72

AUS 4/43

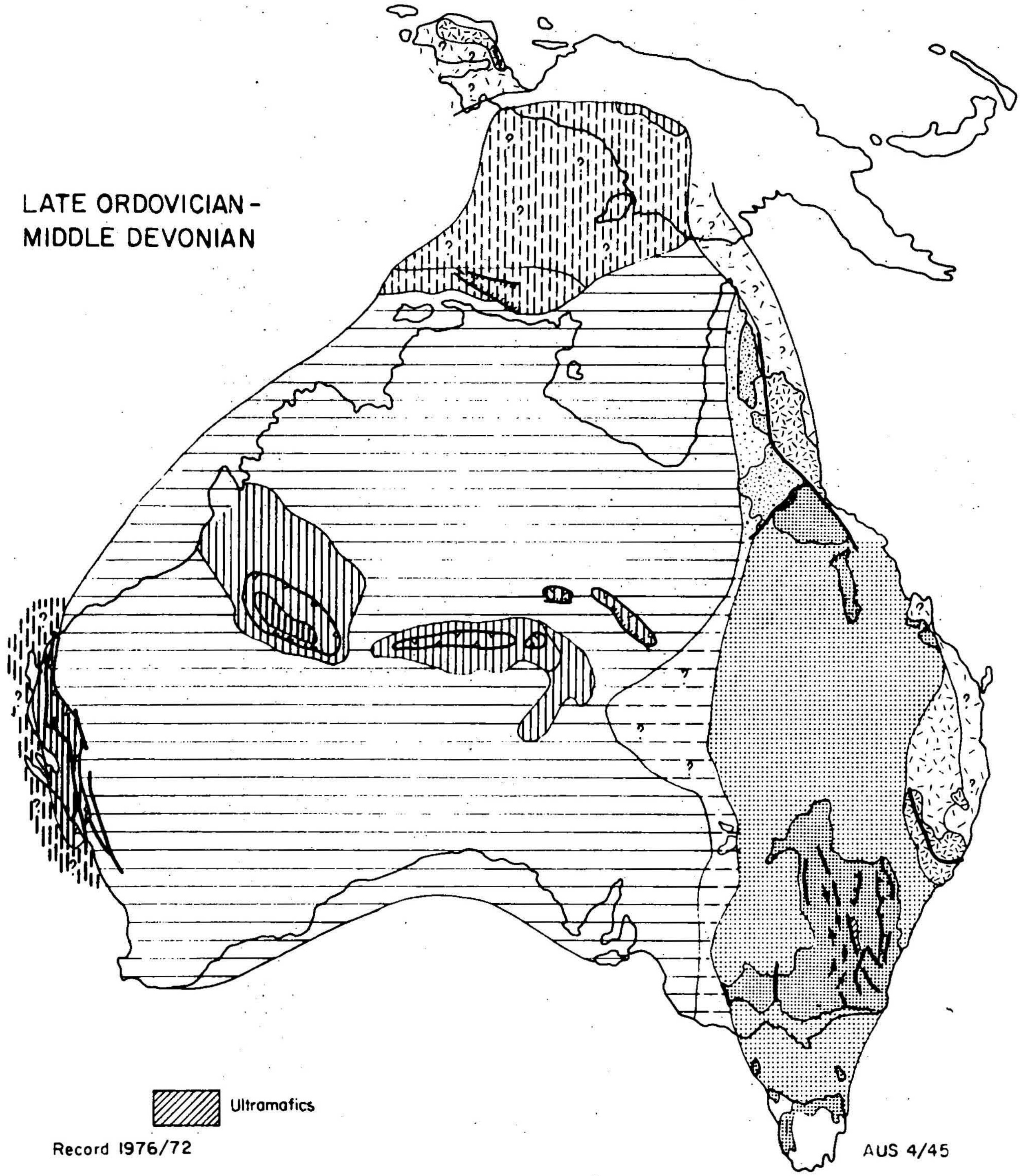
Fig. 9



Record 1976/72

AUS 4/44

Fig 10



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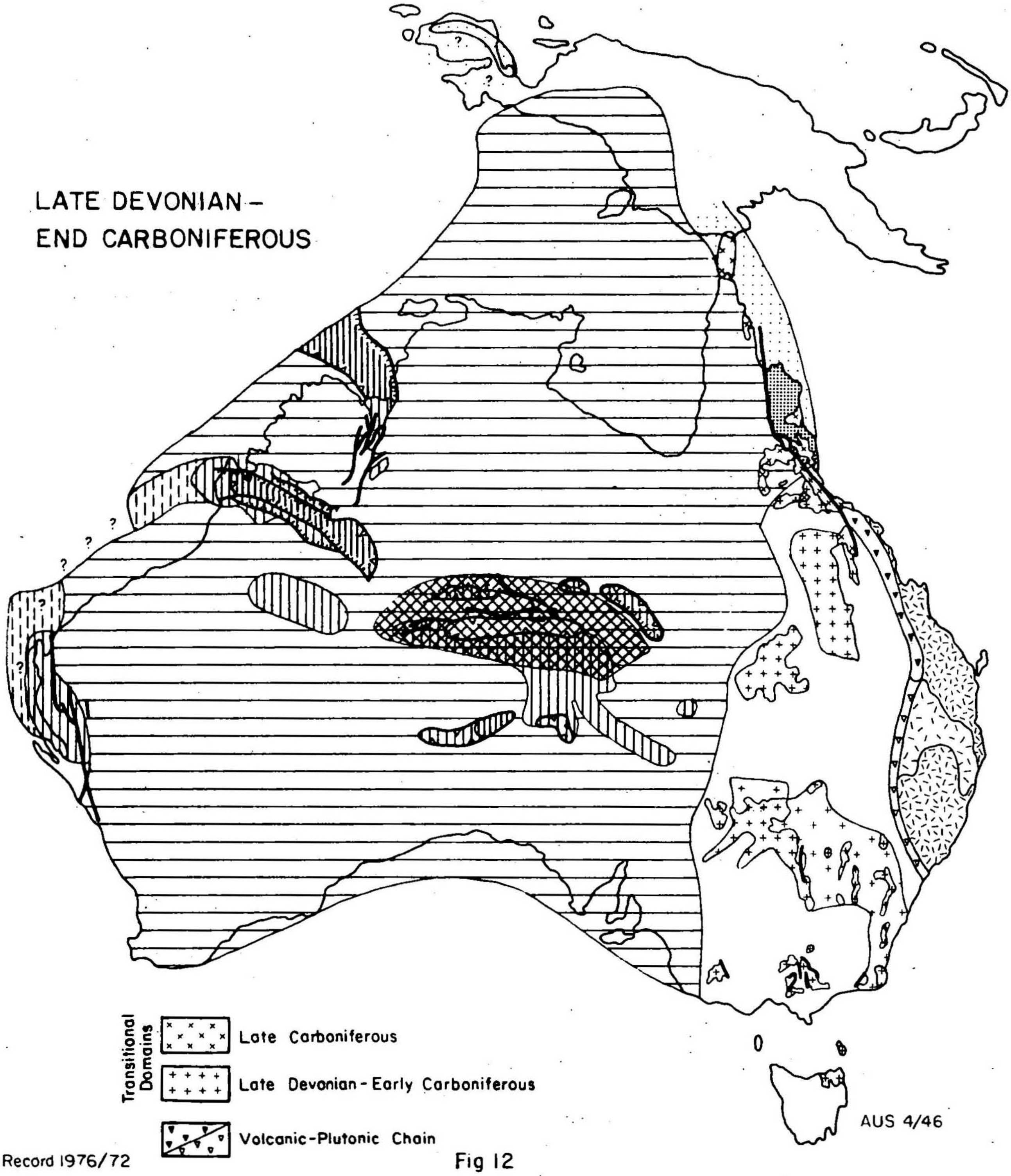
AUS 4/45

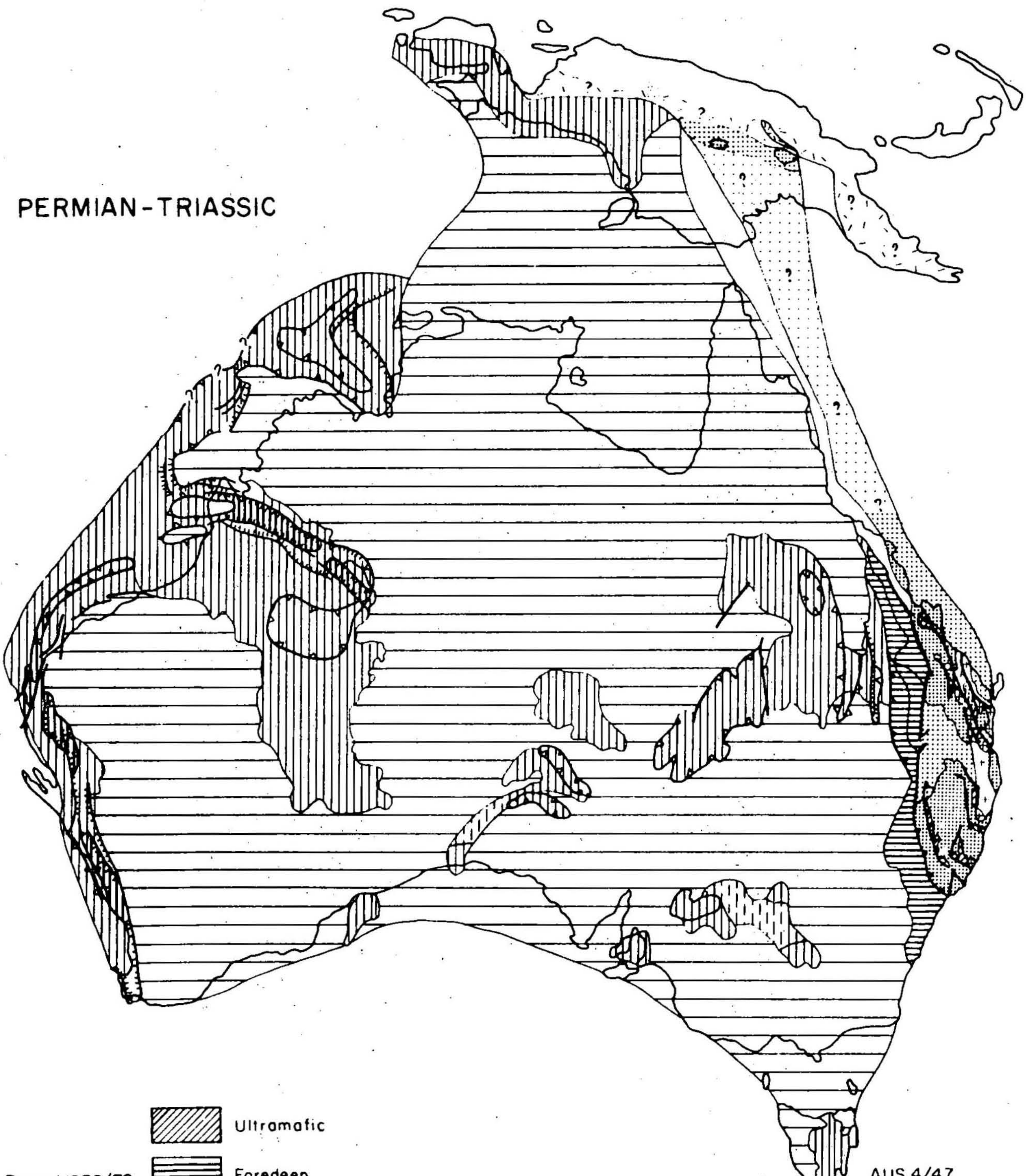
Fig. 11



Record 1976/72

Fig 12

PERMIAN-TRIASSIC



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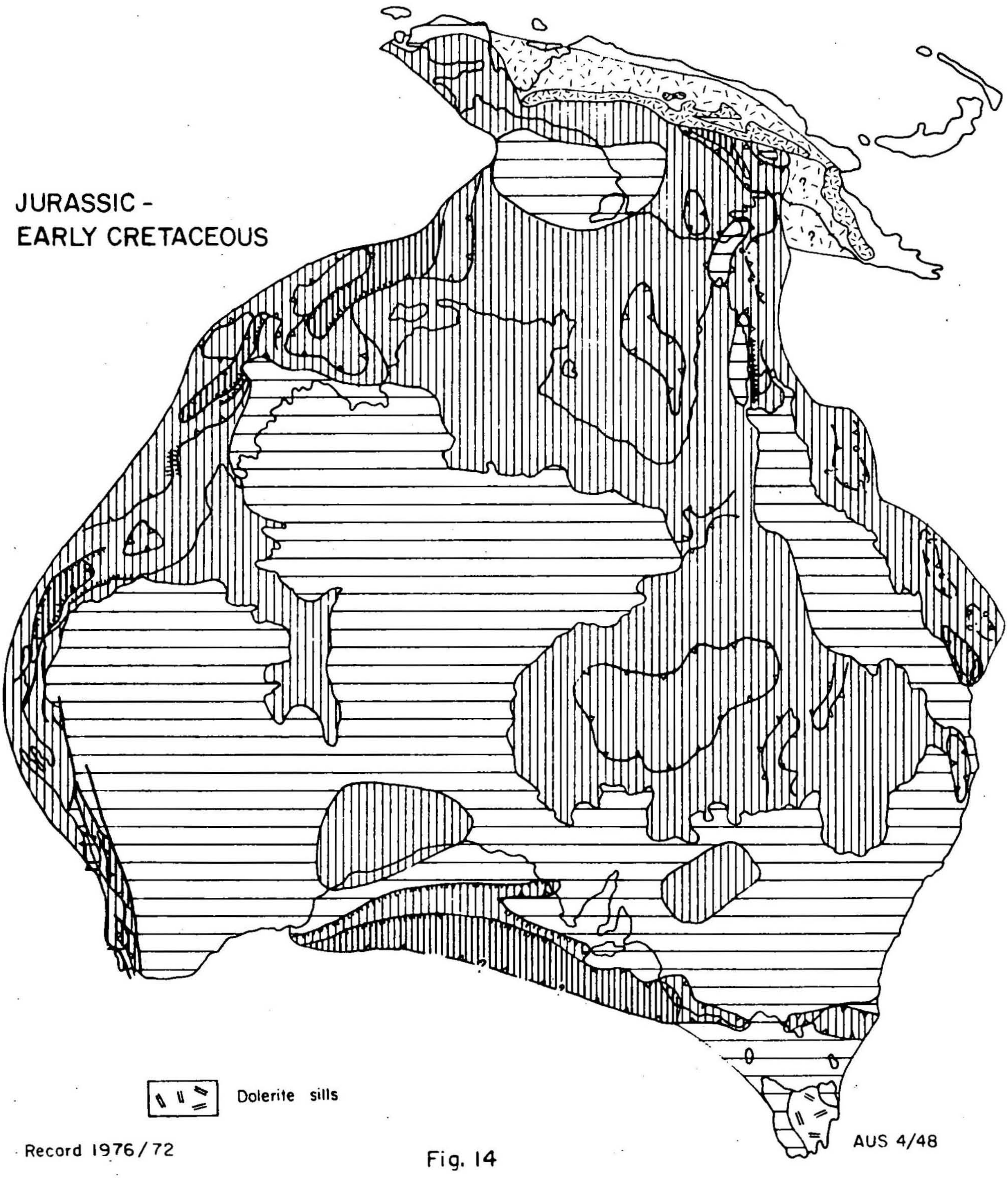
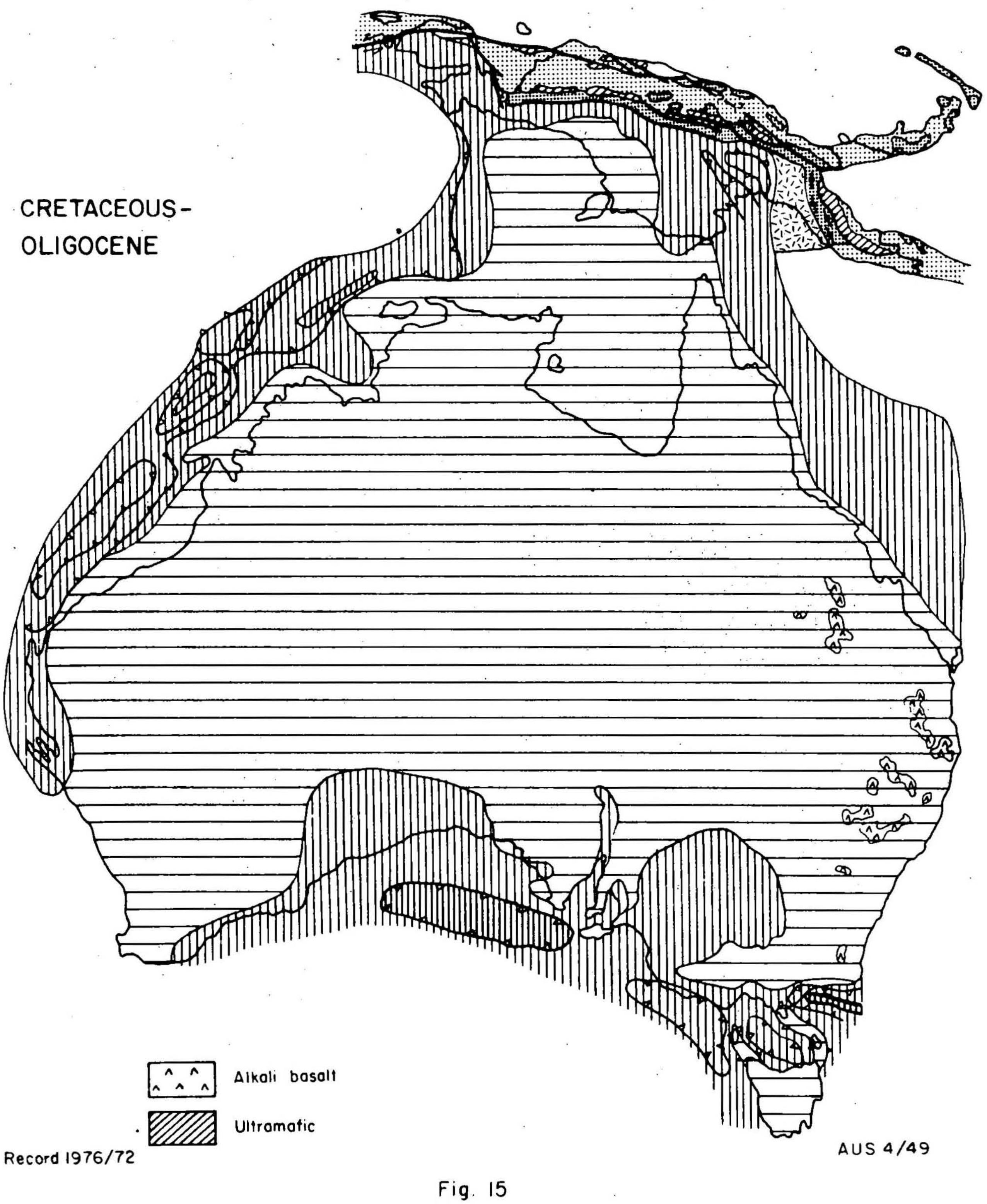
AUS 4/47

Fig. 13



Record 1976/72

Fig. 14



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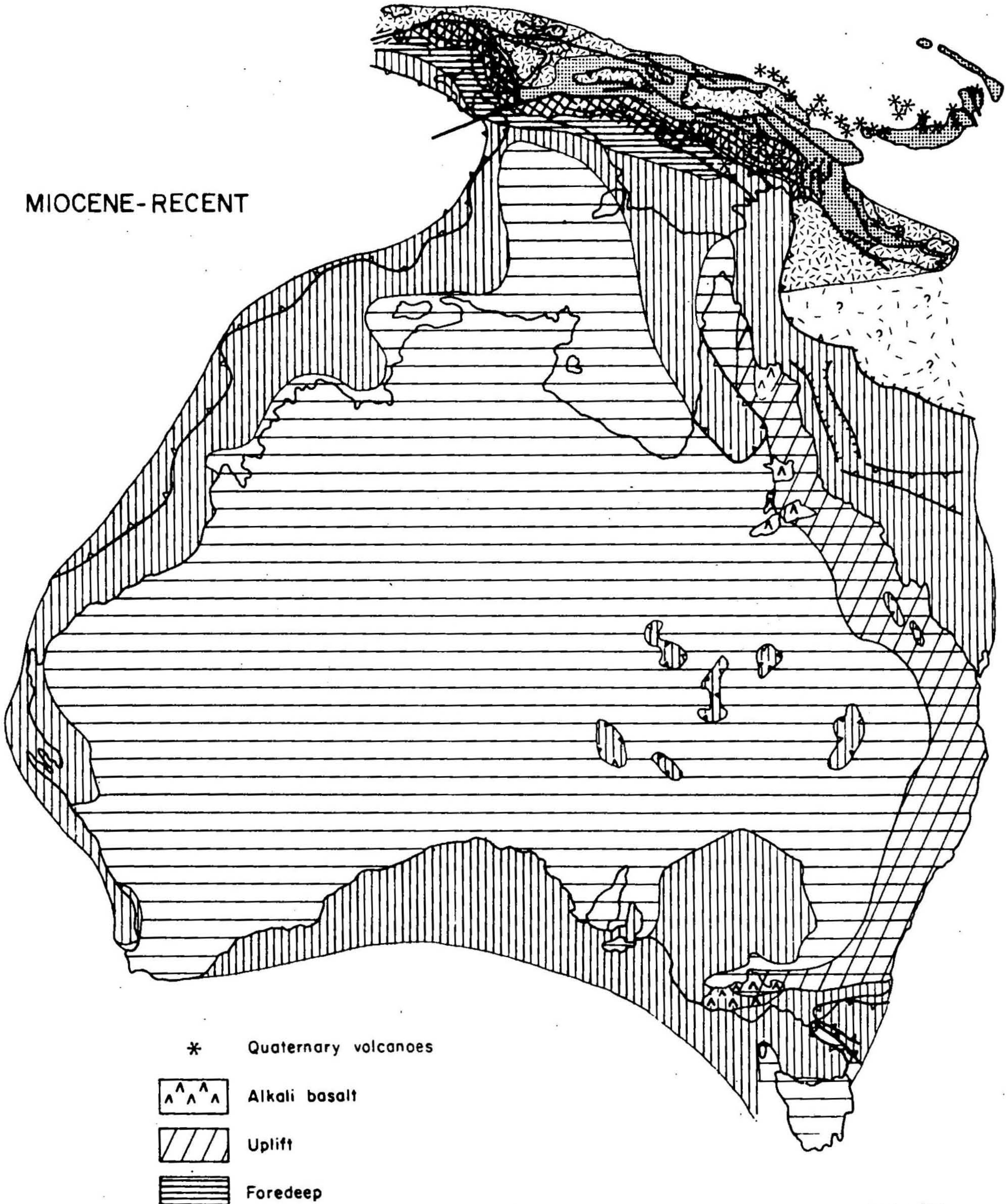
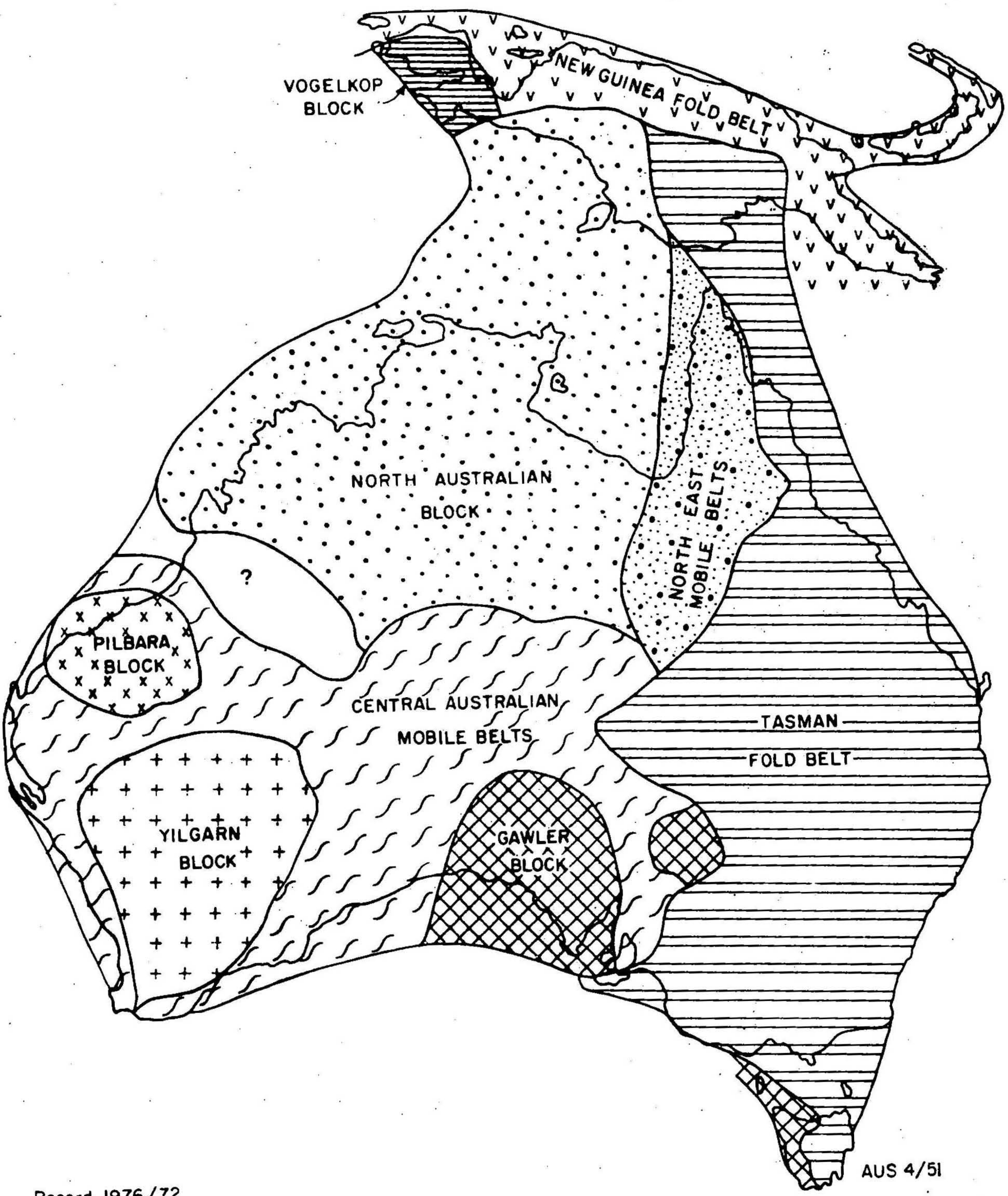
AUS 4/49

Fig. 15



Record 1976/72 Fig. 16 AUS 4/50



Record 1976/72

Fig. 17 Major crustal subdivisions