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Preface

Tertiary sedimentary rocks, in places up to 200 m thick, occupy a series of elongate basins within the Arunta crystalline basement in the Alice Springs region, central Australia. The sequences of sedimentary rocks within these basins remain poorly known; our understanding of most aspects of them is at reconnaissance level only. Understanding of the evolution of the basins and the nature of the sedimentary record within them is hampered by poor outcrop, limited high quality data from drilling, and by the intense weathering which is repeated throughout the sequence.

A summary of available information on these basins is presented in the paper by Senior et al. (AGSO Journal Vol.15 [4], 1994). This record incorporates the text of that review, but adds to it more detailed data on the lithology of individual sequences, in the form of lithological and gamma-ray logs for selected drillholes. It should be stressed that the data are patchy, and represent only what is currently available many years after the end of the drilling program. However, it was felt that making public such information as is available could be useful particularly for groundwater assessment. Also included in this record are details on the palaeomagnetism sampling program that has contributed valuable information on the age of key sequences. It should be noted that the information presented here was gathered during the period 1973 to 1986.

An understanding of these small sedimentary basins has implications for assessment of potential mineral and groundwater resources in the region, as well as for enhancing our knowledge of the tectonic and climatic processes that have shaped Australia. The preliminary nature of the work presented here cannot be emphasised too strongly. The extent and boundaries of the known basins are poorly known; there is a dearth of information on the sediments within them - on their mineralogical and chemical composition, and on sedimentary structures; importantly too, there is very little data on age control. What is presented, however, should provide a basic framework for future studies.

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Introduction

We provide here an updated geographic and stratigraphic framework of some of the Tertiary basins of central Australia. These have received little attention in the geological literature since the 1960s. This is due in part to the poorly outcropping nature of sequences within these basins, and to strong weathering overprints. As a consequence, this study depends heavily on analyses of drill hole cuttings, supplemented by a few cores. Drilling and reconnaissance geological mapping has shown that the basin sequences have been profoundly altered by weathering, with associated mineralogical and chemical changes. The sedimentary sequence also contains contemporaneous siliceous and calcareous beds, as well as redeposited or recycled sediments including former weathered and/or chemically precipitated rock types.

This paper is, therefore, an attempt to unravel the complicated history of development of these basins. It provides a framework for reconstruction of the probable Cainozoic depositional, weathering, climatic and tectonic history of central Australia. Although there are large gaps in knowledge, the data presented has wide implications regionally for the palaeogeographic and tectonic evolution of the Australian Plate. Locally, it is valuable fo the assessment of mineral and groundwater resources. Many of the specific palaeo-environmental interpretations are tentative as, for example, details of the depositional, sedimentary, and stratigraphic details remain to be investigated.

Previous investigations

The distribution and stratigraphy of the Tertiary basins in general were discussed by Perry et al. (1962), Hays (1967), and Mabbutt (1967). Early investigations of specific basins were often for groundwater, and include reports on the Utopia arm of the Waite Basin, (Woolley, 1965a), on the Farm Basin south of Alice Springs (Woolley, 1965b), and the Kulgera water supply (Woolley, 1966). Other groundwater investigations include those by McDonald et al. (1988) and O'Sullivan (1973a, b) on the Ti-Tree Basin, Morton (1965) on the Willowra Basin, and Jacobson et al. (1980) on the basins of the Uluru (Ayers Rock) region (see Fig.1). Other investigations were for lignite in the Hale Basin, for vertebrate fossils at

Alcoota in the Waite Basin (Woodburne, 1967), and for uranium in the Ti-Tree Basin (O'Sullivan, 1973; Hughes & O'Sullivan, 1973).

Present study

This study reviews current understanding of Cainozoic sedimentary basins in the eastern part of the Arunta Block where stratigraphic drilling by the Bureau of Mineral Resources (BMR; now the Australian Geological Survey, AGSO) was carried out from 1973 to 1986. Particular attention is focussed on the Hale, Ti-Tree, Waite, Bundey, and Aremra Basins. Besides drilling, the main stratigraphic information comes from geological reconnaissance in several Tertiary basins. The Waite Basin (Alcoota 1:250 000 Sheet area) was investigated by Yeates (1971). Parts of the Sixteen Mile, the Burt and the Ti-Tree Basins were drilled in 1973. Both the Aremra Basin (Illogwa Creek 1:250 000 Sheet area) and southwestern part of the Ti-Tree Basin (Alcoota 1:250 000 Sheet area) were investigated by BMR in 1979. The Hale River Basin was also drilled by BMR in 1979. Results from drilling in the Hale Basin by the Northern Territory Geological Survey (NTGS; Clarke, 1975) and by industry in the early 1980's are also incorporated.

Much of this investigation was carried out by B.R. Senior (Senior, 1972; Shaw et al., 1982). A multidisciplinary study of the sedimentation, age and weathering history of Cainozoic epicratonic basins commenced in BMR in 1979. This study included preliminary palaeomagnetic dating of ferruginous weathered profiles and palynological studies of a carbonaceous and lignitic succession from the Hale Basin, as well as further geological studies elsewhere in the region. Palynological work was carried out on lignite and carbonaceous rock types in drill core supplied by the Northern Territory Geological Survey from the Hale Basin east of The Garden homestead, (Truswell & Marchant, 1986). Ferruginised rocks were studied palaeomagnetically to establish the timing of weathering events in the Alice Springs region. This paper summarises the published palynological work, as well as interim results of the palaeomagnetic work already mentioned. It also attempts to synthesize the findings, up to 1994, of other BMR/AGSO research in the region.

In the first part of this paper, the stratigraphic successions in the Ti-Tree, Waite, Bundey, Aremra, and Hale Basins (Fig.1) are described and discussed. Selected logs of individual drill holes are presented in

Appendix 2 of this report, either in diagrammatic form or as the original, descriptive log. The outcrop distribution of individual units is also available separately in the concurrent 1:250 000 and 1:100 000 geological map series. The second part of this paper discusses the implications of the reconnaissance, and in some instances, more detailed, geology and of the drilling and palaeomagnetic results (see also Appendix 1 herein) for the Cainozoic stratigraphic framework of the region.

Outline Of Cainozoic geology

Tertiary rocks in the Alice Springs region occupy elongate intermontane basins (which are, at least in some cases, fault-controlled) and flanking palaeodrainages and piedmont deposits. In places, the successions are more than 200 m thick. Outcrops are rare; most are deeply weathered. The Tertiary sequences are mantled by widespread unconsolidated Quaternary sediments forming the flat or subdued depositional landscapes of the main river systems, including those of the Ti-Tree, Hanson, Plenty, Bundey, Illogwa, and Hale systems. Most of the plains associated with the river systems are partly bounded by steep, deeply dissected mountain ranges, some merging with lowlands of bedrock interspersed with flat-topped residuals.

Most of the Cainozoic sedimentary successions overlie crystalline Proterozoic Arunta basement. Some, however, overlie parts of the Neoproterozoic to Palaeozoic Amadeus and Georgina Basins (Fig. 1). Much of the Tertiary sedimentary succession has been eroded from the northwestern, central and southeastern parts of the Amadeus Basin.

Some of the basins appear to have been initiated as early as the Late Cretaceous (Harris & Twidale,1991). Evidence presented in this paper suggests that, for the most part, sediment accumulated in two separate pulses, one in the Paleogene and the other in the Neogene. The first pulse partly filled basins which developed in narrow depressions within mountainous regions dominated by the Precambrian crystalline Arunta basement. Examples are the Hale, Burt, Mount Wedge, and Whitcherry Basins. In the second pulse, deposition was in palaeodrainage depressions on the northern and eastern flanks of the uplands formed by the basement. Depressions preserving this second pulse include, for example, the Aremra, Bundey, Ti-Tree, Willowra, Ngalabaldjiri, and Yaloogarie Basins.

On the southernmost flanks of the uplands (which here include part of the Neoproterozoic to Palaeozoic Amadeus Basin), the Cainozoic history was very different. Here, piedmont fans formed on actively steepening slopes were dissected both during and after deposition, to form the disconnected series of mesas shown in Figure 1. The most active period of dissection started possibly in the late Pliocene with uplift in the MacDonnell Ranges (Shaw & Wells, 1983). Only in the Ayers Rock Basin was deposition more-or-less continual (Jacobson et al., 1989).

An idealised overview of how the mapped lithostratigraphic units relate to landforms is given in Figure 2. This shows the relationship of lithostratigraphic units to landscape in the Hale Basin and regions bordering the eastern MacDonnell Ranges.

The basement complex and the Tertiary sequences appear to have undergone more than one period of intense chemical weathering. According to Senior (1972), a trizonal weathered profile with developed in crystalline Arunta rocks. This profile is up to 40 m thick and grades from a lowermost leached zone through an intermediate mottled zone to a ferruginous top. Erosion subsequently stripped the profile from most of the area, some of the detritus being incorporated into sediments accumulating within the intermontane basins. The Tertiary rocks were in turn weathered and crusts of silcrete, ferricrete, and thin ferruginous profiles developed in the Yaloogarie Basin (Stewart, 1976), Hale Basin (this paper), and in the western Ti-Tree Basin (O'Sullivan, 1973). Earlier, Mabbutt (1967) drew attention to the lateral variation from laterite at the centre to silcrete at the margins of the Hale Plain (Hale Basin), attributing this variation to a shallower, less-fluctuating former water table in the axial region, together with possible down-slope migration of iron.

Results from reconnaissance geology indicate that ferruginous profiles on the Lower to Upper Jurassic Hooray Sandstone, along the northwest margin of the Eromanga Basin in the Illogwa Creek Sheet area, contain ferruginisation which possibly occurred during the Late Cretaceous and Paleocene. Within the Hale Basin, and at three localities in the Arunta basement rocks, a mid-Tertiary ferruginisation event was recognised, and supported by the palaeomagnetic work.

Because of the complex weathering history, which altered the mineralogical composition of much exposed rock, and the absence or destruction of fossils, age relationships between individual Cainozoic rock units in the Alice Springs region remain uncertain. Nevertheless, some idea of the most likely stratigraphic framework is provided by palaeontological evidence from adjacent areas that appear to have a parallel history.

Palynological work in the area between Ayers Rock and the Olgas suggests that deposition there may have begun as early as the Late Cretaceous, possibly even earlier. Lignites near the base of the 100 m thick succession were dated originally as Paleocene (Twidale & Harris, 1977), but a recent re-assessment, based on discovery of further diagnostic spore species, suggests that parts of the section are as old as the Maastrichtian Stage of the Late Cretaceous (Harris & Twidale, 1991). These latter authors concluded that there were at least three depositional phases in the area, i.e. a Late Cretaceous, a possible mid to Late Paleocene, and a Late Eocene phase.

Palynology indicates that carbonaceous clay in BMR Napperby 1, in a probable arm of the Whitcherry Basin (Fig. 1), is also of Eocene age (Kemp, 1976). Carbonaceous sediments in the Ti-Tree Basin were described by Galloway & Kemp, (1977) as of possible Miocene age, but they could, on more recent data, be as old as Eocene. Vertebrate fossils indicate a Late Miocene or Early Pliocene age for the upper part of the Waite Formation near Alcoota station (Woodburne, 1967). The palaeontological evidence, therefore, suggests that most of the sedimentary succession in the eastern Arunta region ranges from Late Cretaceous to Miocene or Pliocene in age. From the Pliocene to the present day, sedimentation continued intermittently within local depressions.

The sequence of poorly to moderately lithified sedimentary rocks (conglomerate, sandstone, siltstone, mudstone, lignite, oil shale and calcarentic, chalcedonic limestone) and weathered profiles of Cainozoic age in the Hale Basin northeast of Alice Springs are shown in Table 1. This composite reference section, established there from surface mapping and drilling, forms the basis of the regional stratigraphic framework described here. It incorporates data from Lloyd (1968), Senior (1972), Shaw & Warren (1975), and Shaw et al. (1979a & b), as well as the results of more recent studies. The stratigraphic succession and ages of some units, and particularly of weathering events, have been updated in accordance with evidence discussed here.

Hale Basin

This basin lies about 80 km northeast of Alice Springs (Figs 1 to 3). It underlies the Hale Plain between Claraville and The Garden homesteads, and is one of a number of small, sediment-filled depressions lying on a deeply weathered surface of Proterozoic and early Palaeozoic rocks. The basin forms a complex arcuate depression about 45 km long and up to 13 km wide. Its southern margin may have been a fault which controlled initial subsidence in the Late Cretaceous or Early Paleocene. The full succession is developed in the more extensive western part of the basin where the reference succession is located in BMR DDH Alice Springs SH 2, and another section has been described from the NTGS DDH 1 (Figs 4 and 5). A thinner sequence is preserved in the east in the Claraville Sub-basin, which is separated from the main basin by a basement ridge. The surrounding basement rocks comprise largely metamorphic rocks and granites of the Arunta Block (Shaw & Wells, 1983).

The basin is filled with mainly fluviatile and lacustrine clastics (Clarke, 1975; Senior in Shaw et al., 1982; Shaw et al., 1984). The spatial and temporal distribution of the deposits has been determined from reconnaissance mapping (Shaw & Langworthy, 1984; Shaw et al., 1984), the logging of chip samples left *in situ* by an exploration company (Fig. 5), and stratigraphic drilling by BMR in 1966 and NTGS in 1975 (see Fig. 3 for locations). Figure 4 shows a stratigraphic log for NTGS DDH1 as well as its relation to the composite stratigraphic section. In Figure 5 the sequence in BMR DDH Alice Springs SH 2 is related to sequences identified in company drilling in the basin.

Stratigraphy

At the base of the succession, overlying the deeply weathered metamorphics of the basement complex (Tlf of the map units, Table 1; Weathering Event A in Figure 4), is the Hale Formation (Th) (defined in Stewart et al., 1980a; Shaw et al., 1984), a unit of kaolinitic quartz sandstone, siltstone, and mudstone, which grades into coarser sediments at the basin margins. Within the Hale Formation (Fig. 4; Table 1) the succession begins with the informally named 'Ambalindum Sandstone Member' (Thg), of argillaceous, poorly sorted sandstone, with intercalations of granule and pebble conglomerate. This sandstone unit is about 55 m thick in BMR DDH Alice Springs No. 2. Conformably overlying this unit in the main western part of the basin is the Ulgnamba Lignite Member (Thu), formally defined and described by Stewart et al. (1980b) as the unit of lignite and carbonaceous shale which is 4 m thick in its type section in BMR DDH Alice Springs SH 2. The lignite also crops out, in a very weathered state, in a mesa 3 km west-northwest of Claraville Homestead. Locally, the lignite is accompanied by pockets of oil shale. In the Claraville Sub-basin, an olive-green unit of mudstone and siltstone lies immediately below a discontinuous, carbonaceous clay unit assigned to the Ulgnamba Lignite Member. The olive-green unit is informally referred to as the Claraville Mudstone Member (Thc) and appears to belong to the same episode of deposition as the lignite. Thus, the Ulgnamba Lignite Member is a facies variant of the upper part of the Claraville Mudstone Member.

In the eastern Claraville Sub-basin, the Claraville Mudstone Member rests in places on weathered (yellow) sandstone (Weathering Event B in Figs 4 and 5), presumed to be the Ambalindum Sandstone Member (Fig. 5). The Claraville Mudstone Member (Thc) occurs as lenses in several of the drill holes penetrating the Hale Plain. The Claraville Mudstone Member becomes sandier westwards so that in the region of BMR DDH Alice Springs SH2 it equates with a sandstone unit above a thin conglomerate unit (Fig. 5).

Above the lignite, the uppermost part of the Hale Formation has been referred to informally as the 'Arltunga Member', a unit mapped in the Paddys Basin several kilometres to the south. This is a succession of poorly consolidated, fine-grained brown silty sandstone, with minor sandy siltstone, and clay interbeds. There is some confusion about the nomenclature of this sedimentary unit, as the name Arltunga beds has been used for calcarenitic limestones which may be more appropriately grouped with either the Hale Formation (Senior in Shaw et al., 1979) or the overlying Waite Formation equivalents (Shaw & Wells, 1983; Shaw et al. 1984). For this reason, this unit is placed in a new unit, herein informally named the 'Tug Sandstone Member' (Tht).

The Hale Formation appears to record deposition in a progressively flooding and slowly subsiding basin (Clarke, 1975). The basal sandstones reflect a relatively high-energy, fluvial environment, whereas the Ulgnamba Lignite Member records a marsh or swamp habitat, and the Tug Sandstone Member probably represents a phase of relatively low-energy, fluvio-lacustrine sedimentation. As noted earlier, such specific palaeo-environmental interpretations need to be confirmed by more detailed future studies - for example. little information on sedimentary structures is at present available.

Formation of silcrete (Ts), within former porous and permeable quartzose sandstone, presumably by groundwater movements, and another interval of deep weathering (Weathering Event C in Figs 4 and 5) affected deposits of the Tug Sandstone Member along with the adjoining basement. This weathering preceded deposition of a fine-grained clastic unit equated with the Waite Formation (Tw). In the surrounding basement, the ferruginous weathering unit, now placed in unit Tl, had been previously assigned to unit Tlf (Shaw et al., 1984). The Waite Formation was originally defined in the Waite Basin to the northeast (Shaw et al., 1982), where Woodburne (1967) described a Late Miocene to Early Pliocene vertebrate fossil assemblage.

Age of the Ulgnamba Lignite Member (Thu)

Dating the relatively thin successions in the Cainozoic basins of inland Australia continues to be a major problem. The difficulties of setting up a time framework within these basins were outlined by Truswell & Harris (1982): the sequences are entirely non-marine, and frequently deeply weathered; there are no intercalated volcanics that would allow radiometric dating; and the sequences are for the most part too thin to permit the use of magnetic reversal stratigraphy as a dating tool. In addition, they are remote from key palynological reference sections for Australia, which have been defined in the southeast.

In the Hale River Basin, the Hale Formation is both underlain and overlain by deeply weathered profiles. The climatic event that produced a trizonal weathered profile in the basement Arunta rocks on which the Cainozoic sequences rest is likely to have occurred in the Late Cretaceous and/or Paleocene, based on a comparison with the chronology of weathered profile development in the Eromanga Basin of southwest Queensland. The second, younger, weathering event, which affected the top of the Hale Formation, was suggested by Senior (in Shaw et al., 1979b) to be Late Oligocene to Early Miocene, on the assumption that this event correlated with the younger of the two weathering events in the Eromanga Basin (see Senior et al., 1978). However, preliminary palaeomagnetic results from the Hale Basin indicate Late Eocene as the most likely age for the weathering (see Discussion below), suggesting Late Eocene as the probable younger age limit for the Hale Formation and its included Ulgnamba Lignite Member. The outcropping ferruginised or deeply weathered basement rocks sampled north of the Hale Basin similarly record a Late Eocene age of magnetisation.

Truswell & Marchant (1986) described palynomorphs from the Ulgnamba Lignite Member, at 42.2 m depth in the borehole DDH-1, drilled by the Northern Territory Geological Survey. The assemblage was correlated with the middle *Nothofagidites asperus* Zone of the Gippsland Basin, which, in its type area, spans the Middle to Late Eocene boundary. The correlation rests on relatively small numbers of index species, namely, on the presence of *Nothofagidites falcatus, Santalumidites cainozoicus,* and *Proteacidites confragosus,* so that precise relationships are difficult to determine. Assuming that the time ranges of species are similar in central and southeastern Australia, then a Middle to Late Eocene age is implied, consistent with the palaeomagnetic results.

Ti-Tree Basin

The Ti-Tree Basin lies mainly in the northwestern Alcoota Sheet area, and also overlaps the Napperby and Barrow Creek Sheet areas (Fig. 6). The basin covers an area possibly as large as 1000 km^2. Exposure of the basin deposits is limited to low, sandy soil-mantled rises, and most of the succession is known only from drill holes and from driller's lithological logs of water bores. The basin is thought to be thickest in the east, where it crosses both the Woodforde River and the Stuart Highway, south of the Ti-Tree roadhouse (Fig. 6).

Previous investigations

The groundwater potential of the basin has been investigated by Edworthy (1966) and McDonald (1988a, b). The recharge mechanism and groundwater age has been assessed by Calf et al. (1991). The uranium potential of the basin was examined by O'Sullivan (1973) and Hughes & O'Sullivan (1973).

Distribution and stratigraphy

Hanson River region

This northeastern-most part of the basin, south of the Ti-Tree roadside village has been investigated by industry drilling (O'Sullivan, 1973; see Appendix 2 herein). Depths to basement, recorded in six stratigraphic holes drilled by CRA Exploration Pty Ltd, ranged from 146 to 319 m.

The succession is shown schematically in Figure 9. Weathered rocks were intersected at the base of the succession in two of the holes. In the deeper holes, a unit, up to 130 m thick, of white siltstone and claystone rests on basement and is overlain by lenticular units of lignite and carbonaceous claystone. The carbonaceous units, or where they are absent, the 'white beds', are overlain by greenish-grey siltstone and silty sandstone. These units pass, in turn, upwards into their weathered and oxidised equivalents. The uppermost 60 m or so is commonly dominated by reddish-brown sandy siltstone, whereas the lower 60 m or so are, in places, characterised by multi-coloured (pale grey, brownish-grey, white or yellow) siltstone or mudstone, and includes minor coarse sandstone and gritty sandstone layers. In one hole, a second weathered sequence was intersected within a greenish-grey siltstone unit, which lacked carbonaceous intervals. The greenish siltstone unit and the associated carbonaceous lenses were absent in two holes.

The age of this succession is inferred on the basis of correlation with the nearby Whitcherry Basin (Fig.1). Similar carbonaceous sediments to those in the Ti-Tree Basin were intersected in an arm of the Whitcherry Basin at a depth of 136 -139 m in BMR Napperby No.1 located 13.5 km southwest of Napperby homestead (Fig. 1). These carbonaceous sedimentary rocks contain a Middle to Late Eocene microflora (Kemp, 1976). If these correlations are correct, they suggest that the weathered profile at the base of the succession in the northwestern part of the Ti-Tree Basin may be older than Middle Eocene. The second profile, recognised locally in the greenish-grey siltstone unit, may correlate with Weathering Event B of the Hale Basin (Fig. 4).

Bushy Park region

In the southwestern part of the Ti-Tree Basin (in the southwestern Alcoota Sheet Area), the Cainozoic succession reaches a thickness in excess of 194 m, as recorded in BMR SH 2 (Fig. 6). Reduced successions were intersected in other stratigraphic holes, such as BMR Alcoota Nos 2, 18 and 19 (see Appendix 2). In the nearby BMR Alcoota No. 20 (Appendix 2), a 25 m thick sequence — comprising calcareous siltstone, green claystone, minor granule conglomerate, and rare limestone — was found to overlie silicified sandstone basement at a depth of about 184 m. The overlying 70 m thick unit of olive-green or white mudstone includes a 12 m interval of grey, green and brown siltstone and sandstone in its upper part. Plant fossil fragments were recorded infrequently in this interval. This mudstone unit is correlated with unit Ta in the Waite Basin (Fig. 7; see below) and with the Claraville Mudstone Member of the Hale Formation in the Hale Basin (Fig. 7; see above). The remaining interval of about 87 m is assigned to unit TQt (see below) and consists of variously oxidised red and brown silty sandstone, minor siltstone, and pebbly silty sandstone. It is overprinted by ferruginous weathering.

This upper unit, TQt, can be divided in the southeastern Ti-Tree Basin region, into four sub-units (TQt_{1-4}), three of which ($TQt_{1,2,3}$) are represented in Alcoota No. 20. These sub-units (and the correlative units Ta_{4-5}) are as follows:

- The lowest unit (TQt_1) up to 30-40 m thick, is dominated by siltstone and minor silty sandstone. A similar lutite was intersected in BMR Alcoota 3 in the Waite Basin (see below and Fig. 6). The lower, more silty part of unit TQt in the southeastern Ti-Tree Basin may correlate with the unit of multi-coloured siltstone and, in places, mudstone and coarse angular sandstone lenses, intersected in drill holes in the northwestern part of the Ti-Tree Basin (e.g. hole TT4 in O'Sullivan, 1973). Unit TQt_1, the lower part of unit TQt, may also correlate, in part, with the Waite Formation (see above), as well as Unit Ta_4. The lowest part of this unit in BMR Alcoota 20 includes grey siltstone and white sandstone, lithological types reminiscent of the 'clean' sandstones in unit Ta_4 in the Aremra Basin (see below).

- The next unit (TQt_2) is commonly sand dominated and is up to about 25 m thick. It may be multi-coloured in places rather than red-brown. It commonly includes high proportions of silt and clay, rarely includes calcareous elements and conglomeratic intervals containing white mica and basement clasts. It may correlate with the unit of multi-coloured siltstone and, in places, mudstone and sandstone and coarse angular sandstone, intersected in drill holes in the northwestern part of the Ti-Tree Basin (e.g. hole TT4 in O'Sullivan, 1973). This lower part of unit TQt may also correlate, in part, with the Waite Formation (see above), and the lower part of Unit Ta_5.

- The upper unit (TQt_3) is about 20 m thick and is commonly dominated by brown or red-brown, poorly sorted sandstone. It may correlate with the upper unit of reddish sandy siltstone and sandstone of the northwestern part of the basin (O'Sullivan, 1973), as well as the upper part of unit Ta_5 in the Aremra Basin (see below), characterised by red-brown silty sandstone. In BMR Alcoota 20 it has a strong ferruginous overprint.

- Unit TQt consists of calcrete and brown silty sandstone. Chalcedonic cappings and strong ferruginisation, which are characteristic of the Waite Formation (see below and also McDonald, 1988) are absent. The lack of these weathering imprints indicates that the upper part of Unit TQt most likely post-dates the Waite Formation of the Waite Basin.

Allungra Creek region

Drilling by Northern Territory Power and Water Authority (McDonald, 1988a) in this central-northern part of the basin (Fig. 6) delineated an 80 m-thick unit made up of a poorly consolidated, oxidised silty sandstone. McDonald considered this unit to be TQt and interpreted it as representing a fluviatile environment. In the deeper part of the basin it grades downwards into grey-green mudrock (Ta_2) of possible lacustrine origin (McDonald, 1988a). Unit TQt is not readily subdivided as its shows wide lithological variation within a complex drainage system. The unit is commonly calcareous, and locally appears to interfinger with chalcedonic, calcarenitic limestone of the Waite Formation type (Tw).

Palaeogeography

The palaeodrainage system within the western Ti-Tree Basin (Hanson Plain of Shaw et al., 1979b; Shaw & Warren, 1975) is considered to have formed at about the same time as the 'Waite Surface' (see below) and to have continued to evolve during the Pleistocene and into the early Holocene. The unit TQt may span a stratigraphic interval ranging from that of the Tug Sandstone Member of the Hale Formation to that of the Waite Formation (Tw), i.e. from the Late Eocene to the Late Miocene or younger, and in places possibly through to that of the oxidised alluvial unit Qr. In places, marginal tilting appears to have occurred at some stage, resulting in erosion of unit Tw before final deposition of the last phase of unit TQt (see McDonald, 1988a). The complex drainage system, outlined by calcrete deposits, then shifted slightly to a new location and continued to evolve as a coalescing northerly flowing palaeodrainage system. In the Pleistocene, the depositional basin (the Hanson Plain) became covered by ferruginous 'red earth' soil (Qr), then by aeolian sand which contains subdued dune landforms. Wet interludes, in this otherwise arid period, produced north-flowing drainage channels with deposition of alluvium. Since then, these drainage channels have been largely abandoned, to be replaced by the present Hanson drainage system.

Waite Basin

The Waite or Plenty River Basin is an east-west depression north of the Harts Range, covering possibly 1200 km^2 (Figs 1, 6 and 7). The basin has up to 180 m of Tertiary lacustrine and fluviatile sedimentary rocks, referred to informally as the Alcoota beds (Ta). These rocks are similar to those in the subsurface at the eastern part of the Ti-Tree Basin, but have been uplifted and dissected to a limited extent. The outcropping and dissected sequence in the western part of the Waite Basin belongs to the younger Late Miocene to Early Pliocene Waite Formation (Woodburne, 1967).

Uplift within the MacDonnell, Strangways, and Harts Ranges - together with probable subsidence to the north (i.e. northern part of the Alcoota Sheet area) - terminated much of the southeasterly drainage in the western part of the Waite Basin, possibly in the Pliocene. As a result, the Sandover and Bundey River systems developed on new, largely north-dipping, slopes. The eastern part of the Plenty River System continued eastwards in the direction of the earlier river system that deposited the Waite Basin succession.

The Alcoota beds (Ta)

(Map units Ta, Waite Formation Tw, and minor TQt)

The Alcoota beds are an informal name applied to Tertiary units, largely preserved in subcrop in the Alcoota Sheet area. The exposed thickness of Tertiary sedimentary units is approximately 15% of their total thickness. The Alcoota beds have a composite thickness of about 250 m, as inferred from drill holes [(BMR Alcoota Stratigraphic Holes (SH) Nos 1, 2 and 3)]. Of this, the basal mudstone and siltstone sequence (unit Ta) is represented by less than 5 m of outcrop in the Plenty River valley. The Waite Formation (unit Tw), a subunit of the Alcoota beds, crops out extensively in escarpments that encircle flat-topped landforms in a belt roughly peripheral to the margins of the Waite Basin (Woodburne, 1967) in the southeast quadrant of the Alcoota Sheet area.

Near the margins of the Waite Basin, the Waite Formation unconformably overlies a partly truncated weathered profile developed in crystalline rock (Fig. 6). It seems likely that the onset of deposition of the Waite Formation related to former low-lying zones within the Arunta Block, where surface drainage and groundwater conditions were conducive to development and preservation of this profile. Further downwarping of this weathered surface, combined with some erosion and dispersion of weathered materials, replicated the position of the developing Waite Basin. The youngest sediments, originally mapped as the unit TQt and included in the Alcoota beds, are represented at the surface by only a few metres of fine quartz sandstone, chalcedonic, calcarenitic limestone, and greenish-grey siltstone (Fig. 6). Unit TQt is restricted to the Ti-Tree Basin (see above) and, hence, is excluded from the Alcoota beds. Unit TQt in the Ti-Tree Basin correlates in part with the Waite Formation, but includes younger elements and probably also older elements.

The lithology of the Alcoota beds in subcrop differs appreciably from the lithology of the majority of outcrops, but for ease of mapping (see Shaw & Warren, 1975) the name Alcoota beds was applied informally to the entire succession. The formally defined Waite Formation (Woodburne, 1967) becomes the middle unit within this framework. The lower limit of the Alcoota beds is unknown: the only two drill holes in the basin, BMR Alcoota 2 and 20 (see Appendix 2), failed to reach the basement.

The lithology and possible correlation between units in the Alcoota beds are shown in Figure 7. The coarse-grained sediments in BMR Alcoota No. 3 are thought to be a facies equivalent of the Waite Formation and to have been derived locally from the nearby Harts Range.

These thick Tertiary sediments, discovered during drilling in 1971 in the Alcoota Sheet Area, may have potential for hosting uranium as they derive from nearby crystalline basement where felsic plutonic source rocks are abundant and include rocks with significant U values. The sediments appear to have been deposited in fluviatile and lacustrine environments and show a variety of red, white and green zones, the result of alternating periods of oxidation and reduction. Such conditions are known to favour uranium precipitation.

Gamma-ray logs were run in BMR Alcoota 2 and in three abandoned water bores on Annitowa Station (previously Woodgreen station). Two of the holes indicate small and apparently anomalous zones of relatively high radioactivity. In BMR Alcoota 2 (Fig. 7), the small anomaly, recorded from a sandy conglomerate bed in the interval 90 to 100 m (see Appendix 2), may reflect very low concentrations of uranium in groundwater (Senior, 1972). The second anomaly, obtained in the bore Woodgreen No.1, is 10.5 m thick and, according to the driller's log, lies in a median position between a red micaceous sandstone and a green and grey medium-grained sandstone (Senior, 1972, his fig. 7). However, subsequent investigation of the Tertiary sediments in the Ti-Tree Basin in the northwest of the Alcoota 1:250 000 Sheet area revealed only low U contents, the maximum reported being 23 p.p.m.. Here, calcrete assigned to unit TQt was intersected in shallow bores was from 6 to 12 m thick, forming an irregular channel-like body, closely linked with basement morphology (c.f. O'Sullivan, 1973).

Unit Ta

BMR Alcoota SH1 and SH2 drill holes penetrated a massive mudstone and siltstone unit below the Waite Formation to a total depth of 194 m (Senior, 1972, fig. 5). The upper part of these argillaceous deposits is weathered, mottled and stained by red iron oxide. This red coloration is especially evident in BMR Alcoota SH1.

However, in both holes the unit includes a zone of slightly leached white mudstone and siltstone, which in BMR Alcoota SH2 grades into a basal sequence of green and grey, unaltered mudstone. These sedimentary rocks are almost devoid of bedding except for a few faint laminations. The lack of sedimentary structure may reflect deposition within a quiet-water lacustrine environment.

Waite Formation (Tw)

The type section is a small mesa on the north side of Waite Creek, 6 km southwest of Alcoota homestead and 15 km northeast of Mud Tank Bore. Only about 40 m of the upper part of the formation crop out, and the full thickness is not known.

In outcrop, the Waite Formation consists of interbedded chalcedonic, calcarenitic limestone, sandstone, siltstone, and minor sandy conglomerate. Beds of cream or white chalcedonic calcarenitic limestone form the hard resistant summit caps on many low plateaus and mesas. In places, chalcedonic silica is dominant and there is a lack of clastic detritus which indicates that they formed by chemical precipitation of silica and are contemporaneous with interbedded clastic deposits of the Waite Formation. Some of these siliceous beds have a calcareous fabric and penecontemporaneous replacement of calcium by silica, due to alternating pH/Eh, is likely to have played a part in altering the composition of the original chemical sediments. A sample of chalcedonic limestone analysed by x-ray fluorescence consisted dominantly of SiO_2 (96.7%) with minor iron oxides (0.77%), calcium oxide (0.35%), and phosphorous pentoxide (0.25%).

In most outcrops, the grain-size of clastics in the Waite Formation increases upwards. In the Alcoota Sheet area, Woodburne (1967) attributed this to a change from a lacustrine to a fluviatile environment of deposition. Core from BMR Alcoota SH1 drill hole tends to confirm an initial lacustrine environment, because the subsurface sediments are dominantly argillaceous and include abundant mudstone, siltstone, and claystone. The sedimentary sequence may well equate with deposition within a regressive lake.

Vertebrate fossils in the outcropping lacustrine part of the sequence were described as being of Late Miocene or Early Pliocene age (Woodburne, 1967). Subsequently, in an overview of the stratigraphic relationships of Australia's fossil mammal faunas, Woodburne et al. (1985) tentatively placed the Alcoota fauna in the Late Miocene on the basis of evolutionary relationships, equating it with faunas of the Cheltenhamian Stage in southeastern Australia.

The prolific iron staining observed from near the top of BMR Alcoota SH1 [("grey-red mottled 'soapy' siltstone" (Fig. 7): the result of contemporaneous weathering)] suggests correlation with Weathering Event C affecting the Tug Sandstone Member in the Hale Basin. Sediments from cuttings in the depth interval 102 to 105 m in BMR Alcoota SH1 (unit Ta) were palynologically barren.

The distribution of Tertiary sediments (Figs 1 and 6) shows two north-trending extensions of the Waite Basin. On the westernmost extension at a site 10 km south of Utopia homestead, coarse-grained sediments contain pebble to small boulder- sized clasts. The linear distribution and coarse clastic composition of these deposits, coupled with decrease in grain-size southwards, indicate a northerly source for the detritus. This is the reverse to the present-day drainage direction. If the vertebrate fossils present in the upper part of the Waite Formation are Late Miocene in age, then the Waite Basin must have been dissected after this date.

Deeply Weathered Rocks — Ti-Tree And Waite Basins
(Includes older units Tla and Tlf and younger unit Tl)

In the region surrounding the Ti-Tree and Waite basins, a well-developed profile is formed the Arunta igneous and metamorphic basement rocks, and on lacustrine and fluviatile Tertiary sediments referred to as the Alcoota beds (see above; mainly in the Alcoota 1:250,000 Sheet area). Deep chemical weathering has altered the upper 40 m of exposed crystalline rocks, forming a trizonal profile comprising a lowermost leached zone, an intermediate mottled zone, and a ferruginous upper zone. In subcrop, it underlies some of the Cainozoic sediments as seen from drill cuttings. In outcrop, only the Waite Formation rests unconformably on the weathered profile developed in Arunta basement rocks.

This trizonal weathered profile has been most extensively studied in the Alcoota Sheet area (Senior, 1972), where it is widely preserved. A mid-Tertiary age was initially assigned (Senior, 1972) on the assumption, proposed by Woolnough (1927), that such profiles formed during a continent-wide phase of chemical weathering. Subsequent stratigraphic and palaeomagnetic studies of thick, deeply-weathered profiles in western Queensland indicated two major weathering episodes (Senior et al., 1978; Senior & Mabbutt, 1979). The older of these is either of Late Cretaceous or early Tertiary age (Morney profile) and the younger is middle Tertiary (Canaway profile). The Canaway profile overprinted the partly eroded Morney profile over extensive areas of the Eromanga and Surat Basins. Within the current study area, palaeomagnetic studies at three sites have identified only a mid-Tertiary, probably Late Eocene, magnetic age of ferruginisation.

Drilling has revealed that the Arunta basement rocks underlying the Hale Basin (Weathering Event A in Fig. 4) and the Aremra Basin are deeply weathered. The probable Middle to Late Eocene Ulgnamba Lignite Member is sandwiched between strongly oxidised rocks that appear to represent either contemporaneous weathering and/or input of former weathered detritus. It seems possible, therefore, that the Arunta basement profile in these drill holes (equivalent to Weathering Event A in Figs 4 and 5) may be equivalent, at least in part, to the Morney profile of the Eromanga Basin (i.e. Late Cretaceous and/or Paleocene). From palynological evidence, deposition may have begun in the central Australia region in the Late Cretaceous, or possibly earlier, implying that the deep weathering of Arunta basement is Cretaceous or older. A third weathering profile (Weathering Event C in Figs 4 & 5) appears to affect the Tug Sandstone Member exposed at Red Ochre Dam (see map accompanying Shaw et al., 1984).

As noted above, a pilot palaeomagnetic study of weathered profiles indicates a possible Late Eocene magnetic age for outcropping profiles in the Hale Basin area, in agreement with results from the northern margin of the Waite Basin. The age estimate is based on 44 samples collected from seven localities (Appendix 1). Thermal demagnetisation using 13-18 steps yields a palaeomagnetic pole at lat.113.0°E, long. 65.8°S (radius A_{95} of 95% confidence circle 3.9°), coincident with the Late Eocene pole on the Australian apparent polar wander path (Idnurm, 1994, and Appendix 1, Fig.1 herein). Late Eocene is, therefore, the most likely age, but Early Eocene or Late Oligocene can not be ruled out with 95% confidence. The confidence circle for the pole does not enclose the pole of the Canaway profile of southwest Queensland, suggesting a possible shift in timing of a single mid-Tertiary weathering event or two separate events, one in each region. (It should also be noted that the confidence circle does not enclose the older Morney profile pole).

A period of erosion (possibly in the Oligocene, cf. Kamp, 1991; see Table 2) removed part of the Eocene and older profiles from the area, and detritus was incorporated into the Waite Formation (see Table 1 and below). In some depressions, such as in the southeastern part of Alcoota 1:250 000 Sheet area (see Senior, 1972; fig. 4), an almost complete weathering profile is preserved below the Waite Formation. The trizonal character of this profile implies that it largely corresponds to Weathering Event A (largely mapped as units Tl, Tla - see Table 1), but that it has been overprinted by Weathering Event C (mapped as units Tl, Ts). The fact that the deep trizonal profile normally predates the initiation of Tertiary deposition has been established from surface mapping in the Hale Basin. The less-well-developed mottling and ferruginisation of sediments, probably equivalents of the Tug Sandstone Member, immediately underlying the Waite Formation (Fig. 7) is correlated with Weathering Event C from the Hale Basin.

The leached or clay-rich zone at the base of the exposed profile, developed in Arunta Block rocks, grades from relatively unweathered parent rock upwards into a zone dominated by white kaolinitic clay minerals. It is generally possible to identify the gross lithology of the parent rock in the basal to middle part of this zone. In this zone, textural features of the host rock are preserved, together with quartz veins and remnants of large phenocrysts, such as quartz and muscovite.

The kaolinitic zone grades up into a multi-coloured or mottled zone, up to 10 m thick. This zone contains patches stained pink, purple, brown or yellow by iron oxides, contrasting markedly with the white clay-rich matrix. Individual stained patches or mottles vary from small nodules to structureless masses. Iron oxide staining and enrichment increase upwards through the mottled zone. Kaolinite and quartz are dominant, with subordinate amounts of hematite and goethite (see Senior, 1972; table 1). The texture of the parent rock cannot be recognised at the top of the mottled zone, even though there is a tendency for this type of profile to have developed within formerly strongly textured, coarsely crystalline gneissic or granitic rock types.

Overlying the mottled zone is a ferruginous zone up to 8 m thick. This, the most strongly indurated part of the profile, forms prominent vertical escarpments with generally a columnar structure. Goethite and hematite are the dominant iron minerals. The rock is generally fine-grained and massive, except for an irregular mosaic of fine fractures. Numerous vertical and subhorizontal joints give the zone a pronounced columnar structure similar to that developed in some soil profiles as a result of volume changes. In places, the upper 3 or 4 m of the ferruginous zone is reworked by pedogenic processes and consists of a re-cemented layer of fragments and pisolites. The latter are up to 1 cm in diameter and have a simple layered structure of concentric shells of contrasting colour iron oxides. This material has locally slumped down vertical fractures into the underlying ferruginous zone, thereby forming 'pipe-like' infillings. Some pisolites are strongly magnetic, probably due to some near-surface process whereby goethite and hematite are converted to maghemite. The morphology of the ferruginous zone is very similar to that of the upper crust-forming portion of the Canaway profile of western Queensland and may have formed by analogous processes. As previously mentioned, the timing of the weathering events as determined palaeomagnetically

(Idnurm & Senior, 1978) indicates that weathering began earlier (Late Eocene) in the Alice Springs region, compared to a Late Oligocene or Early Miocene age for the Canaway profile.

X-ray diffraction and X-ray fluorescence studies (Senior, 1972) show that the profile developed through *in situ* rock decomposition, liberation of alkali and alkaline earth metals (K, Na, Ca, Mg), as well as leaching of silica, and allowing concentration of iron and aluminium oxides in addition to hydroxides. In general, iron oxide concentrations increase upwards, reaching 40% or more in the ferruginous zone. The abundances of SiO_2 in the leached and mottled zones are similar, but in the ferruginous zone the SiO_2 content is markedly reduced.

Bundey Basin

The name Bundey Basin is applied to a sedimentary fill up to 40 m thick, intersected in water bore holes along the Bundey River in the Huckitta 1:250 000 Sheet area (Fig. 1). These sediments consist of siltstone and claystone with interbedded sandstone and conglomerate beds. Drilling by the Northern Territory Geological Survey in 1982 intersected chalcedonic limestone at shallow depths and most of the sedimentary rocks in the water bores may be regarded as Waite formation equivalents or unit TQt (Freeman, 1986). However, cored hole NTGS HUC11, on the Huckitta 1:250 000 Sheet Area, intersected partly carbonaceous siltstone, then sandstone and siltstone down to a total depth of 127 m (see Appendix 2). This thickness exceeds that of other Cainozoic sedimentary rocks in the Bundey Creek region. Preliminary palynological determination (Truswell, 1987; Freeman, 1986) suggested that the carbonaceous siltstone accumulated in the Paleocene. However, the carbonaceous claystone contains many undescribed pollen types including forms morphologically similar to species that Harris & Twidale (1991) now consider to be Late Cretaceous, described from lignitic sedimentary rocks above the basement between Ayers Rock and the Olgas, and the material from HUC11 could well be as old as this.

Aremra Basin

The Aremra Basin, in the southwestern part of the Illogwa Creek 1:250 000 Sheet area (Figs 1 and 8), is known only from the subsurface and is named after Aremra Creek. The basin appears to extend from just west of Gidyea Bore southwards, for 80 km or more, along the eastern margin to ranges of metamorphic rocks bordering Illogwa Creek. Structurally, the basin is made up of flat-lying beds that occupy a southeast-trending depression centred on the present-day position of Aremra Creek.

The succession in the Aremra Basin, referred to as unit Ta, is similar to that in the Ti-Tree and Waite Basins (Alcoota and Napperby 1:250 000 Sheet areas). Unit Ta rests unconformably on schists and gneisses of the Arunta Block (BMR Illogwa Creek 2, see Appendix 2), except in the southeast where it probably rests unconformably on the Hooray Sandstone, a Late Jurassic and Early Cretaceous unit within the Eromanga Basin succession. The unit Ta is overlain, probably conformably, by Waite Formation equivalents (Tw), as well as by unconsolidated Quaternary deposits.

The oldest lithological components in the basin are claystone and interbedded sandstone. The massive nature of the claystone suggests quiet-water deposition. There is a lack of terrigenous detritus from the nearby ranges. These rocks pass abruptly upwards into poorly sorted clastics deposited as a series of coalescing piedmont fans. These clastics are intensely weathered and contain abundant iron oxide pisoliths. The succession is capped by a thin veneer of chalcedonic calcarenitic limestone (Tw), which is distributed more extensively in the east where it caps weathered metamorphic rocks. As the succession in this basin provides an additional key reference section for Cainozoic stratigraphy in the Alice Springs region, it is described in some detail below. A generalised stratigraphy is given in Figure 9.

Deep-weathering profiles in the Aremra Basin region
(Tl, Tla, Tlf - in the Aremra Basin region, Illogwa Creek Sheet area)

As mapped, Tl is a composite unit incorporating several weathering events. These profiles are most extensively developed to the north and west of the Aremra Basin (Fig. 8). They are best preserved along the interfluve between Huckitta and Atula Creeks, and form scattered exposures in the flatter eastern two-thirds of Illogwa Creek 1:250 000 Sheet area, away from the higher ranges.

The most widespread and probably the oldest weathered profile (Tla, Tlf) is up to 30 m thick and has a trizonal arrangement comprising a lowermost kaolinised zone, an intermediate mottled zone, and a ferruginous top. The profile is correlated with an identical profile in the Alcoota 1:250 000 Sheet area (see above and Senior, 1972), suggesting former continuity between these two regions. Decomposed, soft, kaolinitic, metamorphics of the Arunta Block that may have been affected by the same weathering event, were intersected below the unnamed Cainozoic sediments (Ta) in BMR Illogwa Creek 1 and 2 (Appendix 2). The marked ferruginisation that is widely developed on the Mesozoic Hooray Sandstone is also correlated with this deep weathering profile (Senior in Shaw et al., 1982).

In addition, several younger periods of intensive oxidation leading to weathered profile development are recorded within Unit Ta in the Aremra Basin, indicating that intense weathering continued during deposition. Of these profiles, the one associated with the strongest oxidisation (affecting subunit Ta_3, see below) is correlated with unit Tl. The formerly extensive Tl weathering profiles were buried in the Miocene or Early Pliocene by lacustrine and fluvial sediments of the Waite Formation. The tops of mesas of Waite Formation equivalents (Tw), and the underlying weathered profile, dip gently southwards, diminishing in relief until they become concealed by Quaternary and recent aeolian sands around the northwest periphery of the Simpson Desert.

The revision of weathering chronology on rocks sampled for palaeomagnetic study and described above, suggests a Late Eocene date for the main period of ferruginisation.

Unnamed Cainozoic sedimentary rocks and sediments (Ta) — Aremra Basin

(after Senior in Shaw et al., 1982)

These consist of soft, red and green siltstone, claystone and friable lithic sandstone, with lesser amounts of quartzose sandstone and conglomerate. Carbonaceous matter, gypsum and ironstone are present locally. Calcareous lenses and pedoliths occur at shallow depths. The unit is up to 250 m thick in drill holes. The sequence grades upwards into either Waite Formation equivalents (Tw), or into unconsolidated aeolian and alluvial Quaternary sediments (Qs, Qa, Qr).

The succession is divided into five units on the basis of the results of the drilling of 18 holes by Agip Nucleare (1977, 1979), core drilling of three holes by BMR (Fig. 9) and core drilling of one hole by the Northern Territory Mines Department. From the base upwards these are:

Unit 1 (Ta_1). This unit is up to 20 m thick, but commonly much thinner. It consists mainly of iron-oxide-enriched sedimentary rocks, minor silcrete developed in quartz sandstone, and minor white or greenish claystone. The rocks comprise ferruginised red-brown and yellowish claystone interbedded with reddish quartzose sandstone. A lacustrine environment with fluviatile incursions is implied from the variety of rock types, possibly reflecting a humid climate with dry intervals resulting in oxidation and silicification.

Unit 2 (Ta_2). This unit is dominated by an olive and green claystone with interbeds of quartzose sandstone and minor red-brown siltstone. Gypsum and carbonaceous fragments are present locally. Unit 2 is up to144 m thick and grades upwards, through a mottled zone, into unit 3. Lacustrine and pediment distributary fan and plain accumulations are the likely depositional environments, accompanied by periods of desiccation, resulting in the formation of gypsum. The presence of carbonaceous material and oil shale suggests that vegetation and abundant aquatic organisms were present in marginal swamplands.

Unit 3 (Ta_3). Oxidised, red-brown silty and clayey sandstone intercalated with minor layers of quartzose sandstone characterise this unit. These clastics contain fragments of ironstone derived from weathered profiles and rare carbonaceous matter. This unit varies in thickness from less than

20 m (IR6 and IR9) to more than 100 m (IR11 and IR12). A prominent coarse, 10-15 m thick quartz sandstone is widespread and generally occurs at depths of 50 to 60 m. Rapid filling within intermontane piedmont fans is suggested by the poorly sorted nature of the sedimentary sequence. This would be consistent with an arid climate with sparse vegetation on the Harts, Strangways and MacDonnell Ranges, and rapid erosion in highland source regions. However, such a sedimentary facies would also equate with pluvial conditions in a humid climate. Concurrent tectonic movement is suggested by the tilted peneplain remnants forming concordant summit levels within the western hill country of the Illogwa Creek 1:250 000 Sheet area.

Unit 4 (Ta_4). This unit is widely distributed and consists of up to about 20 m of medium, coarse or very coarse, quartz-lithic sandstone. The sandstone is generally clean but in places may contain a matrix of brown clay. Dominantly fluviatile deposition on a tributary and/or distributary drainage system is inferred by the widespread and generally matrix-free nature of the sandstones. These sediments appear to become increasingly fine-grained towards the axis of the basins, as is indicated by the dominantly fine clastic and lutitic sequence encountered between 10 and 40 m in BMR DDH 1. Stringers of coarse sandstone and conglomerate indicate periodic fluvial incursions within channel-like watercourses.

Unit 5 (Ta_5). The upper unit consists of intensely oxidised, red-brown, silty sandstone with thin, dirty, calcareous layers and nodules of probable pedogenic origin. Plant fragments were noted at a depth of 18 m in BMR Illogwa Creek 3. This unit varies in thickness between 4 and 15 m. Lower energy fluviatile conditions are implied by the siltstone-sandstone facies. Lengthy periods of non-deposition, soil formation, and precipitation of calcareous materials are suggested by the oxidised nature of the sediments and the calcareous layers. The intensely oxidised nature of the sediments and precipitation of chalcedony may reflect seasonal rainfall under a dominantly arid climate.

Unit Ta is correlated with deposits, also mapped as the unit Ta, in the Waite Basin and elsewhere (see above). For example, unit Ta_1 contains a minor silcrete at the base of the succession in the Aremra Basin and may equate with the very hard silcrete (possibly Late Cretaceous in age) encountered below a thick green claystone-siltstone succession in BMR Alcoota 20 (i.e. in the Ti-Tree Basin, Alcoota Sheet area; see Shaw et al., 1979b and Fig. 7; see also Appendix 2). In addition, unit Ta_1 of the Aremra Basin has equivalents elsewhere in the region. For example, similar green claystones and siltstones lie stratigraphically below Mid–Late Eocene lignite and carbonaceous siltstone in the Hale Basin in the Alice Springs 1:250 000 Sheet area and in the southwestern part of the Ti-Tree Basin in the Alcoota 1:250 000 Sheet area (see above).

An early Tertiary, or slightly older, age is implied for the onset of deposition of Unit Ta_1 following silcrete formation. The green claystone and siltstone unit (unit Ta_2) is considered to be Eocene which is the age inferred for the lithologically similar Claraville Mudstone Member (Thc) below the Mid to Late Eocene lignite in the Hale Basin (see above, and Truswell & Marchant, 1986). Weathered elements in unit Ta_3 may correlate with Weathering Event C in the Hale Basin (Fig. 4), where palaeomagnetic data give Late Eocene as the most likely magnetic age. Although unit Tw appears to conformably overlie these units (Ta_{1-5}) it's possible they may be equivalent to or, in the case of Ta_5, slightly younger than unit Tw as they occupy a stratigraphically lower position in the more depressed part of the basin. Thus, deposition of units Ta_4 to Ta_5 may overlap in in time with the deposition of the Waite Formation, which is Late Miocene or Early Pliocene in age.

Waite Formation equivalents (Tw)

These rocks consist of red and green silty-sandstone with irregular calcareous nodules, travertine, calcarenitic and some pelletoidal limestone, and massive chalcedony. Up to 35 m of the unit are exposed on the rim of the Aremra Basin in the Illogwa Creek 1:250 000 Sheet area. Drill holes show that this formation grades downwards into unnamed poorly sorted sandstones and mudstones of thickness exceeding 200 m (Ta).

The unit forms extensive plateaus, mesas and rounded pinnacle-like hills. Its characteristic pale tones on aerial photographs are due to the presence of pale grey to whitish chalcedony layers which are prevalent in the upper part of this formation. Upstanding landforms have flat summits and prominent bounding escarpments formed by beds of resistant chalcedony.

In detail, the unit consists of interbedded, reddish or greenish silty-sandstone, sandstone, siltstone, and minor sandy conglomerate. Reworked clasts of ferruginous pisoliths and angular, conglomeratic, ferruginous fragments occur near the base, particularly where this formation overlies the weathered profile in Arunta basement rocks. In some places, chalcedonic layers are interbedded with fine sandstone, siltstones and mudstone lenses. The multiplicity of chalcedonic layers and the lack of clastic detritus indicate that they were formed by the precipitation of silica, possibly in shallow alkaline lakes or within groundwater discharge areas.

Beds within the unit are flat-lying. Summit levels slope gently southwards, reflecting regional down-warping towards the broad Cretaceous and Cainozoic depression that is the Lake Eyre Basin.

The mapped unit is thought to represent an extensive sedimentary succession deposited in rivers and lakes (cf. Woodburne, 1967). It overlies deeply weathered Arunta basement rocks in many areas, notably north of the Aremra Basin to the north and east of Hugh Dam (Fig. 8). Elsewhere, this unit grades down into unnamed Tertiary sedimentary rocks (Ta).

The unit Tw contains calcified plant debris. It is correlated with the Waite Formation, which is probably Late Miocene at its type section in the Alcoota region (Woodburne, 1967).

Discussion

Stratigraphic framework

Although there is gross lithological similarity between the successions in the basins of the Alice Springs area, detailed correlation has been hampered by the weathering of many lithologies and the lack of fossils. The subcrop distribution of lithologies suggests that the Ti-Tree, Waite, and Aremra Basins were formerly interconnected. The Hale Basin evolved as a separate, isolated feature; it is used as a key reference section because of the better stratigraphic control established there. Dating within the basins is hampered by the poor recovery of palynomorphs from the largely weathered sediments, with only a few sites yielding spores and pollen.

Although the Hale Basin evolved separately, it has a succession broadly comparable to the basins lying to the north and east of the Strangways and Harts Ranges (Fig. 1). Of particular interest is an olive-green mudstone unit present in most of the basins. In the Hale Basin, this mudstone grades upwards into a lignite-bearing carbonaceous succession; both the lignite and mudstone contain a rich flora of probable Mid-Late Eocene age. Widely distribed olive-green mudstone units in many of the basins (Fig. 9) are possibly correlative with the mudstone in the Hale Basin and suggest the presence of penecontemporaneous, or a series of interconnected lakes and swamps during the Mid to Late Eocene.

Younger rocks in these basins consist of oxidised, coarse-grained, poorly sorted sandstone (e.g. Ta3, Tht) which may have been rapidly deposited in coalescing piedmonts. The weathered profile developed in these sediments in the Hale Basin records the same Late Eocene magnetic age as weathered profiles preserved on topographically high residuals of Arunta basement. Tectonism and an hiatus in sedimentation may have preceded the deposition of younger sediments because the sites of deposition shifted in some regions. Late Miocene to Early Pliocene fossils reflect a diverse fauna of primitive marsupials, crocodiles, ringtail possums and other vertebrates and invertebrates, suggesting a change to lacustrine environments, probably with vegetated margins, during which interbedded red and green clayey siltstone, sandstone and lacustrine carbonate accumulated (e.g. Tw, TQt). These rocks are now protected from rapid erosion by resistant cappings of chalcedony, and thereby form low plateaus bounded by steep scarps. Sub-surface sedimentary rocks (units Ta4, Ta5), comprise some probable pedogenic ferruginous and calcareous layers and may be either equivalent to these lake deposits (i.e. Tw) or represent a more extended period of sedimentation characterised by restricted intermittent deposition punctuated by episodes of exposure and erosion.

Figure 10 represents an evolutionary model for the depositional episodes, plotted in terms of current understanding of correlations, inferred age, and rates of deposition. It shows time versus thickness diagrams for the Tertiary segment of basin deposition. This plot is based on the lithological correlations shown in Figure 9, on presumed breaks in the sedimentary record corresponding to periods of deep weathering recognised in the Hale Basin (see Figs 4 and 5), and, to a lesser extent, on possible correlation with weathering profiles that have been dated palaeomagnetically in the Eromanga Basin (Idnurm & Senior, 1978). The time slices adopted are consistent with the international time-scale of Harland et al. (1989), but boundaries are poorly constrained.

The most rapid sedimentation appears to have been in the Palaeogene during deposition of the mudrock unit (Ta_2). Although the order-of-magnitude accumulation rate of 1-15 m/Ma is slow, it is nevertheless within the range of rates recorded in intracratonic basins (cf. Schwab, 1986). In order to maintain consistent rates of sediment accumulation, a major break is needed between Paleogene and Neogene sedimentation phases. The apparent lack of an equivalent weathered profile to the Late Oligocene to Early Miocene Canaway profile recognised in the Eromanga Basin in southwest Queensland, may mean that the Oligocene to Early Miocene was a period of active erosion and possibly uplift in central Australia. The plot provides a model for the stratigraphic framework to be tested and refined by future work.

Chronology of chemical weathering

At least two main periods of intense chemical weathering can be identified in the central Australian basins. The first is represented by a relict profile in the Hale Basin, developed near the top of the Hale Formation (Weathering Event C in Figs 4 and 5). This profile has a Late Eocene preliminary palaeomagnetic age, consistent with a Middle to Late Eocene palynological age for the underlying Ulgnamba Lignite Member (Truswell & Marchant, 1986). Its possible age equivalents are found in other Cainozoic basins in central Australia. Examples include thickly weathered intervals in Cainozoic successions intersected by drilling in the Yaloogarie (Stewart, 1976) and Ti-Tree Basins (O'Sullivan, 1973). An exposed possible equivalent is in breakaways along the northern flanks of the MacDonnell Ranges (unit Tlf of Warren & Shaw, 1993). Palaeomagnetic dates suggest ferruginisation of the Arunta basement rocks in the region north of the Hale Basin during the same period, implying that the basement there was exposed.

The second, older weathering period is represented by relict weathered profiles developed in the Arunta basement rocks. In the Bundey and Ayers Rock Basins their maximum age, obtained by palynological evidence in overlying sediments (Truswell, 1987), is either Palaeocene or

Late Cretaceous (Harris & Twidale, 1991). Similar weathered profiles are widespread in the Arunta basement where it is covered by Cainozoic sediments, including the Hale Basin (Weathering Event A in Figs 4 and 5). It is possible that basement weathering through central Australia may record the same earliest Tertiary, or older, event.

In addition to the two main weathering periods, variously oxidised, mottled, silicified, and partly calcified rocks in several of the basin successions indicate other, lesser, periods of interrupted sedimentation and intense weathering. Examples of such intervals are Weathering Event B in the Hale Basin (Figs 4 and 5), paleosols at several levels in unit Ta5 in the Aremra Basin, the chalcedonic top of Unit Tw, and the markedly oxidised soils of Unit Qr.

Some weathering events in central Australia may have extended to adjacent regions. In particular, the older period of weathering may be represented in the Eromanga Basin by the Morney profile, dated palaeomagnetically as Late Cretaceous/Early Tertiary (Idnurm & Senior, 1978). The same chemical weathering may have ferruginised the Mesozoic Hooray Sandstone along the northwestern margin of the Eromanga Basin, and its equivalent in the Hay River 1:250 000 Sheet. Similarly, Weathering Event B in the Hale Basin may correlate with an early Middle Eocene hiatus in the Eromanga Basin. On the other hand, the prominent Late Eocene weathering profile in the Hale Basin region (Weathering Event C) seems to have no age equivalent in the Eromanga Basin: the Canaway profile, which resembles the trizonal Hale Basin profile, has a poorly defined but distinctly younger (approximately Oligocene) palaeomagnetic age. More dates are needed to test the central Australian as well as inter-regional tentative correlations.

Table 2 relates the central Australian weathering to the palaeogeographic setting of the continent.

Palaeoenvironmental and palaeoclimatic implications

Palynological investigations in the Hale Basin have provided both age control and climatic information. Pollen assemblages from the lignites and the underlying green mudstones contain, as very rare elements, pollen types confined to the Mid to Late Eocene interval in southern Australian coastal basins. Pollen assemblages at Hale River are dominated by *Nothofagus* (Brassospora spp.) the southern beech, and by pollen of a number of podocarpaceous (southern conifer) genera, suggesting that rainforest trees grew in the vicinity, under conditions of high humidity. Pollen of Casuarinaceae occurs in all assemblages, and, assuming that these were non-rainforest species, there may have been some open forest vegetation, possibly on lake margin sites. The pollen cannot, however, be distinguished from rainforest members of the family. Pollen of aquatic plants, reeds and sedges, is locally common.

The pollen suite from the Ulgnamba Lignite bears some resemblance to suites of probable Middle Eocene age described from the Lake Eyre Basin (Sluiter, 1991), for which quantitative estimates of palaeoclimates have been made. Some of the Lake Eyre assemblages are similar in that there is a high frequency of *Nothofagus* pollen and Casuarinaceae, but they differ in having a considerable abundance of pollen of Myrtaceae and Cunoniaceae. The two localities are similar in having significant quantities of pollen of aquatic taxa.

Sluiter (1991) used the climatic parameters controlling modern forest taxa as the basis for palaeoclimate estimates. The underlying assumption is that the ecophysiologic characteristics that determine the broad climatic responses of the vegetation are unlikely to have changed through time. On this basis, it was estimated that the mean annual temperature in the Eocene of central Australia was 17 - 18 ^{o}C, and the mean annual precipitation around 1500 mm. While the Lake Eyre and the Hale Basin microfloras differ in some respects, they were sufficiently comparable to conjecture that similar conditions may have pertained in the Hale Basin in the Eocene. A tentative reconstruction of climatic conditions is outlined in Table 2.

Tectonic Implications

On a continental scale, changes in the patterns of subsidence, including those in central Australia, appear to follow major phases of plate realignment and switches in the sites of sea-floor spreading (Table 2). The earliest recognised period of widespread deep weathering in central Australia may have begun in the Late Cretaceous and its termination may have been related to a broad uplift, affecting much of the continent. This uplift was greatest along the Eastern Highlands (see Veevers et al., 1991). Lister et al. (1986) suggest that this uplift of the Eastern Highlands was related to extension immediately prior to sea-floor spreading in the Tasman Sea. The central Australian intermontane basins may have been initiated at this stage or slightly later (i.e. Units Ta_1, Thg; Table 2).

The succeeding phase of rapid Eocene infilling in the Cainozoic basins of central Australia (i.e. units Ta_2, Thu, Thc) appears to correspond to the rapid drift of Australia away from Antarctica (cf. Veevers et al., 1991). A major reorganisation of plate motions (Australian-Pacific Plates) took place at c. 43 Ma (i.e. in the late Mid-Eocene; see Wells, 1989), and this event may correspond to minor tilting of piedmont fans (units Ta_3, Tht; see Table 2) as a result of limited updoming of the ranges in central Australia. A period of more restricted deposition and widespread deep weathering followed in central Australia (units Tl, Ts and widespread overprinting of Tlf; Table 2). The end of widespread deep weathering is probably recorded by the Late Eocene magnetic date from the Hale Plain and surrounding region. More work is needed to clarify the timing, nature and correlation of these early Tertiary events.

In about the Oligocene, a widespread hiatus and a slight shift in the drainage systems in central Australia was accompanied by a switch in the sites of sedimentation (units Ta_4, TQt, then Tw; see Table 2). It is speculated that this period of apparent uplift of the central Australian ranges may be related to a rearrangement in the Pacific plate and the beginning of the northern Australian collision with Papua New Guinea at about 25-27 Ma (late Oligocene: see Kamp, 1991; Etheridge et al., 1991). In this case, the hiatus may be the result of renewed, but slight, regional uplift and erosion of parts of the continent and may be related to compressional tectonism.

A similar, but later, compressional stress may explain the limited uplift of the central Australian ranges, which led to the major drainage reversal of the Sandover River. Tilting of the western MacDonnell Ranges, with some inferred uplift of the MacDonnell Ranges in the region of the Redbank Thrust Zone, probably took place in the latest Pliocene (Tertiary) or earliest Pleistocene (Quaternary), as suggested by both the doming of earlier weathering profiles in the MacDonnell Ranges and, to a lesser extent, by the development of extensive fanglomerate deposits (e.g. unit Tuc, previously Czc as in Table 2). At this time, the duricrust capping the Late Devonian conglomerates, the Undandita Member (of the Brewer Conglomerate) appears to have been tilted along the western MacDonnell Ranges (Warren & Shaw, 1993). The steep gradient to the Todd River and the beginning of dissection of the Sixteen Mile Basin (Fig. 1) may also date from this period. The inferred doming in the region of the MacDonnell Ranges seems to have been accompanied by subsidence in the region of the Lake Eyre Basin. The possibly Late Pliocene uplift of the MacDonnell Ranges was followed by a period of partial peneplanation and ferruginisation (Unit Qr), which pre-dates the last phase of major erosion in the Holocene (units Qa, Qs, Ql, see Shaw & Wells, 1983).

Implications for groundwater assessment

Some of the most productive aquifers within the Cainozoic sequences are commonly complex deeper channel sandstones, separated by claystone - and siltstone - dominated aquicludes (e.g. unit TQt). These represent older drainage systems lying below the present drainage channels. Such aquifers have been investigated for their irrigation potential at Willowra (Morton, 1965), and Kulgera (Woolley, 1965a, b), the Farm-area Basin near Alice Springs (Woolley, 1966; Quinlan & Woolley, 1969), and Ti–Tree (McDonald, 1988). Groundwaters from these aquifers have variable low to high salt contents. Given the potential of this style of aquifer for recharge, these more permeable and porous upper parts of the Tertiary basins remain an important source for small to moderate renewable water supplies. Consequently, the identification and mapping of palaeodrainage systems within the Neogene fill remains an important target for future investigation.

The older Paleogene sedimentary rocks, lying at even greater depths (e.g. Units Ta_2, Thu), tend to be dominated by claystone or mudstone, resulting in poor permeability. Similarly, deeply weathered bedrock generally yields only poor quality water, for which the quality and supply depend on the permeability of the weathered zone.

Future research

Stratigraphic studies need to be extended into the wider region including the western Arunta Block, the Amadeus Basin and the Eromanga Basin. For example, similar basins overlying the western Arunta basement and the Palaeozoic and Late Proterozoic rocks of the Amadeus Basin need to be more accurately delineated using remote-sensing and techniques that estimate depths to magnetic basement. Further drilling is needed in these western basins to see if basin development is similar to that in the eastern part of the Arunta Block. Analogous basins may also include the Horse Creek, Springvale, Marion, Austral Downs, and Noranside Basins previously described by Paten (1964) in western Queensland. Comparison of sedimentary sequences throughout central Australia may enable a closer analysis of depositional environments and provide a basis for understanding continent-wide Cainozoic stratigraphic evolution.

Preliminary data reported here, together with geological mapping in the Hermannsburg 1:250 000 Sheet area (Warren & Shaw, 1993), point to several research topics concerning the Cainozoic geology of central Australia require further examination. These include:

- Detailed stratigraphic, lithologic. petrologic and petrographic studies of the key successions to select sections suitable for developing models of past climatic regimes.

- A study of Cainozoic warping as observed from tilted strata, and sediment distribution in relation to peneplain development. For example, the origin of intermontane basins containing up to 300 m of sedimentary rocks implies some degree of extension. On the other hand, some compressional tectonism might be explained by the relationships between the exhumation history of peneplain surfaces along the MacDonnell Ranges and the growth and dissection of piedmont fans straddling the MacDonnell Ranges.

- A search for Permian and Mesozoic basins underlying the Cainozoic successions and assessment of their groundwater potential. Although only a thin Permian succession has been identified locally in the subsurface northeast of Haast Bluff (Truswell, 1985) it is possible that a much thicker succession is preserved elsewhere. For example, it is likely that a considerable thickness, up to 300 m or more, of sedimentary rocks occurs along the BMR deep seismic line (J. Taylor, AGSO, pers. comm. 1991).

- Reconstruction of the palaeogeography as the basis for an assessment of the presence of as yet unknown basin sequences. The extent and boundaries of the known basins is as yet incompletely understood.

- Recharge studies of the Tertiary basins should be undertaken to more accurately determine aquifer characteristics and potential yields of groundwater. For example, the Burt, Sixteen Mile and Mount Wedge basins (Fig. 1) deserve particular attention because of their proximity to Alice Springs. In the eastern Mount Wedge Basin potential recharge is provided by the outwash and alluvial plains of the Derwent and Dashwood Rivers. In the Burt Basin, potential for recharge is largely unknown and warrants a more detailed investigation.

- Regolith studies including relationship of basins to landscape development.

- Improved age control could be achieved by additional palaeomagnetic studies or implementation of $^{40}Ar/^{39}Ar$ weathered rock dating techniques. In addition, the use of oxygen and hydrogen isotopes should be explored for elucidating past climates, palaeolatitudes and ages of weathering profiles.

Summary and conclusions

Analyses of Cainozoic sedimentary basin successions, supported by palynological and palaeomagnetic data, indicate two main episodes of deposition within several distinct basins. The first episode is represented by thick deposits that date from a Paleocene phase of basin infilling. Locally, as in the Ayers Rock Basin, an even earlier but less-widespread phase may have begun in the Late Cretaceous. Initial fluviatile sand deposition in several of the basins gave way, perhaps in the Middle Eocene, to widespread silt and mud accumulations within a series of interconnected lakes. Swamps and forests were prevalent at this time in regions such as that surrounding the Hale Basin. Then followed deposition of coarse lithic sands with derived weathered rock components, together with scattered woody debris and charcoal. Siliceous and calcareous rock types were chemically precipitated during this interval. The second episode of subsidence took place in the Late Miocene to Early Pliocene and was preceded by an extended period of hiatus, possibly spanning the Oligocene. This interval was characterised by deposition of sand, silt and clay, intercalated with calcareous and chalcedonic sediments, some of which appear to represent the products of weathering and groundwater processes.

The centres of deposition shifted between these two main phases of deposition, implying a change in the tectonic driving forces affecting the region. The Late Eocene magnetic date obtained for Weathering Event C is considered to record the time when weathering processes ceased over much of the region as a result of the implied tectonic rearrangement.

To gain an understanding of the Cainozoic sedimentary sequences of central Australia there is a particular need for better time control using palynological and paleomagnetic studies, as well as other techniques. Dating of clay minerals (e.g. illite, cryptomelane-hollandite) by K-Ar methods shows considerable promise in providing time constraints, although it would be necessary to consider possible age modification of the clays brought about by weathering and diagenesis. Stratigraphic studies of clay minerals using semi-quantitative techniques may also allow greater precision in correlating sedimentary units and weathering events.

Extension of these techniques to basins surrounding those in central Australia would greatly assist in piecing together the continent-wide Cainozoic successions, leading to an improved knowledge of tectonics and palaeoclimates. Because of the generally poor outcrop, improved drilling techniques leading to better sample recovery would be of considerable benefit. Wireline logging of drill holes is considered essential for improved correlation of both rock units and weathered profiles.

A full assessment of the resources in the Cainozoic units warrants further investigations. These rocks have a potential for sedimentary uranium, although investigations to date have been largely disappointing. These Cainozoic deposits may well conceal economic mineral deposits that lie within the basement rocks. Geochemical mineral exploration is also hampered by the poorly understood effects of deep weathering on chemical dispersal. The presence of potentially commercial lignite and oil shale in basins of comparable age and sedimentary facies, such as the massive Stuart and Rundle deposits in Queensland, means central Australia remains prospective for similar resources.

These basins represent potential sources of sustainable water supplies for use by small communities or in for irrigated agriculture. However, their recharge characteristics remain largely unknown.

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References

Agip Nucleare Australia Pty Ltd., 1977. Annual Report, Exploration Licence 1056, Illogwa Creek, July, 1977. *Open File Report, Northern Territory Geological Survey,* CR 77/82 (unpublished).

Agip Nucleare Australia Pty Ltd., 1979. Final Report, Exploration Licence 1056, Illogwa Creek, July, 1979. *Open File Report, Northern Territory Geological Survey,* CR 79/63 (unpublished).

BMR Palaeogeographic Group, 1990. *Australia: Evolution of a continent. Bureau of Mineral Resources, Geology and Geophysics,* Australia.

Calf, G.E., McDonald, P.S. & Jacobson, G., 1991. Recharge mechanisms and groundwater age in the Ti–Tree Basin, Northern Territory. *Australian Journal of Earth Sciences* , 38, 299-306.

Clarke, D., 1975. The Hale River Basin. Alice Springs 1:250 000 Sheet area, S53-14, N.T., Report 1. Preliminary Review. *Northern Territory Geological Survey Report* G.S. 75/13 (unpublished).

Edworthy, K.J., 1966. Preliminary appraisal of the Ti–Tree groundwater basin, Northern Territory. *Report of the Resident Geologist's Office for the Mines Branch, Northern Territory Administration, Alice Springs* (unpublished).

Etheridge, M., McQueen, H. & Lambeck, K., 1991. The role of intraplate stress in Tertiary (and Mesozoic) deformation of the Australian continent and its margins: key factor in petroleum trap formation. *Exploration Geophysics* , 22, 123-128.

Freeman, M.J., 1986. Huckitta, Northern Territory 1:250 000 geological series (2nd edition). *Northern Territory Geological Survey, Australia, Explanatory Notes,* SF/53-11.

Galloway, R.W. & Kemp, E.M., 1977. Late Cainozoic Environments in Australia. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Record* 1977/40.

Harland, W.B, Armstrong, R.L., Cox, A.V., Craig, L.E., Smith, A.G. & Smith, D.G., 1990. A Geological Time-scale. *Cambridge University Press, Cambridge.*

Harris, W.K. & Twidale, C.R., 1991. Revised age for Ayers Rock and the Olgas. *Transactions of the Royal Society of South Australia*, 115 (2), 109.

Hays, J., 1967. Landsurfaces and laterites in the north of the Northern Territory. *In* Jennings, J.N. & Mabbutt, J.A. (Editors). Landform Studies from Australia and New Guinea. *Australian National University Press*, 144-181.

Hughes, F.E. & O'Sullivan, K.N., 1973. Final Report, EL 52, Woola Downs, N.T., CRA Exploration Pty Ltd Report 73/009. *Open File Report N.T. Geological Survey*, NT 53-10 (unpublished).

Idnurm, M., 1985. Late Mesozoic and Cenozoic palaeomagnetism of Australia - I. A redetermined apparent polar wander path. *Geophysical Journal of the Royal Astronomical Society*, 83, 399 - 418.

Idnurm, M., 1994. New Late Eocene pole for Australia, time-averaging of remanence directions, and palaeogeographic reference systems. *Geophysical Journal International*, 117, 827 - 833.

Idnurm, M. & Senior, B.R., 1978. Palaeomagnetic ages of weathered profiles in the Eromanga Basin, Queensland. *Palaeogeography, Palaeoclimatology, Palaeoecology* , 24, 263-277.

Jacobson, G., Lau, G.C., McDonald, P.S. & Jankowski, J., 1989. Hydrology and Groundwater Resources of the Lake Amadeus and Ayers Rock Region, Northern Territory. *Bureau of Mineral Resources, Geology and Geophysics*, *Bulletin* , 230, 70pp.

Kamp, P.J.J., 1991. Late Oligocene Pacific-wide tectonic event. *Terra Nova*, 3, 65-69.

Kemp, E. M., 1976. Early Tertiary pollen from Napperby, central Australia. *BMR Journal of Australian Geology and Geophysics* 1, 109-114.

Litchfield, W.H., 1969. Soil surfaces and sedimentary history near the MacDonnell Ranges, Northern Territory. *CSIRO Publication* 25.

Lister, G.S., Etheridge M.A. & Symonds, P.A., 1986. Detachment faulting and the evolution of passive continental margins. *Geology*, 14, 246-250.

Lloyd, A.R., 1968. Outline of the Tertiary geology of Northern Australia: *In* Palaeontological papers, 1965. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Bulletin* , 80, 105-132.

Mabbutt, J.A., 1967. Denudation chronology in central Australia. Structure, climate, and landform inheritance in the Alice Springs area. *In* Jennings, J.N. & Mabbutt, J.A. (Editors). Landform Studies from Australia and New Guinea. *Australian National University Press, Canberra,* 144-181.

McDonald, P.S., 1988a. Groundwater studies, Ti–Tree Basin, 1984-1988. *Northern Territory Government, Power and Water Authority, Report* 1/90.

McDonald, P.S., 1988b. Groundwater resources of the central Ti-Tree Basin. M. Appl. Sc. thesis, University of New South Wales, Sydney (unpublished).

Morton, W.H., 1965. The occurrence of groundwater suitable for irrigation, Willowra Station, Northern Territory. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Record* 1965/146.

Ollier, C.D., Chan, R.A., Craig, M.A. & Gibson, D.I., 1988. Aspects of landscape history and regolith in the Kalgoorlie region. *BMR Journal of Australian Geology and Geophysics*, 10, 309-321.

Ollier, C.D. & Galloway, R.W., 1990. The laterite profile, ferricrete and unconformity. *Catena*, 17, 97-109.

O'Sullivan, K.N., 1973. Stratigraphic drilling, Ti–Tree area, Northern Territory. *CRA Exploration Pty Ltd., Northern Territory Geological Survey, Open File Report,* NT 168 (unpublished).

Paten, R.J. 1964. The Tertiary geology of the Boulia region western Queensland. *Bureau of Mineral Resources, Geology and Geophysics, Australia*, Report 77.

Perry & others, 1962. General Report on Lands of the Alice Springs area, Northern Territory, 1956-57. *CSIRO Australian Land Research Series* , 6.

Quinlan, T., & Woolley, D.R., 1969. Geology and hydrology, Alice Springs town and inner farm basins, Northern Territory. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Bulletin,* 89, 64pp.

Schwab, F.L., 1986. Sedimentary 'signatures' of foreland basin assemblages: real or counterfeit? *Special Publication of the International Association of Sedimentologists* , 8, 395-410.

Senior, B.R., 1972. Cainozoic laterite and sediment in the Alcoota Sheet area, Northern Territory. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Record* , 1972/47.

Senior, B.R., Mond, A. & Harrison, P.L., 1978. Geology of the Eromanga Basin. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Bulletin,* 167.

Senior, B.R., & Mabbutt, J.A., 1979. A proposed method of defining deeply weathered rock units based on regional geological mapping. *Journal of the Geological Society of Australia*, 26, 237 - 54.

Senior, B.R., Truswell, E.M., Idnurm, M., Shaw, R.D. & Warren, R.G., 1994. Cainozoic sedimentary basins, eastern Arunta Block, Alice Springs region. *AGSO Journal of Australian Geology & Geophysics* , 15.

Shaw, R.D., & Langworthy, A.P., 1984. Strangways Range Region, Northern Territory - 1:100 000 Geological Map Commentary. *Bureau of Mineral Resources, Geology and Geophysics, Australia.*

Shaw, R.D., Etheridge, M.A. & Lambeck, K., 1991. Development of the Late Proterozoic to Mid-Proterozoic, intracratonic Amadeus Basin in central Australia: a key to understanding tectonic forces in plate interiors. *Tectonics*, 10 (4), 688-721.

Shaw, R.D., Freeman, M.J., Offe, L.A. & Senior, B.R. 1982. Geology of the Illogwa Creek 1:250 000 Sheet area, central Australia - Preliminary Data, 1979-80 Surveys. *Bureau of Mineral Resources, Geology & Geophysics, Australia, Record* ,1982/23. BMR microform 193.

Shaw, R.D., Langworthy, A.P., Offe, L.A., Stewart, A.J., Allen, A.R. & Senior, B.R., 1979. Geological report on 1:100 000 scale mapping of the southeastern the Arunta Block, Northern Territory. *Bureau of*

Mineral Resources, Geology and Geophysics, Australia, Record, 1979/47. BMR microform 133.

Shaw, R.D., Rickard, M.J. & Stewart, A.J., 1984. Arltunga-Harts Range Region, Northern Territory - 1:100 000 Geological Map Commentary. *Bureau of Mineral Resources, Geology and Geophysics, Australia.*

Shaw, R.D. & Warren, R.G., 1975. Alcoota, Northern Territory 1:250 000 geological series. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Explanatory Notes* SF/53-10.

Shaw, R.D., Warren, R,G., Senior, B.R. & Yeates, A.N., 1979b. Geology of the Alcoota 1:250 000 Sheet area, Northern Territory. *Bureau Mineral Resources, Geology and Geophysics, Record,* 1975/100; BMR Microform MF107.

Shaw, R.D. & Wells, A.T., 1983. Alice Springs, Northern Territory 1:250 000 geological series (2nd edition). *Bureau of Mineral Resources, Geology & Geophysics, Australia, Explanatory Notes.* SF/53-14.

Sluiter, I.R.K., 1991. Early Tertiary vegetation and climates, Lake Eyre region, northeastern South Australia. *In* Williams, M.A.J. De Deckker, P. & Kershaw, A.P. (Editors). The Cainozoic in Australia: a reappraisal of the evidence. *Geological Society of Australia, Special Publication,* 18, 99 - 118.

Stewart, A.J., 1976. Mount Theo, N.T. 1:250 000 geological series. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Explanatory Notes.* SF/52-8.

Stewart, A.J., Shaw, R.D., Offe, L.A., Langworthy, A.P., Warren, R.G., Allen, A.R. & Clarke, D.B., 1980a. Stratigraphic descriptions of named units in the Arunta Block, Northern Territory. *Bureau Mineral Resources, Geology and Geophysics, Record,* 80/216, 70 pp. BMR Microform 104.

Stewart, A.J., Offe, L.A., Glikson, A.Y., Warren, R.G. & Black, L.P., 1980b. Geology of the Northern Arunta Block, Northern Territory. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Record* 1980/83, BMR Microform 152.

Truswell, E.M., 1985. Late Permian sediments in the Amadeus Basin, Northern Territory: a palynological examination. *Bureau of Mineral Resources, Geology & Geophysics, Australia, Professional Opinion* , 85/003.

Truswell, E.M., 1987. Palynology of DDH HUC II, Huckitta Sheet area, Northern Territory. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Professional Opinion* 87/002.

Truswell, E.M. & Harris, W.K., 1982. The Cainozoic palaeobotanical record in arid Australia: fossil evidence for the origins of an arid-adapted flora. *In* Barker, W.R. & Greenslade, P.J.M. (Editors). Evolution of the Flora and Fauna of Arid Australia, *Peacock Publications, Frewville, South Australia,* 67-83.

Truswell E.M. & Marchant, N.G., 1986. Early Tertiary pollen of probable Droseracean affinity from central Australia. *Special Papers in Palaeontology* , 35, 163-178.

Twidale, C.R. & Harris, W.K., 1977. The age of Ayers Rock and the Olgas, central Australia. *Transactions of the Royal Society of South Australia,* 101, 45-50.

Veevers, J.J., Powell, C.McA. & Roots, S.R., 1991. Review of sea-floor spreading around Australia. I. Synthesis of the patterns of spreading. *Australian Journal of Earth Sciences*, 38, 373-389.

Warren, R.G. & Shaw, R.D., 1993. Hermannsburg, N.T. 1:250 000 Geological series, *Bureau of Mineral Resources, Geology and Geophysics, Australia, Explanatory Notes*, SF/53-13.

Woodburne, M.O. 1967. The Alcoota fauna, Northern Territory. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Bulletin,* 87, 187 pp.

Woodburne, M.O., Tedford, R.H., Archer, M., Turnbull, W.D., Plane, M.D. & Lundelius, E.M., 1985. Biochronology of the continental mammal record of Australia and New Guinea. *Department of Mines and Energy, South Australia, Special Publication,* 5, 347 - 363.

Woolley, D.R., 1965a. The availability of groundwater in Utopia irrigation area, Northern Territory - a preliminary proposal. *Bureau* *of Mineral Resources, Geology and Geophysics, Australia, Record,* 1965/9.

Woolley, D.R., 1965b. Preliminary appraisal of the prospect of locating supplies of ground water suitable for Kulgera, N.T. town water supply. *Bureau of Mineral Resources , Geology and Geophysics, Australia, Record*, 1965/79.

Woolley, D.R., 1966. Geohydrology of the Emily and Brewer Plains area, Alice Springs, N.T. Report of the Resident Geologist's Office, NT Administration, *Alice Springs, Northern Territory Geological Survey, Report,* GS 66/2, 35 pp.

Woolnough, W.G., 1927. Presidential address. Part 1 - The chemical criteria of peneplanation: Part 2 - The duricrust of Australia. *Journal of the Royal Society of New South W.*ales, 61, 17-53.

Yeates, A.N., 1971. Shallow stratigraphic drilling, western Eromanga Basin and Alcoota area, Northern Territory. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Record,* 1971/120.

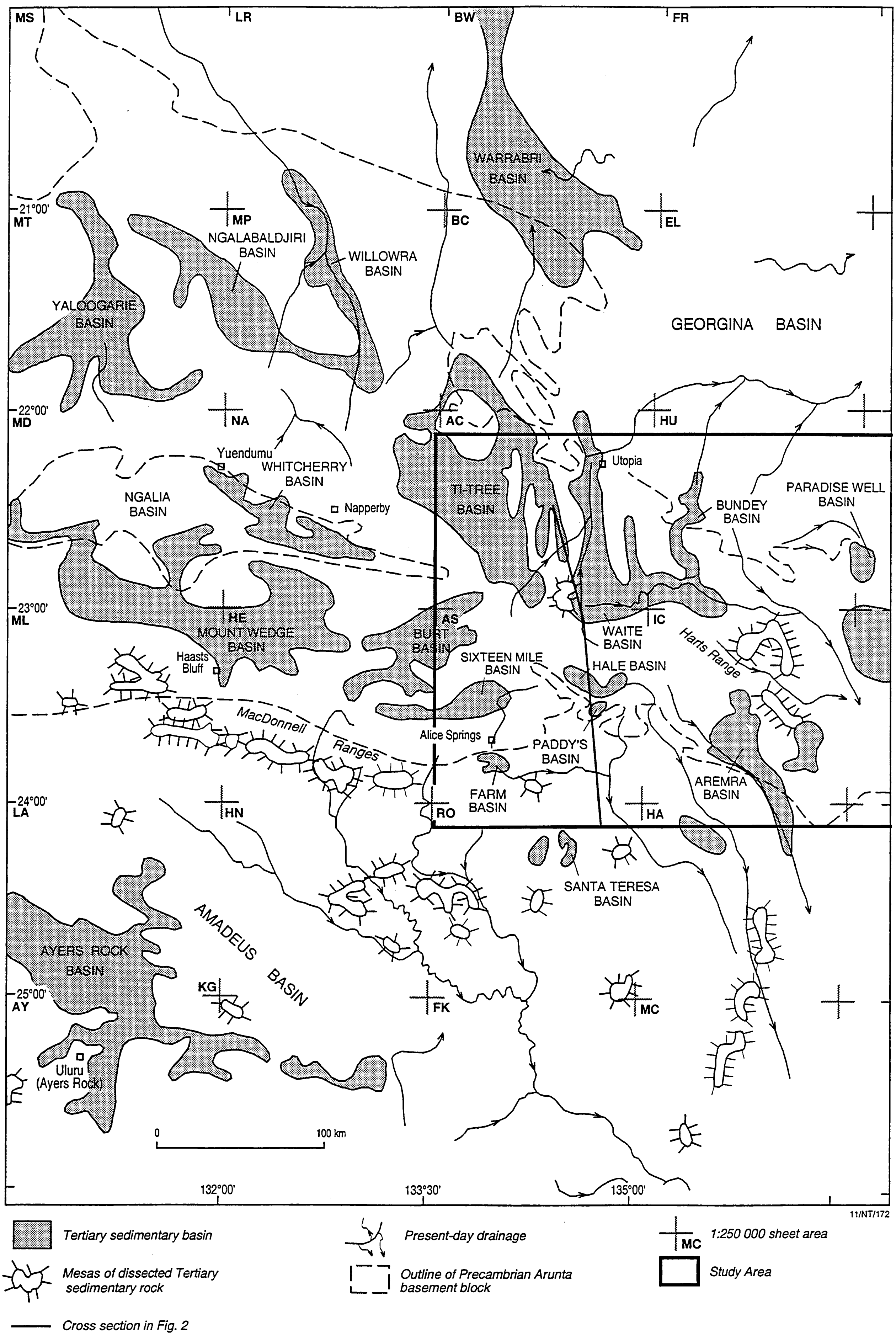
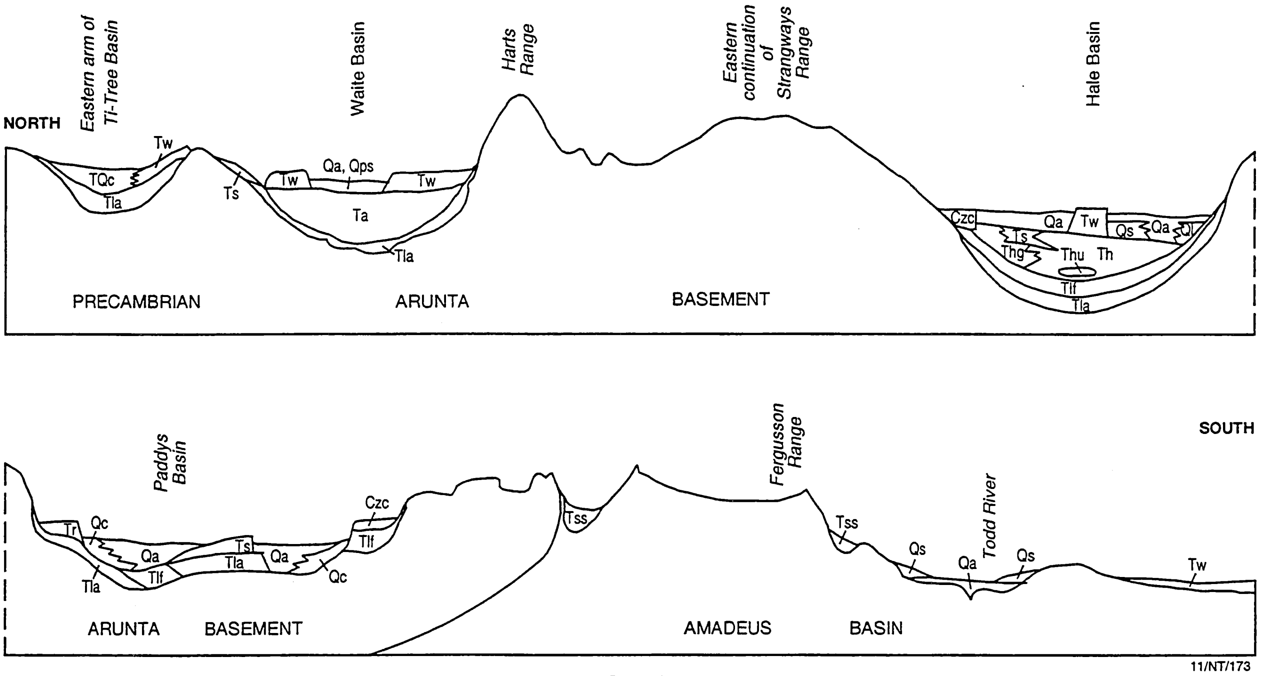


Figure 1. Inferred outline of Tertiary basins, showing their relation to the underlying Arunta basement (non-standard projection). The 1:250 000 map sheets are abbreviated as follows: AC—Alcoota, AS—Alice Springs, AY—Ayers Rock, BC—Barrow Creek, BW—Bonney Well, EL—Elkedra, FK—Finke, FR—Frew River, HA—Hale River, HN—Henbury, HE—Hermannsburg, HU—Huckitta, IL—Illogwa Creek, KG—Kulgera, LA—Lake Amadeus, MC—McDills, MD—Mount Doreen, ML—Mount Liebig, MP—Mount Peake, MS—Mount Solitaire, MT—Mount Theo, NA—Napperby, RO—Rodinga.



Qa *Alluvium; Ql Calcrete; Qs Aeolian sand*
Qps *Aeolian sand; Qc Scree, gravel, colluvium*
Czc *Fanglomerate*
Ts *Silcrete (silicified quartz sandstone)*
Waite Formation equivalent
Tw *Chalcedonic limestone*

Hale Formation
Th *Kaolinitic clastics*
Thg *Conglomerate*
Thu *Lignite*
Arltunga Beds
Tr *Limestone*

Alcoota Beds
Ta *Mudstone*
Tss *Sandstone*
Tlf *Ferricrete*
Tla *Undivided deeply-weathered rock in Arunta Basement*

Figure 2. Diagrammatic N–S cross-section of the Hale Basin and regions bordering the eastern MacDonnell Ranges, showing the relationship between the surficial geological units and the topography.

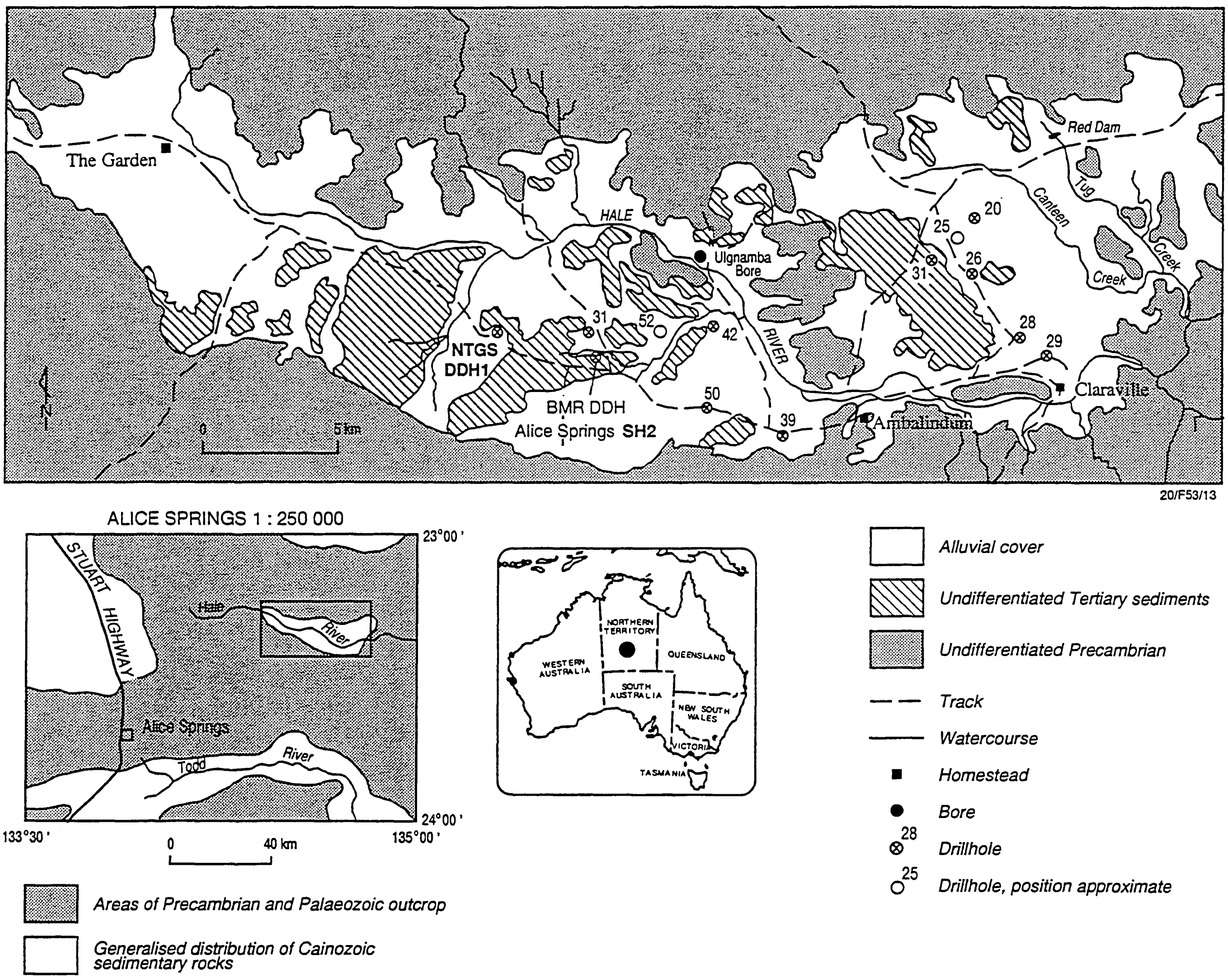


Figure 3. Sketch map of the Hale Basin, showing the location of NTGS DDH1, BMR DDH Alice Springs SH2 and a series of company drill holes.

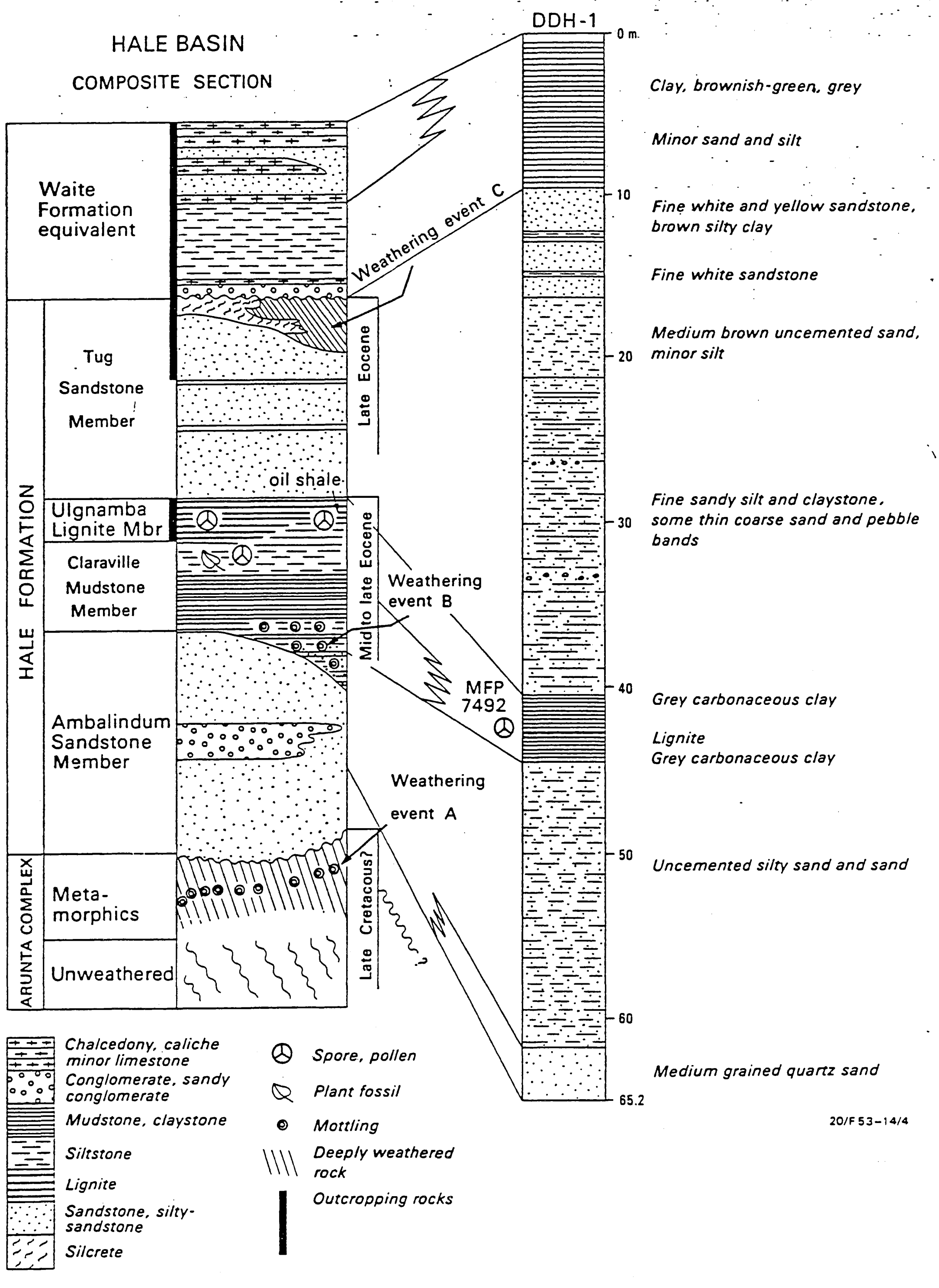


Figure 4. Stratigraphic column for NTGS DDH1, showing correlation with a generalised section of the Hale Basin, which is based in part on the succession intersected in BMR DDH Alice Springs SH2.

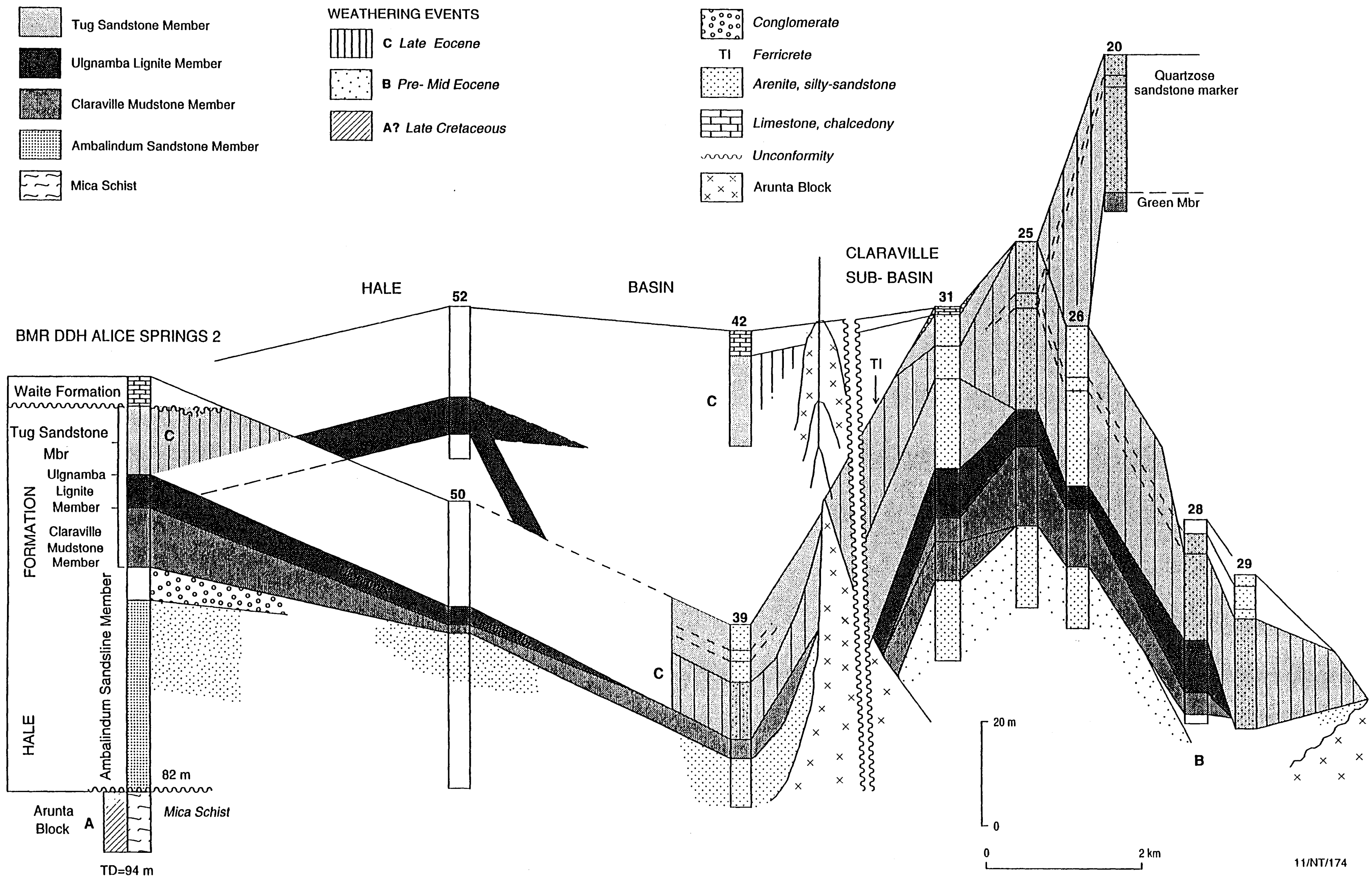


Figure 5. Panel diagram showing members of the Hale Formation and their relationship to weathering events within the eastern part of the Hale Basin and the Claraville Sub-basin; based on selected company scout holes as numbered in Fig. 3. Note, Claraville homestead is located at the eastern (RHS) apex of the diagram (see Fig. 3).

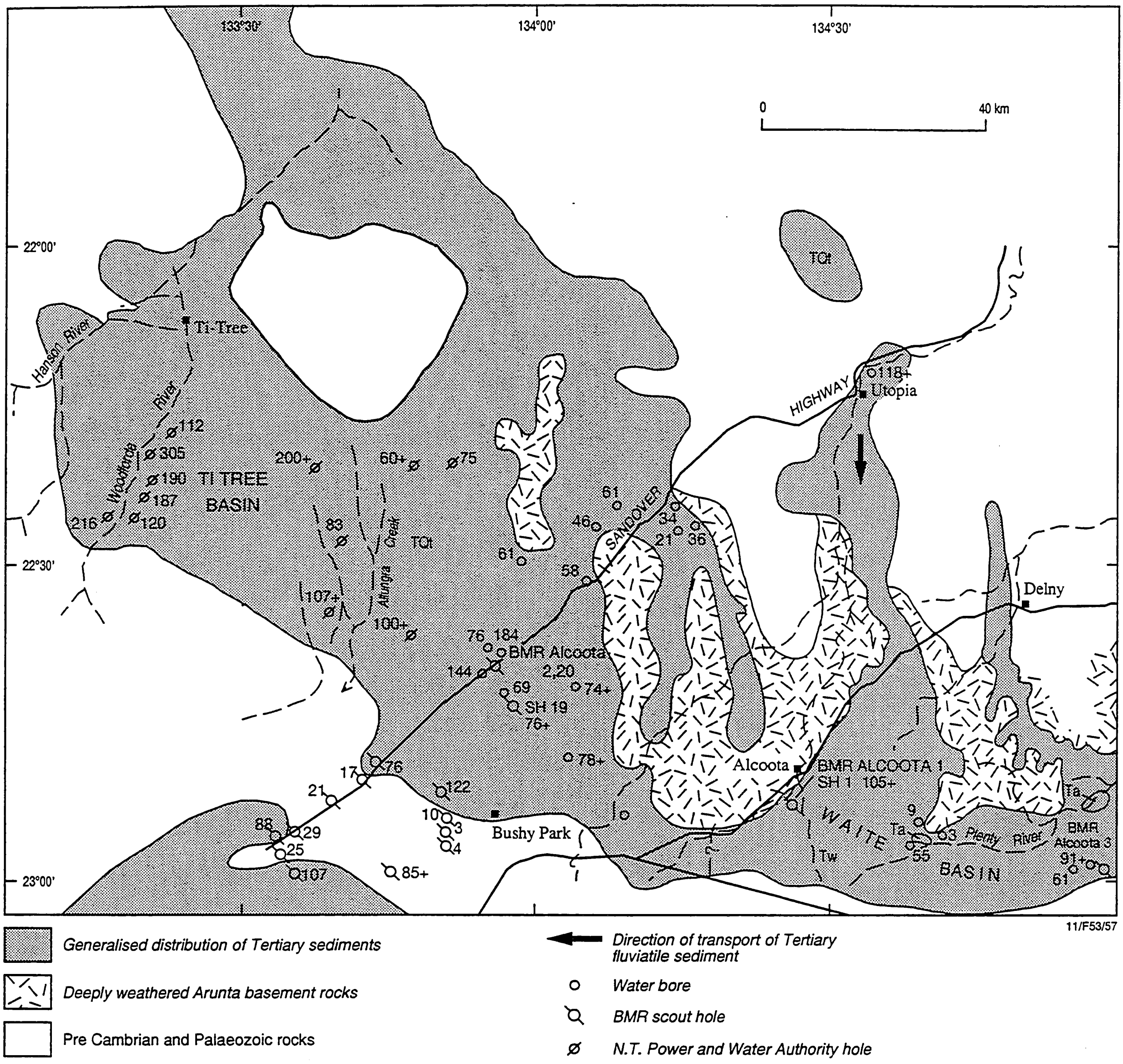


Figure 6. Distribution of deeply weathered rocks and Cainozoic sediments, Ti-Tree and Waite Basins, showing the location of selected drill holes and estimated depths to basement.

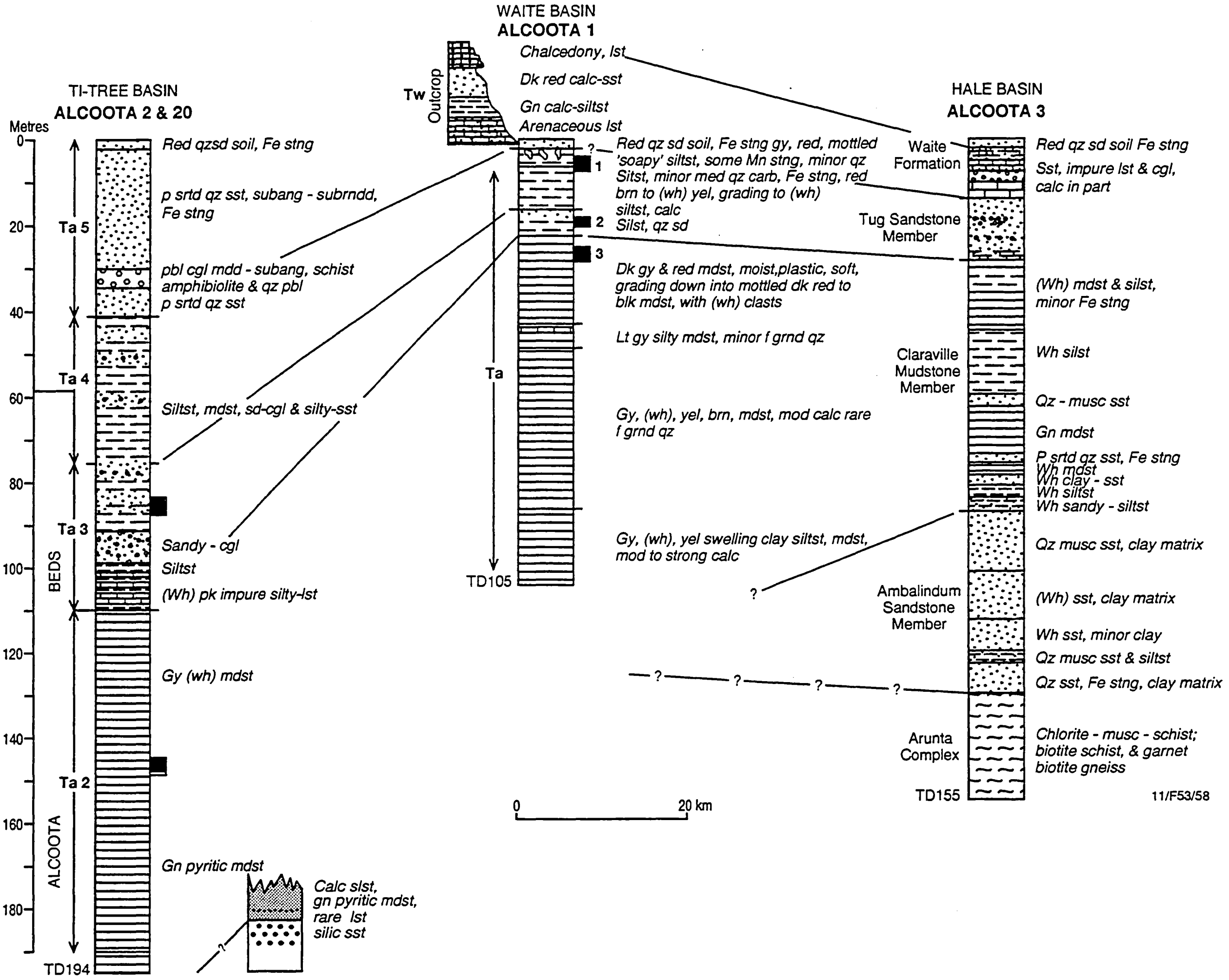


Figure 7. Correlation between drill holes in the Ti-Tree and Waite Basins, and possible correlation with the units of the Hale Basin.

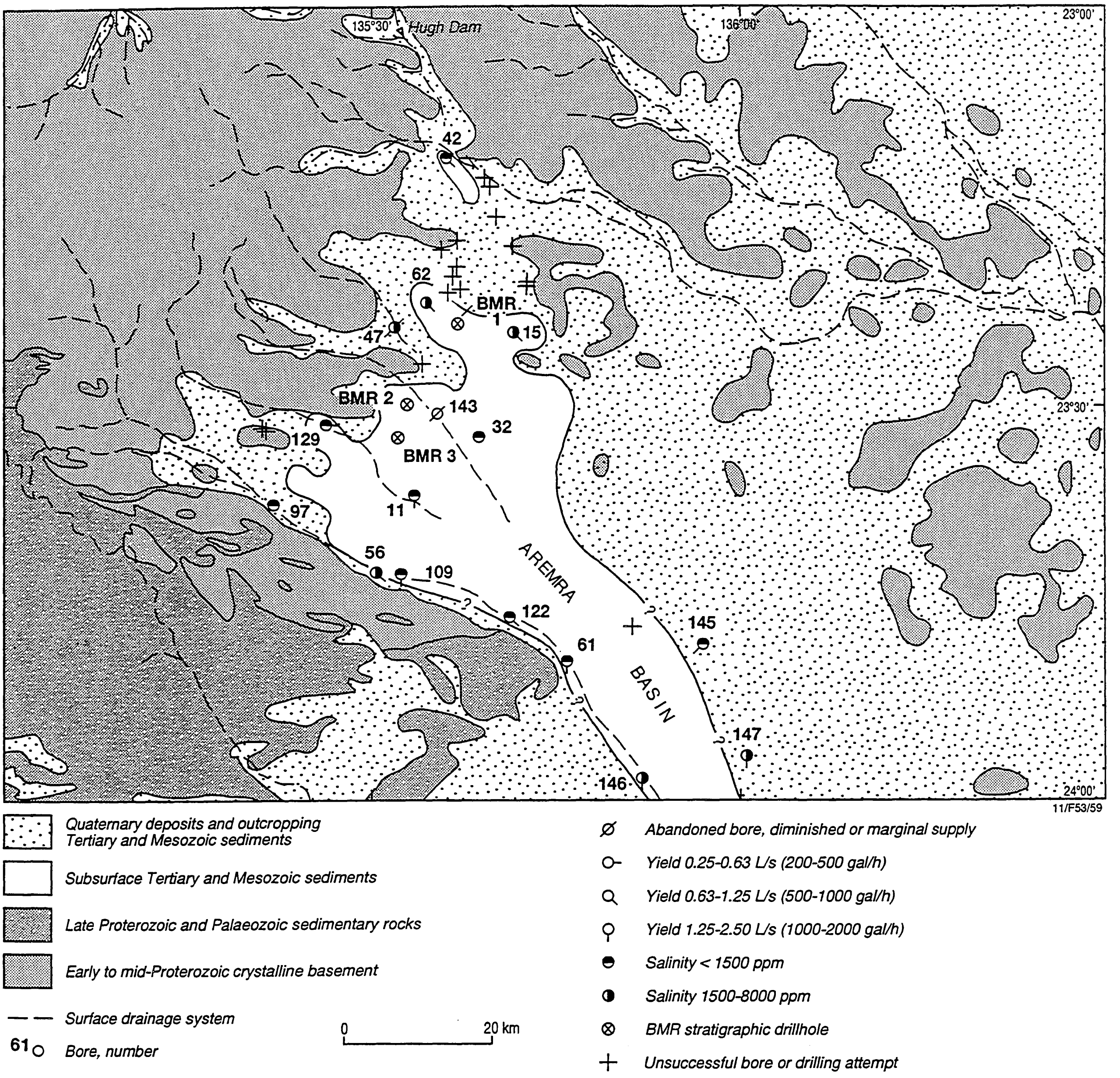


Figure 8. Sketch map of Cainozoic sediments in the Illogwa 1:250 000 Sheet area, showing the approximate outline of the Aremra Basin and details of drilling for groundwater.

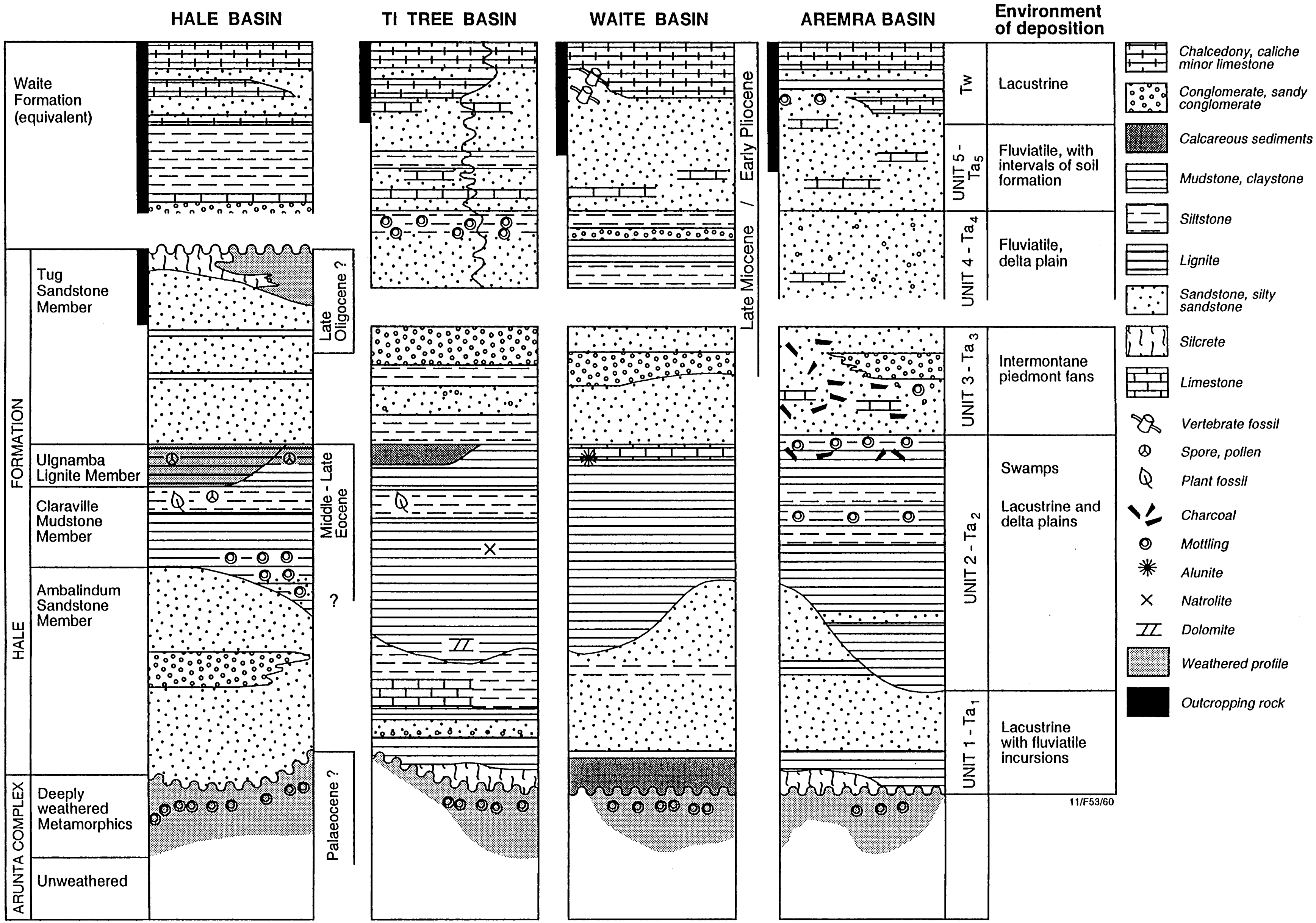


Figure 9. Diagrammatic correlation model for Tertiary units overlying the eastern part of the Arunta Block.

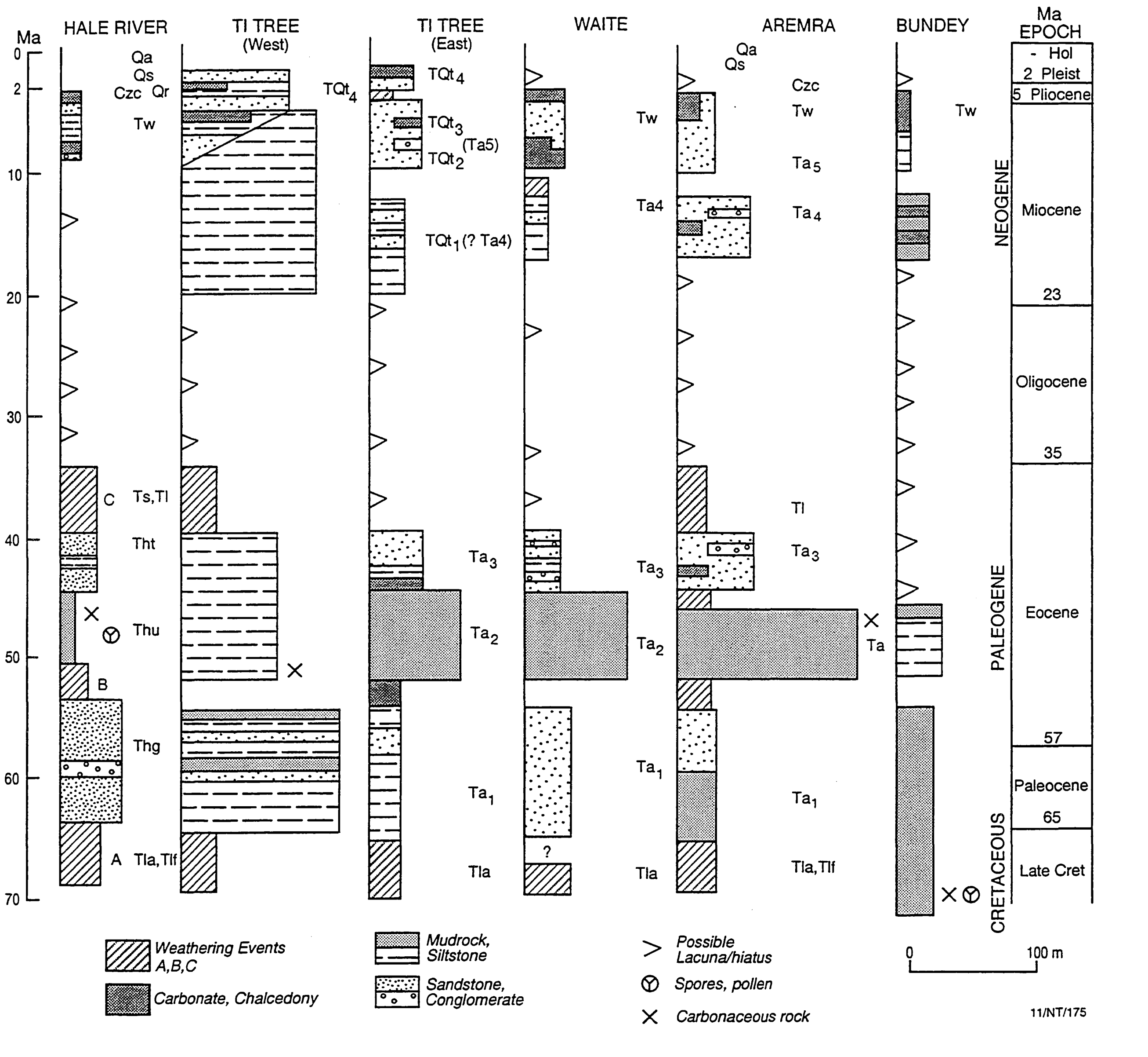


Figure 10. Interpretative time/depth plots for Cainozoic sedimentary units within the main basins overlying the eastern part of the Arunta Block. The timescale (Ma) is that of Harland et al. (1990).

Table 1. Summary of stratigraphy.

Rock unit	*Lithology*	*Thickness*	*Tectonic events*	*Environment, fossils and age*
Qa	Fine and coarse clay-quartzose sand, silt and minor gravel, lacking a marked soil profile		Possible uplift in the area of the Harts, Strangways and MacDonnell Ranges or rejuvenation due to subsidence within the Lake Eyre Basin	Channels date from latest pluvial period—either Holocene or latest Pleistocene.
Ql	Calcrete; hard calcareous cements within formerly porous sediments			Humid oxidising conditions succeeded by aridity and aeolian activity. Cementation of porous surface sediments and colluvium forming calcareous crusts.
Qs, Qps	Quartzose sand (Qs); with fixed dunes (Qps)		Region tectonically stable	Development of broad sand plains with minor dune fields.
Qc	Colluvium, eluvium, scree			
Qr	Shallow red, oxidised, clayey and sandy oxidised soil ("Red earth"), clayey, oxidised silty-sand			Soil produced by repeated phases of alluviation and burial. Mixed with sheet sands (Qs) suggesting that the unit began forming in the late Pliocene (Litchfield 1969).
Czg	Redistributed ferricrete and quartz gravel	20 m		Transported ferruginous clastics derived from deeply weathered profiles.
Czc	Fanglomerate	20 m	Movement on some faults	Alluvial fan deposits flanking uplands.
Tw Waite Formation and equivalents	Greenish grey siltstone and chalcedonic limestone in type area.	20 m	Region tectonically stable	Argillaceous sediments and chemical precipitates in very quiet lacustrine environments. Age is Late Miocene–Early Pliocene (Woodburne 1967).
Arltunga beds Tr	Arenaceous limestone, silicified limestone, pebbly sandstone	4 m	Probable mild uplift and warping of some fault-bounded blocks	Coarse clastics grading to minor lake sediments. Probably equivalent to Tw (above) or, less likely, Th (below). Preceded by widespread hiatus.
Ts, Tl (overprint of Tlf, Tla)	Silcrete (strongly silicified quartzose sedimentary or felsic igneous rocks), Weathering Event C		Region tectonically stable	Groundwater silica sourced from felsic igneous rocks in regions of restricted drainage (e.g. margin of Hale and Paddys Plain Basins). Late Eocene age for Weathering Event C determined palaeomagnetically.
Hale Formation Th, (Thr, Thu, Thc, Thg)	Kaolinitic quartzose sandstone, siltstone and mudstone, minor conglomerate and lignite	195 m in Sixteen Mile Bore (Nth of Alice Springs)	Probable mild uplift and warping of some fault-bounded blocks	Lakes and swamps succeeded by river sediments grading laterally to coarse, poorly sorted clastics along intermontane margins. Probably equivalent to unit Ta of the Waite and Aremra Basins.
Tug Sandstone Member Thr	Brown sand and minor silt (subsurface)	30 m in NTGS DDH-1		
Ulgnamba Lignite Member, Thu	Grey carbonaceous clay, lignite	10 m in NTGS DDH-1		Marsh or swamp habitat. Lignite is probably mid-Late Eocene (Truswell & Marchant 1986).
Delaney Mudstone Member, Thc	Olive green mudstone and siltstone, locally developed mottled Weathering Event B	Equiv. unit 72 m in BMR Alcoota 20		Weathering Event B
Ambalindum Sandstone Member, Thg	Poorly sorted boulder conglomerate at basin margin in outcrop; Silty sand and sand in subsurface	55 m in DDH BMR Alice SH2		High energy fluviatile deposits
Tlf	Ferricrete (Weathering Event A extensive, Weathering Event C overprint)		See below	See below
Tla	Undivided weathered profile with ferruginous, mottled and leached zones, in places grading down into unweathered rocks. Well developed on coarsely crystalline igneous rocks. Weathering Event A.	±20 m	Region tectonically stable, widespread weathering.	Deep weathering under humid conditions. Seasonal precipitation, and fluctuating water-table, forming a trizonal weathered profile. Palaeomagnetic evidence from the Eromanga Basin suggests a Maastrichtian to Early Eocene weathering event (Idnurm & Senior 1978).

Table 2. Tentative interpretation of tectonic and palaeogeographic setting.

Period approx.	*Age[1] (Ma) ~ base*	*Units*	*Plate-wide[3,4] tectonism*	*Central Australian tectonism*	*Lat.[4] C. Aust °S, °shift*	*Plate-wide palaeo-geography[2, 7]*	*Suggested central Australian depositional environment*	*Tentative central Australian climate*
Holocene	0.01	Qa, Qs, Ql	Craton stable	Stable	24, 0	Present-day conditions	Present-day drainage and deposition	Present-day dry conditions
Pleistocene–latest Pliocene	~ 2	Qps, Qa, Qs	Craton stable	Stable	24+, 0	Waxing & waning of ice caps	Sand plains, minor dune fields	Dry, sporadic pluvial period
Late Pliocene	~ 3	Qr, TQt_4 Czc, Czg	Localised uplift, ?compressional tectonism	Upward doming of ranges, drainage reversal of Sandover River	24+, 0	Rejuvenation of drainage	Oxidised soil development, sheet sand	Wetter conditions, followed by increasing aridity
Early Pliocene–Late Miocene	~ 3–20	Tw, Tr, TQt_{1-3}, Ta_{4-5}	Craton stable	Switch in sites of sedimentation	25+, –1	Lowering of sea level & expansion of ice cap	Restricted drainage, lakes including salt lakes	Moderate temperatures, seasonal rain
Early Miocene to Oligocene	~ 20–35	Hiatus	Beginning of N Aust. collision[5]	Widespread uplift	≥43, –19	Sea level rise at ~ 20 Ma after episode of widespread weathering (Canaway Profile eq.)	Widespread hiatus	?Drier
Late Eocene	~ 35–45	Tl, Ts	Plate rearranngement. Inversion and wrenching of early structures at plate margins. Uplift of parts of continent	Reduced rates of subsidence, break in sedimentation in Claraville sub-basin	46, –22	Beginning of expansion of Antarctic ice cap and sea level fall	End of widespread deep weathering, especially east of ranges	Uncertain
Late to mid-Eocene	~ 45±	Tht, Ta_3,Tss	Pacific plate rearrangement[6]	Limited upward doming of ranges, minor tilting east of ranges	48, –24	Humid, temperate climate over much of the continent	River sediments, sheet outwash, coelescing piedmonts	Warm, moist
Mid - Eocene	~ 50±	Thu, Thc, Ta_2,Tss	Start of rapid spreading away from Antarctica, end Tasman Sea spreading, start spreading Coral Sea, subsidence in Murray Basin and in Eromanga Basins after break	Renewed localised subsidence after local break	≥50, –26	Moist, increased circulation of warmer seas, presence of lakes, peat swamps and forest	Localised lakes and peat swamps, forest on slopes.	Warm, moist, possibly with dry phases
Early Eocene - Paleocene	~ 55–65	Thg, Ta_1, Tss	Continued spreading between Australia and Antarctica, subsidence in Eromanga Basin	Narrow intermontane basins, rapid local subsidence	54, –30	Main present-day river systems established, major disturbance of ocean currents, negligible ice cap	Coarse river deposits, forest and peat swamps very locally	Warm, moist, possibly with some dry episodes
Earliest (?) Paleocene - Late Cretaceous	~ 70–90	Tlf, Tla	Start of Tasman Sea rifting, and continued spreading between Australia and Antartica	Broad uplift over much of continent, more marked in the Eastern Highlands	58, –34	Subaerial erosion (Morney Profile eq.) of much of Australia and Antartica	Widespread deep weathering (age uncertain)	Warm, moist, possibly seasonal rain

References: 1) Harland & others 1990, 2) BMR Palaeogeographic Group 1990, 3) Etheridge et al. 1991, 4) Veevers et al. 1991, 5) Kamp 1991, 6) Wells 1989, 7) Truswell & Harris 1982.

APPENDICES

APPENDIX 1. Palaeomagnetism studies of Cainozoic Sedimentary Basins in the Eastern Arunta Block, Alice Springs Region.

APPENDIX 2.
PART A.
(i) Technical details of drilling
(ii) location of drill holes
(iii) Details of BMR drilling in the Burt Basin
PART B. Lithological logs: Tabular presentation
DDH BMR Alcoota No. 18, Ti–Tree Basin
DDH NTGS Huckitta 11, Bundey Basin
PART C. Diagrammatic presentation of selected drill holes

APPENDIX 1. Palaeomagnetism studies of Cainozoic Sedimentary Basins in the Eastern Arunta Block, Alice Springs Region.

Palaeomagnetic Results

The results reported here represent the first of two stages of sampling, and are considered preliminary. The samples from this stage were collected from the mottled zones of weathered profiles and from ferruginous cappings on hills at three localities: the southeastern part of the Alcoota Sheet, at Hale Plain and immediately west of the Hale Plain. At the Alcoota Sheet localities, the parent rocks are identified as metamorphics of the Arunta Block; elsewhere definite identification was not possible because of the intensity of weathering. Table 1A lists the sampling details.

The samples were obtained by coring with a small portable drill, the cores being oriented with both sun and magnetic compasses. All measurements were made at the Black Mountain palaeomagnetic laboratory, Canberra: remanences were measured on either an ScT cryogenic magnetometer or a Digico spinner magnetometer; and demagnetisation was carried out in furnaces similar to those described by McElhinny and others (1971). Remanence directions were determined from the demagnetisation data by principal components analysis (Kirschvink, 1980). A direction was accepted for pole calculation if its mean angular deviation was 5°.

Two of the nine sampling sites failed to give reliable remanence directions because of a large directional scatter between samples (Locality 2-2 in Table 1A) or unstable remanences (Locality 2-3). Most samples from the other sites contained, beside low unblocking temperature components, a single component of remanence. In some samples, however, additional components were evident from breaks in slope in the orthogonal projection plots at intermediate temperatures, or from complex behaviour of remanence during demagnetisation. For a few samples where the direction of a second component could be determined, the component with the lower unblocking temperature always had an appreciably lower inclination, and therefore appears to represent a later overprint. Only the higher unblocking temperature component is reported here.

The remanence directions are shown in Fig. A1 where they form antiparallel groups of normal and reverse polarity. The lack of pronounced elongation in the groups suggests that, despite the variety of weathered materials and geomorphic settings, the magnetisations were acquired during a single period. Therefore for the present preliminary age estimates, the directions from all sites are pooled, giving the mean 12.0°, - 62.8° (95% confidence angle 2.7°). The corresponding pole, falls close to the pole from the Browns Creek Clays, Otway Basin (Idnurm, unpublished) on the Late Mesozoic - Cainozoic pole path for Australia (Fig. A2, after Idnurm, 1985). The clays are dated biostratigraphically as Late Eocene (Shafik, 1983), which is therefore the best estimate of the magnetic age of weathering.

References (Appendix 1)

Idnurm, M., 1985. Late Mesozoic and Cenozoic palaeomagnetism of Australia - I. A redetermined apparent polar wander path. Geophysical Journal of the Royal Astronomical Society, 83, 399-418.

Kirschvink, J.L., 1980. The least-square line and plane and the analysis of palaeomagnetic data. Geophysical Journal of the Royal. Astronomical Society, 62, 699-718.

McElhinny, M.W., Luck, G.R. & Edwards, D., 1971. A large volume magnetic field free space for thermal demagnetization and other experiments in palaeomagnetism. Pure & Applied Geophysics 90, 126-130.

Shafik, S., 1983. Calcareous nannofossil biostratigraphy: an assessment of formaniferal events in the Eocene of the Otway Basin, southeastern Australia. BMR Journal of Australian Geology and Geophysics, 8, 1-17.

Schmidt, P.W. and Ollier, C.D., 1988. Palaeomagnetic dating of Late Cretaceous to early Tertiary weathering in New England, N.S.W. Australia. *In*: Landscapes of the Southern Hemisphere (ed). J.B. Firman, Earth Science Reviews, 25, 363- 371.

Figure captions (Appendix 1)

Fig. 1. Remanence directions from thermal demagnetisation plotted on an equal angle projection diagram. Open (filled) symbols indicate upper (lower) hemispheres of the projection.

Fig. 2. Mesozoic-Cainozoic pole path for Australia. Pole acronyms are as in Idnurm (1985), after which this diagram is drawn. Additional acronyms are NE for a pole from New England (Schmidt & Ollier, 1988), BC from Browns Creek Clays (Idnurm, unpublished) and AR, the present pole. Circle shows 95% confidence for AR.

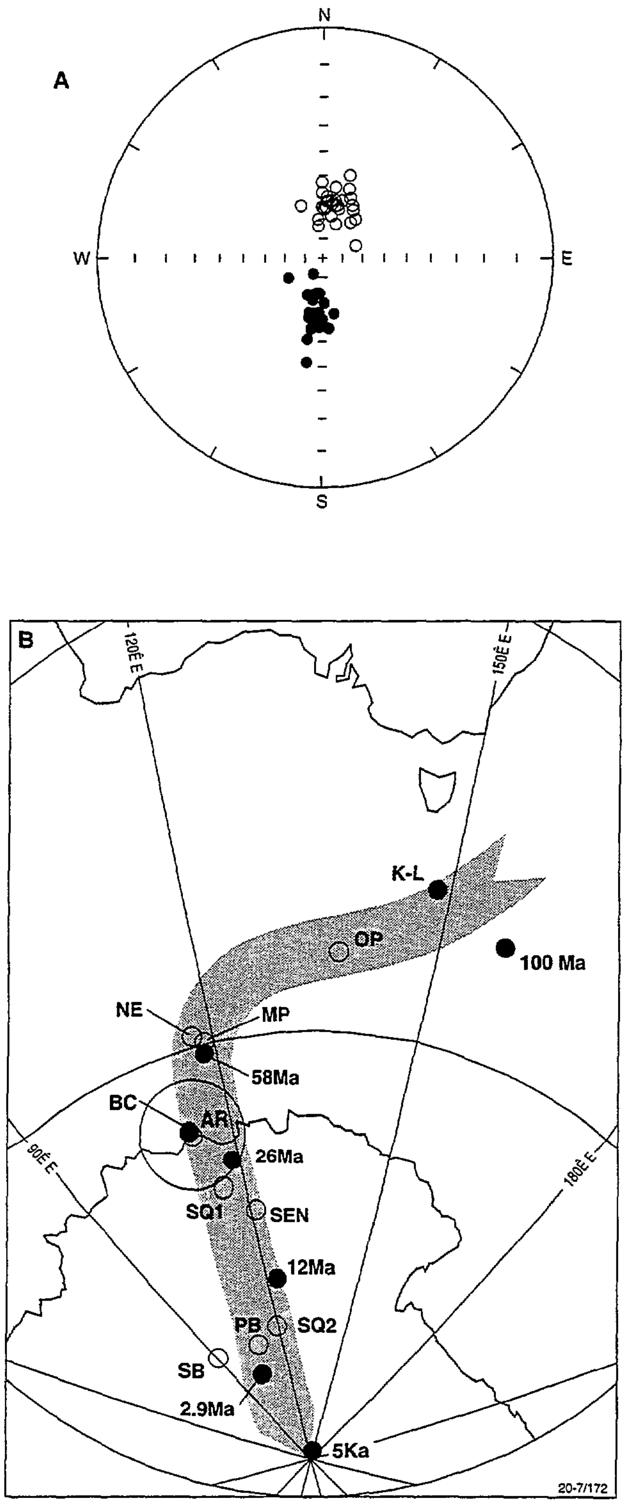

A
N
W
E
S
B
120E E
150E E
90E E
180E E
K-L
OP
100 Ma
NE
MP
58Ma
BC
AR
26Ma
SQ1
SEN
12Ma
PB
SQ2
SB
2.9Ma
5Ka
20-7/172

Table 1. Sampling Localities (Appendix 1)

Locality	**No. of Samples**	**Map Reference (1:250 000 maps)**	**Type of material**
2-1A	11	Alice Springs 229094	Ferruginous capping
2-1B	6	Alice Springs 229094	Mottled zone
2-2	11	Alice Springs 258098	Ferruginous capping
2-3	8	Alice Springs 260097	Mottled zone
2-4	5	Alice Springs 229093	Ferruginous capping
2-5	6	Alice Springs 160096	Mottled zone
4-1	6	Alcoota 488483	Mottled zone
4-2	5	Alcoota 477477	Ferruginous capping
4-3	12	Alcoota 475473	Ferruginous capping

APPENDIX 2. DRILLING RESULTS

PART A.

(i) Technical details of drilling

(ii) location of drill holes

(iii) Details of BMR drilling in the Burt Plain (Table 1).

PART B. Lithological logs: Tabular presentation

DDH BMR Alcoota No. 18, Ti–Tree Basin

DDH NTGS Huckitta 11, Bundey Basin

PART C. Diagrammatic presentation of selected drill holes

APPENDIX 2: PART A. Drilling Methods and Drill Hole Locations

(i) Technical details of drilling

In 1979 BMR drilled 2 holes totalling 345 m in the southwest part of the Ti Tree Basin using a MAYHEW 1000 rig. Simultaneously, a GEMCO rig drilled one hole in this basin and was subsequently moved to the Illogwa Creek 1:250 000 Sheet area where an additional 3 holes were drilled totalling 309 m. In each case, cuttings were taken from 3 m - intervals. A geologist was on site and made a rapid examination of cuttings using a binocular microscope. For those holes drilled by the MAYHEW, conventional cores were cut from intervals selected by the geologist, whereas the GEMCO rig attempted to fully core all holes, but unfavourable drilling conditions led to very poor, discontinuous core recovery.

A WIDCO wireline logger was used on each hole and gamma-ray, spontaneous potential and resistivity logs were run wherever possible. These logs were run at 1:600 scale and the traces were photographically reduced for this report. Considerable difficulty was experienced in obtaining satisfactory logs due to spurious electrical interference within the logging unit. As a result, several suites of logs were run and only those which gave a satisfactory repetition of data were used. However, there is generally poor correlation between the actual rock types and the lithological types indicated by these logs. This apparent lack of correlation may be because the original rock types have been altered as a result of eluviation of clays, combined with selective silicification and ferruginisation.

All cores and cuttings were transported and stored at the BMR Core and Cuttings Laboratory, Fyshwick, A.C.T. in 1979. Detailed re-examination of the material was made between January and March 1980. Selected samples were submitted for palynological examination.

(ii) LOCATION OF DRILL HOLES

ALCOOTA BMR 18
39 km northeast of Stuart Highway and 4 km north of Spinifex Bore
Ti–Tree Basin
Lat. 22° 40.75' Long. 133° 54.16'
Elevation G.L. 602 m
Drilling BMR
Rig type MAYHEW
Spudded 8-5-79: Completed 11-5-79
TD 156.8 m Logs gamma-ray to 147 m
Stratigraphic

ALCOOTA BMR 19
2.5 km southeast of Spinifex Bore
Ti–Tree Basin
Lat. 22° 44.43' Long 133° 56' 00"
Elevation G.L. 603 m
Drilling BMR
Rig type Gemco
Spudded 11-5-79: Completed 18-5-79
T.D. 76 m
Stratigraphic

ALCOOTA BMR 20
46 km northeast of Stuart Highway, 3.5 km southeast of Top Corner Bore
Ti–Tree Basin
Lat. 22° 38.42' Long. 133° 57.5'
Elevation G.L. 603 m
Drilling BMR
Rig type Mayhew
Spudded 12-5-79: Completed 22-5-79
T.D. 188.4 m Logs gamma-ray to 186 m
Stratigraphic

ILLOGWA CREEK 1
5.3 km southeast of new No 10 Bore
Lat. 23° 23' 10" Long. 135° 38' 00"
Elevation G.L. 400 m
Drilling BMR
Rig type Gemco
Spudded 17-5-79: Completed 31-5-79
TD 91 m
Stratigraphic

ILLOGWA CREEK 2
7.5 km northeast of Warnarta bore on boundary fence between Indiana and Numery.
Lat. 23° 30' 00" Long. 135° 32' 40"
Elevation G.L. 370 m
Drilling BMR
Rig type Gemco
Spudded 1-6-79: Completed 4-6-79
T.D. 55 m
Stratigraphic

ILLOGWA CREEK 3
56 km south of boundary fence between Indianna to Numery and 6 km east-southeast of Warnarta Bore.
Lat. 23° 32' 55" Long. 135° 31' 40"
Elevation G.L. 372
Drilling BMR
Rig type Semco
Spudded 5-6-79 Completed 13-6-79
T.D. 87 m
Stratigraphic

DDH NTGS HUC 11, BUNDEY BASIN
Collar locality: Bundey River plain, 3 km NE of Old MacDonald Downs homestead
Lat. 22°39'30"S Long. 135°15'00"E
Grid Reference: NR255159
Map: 1:100 000 MacDonald Downs 5953
Drill hole dip at collar: 90°
Drill hole collared 30/9/82, Completed 3/10/82
Logged by: N. Donnellan

(iii) DETAILS OF BMR DRILLING IN THE BURT BASIN

Basement drill hole information and total depths for a series of holes drilled in 1973 along the Stuart Highway in the west of the region is given in Table 1, Appendix 2 (see Shaw & others, 1979a, b). Most of these holes are located in the Alice Springs 1:250 000 Sheet map area (Shaw & Wells, 1983) and the remainder are listed in Appendix 2 part (ii). Cuttings from these holes are held in the AGSO (previously BMR) Cores and Cuttings Laboratory, Fyshwick, ACT.

APPENDIX 2

PART B. LITHOLOGICAL LOGS: TABULAR LOGS FOR SELECTED DRILL HOLES

List of Selected Well Logs
1. BMR ALCOOTA 18
2. NTGS. HUC 11, BUNDEY BASIN

DDH BMR ALCOOTA 18, Ti–Tree Basin

T.D. 156.8 m, 3 cores

Summary lithological log

Metres	Description
0.0 - 3.0	dk red, fe, sft sd Sl
3.0 - 7.0	dk brn, c grnd, sft, qzs Sd
7.0 - 12.0	as above, f-med grnd, sf, becoming pl pk
14.0 - 27.0	f red-brn silty-Sst, with iron-oxide cemented red brn Sst
27.0 - 33.0	Pebble Cong with clasts of w rndd amphibolite & Qz; mtx of m-c grnd qzs Sst.
33.0 - 42.0	brn, clayey and silty Sst with some fe cement
42.0 - 45.0	granule Cong with Qz & crystalline metamorphics, fe cement
45.0 - 57.0	brn, vf clayey Sst with tr of (yel) & gy land Mdst, calcite.
57.0 - 60.0	med-c grnd qtz Sst with granules
60.0 - 62.5	med-c grnd clayey qtz Sst with sft v f Sd & tr (yel) & gy Mdst
62.5 - 67.5	gy, sft Mdst with (red) Sst cavings?
67.5 - 70.0	(red) c grnd Sst with minor sft Mdst
70.0 - 78.0	brn qtz, Fe stnd, Sst, with minor Sltst, tr calcite
78.0 - 81.0	pl brn, m grnd qtz Sst
81.0 - 88.0	(wh), c grnd qtz Sst
88.0 - 90.0	sd Cong
90.0 - 92.0	(red) - brn, sft Mdst.
92.0 - 104.0	(rde) - brn, poorly srtd, silty Sst, some c grnd Sst
104.0 - 106.0	(yel) Mdst with minor c grnd Sst cavings?
106.0 - 110.50	hd (wh) silic Mdst with minor sft Mdst Manganese stng.
110.50 - 114.0	pl (gn), sft Mdst.
114.0 - 117.0	(wh) Mdst
117.0 - 125.0	(wh) & (yel) Om Mdst. Possible c grnd Sst at 124.5 m

125.0 - 132.0	sft, ang to w rndd qtz Sst with clasts of Qz & gneiss; minor (yel) & gy Mdst, tr carb?
132.0 - 141.0	(wh) Sltst, with minor c grnd qzs Sst. Becoming v fe
141.0 - 144.0	gn Mdst with qtz Sst cavings, minor biotite flakes
144.0 - 150.0	biotite-feldspar-quartz-garnet gneiss
150.0 - 151.35	**Core 1** as above, c crystalline weath.
151.35 - 153.77	**Core 2** as above, weath
153.77 - 156.77	**Core 3** as above, with thin veins of (gn) epidote. Schistosity dips at approx 60°

156.77 T.D.

DDH NTGS HUC 11, BUNDEY BASIN

Collar locality: Bundey River plain, 3 km NE of Qld Macdonald Downs homestead
Lat 22°39'30"S Long 135°15'00"E
Grid Reference: NR255159
Map: 1:100 000 Macdonald Downs 5953
Drill hole dip at collar: 90°
Drill hole collared 30/9/82, completed 3/10/82
Logged by: N. Donnellan

Summary lithological log

Metres	Description
0.0-6.7 m	No core
6.7-9.7 m	Silicified limestone with cap of calcedony; yellow-grey to white
9.7-43.7 m	No core drilling, indurated sandstone and mudrock
43.7-49.9 m	Marl, weakly cohesive; grades into clay in some intervals; pale green down to 45 m, then turns grey possible unconformity
49.9-57.0 m	Mudrock, sandy, grey, poorly bedded
57.0-95.3 m	Siltstone with mudrock and sandy interbeds; locally slightly calcareous; ranges yellow to grey or red;
95.3-108 m	Black claystone to mudrock, with wood fragments and, at 96.2 m "Compressed leaf litter", carbonaceous; with interbeds and interlaminae of pale grey sandy mudrock
108.1-126.7 m	Interbedded claystone, siltstone and sandstone; yellowish-grey
126.73 m	E.O.H.

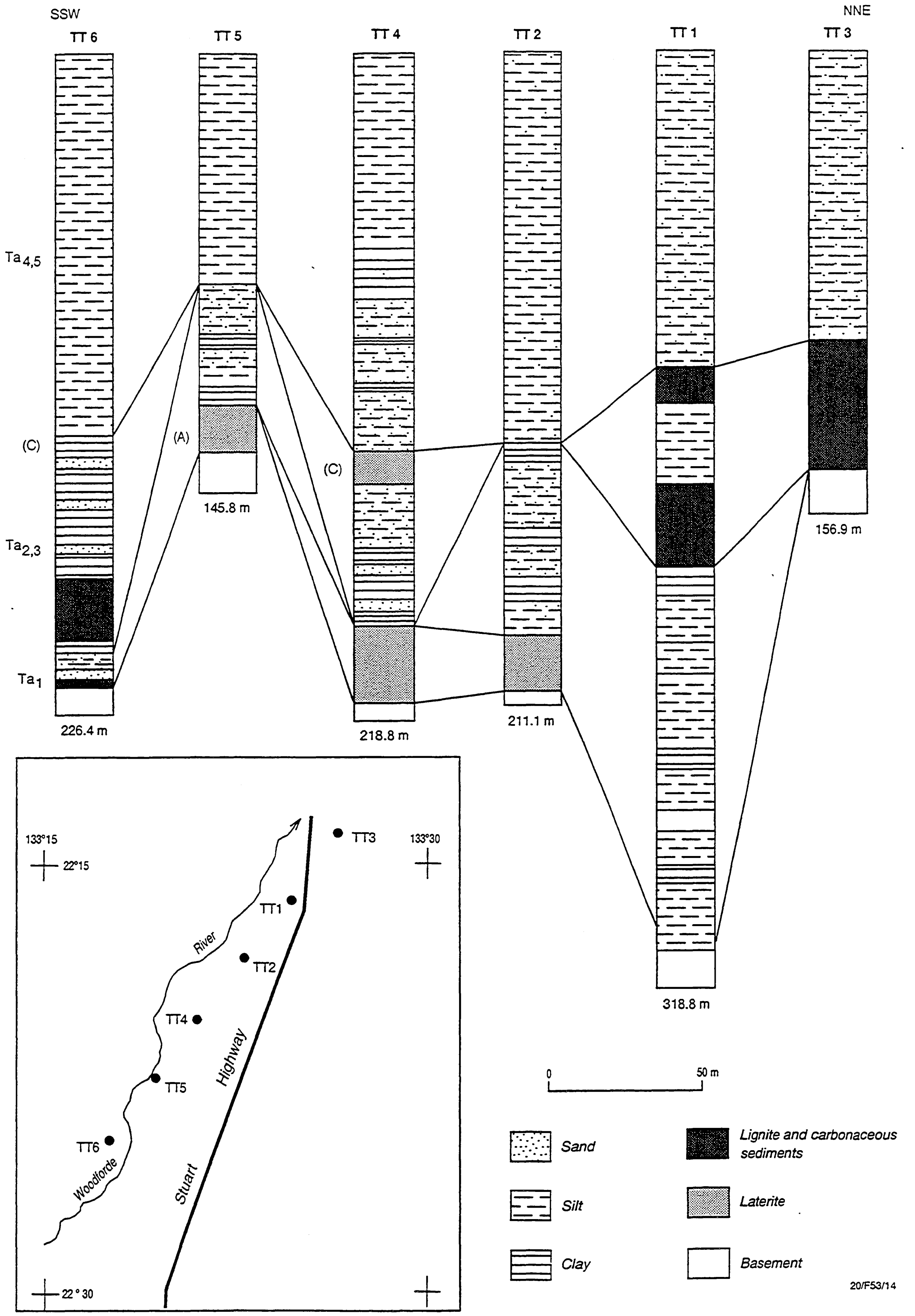
Stratigraphic log
0.0-26.73 m Tertiary sequence. Waite Formation equivalents (Mio-Pliocene) in limestone to 10 m
E. Truswell has examined the palynological components of the carbonaceous core (7 samples between 96.2 and 108.8 m) and considers they are of Paleocene or Late Cretaceous age.

APPENDIX 2

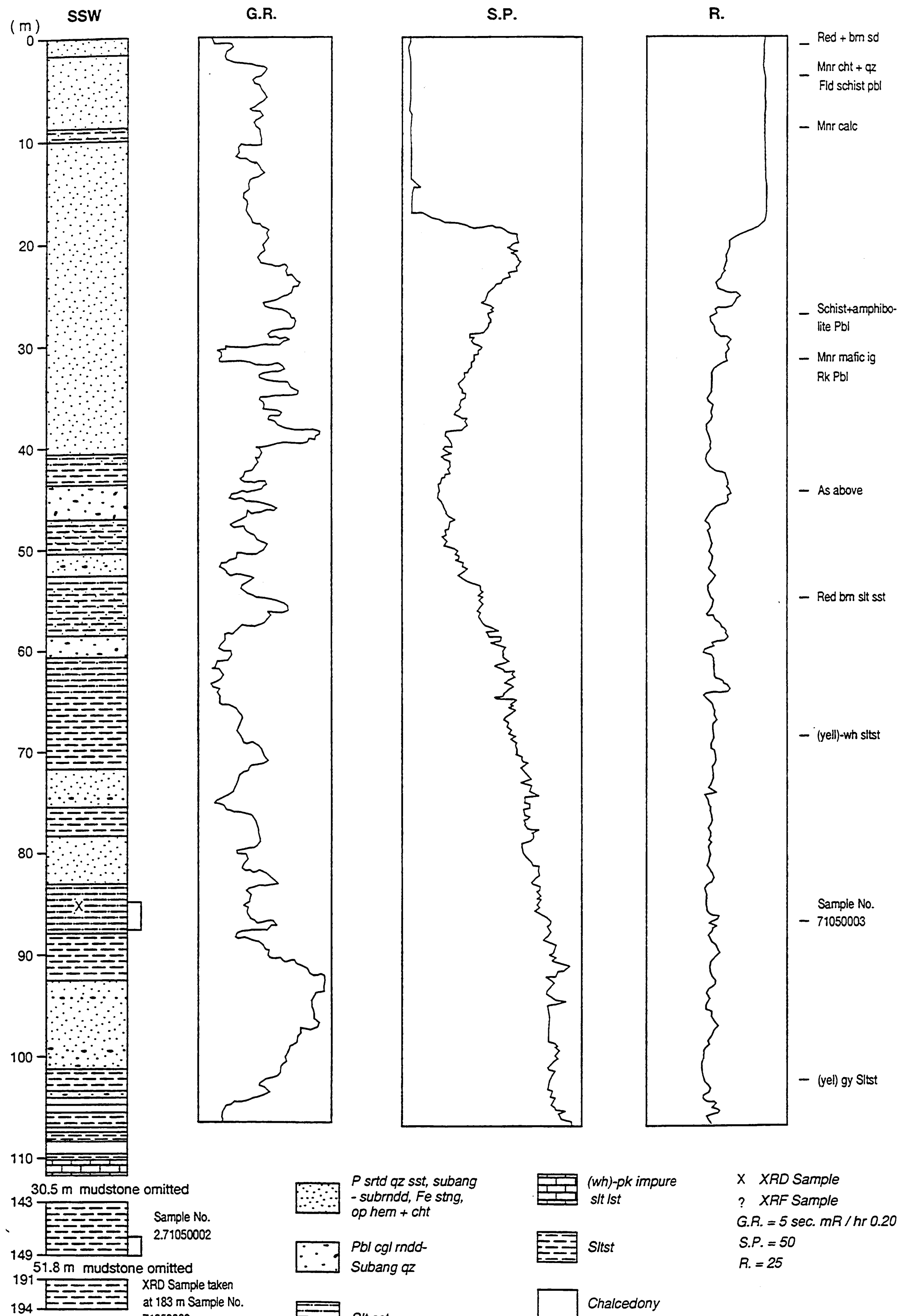
PART C. DIAGRAMMATIC PRESENTATION OF SELECTED DRILL HOLES

1) CRA Exploration drilling in NW Ti-Tree Basin. Nos 1 - 6 (after O'Sullivan 1973)
2) BMR ALCOOTA 2, Gamma Ray, Spontaneous Potential and Resistivity Logs.
3) BMR ALCOOTA 6, 7 & 9, showing possible correlation.
4) BMR ALCOOTA SCOUT HOLES 4 - 11, showing possible correlation.
5) BMR ALCOOTA 18, Ti-Tree Basin.
6) BMR ALCOOTA 19, Ti-Tree Basin.
7) BMR ALCOOTA 20, Ti-Tree Basin.
8) BMR ILLOGWA CREEK 1 Aremra Basin.
9) BMR ILLOGWA CREEK 2, Aremra Basin.
10) BMR ILLOGWA CREEK 3, Aremra Basin.

APPENDIX 2 - Fig.1



APPENDIX 2 - Fig.2



P srtd qz sst, subang - subrndd, Fe stng, op hem + cht

Pbl cgl rndd- Subang qz

Slt sst

(wh)-pk impure slt lst

Sltst

Chalcedony

X *XRD Sample*

? *XRF Sample*

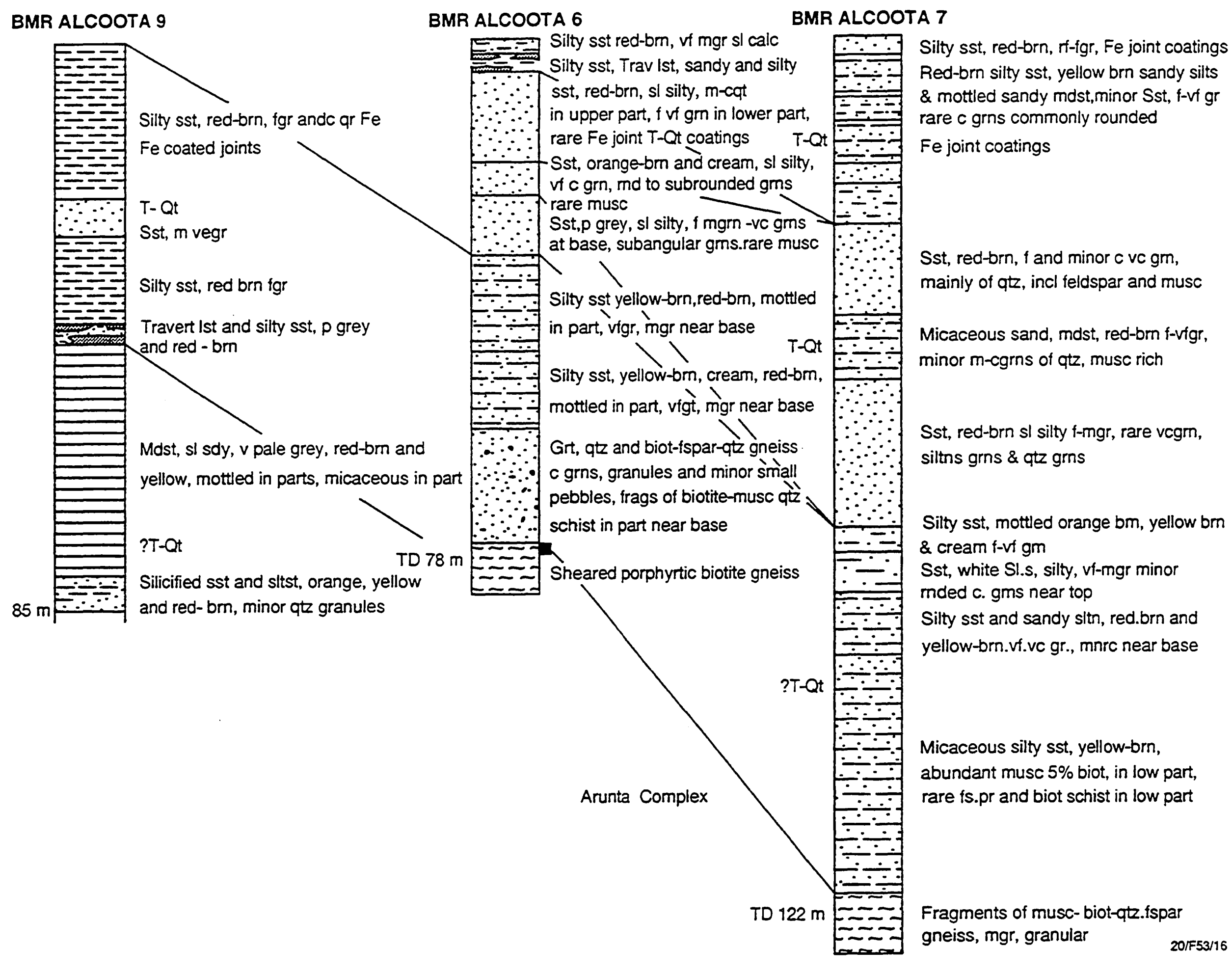
G.R. = 5 sec. mR / hr 0.20

S.P. = 50

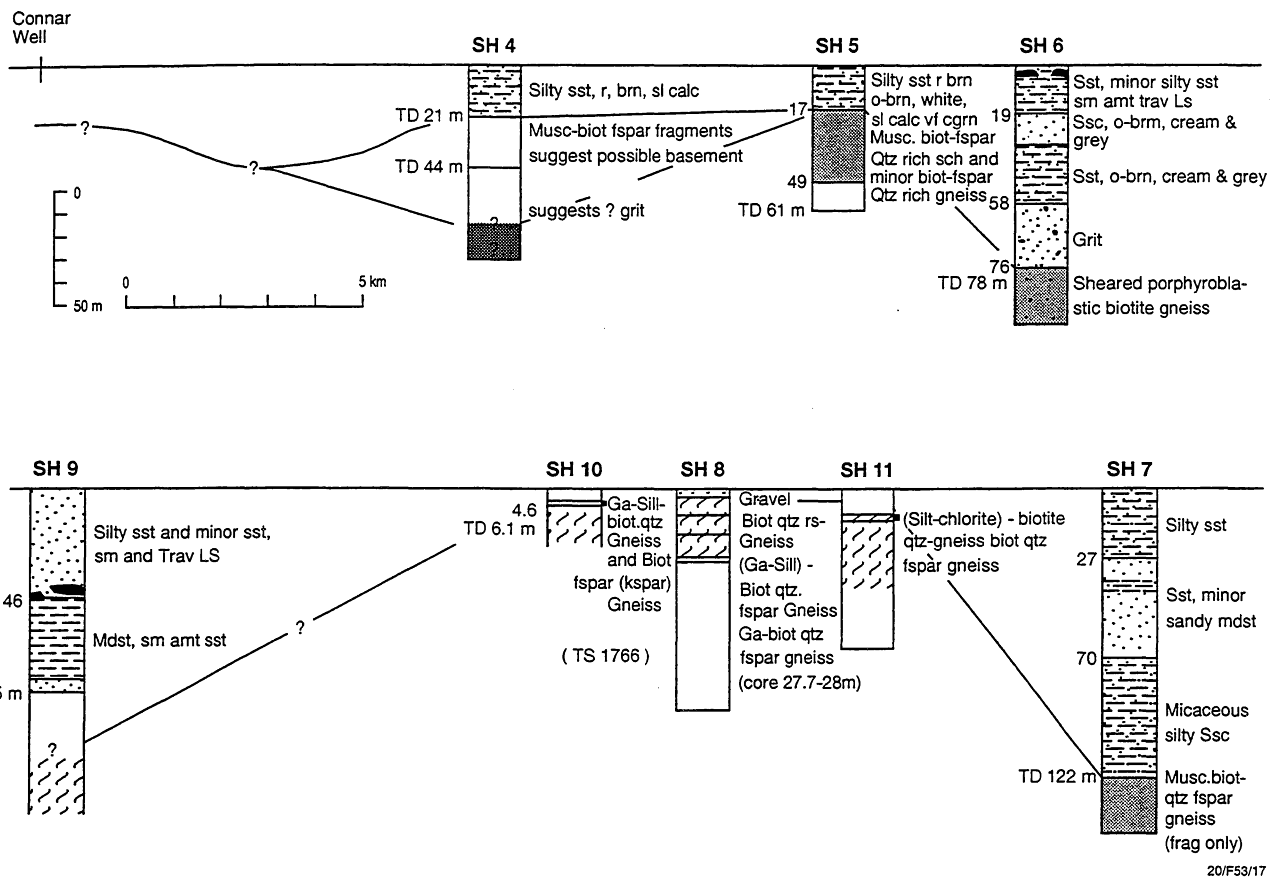
R. = 25

20/F53/15

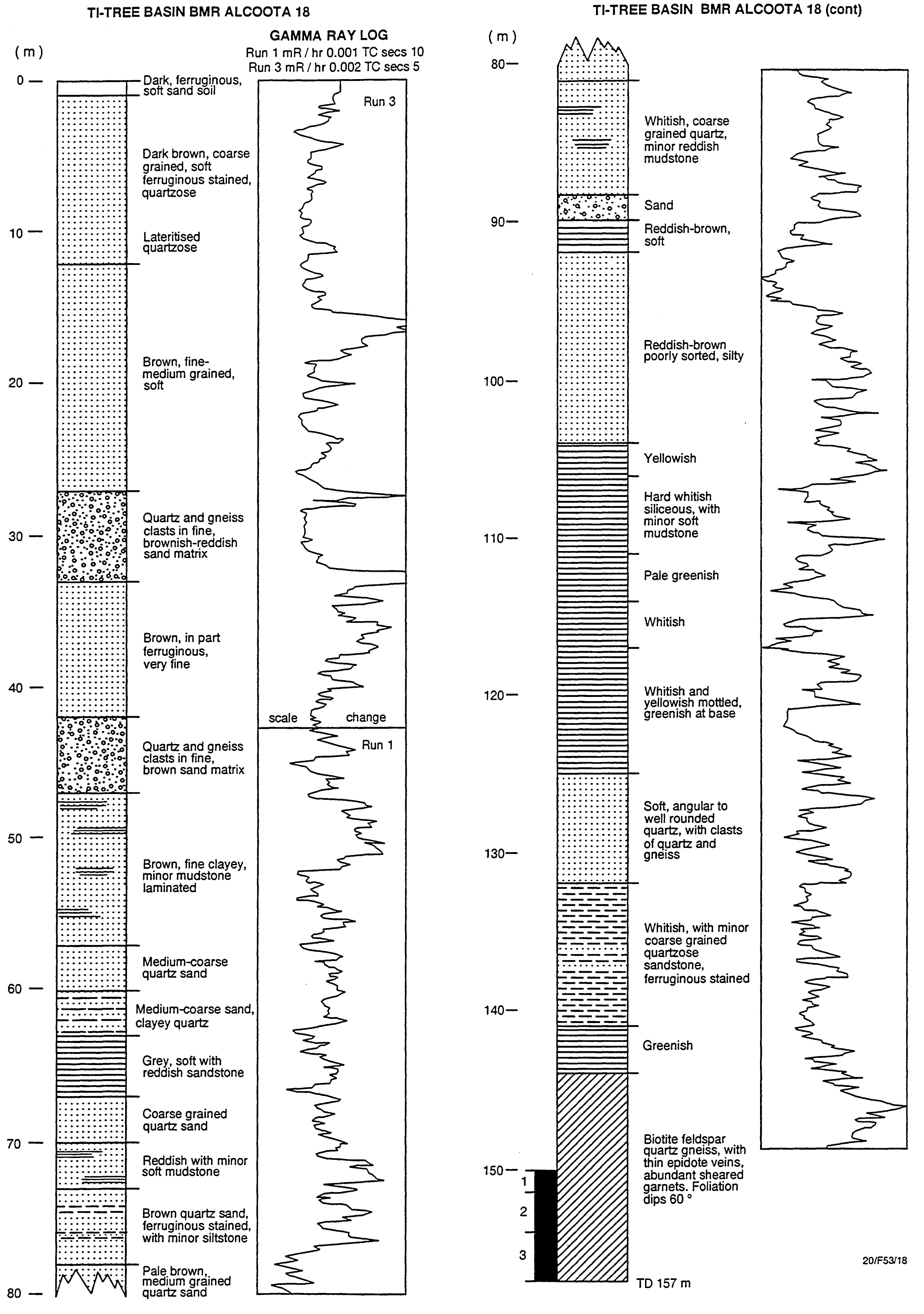
APPENDIX 2 - Fig.3



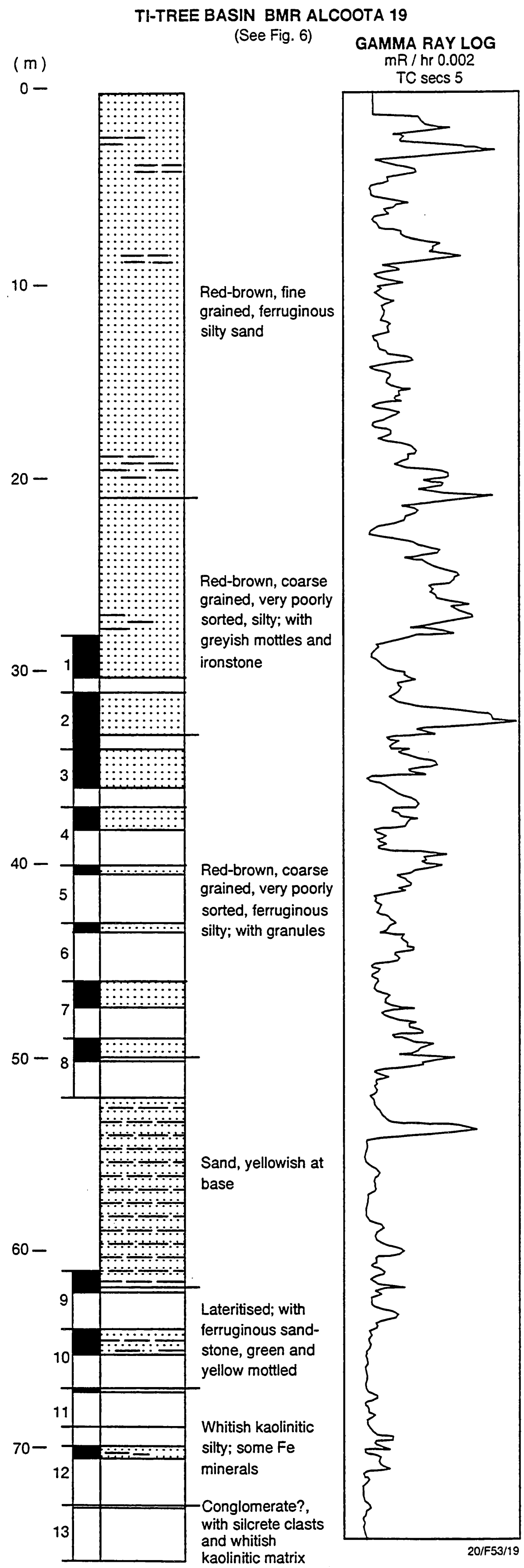
APPENDIX 2 - Fig.4



APPENDIX 2 - Fig.5



APPENDIX 2 - Fig. 6



APPENDIX 2 - Fig.7

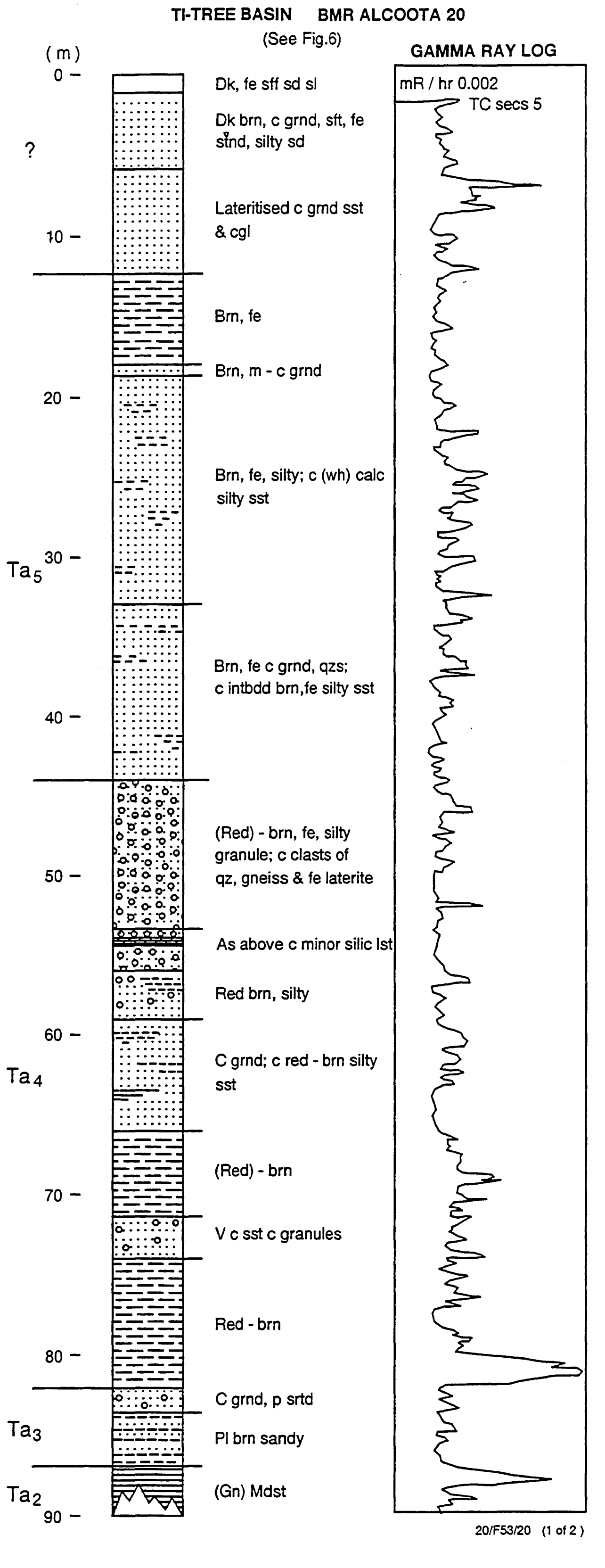
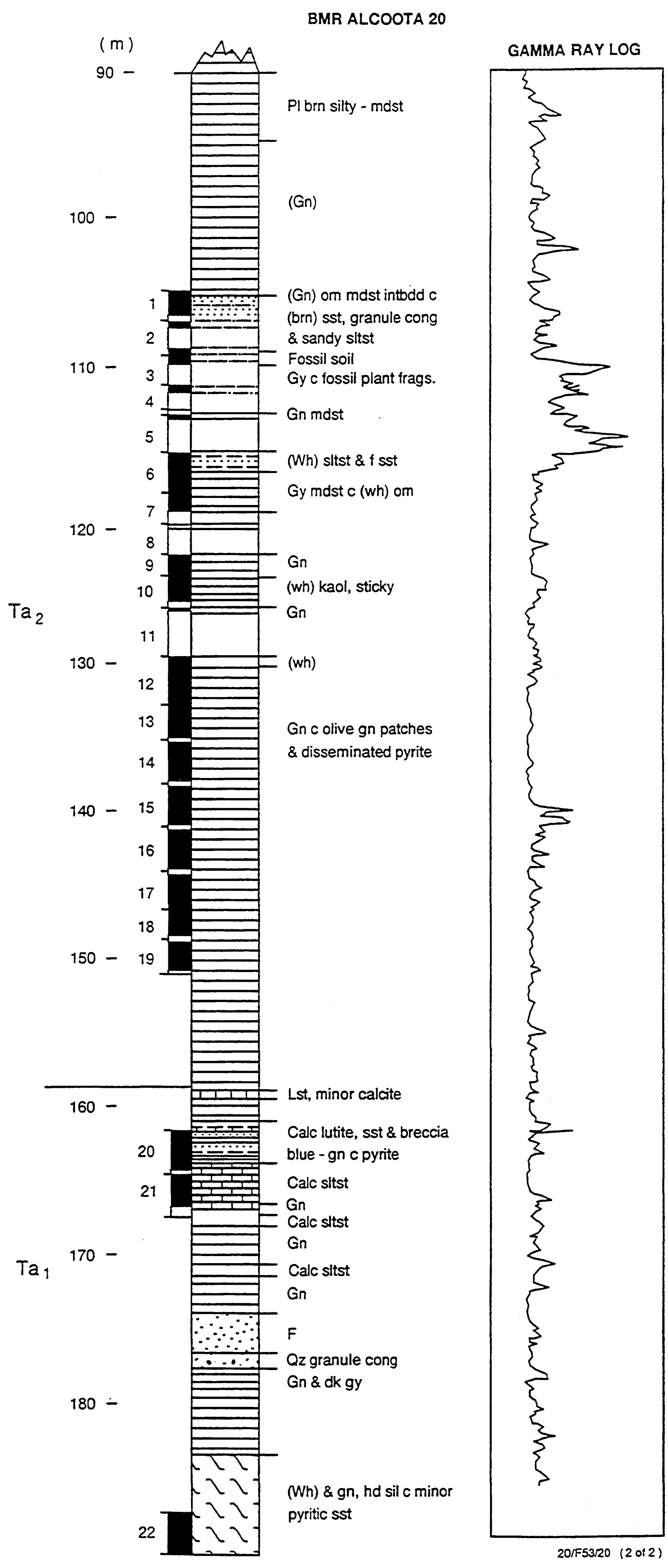


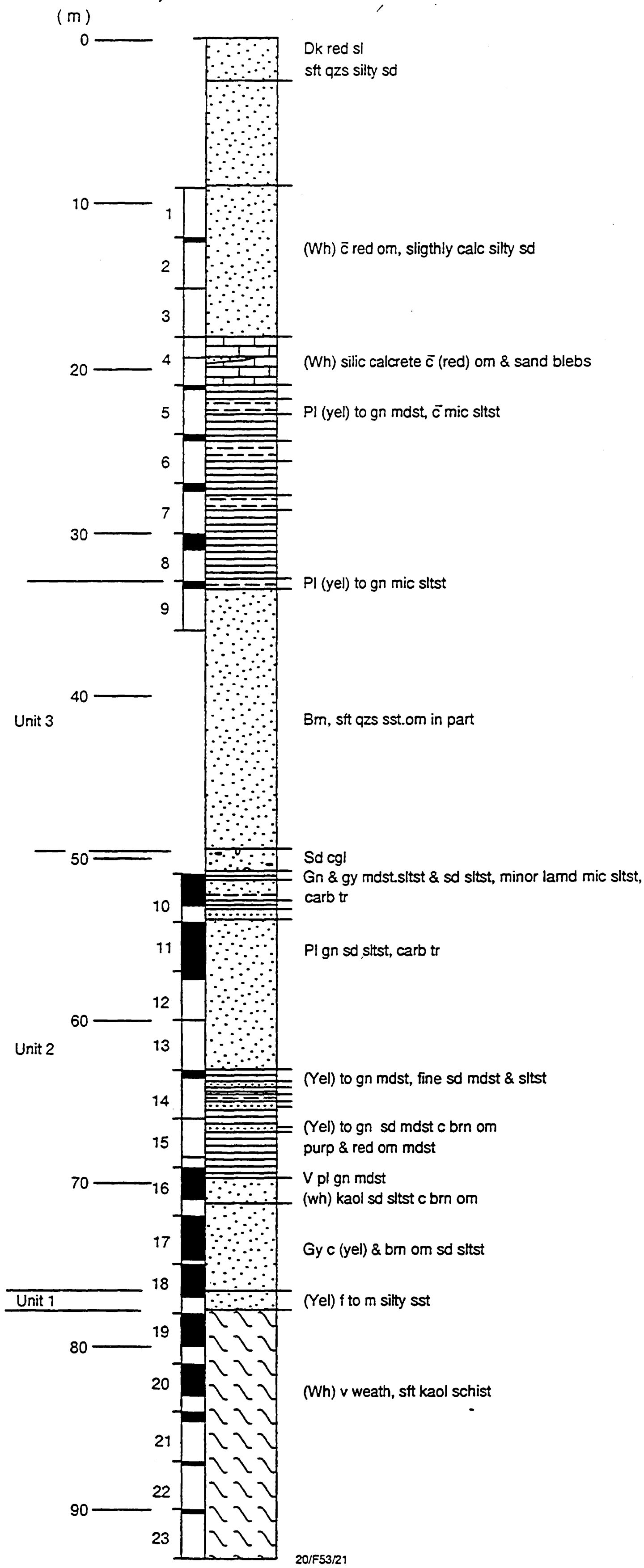
Fig.7 (cont.)



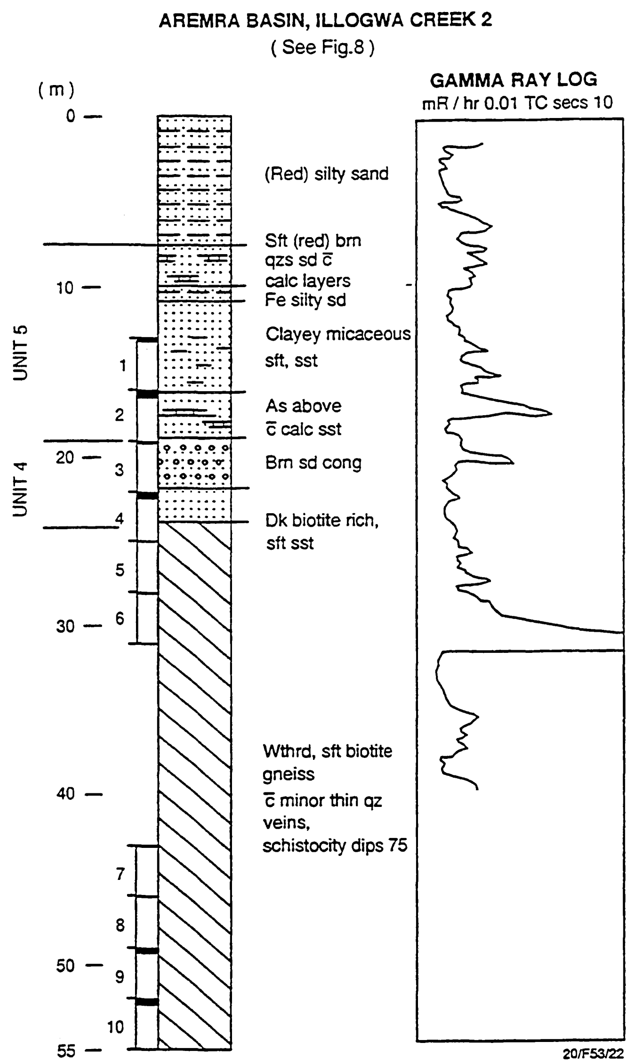
BMR ALCOOTA 20
(m)
90
100
110
120
130
140
150
160
170
180
Ta 2
Ta 1
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
Pl brn silty - mdst
(Gn)
(Gn) om mdst intbdd c
(brn) sst, granule cong
& sandy sltst
Fossil soil
Gy c fossil plant frags.
Gn mdst
(Wh) sltst & f sst
Gy mdst c (wh) om
Gn
(wh) kaol, sticky
Gn
(wh)
Gn c olive gn patches
& disseminated pyrite
Lst, minor calcite
Calc lutite, sst & breccia
blue - gn c pyrite
Calc sltst
Gn
Calc sltst
Gn
Calc sltst
Gn
F
Qz granule cong
Gn & dk gy
(Wh) & gn, hd sil c minor
pyritic sst
GAMMA RAY LOG
20/F53/20 (2 of 2)

APPENDIX 2 - Fig.8

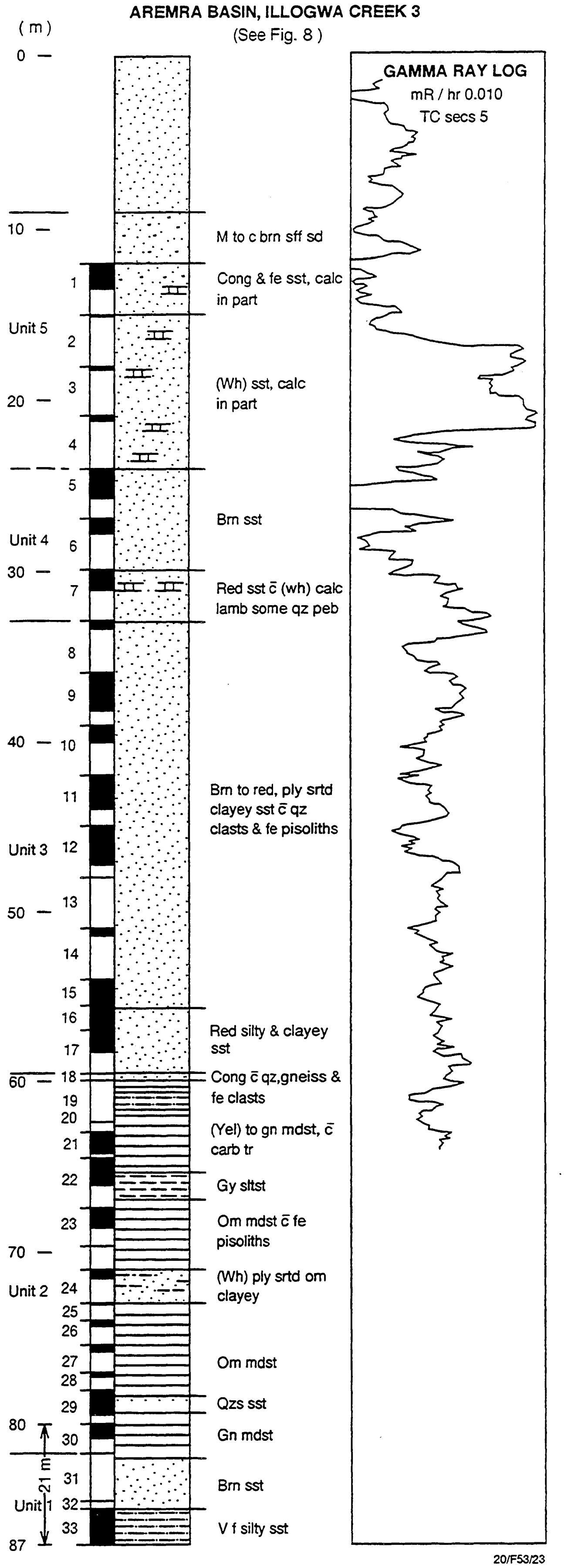
AREMRA BASIN, BMR ILLOGWA CREEK 1



APPENDIX 2 - Fig.9



APPENDIX 2 - Fig.10



SYMBOLS USED ON LITHOLOGICAL LOGS AND MEASURED SECTIONS

BEDDING STRUCTURES

Bioturbation

Concretions

f ferruginous

c calcareous

Thin 1-5

Thick 60-120

Laminate <1

Thick 60-120

Very thick > 120 cm

Thick 60-120

Thick 60-120

Thick 60-120

Medium 5-60

Thick 60-120

Thin 1-5

Thick 60-120

Laminate <1

FOSSILS

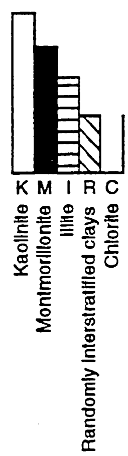
Plant fossil

Fossil wood

Spore or pollen

CLAY MINERALOGY

dominant	> 50 %
subdominant	20-50 %
accessory	5-20 %
trace	< 5 %



BED THICKNESS

Very thick > 120 cm

Thick 60-120

Medium 5-60

Thin 1-5

Laminate <1

LITHOLOGICAL SYMBOLS

Sandstone

Pebbly sandstone

Conglomerate

Sandy limestone with clasts

Silcrete

Siltstone

Mudstone

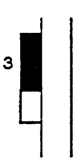
Ferruginous layers

Limestone or calcareous sandstone

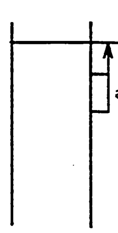
Lignite

DRILLING DATA

cored interval 3
& recovery



GROUNDWATER



standing water level

aquifer