ASPECTS OF PALAEODRAINAGE IN THE NORTH LACHLAN FOLD BELT REGION

D L GIBSON & R A CHAN

CRC LEME, Australian Geological Survey Organisation, GPO Box 378, Canberra, ACT, 2601

ABSTRACT

Evidence for the configuration of palaeodrainage in the north Lachlan Fold Belt (LFB) region is essential to determine landscape history of the area, and is mainly provided by alluvial deposits and valley basalts of various ages, and analysis of drainage directions and valley character The oldest alluvial sediments are Jurassic, and are part of the Great Australian Basin (GAB), deposited by north-flowing watercourses. We consider that the course of the Darling River is most likely tectonically determined, and that the northwest to westward courses of the other major rivers now draining to the Murray Basin most likely result from superimposition of drainage from now-removed GAB sediments The direction of flow of this drainage is a result of uplift and tilting initiated at the close of sedimentation in the GAB prior to rifting of the eastern margin of Australia Thus this drainage predates the initiation of the Murray Basin By the Eocene, the major rivers, and many of their tributaries (many flowing in strike valleys in LFB rocks exhumed from beneath the GAB cover) were well established and incising into their broad valley floors in their middle reaches in response to low base levels in the subsiding Murray Basin These palaeo-gorges began to alluviate in response to climatic and base level changes in the late Eocene, with most deposition occurring from the late Miocene to the present day They are economically important as sources of groundwater, and metals in 'deep leads'. Cainozoic volcanism affected drainage in the east of the area from the Eocene onwards We conclude, from apatite fission track (AFT) and vitrinite reflectance (VR) studies, and from our model of superimposition of drainage, that Mesozoic sediments originally extended far to the south of the preserved margin of the GAB and may have covered most of the southeastern Great Divide However, there may be problems in interpreting amounts of stripping from AFT and VR data in areas close to the locus of upwarp associated with continental breakup of eastern Gondwana

INTRODUCTION

Knowledge of palaeodrainage is essential to unravel landscape history in the Lachlan Fold Belt area Evidence for the configuration of palaeodrainage in the north Lachlan Fold Belt (Fig 1) is provided by field exposures of alluvial deposits and valley fill basalts, drillhole information, seismic surveys, magnetic and radiometric data, and analysis of drainage directions and valley character The direction of palaeodrainage may be indicated by aligned segments of modern drainage, buried and topographically inverted palaeoalluvium, and basalt flows Palaeodrainage deposits in the region vary in age from Mesozoic to Recent In some cases, palaeodrainage directions were oblique to modern drainage, or valleys had different gradients and base levels to those of today, indicating a dynamic palaeohydrological regime affected by factors such as climate, sea level, continental breakup, and basin subsidence (see Chan, 1999). This paper reviews several palaeodrainages and their deposits, and records new information recently gained by the authors in their regional regolith and landscape mapping in the northern Lachlan Fold Belt. It also draws attention to some problems in the interpretation of palaeodrainage in the area, and provides several possible models for the evolution of parts of the major rivers draining to the Murray Basin We also review some Apatite Fission Track (AFT) and Vitrinite Reflectance (VR) data pertinent to landscape evolution in eastern Australia, and conclude that there are problems in interpretation of this data which must be resolved

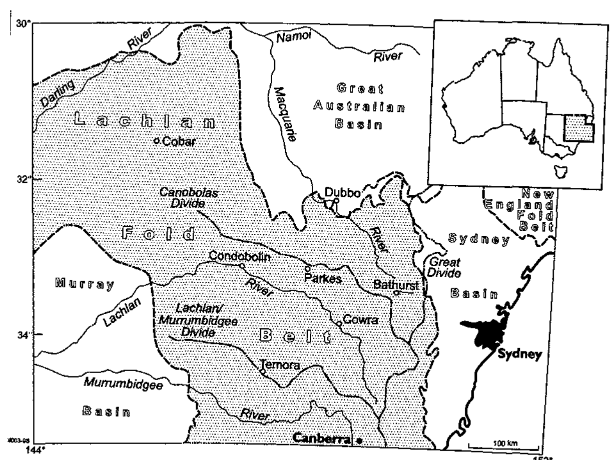

Figure 1: *Location map.*

REMNANTS OF MESOZOIC DRAINAGE

TRIASSIC DRAINAGE

Current directions in the mid-Triassic Hawkesbury Sandstone of the Sydney Basin indicate a sediment source to the southwest (Branagan et al , 1979), encompassing the Bathurst area East of Bathurst (Fig 1), but now west of the Great Divide, aligned northeast-trending segments of modern drainage suggest a prior integrated system draining to the northeast, which may have contributed to the Hawkesbury Sandstone This postulated system has since been incised and modified by stream capture and in places reversal of drainage direction This palaeodrainage is discussed further by Chan (1999)

REMNANTS OF JURASSIC AND CRETACEOUS DRAINAGE

Scattered topographically inverted alluvial deposits, some dated as Jurassic and Cretaceous, are present over a wide area of the north Lachlan Fold Belt

Molong Area

In the area west of Molong, topographically inverted alluvial deposits are present on and around the modern Canobolas Divide (the drainage divide between the modern Lachlan and Darling Rivers) These deposits crop out very poorly, except where artificially exposed in gravel pits or road cuttings, and are known mainly from lag of rounded clasts of pebble to boulder size, and fragments of iron cemented sandstone and conglomerate These are generally present on rounded rises, and also on an undulating plateau surface at Killonbutta State Forest, 14 km west of Molong Cuttings from seismic shotholes drilled by Australian Geological Survey Organisation in 1997 show that at Killonbutta, the preserved maximum thickness of the sediments exceeds 41 m (Fig 2) These include poorly- to moderately-cemented weathered sandstone and conglomerate, and grey mudstone, overlying granite Samples of the mudstone were collected for palynological analysis, and spores present indicate a Late Jurassic age (C Foster, AGSO, pers comm 1998), similar to that of the Pilliga Sandstone of the Surat Basin to the north, and no marine influence in the depositional environment A nearby large outcrop (along a forest track at about grid ref 55H 661200 6339800) of sandstone with minor pebbly beds, unconformably overlying granite, is strongly crossbedded The vector average of 16 palaeocurrent directions we measured from foreset directions, was due north (Fig 3) The sediments intersected by the drilling at Killonbutta range in elevation (surveyed by differential GPS) from 577 m (base of a hole 1030, which bottomed within sediment) to 647 m at the collar of hole 982 (Fig 2) We have no reason to suspect tectonic disturbance of the sediments, thus an original thickness in excess of 70 m is indicated Elsewhere in the area, similar sediments are present down to about 550 m, suggesting an even greater original thickness in palaeovalley floors, although tectonic disturbance cannot be ruled out

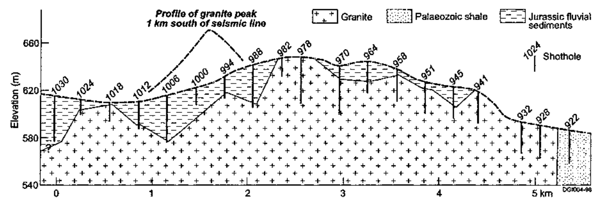

Figure 2: *Section through drillholes along 1997 AGSO seismic line, Killonbutta area, west of Molong*

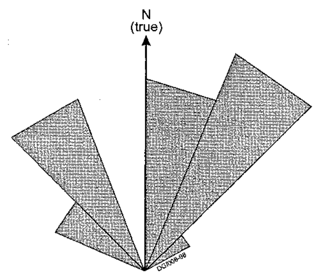

Figure 3 *Rose diagram of cross-bedding foreset directions in Jurassic sediments, Killonbutta area, west of Molong Vector mean of readings is due north*

The drillhole log section along the seismic line (Fig 2) shows considerable relief on the Jurassic unconformity over granite, with slopes reaching 6°, and original pre-sedimentation relief in excess of 70 m A nearby granite peak reaches 671 m, implying pre-sedimentation relief reaching 90 m if there has been no tectonic disturbance A further example of relief on the unconformity is from the property 'Calema Park', 7 km northwest of Molong The drillers log of a water bore drilled at the homestead, on the crest of a local hill, shows that it intersected 24 m of poorly consolidated red clayey sandstone above Silurian limestone (Fig 4) Pebble float and fragments of iron cemented sandstone on the southeast side of the hill, and elevation of the hilltop at about 610 m suggest that this sediment can be correlated with that at Killonbutta, 7 km away Limestone crops out on the hillside 70 m northwest from the bore, only a few metres in elevation below the bore collar Tectonic disturbance is not suspected, and thus a maximum slope of at least 15° on the pre-sedimentation landscape is indicated

At another nearby location, 4 km west of Molong, rounded pebble and boulder lag indicates that Jurassic sediments are present on a low rise at about 620 m near the axis of a strike valley cut in Devonian limestone, sandstone and shale, bounded by ridges of resistant Devonian sandstone up to 680 m in elevation (Fig 5) It is not only inferred that there was more than 60 m relief in the local landscape prior to deposition at this location, but also that the present day strike valley was already well established by the Jurassic It was partly, or even completely filled by Mesozoic deposits, and has since been exhumed

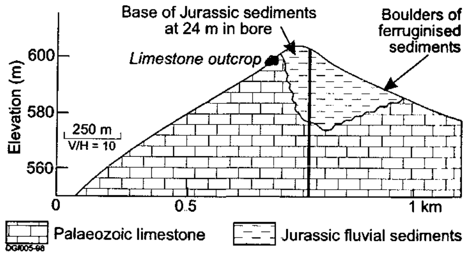

Figure 4: *Sketch section through hill at 'Calema Park', 7 km northwest of Molong*

Parkes Area

An apparent inverted Jurassic palaeodrainage is present 20 km west of Parkes The Parkes Special 1:100 000 geological sheet (Krynen et al , 1990) shows Jurassic sediments to continue to the north-northwest for about 40 km in a meandering belt about 5 km wide These consist of poorly cemented sandstone and conglomerate present along a broad ridge at 300-320 m elevation Plant macrofossils in sandstones in the unit are too fragmental for reliable identification, but are consistent with Jurassic genera (Clarke & Sherwin, 1990) Cross bedding exposed in a gravel pit on the Parkes-Bogan Gate road indicates a northward current direction, but no specific readings have been taken by the authors The palaeochannel passes through a gap in a ridge of Devonian quartzite, indicating that the ridge and gap were present in the Jurassic The overlapping Narromine 1:250 000 geological sheet (Sherwin, 1997) shows the extent of the Jurassic sediments to be much wider than that shown on the 1:100 000 map, with the sediments forming a 15 km wide swath in a valley in the axis of the Tullamore Syncline Hence it is uncertain whether the sediments are the remnant of a discrete Jurassic palaeochannel, or whether they are an erosional remnant of a broad sheet of sediment deposited in a wide Jurassic valley, draining northward to the Surat Basin proper

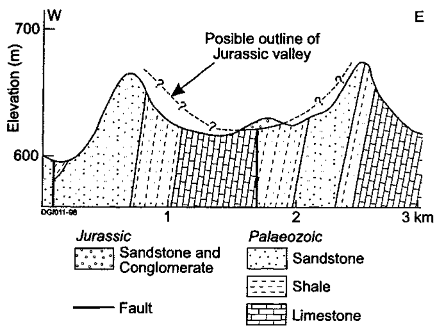

Figure 5: *Sketch across strike valley, 4 km west of Molong*

Cobar Area

Sediments dated as Early Cretaceous by microfauna have been identified 60 km west of Cobar (Rayner, 1969) Our investigations suggest that the dated sediments are from exposures of possible glacio-fluvial to lacustrine fine sandstone and siltstone containing matrix supported boulders in road cuttings on a former alignment of the Barrier Highway, 1-2 km west of The Meadows historic site, to the south of the modern highway The subrounded boulders, up to 1 metre in size, in the sediments are mostly of quartzite, consistent with local derivation from Middle to ?Late Devonian fluvial sediments (Mulga Downs Group) forming hills in the area The Barnato 1:250 000 geological sheet (Rose, 1965) shows one small area of Cretaceous rocks, centred on the cutting exposures, and numerous areas of silcrete in the area Many of the areas mapped as silcrete have a pebble to boulder lag similar to that of the area with the dated exposure, as well as silcreted sediment, and there are poor exposures of poorly consolidated sandstone and conglomerate Hence it appears that the Cretaceous sediments formed a broad valley fill, surrounded by higher ground made up of resistant Devonian rocks The Cretaceous sediments have since been dissected, leading to local topographic inversion, although they still occur in a broad valley cut in the Devonian rocks

Sixty km north-northwest of Cobar, fluvial sediments cap several small mesas at and around Tyncin trig point The sediments include clasts of quartzite up to 1 m in size, indicating either a very local source for these clasts, very high water velocities, or ice transport The present-day nearest outcrop of a possible source for the quartzite clasts is about 20 km distant In addition, the deposits are all at a similar elevation, implying low depositional gradients. Hence it is concluded that ice has been a factor in sediment transport, and that the sediments are of Late Jurassic to Early Cretaceous age. Frakes & Francis (1988) and Frakes et al. (1995) record that large, ice-rafted boulders to 3 m in diameter, are common in shales in the southern Eromanga Basin, and pseudomorphs after ikaite (a hexahydrate of calcite which is unstable above 5°C) have been reported (Sheard, 1991). Frakes et al. (1992) point out that eastern Australia was at a latitude of 65-75 degrees south, and subject to seasonal ice in the Late Jurassic to Early Cretaceous. Indications of Jurassic to mid-Cretaceous seasonal ice are also present in North America, Siberia, and Spitzbergen, all of which had palaeolatitudes of 60 to 80 degrees north at the time.

The effect that seasonal ice would have on the sediment load of the rivers draining to the 'Eromanga sea' is extremely important. Bedload boulders would be enclosed within the ice of frozen rivers during winter, and transported by ice-rafting during spring thaw. Hence it is expected that any Late Jurassic to Early Cretaceous drainage system would have the potential to include large ice-rafted boulders. In a purely fluvial situation, these would imply exceptionally high water flow velocities, or extremely local derivation in high relief areas, for instance from landslides, and individual blocks falling down steep slopes into the river. However, with ice transport, such extremes are not necessary.

REMNANTS OF CAINOZOIC DRAINAGE

The Lachlan and Darling River Systems

The modern Lachlan River below Cowra and some of its tributaries, and the Darling River and its major tributaries, flow over filled palaeovalleys, previously eroded up to 140 m below present day river level. The alluvial fill in these palaeovalleys has been investigated in detail by the Water Resources Commission of NSW, because it contains large groundwater resources, and in places stores and releases salt into the modern riverine system.

Mount (1992) describes the system downstream from Bourke, where there is a 140 m thick sequence of alluvium. An Early Miocene date for a sample from 56 m depth has been determined by Martin (in Mount, 1992). Mount attributes the thickness of sediment to deposition in small subsiding transtensional Cainozoic basins along the Darling River Lineament, but there must have been a continuous incised valley beneath the Darling in the Bourke area. This has been shown to be the case further upstream in the Darling and its tributaries (see Martin, 1991), and erosion of an incised river course in these areas would require a far lower base level in the Bourke area than is present today; the subsiding basin model would not necessarily give this low base level. Most of the sediment fill beneath the upper Darling and its tributaries is Late Miocene or younger, but Early Miocene sediments are locally present near the base of the sediment pile, for example in the Castlereagh River palaeovalley fill near Gilgandra, and the Macquarie River palaeovalley fill near Mudgee (Martin, 1991).

The sediments beneath the modern Lachlan River downstream from Cowra (Fig 6), and along buried palaeovalleys beneath Back and Bland Creeks, have been studied by drilling and shallow seismic techniques by the NSW Department of Water Resources. The alluvial fill is mostly of Late Miocene to Recent age, and has been divided into two units, the older Lachlan and younger Cowra Formations, which are separated by an erosional hiatus (Williamson, 1969, 1986; Anderson et al., 1993). However, Early Miocene sediments are also present at the base of the sequence at Jemalong Gap, downstream from Forbes (Martin, 1991).

In our abstract for this paper (Chan & Gibson, 1998), we incorrectly attributed the incision of the rivers to the

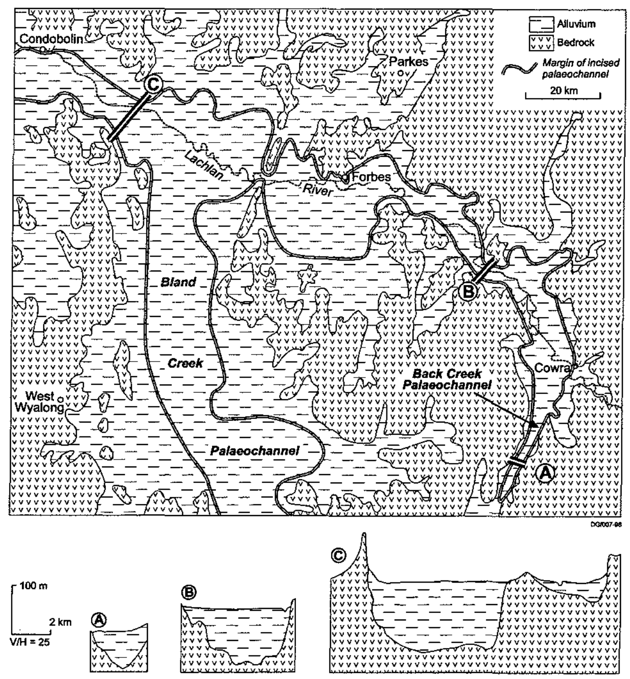

Figure 6. *Extent of, and sections through Lachlan palaeovalley between Cowra and Condobolin. After Williamson (1969, 1984) and Anderson et al. (1993).*

Miocene global sea level low (e.g., Haq et al., 1988; Pigram et al., 1992), but the incision must be older than this if Early Miocene sediments are locally present at the base of the palaeovalley fill. The Murrumbidgee River also has a buried palaeovalley, and sediments in this date back to the Late Eocene (Martin, 1991). We consider that the Murrumbidgee River had a similar history to the Lachlan, and thus it is probable that entrenchment of the Lachlan predated the Late Eocene. Major alluviation of these palaeovalleys commenced in the Late Miocene, probably in response to climate change associated with the sea level low (Martin, 1991). Although the alluviated palaeovalley along the Lachlan River is generally referred to as a gorge, its width varies markedly from about 12 km (e.g., at Forbes), to 1.5 km at Jemalong Gap, 22 km downstream from Forbes (Fig. 6). Cross sections from drilling and seismic surveys (Williamson, 1969, 1986; Anderson et al., 1993) also show marked variation in valley shape (Fig. 6). The variation in morphology is most likely to result from differential erosion, as the course of the river passes across rock units with markedly different resistance to erosion. For example Jemalong Gap is cut across a ridge of resistant Devonian sandstone, whereas weathered Early Palaeozoic volcanics and sediments are present downstream where the valley widens.

Further downstream in the Lake Cargelligo area, Woolley & Williams (1994) show that the buried valley averages about 10 km wide, and that it divides into two downstream branches about 50 km upstream of the margin of the Murray Basin proper, with one branch proceeding west, and the other more southwest, roughly along the course of the modern Lachlan River from Euabalong to Hillston. We cannot presently explain the bifurcation without major alluviation, incision and then further alluviation. Woolley & Williams (1994) indicate that the Lachlan probably originally flowed along the northern arm, but then cut a new channel to the south, possibly in the Pliocene, which has since filled with sediment. We consider that to move to a new channel location, the original valley would need to have been alluviated to the extent that the river could evulse or be captured to a new course to the south, across bedrock. Reduced base level (we can only speculate as to a mechanism for this, unless it is the global sea level low in the Late Miocene, which corresponds with a major depositional hiatus and time of incision in the Murray Basin (Brown & Stephenson, 1991)) would then initiate the erosion of a new gorge in bedrock back to the old valley by nickpoint retreat, and presumably then rapidly erode the valley fill in the original gorge for an unknown distance upstream. A nickpoint could also retreat along the old abandoned northern course of the Lachlan, but in a westerly direction (drainage in this part of the valley would be reversed) with little vigour due to the vastly reduced catchment of this part of the valley. Beginning at some later date and continuing to the present, both valleys would be again be alluviated up to the present day level. If the Lachlan continued to flow along the southern valley during this alluviation, the two packets of second stage valley fill sediment would probably be markedly different, with the northern valley having a fill of locally derived sediment transported by the now grossly underfit streams flowing along it, and the southern valley having a fill derived from the hinterland catchment of the Lachlan. Woolley & Williams (1994) indicate that the fill of the northern valley is finer, and consider it to be older than that in the southern valley.

The pre-alluviation lower local base level along the Lachlan has had a marked effect on its tributaries. Williamson (1986) and Anderson et al. (1993) describe two alluviated tributaries. The Back or Crowther Creek palaeochannel (Fig. 6), from Young to near Cowra, has been steeply incised into a little-weathered bedrock dominated terrain with several hundred metres relief, its linear course suggesting structural bedrock control. In contrast, the Bland Creek palaeochannel, flowing north from near Temora is cut through a weathered terrain. The area of deepest erosion was about 20 km wide, but the total width of the alluviated valley reaches 60 km southeast of West Wyalong.

Another example of an alluviated valley incised to a deeper base level than present today, south of the Lachlan River, is at the Gibsonvale alluvial tin workings, 55 km west-northwest of West Wyalong, described by Campi et al. (1975). Present day relief in the area is generally low, but the pre-alluviation landscape appears to have been a valley up to 1 km wide and 35 m deep, flowing near the boundary of a granite batholith and surrounding Palaeozoic metasediments. The palaeo-stream bed, exhumed by open cut mining, had features such as steep banks, rapids, and scour holes, eroded mostly in weathered granite. Campi et al. (1975) favour an Oligocene age, when a 'youthful stream pattern was active in the general region', for incision of the valley. Modern drainage does not follow the palaeo-stream.

To the north of the Lachlan River, several broad alluviated valleys extend northward across the Nymagee 1:250 000 sheet area, as shown by Suppel & Gilligan (1993) and Gibson (1996). Another area of alluvial tin workings, Tallebung, is at the western margin of one of these valleys. Here, an integrated drainage system on bedrock has been traced to about 30 m depth beneath alluvium (Suppel & Gilligan, 1993), within one kilometre of bedrock outcrop. Palaeo-stream gradients are as high as 1 in 20, far higher than present today in adjoining outcrop areas. Sediment depth in the axis of the main valley is unknown, but a water bore (No 14077, Water Resources Commission) in a similar valley to the west intersected 95 m of clay and sand (Scheibner, 1987), and company data indicate alluvium to at least 50 m thick in an eastern branch of the Tallebung system palaeovalley, in the far east of the sheet area. Hence there is a general indication of broad valleys draining south into and graded to the incised Lachlan River. These were alluviated along with the main Lachlan valley, with deposition reaching far up the valleys to form broad valley plains with little modern integrated drainage.

Buried palaeodrainage deposits with a magnetic component

Many scenes of magnetic imagery across the northern Lachlan Fold Belt area show areas of small branching anomalies which appear to be unrelated to bedrock. The anomalies are generally of high frequency, but small amplitude. These anomalies are interpreted to be mostly alluvial channel deposits which contain detrital magnetic (most probably maghemite) pisoliths as part of the granule to small pebble sized component of the sediment. Ford (1996) has described pisoliths from a magnetic palaeochannel north of Cobar, and we have observed sediments with detrital pisoliths at the Gibsonvale alluvial tin workings (see above), and at excavations at the West Wyalong rubbish tip (see below), where sediments are exposed in a 6 m deep trench. Magnetic susceptibility of the sediments, measured with a hand held meter, is up to 20 000 x 10^{-5} SI.

Gidley (1981) demonstrated that magnetic surficial materials are widespread in the Cobar region. These can be clearly seen in magnetic images over the Cobar area as areas of small amplitude and short wavelength anomalies. Broad anomalies generally correspond with thin accumulations of maghemite-bearing sediment associated with modern channels. However, there are narrower, more intense anomalies which correspond to buried incised palaeochannels. A good description of one of these, and coloured magnetic images, are given by Ford (1996). Ford attributes the erosion of this palaeovalley to differential uplift or subsidence, but we consider it far more likely that it represents a southern tributary gorge of the Darling River gorge mentioned above, graded to a far lower base level than is present today.

Numerous areas with magnetic palaeodrainage lines have been interpreted from aeromagnetic images as far east and south as Barmedman, between Temora and West Wyalong, and we have observed magnetic pisolith lag as far southeast as Temora. Northeast of Lake Cargelligo, some short magnetically defined palaeochannels appear to have fringed the palaeo-Lachlan gorge, whilst others flowed from an area of low hills (Fig 7). Areas of magnetic lag, if dense enough, may show as being thorium rich on radiometric imagery, thorium being geochemically associated with iron. A broad thorium rich area north of West Wyalong (Fig 8) appears to correlate with an area of mottled granite saprolite, and magnetic pisolith lag derived from erosion of the saprolite and locally-derived pisolith-bearing sediment (the West

Figure 7: *Magnetic image from Lake Cargelligo area showing magnetic palaeochannels.*

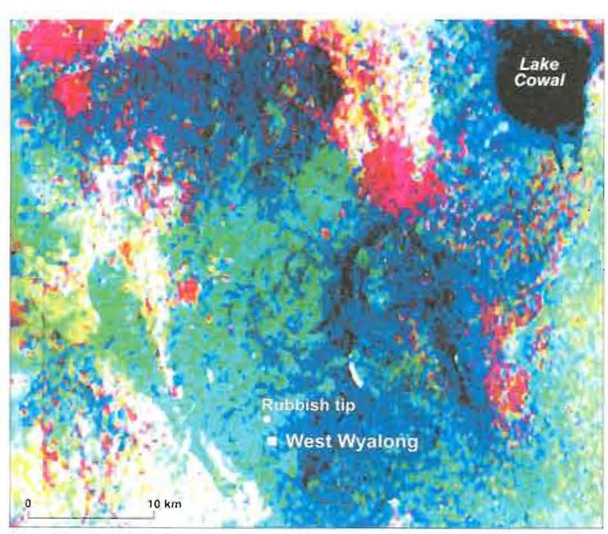

Figure 8: *Radiometric image showing area with mottled granite saprolite and magnetic pisolith lag (light blue/green) north of West Wyalong.*

Wyalong garbage tip site mentioned above is an exposure of this material).

The presence of detrital magnetic pisoliths in the fill of incised valleys graded to the Lachlan and Darling River systems points to a source which became available possibly as early as Late Miocene Martin (1991) shows a vastly increased charcoal content of the sediments of the Lachlan Valley from the Late Miocene onwards, and we consider that the inferred change in fire regime may have initiated the development of maghemite from goethitic precursors present at the land surface due to heating of surface goethite during bush fires (see eg Anand & Gilkes, 1987) Alternatively, increased dryness may have initiated the formation of microbial varnishes which may include maghemite The presence of possible goethitic precursors does not necessarily imply erosion of an iron-rich weathering crust; small goethitic masses may grow in soils in colluvial and residual deposits, and erosion of these soils will liberate them to the surficial environment for possible crystalline transformation, and transport to depositional sites.

Inverted palaeodrainage defined by basalt flows

Numerous inverted basalt flows overlying alluvial sediments are known from the eastern part of the area, with basalts ranging in age from 41 to 11 Ma. A prior course of the Macquarie River between Bathurst and Dubbo is defined from a series of linear 12 Ma basalt flows adjacent to the modern river The basalts overlie alluvial sediments of rounded pebbles in a sandy matrix Since extrusion of the basalt, the river has incised up to 210 m, an average incision rate of about 18 m/Ma

To the southwest of Orange, a large basalt flow from the 12 Ma Canobolas volcano flowed to the west along the palaeovalley of Bourimbla Creek, then down the valley of Mandagery Creek (Fig 9). In the east, the basalt has been incised by as much as 100 m In the vicinity of Toogong, the base of the basalt is approximately at present day stream level, indicating no net erosion in 12 million years Further to the west, Williamson (1986) reports 12 m of 12 Ma basalt beneath 73 m of alluvium in the lower reaches of Mandagery Creek, near its junction with the Lachlan River Assuming no differential uplift, the gradient of the Mandagery-Bourimbla Creek system has been lowered considerably since 12 Ma, by aggradation of lower reaches, and incision of upper reaches of the system. However, it is possible that the area around the Canobolas volcano has been domed by magma injection at depth since extrusion of lavas (Wellman, 1986).

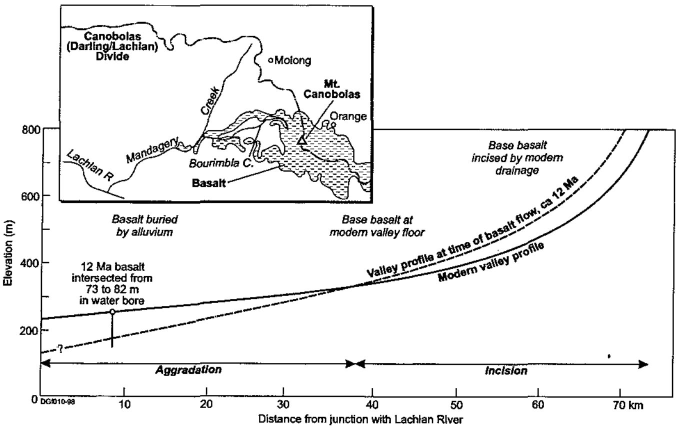

Figure 9: *Profile along Bourimbla/Mandagery Creeks, showing extent of incision and aggradation since 12 Ma basalt flows.*

Olivine leucitite flows northeast of Cobar have been described by Byrnes (1993) and Cundari & Ollier (1970). Their age is about 12 Ma (Wellman & McDougall, 1974) From the plan outline of one flow, Cundari & Ollier concluded that the flow was constrained by a valley sloping to the southeast, the generally opposite direction to present day drainage and inferred Mesozoic palaeodrainage to the Eromanga Basin (Ollier & Pain, 1994) Byrnes (1993, p 68) concluded that the flows, which locally exceed 40 m in preserved thickness, were constrained by valley sides of weathered rock. If this were the case, there has been removal of at least 40m of surrounding rock since extrusion. We consider that erosion rates in the Cobar area have generally been much lower than this, and there is thus a conflict of interpretation It is possible that the flows were not constrained, but gained their thickness through formation of a skin over the flow, and inflation by injection of more lava beneath that skin (K McQueen, University of Canberra, pers comm 1997) These deposits need to be studied in more detail to determine whether the conclusions of Cundari & Ollier (1970) and Byrnes (1993) are correct

Deep leads

Numerous auriferous 'deep leads' were mined for gold last century across the northern Lachlan Fold Belt These are generally steep-sided and steep-gradient alluviated valleys, with floors at depths of 30-140 m below present day land surface (Wilson & McNally, 1996). We consider these to be the alluviated proximal portions of valleys graded to the incised Lachlan River and other major rivers, eroded prior to the Late Miocene, and probably alluviated since that time Whilst eroding, these valleys would have had a considerable amount of sediment passing though them, the high stream gradients assuring transport of gold particles from eroding bedrock deposits, as well as less dense detritus. Natural riffles in the high gradient stream bed would trap the gold along with coarser gravels. These would be buried with finer sediment during alluviation, giving rise to buried 'wash', so eagerly sought after by the miners last century. A corollary of this interpretation is that no local tectonic movements are necessary to initiate erosion of the deep leads. Also, the leads should form an integrated network with other alluviated palaeovalleys, many of which remain undetected.

There are reports of deep leads suddenly terminating against a steep wall of bedrock, possibly implying tectonic displacement. We interpret that in these cases, the gorge in which the deep lead was deposited joined a larger incised gorge, and the 'bedrock wall' is in fact the far wall of the larger gorge, not a fault. If the early miners had turned left or right, they would probably have found more bedload 'wash', but probably without the high gold content of the deep lead, as they now would be in the original bed of a larger stream with its headwaters not necessarily in gold bearing rocks.

PROBLEMS IN THE INTERPRETATION OF PALAEODRAINAGE AND LANDSCAPE HISTORY

Many features of palaeodrainage across the northern Lachlan Fold Belt differ from those of modern drainage. Drainage directions of major rivers have changed from north to northwest or west, some watercourses appear to have been reversed, valleys have at times been incised and since been alluviated, valley gradients have changed, and grainsize of bedload deposits has varied. In trying to erect an integrated model for drainage evolution across the area, many assumptions have to be made. The most pertinent questions we consider need answering, and our responses (in some cases a best guess only) are given below.

WHAT DETERMINED THE COURSE OF THE DARLING RIVER, AND WHEN?

The proto-Darling River probably came into existence in the Late Cretaceous as a result of upwarp of the eastern highlands of Queensland and northern NSW. Senior & Exon (1976) postulate that the plain left by regression of the Early Cretaceous sea in the Eromanga and Surat Basins sloped to the north, towards the Gulf of Carpentaria, and attribute a change in drainage direction towards the Murray and Eyre Basins to uplift of the eastern highlands in the mid-Tertiary. Apatite fission track data show that this uplift in fact occurred much earlier, at about 95 Ma in the Late Cretaceous (e.g., see Lister et al., 1991; O'Sullivan et al., 1995; O'Sullivan et al., 1996).

The northeast trending Darling River Lineament (Sherbon Hills, 1956, and later authors) is suggested by the alignment of the Darling River and some of its tributaries. However, these rivers flow for the most part over Eromanga/Surat Basin and younger sediments, which would not be expected to impart a linear course to the river. We interpret that post-sediment movement must have occurred along the lineament. Kohn et al. (1997) have interpreted from apatite fission track data that there has been a long history of differential movement across the Darling River Lineament, with latest movements being in the mid-Tertiary, south side up by ~1 km. We cannot accept this figure, on the grounds that Cretaceous sediments are still preserved south of the lineament, west of Cobar as described above. However, a small displacement could initiate the course of a new drainage (the proto-Darling River) along a fault angle depression. Mount (1992) shows several faults along the Darling River which have displaced sediments by up to 50 m. Alternatively, the Darling River Lineament may have been the locus of the intersection of a northwest palaeoslope developed in NSW, and a south-southwest palaeoslope in Queensland after uplift of the eastern highlands, and thus form a structural drainage depression.

We interpret that the Darling River has probably always drained to the Southern Ocean via the area which is now the Murray Basin. It predates the Murray Basin, and thus is not dependent on downwarping of the basin for its inception. According to Ollier & Pain (1994), our interpretation is not in agreement with Stephenson & Brown (1989), whom Ollier & Pain claim to have noted that "drainage into the Murray Basin from the north did not develop until at least the early Tertiary". However, Stephenson & Brown in fact state that it is "probable that some south-flowing precursor of the Darling existed throughout the Cainozoic", implying a Cretaceous age for the initiation of a proto-Darling.

WHY AND WHEN DID MAJOR RIVERS IN NSW BEGIN TO FLOW WEST?

The upper reaches of the Lachlan, Murrumbidgee, and Murray Rivers are generally in valleys controlled by north-trending structures of the Lachlan Fold Belt. However, the middle reaches of these rivers, upstream of where they leave the Fold Belt to flow over the Murray Basin proper, are at an oblique angle to structure In these middle reaches, all three rivers have longer southern tributaries than northern, and the northern tributaries have higher gradients. Many of these tributaries are in valleys parallel to local structure. Ollier & Pain (1994) have argued that these tributaries form segments of a now disrupted Mesozoic drainage system flowing north to the 'Eromanga Sea'; we do not dispute this. However, the mechanism for formation of new cross-cutting courses for these three major rivers has been unclear. Any model must take into account the fact that these rivers were flowing to the Murray Basin from its inception in the Palaeocene, and that by the Eocene they were entrenched into the surrounding Lachlan Fold Belt rocks (late Eocene sediments are known from the base of the ~155 m thick alluvial sequence in the Murrumbidgee valley at Narrandera; Martin, 1991).

Three possible explanations for the origin and courses of these rivers are capture, structural control, and superimposition. Ollier & Pain (1994) argue that the proto-Canobolas Divide between the Lachlan and Darling Rivers was formed by downwarping of the Murray Basin, implying that it was initiated in the very early Tertiary by a tectonic warp which downwarped not only the area which is now the Murray Basin, but also the area to the east of the basin. They do not give a mechanism for generation of new river courses, the reader being left to surmise that the downwarp was sufficient to cause wholesale rearrangement of drainage. If this was by capture or evulsion of drainage already flowing on Lachlan Fold Belt rocks, one would expect to find a network of major drainage zigzagging across the area, with north-flowing reaches of the rivers being parts of the original northerly-flowing drainage, and west-flowing reaches originally being new west-flowing tributaries initiated by the tilting, which then captured older drainage. This is not the case. Additionally, the capturing, and formation of the new system would have to take place very rapidly, as the river systems were already in place, and incised by up to 150 m, early in the history of the Murray Basin.

Structural control of the rivers is possible. The middle reaches of the Lachlan River, from Wyangala Dam to Condobolin, flow along the general area of what has been termed the Lachlan River Lineament (e.g., Scheibner 1974; Scheibner & Stevens, 1974). Scheibner concluded that resurgence of fault activity, expressed as the emplacement of Jurassic explosive vents in the Sydney Basin and the Miocene Canobolas volcano, occurred in the Mesozoic and Cainozoic along this lineament. For the Lachlan River Lineament to control the course of the Lachlan River, we consider that there must have been movement, north side up, along the lineament, which diverted north-flowing drainage along a fault angle depression which became the locus of the river in this area. If this is the mechanism for the Lachlan, what about the Murrumbidgee and Murray? To our knowledge there are no recognised structures along their courses, so a different mechanism is required for these. Secondly, if there was north side up differential movement across the Lachlan River Lineament, this might be reflected in landforms in the area. We consider that strike ridges of resistant Devonian sandstones in the area are old landforms with very low erosion rates. The Lachlan River flows through in a narrow gap in one of these ridges, (Jemalong Range), between Forbes and Condobolin. The crest of the range on either side of the river is at the same height, implying that there has been no differential movement along a possible fault.

Superimposition is a third possibility. Chan (1999) argues that the northwest course of the Lachlan and Macquarie Rivers is superimposed from now-eroded sediments of the Surat Basin, the northwest to north-northwest flow direction being initiated by uplift of the eastern highlands at about 95 Ma. Prior to tilting, rivers would have flowed to the north on low gradient floodplains over the Surat Basin, and adjustment of drainage directions due to tilting could be easily accommodated by drainage migration, evulsion, and capture on these plains. The uplift would also result in incision, through the sediments, and then into the Lachlan Fold Belt rocks below, thus superimposing the new major drainage lines. However, many tributaries would not have the erosive power to superimpose their courses onto the pre-sediment topography, and would re-establish themselves in the pre-sediment valleys by preferential erosion of the softer basin sediments. The new southern tributaries would flow down the original slope of the valley floors, but the northern tributaries would be reversed.

Given the proximity of the preserved Surat Basin and its outliers to the Lachlan River, this appears to be a reasonable explanation for that river. However, the Murrumbidgee and Murray are far distant. Did the sediments of the Great Australian Basin extend far to the south of their modern distribution, to be rapidly eroded after uplift and tilting by the proto Lachlan, Murrumbidgee and Murray Rivers, which were themselves products of the tilting? If so, perhaps this is an explanation for the 'kilometre scale denudation' that uplift early in the Late Cretaceous They also state that there is indirect evidence of "significant sedimentation beyond the limits of the Otway-Gippsland Basins in the interval 130-95 Ma", and speculate that Late Triassic, or Late Jurassic to Early Cretaceous sediments extended over the Sydney Basin In addition, recent AFT data from north Queensland (e g , Marshallsea, 1998) indicates removal of up to several kilometres of rock from the eastern highlands in the area south of the Laura Basin Marshallsea (pers comm 1998) has indicated that extensions of the Jurassic to Early Cretaceous Laura and Carpentaria Basins could well have formed part of the eroded rock. Finally, Brown (1996) has suggested that AFT data can be reconciled with the presence of Late Cretaceous lavas at Mt Dromedary on the NSW south coast (Nott & Purvis, 1995). He suggests that the volcanics may be interpreted as "a small remnant of what was once a thick extensive cover of Early Cretaceous volcanic rocks and volcanic-derived sediments, which was rapidly eroded in the early Late Cretaceous (about 90 Ma) to exhume an old low relief land surface on Palaeozoic rocks". We agree with the suggestions of these authors, and would like to reinforce Brown's interpretation of an exhumed surface being the low relief warped surface that is evident over much of the eastern highlands

Is there a problem in the interpretation of AFT and VR data?

AFT and VR data pose a dilemma for the geomorphologist, suggesting rapid kilometre scale denudation of the eastern highlands of Australia in the period 100-80 Ma (e g., Raza et al , 1995; O'Sullivan et al , 1995; O'Sullivan et al , 1996) The geomorphologist interprets landscape in the area as being somewhat stable, with rapid incision in some upland areas over the last 10-20 Ma, but preservation of 40 Ma landforms (as shown by dated basalt flows) in others Pillans (these proceedings) has inferred, from palaeomagnetic studies, that weathering has been an on-going process near Parkes since at least late Palaeozoic time, implying a very ancient landscape for this area. Ollier & Pain (1994) contend that much of the landsurface of southeast Australia consists of a 'palaeoplain' which has been little modified since the Early Cretaceous.

We consider there may be a problem with interpretation of AFT and VR data in the eastern highlands region, for example the kilometre scale denudation in the Bathurst area predicted by O'Sullivan et al (1995), but from a basin development rather than landscape point of view Data from the wells Macintyre 1 and Flinton 1, drilled near the NSW/Queensland border through the Surat Basin, indicate 1 3-1 4 km of stripping (Raza et al., 1995; 1998 unpublished ms). This figure is in accordance with data from other wells in the area, also determined by Raza et al , but these two wells penetrated 300-400 m of Griman Creek Formation at the top of their stratigraphic section. This unit averages 300 m thick (Senior & Exon, 1976), and has a maximum preserved thickness of 480 m (Raza et al, 1998). It is the youngest preserved unit of the Surat Basin, and is regressive and mostly non-marine. The sediment removed during the stripping in the vicinity of these two wells must have been the top part of the Griman Creek Formation, and possible younger rocks which have been completely removed in all areas Not only was the eroded sequence 1300-1400 m thick, the stratigraphic table provided by Raza et al implies that it must have been deposited very rapidly, as the deposition of the Griman Creek Formation commenced only about 5 My prior to the beginning of uplift.

However, Raza et al show that AFT data from other wells from further north in the Surat Basin which are spudded into the basal units of the Basin sequence (e g , Cockatoo Creek 1, Burunga 1,Wandoan 1, and Canaan 1) still require only ~1-1 5 km denudation, and data from wells to the south which also penetrated the basal part of the sequence (Narrabri 2 and Springfield 1; A Raza, pers comm 1998) indicate 0 9 and 2 km of erosion respectively. This amount of denudation requires deposition of a typical or even condensed Surat Basin sequence before uplift and erosion, without recourse to a further 1300-1400 m overlying sequence Thus the laboratory data imply vast variations in original thickness of the Griman Creek Formation and possible overlying units, and where thickest, a depositional rate of about 300 m/Ma, far in excess of any other unit in the Basin. Is there another explanation for the Surat Basin data which doesn't include great depositional contrasts, and interestingly, roughly the same amount of stripping, no matter what stratigraphic level of the Surat Basin is present at the surface? We cannot presently provide any alternative, but we consider these data need further study from both a geodynamic, basin analysis and landscape history point of view If there are other reasonable explanations, might these also apply to interpreted AFT/VR data from the eastern Lachlan Fold Belt area?

It should be noted that Marshallsea (1998) has speculated that high palaeotemperatures in the Jurassic to Early Cretaceous Laura Basin in northern Queensland may be "related to the introduction of heat at a shallow level within the section, possibly as a result of hot fluid circulation".

CONCLUSIONS

Evidence for the configuration of palaeodrainage on the northern Lachlan Fold Belt is varied, ranging from field exposures of alluvial deposits and valley fill basalts, drillhole information, seismic surveys, magnetic and radiometric data, and analysis of drainage directions and valley character A key to understanding landscape evolution is drainage, as it is the configuration of rivers that shapes the landscape The assessment of various aspects of drainage evolution in this paper highlights that while we know some of the drainage, and thus landscape history, of the area, there are important questions still to be answered Primarily, we must assess the extent of sedimentation of the GAB southward across the Lachlan Fold Belt, and the extent of uplift in the mid-Cretaceous These two factors will have an important effect of on the drainage history of the Lachlan Fold Belt. Secondly, AFT/VR data from eastern Australia must be carefully studied by geomorphologists, sedimentologists, basin analysts and structural geologists, with a view to resolve the apparent conflict in interpretation of depositional and landscape history of the eastern highlands of Australia.

ACKNOWLEDGEMENTS

This paper is published with the permission of the executive director, AGSO, and the director, CRC LEME Thanks to A Vartesi, and C. Steel for preparing the illustrations, P. O'Sullivan and A Raza (Australian Geodynamics CRC) for stimulating discussion on implications of AFT data, and C Pain and P de Caritat for reviewing the manuscript

REFERENCES

ANAND, R R & GILKES, R J, 1987. Occurrence of maghemite and corundum in Darling Ranges laterites, Western Australia Australian Journal of Soil Research, 25, 303-311

ANDERSON, J, GATES, G & MOUNT, G J., 1993. Hydrogeology of the Jemalong and Wyldes Plains irrigation districts New South Wales Department of Water Resources, Technical Services Report 93 045

BRANAGAN, D F, 1983 The Sydney Basin and its vanished sequence Journal of the Geological Society of Australia, 30, 75-84

BRANAGAN, D F, HERBERT, C & LANGFORD-SMITH, T., 1979 An outline of the geology and geomorphology of the Sydney Basin The University of Sydney, Sydney

BROWN, C M. & STEPHENSON, A.E, 1991. Geology of the Murray Basin, southeastern Australia. Bureau of Mineral Resources, Australia, Bulletin, 235.

BROWN, M.C., 1996. Discussion and reply: Geomorphic and tectonic significance of Early Cretaceous lavas on the coastal plain, southern New South Wales Australian Journal of Earth Sciences, 43, 688-689.

BYRNES, J.G., 1993. Bourke 1:250 000 metallogenic map. Metallogenic study and mineral deposit data sheets Geological Survey of New South Wales, Sydney.

CAMPI, D, McGAIN, A. & ELLEM, C, 1975 Gibsonvale alluvial tin deposit, N S W In: Knight, C.L. (Editor), Economic Geology of Australia and Papua New Guinea, 1. Metals. The Australasian Institute of Mining and Metallurgy, Melbourne 1049-1053

CHAN, R A, 1999 Palaeodrainage and its significance to mineral exploration in the Bathurst region, NSW. Proceedings of Regolith 98 Conference, Kalgoorlie, WA, May 1998 CRC LEME, Perth.

CHAN, R.A & GIBSON, D L, 1998 Aspects of palaeodrainage in the north Lachlan Fold Belt region Regolith 98, Abstracts CRC LEME, Perth, 36

CLARKE, I & SHERWIN, L, 1990 Geological setting of gold and copper deposits in the Parkes area, New South Wales. Records of the Geological Survey of New South Wales, 23(1)

CUNDARI, A. & OLLIER, 1970. Inverted relief due to lava flows along valleys. Australian Geographer, 11, 291-293.

FORD, A.H, 1996. Re-interpreting the north eastern margin of the Cobar Basin using drainage channel morphology In Cook, W.G (Editor), The Cobar Mineral Field, a 1996 perspective The Australasian Institute of Mining and Metallurgy, Melbourne.

FRAKES, L A. & FRANCIS, J E, 1988 Early Cretaceous Ice Geological Society of Australia, Abstracts, 21, 144-145.

FRAKES, L A, FRANCIS, J.E. & SYKTUS, J I, 1992. Climatic Modes of the Phanerozoic. Cambridge University Press, Cambridge.

FRAKES, L A, ALLEY, N F & DEYNOUX, M, 1995 Early Cretaceous ice rafting and climate zonation in Australia International Geology Review, 37, 567-583

GIBSON, D L, 1996 Cobar Regolith Landforms (1:500 000 map scale). CRC LEME, Perth

GIDLEY, P.R., 1981 Discrimination of surficial and bedrock magnetic sources in the Cobar area, New South Wales BMR Journal of Australia Geology and Geophysics, 6, 71-79

HAQ, B U., HARDENBOL, J & VAIL, P.R., 1988 Mesozoic and Cenozoic chronostratigraphy and eustatic cycles. Society of Economic Palaeontologists and Mineralogists, Special Publication 42, 71-108

JONES, J.G & VEEVERS, J J., 1983. Mesozoic origins and antecedents of Australia's eastern highlands. Journal of the Geological Society of Australia, 30, 305-322

KOHN, B P., O'SULLIVAN, P, GLEADOW, A J W, FOSTER, D A & COX, S D J, 1997 Recognition and visualisation of basement reactivation in eastern Australia using apatite fission track thermochronology Abstracts, Geodynamics and Ore Deposits Conference, Australian Geodynamics Co-operative Research Centre, Ballarat, Victoria, 55-58

KRYNEN, J P., SHERWIN, L & CLARKE, I., 1990 Parkes Special 1:100 000 geological sheet Geological Survey of New South Wales, Sydney

LISTER, G S., ETHERIDGE, M A & SYMONDS, P A, 1991 Detachment model for the formation of passive continental margins Tectonics, 10, 1038-1064

MARSHALLSEA, S J., 1998 Thermal history of the Hodgkinson and Laura Basins, far north Queensland Geological Society of Australia, Abstracts, 49, 291

MARTIN, H E., 1991 Tertiary stratigraphic palynology and palaeoclimate of the inland river system in New South Wales In WILLIAMS, M A J et al (eds), The Cainozoic in Australia: a reappraisal of the evidence Geological Society of Australia, Special Publication No 18, 181-194

MOUNT, T J, 1992 Yanda Creek salt inflows project, Bourke NSW - hydrogeological framework studies, 1991-92 New South Wales Department of Water Resources, Technical Services Division, File TS 92.032

NOTT, J & PURVIS, A C, 1995 Geomorphic and tectonic significance of Early Cretaceous lavas on the coastal plain, southern New South Wales Australian Journal of Earth Sciences, 42, 145-149

OLLIER, C D & BROWN, M J F, 1971 Erosion of a young volcano in New Guinea Zeitschrift fuer Geomorphologie, 15, 12-28

OLLIER, C D & PAIN, C F, 1994 Landscape evolution and tectonics in southeastern Australia AGSO Journal of Australian Geology and Geophysics, 15, 335-345

O'SULLIVAN, P B, KOHN, B P, FOSTER, D A, & GLEADOW, A J W, 1995 Fission track data from the Bathurst Batholith: evidence for rapid mid-Cretaceous uplift and erosion within the eastern highlands of Australia Australian Journal of Earth Sciences, 42, 597-607

O'SULLIVAN, P B, COYLE, D A, GLEADOW, A J W & KOHN, B, 1996 Late Mesozoic to Early Cenozoic thermotectonic history of the Sydney Basin and the eastern Lachlan Fold Belt, Australia Geological Society of Australia, Extended Abstracts No 43, 424-432

PIGRAM, C J, DAVIES, P J., FEARY, D A & SYMONDS, P A, 1992 Absolute magnitude of the second-order middle to late Miocene sea-level fall, Marion Plateau, northeast Australia Geology, 20, 858-862

POSAMENTIER, H W & VAIL, P R., 1988 Eustatic controls on clastic deposition II - sequence and systems tract models Society of Economic Palaeontologists and Mineralogists, Special Publication 42, 125-154

RAYNER, E O, 1969 The Copper ores of the Cobar Region, New South Wales Geological Survey of New South Wales, Memoirs, Geology 10

RAZA, A., HILL, K C & KORSCH, R J, 1995 Mid-Cretaceous regional uplift of the Bowen-Surat Basins, Queensland and its relation to Tasman Sea rifting In: Follington, I W, Beeston, J W & Hamilton, L H (editors), Bowen Basin Symposium 1995 . 150 Years On .. Proceedings Geological Society of Australia, Coal Geology Group, Brisbane, Supplement, 1-8

RAZA, A., HILL, K C & KORSCH, R J, 1999 Mid-Cretaceous uplift of the Bowen-Surat Basins, Eastern Australia; its relation to Tasman Sea rifting, from apatite fission track and vitrinite reflectance data AGSO Bulletin, in press

ROSE, T, 1965 Barnato 1:250 000 geological sheet, SH/55-13 Geological Survey of New South Wales, Sydney

SCHUMM, S A, 1993 River response to baselevel change: implications for sequence stratigraphy Journal of Geology, 101, 279-294

SENIOR, B R & EXON, N F, 1976 The Cretaceous of the Eromanga and Surat Basins BMR Journal of Australian Geology and geophysics, 1, 33-50

SCHEIBNER, E., 1974 Fossil fracture zones (transform faults), segmentation, and correlation problems in the Tasman Fold Belt system In Denmead, A K et al (eds), The Tasman Geosyncline, A Symposium Geological Society of Australia, Queensland Division, 71-89

SCHEIBNER, E, 1987 Geology of the Mount Allen 1:100 000 sheet 8032 Geological Survey of New South Wales, Sydney

SCHEIBNER, E & STEVENS, B P J, 1974 The Lachlan River Lineament and its relationship to metallic deposits Geological Survey of New South Wales, Quarterly Notes, 14, 8-18

SHEARD, M 1991 Glendonites from the southern Eromanga Basin in South Australia: palaeoclimatic indicators for Cretaceous ice Geological Survey of South Australia, Quarterly Geological Notes, 114, 17-23

SHERBON HILLS, E, 1956 A contribution to the morphotectonics of Australia Journal of the Geological Society of Australia, 3, 1-15

SHERWIN, L., 1997 Narromine 1:250 000 geological sheet, SI/55-3, Second Edition Geological Survey of New South Wales, Sydney

STEPHENSON & BROWN, C M , 1989 The ancient Murray River System BMR Journal of Australian Geology and Geophysics, 11, 387-395

SUPPEL, D W & GILLIGAN, L B , 1993. Nymagee 1:250 000 metallogenic map SI/55-2: Metallogenic study and mineral deposit data sheets Geological Survey of New South Wales, Sydney

WELLMAN, P , 1986. Intrusions beneath large intraplate volcanoes Exploration Geophysics, 17, 135-139

WELLMAN, P. & McDOUGALL, I., 1974 Potassium-Argon ages of the Cainozoic volcanic rocks of New South Wales Journal of the Geological Society of Australia, 21, 247-272

WILLIAMSON, W.H , 1969 Cainozoic rocks outside the Murray basin - 3 The Lachlan Valley In Packham, G H (Ed), The Geology of New South Wales Journal of the Geological Society of Australia, 16 (1), 545-549.

WILLIAMSON, W H , 1986 Investigation of the groundwater resources of the Lachlan Valley alluvium Part 1: Cowra to Jemalong Weir. Water Resources Commission of New South Wales, Hydrogeological Report 1986/12

WILSON, I R & McNALLY, G H., 1996 A geological appraisal of Tertiary deep leads in the Parkes-Forbes area Abstracts, The Geological Evolution of Eastern Australia. Sydney Universities Consortium of Geology and Geophysics, 71-73

WOOLLEY, D R & WILLIAMS, D R , 1994 Cargelligo Hydrogeological Map (1:250 000 scale) Australian Geological Survey Organisation, Canberra