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Drainage evolution in the Moore-Monger System, Western Australia

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Abstract

The Moore-Monger Drainage System in the south-west of the Yilgarn Craton is examined in this study. It comprises the catchments of the Salt River rising near Mt Magnet and of the Monger River, both of which find their way into the Yarra Yarra Lakes. The Monger catchment includes both the extensive playas of Lake Monger and Lake Moore. All drainage lines are at low grade and extensively salinised with only intermittent flow. From the Yarra Yarra Lakes to the south there is an intermittent outlet along the line of the Darling Fault which unites with the north branch of the Moore River at Moora and further south with the east branch. These are short active rivers rising not far inland. The combined stream makes its way westwards to the coastal plain and the sea. Drainages located between the Moore-Monger System and the sea, such as the Hill, Arrowsmith, Irwin and Greenough Rivers, are also discussed. These rivers provide numerous examples of apparent disruption of drainage, diversion and reversal attributed to tectonic movements, in particular to upwarping of the cratonic margin in a belt some 70 km wide east of the Darling Fault and affecting the adjacent Perth Basin. This uplift appears gradually to die away towards the north and disappears at Morawa. An upward tilt to the north of the Western Shield has induced rivers to flow southward. This cannot be dated but the marginal uplift of the Yilgarn Craton is concluded to be late Eocene.

Keywords: watershed, drainage, river system, palaeodrainage

Introduction

This paper is a companion to a recent study of the South-West Drainage Division (Beard 1999). The Monger System was defined and included in that Division by Mulcahy & Bettenay (1972) but was omitted from Beard's recent paper on grounds of space. It was named from the large playa lake, Lake Monger, which is its central feature. As it includes the two branches of the Moore River which share the same drainage outlet, it is accordingly renamed the Moore-Monger System. It lies between the Avon System to the south and the Murchison System to the north, both of which include some active rivers, but the Moore-Monger System is less well-defined, consisting of flat country with drainage in the form of salt flats, indistinct channels and playas.

With the aid of recent geological and topographic maps the Moore-Monger System can be quite readily understood, but it contains some unusual and interesting features. The system (Fig 1) is roughly circular in plan with a diameter of about 300 km and an area of about 20 000 km^2. It is composite and contains several historically distinct elements, the unifying feature of which is that they converge into the Yarra Yarra Lakes in the west. The lakes have an outlet, now only intermittently active, leading southward through an incised valley to join the North Branch of the Moore River at Moora. To the south, beyond Gillingarra, the channel unites with the East Branch and the combined river turns to the west and reaches the sea across the coastal plain. Both branches of the Moore River are active during the winter and above Moora there is an active channel, the Coonderoo River, in the northern part of the valley from about 10 km south of Lake Pinjarrega.

The watersheds bounding the System and some internal ones are shown in Fig 1. Mulcahy & Bettenay (1972) united Lake Moore to the Avon System through a hypothetical Ninghan Palaeoriver rising in the Boodanoo Depression and running south along the line of Lake Moore, but it was later shown that Lake Moore in fact connects to Lake Monger (Beard 1973; Van de Graaf *et al.* 1977), A continuous watershed to the south of Lake Moore forms a ridge 100 m above the level of the lake and separates it from the Avon System.

The Moore-Monger System lies almost entirely on the Yilgarn Craton of the Western Shield, composed mainly of Archaean granite and gneiss with interdeveloped greenstone belts. The Darling Fault separates the craton from the Perth Basin to the west. The Fault is a major feature 1000 km long. It originated in the Palaeozoic to form the eastern side of a rift valley bordering the Yilgarn Craton. West of the fault a trough filled with sediments derived from adjacent continental landmasses. Movement along the fault ceased in the Neocomian (Playford *et al.* 1976), but sedimentation continued until the Late Cretaceous after which the Perth Basin and Yilgarn Craton were uplifted together. A narrow strip of the Perth Basin, part of the Dandaragan Plateau, is included in this drainage system.

The granite and gneiss terrain of the craton is generally of low relief sloping down gently from the central watershed at about 500 m to the Yarra Yarra Lakes at 240 m. Internal watersheds stand about 100 m above valley floors. The greenstone belts are generally hilly with the basalts forming large but isolated rounded hills as in the Gnow's Nest Range south-east of Yalgoo. Here they rise about 150 m above the surrounding country but are higher in the south as at Warriedar Hill (543 m) and Mt Singleton (678 m), a basaltic massif standing beside Lake

Moore. Except perhaps for Mt Singleton the greenstones do not appear to have influenced the general drainage pattern. The Salt River passes through the Gnow's Nest Range at Yalgoo as does Lake Monger at Warriedar, while the outlet from Lake Moore passes round the northern flank of Mt Singleton. Rocks exposed today in the Perth Basin consist mainly of Jurassic sandstones overlying Permian tillites. Some Cretaceous sandstones, greensand and chalk complete the sequence.

The general environmental features of this area including climate, geology and vegetation, have been described by Beard (1976, 1981). Rainfall averages 500 mm per annum in the south-west of the System, declining in the north-east to only 200 mm. Climate above the 300 mm isohyet has a winter rainfall maximum and is suitable for agriculture so that most original vegetation has been cleared. Further inland there is no assured growing season, the country is subject to pastoral use, and the vegetation has been modified to some extent but not cleared.

Methods

Methods followed were the same as for previous papers (Beard 1998, 1999). Fig 1 was produced by reduction from the latest maps in the National Topographic Map Series scale 1:250 000 (NATMAP, Canberra) and data from the previous papers were drawn upon, particularly for the definition of watersheds. Information on surface deposits was obtained from the local geological maps and memoirs published at 1:250 000 by the Geological Survey of Western Australia. For the interpretation of geological history, principal reliance was placed upon Playford *et al.* (1976) and Cockbain (1990). Relevant papers are referenced in the text and individuals consulted are listed in the Acknowledgments. The author has drawn upon his knowledge of the country acquired during field work for the Vegetation Survey of Western Australia.

Results

General description of the catchments

The Moore-Monger System consists of a number of discrete elements, several of which have been independent in the past. It is apparent that this has never been a single river catchment. It consists rather of separate catchments which have been amalgamated by tectonism into the single outlet of the Moore River (Fig 1). The northernmost component is the Salt River, rising near Mt Magnet, trending west to Yalgoo, then south to join the Monger River near Lake Nullewa. This was named the Yalgoo River by Mulcahy & Bettenay (1972) but appears as Salt River on official maps. The largest catchment is that of the Monger River, named by Mulcahy & Bettenay (1972.) from Lake Monger at its centre. Most of the catchment is very flat and drainage is marked by extensive playas. It comprises three main branches, a northen one of intermittent creeks coming down from Kirkalocka to Warriedar, a central one containing the extensive playa of Lake Moore, and a southern member consisting of the chain of salt lakes from Lake Hillman to Lake Goorly. The playas are surrounded by extensive salt flats with saltbush and samphire vegetation. These branches unite into the two-pronged lake system, called Lake Monger, consisting of long narrow playas over a distance of 60 km along each arm with little or no fall from one end to the other. The playas are continuous though often too narrow to be shown in width on the scale of Fig 1. Country along the chain of lakes from Lake Hillman to Lake Monger is even flatter and it would seem that little or no drainage ever passes today along this line. Drainage from Lake Monger to the west is blocked by a continuous north-south ridge averaging about 75 m in height above the lake bed, and an escape route exists round the north of this ridge in the vicinity of Perenjori, then north to Weelhamby Lake, west through Lake Nullewa connecting with the Salt River on the way, and thence south-west to the Yarra Yarra Lakes. As far as Lake Nullewa the alignment appears to be completely flat so that little drainage is likely to pass except in times of flood. From Lake Nullewa to the Yarra Yarra Lakes there is a drop of 35 m in 60 km, and there is a distinct channel winding between salt flats and pans. Exit to the west from the Yarra Yarra Lakes is again barred by a north-south ridge 75 m above the lake bed so that these lakes act largely as a sump. Two small creeks enter them from the east between Three Springs and Coorow. South of Coorow there is a more extensive system larger than the Moore River but mostly inactive. From its lower channel which normally feeds north into the Yarra Yarra Lakes, an overflow channel takes off for the south. It is probable that this takes some overflow in exceptionally wet years, but it is normally dry. There is no coherent channel, only a chain of salt lakes and salt flats such as Lake Pinjarrega. About 10 km south of the latter a channel takes shape, known as the Coonderoo River, fed by small streams rising in the Watheroo area. Still further south at the town of Moora this is joined by the Moore River from the east, an active stream, and the combined watercourse flows on due south for another 40 km until it joins the stream known as the Moore River East Branch, where it turns sharply to the west into a narrow valley issuing some 30 km further down onto the coastal plain. Across this it meanders to reach the sea at Guilderton. From the Yarra Yarra Lakes to the East Branch the drainage has taken a linear course heading slightly east of south, and it must be significant that this follows the line of the Darling Fault, mainly on its east side.

Salt River Catchment

The Salt River originates in salt flats south of the mining town of Mt Magnet. A coherent channel appears 50 km to the west and there are some small playas, but the channel is lost again approaching Yalgoo to the west. Past Yalgoo the Pindathuna Creek comes in from the north. It has a well-marked channel and is not salinised. West of the confluence the channel almost disappears for 10 km but is resumed again now flowing southwards past Mellenbye Station. This is shown in Fig 1 as a continuous river but is only a channel winding through salt flats and small playas. It meets the Monger drainage between Lakes Nullewa and Weelhamby.

The Salt River is cut off from the Greenough and Irwin Rivers to the west by a watershed branching off from the main east-west watershed and trending south-west and then south parallel with the Salt River. A similar continuous watershed can be traced dividing the Salt and Monger Rivers (Fig 1). Neither of these watersheds is topographically eminent, and map contours are needed to locate them. Headwater streams in the catchment are generally steep enough to be active *e.g.* the Pindathuna Creek above Yalgoo falls at 1.0 m km^{-1} but the main channel of the Salt River from a spot height of 369 m south of Mt Magnet down to Yalgoo at 312 m grades at 0.63 m km^{-1}, which is reduced to 0.25 m km^{-1} from Yalgoo to Lake Nullewa, steepening to 0.50 m km^{-1} from there to the Yarra Yarra Lakes. Grades on the main outlet of the system are: Yarra Yarra Lakes to Lake Pinjarra 0.16 m km^{-1}; Coonderoo River to Moora 0.47 m km^{-1}; Moora to confluence with East Branch 1.l m km^{-1}.

Monger Catchment

The northern branch consists of intermittent small creeks between Kirkalocka and Warriedar, which are not salinised. The main channel drops at about 1.0 m km^{-1} over this distance. Downstream of Warriedar, the valley is occupied by the 60 km long north branch of Lake Monger which is almost flat, dropping at only 0.20 m km^{-1}. The middle branch of the catchment features Lake Moore, one of the largest playas in Western Australia, 120 km long and 10-20 km wide. A tributary, the Warne River, comes down from the north-east from the direction of Lake Boodanoo which is situated in a depression with no outlet. This is discussed below.

Spot heights on the bed of Lake Moore are between 301 and 304 m. There is an intermittently active outflow channel to Lake Monger which is about 20 m lower, passing round the north flank of Mt Singleton. It is possible that in the past the lake emptied through a parallel channel further south in addition. The third and southernmost branch of the catchment consists of a chain of playas and salt flats in very flat country leading NNE from Lake Hillman to the south branch of Lake Monger. A spot height of 297 m south-east of Lake Hillman gives a grade of 0.35 m km^{-1} along this stretch. From the south branch of Lake Monger, channels wind to the north-west past Perenjori and through Lake Weelhamby to Lake Nullewa. As Lake Nullewa is at the same elevation as Lake Monger it is evident that drainage can only pass along this stretch of 150 km in the event of exceptionally heavy rainfall.

Yarra Yarra Catchment

This term may be used to include drainages leading into the Yarra Yarra Lakes from the north-south ridge which obstructs flow from Lake Monger. They consist of shallow valleys floored with lacustrine deposits. The southernmost branch has become choked by an aeolian sandsheet that has been mapped and described by Beard (1979, 1984) and is shown in Fig 1. This was also mapped in the local geological survey (Carter & Lipple 1982) as "Qs, sand, mainly aeolian, quartz sand" without special comment. It is distinguished by its markedly yellow colour and a type of kwongan vegetation named the *Banksia-Xylomelum* alliance (Beard 1979). It was suggested by Beard (1984) that this sandsheet is a Quaternary deposit transported to the south-east from the Yarra Yarra Lakes area during an arid climatic phase with strong north-west winds. Several similar deposits elsewhere were attributed to this phase as well as the lunettes which typically border the south-east side of lakes in the southern part of the State.

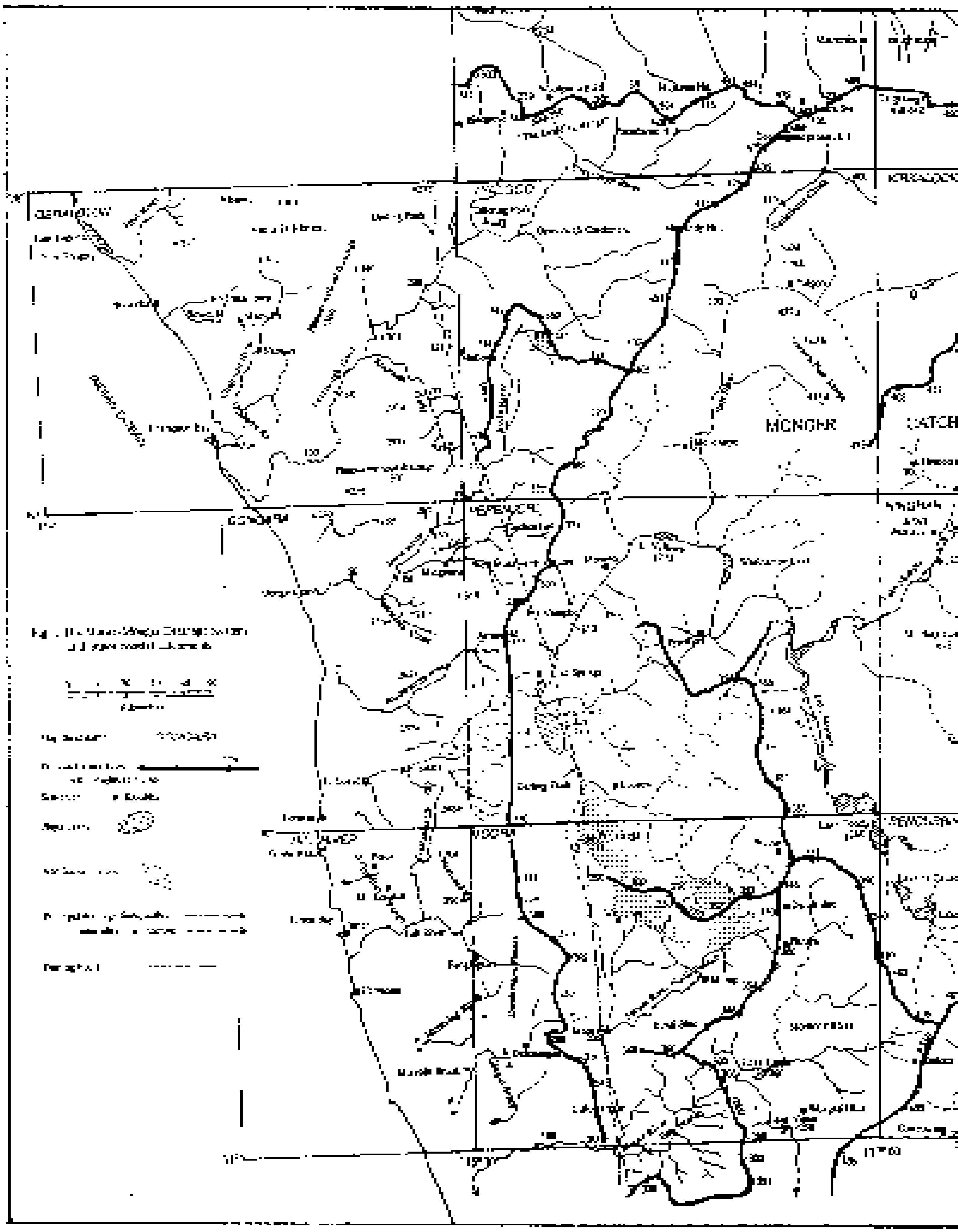
Moore Catchment

The Moore River on the Yilgarn Craton consists of two quite distinct streams, the so-called North Branch which flows down from the vicinity of Dalwallinu and Pithara to Moora, and the East Branch further south. Both of these rise in a continuation of the north-south ridge which obstructs the outflow of Lake Monger, and the same effect is visible. On the east side of the ridge there are west-flowing drainages aligned with those in both branches of the Moore River, but they have been ponded in Lake Hinds and Lake Ninan and deflected south to join the Mortlock River, part of the Swan-Avon System (Beard 1999). The two branches of the Moore River have been obstructed in turn beyond the Darling Fault by the higher ground of the Dandaragan Plateau. The East Branch has cut through to the coastal plain on the west, while the North Branch has developed a channel to join it following the Darling Fault southward and continuing the drainage line from the Yarra Yarra Lakes. The latter are at 240 m and Moora is at 205 m, a fall of 35 m in 100 km.

Coastal Catchments

Numerous catchments, some small and some large, have developed in the Perth Basin between the Darling Fault and the coast. North of the lower course of the Moore River there are several minor streams such as the Minyolo Brook and the Mullering Brook which rise on the Dandaragan Plateau, descend the escarpmemt and terminate in swamps on the coastal plain. The Quaternary Tamala Limestone, lithified from former dunes, mostly forms a barrier along the coast itself. The Hill River carries more water (or has done in the past) and has cut an outlet to the sea. A tributary, the Coomallo Brook, drains the country between the Gairdner and Herschel Ranges. This pattern is continued further north where some minor streams near Eneabba terminate in Lake Logue. The Arrowsmith River, which rises not far from the Yarra Yarra Lakes, turns north on the coastal plain and mostly evaporates in pans before entering a tunnel under the limestone. The Irwin River has cut an outlet to the sea through a substantial valley which broadens upstream in the Mingenew area into a belt of rolling country developed on erodible Permian sediments extending to the Darling Fault. The main Irwin River (not its tributaries) penetrates the Victoria Plateau further inland by a canyon-like feature, to rise near Pindar.

North of the Irwin River the Victoria Plateau forms a gently undulating plain with a general height of about 300 m. As the coastline trends away to the west, the plateau broadens until it is over 100 km wide. The coastal belt is dissected by the short Hutt and Bowes Rivers and the longer Chapman River. The Moresby Range which dominates Geraldton is a mesaform remnant of the plateau. The Greenough River winds across the whole plateau from north-east to south-west in incised meanders. Unlike the Irwin, the Greenough has had to dissect hard Jurassic sandstones and has not developed a broad valley nor significant tributaries. The sandy soil absorbs most of the precipitation so that extensive stretches of the plateau are without drainage. West of the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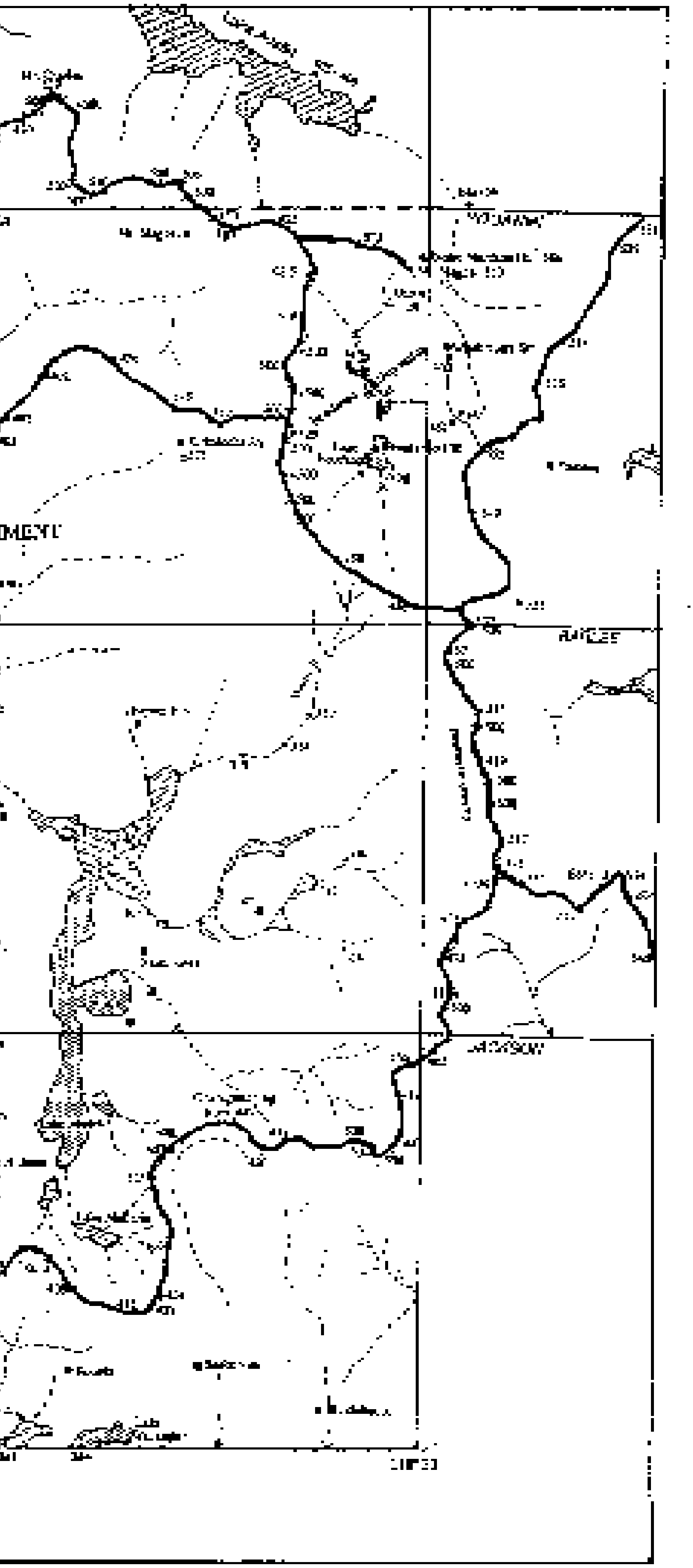

Figure 1. The Moore-Monger Drainage System and minor coastal catchments. Principal watersheds from Beard (1998).

Darling Fault there is a slight depression drained by the Kockatea Gully and small tributaries leading into the Greenough River, but there is otherwise no topographic break at the Fault. East of it the Greenough River drains a considerable catchment 120 km long and 100 km wide with numerous branches.

Boodanoo Depression

At the north-west corner of the Monger System is a feature which will be termed here the Boodanoo Depression. It is a valley trending north-south, 100 km long and 50 km wide which has no present outlet nor any obvious previous outlet, so that it is unclear whether it formerly drained south to Lake Moore or north to Lake Austin. The valley contains a 40 km long chain of playas. The largest at the southern end was named Lake Boodanoo in the geological survey (Baxter *et al.* 1983) after Boodanoo Hill, an outcrop of gabbro bordering the lake. There is also a Boodanoo Station a few kilometres further south. The lake has a spot height of 420 m. The topographic map shows minor watercourses leading into it from all sides. The depression is bounded on the east by the Central Watershed (Fig 1) at a height of about 550 m and a spur running north to Windimurra Station at 450 m. On the north the main ridge forming the watershed between the Monger and Murchison Systems, passing to the north of Mt Magnet town, continues to the east as far as Mt Magnet Hill (563 m), but its continuation south-east to join the Windimurra ridge descends to a col at 429 m. The western side of the Boodanoo Depression is bounded by a well-marked ridge at about 500 m which is in many places wide and capped by sandplains. However it does not extend round to the south of the depression to join the Central Watershed. Between Boodanoo and the tributaries of the Warne River there is no distinct ridge but a flat plain with spot heights of 450 and 446 m. It is therefore unclear whether the depression originally drained south or north. Beard (1973) favoured the south, Van de Graaf *et al.* (1977) the north. Current opinion seems in favour of the latter *e.g.* Commander (1989). If this is correct it is probable that the southward tilt of the Western Shield has been mainly instrumental in disrupting the drainage. Fig 1 excludes the depression from the Monger System.

Discussion

The drainage in the Moore-Monger System exhibits a number of peculiar features which need to be explained. Why is the westerly drainage of the Monger catchment obstructed by a north-south ridge which has apparently caused ponding and deposition of valley fill along the corresponding arm of Lake Monger? Why does this ridge continue southward separating the Mortlock and Moore Rivers? Why is the Salt River deflected southward at Yalgoo? At the edge of the Yilgarn Craton, why do these rivers not continue westward across the Dandaragan Plateau, developing instead a lengthy southward channel along the line of the Darling Fault? These anomalies resemble features of the other west coast rivers further south, *e.g.* the Avon, Murray and Collie systems, for which solutions were presented in a previous paper (Beard 1999) and can be applied here. A diagrammatic illustration (Fig 2, adapted to this area from Fig 5 of Beard 1999) shows successive stages of development in sections drawn across the System in an east-west direction from the Yarra Yarra Lakes to the Central Watershed at Youanmi. At the epoch of Stage 1, the formation of the Mesozoic surface of the Yilgarn Plateau is held to have been completed (Beard 1998), sloping gently down to the coast from the Central Watershed and drained by sluggish rivers in shallow valleys. The grades and levels were in accord with the high sea level of that time, with the shore line initially along the Darling Fault but gradually moved a few kilometres to the east of it by marine erosion. At this stage a height of 300 m for the Central Watershed has been assumed as it is in accord with later evidence.

At Stage 2, recession of sea level at the end of the Cretaceous has had the effect of raising the river mouths along the Darling Fault, discharging onto a plain below floored with the latest Upper Cretaceous deposits. This plain has become the Dandaragan and Victoria Plateaus. At the time, the surface was evidently not far above sea level. The Dandaragan Plateau area appears to have been exposed, but the Victoria was still receiving thin deposits into the Eocene. The assumption is made that the sea withdrew by an amount equal to the depth when the uppermost Cretaceous deposits were laid down, accepted as 200 m by Beard (1999) on advice from A E Cockbain (personal communication). The recession of sea level at this time, inferred from local geological evidence, is not necessarily in accord with global sea level changes (Haq *et al.* 1988) since local epeirogeny must also be considered. There is evidence for high sea level on the west coast of Western Australia during the Cretaceous, but none on the south coast, where transgression took place during the Eocene instead, leaving the west coast unaffected (summarised by Beard 1999).

Late Cretaceous regression having raised the river mouths above sea level, and rainfall being high at that epoch, it is likely that the rivers lowered their beds to the new base level, adjusting the valleys accordingly throughout the catchments. A period of 30 million years from the Maastrichtian to the Upper Eocene is available for this process. At Stage 3, post-Eocene, an uplift occurred in a belt 70 km wide east of the Darling Fault and for a certain distance west of it. The Dandaragan Plateau stands today at about 300 m above present sea level. Little erosion has taken place since uplift as the post-Neocomian deposits are relatively thin, the full sequence is present locally and there is no evidence for later deposits which have disappeared. However in uplift the surface was tilted up to the west so that the underlying Yarragadee Formation has become exposed along the crest of the Gingin scarp, continuing north into the Herschel Range. The Gingin scarp represents today the western edge of the uplift, the Perth Basin having subsided west of it into the Swan Syncline (Davidson 1995). This tilt of the plateau reversed drainage, causing ponding along the previous shore line which marine erosion had advanced for 2-4 km east of the actual line of the Darling Fault. A new outlet developed first south then west. In the same way the Victoria Plateau exhibits a drainage depression along the Darling Fault. The difficult and inefficient outlet from the Yarra Yarra Lakes has been to a large degree responsible for the lack of rejuvenation of the Salt and Monger Rivers, compared with the Avon and other rivers further south. At the present day the

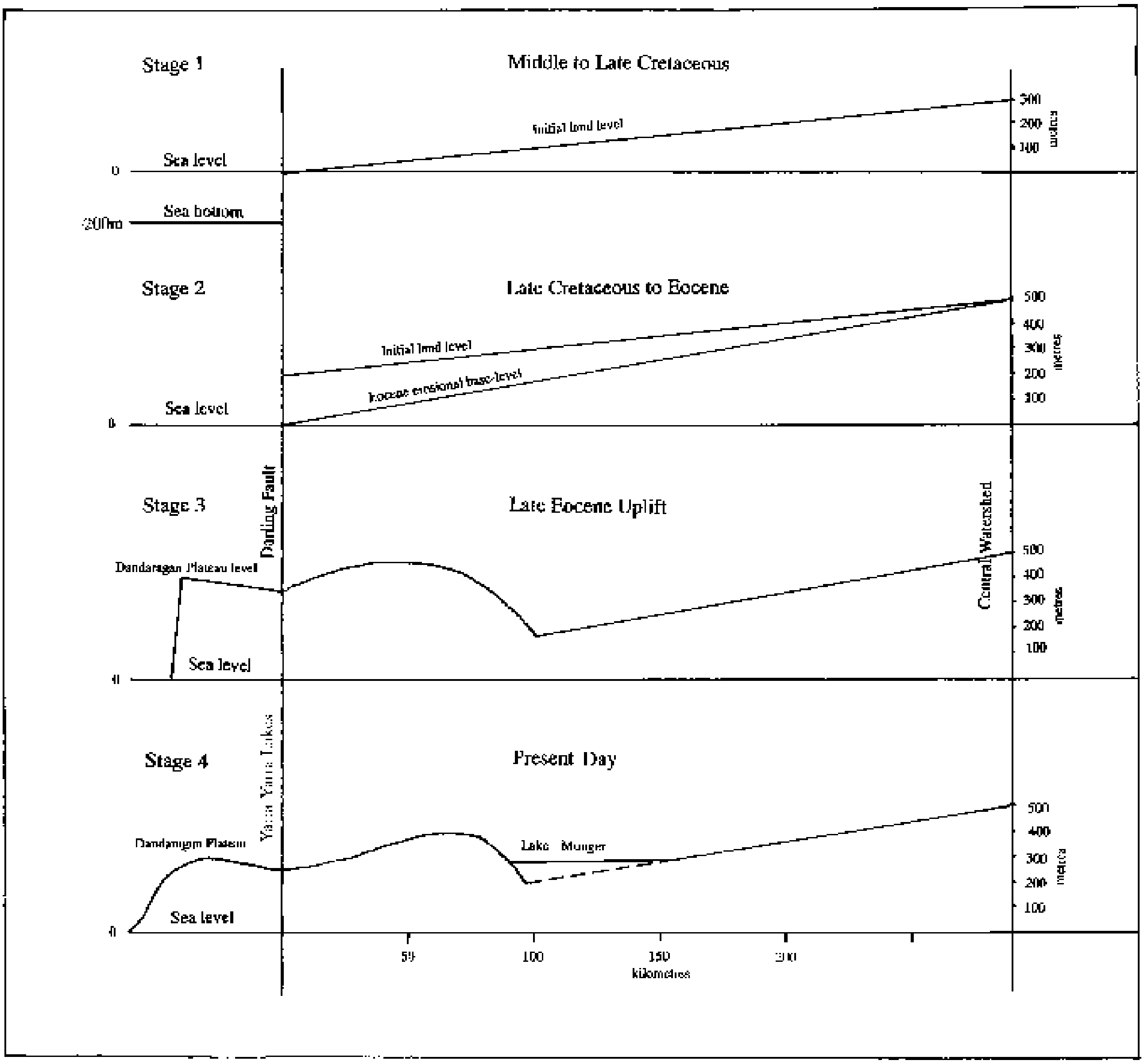

Figure 2. Cross-section of the Moore-Monger System drawn ENE from the Yarra Yarra Lakes to the Central Watershed at Youanmi, at successive geological stages.

Dandaragan Plateau narrows towards the south and gradually pinches out against the Yilgarn Plateau just north of the emergence of the Swan River from the Range. It is missing from the southern part of the Perth Basin until the corresponding feature of the Blackwood Plateau is reached. Its disappearance was formerly attributed to marine erosion (Playford *et al.* 1976) but is now seen as due to synclinal subsidence (Davidson 1995) which has carried down the Jurassic and Cretaceous sediments in the Perth Basin south and west of the present Gingin scarp, leaving the Dandaragan Plateau intact further north. No movement along the Darling Fault is implied, the syncline being treated as slumped against the edge of the Craton. It is this subsidence which has caused the rivers crossing the Darling Scarp to steepen their grades sharply in making a descent to the coastal plain (Beard 1999). This scope for rejuvenation was not available to the Salt and Monger Rivers terminating in the Yarra Yarra Lakes which today are at 240 m asl. The lakes must obviously contain some thickness (unknown) of sediments, but the basement must be at 150-200 m, allowing little fall from upstream.

It was concluded by Salama (1997) that uplift of the Darling Range obstructed flow of the Avon and Yilgarn Rivers which found a new outlet along the present course of the Avon through Northam. It can be seen (Fig 1) that this situation is repeated in the Monger System. A north-south ridge blocks the continued south-westerly flow of the Monger River, forming a lake 50 km long parallel to it, and backing the river up for 50 km upstream. Unlike the Avon the Monger River has been unable effectively to find a new outlet. Channels join it to the Salt River at Lake Nullewa but there is no fall from one end to the other. The System has remained at a much earlier stage of development. On the western slope of the uplift the decapitated rivers have established new catchments. It was shown in the previous paper (Beard 1999) that the two branches of the Moore River continue alignments that have been diverted to the south. North of them an unnamed river system between Coorow and Wubin probably preserves in its north branch the location of the original outlet of the Monger River.

At Stage 4 in Fig 2, *i.e.* the present day, there has been stability and erosion since uplift. The Dandaragan Plateau has developed a rounded contour, and the uplift east of the Darling Fault has been dissected and eroded down. The drainage channel through the Yarra Yarra Lakes was first excavated, then filled with sediment. Lake Monger formed at the back of the uplift. This model predicts that it should contain up to 75 m of sediment.

The marginal uplift in the Moore-Monger area seems to represent a declining northerly extension of a feature more strongly developed in the Darling Range further south. The country is hilly in the Moore River catchments, flattening towards the north. The uplift seems to die away before reaching Lake Nullewa. North of this there is still a slight rise traceable as the watershed between the Salt River and the Irwin and Greenough. This takes a north-easterly trend and in the form of a linear axis similar to the Jarrahwood Axis of Cope (1975). It is tempting to suggest that it may represent a minor axis of uplift which extended further to the north-east and was responsible for cutting off the upper Sandford River and so forming the huge playa of Lake Austin. On the other hand the southward deflection of the Salt River may have been only a response to the tilt of the Western Shield.

This tilt, demonstrated by Beard (1998), must be considered in addition to any other tectonic movements. The central watershed rises from 400 m in the south to a maximum of 750 m in the north so that the tilt is slight over a distance of 1036 km but has been inferred elsewhere to have influenced drainage patterns (Beard 1998, 1999). The Salt River west of Yalgoo abruptly turns to the south. After Lake Nullewa it is again south to the Yarra Yarra Lakes, then south again. The Dandaragan Plateau shows a slight tilt to the south, which is also visible in the south arm of Lake Monger, Lake Goorly and to the south of it, and on Lake Moore. Without being sufficient to reverse drainage, the tilting has caused ponding and promoted playa formation. After tilting, run-off water would have flowed to the southern part of Lake Moore and evaporated there instead of continuing to deepen the outflow channel at the north end. With the lower rainfall of the later Tertiary/Quaternary there would rarely be enough run-off to use the outflow channel so that salinity would increase and the lake gradually spread.

The formation of playas is an integral part of landscape evolution in semiarid areas. Small headwater streams still flow when there is rain and their silt is deposited to remain on the valley floor. Valleys gradually fill, and the fill would be uneven leading to ponding of runoff. Salinisation then sets in, the small lakes formed turn salt and become playas. Every time there is a flood, a layer of fine clay is deposited together with coarser material which may be blown out of the lake and deposited in dunes. The lake bed is slowly raised by this process and the playa spreads by absorbing adjacent country and killing the vegetation. Large playas are the ultimate stage. This process can be reversed at any time by the return of more pluvial conditions or reinitiated. Conversion of a valley from attrition to accumulation may also be effected by epeirogenic movement. Sinking of a valley may convert it to internal drainage while crustal uplift or tilting may do the same or cause either reduction of reversal of flow. All these effects are observable in Western Australia.

Conclusions

The most important conclusion from this paper is that it provides additional evidence for marginal uplift along the western side of the Yilgarn Craton from Morawa down to the south coast, a distance of some 600 km. The width of the uplift zone is about 70 km. No evidence exists as to whether it was raised by faulting or marginal upwarp. North of it there is evidence for a possible minor uplift axis trending to the north-east above Morawa and perhaps extending into the Murchison River catchment west of Lake Austin.

No date can be suggested for the north-south tilt of the Western Shield, but the uplift of the western margin of the craton probably took place in the late Eocene (Beard 1999). A reconstructed palaeodrainage is given for the Eocene period after recession of Cretaceous high sea level but preceding the late Eocene uplift. The geological maps are most helpful in establishing former courses as they show how valley deposits extend close to one another on either side of present watersheds. Continuing more or less west from Yalgoo the Salt River probably connected with a branch of the Greenough River. On reaching the Darling Fault the valleys of the Greenough and its tributaries change their form. They unite into a single stream which has incised earlier meanders into the plateau, showing that it perpetuates a course established when flowing out across the sedimentary plain at the close of the Cretaceous. The valley of the Irwin River below Mingenew is straighter, deeper and wider than that of the Greenough so that it is tempting to infer that it must have received substantial run-off from the Yilgarn Craton. Connections may have occurred through its tributary the Lockier. Drainages rising in the Gnow's Nest Range may have continued west at Mellenbye to connect with the next valley (now dry), following it down to a side valley which comes in with an anomalous direction heading to the north-east, and through this to the Lockler River north of Cookes Hill. The development of the Irwin west of the Darling Fault has also been strongly influenced by its exploitation of easily erodible Permian sediments.

The next connection further south is with the Arrowsmith River where there are clear signs of a link to interior drainage at Arrino. At both the north and south ends of the Yarra Yarra Lakes there are signs of possible westerly flow. The upper catchment of the Coonderoo River at Watheroo seems to have connected to the Hill River while the Moore River North Branch shows clear signs of having flowed west to the Minyolo Brook. A valley containing salt flats and small playas, *e.g.* Lake Dalaroo, extends due west from Moora beyond which it is only another 4 km to the source of the Minyolo. The col in between appears to be about 60 m above the Moore River at Moora.

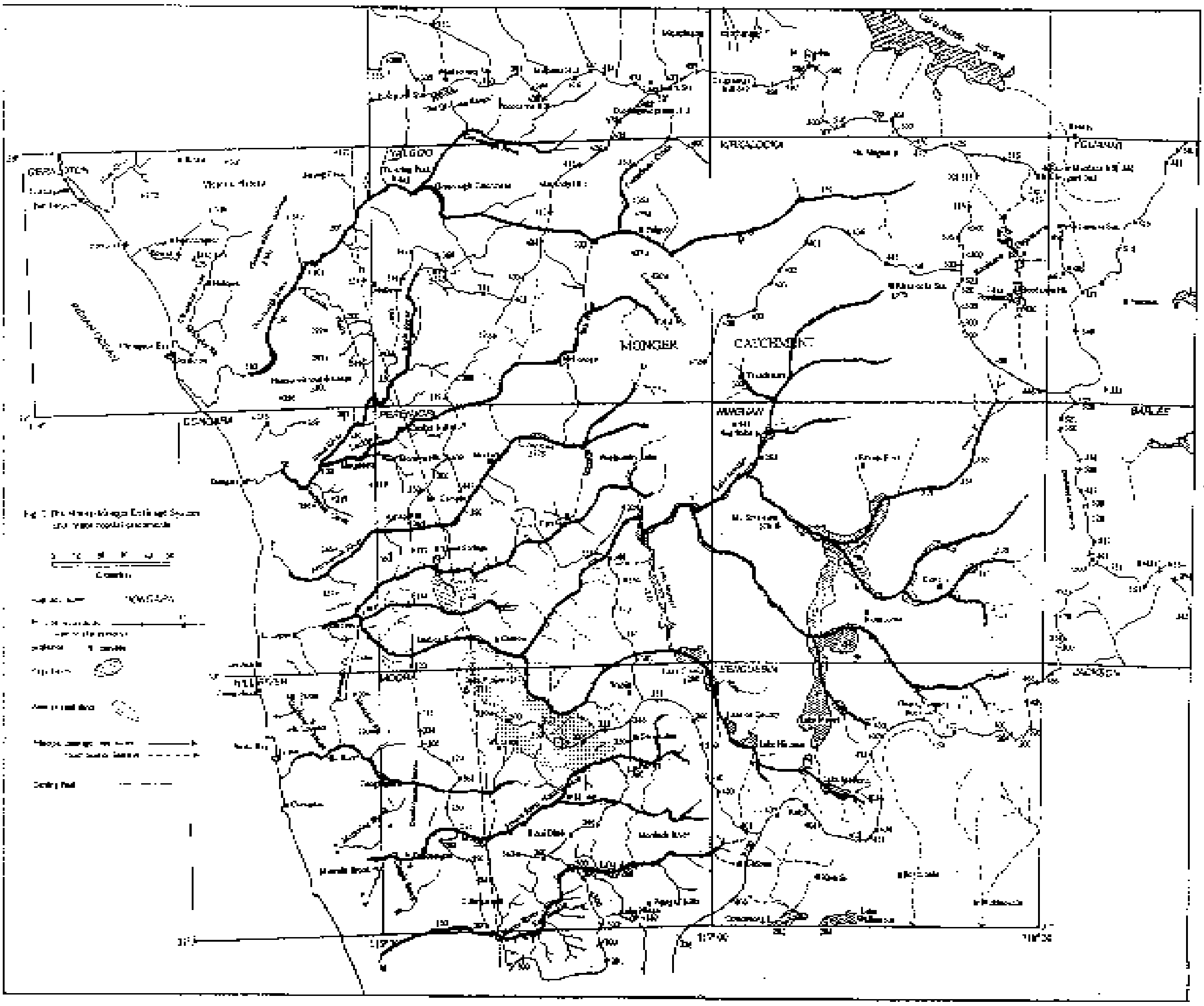

Figure 3. The Moore-Monger area showing inferred drainage patterns of the early Tertiary superposed on Fig 1. Position of the Eocene shoreline is not known.

Further inland it seems clear that drainages must have crossed the present watershed which has resulted from the uplift. The geological map shows that deposits in valleys leading to the Yarra Yarra Lakes are almost continuous with others leading the other way into Lake Monger in the vicinity of Perenjori, with only a short interruption at the watershed. This applies also at several places further south. One valley which leads into the north end of Lake Monger from a point on the watershed marked 366 (Fig 1) was studied by Salama *et al.* (1993) who reported that the watercourse in the 23km long catchment is underlain by alluvial sediments to a depth of 28m. These are undated and were presumably deposited after drainage reversal. The main channel from the Monger catchment may have used this valley or another slightly further south. Northernmost drainages into Lake Moore are shown in Fig 3 as using the present outlet, and the southern as using the alternative outlet south of Mt. Singleton.

For the headwaters of the Mortlock River the geological map (Baxter & Lipple 1985) suggests a former course to the west north of Pithara as well as a possible connection due east of Dalwallinu from Lake Goorly to Lake Hillman, as it seems reasonable to suggest that the north-trending section here of the main watershed between the Moore-Monger and Avon Systems may be an artifact of the uplift. This watershed would originally have taken a south-westerly trend through Cadoux. Other branches of the Mortlock River are in line for connections to the Moore River. From Lake Hinds the geological map suggests a former course to the west via a gap in the ridge at Gabalong 10 km south of Bindi Bindi. It does not seem possible to throw more light on the situation unless drilling data become available.

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