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ALLUVIAL LANDSCAPES OF THE NORTHERN KENNEDY GAP AREA, MT ISA DISTRICT, QUEENSLAND

M.R. Jones

CRC LEME OPEN FILE REPORT 130

March 2002

(CSIRO Exploration and Mining Report 382R/CRC LEME Report 48R, 1997.
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CRC LEME is an unincorporated joint venture between CSIRO-Exploration & Mining, and Land & Water, The Australian National University, Curtin University of Technology, University of Adelaide, University of Canberra, Geoscience Australia, Bureau of Rural Sciences, Primary Industries and Resources SA, NSW Department of Mineral Resources-Geological Survey and Minerals Council of Australia.
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CSIRO/CRC LEME/AMIRA PROJECT P417
GEOCHEMICAL EXPLORATION IN REGOLITH-DOMINATED TERRAIN, NORTH QUEENSLAND 1994-1997

In 1994, CSIRO commenced a multi-client research project in regolith geology and geochemistry in North Queensland, supported by 11 mining companies, through the Australian Mineral Industries Research Association Limited (AMIRA). This research project, "Geochemical Exploration in Regolith-Dominated Terrain, North Queensland" had the aim of substantially improving geochemical methods of exploring for base metals and gold deposits under cover or obscured by deep weathering in selected areas within (a) the Mt Isa region and (b) the Charters Towers - North Drummond Basin region.

In July 1995, this project was incorporated into the research programs of CRC LEME, which provided an expanded staffing, not only from CSIRO but also from the Australian Geological Survey Organisation, University of Queensland and the Queensland Department of Minerals and Energy. The project, operated from nodes in Perth, Brisbane, Canberra and Sydney, was led by Dr R.R. Anand. It was commenced on 1st April 1994 and concluded in December 1997. The project involved regional mapping (three areas), district scale mapping (seven areas), local scale mapping (six areas), geochemical dispersion studies (fifteen sites) and geochronological studies (eleven sites). It carried the experience gained from the Yilgarn (see CRC LEME Open File Reports 1-75 and 86-112) across the continent and expanded upon it.

Although the confidentiality period of Project P417 expired in mid 2000, the reports have not been released previously. CRC LEME acknowledges the Australian Mineral Industries Research Association and CSIRO Division of Exploration and Mining for authority to publish these reports. It is intended that publication of the reports will be a substantial additional factor in transferring technology to aid the Australian mineral industry.

This report (CRC LEME Open File Report 130) is a second impression (second printing) of CSIRO, Division of Exploration and Mining Restricted Report 382R, first issued in 1997, which formed part of the CSIRO/AMIRA Project P417.

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PREFACE

The principal objective of Project P417 is to improve geochemical methods of exploration for base metal and gold deposits obscured by weathering, or under younger cover in north Queensland. The research includes geochemical dispersion studies, regolith mapping, regolith characterisation, dating of profiles, and investigation of regolith evolution. This report details studies of Quaternary landscape evolution in the Northern Kennedy Gap area northwest of Mt Isa.

The Northern Kennedy Gap area covers the divide separating northward drainage to the sea and southward drainage to central Australia. Rivers and streams transport detritus from the exposed ridges of north-striking metamorphic rocks of the Mt Isa Inlier to the surrounding plains. Six major streams with distinctive drainage patterns are contrasted. The report describes the dynamics of the streams, their sediments and their sources, the evolution of the alluvial landscapes, evolutionary cycles, and the development of the gilgai plains.

Two reports on Quaternary landscapes in the Mt Isa region have been prepared for Project P417. This report discusses the western side of the Mt Isa Inlier, and the other report describes landscapes on the eastern side in the Maronan area southeast of Cloncurry.

R.R. Anand
Project Leader

I.D.M. Robertson
Deputy Project Leader

22nd April 1997

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1. SUMMARY

Quaternary landscape evolution has been investigated in an area located mid-way between Mt Isa and Camooweal, on the Kennedy Gap 1:100 000 sheet. Here, Proterozoic bedrock forms prominent ridges having a general north-south orientation and rising up to 180 m above the surrounding plains. Drainage is provided by streams whose upper catchments are confined by bedrock ridges. The area extends only marginally onto the plains that continue from the base of the Mt Isa Inlier to the south and west. Despite the arid environment, the principal agents of landscape evolution are the rivers and creeks which carry away the products of weathering in the high country and distribute these sediments across the lowlands. The study area lies across the divide separating northward drainage to the sea and southward drainage to central Australia.

There are six major streams present, each with distinctive drainage patterns associated with different levels of erosional activity. The most active of the streams is the northward-flowing Judenan Creek, which has a highly channelled catchment. The stream is continuing a long-term trend for expansion to the west and south along erosion scarps in bedrock. Weathered Eastern Creek Volcanics in the Judenan Creek catchment are susceptible to erosion, and the numerous channels ensure that the weathered mantle is readily removed. The sediments produced are derived from a wide area of bedrock, and are predominantly "new" sediments. In contrast, the adjoining Cattle Creek catchment to the west contains a mixture of older alluvial deposits now being reworked, and only minor "new" sediments derived from low lying bedrock outcrops.

Other catchments in the area include the bedrock-confined and aligned Gidya Creek, which drains to the north, and Buckley River, which flows westwards across the strike of the bedrock. In the south, Johnson and Wilfred Creeks are conduits for westward moving sediments produced in their upper catchments. Johnson and Cattle Creeks join Buckley River, and contribute to the drainage towards central Australia.

The sediments are derived from the area within 2-5 km of the drainage divides between the upper catchments. For the most part, the surficial sediments are thin and young. There is no evidence of widespread thick sequences of transported deposits overlying an incised and back filled bedrock surface. Rather, the alluvial deposits are mainly confined to narrow corridors along the valley floors. The alluvial deposits form a blanket which protects the shallow underlying bedrock from significant erosion.

The alluvial deposits are only a proportion of the total sediment throughput during the evolution of the landscape to its present form. The blanketing unconsolidated sediments are in transit to distant depositional areas. It is unlikely that these deposits would remain in place long enough for geochemical haloes to develop from underlying mineral deposits. Overall, the processes of erosion, transport and deposition are diffusive for indicator minerals. However, there is the potential for stream bed concentrations of heavy minerals which could be related to up-catchment sources.

The differences between the catchments are related to the confining geology that determines the lateral limits of catchment development, and the underlying geology that determines the erodability of the catchment substrate. Judenan Creek is the main catchment where erosional processes are most active. In part this can be related to Judenan Creek having a steeper slope to its base level (Gulf of Carpentaria) in comparison with the other streams draining to the west and south towards Lake Eyre. The Judenan Creek catchment may also contain more erodable bedrock than in neighbouring streams. The erodability could be related to deep weathering and or fracturing of the bedrock allowing surface or near-surface chemical concentrations indicating underlying mineral deposits. The Judenan Creek catchment contains known occurrences of copper and uranium mineralisation. This catchment may need further evaluation of its potential to contain economic mineral deposits.

The Eastern Creek Volcanics also underlie parts of the Gidya Creek catchment, which may warrant investigation for anomalies in the regolith. Stream sediment geochemistry could assist exploration in the Judenan and Gidya Creek catchments.

Iron-rich pisoliths and nodules have proved to be useful sampling media for geochemical exploration in Western Australia. In the Kennedy Gap area, iron pisoliths and nodules are abundant. Haematitic and goethitic pisoliths and nodules occur *in-situ* in weathering profiles, and also in transported deposits where secondary goethitic cementation has occurred. Geochemical analyses of goethitic cutans and haematitic centres of iron pisoliths are expected to give different results. Careful interpretation of the environment of deposition is required before selecting samples for analysis. This is essential if geochemical anomalies are to be successfully related to source areas.

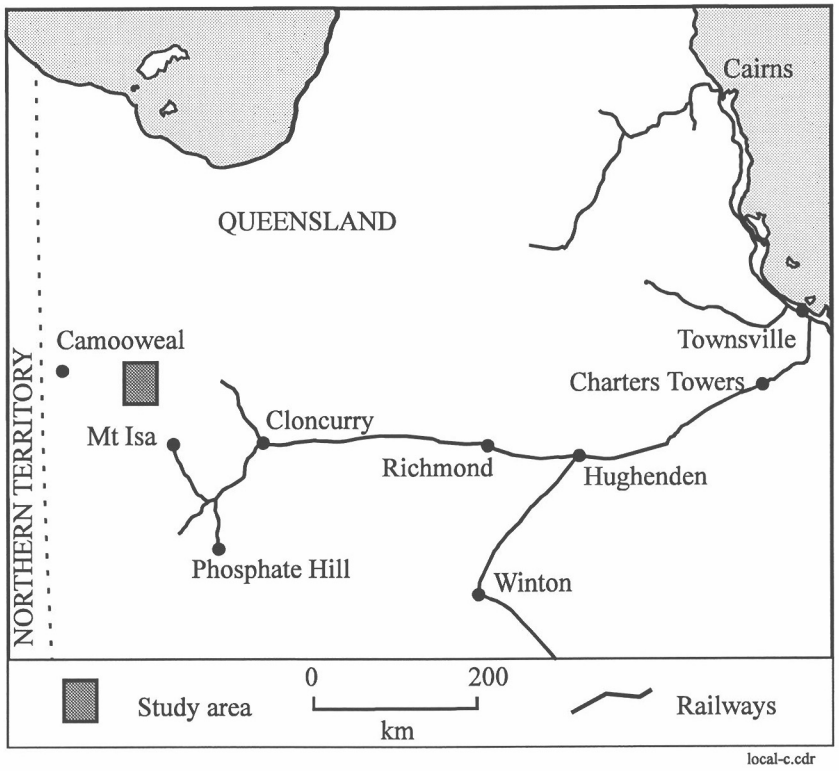

Figure 1: Locality map showing study area.

2. INTRODUCTION

This study forms part of AMIRA Project 417 - Geochemical Exploration in Regolith-Dominated Terrain of North Queensland. An understanding of landscape evolution can aid the planning of effective exploration programs. Landscape evolution information can assist in determining which horizons are likely to provide the most useful geochemical data. It can also provide information on

the thickness of cover deposits over bedrock;
the amount of reworking of these deposits;
the likelihood of geochemical haloes in the regolith; and,
the likelihood that anomalies are related to either underlying or distant mineral deposits.

This report complements similar investigations of Quaternary landscape evolution on the eastern side of the Mt Isa Inlier in the Maronan area between McKinlay and Cloncurry (Jones, 1997).

The study area lies between Mt Isa and Camooweal, mainly on the northwestern part of the Kennedy Gap 1:100 000 sheet (Figure 1). It comprises an area of about 3500 km^2 (approximately 55 km east-west, and 65 km north-south). The upland areas are part of the Isa Highlands, a predominantly erosional region since at least the Pliocene (Grimes and Doutch, 1978). Silcrete and laterite of the Tennant Creek Surface (Eocene to Oligocene) have been recognised in the area (Grimes, 1980). The Tennant Creek Surface is equivalent to the Aurukun Surface, remnants of which occur further to the north and east of Mt Isa near Burketown and Normanton, and on Cape York (Doutch, 1976; Grimes, 1980). Mapping of the regolith landforms in the present study area at 1:50 000 was completed by Wilford and Anand (1995). Initial interpretations of regolith-landforms and geochemical results are presented by Anand and Wilford, 1995, and Anand et al, 1996.

3. STUDY METHODS AND RESULTS

3.1 Field Inspections

Field inspections were made at 100 field sites which extended from upper catchments in the Waggaboonyah Range to the plains in the west and south (Figure 2). Locations were determined using a hand-held GPS unit. Many sites were in creek beds where exposures of the regolith could be observed. The observations included the types of sediment in the stream bed and banks, stratigraphy, stream dimensions, surface deposits and evidence of evolutionary processes. Informal notes on the landscape between field sites were also made.

3.2 Data storage

All field data are stored in a database in MS-Access, which is linked to map displays in MapInfo. The results of queries run in MS-Access can be exported to MapInfo to display results such as the distribution of bedrock, calcrete, and iron-rich gravels at the field inspection sites. Interpretation of the significance of observations can be displayed as thematic layers in MapInfo.

3.3 Estimating the age of the deposits

The degree of compaction provides a qualitative indication of the age of parts of the regolith. This approach is based on investigations of the nearshore zone along the coastline (eg. Jones and Hekel, 1979; Jones and Stephens, 1984). Here the influence of sea level change is well documented by facies changes, and provides an indisputable time frame for comparative age estimation. Even in shallow areas, it is typical to have a sequence of unconsolidated marine sediments overlying a cohesive plastic clay. The marine mud is of Holocene age, having been deposited during the last ~6 000 years of comparatively stable high sea level. The underlying clay relates to the preceding period of subaerial exposure during which dewatering, consolidation, and weathering of former marine deposits (mid to late Pleistocene) took place. The cohesive clays may contain ferruginous mottles and incipient ferruginous nodules, and are clearly of late Pleistocene age.

The cohesion of the coastal Pleistocene clays is similar to or greater than the mottled clays found in some areas at the base of the alluvium in the Kennedy Gap district. Therefore, these mottled alluvial clays are inferred to be of Pleistocene age, and the overlying unconsolidated deposits are likely to be of late Pleistocene to Holocene age.

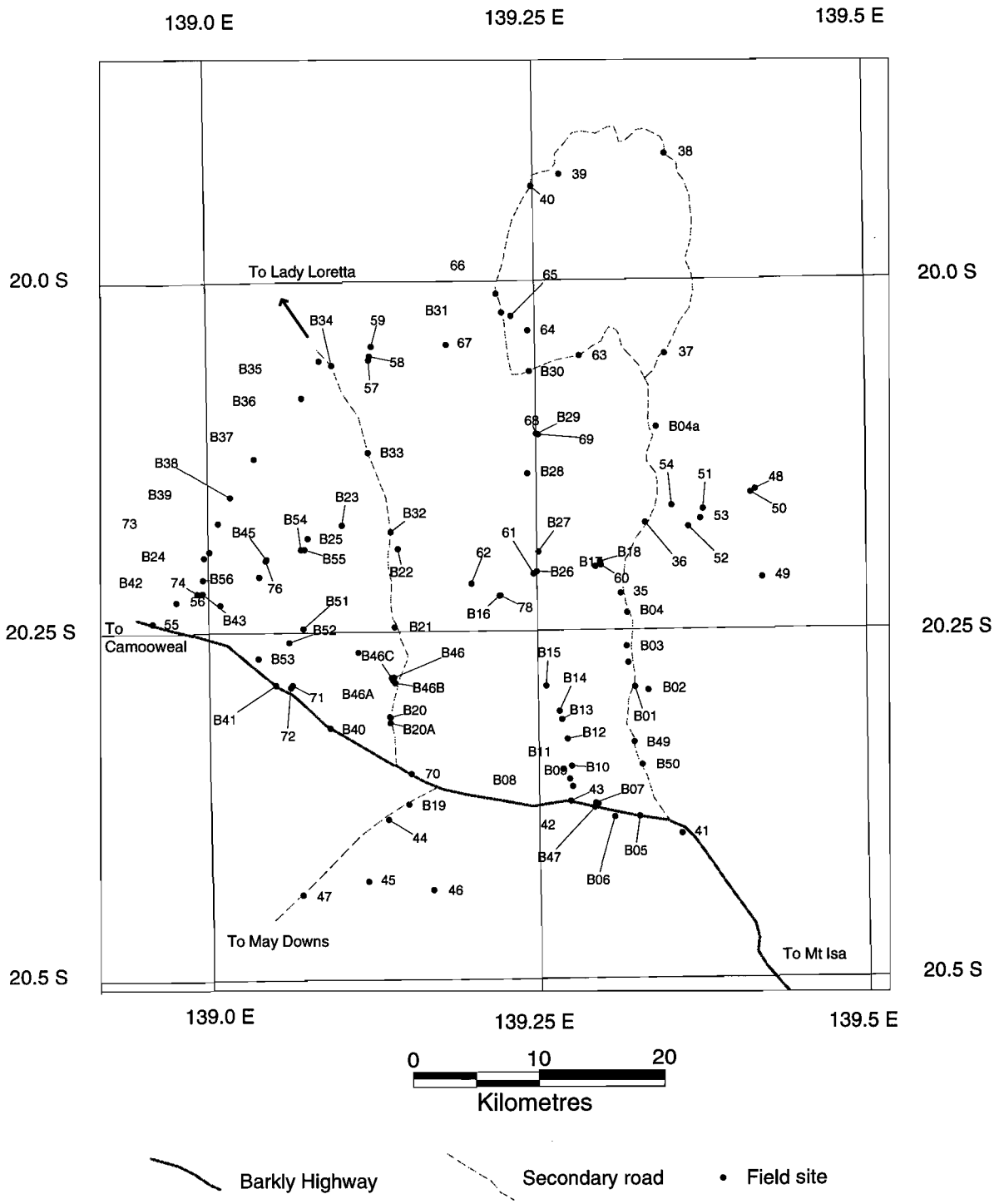

Figure 2: Location of field sites.

4. PHYSIOGRAPHY AND GEOLOGY

The bedrock geology of the area was mapped by Wilson and Little (1977). The area comprises highlands in the east, diminishing in elevation westwards and merging with flat lying plains to the west and south. All elevations referred to are above Mean Sea Level.

The highest parts of the area are a series of three sub-parallel, north-south ridges in the east. These three ridges define the adjacent drainage basins of Judenan and Gidya Creeks (Figure 3). The eastern ridge has an elevation of 470-500 m and consists of the Leander Quartzite, which includes orthoquartzite, feldspathic quartzite, micaceous metasiltstone, phyllite, and tuff. It forms the eastern margin of the **Gidya Creek** catchment.

On the western side of Gidya Creek are the linear ridges of the Waggaboonyah Range. The range has an elevation of 460-480 m, and includes the Judenan Beds (quartzite, feldspathic quartzite, feldspathic sandstone, and siltstone) and the Lena Quartzite Member of the Eastern Creek Volcanics (quartzite, feldspathic quartzite, and siltstone). The valley of Gidya Creek is underlain by the Cromwell Basalt Member of the Eastern Creek Volcanics. The rocks include metabasalt, flow top breccia, and tuff.

The Waggaboonyah Range also forms the eastern side of the catchment of **Judenan Creek**. The western side of the Judenan Creek catchment is formed by another set of linear ridges reaching elevations of 300-450 m. These are composed of the Gunpowder Creek Formation - orthoquartzite, conglomerate, micaceous siltstone, and ferruginous siltstone - and the Judenan Beds - quartzite, feldspathic quartzite and siltstone. Although parallel to the Waggaboonyah range, these ridges converge marginally to the south in the upper reaches of Buckley River.

The Cromwell Basalt Member of the Eastern Creek Volcanics also underlies the catchment of Judenan Creek, as well as occurring in parts of the Wilfred Creek catchment in the south.

The three sets of ridges become progressively lower from east to west. In the west and south, the plains are at an elevation of 320-340 m. The variation in relief in the whole study area is 180 m, occurring in an elevation range from 320 to 500 m.

Overall, the area is dominated by bedrock outcrops high in silica, with some iron-rich horizons as well. Weathering has remobilised silica and iron to form silcrete and ferricrete caps on the ridges. These duricrust-capped ridges are resistant to erosion.

4.1 Regional drainage patterns

The sources of six significant streams occur in the study area. The streams occupy neighbouring catchments, and each shows distinctive patterns of channel hierarchy, channel density, and catchment shape (Figures 3, 4). These differences can be related to factors such as the type of underlying bedrock, the bedrock structure, and the amount of weathering that has taken place.

Bedrock outcrops define much of the catchment perimeters, and are also common in the stream beds. The drainage channels are typically narrow and shallow. Most are less than 10 m wide and 1-2 m deep in the upper catchments, and less than 20 m wide and 3-4 m deep in the lower catchments. In the lower catchments, the streams are incised in wider flood corridors. The incised streams do not erode laterally for any great distance. Only Buckley River, Cattle Creek, and the lower parts of Wilfred Creek contain meanders and or abandoned channels in their floodways, indicating lateral migration.

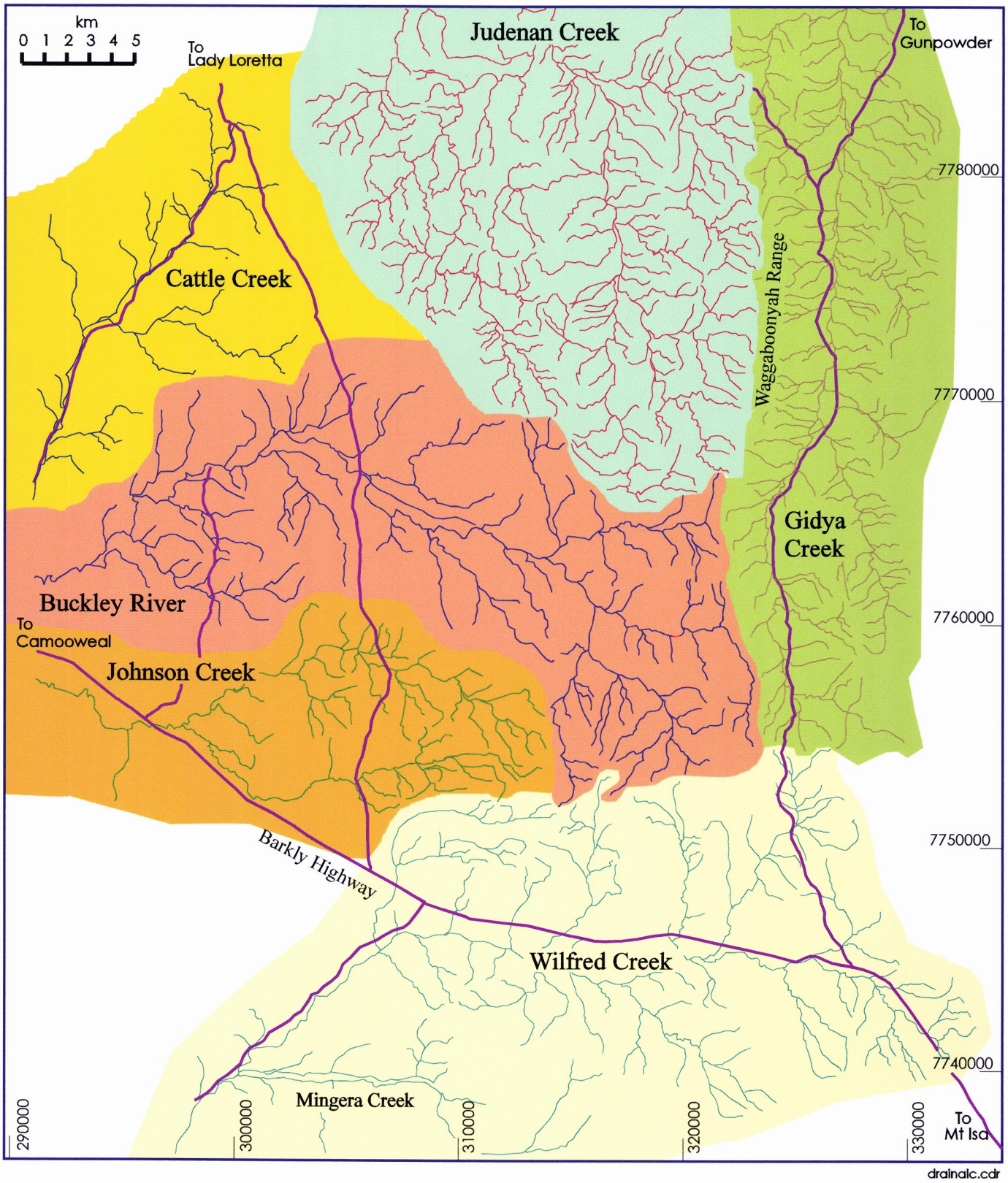

Figure 3: Major catchments, northwest Kennedy Gap 1:100 000 sheet.

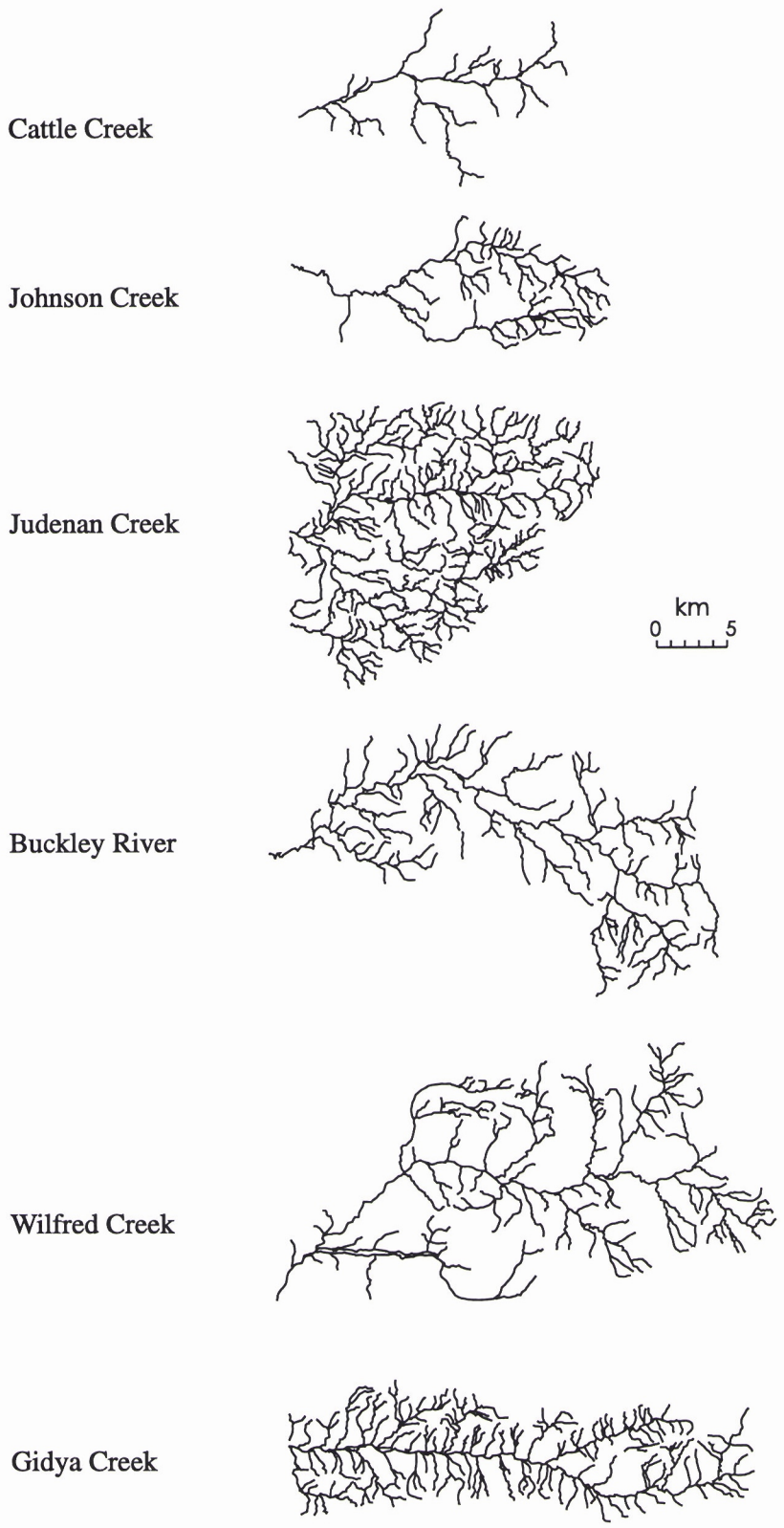

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Figure 4: Comparison of the major catchments. The streams have been rotated to a common flow direction (to the left) to allow comparison of catchment shape, channel density, and channel patterns. The simple pattern of Cattle Creek contrasts with the intensely channelled Judenan and Gidya Creeks where erosion is more rapid. Johnson Creek is complex in its upper reaches, but has a simpler pattern downstream. Buckley River and Wilfred Creek have moderate density drainage throughout their catchments.

Because the streams have incised narrow channels, overbank flow occurs during floods. On the plains bordering the streams, the land surface shows evidence of scouring from overbank flow from either the main creek or from secondary tributaries.

Catchment erosion is partly dependent on the ability of the drainage systems to remove the unconsolidated products of weathering. In the Kennedy Gap area, the streams are active agents in the evolution of the landscape. The upper, middle and lower catchments contain different landscape features:

4.1.1 Upper catchment

The upper catchment comprises the steeply sloping zone adjacent to the drainage divide between neighbouring catchments. The land surface here is the steepest of any part of the catchment. The zone is characterised by short tributaries with V-shaped channels in bedrock, containing minor residual coarse deposits "in transit". Bedrock outcrops are common in the channels. Downstream, the channels may cut into unsorted colluvial sediments. On the colluvial aprons at the foot of the ridges, water flows rework the colluvial deposits and transport partially sorted fractions on to the alluvial plain (Figure 5).

4.1.2 Mid catchment

In the mid catchment, the short streams from the upper catchment merge. The increased sediment load is carried in wider channels, and larger bed deposits form. Erosion in the stream exposes cemented alluvial deposits overlying bedrock. As the slope of the stream bed declines further downstream, gravels in transit are temporarily deposited. Water velocity varies as channel dimensions change, enabling scour holes and gravel bars to form. There are minor point bars of poorly sorted gravel, sand, and mud, indicating short term excess of supply over transport capacity. In the mid catchment, these deposits form narrow and in places discontinuous alluvial plains.

4.1.3 Mid-to-lower catchment

In the mid-to-lower catchment, channel dimensions expand to carry the increasing volume of water from the numerous feeder streams. Larger tributaries join the main stream in the mid-to-lower catchment. However, the slope of the land surface is low, enabling friction to retard stream velocities. The sediment supply may exceed the short term transport capacity of the streams, resulting in mixed deposition of gravel, sand, and mud.

Buckley River and Cattle Creek have developed flood corridors in their mid-to-lower catchments. The flood corridor is confined laterally by bedrock outcrops or colluvial fans. The corridor contains sediments abandoned by flood waters that were no longer flowing swiftly enough to keep the sand and gravel load entrained. The main drainage channels incise the unconsolidated alluvial deposits. Past channel movement is indicated by meanders and preserved cut-off channels within the flood corridor.

Cycles of deposition and reactivation sort the alluvial deposits into basal gravels and blanketing fine alluvium. In the mid-to-lower catchment, water velocities decline due to decreasing gradients and increased friction affecting overbank flows. The lower velocities enable coarse sediment deposition, whereas fine components are passed on to the lower catchment.

4.1.4 Lower catchment

The lower catchments occur outside the study area. They comprise wider flood corridors than in the mid-to-lower catchment. Sediments become finer further down stream and deposition occurs over a larger area. Braided channels re-transport and deposit sediments in cyclic fashion in flood corridors. Major evolutionary phases involve lateral shifting of the entire flood corridor. In the lower catchment, interfluves of older alluvium separate flood corridors acting as distributaries of sand and fine gravel sourced from the Isa Highlands.

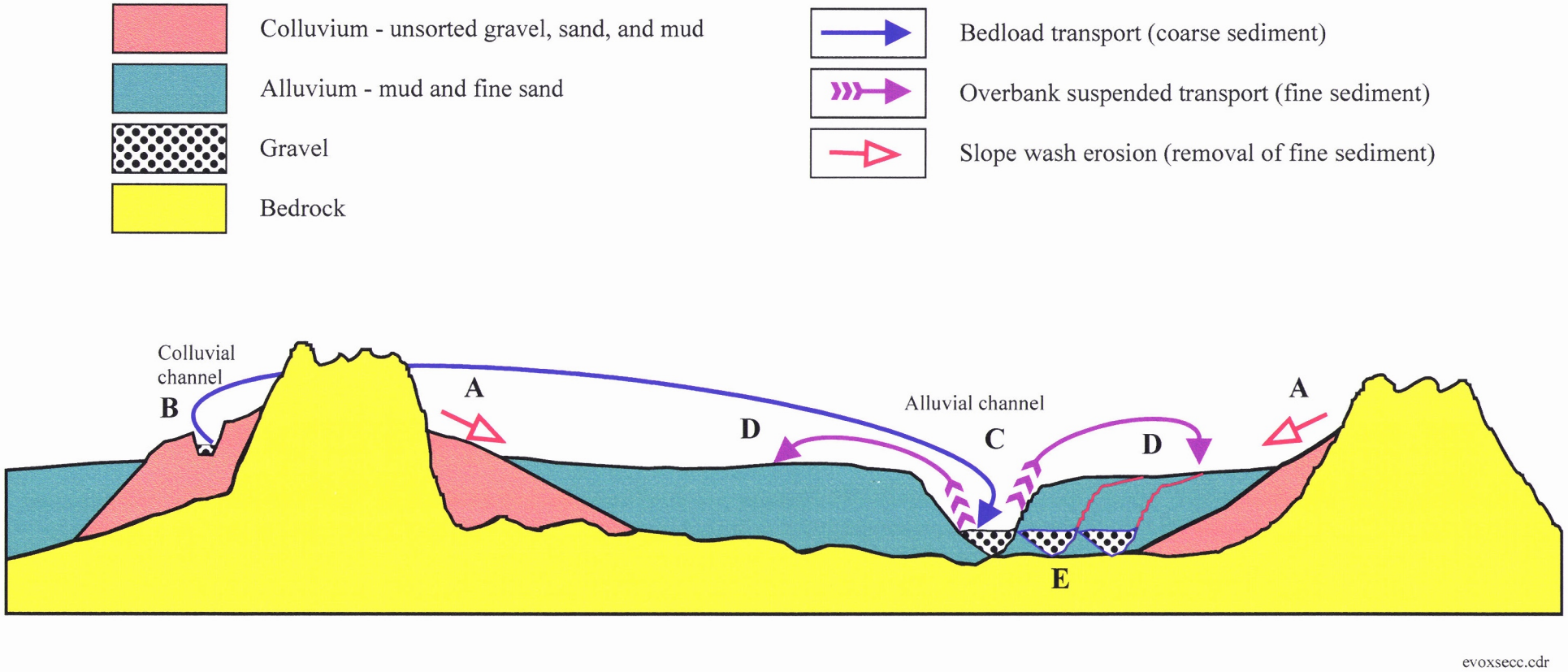

Figure 5: Quaternary units and sediment transport - Slope wash erosion across the colluvium (A) removes mud and leaves a gravel lag at the surface. Minor channels in the colluvium (B) supply coarse bedload directly to the main channel (C) on the alluvial plain. Overbank flow from the main channel delivers blanketing deposits of mud and fine sand to aggrade the alluvial plain (D). Lateral movement of the channel preserves pods of stream bed gravels below the alluvial mud (E). As the stream migrates across the alluvial plain, the pods coalesce as a gravel horizon at the base of the alluvium. (Thickness of alluvium and colluvium greatly exaggerated).

4.2 Major catchments

The streams contain features produced by waning floods as conditions decline from "bank-full" to "less than bank full" flows, and finally to dry bed. The channels include scour hollows and sediment shoals, sand sheets with ripple marks, and point bars, which are preserved from one flood to the next.

The interpretation of the Quaternary landscape evolution is based on the characteristics of the six major catchments.

4.2.1 Gidya Creek

Channel characteristics - The northward flowing Gidya Creek has an elongate parallel-sided catchment 2-6 km wide with confining ridges of bedrock. The creek is centrally placed along the axis of the catchment, and has one of the steepest slopes of any of the streams in the area (Figure 6). Gidya Creek is fed by numerous but generally short feeder channels draining steep slopes (Figures 3, 4). There are seven major tributaries in the catchment, and numerous short feeder channels, with over sixty feeding directly into the Gidya Creek channel alone. Although there are steep slopes adjacent to the ridges bounding the catchment, the valley floor is flat in comparison. Bedrock is at shallow depth across the valley, as indicated by stream bed outcrops.

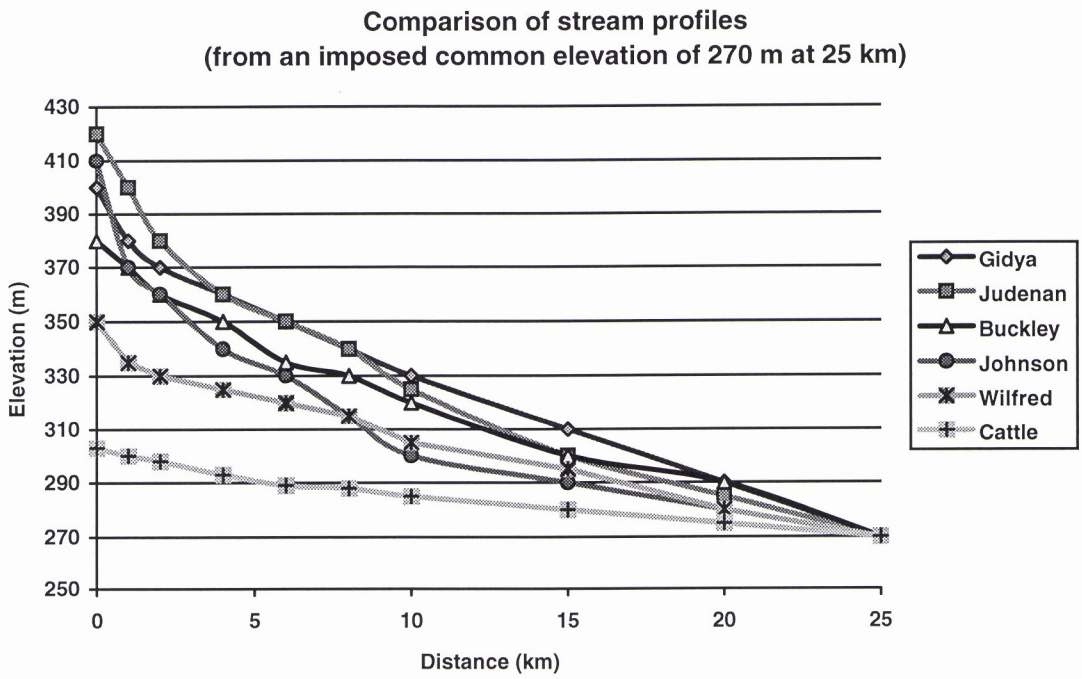

Figure 6: Comparison of the gradients of the six major streams (based on data from Kennedy Gap 1:100 000 topographic sheet).

Sediment variations - Colluvial aprons fringe the bedrock ridges along the perimeter of the valley. These deposits are poorly sorted gravel, sand, and mud. The surficial gravel is a residual deposit produced by removal of the fine component (mud size) from the colluvium. The mud is removed by sheet wash and laid down as a blanketing deposit on the valley floor beyond the colluvial margin. Small channels across the colluvium act as conduits for the coarse sediments to reach the main stream along the valley axis. The stream bed deposits typically consist of 75-100 mm gravel and very coarse sand containing quartz, ferruginous pisoliths, silcrete, and quartzite. Mud lenses occur in depressions on the channel floor.

Inferences - The ridges along either side of the catchment act as linear sediment sources to the valley floor, with the sediments being delivered to the main channel along short feeder streams. These streams deliver coarse sediments to the axial channel along the entire catchment, negating any possibility of along stream sediment sorting in Gidya Creek. Sediment composition in Gidya Creek is comparatively uniform as the source rocks are much the same along the strike ridges that define the drainage basin in the east and west. These erosion resistant ridges have prevented the lateral expansion of the catchment, and forced the creek to develop a long and narrow valley.

The catchment has evolved by the long-term southward extension of its headwaters between the confining ridges. In the south, the upper catchment of Gidya Creek merges with the inland-draining catchment of Wilfred Creek. However, the greater slope of the Gidya Creek catchment (Figure 6) has probably enabled it to expand at the expense of Wilfred Creek for some time. Sediments previously in transit to the south have been redirected northwards by the encroachment of Gidya Creek. Developments such as this complicate patterns of sediment dispersal on the landscape.

4.2.2 Judenan Creek

Channel characteristics - Judenan Creek drains northwards, with numerous intricate secondary channels linked to the main channel. The upper catchment contains steep slopes and narrow channels incised to bedrock. The catchment widens to the north and contains several areas of plateaux and ridges. Because of these high areas, a number of major tributaries drain sub-catchments within the total drainage basin of Judenan Creek.

The stream gradient is similar to that of Gidya Creek, and is one of the steepest in the area (Figure 6). The catchment is more severely eroded than that of Gidya Creek, as indicated by the complex network of drainage channels (Figure 4). These channels provide a comparatively high erosional power. There are five main tributaries to Judenan Creek, and three of these channels also have significant tributaries. On the main Judenan Creek channel, there are about 40 short feeder channels, and well over 100 similar channels on the tributaries.

In the east, the catchment perimeter is defined by the same erosion-resistant Judenan Beds that have restricted the expansion of the neighbouring Gidya Creek catchment. On the western side of the catchment however, the headwaters of the tributaries lie along an indented bedrock escarpment. At the top of the escarpment is the gently sloping upper alluvial plain of Cattle Creek. The Cattle Creek alluvium thinly overlies steeply dipping bedrock exposed along the escarpment. The escarpment continues to the southeast where it forms the boundary with the upper Buckley River catchment .

Sediment variations - The stream bed gravels are composed of silcrete, ferruginous pisoliths, quartz, silcrete, and basalt. The underlying bedrock in places is weathered to soft clays, and younger gravels are embedded in the top of the weathered zone. Cemented alluvial gravels at the base of the unconsolidated surficial deposits are also present.

Inferences - The catchment has expanded rapidly by erosion along its western and southern margins, leaving ridges and mesas within the catchment. These continue to be eroded, providing a large area for sediment generation. In the east, the catchment is confined by the Waggaboonyah Range whereas in the west, lower bedrock ridges have been cut by streams in several places. Catchment evolution can be summarised as confinement in the east, and expansion along steep slopes in the west and south. Along the escarpment, weathering and erosion of the bedrock yields gravels composed of mudstone to very fine sandstone clasts. At the top of the escarpment, iron-cemented gravels contain quartz, silcrete, and iron pisoliths. These, together with rounded silcrete and quartz gravels enter the Judenan Creek drainage system along the escarpment.

4.2.3 Cattle Creek

Channel characteristics - Cattle Creek is in the northwest part of the Kennedy Gap 1:100 000 sheet where topographic relief is only about 30 m. The stream drains to the southwest, and consists of shallow channels (1-3 m deep) incised in mainly gilgai alluvium. For most of its length, Cattle Creek does not have a well defined single primary channel but instead has a series of anastomosing channels

on a flood corridor about 500 m wide. The gradient of the flood corridor is the lowest in the region (Figure 6). There are two significant tributaries, and about 20 short feeder channels draining directly into the flood corridor or the tributaries.

Sediment variations - In the upper reaches of Cattle Creek, the channel is barely a depression in the land surface, and the alluvial deposits are thin (less than 1-2 m). The channel contains angular to sub-rounded gravel that has not moved far from low-lying bedrock outcrops. Downstream, the gravels continue as a layer overlying shallow bedrock. Above the gravel is alluvial mud, commonly comprised of cracking clays. Further downstream where the creek has developed a flood corridor and alluvial plain, sand becomes an important component of the stream bed deposits. Near the junction with Buckley River, the flood corridor is composed largely of alluvial mud (cracking clay) and fine sand. However, overbank flows that produced sediment splays also transported some gravels which remain as scattered deposits on the mostly unvegetated sandy surface of the flood corridor.

Inferences - The lack of a continuous substantial channel leading into Buckley River suggests that channel-confined flow is not a major means of sediment transport in Cattle Creek. Also, the flood corridor contains large overbank splays of very fine sand and mud, indicating large flows outside of the incised channels during floods. The flood corridor contains blind scour channels formed during floods, and shallow meandering channels formed during the late stages of a waning flood.

The main geological activity of Cattle Creek appears to be recycling the thin alluvial deposits of the plains. There is an increasing volume of sediment in transit downstream, predominantly of mud and fine sand size. Some gravel is present in the stream bed and a proportion of this is transported on to the overbank splays. Near the junction with Buckley River, there is a large accumulation of sediment from Cattle Creek. Here, lateral movement of Cattle Creek's flood corridor has deposited sediment over a wide area.

4.2.4 Buckley River

Channel characteristics - Buckley River flows to the west in the central part of the study area. Its upper reaches are in the Waggaboonyah Range near the headwaters of Judenan Creek. In addition to the main channel there are six main tributaries, two of which have significant secondary channels. Approximately 60 short feeder channels are present. The gradient of the primary channel is less than that of either Gidya or Judenan Creeks (Figure 6). Because of its relatively gentle slope, the Buckley River catchment contains far fewer channels than Judenan and Gidya Creeks.

The river flows across the bedrock alignment, in contrast with Gidya and Judenan Creeks which parallel the geological structure. The upper catchment tributaries of Buckley River do show some north-south alignment matching the underlying geology. However, instead of continuing north to join Judenan Creek, the tributaries turn westwards, cutting through the bedrock ridges along an inferred fault (Wilson and Little, 1977). Bedrock structure influences the orientation of Buckley River.

Sediment variations - In the upper catchment, unconsolidated deposits in the channel bed contain angular gravel comprised of silcrete, shale, and ferruginous pisoliths. Alluvial sands and gravels cemented by clay, silica, and iron occur in parts of the stream bed. The cemented deposits form a discontinuous layer which directly overlies bedrock. Minor depressions in the bedrock surface contain pockets of ferruginous pisoliths cemented in an iron-rich matrix. Steeply dipping bedrock exposed in channels is typically covered by about 1 m of sheet wash gravels, sand, and mud. In general, the unconsolidated deposits of the upper catchment are poorly sorted gravel, sand, and mud. Lateral channel movement reworks poorly sorted colluvial deposits. Mud is removed, improving the sorting of the sediments in the stream bed.

In the mid-catchment of Buckley River (east and west of the Lady Loretta road) is an elongate plain - the flood corridor for the river. The poorly vegetated plain has a surficial cover of silt and fine sand. Air photos show abandoned channels across its surface. Stream bed deposits comprise mainly gravel, with some sand and mud.

Streamlet headwater erosion is affecting parts of the margin of the plain near the main river channel, with incision up to 1-2 m. On the banks of Buckley River, exposures of over 3 m are present. The

exposed profile comprises weakly consolidated to unconsolidated surficial alluvium overlying a cohesive sequence of mottled clays and cemented gravels on bedrock (Figure 7).

On the western margin of the study area, Buckley River is joined by its major tributary, Cattle Creek. Upstream of the junction with Cattle Creek, the bed of Buckley River changes from one dominated by gravel to a bed of very coarse sand and fine gravel with well developed ripples. This change represents a fairly abrupt downstream improvement in the sorting of the stream bedload. In part, this is due to preferential transport of sand as stream velocities decline below the minimum for entrainment of gravels. Also the river channel intersects a large sediment deposit at the confluence with Cattle Creek. The deposit of Cattle Creek sediments probably contains more sand and less gravel than the Buckley River alluvium. Reworking of the Cattle Creek deposit by Buckley River contributes to the change in the sediments in the river bed.

Inferences - The upper catchment of Buckley River contains alluvial deposits of poorly sorted gravel, sand, and mud. Sediment transport includes sheet wash, bedload movement down narrow channels, and the reworking of colluvium through lateral movement of channels. Separation of the alluvial deposits into a layer of mud overlying a layer of gravel occurs even in the discontinuous alluvial plains of the upper catchment. Boulders are the common short term deposits in the beds of upper catchment streams.

Stream erosion is active throughout the catchment, indicated by the clean bank exposures and eroded remnants of cemented deposits in the stream bed. In the channels, erosion and deposition occur on the bed, and erosion of the channel walls also takes place. In the remainder of the corridor, the land surface aggrades through the deposition of fine sediments from overbank flow. The rate of supply is low, as abandoned meander channels in the corridor are still unfilled.

The banks of Buckley River expose an alluvial sequence with two contrasting degrees of consolidation. Different ages are suggested for these, as shown on Figure 7. The uppermost fine alluvium is interpreted as Holocene age, and the more consolidated mottled alluvium below, as Pleistocene age.

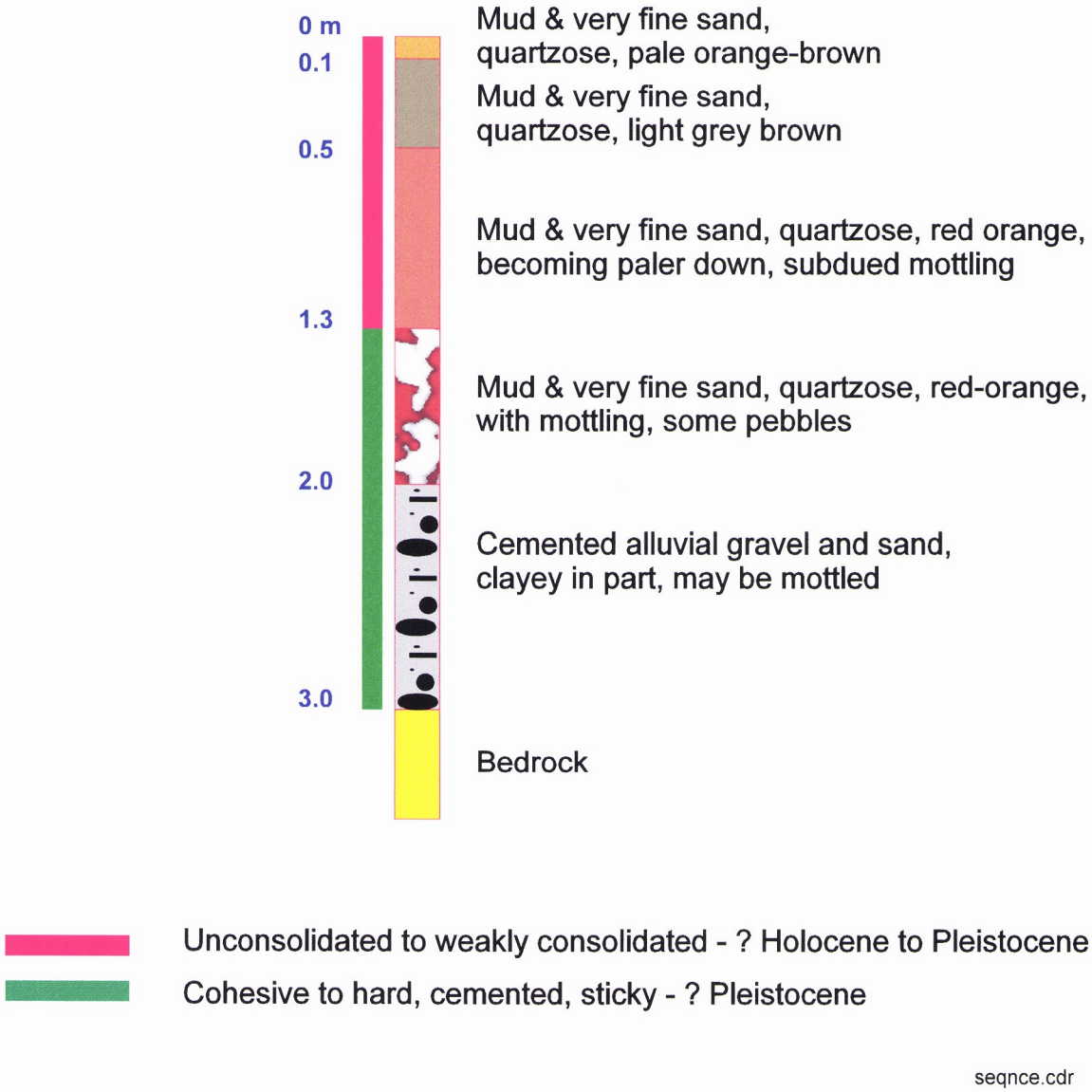

Figure 7: Alluvial sequence over bedrock in the Buckley River flood corridor (Site B23).

4.2.5 Wilfred Creek

Channel characteristics - Wilfred Creek lies in the southern part of the study area, and drains to the west and south. In the upper catchment, tributaries are about 1 m deep and 6-8 m wide. Bank exposures comprise red-brown alluvial mud extending to the channel bed or overlying gravel lenses. The gravels were deposited on the bed of abandoned channels that were back filled with mud (from sheet wash or overbank flooding). The gravel exposed in the bank consists of silcrete fragments, quartz, and case-hardened ferruginous pisoliths in an alluvial mud matrix. In the upper alluvial mud are thin gravel layers, past equivalents of the gravel layer commonly found on the modern land surface.

On the flood-washed surface adjacent to the channels, micro-erosion scarps around vegetation clumps indicate erosion, at least in the short term. Gravel stringers, which include ferruginous pisoliths, have been left behind during erosion of the surface.

The stream exposes bedrock on the banks and in the bed. Downstream increases in flood water flows enable transport of fine and coarse sediments, resulting in the deposition of 2-3 m of gravel in a mud matrix over the bedrock. The gravels are weakly cemented in some parts of the channel. Sand "shoals" that are slightly higher than the adjacent boulder-floored bed also occur in the channels.

Mingera Creek to the south of the Barkly Highway, is a major tributary of Wilfred Creek, and drains a catchment containing large areas of Sybella Granite. Its channel has bank-full dimensions of about 50-70 m wide, and 0.5-1.5 m deep. The bed deposits are dominated by quartzose sand and fine gravel formed into large bedforms.

Sediment variations - On the ridges and upper slopes of the catchment are fracture gravels dominated by silcrete. Ferruginous duricrust is also present. The siliceous and ferruginous crusts form side by side in response to differences in bedrock composition. The ferruginous duricrust fragments contain milky quartz with diameters up to 10-20 mm and even 50 mm. Some of the grains are rounded.

In other parts of the upper catchment, cemented gravel overlies bedrock in the floor of the creek. The gravel consists of boulder-sized silcrete, ferruginous duricrust fragments, ferruginous pisoliths, and quartz. Stream bed sediments range from gravel, sand, and mud in unsorted deposits to the same components sorted into separate units.

Inferences - In the Wilfred Creek Catchment, weathering of bedrock produces fracture gravels at the surface. Siliceous and ferruginous fracture gravels on the ridges reflect differences in the parent rock. On low rises in particular, the gravels are resistant to water transport, and are retained as a residual lag deposit.

The rounded quartz in some ferricrete indicates that ferruginisation has cemented transported sediments as well as *in-situ* bedrock. The poor sorting of the alluvium in parts of the upper catchment indicates mass transport and rapid deposition. In other areas, mud and fine sand released by weathering on the ridges is washed onto the flat alluvial plain on the valley floor. Here, the surface of mud to very fine sand is commonly strewn with ferruginous pisoliths, silcrete, and quartz.

Stream evolution enables re-erosion of cemented channel floor gravels. The original cementation may have occurred by precipitation from water percolating through a porous gravel layer overlying comparatively impervious bedrock. Overall, channel incision is limited due to shallow bedrock which is resistant to erosion.

Mingera Creek has a contrasting sediment load to the main Wilfred Creek, and provides a substantial contribution to the sand and fine gravel component downstream of their junction.

4.2.6 Johnson Creek and tributaries

Channel characteristics - The Johnson Creek catchment contains two major streams that join to form a single channel just upstream of the Barkly Highway crossing. The upper part of the Johnson Creek catchment contains numerous channels incised to bedrock. The streams occupy shallow V-shaped valleys and retain limited volumes of channel floor gravel and sand. In the upper catchment, there are no substantial alluvial plains.

Further downstream is the typical sequence of surficial mud overlying unconsolidated gravels, and basal cemented gravels. In the mid catchment near the Lady Loretta road, the cemented deposits include a basal unit containing rounded translucent white quartz pebbles, and quartzose sand lenses. The deposits of sandstone and conglomerate contain patches of orange-brown mottling, and extend beyond the creek on to a low ridge where iron-stained outcrops occur. Rounded quartz gravel released by weathering of the matrix is scattered across the surface of the ridge. Layering in the sandstone and conglomerate is essentially horizontal, and exposures on the silcrete ridge show cemented sand and gravel remnants in hollows in the bedrock.

In the vicinity of the Python Prospect on Johnson Creek, iron-cemented gravels overlie the bedrock which now forms the high banks on the western side of the channel. These cemented gravels at the top of the bedrock cliff mark a former channel now truncated by erosion. Both the truncated channel and the modern stream bed contain poorly sorted boulder gravel and sand.

Near the Barkly Highway, the bed of Johnson Creek contains boulders, gravel, and sand. The bank contains light brown to orange brown alluvial mud up to 4 m thick, with cemented muddy sands and gravels at the base. There is little evidence of soil profiles developed on the alluvial mud overlying the cemented gravels. On the adjacent plain, a flat gravelled surface provides evidence of removal of fine grain sizes by sheet wash processes. Nodular silcrete exposures are fractured, as are surface outcrops of iron-cemented bedrock.

Inferences - Shallow bedrock forms the base level of downcutting and the creek banks expose the complete alluvial sequence, approximately 5 m thick. The quartzose sandstone and conglomerate overlying bedrock in the floor of parts of Johnson Creek also occur above steeply dipping shales on the tops of ridges further to the north. The dominance of quartz in these sandstone/conglomerates reflects a different sediment dispersal environment to that of more recent times. Silcrete crusts have developed on these deposits in some areas (eg. Site B46 (Figure 2)).

5. SEDIMENT GENERATION, TRANSPORT AND DEPOSITION

Duricrust caps on bedrock increase its resistance to erosion. In the Kennedy Gap region, high relief areas capped by silcrete and or ferricrete are common. The generation of **new** sediment must occur from these and other elevated areas. Paradoxically, the erosional resistance of high relief areas cause them to be the focus of further weathering and erosion to generate new sediments. While new sediments are being produced principally on the bedrock ridges, the remainder of the catchment is largely protected from mechanical erosion by the alluvial cover.

Sediments are produced by weathering processes which commence with the mobilisation of alkalis and alkaline earths, followed by silica and iron. The chemical transport causes zones of weakness along which fractures occur. The process releases gravels composed of weathered fragments between fracture surfaces. Finer grain sizes are released from the fracture zones and from surface micro-erosion of the gravels.

Low lying outcrops on the floor of the catchment also produce weathered bedrock fragments ready for transport. These windows of bedrock have low slopes, and water flows across their surface are unlikely to entrain coarse particles. Many of these outcrops develop residual surface gravels as the finer grain sizes are preferentially removed by water, or even wind.

The catchment profiles (Figure 6) show that the steepest slopes occur in the topmost few kilometres of each stream. In the zone within 2-5 km of the drainage divides, slopes are steepest, and it is from this area that new sediments are supplied. Accordingly, it is the geology of this zone that has a strong influence on the composition of the sediments in the fluvial system. For Buckley River, Gidya Creek, Wilfred Creek, Judenan Creek, and Johnson Creek, the region of steep slopes is around the upstream perimeter of the catchment. However, the catchments of Judenan and Johnson Creeks also contain substantial tributaries separated by steeply sloping ridges flanking bedrock remnants. These **additional** areas of high slope provide a larger sediment producing zone than in some of the neighbouring more completely eroded catchments. A higher sediment yield per unit area of catchment is expected for Judenan Creek and the upper parts of Johnson Creek in comparison with Buckley River, Gidya Creek and Wilfred Creek. Cattle Creek, because of its low catchment slopes, is a reprocessor of old alluvial deposits rather than a supplier of new sediments from bedrock breakdown. Bedrock is at shallow depth beneath the alluvial cover. Cattle Creek may cause less frequent overturning of its alluvium than other streams.

The parts of the catchments beyond the steeply sloping areas are protected from erosion by an alluvial blanket. Nevertheless, most streams are capable of cutting narrow channels through this cover and into the top of the bedrock. The volume of new sediment produced by erosion of the bedrock in these channels is likely to be low. Stream bed erosion is a localised process, at any time affecting only a narrow zone extending down the catchment. Bedrock is relatively common in the floors of channels, but on the alluvial plains of the mid and lower catchments, most streams are not deeply incised. However, Judenan Creek has incised bedrock terrain along much of its length.

5.1 Sediments of the alluvial plains

The unconsolidated deposits in the region consist of colluvium and alluvium occupying the stream valleys. In the upper parts of the catchments, the deposits are a poorly sorted mixture of gravel, sand, and mud. The major components of the deposits are silcrete, ferruginous pisoliths, and quartz. Further downstream, the deposits become better sorted, with a separation into two units:

alluvial mud and very fine sand; and,
gravel (with minor sand and mud).

A typical sequence is an upper alluvial mud 1-2 m thick - in some areas containing gravel layers - overlying approximately 1 m of gravel. The gravel clasts usually have their long axes horizontal or nearly so, providing evidence of water deposition. The gravels are interpreted as having been transported as bedload during floods, and deposited during late stages as water velocities waned.

The unconsolidated alluvial deposits overlie bedrock, or flat lying cemented gravel and sand (Figure 7). The cemented deposits are similar to the overlying alluvial gravels and are believed to be their older equivalents. At some exposures they are mottled and iron-stained.

The cemented deposits are commonly exposed in the beds of the streams. Present day channel erosion exposes the older deposits and also erodes them to form small stacks, bars, and scour holes. The cemented gravels occur beneath the unconsolidated deposits in all of the drainage basins in the study area except for Gidya Creek. Likely modes of cementation include the *in-situ* breakdown of rock fragments and pisoliths to produce cementing iron-rich clays. Cementation by ground water percolation resulting in the precipitation of dissolved compounds is also possible.

5.2 Sediment transport and deposition

Sediments are transported from the ridges principally by gravity movement assisted by water flow. Around the flanks of the high ridges, colluvial aprons of poorly sorted mud, sand, and gravel develop. These typically consist of a mixture of silcrete, ferricrete, quartz gravels, and sand, together with iron-stained mud.

On low rises, the transporting agents preferentially remove the finer grain sizes, leaving lag deposits of surficial gravels. These may be:

- angular bedrock fracture gravels where bedrock outcrops;
- ferruginous nodules and ferruginous pisoliths where soil profiles are being eroded;
- siliceous nodules (silcrete gravels) where nodular silcrete is being eroded;
- angular ferruginous gravels where ferruginous saprolite is being eroded;
- angular siliceous gravels where silicified saprolite is being eroded.

The coarse deposits at the base of the alluvial sequence on the flood corridors represent the amalgamation of channel floor deposits resulting from lateral channel movement.

6. LANDSCAPE EVOLUTION

6.1 Conceptual models of landscape evolution

Conceptual models of landscape evolution describe the land surface evolving through weathering and erosion. The landscape comprises areas that are generating sediments, areas of sediment in transit, and areas of sediment deposition. There may also be parts of the landscape where erosion progresses much more slowly than elsewhere. These become the highlands on the developing land surface.

Examination of the slopes in the catchments shows that all of the streams except for Cattle Creek have steepest slopes in a zone that extends 2-5 km from the drainage divide. This zone is the main source of the new sediments being added to the fluvial system. Once weathering breaks down the bedrock into fragments, these become available for transport. Sediment generation, transport, and deposition is a key cycle in the evolution of a landscape. The cycle may be repeated many times as the landscape continues to evolve. Sediment may be generated at its source and transported to a depositional site only to be subsequently re-activated by later processes.

In the Kennedy Gap area, sediments are generated principally on the ridges where the Proterozoic bedrock is at or near outcrop. The rate of sediment generation is influenced by:

- the presence or absence of an erosion-resistant cap of silcrete or ferruginous duricrust;
- the amount of fracturing of the bedrock;
- the grain size and porosity of the bedrock;
- activity of chemical weathering;
- susceptibility to sun fracturing;

From the ridges, the sediments are transported to the colluvial apron by gravity or sheet wash (Figure 5). Subsequent transport downslope from the colluvial apron may be grain-size specific. On the colluvial apron, both sheet wash and incised channels are active. In the incised channels, water transports sediments of all grain sizes to the alluvial plain. In contrast, sheet wash moves primarily the finer fractions to the plain, leaving a coarse surficial lag gravel. Hence the channels contribute to bulk removal of colluvial deposits. The removal of fines by sheet wash coarsens the overall grain size of the remaining colluvium.

The alluvial sheet on the valley floor is influenced by surficial sheet wash and by streams:

Sheet wash across the surface may be erosional or depositional. Under less than bank-full conditions in the main stream, sheet wash from side slopes and secondary tributaries may have an erosional effect on the plain adjacent to the stream. Under flood conditions when the alluvial plain is inundated, sheet wash from the colluvial slopes is added to the overbank sediment load of the stream proper. A blanketing deposit accumulates on the plain.

Stream processes involve lateral channel movement which reworks the alluvial sequence from the surface to the depth of channel incision. As the streams move laterally, a stream-bed gravel unit is preserved beneath the accreting channel bank. In the Kennedy Gap area, the streams have eroded through the entire unconsolidated sequence and into the underlying cemented sequence to varying degrees. In places, streams have eroded into bedrock.

The landscape is the product of repeated episodes of rain-caused erosion, and water transport of sediments produced by weathering. The features of the landscape reflect the varying intensity of these processes through time. Relict features in the flood corridors record the more significant events of very large floods. Lesser but more frequent floods may not have the capacity to cover or rework high energy landforms such as abandoned channels and meander cut-offs. The more common floods have localised influence but still cause major reworking of the flood corridor deposits in narrow swiftly flowing channels.

The flood corridor deposits are sufficiently competent to resist later channel erosion. The channels are relatively narrow, with **most of the erosion energy confined to the bed,** where a coarse abrasive slurry is in transit. The channels are associated with bed erosion, and with lateral undercutting and erosion of alluvial deposits.

The flood corridor surface away from the channels is slightly aggradational although the thin sequence indicates slow net deposition.

6.2 Sediment transport environment

There are several modes of sediment transport occurring in the catchments of the Kennedy Gap area:

- In the upper catchment, **sheet wash** delivers sediments to drainage channels.
- With "less than bank full" or "bank full" flow, sediment transport is constrained to drainage channels.
- With overbank flow, transport occurs over the flood corridor.

A nominal channel 4 m deep and 18 m wide has a bank full flow capacity of about 1 Mm^3/hr at a flow velocity of about 4 m/s. Such a stream could cope with 100% runoff from a 100 km^2 catchment receiving rainfall at a rate of 10 mm/hr. Further down the catchment however, the increasing runoff volume could only be catered for by either enlarging the channel, or by overbank flow. Field evidence suggests that the rate of cumulative increase in **catchment area** and consequent runoff volume with distance downstream exceeds the rate of increase of **channel size**. The channels cannot cope with the cumulative runoff, so overbank flow typically accompanies even moderate widespread rain. In the streams of the Kennedy Gap area, the nominal 100 km^2 catchment is typically attained at 10-15 km down the drainage basin axis. In this scenario, the uppermost 10-15 km of the catchment may expect infrequent overbank flow; and beyond 10-15 km, overbank flow would be relatively common.

During floods, the coarse sediments carried as bedload remain largely confined to the channels, where velocities are greatest. Overbank flow produces shallow water depths, but covers a wide area. Water velocities are less than in the channels, but are sufficient to transport a suspended load of very fine sand to mud. As the water moves across the flood plain, friction reduces the velocity and the sediments are deposited. Overbank flow enables widespread deposition of a thin blanket of fine sediments.

The catchments consist of an upper zone where sheet wash dominates, and it follows that the deposits of this zone will have characteristics as follows:

- poor sorting, with angular to rounded gravels mixed with sand and mud;
- close to source;
- no cover of alluvial mud;
- relatively low dilution of source specific minerals.

Further down in the catchment, the sediments will have different characteristics:

- improved sorting and separation of grain sizes - overbank flow transports fine grain sizes, with gravel and sand transport occurring as bedload within the channel confines;
- separation of alluvial mud and gravel into distinct units;
- further from source;
- increased dilution of source specific minerals.

Elevation differences between upper catchments of adjacent streams provide opportunities for stream capture. Development of the western part of the Judenan Creek catchment has enabled the headwaters of secondary tributaries to encroach upon the upper catchment of Cattle Creek. Judenan Creek is similarly encroaching upon Buckley River.

The mechanical processes of landscape evolution range from the production of fracture gravels at rock outcrops to the accumulation of stream bed gravels in creeks. However, sediments may be influenced by both chemical and mechanical transport. Chemical processes are largely unseen but are extremely important in the development of resistant surfaces such as silcrete and ferruginous duricrusts. Such processes can also act on bedrock to produce more or less erosion-resistant horizons. Chemical breakdown of susceptible minerals in mixed alluvial gravels leads to cementation, mottling and iron staining. Chemical processes can also produce armoured cases on ferruginous pisoliths produced by chemical segregation in soil profiles.

Poorly sorted sediments containing boulder- to mud-size components are released by weathering in the upper catchments. During seasonal floods, runoff is high and the surface flows are sufficient to move

the available sediments, at least in the upper catchments. These coarse sediments in transit act as an abrasive slurry on the bedrock, at first producing minor linear depressions which evolve into incised channels. Most of the sediment supplied from the upper catchment is transported through the upper reaches of the drainage basins and very little is retained. Hence the channels are characterised by minimal bed deposits dominated by gravels, and outcropping bedrock in the channel floor. The landscape comprises shallow V-shaped valleys with minimal alluvial plains. This is the active part of the catchment where bed levels are being lowered by the abrasive action of the mobile coarse sediments. Steeper slopes produce greater water velocities, and increased erosive power. Hence, much of the work of landscape evolution occurs in the steep terrain.

6.3 Sediment budget

The evolution of the landscape can be considered in terms of a long term sediment budget. The sediment budget relates the rates of **sediment production (P)** and **sediment removal (R)** from a source area (Figure 8).

The process of sediment **production** is the conversion of bedrock into transportable components, usually by weathering. Sediment **removal** is the transport of the products away from their site of formation. A landscape may be assessed by considering the overall relationship between P and R. In detail however, the locations of sediment production on the landscape will have an evolving P-R relationship over time. Also, the effectiveness of the transporting agents may vary with the nature of the sediments produced in the source areas, for example removing fine grains more readily than coarse.

The evolutionary trends for a notional landscape are considered from an initial state where a prominent bedrock ridge is flanked by colluvial deposits merging onto an alluvial plain. Streams on the alluvial plain are incised to bedrock (Figure 8). The evolution of the landscape is considered under different conditions of P and R. The possible options are:

1. **P<R**;
2. **P=R** (approximately); and
3. **P>R.**

P<R:

Where the long term trend is for the rate of sediment production to be less than the rate of sediment removal, the landscape becomes denuded of sediment cover. The elevated areas are bordered by comparatively steep slopes of exposed bedrock. With time, elevation differences across the landscape are accentuated, with bedrock ridges becoming more prominent. Colluvial fans at the base of the slopes are minimal and are not preserved for long in the geological record. A transported cover of coarse sediments blankets the plains. Here, the landscape is lowered as the finer grain sizes are transported further away, and a residual stratigraphy of coarsening sediments develops. Remnants of older land surfaces may be exhumed and eventually appear as mesas. Windows of bedrock may also be exposed. The sediment-denuded landscape provides an opportunity for deep weathering of the exposed bedrock.

P=R:

Where sediment production approximately equals sediment removal, the evolution of the landscape is characterised by degrading bedrock ridges. The adjacent alluvial plains have a dynamic stratigraphy reflecting short term fluctuations in sediment supply and removal. The plain may be slightly aggradational due to the supply of coarse to fine grained sediments by streams whose transport capacity is declining. Overall, the alluvial deposits comprise a thin cover in transit. There may be limited preservation of colluvium abutting the bedrock ridge. Concealed bedrock and remnants of former land surfaces remain hidden.

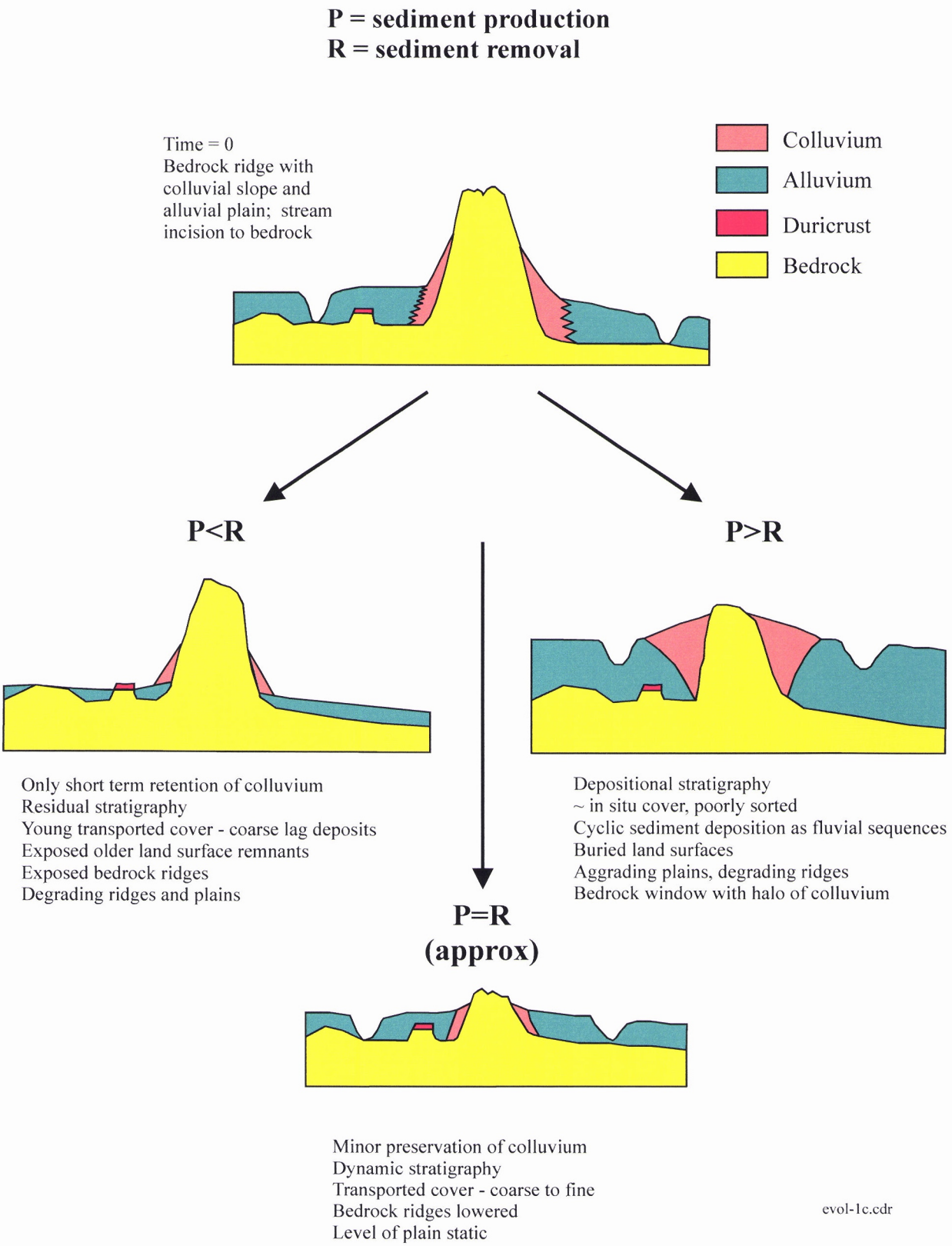

Figure 8: Model of landscape evolution in the Western Succession, Mt Isa.

P>R:
Where the rate of sediment production exceeds the rate of removal, the landscape will eventually "drown" in its own sediment products. However, this final state may not be achieved due to the intervention of other factors such as declining sediment production as high areas on the landscape are eroded. At the site of sediment production on the ridges, the colluvial fans become more extensive as the ridges are degraded. Eventually this will lead to a bedrock window surrounded by a colluvial halo. On the plains, the depositional stratigraphy is preserved in poorly sorted cover that has not been transported far from its source. The stratigraphy may contain evidence of cycles of deposition recording fluctuations in long term trends of sediment supply and removal. Buried land surfaces are covered by greater thicknesses of cover as the landscape continues to evolve. Deep weathering profiles are developed in the alluvial deposits.

The Kennedy Gap area is characterised by prominent bedrock ridges, thin sediment cover, and a number of duricrust capped ridges and mesas. Overall, the landscape is one in which the rate of sediment production is less than the rate of sediment removal (**P<R**). Fluctuations in P and R enable short term cycles of sediment retention and removal. At any time, the preserved sequence is therefore likely to be young. The substrate geology is unlikely to be effective in producing strong geochemical haloes in the alluvial cover. The mobility of the surficial deposits is expected to diffuse rather than concentrate trace element additions from the bedrock.

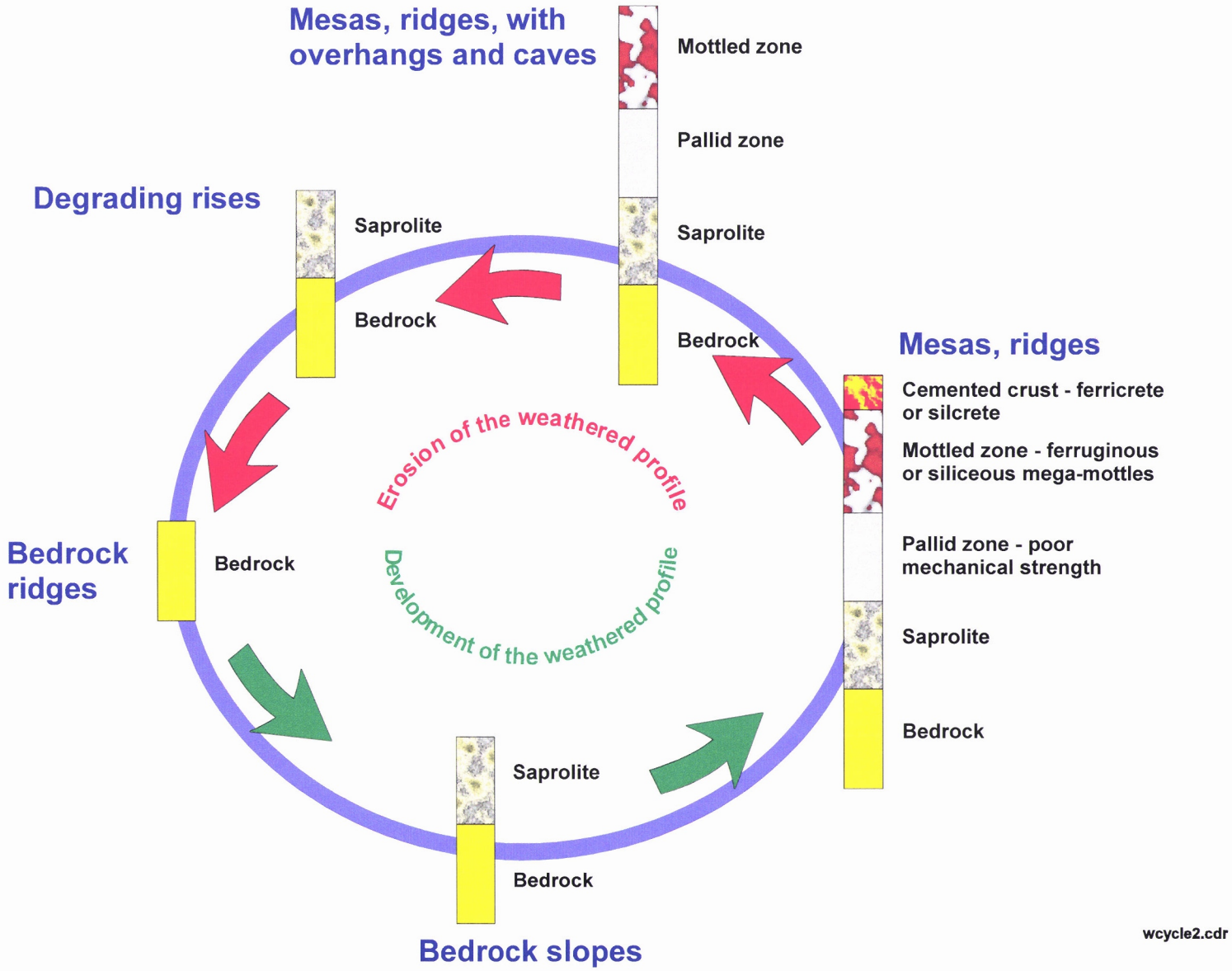

Figure 9: Diagrammatic cycle of weathering and erosion in non-depositional (elevated) areas.

6.4 Evolutionary cycles

Although this high country dominates the landscape, weathering continues to make subtle changes to the bedrock, eventually leading to its fragmentation and lowering through erosion. From field observations of soil profiles on ridges and scarps, a cyclic process of landscape evolution is inferred (Figure 9):

1. Weathering initially produces a saprolite zone overlying fresh bedrock. Sun fracturing of the bedrock is important in producing gravels and allowing percolation of water.
2. As weathering extends further downwards, the saprolite zone becomes deeper. Chemical changes take place in the upper part of the saprolite. Solution and transport of soluble minerals such as calcium, iron, and silica occurs.
3. Re-deposition of soluble minerals produces a mottled zone, and at the surface, a hard crust (duricrust) typically of ferricrete or silcrete. The extent of duricrust development is variable, ranging from minor to massive cementation. In the cemented crust and in the mottled zone, traces of the original bedrock fabric may still be present. Cementation may also extend upwards into surficial transported deposits. In the mottled zone and below is a depleted region from where the soluble minerals were derived. This zone is typically clayey, and the lower parts have poor mechanical strength.
4. The duricrust is eventually eroded, in the process forming short-term surficial lag gravels. Further erosion exposes the underlying mottled zone. This zone is also resistant to erosion and forms mesas and ridges. Along breakaways, the underlying depleted zone is exposed. Its poor mechanical strength enables caves and overhangs to form. These undermine the overlying mottled zone (and any remaining duricrust), and large blocks fall away.
5. Once the mottled zone and duricrust have been lost, the pallid zone (or clay zone) is rapidly removed, exposing the base of the saprolite as a degraded rise. The saprolite may or may not be removed, and the cycle is ready to be repeated.

The model of bedrock weathering in elevated areas explains how apparently slightly weathered bedrock can overlie a pale clay zone which overlies less weathered bedrock. Different parts of the catchment can be at various stages of the weathering cycle, which influences the sediment yield. Most of the sediments supplied from the mottled and duricrust zones are silcrete nodules and fragments, or ferricrete nodules and fragments. The pallid zone releases clays, and quartz sand and gravel.

6.5 Development of the gilgai plains

Much of the grey cracking clay is found in the catchment of Cattle Creek. The clay is a significant part of the sediment load, particularly in the lower reaches where it makes up much of the sediments in the flood corridor. During flooding, the grey clays are readily transported in suspension and deposited as overbank splays in the flood corridor of Cattle Creek. They are also in the channels of the smaller streams draining into Cattle Creek and appear to be readily transported in suspension in these areas as well. The blanketing deposits in the upper catchments of the minor streams are quite thin (<1 m), with windows of residual gravels at the surface. Evidence from the lower catchment of Wilfred Creek indicates that the cracking clays have filled former drainage channels in red-orange alluvium. The cracking clays are being distributed across the landscape by streams.

In the northwest of the study area, the Lady Loretta road crosses an open area of gilgai plain at the headwaters of Cattle Creek (Figure 10). The area has a pale photo pattern which includes fine parallel lineations and disconnected line and dot markings similar to "linear" and "normal" gilgai described by Hubble and others (1983). On the southwestern side of the plain, strike ridges of the underlying bedrock (Shady Bore Quartzite) can be seen on air photos. Immediately to the northeast of the plain, air photos show linear ridges of the Esperanza and Paradise Creek Formations. The bedrock is likely to be at a shallow depth below the surface of the gilgai plain which separates these outcrops. There are no modern drainage channels that cross the gilgai plain. Rather, the drainage is around the periphery. These features enable a conceptual model for the formation of the plain to be developed:

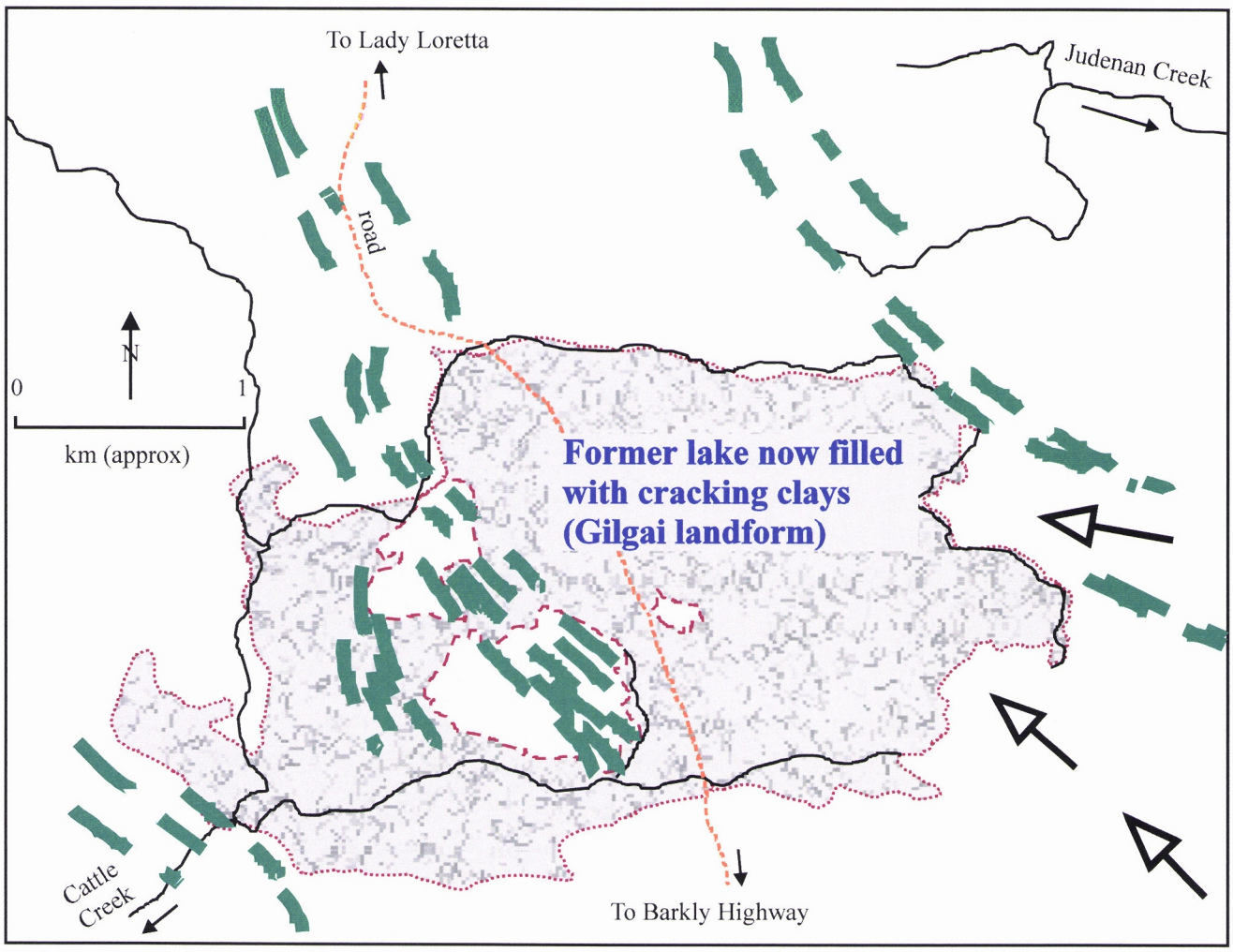

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Figure 10: The gilgai plains in the upper reaches of Cattle Creek overlie shallow bedrock of the Shady Bore Quartzite and Esperanza Formation, indicated by well defined strike ridges (large dashed lines). Sediment transported from the southeast (large arrows) supplied cracking clays in suspension, depositing them in the shallow basin. With repeated cycles of wetting and drying, the lake deposits developed into a gilgai plain having positive relief, causing modern drainage channels to develop around the perimeter of the raised area.

The model envisages a former shallow basin in the bedrock. Small seasonal streams flowing into the depression brought with them suspended sediments rich in clays. These streams probably drained the low lying areas to the southeast and south. During the wet season, the depression was a shallow lake in which the mud-sized suspended sediments were deposited. Cycles of development included lake-filling, deposition of mud during the wet seasons, and desiccation during dry seasons. During the cycles of wetting and drying, the swelling and cracking characteristics of the clays gradually produced positive relief. Impeded drainage and weathering allows smectites to form and these are believed to be a key component of gilgai soils (Robertson, pers comm). At present, streams no longer flow into the former basin as it is higher than the adjacent landscape. The former lake is now a treeless plain.

6.6 Age estimates for the alluvium

In the absence of isotopic age determinations, estimates of the age of the alluvium can be attempted by considering possible erosion rates, and sediment retention rates. An erosion rate of 1 mm/yr over an area of 30 km^2 (a rough estimate of the sediment producing zone in the study area) will produce sufficient sediment to cover an area of 1200 km^2 to a thickness of 25 m in 100 000 years. The erosion rate of 1 mm/yr will lower the catchment elevation by 100 m in 100 000 yrs. The same erosion rate would produce accretion of 2.5 m in 10 000 yrs.

On the alluvial plains, there is 5-10 m of accretion, which would require about 20 000 to 50 000 years to be achieved. However the sediment retention rate would be much less than 100%. Considering a nominal 50% retention rate and a 50% throughput of alluvial sediments, the time for the accretion of 5-10 m would be doubled. An estimate of the age of the alluvial blanket would be 40 000 to 100 000 years. This may be a starting point for estimating the age of the deposits. A significant variable likely to impact on the age estimates is climate and vegetation. Changes in these environmental factors cause variations in sediment production and catchment sediment yield.

Well developed soil profiles are present on some bedrock outcrops where strongly iron-stained horizons grade downwards into mottled clays, pallid zone clays and saprolite. In most places, these soils are formed by the *in-situ* weathering of bedrock and saprolite. In general, the **alluvial** deposits show poor development of soil profiles. The age estimate of up to 40 000 to 100 000 years for these deposits provides an abundant time period to develop well defined soil profiles on undisturbed deposits. The absence of soil profiles in the alluvium may be due to transporting processes causing frequent overturning of the sediments. The alluvium could also be much younger than the 40 000 to 100 000 years estimate.

Investigations of alluvial sedimentation rates in India (Sinha and others, 1996) indicate accretion rates of 0.62-1.45 mm/yr over the last 2 700 yrs. This would be sufficient to enable 5 m of accretion in 3 500-8 000 yrs. Other data also reported by Sinha and others (1996) suggest alluvial sedimentation rates of 0.2-0.05 mm/yr over periods of 10 000 yrs, enabling 5 m of accretion to be achieved in 25 000-100 000 yrs. The limited data from India enables order-of-magnitude comparisons to be made for such catchments as Buckley River. The information suggests that the alluvial sequence is probably less than 50 000 yrs old.

7. IMPLICATIONS FOR MINERAL EXPLORATION

Stream transport disperses rather than concentrates most alluvial components. Heavy minerals are an exception and may be concentrated as placer deposits. Studies in Canada (Day and Fletcher, 1991) showed that heavy minerals can be concentrated in specific areas of the bedload deposits. Their studies confirmed that concentrations of heavy minerals such as gold and magnetite are found at the heads of gravel-bar deposits (downstream ends) rather than at the tails. Also, the sand fraction in the gravel-bar deposits is more likely to contain heavy minerals than sand-bar deposits (Day and Fletcher, 1991). These concentrations are found principally in the silt to fine sand size range (53-210μ). The studies indicate that stream sediment geochemistry will be more successful in identifying anomalies if sand samples are obtained from the coarse-gravel bar deposits and analyses are targeted at the silt to fine sand fractions. Judenan Creek, Gidya Creek, and the upper part of Johnson Creek would be suitable for examining the heavy mineral content of gravel bar deposits.

The chemical processes of sediment transport provide other opportunities for concentrating indicator minerals. On the ridges, chemical solution and precipitation of silica and iron forms duricrust. In the valleys, chemical processes cause the breakdown of soft minerals, and clay cementation. For the chemical processes to develop geochemical haloes from underlying bedrock, stable deep weathering profiles are necessary. However, in the Kennedy Gap area, the superficial sediments of the valleys and plains are thin and mobile (P<R), and therefore not conducive to developing chemical anomalies.

The extent of weathering of bedrock is variable. The streams that have the most complex drainage patterns are Gidya and Judenan Creeks. The large number of channels in these two catchments indicates active erosion. The erodability of the catchment is influenced by the mechanical strength of the underlying rocks, which is related to the rock type, and amount of weathering. In the Gidya and Judenan Creek catchments, the bedrock is mainly the Cromwell Basalt Member of the Eastern Creek Volcanics. Erosion of the volcanics in these catchments suggests a greater depth of weathering and or fracturing in these rocks, or a lack of a protective duricrust cap in comparison with other bedrock in the region. These factors may influence mineral occurrences. Copper and uranium mineralisation is already known from the area (Wilson and Little, 1977). Oxidised zone copper was also observed during field work several kilometres to the south of the Queens Gift prospect on Judenan Creek.

An assessment of catchment morphology and geology also provides information on the minerals in the streams. Gidya Creek for example is locked between two sub-parallel steeply dipping ridges. A uniform assemblage of minerals in the alluvium can be expected because of the uniformity of source down the catchment. Buckley River in contrast, runs westwards across strike. Hence a more diverse mineral assemblage can be expected, reflecting the range of rock types in the catchment.

7.1 Identifying mineral deposits using Quaternary regolith

The sequence of units comprising the cover deposits over basement is shown in Figure 11. Sampling of any of these units may reveal geochemical anomalies. However, the anomalies in different units may not be generated by the same source. It is important to examine the genesis of each of the units to determine the source or sources of any anomalies that may be present.

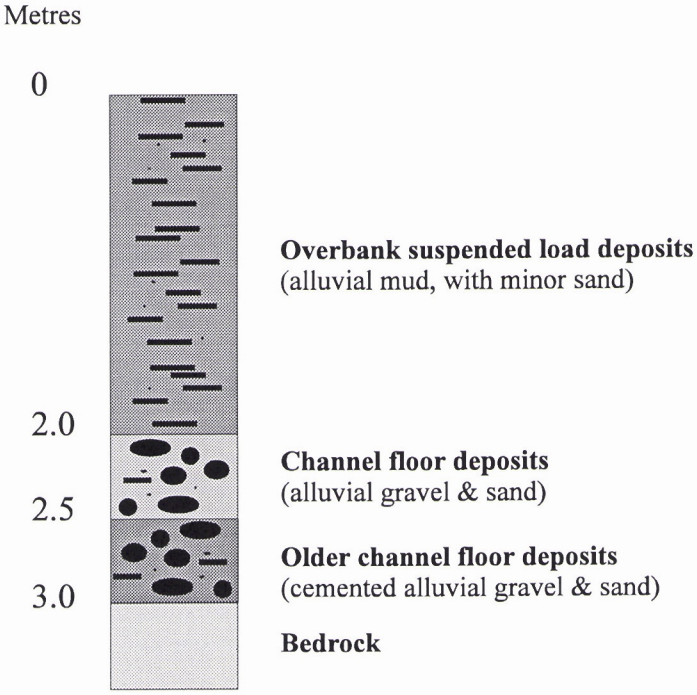

Figure 11: Alluvial sequence overlying bedrock in the catchments.

Geochemical sampling of each of the stratigraphic units in the catchments is likely to provide information on different sources, as follows:

Overbank suspended load deposits - These deposits are mainly fine sediments transported in suspension. In the study area, the overbank deposits do not have well developed soil profiles. They are likely to be young deposits subject to relatively frequent reworking through bank erosion .

1. Geochemical data are likely to provide diffused indications of "up-catchment" sources. These sources are likely to be located in the sediment production zone of the catchment ie. 2-5 km from the upper catchment divide.

Channel floor deposits - These deposits accumulate through bedload transport in incised channels. Bedload transport involves mainly coarse grain sizes (coarse sand to boulder gravel). Channel floor deposits include all sizes from mud to gravel.

1. Geochemical data from the sand fraction are likely to provide diffused indications of up-catchment sources.
2. Individual gravel particles are supplied from a variety of sources, depending on the geological complexity of the upper catchment. These may include mineralised "floaters" from up-catchment outcrops. The largest particles have probably travelled the least distance from their source outcrops; fine particles are likely to represent more distant source areas. Geochemical samples from the gravel fraction need to be large to be representative of up-catchment sources.
3. Heavy mineral concentrations, derived from up-catchment sources, may be present in the fine sand sizes.

Older channel floor deposits - These are old channel bed deposits of coarse sand to boulder gravel. Chemical transport has supplied a cementing matrix either from *in-situ* rock breakdown, or chemical precipitation. In most places, the components in the gravel and sand are similar to present day streams, implying similar drainage patterns and sediment sources to the present. Different assemblages imply different patterns of sediment dispersal.

1. Geochemical data from the sand fraction are likely to provide diffused indications of up-catchment sources.
2. Individual gravel particles are supplied from a variety of sources, depending on the geological complexity of the upper catchment. These may include mineralised "floaters" from up-catchment outcrops. The largest particles have probably travelled the least distance from their source outcrops; fine particles are likely to represent more distant source areas. Geochemical samples from the gravel fraction need to be large to be representative of up-catchment sources.
3. Potential anomalies present in the matrix/cement are likely to indicate up-catchment sources due to the influx of cementing (and other) chemicals. Zones of iron staining and ferruginous mottling in the cemented deposits may contain concentrations of trace elements, a result of the chemical scavenging properties of the iron.
4. Geochemical anomalies in the matrix/cement may also indicate localised sources in the underlying bedrock.
5. Heavy mineral concentrations, derived from up-catchment sources, may be present in the fine sand sizes.

Bedrock - Erosion of the bedrock is minimised due to the protective overlying cover. In the mid and lower catchment, bedrock has only minor stream incision. Chemical weathering of the bedrock enables minerals to be transported in solution and deposited as cements. Geochemistry may provide diffuse or concentrated indications of the local (possibly weathered) bedrock.

7.2 Significance of ferricrete, iron pisoliths, and ferruginous nodules

There are a number of ferricrete-capped mesas in the Kennedy Gap area. Although they may have been part of old land surfaces, the ferricrete horizons appears to be more directly related to underlying iron-rich bedrock. Cementation has increased the resistance to erosion, and the cemented caps have become elevated remnants as the more easily eroded units to each side were removed. The ferricrete is of variable composition and includes haematite, manganese minerals, traces of bornite, and goethite. Depleted zones underlie the ferruginised caps, and contain iron-rich mottles and weathered pods of soft cream to white clay.

Erosion of the ferricrete caps and the ferruginous mottled zones below provides a rich source of iron-stained lithics, nodules and pisoliths available for transport across the land surface. The gravels form sheet deposits that may become cemented by iron, examples of which are present along the catchment divide between Cattle and Judenan Creeks. In some locations, grains with haematitic centres develop goethitic cutans. With transport, these cutans can be abraded away, leaving polished dark brown to black pisoliths composed of haematite. Transported iron-rich grains can also be re-cemented with goethite, resulting in a slaggy texture enveloping composite and individual grains. The source of this later goethite may be quite different from the source of the core pisoliths.

Ferruginous nodules and pisoliths have been used as sampling media in geochemical exploration. Goethite in particular is active in scavenging tracer elements. However, the history of pisoliths may be complex, from formation in a soil profile, to erosion and transport resulting in the loss of outer layers, and later deposition of new outer layers. Distinguishing transported and *in-situ* pisoliths can be important in interpreting geochemical analyses (Figure 12).

For transported pisoliths, the geochemistry of the cores may be quite different from that of the outer cases. Any anomalies detected are likely to relate to laterally displaced sources. In contrast, anomalies from *in-situ* pisoliths and iron-rich nodules are more likely to indicate underlying sources.

7.3 Distinguishing transported and lag deposits

Transported deposits can be recognised by their diverse assemblage of components (eg. quartz, lithics, and pisoliths), with a mixture of grain sizes. Gravels supported by a fine matrix indicate mass sediment transport to the depositional site without in-transit sorting. If the long axes of gravels are somewhat horizontal, water transport was probably involved in the formation of the deposit.

In many areas, there are surficial sands and gravels interpreted as lag deposits. Some of these deposits are assumed to have formed by loss of fines in a mottled soil profile, leaving a residuum of iron-rich nodules or pisoliths. However, the thickness of the surficial deposits assumed to be a lag accumulation is often little more than the diameter of the gravels. Underneath are clay rich soils, in some cases containing fines-supported pisoliths and other grains. The surficial deposit therefore probably represents a concentration of, at the most, the uppermost few centimetres of the total regolith now present. Unsorted transported regolith of this type probably has a fluvial origin. The surficial gravels are produced by reworking only the topmost centimetres of the alluvium, and are likely to be entirely removed on occasions by surface wash.

An ***in-situ*** lag deposit produced by preferential removal of interstitial fines should consist of a significant thickness of gravel with a **grain-supported fabric**. If there is not a grain supported fabric, the deposits are transported, with the sources being in the upper catchment. True lag deposits should overlie the lower parts of an *in-situ* soil profile such as a mottled or pallid clay zones, or even saprolite or bedrock.

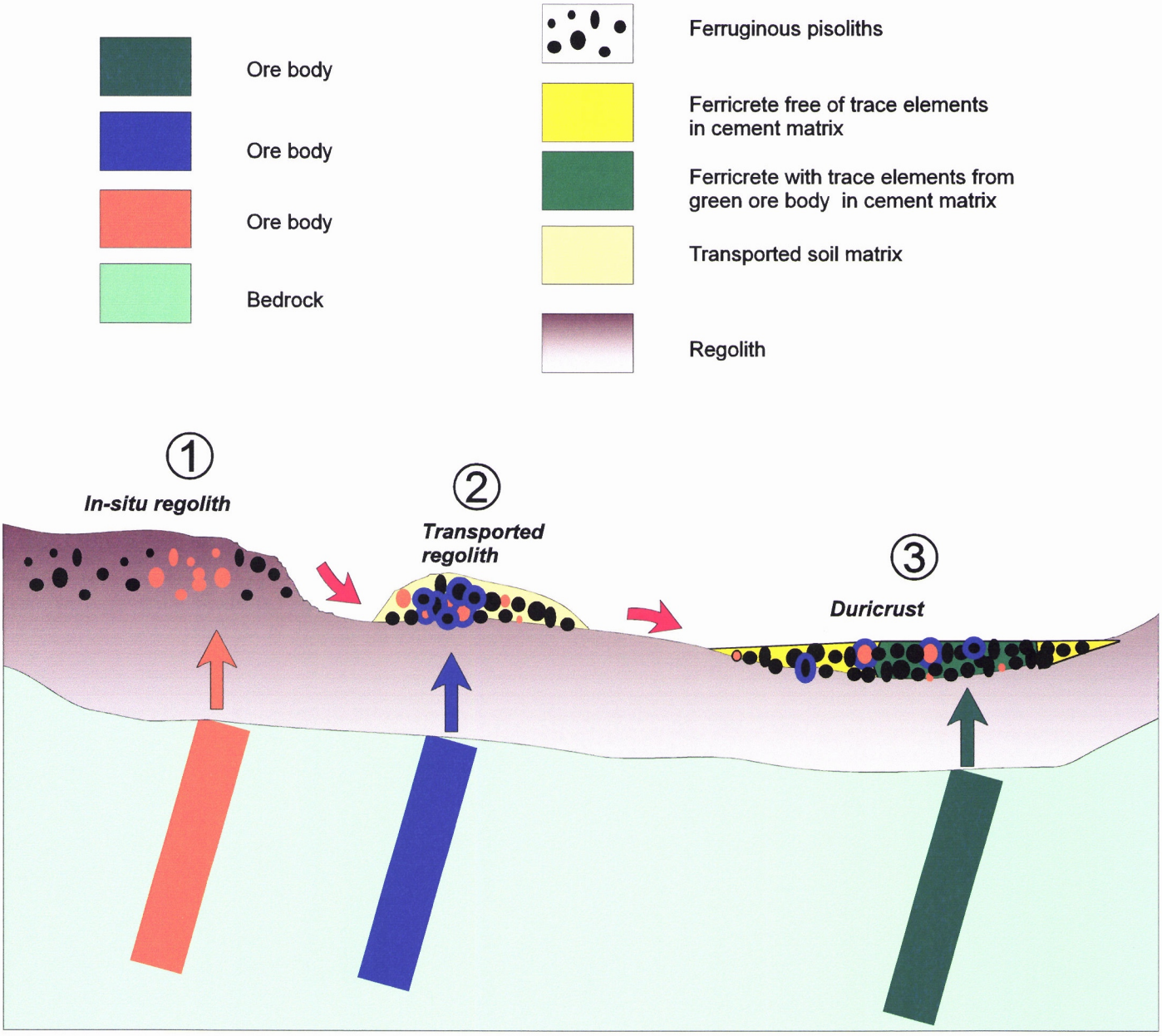

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Figure 12: Model of trace elements diffusing from concealed mineral deposits up into the regolith where they are taken up by regolith components such as iron pisoliths. 1: Hydromorphic dispersion from the orange ore body is preferentially taken up by ferruginous pisoliths forming in the mottled zone. Pisoliths do not contain trace elements beyond zone of diffusion. 2: Eroded pisoliths are transported and temporarily deposited in a soil matrix. Hydromorphic dispersion from the blue ore body is absorbed by chemical processes active at the grain surfaces. 3: Further transport moves pisoliths to a site where an influx of iron cements them, forming a ferruginous duricrust. Trace elements from the green ore body are incorporated in the iron cement. The duricrust then contains separate geochemical signatures in pisoliths, pisolith cutans, and ferruginous cement.

8. CONCLUSION

Since the Proterozoic, the overall evolutionary trend for the area has been for erosion. The products of erosion have largely been transported away from the area, with only minor remnants of former alluvial deposits still present. The drainage basins act as conduits for sediments in transit to distant depositional sites on the plains. Weathering and erosion of the Proterozoic bedrock is continuing in the elevated parts of the region. The sediment yield from the catchments is heavily dependent on the frequency and severity of rainfall, which provides the runoff which powers the main landscape altering process - fluvial flow. On the valley floors, deposition takes place, but the net rate of accumulation appears to be relatively low. The low slope of the landscape away from the ridges provides a suitable environment for accumulating sediments eroded from the upper catchments. When these are distributed across wide areas, the resulting deposit are thin. Although the overall geological record is for erosion, the existence of ferruginous and siliceous duricrusts on transported alluvial gravels on ridges suggest episodes of past sediment accumulation.

The modern landscape is dominated by the drainage basins of six major streams. In terms of landscape development, the present land surface is mature with catchments abutting one another along mostly narrow and well defined drainage divides. Different erosional activity is present in different catchments. The greater erosive power of Judenan Creek is enabling it to expand its catchment at the expense of lesser streams such as Cattle Creek. The north flowing Judenan and Gidya Creeks are more active because of their catchment geology. Their gradients are also steeper than the other west and south flowing streams.

The upper catchments of the streams are erosional, and the lower catchments are depositional. The boundary between the two regions is gradational, being influenced by the severity and frequency of floods. At the upstream margin of the zone of transition, the sediments are extremely mobile, and a high sediment throughput ensues. This area is affected by low intensity floods. At the downstream margin of the transition zone, much of the sediment is unaffected by average floods. However, the arrival of a massive flood causes massive reactivation of sediments. During these infrequent events, sediment transport is considerable. The effect on the geological record is related to the severity of the impacts, and the time separating return events. The existing geological record contains depositional features and channel patterns that have been preserved since the last major flooding. These features will be preserved until the next similar or greater magnitude flood occurs.

Preserved features on the present day land surface include:

1. abandoned channels;
2. meander cut offs;
3. sediment deposition at the junction of major streams (such as at the junction of Cattle Creek and Buckley River); and,
4. in the lower catchments, abandoned flood corridors.

The valleys act mainly as sediment conduits, and are not able to store sediment for long periods. The cemented deposits at the base of the alluvium represent a period of accretion during which the deposits remained undisturbed. More recently these deposits are being exposed by stream incision, suggesting a more erosional environment than in the past. The cemented deposits are presently being eroded in the stream beds. Their extent beyond the proximity of the present channels is unknown. Rotary Air Blast (RAB) drilling to bedrock in the Buckley River corridor west of the Lady Loretta road intersected cemented gravels in some of the holes. The results suggest cemented pods rather than a continuous layer of cemented gravel beneath the younger alluvium and overlying bedrock.

Is the current alluvial land surface in the catchments aggrading or degrading? If sediment production in the upper catchment source areas is less than the total transporting capacity of the streams, then erosion can be expected in the alluvial deposits. This would be indicated by features such as steep, unvegetated, freshly eroded stream banks. In the stream beds, exposures of resistant horizons would be present. All of these are in evidence in the modern catchments, suggesting a degrading alluvial surface and reworking of existing largely unconsolidated deposits.

Geochemical exploration in the Kennedy Gap area must contend with the widespread but relatively thin regolith cover. Being young and also subject to reworking, the regolith comprises weathered bedrock, residual *in-situ* soils, and a mobile alluvial carpet associated with fluvial and possibly even lacustrine environments. An understanding of these deposits - particularly their environments of deposition, and their areal distribution - will assist in the interpretation of geochemical data.

The Judenan Creek catchment is considered to be the most suited to stream sediment geochemistry, due to the amount of bedrock exposure or near exposure, and the erosional activity taking place. From the studies of Day and Fletcher (1991), the best heavy mineral concentrations will be found in the silt to fine sand fraction at the head (downstream end) of gravel-bar deposits.

8.1 Acknowledgments

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10. PHOTOGRAPHS 1

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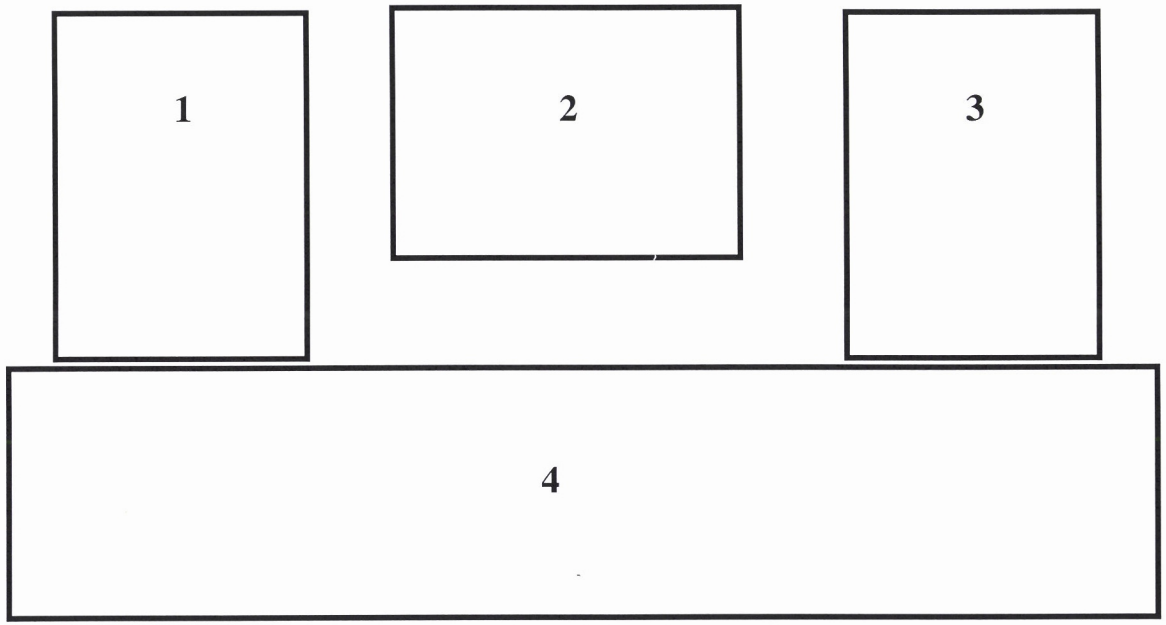

Photo 1: Ferricrete cap contains quartz pebbles and overlies steeply dipping iron-rich bedrock.
Photo 2: Upper catchment channel activity - lateral erosion of unsorted colluvium, Gidya Creek.
Photo 3: Cemented alluvial gravels underlie the unconsolidated alluvial sequence, upper Buckley River.
Photo 4: Buckley River panorama showing alluvium over cemented deposits and bedrock.

11. PHOTOGRAPHS 2

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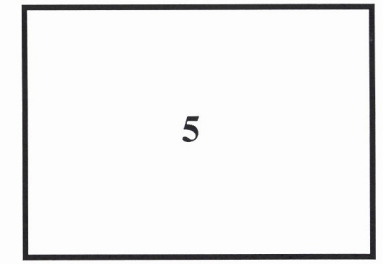

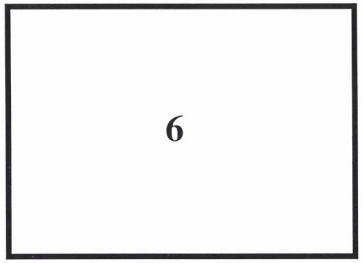

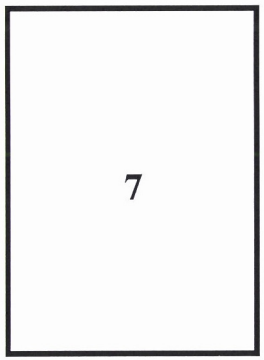

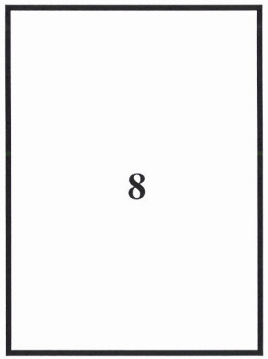

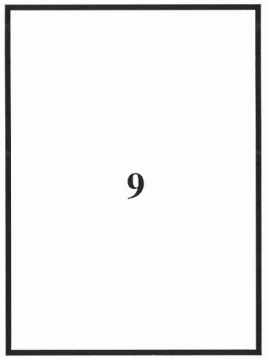

Photo 5: Red orange alluvial mud typically deposited by overbank flow in the flood corridors (tributary of Gidya Creek).
Photo 6: A lag accumulation of silcrete nodules at the top of an eroding weathered profile on bedrock (Johnson Creek catchment).
Photo 7: Weathering and erosion of mottled and pallid clay zones below silcrete cap (Johnson Creek catchment).
Photo 8: Weathering of bedrock on low rises produces mottled and strongly iron-stained saprolite.
Photo 9: Iron-cemented transported gravels (foreground) adjacent to massive *in-situ* silcrete (middle distance). (Cattle -Judenan Creek drainage divide.)