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CLIFF OLLIER (*)

TECTONICS AND LANDSCAPE EVOLUTION IN SOUTHEAST AUSTRALIA

Abstract: OLLIER C., *Tectonics and landscape evolution in Southeast Australia.* (IT ISSN 0391-9838, 1993).

In SE Australia the history of river development, basin sedimentation and the evolution of major divides can all be correlated. The region has a basement of Palaeozoic rocks eroded to a palaeoplain on which lie two sedimentary basins separated by a system of warp axes. The Great Artesian Basin (GAB) is Mesozoic; the Murray Basin is Cenozoic. The Cretaceous-Cenozoic Gippsland-Otway Basin lies to the South, and a Cenozoic sedimentary wedge on the continental shelf to the East. Rivers flowing North and West across southeast Australia are older than the formation of the eastern continental margin, the eastern highlands and the Murray Basin.

In the Jurassic, before the breakup of Gondwana, Australia extended further East and South. Rivers from the South and East provided coarse sediment to the GAB. This drainage pattern is older than the formation of the continental margin, the eastern highlands, and the Murray Basin, and traces survive today.

The catchment of Jurassic drainage was bounded to the E by the Tasman Divide. Later downwarping of the palaeoplain formed the Victoria Divide and the Gippsland Basin in which Cretaceous sediments accumulated. Rifting and seafloor spreading formed the Tasman Sea, starting about 80 Ma ago. The palaeoplain was downwarped, creating the Great Divide and a new continental shelf on which marine sediments accumulated. The palaeoplain is thus equated with the breakup unconformity. Drainage from the Victoria Divide and the Great Divide continued to flow to the GAB until the Murray Basin started to subside starting in Paleocene times. A new warp axis, the Conobolas Divide, appeared between the GAB and the Murray Basin. Basically west-flowing drainage developed in the Murray Basin, Cenozoic sediment accumulated, and sediment supply to the GAB was further depleted.

Ancilliary features consistent with this morphotectonic history include: Old channels with gravels cross the Victoria, Great and Conobolas Divides. Volcanicity follows the warp axes. Reversed rivers are found on the coastal side of the Victoria and Great Divides. Deposition on the continental shelf is roughly equal to erosion on land. The change from coarse to fine sediment which gives the GAB its artesian character fits with the shrinkage of its catchment. The Divides are in different stages of erosion consistent with their ages.

The morphotectonic development of Southeast Australia, with responses to non-cyclic unique events on the time scale of global tectonics, is an example of evolutionary geomorphology.

KEY WORDS: Basins, Divides, Drainage patterns, Morphotectonics, Subsidence, Volcanoes, Cenozoic, Australia.

Riassunto: OLLIER C., *Tettonica ed evoluzione del paesaggio nell'Australia Sud-Orientale.* (IT ISSN 0391-9838, 1993).

Nell'Australia Sud-Orientale la storia dello sviluppo dei corsi d'acqua e dei bacini di sedimentazione e l'evoluzione dei maggiori spartiacque possono essere correlati tra loro. La regione in oggetto ha un basamento di rocce paleozoiche peneplanate sulle quali giacciono due bacini sedimentari separati da un sistema di assi deformati. Il *Great Artesian Basin (GAB)*è Mesozoico mentre il *Murry Basin* è Cenozoico. Il *Gippsland - Otway Basin*, del Cretaceo-Cenozoico, si trova a Sud e un cuneo sedimentario Cenozoico ad Est sul margine continentale. I fiumi che scorrono verso Nord e verso Ovest attraverso l'Australia Sud-Orientale sono più vecchi delle formazioni sul margine continentale orientale, gli altopiani orientali e il *Murray Basin*. Nel Giurassico, prima dello smembramento del Gondwana, l'Australia si estendeva maggiormente verso Est e verso Sud. I fiumi da Sud e da Est fornivano sedimenti grossolani al *GAB*. Tale *pattern* è più vecchio delle formazioni sul margine continentale, degli altopiani orientali e del *Murray Basin*, e sue tracce sono tuttora riconoscibili. Il bacino del drenaggio Giurassico era delimitato ad Est dal *Tasman Divide.* Successivamente la deformazione del penepiano ha formato il *Victoria Divide* e il *Gippsland Basin* in cui si sono accumulati sedimenti Cretacei. A partire da circa 80 Ma, la spaccatura del continente e l'apertura dell'oceano ha formato il *Tasmanian Sea.* Il penepiano fu deformato, dando luogo al Great Divide e a una nuova piattaforma continentale su cui si sono accumulati sedimenti marini. Il drenaggio ha continuato a defluire dal *Victoria Divide* e dal *Great Divide* verso il *GAB* finché il *Murray Basin* ha cominciato, a partire dal Paleocene, ad essere in subsidenza. Un nuovo asse di deformazione, il *Conobolas Divide*, comparve tra il *GAB* e il *Murray Basin.* Fondamentalmente, nel *Murray Basin* si è sviluppato un drenaggio che scorreva verso Ovest, accumulando sedimenti Cenozoici e privando così di sedimenti il *GAB*. Caratteristiche subordinate connesse con questa evoluzione morfotettonica comprendono: vecchi alvei con ghiaie attraversano i *Victoria, Great* e *Conobolas Divides*; il vulcanismo segue gli assi di deformazione; corsi d'acqua anaclinali si trovano nella parte costiera dei *Victoria* e *Great Divides*; l'entità del deposito sulla piattaforma continentale è grossomodo uguale all'entità di erosione sulla terraferma; il cambiamento da sedimenti grossolani e sedimenti fini che conferisce al GAB il suo carattere artesiano concorda con il restringimento del suo bacino idrografico; gli spartiacque sono in diversi stadi di erosione in relazione alle rispettive età. Lo sviluppo morfotettonico dell'Australia Sud-Orientale, con responsi ad eventi unici e non ciclici alla scala della tettonica globale, è un esempio di geomorfologia evolutiva.

TERMINI CHIAVE: Bacini, Spartiacque, Rete di drenaggio, Morfotettonica, Subsidenza, Vulcani, Cenozoico, Australia.

INTRODUCTION

A hypothesis is presented here of the landscape evolution of Southeast Australia which brings together evidence of landforms, drainage patterns and sedimentary basins to make a consistent picture. The sedimentary record of the basins provides evidence of variation in the location and extent of erosion in the highlands, and the timing of major changes in drainage direction. The major rivers have remarkable antiquity, and despite many later changes can be traced back to Mesozoic and even Permian precursors.

(*) *Department of Geography and Planning, University of New England, Armidale NSW 2351.*

FIG. 1 - Main geographic features mentioned in the text.

OUTLINE OF PHYSIOGRAPHIC EVOLUTION

Basically this story is one of formation of successive divides that create or confine sedimentary basins, with associated changes to drainage patterns. The story is complicated so I shall first tell the simple story, and provide further details and discussion later. The main geographical features are shown in fig. 1 and fig. 2 shows the location of major sedimentary basins and divides in the area of concern.

In the Jurassic, Australia was still attached to Antarctica and land masses to the East (Pacifica) as shown in fig. 3. A watershed on the latter (the Tasman Divide) was located perhaps two to three hundred kilometres East of and

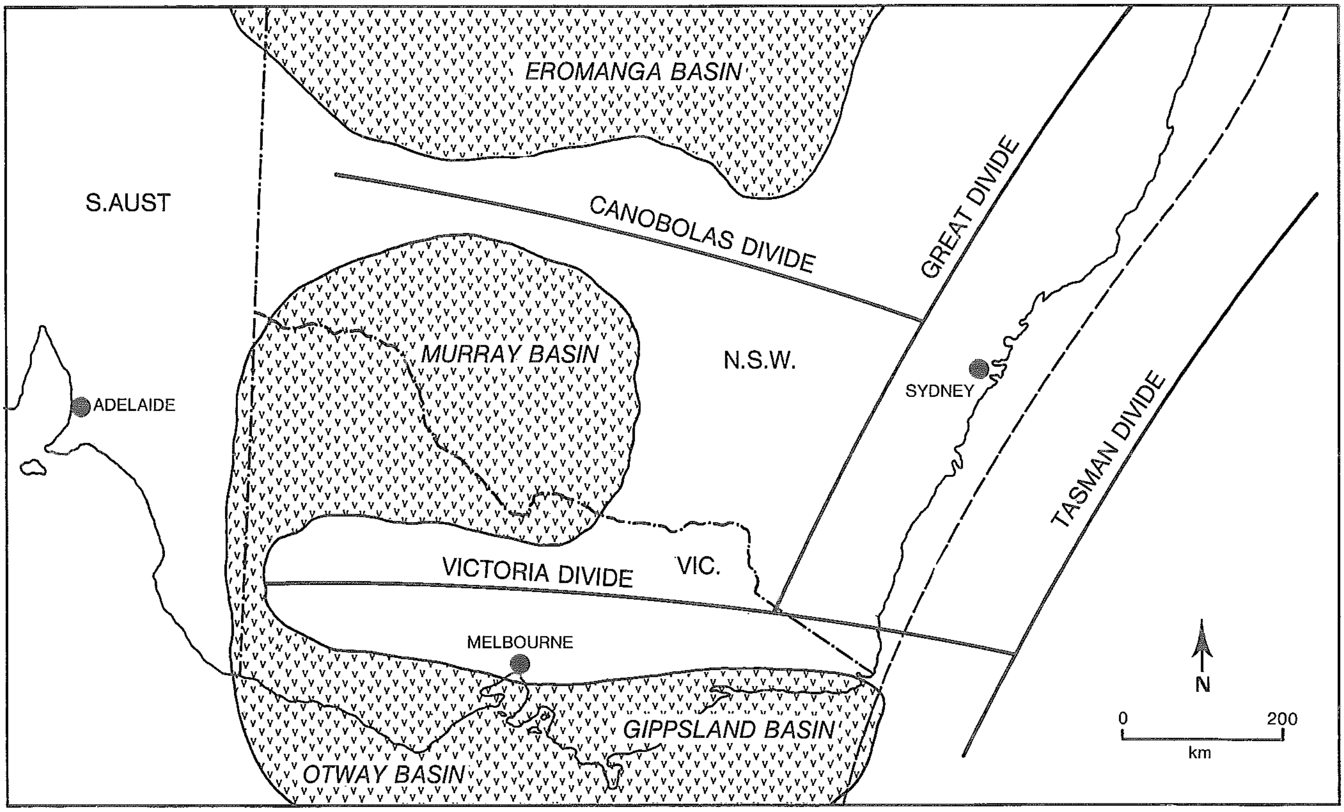


FIG. 2 - Diagramatic representation of the major basins and divides in South-East Australia.

parallel to the present coast, and from it rivers carried sediment to the Eromanga-Surat Basin (roughly the Great Artesian Basin).

In the Cretaceous an East-West trending ridge appeared, the Victoria Divide, extending from the Tasman Divide through what is now the Victorian Highlands separating the Eromanga-Surat Basin from the Otway and Gippsland Basins. Rivers carried sediment North from the Victoria Divide to the Eromanga-Surat Basin, and South to the Otway-Gippsland Basin.

About 80 Ma ago the Tasman Sea opened by rifting followed by sea-floor spreading to form the modern continental edge of Australia and a new coastline. The eastern edge of the Australian continent was downwarped to the new coast, some major rivers were reversed, and an early Great Divide was formed between the coast and the inland sedimentary basins. Much of the drainage from the old Tasman catchment was therefore cut off from the Eromanga-Surat Basin. The Great Divide has since been shifted at times by volcanism, scarp retreat and river capture. As new easterly drainage developed, valleys coalesced to form a Great Escarpment facing the Tasman Sea, separating a plateau from a highly eroded coastal belt. Cenozoic volcanism and Miocene faults with throws of hundreds of metres have further complicated the topography.

At the beginning of the Tertiary the Murray Basin started to subside. The rivers flowing North from the Victoria Divide no longer reached the Eromanga-Surat Basin (which was thus deprived of coarse sediment from the south), but started to flow to the West like the modern drainage of the Murray Basin. Subsidence of the Murray Basin created a new divide between the Murray and Eromanga-Surat Basins, which is here called the Canobolas Divide. Traces of the ancient North-flowing rivers are still to be found crossing the Canobolas Divide.

THE BASINS

The Eromanga-Surat Basin (roughly Great Artesian Basin) is filled with Jurassic and Cretaceous sediments, mainly derived from the East and South. The present paper is mainly concerned with the Eastern, Surat Basin, and its Southern end (the Coonamble Embayment).

The Otway Basin originated as a rift associated with opening of the Southern Ocean, while the Gippsland Basin formed as a result of incomplete rifting of an arm of the Tasman Sea. They existed through Cretaceous and Tertiary times. They derived some sediment from bounding hills to the North but for much of their history they were

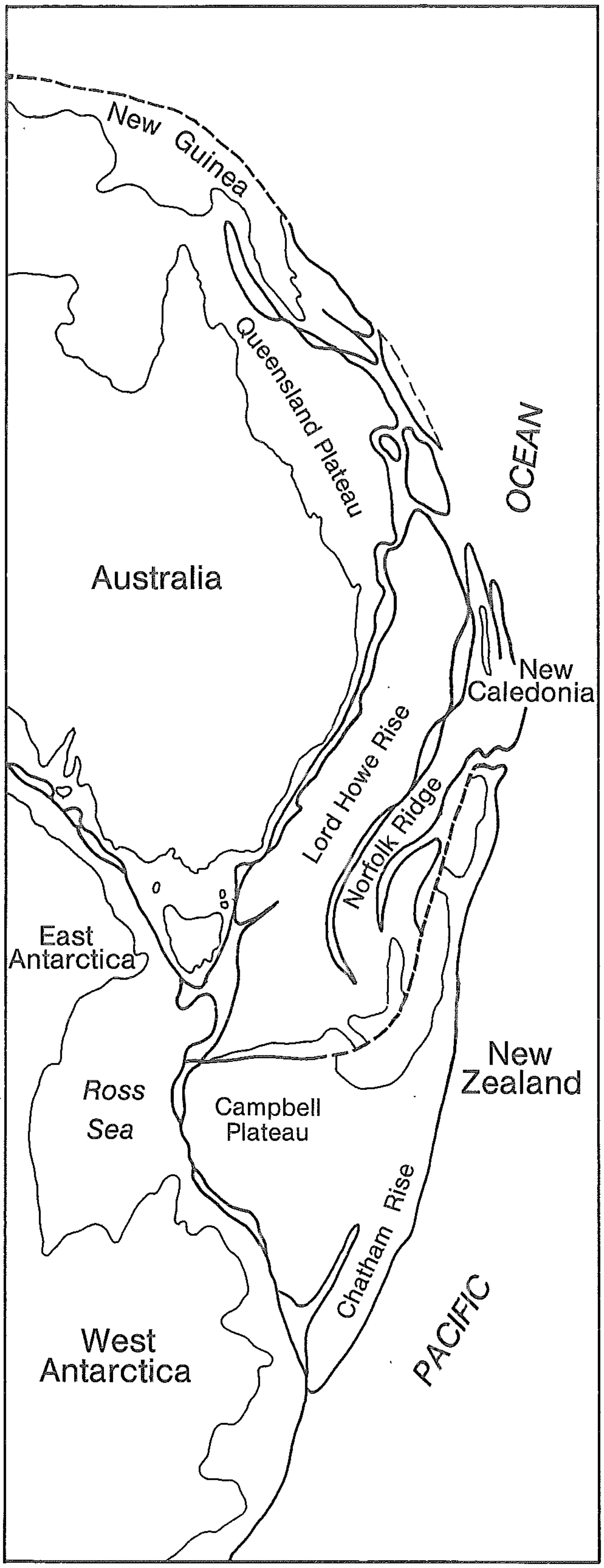


FIG. 3 - The position of Southeast Australia before the separation of Antarctica and land to the East (Pacifica).

mainly filled by volcanogenic sediment derived from the East. The Lower Cretaceous fill is entirely terrestrial, but there is evidence of marine incursions in the younger strata.

The Murray Basin is mainly filled with Tertiary sediments. No Jurassic rocks are known but extensive Lower Cretaceous sediments underlie Western and Northern areas of the Basin. These are partly marine and can be correlated with those of the Eromanga Basin. A North-South bedrock rise separates the Eastern and Western parts of the Murray Basin and marine beds are essentially confined to the Western half.

South flowing drainage into the Murray Basin from the North did not develop before the Tertiary. From the Middle Eocene onwards fluvial sedimentation of an early Murrumbidgee built a huge fan, and the sediment derived from the East marks the creation of the Eastern highlands as a major topographic feature. In the Oligo-Miocene, a major marine incursion flooded the Murray Basin. The present day continental shelf of New South Wales is receiving sediment, as it has since the initiation of the coast, and is a narrow sedimentary basin. A wedge of Cretaceous and younger sediments overlies older rocks. The base of the Cretaceous sediments is known as the break-up unconformity (related to the break-up of Gondwanaland), and has been equated with the downwarped terrestrial palaeoplain (fig. 4).

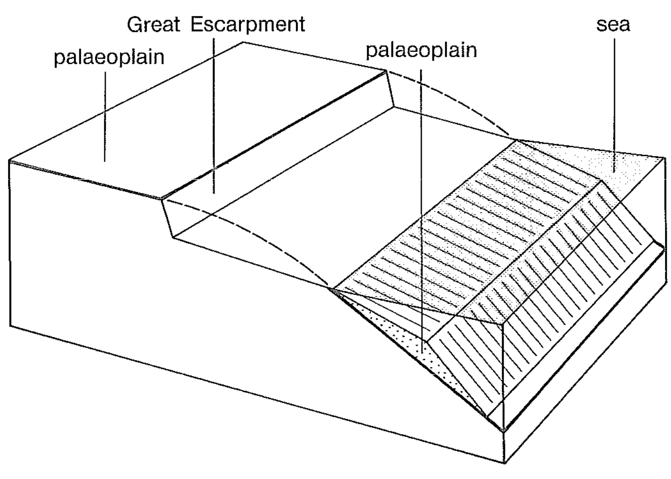


FIG. 4 - Morphotectonic features of the coast of New South Wales. The palaeoplain is downwarped to form the basement for marine sediments, known as the breakup unconformity. Erosion of the land in front of the Great Escarpment provided the sediment for offshore deposition, so the volume of material eroded is roughly equal the volume deposited offshore (OLLIER, 1991).

THE DIVIDES

The Tasman Divide

Little is known of this divide, but JONES & VEEVERS (1983) speculate on its nature in plate tectonic terms. They say that while the Tasman Divide existed, cratonic sedimentation in eastern Australia was dominantly by labile sediment from an andesitic orogen.

The Victoria Divide

In the Cretaceous an East-West divide ran through Victoria, roughly parallel to the present divide but further South. From it a river system flowed North to the Eromanga-Surat Basin. The divide appears to have been originally fairly flat, and to have been developed along a palaeoplain which probably dates back to the Triassic (HILLS, 1975).

Drainage South of the divide flowed into the Otway and Gippsland Basins, which, however, were mainly filled by sediment brought in from the West.

Valleys were cut into the palaeoplain and there was probably a stage of Great Escarpment formation as on the East coast, but this divide is older than the Great Divide and erosion has gone much further. Apart from a major plateau in the Kosciusko area, the palaeoplain is preserved as isolated smaller plateaus, and the Divide is a sharp ridge. Because the South draining rivers in eastern Victoria were steeper and more erosive than the North-flowing ones, the divide has migrated North, and most of the Victorian High Plains are South of it.

Although the East-West divide through Victoria appears to be a single entity, the part West of the longitude of Melbourne is in many ways distinct. From it rivers drain North to the Murray Basin and South to the volcanic western plains, and the divide crosses subdued topography. Older volcanoes (up to 7 Ma old) erupted on or near the Divide, as did many Miocene and younger volcanoes. Lava flows filled the old valleys and provide valuable information on age, gradient and evolution of valleys. Much evidence comes from «deep leads», gold-bearing alluvium preserved beneath the lava flows. Certainly the position of the Divide has moved tens of kilometres North since «deep lead» times (OLLIER, 1988; 146). It is possible that some of the major valleys once flowed right across the Western Victoria Divide from a source much further south, but this has not yet been proved. Old gravels in the Bendigo area are thought to be traces of huge Cretaceous rivers (WILLIAMS, 1983).

The Great Divide

The Great Divide lies roughly parallel to the coast of New South Wales, and separates the Murray Basin and Eromanga-Surat Basins from the Tasman Sea. Much of this divide lies along a palaeoplain, sloping gently to the west and cut off abruptly on the eastern side by the Great Escarpment. In some places the present Great Divide seems to follow an ancient line, possibly the original palaeodivide. In such situations streams on both sides of the Great Divide area not incised and have the same gradients, implying great age. The Divide in such places may even go around both sides of lakes on the flat summit of the divide. Elsewhere the divide has moved from its original tectonic position as a result of headward erosion of rivers, or of river capture. Note that any river capture or diversions of streams to the East adds a new drainage basin to the easterly drainage, and the Great Divide «leaps» to the Western side of the captured basin.

In some places headward erosion on both sides of the Divide has formed ridge-type divides. Elsewhere scarp retreat has isolated individual plateaus east of the Great Divide, such as the Bulga and Comboyne Plateaus (PAIN & OLLIER, 1986).

The Canobolas Divide

This divide crosses an undulating plateau between the Great Divide and the volcano Mt Canobolas, and continues to the West as a low divide between Murray Basin Drainage and Eromanga-Surat Basin drainage. The divide was in existence by at least the Middle Eocene (STEPHENSON & BROWN 1989), and formed by down warping of the Murray Basin rather than uplift of a ridge. Former North-flowing rivers were diverted to the West.

Lava flows from Canobolas Volcano flowed down valleys to the North, South and West, showing that the valleys were established by 11.7 Ma (WELLMAN & MCDOUGALL 1974; MIDDLEMOST 1981). The lower ends of the subvolcanic valley are incised 100 m and more below the basalt, but modern river incision nowhere reaches the divide. The present divide was thus in existence in the Middle Miocene and has suffered minimal erosion since then.

Late Mesozoic drainage crossed this divide from South to North as indicated by the large volume of quartzose sediment in the Coonamble Embayment (the Southern part of the Surat Basin) and by fluvial sediments of possible Cretaceous age preserved at low points in the watershed and under Mt Conobolas volcano.

THE RIVERS

In this section I will not describe all the drainage of Southeast Australia, much of which is very modern, but shall outline those aspects relevant to the interpretation of the drainage evolution on the long timescale.

The evolution of the Clarence River was described by HAWORTH & OLLIER (1992). The barbed tributaries, the apparent continuation with the simple Condamine River beyond the Great Divide, and the relationship to the formation of the Jurassic Clarence-Moreton Basin all suggest that this river existed in Jurassic times and was reversed in post-Cretaceous and probably pre-Miocene times.

GALLOWAY (1967) presented a careful analysis of the Hunter River and showed that it was reversed. It already flowed in its present direction at the time the Goulburn lava flow was erupted in Miocene times, but the date of its origin has not yet been established.

The lower Shoalhaven is a controversial areas of drainage, but workers such as TAYLOR (1911), and OLLIER (1978) interpret the barbed drainage, with the Kangaroo and other rivers joining the main stream at acute angles,

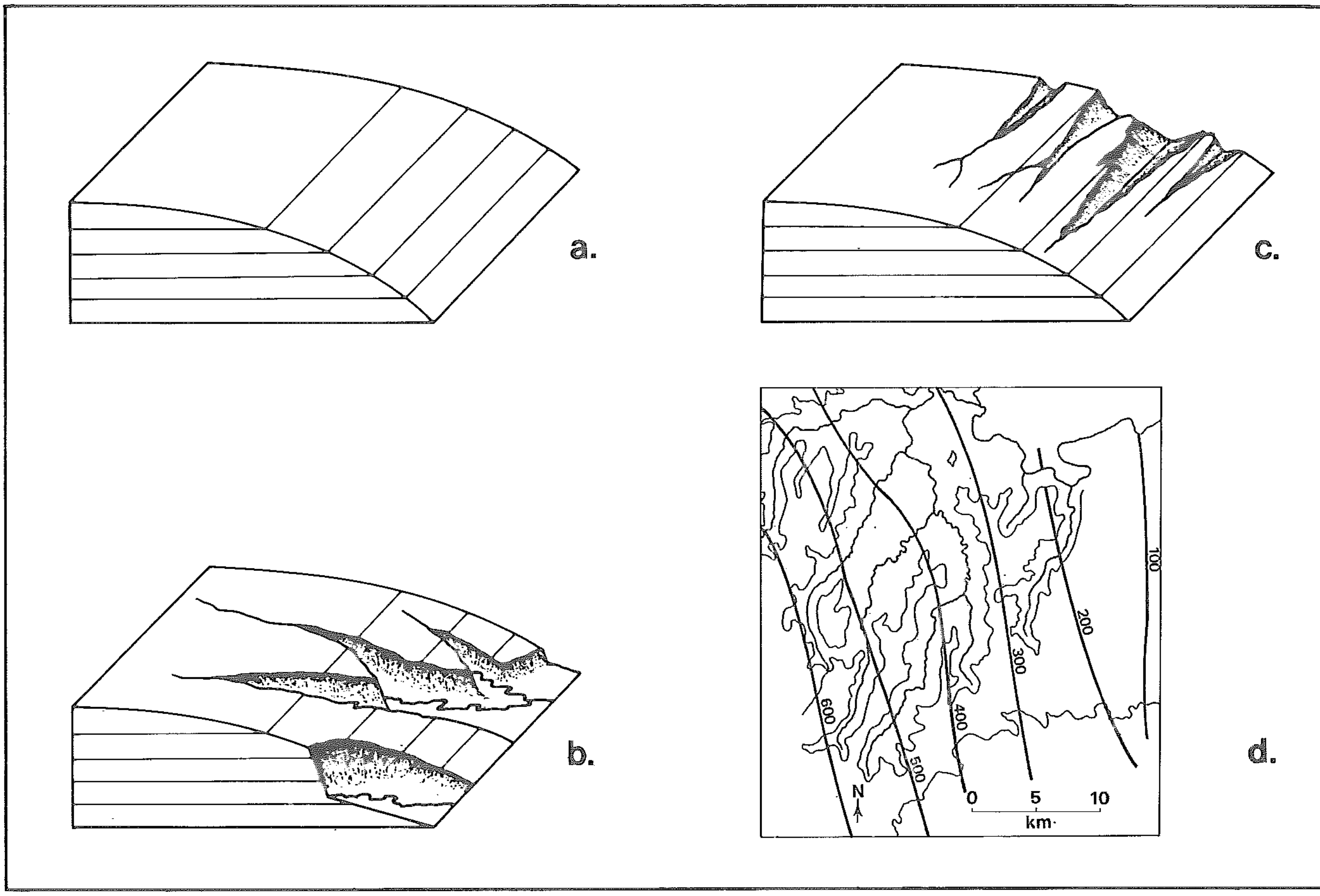


FIG. 5 - Generalised contours on a warped surface, and the evolution of the Lower Shoalhaven. a. Contours on a downwarped surface. b. A downwarped surface dissected by valleys. Contours on the flat interfluves permit reconstruction of the old surface. c. A block diagram of the downwarped surface in the Lower Shoalhaven area, with valleys almost parallel to the contours of the old surface. The situation in Figure 6b above would occur if rivers were initiated on a simple downwarped surface. The pattern in Figure 6c suggests the valleys were incised before the downwarp, i.e. they are antecedent. d. A map of the gorges and generalised contours in the Lower Shoalhaven area (after OLLIER & WYBORN, 1989). Note the similarity between this and Figure 6c.

as evidence of reversal. The southern tributaries are very instructive, as this part of the Shoalhaven system is cut in deep gorges. The model is shown in fig. 5, and suggests downwarping of the palaeoplain to the east after the incision of the gorges across it.

Some aspects of the Deua River are shown on fig. 6, and details are explained in the caption. This is one area where the Great Divide, the Great Escarpment, the coast and the continental edge are all close together. The main story is of early drainage being to the north and northwest, only modified after the formation of the new continental edge and subsequent scarp retreat and river capture.

Although river capture is responsible for some of the complexities of the east coast rivers, more are tilt-induced reversals of rivers that followed their present course in the lower Mesozoic but in the opposite direction. Uplift of the divide and lowering of the coast are not just relative terms, but affect river patterns in different ways as argued by OLLIER (1992), and the balance of evidence suggests that downwarping of the coast is more significant than uplift in many parts of eastern Australia.

Near the area where the Great Divide meets the Victorian Divide (and close to Australia's highest land in Mt Kosciusko) is a large area of basalt interpreted as an Eocene volcano (OLLIER & TAYLOR, 1988). Prevolcanic drainage came from the south as shown in fig. 7 but evidence is largely destroyed by retreat of the Great Escarpment, though a small section of the old drainage is preserved as Saucy Creek, complete with a terrace of Paleocene sediment.

Rivers now flowing south from the Great Escarpment may still be on the line of original northerly drainage, as suggested in fig. 8.

Headwaters of the upper Murray rise on a plateau and drain North. The rivers encounter a series of faulted tilt blocks through which they have cut deep gorges in antecedent courses. Fault displacements were in the range of 200 to 400 m.

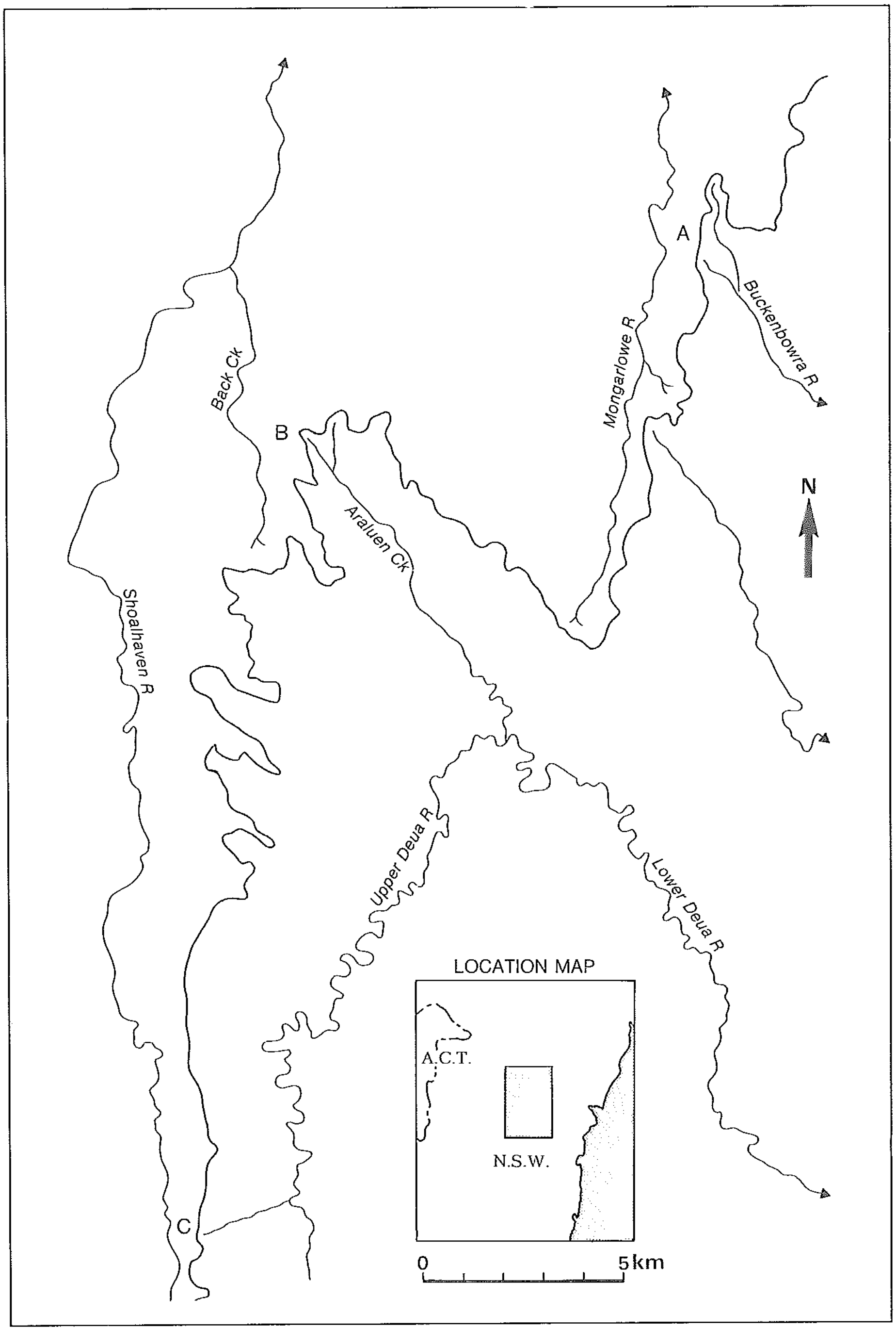


FIG. 6 - The Great Escarpment separating North-flowing rivers on the palaeoplain (left) from deranged drainage on the coastal side. Many rivers in the area show the marked bend exhibited by the Deua. Such bends could easily occur by river capture, as a points A and B. After capture, the intervening narrow plateau remnant would be rapidly reduced. Possibly the Upper Deua was once continuous with the Mongarlowe until captured by the Lower Deua. Another imminent capture is at point C. The Deua is tributary to the Moruya River shown in Fig. 1.

North of the Western Victoria Divide, pre-Tertiary contours and isopachs on Paleocene-Eocene Renmark Beds show two main rivers trending northwards into the Murray Basin (MACUMBER, 1977), an Eastern system that continues the line of the present Loddon River and a western system which is a wholly buried valley. The Loddon River of today follows the course of Permian glacial deposits confined to a palaeo-Loddon valley, and overlain by Tertiary deep leads (MACUMBER, 1977). Similarly the Ovens Valley was a valley in Permian times, filled with glacial gravels. These gravels were stripped and replaced by Tertiary gravels, which were in turn stripped by the modern Ovens Valley erosion (CRAIG, 1984).

In brief, in the Mesozoic a simple system of rivers drained north and northwest over most of southeast Australia, but this pattern has been modified by later tectonism and the drainage of the modern Murray is now generally to the West (fig. 9).

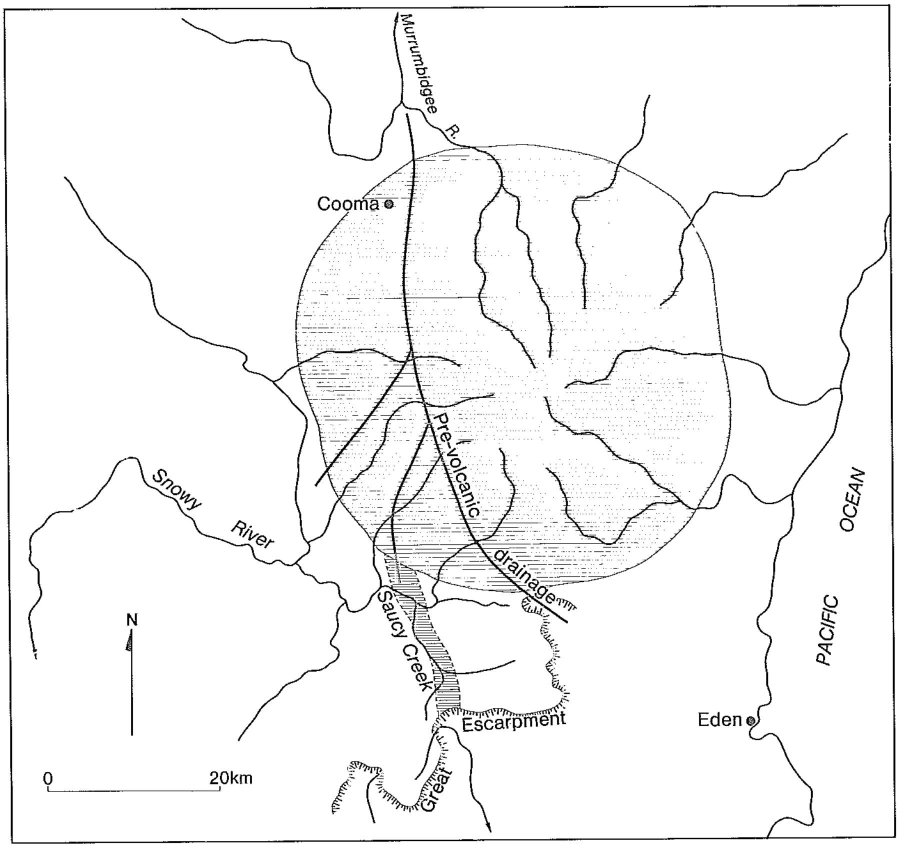


FIG. 7 - Diagram of the evolution of drainage near the Upper Murrumbidgee. Originally rivers flowed from South to North. Eruption of a huge volcano initiated radial drainage on its surface and blocked Saucy Creek, which diverted into the Snowy River. Retreat of the Great Escarpment removed the headwaters of Saucy Creek and other Southern rivers, and also removed much of the volcano (based in OLLIER & TAYLOR, 1988).

TECTONICS, VOLCANISM AND EUSTASY

Several major faults affect Gippsland and the Kosciusko area (fig. 10). They have throws of several hundred metres, possibly reaching a kilometre. They are complicated, being straight in plan even across country of high relief, yet in detail show low-angle thrusts. OLLIER & WYBORN (1989) suggested that they are basically normal faults which have undergone late thrusting at the base by spreading of the highlands. Tilt block movement has caused river reversal (upper Snowy), superimposition (Murray gorges), blockage (Lake George) and diversion (northern tributaries of Lake George). The major uplift of the Gippsland-Snowy Mountains block took place in Miocene times.

Volcanoes erupted throughout the Cenozoic, especially along the main divides (Great Divide, Victoria Divide and Canobolas Divide). There was very little volcanic activity in the sedimentary basins except for the Late Tertiary and Quaternary activity of the western Victorian lava plains, where volcanics overlie a Tertiary syncline (JOYCE, 1975). Volcanicity, in the form of lava flows with small or unknown sources, was widespread on the Great Divide and the Eastern part of the Victoria Divide in Oligo-Miocene times, but was reduced or ceased in the Late Miocene. Major shield volcanoes on or near the Great Divide include the Ebor Volcano (OLLIER, 1982b), the Barrington Volcano (PAIN, 1983), and the Monaro Volcano (OLLIER & TAYLOR, 1988). The Canobolas Volcano was erupted on the Canobolas Divide (MIDDLEMOST, 1981). These large volcanoes resulted in the formation and superimposition of radial drainage in the vicinity of the volcano, and major drainage disruption in neighbouring regions, even affecting big rivers such as the Hunter and Snowy Rivers.

Sedimentary cycles are found in all the basins, and can be interpreted as eustatic cycles (BROWN, 1983; BROWN & STEPHENSON, 1989). In the Late Miocene there was a major eustatic fall in sea level, leading to major valley downcutting, especially in Gippsland. The Murray Basin was flooded by a eustatic sea level rise in the Early Pliocene. Appreciation of eustatic cycles is important, because sedimentary cycles can also be interpreted as reflections of tectonic movement in the highlands (JONES & VEEVERS, 1983).

DISCUSSION

Movement up or down?

Rivers can respond to tectonic uplift in two different ways (OLLIER, 1991b). If land is uplifted across the course of a large river, the river continues in its course by cutting an antecedent gorge. This is a simple response to the

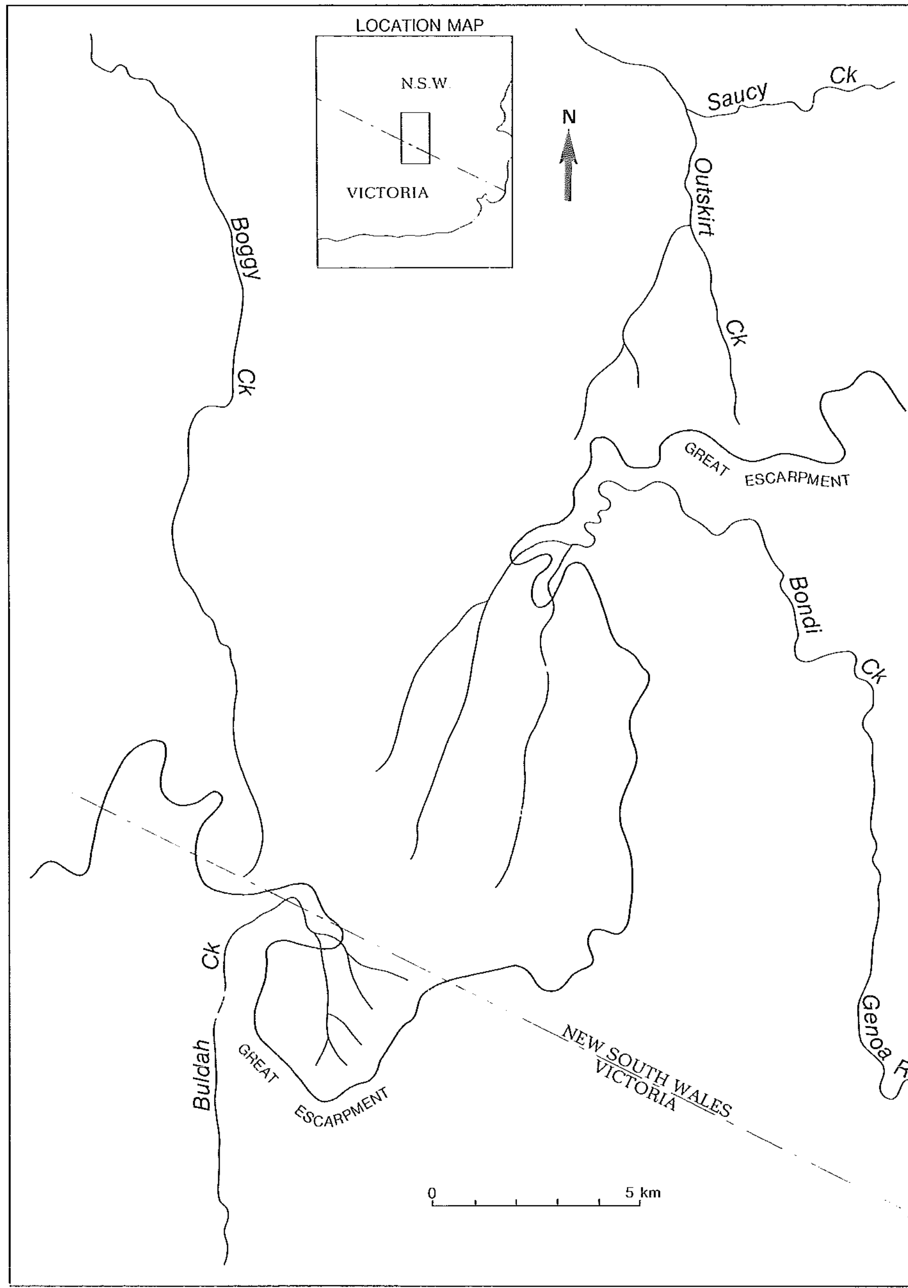


FIG. 8 - River captures on the South-facing Great Escarpment. The present South-flowing rivers (Buldah, Bondi, Genoa) are possibly in the same location as original North-flowing rivers.

relatively fast rates of river down-cutting versus slow rates of uplift. Conversely, if a river is back-tilted, it cannot flow uphill and so is reversed. On this basis we can work out the sense of earth movements. Uplift and downwarp are not just relative - they are indicated absolutely by river behaviour.

From these two basic rules of river behaviour, it is concluded that the Upper Murray cut antecedent gorges across uplifting fault blocks, whereas the coastal rivers were reversed by back tilting with massive reorganisation of the drainage. Subsidence of the Murray Basin (rather than the uplift of the Canobolas Divide) diverted rivers from flowing North to the Eromanga Basin. The major divides were thus formed not only by uplift, but by subsidence of their surroundings.

Ancient river profiles preserved beneath basalt in western Victoria have profiles different from those of the present valleys, being higher in the highlands and lower in the plains. This suggests uplift in the highlands, and subsidence in the plains.

It is not a question of either up or down. Both uplift and subsidence have had a role in landscape evolution.

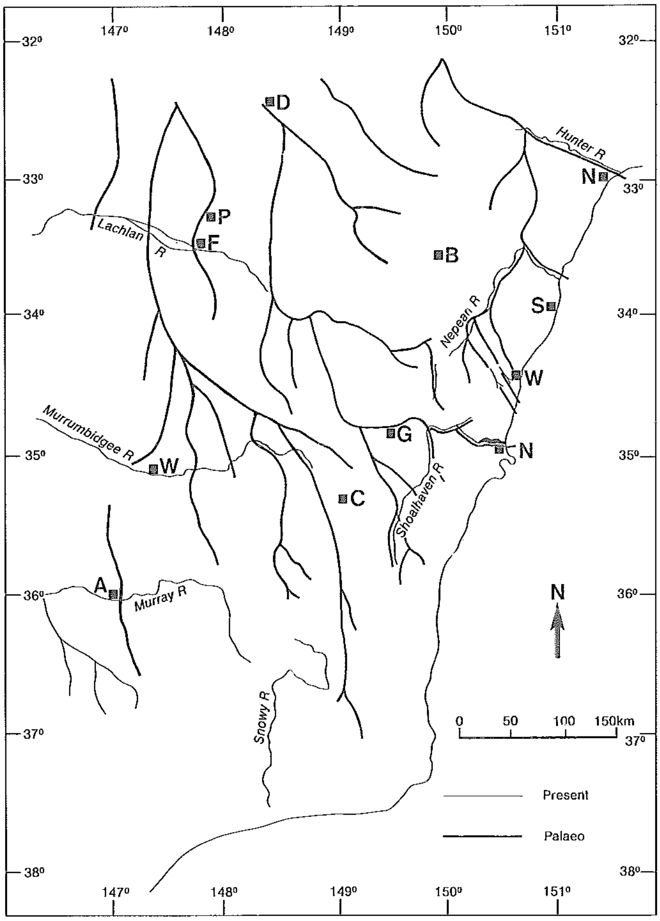


FIG. 9 - Approximate palaeodrainage and modern drainage in Southeast Australia.

Uplift of the Eastern Highlands

There has been a great deal of speculation on this topic, some specific to the region, and some in search of fundamental mechanisms. Only a few ideas can be discussed here.

Early writers believed uplift was largely associated with the «Kosciusko Uplift», a tectonic event at the very end of the Tertiary. The most recent exponent of this idea was probably BROWNE (1969), who wrote of «*Repeated differential uplift, chiefly in Late Pliocene and Early Pleistocene time* (Kosciusko Epoch)». This idea was shown to be false by OLLIER (1978), while the evidence in the present paper shows the presumed date of uplift to be quite wrong.

SMITH (1982) and KARNER & WEISSEL (1984) regarded the uplift as due to the passage of Australia over a hot spot (or hot line). Given the different directions of the divides it seems impossible to design a plan of suitable hot lines that would be effective, and the different ages of the divides makes it even less possible.

LAMBECK & STEPHENSON (1986) suggested that residual stresses from a Palaeozoic orogeny were somehow revived in Cretaceous or Tertiary times to form the Southeast highlands. In fact, the fold axes of the Palaeozoic bedrock are essentially North-South, but the present divides all differ from that direction, and from each other. The Miocene faults follow a different alignment again. Furthermore there is no «orogeny» that caused uplift, and some divides were formed by subsidence of neighbouring areas.

JONES & VEEVERS (1982) proposed a complex system of uplifts and subsidences in the Eastern Highlands and adjacent basins, to relate sedimentary cycles, tectonics and volcanism. The cycles may possibly be better explained by eustacy at least in the Murray Basin (BROWN, 1983).

DUMITRU & *alii* (1991) studied fission track data in Southeast Australia. They concluded that there had been 1.5 – 3 km of uplift and erosion along the Tasman Sea and Bass Strait coast, and that uplift and erosion were much less 100 km inland. This is inconsistent with the view of geomorphic evolution presented here, where basalts show only a few hundred metres of erosion on most of the palaeoplain, and less than 1 km of erosion at the Great Escarpment. The young fission track ages are all on the eroded side of the Great Escarpment, or where exceptional valleys have incised deeply into the palaeoplain. A thermal event might explain the fission track data better than regional erosion, but it is hard to see a thermal event taking the strange geographical pattern of the Great Escarpment. Perhaps the deep erosion is merely exposing a zone where depth related temperature has caused apparently young fission track ages.

In previous articles I have been reluctant to provide a fundamental mechanism for uplift, not because I don't have one but because there are have too many, and elsewhere I have listed 20 possibilities (OLLIER, 1990). But the evidence present in the present paper suggests that the sagging of the basins is as important as uplift of the divides. Uplift and downwarp are, of course, relative terms, but the evidence of the rivers, which can be interpreted despite eustatic changes, shows that subsidence has been a major tectonic factor.

Instead of asking «what caused uplift of the highlands?» we should ask «what caused subsidence of the basins?». No doubt the two are related, but just how is beyond present knowledge.

PARADIGMS OF LANDSCAPE EVOLUTION

The watersheds in the study area have evolved from low relief palaeoplains through a stage of plateau remnants to knife-edge ridge divides, the reverse of «peneplanation» as commonly conceived (fig. 11). Presumably if the erosion continued with no more complications a new plain at a lower level would be formed. This would constitute something that could be regarded as a Davisian Cycle. However, our first palaeoplain goes back to Triassic times, and the end of the cycle is not in sight. If the «cycle of erosion» has any meaning, it is operating here on a vast timescale. But there seems to be no reason to believe con-

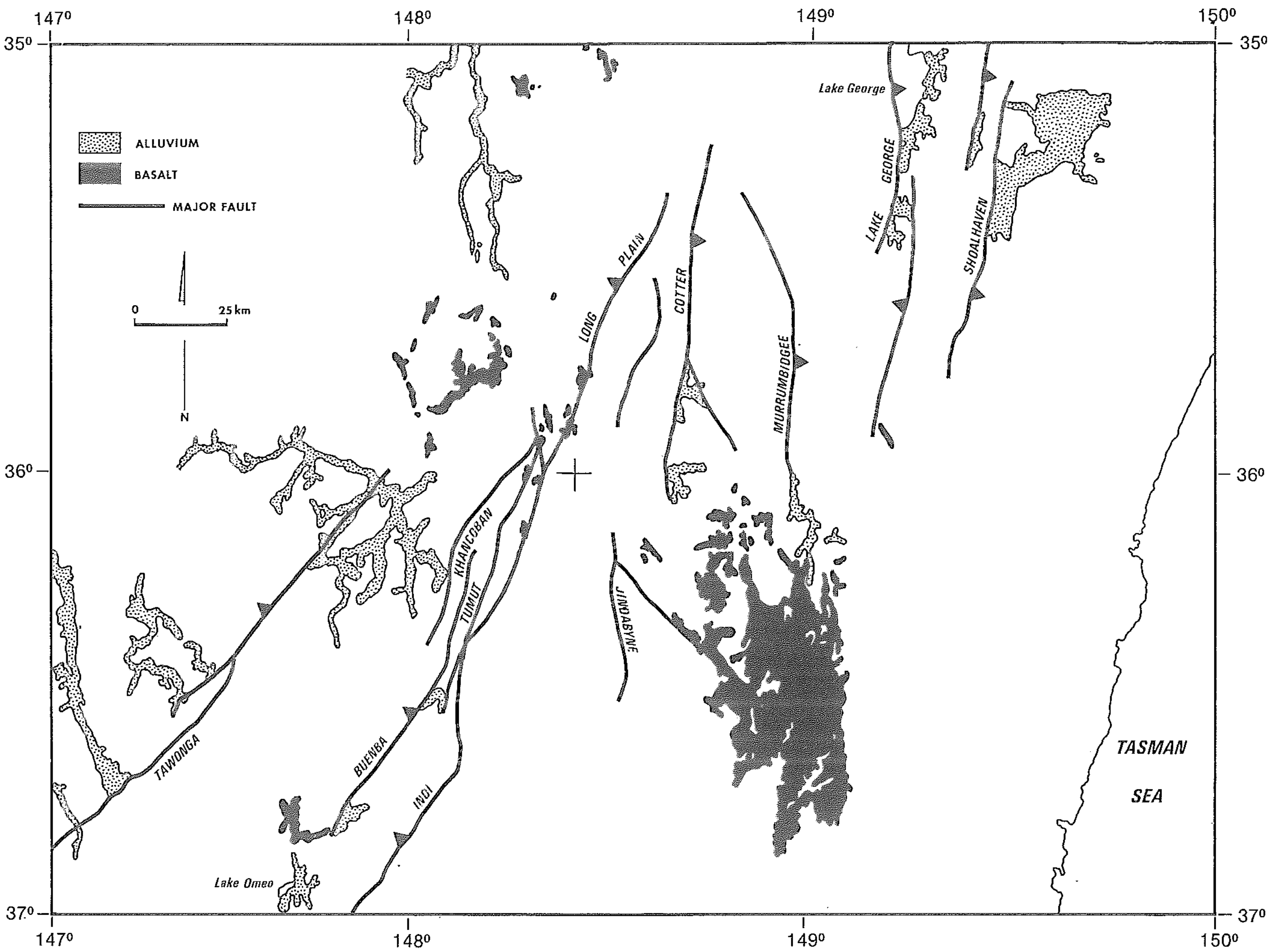
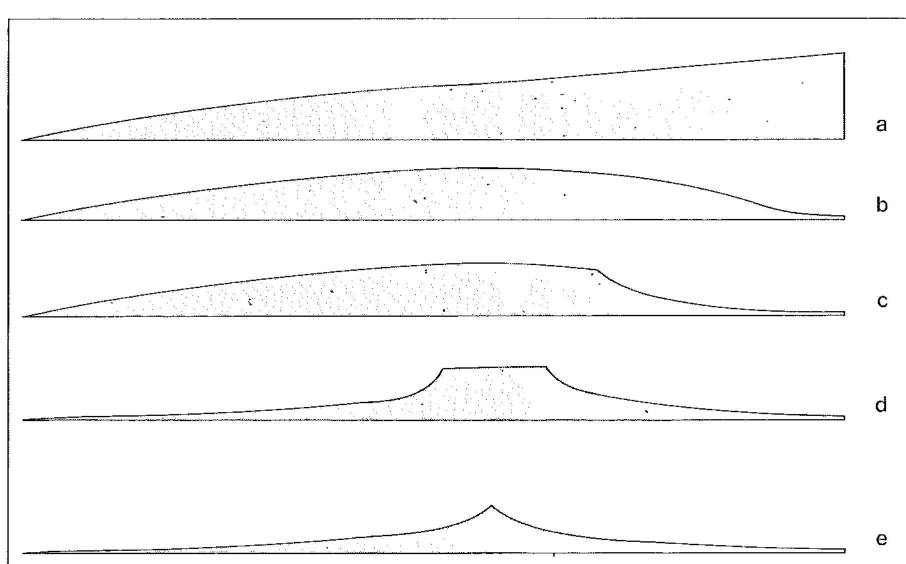


FIG. 10 - Major faults and lava plains in South-East Australia.

FIG. 11 - Evolution of the Divides of South-East Australia a. Initial palaeoplain sloping down from the Tasman Divide. b. Downwarp of palaeoplain to coast, forming an initial divide. c. Formation and retreat of the Great Escarpment facing the coast. Much of the Great Divide is in this stage. d. Retreat of slopes from the coast and inland reduces the palaeoplain to isolated High Plains, common on the Victoria Divide. e. Continued retreat of the escarpment of the inland slopes concsumes the High Plains and produces a sharp ridge divide, as along much of the Victoria Divide.



ditions will stay still and allow the cycle to continue to an end, to a peneplain stage. If the past is the key to the future we can expect complications of tectonics to interrupt erosional processes. The succession of varied unique events such as sagging of the Murray Basin, opening of the Tasman Sea and creation of a new continental margin, eruption of the huge Monaro Volcano, and the huge block faults of Miocene age makes up a sequence of events in the evolution of the landscape that have no cyclic connotation. Nor can the landscape be regarded as in a steady state. Climate has no effect on major landforms. The area is in example of Evolutionary Geomorphology on a very long timescale.

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