EXAMINING THE LANDSCAPE EVOLUTION MODELS OF THE COBAR REGION, NEW SOUTH WALES, EVIDENCE FROM REGOLITH-LANDFORM FEATURES.

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The Cobar area in central New South Wales contains a complex array of regolith materials which have been incorporated into geomorphological models developed for the Cobar region earlier this century. Models of peneplanation and pediplanation are based on the low relief of the area and are related to models of long term landscape stability. At Cobar, palaeodrainage channels of varying morphologies preserve a record of early drainage evolution in central New South Wales from at least the Cretaceous until the present and provide evidence for ongoing change in the landscape. Recent tectonic movements along the Darling River Lineament and in the Murray Basin suggest there may also have been reactivation of the Cobar landscape since the Cretaceous. A revised landscape evolution framework that incorporates these features can be used to assess previous frameworks and will provide models for regional scale drainage and landscape evolution of the Cobar area.

INTRODUCTION

The Cobar region has been the subject of a large number of geological studies related to aspects of bedrock geology and the mineralisation for which the region is renowned. Considerably less attention has been paid to the region's regolith and landscape evolution. The prevailing models of landscape evolution for the Cobar area were developed earlier this century and are based on geomorphic processes of peneplanation and pediplanation. The evidence from regolith materials and landscape features at Cobar suggests these models require review.

Cobar is located on a major continental drainage divide and therefore provides an opportunity to also examine the drainage history of central NSW. As the search for mineral deposits extends into areas of deeper cover and transported regolith at Cobar, there is potential for new exploration approaches to develop as a result of a new understanding of the evolution of the landscape. This paper presents an overview of previous regolith and landform studies from the region, and examines the suitability of previous landscape evolution models to the Cobar area. Some of the main themes considered in relation to the study of the regions' regolith and landscape features include drainage evolution, morphotectonic evolution and duricrusts.

STUDY AREA

Cobar, in the Western District of New South Wales has a sedimentary and minor volcanic bedrock geology of the Early Devonian which overlies an Ordovician basement (Figure 1). Mining of structurally controlled Ag, Cu, Pb and Zn, and Au deposits has been a major source of income in the region. (A comprehensive review of the geology is provided by Glen et al. (1996)). Vegetation in the area is broadly subdivided into three groups a) Bimble box-ironwood-mulga association in the north, b) Bimble box-white pine association in the southeast and c) acacia-eremophila association in the southwest (Beadle 1948). The region has a semi-arid climate with a mean annual rainfall of 352 mm. Temperatures vary between an average summer maximum of 35°C, to an average winter minimum of 4.2°C (Cunningham et al. 1992). The area is of generally low relief (200-250 m elevation) although there are several small ranges in the region rising 200 metres above the local undulating plain. The thickness of the regolith varies in response to landscape position, from shallow bedrock cropping out at the surface to weathering fronts extending to 100 m depth (Cohen et al. 1996).

REGOLITH/ LANDFORM MAPS

Existing geological maps for the Cobar area at 1:100,000 and 1:250,000 scales (both geological and metallogenic) provide information on some regolith materials, including duricrusts (eg. Baker 1977; Brunker 1969; Glen 1994a; Gilligan et al. 1994). These maps,

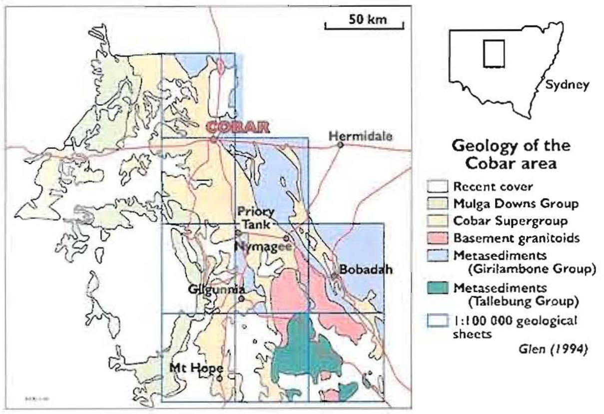


Figure 1: *Location and geology of the Cobar area (Glen 1994).*

whilst providing a regional overview do not provide any detailed description of regolith types and are not designed to be representative of all surficial materials. As a result regolith-landform maps showing the distribution of regolith have been devised at various scales for the Cobar area. A 1:500,000 scale reconnaissance regolith/landform map by Gibson (1996) shows the broad distribution of regolith units in the Cobar area while Senior (1992, 1994) mapped parts of the Cobar and Wrightville sheets at 1:100,000 scale. Localised regolith mapping (1:25,000 scale) has been conducted by Tan (1996) and Reilly (1998) around mineralised sites and further regolith-landform maps are being produced in conjunction with exploration companies in the region. A significant amount still remains to be understood about the evolution of the regolith and its influence on mineral exploration in the Cobar area.

Vegetation, soil and landform maps provide some detail on the distribution of regolith materials and can be used as a mapping surrogate. Vegetation maps (eg. Beadle 1948) commonly reflect the distribution of regolith substrate, for example mulga is usually associated with regolith having a neutral to slightly acid pH typically corresponding to bedrock rises with limited regolith carbonate development in the Broken Hill area (Hill et al. 1998) and a similar situation may apply at Cobar. Land System Maps (produced by the Soil Conservation Service of NSW 1978b) show regolith related features at a regional scale, for example soil and drainage distribution. Condon (1961 cited in Soil Conservation Service of NSW 1978a) mapped landforms in the Cobar district based on three major landforms and their associated soil types.

EARLY LANDSCAPE EVOLUTION MODELS AT COBAR

Recognition and interpretation of ancient landsurfaces have been a major theme of Australian landscape studies. The relatively low relief of much of the continent has helped to promote interpretations of large parts of the Australian landsurface as palaeoplains within the context of various genetic models, including peneplains and pediplains (Figure 2). Many early geomorphological studies favoured the Davisian idea (Davis 1889) that a vast area of the Australian landscape has evolved through cycles of landscape lowering and relief reduction, punctuated by episodes of landscape rejuvenation. A notable example is the concept of the "Great Peneplain", thought to be a single, regionally extensive landsurface found across much of the continent (eg. Andrews 1903; 1910; Gregory 1903; Woolnough 1927).

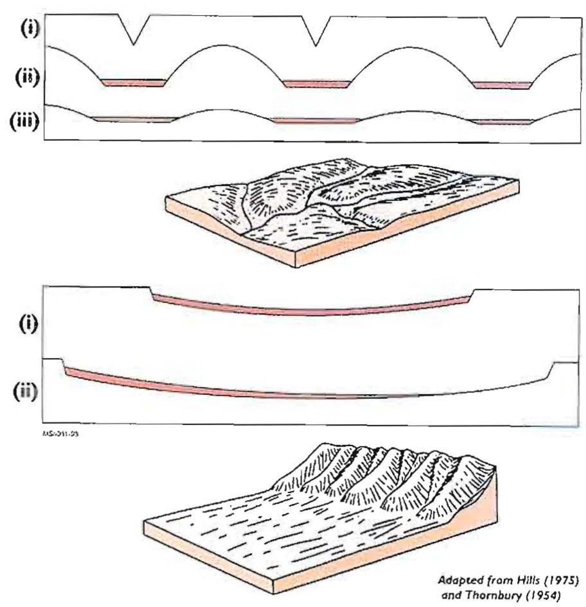


Figure 2: *The peneplain and pediplain models. Peneplains are formed from the downwearing of a landsurface. Pediplains are formed by scarp retreat. (Adapted from Hills 1975 and Thornbury 1954).*

Interpretations of regional peneplains have been suggested in the Cobar region through the early studies of David (1911 cited in Dury & Langford-Smith 1964) and Taylor (1940) who applied the term "Cobar Peneplain" to the region. E. C. Andrews a firm advocate of regional peneplains in his landscape studies, referred to the Cobar region as the "Great Cobar Plain" (1914 cited in Ongley 1970). Other interpretations of a regional peneplain extending across this region have included

Sussmilch (1922), Craft (1933) and Mulholland (1940). The interpretations of Stannard are particularly significant, who argued that the Cobar peneplain is an extension of a peneplain in the Eastern Highlands (Stannard 1957).

In contrast, Dury & Langford-Smith (1964) and Langford-Smith & Dury (1965) preferred to interpret ancient low-relief landscape facets in the region as evolving through processes dominated by slope retreat as suggested by workers such as Penck (1953) and King (1953). They therefore proposed the term "Cobar Pediplain" as an alternative to "Cobar Peneplain" for the region. Dury (1966) argues this term is more suitable for the Cobar landscape because low divides are typically cut into bedrock, as opposed to being thickly mantled with the rockwaste that accumulates during peneplanation. Both Dury and Langford-Smith were strong advocates of pediplanation as a result of their landscape studies in areas featuring duricrusts (eg. Dury 1966) or pediments flanking locally resistant bedrock lithologies (Langford-Smith & Dury 1964).

Inherent in many early models of landscape evolution was the notion that the landscapes of Australia result from numerous cycles of uplift and peneplanation, and are characterised by young tectonism eg. the "Kosciusko uplift" in the Plio-Pleistocene (Andrews 1910; Davis 1899; Browne 1969). With the advent of more detailed mapping and chronological control (eg. K-Ar age determinations) especially on samples from the Eastern Highlands, a shift occurred in the 1970's toward models based on landscape antiquity and stability (eg. Wellman & McDougall 1974; Ollier 1978; Young 1983; Ollier 1985; Bishop 1985; Gale 1992). However at Cobar models of tectonic stability punctuated by a single episode of tectonism and landscape rejuvenation in the Late Tertiary are still widely used. Interpretations of uplift and incision of a Miocene erosion surface (eg. Ongley 1970) and the "Late Pliocene" uplift (eg. Ford 1996), can be related to these early landscape models. Evidence for a regional uplift event in the Plio-Pleistocene in the Cobar area is not well documented.

The concept of duricrust was first proposed by Woolnough (1927) and has since been widely used as a basis for the study and interpretation of weathered landscapes. Woolnoughs' duricrust concept integrated popular models such as Davis' model of cyclical landscape evolution and peneplain development. Duricrusts were incorporated into Woolnoughs' (1927) model as a morphostratigraphic marker. The Cobar region features a range of duricrust types which have been used to support models of peneplanation and pediplanation in this area. Early geomorphologists argued that duricrusts at Cobar, especially silcrete ("grey billy") were duricrusted residuals of a former land surface (eg. Dury 1966) and assigned these duricrusts a Miocene age because they were believed to pre-date the "Kosciusko Uplift" (eg. Ongley 1974).

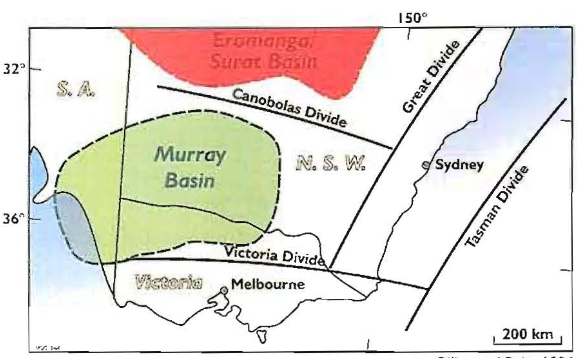
The preservation of ancient regolith materials along specific upland landsurfaces indicates the presence of more than one palaeosurface in this region. Glen (1994b) has interpreted at least two former land surfaces in the northwest of the Cobar 1;100,000 geological sheet. At Tyncin Trig (NW of Cobar) silcrete, ferricrete and gravels cover a flat-topped hill with an elevation of c. 240 m elevation. Along the Louth Road, a lower surface of c. 200 m elevation is marked by silicification (Glen 1994b). A third land surface has been identified at c. 220m elevation and is represented by a silcrete breakaway at Tinderra Tank (5e Km N of Cobar). The stratigraphy, ages and palaeogeographic significance of these ancient landscape facets are poorly constrained.

DRAINAGE EVOLUTION

There has been a long and complex history of drainage development within the Cobar region suggesting that the present landscape may not be formed by a single period of uplift and landscape lowering as indicated by the prevailing models of peneplanation and pediplanation. Several periods of dissection of the landscape ranging in age from the Cretaceous to the present can be identified within the Cobar area, each of which show quite different sedimentological character and morphology and indicate that the landscape has been continuously changing over the course of landscape development. In addition, the same sediments are being continuously recycled and deposited in subsequent depositional environments.

The modern drainage consists of a series of intermittent and some perennial streams which typically form low broad areas of drainage and have channelled flow in times of heavy rain. The drainage in Cobar is both structurally and lithologically controlled as well as dendritic in some areas, for example drainage interpretation at 1:100,000 scale reveals that the course of Buckwaroon Creek to the west of Cobar may be structurally controlled but controls from changes in bedrock lithology could also be important. Major streams include Yanda Creek to the north and east of Cobar, Buckwaroon Creek to the west and Sandy Creek to the south. These broad depressions contain taller vegetation than the surrounding rises and are characterised by sheetwash dominated by red silty sand and fine grained lag, typically including maghemite pisoliths.

A major continental drainage divide, known as the Canobolas Divide (Ollier & Pain 1994) (Figure 3) passes through the Cobar area and represents the watershed between drainage flowing north toward the Darling River (which is located to the northwest and west of Cobar), from drainage flowing south toward the area of the Murray Basin. This divide however is breached by the Darling River to the west of Cobar and so does not extend beyond this point. A major local drainage divide occurs to the west of Yanda Creek which separates drainage flowing northwest toward the Darling River from drainage flowing toward the southeast into Sandy Creek.



Ollier and Pain, 1994

Figure 3: *The Canobolas Divide separates drainage flowing north into the Eromanga/Surat Basin from drainage flowing south into the Murray Basin (Ollier & Pain 1994).*

A number of modern drainage channels along the drainage divide to the northwest and west of Cobar show some degree of rearrangement as a result of lateral migration of the major drainage divide through time. At one location along the western edge of the drainage divide (eg. near Mulgaroon property at 0357650 6584280 AGD 66) drainage that originally trended east-west has been diverted into a channel flowing to the southwest. Greater propagation of baselevel lowering along the southwest flowing stream has facilitated this diversion. Breaching of the divide and drainage diversion have been identified from aerial photograph interpretation in the Cobar region at a number of further localities.

Remnants of older drainage systems are preserved in the Cobar area. The widespread occurrence of maghemite bearing palaeochannels (identifiable on aeromagnetic images) and their different morphology from the present drainage pattern indicate a major change in drainage conditions sometime since the Cretaceous. A palaeochannel with valley fill up to ~30 m thick with a strong magnetic signature due to a concentration of maghemite has been reported by Ford (1996) in an area to the north of Cobar, between 5 and 25 km along the Bourke Road (Figure 4). These gravels are likely to represent a former tributary of Yanda Creek. In addition maghemite bearing channels are widespread across the Cobar landscape where they form deeply incised channels with low topographic relief. The modern drainage channels have a distinctly different signature on aeromagnetic images because maghemite is currently deposited in broad wash zones rather than in concentrated channels. In addition the morphology of the drainage differs markedly between the palaeo and modern drainages (Ford 1996). Leah (1996) proposed that the maghemite filled channels in the Cobar area were backfilled during the Late Miocene-Late Pliocene, which has been correlated with rising sea levels and raising of local base levels in the Murray Basin. The age of formation of the deeply incised valleys is unknown however Leah (1996) equates the incision responsible for forming these channels with lower base levels in the Murray Basin in the Late Miocene.

Palaeochannels dominated by quartzose gravels are also preserved throughout the Cobar area. These channel deposits contain no maghemite, suggesting that either the sediments were deposited prior to widespread conversion of surface Fe oxides to maghemite or maghemite does not occur in this area. These inverted palaeochannels represent remnants of previous landscapes and can be used to determine the long term drainage evolution of the Cobar area and the regional drainage history of central New South Wales.

At Belah Trig, 36 km west of Cobar along the Barrier Highway, ~20 m thick sediments are preserved at elevations up to 225 m. The sediments are composed of alternating beds of coarse to fine sediment and are dominated by rounded quartz pebbles in a kaolinitic matrix. The kaolinitic matrix of these gravels indicates that they post-date deep weathering in the Cobar area.

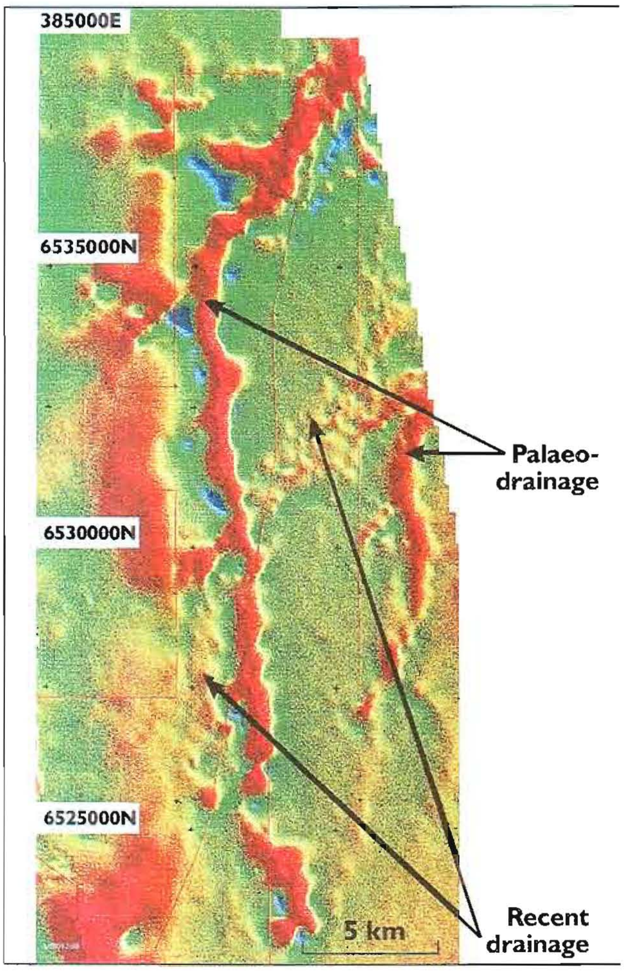


Figure 4: *A series of palaeochannels incised into the bedrock in Cobar are up to 30 m deep and are confined to deep narrow valleys (Ford 1996).*

Current directions indicate a southeasterly to southwesterly flow direction. The present drainage in the Belah Trig area is at ~180 m elevation and flows to the southwest toward Buckwaroon Ck. The present drainage is ~45 m below the upper surface of the inverted quartz rich gravels indicating incision of ~45 metres since gravel deposition. The uppermost 2 m of the sediments are silcreted which has contributed to local relief inversion. The sediments at Belah Trig occur south of the modern drainage divide and suggest that the divide has been to the north of the Belah Trig area since the deposition of these sediments sometime after the formation of the Murray Basin in the Early Tertiary.

Cretaceous forams (Ludbrook pers. comm. in Rayner 1969) in sediments ~60 km west of Cobar (along the Barrier Highway) indicate the antiquity of portions of the Cobar landscape and preserve a record of sediment deposition prior to the development of the Murray Basin. Gravels at this location are preserved as small outliers which form locally resistant hills trending east-west. The gravels at this location are up to ~7.5 m thick and contain well rounded boulders of quartzite to 1 m diameter which are likely to be reworked from the nearby Mulga Downs Group. Current directions on cross-bedded sediments indicate a northwesterly palaeoflow direction, indicating that prior to the development and subsidence of the Murray Basin the drainage divide was located to the south of this location.

MORPHOTECTONIC EVOLUTION

There is increasing evidence of neotectonic activity within so-called "stable" tectonic areas in the interior of Australia, for example at Broken Hill ~500 km west of Cobar there is evidence for tectonism throughout the history of long-term landscape development (Hill & Kohn 1999). (The term "morphotectonics" may be used to describe the general influence of tectonics on landscape formation (Hills 1975; Summerfield 1991) and "neotectonics" refers to the study of recent tectonic activity (the history of the term is discussed by Pavlides 1989)). Within the Cobar region major tectonic features such as the Darling River Lineament (DRL) (Figure 5) have been active in the Tertiary (Kohn et al. 1999) and may have influenced the regional morphology of the Cobar area. The neighbouring Murray Basin also has a history of tectonic, as well as eustatic, activity throughout the Cainozoic (Brown & Stephenson 1991; Wasson 1989; Bishop & Brown 1992; Williams & Goode 1978).

Palaeocene Eyre Formation sediments and equivalent quartzose and kaolinitic sediments in the Murray Basin (eg. Renmark Gp.) are thought to have been derived from relative uplift of the Cobar region as a result of tectonism, or may be related to tectonic subsidence in the Murray and Lake Eyre Basins (Wopfner et al. 1974) after the Cretaceous. Wopfner argues that the structural high extending through the Olary Block to the "Cobar Hill", which separates the Murray Basin from the Eromanga Basin, was uplifted in Early Tertiary time. Ollier & Pain (1994) suggest that the Canobolas Divide, which represents the same feature, was formed in response to downwarping of the Murray Basin at this time and was preceded by north flowing drainage patterns.

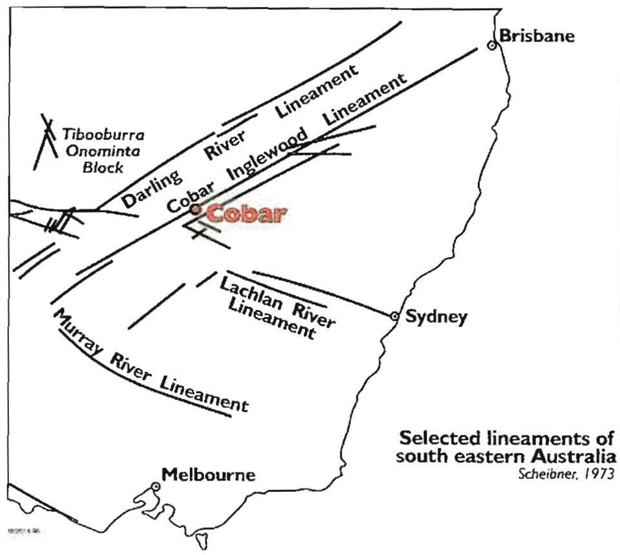


Figure 5: *The proximity of Cobar to major tectonic features such as the Darling River Lineament and Lachlan River Lineament may have caused morphotectonic changes in the area (Scheibner 1973).*

Apatite Fission Track (AFT) data has shown that the DRL, which is a major continental tectonic feature, was subject to a regional cooling episode in the mid-Tertiary (Kohn et al. 1999). This is interpreted to represent a displacement of rocks south of the DRL upwards by ~1 km relative to rocks to the north in the mid-Tertiary (Kohn et al. 1999). Some Palaeozoic faults in the Cobar area may also have been reactivated during the Tertiary, either with strike slip or vertical offsets. The maghemite bearing palaeochannels (Figure 4) in Cobar are confined to deep narrow valleys. At one location Ford (1996) has suggested that incision along these valleys may have been accommodated by movement on the Rookery Fault (a Palaeozoic structure) or at least an underlying weakness in the bedrock. Interpretation of morphotectonics are complicated by the difficulty of distinguishing between lithological controls on differential weathering and erosion, and movements due to reactivated tectonics.

DURICRUSTS

SILCRETE

The identification and description of silcretes in the Cobar area has been a matter of some controversy. Langford-Smith & Dury (1965) and Dury (1966) identified silcrete at locations such as Biddabirra Hill (16 km W of Cobar), the Ballast Quarry (72-74 km W of Nyngan) and Mt Buckambool (48 km SW of Cobar). Dury (1966) argued that these silcretes were remnants of a former landsurface of extremely low relief (a pediplain) which may have extended as far east as Dubbo. These sites were re-examined by Wasson et al. (1979) and Hunt (1985) who showed that previous recognition of silcrete at these sites were incorrect. They argue that "the siliceous materials outcropping at these locations are siliceous bedrock essentially unaltered since Palaeozoic burial and deformation" (Wasson et al. 1979). Glen & Hutton (1983) concur with Wasson et al. (1979) that the materials described by Dury (1966) are not silcrete but maintain that silcretes are present elsewhere within the Cobar area, forming restricted occurrences rather than extensive sheets. Thus, the field evidence from Cobar indicates that duricrusts do not occur in extensive sheets that are representative of one palaeosurface, and therefore cannot be used as a morphostratigraphic marker.

Silcrete forms in a variety of different environments and landscape settings. In Cobar, silcrete typically occurs in areas underlain by sediments of the Early Devonian Cobar Supergroup, with minor occurrences on basement and pallid zone materials (Glen & Hutton 1983). Silcrete also occurs in Cainozoic conglomerate for example at Belah Trig, 35 km west of Cobar on the Barrier Highway (McQueen & Gibson 1996). Gilligan & Byrnes (1994) report the presence of silcrete and silicified conglomerate around the base of leucitites at El Capitan (northeast of Cobar) and suggest a pre-Tertiary age for some bodies. In addition, silcretes within the Cobar area contain rounded clasts of silcreted sediment suggesting multiple episodes of silcrete formation. Other occurrences of silcrete have been reported by Andrews (1911), Mulholland (1940), David & Browne (1950), Jessup (1960b), Baker (1978), Glen (1986), Glen (1994b) and Gilligan & Byrnes (1994). At least some silcretes within the Cobar area have been assigned to a period of development associated with the prevailing landscape model of pediplain development (eg. Late Pliocene to Recent period, Leah 1996).

FERRICRETE

Ferricretes at Cobar are typically massive and hard with a dark colouring and are locally known as ironstones (eg Gilligan & Byrnes 1994) They occur less commonly in a soft form with an oolitic fabric (Baker 1978) and as heterogeneous ferricretes of detrital type (Cohen et al 1996) Baker (1978) argued that in some places silcrete appears to grade laterally into ferricrete Ferricretes have also been identified in the area by Senior (1992), Leah (1996) and Ford (1996) Ferricretes at Cobar have developed mainly from the ferruginisation of Devonian sedimentary rocks, developing preferentially in response to differences in permeability and porosity of the host sediment

CALCRETE

Calcretes (or Kunkar) have been identified in the region by Dury (1966), Jessup (1960 a; b, 1961), Wasson et al (1979) and Ford (1996) Williams et al (1991) conducted radiocarbon dating of carbonates in an area 60 km west of Cobar and found that aeolian accessions of calcareous dust are reflected in two episodes of calcium carbonate precipitation at 33-21 ka and 16-13 ka These authors rule out the possibility of a local derivation for the carbonate because the bedrock lithologies contain no likely clay or carbonate source Hill et al (1999) suggest that as well as aeolian additions, contributions of alkali earth elements (eg Ca and Mg) in rainfall may be important sources for regolith carbonate minerals in the region

APPLICATIONS

The evolution of the drainage within the Cobar area provides a vital key to an understanding of landscape change and rates of change Palaeochannels within the Cobar area clearly reflect a number of periods of dissection of the landscape Instability of these drainage systems through time has implications for mineral exploration requiring an understanding of physical dispersion patterns Source areas for some channels may have altered through time making it difficult to relate channel anomalies to mineralisation in current source areas

Models of regolith and landscape evolution provide a framework to assess physical and chemical dispersion pathways in surficial materials If the Cobar landscape is not the result of a long period of erosion and pediplanation, but has been influenced by factors such as tectonic, climatic and eustatic changes, then the pattern of physical and chemical dispersion within the weathering environment will be very complex

Some of the techniques currently employed in mineral exploration at Cobar, such as geochemical techniques are less effective in areas of deeper cover The majority of known mineralised deposits at Cobar occur as topographic highs in the landscape or crop out as a result of silicification Deposits of lower relief do exist, for example the McKinnons gold deposit, and it is likely that there are other similar and buried deposits A geomorphic model of the evolution of different aged landscapes at Cobar would provide information which can help predict element dispersion both in the modern and the palaeo-environments, thus enhancing exploration techniques in areas of deeper and transported cover

Lag sampling is commonly employed in regional mineral exploration at Cobar The origin of lag materials sampled is of crucial importance to the interpretation of results of a sampling program Alipour et al (1996; 1997) have developed a classification system for lag types in Cobar based on their morphology and landscape position Lag materials have been classified into lithic, pisoidal and detrital/clastic lag types Combined with detailed regolith-landform maps and a revised landscape evolution framework, these classifications will provide a guide to sampling and sample processing methods involving lag for mineral exploration

Recent studies by Hill et al (1999) have examined the potential of calcrete and other regolith carbonate accumulations as a sampling medium for gold at Cobar This technique requires an understanding of the morphology and genesis of the carbonate profile as well as the mechanisms of trace element transportation Initial results of Hill et al (1999) suggest that pedogenic carbonates with low magnesium contents are more likely to host gold anomalies. These types of carbonate are usually found in the upper nodular parts of pedogenic carbonate profiles. The morphology of calcrete has not been studied in detail at Cobar, and further work is required to fully ascertain the suitability of calcrete as a gold sampling medium at this location. The potential of other duricrusts as a sampling medium has not been extensively investigated in this region

CONCLUSION

Previous landscape studies of the Cobar area have incorporated models involving processes of peneplanation and pediplanantion There is increasing evidence that a variety of different aged landscape facets exist in the Cobar region and it may therefore be inappropriate to use models based on a peneplained or pediplained surface for models of landscape evolution or as a basis for mineral exploration. The modern and palaeo-landscapes around Cobar suggest that the Cobar landscape has been continuously changing over the course of landscape development and that previous models of landscape evolution may not account for all facets of the landscape history

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