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The stratigraphic sequence of old land surfaces in northern Queensland

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In northern Queensland there are several old land surfaces which are related to previous periods of erosional and depositional activity. The surfaces are of two main types—buried and exhumed unconformity surfaces formed during periods of active erosion and deposition; and terminal planation surfaces of both erosional and depositional origin which formed as stability returned at the end of each cycle of erosional activity. These terminal surfaces have generally been deeply weathered or duricrusted. The oldest landforms are exhumed unconformity surfaces of Cambrian and Mesozoic age which formed the base of the Georgina and Carpentaria Basins respectively. Three sets of unconformity and terminal surfaces are related to cycles of activity within the Cainozoic Karumba Basin. They have been correlated with surfaces elsewhere in Queensland and the Northern Territory. There are also subsidiary depositional surfaces of the current cycle, and a suite of arid landforms which has previously been treated as a 'surface'.

Introduction

This paper defines and discusses the nature and stratigraphy of old land-surfaces in the Cainozoic Karumba Basin, and in the Burdekin Uplands to the southeast (Fig. 1). It reports one aspect of the study of the Mesozoic Carpentaria and Cainozoic Karumba Basins by a combined Bureau of Mineral Resources and Geological Survey of Queensland team, which worked in the area between 1969 and 1974. The geology of the Karumba Basin is discussed by Doutch (1976) and Smart & others (in prep.). This study of the land surfaces builds on the earlier work of King (1949), Twidale (1956, 1966), Galloway & others (1970), and Wyatt & others (1970, 1971).

The distribution of the old land surfaces is shown in Figure 1, based on plate 2 of Smart & others (in prep.). The southeastern part of this figure is outside the area studied by the field party and the distribution of surfaces in this area is based on an interpretation of air photos and previously published geological maps and reports, together with a brief field reconnaissance. Correlation of surfaces between this area and the Karumba Basin is only tentative, and a separate nomenclature is therefore maintained. The Cairns hinterland has not been included in this study. Its geomorphic evolution is interpreted by de Keyser & Lucas (1968).

In referring to physiographic regions, the nomenclature of Smart & others (in prep.) is followed. This incorporates many of the units originally named by Twidale (1966).

Terminology and concepts

Some of the old land surfaces within the area have been named by earlier workers; the nomenclature is further formalised here. In naming the surfaces the use of age terms has been avoided, as this can lead to problems if the chronology of the surfaces is later revised. Although a relative sequence of events is fairly well established in the region, the absolute ages of the surfaces are still uncertain.

The old land surfaces within the study area can be classified into two major and several subsidiary types. The two major types are genetically related to erosion cycles within the region. The concept of these cycles is discussed in Smart & others (in prep.). In general each cycle was started by uplift at the basin margins, or by some other disturbance, and its initial phase was one of active erosion at the margins and deposition in the adjoining depressions. In time, erosion, and therefore deposition, became less active as the source areas were worn down and the depressions filled as the cycle entered its final phase. Eventually, a terminal surface of low relief appeared and deep weathering of both its erosional and depositional parts became the dominant process. The development of the Mesozoic Carpentaria Basin was one such cycle, and three cycles occurred in the evolution of the Cainozoic Karumba Basin (Smart & others, in prep.).

The two main types of old land surface recognised in the area are the unconformity surfaces which formed and were buried during the initial active phase of a cycle; and the terminal planation surfaces which appear during the final stable phase of each cycle.

The **unconformity surfaces** are generally erosional surfaces, buried beneath the sediments of an expanding or migrating depositional area—though in the central part of the basin, where deposition commenced early in the cycle, downwarped remnants of earlier surfaces may have been buried and preserved with little erosion. The buried unconformity surfaces are generally diachronous, as erosional development was continuing in some areas at the same time as depositional preservation elsewhere. The oldest parts are generally near the basin centre where deposition first commenced, and the youngest parts near the basin margin, where burial only occurred late in the cycle. This concept is illustrated in Figure 2, in which the age of the surfaces is shown on the vertical scale and geographic position on the horizontal scale.

Generally unconformity surfaces remain buried, and their shape can only be interpreted in general terms from borehole data or geophysics. For example, Grimes & Doutch (1978, fig. 5) have mapped broad valleys and ridges of the Sub-Claraville Surface in this manner. Exposure by later erosion will generally destroy the surface, leaving only the unconformity trace between the older and younger rocks. However, if the rock below the unconformity is more resistant to erosion than the sediments above it, then the surface may be exhumed with little modification.

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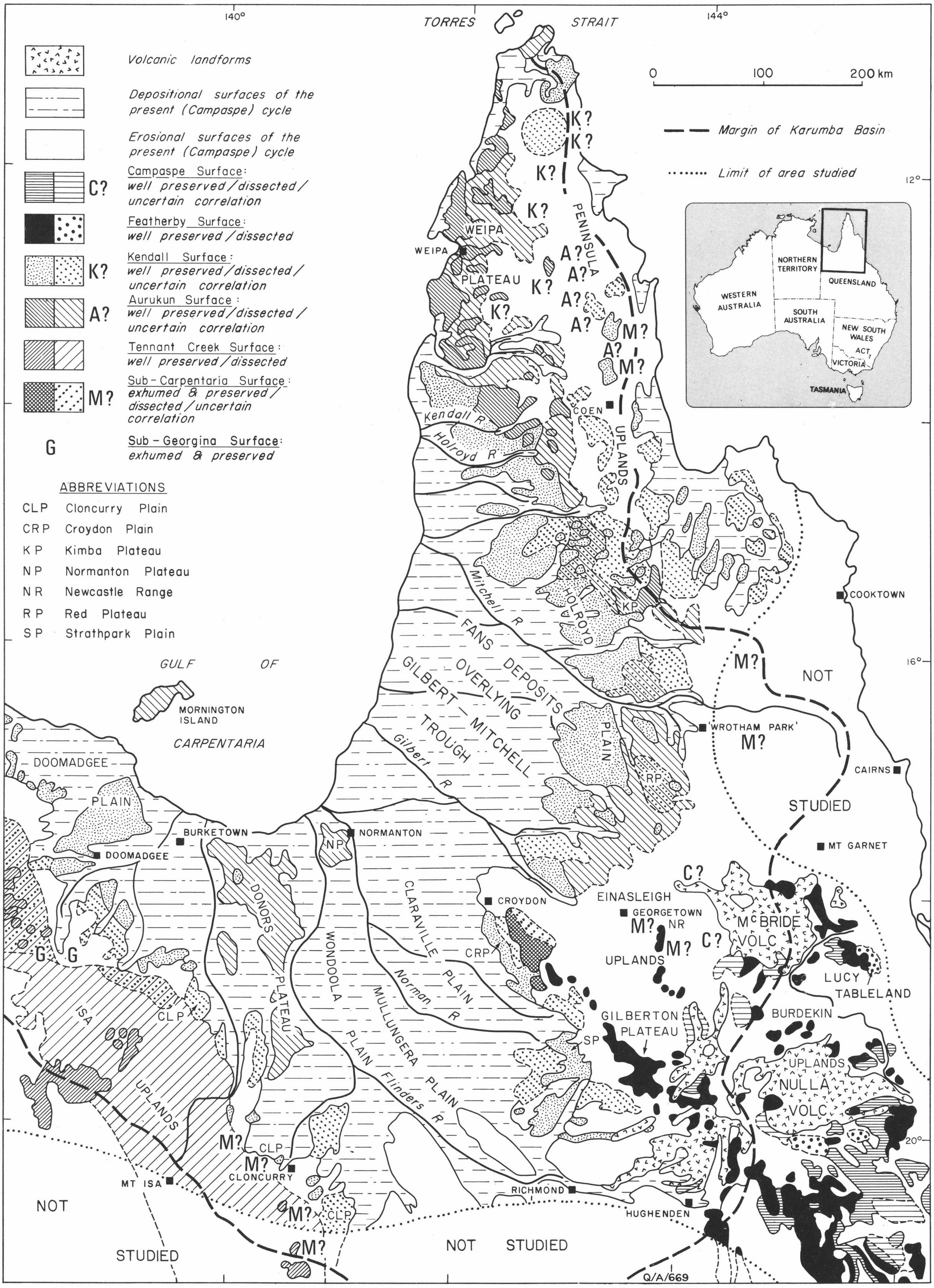


Figure 1. Present distribution of old land surfaces in northern Queensland.

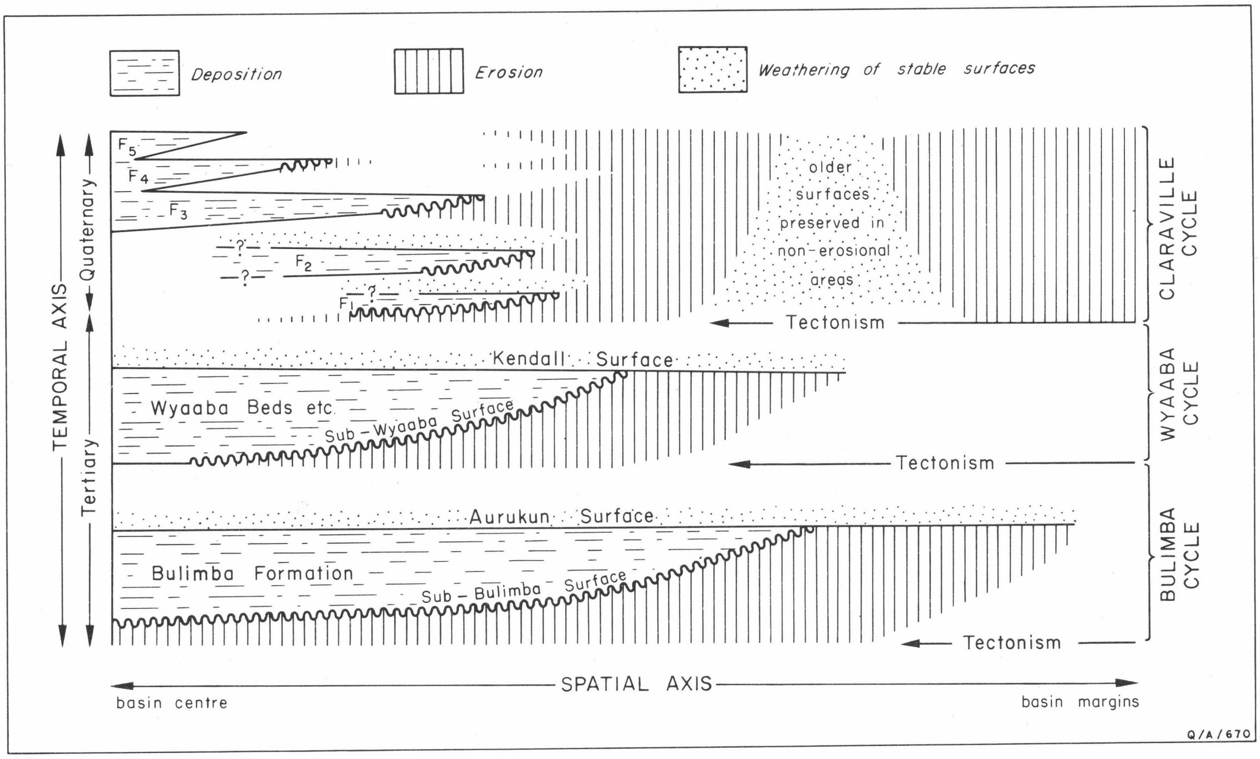


Figure 2. Temporal-spatial relationship diagram showing the relationship between erosional, depositional and weathering events; old land surfaces; and cycles of development in the Karumba Basin. Stages of fan deposition are indicated by F_1, F_2, . . .

Within the region studied, the Sub-Georgina, Sub-Carpentaria, Sub-Bulimba, Sub-Wyaaba and Sub-Claraville Surfaces are all unconformity surfaces. The names are taken from the overlying deposits, or the basins which they floor. Only the Sub-Georgina and Sub-Carpentaria Surfaces have been extensively exhumed. The younger unconformities are generally only recognisable in the subsurface.

The more widespread type of old land surface recognised in the region is the **terminal surface,** which appeared as the relief was reduced towards the end of an active phase of erosion and deposition. The evolution of this type of surface is comparable to that of modern 'peneplains' or 'pediplains', though the genetic distinction between these two types generally cannot be made for ancient surfaces and the general term 'planation surface' is more appropriate. Terminal surfaces can have both erosional and depositional components, the former being most common near the margins of a basin, and the latter in its central parts (cf. Fig. 2). The Aurukun, Tennant Creek, Featherby, Kendall and Campaspe Surfaces are terminal surfaces, though the Campaspe Surface is not as widespread as the others and formed at the end of a subsidiary cycle.

In addition to the types discussed above, several **depositional surfaces** occur on the younger set of fans and alluvial deposits in the area (Grimes & Doutch, 1978). They are only subsidiary breaks within the current Claraville cycle (cf. Fig. 2), and have not been given formal names. The name **Holroyd Surface** was used by Doutch (1976) for a set of desiccation features which he attributed to a period of aridity in late Pleistocene times.

Because the terminal surfaces are of low relief and have survived in the landscape for a considerable time, the rocks beneath them have been subjected to deep weathering and the formation of duricrusts: a factor which has aided in their preservation, and which assists in their recognition and interpretation. Duricrust is used here as a general term for any indurated zone resulting from cementation at or below a land surface as a part of a weathering process. A ferruginous laterite is a duricrust which is cemented by iron; aluminous laterites, some of bauxite grade, are also present. Siliceous duricrusts are impregnated by silica, and when completely silicified are known as silcretes. The cemented duricrust is commonly the upper part of a deep weathering profile. In addition to a thin cover of loose sand at the surface, a laterite profile generally comprises an upper ferruginous or aluminous, cemented zone, the laterite; a middle mottled zone; and, in some places, a lower pallid zone. Ferricrete is used by some authors in the same sense as ferruginous laterite, but here it is used for less well developed ferruginous crusts and iron-cemented weathering detritus which have only a poor profile development, or none at all.

Pre-Cainozoic land surfaces

The pre-Cainozoic geomorphic history is not well known except by deduction from the Mesozoic and older sedimentary rocks (see Smart & others, in prep.). Exhumed remnants of two buried unconformity surfaces are known: the late Precambrian to Cambrian Sub-Georgina Surface, and the Mesozoic Sub-Carpentaria Surface. Both have a fairly high local relief in the areas where they have been exhumed.

The term **'Sub-Georgina Surface'** is suggested here for the 'Pre-Middle Cambrian surface' recognised by Twidale (1966) and de Keyser (1969) in the south-western part of the region (Fig. 1). The non-chronological term is preferred. This is an unconformity surface at the base of the Georgina Basin sequence which has been exhumed in parts of the Isa Uplands. De Keyser & Cook (1972) illustrate a surface which

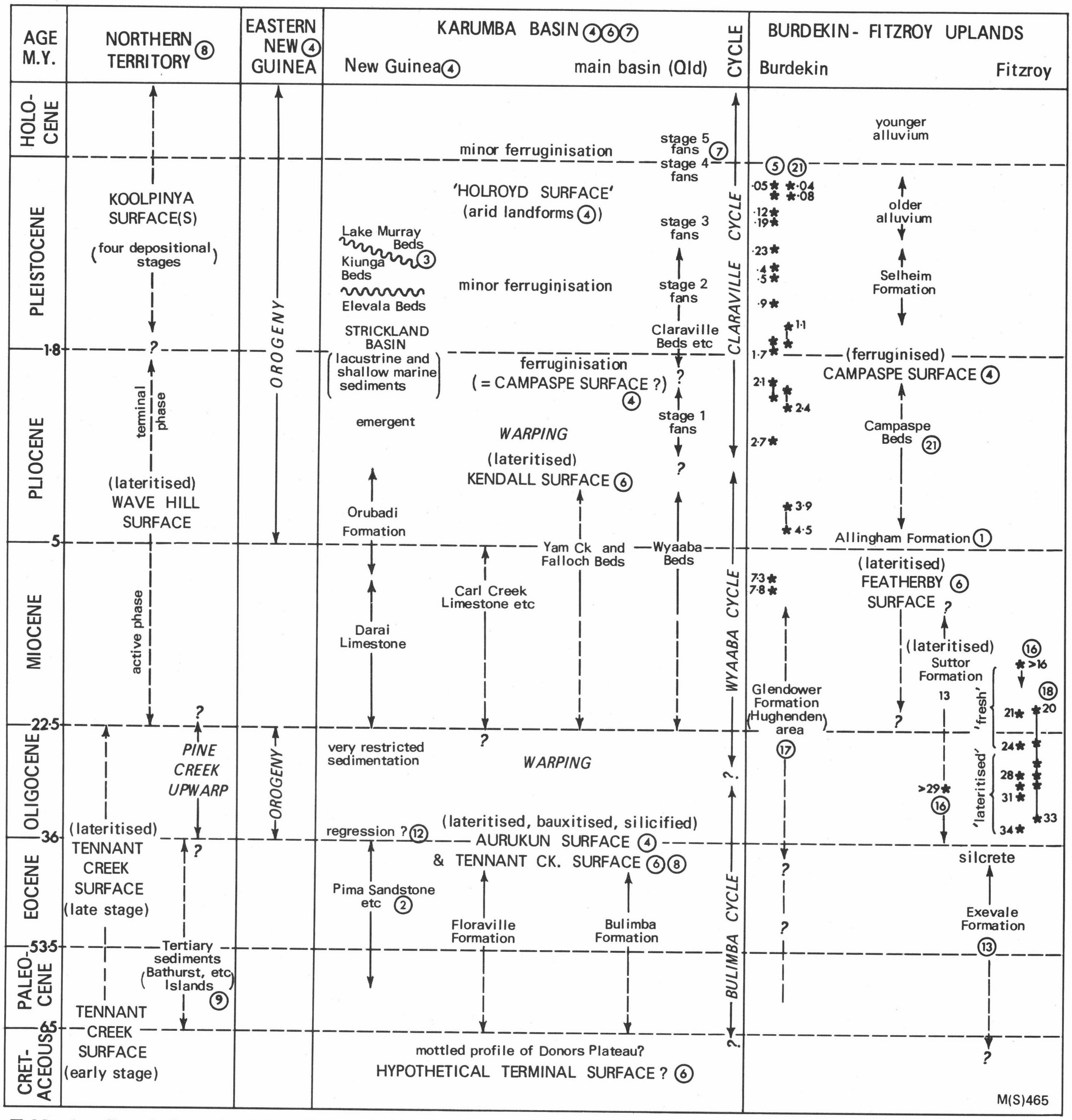
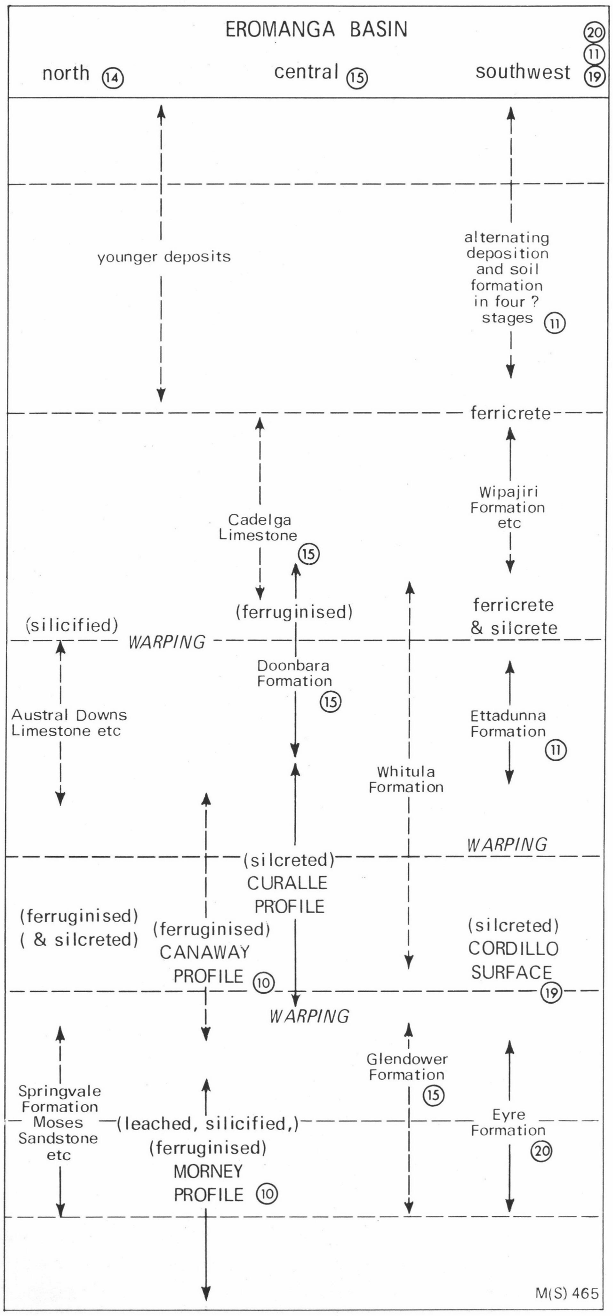


Table 1. Correlation chart for Cainozoic land-surfaces and events in northern Queensland and adjacent regions. NOTES—*basaltic vulcanism with ages in millions of years. (1) Archer & Wade (1967), (2) Bain & MacKenzie (1974), (3) Blake (1971), (4) Doutch (1976), (5) Griffin & McDougall (1975), (6) Grimes—this paper, (7) Grimes & Doutch (1978), (8) Hays (1967), (9) Hughes & Senior (1974), (10) Idnurm & Senior (1978). (11) Jessup & Norris (1971). (12) Kennett & others (1972). (13) Malone & others (1964), (14) Paten (1964), (15) Senior (1976, 1978), (16) Sutherland, Stubbs & Green (1977), (17) Vine & others (1963), (18) Webb & McDougall (1967), (19) Wopfner (1974), (20) Wopfner & others (1974), (21) Wyatt & Webb (1970).

appears to have had a moderately strong relief. Exhumed remnants of the surface also occur further south (cf. Twidale, 1966, p. 31 & 42).

The **Sub-Carpentaria Surface** is the Jurassic to Early Cretaceous unconformity surface at the base of the Carpentaria Basin sequence. It was buried by the Jurassic and Cretaceous sandstones and the transgressive Wallumbilla Formation and has been exhumed by later erosion in several areas. This is the 'pre-middle Mesozoic Surface' of Twidale (1956, 1966), and the 'Gondwana Surface' of King (1949). The main requirement in the recognition of exhumed parts of this surface is the ability to trace the surface on pre-Mesozoic rocks up to and beneath outcrops of Mesozoic sediments—thereby demonstrating its continuity with the buried unconformity (see Fig. 3 of this paper; and Twidale, 1956, fig. 2). In the absence of Mesozoic deposits the surface can be assigned to an upland surface or summit conformity provided that this lies above the levels of the Tertiary surfaces.

The exhumed surface is best preserved to the southeast of Croydon (Fig. 1) where the Mesozoic sandstones have been stripped from Precambrian volcanics. Here remnants of the sandstone are common in the valleys, well below the level of adjacent hills of the older volcanics. Much of the present drainage pat-



tern and general topography of this area appears to be similar to that which existed in Jurassic times. Twidale (1956, 1966) also recognised the following exhumed and dissected remnants of the surface: the plateau surface of the Newcastle Ranges and other areas of resistant volcanic rocks in the Einasleigh Uplands, the mesas and summit conformities of parts of the Isa Uplands (see also Grimes, 1974), and the benches in the Burke Plain to the south of the Isa Uplands. In the Cloncurry Plain accordant summits dipping towards the Carpentaria Basin appear to be related to a continuation of the buried unconformity (Twidale, 1956; Grimes, 1974). The Sub-Carpentaria may also be present on the dissected high surface of the McIlwrath Plateau in the Peninsula Uplands (Whitaker & Gibson, 1977).

The Sub-Carpentaria Surface has an undulating and in places quite marked local relief; for example, east of Wrotham Park the unconformity beneath the Mesozoic sandstones has abrupt changes in elevation of up to 40 m, resulting from differential erosion of the resistant Palaeozoic volcanics and more easily eroded older sediments. Old gorges and valleys with Mesozoic infillings are also present in the northwestern part of the Isa Highlands (Fig. 3). A seismic reflector which shows a rugged relief beneath the western part of the Gulf is probably a buried part of the Sub-Carpentaria Surface (Smart & others, in prep.).

Deposition in the Carpentaria Basin ended as the sea withdrew before late Cretaceous times. By analogy with the Cainozoic cycles discussed below one would expect a terminal planation surface to have formed as activity in the Carpentaria Basin drew to a close. Such a surface has not been definitely recognised within the study area though de Keyser and Lucas (1968, p. 147) refer to a 'post-Lower Cretaceous' erosional plain which lies to the east of the Carpentaria Basin. The late Cretaceous to early Eocene Morney Profile of Idnurm & Senior (1978) may have developed on a contemporary surface in the Eromanga Basin, and the early stage of the Tennant Creek Surface in the Northern Territory (Hays, 1967) may also be contemporaneous (see Table 1).

Cainozoic land surfaces

The Karumba Basin

The development of the Karumba Basin can be divided into three major cycles, each of which produced deposits and land surfaces (see Introduction and Fig. 2).

The Bulimba Cycle. This first cycle commenced with upwarping of the basin margins in the early Tertiary; it continued into the mid-Tertiary (?Oligocene). In the initial active phase erosion occurred in the uplands and deposition in the depressed areas. These sediments included the continental arkosic sand and clay of the Bulimba Formation on the western side of Cape York Peninsula, and the Floraville Formation to the south of the Gulf of Carpentaria. Both these formations may extend for some distance beneath the present area of the Gulf. As the relief of the area was reduced, a stable planation surface evolved. The surface was lateritised, and in places silicified (the Aurukun Surface).

The **Sub-Bulimba Surface** is the unconformity at the base of the Bulimba Formation and its equivalents (Fig. 4). It has only been locally exhumed. Smart & others (in prep.) show the generalised form of the buried surface beneath the area of the Gilbert-Mitchell Trough. On the basis of its outcrop trace in the Weipa area, and from detailed drilling (Pettifer & others, 1976) it appears to have had a moderately low, undulating, local relief. The Sub-Bulimba Surface was progressively buried by the spreading sediments as the downwarped area was filled. It is therefore a diachronous surface of early Tertiary age, that is it had a similar time span to the Bulimba Formation—which formed with it and buried it (cf. Fig. 2).

The **Aurukun Surface** (Doutch, 1976) is an early to mid-Tertiary planation surface which formed both as a depositional surface on the Bulimba Formation and as an erosional surface on the adjoining areas of older rocks. It is a flat or gently undulating surface which is best preserved on the Weipa Plateau (Smart, 1977) (Fig. 1), where it has a broad pattern of dendritic and commonly swampy valleys. This drainage pattern may have been inherited from the original surface (MacGeehan, 1972), although Doutch (pers. comm.)

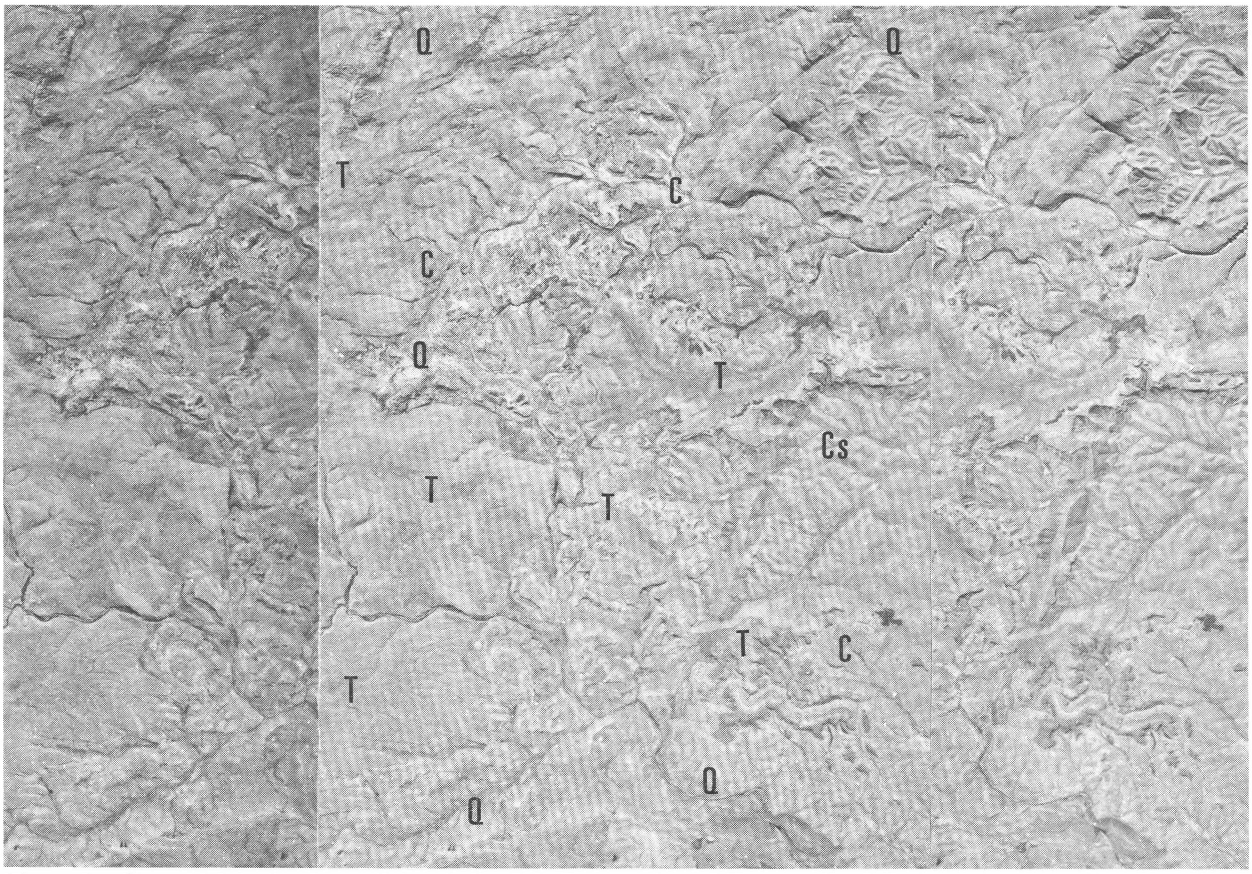


Figure 3. Stereotriplet showing relicts of the Sub-Carpentaria and Tennant Creek Surfaces in the Isa Uplands. (Lawn Hill, CAB 4012, photos 2284, —6, —8). T = Tennant Creek Surface, C = Sub-Carpentaria Surface, Cs = summit levels related to the Sub-Carpentaria Surface, Q = Quaternary erosional areas.

points out that though the valleys pre-date the bauxite they could still be younger than the original Aurukun Surface as the bauxite has developed in several stages.

Deep weathering of the Aurukun Surface has resulted in the formation of well developed laterite and bauxite profiles (Smart & others, in prep.). As later deep-weathering events appear to be superimposed on the mid-Tertiary profile its original nature is difficult to assess. Ferruginous laterites which occur in places buried beneath the Wyaaba Beds in the Gilbert-Mitchell Trough are thought to be part of this profile because of their stratigraphic position, but in the Weipa Plateau, Smart (1977) considers that it was initially an aluminous laterite which has been upgraded to bauxite by later weathering events. Some silicified horizons occur at intervals in the profile in the southern part of the Weipa Plateau and true silcretes have been observed in a few places. Whether this silicification is related to the original or later weathering events is not known. In the Weipa Plateau, the laterite profile is generally capped by about a metre of residual sand, which may represent the A horizon of the profile (Smart, Appendix 4 *in* Doutch & others, 1973). The Kimba Plateau south of Coen, is the only undissected part of the surface

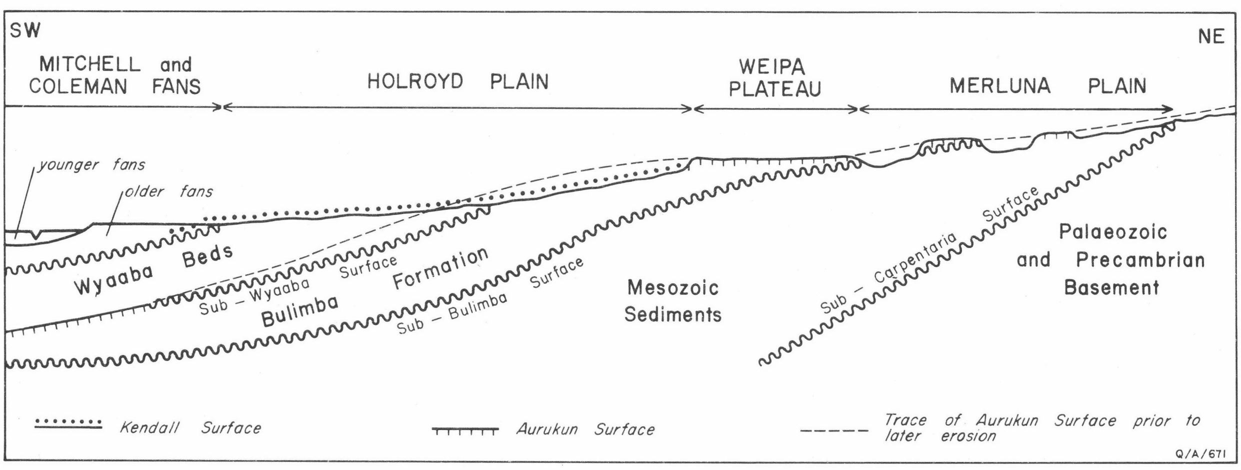


Figure 4. Diagrammatic cross section of the northern flank of the Gilbert-Mitchell Trough. Showing relationships between old land-surfaces and depositional units.

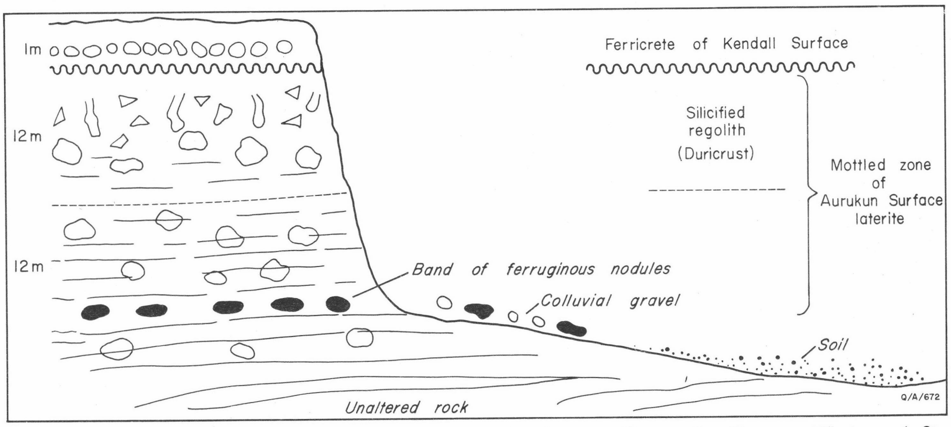


Figure 5. Diagrammatic section of the deep weathering profile on the Donors Plateau (after Doutch & others, 1970).

apart from the Weipa Plateau; ferruginous laterite is developed in this area. Elsewhere in the Karumba Basin erosion has generally removed the upper part of the profile, leaving only the mottled and pallid zones—which have commonly been silicified (Fig. 5). Such areas are the hills and ridges to the east of the Weipa Plateau and, further south, in the Red, Mornington, Normanton, and Donors Plateaus (see Fig. 1). Accordant summits and a few plateau surfaces in the Peninsula Uplands may also be derived from the Aurukun Surface, as some of these have lateritic remnants and they lie above the level of nearby areas of the younger Kendall Surface (cf. fig. 2 of Whitaker & Gibson, 1977).

The age of the Aurukun Surface can at present only be deduced from its position in the overall sequence of development (see Table 1). It is developed on the Bulimba Formation, which is thought to be of early Tertiary age, though this estimate is partly based on ideas concerning the age of the Aurukun Surface (Doutch, 1976; Smart & others, in prep.). The Aurukun Surface pre-dates the Wyaaba Beds, which are probably of Miocene to early Pliocene age. An early to mid-Tertiary age is therefore the best estimate from evidence within the basin.

Doutch (1976) suggested correlations with several early Tertiary surfaces in Australia including the Tennant Creek Surface (Hays, 1967) in the Northern Territory (see below). The termination of the Bulimba Cycle, and therefore of the Aurukun Surface development, could well be related to the Oligocene orogenesis in New Guinea, and warping similar to that in the Karumba Basin occurred elsewhere in Australia in mid-Tertiary times. A mid-Tertiary (Eocene to Oligocene) age is therefore most likely (cf. Table 1).

In summary, the main criteria in the recognition of areas of Aurukun Surface are: firstly its stratigraphic position (illustrated in Fig. 4), and secondly its topographic position above the later Kendall Surface (Fig. 6). The broad drainage pattern and well developed lateritic or bauxitic weathering profile also assist but are not in themselves diagnostic.

The **Tennant Creek Surface** (Hays, 1967) is a Late Cretaceous to early Tertiary planation surface that is well developed in the Northern Territory (Wright, 1963; Hays, 1967). It is correlated here with the surface which caps the Mullaman Beds and the Precambrian rocks of the Isa Uplands in the southwest of the area (see Figs. 1 & 3), i.e. the upland part of the 'Tertiary Surface' of Grimes (1974) and the 'Early to mid-Tertiary Surface' of Twidale (1956, 1966).

In the Isa Uplands the surface is preserved on the top of Mesozoic mesas, and elsewhere as an extensive summit conformity (Fig. 1) (cf. Grimes, 1974, fig. 11). It appears to have been a plain which truncated both the Mesozoic sediments and more resistant Precambrian rocks. Some remnants of old shallow drainage lines are present on the mesa surfaces (Fig. 3). The surface has generally been deeply leached, lateritised and silicified; with thick porcellanites developed on the Mesozoic mudstones.

Hays (1967) deduced a Late Cretaceous to mid-Tertiary age for the Tennant Creek Surface in the Northern Territory, but there seems to have been two stages in its development there (Table 1). The older stage is a laterite developed on Mesozoic rocks and underlying the early Tertiary Van Diemen Sandstone on Bathurst and Melville Islands (Hughes & Senior, 1974; Hays, 1967, p. 198) while the younger stage, which is also lateritised, overlies the Tertiary sediments. In the Isa Highlands the Tennant Creek Surface is developed on the Cretaceous sediments and pre-dates the mid-Miocene Carl Creek Limestone which lies in a valley cut below the level of the surface (Smart & others, in prep.). The surface therefore pre-dates the Wyaaba Cycle, but one cannot be sure which of the two Northern Territory Stages (if not both) is represented in the Isa Uplands. On Table 1 the surface is tentatively correlated with the younger of the two stages, and with the Aurukun Surface.

The term **Strathgordon Surface** was first used, without definition, by Powell & others (1976) for a (ferruginous) surface developed on the Wyaaba, Lilyvale, Yam Creek and Falloch Beds, which they considered to be contemporaneous units. Doutch (1976) considered, on the basis of denudation chronologies in the separate areas, that the Wyaaba Beds were older than the other units. He used the name Strathgordon Surface for a set of silicified surfaces within the Karumba Basin which he thought postdated the Wyaaba Beds. He correlated the ferruginous surface on the other units with the Campaspe Surface (see below). Doutch's description of the Strathgordon Surface is brief and no reference area is given. It contains a conflict between the criteria of silicification and of post-Wyaaba age, and further by his apparent application of the term to ferruginised surfaces on the Wyaaba Beds and elsewhere. Doutch (pers. comm.) has indicated that he considers the criteria of silicification more important than the concept of a post-Wyaaba age in defining the Strathgordon Surface.

The main siliceous surfaces in the Karumba Basin are older than the Wyaaba Beds and are either equivalent to the Aurukun Surface or represent a late stage in its development. To avoid the confusion resulting from the different applications of the term 'Strathgordon', the name Kendall Surface will be applied below to the ferruginised terminal surface on the Wyaaba Beds.

'Strathgordon' silicification in the Karumba Basin is best developed on the Tennant Creek Surface on the Isa Uplands, and in conjunction with mottled and pallid zones of the Aurukun Surface in the Donors and Red Plateaus, though most of the surfaces in the region have localised areas of minor silicification.

Doutch & others (1970) described a profile in the Donors Plateau which consists of a ferricrete zone (commonly stripped) and a mottled zone which has been silicified in its upper part to form a duricrust (Fig. 5). They attributed this profile to three stages of deep weathering: an initial mottling as part of a laterite profile, a second stage in which the mottled zone was silicified after stripping of the upper part of the profile, and a final stage in which the ferricrete zone was formed. Doutch (pers. comm.) would correlate these three stages with the Aurukun Surface, the 'Strathgordon Surface' (in his sense), and the Kendall Surface (as used here) respectively.

On the Donors Plateau the 'Strathgordon' duricrust produces a pattern of old valley forms which are now in inverted relief as a result of the erosion of their presumably less indurated interfluves. Similar valley forms in inverted relief occur in the Red Plateau, north of Georgetown. There, some of the duricrusted valleys contain a younger fill which is correlated with the Wyaaba Beds as in places it can be seen continuing beneath the Kendall Surface at the margins of the Holroyd Plain, and Wyaaba Beds underlie this surface.

Doutch's 'Strathgordon Surface' would therefore appear to have developed prior to the deposition of the Wyaaba Beds. If the underlying mottled profile in the Donors Plateau is assigned to the Aurukun Surface, then the relationship suggests that the 'Strathgordon Surface' is a late stage of the Aurukun Surface in which siliceous solutions leached from the interfluves were deposited in the adjoining valleys. On the other hand if the mottled material were considered to be older, and perhaps could be correlated with the Morney profile of Senior (1976), then the Strathgordon Surface would be a simple correlate of the Aurukun Surface.

Silcretes and siliceous duricrusts become more common and better developed towards the south. No silcretes have been identified north of about 13°S latitude. On the other hand the Tennant Creek Surface on the Isa Uplands is extensively silicified. This trend could represent a climatically controlled transition within the weathering profiles of the time; from dominantly lateritic in the north to dominantly siliceous in the inland parts. Lithology exerts some local control but the regional trend is seen on all the lithologies.

In view of the differing uses to which the term 'Strathgordon Surface' has been put, and the suggestion here that if applied as a siliceous surface it is mainly a chemically distinctive 'facies' of the Aurukun Surface, it is recommended that the term 'Strathgordon Surface' be discontinued.

The Wyaaba Cycle. This cycle commenced in the late Oligocene as a result of renewed upwarping of the Karumba Basin margins and downwarping of the Gil-

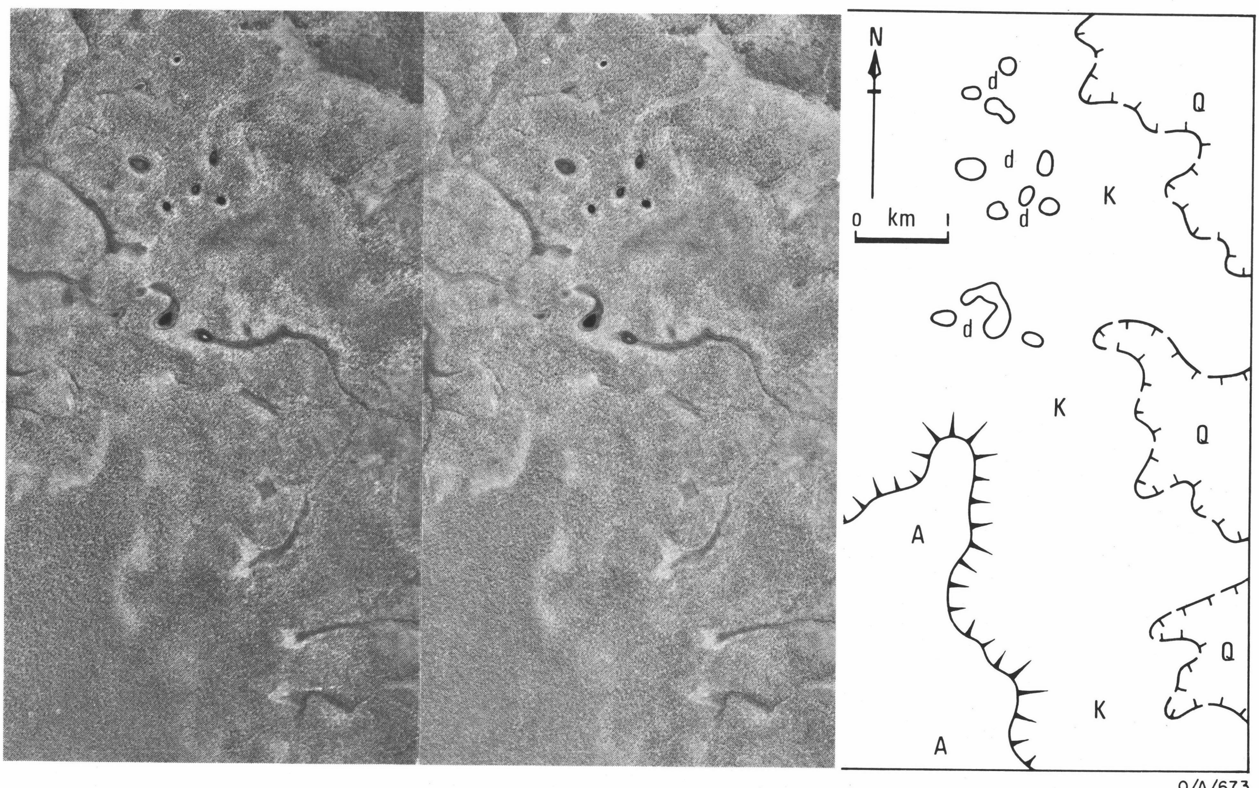


Figure 6. Stereopair showing Aurukun (A) and Kendall (K) Surfaces, and more recent erosion (Q) at the south-eastern margin of the Weipa Plateau (Ebagoola CAB 358, Run 2, photos 66, 68). d = closed depressions on the Kendall surface which Doutch (1976) considers to be deflation features of the Holroyd Surface, but which this author attributes to a laterite-karst effect.

bert-Mitchell Trough. The initiation of the cycle may be related to an Oligocene orogeny at the northern edge of the Australian Plate in New Guinea. The active phase disrupted the development of the Aurukun and Tennant Creek Surfaces. Dominantly continental deposition of a similar type to that of the preceding cycle occurred in the Gilbert-Mitchell Trough (Wyaaba Beds), and in smaller isolated basins (the Yam Creek and Falloch Beds in Cape York Peninsula, and the Lilyvale Beds of the Laura Basin). The sea appeared in the Gulf area for a brief period during deposition of the Wyaaba Beds. Springs deposited the Carl Creek and Gregory Downs Limestones in the southwest of the Karumba Basin. As the cycle's active phase drew to a close the Kendall Surface developed and was lateritised or ferricreted. The Featherby Surface of the Charters Towers area also formed at the end of this cycle, though in that area stability would seem to have been achieved earlier than in the Karumba Basin. Both surfaces were disrupted and the cycle terminated by uplift, with associated vulcanism, in the Pliocene.

The **Sub-Wyaaba Surface** is the unconformity surface which has been recognised beneath the Wyaaba Beds in the Gilbert-Mitchell Trough (Fig. 4). No exhumed equivalents have been recognised, as the outcrop trace of the surface is mantled by younger colluvial sands. Mottled material has been identified in drill holes from immediately beneath the unconformity surface. This is probably a partly truncated remnant of the earlier Aurukun Surface weathering profile (Fig. 4). Equivalent unconformity surfaces exist beneath the Lilyvale, Falloch, and Yam Creek Beds (Whitaker & Gibson, 1977).

The name **Kendall Surface** is applied here to the planation surface which is preserved in the interfluves of the Holroyd, Croydon, and Strathpark Plains (Fig. 1). This is the surface which was originally referred to (without definition) as the 'Strathgordon Surface' (Powell & others, 1976), but, as discussed as above, that name is best discarded. In the Explanatory Notes accompanying the geological maps of Cape York Peninsula, the Kendall Surface, as used here, was generally referred to as the 'Campaspe Surface', following Doutch's (1976) correlations. The latter term is best restricted to the Burdekin Uplands as its correlation with the Karumba Basin surfaces is uncertain (see below).

The name Kendall Surface is derived from the Kendall River and the northern part of the Holroyd Plain between the Kendall and Holroyd Rivers is suggested as a reference area. The surface is widespread throughout the Karumba Basin (see Fig. 1). On the Holroyd Plain it has a characteristic dendritic drainage pattern of shallow swampy valleys, which is illustrated in Doutch & others (1971, fig. 3).

The Kendall Surface developed towards the end of the Wyaaba Cycle as a depositional surface on the Wyaaba Beds around the Gilbert-Mitchell Trough; on the Lilyvale, Falloch, and Yam Creek Beds in the Laura Basin and Cape York Peninsula; and as an erosional surface developed at the expense of the Aurukun Surface on parts of the Bulimba Formation and older rocks elsewhere (Fig. 4). The depositional surface has undergone some mild erosional modification since its formation. The surface has been lateritised and ferricreted, and is also silicified in some places. The laterites are best exposed along the western side of the Lynd River and in the Strathpark Plain. The Yam Creek Beds have ferricrete cappings up to 3 m thick.

Part of the Doomadgee Plain may be a correlative of the Kendall Surface (Fig. 1). Here the laterites are very well developed. In the Laura Basin the Jack Plain may also be equivalent; it has been poorly lateritised and, in places, silicified.

The Kendall Surface is of Pliocene age as it post-dates the Wyaaba Beds, of Miocene to Pliocene age (Smart & others, in prep.), and pre-dates the late Pliocene to Quaternary fan deposits (Grimes & Doutch, 1978). The Gilberton Plateau was upwarped during the Pliocene (Smart & others, in prep.); the duricrusted surface on the plateau could be an upwarped equivalent of the Kendall Surface on the Strathpark Plain to the west (Smart, 1973). This plateau surface is an extension of the Featherby Surface of the Burdekin Uplands. If the correlation with the Strathpark Plain is valid then the overall Kendall-Featherby surface must be diachronous, as to the southeast the Featherby Surface is older than Pliocene. In view of the different ages, and the lack of positive proof of continuity, a separate terminology is adopted for the two areas.

The main criteria for the recognition of the Kendall Surface are firstly its stratigraphic position: younger than the Wyaaba Beds and Aurukun Surface, but older than the current cycle of erosion and deposition; secondly its topographic position below the level of the Aurukun Surface; and to a lesser extent its typical landform in the Holroyd Plain, and the nature of its laterite profile which is generally not as strongly developed as the Aurukun Surface.

The Claraville Cycle. Pliocene tectonism upwarped the Gilberton Plateau and other areas, and initiated the Claraville cycle. This cycle has continued to the present; it contains a number of recognisable subcycles, for instance the five stages of fan development in the Gilbert-Mitchell area (Grimes & Doutch, 1978). Contemporaneous volcanism occurred in the Burdekin Uplands.

The **Sub-Claraville Surface** is an unconformity surface beneath the deposits of the present Claraville Cycle. It has not been exhumed. The lithological similarities between the fans and the older Wyaaba Beds make the surface difficult to identify in some areas. It has only been mapped south of the Gilbert-Mitchell Trough, where the deposits overlie Cretaceous rocks (Grimes & Doutch, 1978, fig. 5).

Grimes & Doutch (1978) have recognised five stages of deposition of fans and related alluvial plains in the Karumba Basin. Each of these stages has left a depositional surface, and the recognition of the stages is based to a large extent on the morphology and relationships of these surfaces.

Within the Gilbert and Mitchell fans area the oldest, stage 1, fans are generally restricted to valley sides in the fan heads. Further to the south and west, stage 1 plains stand topographically above the younger surfaces; they have been ferruginised. Stage 2 fans are also ferruginised. Stage 3 fans are widespread and may have formed during the last interglacial. Stage 4 and 5 are late Pleistocene and Holocene flood plains.

Doutch (1976) applied the name **Holroyd Surface** to a suite of features developed on Stage 3 fans and most older surfaces, which he considers formed during a period of desiccation. The concept is therefore different to that of the other surfaces discussed here. Doutch cited 'sand dunes on the Millungera Plain and dune-like forms, sand plains with clay pans, deflation features and choked drainage' as evidence for aridity. He considered that these features occurred after the formation of the

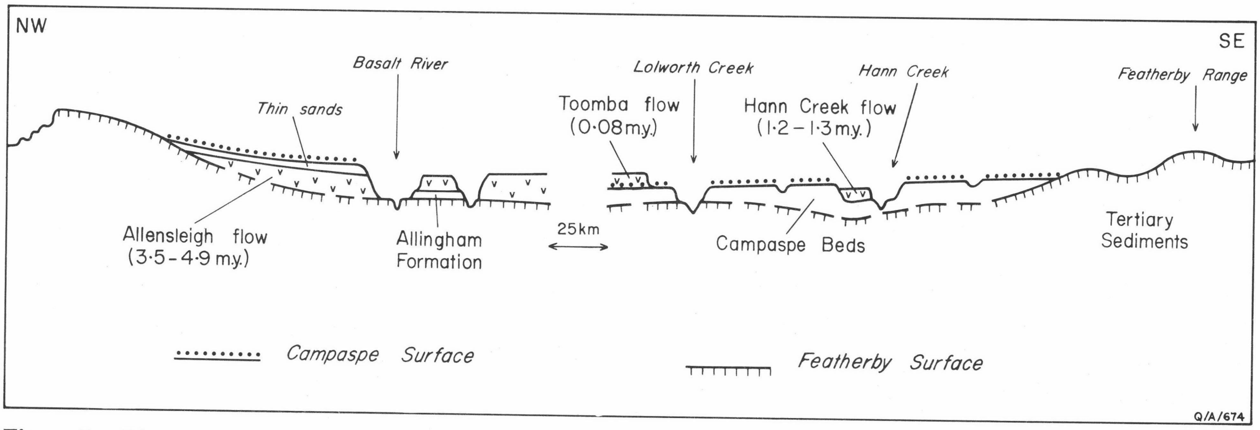


Figure 7. Diagrammatic cross section north-west of Charters Towers, showing the relationship between the old land surfaces and dated basalt flows.

Stage 3 fans and the oldest beach ridges (100 000-120 000 years B.P.) and before the formation of the stage 4 fans and the younger, Holocene ridges (6500 years B.P. or older). They may correlate with the end of the last glacial maximum, which was a time of lower rainfall (Kershaw, 1975).

Although I do not dispute that there was a period (or periods) of aridity during the last glaciation, I doubt if all of the features cited by Doutch should be attributed to arid effects. Some of the 'clay pans', which Doutch apparently considers to be deflation hollows, could also be laterite-karst depressions of the type described on the Doomadgee Plain (Grimes, 1974), or even true karst in the case of the leached beach ridges. Most of the sand plains in the Karumba Basin lie above lateritised surfaces; these sands probably represent the A horizons of the laterite profiles (cf. Smart, appendix 4 *in* Doutch & others, 1973); that is, they indicate a seasonal humid climate, rather than aridity. By 'dune-like forms' Doutch (1976) appears to be referring to the wanderrie patterns described by Grimes & Doutch (1978). These occur only on the Stage 1 and 2 fans, and are truncated by the earliest of the Stage 3 fans. On the other hand the 'clay pans' and the dunes of the Millungera Plain are younger, because they occur on the stage 3 fans and the oldest beach ridges. This suggests at least two periods of aridity, whereas Doutch's usage of the term Holroyd Surface implies a single event.

Land-surfaces of the Burdekin Uplands

The early Tertiary history of the Burdekin Uplands is not well known. The Glendower Formation, though considered to be of Pliocene age by Whitehouse (1940), may well be older and related to the Wyaaba Cycle—or possibly even the Bulimba Cycle (cf. Table 1). The nature of its contained silcrete boulders has been debated by Vine & others (1963) who consider that they may have formed *in situ,* and not been derived from an older silcreted surface as was suggested by Whitehouse. However, the conglomerates in the formation contain silcrete cobbles which appear to be definitely detrital. The Glendower Formation would seem to have formed after a period of silicification; the Formation has subsequently been lateritised, and locally silicified—possibly in separate events. Tertiary sediments, the Southern Cross Formation of Wyatt (1970), occur beneath a lateritised surface in the Charters Towers area, and may be of similar age.

The name **Featherby Surface** is applied here to an undulating lateritised surface in the Burdekin and Einasleigh Uplands (Figs. 7 & 8). The surface was first mapped by Wyatt & others (1970, 1971) as laterite (unit Tl) on the Charters Towers and Townsville 1:250 000 Geological Sheets. A suitable reference area for the surface is on, and west of, the Featherby Range, about 18 km west of Charters Towers. It would appear to have been a stable surface which was lateritised at the end of the Wyaaba Cycle. Wyatt & others (1970, p. 63) described the well-developed laterite profile, and they also related the silcretes in the area to this surface. The Featherby Surface is well developed on the Tertiary sediments and older rocks in the Charters Towers-Hughenden area and further south. Farther to the north and west it is generally only represented by isolated mesas (Fig. 1), which hinders its extrapolation into the Karumba Basin. However, these remnants can be traced as far as the Gilberton Plateau and the Lucy Tableland (Fig. 8). The older parts of the Alice Tableland to the south (Whitehouse, 1940; Vine & Doutch, 1972) would also appear to be correlates of the Featherby Surface; as would the gently undulating surface of the 'Denna Plain' (Coventry, in prep.) and the surface on the Glendower Formation, both areas lying east of Hughenden.

Although typified by thick laterite profiles and red-earth soils, parts of the surface also exhibit yellow earths (Coventry, in prep.). The undulating nature of the surface on the Southern Cross Formation indicates that there has been some erosion since the deposition of that unit. It may be that there has been more than one stage of weathering in the evolution of this surface, with the yellow earths formed by partial stripping and reweathering of the initial laterite profile. Some thick, uniform, red earths found in the lower parts of the surface may be redistributed lateritic soils derived from the interfluves.

The Featherby Surface can be traced beneath the Campaspe Beds (Fig. 7), and buried laterites of the surface are exposed at Red Falls (Wyatt & others, 1970; p. 63 and figs. 16 & 17). The surface also occurs beneath basalt flows of the Nulla Province; slightly stripped laterite profiles of the surface underlie both the Allensleigh Flow (dated at 4.5 m.y. by Wyatt & Webb, 1970) and the early Pliocene Allingham Formation; near Allensleigh and Bluff Downs homesteads respectively (Wyatt, 1969; Archer & Wade, 1976). Thus the Featherby Surface has an upper age limit of earliest Pliocene.

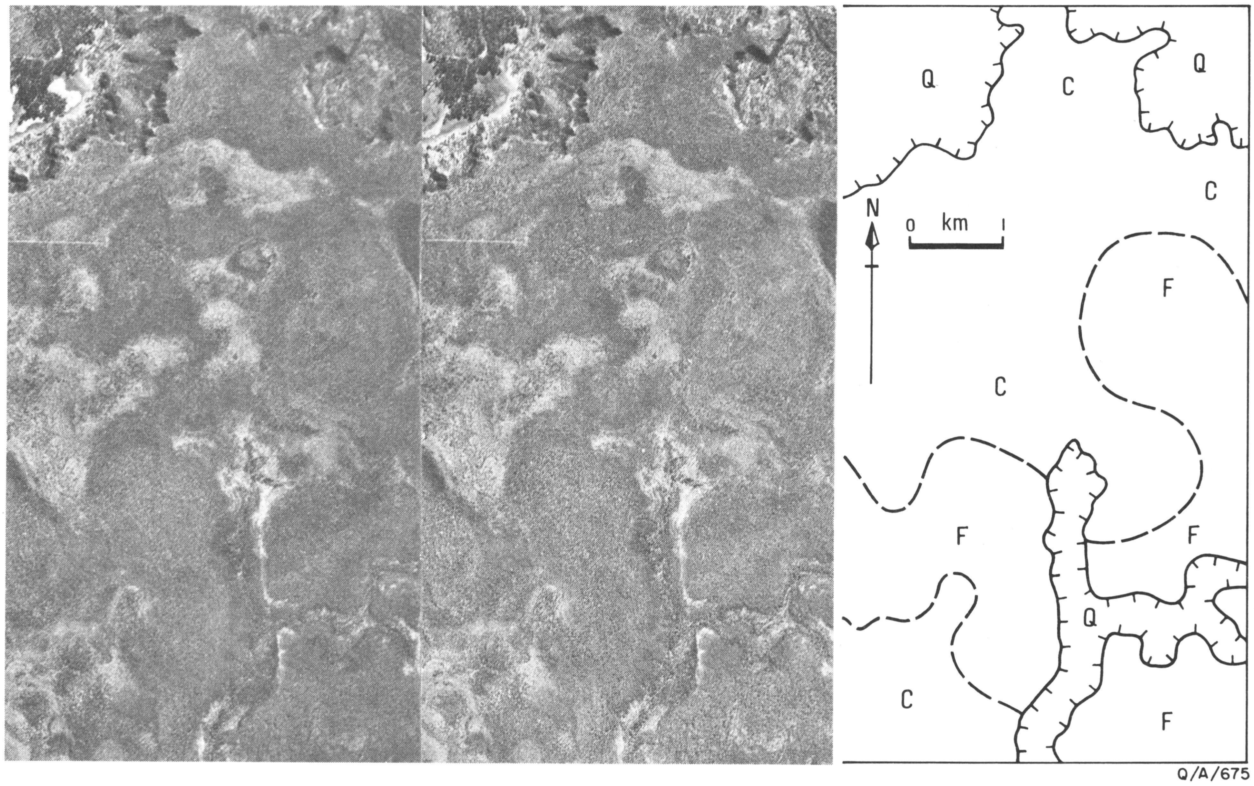


Figure 8. Stereopair showing Featherby (F) and Campaspe (C) Surfaces, and more recent erosion (Q) in the Lucy Tableland, south of Mount Garnet. (Einasleigh CAB 278, Run 5, photos 30, 32).

Remnants of the surface can be traced on air photos into the Mount Coolon 1:250 000 Sheet area, which is southeast of the area shown on Fig. 1. On the Mount Coolon Sheet a possible lower age limit can be deduced. Here the surface is developed on the Suttor Formation, which in turn overlies a lateritised basalt flow with a minimum age of least 29.2 m.y. (Sutherland & others, 1977). If the correlation between the two areas is valid then the age of the Featherby Surface could range from Oligocene to earliest Pliocene, with a Miocene age most likely.

The Featherby Surface can be recognised by its stratigraphic and topographic position (Figs. 7 & 8): it either stands above the younger Campaspe Surface, or is buried by the Campaspe Beds and their equivalents. The undulating surface is distinct from the flat to gently sloping Campaspe Surface. The laterite is generally better developed on the Featherby Surface.

The early Pliocene upwarping heralded the start of the current Claraville Cycle. The earliest deposits in the Burdekin Uplands are the Campaspe Beds (Wyatt & others, 1970). The **Campaspe Surface** is the flat-lying depositional surface on these beds in the Charters Towers area. It has a ferricreted surface which Wyatt & others (1970, 1971) mapped as unit Tf. Doutch (1976) first applied the name Campaspe Surface, and correlated it with the surfaces on the Yam Creek and Falloch Beds in the Karumba Basin. The term was also applied to what is here called the Kendall Surface (see above).

The Campaspe Surface is best developed on the Campaspe Beds northwest of Charters Towers. There it is a depositional surface, but some erosional equivalents can be recognised elsewhere in the region (see below). Wyatt & others (1970, p. 63) describe the poorly developed laterite profile, which consists of less than a metre of ferricrete overlying a thin mottled zone. This profile is not as well developed as the laterite of the older Featherby Surface, although in the Lucy Tableland (Fig. 8) an equivalent of the Campaspe Surface has a better developed profile, which is difficult to distinguish from adjoining areas of Featherby Surface. The Campaspe Surface is well preserved in the Charters Towers area, generally with only minor dissection near streams. In places it is buried by deposits that are apparently equivalent to the Stage 3 and younger fans of the Karumba Basin (cf. Grimes & Doutch, 1978). In the Einasleigh Uplands there are erosional and depositional surfaces which lie below the level of the remnants of the Featherby Surface, but pre-date later erosion; they are therefore correlated with the Campaspe Surface.

The age of the Campaspe Surface can be deduced in the Charters Towers area (Fig. 7). Wyatt (1969) reported that ferricretes, probably part of the Campaspe Surface, are developed on a thin outwash deposit covering the Allensleigh Flow of the Nulla Basalt. Wyatt & Webb (1970, p. 47) suggest that the Campaspe Beds, which underlie the Campaspe Surface, may also postdate the Allensleigh Flow, which has an age between 3.9 and 4.5 m.y., though they admit to some uncertainty. Near Wyandotte homestead in the Einasleigh 1:250 000 Sheet area, a 2.3 m.y. basalt flow (Griffin & McDougall, 1976) antedates an erosional surface which might correlate with the Campaspe Surface. The Campaspe Surface antedates the Hann Creek Flow (1.2-1.3 m.y.) which lies in a valley cut into the surface (Fig. 7) (Wyatt & others, 1970, p. 66). The age of the surface may therefore be between 3.9 and 1.3 m.y.—possibly between 2.3 and 1.3 m.y.; that is mid-Pliocene to early Pleistocene.

Conclusions

This paper defines and describes a number of old land surfaces in northern Queensland. Many of these had already been recognised by earlier workers (e.g. Twidale, 1956, 1966; Wyatt & Webb, 1970) but had not been formally named. Some age names had been used, but I consider this inadvisable because of the lack of definite data on the ages of the surfaces.

Usage of the term 'Strathgordon Surface' has become confused, and this term should be abandoned.

The recent geological mapping in the Carpentaria and Karumba Basins, together with correlations with adjoining regions, has allowed the surfaces to be placed in the overall stratigraphic sequence. The regional correlations of the old land surfaces were complicated by differences in the local tectonic histories in different areas, and by variations in the nature of the weathering profiles. The tectonic variations caused differences in the times at which the periods of stability and activity started and ended. The variations in profile are probably the result of regional differences in the climates of the time.

The old land surfaces were recognised in the first place by their topographic form and their soils—which contrast with the currently forming surface. Particular land surfaces were then identified and correlated on the basis of their stratigraphic and topographic relationships, and to a lesser extent by their surface morphology and the nature of the duricrusts or weathering profiles developed on them. In the case of the exhumed unconformity surfaces the main criteria was the ability to trace the surface back to the unconformity and thereby establish its stratigraphic position (cf. Fig. 3). Where this was not possible then the topographic position in places allowed the surface to be identified.

The terminal surfaces were identified by their stratigraphic relationships to each other and to the related deposits. These relationships are illustrated in Figs. 2, 4, & 7. In addition, their relative topographic positions helped in the recognition of the sequences. The younger surfaces either lie at a lower level and evolved at the expense of the older, higher surfaces (Fig. 6), or formed on deposits which have buried the older surfaces (Fig. 8). Most of the terminal surfaces have a similar form, but the Kendall Surface sometimes has a distinctive drainage pattern, while the undulating nature of the Featherby Surface is useful in distinguishing it from the flatter Campaspe Surface in the Burdekin Uplands. The duricrusts and weathering profiles, while diagnostic of the terminal surfaces as a group, were less useful in distinguishing or correlating particular surfaces, as the degree of weathering and its nature shows regional variations resulting from climatic trends, and local variations caused by lithological differences. The laterites could provide material suitable for palaeomagnetic dating.

The oldest surfaces within the region are the Sub-Georgina and Sub-Carpentaria Surfaces. These are both preserved as unconformities beneath a sediment cover, and have been partly exhumed. The oldest terminal surface expected in the area would be that formed at the end of the Carpentaria Basin cycle, but within the region this appears to have been completely destroyed by later erosion. However, in the Northern Territory it could be represented by the early stage of the Tennant Creek Surface (Hays, 1967); and to the south of the region the late Cretaceous to early Eocene Morney Profile of Idnurm & Senior (1978) is developed on an analogous terminal surface in the Eromanga Basin (see Table 1).

The geological evolution of the region in the Cainozoic is summarised in Table 1. The Bulimba Cycle was initiated by earth movements in late Cretaceous or early Tertiary time. The Sub-Bulimba Surface is the unconformity buried beneath the early Tertiary sediments of this cycle. The terminal Aurukun Surface appeared towards the end of the cycle, and has been deeply weathered to form aluminous and ferruginous laterites, with some silicification in the south. Possible equivalents outside the Karumba Basin are the later stage of the Tennant Creek Surface (Hays, 1967) in the Northern Territory, which extends as a ferruginised and silicified surface into the Isa Uplands, and the silicified and ferruginised Curalle and Canaway Profiles developed on the Cordillo Surface of the Eromanga Basin (Wopfner, 1974; Idnurm & Senior, 1978). The Canaway Profile has been dated as late Eocene to early Miocene (Idnurm & Senior, 1978). The pre-basaltic silcretes of the Fitzroy uplands may also be contemporaneous (Table 1) with this profile.

The Wyaaba Cycle started with Oligocene warping, and continued until early Pliocene times. The terminal Kendall Surface of this cycle has a laterite profile developed on it. It is of Pliocene age and may correlate with the Wave Hill Surface of Hays (1967) in the Northern Territory. The Featherby Surface in the Burdekin Uplands occupies a similar stratigraphic position, but appears to have been terminated earlier by renewed earth movements in the late Miocene and Pliocene. Correlations with the Eromanga Basin are uncertain at present, though some late Miocene to Pliocene silcretes and ferricretes do occur in that area (Table 1).

The Campaspe Cycle started in the Pliocene, and has continued to the present. The Kendall Surface may have been continuous with the Featherby Surface of the upwarped Gilberton Plateau, and if one compares the local denudational sequences then the relationship between the Featherby Surface, Campaspe Beds, Campaspe Surface, and younger alluvial deposits in the Charters Towers area is similar to that between the Kendall Surface and the fans units in the Carpentaria Plains (Table 1). If compared in this way the Kendall Surface occupies a similar position in the sequence to the Featherby Surface, and the Campaspe Beds and Campaspe Surface might be equivalent to the oldest fans, Stage 1 in the nomenclature of Grimes & Doutch (1978). As discussed above the oldest fans surfaces in the Karumba Basin have been partly ferruginised and silicified. In the Northern Territory the Koolpinya surfaces formed in several stages during this cycle (Hays, 1967). The Holroyd Surface of Doutch (1976) differs in concept from the other surfaces in the region. The term was used for a set of climatically controlled landforms.

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