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# The urban geology of Darwin, Australia

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**Abstract**

Darwin, on the north coast of the Australian mainland lies only 12° south of the equator, and experiences a pronounced wet–dry tropical monsoonal climate. This latitudinal position has strongly influenced the local geology for Darwin is dominated by deeply weathered lateritic regolith formed on labile Cretaceous marine sediments. Close to 2 billion years of geological history is lost from this immediate region because the largely horizontally bedded Cretaceous strata unconformably overly folded Proterozoic metasediments. Models of the landscape evolution of this region, and indeed across much of northern Australia, have been based upon the incorrect interpretation of a type section, displaying weathered Cretaceous strata, close to Darwin city. A recent reinterpretation of this type section has shown that the landscape here is a function of deep weathering and structural controls within the Cretaceous strata rather than repeated cycles of uplift and pediplanation during the Cainozoic. The low relief of this landscape, low rates of denudation and preservation of Cainozoic deep weathering profiles and predominantly rocky shore have meant that Quaternary sediments are restricted to shallow alluvial deposits in creek valleys and marine sediments forming beaches with limited dune and beach ridge development.


## 1. Introduction

The most remarkable aspect of the urban geology of Darwin is the angular unconformity, which extends beneath most of the urban area, separating lower Proterozoic rocks from near horizontal Cretaceous strata. This near 2 billion year gap in geological history constrains our understanding of much of the geological evolution of the immediate Darwin region. The city of Darwin sits upon the Cretaceous strata and the Proterozoic strata are principally exposed in road cuts and sea cliffs along Darwin's foreshore. The labile nature of the marine Cretaceous rocks together with the tropical monsoonal climate has resulted in extensive deep weathering of these strata. It is the nature of this deep weathering and the unconformity that have shaped views on the Cainozoic geological evolution of this area. Quaternary sediments are limited in area in the Darwin urban region, in contrast to the Alligator Rivers region to the east where extensive marine and alluvial deposits record the Holocene sea-level rise and stabilisation and changing estuarine environments throughout the late Holocene.

## 2. Location and environmental setting

Darwin is located on the northern coast of Australia at latitude 12.5° south and longitude 131° east (Fig. 1). The climate is monsoonal, with rainfall almost solely restricted to the period December–April with a pronounced dry season throughout the remainder of the year. Precipitation during the wet season ranges between 900 and 2500 mm and averages approximately 1500 mm. Dry season precipitation rarely exceeds 50 mm. Diurnal temperatures range from 34°C to 24°C during the months October–April and 32–17°C between May and September (McAlpine, 1976).

The topography of the Darwin region is dominated by a relatively flat to gently undulating surface generally less than 30–40 m above sea level. The city and suburbs with their coastal location are bounded along the western shore by sea cliffs, between 1 and 30 m in height, and shore platforms at the base of headlands along with small pocket bayhead beaches

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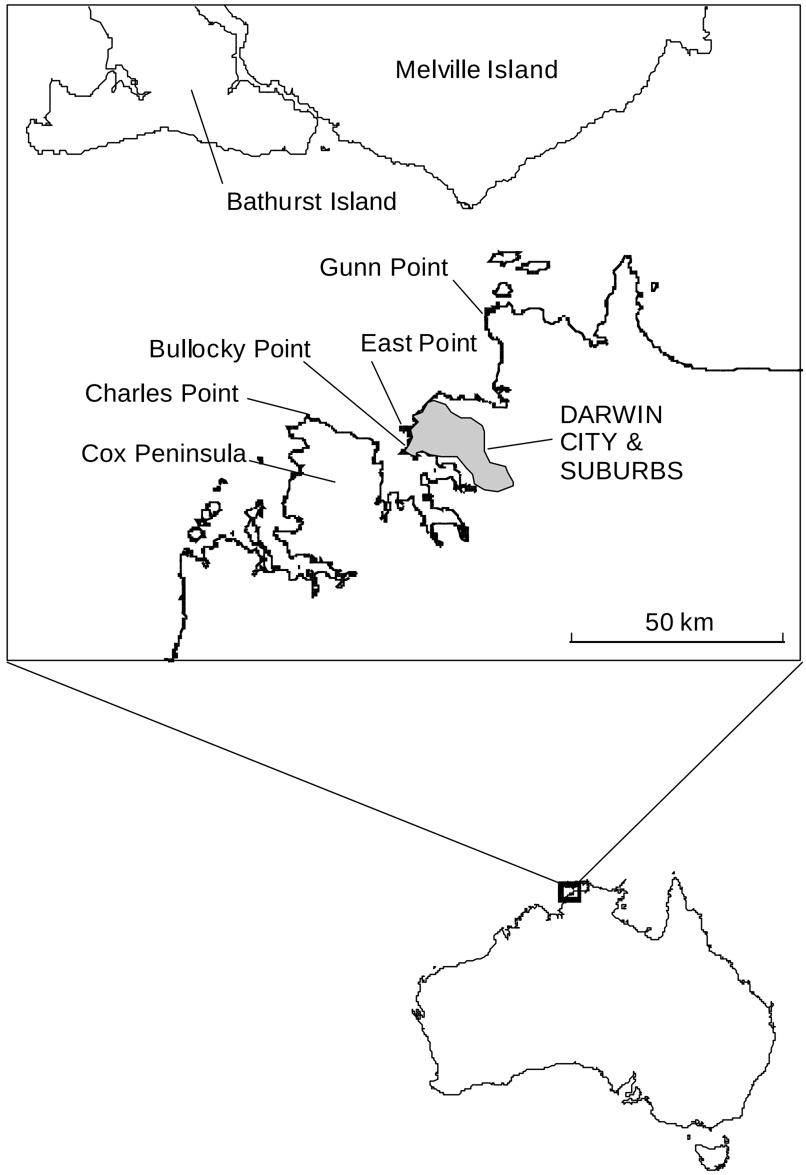


Fig. 1. Location map of Darwin urban region and adjoining areas.

and much longer beaches up to 10 km in length. The coastal cliffs have been carved largely from the horizontal to gently undulating bedded Cretaceous strata.

## 3. Geology of the Darwin region

The Darwin region forms part of the Australian Precambrian shield which has been comparatively stable since middle Proterozoic times (Stuart-Smith et al., 1980). Overlying the Archaean basement are metasediments of the Pine Creek geosyncline which were successively folded and uplifted during the early to middle Proterozoic. Following erosion of the Proterozoic rocks, essentially flat lying Mesozoic and Cainozoic strata were deposited.

### 3.1. Proterozoic strata

The early Proterozoic strata in the Darwin region vary according to metamorphic grade. To the west, near Cox Peninsula (Fig. 1) the unconformable Cretaceous strata overlie upper greenschist to amphibolite facies quartzofeldspathic and mica schists, gneiss and minor quartzite. To the east, near Gunn Point (Fig. 1), lower greenschist facies metasediments occur. The Proterozoic strata underwent one major deformation approximately 1800 Ma resulting in tight folds with limbs dipping steeply at more than 50° (Pietsch, 1983).

### 3.2. Mesozoic strata

Mesozoic strata in the Darwin region are dominated by the Darwin Member of the early Cretaceous Bathurst

Island Formation. Other units within the Bathurst Island formation include the Wangarlu Mudstone Member and overlying Mookinu Member. The Wangarlu Mudstone Member does not crop out in the urban Darwin area and is restricted to the region near Gunn Point. The Mookinu Member is not present at all on the mainland but lies stratigraphically above the Wangarlu Member which in turn overlies the Darwin Member on Bathurst Island to the north of Darwin (Fig. 1). In the Darwin region, the Darwin Member is composed dominantly of a white siliceous siltstone containing numerous radiolarians. At the base, resting unconformably upon the Proterozoic Burrell Creek Formation, is a coarser-grained facies composed of a layer of lag gravels, generally no greater than 1–2 m thick, which grades upwards into sandstone and then siltstone. The texture of the Darwin Member coarsens westwards to Cox Peninsula, to the west of Darwin, where it is dominated by fine to coarse–grained sands.

Drill core and seismic data show that the pre-Cretaceous landscape in the Darwin region had moderate relief (Fig. 2). This was especially the case in those areas where carbonate-rich rocks were exposed at the surface (Jolly, 1983). Where Cretaceous strata rest on Proterozoic metasediments the unconformity is not as irregular, but it nonetheless displays considerable relief (Power and Yin Foo, 1988). The origin of the undulating Proterozoic/Cretaceous unconformity, as clearly displayed in coastal cliff sections, is likely to be due to the irregularities of the late Jurassic/early Cretaceous land surface.

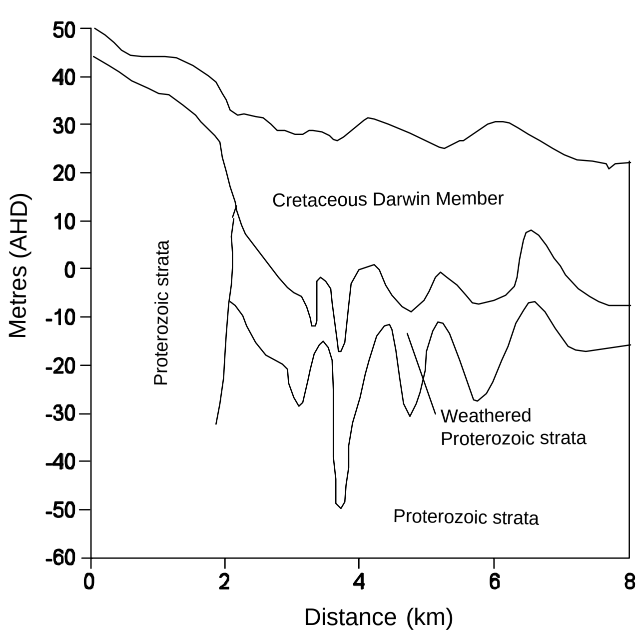


Fig. 2. Bedrock stratigraphy near Darwin. Note the greater extent of pre-Cretaceous relief compared to present day. AHD is Australian Height Datum. Diagram adapted from Jolly (1983).

Towards the base of the Darwin Member, generally within the siltstone facies, lies a bioturbated bed, up to 1 m thick, containing a disorderly array of belemnites and worm burrows (Fig. 3). This bed lies between 2 and 13 m above the unconformable contact with the Proterozoic Burrell Creek Formation. Immediately below and above the bioturbated bed, and in places interbedded with it, lie beds containing abundant phosphorite nodules. All of these beds are gently undulating with dips no more than 5°.

The bioturbated bed parallels the variable undulations in the Proterozoic/Cretaceous unconformity. Other beds within the Darwin Member also mimic the undulations of the bioturbated bed and the Proterozoic/Cretaceous unconformity. At Bullocky Point, close to Darwin city, for instance, a 0.5–1 m thick bed of sandstone, which lies stratigraphically below the bioturbated bed, also parallels these undulations. At the same location, however, beds of claystone, stratigraphically above the bioturbated bed, display much shallower dips and become horizontally bedded towards the top of the 10 m high exposure (Nott, 1994). This same phenomenon also occurs elsewhere suggesting that the undulations in this bedding are likely to be less of a function of post-Cretaceous warping and more likely a function of sediment draping the topographic irregularities of the pre-Cretaceous land surface.

### 3.3. Tertiary and Quaternary strata

Cainozoic sediments cover much of the Darwin area. These can be divided into two main groups; Tertiary weathering products or regolith and Quaternary sediments. Because the city of Darwin is situated on a slightly elevated plain of largely deeply weathered Cretaceous strata, the Quaternary sediments are restricted in area to coastal beach and dune sands and minor amounts of alluvium in creek valleys and colluvium on shallow slopes. Extensive Quaternary deposits occur directly to the east and south of Darwin in the Alligator Rivers region (Fig. 4) where broad estuarine and alluvial plains record a history of Holocene sea-level rise and environmental change. Woodroffe et al. (1989) and Woodroffe and Mulrennan (1993) have shown that extensive floodplains to the east of Darwin, which today in many places lie below the level of the highest tides, started to accumulate around 7000 yr BP during the Holocene marine transgression. By approximately 6500 yr BP when sea level stabilised in the region (Fig. 5) broad areas of these plains were dominated by mangroves for the next approximately 1000 yr during which time, an extensive blue–grey mud facies was deposited. Ensuing vertical accretion by the tidal stream systems gradually raised the level of the coastal floodplains such that the mangrove habitats became restricted to discontinuous fringes along tidal

Fig. 3. View of deeply weathered Cretaceous strata near Darwin city. Note weathering profile (saprolite) terminates at shore platforms. The base of the weathering profile here is marked by the bioturbated bed. The angular unconformity separating Cretaceous strata from Proterozoic rocks is below sea level at this location.

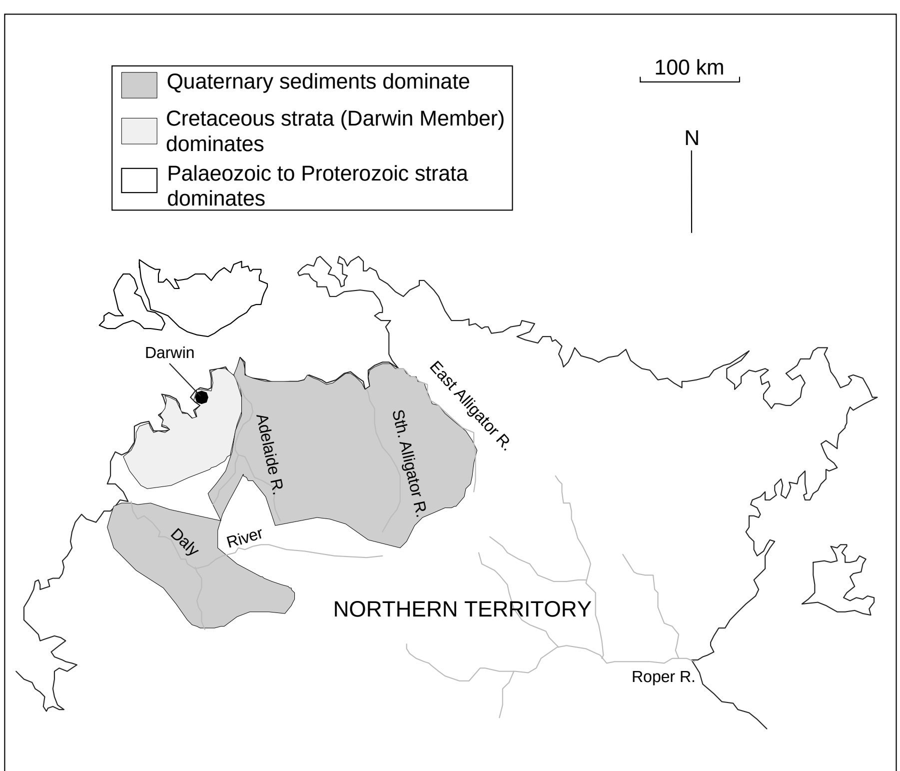


Fig. 4. Simple geology map showing Alligator Rivers region to the east of Darwin where Quaternary sediments dominate and the lack of Quaternary sediments in the immediate Darwin region.

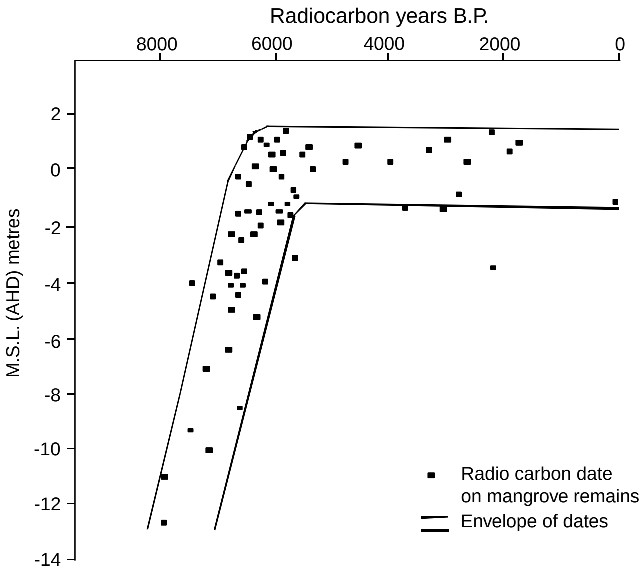


Fig. 5. Sea-level envelope curve developed from carbon-dated mangrove remains in the Alligator Rivers region. Curve adapted from Woodroffe and Mulrennan (1993).

streams and prograding sections of coast and shoaling mid-channel islands and channel point bars. The plains today are known as black soil plains and are dominated in the upper stratigraphy by estuarine and marine sands and muds which overlie the mangrove muds deposited during the extensive mangrove-dominated phase otherwise known as the 'big swamp phase' (Woodroffe et al., 1989). Chenier ridges also occur in numerous locations across these floodplains and vary in age from 5500 yr BP to less than 1000 yr BP.

Virtually, all of the beaches in the Darwin area are sandy. The macrotidal range of 6–7 m means that at low tide broad, up to 100 m wide, stretches of sandy coast are exposed. Many of the beaches are backed by low cliffs carved from the weathered Cretaceous strata and here at high tide the entire beach is inundated; sand dune development is, as a consequence, limited. Elsewhere where the local bedrock dips toward and below sea level, minor dune systems have developed and at one location along Darwin's northern beaches low elevation late Holocene beach ridges occur. This is the only evidence for coastal progradation in the immediate Darwin area. At other locations coastal recession is obvious. Darwin was the scene of battles during World War II and in 1945 extensive amounts of artillery and associated materials were dumped off the coastal cliffs at Nightcliff approximately 15 km north of Darwin city. These materials landed at and close to the base of the cliff and mark the position of the cliff at that time. Since then the cliff has receded approximately 6–8 m, due to wave action, giving an average rate of cliff erosion of 30–40 cm per year.

### 3.4. Weathering

Deep weathering profiles, especially within the upper radiolarians-rich siltstone unit of the Cretaceous Darwin Member, have resulted in 5–20 m deep lateritic profiles dominating the geology of the immediate Darwin area (Fig. 3). The deep weathering profiles are varied, with at least four different forms of laterite occurring throughout the area. The two predominant types of laterite are a conglomeratic laterite composed of reworked and recemented pisoliths, along with minor inclusions of claystone and angular to sub-rounded quartz fragments, and an in situ laterite formed within the Cretaceous strata. The term detrital laterite has been used in this region to generally refer to a relateritised colluvial mantle where the colluvial debris has been derived from an in situ or earlier generation of detrital laterite higher in the landscape (see for example Christian and Stewart, 1953; Hays, 1967, 1968). In this sense it has been used as evidence of scarp retreat or pediplanation.

In this region, it is often difficult to differentiate between the in situ and detrital varieties of laterite. Where in situ bedrock is visible faint bedding structures can sometimes be traced laterally or vertically into the deeply weathered profile. Such a situation occurs at East Point (Fig. 1) where the deeply weathered profile and associated laterite is clearly in situ. Further downslope at the same site, however, rounded quartz clasts up to 3 cm in diameter occur approximately 2 m from the base of the 4 m high-weathered profile and above this the profile is dotted with rounded to angular quartz clasts. As the bedrock both below and upslope of the weathered profile is claystone, it is clear that this section of the weathered profile is detrital in origin. At other locations such as at Charles Point on Cox Peninsula (Fig. 1) where unweathered bedrock does not crop out, bedding structures can at times be seen in the weathered Cretaceous strata. Here the bedding structures can be traced to the crest of the cliff, thereby indicating that this profile has developed within undisturbed Cretaceous strata, and is not detrital.

## 4. Evolution of landscape

Jensen (1915) first described the existence of a number of surfaces at different altitudes in the northern part of the Northern Territory including the Darwin region. Subsequently, numerous workers postulated theories as to the origin of these surfaces, the most detailed and recent of which was developed by Hays (1967, 1968). Hays recognised the oldest and highest of these, the Ashburton surface, preserved as a series of accordant summits across steeply dipping lateritised lower Proterozoic strata that rise up to 90 m above the Tennant

Creek surface to the south of Darwin. Hays (1967) suggested that sediments deposited in the Cretaceous sea were derived from the Ashburton and Tennant Creek surfaces. Thus the Tennant Creek surface had developed prior to regression of the Cretaceous sea. The southernmost extent of the Aptian sea well to the south of Darwin, Hays argued, corresponded to the northern limit of the Ashburton surface.

According to Hays, deep weathering and lateritisation of the Cretaceous sediments took place from the close of the Cretaceous to the middle Tertiary. This formed a 'standard' laterite profile, which consisted of an in situ trizonal profile composed of a ferruginous (plinthite) layer overlying a mottled and then pallid zone. According to Hays this was the period of 'main lateritisation'. He suggested that two successive episodes of uplift or warping, pediplanation and detrital laterite formation followed. Receding scarps cut back into the Tennant Creek surface to form the Wave Hill surface and later, following another episode of uplift, younger scarps cut back into the Wave Hill surface to form the Koolpinyah surface. The criteria for recognition of these last two surfaces was regarded by Hays as the presence of detrital laterite, often with two stratigraphic units of detrital laterite on the Koolpinyah surface, as well as their respective differences in altitude. The Wave Hill and Koolpinyah surfaces dominate the topography of the Darwin region.

In the Darwin region Hays regarded the profile (his type section) at Charles Point on Cox Peninsula to be a typical detrital laterite profile, rejecting the earlier suggestion of David and Browne (1925) that this was actually an in situ laterite profile. Nott (1994), after detailed inspection of the 15 m high profile at Charles Point showed that David and Browne were correct for the entire profile here has developed in undisturbed Cretaceous strata. Hays argued that at Cox Peninsula the original laterite profile had twice been truncated and replaced by two generations of detrital laterite, and that only the lower section of pallid zone remained as part of the original 'standard' laterite profile developed on the Tennant Creek surface. Nott (1994) showed, however, that bedding structures extend from the pallid zone at the base of the profile at Cox Peninsula through the supposedly detrital zones to the crest of the cliff. Even the capping ferricrete can be seen to contain bedding structures and in situ blocks of less weathered Cretaceous claystone. The same is true of many of the weathering profiles along the Darwin coast and also at Gunn Point where Hays argued for the presence of detrital profiles forming the Wave Hill surface. At Gunn Point the profiles too, like Charles Point, have developed in undisturbed Cretaceous strata. A pedogenetic laterite/ferricrete capping, consisting of a packed pisolithic layer (residuum) approximately 0.5–1 m thick, penetrates into the profile below and in many places has extended down cracks and root channels to a depth of 1–1.5 m.

Deep weathering of the Cretaceous strata in the Darwin region and formation of saprolite has been controlled by the bioturbated bed. A layer of opaline silica, a result of the weathering and translocation of silicates in the Cretaceous sediments, has accumulated immediately above the bioturbated bed forming a resistant barrier to denudation in the region. This bed has controlled both the elevation and to a certain extent the topography of the Darwin region. The Wave Hill and Koolpinyah surfaces in the Darwin region are largely a function of the depth to which weathering has been allowed to occur. Hence successive cycles of uplift, planation and weathering are no longer required to explain the evolution of the Darwin landscape.

## 5. Geological hazards

Seismically, the northern part of Australia and the Darwin region are comparatively stable. Large magnitude earthquakes here are rare. Most of the earthquakes felt in the Darwin region occur approximately 500–600 km to the north along the convergent plate margin near the Banda Sea to the north-east of Timor. The greatest felt earthquake intensity in Darwin, during historical times, was from the MS 7.3 earthquake which occurred at a depth of 16 km, 530 km north of Darwin on 7 October 1960 (Vanden Broek, 1980). The maximum modified Mercalli (MM) magnitude was about MM V and possibly MM VI. Damage to concrete fixtures, toilet fixtures, and walls occurred as a result of this event. An earthquake with a felt intensity of MM V in the Darwin area can be expected at least once every 50 years. There are few buildings in the immediate Darwin City area that are built upon soft alluvial foundations where liquefaction and amplification of seismic waves could occur. However, Darwin City is underlain by a thick soil mantle which in places is consolidated into ferricrete and elsewhere a less consolidated lateritic earth. The specific geology, therefore, will determine the extent of damage during these one in 50 years or greater magnitude events.

Darwin does not appear to be subject to large or even moderate size tsunami despite its proximity to the convergent plate margin near Indonesia. There are no reports of tsunami affecting Darwin during historical times (approximately 140 years). It is likely that tsunami generated near Indonesia are largely attenuated as they travel across the 200–300 km wide continental shelf to the north of Darwin. Tropical cyclone-generated storm surge is, however, a major hazard threat to Darwin. There are many buildings and houses at elevations within 2–3 m above sea-level in Darwin's northern suburbs and it could be expected that these structures


Fig. 6. View across Darwin suburbs of destruction resulting from Tropical Cyclone Tracy, 25 December 1974.

would be inundated by storm surge and waves during an intense tropical cyclone. To date, storm surge has not been a hazard but this has been a case of good luck rather than a lack of community vulnerability or low community risk. Tropical Cyclone Tracy, for example, which passed directly over Darwin in the early hours of Christmas Day 1974 produced a 4 m high storm surge on Darwin's northern beaches. Fortunately, the storm surge occurred during neap tides and inundation of buildings did not occur (Darwin has a 7 m tidal range). However, wind damage was extensive with the vast majority of buildings left uninhabitable (Fig. 6).

## 6. Conclusion

The geology of Darwin is dominated by Cretaceous marine sediments that have been deeply weathered into lateritic crusts and soils. Sedimentation during the Cretaceous marine transgressions smoothed an already subdued landscape to one that is now dominated by broad, flat to undulating surfaces up to 40 m above sea level. The present landscape has been argued to have resulted from repeated cycles of uplift and pediplanation during the Tertiary but close inspection of the local geology shows that this low-relief landscape is a function of deep weathering under a tropical monsoonal climate and structural controls in the Cretaceous strata. Distant earthquakes near Indonesia can impact Darwin but to date there have been no recorded tsunami impacting Darwin's shores despite its relative proximity to the convergent margin between the Australian and South East Asian tectonic plates.

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